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Platform Irene One Mile Marine Environmental Documents Review for CalWave

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Overview

This short report constitutes a review of information available on the marine environment within a one mile radius of Platform Irene offshore from the Vandenberg Air Force Base in Santa Barbara County, California. This information includes marine biological and oceanographic environmental conditions that have been observed and reported within one mile of Platform Irene. The short report is intended to support the ongoing development of the CalWave project, with a particular emphasis on supporting the development of future permitting documents and studies. On this basis, this report seeks to identify documents prepared for, and/or that are relevant to, prior permitting work done at the Platform Irene facility. The report also seeks to identify information in those documents that relates to the one mile radius around Platform Irene and is likely to be important in the planning process for the CalWave project should it pursue infrastructure associated with Platform Irene. Some of the referenced reports are included as an electronic addendum to this report.

Platform Irene is the most northern of the 27 existing offshore oil production facilities adjacent to the California coastline in State and Federal waters. It is located approximately 5.0 miles (~8 km) offshore in Federal waters at a depth of 242 ft (~74 m). The California platforms range from 1.4 miles (~2 km) to 12.1 miles (~19 km) offshore and the median depth of platform locations is 211 ft (64 m) (CDFG 2007). Platform Irene is currently operated by Freeport-McMoRan Oil and Gas LLC. The platform accesses the Point Pedernales Unit Area in the central portion of the Santa Maria Basin. This unit includes 5 leased licensing blocks OCS-P 0437, OCS-P 0438, OCS-P 0440, OCS-P 0441 and OCS-P 0444. The facility was installed on August 7, 1985 and first production occurred on April 13, 1987. Three pipelines and a 34.5kV cable connect the facility to shoreside infrastructure[1].

[1] ADL 1985 pp. 2-462

The following technical memo describes three major bodies of work associated directly with Platform Irene. Prior to Platform Irene's installation, an EIR/EIS was prepared on behalf of the regulatory agencies for review under CEQA and NEPA, respectively. Subsequent to that EIR/EIS, a proposal to expand the production capacity at the facility was made for an additional production area, the Tranquillon Ridge field. A full EIR was completed under CEQA for this project. Ultimately the project was denied a permit by the State of California and the project was not pursued. Finally, a body of scientific study was completed, primarily by the Milton Love Lab at the University of California, Santa Barbara, into the fish assemblages that have developed on offshore platforms. These studies include specific information on Platform Irene that is summarized in this report.

Platform Irene EIR

Prior to the installation of Platform Irene by Union Oil, Exxon, and their partners in 1985, an EIR/EIS was prepared on behalf of the county, state, and Federal agencies (Santa Barbara County Resource Management Division, Minerals Management Service, California State Lands Commission, and California Coastal Commission). In addition to the assessment of effects in the offshore environment due to construction and operation of Platform Irene and its associated pipelines and cable infrastructure, the EIR/EIS project scope included a second platform facility called Platform Shamrock and associated infrastructure. Platform Shamrock was proposed to be situated approximately 2.5 miles (~4 km) to the west of Platform Irene and the platforms would be connected together and to shore side facilities by several pipelines and cables. An alternative pipeline and cable connection from Platform Shamrock to another existing facility, Platform Hermosa, was also assessed in this report. Platform Hermosa is approximately 10 miles (~16 km) to the south of the proposed facilities. Platform Shamrock was an Exxon project, unlike Irene which was a Union Oil project. Platform Shamrock and the subsequent connections between the facilities were ultimately never built. The major impacts to marine biology from the facility were described as:

1. Effects from the construction of the platforms and pipelines – these effects were determined to be short term and therefore impacts were of low significance as defined under the terms of the impact assessment.
2. Effects from the discharge of a variety of pollutants during operation – these effects were determined to be of moderate significance to sediment communities due to potential for accumulation, and of low significance for water column communities due to the anticipation of rapid dilution within 328-656 ft (100-200 m) of the facility. There was some uncertainty as to this conclusion, so monitoring and adaptive management was proposed as mitigation.
3. Effects from a major oil spill – this effect was determined to have a low probability of occurrence, however should it occur there was a 30-50% chance of it making landfall and, due to the magnitude of consequence of a spill, particularly from a section of pipeline close to shore, this was considered to have a significant adverse impact that could not be mitigated to an insignificant level.
4. Effects of the addition of hard substrate – this effect was determined to have a significant beneficial impact of local significance.

5. Effects of construction – these were only considered for the pipeline connecting between the proposed facilities and the Platform Hermosa facility. This was a project alternative included on the basis of Exxon's preferred alternative for its Shamrock facility. Anchor-scarring was considered to have significant adverse impacts that could not be mitigated to an insignificant level along the southern half of the pipeline route.[2]

As part of the project development, McClelland Engineers assessed the seabed along the pipeline corridor and at the location of the platforms (1983 and February 1984).[3] The seabed was described in the EIR/EIS (ADL 1985), citing the McClelland study, as "*...sandy firm bottom with only minor rock outcroppings*"[4] and "*...clayey silt with varying content of sand*"[2]. Annual side scan sonar surveys of the pipeline corridors were proposed but not cited and these could not be identified as part of this literature search.[5]

Physical and chemical oceanographic characteristics are mostly described in general terms in the EIR/EIS (ADL 1985) for a large region from Long Beach to Morro Bay. Only one page is dedicated to a description of the oceanographic features for the platform sites,[6] although it is likely this information is generalized from the wider regional assessment as no specific reference to studies in the project area are made and currents are described as poorly defined, implying they have not been monitored at the specific location. Near-surface currents are described as being mostly in a southerly direction during late summer (July through October), northerly in late fall and winter (November through February) and mostly offshore during the spring-summer upwelling period (March through June). Bottom currents are described as potentially flowing in the opposite direction during upwelling. Tides, wind driven surface currents and gyres are noted as having the potential to interfere with these patterns. Mean currents are described as being expected at around 0.33-0.66 ft per second (fps) (0.10-0.30 m per second [mps]), with current speeds expected to decrease with depth. Maximum currents with an expected 100 year return interval are described as 4.3 fps (1.3 mps) at the surface and 0.88 fps (0.27 mps) at the seafloor, although the authors note that "*Higher maximum current speeds at the seafloor (some over 1.5 m/s) have been reported based on visual observations from submersibles*".[7] They do not state the specific location of these submersible surveys, however submersibles (ROVs) were used in the McClelland Engineering surveys of the site and pipeline corridors, and observations during these surveys may be the source of this anecdotal observation.

The EIR/EIS (ADL 1985) provides a detailed description of the geology surrounding the platform prior to its construction, including a brief description of the seabed character. This has important implications for identifying marine benthic habitat and associated marine biology. Based on marine surveys conducted by Nekton (1981 cited in ADL 1985) the sea floor is described as generally smooth with a few isolated depressions with relief up to 15 ft (4.6 m).[8] Remote operated vehicle surveys reported in 1984 by McClelland Engineers and Dames and

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[2] This is well outside of the one mile boundary of platform Irene that constitutes the scope of the current assessment.
[3] pp. 4.1-33 in ADL 1985.
[4] pp. 2-36 *Id.*
[5] pp. 2-44 *Id.*
[6] pp.4.4-6 *Id.*
[7] *Id.*
[8] pp. 4.1-32 *Id.*

Moore confirmed the findings of previously conducted geohazard surveys (uncited in ADL 1985) that there was no hard bottom substrate within approximately a 5,000 ft (~1 mile) (1,500 m [1.5 km]) radius of the proposed facility.[9]

The EIR/EIS (ADL 1985) also describes benthic infaunal surveys that were conducted around the location of Platform Irene, as well as along the proposed pipeline corridors and proposed Platform Shamrock site. Biomass data from six stations around the location of Platform Irene indicated an average infaunal standing crop biomass of 114.6±33 grams per m^2. Platform Hidalgo, which is the next closest platform, has a similar average standing crop biomass of 134 grams per m^2 and 151 grams per m^2 was recorded in an area off Point Conception.[10]

ROV, otter net tows and diver surveys were undertaken by McClelland Engineers on the site of Platform Irene to characterize fish communities.[11] Dominant fishes observed at depth on the site by ROV were reported as pink surfperch (*Zalembius rosaceus*) with flatfishes including sanddabs (*Citharichthys* spp.) and English sole (*Parophrys vetulus*) less frequently observed. Fisheries data are provided for block 644, the block within which Platform Irene is located. Catches for the most abundant taxa are reported from 1975 through 1983,[12] and of course this information will have been significantly updated since the EIR/EIS was prepared. This block is approximately 9.5 by 44.5 miles 15.3 by 71.6 km) and Platform Irene is located approximately 2.5 miles (4.0 km) NNE of the centre of the block. Marine mammals and seabirds are discussed in general terms, although the haulout sites for pinnipeds and nesting areas for birds are described explicitly. None of these occur within one mile of Platform Irene.

Sightings of marine mammals are recorded in surveys associated with the Platform Irene project in the EIR/EIS (ADL 1985),[13] however the sightings may be outside of the one mile radius of the platform. The remainder of the discussion of distribution in the EIR/EIS is either generic information on distribution, or specific to other aspects of the project, such as the pipeline landing relative to haulout locations. No explicit bird observations are reported for the one mile radius of the project site. Similar to the section covering marine mammals, generic information on birds is presented on broad distributions and subsequent likelihood of occurrence in the project area. Spatially explicit descriptions were limited to areas well outside of the one mile radius of Platform Irene, particularly along the shoreline and estuarine/wetland areas of the coast.

Tranquillon Ridge EIR

In 2008, Santa Barbara County Planning and Development Office (SBCPDO) as lead agency under the California Environmental Quality Act (CEQA) produced an EIR for the Tranquillon Ridge Project (TRP) (Aspen 2008). In January 2009, the project was denied a project lease request by the State Lands Commission (SLC) following recommendations by the SLC staff.

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[9] pp. 4.5-10 *Id.*
[10] *Id.*
[11] pp. 4.5-17 *Id.*
[12] pp. 4.10-12 *Id.*
[13] Table 4.5-3 pp.R-4.5-22 *Id.*

According to the SBCPDO website,[14] the primary reason for the denial was that approving the lease request would send a message that additional drilling would be permitted off the California coast.

The TRP intended to develop oil and gas wells from Platform Irene into the Tranquillon Ridge Field, which is inshore of the current Point Pedernales Field, where Platform Irene maintains on ongoing extraction lease. The proposed project intended to comingle the oil and gas at Platform Irene before sending it ashore through the existing oil and gas pipelines. The project proposed the drilling of 22 to 30 new production wells to access the new field, increasing the platform's production from 7,000 barrels per day (bpd) to about 30,000 bdp of oil and 2.6 million standard cubic feet per day (mmscfd) to 6 mmscfd of gas. The project also included the addition of a new electrical cable to the platform to power new pumps needed to push the additional oil and gas ashore.

It is notable that no original data on marine resources were collected as part of the TRP EIR. Instead the EIR relies entirely on a literature based analysis using previous studies. Subsequently, the TRP EIR also relies heavily on generic information, even relative to the ADL (1985) EIR/EIS, which also relied on this kind of information.

Other than papers describing broad patterns of distribution, the fishes around the platform are largely described based on one paper (Love et al. 1999) in the TRP EIR. The Love et al. (1999) paper summarizes data from surveys conducted across several California offshore platforms. In addition to the adult fish population characterization specific to Platform Irene, the TRP EIR provides spatially explicit information on larval fishes, citing Watson et al. (2002). This study collected data on the abundance of larval fishes near the platform Irene location in 1998 and 1999 during late winter and early summer. The precise locations of the samples are not provided in their report; however several stations appear to be within two miles (3.2 km), and may be within one mile (1.6 km), of Platform Irene. This site is significantly closer than the closest CalCOFI station at which ichthyoplankton has been collected, line 80, which is approximately 16 miles (27 km) to the southeast. Broadly, Watson et al. (2002) conclude that the production of eggs and larvae from the State marine protected area nearest Irene (Vandenberg State Marine Reserve) is not very high compared with the other areas considered in the study (the Channel Islands and Big Sycamore Canyon near Point Mugu). The Watson et al. (2002) survey period spans a large El Nino event, which is likely to have an effect on any comparison between this data and data collected from non-El Nino periods.

Stinson (1984) is cited within the TRP EIR as stating that "frequent sightings of olive ridley turtles around Point Conception" occur and that "most sightings in the Point Conception area occur during July to September". However, upon investigation of this publication for the proximity of these sightings to Platform Irene, this statement could not be substantiated within Stinson (1984; see Appendices C, G and D in this reference). No sightings around Point Conception appear to have been made in this publication, and therefore do not occur within one mile of Platform Irene. It is clear that Platform Irene is within the range of several marine turtle species, however this is the case for many other marine species, including numerous charismatic

[14] http://www.sbcountyplanning.org/energy/projects/Tranquillion_Pedernales.asp Accessed February 2017

megafauna such as marine mammals, sharks, etc. The closest listed citing of a marine turtle in Stinson (1984) is several miles to the northwest of the platform location, described as a pair of unidentified sea turtles.

The bird surveys undertaken closest to Platform Irene cited in the TRP EIR are from Karnovsky et al. (2006). They summarize shipboard and aerial surveys at sea of Scripps and Guadalupe murrelets (*Synthliboramphus scrippsi* and *S. hypoleucus* respectively), bird species listed as threatened under the California Endangered Species Act (CESA) since 2004. However, the paper does not explicitly reference the locations observations were made. The citation is included in this short report because graphics in the paper indicate observations of these birds were made potentially very close to Platform Irene and may be within one mile of the facility.

Johnson et al. (2011) made nighttime observations of birds and bird behavior on Platform Irene. This citation is not used in the TRP EIR, however the letter reports cited in this study are referenced, although only in the impact statement (and not in the baseline section, which is seems unusual). It would appear that the insertion of this reference occurred in the drafting stages of the EIR as it is noted as an amendment (with track changes) on the final version of the EIR. This may explain why it does not appear in the baseline sections at the start of the report. Observations reported in Johnson et al. (2011) of seabirds by survey scientists at Irene occurred over two days in September and one day in October 2010, for two days in April and five days in May 2011. A total of 134.5 hours of observation were made over these periods. The highest number of birds was observed during the 2010 surveys, although Johnson et al. (2011) concluded that aggregations of 'entrapped' birds at the platform are likely to occur infrequently.[15] The TRP EIR draws a more nuanced conclusion in relation to entrapment effects on birds stating that "artificial night lighting on Platform Irene could have an adverse effect on individuals and potentially on populations of sensitive bird species, specifically the threatened Xantus' murrelet and the ashy storm-petrel, a California Species of Special Concern".[16] The report cites two "Strommer Letter Reports" (2007 and 2008 respectively as cited from Johnston et al. 2011) on the nighttime surveys as follows: "birds observed were mostly Wilson's phalaropes (*Phalaropus tricolor*), a spring and fall migratory species that migrates between the western Canada/U.S.A. prairies and the Argentine Andes region." Other birds are reported as having landed on the platform (purportedly due to exhaustion) and include a sooty shearwater (*Puffinus griseus*) and a Nashville warbler (*Vermivora rufivapilla*). Birds were apparently attracted by the bright lights of the platform. This conclusion was drawn on the basis of the birds' behavior, being attracted to the lights through the night but moving on at dawn. The TRP EIR also includes that, on the basis of similar concerns for protected Xantus' murrelets, CDFG are quoted as making the following statement:

> "The Department is not aware of any interactions between offshore oil platforms, including Platform Irene, and Xantus' murrelets, though field studies have not been conducted. There is also a general lack of information on the nighttime habits of murrelets and their interactions with oil production platforms. Because field studies have not occurred, it is unknown if the impacts that have been seen between these

[15] Johnson et al. (2011) pp. 24.
[16] Tranquillion Ridge EIR pp. 5.5-80

birds and vessels on the ocean surface may also be occurring on the waters surrounding Platform Irene."[17]

Furthermore, CDFG make explicit recommendations for the project reported in the TRP EIR to:

1. Minimize use and wattage of night lighting to the extent feasible while not compromising safety, spill detection capabilities, or platform operations.
2. Shield lights, cover filaments, direct downward as much as feasible.
3. Vessels associated with the platform comply with low wattage/shielding/filament-covering measures.
4. Develop a monitoring program for the waters around Platform Irene that includes Xantus' murrelet, ashy storm petrel, and Cassin's auklet. This program will be developed with input from murrelet experts and take into consideration various murrelet behaviors, along with their seasonal movements.

Although the TRP EIR concluded that the project would result in benthic habitat impacts, no data on benthic communities was collected. Within the TRP EIR, the only study of benthic habitats clearly within a one mile radius of Platform Irene that is cited is the pre-construction survey conducted by McClelland Engineers (1984) already detailed above in the section on the original Platform Irene EIR/EIS. The benthic habitat assessment in the TRP EIR relies heavily on data collected during the MMS managed CAMP Phase II (Hyland et al. 1990) and Phase III (Diener and Lissner 1995) monitoring program and is further supplemented by other more generic citations relating to benthic communities and potential impacts from oil and gas facilities in general. Neither of these two studies was publicly available and the abstracts to the papers do not indicate whether data were collected within one mile of Platform Irene. It is considered unlikely that these studies would have collected samples close to Platform Irene as they were not explicitly targeting areas very close to platforms, but were interested in characterizing parameters throughout the Outer Continental Shelf (OCS).

Summary of Marine Fish Surveys of Platform Irene.

Annual surveys of fish communities associated with the submerged structures that support platforms offshore of California, including Platform Irene, have been conducted since 1995 by several marine scientists under the guidance of the Bureau or Ocean Energy Management (BOEM, previously the Mineral Management Service [MMS]). Studies were initiated, at least in part, following public objections from recreational angling groups to the decommissioning of three offshore platforms in the mid 1990s. The groups wished to see the platforms left in place due to their fishery value (Love et al. 2003).

Surveys were conducted at platforms from 1995 through 2001 and again from 2004 through 2010 (except 2007). Deep-water sections of several remaining active platforms were surveyed using a research submersible and shallow and midwater sections were surveyed by SCUBA. At

[17] Pp. 5.5-81 *Id.*

Platform Irene, no surveys were conducted in 2010 and all surveys included only midwater, bottom and shell mound habitats. Shell mounds form due to the dislodgement of mussels, barnacles, sea anemone and other fouling organisms that grow on the shallower sections of the platform structures. They constitute an important habitat at the base of all the platforms studied.

Table 1 Survey years and habitats at Platform Irene.

Year	Midwater	Bottom	Shell Mound
1995	●		
1996	●	●	●
1997	●	●	●
1998	●	●	●
1999	●	●	●
2000	●	●	●
2001	●	●	●
2002			
2003			
2004	●	●	●
2005	●	●	●
2006	●	●	●
2007			
2008	●	●	●
2009	●	●	●
2010			

Source: Appendix 1 to Love et al. (2003), Table 2 in Love et al. (2010), Table 1 in Love et al. (2012)

Data from observations are partially reported in Love et al. (2003) and Love et al. (2010), however much of the reported data and analysis in these two studies are anecdotal, or are missing key assumptions (for example survey effort in Table 5 of Love et al. 2010) such that objective/quantitative description of the fish abundances at Platform Irene could not be determined. Other aspects of the data and analysis presented in these reports are generic to all the platforms in California and do not include conclusions specific to Platform Irene (for example Figure 3.5 in Love et al. 2003). However, significant amounts of data exist on the abundance of rockfishes and other fishes resident on the structures. These data are likely to be accessible on request and should form the basis of any characterization of fishes at these locations. The following section provides a brief summary of statements and observations made from these two key summary papers and other reports associated with this work that pertain specifically to Platform Irene.

Love et al. (2003 and 2010) analyze the similarity among the fish communities at multiple platforms in California using canonical discriminant analysis (CDA). In the analysis of data for

midwater species observed between 1996 and 2001 (Love et al. 2003) Platform Holly was very dissimilar to all the other sites in the analysis for midwater assemblages.[18] Subsequently, midwater assemblages across the remaining platforms did not indicate a unique pattern of fish assemblages at Irene compared to the other platforms. Using the same CDA analysis for more platforms on data collected between 2004 and 2010 (Love et al. 2010), the results indicated a separation in platform assemblages between the southern and northern platforms, although no explicit differences between Platform Irene and other platforms within the Santa Barbara channel, including Platform Holly, were described.

Fish densities in midwater depths at Platform Irene (between 102 and 197 ft [31 and 60 m]) were the highest densities recorded at any of the platforms studied between 1996 and 2001 (~1400 fishes per 100 m^2 at Platform Irene compared to ~600 fishes per 100 m^2 at the next most abundant Platform Hermosa).[19] Densities for all fishes were not directly reported in Love et al. (2010), however they are graphically illustrated (**Figure 1**). Platform Irene did have very high abundance of fishes compared with other platforms in the area at these depths again, appearing amongst the most abundant of all platforms.[20] For all platforms upcoast of Platform Grace, midwater abundances at Platform Irene were the second highest for total fish observed (14,513 fishes observed) after Platform Holly (15,585 fishes observed).[21] Because the report authors state absolute figures, it is assumed that sampling effort was sufficiently similar across all platforms to compare between these values, even though this information is not presented in the report.

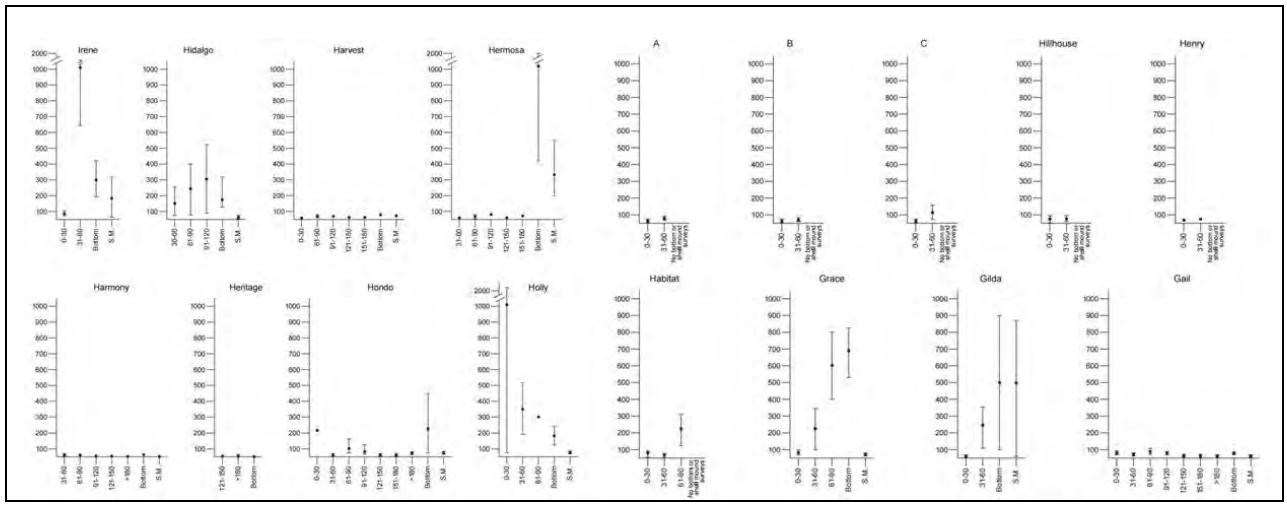

Figure 1 Density of fishes at offshore platforms in California by depth from Love et al 2010. Error bars are standard error.

Midwater communities are dominated by young-of-year (YOY) fishes, particularly rockfishes. YOY are juvenile fishes that have just transformed from their pelagic juvenile/larval phases and

[18] Love et al. 2003 Figure 3.3a.
[19] Love et al. 2003 Figure 3.6
[20] Love et al 2010 Table 5
[21] *Id.*

typically associate with habitat structure such as natural reefs. YOY settle onto structure following their planktonic larval (pre-juvenile) life stage. Shortbelly and widow YOY were very common in the midwater surveys at Platform Irene between 1996 and 2001 (378 fish per 100 m^2 and 120 fish per 100 m^2 respectively),[22] and again between 2004 and 2009 (78.8 fish per 100 m^2 and 211.1 fish per 100 m^2 respectively).[23] Approximately 90% by number of all fishes observed in the midwater habitat at Platform Irene were YOY rockfishes. This pattern was consistent at many of the other platforms.[24] Bocaccio, blue, shortbelly, squarespot, treefish, and widow rockfish plus a complex of rockfishes typically difficult to identify at a young age consisting of black-and-yellow, copper, gopher,r and kelp rockfish, were identified as making up a significant portion of the mid-water YOY at Platform Irene between 1996 and 2001. Young painted greenling were also abundant on the platform jacket. Jack mackerel and Pacific sardine were seen in large numbers intermittently at the location. These are both pelagic schooling species that typically occur in large aggregations but their occurrence is likely to be patchy.

The community similarity analysis amongst platforms in Love et al. (2003 and 2010) for fish communities at the bottom of the platforms and those associated with shell mound habitats showed a distinct pattern of similarity between platforms according to depth (**Figure 2**). Platform Irene (240 ft [73 m] deep) was one of the shallower platforms included in the studies and its bottom and shell mound communities were closely matched to those at the other shallow platforms analyzed; Platform Holly (210 ft [64 m] deep), Edith (260 ft [80 m] deep), and Gilda (203 ft [62 m] deep)[25]. Love et al (2003) report that Irene and Holly bottom and shell mound fish communities were dominated by brown (*Sebastes auriculatus*), calico (*S. dallii*), copper (*S. caurinus*). and vermillion (*S. miniatus*) rockfishes, and lingcod (*Ophiodon elongatus*).[26] At the bottom of the platform, halfbanded rockfish (*S. semicinctus*) was the most abundant fish (217 fish per 100 m^2). This species was also the most abundant fish on the shell mounds (45 fish per 100 m^2) (Love et al 2003). Between 2004 and 2009 (except for 2007, which was not surveyed) the same species dominated in these areas again.

[22] Love et al. 2003 Appendix 3
[23] Love et al. 2010 Table 5
[24] Love et al. 2010 Table 5 for Platform Irene.
[25] Love et al. 2003 Figure 3.2a. Love et al. 2010 Figure 9 and 13
[26] *Id*. pp. 3-5

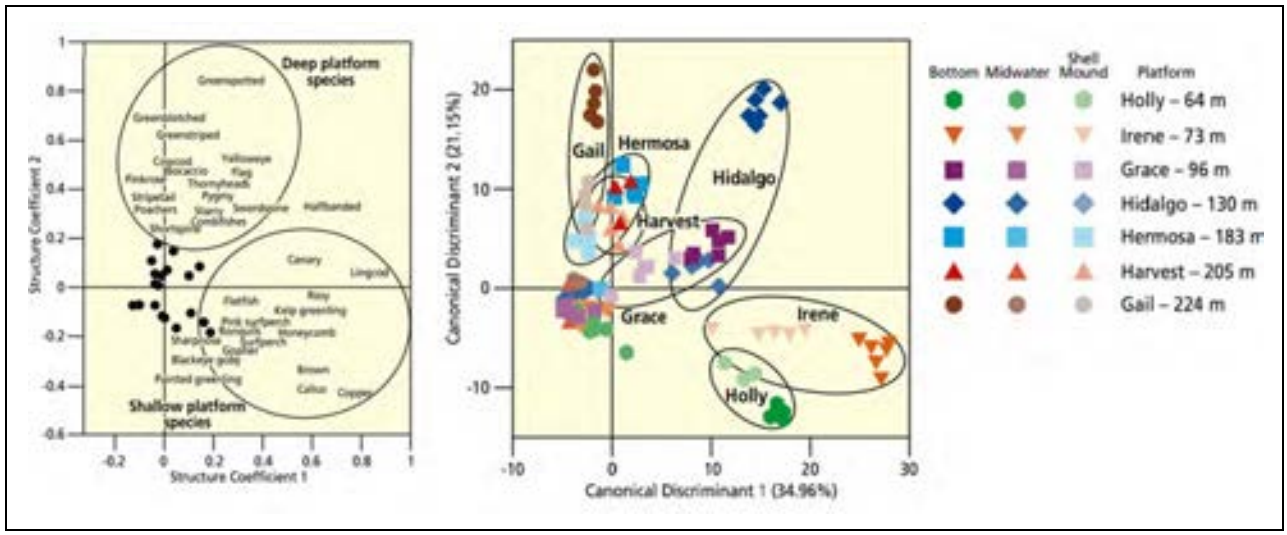

Figure 2 Similarity analysis of bottom, midwater and shell mound assemblages at seven platforms from 1996-2001. Source: Figure 3.2 Love et al 2003.

Shell mounds typically harbored smaller fishes than the seabed surrounding the shell mounds. Dominant species of adult fishes at the bottom (benthic) habitats appeared to remain stable year to year, indicating that these fishes were not moving away from the platforms to other areas. The authors of Love et al. (2003) note that they suspected they were observing many of the same individuals year to year in this case. However, recruitment was highly variable between years, with numbers of species' recruits differing by up to two orders of magnitude between years. There is some indication that this could be related to long term climatic cycles, such as El Niño. However, it is equally likely that it is related to combinations of many other spatially and temporally discrete factors including settlement viability, aggregated patterns of larval distribution (a common feature of planktonic distribution patterns), mesoscale oceanographic features such as gyres and fronts, and other ecological factors. Young-of-year lingcod, a dominant predatory fish that associates closely with seabed habitat, were notably abundant at the base of Platform Irene relative to natural reefs. It is suggested that the base of Platform Irene could be quite important to this and other species for shelter and food. Between 20 and 30 fish species associated with shell mounds on Platform Irene. Most species occupying shell mounds are solitary species (as opposed to schooling species) such as lingcod, copper rockfish and painted greenling (*Oxylebius pictus*), although halfbanded rockfish were present in large schools associated with shell mounds.

Love and York (2006) describe the importance of the habitat provided by the crevice formed by the undercut bottom cross beam on several platforms (including Irene) for certain shelter-seeking fishes such as bocaccio (*S. paucispinis*), flag (*S. rubrivinctus*), and canary (*S. pinniger*) rockfishes and cowcod (*S. levis*). The latter two (canary and cowcod) are both species whose population levels are sufficiently low to require focused management by CDFW. Rockfishes associated with the bottom of Platform Irene tended to be adult half banded, vermillion, calico, and brown rockfishes, and sub-adult and adult copper rockfishes. Canary and yellowtail rockfishes were also seen in these habitats. Juvenile lingcod, pile perch, painted greenling, and Pacific sanddab are species not of the genus *Sebastes* (rockfishes) associated with the bottom of

Platform Irene (Love et al 1999). Fishes observed during SCUBA surveys in the shallower sections of Platform Irene were dominated by three schooling rockfish species; blue (32.3 fish per 100 m^2), shortbelly (57 fish per 100 m^2), and widow (141.4 fish per 100 m^2) rockfishes. No indication is given in the report as to whether these values are for adult, subadult or YOY individuals.

Goddard and Love (2010) used 7 years of quadrat sampling from 1997 through 2005 from video collected during the surveys at Platform Irene described above to characterize large invertebrates (>one cm high and visible in photographs) living on the shell mounds surrounding platforms including Irene. They noted that areas of the seabed around Platform Irene included scattered cobble, although they noted no rocky outcrops. Taxa at Platform Irene included numerous starfish such as the bat star (*Patiria miniata*), sea star (*Pisaster* spp.), sunflower (*Pycnopodia helianthoides*) and *Dermasterias*-like sea stars as well as brittle stars (ophiurid ophiuriods), sea slugs (*Pleurobranchaea californica*) and rock crabs (*Cancer* spp.).

The presence of large numbers of YOY on the platforms is an important feature determinant in stock assessments of fishes and can be a limiting factor in the abundance of adult fishes. Claisse et al. (2014) describe the importance of platforms as providing large amounts of habitat for juvenile and adult demersal fishes over a relatively small footprint of seafloor. Based on modeling using derived surface currents, Washburn (2006) proposes that Platform Irene could be a source for larval supply to adult populations. This is one of the core reasons for the fish surveys conducted in California on the offshore platforms, as the structures may act as artificial reefs that either directly contribute additional adult fishes to fish populations throughout California after they have recruited at the platforms or indirectly contribute fish to nearshore populations by increasing the abundance of pre-juvenile (larval) fishes and subsequently the recruitment of these fishes to areas other than just the platforms from which they originated.

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DELFT 3D Numerical Analysis of 200 Year Return Period Impact on a Coastal Breakwater on the California Central Coast

Draft Final

Brendan P. Dooher

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1.0 Purpose

This paper was performed as part of an assessment of extreme Storm Waves along the California Central Coast as part of the CalWave evaluation. The assessment focuses on the 200 year return period storm waves and numerically modeling these extreme waves, based on data from buoys having some of the longest history along the California Pacific Coast.

The paper numerically estimates the storm surge and wind wave response at NDBC Station 46215 based on wave data collected by this buoy since 1983, and estimated for return periods of up to 200 years. This effort uses as inputs the estimate return periods associated with significant wave height, H_s, wave peak period, T_p, and the primary direction of approach of these large storm waves, W_{dir} as calculated in Dooher, 2017 and further developed herein.

2.0 Background

This effort presents a numerical evaluation of major storm wave (return periods of 200 years), based on data collected along selected California Central Coast buoys, NDBC Station 46215 and four other NDBC Buoys (Figure 1, NDBC 46028, NDBC 46011, NDBC 46023, and NDBC 46218) and the estimated 200 year return period extreme waves as described in Dooher, 2017, expanded herein. The data for NDBC 46215 and NDBC 46218 is collected and managed by the University of California, Scripps Institution of Oceanography, Coastal Data Information Program (CDIP, 2017), since 1983. The data for NDBC 46028, NDBC 46011, and NDBC 46023 is collected and managed by the National Ocean Atmospheric Administration (NOAA, 2107) and goes back as far as 1980. Two hundred year return period estimates of the significant wave height, H_s, primary wave peak period, T_p, and the primary direction of approach of large storm waves, W_{dir} are estimated based on Dooher, 2017 for use in the numerical calculation.

2.1 NDBC Buoy Basic Statistics

In Dooher, 2017, 16 NDBC buoys along the California Central Coast were statistically determined in detail. In order to develop complete inputs for the numerical model, Delft3d WAVE/SWAN, this effort further focused on five different buoys. Two of these buoys, NDBC 46215 and NDBC 46218 are also Waverider buoys and managed by UCSD Scripps. The other three are larger stations, and collect not just wave spectra and direction, but wind speed, direction, and atmospheric pressure. Figure 1 shows the five NDBC buoys in relation to the California Coast.

A MATLAB series of mat files were developed to hold and arrange the data, and to determine some basic statistics (such as daily maximum significant wave height) and to correlate the five buoys by day. Daily statistics were chosen so as to allow for easier comparison of time and spatially dependent hourly data. Table 1 and Table 2 show from this database the maximum daily wave heights for all five stations where all five stations have data together. This is not all the daily data – some stations have longer collection periods, but it represents a minimum cut set to examine the available information.

By examining wave heights, wind speeds, and relevant directions, a better understanding of the behavior of wind and waves along the California coast is attained. Maximum daily significant wave heights don't all correlate together, but there is some continuity. The maximum measured wave height at these five stations was measured on 2/24/2008 at NDBC 46218, at 9.97 m. It was characterized by a southerly wind direction, high average wind speeds (~10 m/s), and south-westerly wave trains. However, it only resulted in high, but not close to record breaking, wave heights at NDBC 46215 (5.58 m) and the other three stations.

Of more interest is the observations on 1/11/2001, which resulted in very high wave heights at all stations, with maximum recorded wave heights at NDBC 46023 (7.66 m) and at the NDBC 46215 buoy (6.5 m). Wave directions were westerly, with similar average wind speeds (~9.3 m/s) to those measured on 2/24/2008.

Another date of interest was on 1/5/2008, which resulted in the maximum wave at NDBC 46011 (8.62 m) and NDBC 46028 (8.96 m). The wave heights at NDBC 46215, NDBC 46218, and NDBC 46023 were 6.42 m, 7.08 m, and 7.61 m. Wave directions were once again from a westerly direction (~270°). Average wind speeds were ~5.5 m/s.

Table 2 specifically seems to show that there is no specific correlation between the variables – although the maximum wave heights for NDBC 46215 are consistently less than the other NDBC observation points, by an average of approximately ¾. This can be seen again in scatter plots of NDBC 46215 against the maximum daily wave height as seen in Figures 32 through 35.

Significant wave height, peak period, wave direction, as well as wind speed and wind direction (available partially for NDBC 46028, NDBC 46011, and NDBC 46023) were examined in detail with exploratory statistics using Mathworks MATLAB Statistics Toolbox, in order to get a better understanding of the wave and wind dynamics found along the Central Coast. These detailed basic statistics are shown in Figure 5 through Figure 50, including scatterplots of wind speeds vs. wind directions, wave heights vs wave directions, wave directions vs wind directions, as well as other cross correlations and statistical fits of the data. Not surprisingly, the buoys located in deeper waters show significantly greater wave heights, but the correlations between them are not perfect. All wave heights show a pronounced bimodal directionality based distribution, with the greatest wave heights coming from a westerly to northwesterly direction. This is especially true at the most shallow buoy (NDBC 46215), as seen in Figure 14.

The statistical fits developed are shown in Table 3 though Table 13. From these, the 200 year return period for all five NDBC buoys were found, as is seen in Figure 51. All these data sets and correlations were taken into consideration in order to assess the characteristics of inputs for wave heights, average wind speeds, and relevant directions for the numerical model development.

To determine the possible storm surge associated with low pressure regimes, the historical pressure measurements of NDBC 46028, NDBC 46011, and NDBC 46023 were examined. The correlation of minimum daily pressures are seen in Figure 48 through Figure 50. There is a high correlation of pressure fields across the widely spaced buoys. To calculate the expected delta pressure and associated sea level rise, the conservative minimum and maximum average historical pressure are used from these three data sets. Historically measured maximum, minimum, and average values for the three buoys are shown in Table 14. Table 14 also shows the pressure differential between average and minimum pressures for each buoy. The minimum and average atmospheric pressure results from NDBC 46028 are used to be conservative.

3.0 Background

The modeling focus is located on the Pacific Ocean in San Luis Obispo County, California, approximately 12 miles southwest of the city of San Luis Obispo. The reason for this is that the site has been well studied as part of the evaluation of potential impacts to a local breakwater that was partially damaged in a major 1981 storm event. This includes substantial assessments of return times of major Pacific storms recreated based on historical records going back to the late 19th century. Although the NDBC buoys only have records going back to the early 1980's, the ability to independently compare storm return times to the DELFT SWAN model is an invaluable opportunity that will allow an independent ground truth of the extreme return times

found here. Therefore, because these earlier storm models focused on the Central Coast breakwater, the DELFT-3D SWAN model will also focus there.

In 2009, the USACE Engineer Research and Development Center/Coastal and Hydraulics Laboratory (ERDC CHL) was tasked to review NOAA Technical Report NWS 23 (NWS, 1979). USACE found that several assumptions in the Probable Maximum Hurricane (PMH) that could possibly impact the West Coast as described in NWS 23 are not consistent with the current state of knowledge and recommended that the PMH concept be updated in accordance with new theoretical concepts and data.

What is the possible influence of hurricane based storm surges such as those found on the East and Gulf Coasts to the California Central Coast? Hurricane storm surges are produced by a combination of low atmospheric pressure and high winds. The low atmospheric pressure on the ocean water surface results in an increase in the height of the ocean. When coupled with hurricane type winds of 50 to 100 mph, ocean waters are forced to “pile up” against shorelines, especially when associated with extended, shallow, continental shelves. If the seawater mound impacts a coastal inlet, the piled up water can rise even higher, with tidal forces acting to compound the overall rise.

The Galveston, Texas hurricane that made landfall on September 8, 1900 was one of the worst recorded natural disasters in U.S. history. With wind speeds of 145 mph, and with Galveston built on an 8 foot maximum elevation sandy barrier island, the resultant storm surge reached heights of up to 4.6 m (15 feet). Other worst case hurricane induced storm surge elevations include Hurricane Camille (1969), where the storm surge exceeded 7.32 m (24 feet) and Katrina (2005) with a maximum storm surge exceeding 7.62 m (25 feet) at New Orleans (Blake et al., 2011). In comparison, the 1983 El Niño resulted in Pacific sea level elevations exceeding tidal elevations by approximately one foot.

Hurricanes, however, are rare events in California. Historically, even if a hurricane travels towards California, by the time it reaches the California coast, the hurricane has spent considerable time in the colder Pacific waters, becoming a Tropical Depression or Storm. One such event occurred in 1997, when Tropical Storm Ignacio made its way towards California, making landfall on August 20, 1997. Maximum wave heights observed at the NDBC 46215 Waverider Buoy showed a significant wave height (Hs) of 2 m, with a period of around 4 seconds (Figure 3). This is not atypical of such events along the California Coast, and the significant wave height (Hs) of 2 m is small compared to historical wind wave storm surges produced by the Pacific Ocean Fetch. Larger wave events tend to not come from a southerly direction (based on observations at multiple Central Coast buoys), but from the north westerly to westerly direction.

Wave dynamics on the US West Coast are significantly different than those associated with those on the Gulf and East Coasts. The primary factors that result in the different (and significantly larger) West Coast wind wave heights are long prevailing winds that can occur across what is referred to as the Pacific Ocean Fetch. Waves do not significantly loose energy once wind action has imparted energy to them (unless they run into winds blowing in the opposite direction), so waves produced by winds and strong storms across the entire very long Pacific Ocean fetch join together in wave trains that then impact the US West Coast, with large wave heights and long periods. The major wave heights associated with the California Central Coast are generally prevailing from the west-south-west to westerly directions.

Additionally, unlike the East Coast and Gulf, the continental shelf in the West is narrow and “steep”, and so long period wave energy, which usually loses energy through frictional interaction with the sea floor, has very little time in contact with shallow sea floors, unlike on the

East Coast and Gulf where the continental shelves are broad and where there is significant frictional interaction with Atlantic incoming waves, resulting in significantly smaller fetch based waves.

For approximately 30 years, an increasing number of wave buoys have been collecting time averaged wave height, period, and directional data (and in some cases much more detailed wave data) along the West Coast. Each of these data sets acts as an "integrator" of actual storm and wind wave events that cross the Pacific Ocean and land on coastal environs, and can be used to statistically predict the joint significant wave height and period for return periods of up to 10,000 years (Galiatsatou and Prinos, 2012). The usage of these data sets allow for a much higher confidence in the base wave height and periods that can be used as a source to predict extreme wave and high energy events, including the 200 year return period.

Probabilistic-only and the deterministic-only approaches to the estimation of very low-probability storm surges have their strengths and deficiencies, depending on the safety hazard assessment objective. Previous hazard assessments for storm surge have used a deterministic-only hazard approach. A probabilistic-deterministic methodology for storm surge or wind wave hazard assessment using a 10,000 year return period methodology was developed by Galiatsatou and Prinos, 2012, van den Brink, H.W., and G. P. Konnen, 2009, and Menéndez et al., 2008, in order to minimize the risk from the design basis storm surge. This 10,000 year horizon is somewhat unrealistic – 10,000 years ago the last ice age was coming to an end, and sea levels were rising from levels that were lower by as much as 50 m. However, the methodology as used for hurricane surges uses an integrative, interdisciplinary approach that incorporates state-of-the-art knowledge in hurricane science, hydrology, and probabilistic methods. That methodology is adapted here to include the following steps:

(1) Develop a stochastic set of significant wave height (H_s), peak period (T_p), and wave direction (W_{dir}) affecting the region of interest, as well as a stochastic set of expected wind speeds associated with the breakwater locale. This joint probability method will use historical data from the multiple wave buoys near the California Central Coast, and examine and compare that to the data from surrounding buoys along the California continental shelf to determine return period estimated curves for H_s, T_p, and W_{dir} up to 200 year.

(2) Develop a numerical hydrodynamic simulation of the region of interest using a high-resolution wave surge model, DEFLT 3D Flow and Wave, which uses SWAN (Simulating WAves Nearshore) (Deltares, 2017a, 2017b) as the primary wave analysis tool.

(3) Use of the relevant return period data of H_s, T_p, and W_{dir} and the numerical model, as described in Steps (1) and (2), develop information on the storm surge height events at the breakwater and cove near NDBC 46215.

A previous effort (Dooher, 2017) was the focus of step (1). This effort focuses on steps (2) and (3) and expands upon Step (1) using data from buoy NDBC 46028, NDBC 46011, NDBC 46023, and NDBC 46218.

4.0 Analysis

4.1 Previous Storm Surge Studies

A previous estimate of the maximum 200-year return period wave height was developed based on studies of a damaged breakwater in 1982-1984 (Resio, 1982, Borgman and Resio, 1982, Strange and Graham, 1982, Borgman and Strange, 1982, and Borgman and Strange, 1984) that attempted to hindcast a series of storms that could then be used to develop a Poisson based return period. The effort included the two teams deciding upon a series of historical storms that would use two different atmospheric modeling hindcast tools available at the time to

estimate H_s, T_p, and W_{dir}. Resio's and Strange's modeled locations for deep water are seen on Figure 1. The group then estimated the wave height at a location that would eventually become the mooring location for NDBC 46215, as seen in Figure 1. Resio's efforts resulted in wave peak periods significantly less than measured, as well as smaller significant wave heights, so the results of Strange and Graham were then used for further efforts. The significant wave height is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves (although the actual calculated significant wave height is defined slightly differently, this definition is appropriate for usage here).

Borgman and Strange (1984) used the distribution of estimated wave heights and energy to develop the Poisson average return period, and then projected the 200-year return period. The final estimate, based on Strange and Borgman's efforts, gave the "maximum individual wave height" of 13.95 m (45.75 feet). The maximum individual wave height is commonly considered to be 1.8 times the significant wave height, and represents only a small percentage in time of the total wave train (based on the frequency shape of the total wave train). This would make the 200-year return period for the significant wave height to be 7.75 m (25.43 feet).

Dooher, 2017 evaluated the historical record of wave heights from storms that have been measured at 16 California Central Coast NDBC buoys since the early 1980's, when a Waverider Buoy was installed at the location where the Resio (1982) and Strange and Graham (1982) efforts had estimated their significant wave heights. The Waverider is designated NDBC 46215, or CDIP 076. University of California Scripps Institute, CDIP, is responsible for archiving all data. This data is re-evaluated here and compared to four other NOAA Buoys, NDBC 46028, NDBC 46011, NDBC 46023, and NDBC 46218.

4.2 Extremal Estimates of Return Periods Based on Historical Records

For the storm surge at the breakwater, a computer-based numerical model is used to estimate the surge and wave effects based on a statistical assessment of measured storm waves at NDBC 46215/CDIP 076, which predicted the 200 year return period storm surge at the breakwater. Additionally, 200 year return periods are determined based on the historical data collected from NDBC 46028, NDBC 46011, NDBC 46023, and NDBC 46218, and is seen in Figure 51. The 200 year return periods are used to calibrate the numerical model, by matching numerical run results to the five estimated return periods.

4.3 Numerical Wave Model and Input

The numerical model is developed using the DELFT3D software package (Deltares, 2017b). Wave transformation is performed using Simulating WAves Nearshore (SWAN), part of Delft3D WAVE/SWAN. SWAN is a spectral wave model that evaluates the refracted wave height and wave angle based on a spectrum of waves using linear wave theory. The main inputs to SWAN include the water depth, the wave spectra, and the friction factor. The SWAN model accounts for (refractive) propagation due to current and depth and represents the processes of wave generation by wind, dissipation due to whitecapping, bottom friction and depth-induced wave breaking, and non-linear wave-wave interactions (both quadruplets and triads) explicitly with state-of-the-art formulations. Wave blocking by currents is also explicitly represented in the model. Output from the model includes significant wave height, wave period, wave dissipation, and wave direction at each point within the computational grid.

The SWAN model is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequencies). The latter implies that short-crested random wave fields propagating simultaneously from widely different directions can be accommodated (e.g. a wind

sea with super imposed swell). SWAN computes the evolution of random, short-crested waves in coastal regions with deep, intermediate and shallow water and ambient currents.

Coastal surges are driven primarily by momentum transmitted to the water column towards the coast by winds and momentum. Waves propagate energy and momentum toward the coast due to the processes of refraction, diffraction, and dissipation. This momentum transfer causes a horizontal variation of the water column, commonly called wave setup. This variation is obvious in the variation of a significant wave height. The corresponding variation in momentum transport is less obvious. This notion of spatially varying momentum transport in a wave field is called "radiation stress" (Deltares, 2017b). Wave setup that occurs due to the momentum transfers from waves must also be included in maximum surge elevations.

The momentum transfer and loss rate from wave breaking is dependent on the slope and depth of the sea bottom, and varies considerably throughout a region of interest and from site to site. The wave forces will, among others, enhance the energy dissipation near the bottom in the storm surge model and generate a net mass flux affecting the current, especially in the cross-shore direction. Additionally, wind stresses can be added into the model to create local wind run ups. Water levels and directly input into the wave model, which is then used to compute the wave parameters.

The wave and storm surge analyses are performed using the Delft3D WAVE/SWAN module to simulate wave propagation (wave spectra, height, period, and setup) through a water body (Pacific Ocean) when acted upon by external forcing functions (wind fields). Antecedent tidal levels, low atmospheric pressure impacts on sea level, and sea level rise are examined by setting the water level to match those expected levels. Although Delft3D WAVE can be used interactively with Delft3D FLOW, this was not done for this project since the California Central Coast is not exposed to extremely low pressure tropical storms or hurricanes and the winds associated with them.

The physical features of the numerical model are created from regional and local bathymetry and topography. The model was then calibrated to calculated 200 year return period significant wave heights based on observations from the Central Coast NOAA NDBC Buoy network.

The antecedent water level conditions including 10 percent exceedance high and low tides and potential sea level rise are included in the numerical model. Sea level rise is estimated based on the local sea level rise at the Port San Luis tidal stations as well as a 0.52 m sea level rise sensitivity factor. The exact water level inputs as used in Delft3D Simulation are found in Table 15, which includes the NADV88 0 m water level, the High Antecedent Water Level (HAWL) of 2.13 m NAVD88 (7 feet) and the Alternative High Antecedent Water Level (HHWL) of 2.65 m NAVD88 (8.7 feet).

In order to address storm surge (associated with low atmospheric pressures) the results as found in Table 14, based on historically measured average and minimum pressures at NDBC Buoy 46028, were used. In order to calculate the pressure induced surge rise, the change in sea level is solved as:

$$\Delta h = \frac{\Delta P}{\rho g}$$

Where the density, ρ, is the density of sea water, and g is the acceleration of gravity. The resultant surge is ~0.383 m. This is added to the HHWL level of 2.65 m to get a total of 3.03 m NAVD88, shown in Table 15, and becomes the Surge Antecedent Water Level (SAWL).

The numerical model extends to the edge of the continental shelf, to the south of Point Arguello, and to the north of Monterey. The domain size was chosen such that the boundaries are of

sufficient distance so that influences at the model boundaries do not affect the results at the area of interest. The numerical model domain is shown in Figure 52 through Figure 54 and uses a nested grid approach to account for the regional (deep ocean) and local characteristics (i.e., shallow coastal waters and the breakwater).

Delft3D can employ a nested grid approach when models extend over large domains. Delft Dashboard used two bathymetric domains to develop the nine level nested model used here. Large-spaced grids are used in the overall domain, and successively finer detailed grids are used nearer the area of interest. In this model, three nested grids are used. The nested grids and details as used in Delft3D simulation are found in Table 16. The gridded domain is created with the Delft Dashboard module, and uses a UTM10 horizontal grid (meters, northing and easting) for the computational domain, with the vertical datum referenced to NAVD88 (meters). Detailed local and regional bathymetric and topographic data sources are used to develop the boundary conditions: Development of the bathymetry is detailed 2014.

Many of the default parameters for the Delft3D WAVE/SWAN model were used without change. Critical inputs however are wave direction and significant wave height, as well as average wind speed and direction. Maximum wave patterns typically derive from the West to North West, at approximately 270° to 285°. To be conservative, the model uses as inputs a westerly wave direction combined with an average wind speed of 10 m/s, also coming from the west a 270°. The combination of the two were used to assist in calibrating the wave heights at wave buoy NDBC 46215, as well as the outlying NDBC buoys (NDBC 46011, NDBC 46023, NDBC 46028, and NDBC 46218) to match the 200 year return period as conservatively calculated both here and in Dooher, 2017.

Table 17 shows major changes of inputs to the numerical model, including the use of a 0.1118 Collins bottom friction coefficient as calibration parameter to match extremal 200 year return period significant wave heights for the NDBC deeper water buoys to the estimated extremal 200 year return period. The Collins friction coefficient was adjusted until the simulated significant wave heights were close to estimated five NDBC buoy extremal 200 year return period levels (resulting in less than 1% average difference) and are seen in Table 18.

5.0 Results and Conclusion

Table 19 through Table 22 shows the numerical results for significant wave height and other pertinent outputs for the five NDBC Buoys. A 270° input results in a wave direction of approximately 255° (which is in keeping with earlier modeling work by Strange and others).

Discussed earlier, and repeated here is the concept of the maximum wave height. The maximum wave height is taken to be 1.8 x the significant wave height, and represents only a small percentage of the state of the overall wave train (based on the wave energy shape) of the total significant wave height, which itself is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves (although the actual calculated significant wave height is defined slightly differently, this definition is appropriate to the moment).

Figure 55 shows observation points for the Delft3D numerical output, seen in detail in Table 23 through Table 27. Figure 56 and Figure 57 show the calculated 200 year return period significant wave height and the maximum wave height for 0.0 m NADV88 at the observation points as found in Figure 55. Shaded cells in the Tables represent observation points within the Intake Cove as protected by the breakwater. For the HHWL antecedent sea level rise to 2.65 m NAVD88 (Figure 58 and Figure 59), a calculated 200 year return period peak significant wave height at the buoy (8.03 m) with the maximum wave height seen at 14.45 m. Wave heights at the breakwater are slightly less, 7.9 m.

For the additional surge related to atmospheric low pressure, the result is a slightly increased significant wave height at the buoy of 0.016 m, raising the significant wave height there to 8.04 m SAWL. The results for the surge due to atmospheric pressure conditions can be seen in Table 26. Figure 60 and Figure 61 show the significant and maximum wave heights, respectively, at the buoy and outside the breakwater, although the increases are slight.

In order to assess how high the tops of the waves actually rise, the concept of the Crest Wave Level is introduced, or the elevation at the top of the wave (whether it be significant wave height or maximum wave height). The Crest Wave Level is defined as:

$$CWL = \frac{1}{2} H + AWL$$

The Crest Wave Level can be determined for any combination of antecedent water level and wave height. Table 27 specifically shows the maximum wave height in both metric and English units, as well as the Crest Wave Level referenced to NAVD88 for the four antecedent water levels. The maximum wave height found within the breakwater area is approximately 1.8 m (near the breakwater entrance); the maximum wave height near the Intake Structure is approximately 1 m at 3.03 m NAVD88 SAWL.

The maximum CWL found near the Intake Structure is 3.48 m, NAVD88. For comparison, the Intake Structure's Main Deck is 6.22 m. Figure 62 shows, for the SAWL conditions of 3.03 NAVD88, the estimated Crest Wave Level at the various observation points near the breakwater and inside the Intake Cove. Maximum CWL at the outside of the breakwater is 10.2 m, averaging approximately 9 m in front of the breakwater.

As can be seen in Figure 56 through 62, and in Table 23 through 27, wave heights significantly decrease from outside the breakwater to inside the breakwater near the Intake Structure and through the Intake Cove. The breakwater reduces overall wave heights by a factor of ~15 to 1. This is consistent even with higher antecedent water levels.

In comparison to the calculated results of Borgman and Strange (1984), they projected a 200-year return period "maximum individual wave height" of 13.95 m, which is 0.53 m below the level calculated here for maximum SAWL wave height. Their calculated 200-year return period for the significant wave height was 7.75 m, or 0.29 m less than the SAWL 200 year return period significant wave height calculated here. Borgman and Strange (1984) calculated their wave statistics at a site referred to as the SCAN site, which became the eventual location for NDBC 46215. Considering the uncertainties and differing methods used to calculate these numbers, these differences are insignificant.

Figure 60 through Figure 71 show the Delft3D output for the following different physical variables, calculated for a 0.0 m NAVD88, 2.13 m NAVD88 antecedent water level (HAWL), and 2.65 m NAVD88 (HHWL) sea level rise at a 2 m spatial resolution. The variables examined are:

- Significant Wave Height [m];
- Fraction of Wave Breaking [-];and
- Mean Wave Period [s].

For significant wave height (Figure 63 through Figure 66), the increases within the breakwater between the 0 m NAVD88 and 2.65 m NAVD88 HHWL sea level are minor, and are barely visible in comparing Figure 63 through Figure 66. Figure 66 begins to show visible differences in wave height inside the breakwater, but even then significant wave heights inside the breakwater don't generally exceed 1 m throughout the majority of the Intake Cove, with maximum levels

found near the northern breakwater entrance (as discussed above in reference to the observation points). The area of the breakwater impacted by storm waves has visibly increased at the 3.03 m NAVD88 SAWL. More highly resolved figures of the Intake Cove are discussed below.

Figure 67 through Figure 70 show the fraction of wave breaking, with slightly more wave breaking as water levels increase. As would be expected, the majority of wave breaking occurs at the northern breakwater, with more breaking visible in Figure 70 at the 3.03 NAVD88 SAWL.

For mean wave period (Figure 71 through Figure 74), the greatest variability in mean wave periods are seen inside the breakwater. For the 0 m NAVD88, a clear demarcation between high periods and low period waves is seen inside the breakwater, although wave heights are still insignificant inside the breakwater. For the 2.13 m and 2.65 m water levels, the mean period is more chaotic. Interestingly, Figure 74 shows a return to the clear demarcation pattern found at the 0 m NAVD88 wave level, although it is a bit more pronounced. The differences in these figures seem to indicate that minor seiche conditions are occurring inside the breakwater area.

To examine this, we introduce the equation for a surface seich. We assume that the Intake Cove is “closed” and therefore the equation of interest for a surface seiche is:

$$T_n = \frac{2l}{n\sqrt{gz}}$$

Where l is the basin length, z is the average basin depth, n is the number of nodes of the natural frequency, and g the acceleration of gravity.

Table 28 and Table 29 show the natural seiche periods for two different basin lengths (the short direction and the long direction, as seen in Figure 75, which shows the basin water depths for the 3.03 m NAVD88 SAWL. For the first mode, the Intake Cove shows no possibility to have a seiche occurring (as based on the results in Figure 71 through Figure 74). However, for smaller wavelengths (and higher nodal points), there appears to be a possibility of a seiche effect. So although the mean wave periods as seen in Figures 71 through 74 do seem to indicate that a seiche is taking place, the wave heights found are small, and the energy that would be associated with the seiche is low and not of concern.

This is confirmed by examining Figures 75 through 79, significant wave height in the Intake Cove, limited to a 3 m significant wave height, so as to obtain better resolution of wave conditions. All figures show that the wave height in the interior of the cove is small, typically less than 1 m, indicating this would be the maximum possible seiche level.

6.0 References

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Table 1: Table of Maximum Wave Heights, Wind Speeds, and Direction (by Date) Part 1.

			Wind Direction Avg			St Dev Wind Direction			Max Daily Wind Speed			Avg Daily Wind Speed			St Dev Wind Speed		
Year	Month	Date	46011	46023	46028	46011	46023	46028	46011	46023	46028	46011	46023	46028	46011	46023	46028
2008	2	24	175.0	179.8		24.4	30.4		17.5	20.1		9.8	10.0		4.2	5.0	
2008	2	25	316.8	326.3		32.1	33.3		9.5	9.9		6.0	7.1		2.0	2.1	
2007	12	4	329.7	340.0		11.3	8.3		10.8	11.8		7.2	8.1		1.8	2.1	
2001	1	11	218.7	214.0	206.4	33.6	32.3	27.7	14.5	16.3	13.3	8.7	10.0	9.1	2.4	2.4	2.3
2001	1	12	189.1	189.3	229.3	40.9	44.4	90.4	12.9	12.8	9.8	7.2	7.4	5.8	3.2	3.9	2.7
2007	12	5	336.3	340.6		10.9	9.1		11.5	12.5		8.3	10.0		1.5	1.2	
2004	2	26	216.4	238.8	234.3	56.6	52.5	35.8	7.2	7.7	8.6	4.5	5.2	5.9	1.7	1.4	1.4
2007	1	5	319.8	283.5	347.0	68.7	128.0	5.5	16.4	18.6	17.3	12.9	14.5	15.5	2.4	2.9	1.0
2008	1	5	192.5	210.8		34.6	34.7		14.2	14.2		5.4	5.6		3.8	4.1	
2000	12	22	330.4	312.5	306.9	10.1	8.0	17.0	10.2	11.4	9.1	7.6	8.7	5.2	1.7	1.8	2.4
1999	4	4	308.2	299.5	312.0	11.3	7.5	5.7	18.4	20.9	18.1	12.7	15.2	14.3	3.1	3.0	2.3
1999	1	27	169.7	258.0	322.3	154.9	132.2	6.6	10.7	13.2	13.0	6.3	8.4	9.9	1.6	2.0	1.6
2001	12	21	267.8		268.1	37.4		37.3	11.8	11.0	13.8	8.1	9.2	10.1	1.9	2.1	2.0
1998	12	9	174.5	282.0	278.2	164.9	124.7	90.8	10.9	13.1	13.0	7.1	8.9	9.5	1.8	1.8	4.0
1998	12	1	192.3	163.4	220.8	137.1	135.7	98.7	10.7	12.7	10.6	5.2	5.5	6.9	2.6	3.4	2.3
1999	1	26	259.0	256.2	265.0	20.2	14.3	14.0	11.2	14.0	10.7	6.6	8.1	7.0	2.2	2.6	2.0
2000	12	23	316.5	312.2	318.5	67.4	9.1	6.5	10.5	12.6	11.8	6.7	10.2	9.1	2.6	1.7	0.9
2001	5	2	323.8	324.4	315.8	4.1	5.2	4.4	12.3	14.0	17.2	9.8	12.0	14.9	1.4	1.2	1.2
2009	11	8	332.3	272.5		15.6	341.1		10.5	11.4	13.3	8.2	9.8	8.7	1.3	1.5	2.6
1998	11	26	260.6	299.0	249.5	125.9	59.9	90.4	9.5	9.7	6.0	4.5	5.8	3.1	2.0	1.6	1.8
2009	11	7	319.2	333.5		5.2	4.3		11.8	14.2	14.5	9.5	11.2	11.5	1.3	1.6	2.1
2008	5	22	315.7	327.5	326.6	5.6	4.8	3.2	15.1	18.2	17.2	13.4	15.8	15.8	1.5	1.6	1.1
2008	1	6	229.0	224.3		62.8	74.3		10.6	11.4		5.5	6.0		2.5	2.8	
1999	2	17	223.4	290.7	243.5	118.3	20.0	65.9	8.2	9.0	6.1	3.3	4.3	3.9	2.1	2.2	1.1

Table 2: Table of Maximum Wave Heights, Wind Speeds, and Direction (by Date) Part 2.

			Maxi Daily Significant Wave Height					Max Daily Peak Significant Wave Period					Avg Daily Wave Direction				Std Dev, Wave Direction			
Year	Month	Date	46011	46023	46028	46215	46218	46011	46023	46028	46215	46218	46011	46028	46215	46218	46011	46028	46215	46218
2008	2	24	6.99	7.42	5.78	5.58	9.97	21.05	20.00	19.05	20.00	20.00	228.0	210.8	225.2	214.4	43.0	46.2	30.5	57.9
2008	2	25	6.95	7.26	5.68	5.04	7.5	17.39	20.00	16.00	18.18	18.18	272.5	281.6	254.9	271.1	5.1	10.1	7.1	4.6
2007	12	4	5.05	5.73	5.92	4.2	7.37	19.05	20.00	19.05	20.00	20.00	272.6	275.1	254.3	267.3	8.6	9.5	5.2	5.0
2001	1	11	6.98	7.66	8.51	6.5	7.23	16.67	16.67	16.67	16.67	16.67			269.9	293.6			7.0	5.1
2001	1	12	7.04	6.67	6.95	5.6	7.21	16.67	16.67	16.67	16.67	16.67			267.4	294.7			8.6	4.3
2007	12	5	5.62	7.23	5.59	4.72	7.14	19.05	20.00	19.05	20.00	18.18	273.3	280.2	251.0	266.1	7.5	6.5	7.5	4.1
2004	2	26	7.16	6.75	7.65	5.94	7.13	16.67	20.00	20.00	18.18	18.18		259.3	264.2	287.0		39.3	13.7	6.0
2007	1	5	6.22	6.66	6.92	3.96	7.12	17.39	16.67	17.39	18.18	16.67	299.3	311.0	264.8	305.5	9.4	13.5	11.7	8.8
2008	1	5	8.62	7.61	8.96	6.42	7.08	19.05	20.00	19.05	20.00	20.00	276.5	268.5	254.8	278.0	34.4	33.1	18.8	23.1
2000	12	22	6.21	5.28	7.91	6.05	6.4	20.00	20.00	20.00	20.00	20.00			261.8	283.9			6.7	7.8
1999	4	4	6.64	6.58	7.72	3.66	6.57	12.50	14.29	14.29	15.38	15.38			274.8	311.0			5.5	3.4
1999	1	27	6.65	6.26	7.7	5.33	6.06	16.67	16.67	16.67	16.67	16.67			269.8	302.1			3.4	4.7
2001	12	21	6.37	7.1	7.68	5.45	6.12	16.67	16.67	16.67	16.67	16.67			264.5	287.2			5.5	4.8
1998	12	9	6.52	6.84	7.5	4.15	4.83	20.00	20.00	20.00	20.00	18.18			270.6	301.0			6.9	5.8
1998	12	1	6.27	6.71	7.44	5.33	5.78	20.00	20.00	20.00	20.00	18.18			264.3	289.4			6.5	6.2
1999	1	26	4.22	3.73	7.31	4.37	4.07	16.67	16.67	16.67	16.67	16.67			273.5	302.8			4.0	6.1
2000	12	23	7.21	6.78	7.27	6.12	6.39	20.00	16.67	16.67	18.18	18.18			266.1	288.3			5.2	3.4
2001	5	2	6.33	5.86	7.22	4.33	6.05	16.67	16.67	14.29	16.67	15.38			272.4	305.5			3.9	4.5
2009	11	8	5.35	6.68	7.19	3.42	6.37	19.05	20.00	17.39	18.18	18.18	317.5	317.5	265.3	307.5	7.2	6.3	4.9	3.4
1998	11	26	4.92	5.67	7.09	4.36	4.87	20.00	20.00	20.00	18.18	18.18			269.5	293.2			5.2	4.4
2009	11	7	5.51	6.06	7.03	3.93	6.93	19.05	20.00	19.05	20.00	20.00	314.2	317.8	269.6	305.4	8.6	3.0	4.6	6.3
2008	5	22	5.98	6.02	7	3.7	6.82	12.12	12.50	12.90	13.33	13.33	318.3	316.0	277.3	315.1	4.6	3.6	3.9	4.1
2008	1	6	7.19	7.14	6.14	4.4	5.77	17.39	16.67	17.39	18.18	18.18	298.6	293.9	261.4	296.6	5.1	6.1	4.7	3.9
1999	2	17	7.13	5.4	5.35	4.15	5.55	20.00	20.00	20.00	20.00	20.00			269.1	291.8			6.2	3.8

Table 3: NDBC 46011 Wind Speed Daily Average, Generalized Extreme Value Fit.

Distribution:	Generalized Extreme Value
Log likelihood:	-22865.4
Domain:	-Inf < y < Inf
Mean:	5.54834
Variance:	6.65254

Parameter	Estimate	Std. Err.
k	-0.112878	0.00892865
sigma	2.2816	0.0197421
mu	4.4626	0.0266899

Estimated covariance of parameter estimates:

	k	sigma	mu
k	7.97208e-05	-9.13574e-05	-0.000104259
sigma	-9.13574e-05	0.000389751	0.000167268
mu	-0.000104259	0.000167268	0.000712352

Table 4: NDBC 46011 Wind Speed Daily Maximum, Weibull Fit.

Distribution:	Weibull
Log likelihood:	-24301.5
Domain:	0 < y < Inf
Mean:	8.60286
Variance:	8.68497

Parameter	Estimate	Std. Err.
A	9.60445	0.0319889
B	3.20456	0.025362

Estimated covariance of parameter estimates:

	A	B
A	0.00102329	0.000255889
B	0.000255889	0.000643231

Table 5: NDBC 46011 Significant Wave Height Daily Maximum, Birnbaum-Saunders Fit.

Distribution:	Birnbaum-Saunders
Log likelihood:	-14016
Domain:	0 < y < Inf
Mean:	2.52364
Variance:	1.10233

Parameter	Estimate	Std. Err.
beta	2.328	0.00918045
gamma	0.409979	0.00284858

Estimated covariance of parameter estimates:

	beta	gamma
beta	8.42807e-05	-2.11223e-09
gamma	-2.11223e-09	8.11443e-06

Table 6: NDBC 46023 Wind Speed Daily Average, Generalized Extreme Value Fit.

Distribution:	Generalized Extreme Value
Log likelihood:	-22816
Domain:	-Inf < y < Inf
Mean:	6.93574
Variance:	8.6229

Parameter	Estimate	Std. Err.
k	-0.201551	0.00795515
sigma	2.79566	0.0240143
mu	5.79499	0.0329766

Estimated covariance of parameter estimates:

	k	sigma	mu
k	6.32845e-05	-0.000106763	-0.000107922
sigma	-0.000106763	0.000576685	0.000141632
mu	-0.000107922	0.000141632	0.00108746

Table 7: NDBC 46023 Wind Speed Daily Maximum, Weibull Fit.

Distribution:	Weibull
Log likelihood:	-23423.2
Domain:	0 < y < Inf
Mean:	9.85264
Variance:	10.0591

Parameter	Estimate	Std. Err.
A	10.9614	0.035196
B	3.43424	0.0277322

Estimated covariance of parameter estimates:

	A	B
A	0.00123876	0.000308698
B	0.000308698	0.000769074

Table 8: NDBC 46023 Significant Wave Height Daily Maximum, Birnbaum-Saunders Fit.

Distribution:	Birnbaum-Saunders
Log likelihood:	-12710.8
Domain:	0 < y < Inf
Mean:	2.69821
Variance:	1.16507

Parameter	Estimate	Std. Err.
beta	2.50341	0.0101143
gamma	0.394498	0.00291383

Estimated covariance of parameter estimates:

	beta	gamma
beta	0.000102299	6.08265e-09
gamma	6.08265e-09	8.4904e-06

Table 9: NDBC 46028 Wind Speed Daily Average, Generalized Extreme Value Fit.

Distribution:	Generalized Extreme Value
Log likelihood:	-25798.8
Domain:	-Inf < y < Inf
Mean:	6.54955
Variance:	10.3389

Parameter	Estimate	Std. Err.
k	-0.183688	0.00970359
sigma	3.02103	0.0266125
mu	5.27765	0.0354334

Estimated covariance of parameter estimates:

	k	sigma	mu
k	9.41597e-05	-0.00015725	-0.000163459
sigma	-0.00015725	0.000708224	0.000256997
mu	-0.000163459	0.000256997	0.00125553

Table 10: NDBC 46028 Wind Speed Daily Maximum, Weibull Fit.

Distribution:	Weibull
Log likelihood:	-26273.6
Domain:	0 < y < Inf
Mean:	9.35893
Variance:	11.2633

Parameter	Estimate	Std. Err.
A	10.4736	0.0362254
B	3.04529	0.0246245

Estimated covariance of parameter estimates:

	A	B
A	0.00131228	0.000275603
B	0.000275603	0.000606365

Table 11: NDBC 46028 Significant Wave Height Daily Maximum, Birnbaum-Saunders Fit.

Distribution:	Birnbaum-Saunders
Log likelihood:	-13847
Domain:	0 < y < Inf
Mean:	2.82405
Variance:	1.19417

Parameter	Estimate	Std. Err.
beta	2.63218	0.00994367
gamma	0.381826	0.00272109

Estimated covariance of parameter estimates:

	beta	gamma
beta	9.88765e-05	5.86404e-10
gamma	5.86404e-10	7.40432e-06

Table 12: NDBC 46215 Significant Wave Height Daily Maximum, Birnbaum-Saunders Fit.

Distribution:	Birnbaum-Saunders
Log likelihood:	-10586.9
Domain:	0 < y < Inf
Mean:	1.89145
Variance:	0.570015

Parameter	Estimate	Std. Err.
beta	1.75544	0.0066822
gamma	0.393649	0.00274509

Estimated covariance of parameter estimates:

	beta	gamma
beta	4.46518e-05	4.53201e-09
gamma	4.53201e-09	7.53549e-06

Table 13: NDBC 46218 Significant Wave Height Daily Maximum, Birnbaum-Saunders Fit.

Distribution:	Birnbaum-Saunders
Log likelihood:	-8428.3
Domain:	0 < y < Inf
Mean:	2.75216
Variance:	1.12021

Parameter	Estimate	Std. Err.
beta	2.56727	0.0122202
gamma	0.379515	0.00342783

Estimated covariance of parameter estimates:

	beta	gamma
beta	0.000149333	4.51782e-09
gamma	4.51782e-09	1.175e-05

Table 14: Maximum, Average, and Minimum Measured Atmospheric Pressures.

	Max (hPa)	Min (hPa)	Avg(hPa)	dP (hPa)
46011	1034.5	986.6	1016.022	29.42
46023	1032.9	981.3	1016.09	34.79
46028	1034.7	978.3	1016.774	38.47
Used		978.3	1016.774	38.47

Table 15: Water Level Inputs as Used in Delft3D Simulation.

Calibration Level:	0.00 m, NAVD88
High Antecedent Water Level (HAWL):	2.13 m, NAVD88
Alternative High Antecedent Water Level (HHWL):	2.65 m, NAVD88
Surge Antecedent Water Level (SAWL):	3.03 m, NAVD88

Table 16: Nested Grids and Details as Used in Delft3D Simulation.

Grid Name	Size [m]	Grid points M	Grid points N	Data Source	Projection	Angle
RES0600m	600	351	676	GEBCO 08	WGS 84 UTM Zone 10	36.35°
RES0400m	400	255	651	GEBCO 08	WGS 84 UTM Zone 10	36.35°
RES0200m	200	301	702	Central Coast	WGS 84 UTM Zone 10	30.00°
RES0100m	100	239	761	Central Coast	WGS 84 UTM Zone 10	30.00°
RES0030m	30	247	501	Central Coast	WGS 84 UTM Zone 10	30.00°
RES0010m	10	404	501	Central Coast	WGS 84 UTM Zone 10	30.00°
RES0007m	7	435	556	Central Coast	WGS 84 UTM Zone 10	30.00°
RES0004m	4	426	556	Central Coast	WGS 84 UTM Zone 10	30.00°
RES0002m	2	496	501	Central Coast	WGS 84 UTM Zone 10	30.00°

Table 17: Boundary and Physical Inputs as Used in Delft3D Simulation.

- Significant wave height, 11.2 m
- Peak wave period, 20 s
- Wave Direction, 270° (westerly)
- Directional spreading, 4°
- Wind Velocity, 10 m/s
- Wind Direction, 270° (westerly)
- Water Density, 1,025 kg/m^3
- Collins Bottom Friction Coefficient, 0.1118 (calibrated)

Table 18: Estimated 200 Year Return Period calibrated to Delft3D significant wave height.

NDBC Buoy	200 Yr RP (Hsig) [m]	Delft3D (Hsig) [m]	Percent Difference
46028	11.407	11.5510	-1.26%
46215	7.9061	7.9058	0.00%
46011	11.049	11.0456	-1.37%
46023	11.306	11.2005	-0.43%
46218	11.042	11.3541	-0.03%

Table 19: Locations and H_{sig}, Dir, and Period at NDBC Buoy Locations (0 m NAVD88 water level).

NDBC Buoy	UTM E [m]	UTM N [m]	Depth [m]	Hsig [m]	Dir [deg]	Tm01 [sec]	Dspr [deg]	Ubot [m/s]
46215	694884	3897754	27.2	7.91	254.5	13.9	22.7	1.96E+00
46218	703720	3815178	548.0	11.05	274.4	15.5	17.1	2.46E-02
46028	600897	3955839	1112.9	11.55	276.7	15.8	18.4	5.74E-04
46011	683277	3874886	405.2	11.20	275.4	15.6	17.8	7.29E-02
46023	686202	3843197	388.5	11.35	276.2	15.6	18.3	8.38E-02

Table 20: Locations and H_{sig}, Dir, and Period at NDBC Buoy Locations (2.13 m NAVD88 water level).

NDBC Buoy	UTM E [m]	UTM N [m]	Depth [m]	Hsig [m]	Dir [deg]	Tm01 [sec]	Dspr [degr]	Ubot [m/s]
46215	694884	3897754	29.4	8.01	255.7	13.9	23.3	1.89E+00
46218	703720	3815178	550.1	11.05	274.4	15.5	17.1	2.42E-02
46028	600897	3955839	1115.1	11.55	276.7	15.8	18.3	5.66E-04
46011	683277	3874886	407.3	11.20	275.4	15.6	17.8	7.18E-02
46023	686202	3843197	390.6	11.36	276.2	15.6	18.3	8.25E-02

Table 21: Locations and H_{sig}, Dir, and Period at NDBC Buoy Locations (2.65 m NAVD88 water level).

NDBC Buoy	UTM E [m]	UTM N [m]	Depth [m]	Hsig [m]	Dir [deg]	Tm01 [sec]	Dspr [deg]	Ubot [m/s]
46215	694884	3897754	29.9	8.03	255.9	13.9	23.4	1.87E+00
46218	703720	3815178	550.6	11.05	274.4	15.5	17.1	2.41E-02
46028	600897	3955839	1115.6	11.55	276.7	15.8	18.3	5.64E-04
46011	683277	3874886	407.8	11.20	275.4	15.6	17.8	7.15E-02
46023	686202	3843197	391.1	11.36	276.2	15.6	18.3	8.21E-02

Table 22: Locations and H_{sig}, Dir, and Period at NDBC Buoy Locations (3.03 m NAVD88 water level).

NDBC Buoy	UTM E [m]	UTM N [m]	Depth [m]	Hsig [m]	Dir [deg]	Tm01 [sec]	Dspr [deg]	Ubot [m/s]
46215	694884	3897754	30.3	8.04	256.1	13.9	23.4	1.86E+00
46218	703720	3815178	551.0	11.05	274.4	15.5	17.1	2.40E-02
46028	600897	3955839	1116.0	11.55	276.7	15.8	18.3	5.63E-04
46011	683277	3874886	408.2	11.20	275.4	15.6	17.8	7.13E-02
46023	686202	3843197	391.5	11.36	276.2	15.6	18.3	8.19E-02

Table 23: Local Breakwater Observation Points, Calculated Significant and Maximum Wave Heights, Direction, Period, and Rotational Velocity (at Seafloor Bottom) – 0 m (NAVD88).

Observ Point	UTME [m]	UTMN [m]	Depth [m]	Hsig [m]	Hmax [m]	Hmax [ft]	Dir [deg]	Tm01 [sec]	Dspr [deg]	Ubot [m/s]
46215	694884	3897754	27.2	7.91	14.23	46.7	254.5	13.9	22.7	2.0
1	695142	3898200	7.6	0.19	0.34	1.1	183.5	4.7	8.1	0.1
2	695167	3898191	8.9	0.24	0.44	1.4	197.7	8.0	10.1	0.1
3	695193	3898179	8.9	0.18	0.33	1.1	207.2	10.4	11.1	0.1
4	695136	3898172	6.7	0.27	0.48	1.6	186.7	7.4	6.6	0.1
5	695164	3898163	6.6	0.30	0.54	1.8	202.9	10.3	7.7	0.2
6	695198	3898153	8.2	0.15	0.26	0.9	220.9	9.5	6.8	0.1
7	695096	3898164	3.3	0.70	1.25	4.1	158.1	11.6	8.6	0.6
8	695142	3898128	7.8	0.33	0.60	2.0	198.1	7.2	8.9	0.2
9	695173	3898126	9.4	0.21	0.37	1.2	221.5	9.1	6.6	0.1
10	695204	3898108	11.4	0.18	0.33	1.1	264.3	12.4	6.6	0.1
11	695102	3898112	8.7	0.67	1.21	4.0	165.4	9.0	4.0	0.3
12	695111	3898068	10.0	1.19	2.15	7.1	157.5	12.3	5.0	0.5
13	695132	3898026	12.7	1.71	3.07	10.1	166.5	12.3	8.4	0.7
14	695166	3898008	12.6	2.97	5.34	17.5	200.6	13.2	13.4	1.2
15	695197	3897988	11.3	4.63	8.33	27.3	211.0	14.6	16.7	2.0
16	695236	3897971	12.5	3.83	6.89	22.6	238.1	13.7	12.3	1.5
17	695140	3897975	14.3	3.61	6.50	21.3	200.1	13.3	17.4	1.3
18	695174	3897962	16.7	4.10	7.38	24.2	226.1	13.0	15.2	1.4
19	695217	3897942	12.7	6.10	10.97	36.0	247.6	15.1	17.3	2.5
20	695016	3898166	8.5	4.98	8.96	29.4	234.3	14.2	13.4	2.5
21	695020	3898124	10.4	5.67	10.21	33.5	247.0	14.2	18.0	2.5
22	695022	3898074	10.7	6.46	11.63	38.2	259.9	14.7	24.9	2.9
23	695026	3898012	13.0	4.79	8.62	28.3	251.3	13.7	35.3	1.9
24	695008	3897980	18.0	5.60	10.09	33.1	240.1	13.7	36.3	1.8
25	695039	3897975	8.1	6.57	11.83	38.8	247.9	14.9	23.1	3.4
26	695010	3897935	15.2	7.54	13.57	44.5	254.7	14.4	24.9	2.7
27	695061	3897932	10.8	7.52	13.53	44.4	223.2	15.0	24.4	3.3
28	695104	3897934	19.4	5.23	9.41	30.9	234.8	13.3	15.5	1.6
29	695143	3897922	21.8	6.08	10.95	35.9	239.5	14.1	13.8	1.8
30	695179	3897909	20.9	6.60	11.87	38.9	248.4	14.1	15.3	2.0
31	695237	3897896	10.2	7.38	13.28	43.6	248.6	15.6	30.0	3.4
32	695017	3897900	23.0	7.77	13.98	45.9	254.4	14.1	21.7	2.2
33	695057	3897900	22.9	7.55	13.58	44.6	252.2	14.1	18.6	2.1
34	695100	3897894	22.1	7.45	13.40	44.0	249.5	14.2	17.3	2.1
35	695139	3897888	21.8	7.03	12.66	41.5	249.1	14.0	17.5	2.0
36	695194	3897880	21.0	7.32	13.17	43.2	248.8	14.3	16.4	2.2

* Shaded cells indicate observation points within the breakwater Intake Cove.

Table 24: Local Breakwater Observation Points, Calculated Significant and Maximum Wave Heights, Direction, Period, and Rotational Velocity (at Seafloor Bottom) – 2.13 m (NAVD88).

Observ Point	UTME [m]	UTMN [m]	Depth [m]	Hsig [m]	Hmax [m]	Hmax [ft]	Dir [deg]	Tm01 [sec]	Dspr [deg]	Ubot [m/s]
46215	694884	3897754	29.4	8.01	14.41	47.28	255.7	13.9	23.3	1.89
1	695142	3898200	9.7	0.27	0.49	1.61	182.2	4.8	8.1	0.09
2	695167	3898191	11.0	0.41	0.75	2.45	195.0	9.6	9.7	0.17
3	695193	3898179	11.0	0.36	0.65	2.13	203.5	10.2	9.6	0.15
4	695136	3898172	8.9	0.37	0.66	2.16	184.6	6.3	6.7	0.15
5	695164	3898163	8.8	0.48	0.86	2.81	199.3	10.4	8.1	0.22
6	695198	3898153	10.3	0.35	0.62	2.05	217.4	11.1	7.2	0.15
7	695096	3898164	5.4	0.83	1.49	4.89	160.5	11.8	7.5	0.52
8	695142	3898128	9.9	0.50	0.91	2.98	194.2	7.8	9.3	0.21
9	695173	3898126	11.6	0.46	0.83	2.74	214.7	10.6	9.7	0.19
10	695204	3898108	13.5	0.43	0.77	2.54	258.1	14.4	7.6	0.17
11	695102	3898112	10.8	0.89	1.60	5.25	165.5	10.4	3.9	0.37
12	695111	3898068	12.1	1.34	2.41	7.92	159.2	12.4	5.8	0.54
13	695132	3898026	14.8	1.91	3.45	11.30	169.0	12.7	9.3	0.69
14	695166	3898008	14.7	3.17	5.70	18.71	204.4	13.2	13.7	1.15
15	695197	3897988	13.4	4.65	8.37	27.47	213.0	14.4	16.6	1.81
16	695236	3897971	14.6	3.93	7.07	23.19	238.5	13.3	13.6	1.43
17	695140	3897975	16.5	3.99	7.19	23.58	205.3	13.5	16.5	1.36
18	695174	3897962	18.8	4.38	7.88	25.85	228.1	13.1	15.0	1.36
19	695217	3897942	14.8	6.10	10.98	36.03	247.8	14.8	16.9	2.24
20	695016	3898166	10.6	5.49	9.88	32.41	236.5	14.2	14.9	2.44
21	695020	3898124	12.5	6.06	10.91	35.81	247.8	14.2	19.0	2.44
22	695022	3898074	12.9	6.87	12.36	40.55	259.1	14.6	24.9	2.74
23	695026	3898012	15.1	6.00	10.81	35.46	253.3	14.2	32.5	2.16
24	695008	3897980	20.1	6.59	11.85	38.89	248.7	14.1	35.5	2.00
25	695039	3897975	10.2	7.23	13.01	42.68	254.4	14.8	24.7	3.30
26	695010	3897935	17.3	7.59	13.66	44.83	256.3	14.3	25.5	2.53
27	695061	3897932	12.9	7.83	14.09	46.21	231.0	14.8	26.0	3.12
28	695104	3897934	21.5	5.72	10.30	33.80	237.5	13.5	16.2	1.64
29	695143	3897922	24.0	6.19	11.15	36.57	241.0	14.0	14.5	1.68
30	695179	3897909	23.1	6.73	12.12	39.76	249.4	14.1	15.7	1.87
31	695237	3897896	12.4	7.50	13.51	44.32	247.2	15.3	26.5	3.09
32	695017	3897900	25.1	7.89	14.20	46.57	255.5	14.1	22.2	2.07
33	695057	3897900	25.1	7.68	13.82	45.33	253.4	14.1	19.2	2.02
34	695100	3897894	24.2	7.58	13.65	44.79	250.9	14.2	18.1	2.04
35	695139	3897888	23.9	7.17	12.90	42.32	250.6	14.0	18.1	1.94
36	695194	3897880	23.1	7.45	13.41	44.01	249.9	14.3	16.9	2.07

* Shaded cells indicate observation points within the breakwater Intake Cove.

Table 25: Local Breakwater Observation Points, Calculated Significant and Maximum Wave Heights, Direction, Period, and Rotational Velocity (at Seafloor Bottom) – 2.65 m (NAVD88).

Observ Point	UTME [m]	UTMN [m]	Depth [m]	Hsig [m]	Hmax [m]	Hmax [ft]	Dir [deg]	Tm01 [sec]	Dspr [deg]	Ubot [m/s]
46215	694884	3897754	29.9	8.03	14.45	47.4	255.9	13.9	23.4	1.87
1	695142	3898200	10.2	0.30	0.55	1.8	181.8	4.9	8.0	0.10
2	695167	3898191	11.5	0.46	0.84	2.7	194.8	9.9	9.5	0.18
3	695193	3898179	11.6	0.42	0.75	2.5	202.9	10.5	9.3	0.17
4	695136	3898172	9.4	0.40	0.72	2.4	184.3	6.3	6.5	0.16
5	695164	3898163	9.3	0.53	0.95	3.1	198.9	10.3	8.0	0.24
6	695198	3898153	10.9	0.41	0.73	2.4	216.7	11.7	6.8	0.17
7	695096	3898164	6.0	0.85	1.54	5.0	161.0	11.7	7.3	0.51
8	695142	3898128	10.4	0.56	1.01	3.3	193.7	7.9	9.2	0.22
9	695173	3898126	12.1	0.54	0.97	3.2	213.7	10.9	9.5	0.21
10	695204	3898108	14.0	0.49	0.88	2.9	256.9	15.0	7.6	0.19
11	695102	3898112	11.3	0.94	1.69	5.5	165.6	10.6	4.0	0.39
12	695111	3898068	12.6	1.38	2.48	8.1	159.7	12.4	6.0	0.54
13	695132	3898026	15.3	1.97	3.55	11.6	169.9	12.7	10.0	0.70
14	695166	3898008	15.2	3.24	5.83	19.1	205.5	13.2	14.0	1.15
15	695197	3897988	14.0	4.65	8.36	27.4	213.5	14.4	16.6	1.77
16	695236	3897971	15.1	3.96	7.12	23.4	238.7	13.2	13.7	1.41
17	695140	3897975	17.0	4.10	7.38	24.2	206.6	13.6	16.8	1.37
18	695174	3897962	19.3	4.44	7.99	26.2	228.6	13.1	15.0	1.36
19	695217	3897942	15.4	6.10	10.98	36.0	247.8	14.7	16.9	2.20
20	695016	3898166	11.1	5.60	10.09	33.1	236.9	14.2	15.2	2.42
21	695020	3898124	13.0	6.15	11.07	36.3	248.0	14.1	19.2	2.42
22	695022	3898074	13.4	6.97	12.54	41.2	258.9	14.6	25.0	2.72
23	695026	3898012	15.7	6.29	11.32	37.1	253.9	14.3	32.0	2.22
24	695008	3897980	20.6	6.78	12.20	40.0	249.9	14.1	35.1	2.03
25	695039	3897975	10.7	7.36	13.24	43.5	255.4	14.8	24.8	3.27
26	695010	3897935	17.8	7.60	13.68	44.9	256.6	14.3	25.5	2.49
27	695061	3897932	13.4	7.90	14.21	46.6	232.6	14.7	26.2	3.08
28	695104	3897934	22.0	5.83	10.49	34.4	238.0	13.5	16.5	1.65
29	695143	3897922	24.5	6.22	11.19	36.7	241.4	14.0	14.8	1.66
30	695179	3897909	23.6	6.76	12.18	39.9	249.6	14.1	15.8	1.85
31	695237	3897896	12.9	7.52	13.54	44.4	246.9	15.2	25.7	3.02
32	695017	3897900	25.7	7.91	14.24	46.7	255.8	14.1	22.3	2.05
33	695057	3897900	25.6	7.70	13.87	45.5	253.7	14.1	19.3	2.00
34	695100	3897894	24.7	7.62	13.71	45.0	251.2	14.2	18.3	2.02
35	695139	3897888	24.4	7.20	12.96	42.5	250.9	14.0	18.4	1.92
36	695194	3897880	23.7	7.48	13.47	44.2	250.1	14.3	17.1	2.05

* Shaded cells indicate observation points within the breakwater Intake Cove.

Table 26: Local Breakwater Observation Points, Calculated Significant and Maximum Wave Heights, Direction, Period, and Rotational Velocity (at Seafloor Bottom) – 3.03 m (NAVD88).

Observ Point	UTME [m]	UTMN [m]	Depth [m]	Hsig [m]	Hmax [m]	Hmax [ft]	Dir [deg]	Tm01 [sec]	Dspr [deg]	Ubot [m/s]
46215	694884	3897754	30.28	8.04	14.48	47.5	256.1	13.9	23.4	1.86
1	695142	3898200	10.62	0.33	0.59	1.9	181.7	5.1	7.8	0.11
2	695167	3898191	11.89	0.50	0.89	2.9	195.0	10.2	9.2	0.19
3	695193	3898179	11.94	0.45	0.81	2.7	202.8	10.7	9.1	0.18
4	695136	3898172	9.77	0.43	0.77	2.5	184.3	6.5	6.2	0.17
5	695164	3898163	9.67	0.56	1.01	3.3	198.9	10.4	7.9	0.25
6	695198	3898153	11.24	0.45	0.80	2.6	216.4	12.1	6.6	0.19
7	695096	3898164	6.33	0.88	1.58	5.2	161.3	11.7	7.3	0.51
8	695142	3898128	10.81	0.60	1.08	3.5	193.7	8.2	9.0	0.24
9	695173	3898126	12.46	0.59	1.06	3.5	213.5	11.1	9.3	0.23
10	695204	3898108	14.40	0.52	0.93	3.1	256.5	15.4	7.5	0.19
11	695102	3898112	11.70	0.98	1.76	5.8	165.6	10.8	4.1	0.39
12	695111	3898068	13.01	1.41	2.54	8.3	160.3	12.4	6.4	0.55
13	695132	3898026	15.70	2.02	3.63	11.9	170.8	12.7	10.8	0.71
14	695166	3898008	15.59	3.29	5.92	19.4	206.3	13.3	14.2	1.15
15	695197	3897988	14.35	4.64	8.36	27.4	214.0	14.4	16.7	1.74
16	695236	3897971	15.52	3.98	7.16	23.5	238.8	13.2	13.7	1.39
17	695140	3897975	17.38	4.18	7.52	24.7	207.5	13.7	17.1	1.38
18	695174	3897962	19.70	4.49	8.08	26.5	229.0	13.1	15.1	1.36
19	695217	3897942	15.74	6.10	10.98	36.0	247.9	14.7	16.8	2.16
20	695016	3898166	11.52	5.69	10.24	33.6	237.2	14.2	15.4	2.41
21	695020	3898124	13.42	6.22	11.19	36.7	248.2	14.1	19.4	2.40
22	695022	3898074	13.76	7.05	12.70	41.7	258.7	14.6	25.1	2.70
23	695026	3898012	16.05	6.49	11.68	38.3	254.2	14.4	31.6	2.26
24	695008	3897980	21.01	6.90	12.42	40.7	250.6	14.2	34.8	2.04
25	695039	3897975	11.09	7.44	13.40	44.0	256.1	14.8	24.8	3.24
26	695010	3897935	18.22	7.61	13.69	44.9	256.8	14.2	25.5	2.46
27	695061	3897932	13.81	7.98	14.36	47.1	233.6	14.7	26.2	3.06
28	695104	3897934	22.43	5.89	10.61	34.8	238.4	13.5	16.5	1.65
29	695143	3897922	24.86	6.24	11.23	36.8	241.7	14.0	15.0	1.65
30	695179	3897909	23.96	6.79	12.22	40.1	249.8	14.1	15.9	1.84
31	695237	3897896	13.26	7.53	13.56	44.5	246.8	15.2	25.2	2.97
32	695017	3897900	26.04	7.93	14.27	46.8	256.0	14.1	22.4	2.03
33	695057	3897900	25.96	7.73	13.91	45.6	253.9	14.1	19.5	1.99
34	695100	3897894	25.12	7.64	13.75	45.1	251.5	14.2	18.5	2.01
35	695139	3897888	24.83	7.22	12.99	42.6	251.2	14.0	18.5	1.91
36	695194	3897880	24.04	7.50	13.50	44.3	250.3	14.3	17.2	2.04

* Shaded cells indicate observation points within the breakwater Intake Cove.

Table 27: Local Breakwater Observation Points, Calculated Maximum Wave Heights and Absolute Wave Level (NAVD88).

ObsPts	Hmax [m]				Max Crest Wave Level (NAVD88) [m]				Hmax [ft]				Max Crest Wave Level (NAVD88) [ft]			
	0	2.13	2.65	3.03	0	2.13	2.65	3.03	0.0	7.0	8.7	9.94	0.0	7.0	8.7	9.94
46215	14.23	14.41	14.45	14.48	7.12	9.34	9.87	10.27	46.7	47.3	47.4	47.50	23.3	30.6	32.4	33.70
1	0.34	0.49	0.55	0.59	0.17	2.38	2.92	3.33	1.1	1.6	1.8	1.93	0.6	7.8	9.6	10.91
2	0.44	0.75	0.84	0.89	0.22	2.50	3.07	3.48	1.4	2.4	2.7	2.94	0.7	8.2	10.1	11.42
3	0.33	0.65	0.75	0.81	0.16	2.46	3.02	3.44	1.1	2.1	2.5	2.65	0.5	8.1	9.9	11.28
4	0.48	0.66	0.72	0.77	0.24	2.46	3.01	3.42	1.6	2.2	2.4	2.53	0.8	8.1	9.9	11.21
5	0.54	0.86	0.95	1.01	0.27	2.56	3.12	3.54	1.8	2.8	3.1	3.31	0.9	8.4	10.3	11.60
6	0.26	0.62	0.73	0.80	0.13	2.44	3.02	3.43	0.9	2.0	2.4	2.64	0.4	8.0	9.9	11.27
7	1.25	1.49	1.54	1.58	0.63	2.87	3.42	3.82	4.1	4.9	5.0	5.17	2.1	9.4	11.2	12.53
8	0.60	0.91	1.01	1.08	0.30	2.58	3.15	3.57	2.0	3.0	3.3	3.54	1.0	8.5	10.3	11.72
9	0.37	0.83	0.97	1.06	0.18	2.55	3.14	3.56	1.2	2.7	3.2	3.48	0.6	8.4	10.3	11.69
10	0.33	0.77	0.88	0.93	0.17	2.52	3.09	3.50	1.1	2.5	2.9	3.06	0.5	8.3	10.1	11.48
11	1.21	1.60	1.69	1.76	0.60	2.93	3.49	3.91	4.0	5.2	5.5	5.77	2.0	9.6	11.5	12.83
12	2.15	2.41	2.48	2.54	1.08	3.34	3.89	4.30	7.1	7.9	8.1	8.32	3.5	10.9	12.8	14.11
13	3.07	3.45	3.55	3.63	1.54	3.85	4.42	4.85	10.1	11.3	11.6	11.92	5.0	12.6	14.5	15.91
14	5.34	5.70	5.83	5.92	2.67	4.98	5.56	5.99	17.5	18.7	19.1	19.41	8.8	16.3	18.2	19.65
15	8.33	8.37	8.36	8.36	4.16	6.32	6.83	7.21	27.3	27.5	27.4	27.42	13.7	20.7	22.4	23.66
16	6.89	7.07	7.12	7.16	3.44	5.66	6.21	6.61	22.6	23.2	23.4	23.50	11.3	18.6	20.4	21.70
17	6.50	7.19	7.38	7.52	3.25	5.72	6.34	6.79	21.3	23.6	24.2	24.66	10.7	18.8	20.8	22.28
18	7.38	7.88	7.99	8.08	3.69	6.07	6.65	7.07	24.2	25.9	26.2	26.51	12.1	19.9	21.8	23.20
19	10.97	10.98	10.98	10.98	5.49	7.62	8.14	8.52	36.0	36.0	36.0	36.01	18.0	25.0	26.7	27.96
20	8.96	9.88	10.09	10.24	4.48	7.07	7.69	8.15	29.4	32.4	33.1	33.61	14.7	23.2	25.2	26.75
21	10.21	10.91	11.07	11.19	5.11	7.59	8.19	8.63	33.5	35.8	36.3	36.71	16.7	24.9	26.9	28.30
22	11.63	12.36	12.54	12.70	5.81	8.31	8.92	9.38	38.2	40.6	41.2	41.65	19.1	27.3	29.3	30.78
23	8.62	10.81	11.32	11.68	4.31	7.53	8.31	8.87	28.3	35.5	37.1	38.32	14.1	24.7	27.3	29.11
24	10.09	11.85	12.20	12.42	5.04	8.06	8.75	9.24	33.1	38.9	40.0	40.74	16.5	26.4	28.7	30.32
25	11.83	13.01	13.24	13.40	5.92	8.63	9.27	9.73	38.8	42.7	43.5	43.96	19.4	28.3	30.4	31.93
26	13.57	13.66	13.68	13.69	6.79	8.96	9.49	9.88	44.5	44.8	44.9	44.92	22.3	29.4	31.1	32.41
27	13.53	14.09	14.21	14.36	6.77	9.17	9.76	10.21	44.4	46.2	46.6	47.10	22.2	30.1	32.0	33.50
28	9.41	10.30	10.49	10.61	4.70	7.28	7.89	8.34	30.9	33.8	34.4	34.81	15.4	23.9	25.9	27.36
29	10.95	11.15	11.19	11.23	5.48	7.70	8.25	8.65	35.9	36.6	36.7	36.83	18.0	25.3	27.1	28.37
30	11.87	12.12	12.18	12.22	5.94	8.19	8.74	9.14	38.9	39.8	39.9	40.08	19.5	26.9	28.7	29.99
31	13.28	13.51	13.54	13.56	6.64	8.88	9.42	9.81	43.6	44.3	44.4	44.49	21.8	29.1	30.9	32.19
32	13.98	14.20	14.24	14.27	6.99	9.23	9.77	10.17	45.9	46.6	46.7	46.83	22.9	30.3	32.1	33.36
33	13.58	13.82	13.87	13.91	6.79	9.04	9.58	9.99	44.6	45.3	45.5	45.62	22.3	29.7	31.4	32.76
34	13.40	13.65	13.71	13.75	6.70	8.96	9.50	9.91	44.0	44.8	45.0	45.11	22.0	29.4	31.2	32.51
35	12.66	12.90	12.96	12.99	6.33	8.58	9.13	9.53	41.5	42.3	42.5	42.63	20.8	28.1	29.9	31.27
36	13.17	13.41	13.47	13.50	6.59	8.84	9.38	9.78	43.2	44.0	44.2	44.31	21.6	29.0	30.8	32.10

* Shaded cells indicate observation points within the breakwater Intake Cove.

Table 28: Natural Seiche Periods Based on 140 [m] Basin Length.

		Average Depth, d [m]									
	l = 140	2	4	6	8	10	12	14	16	18	20
Node' n #	1	63.2	44.7	36.5	31.6	28.3	25.8	23.9	22.3	21.1	20.0
	2	31.6	22.3	18.2	15.8	14.1	12.9	11.9	11.2	10.5	10.0
	3	21.1	14.9	12.2	10.5	9.4	8.6	8.0	7.4	7.0	6.7
	4	15.8	11.2	9.1	7.9	7.1	6.5	6.0	5.6	5.3	5.0
	5	12.6	8.9	7.3	6.3	5.7	5.2	4.8	4.5	4.2	4.0
	6	10.5	7.4	6.1	5.3	4.7	4.3	4.0	3.7	3.5	3.3

Table 29: Natural Seiche Periods Based on 215 [m] Basin Length.

		Average Depth, d [m]									
	l = 215	2	4	6	8	10	12	14	16	18	20
Node' n #	1	97.1	68.6	56.0	48.5	43.4	39.6	36.7	34.3	32.4	30.7
	2	48.5	34.3	28.0	24.3	21.7	19.8	18.3	17.2	16.2	15.3
	3	32.4	22.9	18.7	16.2	14.5	13.2	12.2	11.4	10.8	10.2
	4	24.3	17.2	14.0	12.1	10.9	9.9	9.2	8.6	8.1	7.7
	5	19.4	13.7	11.2	9.7	8.7	7.9	7.3	6.9	6.5	6.1
	6	16.2	11.4	9.3	8.1	7.2	6.6	6.1	5.7	5.4	5.1

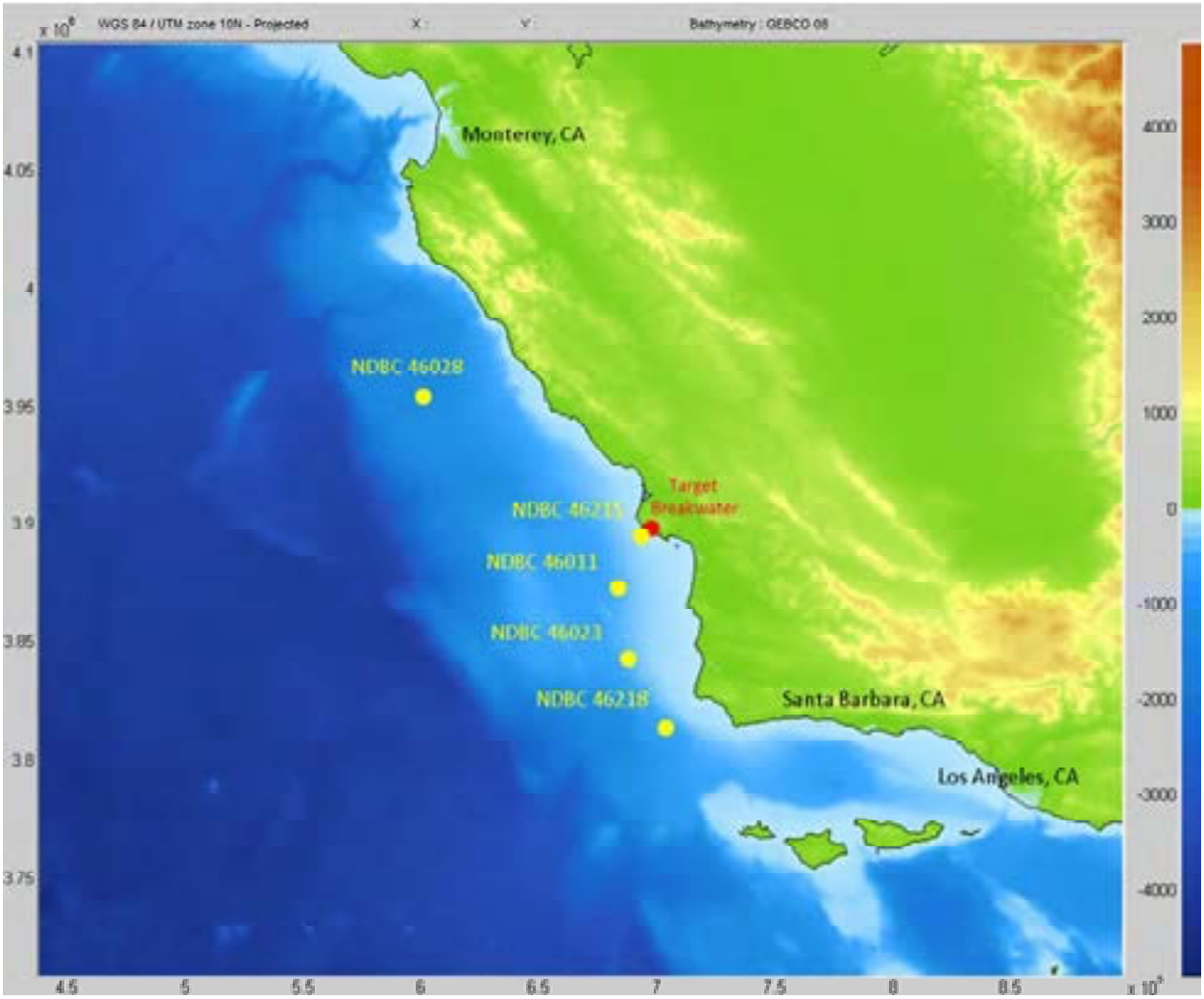

Figure 1: Analyzed NDBC Buoy Network along the California Central Coast (UTM Zone 10) - coordinates are in meters.

Figure 2: Photo of Focus Site for High Resolution Model (Looking south-east).

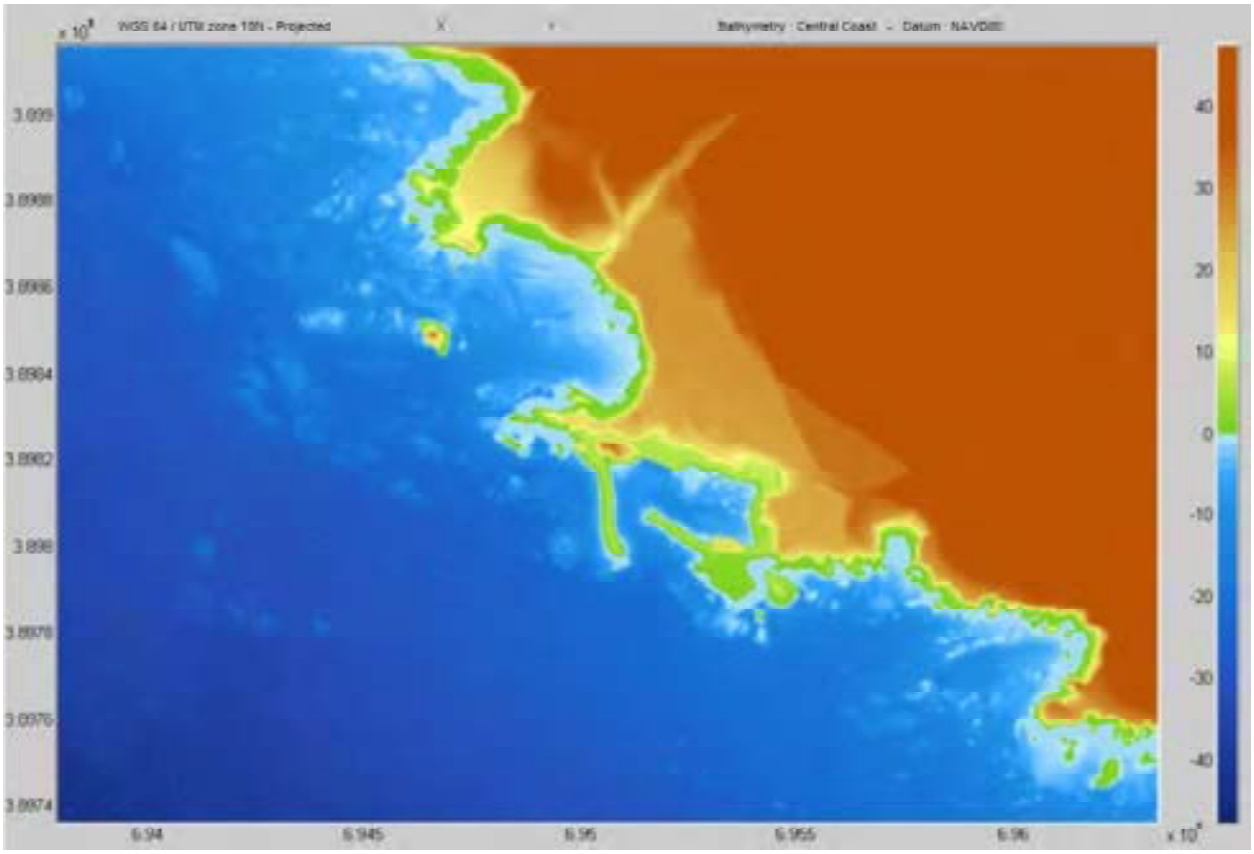

Figure 3: Bathymetry of local breakwater along the California Central Coast (UTM Zone 10) - coordinates are in meters.

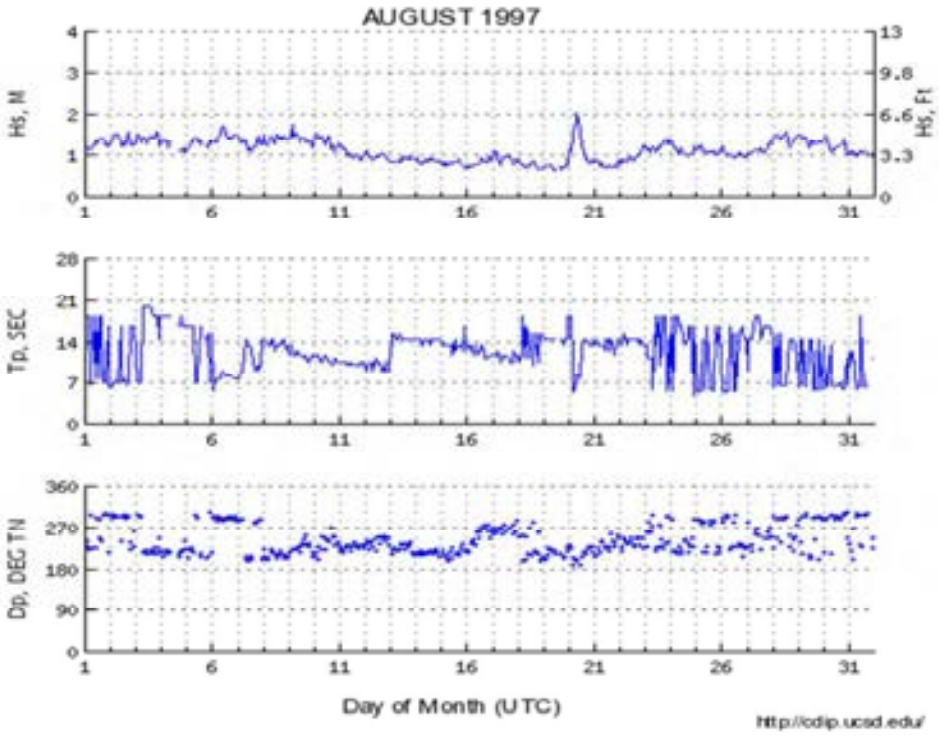

Figure 4: Tropical Storm Ignacio and resulting significant wave heights at the NDBC 46215 Buoy (August 20, 1997).

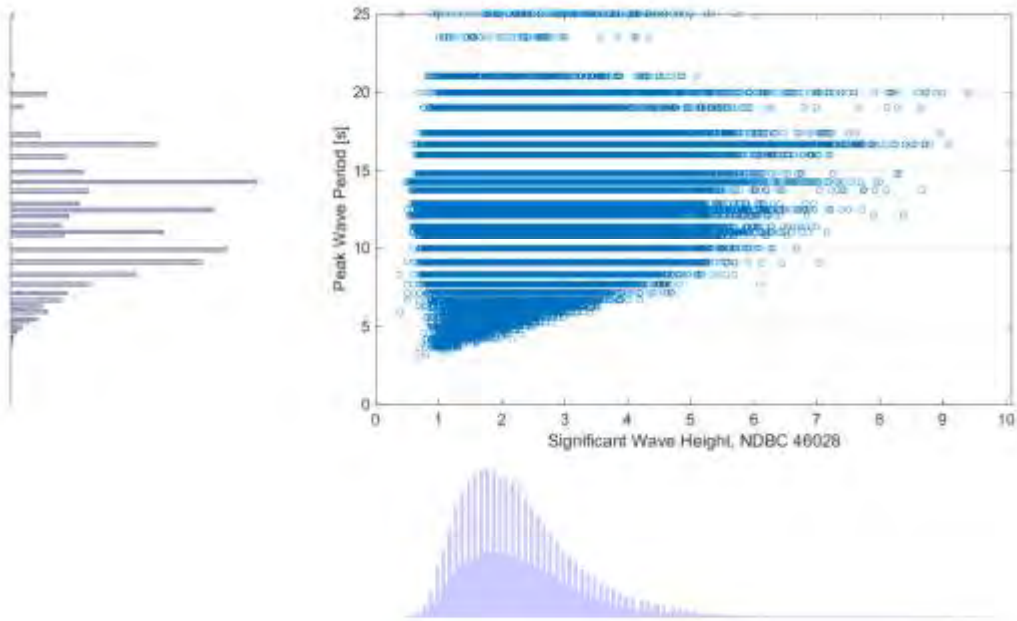

Figure 5: Scatterplot of Significant Wave Height [m] and Peak Wave Direction [s], NDBC 46028.

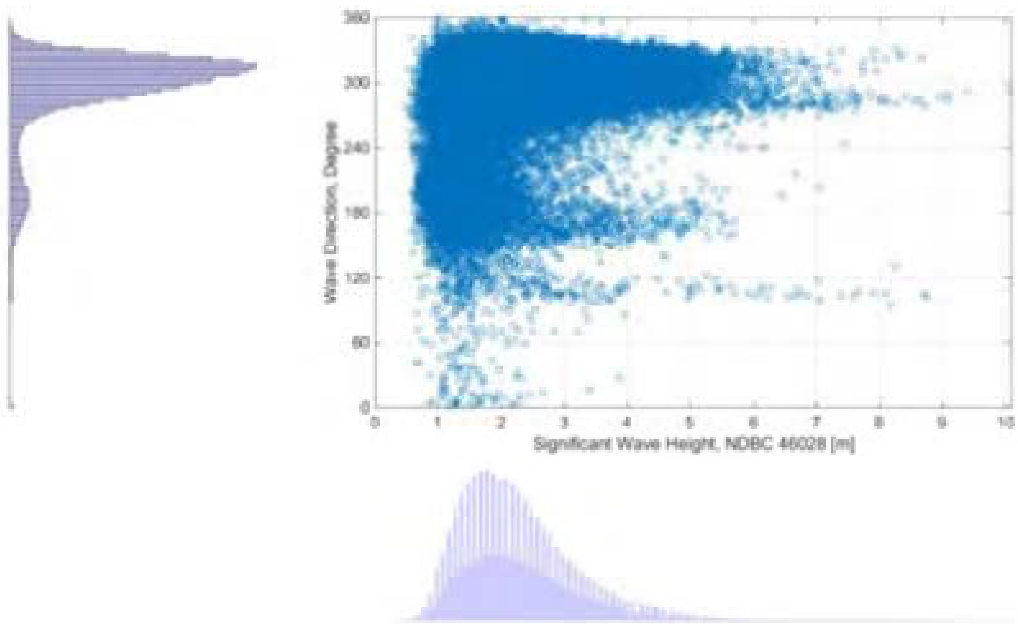

Figure 6: Scatterplot of Significant Wave Height [m] and Wave Direction [deg], NDBC 46028.

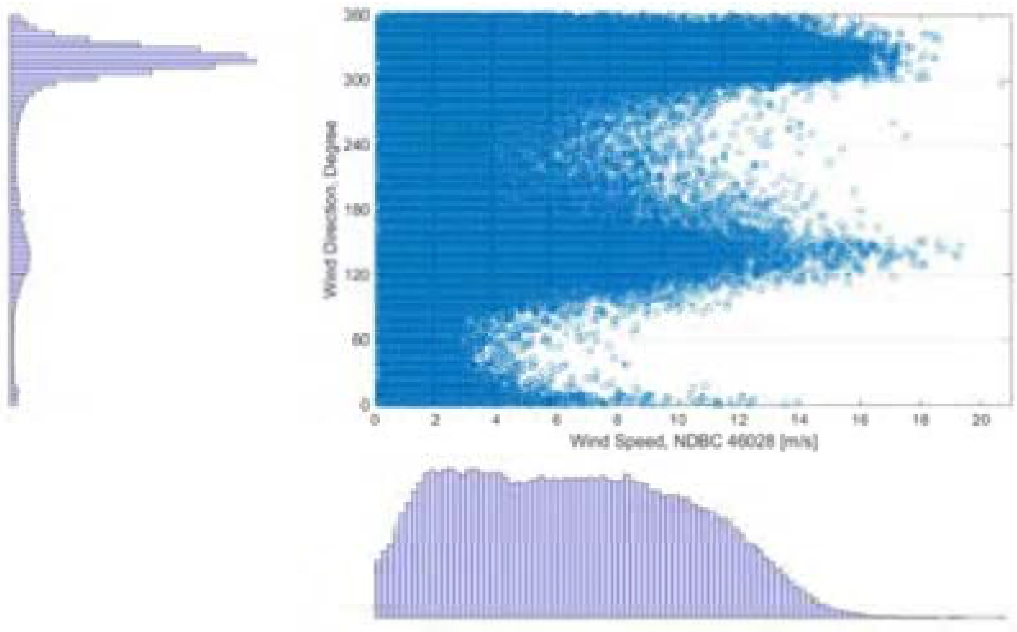

Figure 7: Scatterplot of Wind Speed [m/s] and Wind Direction [deg], NDBC 46028.

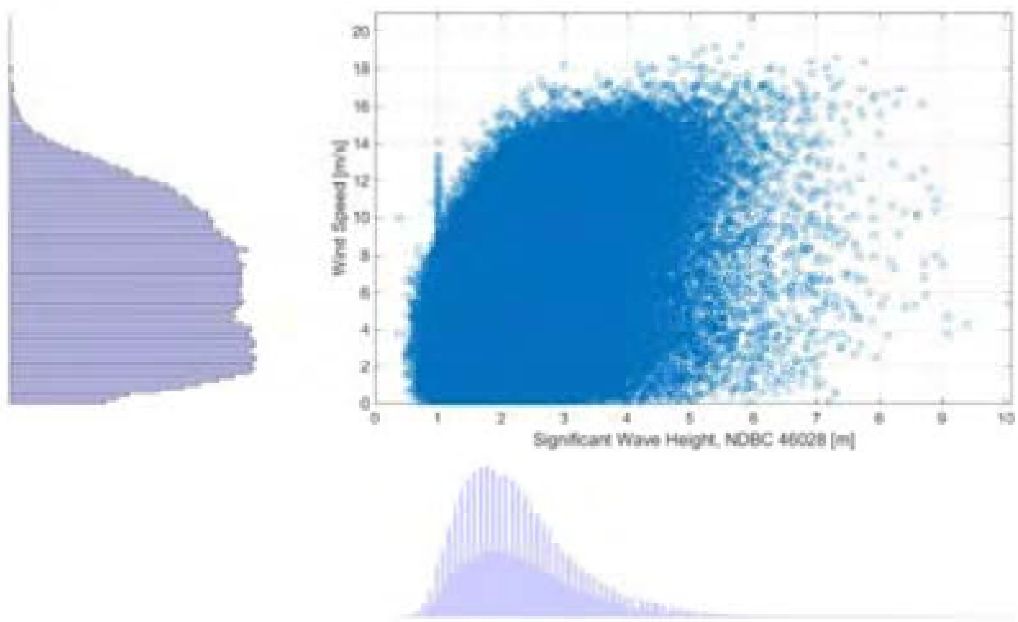

Figure 8: Scatterplot of Significant Wave Height [m] and Wind Speed [m/s], NDBC 46028.

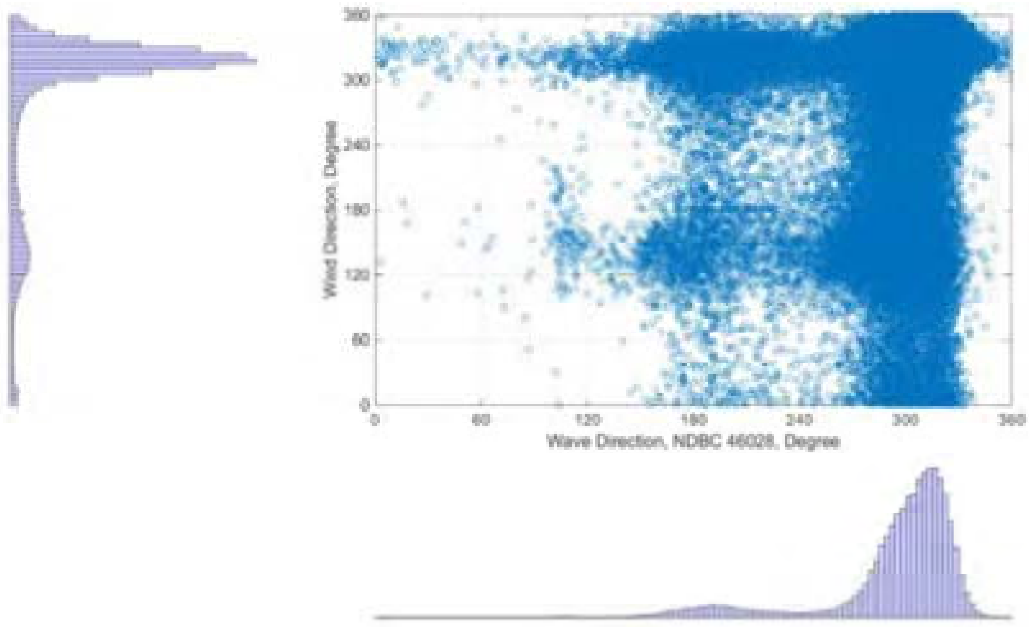

Figure 9: Scatterplot of Wave Direction [deg] and Wind Direction (deg) , NDBC 46028.

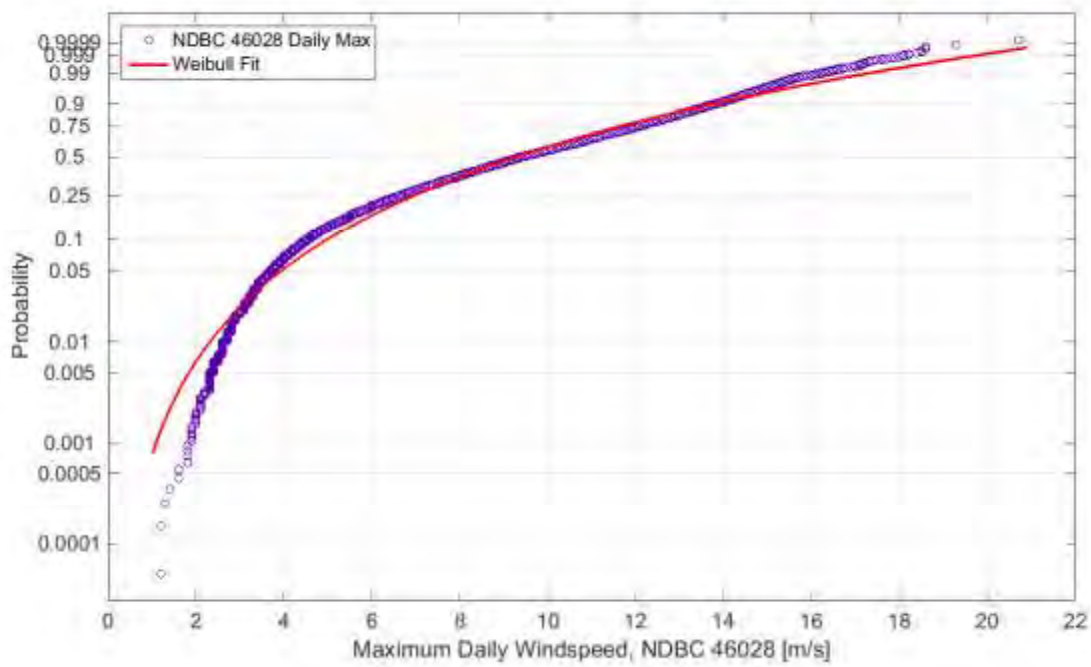

Figure 10: Weibull Fit, Maximum Daily Windspeed, NDBC 46028.

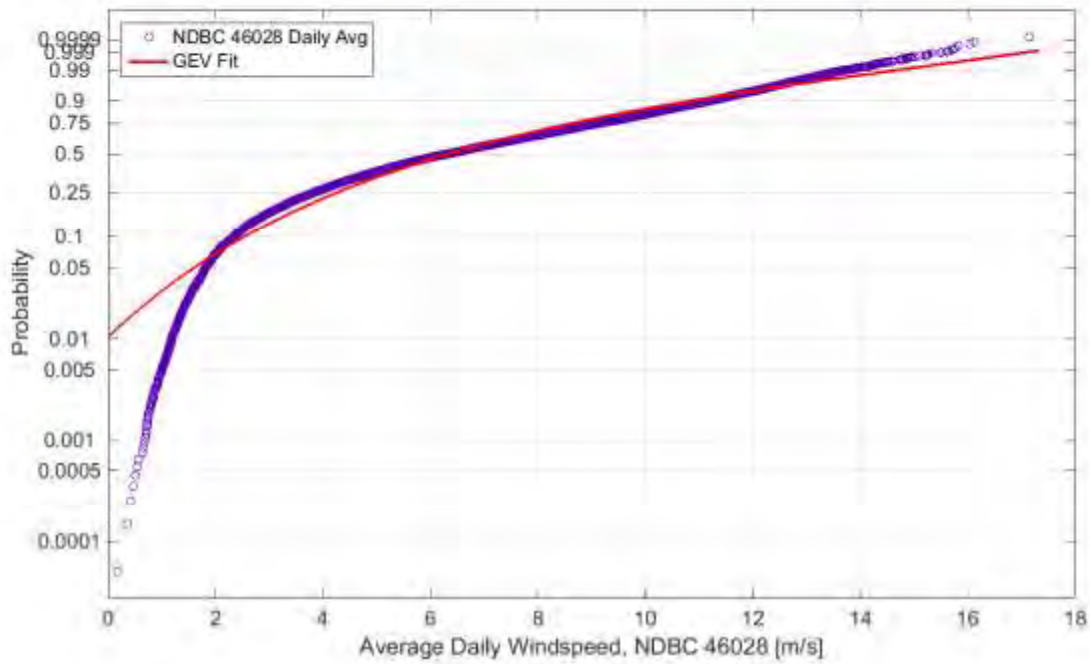

Figure 11: GEV Fit, Average Daily Windspeed, NDBC 46028.

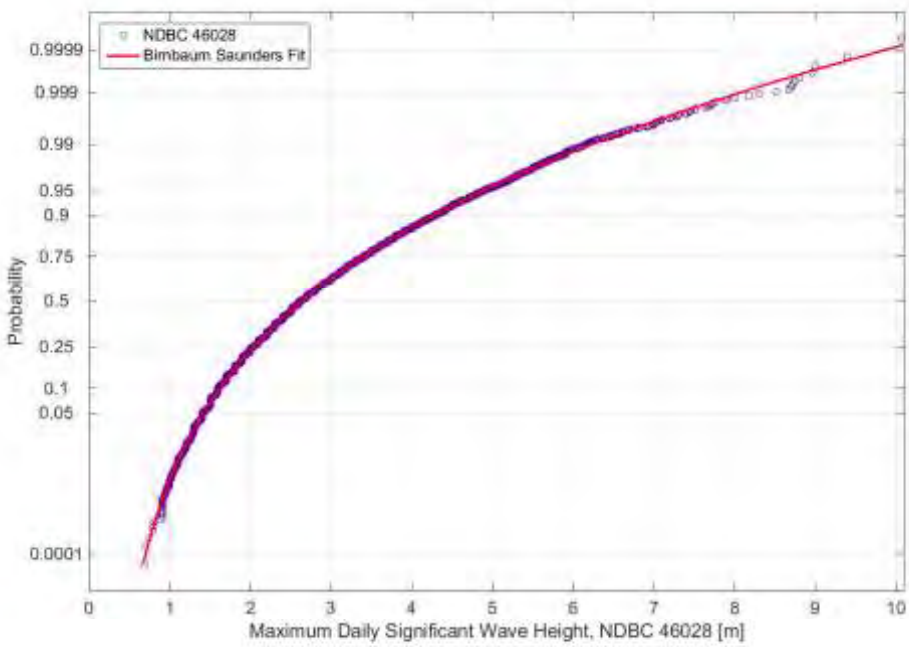

Figure 12: Birnbaum Saunders Fit, Maximum Daily Windspeed, NDBC 46028.

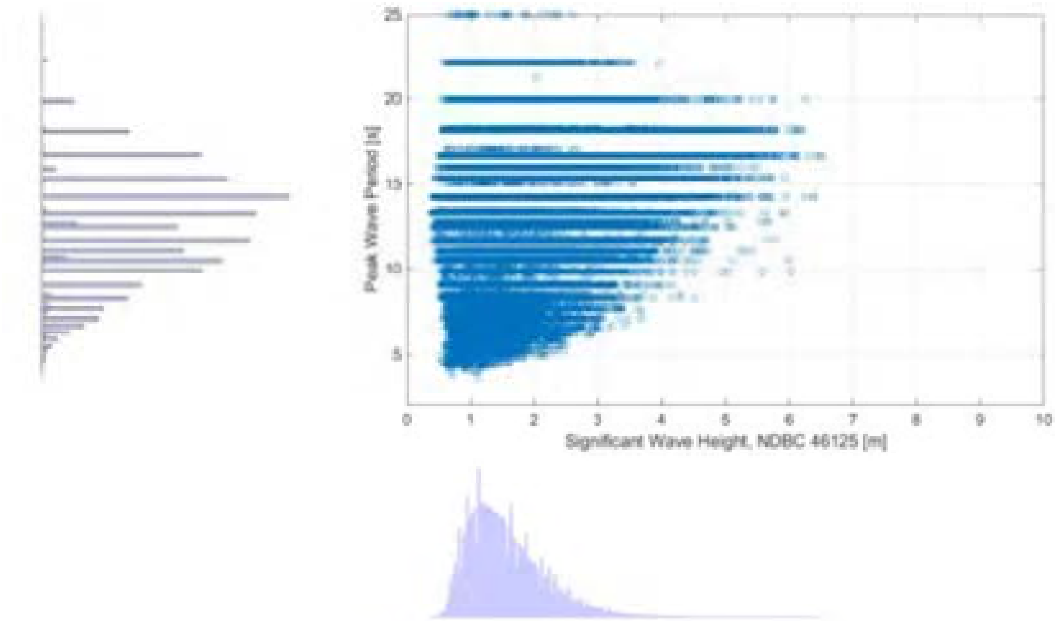

Figure 13: Scatterplot of Significant Wave Height [m] and Peak Wave Period [s], NDBC 46215.

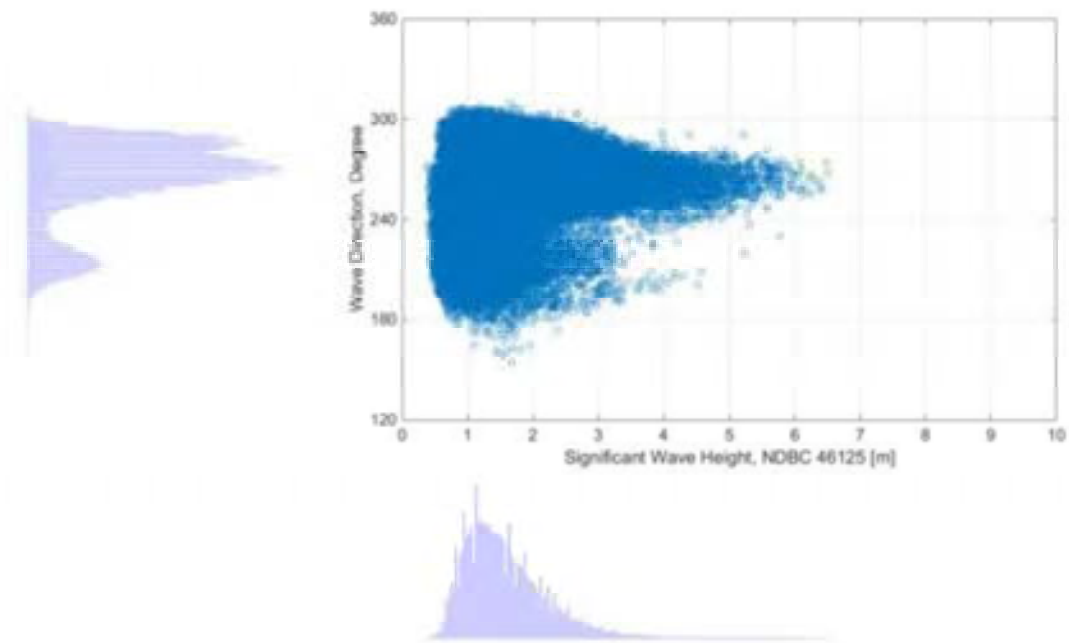

Figure 14: Scatterplot of Significant Wave Height [m] and Wave Direction [deg], NDBC 46215.

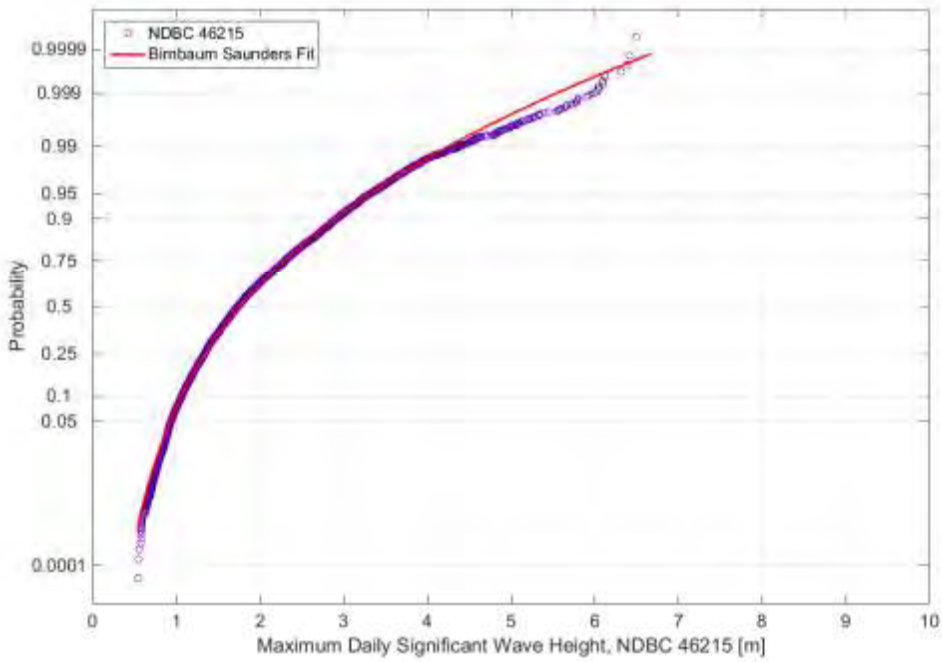

Figure 15: Birnbaum Saunders Fit, Maximum Daily Significant Wave Height, NDBC 46215.

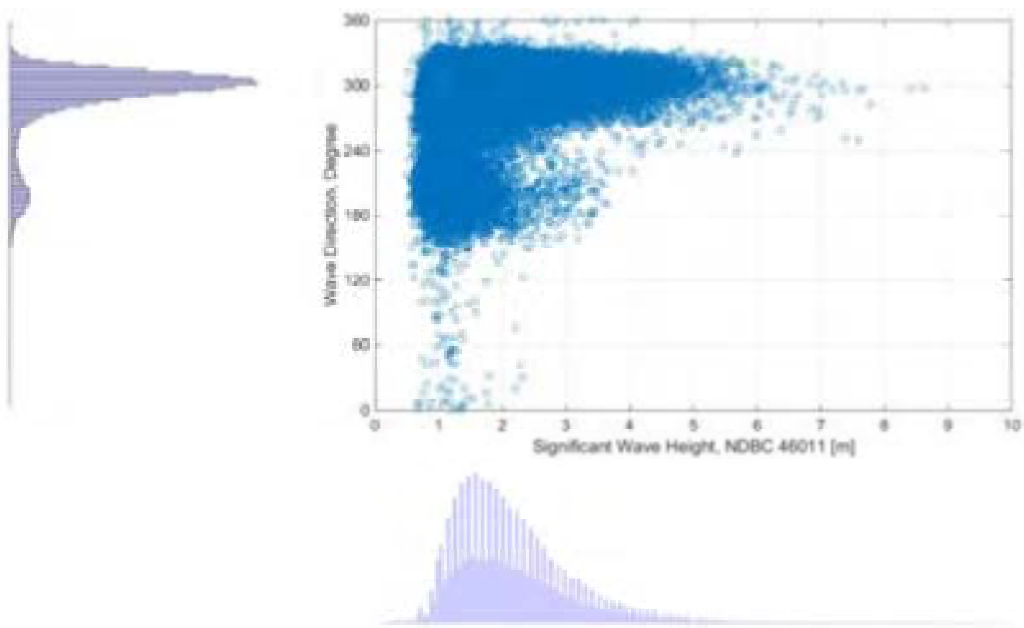

Figure 16: Scatterplot of Significant Wave Height [m] and Wave Direction [deg], NDBC 46011.

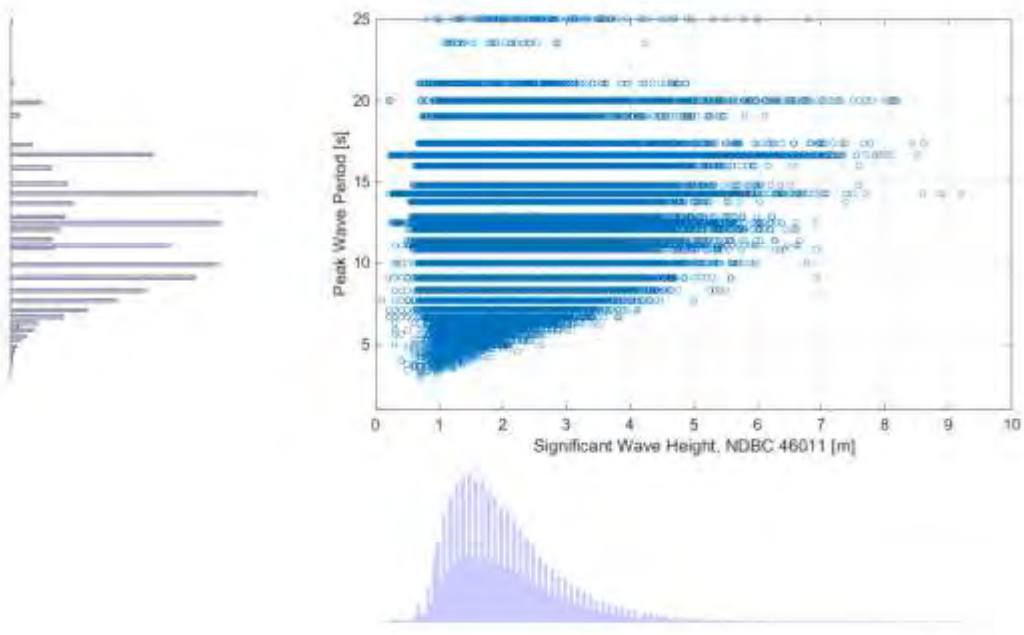

Figure 17: Scatterplot of Significant Wave Height [m] and Peak Wave Period [s], NDBC 46215.

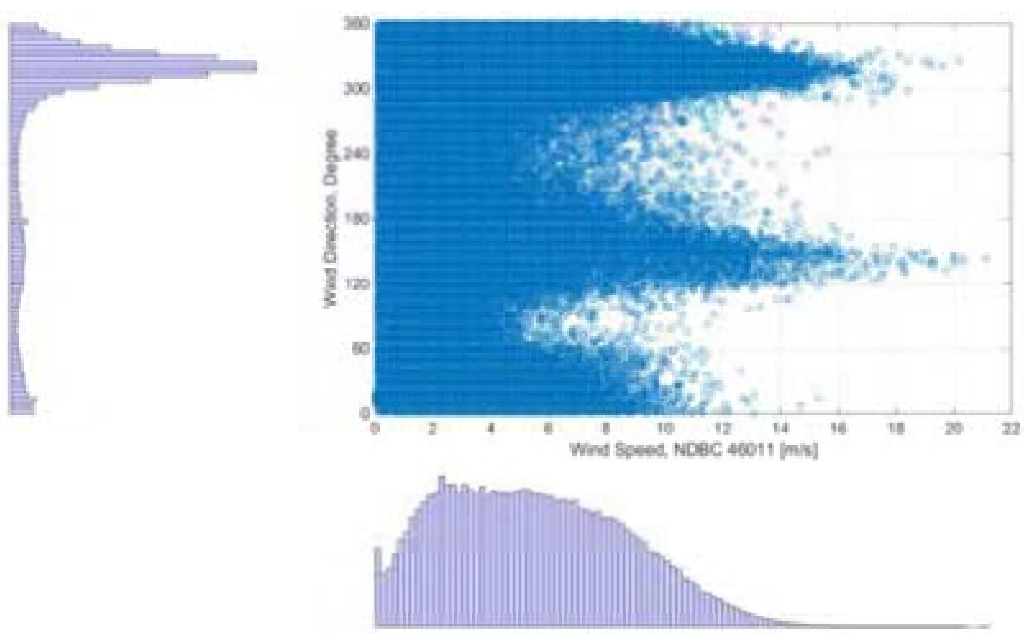

Figure 18: Scatterplot of Wind Speed [m/s] and Wind Direction [deg], NDBC 46011.

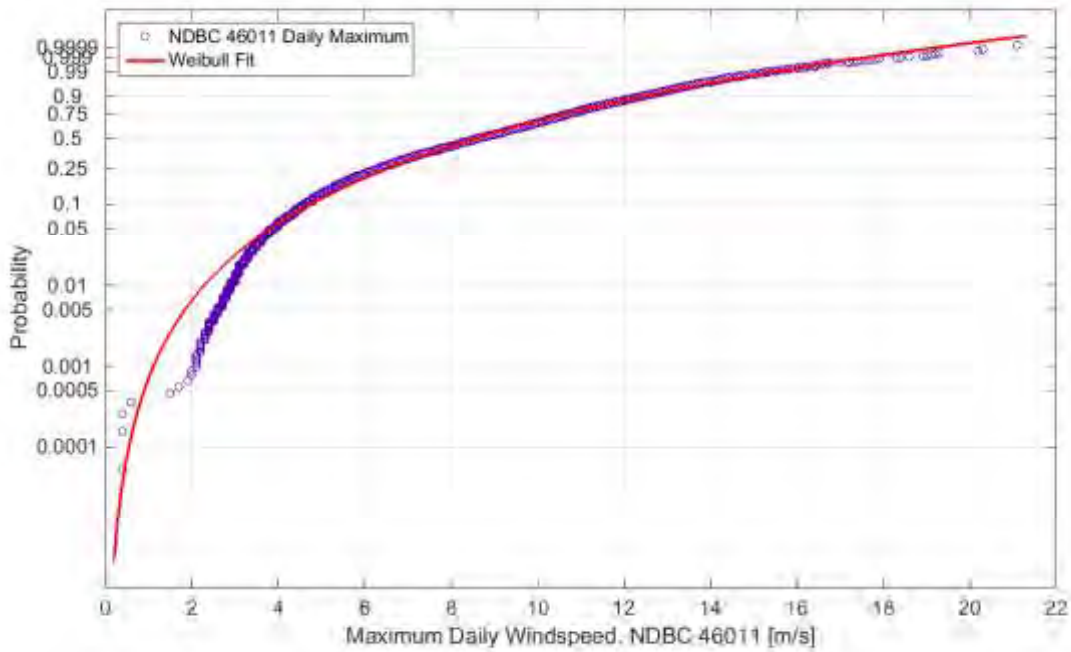

Figure 19: Weibull Fit, Maximum Daily Windspeed [m/s], NDBC 46011.

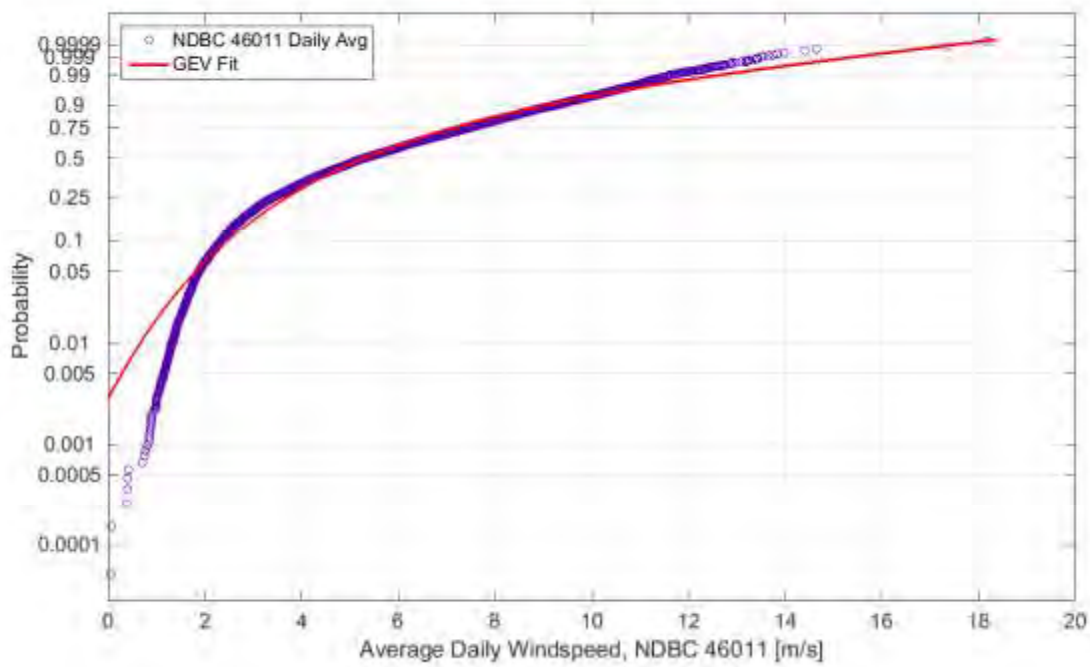

Figure 20: GEV Fit, Average Daily Windspeed [m/s], NDBC 46011.

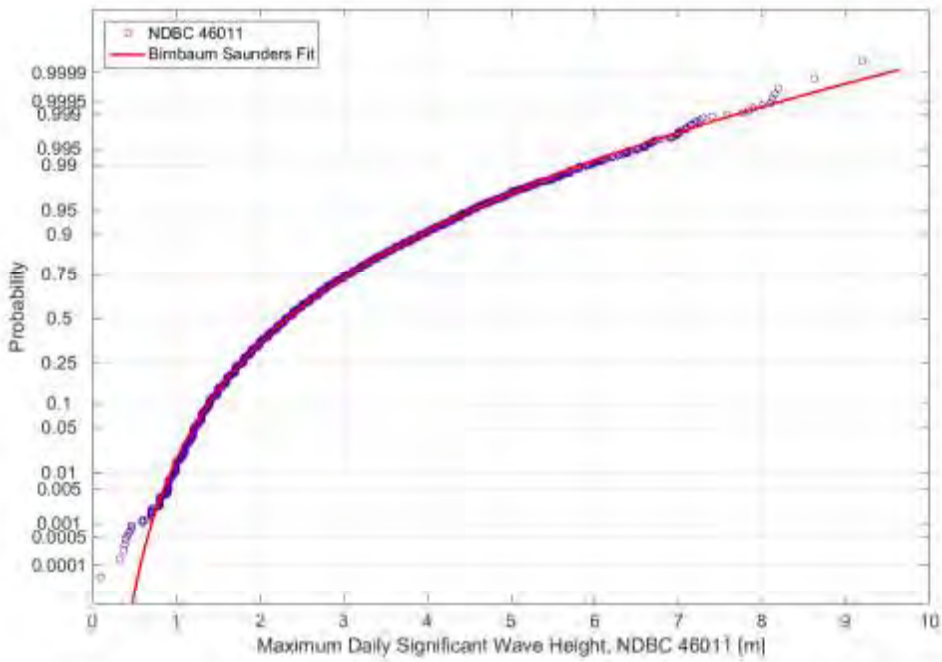

Figure 21: Birnbaum Saunders Fit, Maximum Daily Significant Wave Height, NDBC 46011.

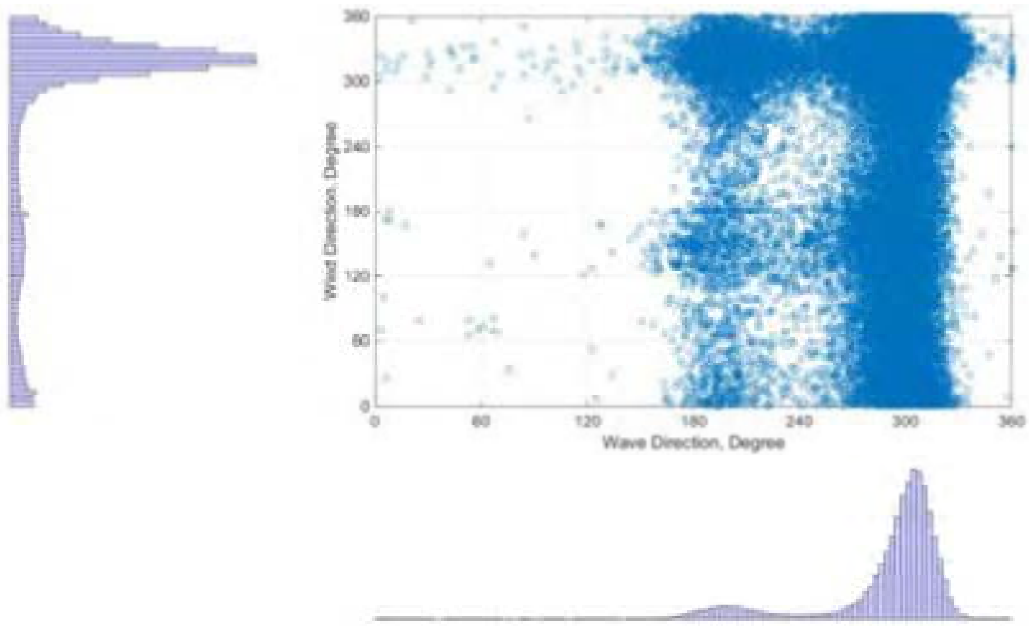

Figure 22: Scatterplot of Wave Direction [deg] and Wind Direction [deg], NDBC 46023.

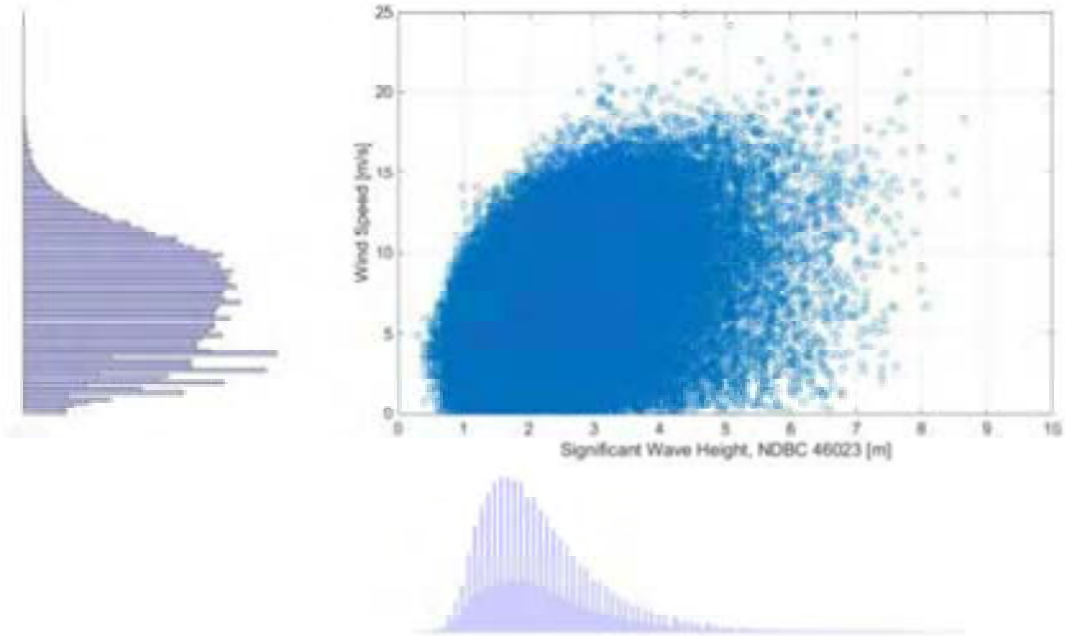

Figure 23: Scatterplot Significant Wave Height [m] of and Wind Speed [m/s], NDBC 46023.

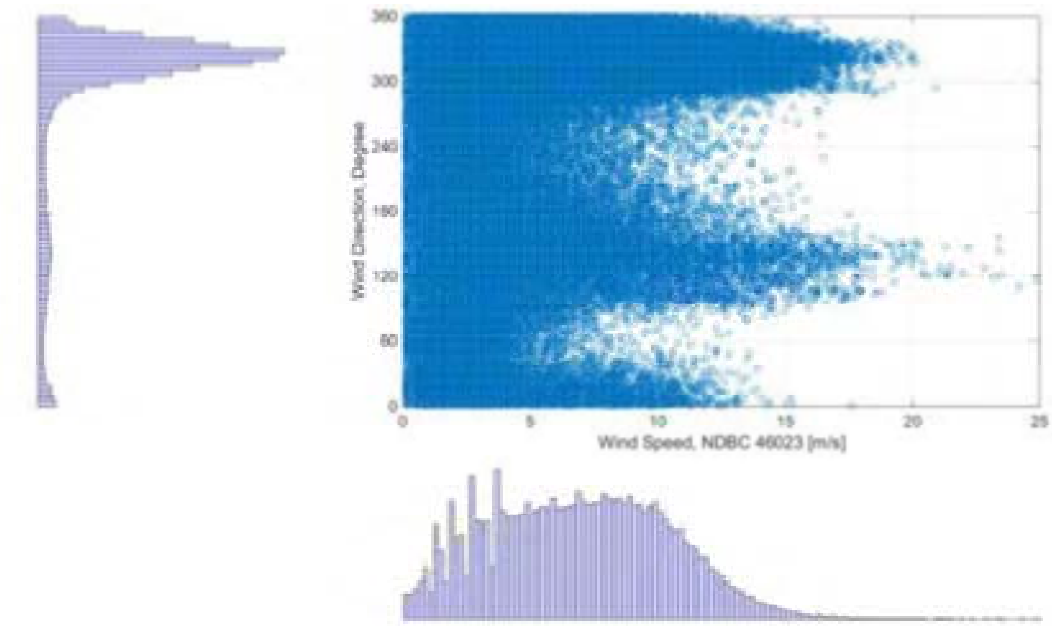

Figure 24: Scatterplot of Wind Speed [m/s] and Wind Direction [deg], NDBC 46023.

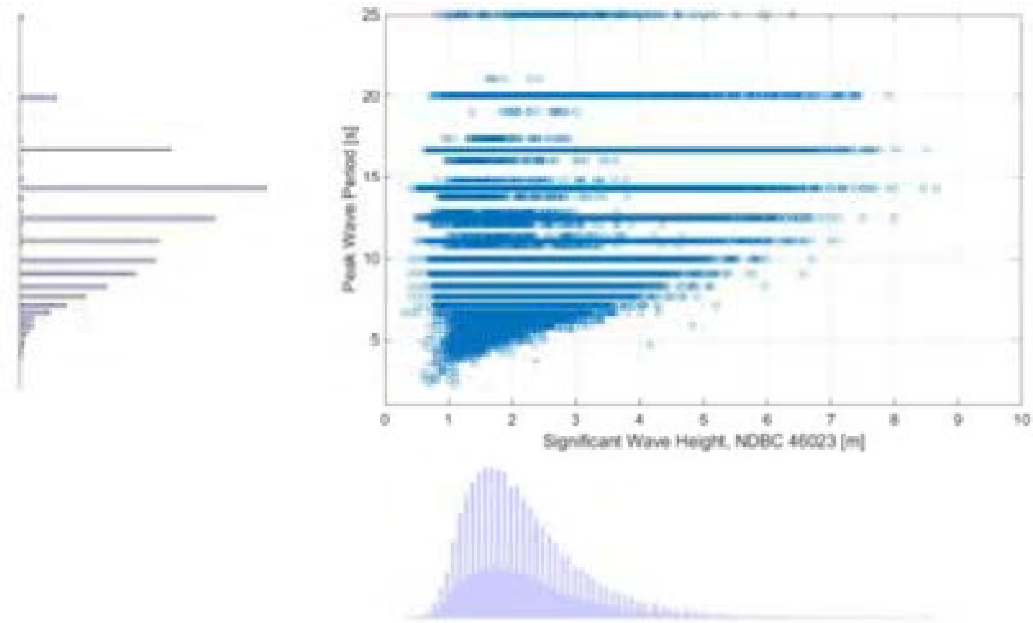

Figure 25: Scatterplot of Significant Wave Height [m] and Peak Wave Period [s], NDBC 46023.

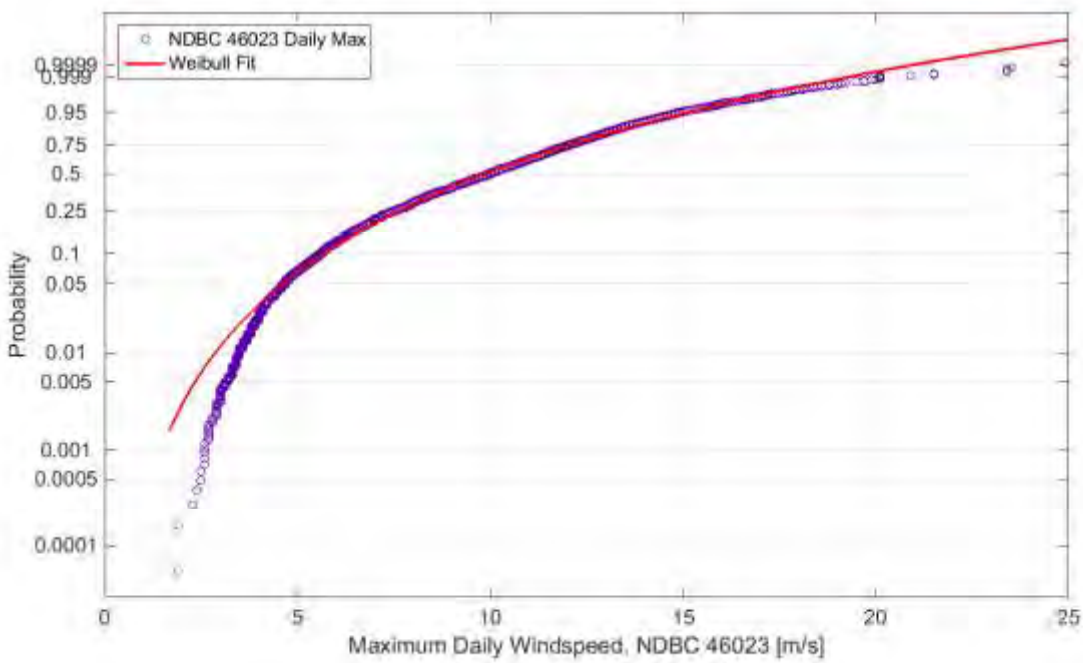

Figure 26: Weibull Fit, Maximum Daily Windspeed, NDBC 46023.

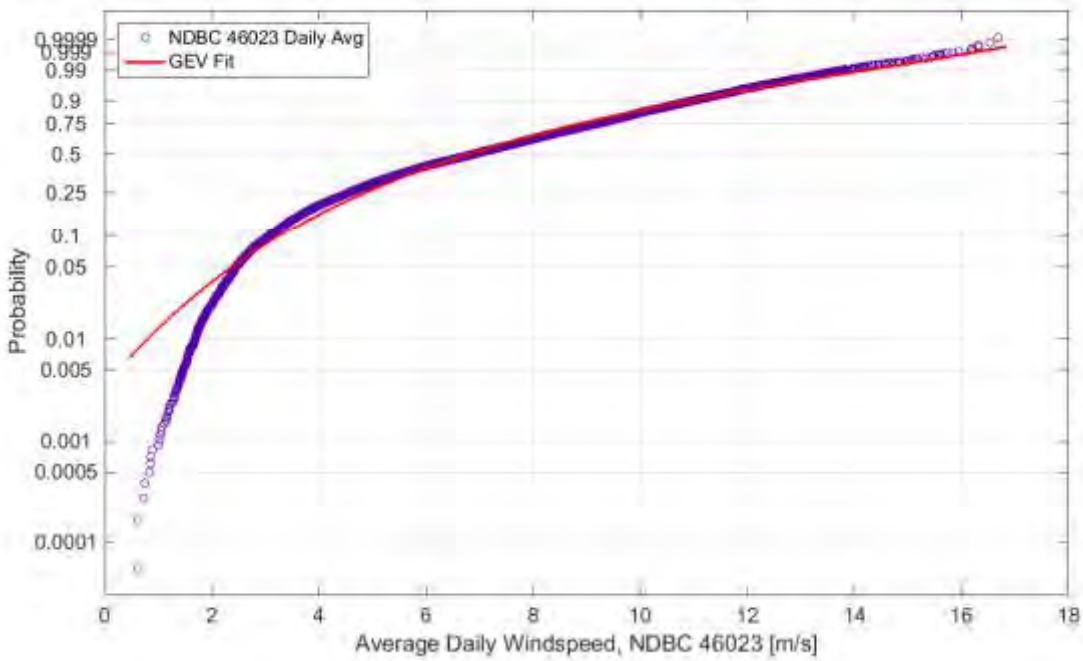

Figure 27: GEV Fit, Average Daily Windpseed, NDBC 46023.

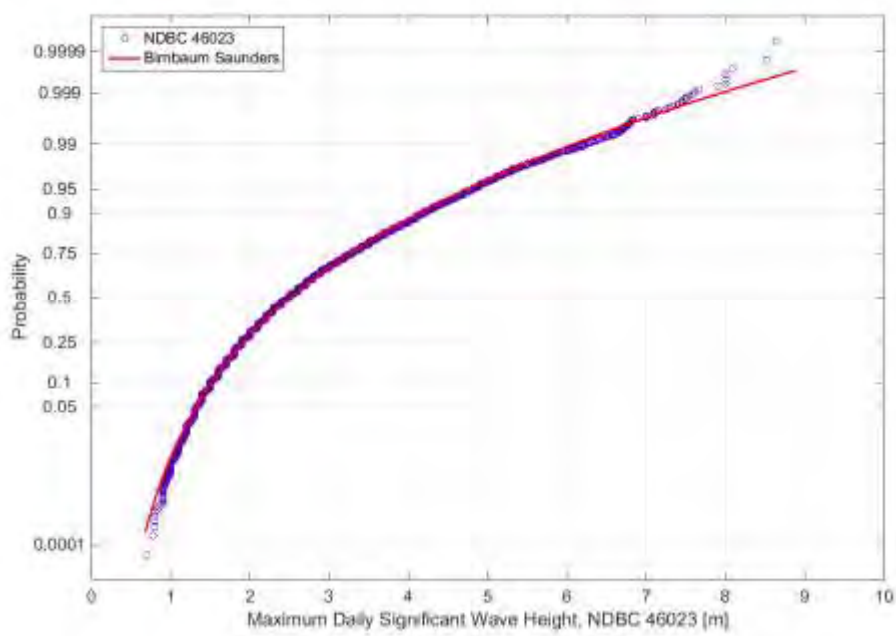

Figure 28: Birnbaum Saunders Fit, Maximum Daily Significant Wave Height, NDBC 46023.

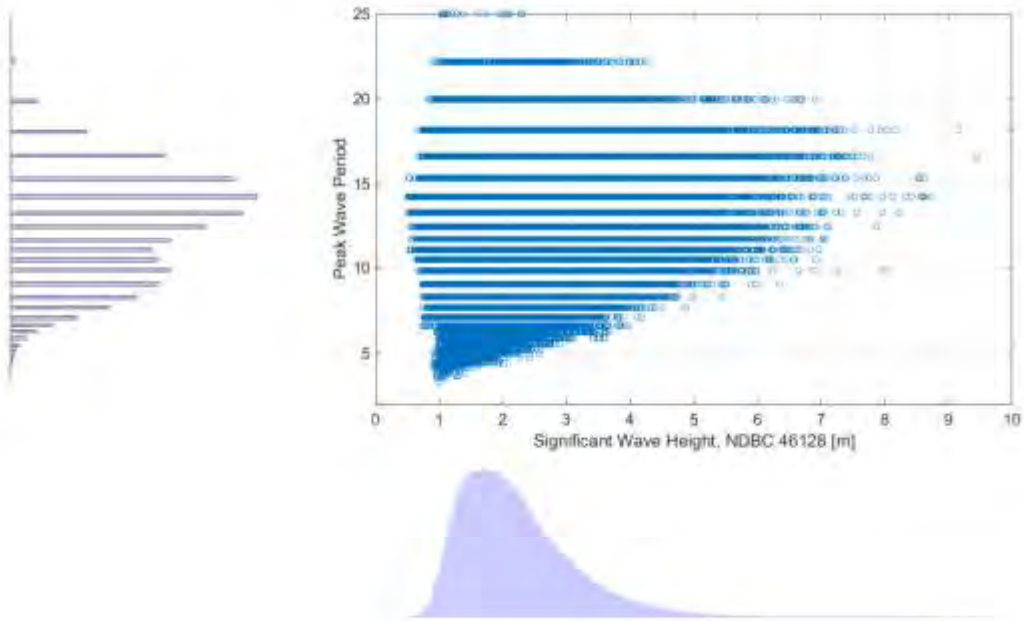

Figure 29: Scatterplot of Significant Wave Height [m] and Peak Wave Period [s], NDBC 46218.

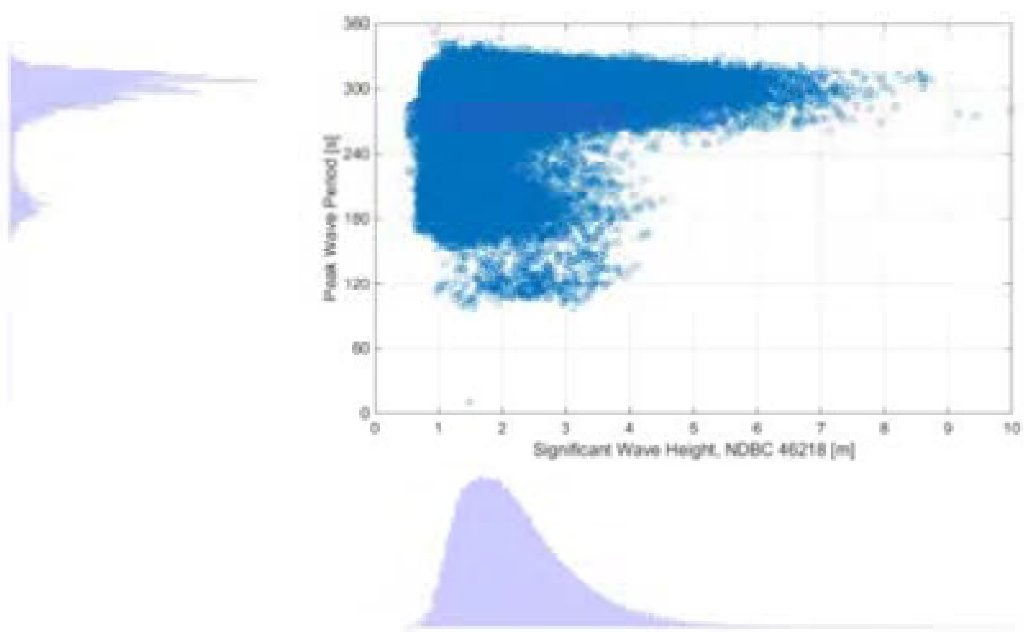

Figure 30: Scatterplot of Significant Wave Height [m] and Wave Direction [deg], NDBC 46218.

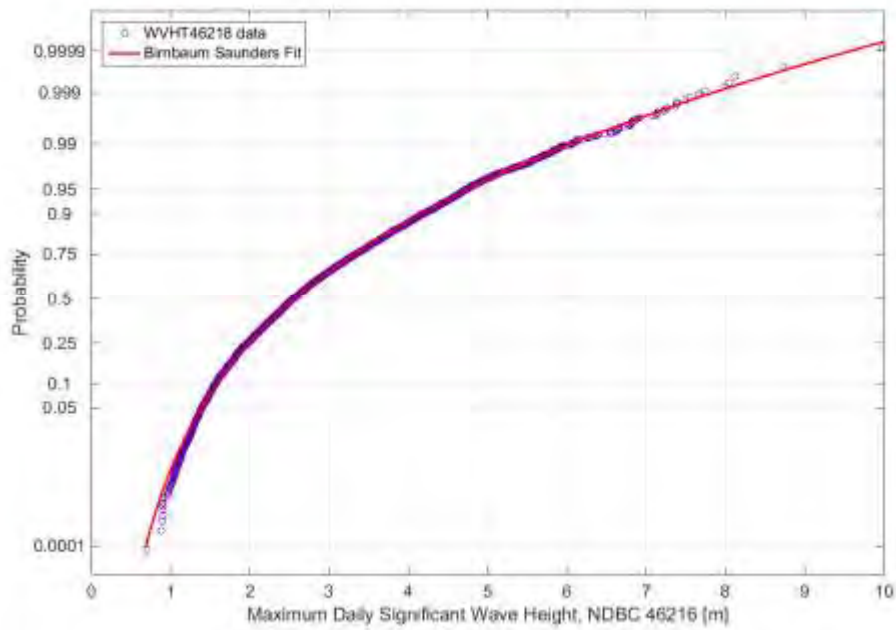

Figure 31: Birnbaum Saunders Fit, Maximum Daily Significant Wave Height, NDBC 46218.

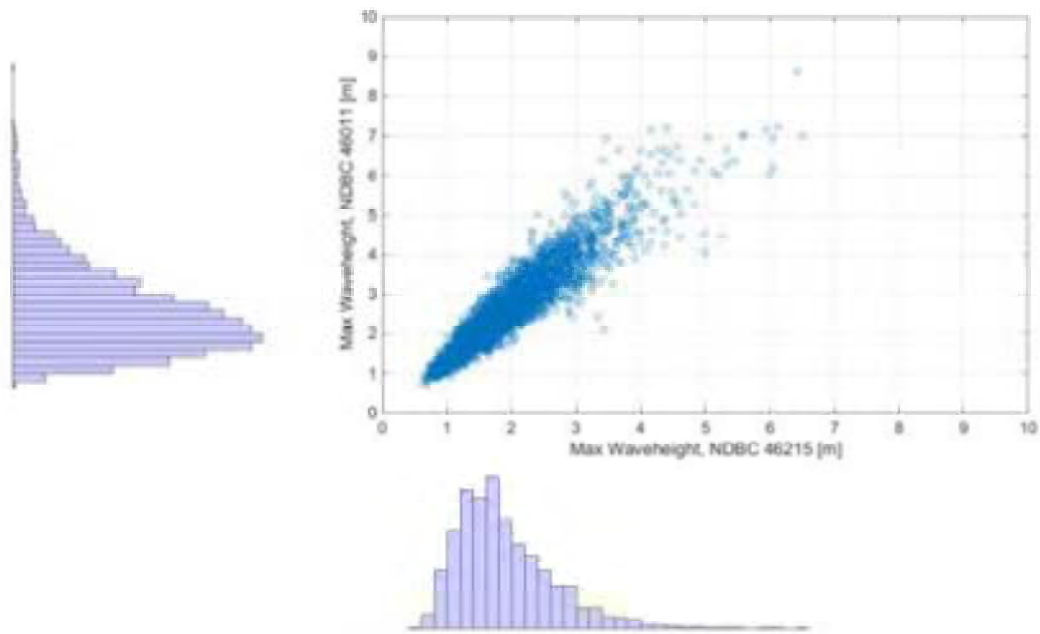

Figure 32: Scatterplot of Max Significant Wave Height [m], NDBC 46215 and NDBC 46011.

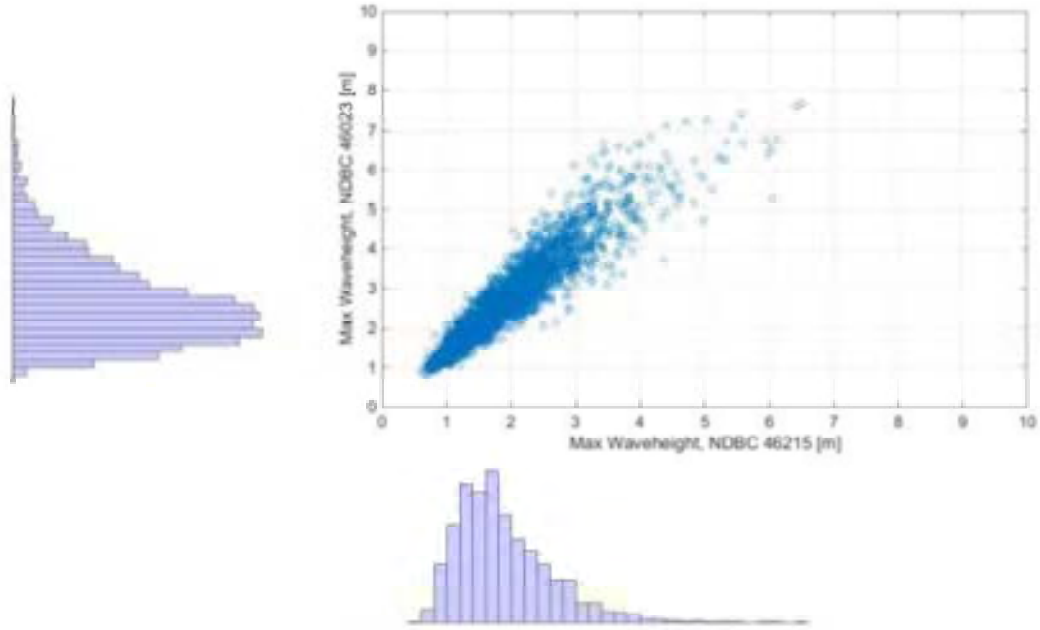

Figure 33: Scatterplot of Max Significant Wave Height [m], NDBC 46215 and NDBC 46023.

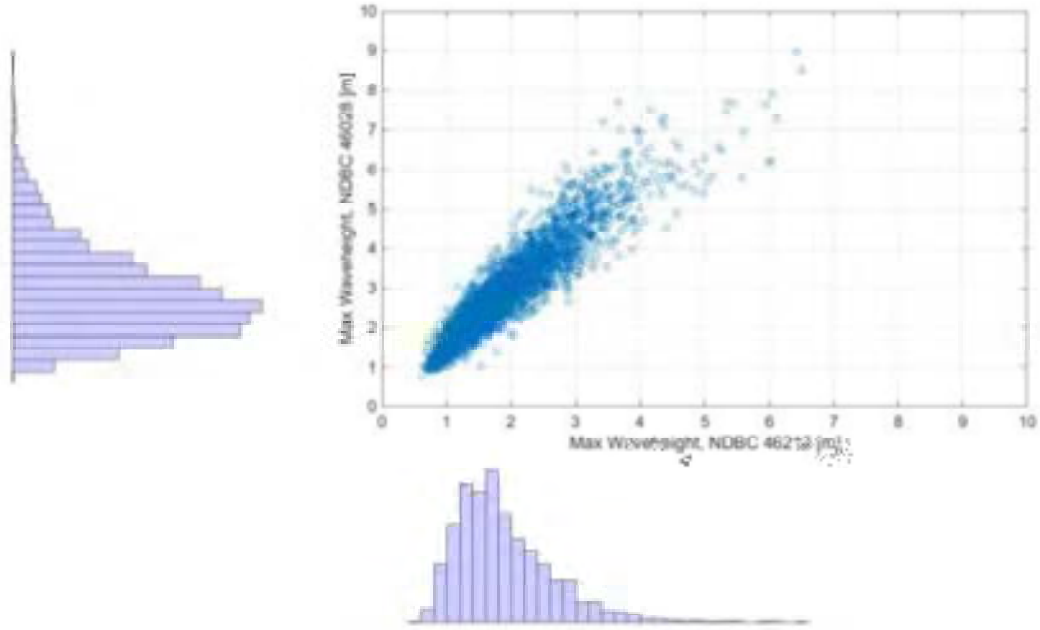

Figure 34: Scatterplot of Max Significant Wave Height [m], NDBC 46215 and NDBC 46028.

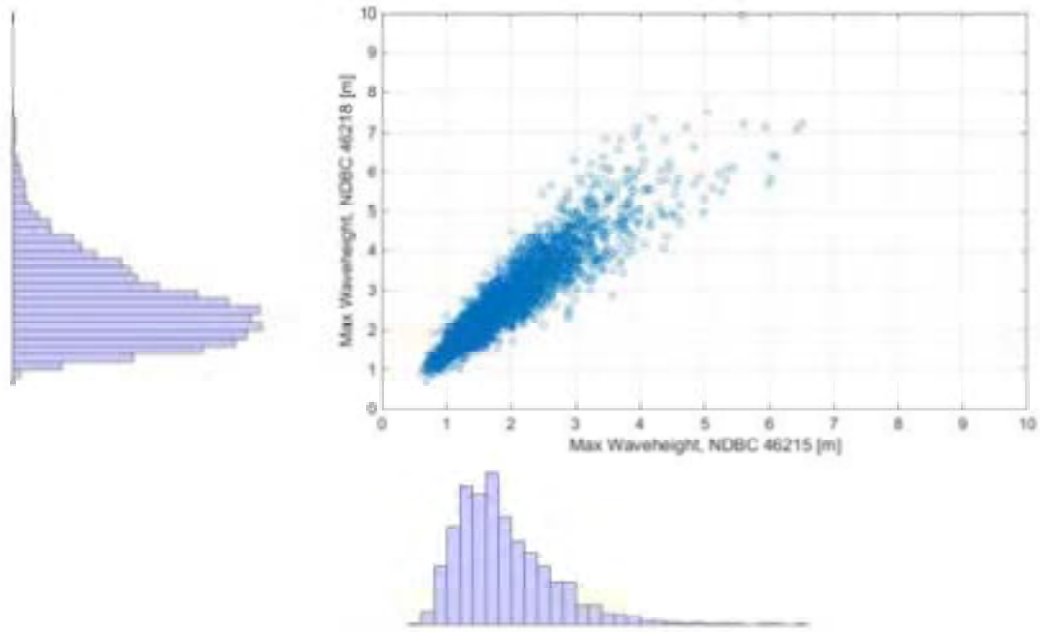

Figure 35: Scatterplot of Max Significant Wave Height [m], NDBC 46215 and NDBC 46218.

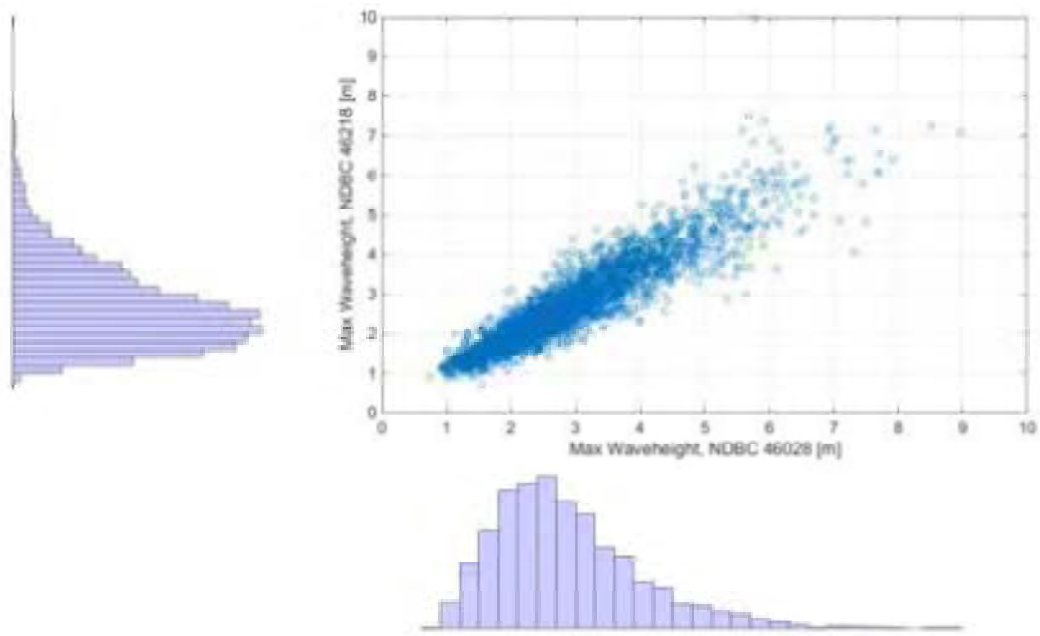

Figure 36: Scatterplot of Max Significant Wave Height [m], NDBC 46028 and NDBC 46218.

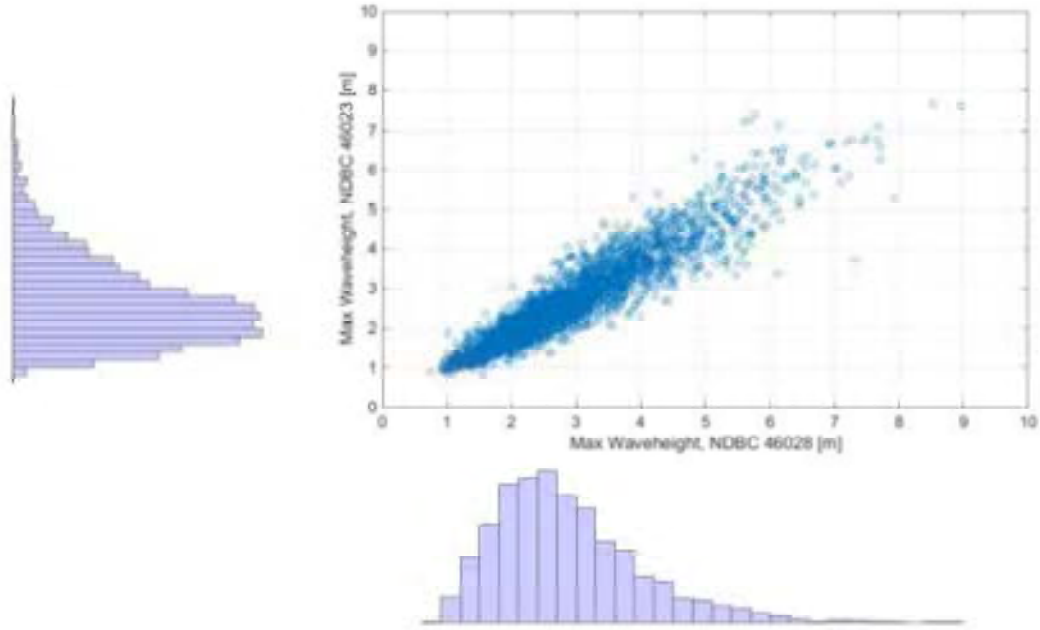

Figure 37: Scatterplot of Max Significant Wave Height [m], NDBC 46028 and NDBC 46023.

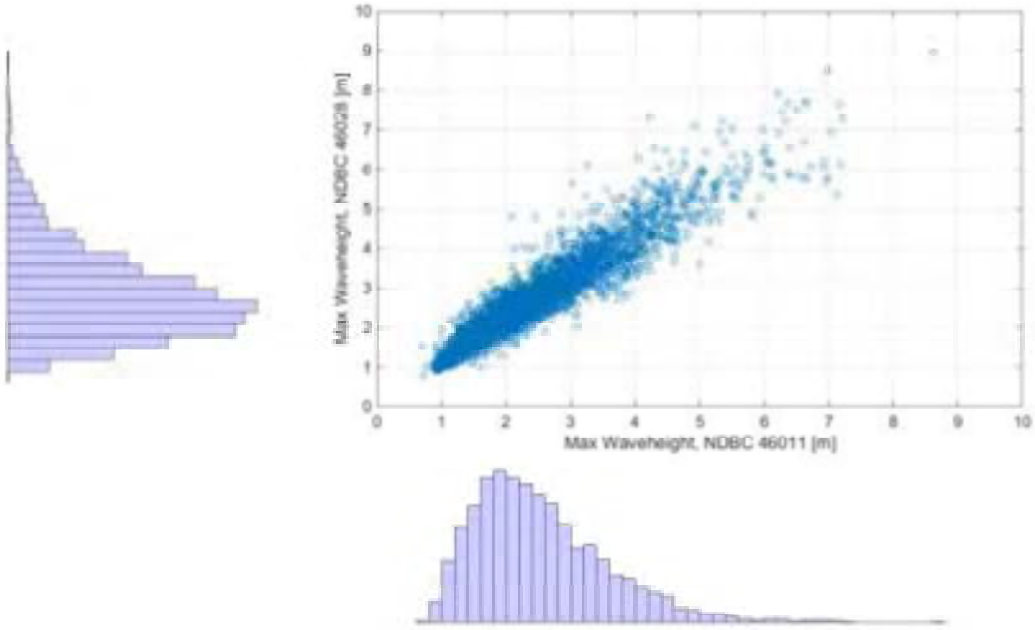

Figure 38: Scatterplot of Max Significant Wave Height [m], NDBC 46011 and NDBC 46028.

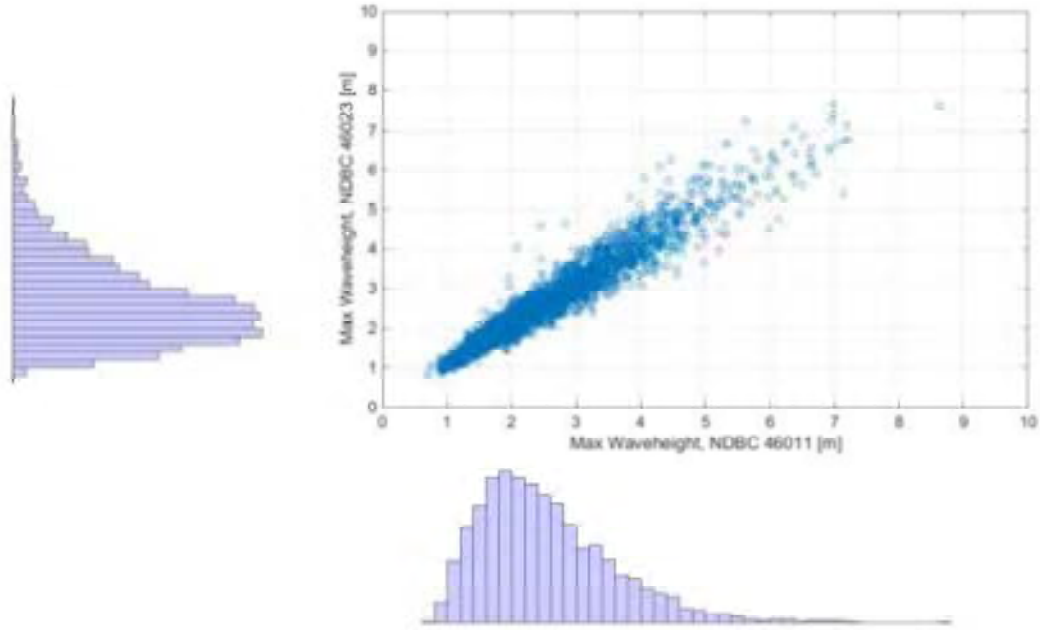

Figure 39: Scatterplot of Max Significant Wave Height [m], NDBC 46011 and NDBC 46023.

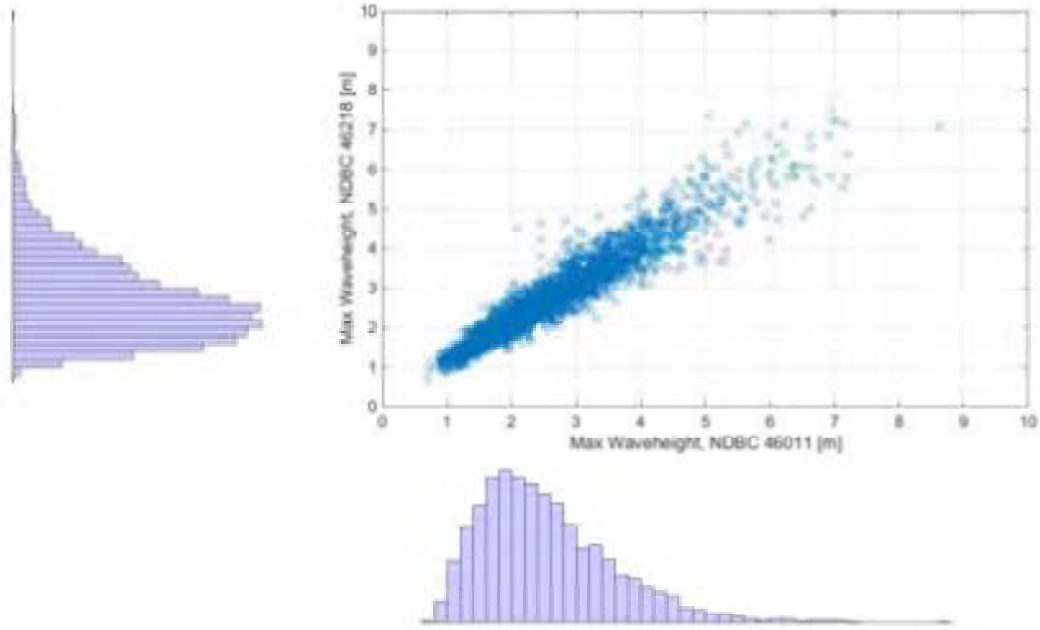

Figure 40: Scatterplot of Max Significant Wave Height [m], NDBC 46011 and NDBC 46218.

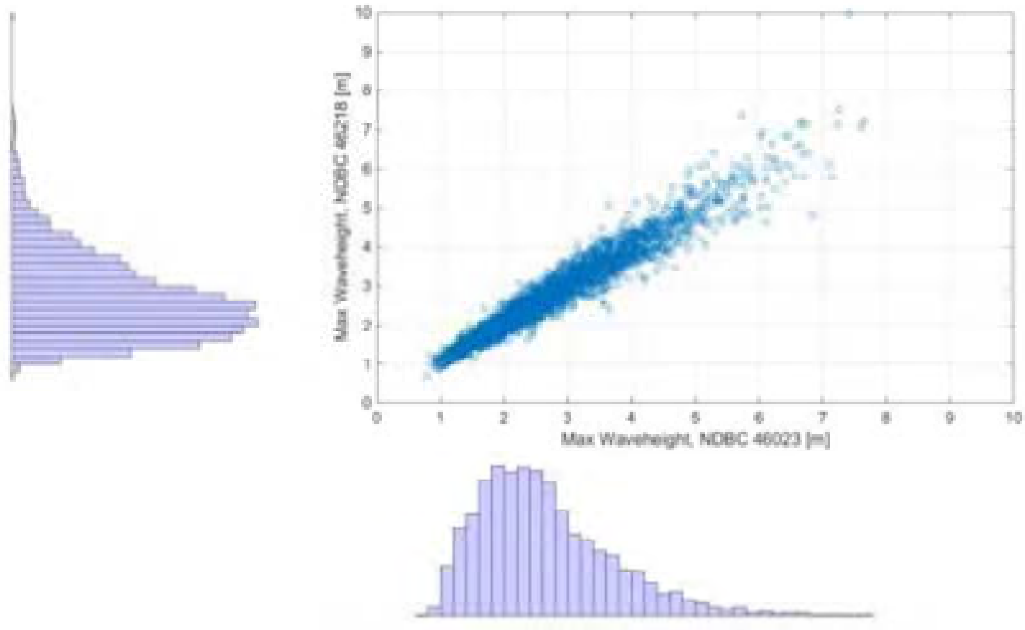

Figure 41: Scatterplot of Max Significant Wave Height [m], NDBC 46023 and NDBC 46218.

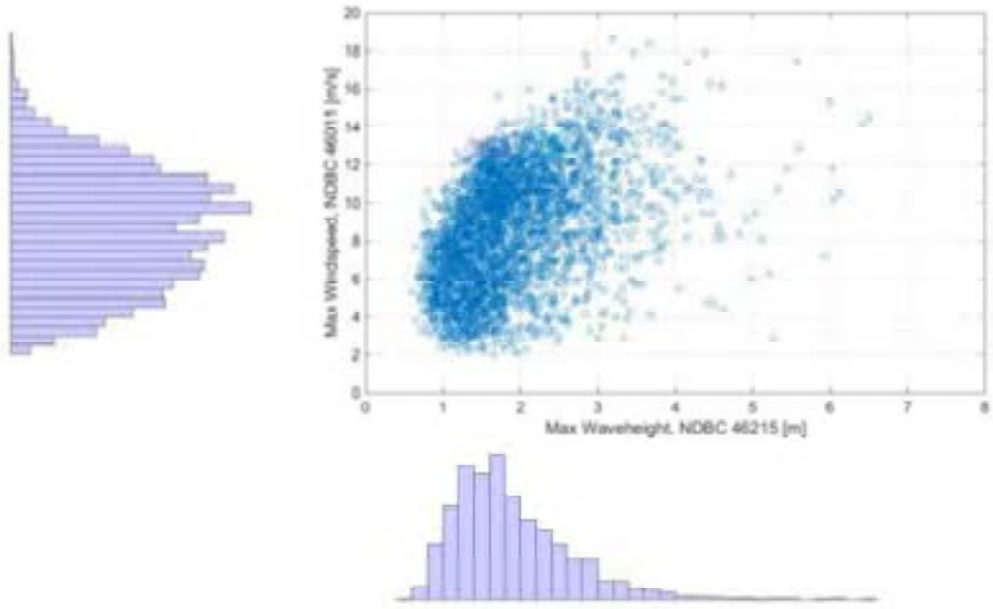

Figure 42: Scatterplot of Daily Max Significant Wave Height [m], NDBC 46215 and Daily Max Windspeed [m/s], NDBC 46011.

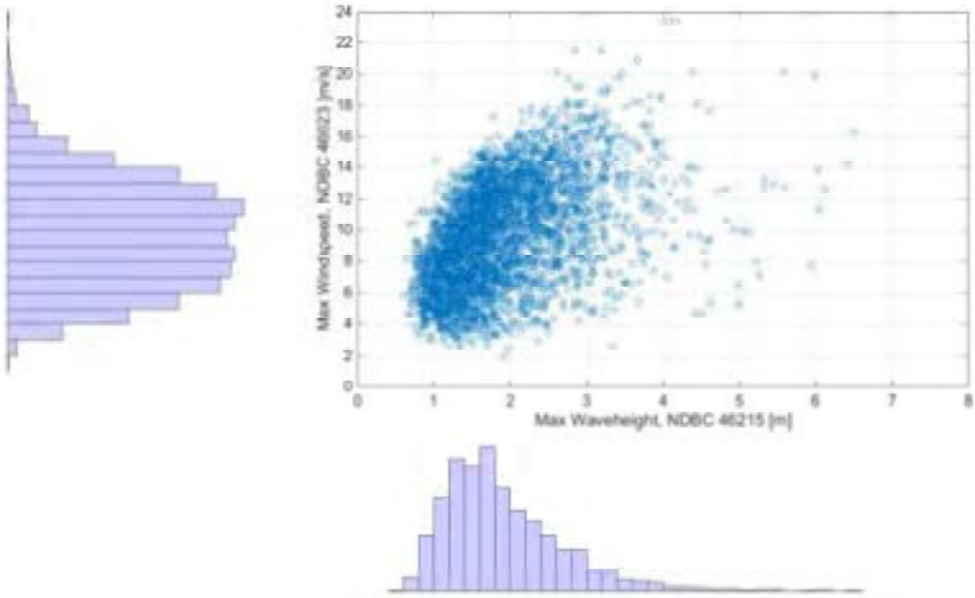

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Figure 43: Scatterplot of Daily Max Significant Wave Height [m], NDBC 46215 and Daily Max Windspeed [m/s], NDBC 46023.

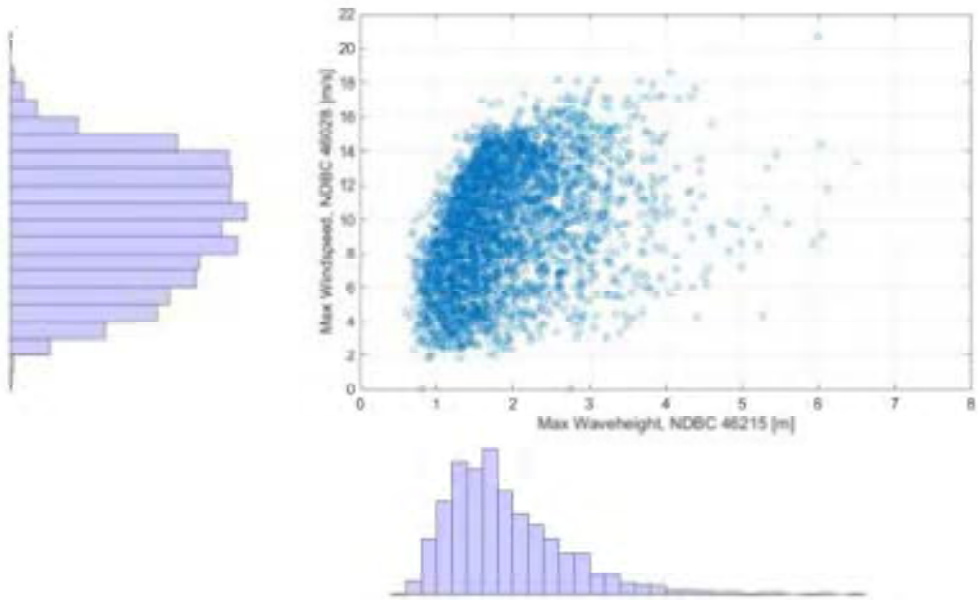


Figure 44: Scatterplot of Daily Max Significant Wave Height [m], NDBC 46215 and Daily Max Windspeed [m/s], NDBC 46028.

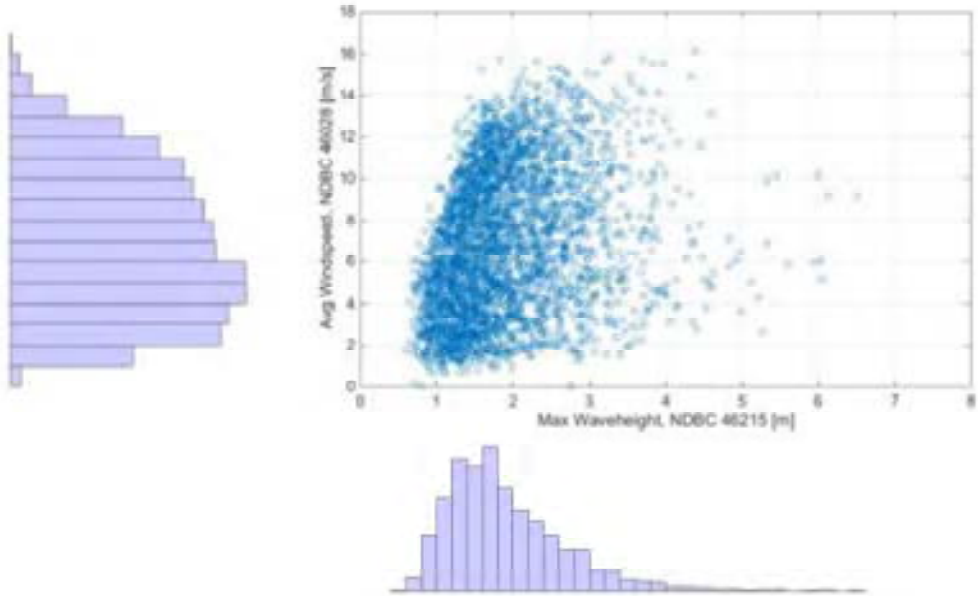


Figure 45: Scatterplot of Daily Max Significant Wave Height [m], NDBC 46215 and Daily Average Windspeed [m/s], NDBC 46028.

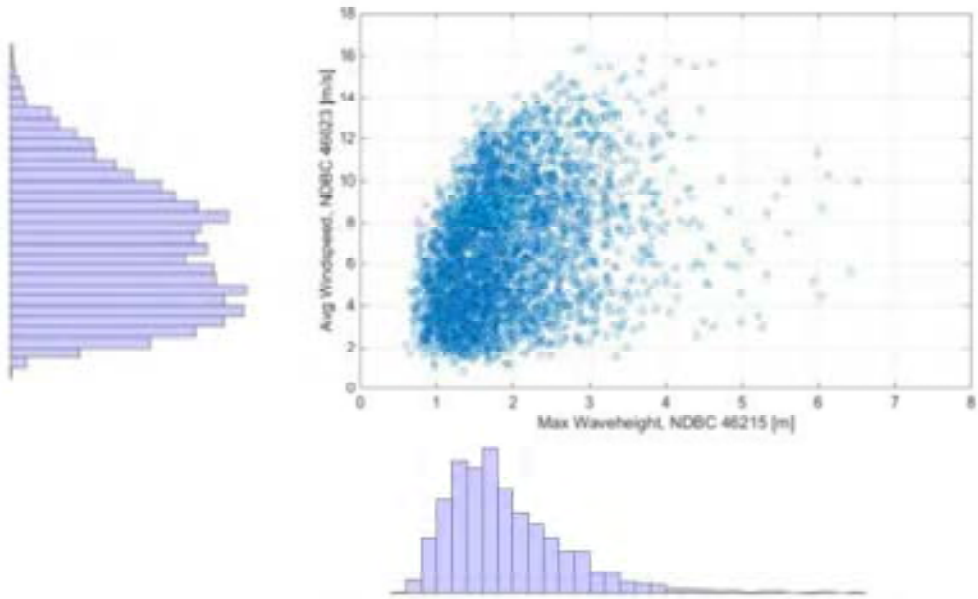


Figure 46: Scatterplot of Daily Max Significant Wave Height [m], NDBC 46215 and Daily Average Windspeed [m/s], NDBC 46023.

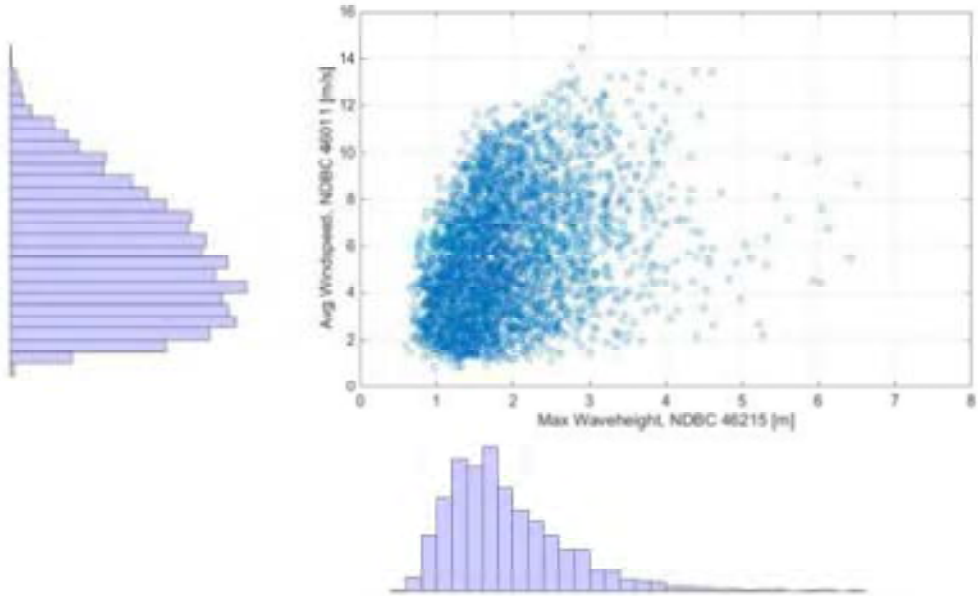


Figure 47: Scatterplot of Daily Max Significant Wave Height [m], NDBC 46215 and Daily Average Windspeed [m/s], NDBC 46011.

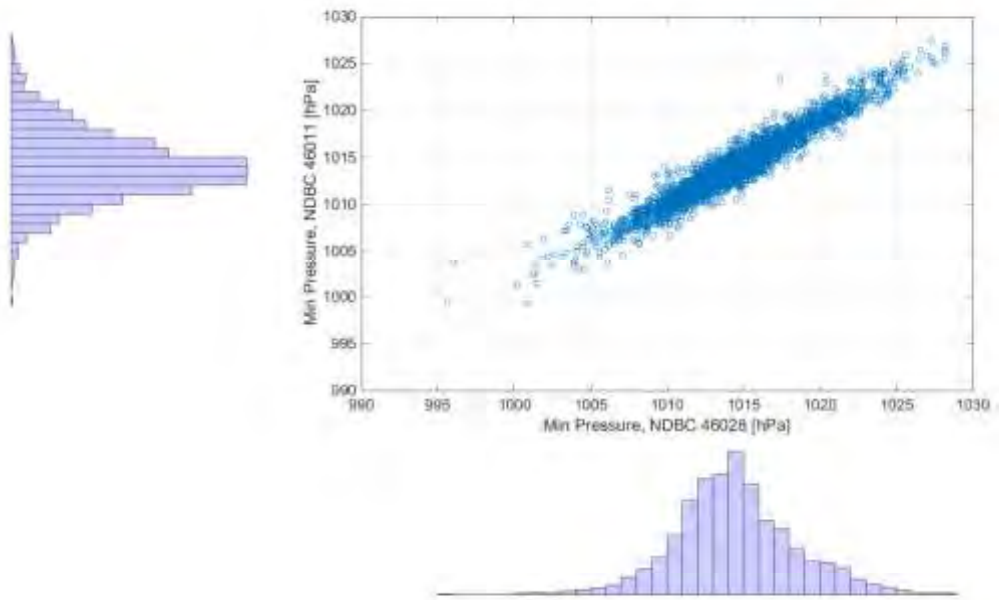


Figure 48: Scatterplot of Daily Min Atm. Pressure [hPa], NDBC 46028 and NDBC 46011.

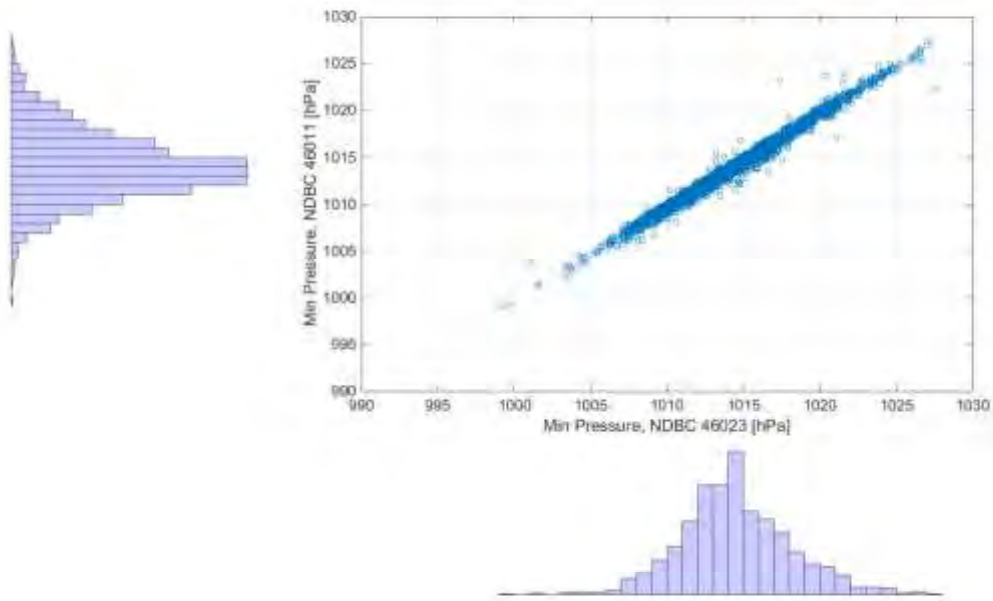


Figure 49: Scatterplot of Daily Min Atm. Pressure [hPa], NDBC 46023 and NDBC 46011.

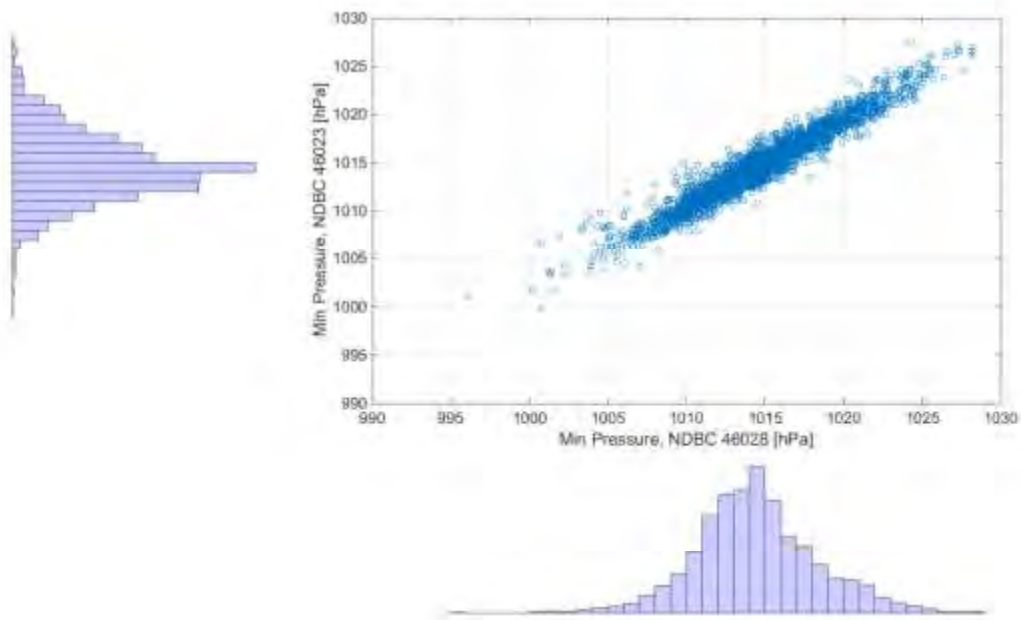


Figure 50: Scatterplot of Daily Min Atm. Pressure [hPa], NDBC 46028 and NDBC 46023.

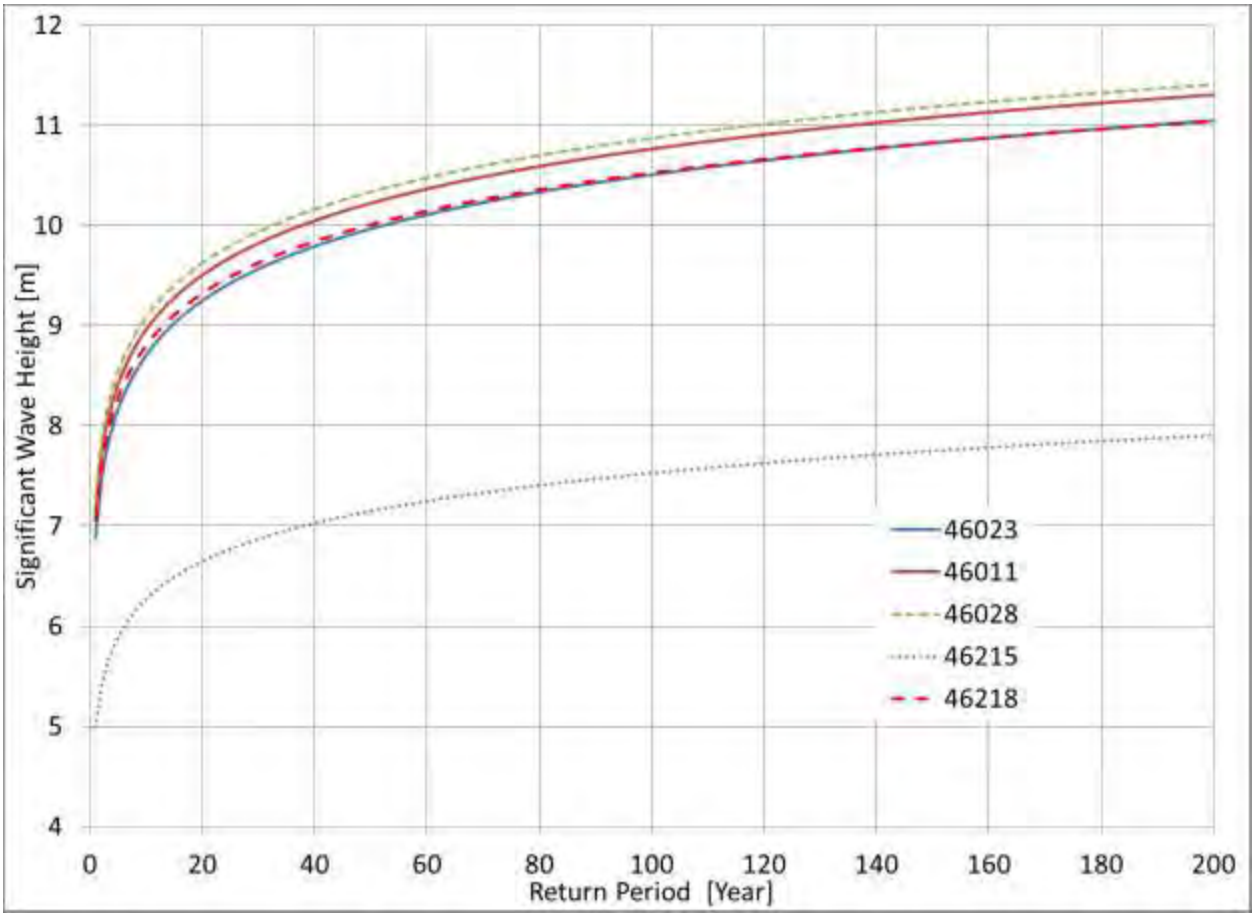


Figure 51: Return Periods for Significant Wave Heights at NDBC Observation Buoys Along the Central Coast.

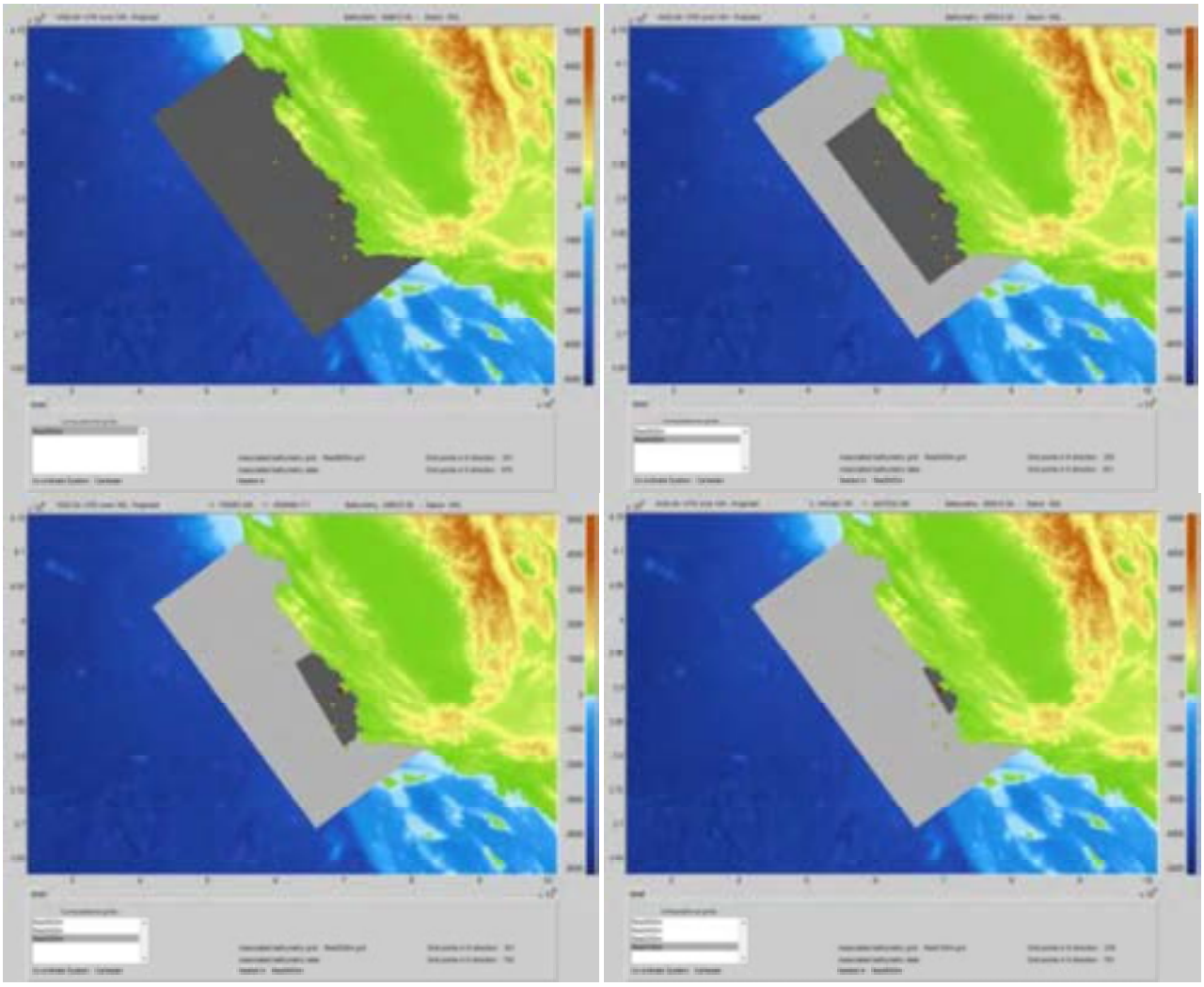


Figure 52: Nesting Grids, 600 m, 400m, 200m, and 100 m Resolution (as described in Table 16).

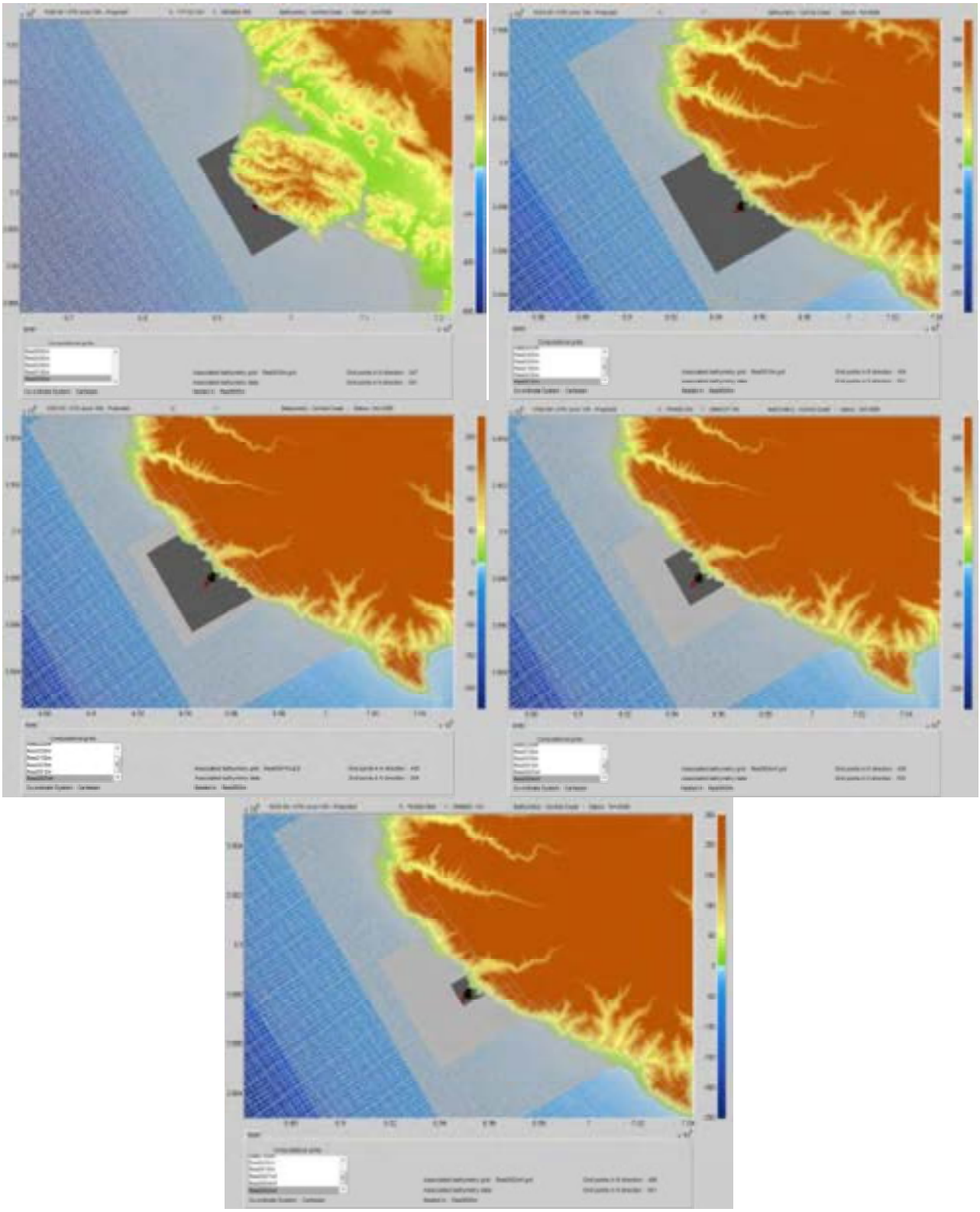


Figure 53: Nesting Grids, 30 m, 10 m, 7 m, 4 m, and 2 m Resolution (as described in Table 16).

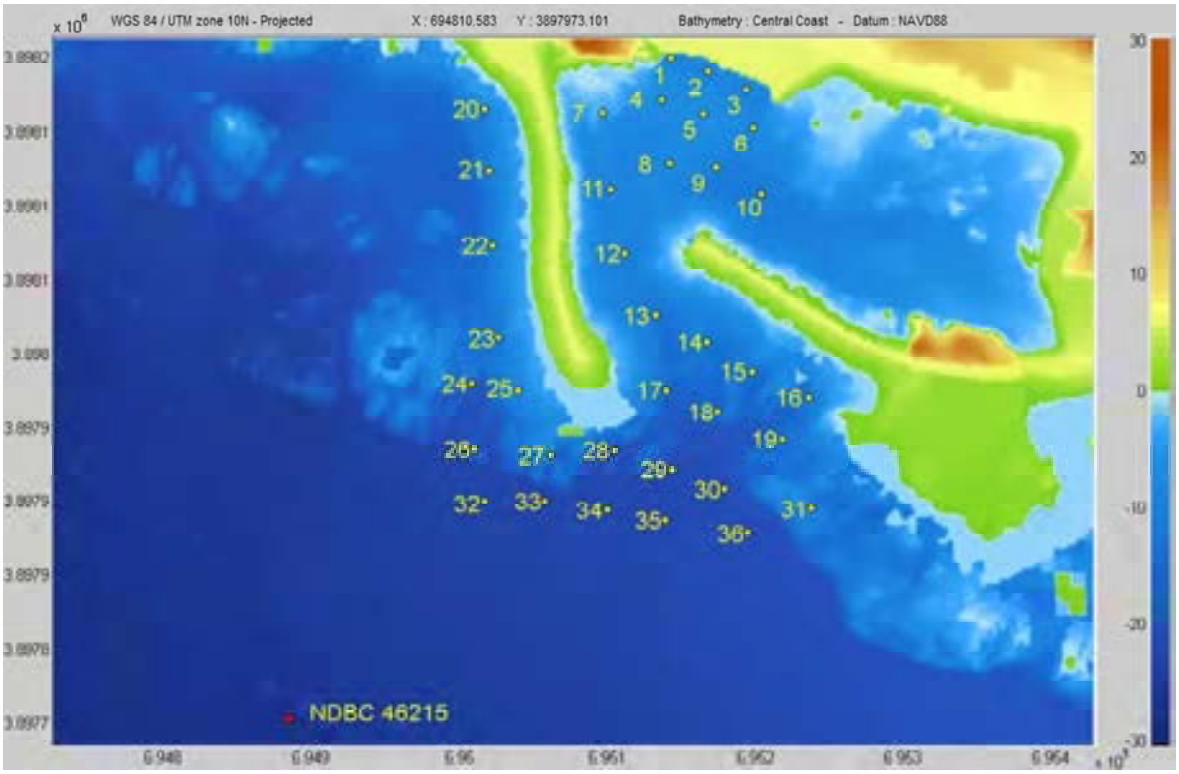


Figure 54: Observation Points for Delft3D Numerical Outputs (as seen in Tables 23-27).

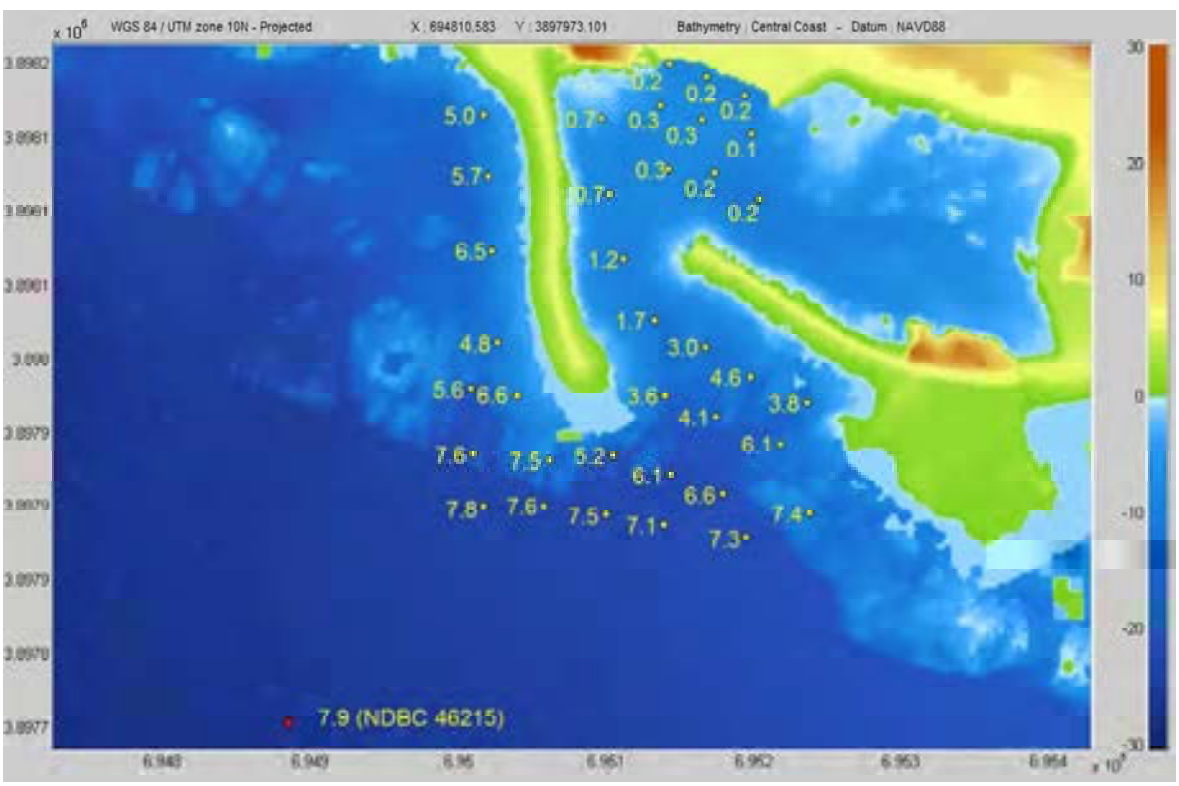


Figure 55: Significant Wave Height [m] at Breakwater Observation Points, 0.0 m.

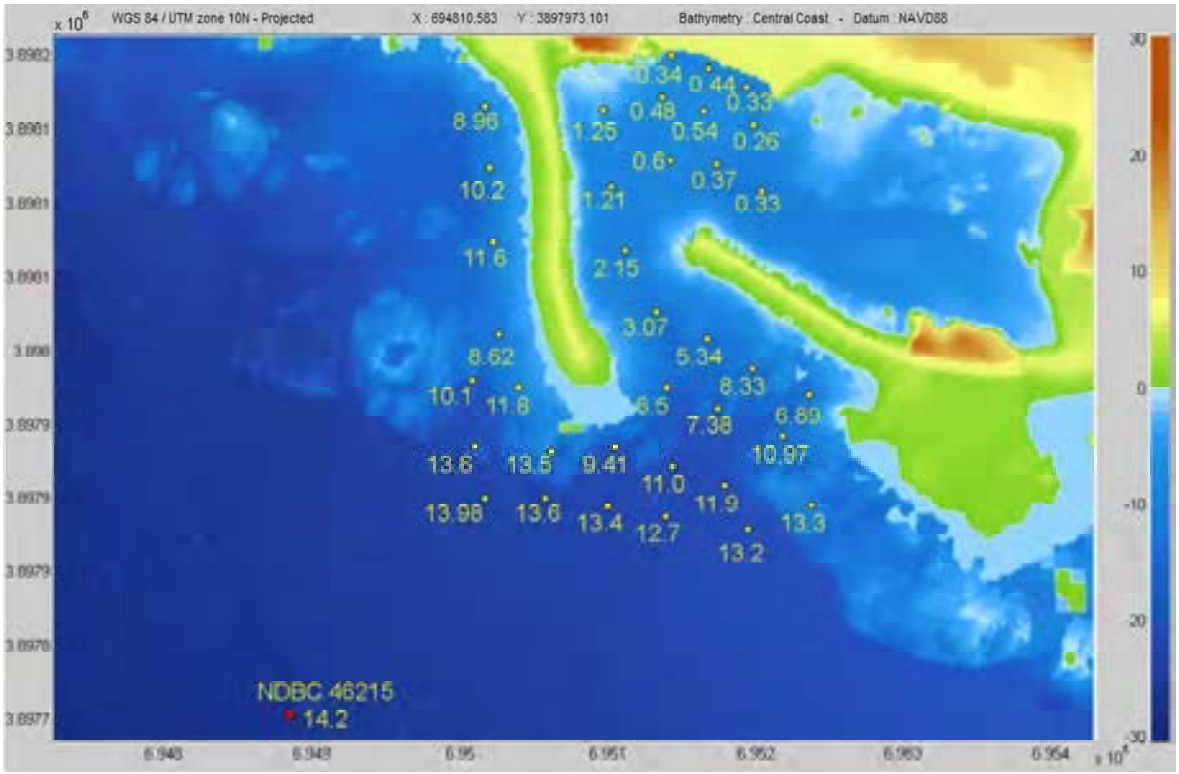


Figure 56: Maximum Estimated Wave Height [m] at Breakwater Observation Points, 0.0 m.

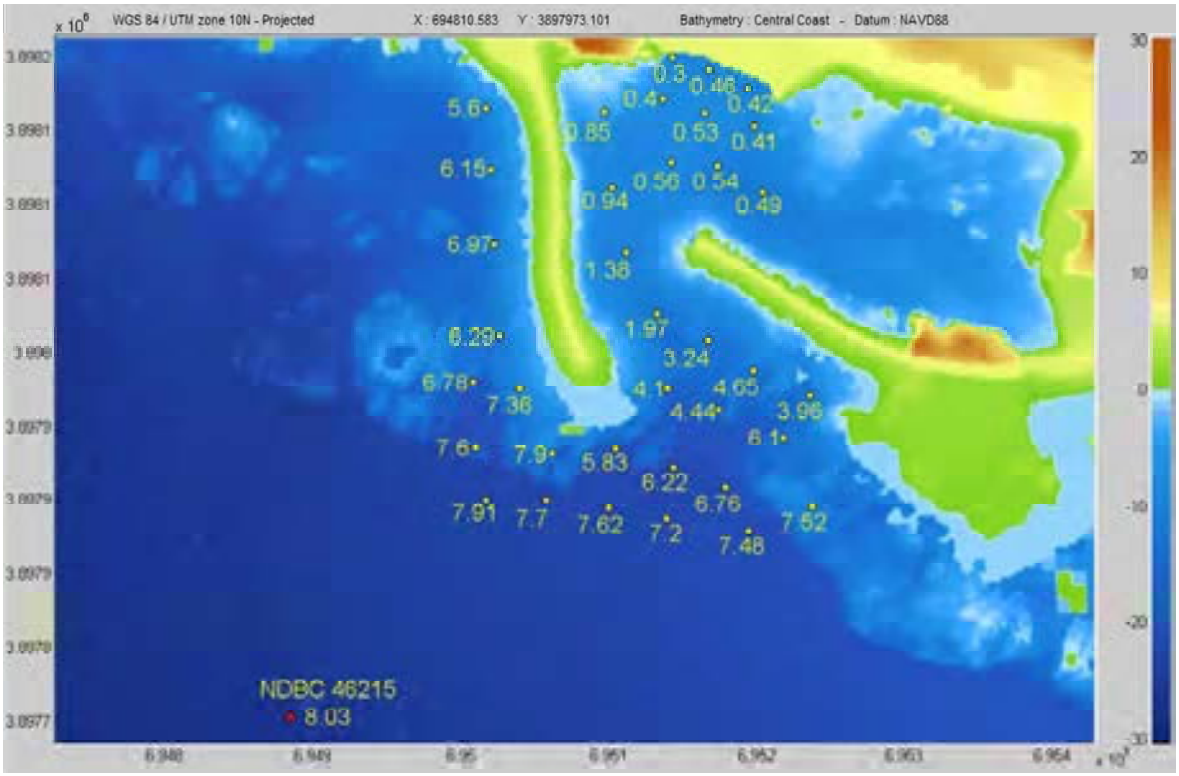


Figure 57: Significant Wave Height [m] at Breakwater Observation Points, 2.65 m (HHWL).

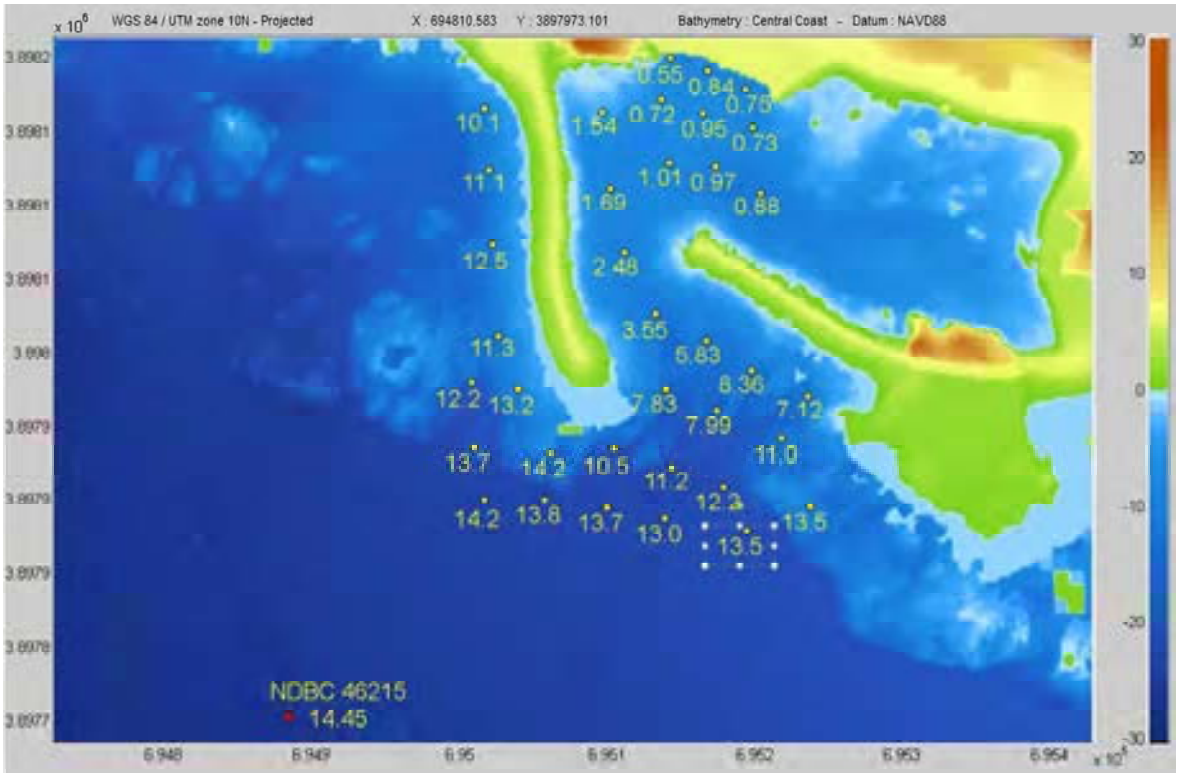


Figure 58: Maximum Estimated Wave Height [m] at Breakwater Observation Points, 2.65 m (HHWL).

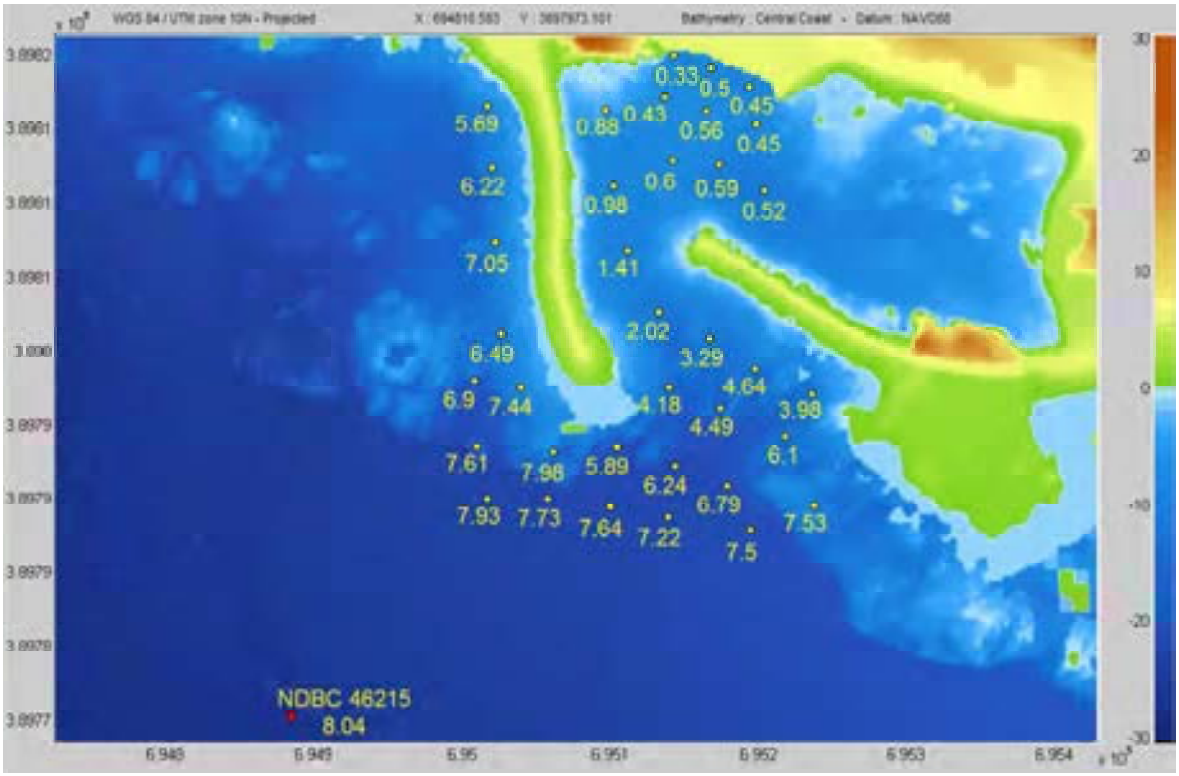


Figure 59: Significant Wave Height [m] at Breakwater Observation Points, 3.03 m (SAWL).

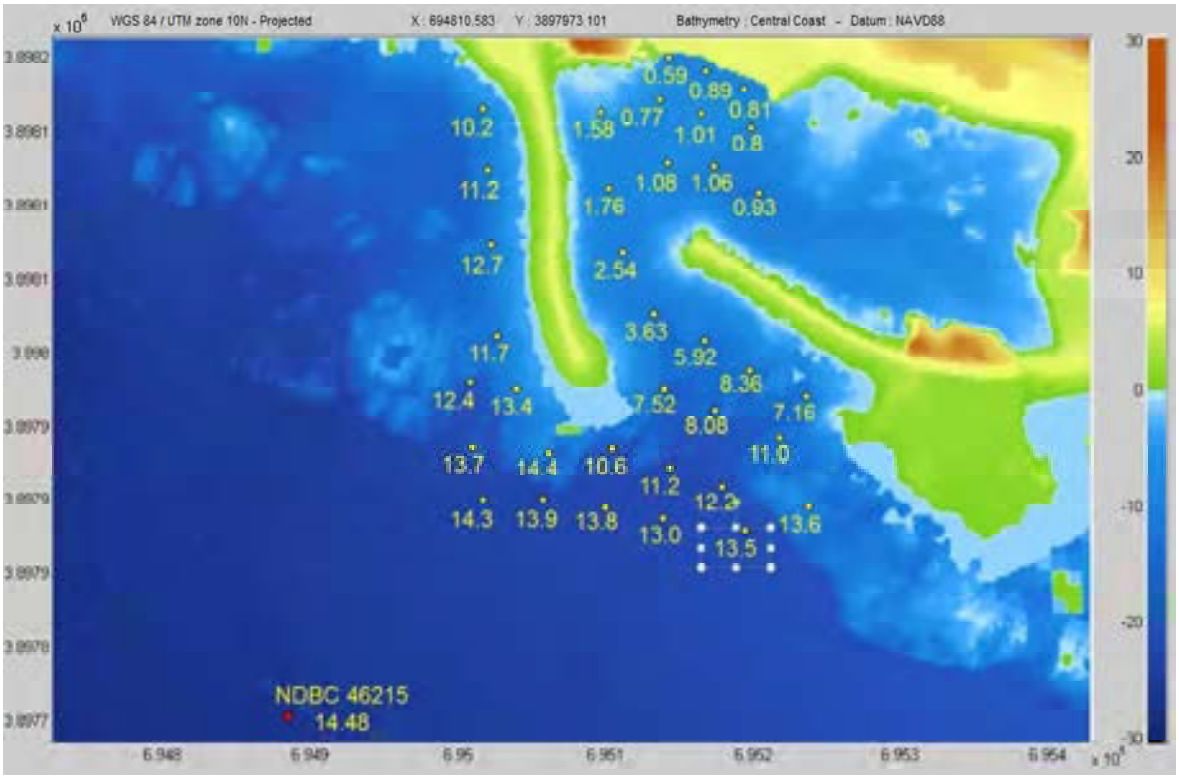


Figure 60: Maximum Estimated Wave Height [m] at Breakwater Observation Points, 3.03 m (SAWL).

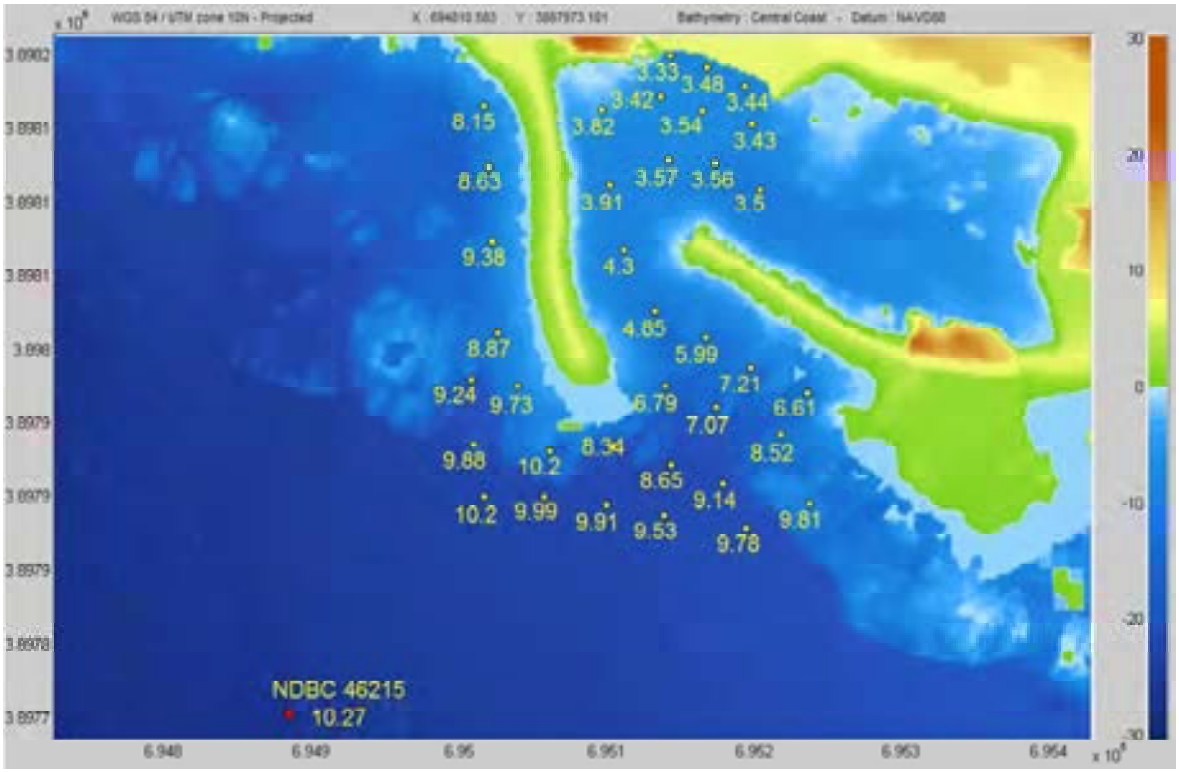


Figure 61: Crest Wave Level, NAVD88 [m] at 3.03 m (SAWL)

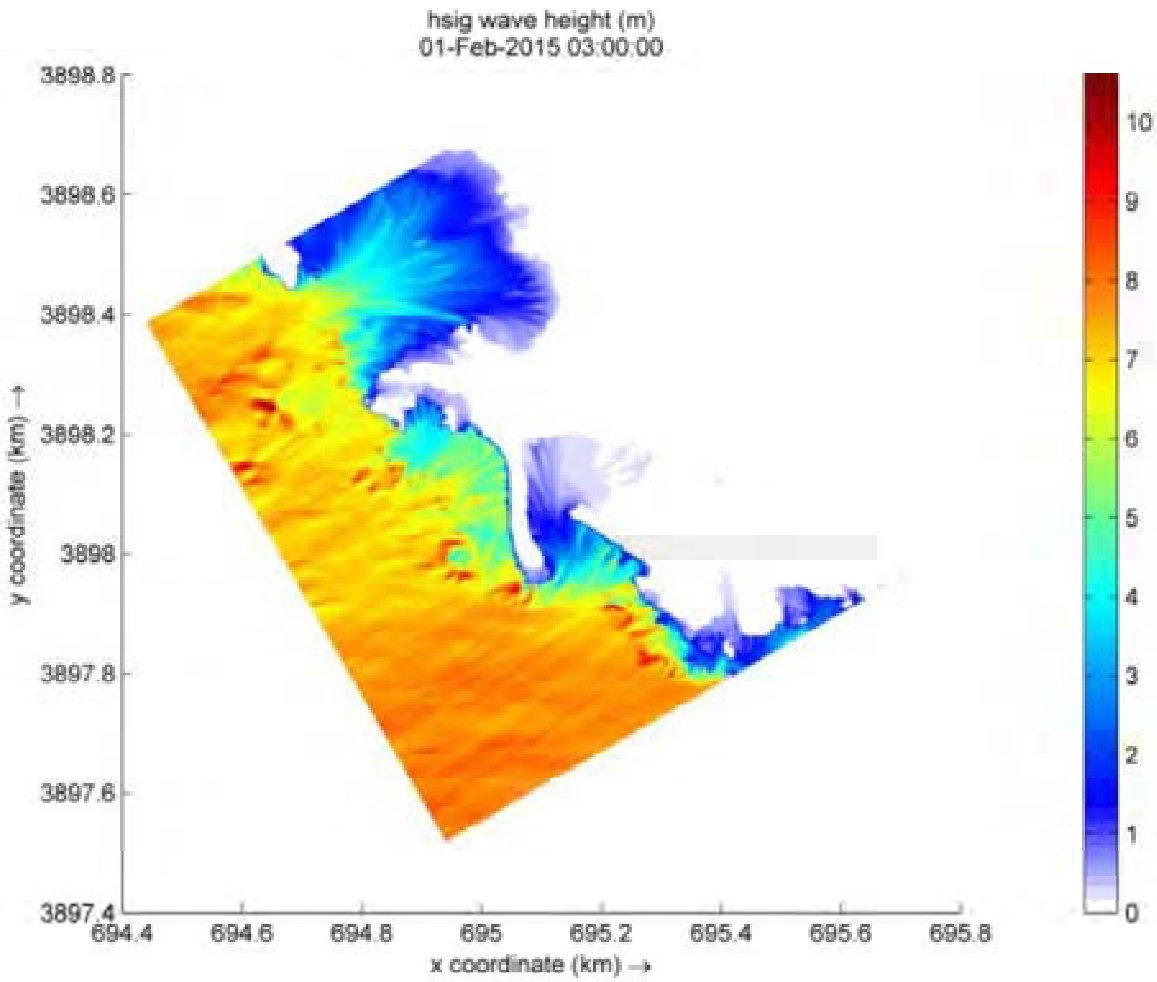


Figure 62: Significant Wave Height, 2 [m] grid resolution, 0 m NAVD88.

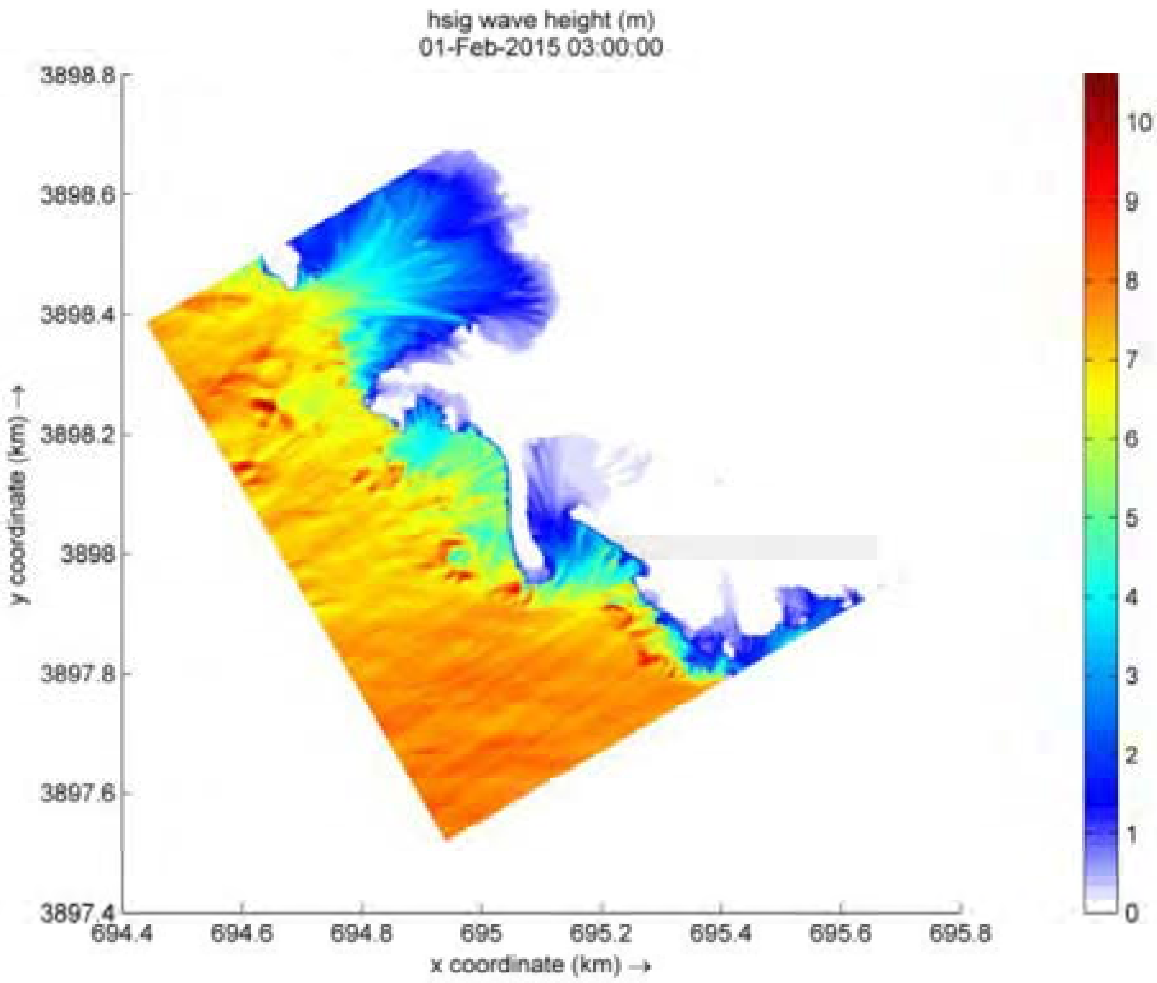


Figure 63: Significant Wave Height, 2 [m] grid resolution, 2.13 m NAVD88.

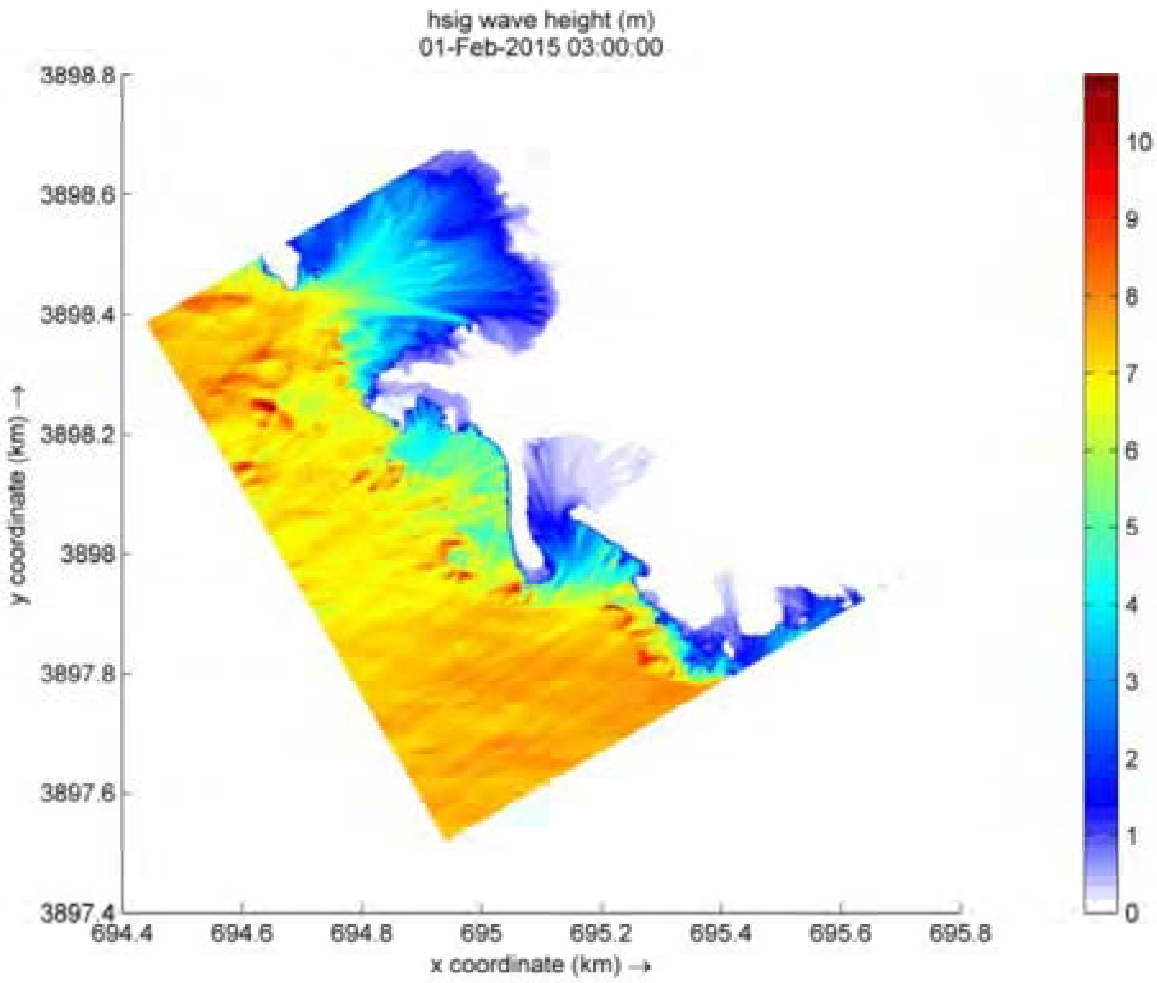


Figure 64: Significant Wave Height, 2 [m] grid resolution, 2.65 m NAVD88.

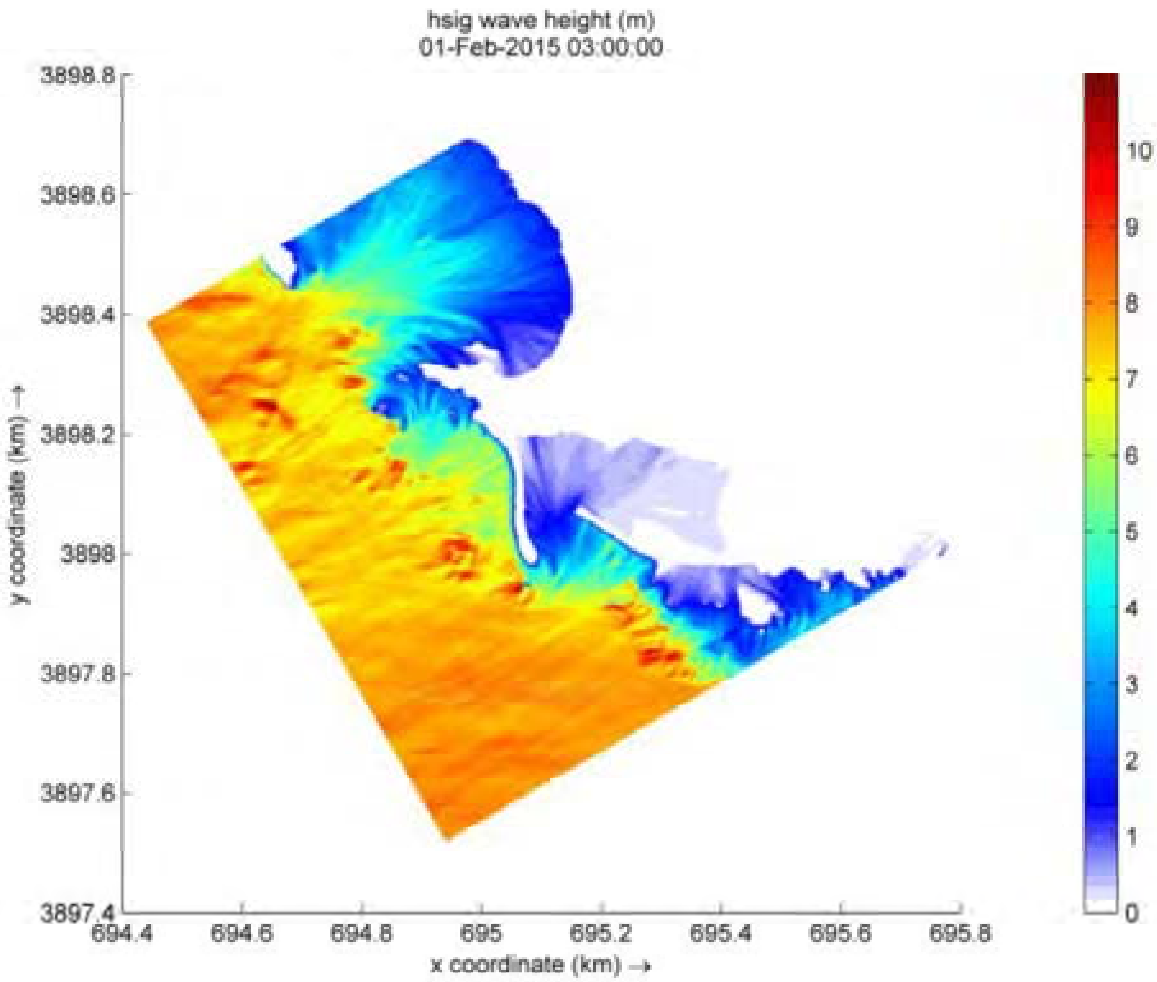


Figure 65: Significant Wave Height, 2 [m] grid resolution, 3.03 m NAVD88.

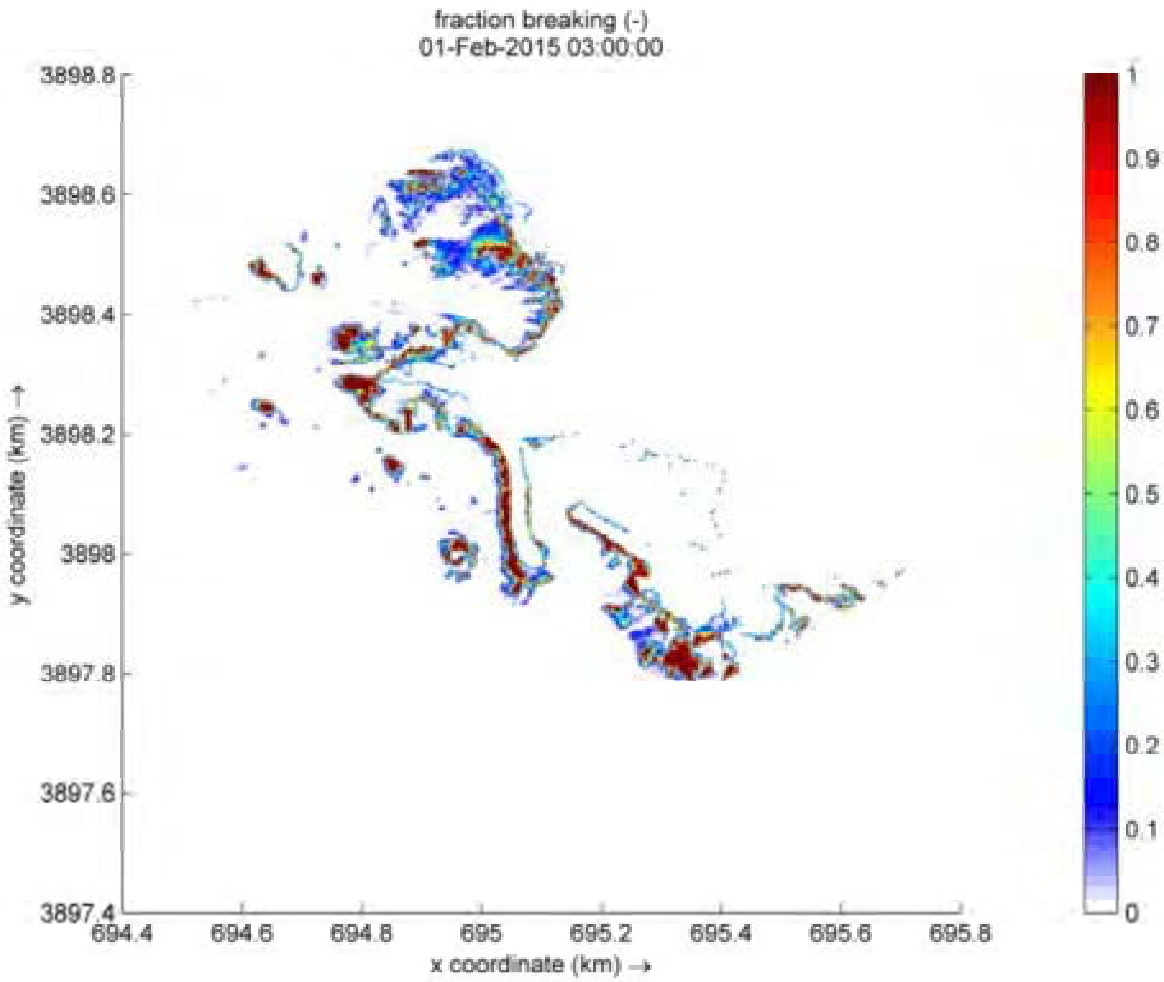


Figure 66: Fraction of Wave Breaking, 2 [m] grid resolution, 0 m NAVD88.

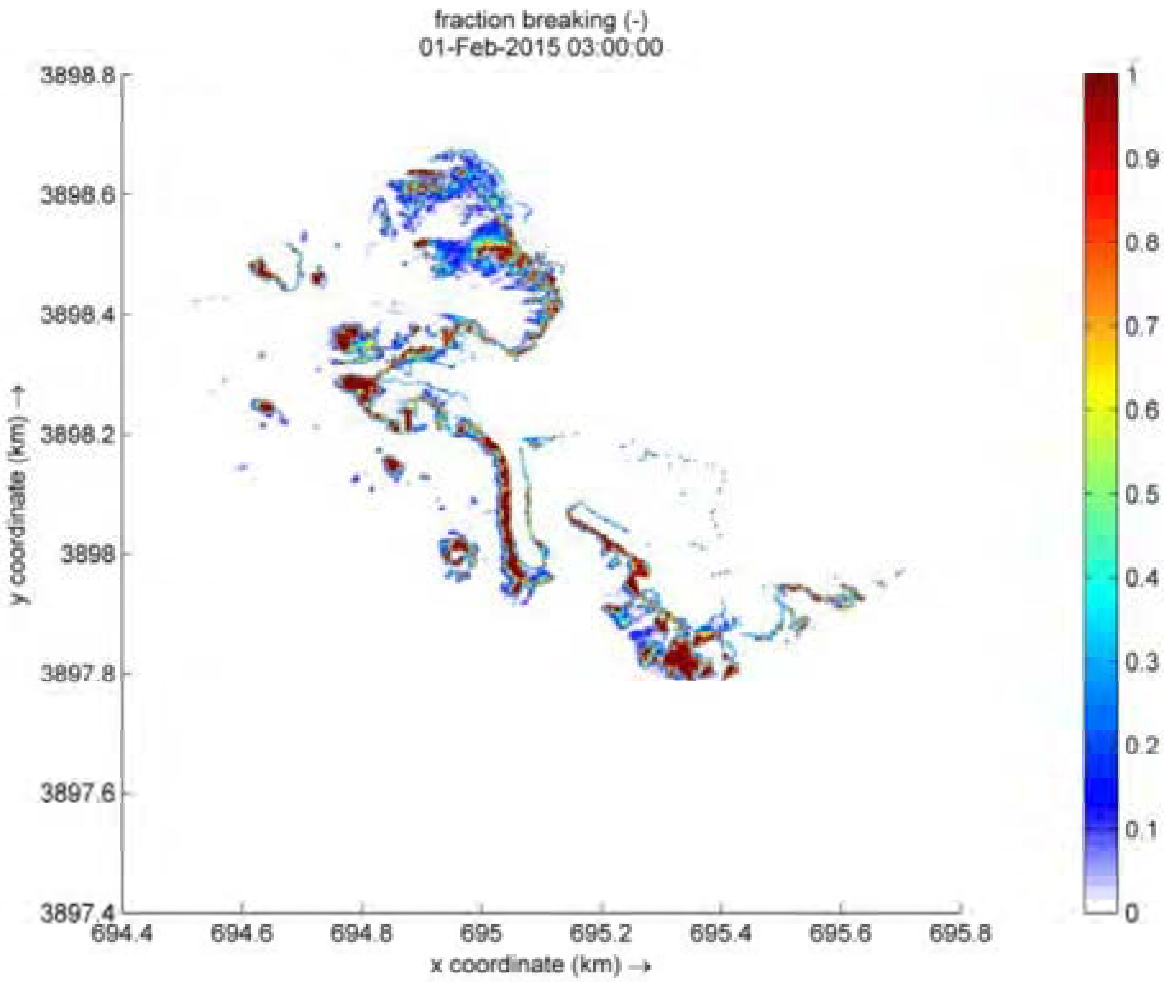


Figure 67: Fraction of Wave Breaking, 2 [m] grid resolution, 2.13 m NAVD88.

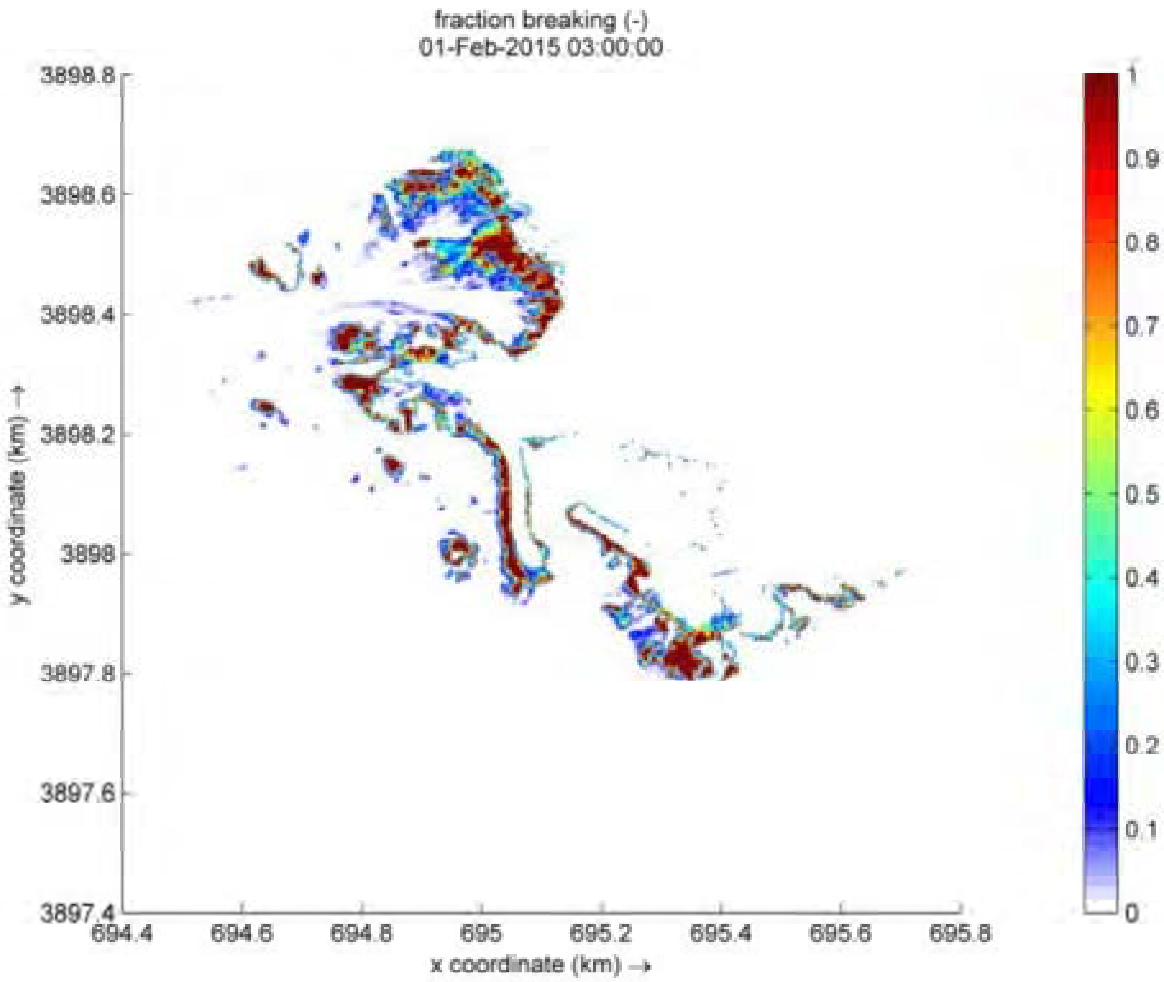


Figure 68: Fraction of Wave Breaking, 2 [m] grid resolution, 2.65 m NAVD88.

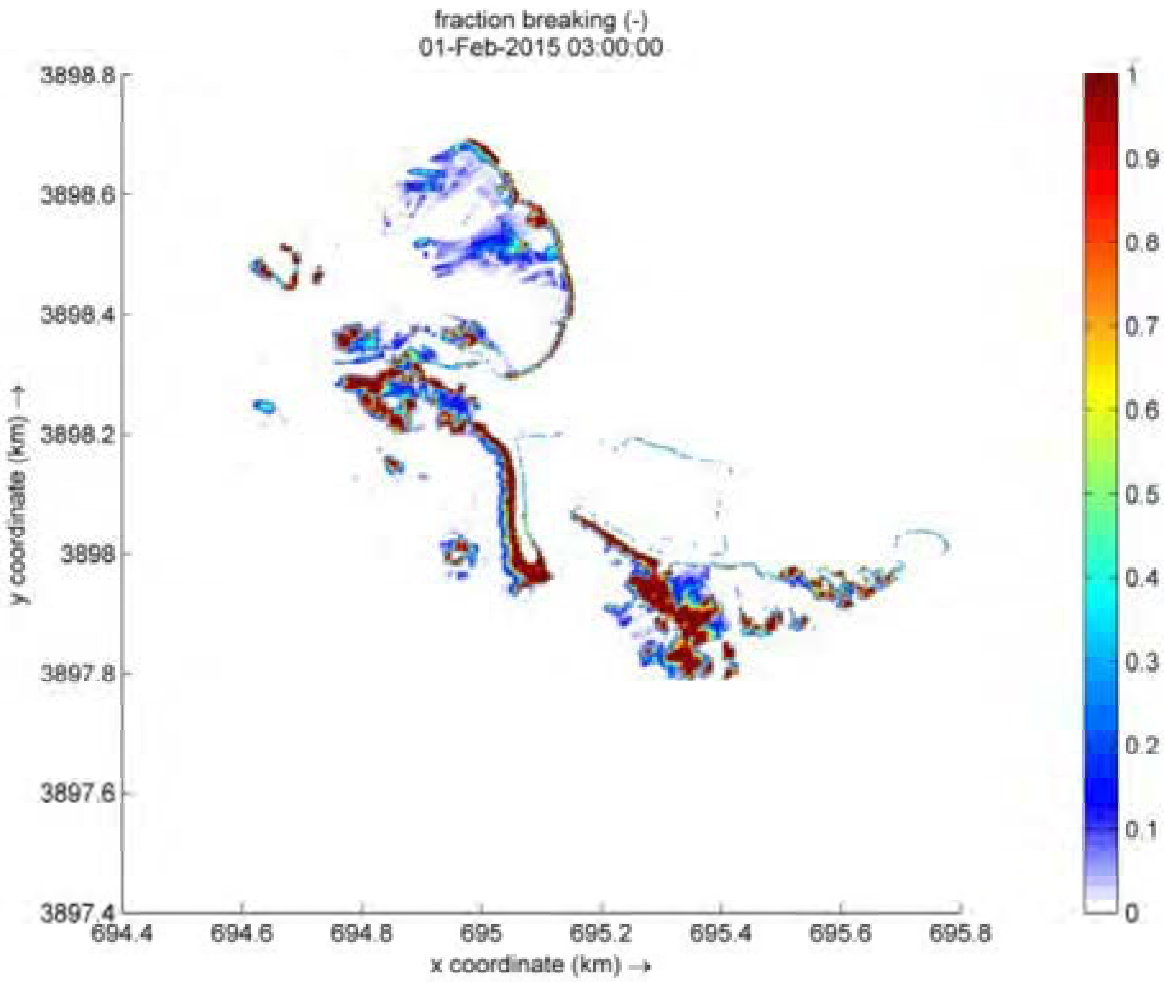


Figure 69: Fraction of Wave Breaking, 2 [m] grid resolution, 3.03 m NAVD88.

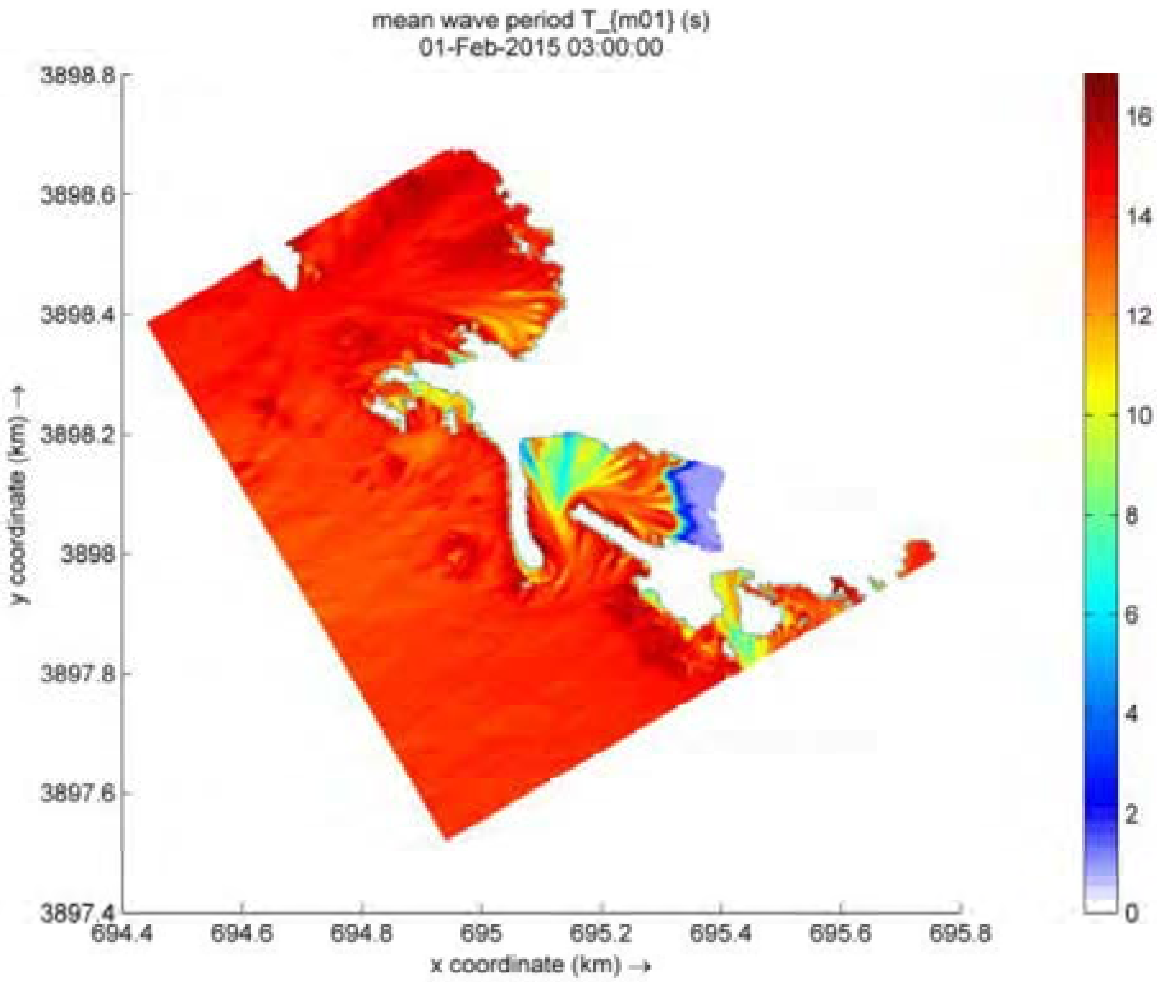


Figure 70: Mean Wave Period, 2 [m] grid resolution, 0 m NAVD88.

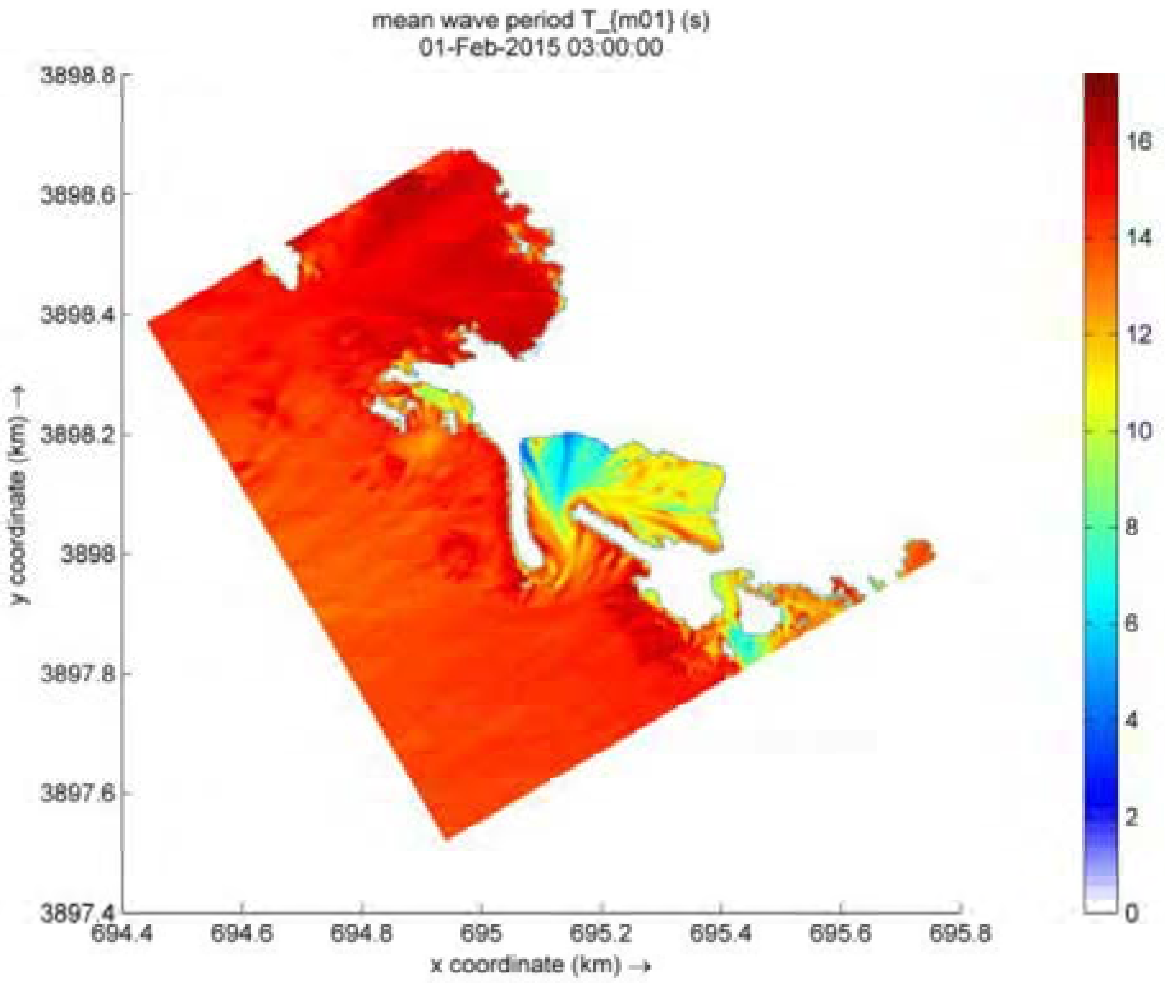


Figure 71: Mean Wave Period, 2 [m] grid resolution, 2.13 m NAVD88.

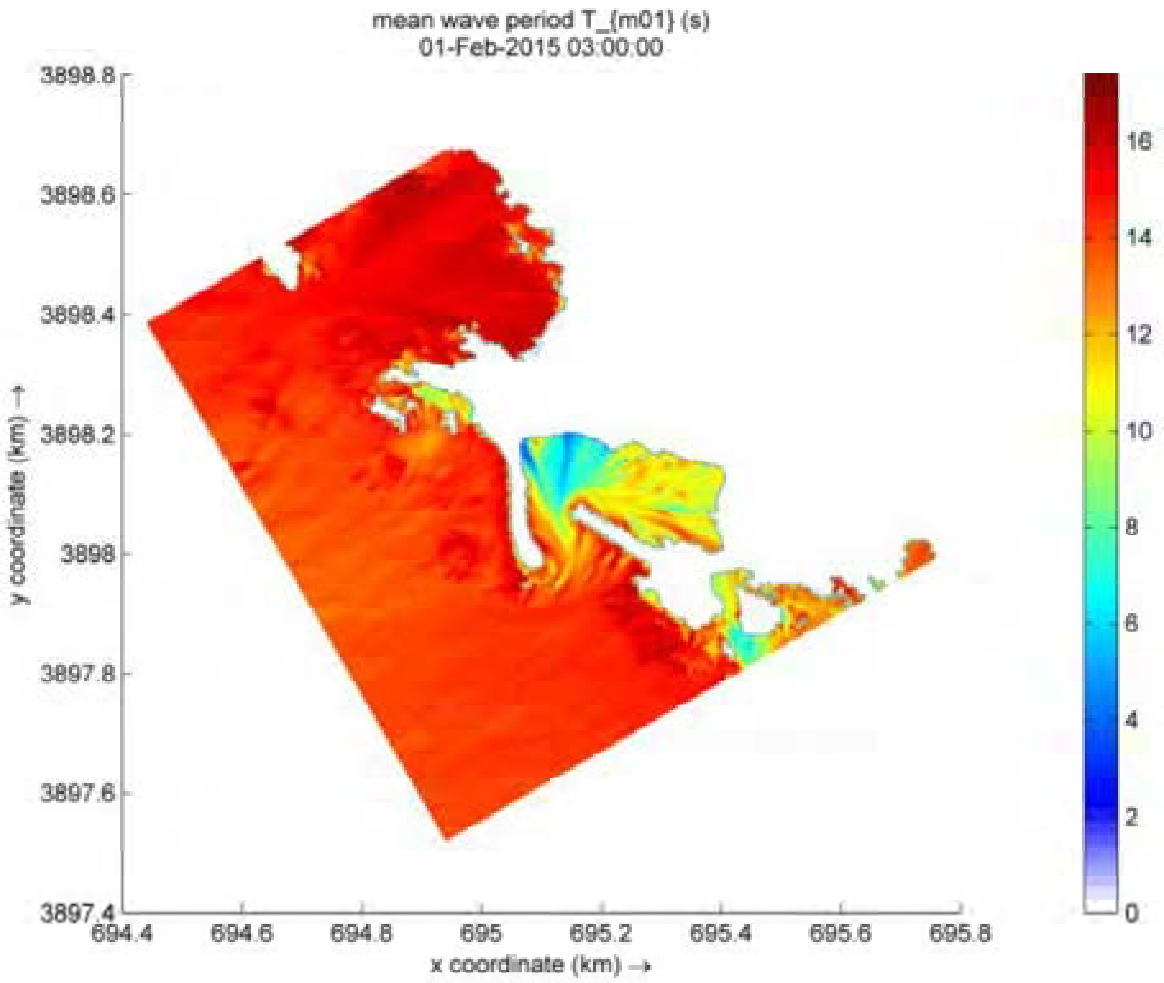


Figure 72: Mean Wave Period, 2 [m] grid resolution, 2.65 m NAVD88.

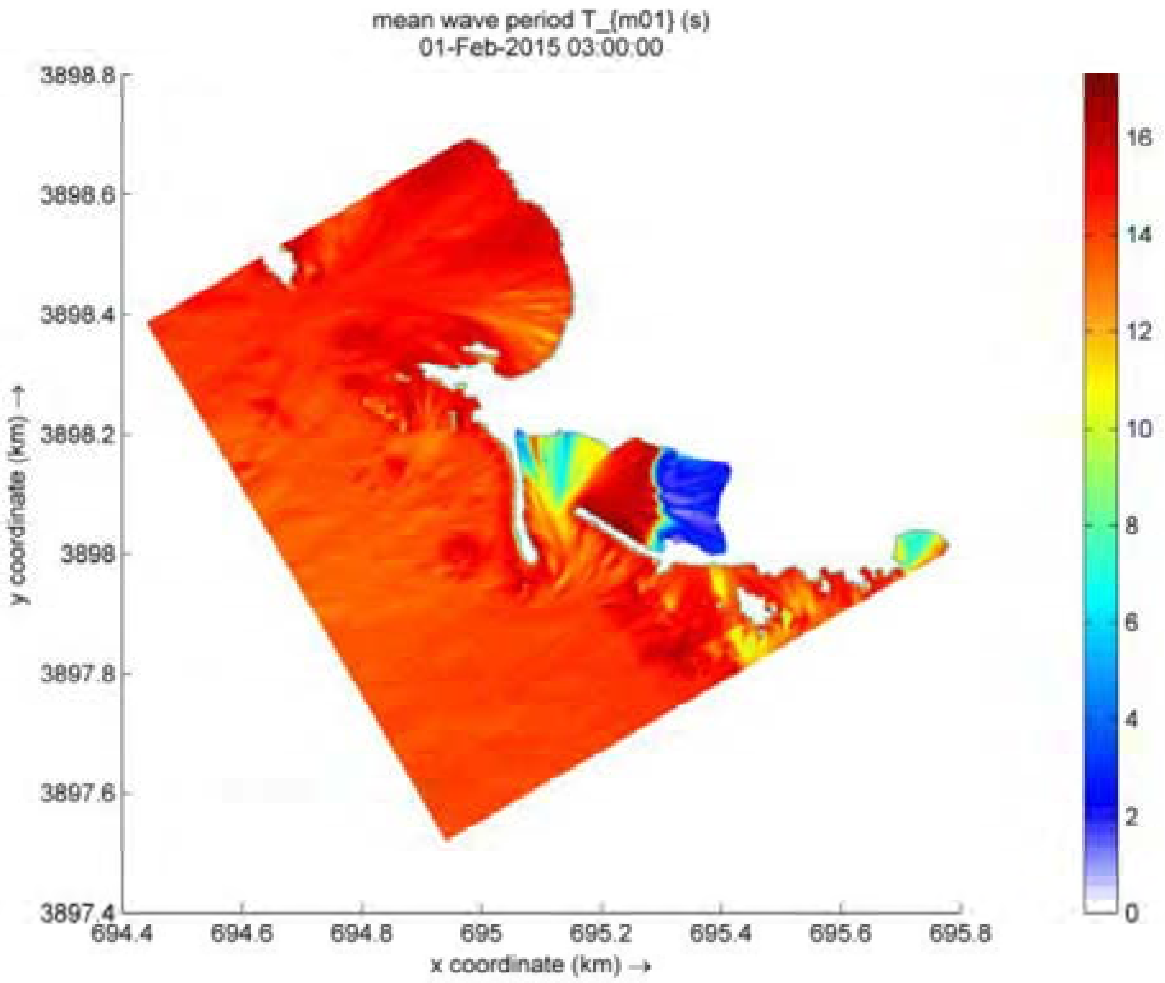
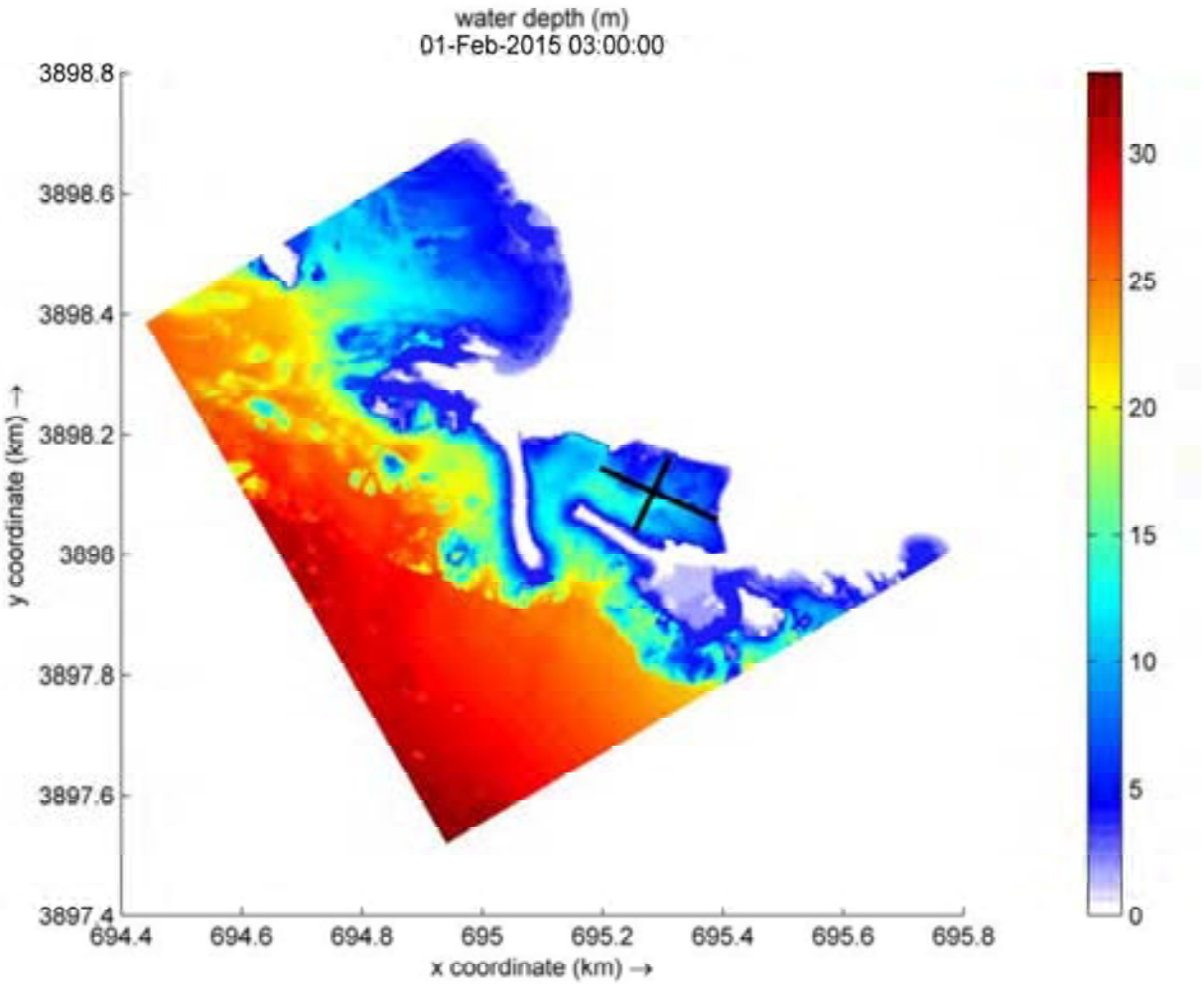


Figure 73: Mean Wave Period, 2 [m] grid resolution, 3.03 m NAVD88.



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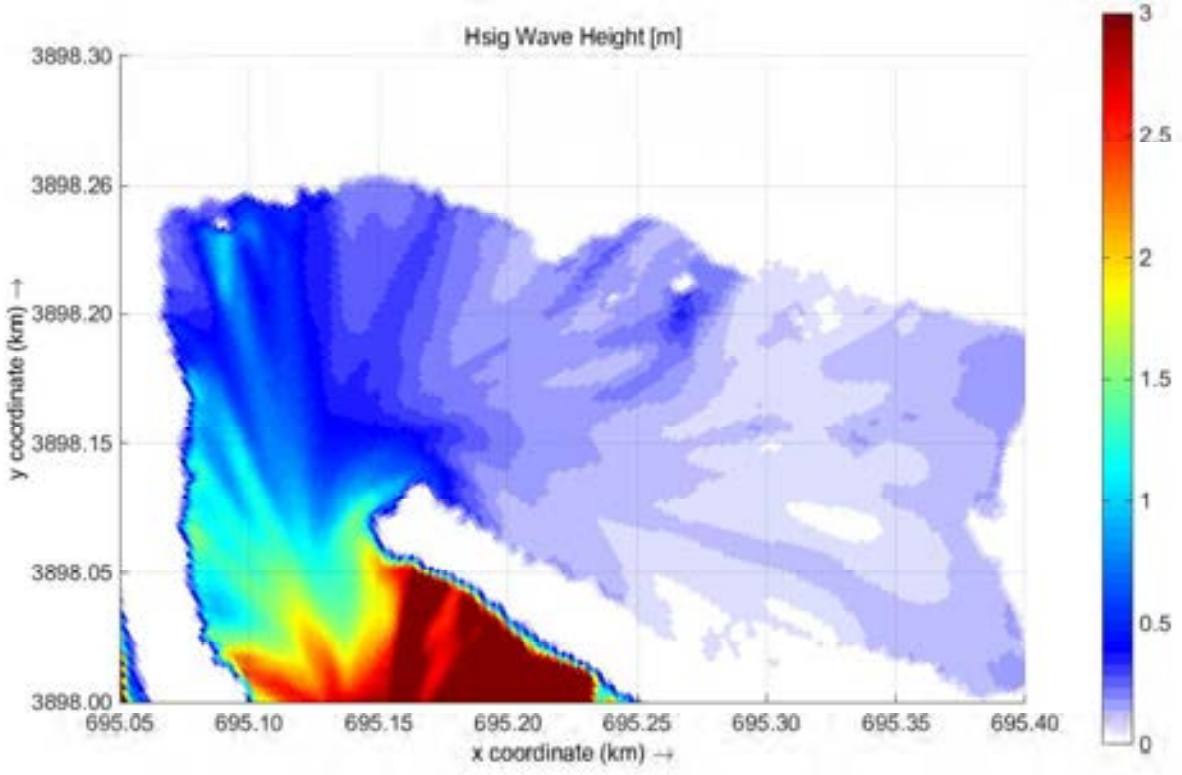

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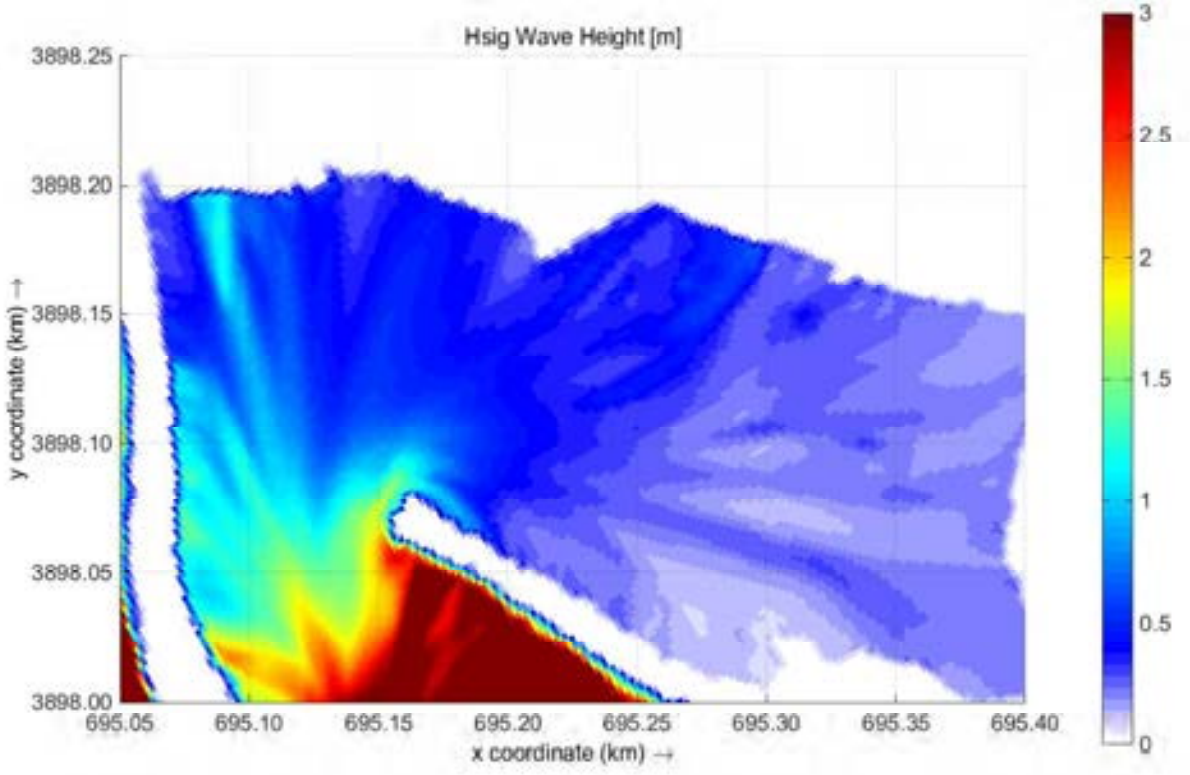

Figure 76: Significant Wave Height [m] in the Intake Cove,
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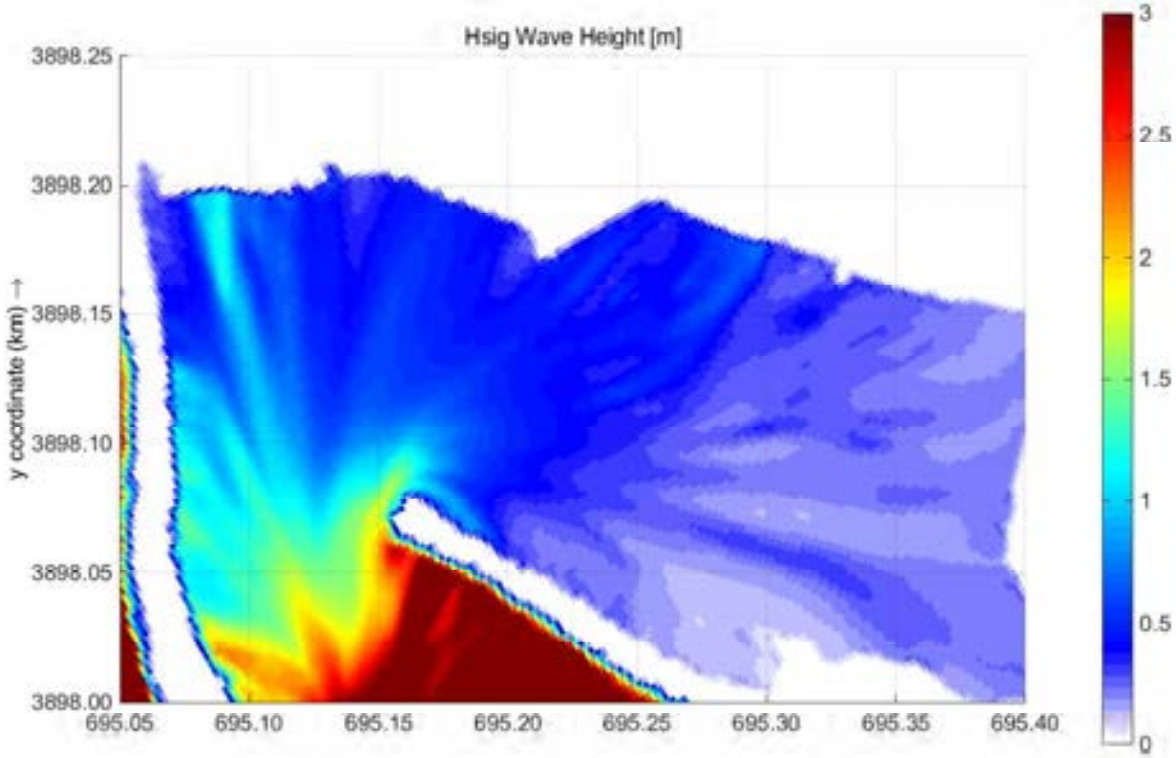

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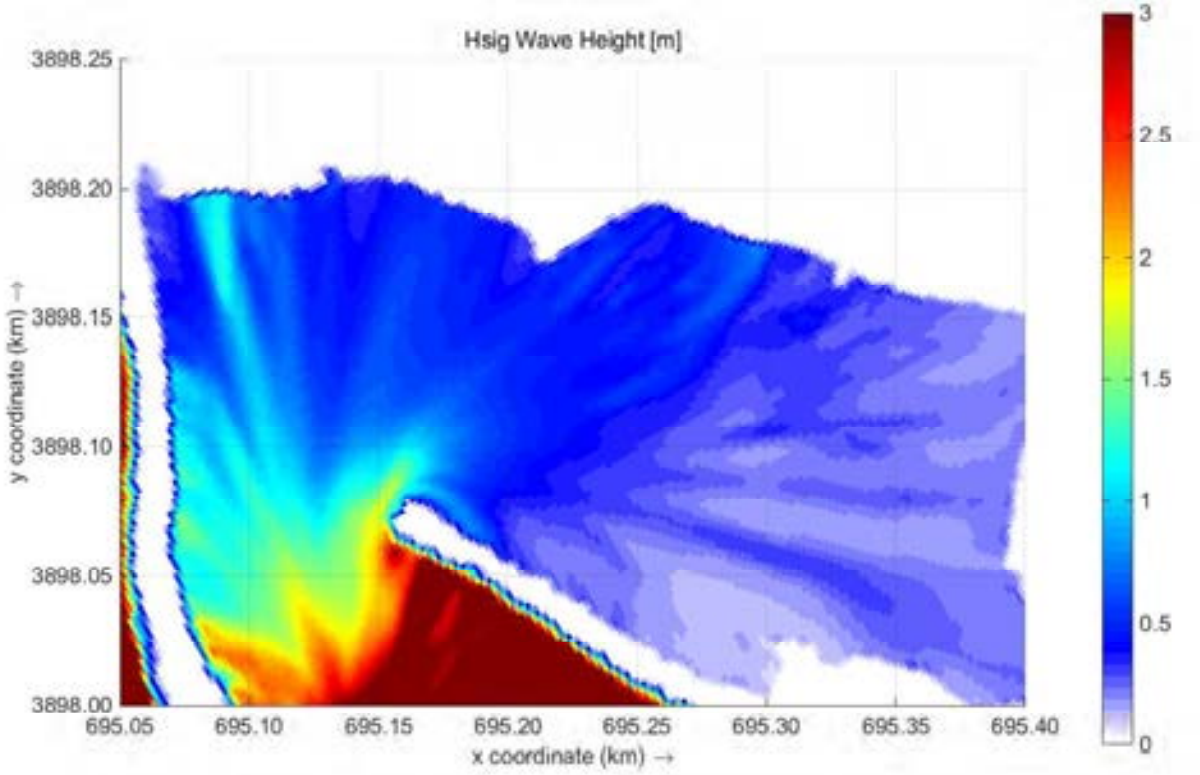

Figure 78: Significant Wave Height [m] in the Intake Cove,
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Extreme Return Period of Wave Heights and Wave Energy on the California Central Coast

Draft Final

Brendan P. Dooher

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1.0 Purpose

This analysis was performed as part of an assessment of extreme return time wave hazards along the California Central Coast in support of the CalWave project.

In any wave energy system, an evaluation of the potential impact of large "extreme event" storm waves is required, in order to set the proper design criteria for mooring and device survival. The purpose of this effort is to analyze the wave data collected by the NOAA NDBC Central Coast buoys since 1980, in order to estimate return periods associated with significant wave height, H_s, wave peak period, T_p, the primary direction of approach of these large storm waves, W_{dir}. In addition, this effort will examine the energy, E, associated with these waves, in order to determine the ultimate design range for off-shore wave energy devices and their moorings.

2.0 Background

This calculation presents the storm wave statistical evaluation, based on data from multiple (16) Waverider and NDBC discus buoys along the California Central Coast region (Figure 1 and Figure 2). This data has been collected and managed by the National Oceanic and Atmospheric Administration's (NOAA, 2107). National Data Buoy Center (NDBC) and the University of California, Scripps Institution of Oceanography, Coastal Data Information Program (CDIP,°2017).

A MATLAB database was developed to hold and arrange NDBC data that in some cases ranges back almost 40 years in order to review and compare detailed statistics (such as daily maximum, mean, and minimum significant wave height, as well as selected percentiles) and to correlate that data across the multiple buoys. Daily statistics were chosen as a minimum set so as to allow for easier comparison of time and spatially dependent hourly data. By examining significant wave heights, H_s, wave average periods, T_p, relevant wave directions, W_{dir}, and wave energy, E, (which is a nonlinear combination of significant wave height and mean period), a better understanding of the behavior of the wave heights and wave energy along the California coast is attained, and how it could impact a nascent wave energy converter industry. The historical data (H_s, T_p, and E) will be fit using extreme value (EV) probability distributions in order to estimate the resulting two hundred year return period of extreme wave height and wave energy associated with

The California Central Coast is an especially attractive location for developing a wave energy industry. Unlike the California North Coast, there are multiple, high voltage, megawatt grid connected locations where no significant improvement of the facilities are necessary in order to develop large scale wave industry. There are also multiple ports that have the capacity to support a wave energy industry. Among the most attractive locations is Platform Irene (Figure 3). Platform Irene is located in an area with high wave energy resources, located near two major support Ports (Port Hueneme and Port San Luis), and most importantly, it has a 25 MW cable already installed. Buoys NDBC 46011, NDBC 46218, NDBC 46257, and NDBC 46259 are the nearest buoys to Irene (as seen in Figure 2). NDBC 46011 has historical data ranging as far back as early 1980, making it one of the longest term monitoring buoys on the California Central Coast. NDBC 46218 ranges back to 1995, and NDBC 46259 is among the newest buoys installed along the coast. The long term data from NDBC 46011 and the more limited data history from the other buoys may actually allow us to produce statistically modeled data at the NDBC 46218 position ranging back as far as 1980, using a method called Neural Net assessment. This will be examined in an additional work.

3.0 Methodology

Wave dynamics on the US West Coast are significantly different than those associated with those on the Gulf and East Coasts. The primary factors that result in the different (and significantly larger) West Coast swell heights are long prevailing winds that can occur across what is referred to as the Pacific Ocean Fetch. Waves do not significantly loose energy once wind action has imparted energy to them (unless they run into winds blowing in the opposite direction), so waves produced by winds and strong storms across the very long Pacific Ocean fetch join together in wave trains that then impact the US West Coast, with large wave heights, long periods, and high energy. The major wave heights associated with the California Central Coast are generally prevailing from the west-south-west to westerly directions.

Additionally, unlike the East Coast and Gulf, the continental shelf in the West is narrow and "steep", and so long period wave energy, which usually loses energy through frictional interaction with the sea floor, has very little time in contact with shallow sea floors. This is unlike on the East Coast and Gulf where the continental shelves are broad and where there is significant frictional interaction with Atlantic and Gulf incoming waves, resulting in significantly smaller fetch based wave heights and shorter wave periods.

For almost 40 years, an increasing number of wave buoys have been collecting time averaged wave height, period, and directional data (and in some cases much more detailed spectral wave data) along the West Coast. Each of these buoys acts as an "integrator" of actual storm and wind wave events that cross the Pacific Ocean and land on coastal environs, and can be used to statistically predict the joint significant wave height and period for return periods of up to 10,000 years (Galiatsatou and Prinos, 2012). The usage of these data sets allow for a much higher confidence in the base wave height and periods that can be used as a source to predict impacts to potential wave energy devices that may be situated along the California Central Coast. They have the further advantage in that they are based on real data, and are not modeled results (which themselves result in a loss of fidelity).

Detailed data was collected and graphed for multiple areas, and the due to the extensive output results, are presented as separate Appendices (Appendix A through Appendix E). Each Appendix presents historical data from the NDBC buoys found in Table 1 and seen in Figure 1 and Figure 2.

Probabilistic and deterministic only approaches to the estimation of very low-probability storm surges have their strengths and deficiencies, depending on the assessment objective. Previous assessments for storm surge have used a deterministic-only approach. A probabilistic-deterministic methodology for storm surge or swell assessment uses a 10,000 year return period methodology (Galiatsatou and Prinos, 2012, van den Brink, H.W., and G. P. Konnen, 2009, and Menéndez et al., 2008) in order to minimize the risk to ocean based structures. The methodology as used for hurricane surges uses an integrative, interdisciplinary approach that incorporates state-of-the-art knowledge in hurricane science, hydrology, and probabilistic methods. That methodology is adapted to include the following steps:

(1) Develop a stochastic set of significant wave height (H_s), peak period (T_p), and wave direction (W_{dir}) associated with the California Central Coast locale. This probability method will use historical data from the NDBC wave buoys, and examine and compared that to the data from surrounding buoys along the California coast to determine 200 year return period estimates of H_s and E.

(2) Develop a numerical hydrodynamic simulation of the region of interest using a high-resolution wave surge model, DEFLT 3D Flow and Wave, which uses such SWAN (Simulating WAves Nearshore) (Deltares, 2017a, 2017b) as the primary wave analysis tool.

(3) Use of the relevant return period probabilities of H_s, T_p, and W_{dir} and the numerical model, as described in Steps (1) and (2), develop probabilistic information on the storm surge height events at a specific location and compare it to historical estimates of return periods.

An assessment of sensitivities and uncertainties should be provided for model parameters that may have significant influence on design-basis storm surge estimates. This effort is focused on step (1). Steps (2) and (3) are assessed in other efforts.

3.1 Previous Studies

A comparison between NDBC 46215 is available for an estimated 200-year return period wave height based on studies performed in 1982-1984 (Resio, 1982, Borgman and Resio, 1982, Strange and Graham, 1982, Borgman and Strange, 1982, and Borgman and Strange, 1984) that attempted to hindcast a series of storms that could then be used to develop a Poisson based return period. The effort included the two teams deciding upon a series of historical storms that would use two different atmospheric modeling hindcast tools available at the time to estimate H_s, T_p, and W_{dir}. Resio's and Strange's modeled locations for deep water are seen on Figure 1. The group then estimated the wave height at a location that would eventually become the mooring location for the NDBC 46215. Resio's efforts resulted in wave peak periods significantly less than measured, as well as smaller significant wave heights, so the results of Strange and Graham were then used for further efforts.

Borgman and Strange (1984) used the probability distribution of estimated wave heights and energy to develop a Poisson based average, and then projected a 200-year return period. The final estimate, based on Strange and Borgman's efforts, gave a "maximum individual wave height" of 13.95 m (45.75 feet). The maximum individual wave height is commonly considered to be 1.8 times the significant wave height. This would make the MSL height approximately 6.975 m (22.88 feet), or the 200-year return period for the significant wave height to be 7.75 m (25.43 feet). This return period can act as an independent evaluation of the historical data based return period developed in this work.

3.2 Historical Records

Wave heights from storms have been measured offshore at NDBC 46215 since 1983, when a Waverider Buoy was installed at the location where the efforts of Resio (1982) and Strange and Graham (1982) had estimated significant wave heights associated with a significant Pacific storm had caused a breakwater collapse in 1981. That installed Waverider was designated NDBC 46215, or CDIP 076.

Although full spectrum data is available from University of California Scripps Institute, CDIP, from 1996 onward, only summary statistics are used since they exist back to the 1980's and allow for easier comparisons.

Wave energy is defined by:

$$E = \rho_w g H^2/8 \qquad \text{Eqn. 1}$$

where ρ_w is the density of seawater, g is gravity, and H is the total wave spectrum, and the resultant energy is considered to be Watts, or more exactly, watts/linear meter of wave front. This can be rewritten (Falnes, 2007) to become, after assuming a typical wave spectrum and the density of seawater:

$$E = 0.49 h_s^2 T_p \qquad \text{Eqn. 2}$$

Eqn. 2 is in units of kW/m. Eqn. 2 is not exactly accurate for a wave spectrum in shallow waters, but it is an acceptable approximation without attempting to develop detailed buoy specific wave spectrums. Energy is used as a statistical indicator in this report since it combines both wave height and period, and high energy events are more of a concern than low energy events.

In reality, a wave's energy is dispersed in multiple directions, with a majority of energy focused in one primary direction. For this effort, we use the summary statistic of wave direction, which will be used as the peak wave direction in any future numerical modeled runs. It can be seen that most of the wave direction comes from the west-north- westerly direction. The 1981 storm wave direction that resulted in the breakwater destruction and Strange and Graham, 1982 efforts was modeled to come from the westerly direction.

Rosio (1982) and Strange and Graham (1982) developed their joint assessment on what they considered to be major pacific storms ranging back to the late 19th century. In order to assess storms for this effort, the time history of the daily maximum wave energy and the daily summed wave energy is assessed to evaluate the temporal behavior of the waves since 1980.

Return period probabilities are calculated by:

$$P(RP) = 1 - 1/(\text{Years x Samples/year}) \qquad \text{Eqn. 3}$$

The GEV distribution is generally recommended to assess wave periods (WMO, 1998 and DNV, 2007) and to subsequently estimate return periods, it is apparent upon close examination that neither the Birnbaum Saunders, the Lognormal, nor the GEV distributions are sufficient to properly estimate extreme return periods.

It should be stated that the developed statistical fits are in all cases (except for the peak wave period of 20 s) conservative, and so any calculated wave height return periods will be significantly greater than what would be expected from a better fitting statistical model. The question arises as to why there seems to be unusual tail behavior, as outliers sometimes are found in data sets. Although the majority of these high energy waves are small probability, long return period extreme events, it is hazardous to make the assumption that they are outliers or errors and ignoring the data, as is sometimes done in a statistical analysis. In this case, the data must be kept.

Statistical distributions are just fits of available data (much like a least squares linear regression approach). Although the GEV has been used to good effect in other areas (WMO, 1998), its use here results in unrealistically conservative high wave heights for even short wave periods. Even the Lognormal distribution results in higher wave heights for already known return period, but it is conservative and is a good compromise of the two statistical models for the higher energy events, and so it is used for a majority of the return period wave heights estimates.

4.0 Results and Analysis

4.1 Appendix A: Historical Data for Wave Height, Period, and Energy, by Buoy, Results

An example of the historical data as found in Appendix A is shown in Figures 4 through 21. Figure 4 through Figure 21 shows daily, monthly, and yearly wave height for NDBC 46011. The historical data goes back, for this buoy, until early 1980. Figure 4 shows max, mean, and minimum daily wave height, based on 24 hourly time periods. Maximum wave heights for this buoy show waves reaching up to almost 9 meters. The vast majority of maximum daily wave heights are less than 5 meters. Mean daily waves range up to 6-7 meters, with the vast majority of wave heights ranging between 2 and 4 meters. Minimum daily wave heights range as high as 6 meters, with the majority of minimum wave heights ranging between 1 and 3 meters. Figure 5 shows percentile ranges for daily wave heights, (5th, 50th, and 95th percentiles). They show similarities to the min, mean, and max wave heights, but exclude some of the extremes. 50th percentiles range slightly lower than mean wave heights.

Figure 6 and Figure 7 show these measures in starker relief, as the maximum, mean, and minimum are based on overall monthly measures (again, taken from the entire universe of hourly measures). The monthly data makes it easier to see specifics, and yearly cycles are easier to see. Maximum monthly ranges from about 2.5 m to typically around 7.5 m. Mean wave heights tend to be slightly above 2 meters, with a range of 1.5 m to 3 m. Figure 7, showing the 5th, 50th, and 95th percentile wave heights, show separation from maximum and minimums, with fewer extremes, as the percentiles are taking from over 720 hourly measurements.

Figure 8 and Figure 9 show yearly max, mean and minimum. The yearly maximum shows clearly those years with high wave heights (1988, 2017) and high mean wave heights (1984, 1998, and 2016). Percentiles tend to show that the yearly maximums are significantly greater than the 95th percentile yearly wave height (where the maximum 95th percentile is found in 1998, at 4.5 m).

Figures 10 through Figure 15 show average periods (in seconds). Maximum daily period ranges from lows of 6 seconds to the highs of 25 second wave (which have the highest energy). Daily periods are of some interest, but it is the monthly period statistics that show trends (such as clear yearly cycles of mean wave periods, as seen in Figure 12. Yearly mean period shows ranges around 11 to 12 seconds.

Figure 16 through 21 are of greatest interest. Although we tend to think in terms of wave height when discussing impacts on survivability of ocean devices such as wave energy absorbers, it is actually energy that has the largest impact, especially on moorings. Figure 16 shows starkly that wave energy devices must be designed to actively work in ranges where they can absorb the highest amount of energy (20 kW/m - 100 kW/m), but must survive energy impacts that can reach almost 800 kW/m. Figure 18 and Figure 19, which exhibit monthly statistics, show this more clearly. Mean monthly wave energy ranges from lows of about 10 kW/m to 15 kW/m, to mean highs as seen in 1998 of up to 150 kW/m. Maximum highs reach up to 750 kW/m in the winter of 2016-2017. The design criteria to handle such extremes may act to significantly increase the cost of moorings as well as the structural designs for wave energy devices. Figure 19 shows that winter of 1997-1998 was an extreme year, with the 5th percentile monthly wave energy reaching 50 kW/m, 50th percentile reaching 180 kW/m, and 95th monthly percentile reaching 325 kW/m.

Figure 20 and Figure 21 show yearly extremes and yearly 95th and 5th percentiles for wave energy. The yearly mean ranges from a low of around 19 kW/m in 1992 to mean highs in 1984 and 1998, exceeding 40 kW/m. Those same years saw the maximum measurements of wave energy, as well as the highest 95th percentile yearly measure. 50th percentile tends to range from 15 kW/m to 20 kW/m, with the 5th percentile yearly lows being approximately 5 kW/m.

Using wave energy as a variable, daily maximum and daily summed wave energy (as calculated by Eqn. 2) are examined over the full 30+ year time frame that California Central Coast buoys have been in operation (specifically shown as Figures 22 through 32, NDBC 46215). There are several time periods where there the buoy was out of operation, but coverage of winter storm events is in general fairly good. It is apparent that winter storm events have the highest energy, which is in keeping with the earlier discussion on tropical storms and their possible influence on the California Central Coast. The work by Strange and Graham (1982) included historical storm episodes that have significantly less energy associated with them (based on their modeling) with modeled storms having wave heights of between 2-3 meters (which are not a characteristic of the largest or most energetic storms observed).

By examining the long trends of storm energy, it is apparent that the outliers are those wave events where the maximum daily measured energy is above 200 kW/m, and the daily sum of energy is above 3000 kW/m/day. To be conservative, one could use 150 kW/m and 2250 kW/m/day. This would provide a method to replicate the Strange and Graham approach if the usage of the full data set fails to show a convincing and realistic return period wave height.

As an aside, the trend for NDBC 46215 was also examined to assess if more extreme energy winter storm periods occur under an El Nino event, and the winter zones are marked with whether they fall under a Cold or Warm Episodic Oceanic Nino Index (ONI). There appears to be no apparent correlation in local number of storms as a function of warm (or cold) ONI episodes (NOAA ONI, 2017) (Figure 22 through Figure 32).

Appendix A therefore gives a comprehensive and easy to visualize assessment of historical data as collected along the California Central Coast.

4.2 Appendix B and Appendix C: Cross Correlated Data for Wave Height, Period, Energy, and Direction, by Buoy, Results

Significant wave height, peak period, and wave direction are assessed as scatter diagrams in order to get a better understanding of the wave dynamics found along the California Central Coast. Appendix B presents 123 cross correlation scatterplot statistics for each buoy, cross referenced for wave height, wave period, and wave direction, as well as showing the general binned distribution for wave height, wave period, and wave direction.

Daily significant wave heights don't all correlate together, but there is some continuity. This is not unsurprising, as while the data is correlated specifically by time, there is also a significant time delay as waves make their way from one station to another. In general, wave directions are found to cluster in originating from the north-west to westerly directions (~330° to ~270°), and are likely associated with long range swell waves. The waves that come from the south (around 190°) are more associated with low period (high frequency) wind-waves.

Appendix B specifically seems to show that there is no high correlation between the variables. In addition, the maximum wave heights for NDBC 46215 are consistently less than the other NDBC observation points, by an average of approximately ¾, as seen in Figures B16 through B29. Not surprisingly, the buoys located in deeper waters show significantly greater wave heights, but the correlations between them are not perfect. All wave heights show a

pronounced bimodal directionality based distribution, with the greatest wave heights coming from a westerly to northwesterly direction. This is especially true for the NDBC 46215 buoy.

Appendix C shows wave energy correlated with wave direction. These plots, where wave period and height are non-linearly combined, confirm that the low energy wind-waves are those that come from the south, with the highest energy always coming from the north-west to west ranging from 270° to 330°. When correlated with wave energy, the scatter diagram in Appendix C shows that the largest wave heights also come from the same general westerly to northerly direction. This gives additional support to the knowledge that tropical depressions (which would come from a southerly direction) are not a major contributor to storm waves for the California Central Coast.

4.3 Appendix D: Monthly Summaries of Wave Height, Period, and Energy, by Buoy, Results:

Appendix D summarizes on a monthly basis wave heights, periods, and energy for each of the 16 buoys examined. It does this by examining monthly percentile results ranging from 1st, 5th, 25th, 50th, mean, 75th, 95th, and maximum monthly measured data. Since this is among the most compact of the summaries, it will be examined in detail.

As an example of the data shown, Figure 33 through Figure 36 detail monthly statistical results for NDBC 46011. Figure 33 shows the maximum measured wave height for this buoy to be in January, at 9.3 m, with minimum maximum measured wave heights occurring in August, at 3.4 m. Wave heights range from a mean low in August (1.5 m) to a mean high in February and in December (2.5 m). Wave period has a mean high in January of ~18 seconds, and a mean low just below 10s in August. Wave energy (Figure 36) shows a high max in January of 743 kW/m, to a low max in July of ~64.2 kW/m. The mean high is in December, at 50.1 kW/m, with the mean low of 10.8 kW/m in August.

Table 3 and Table 4 summarize the maximum monthly maximum, minimum monthly minimum, maximum monthly mean, and minimum monthly mean, as well as the months they occur, for all the buoys in the study. NDBC 46042, near Monterey, is unsurprisingly as the buoy that measures the maximum wave energy and wave height (1014 kW/m and 10.4 m, respectively).

Table 4 also shows the mean mean (properly weighted by month, in contrast to that found later in Table 5, which non-weighted). This shows that the California Central Coast has very good wave energy, especially in the area near Platform Irene, without the high extremes that may be found in the Oregon area. Only four of the buoys show mean wave energy below 30 kW/m. Those are NDBC 46053 (10.5 kW/m), and located well within the shelter of the Santa Barbara Basin, NDBC 46054 (29 kW/m), right at the entrance and where it would be slightly impacted by the change in waves and currents at Point Arguello, NDBC 46069 (29.7 kW/m), which is south of Santa Rosa Island, and NDBC 46215 (18 kW/m) which is located in shallow (22.86 m) water.

The rest exceed 30 kW/m, with the ones of interest being NDBC 46011 (31.1 kW/m) which is more representative of what a wave facility would see, as well as NDBC 46218 (34.8 kW/m), which is locate near Platforms Hidalgo, Hermosa, and Harvest. NDBC 46257 (40 kW/m) is significantly different than NDBC 46218 since it is a very new monitoring buoy, and represents the very energetic 2016-2107 winter season.

4.4 Appendix E: Probability Fits of Wave Height, Period, and Energy, by Buoy, Results

Appendix E (Page E001 through E048) attempts to find best probability fits (based on multiple models) for wave height, wave period, and wave energy. All standard fits as found in the MATLAB Statistics toolbox were used, with the closest fitting probability models shown in the

various figures. As happens in most non-normal distributions, the tails drive the statistical probability model fit. Rare events are at all times difficult to model, as a very rate event can occur and that will throw off the high end of the tail. As a description, probability models that fit above the data line will give non-conservative return periods (i.e., return times that are much longer than expected) while probability models that fit below the lines will give shorter return periods. Therefore, in most cases, for the 200 year return period, the probability model closest to the data and lying below the data are used to estimate the resultant return period curve.

Probability fits are also used to model wave periods, but no attempt is made to estimate 200 year return periods for wave periods. The reason for this is that data is already binned, with the highest bin being 25 seconds. The data quality is therefore not sufficient to give a good estimation. However, probability fits are derived for return periods on wave energy, despite the lack of larger period data. The combination of wave height (squared) multiplied by period gives enough information that an estimate of the return time is warranted.

Figure 36 through Figure 39 shows all the probability distributions for the raw data, for Wave Height and Wave Energy. As can be seen in, the lower probability wave and energy events are associated with NDBC 46215 and NDBC 46053, one of which is located in shallow water, while the other is sheltered in the Santa Barbara Channel. As is always the case, the tails drive the results, and the tails for wave height range from a low of ~6.5 m to a high of ~10.5 m. The tails are difficult to model, since they may actually represent longer return period events that are just captured during the time period of interest.

Figure 40 through Figure 42 show the Probability fit for Wave Height, Period, and Energy. The closest multiple probability fits are shown for an NDBC 46011. For wave height, in general, the Birnbaum-Saunders (BS) fit is best. Although this is initially somewhat surprising, since the Generalized Extreme Value (GEV) is referenced in multiple reports as useful, and is referenced for return periods for rainfall, flooding, and other rare events. It should be emphasized, however, that the BS is a specific version of an extreme value (EV) distribution, with the BS being merely a special transformation of a normal distribution. For the wave energy distributions, it is found that the BS (or the Inverse Gaussian) distribution fits high probability events (such as typical wave energy) well up to 95th percentile events. However, in most cases the lognormal distribution gives a more conservative result for rare events.

Figure 43 through Figure 46 show the conservative return period estimates for the NDBC buoys, up to 200 years.

Table 4 and Table 5 shows the recommended ranges of predictive distributions for wave height and wave energy, based on the results as shown in Appendix E. Figure 36 through Figure 39 shows the various data sets for wave height and energy plotted on a lognormal probability graph. Figure 43 and Figure 46 shows the return period curves for wave height and wave energy, up to 200 years, giving conservative results.

The mean results on Table 4 and Table 5 do not match the results for mean means on Table 2 and Table 3, since they are unweighted.

5.0 Conclusion

In order to bound the results as developed above, the entire history of measurements (from ranging back to 1980) are examined. They are shown in Figure 36 through Figure 39 as probability distributions. As can be seen, the tails drive the probabilities. These were then statistically fit to probability models for significant wave height and wave energy, with Figure 43-Figure 46 showing the modeled return periods for the entire dataset, both for wave energy and wave period.

In most cases, four-out-of-five or three-out-of-four statistical distribution fits for wave height had close (but conservative) matches in the probability zone of interest (0.9999 cumulative probability and above). These are the Lognormal, the Inverse Gaussian, and the Birnbaum Saunders distribution. The GEV fit in general gives unrealistically conservative results. The Birnbaum Saunders distribution is able to span the vast majority of the low probability extreme events for the vast majority of wave heights. Lognormal distributions are the best fit for wave energy distributions.

Figure 43 and Figure 44 shows the distribution of return periods as calculated for these distributions for wave height, with Figure 45 and Figure 46 showing the distribution of return periods as calculated for wave energy. It should be remembered that fits of probability distributions are just models for the data (and may actually end up being somewhat representative in the area of interest). Using the entire history of the wave heights (from 1983 until 2014) for NDBC 46215 gives a Return Period at 200 years of 7.93 m (which is also conservatively high based on a distribution that is not a perfect fit of the data). This estimate is close to what was considered the best extreme event estimate for wave heights from the Strange and Graham (1984), which gave a calculated estimate of 7.75 m. This gives some confidence that the calculated return times, based on data, are generally acceptable, as they are in good agreement with the independently estimated return period of Strange and Graham (1984).

To create a finer assessment for this data, it is recommended that the data sets be split into four seasons. This should allow a better idea of return periods per season, as it is obvious that summer is very distinct from the winter events.

Overall, the California Central Coast shows excellent energy production without the large storm events that can impact northern California or Oregon sites. That, combined with multiple high quality grid connections makes the California Central Coast an attractive location for a nascent wave energy industry.

For the numerical assessment of wave direction, wind and waves will be assessed coming from 270°, in keeping with the main storm direction results of Figure 20 and the work of Strange and Graham. Delft 3D (SWAN) allows the use of standard wave spectrums (such as the JONSWAP) with the input of significant wave height, or a user defined distribution. The JONSWAP will be used for purposes of the numerical effort. This will be examined in another effort.

For the Neural Net (NN) assessment, we will use best NN fit of data to fill in missing time frames for various buoys, so as to give a longer modeled history along the California Central Coast. This will also be examined in yet another effort.

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7.0 Tables

Table 1: Locations of Selected California Central Coast NDBC Buoys.

Station	Alternative	Name	Location	Latitude	Origin Date	Water Depth [m]	Watch Circle [m]
46011	LLNR 215	Santa Maria	21NM NW of Point Arguello (1, 5)	34.956 N 121.019 W (34°57'22 121°1'7)	10/7/1980	464.8	742
46012	LLNR 325	Half Moon Bay	24NM SSW of San Francisco (1, 6)	37.363 N 122.881 W (37°21'45 122°52'52)	11/24/1980	208.8	155
46023	LLNR 213	Point Arguello	17NM WNW of Point Arguello (3, 9)	34.714 N 120.967 W (34°42'50 120°58'0)	4/7/1982	384.1	327
46028	LLNR 275	Cape San Martin	55NM West NW of Morro Bay (1, 5)	35.712 N 121.858 W (35°42'42 121°51'30)	12/1/1983	1036	1405
46042	LLNR 297	Monterey	27NM WNW of Monterey (1, 6)	36.785 N 122.398 W (36°47'5 122°23'54)	6/17/1987	1645.9	1636
46047	LLNR 82	Tanner Bank	121NM West of San Diego (1, 8)	32.398 N 119.498 W (32°23'54 119°29'54)	12/4/1991	1442	1275
46053	LLNR 196	East Santa Barbara	12NM Southwest of Santa Barbara (1, 7)	34.252 N 119.853 W (34°15'9 119°51'12)	1/1/1994	426.7	626
46054	LLNR 198	West Santa Barbara	38 NM West of Santa Barbara (1, 5)	34.265 N 120.477 W (34°15'53 120°28'37)	1/1/1994	469.4	743
46069	LLNR 181.6	Santa Rosa Island	(1, 5)	33.674 N 120.212 W (33°40'28 120°12'42)	12/16/2003	1020.2	1645
46114	185	West Monterey Bay	27NM WNW of Monterey (2, 4)	36.723 N 122.351 W (36°43'22 122°21'3)	9/28/2011	1463	2913
46215	076	Diablo Canyon	1/2 NM off Diablo Canyon (2, 4)	35.204 N 120.859 W (35°12'14 120°51'34)	6/15/1983	22.86	NaN
46218	071	Harvest	17NM WNW of Point Arguello (2, 4)	34.454 N 120.783 W (34°27'16 120°46'59)	12/1/1995	548.6	NaN
46219	067	San Nicolas Island	South of Santa Barbara (2, 4)	33.225 N 119.882 W (33°13'29 119°52'54)	9/8/2004	274.3	NaN
46239	157	Point Sur	SSW of Monterey Bay (2, 4)	36.341 N 122.102 W (36°20'28 122°6'6)	11/7/2008	366	NaN
46257	216	Harvest Southeast	17NM WNW of Point Arguello (2, 4)	34.439 N 120.766 W (34°26'20 120°45'56)	7/10/2015	576.07	NaN
46259	222	Santa Lucia Escarpment	WSW of Avila Beach (2, 4)	34.732 N 121.664 W (34°43'54 121°39'51)	3/4/2016	838.8	NaN

1. Owned and maintained by NDBC
2. Scripps Institution of Oceanography
3. Funding provided by the Minerals Management Service
4. Waverider Buoy
5. 3-meter discus buoy, AMPS payload
6. 3-meter discus buoy, ARES payload
7. 3-meter discus buoy, SCOOP payload
8. 2.3-meter foam discus buoy, SCOOP payload
9. 10-meter discus buoy, DACT payload

Table 2: Monthly maximum max wave height, minimum max wave height, maximum mean wave height, minimum mean wave height, mean max, mean mean, and the month it occurs.

	Max Max H	Month	Min Max E	Month	Max Mean H	Month	Min Mean H	Month	Mean Max H	Mean Mean H
46011	9.3	1	3.4	8	2.5	2	1.5	8	6.5	2.1
46012	9.7	2	3.8	8	2.6	2	1.5	8	6.8	2.1
46023	8.7	12	3.8	7	2.7	12	1.7	8	6.8	2.2
46028	10.1	12	4.1	8	2.7	12	1.8	8	7.0	2.3
46042	10.4	1	3.8	7	2.8	12	1.6	8	7.0	2.2
46047	8.7	12	3.6	8	2.6	12	1.7	8	6.2	2.2
46053	5.6	12	2.2	8	1.6	1	1.0	8	3.7	1.3
46054	8.8	2	3.4	8	2.5	12	1.5	8	6.1	2.0
46069	8.7	1	3.2	8	2.4	12	1.6	8	5.7	2.1
46114	10.4	1	3.5	8	2.7	12	1.5	8	6.2	2.2
46215	6.5	1	2.4	7	2.0	2	1.1	8	4.8	1.6
46218	10.0	2	3.4	7	2.7	12	1.6	8	6.5	2.2
46219	9.1	1	3.4	7	2.5	3	1.7	8	6.0	2.1
46239	10.0	12	3.2	8	2.7	12	1.5	8	6.6	2.3
46257	8.1	1	3.0	8	3.0	1	1.5	8	5.5	2.3
46259	8.3	1	3.1	8	3.3	11	1.7	8	5.6	2.5

Table 3: Monthly maximum max wave energy, minimum max wave energy, maximum mean wave energy, minimum mean wave energy, and mean max, mean mean, the month it occurs.

	Max Max E	Month	Min Max E	Month	Max Mean E	Month	Min Mean E	Month	Mean Max E	Mean Mean E
46011	743.3	1	64.2	7	50.1	12	10.8	8	379.5	31.1
46012	767.0	2	70.6	8	51.7	12	11.1	8	398.2	31.9
46023	611.6	3	70.8	7	57.7	12	13.5	8	376.7	35.5
46028	864.1	12	91.4	8	60.1	12	15.0	8	440.5	36.7
46042	1013.5	1	80.4	7	58.6	12	12.9	8	430.0	34.9
46047	588.6	11	73.1	7	51.8	12	14.8	8	306.0	32.9
46053	290.0	12	18.2	8	19.5	1	3.5	8	115.7	10.5
46054	765.8	2	54.9	7	48.1	12	10.2	8	339.6	29.0
46069	639.0	1	66.2	7	44.4	1	13.2	8	275.2	29.7
46114	965.4	1	60.3	8	60.7	1	12.6	8	315.4	35.4
46215	384.0	1	34.2	7	29.9	2	6.7	8	197.8	18.0
46218	885.5	2	66.8	7	56.4	12	13.9	8	372.9	34.8
46219	818.7	1	71.8	7	44.7	3	14.8	8	277.6	30.5
46239	881.9	12	77.6	8	56.8	1	13.1	8	362.7	36.5
46257	617.8	1	51.5	7	74.4	1	12.6	8	245.2	40.0
46259	594.6	1	54.3	8	81.4	11	16.9	8	238.3	42.6

Table 4: Best probabilistic model 200 year return period and summary statistics of significant wave heights (H_s).

NDBC	200yr	200yr NC	Max	Year	Month	Max2	Year	Month	99th	95th	Mean
46011	11.4 (BS)	8.9 (G)	9.3	2017	1	9.2	1987	6	4.8	3.7	2.0
46012	12.7 (BS)	9.8 (G)	9.7	2004	2	9.0	2006	8	5.0	3.9	2.1
46023	11.8 (BS)	9.3 (G)	8.7	2006	12	8.5	2009	2	5.1	3.9	2.2
46028	12.1 (BS)	9.5 (G)	10.1	2002	12	9.4	2002	1	5.1	4.0	2.3
46042	12.2 (BS)	12.2 (BS)	10.4	2017	1	10.3	2015	8	5.1	4.0	2.2
46047	10.8 (BS)	8.7 (G)	8.7	2006	12	7.9	2006	7	4.9	3.8	2.2
46053	6.9 (BS)	5.5 (G)	5.6	1995	12	5.5	2008	12	2.9	2.3	1.3
46054	10.7 (BS)	10.7 (BS)	8.8	2008	2	8.6	2002	6	4.6	3.6	2.0
46069	10.1 (BS)	10.1 (BS)	8.7	2017	1	7.9	2016	5	4.5	3.6	2.1
46114	15 (LN)	12.2 (BS)	10.4	2017	1	10.3	2017	1	5.1	4.0	2.2
46215	8.2 (BS)	6.6 (G)	6.5	2001	1	6.5	2001	1	3.6	2.8	1.6
46218	11.3 (BS)	11.3 (BS)	10.0	2008	2	9.4	2008	2	4.9	3.9	2.2
46219	11.7 (LN)	10.3 (IG)	9.1	2017	1	8.4	2014	3	4.6	3.7	2.1
46239	12.4 (BS)	9.7 (G)	10.0	2015	12	9.7	2015	12	5.2	4.0	2.3
46257	12.5 (BS)	10 (G)	8.1	2017	1	8.1	2017	1	5.6	4.2	2.3
46259	11.9 (BS)	9.6 (G)	8.3	2017	1	8.2	2017	1	5.4	4.1	2.4

BS: Birbaum-Saunders
IG: Inverse Gaussian
LN: Log-normal

Table 5: Best probabilistic model 200 year return period and summary statistics of significant wave energy (E).

NDBC	200yr	200yr NC	Max	Year	Month	Max2	Year	Month	99th	95th	Mean
46011	1784.6 (LN)	792.1 (IG)	743.3	2017	1	659.0	1983	2	173.2	92.2	29.4
46012	927.6 (IG)	927.6 (IG)	767.0	2004	2	649.4	2015	3	175.5	100.1	32.1
46023	874.2 (IG)	874.2 (BS)	611.6	1983	3	591.5	2009	2	195.2	106.6	34.3
46028	1864.8 (LN)	611.4 (IG)	864.1	2002	12	826.7	2002	1	189.3	107.6	36.1
46042	2005.8 (LN)	891.1 (IG)	1013.5	2017	1	976.9	2015	8	185.1	106.1	34.9
46047	1374.9 (LN)	688.7 (IG)	588.6	2002	11	563.1	2002	5	167.6	97.7	33.1
46053	768.7 (LN)	315.3 (IG)	290.0	2002	12	256.6	2007	11	61.3	33.1	10.5
46054	1801.3 (LN)	785.9 (IG)	765.8	2008	2	680.0	2006	4	162.0	88.7	29.0
46069	1198.7 (LN)	612.2 (IG)	639.0	2017	1	569.4	2016	5	146.3	86.6	30.6
46114	1853.6 (LN)	1853.6 (LN)	965.4	2017	1	898.0	2017	1	186.6	107.1	35.5
46215	828.4 (LN)	404.4 (IG)	384.0	2008	1	368.3	2017	1	98.2	52.6	18.2
46218	1497.2 (LN)	737 (IG)	885.5	2008	2	747.4	2008	2	172.4	101.0	34.7
46219	1061.6 (LN)	1061.6 (LN)	818.7	2017	1	630.1	2014	3	145.9	88.2	31.3
46239	1891.6 (LN)	873.8 (IG)	881.9	2015	12	838.2	2015	12	186.2	109.8	37.3
46257	2196.1 (LN)	1006.5 (IG)	617.8	2017	1	583.0	2017	1	229.0	128.6	41.6
46259	1435.9 (LN)	766.9 (IG)	594.6	2017	1	566.8	2017	1	197.6	116.0	40.3

BS: Birbaum-Saunders
IG: Inverse Gaussian
LN: Log-normal

8.0 Figures

Figure 1: NDBC Buoy Network along the California Central Coast.

Figure 2: Close up of NDBC Buoy Network along the California Central Coast Near Point Arguello.

Figure 3: Photo of Platform Irene (approximate area for wave farm).

Figure 4: Daily Wave Height, Max, Mean, Min, NDBC 46011

Figure 5: Daily Wave Height, Percentiles, NDBC 46011

Figure 6: Monthly Wave Height, Max, Mean, Min, NDBC 46011

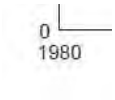

Figure 7: Monthly Wave Height, Percentiles, NDBC 46011

Figure 8: Yearly Wave Height, Max, Mean, Min, NDBC 46011

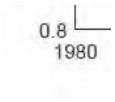

Figure 9: Yearly Wave Height, Percentiles, NDBC 46011

Figure 10: Daily Wave Period, Max, Mean, Min, NDBC 46011

Figure 11: Daily Wave Period, Percentiles, NDBC 46011

Figure 12: Monthly Wave Period, Max, Mean, Min, NDBC 46011

Figure 13: Monthly Wave Period, Percentiles, NDBC 46011

Figure 14: Yearly Wave Period, Max, Mean, Min, NDBC 46011

Figure 15: Yearly Wave Period, Percentiles, NDBC 46011

Figure 16: Daily Wave Energy, Max, Mean, Min, NDBC 46011

Figure 17: Daily Wave Energy, Percentiles, NDBC 46011

Figure 18: Monthly Wave Energy, Max, Mean, Min, NDBC 46011

Figure 19: Monthly Wave Energy, Percentiles, NDBC 46011

Figure 20: Yearly Wave Energy, Max, Mean, Min, NDBC 46011

Figure 21: Yearly Wave Energy, Percentiles, NDBC 46011

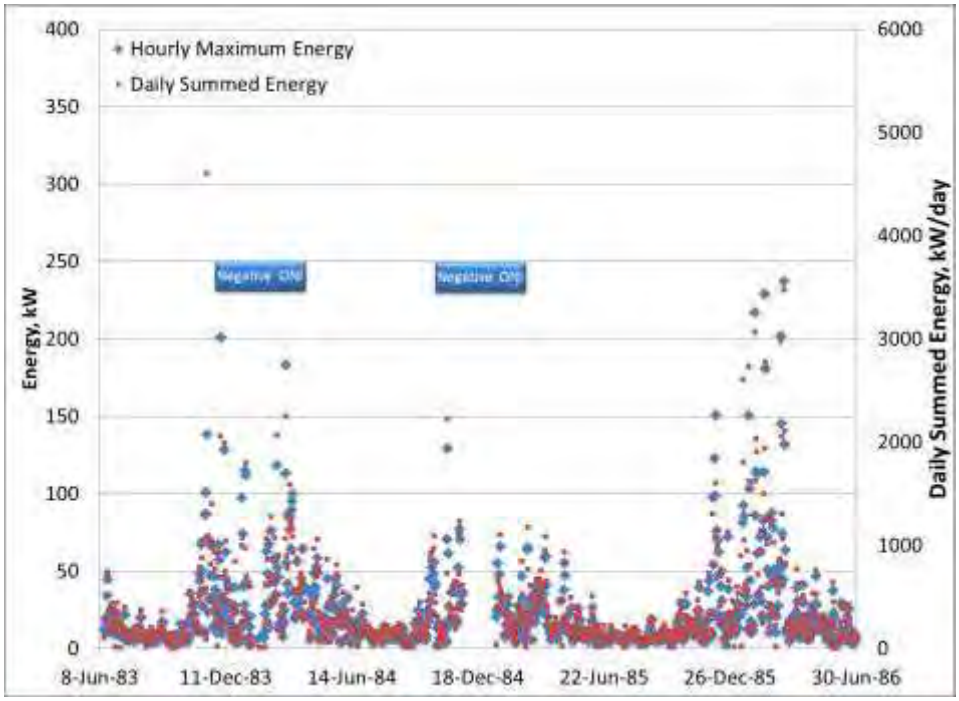

Figure 22: 3 Year Daily Maximum Hour Energy and Summed Energy – 1983-1986.

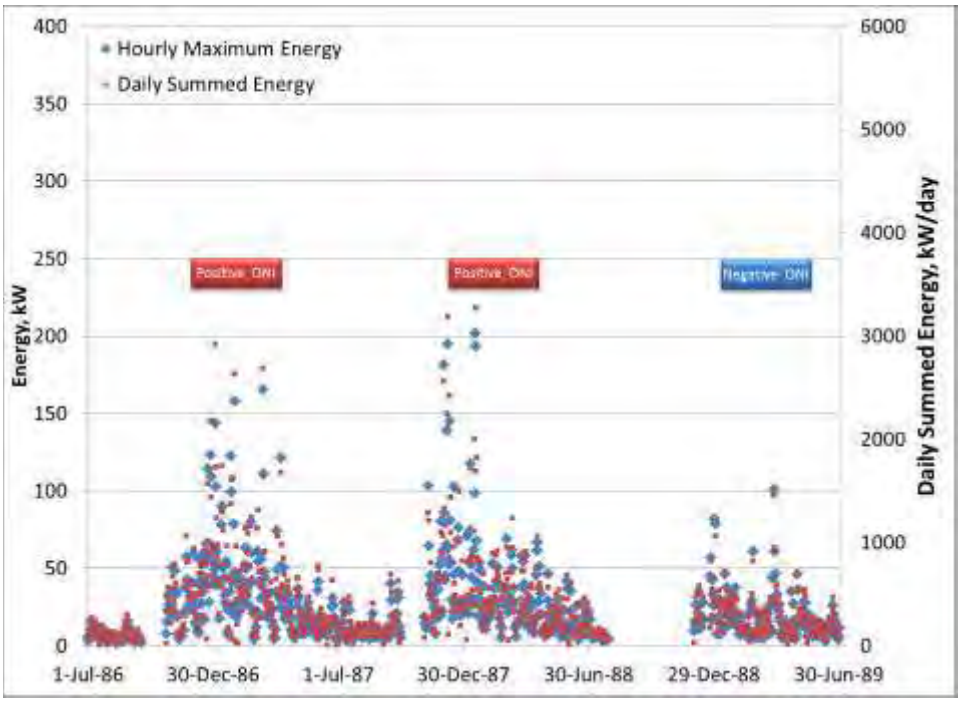

Figure 23: 3 Year Daily Maximum Hour Energy and Summed Energy – 1986-1989.

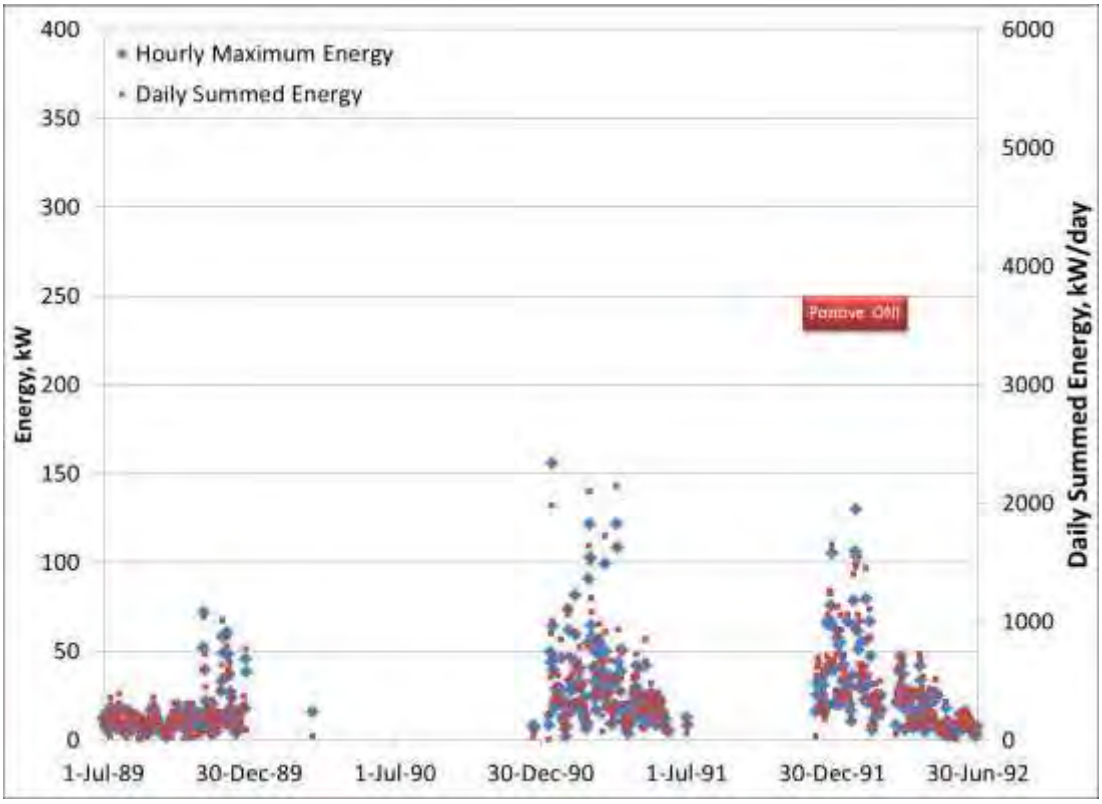

Figure 24: 3 Year Daily Maximum Hour Energy and Summed Energy – 1989-1992.

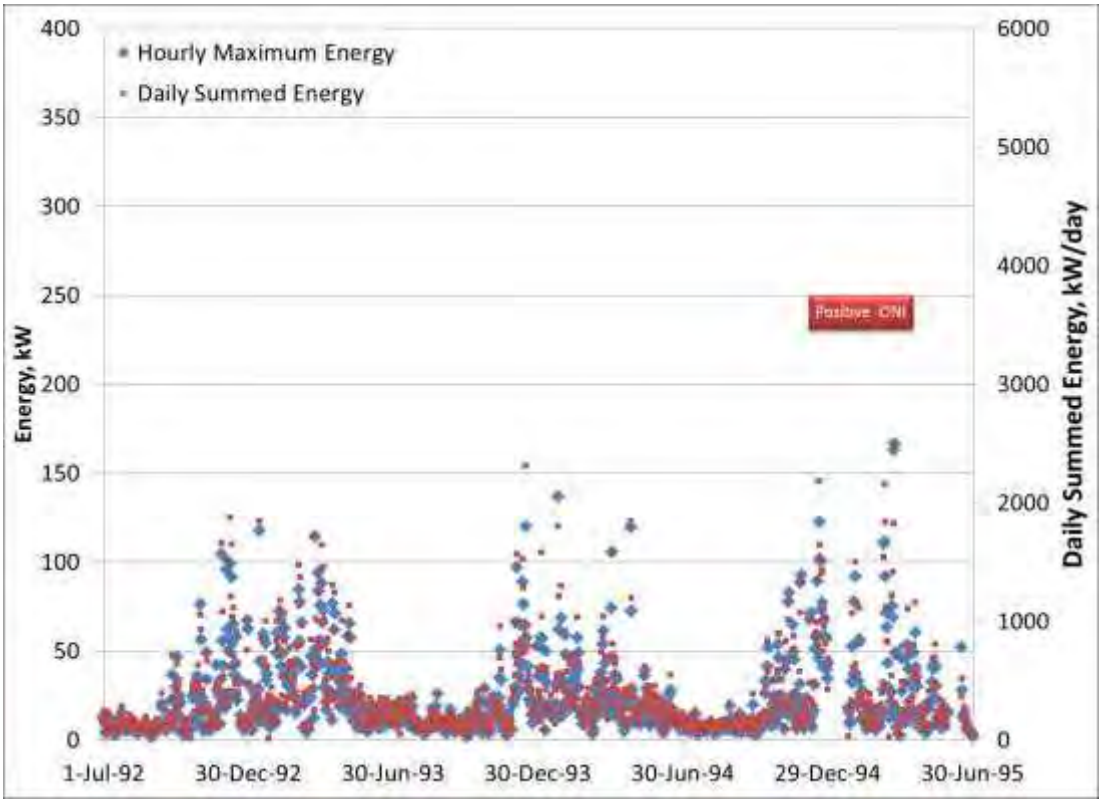

Figure 25: 3 Year Daily Maximum Hour Energy and Summed Energy – 1992-1995.

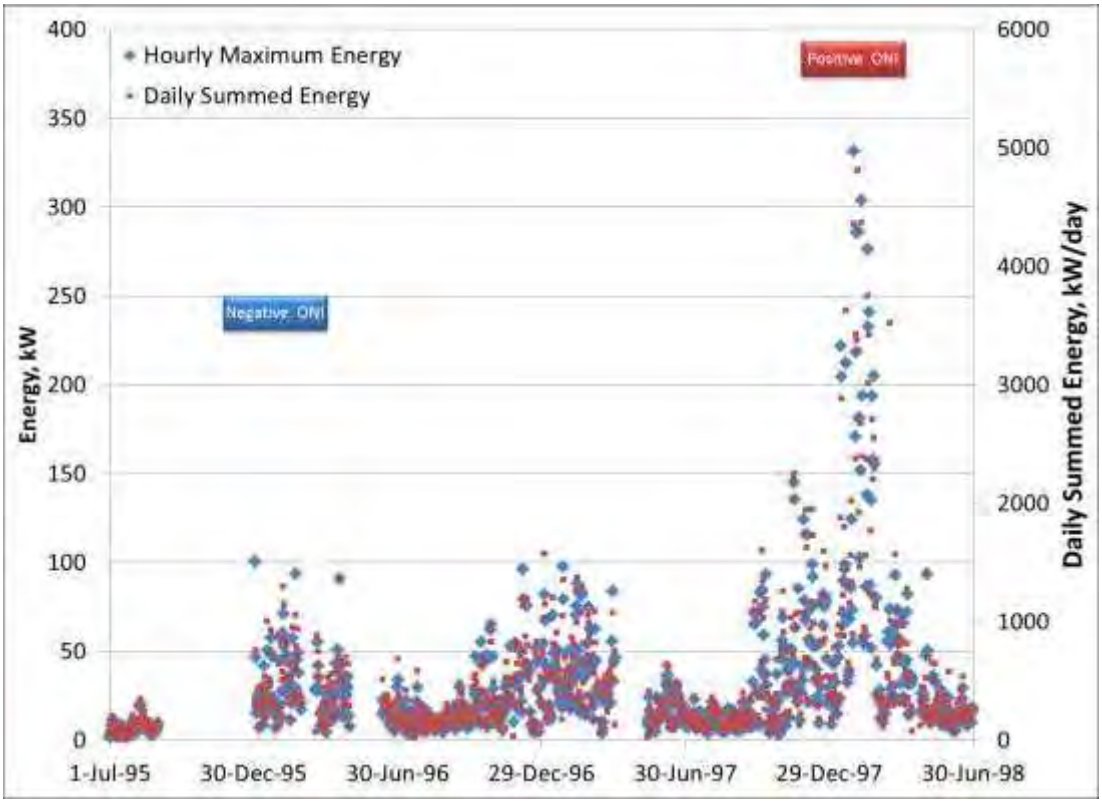

Figure 26: 3 Year Daily Maximum Hour Energy and Summed Energy – 1995-1998.

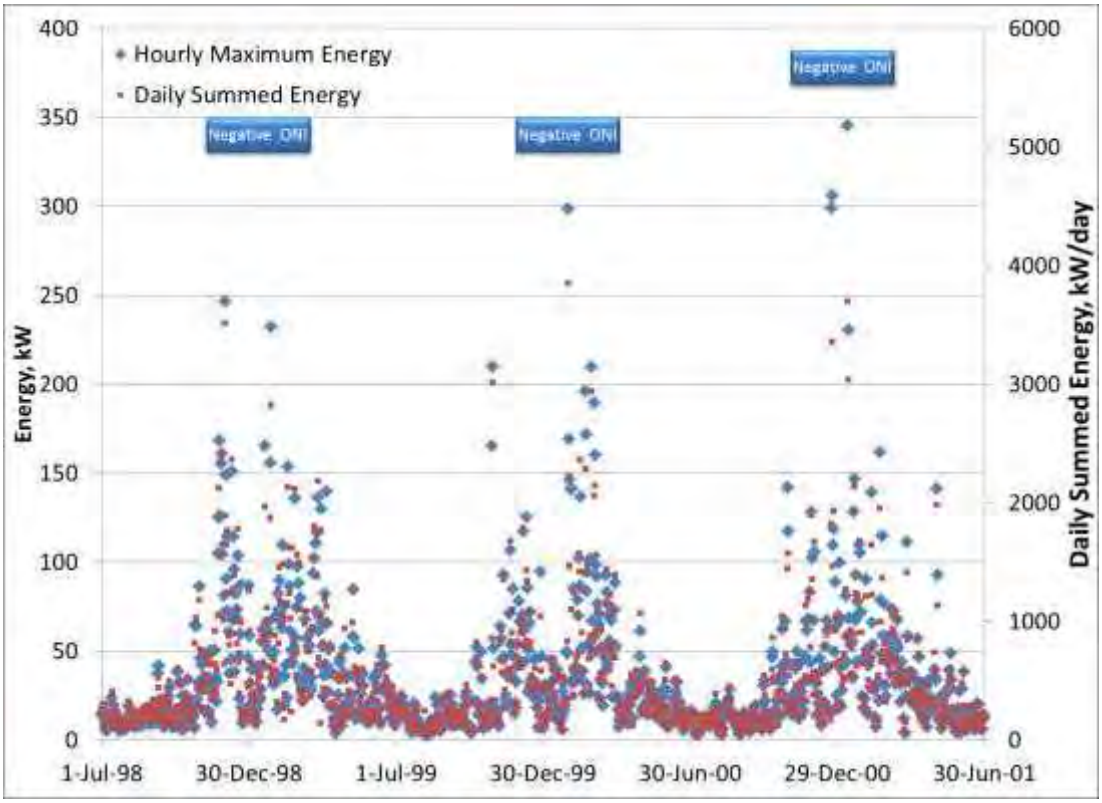

Figure 27: 3 Year Daily Maximum Hour Energy and Summed Energy – 1998-2001.

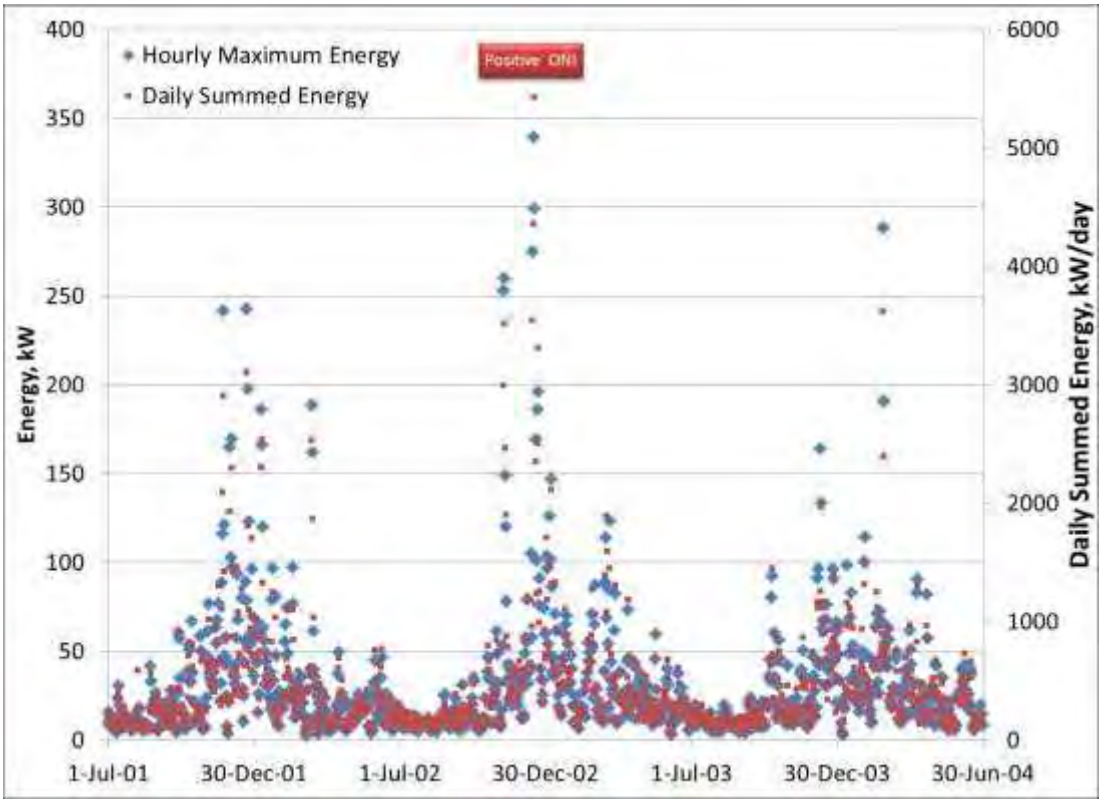

Figure 28: 3 Year Daily Maximum Hour Energy and Summed Energy – 2001-2004.

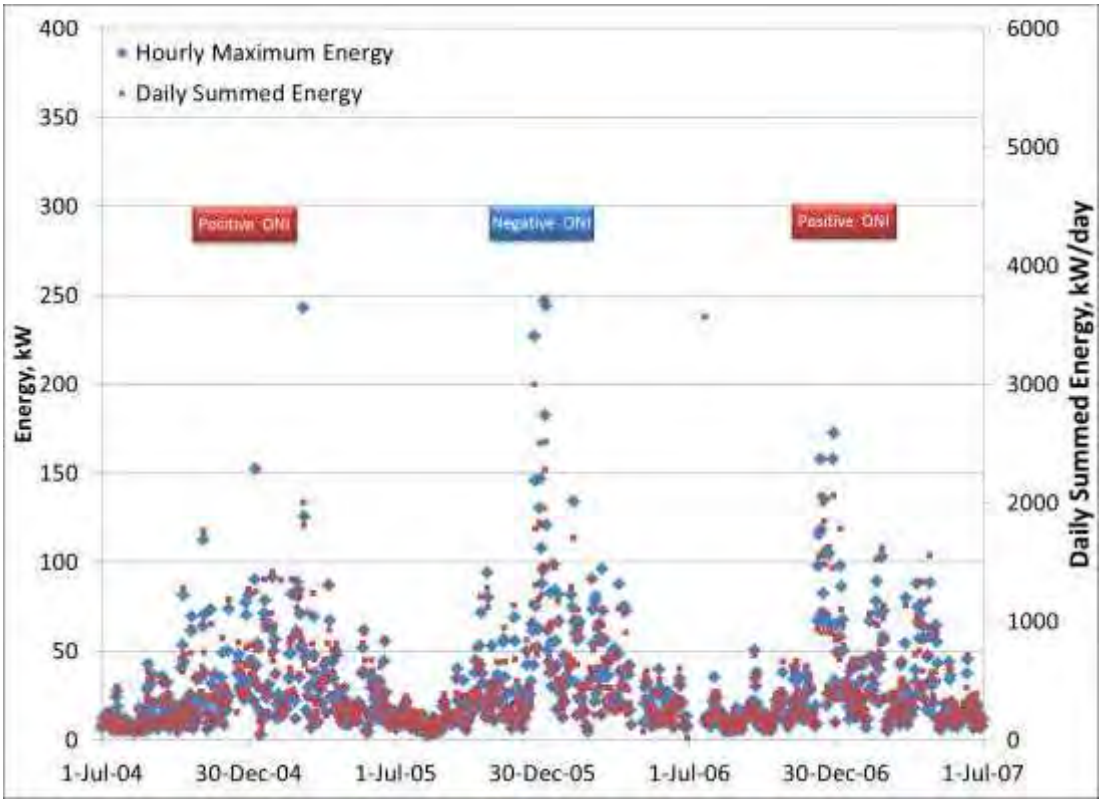

Figure 29: 3 Year Daily Maximum Hour Energy and Summed Energy – 2004-2007.

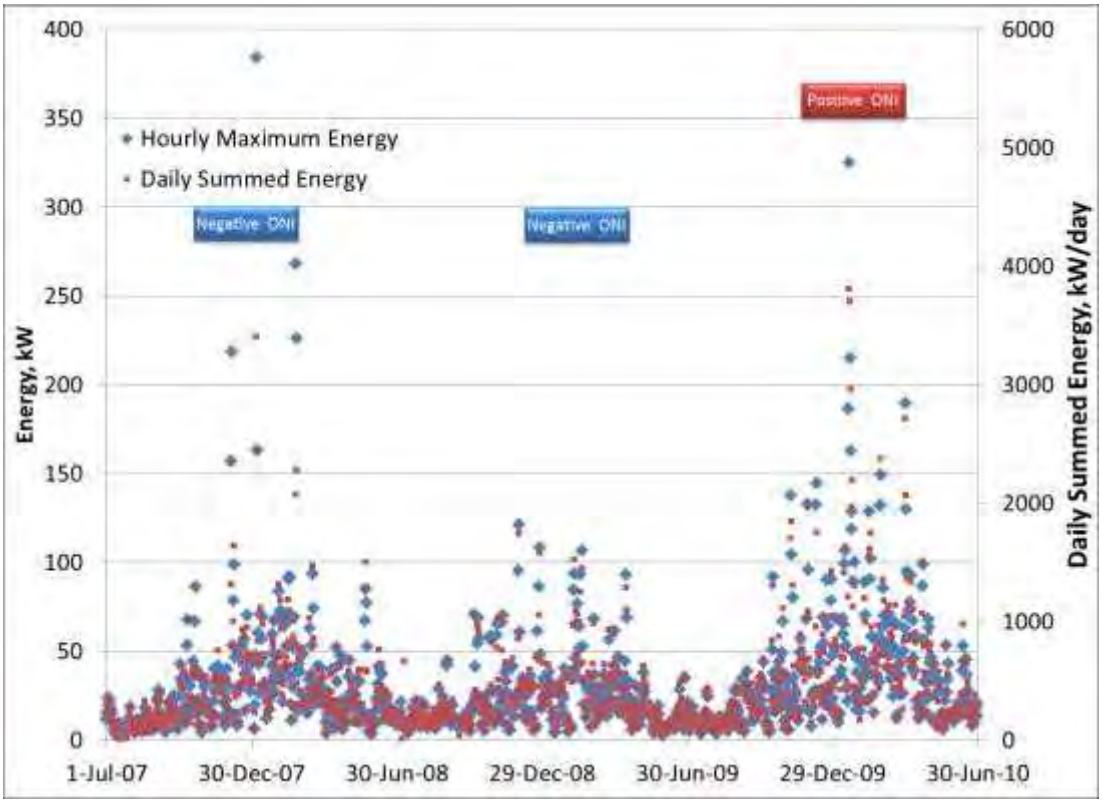

Figure 30: 3 Year Daily Maximum Hour Energy and Summed Energy – 2007-2010.

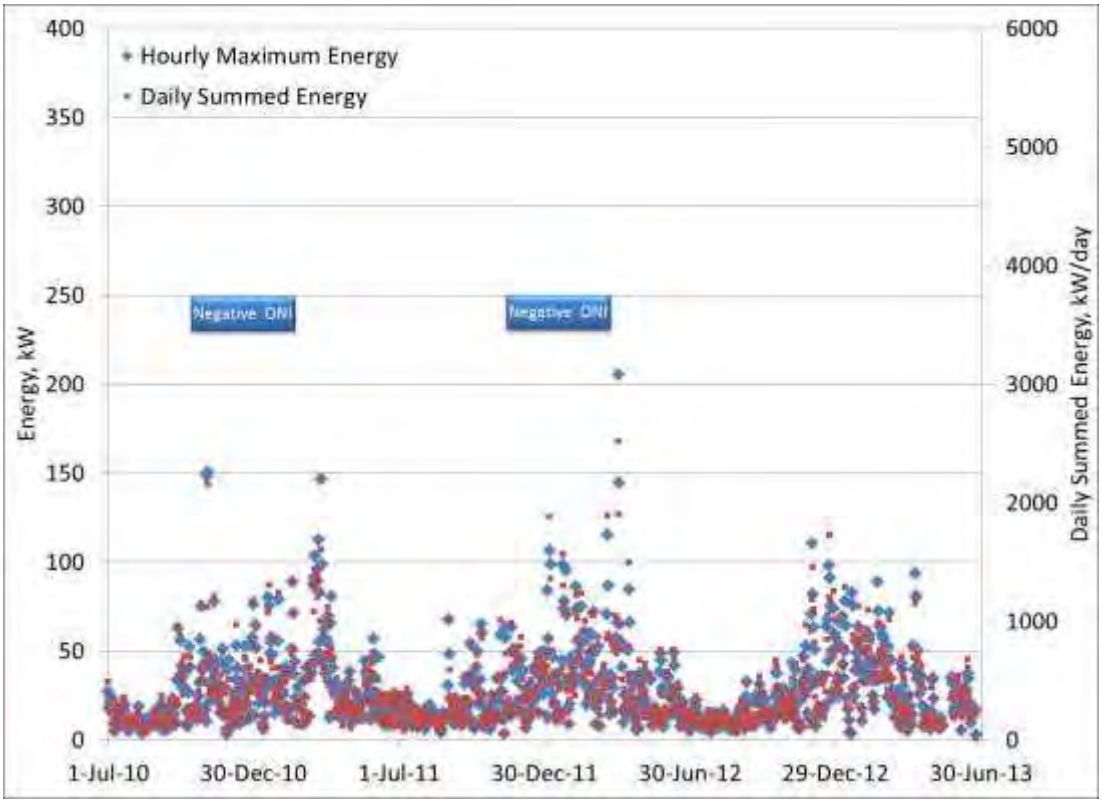

Figure 31: 3 Year Daily Maximum Hour Energy and Summed Energy – 2010-2013.

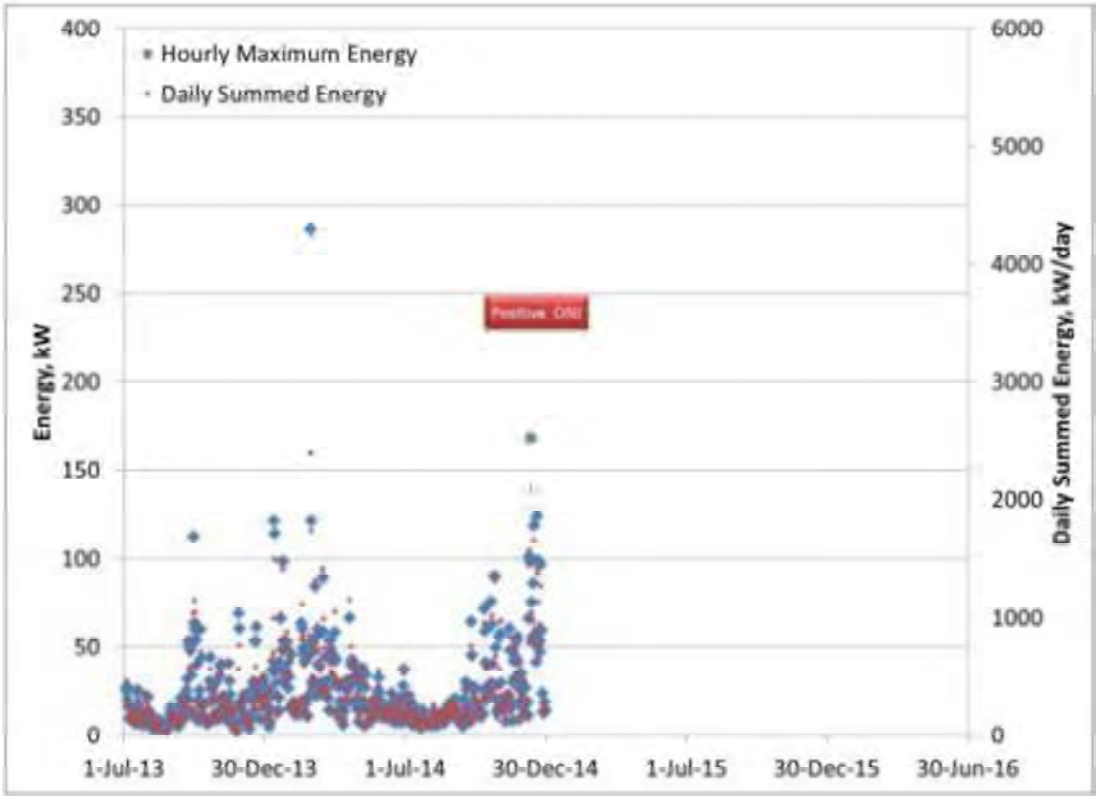

Figure 32: 3 Year Daily Maximum Hour Energy and Summed Energy – 2013-2014 (EOY).

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Figure 33: Monthly Wave Energy Distribution, Max, Mean, and Various Percentiles

Figure 34: Monthly Wave Energy Distribution, Max, Mean, and Various Percentiles

Figure 35: Monthly Wave Energy Distribution, Max, Mean, and Various Percentiles

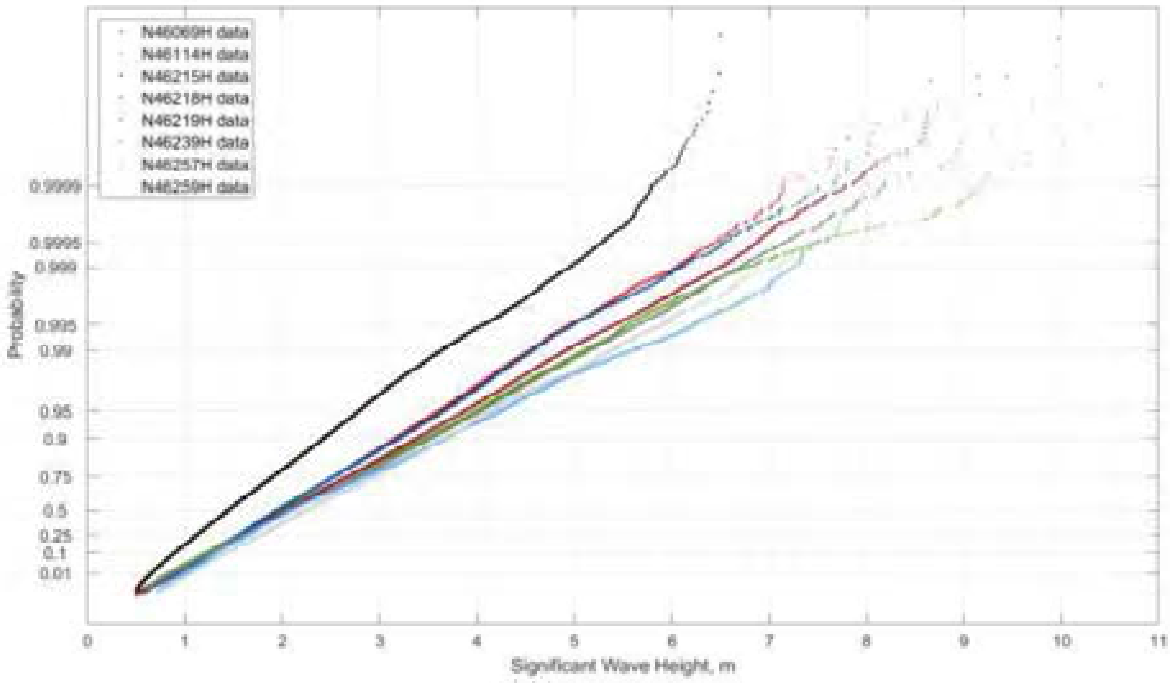


Figure 36: Set of Probability Distributions for Wave Height, m.

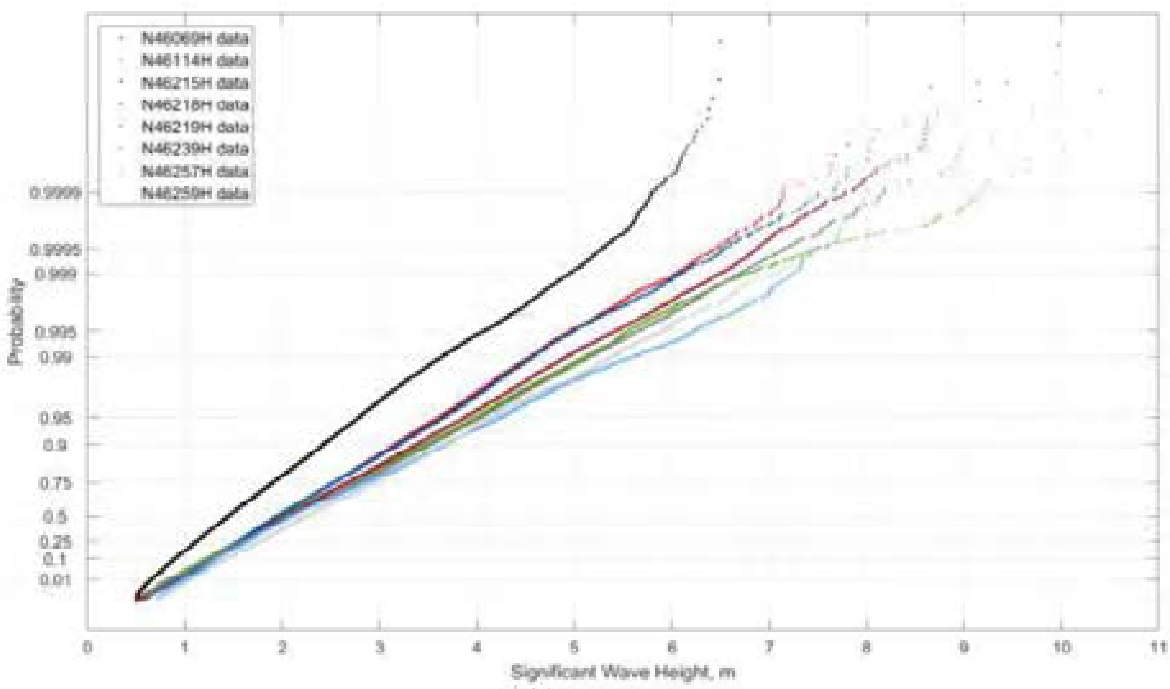


Figure 37: Set of Probability Distributions for Wave Height, m.

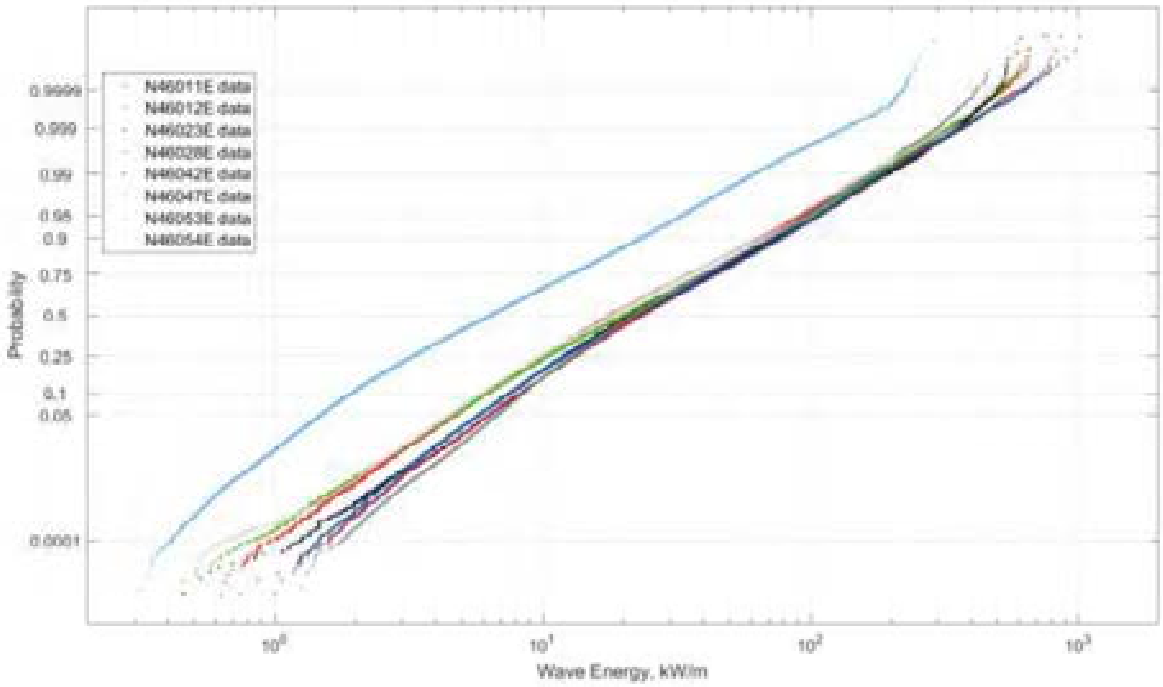


Figure 38: Set of Probability Distributions for Wave Energy, kW/m.

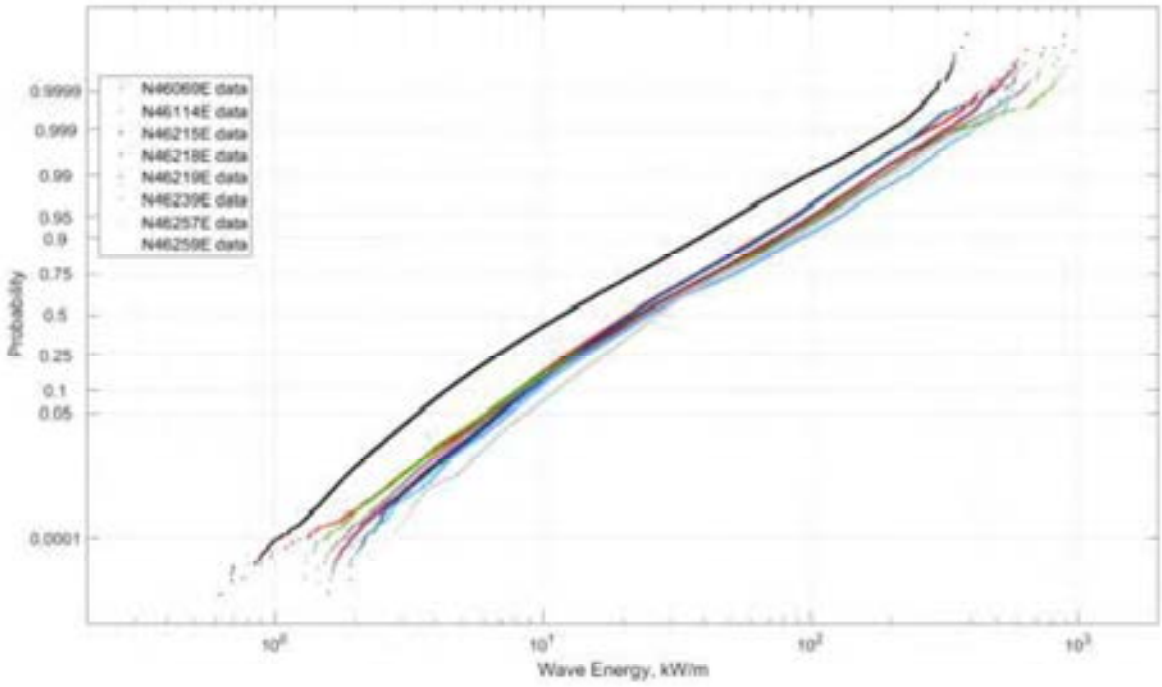


Figure 39: Set of Probability Distributions for Wave Energy, kW/m.

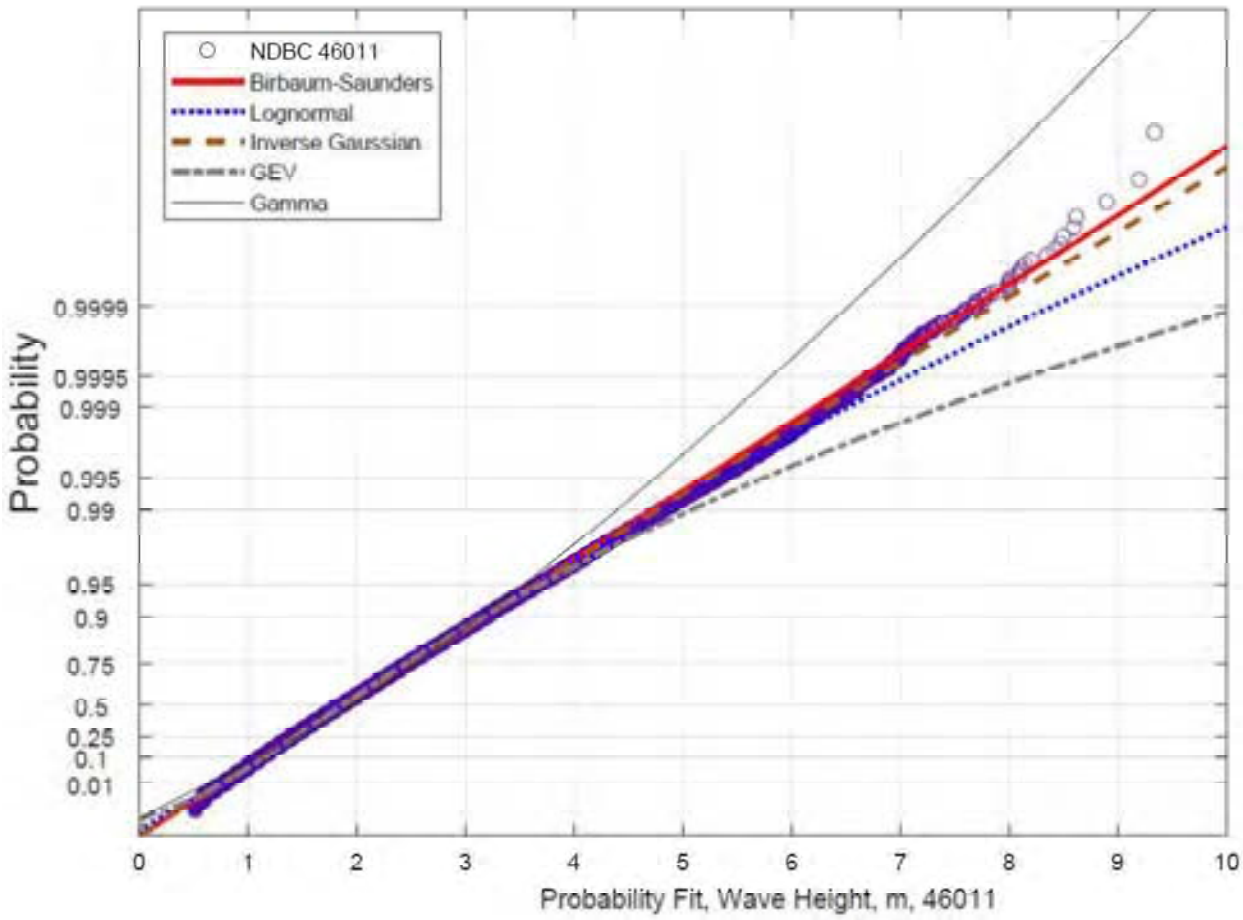


Figure 40: NDBC 46011 Probability Fit for Wave Height, m.

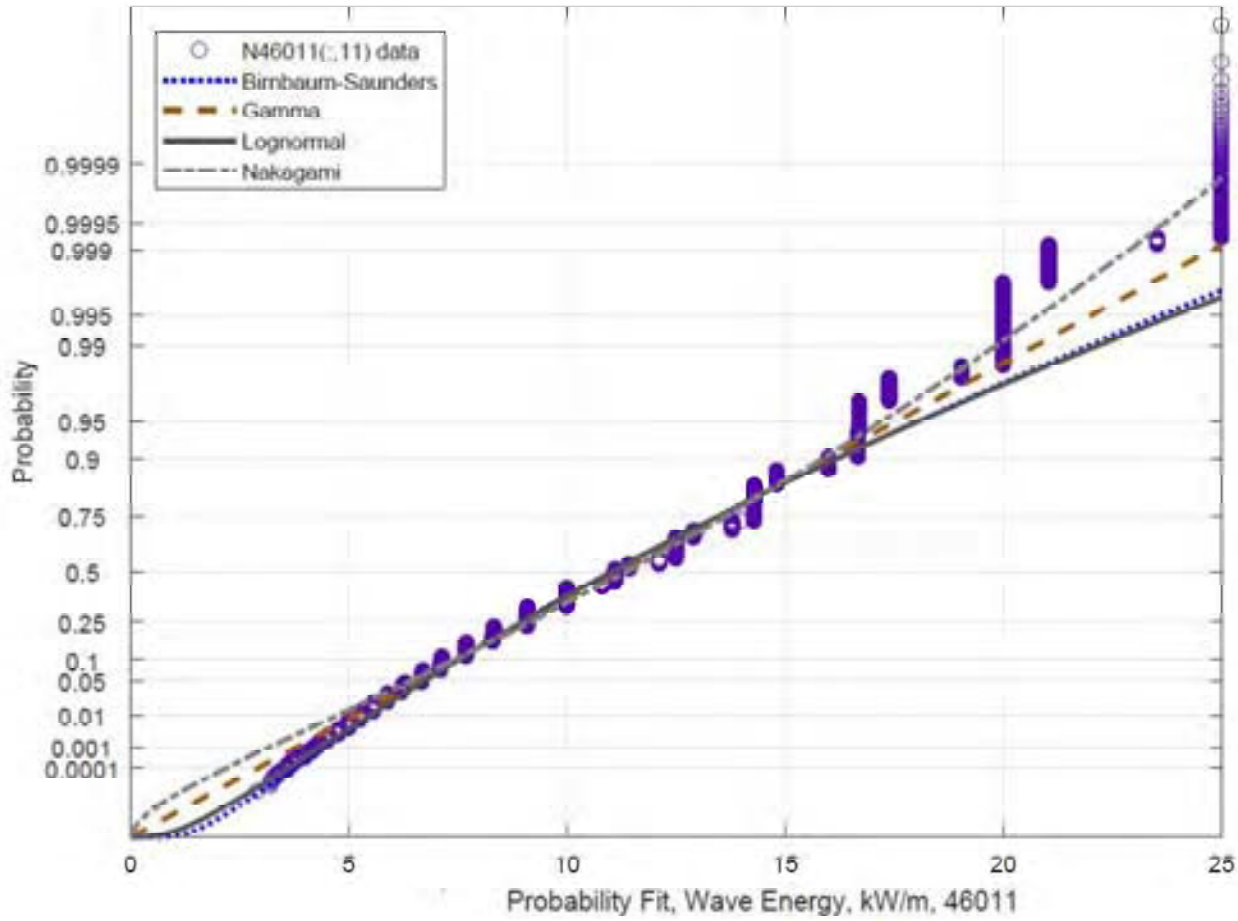


Figure 41: NDBC 46011 Probability Fit for Wave period, s.

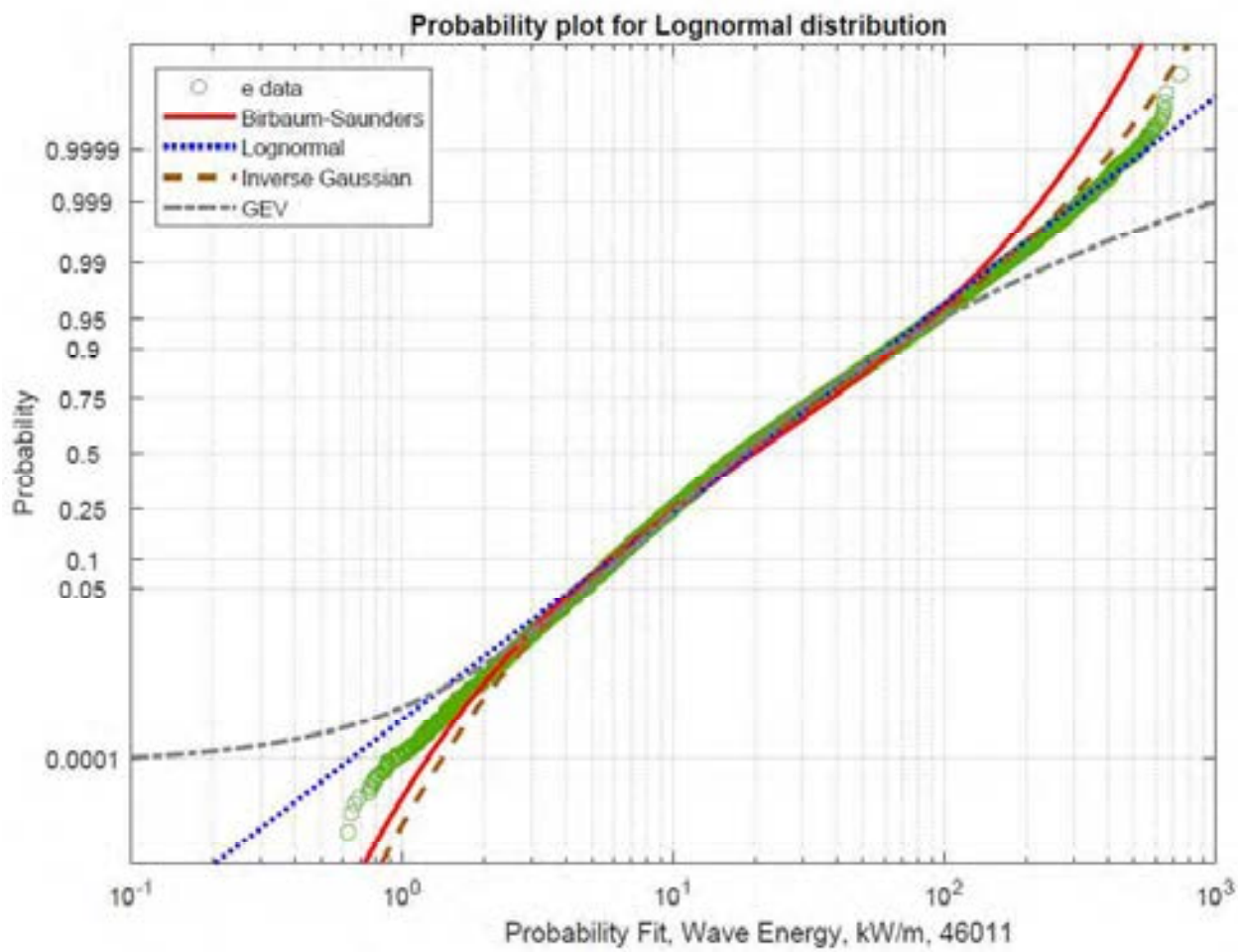


Figure 42: NDBC 46011 Probability Fit for Wave Energy (Log Scale), kW/m.

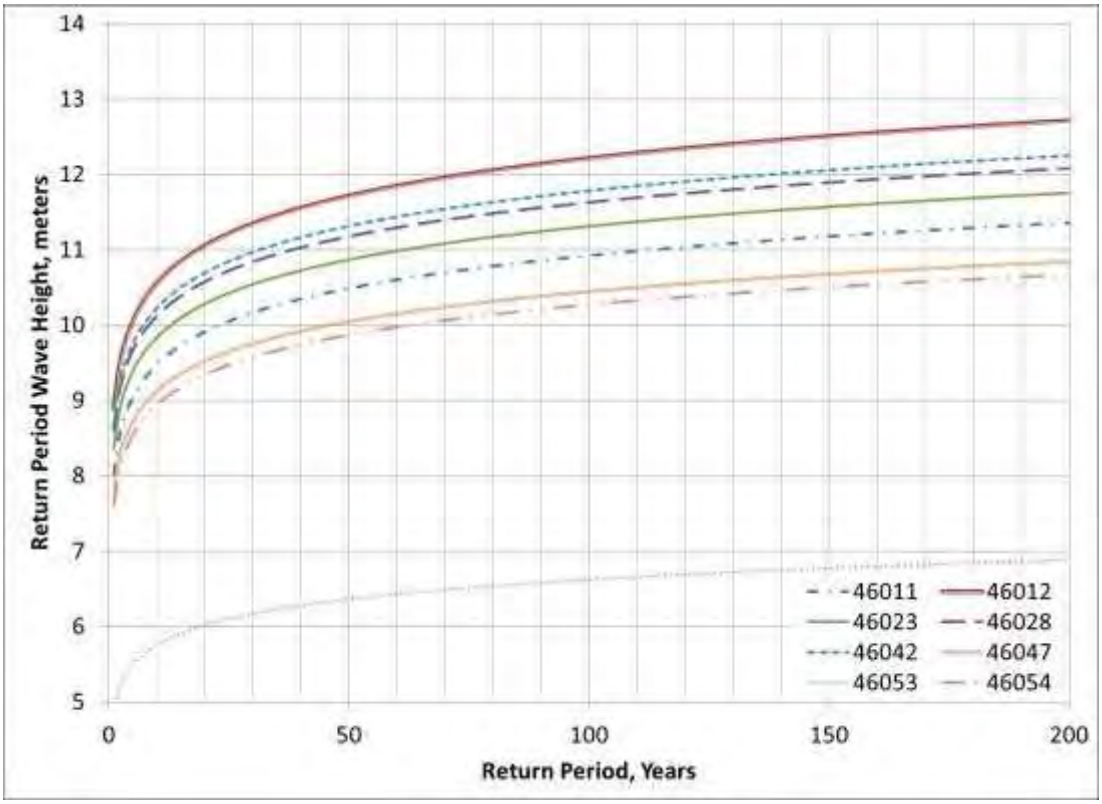


Figure 43: Return Period Estimates, Years, for Significant Wave Height, m.

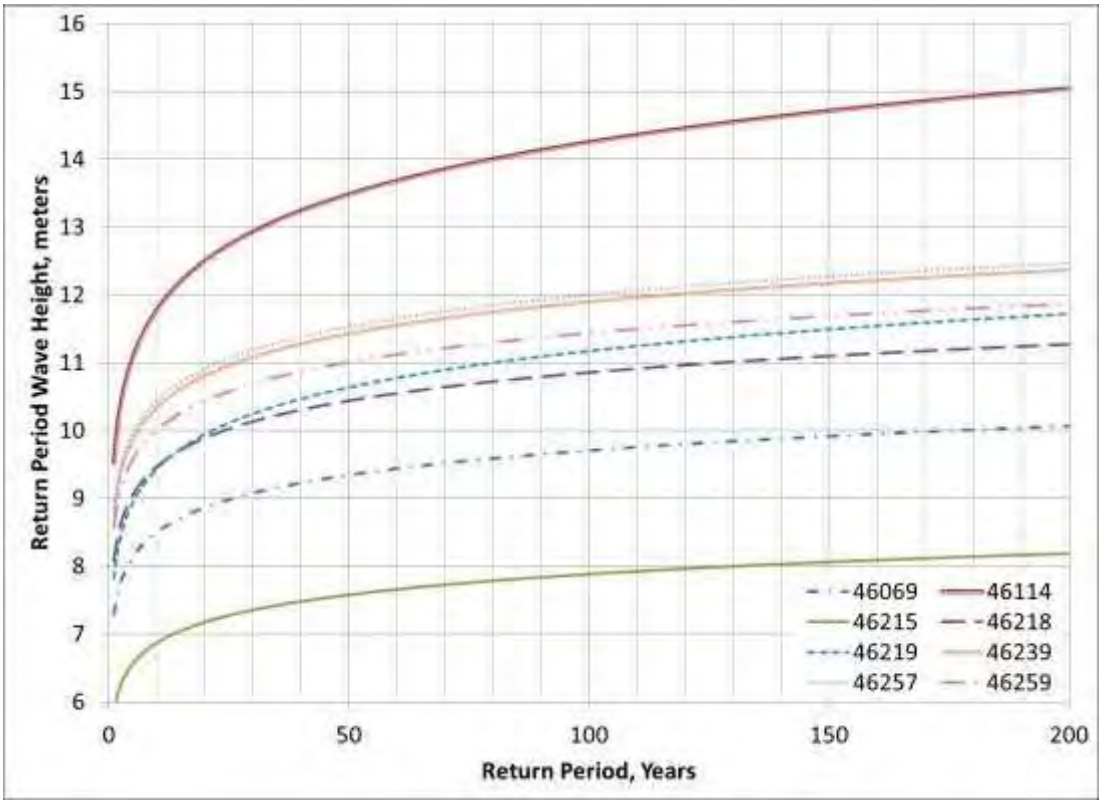


Figure 44: Return Period Estimates, Years, for Significant Wave Height, m.

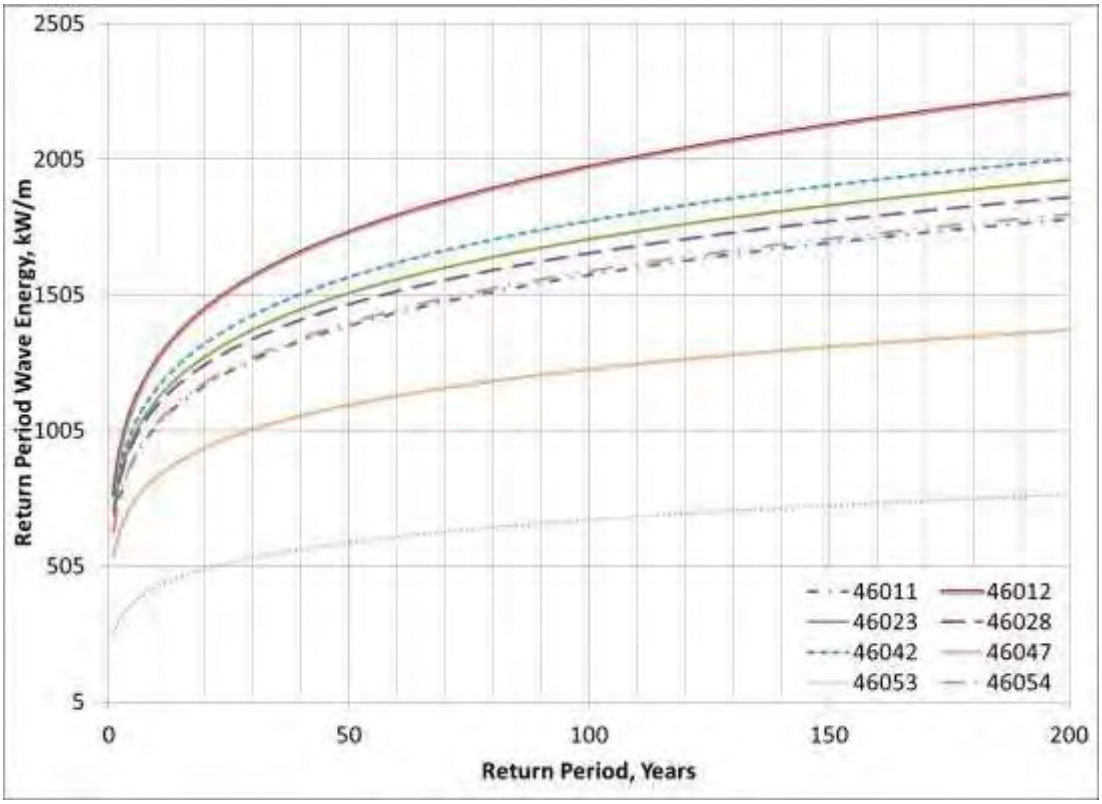


Figure 45: Return Period Estimates, Years, for Wave Energy, kW/m.

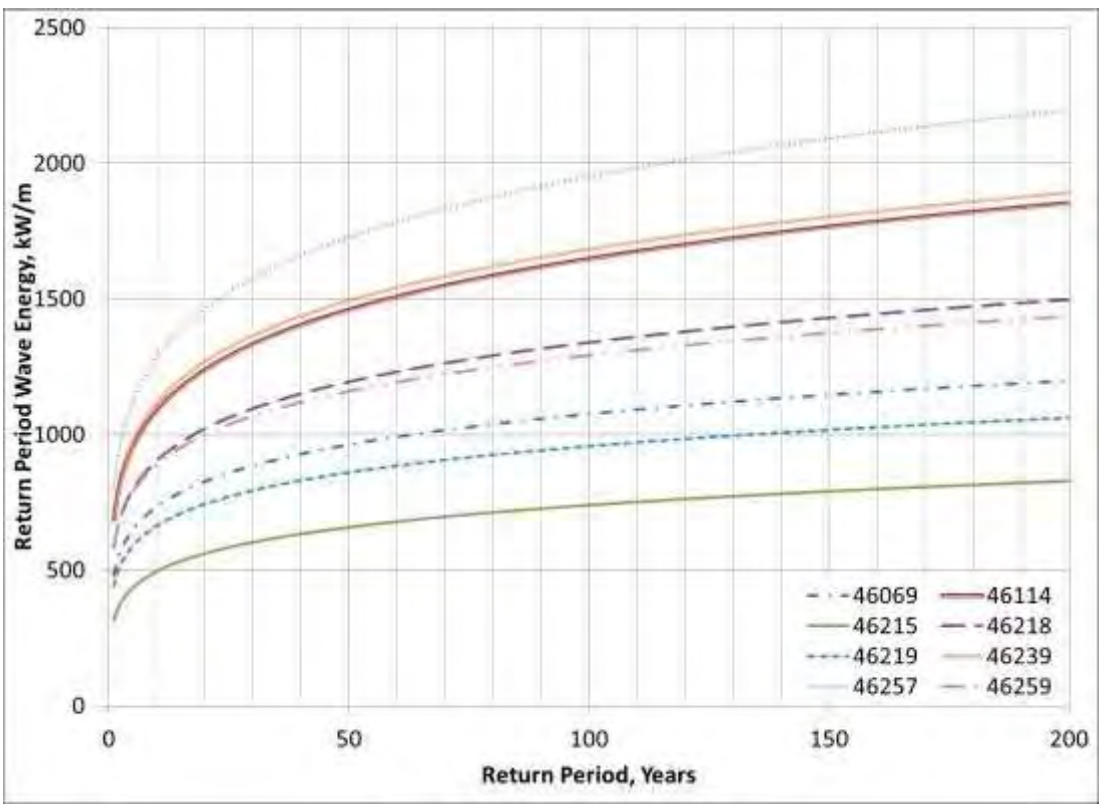


Figure 46: Return Period Estimates, Years, for Wave Energy, kW/m.

APPENDICES

APPENDIX A: Historical Data for Wave Height, Period, and Energy, by Buoy

APPENDIX B: Cross Correlated Data for Wave Height, Period, and Direction, by Buoy

APPENDIX C: Cross Correlated Data for Wave Energy, and Direction, by Buoy

APPENDIX D: Monthly Summaries of Wave Height, Period, and Energy, by Buoy

APPENDIX E: Probability Fits of Wave Height, Period, and Energy, by Buoy

APPENDIX A: Historical Data for Wave Height, Period, and Energy, by Buoy

(Appendix A is included as a separate file due to size)

APPENDIX B: Cross Correlated Data for Wave Height, Period, and Direction, by Buoy

(Appendix B is included as a separate file due to size)

APPENDIX C: Cross Correlated Data for Wave Energy, and Direction, by Buoy

(Appendix C is included as a separate file due to size)

APPENDIX D: Monthly Summaries of Wave Height, Period, and Energy, by Buoy

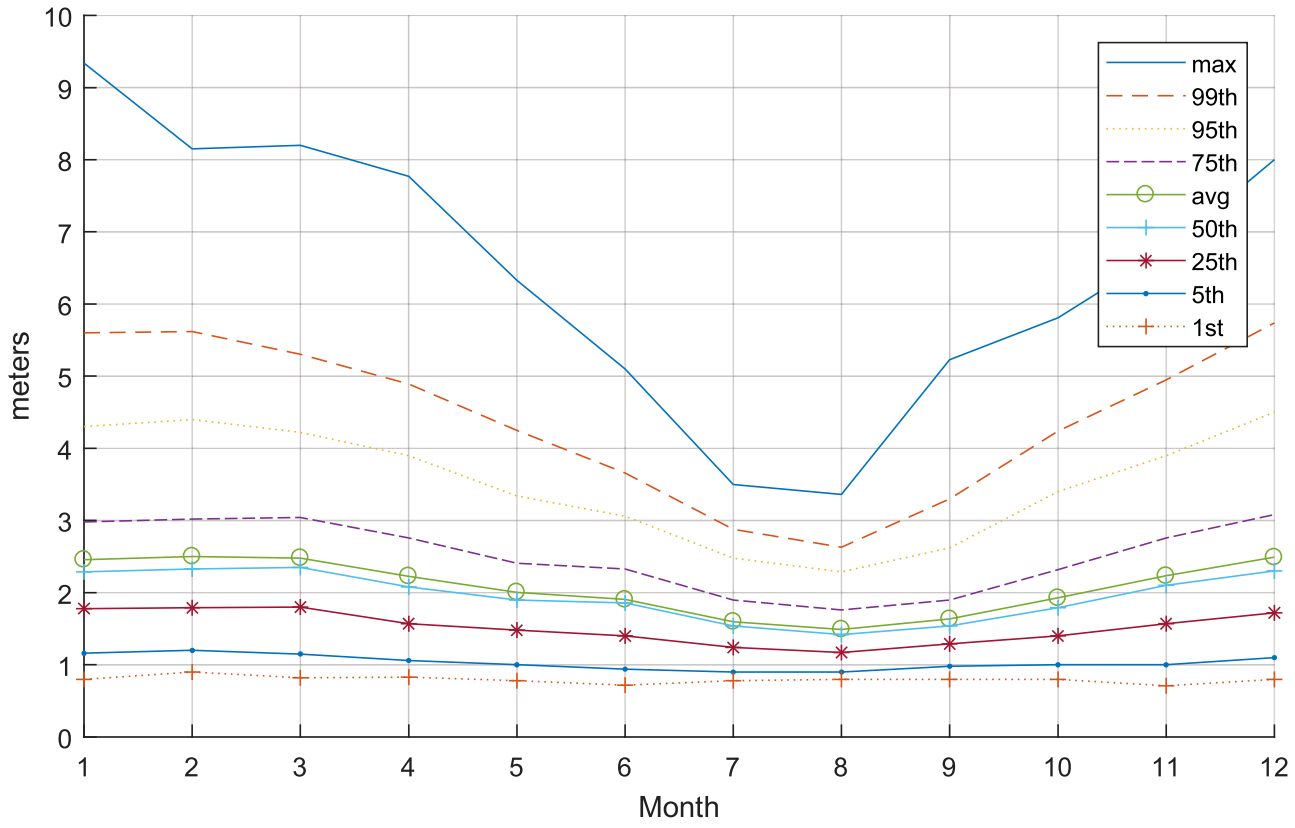


Figure D001.NDBC 46011 Monthly Wave Height Distribution

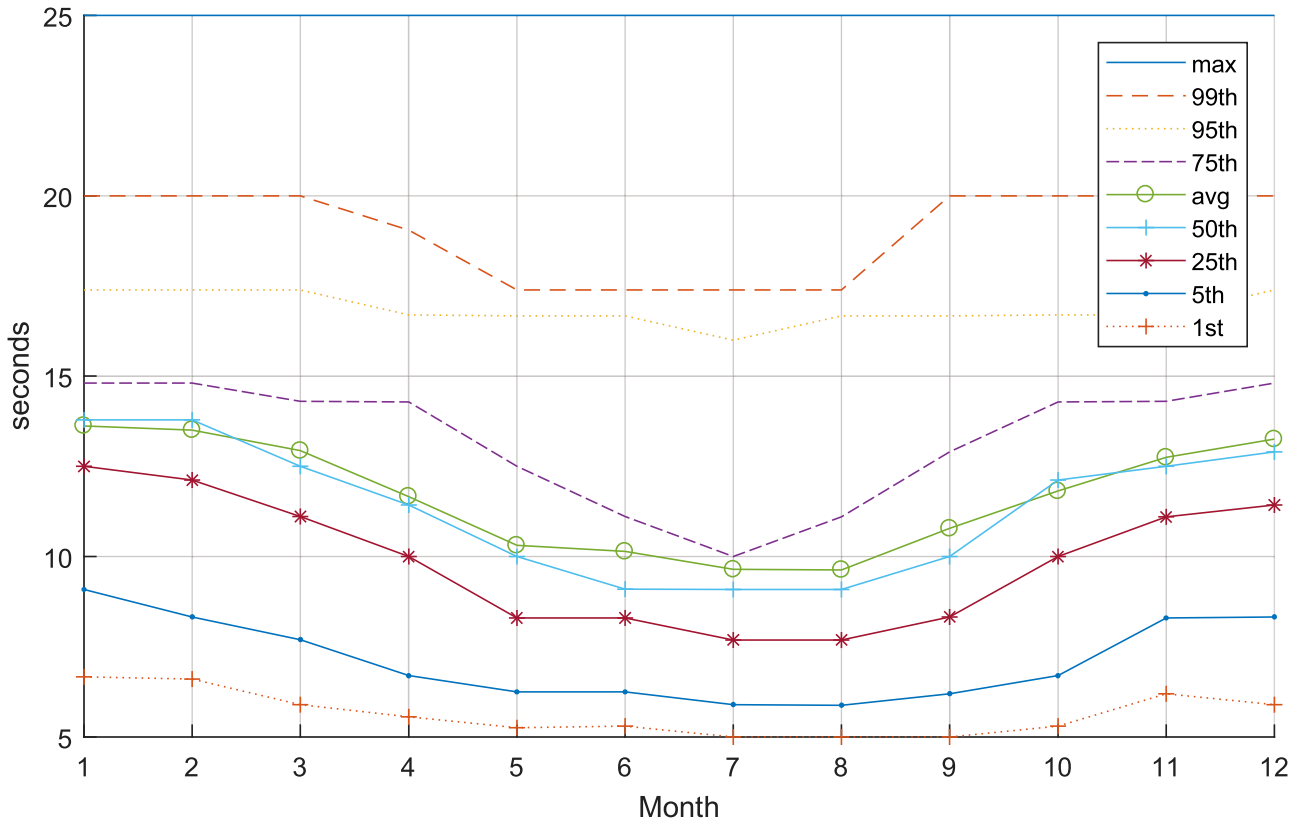


Figure D002.NDBC 46011 Monthly Wave Period Distribution

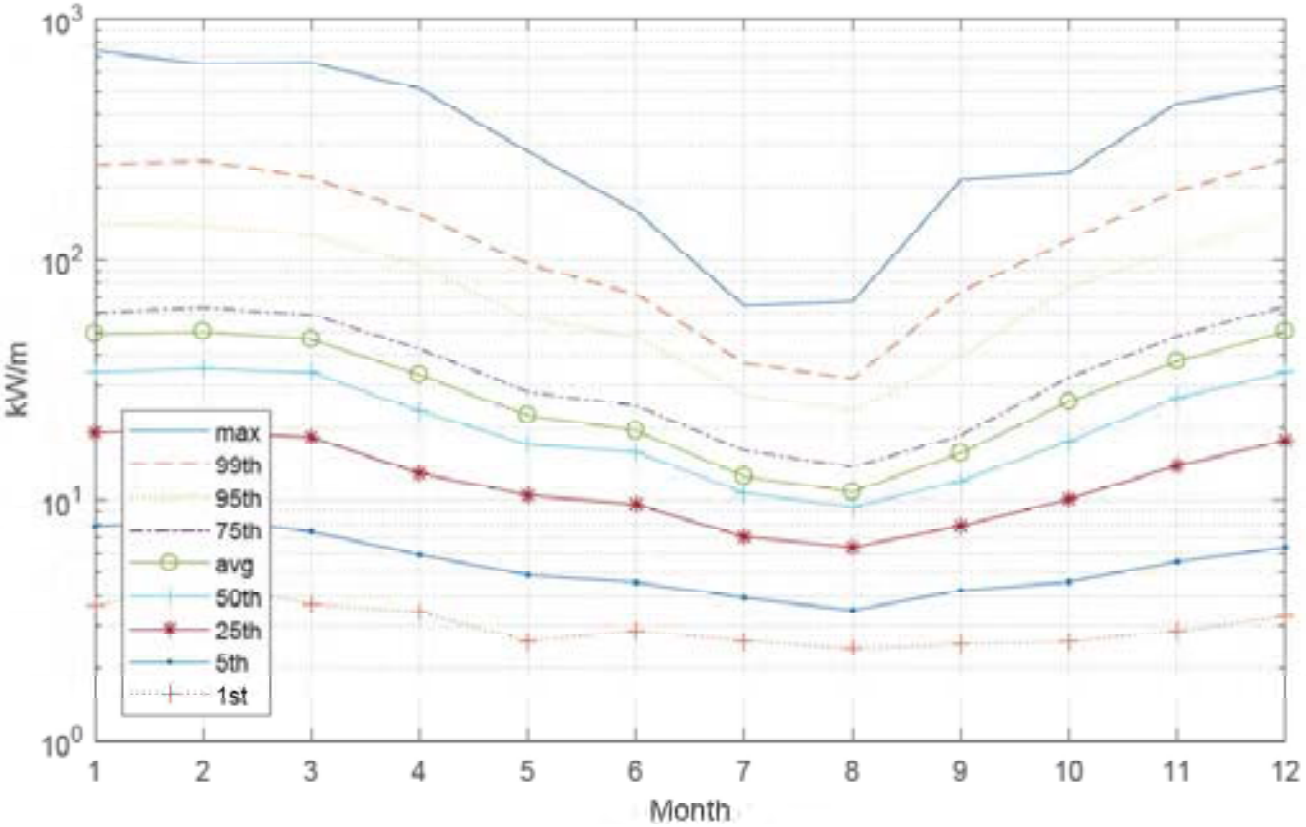


Figure D003.NDBC 46011 Monthly Wave Energy Distribution

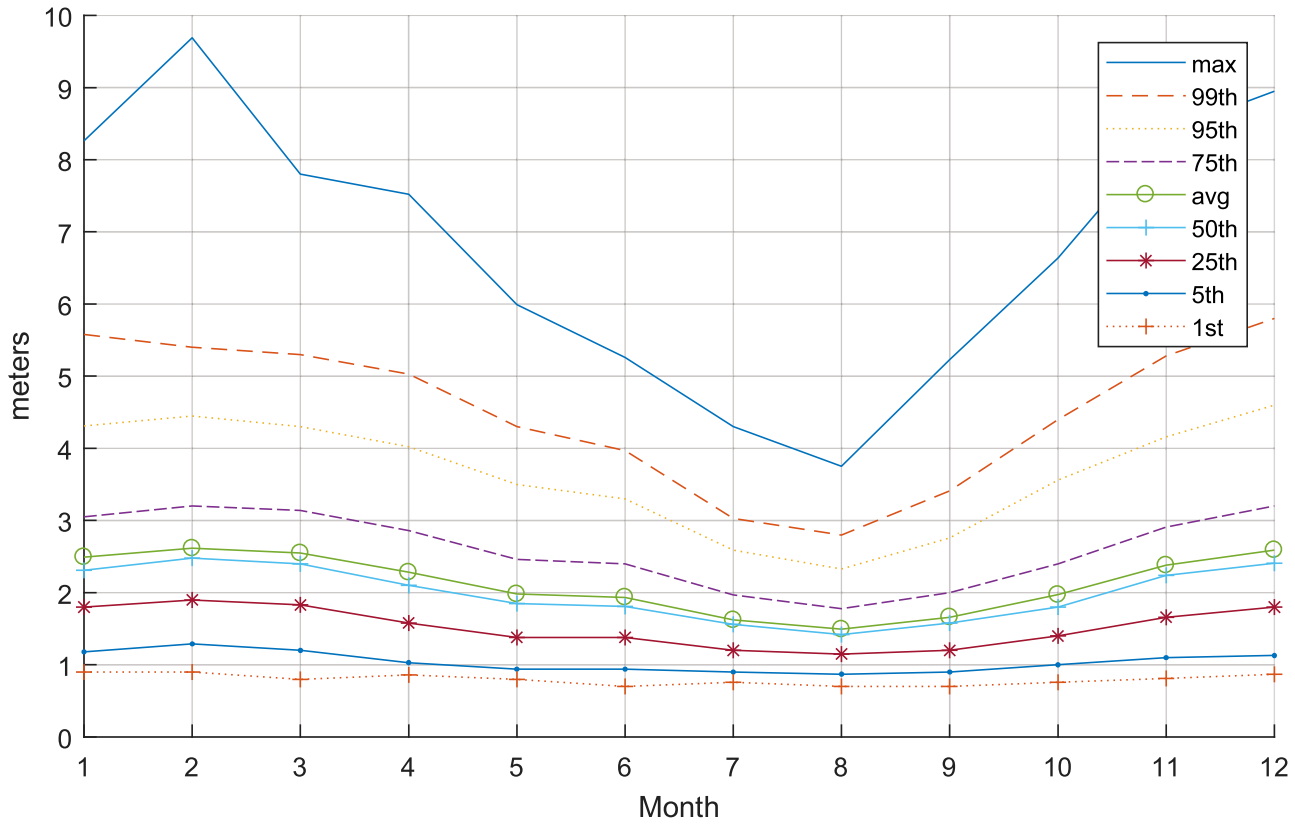


Figure D004.NDBC 46012 Monthly Wave Height Distribution

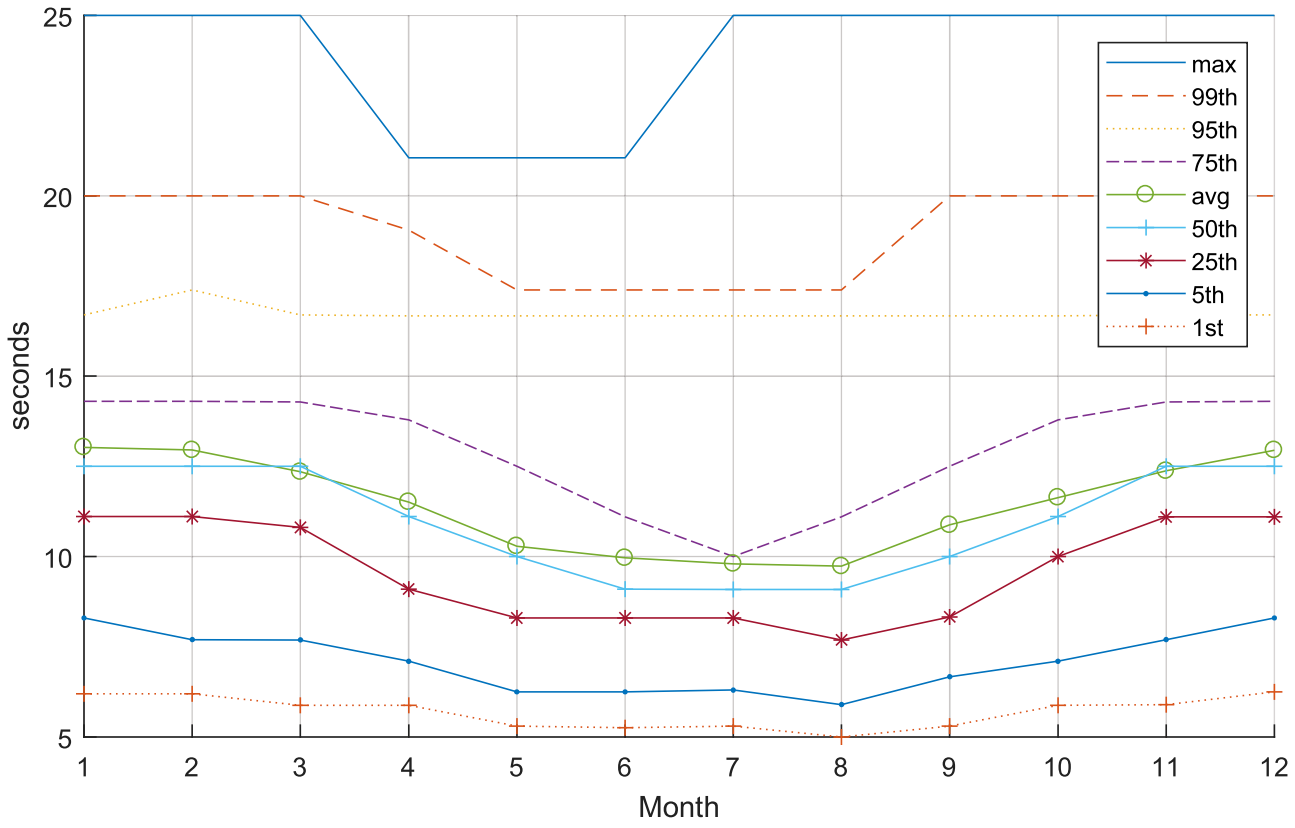


Figure D005.NDBC 46012 Monthly Wave Period Distribution

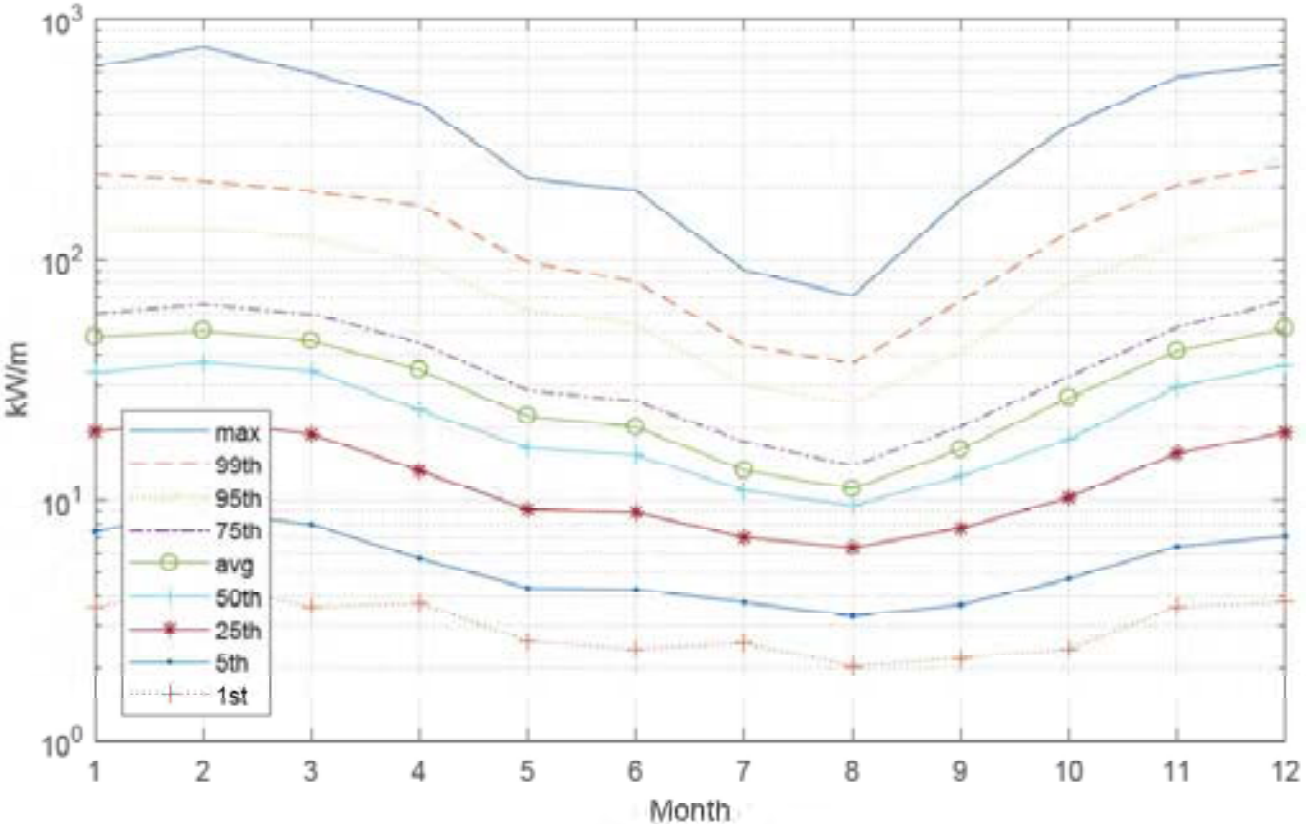


Figure D006.NDBC 46012 Monthly Wave Energy Distribution

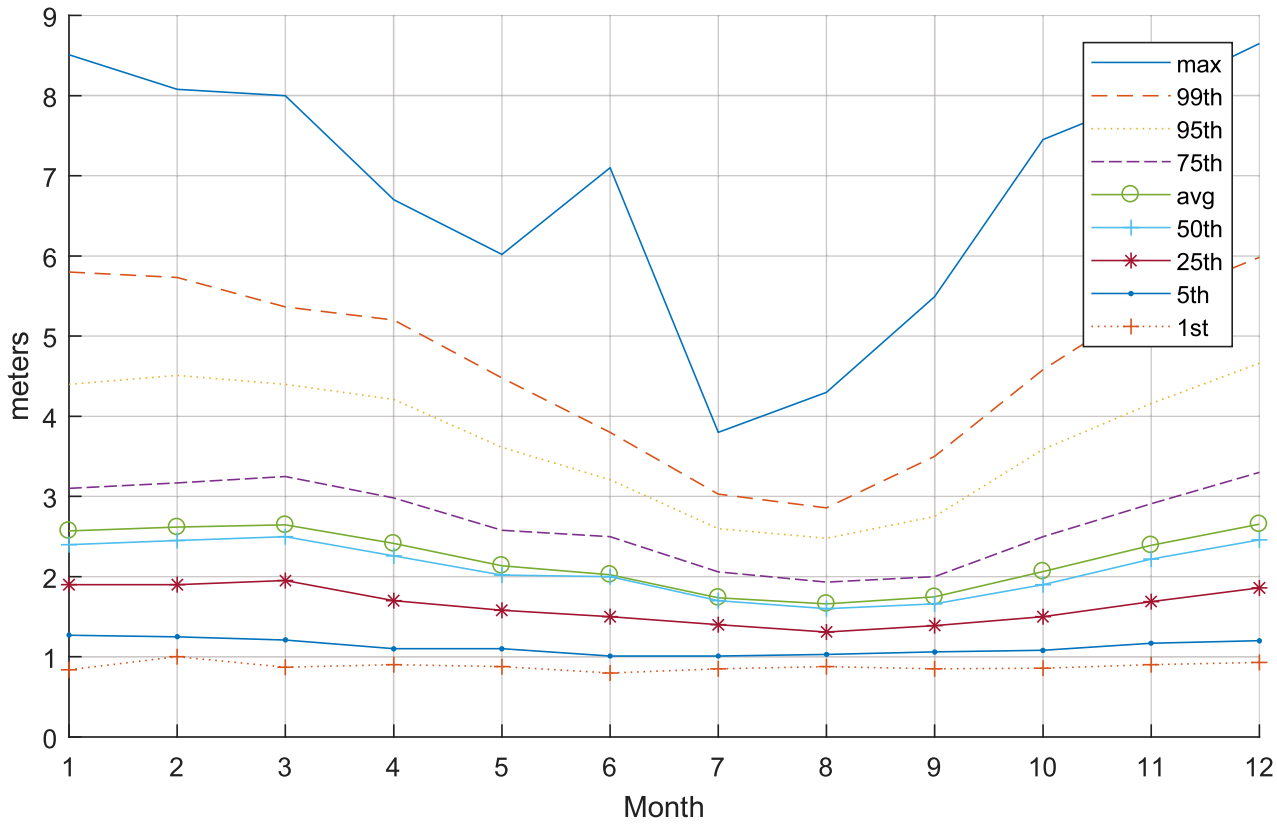


Figure D007.NDBC 46023 Monthly Wave Height Distribution

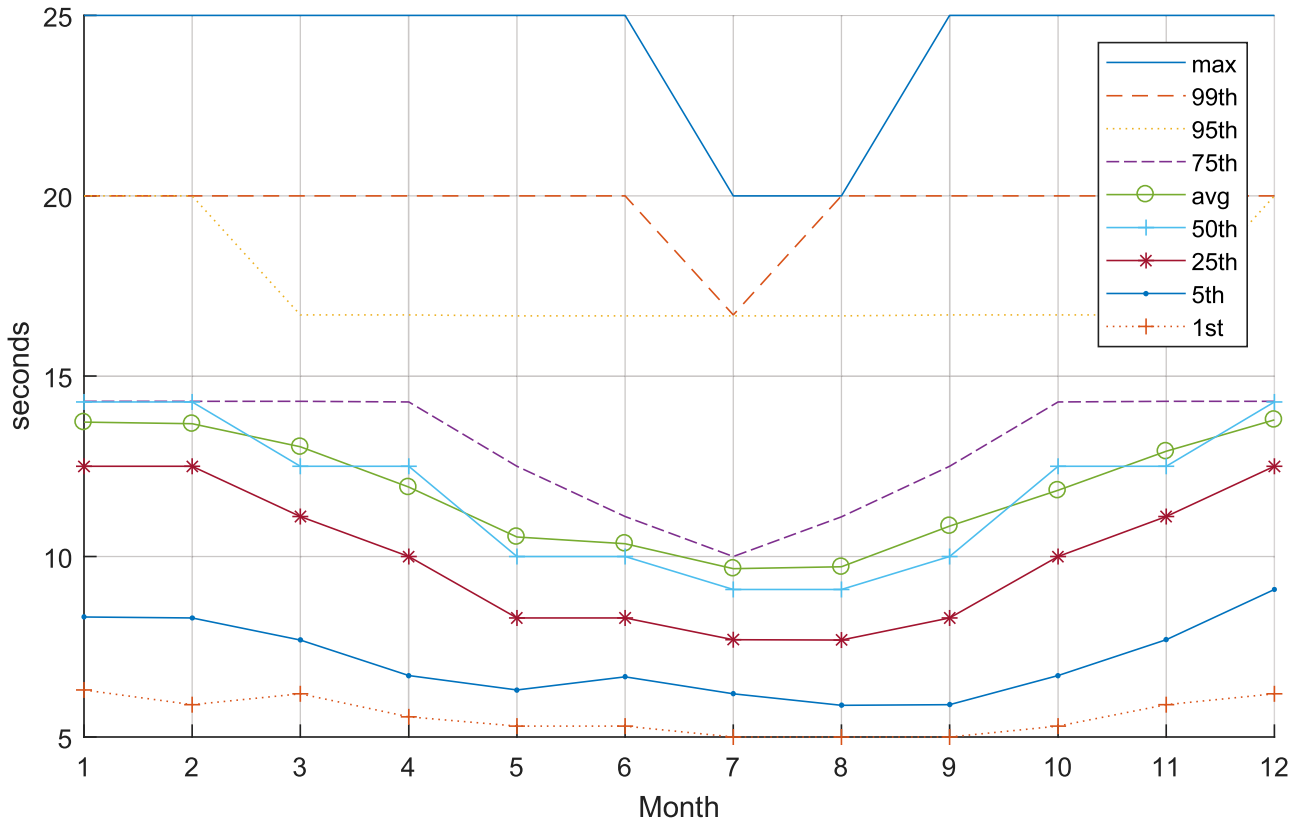


Figure D008.NDBC 46023 Monthly Wave Period Distribution

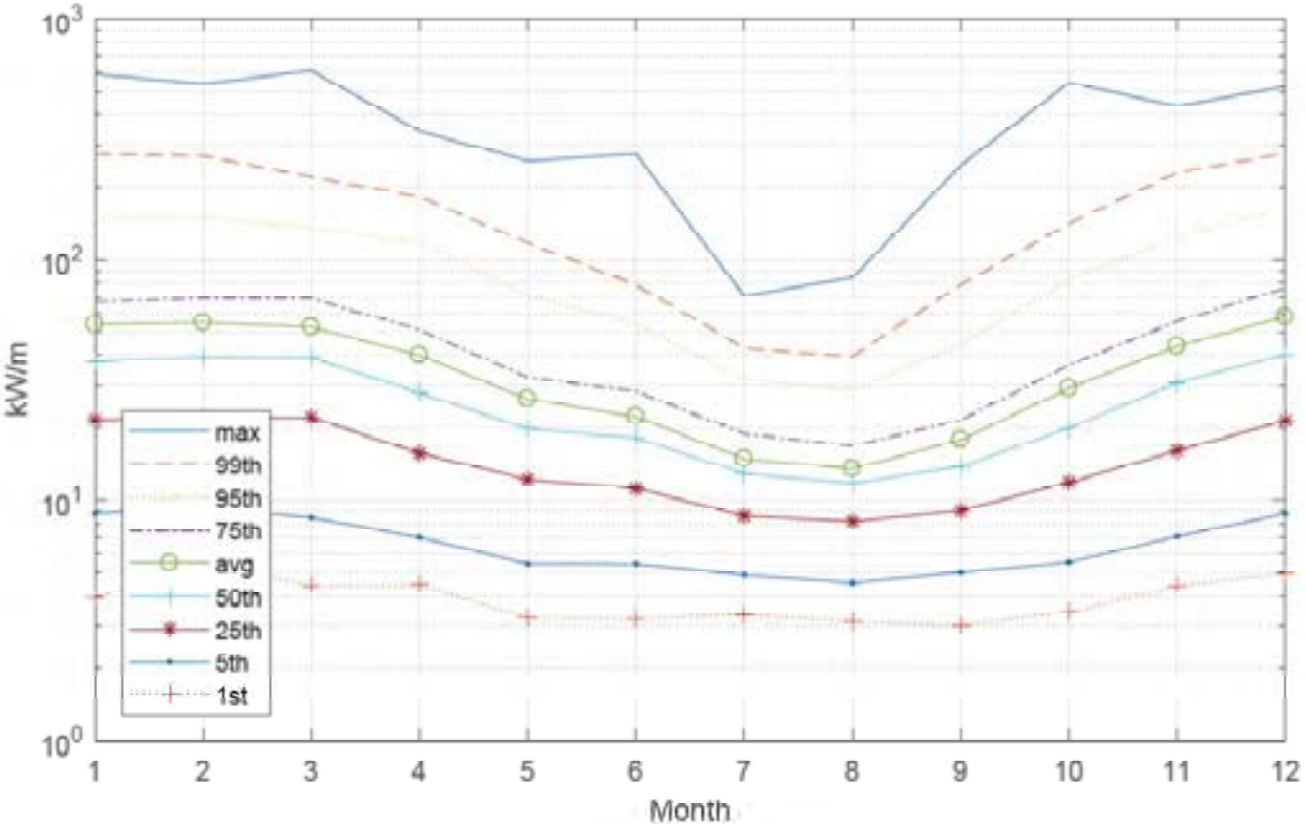


Figure D009.NDBC 46023 Monthly Wave Energy Distribution

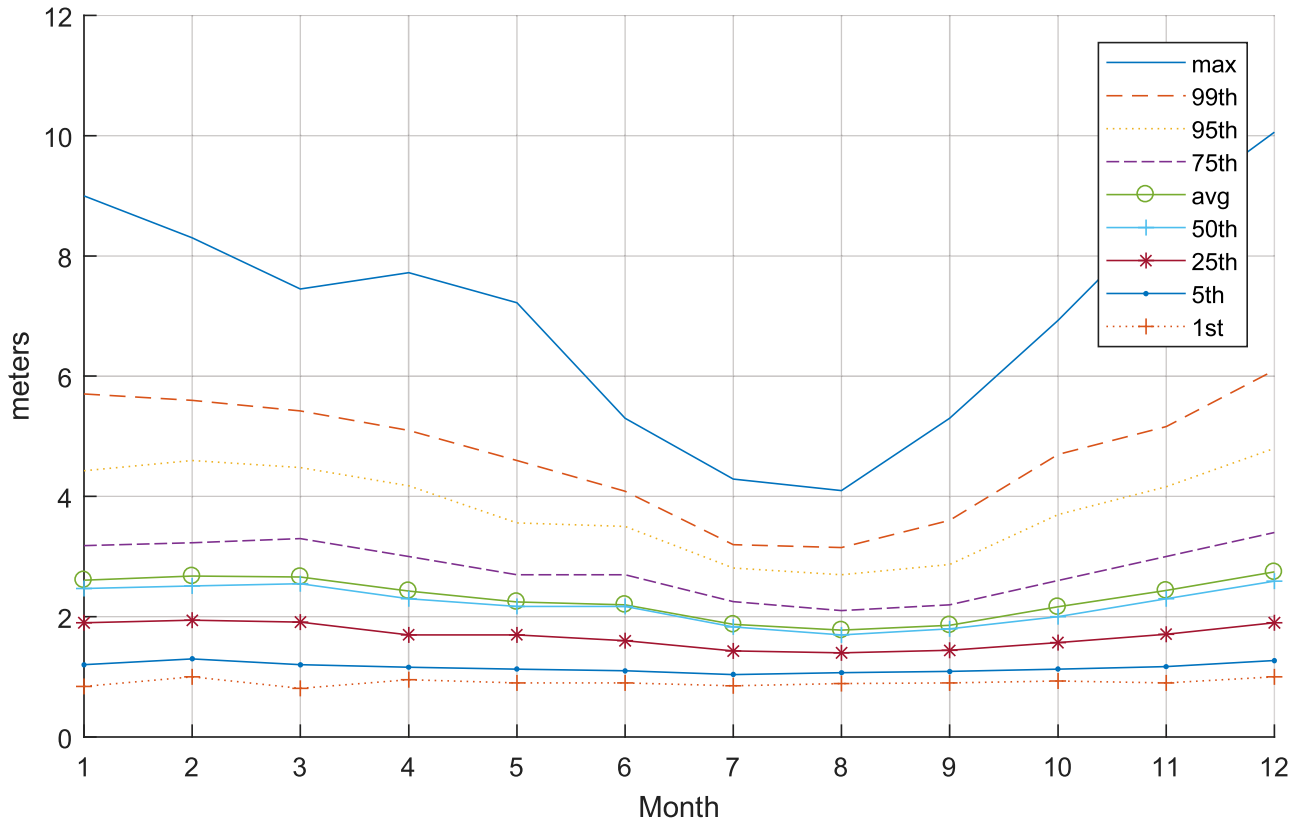


Figure D010.NDBC 46028 Monthly Wave Height Distribution

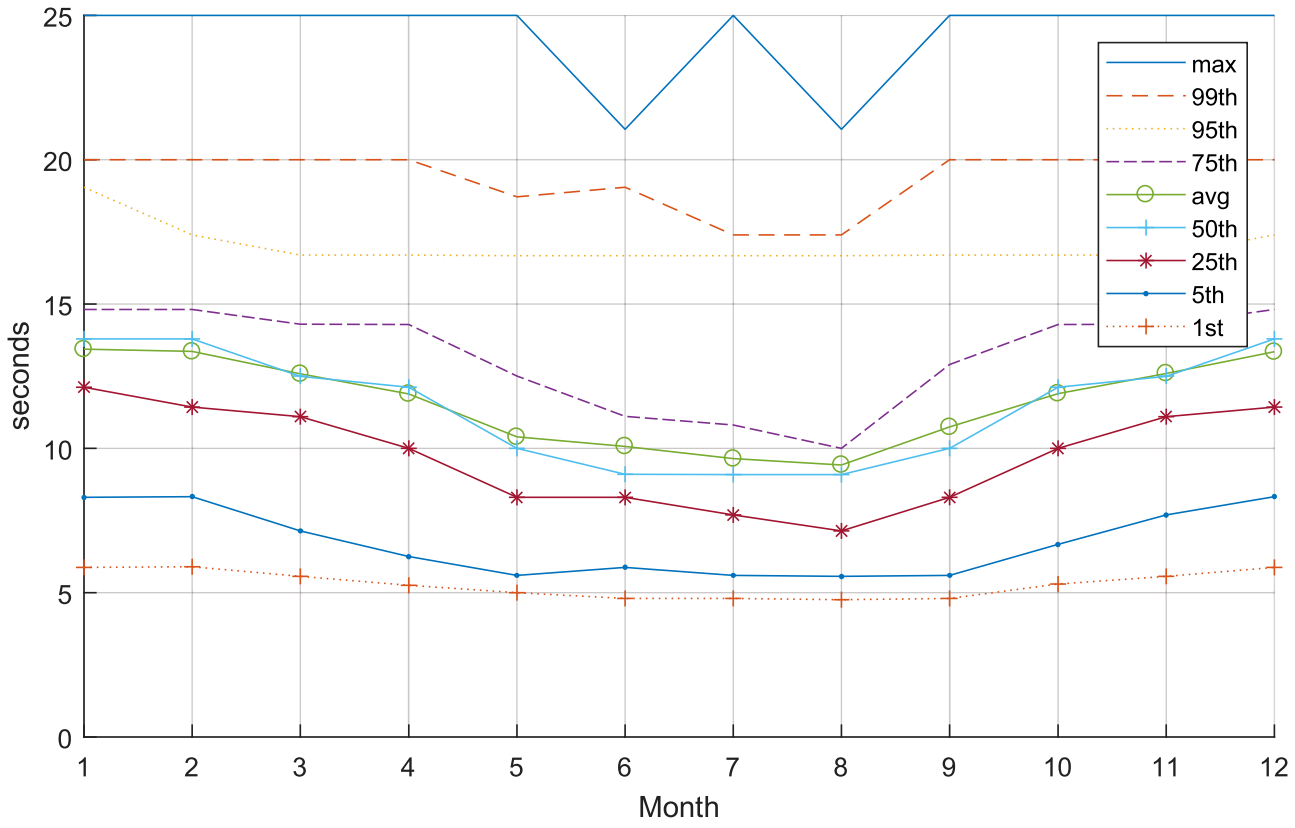


Figure D011.NDBC 46028 Monthly Wave Period Distribution

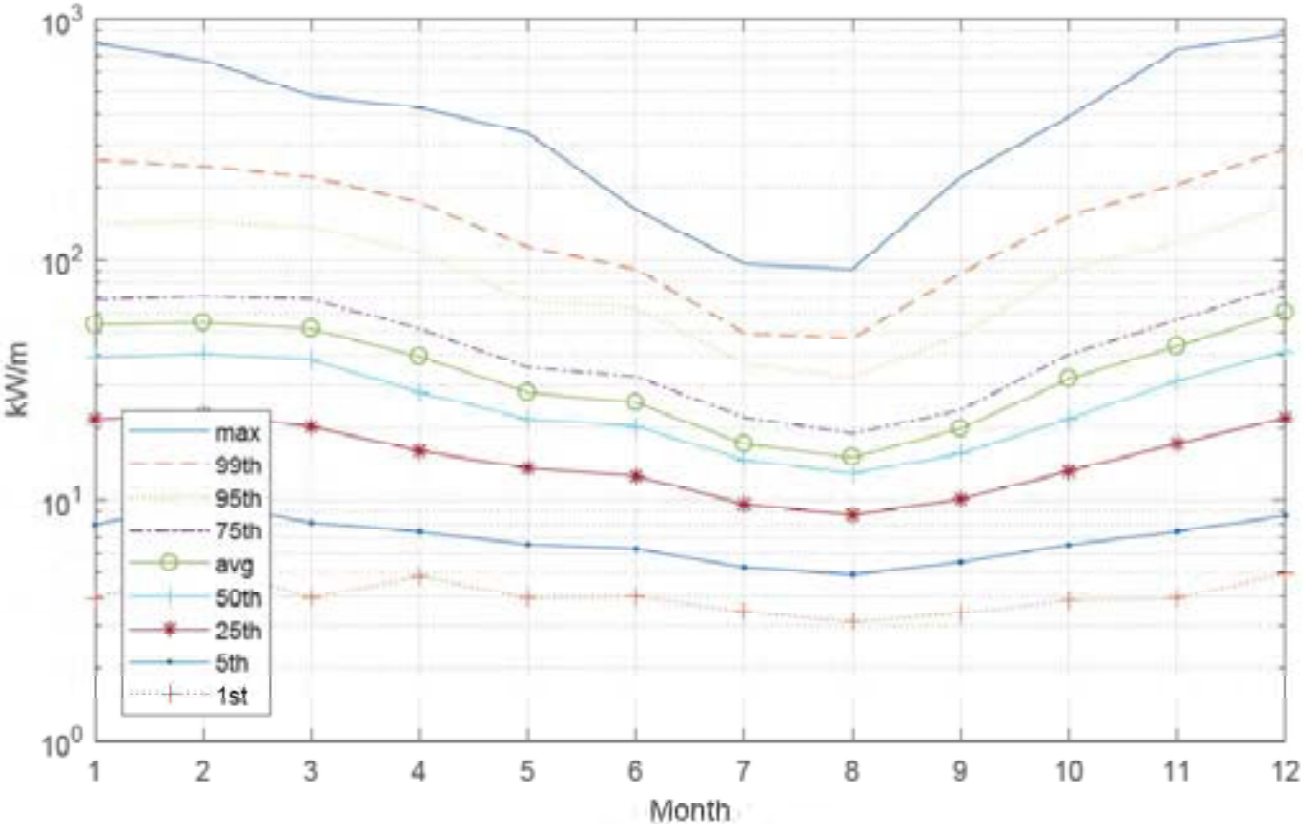


Figure D012.NDBC 46028 Monthly Wave Energy Distribution

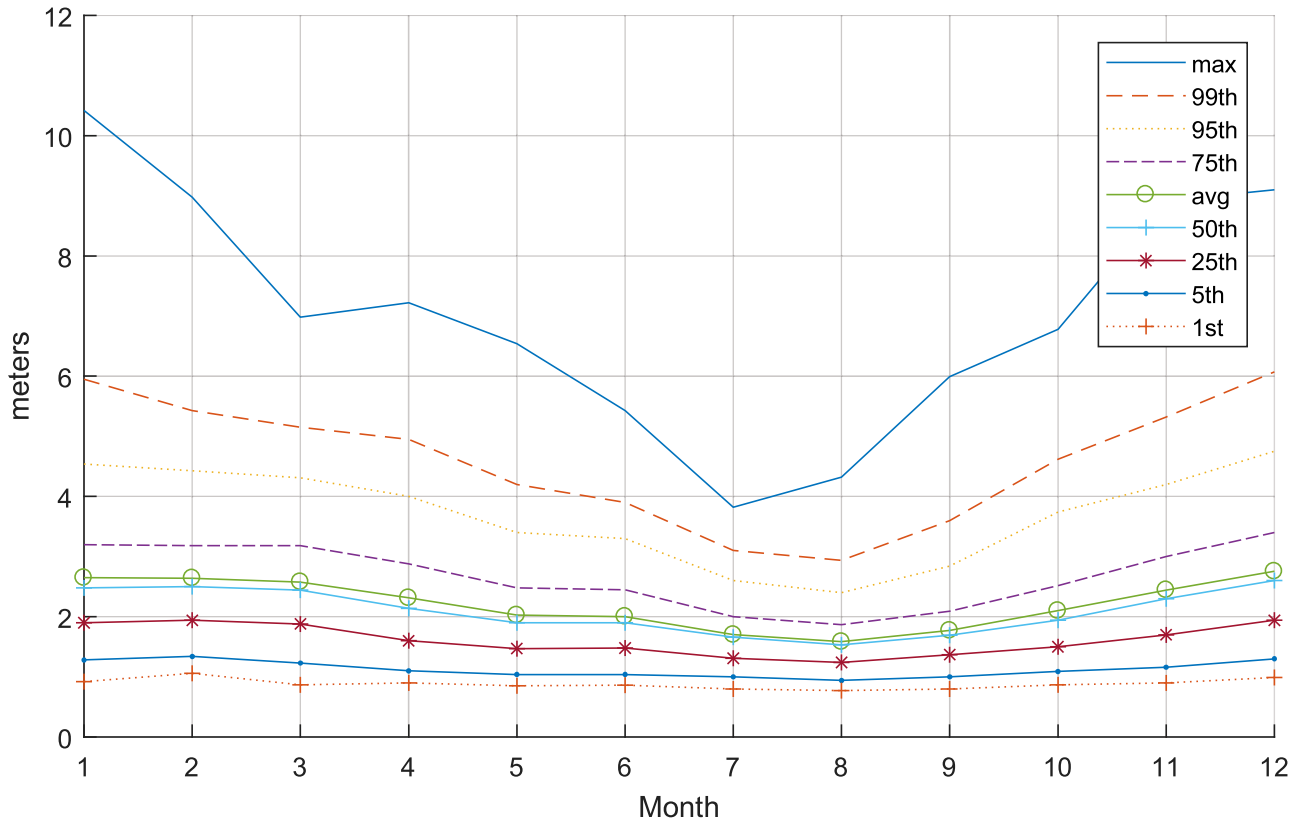


Figure D013.NDBC 46042 Monthly Wave Height Distribution

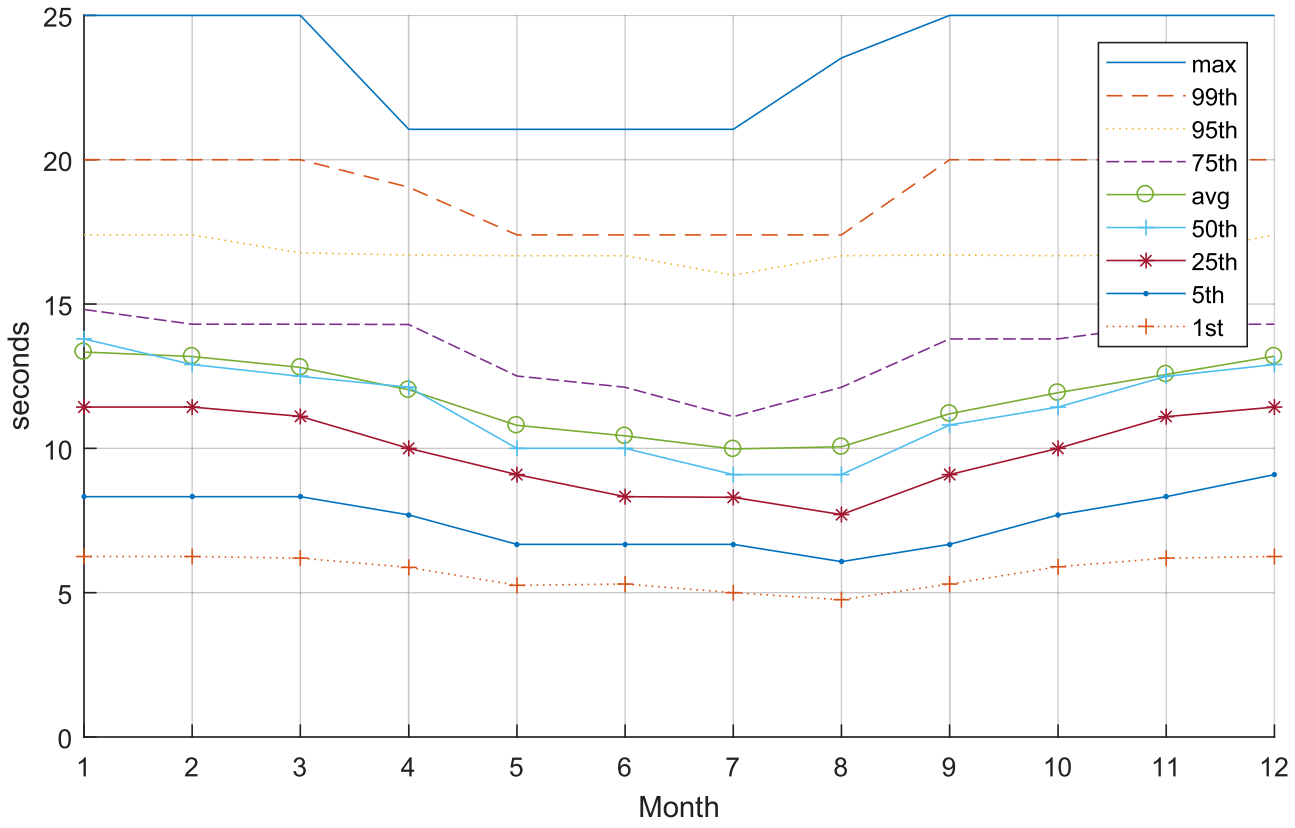


Figure D014.NDBC 46042 Monthly Wave Period Distribution

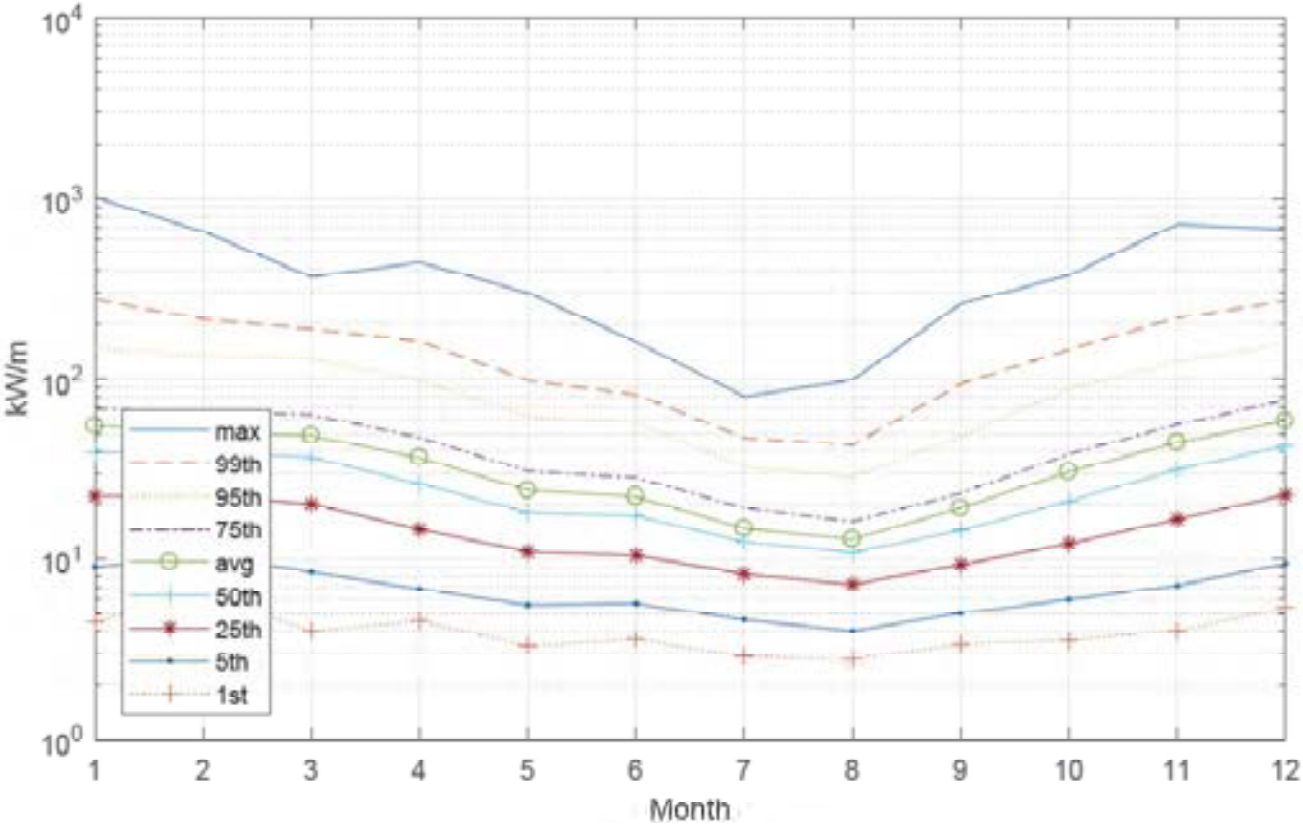


Figure D015.NDBC 46042 Monthly Wave Energy Distribution

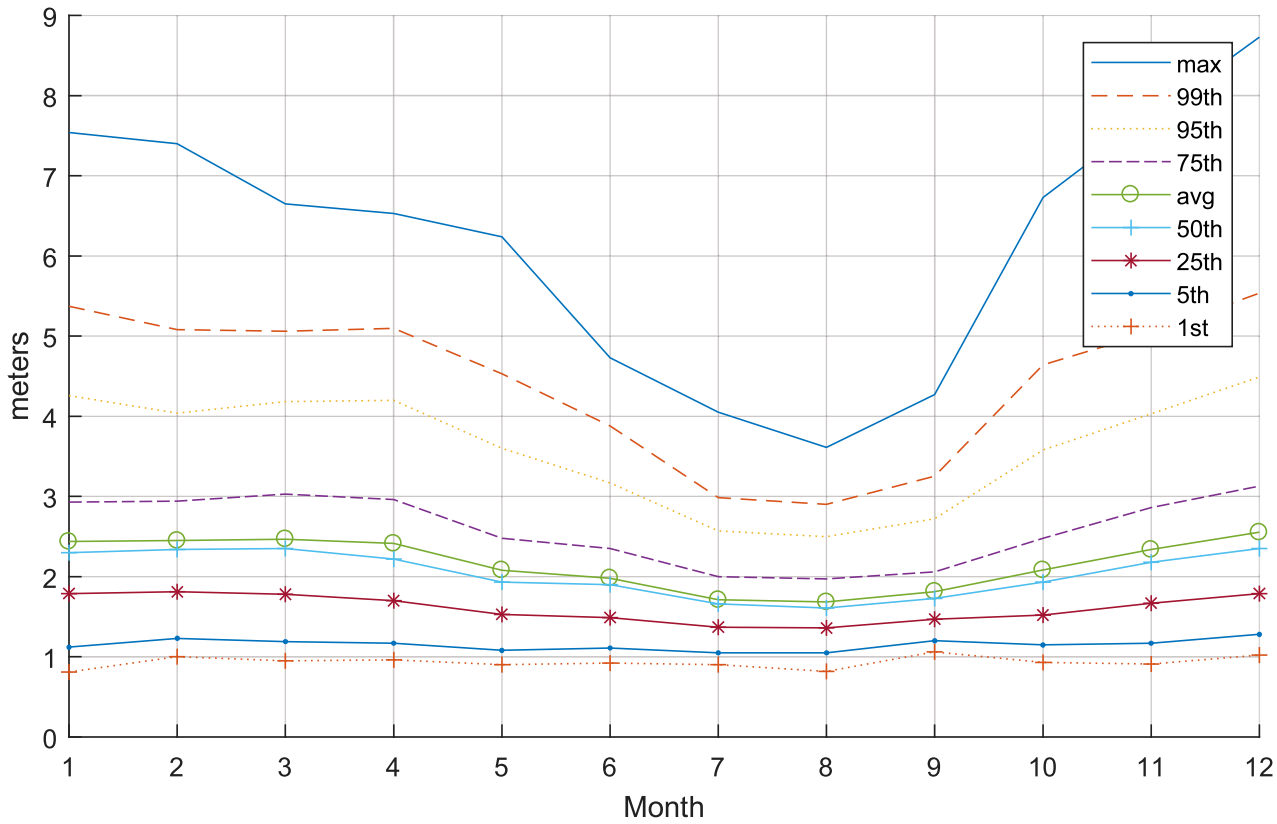


Figure D016.NDBC 46047 Monthly Wave Height Distribution

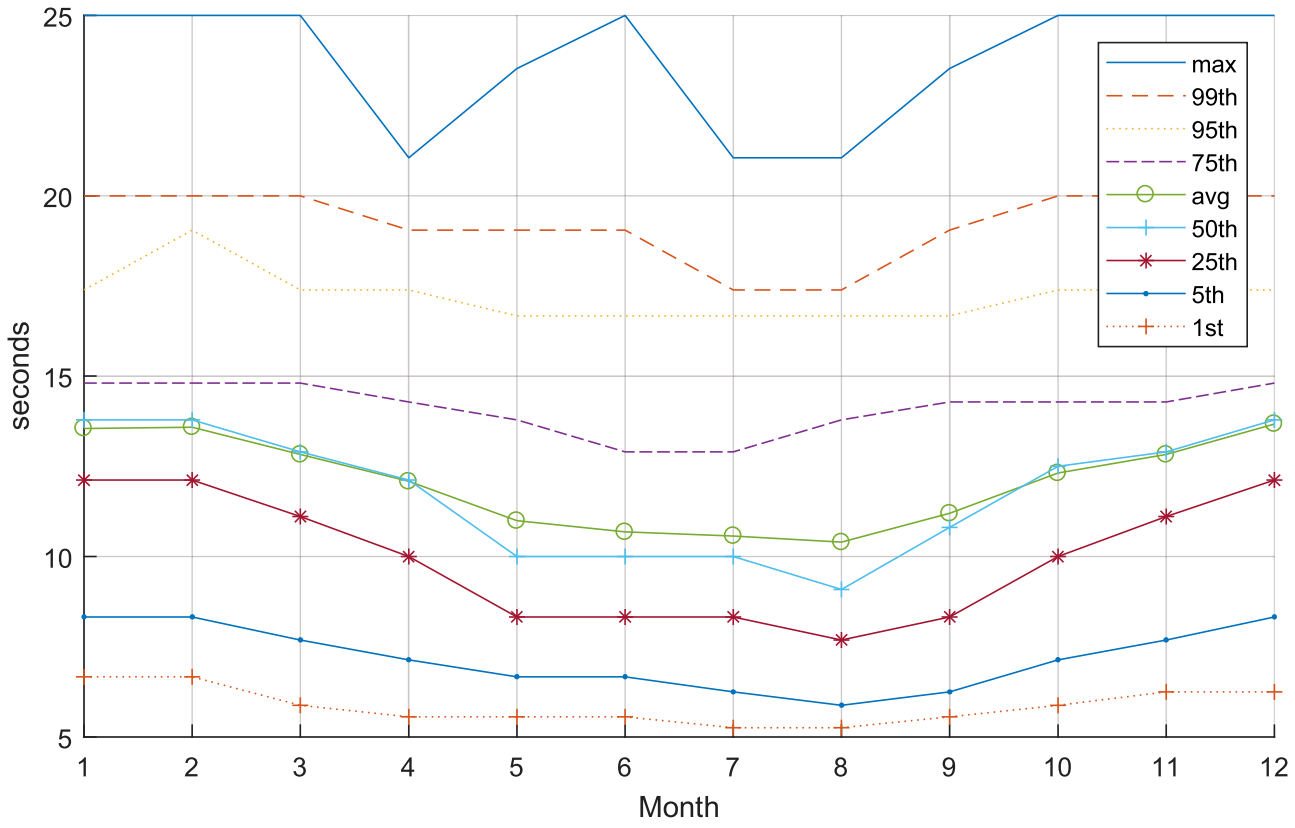


Figure D017.NDBC 46047 Monthly Wave Period Distribution

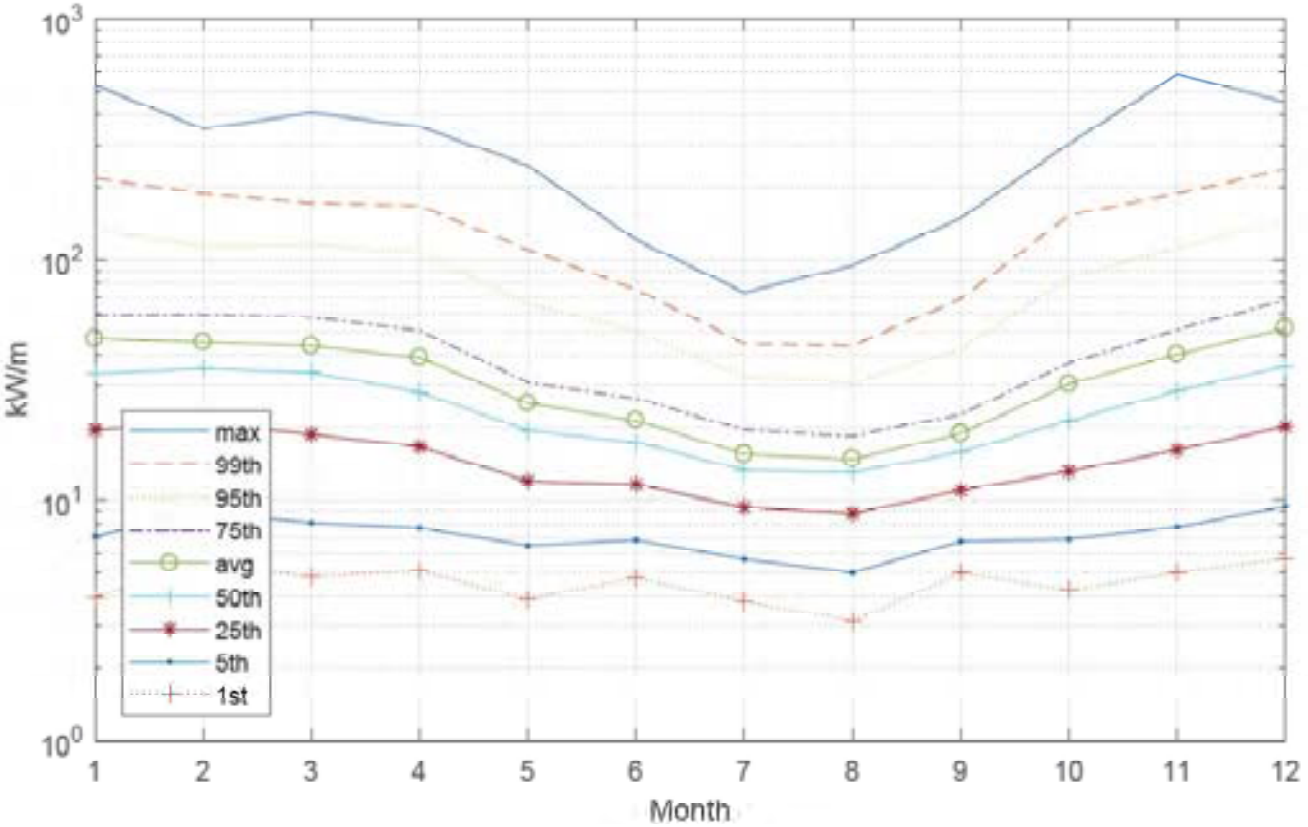


Figure D018.NDBC 46047 Monthly Wave Energy Distribution

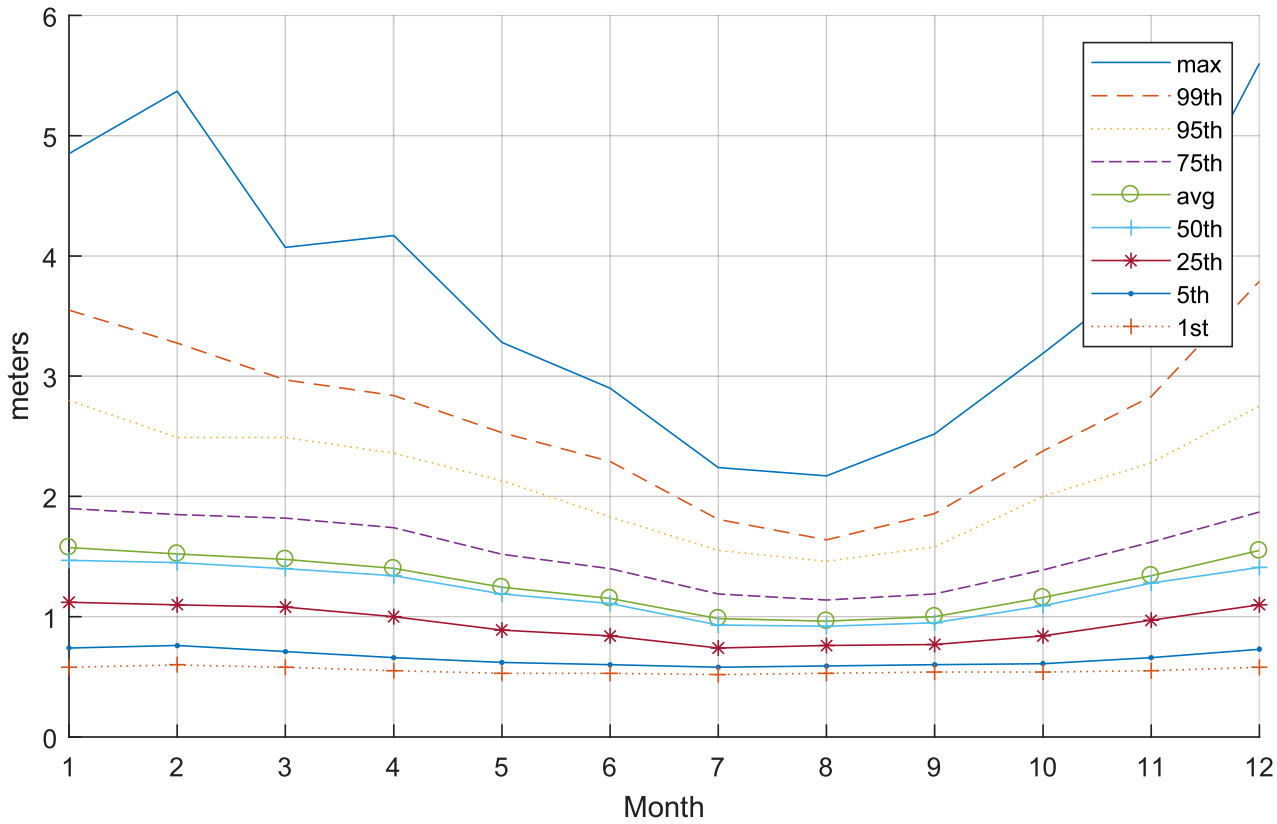


Figure D019.NDBC 46053 Monthly Wave Height Distribution

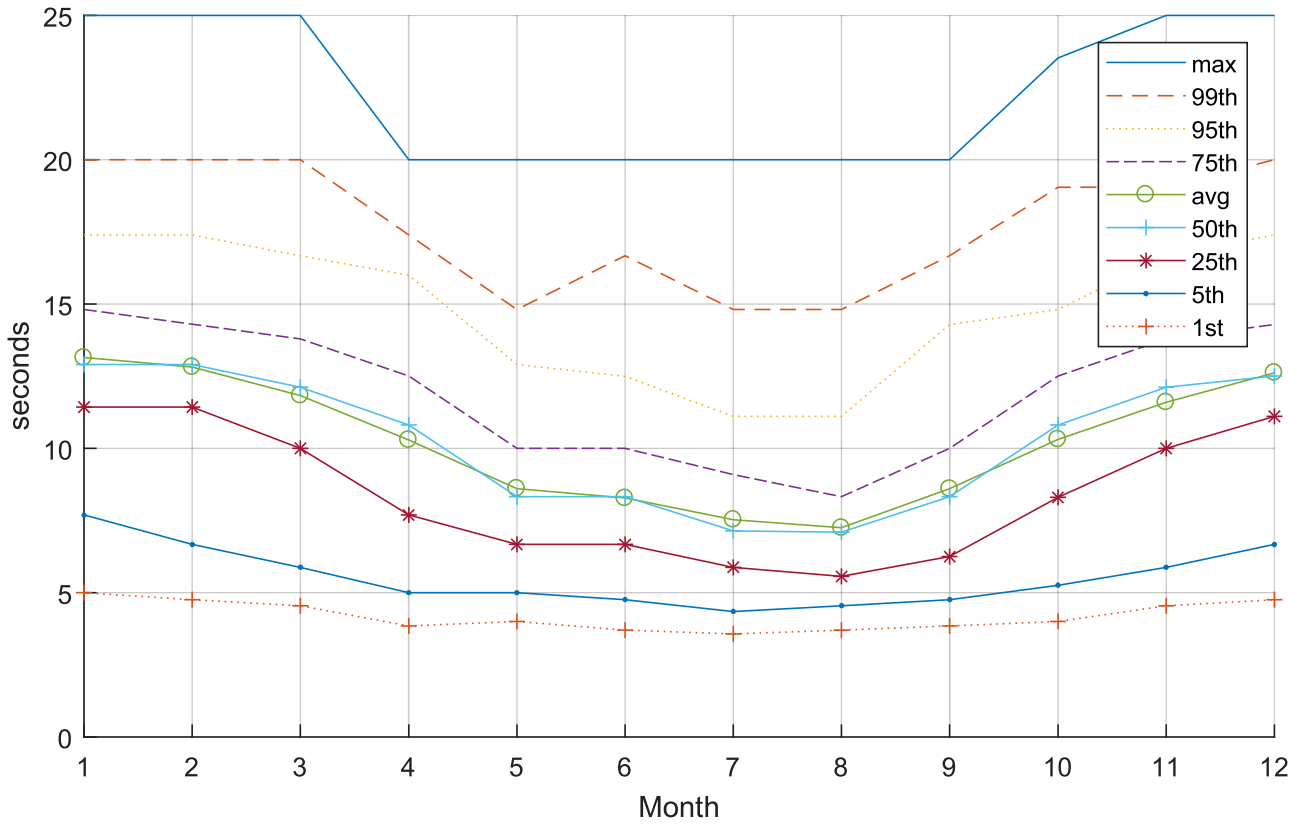


Figure D020.NDBC 46053 Monthly Wave Period Distribution

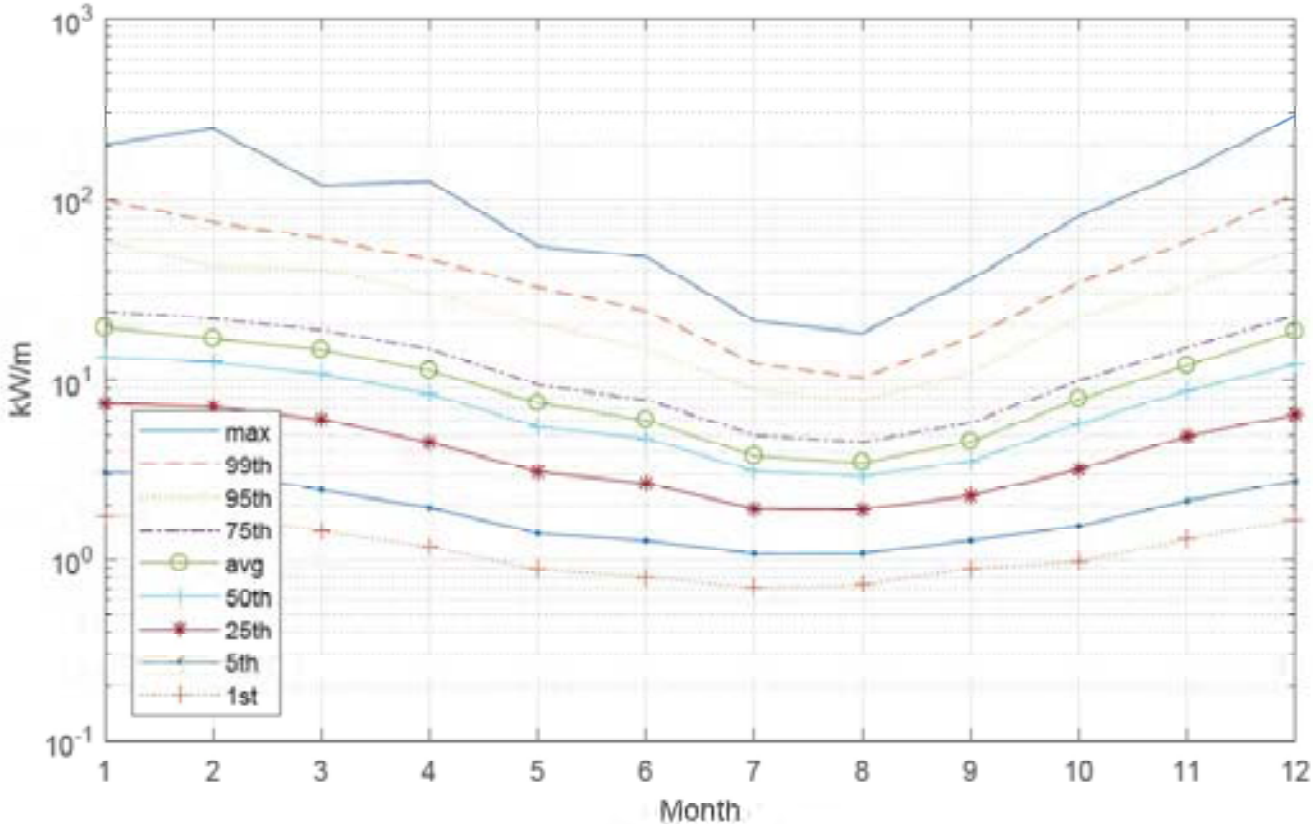


Figure D021.NDBC 46053 Monthly Wave Energy Distribution

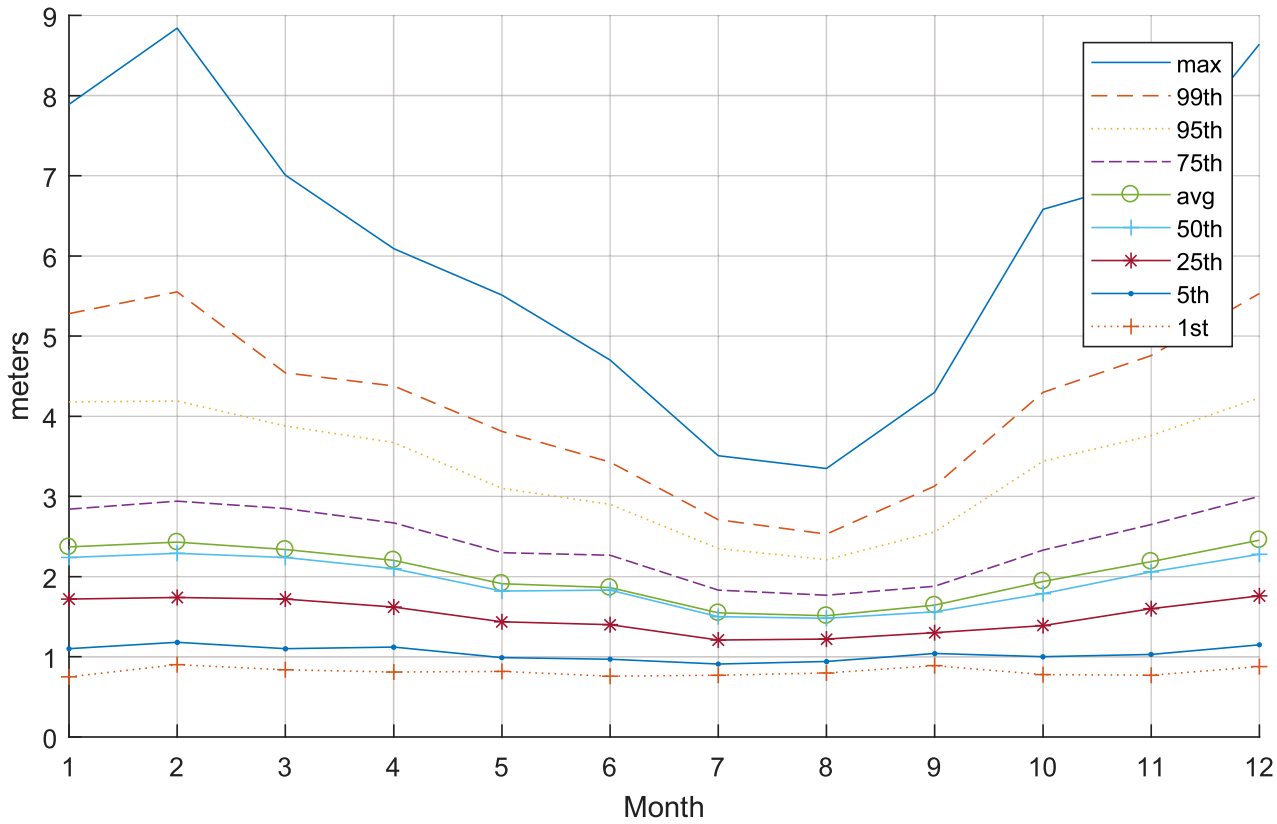


Figure D022.NDBC 46054 Monthly Wave Height Distribution

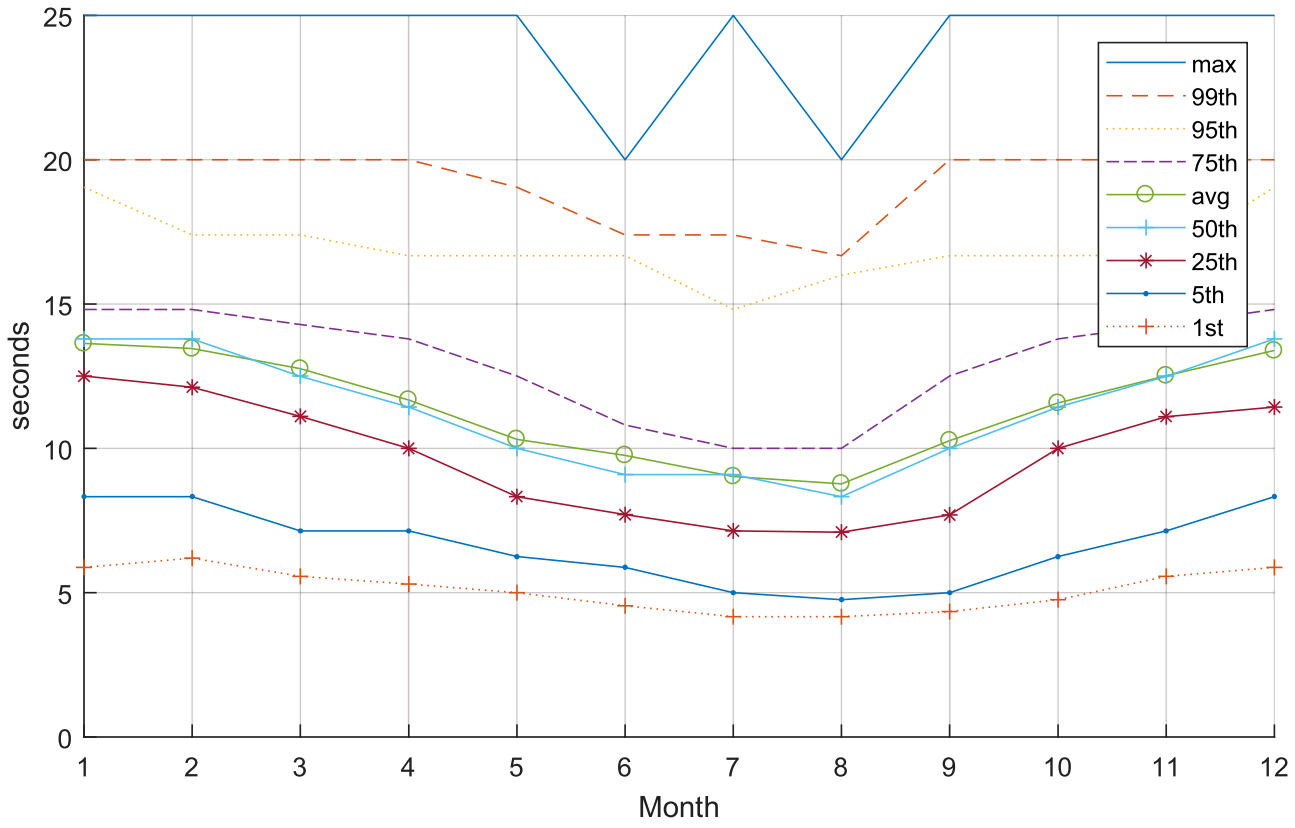


Figure D023.NDBC 46054 Monthly Wave Period Distribution

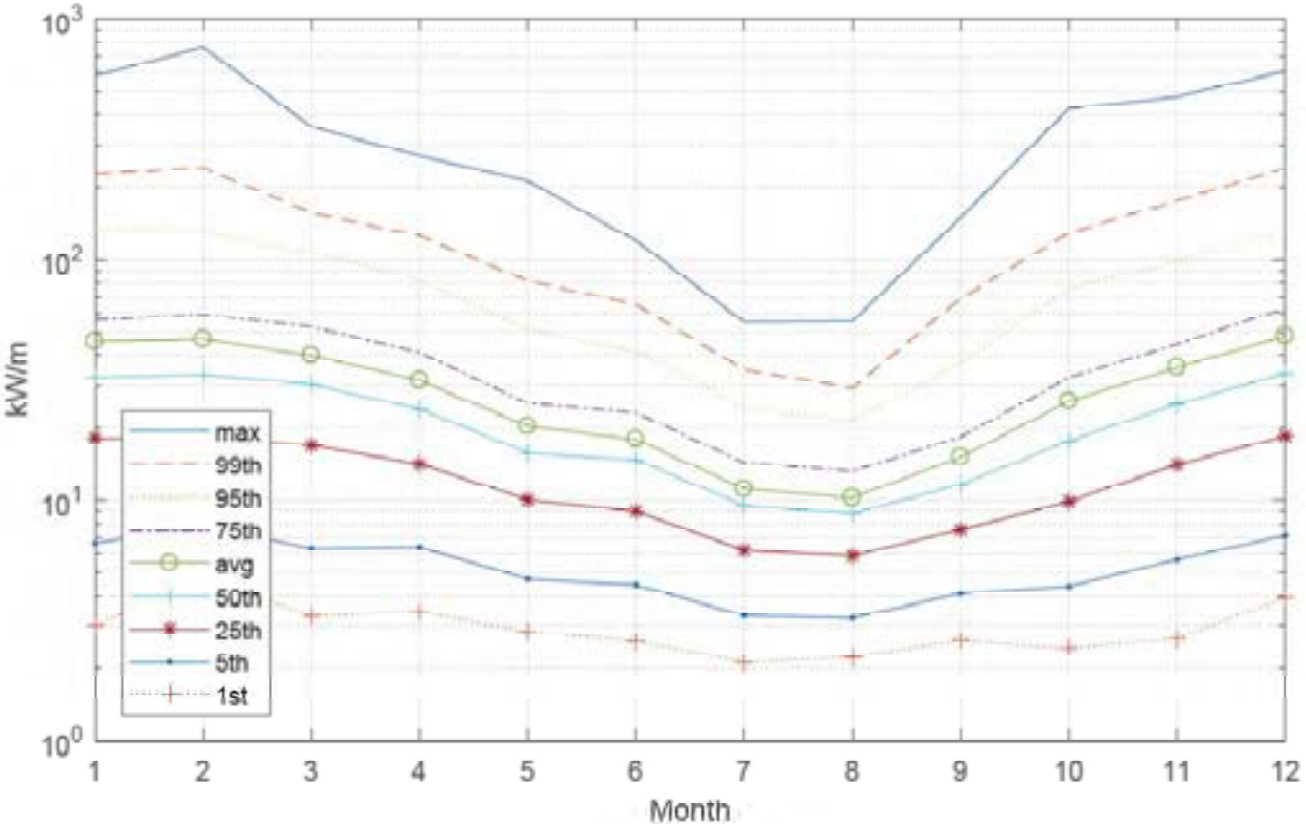


Figure D024.NDBC 46054 Monthly Wave Energy Distribution

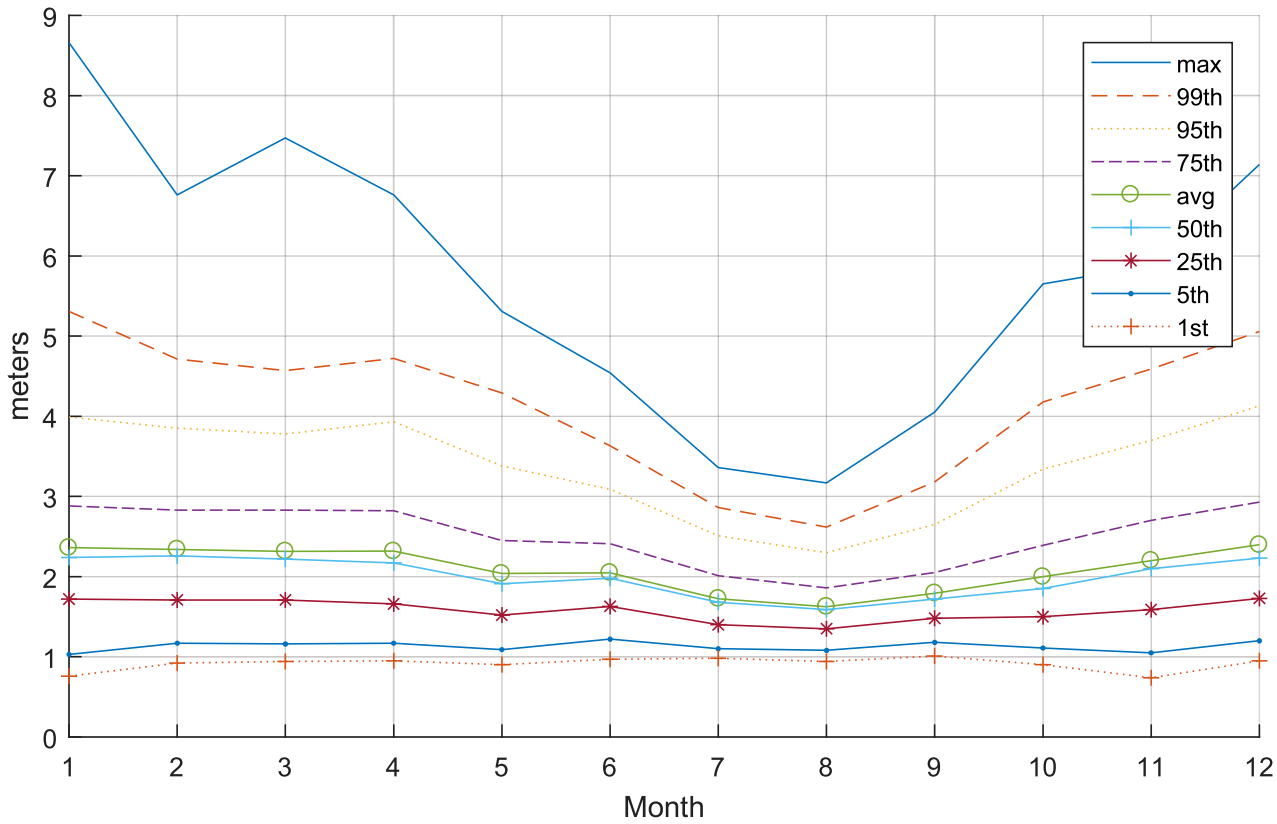


Figure D025.NDBC 46069 Monthly Wave Height Distribution

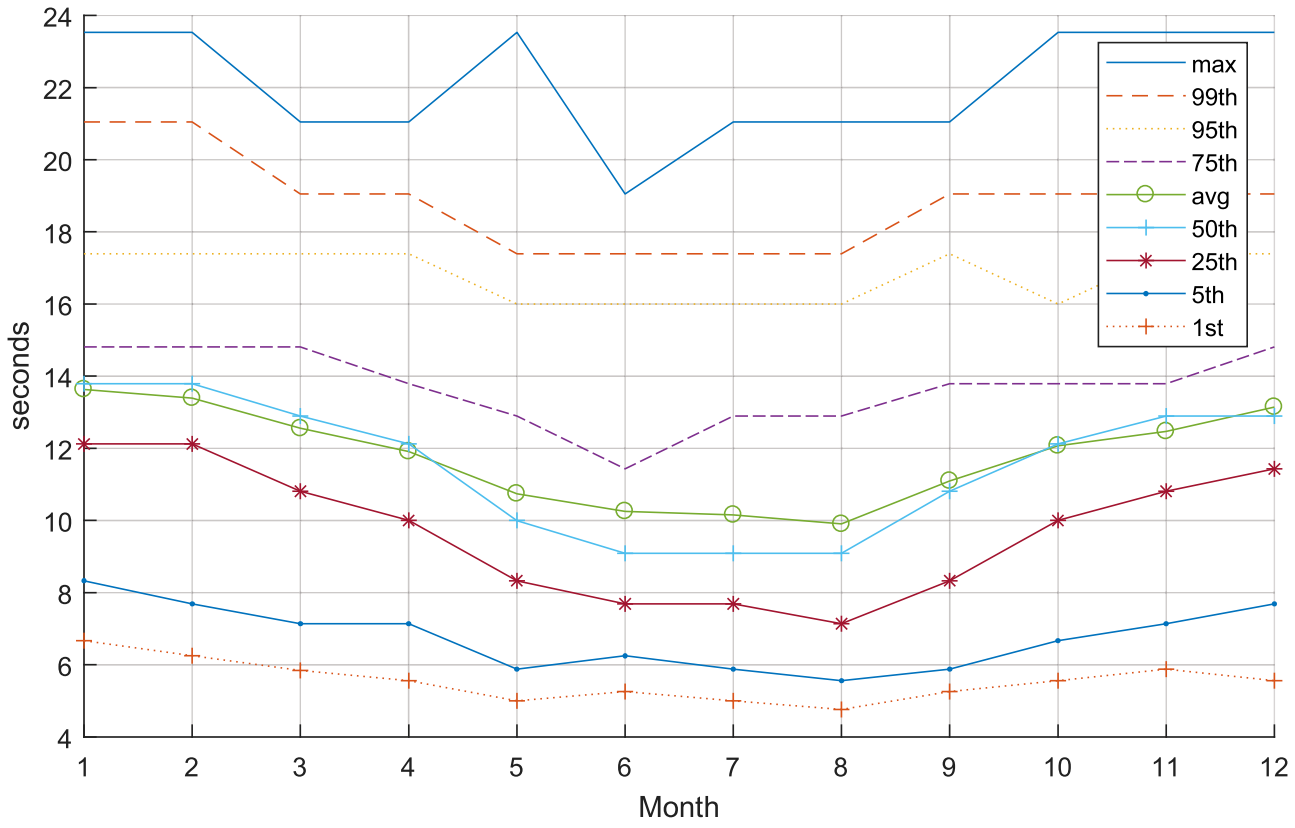


Figure D026.NDBC 46069 Monthly Wave Period Distribution

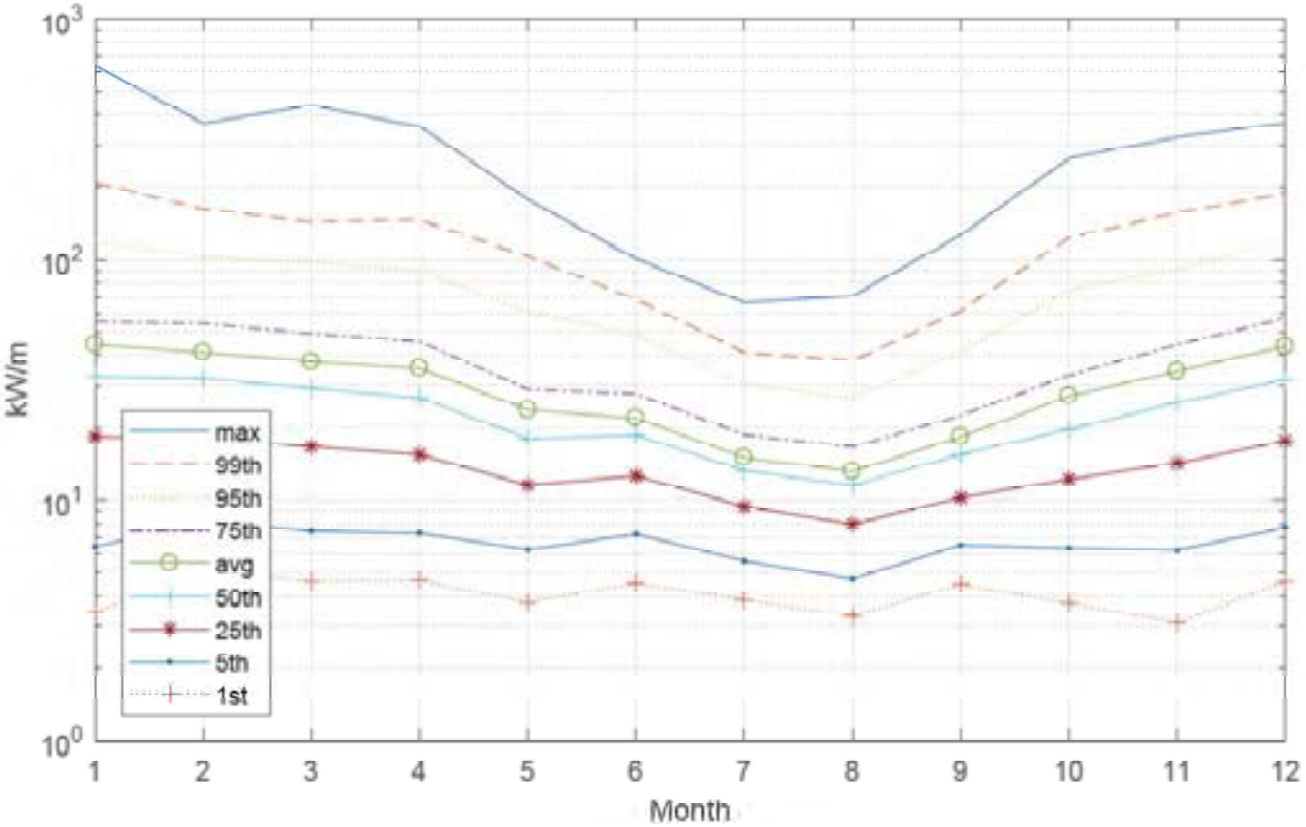


Figure D027.NDBC 46069 Monthly Wave Energy Distribution

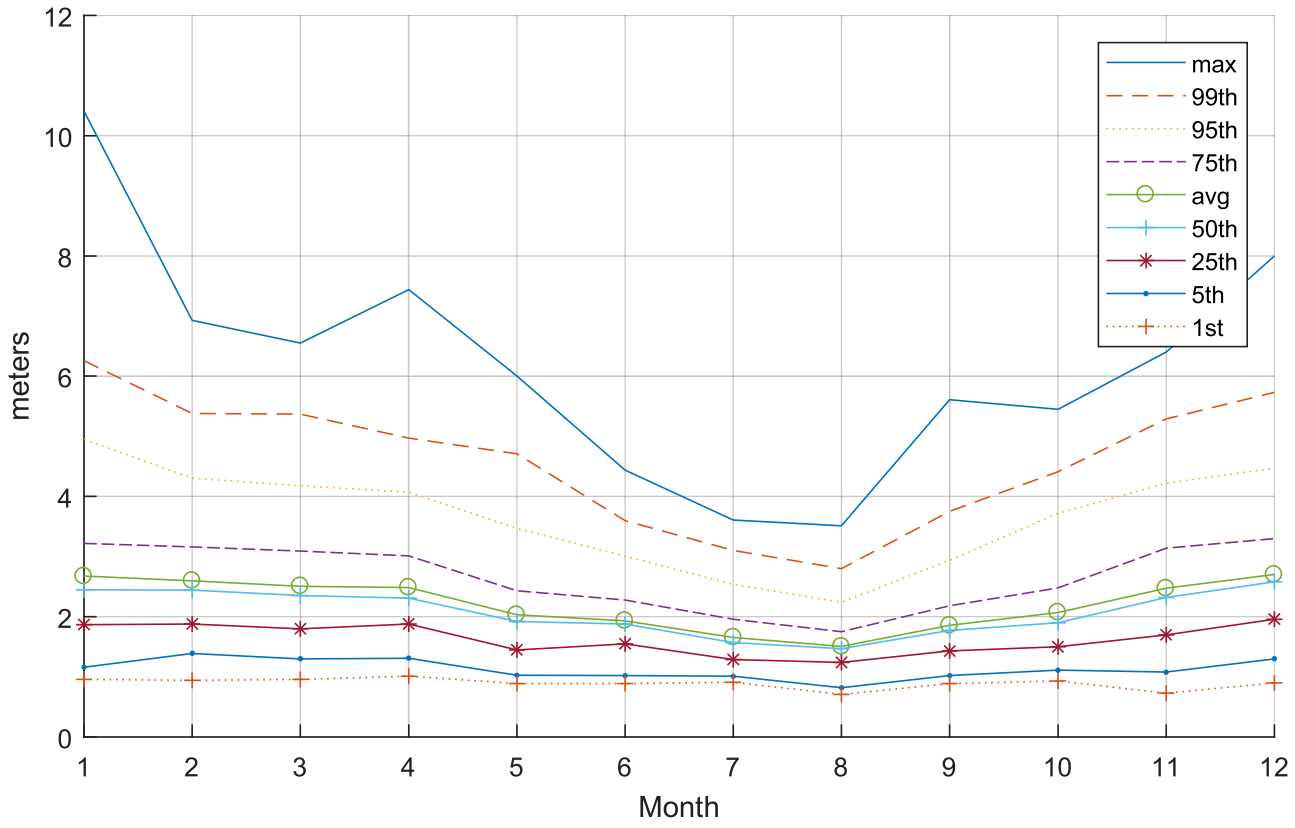


Figure D028.NDBC 46114 Monthly Wave Height Distribution

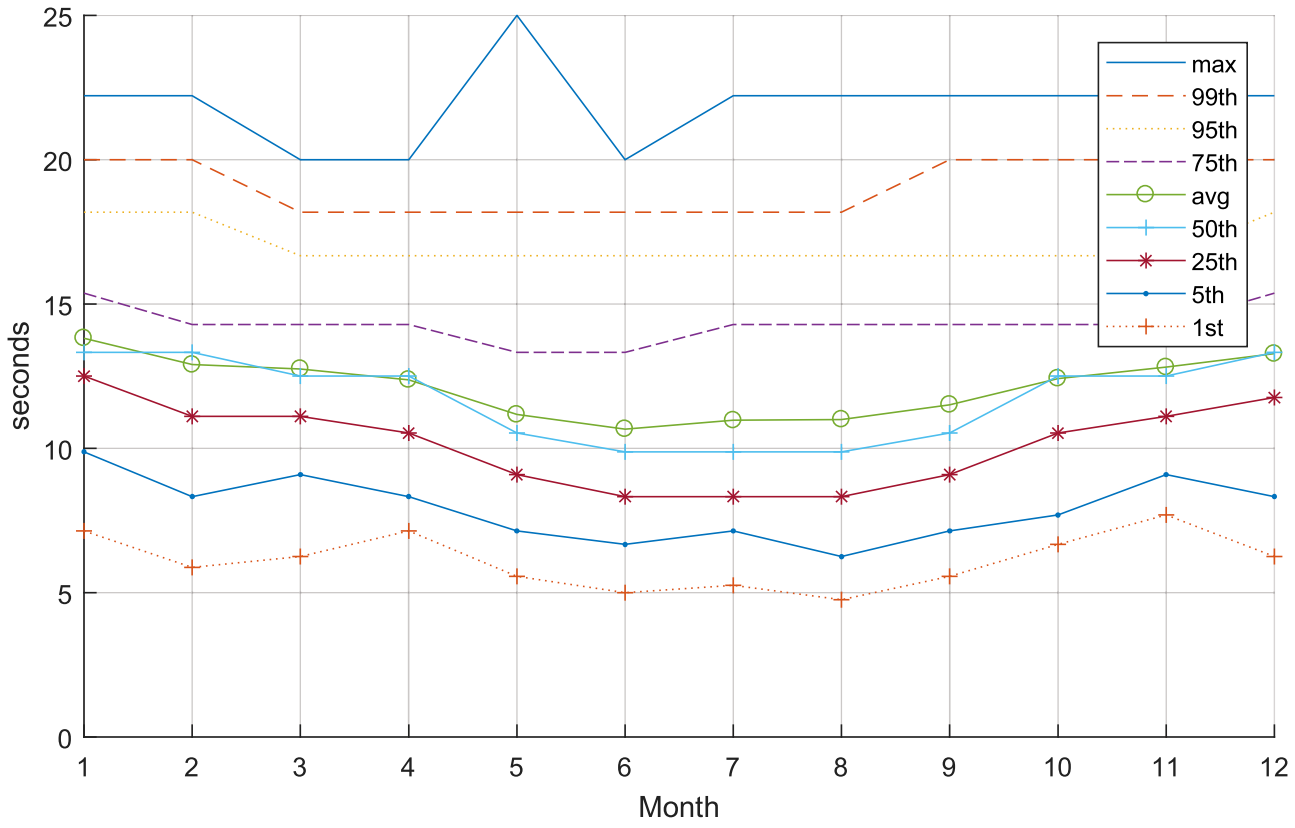


Figure D029.NDBC 46114 Monthly Wave Period Distribution

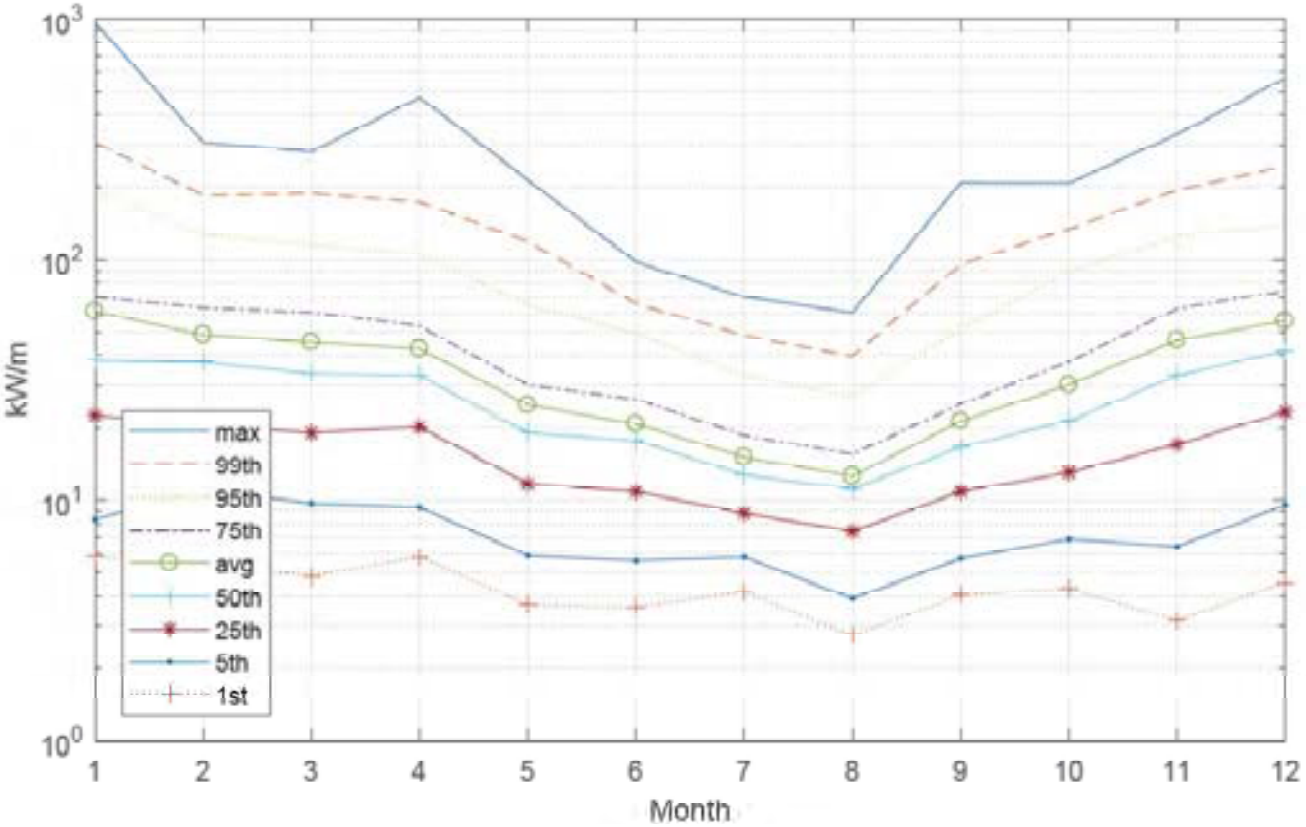


Figure D030.NDBC 46114 Monthly Wave Energy Distribution

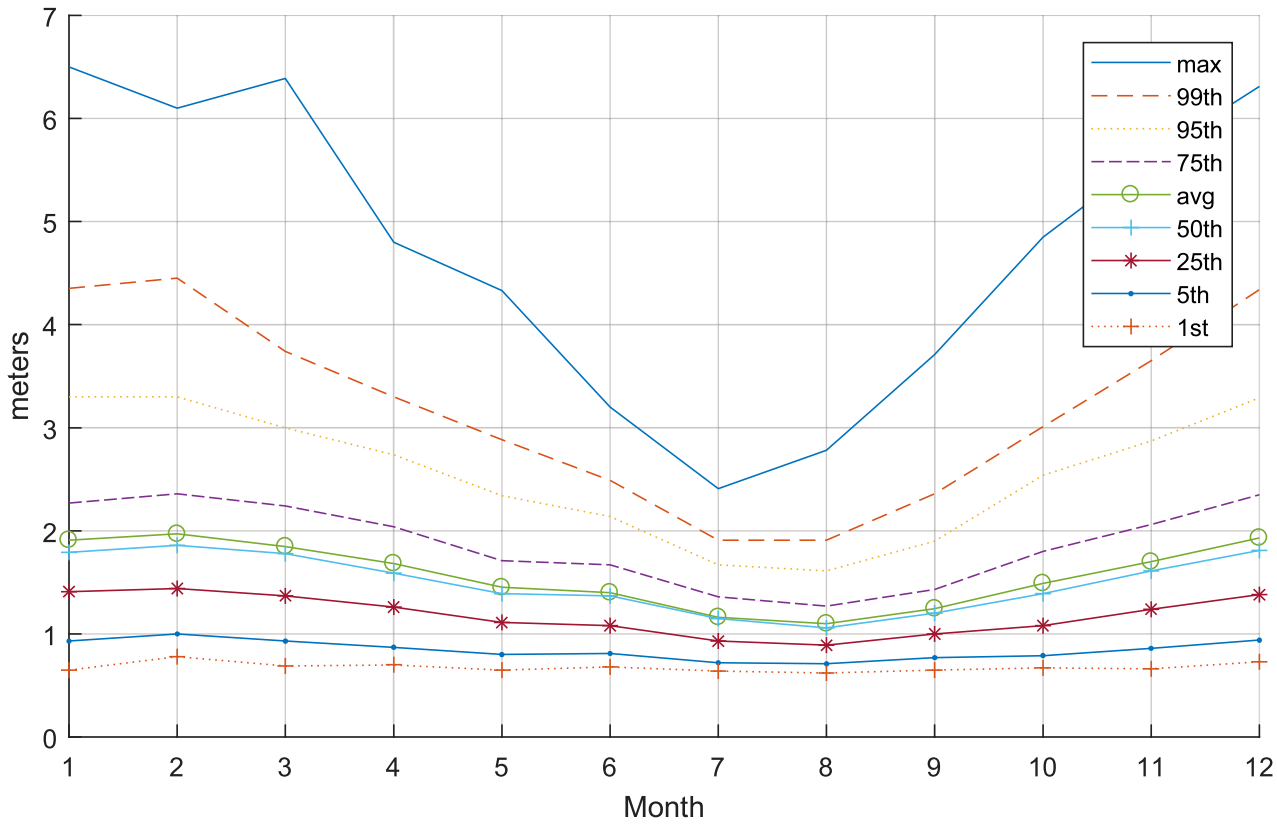


Figure D031.NDBC 46215 Monthly Wave Height Distribution

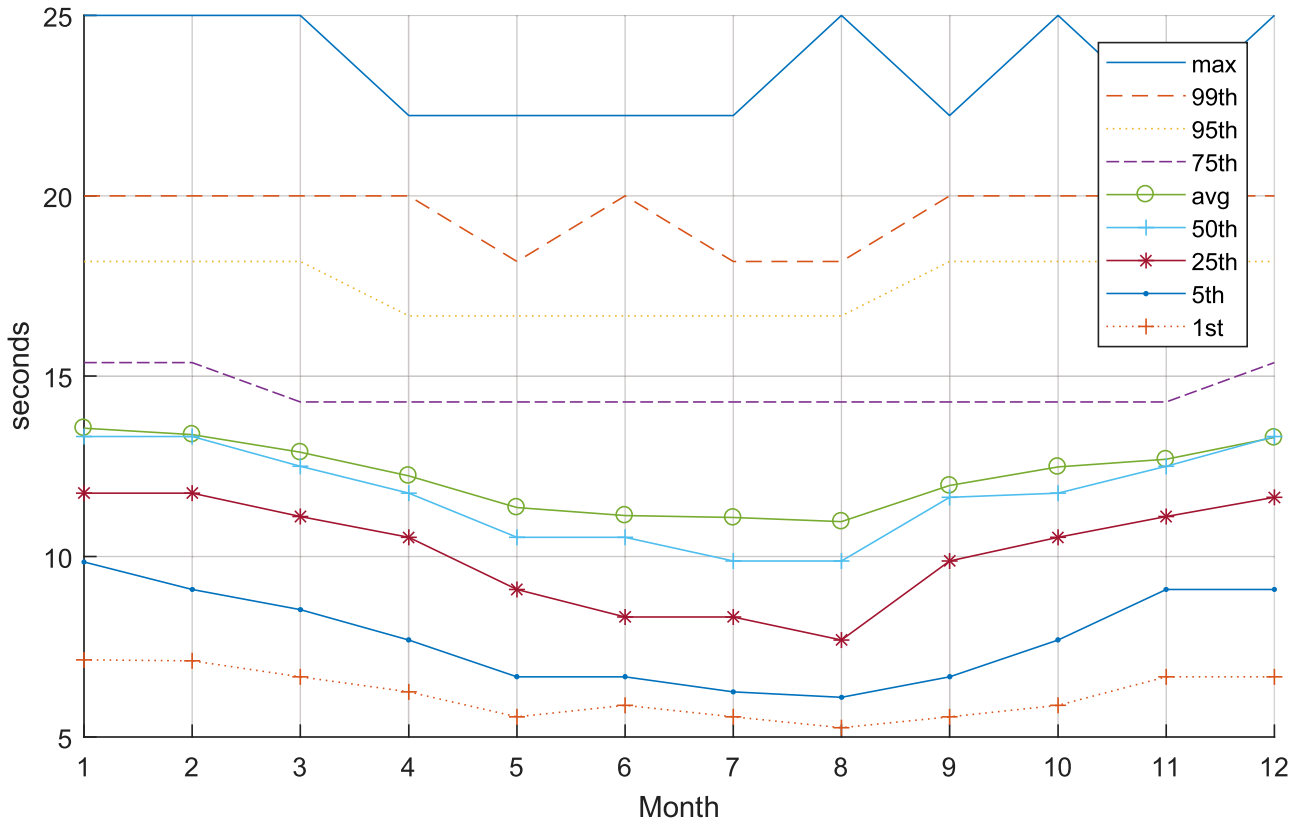


Figure D032.NDBC 46215 Monthly Wave Period Distribution

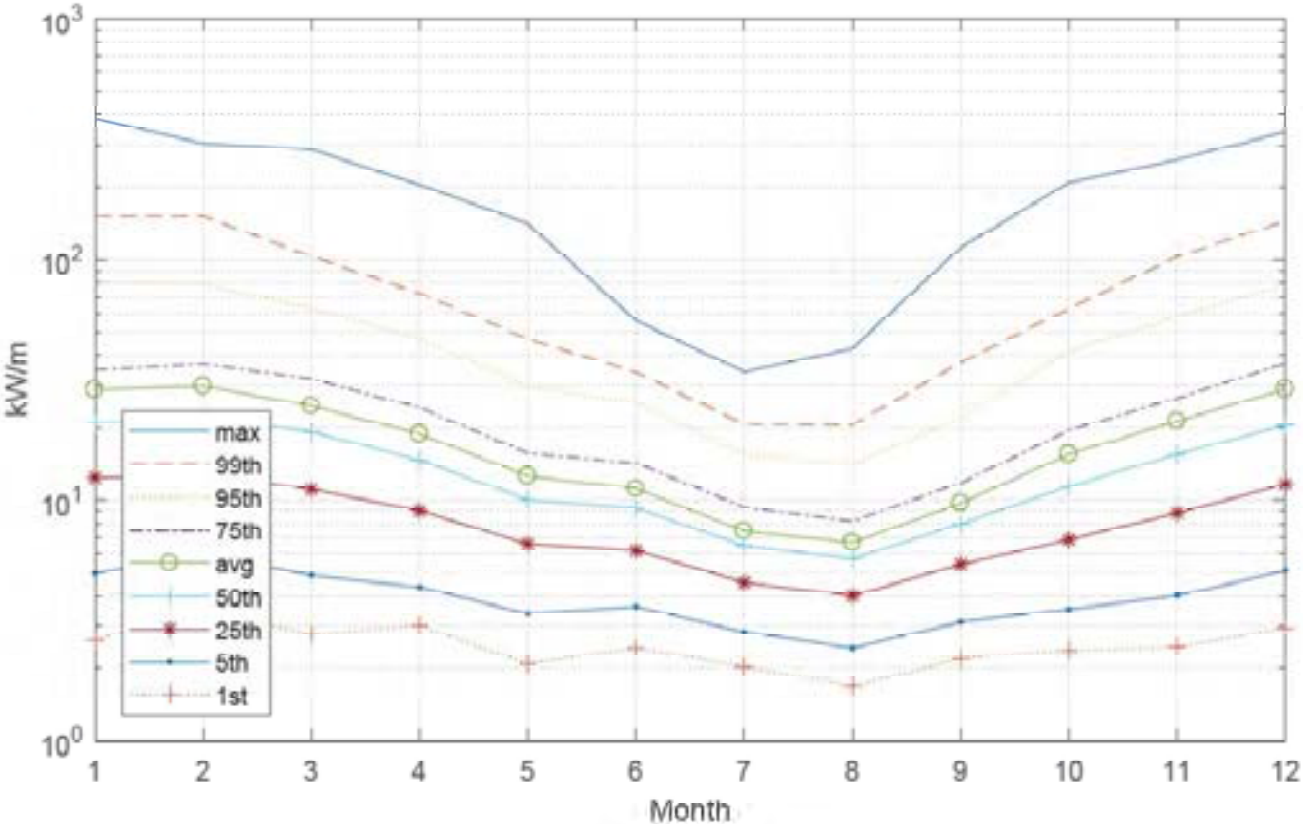


Figure D033.NDBC 46215 Monthly Wave Energy Distribution

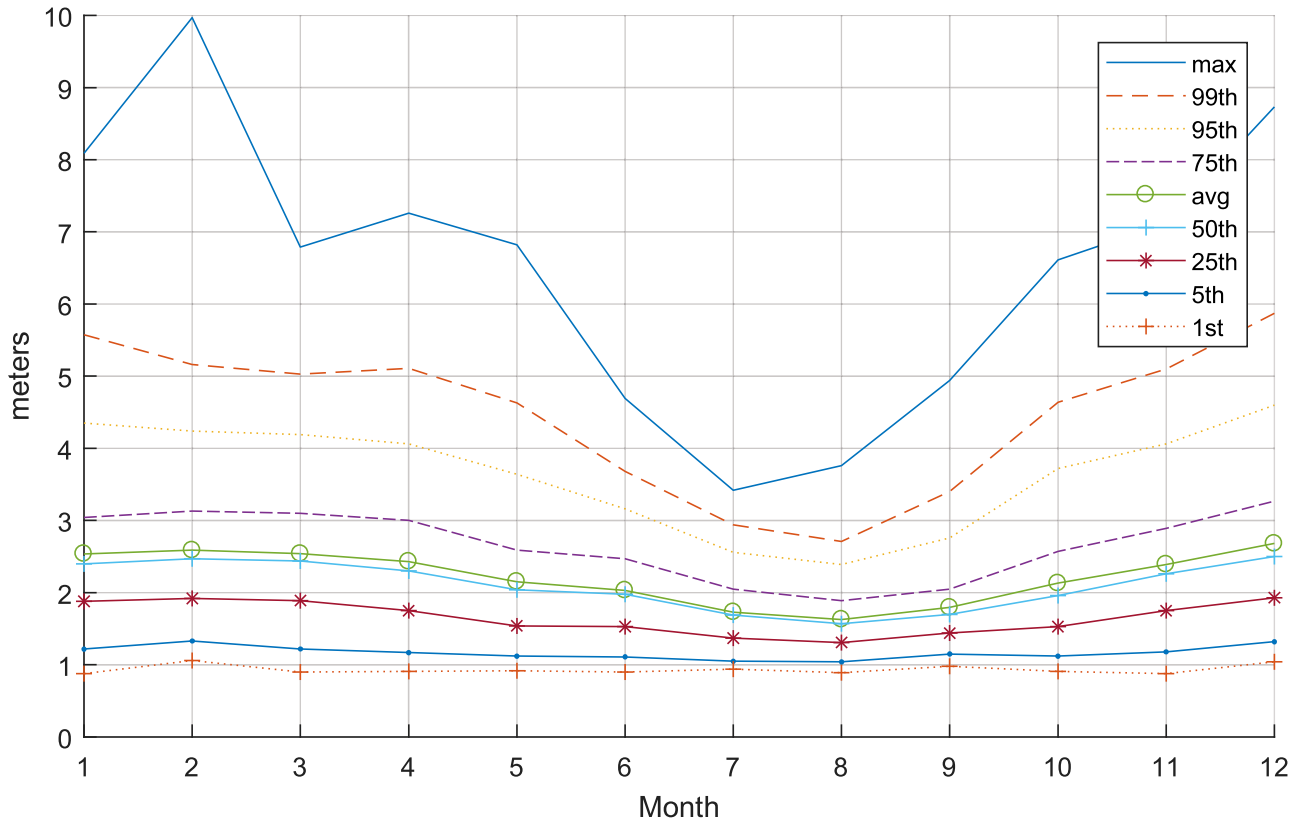


Figure D034.NDBC 46218 Monthly Wave Height Distribution

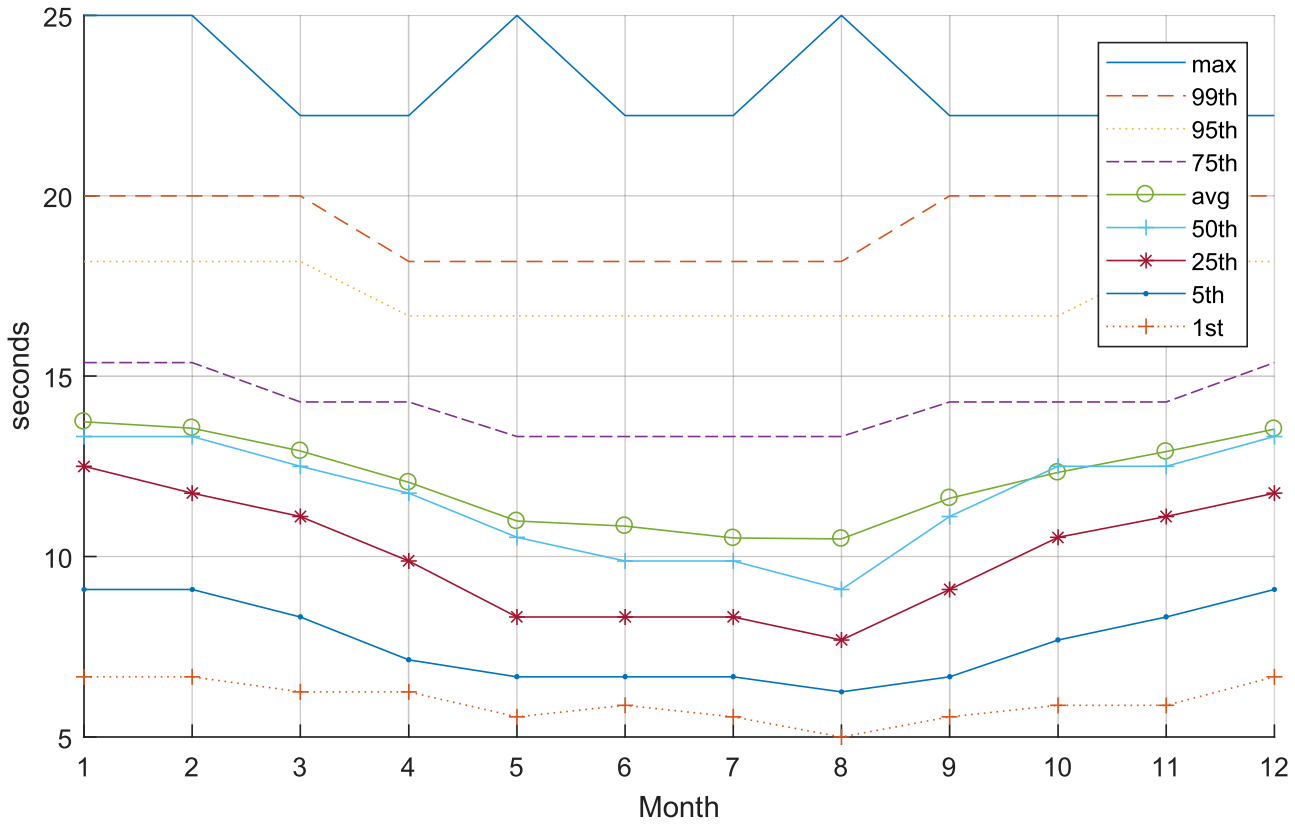


Figure D035.NDBC 46218 Monthly Wave Period Distribution

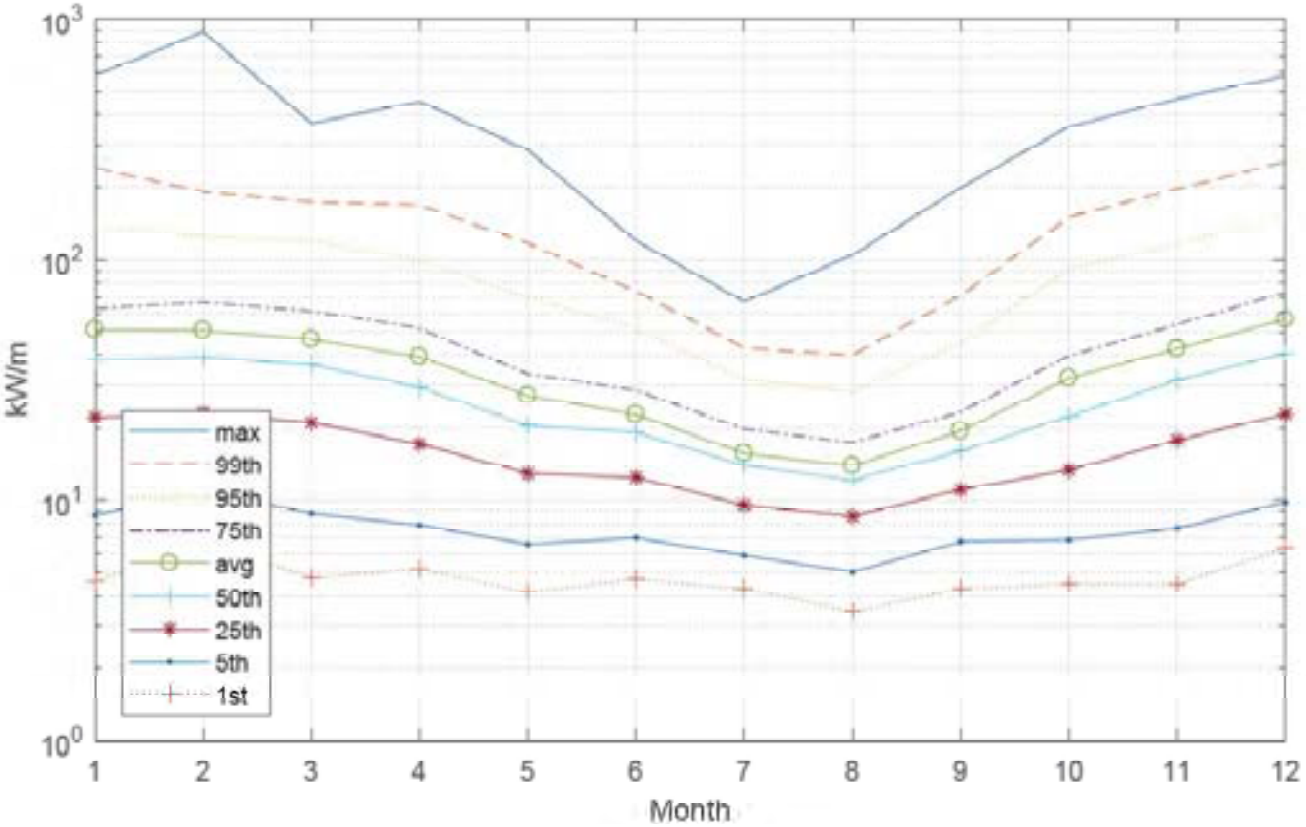


Figure D036.NDBC 46218 Monthly Wave Energy Distribution

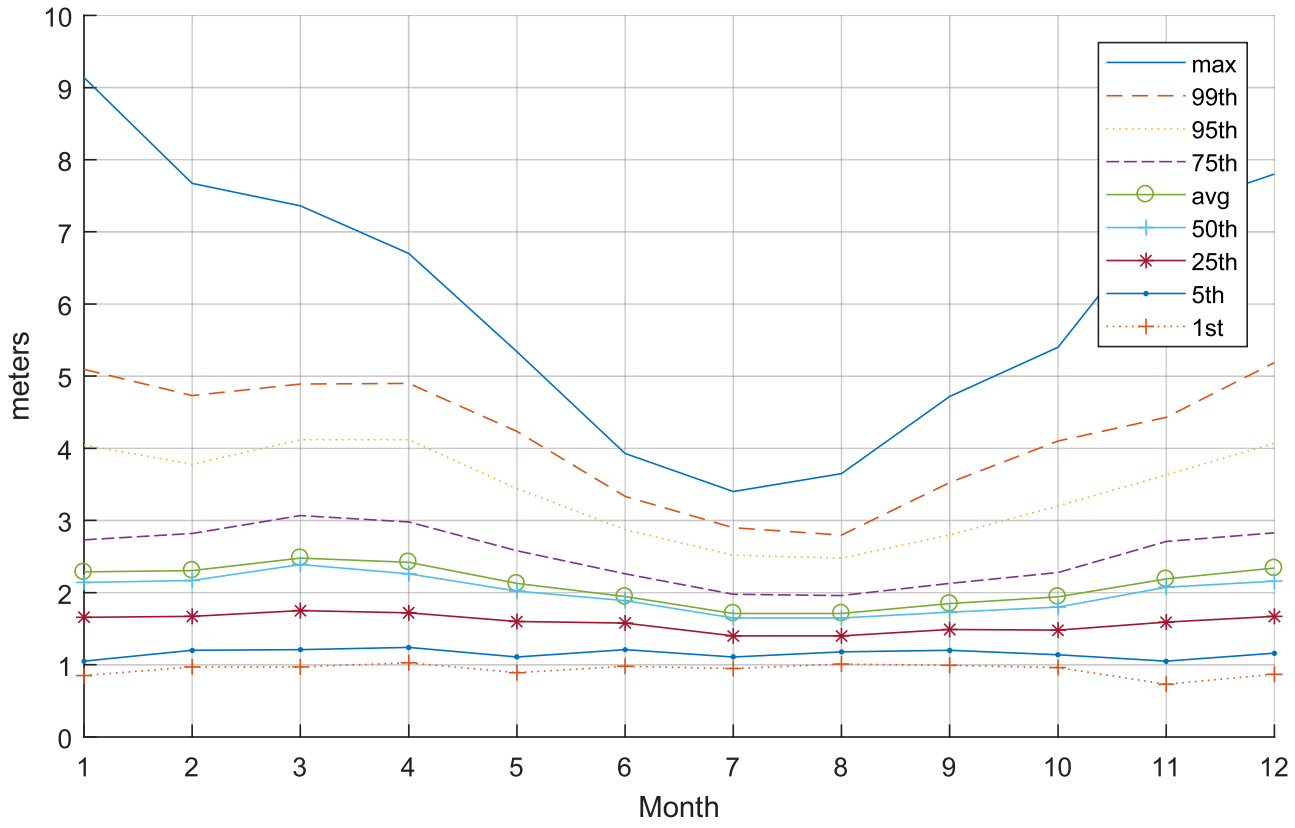


Figure D037.NDBC 46219 Monthly Wave Height Distribution

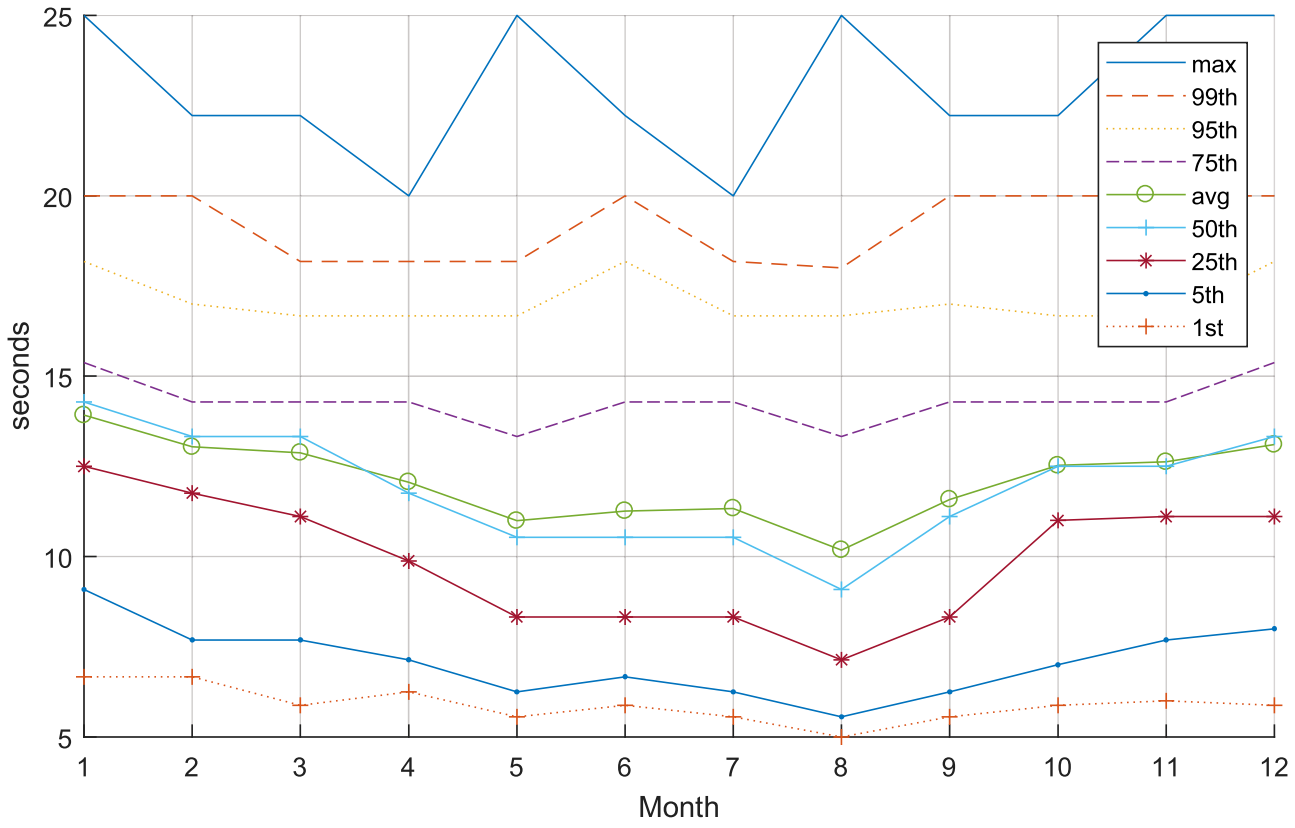


Figure D038.NDBC 46219 Monthly Wave Period Distribution

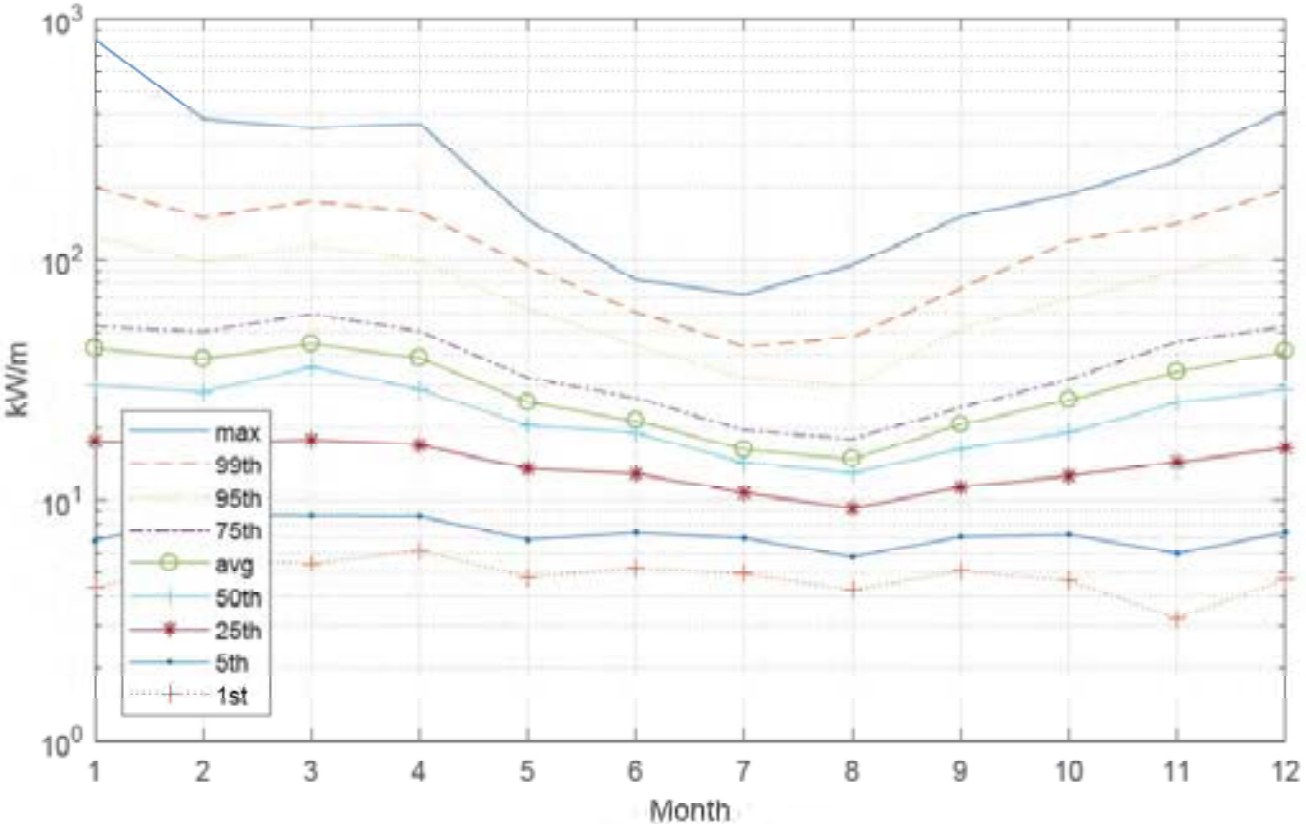


Figure D039.NDBC 46219 Monthly Wave Energy Distribution

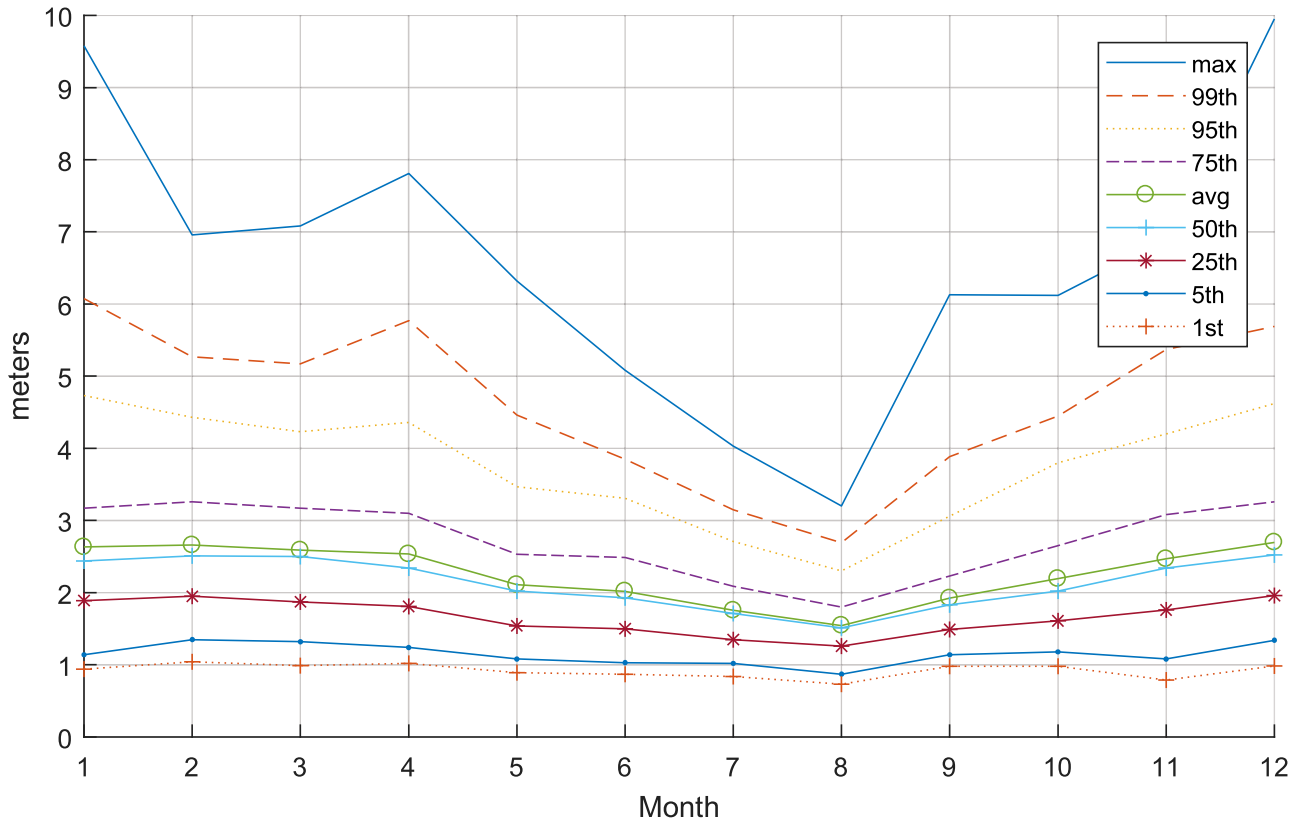


Figure D040.NDBC 46239 Monthly Wave Height Distribution

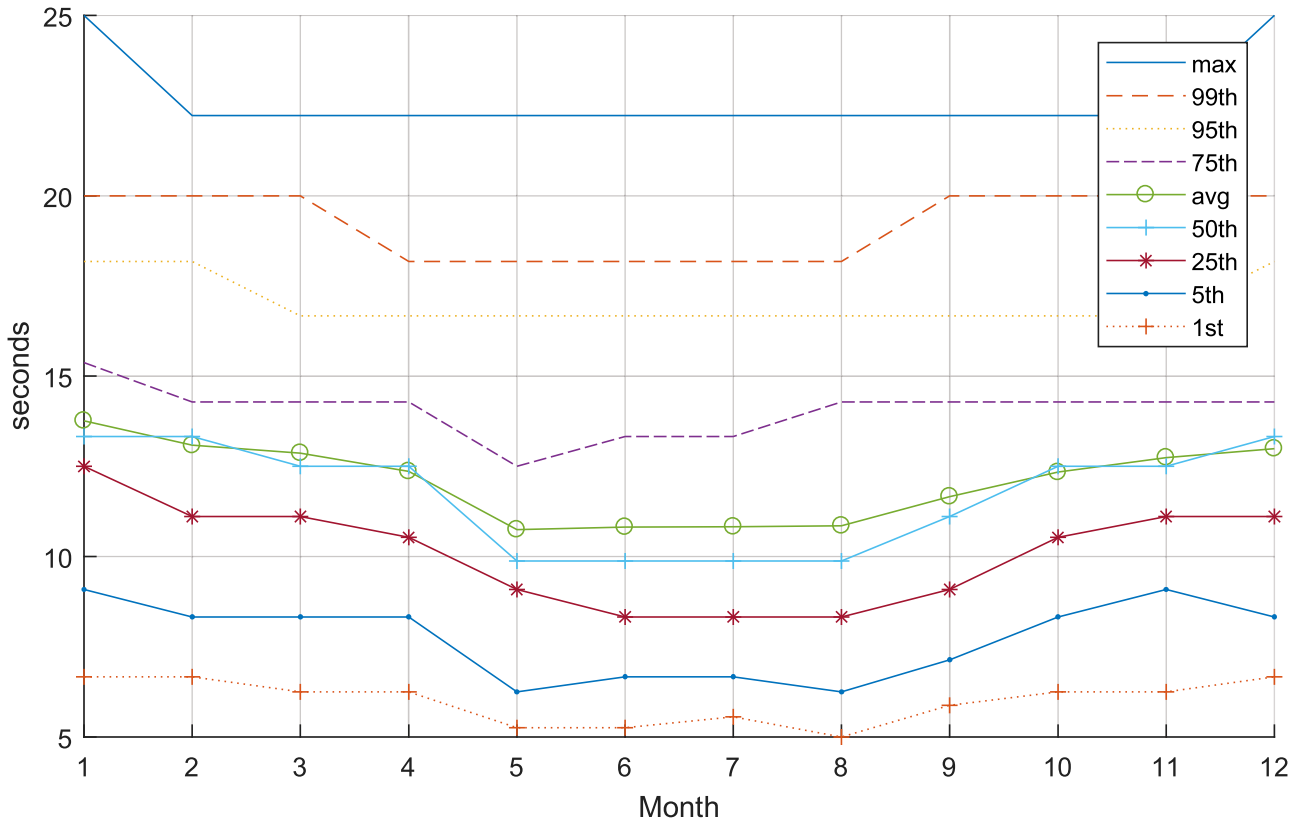


Figure D041.NDBC 46239 Monthly Wave Period Distribution

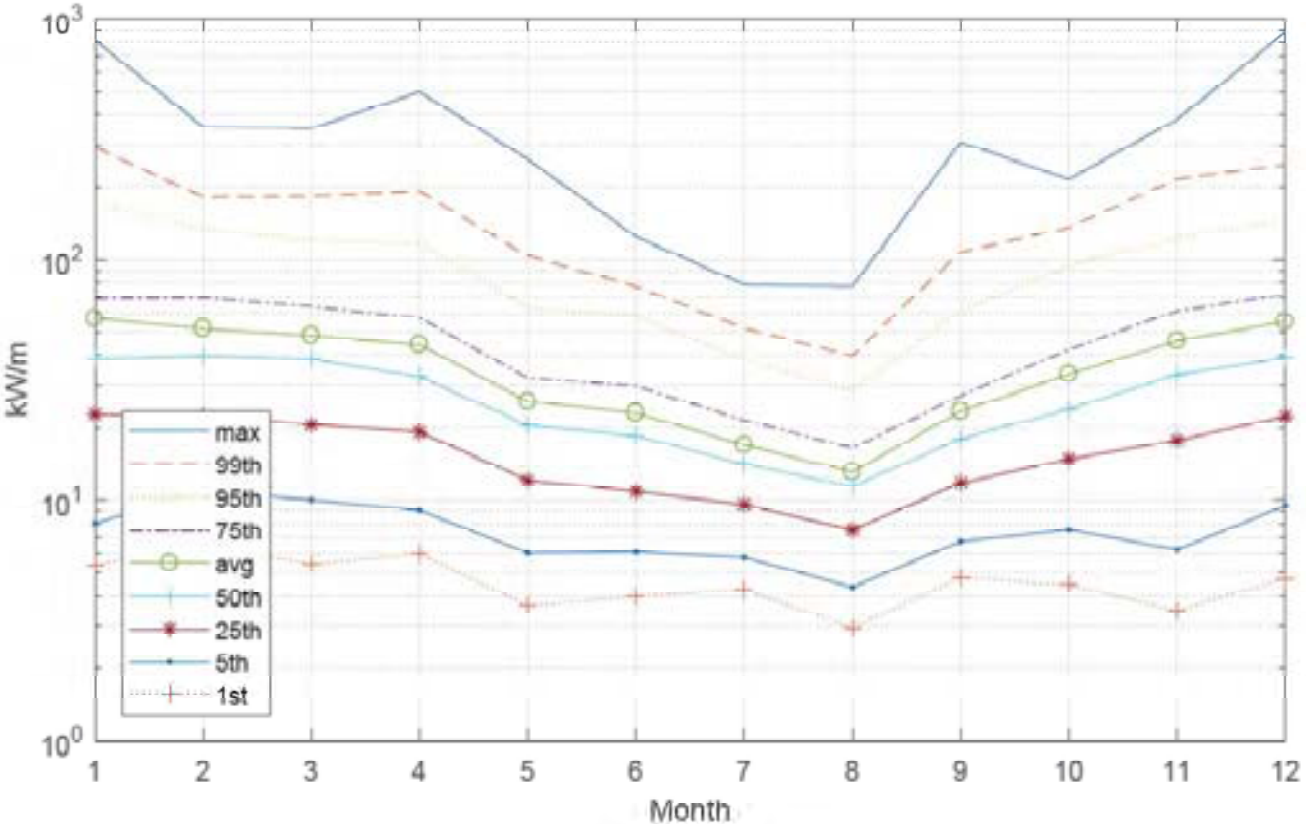


Figure D042.NDBC 46239 Monthly Wave Energy Distribution

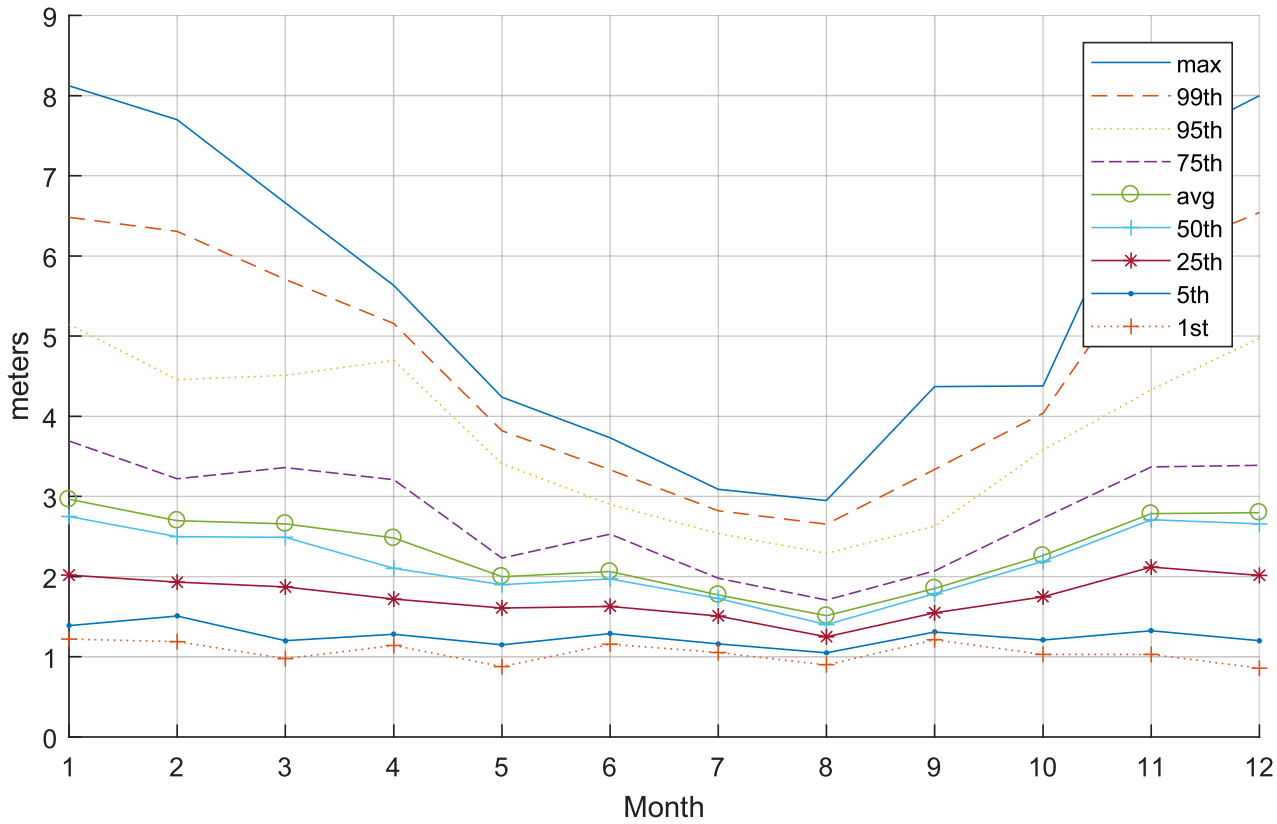


Figure D043.NDBC 46257 Monthly Wave Height Distribution

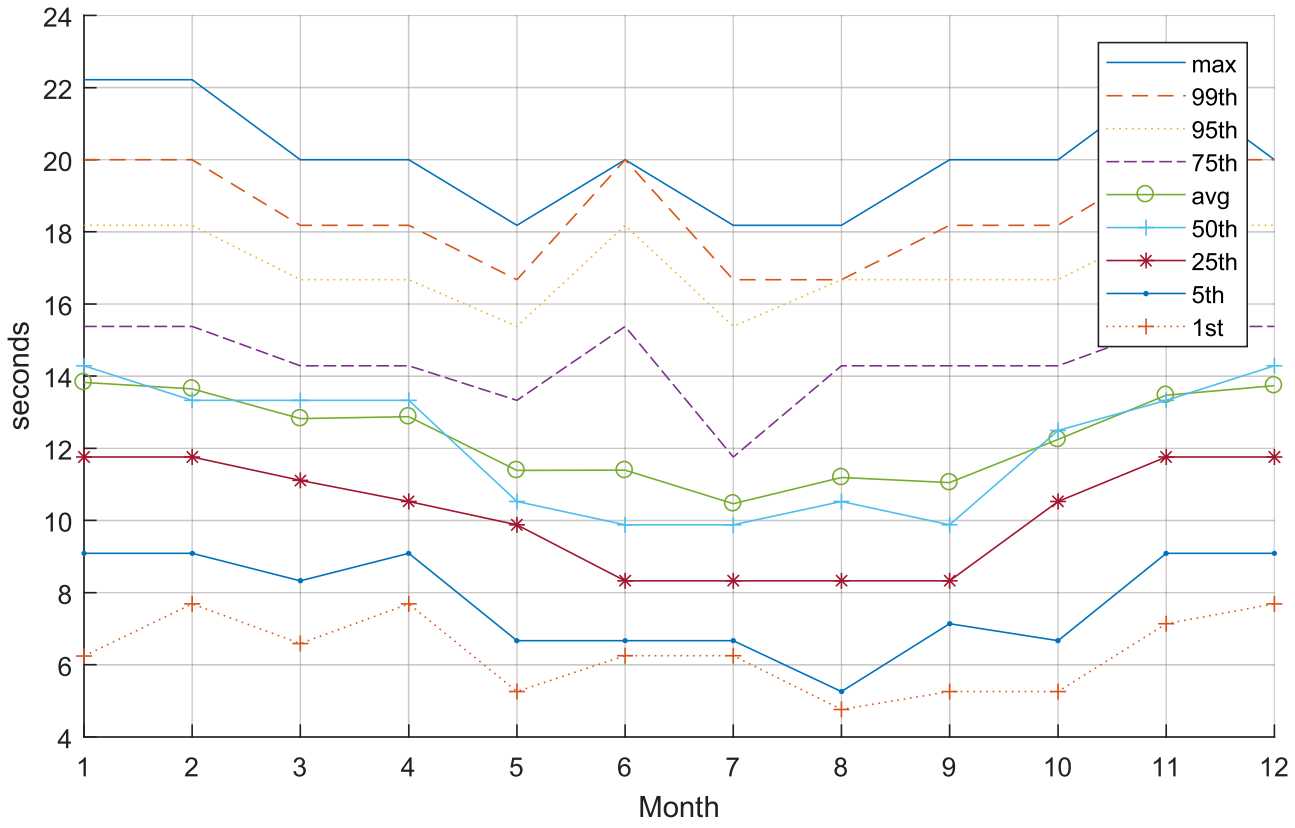


Figure D044.NDBC 46257 Monthly Wave Period Distribution

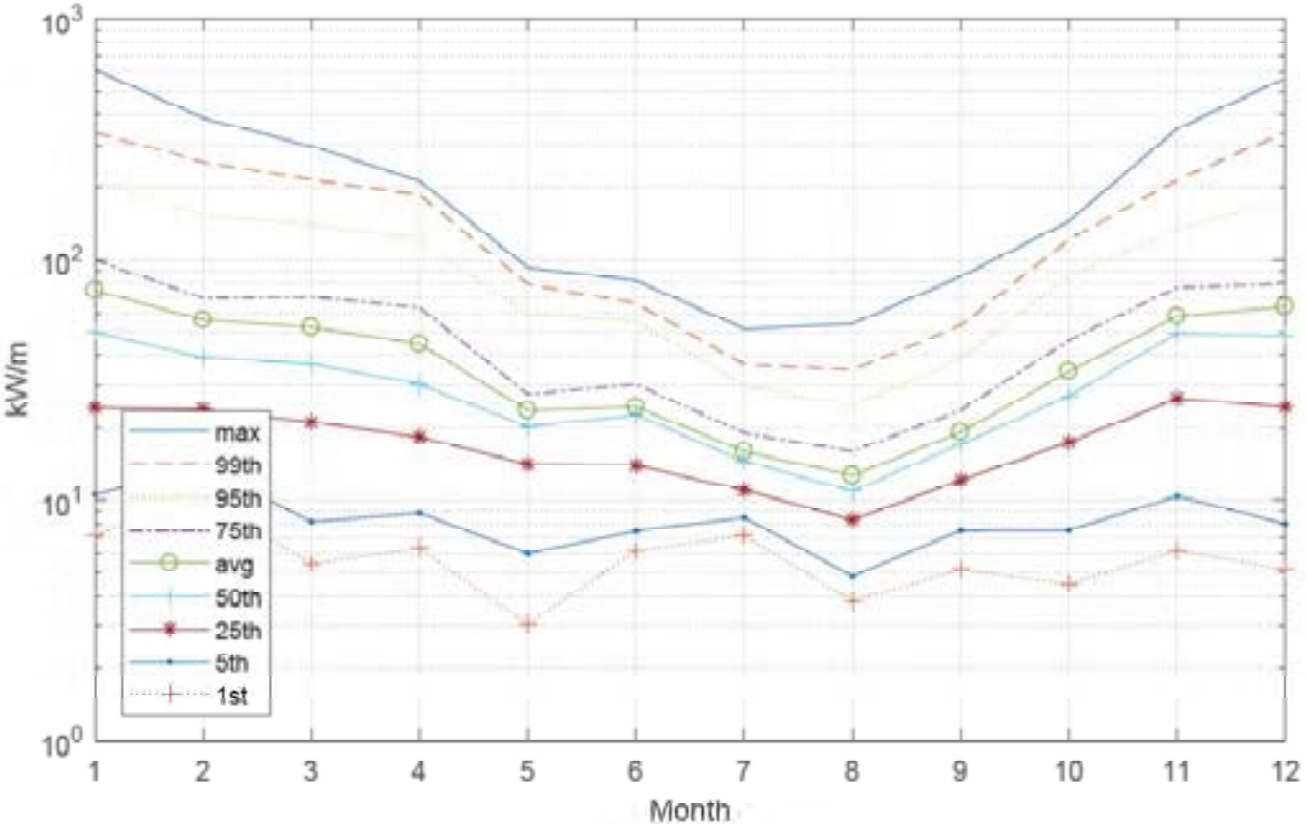


Figure D045.NDBC 46257 Monthly Wave Energy Distribution

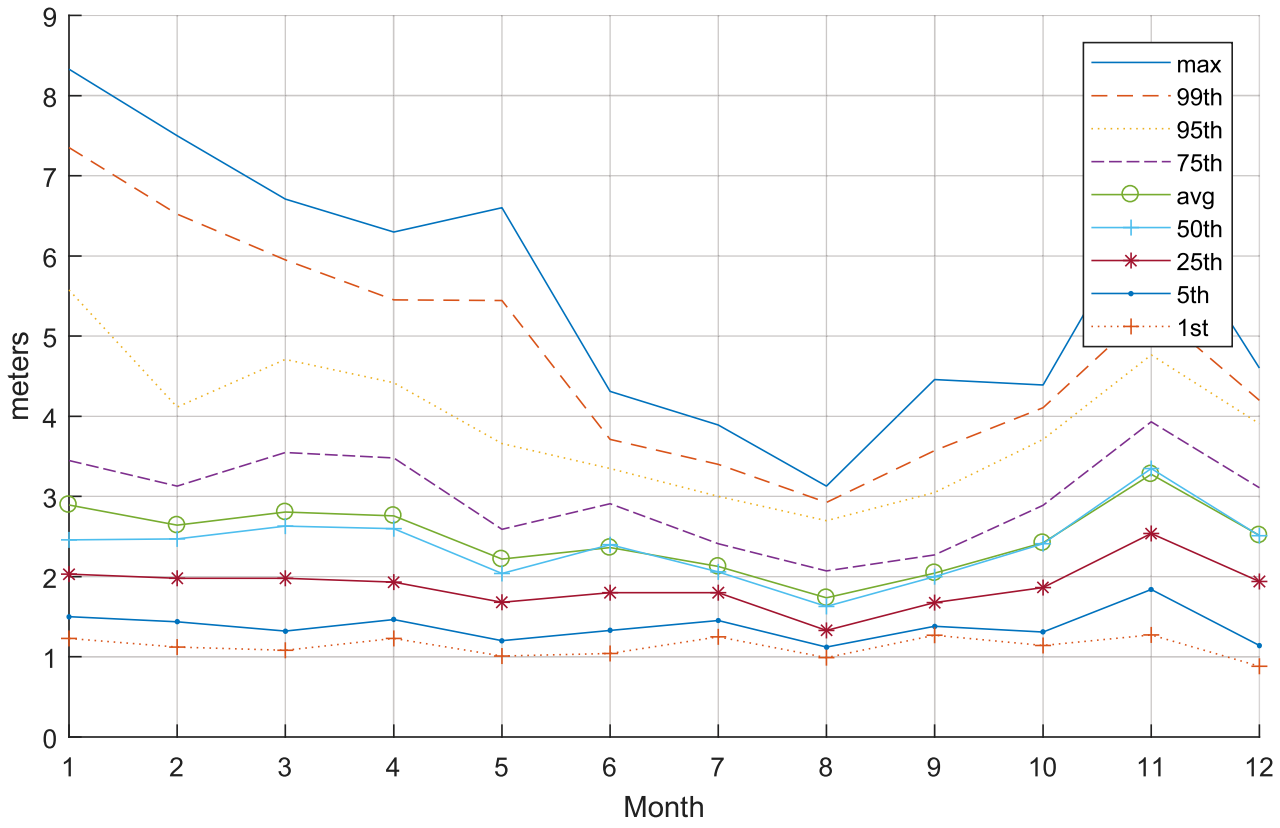


Figure D046.NDBC 46259 Monthly Wave Height Distribution

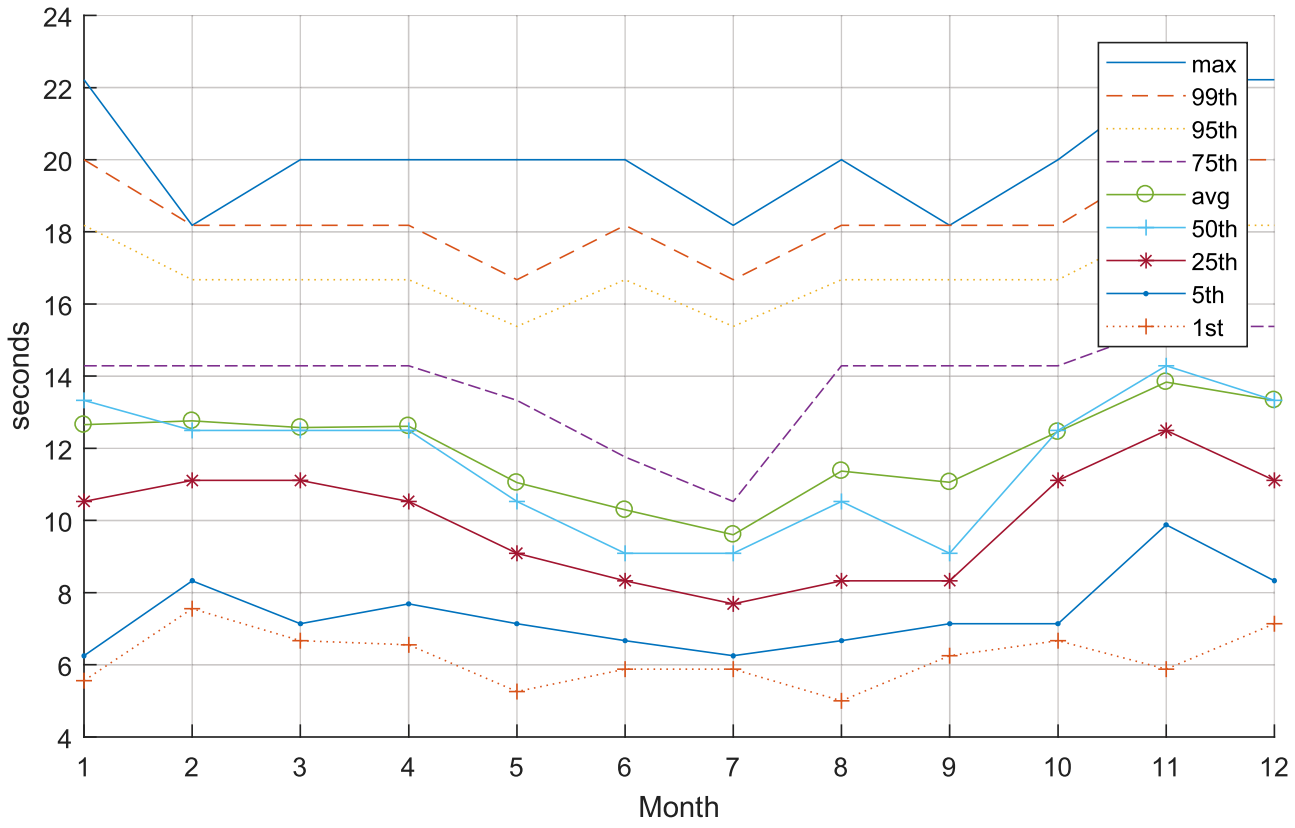


Figure D047.NDBC 46259 Monthly Wave Period Distribution

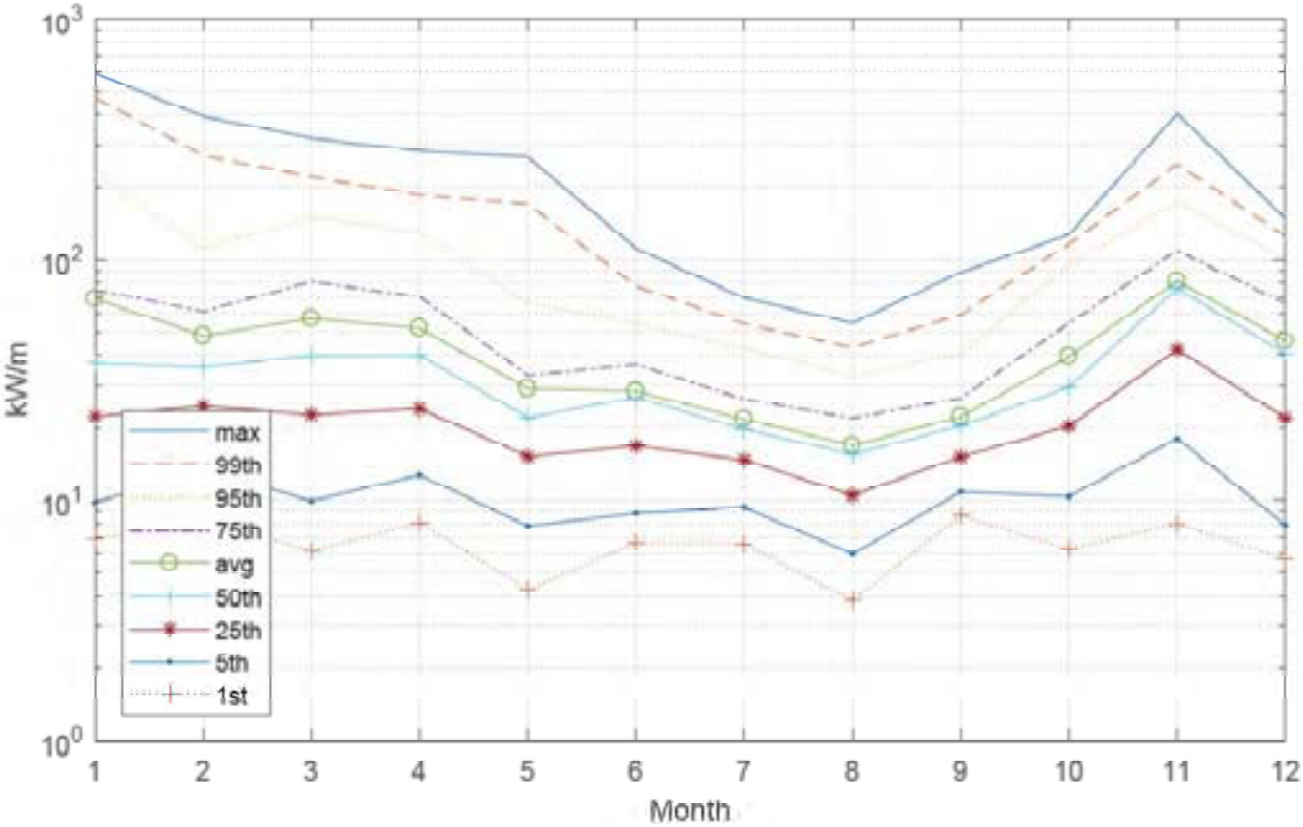


Figure D048.NDBC 46259 Monthly Wave Energy Distribution

APPENDIX E: Probability Fits of Wave Height, Period, and Energy, by Buoy

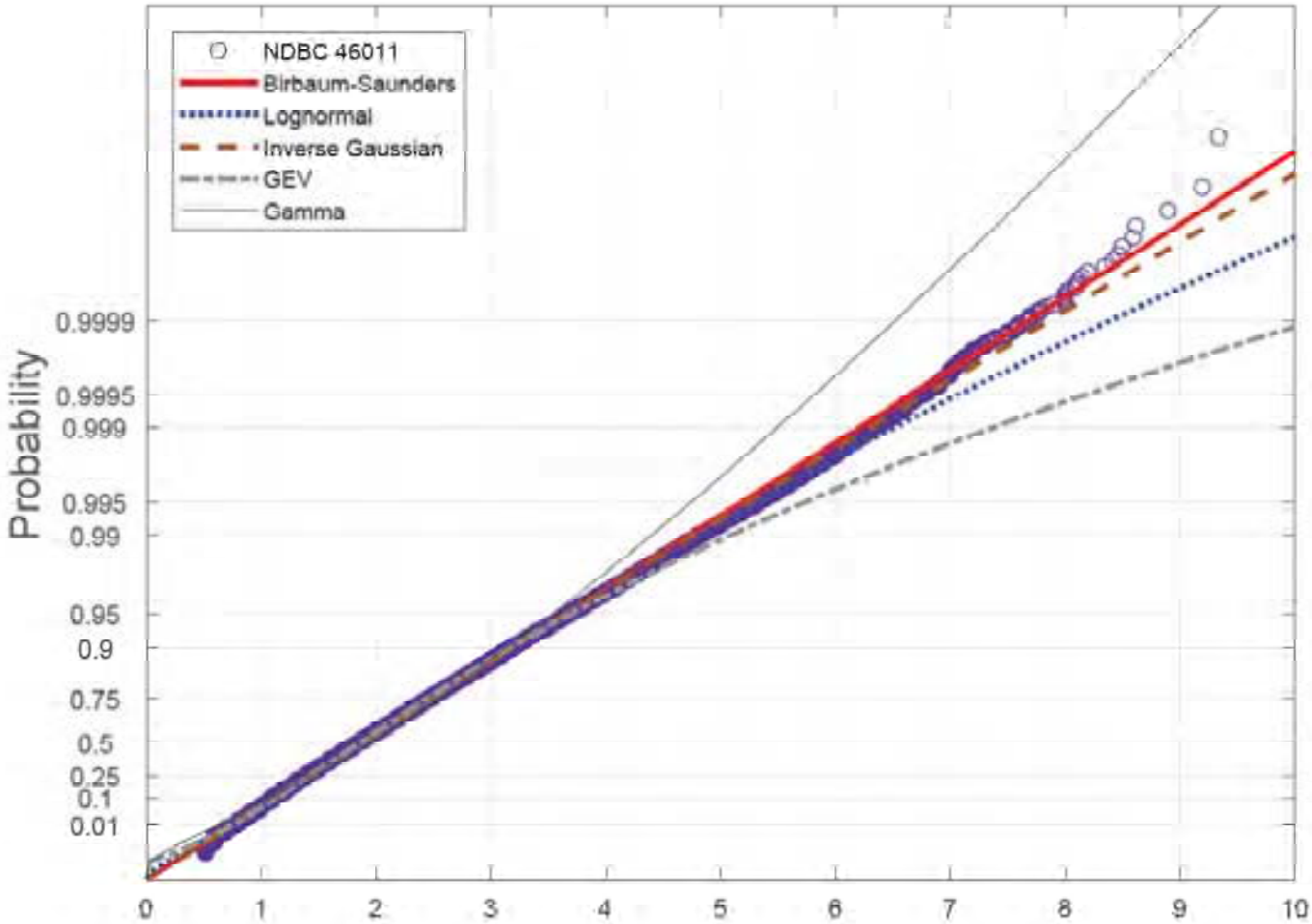


Figure E001, Probability Fit, Wave Height, m, 46011

Page E001

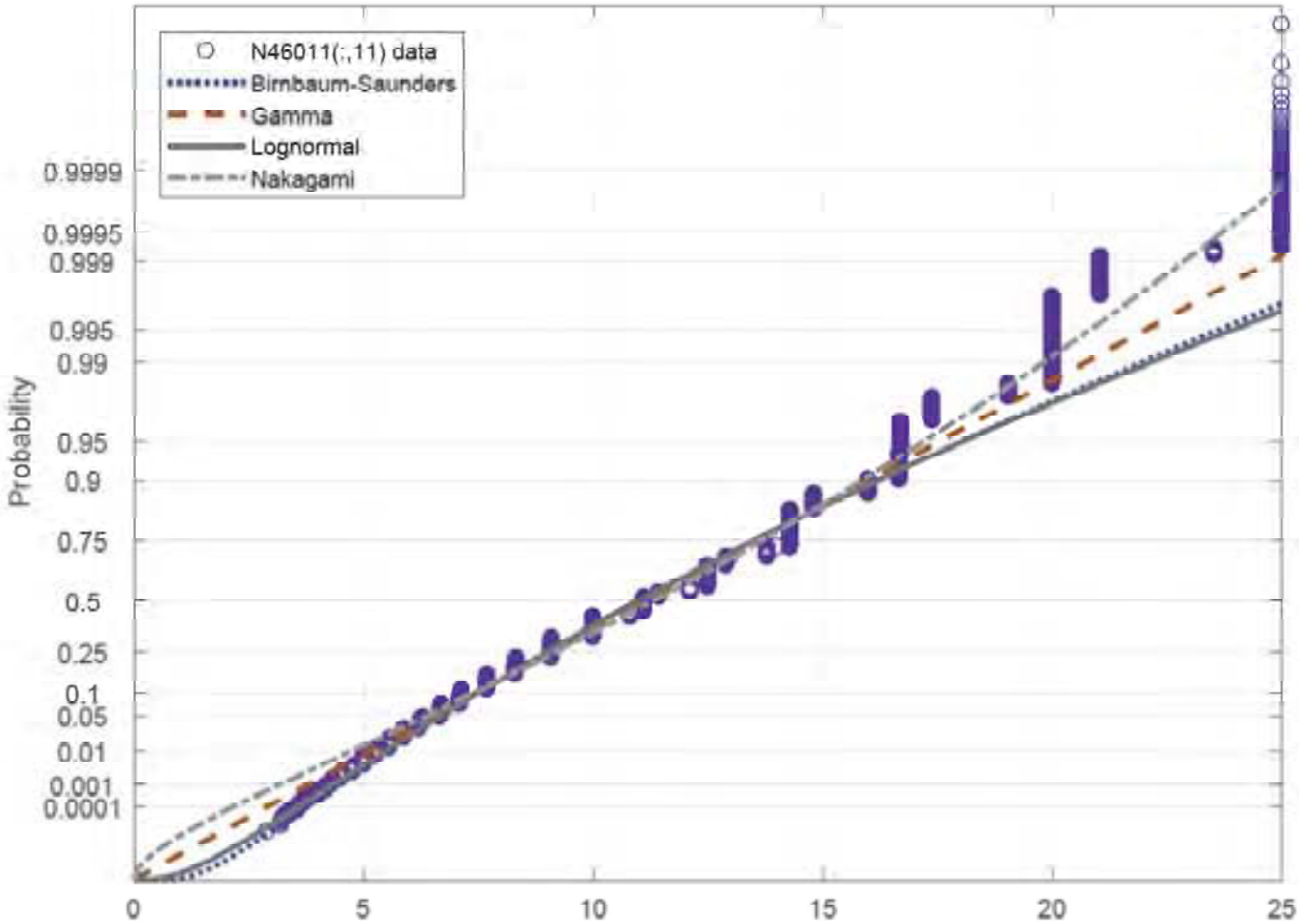


Figure E002. Probability Fit, Wave Energy, kW/m, 46011

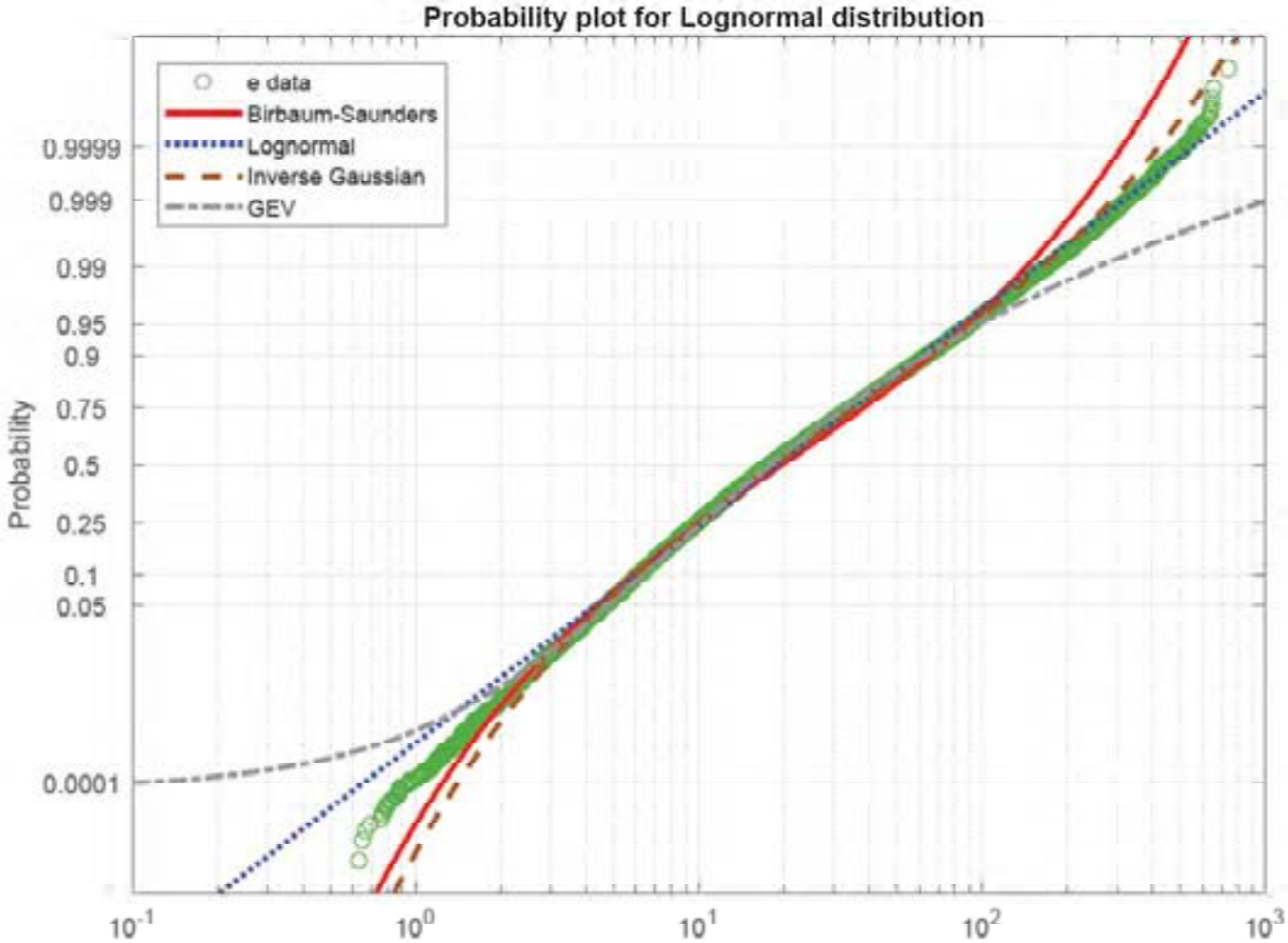


Figure E003. Probability Fit, Wave Energy, kW/m, 46011

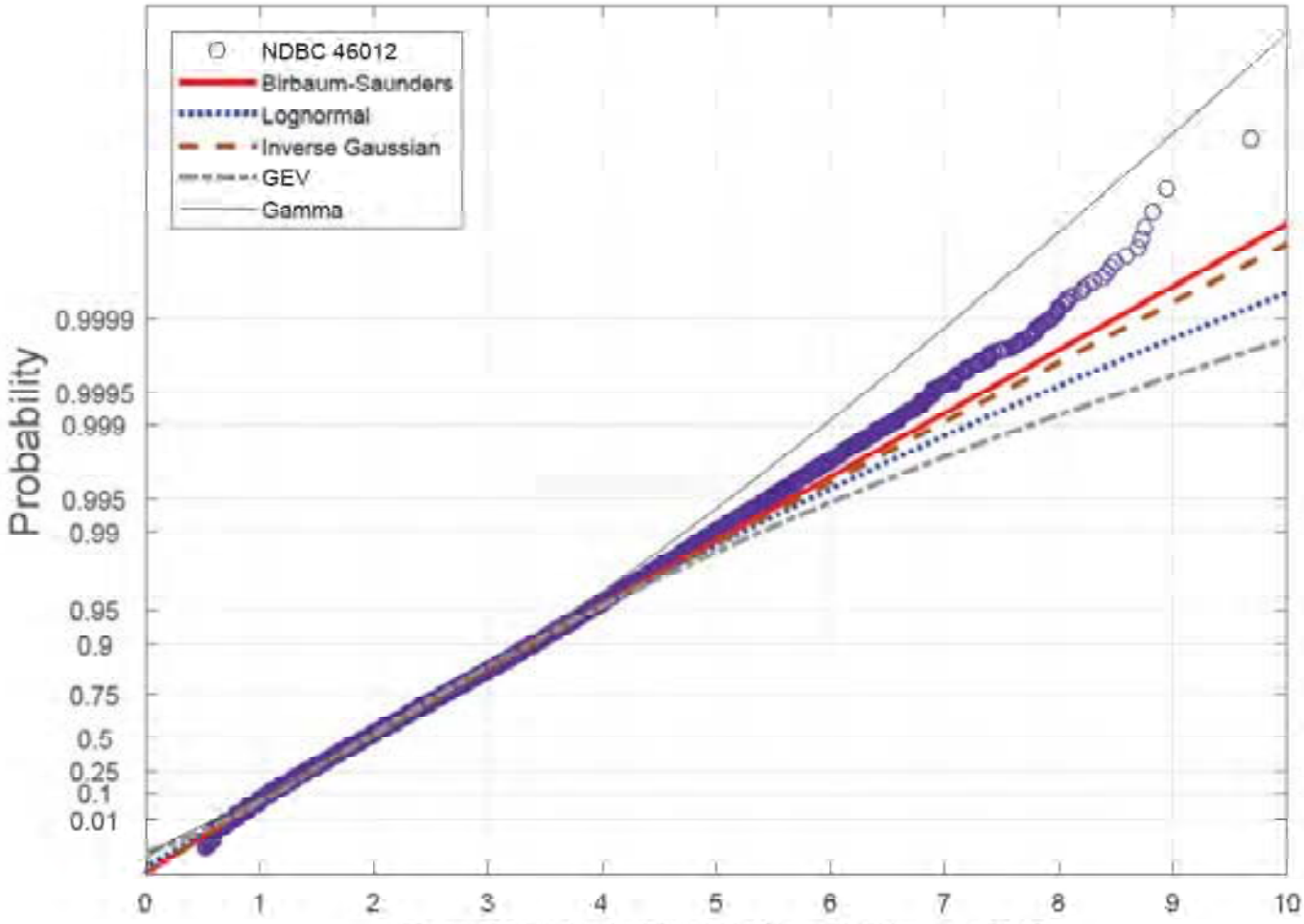


Figure E004, Probability Fit, Wave Height, m, 46012

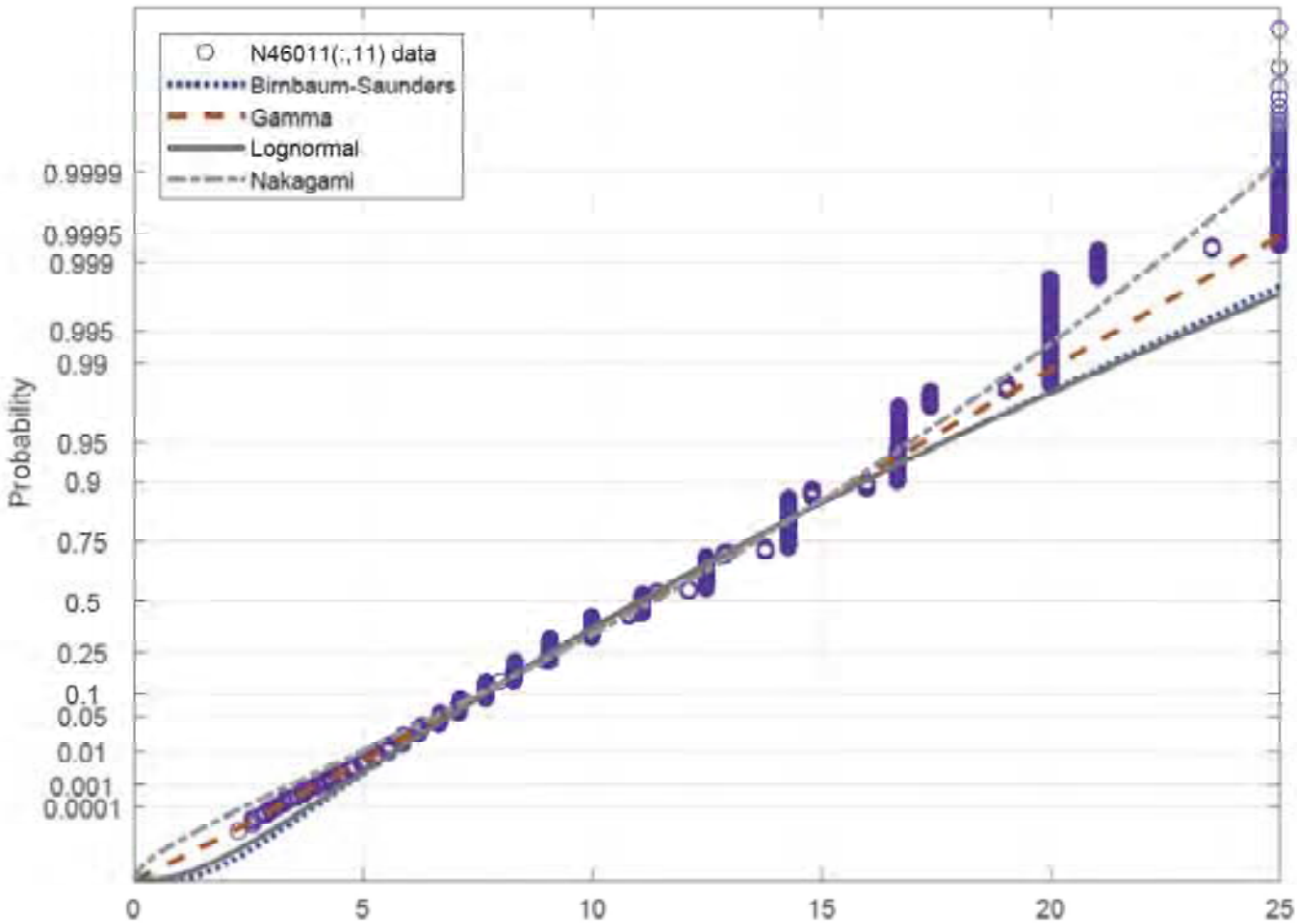


Figure E005. Probability Fit, Wave Energy, kW/m, 46012

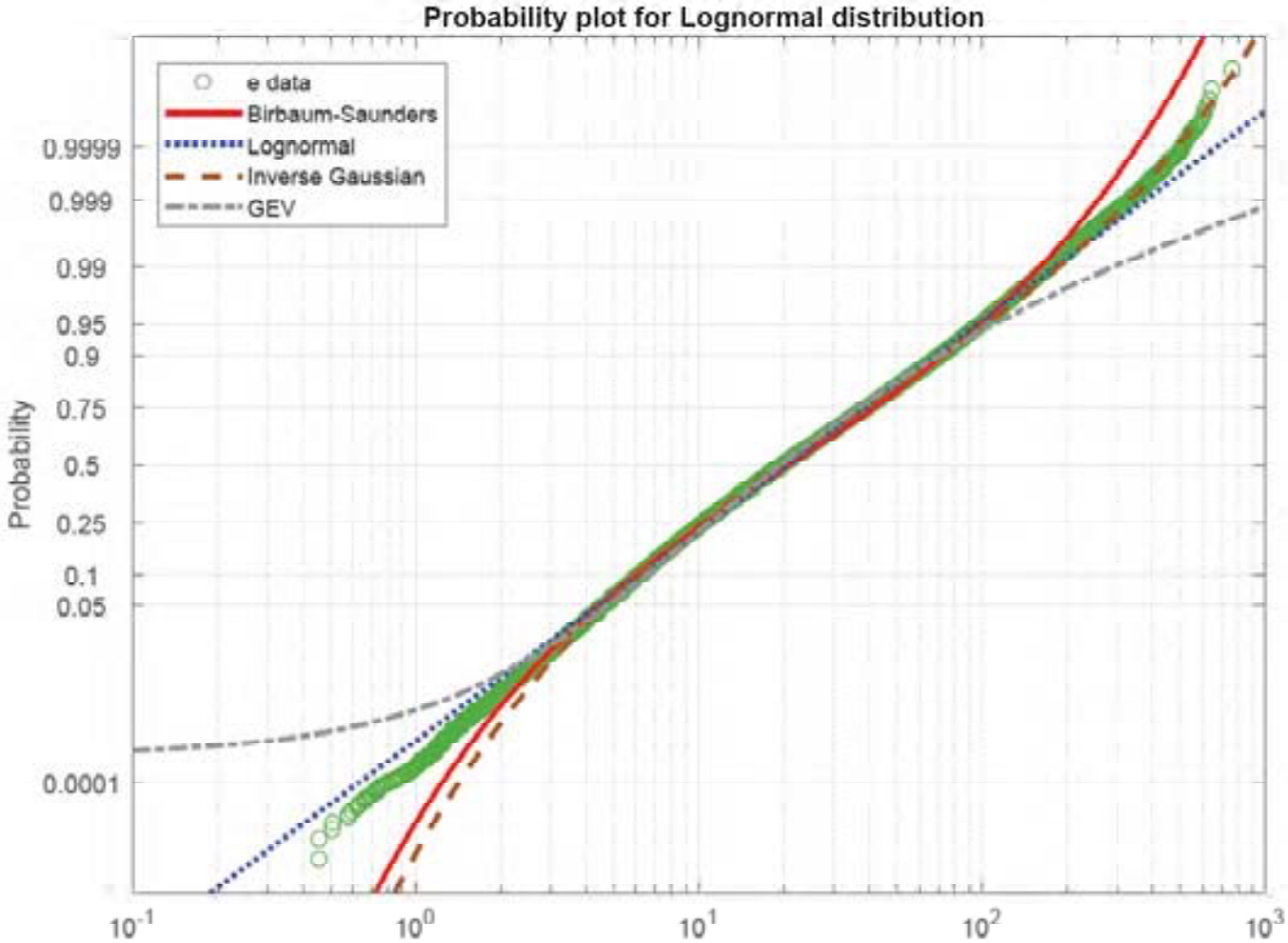


Figure E006. Probability Fit, Wave Energy, kW/m, 46012

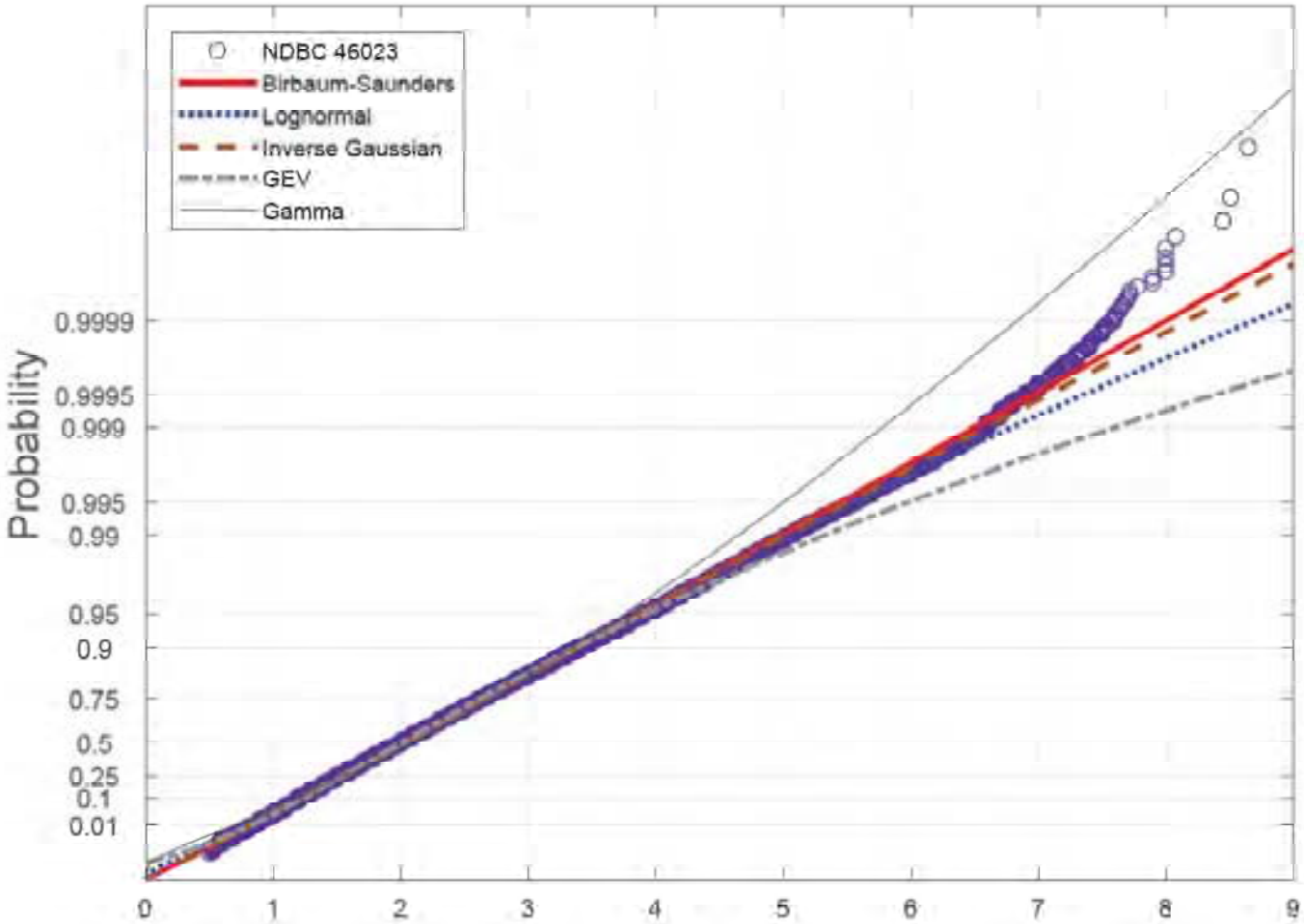


Figure E007, Probability Fit, Wave Height, m, 46023

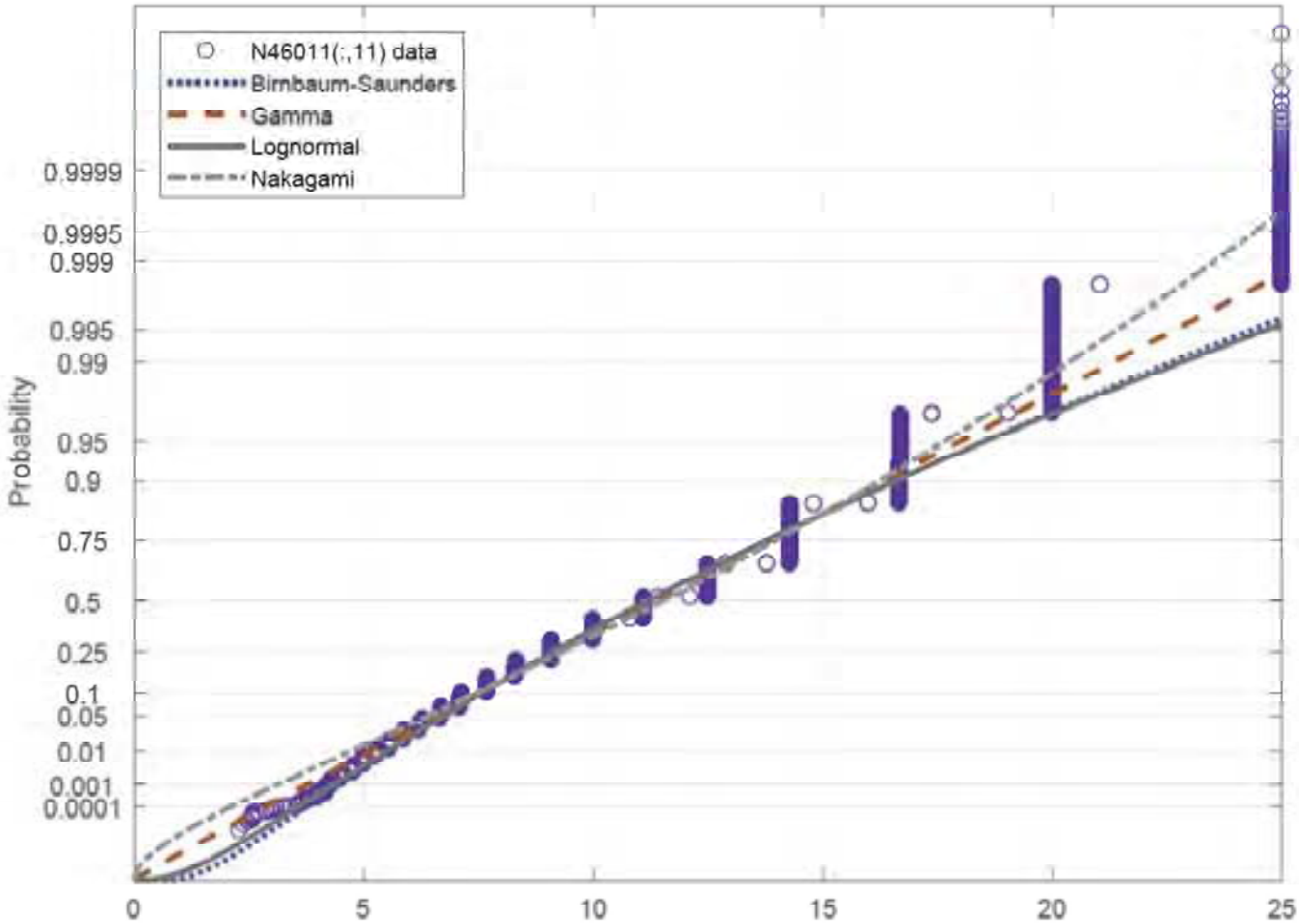


Figure E008. Probability Fit, Wave Energy, kW/m, 46023

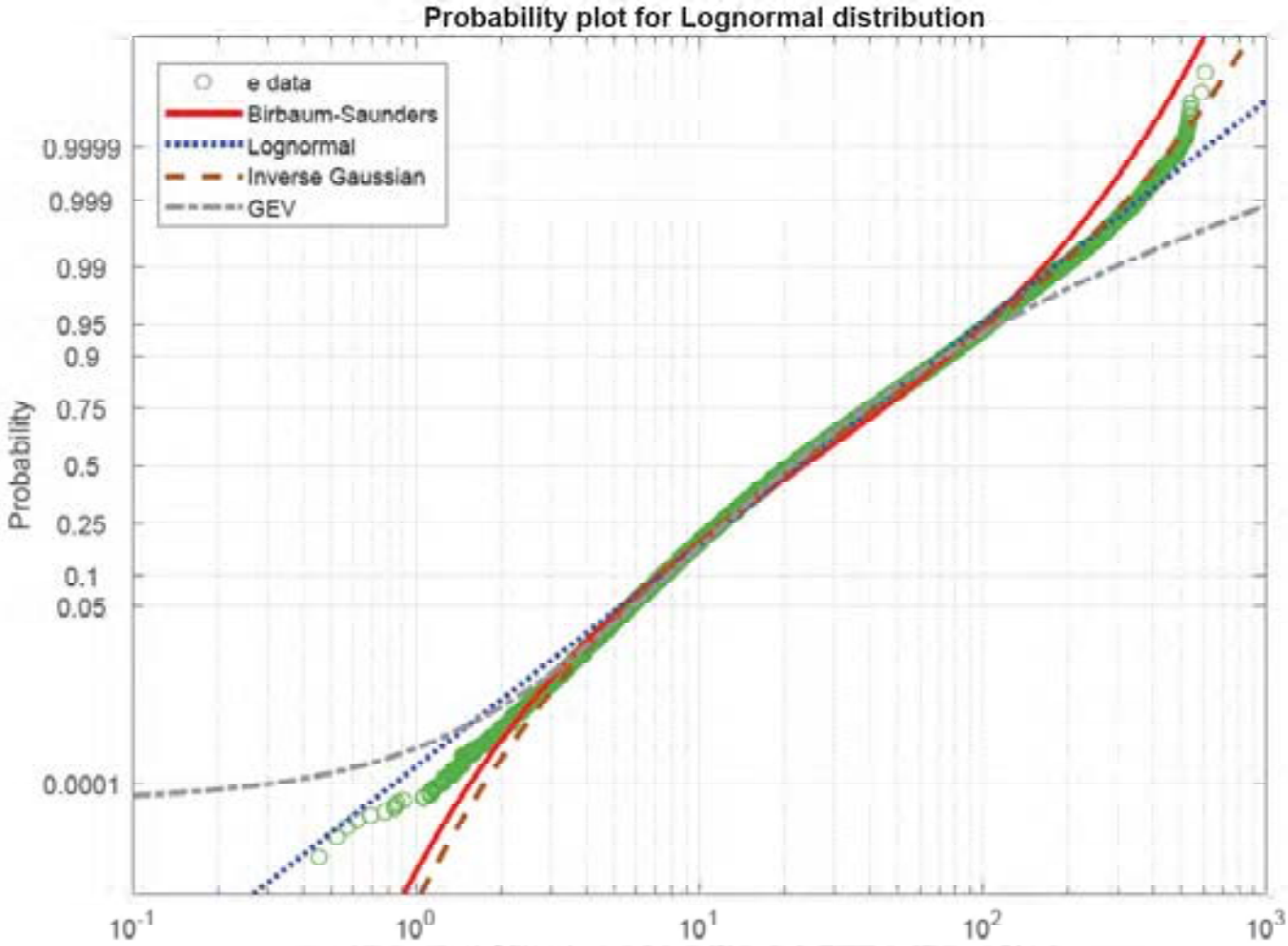


Figure E009. Probability Fit, Wave Energy, kW/m, 46023

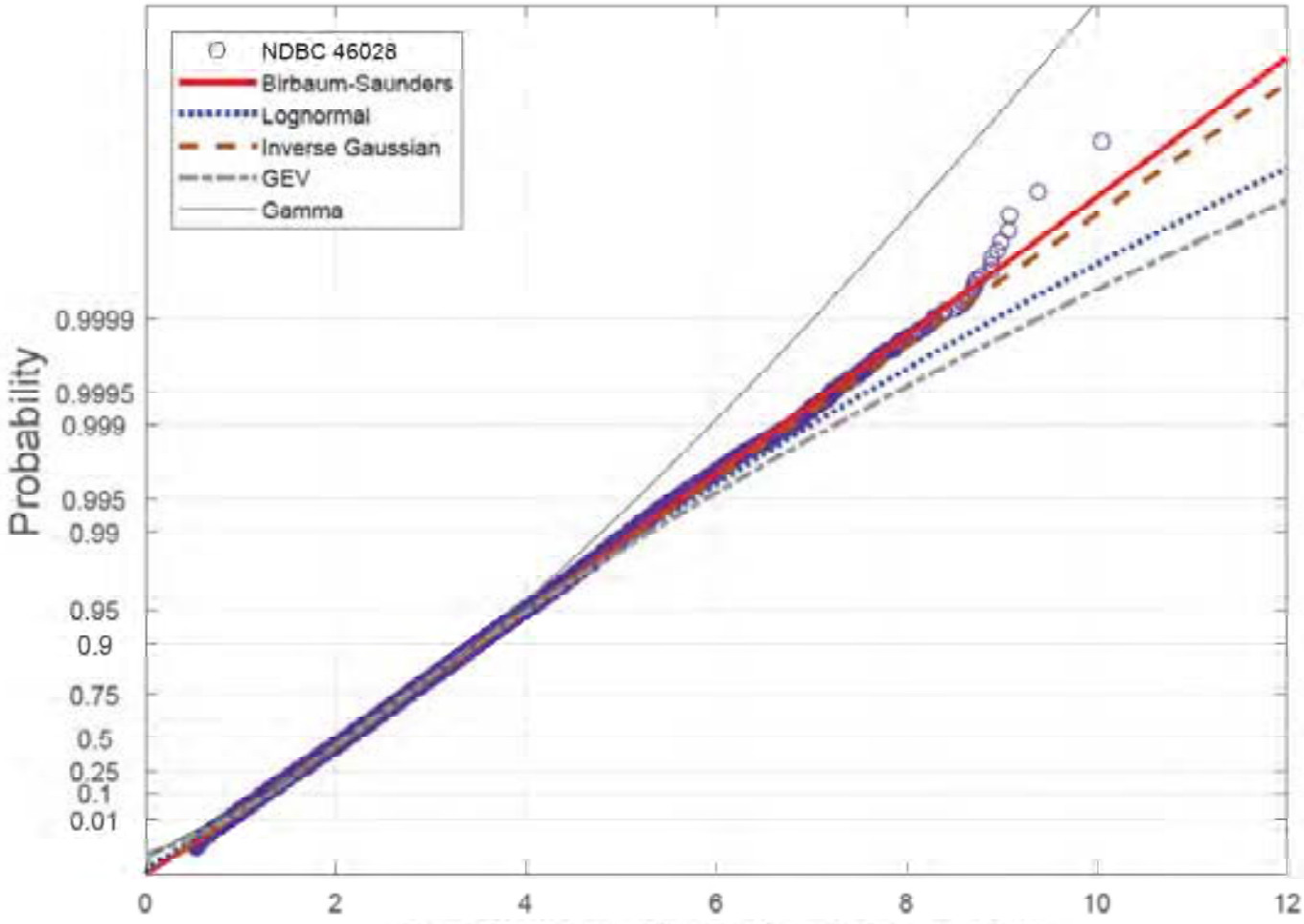


Figure E010. Probability Fit, Wave Height, m, 46028

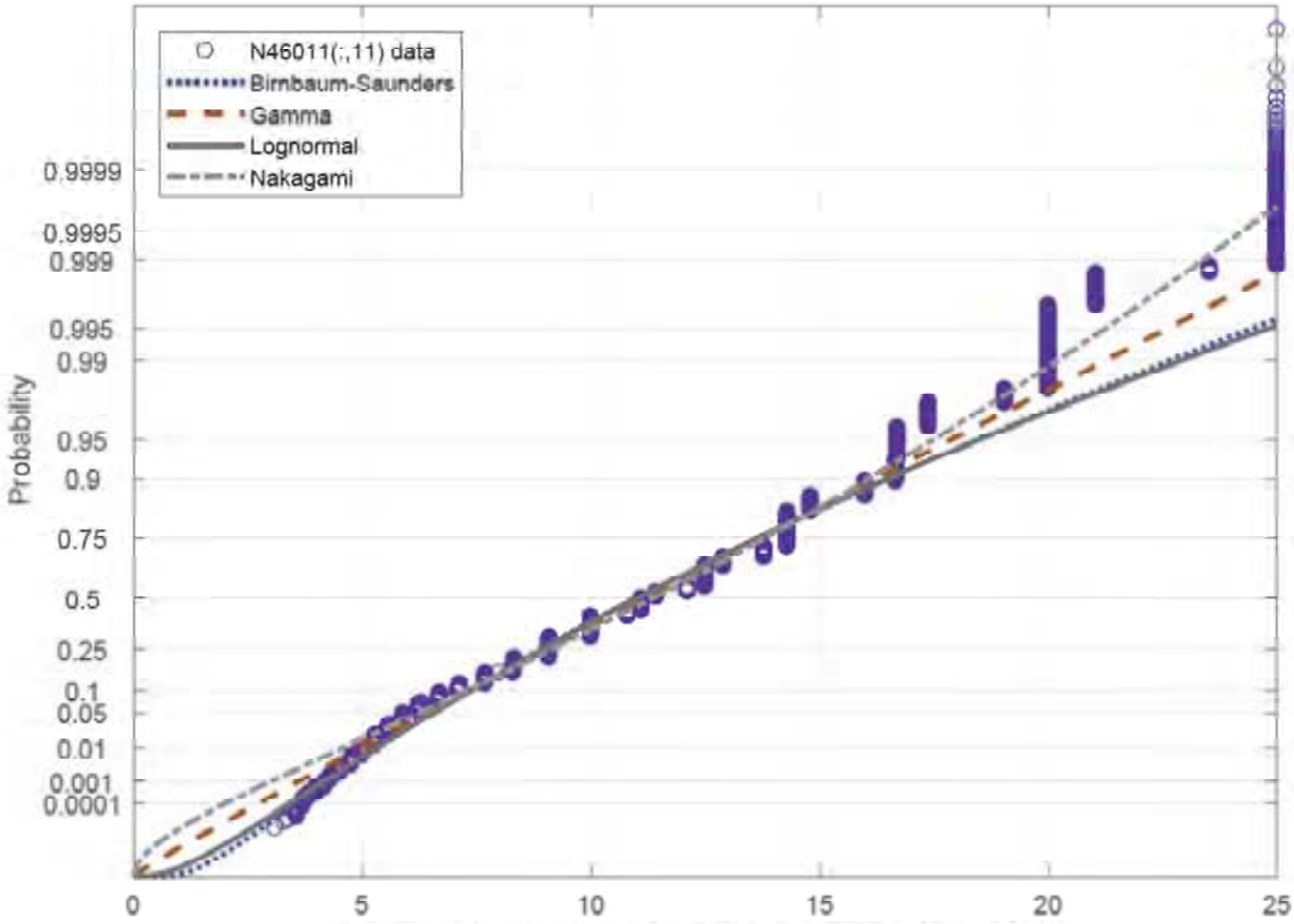


Figure E011. Probability Fit, Wave Energy, kW/m, 46028

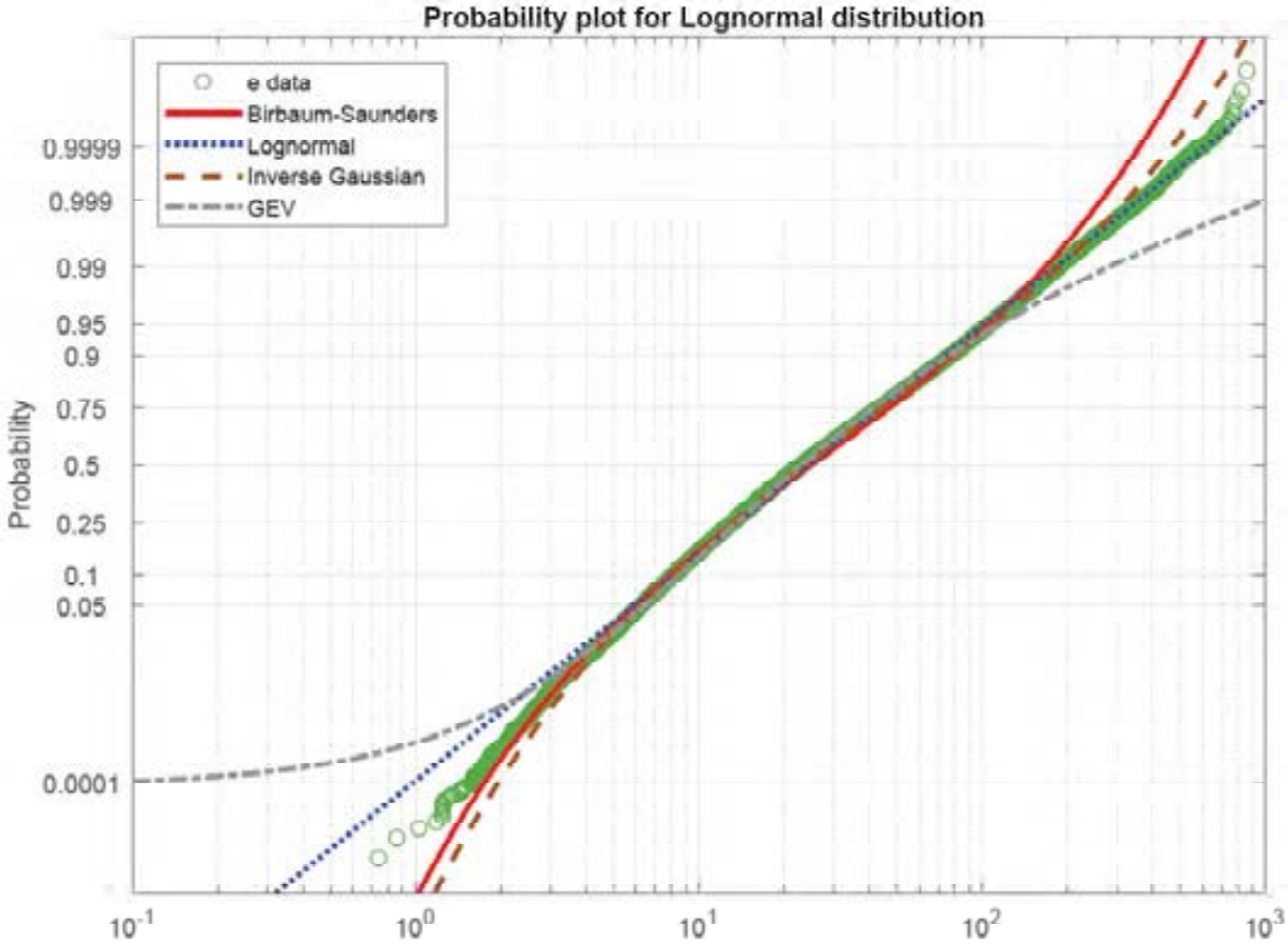


Figure E012. Probability Fit, Wave Energy, kW/m, 46028

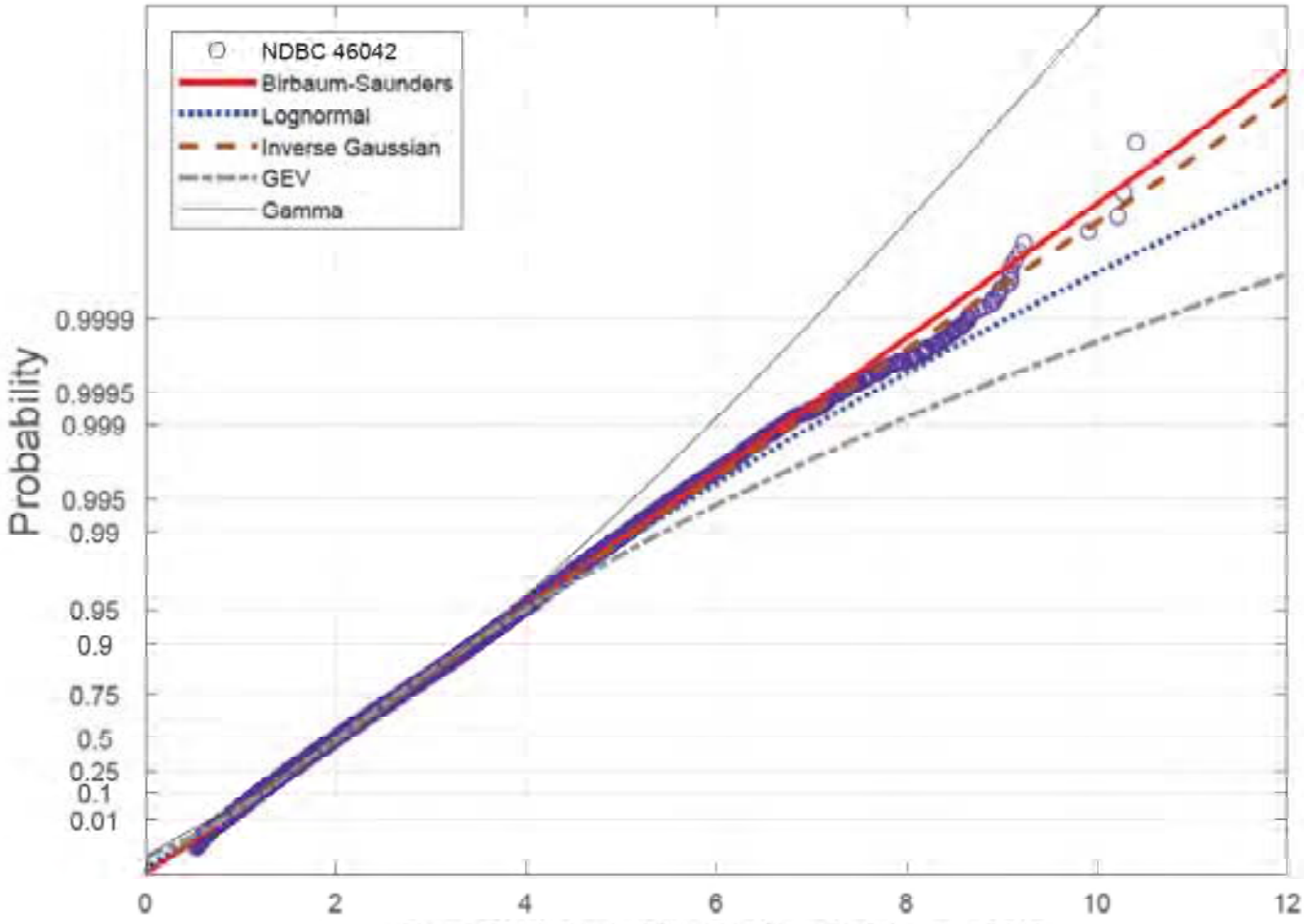


Figure E013, Probability Fit, Wave Height, m, 46042

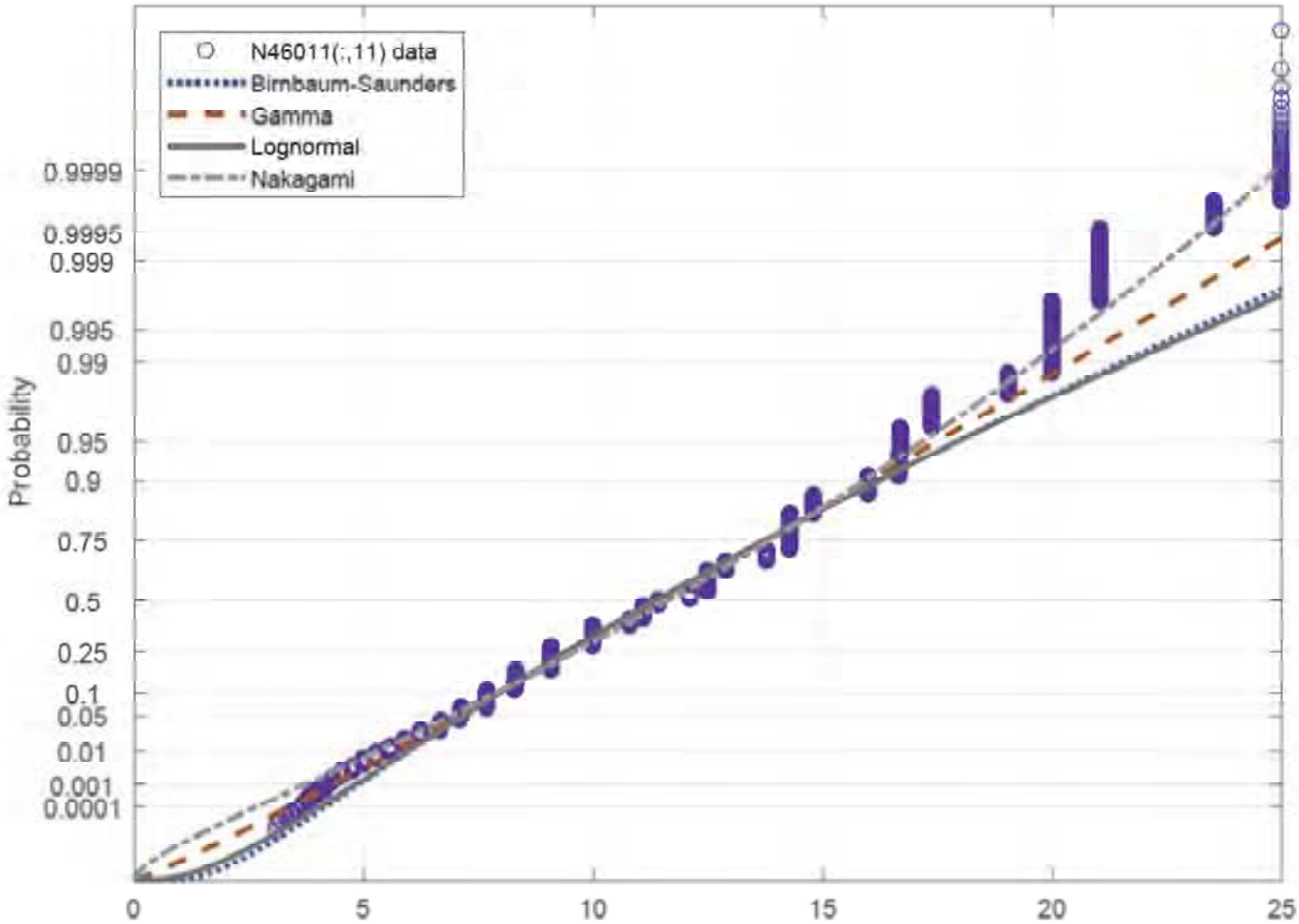


Figure E014. Probability Fit, Wave Energy, kW/m, 46042

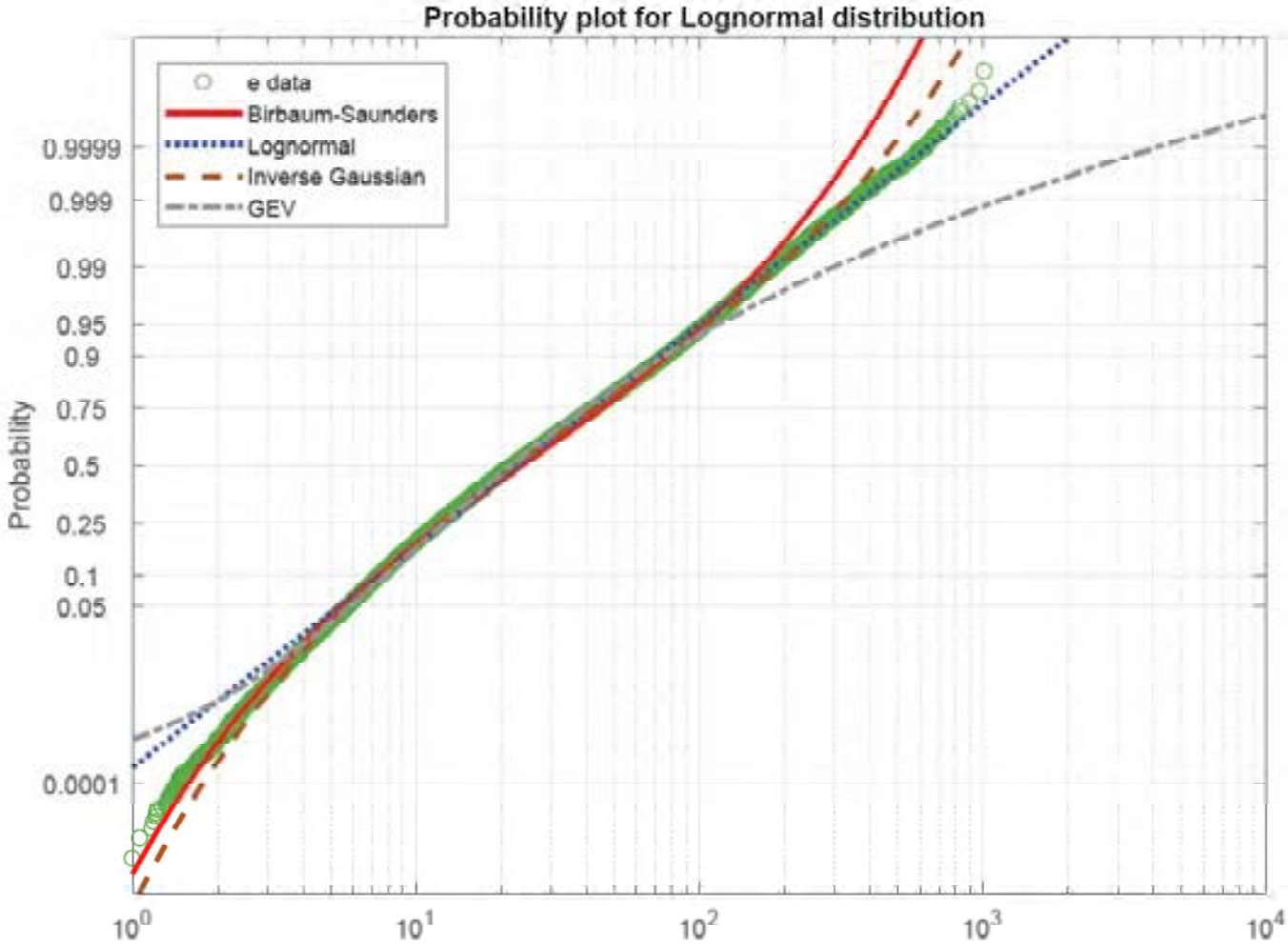


Figure E015. Probability Fit, Wave Energy, kW/m, 46042

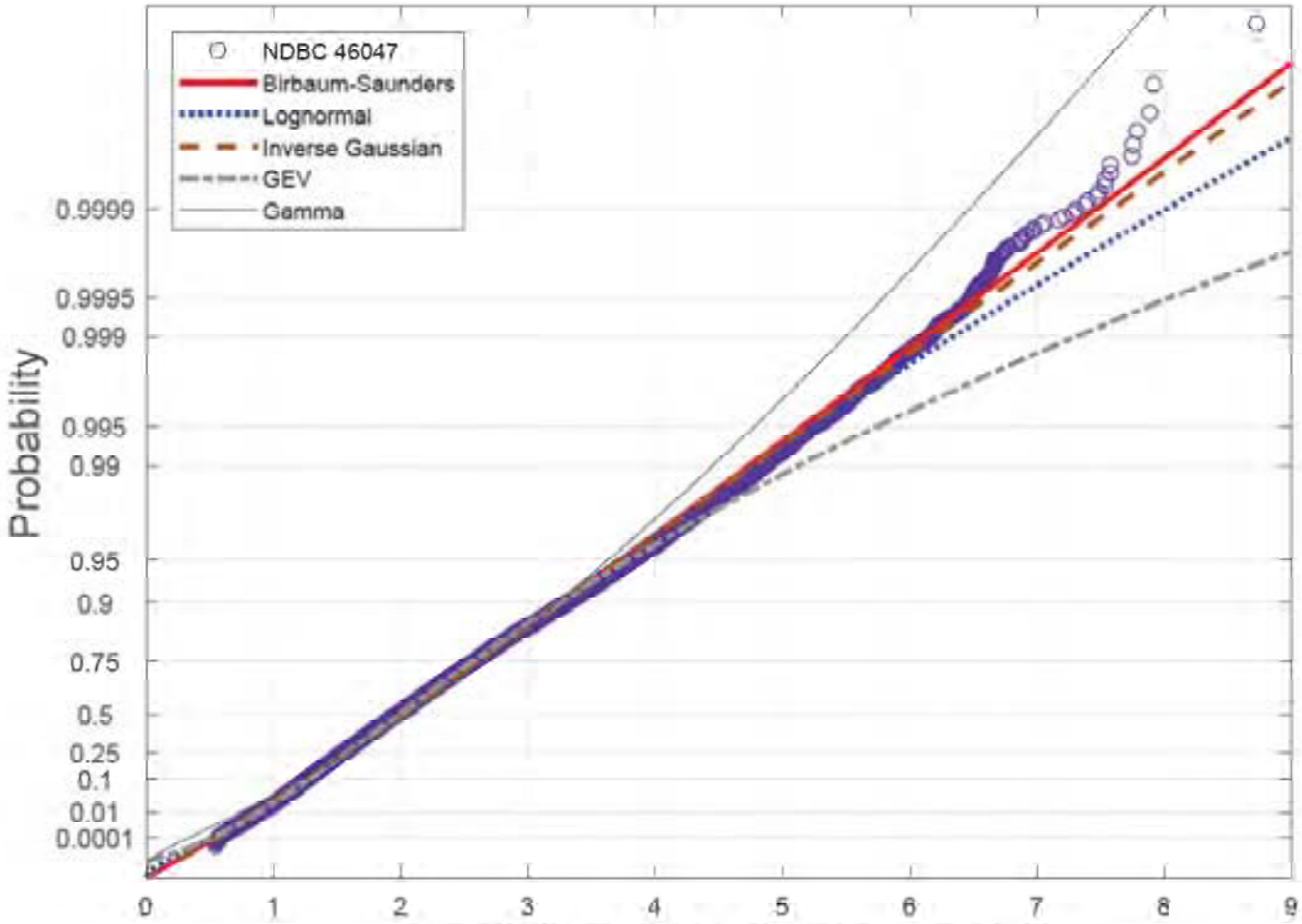


Figure E016. Probability Fit, Wave Height, m, 46047

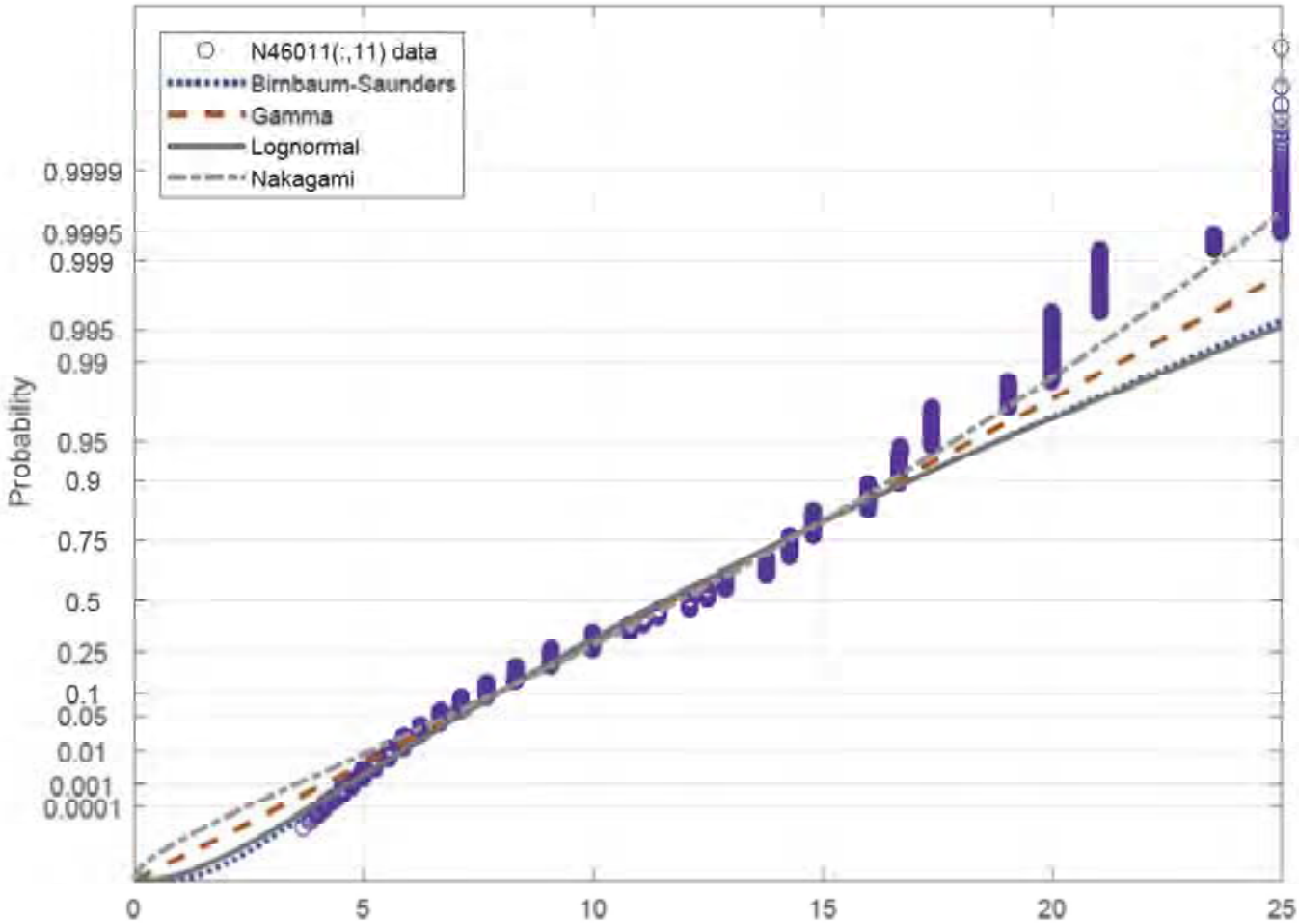


Figure E017. Probability Fit, Wave Energy, kW/m, 46047

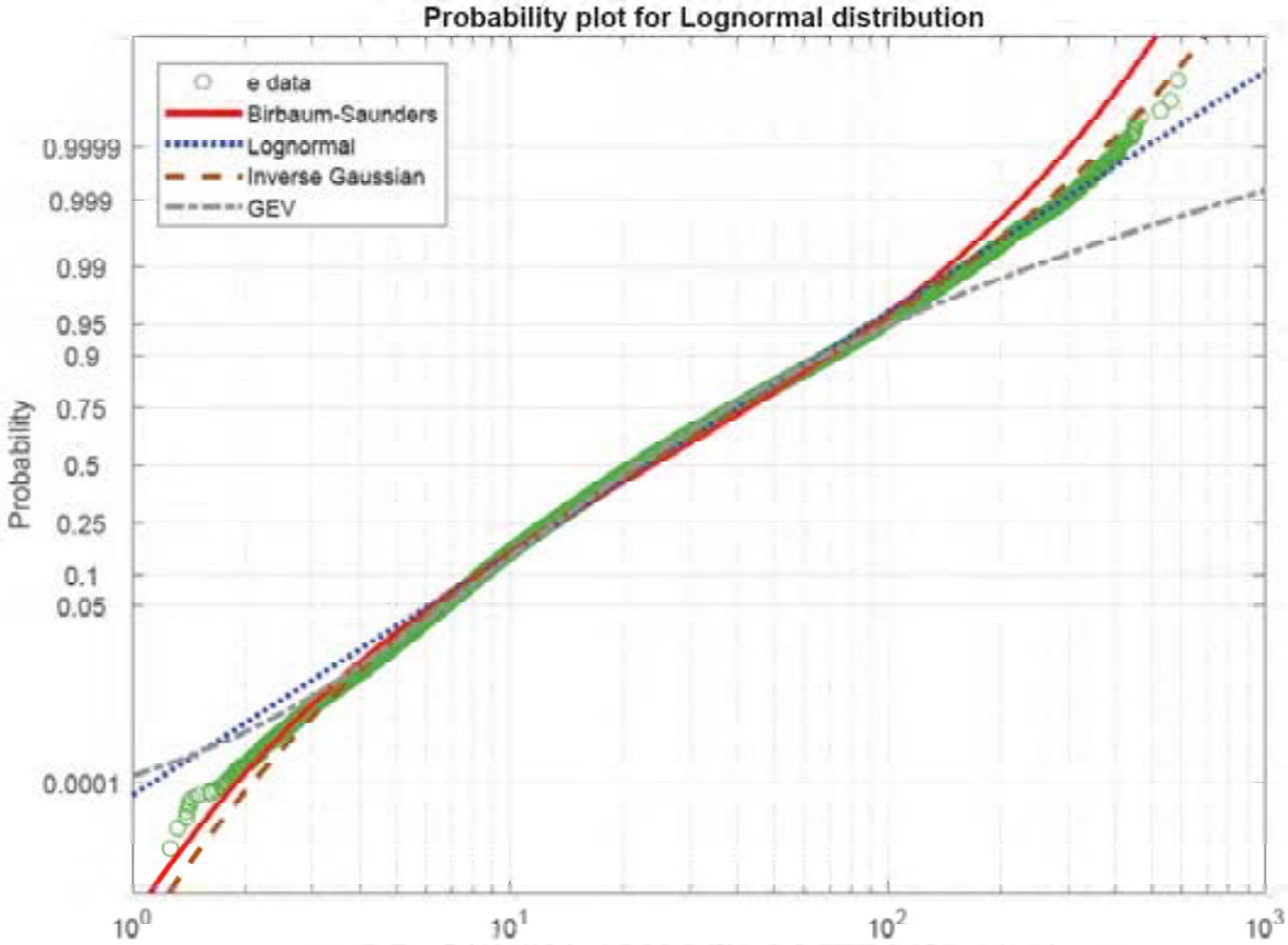


Figure E018. Probability Fit, Wave Energy, kW/m, 46047

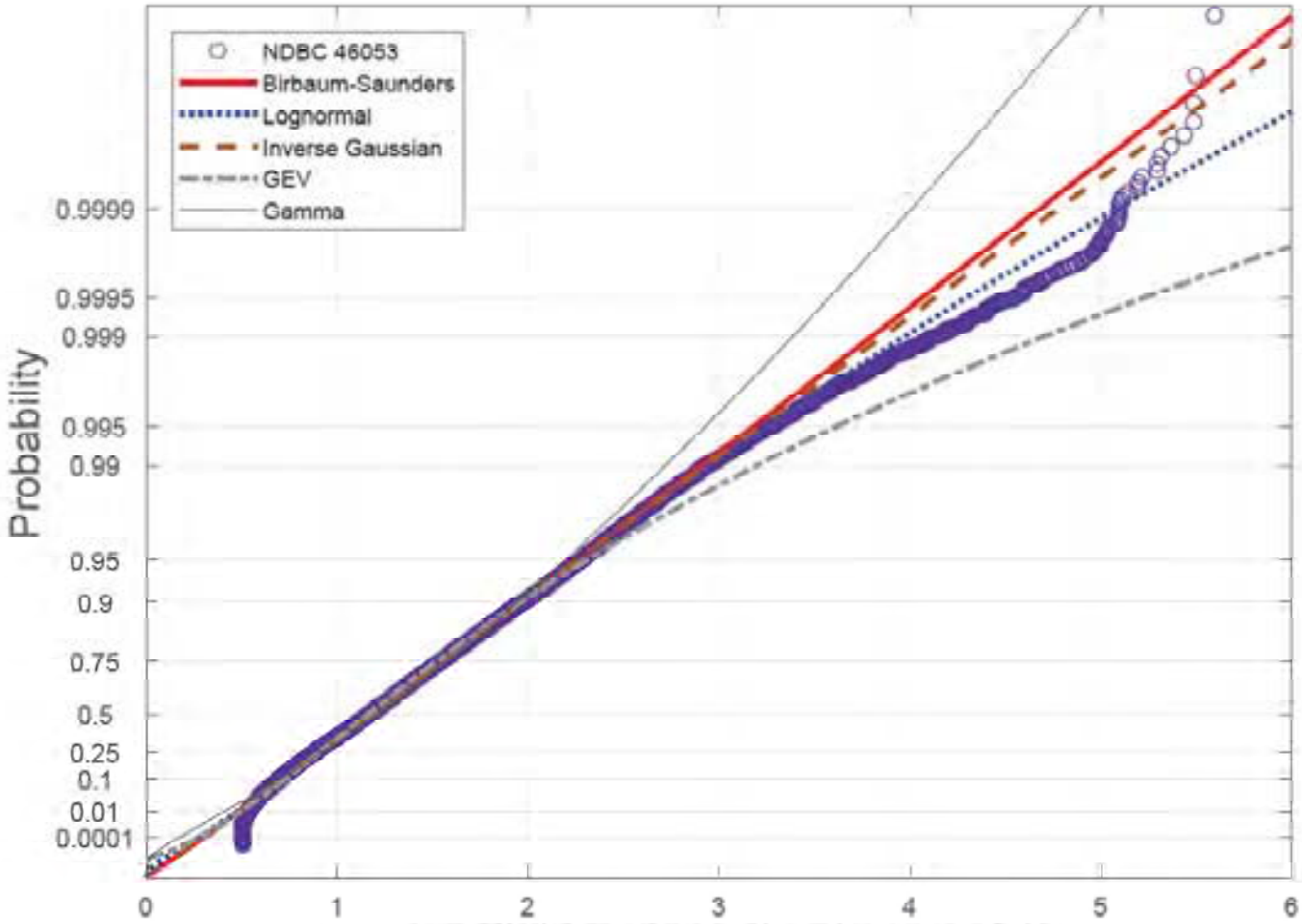


Figure E019, Probability Fit, Wave Height, m, 46053

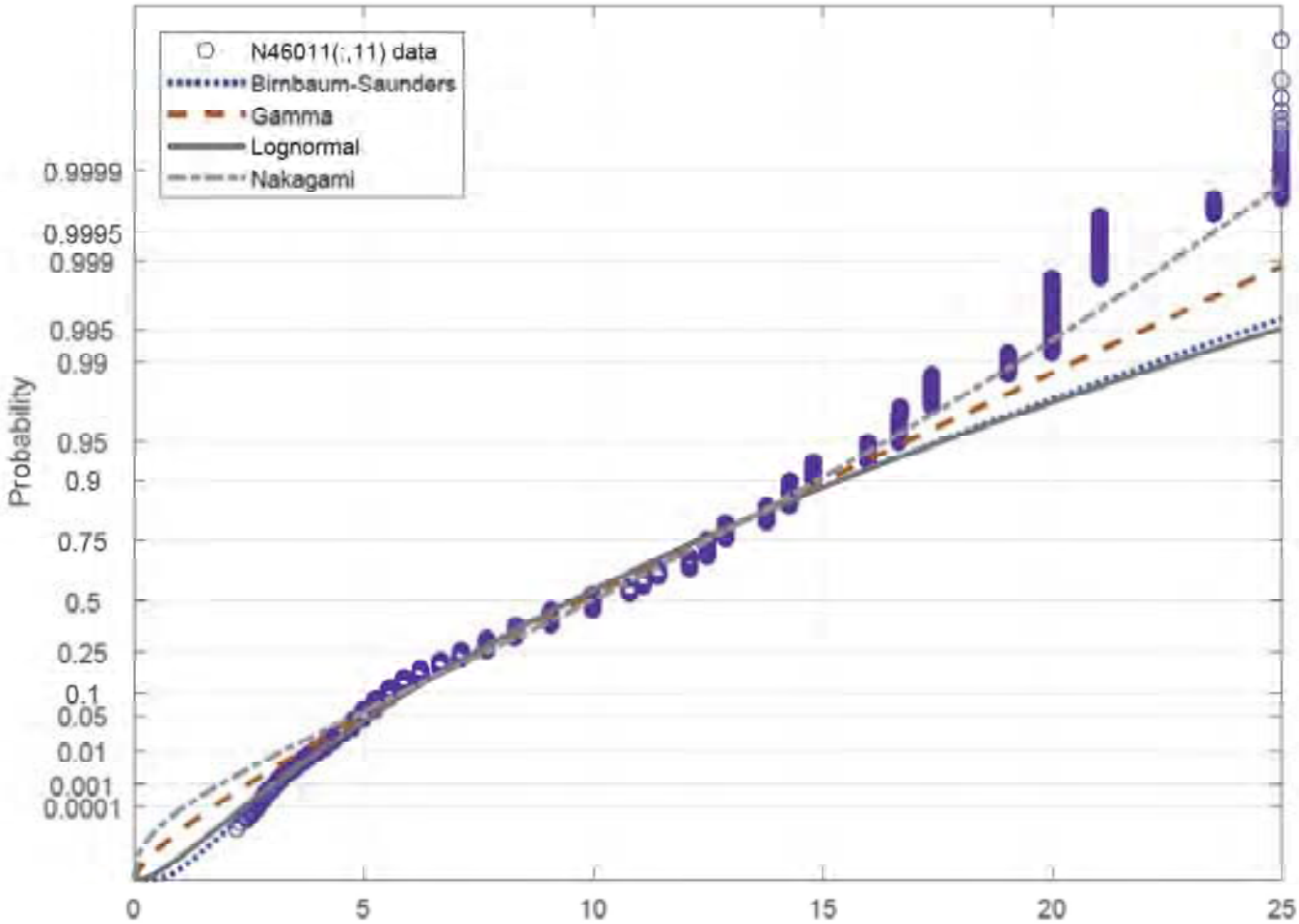


Figure E020. Probability Fit, Wave Energy, kW/m, 46053

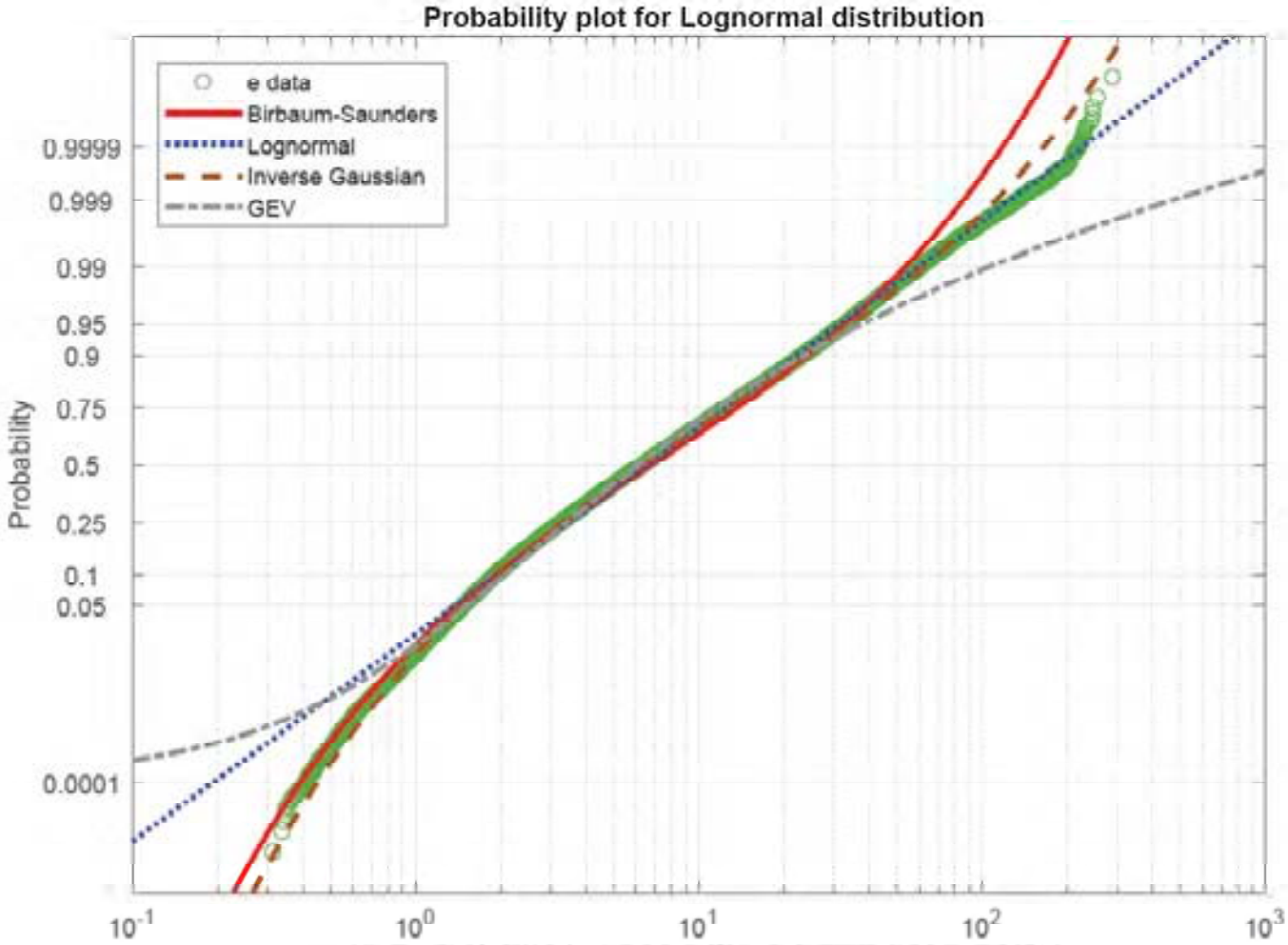


Figure E021. Probability Fit, Wave Energy, kW/m, 46053

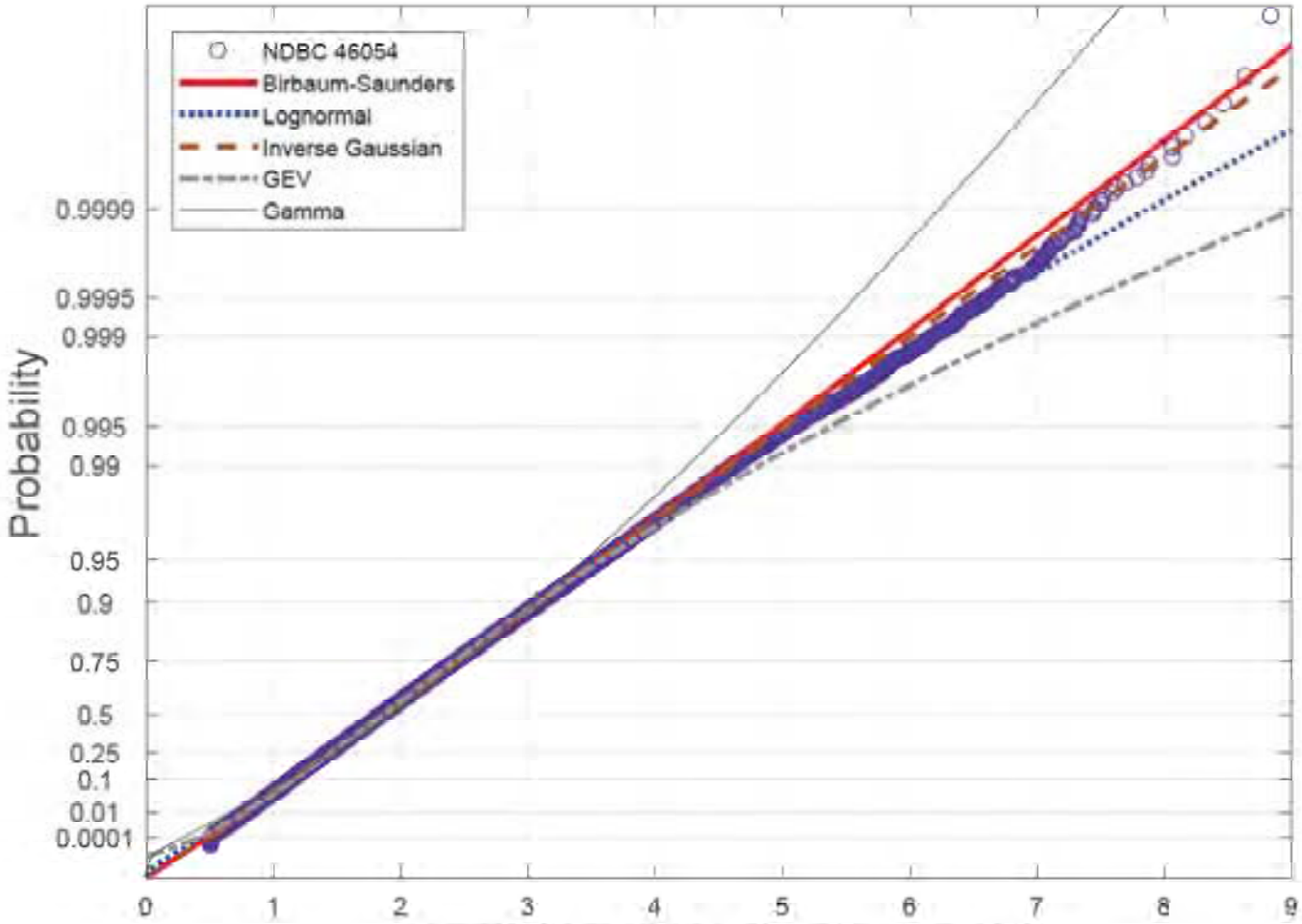


Figure E022. Probability Fit, Wave Height, m, 46054

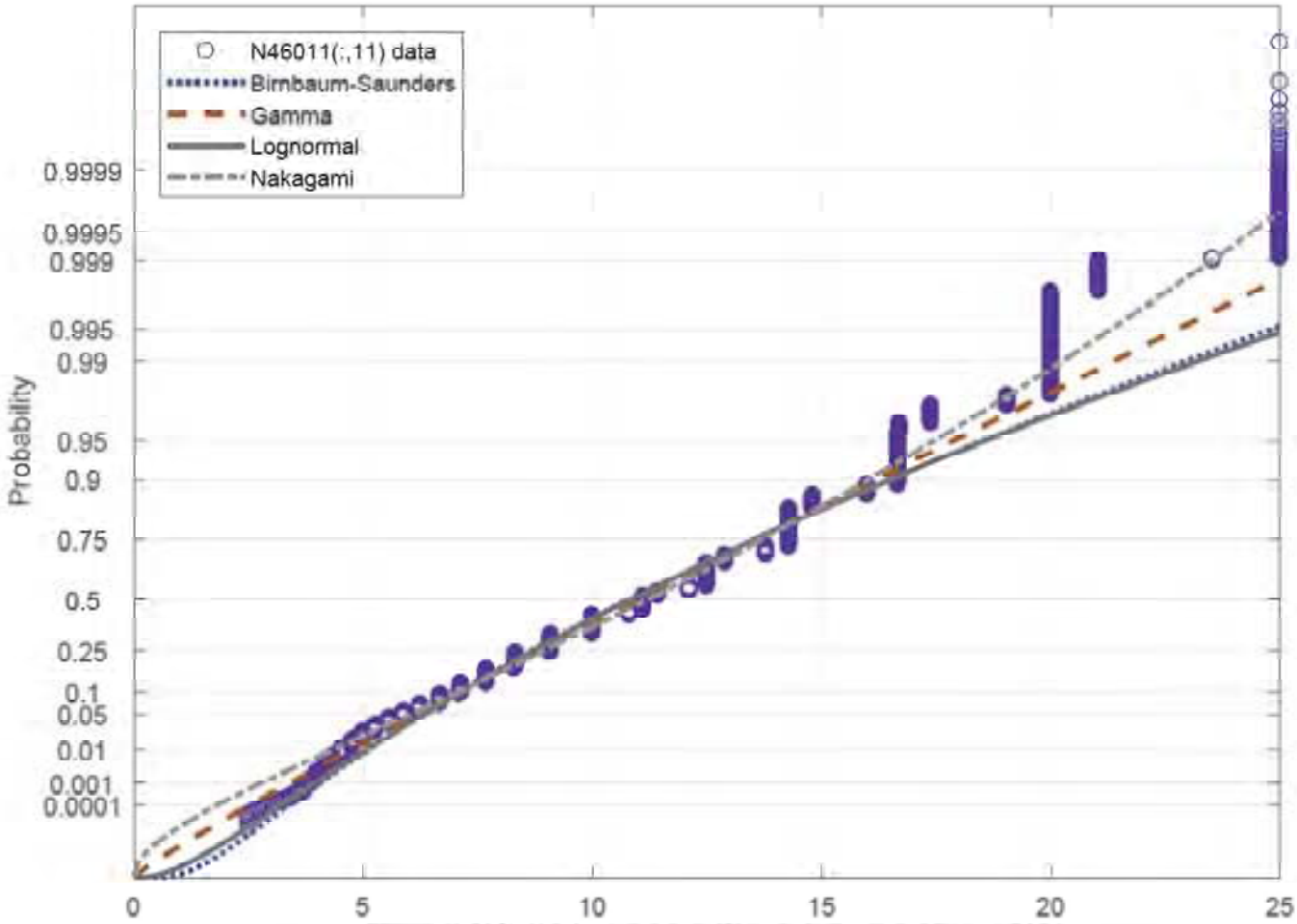


Figure E023. Probability Fit, Wave Energy, kW/m, 46054

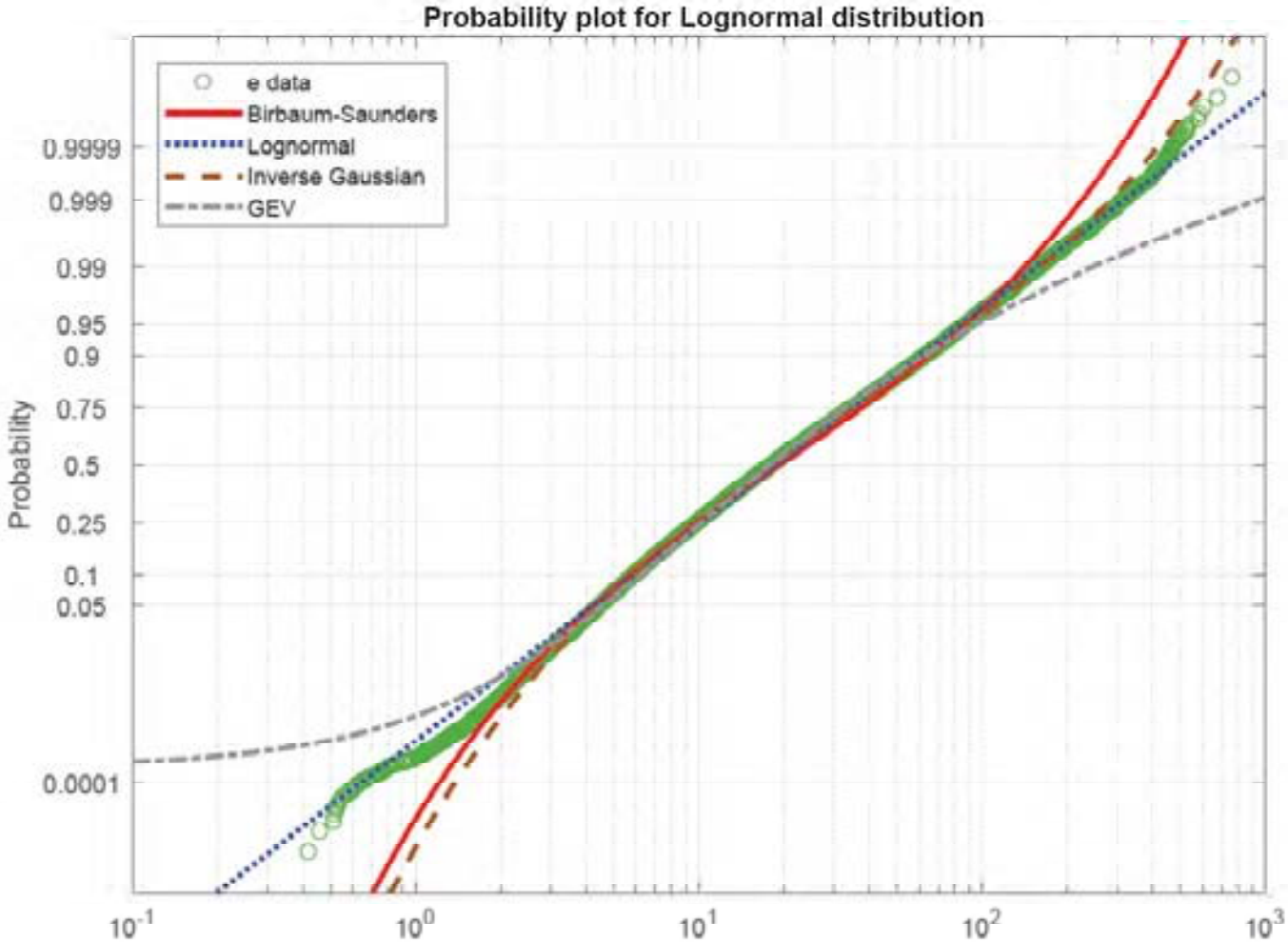


Figure E024. Probability Fit, Wave Energy, kW/m, 46054

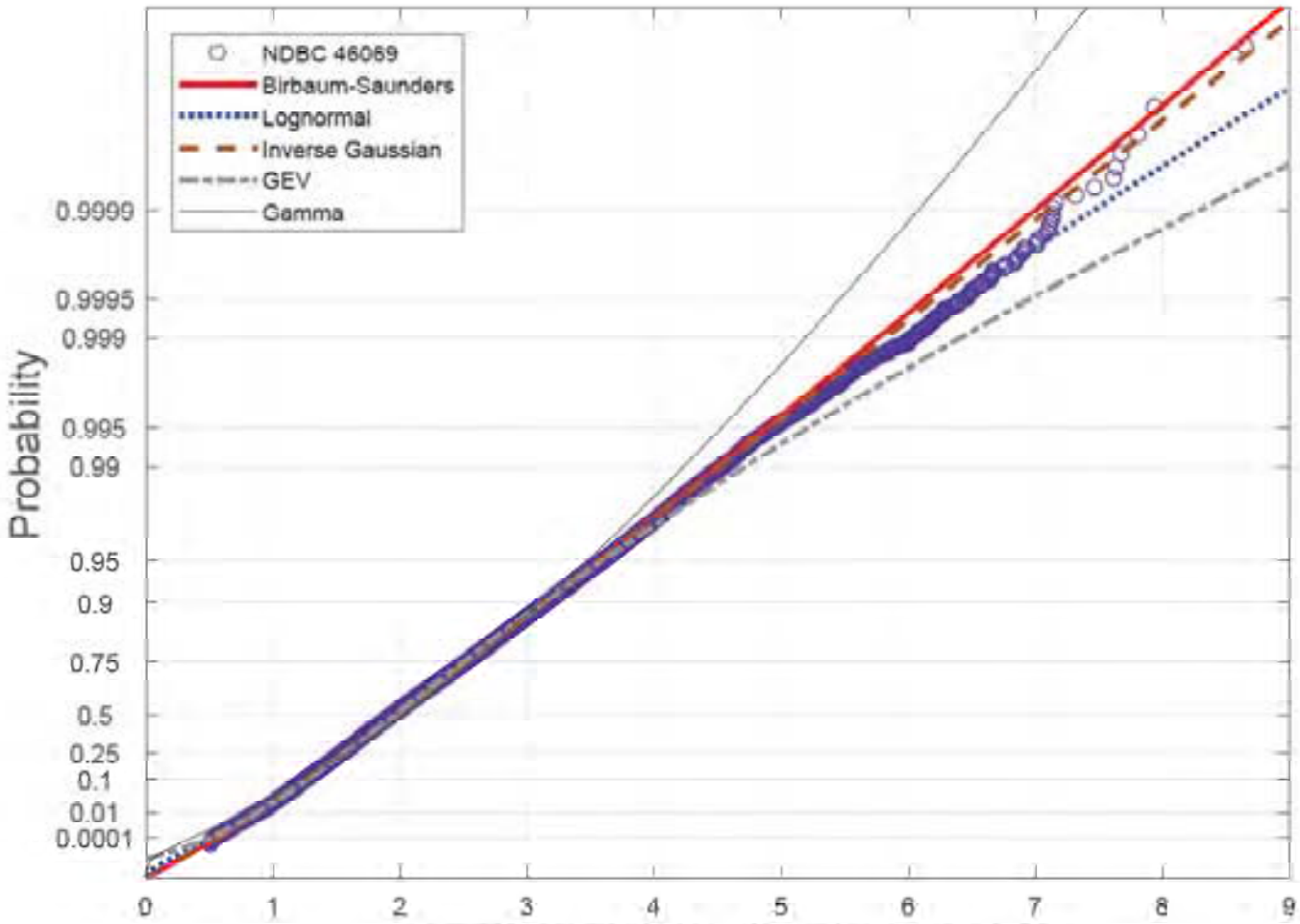


Figure E025. Probability Fit, Wave Height, m, 46069

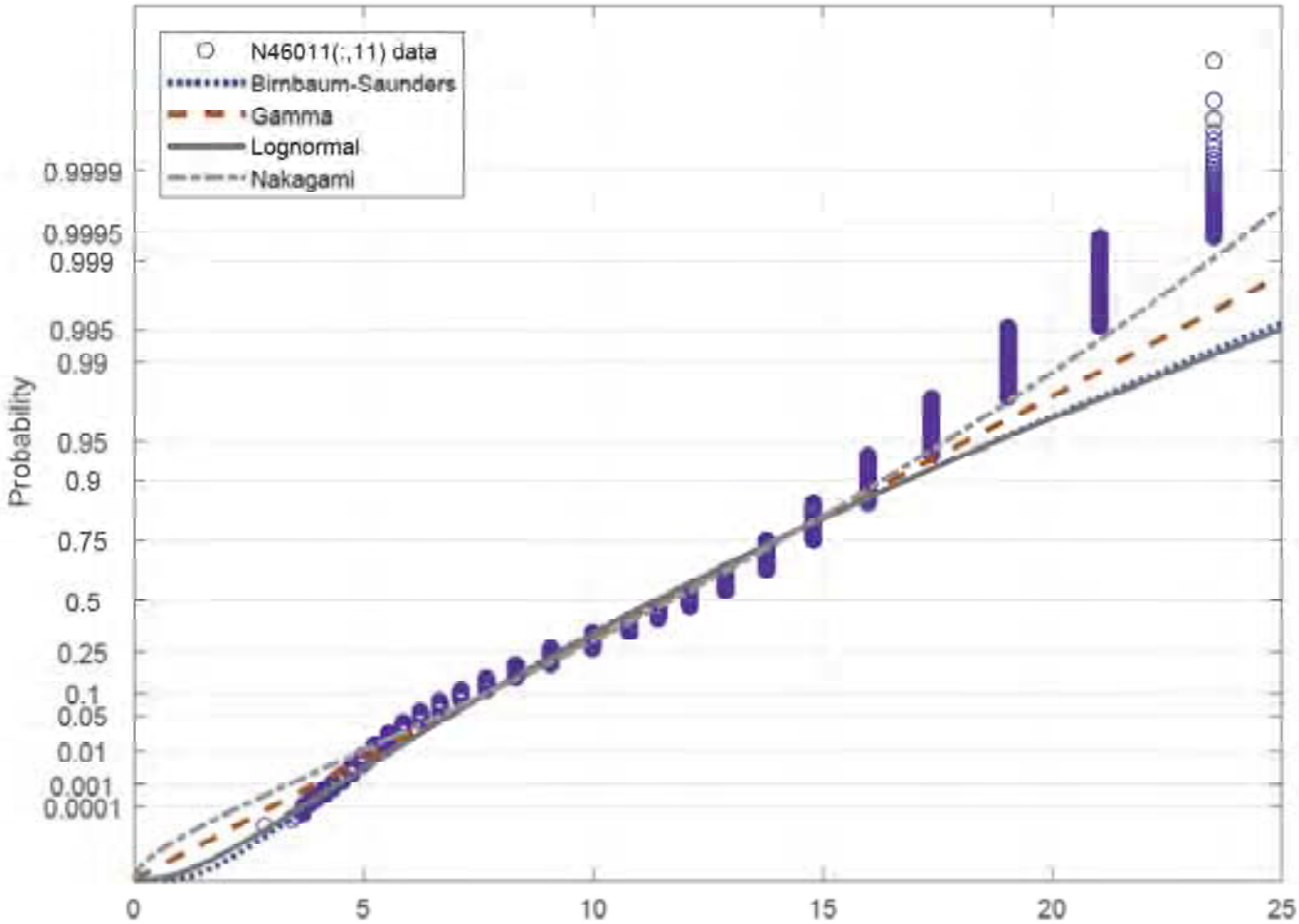


Figure E026. Probability Fit, Wave Energy, kW/m, 46069

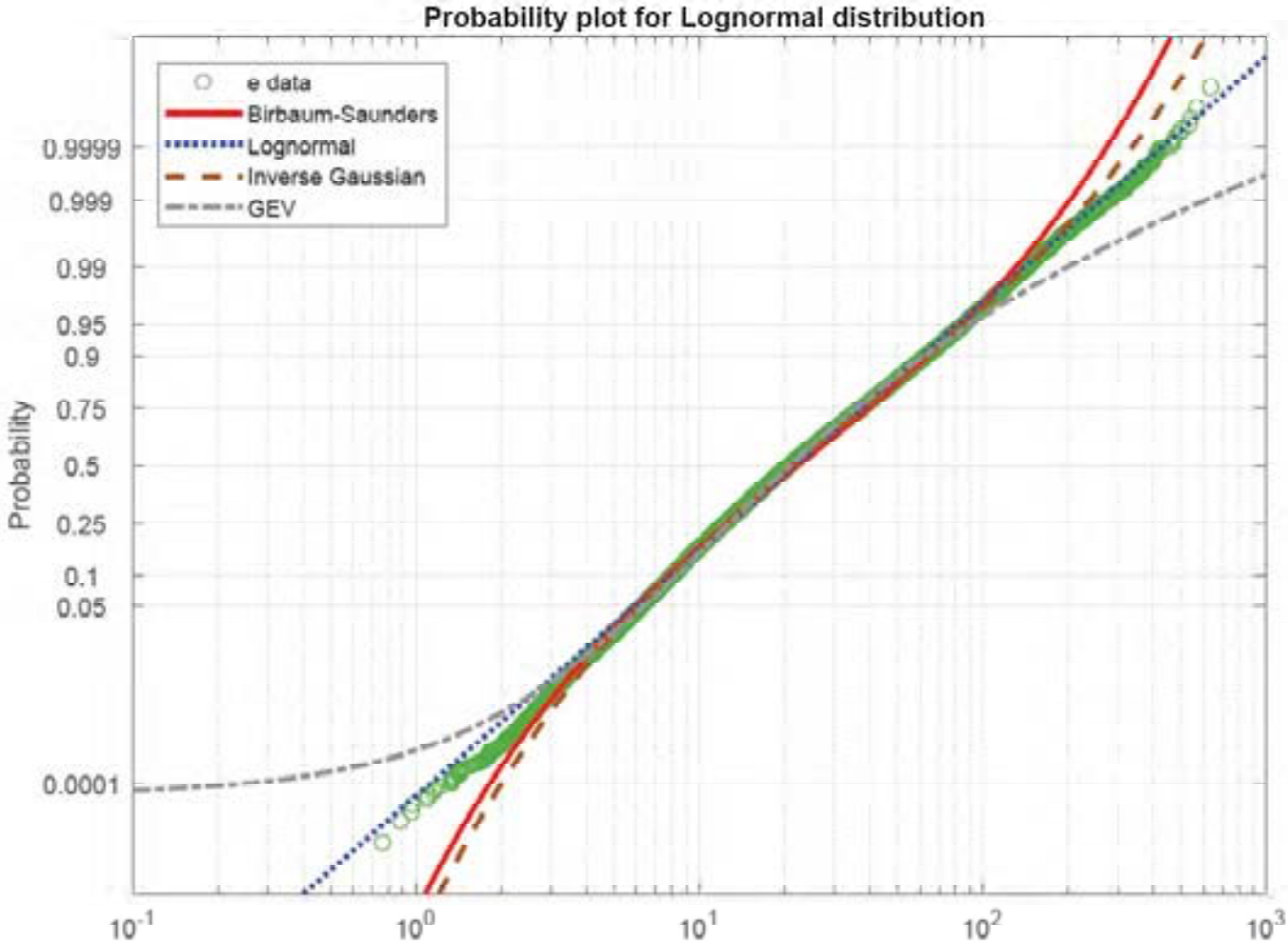


Figure E027. Probability Fit, Wave Energy, kW/m, 46069

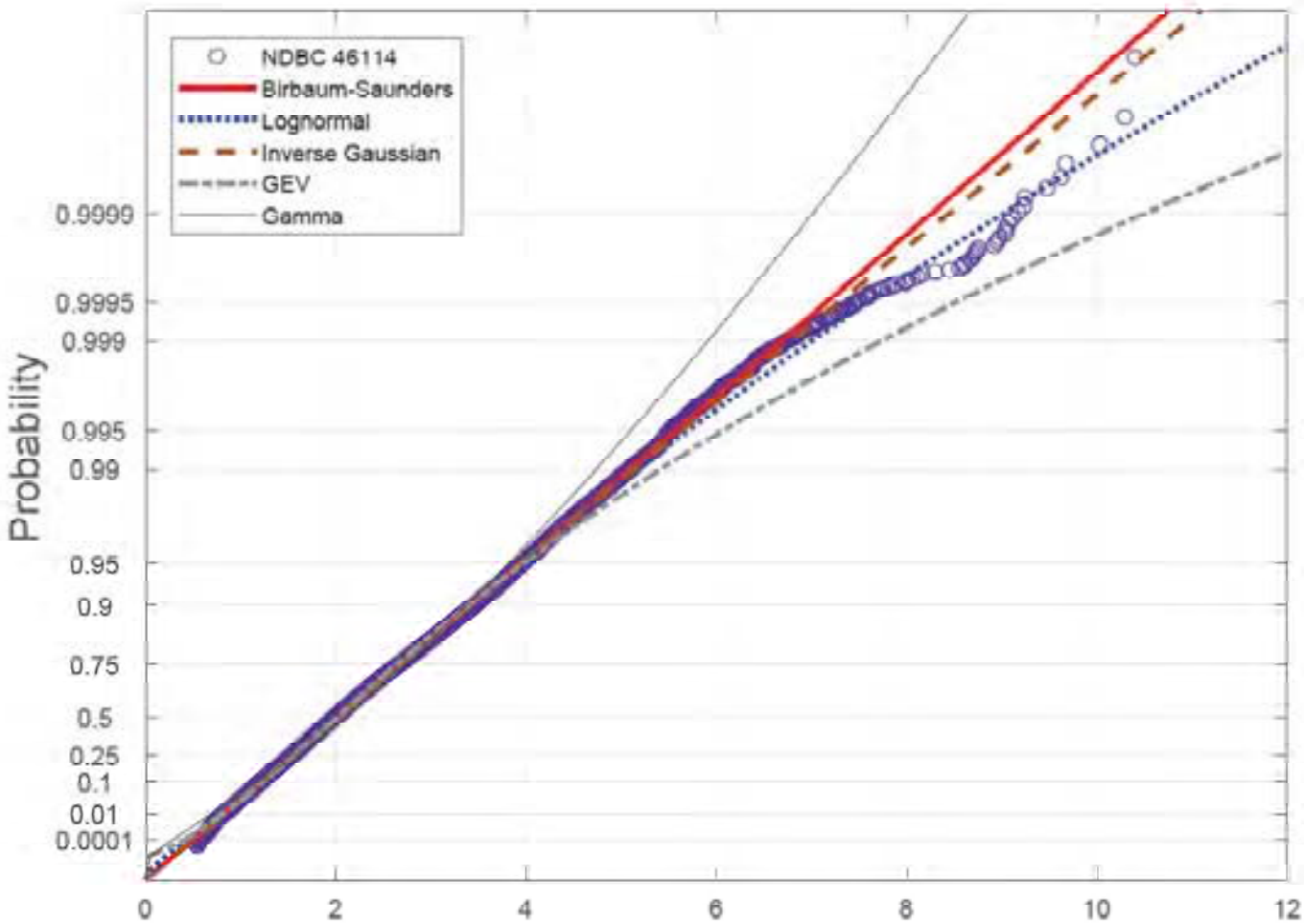


Figure E028. Probability Fit, Wave Height, m, 46114

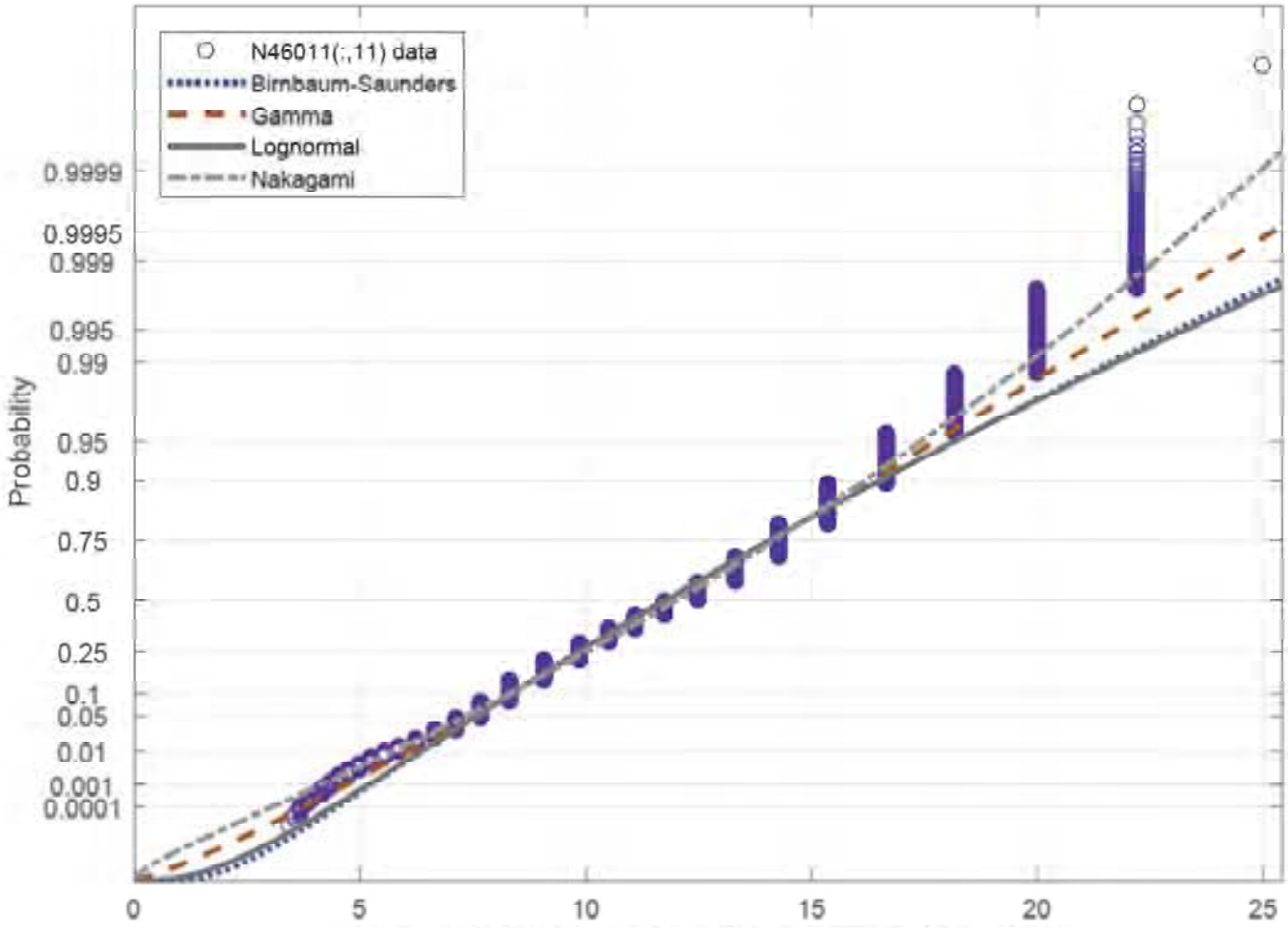


Figure E029. Probability Fit, Wave Energy, kW/m, 46114

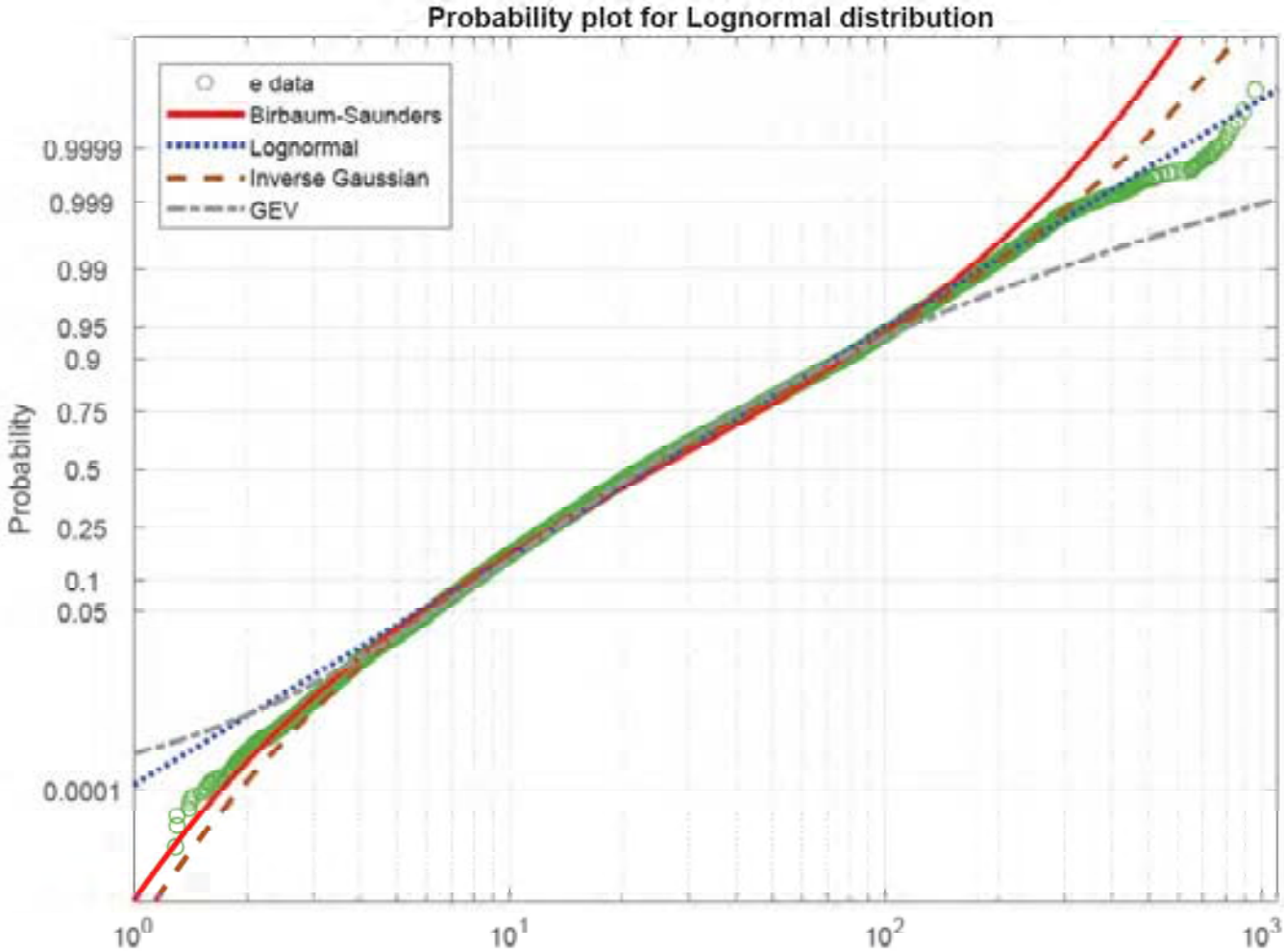


Figure E030. Probability Fit, Wave Energy, kW/m, 46114

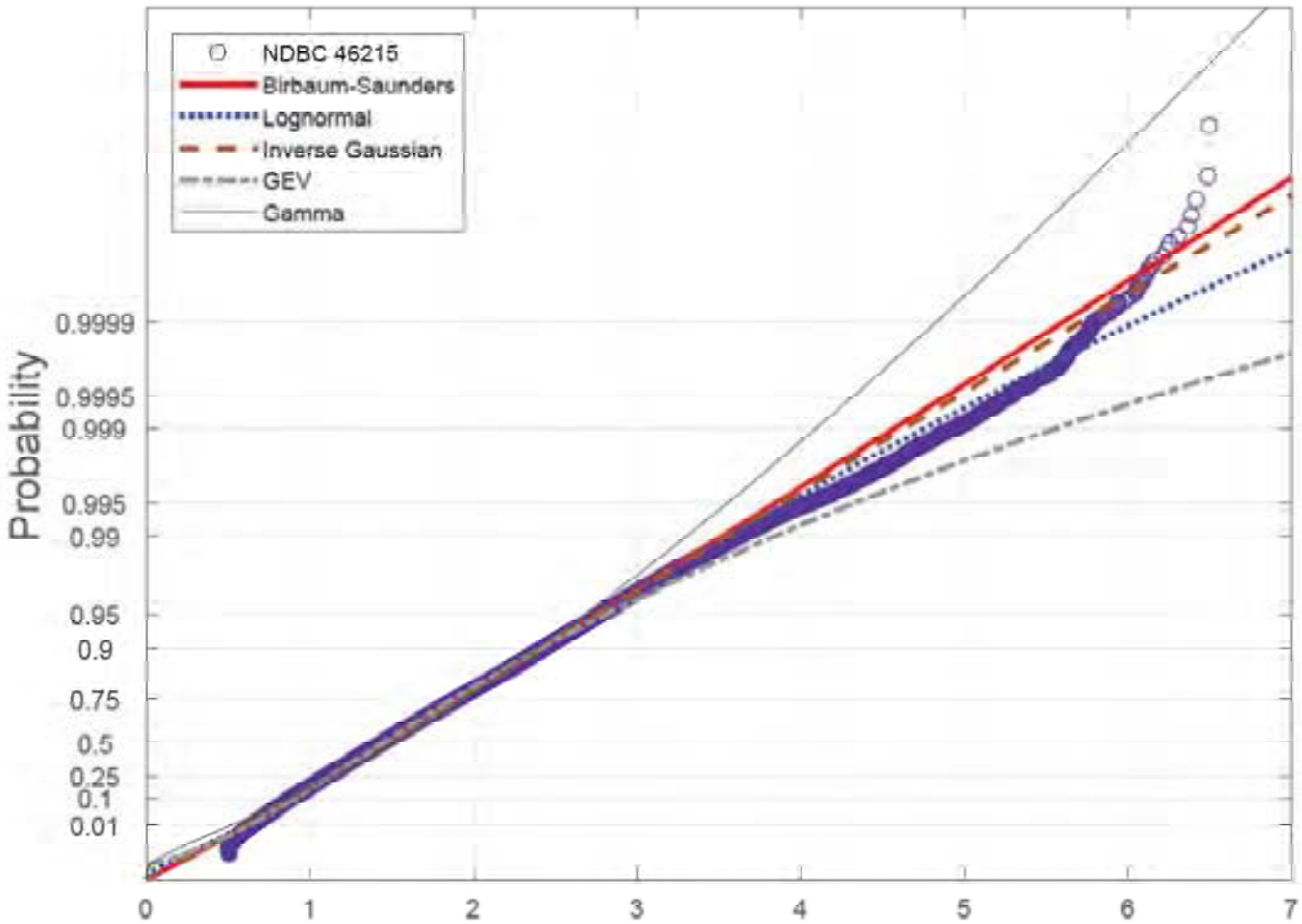


Figure E031, Probability Fit, Wave Height, m, 46215

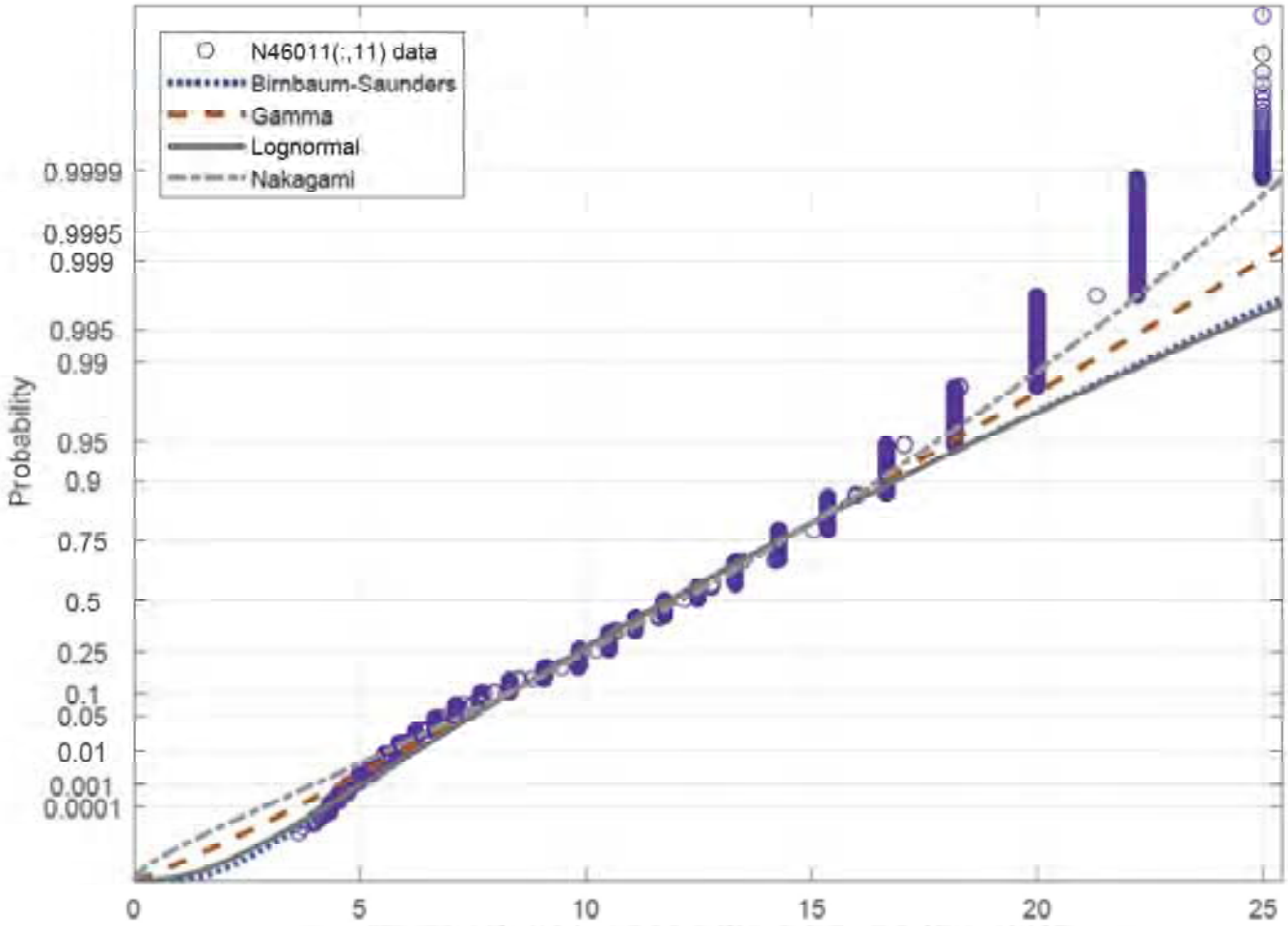


Figure E032. Probability Fit, Wave Energy, kW/m, 46215

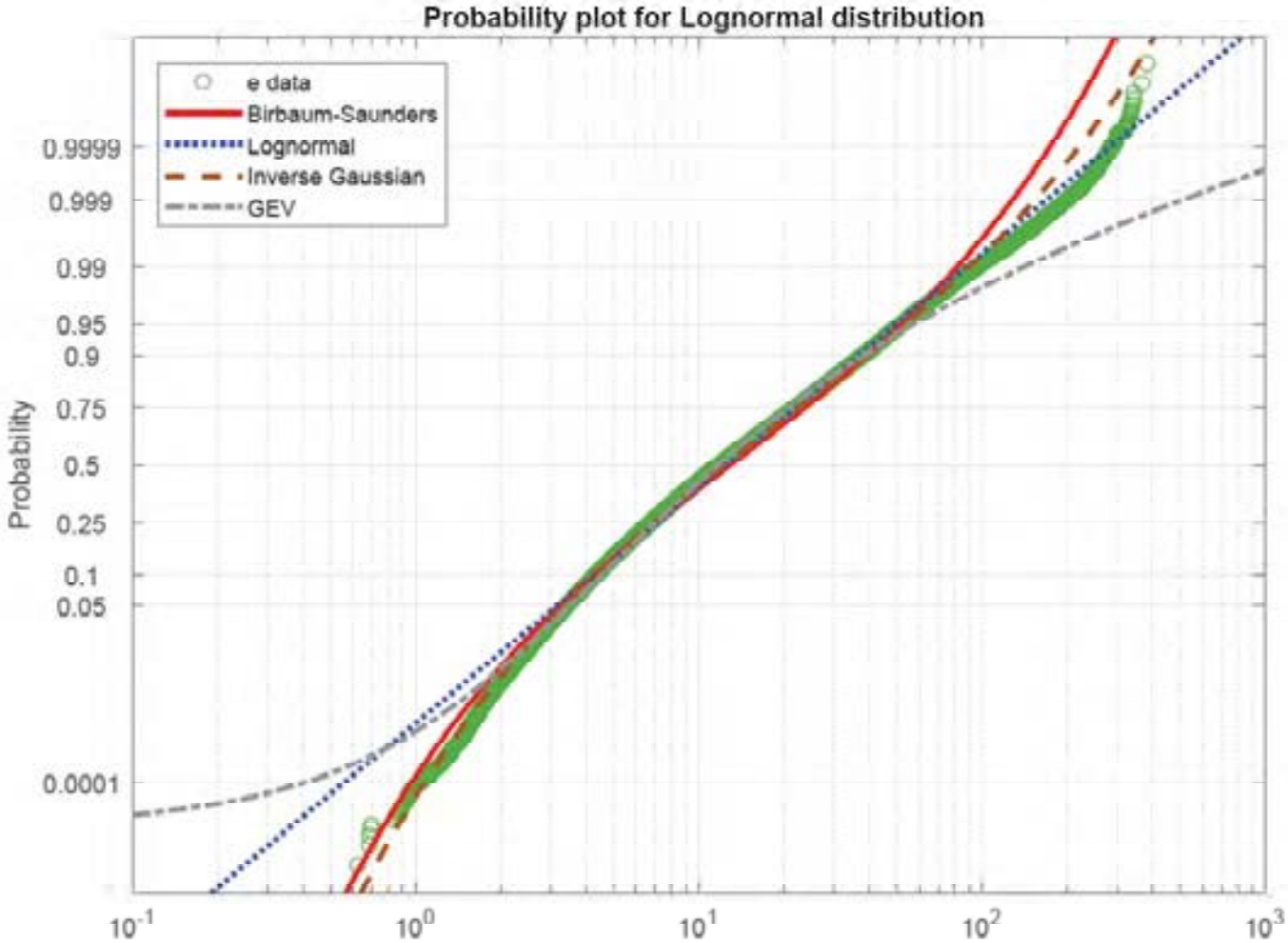


Figure E033. Probability Fit, Wave Energy, kW/m, 46215

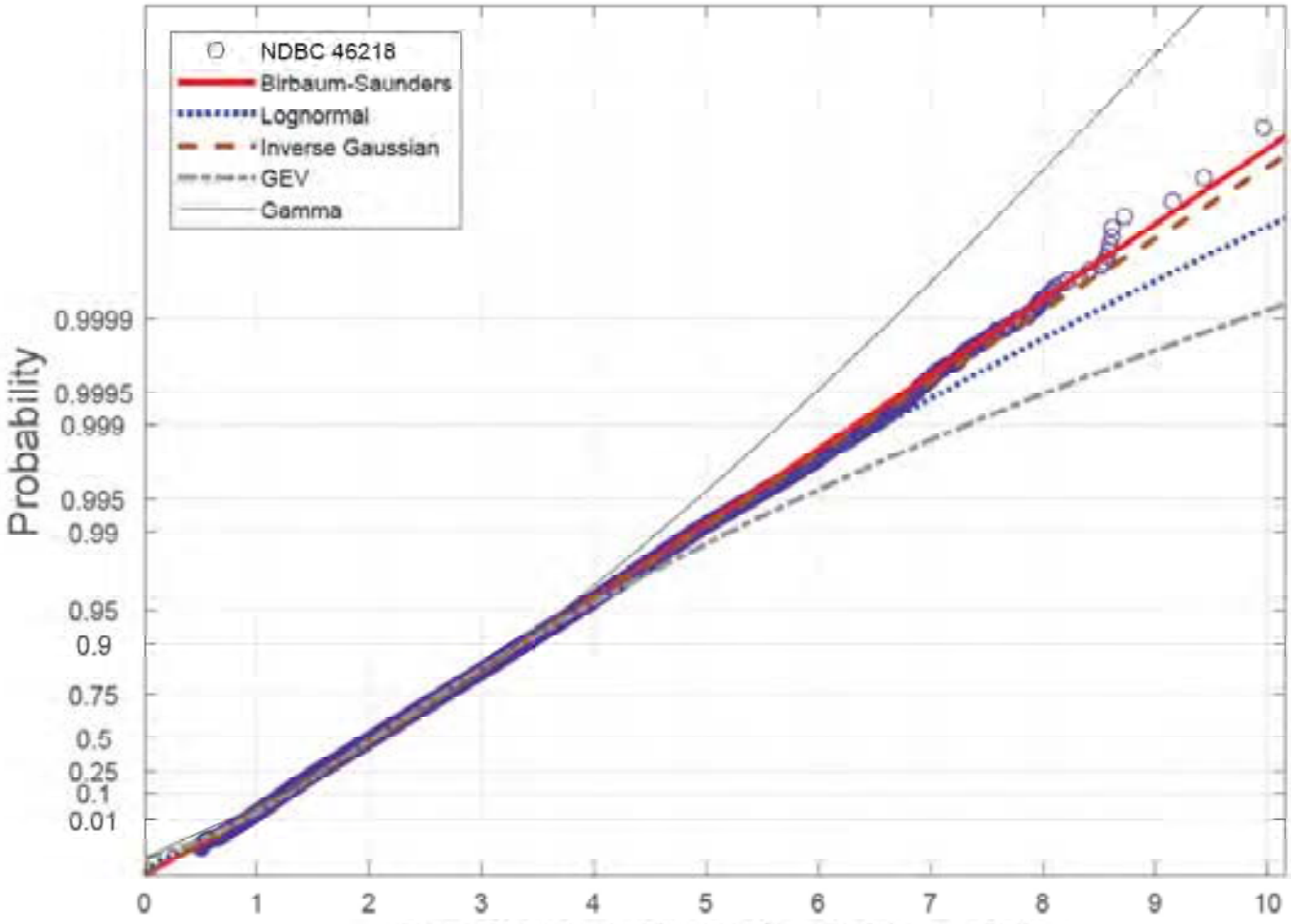


Figure E034, Probability Fit, Wave Height, m, 46218

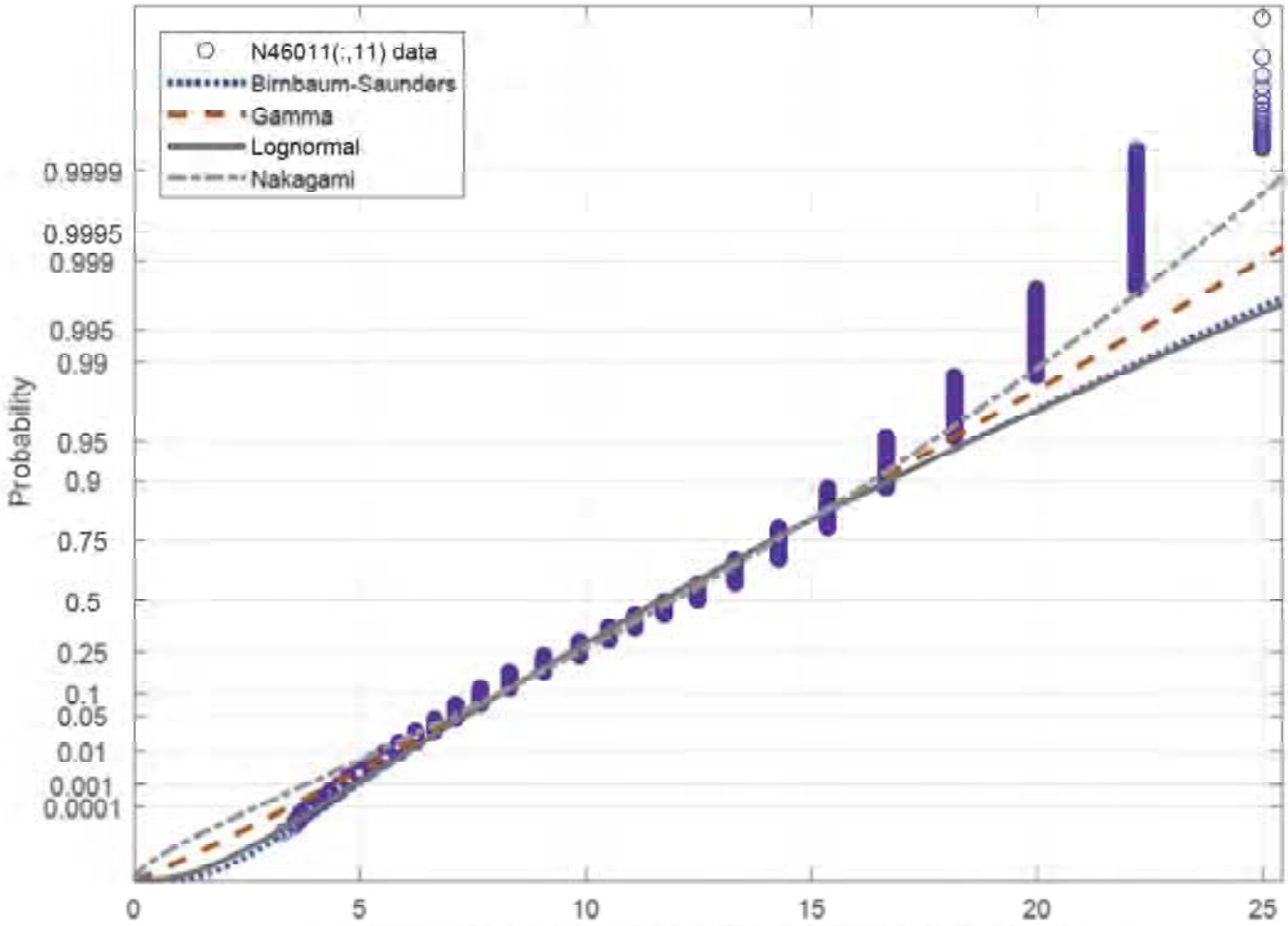


Figure E035. Probability Fit, Wave Energy, kW/m, 46218

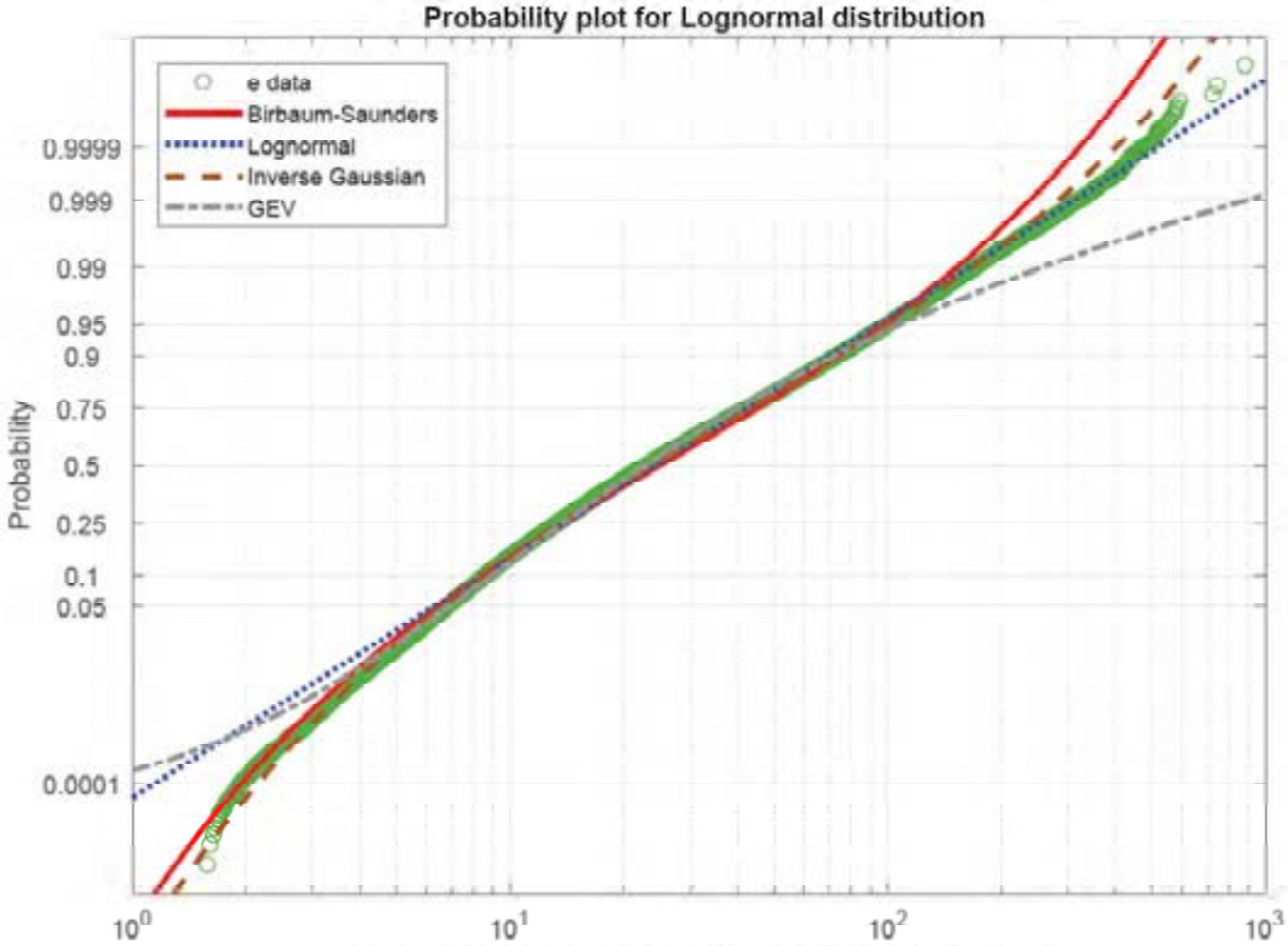


Figure E036. Probability Fit, Wave Energy, kW/m, 46218

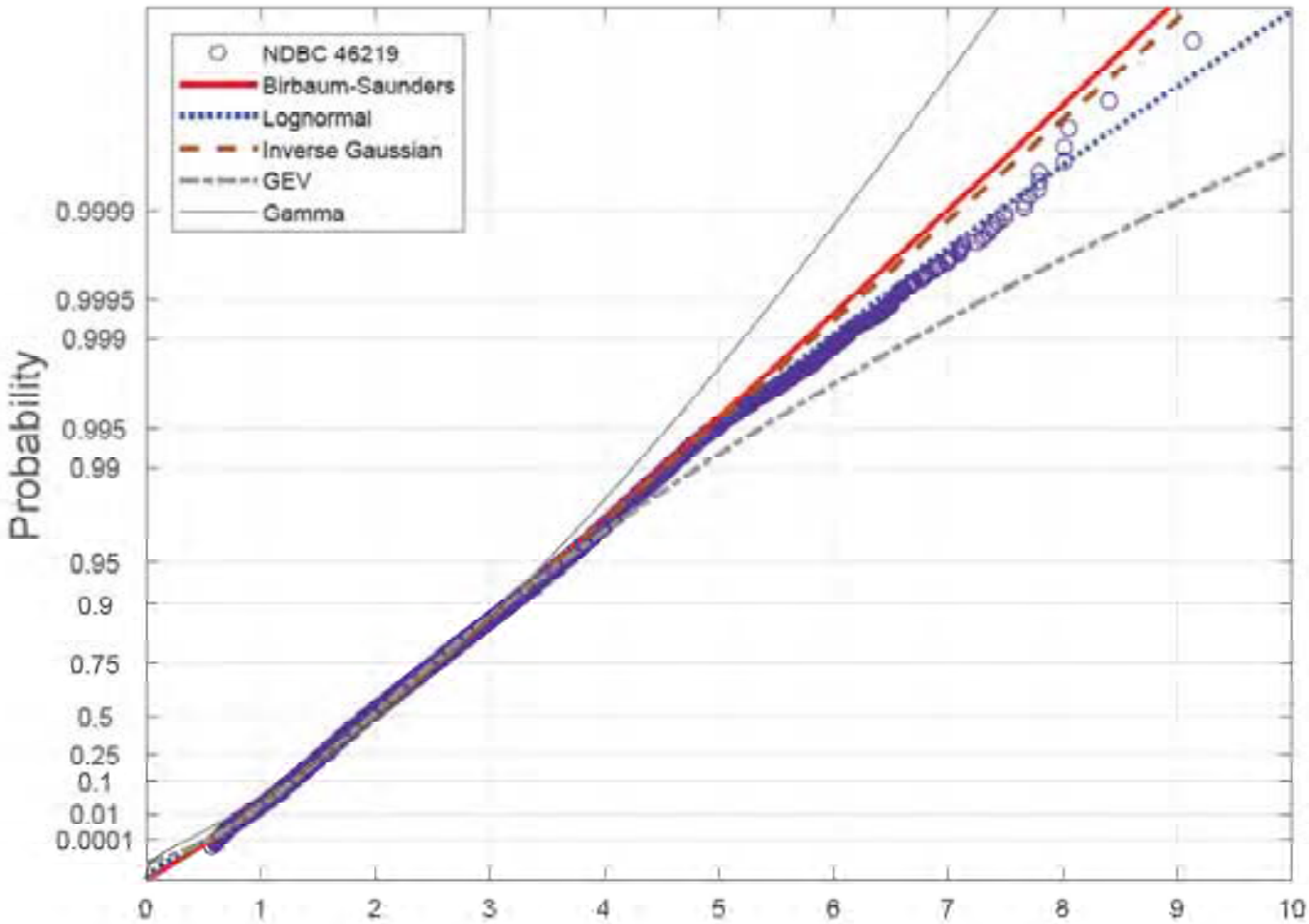


Figure E037, Probability Fit, Wave Height, m, 46219

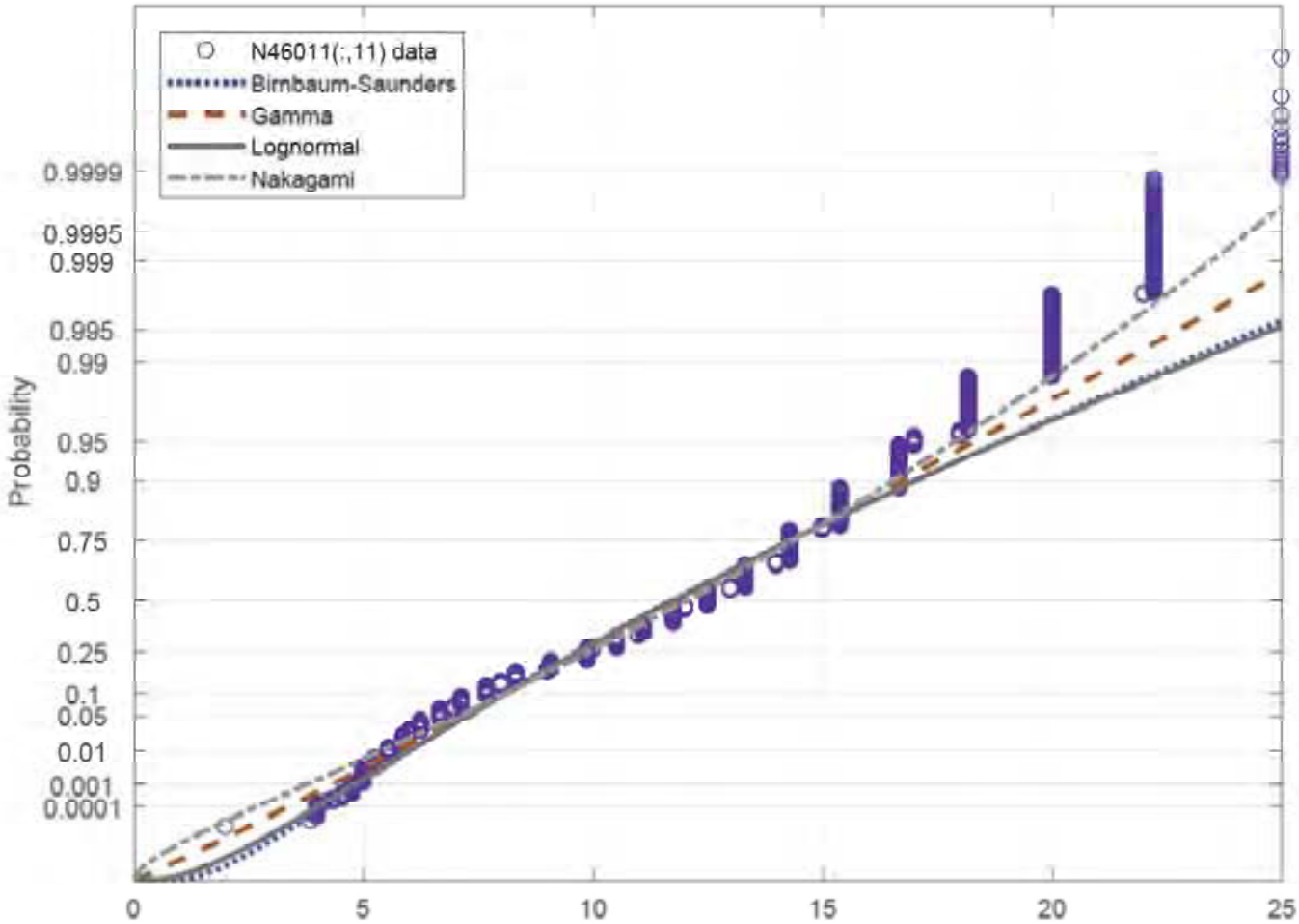


Figure E038. Probability Fit, Wave Energy, kW/m, 46219

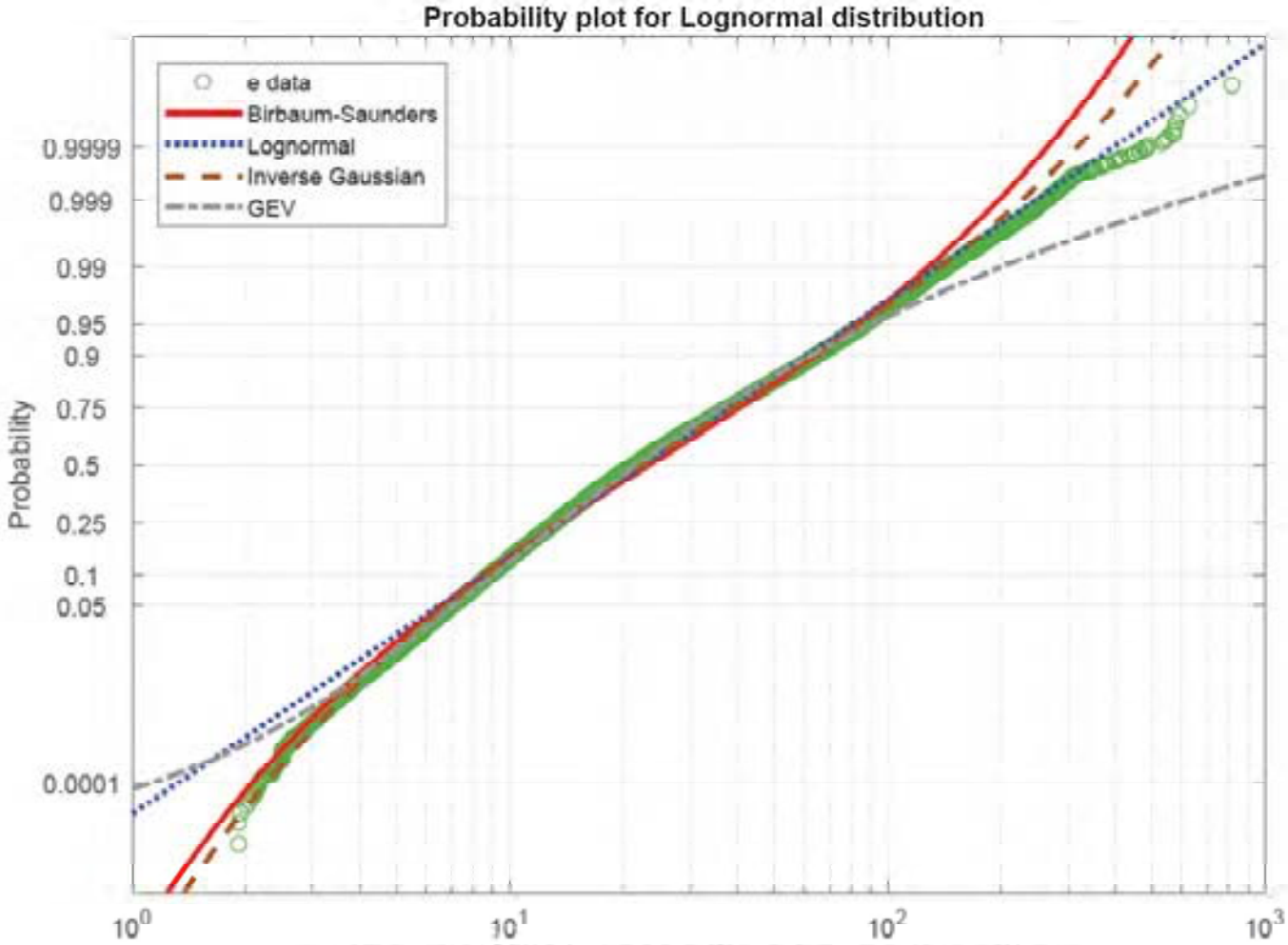


Figure E039. Probability Fit, Wave Energy, kW/m, 46219

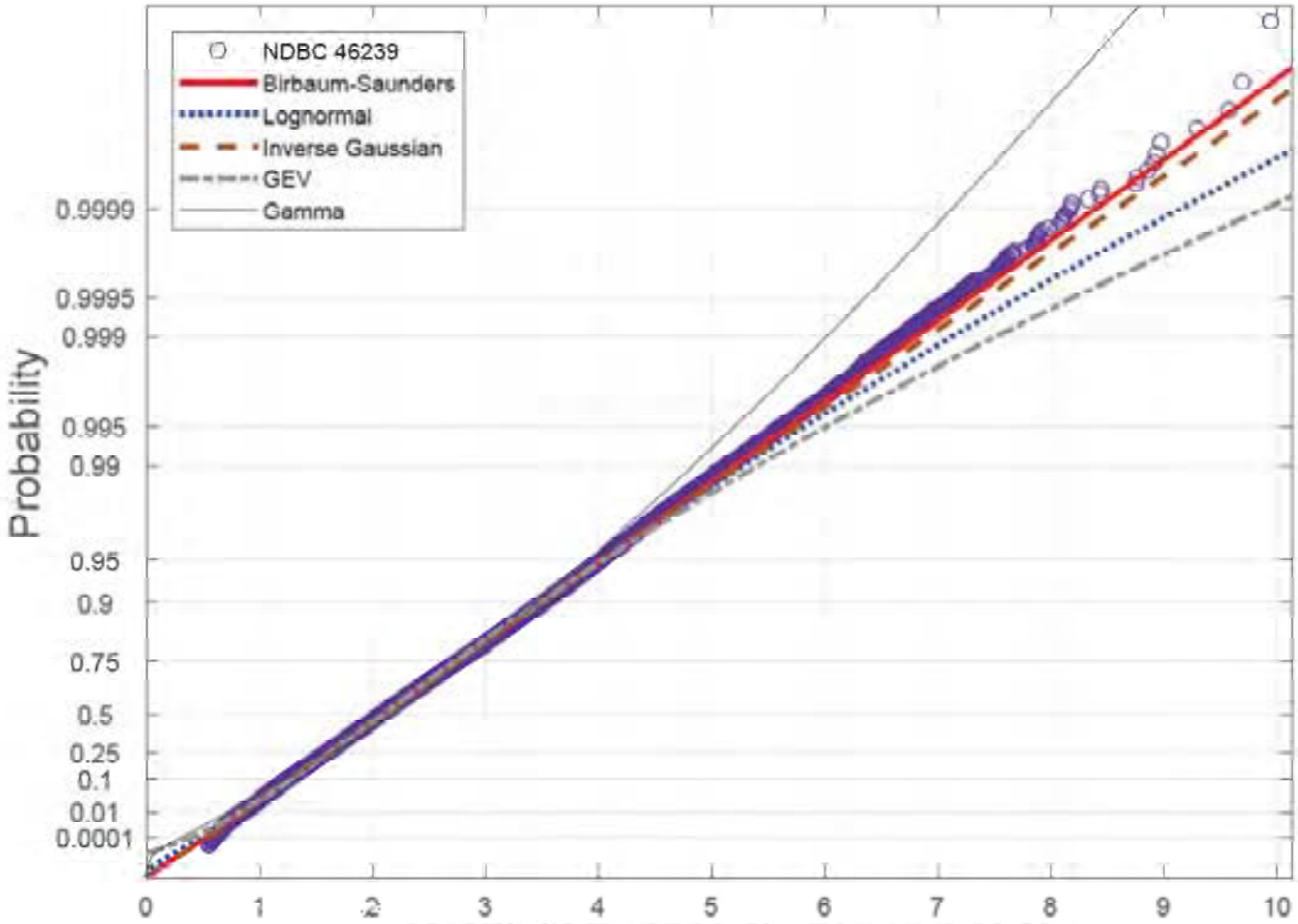


Figure E040. Probability Fit, Wave Height, m, 46239

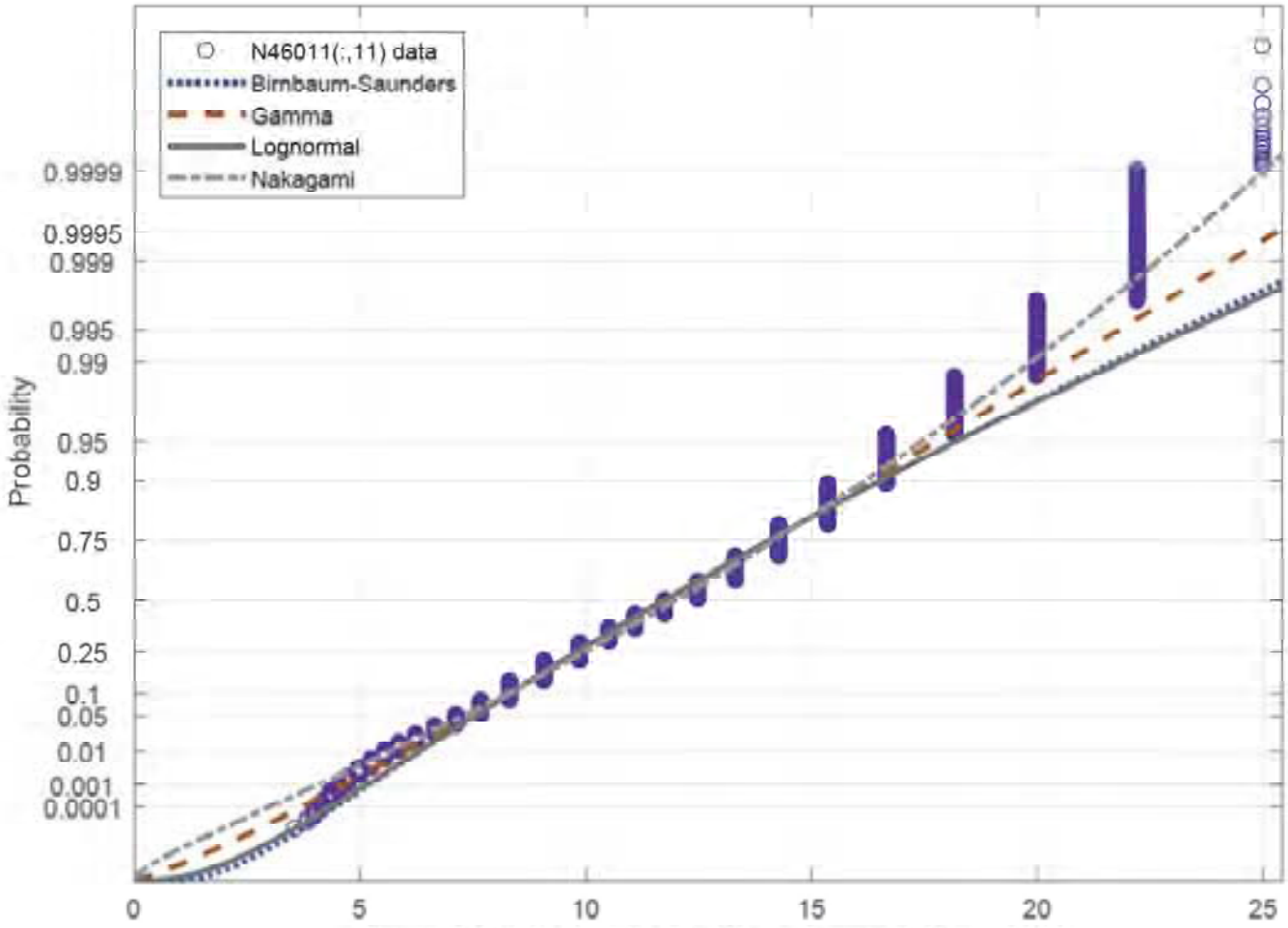


Figure E041. Probability Fit, Wave Energy, kW/m, 46239

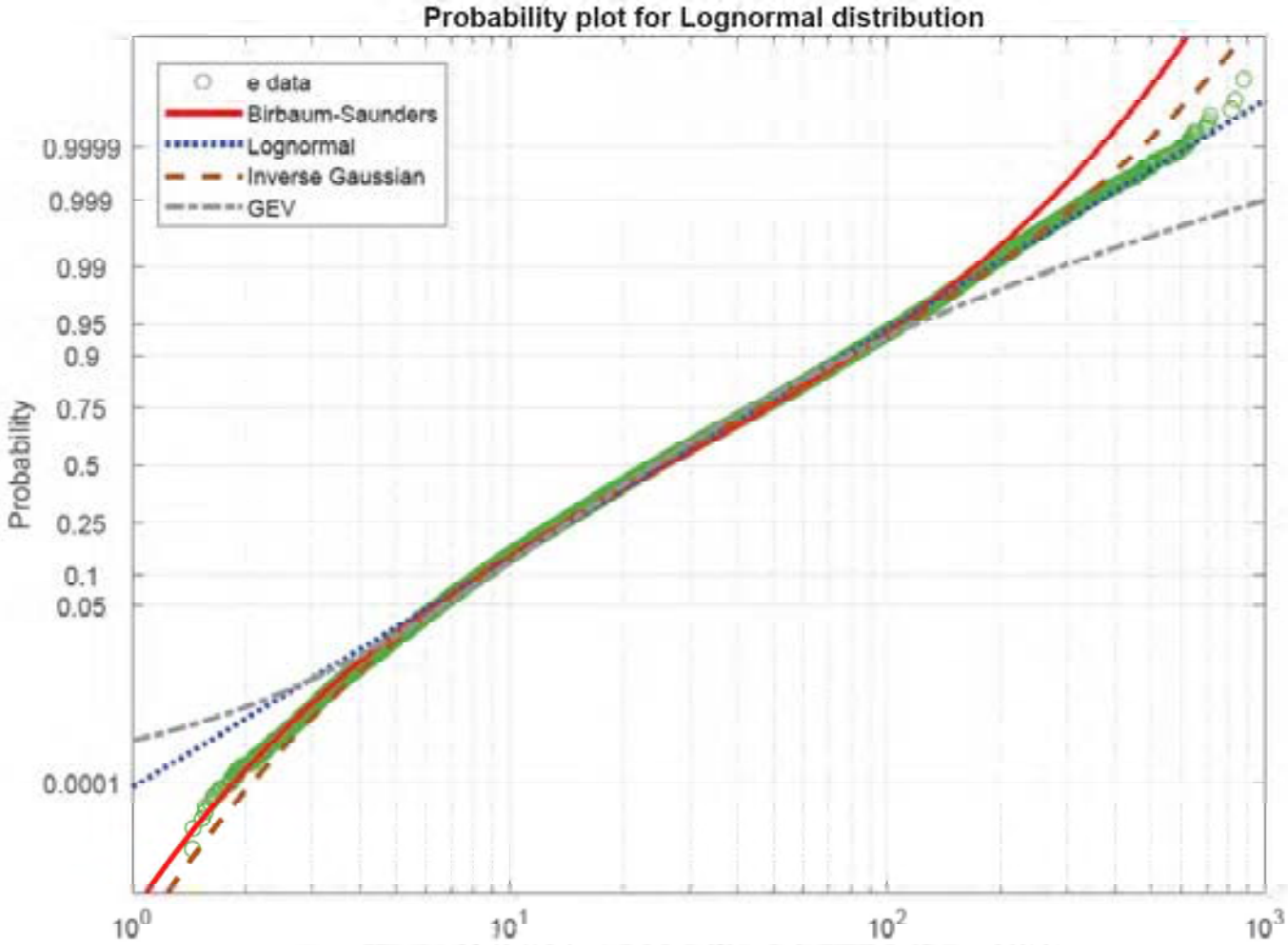


Figure E042. Probability Fit, Wave Energy, kW/m, 46239

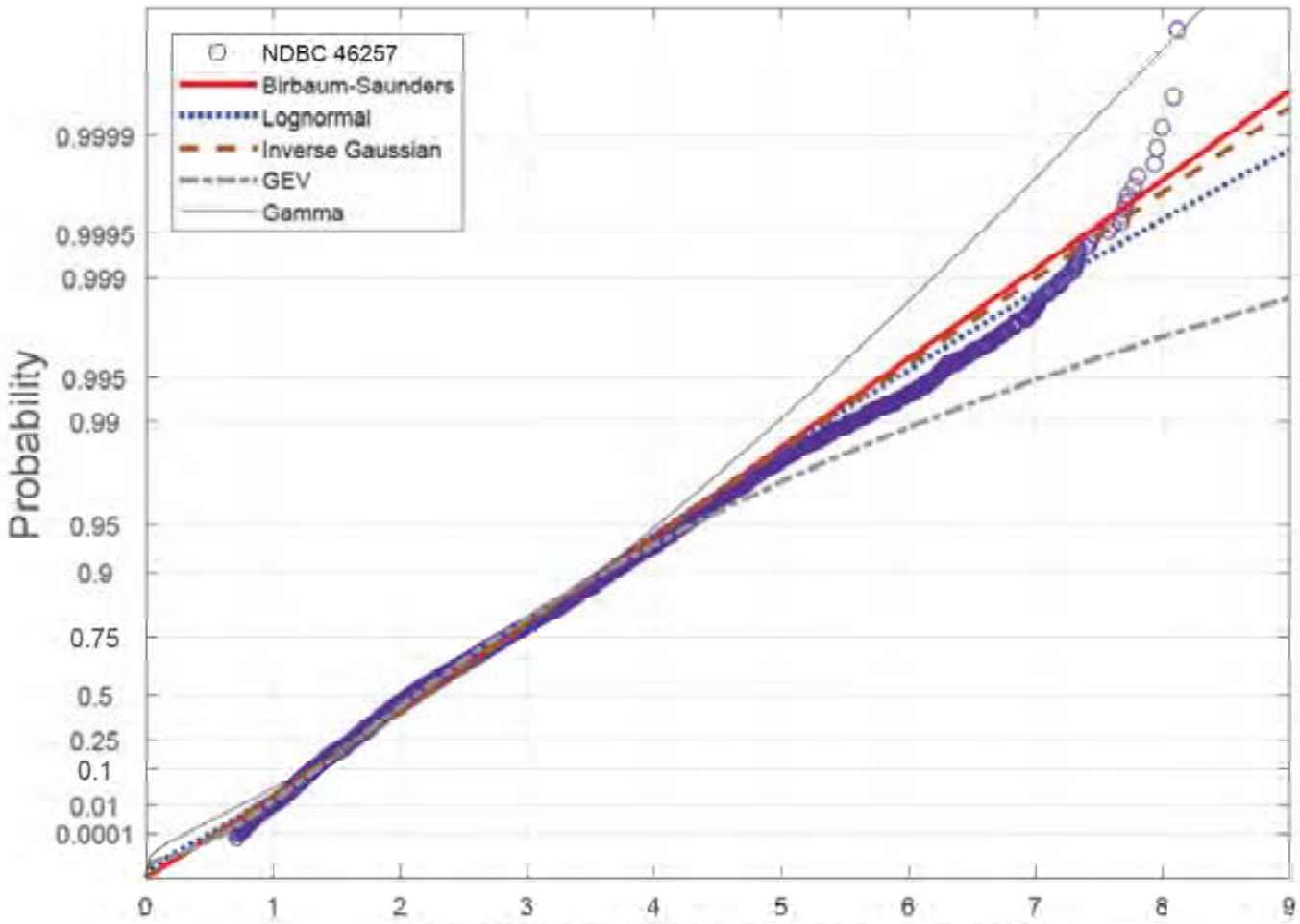


Figure E043, Probability Fit, Wave Height, m, 46257

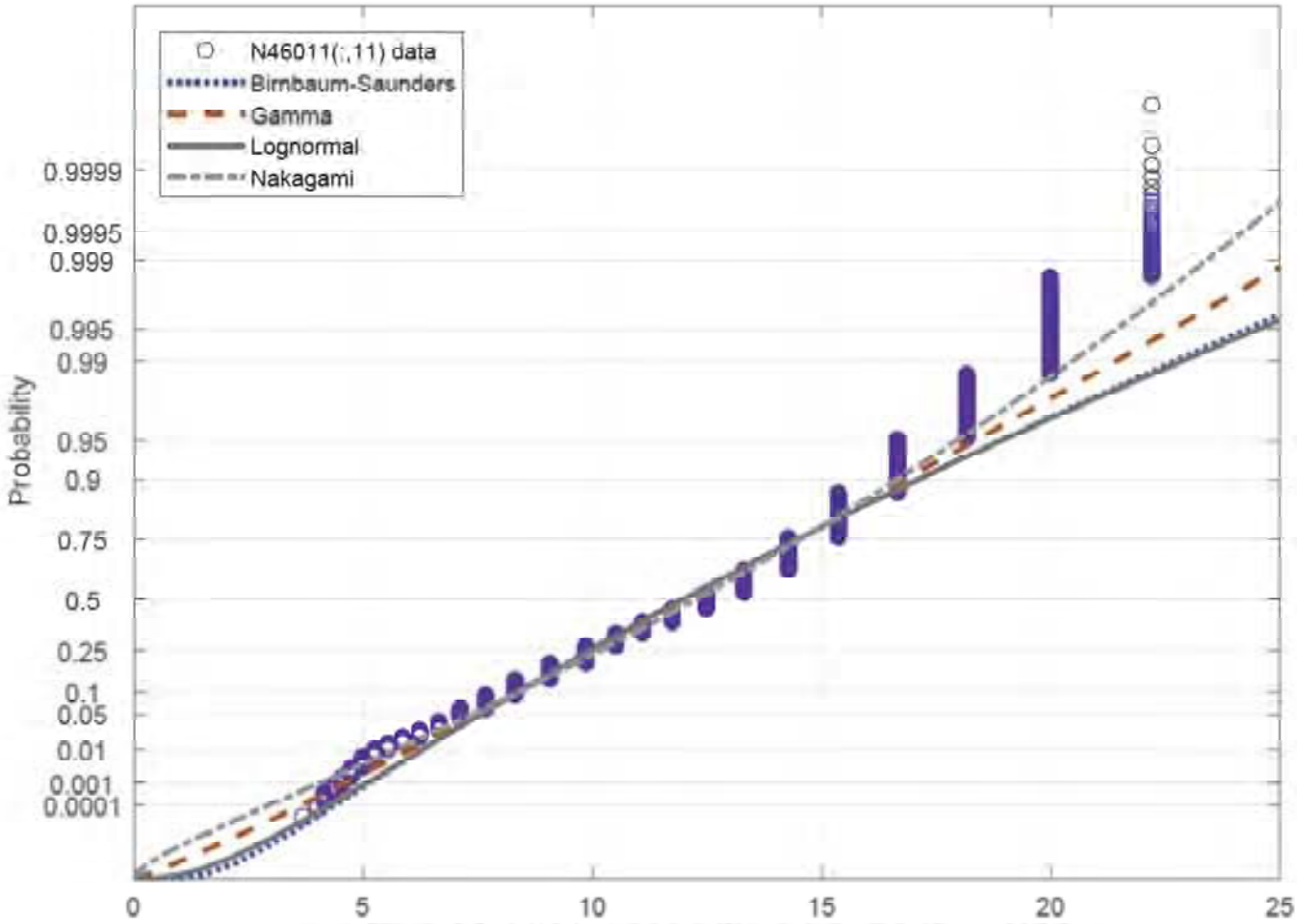


Figure E044. Probability Fit, Wave Energy, kW/m, 46257

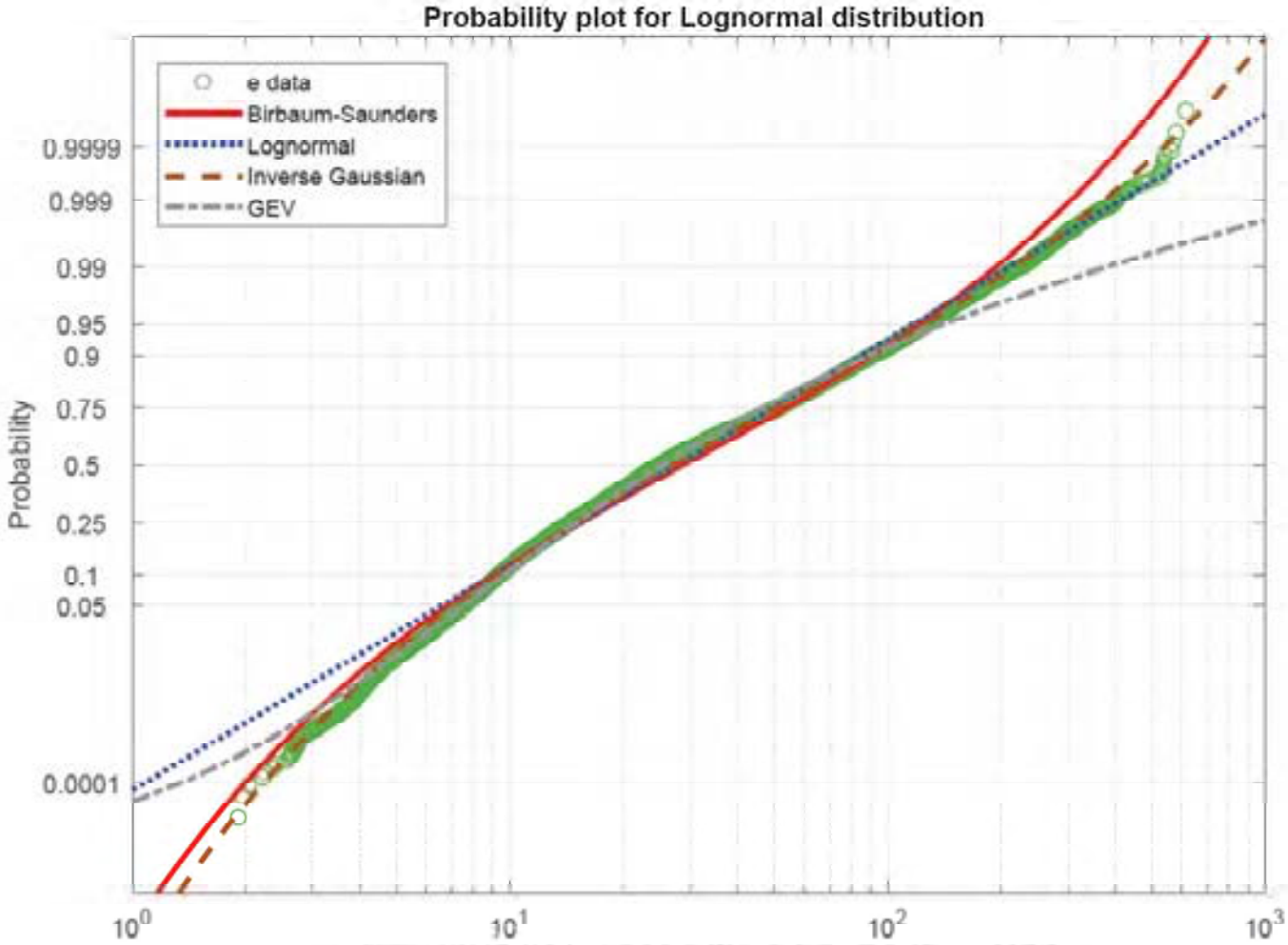


Figure E045. Probability Fit, Wave Energy, kW/m, 46257

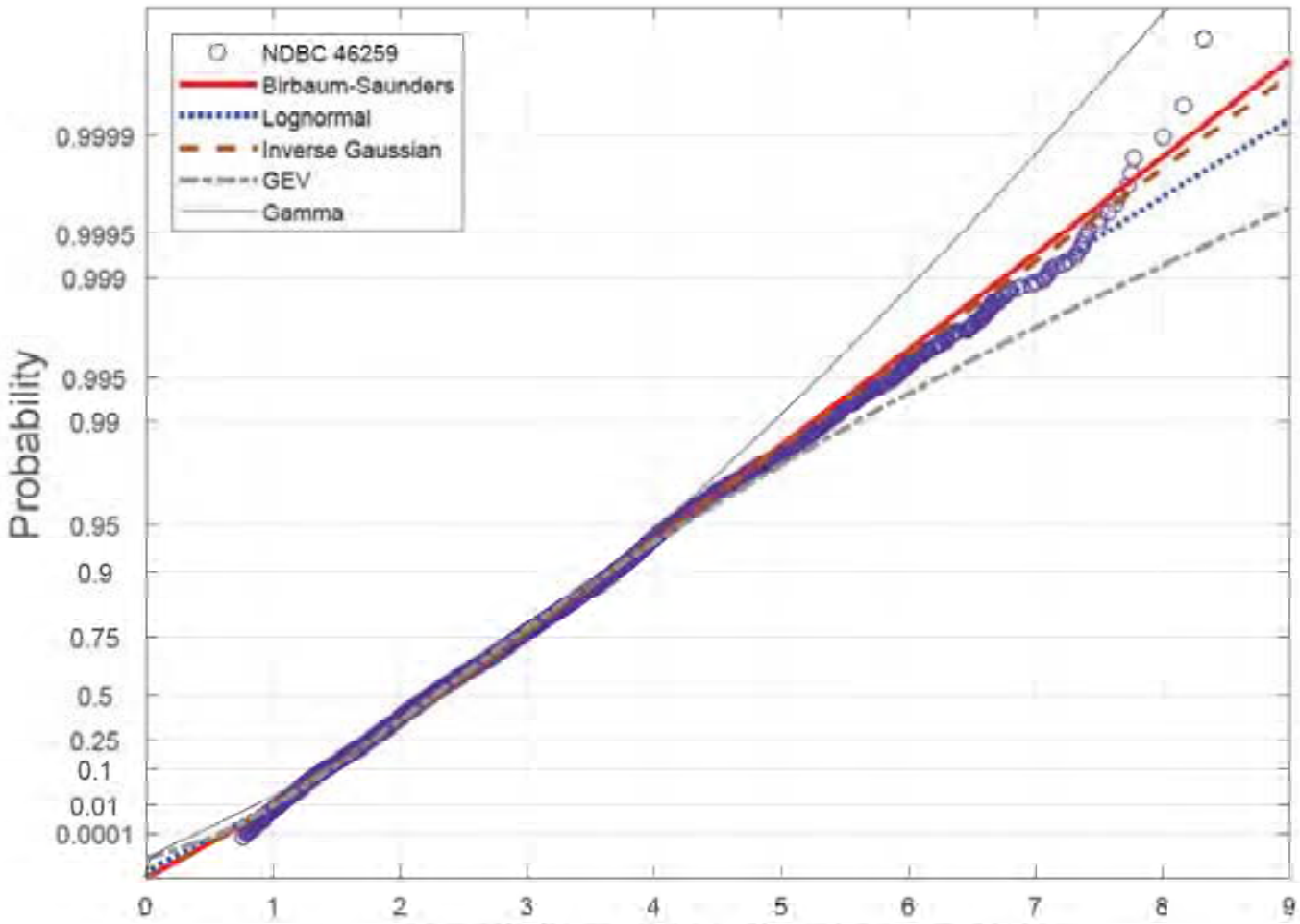


Figure E046. Probability Fit, Wave Height, m, 46259

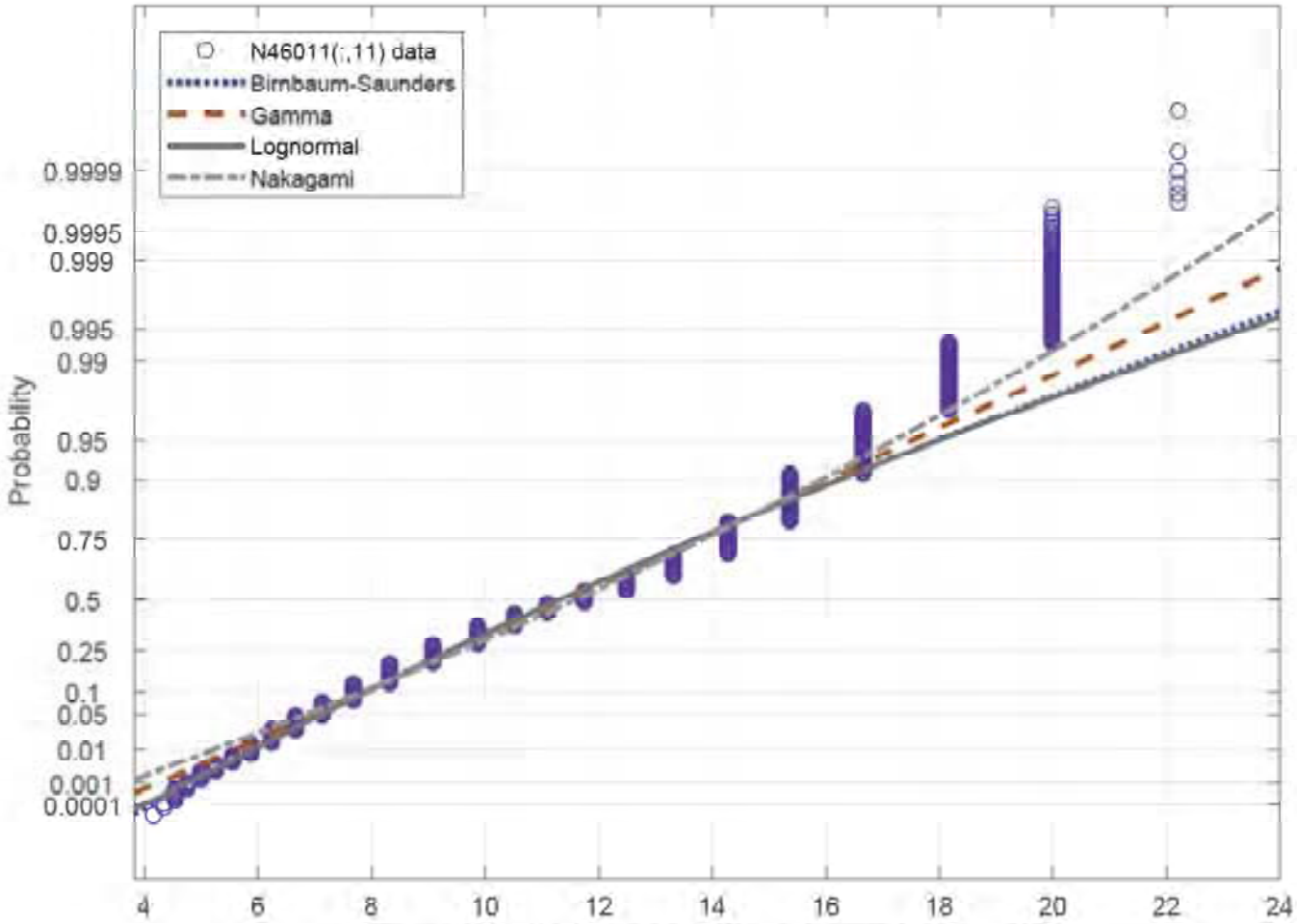


Figure E047. Probability Fit, Wave Energy, kW/m, 46259

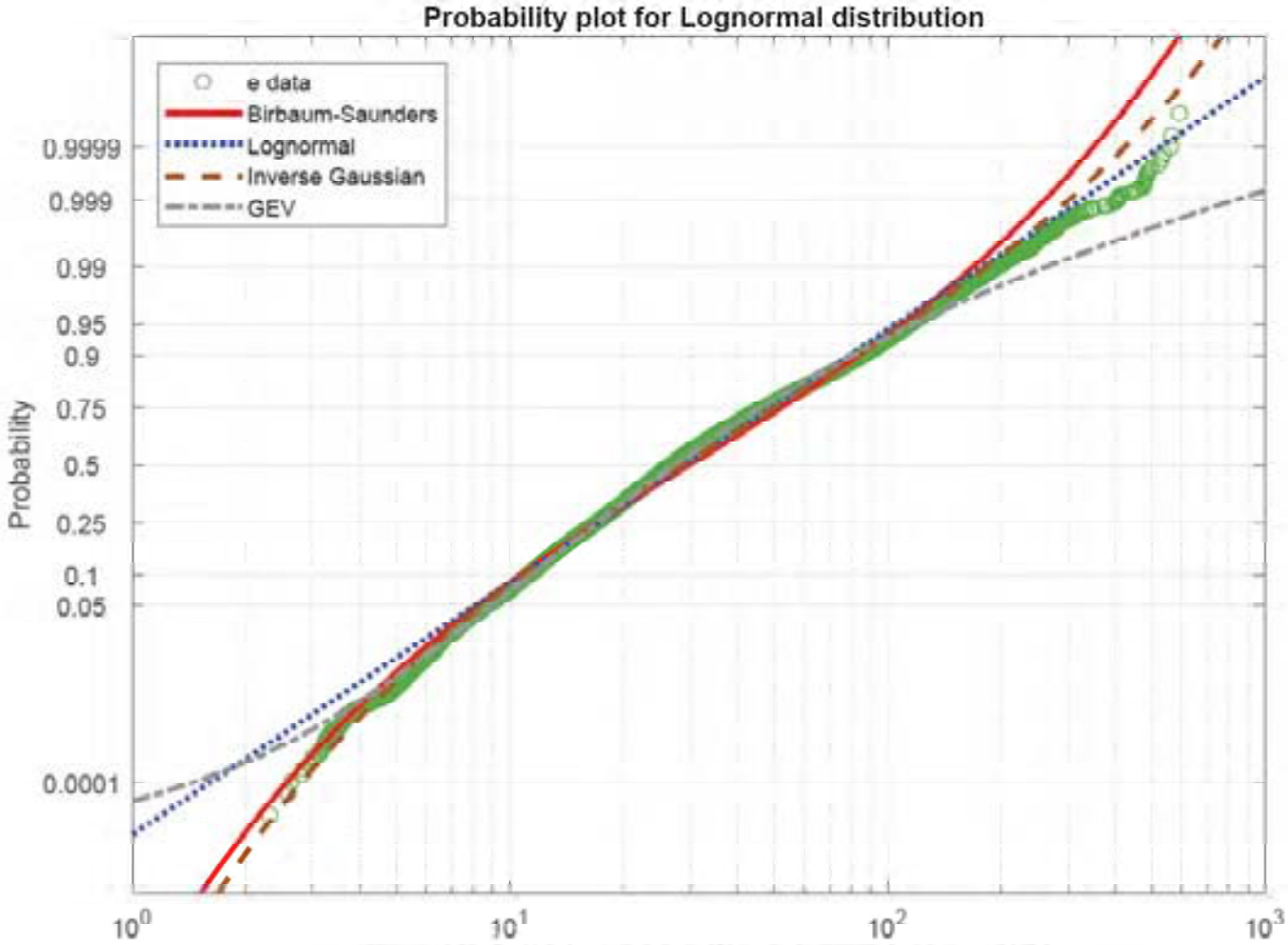


Figure E048. Probability Fit, Wave Energy, kW/m, 46259

APPENDIX A: Historical Data for Wave Height, Period, and Energy, by Buoy

(Appendix A is included as a separate file due to size)

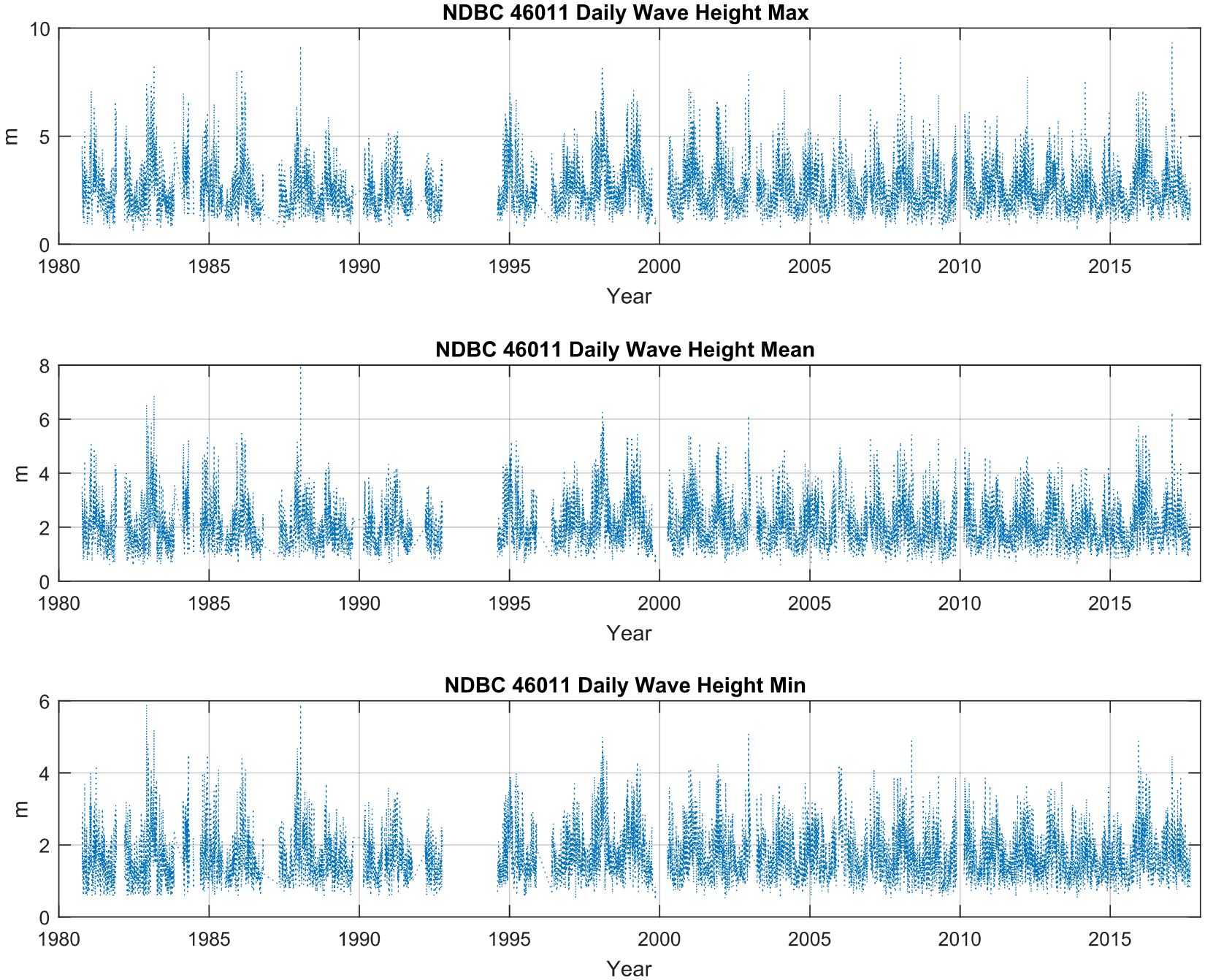


Figure A001. Daily Wave Height, Max, Mean, Min,NDBC 46011

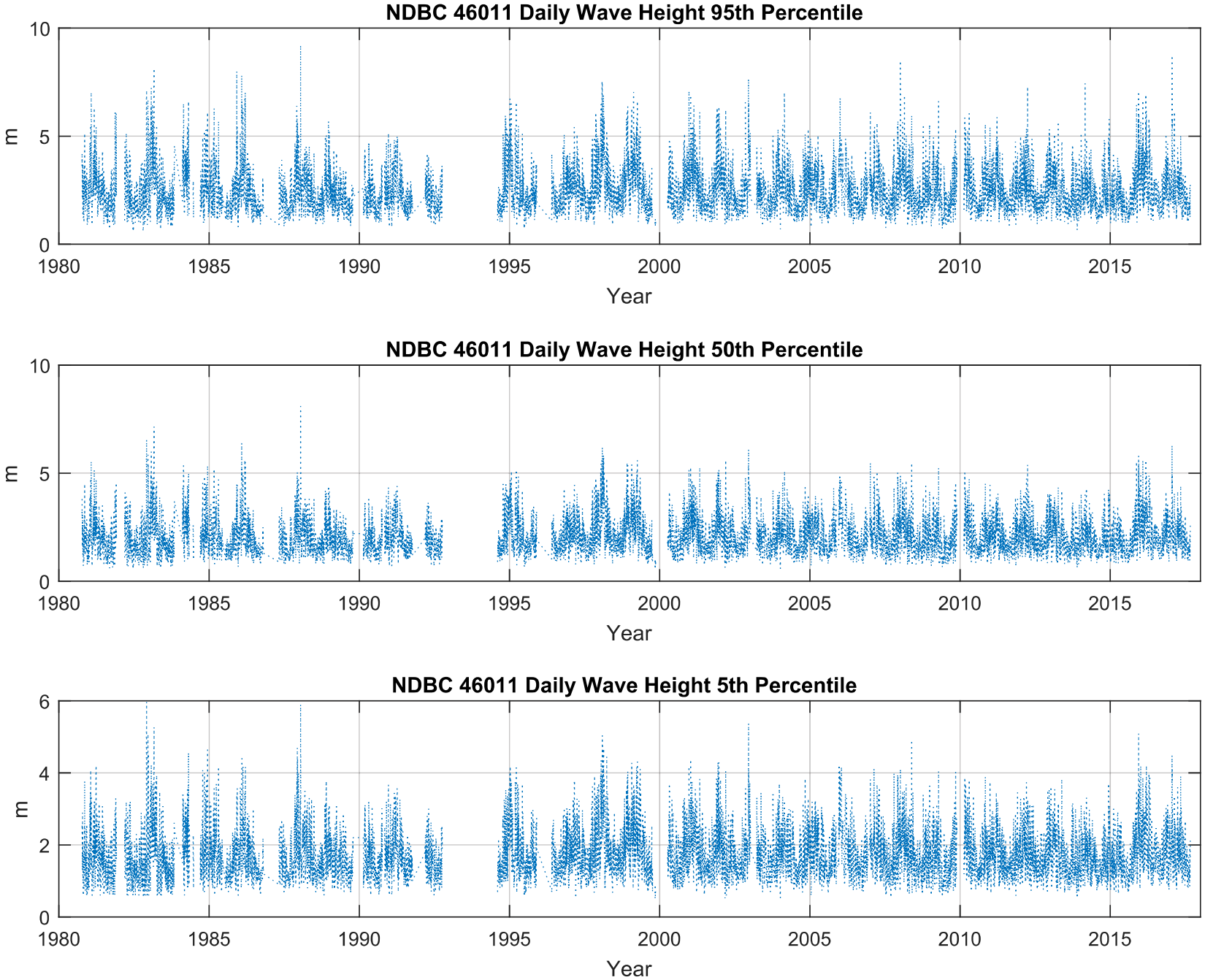


Figure A002. Daily Wave Height, Percentiles,NDBC 46011

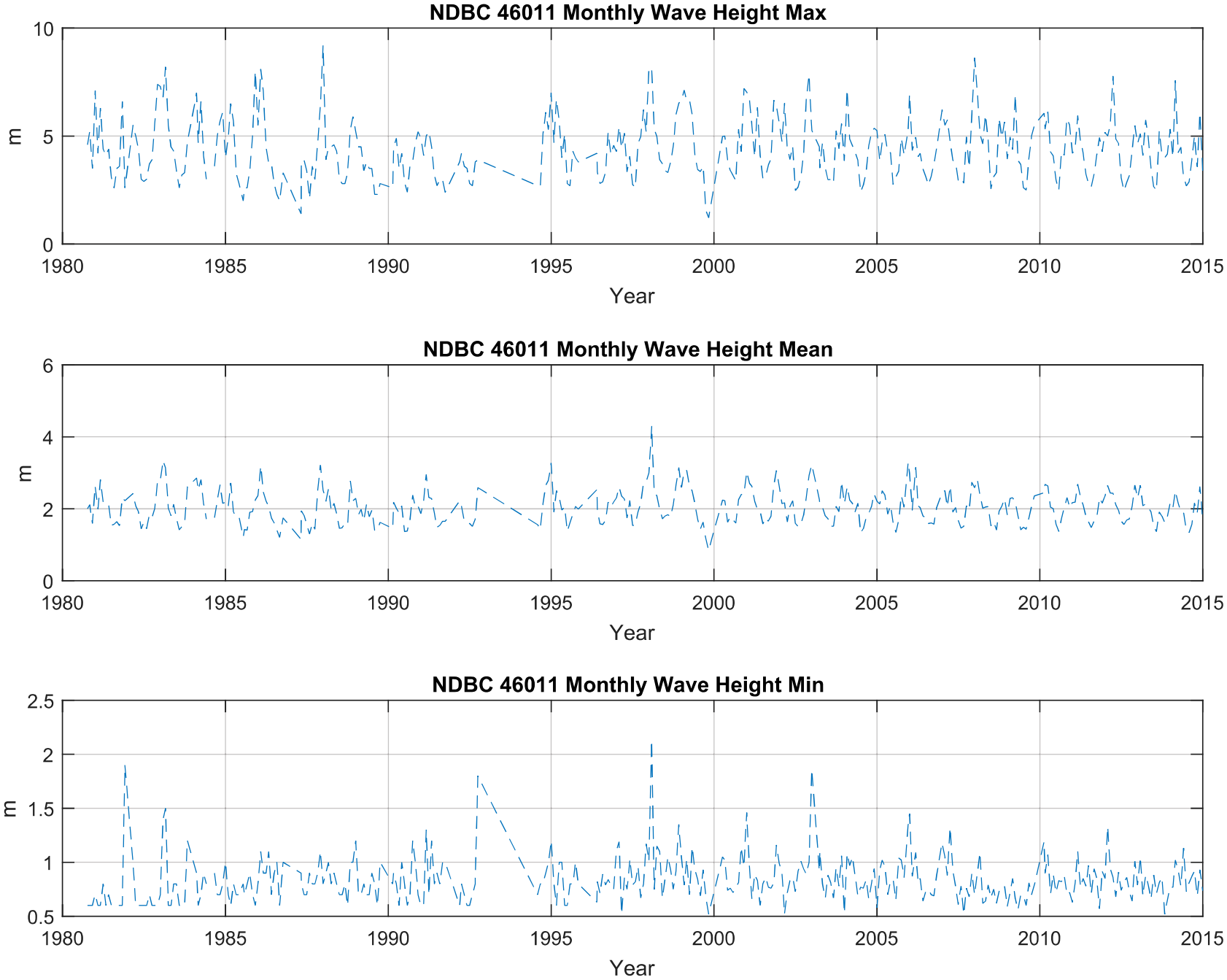
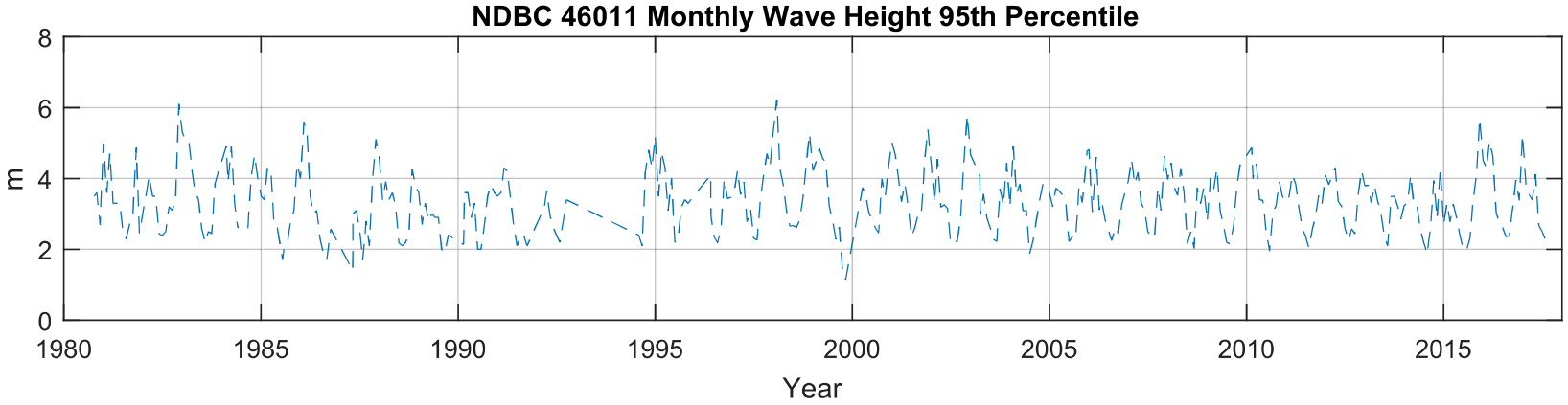
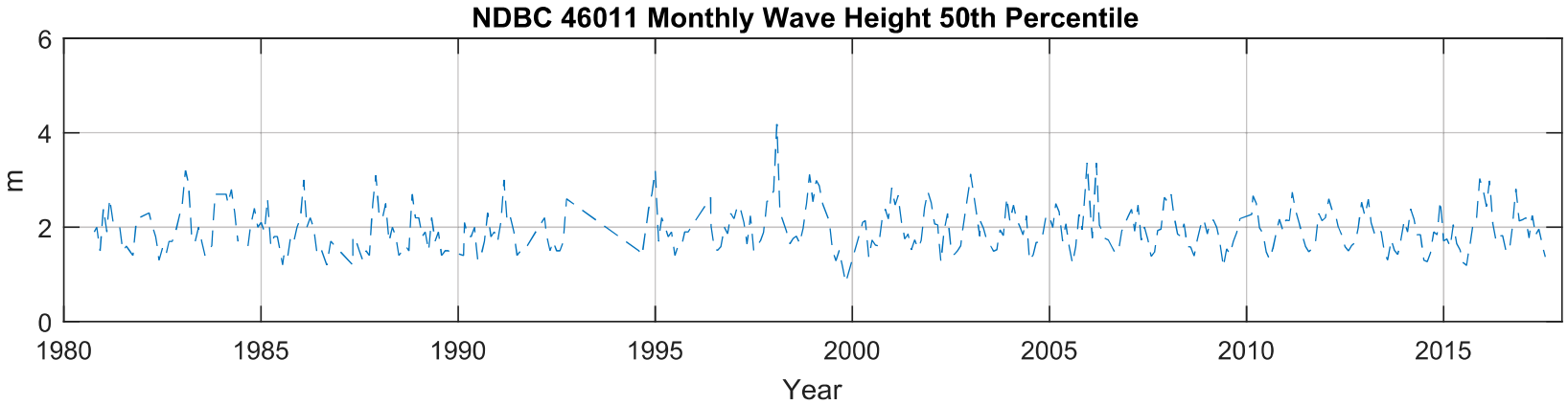


Figure A003. Monthly Wave Height, Max, Mean, Min,NDBC 46011





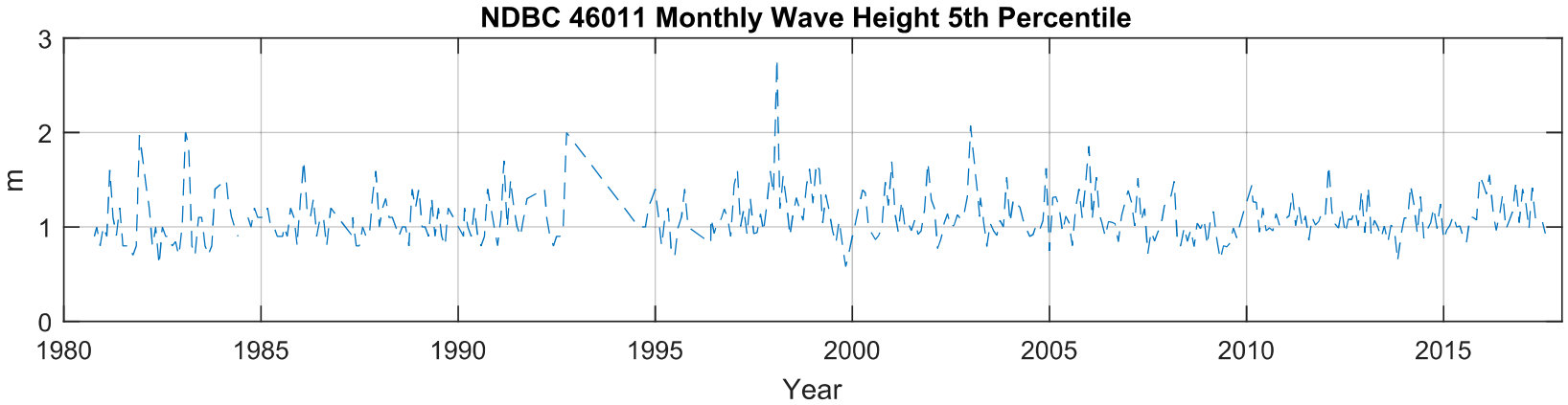


Figure A004. Monthly Wave Height, Percentiles,NDBC 46011

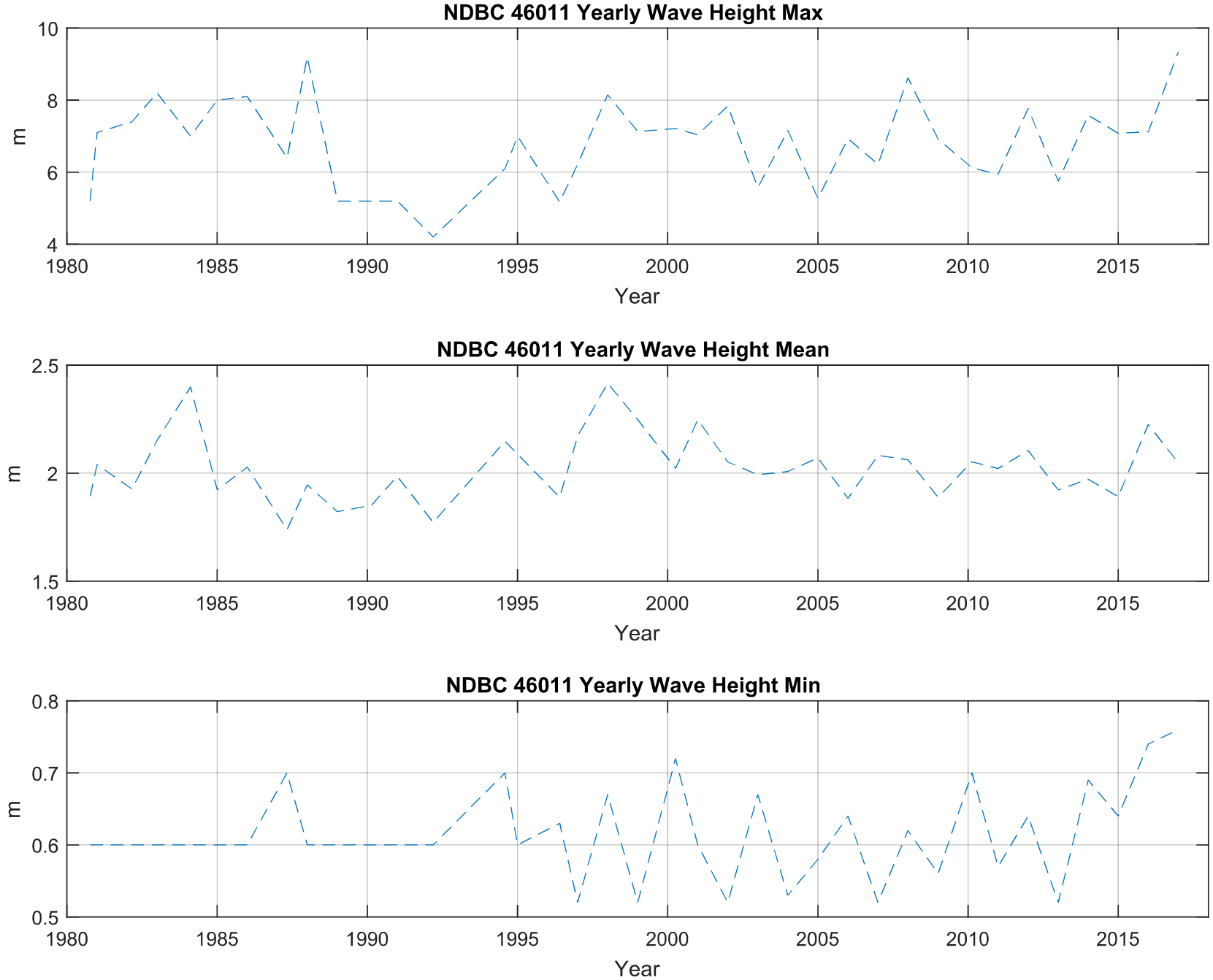
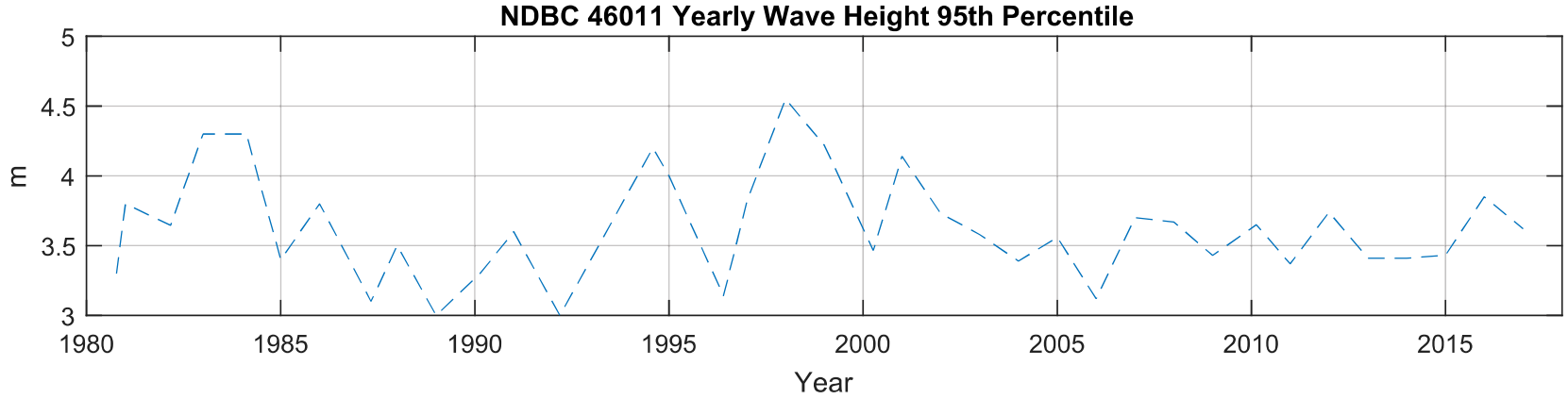
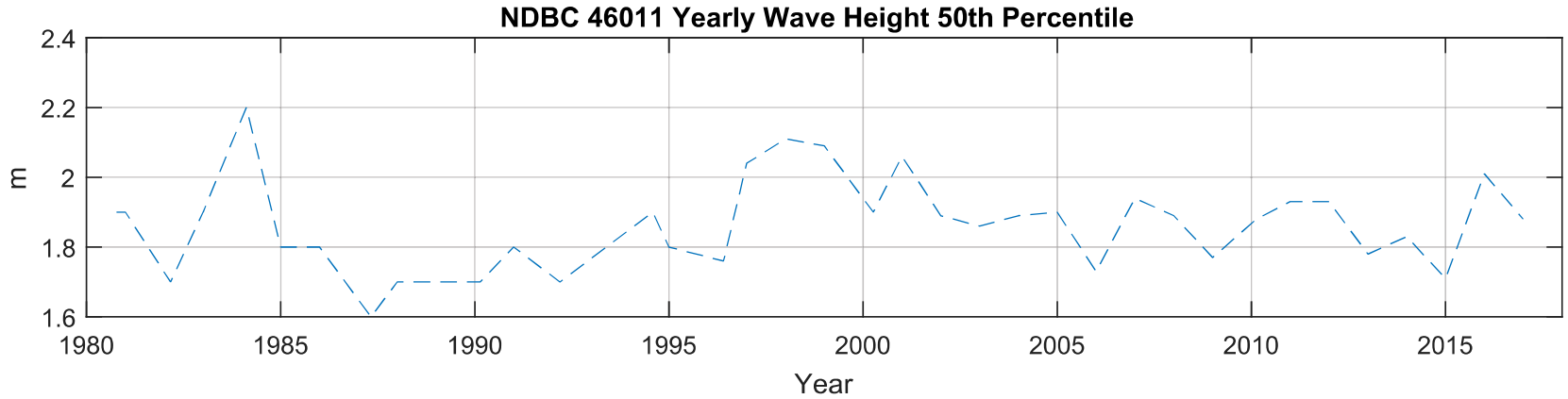


Figure A005. Yearly Wave Height, Max, Mean, Min,NDBC 46011





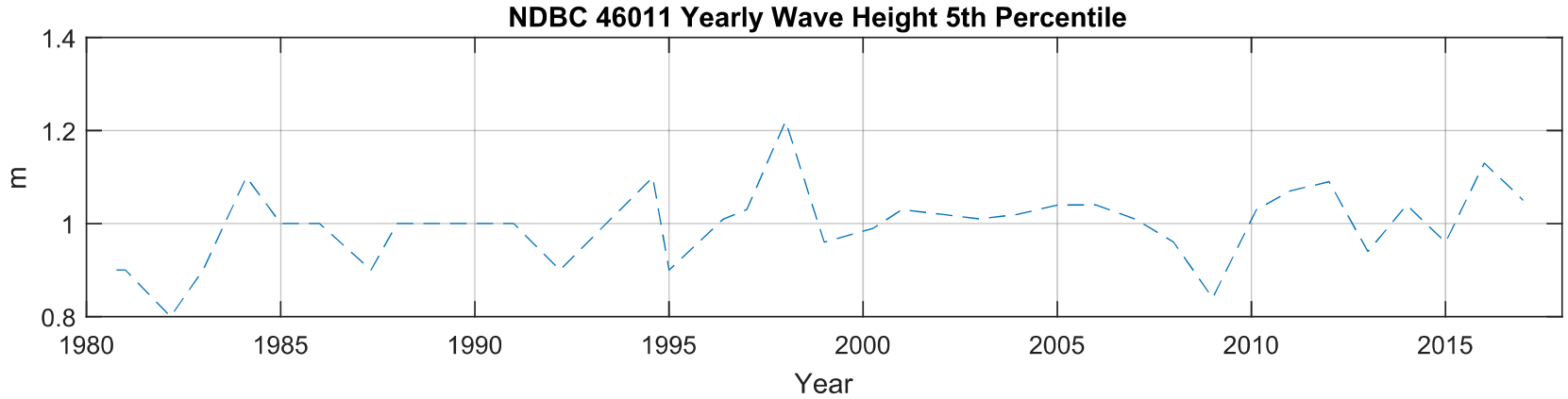


Figure A006. Yearly Wave Height, Percentiles,NDBC 46011

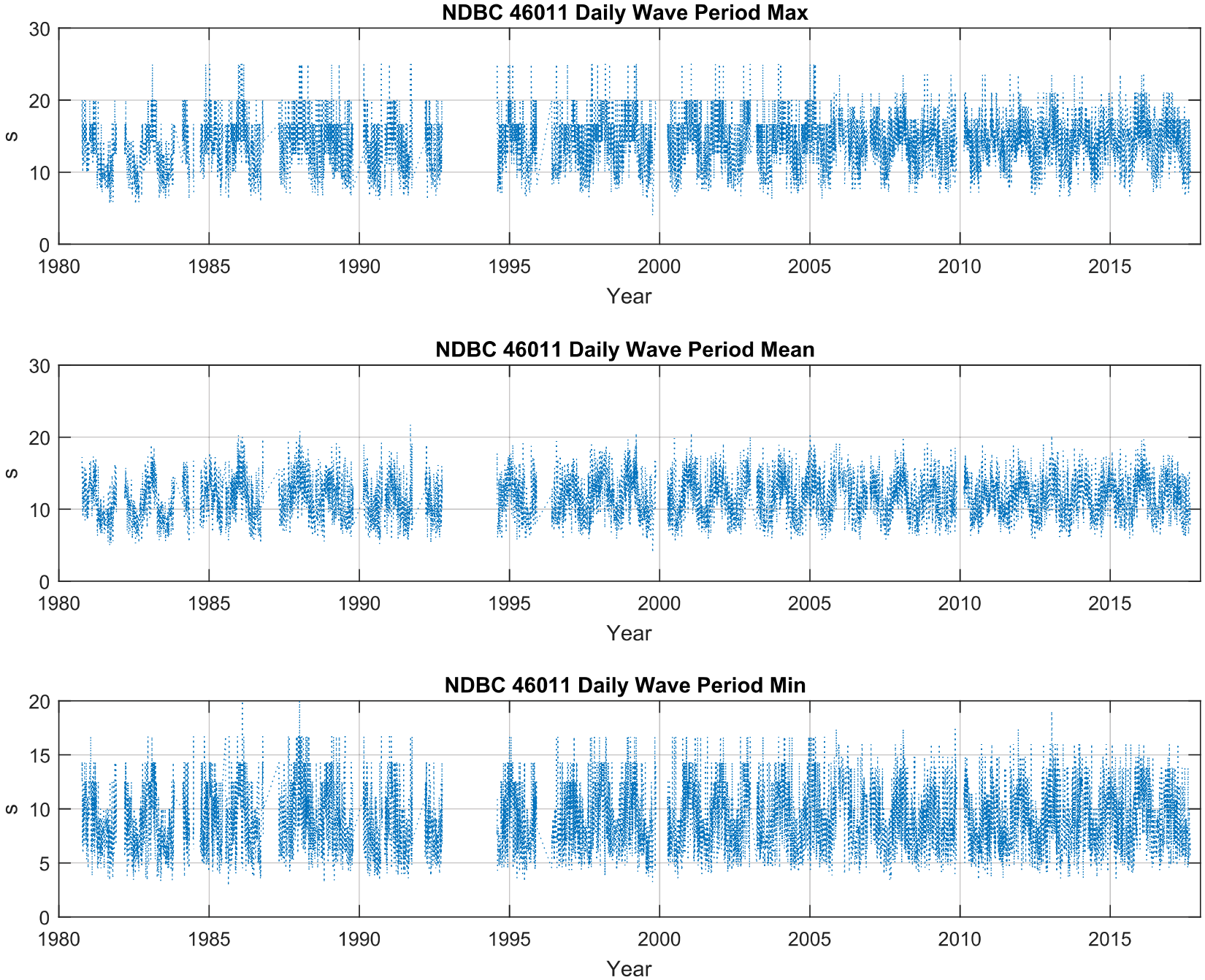
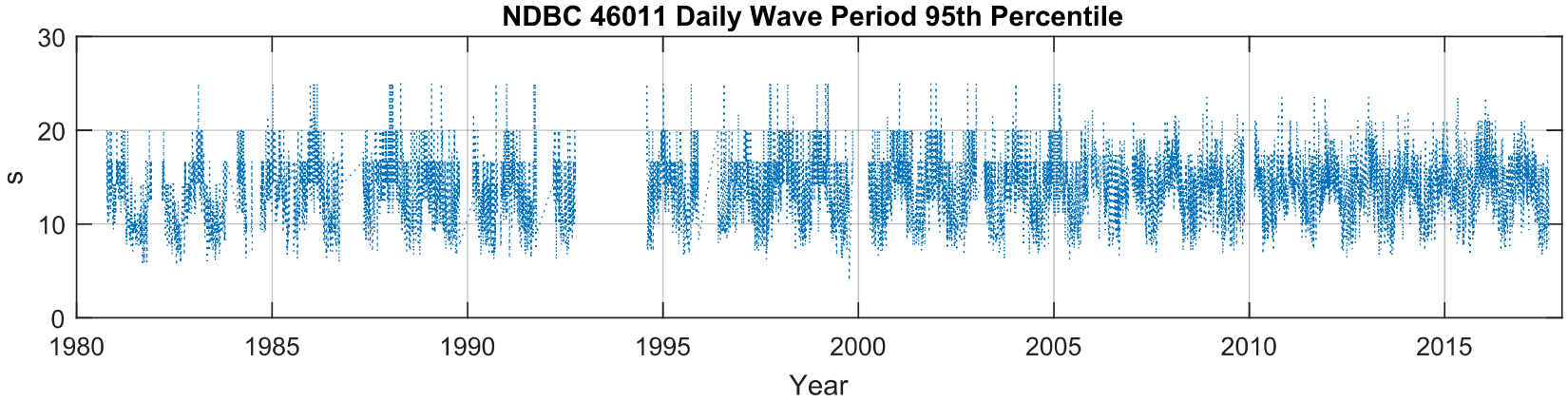
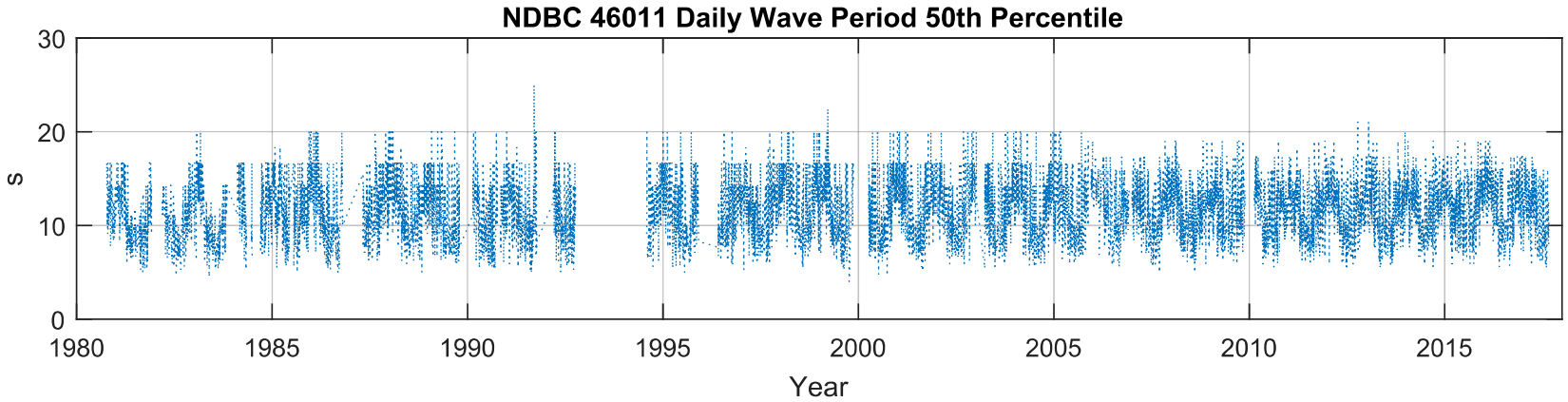


Figure A007. Daily Wave Period, Max, Mean, Min,NDBC 46011





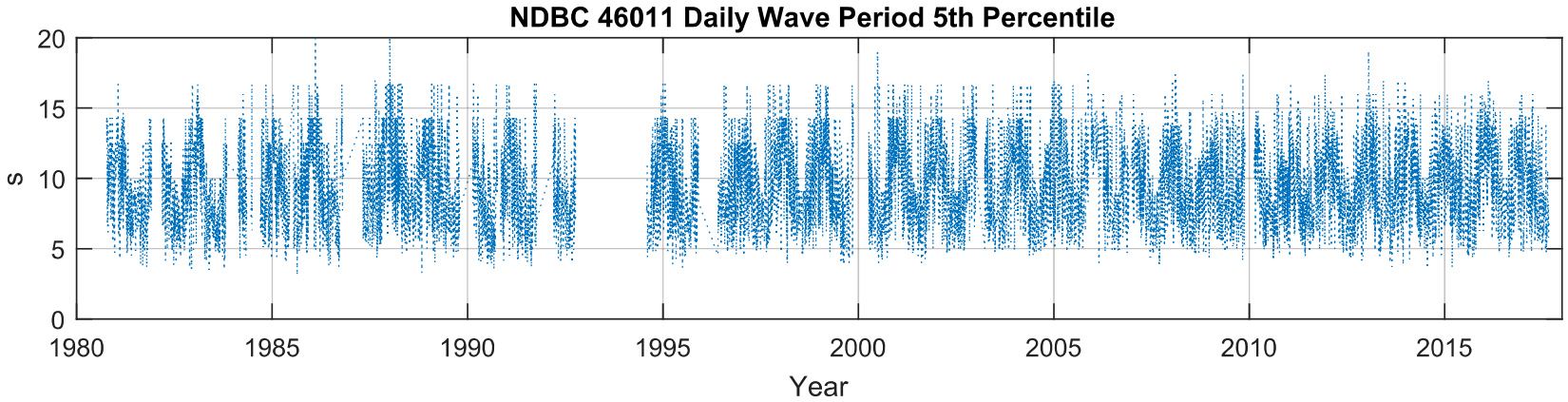
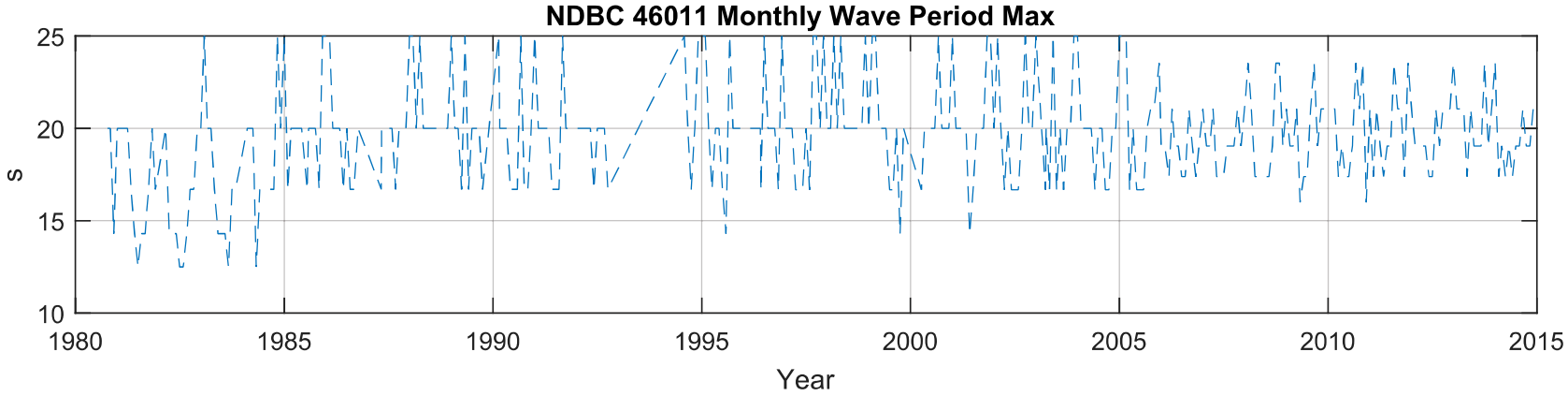
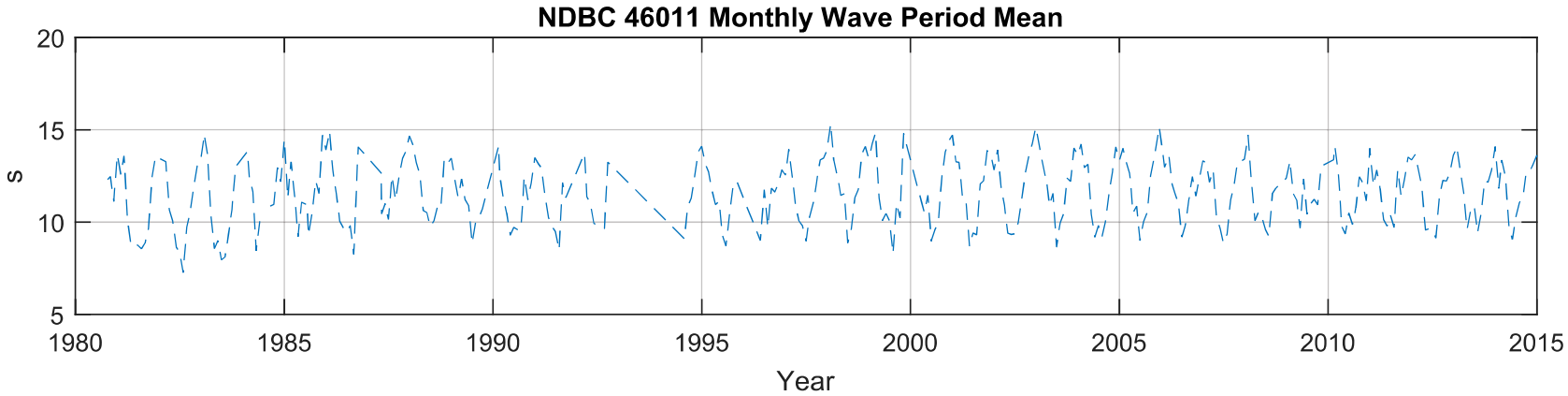


Figure A008. Daily Wave Period, Percentiles,NDBC 46011





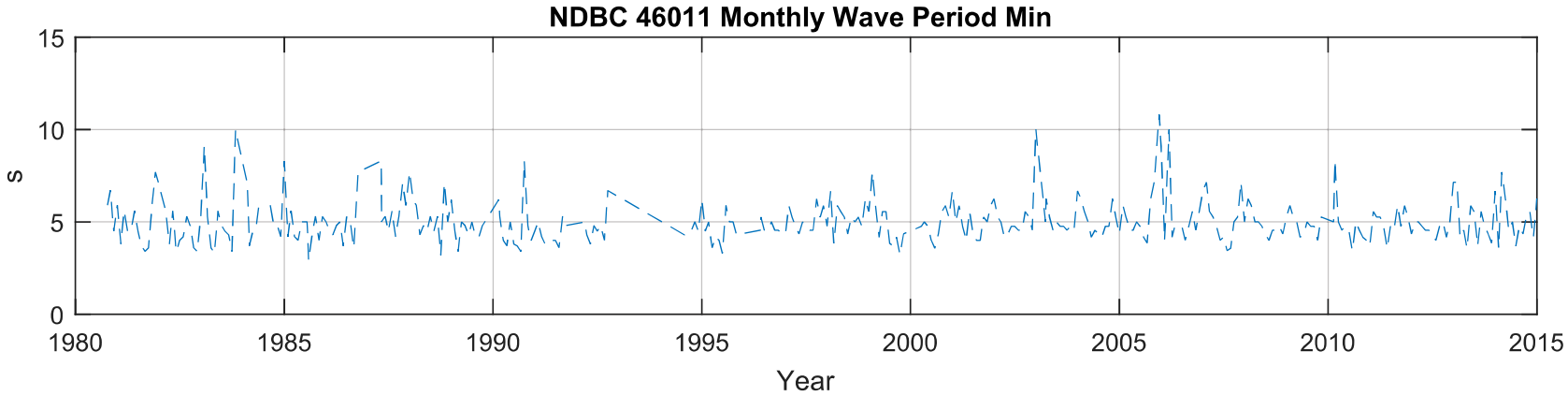
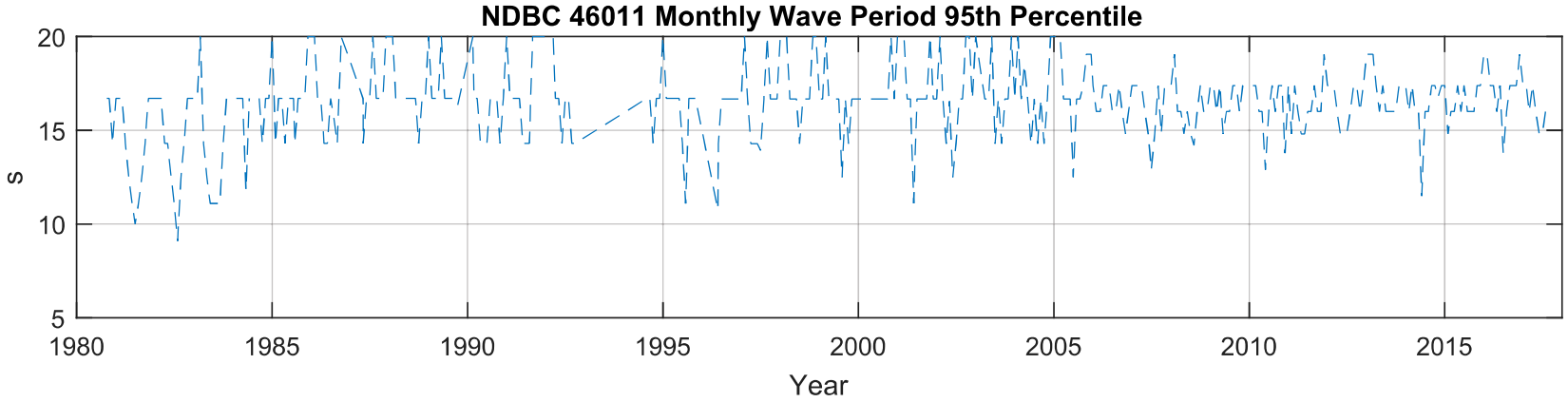
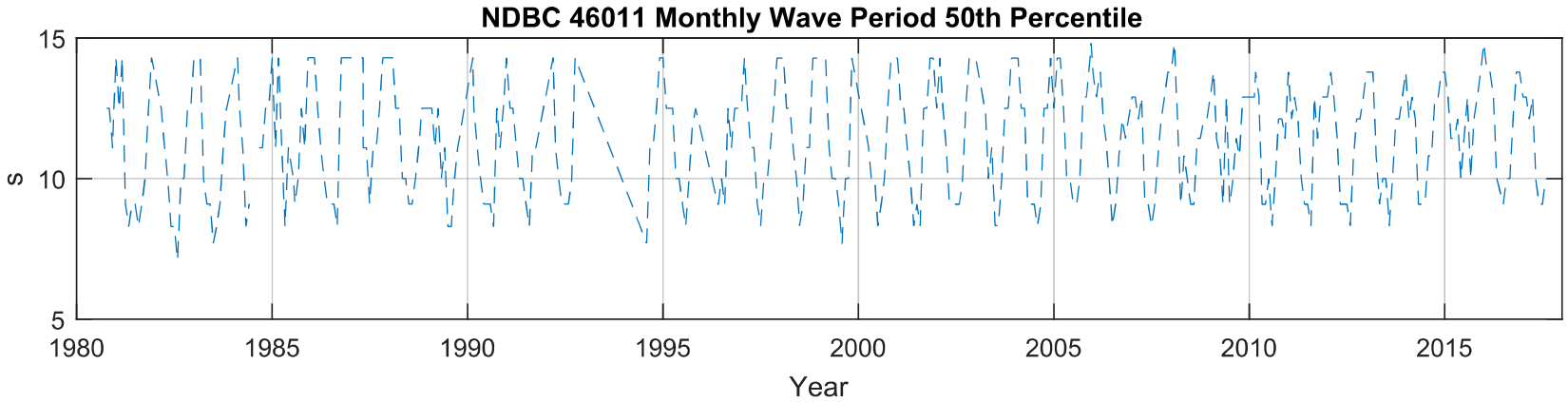


Figure A009. Monthly Wave Period, Max, Mean, Min,NDBC 46011





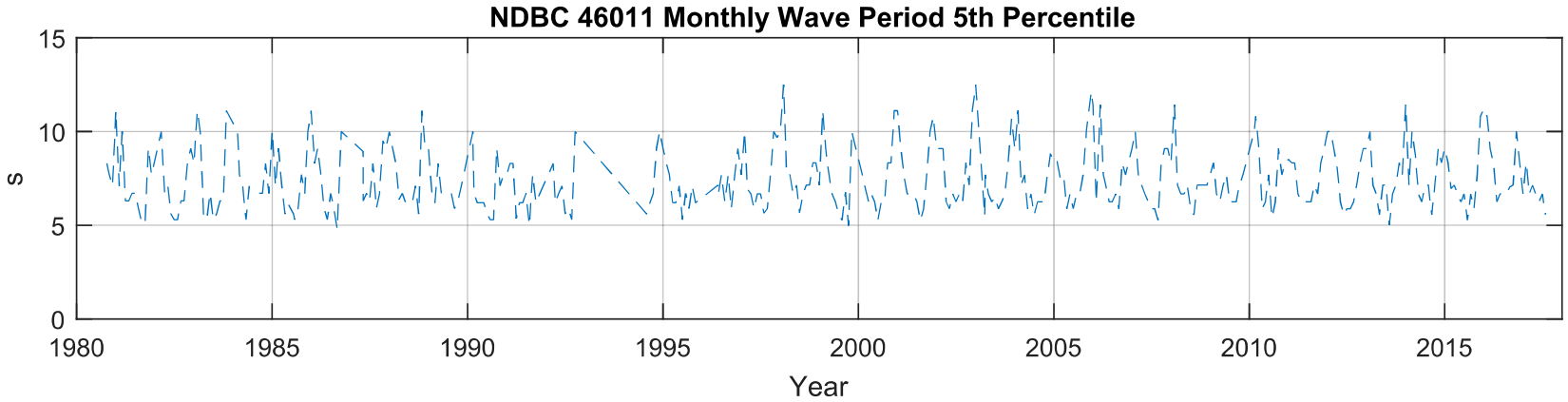
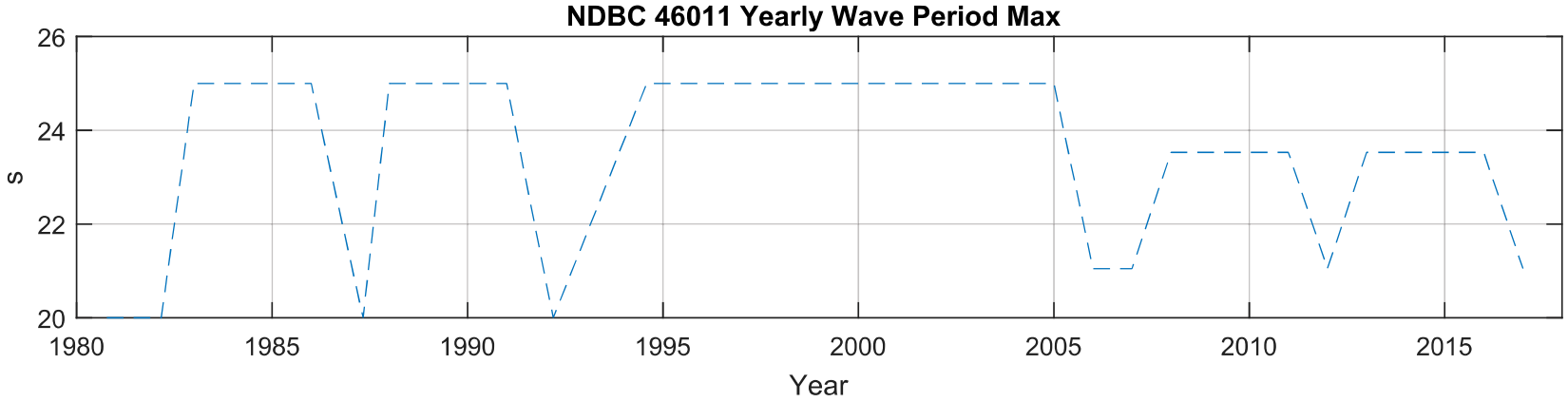
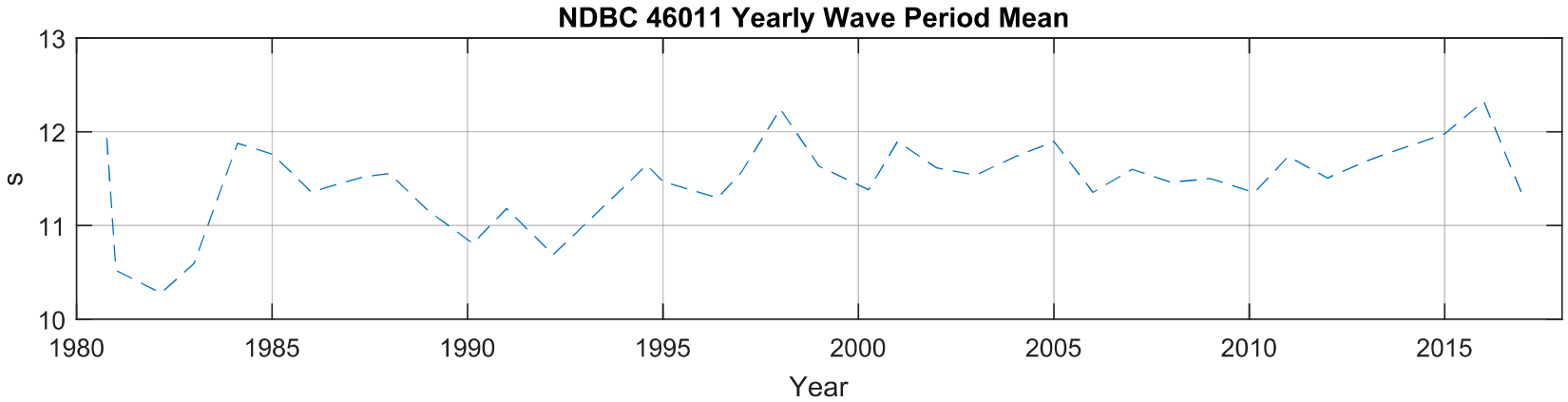


Figure A010. Monthly Wave Period, Percentiles,NDBC 46011





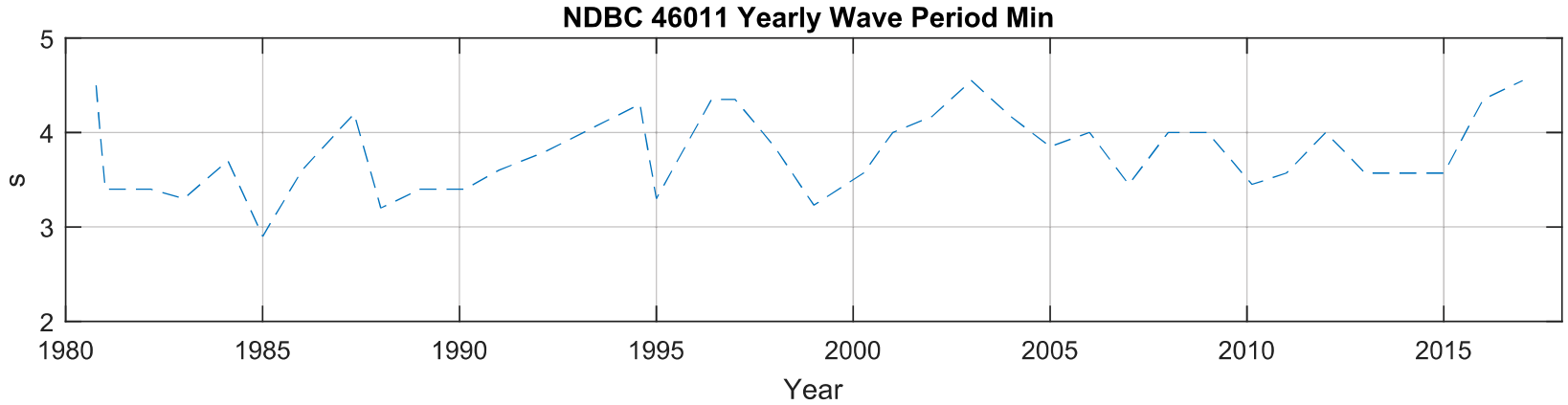
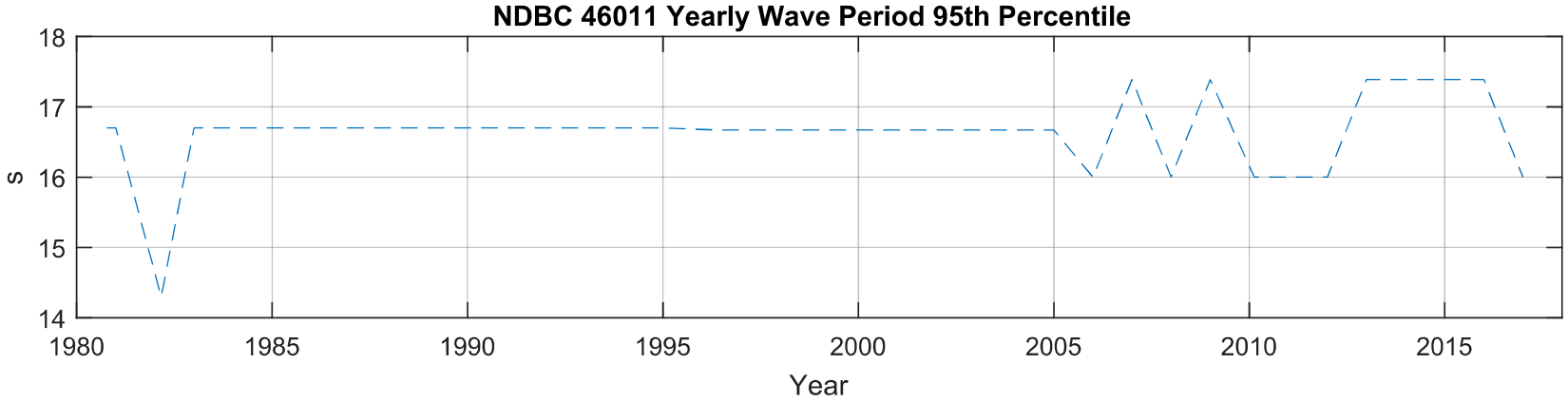
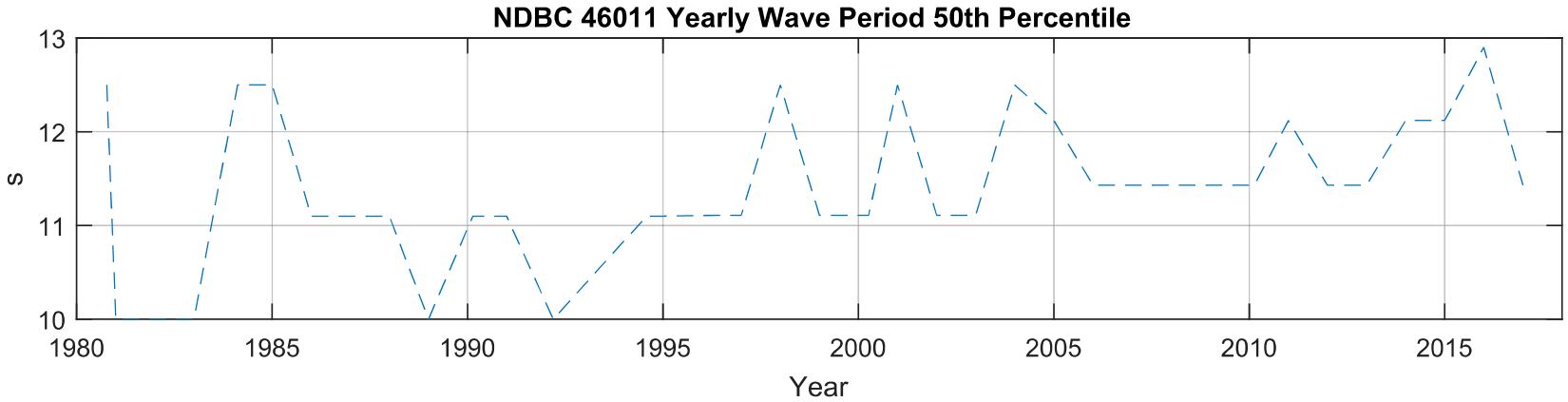


Figure A011. Yearly Wave Period, Max, Mean, Min,NDBC 46011





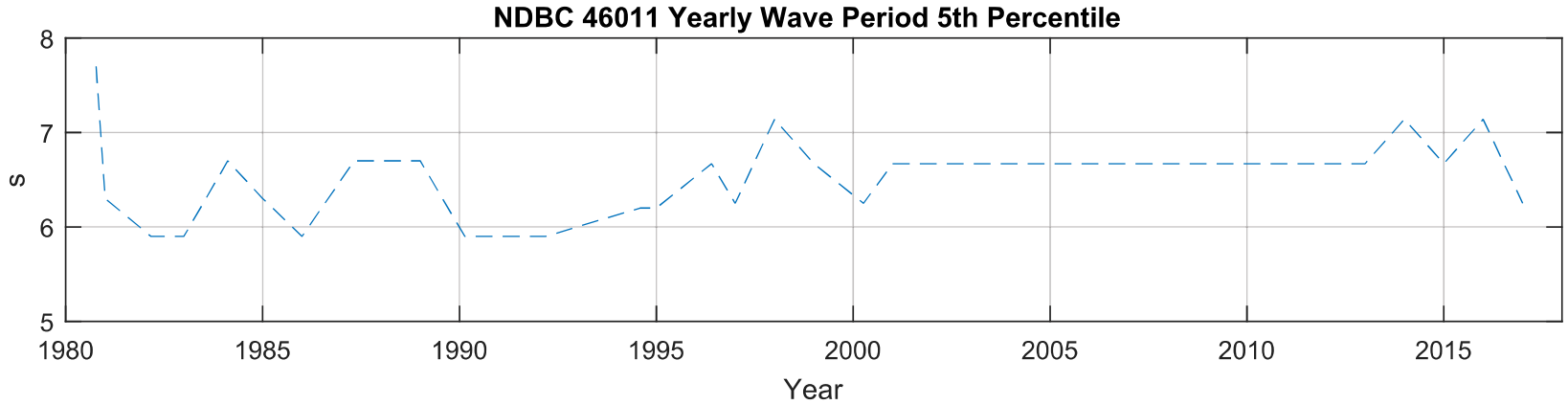


Figure A012. Yearly Wave Period, Percentiles,NDBC 46011

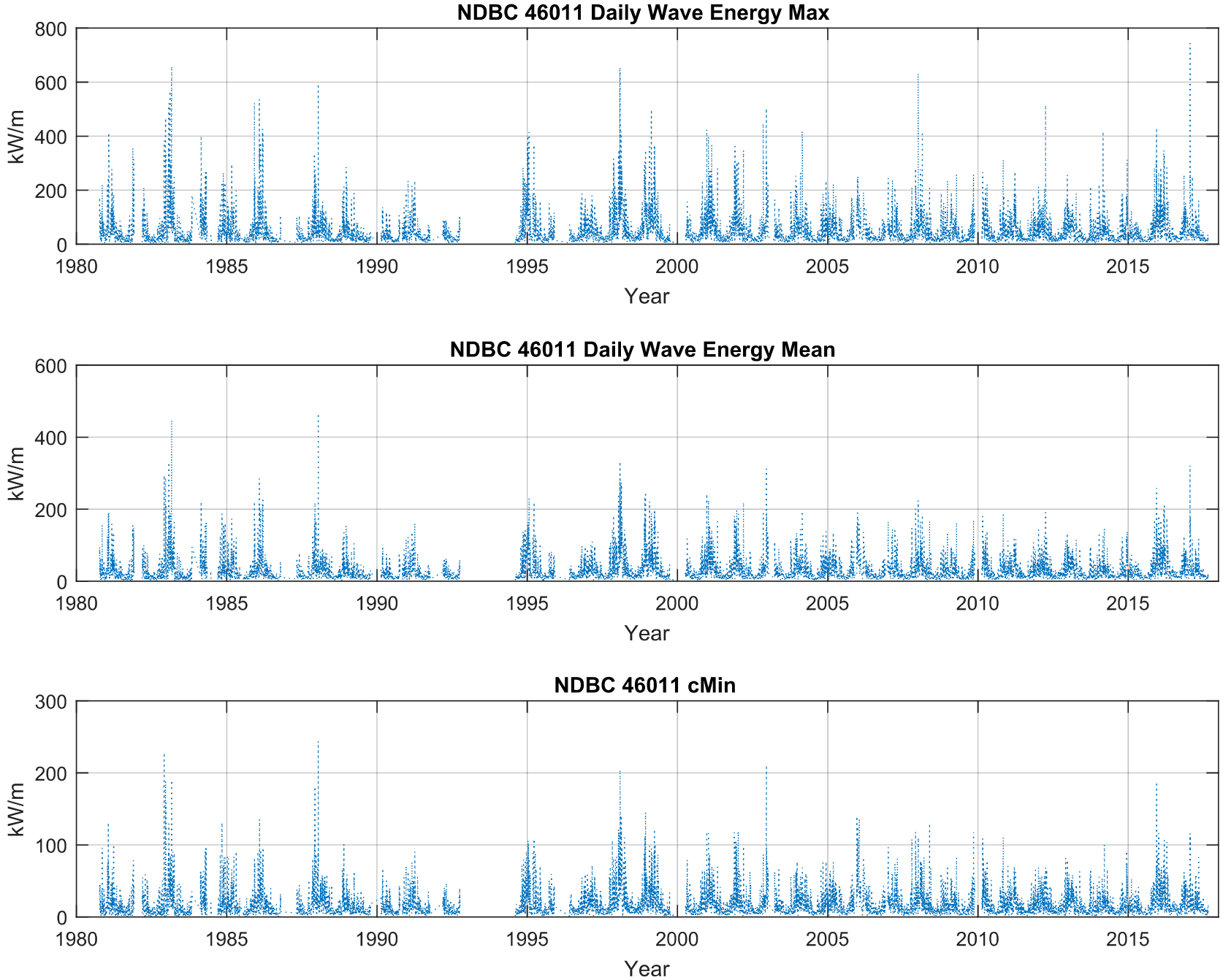
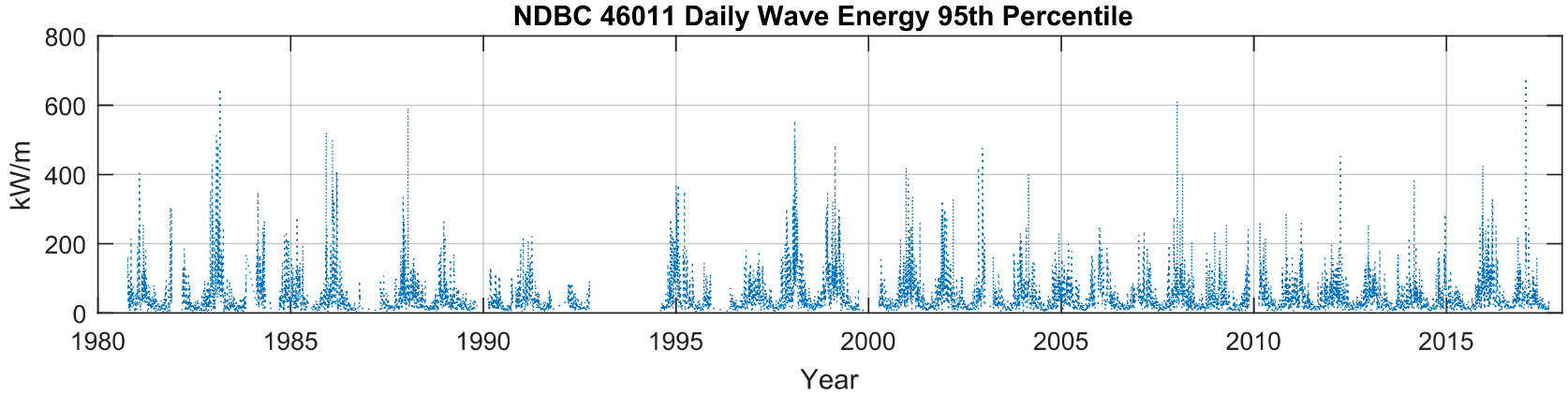
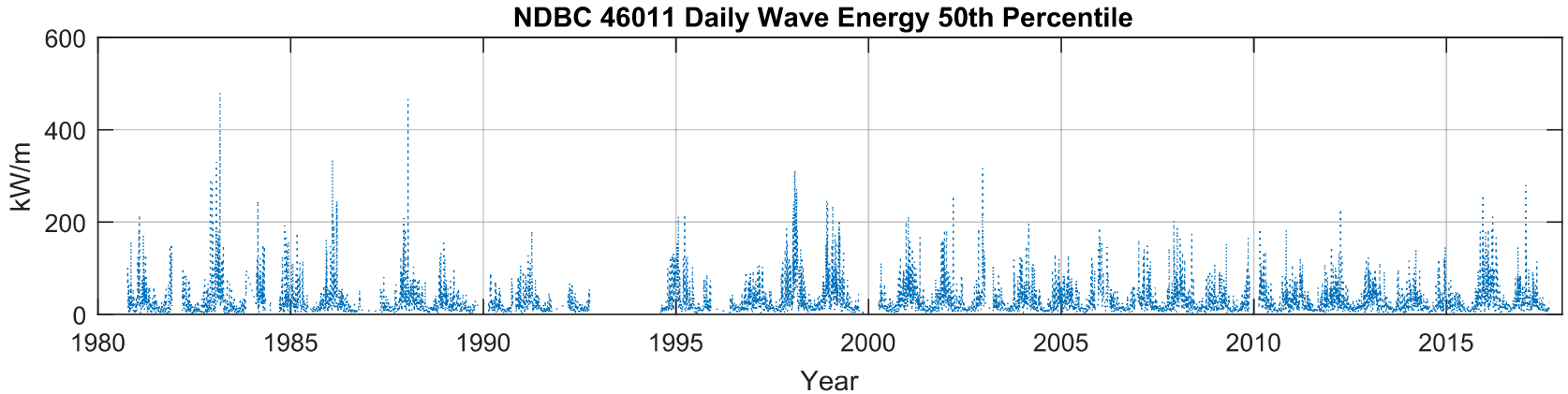


Figure A013. Daily Wave Energy, Max, Mean, Min,NDBC 46011





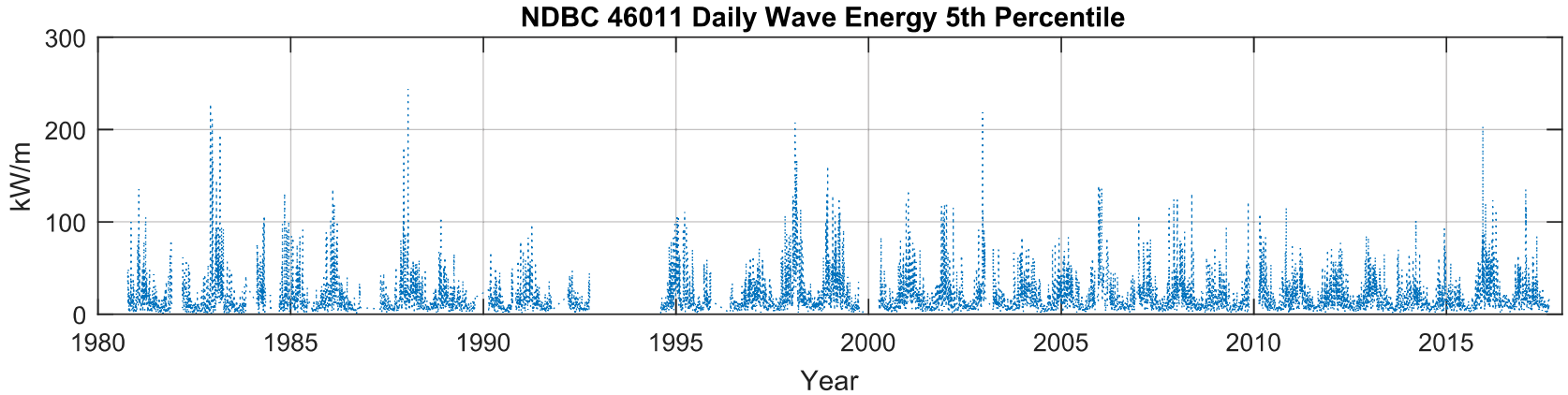


Figure A014. Daily Wave Energy, Percentiles,NDBC 46011

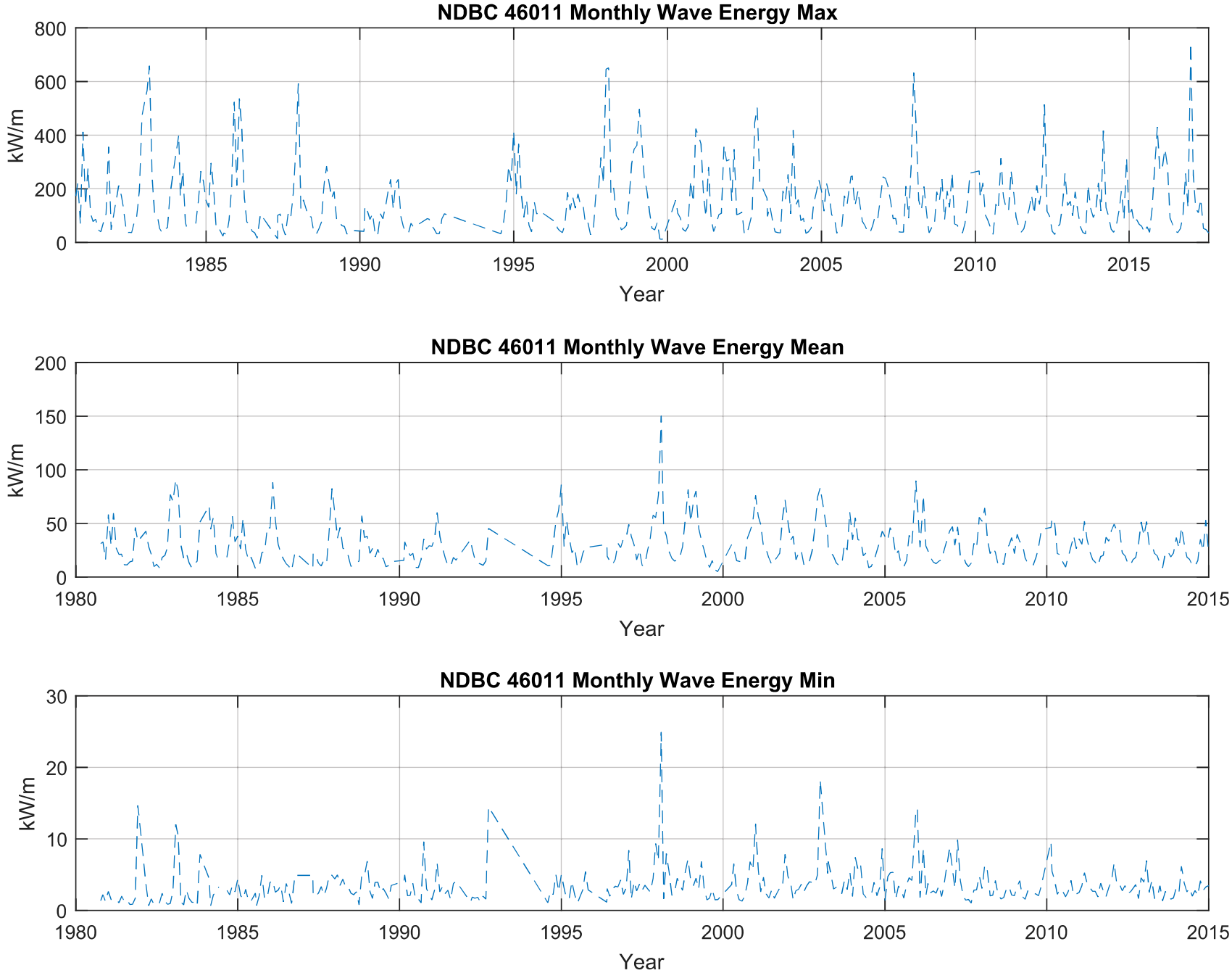
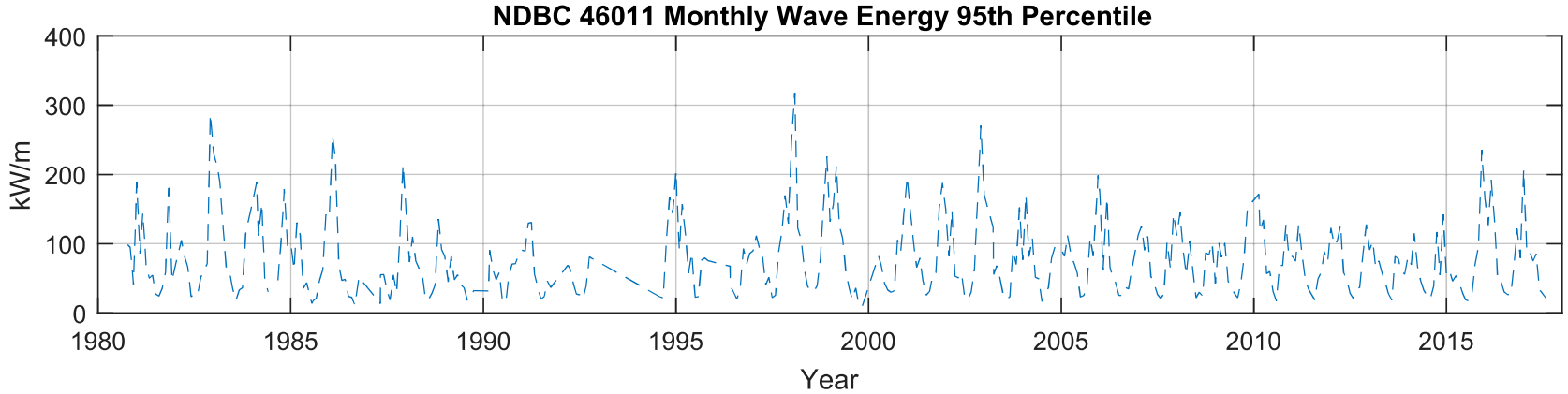
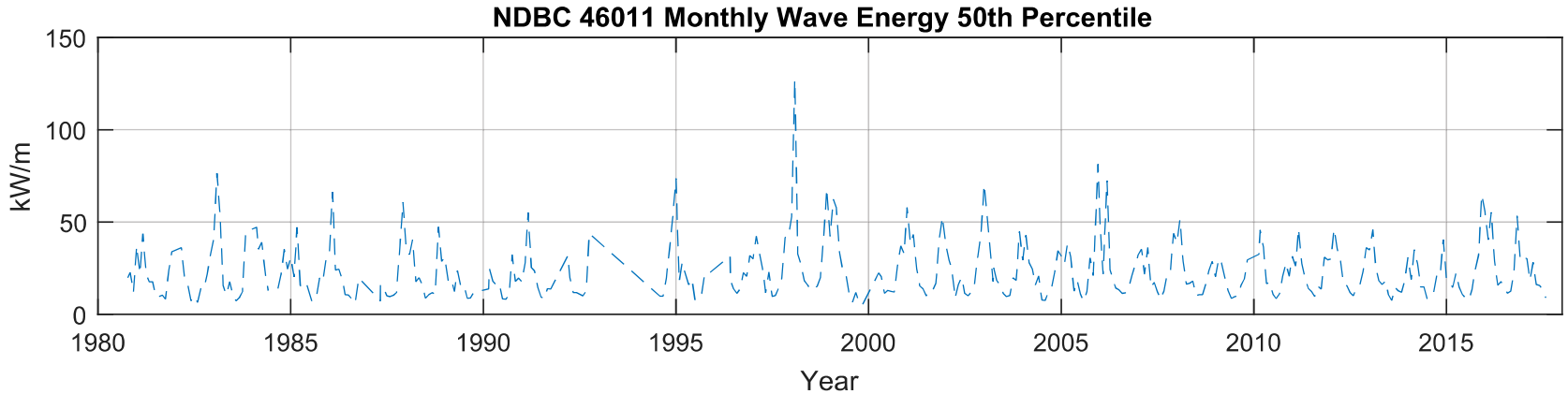


Figure A015. Monthly Wave Energy, Max, Mean, Min,NDBC 46011





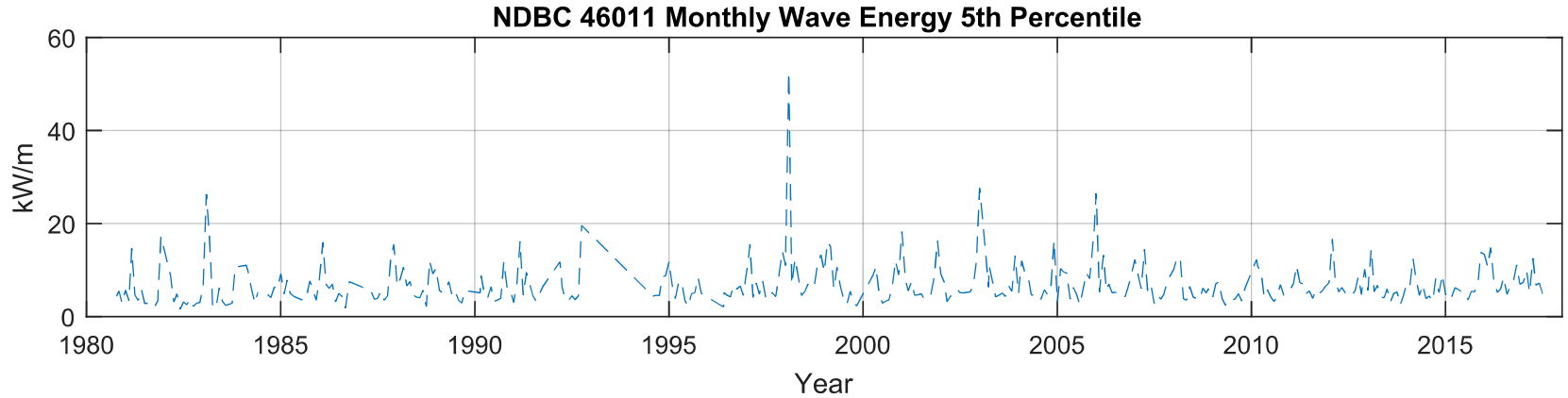


Figure A016. Monthly Wave Energy, Percentiles,NDBC 46011

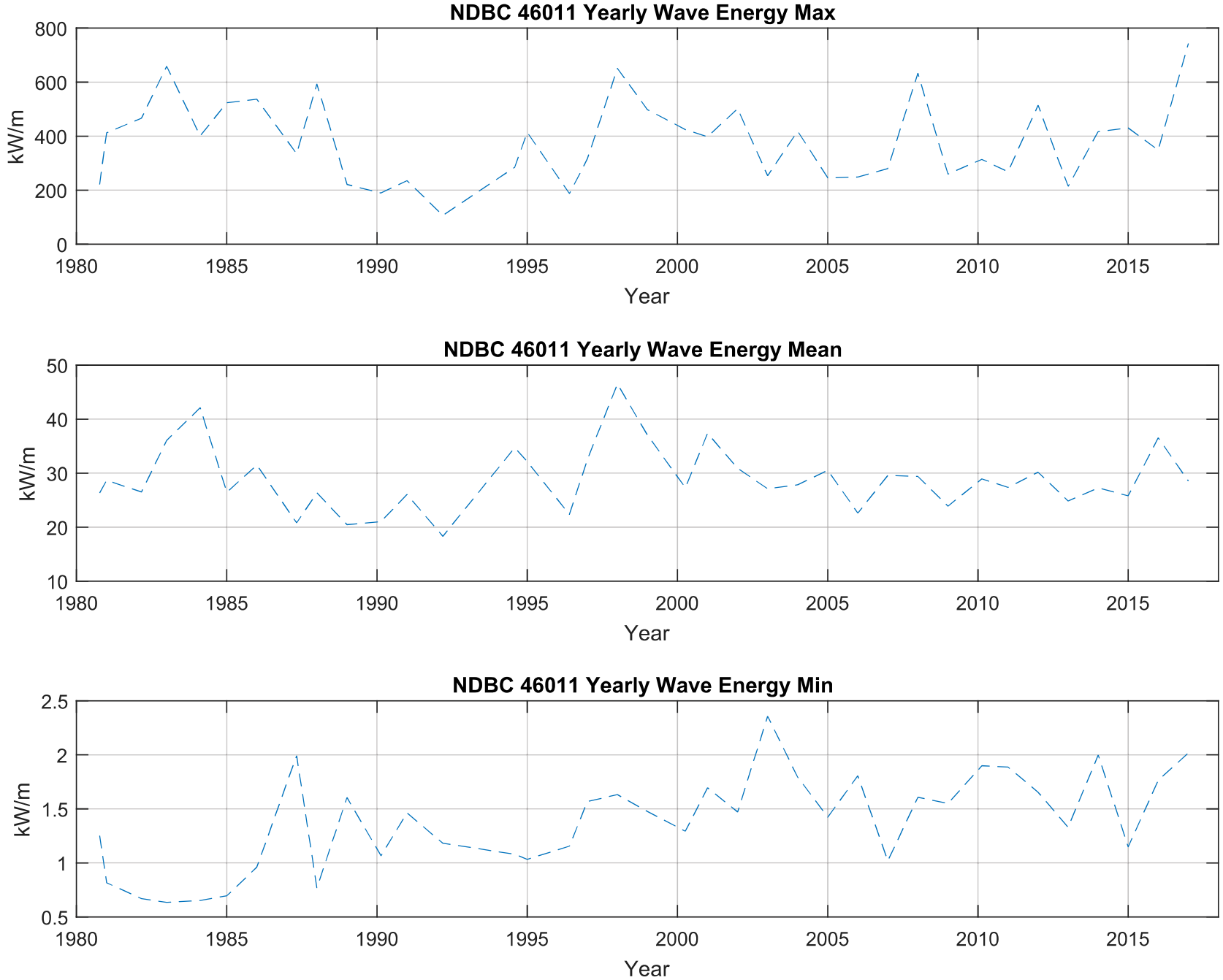
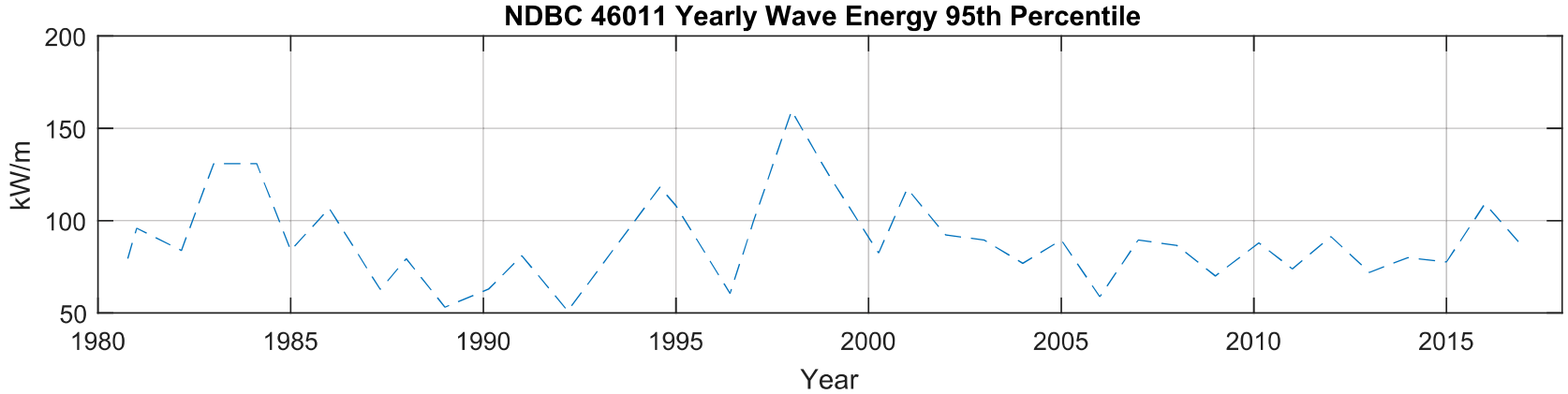
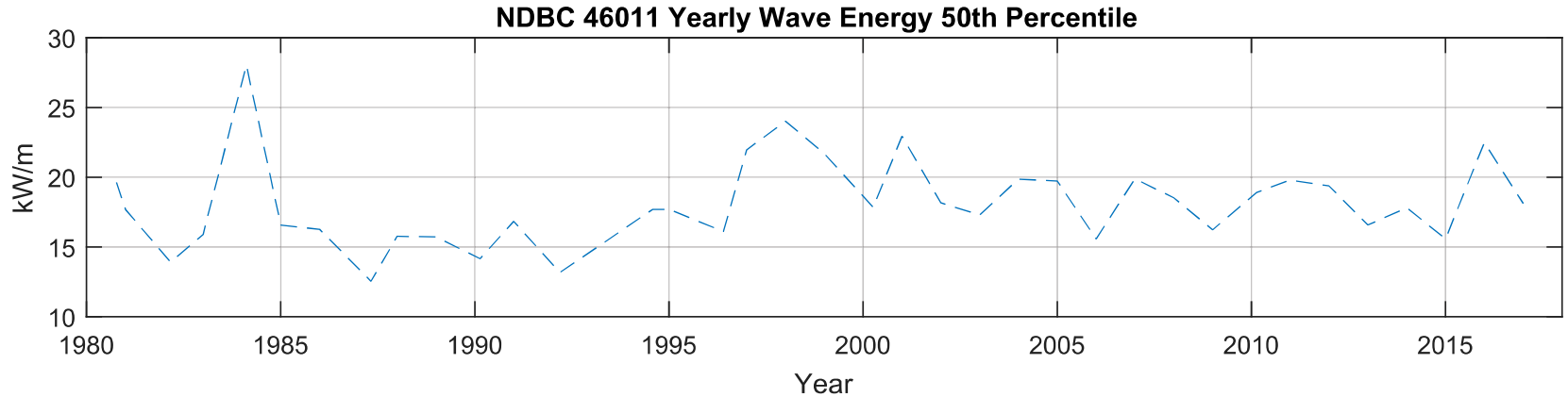


Figure A017. Yearly Wave Energy, Max, Mean, Min,NDBC 46011





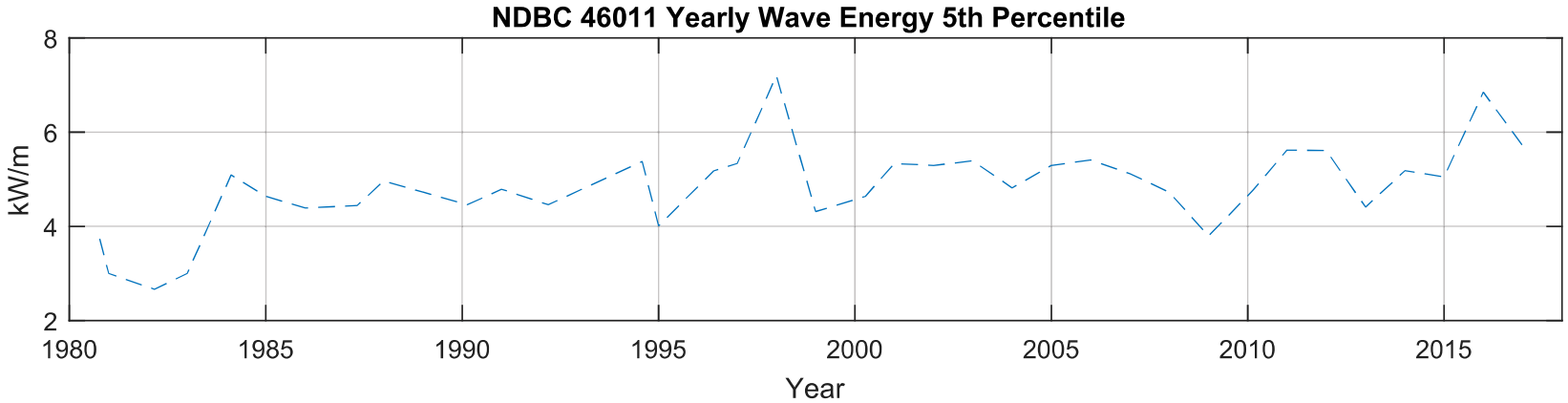


Figure A018. Yearly Wave Energy, Percentiles,NDBC 46011

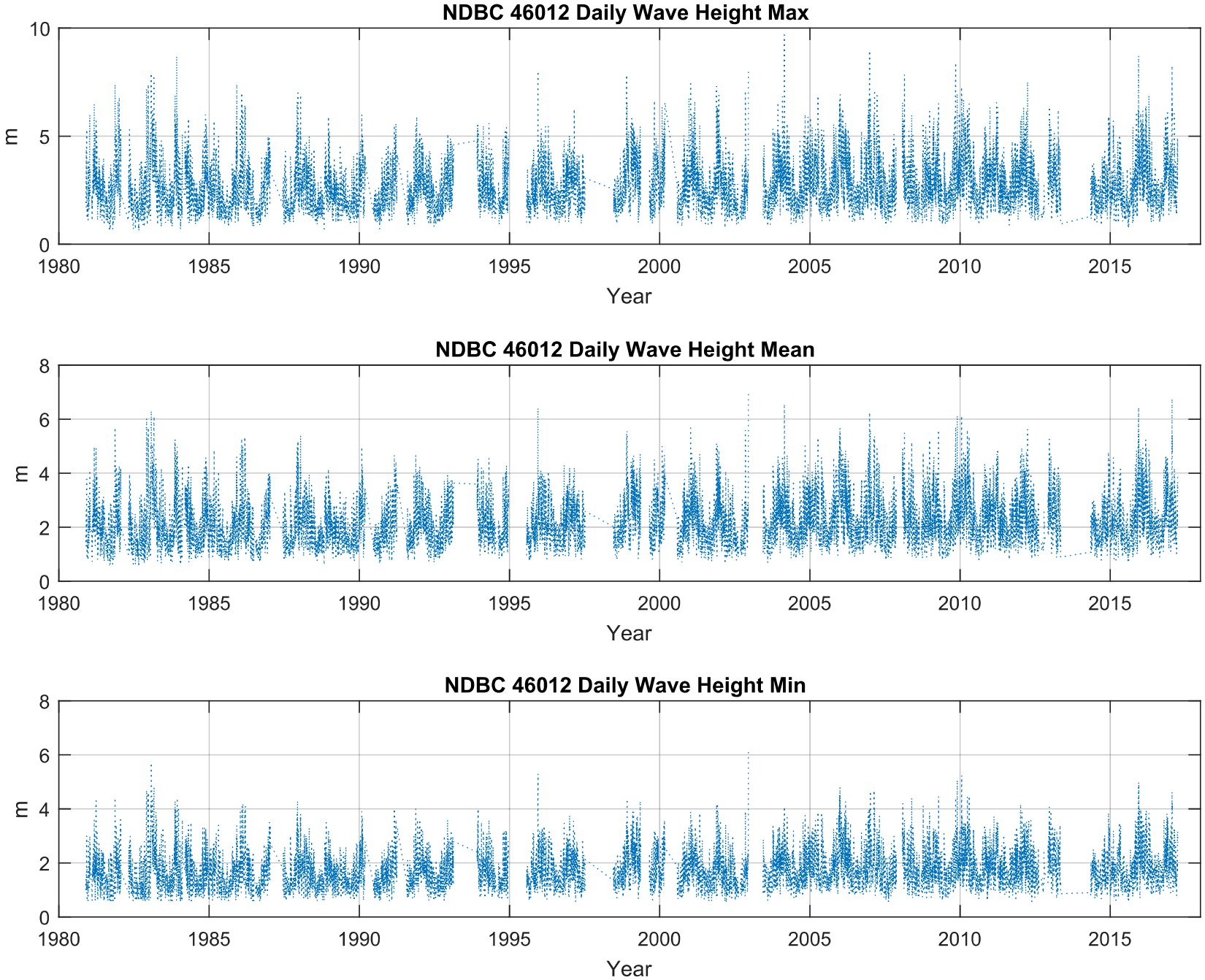


Figure A019. Daily Wave Height, Max, Mean, Min,NDBC 46012

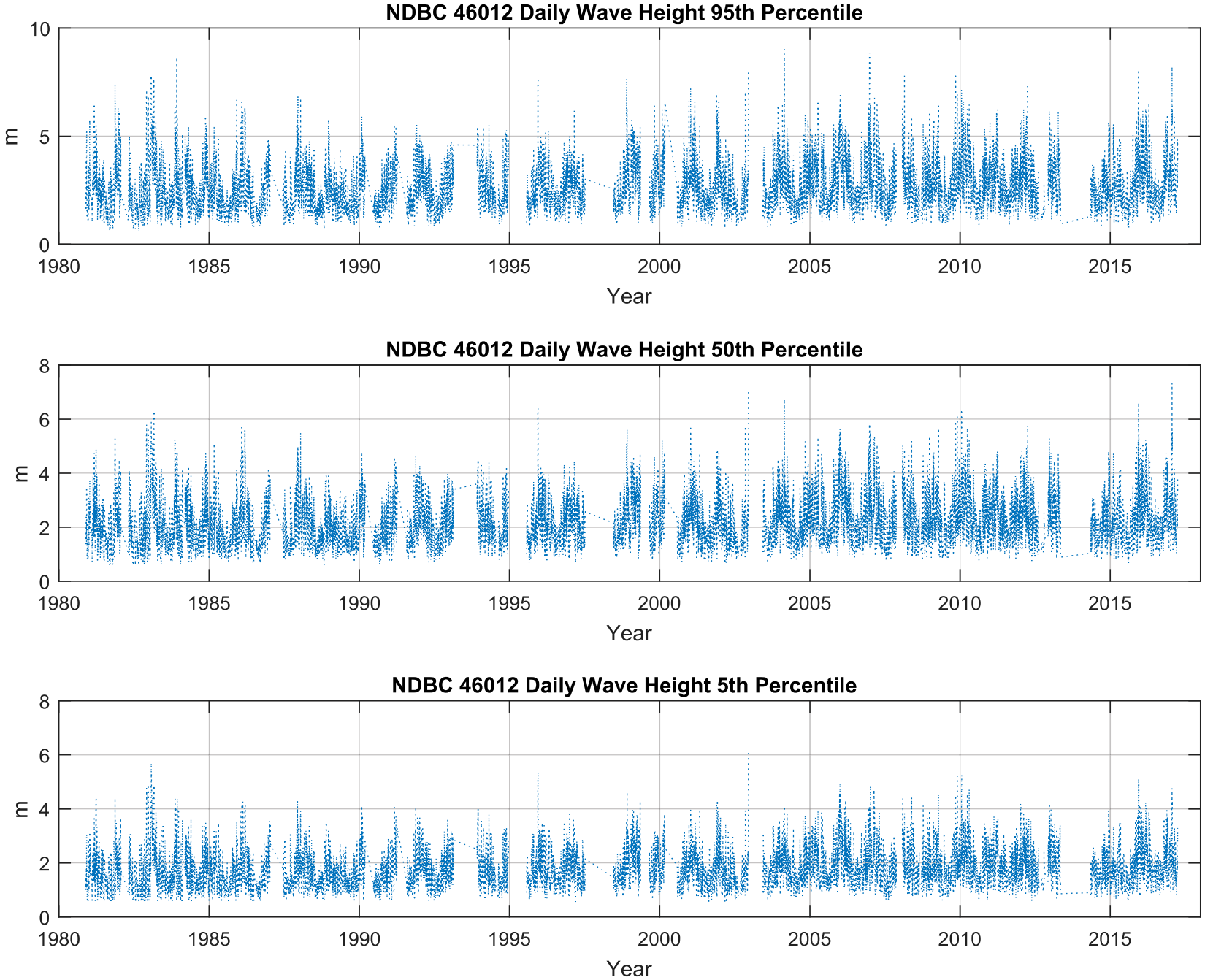


Figure A020. Daily Wave Height, Percentiles,NDBC 46012

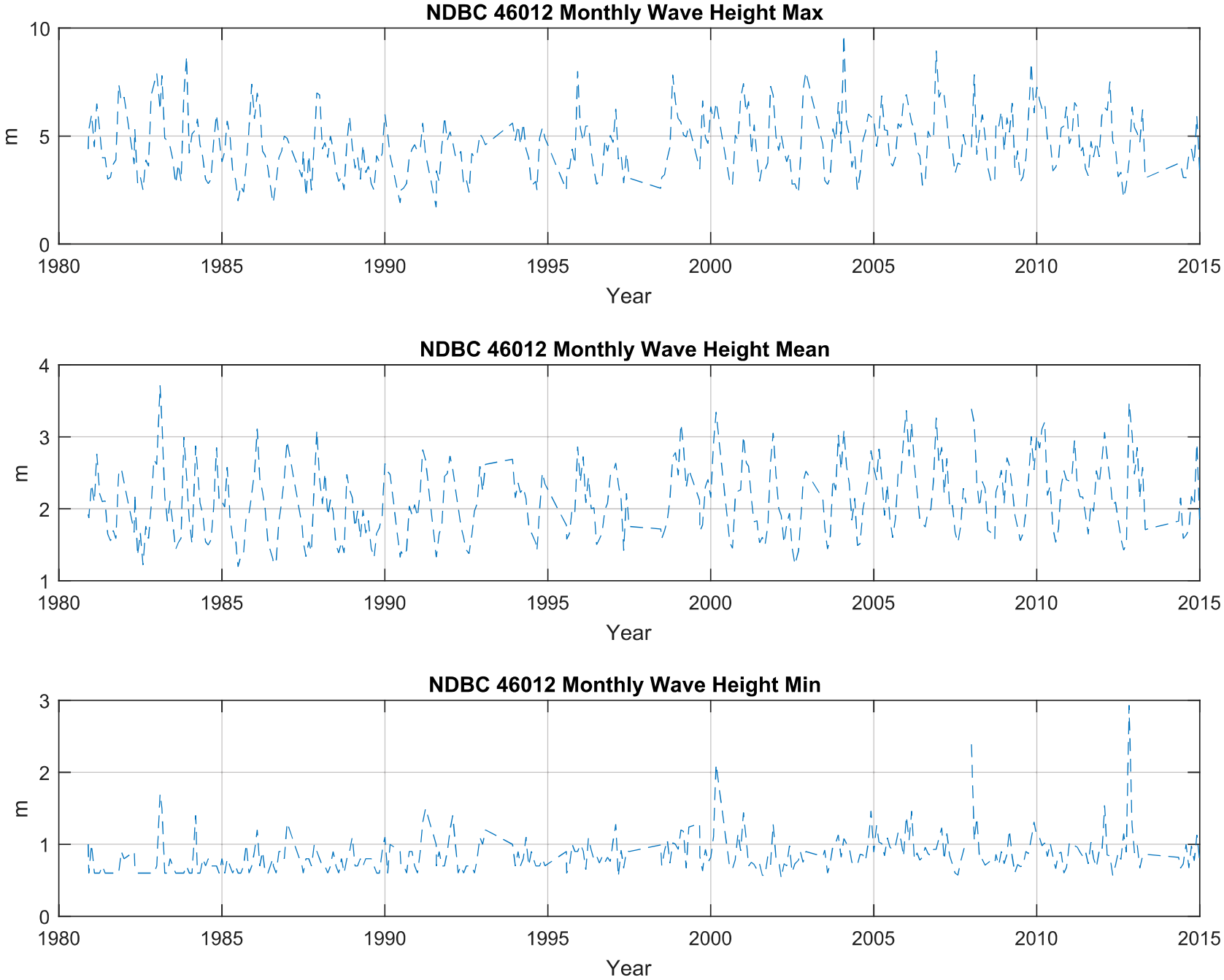
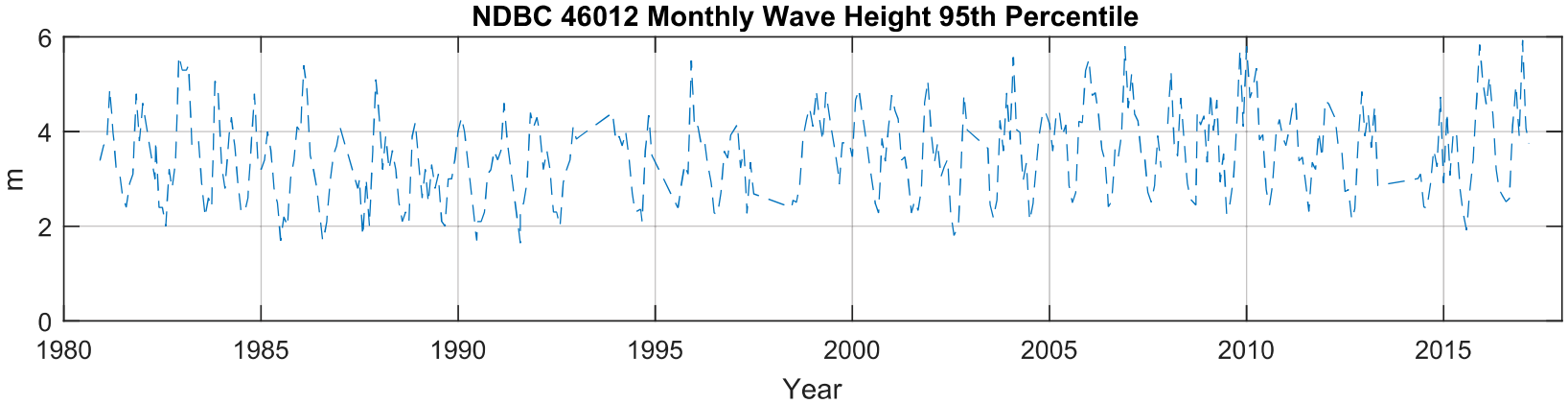
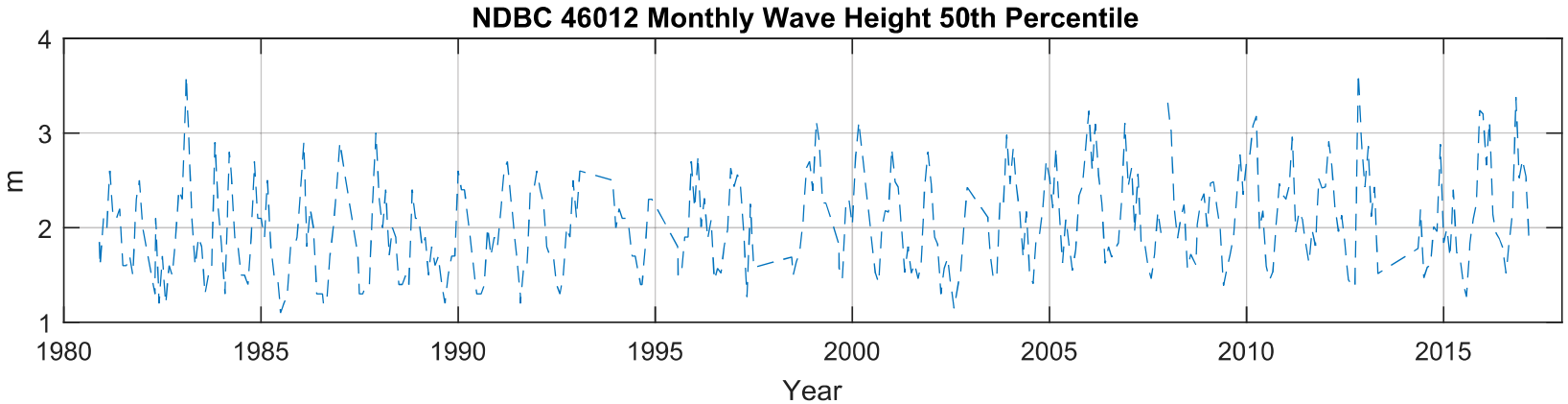


Figure A021. Monthly Wave Height, Max, Mean, Min,NDBC 46012





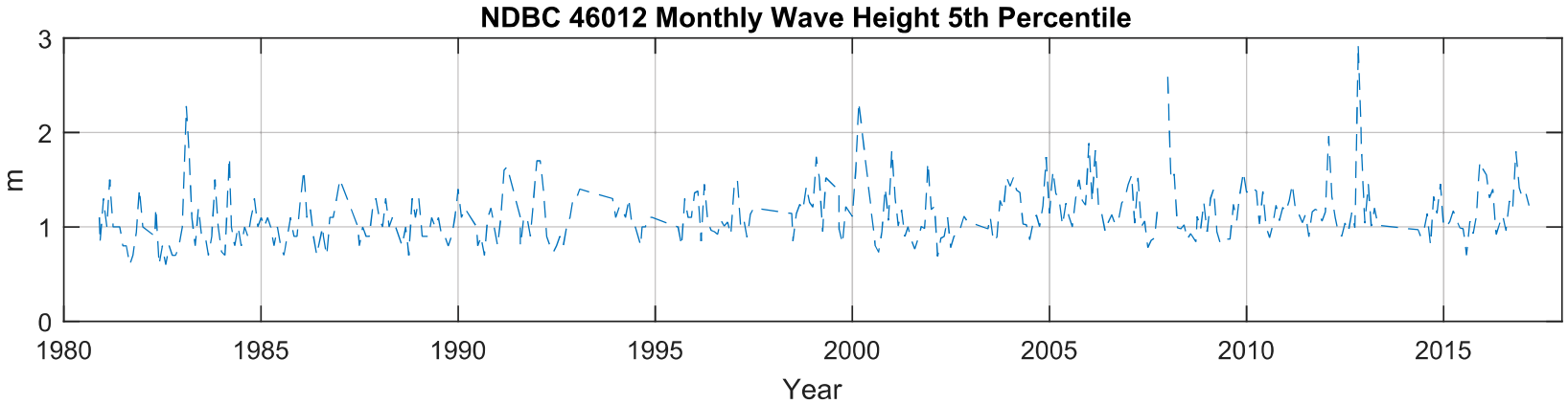


Figure A022. Monthly Wave Height, Percentiles,NDBC 46012

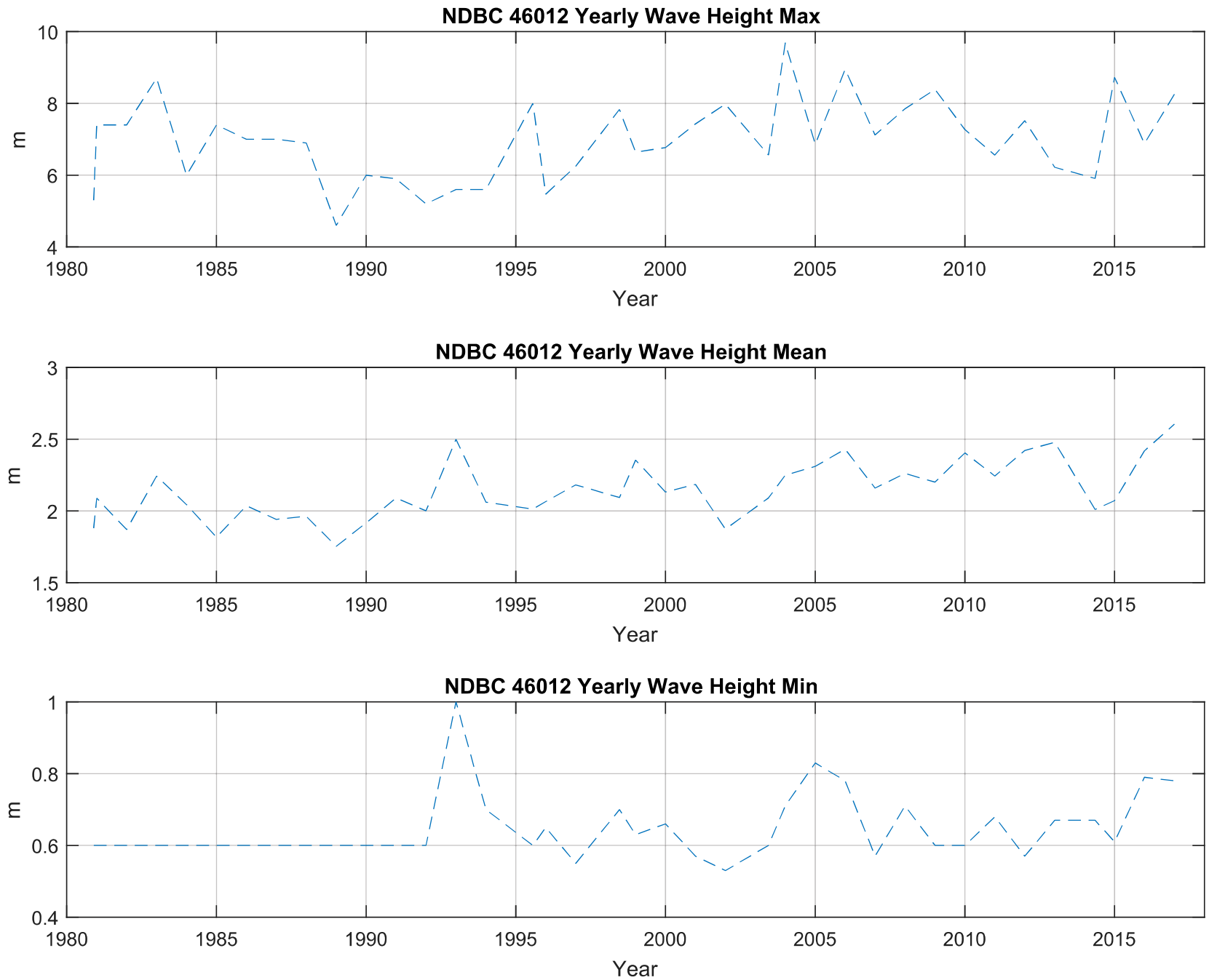


Figure A023. Yearly Wave Height, Max, Mean, Min,NDBC 46012

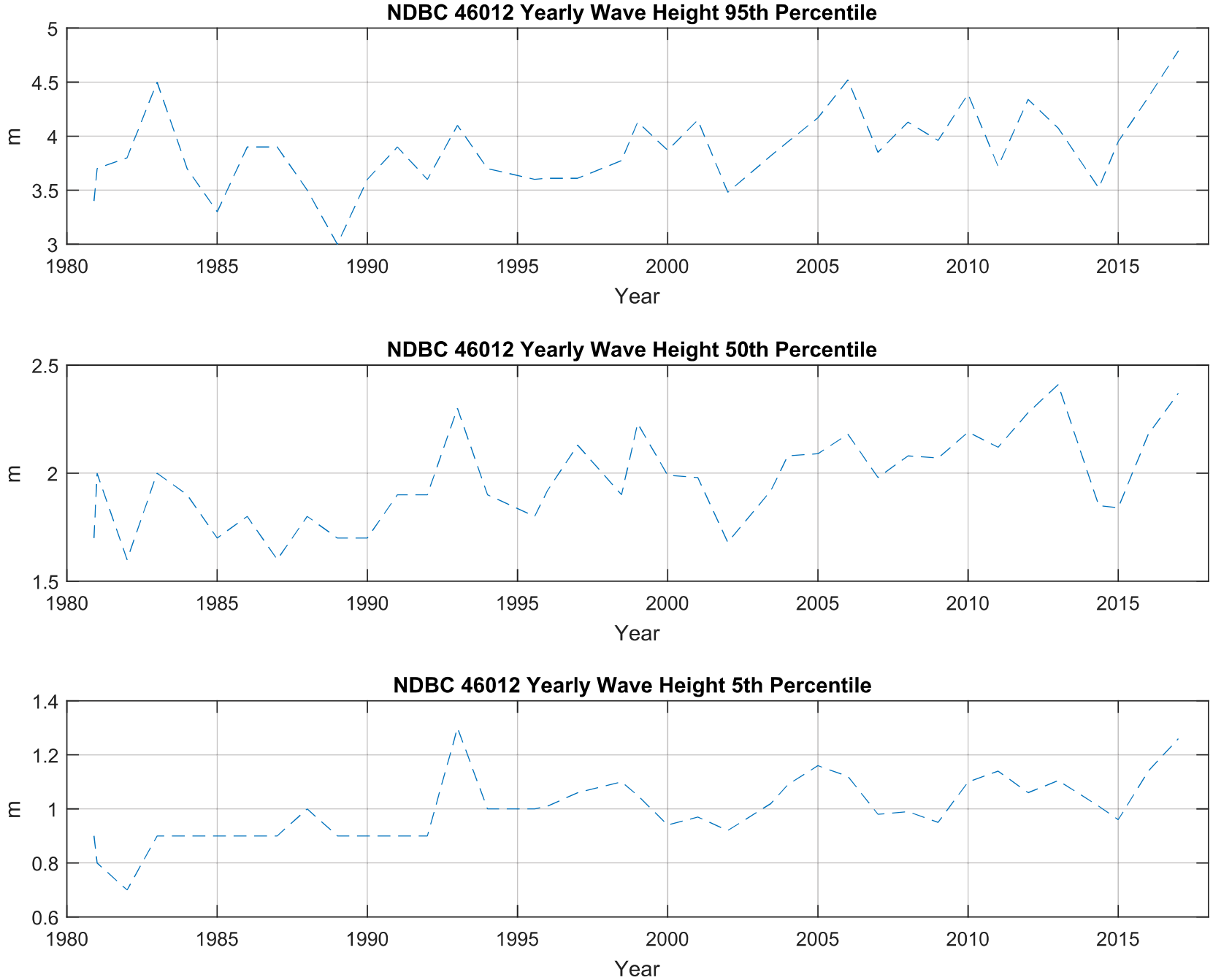


Figure A024. Yearly Wave Height, Percentiles,NDBC 46012

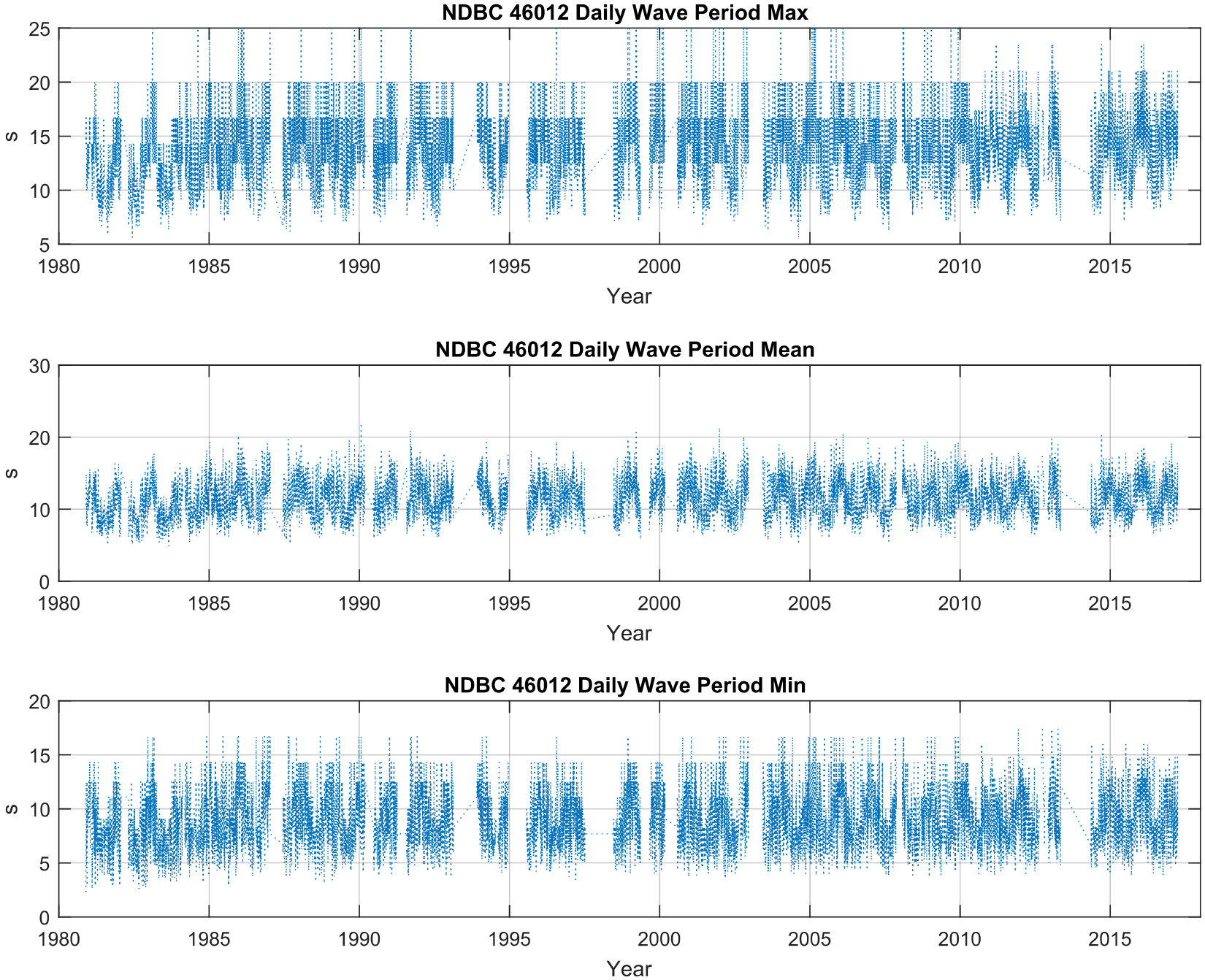
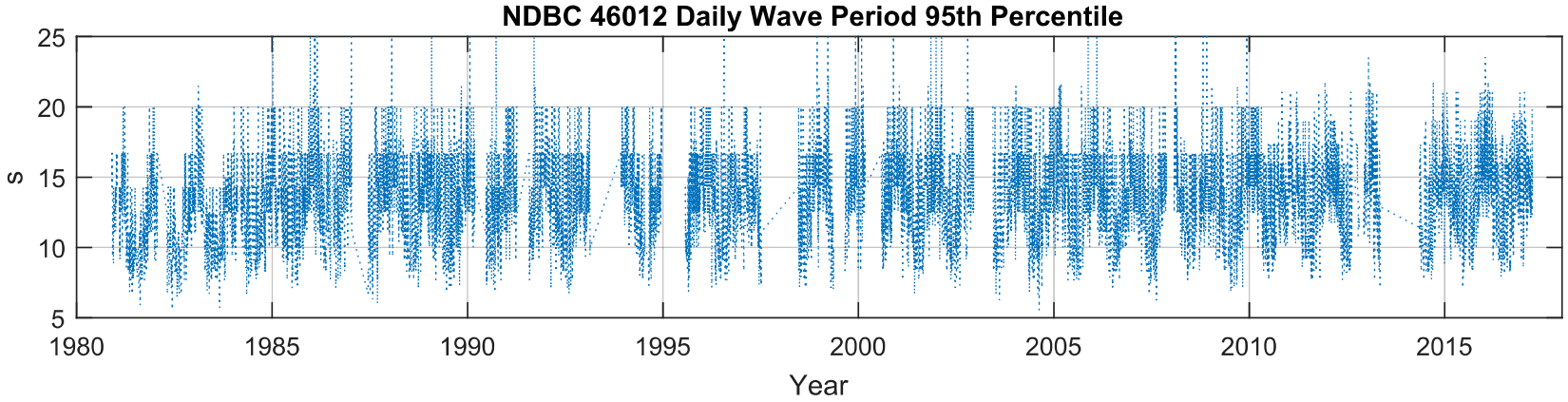
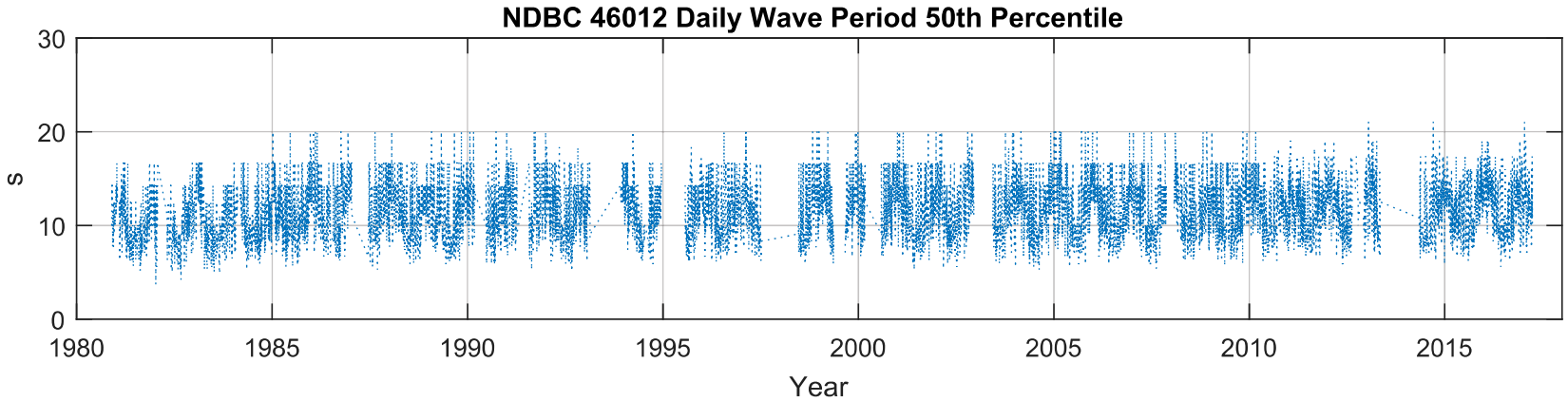


Figure A025. Daily Wave Period, Max, Mean, Min,NDBC 46012





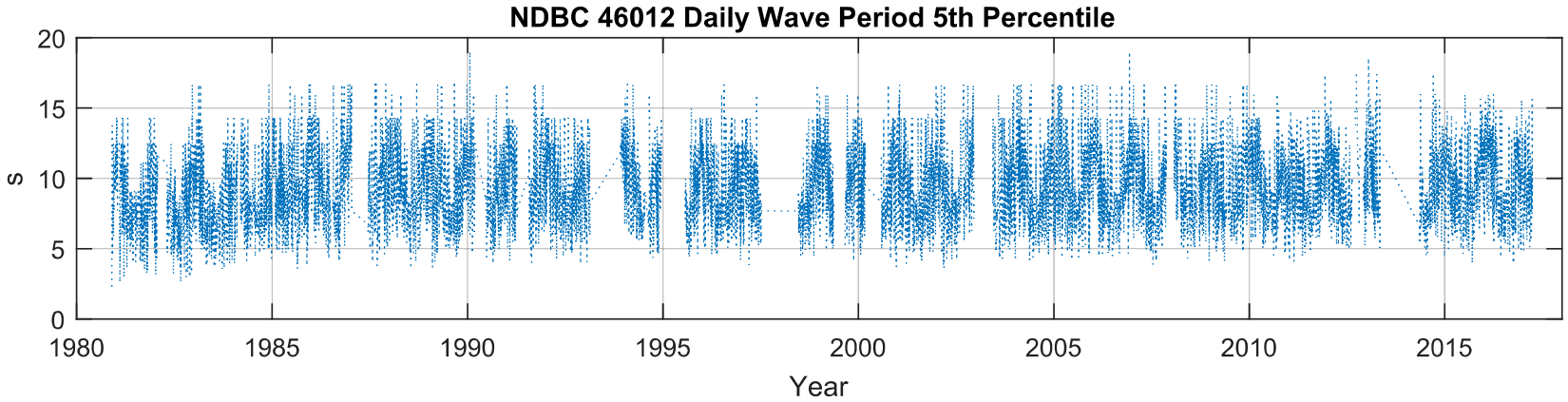


Figure A026. Daily Wave Period, Percentiles,NDBC 46012

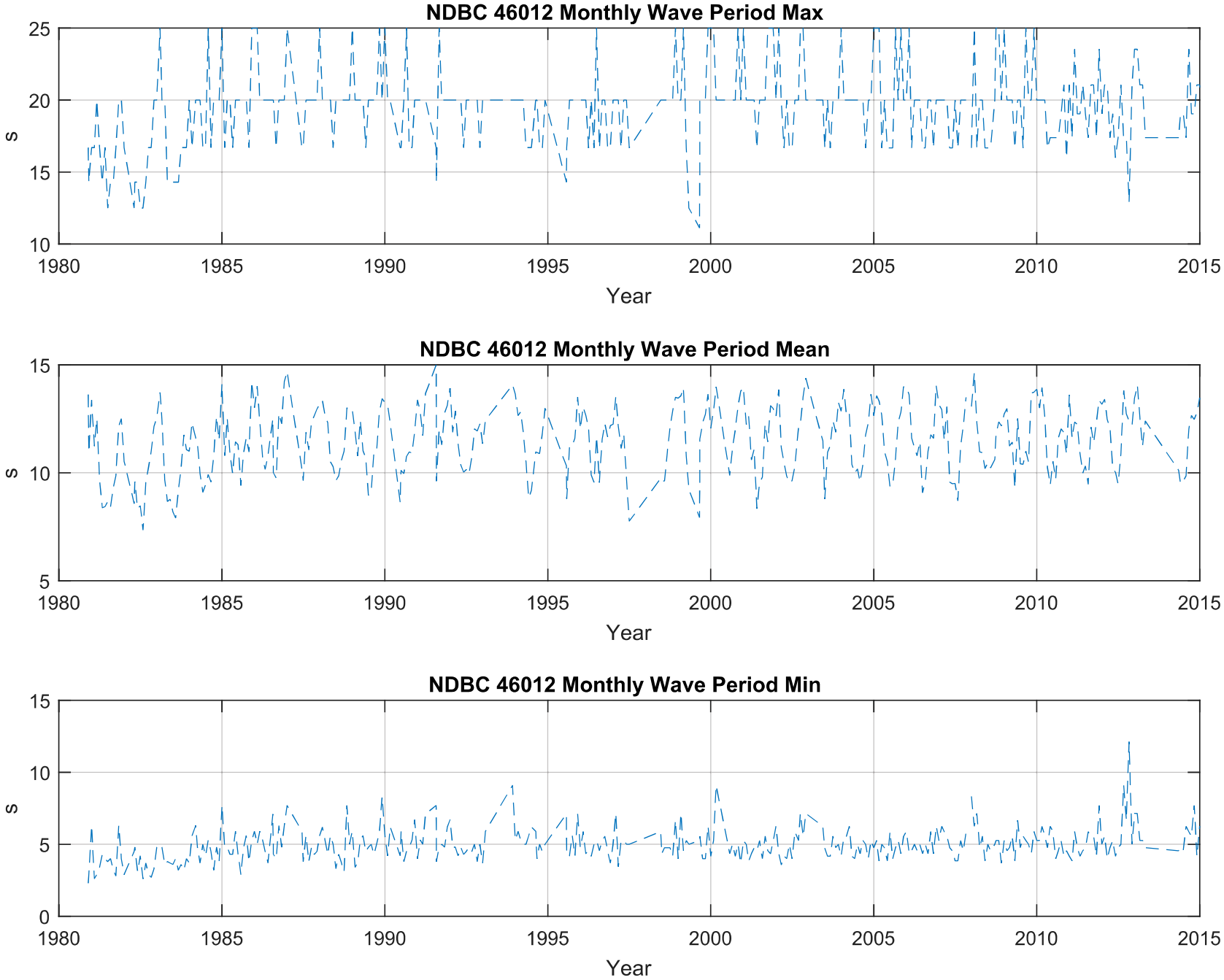
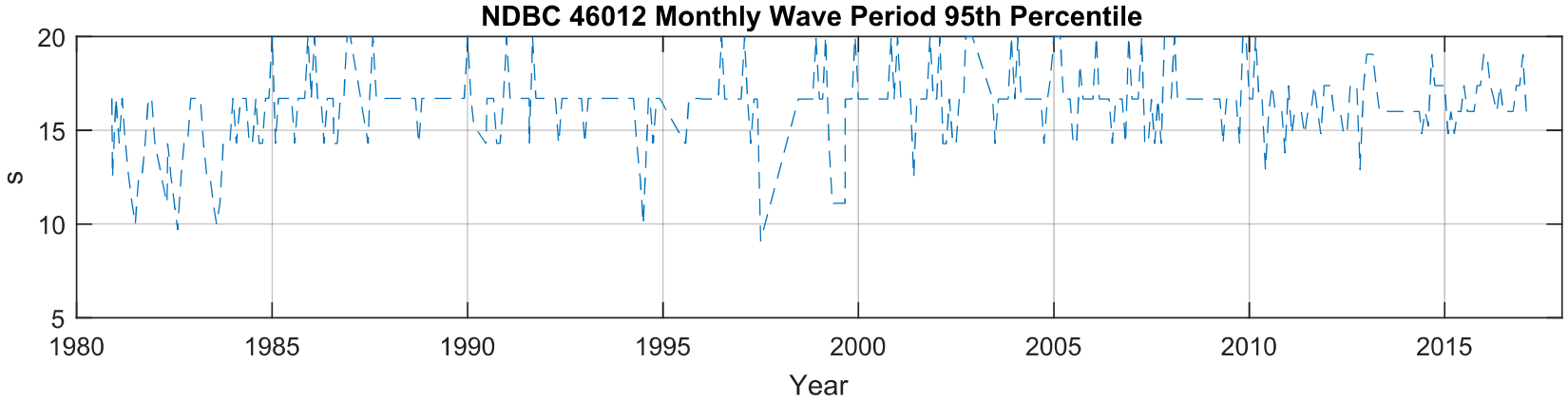
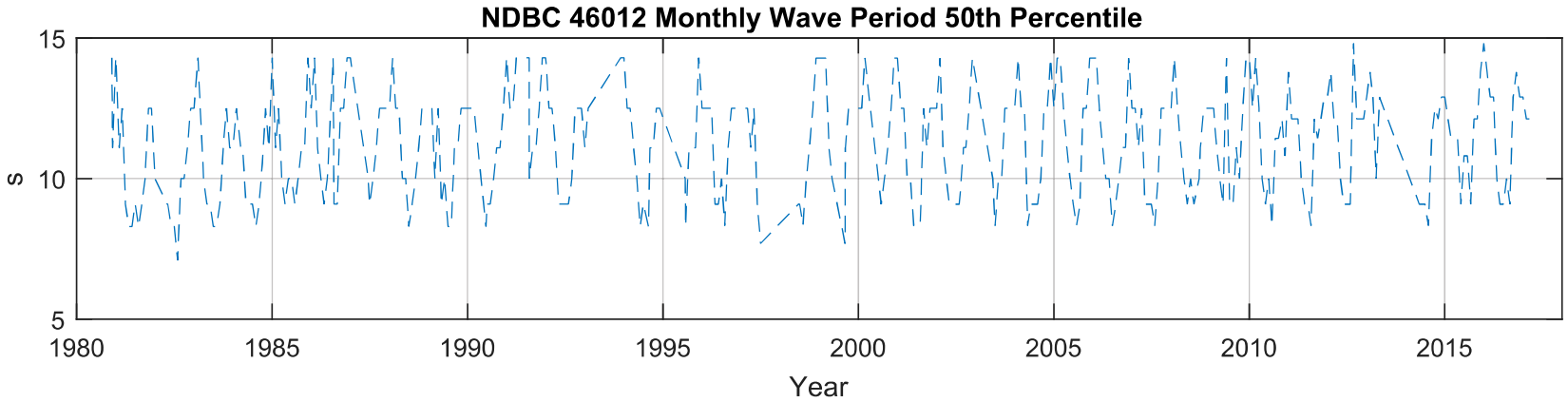


Figure A027. Monthly Wave Period, Max, Mean, Min,NDBC 46012





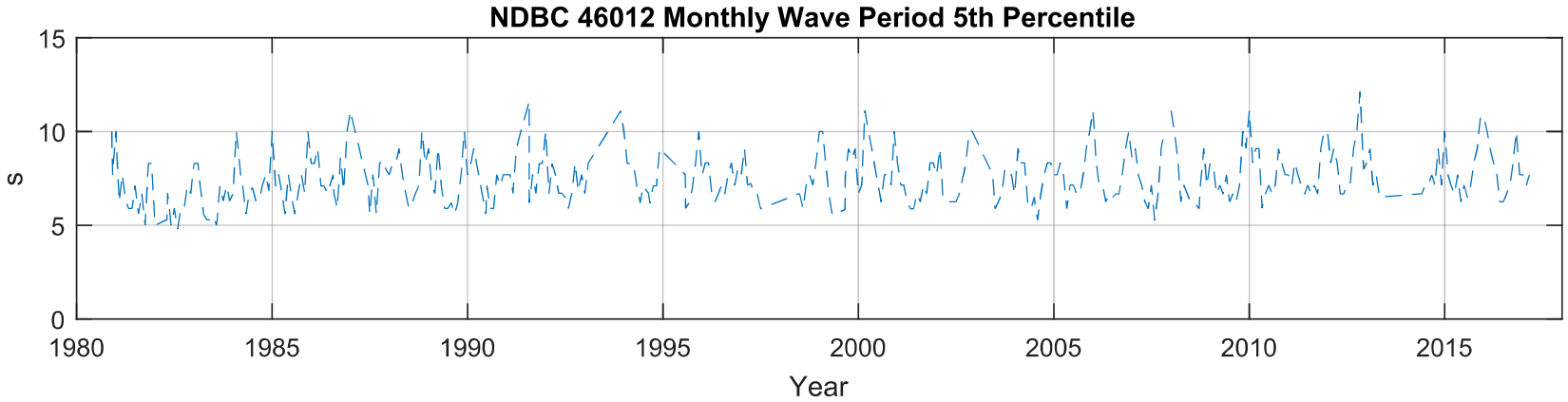


Figure A028. Monthly Wave Period, Percentiles,NDBC 46012

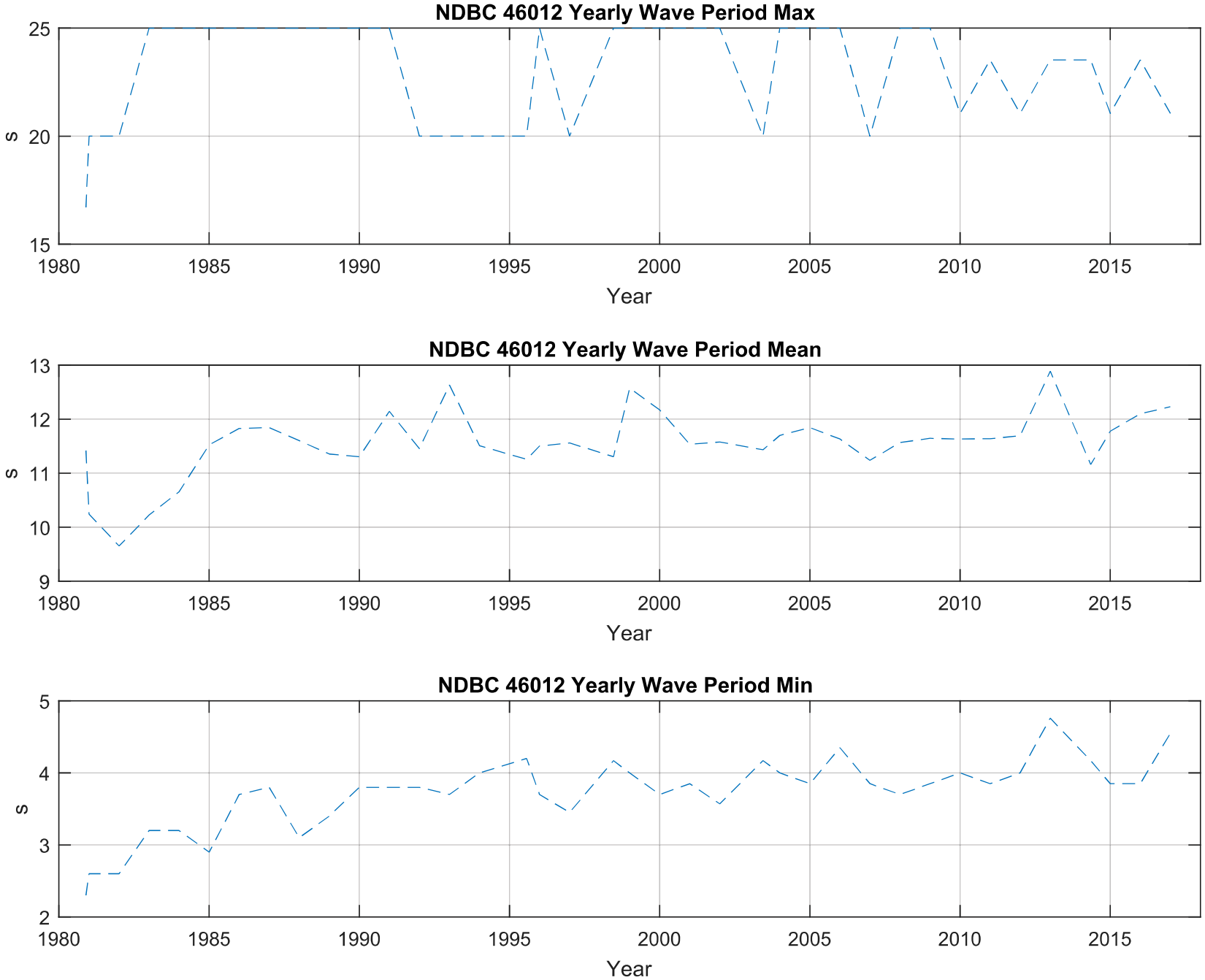
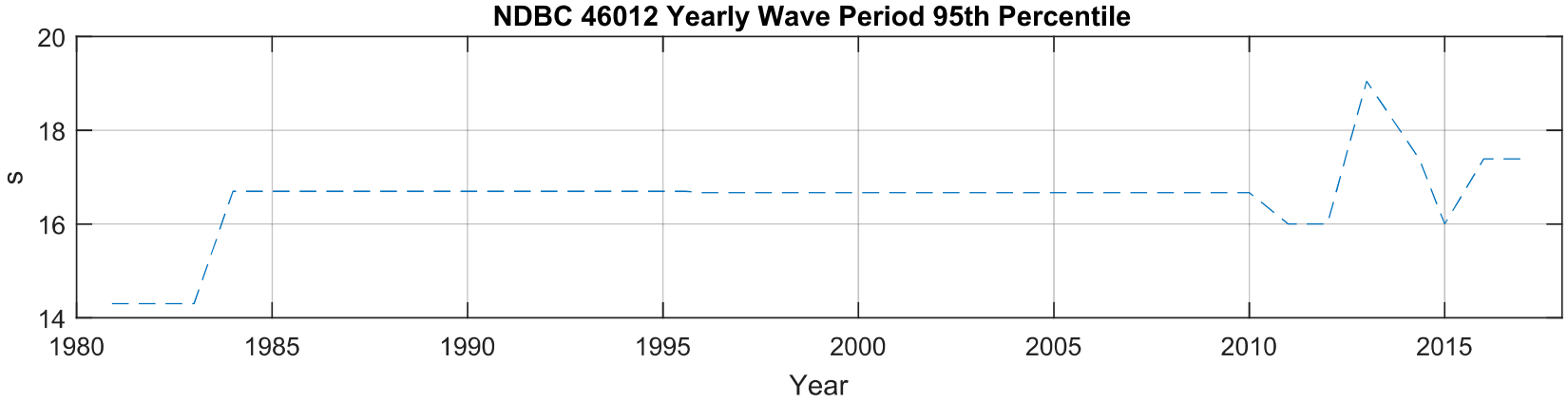
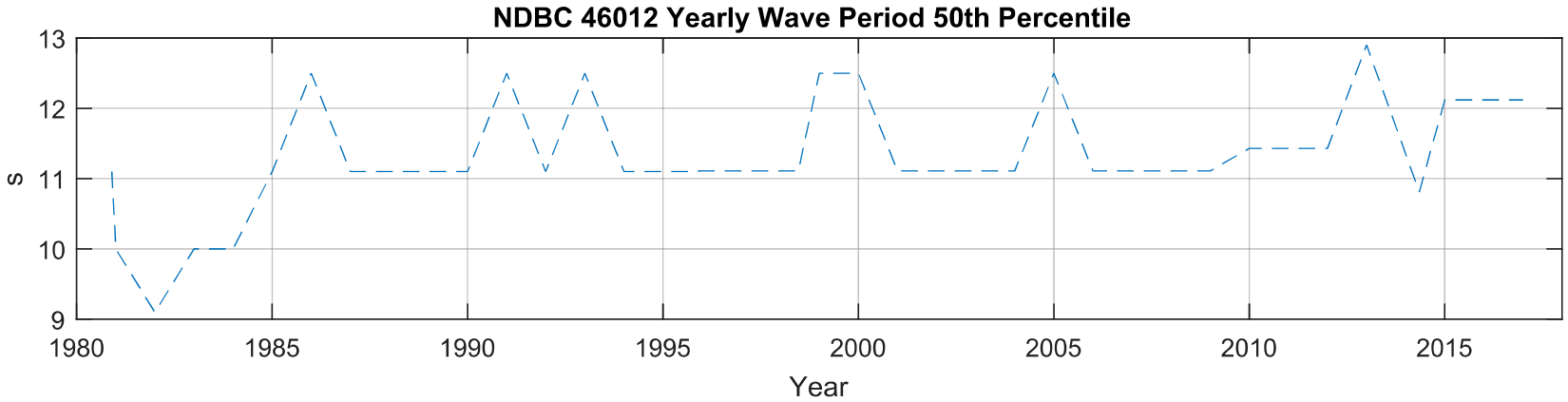


Figure A029. Yearly Wave Period, Max, Mean, Min,NDBC 46012





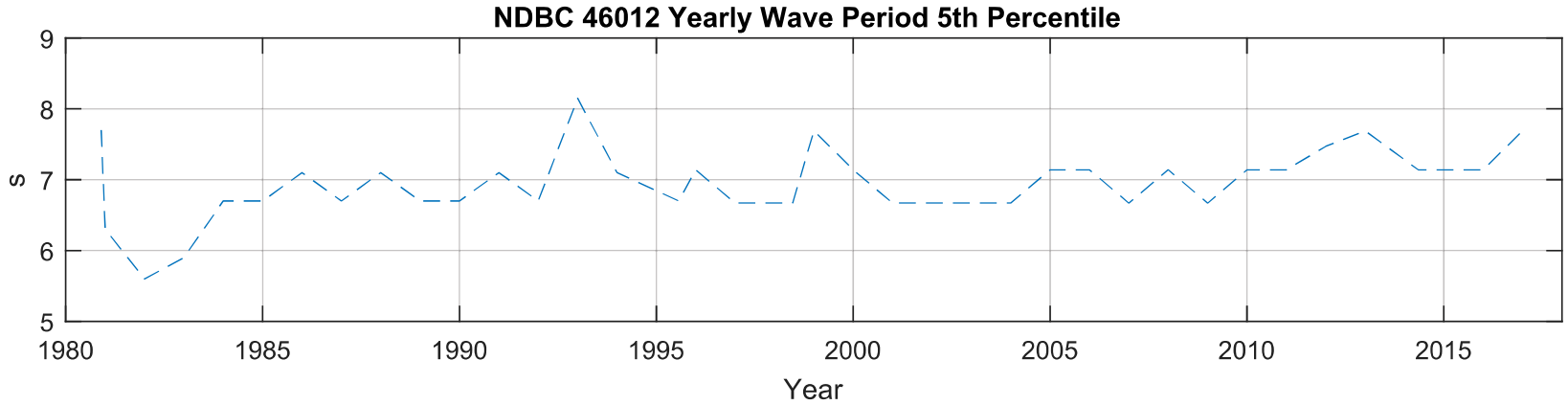
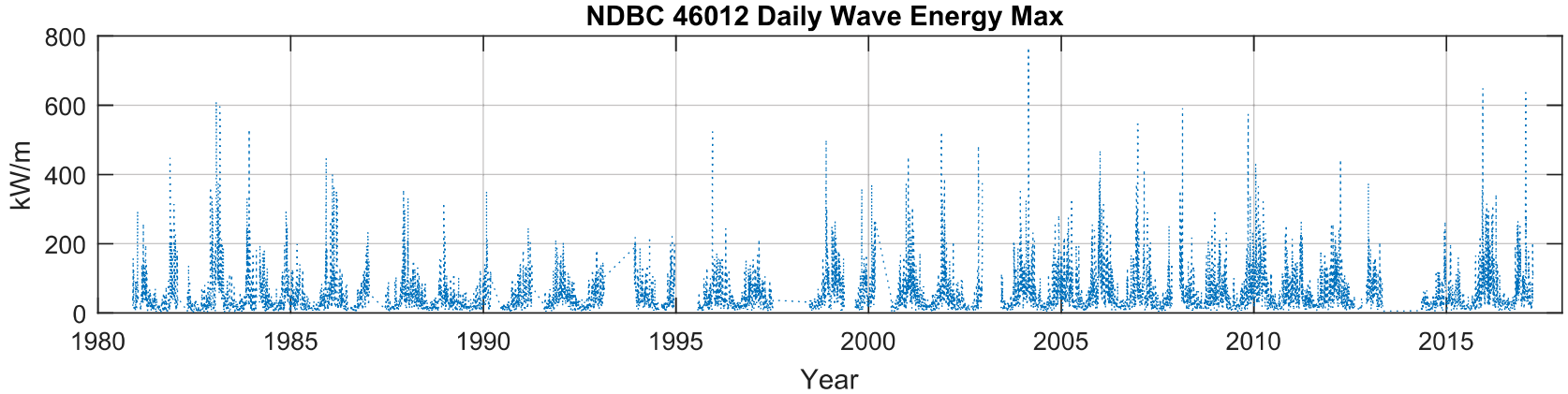
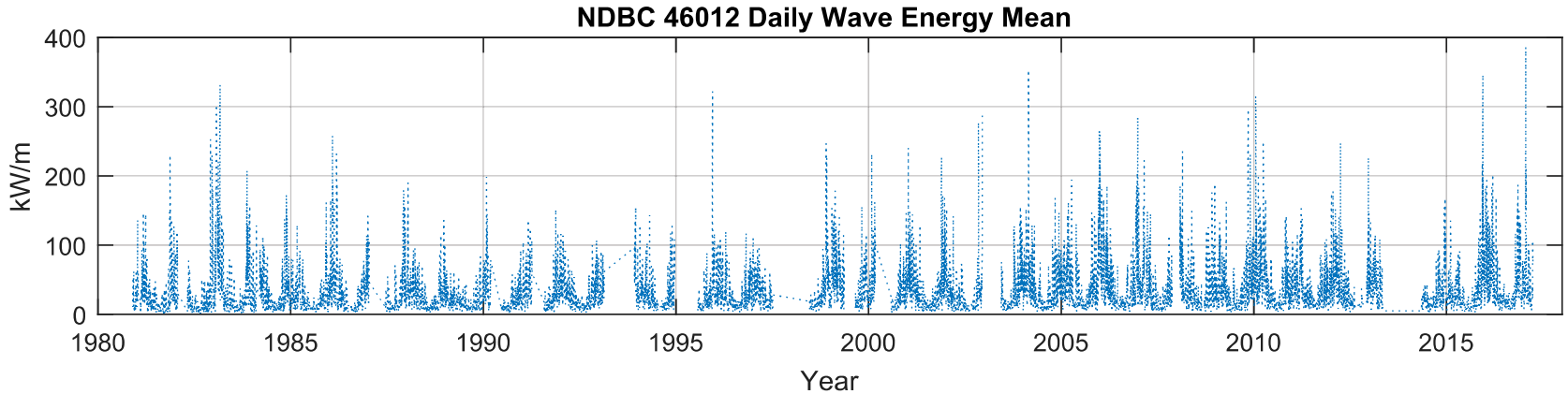


Figure A030. Yearly Wave Period, Percentiles,NDBC 46012





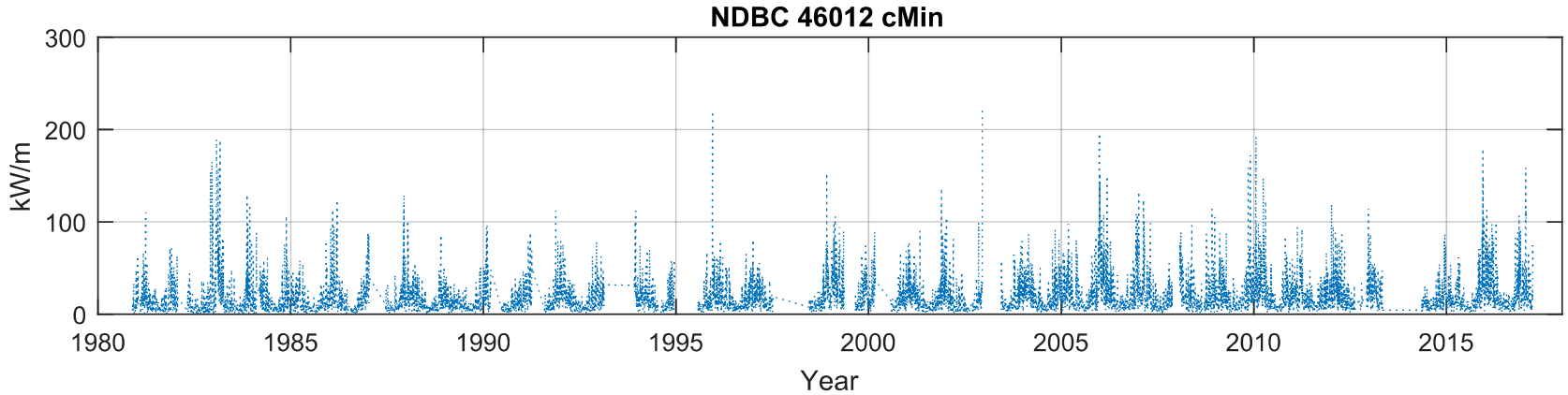
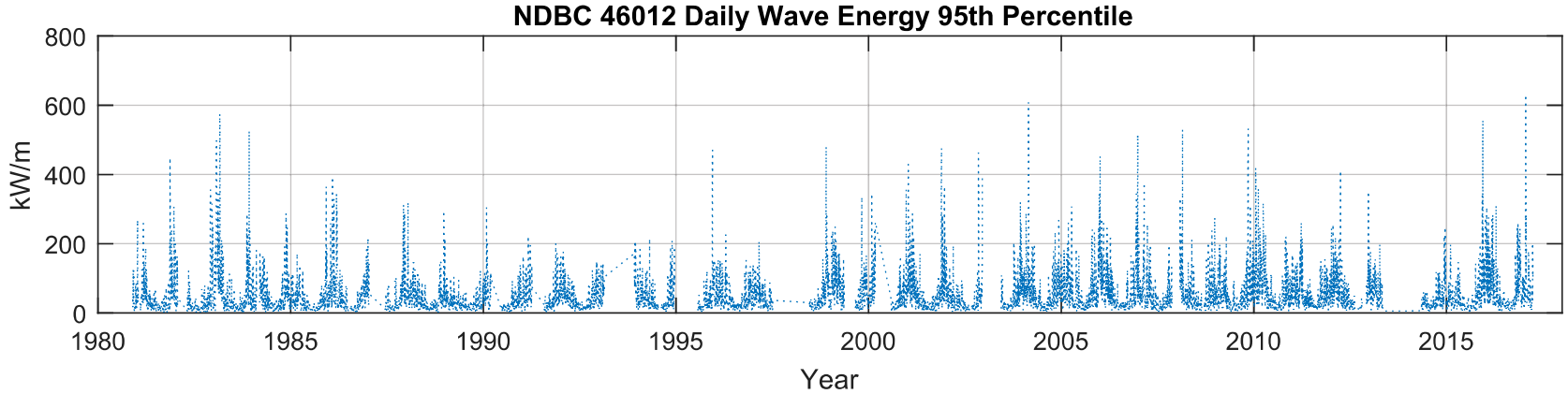
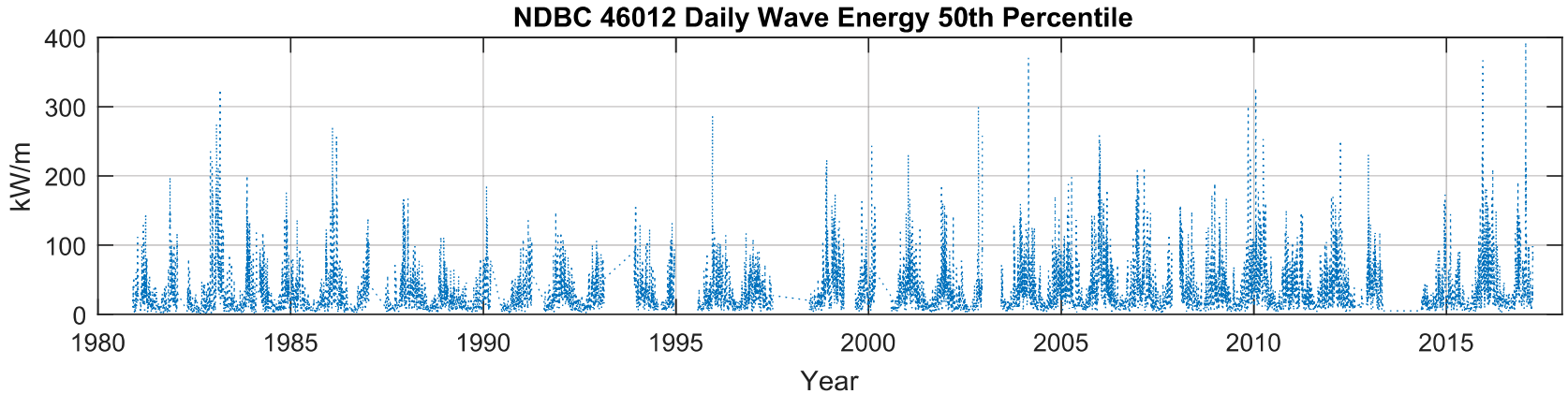


Figure A031. Daily Wave Energy, Max, Mean, Min,NDBC 46012





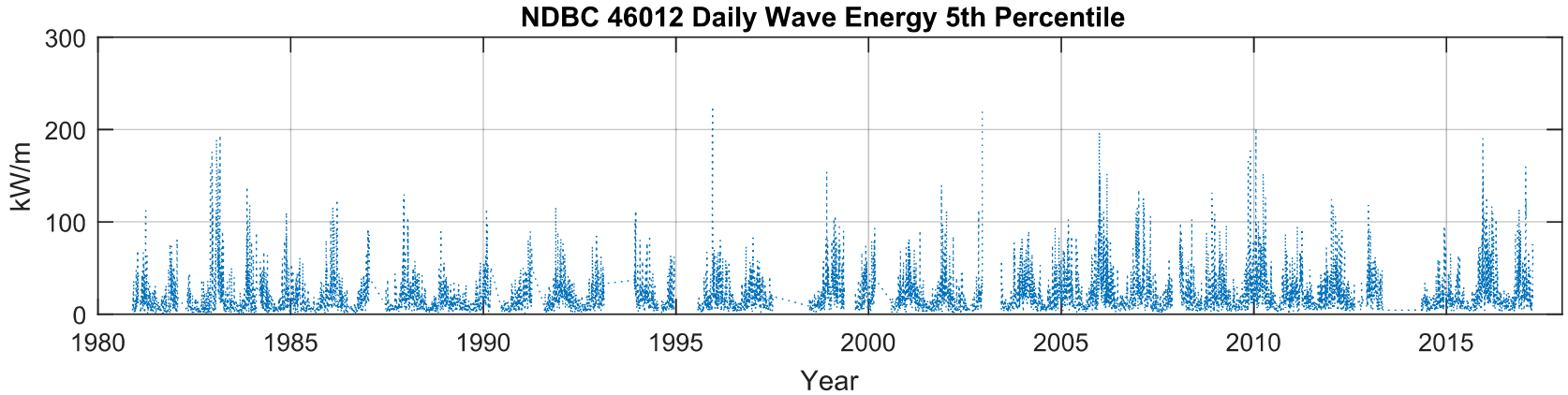


Figure A032. Daily Wave Energy, Percentiles,NDBC 46012

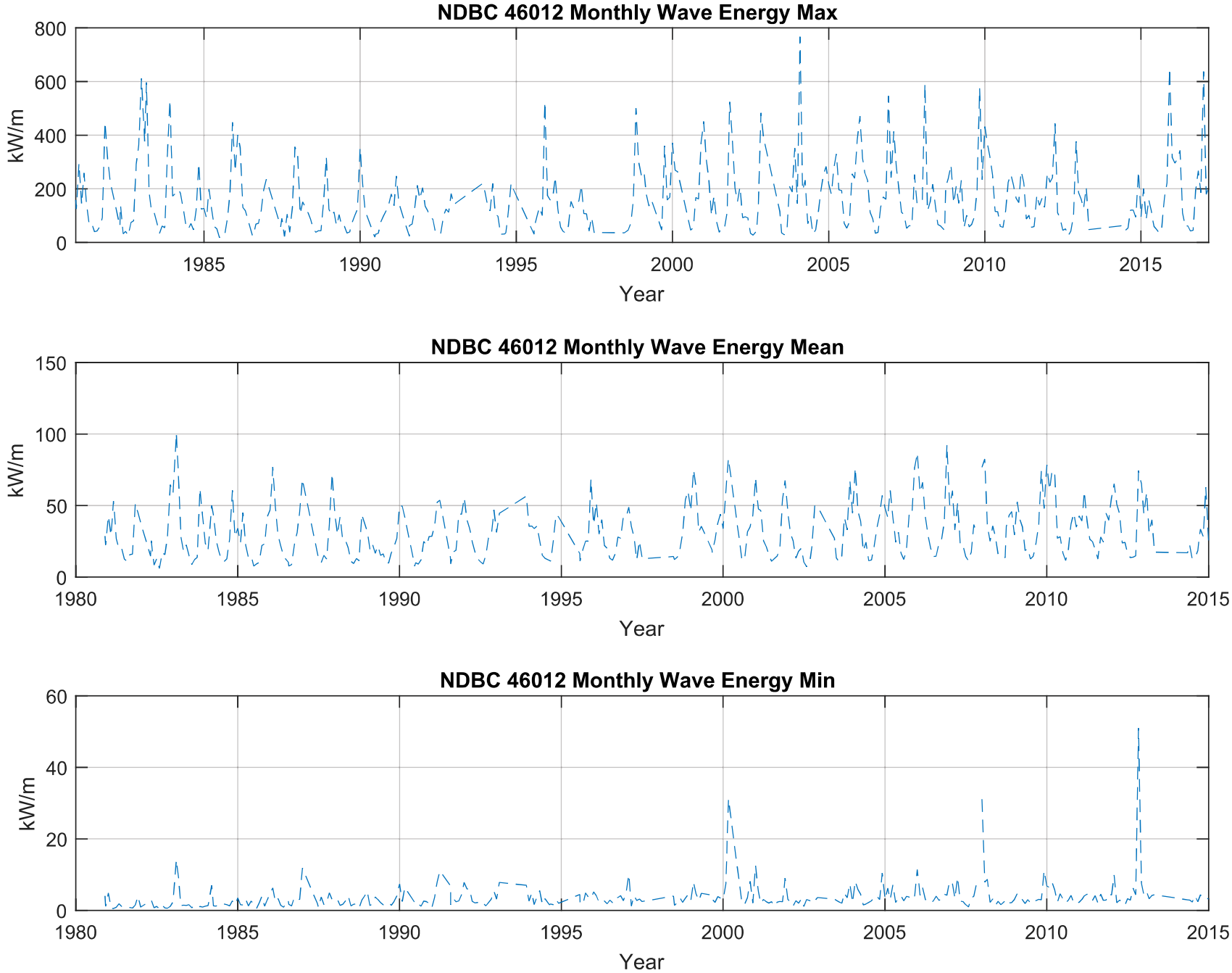
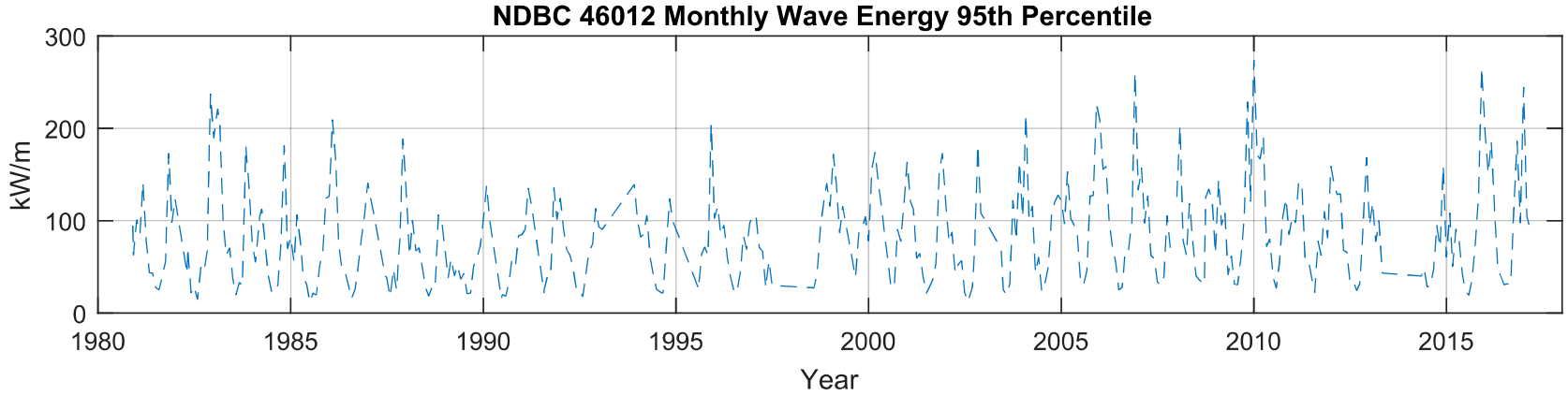
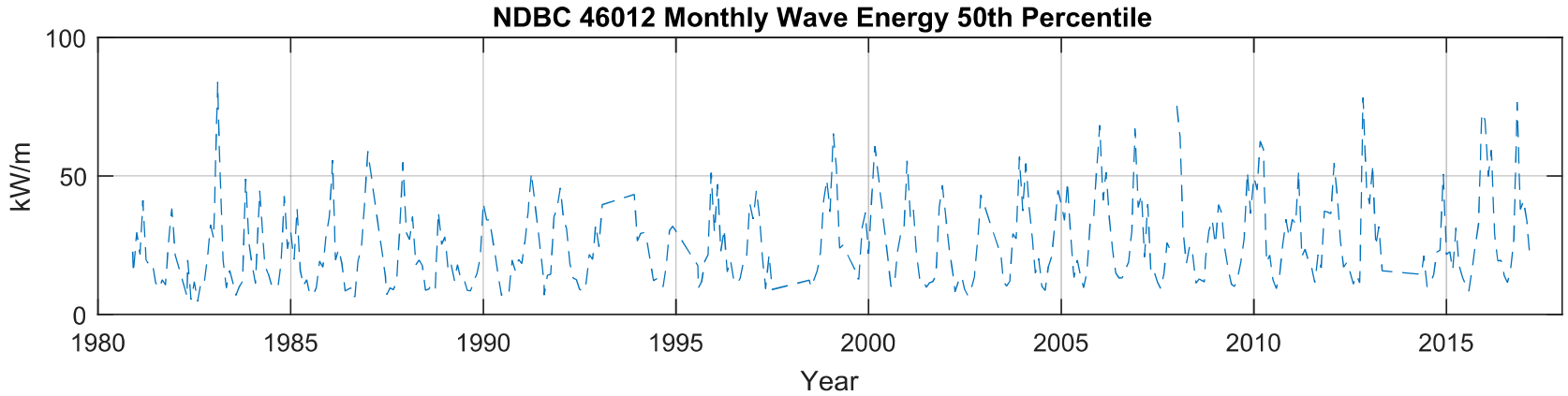


Figure A033. Monthly Wave Energy, Max, Mean, Min,NDBC 46012





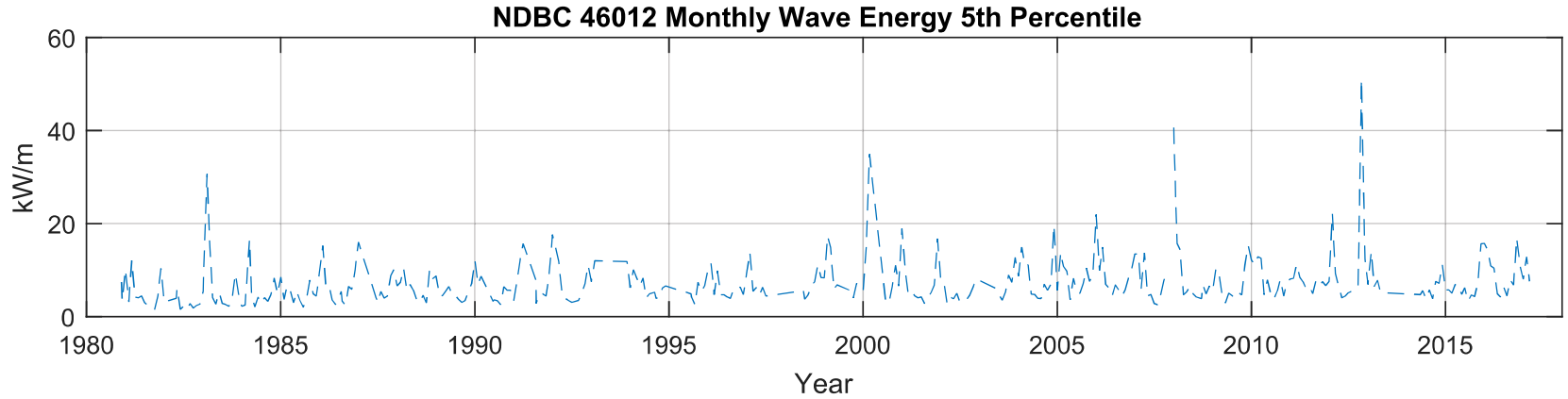
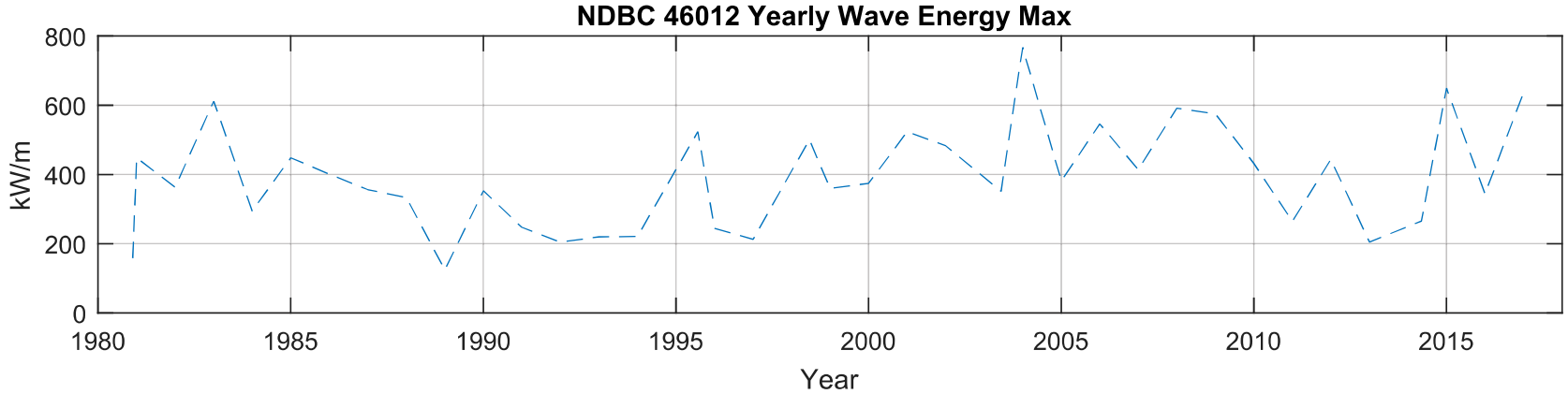
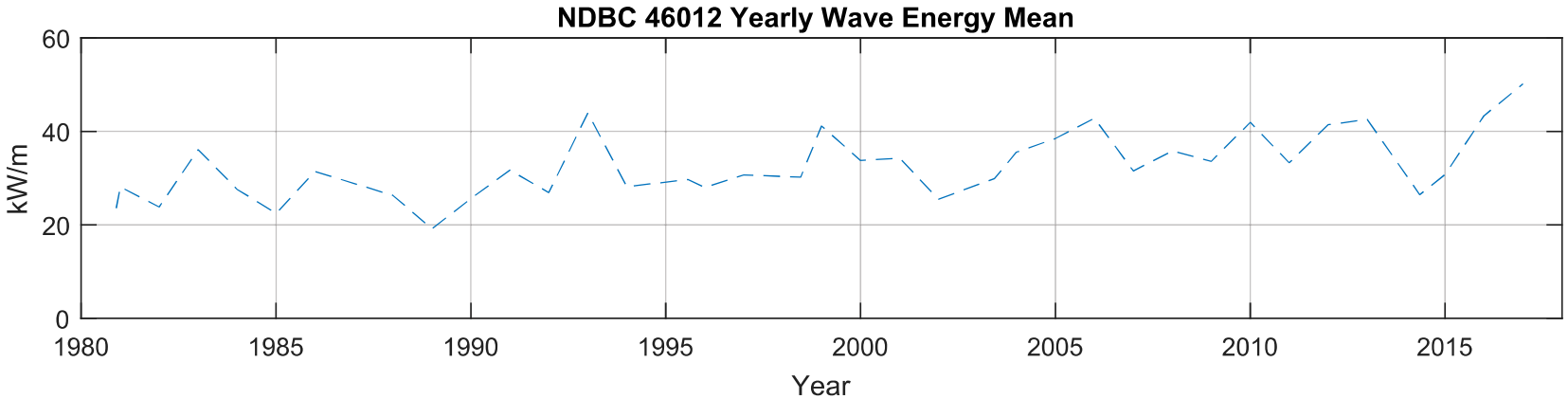


Figure A034. Monthly Wave Energy, Percentiles,NDBC 46012





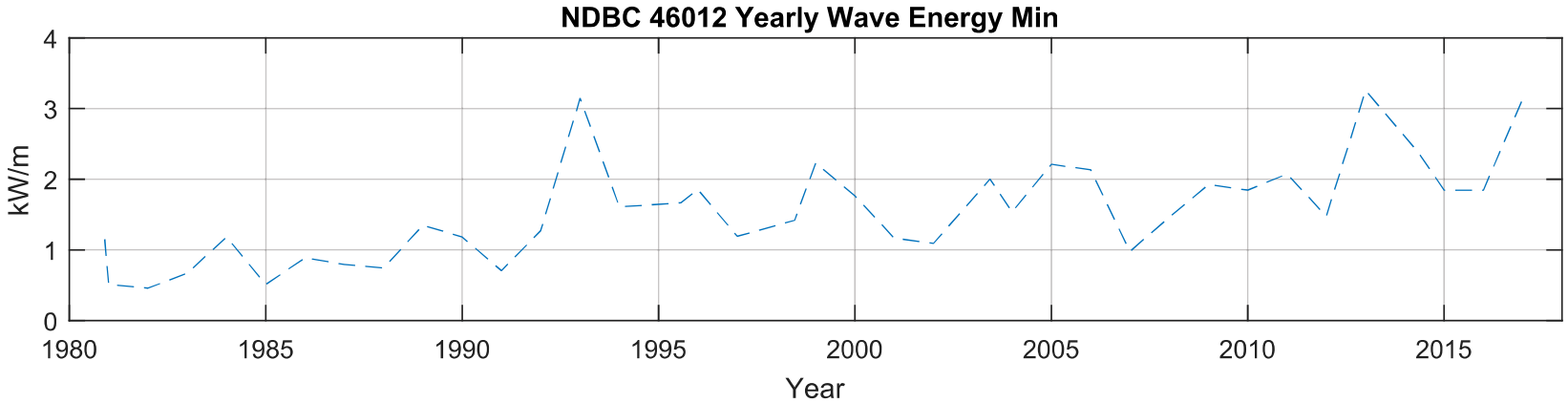
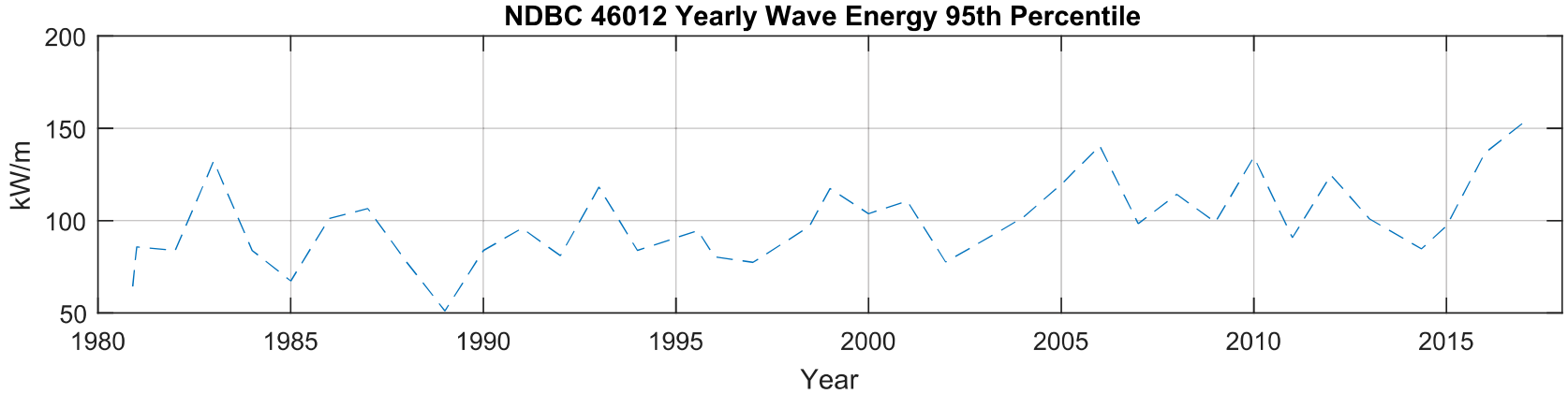
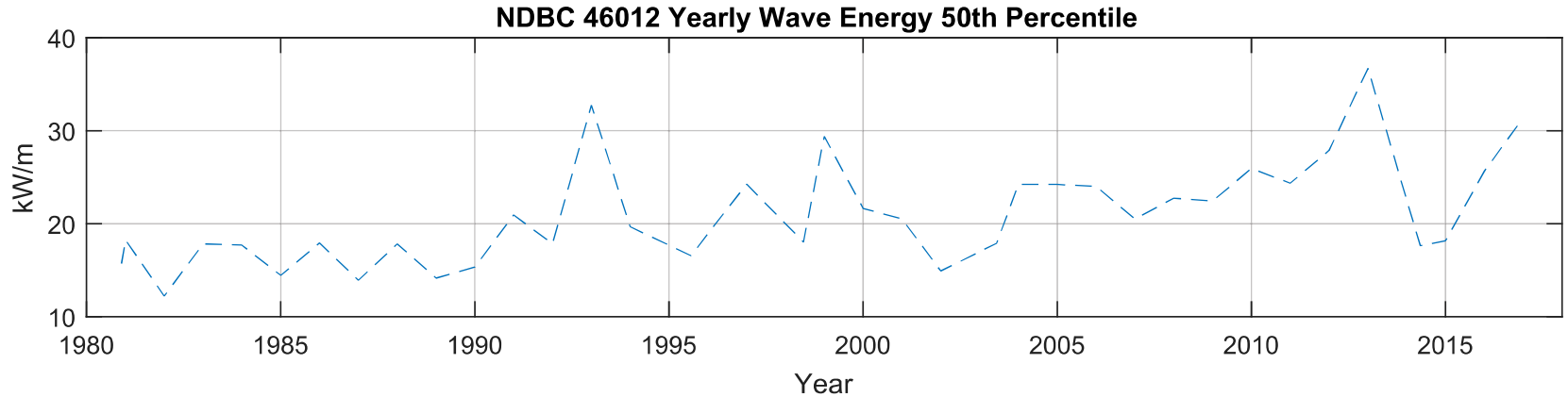


Figure A035. Yearly Wave Energy, Max, Mean, Min,NDBC 46012





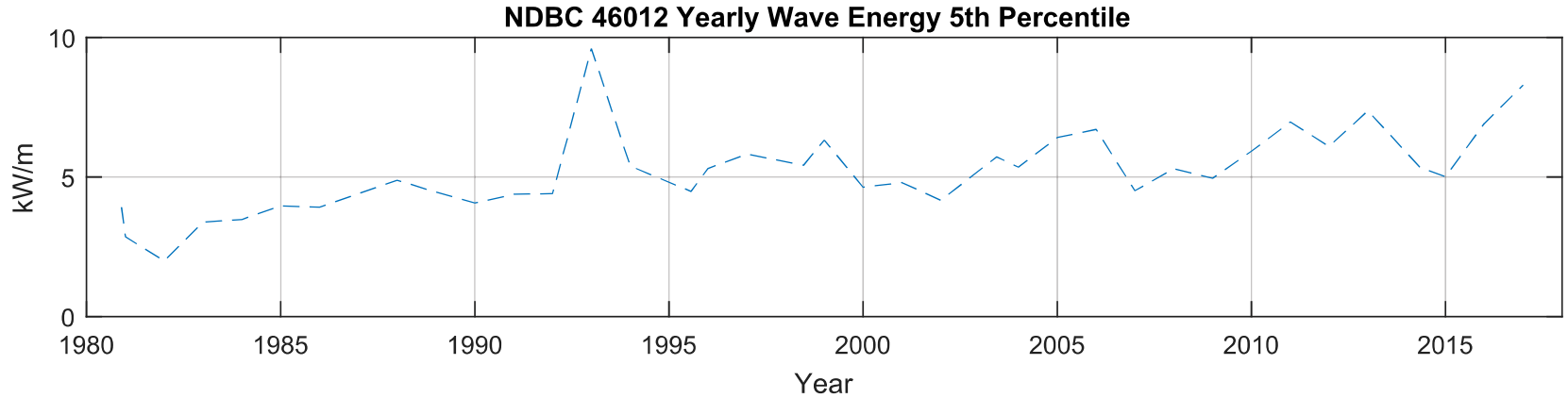


Figure A036. Yearly Wave Energy, Percentiles,NDBC 46012

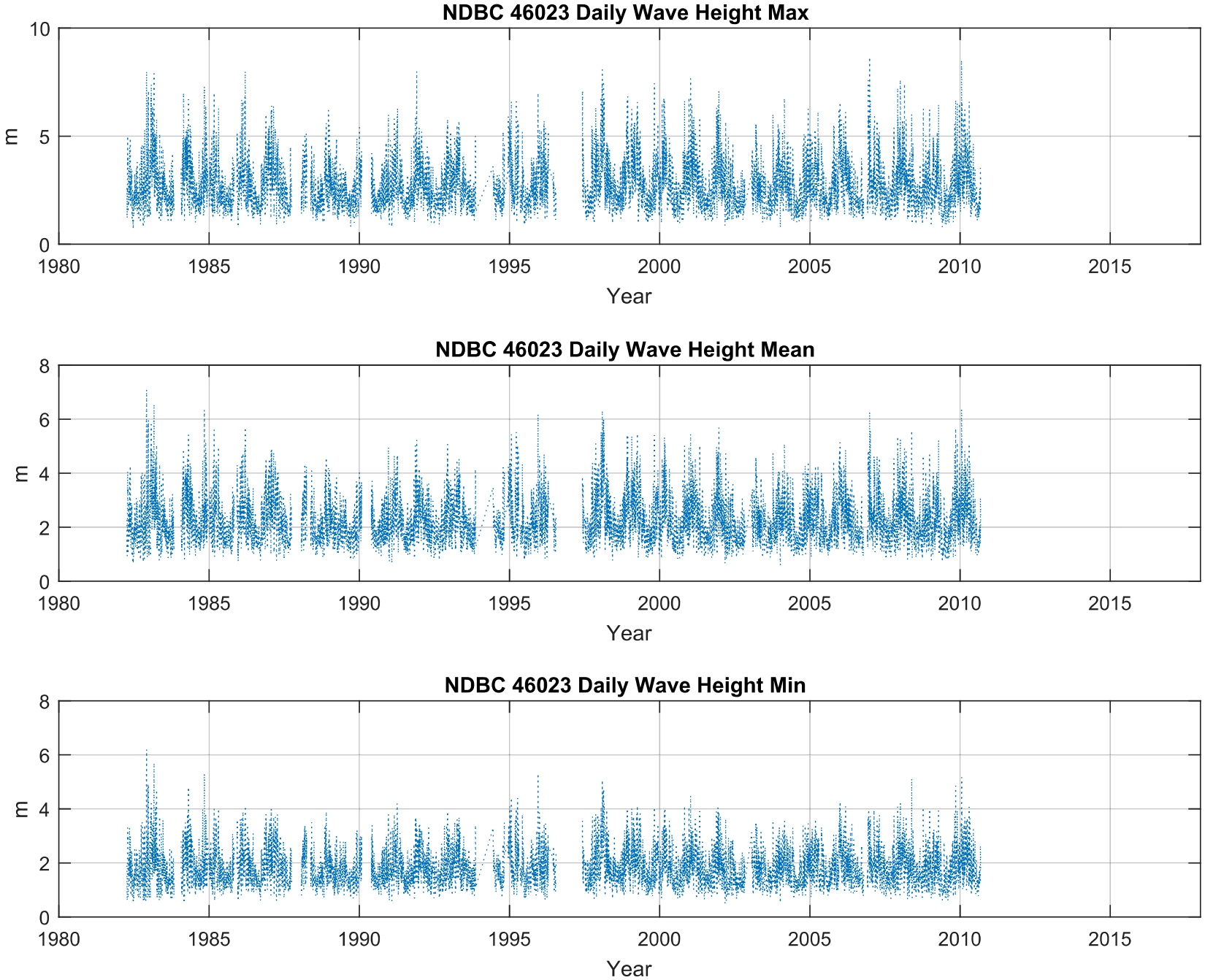
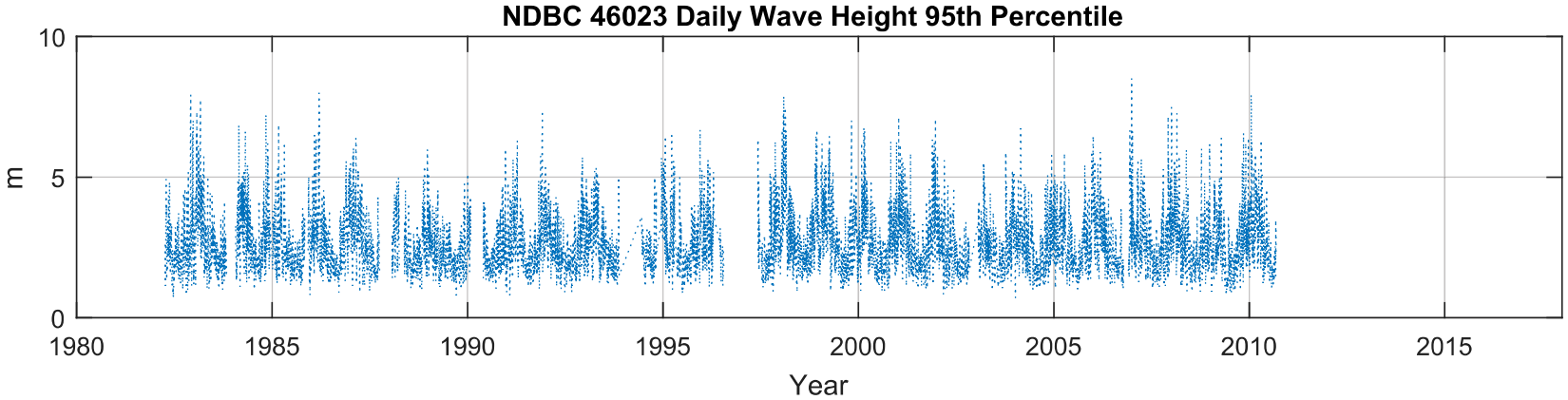
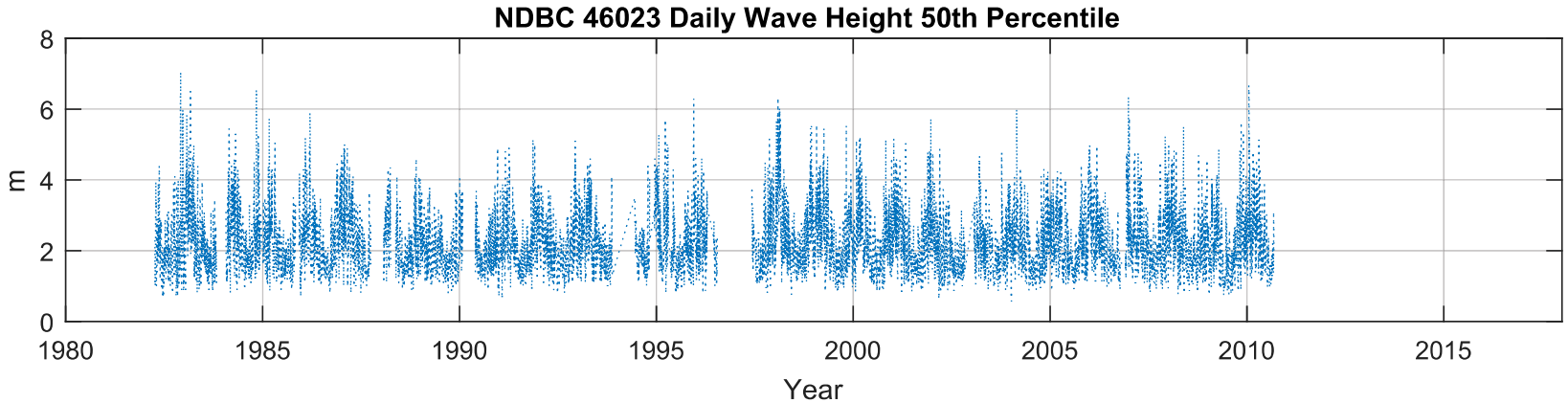


Figure A037. Daily Wave Height, Max, Mean, Min,NDBC 46023





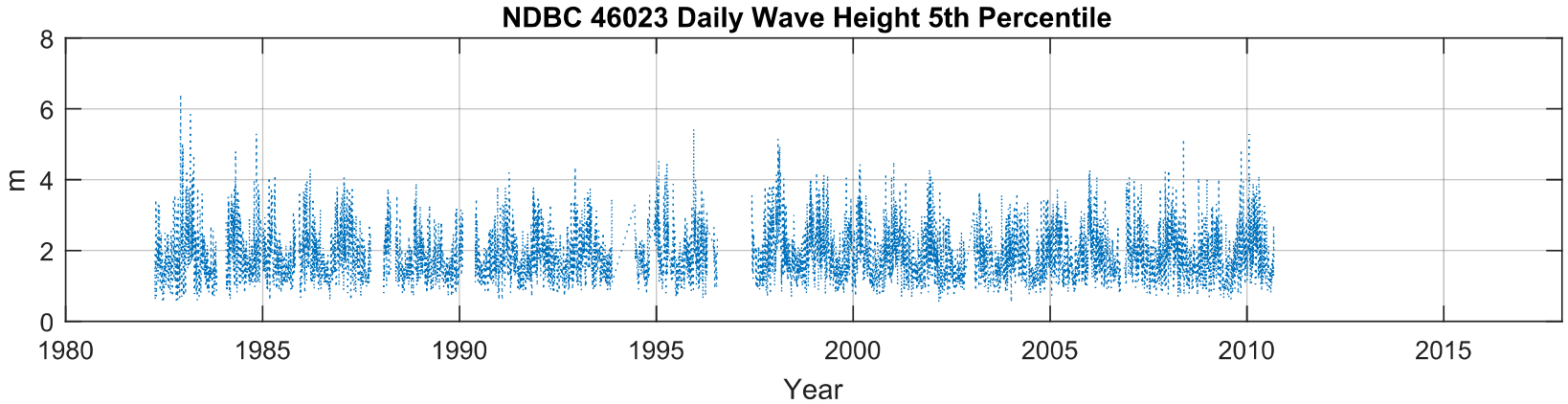


Figure A038. Daily Wave Height, Percentiles,NDBC 46023

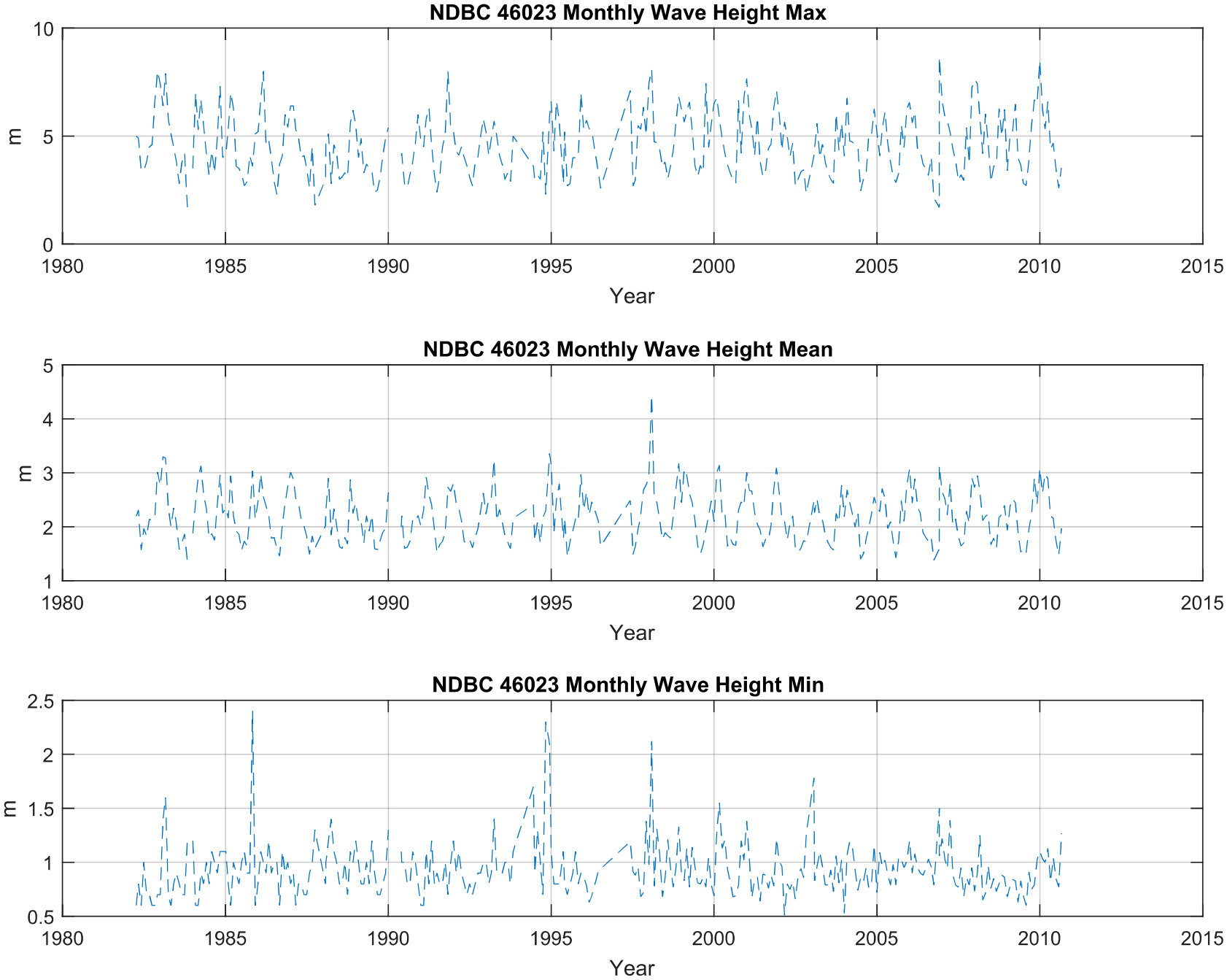
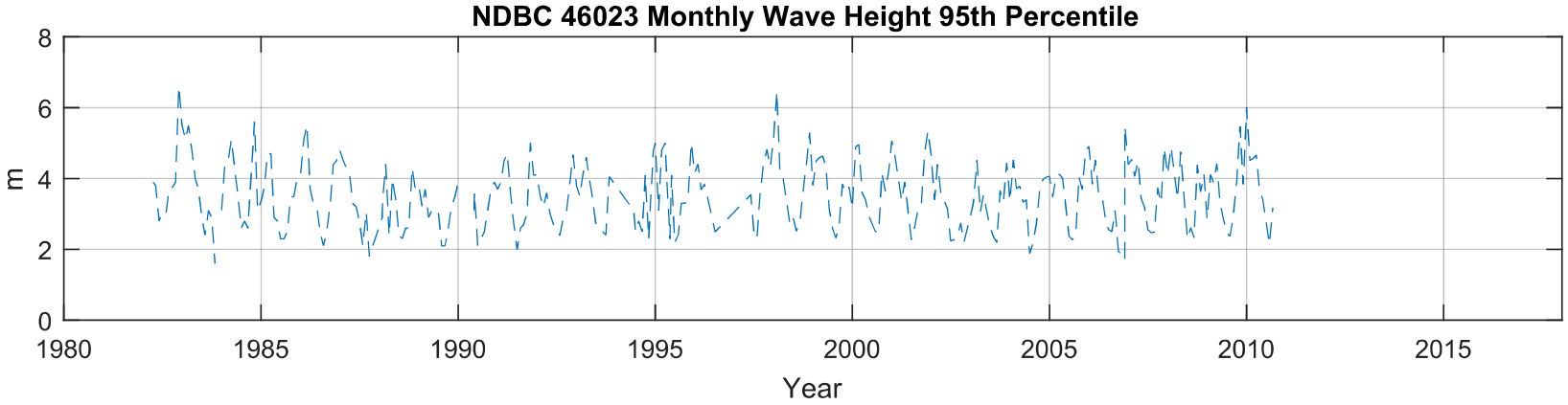
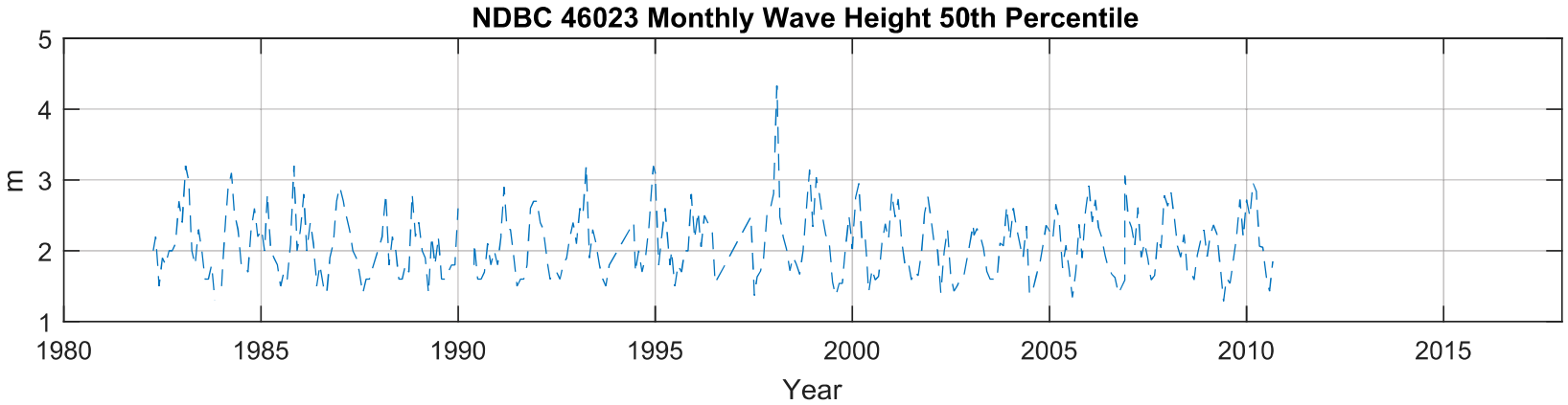


Figure A039. Monthly Wave Height, Max, Mean, Min,NDBC 46023





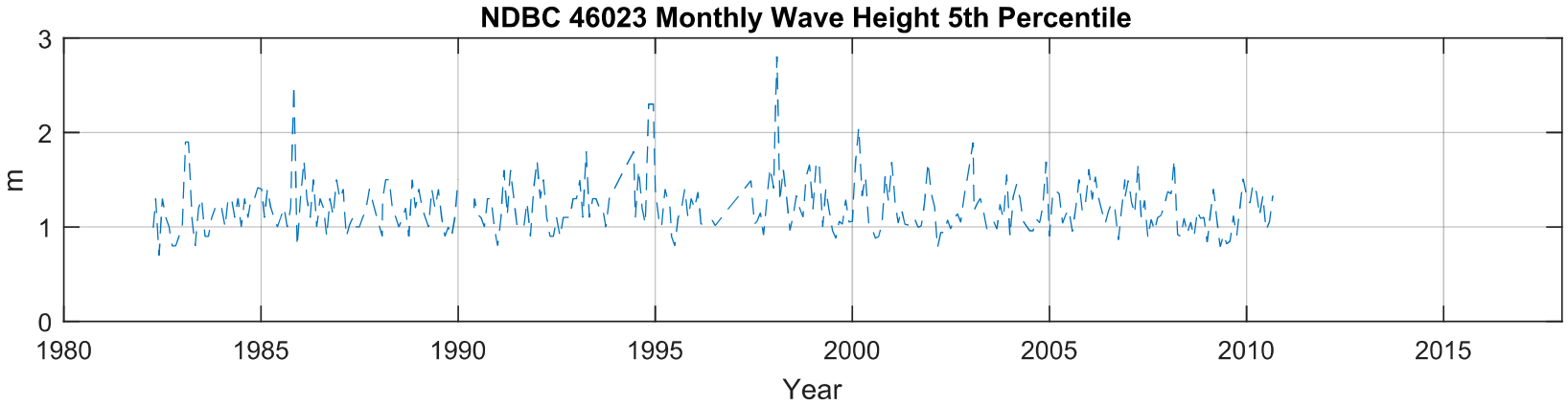


Figure A040. Monthly Wave Height, Percentiles,NDBC 46023

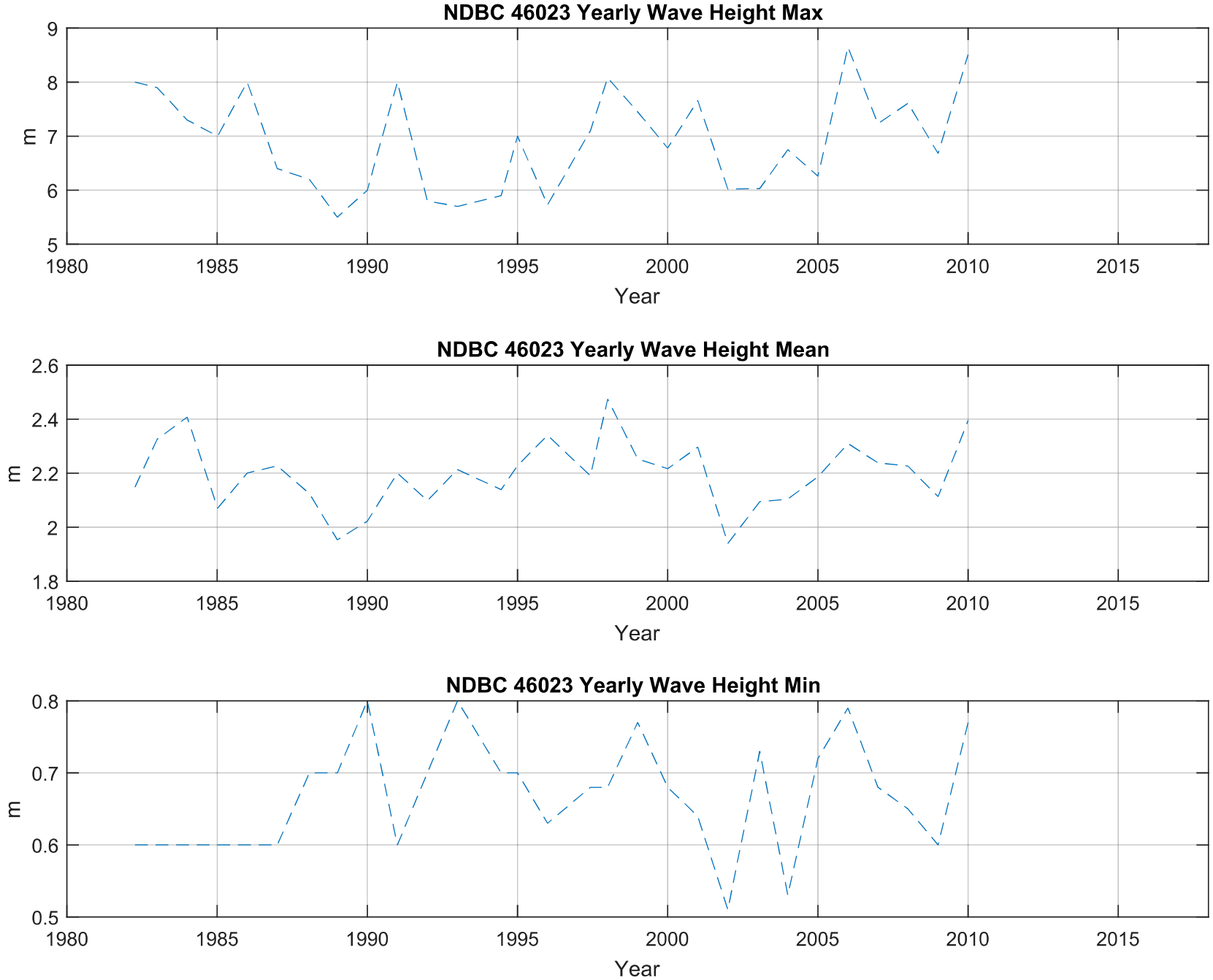
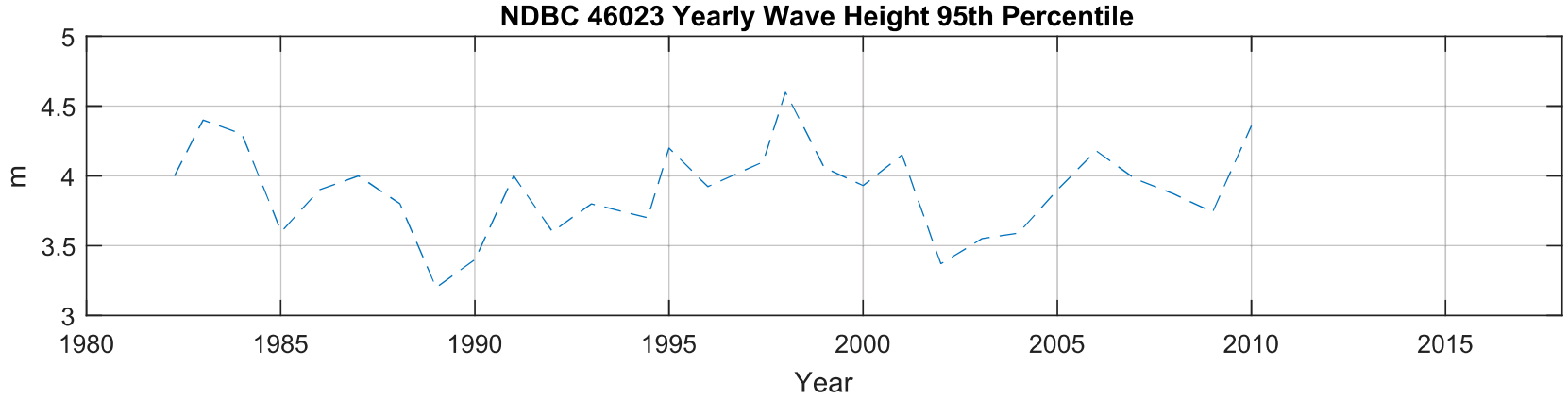
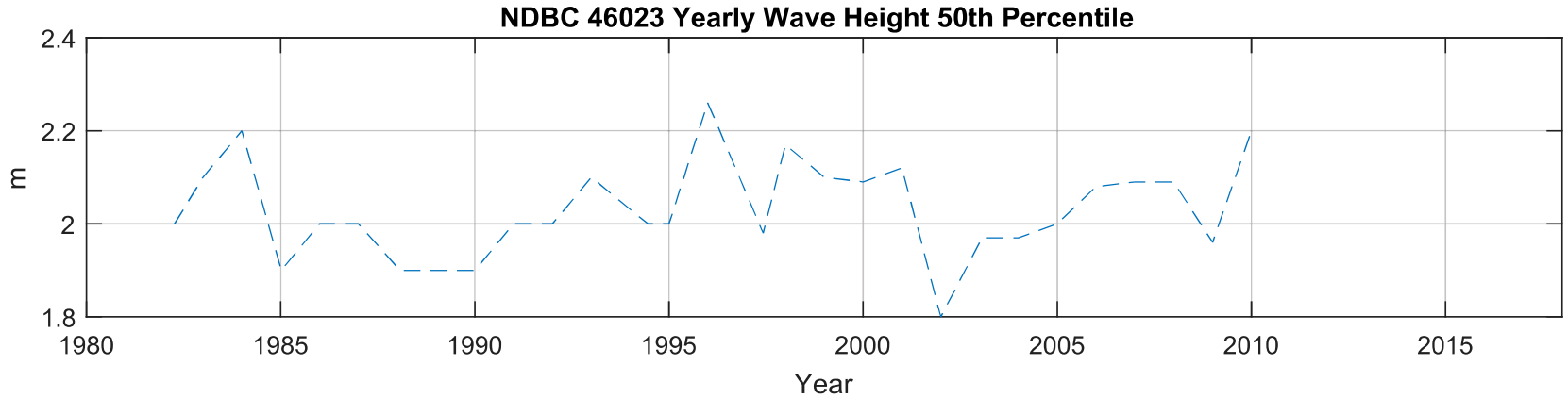


Figure A041. Yearly Wave Height, Max, Mean, Min,NDBC 46023





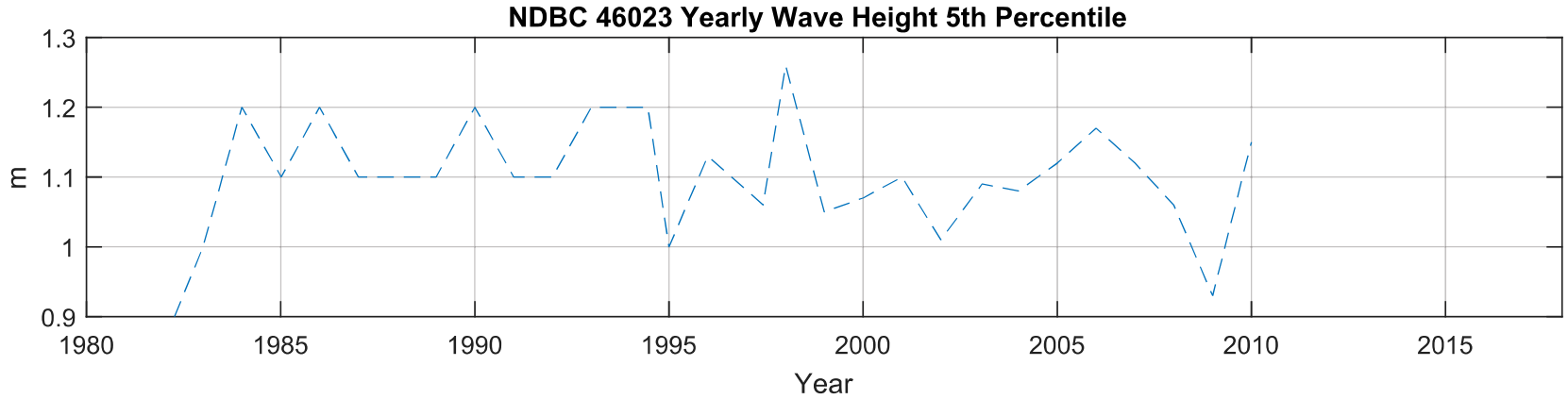


Figure A042. Yearly Wave Height, Percentiles,NDBC 46023

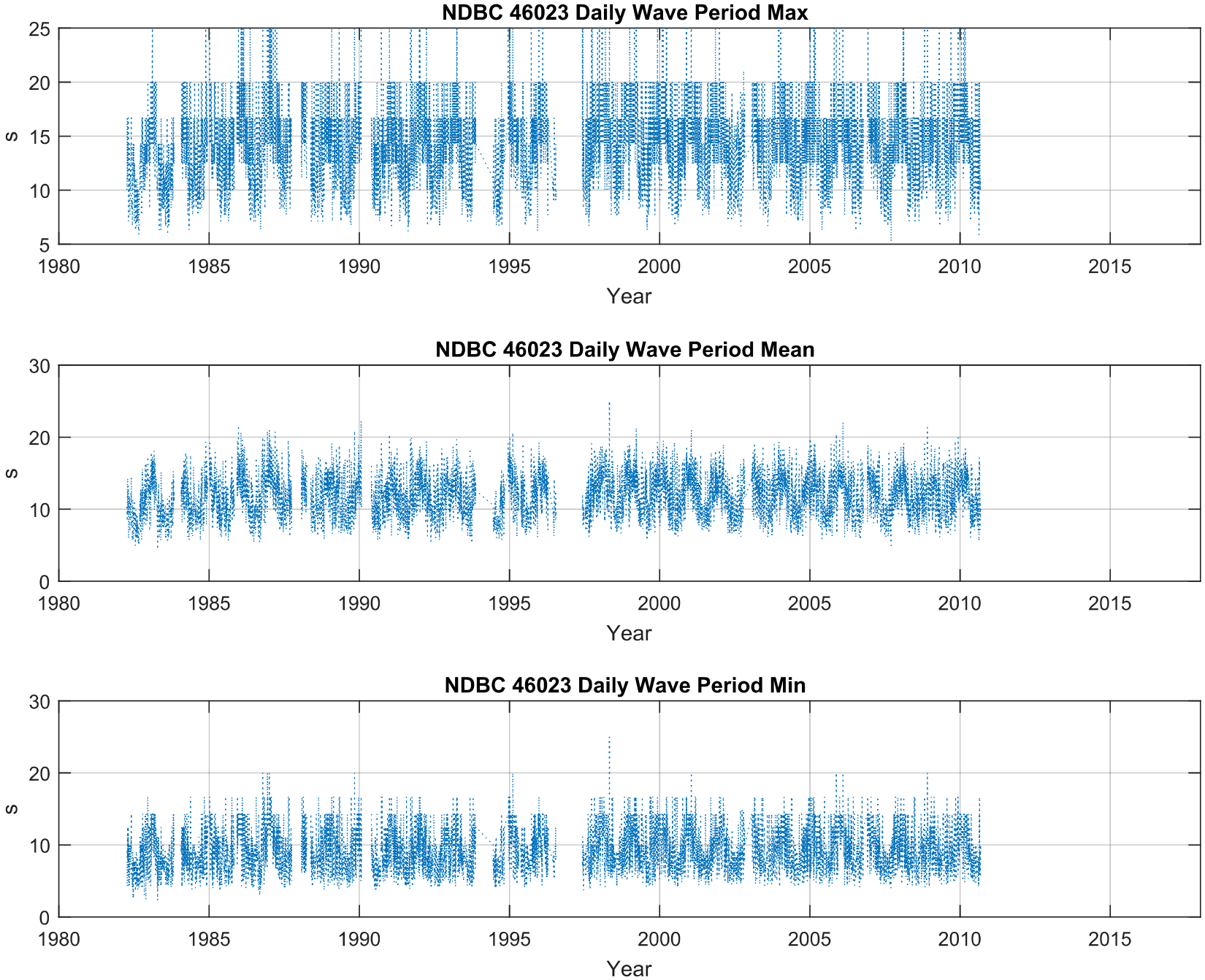
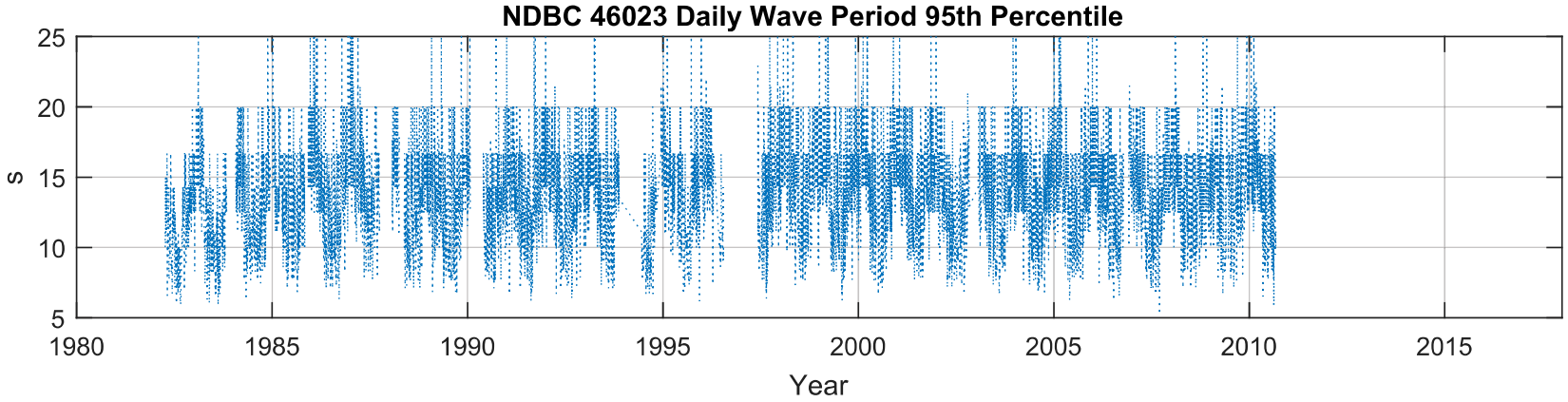
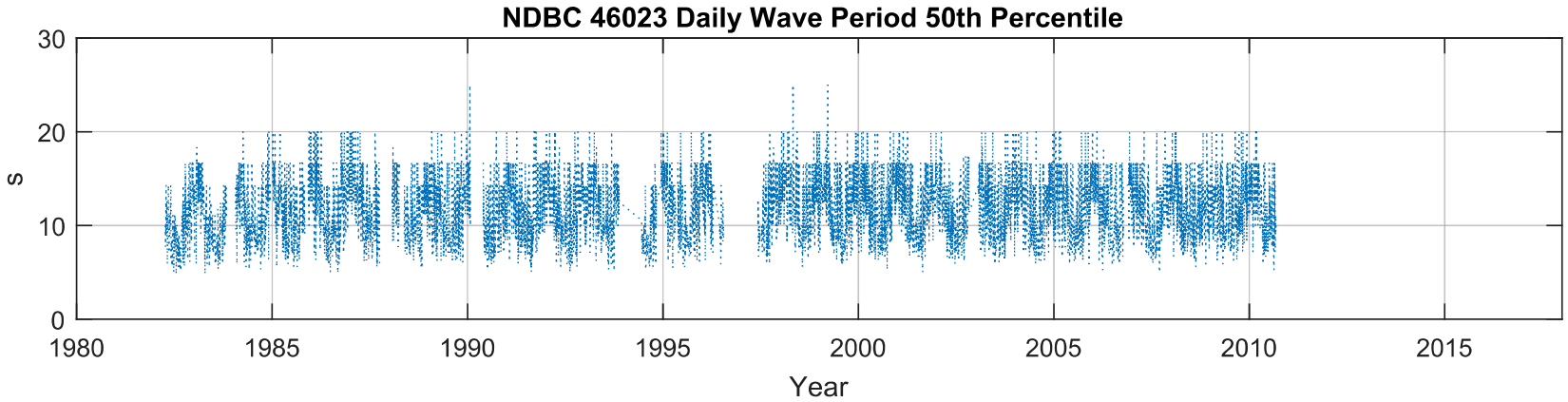


Figure A043. Daily Wave Period, Max, Mean, Min,NDBC 46023





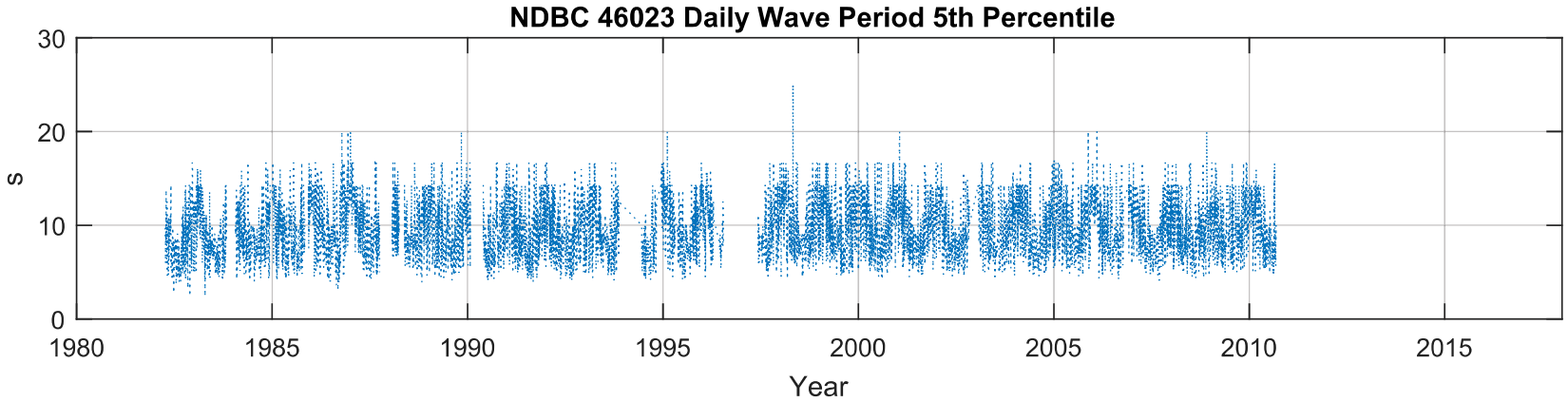


Figure A044. Daily Wave Period, Percentiles,NDBC 46023

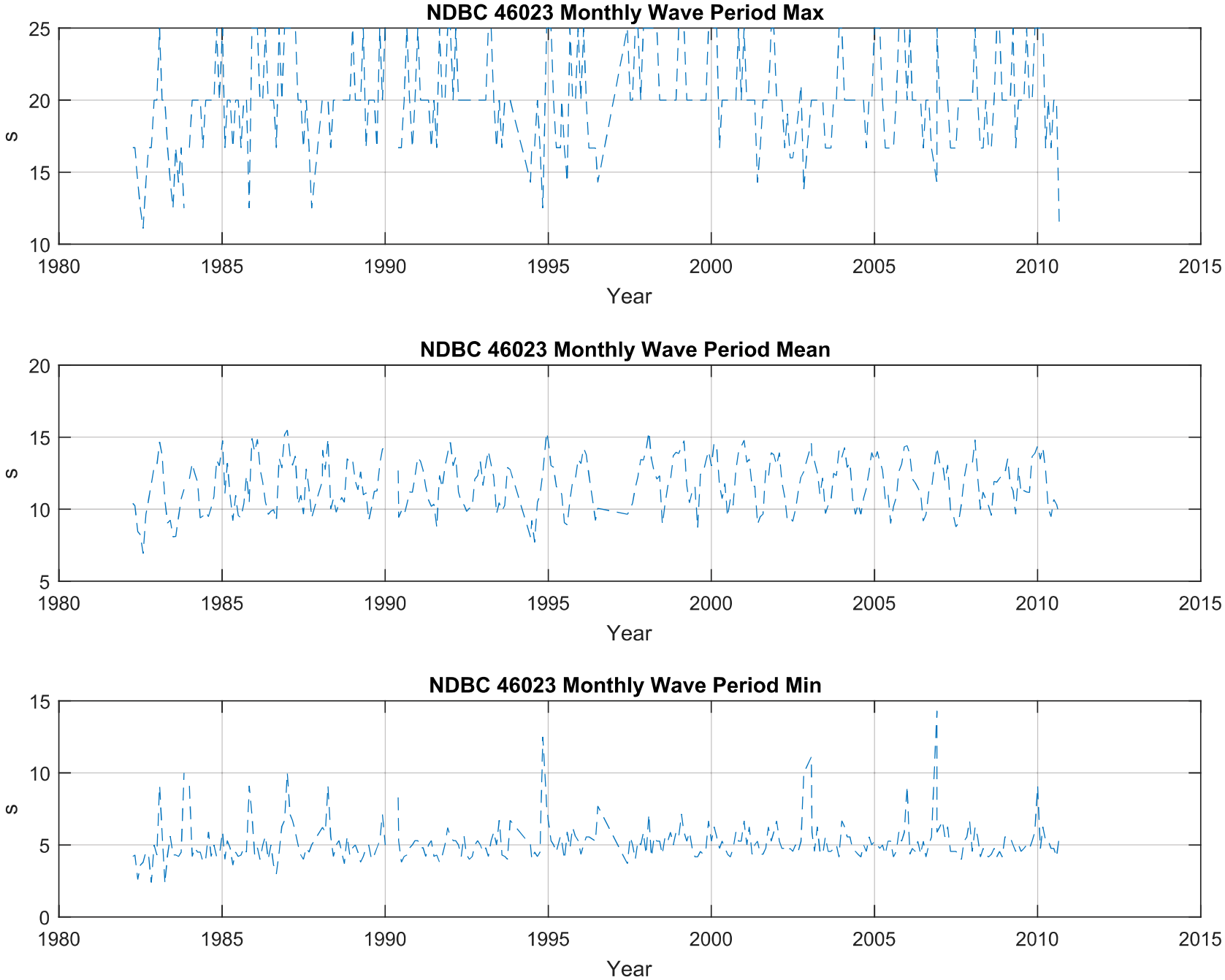
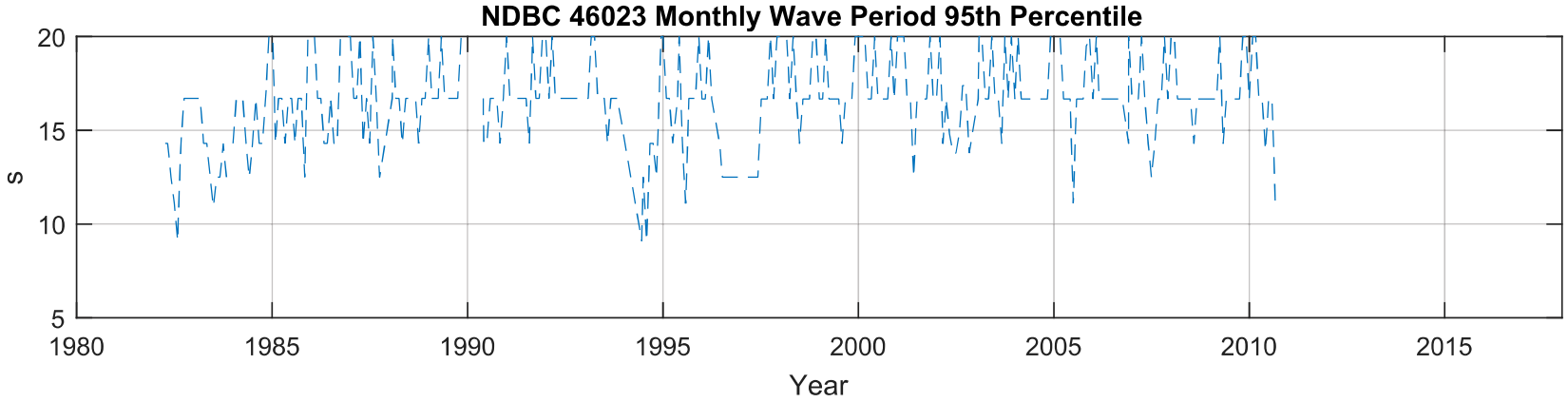
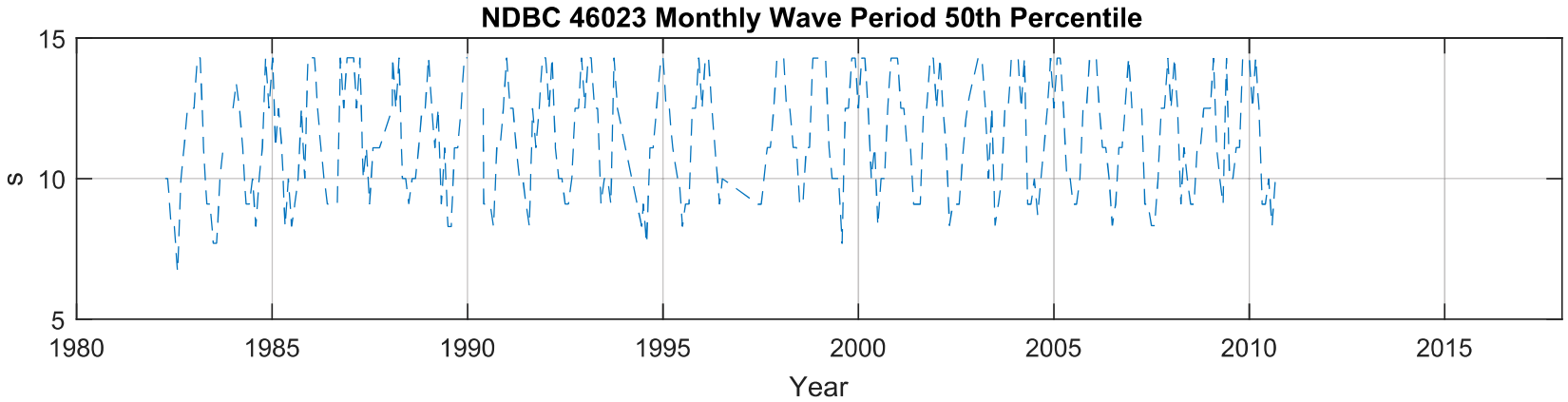


Figure A045. Monthly Wave Period, Max, Mean, Min,NDBC 46023





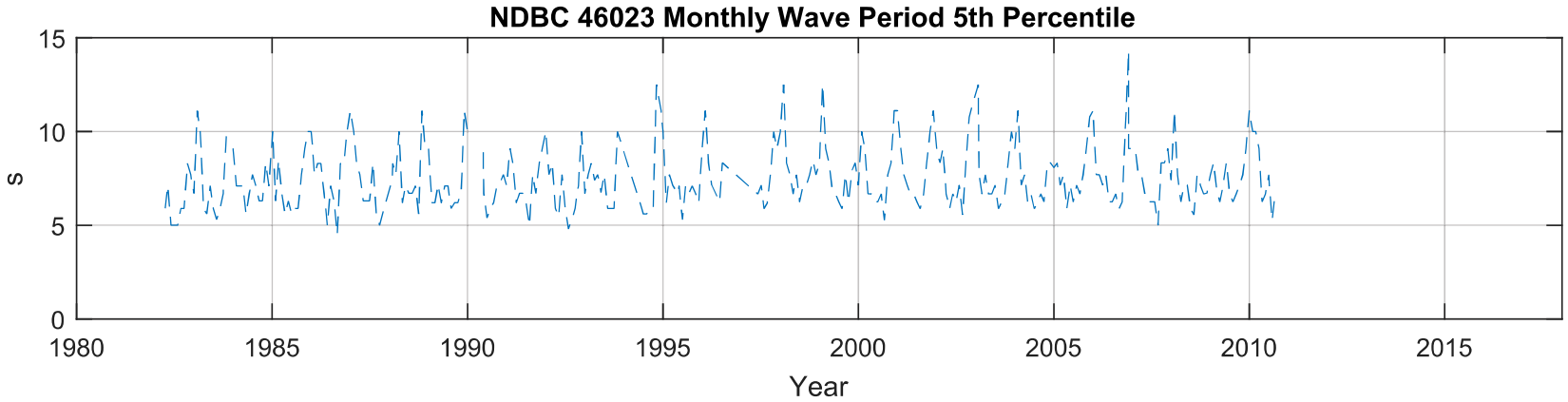
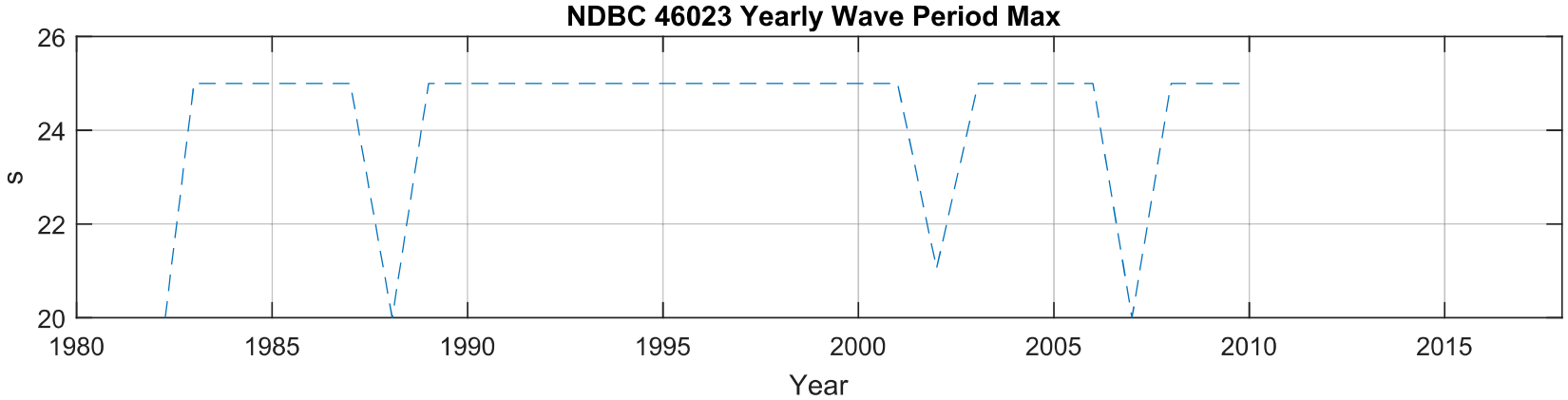
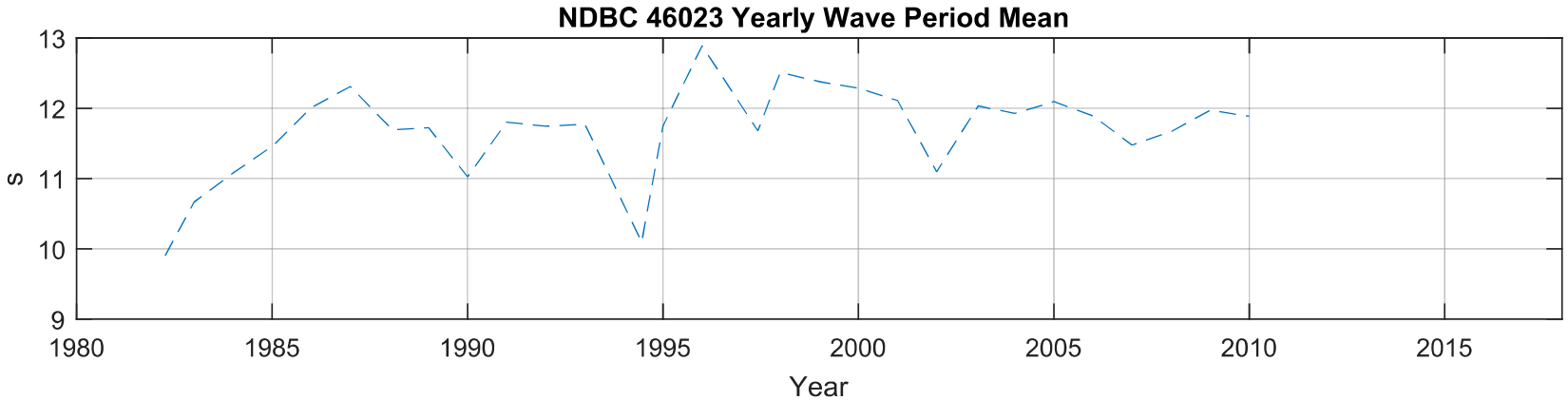


Figure A046. Monthly Wave Period, Percentiles,NDBC 46023





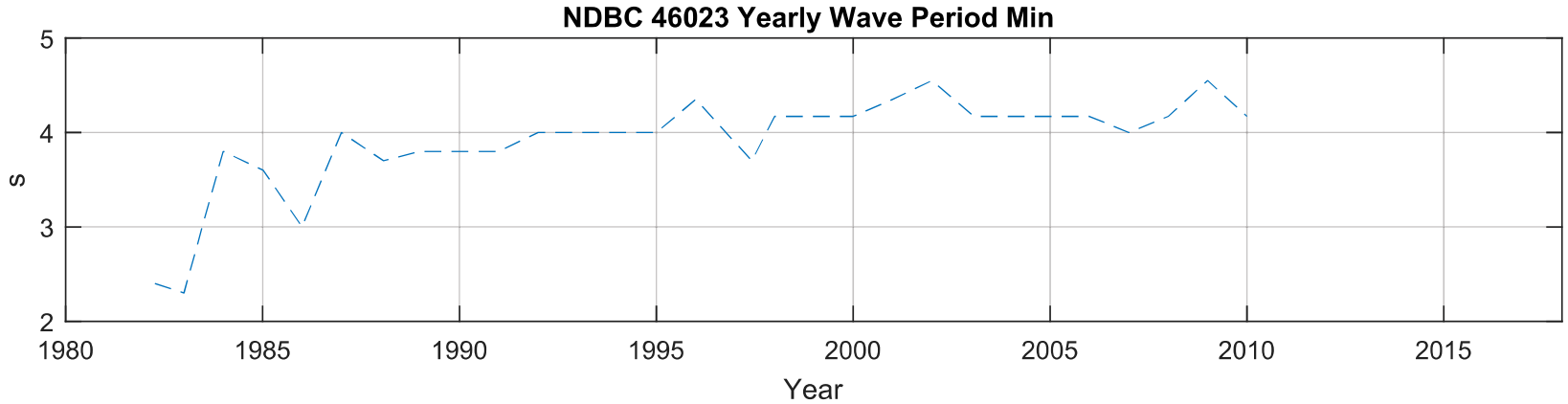
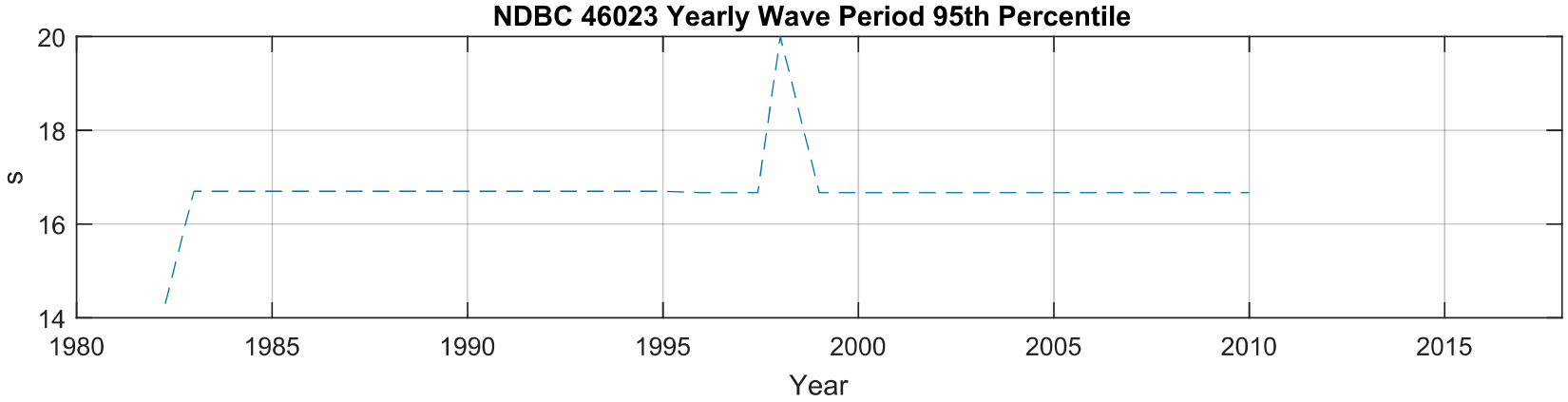
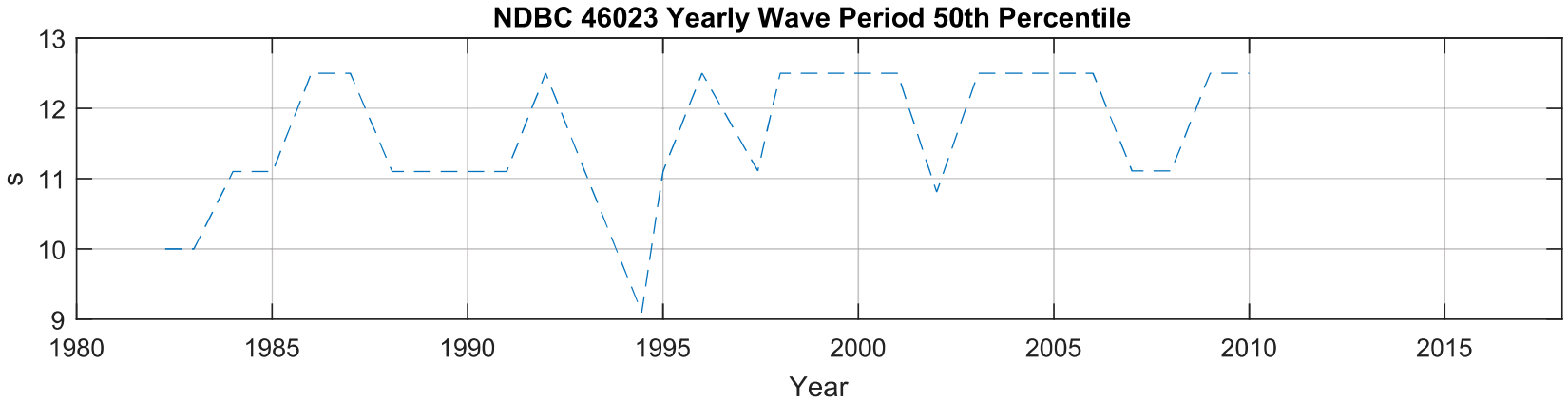


Figure A047. Yearly Wave Period, Max, Mean, Min,NDBC 46023





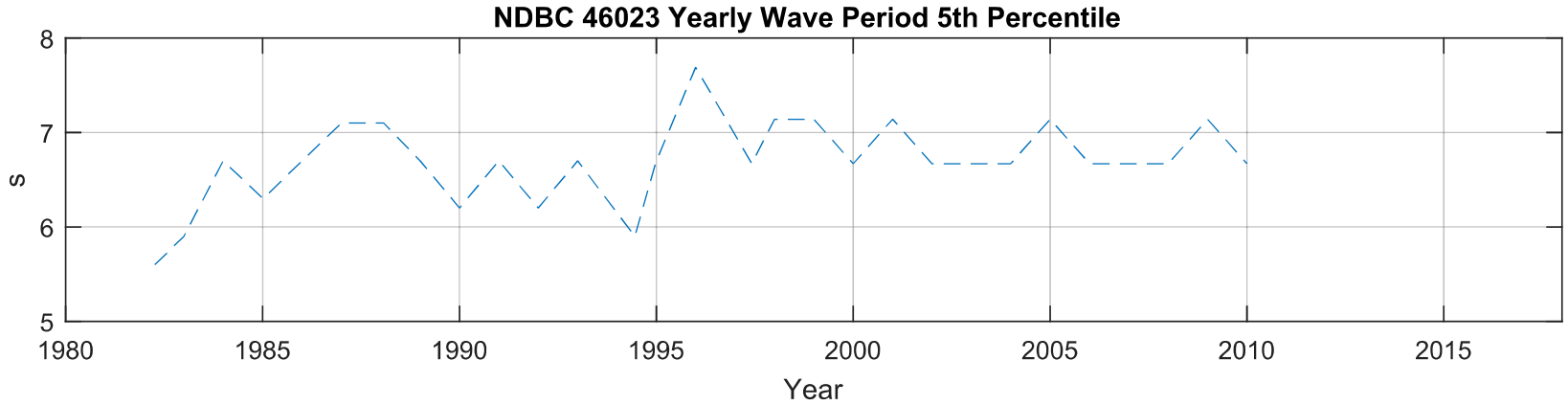
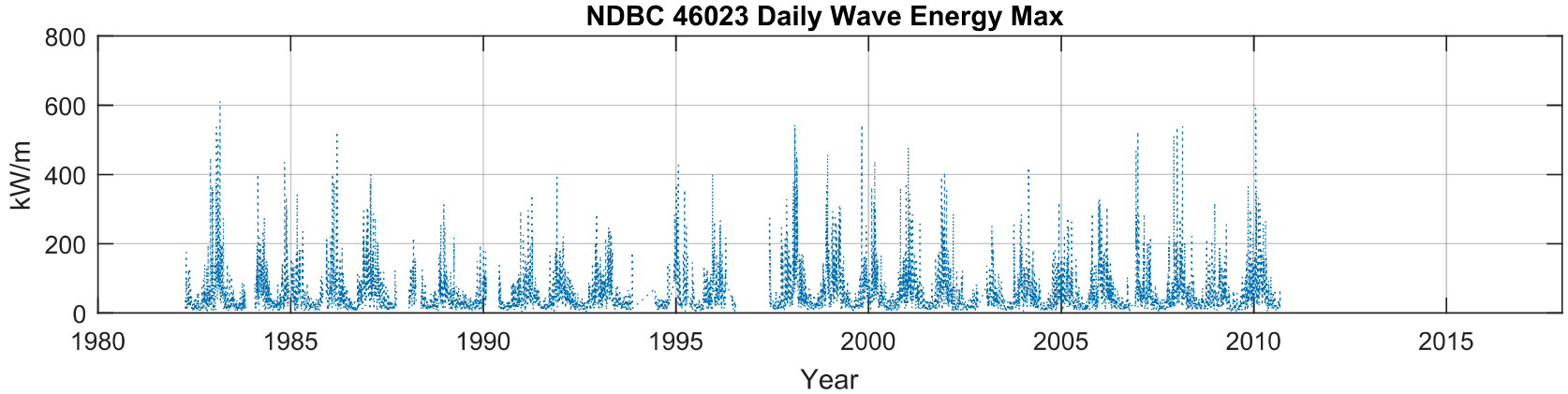
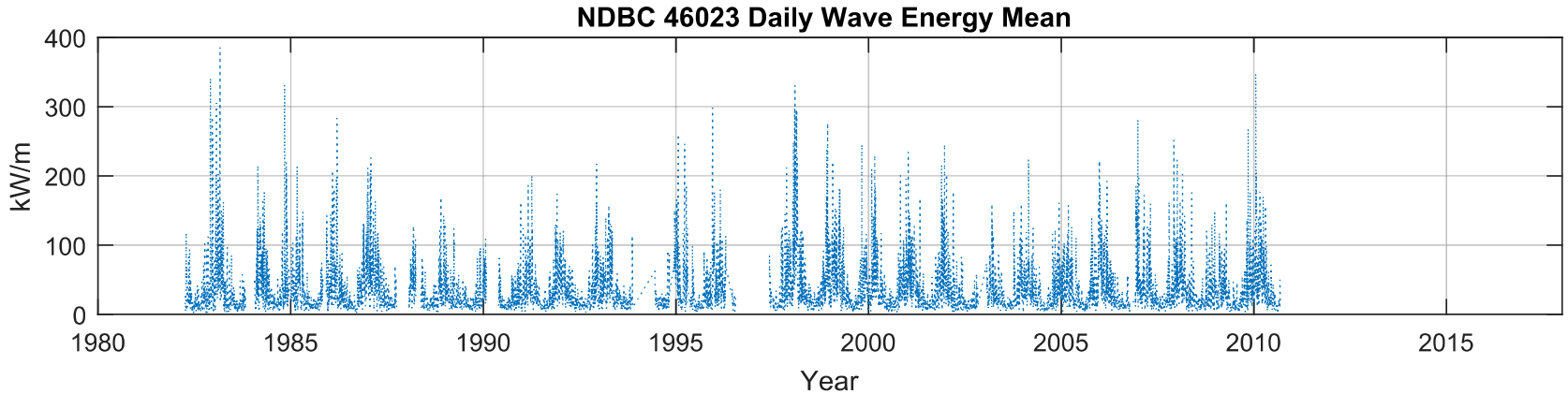


Figure A048. Yearly Wave Period, Percentiles,NDBC 46023





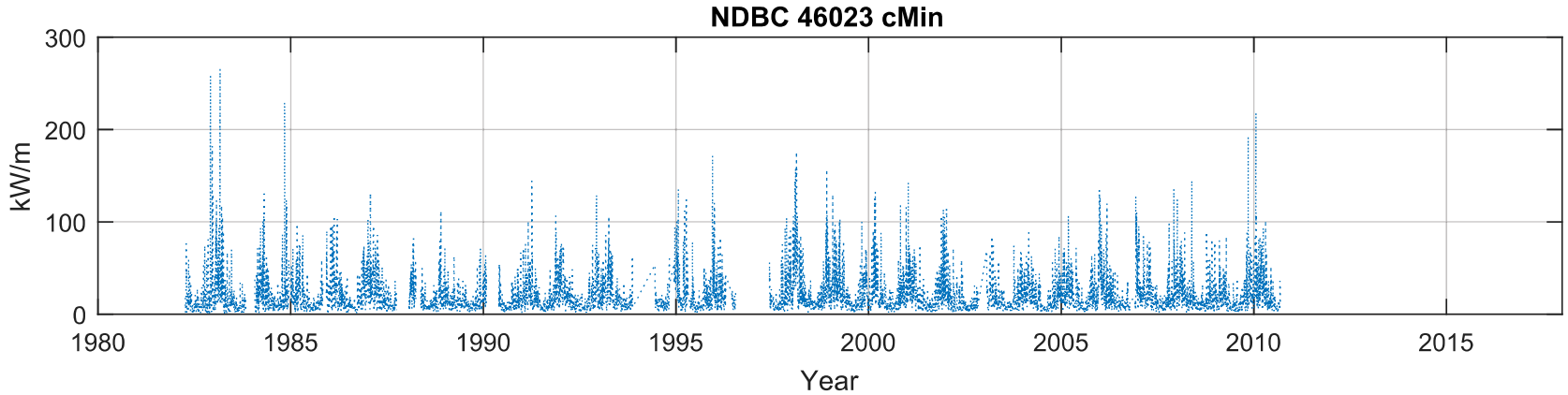
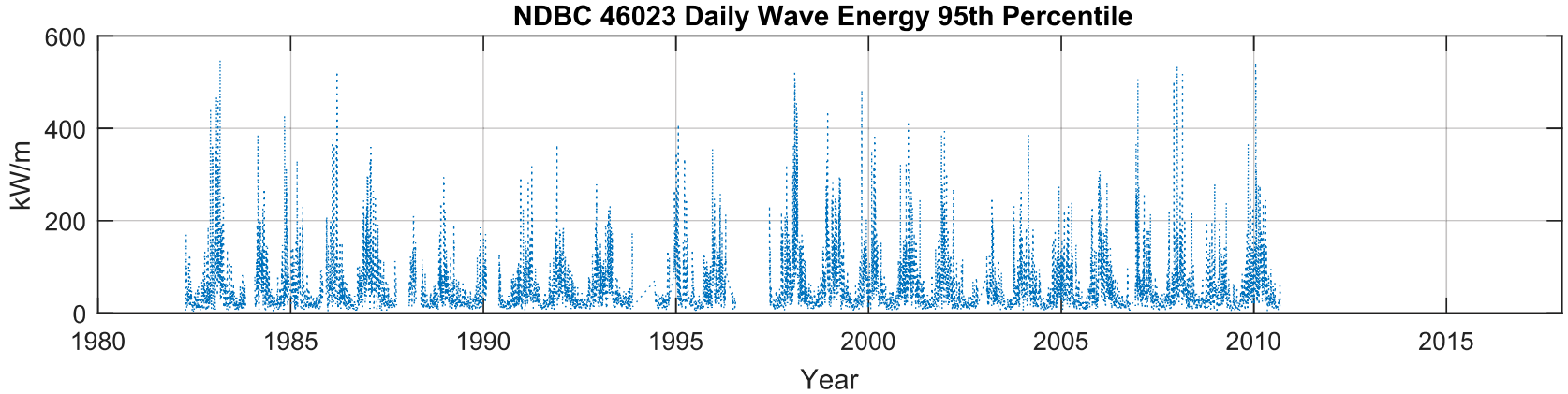
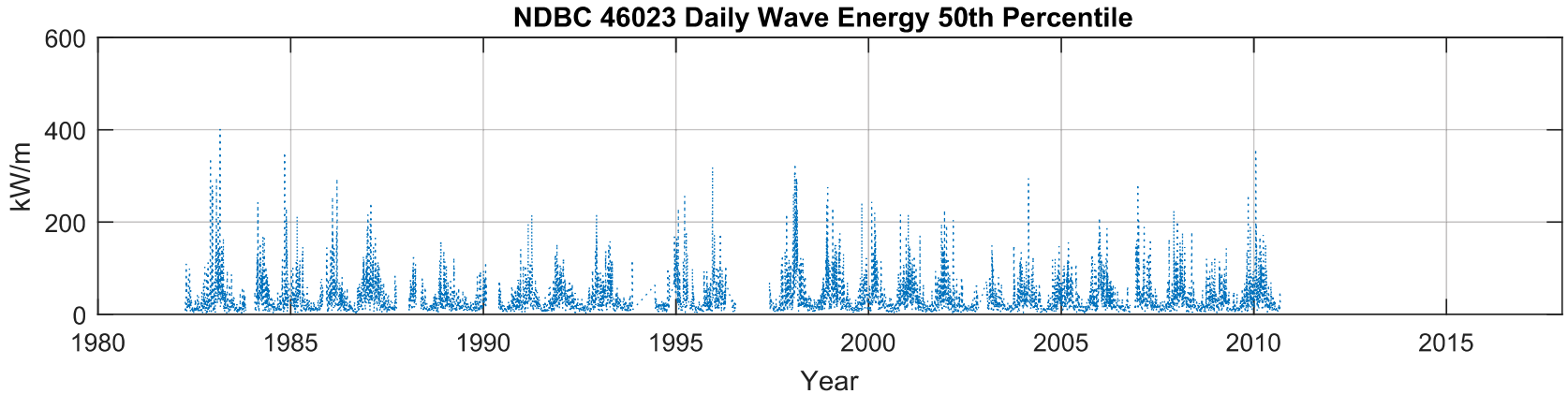


Figure A049. Daily Wave Energy, Max, Mean, Min,NDBC 46023





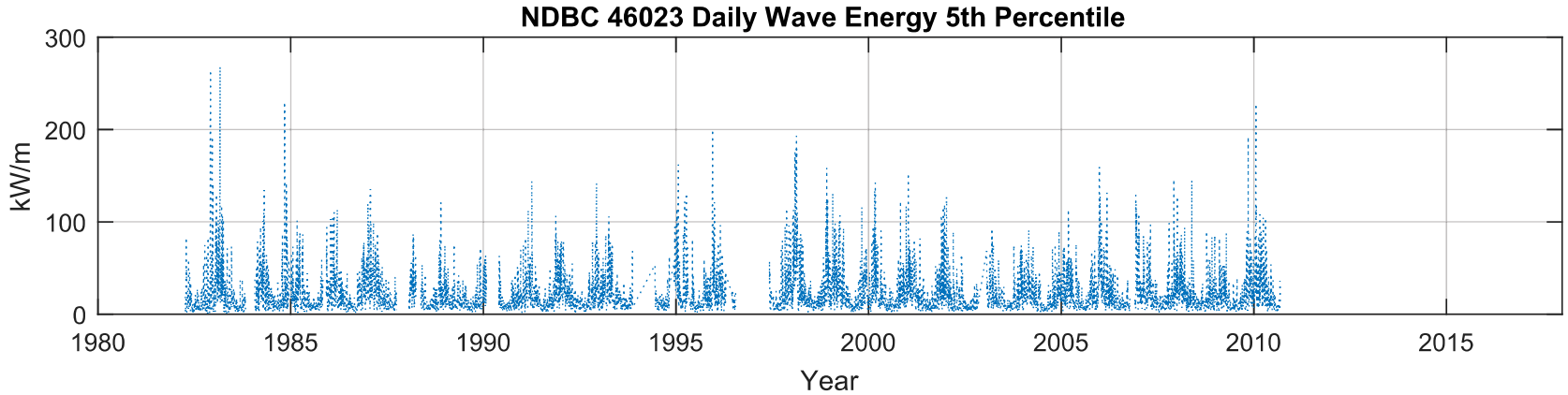


Figure A050. Daily Wave Energy, Percentiles,NDBC 46023

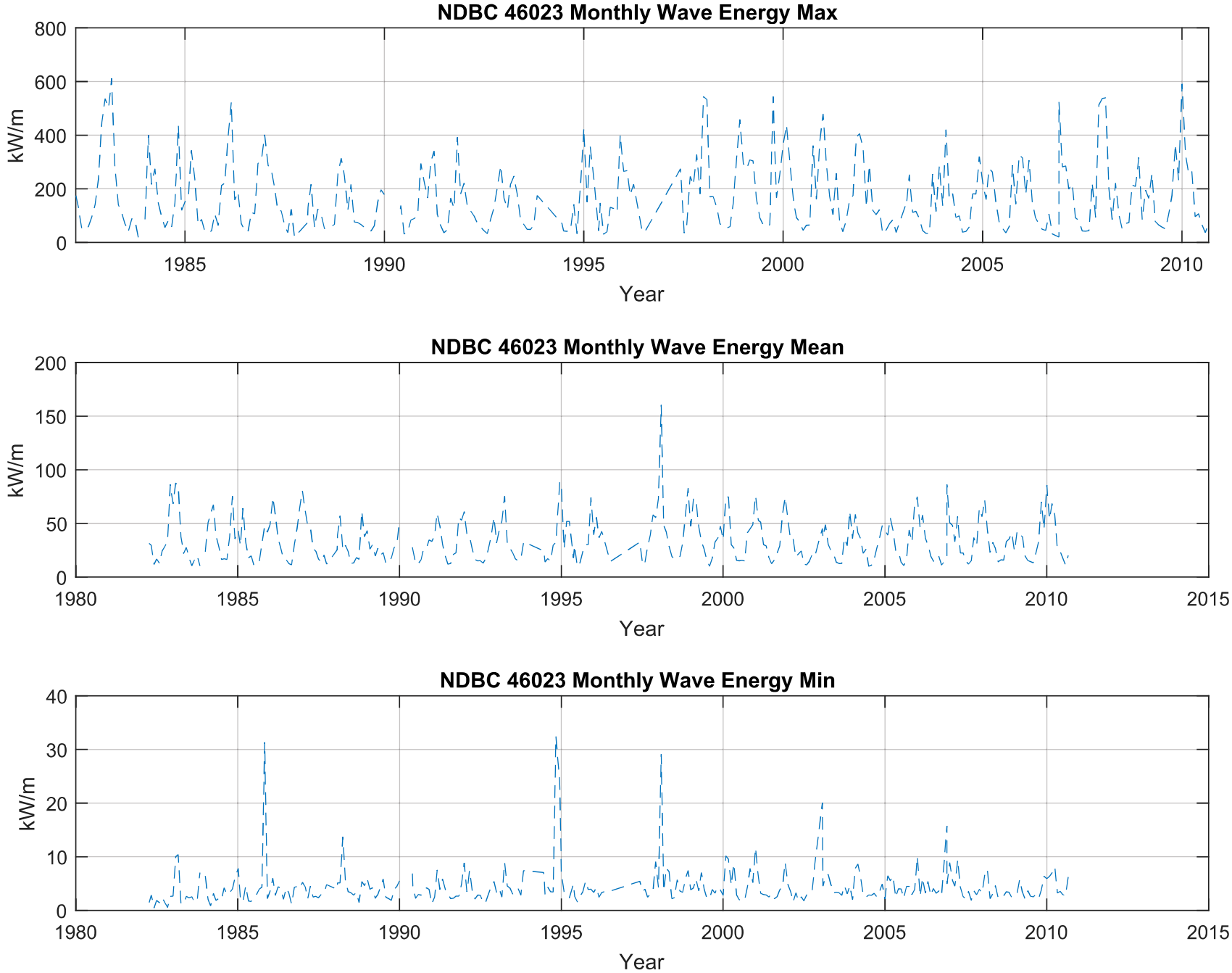
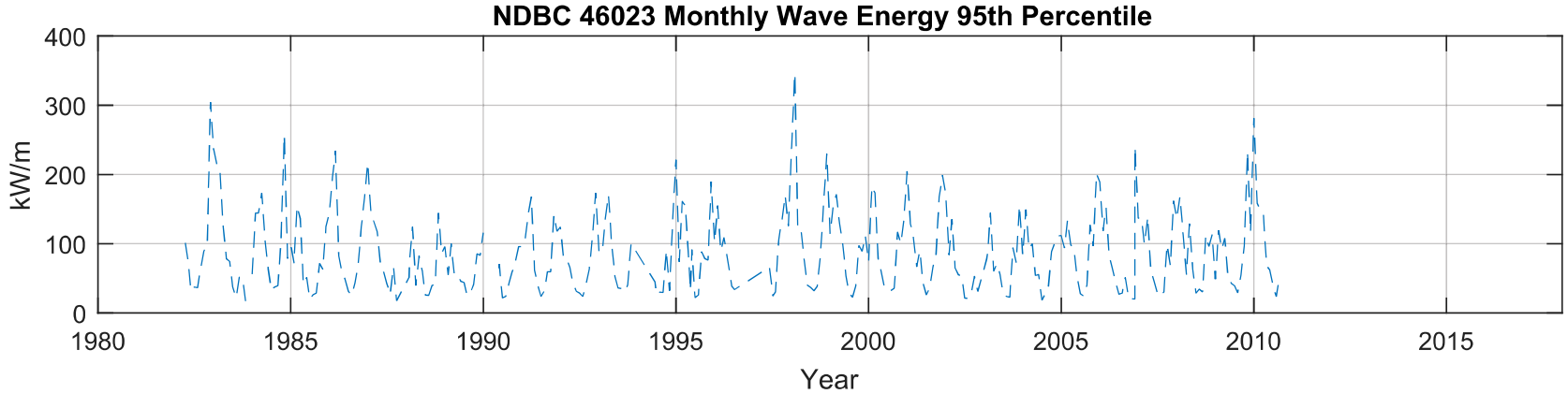
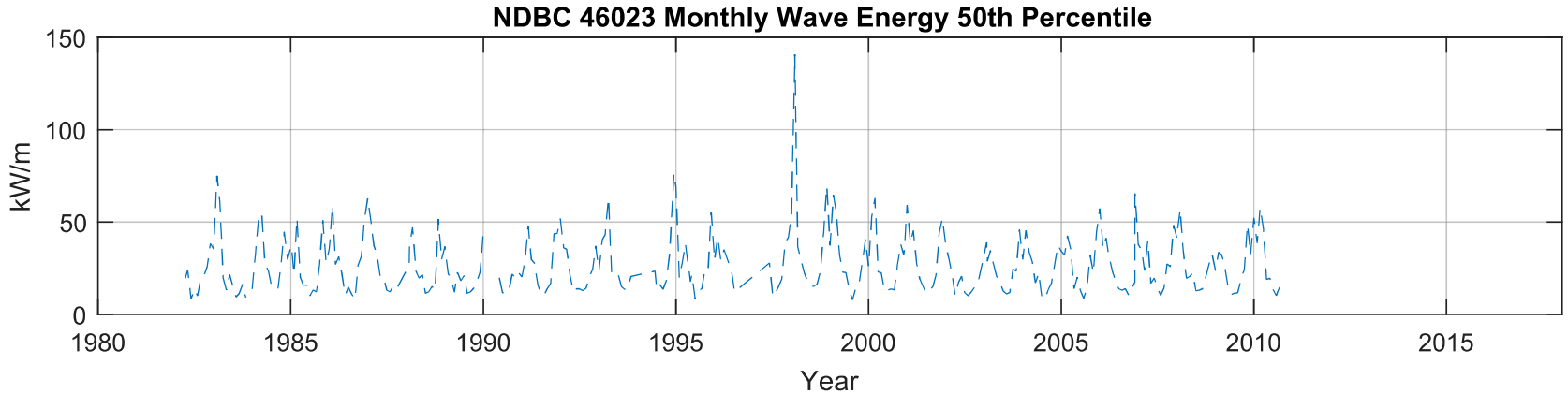


Figure A051. Monthly Wave Energy, Max, Mean, Min,NDBC 46023





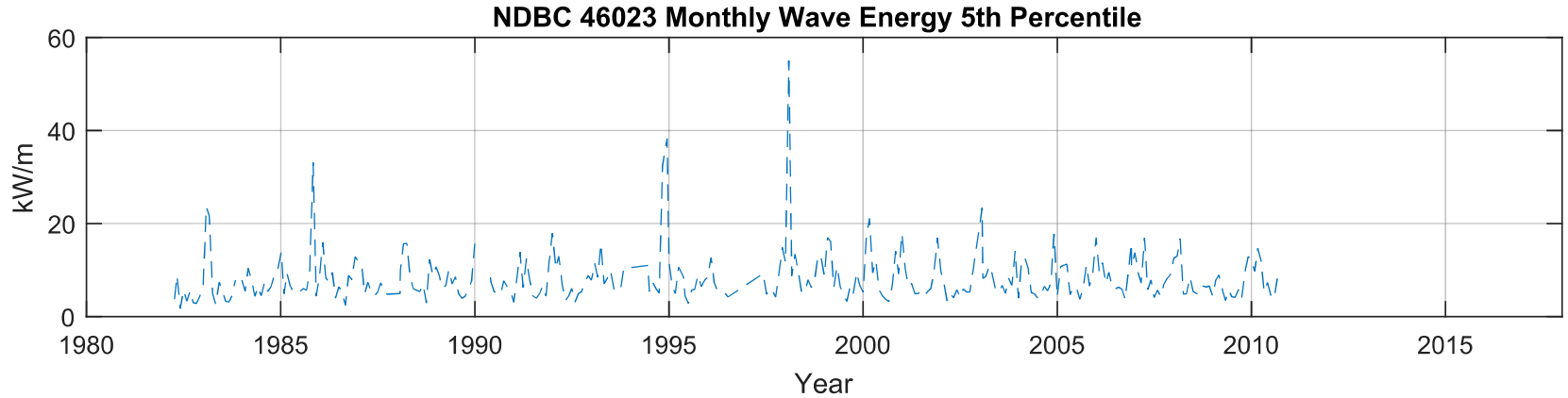


Figure A052. Monthly Wave Energy, Percentiles,NDBC 46023

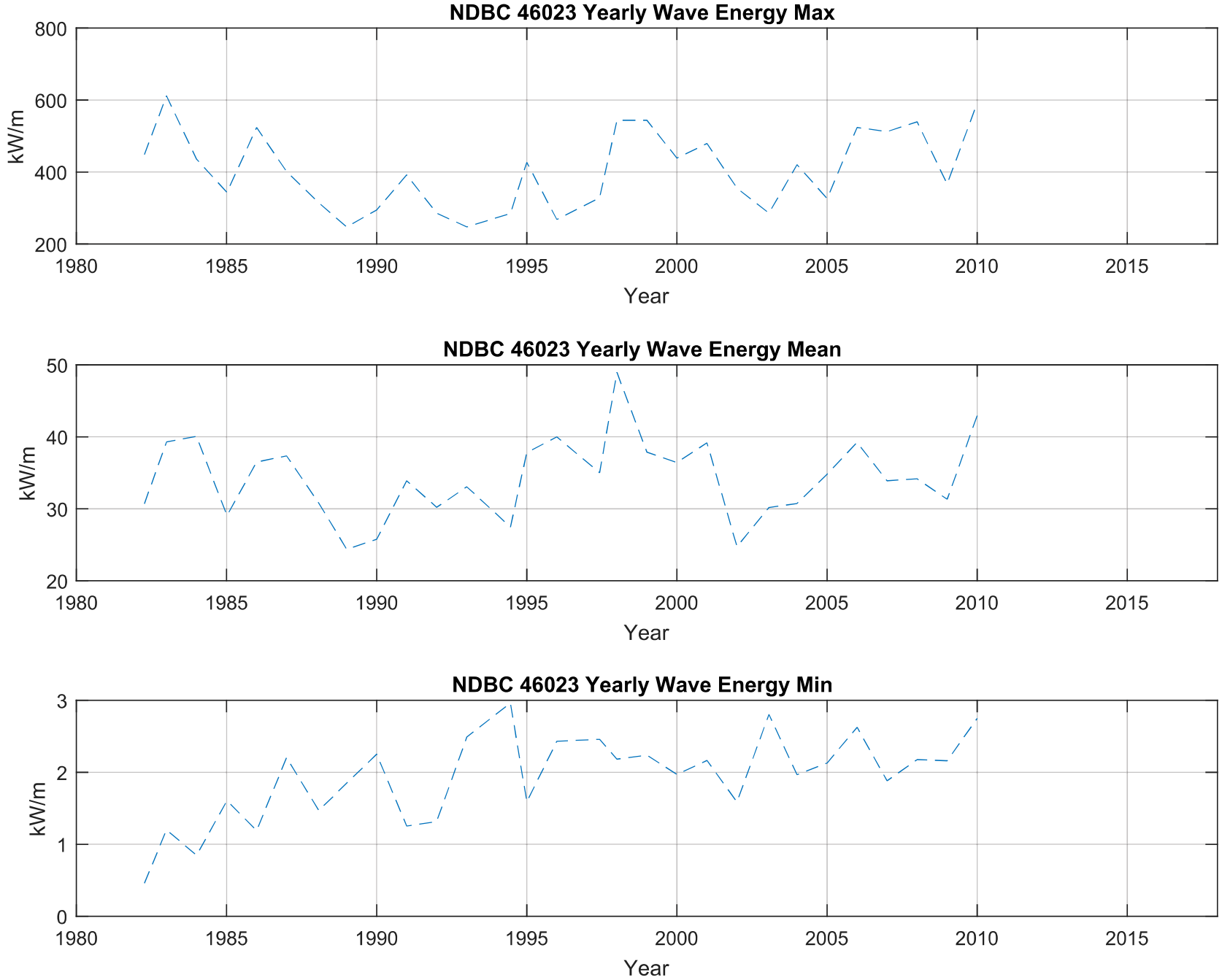
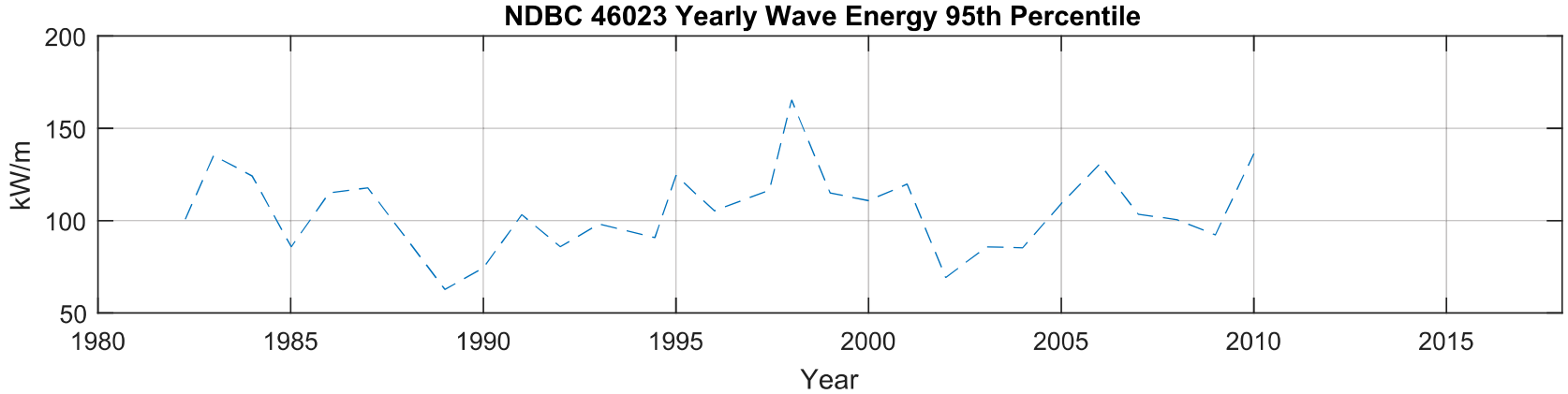
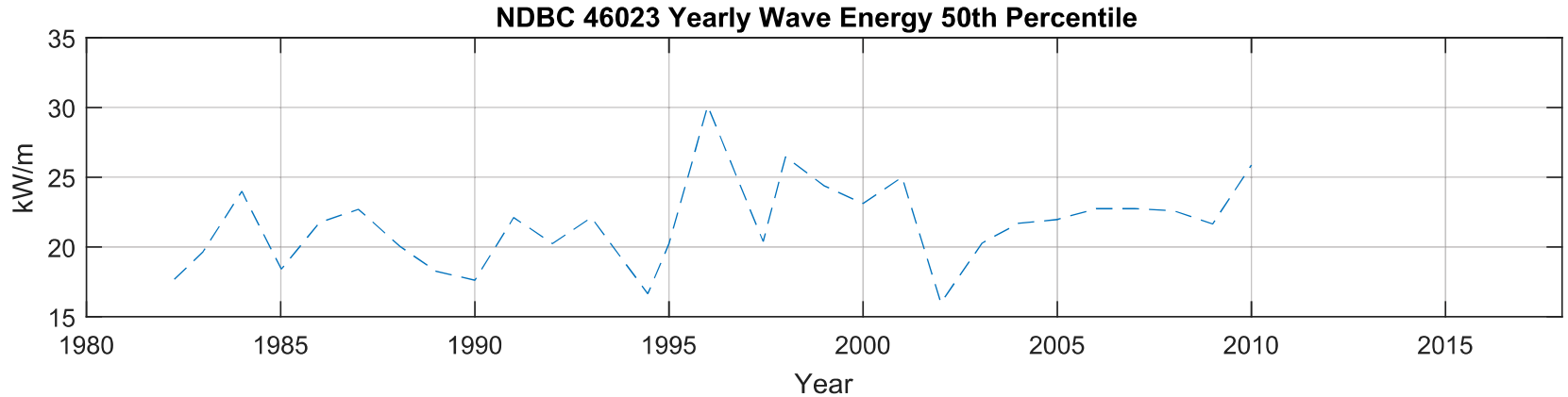


Figure A053. Yearly Wave Energy, Max, Mean, Min,NDBC 46023





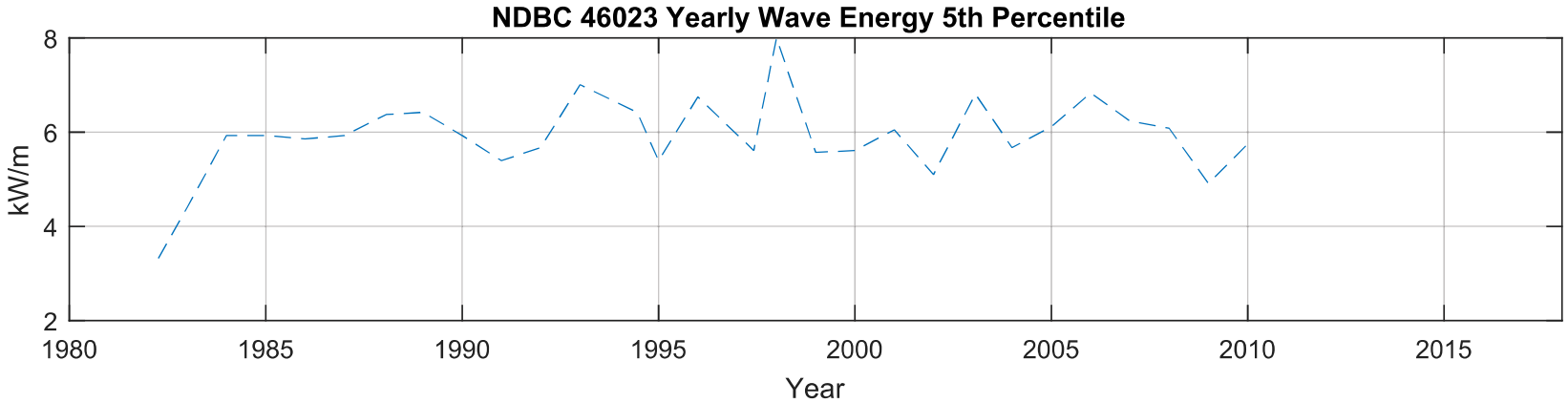


Figure A054. Yearly Wave Energy, Percentiles,NDBC 46023

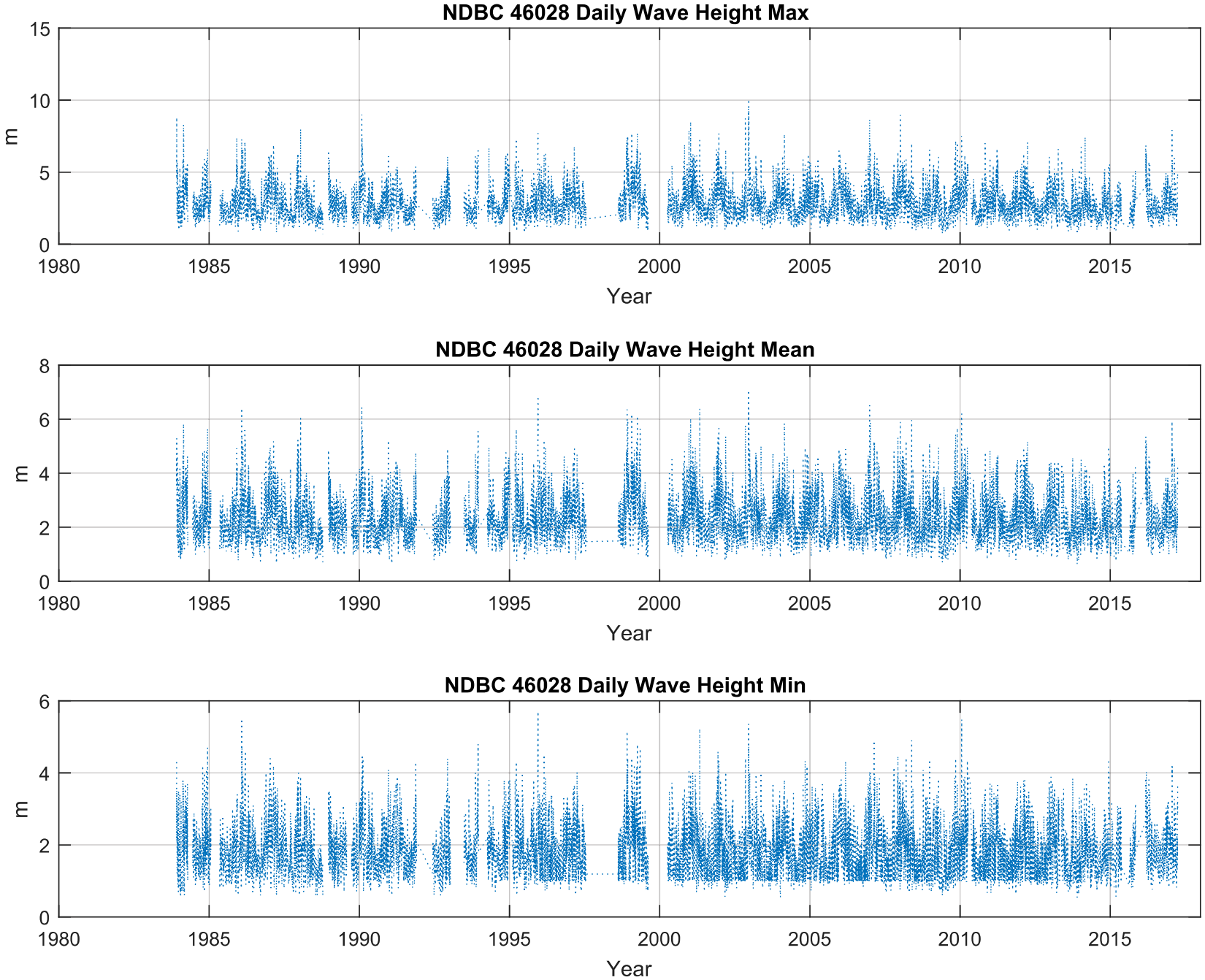
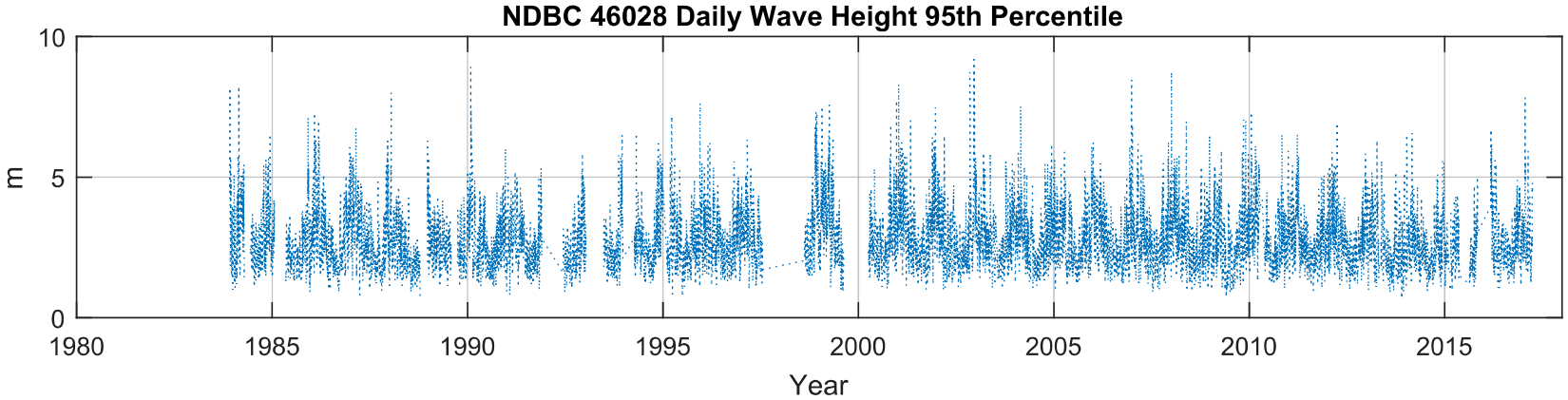
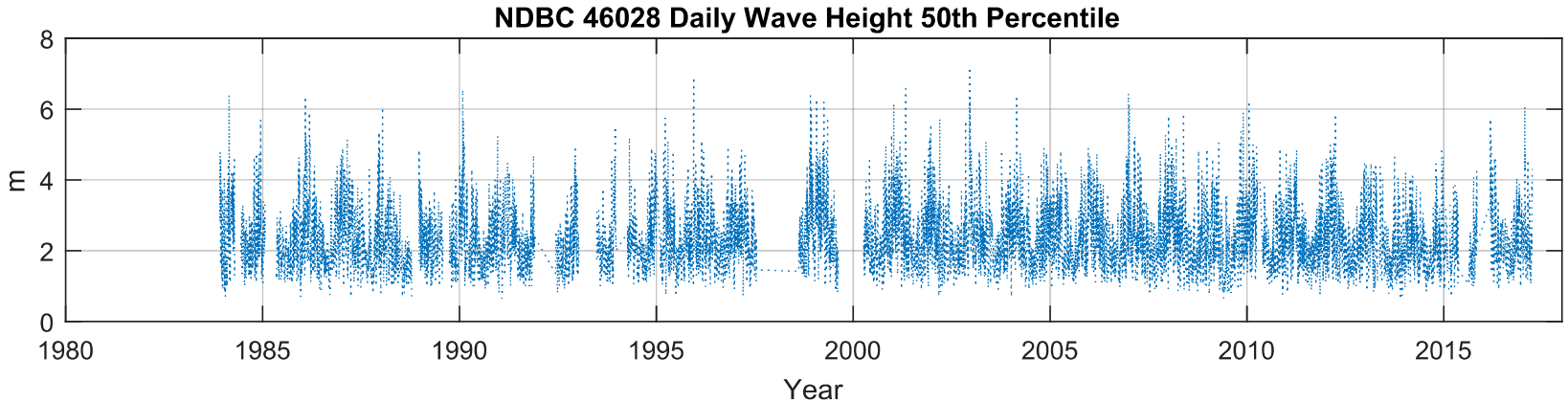


Figure A055. Daily Wave Height, Max, Mean, Min,NDBC 46028





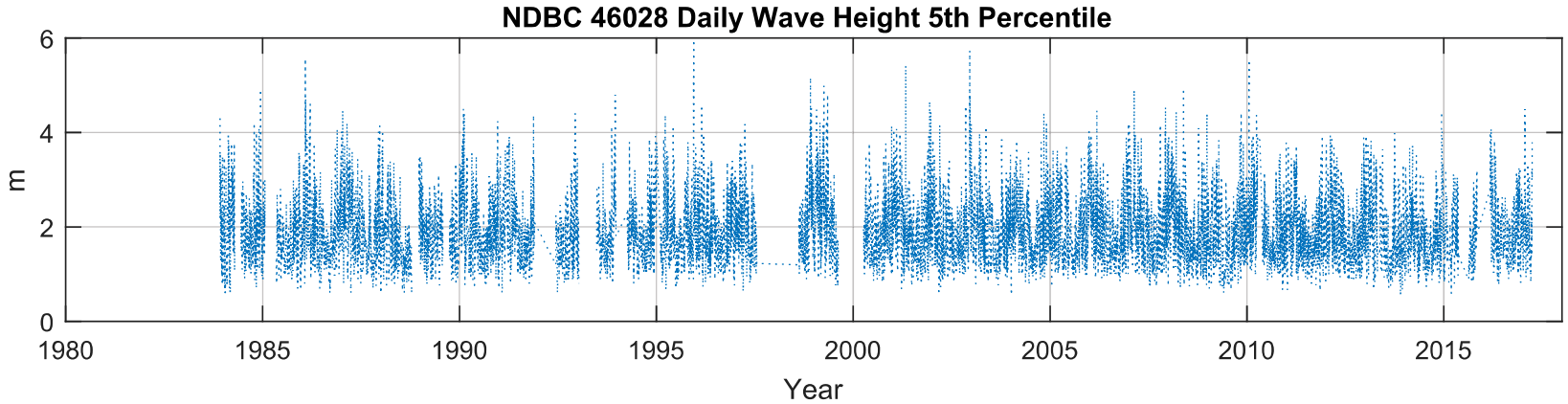


Figure A056. Daily Wave Height, Percentiles,NDBC 46028

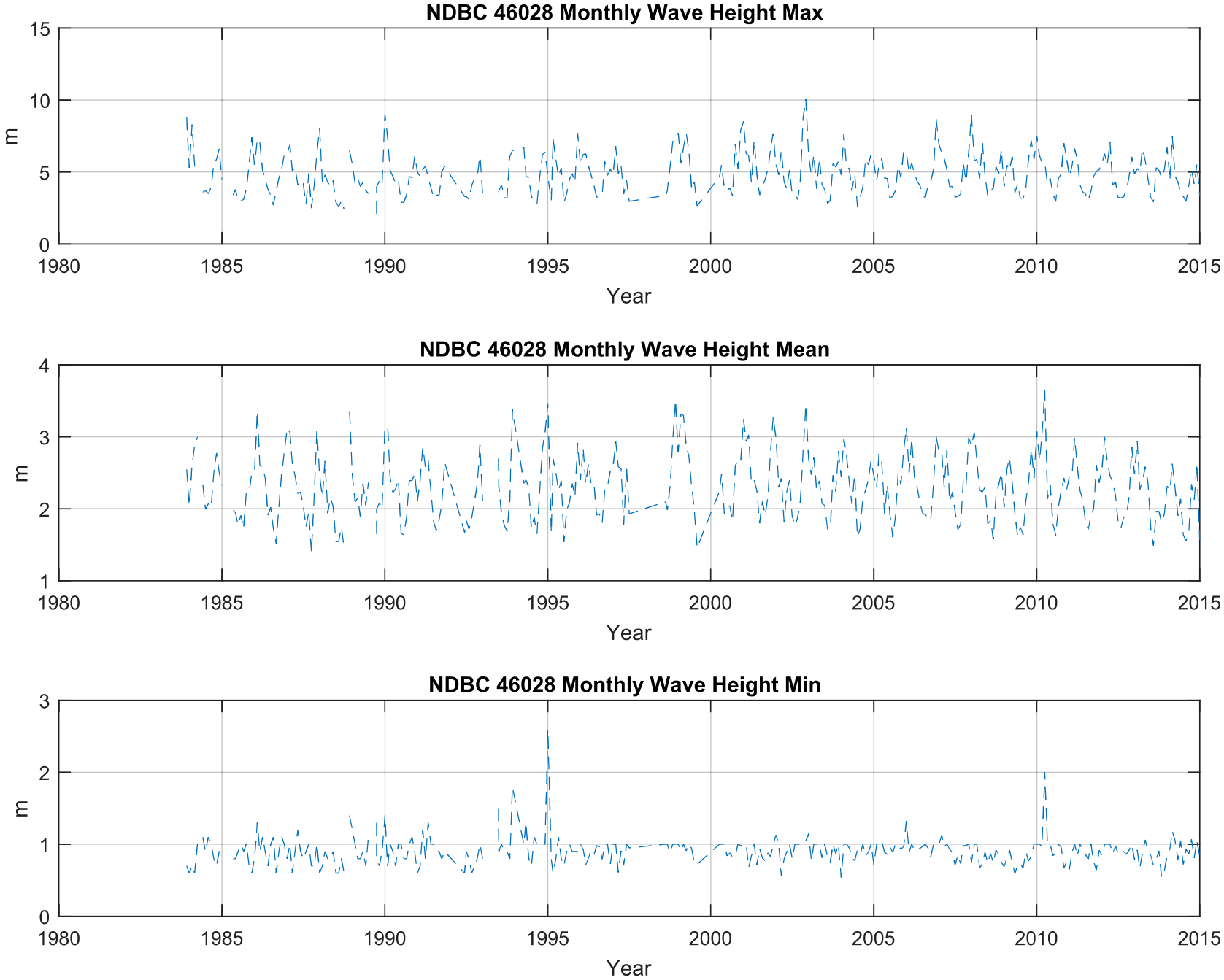


Figure A057. Monthly Wave Height, Max, Mean, Min,NDBC 46028

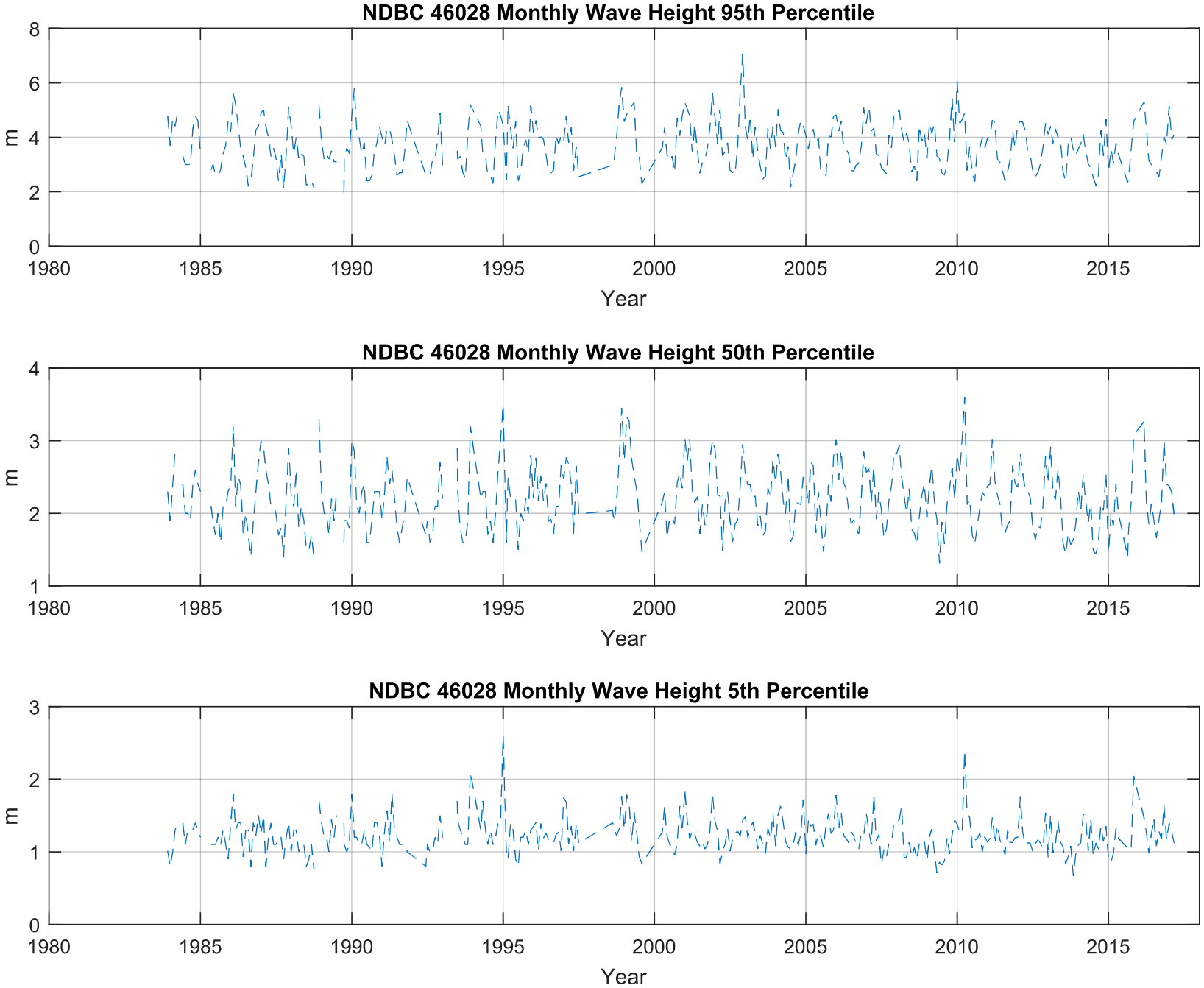
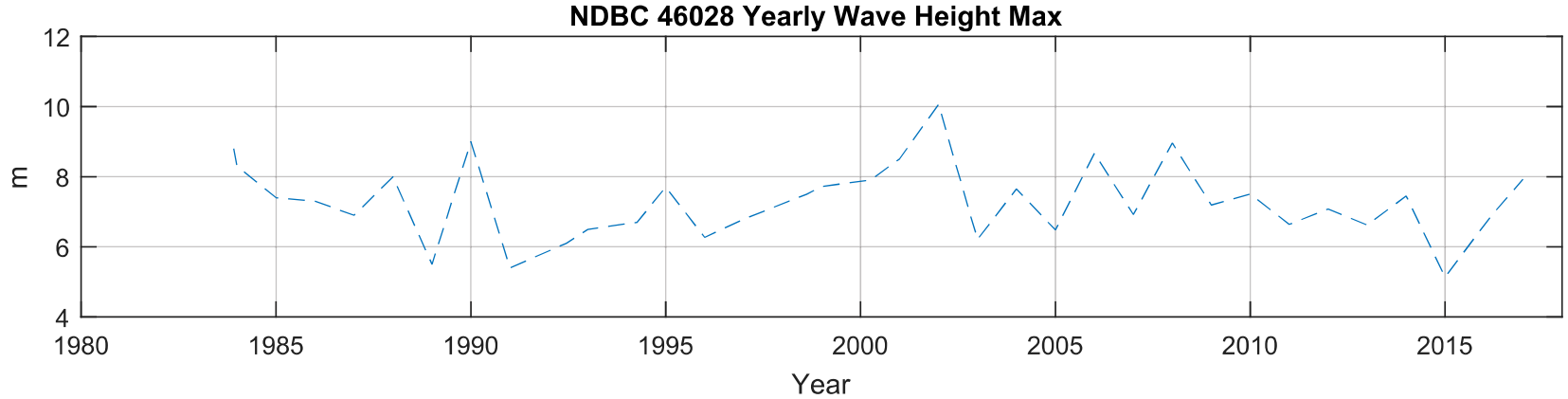
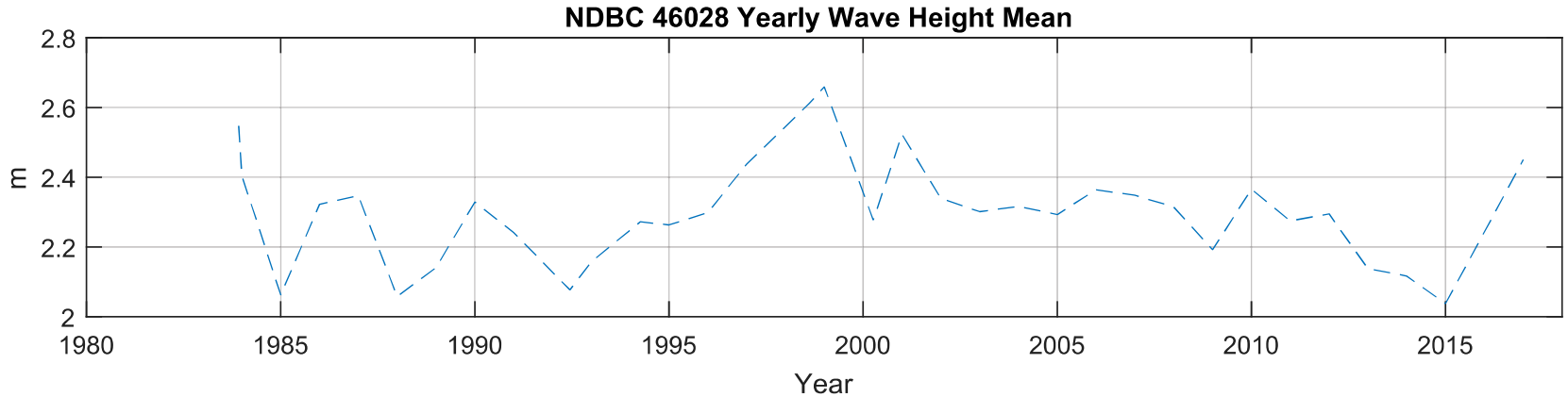


Figure A058. Monthly Wave Height, Percentiles,NDBC 46028





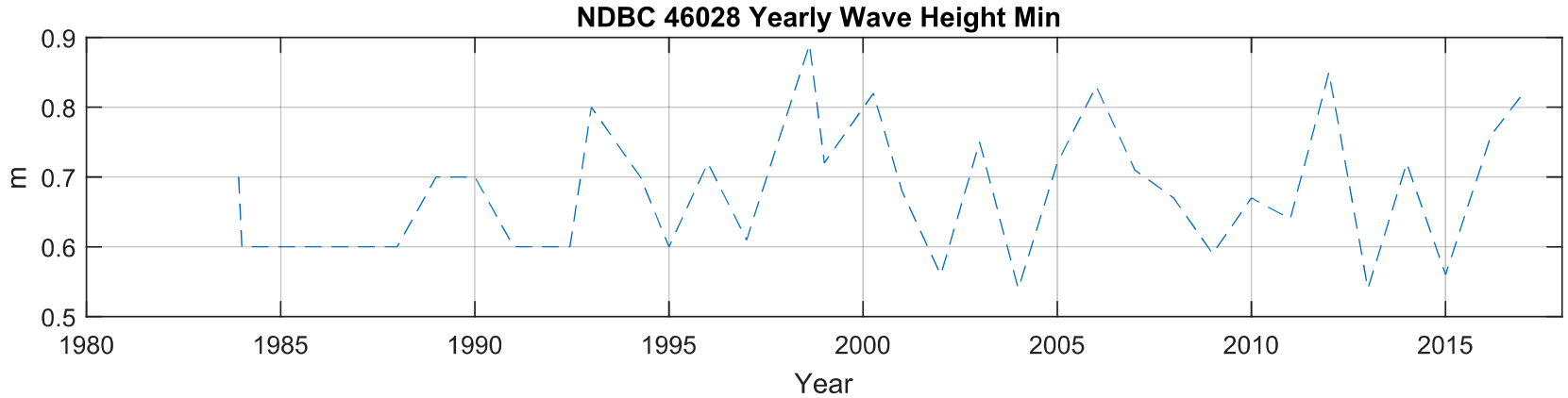


Figure A059. Yearly Wave Height, Max, Mean, Min,NDBC 46028

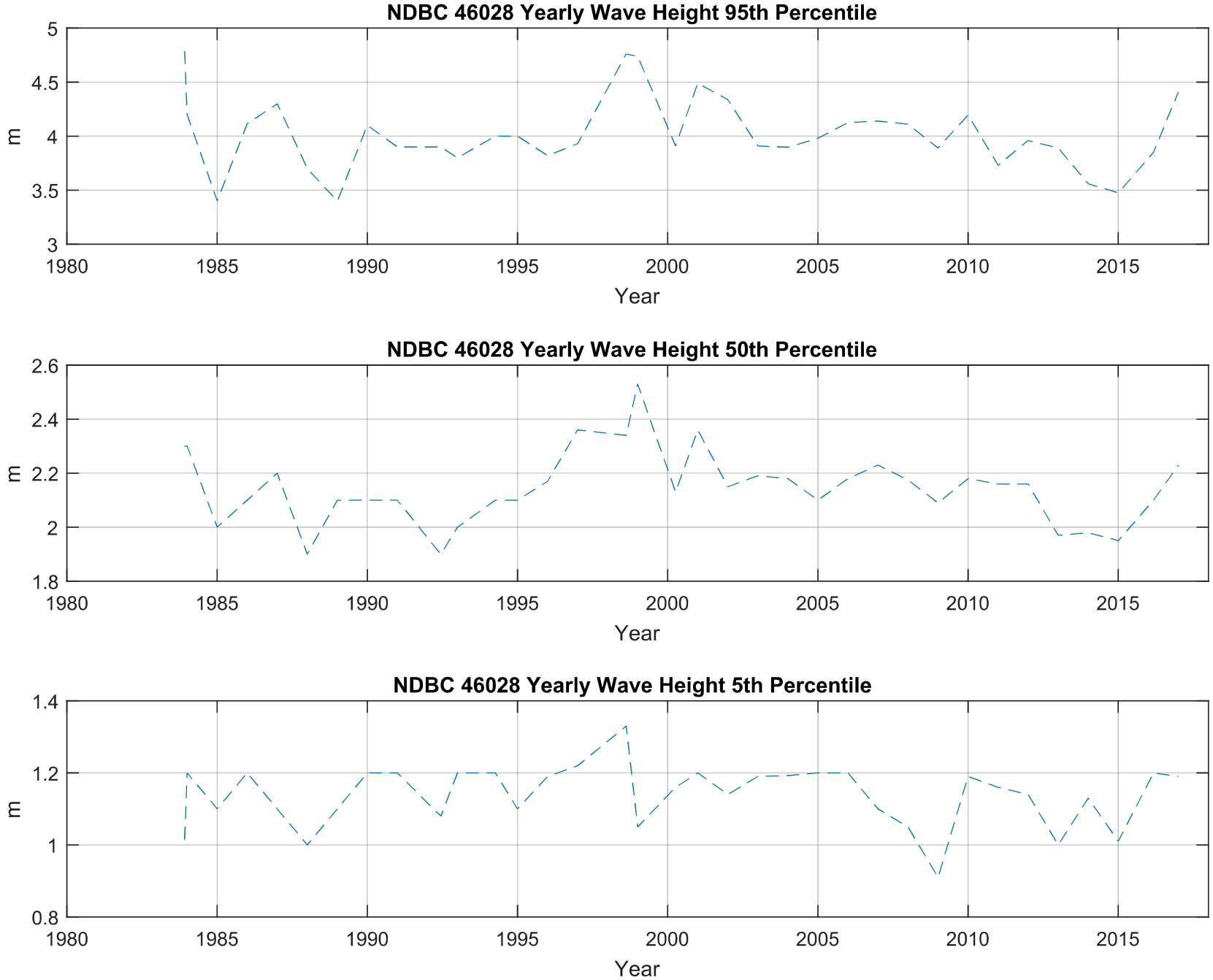


Figure A060. Yearly Wave Height, Percentiles,NDBC 46028

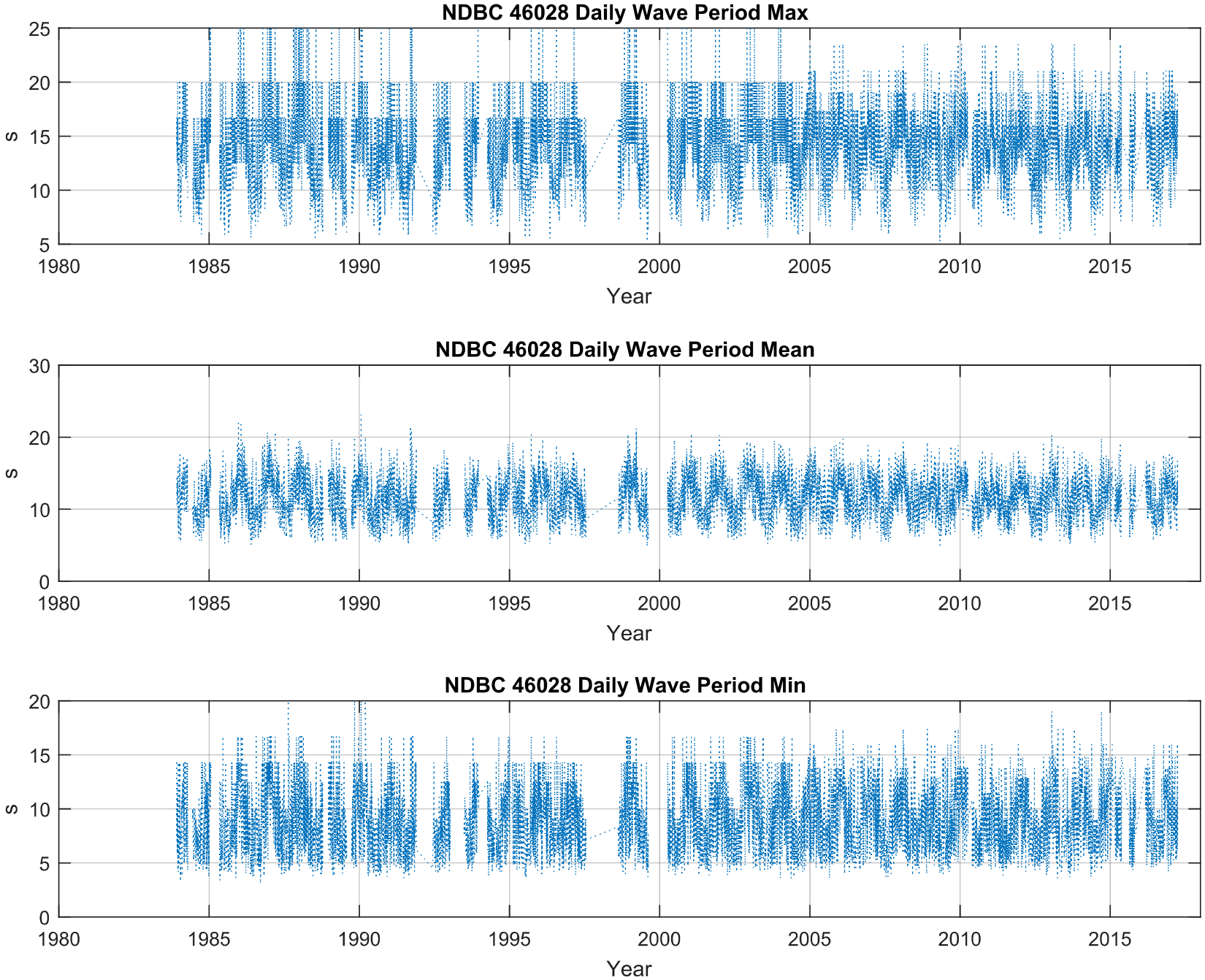
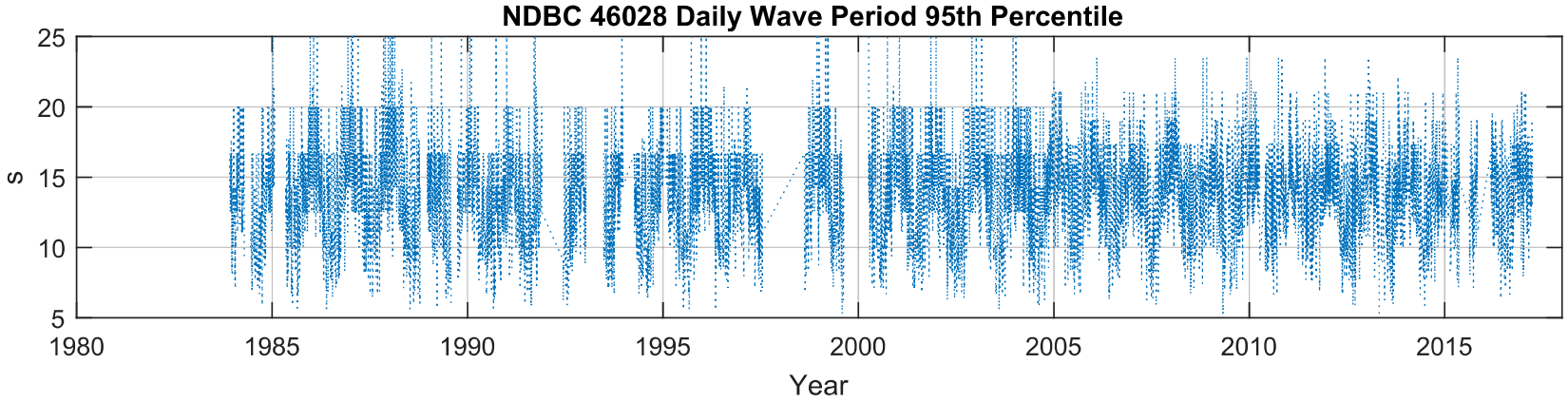
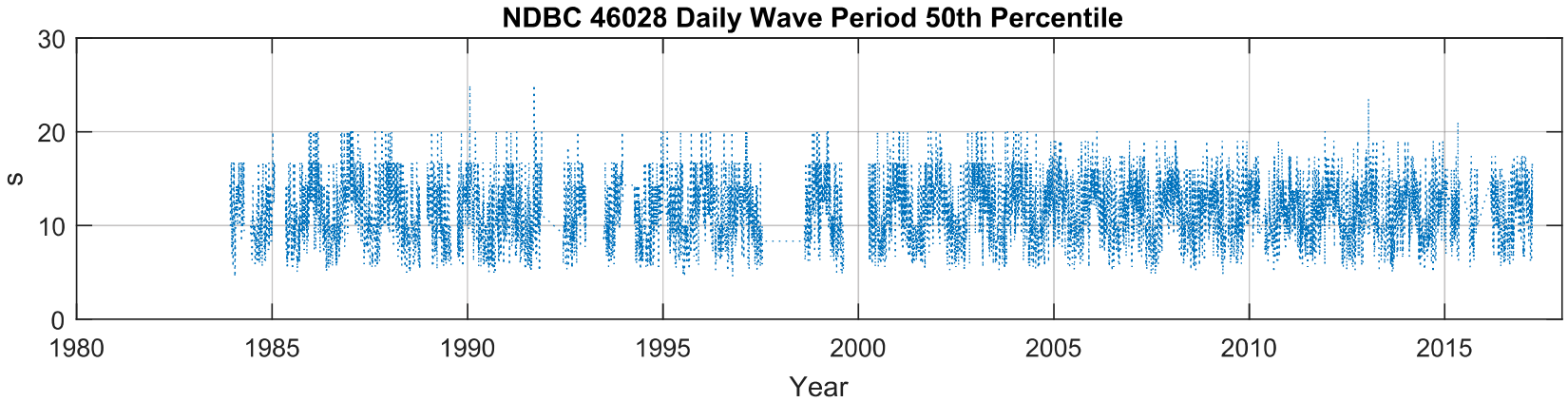


Figure A061. Daily Wave Period, Max, Mean, Min,NDBC 46028





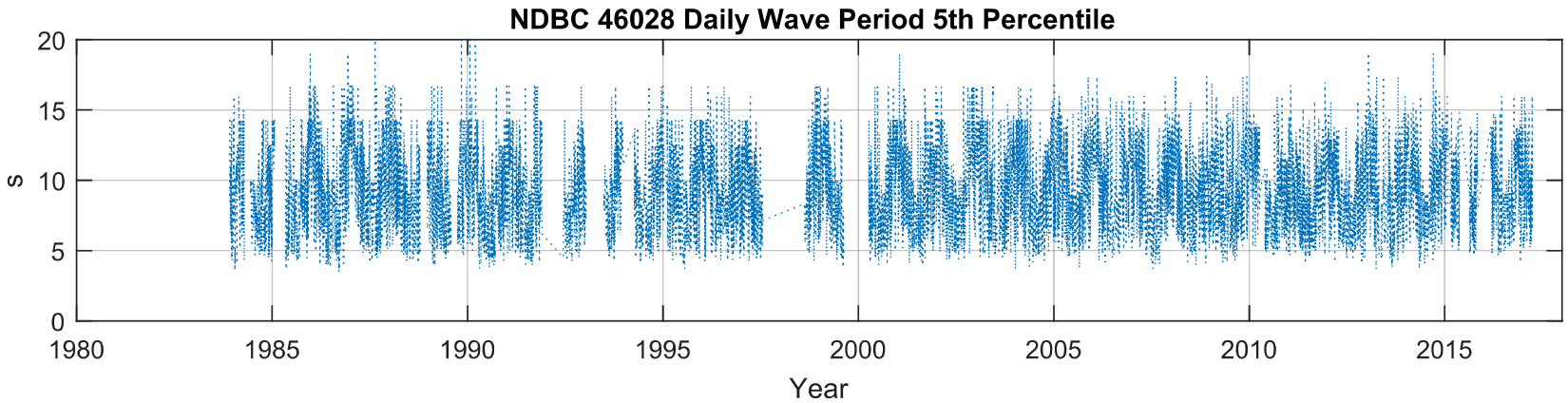


Figure A062. Daily Wave Period, Percentiles,NDBC 46028

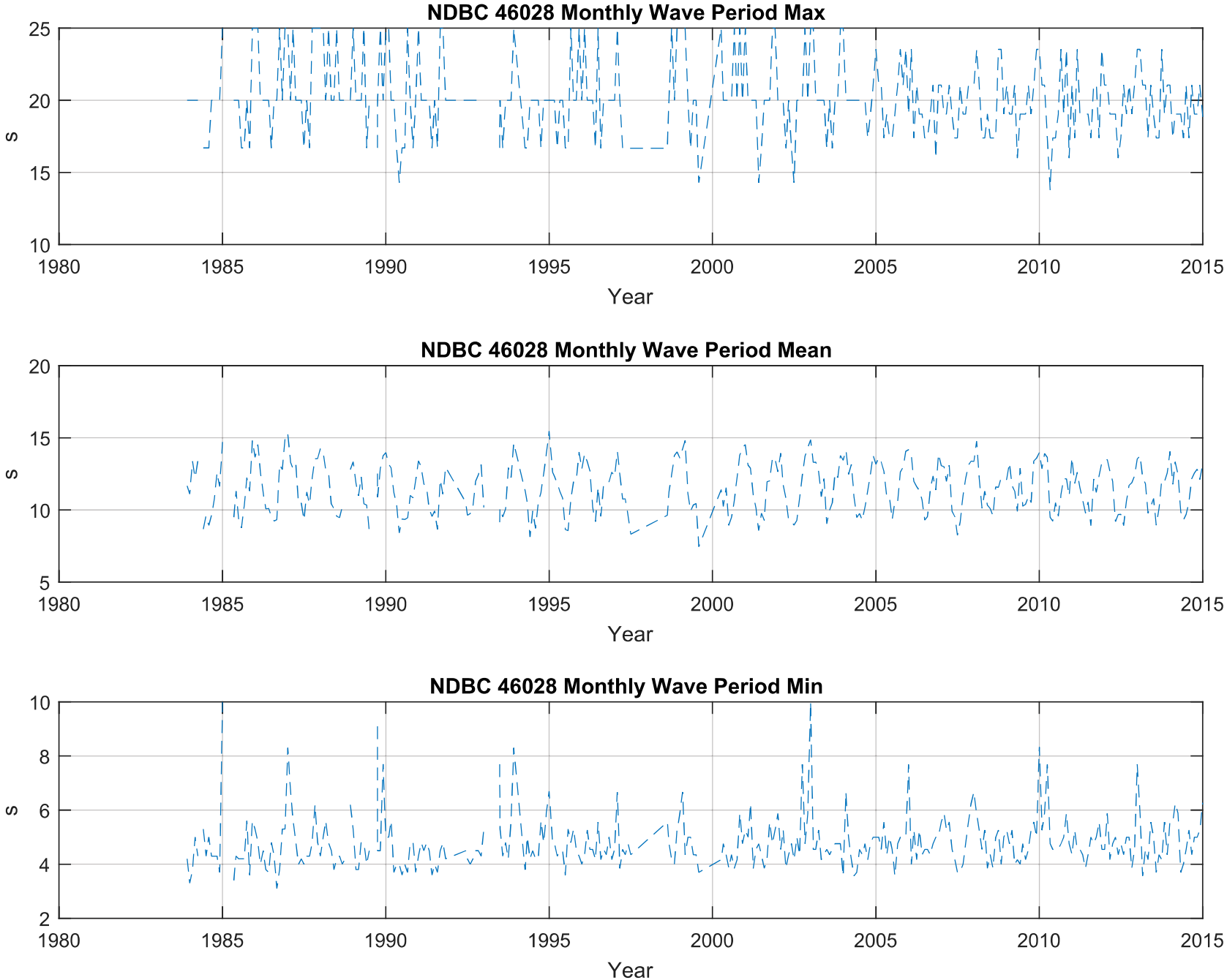


Figure A063. Monthly Wave Period, Max, Mean, Min,NDBC 46028

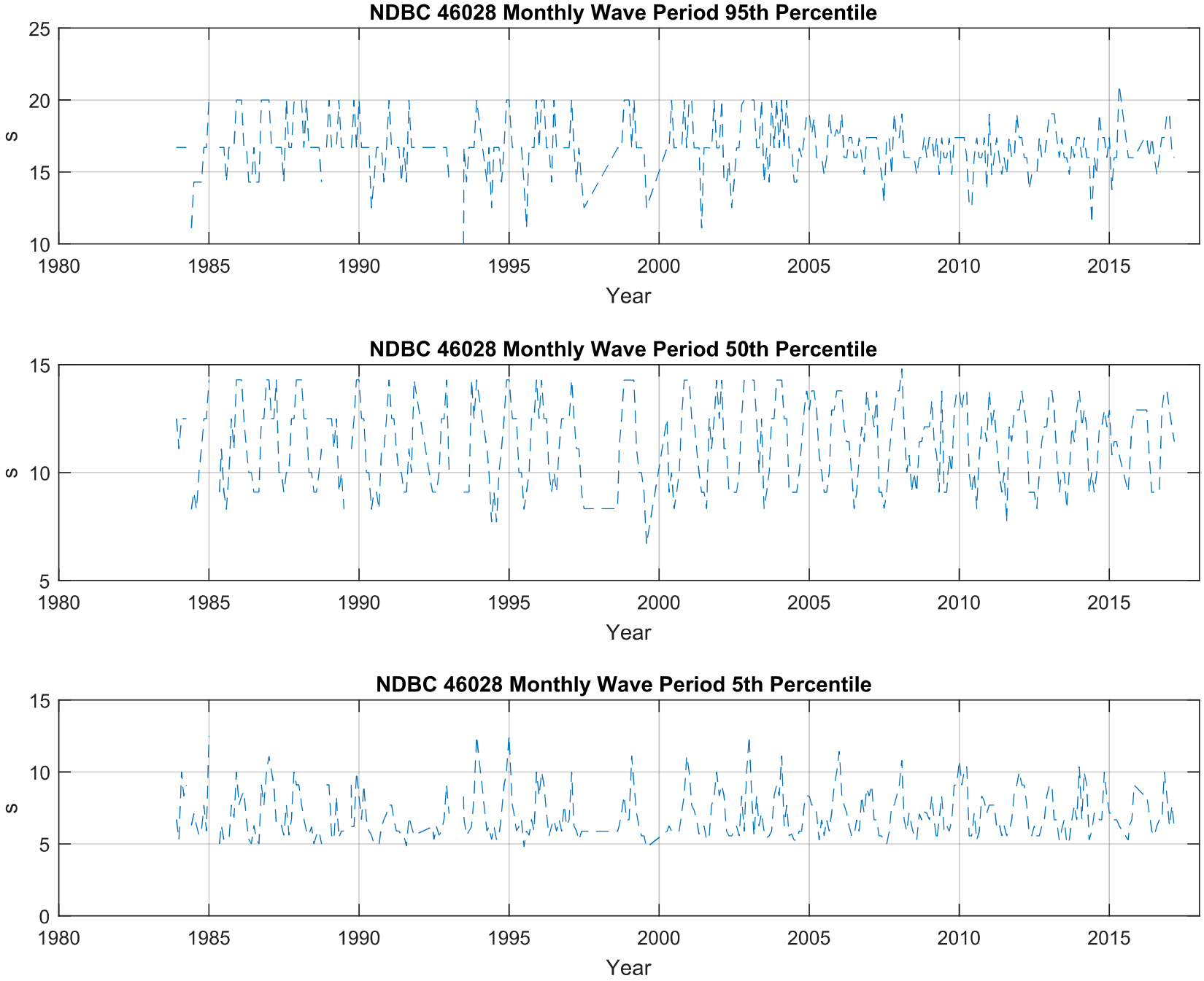


Figure A064. Monthly Wave Period, Percentiles,NDBC 46028

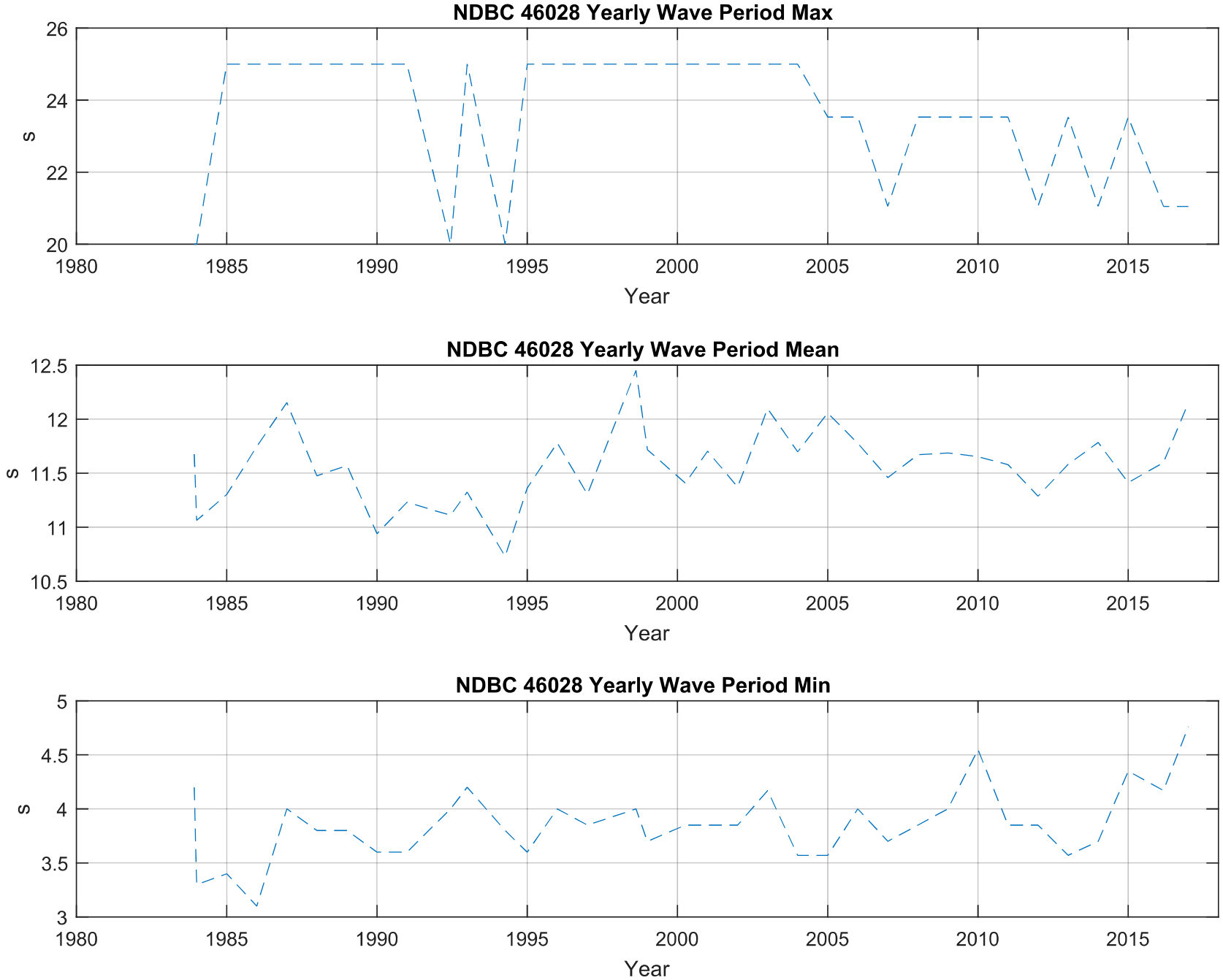
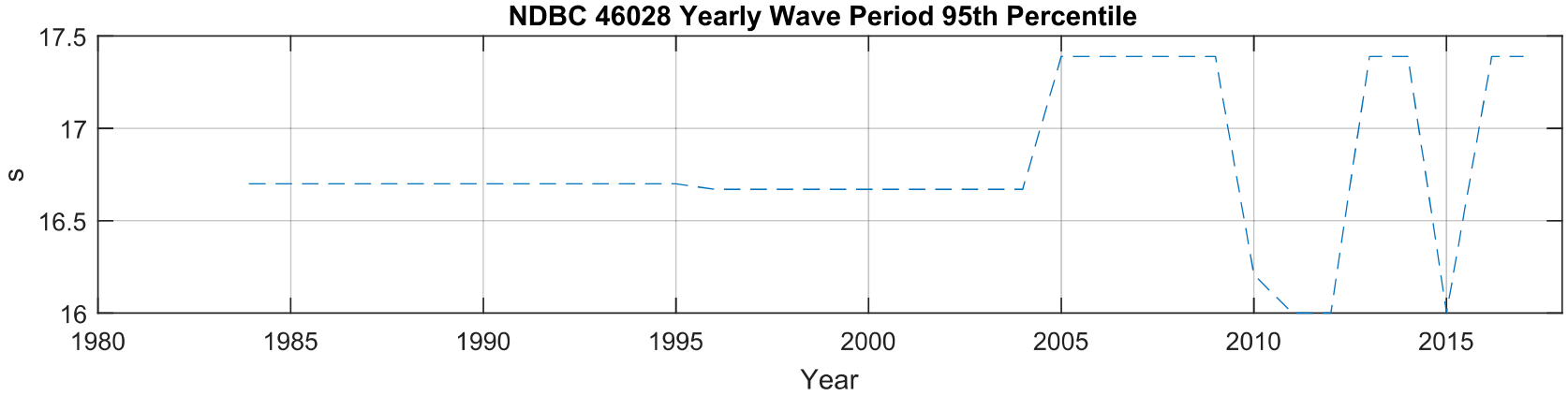
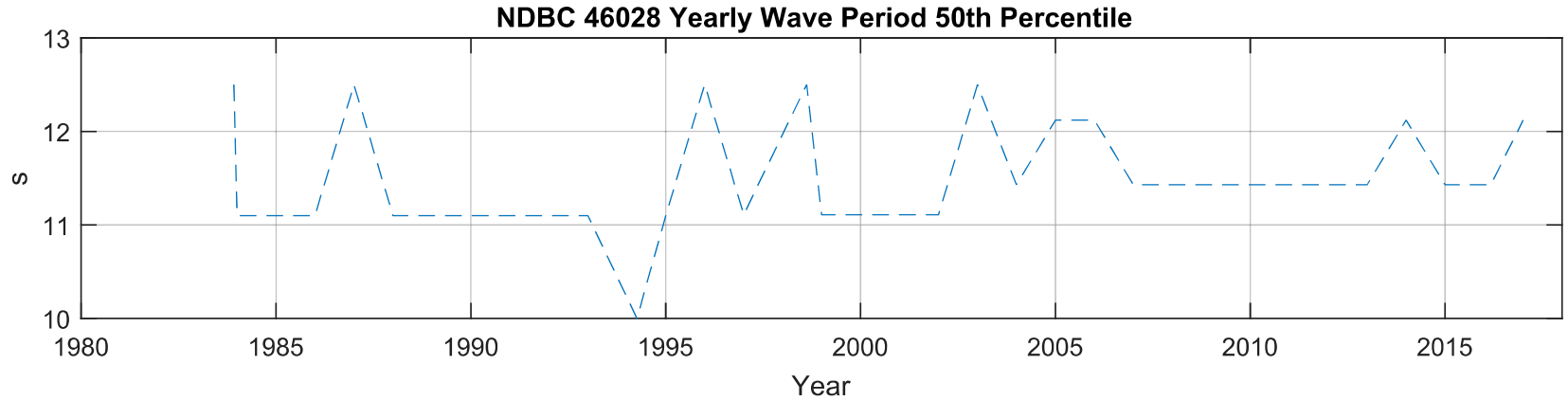


Figure A065. Yearly Wave Period, Max, Mean, Min,NDBC 46028





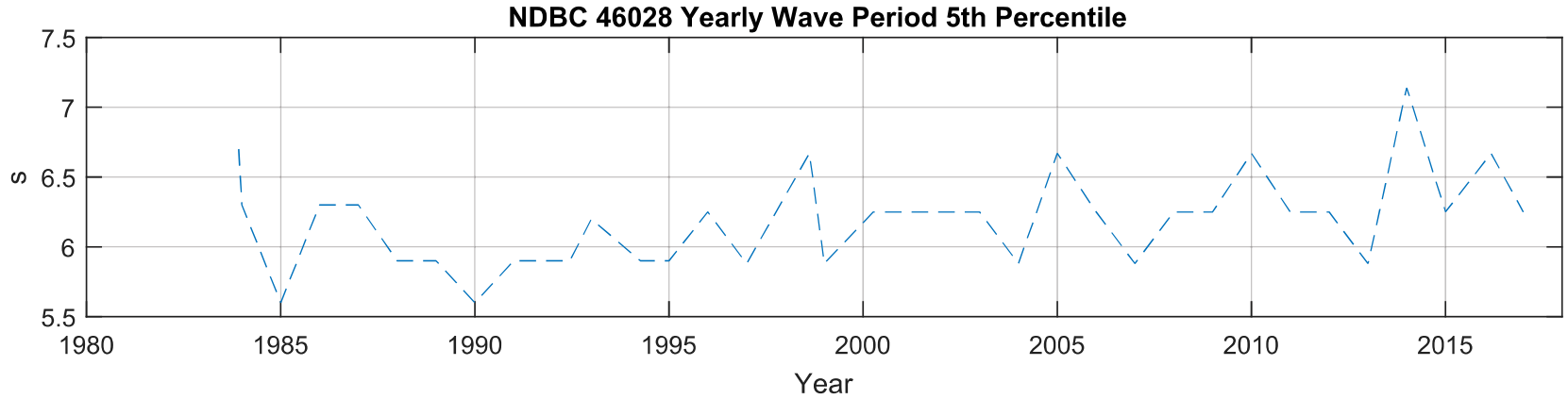
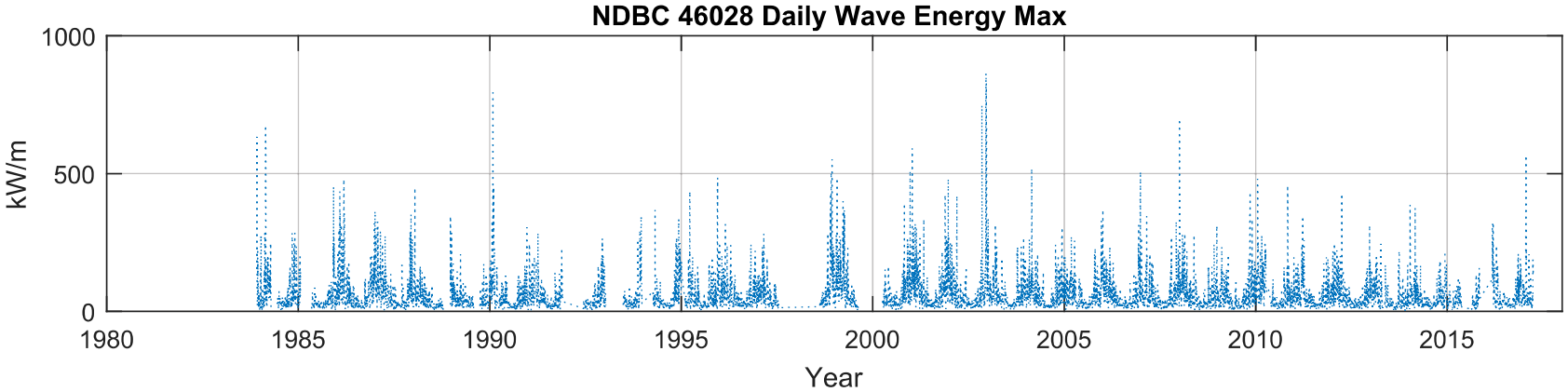
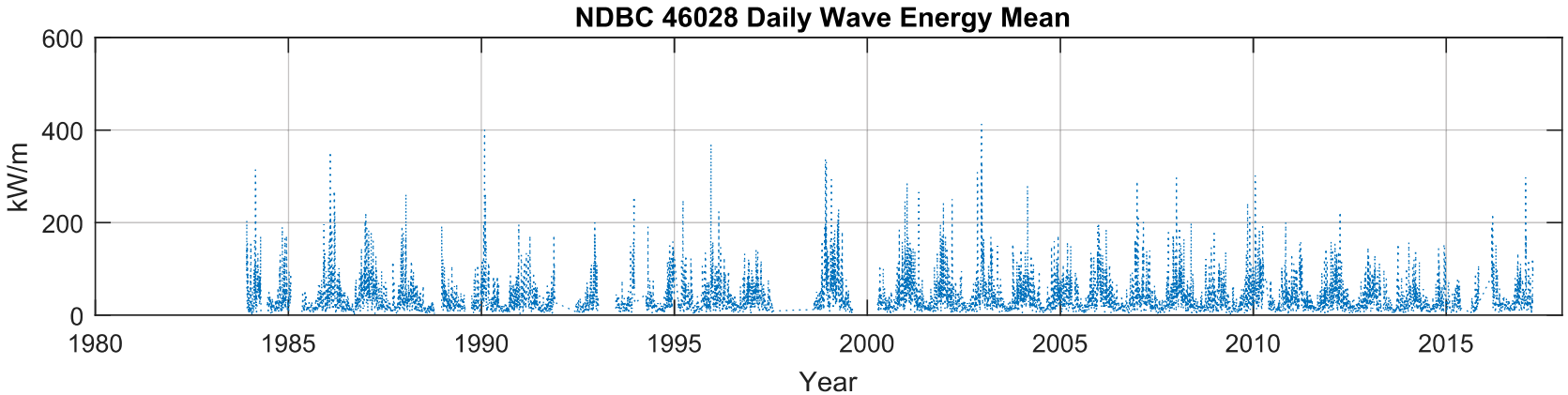


Figure A066. Yearly Wave Period, Percentiles,NDBC 46028





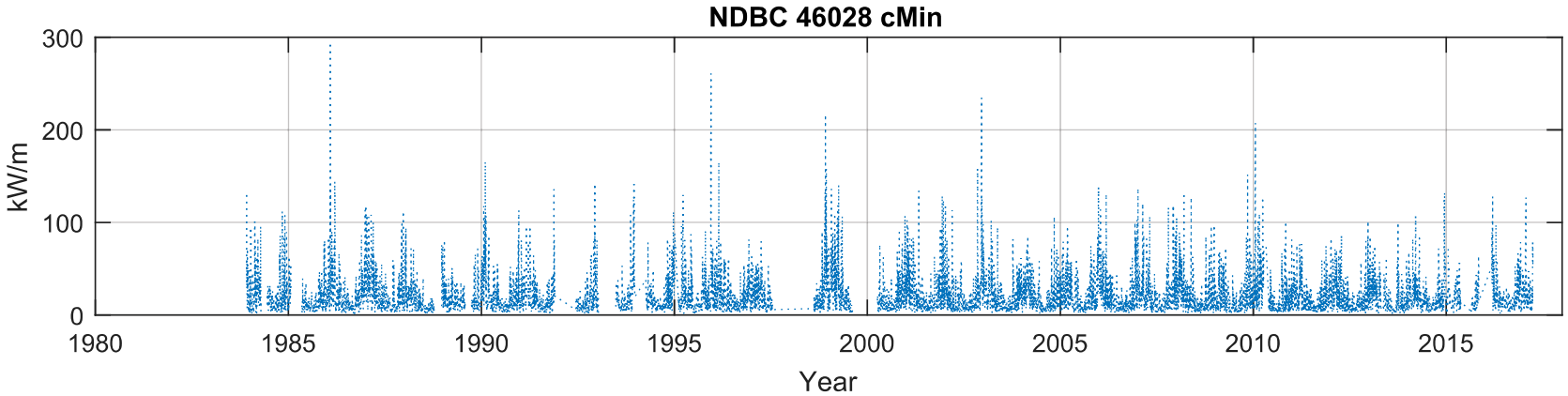
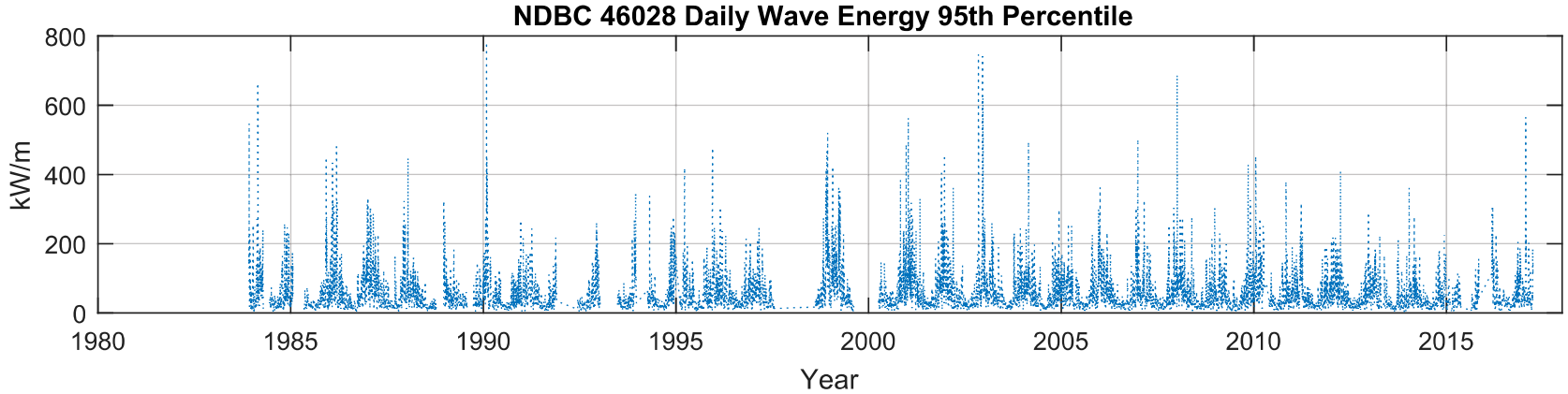
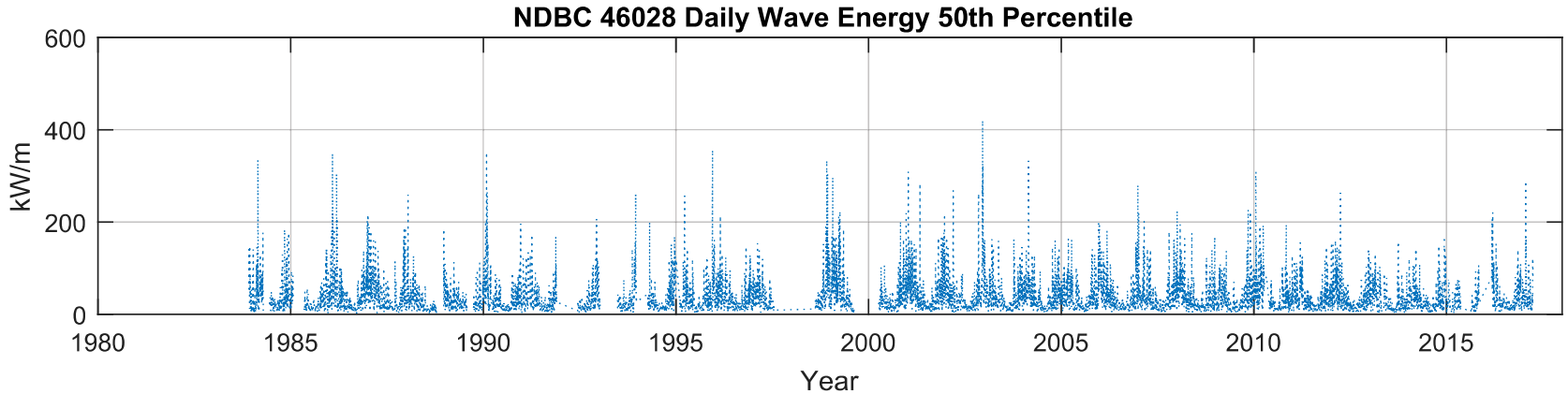


Figure A067. Daily Wave Energy, Max, Mean, Min,NDBC 46028





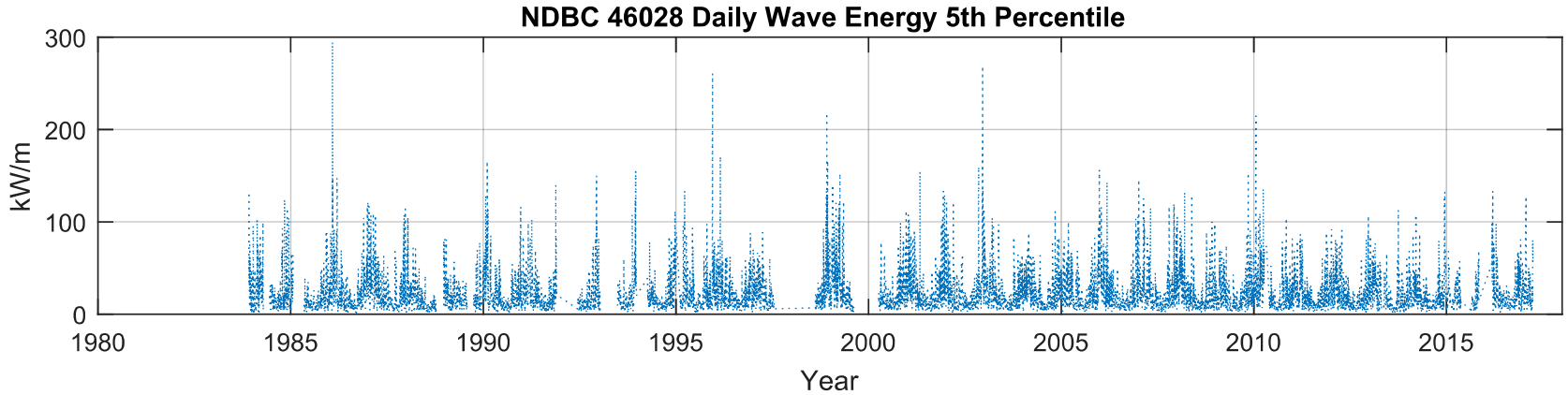
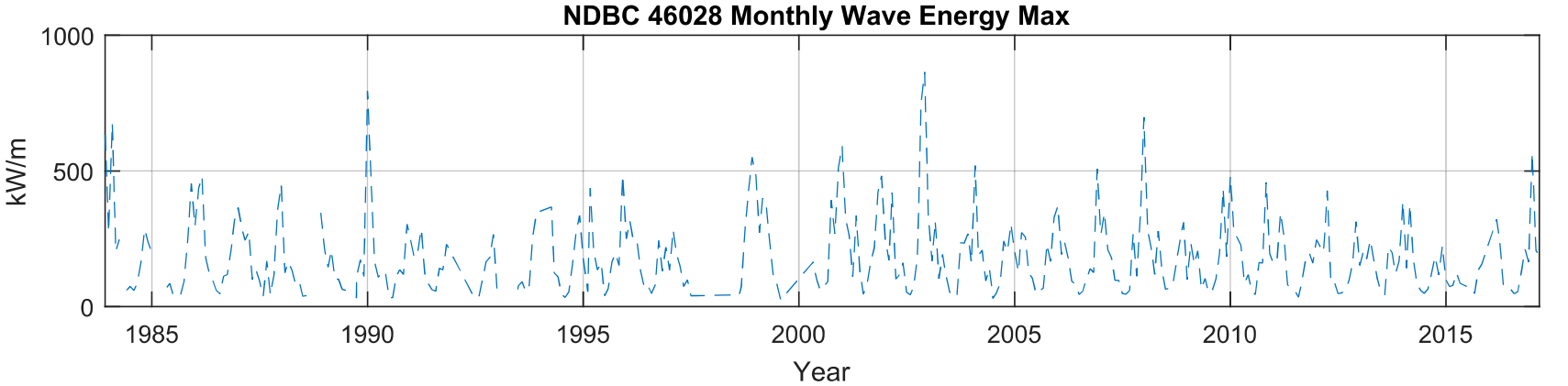
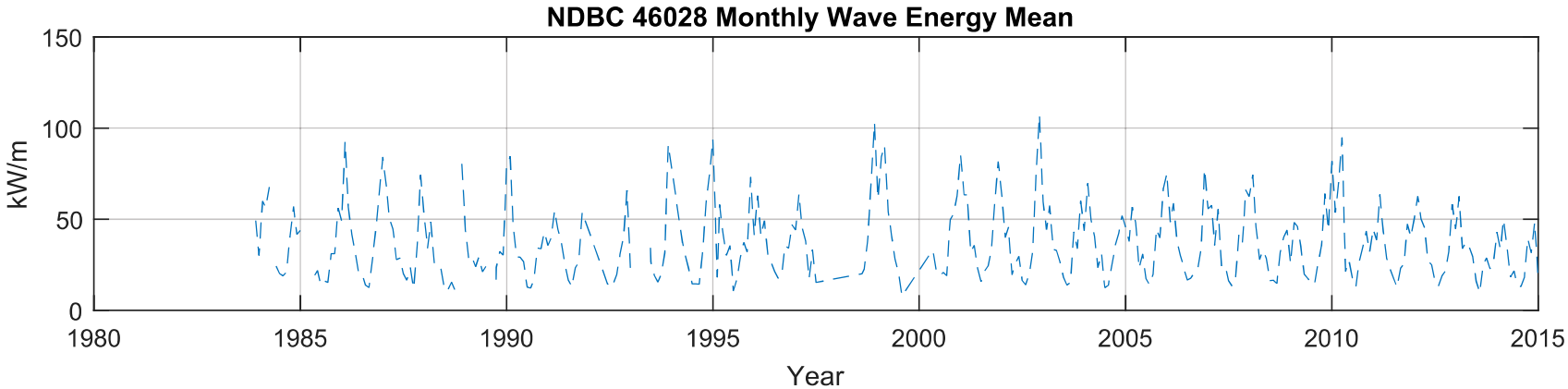


Figure A068. Daily Wave Energy, Percentiles,NDBC 46028





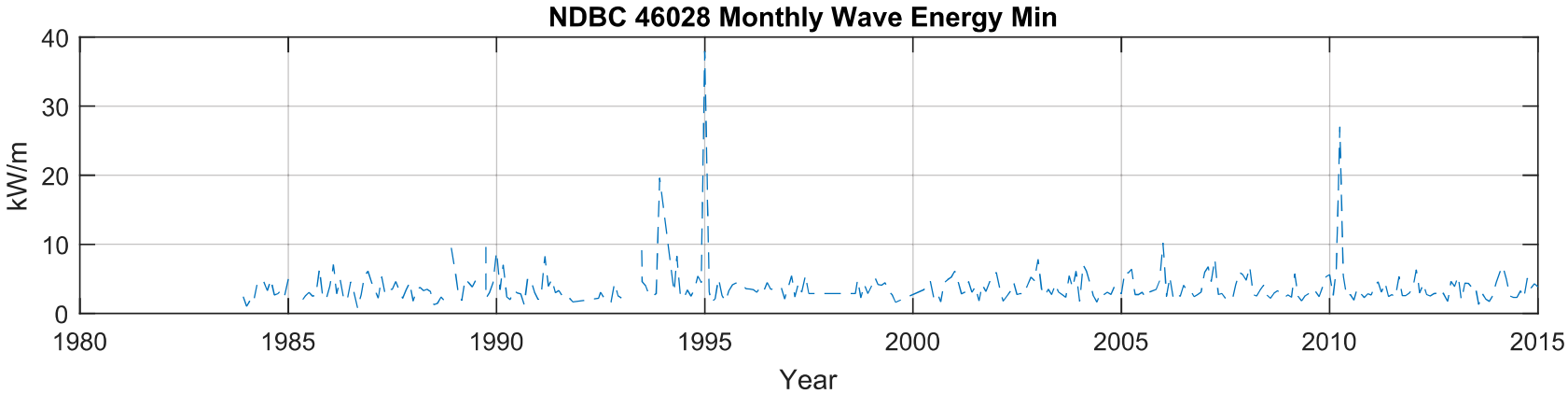
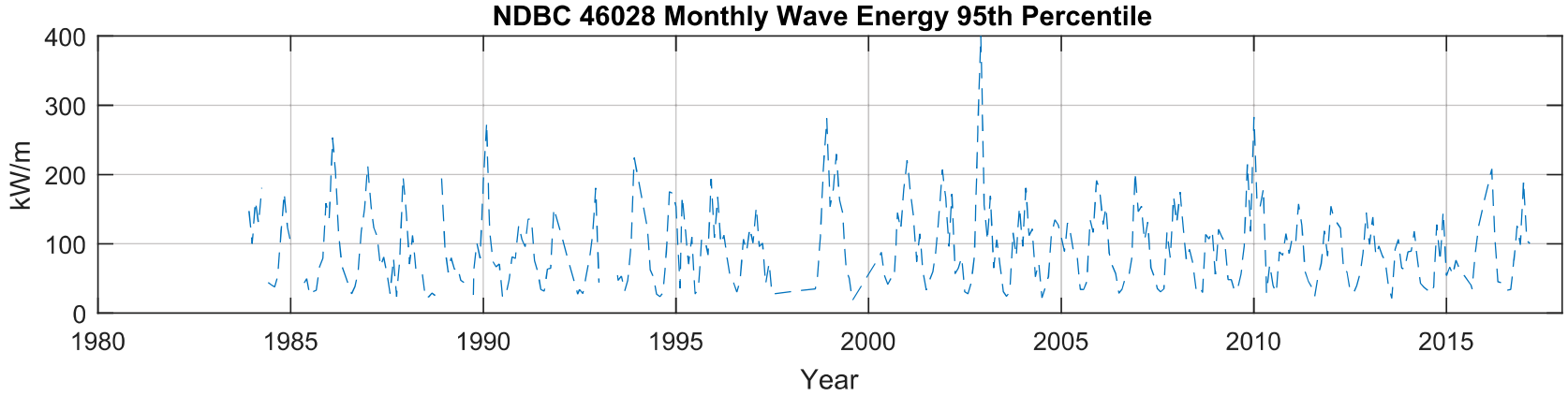
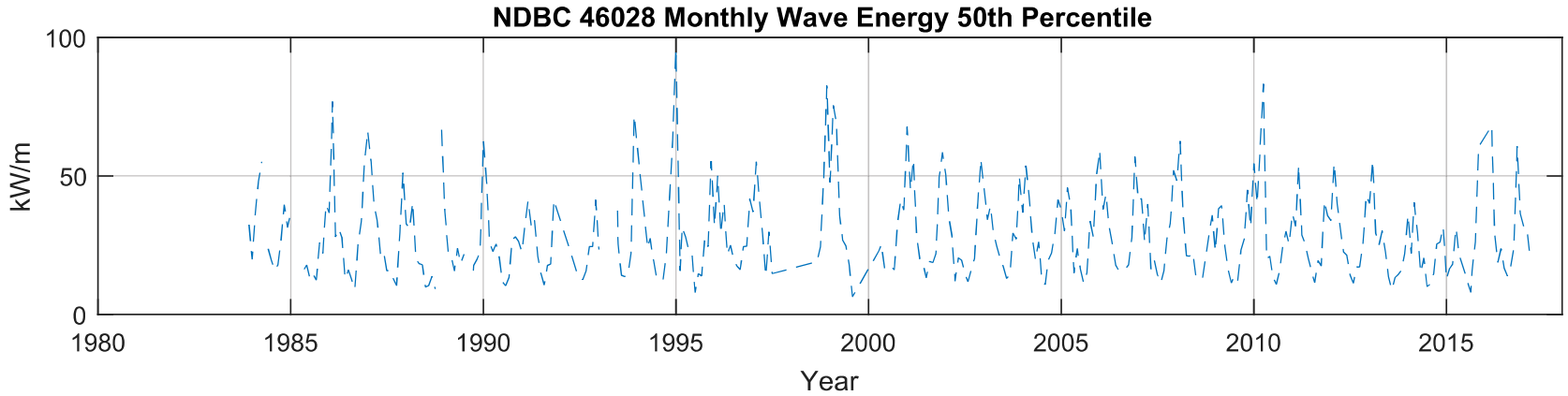


Figure A069. Monthly Wave Energy, Max, Mean, Min,NDBC 46028





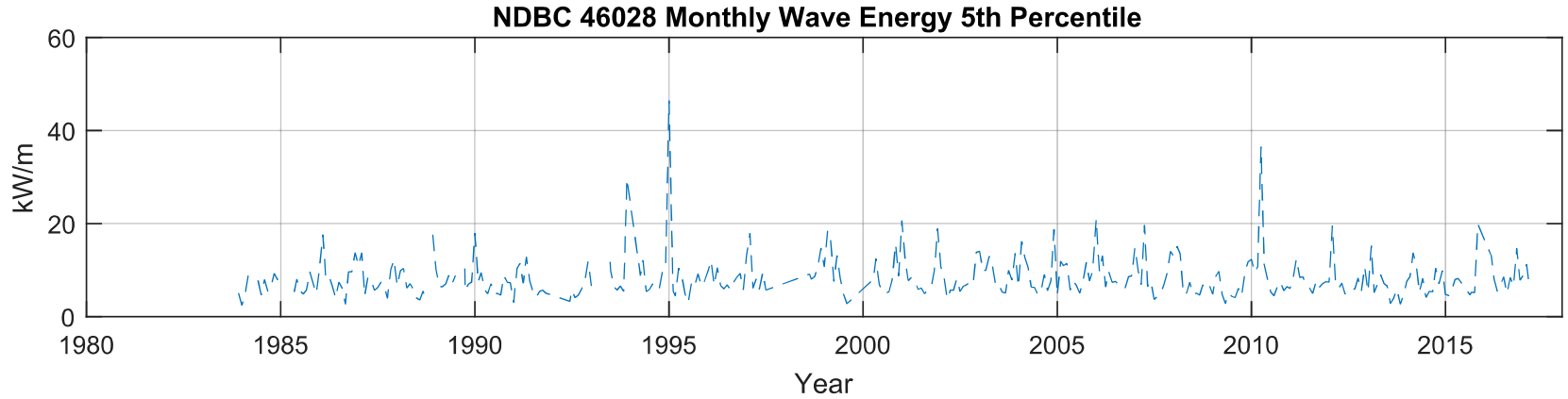


Figure A070. Monthly Wave Energy, Percentiles,NDBC 46028

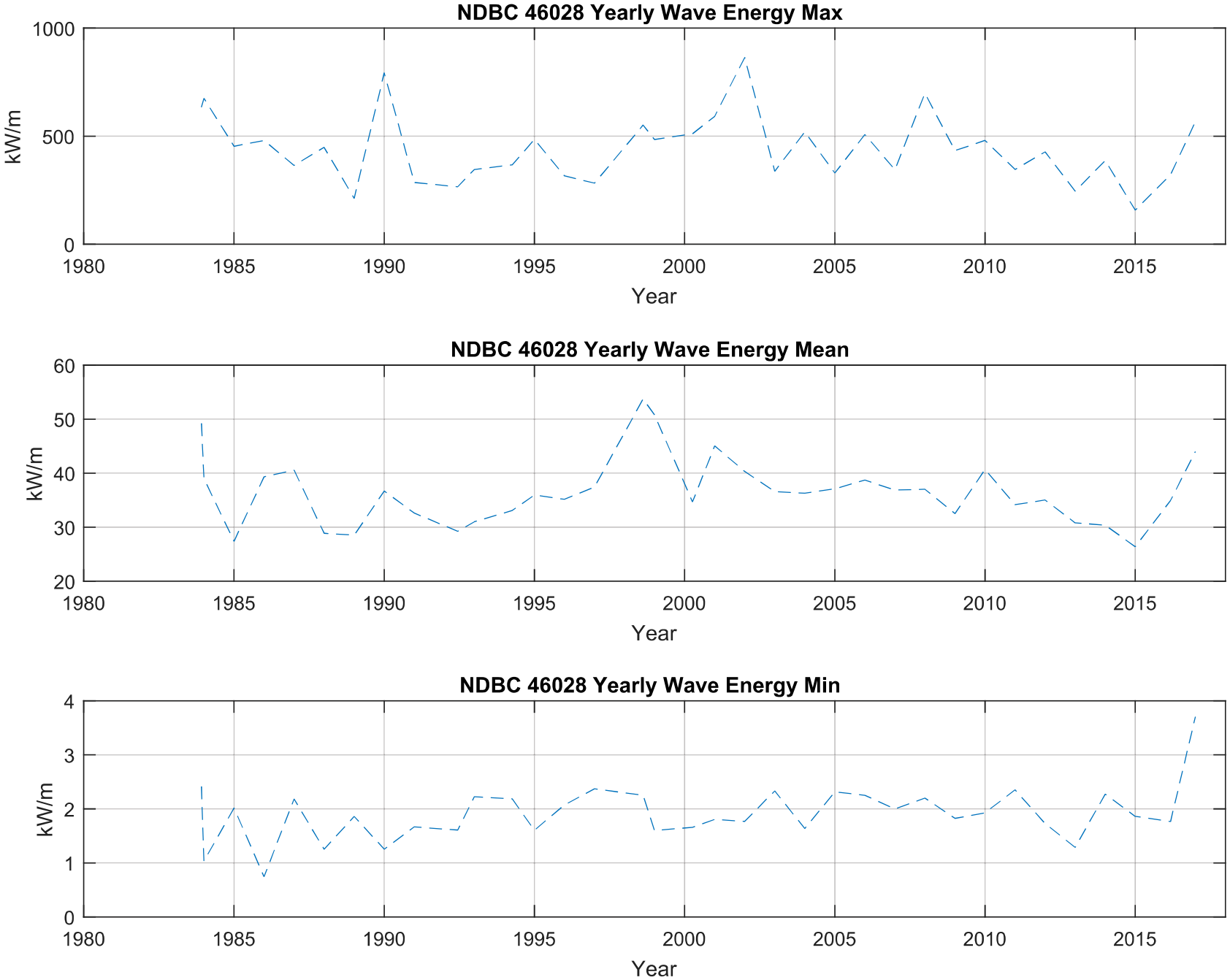
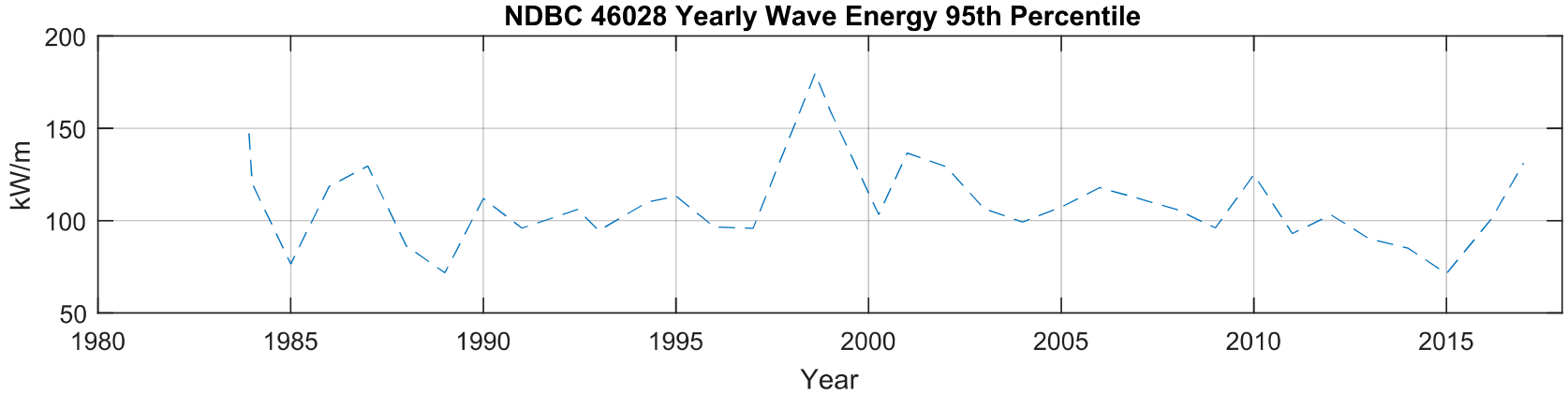
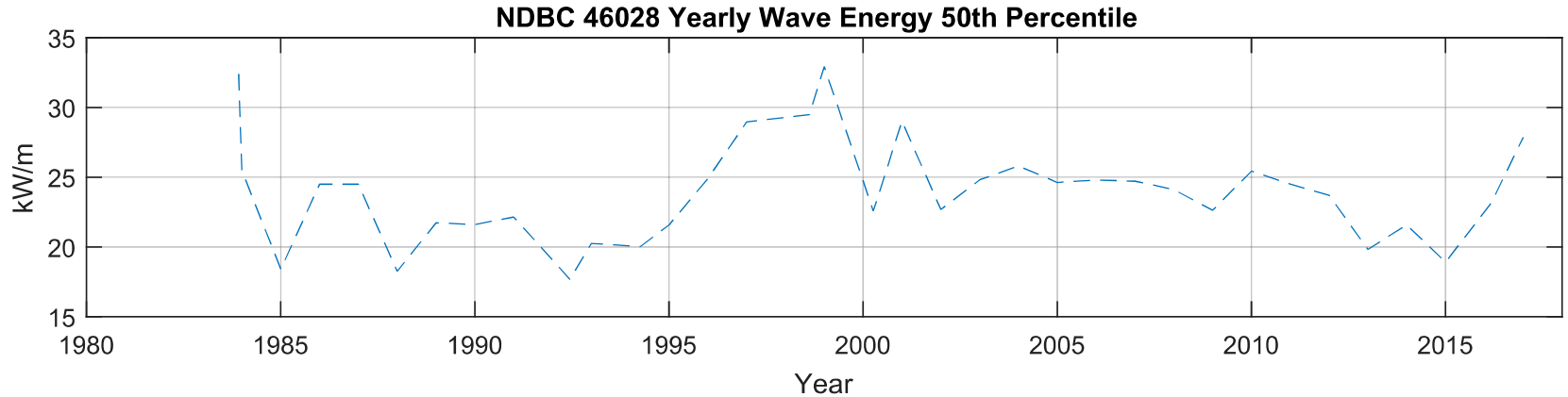


Figure A071. Yearly Wave Energy, Max, Mean, Min,NDBC 46028





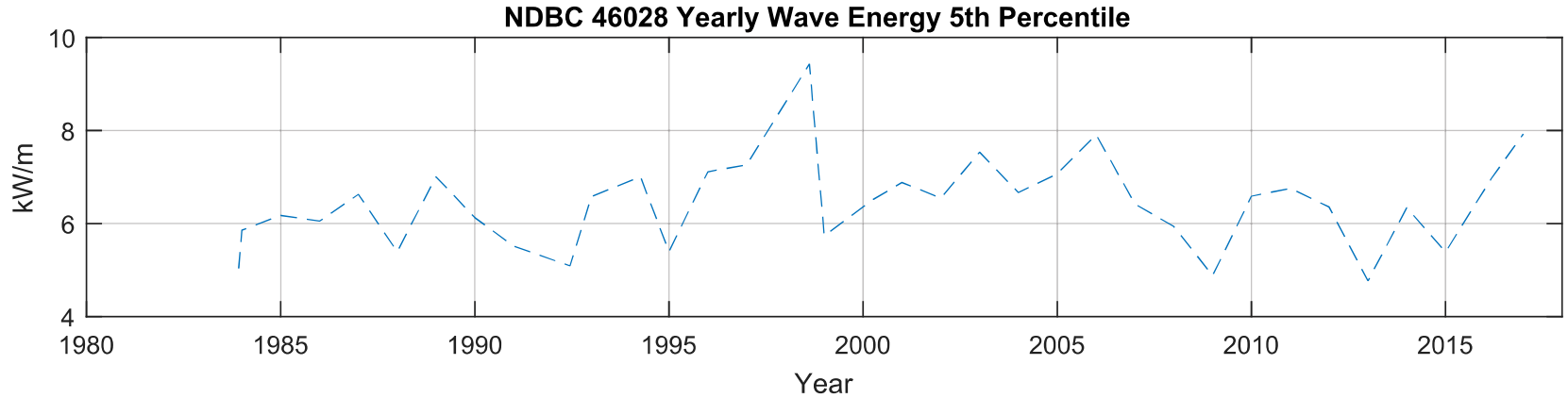


Figure A072. Yearly Wave Energy, Percentiles,NDBC 46028

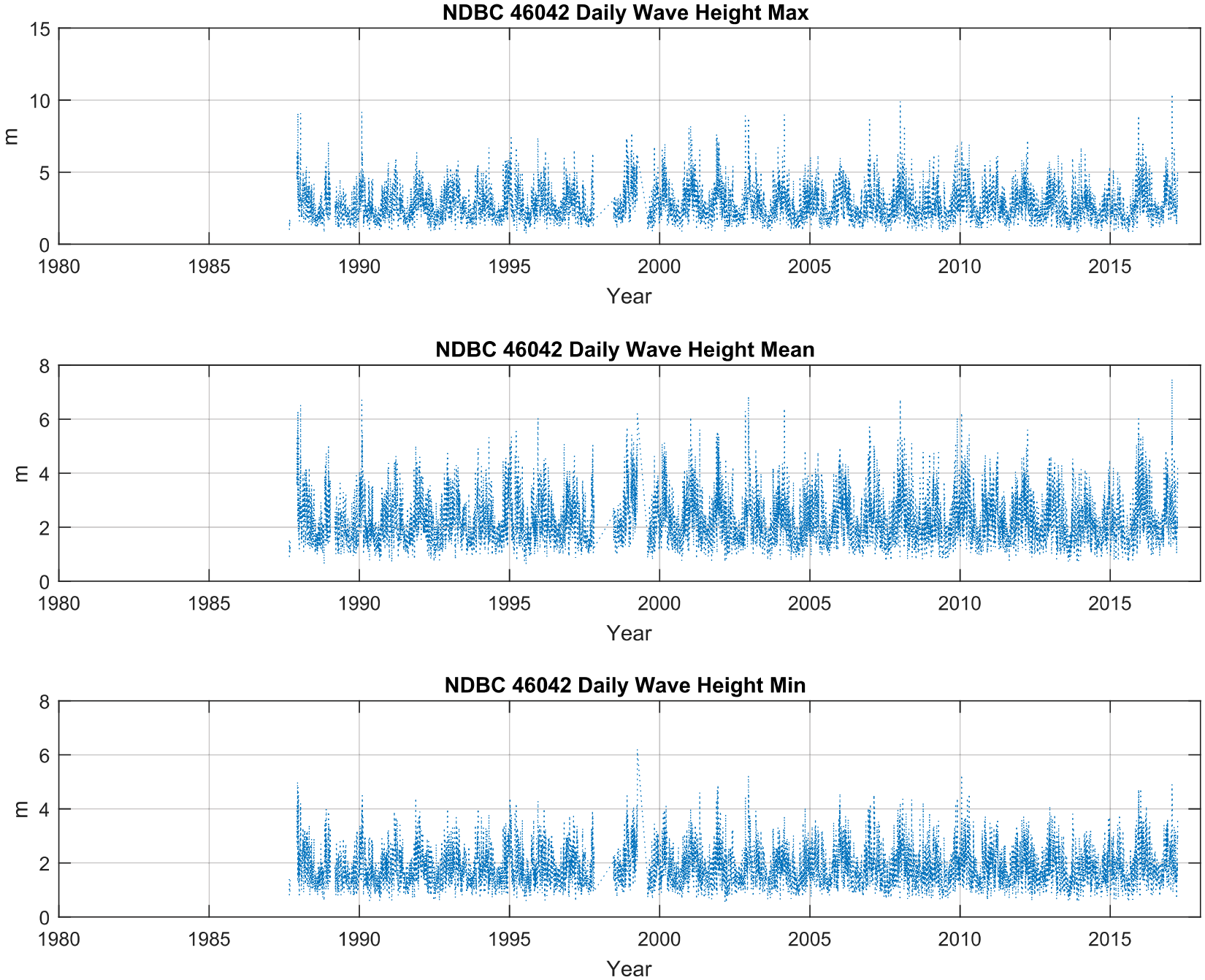


Figure A073. Daily Wave Height, Max, Mean, Min,NDBC 46042

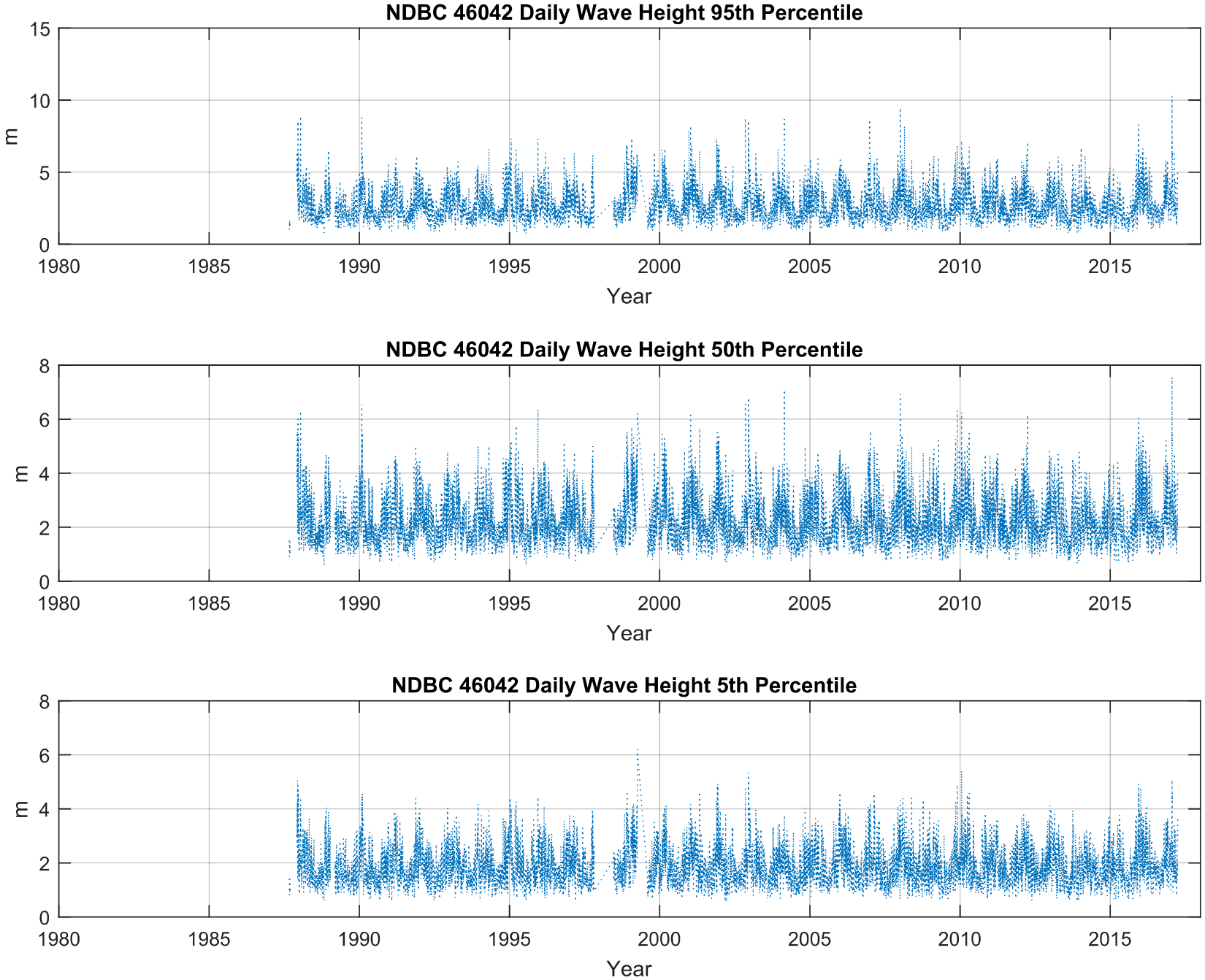


Figure A074. Daily Wave Height, Percentiles,NDBC 46042

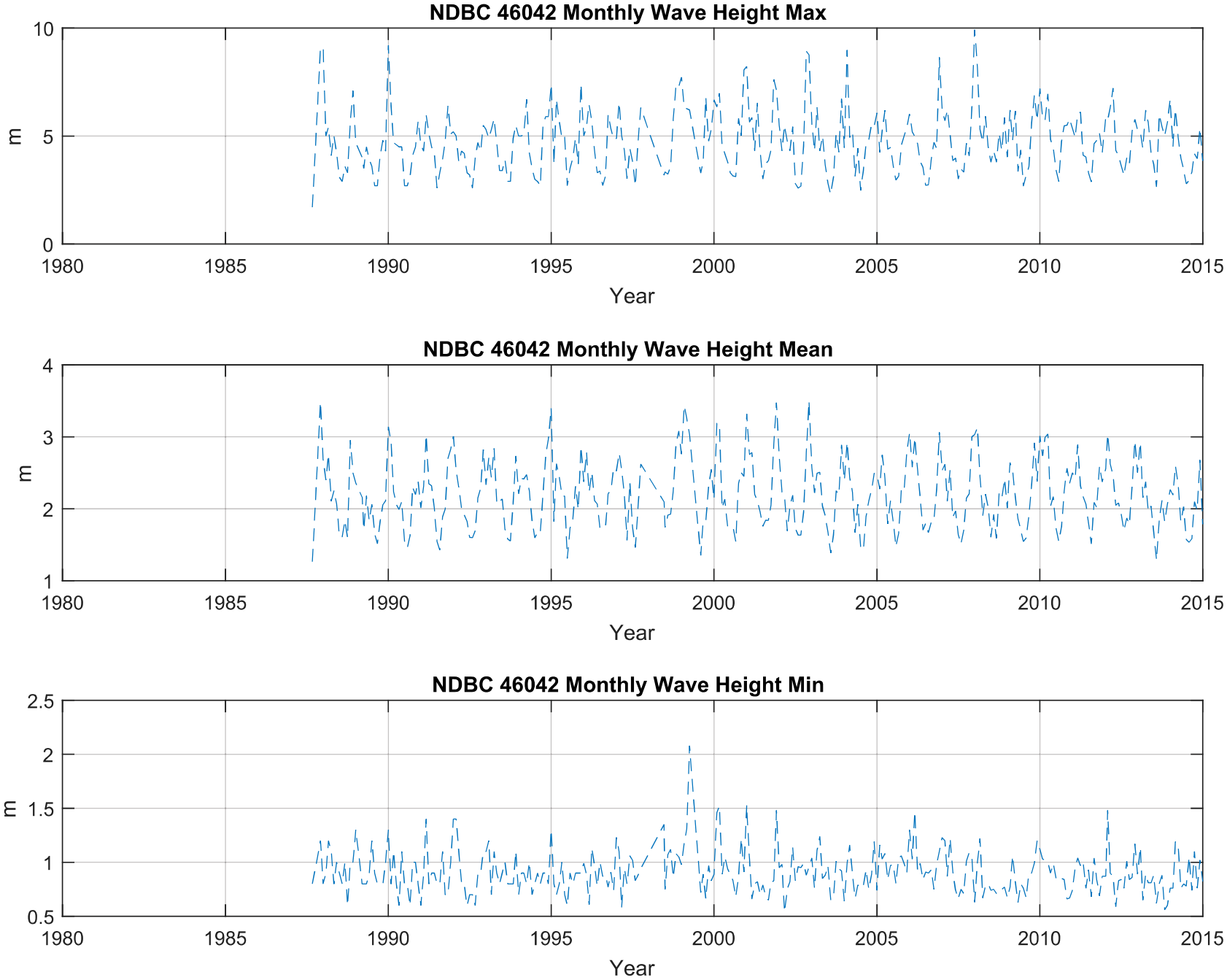


Figure A075. Monthly Wave Height, Max, Mean, Min,NDBC 46042

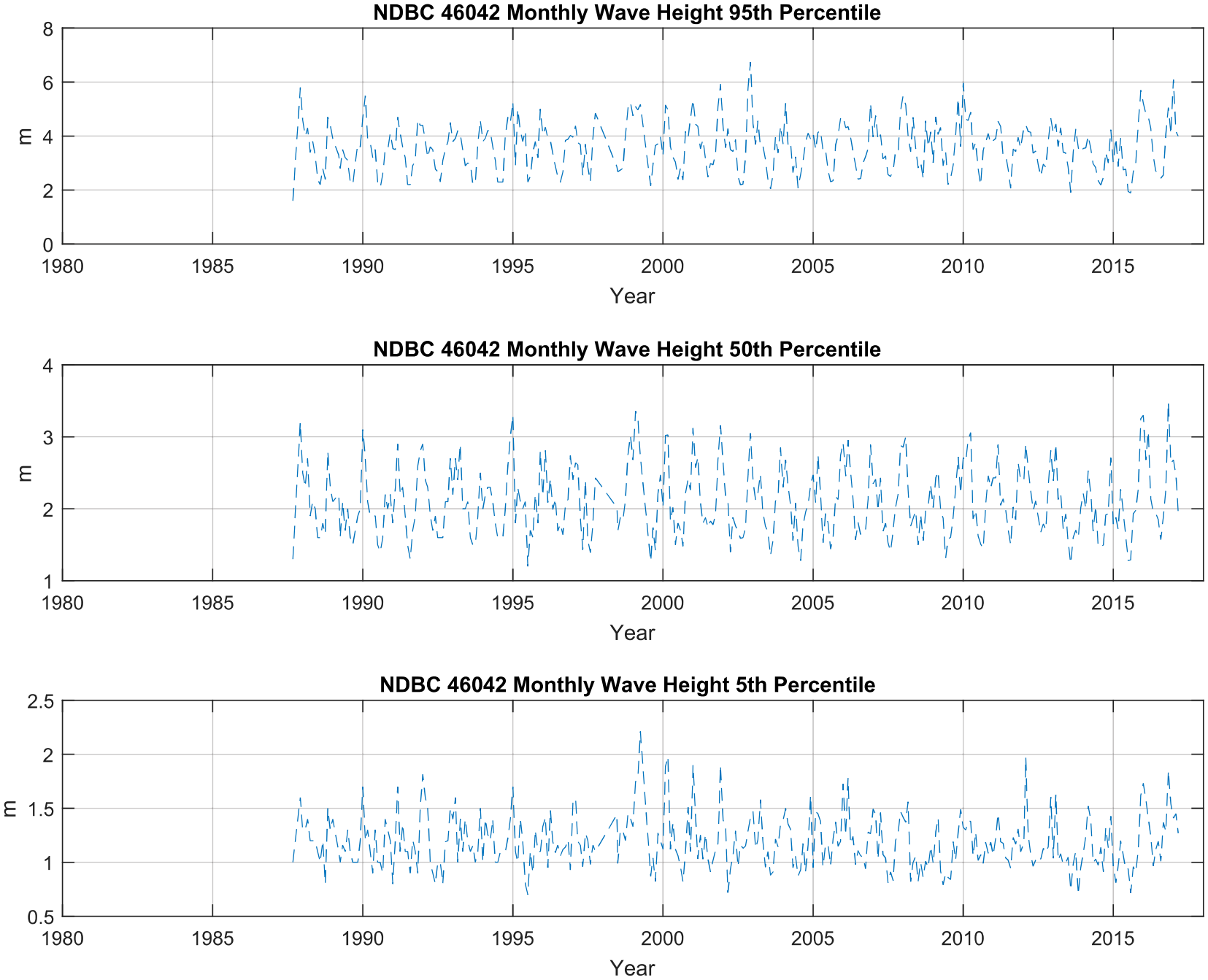


Figure A076. Monthly Wave Height, Percentiles,NDBC 46042

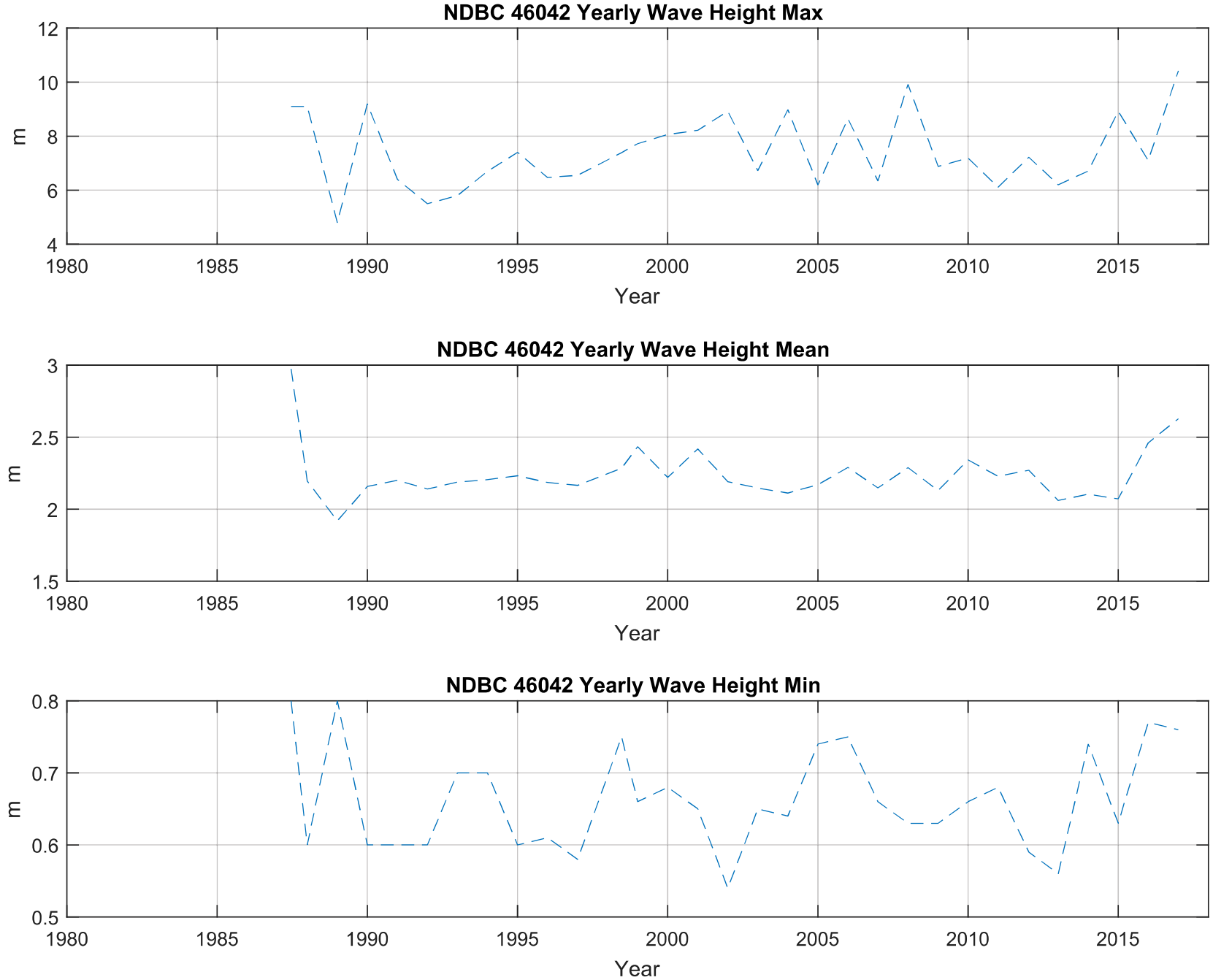


Figure A077. Yearly Wave Height, Max, Mean, Min,NDBC 46042

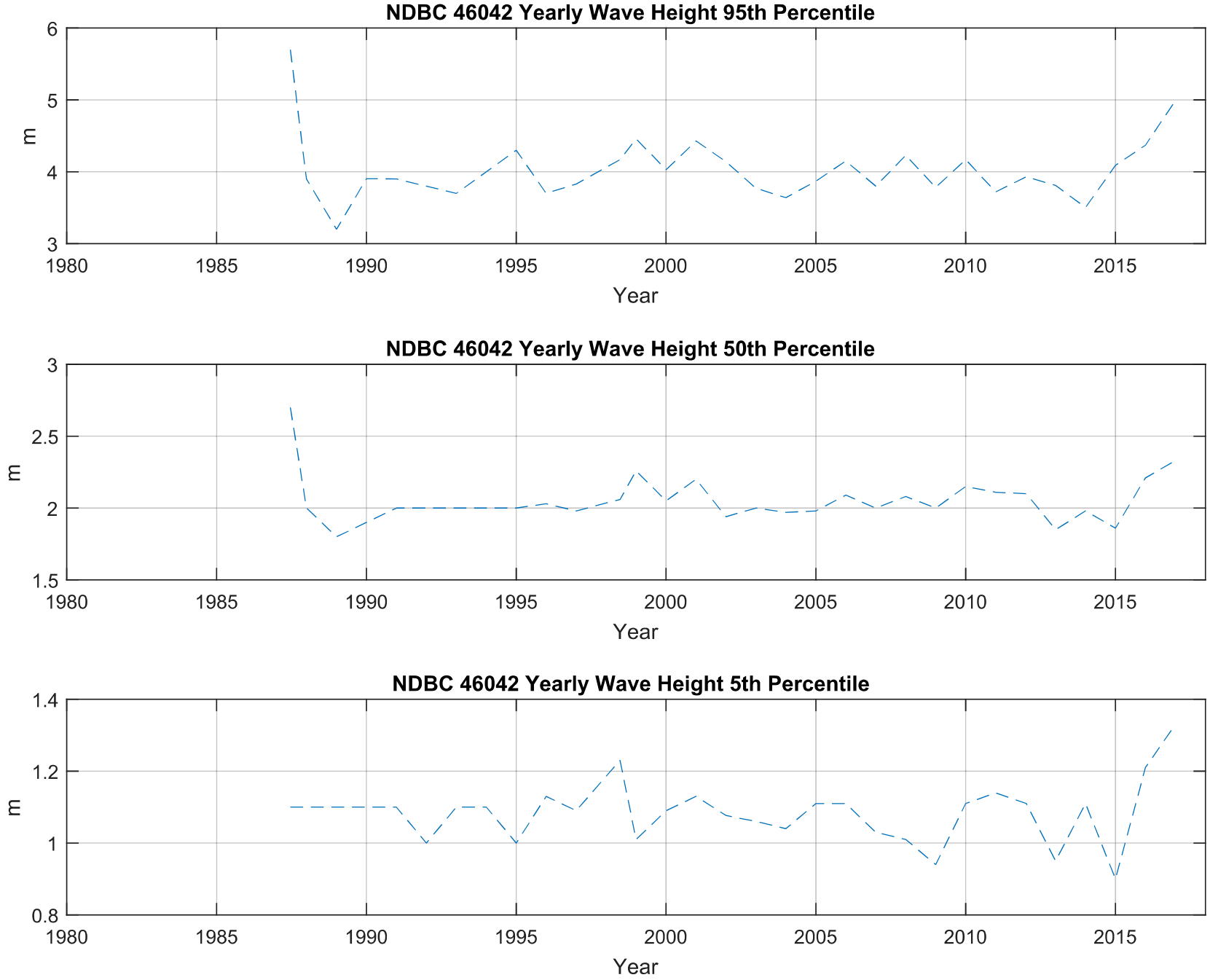


Figure A078. Yearly Wave Height, Percentiles,NDBC 46042

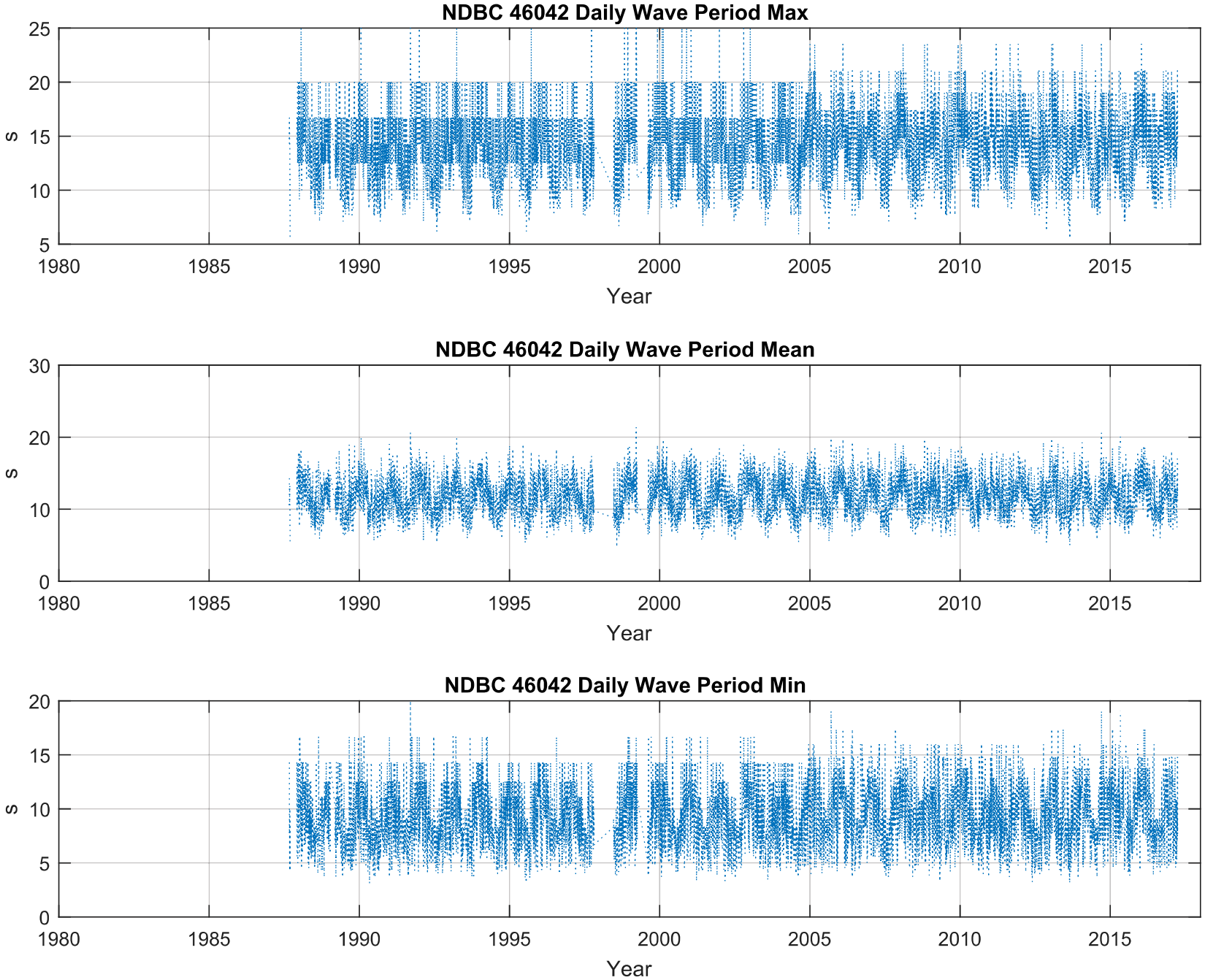
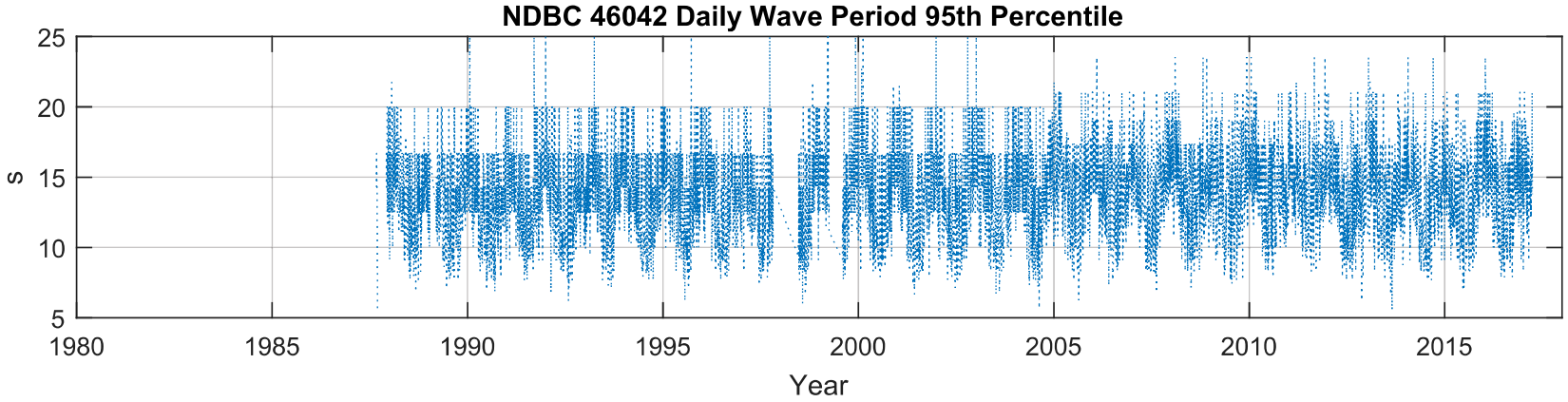
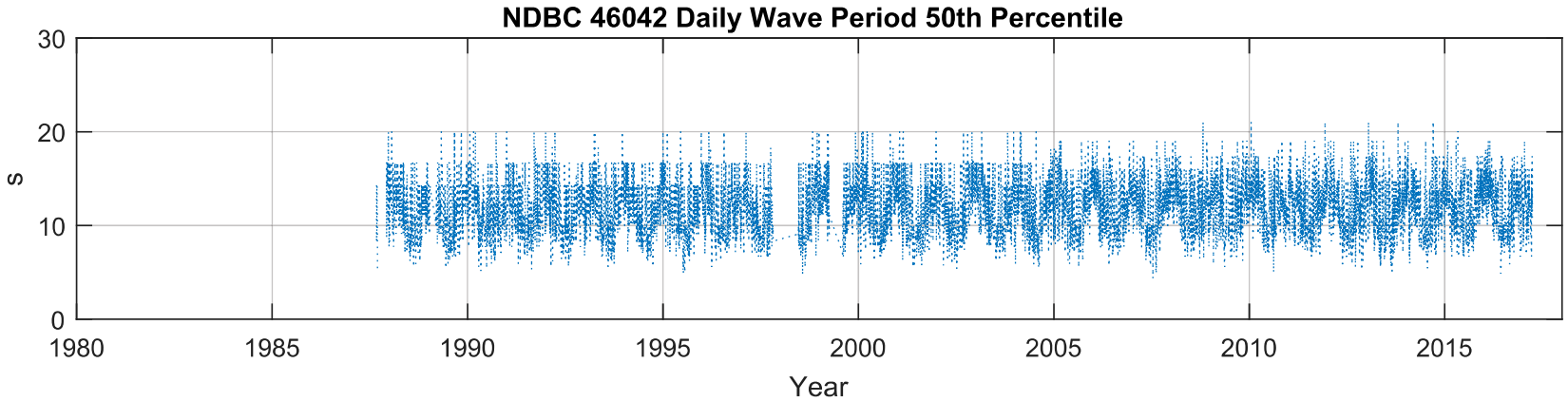


Figure A079. Daily Wave Period, Max, Mean, Min,NDBC 46042





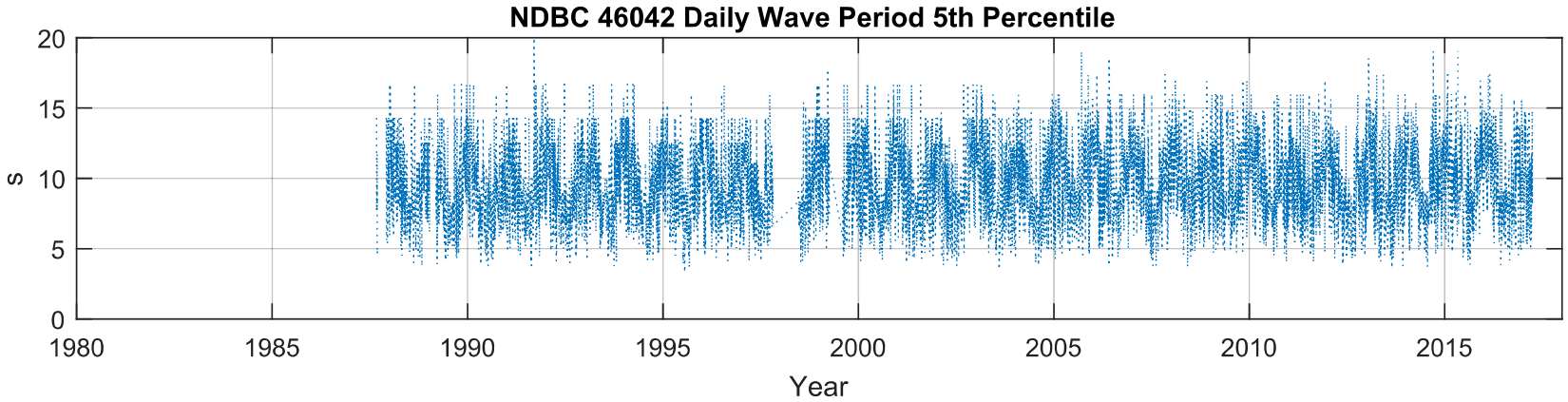
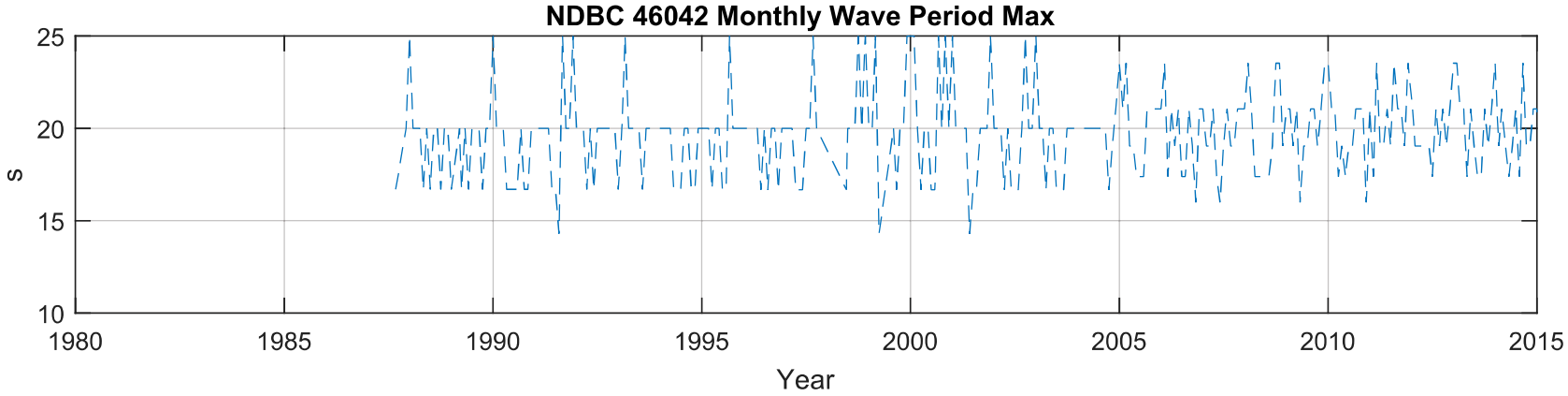
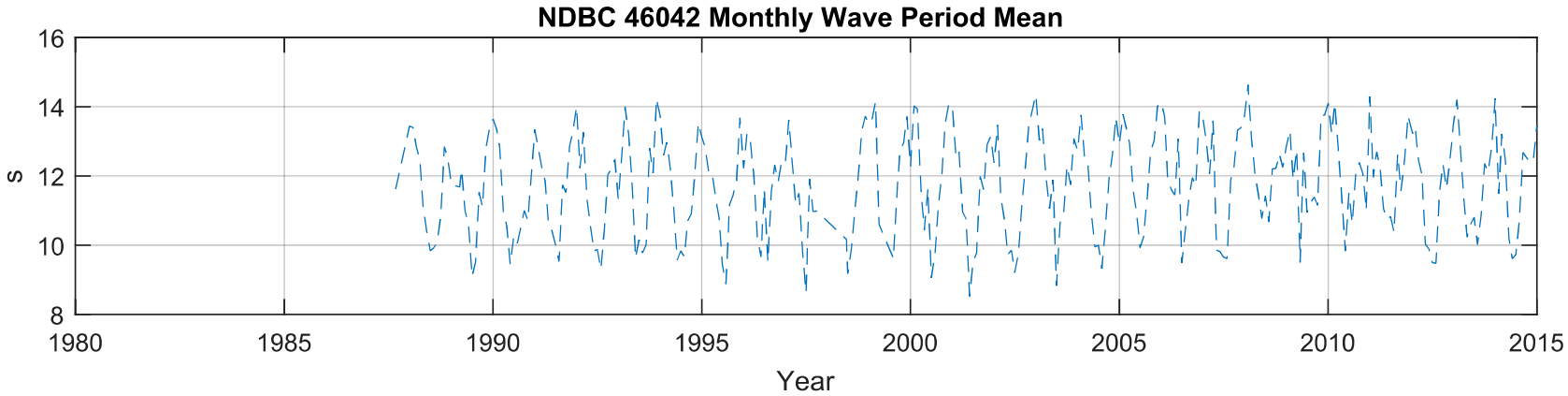


Figure A080. Daily Wave Period, Percentiles,NDBC 46042





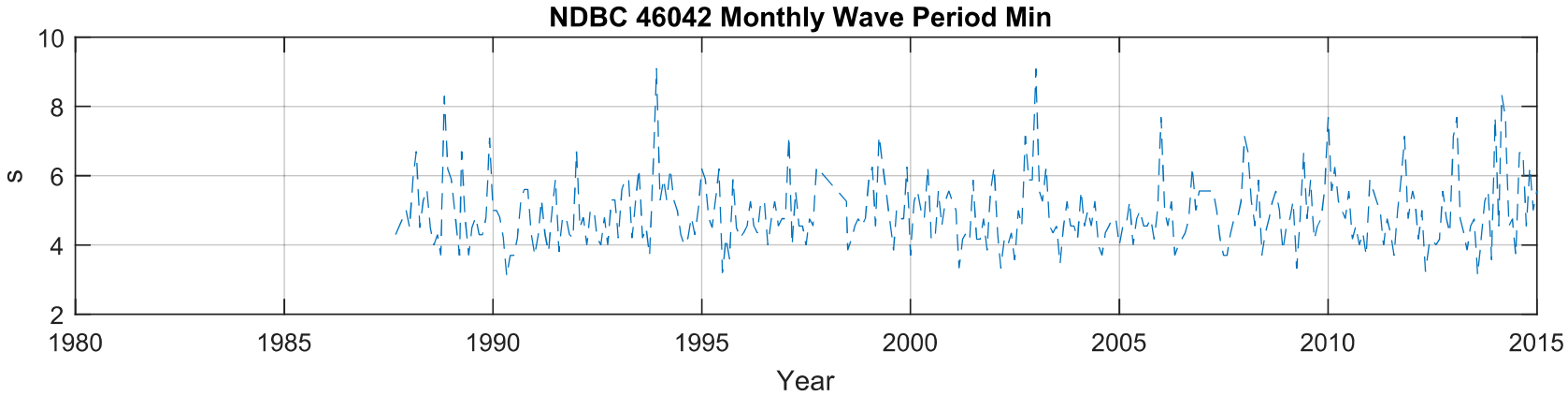
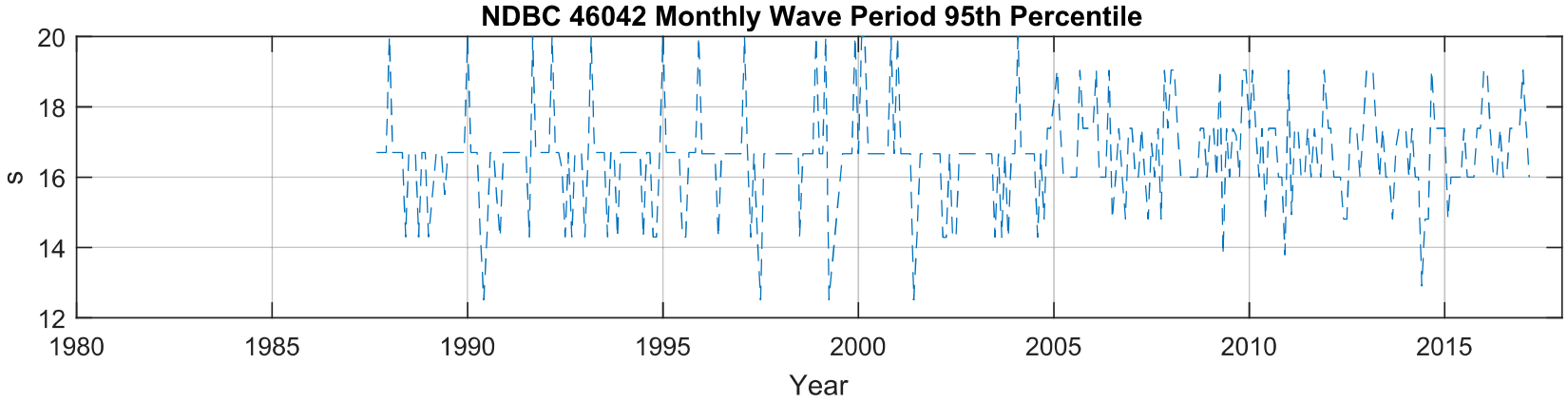
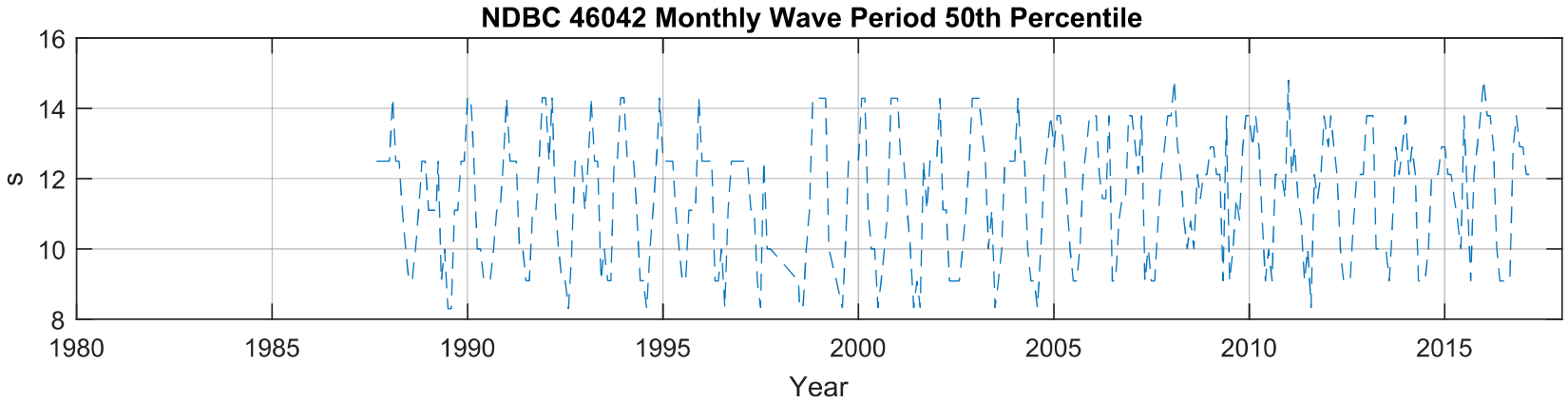


Figure A081. Monthly Wave Period, Max, Mean, Min,NDBC 46042





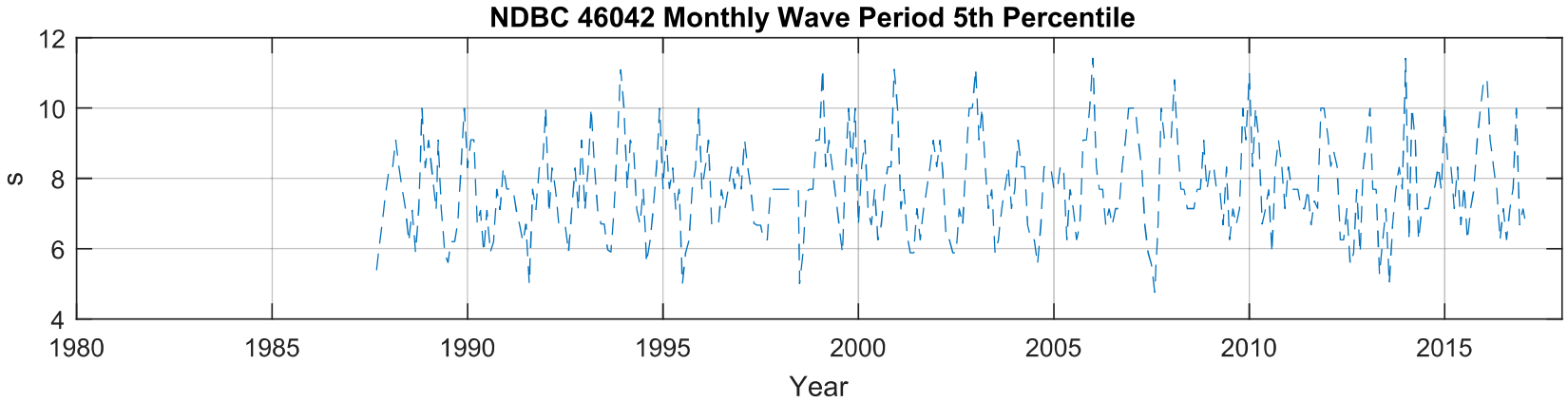


Figure A082. Monthly Wave Period, Percentiles,NDBC 46042

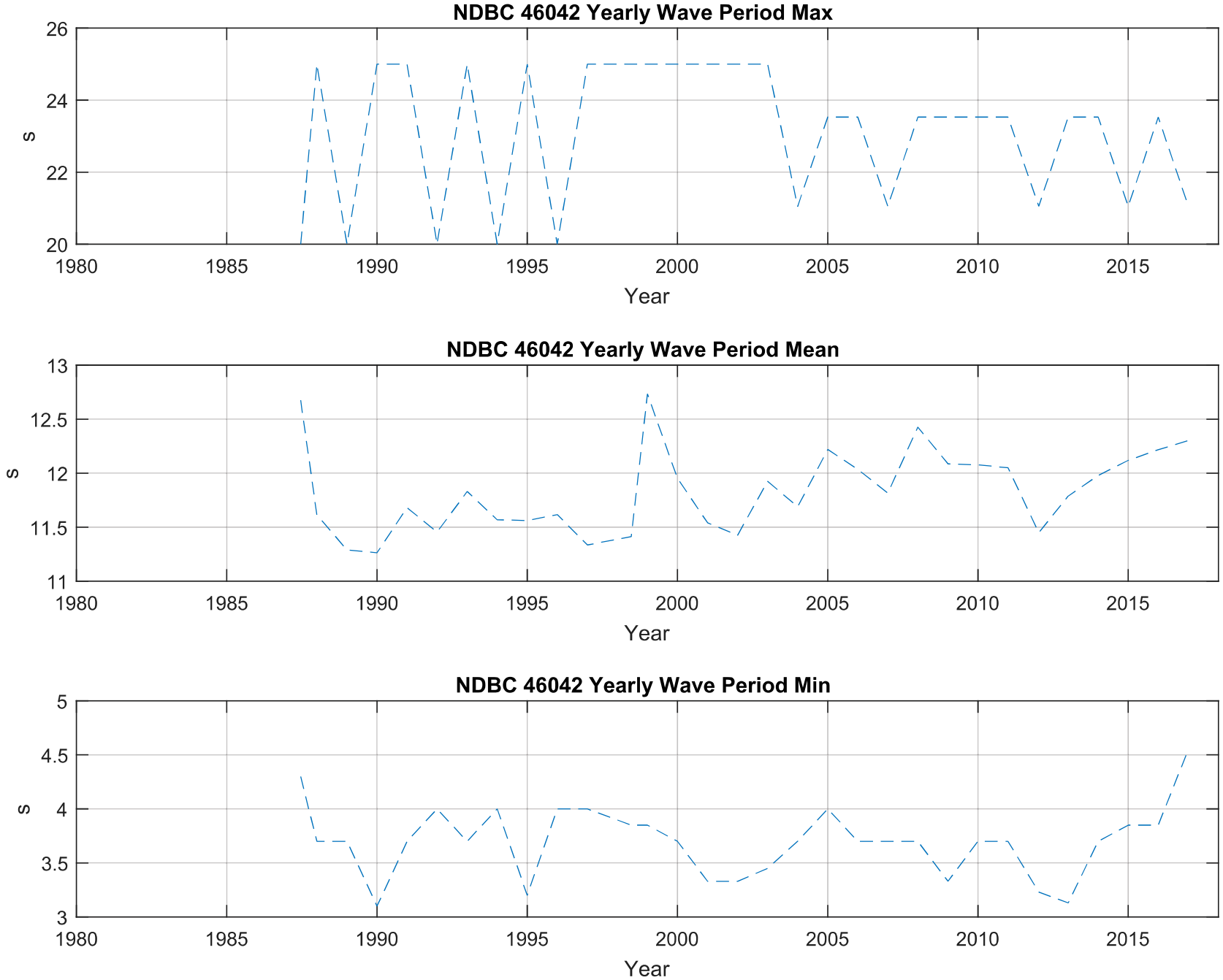
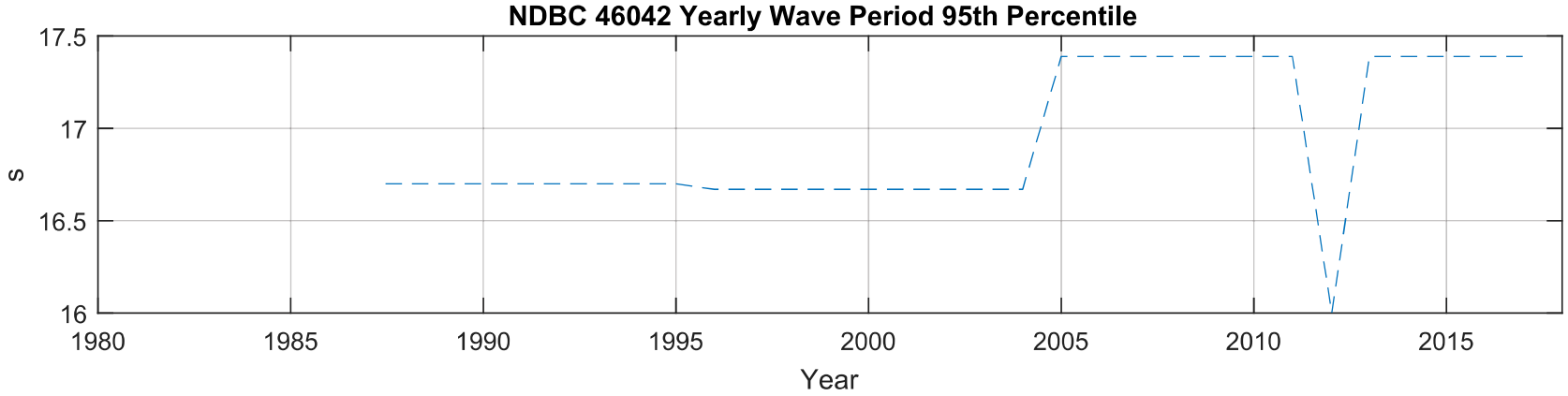
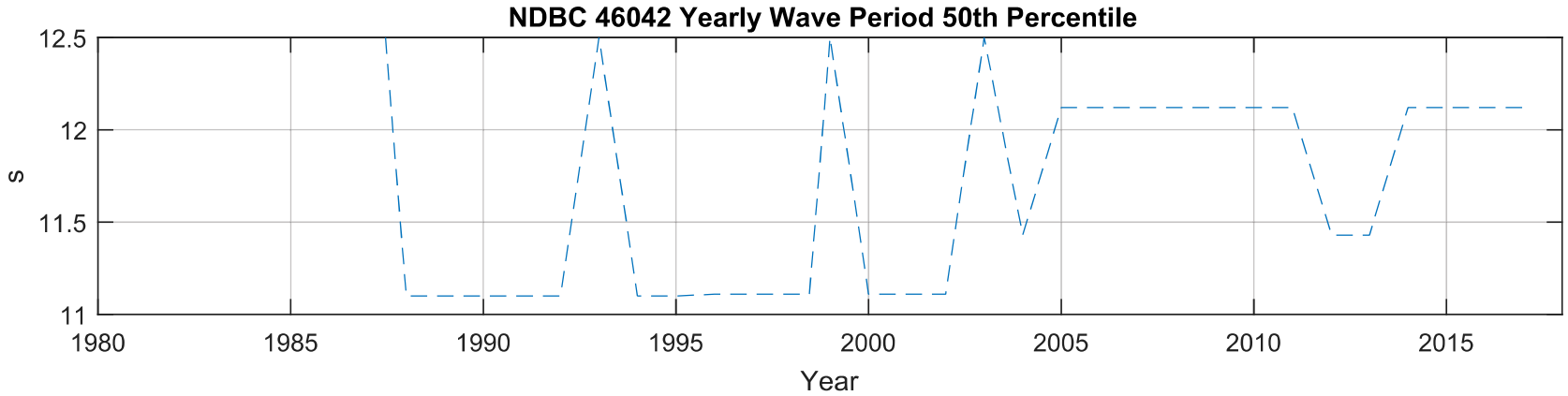


Figure A083. Yearly Wave Period, Max, Mean, Min,NDBC 46042





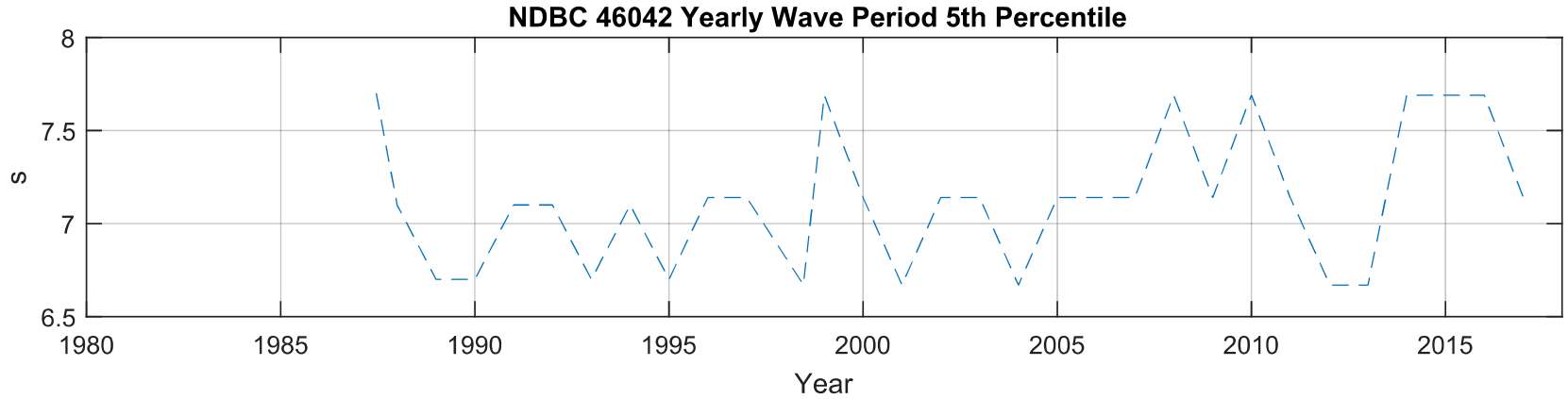
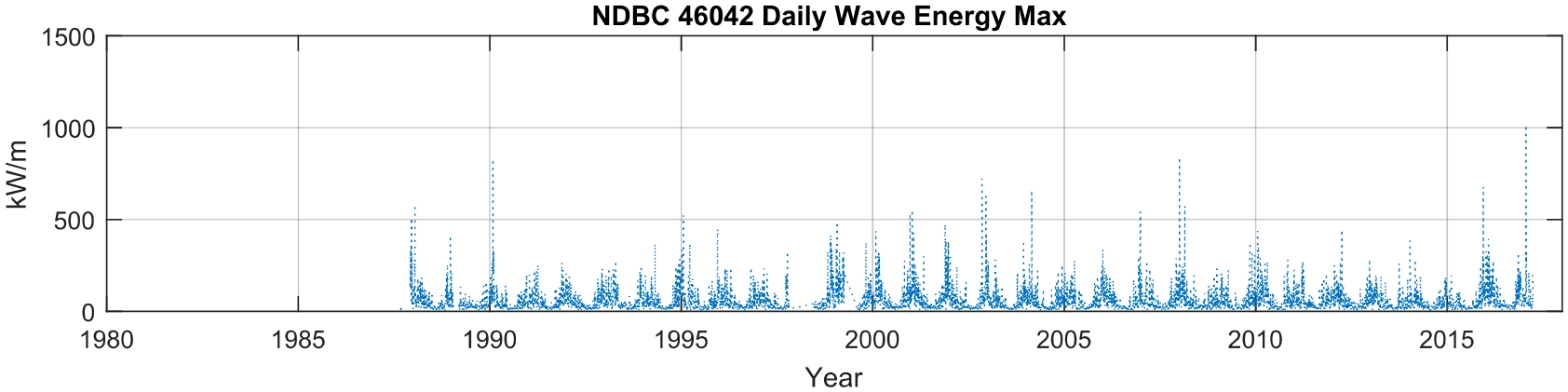
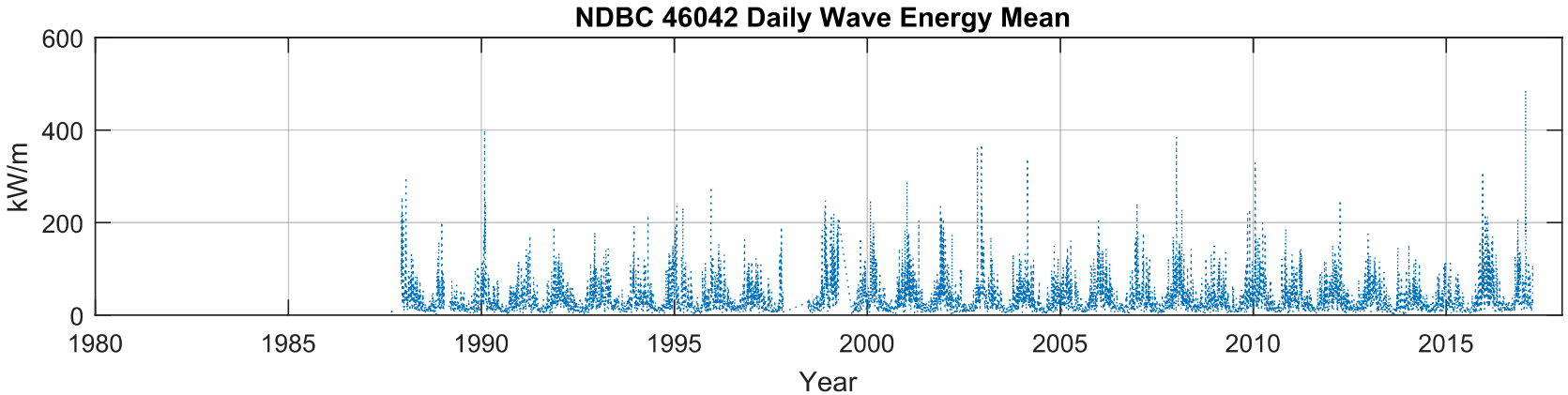


Figure A084. Yearly Wave Period, Percentiles,NDBC 46042





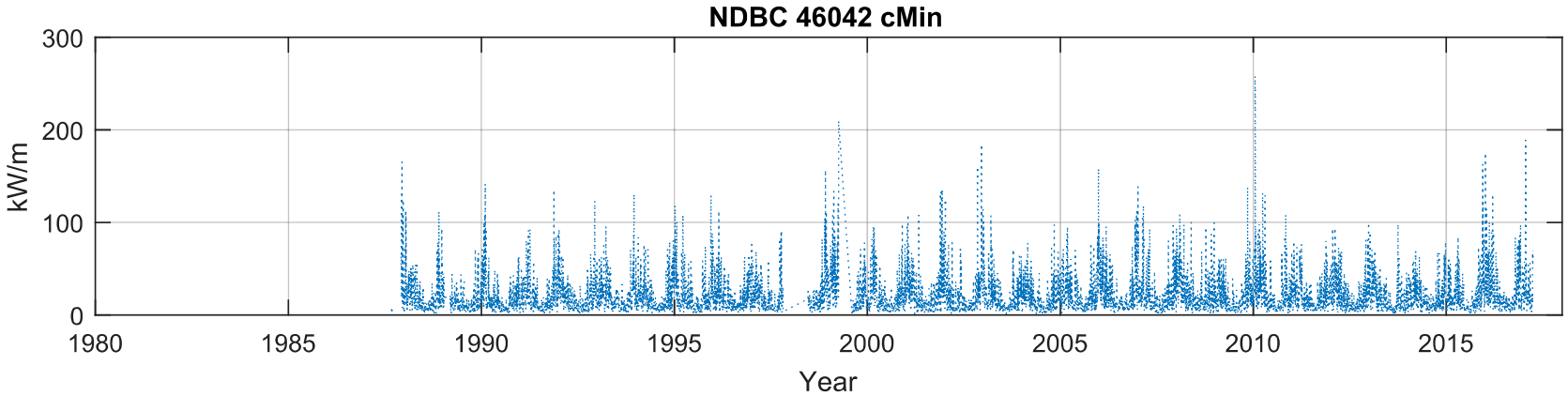
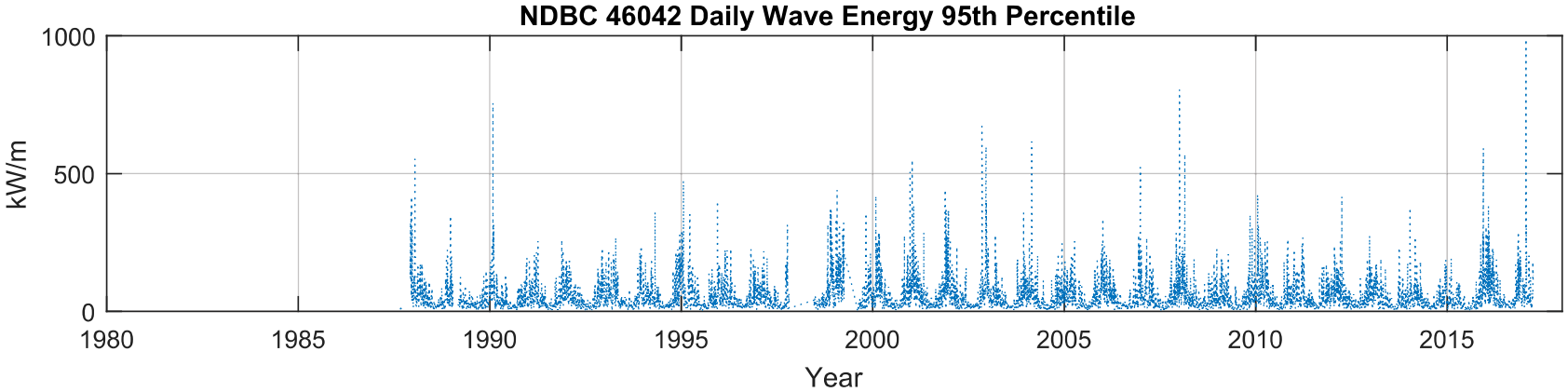
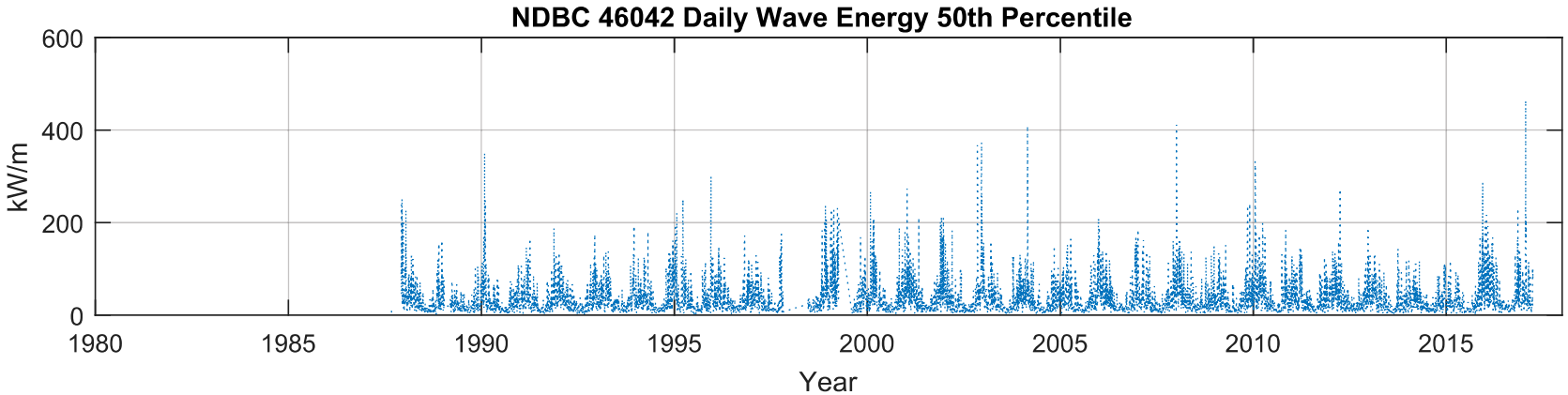


Figure A085. Daily Wave Energy, Max, Mean, Min,NDBC 46042





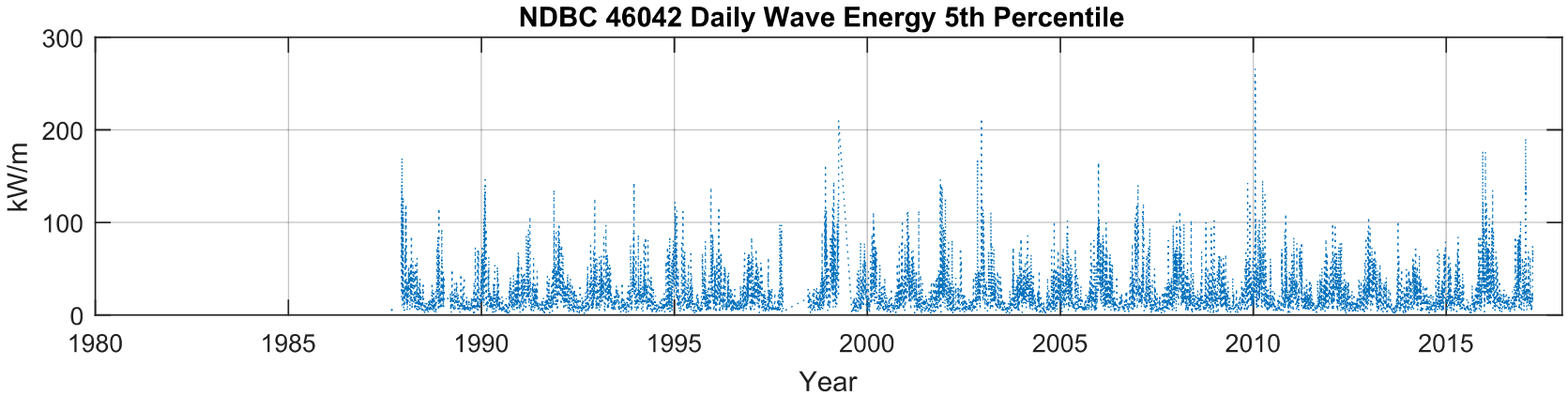


Figure A086. Daily Wave Energy, Percentiles,NDBC 46042

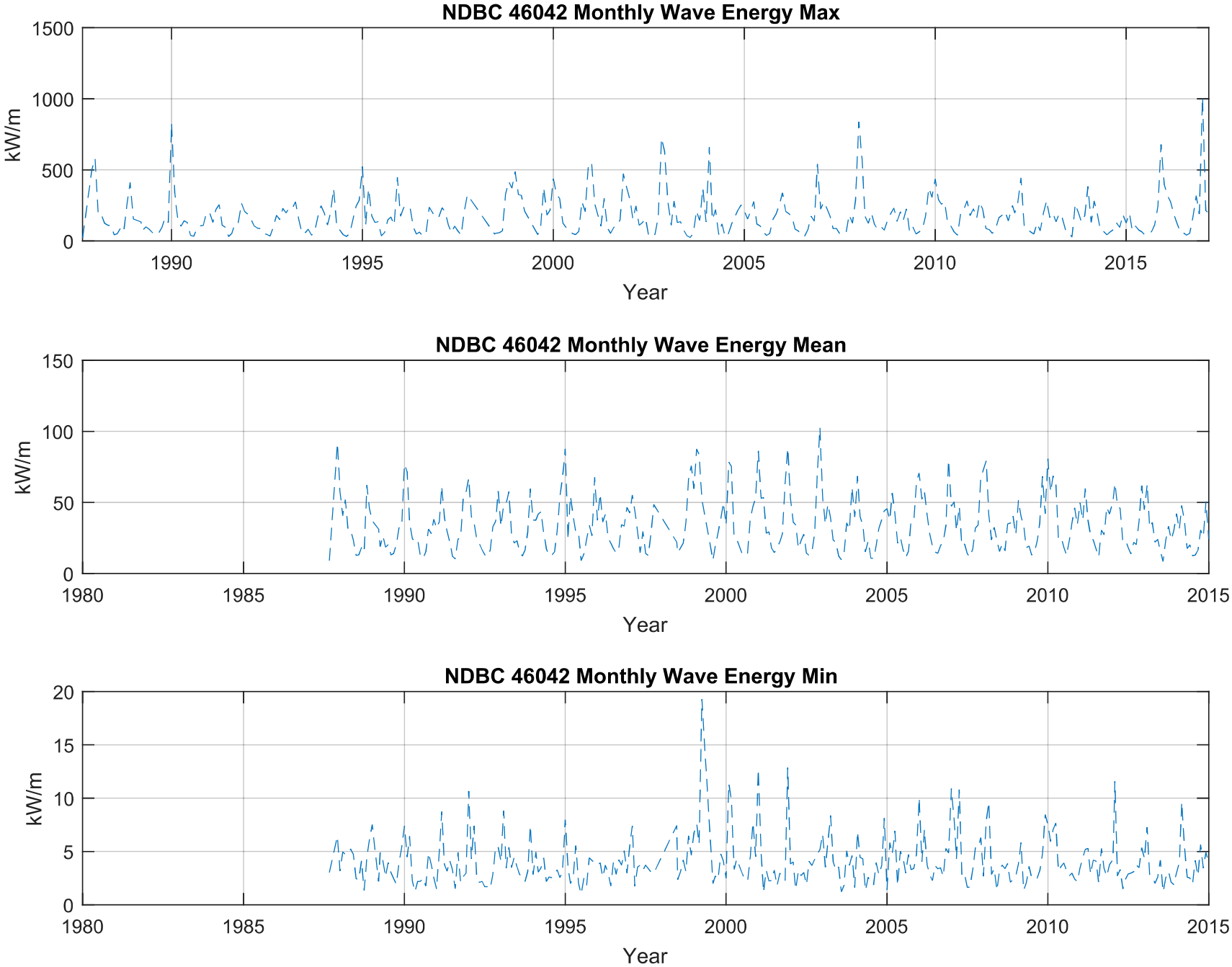
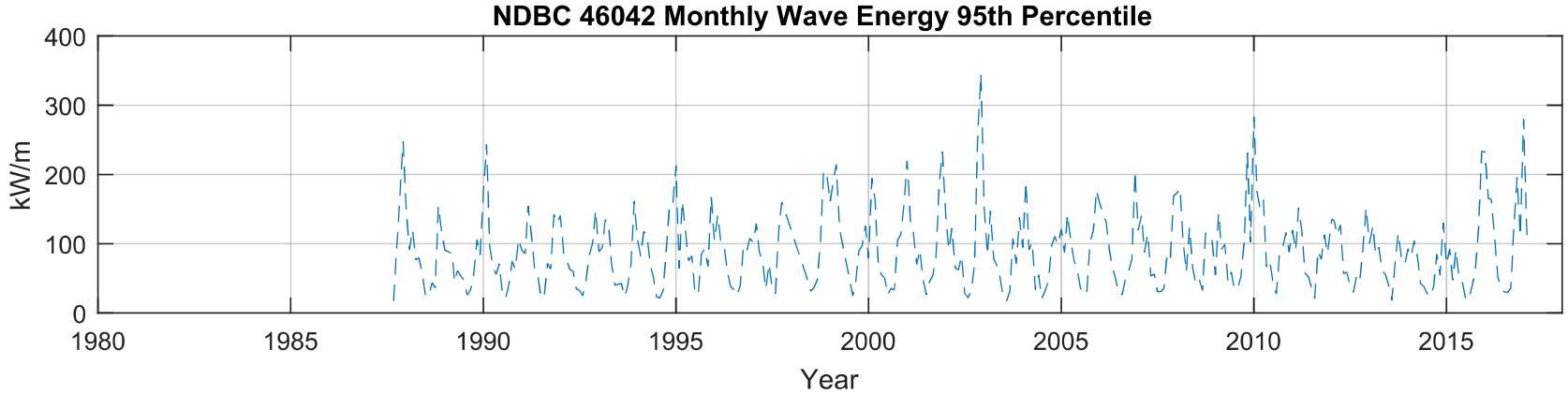
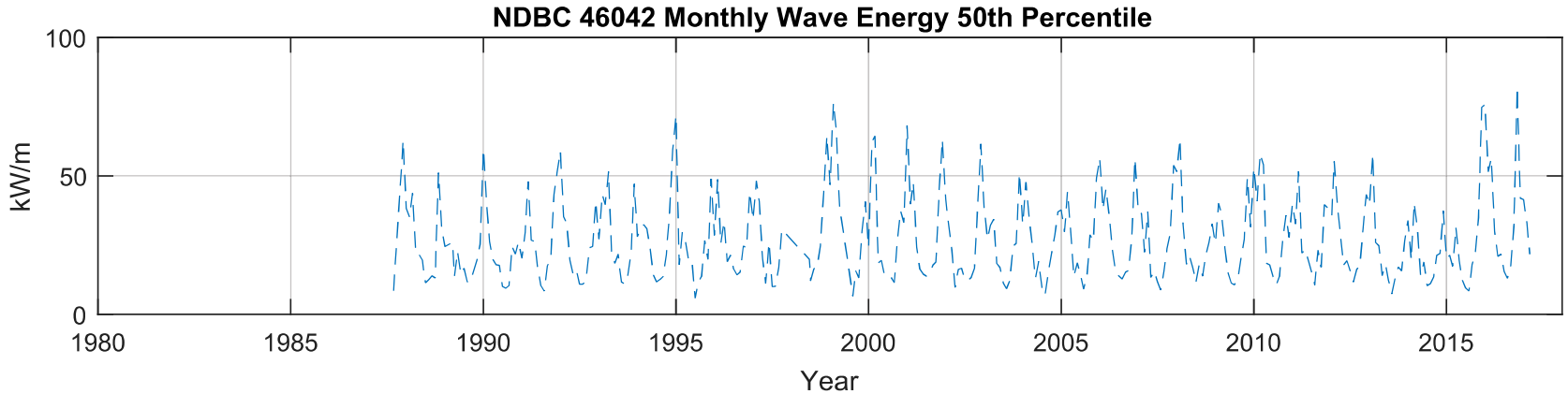


Figure A087. Monthly Wave Energy, Max, Mean, Min,NDBC 46042





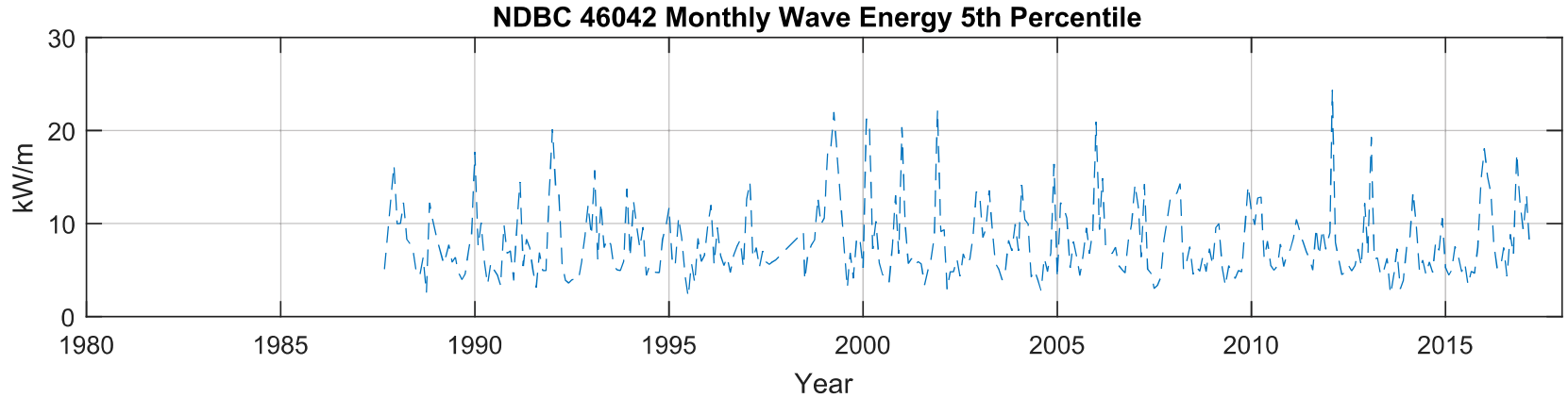


Figure A088. Monthly Wave Energy, Percentiles,NDBC 46042

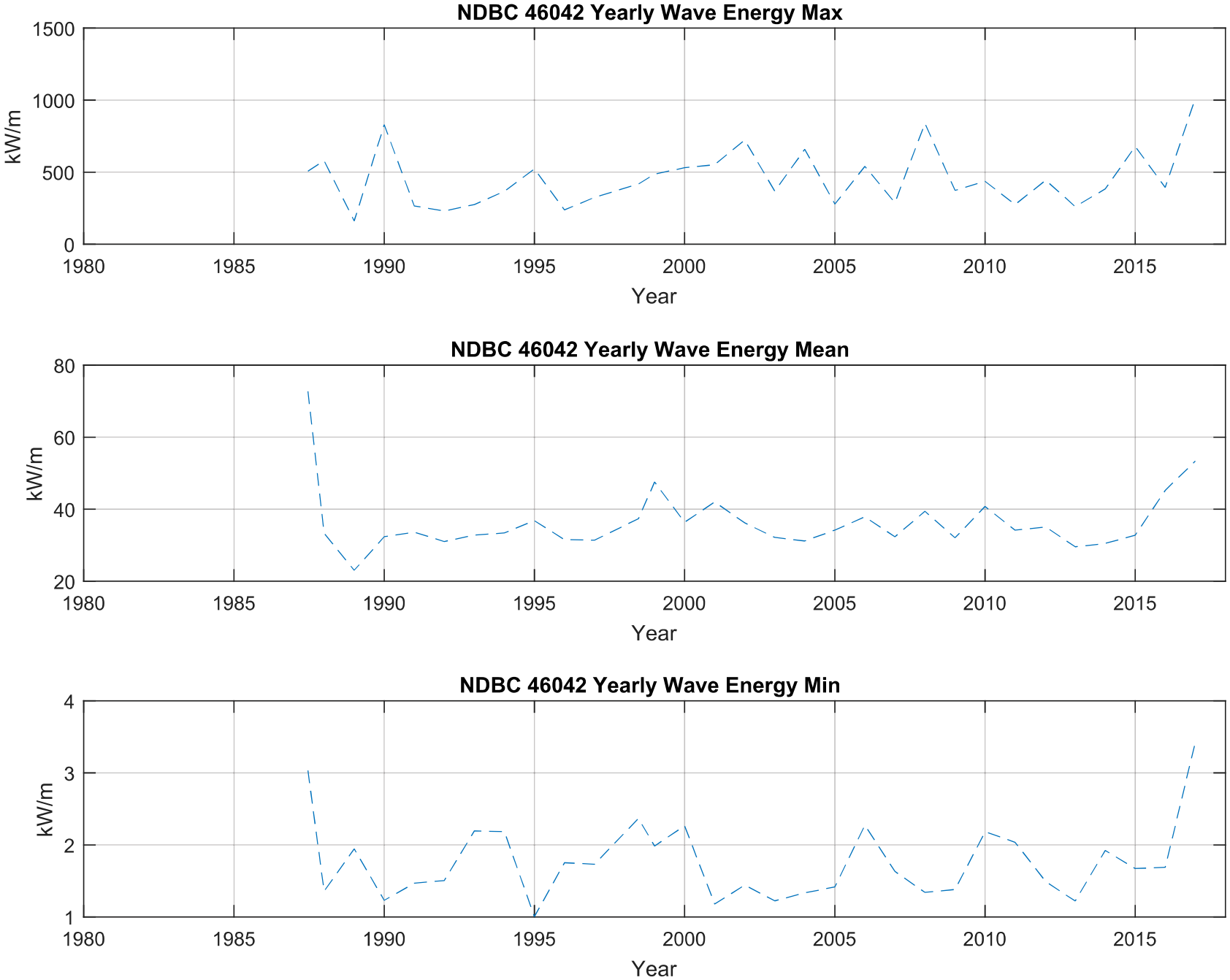
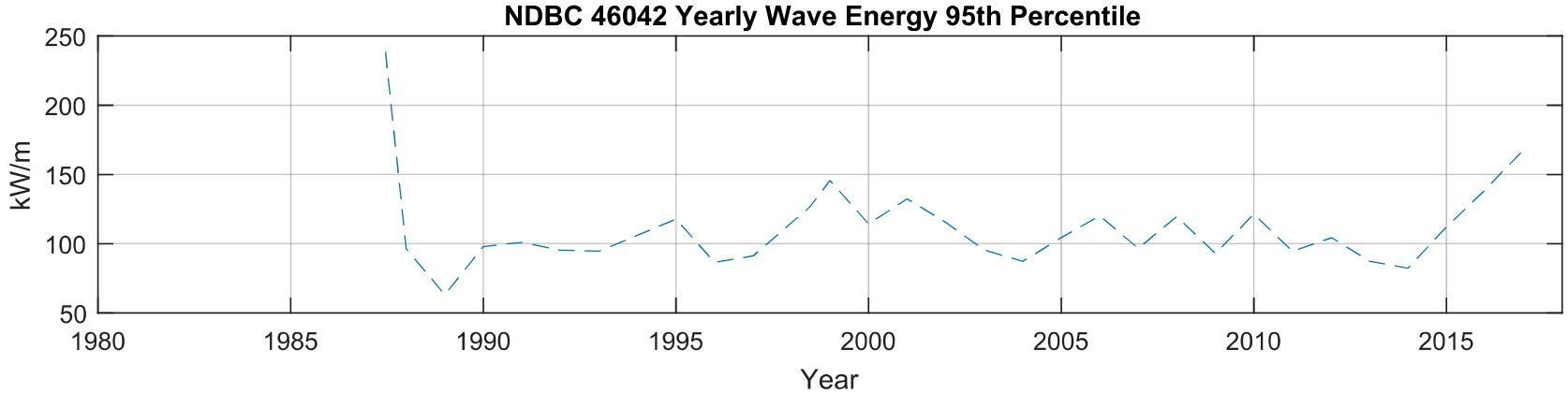
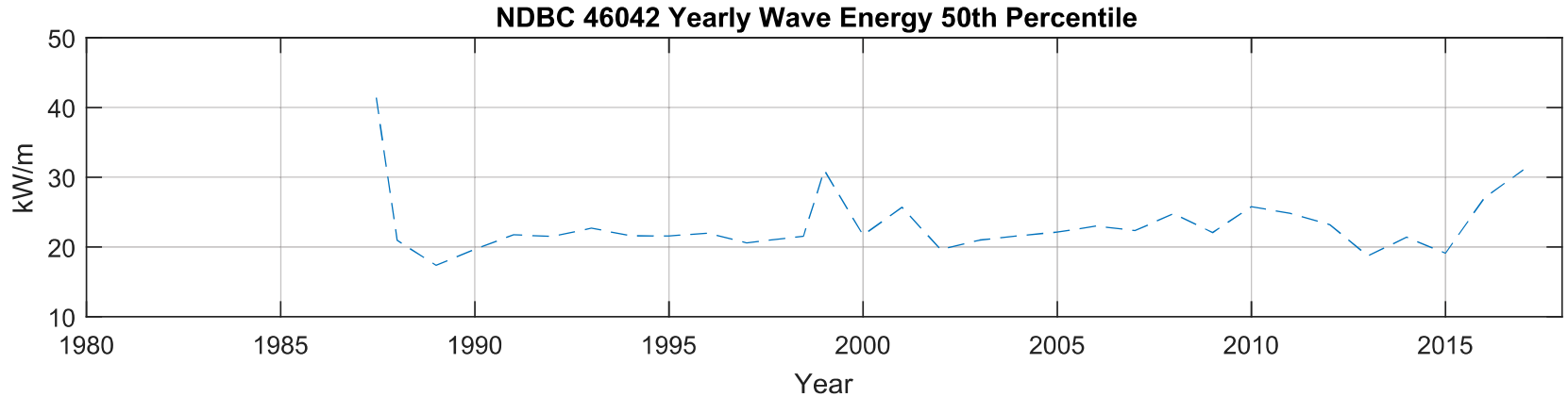


Figure A089. Yearly Wave Energy, Max, Mean, Min,NDBC 46042





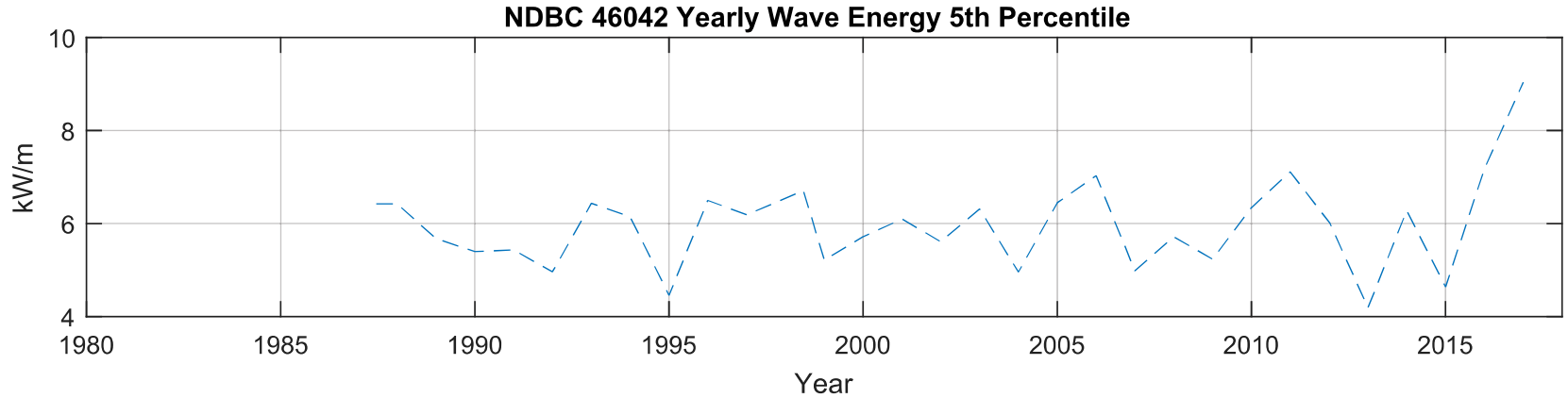


Figure A090. Yearly Wave Energy, Percentiles,NDBC 46042

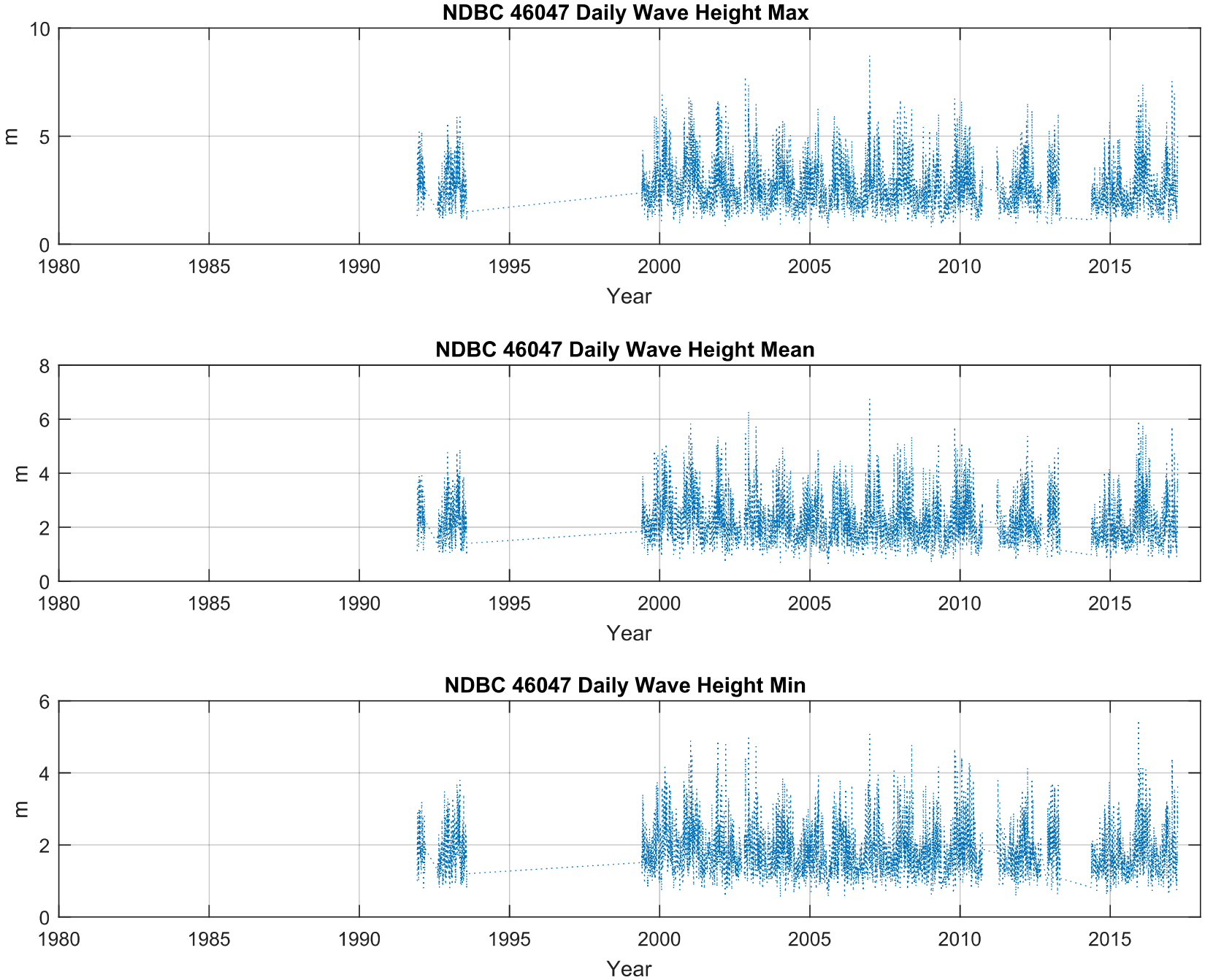
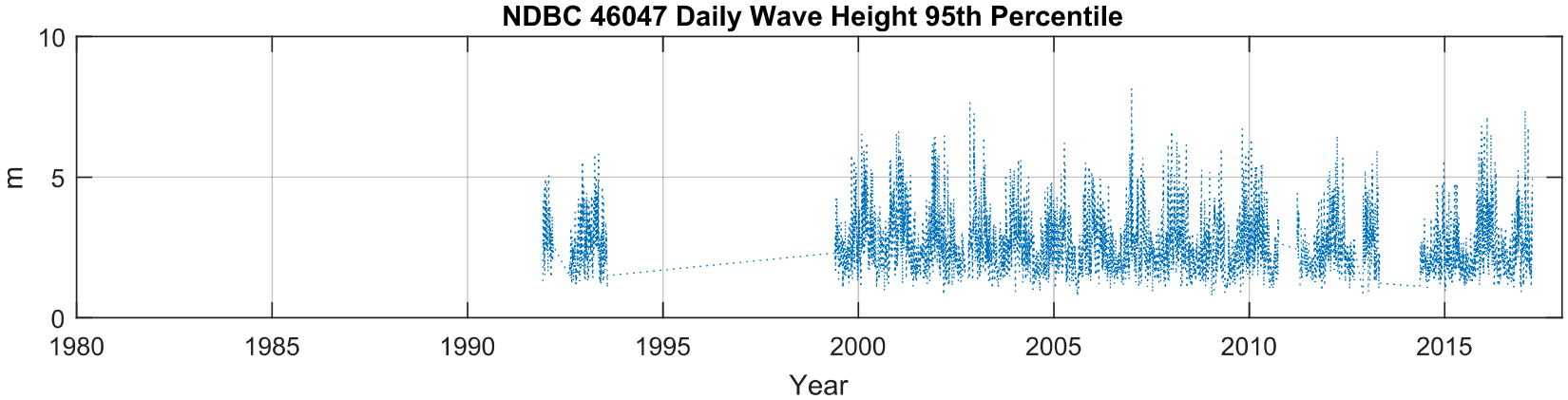
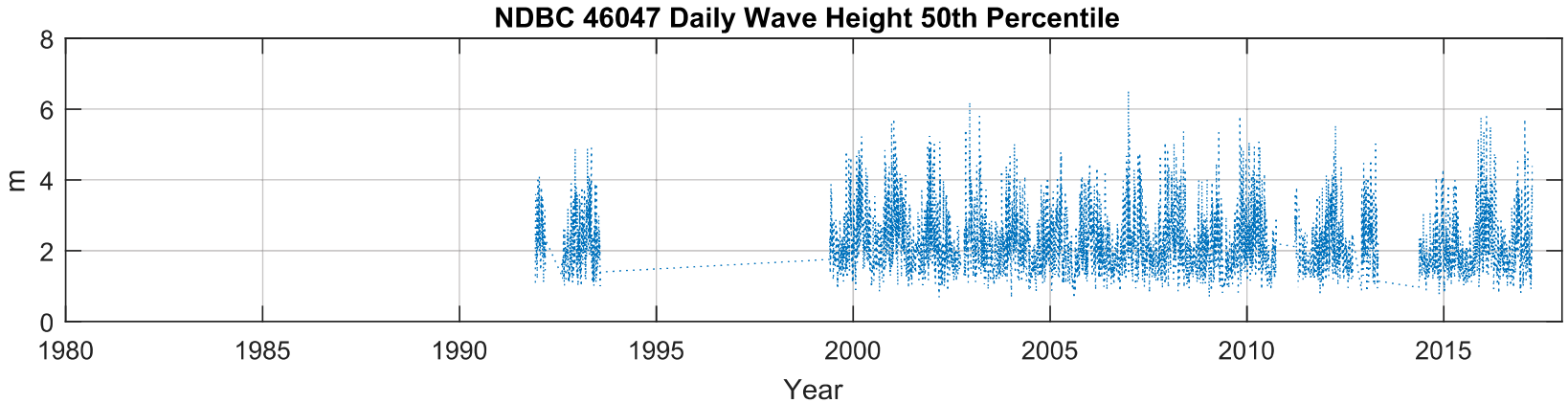


Figure A091. Daily Wave Height, Max, Mean, Min,NDBC 46047





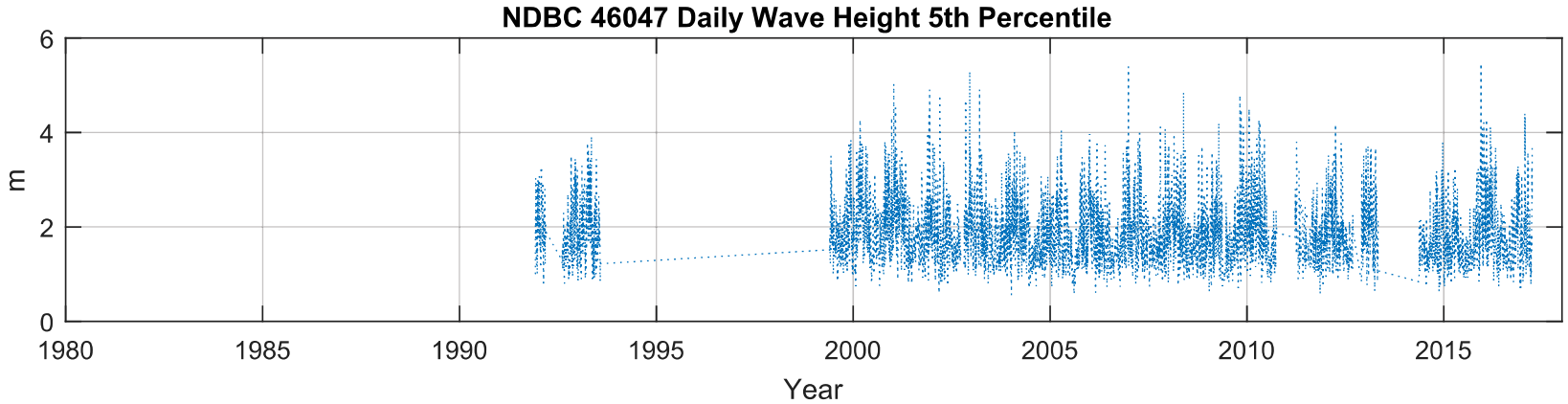


Figure A092. Daily Wave Height, Percentiles,NDBC 46047

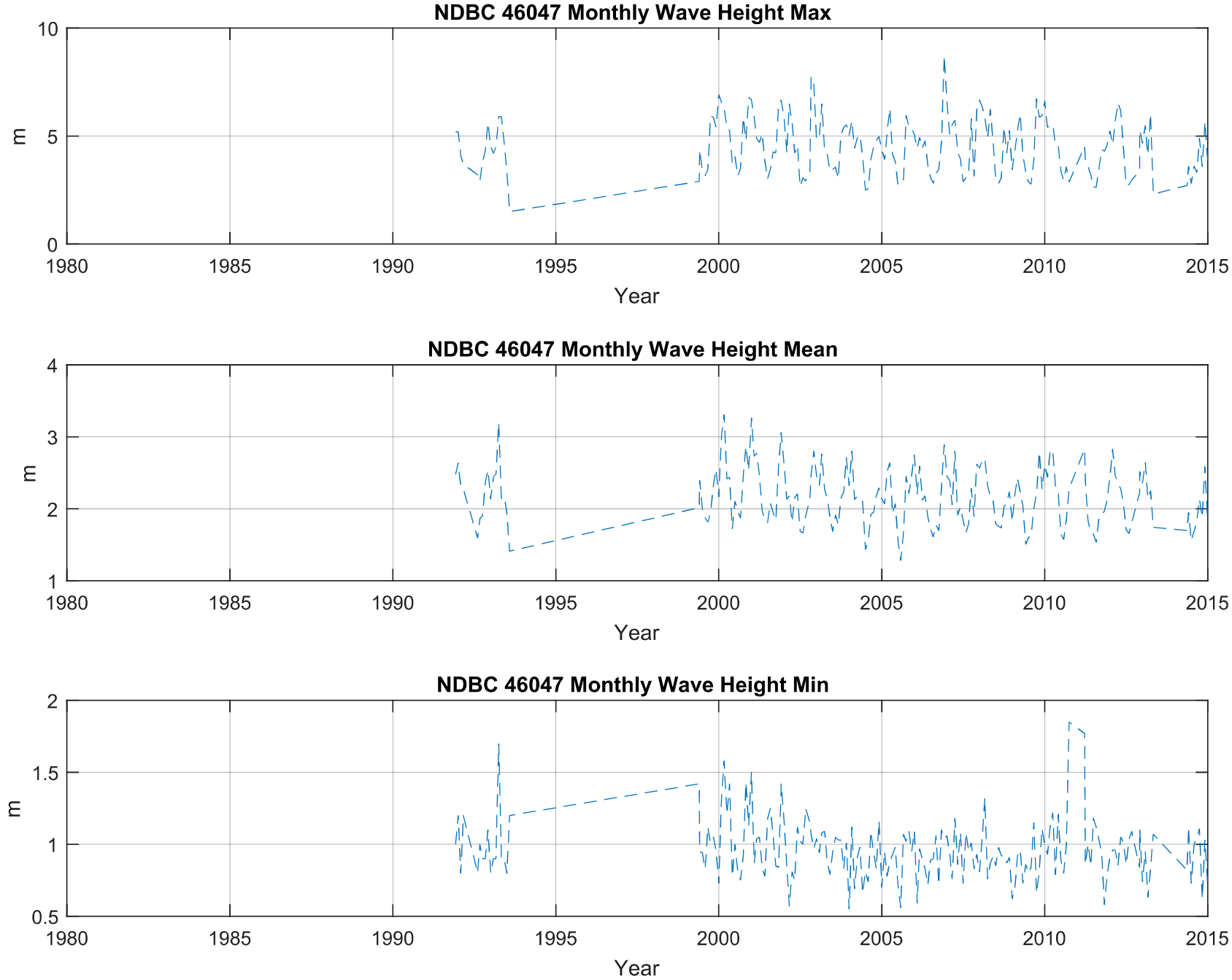


Figure A093. Monthly Wave Height, Max, Mean, Min,NDBC 46047

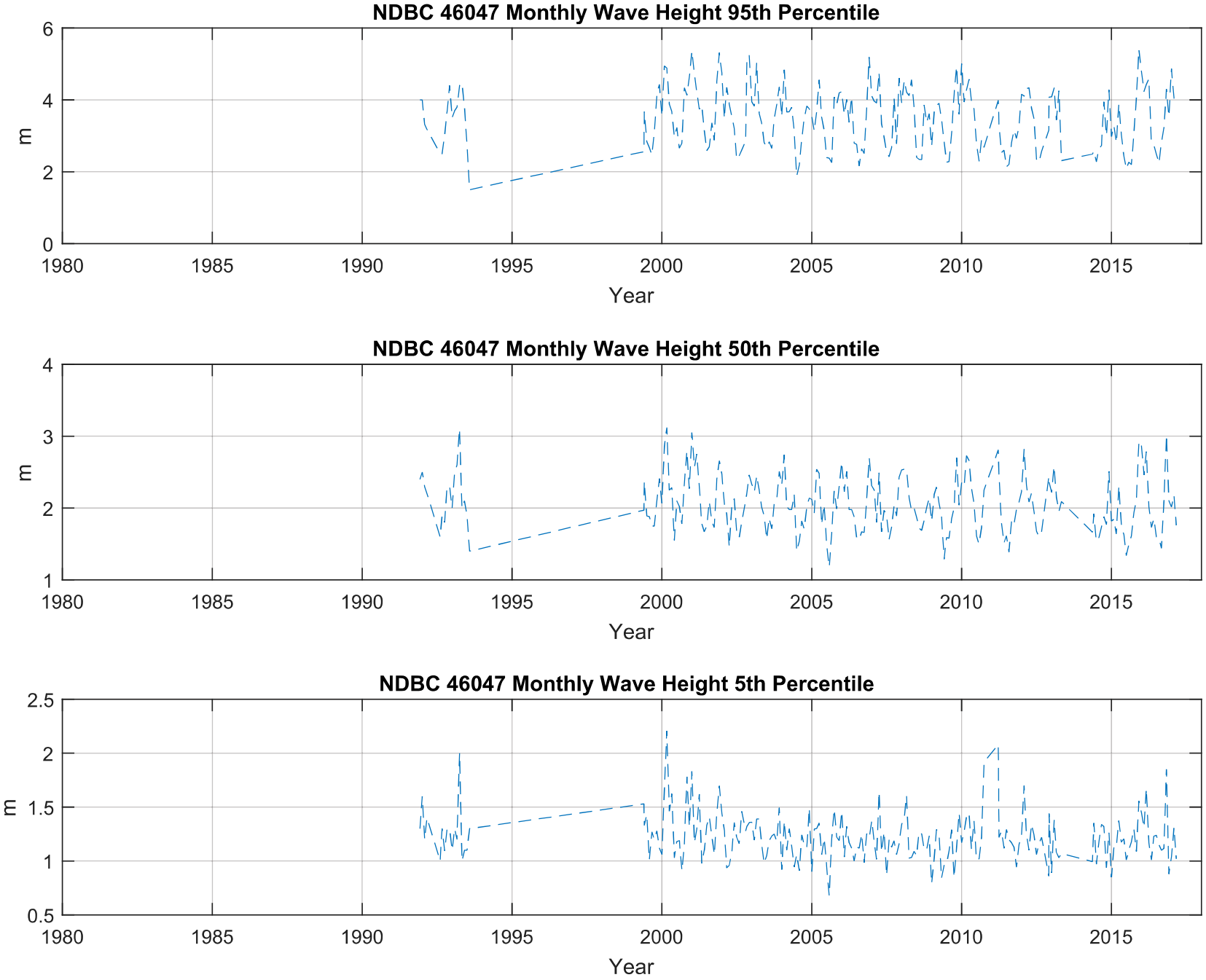


Figure A094. Monthly Wave Height, Percentiles,NDBC 46047

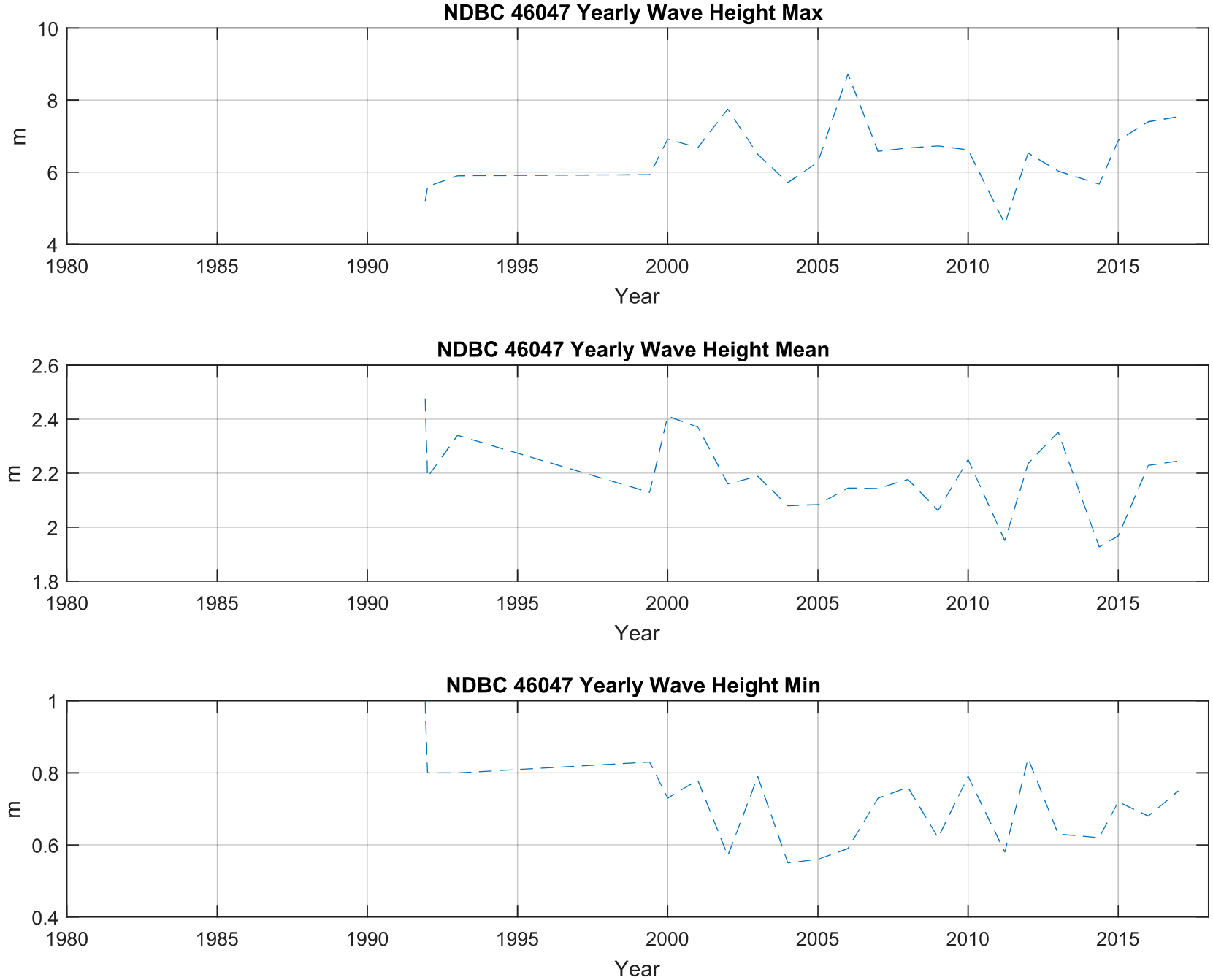
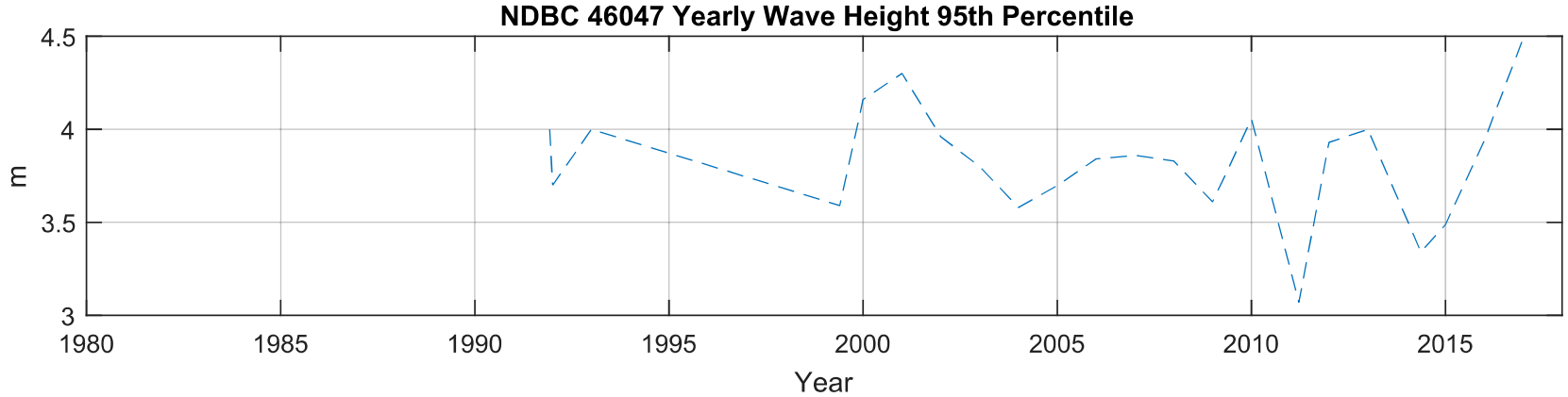
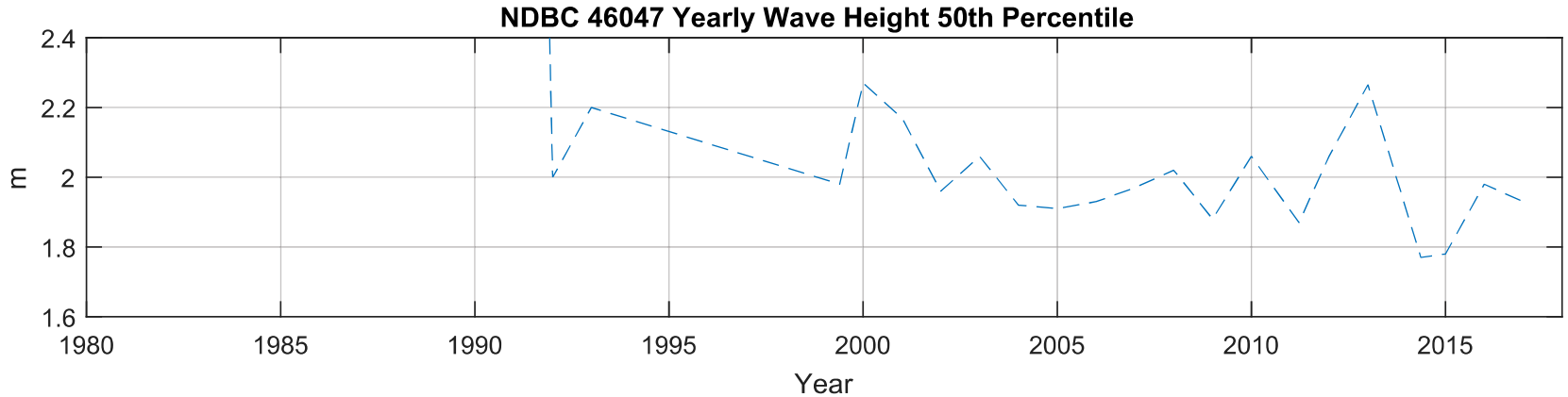


Figure A095. Yearly Wave Height, Max, Mean, Min,NDBC 46047





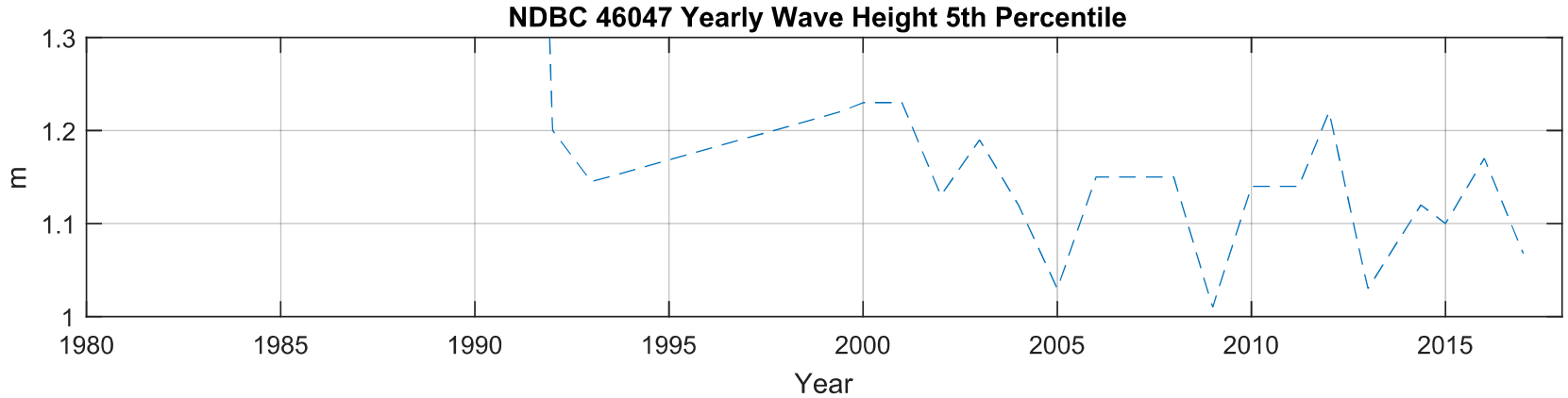
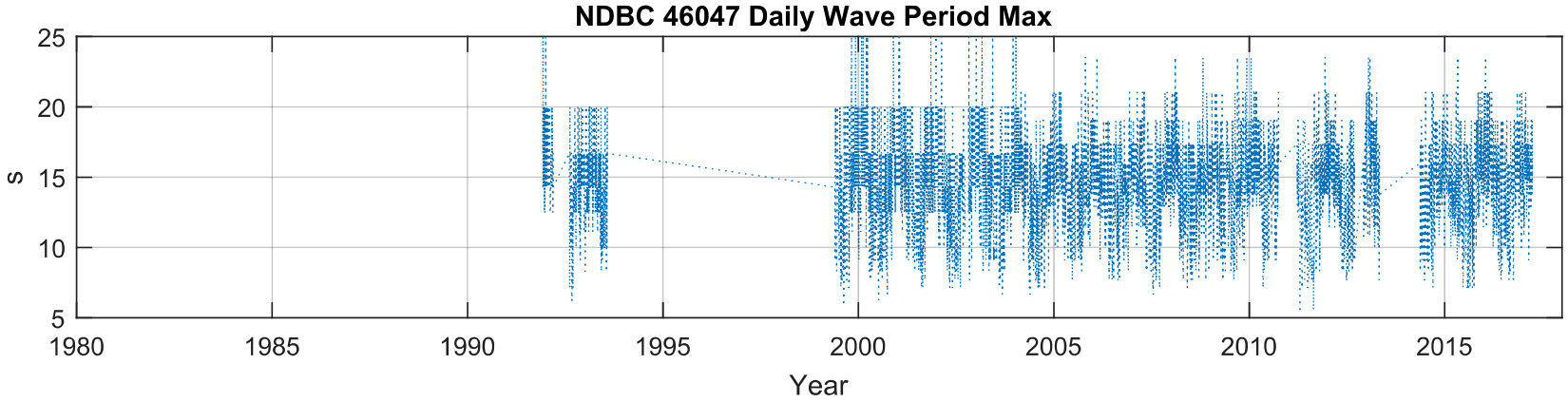
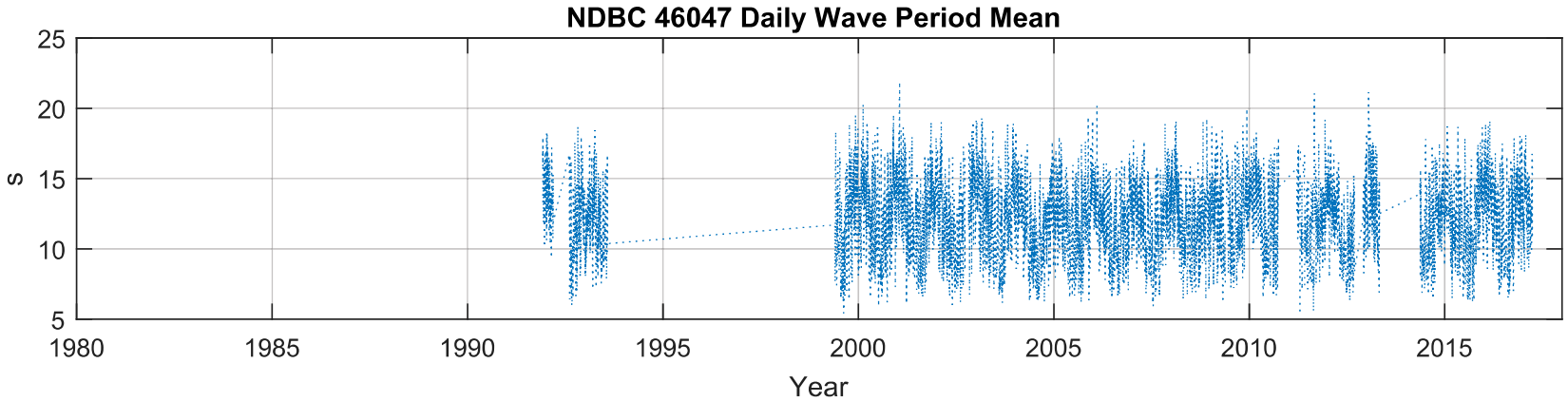


Figure A096. Yearly Wave Height, Percentiles,NDBC 46047





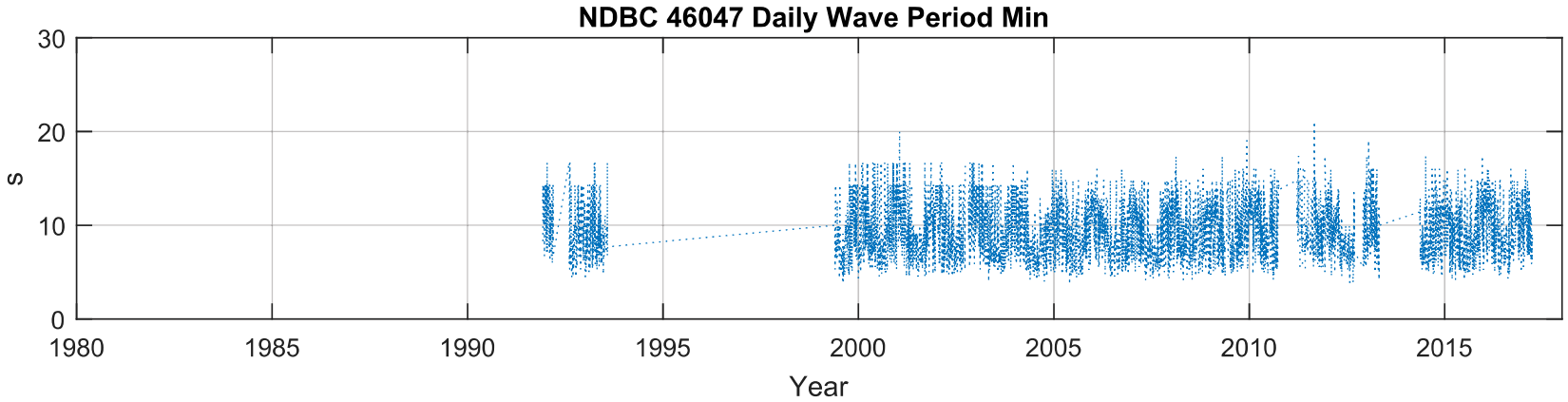
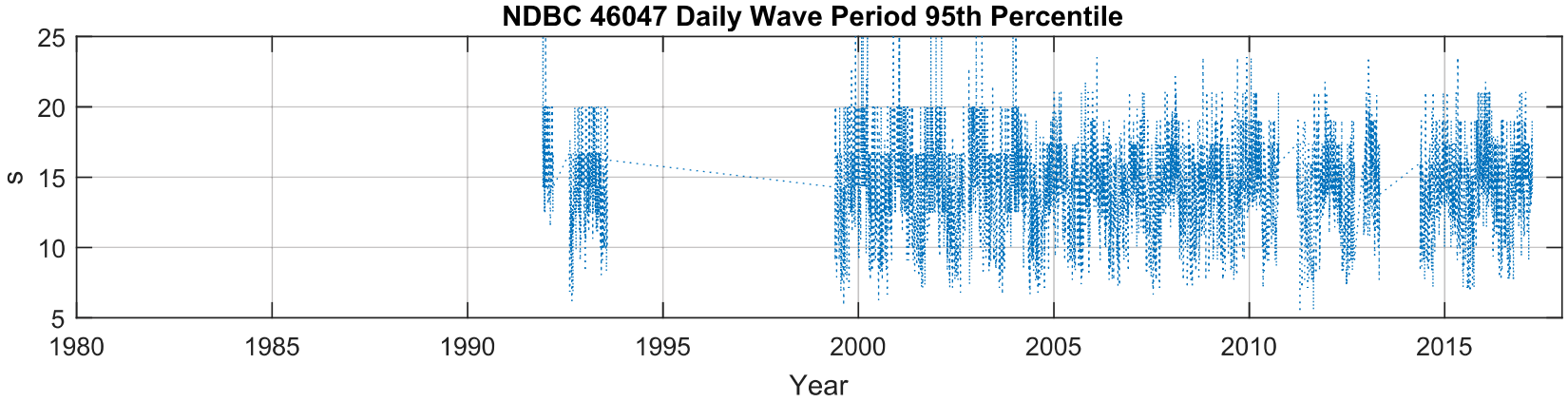
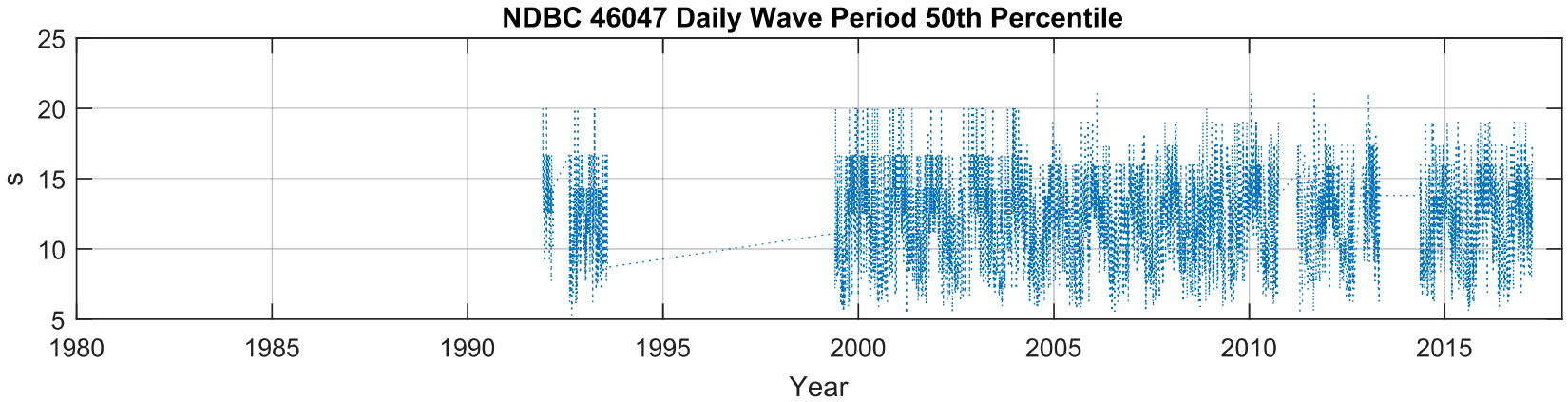


Figure A097. Daily Wave Period, Max, Mean, Min,NDBC 46047





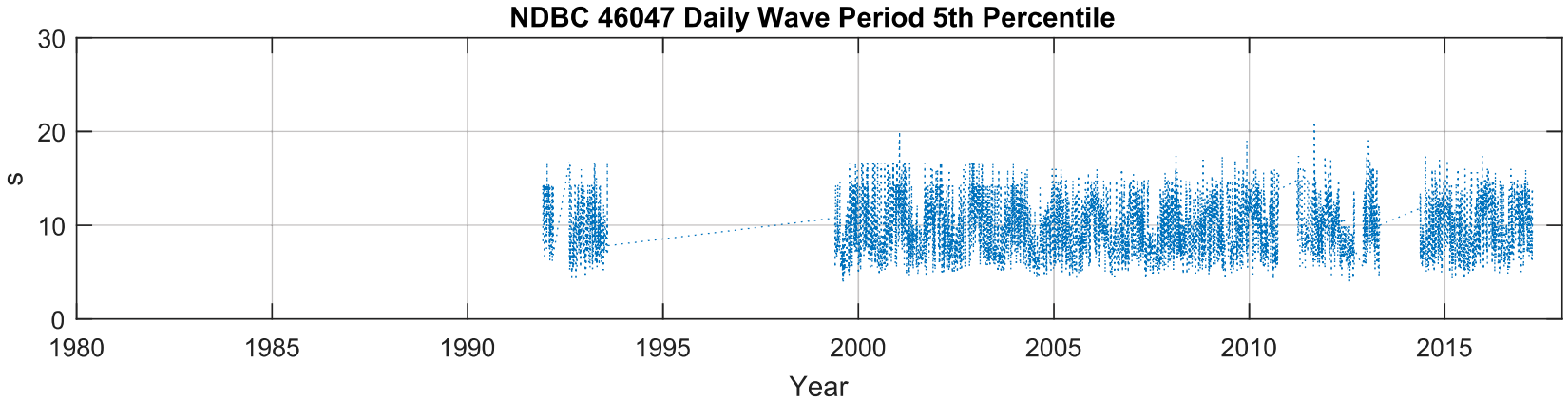
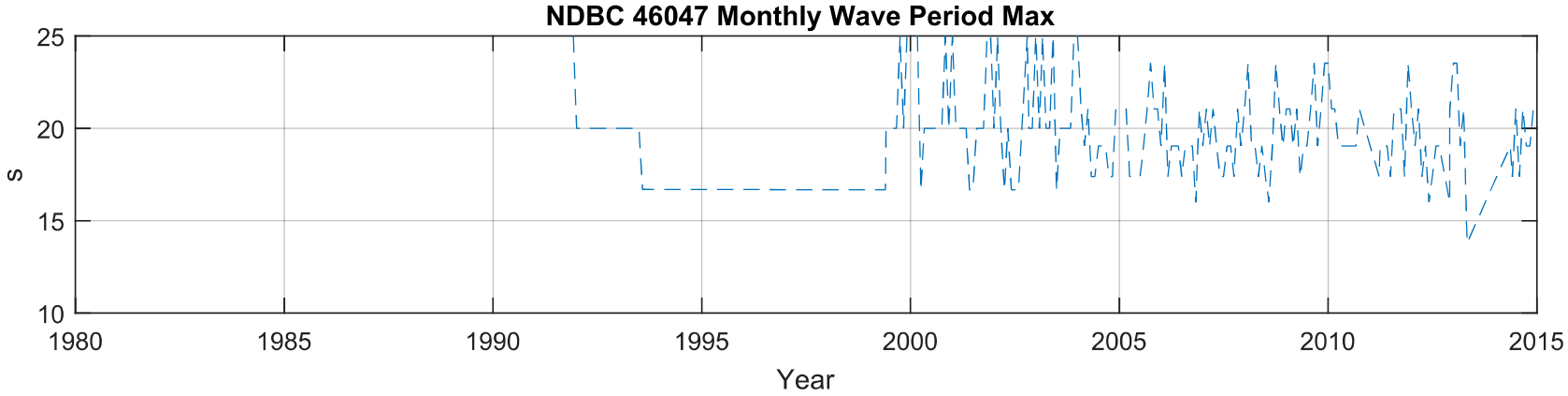
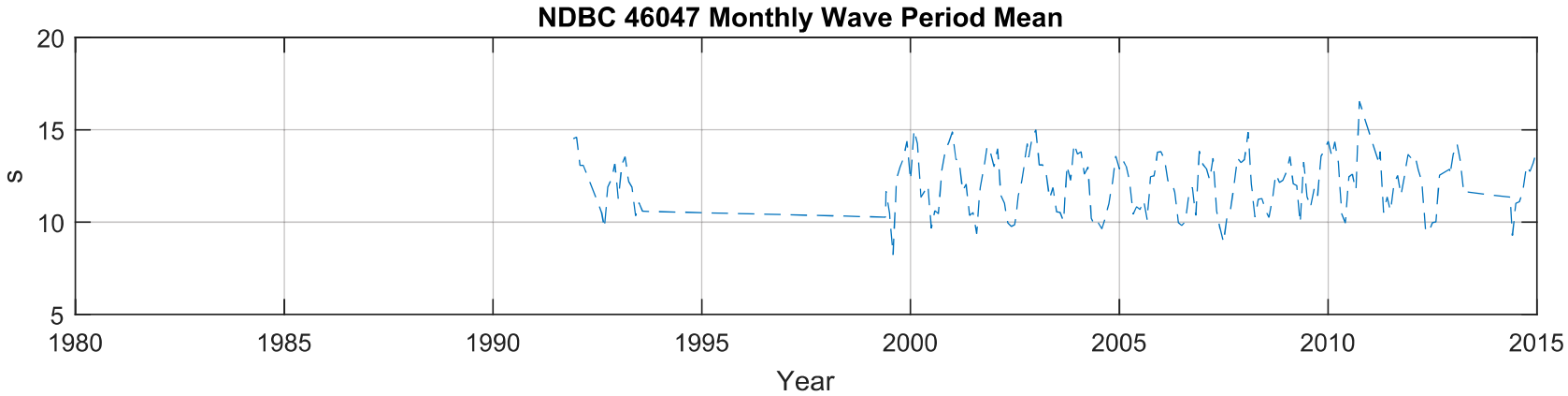


Figure A098. Daily Wave Period, Percentiles,NDBC 46047





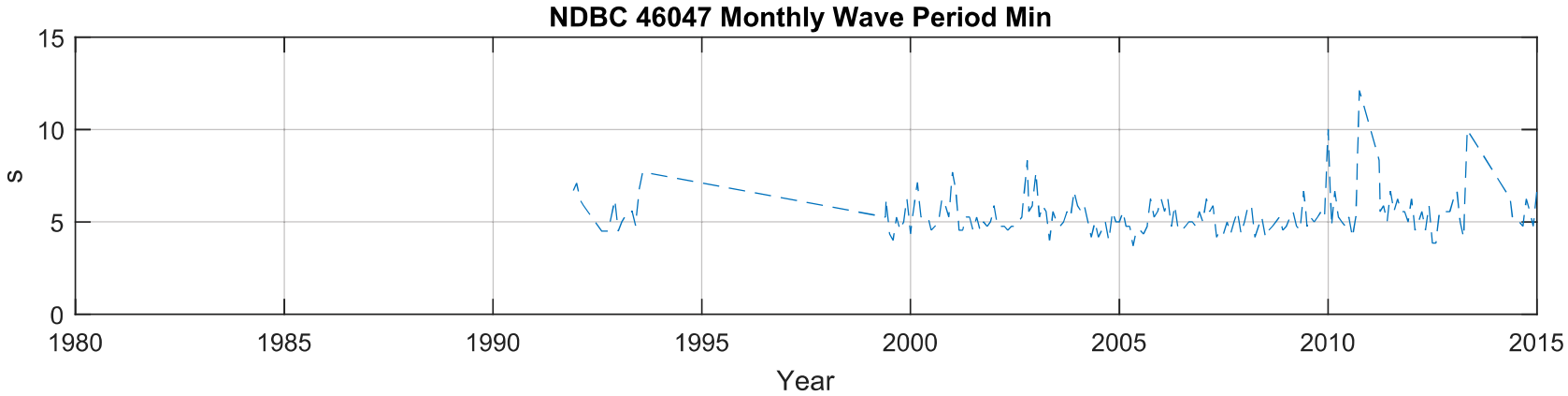
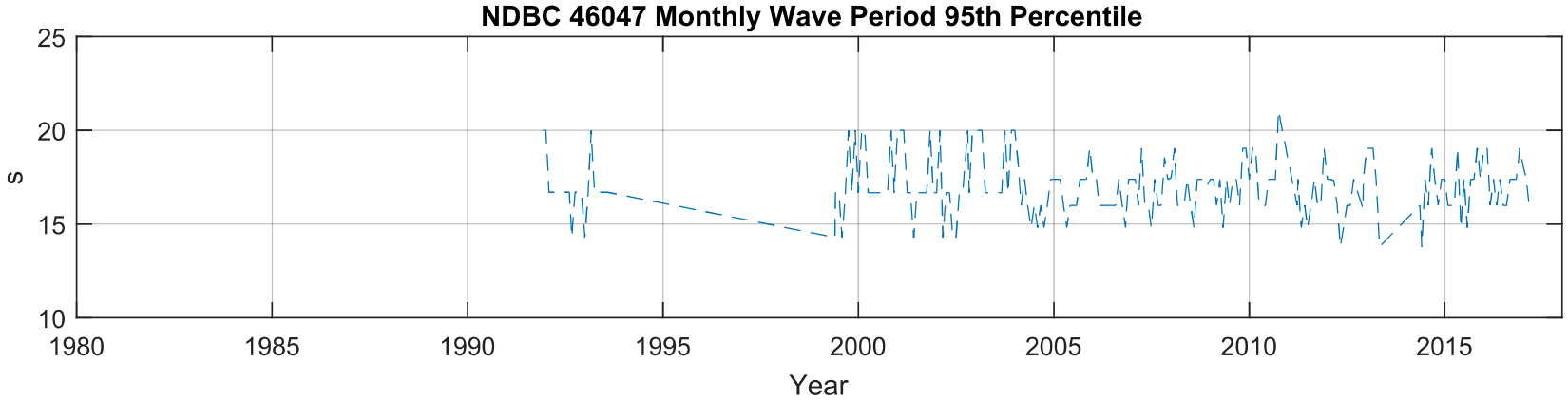
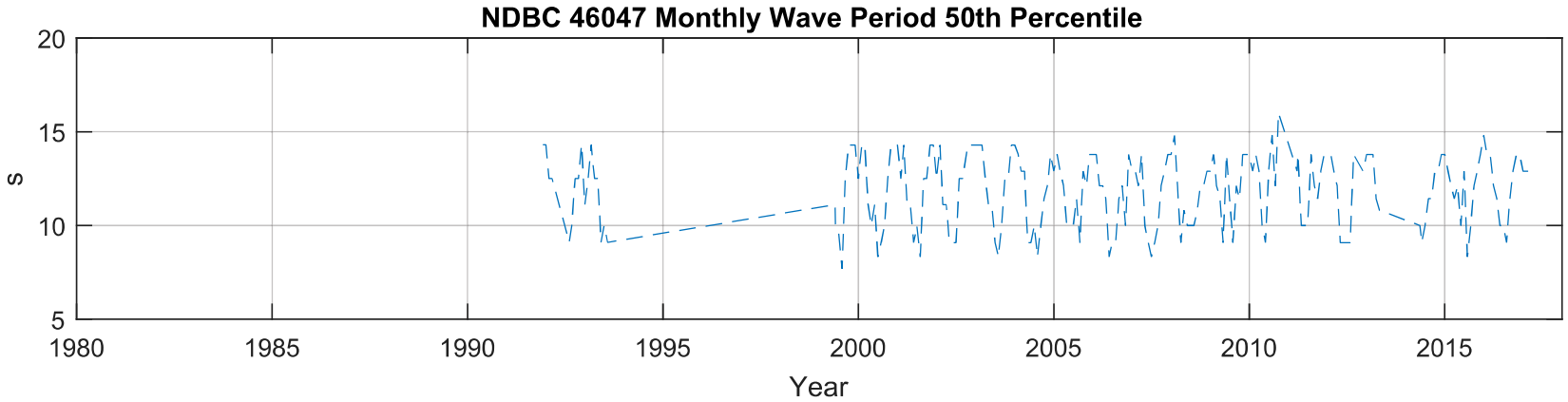


Figure A099. Monthly Wave Period, Max, Mean, Min,NDBC 46047





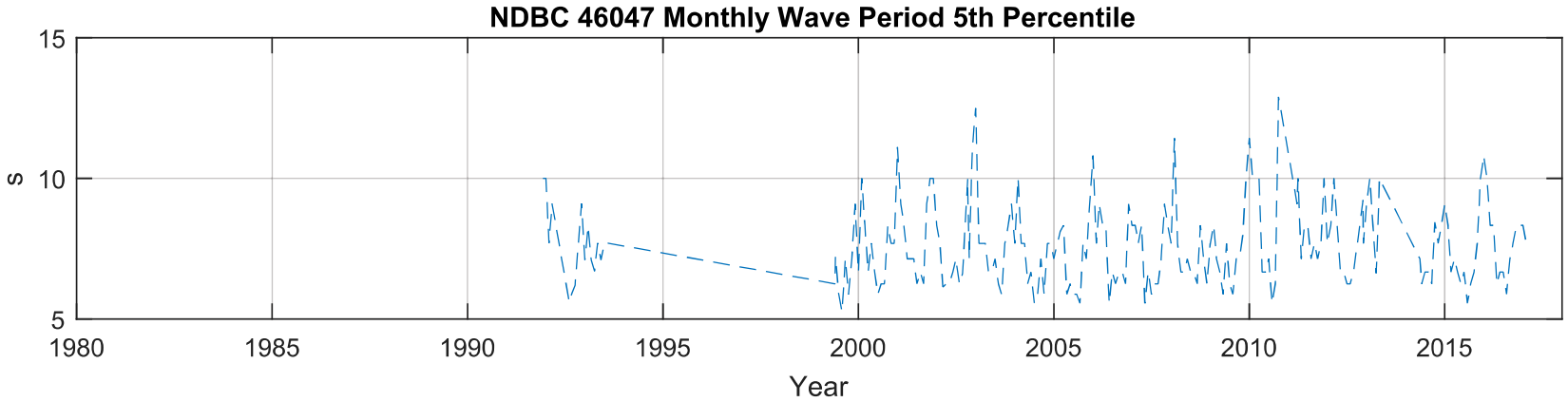
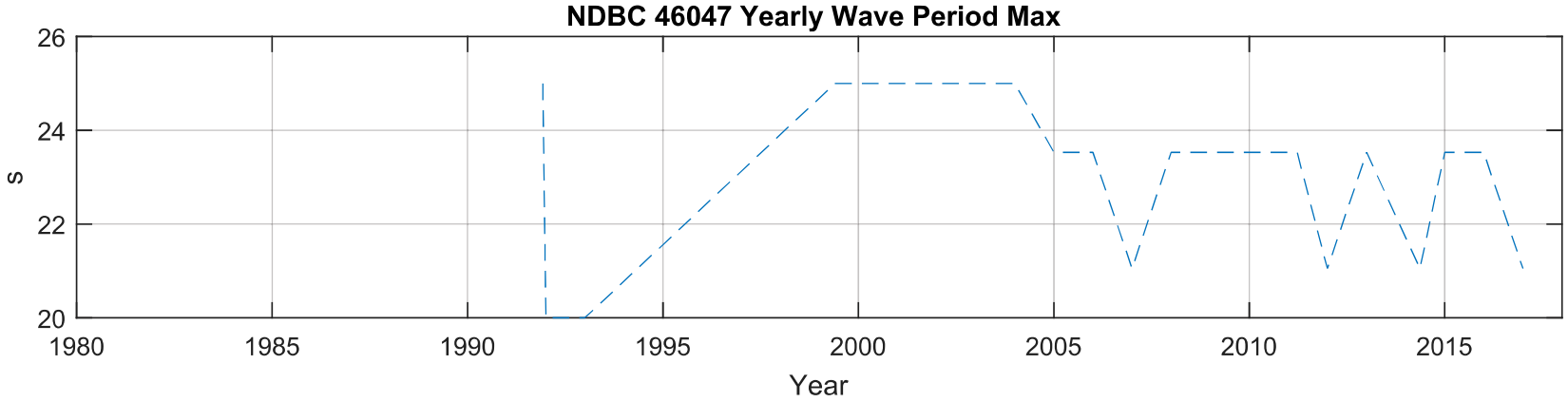
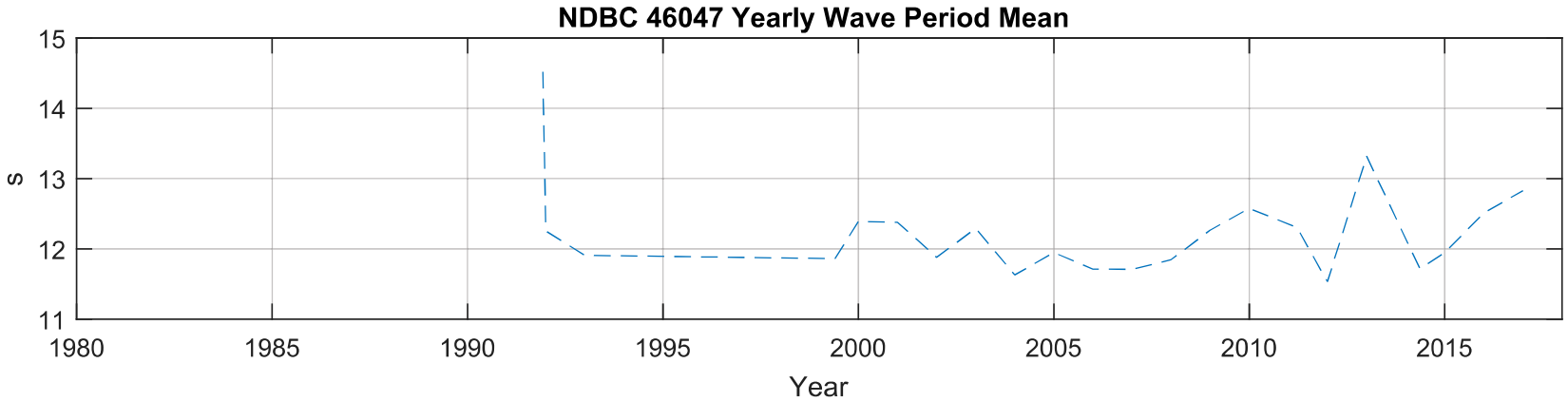


Figure A100. Monthly Wave Period, Percentiles,NDBC 46047





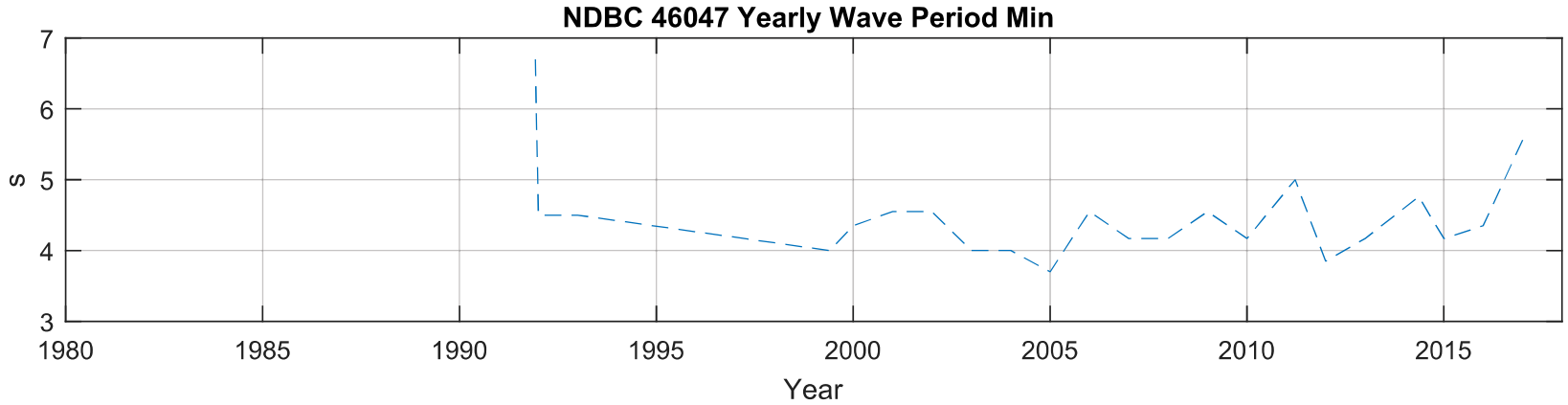
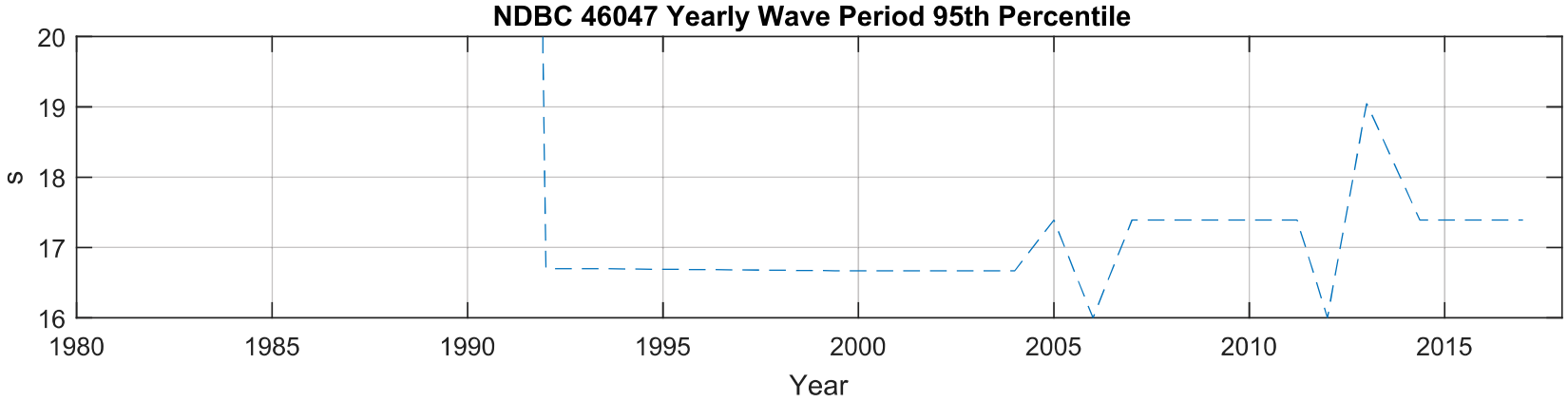
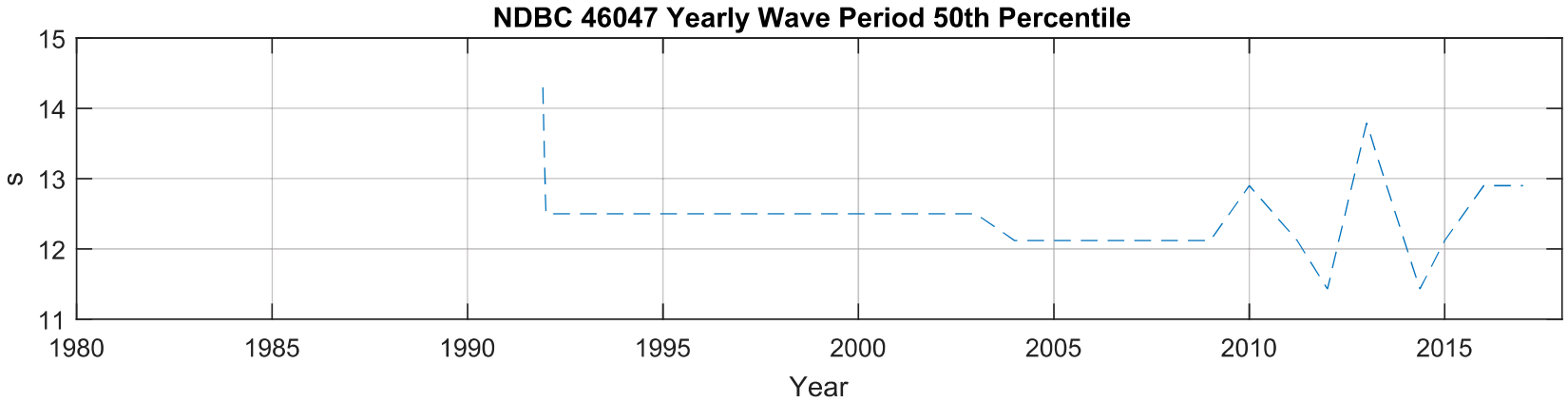


Figure A101. Yearly Wave Period, Max, Mean, Min,NDBC 46047





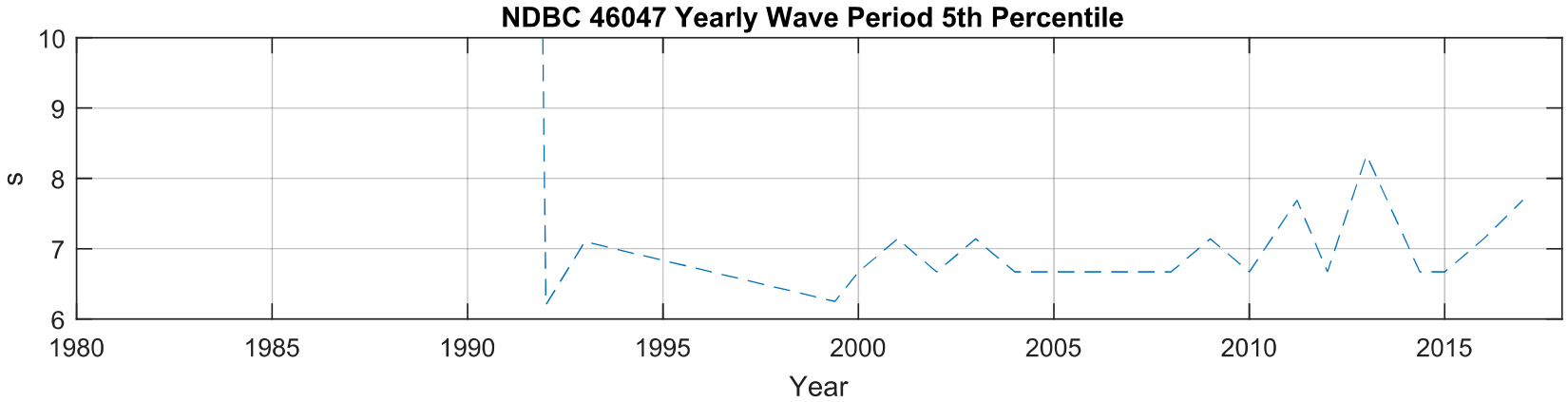


Figure A102. Yearly Wave Period, Percentiles,NDBC 46047

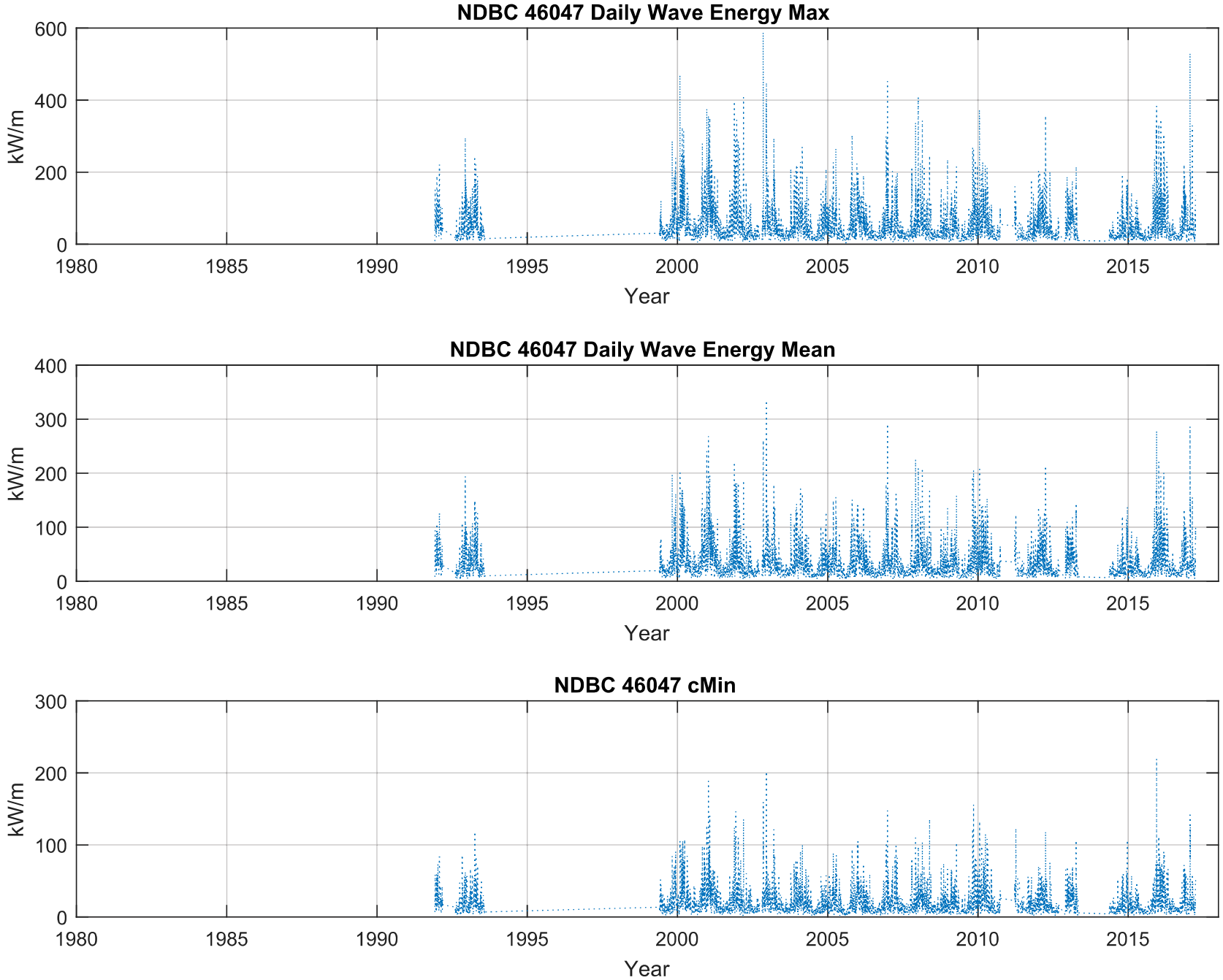
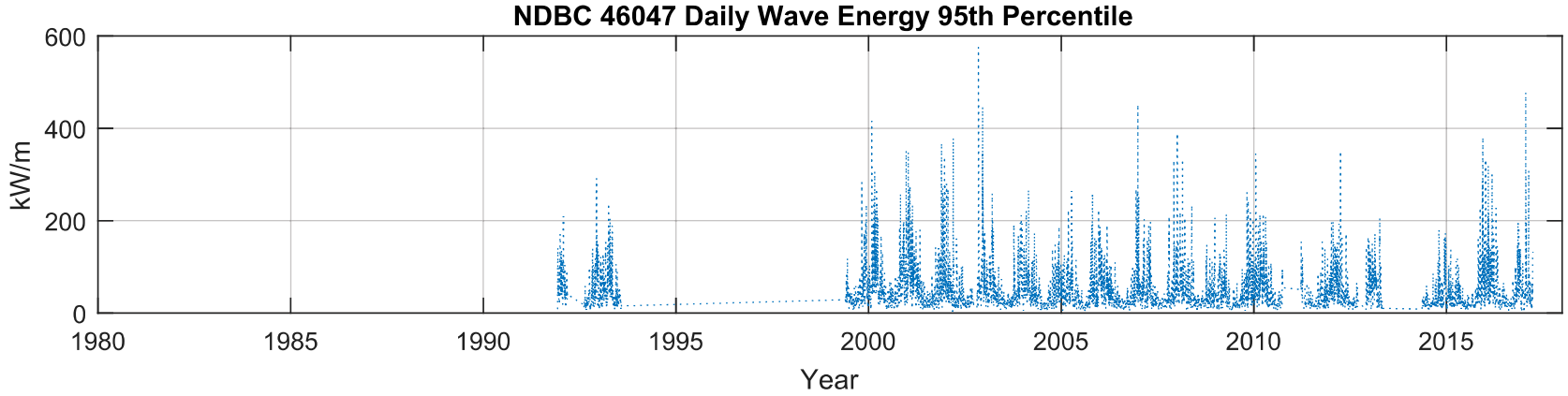
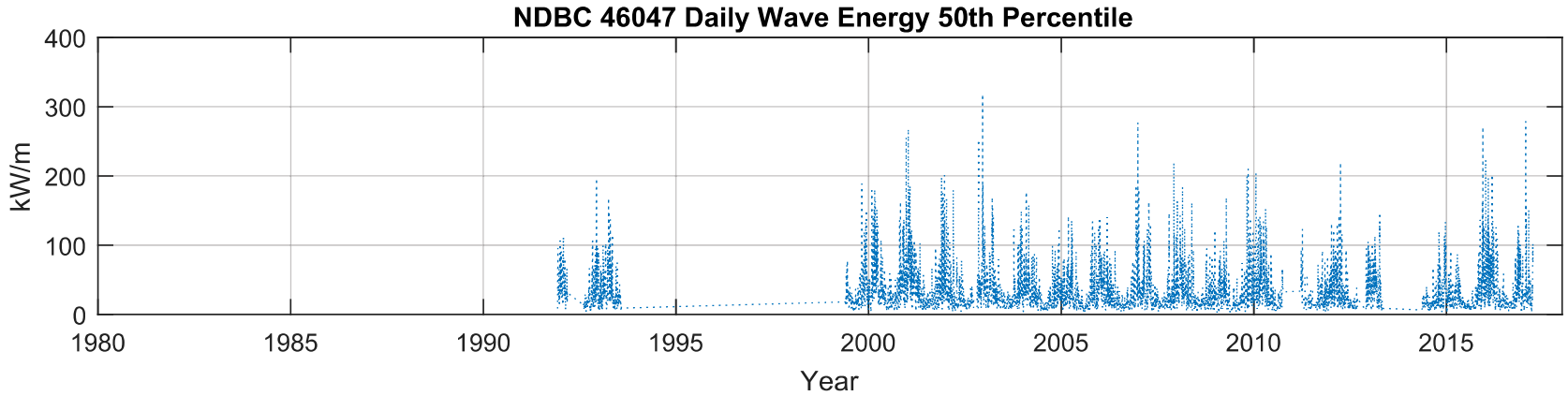


Figure A103. Daily Wave Energy, Max, Mean, Min,NDBC 46047





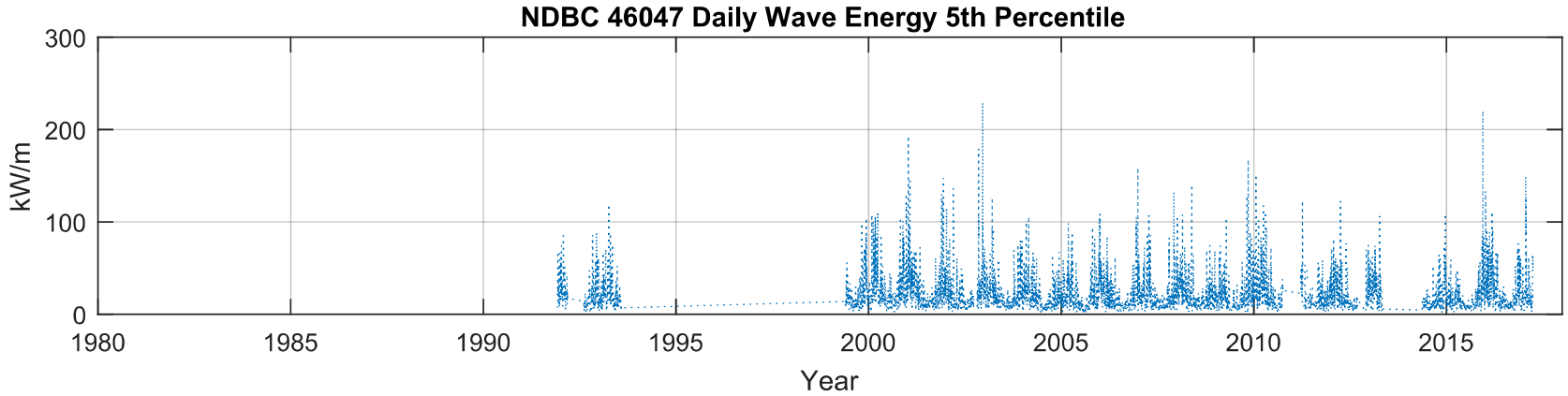


Figure A104. Daily Wave Energy, Percentiles,NDBC 46047

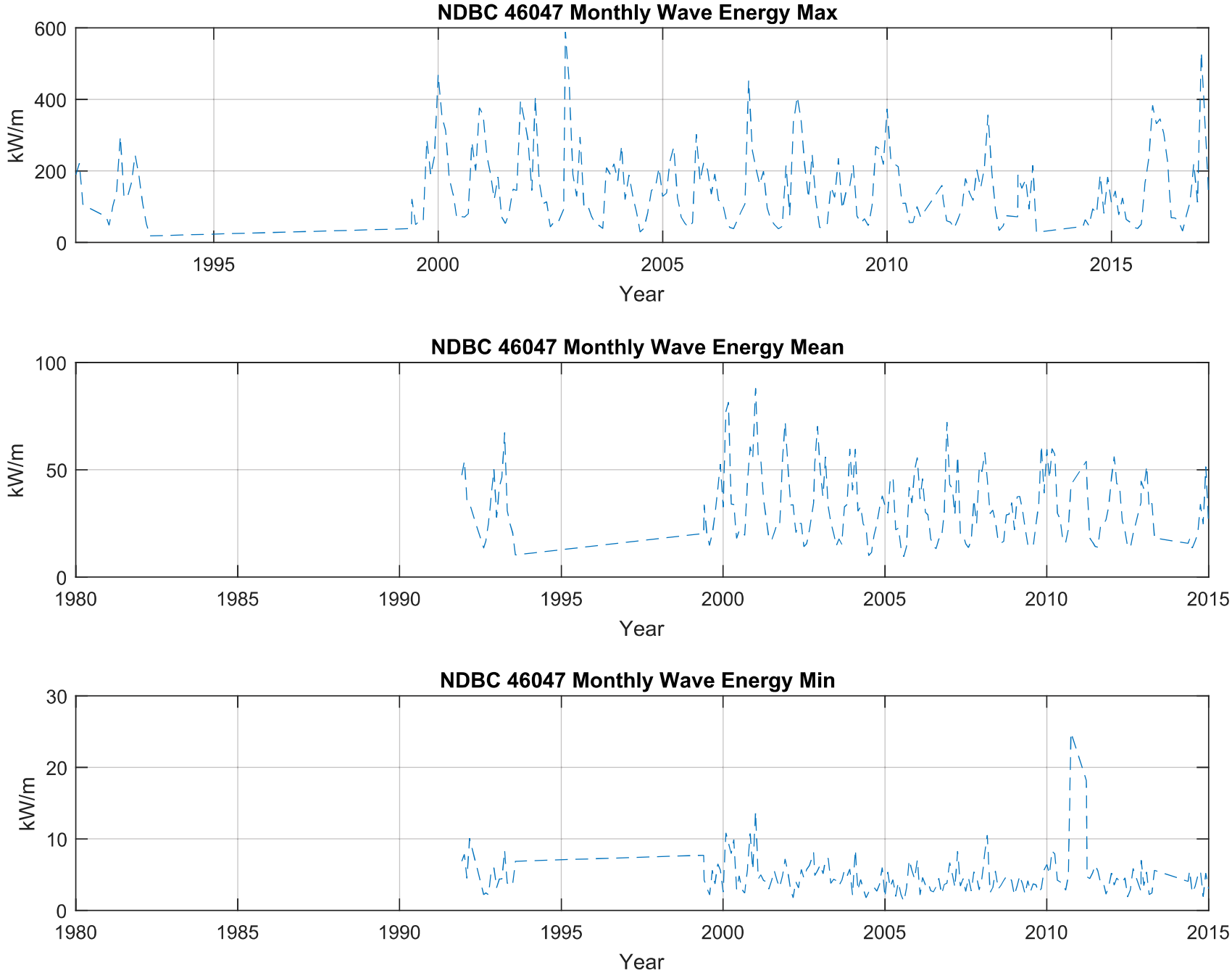


Figure A105. Monthly Wave Energy, Max, Mean, Min,NDBC 46047

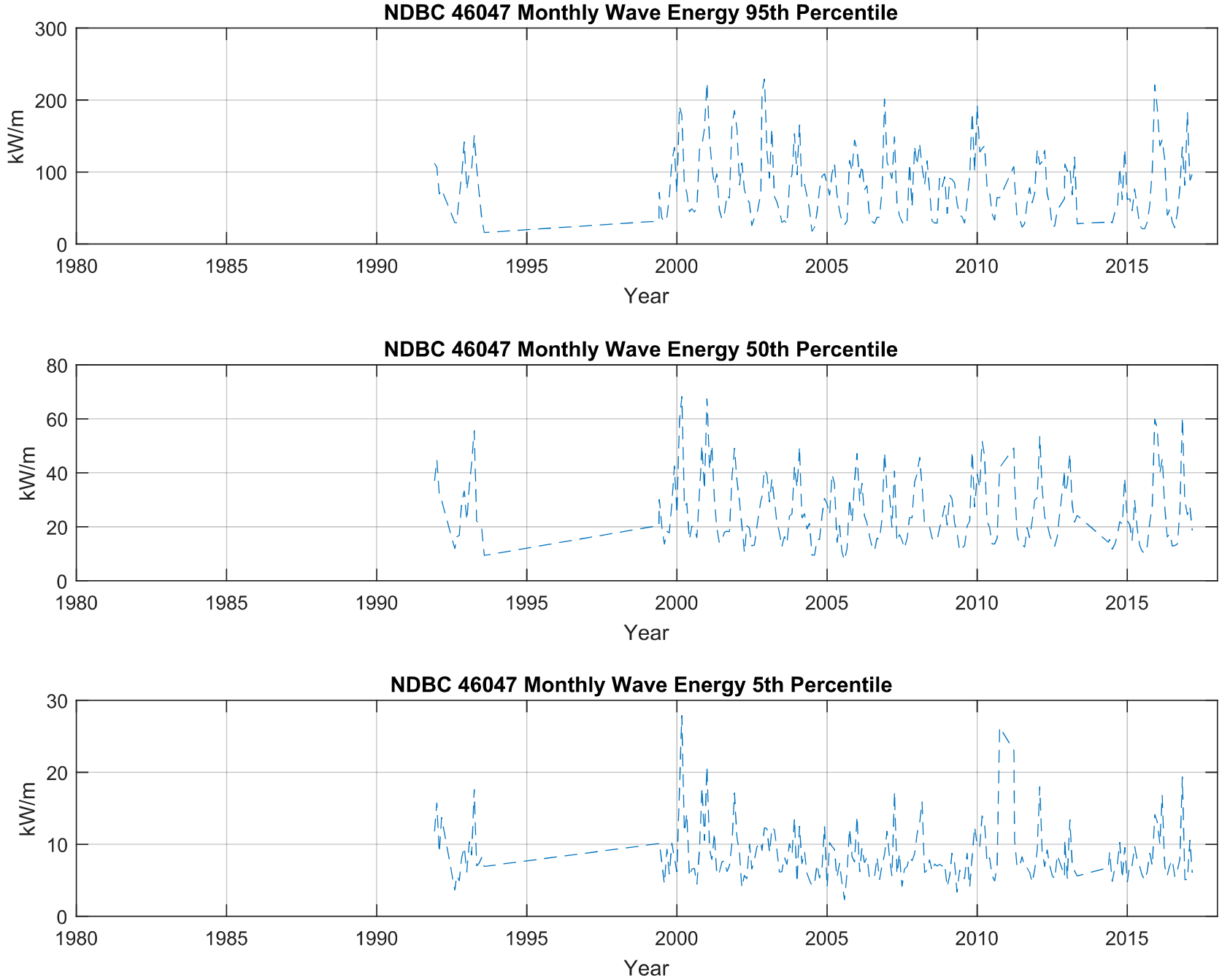


Figure A106. Monthly Wave Energy, Percentiles,NDBC 46047

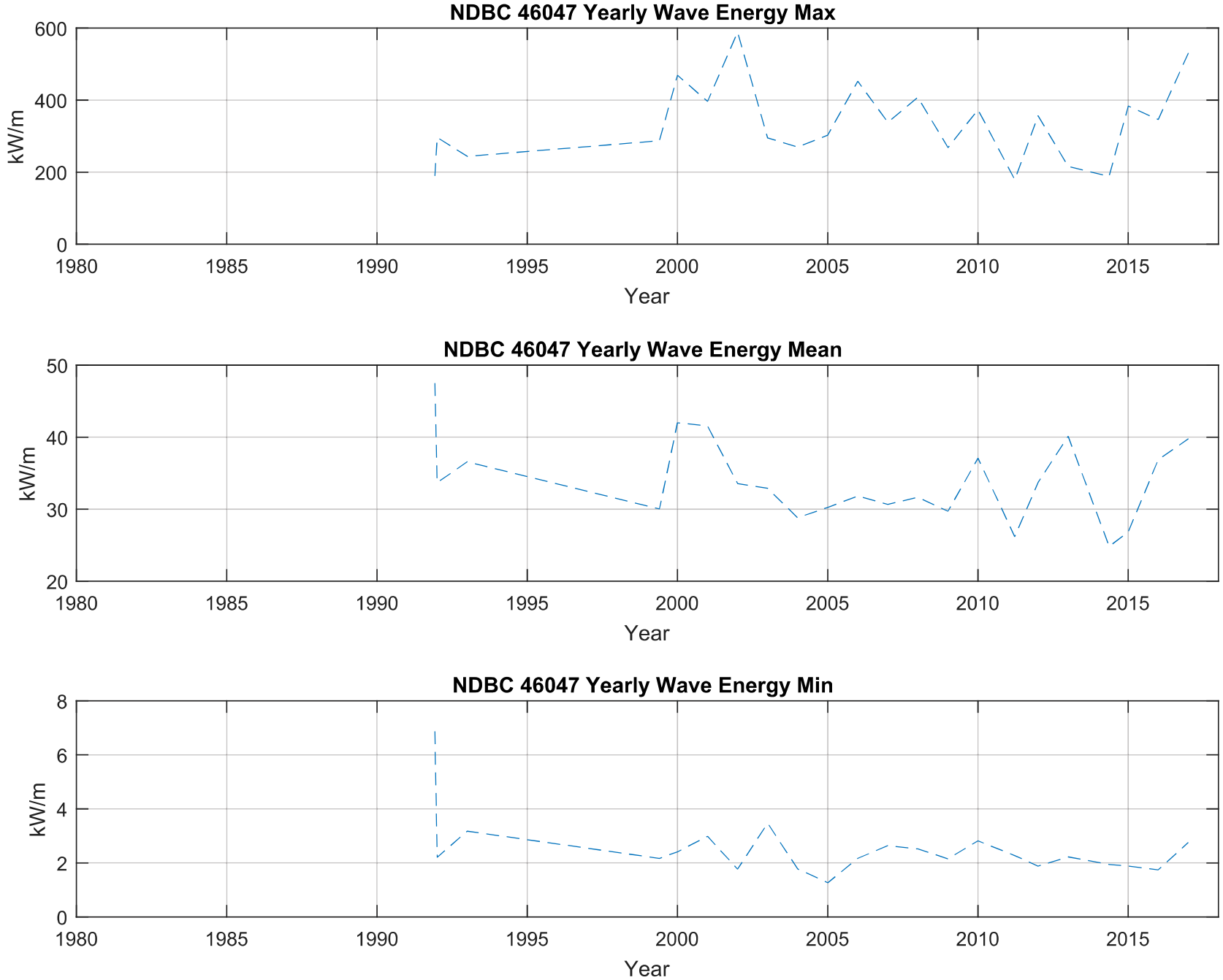
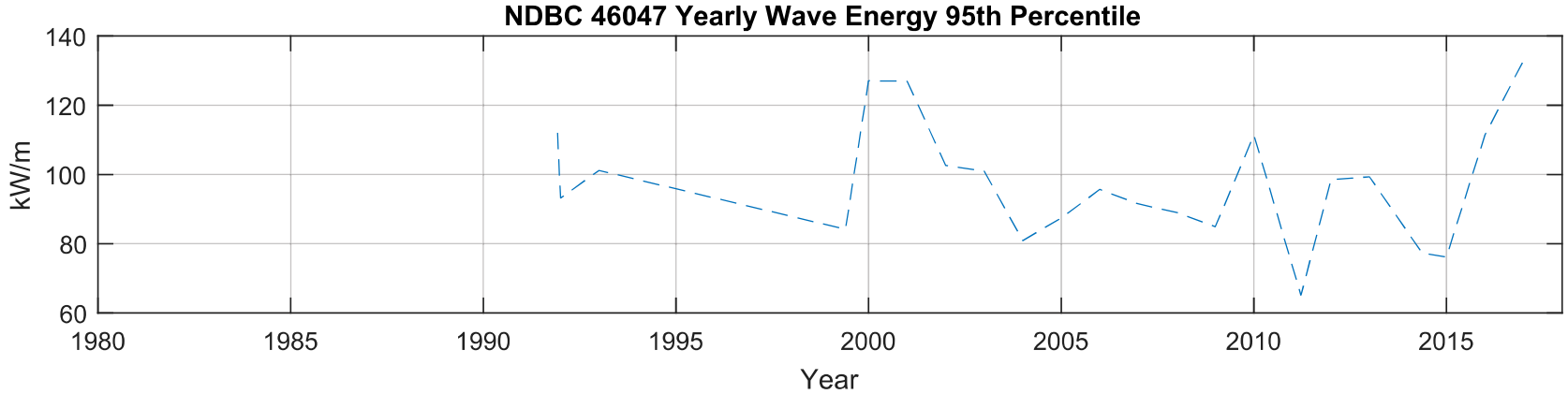
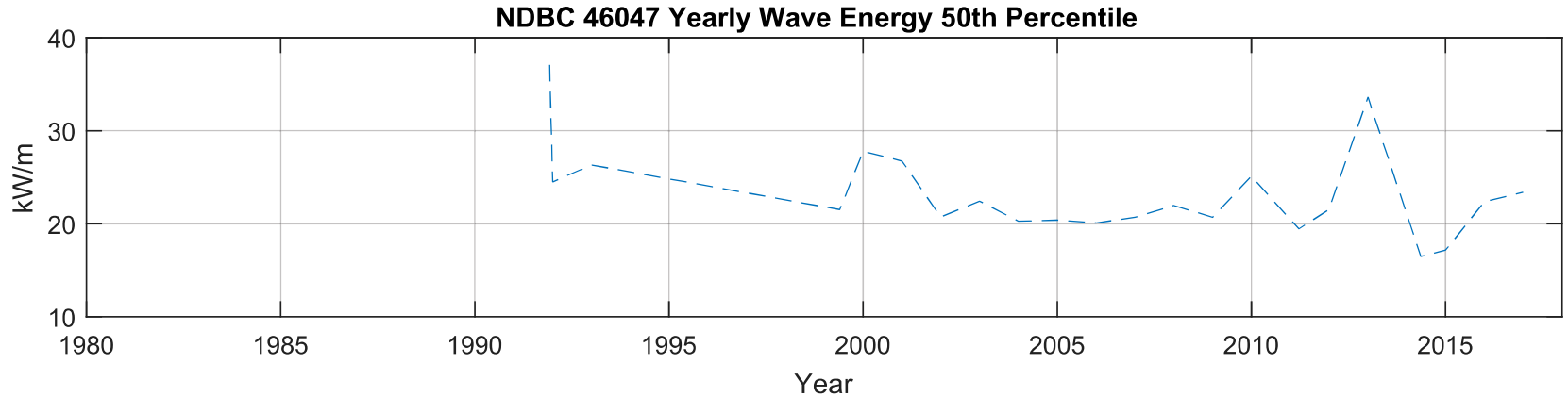


Figure A107. Yearly Wave Energy, Max, Mean, Min,NDBC 46047





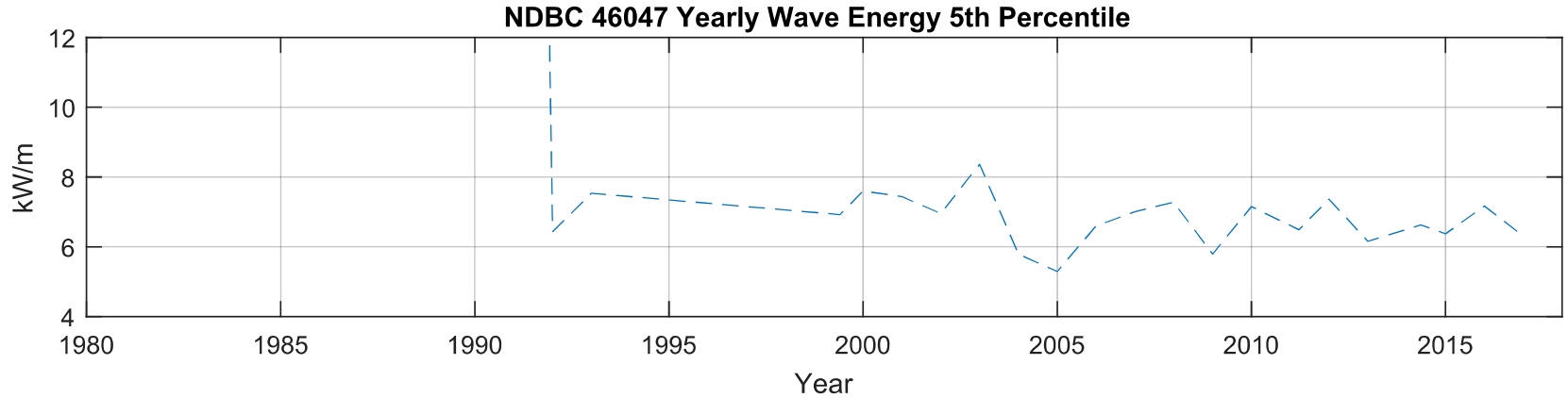


Figure A108. Yearly Wave Energy, Percentiles,NDBC 46047

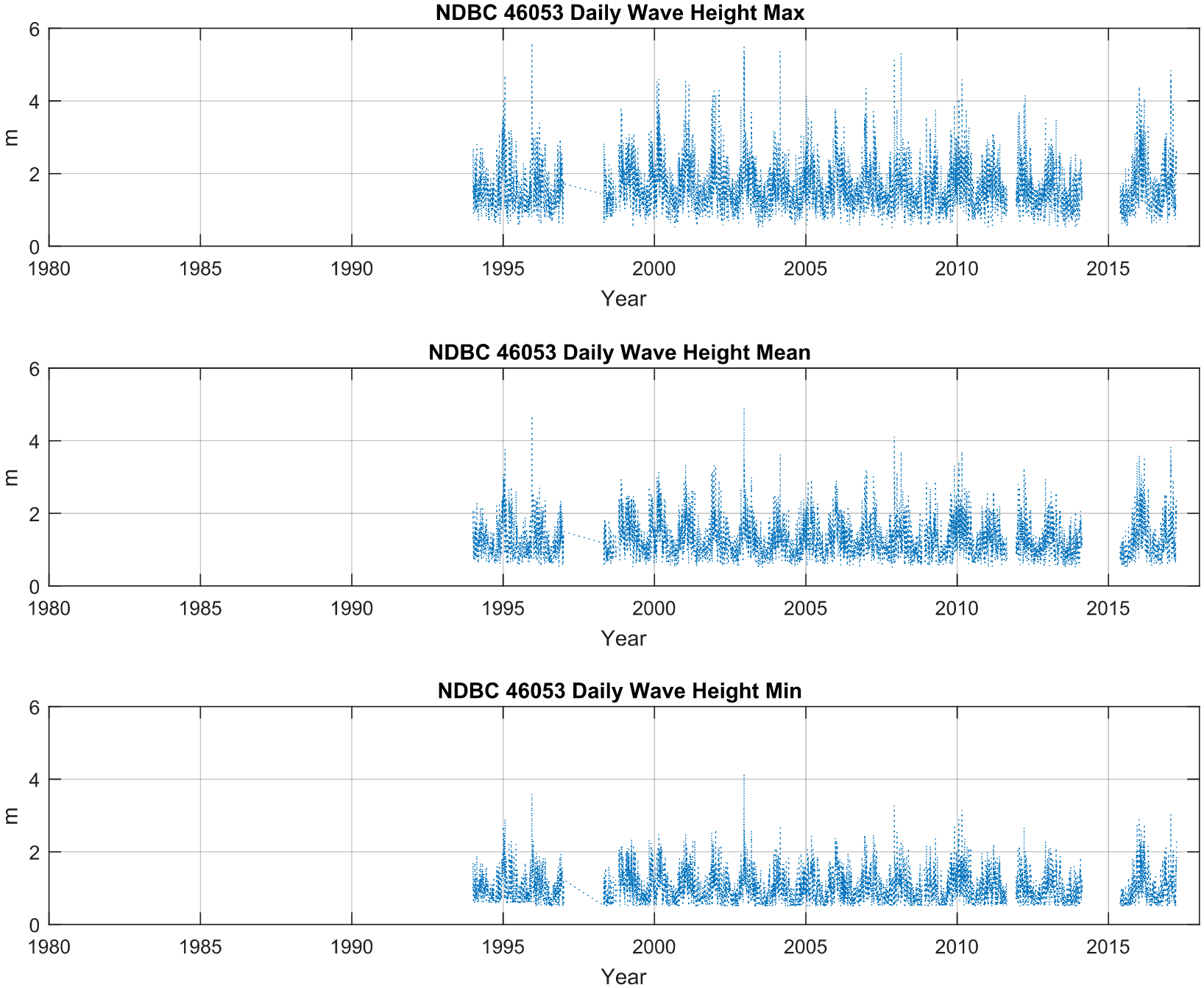


Figure A109. Daily Wave Height, Max, Mean, Min,NDBC 46053

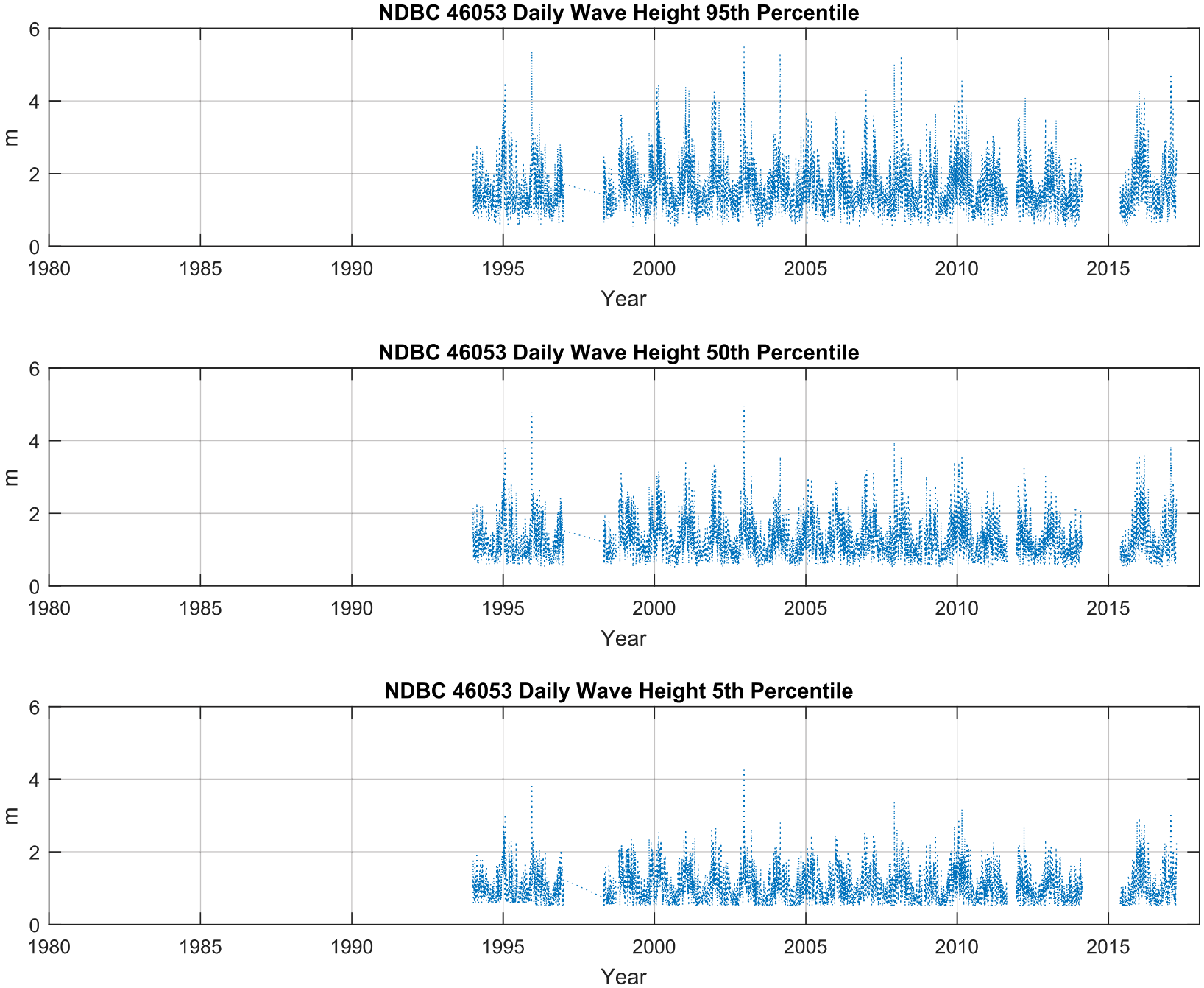


Figure A110. Daily Wave Height, Percentiles,NDBC 46053

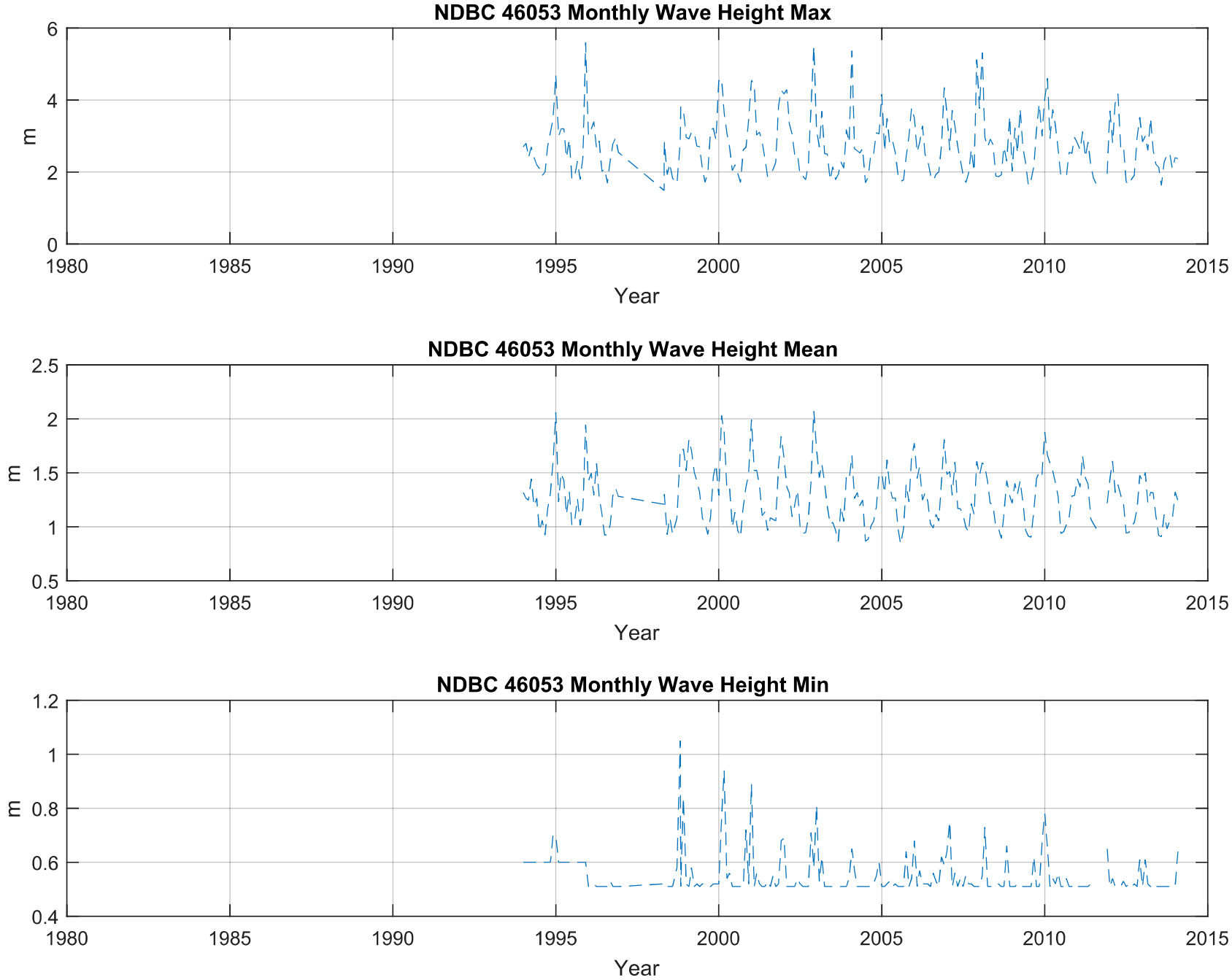


Figure A111. Monthly Wave Height, Max, Mean, Min,NDBC 46053

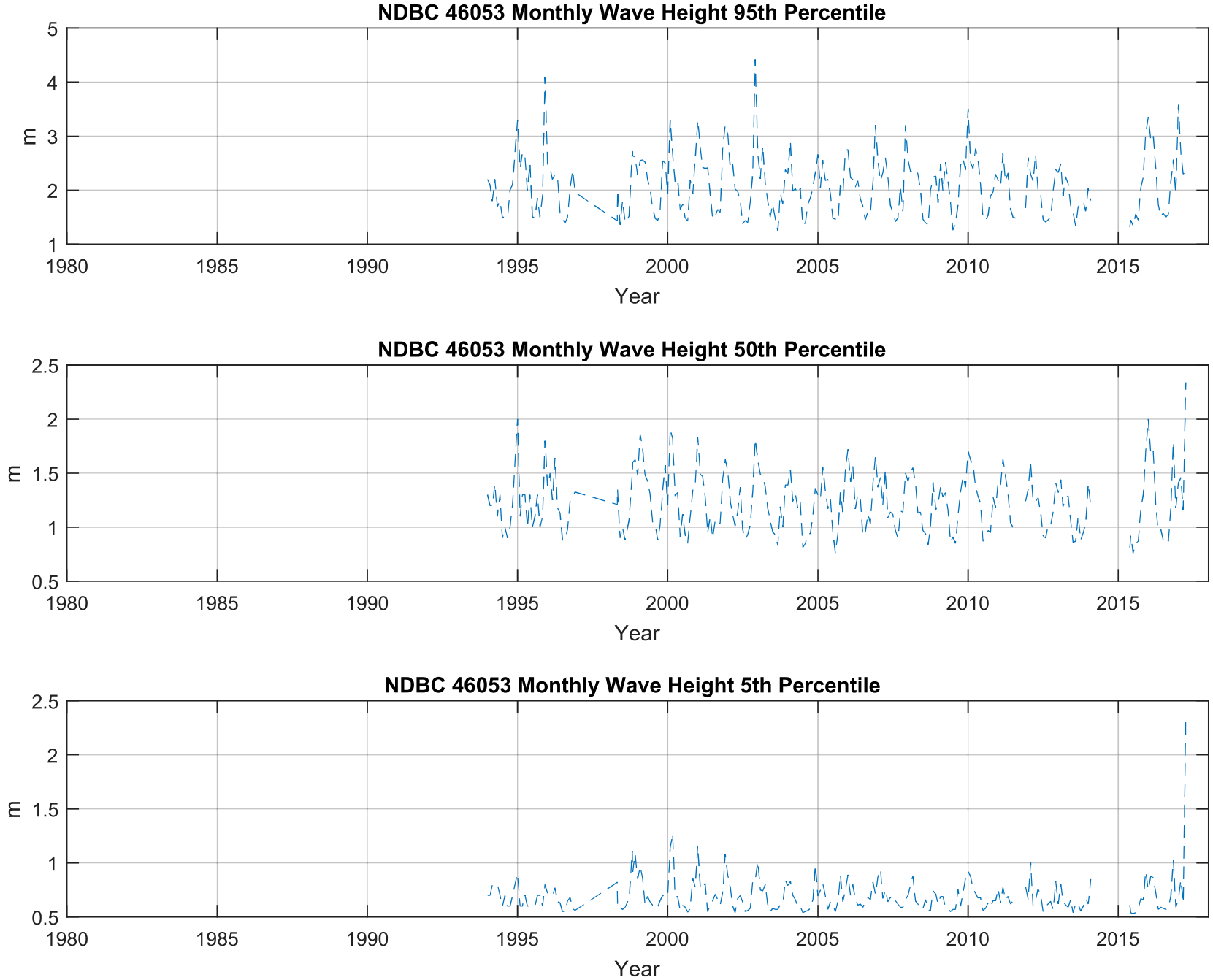


Figure A112. Monthly Wave Height, Percentiles,NDBC 46053

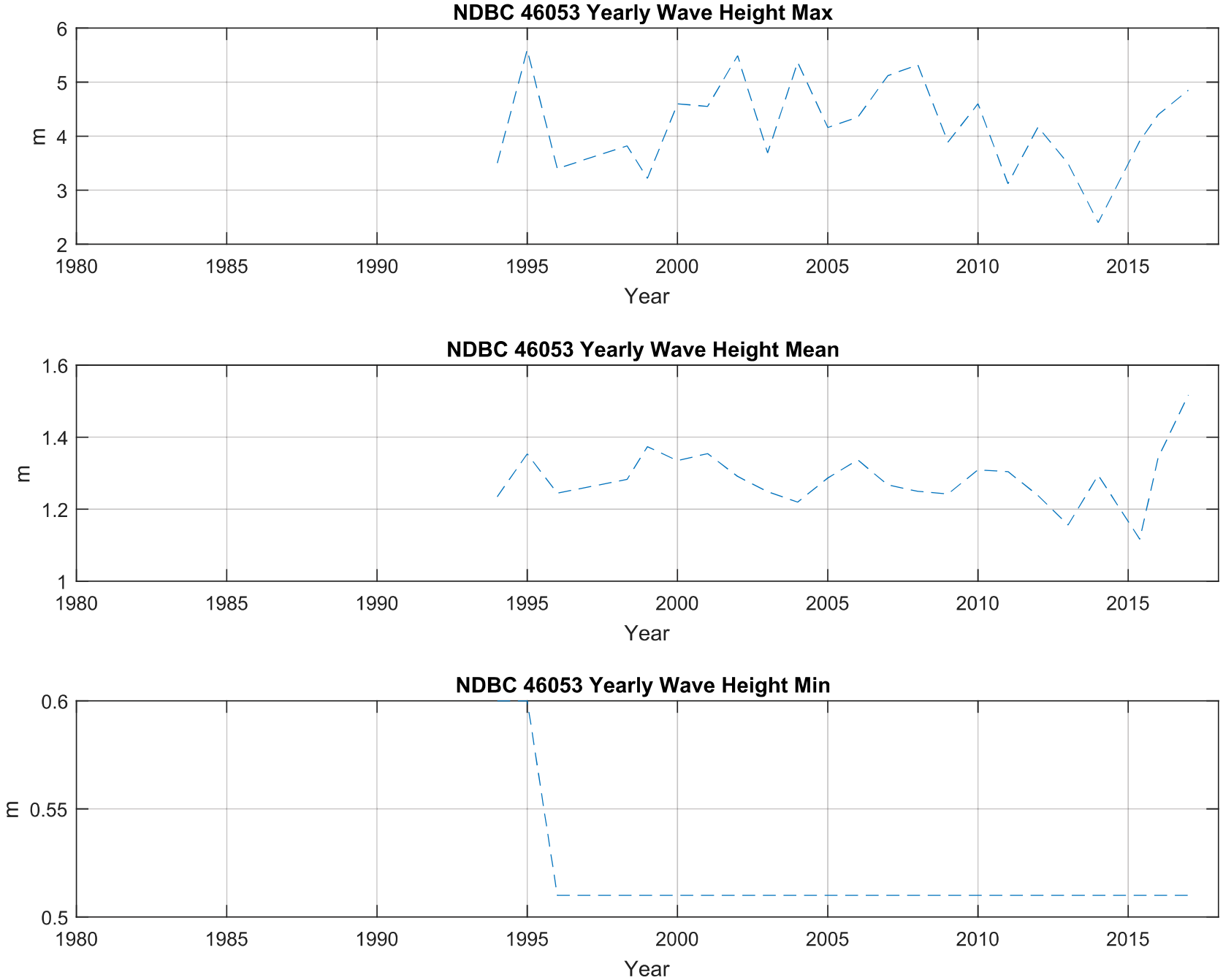


Figure A113. Yearly Wave Height, Max, Mean, Min,NDBC 46053

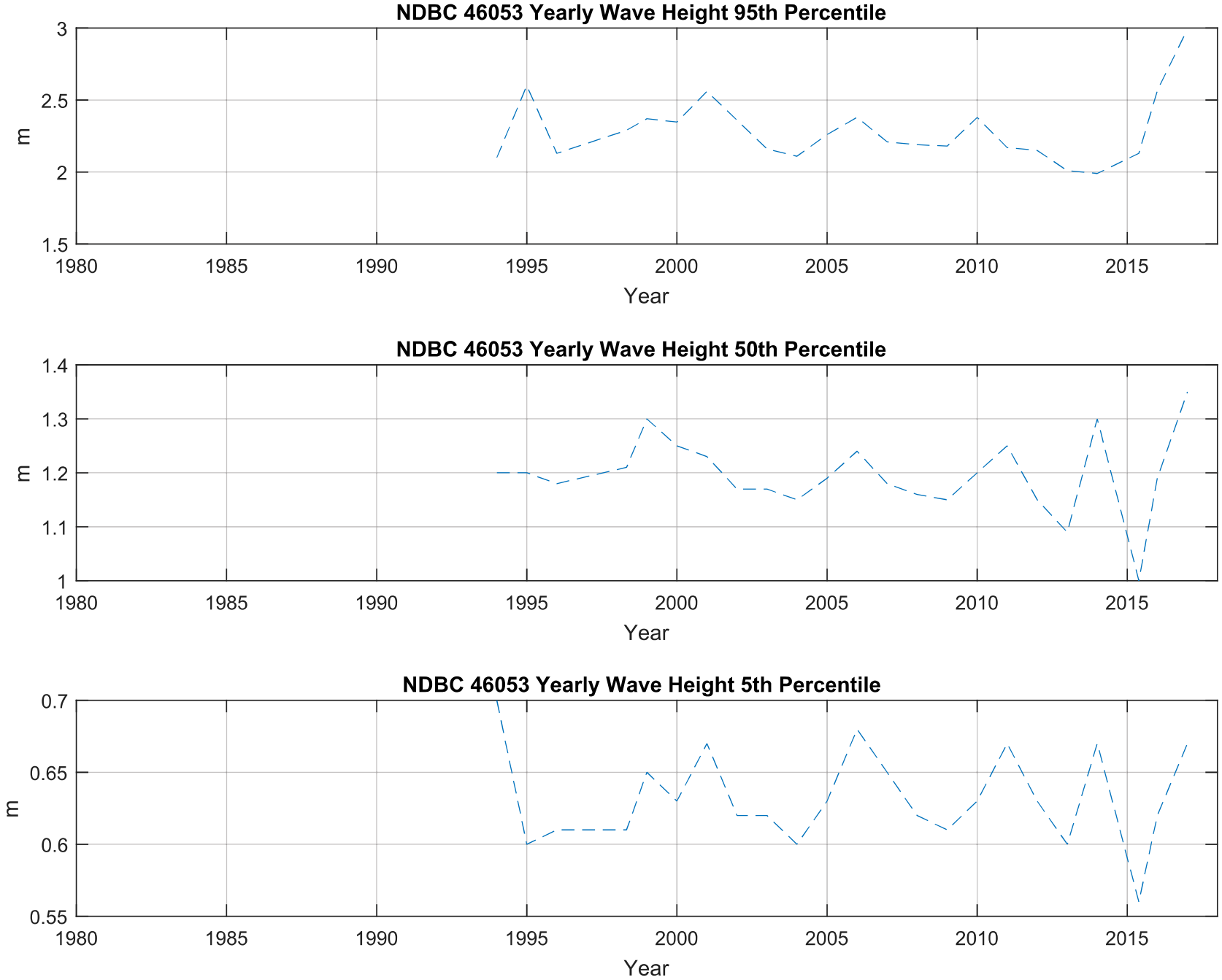
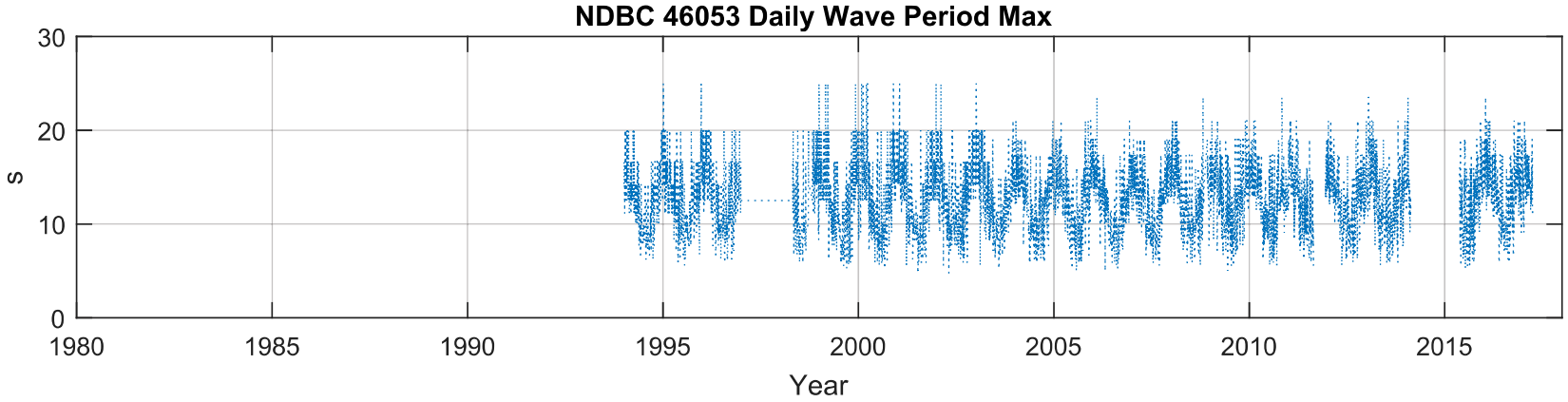
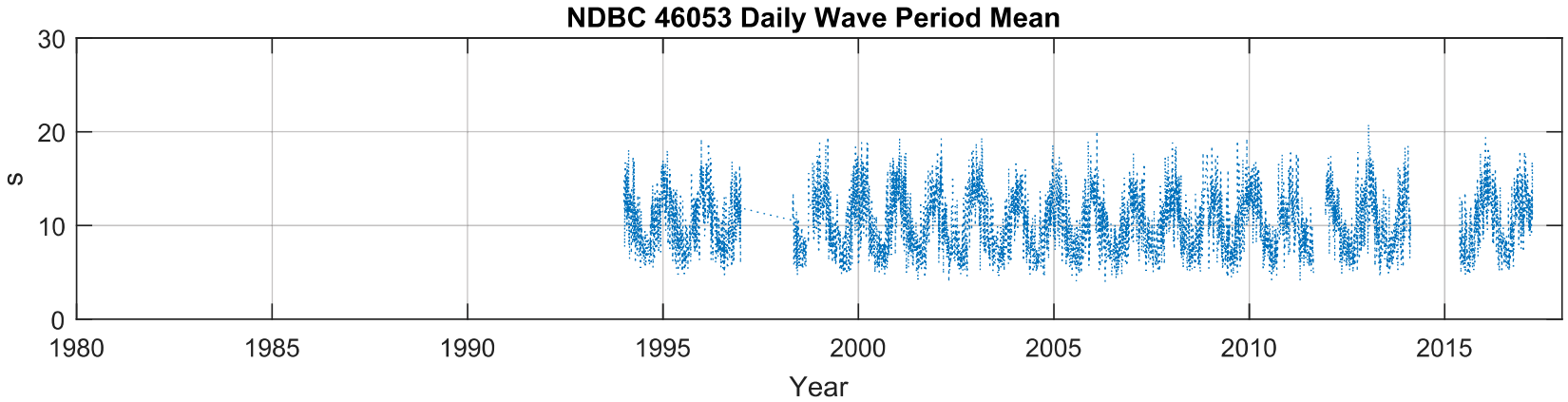


Figure A114. Yearly Wave Height, Percentiles,NDBC 46053





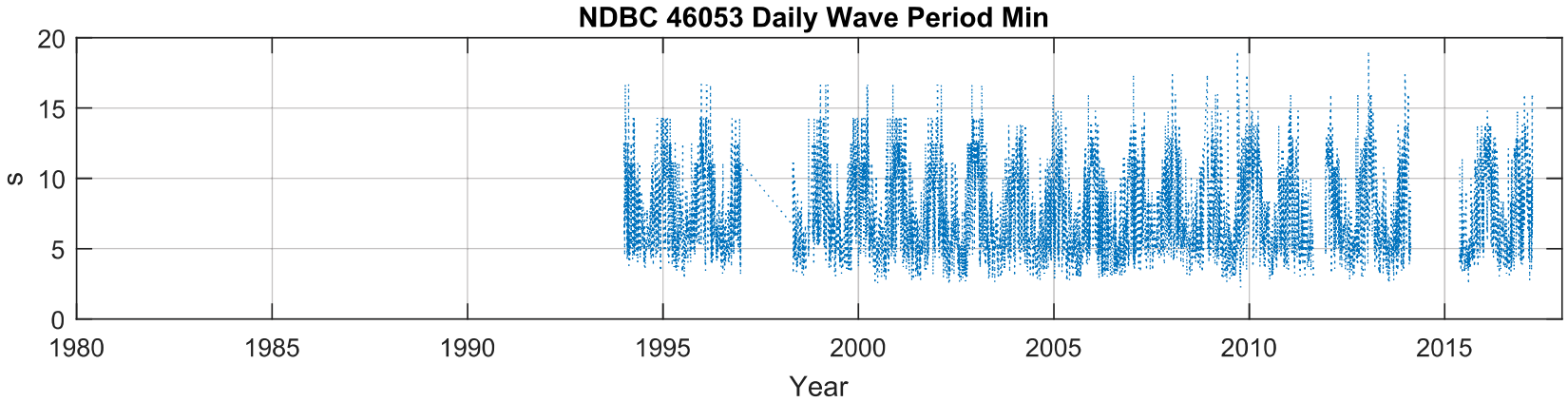
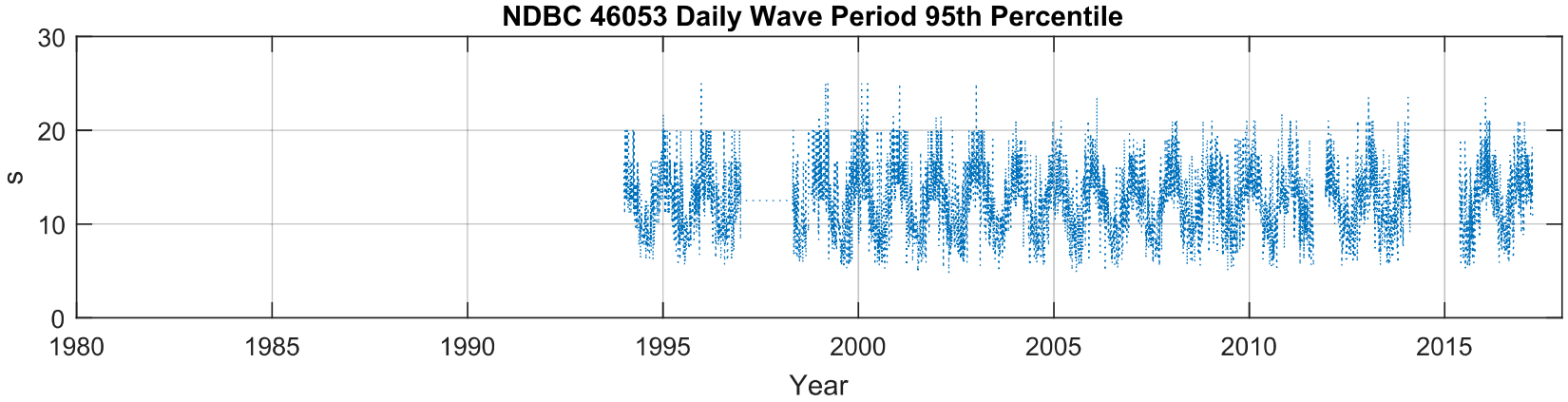
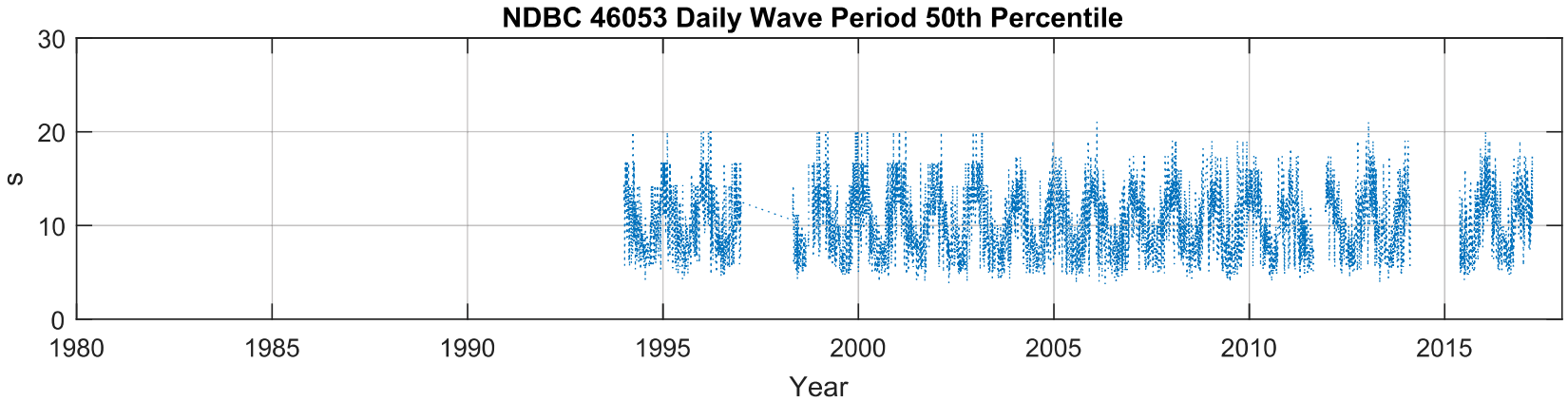


Figure A115. Daily Wave Period, Max, Mean, Min,NDBC 46053





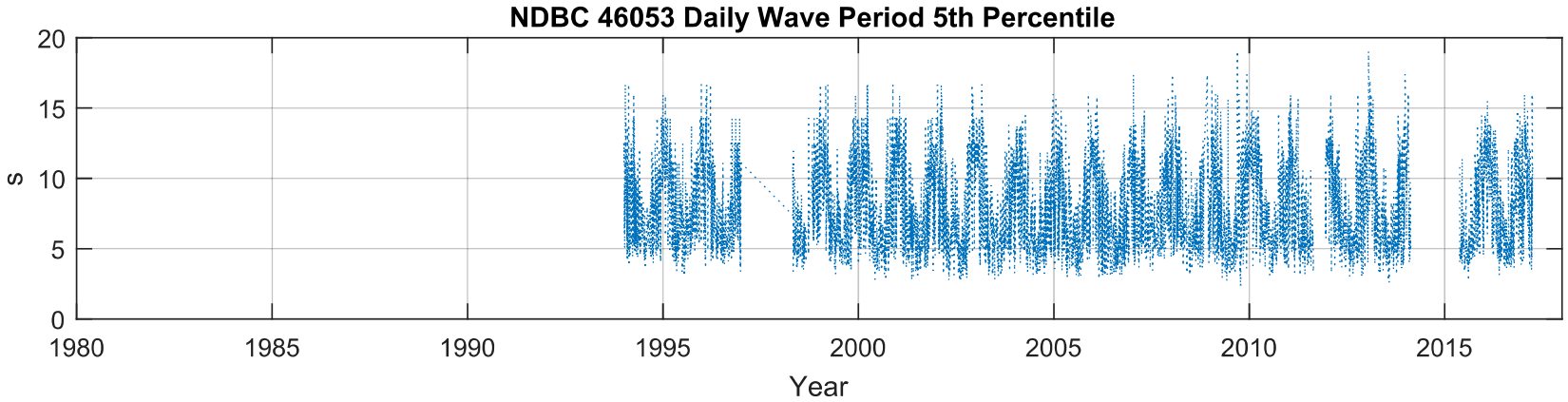
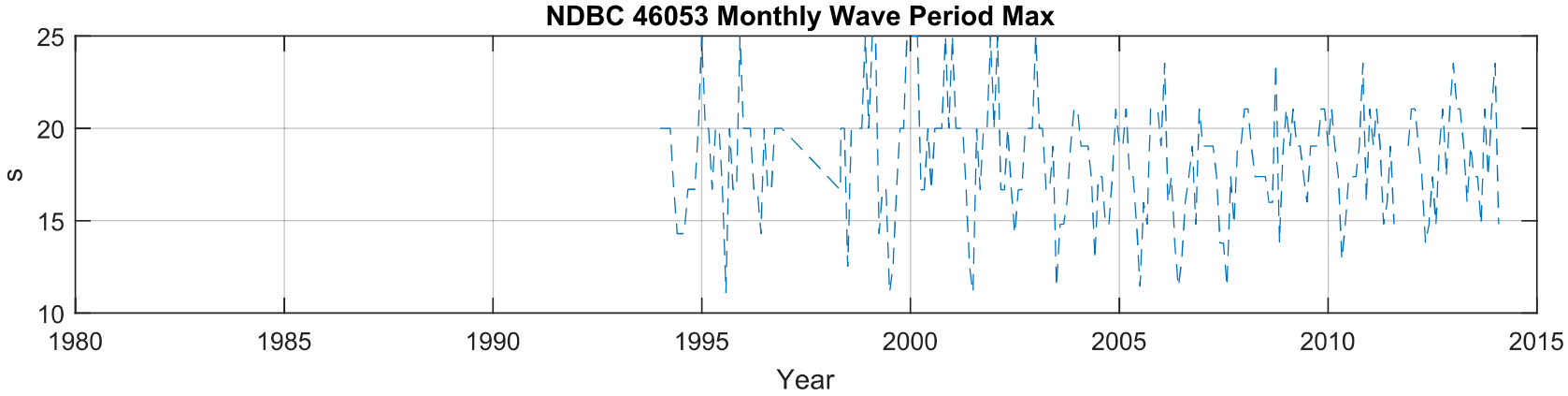
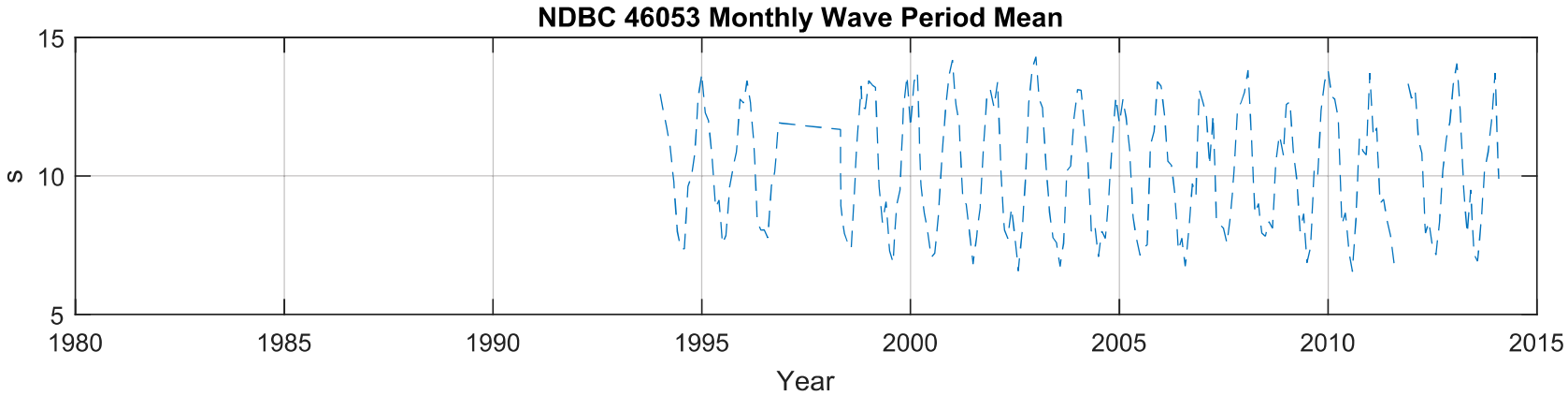


Figure A116. Daily Wave Period, Percentiles,NDBC 46053





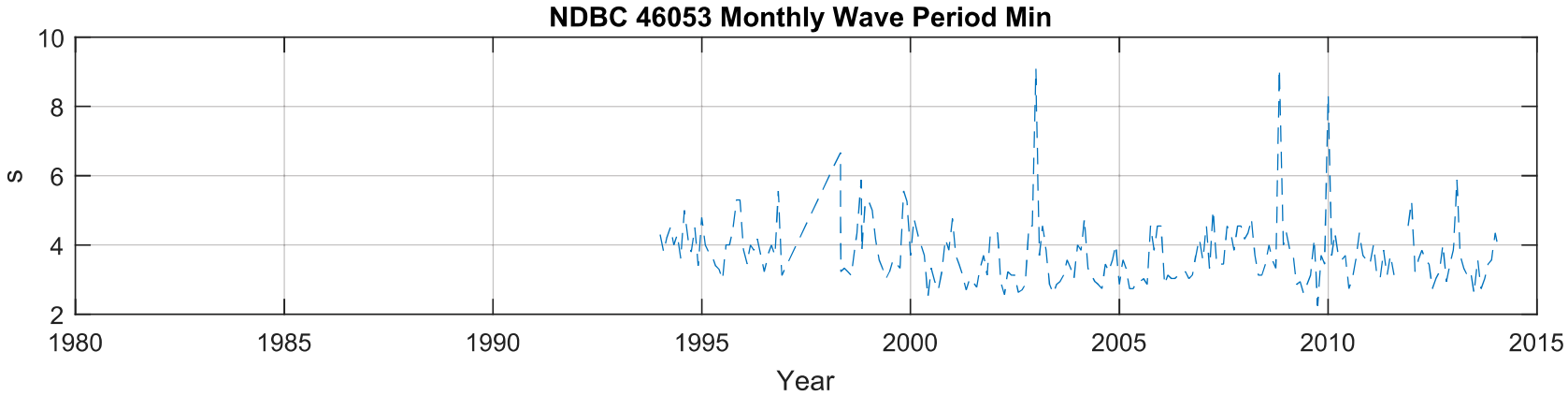
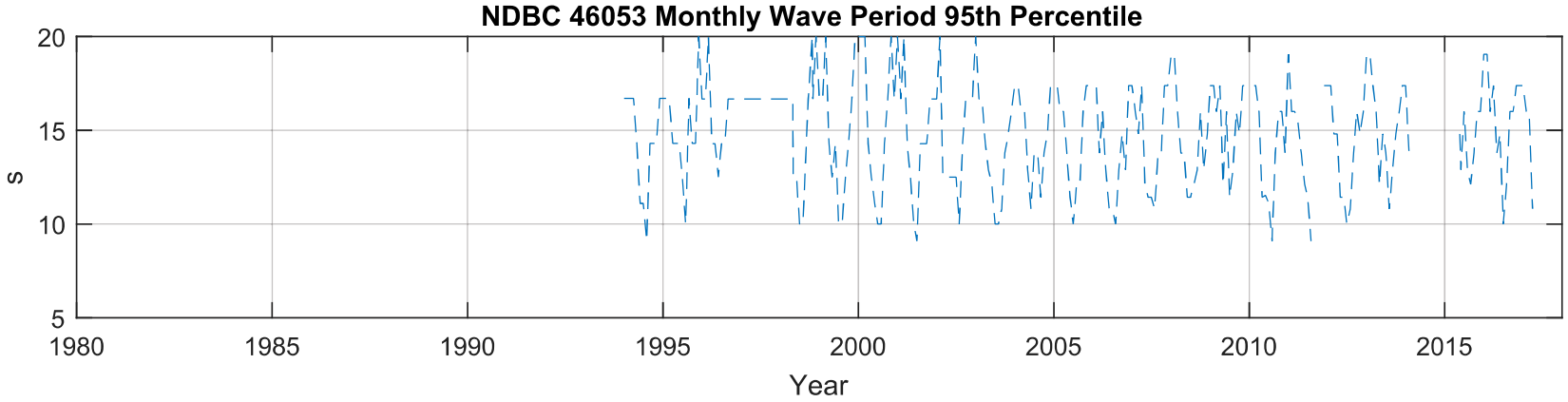
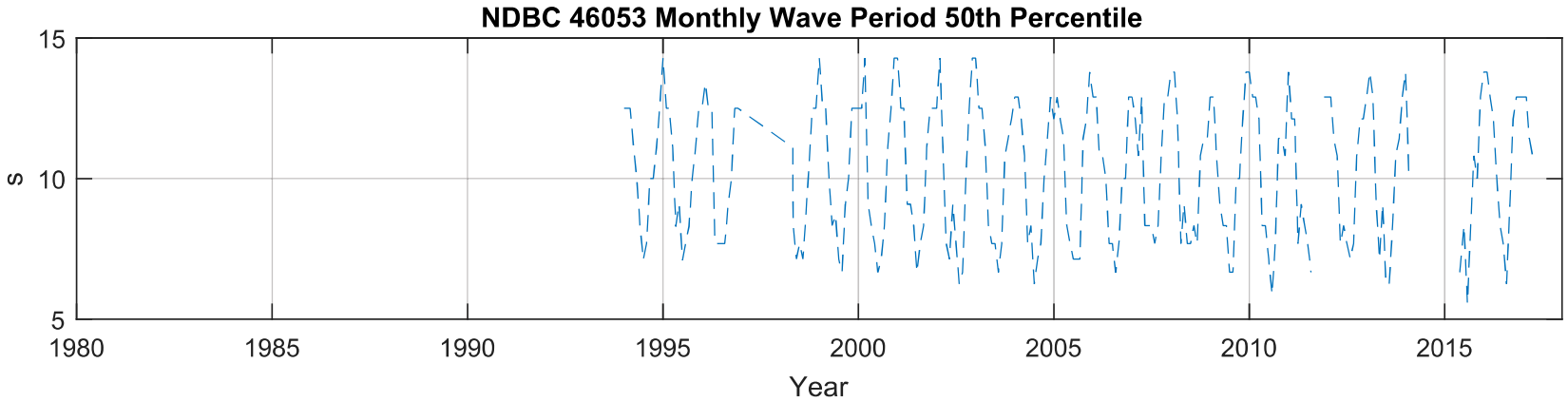


Figure A117. Monthly Wave Period, Max, Mean, Min,NDBC 46053





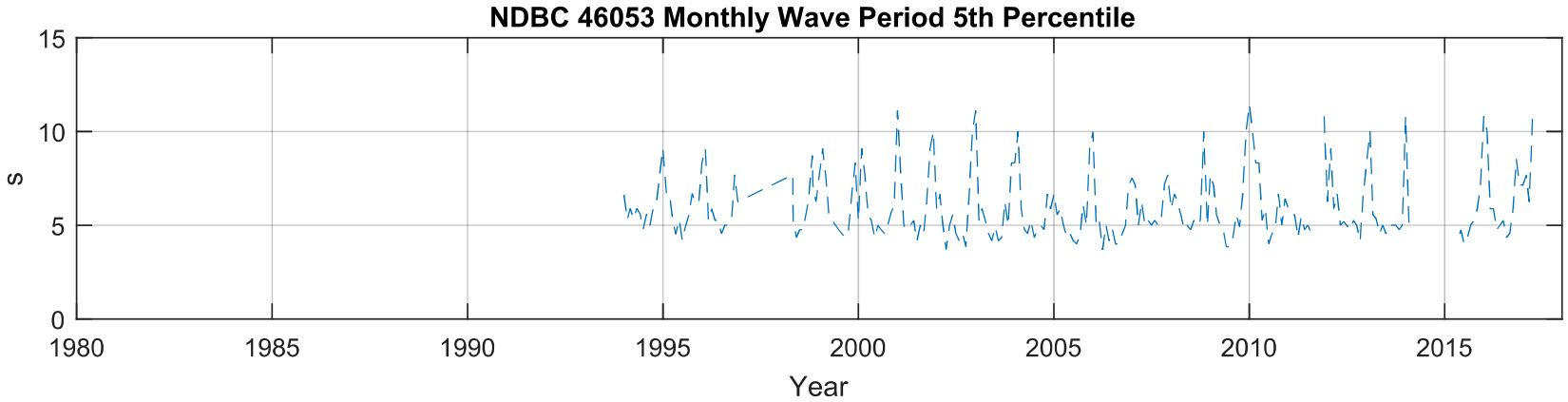


Figure A118. Monthly Wave Period, Percentiles,NDBC 46053

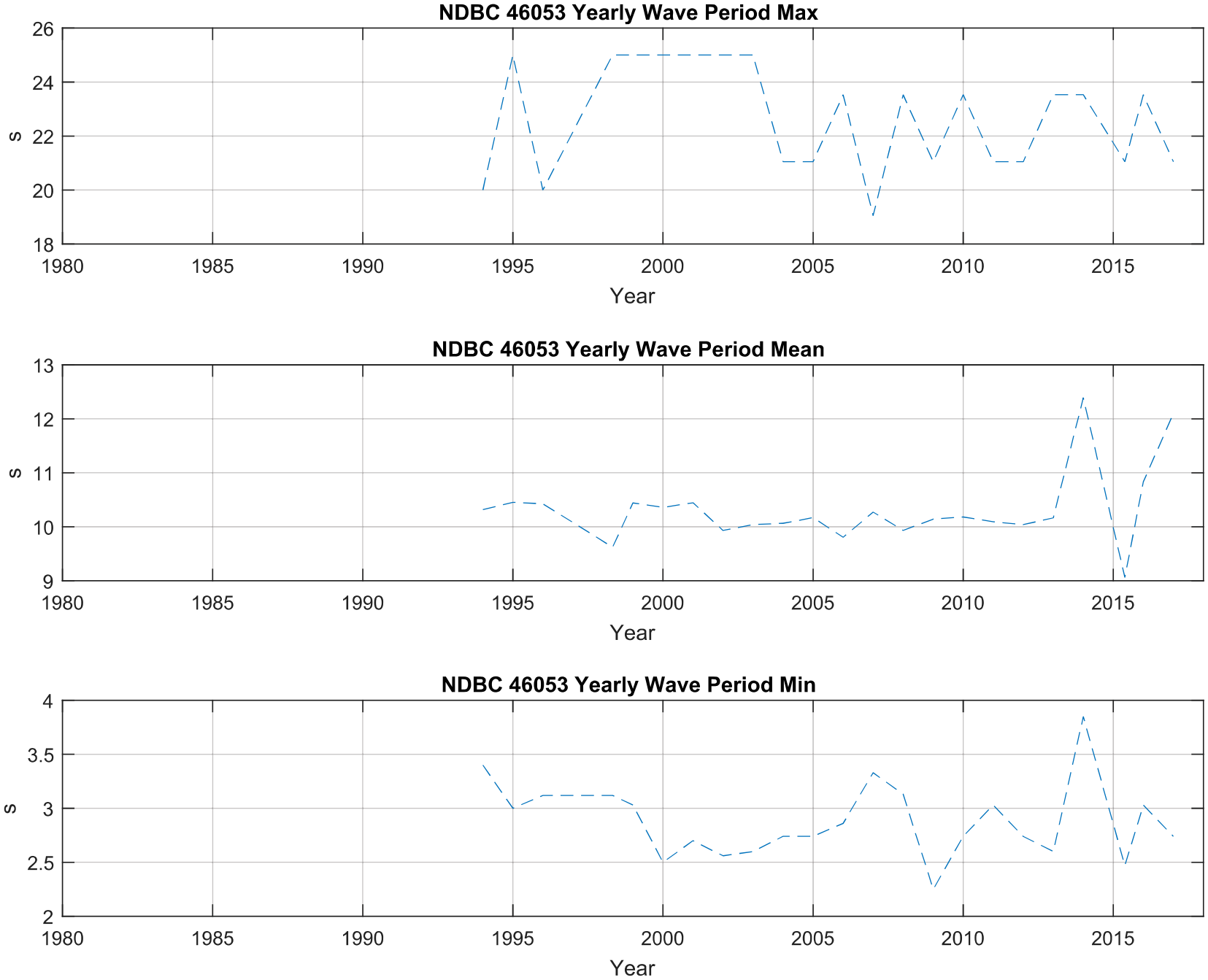
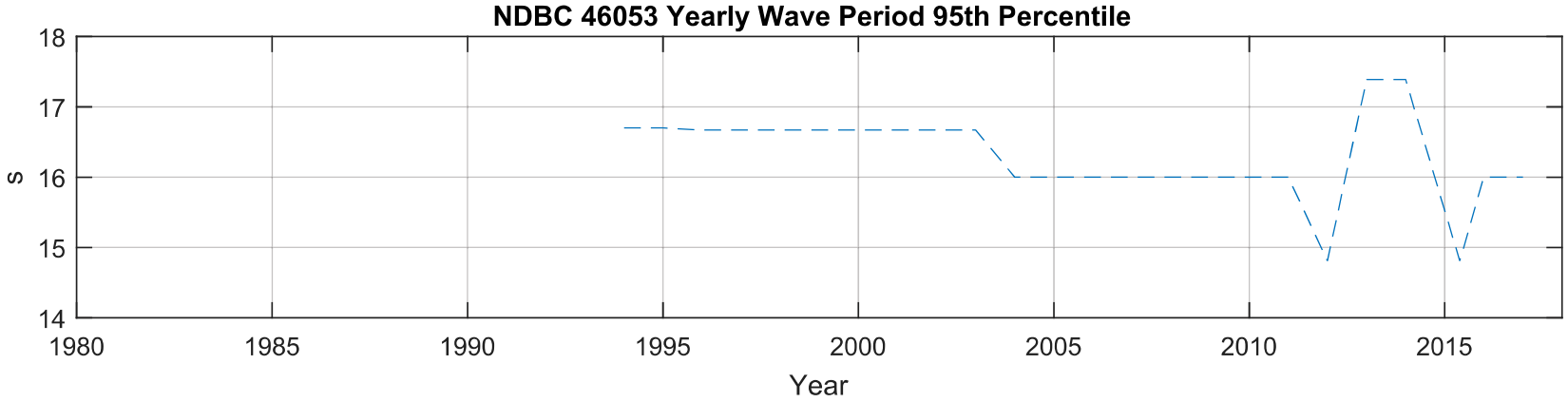
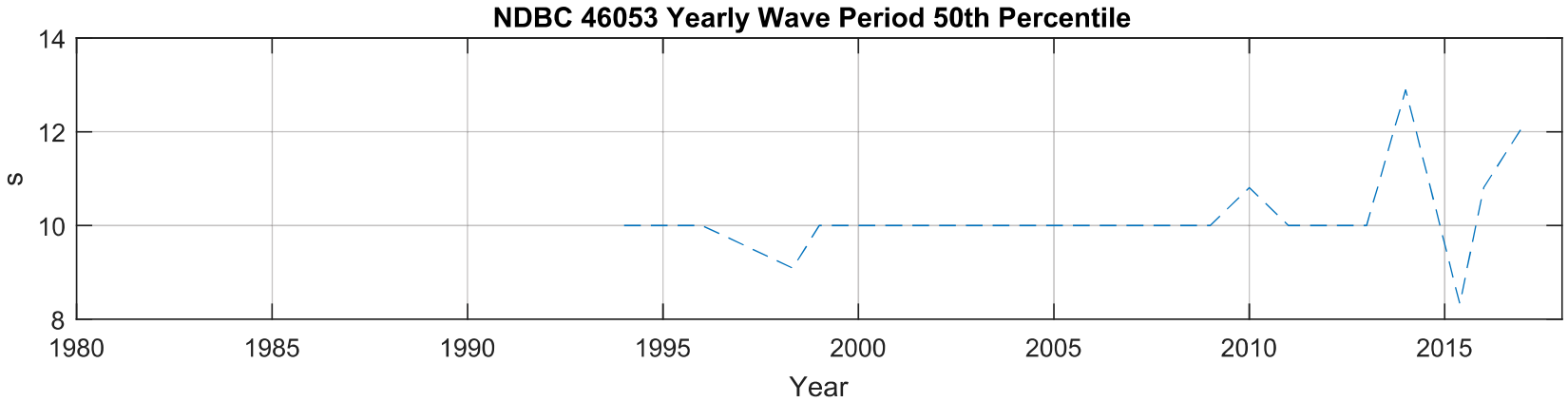


Figure A119. Yearly Wave Period, Max, Mean, Min,NDBC 46053





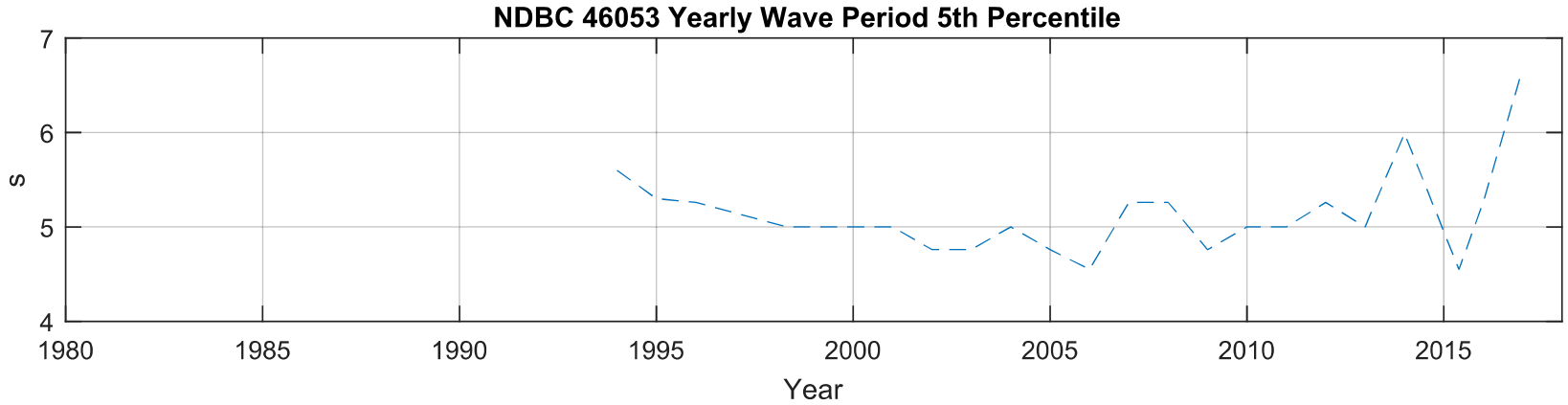


Figure A120. Yearly Wave Period, Percentiles,NDBC 46053

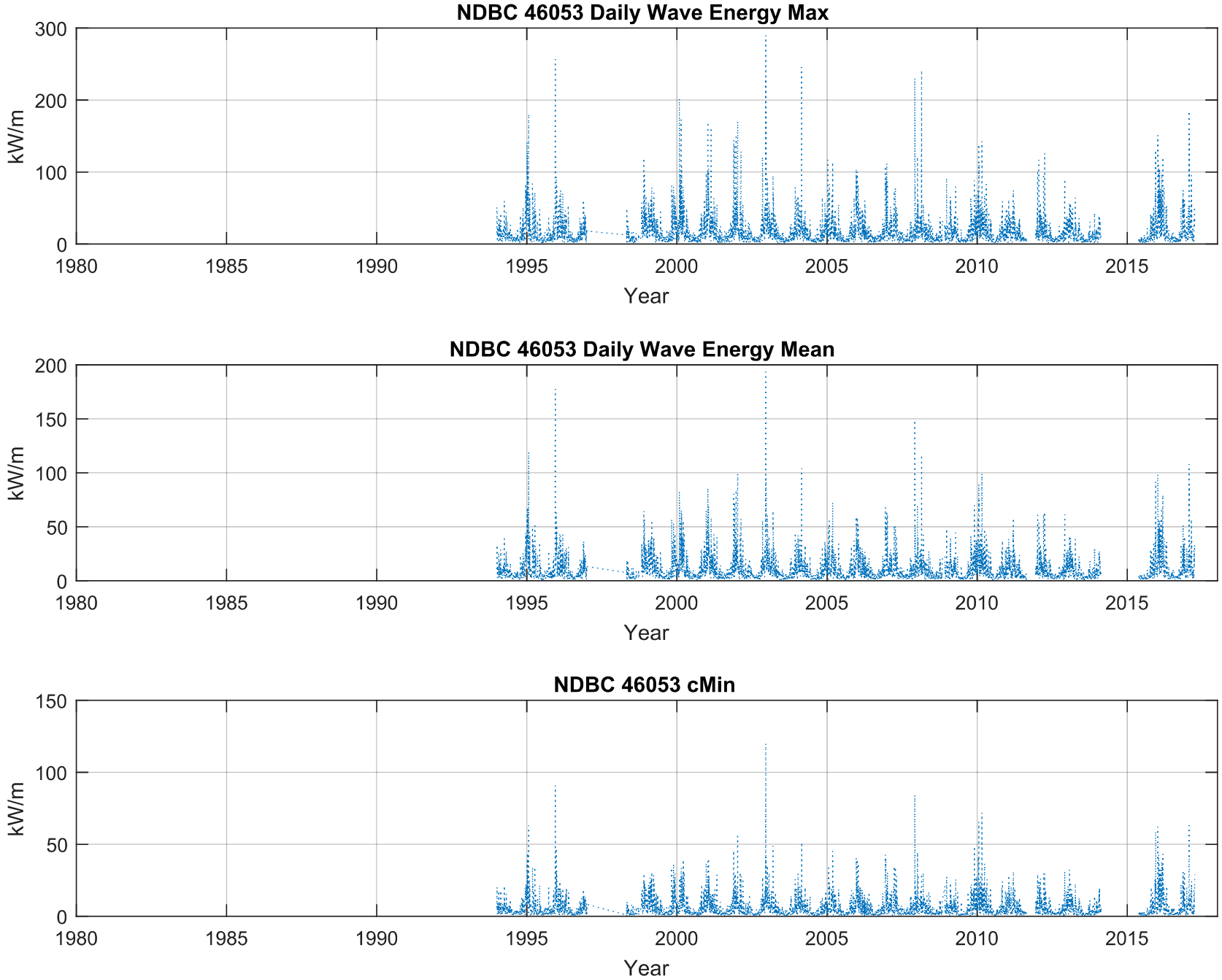
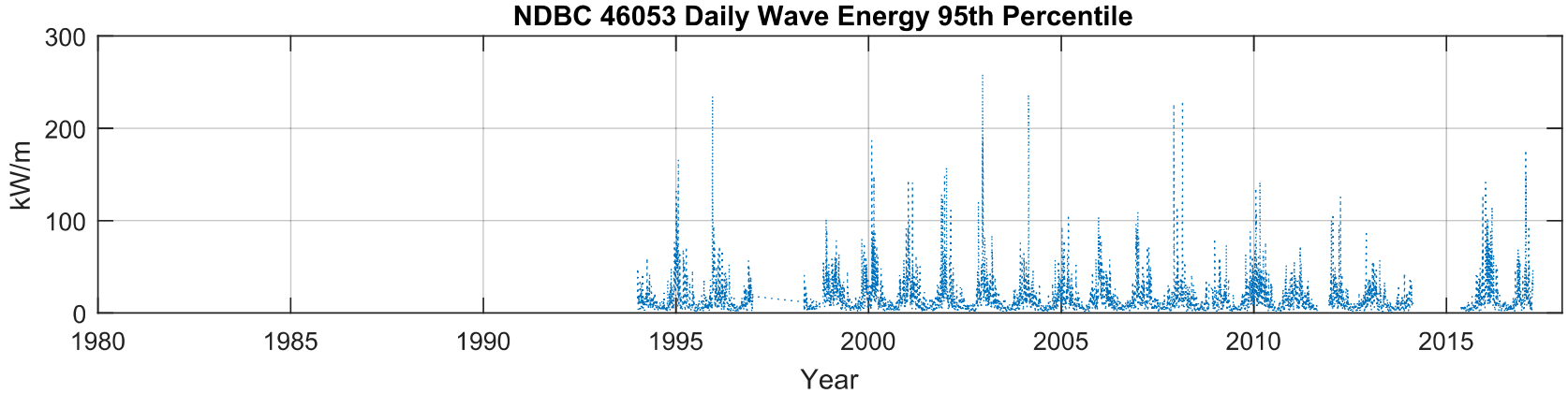
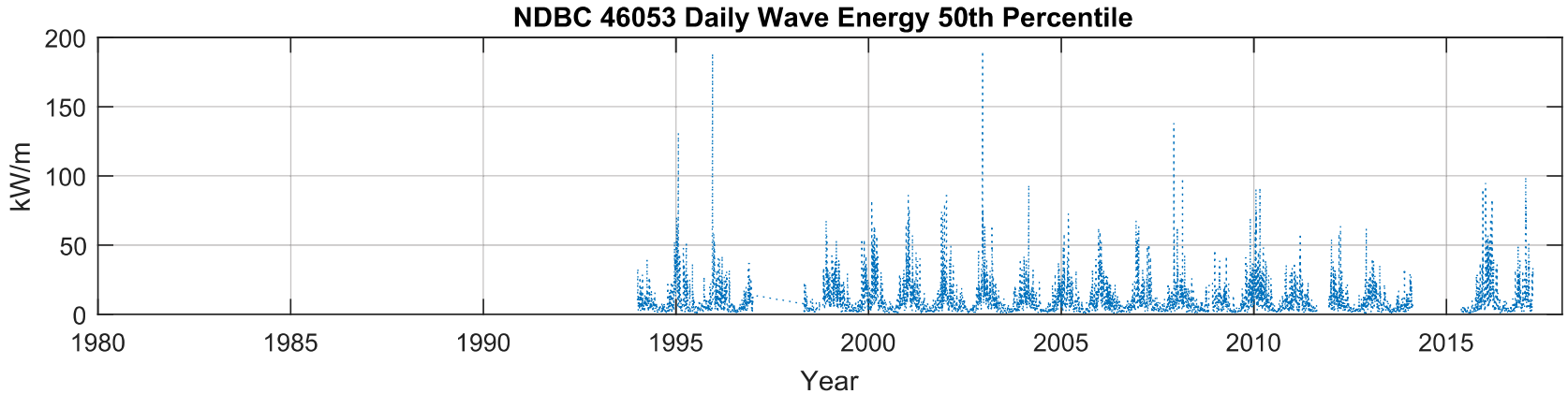


Figure A121. Daily Wave Energy, Max, Mean, Min,NDBC 46053





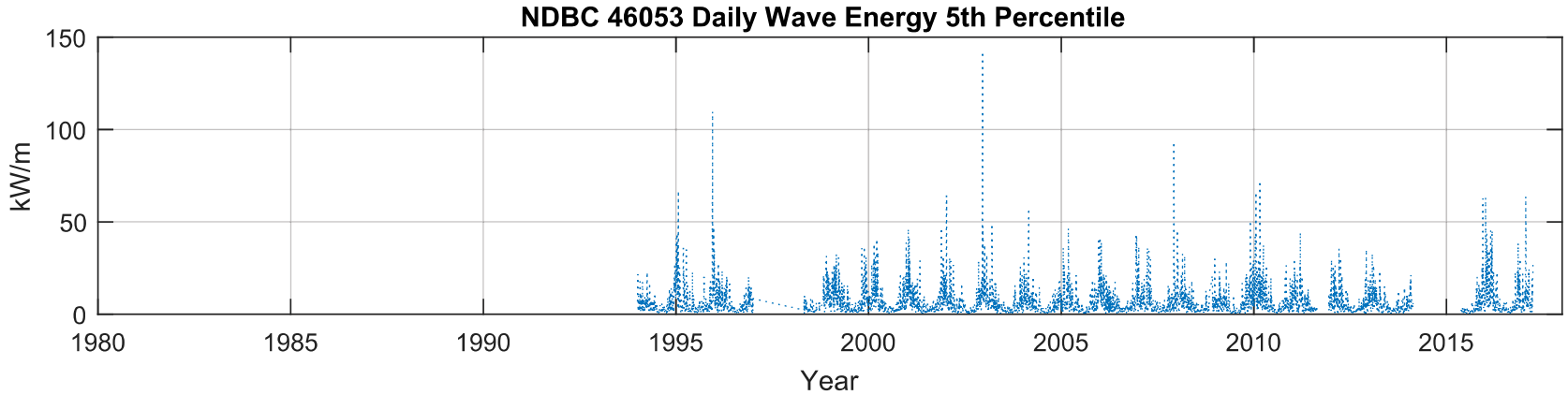


Figure A122. Daily Wave Energy, Percentiles,NDBC 46053

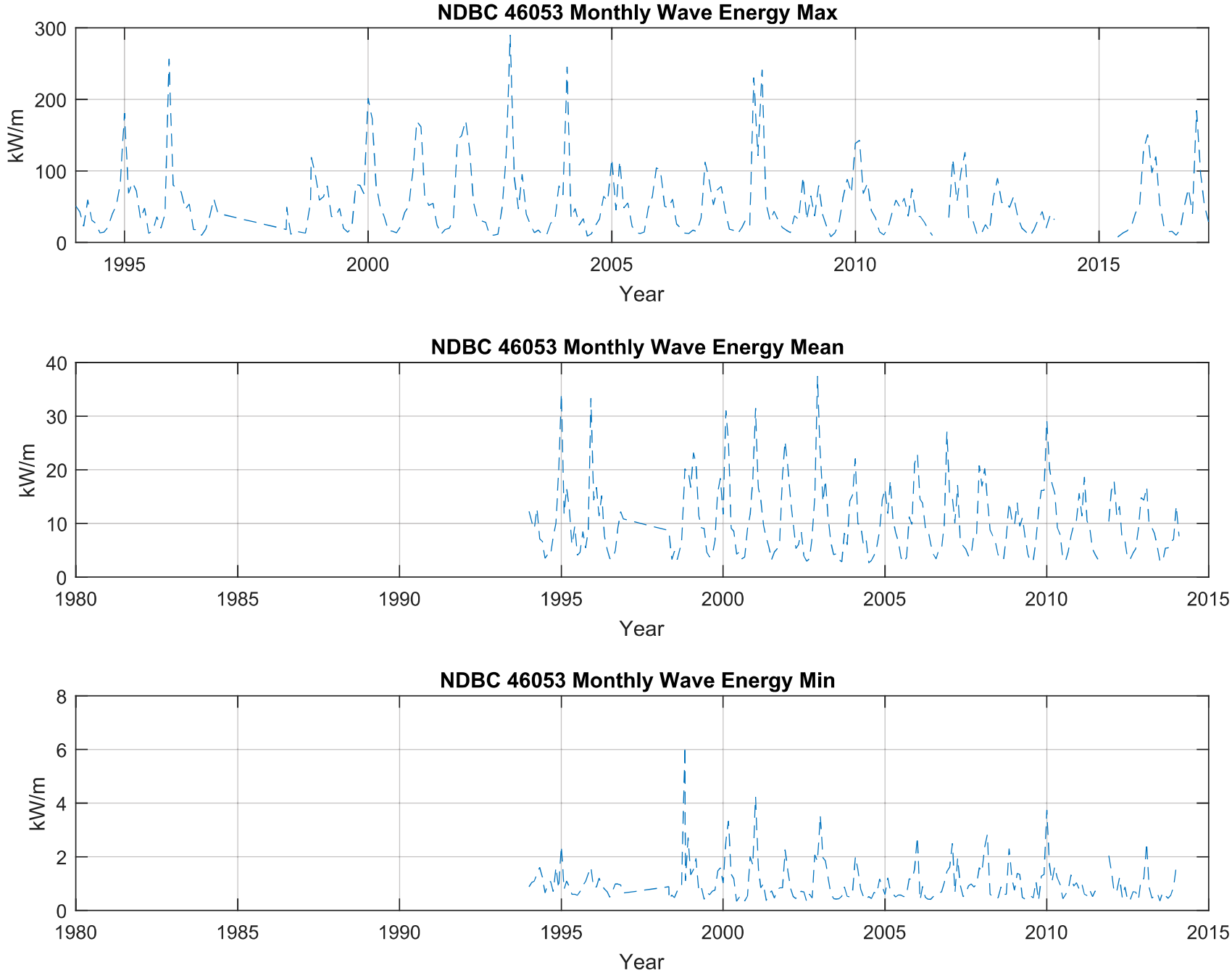
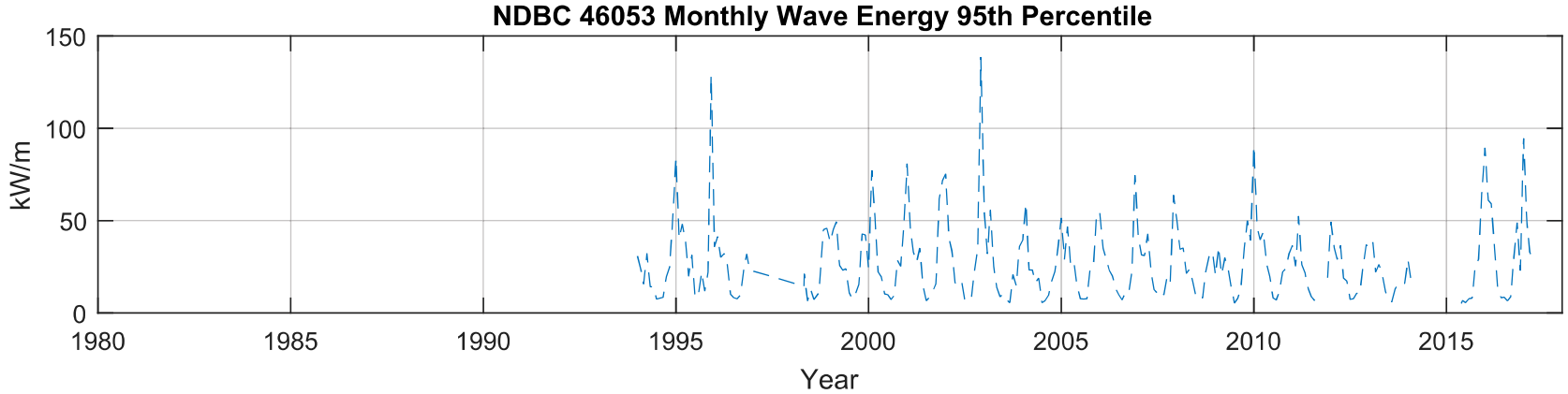
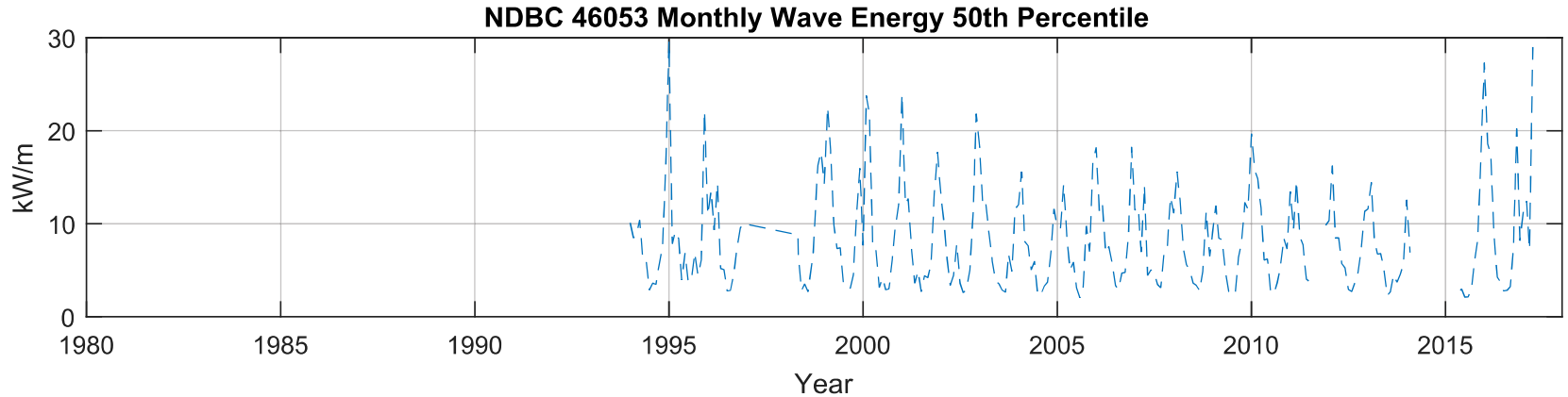


Figure A123. Monthly Wave Energy, Max, Mean, Min,NDBC 46053





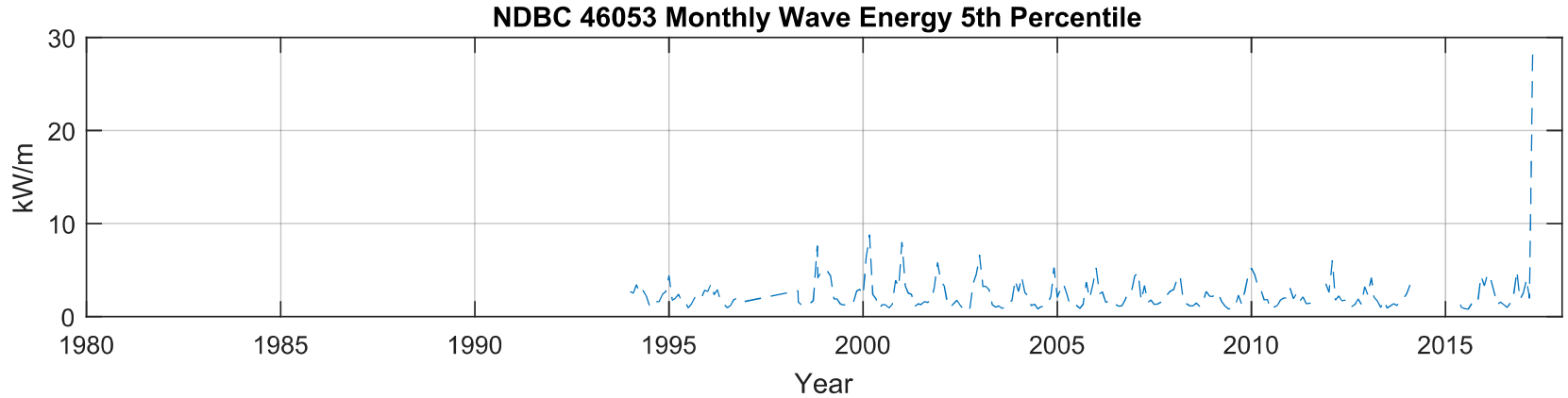


Figure A124. Monthly Wave Energy, Percentiles,NDBC 46053

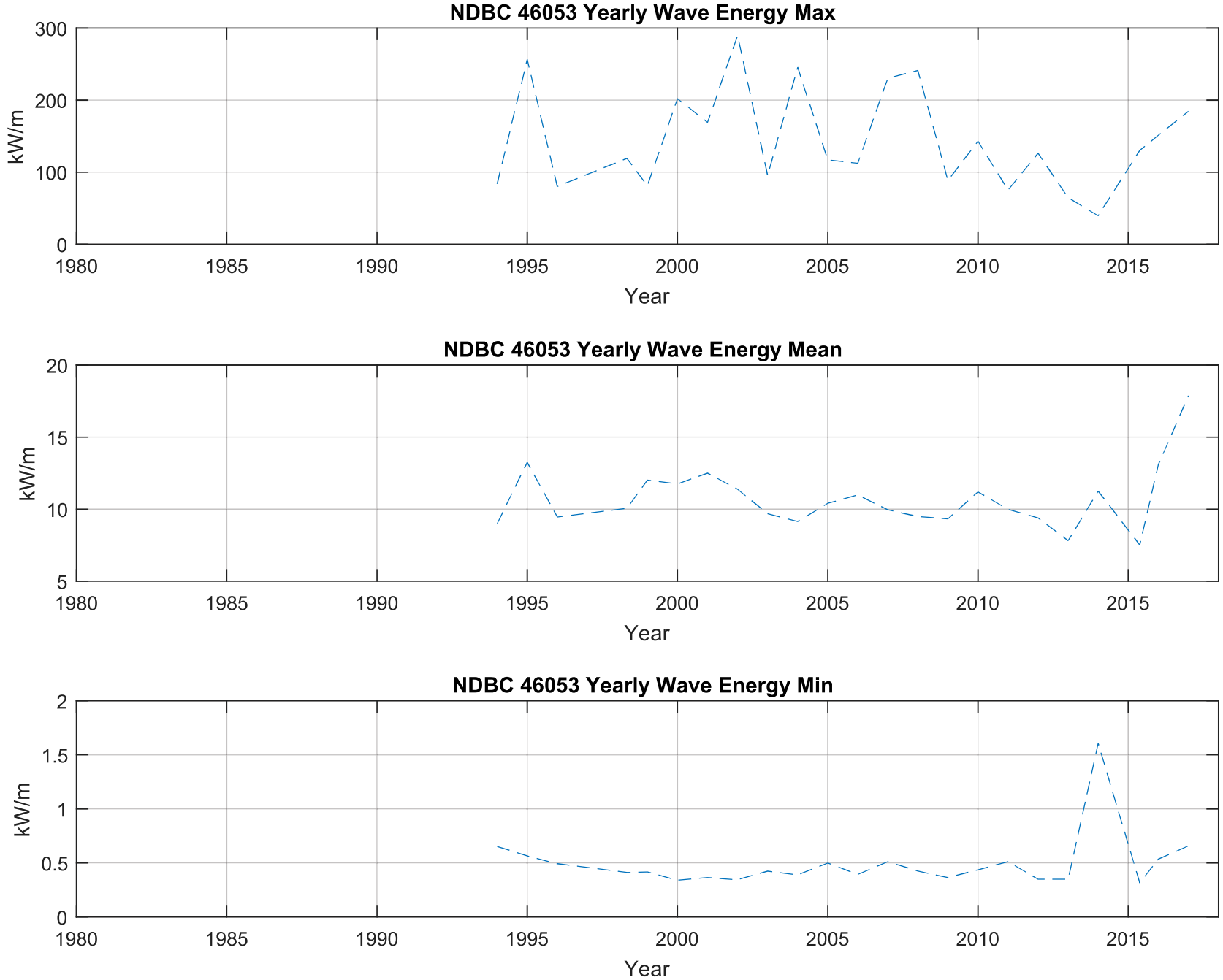
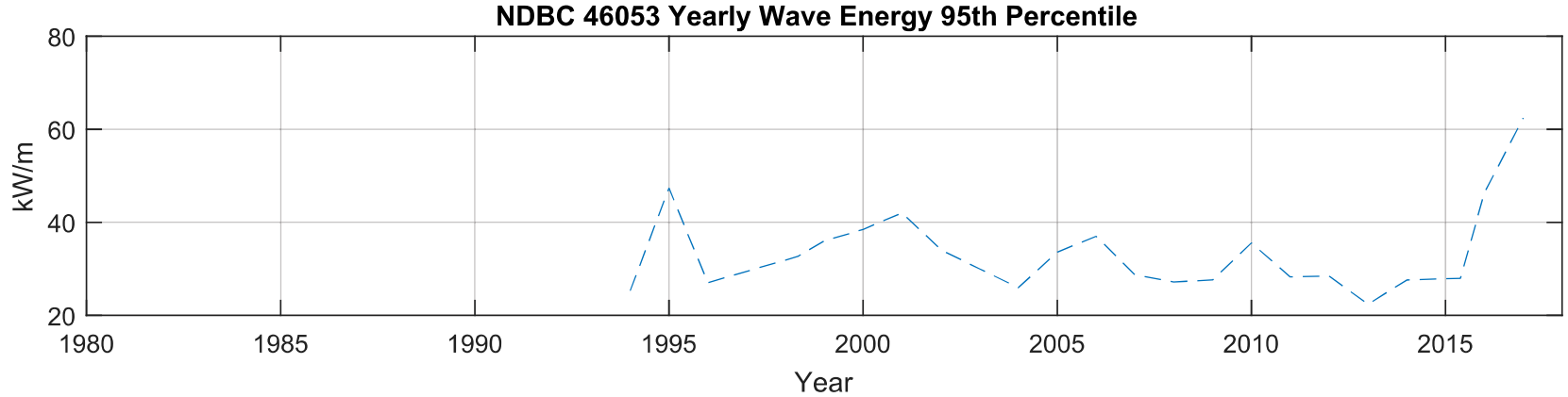
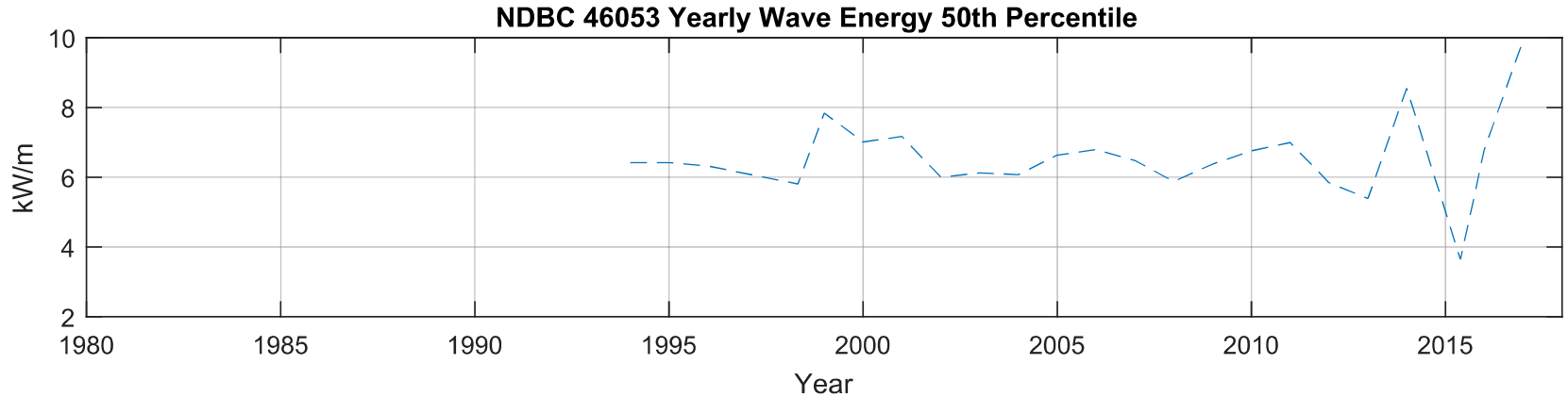


Figure A125. Yearly Wave Energy, Max, Mean, Min,NDBC 46053





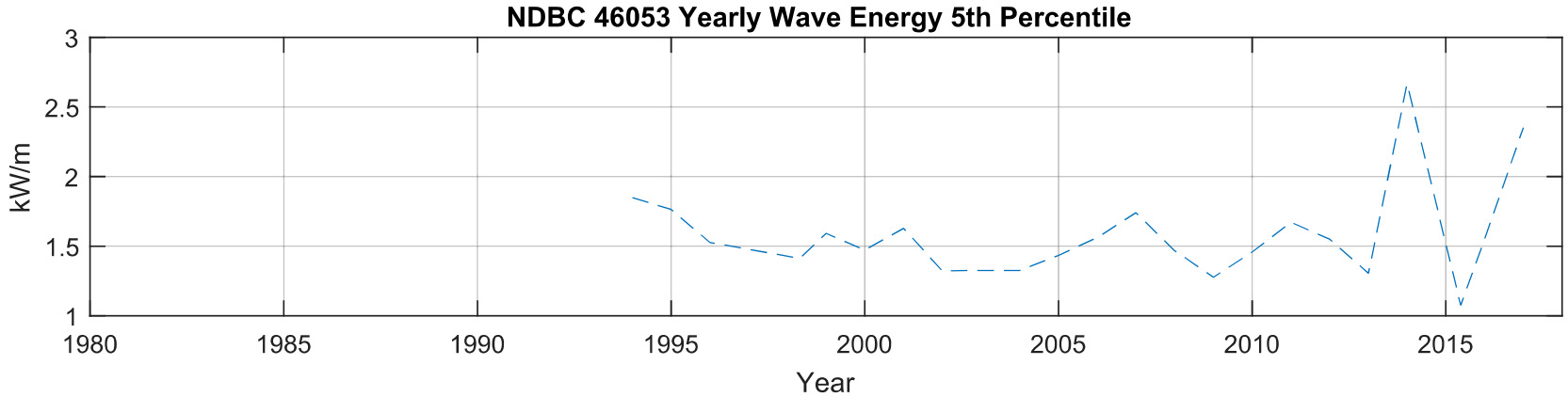


Figure A126. Yearly Wave Energy, Percentiles,NDBC 46053

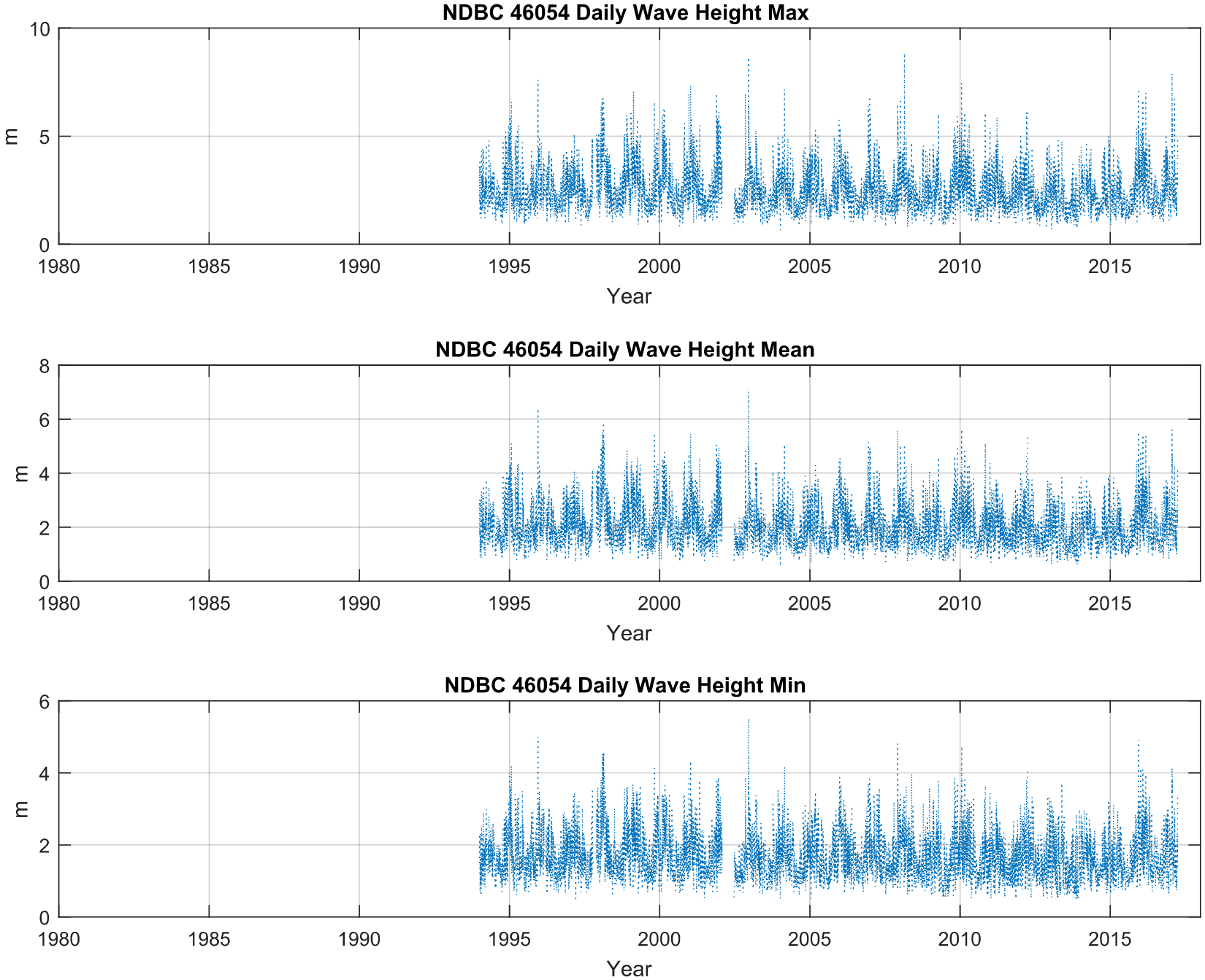


Figure A127. Daily Wave Height, Max, Mean, Min,NDBC 46054

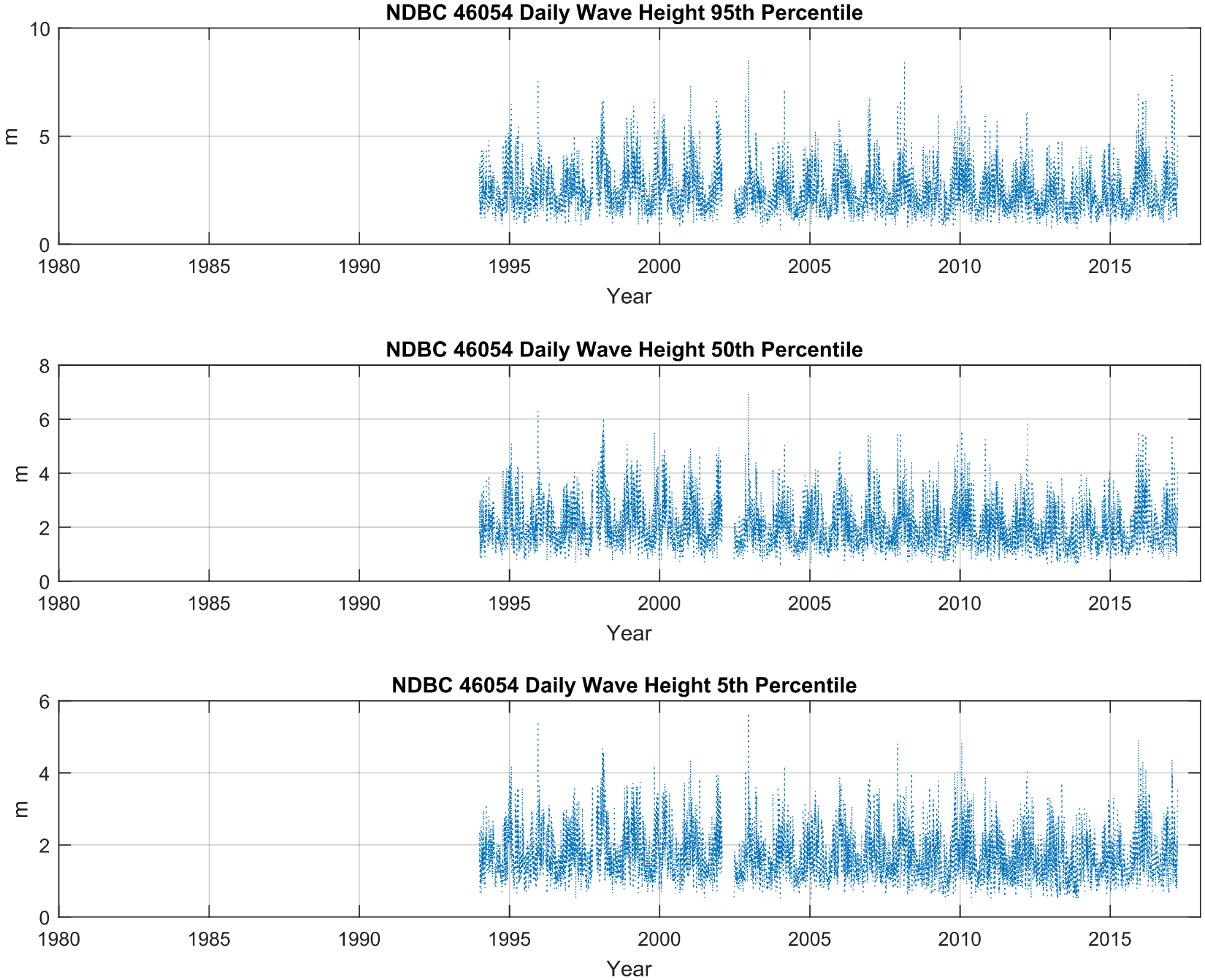


Figure A128. Daily Wave Height, Percentiles,NDBC 46054

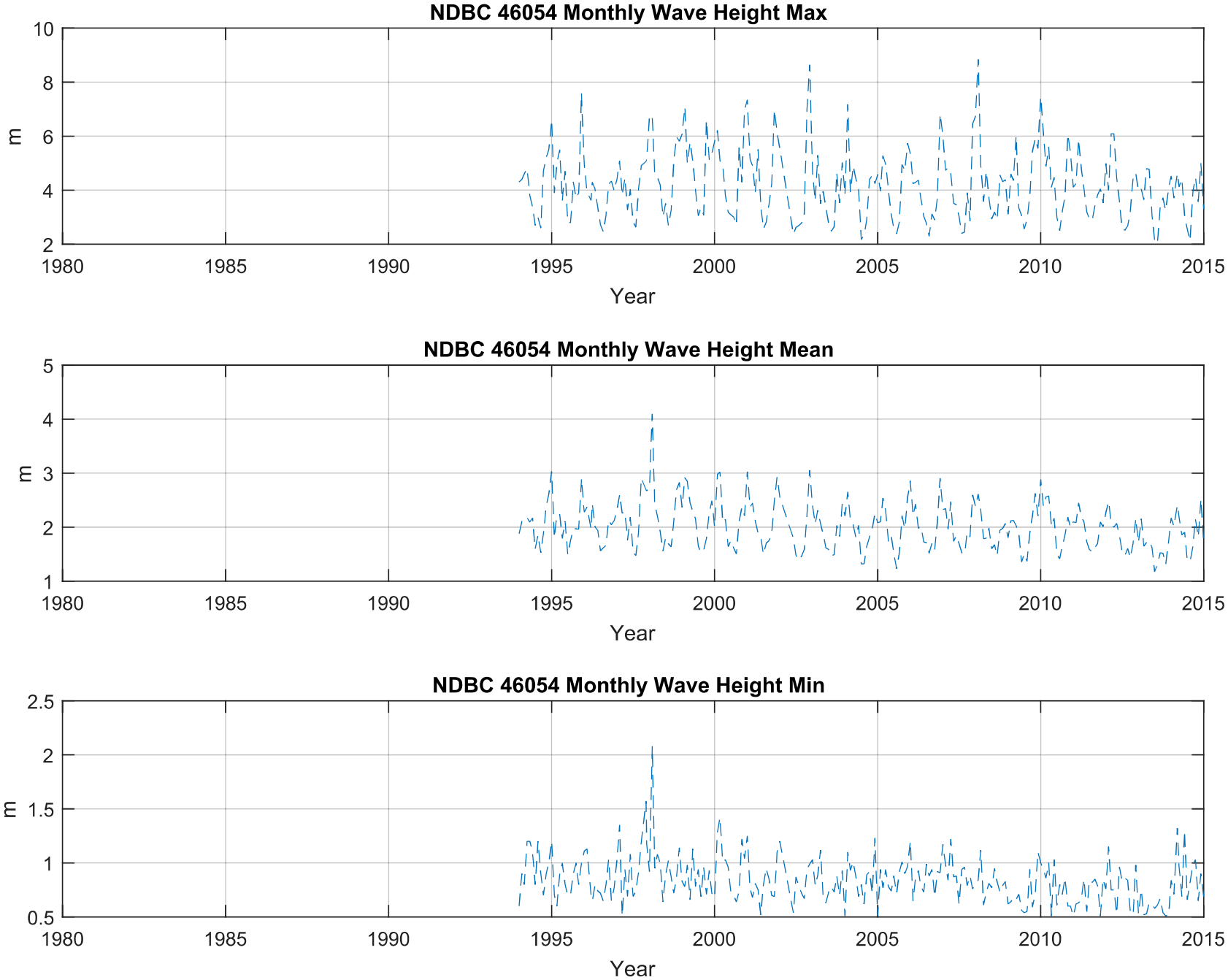
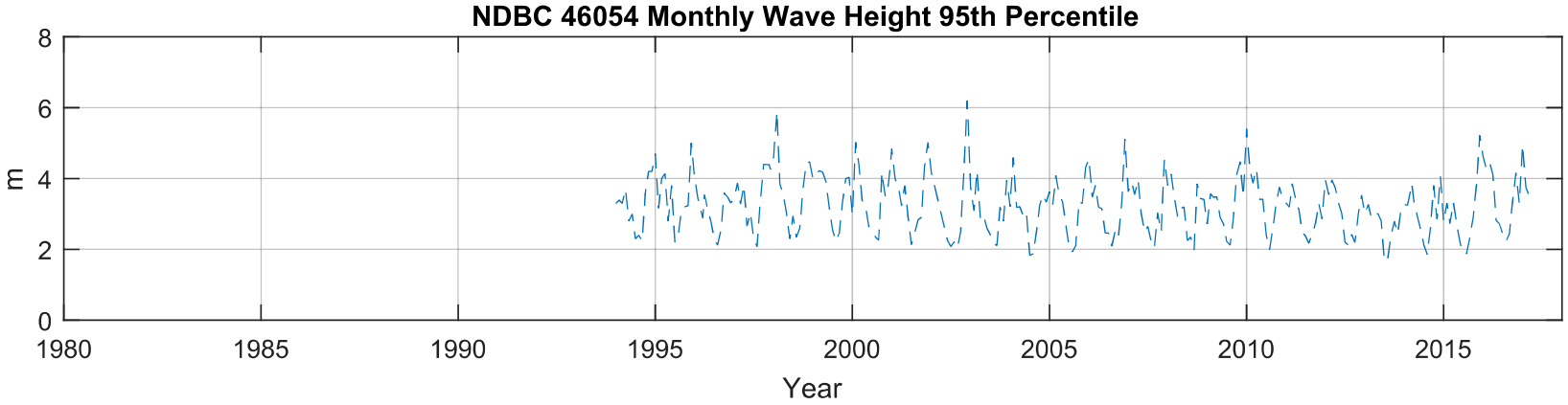
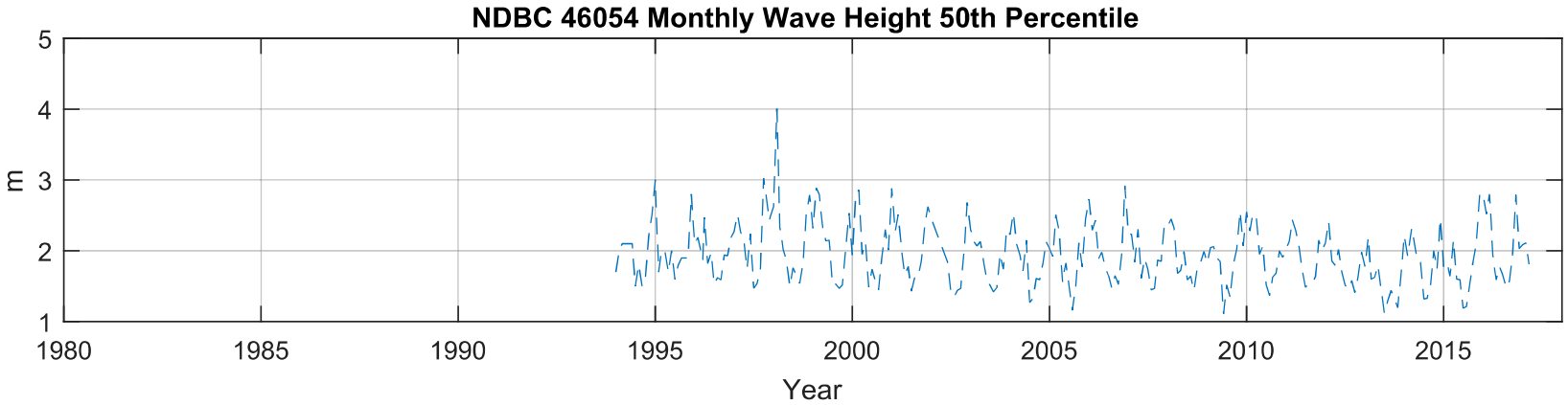


Figure A129. Monthly Wave Height, Max, Mean, Min,NDBC 46054





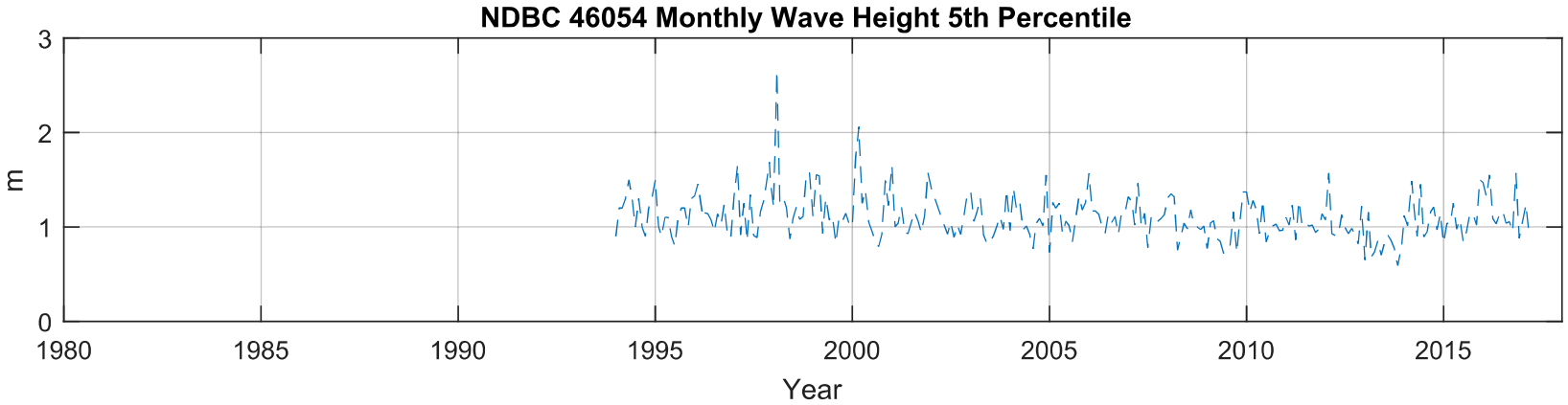


Figure A130. Monthly Wave Height, Percentiles,NDBC 46054

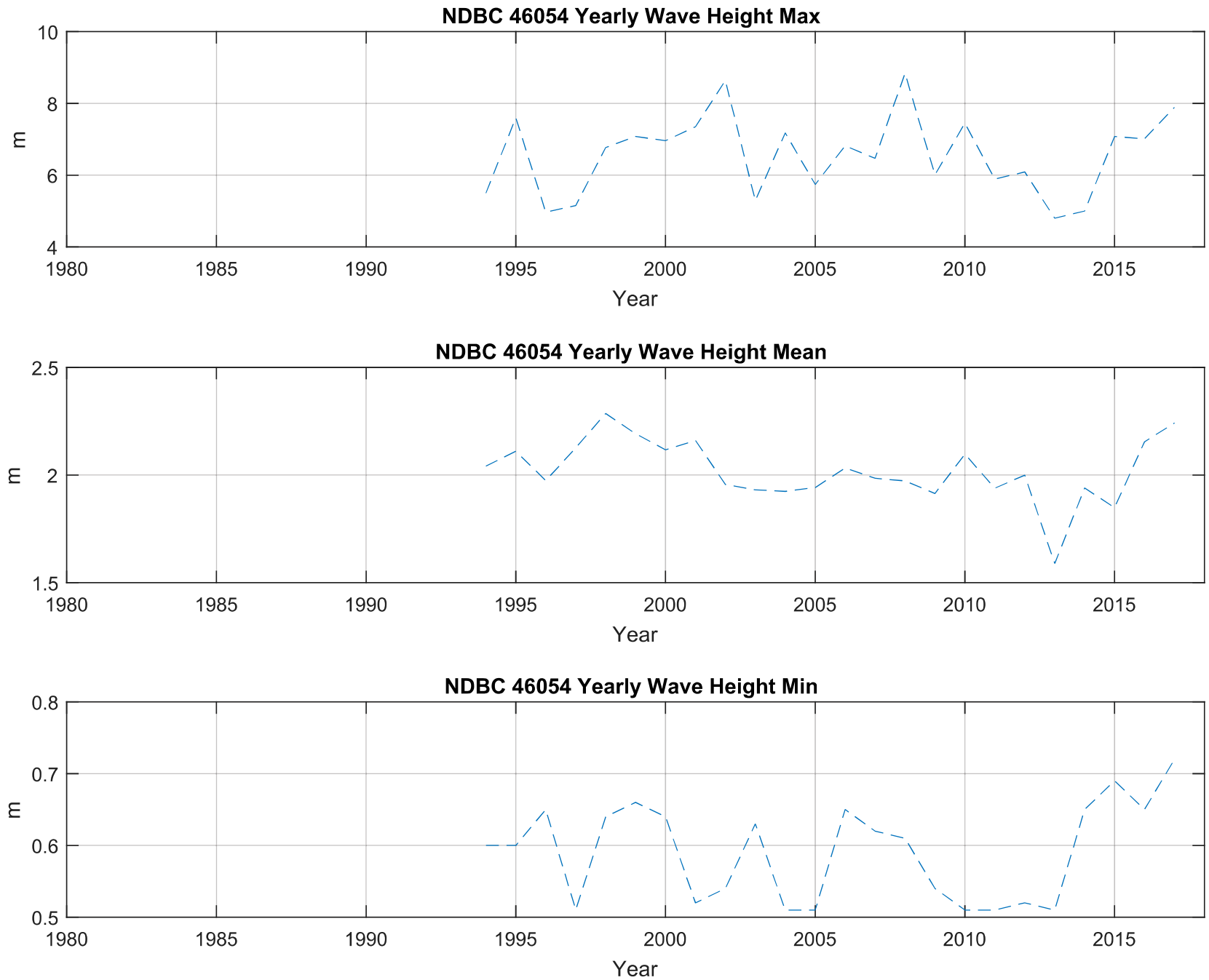


Figure A131. Yearly Wave Height, Max, Mean, Min,NDBC 46054

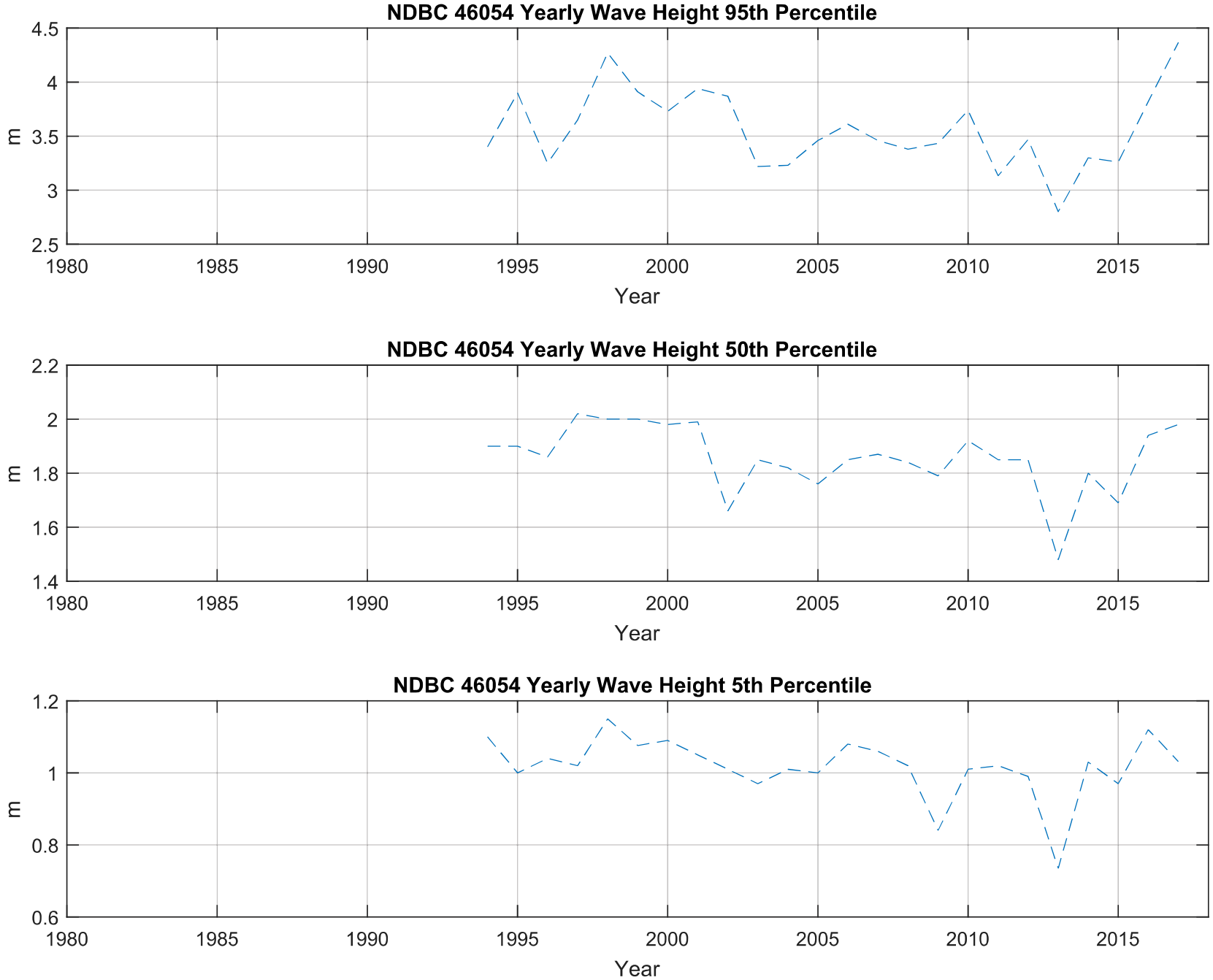


Figure A132. Yearly Wave Height, Percentiles,NDBC 46054

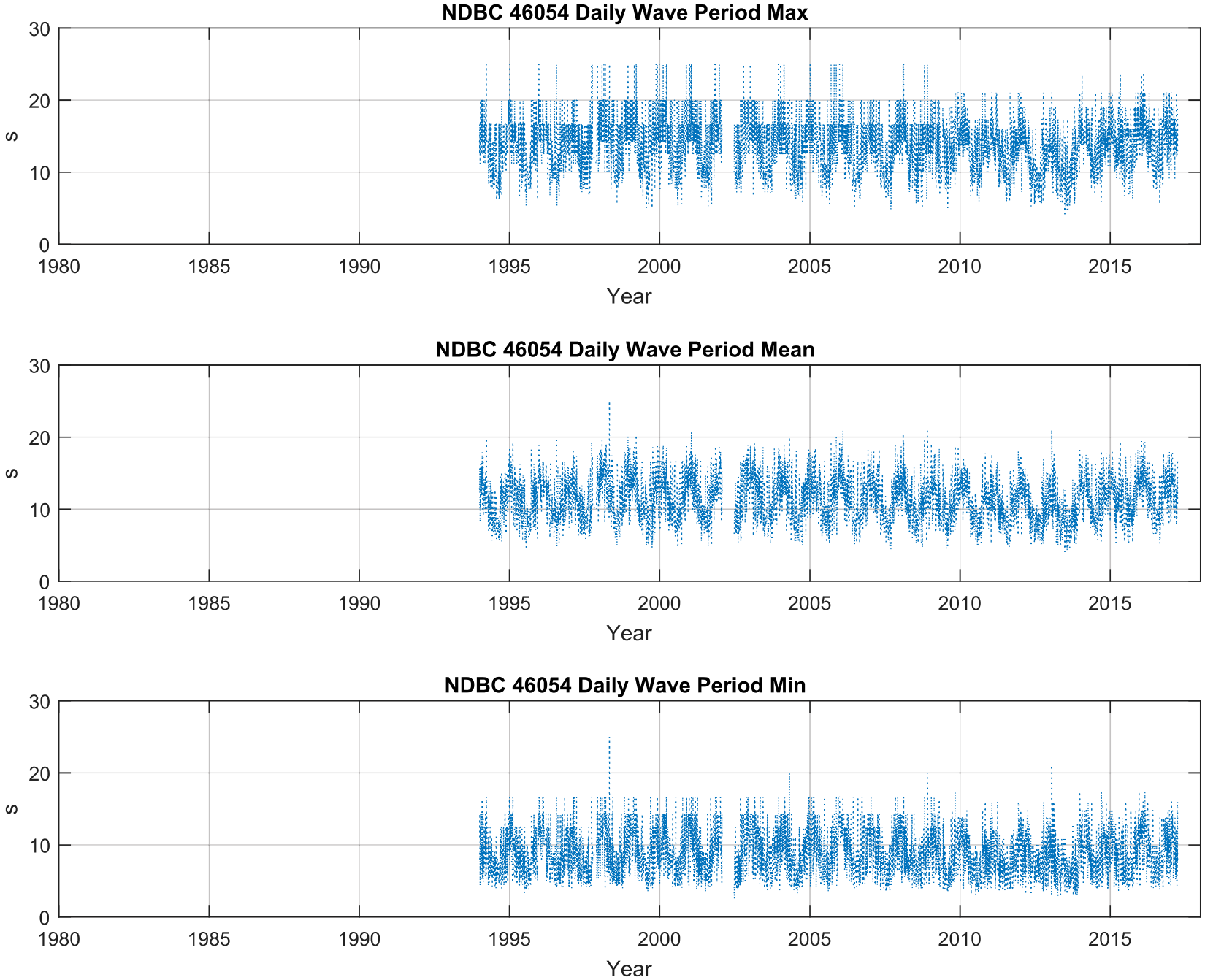
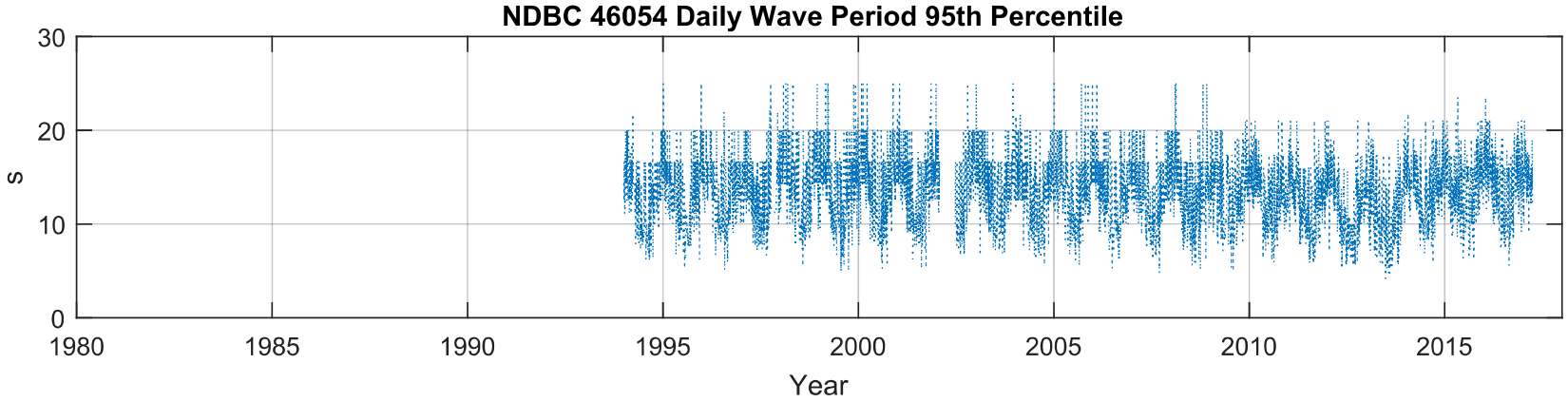
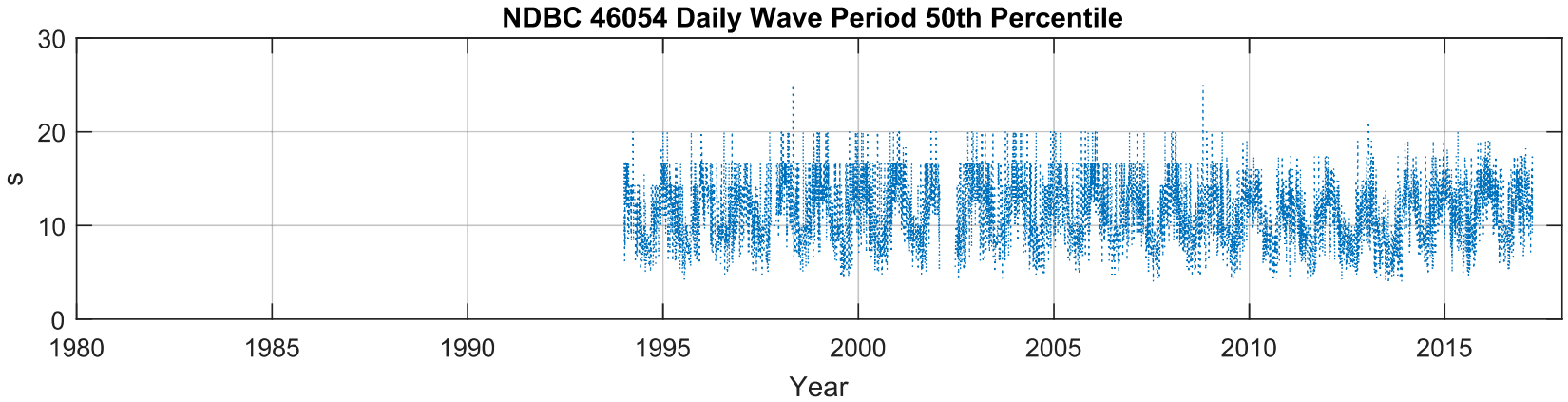


Figure A133. Daily Wave Period, Max, Mean, Min,NDBC 46054





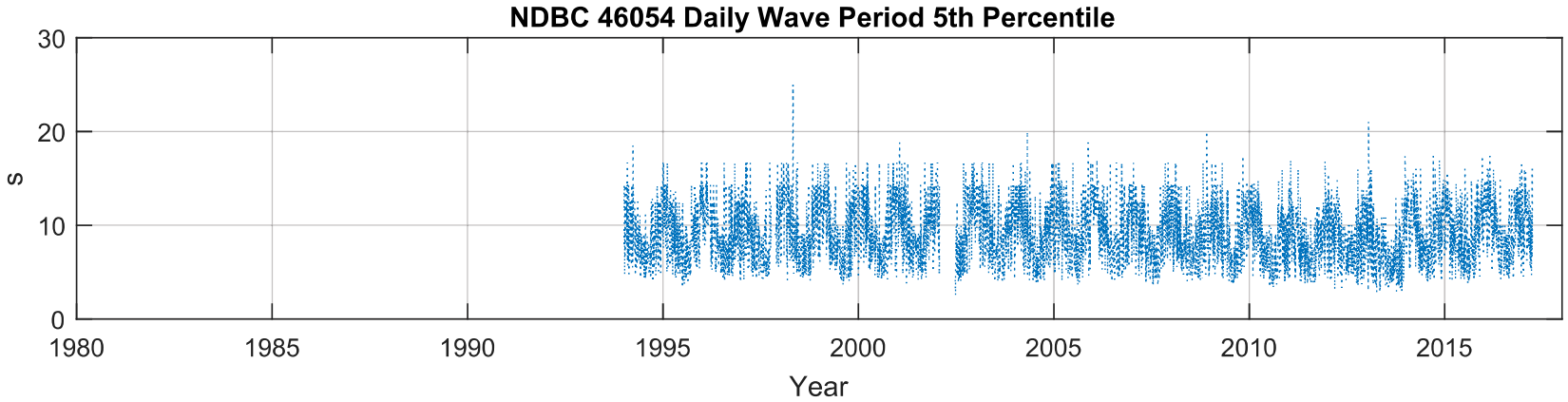
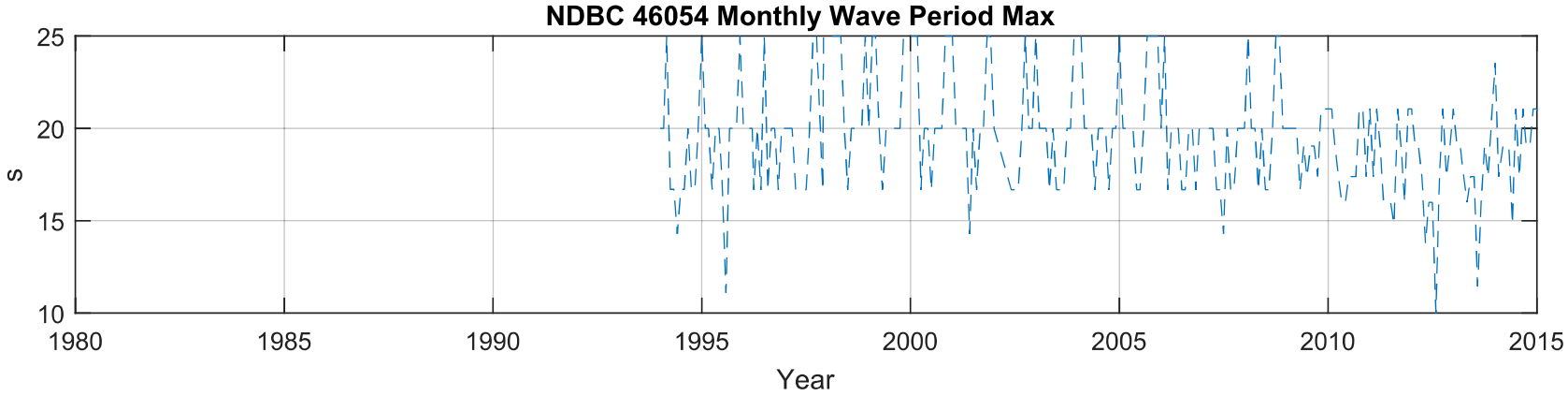
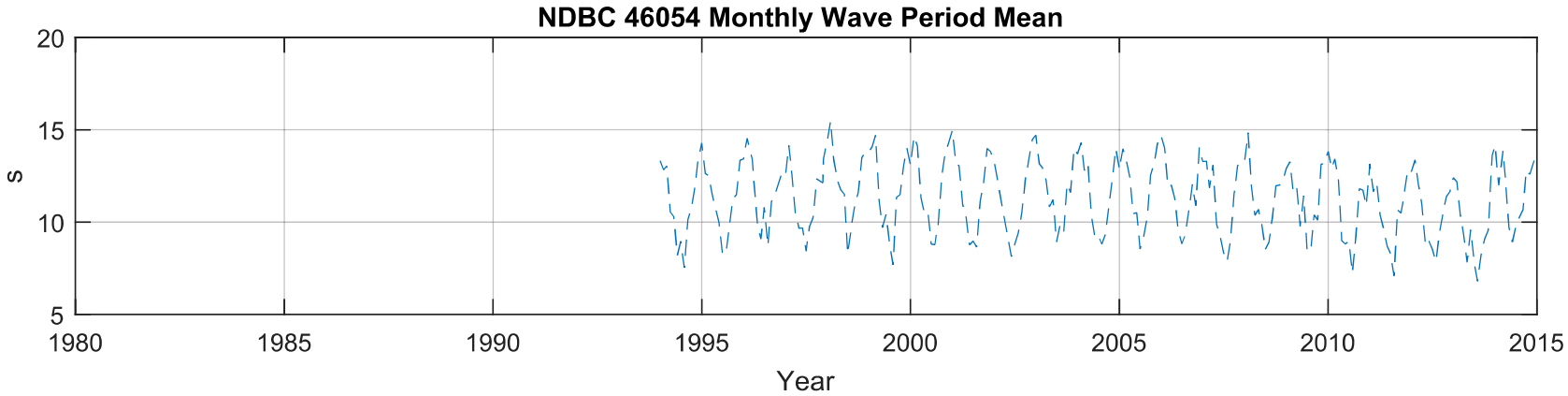


Figure A134. Daily Wave Period, Percentiles,NDBC 46054





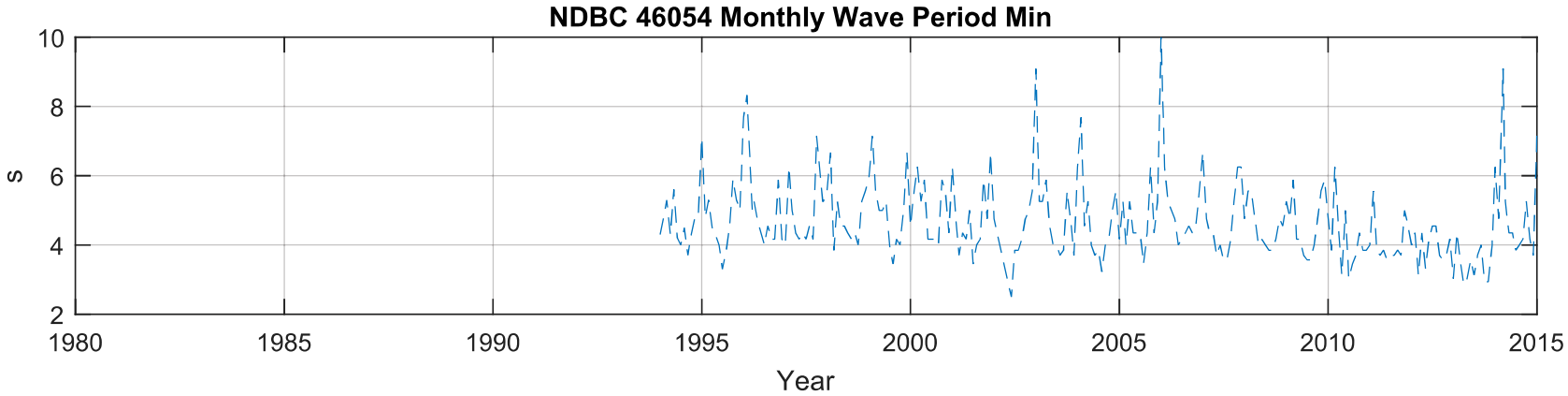
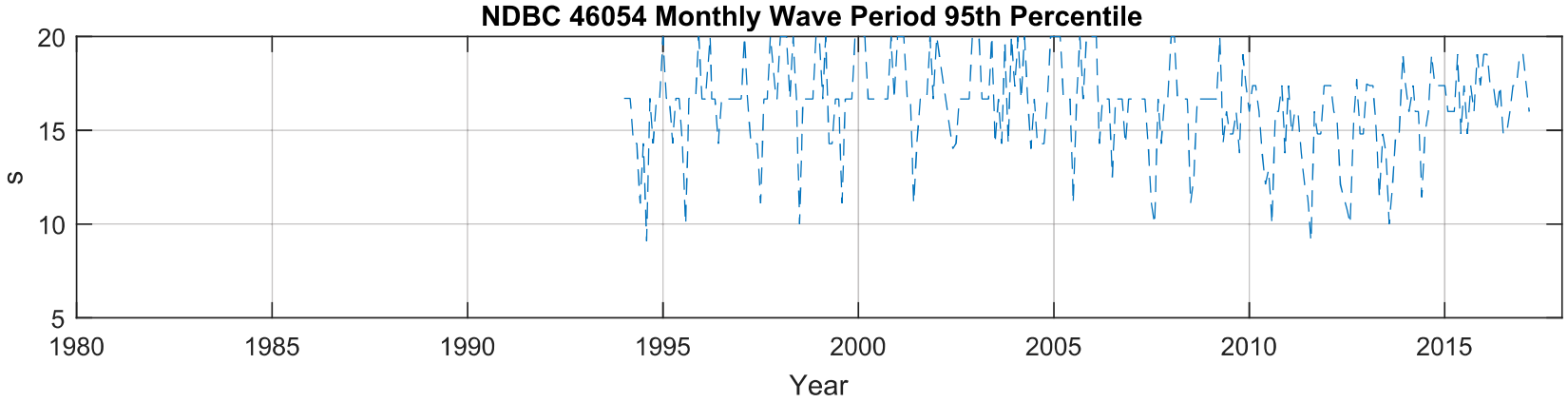
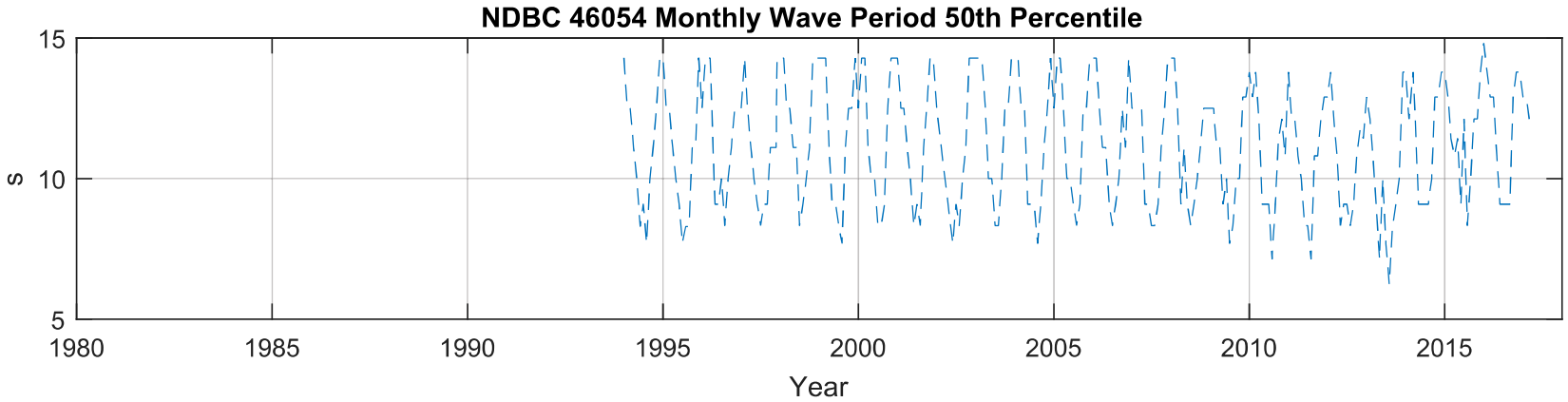


Figure A135. Monthly Wave Period, Max, Mean, Min,NDBC 46054





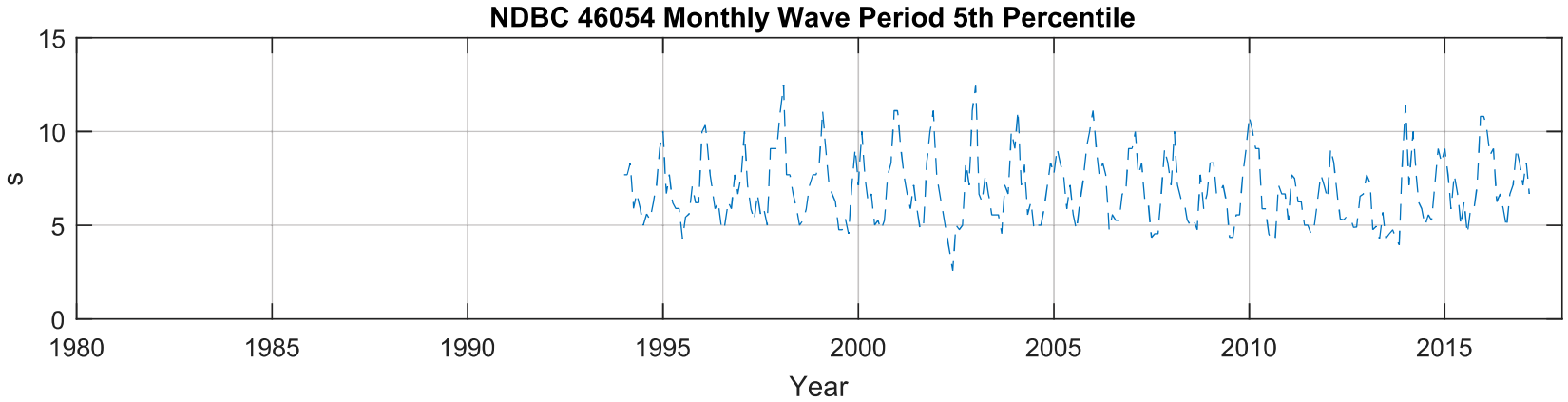


Figure A136. Monthly Wave Period, Percentiles,NDBC 46054

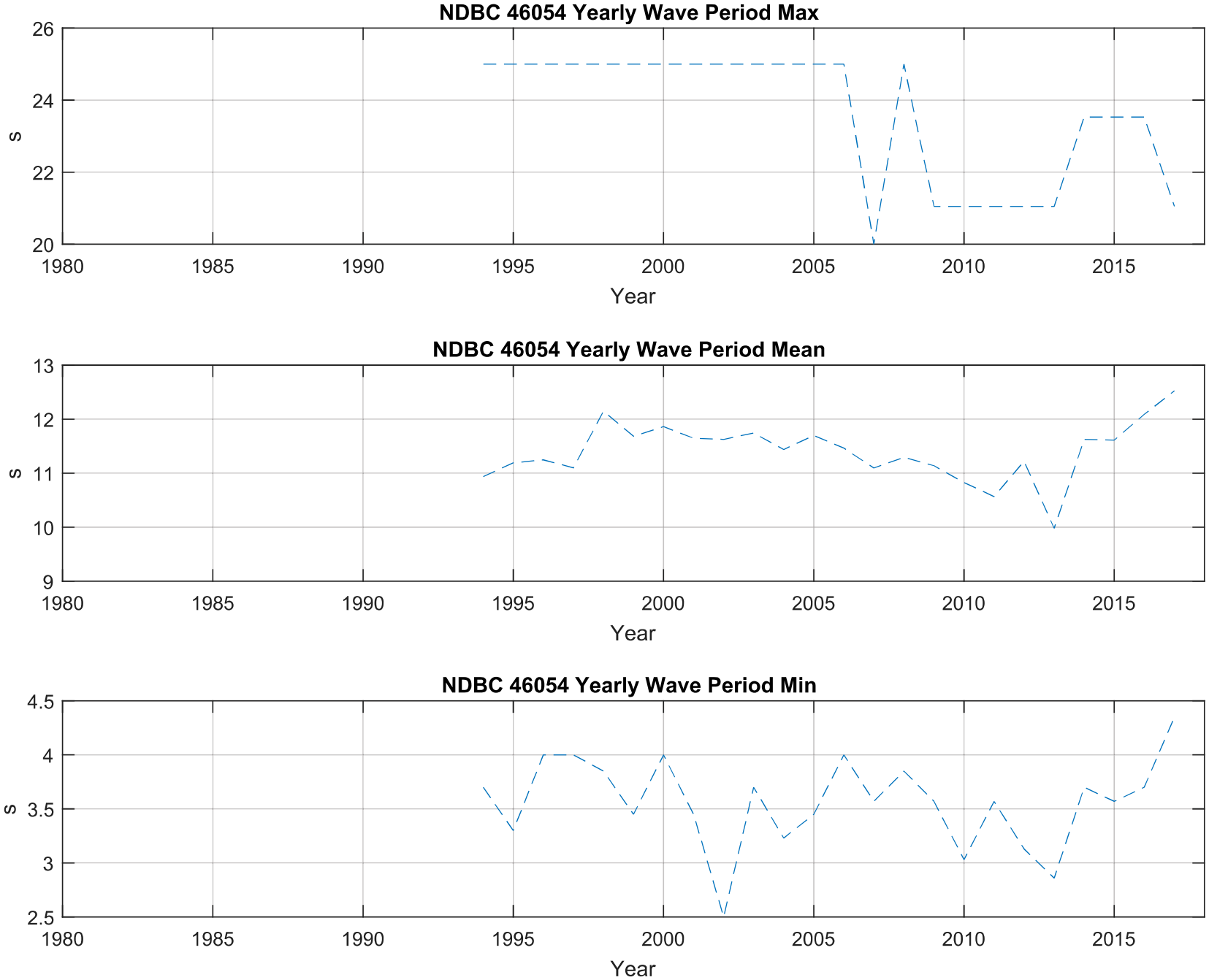
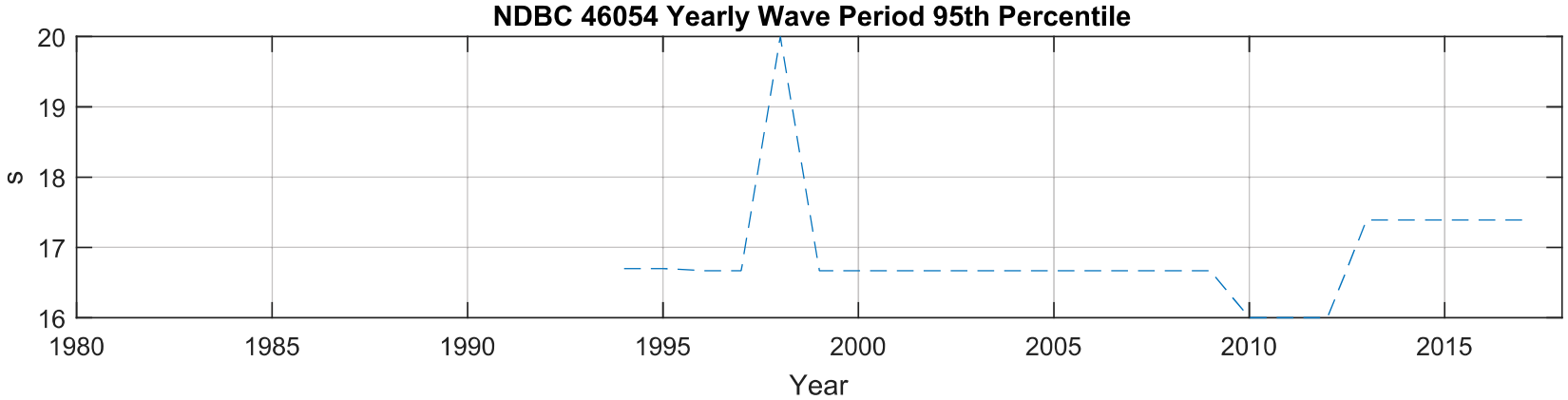
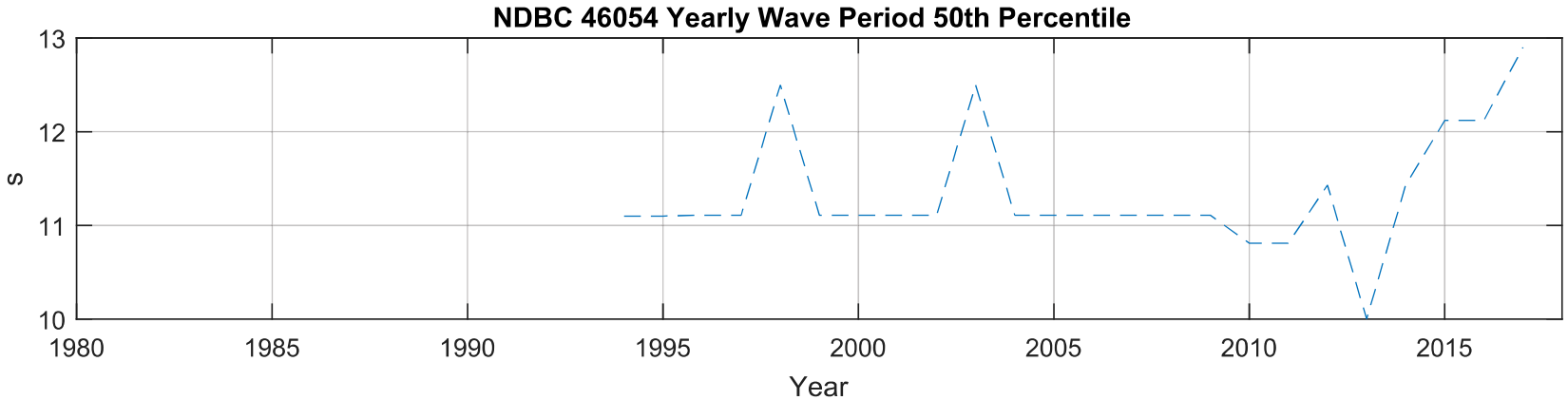


Figure A137. Yearly Wave Period, Max, Mean, Min,NDBC 46054





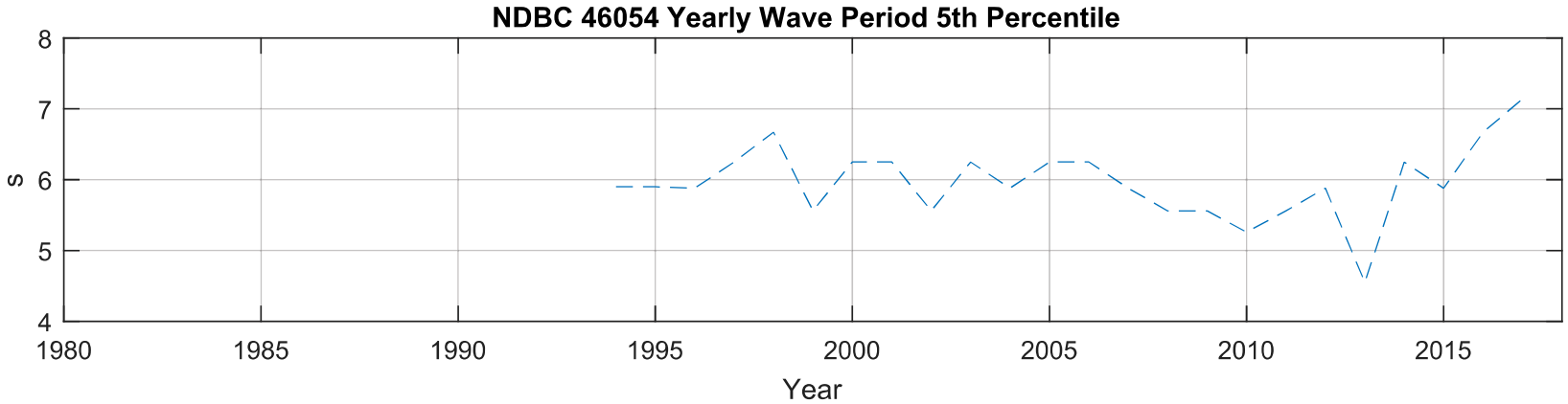


Figure A138. Yearly Wave Period, Percentiles,NDBC 46054

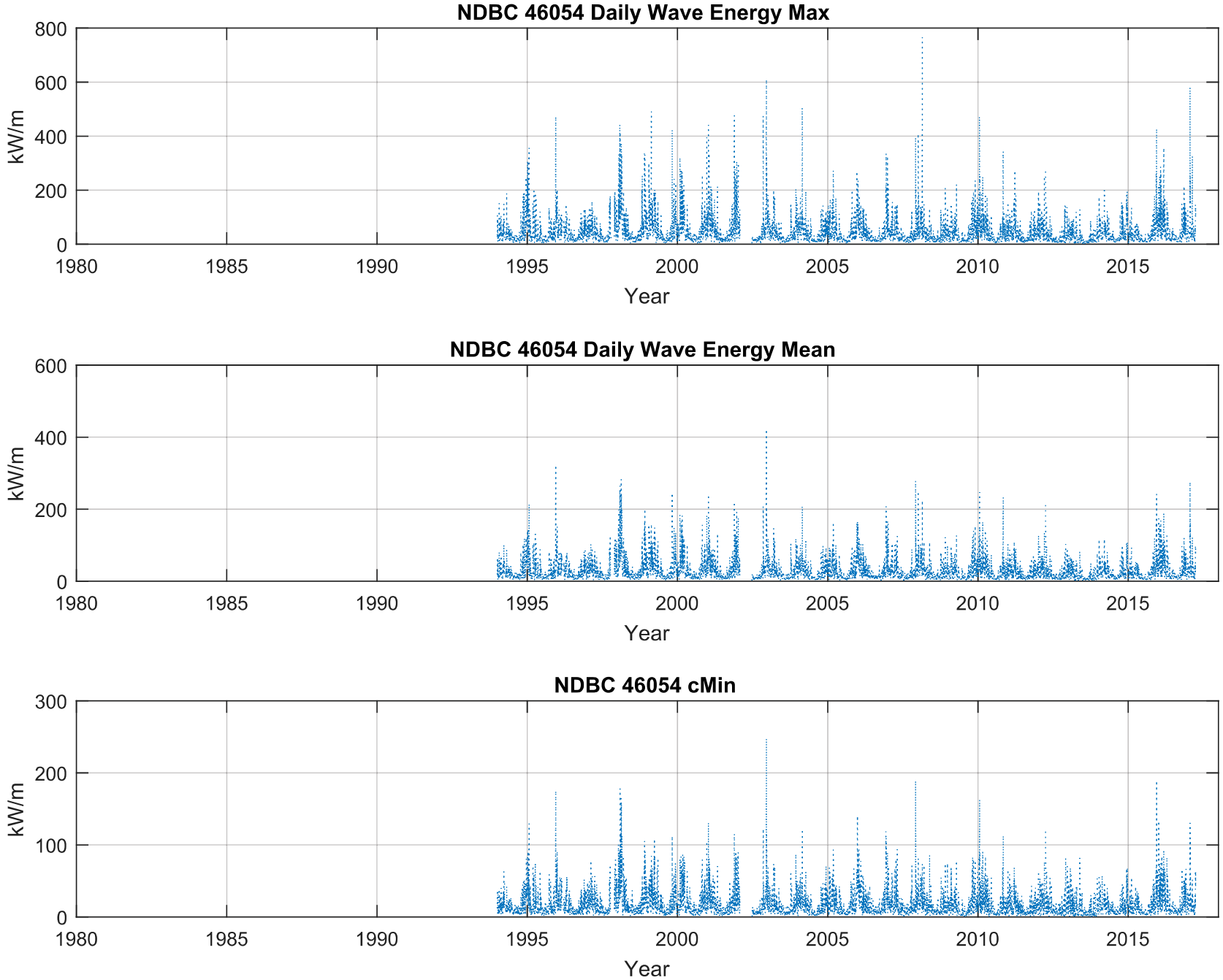
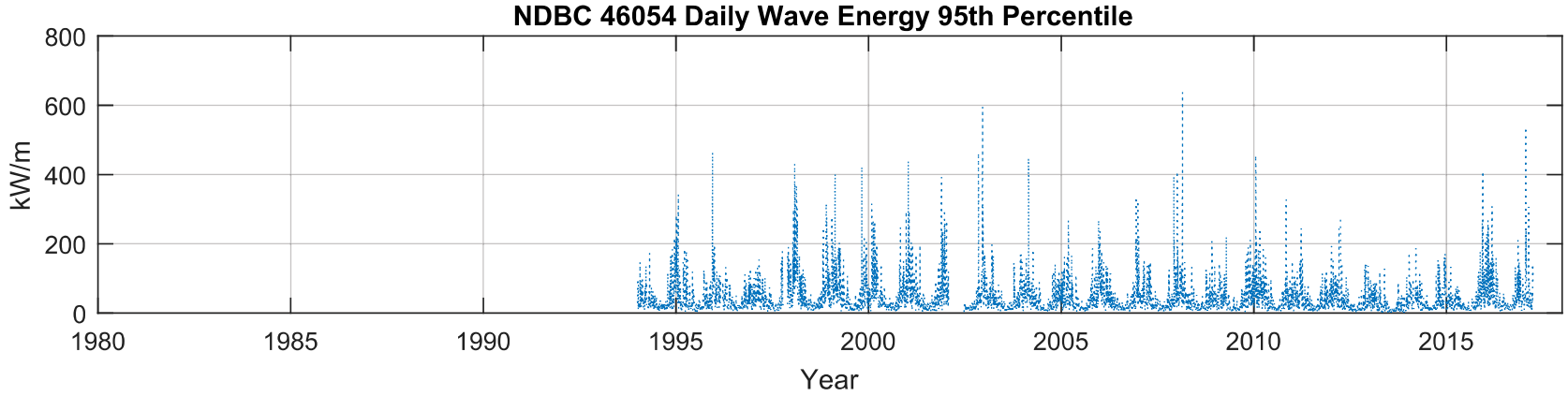
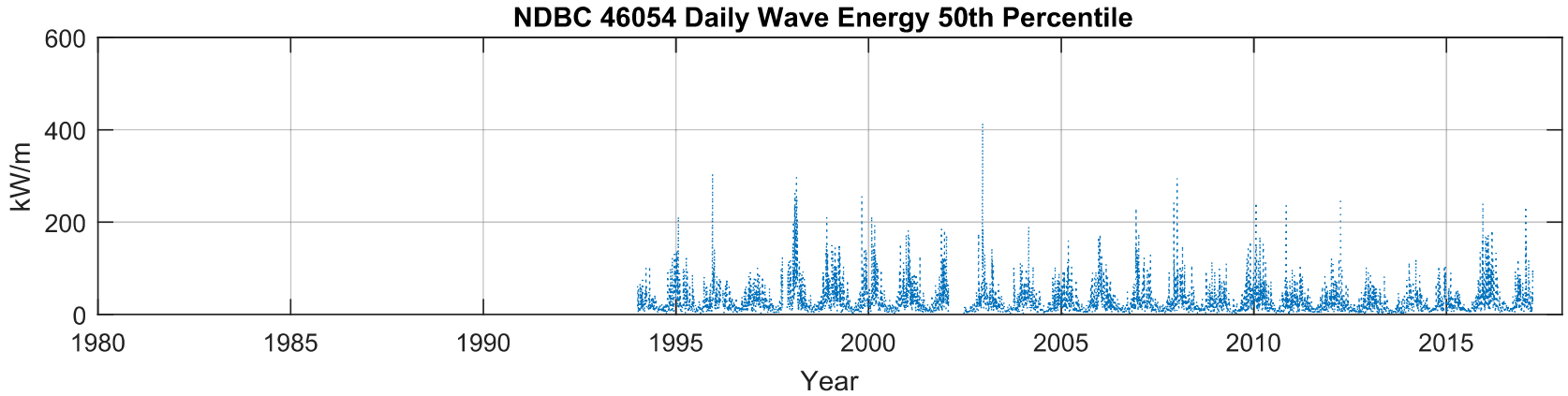


Figure A139. Daily Wave Energy, Max, Mean, Min,NDBC 46054





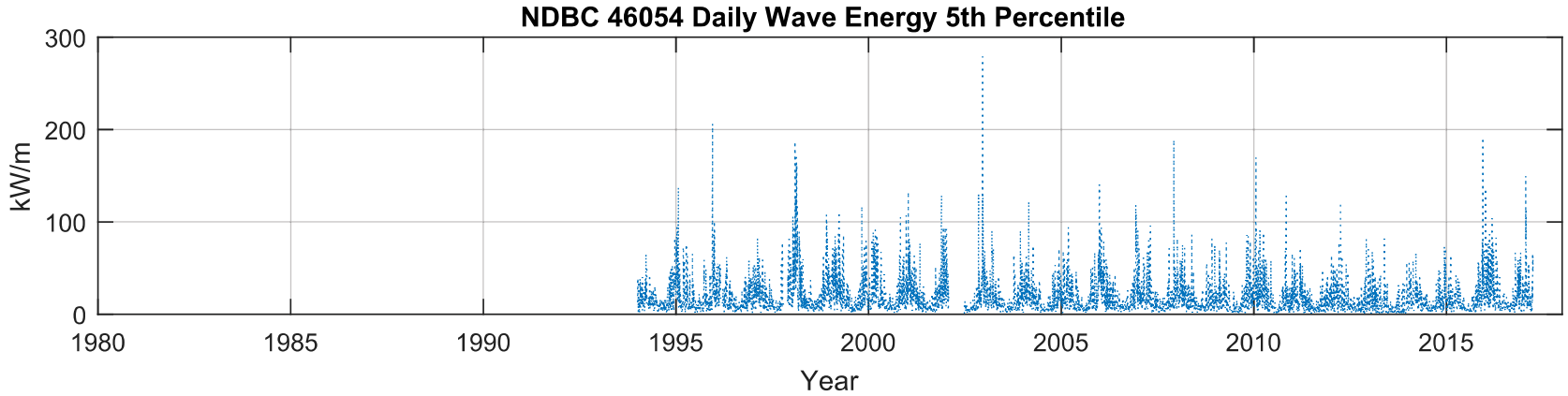


Figure A140. Daily Wave Energy, Percentiles,NDBC 46054

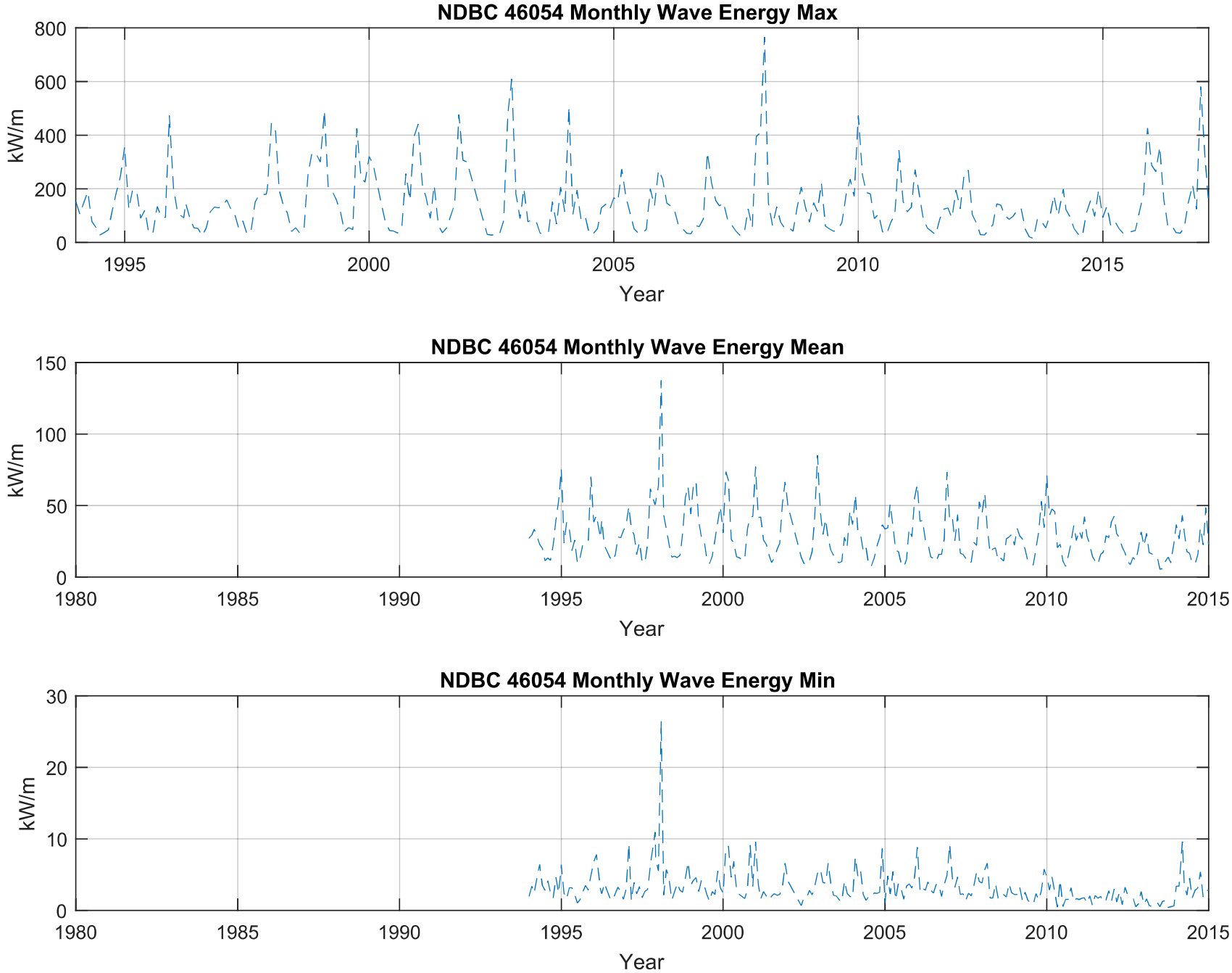
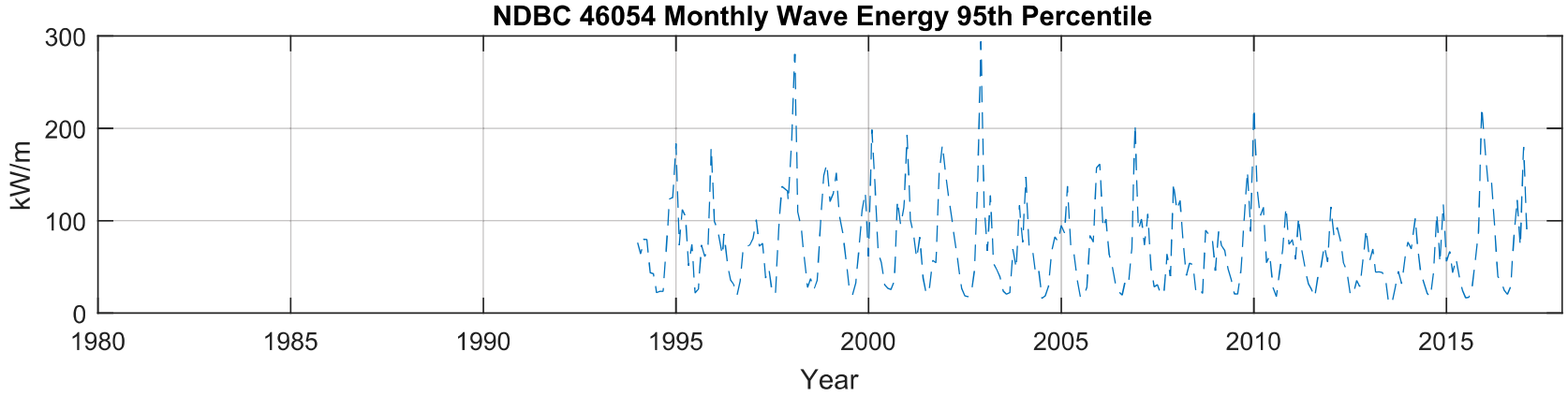
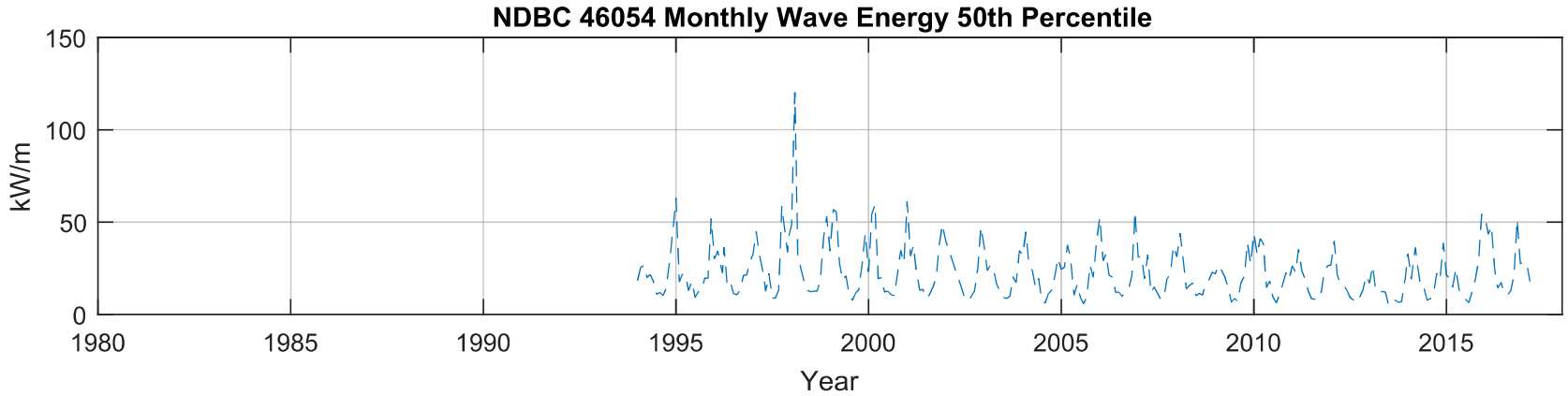


Figure A141. Monthly Wave Energy, Max, Mean, Min,NDBC 46054





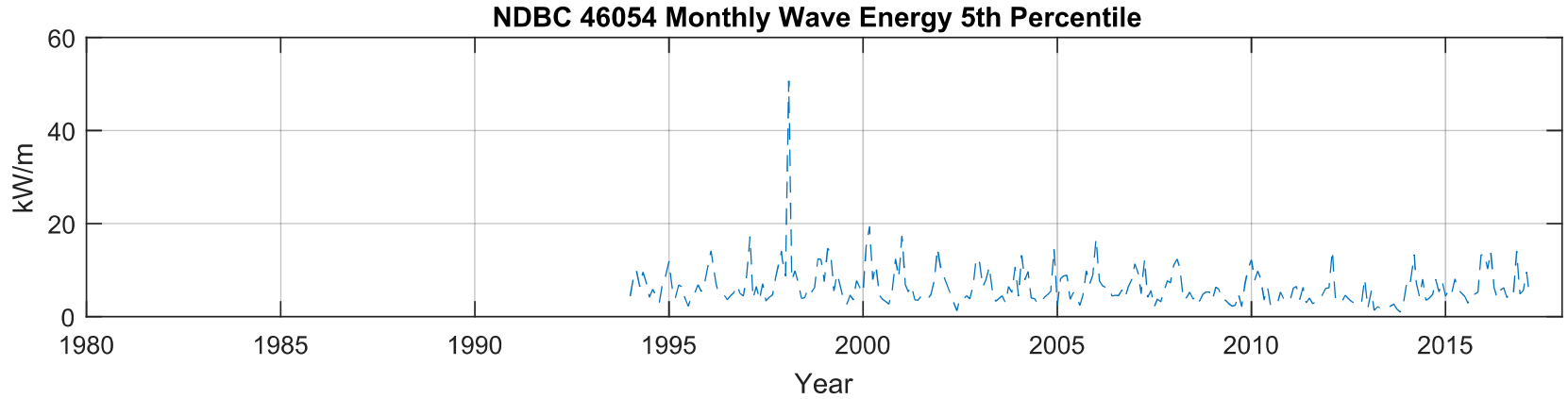


Figure A142. Monthly Wave Energy, Percentiles,NDBC 46054

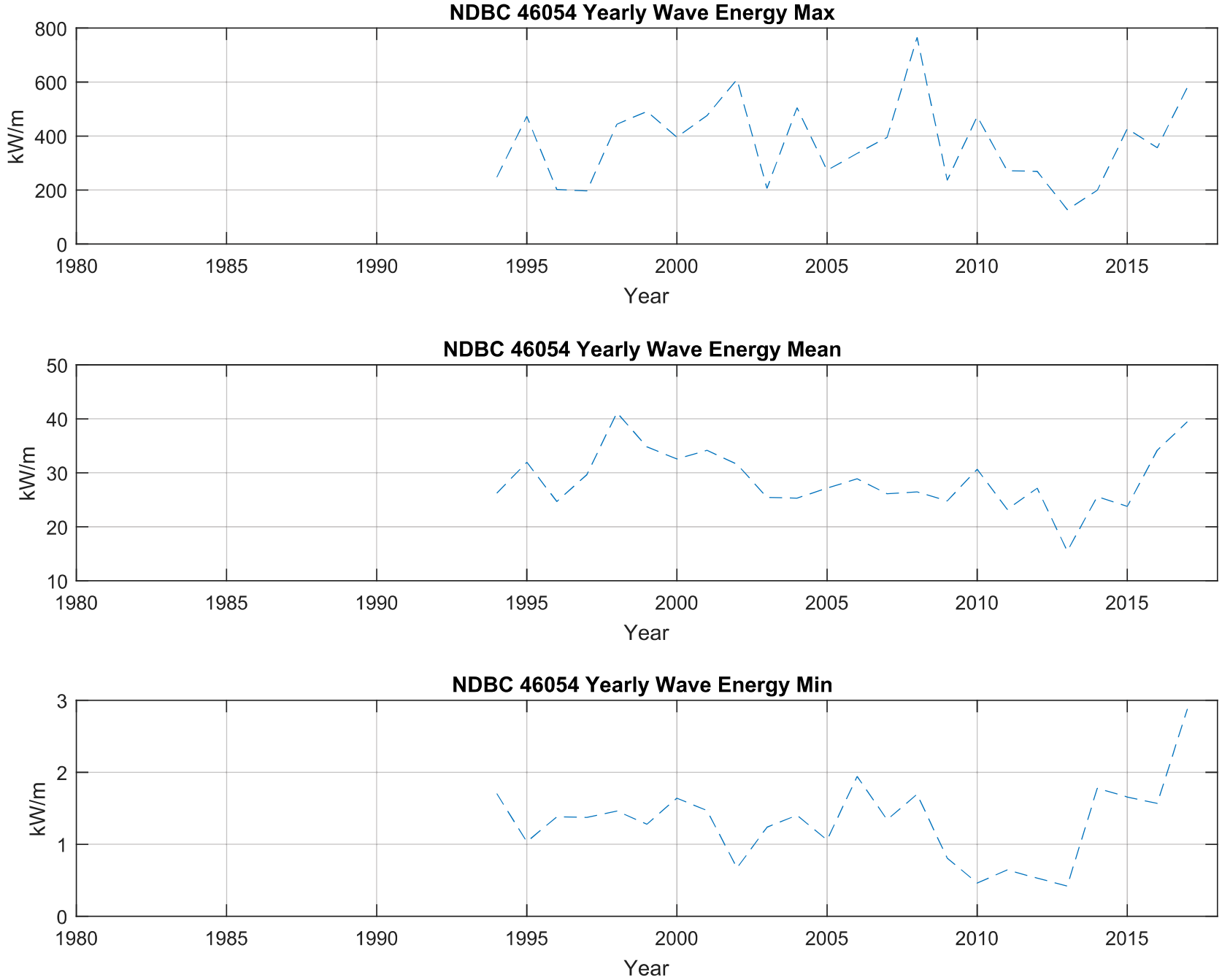
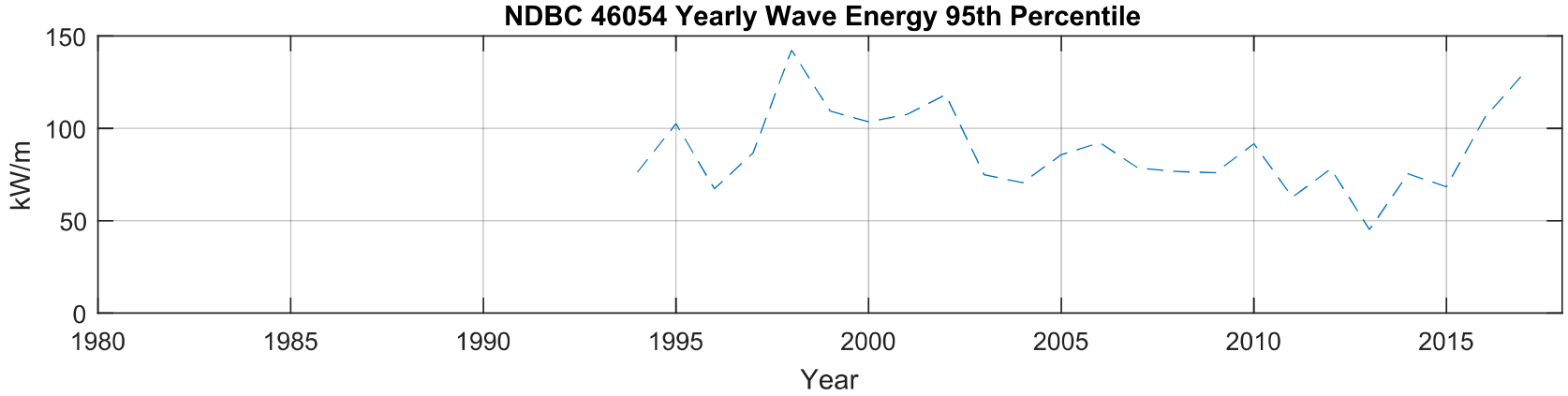
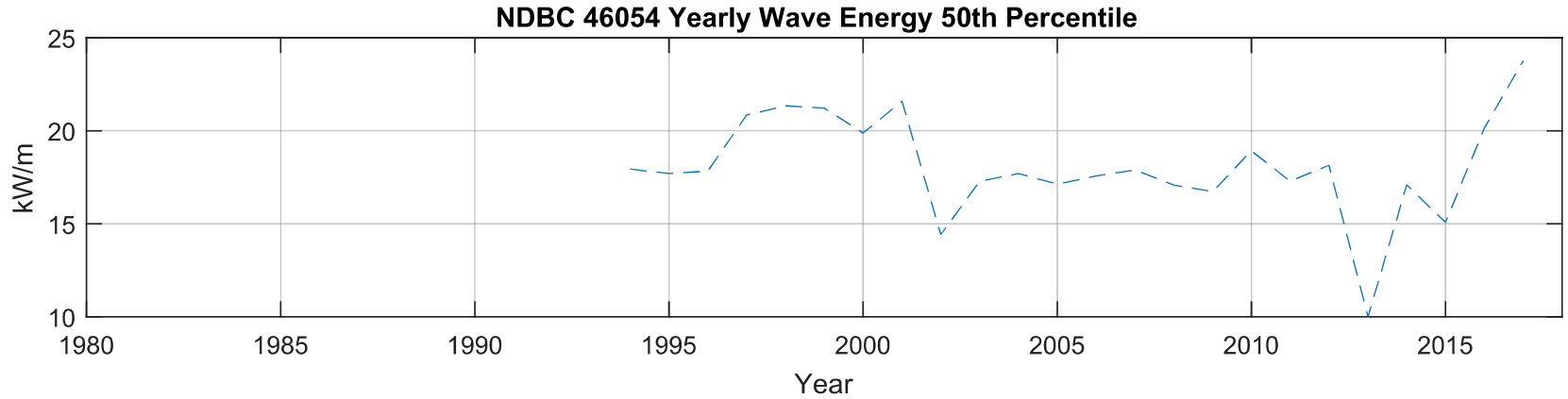


Figure A143. Yearly Wave Energy, Max, Mean, Min,NDBC 46054





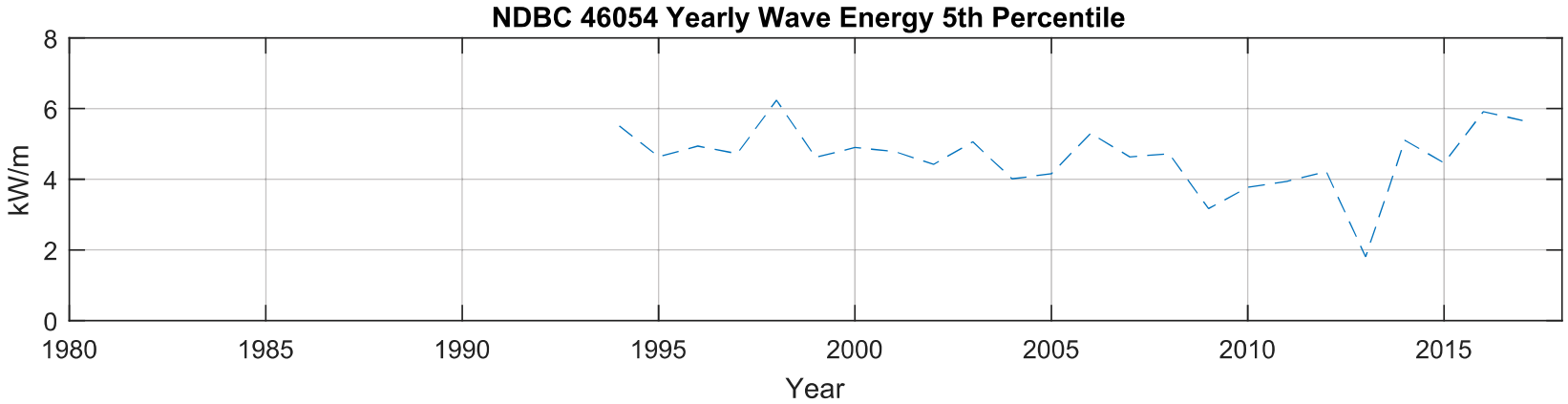


Figure A144. Yearly Wave Energy, Percentiles,NDBC 46054

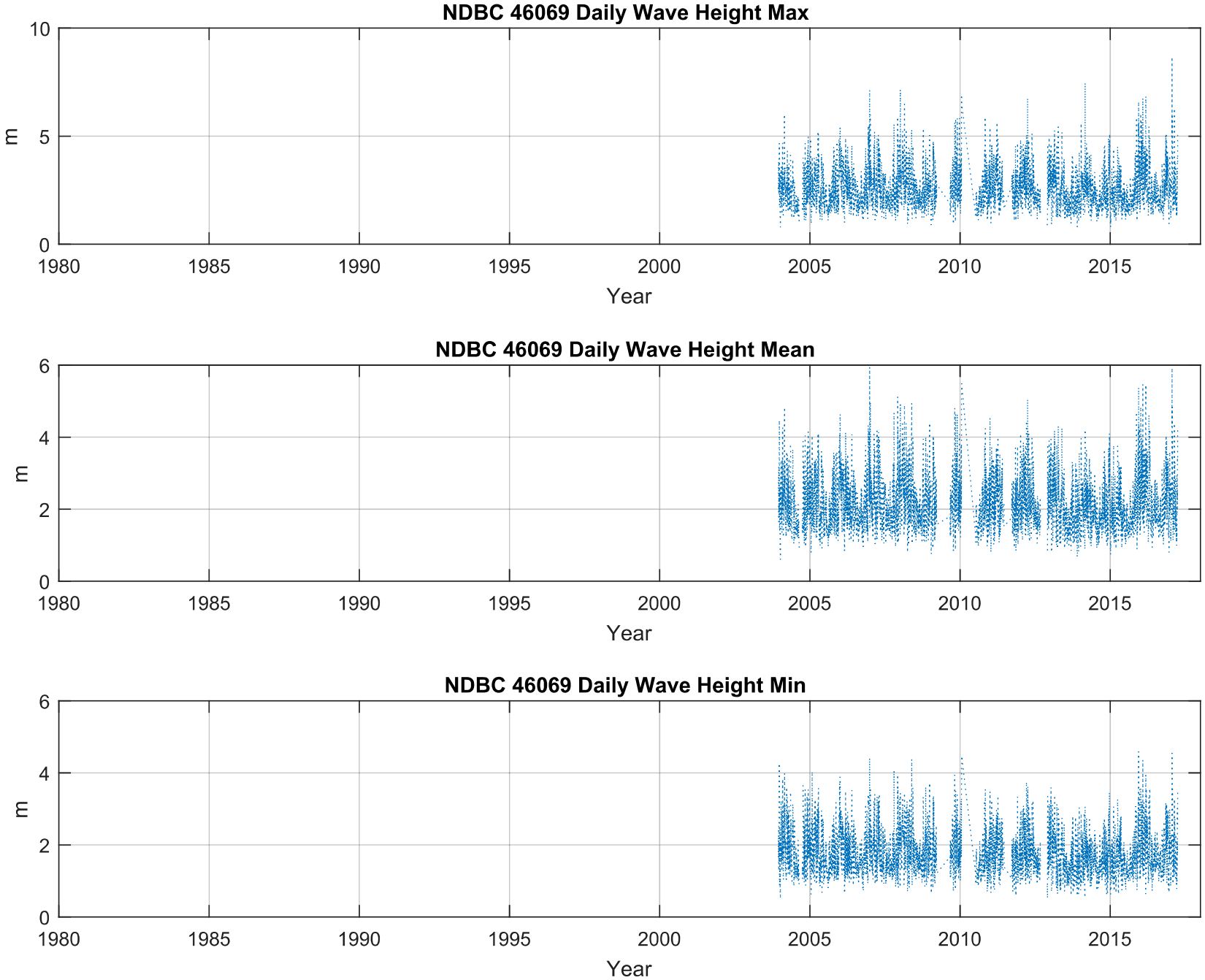


Figure A145. Daily Wave Height, Max, Mean, Min,NDBC 46069

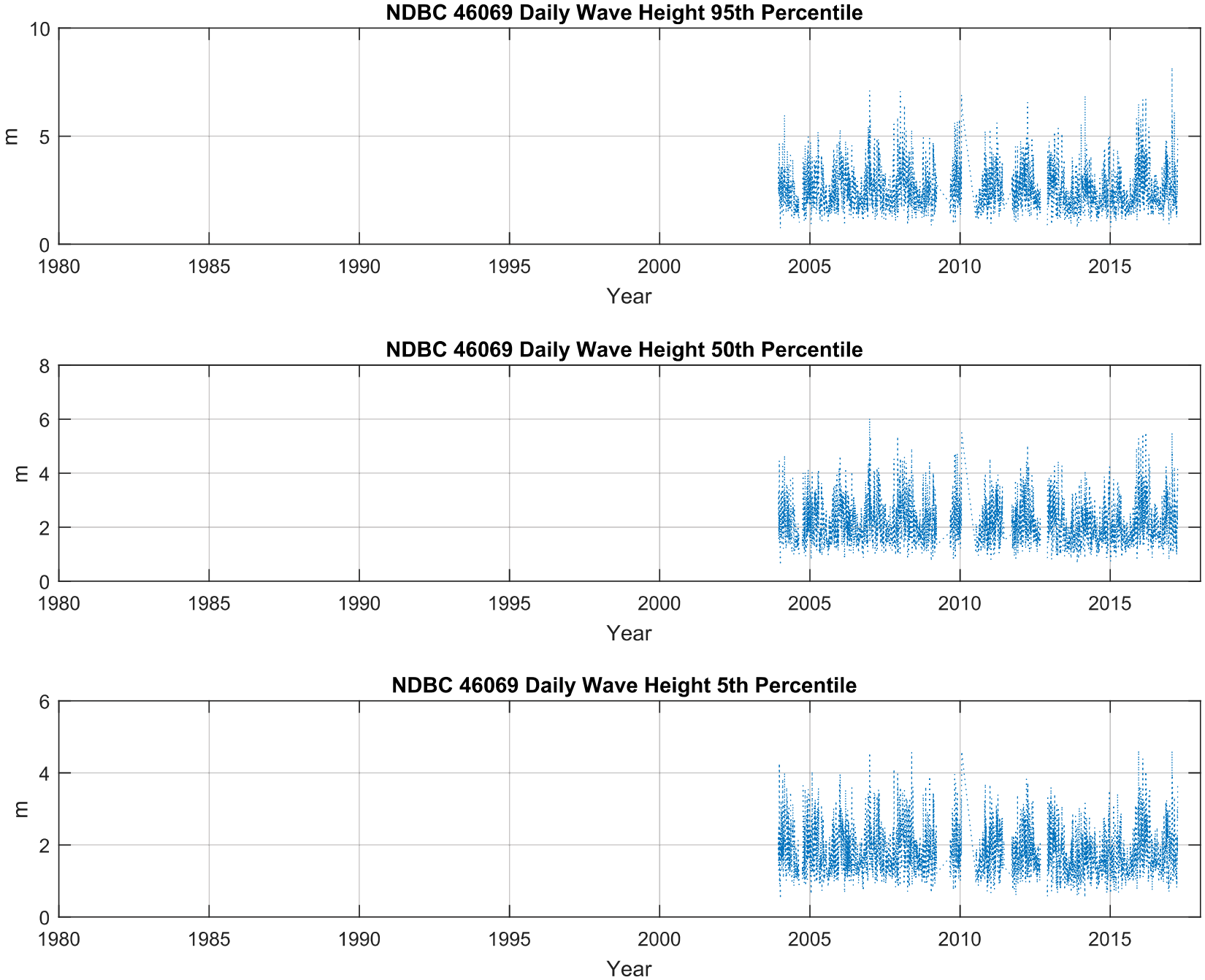


Figure A146. Daily Wave Height, Percentiles,NDBC 46069

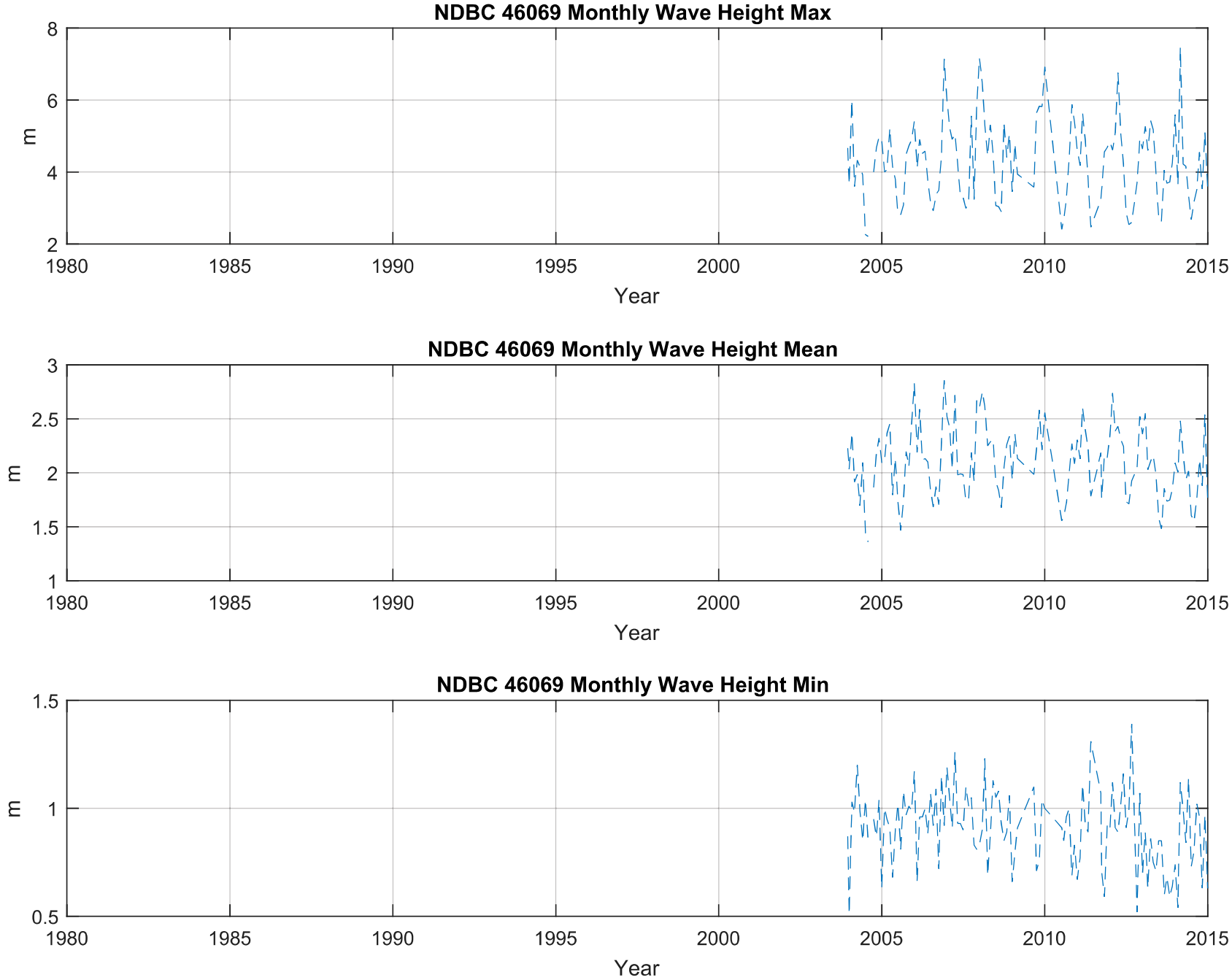


Figure A147. Monthly Wave Height, Max, Mean, Min,NDBC 46069

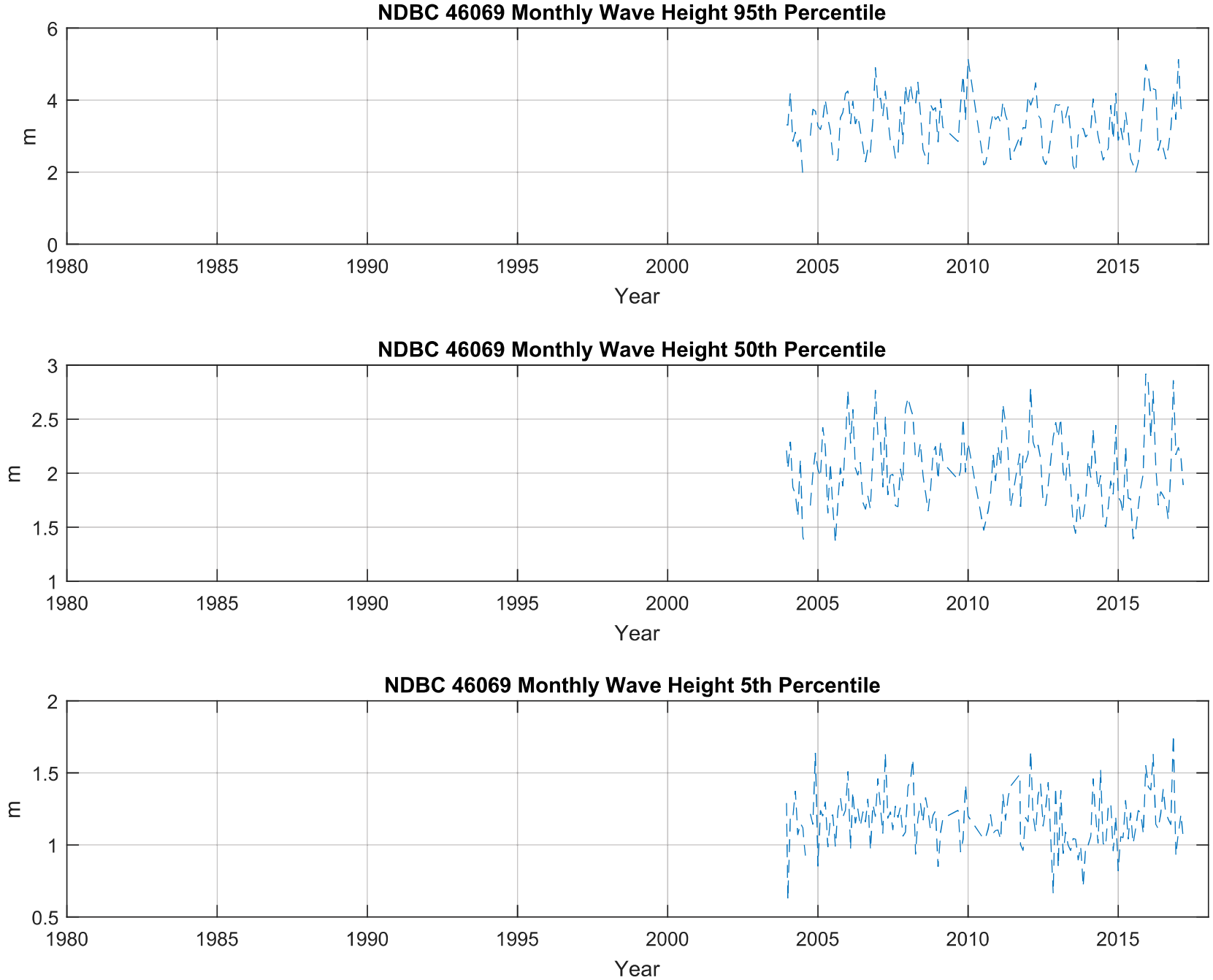


Figure A148. Monthly Wave Height, Percentiles,NDBC 46069

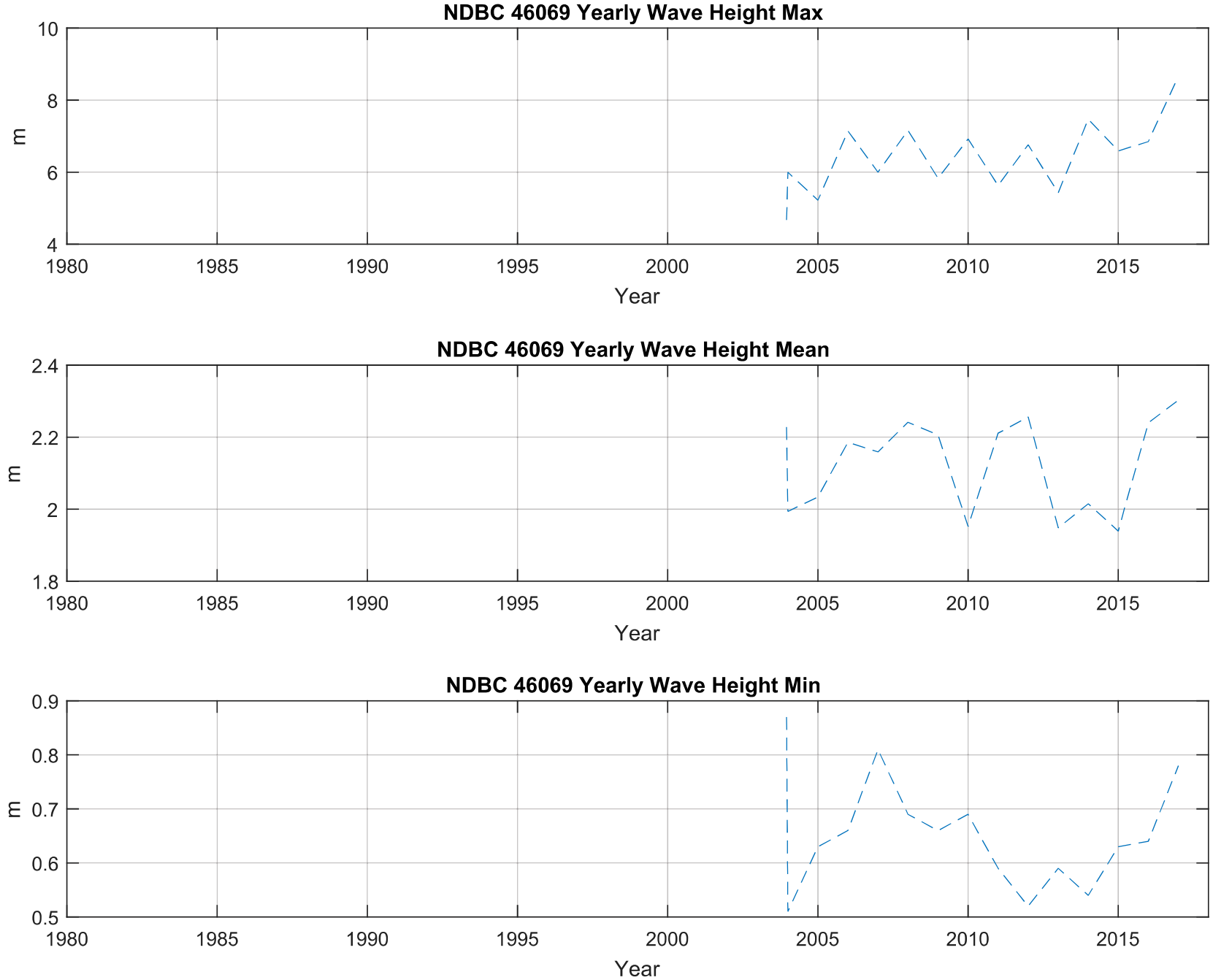
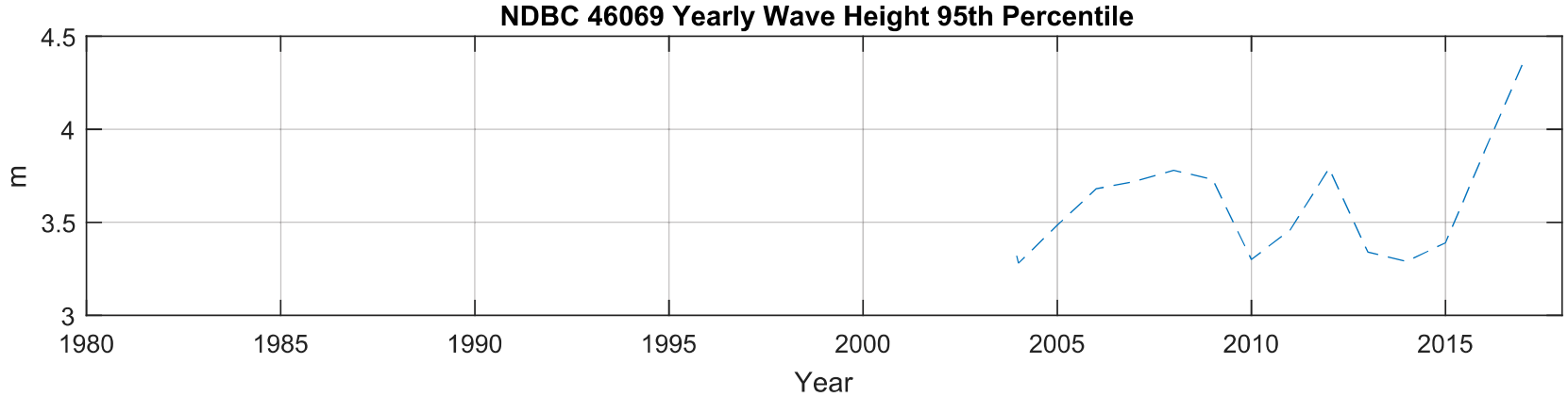
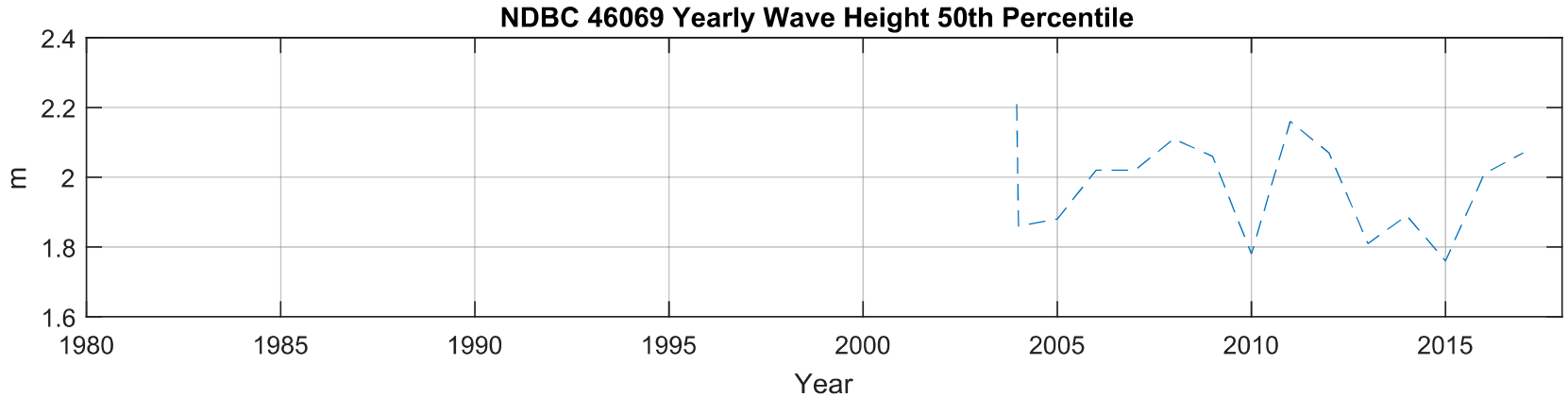


Figure A149. Yearly Wave Height, Max, Mean, Min,NDBC 46069





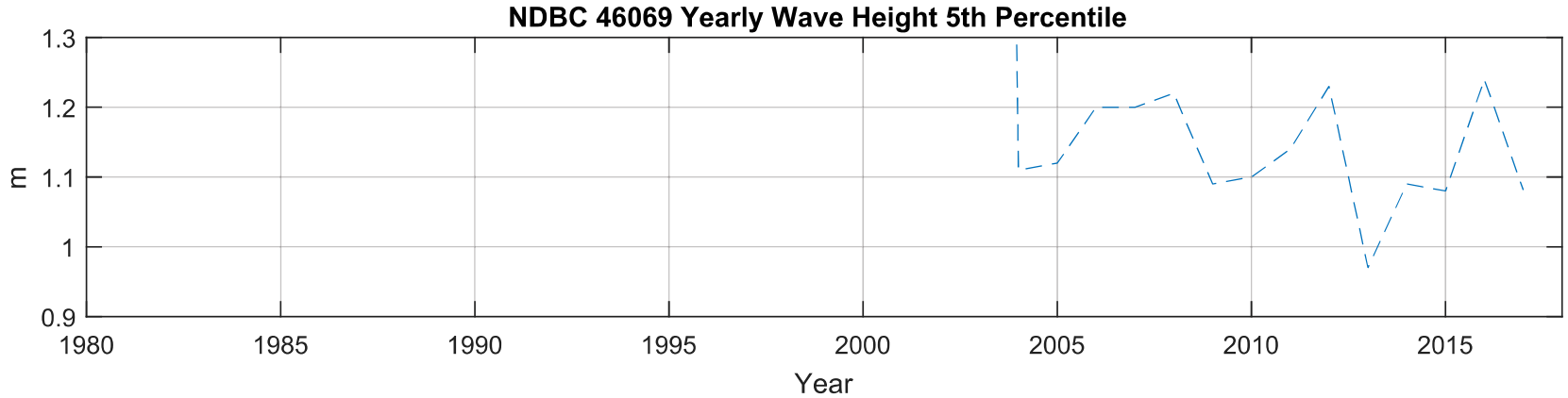
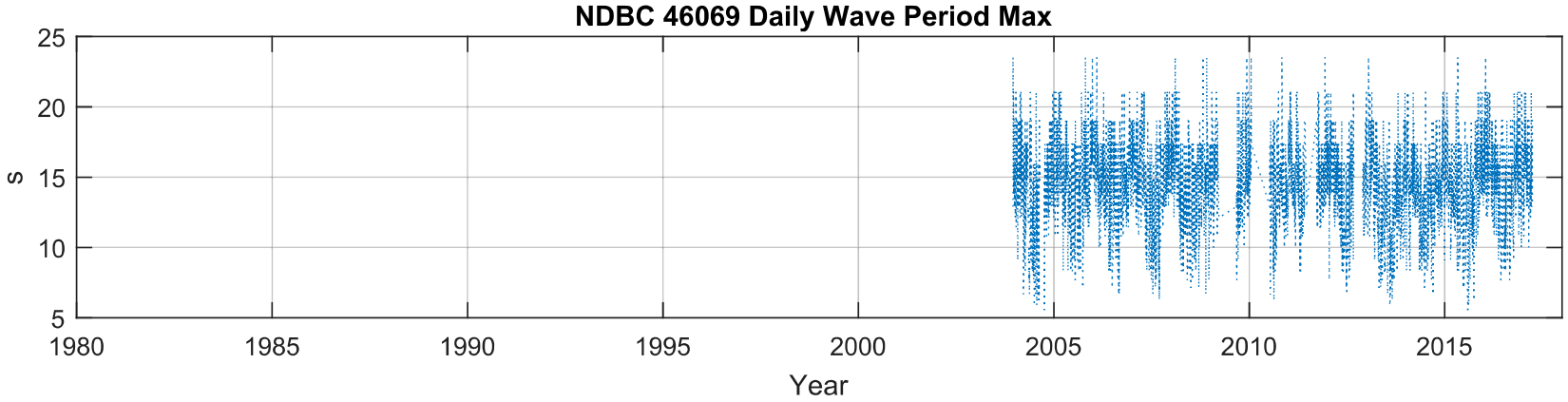
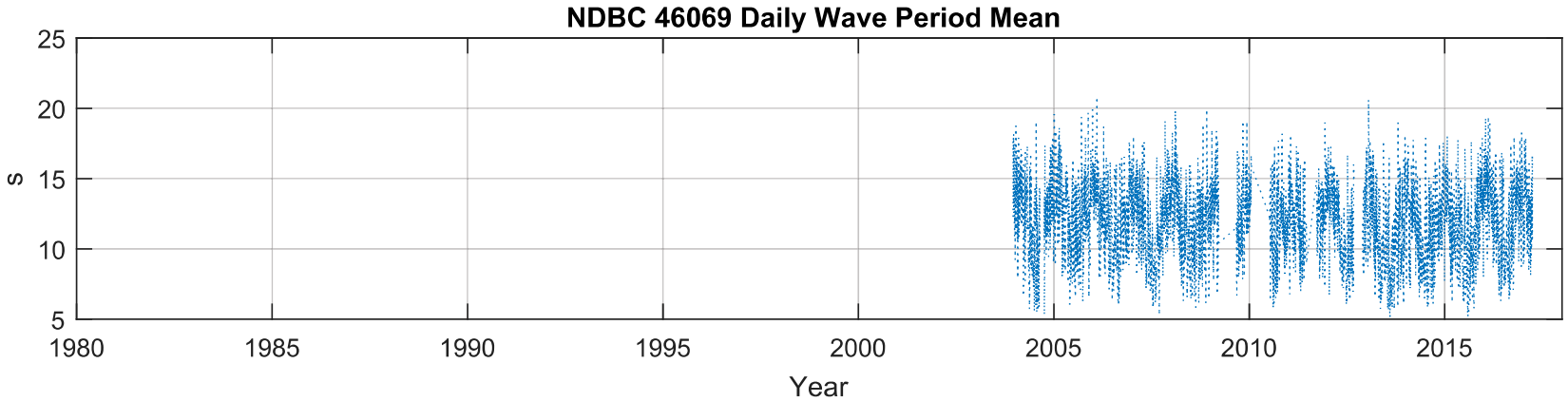


Figure A150. Yearly Wave Height, Percentiles,NDBC 46069





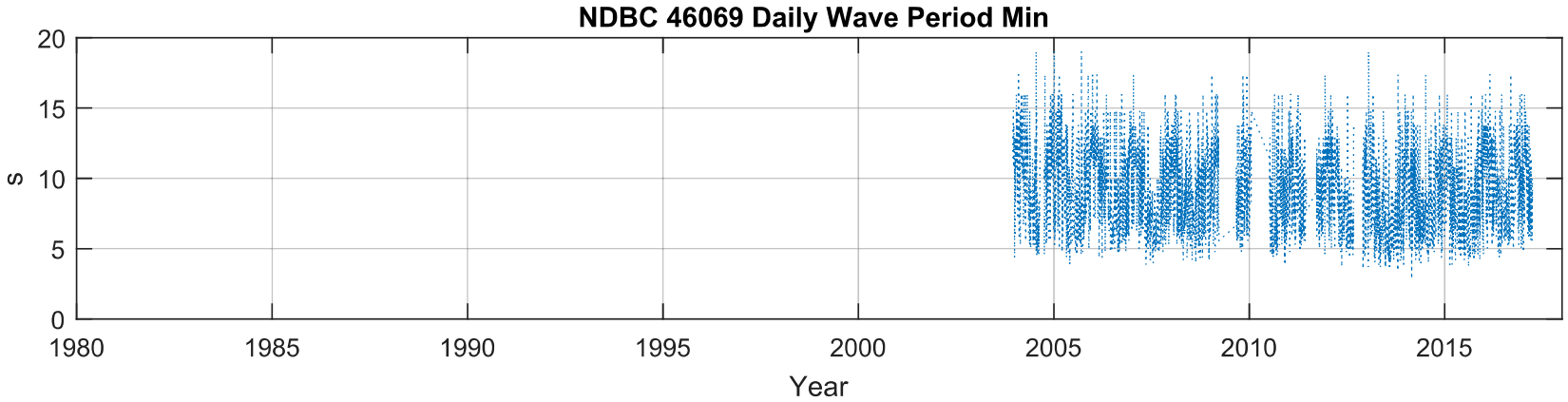


Figure A151. Daily Wave Period, Max, Mean, Min,NDBC 46069

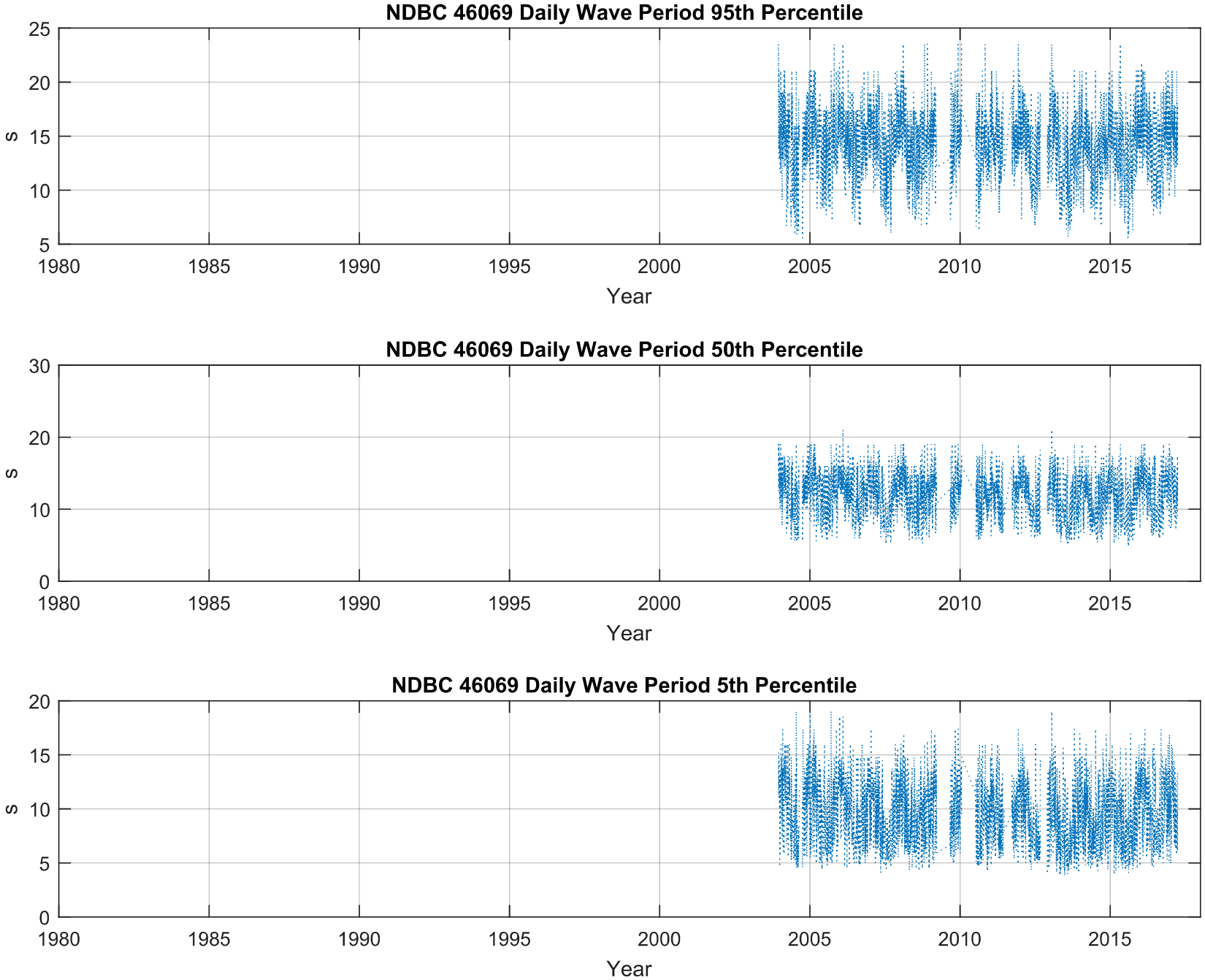
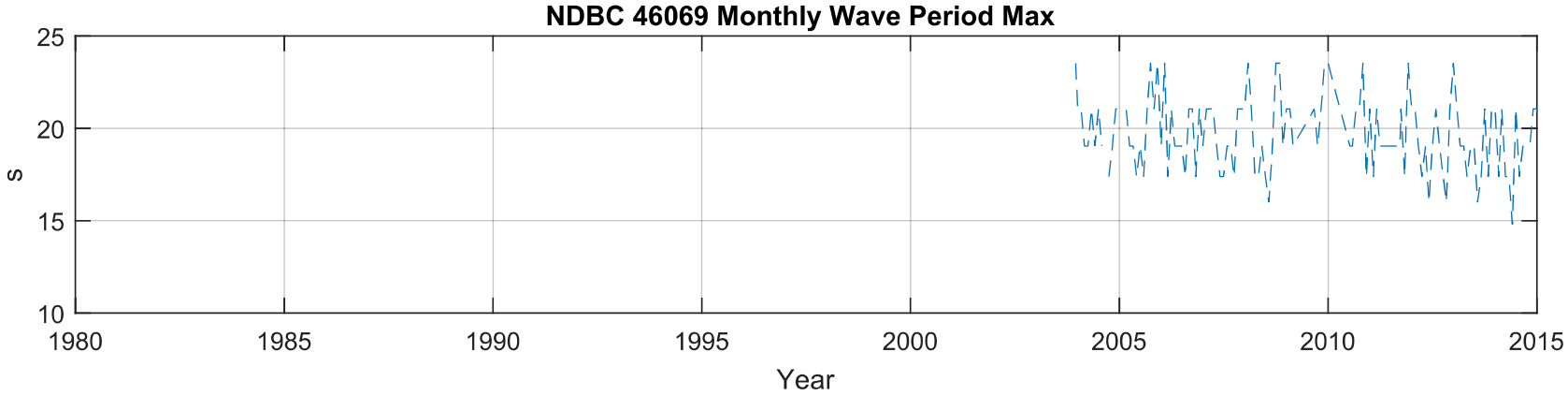
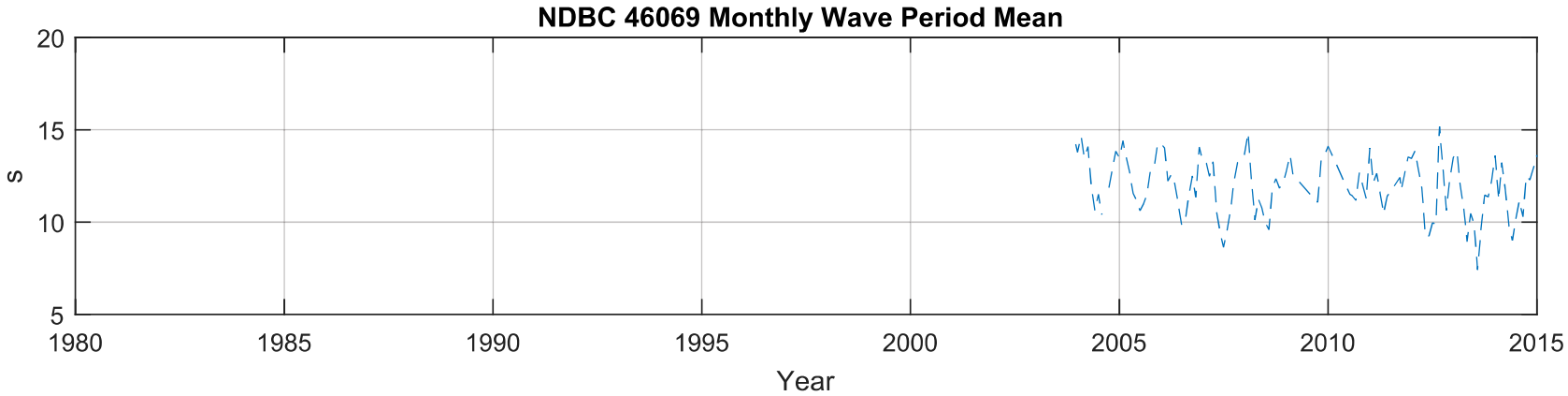


Figure A152. Daily Wave Period, Percentiles,NDBC 46069





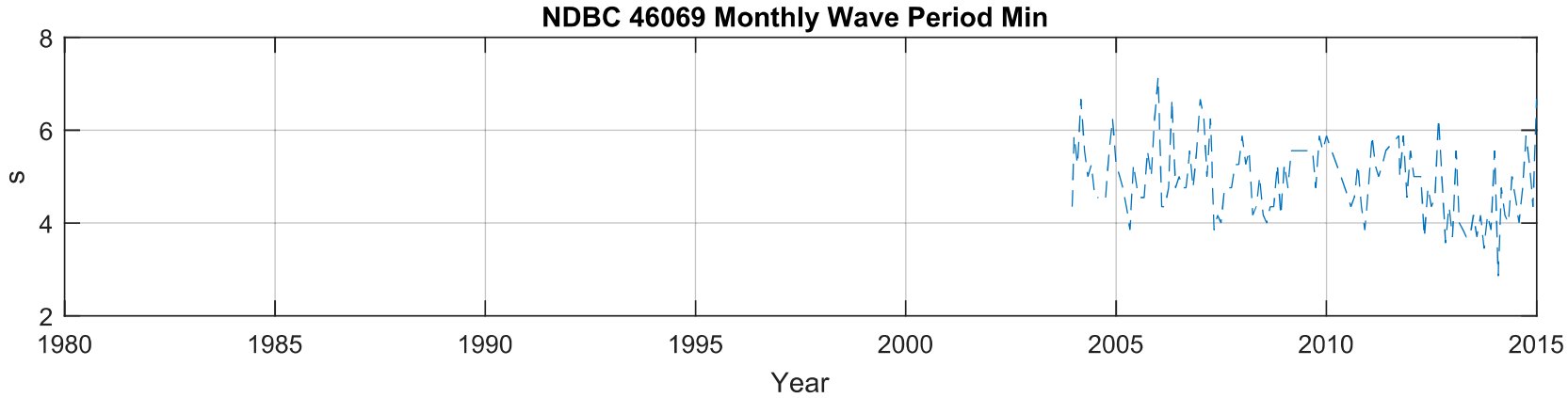
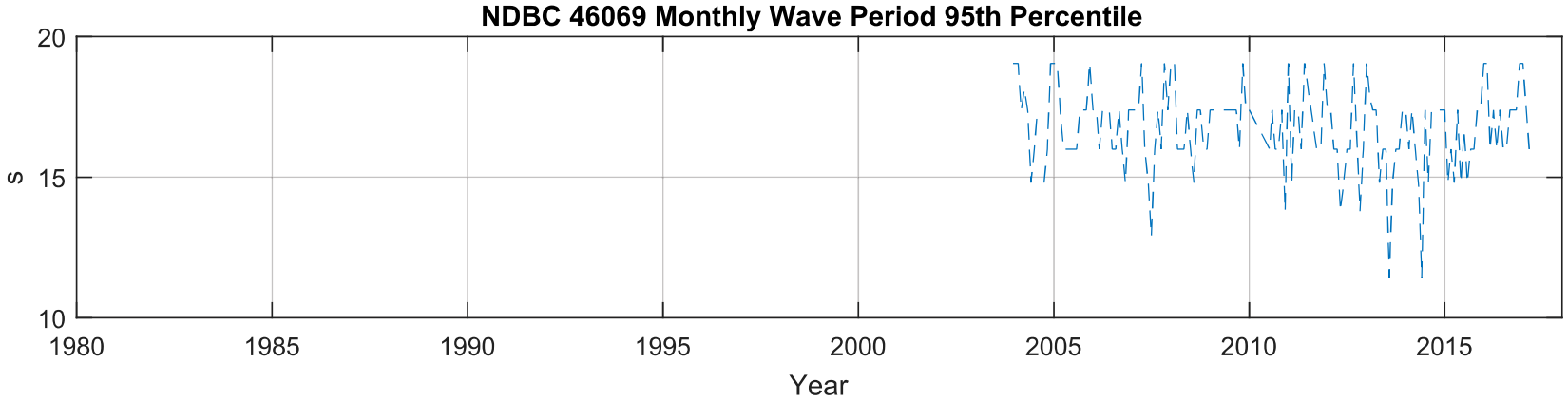
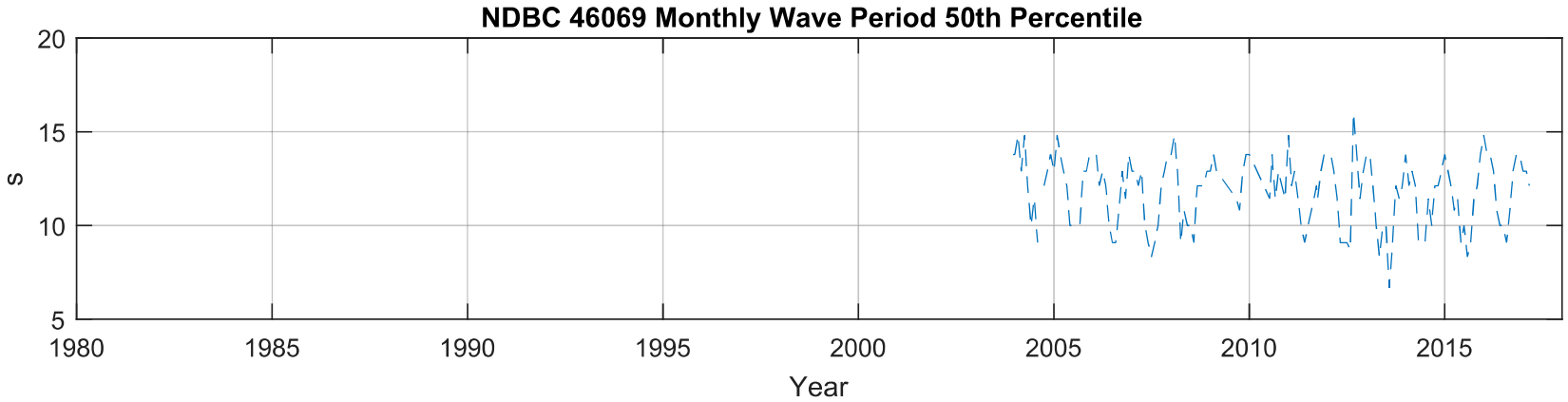


Figure A153. Monthly Wave Period, Max, Mean, Min,NDBC 46069





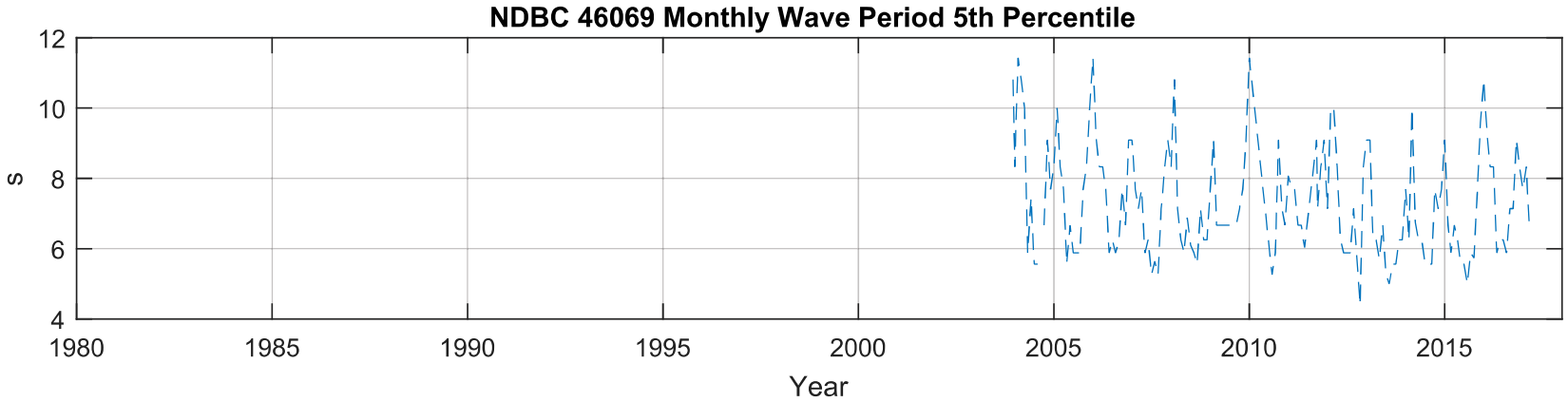
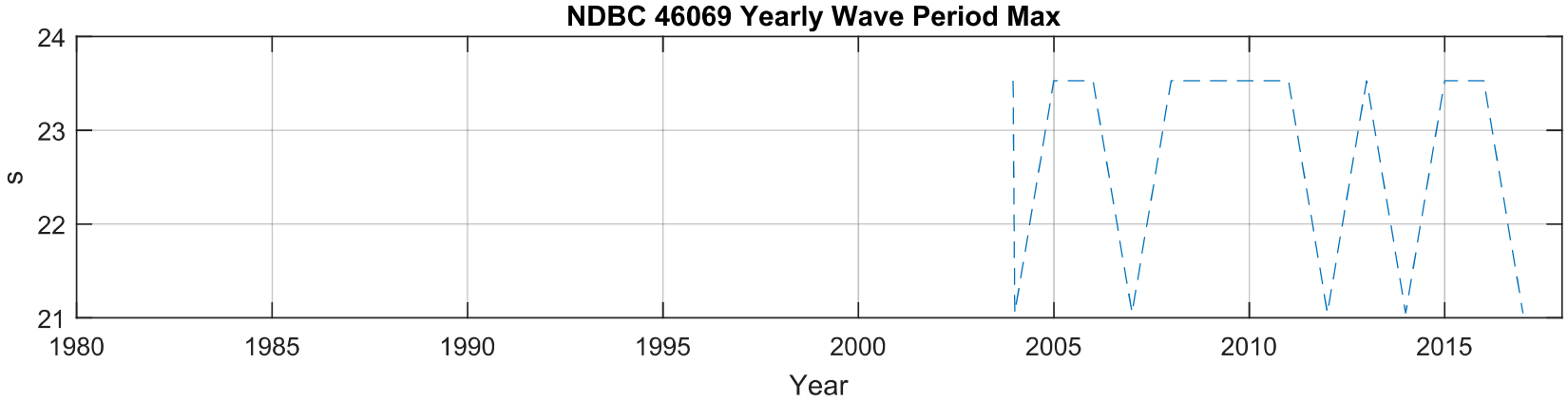
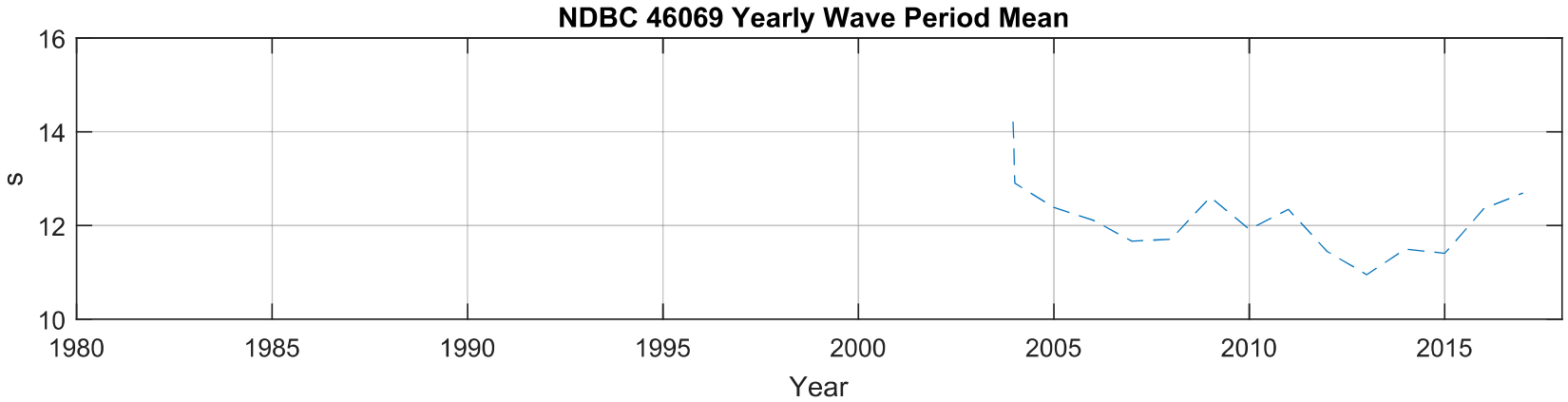


Figure A154. Monthly Wave Period, Percentiles,NDBC 46069





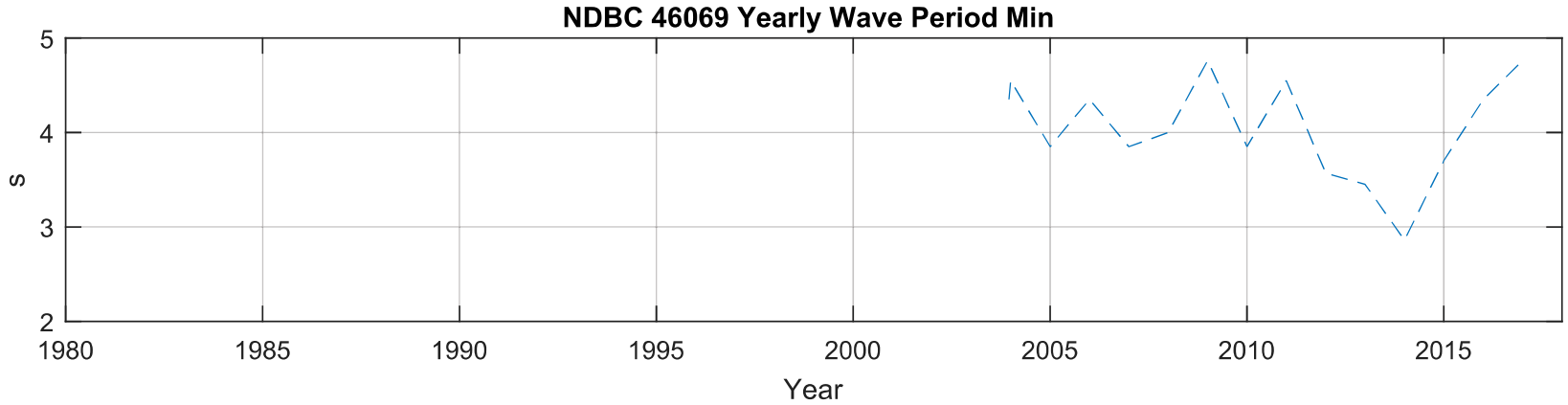
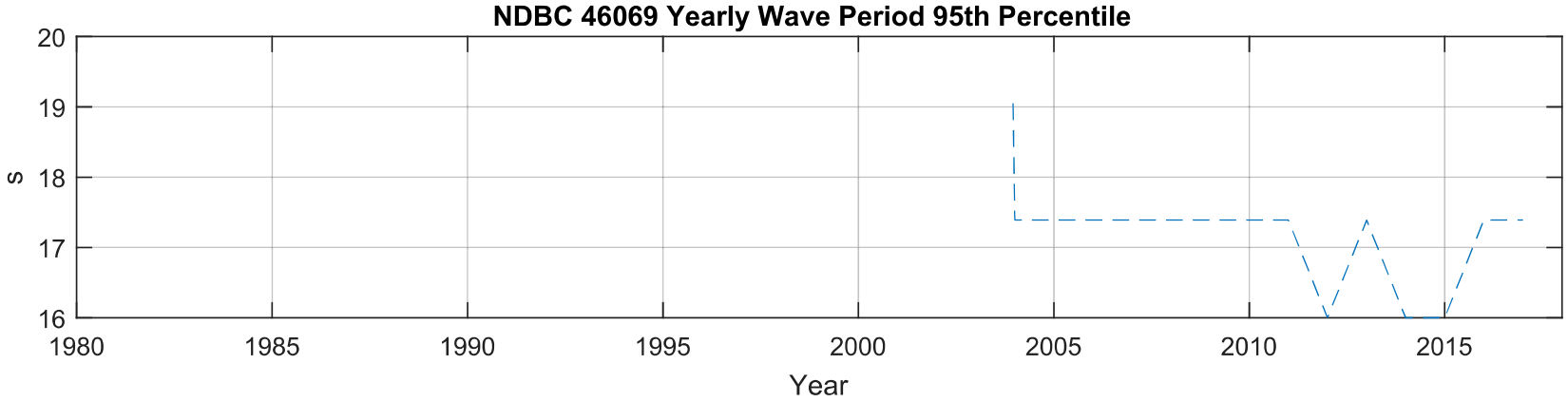
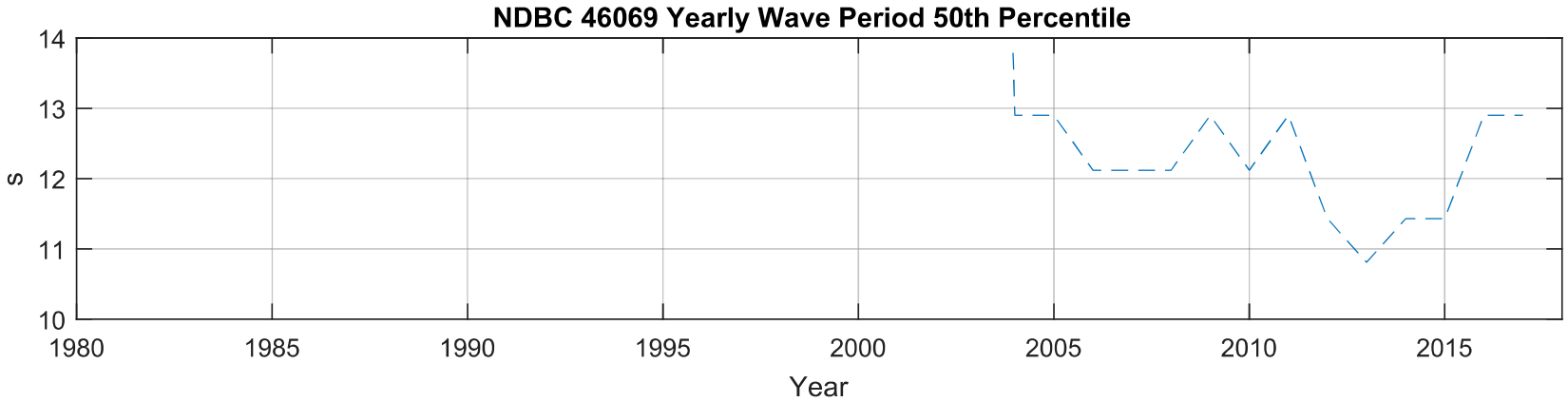


Figure A155. Yearly Wave Period, Max, Mean, Min,NDBC 46069





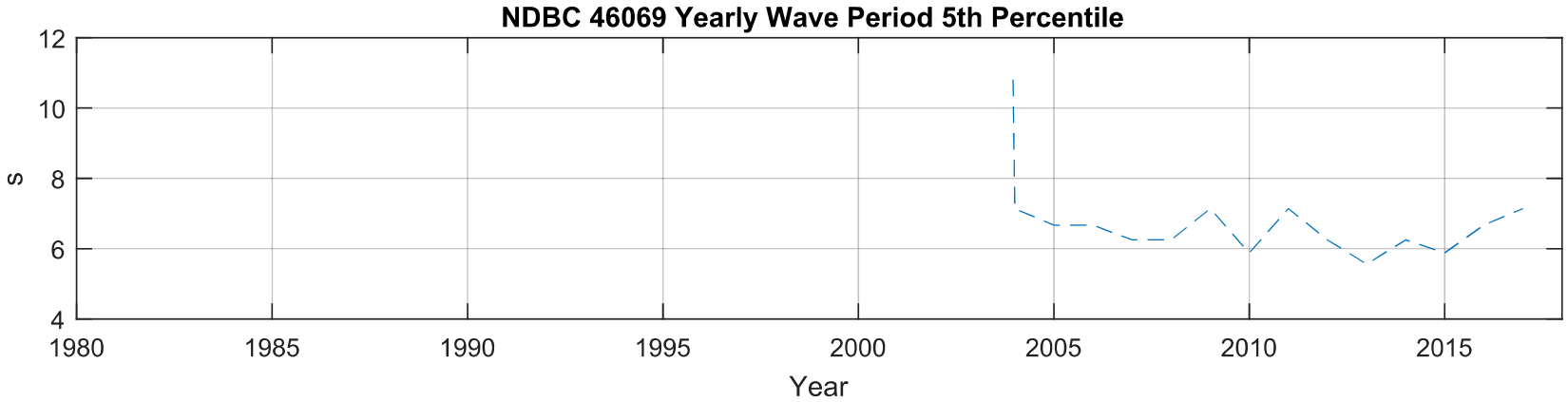


Figure A156. Yearly Wave Period, Percentiles,NDBC 46069

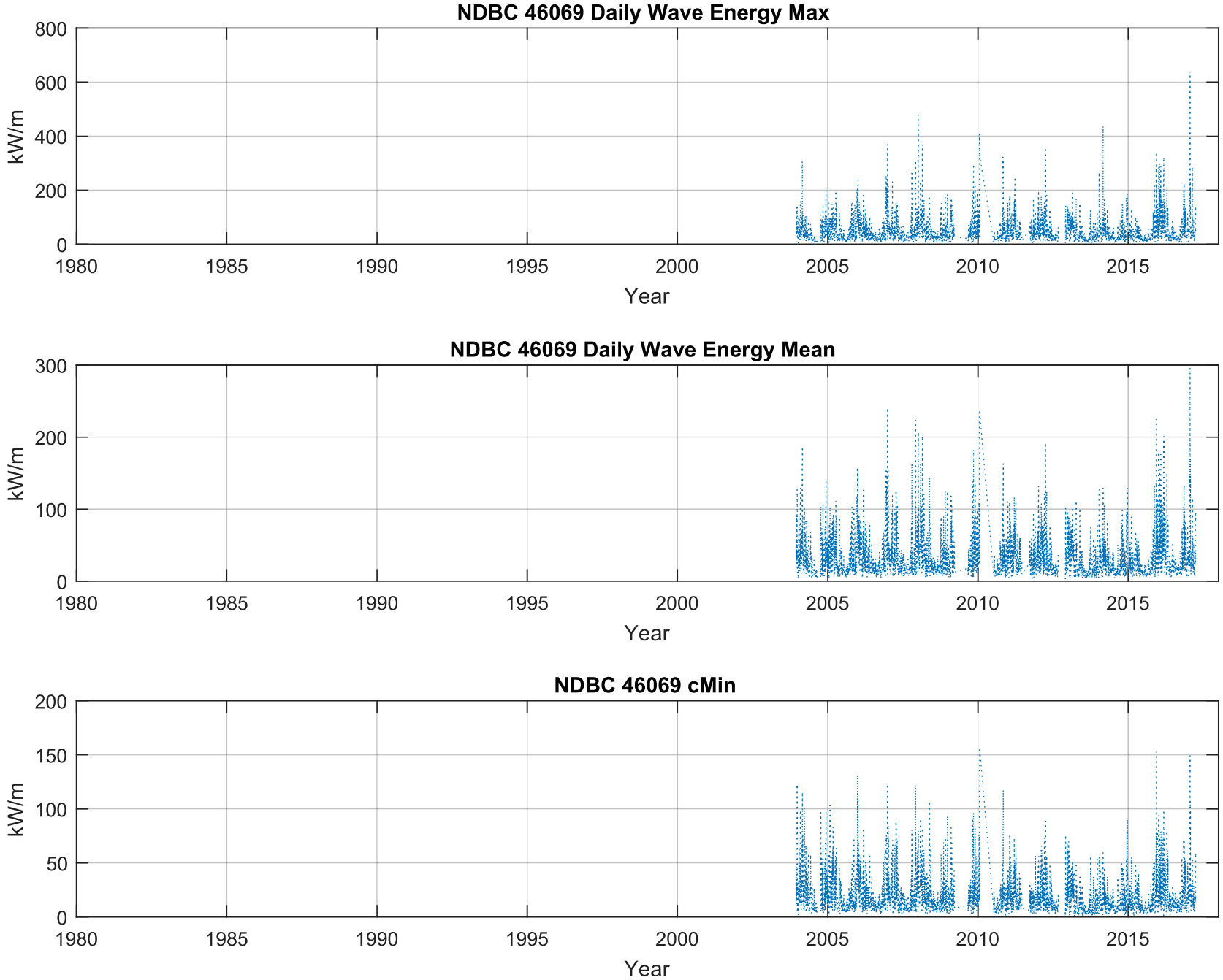


Figure A157. Daily Wave Energy, Max, Mean, Min,NDBC 46069

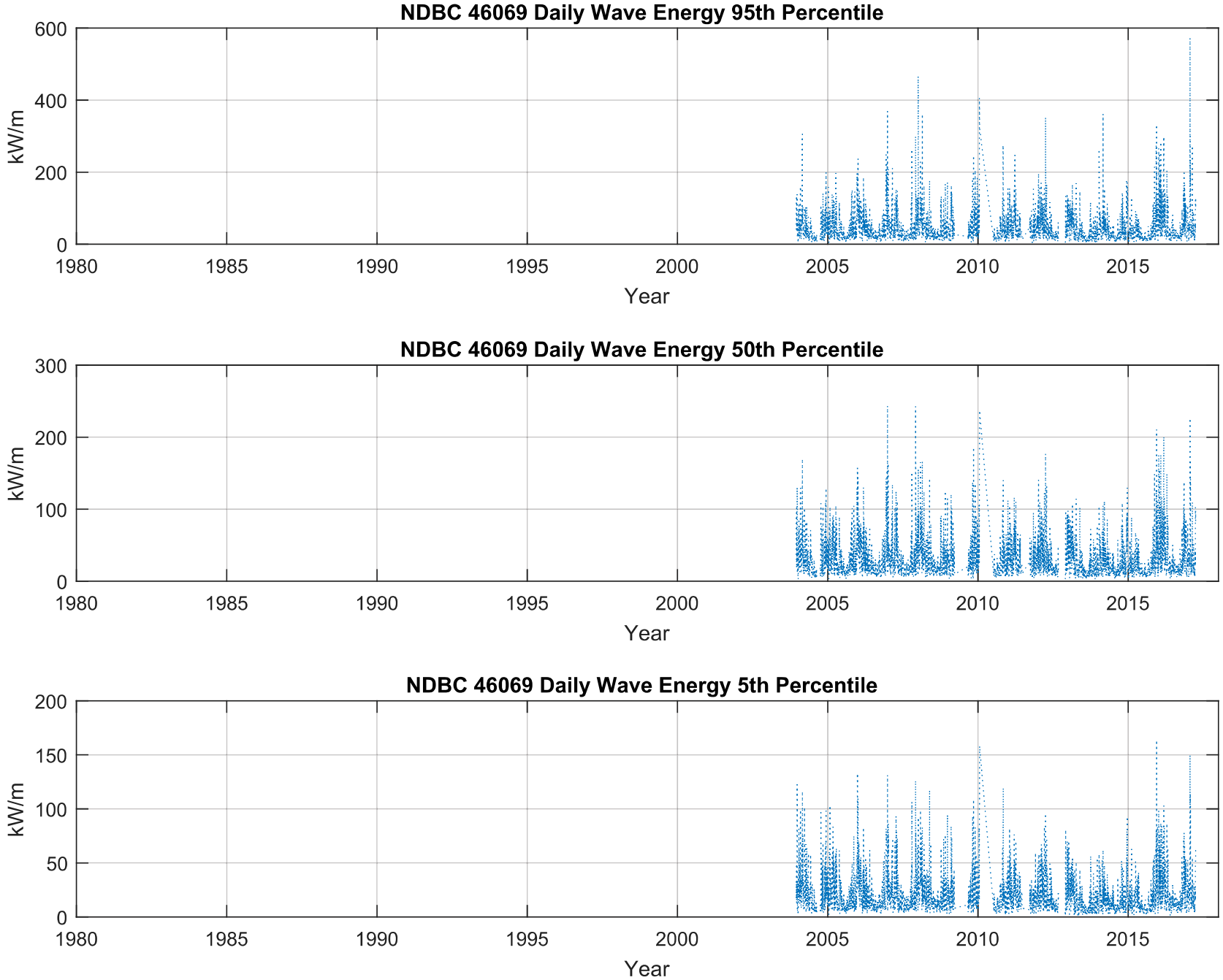


Figure A158. Daily Wave Energy, Percentiles,NDBC 46069

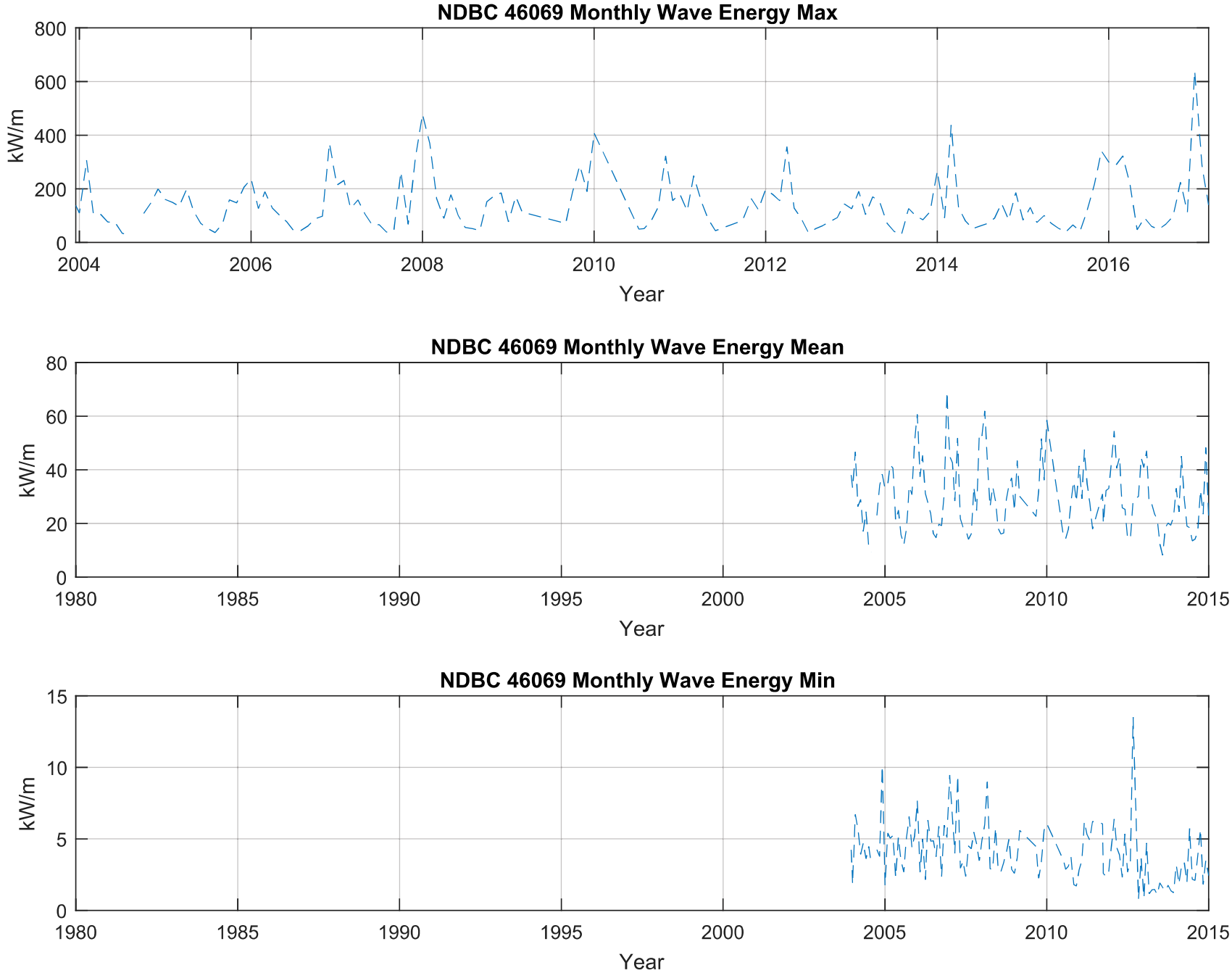


Figure A159. Monthly Wave Energy, Max, Mean, Min,NDBC 46069

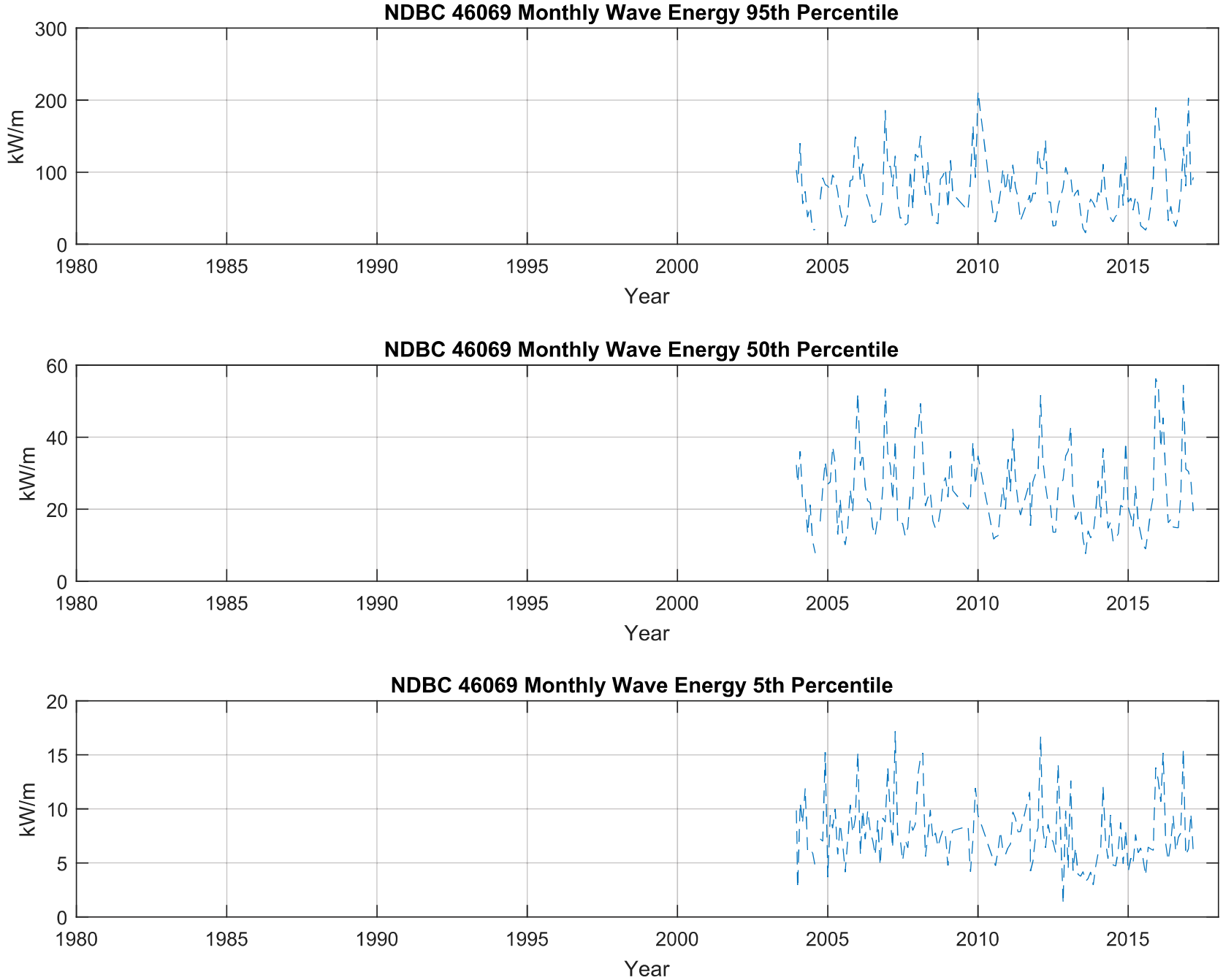


Figure A160. Monthly Wave Energy, Percentiles,NDBC 46069

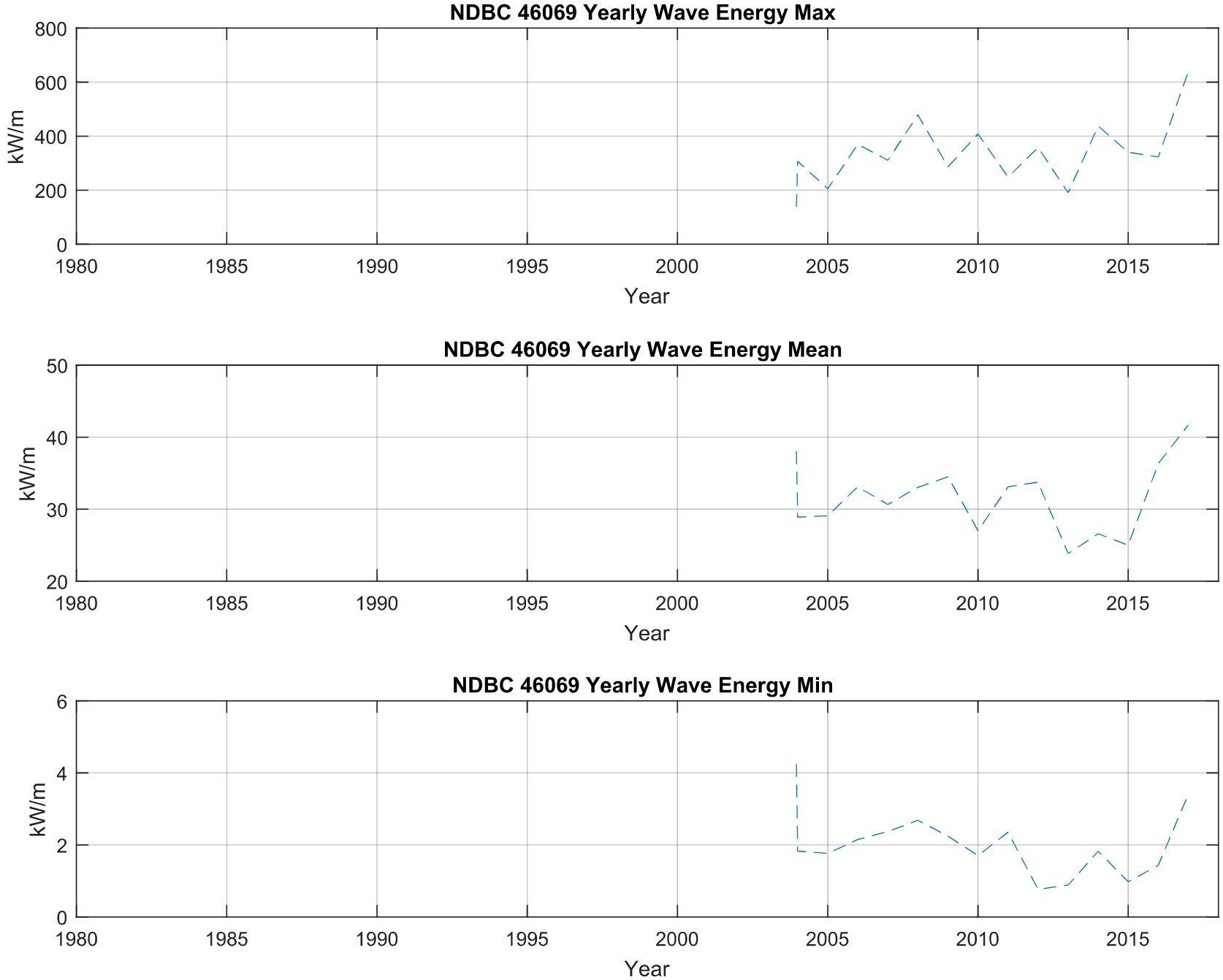
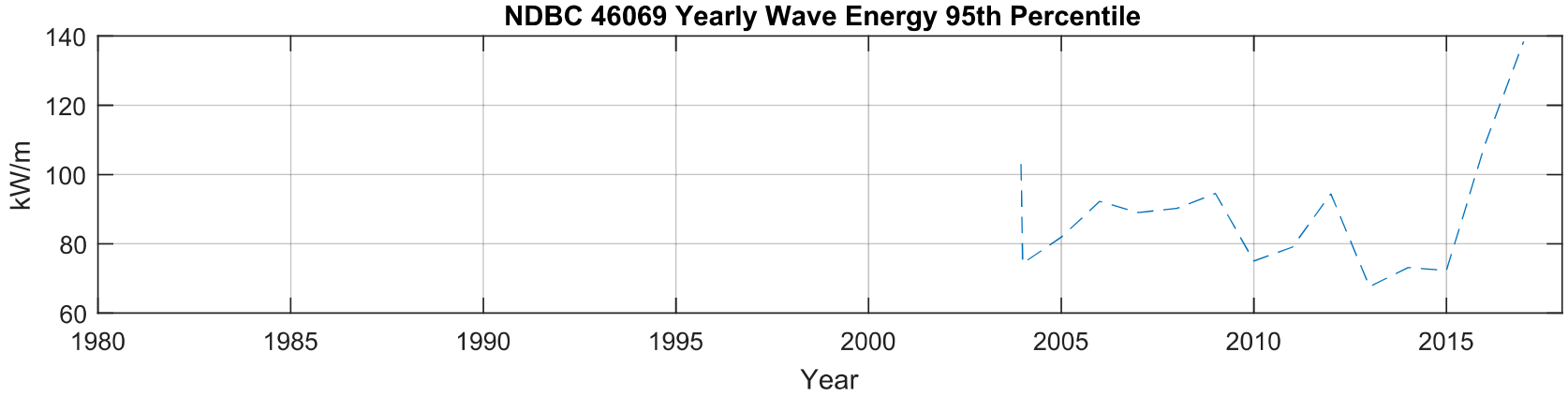
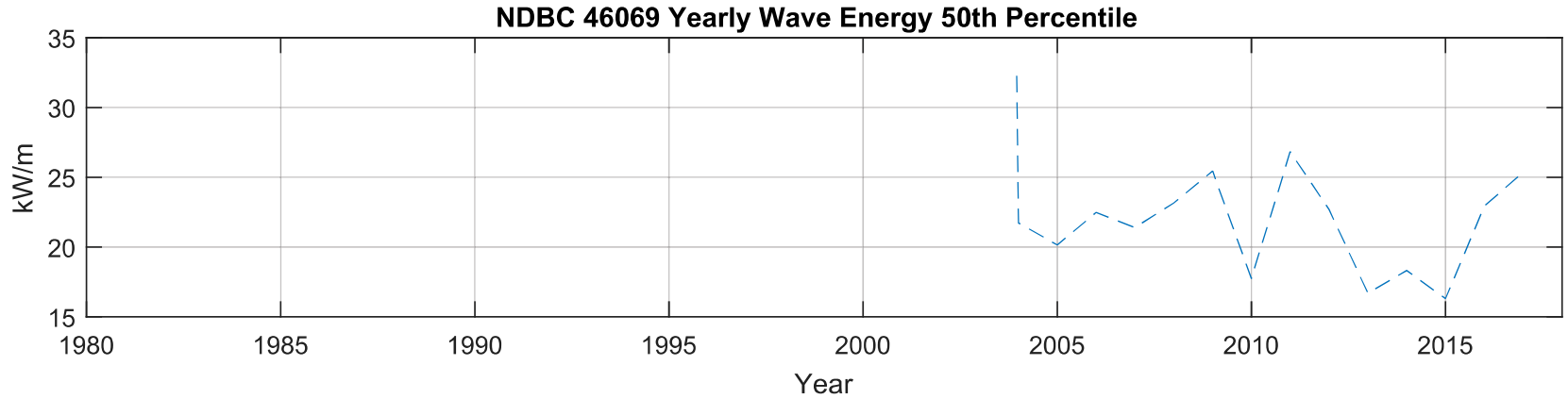


Figure A161. Yearly Wave Energy, Max, Mean, Min,NDBC 46069





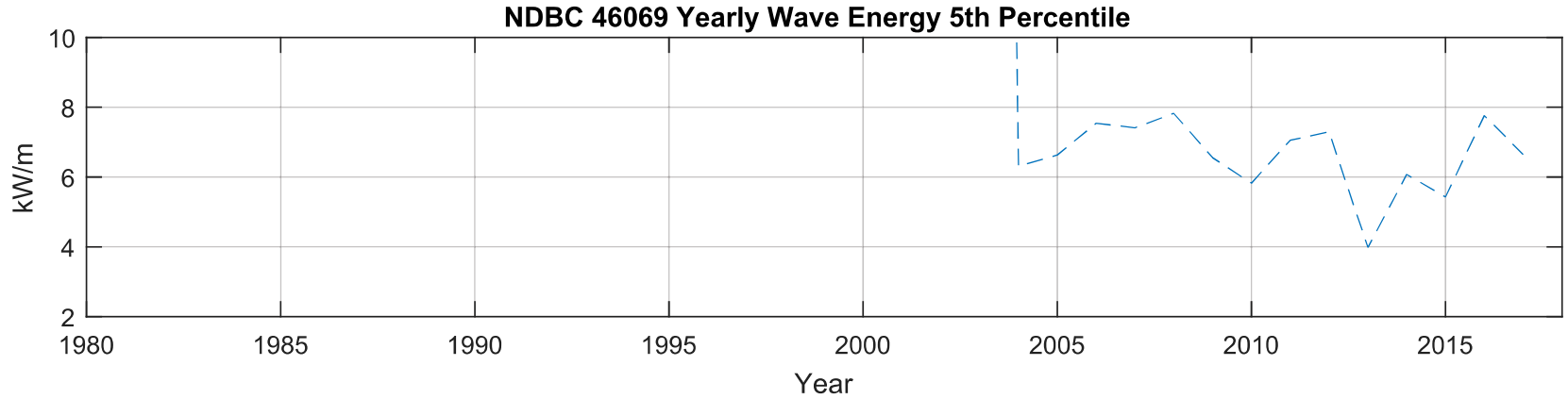


Figure A162. Yearly Wave Energy, Percentiles,NDBC 46069

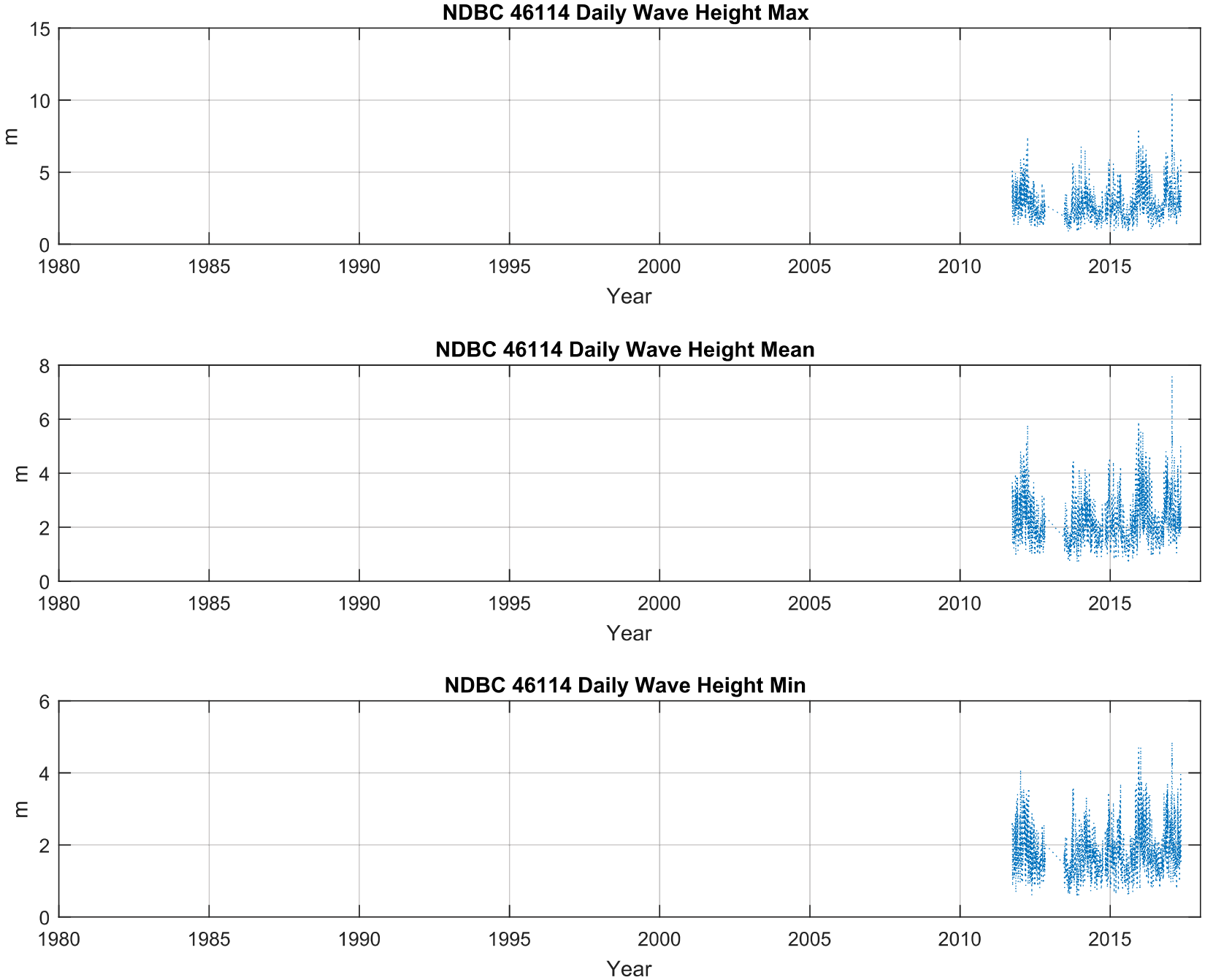


Figure A163. Daily Wave Height, Max, Mean, Min,NDBC 46114

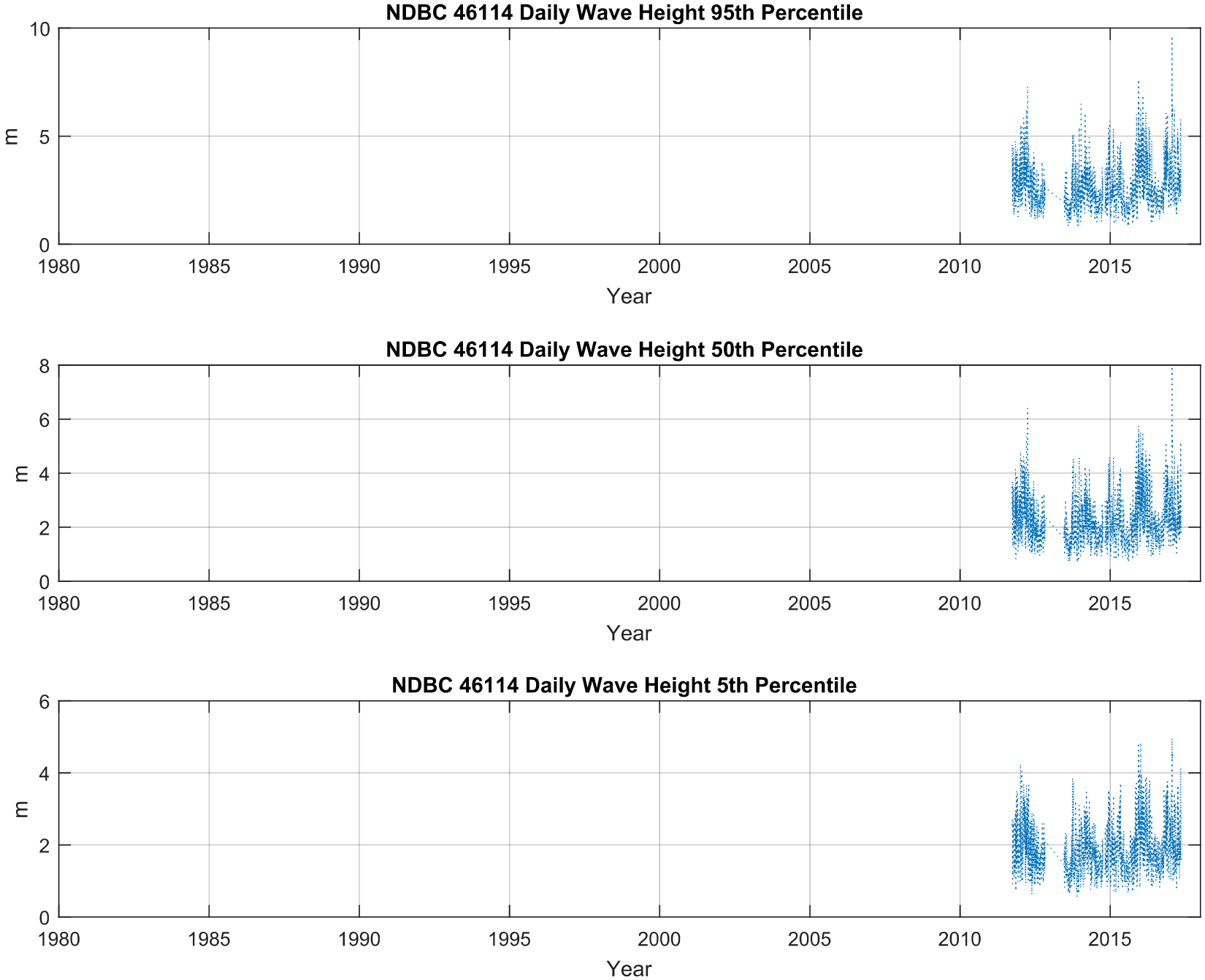


Figure A164. Daily Wave Height, Percentiles,NDBC 46114

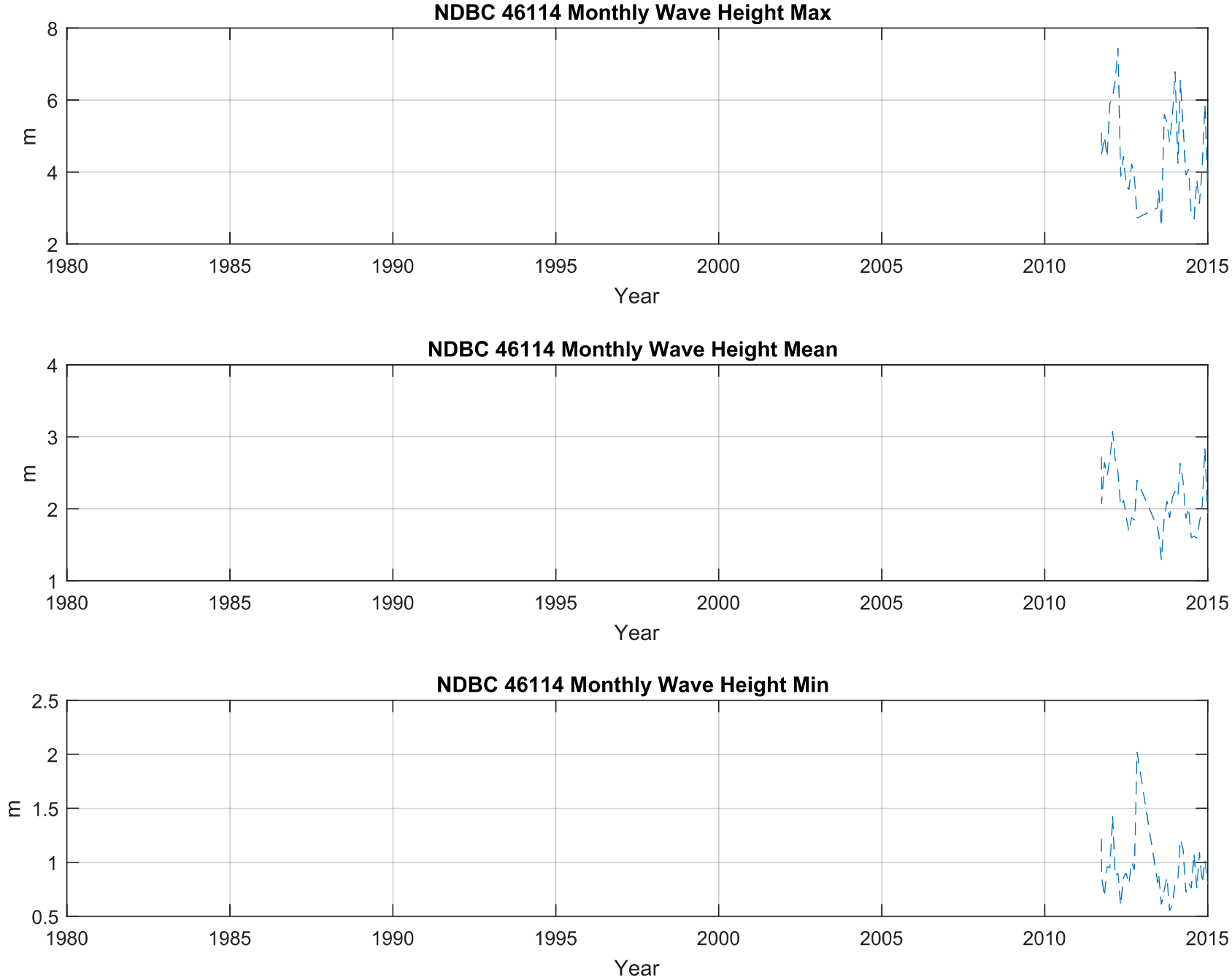


Figure A165. Monthly Wave Height, Max, Mean, Min,NDBC 46114

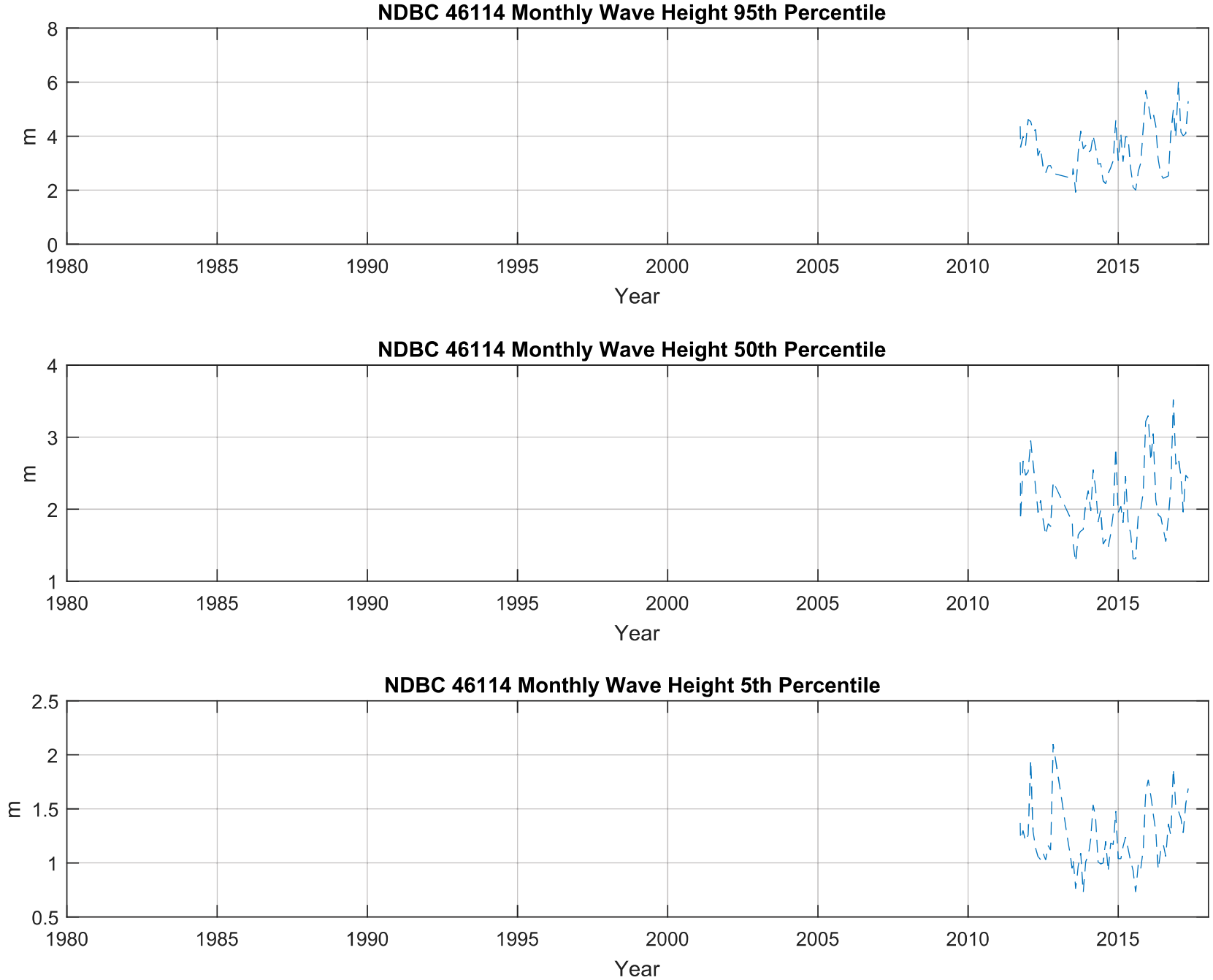


Figure A166. Monthly Wave Height, Percentiles,NDBC 46114

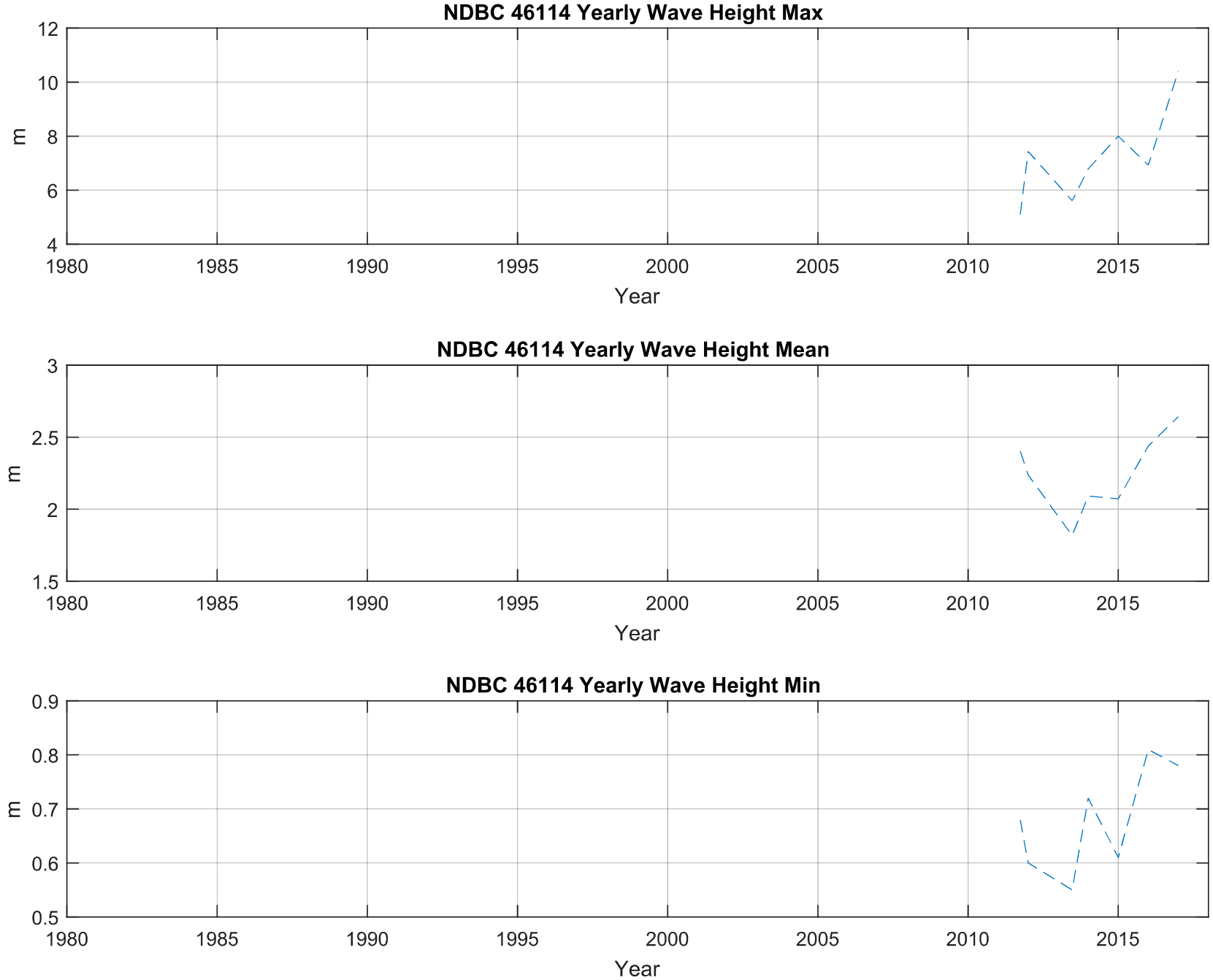
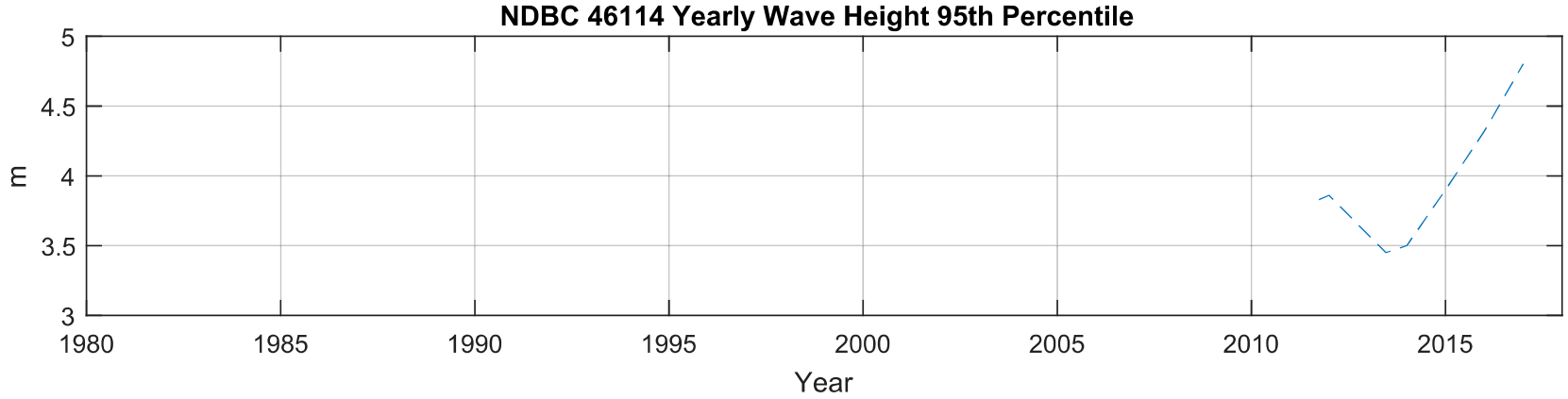
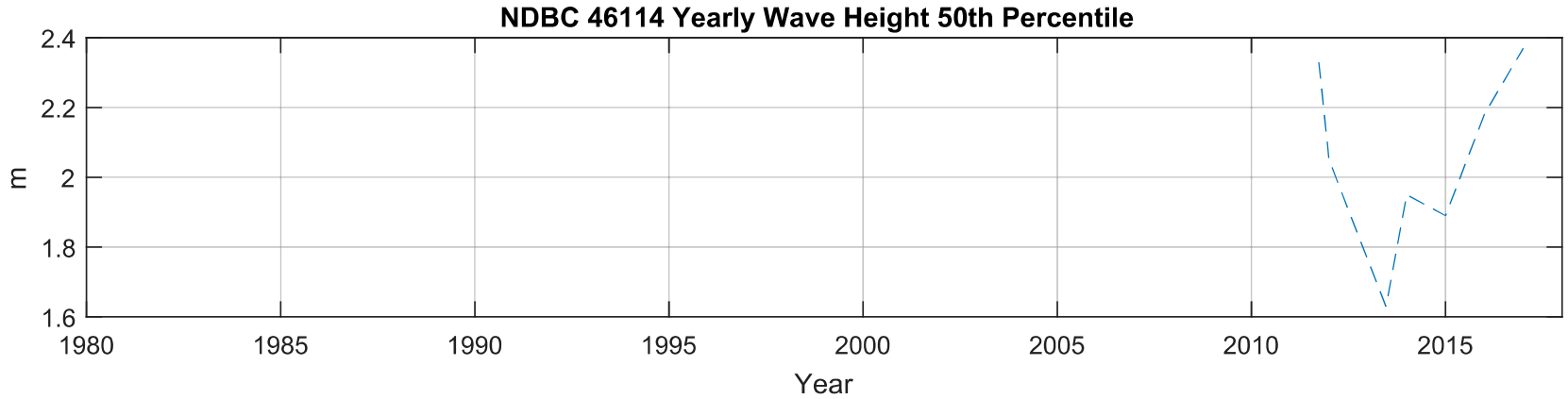


Figure A167. Yearly Wave Height, Max, Mean, Min,NDBC 46114





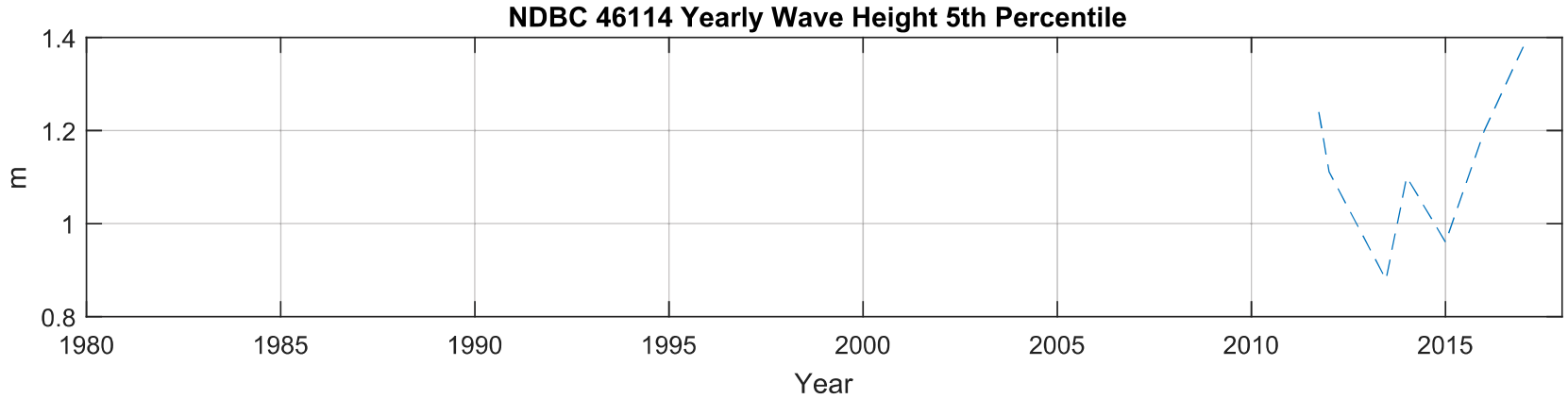


Figure A168. Yearly Wave Height, Percentiles,NDBC 46114

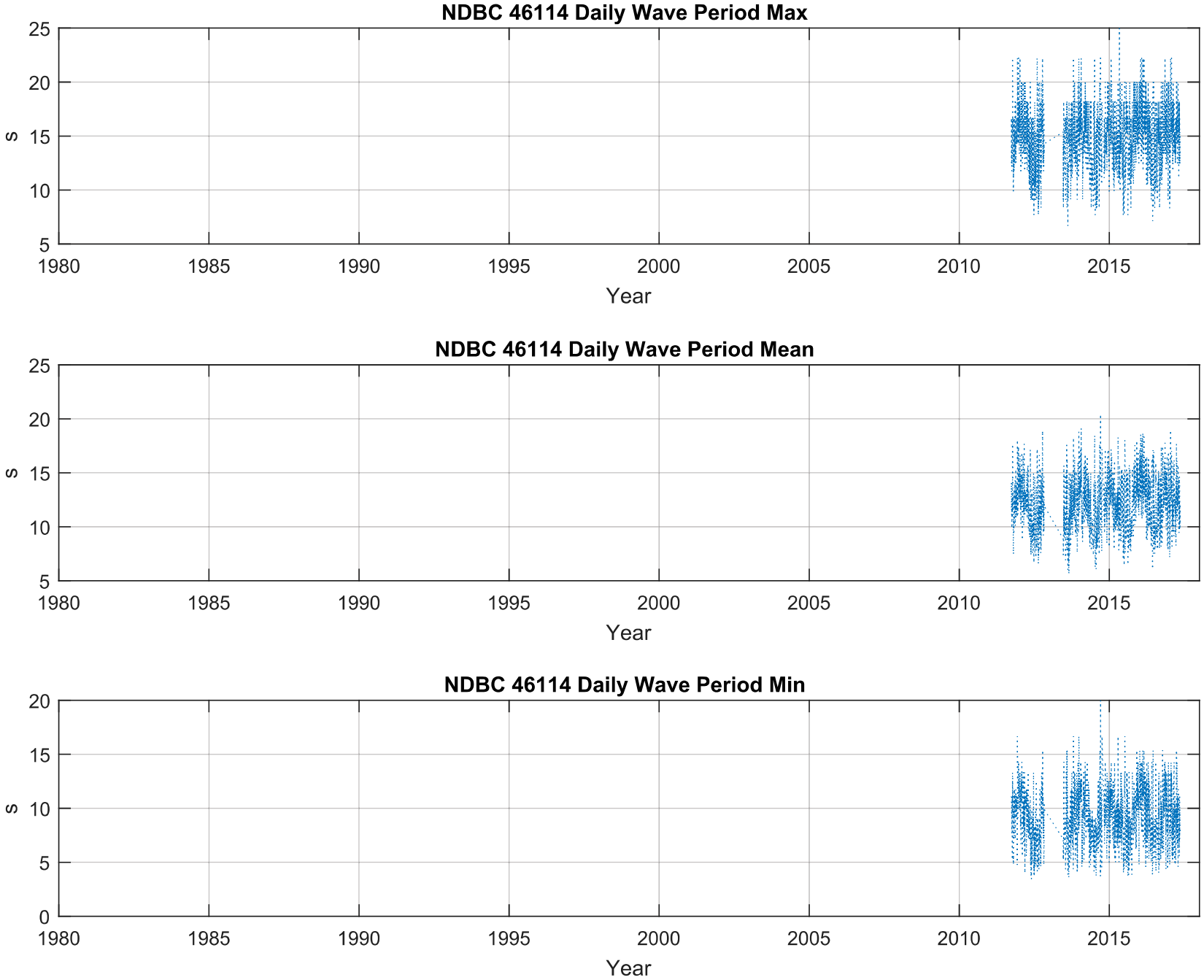
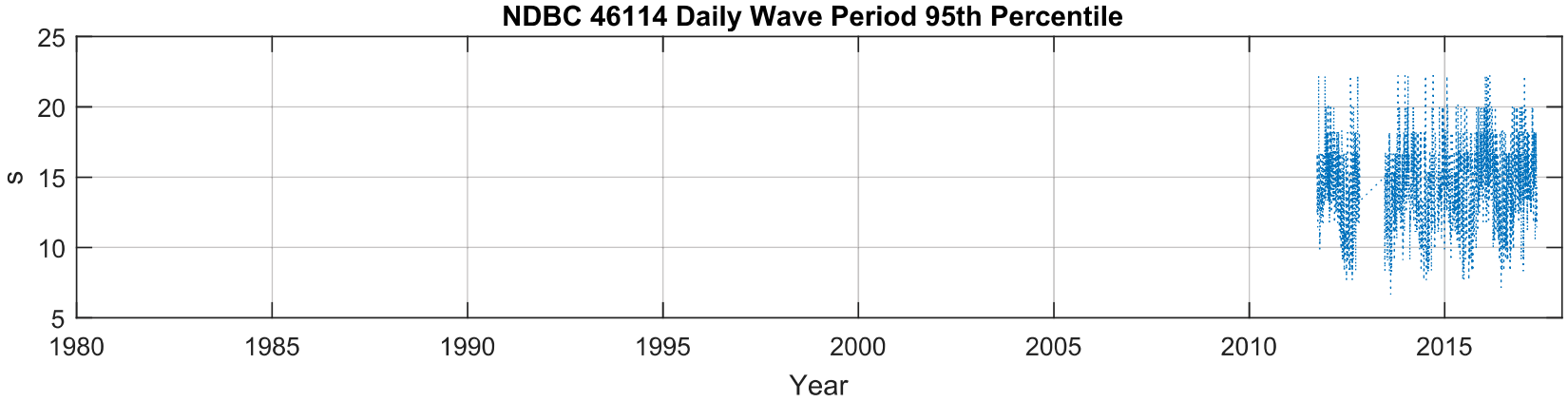
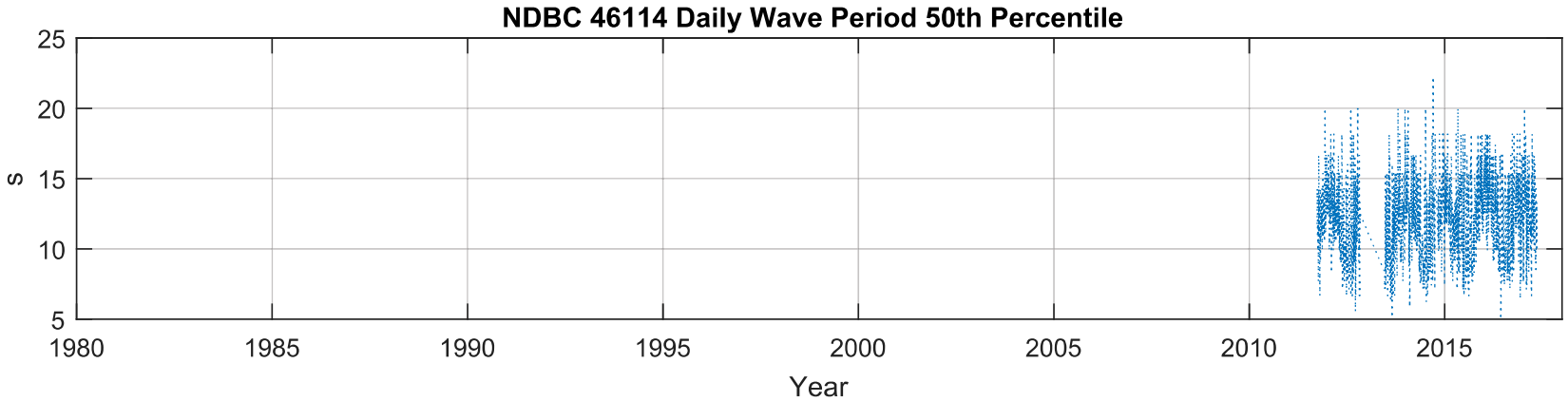


Figure A169. Daily Wave Period, Max, Mean, Min,NDBC 46114





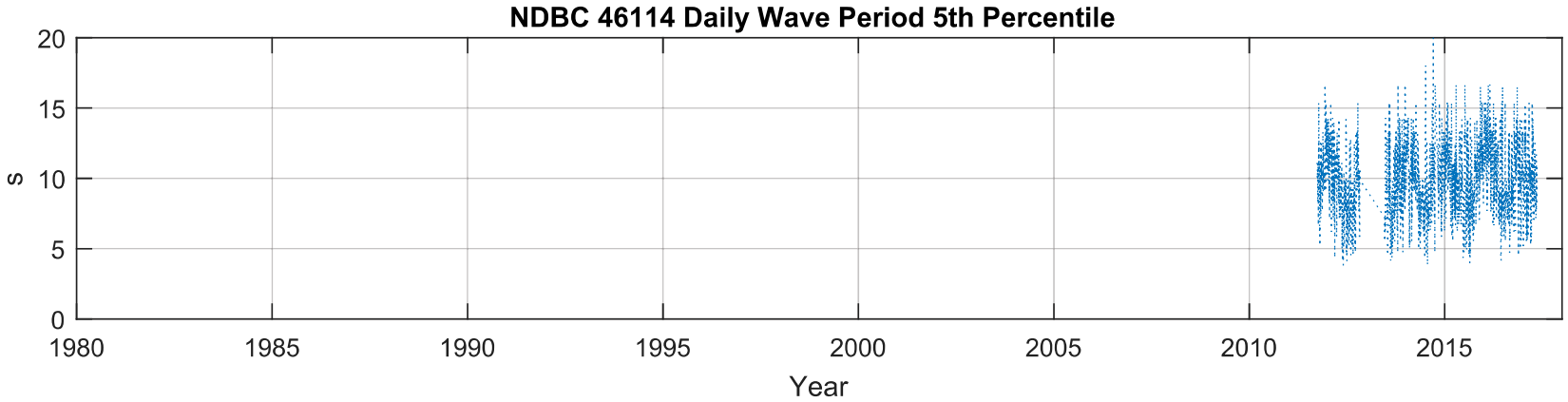
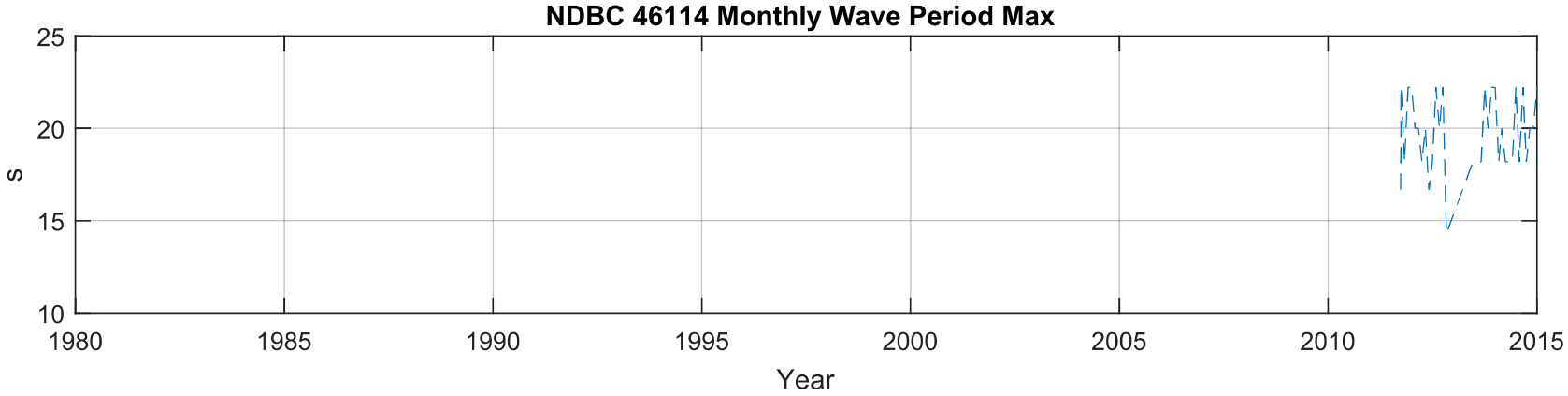
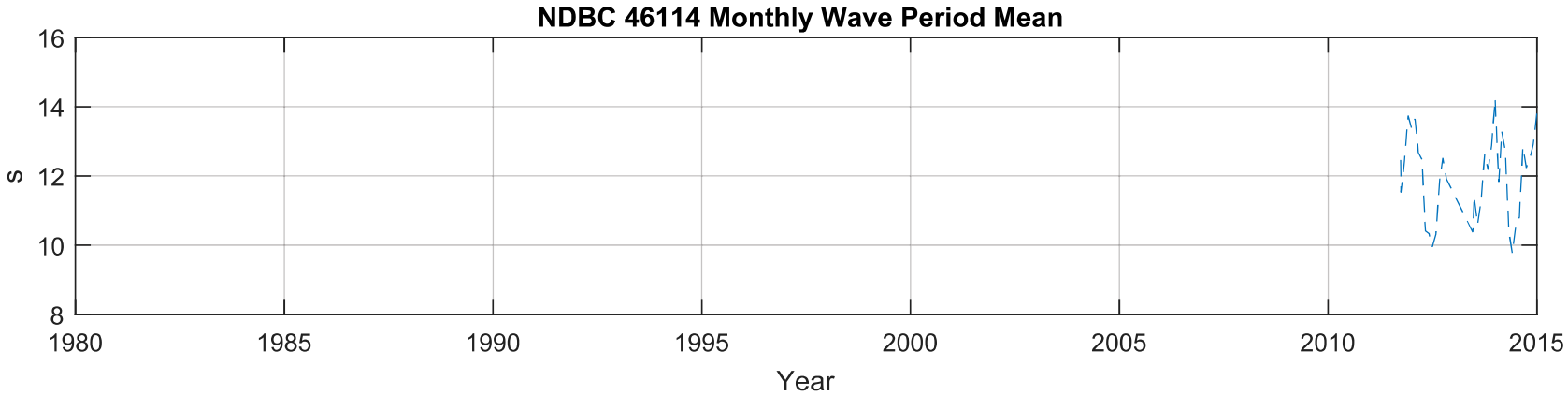


Figure A170. Daily Wave Period, Percentiles,NDBC 46114





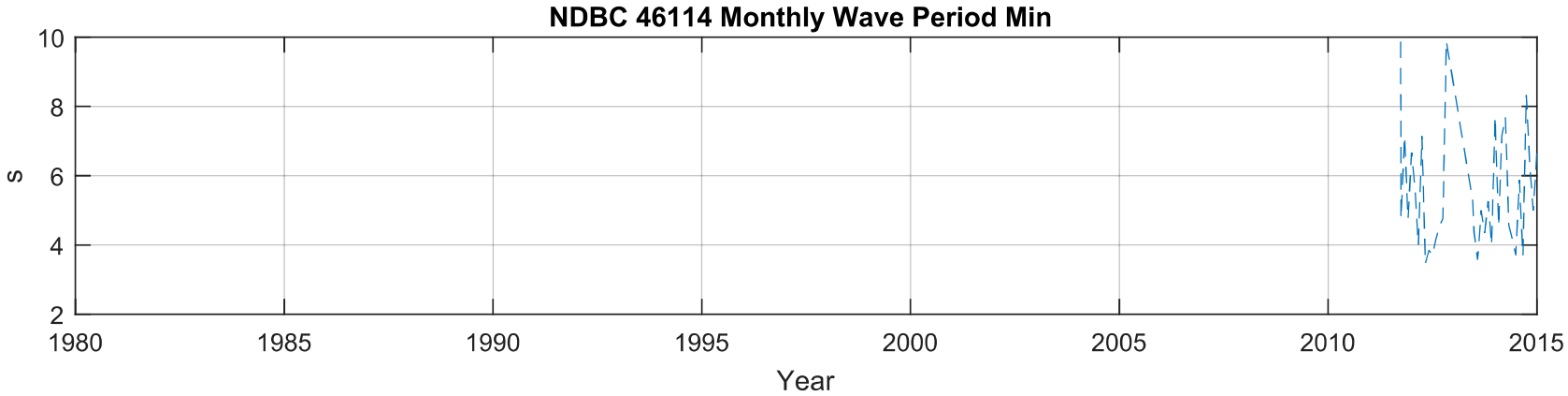
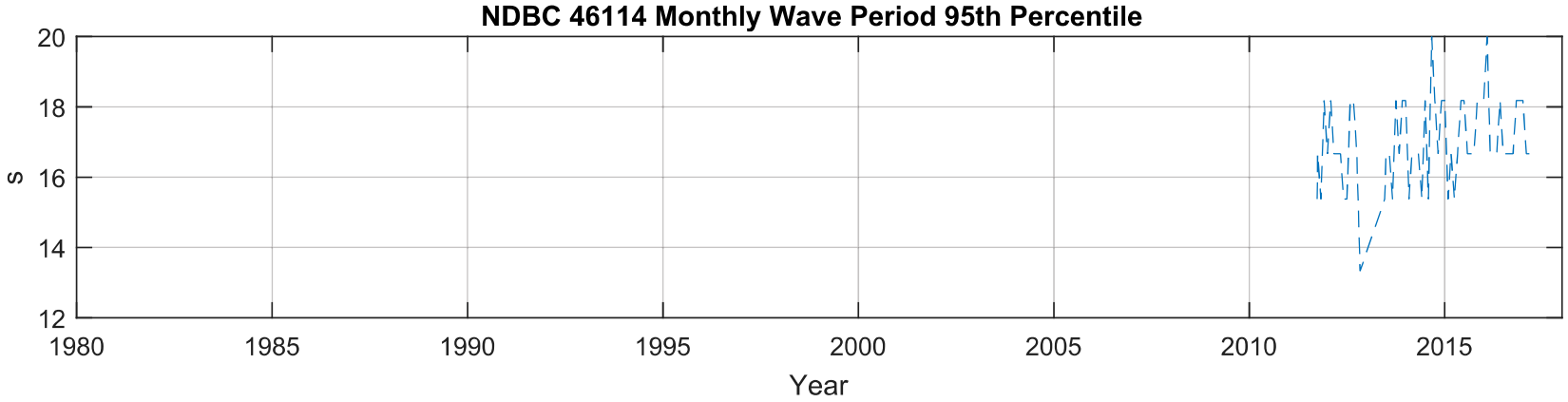
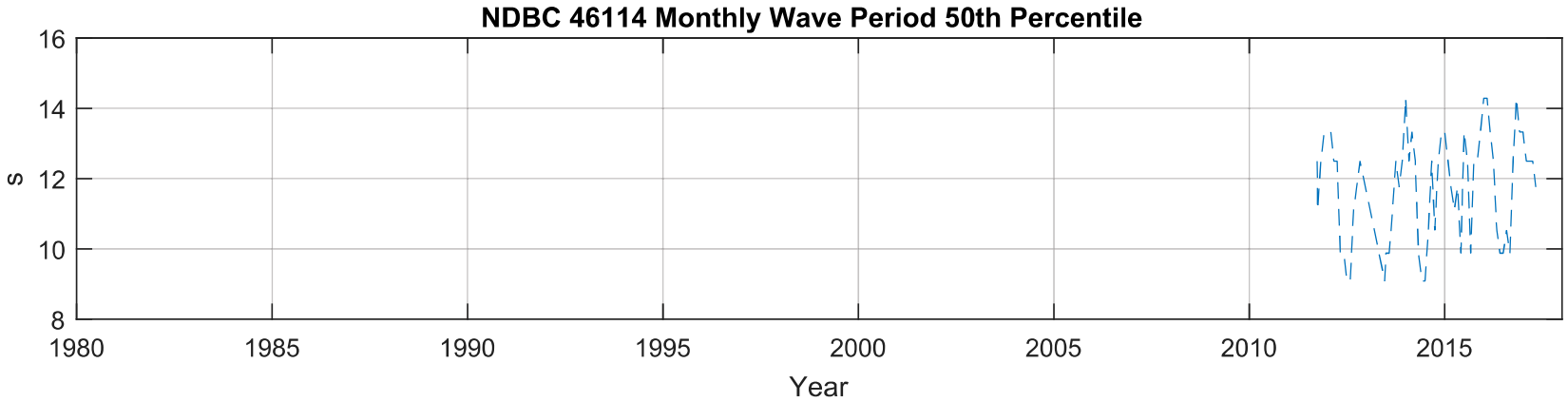


Figure A171. Monthly Wave Period, Max, Mean, Min,NDBC 46114





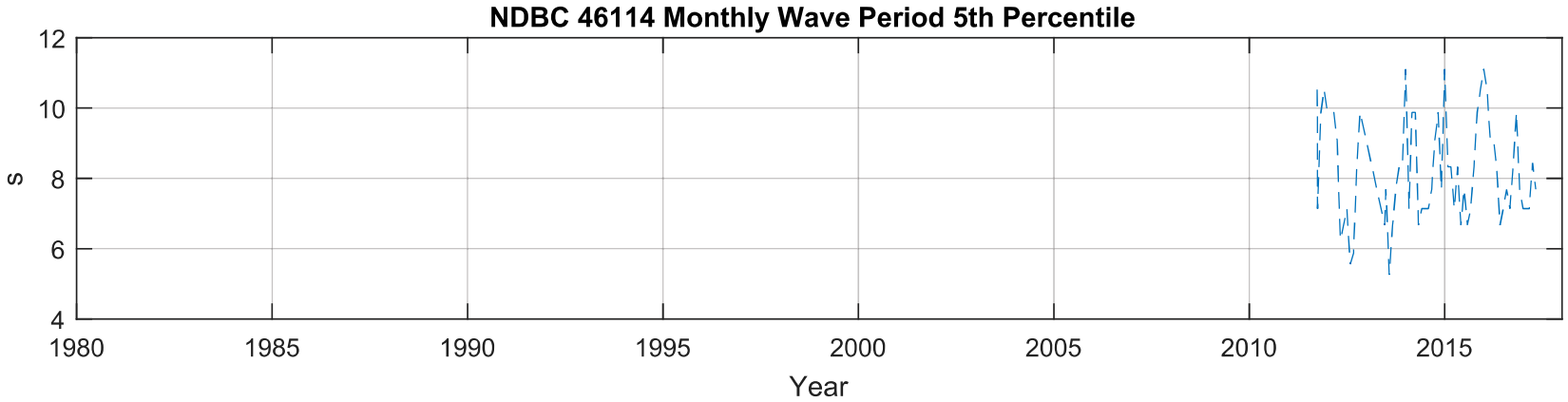


Figure A172. Monthly Wave Period, Percentiles,NDBC 46114

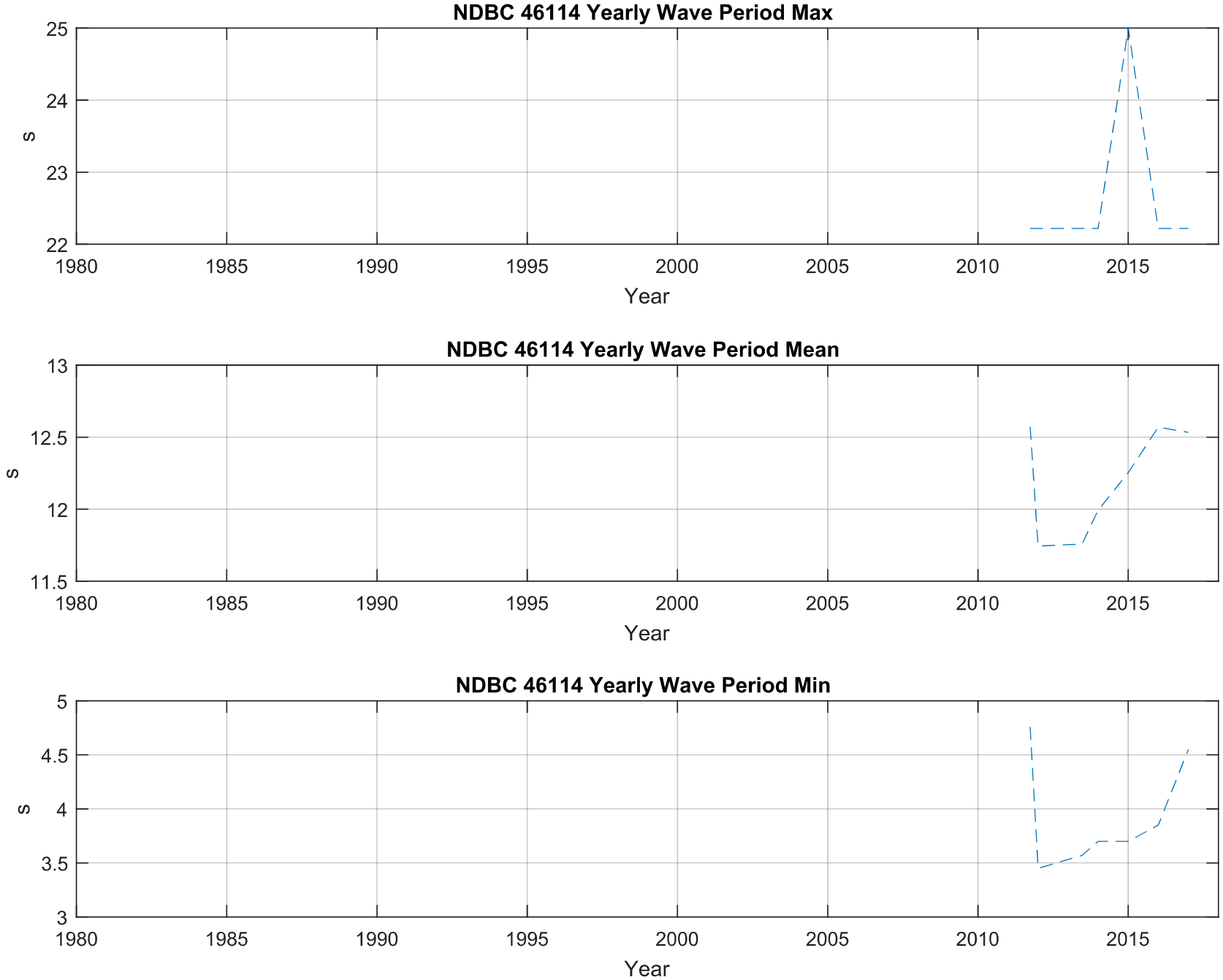
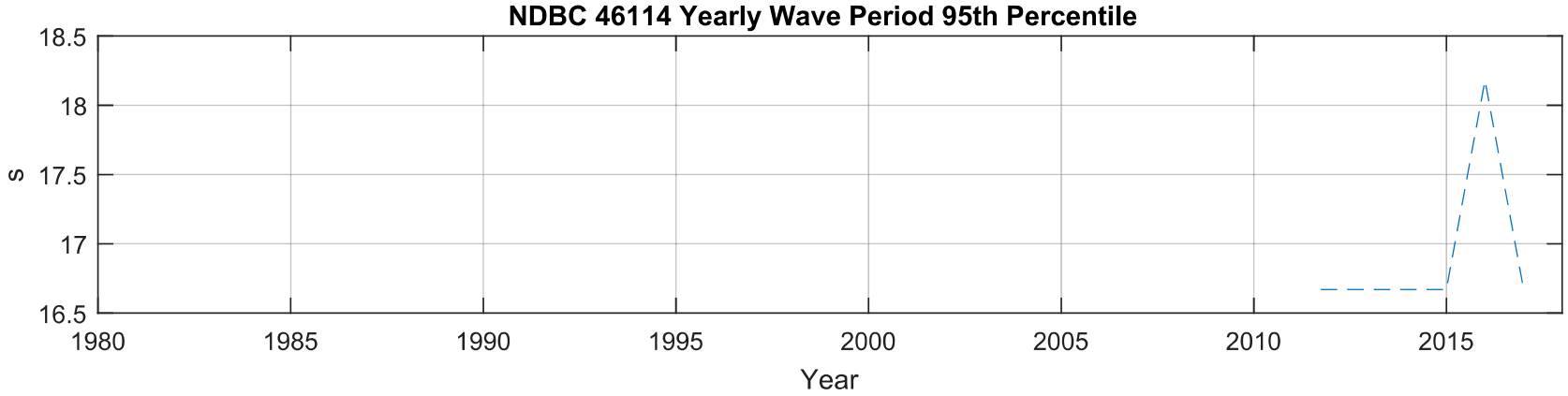
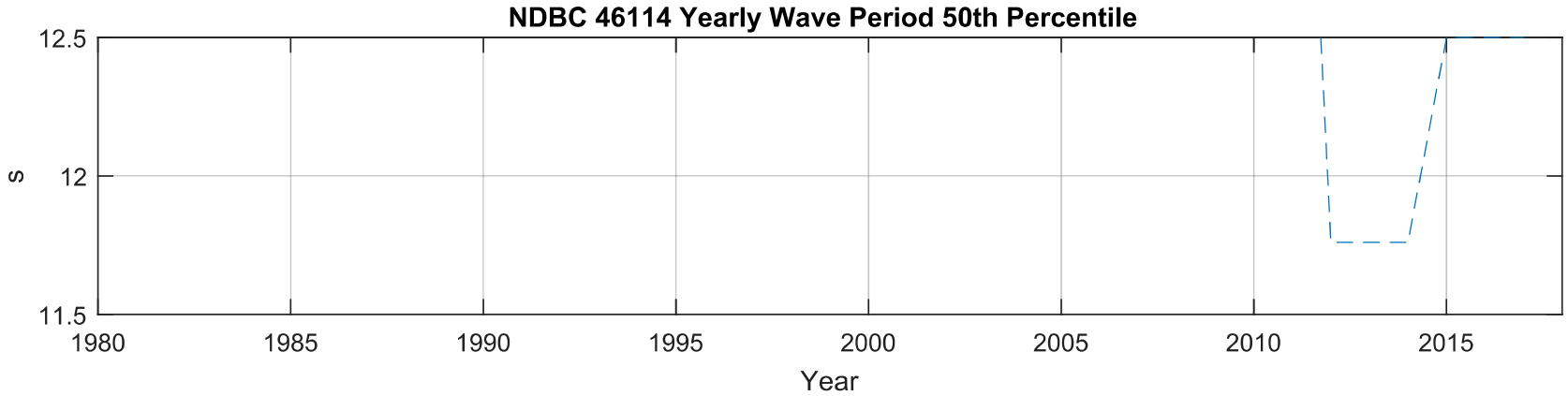


Figure A173. Yearly Wave Period, Max, Mean, Min,NDBC 46114





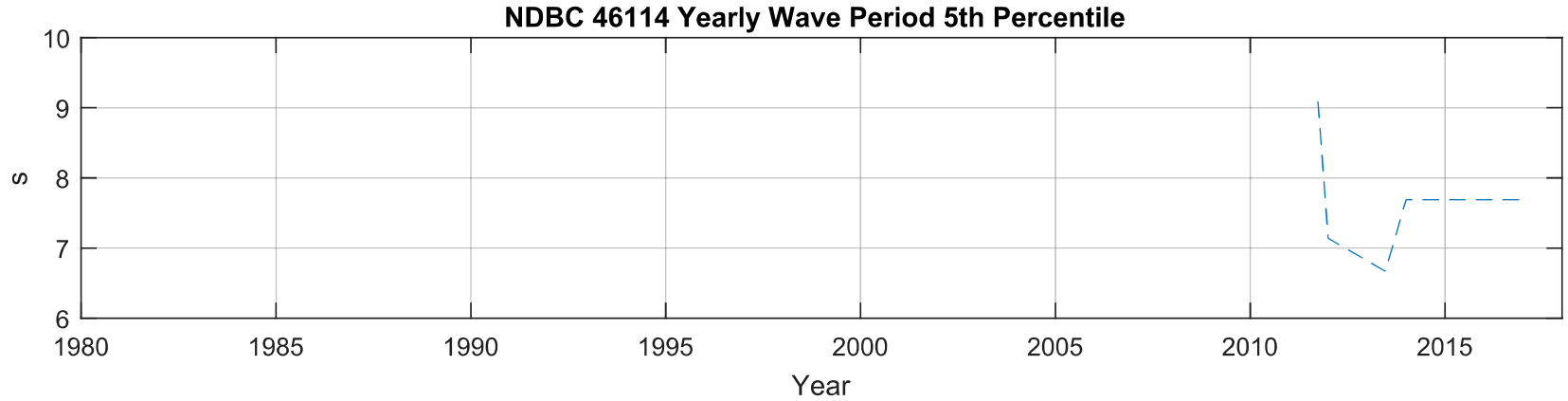
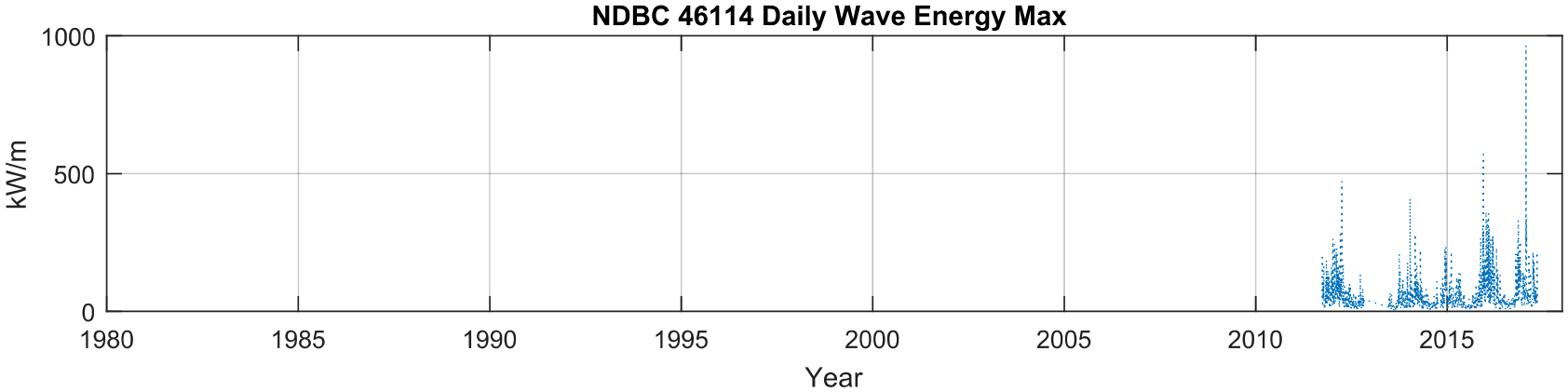
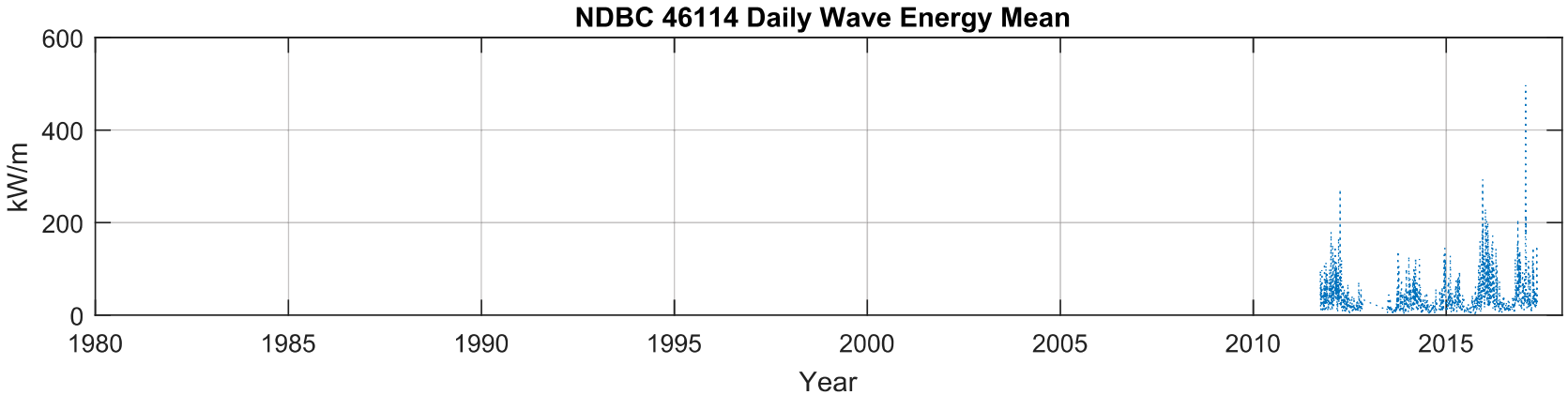


Figure A174. Yearly Wave Period, Percentiles,NDBC 46114





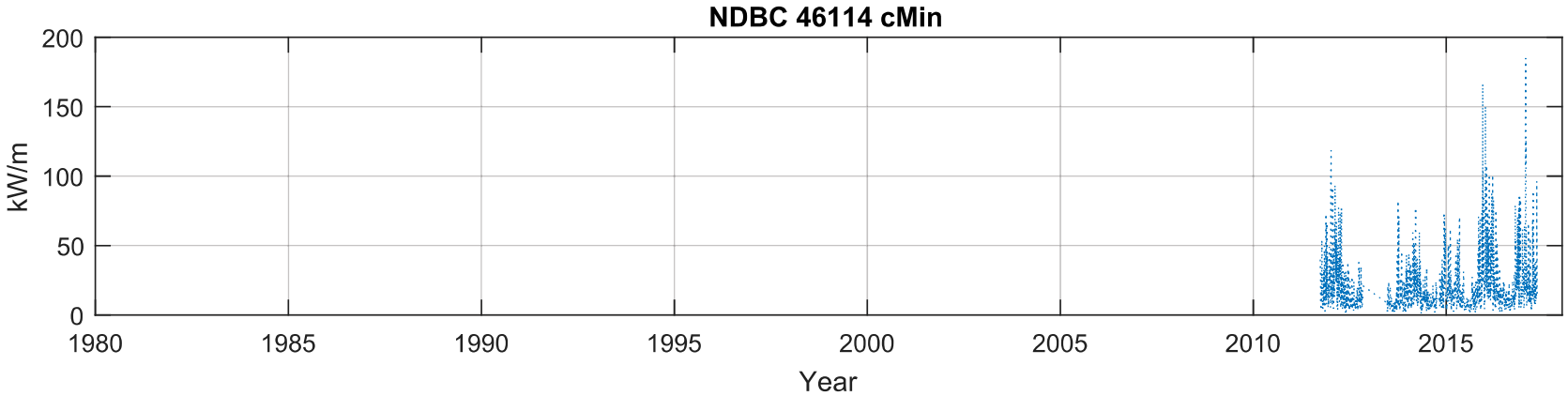


Figure A175. Daily Wave Energy, Max, Mean, Min,NDBC 46114

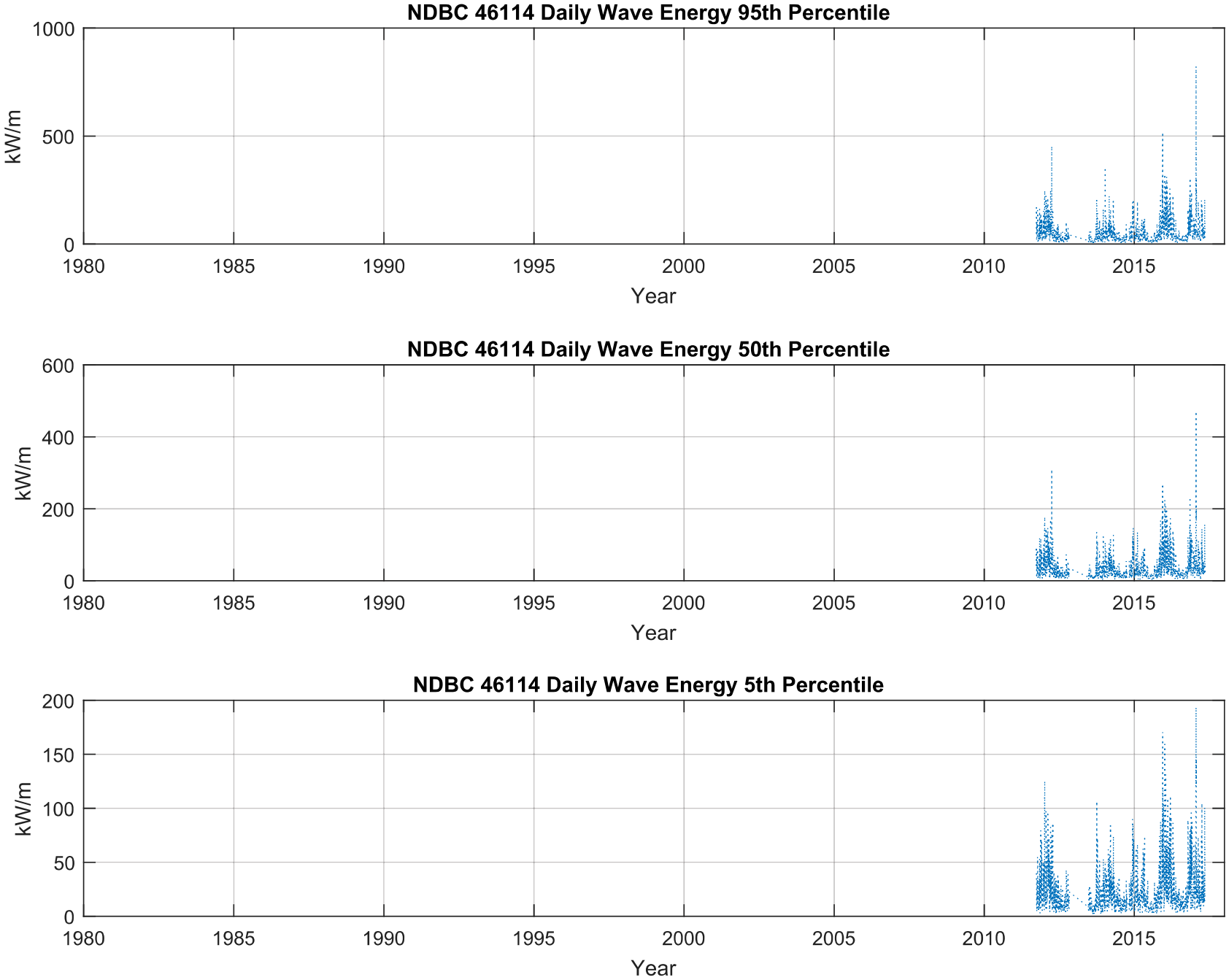


Figure A176. Daily Wave Energy, Percentiles,NDBC 46114

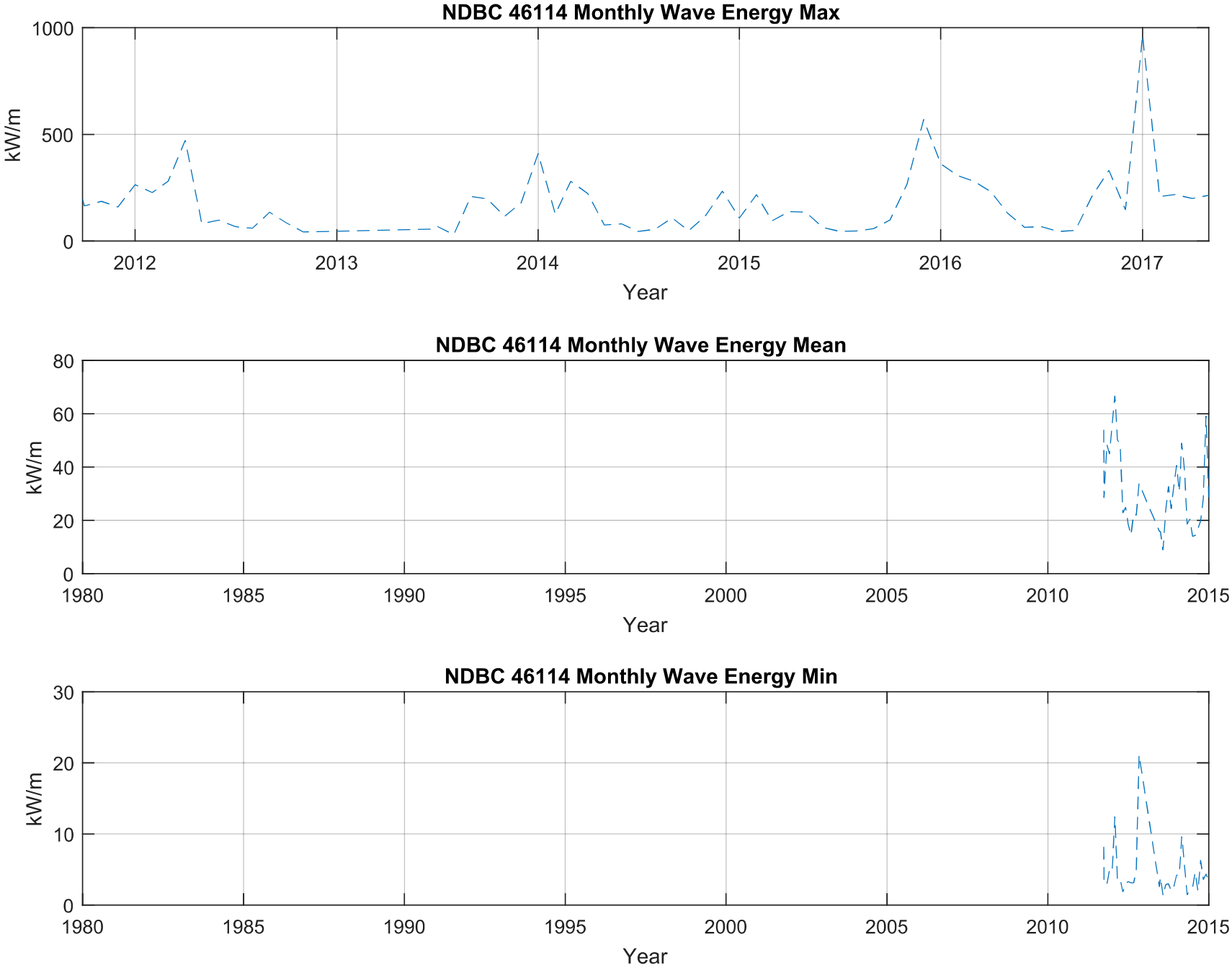


Figure A177. Monthly Wave Energy, Max, Mean, Min,NDBC 46114

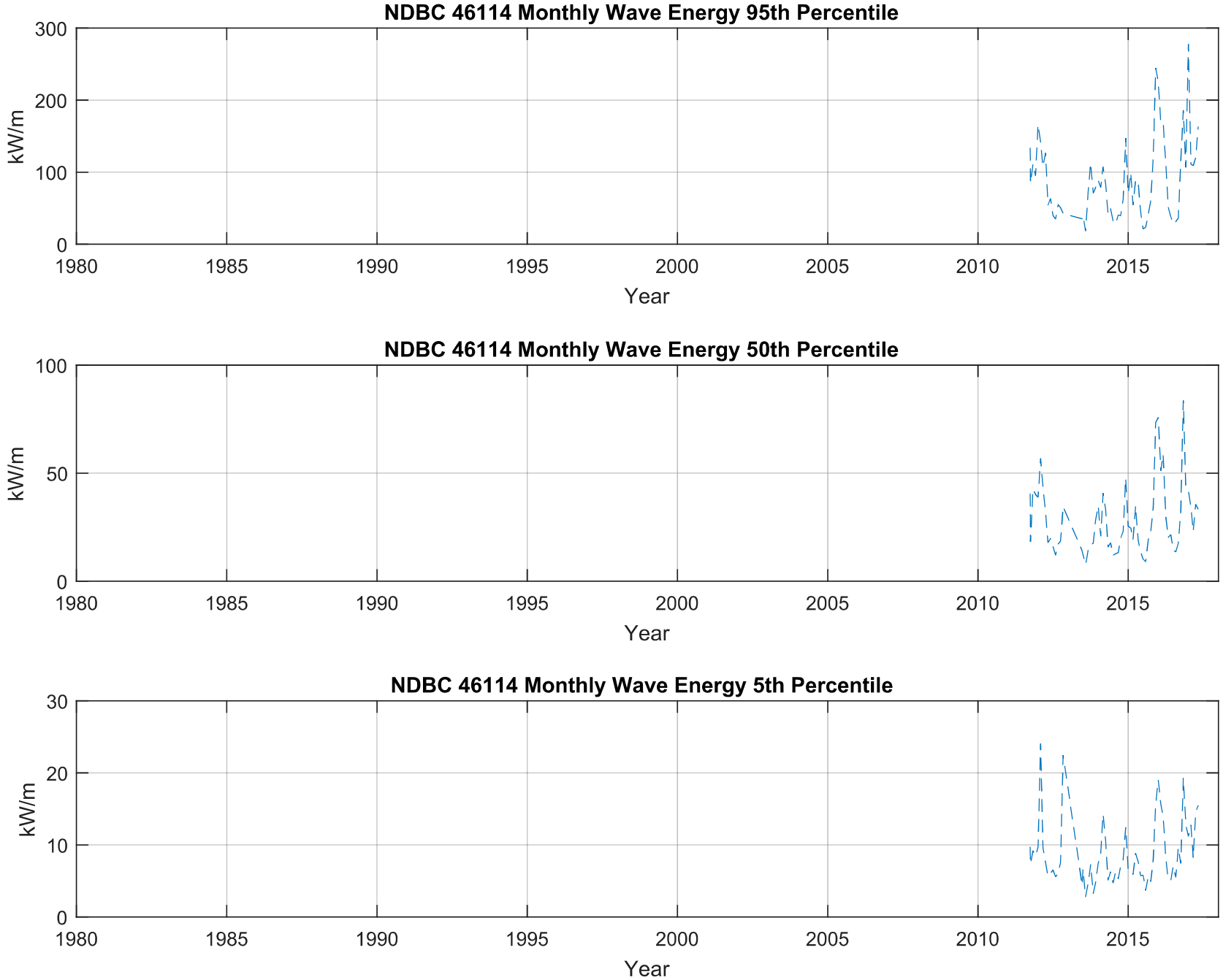


Figure A178. Monthly Wave Energy, Percentiles,NDBC 46114

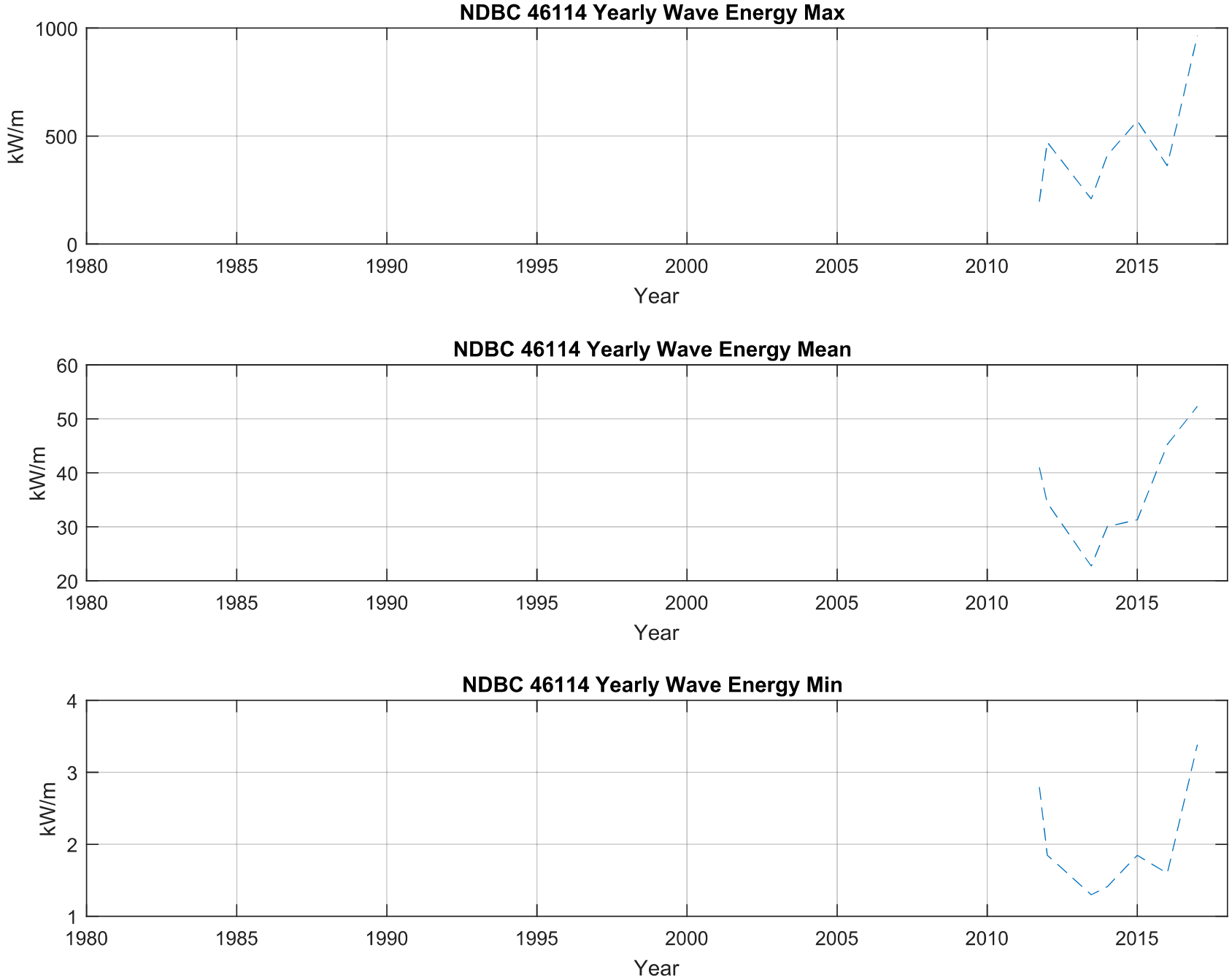


Figure A179. Yearly Wave Energy, Max, Mean, Min,NDBC 46114

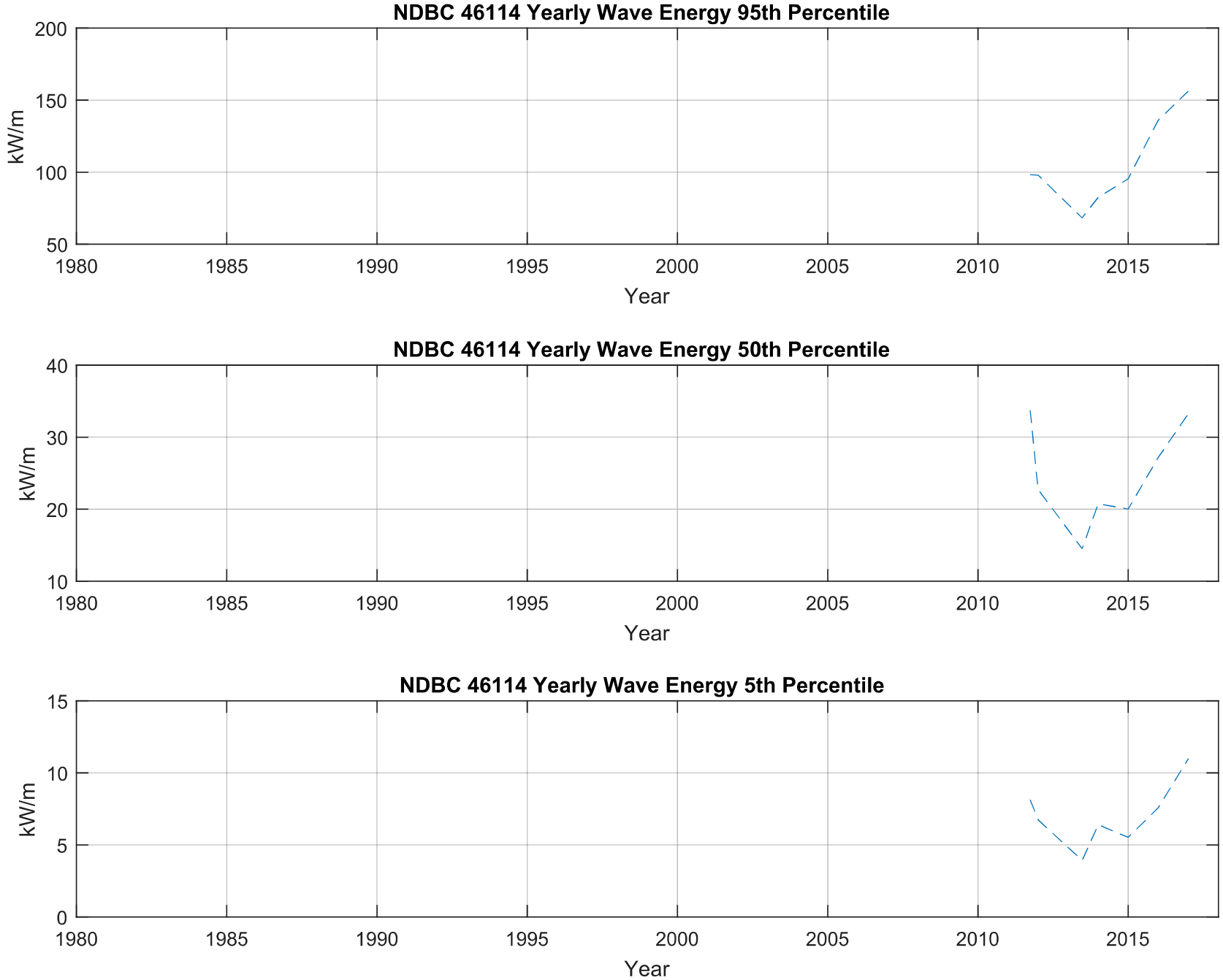


Figure A180. Yearly Wave Energy, Percentiles,NDBC 46114

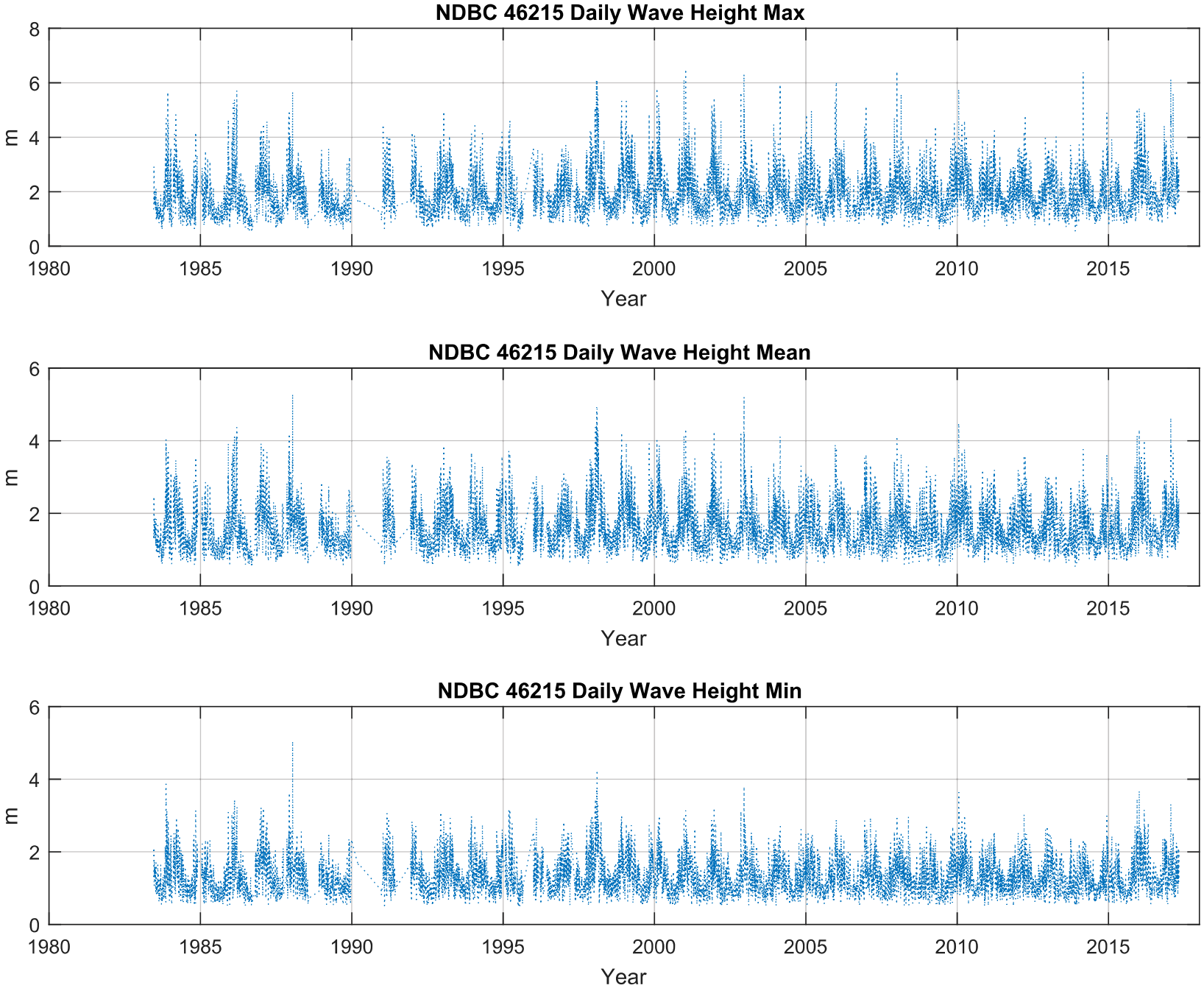


Figure A181. Daily Wave Height, Max, Mean, Min,NDBC 46215

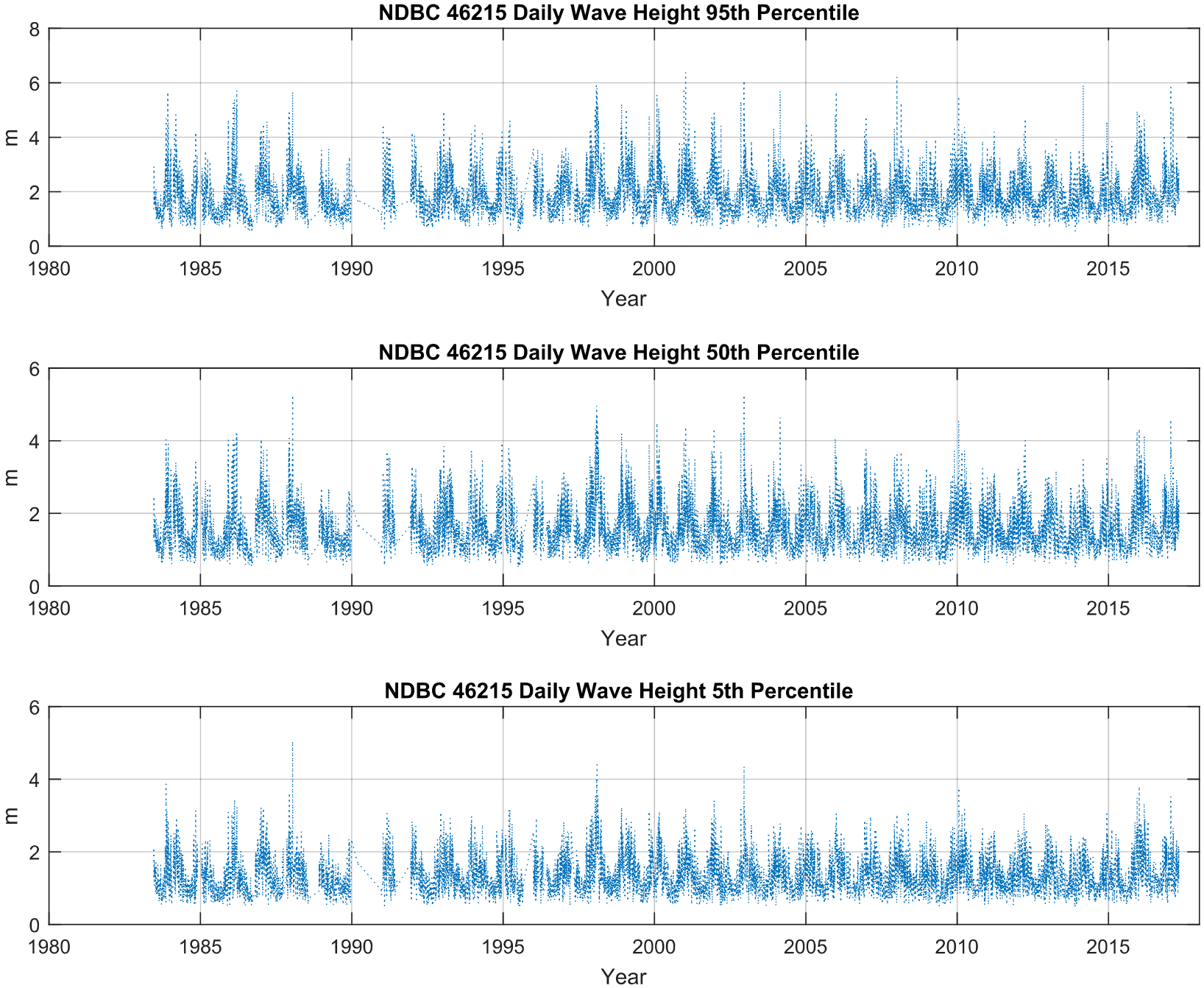


Figure A182. Daily Wave Height, Percentiles,NDBC 46215

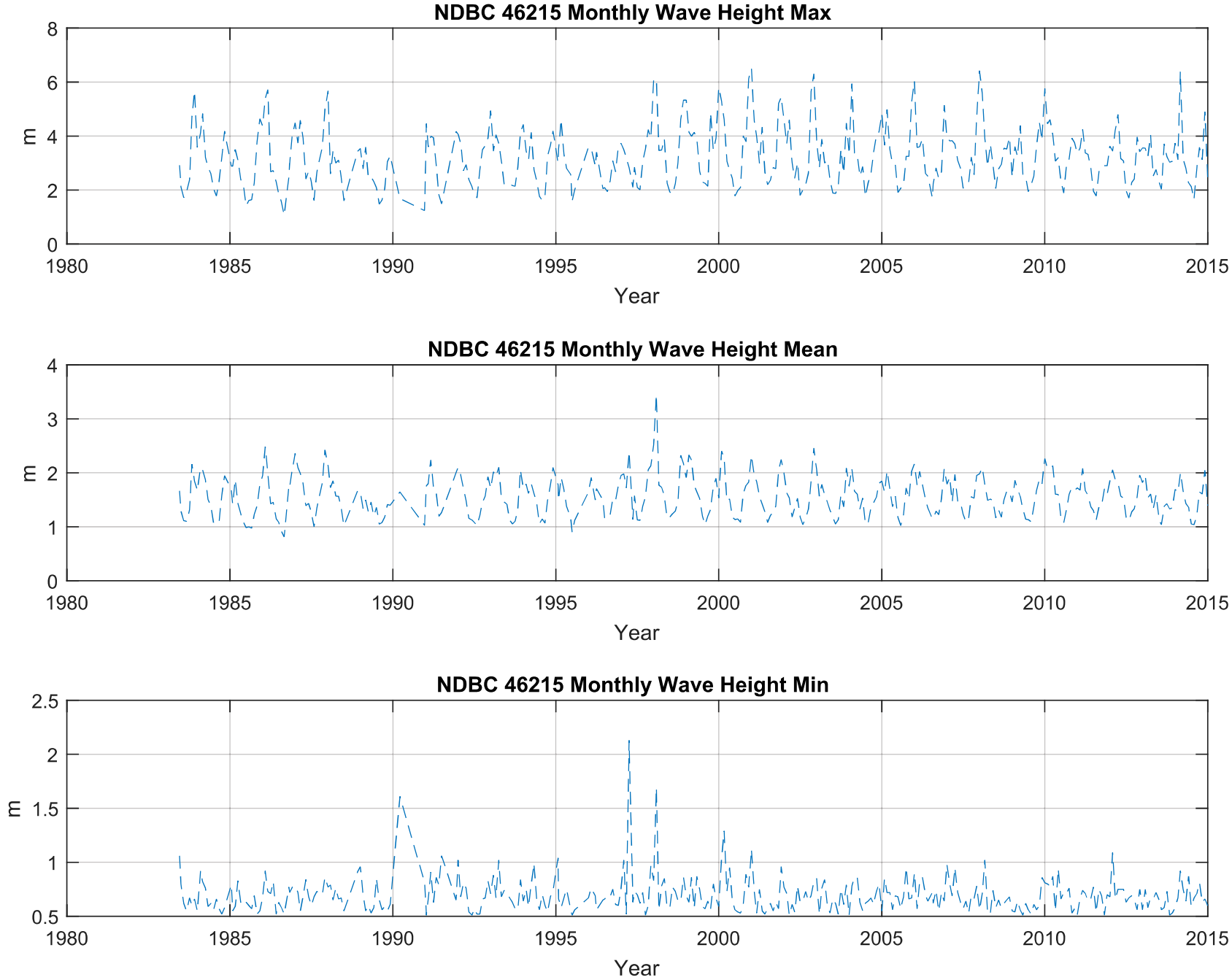


Figure A183. Monthly Wave Height, Max, Mean, Min,NDBC 46215

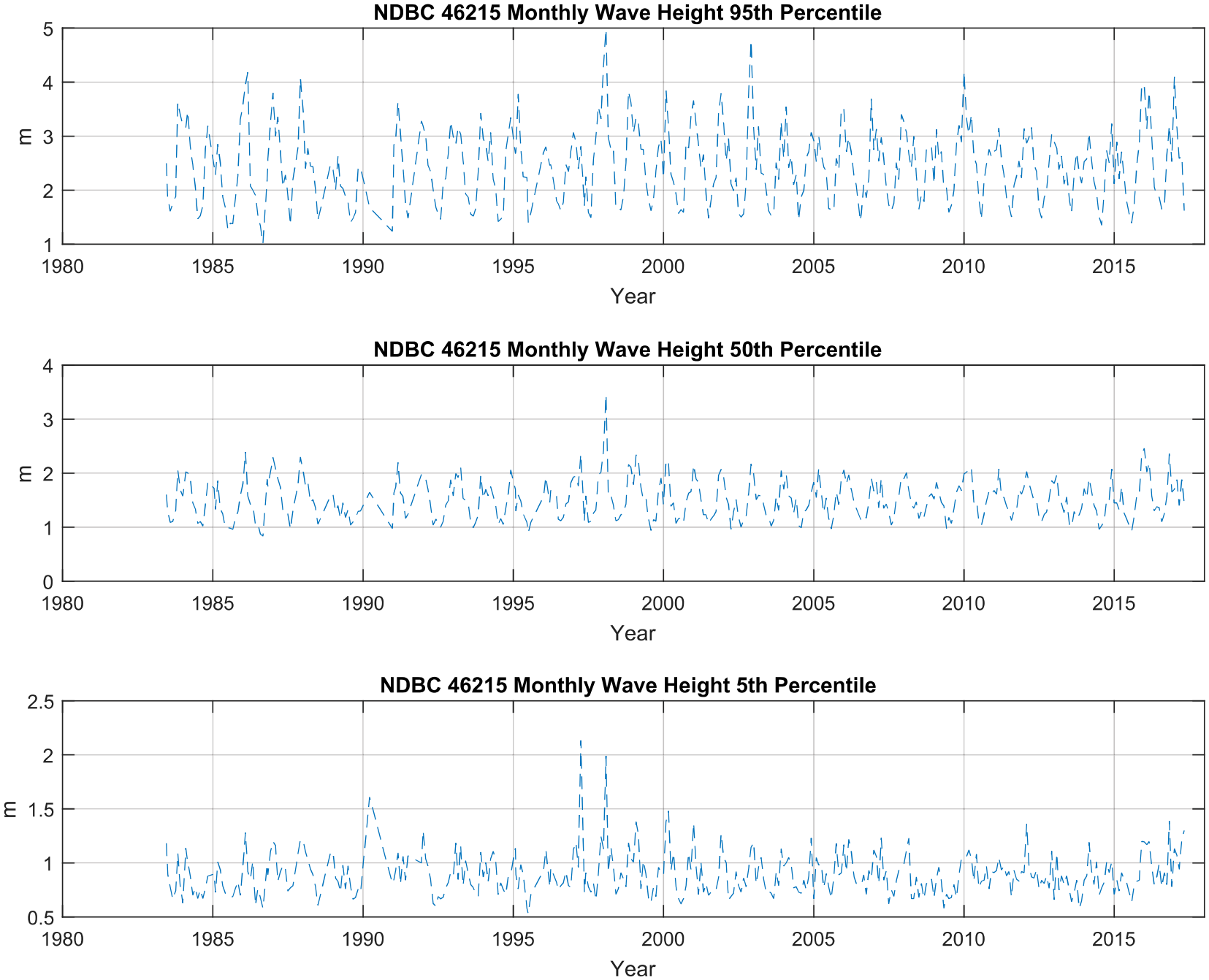


Figure A184. Monthly Wave Height, Percentiles,NDBC 46215

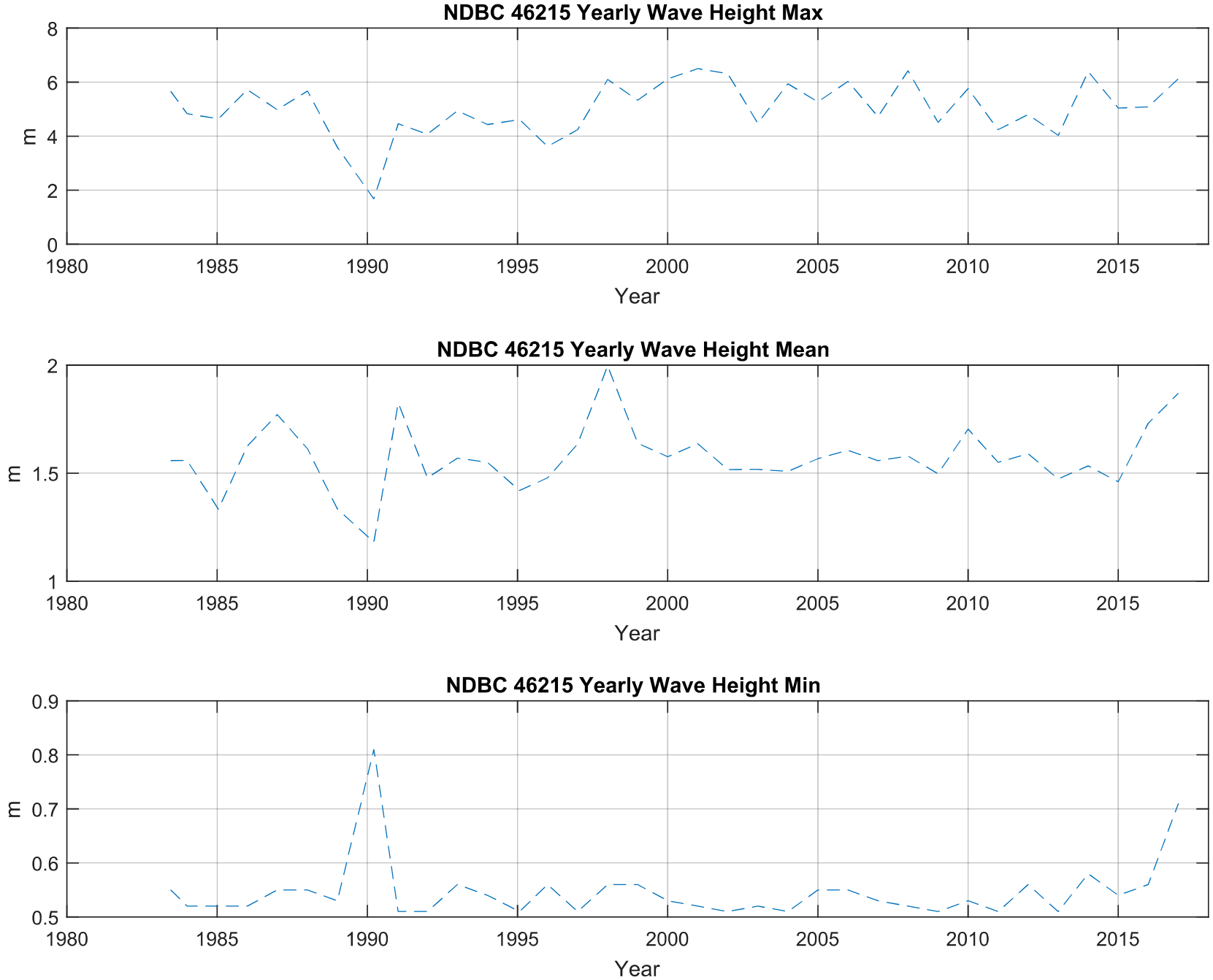


Figure A185. Yearly Wave Height, Max, Mean, Min,NDBC 46215

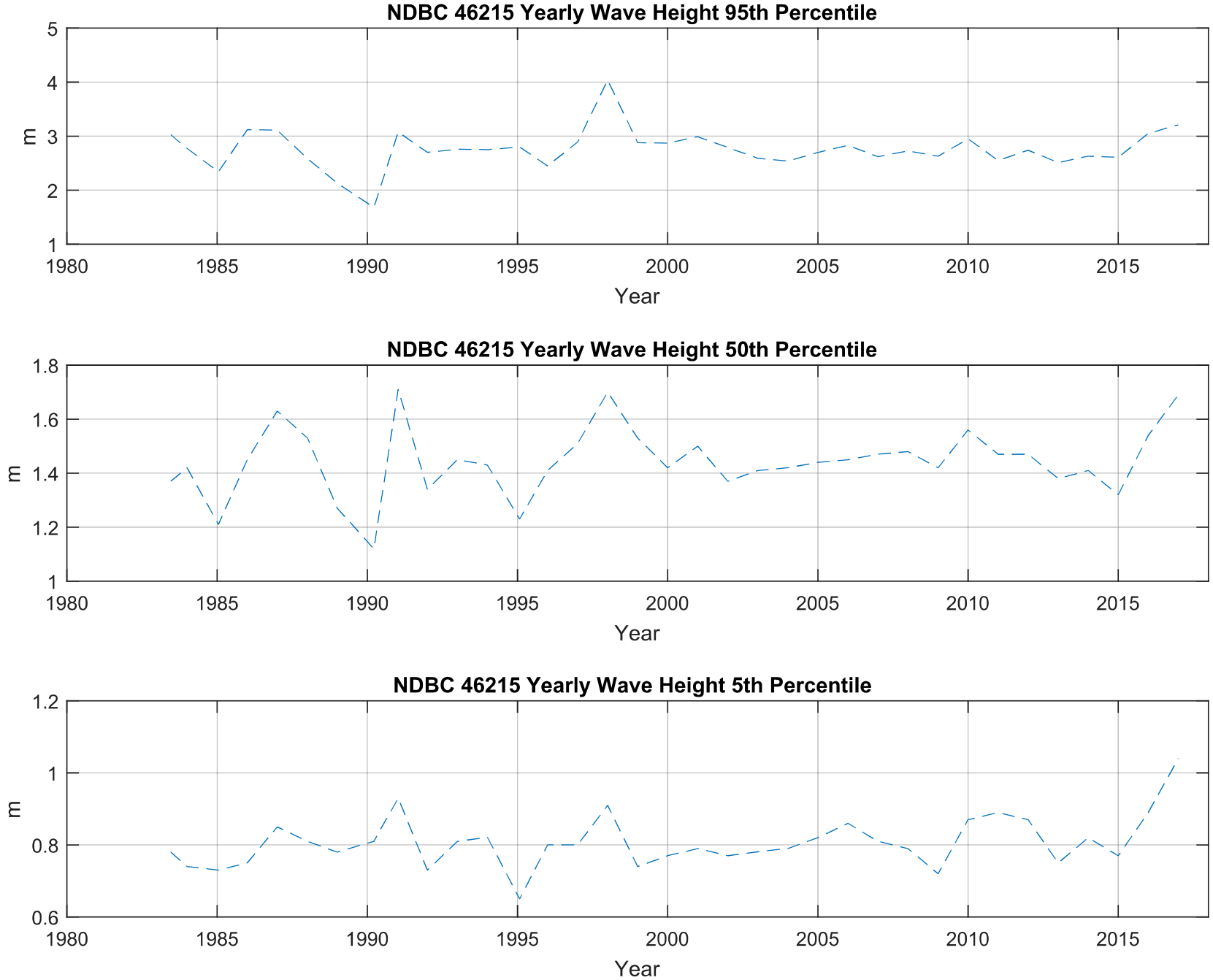


Figure A186. Yearly Wave Height, Percentiles,NDBC 46215

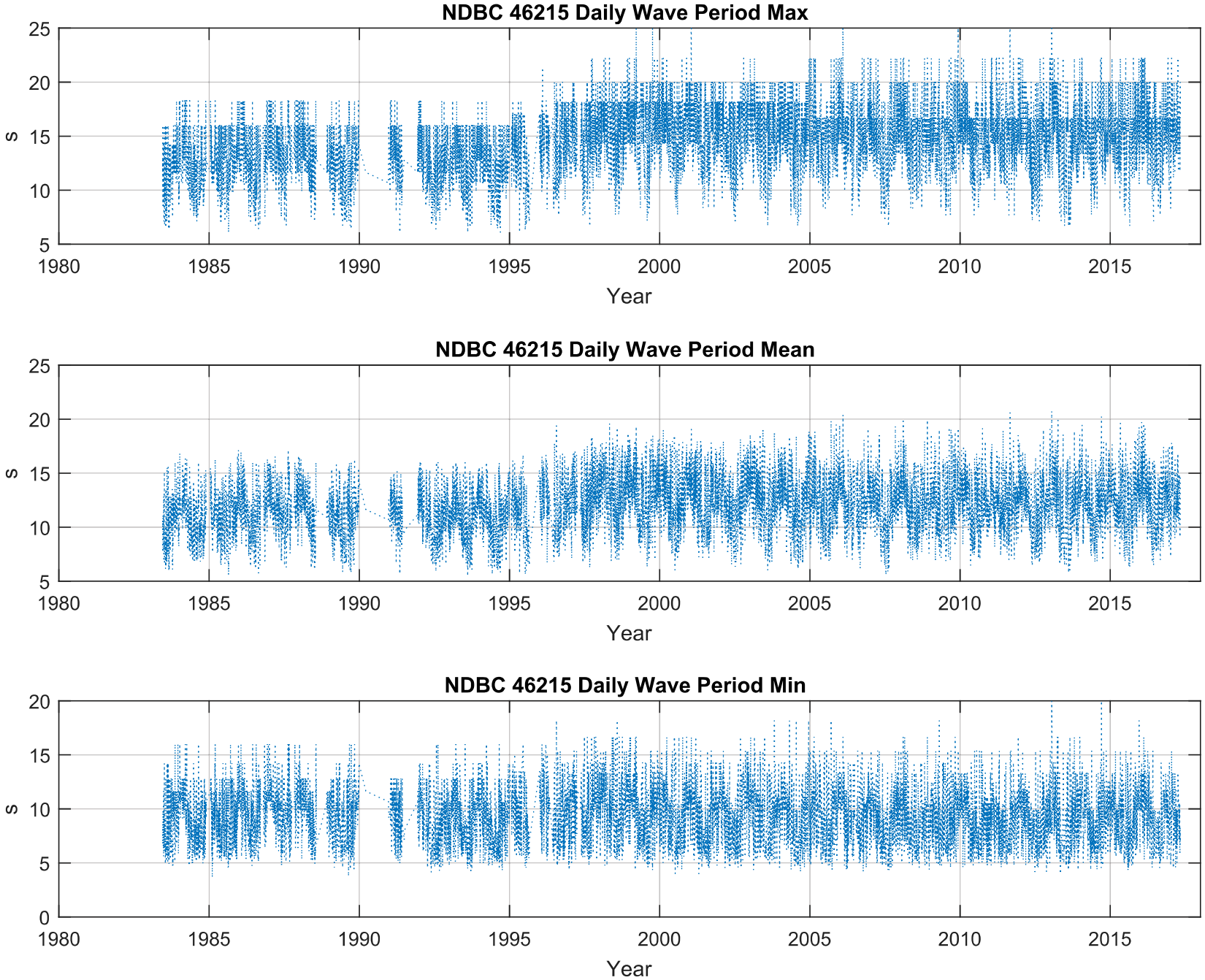


Figure A187. Daily Wave Period, Max, Mean, Min,NDBC 46215

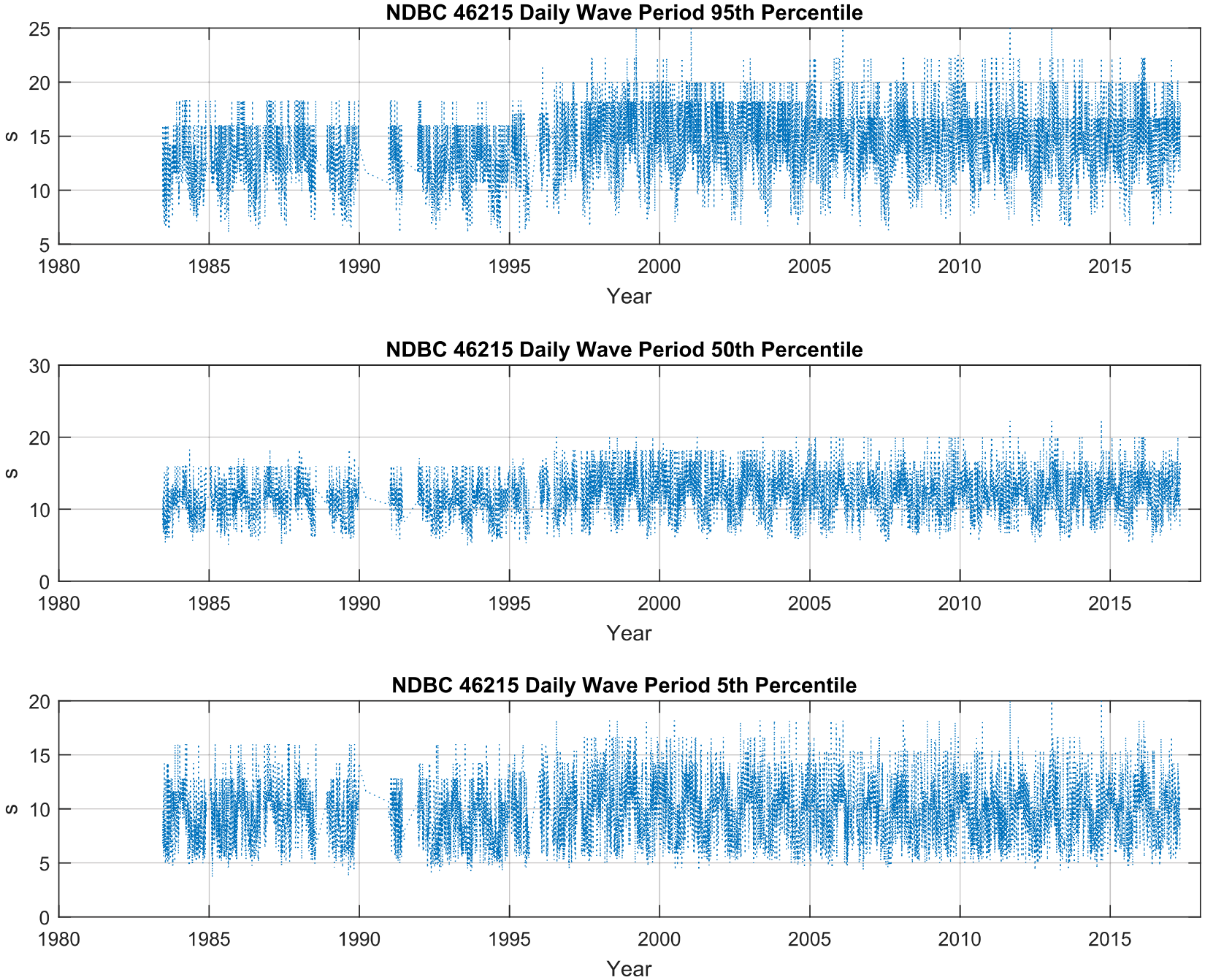


Figure A188. Daily Wave Period, Percentiles,NDBC 46215

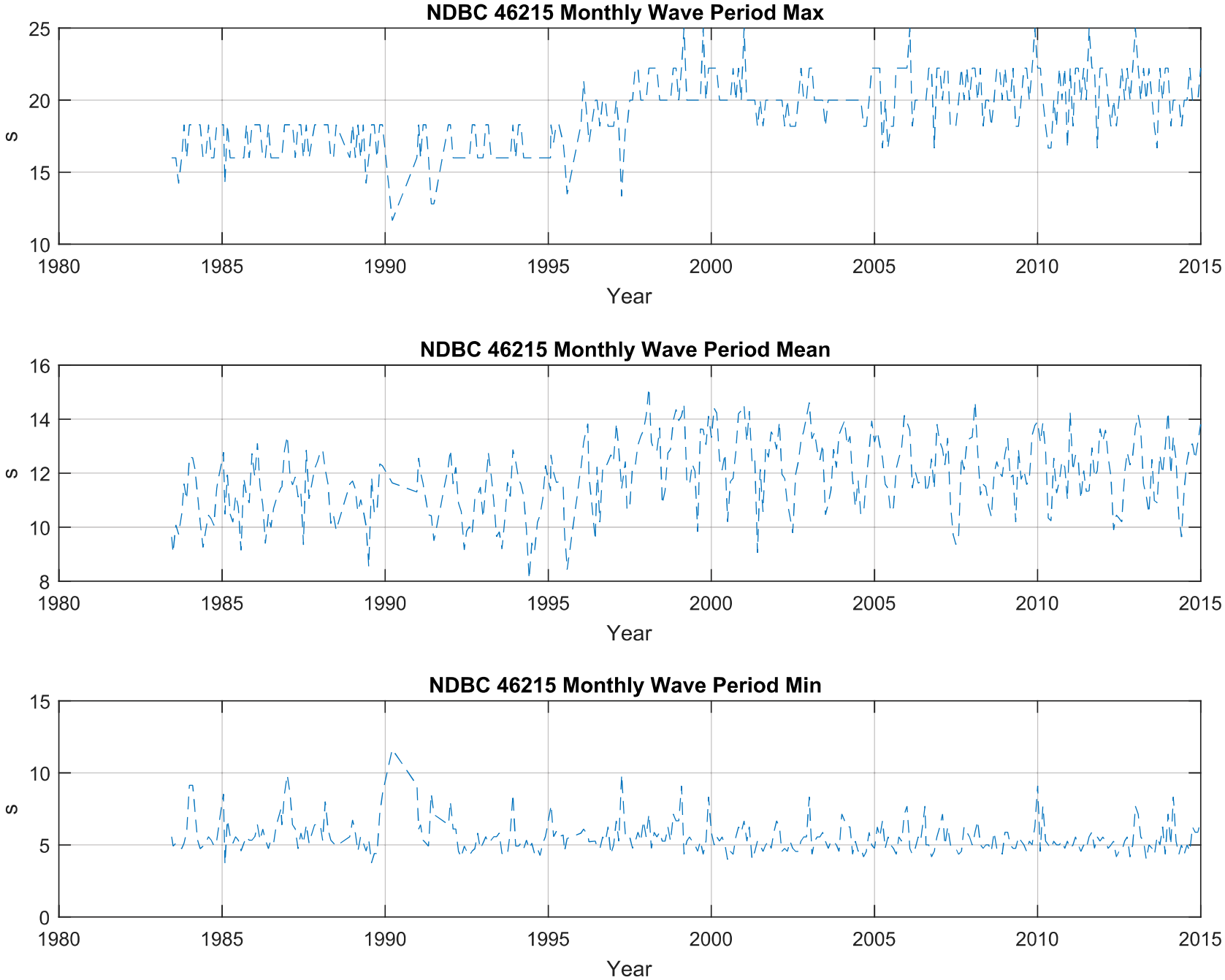
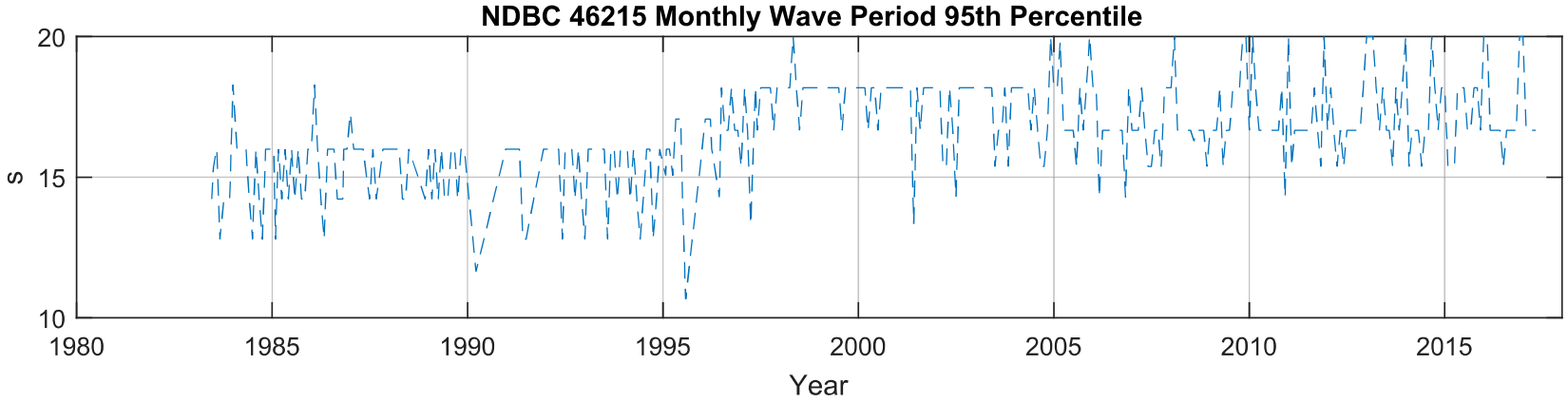
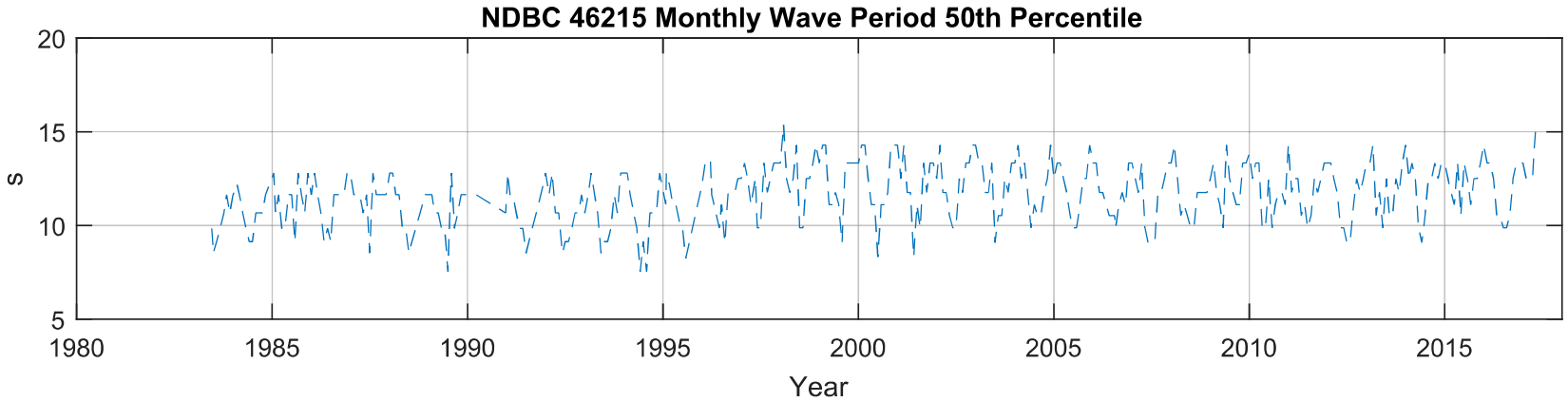


Figure A189. Monthly Wave Period, Max, Mean, Min,NDBC 46215





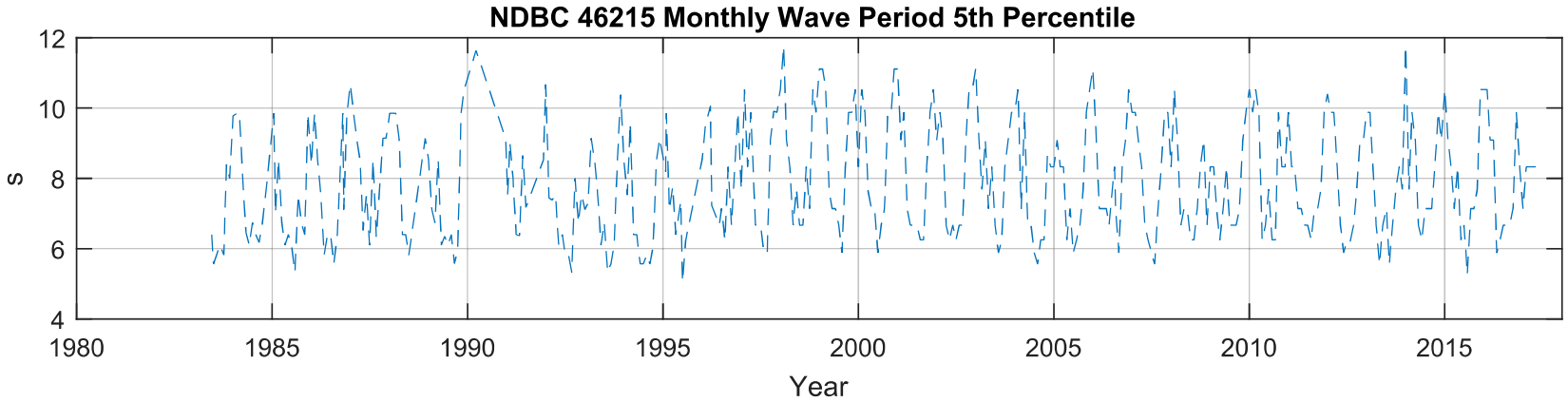


Figure A190. Monthly Wave Period, Percentiles,NDBC 46215

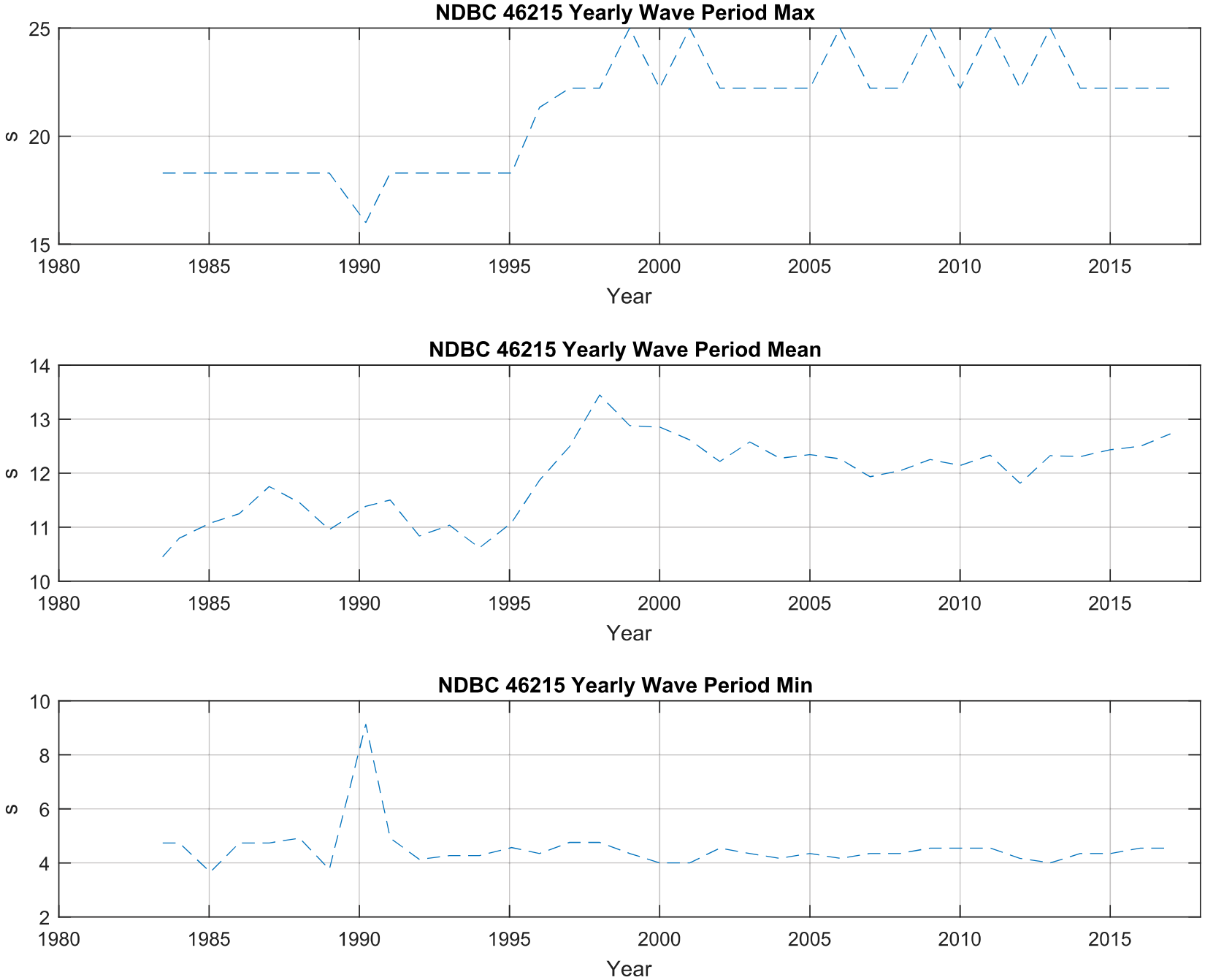
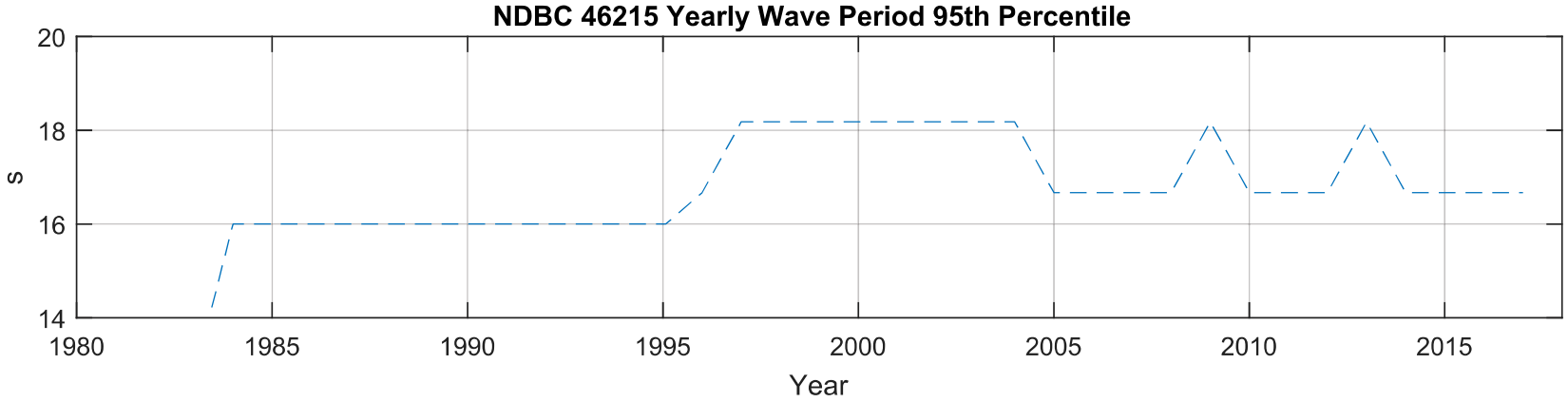
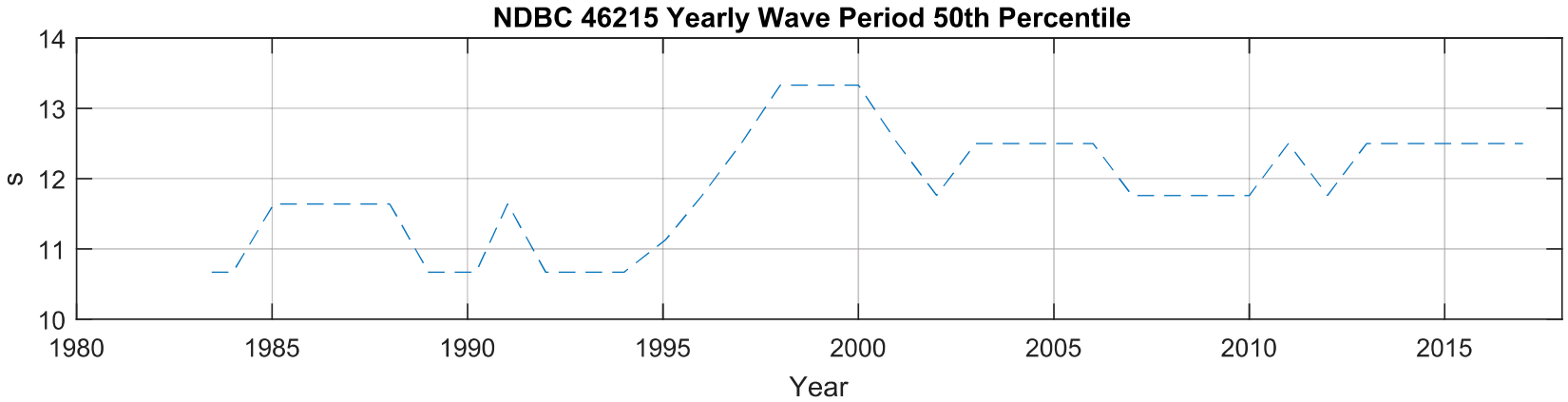


Figure A191. Yearly Wave Period, Max, Mean, Min,NDBC 46215





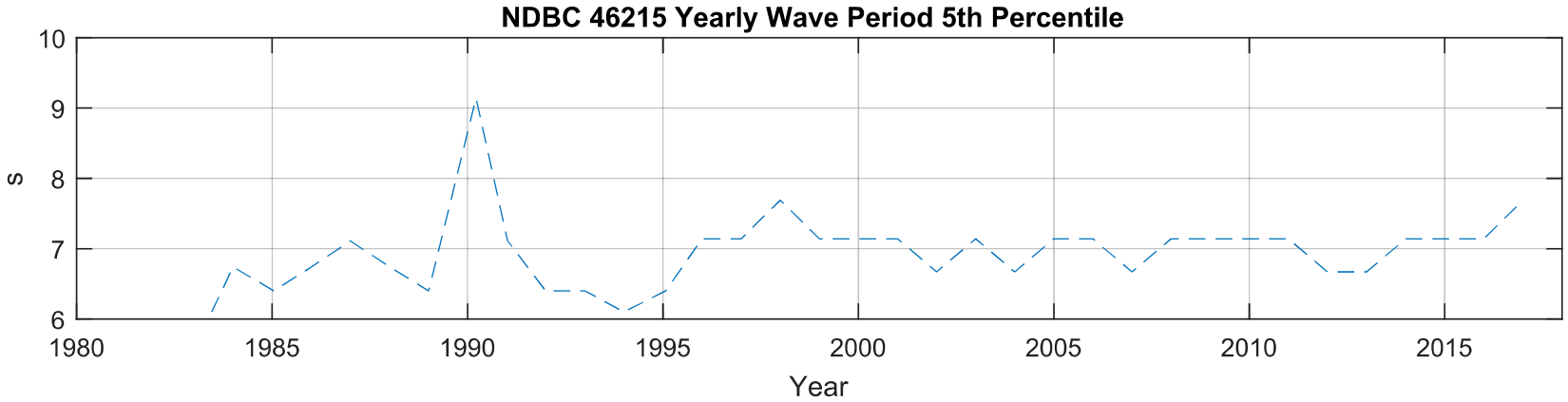


Figure A192. Yearly Wave Period, Percentiles,NDBC 46215

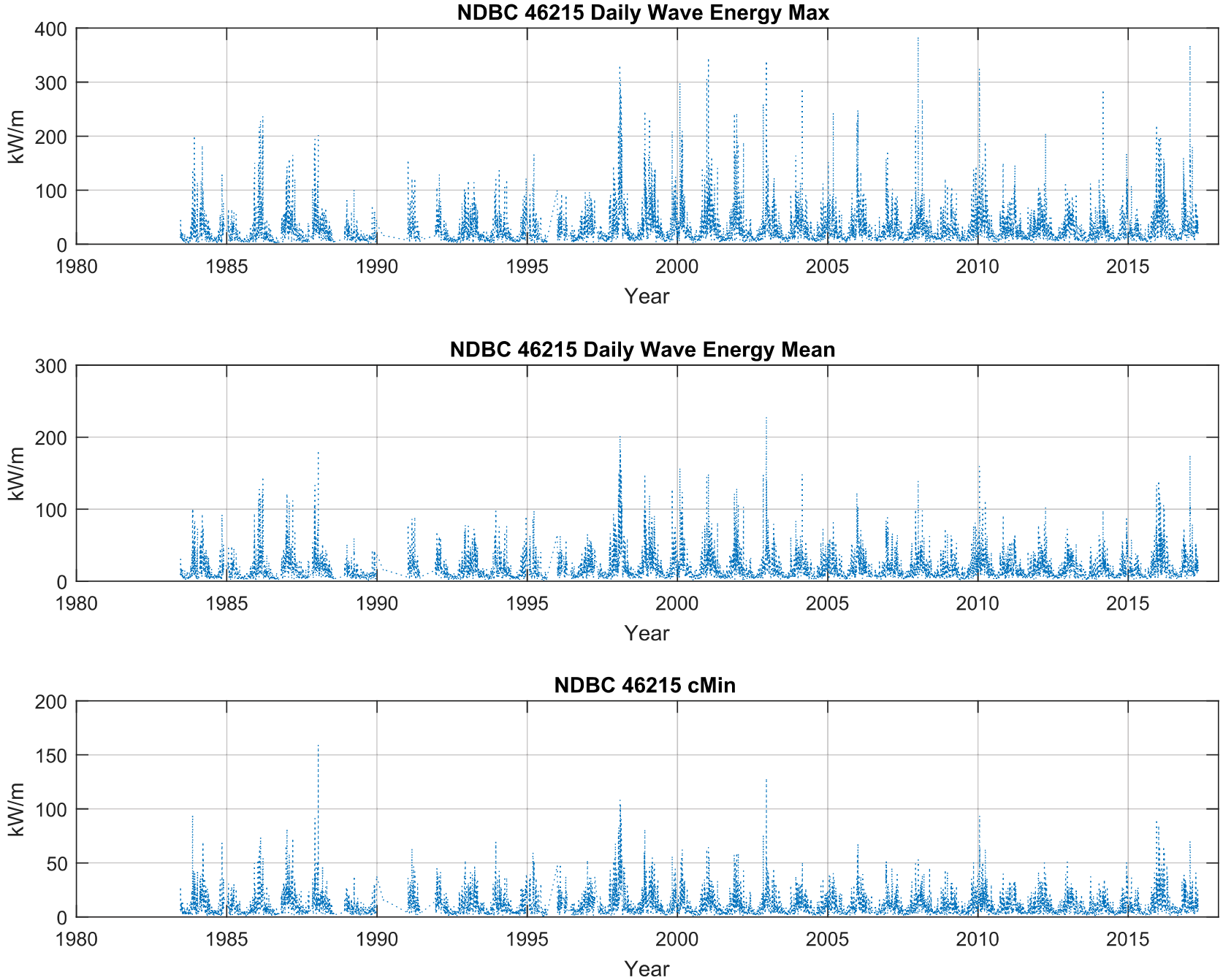
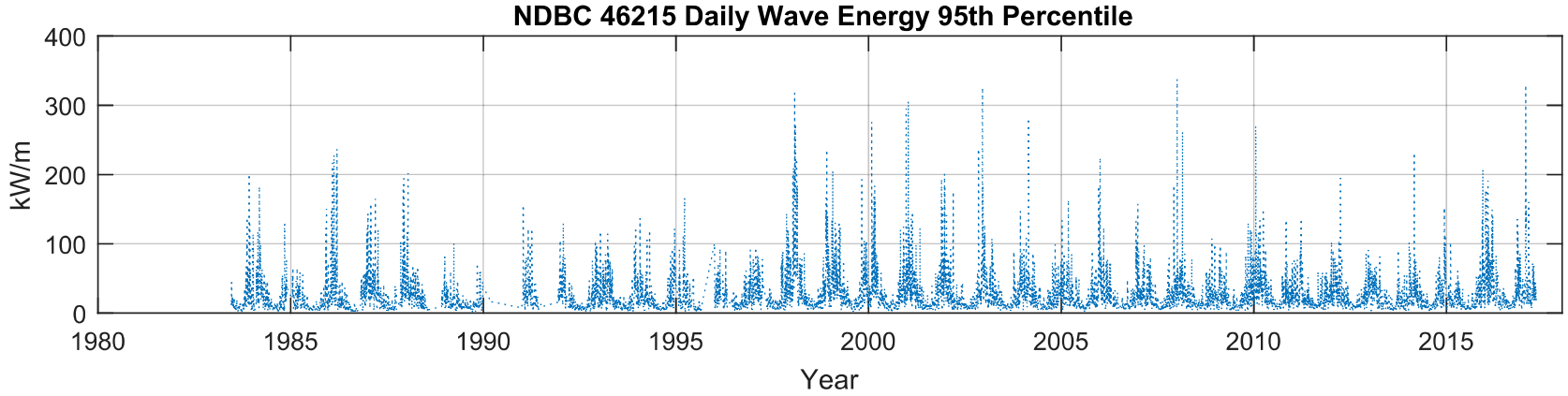
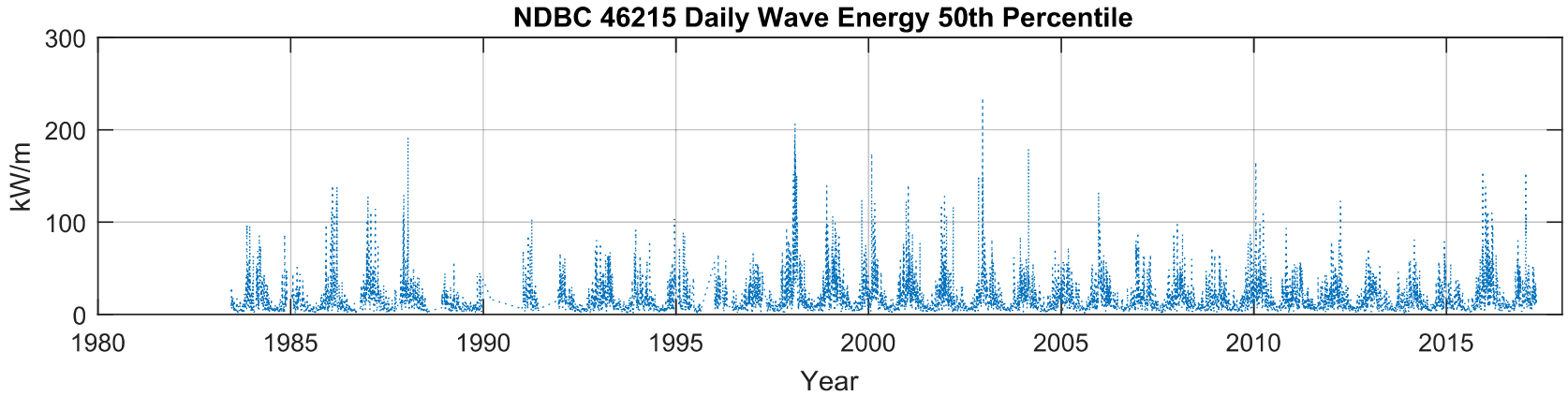


Figure A193. Daily Wave Energy, Max, Mean, Min,NDBC 46215





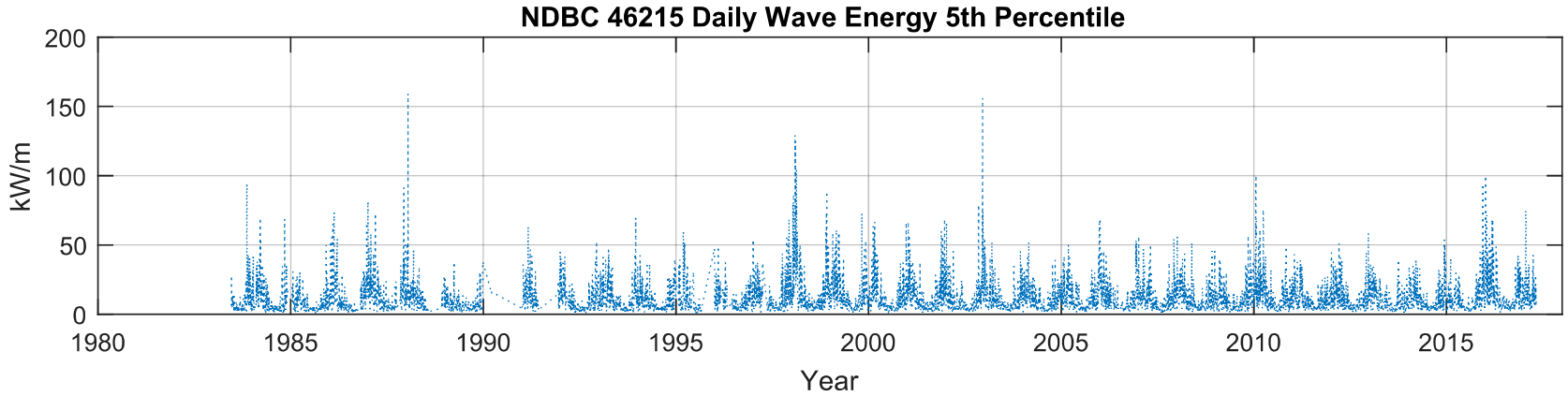


Figure A194. Daily Wave Energy, Percentiles,NDBC 46215

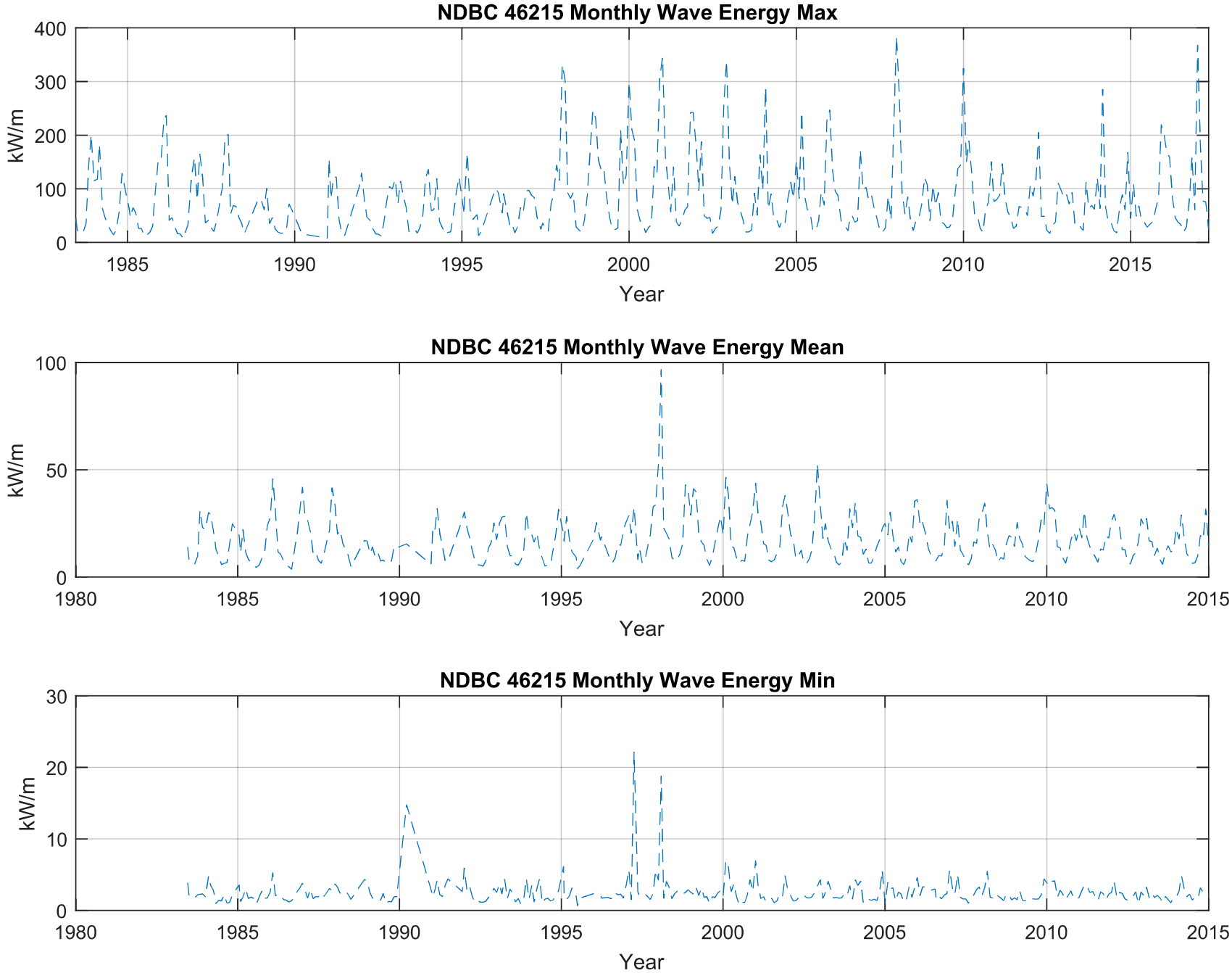
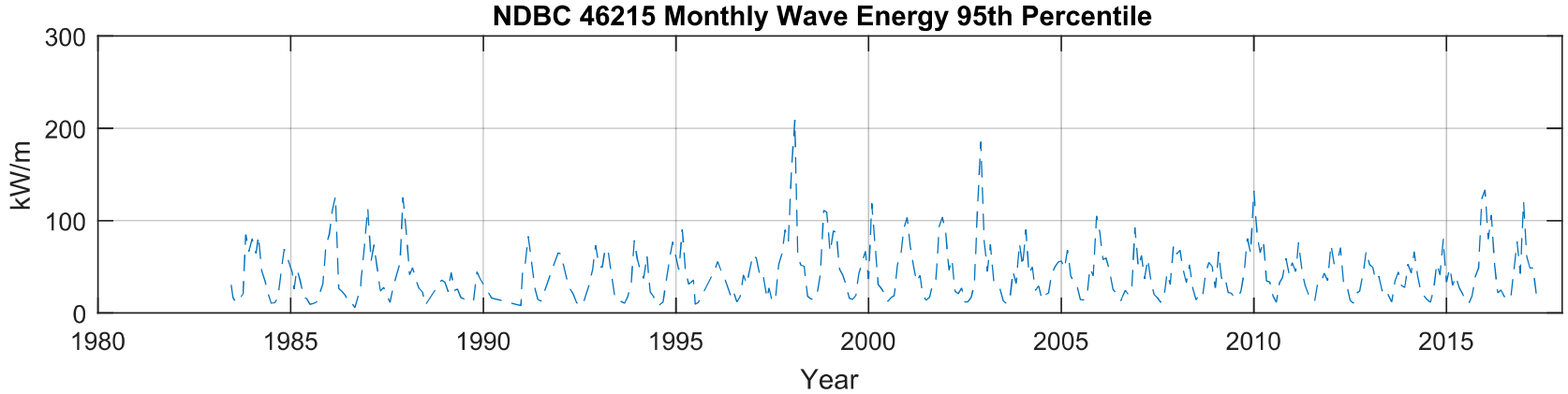
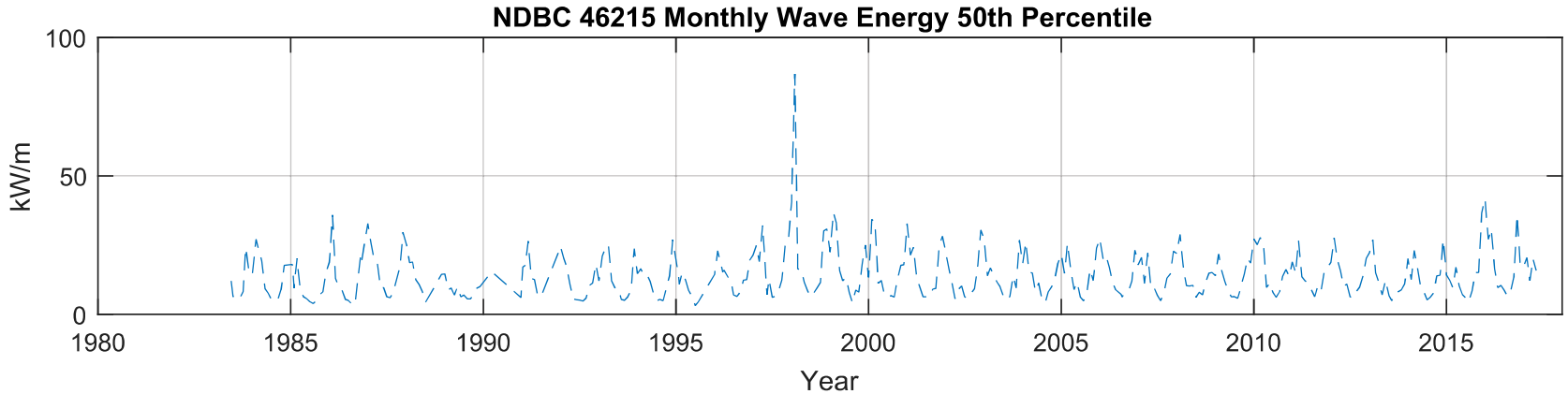


Figure A195. Monthly Wave Energy, Max, Mean, Min,NDBC 46215





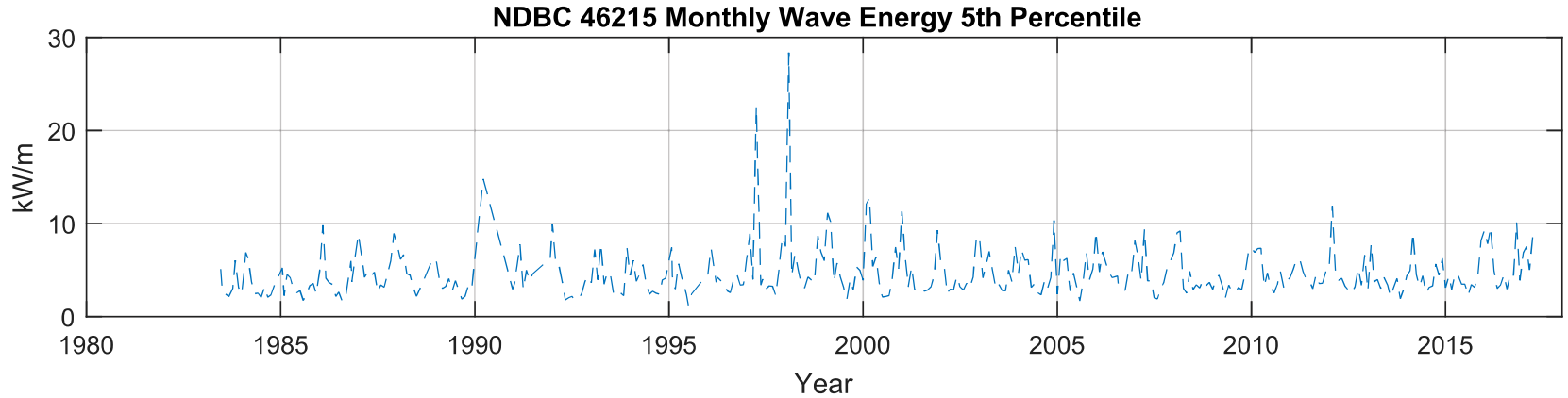


Figure A196. Monthly Wave Energy, Percentiles,NDBC 46215

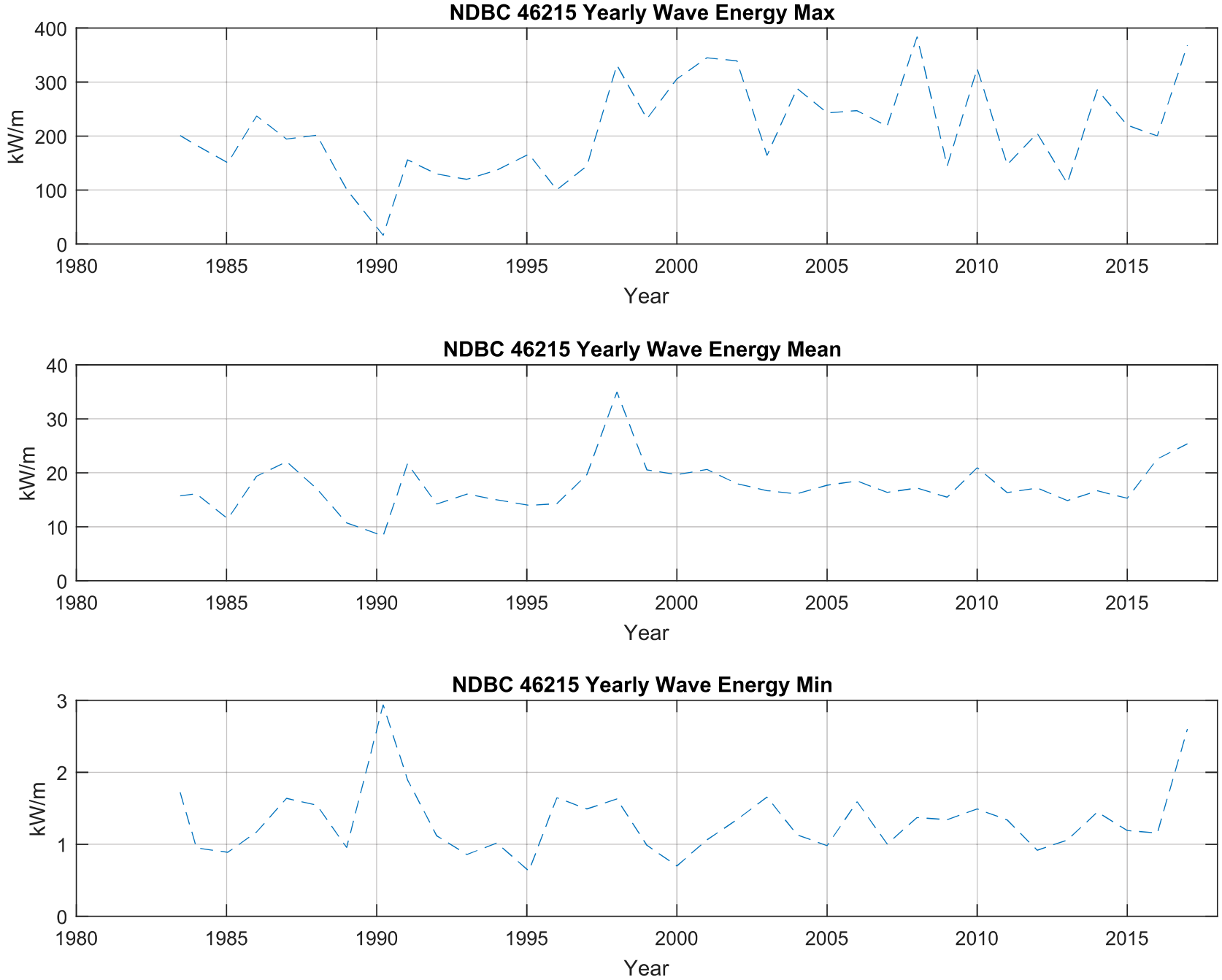
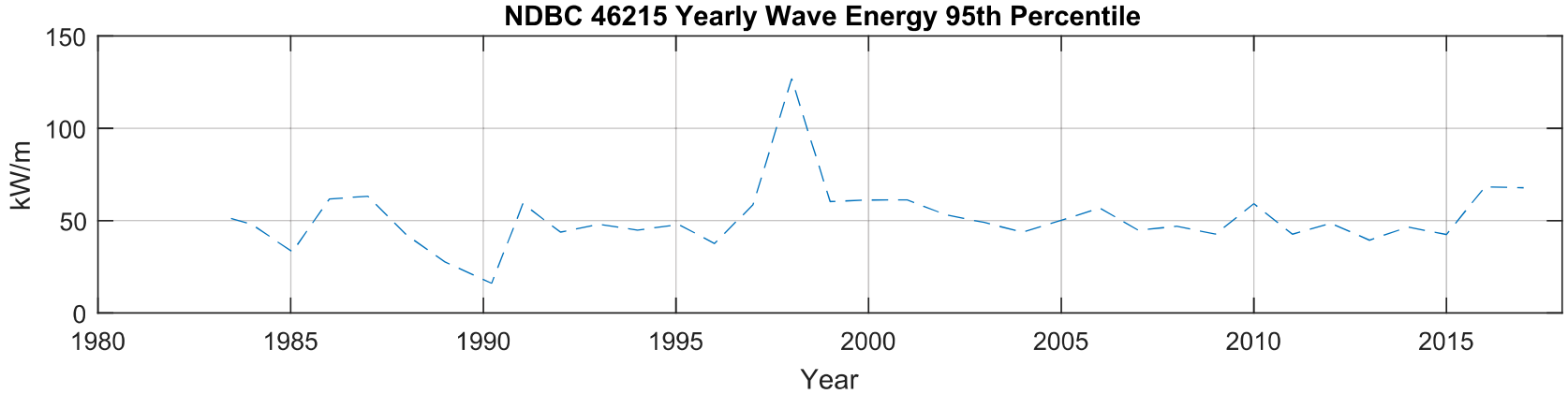
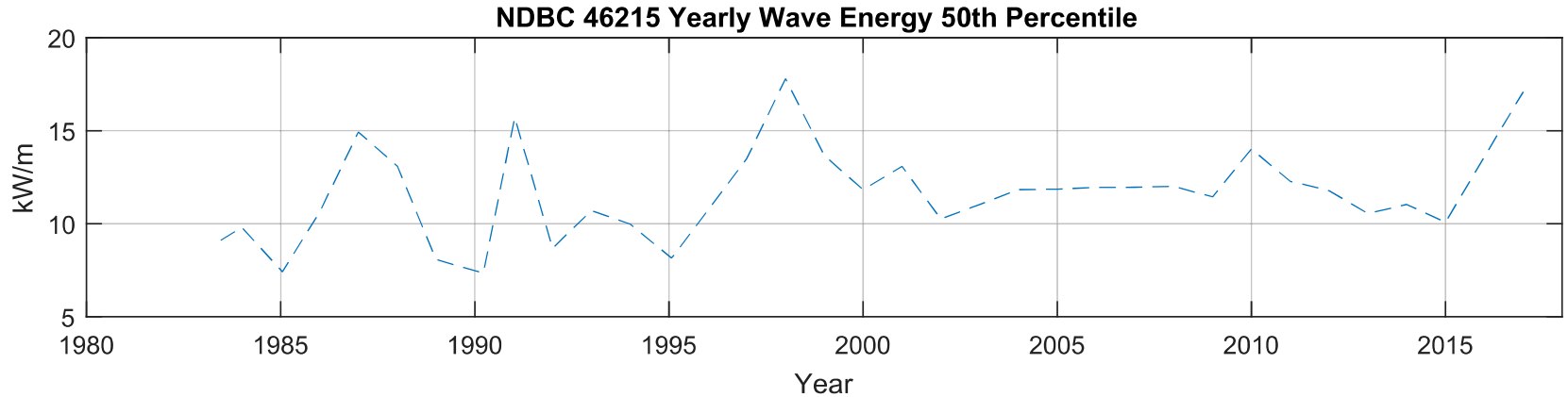


Figure A197. Yearly Wave Energy, Max, Mean, Min,NDBC 46215





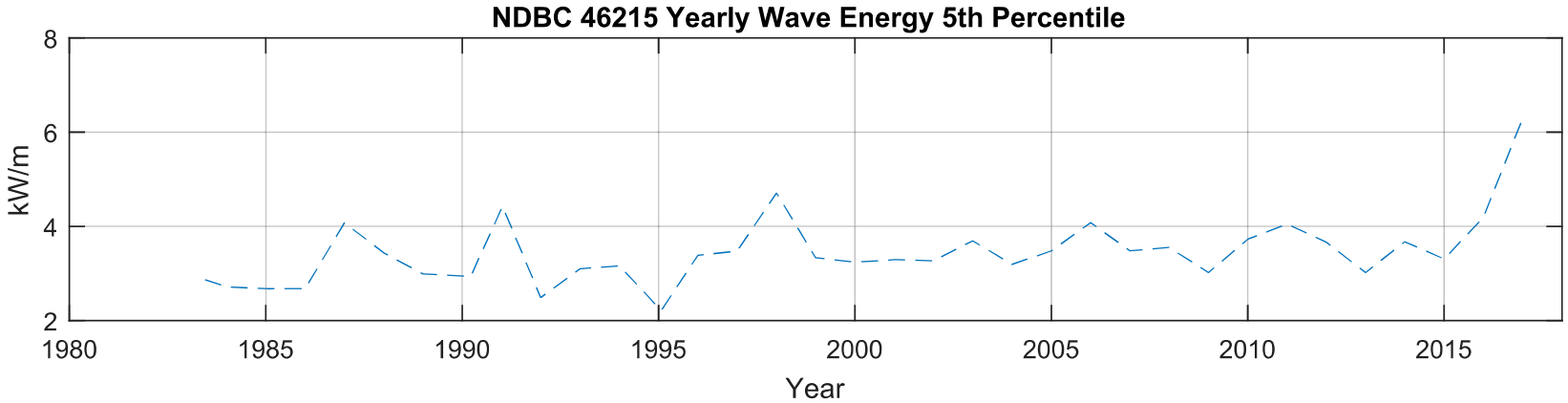


Figure A198. Yearly Wave Energy, Percentiles,NDBC 46215

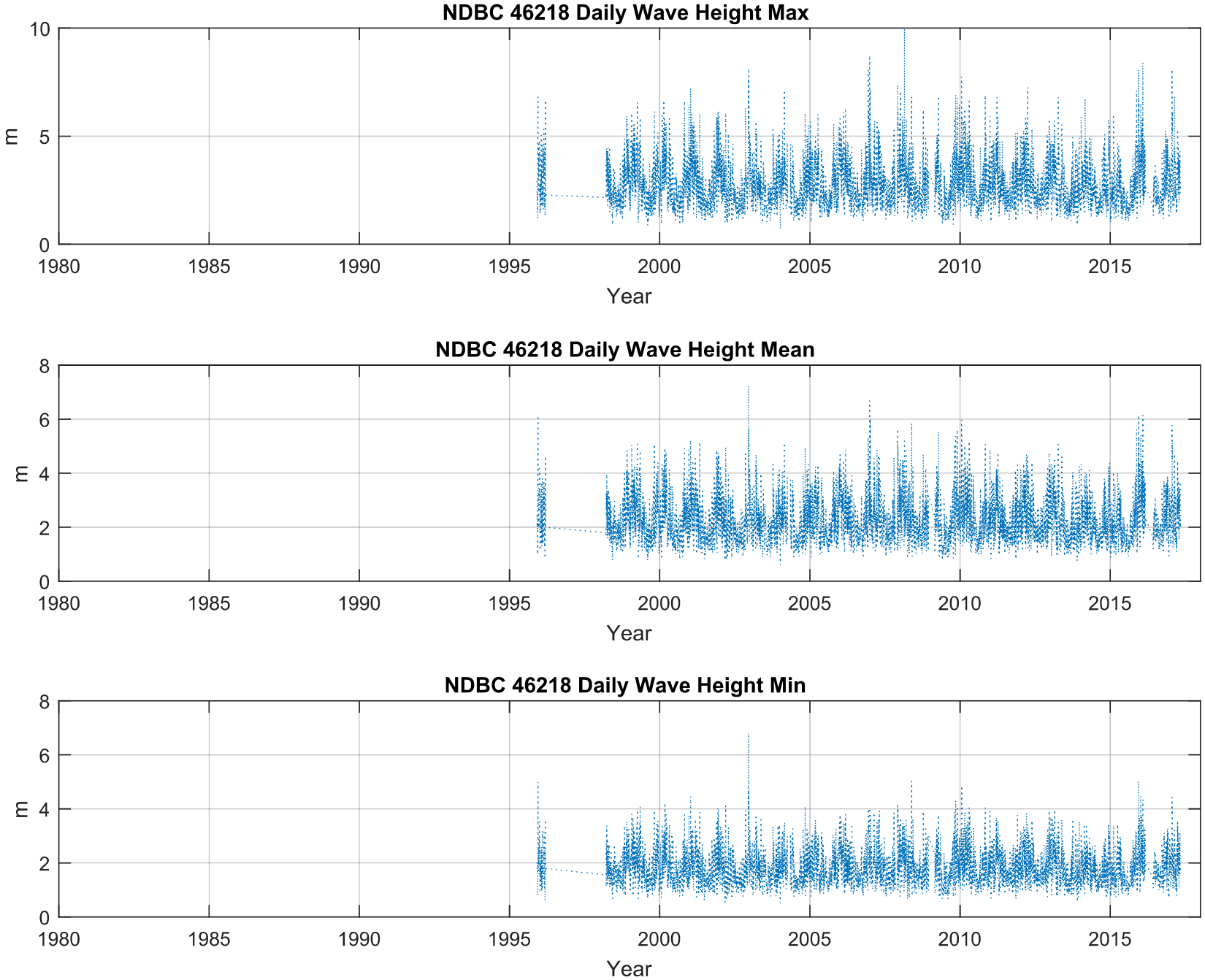


Figure A199. Daily Wave Height, Max, Mean, Min,NDBC 46218

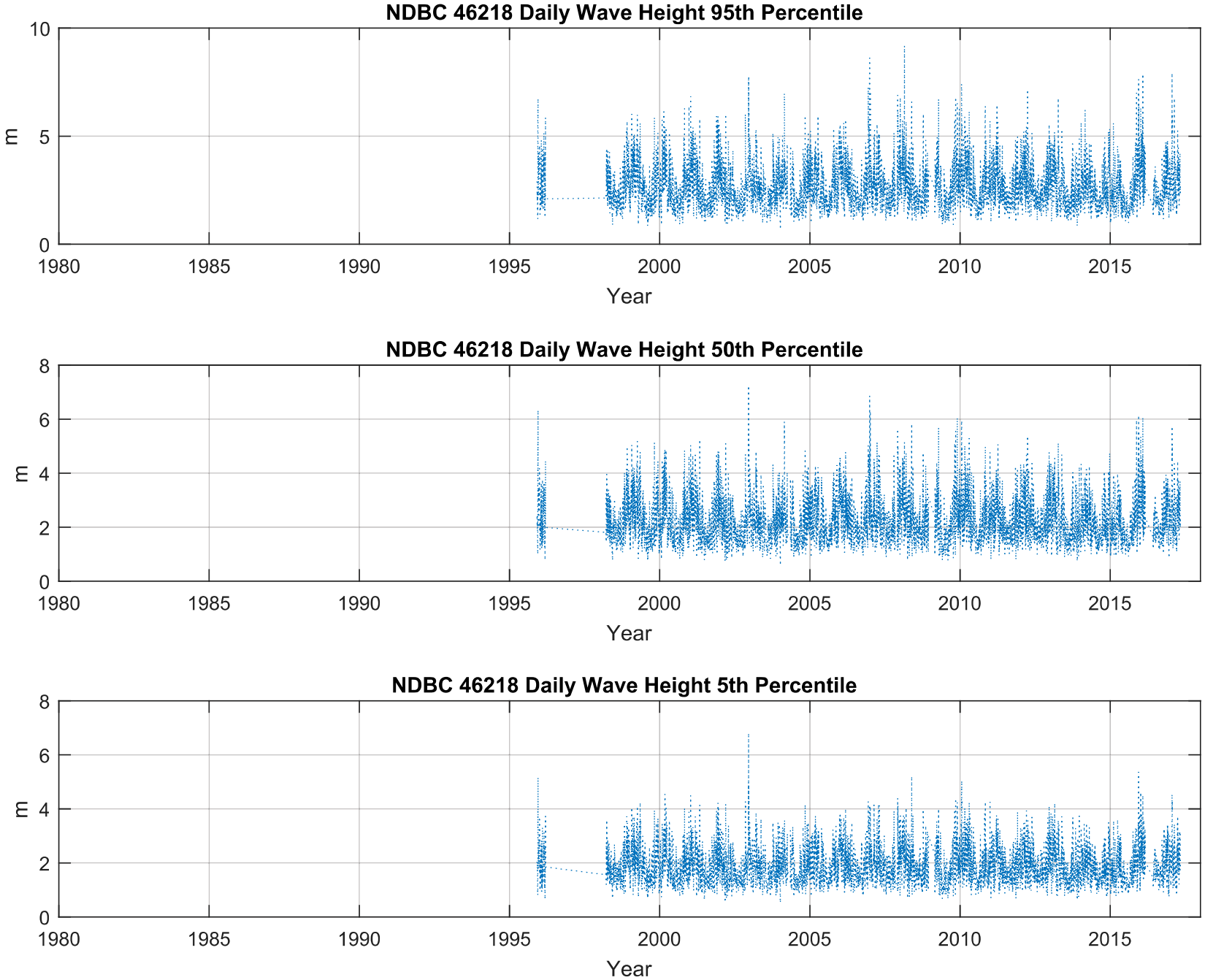


Figure A200. Daily Wave Height, Percentiles,NDBC 46218

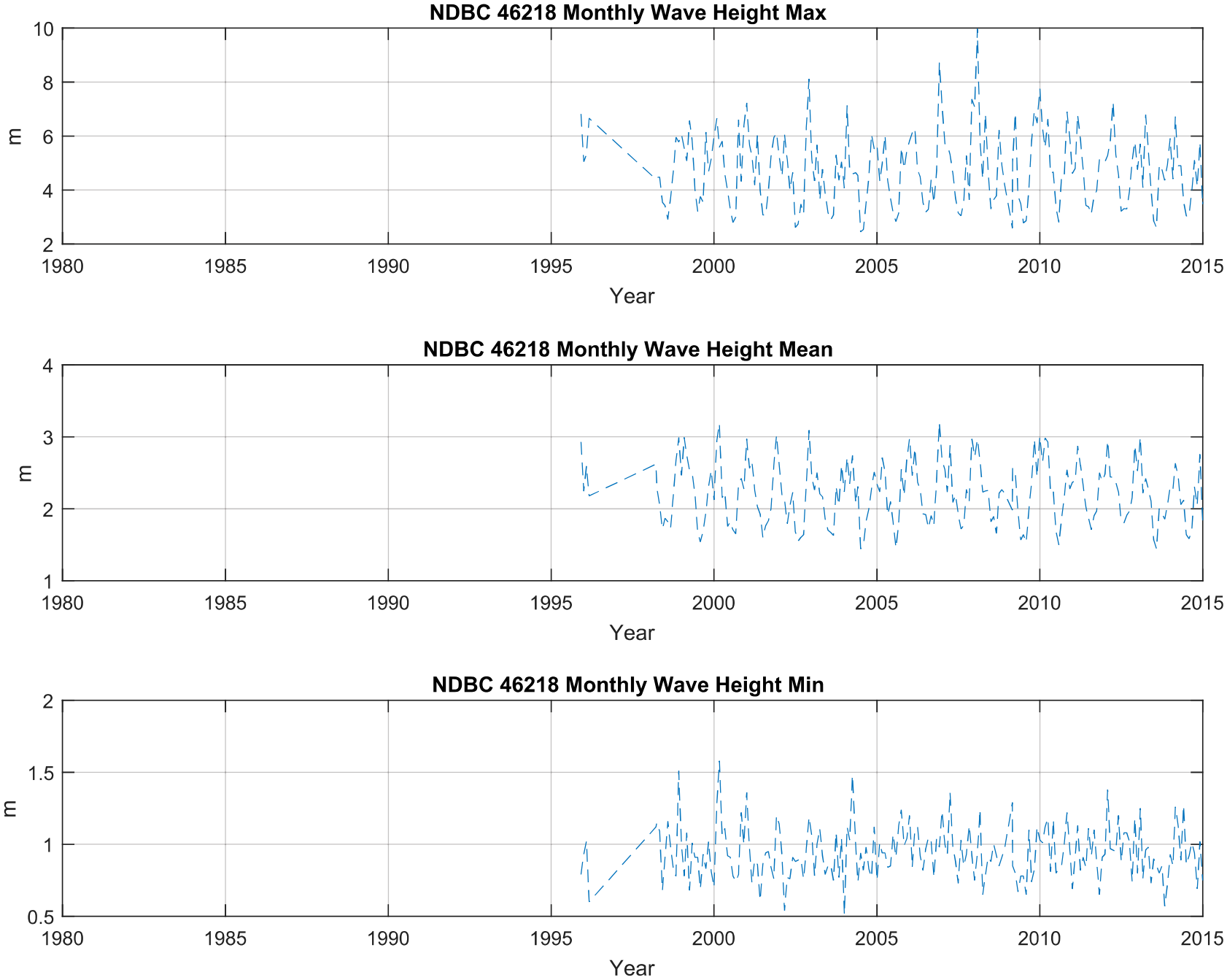


Figure A201. Monthly Wave Height, Max, Mean, Min,NDBC 46218

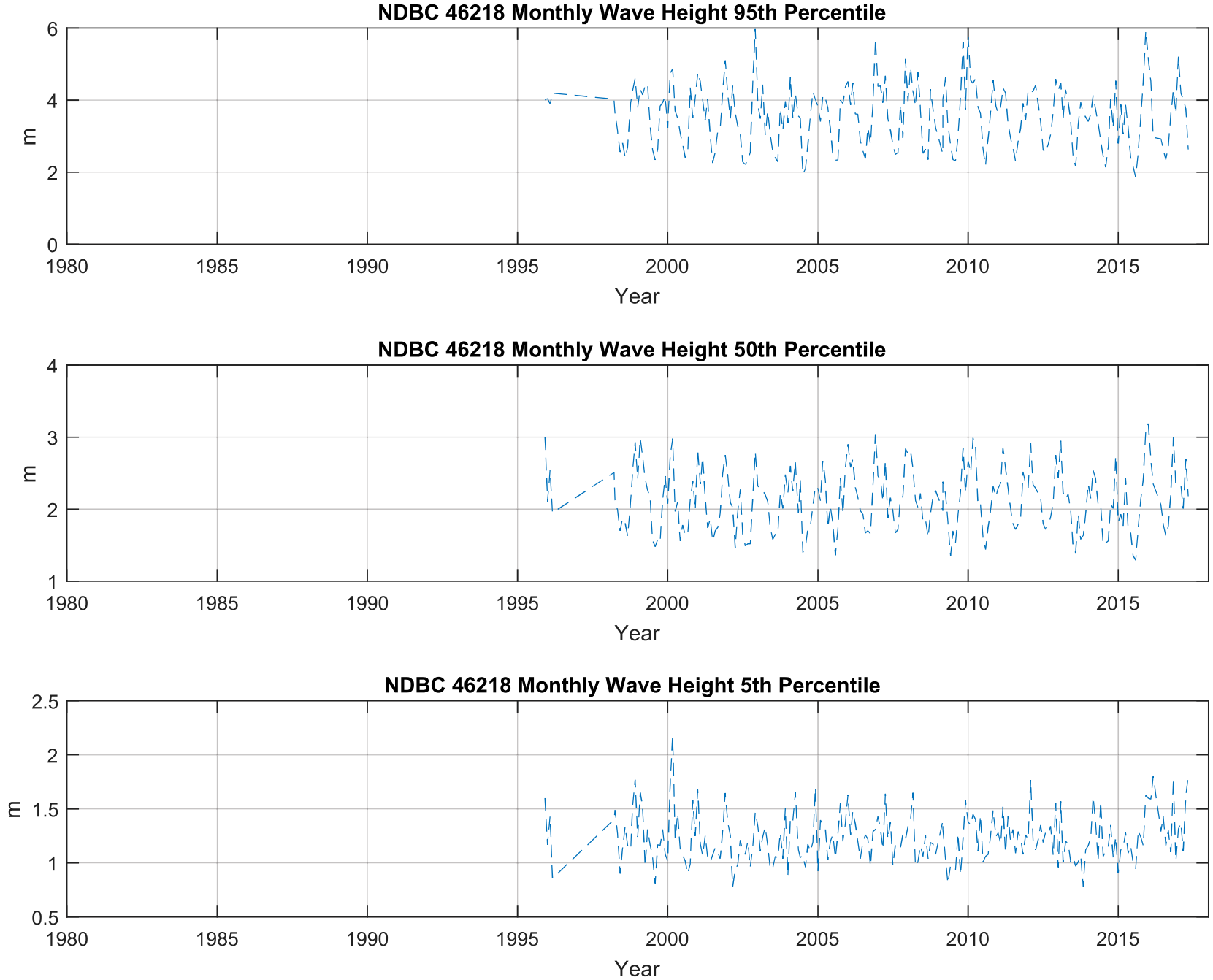


Figure A202. Monthly Wave Height, Percentiles,NDBC 46218

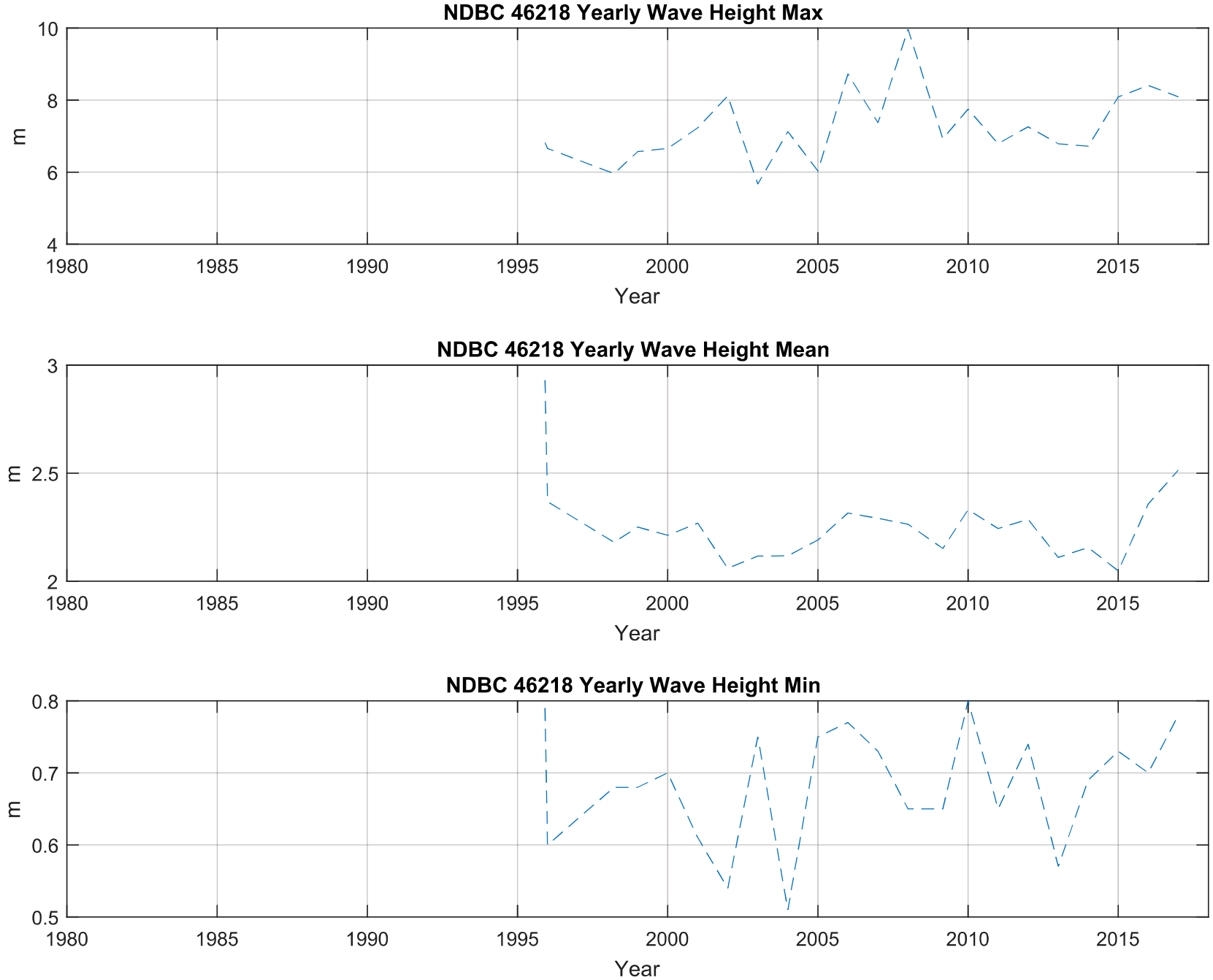
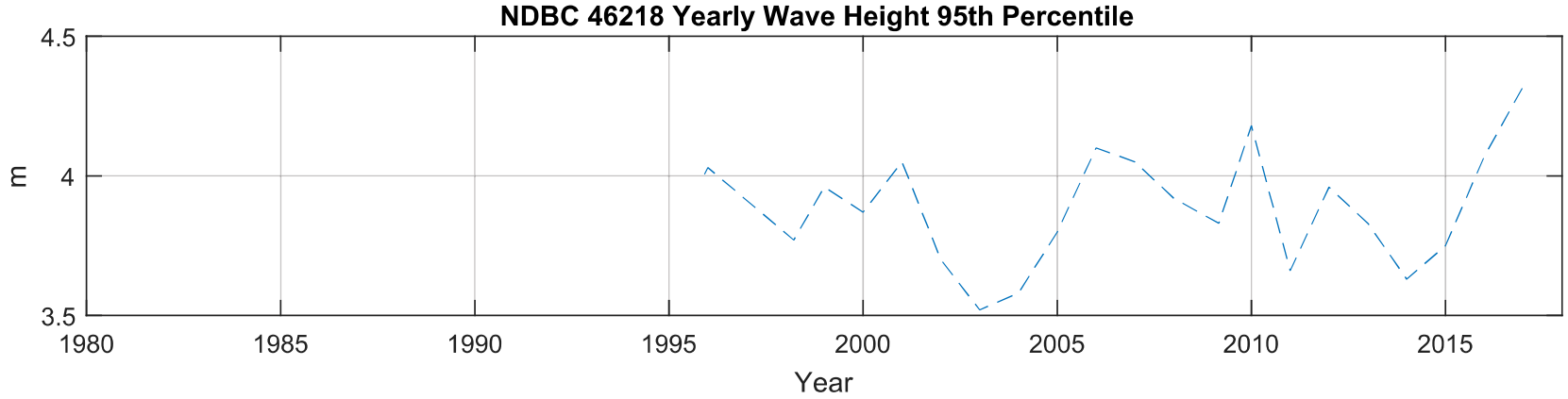
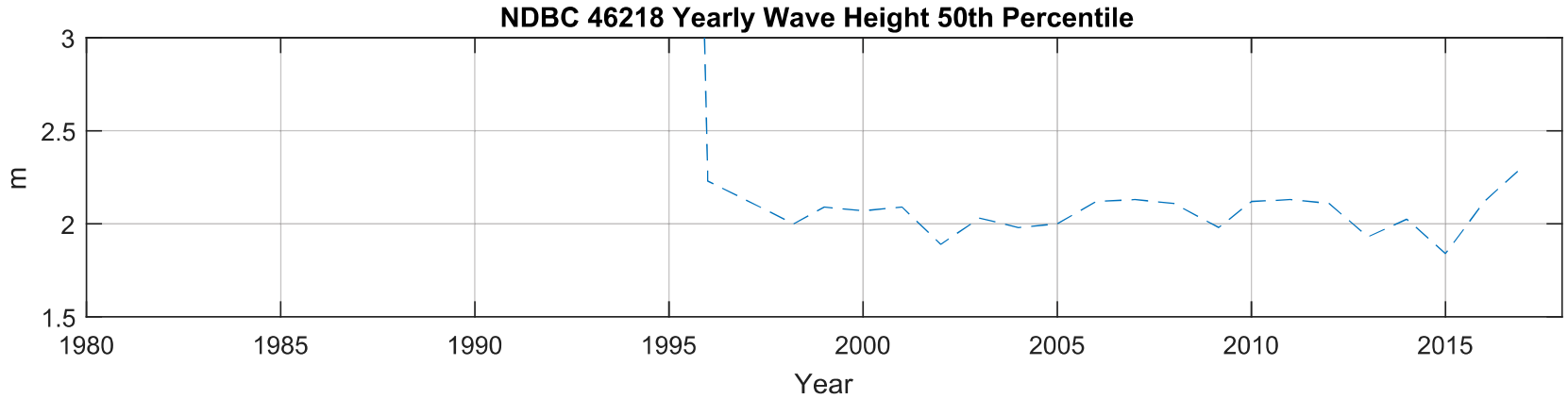


Figure A203. Yearly Wave Height, Max, Mean, Min,NDBC 46218





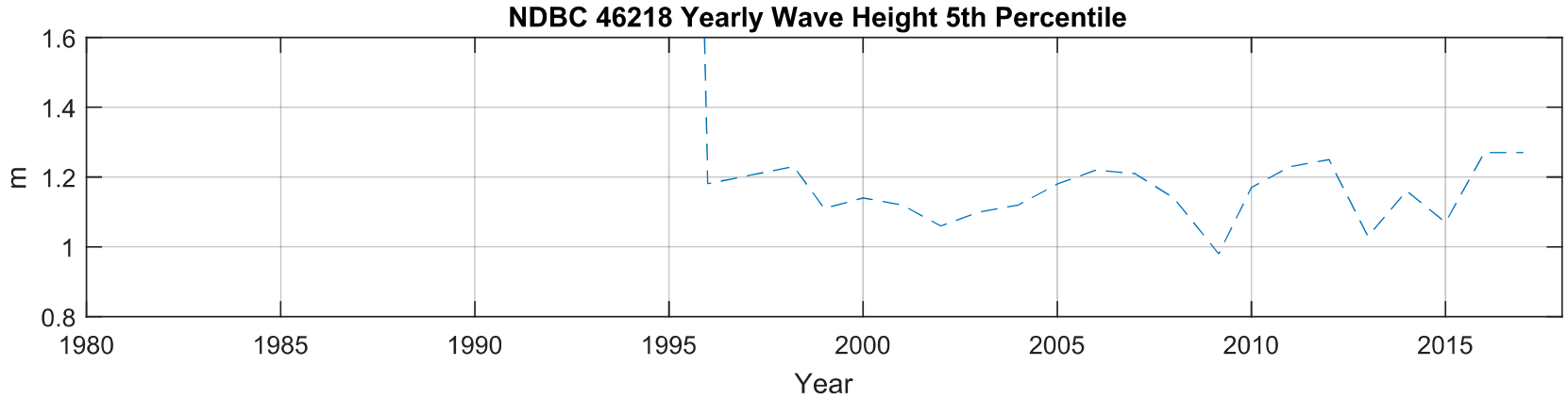
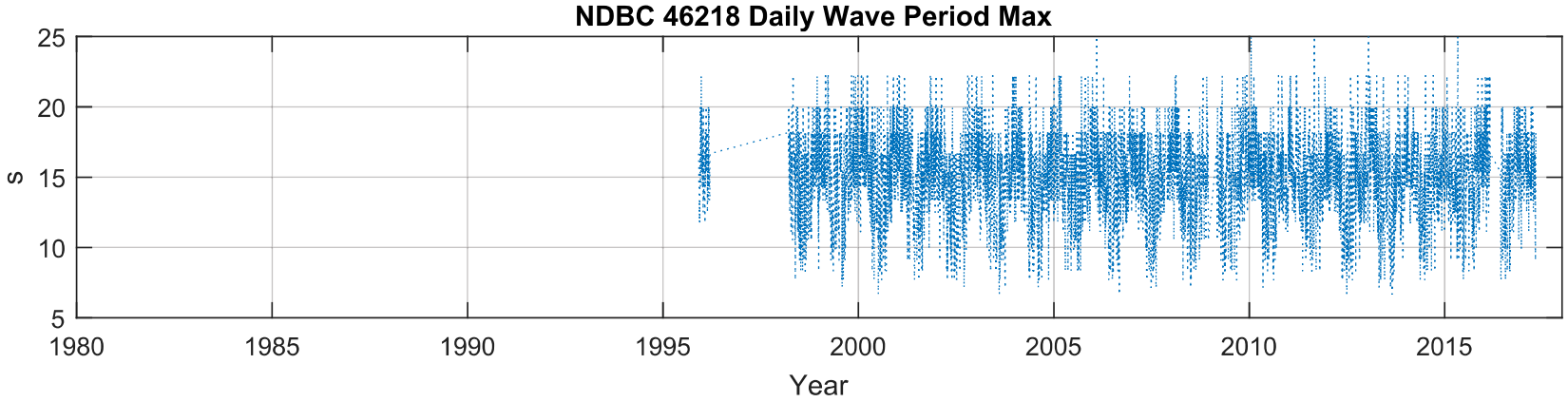
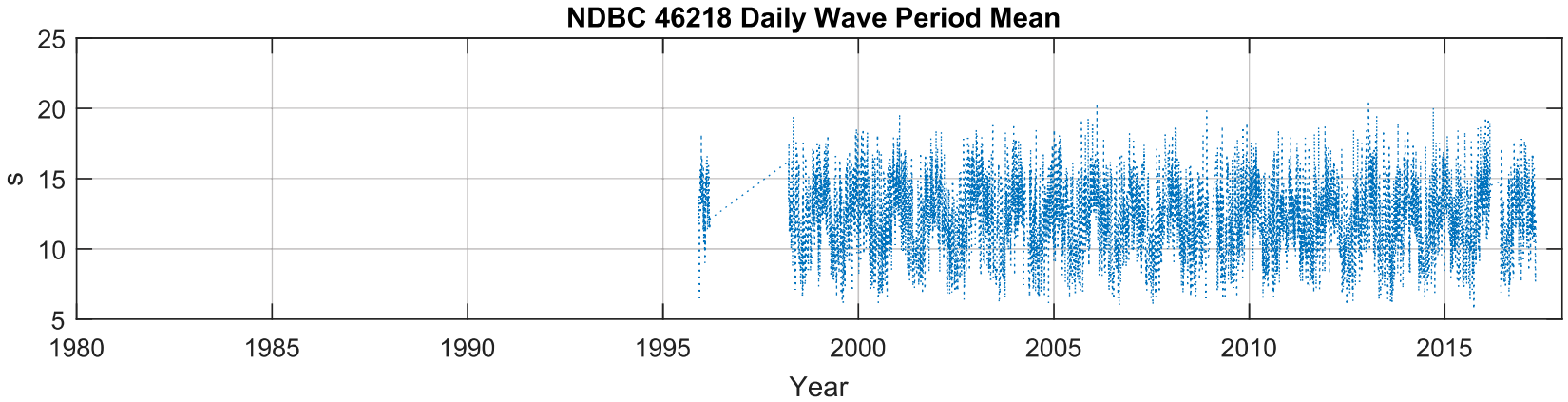


Figure A204. Yearly Wave Height, Percentiles,NDBC 46218





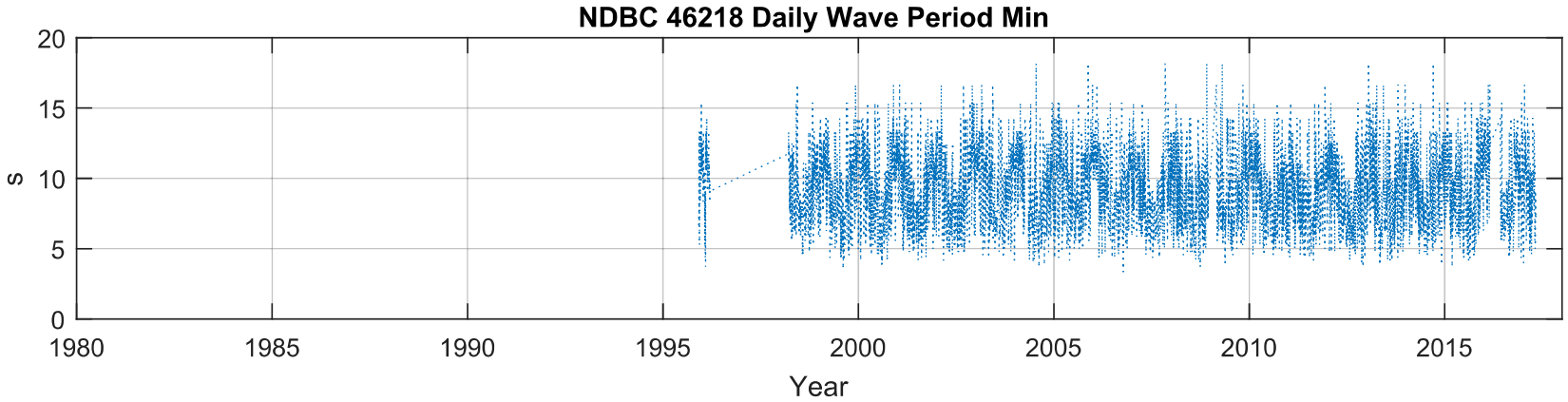
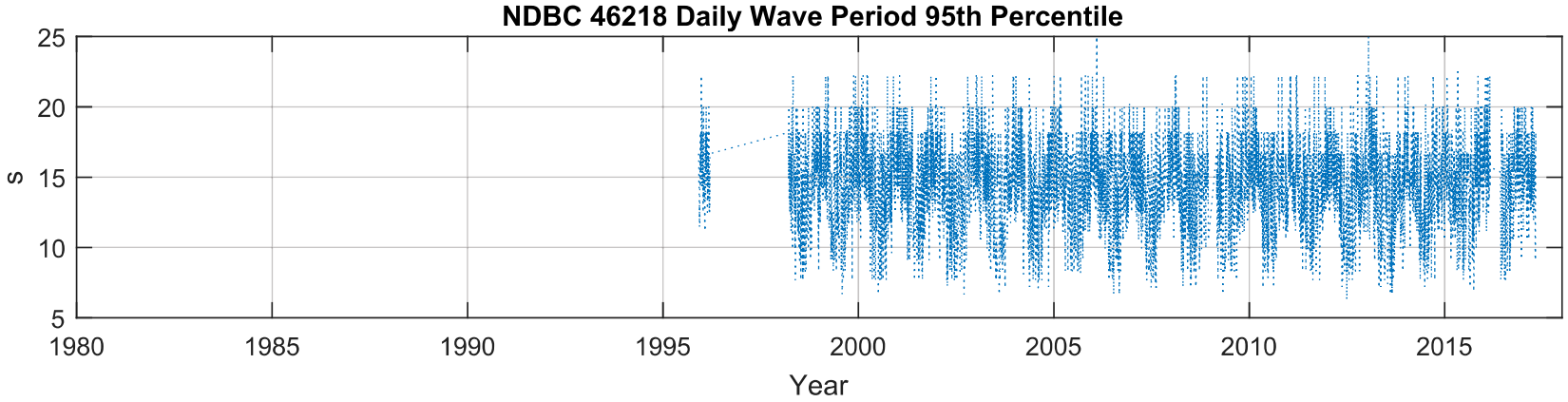
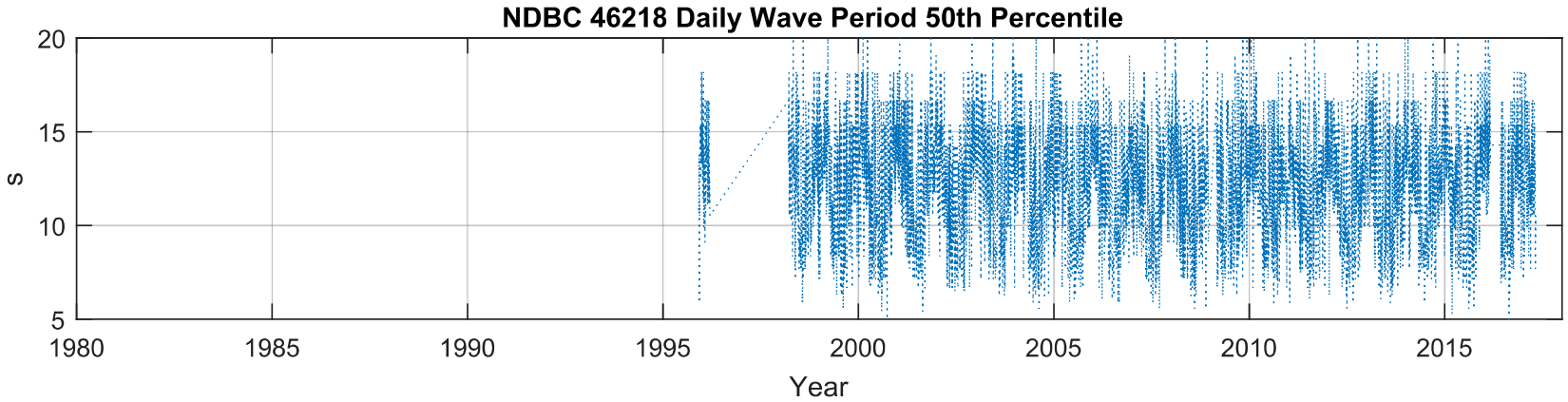


Figure A205. Daily Wave Period, Max, Mean, Min,NDBC 46218





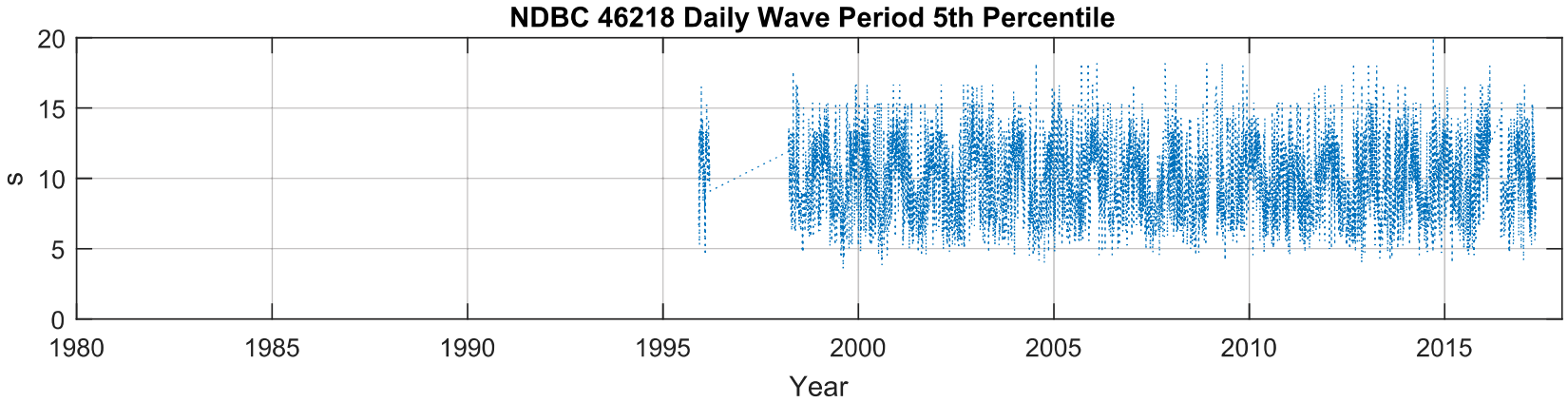


Figure A206. Daily Wave Period, Percentiles,NDBC 46218

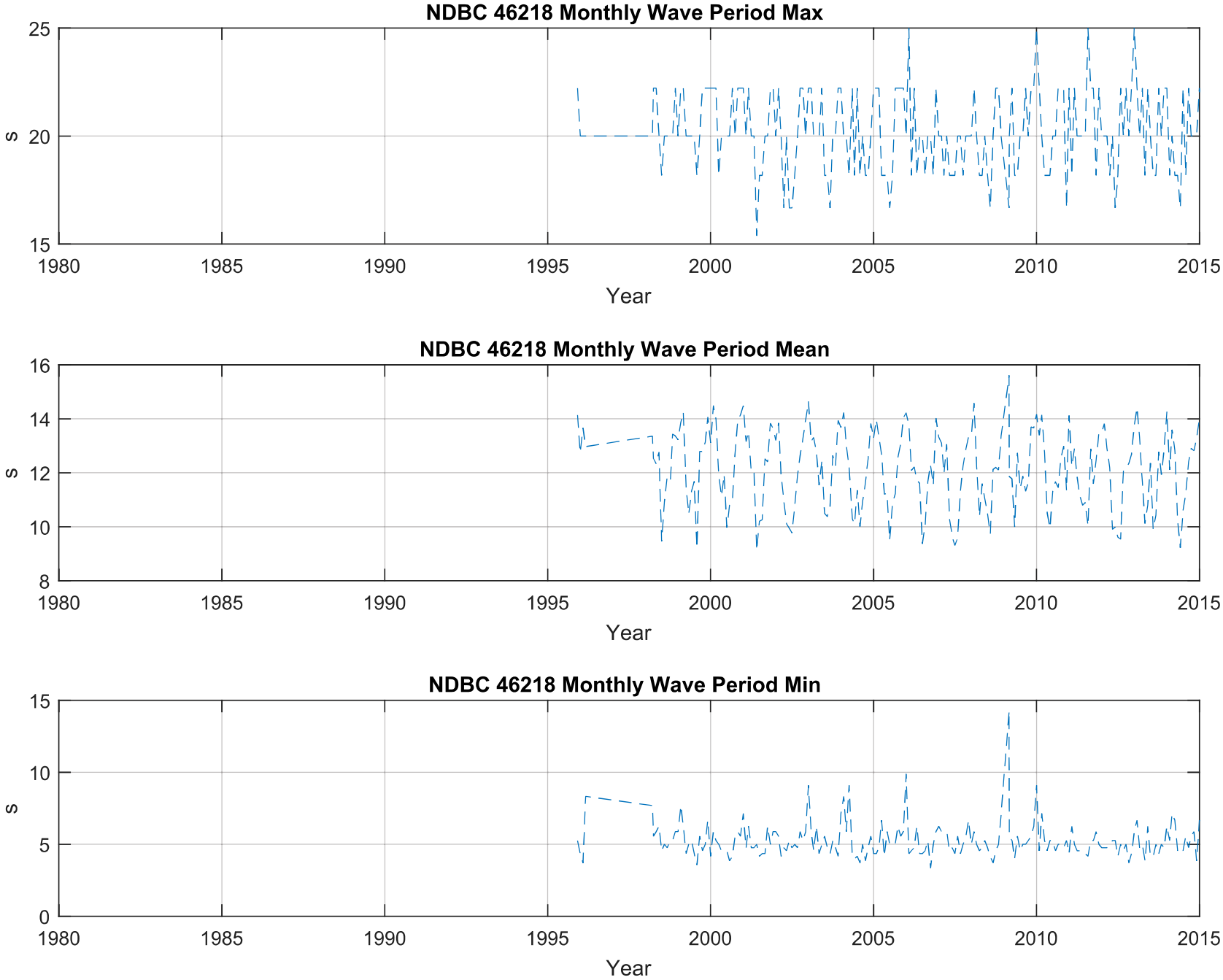
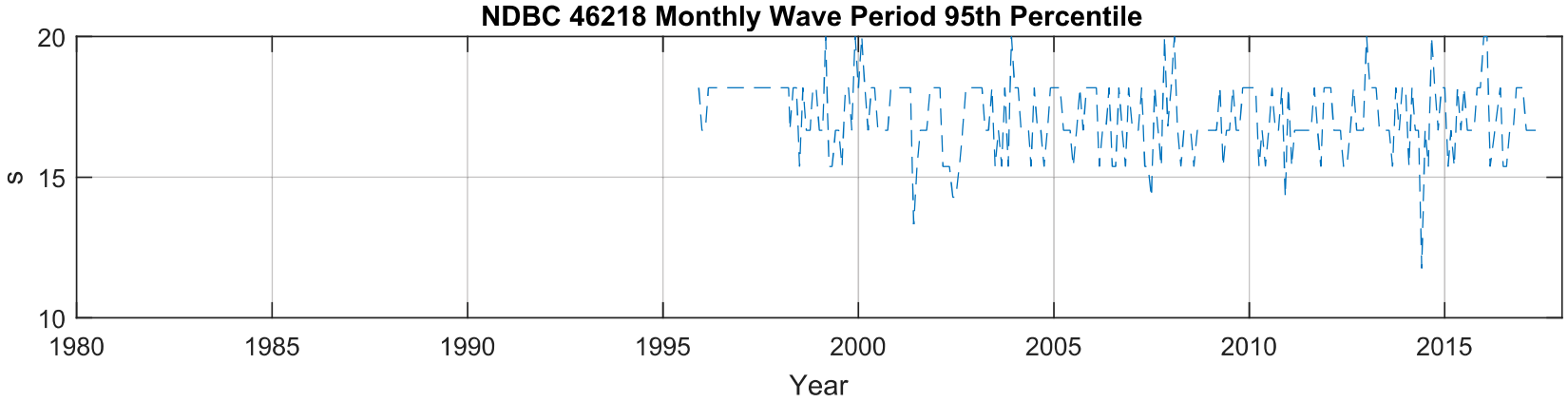
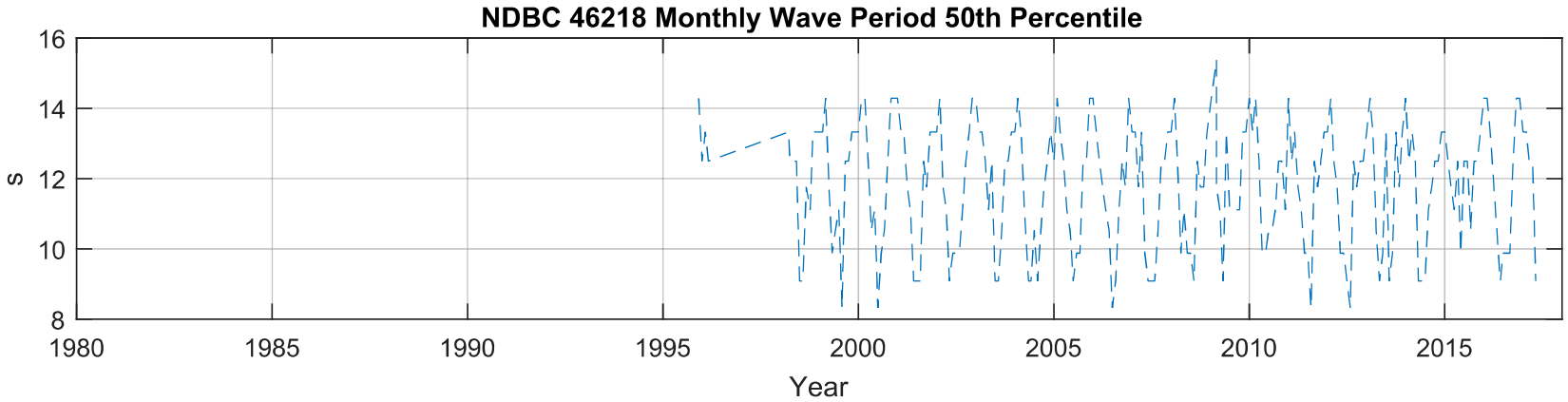


Figure A207. Monthly Wave Period, Max, Mean, Min,NDBC 46218





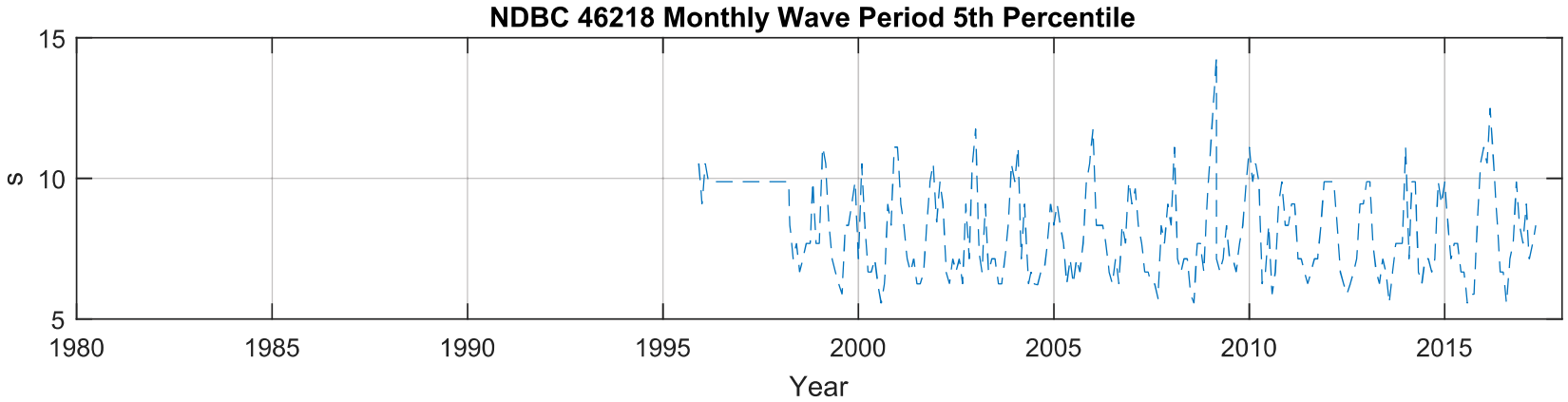


Figure A208. Monthly Wave Period, Percentiles,NDBC 46218

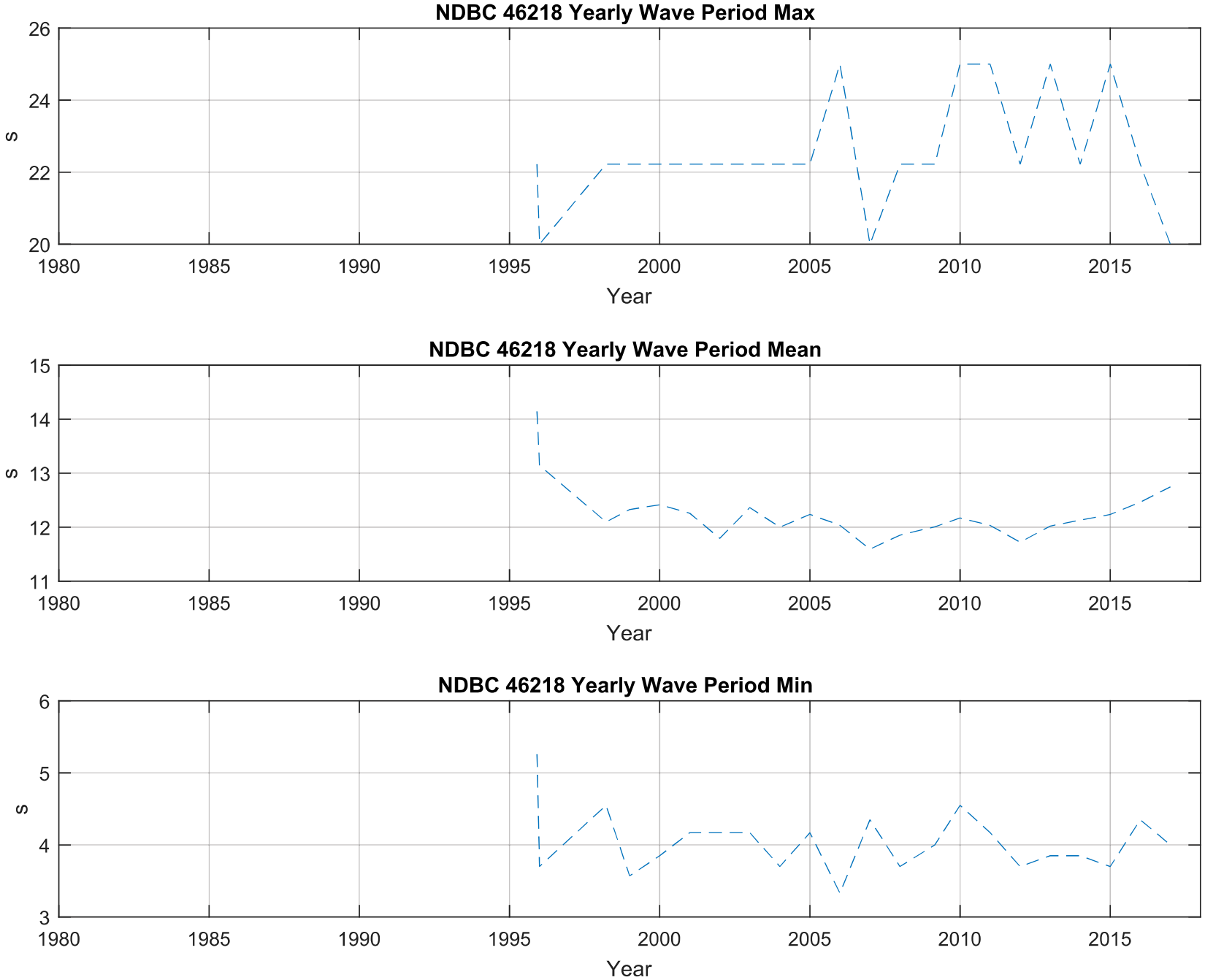
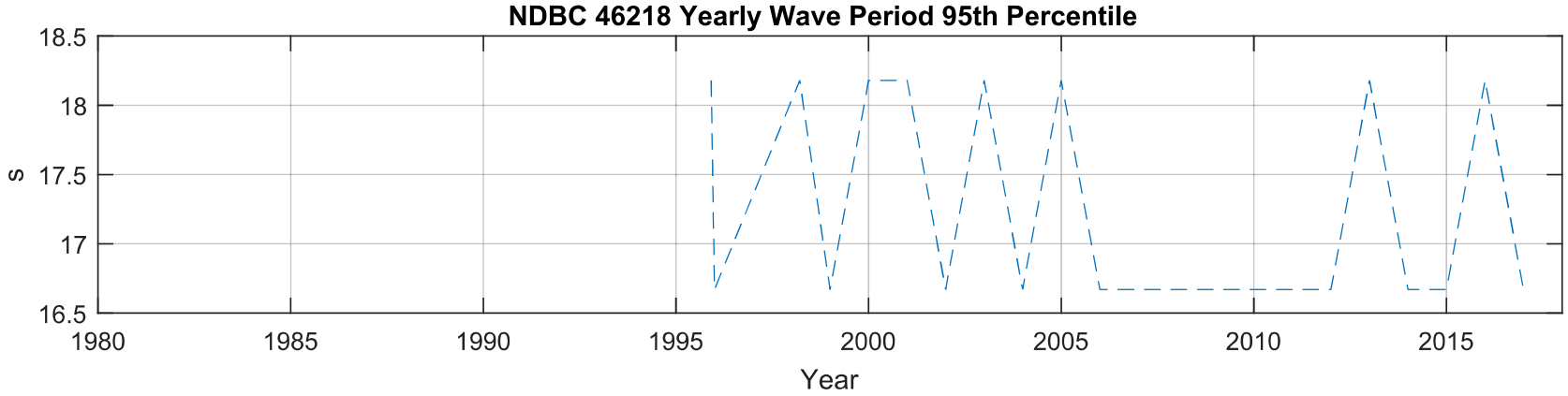
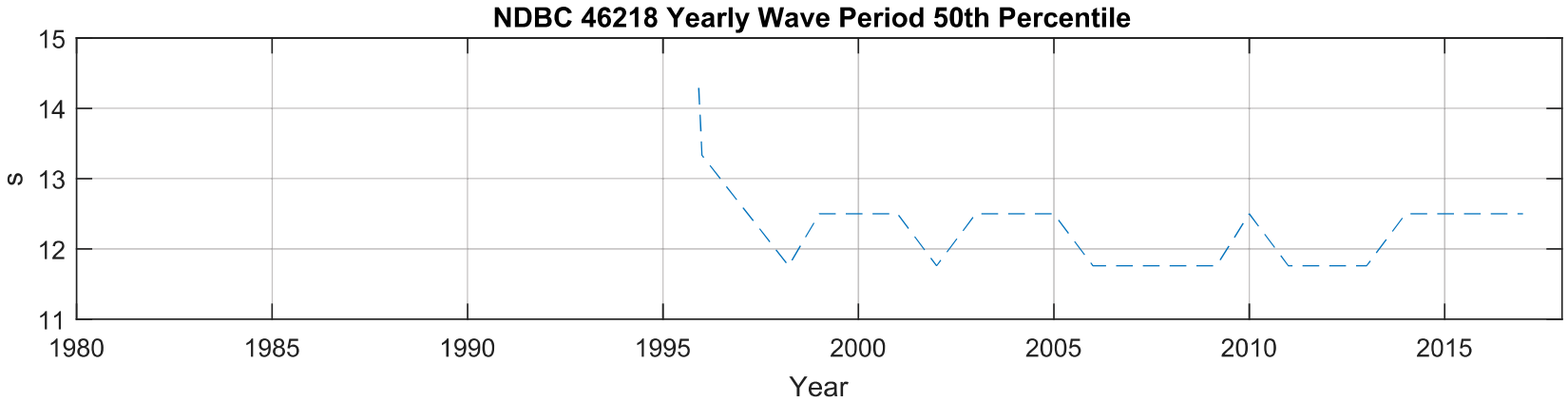


Figure A209. Yearly Wave Period, Max, Mean, Min,NDBC 46218





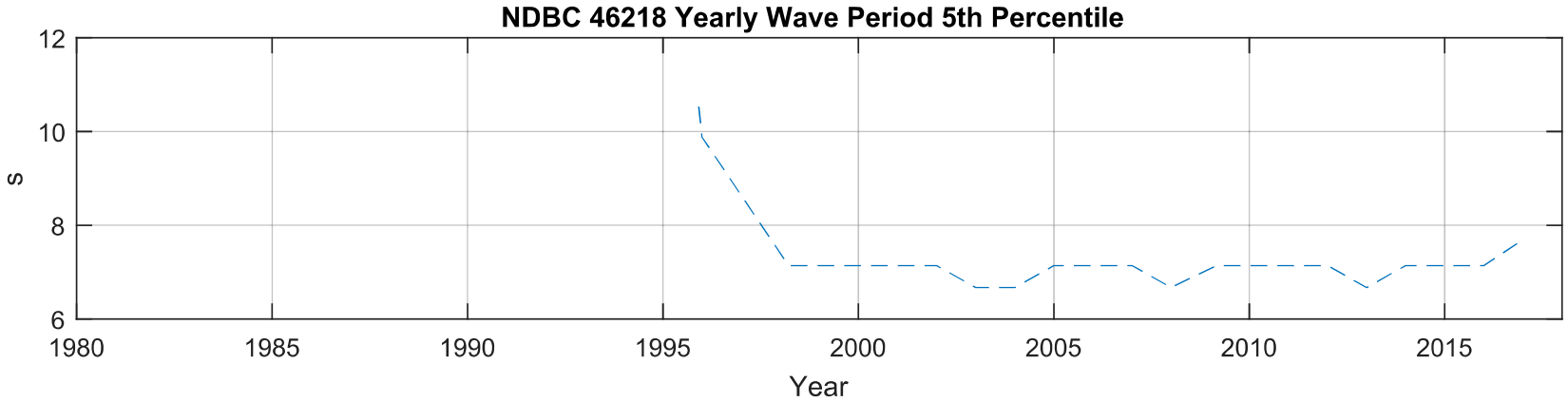
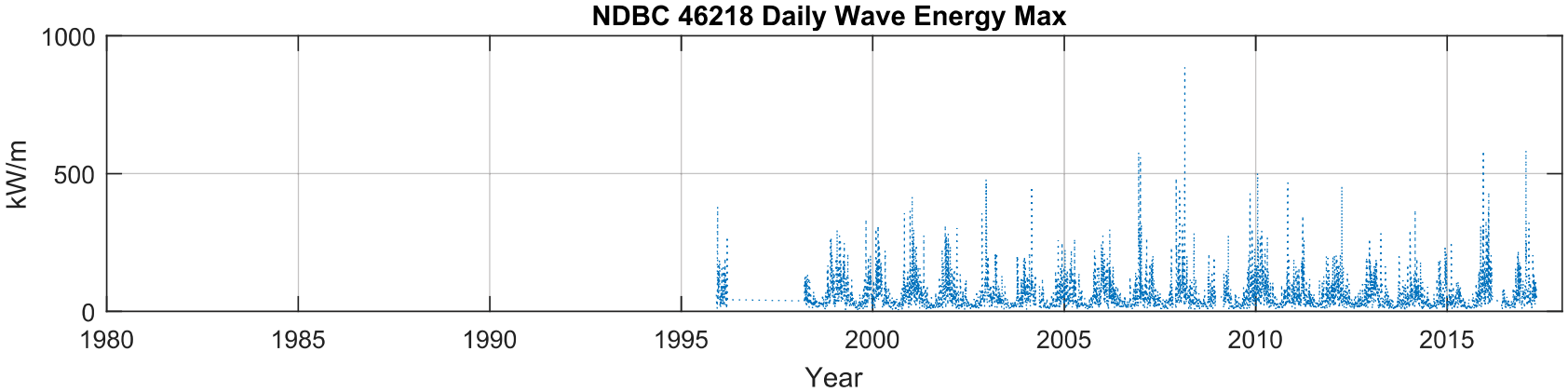
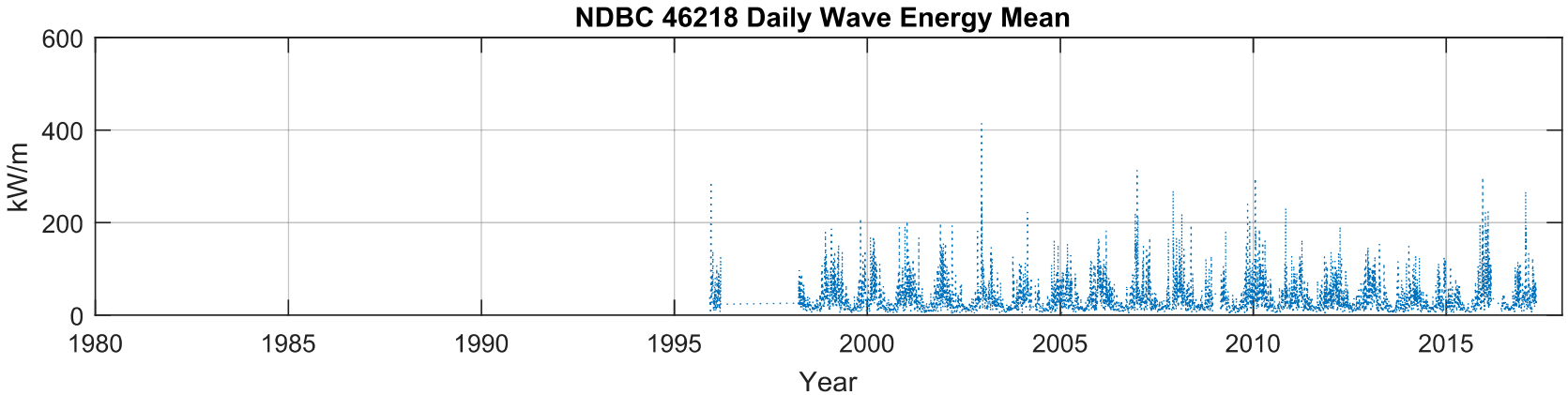


Figure A210. Yearly Wave Period, Percentiles,NDBC 46218





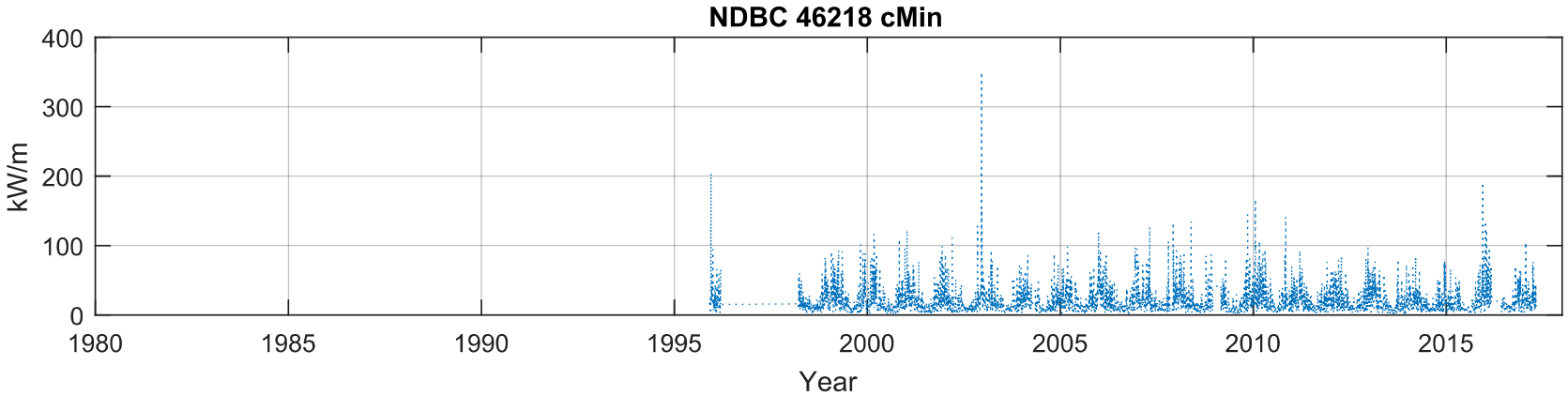
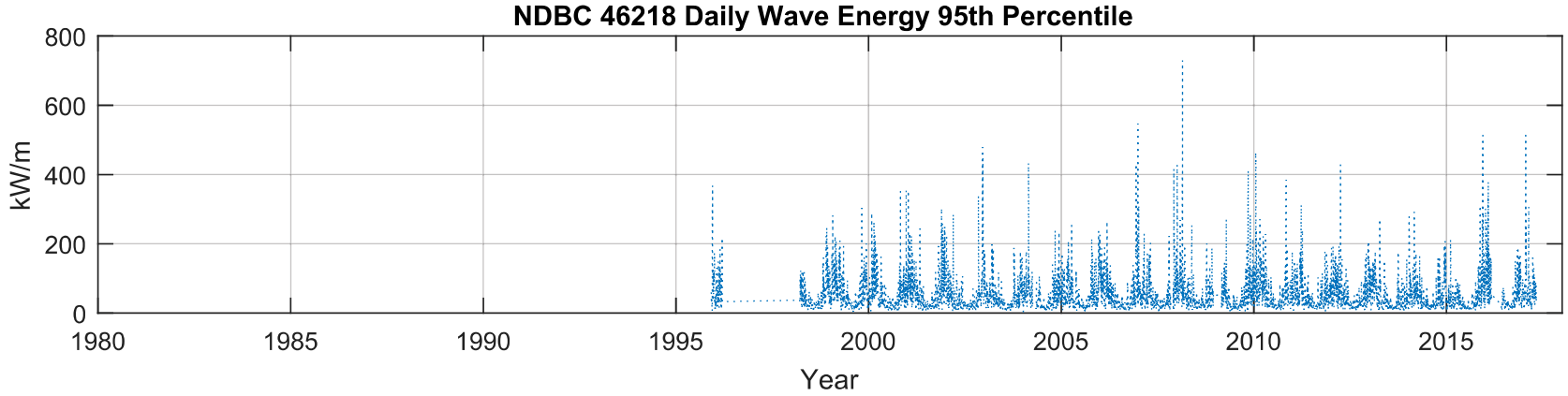
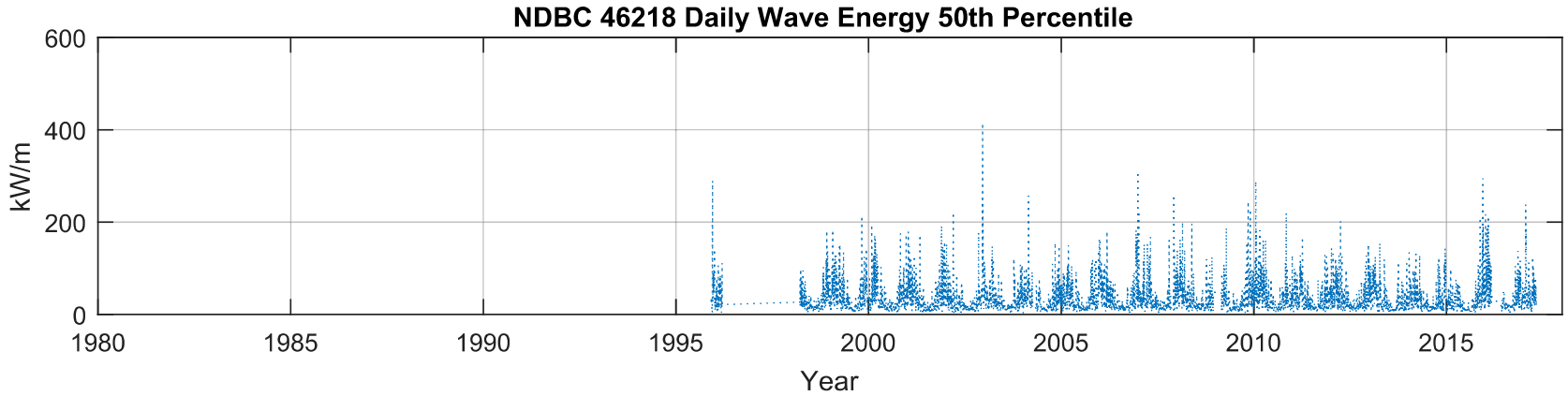


Figure A211. Daily Wave Energy, Max, Mean, Min,NDBC 46218





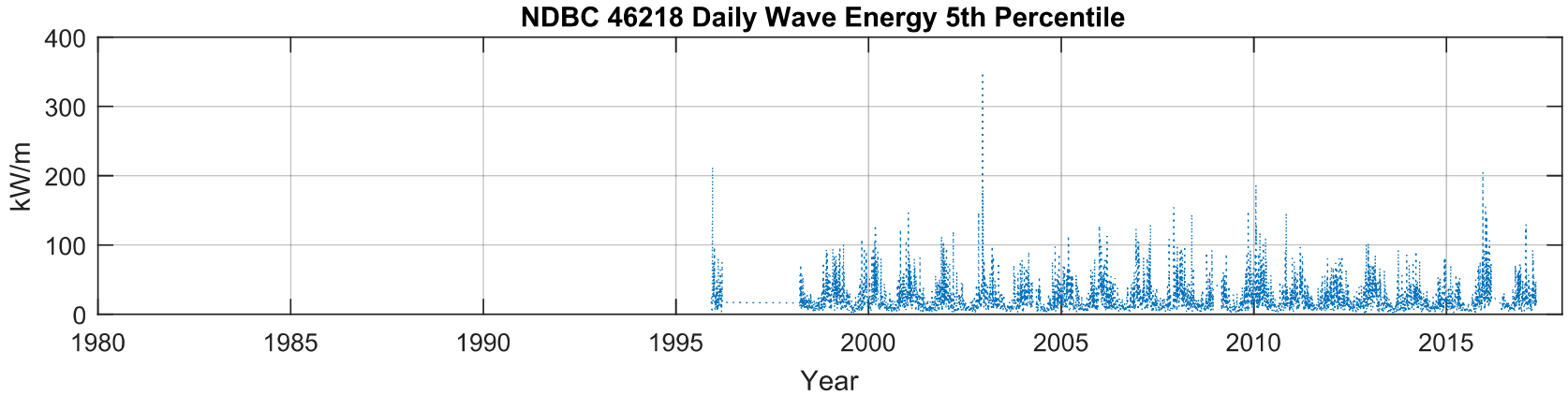


Figure A212. Daily Wave Energy, Percentiles,NDBC 46218

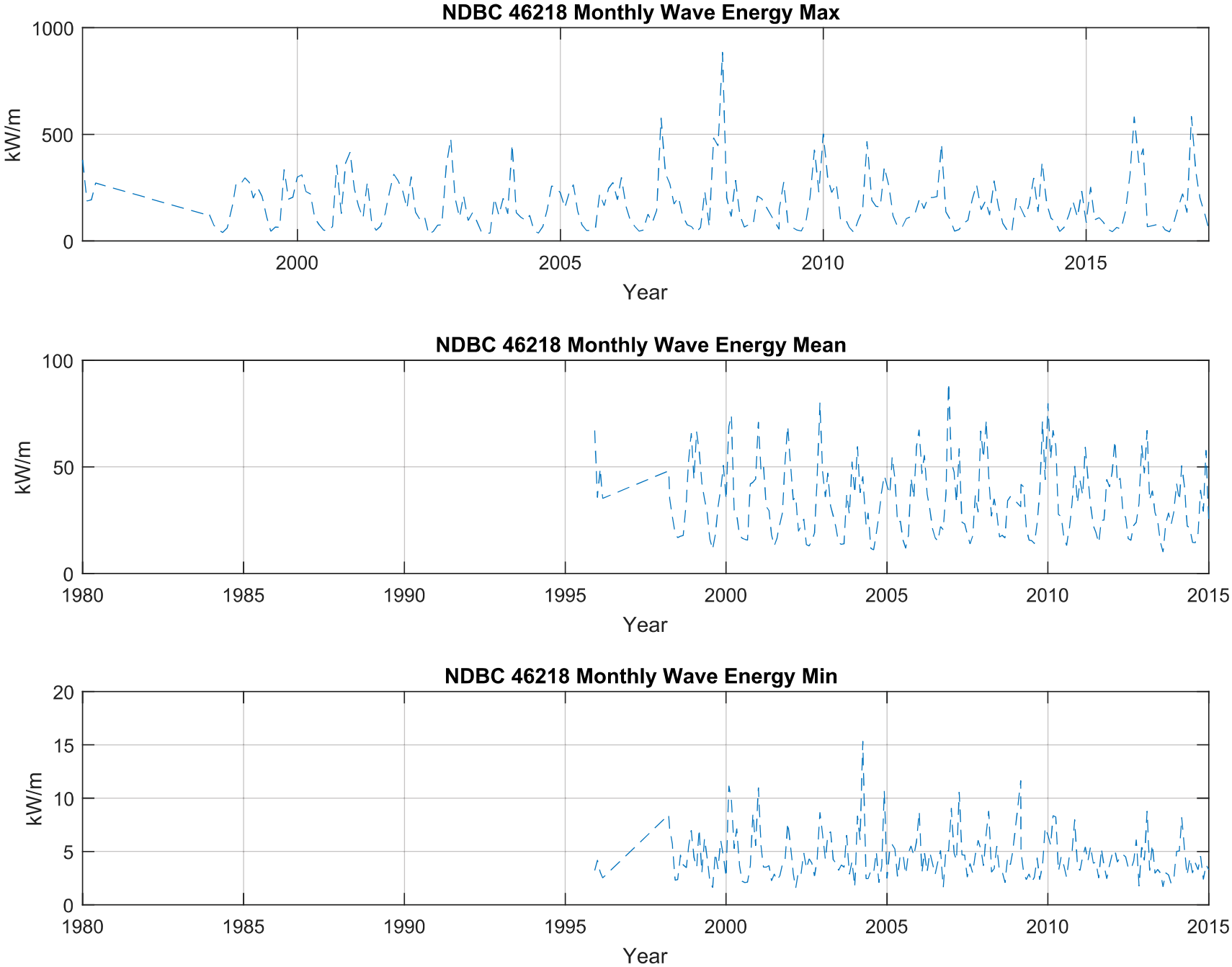
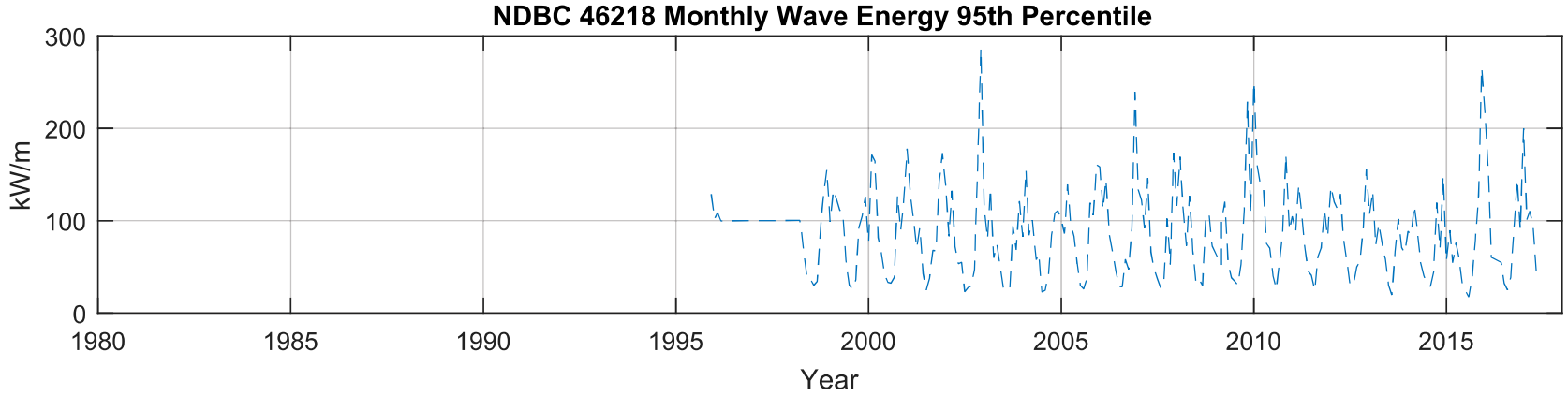
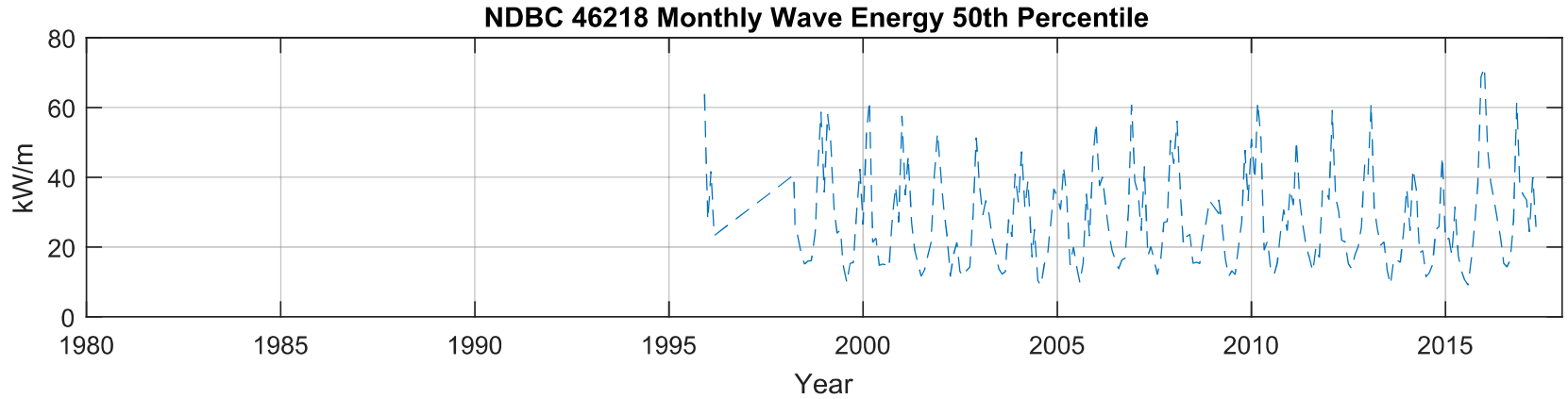


Figure A213. Monthly Wave Energy, Max, Mean, Min,NDBC 46218





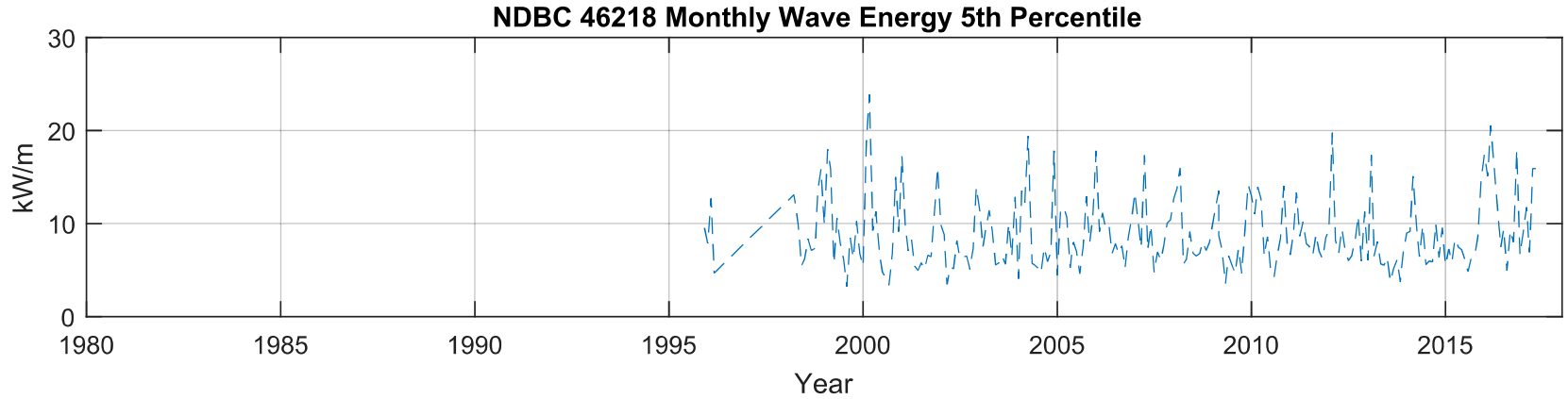
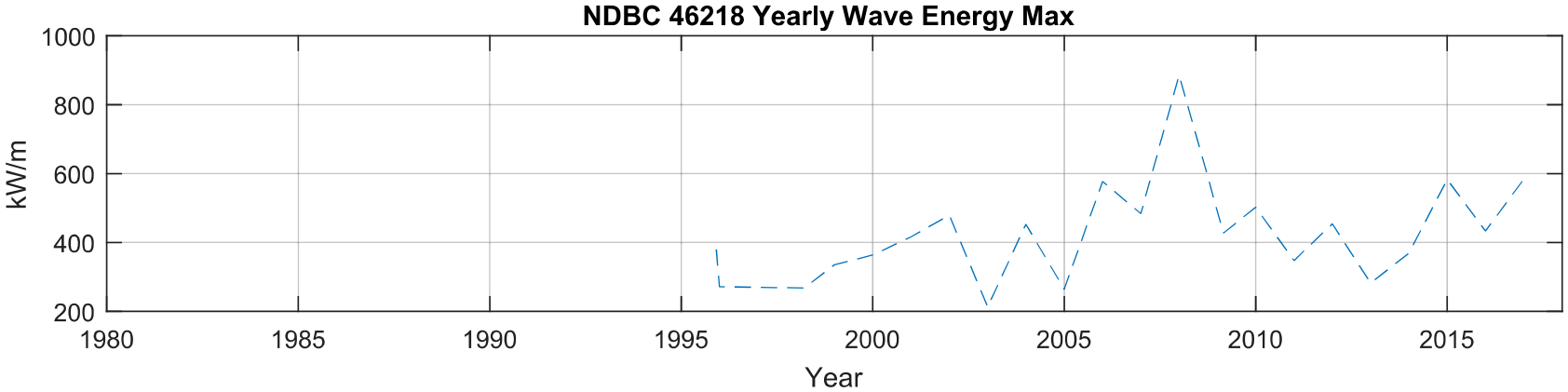
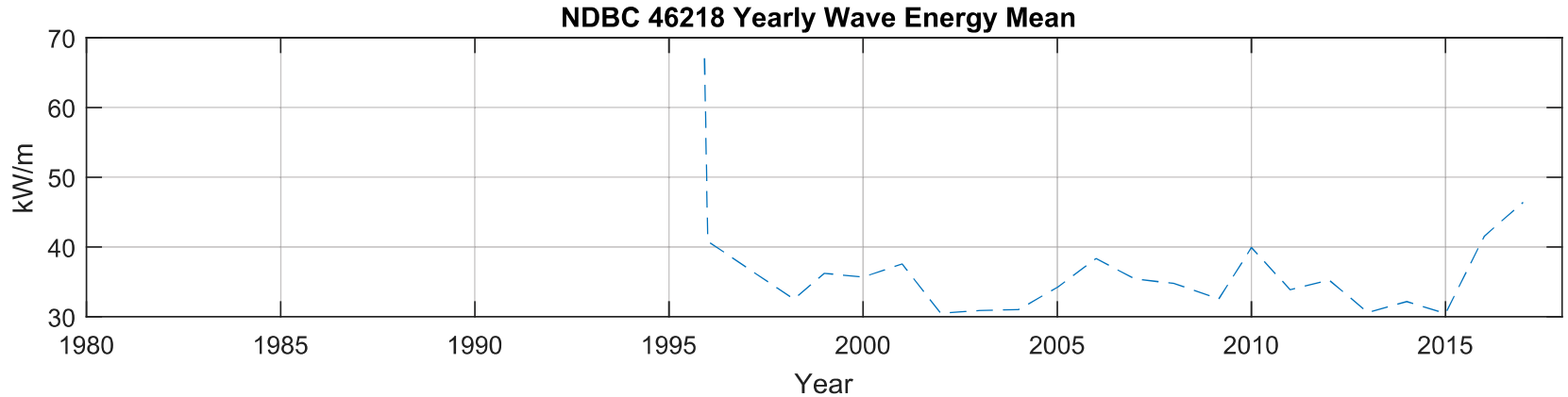


Figure A214. Monthly Wave Energy, Percentiles,NDBC 46218





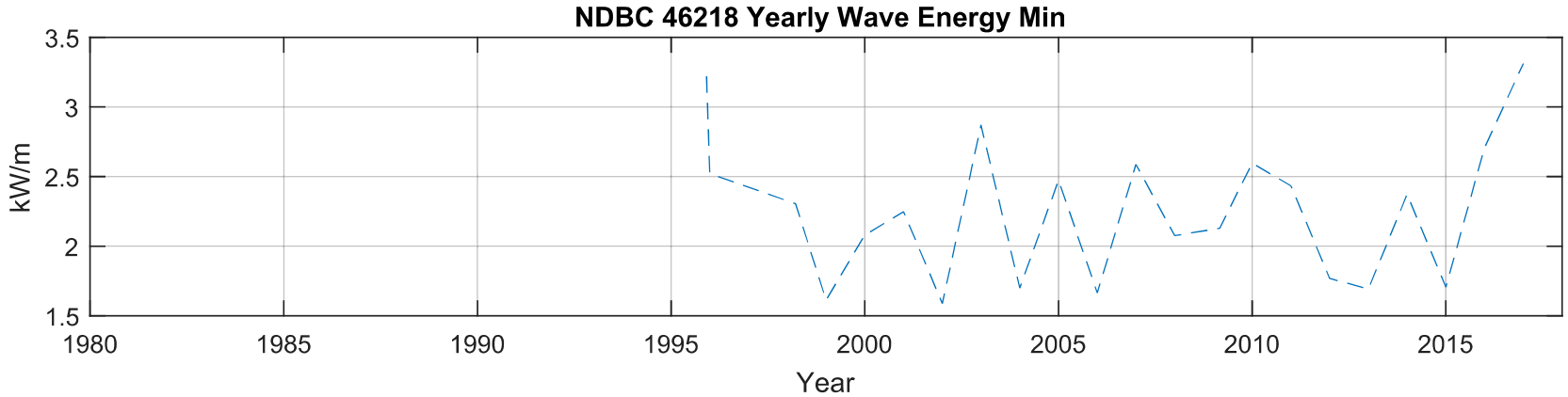
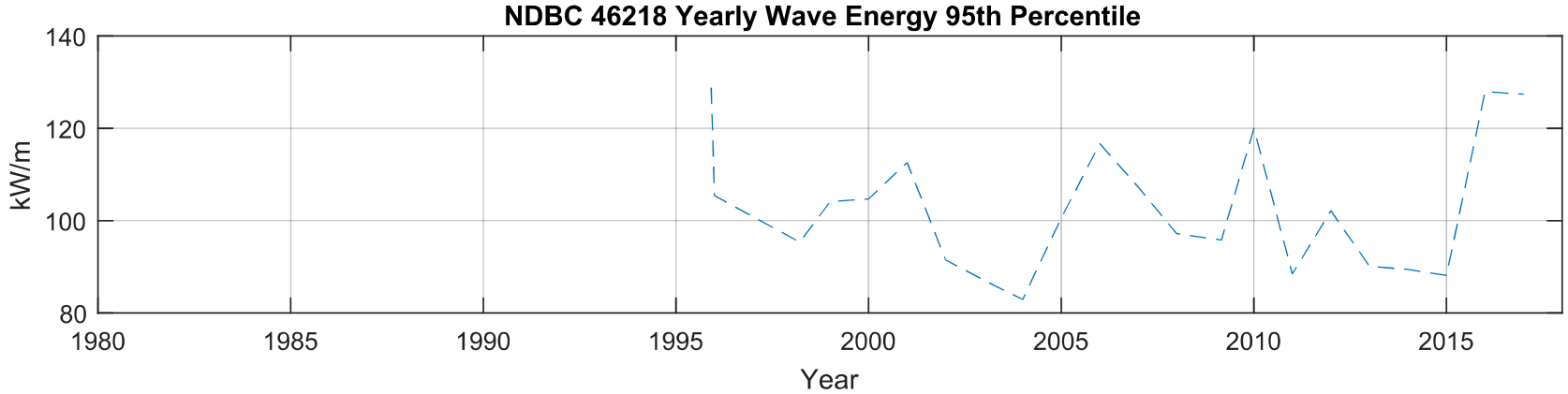
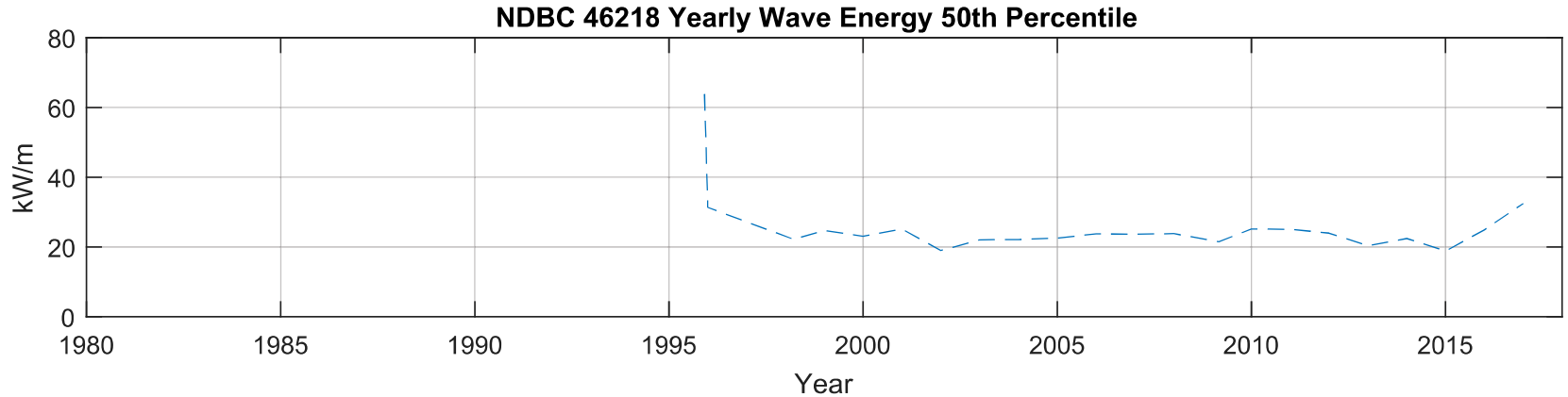


Figure A215. Yearly Wave Energy, Max, Mean, Min,NDBC 46218





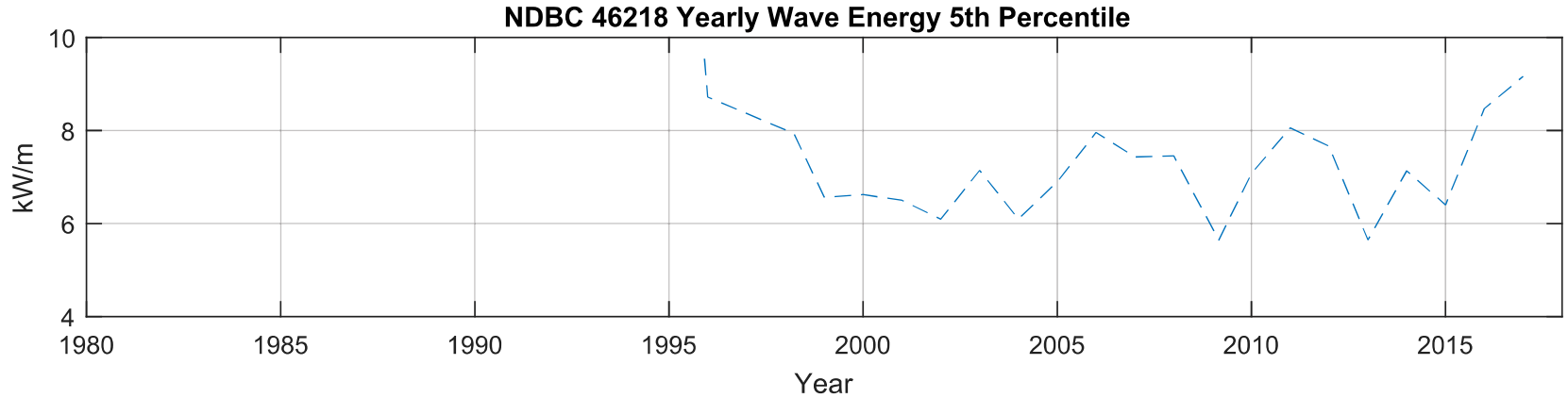


Figure A216. Yearly Wave Energy, Percentiles,NDBC 46218

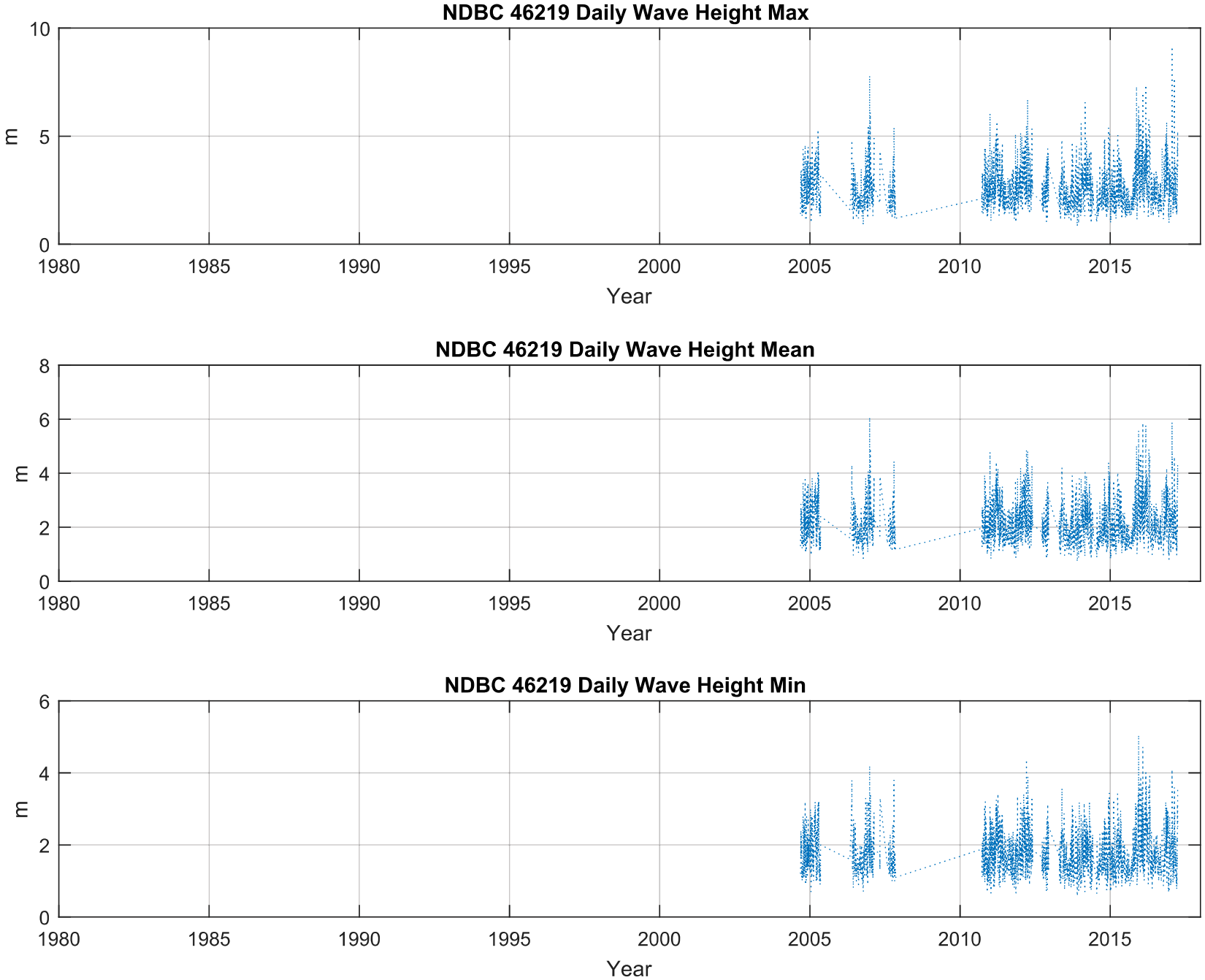


Figure A217. Daily Wave Height, Max, Mean, Min,NDBC 46219

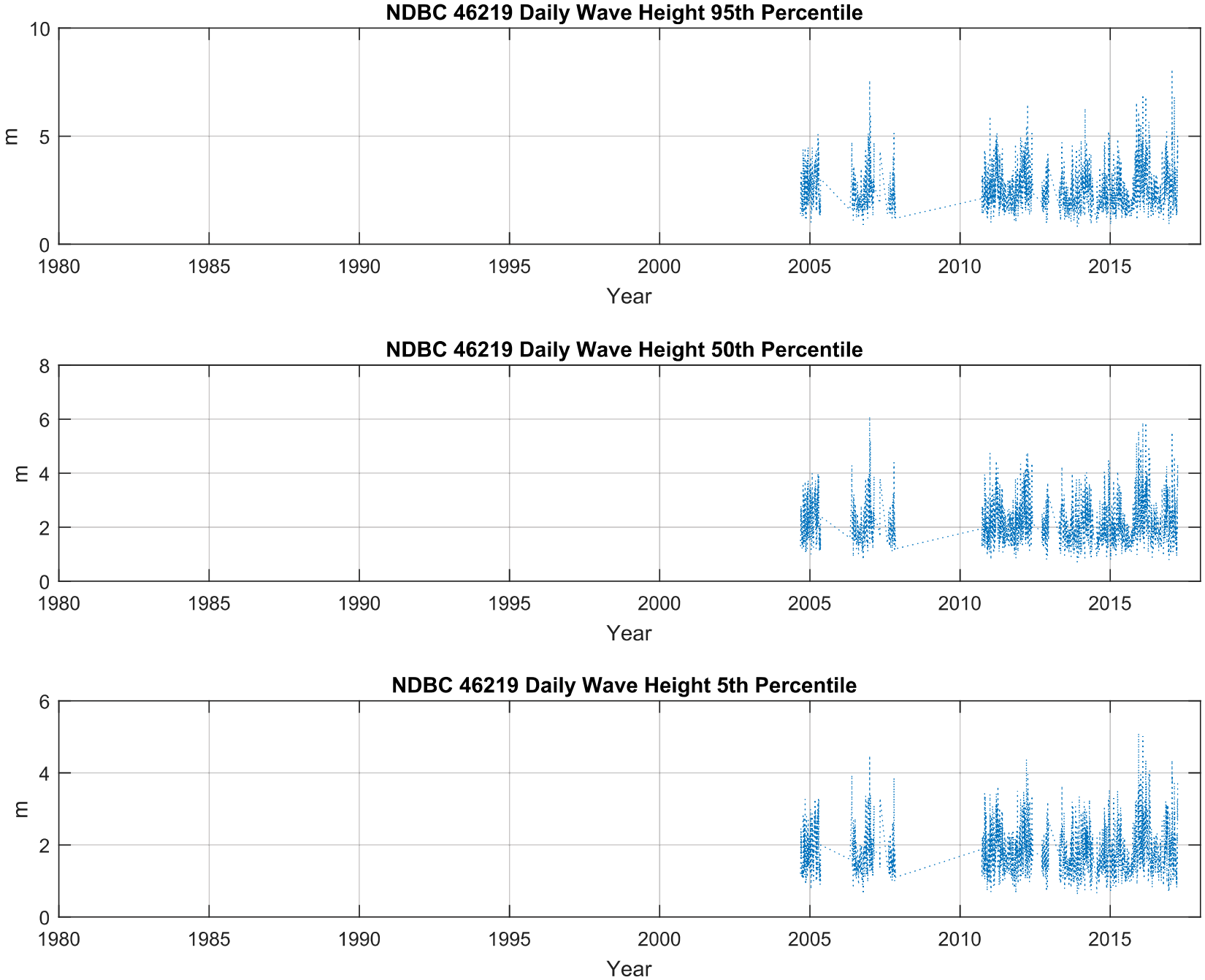


Figure A218. Daily Wave Height, Percentiles,NDBC 46219

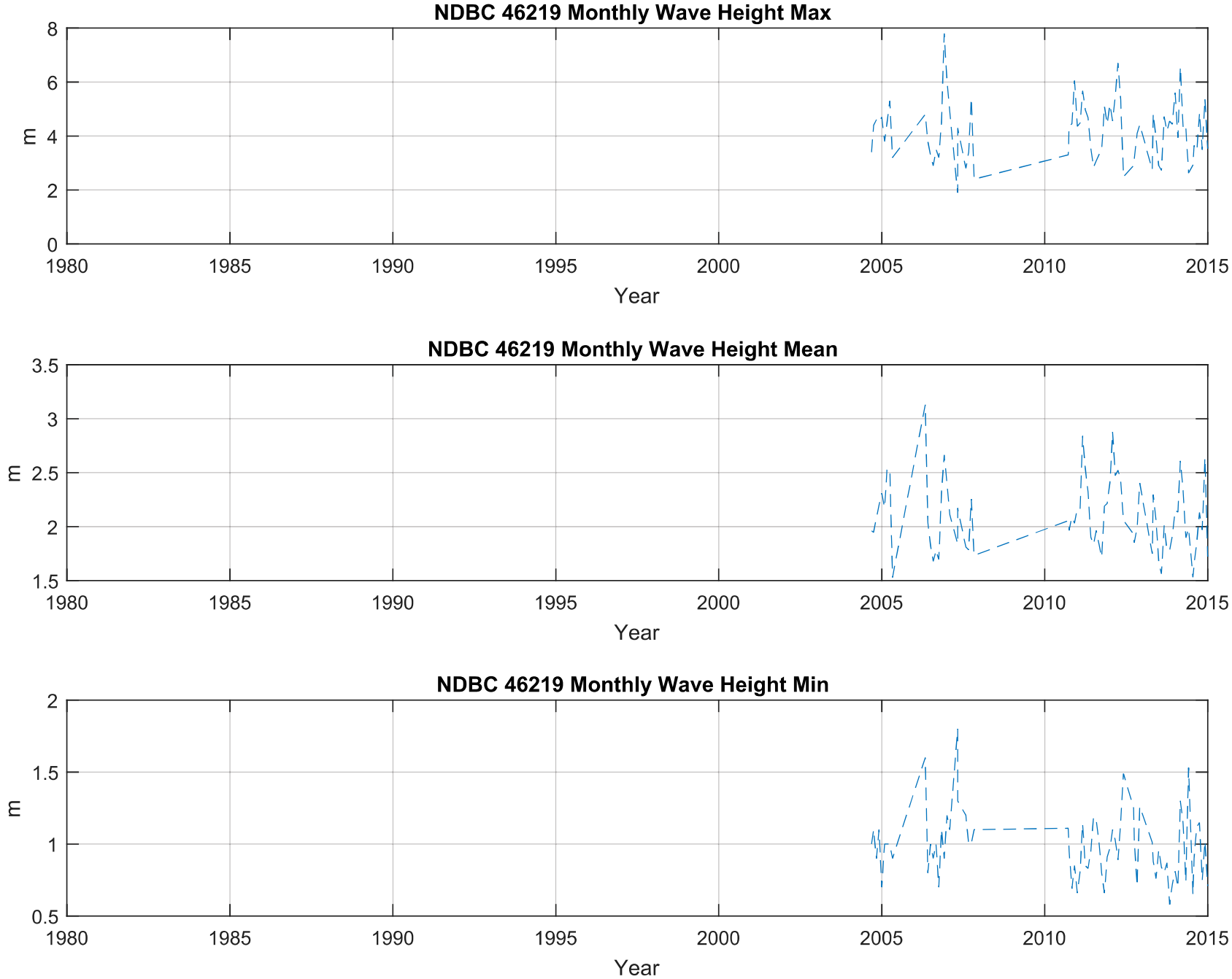
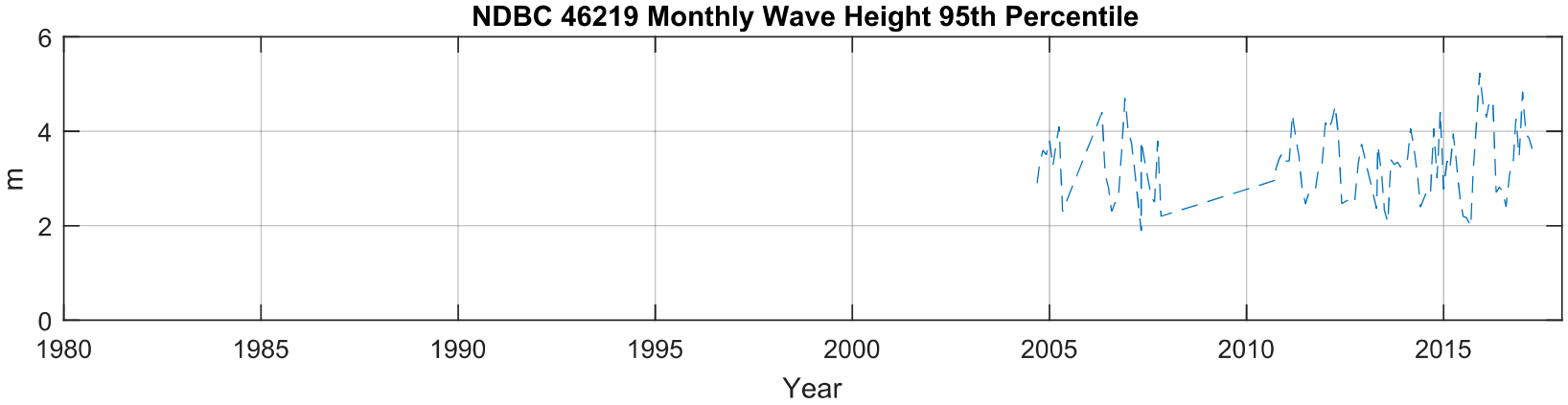
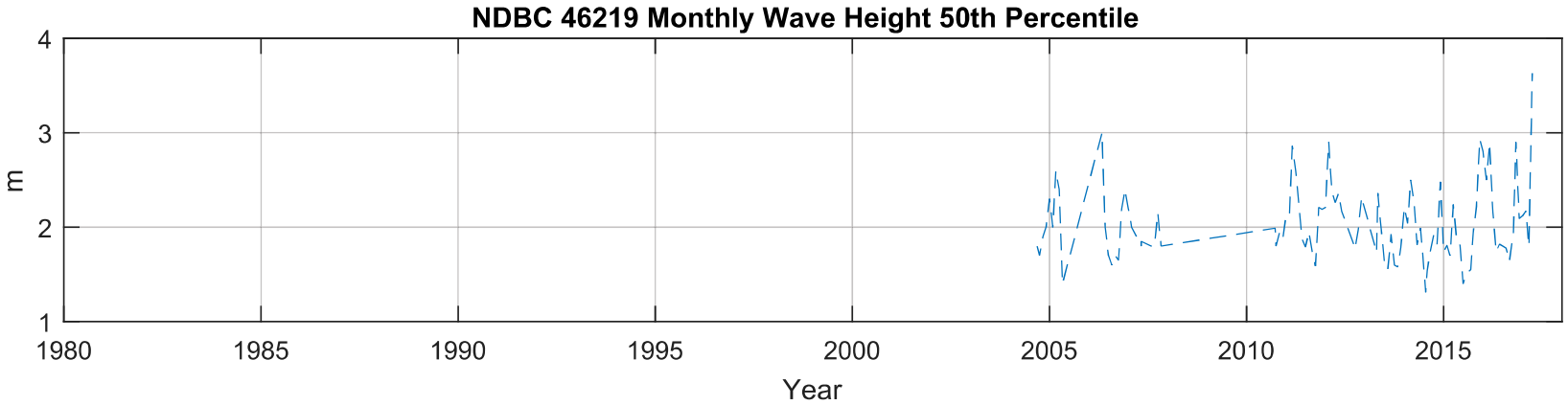


Figure A219. Monthly Wave Height, Max, Mean, Min,NDBC 46219





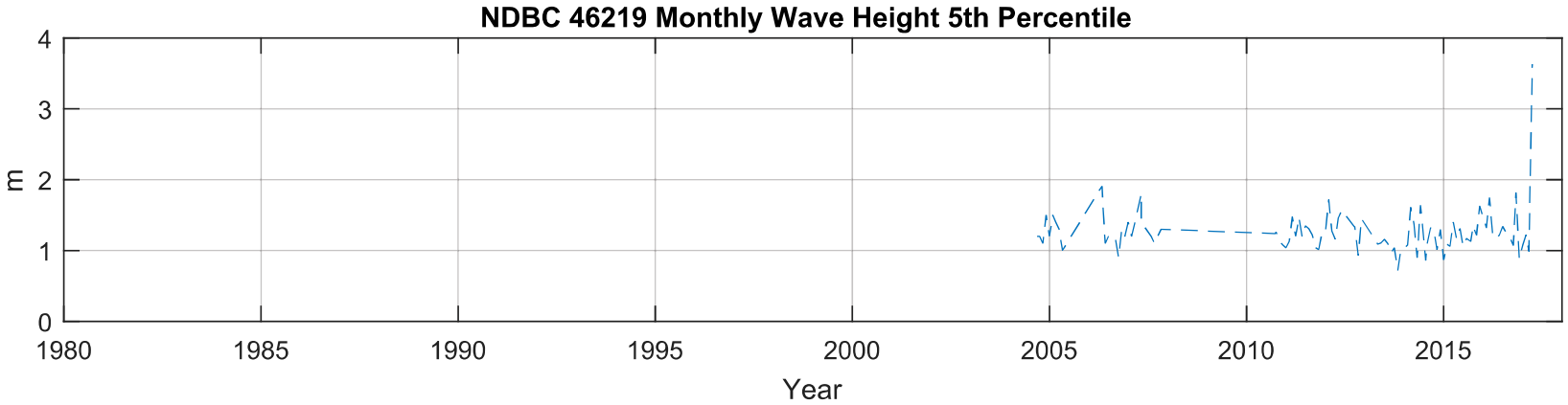


Figure A220. Monthly Wave Height, Percentiles,NDBC 46219

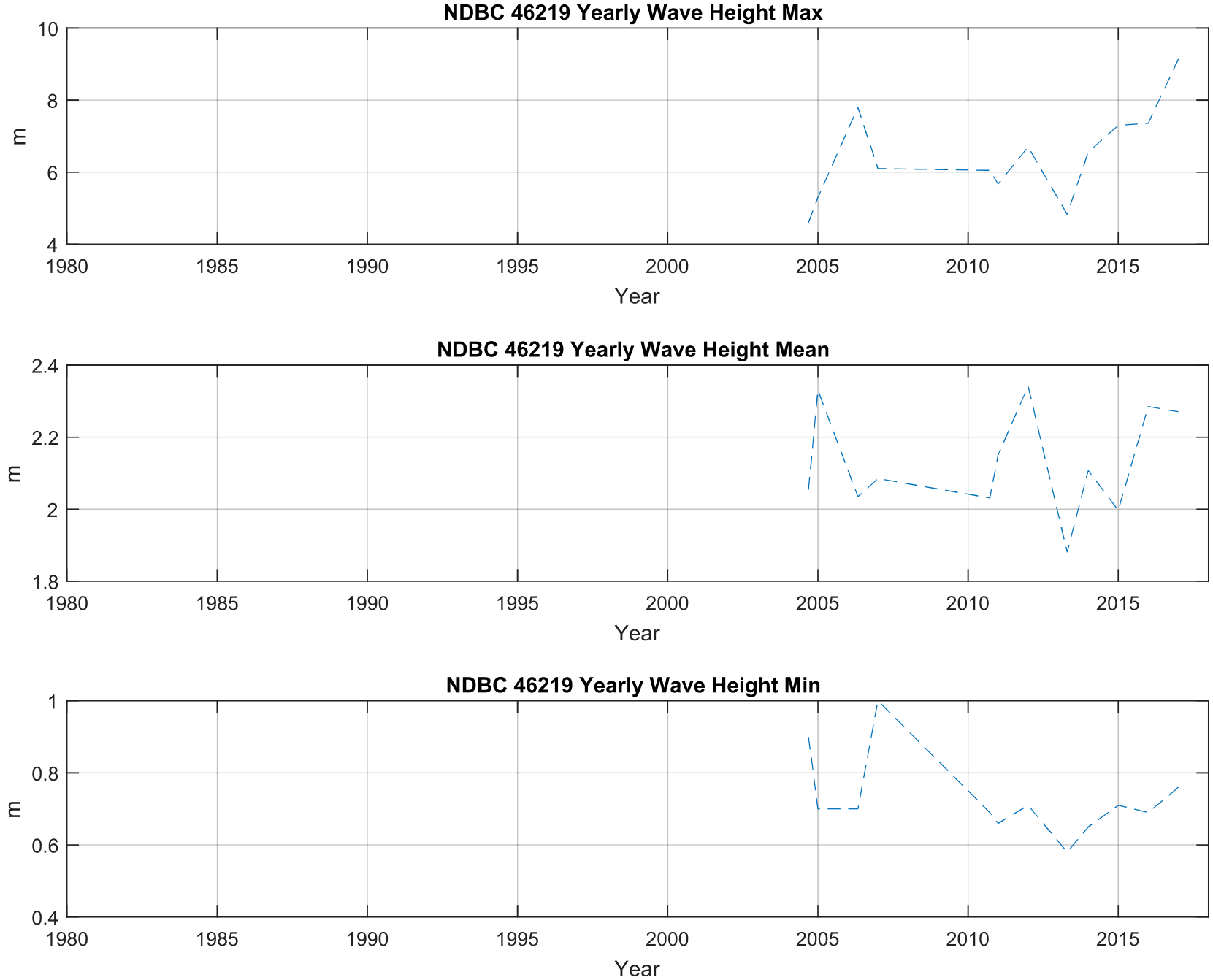


Figure A221. Yearly Wave Height, Max, Mean, Min,NDBC 46219

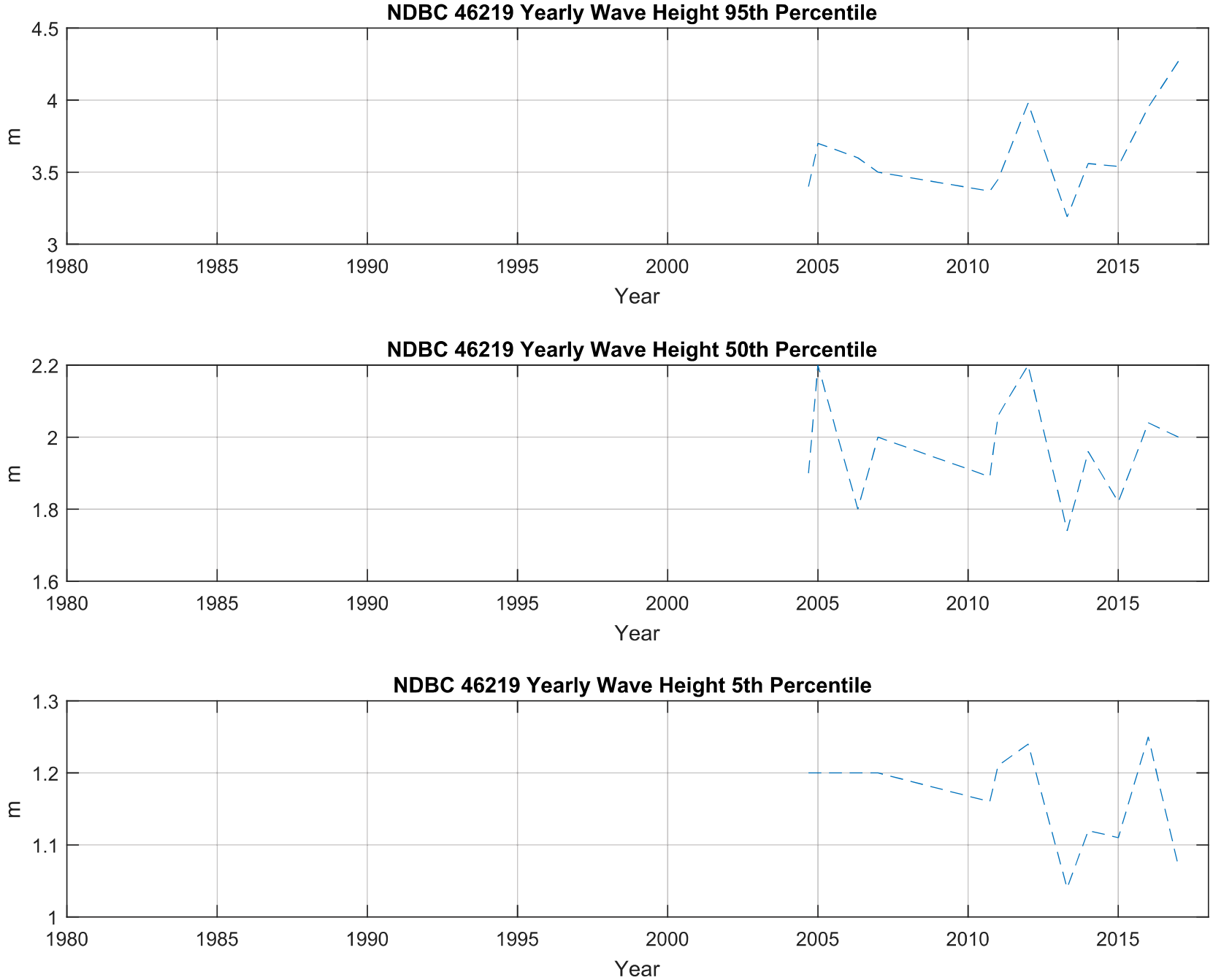


Figure A222. Yearly Wave Height, Percentiles,NDBC 46219

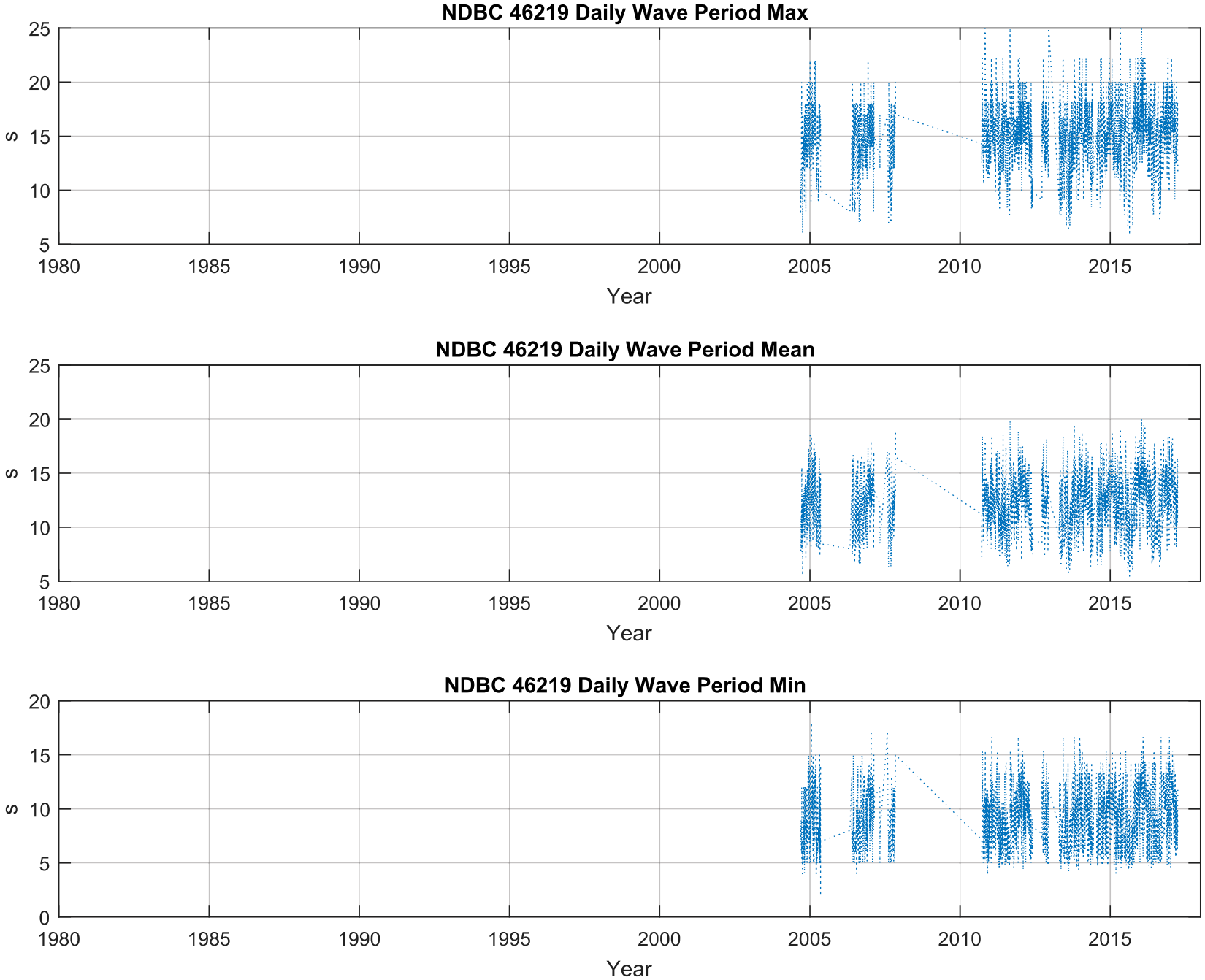
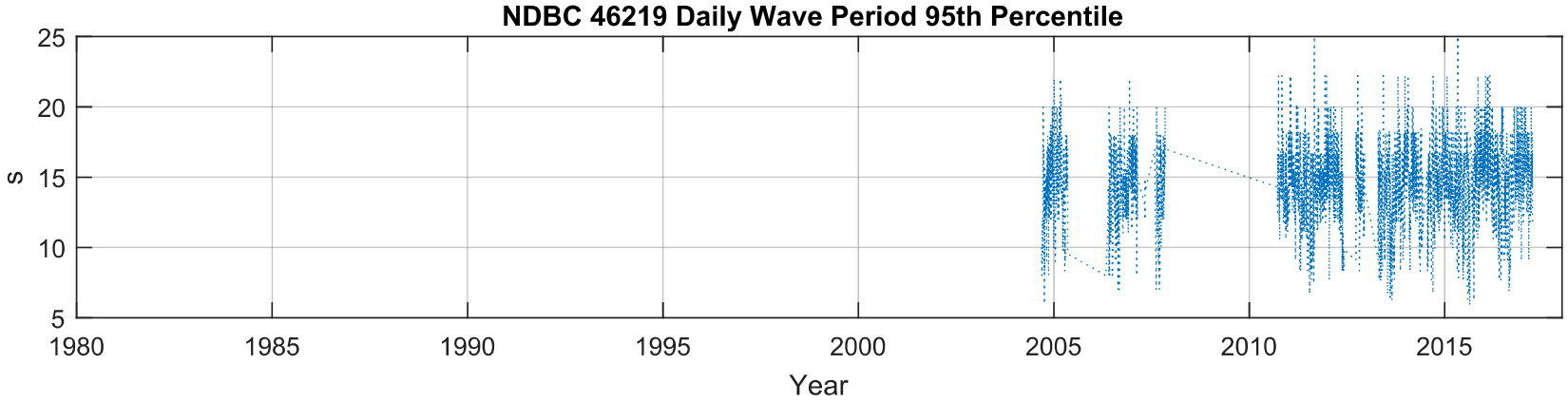
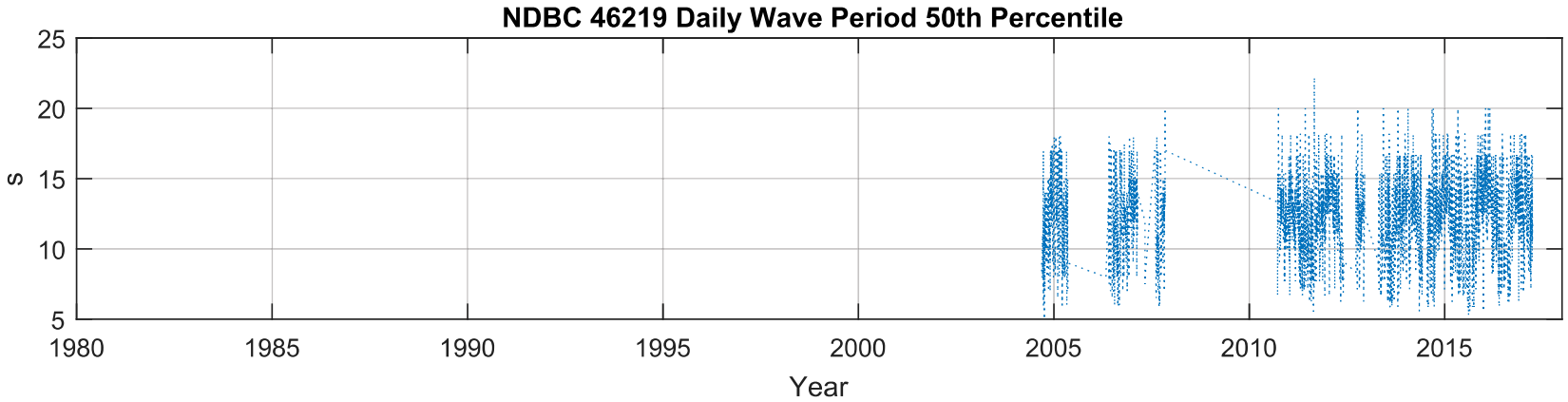


Figure A223. Daily Wave Period, Max, Mean, Min,NDBC 46219





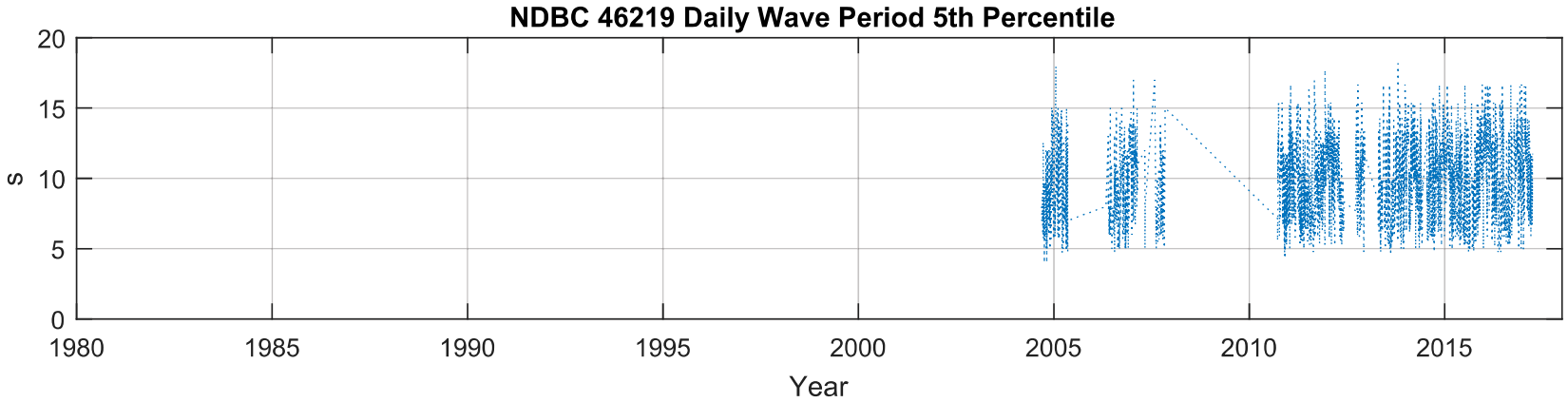
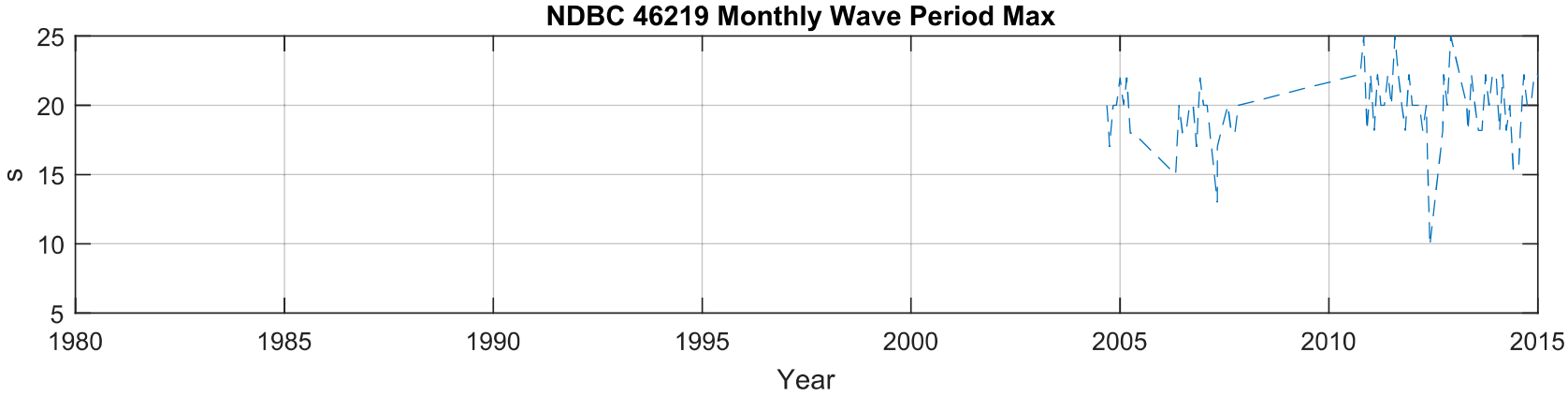
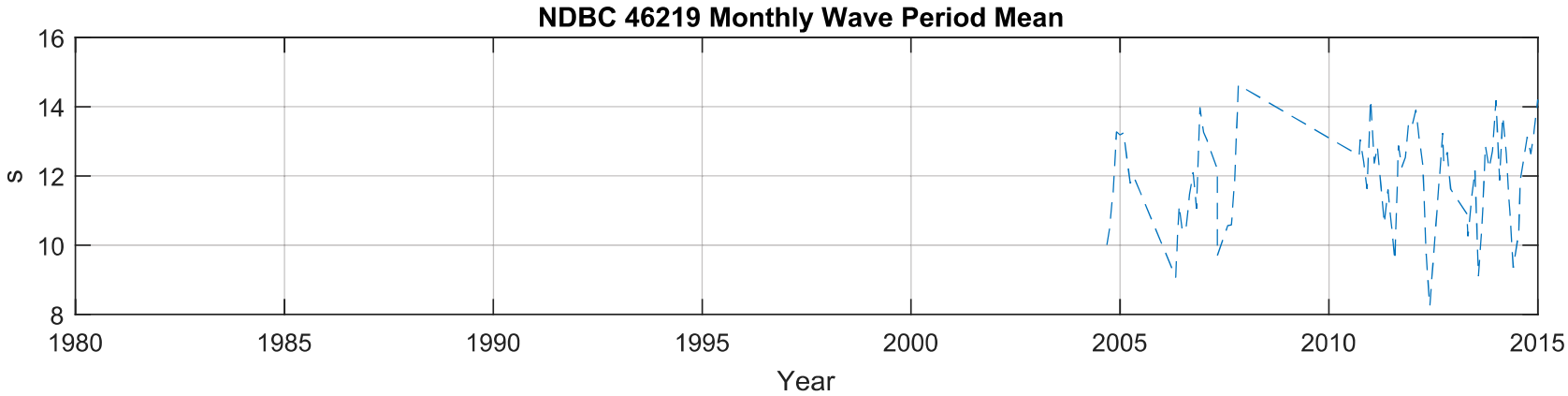


Figure A224. Daily Wave Period, Percentiles,NDBC 46219





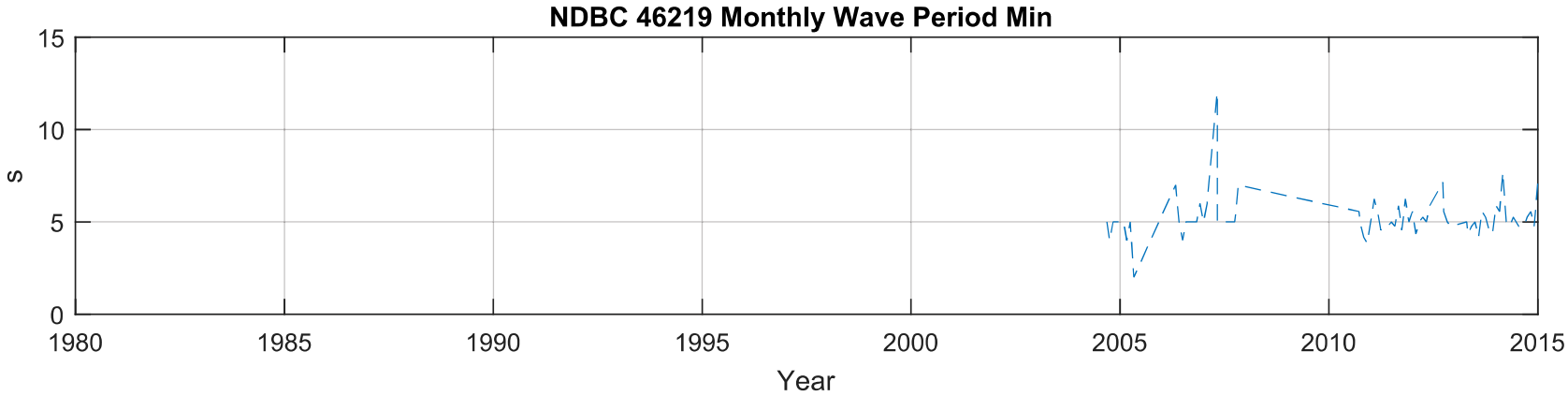
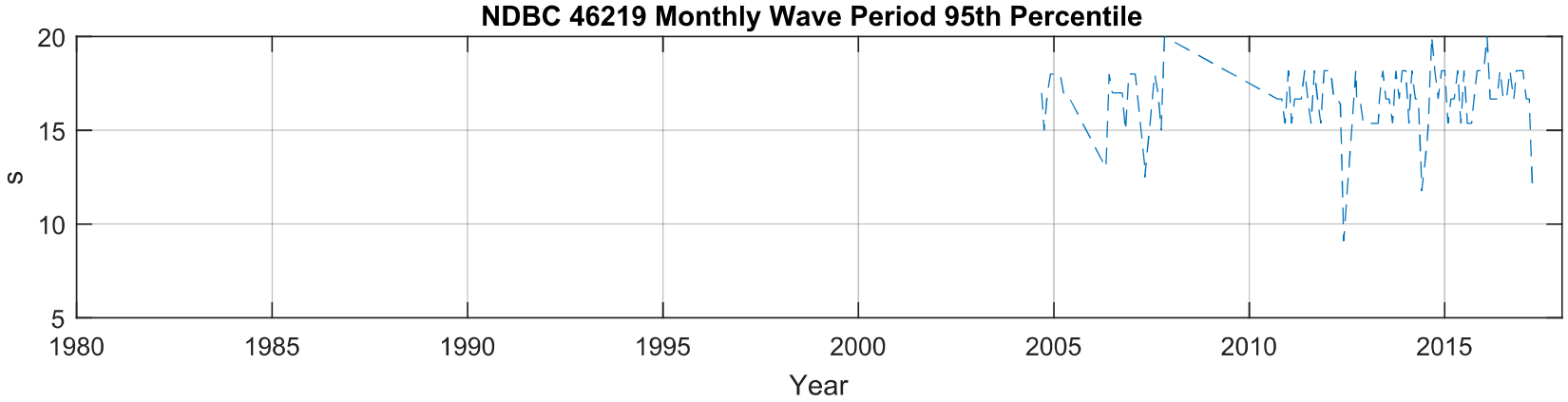
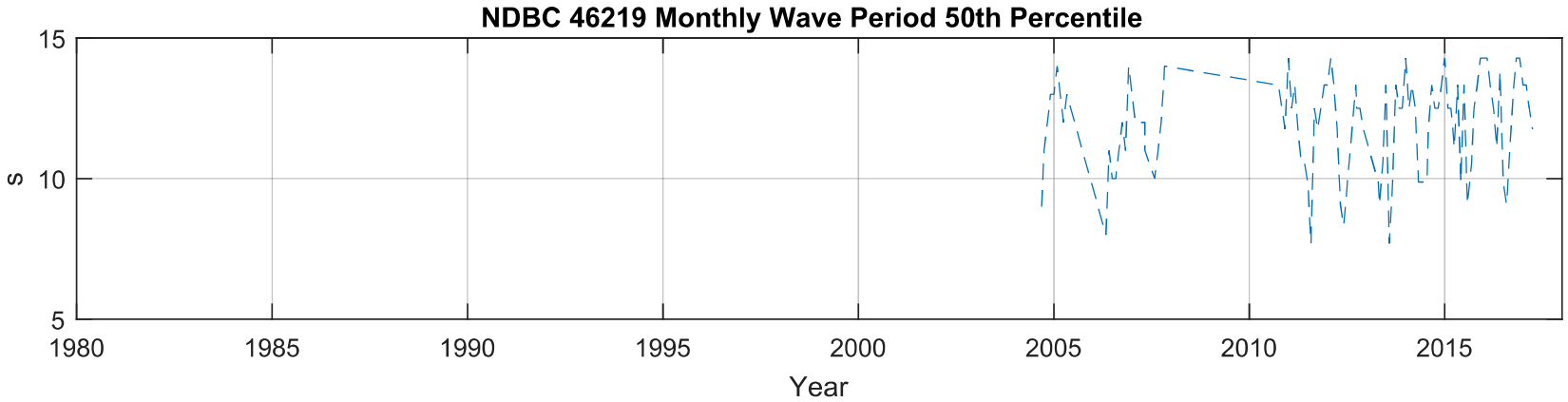


Figure A225. Monthly Wave Period, Max, Mean, Min,NDBC 46219





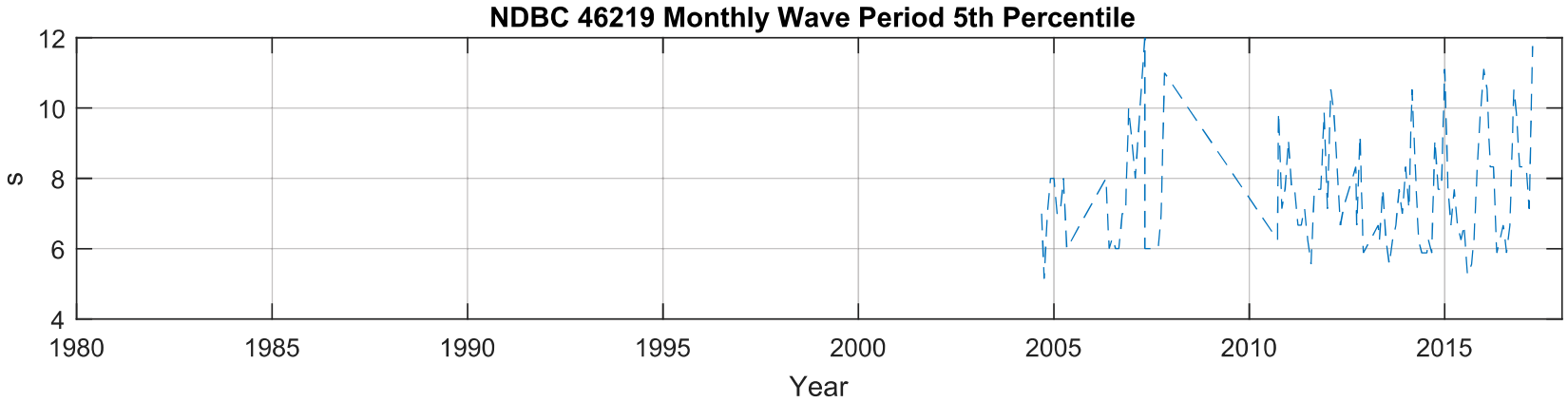


Figure A226. Monthly Wave Period, Percentiles,NDBC 46219

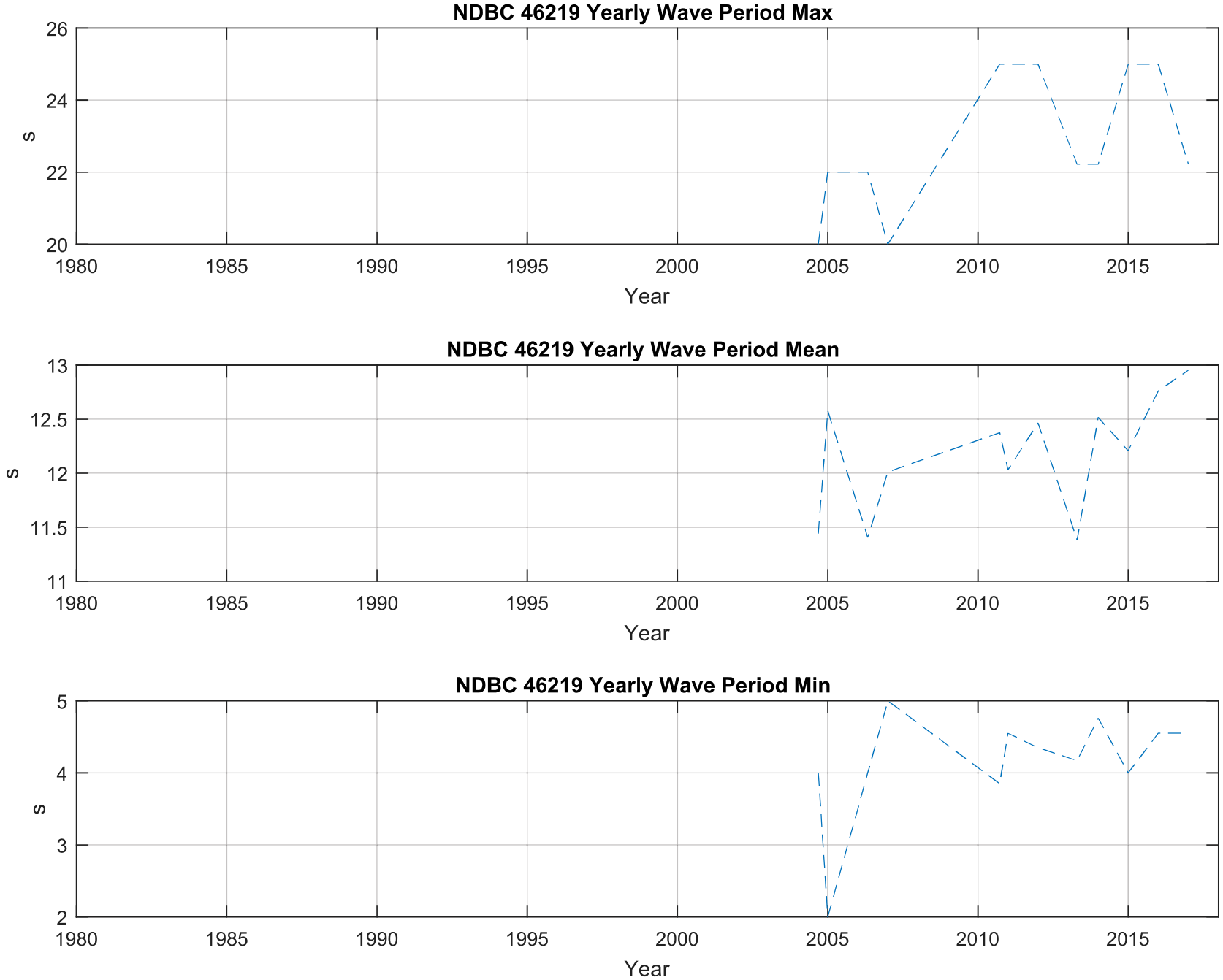
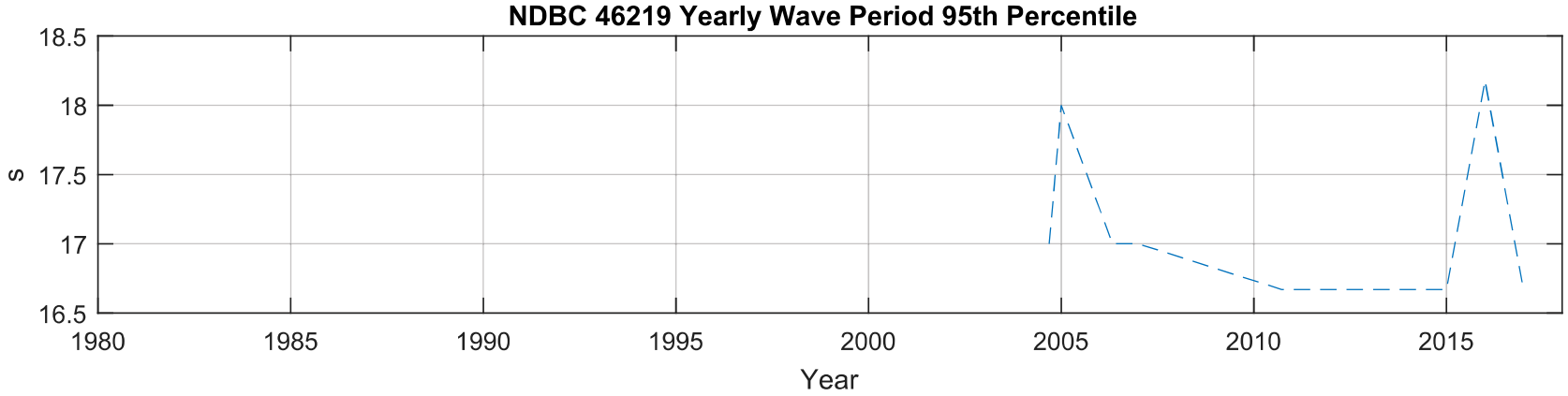
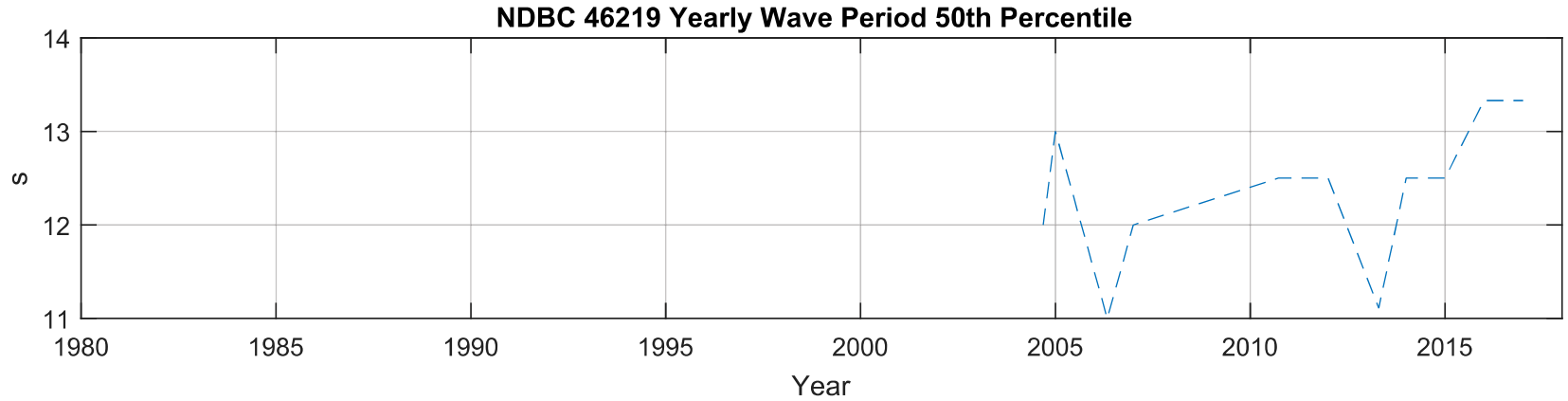


Figure A227. Yearly Wave Period, Max, Mean, Min,NDBC 46219





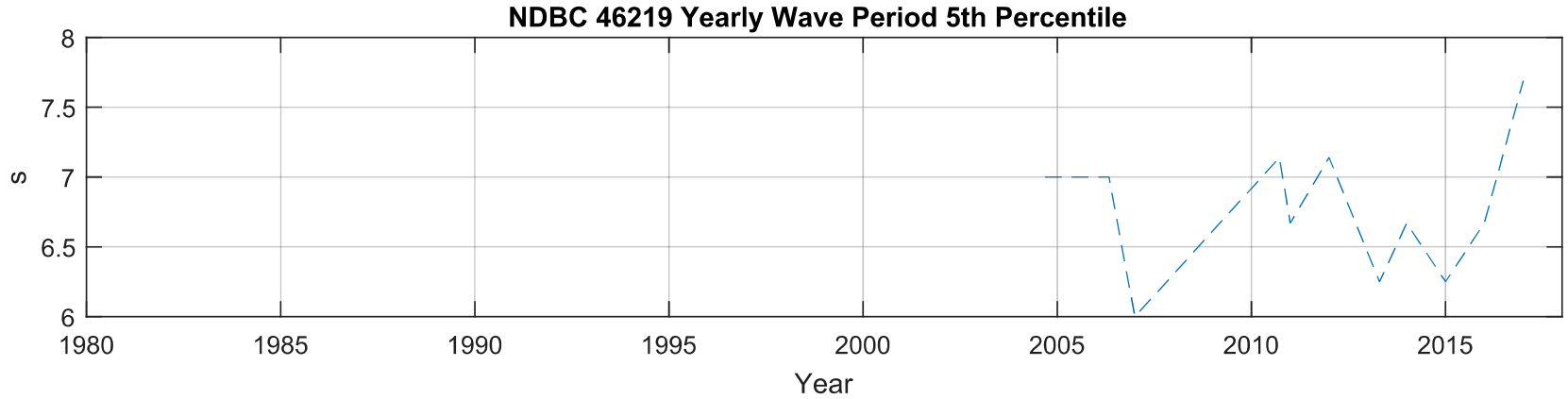
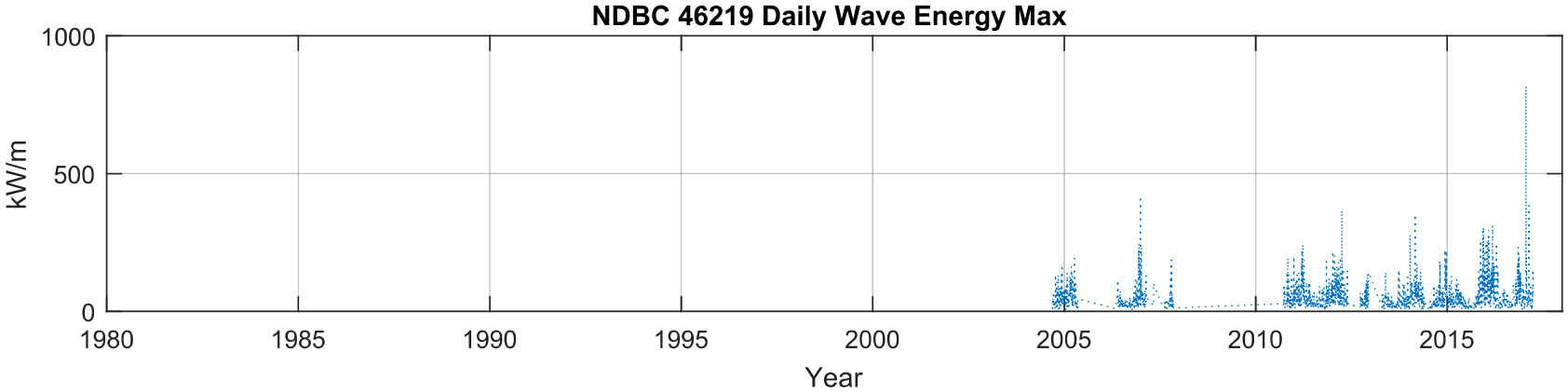
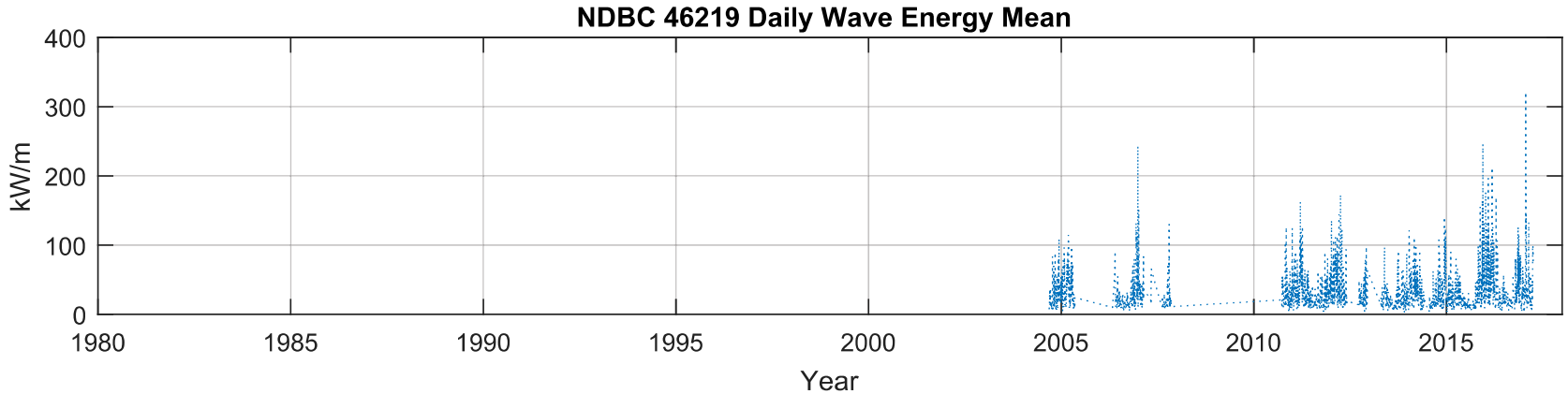


Figure A228. Yearly Wave Period, Percentiles,NDBC 46219





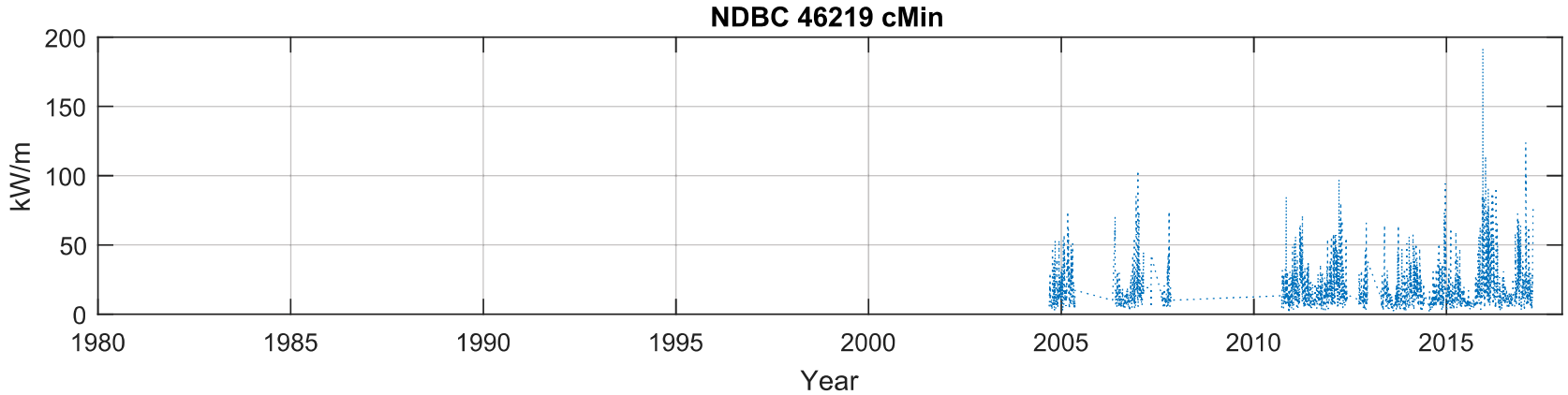
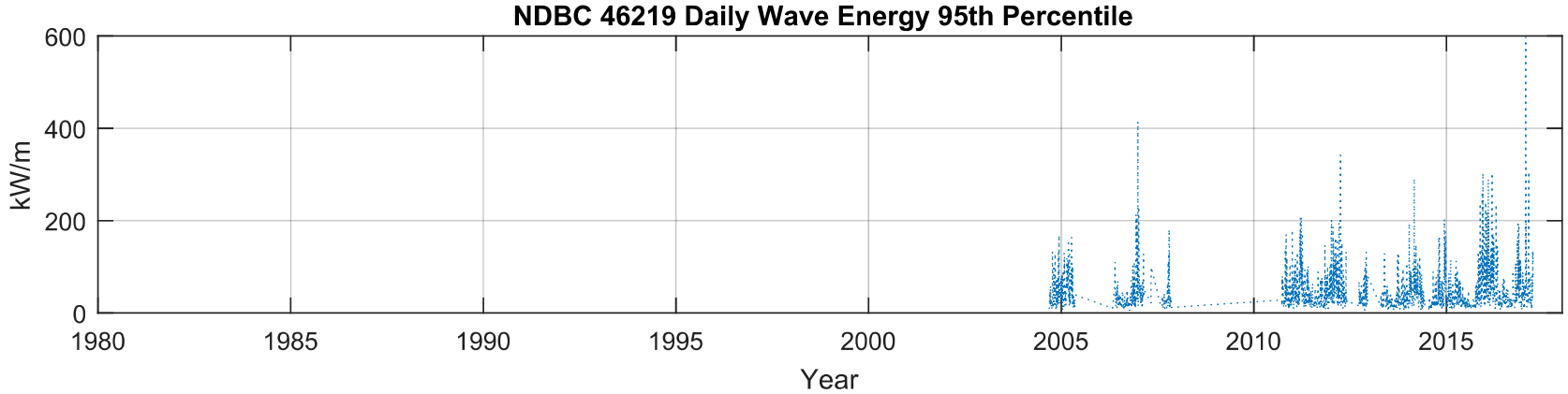
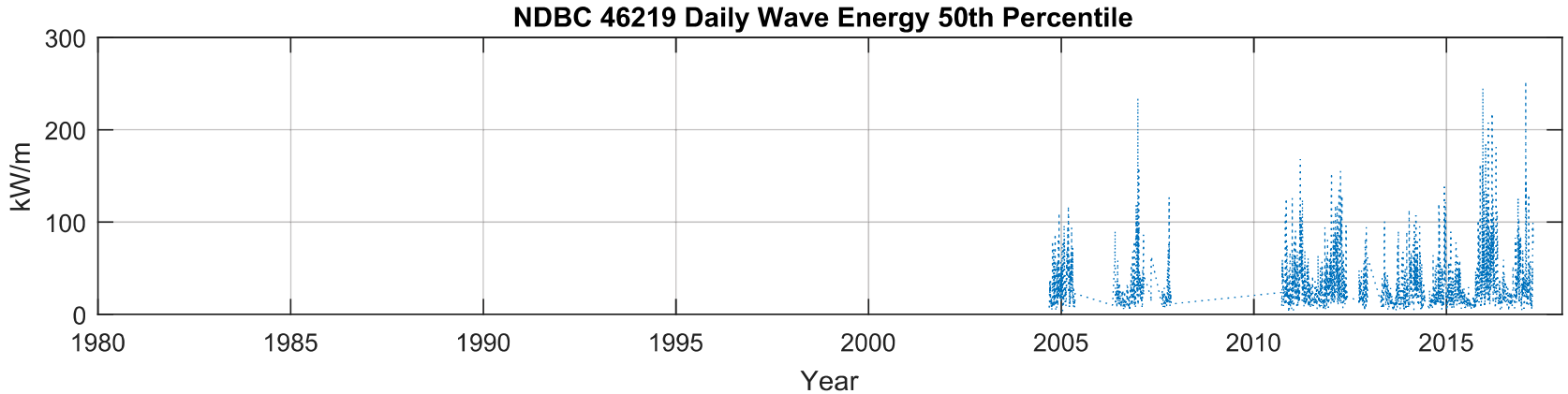


Figure A229. Daily Wave Energy, Max, Mean, Min,NDBC 46219





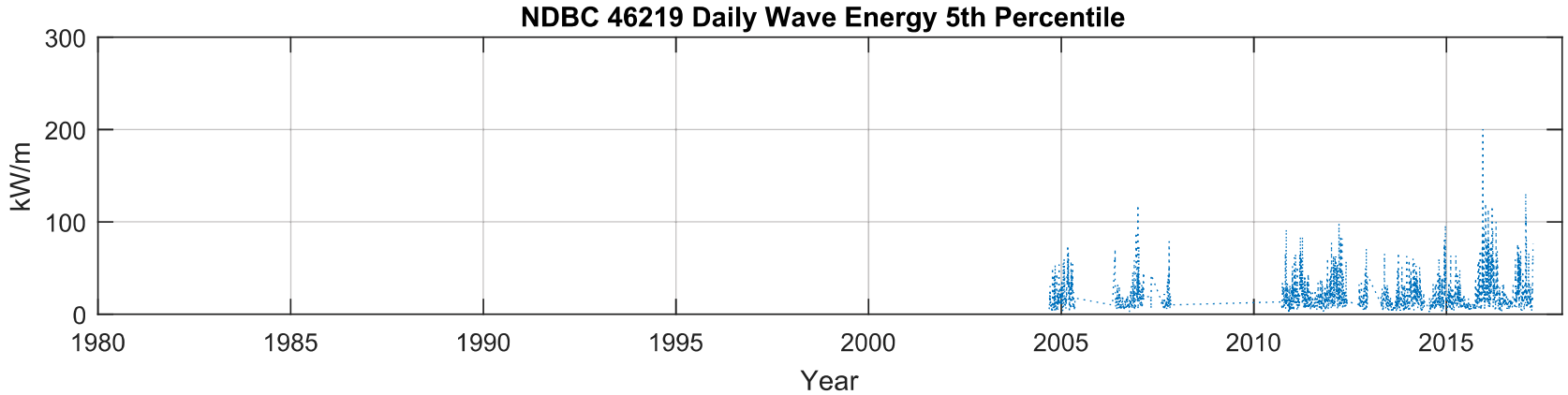


Figure A230. Daily Wave Energy, Percentiles,NDBC 46219

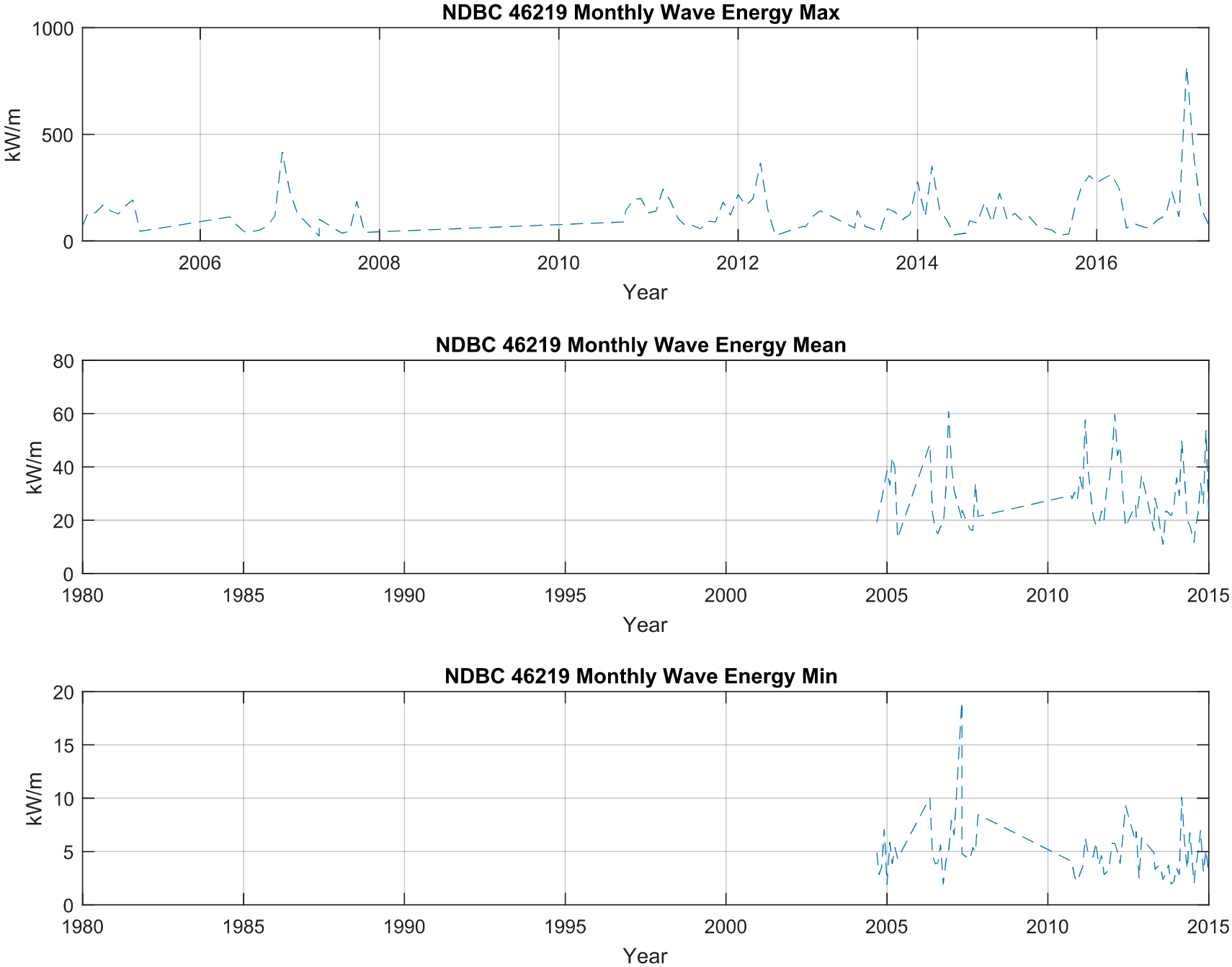
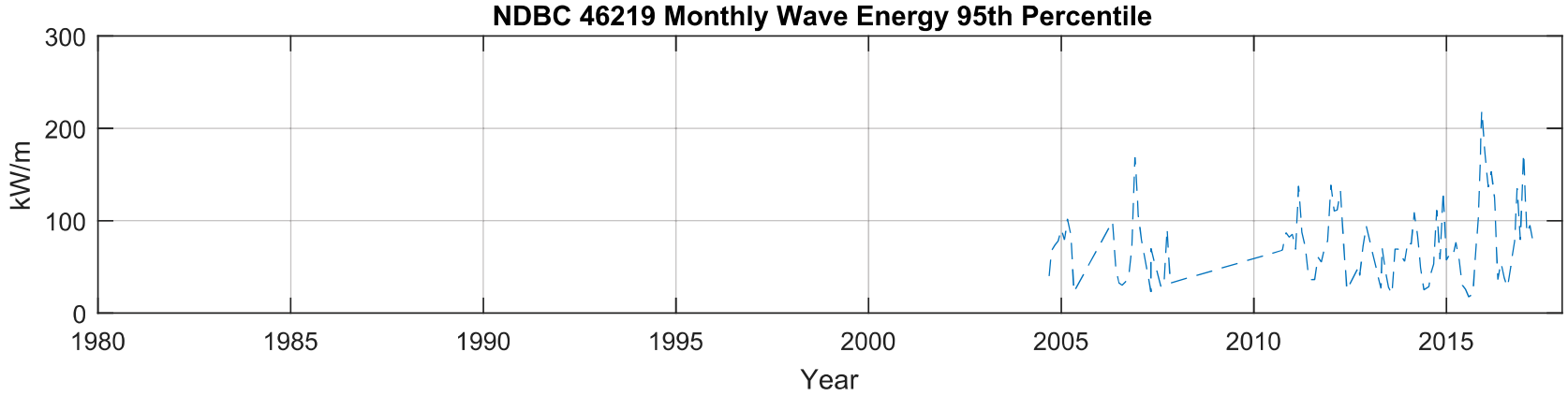
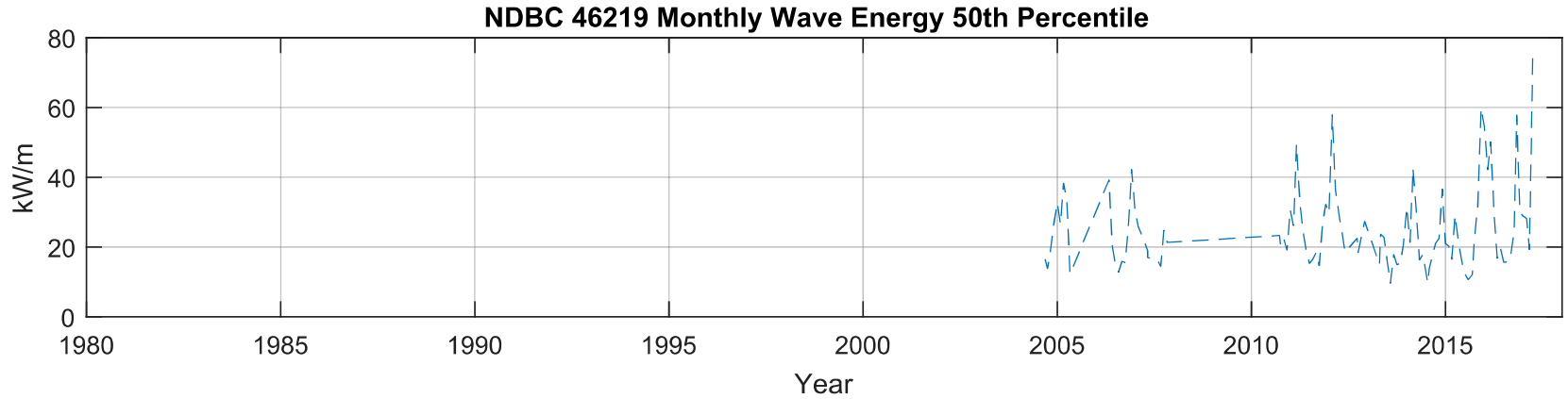


Figure A231. Monthly Wave Energy, Max, Mean, Min,NDBC 46219





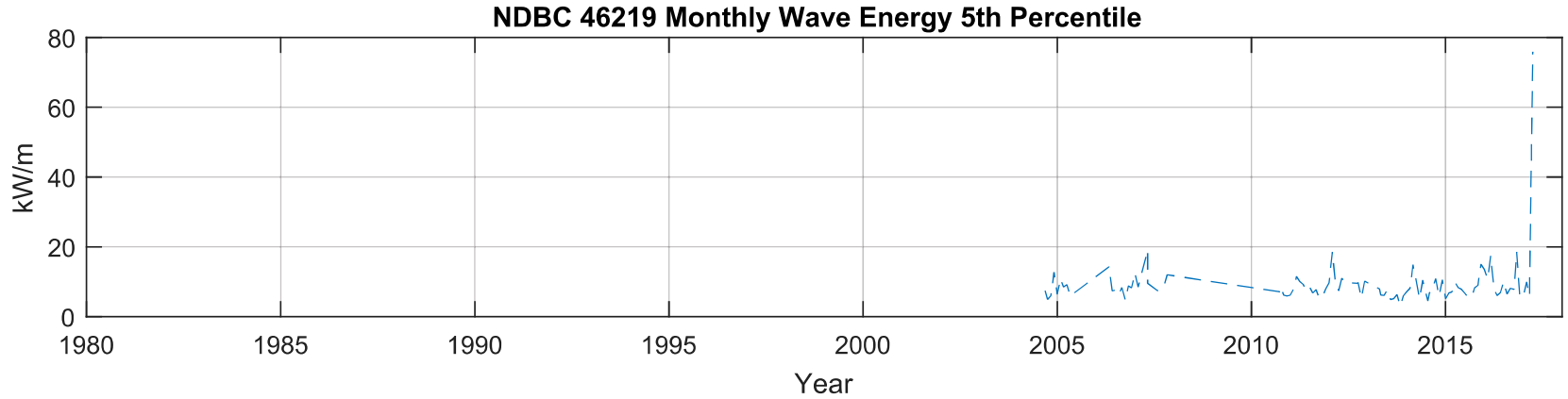


Figure A232. Monthly Wave Energy, Percentiles,NDBC 46219

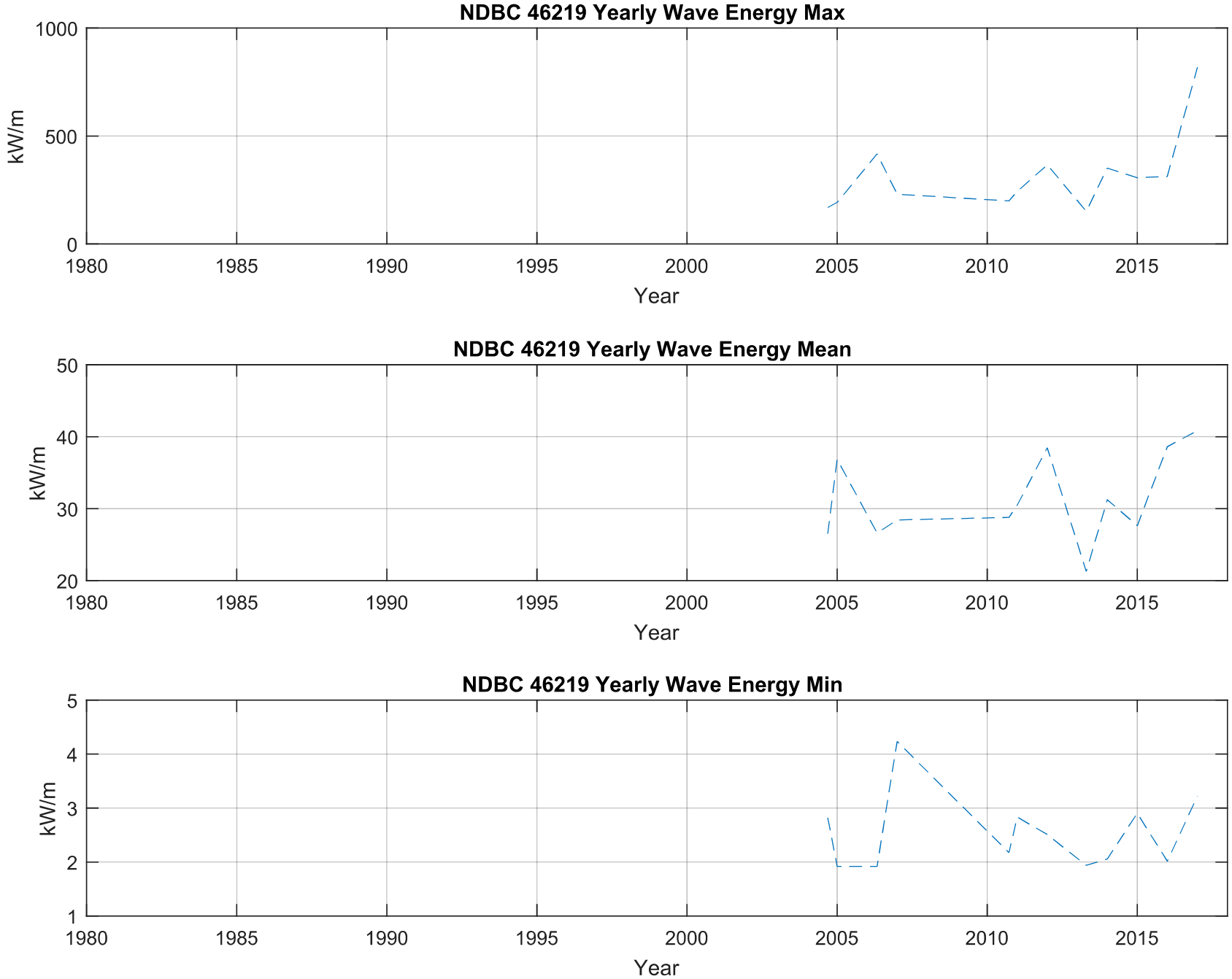
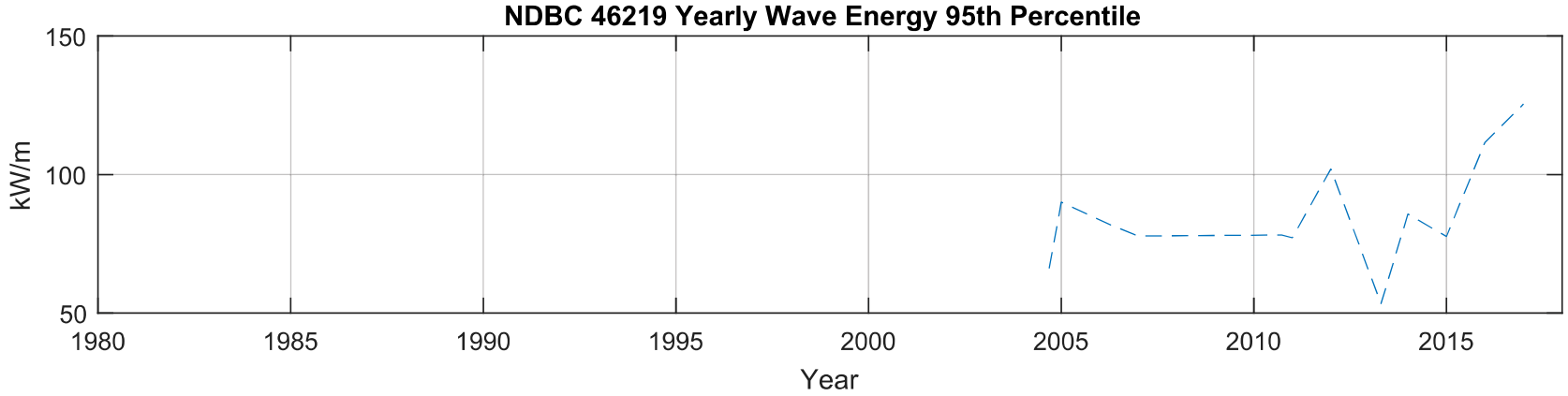
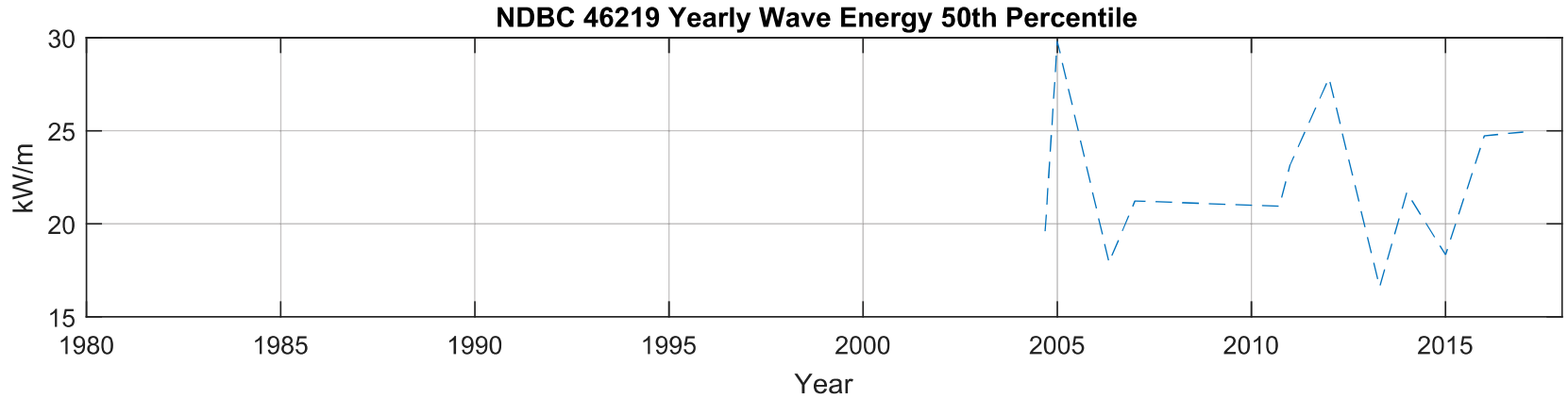


Figure A233. Yearly Wave Energy, Max, Mean, Min,NDBC 46219





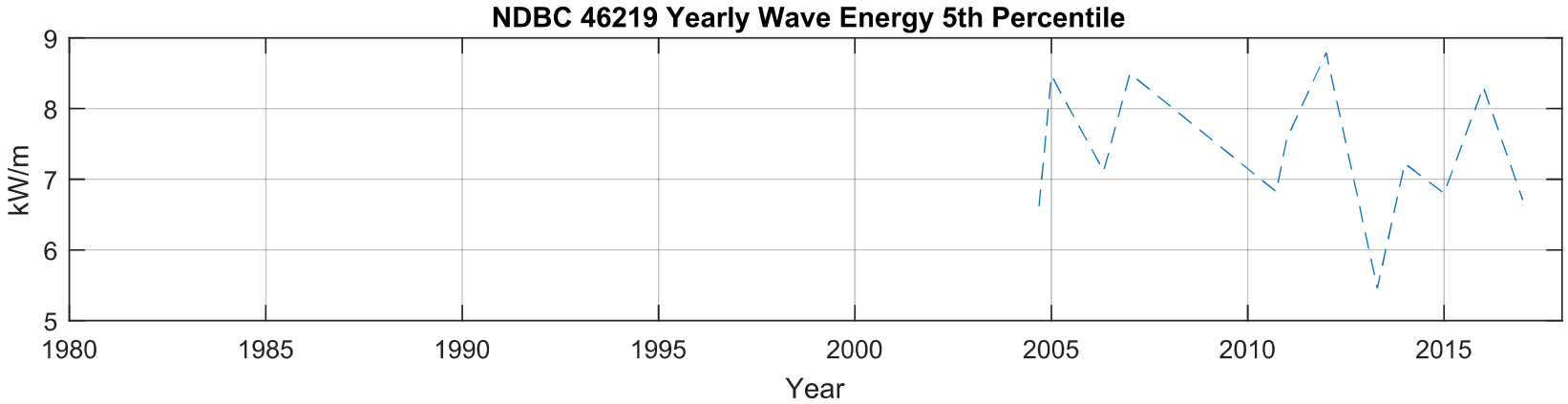


Figure A234. Yearly Wave Energy, Percentiles,NDBC 46219

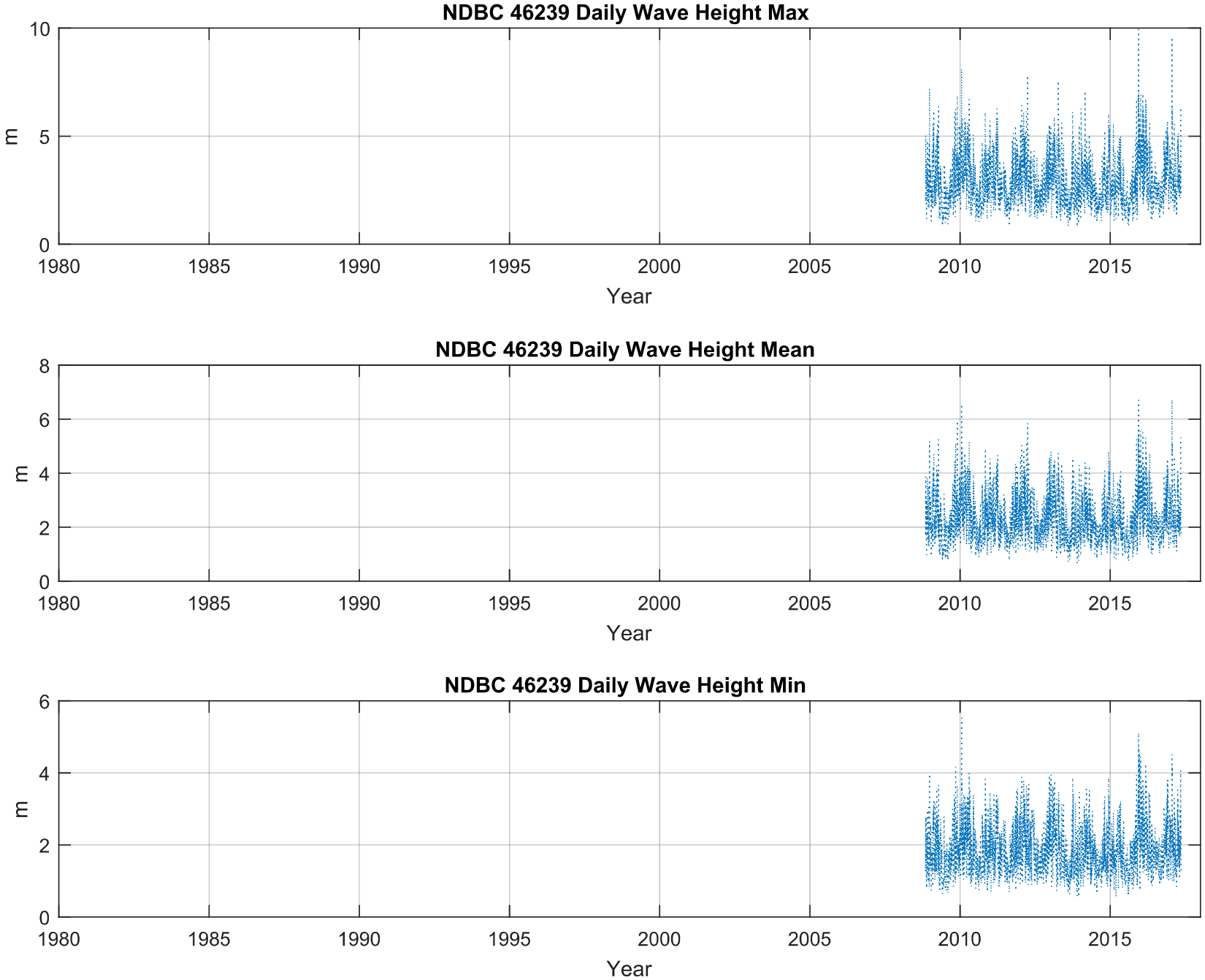
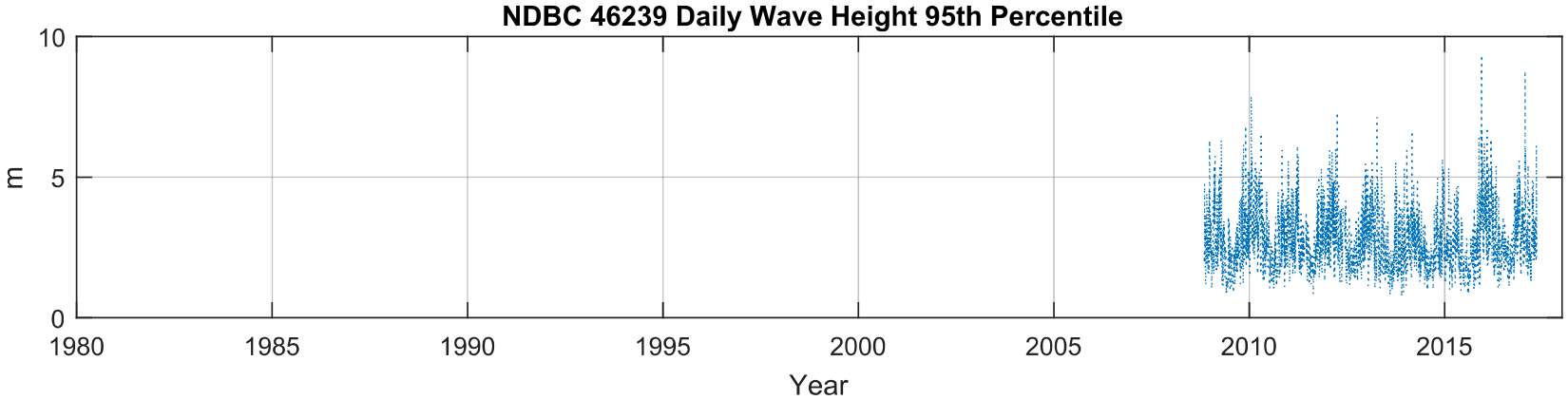
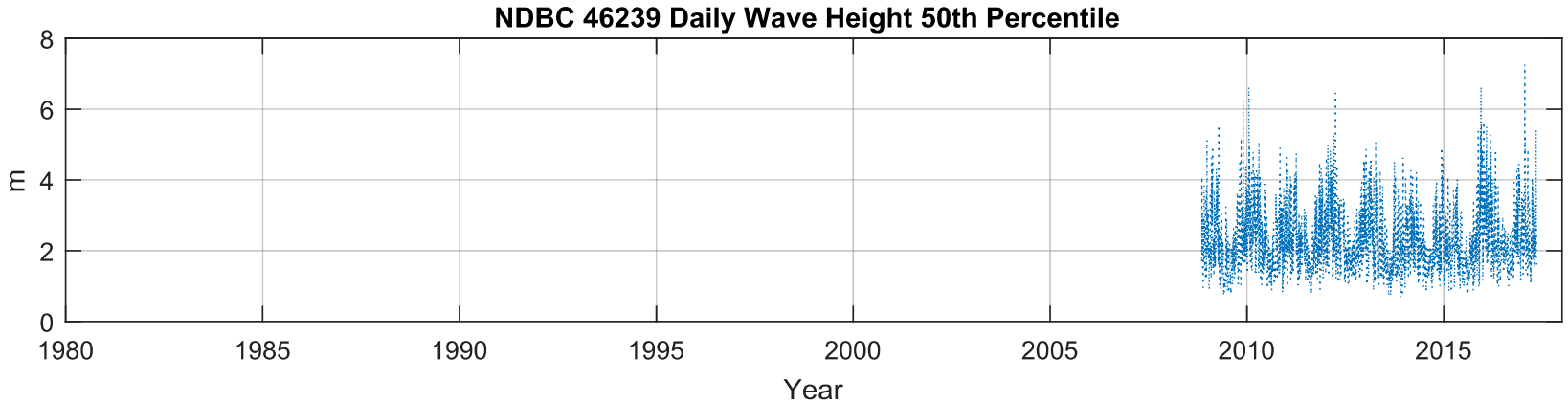


Figure A235. Daily Wave Height, Max, Mean, Min,NDBC 46239





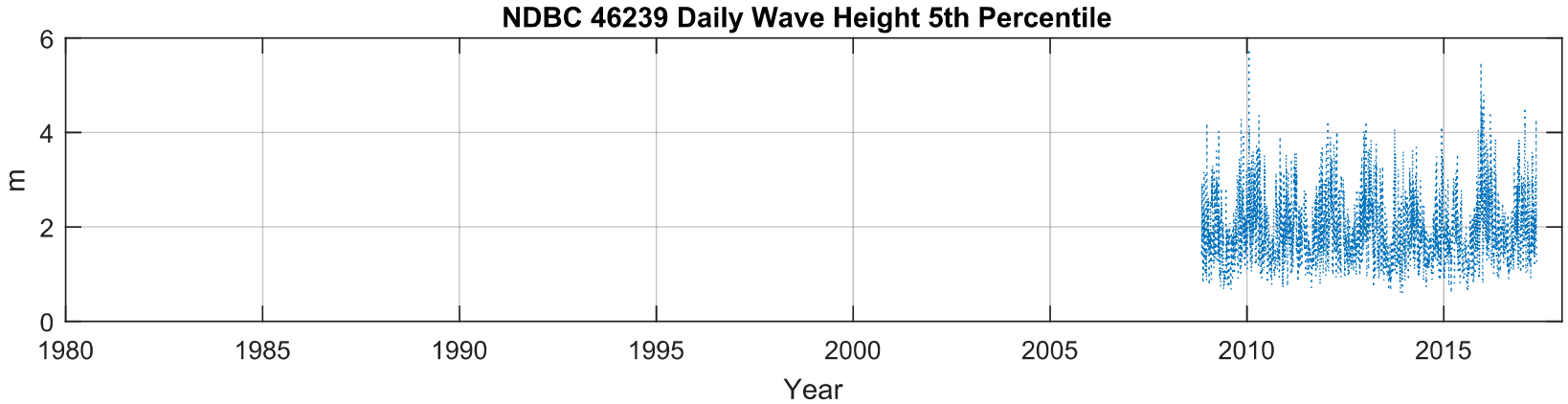


Figure A236. Daily Wave Height, Percentiles,NDBC 46239

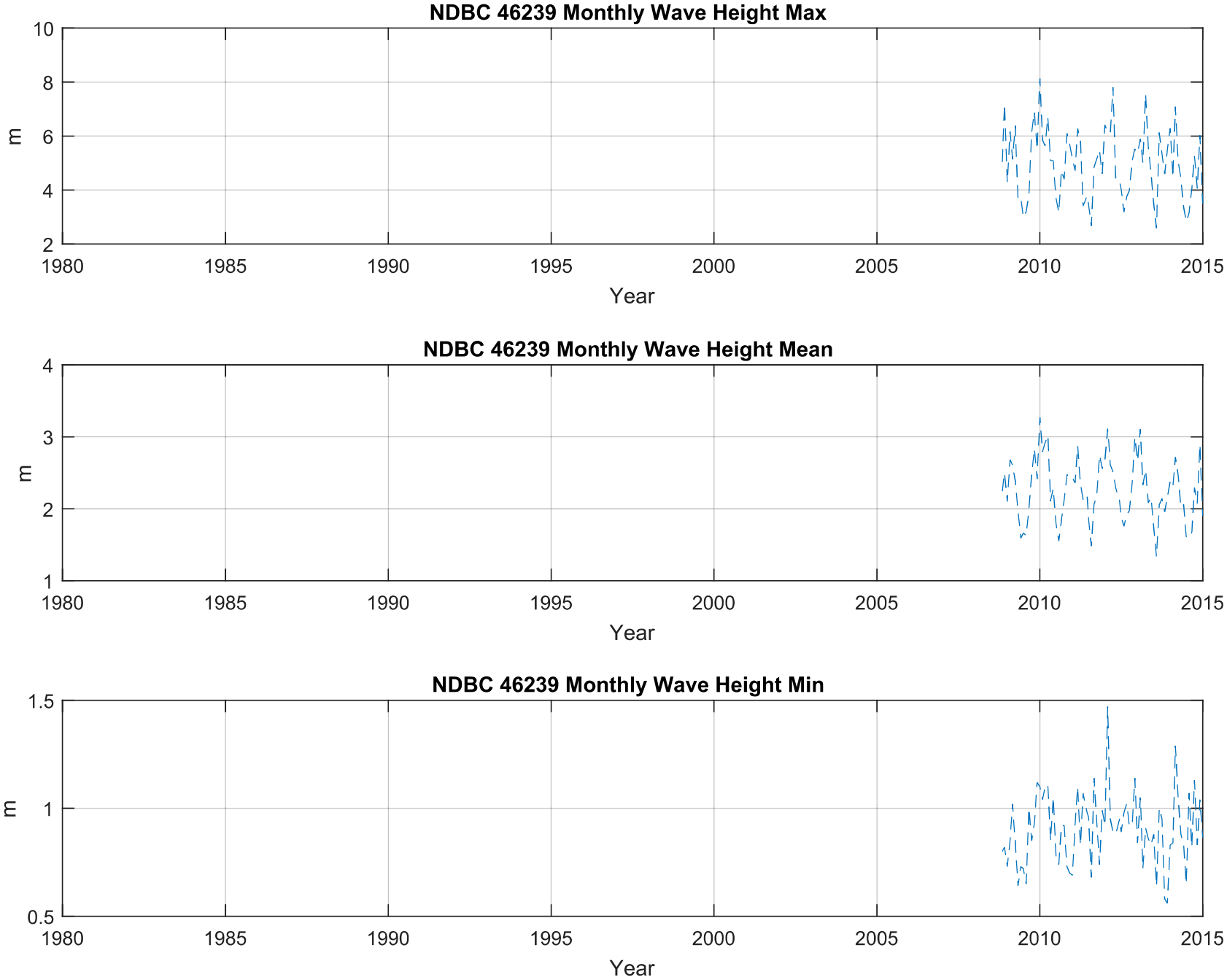


Figure A237. Monthly Wave Height, Max, Mean, Min,NDBC 46239

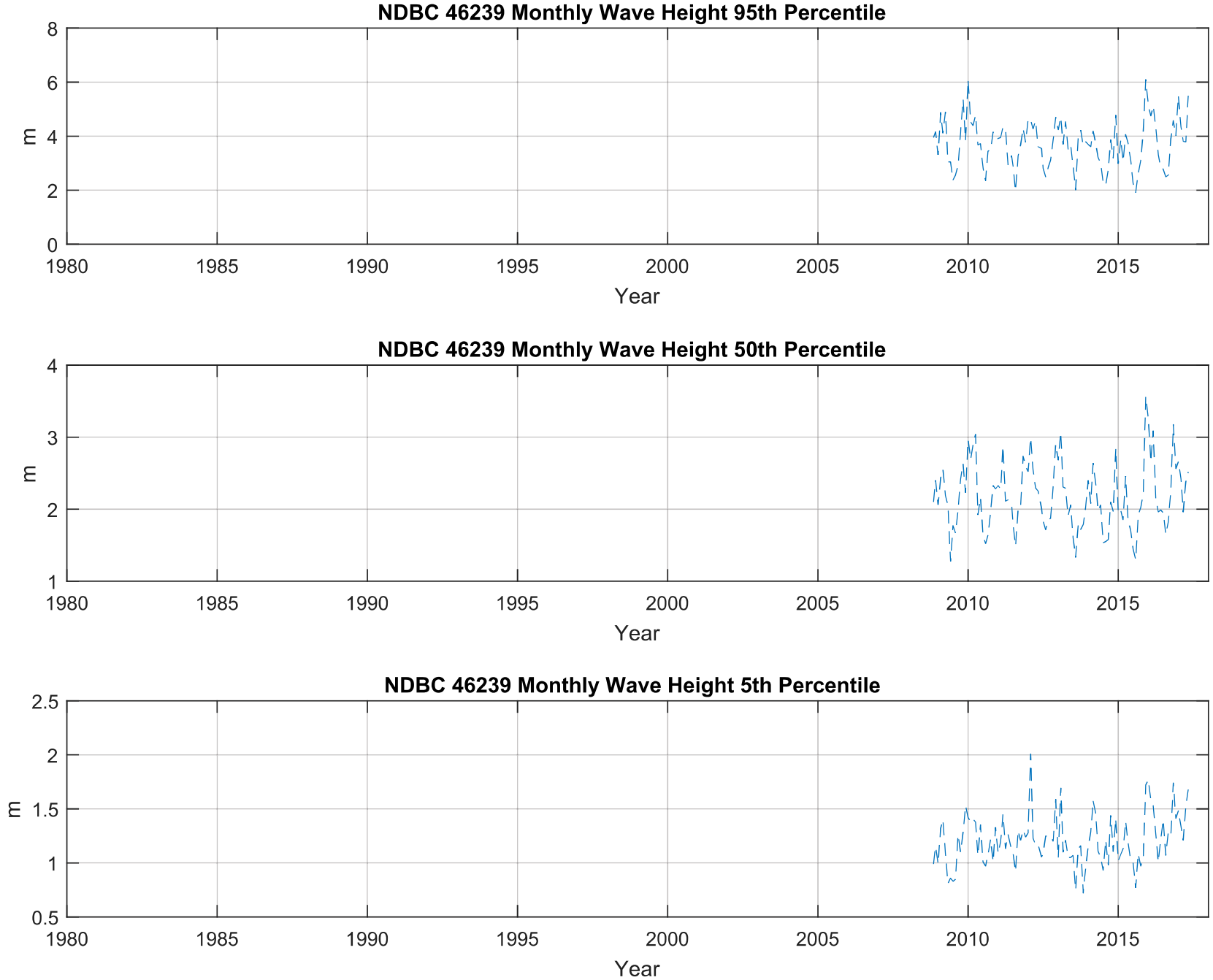


Figure A238. Monthly Wave Height, Percentiles,NDBC 46239

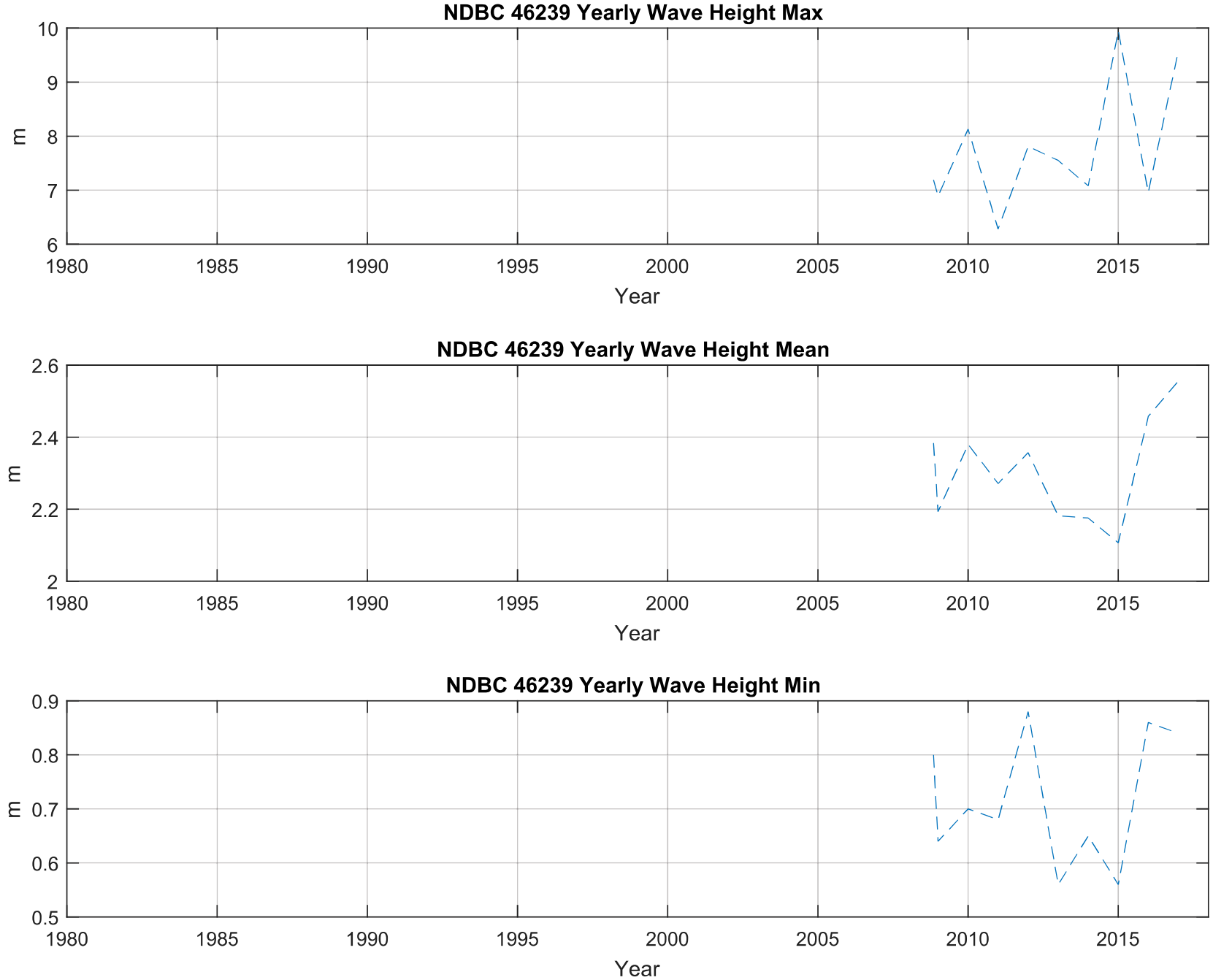
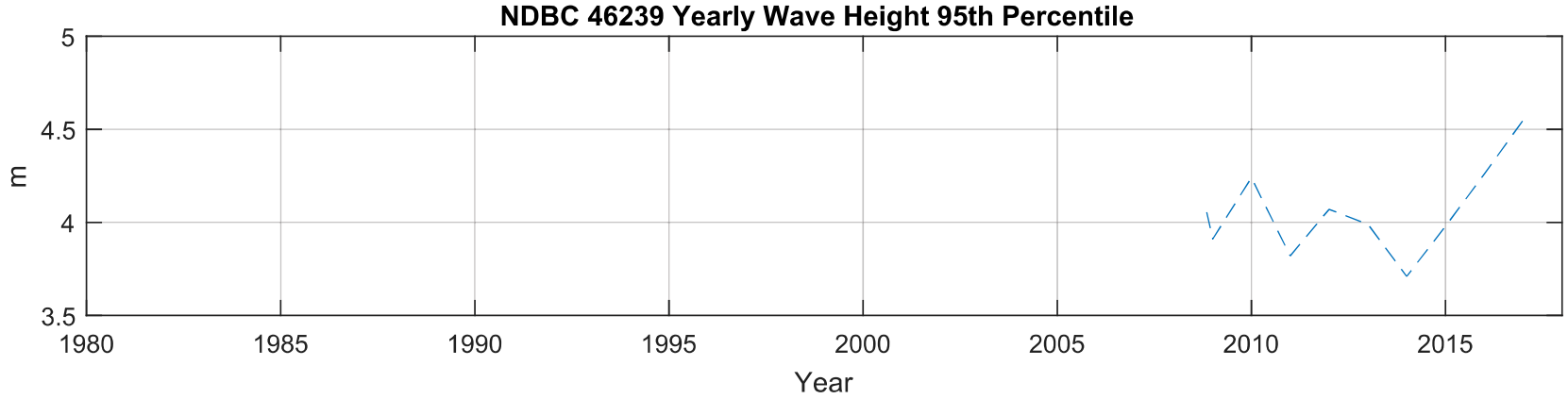
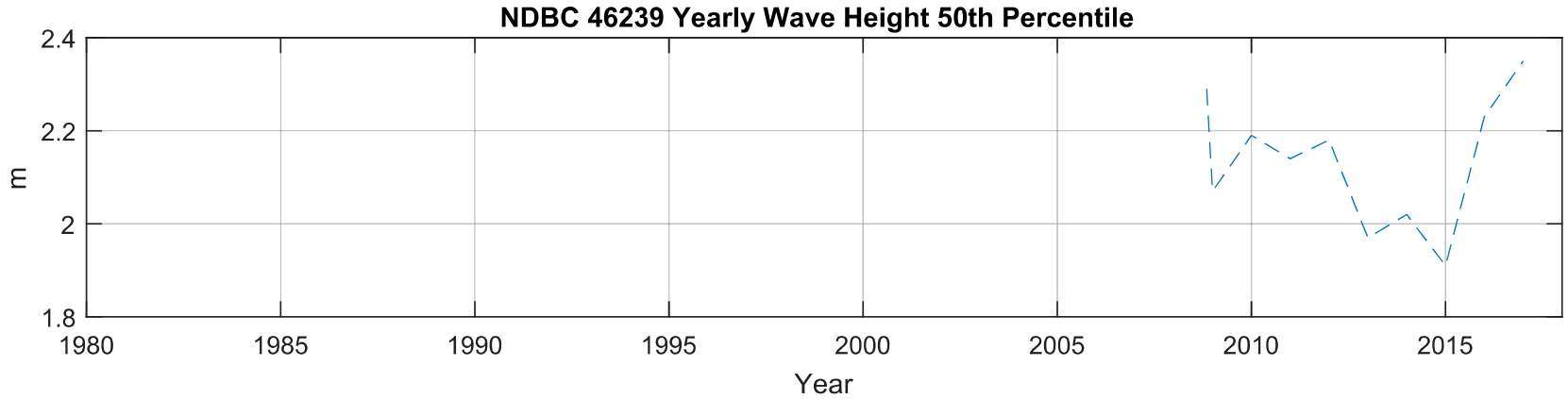


Figure A239. Yearly Wave Height, Max, Mean, Min,NDBC 46239





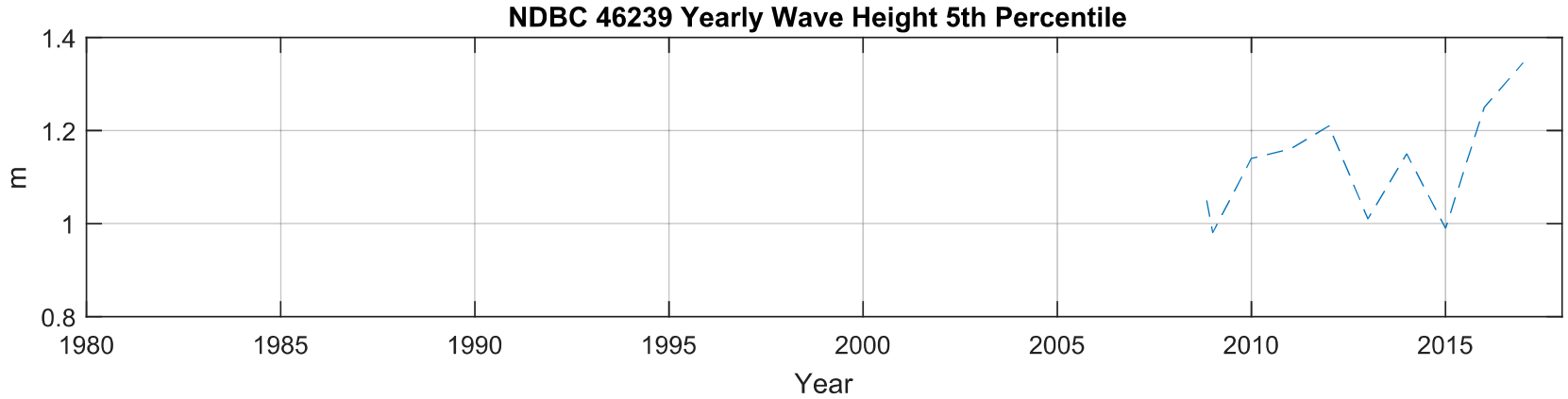


Figure A240. Yearly Wave Height, Percentiles,NDBC 46239

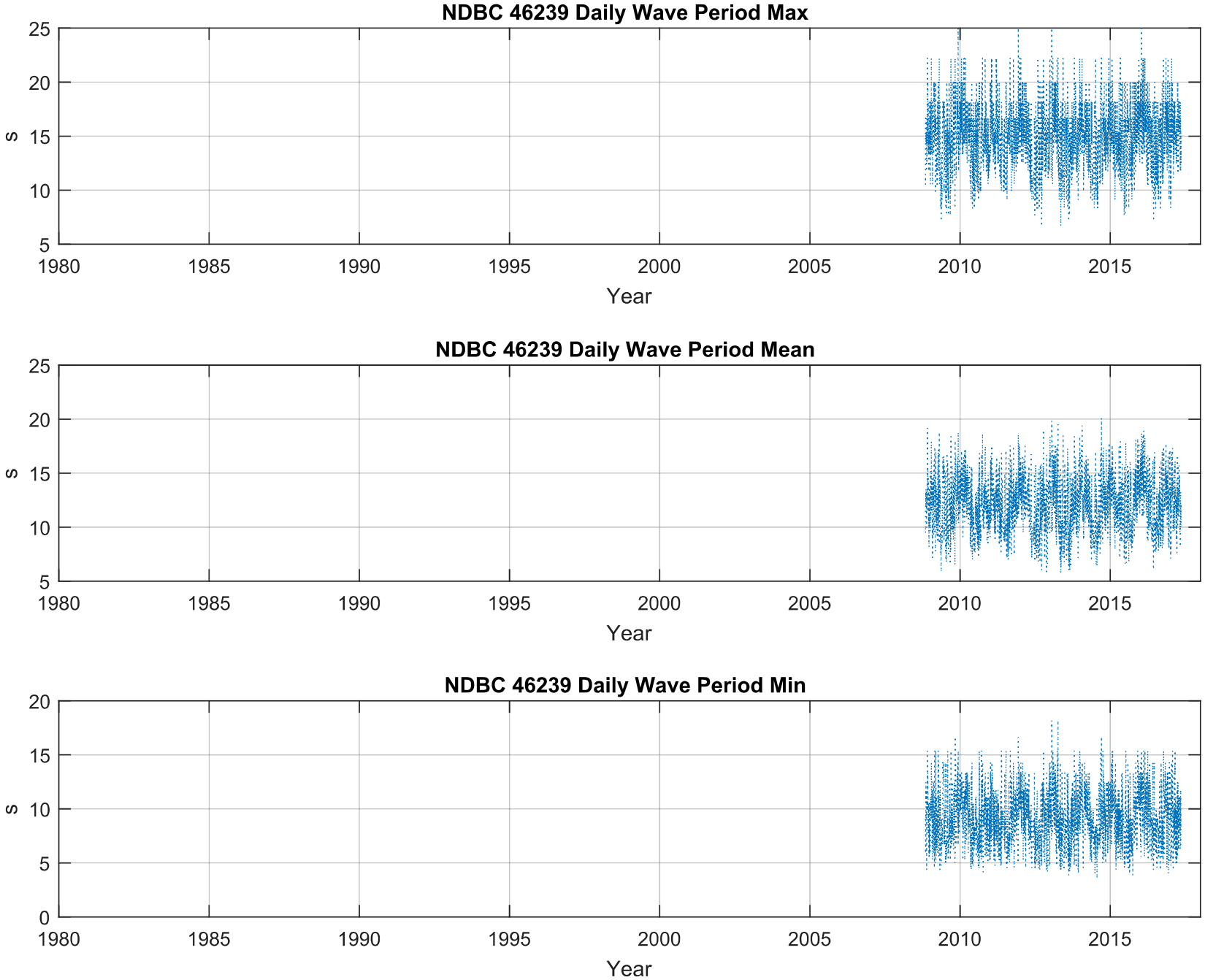
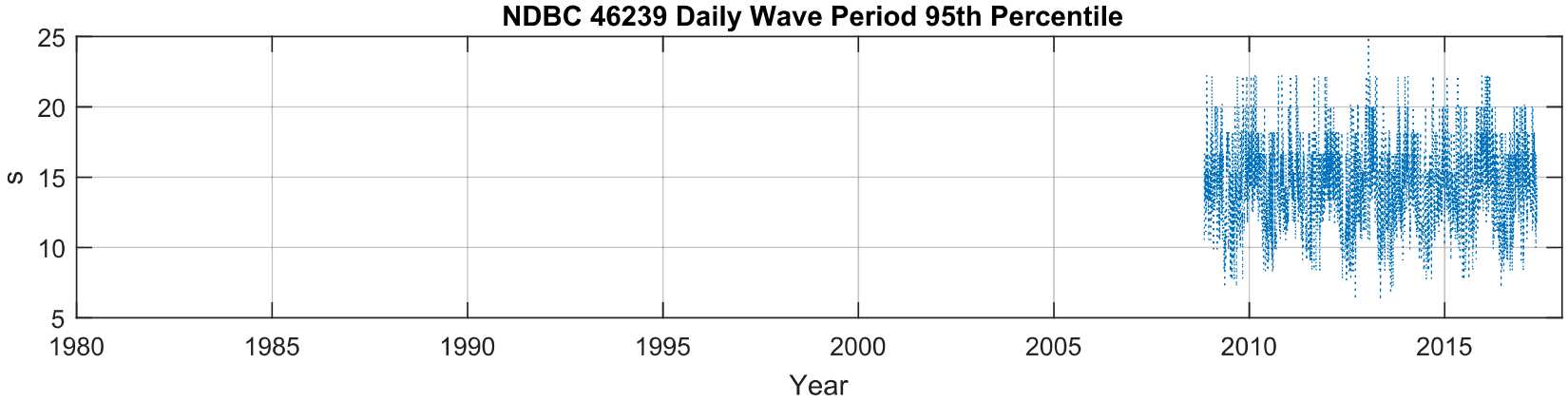
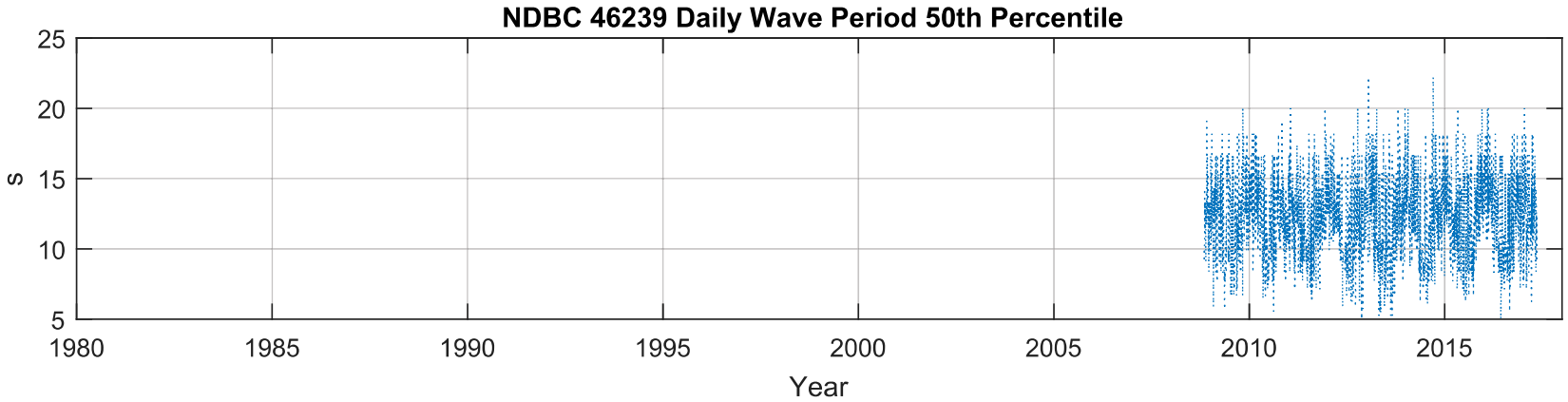


Figure A241. Daily Wave Period, Max, Mean, Min,NDBC 46239





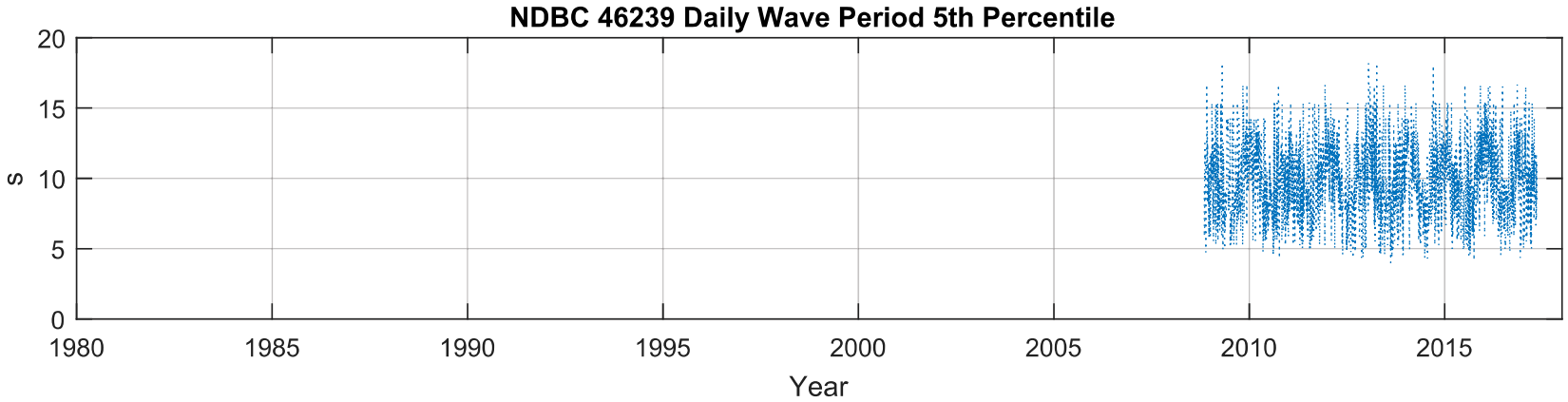
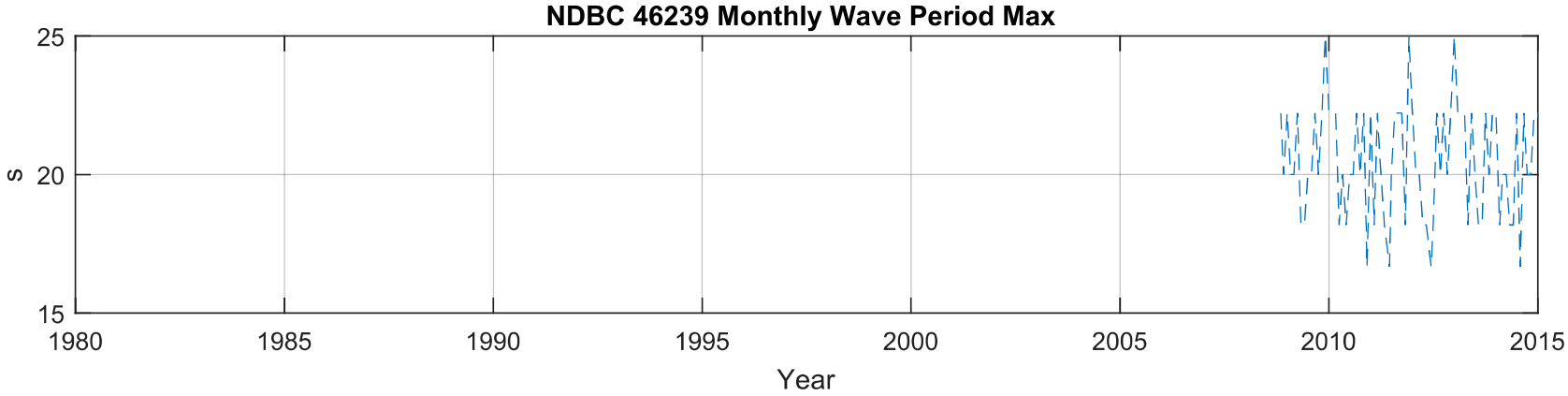
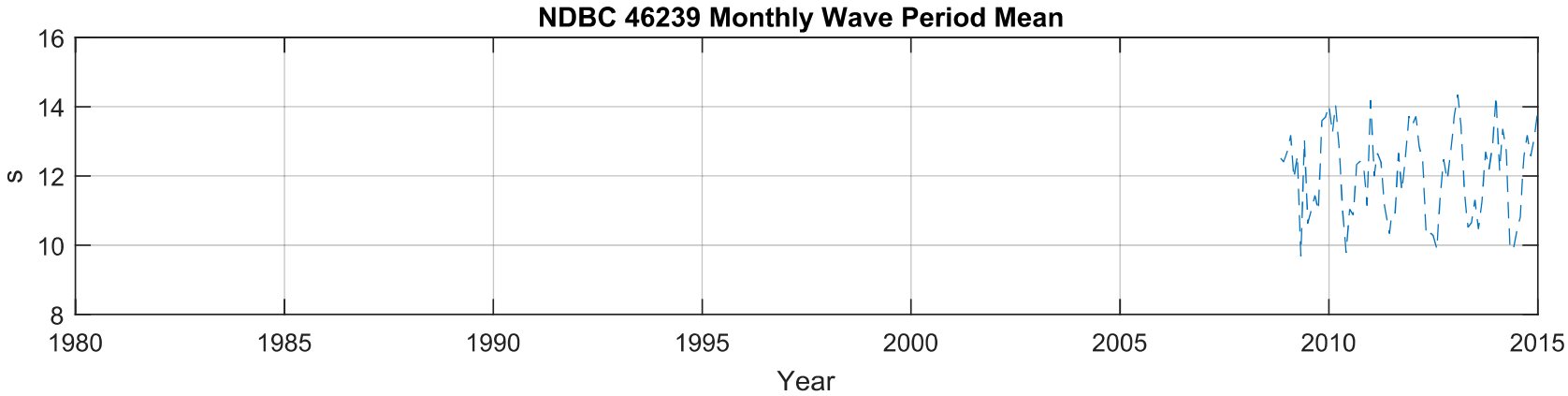


Figure A242. Daily Wave Period, Percentiles,NDBC 46239





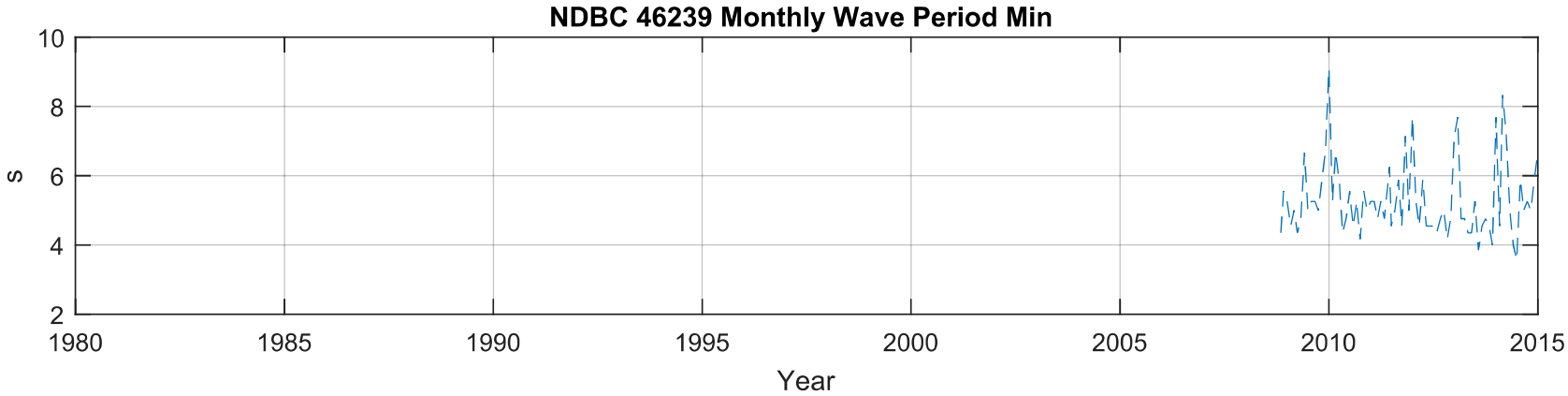
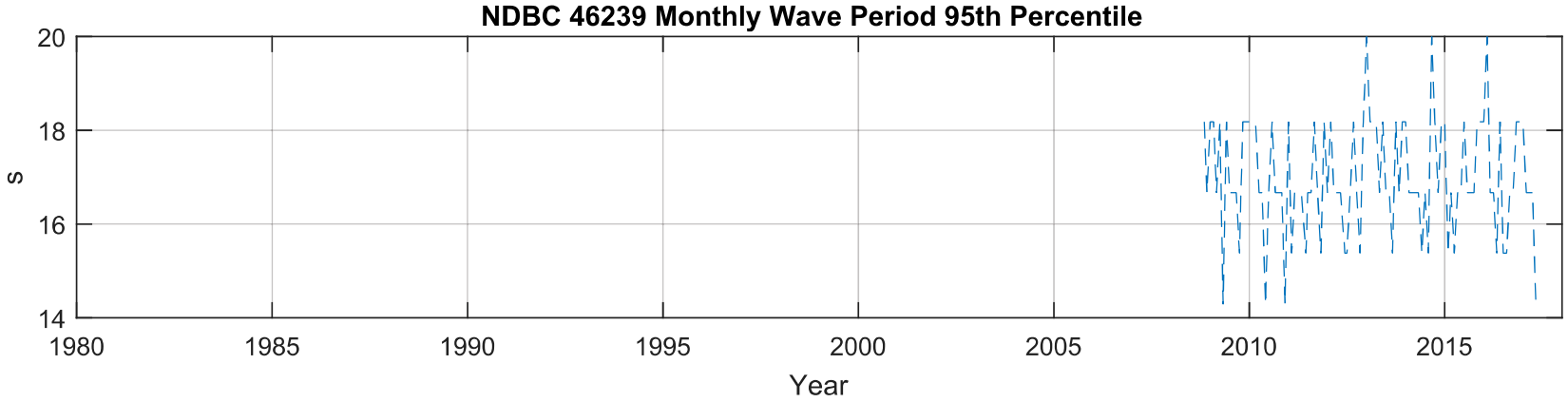
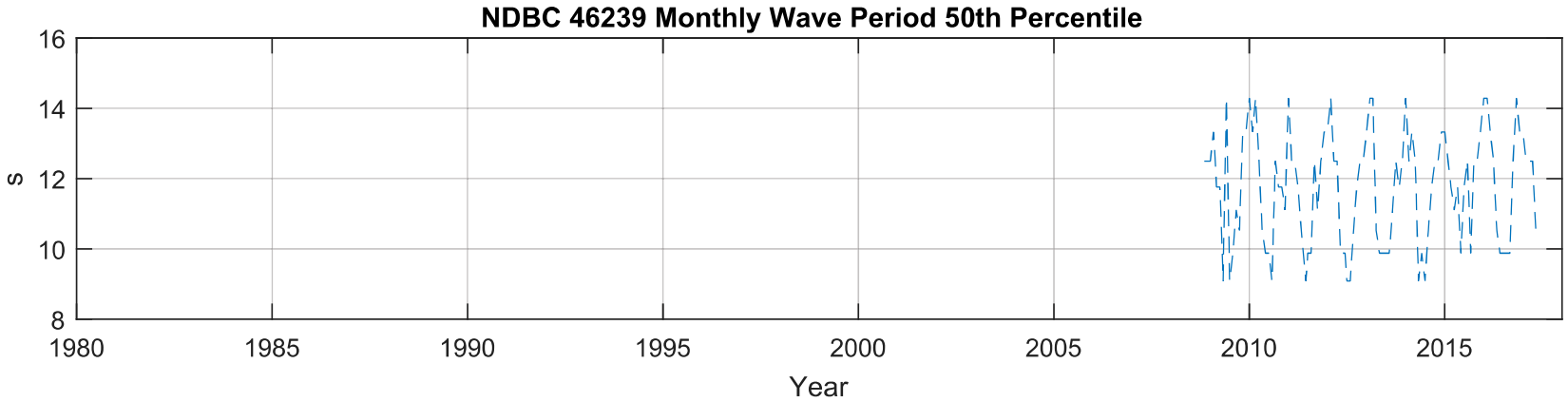


Figure A243. Monthly Wave Period, Max, Mean, Min,NDBC 46239





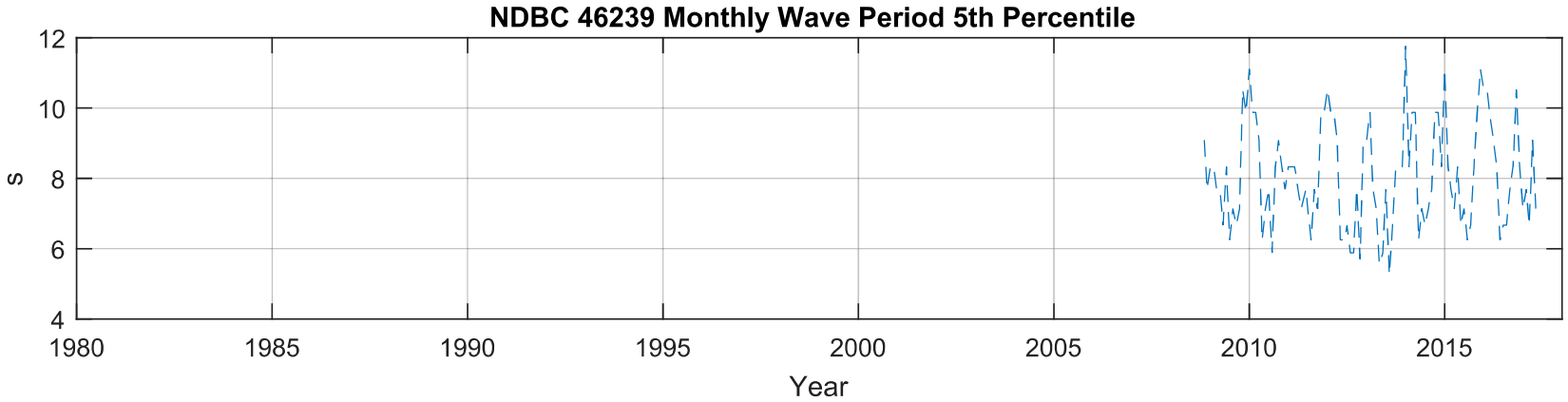


Figure A244. Monthly Wave Period, Percentiles,NDBC 46239

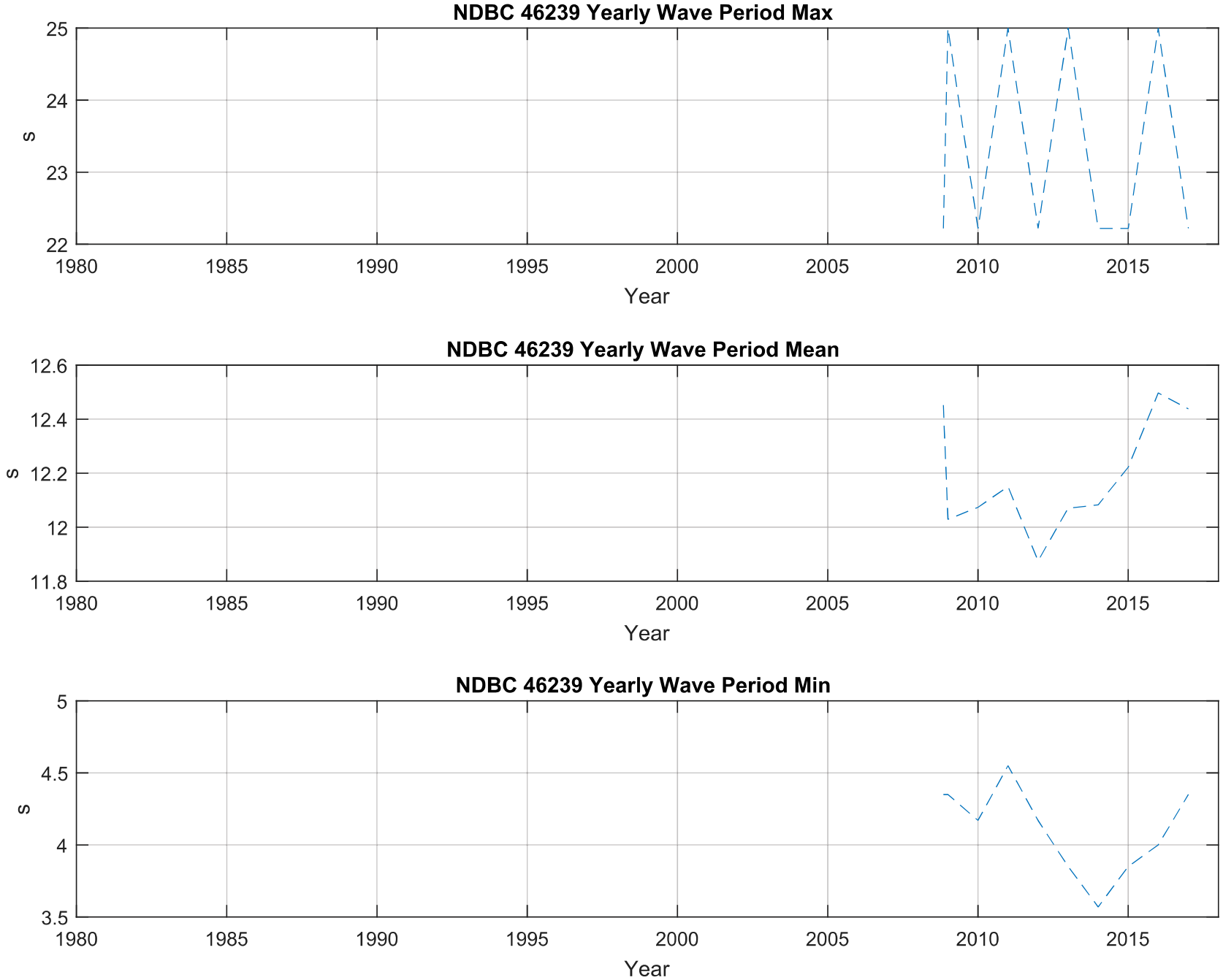
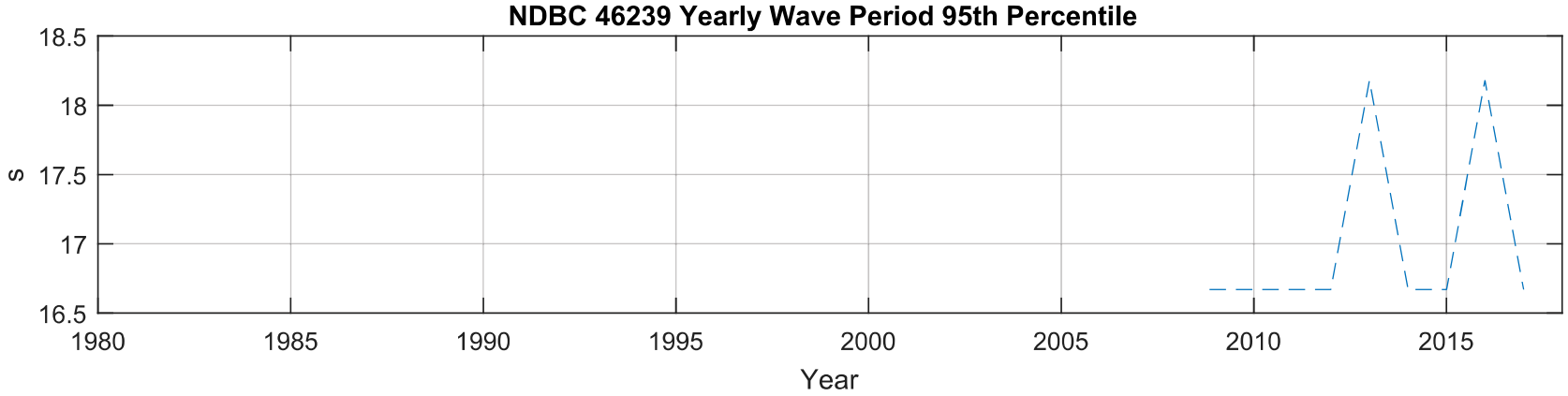
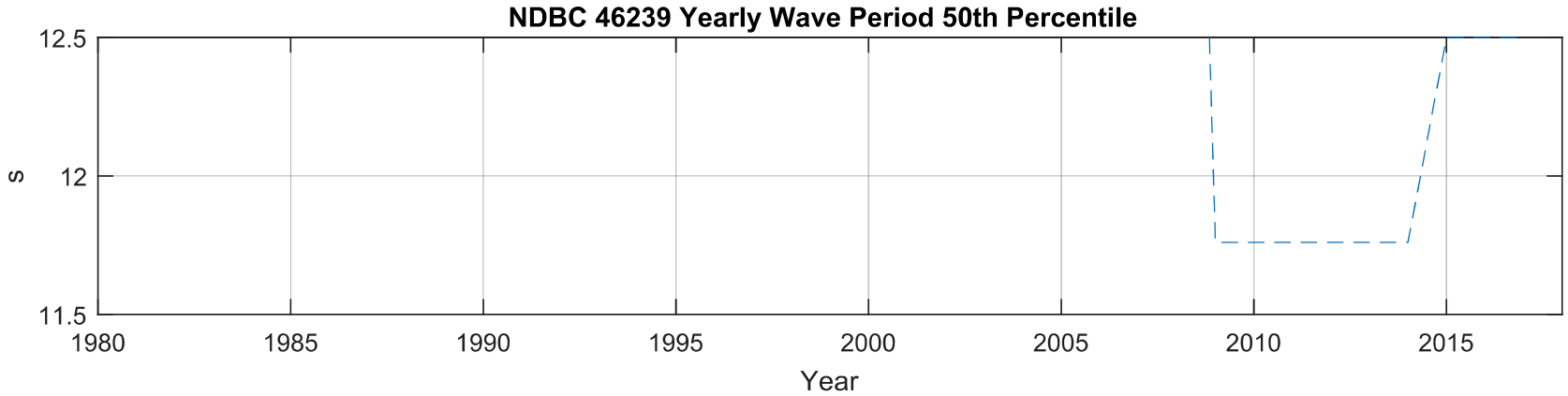


Figure A245. Yearly Wave Period, Max, Mean, Min,NDBC 46239





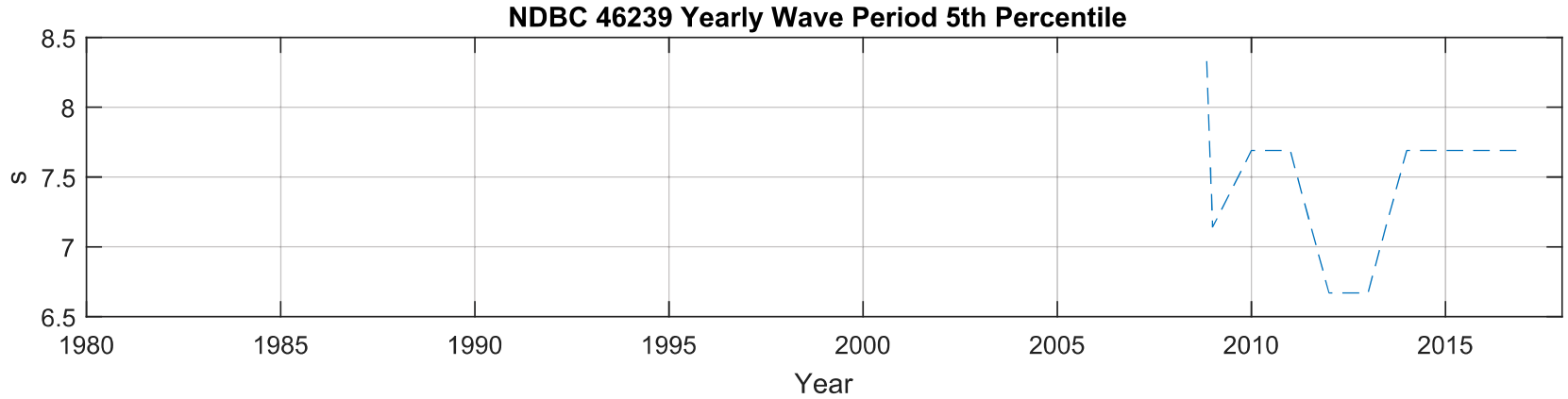


Figure A246. Yearly Wave Period, Percentiles,NDBC 46239

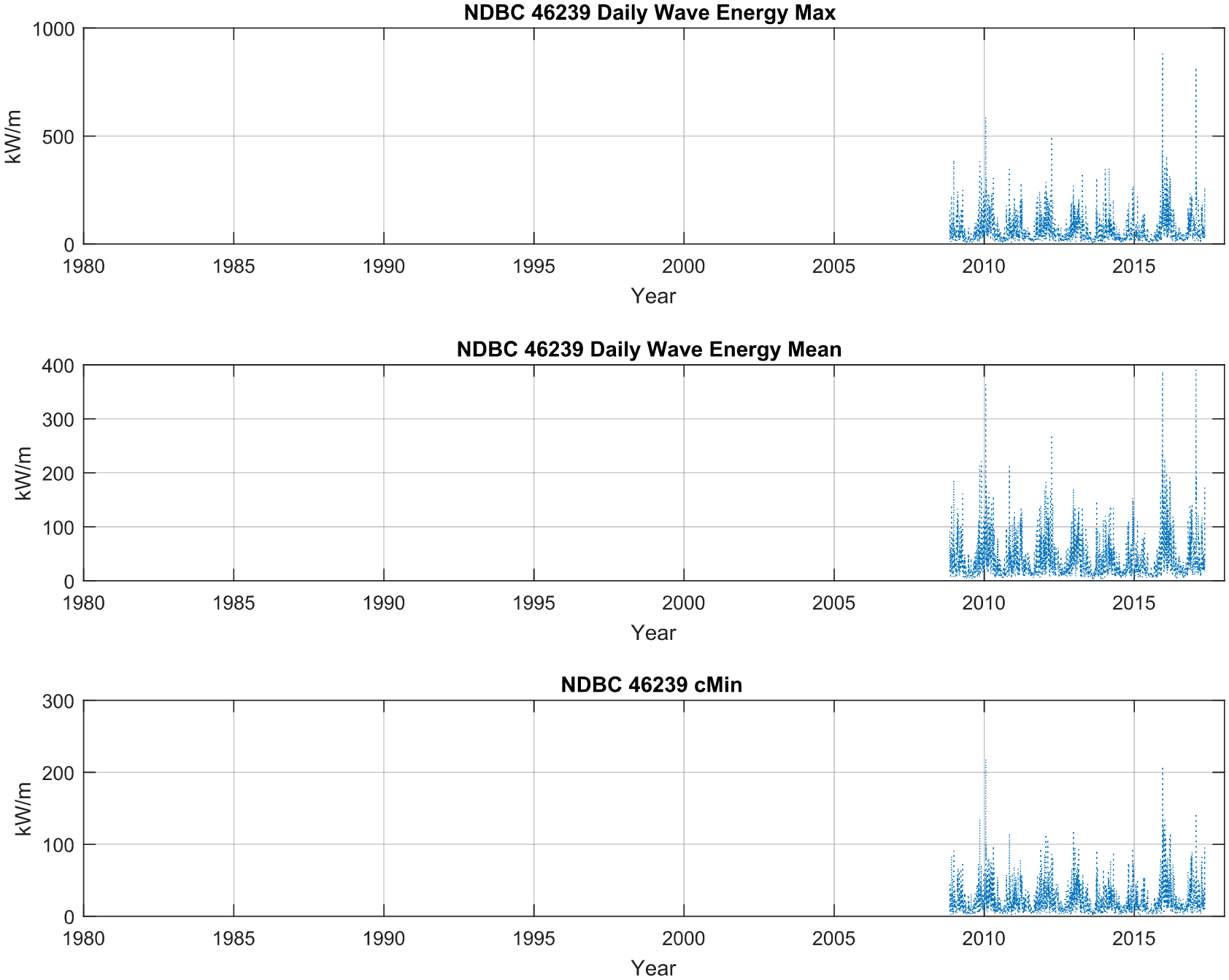


Figure A247. Daily Wave Energy, Max, Mean, Min,NDBC 46239

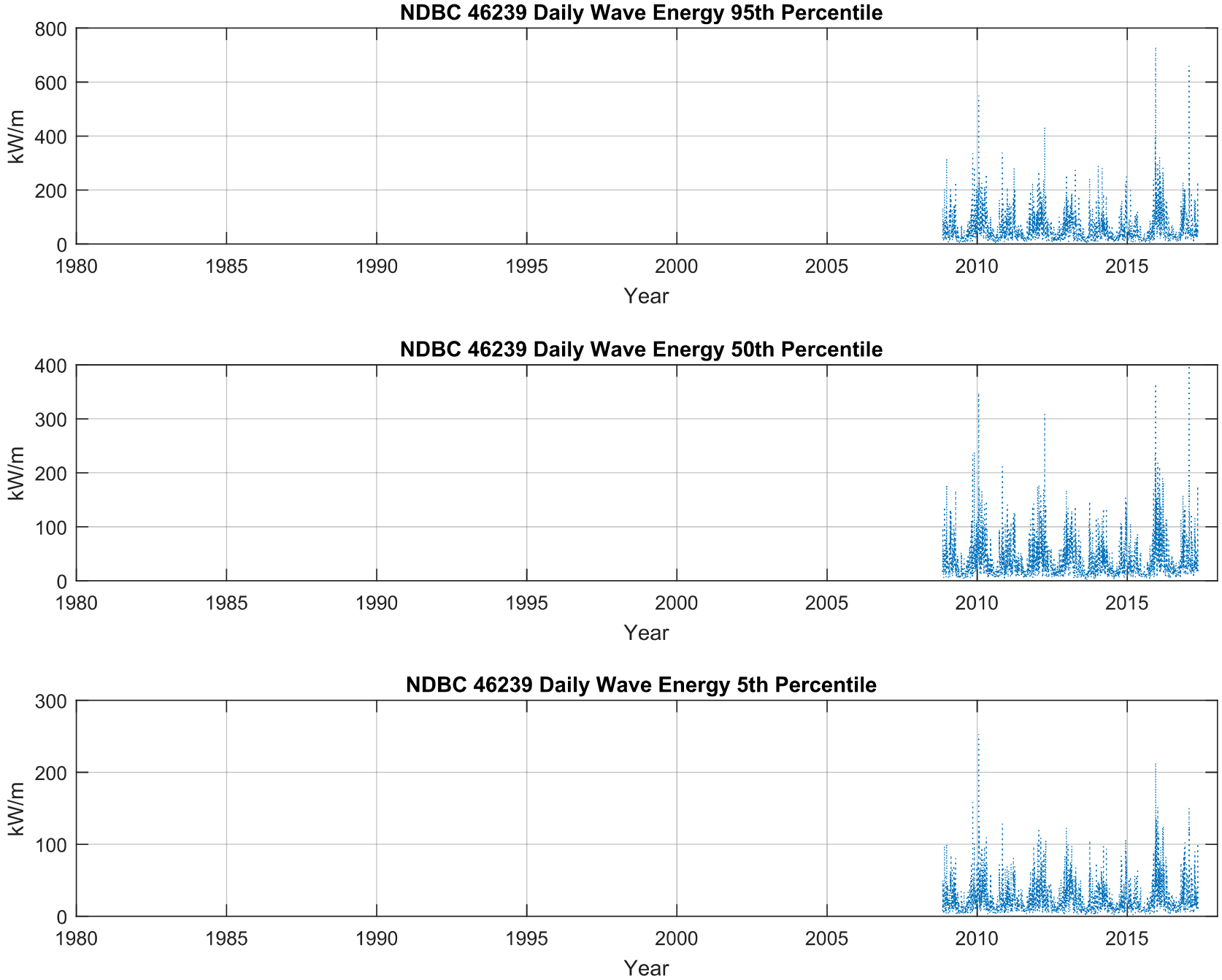


Figure A248. Daily Wave Energy, Percentiles,NDBC 46239

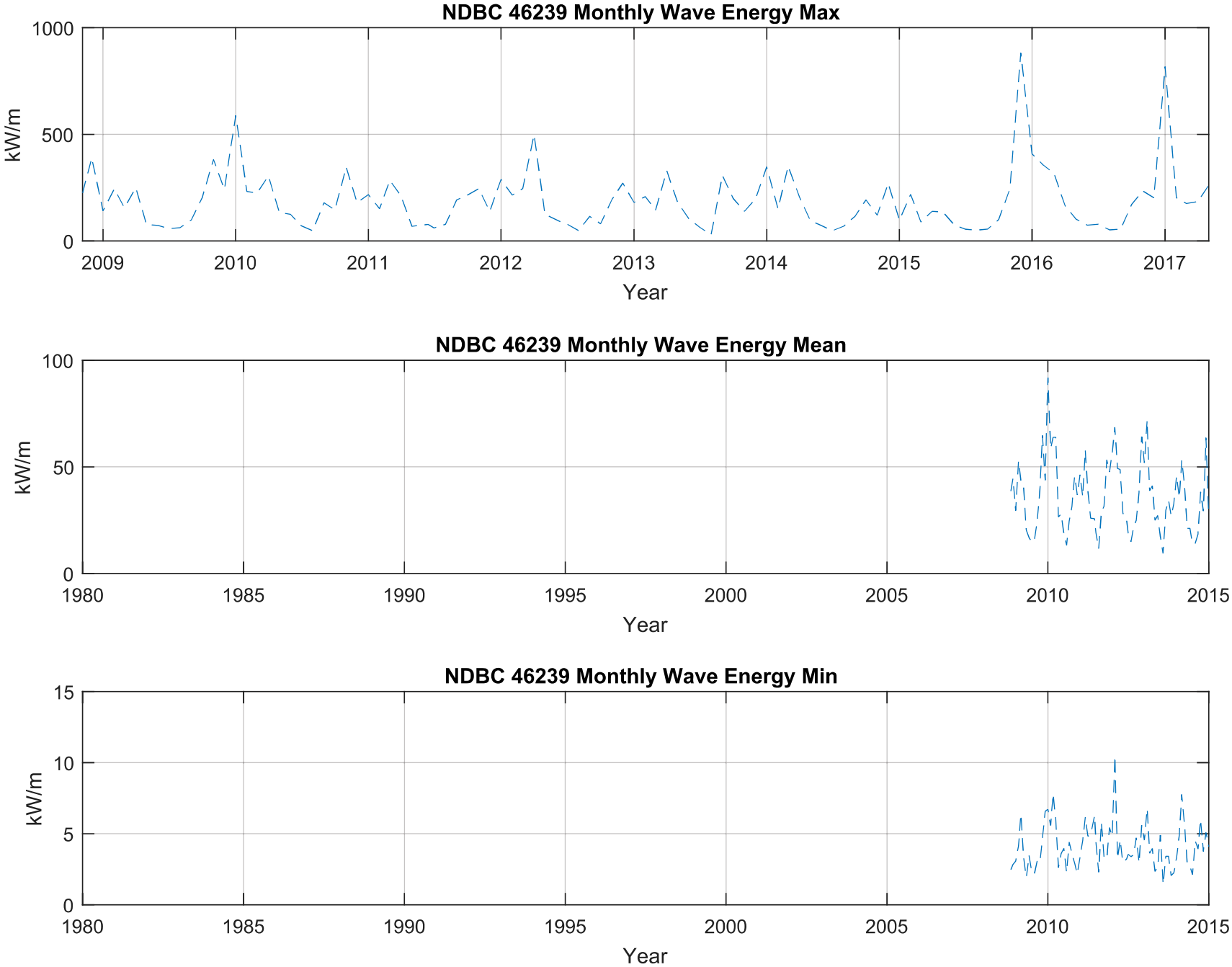
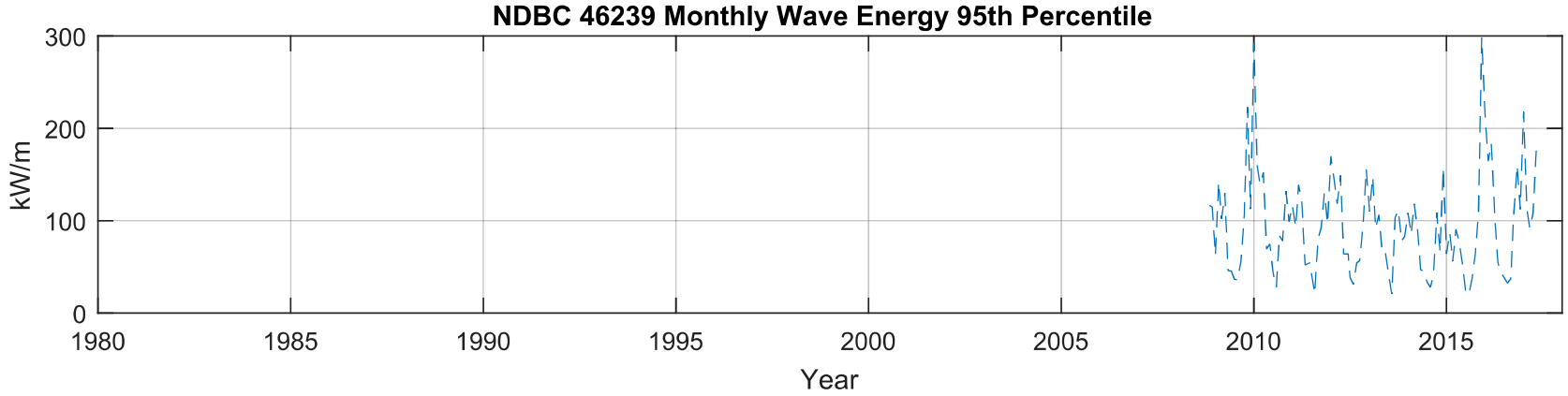
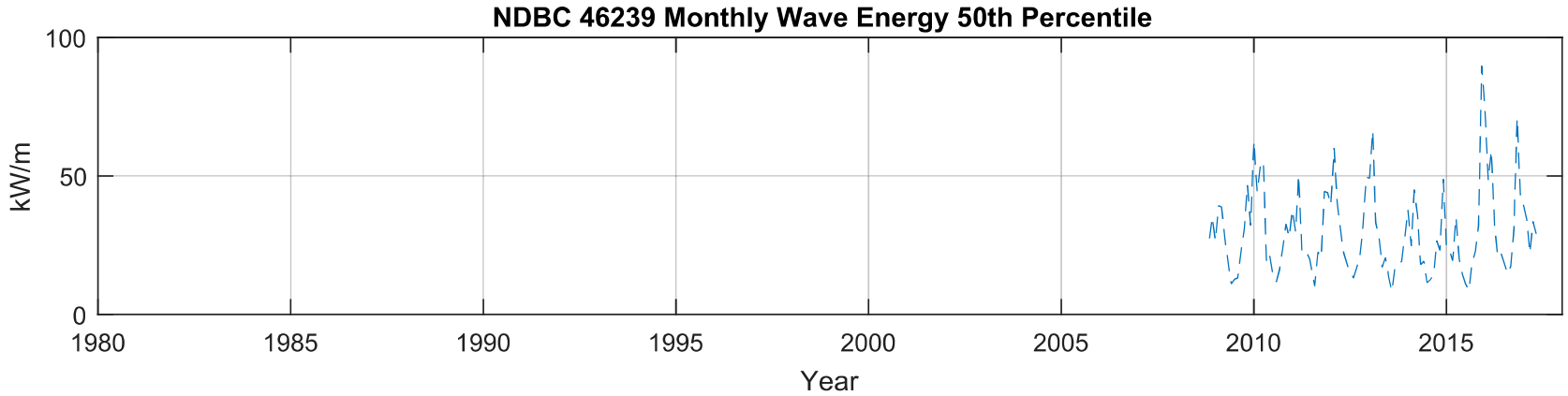


Figure A249. Monthly Wave Energy, Max, Mean, Min,NDBC 46239





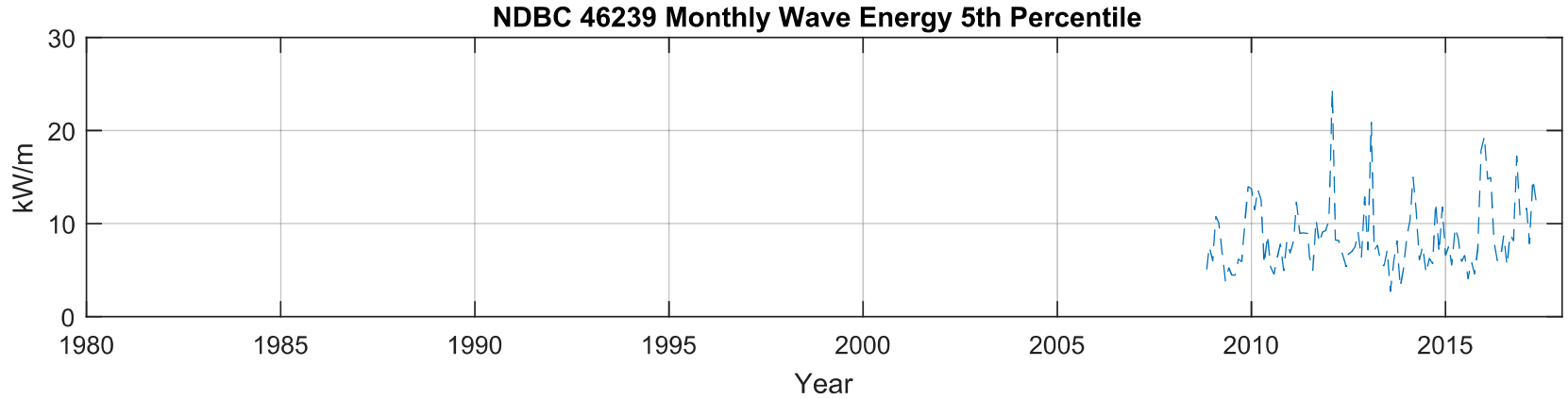
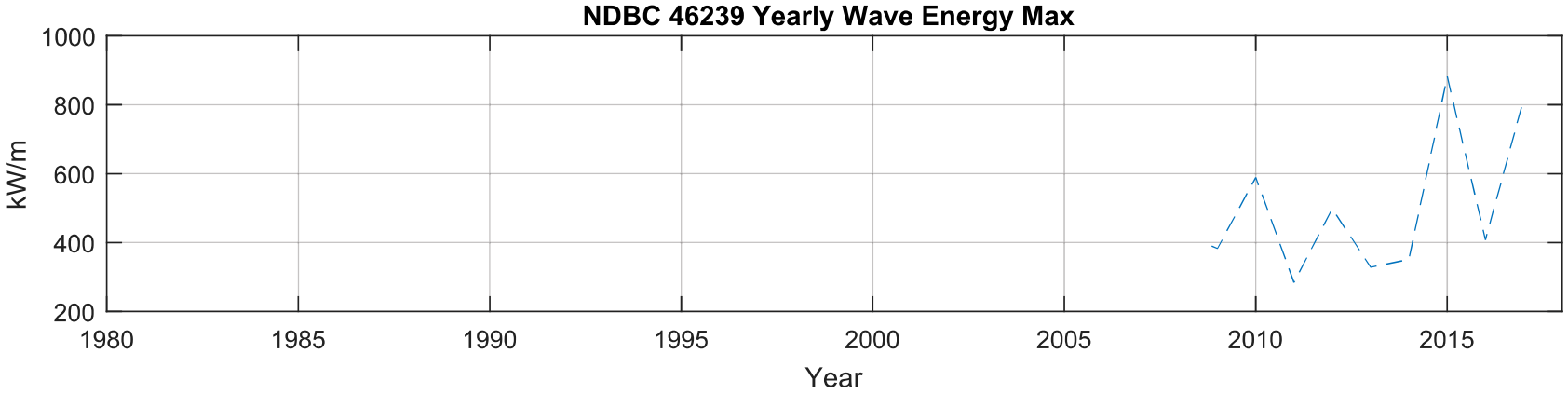
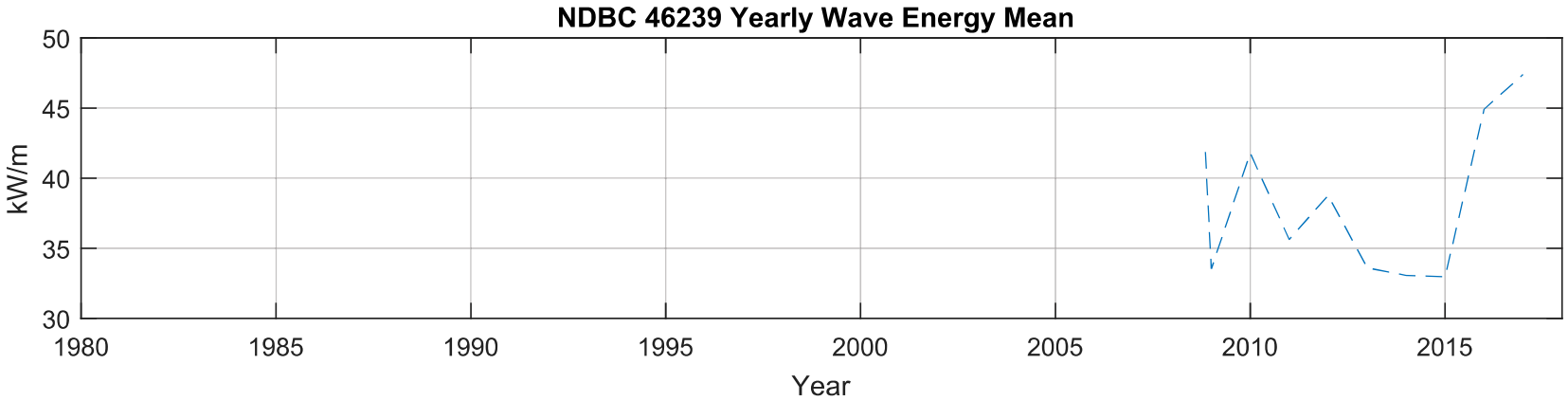


Figure A250. Monthly Wave Energy, Percentiles,NDBC 46239





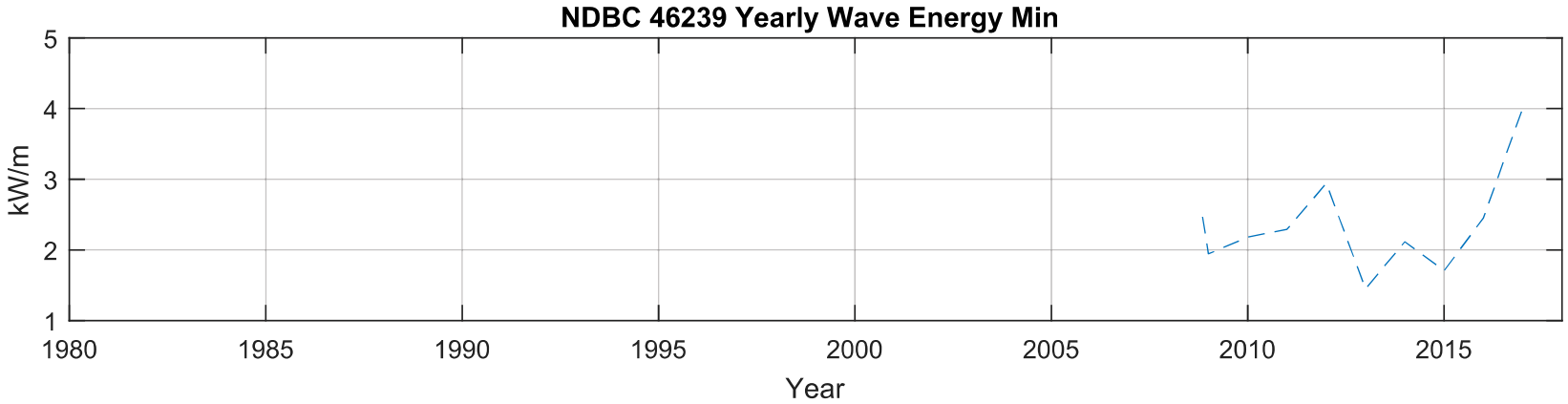
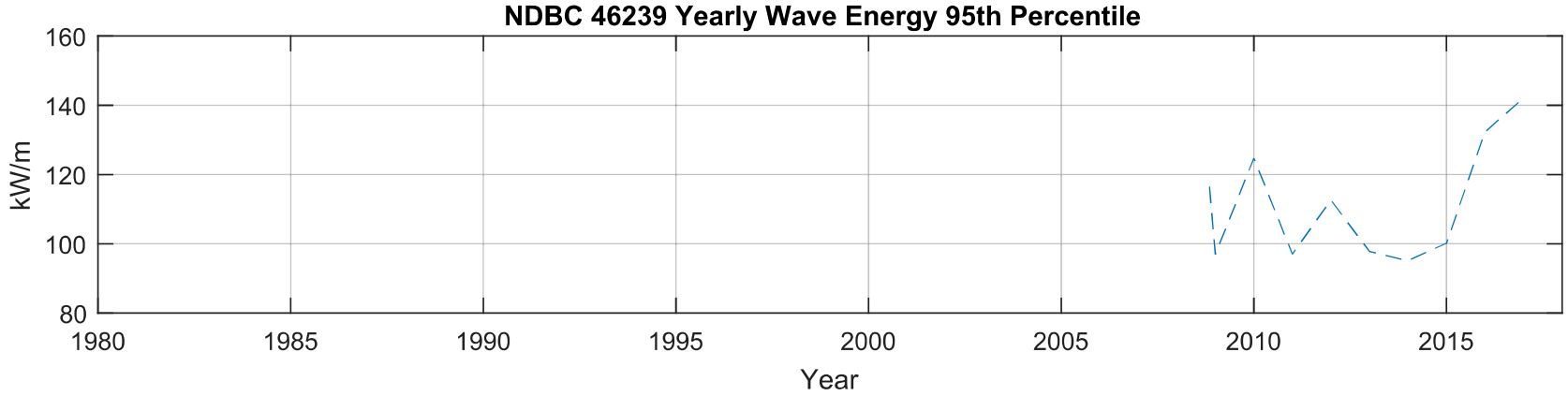
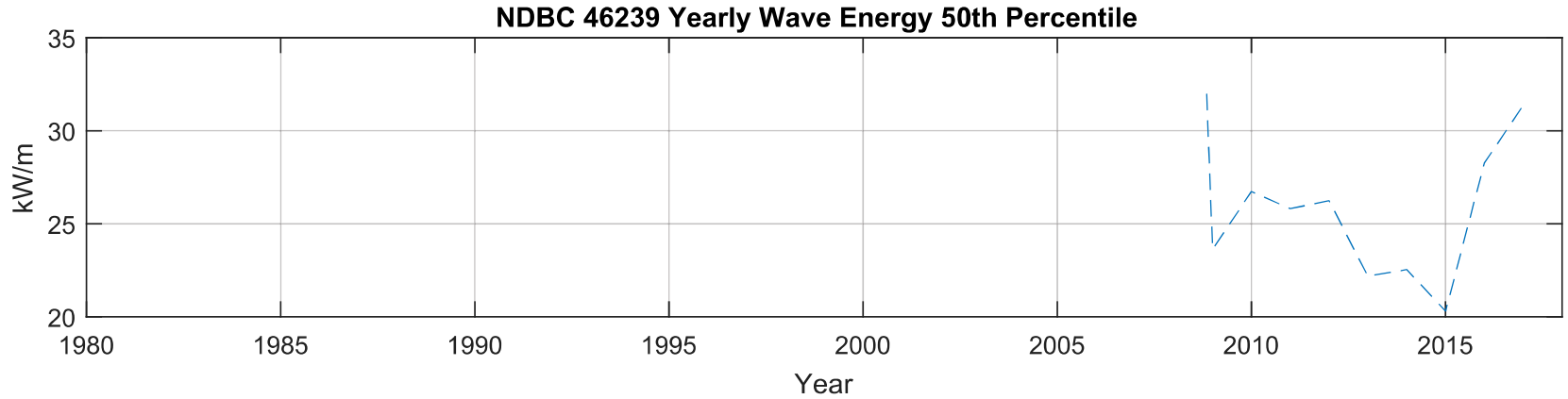


Figure A251. Yearly Wave Energy, Max, Mean, Min,NDBC 46239





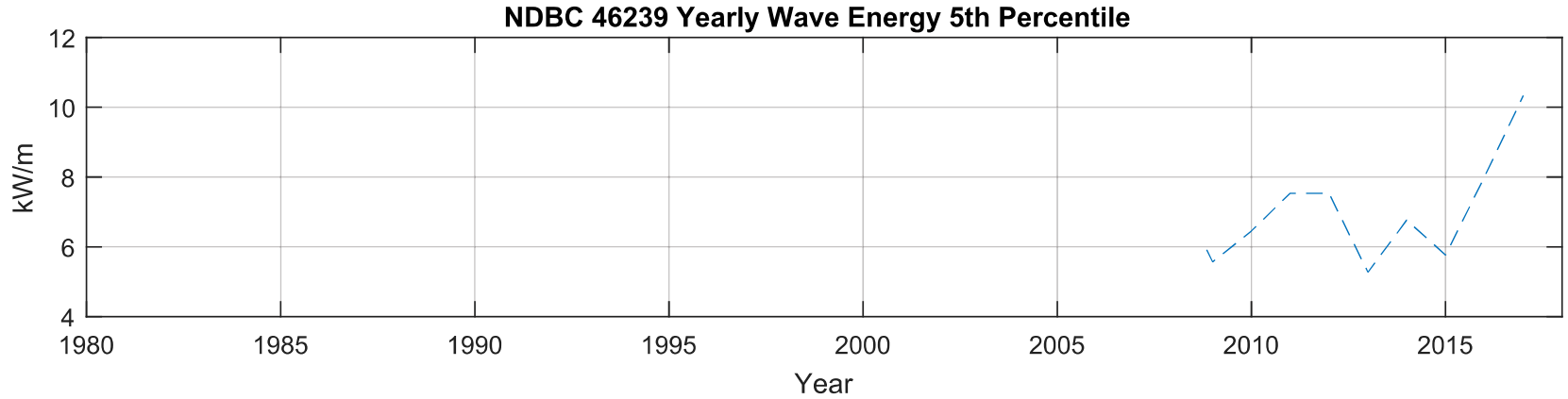


Figure A252. Yearly Wave Energy, Percentiles,NDBC 46239

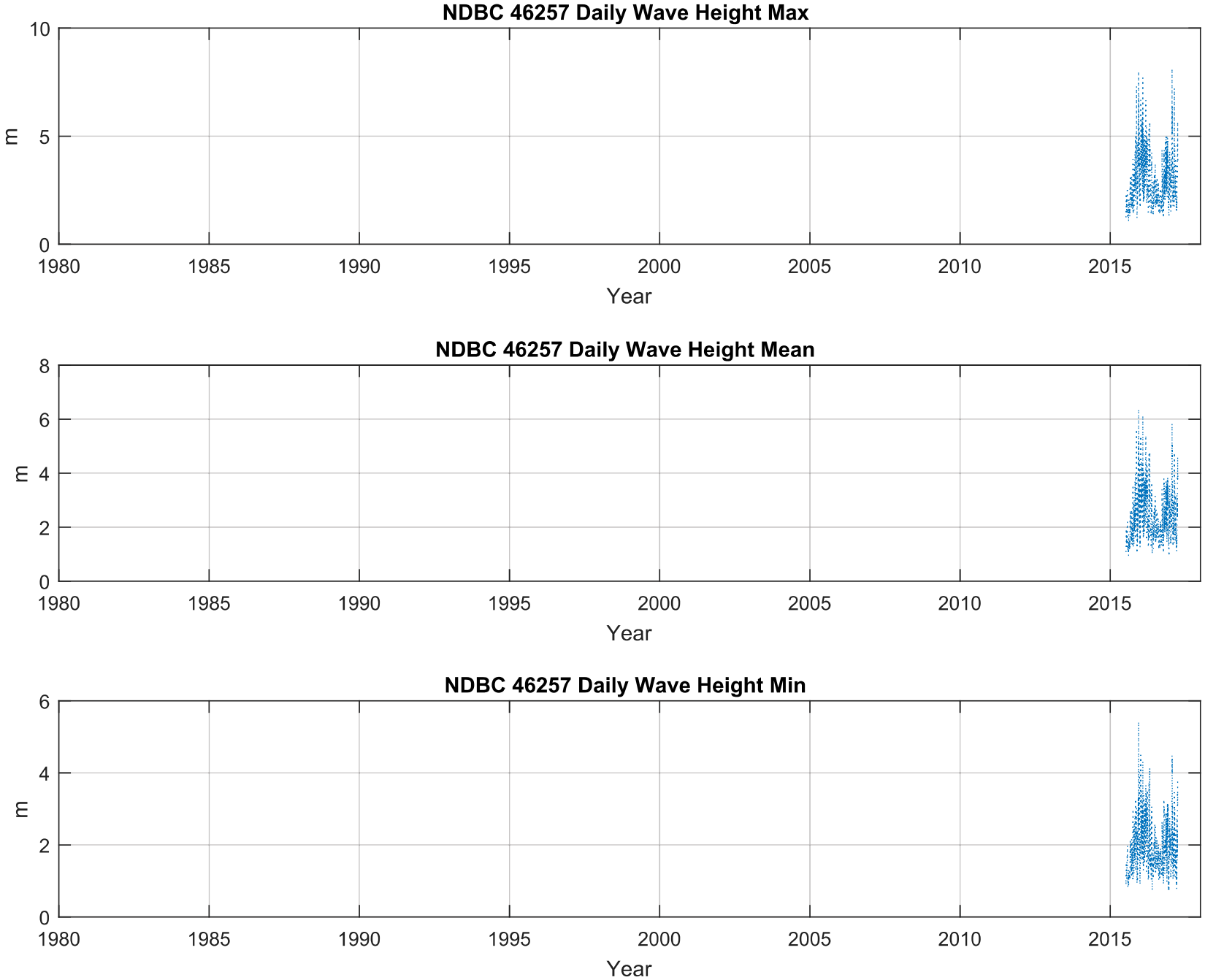


Figure A253. Daily Wave Height, Max, Mean, Min,NDBC 46257

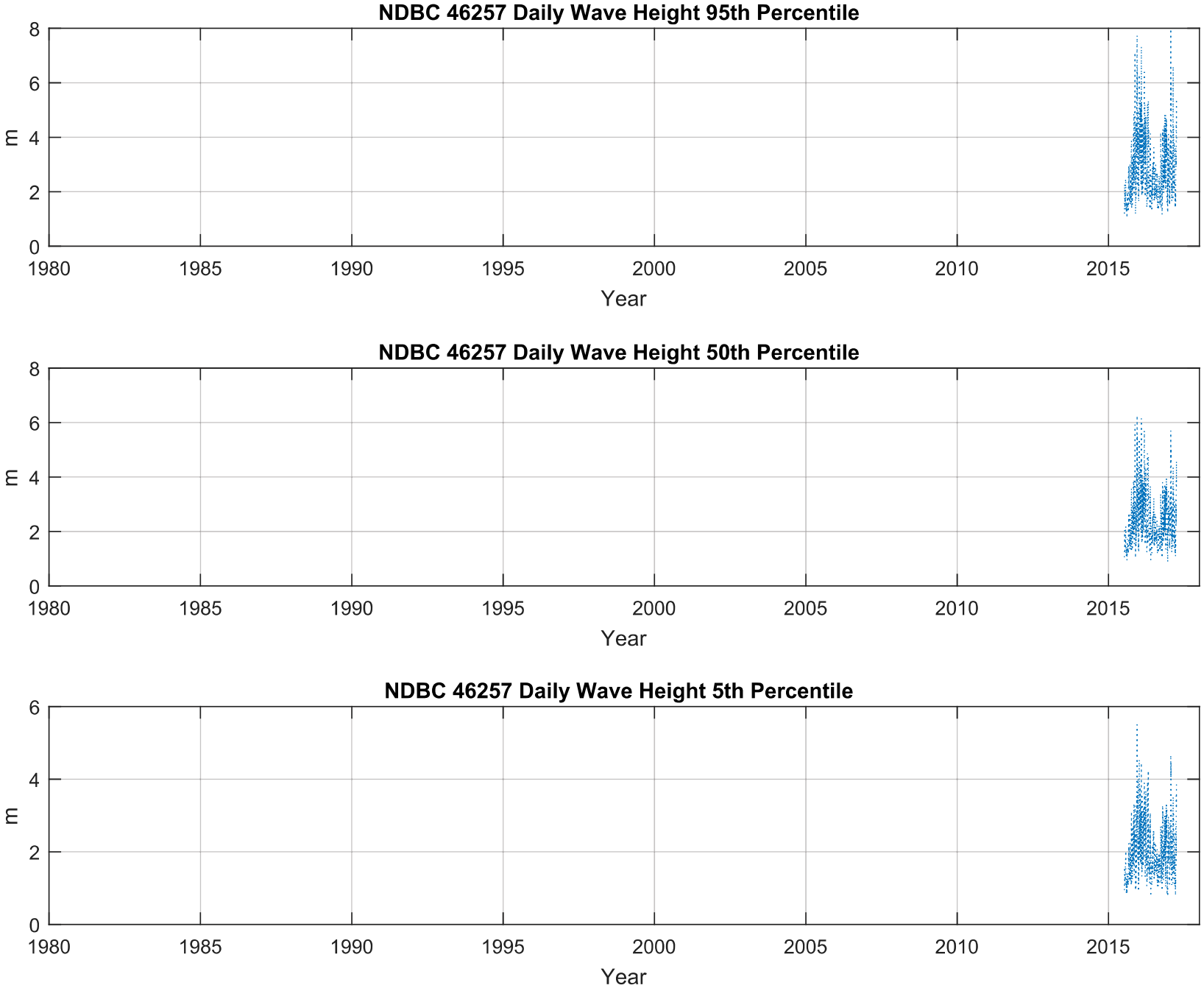


Figure A254. Daily Wave Height, Percentiles,NDBC 46257

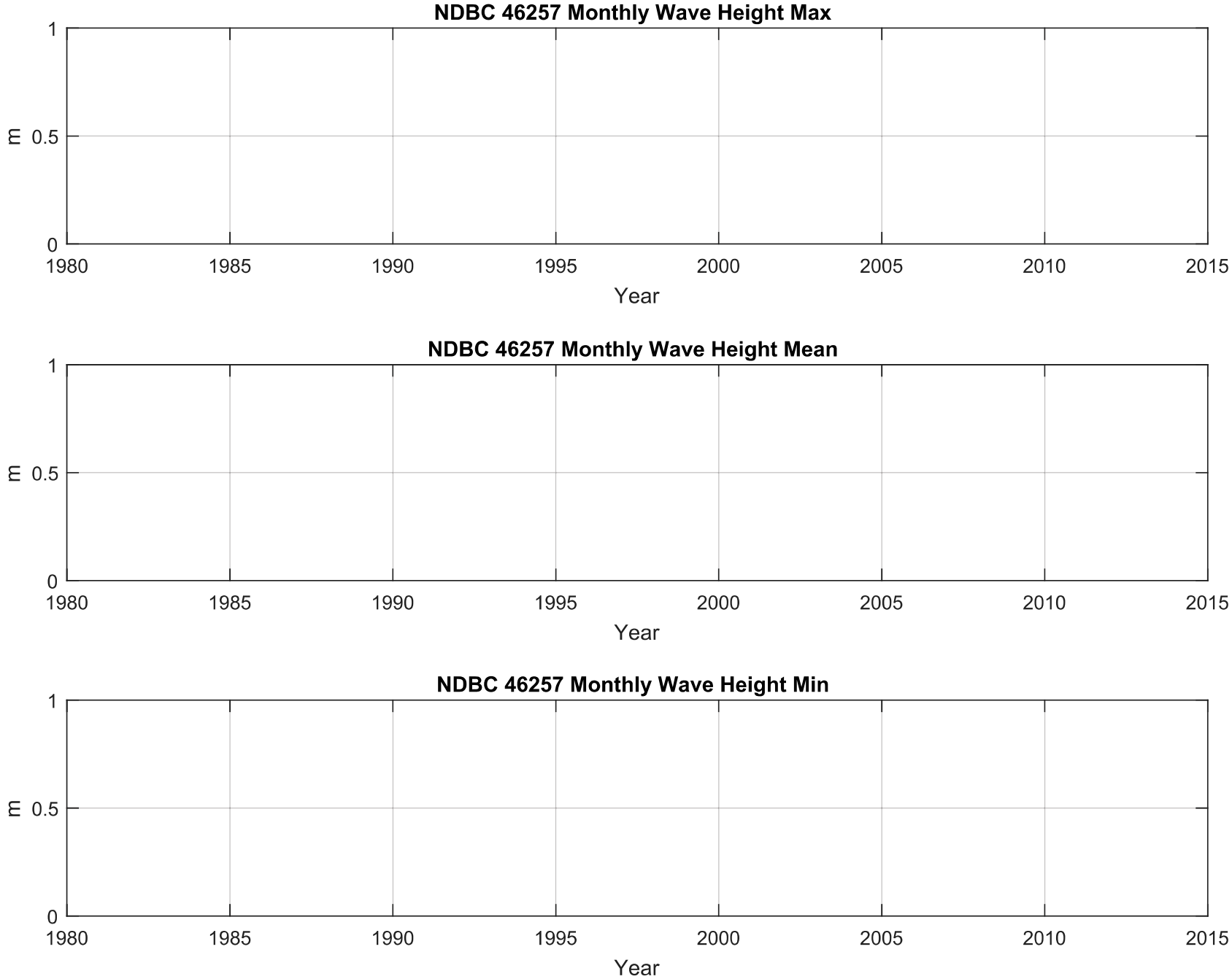


Figure A255. Monthly Wave Height, Max, Mean, Min,NDBC 46257

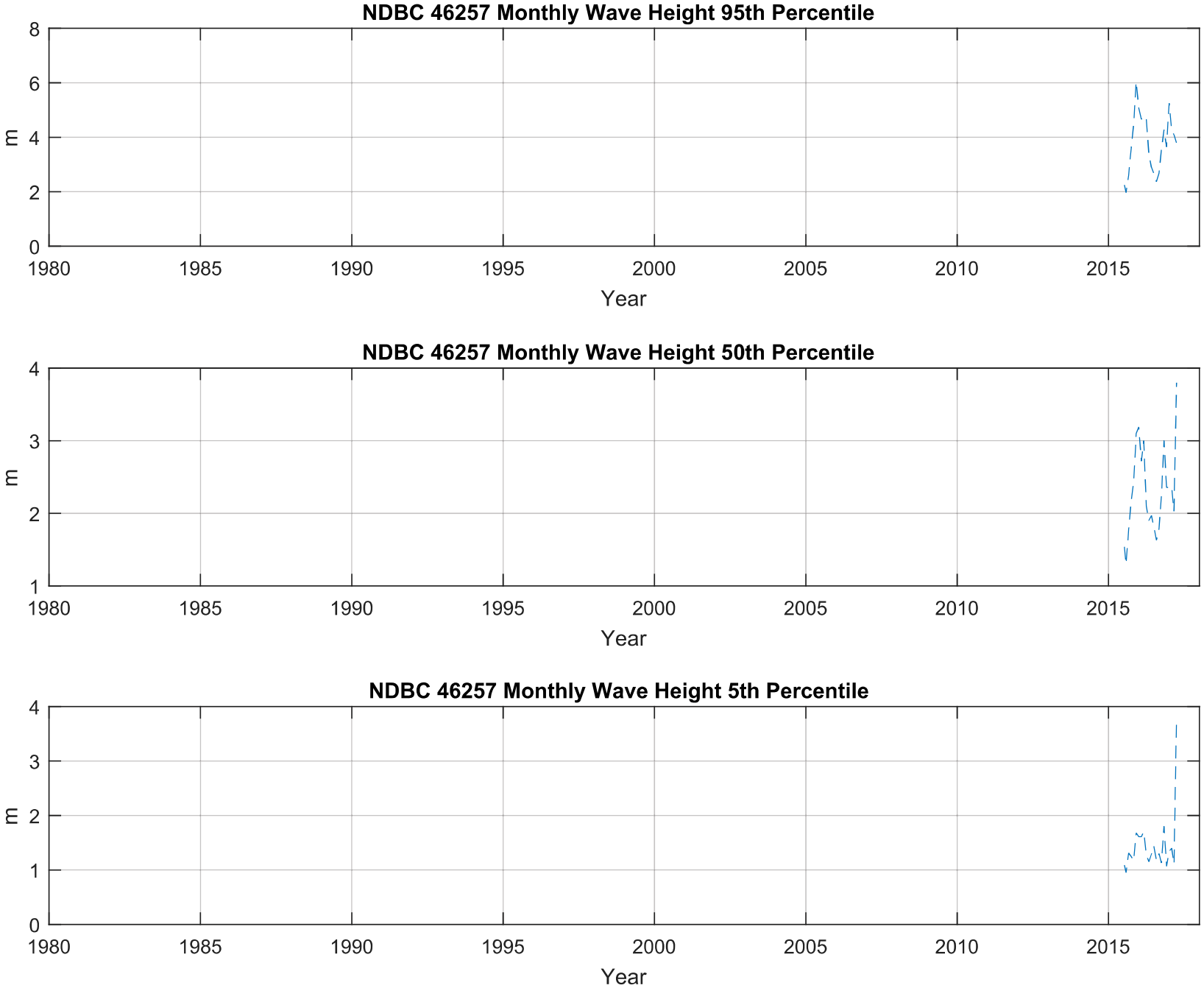


Figure A256. Monthly Wave Height, Percentiles,NDBC 46257

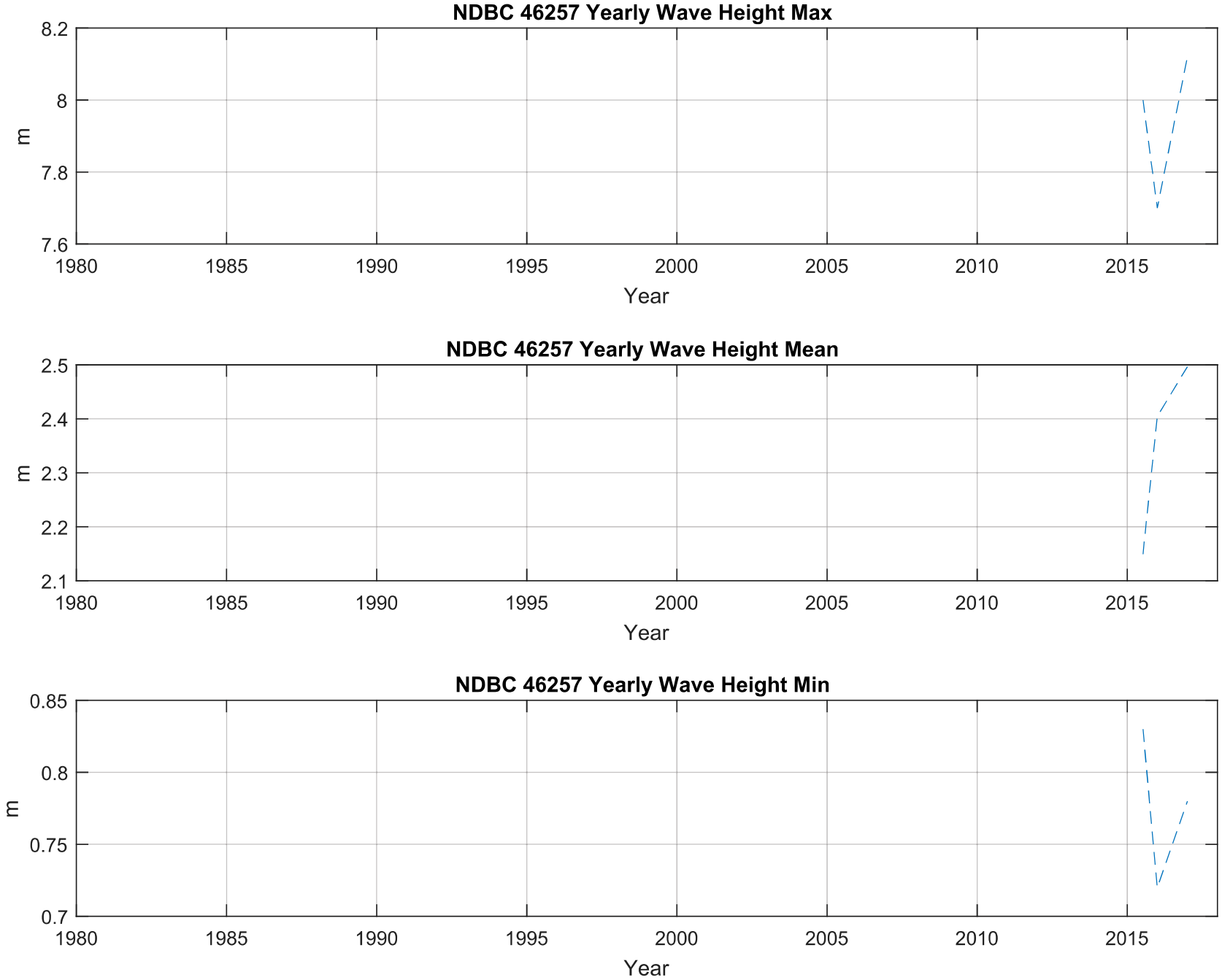


Figure A257. Yearly Wave Height, Max, Mean, Min,NDBC 46257

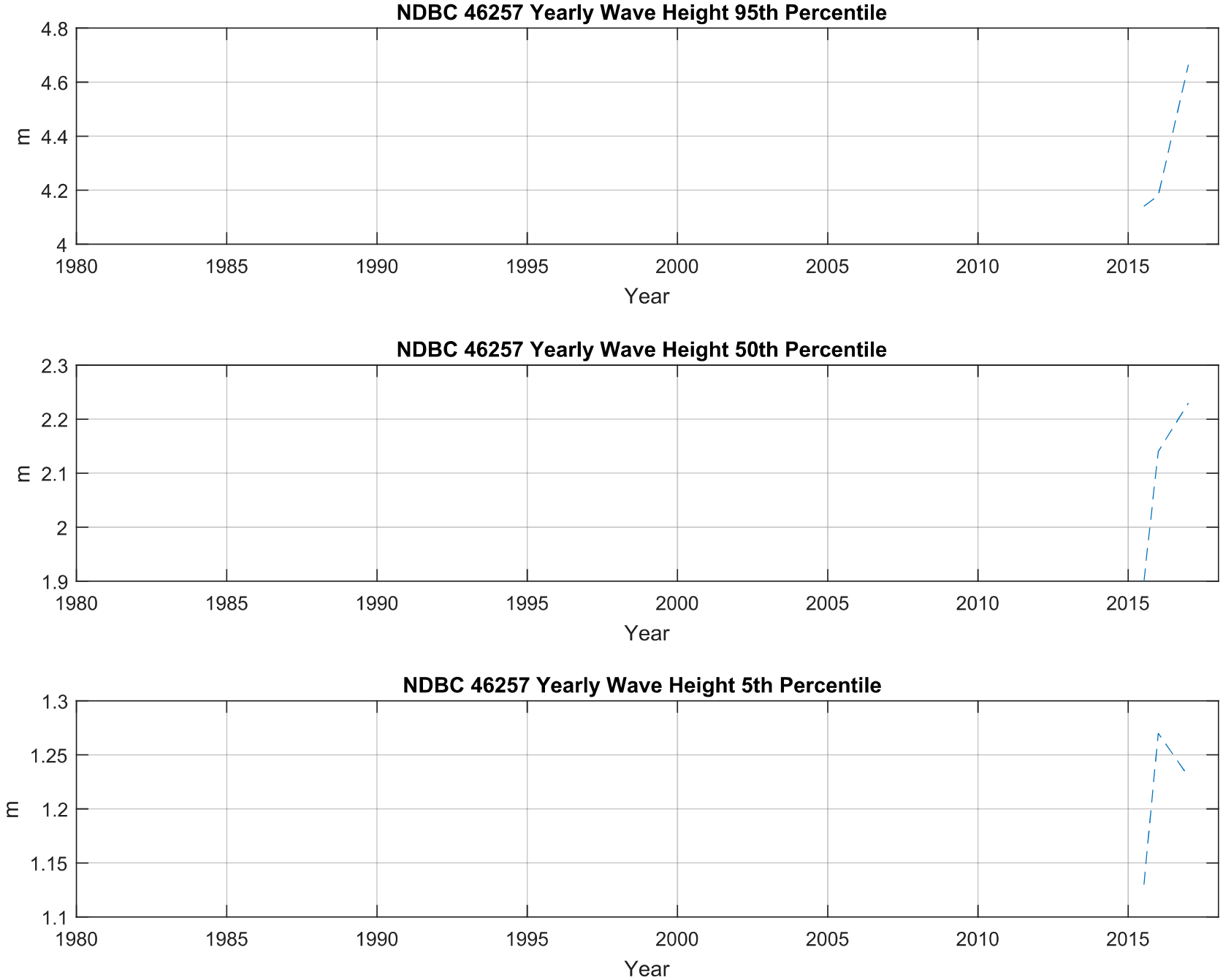


Figure A258. Yearly Wave Height, Percentiles,NDBC 46257

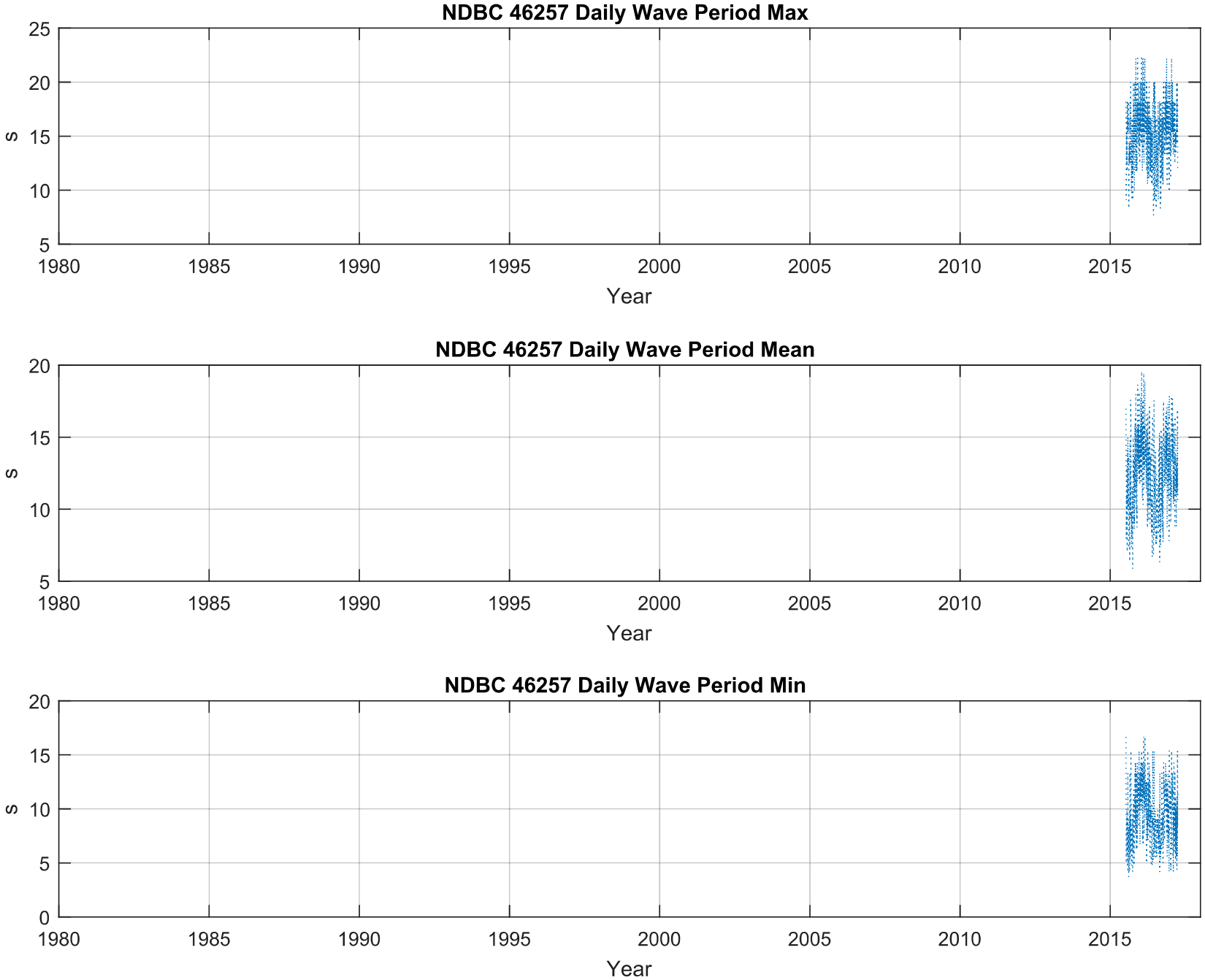
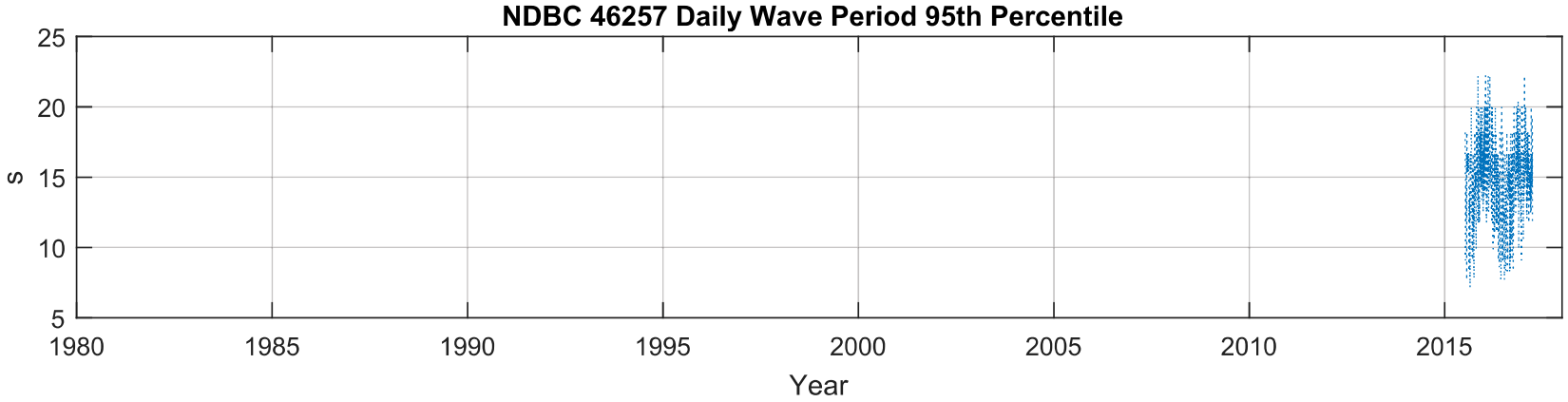
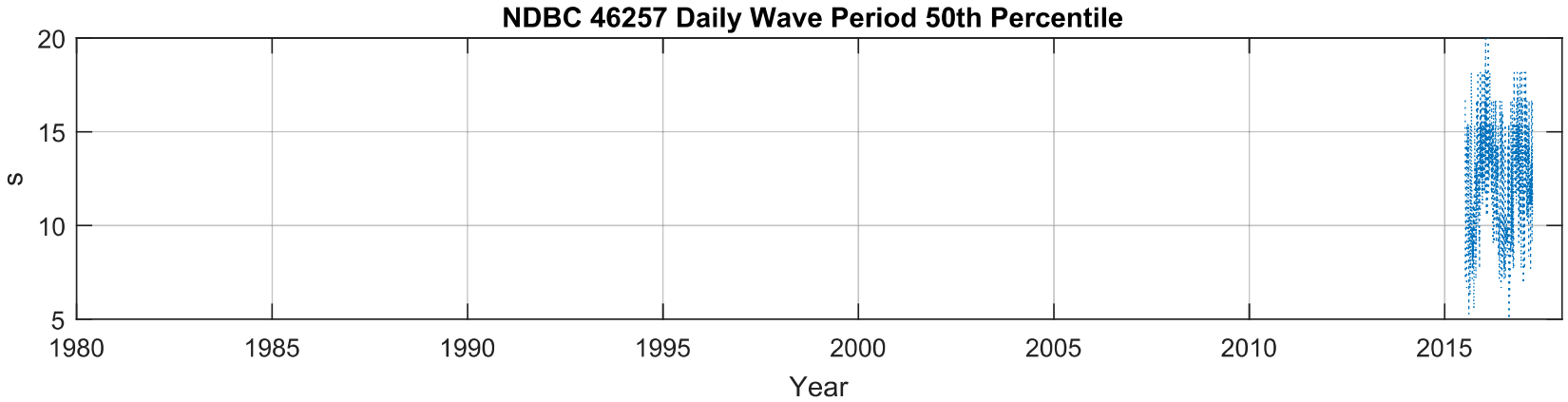


Figure A259. Daily Wave Period, Max, Mean, Min,NDBC 46257





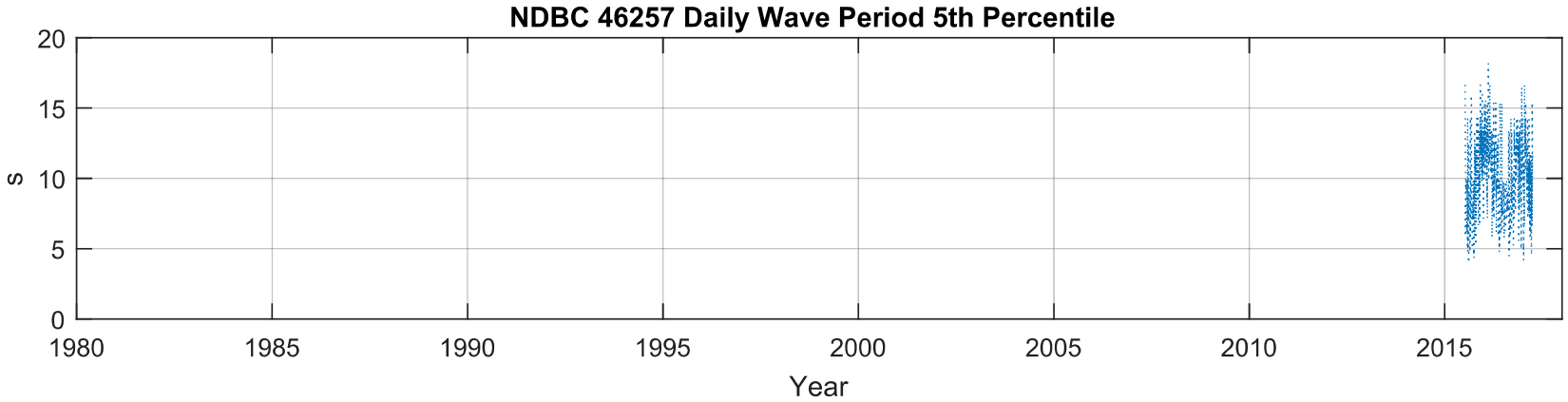


Figure A260. Daily Wave Period, Percentiles,NDBC 46257

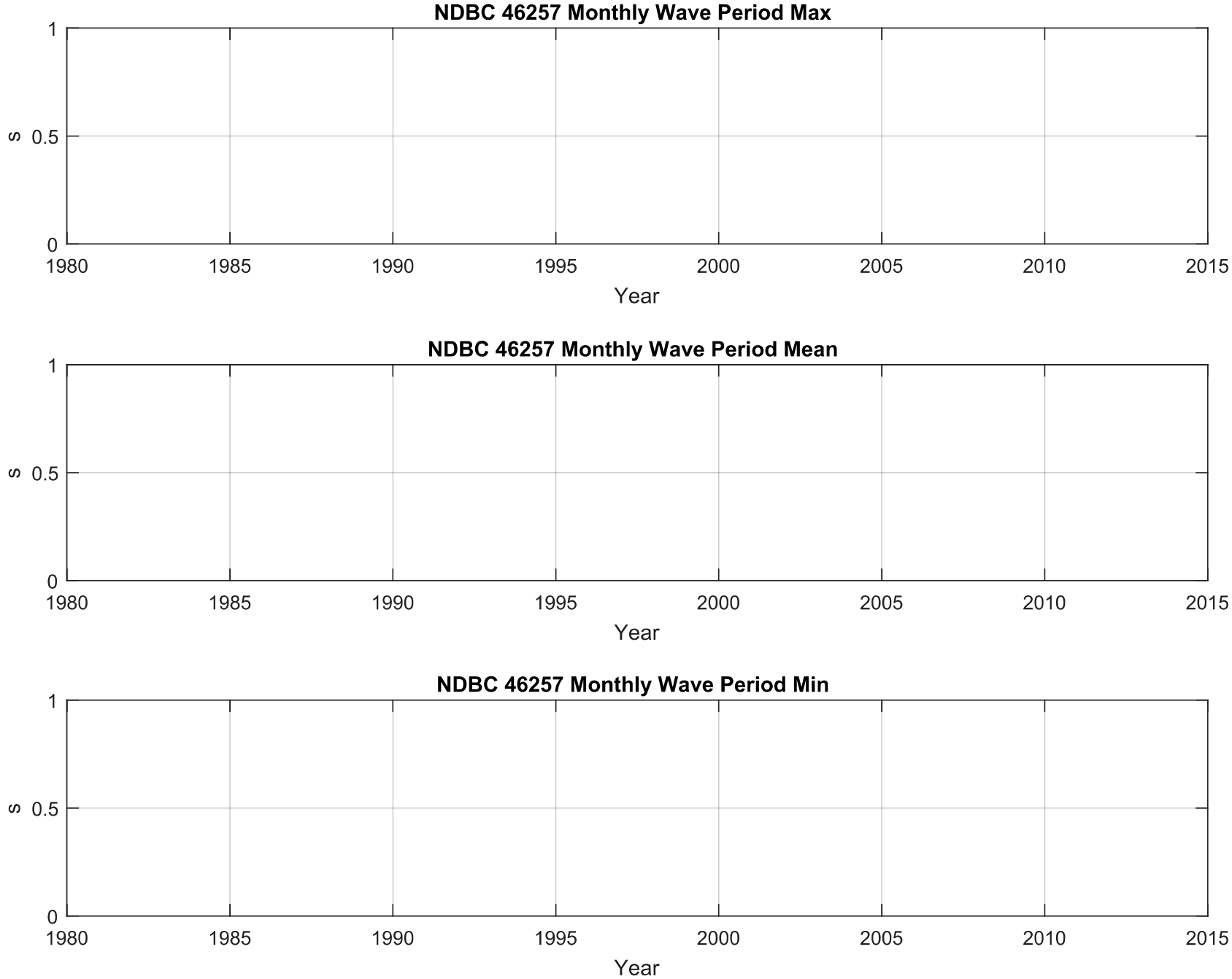
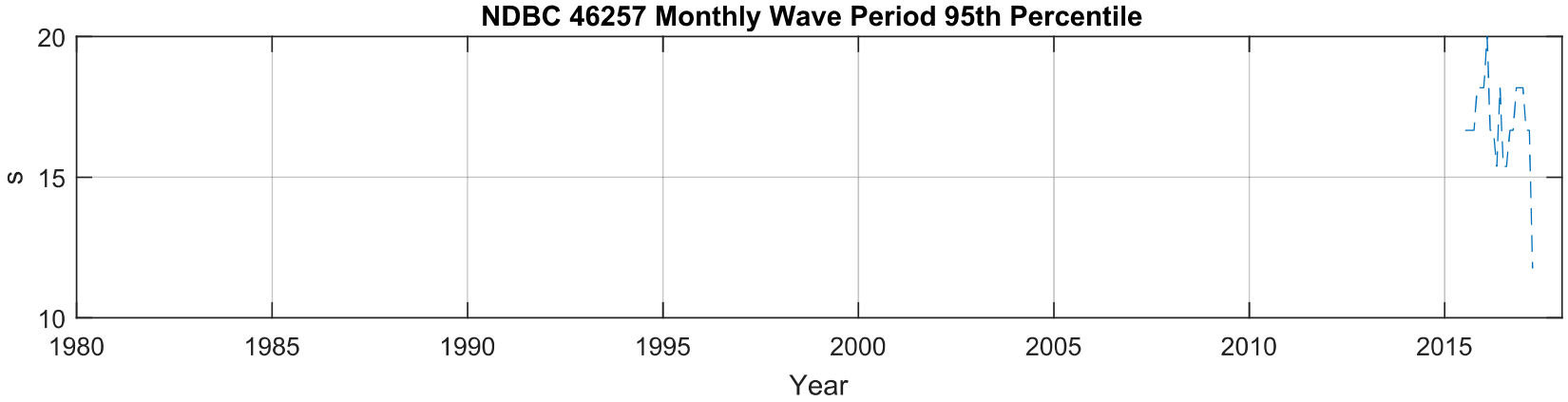
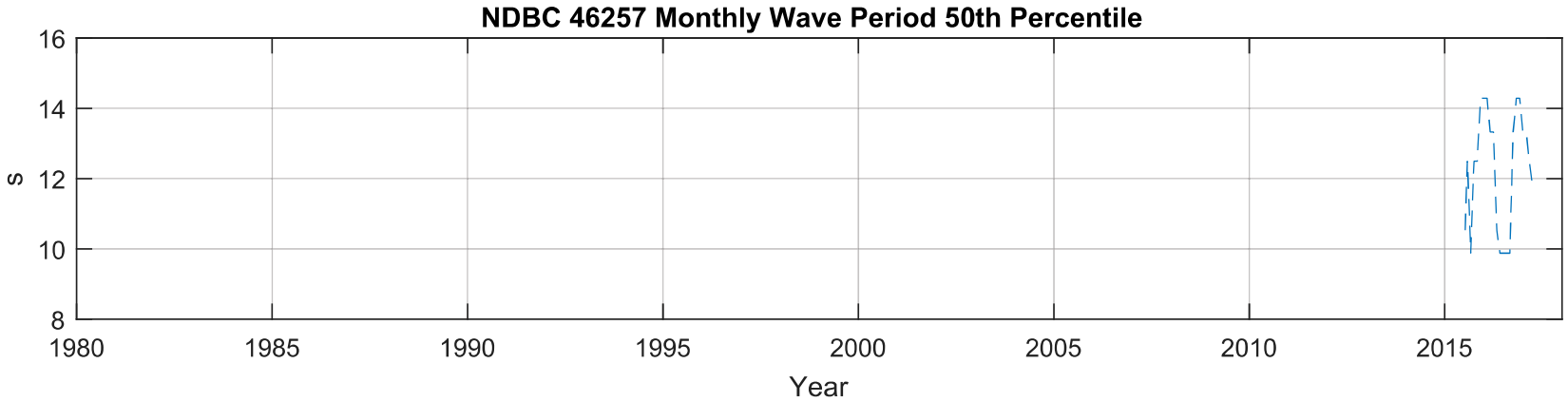


Figure A261. Monthly Wave Period, Max, Mean, Min,NDBC 46257





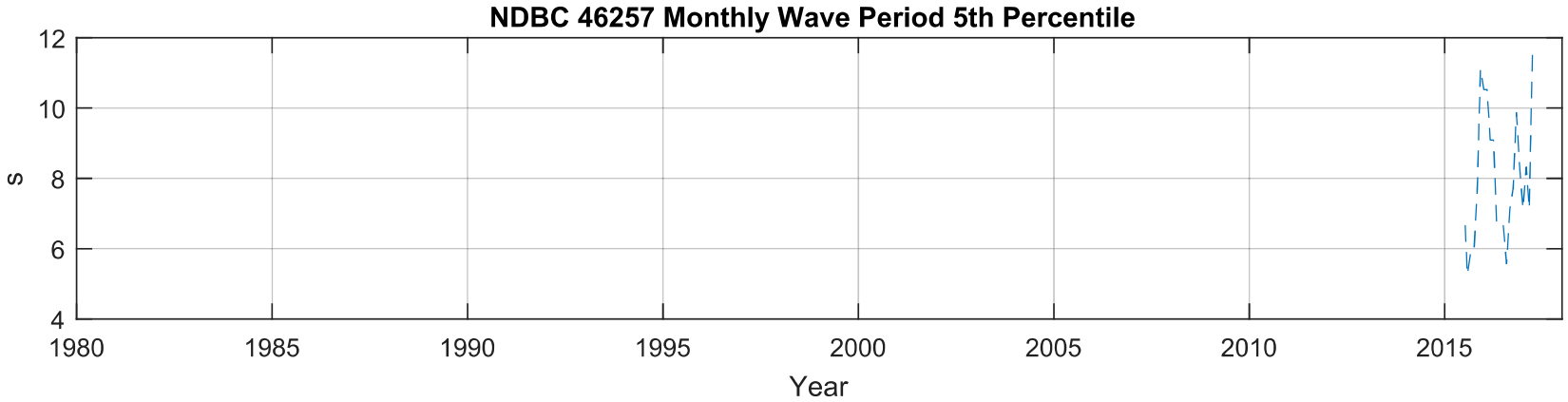


Figure A262. Monthly Wave Period, Percentiles,NDBC 46257

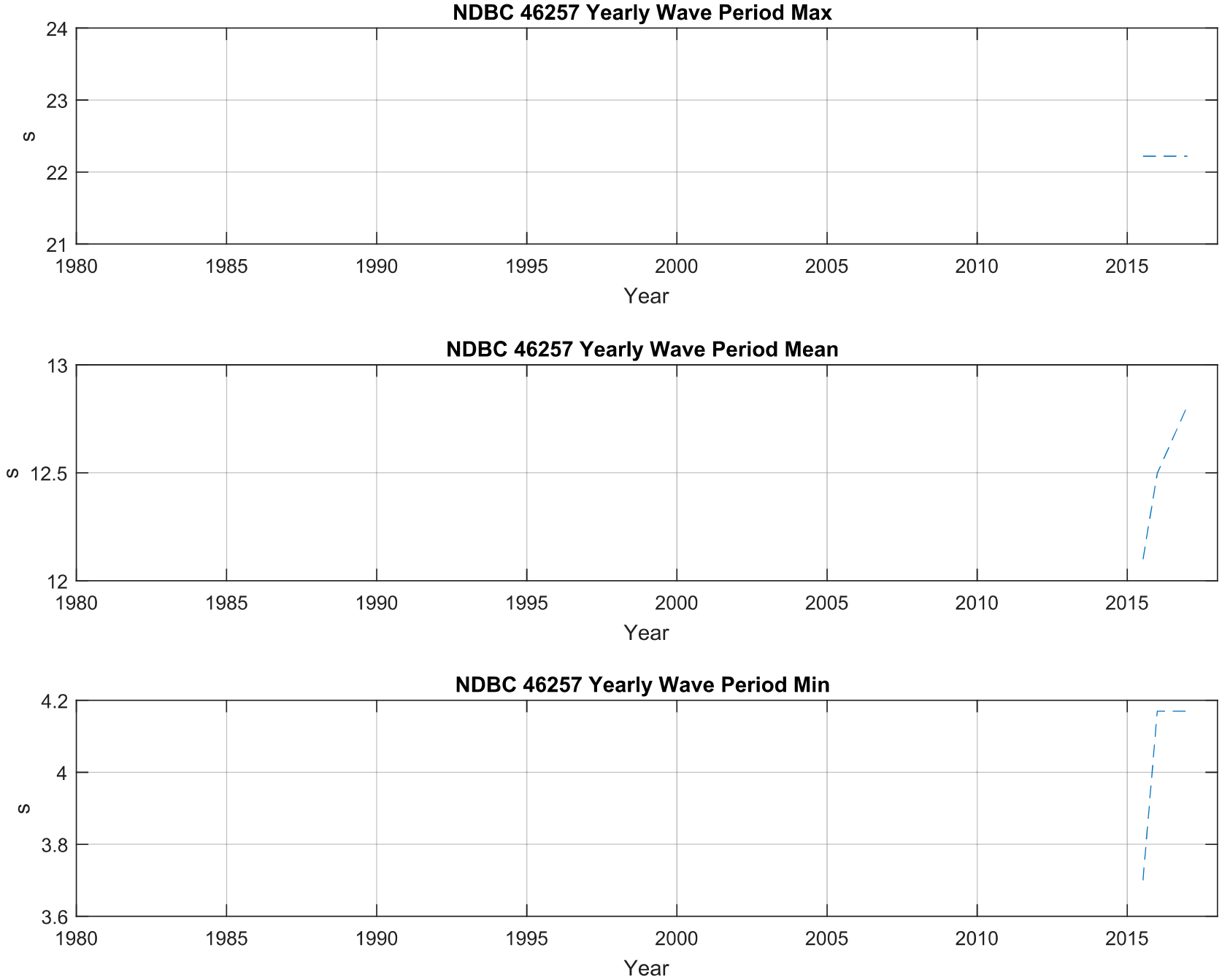
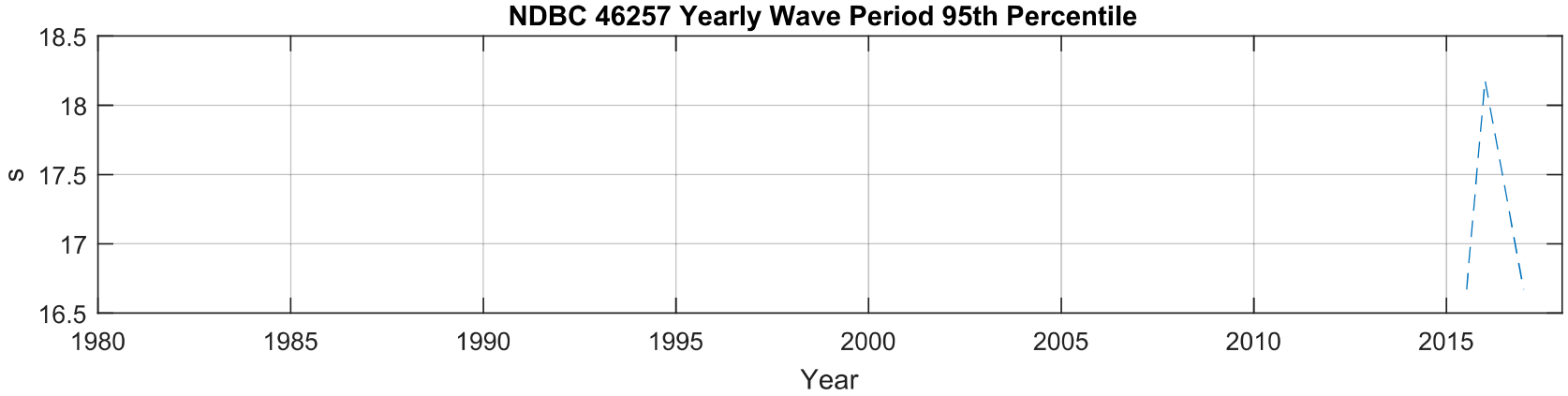
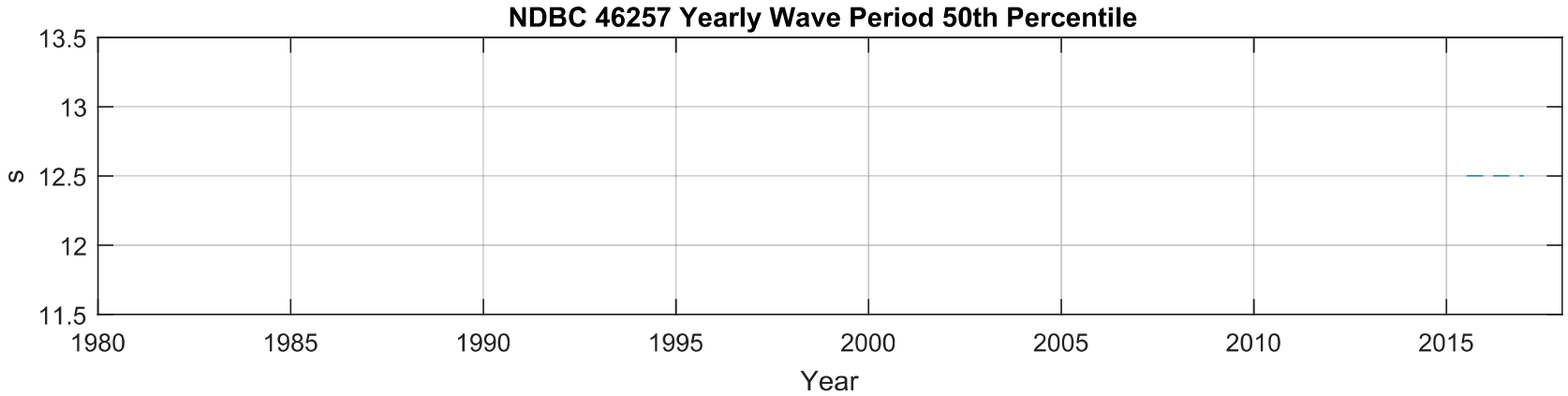


Figure A263. Yearly Wave Period, Max, Mean, Min,NDBC 46257





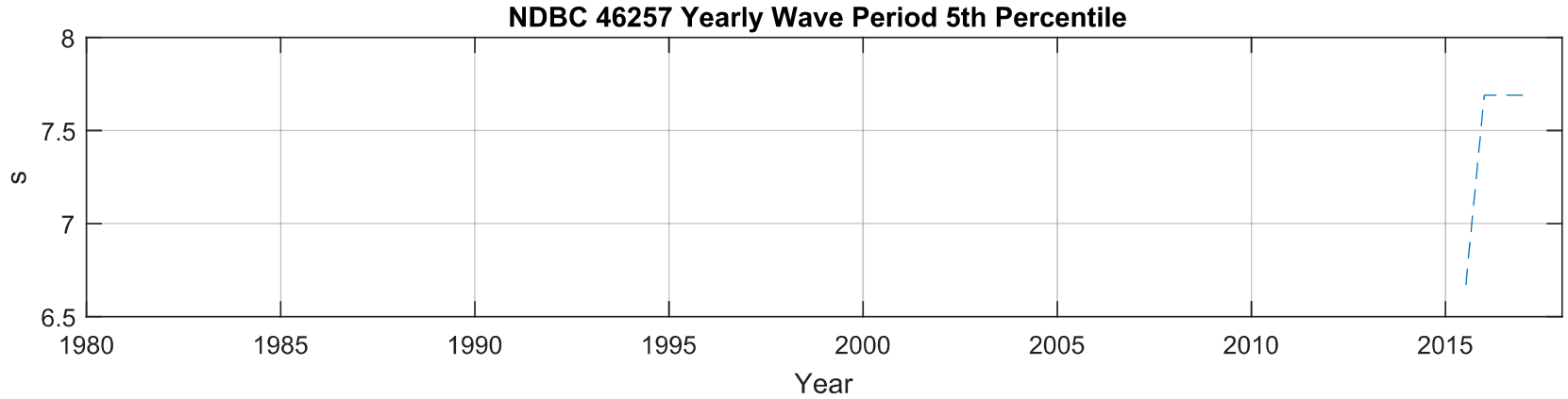
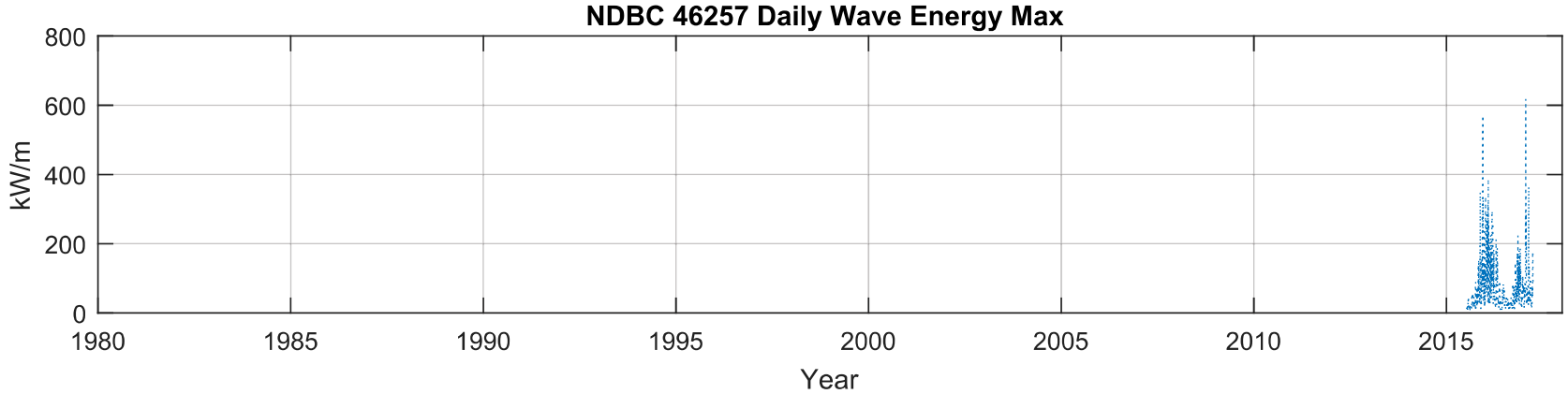
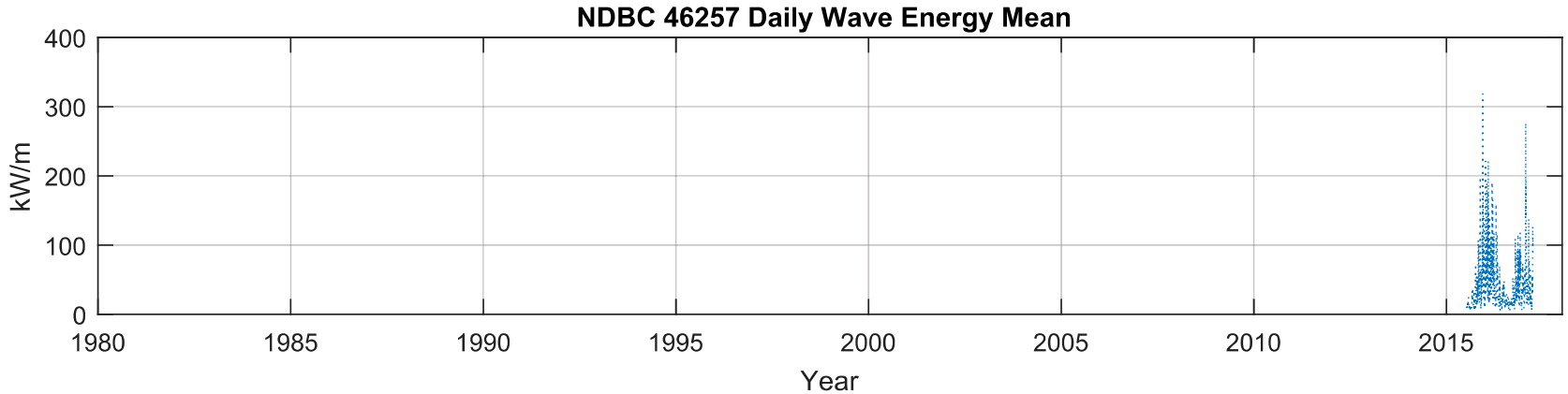


Figure A264. Yearly Wave Period, Percentiles,NDBC 46257





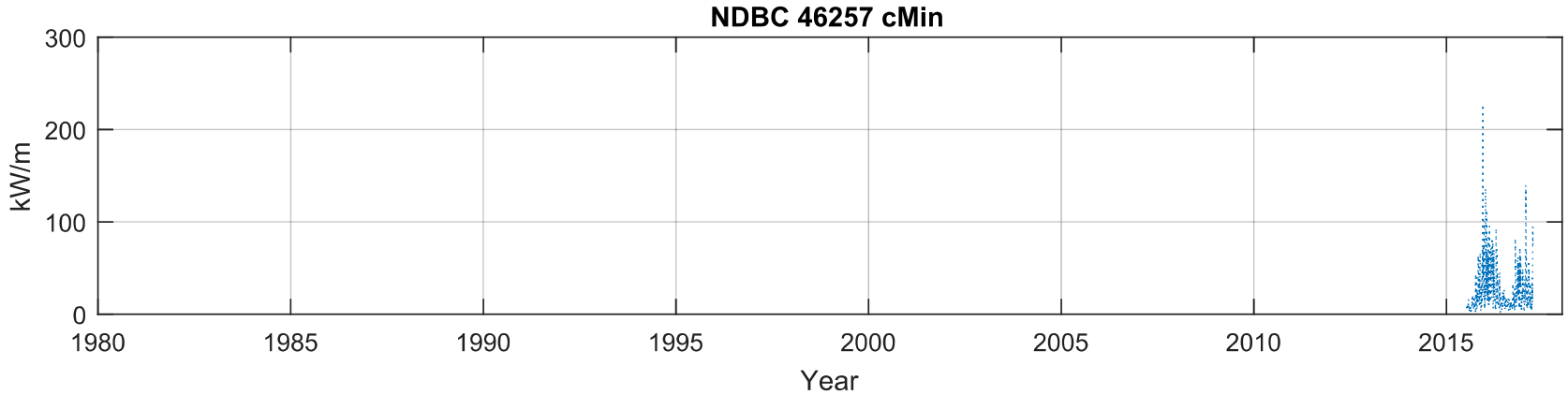
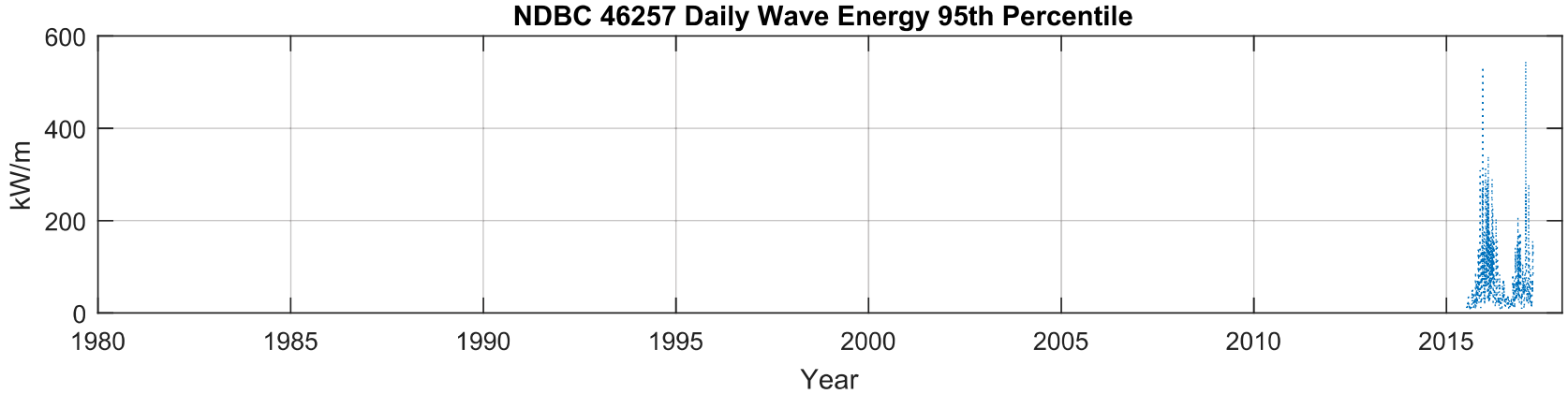
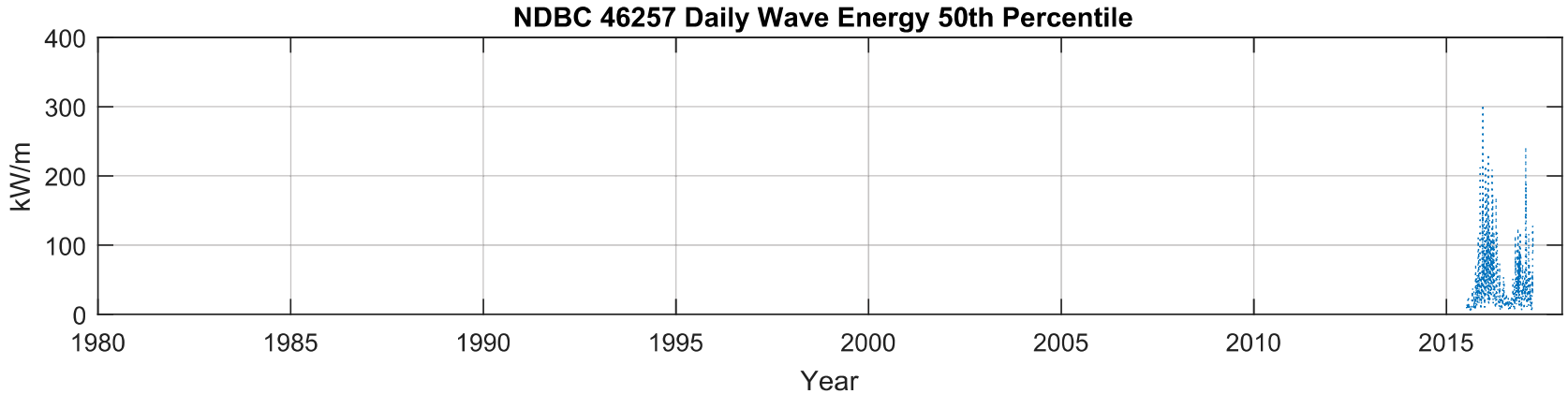


Figure A265. Daily Wave Energy, Max, Mean, Min,NDBC 46257





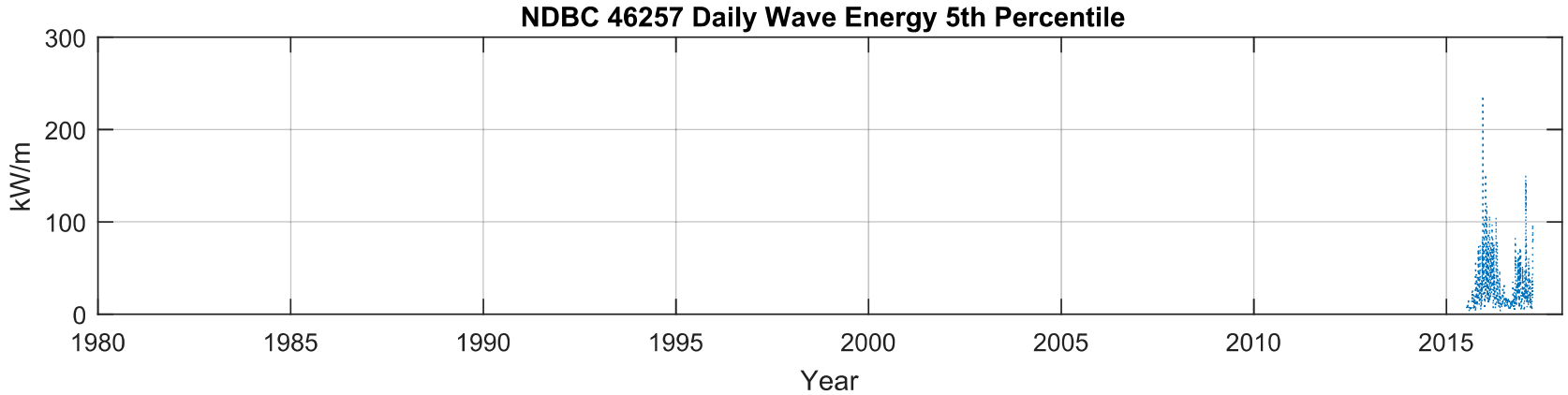
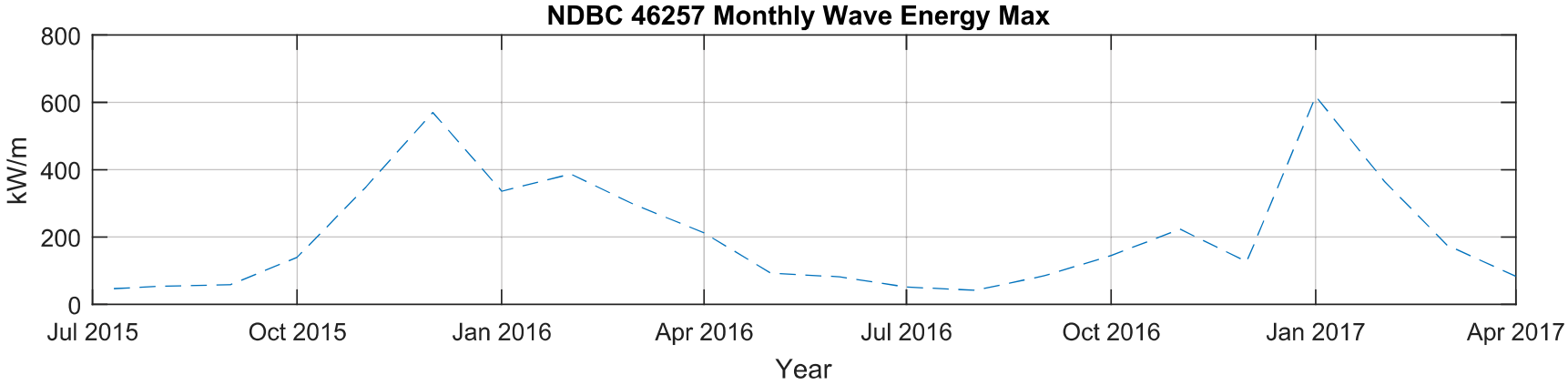
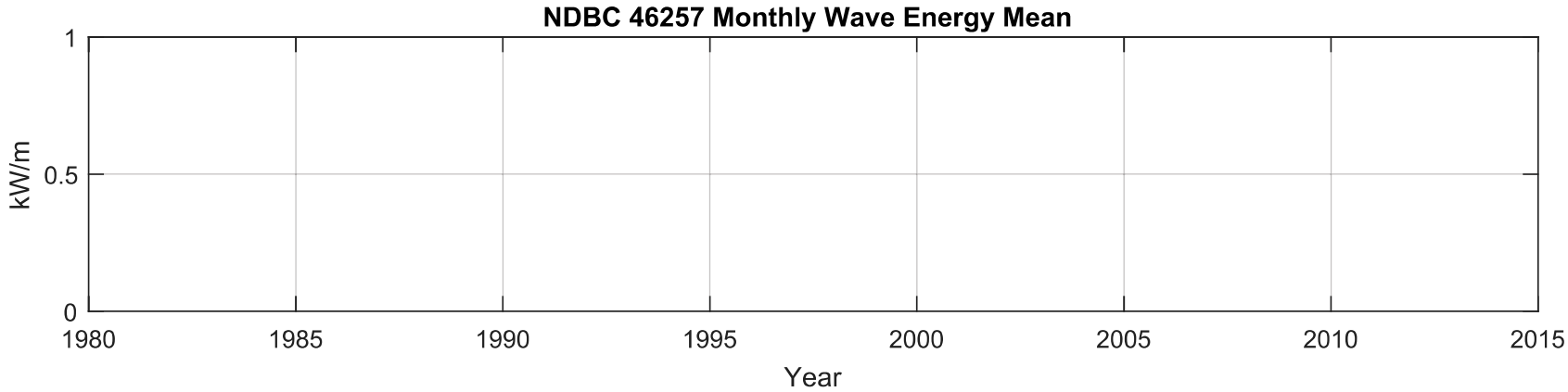


Figure A266. Daily Wave Energy, Percentiles,NDBC 46257





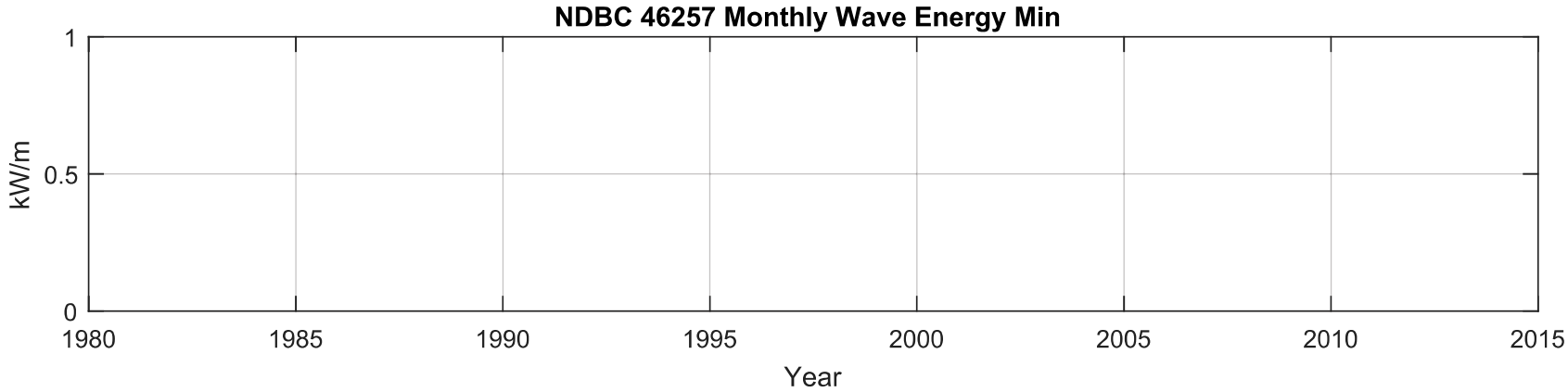
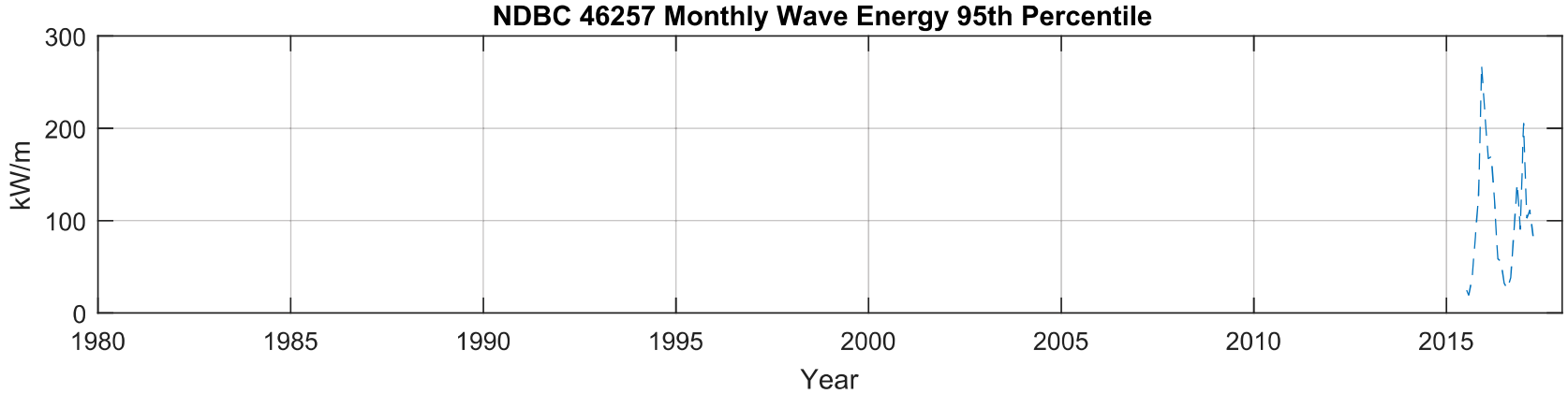
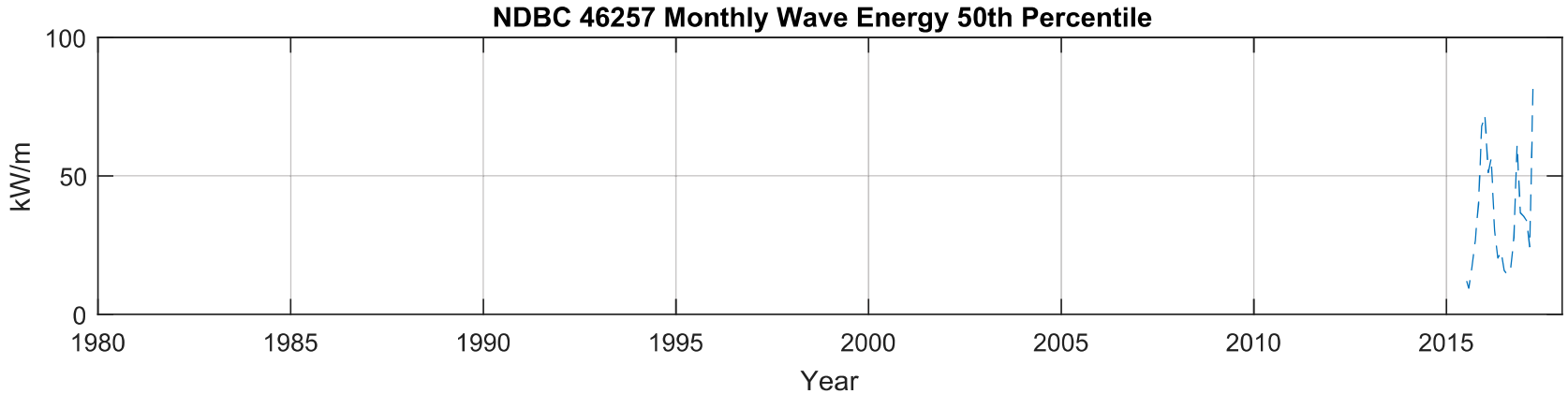


Figure A267. Monthly Wave Energy, Max, Mean, Min,NDBC 46257





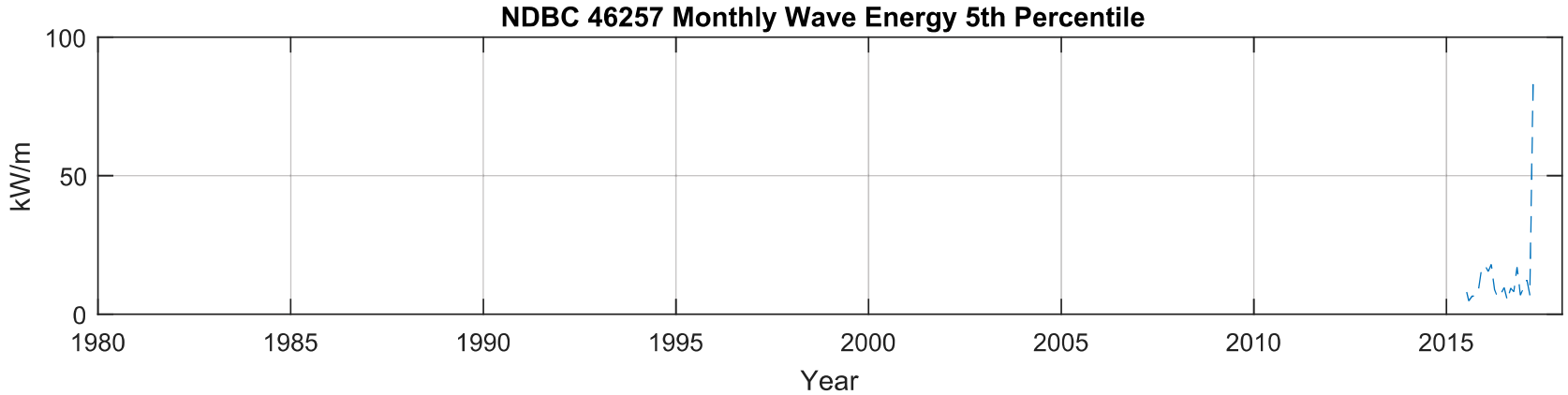
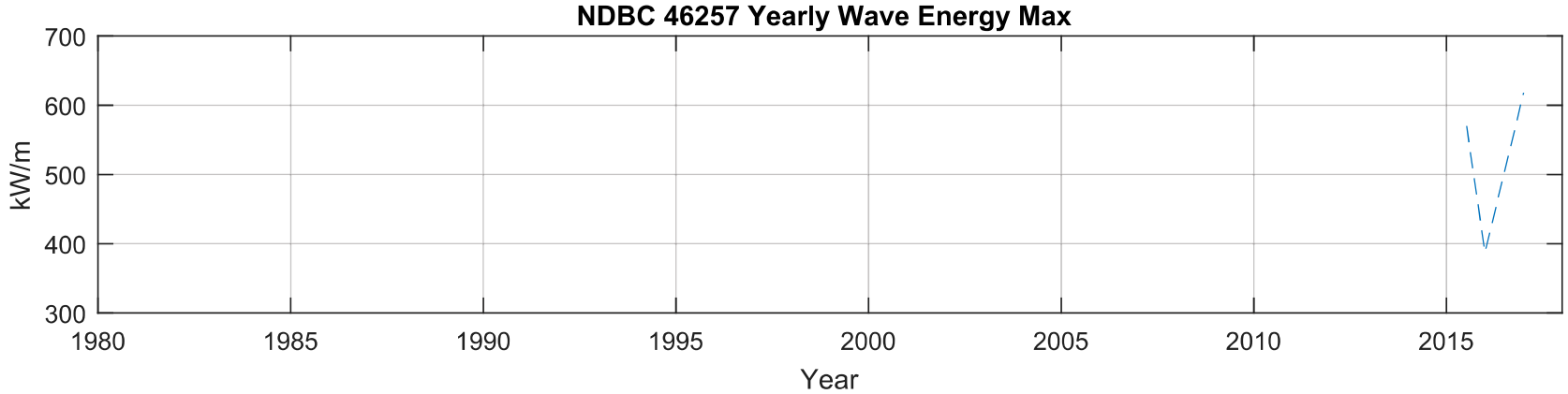
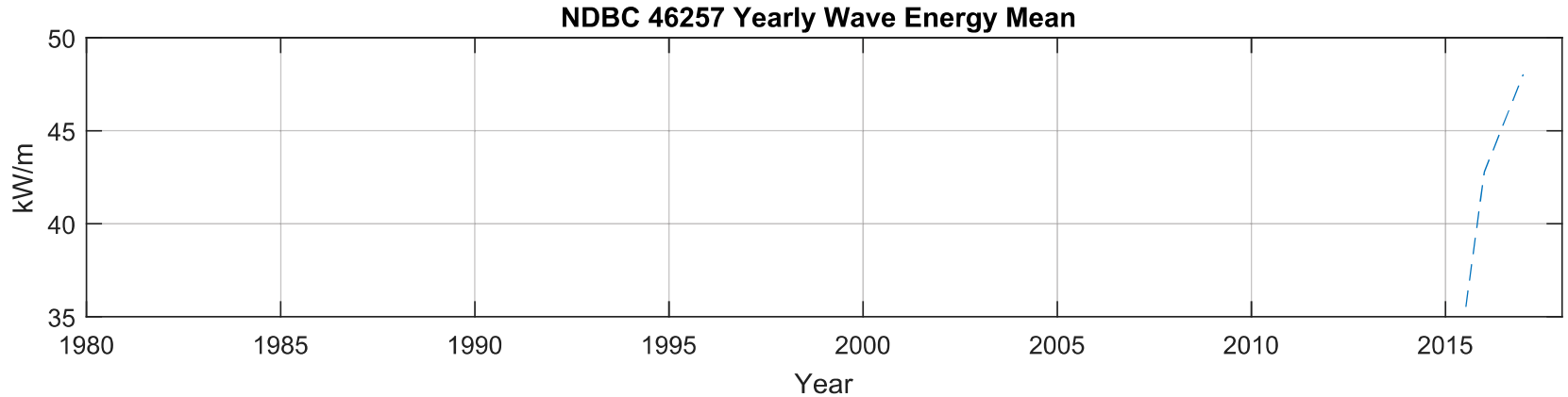


Figure A268. Monthly Wave Energy, Percentiles,NDBC 46257





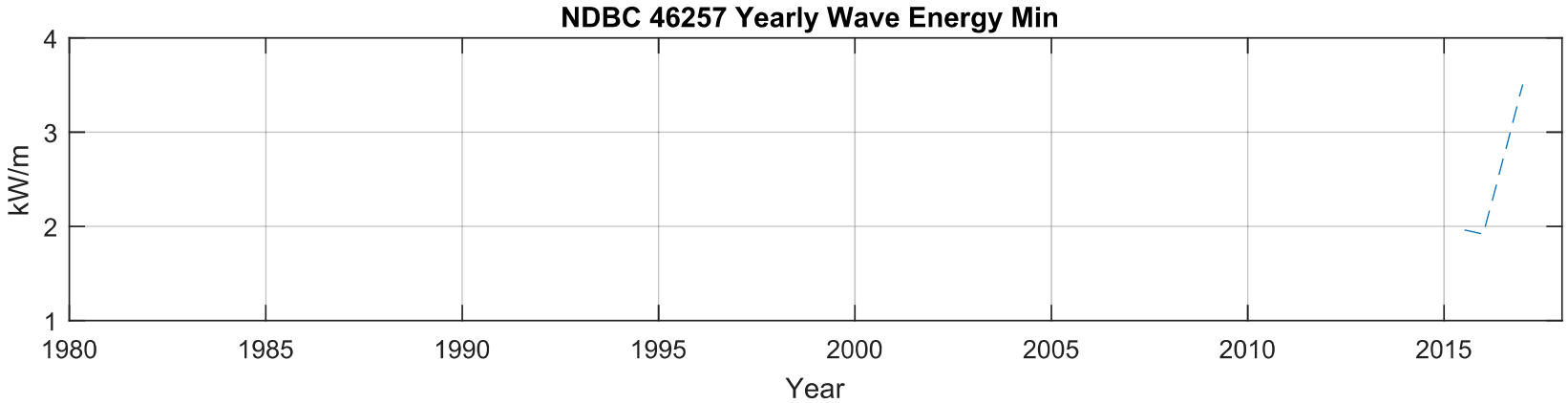
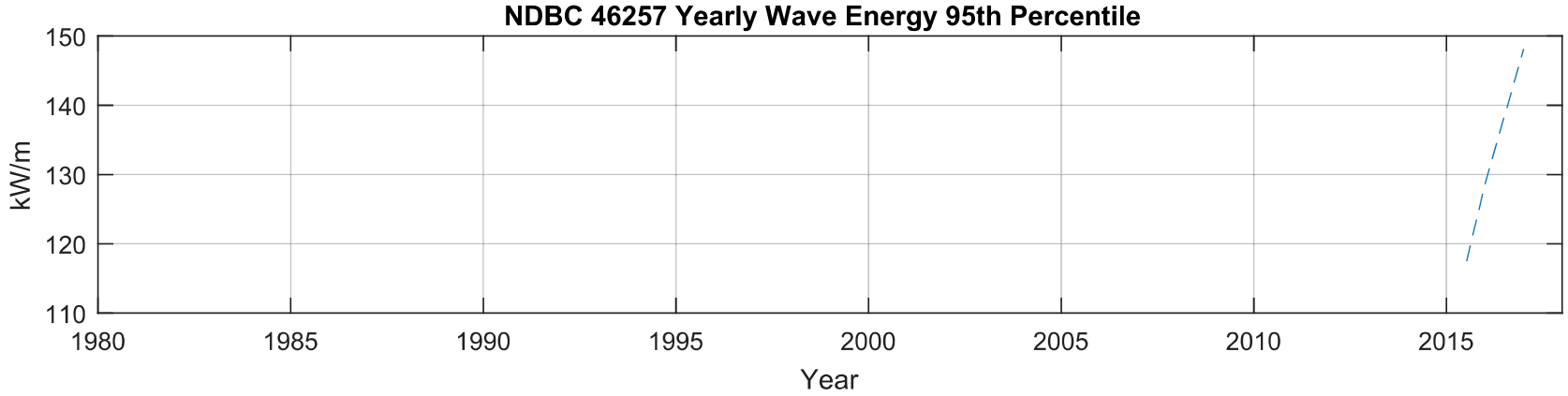
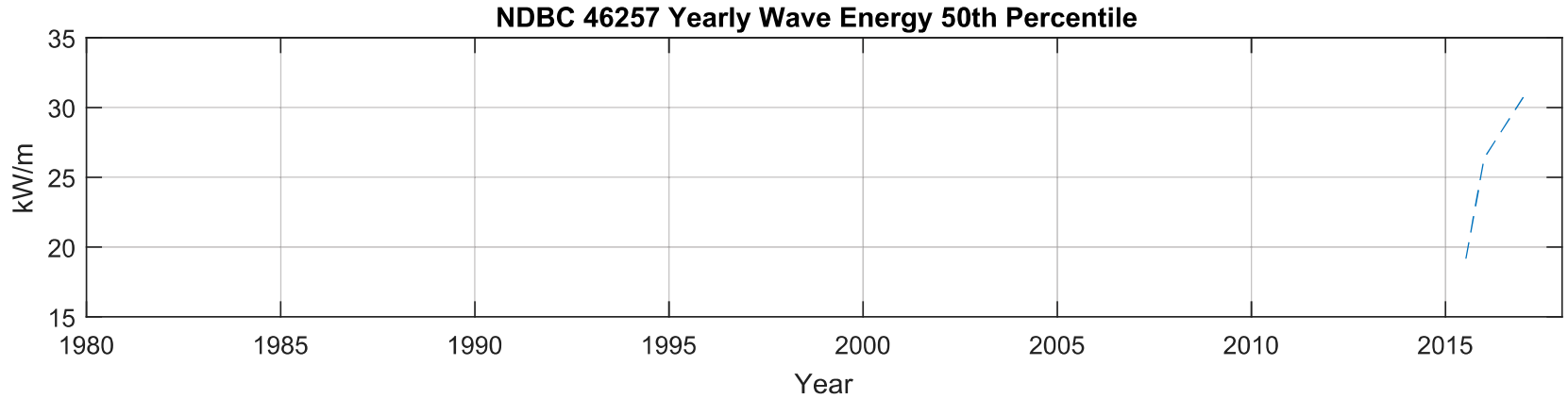


Figure A269. Yearly Wave Energy, Max, Mean, Min,NDBC 46257





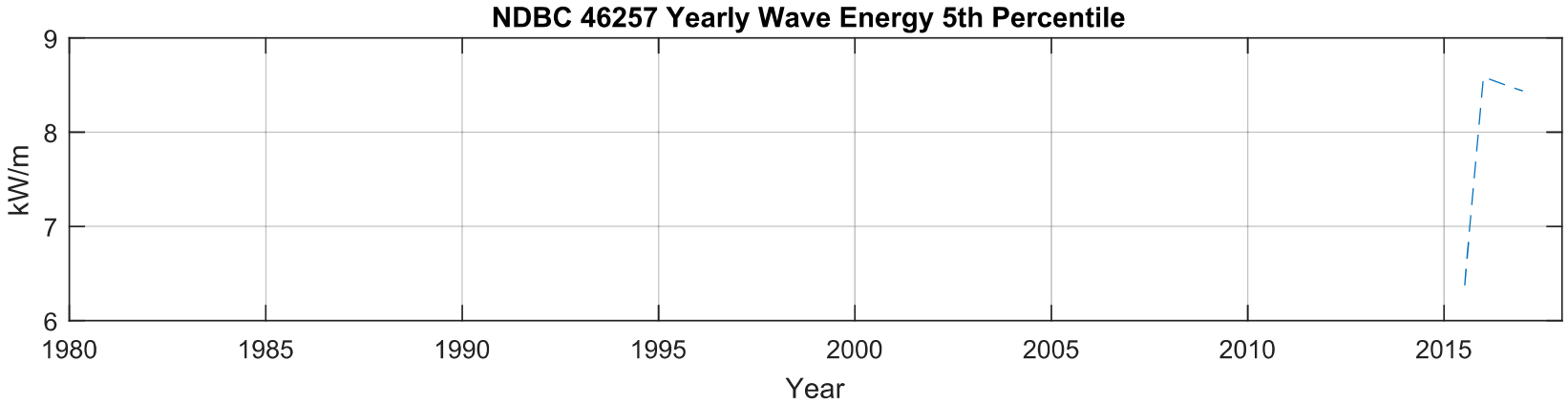


Figure A270. Yearly Wave Energy, Percentiles,NDBC 46257

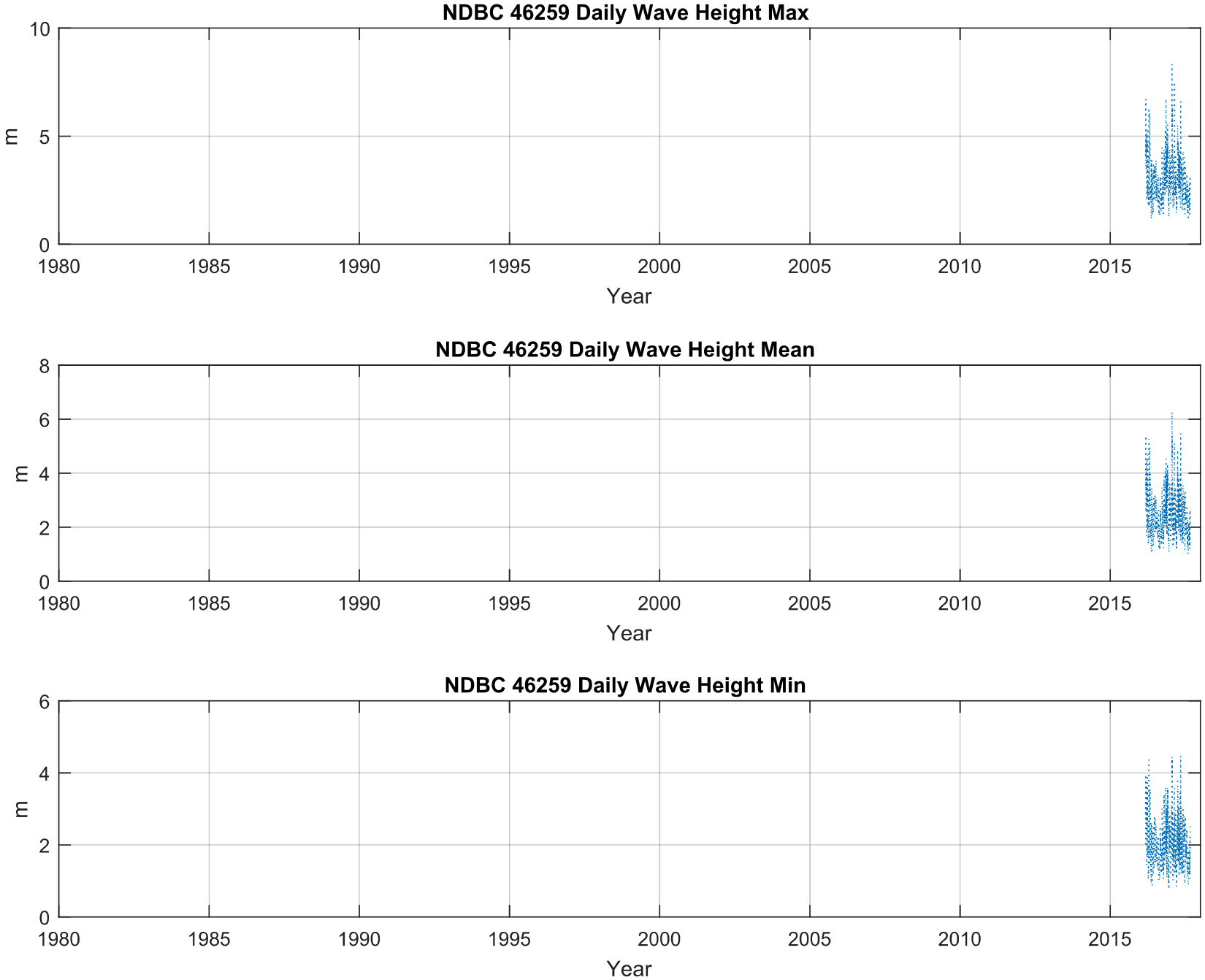


Figure A271. Daily Wave Height, Max, Mean, Min,NDBC 46259

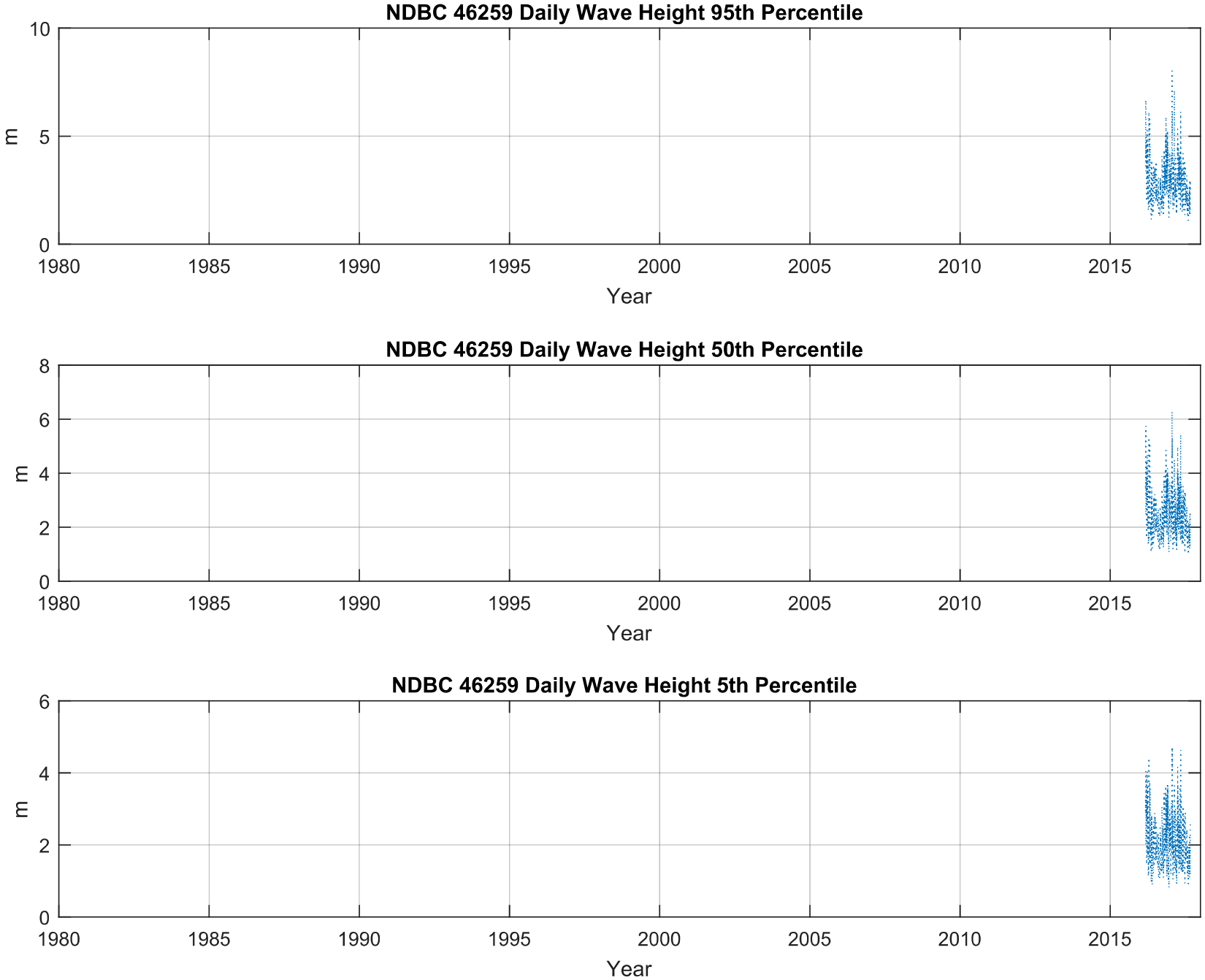


Figure A272. Daily Wave Height, Percentiles,NDBC 46259

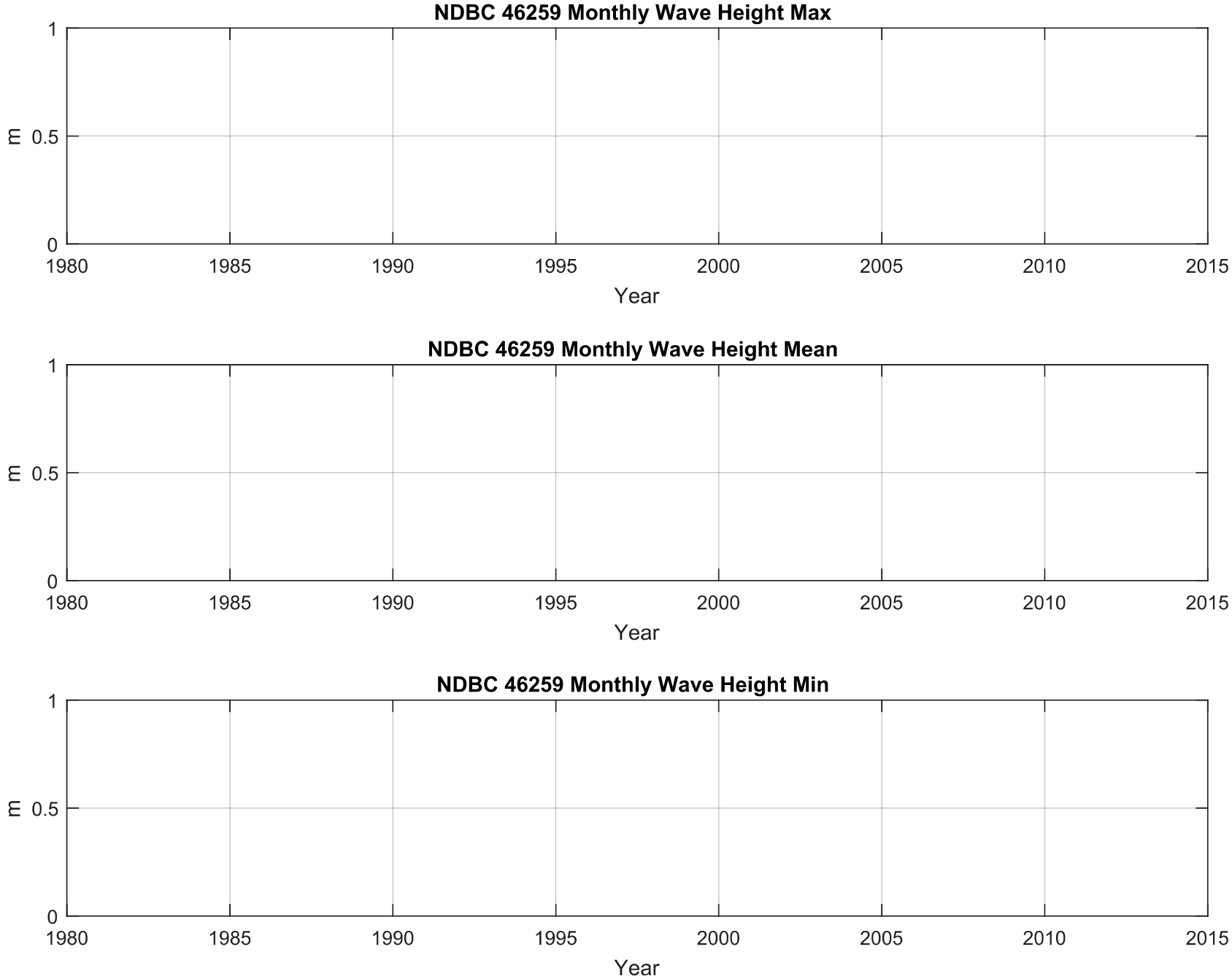


Figure A273. Monthly Wave Height, Max, Mean, Min,NDBC 46259

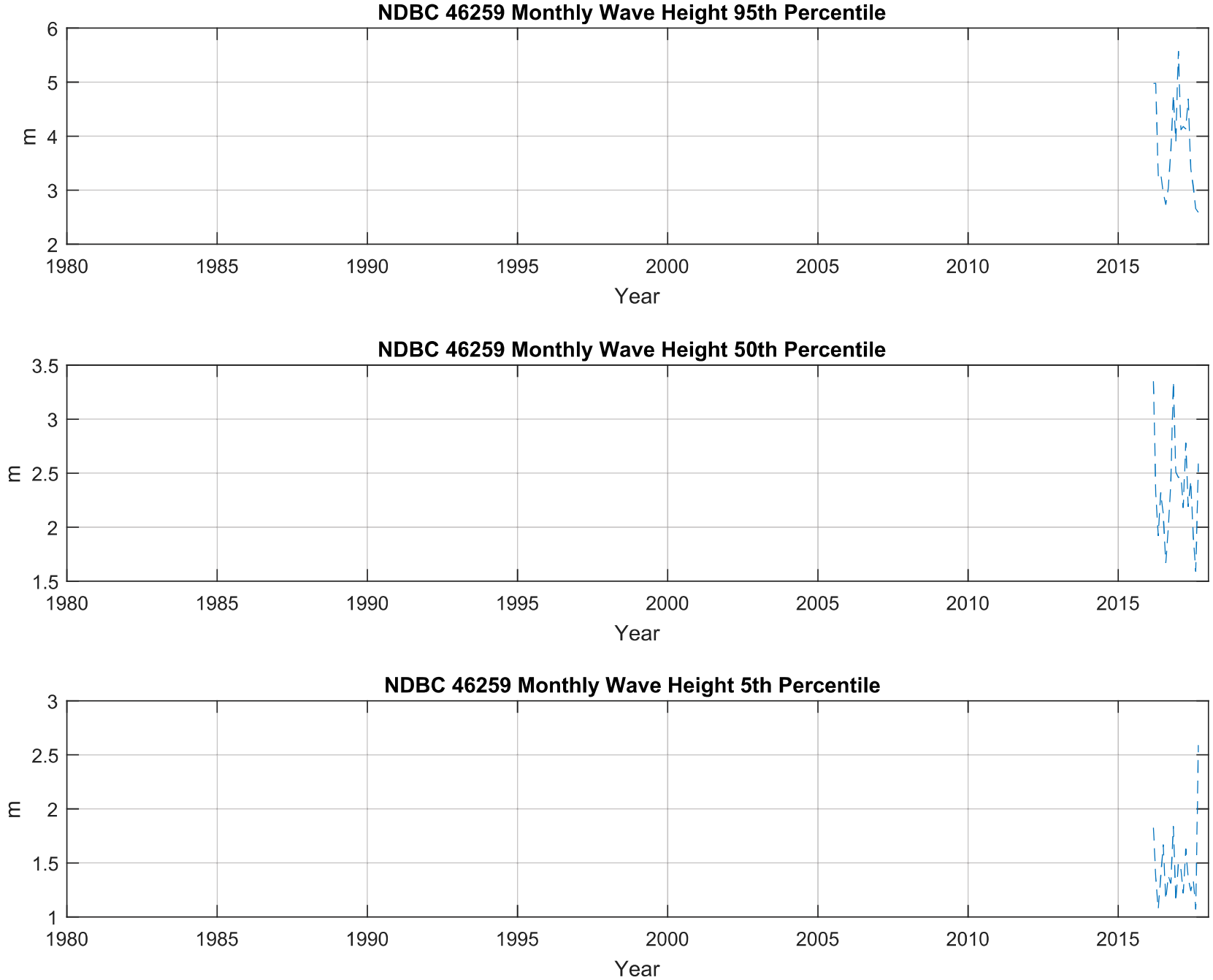


Figure A274. Monthly Wave Height, Percentiles,NDBC 46259

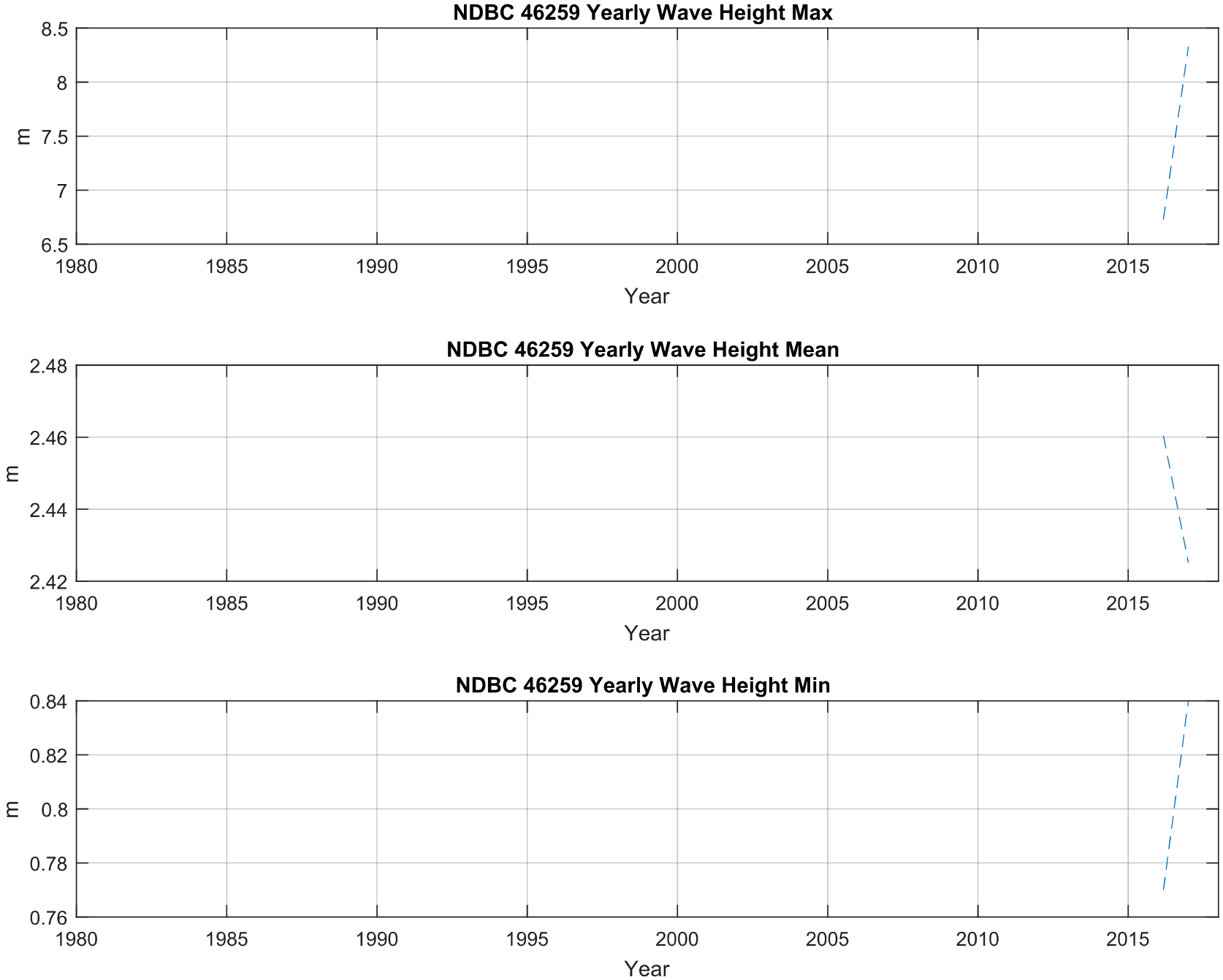
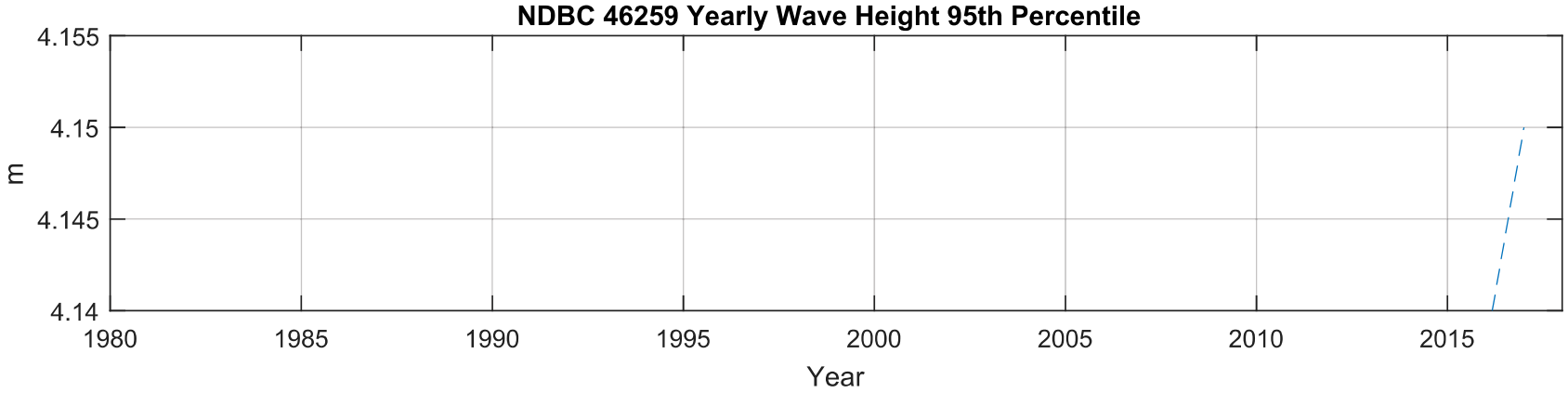
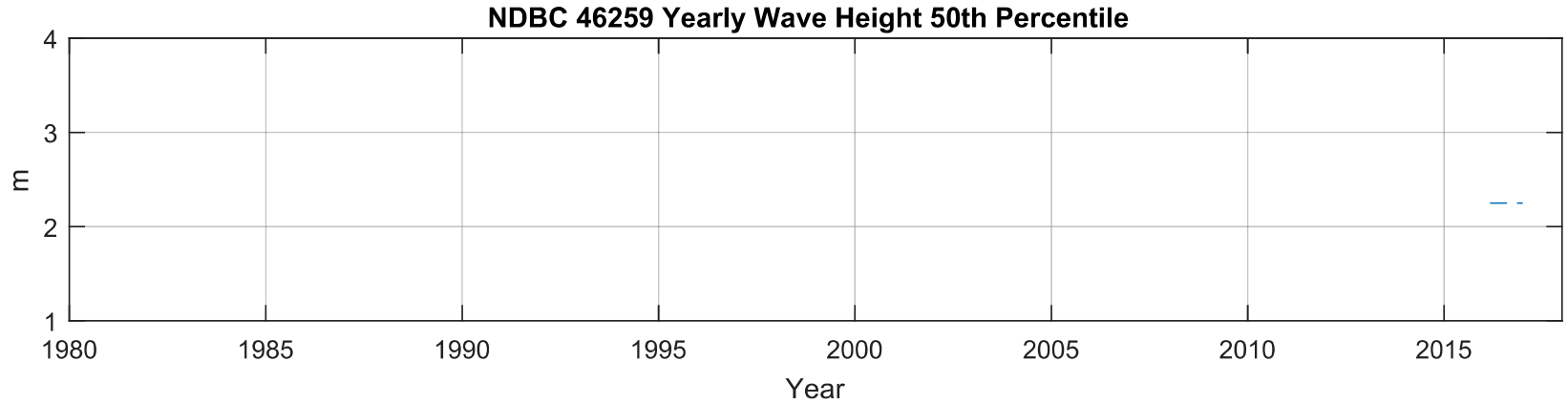


Figure A275. Yearly Wave Height, Max, Mean, Min,NDBC 46259





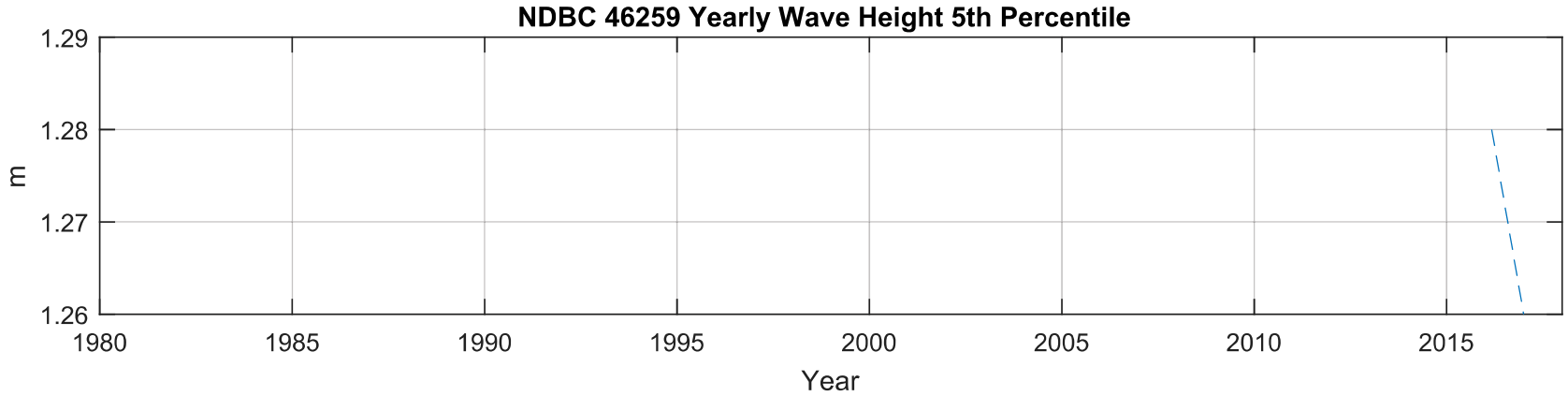


Figure A276. Yearly Wave Height, Percentiles,NDBC 46259

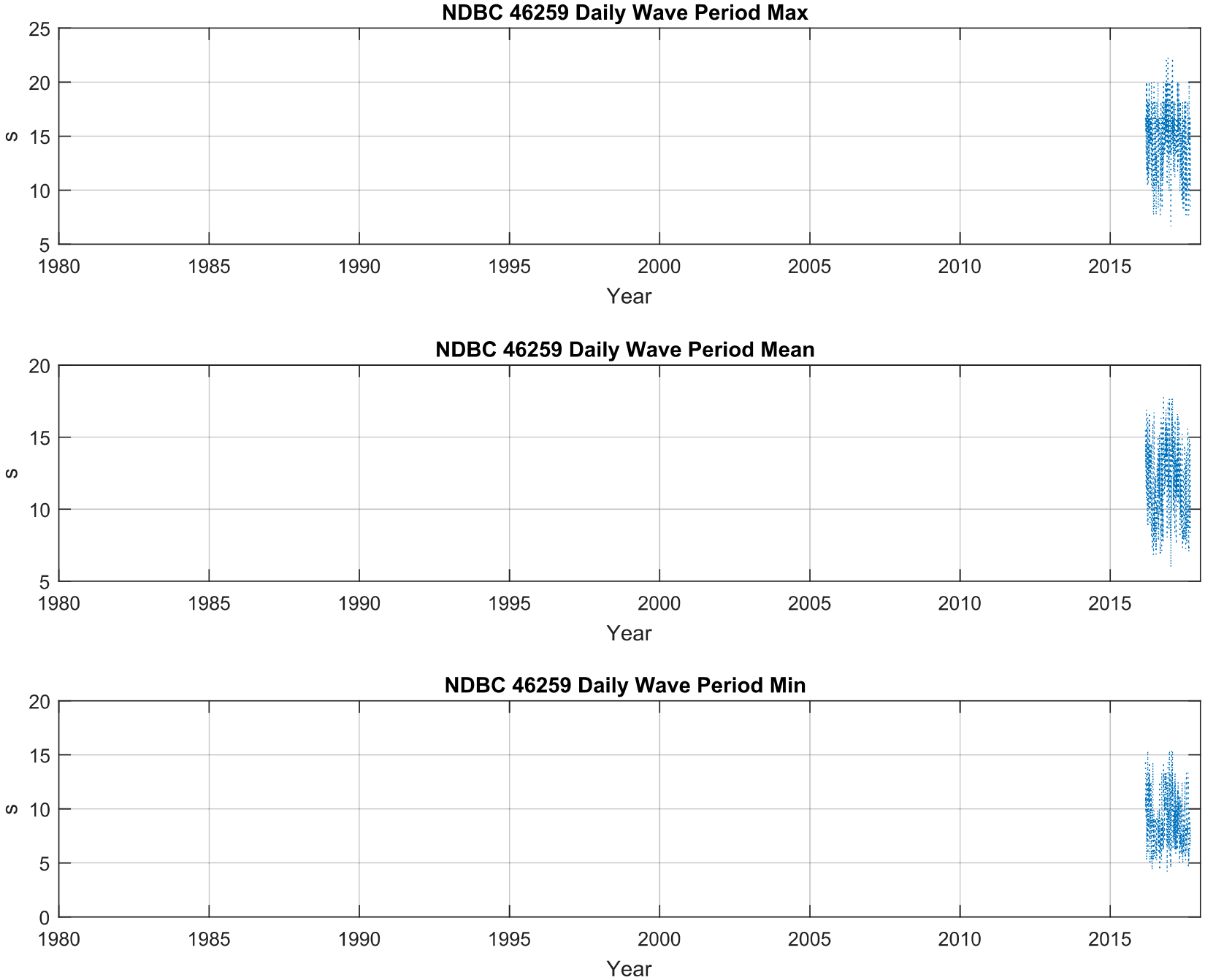


Figure A277. Daily Wave Period, Max, Mean, Min,NDBC 46259

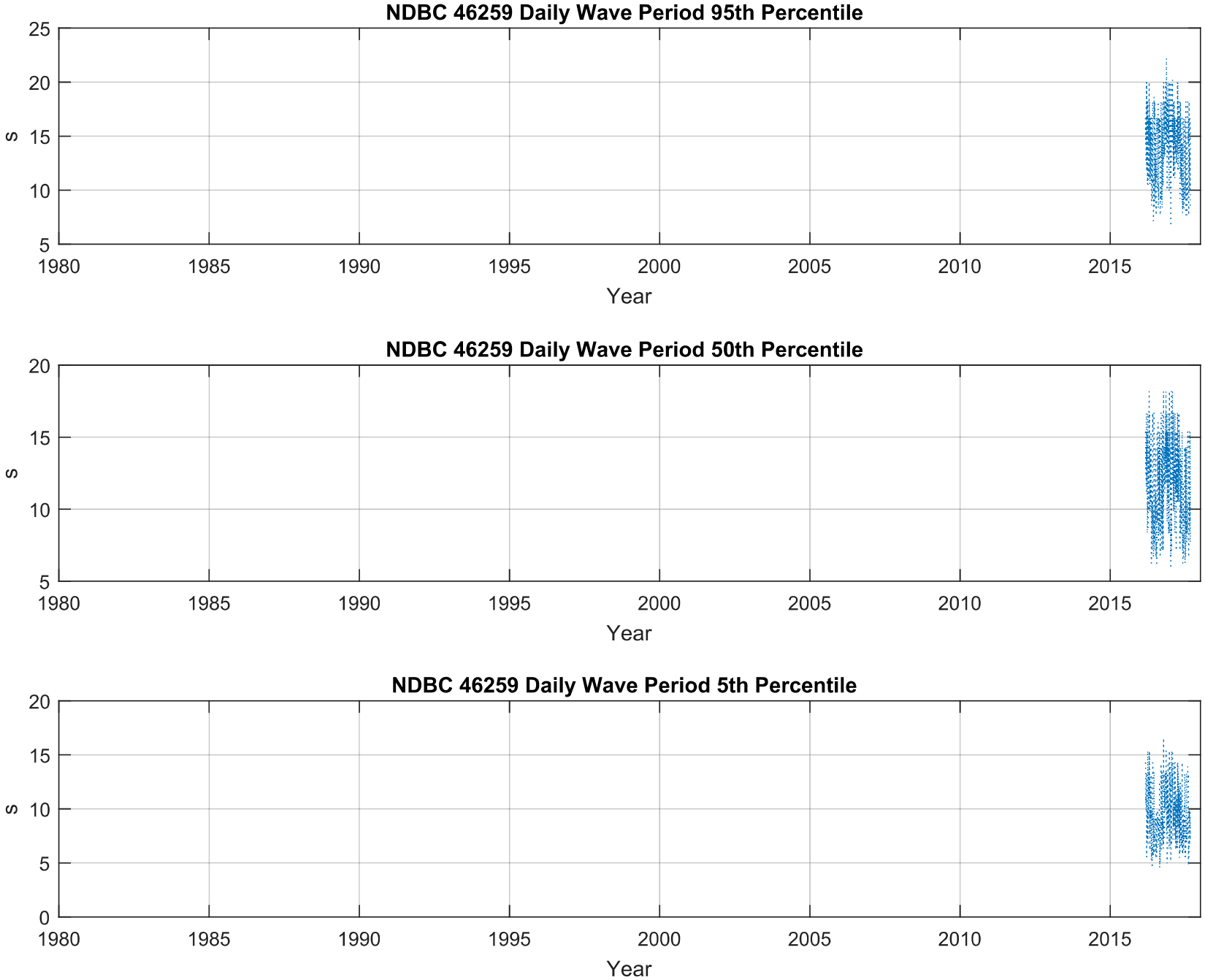


Figure A278. Daily Wave Period, Percentiles,NDBC 46259

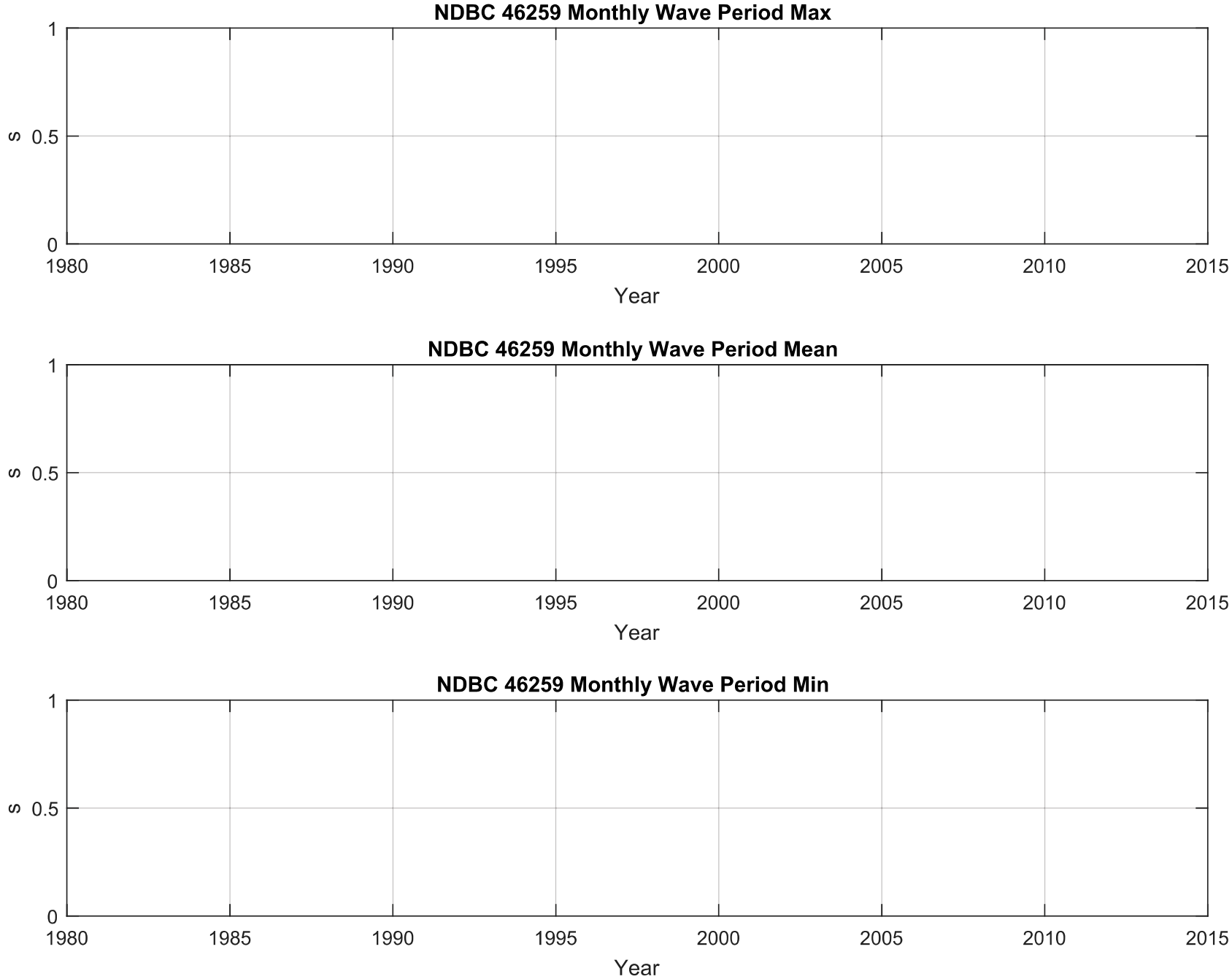
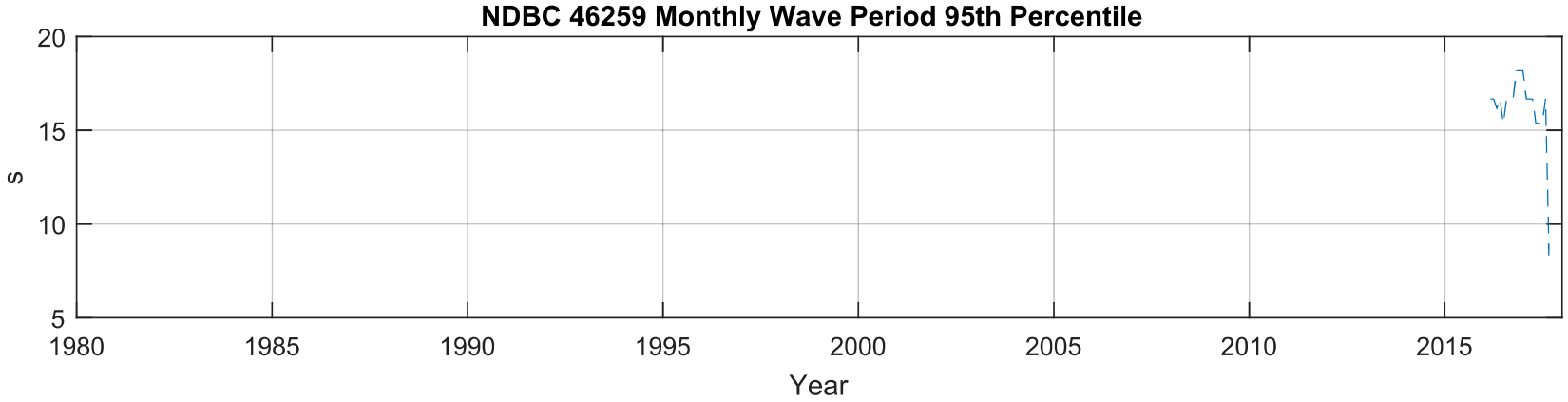
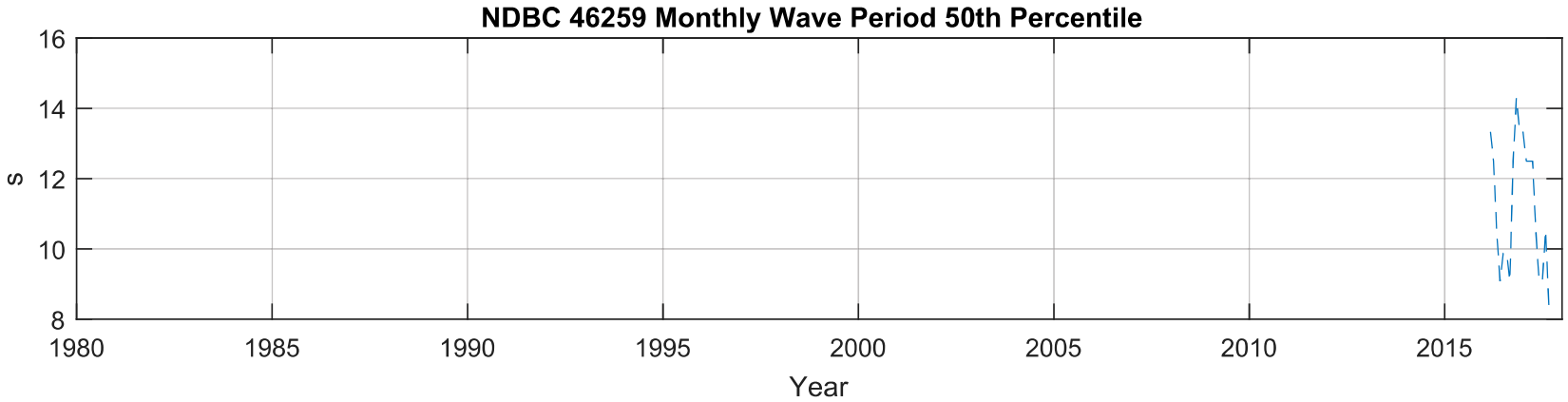


Figure A279. Monthly Wave Period, Max, Mean, Min,NDBC 46259





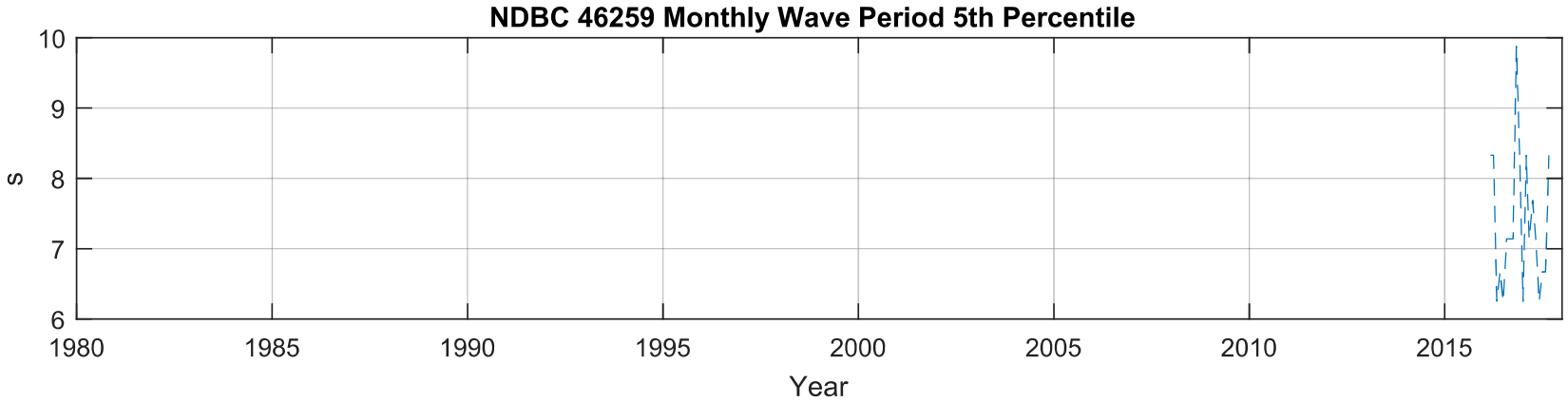


Figure A280. Monthly Wave Period, Percentiles,NDBC 46259

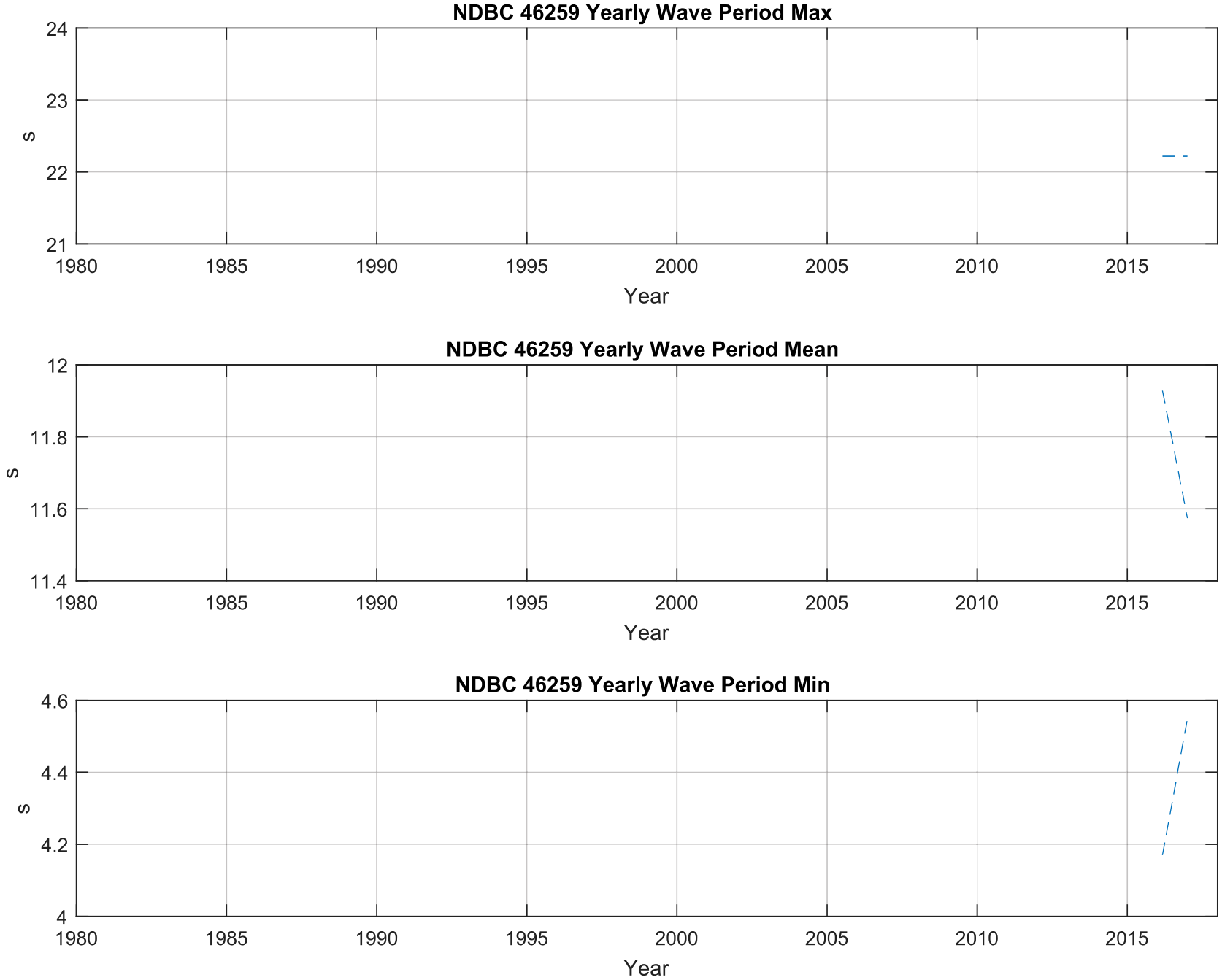
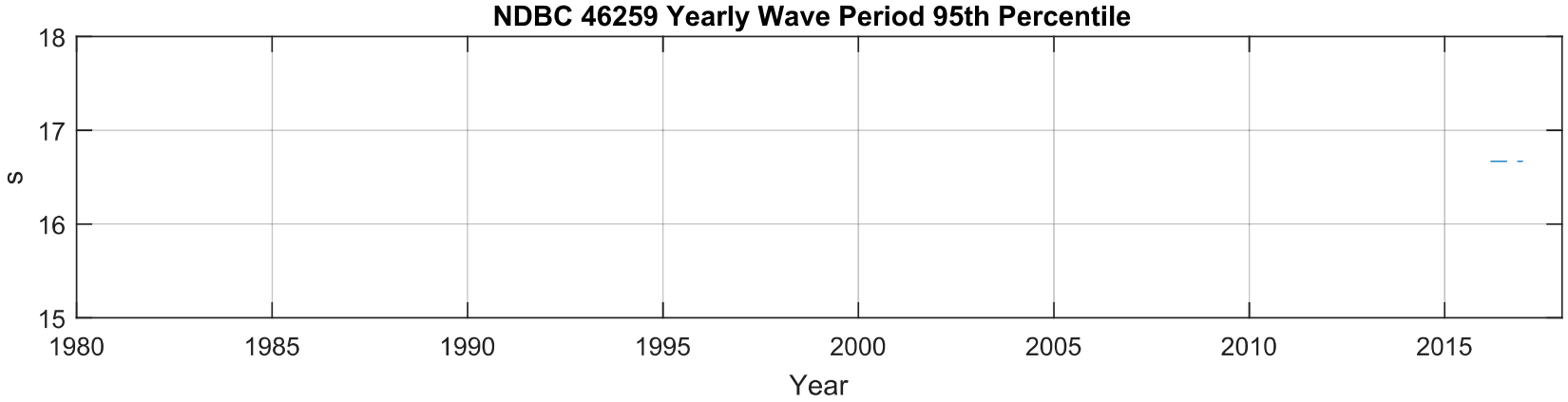
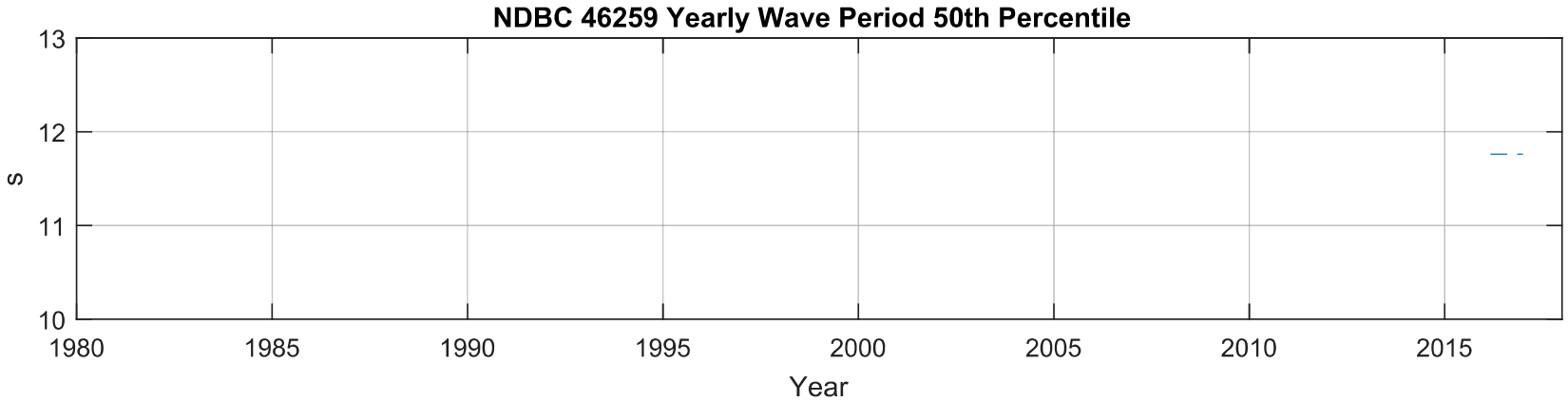


Figure A281. Yearly Wave Period, Max, Mean, Min,NDBC 46259





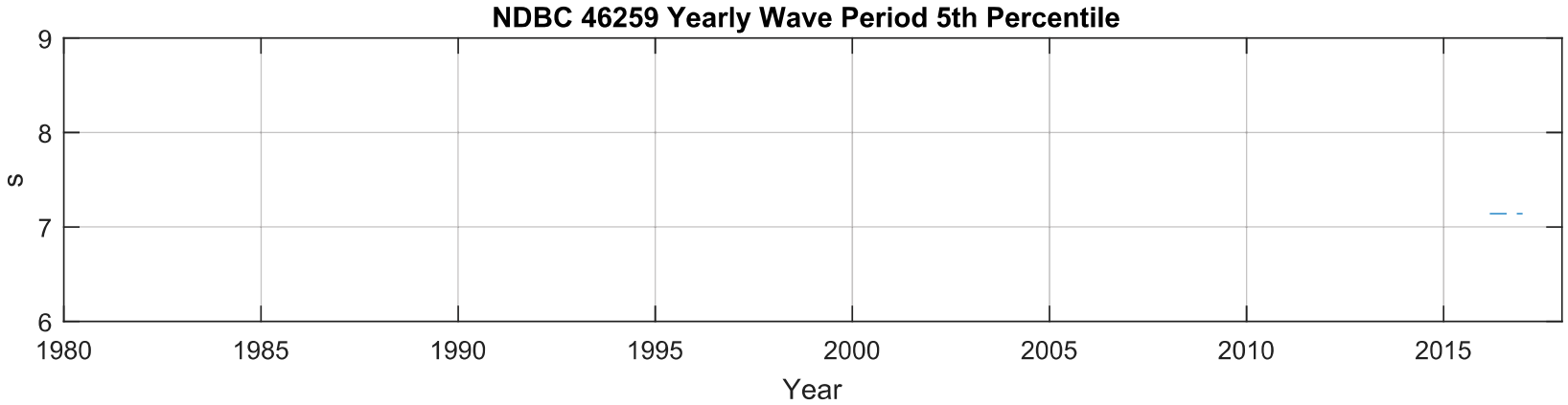
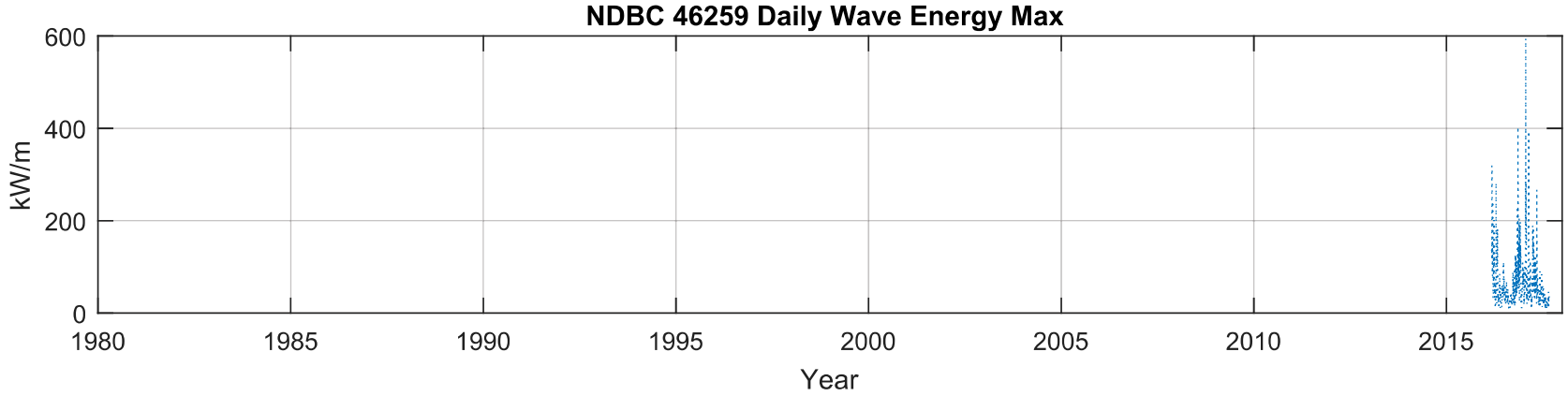
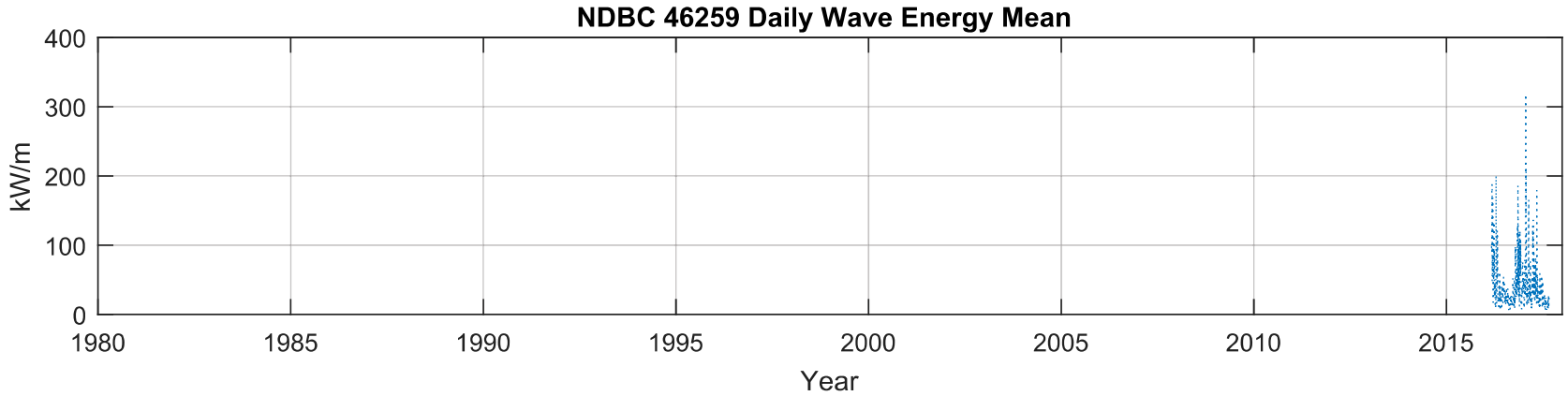


Figure A282. Yearly Wave Period, Percentiles,NDBC 46259





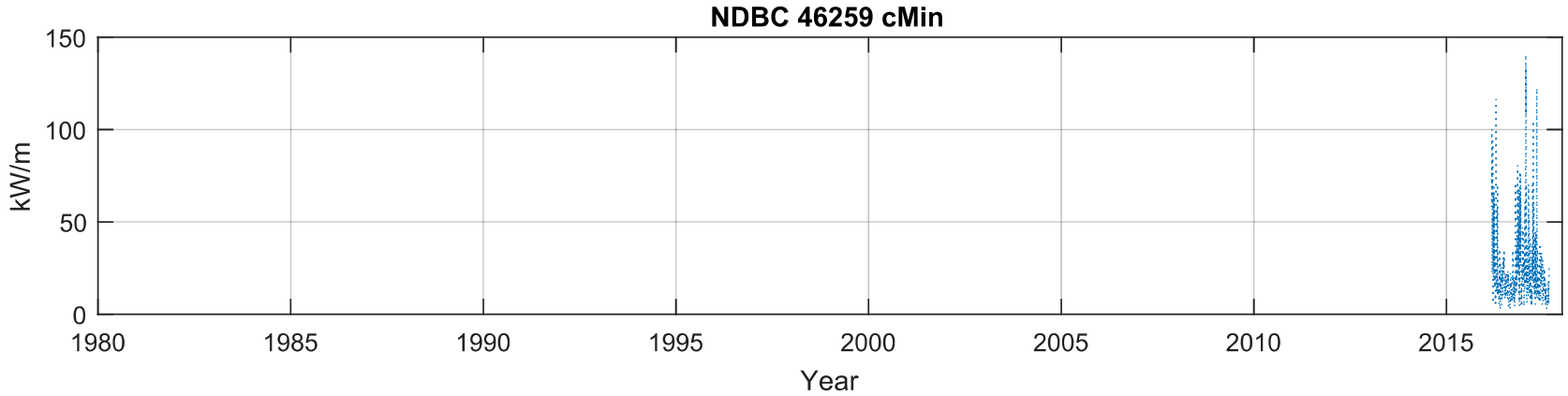
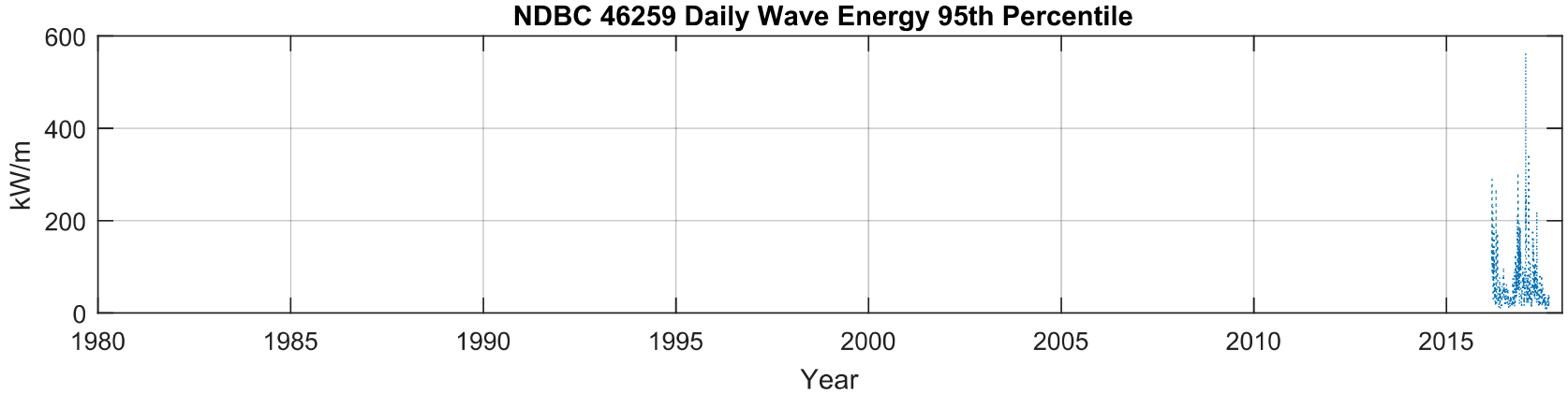
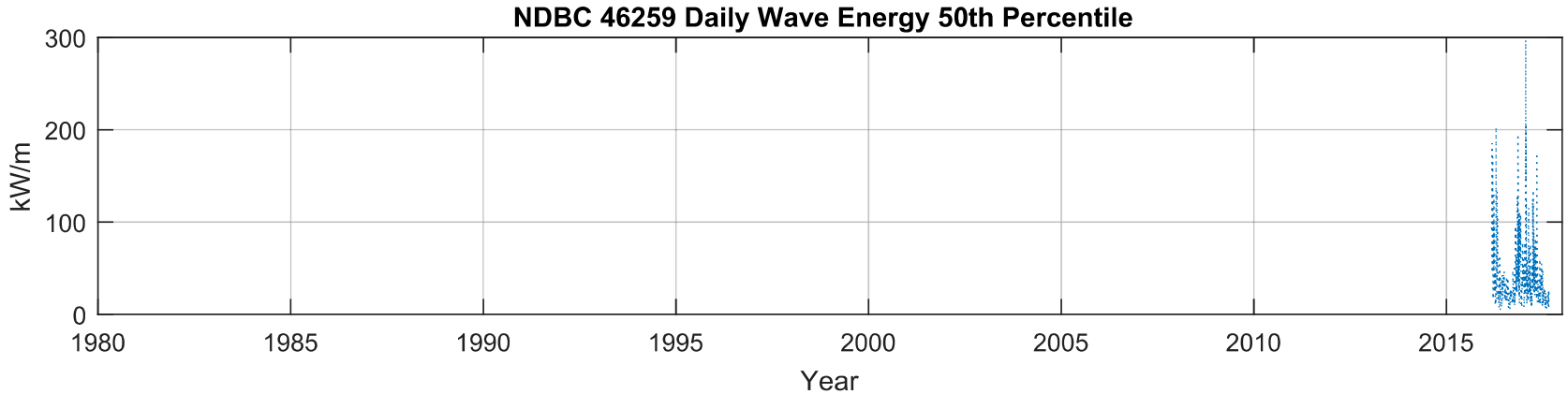


Figure A283. Daily Wave Energy, Max, Mean, Min,NDBC 46259





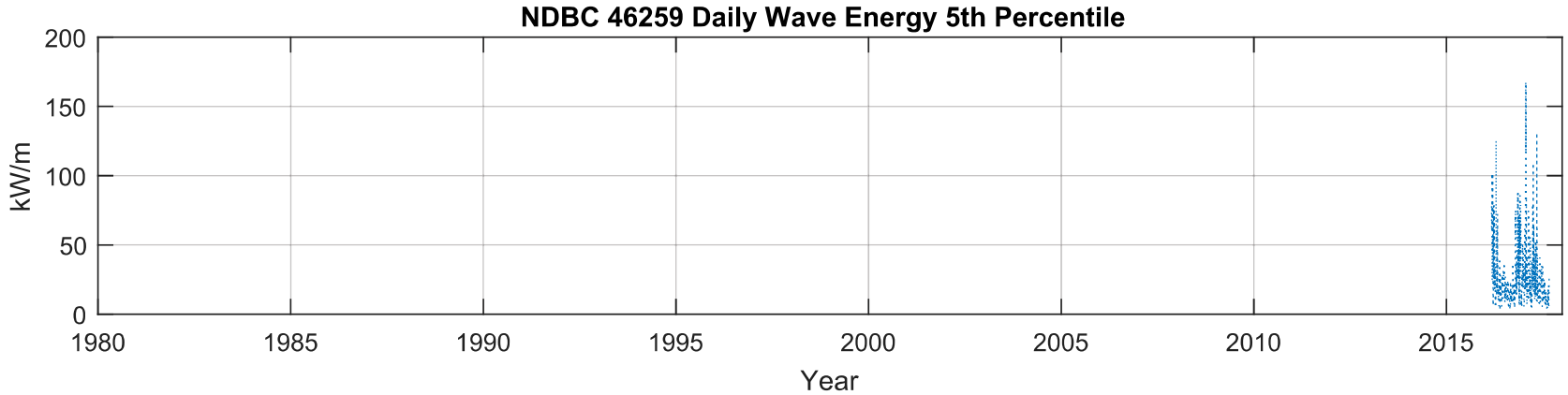
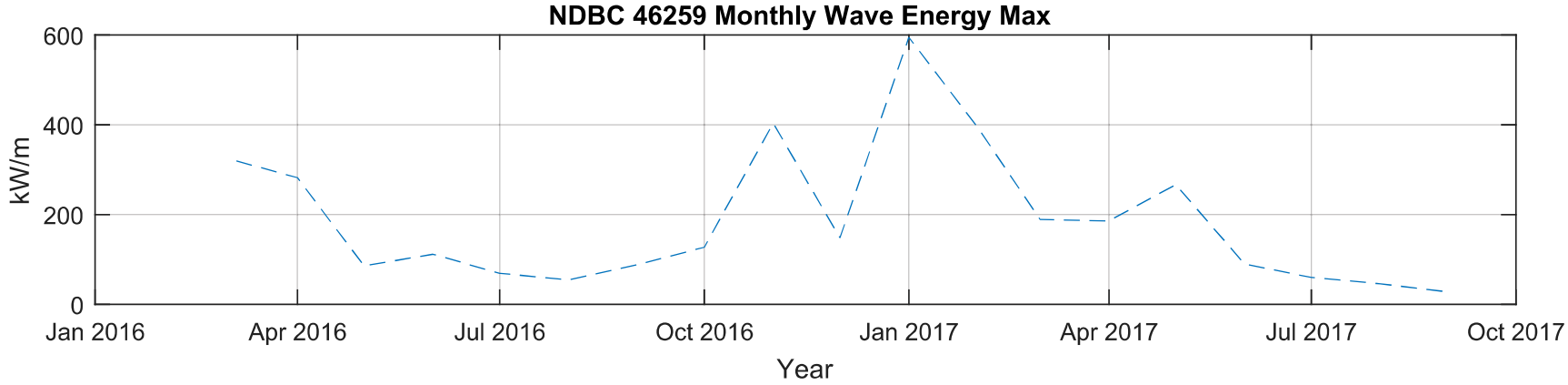
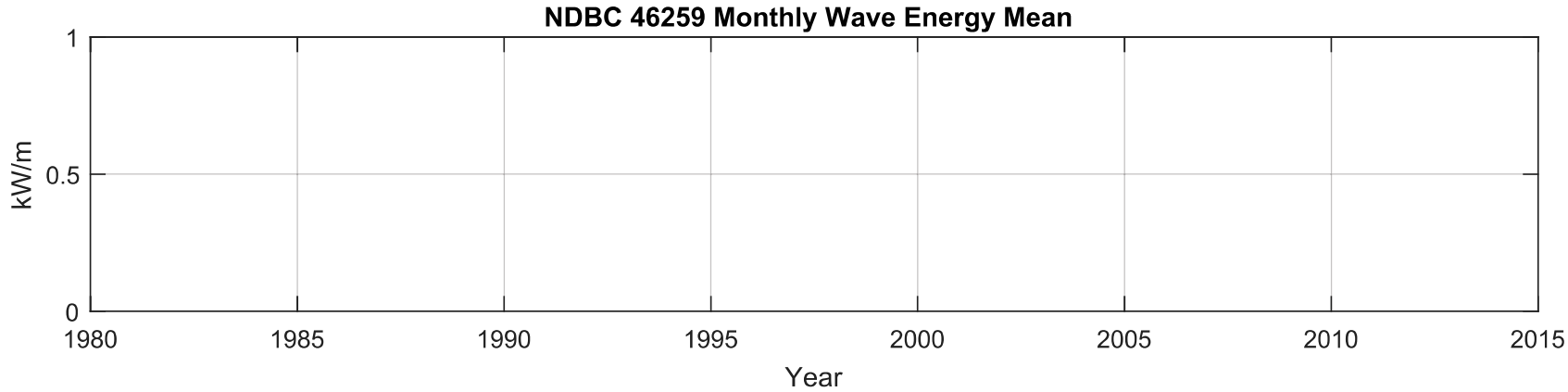


Figure A284. Daily Wave Energy, Percentiles,NDBC 46259





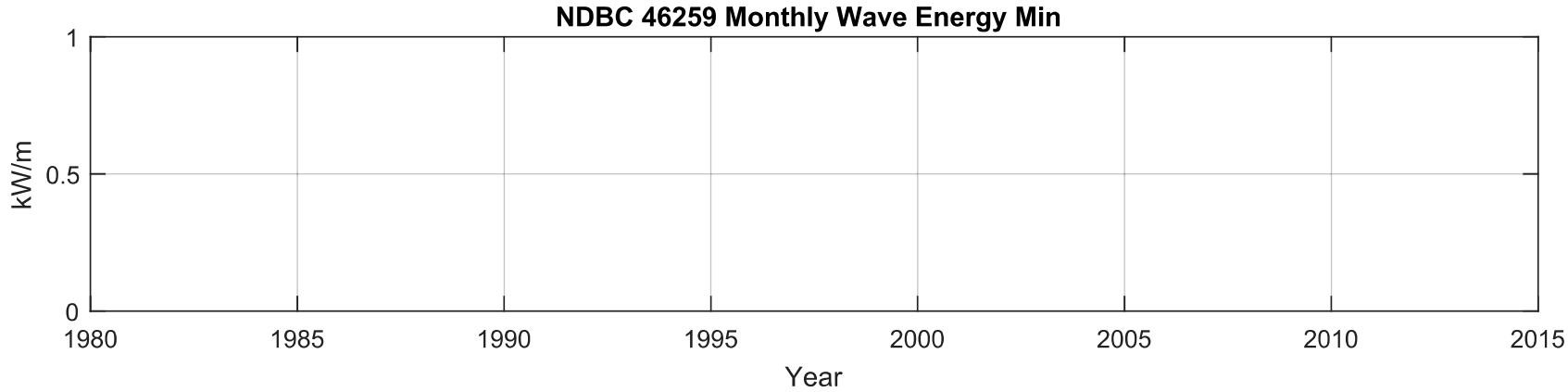
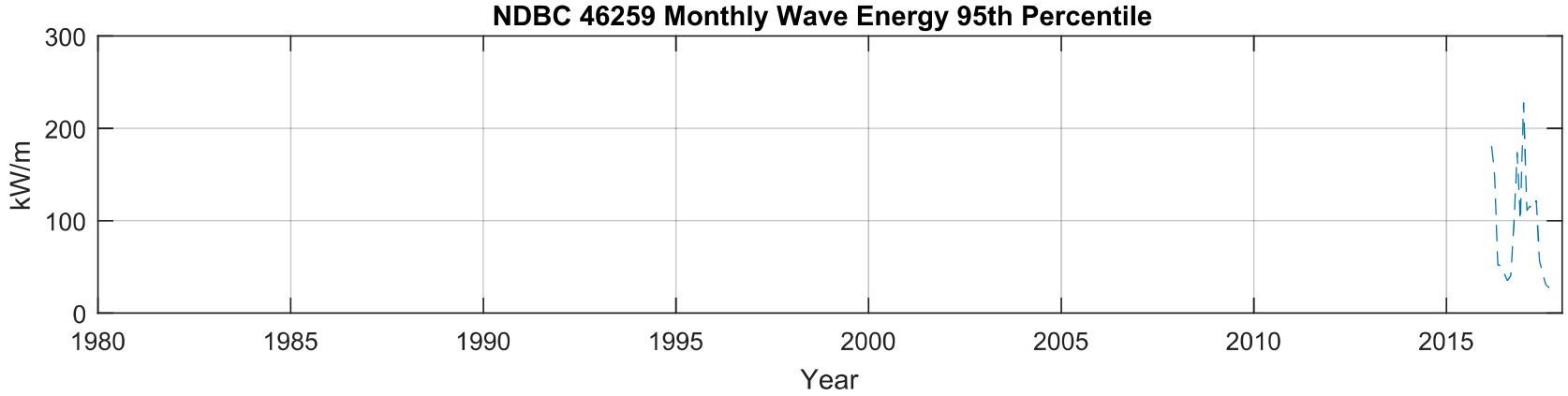
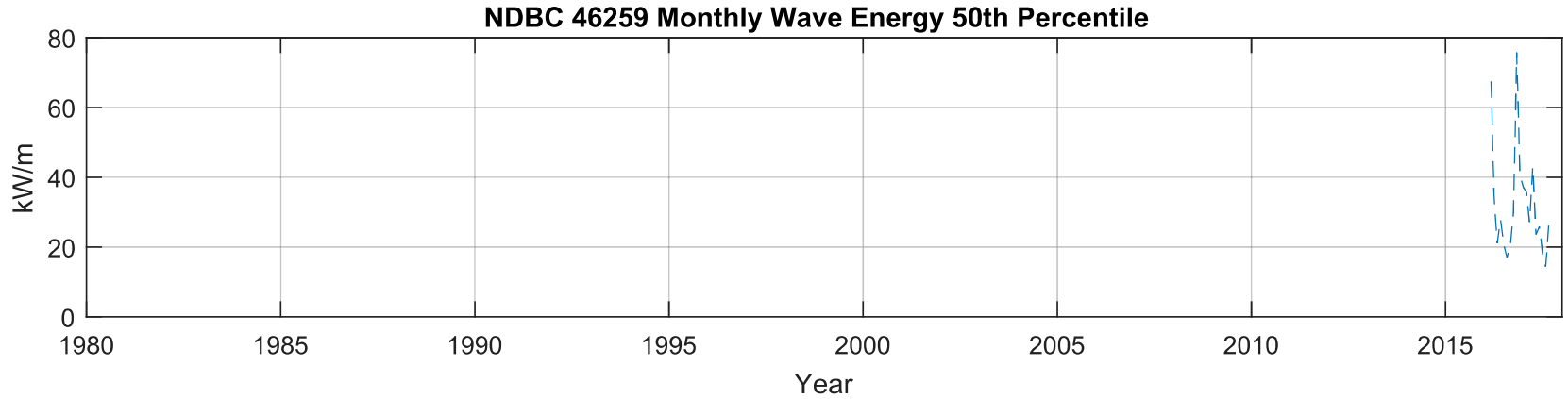


Figure A285. Monthly Wave Energy, Max, Mean, Min,NDBC 46259





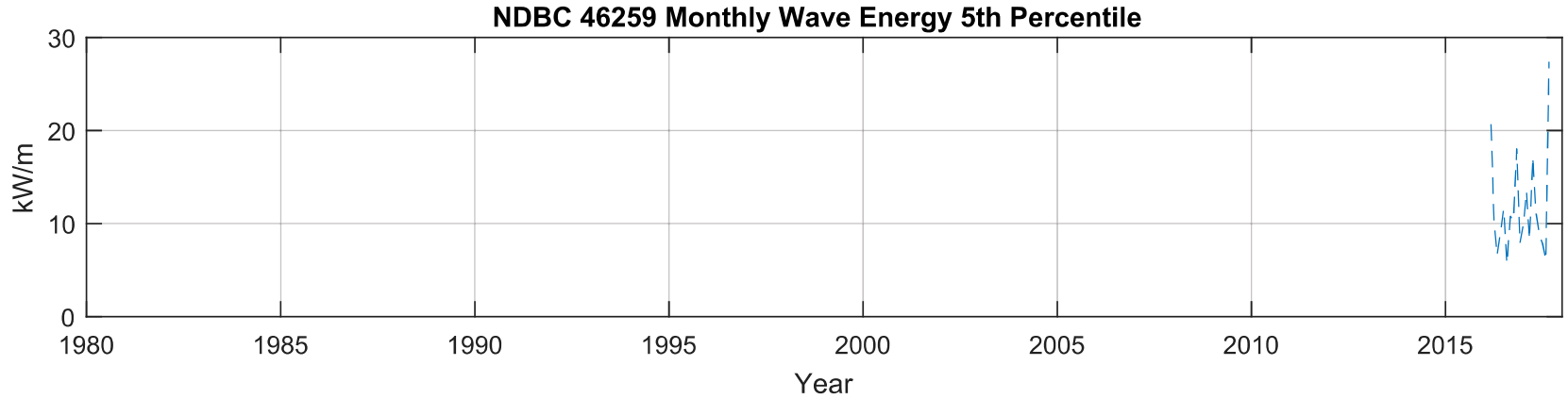
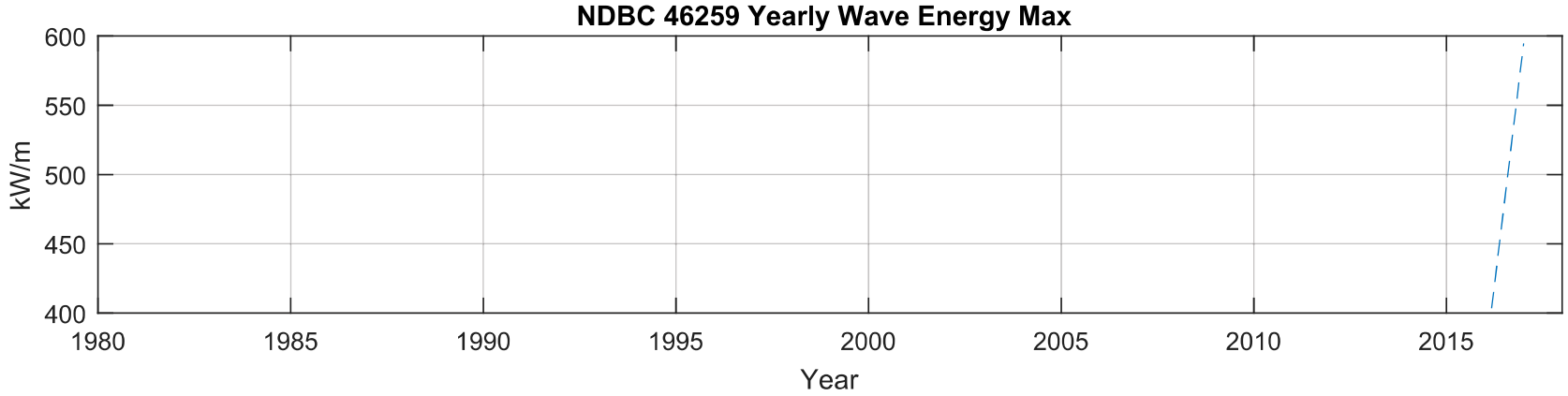
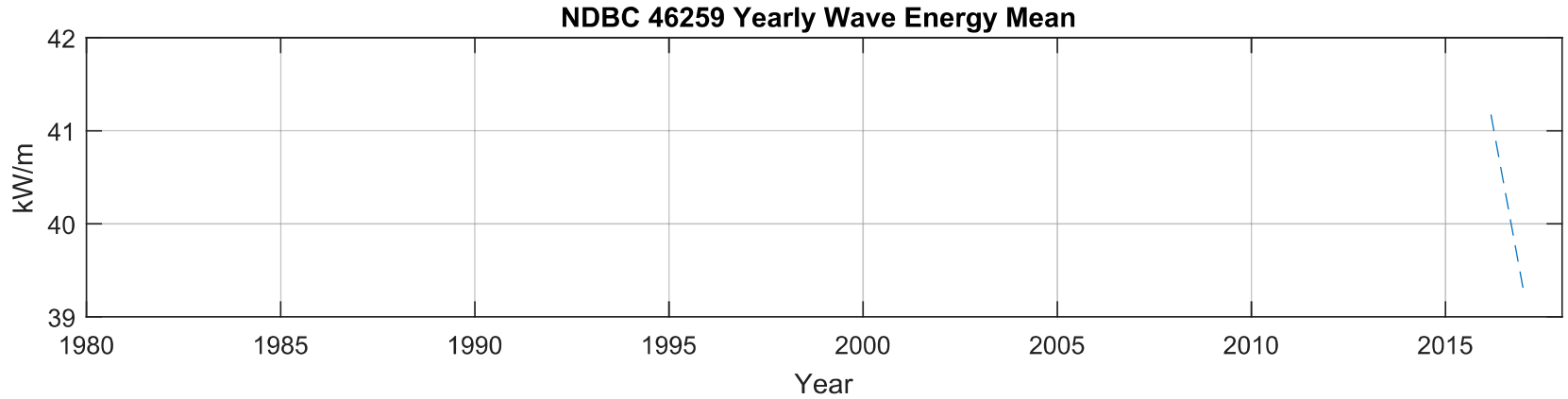


Figure A286. Monthly Wave Energy, Percentiles,NDBC 46259





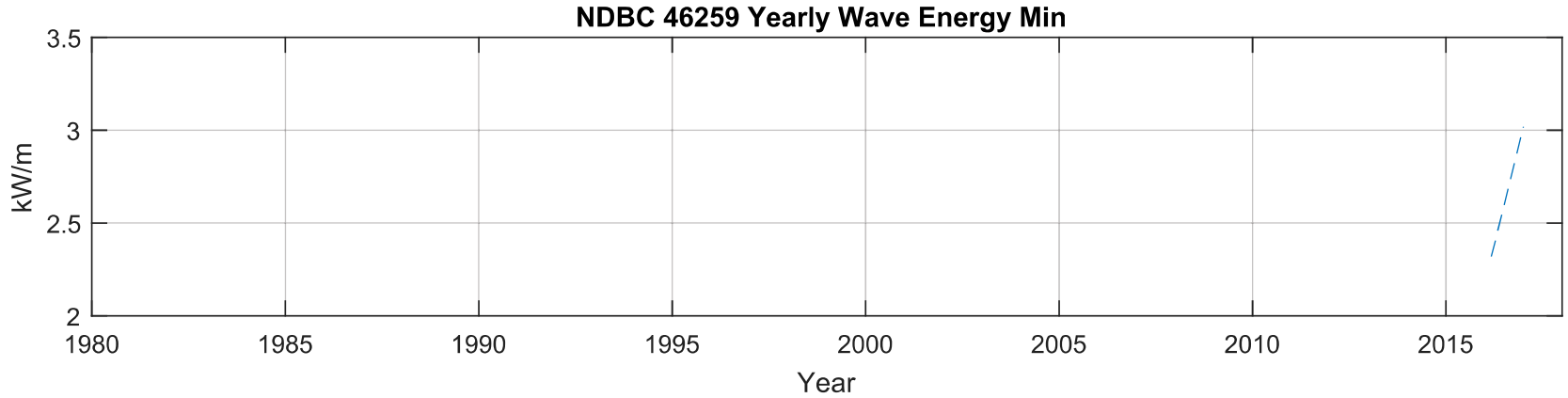
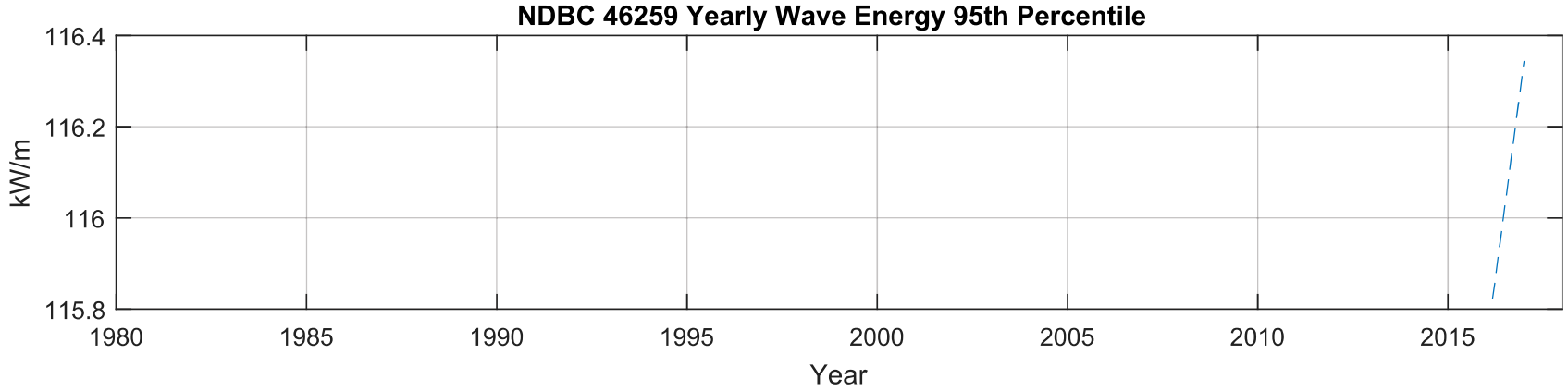
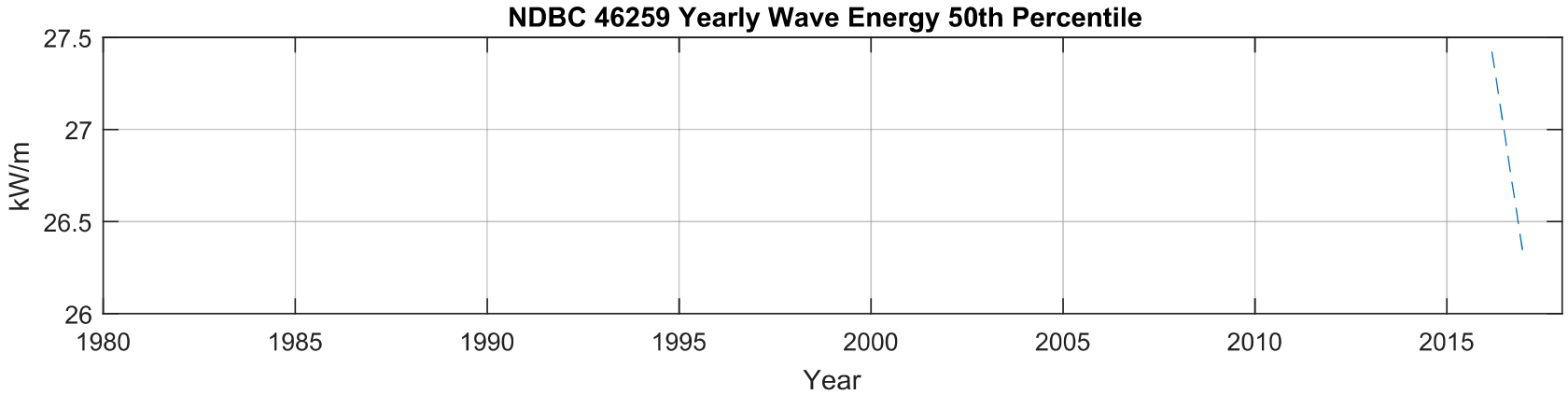


Figure A287. Yearly Wave Energy, Max, Mean, Min,NDBC 46259





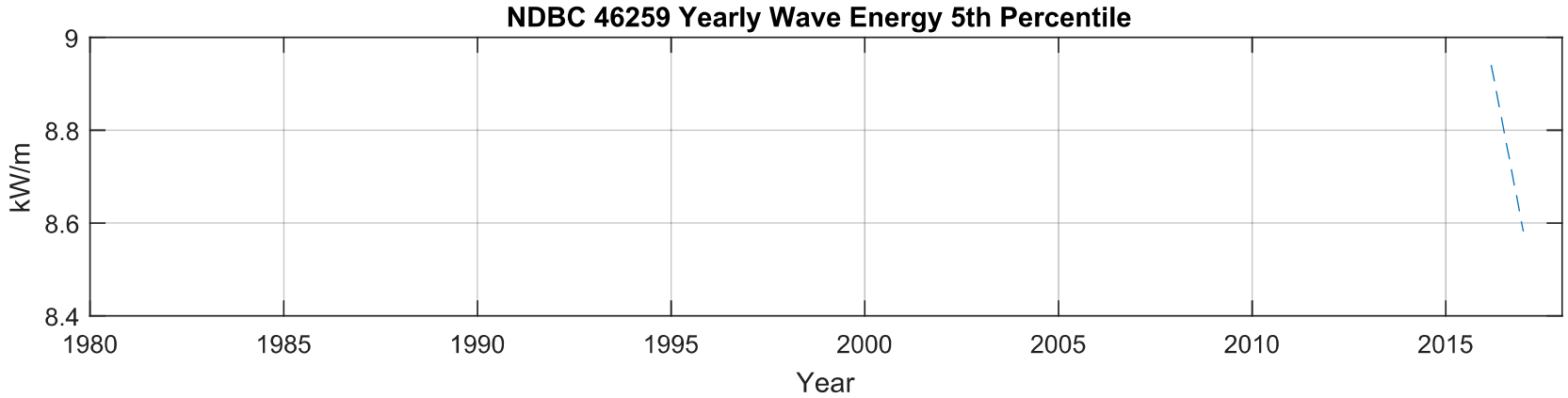


Figure A288. Yearly Wave Energy, Percentiles,NDBC 46259

APPENDIX B: Cross Correlated Data for Wave Height, Period, and Direction, by Buoy

(Appendix B is included as a separate file due to size)

Figure B001: Cross Correlations for Wave Height, Period, and Direction for NDBC 46011 and NDBC 46012.

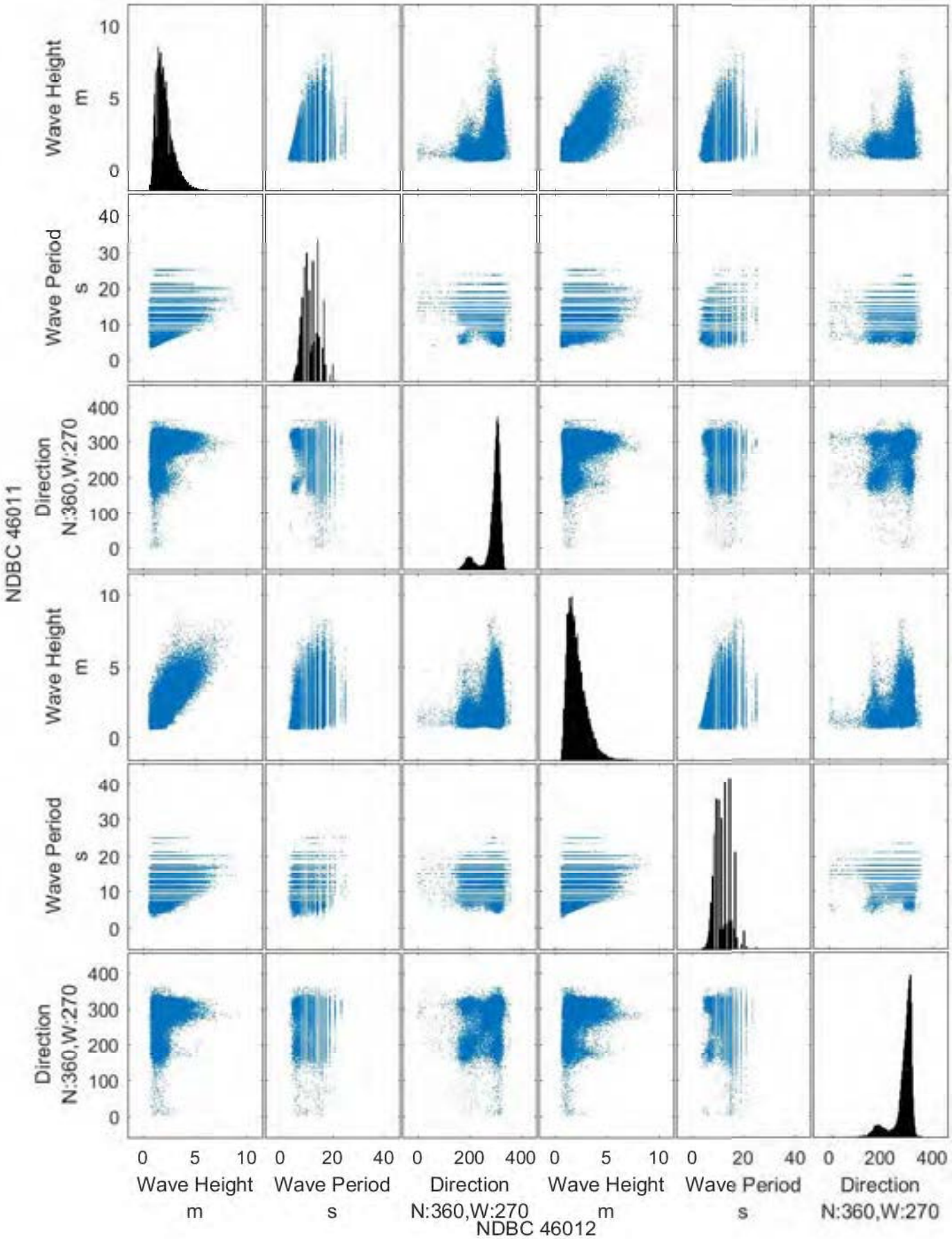


Figure B002: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46023.

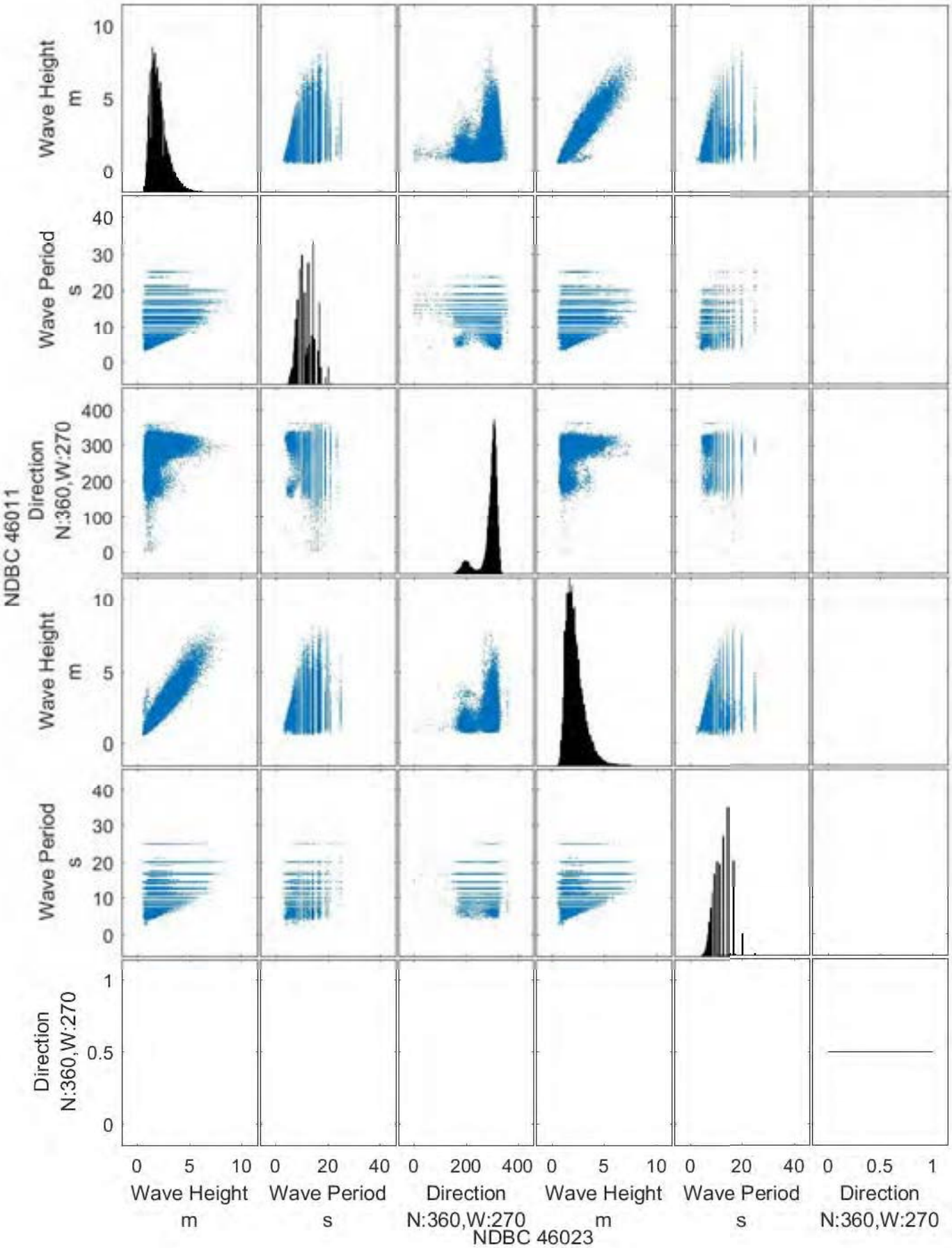


Figure B003: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46028.

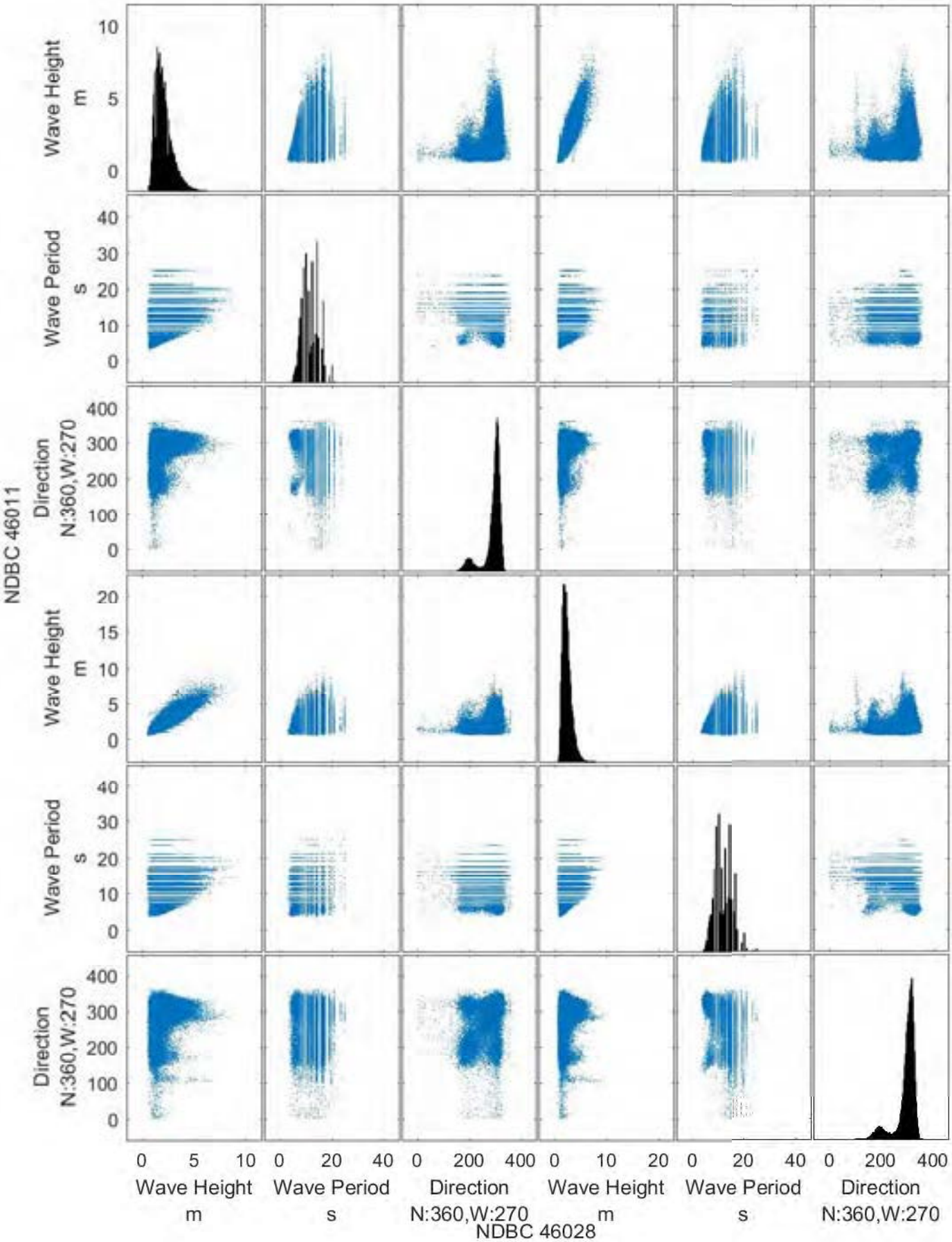


Figure B004: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46042.

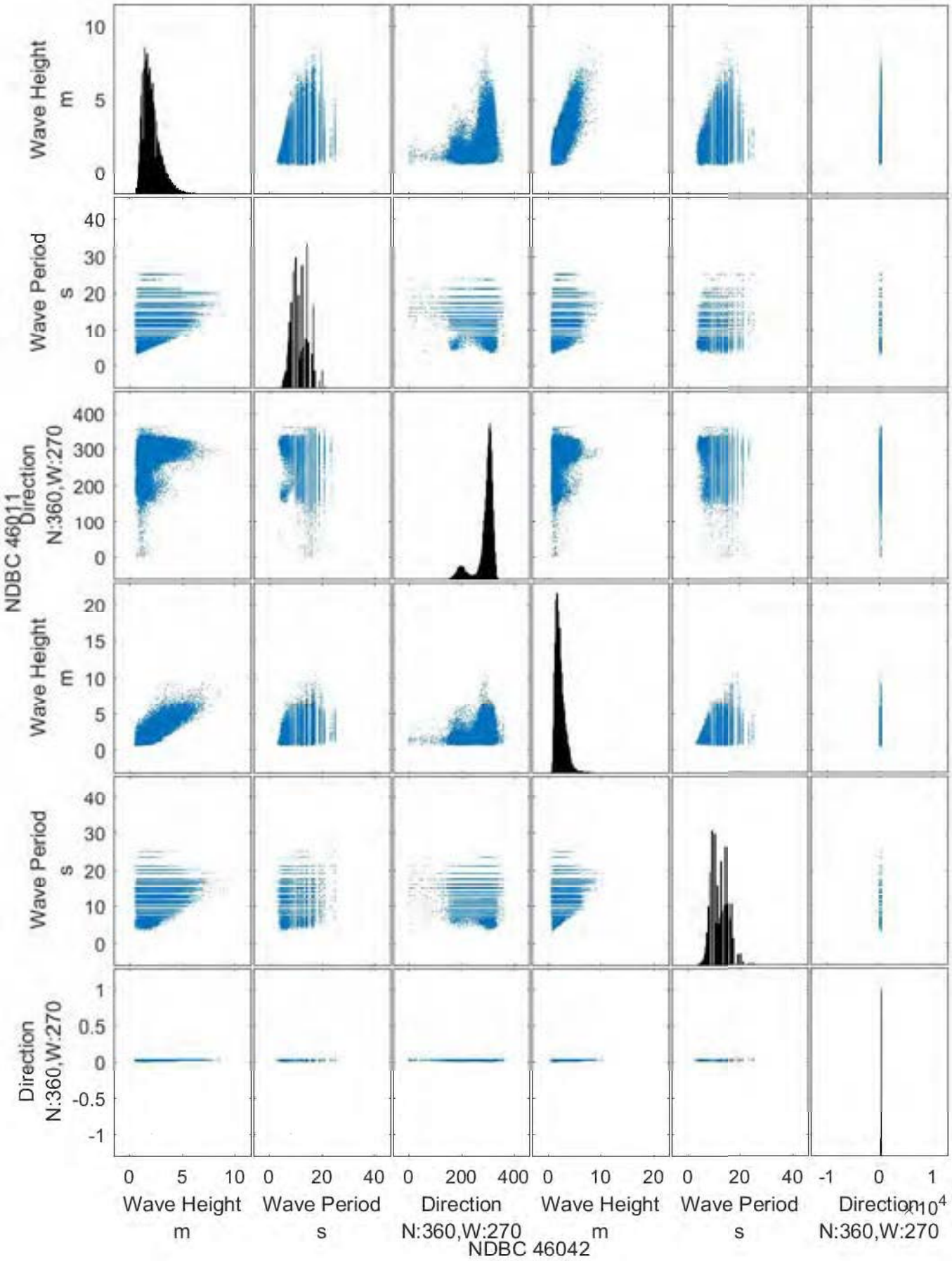


Figure B005: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46047.

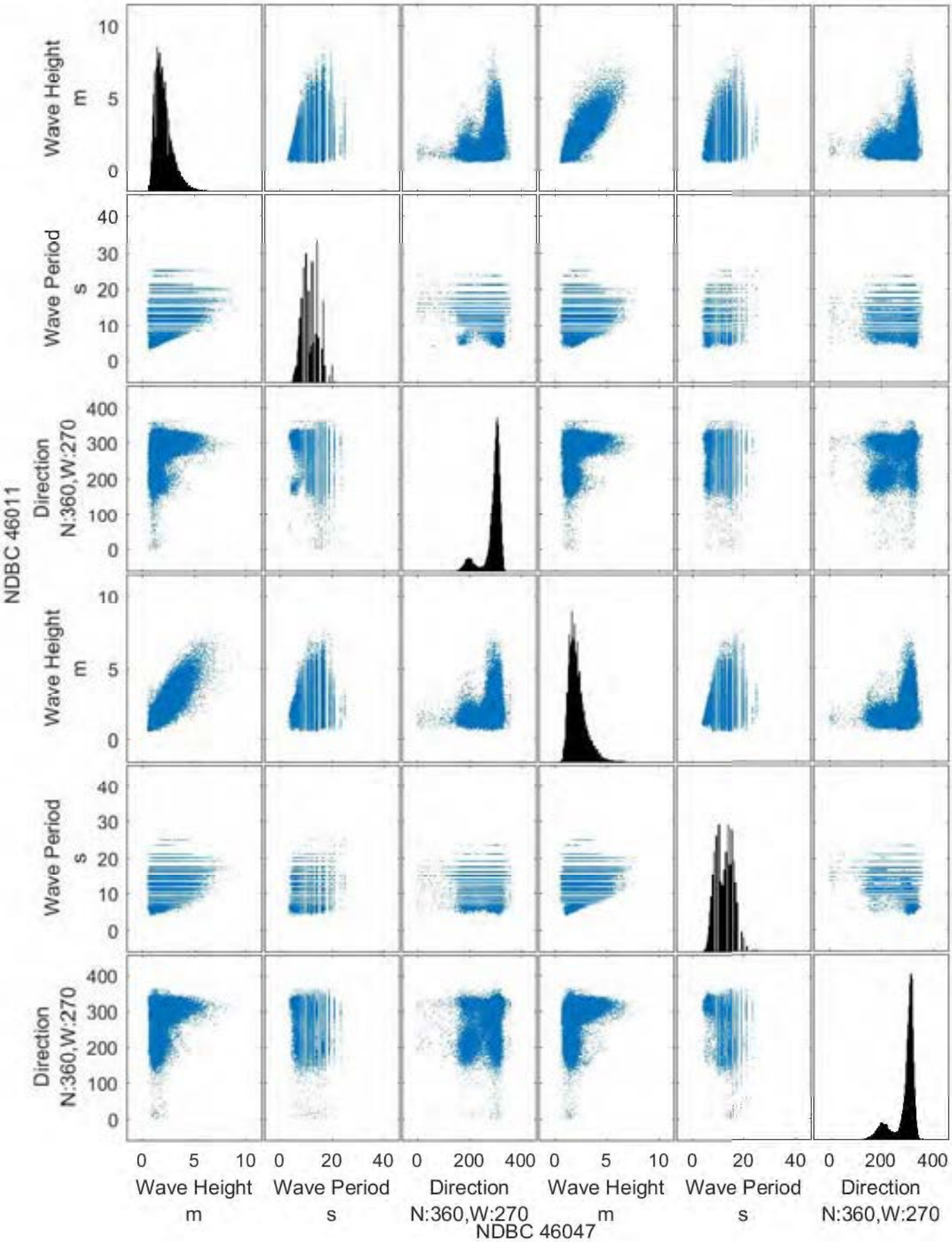


Figure B006: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46053.

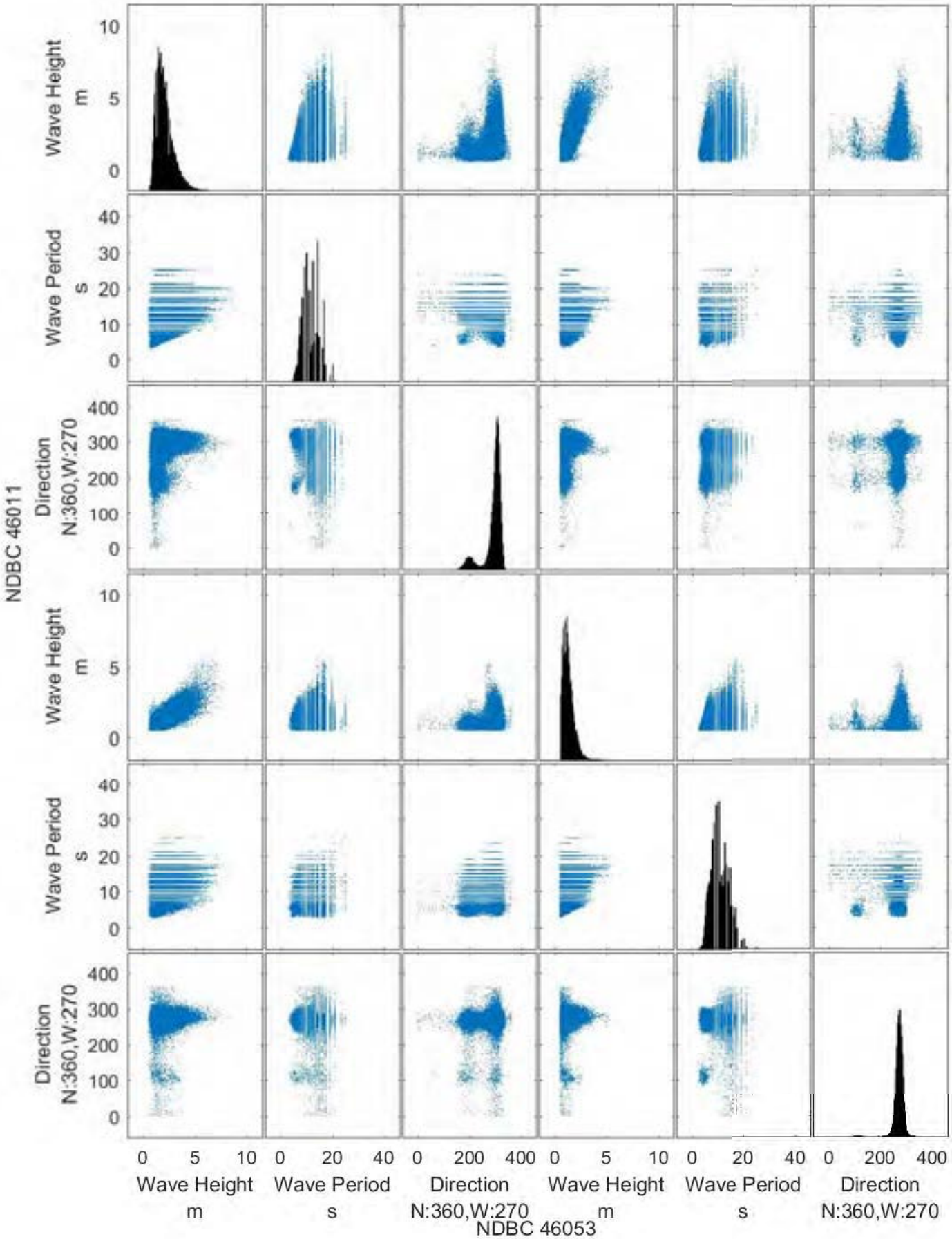


Figure B007: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46054.

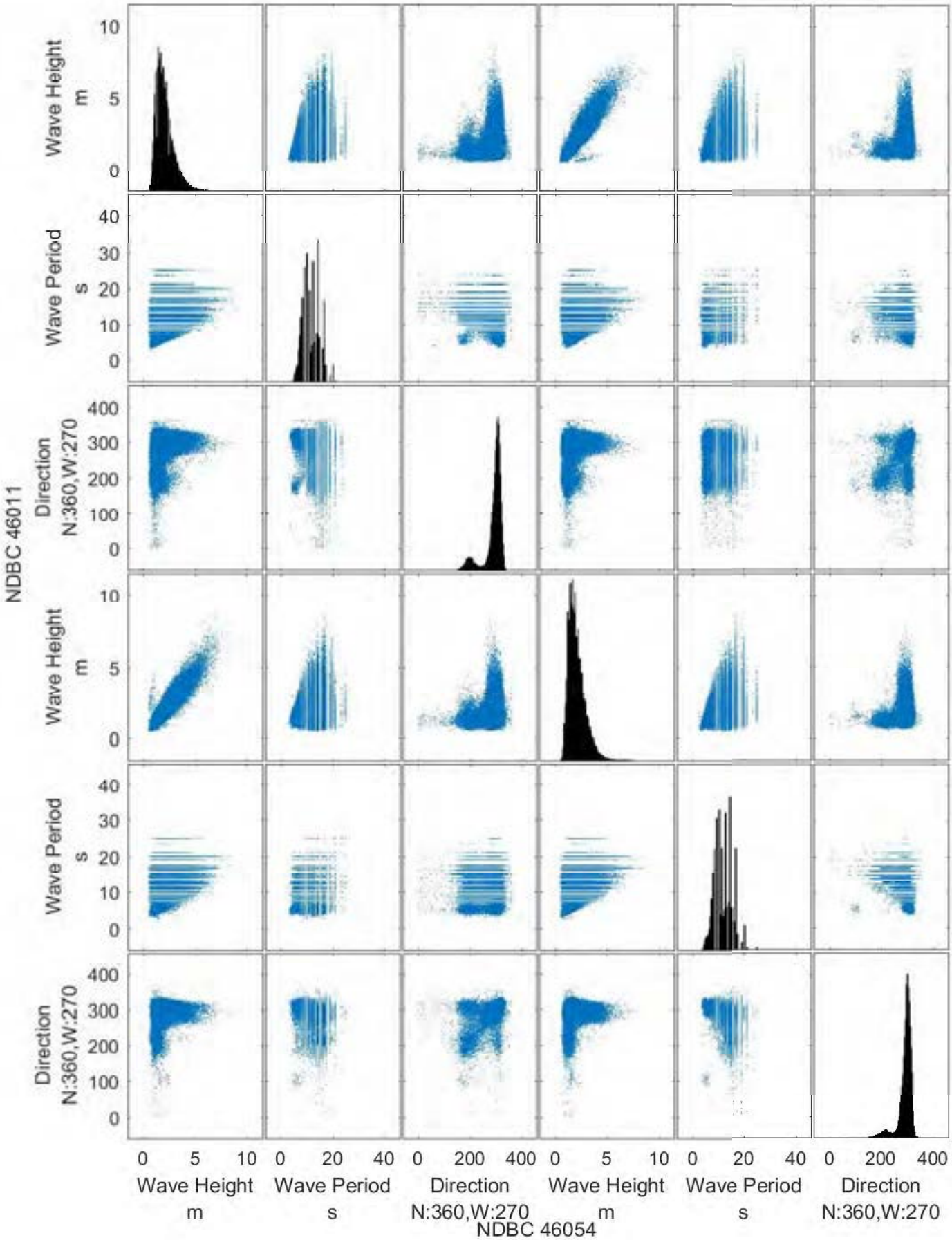


Figure B008: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46069.

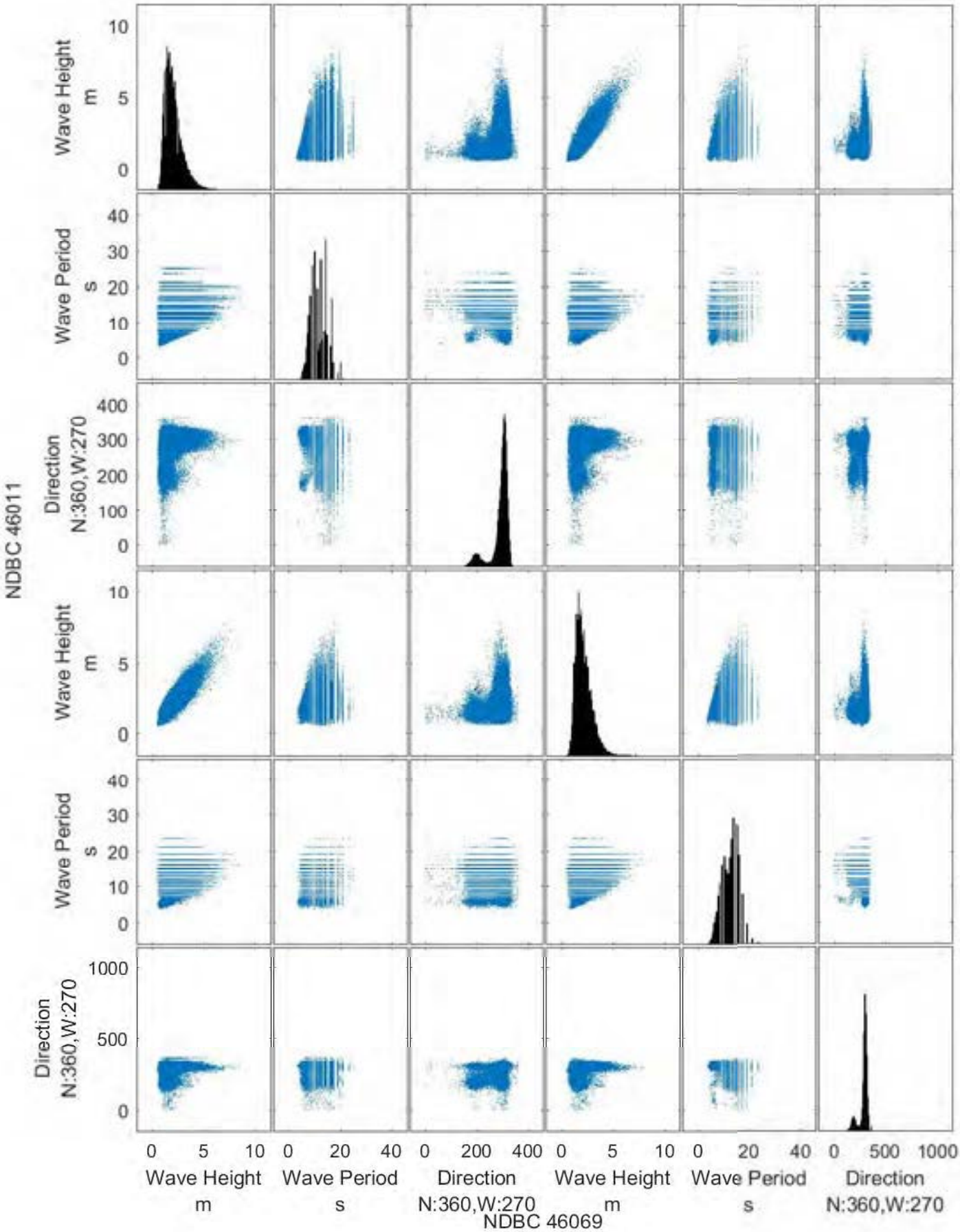


Figure B009: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46114.

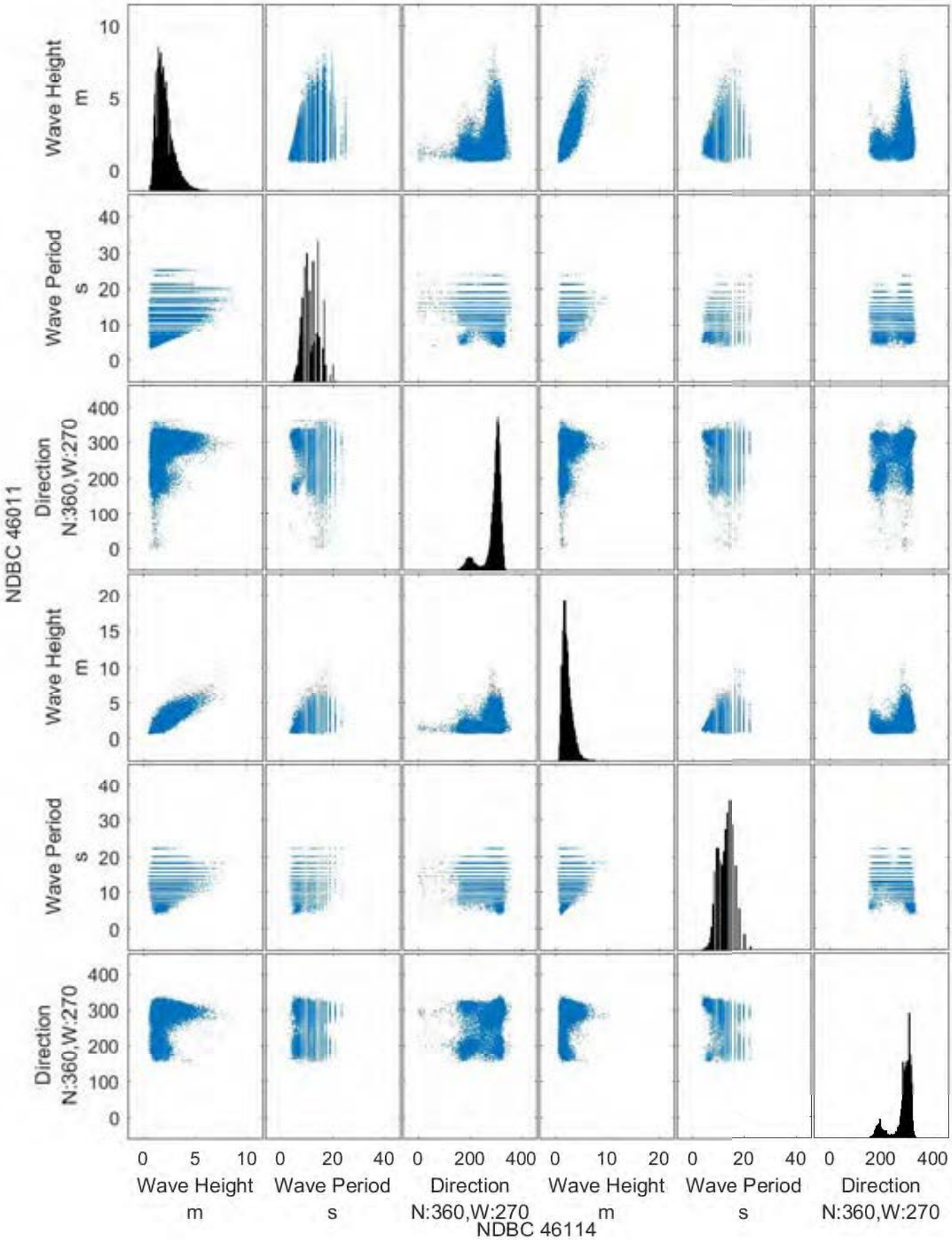


Figure B010: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46215.

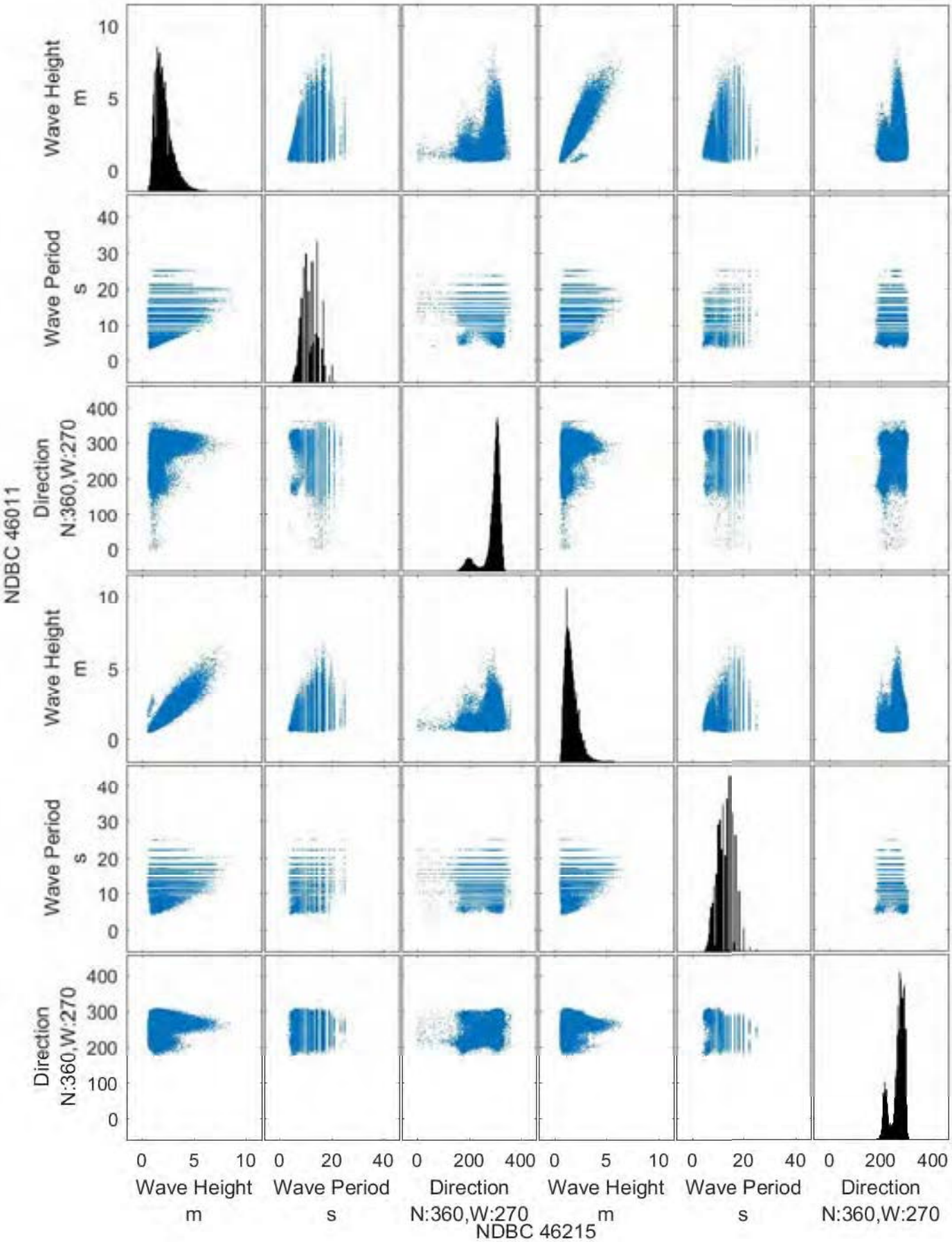


Figure B011: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46218.

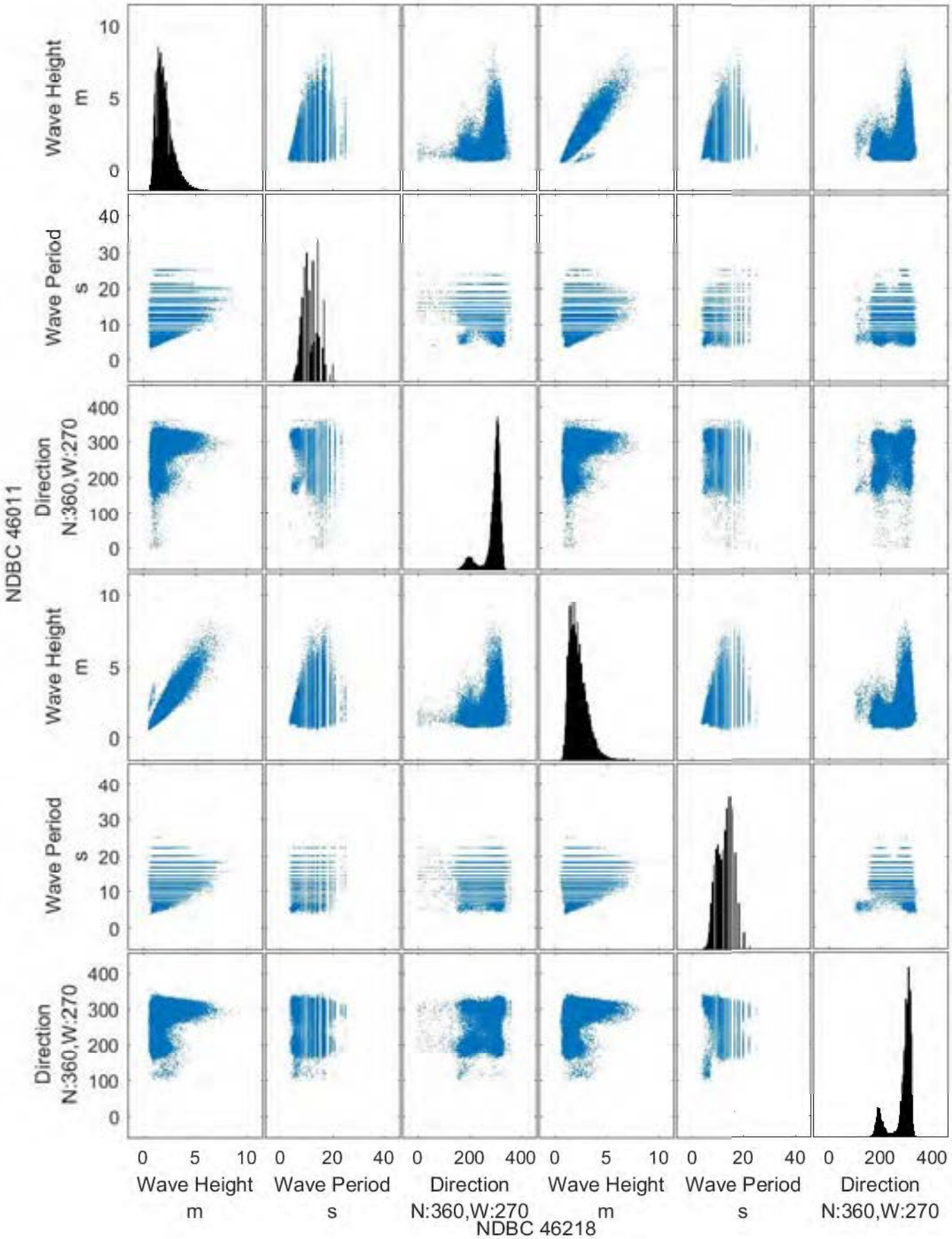


Figure B012: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46219.

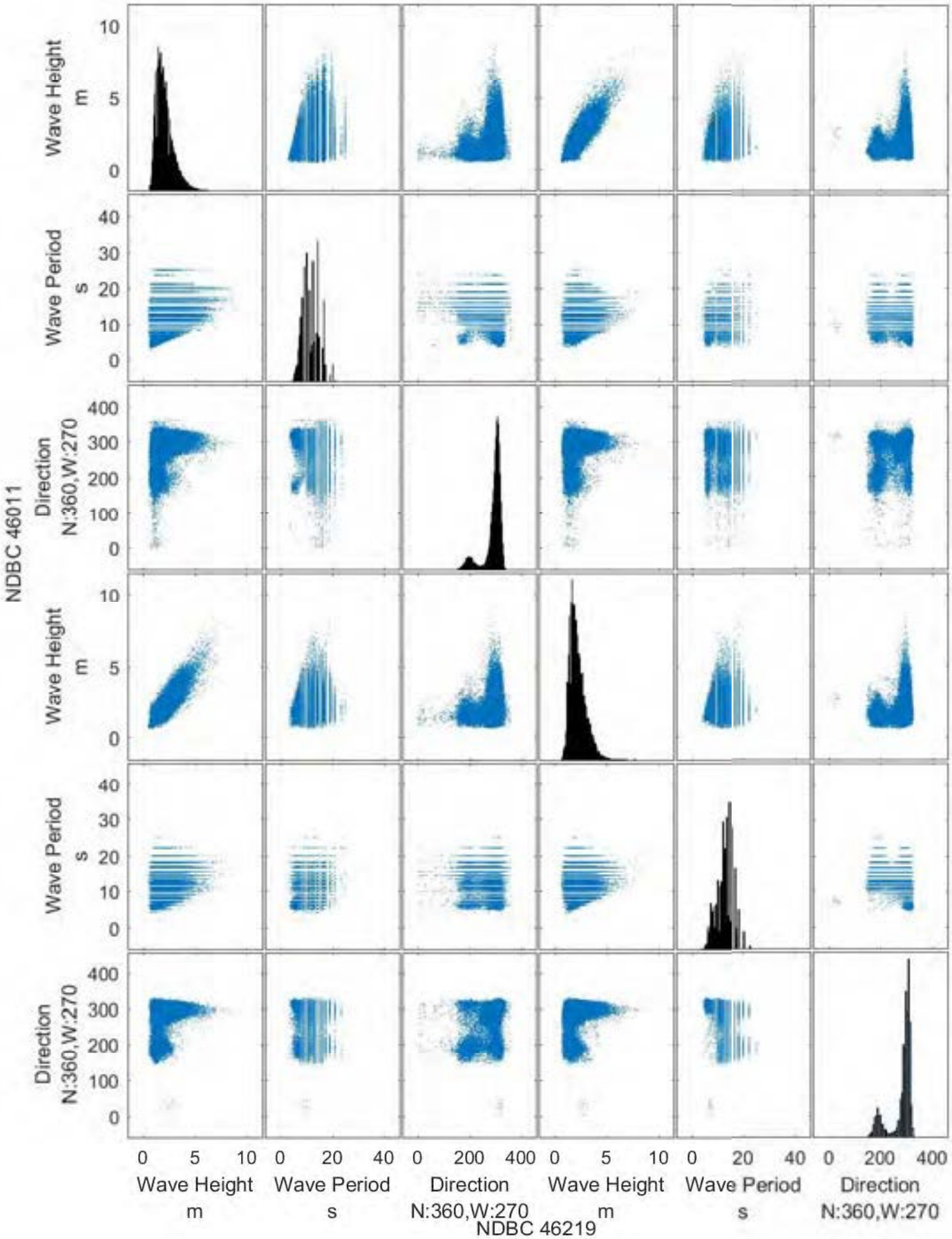


Figure B013: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46239.

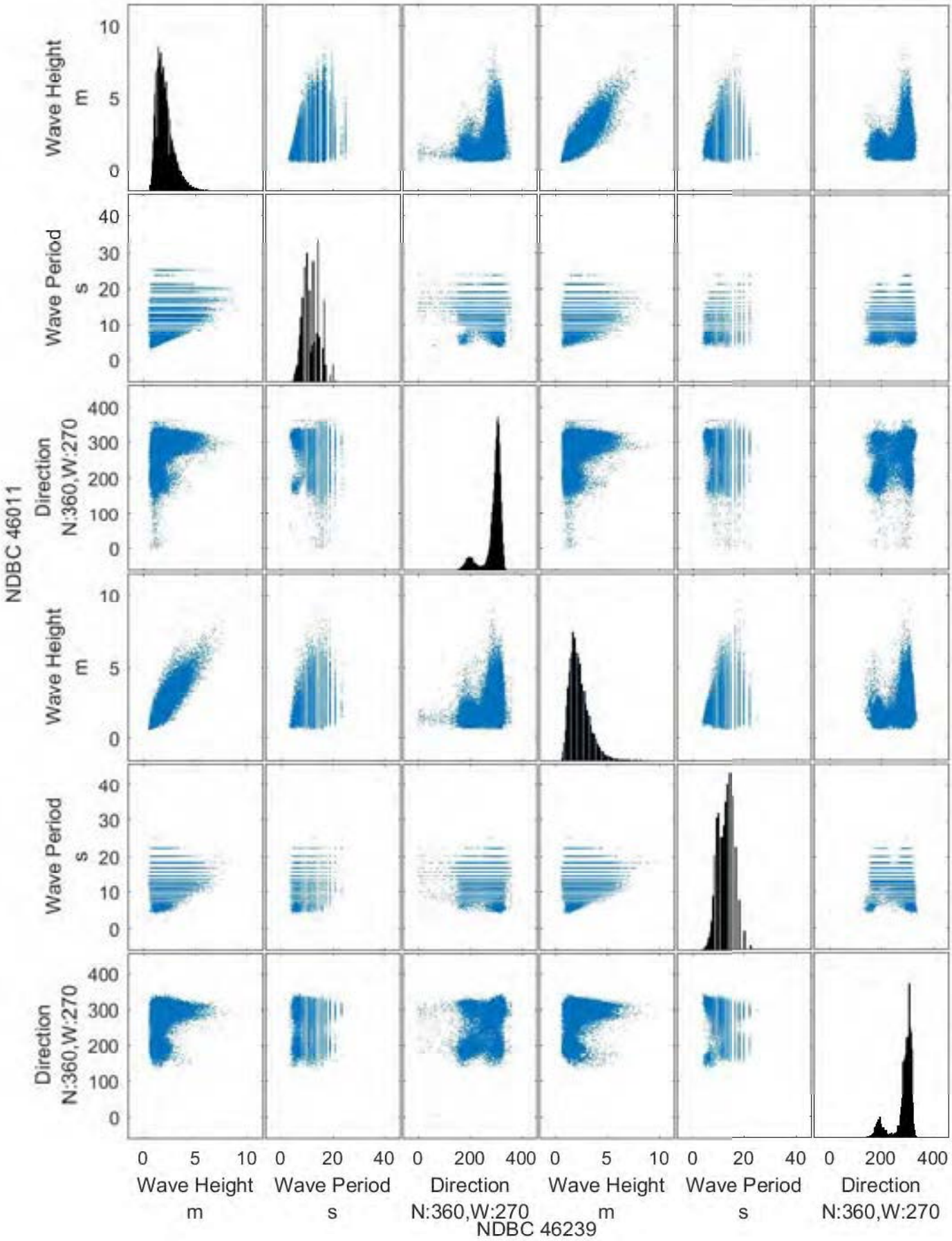


Figure B014: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46257.

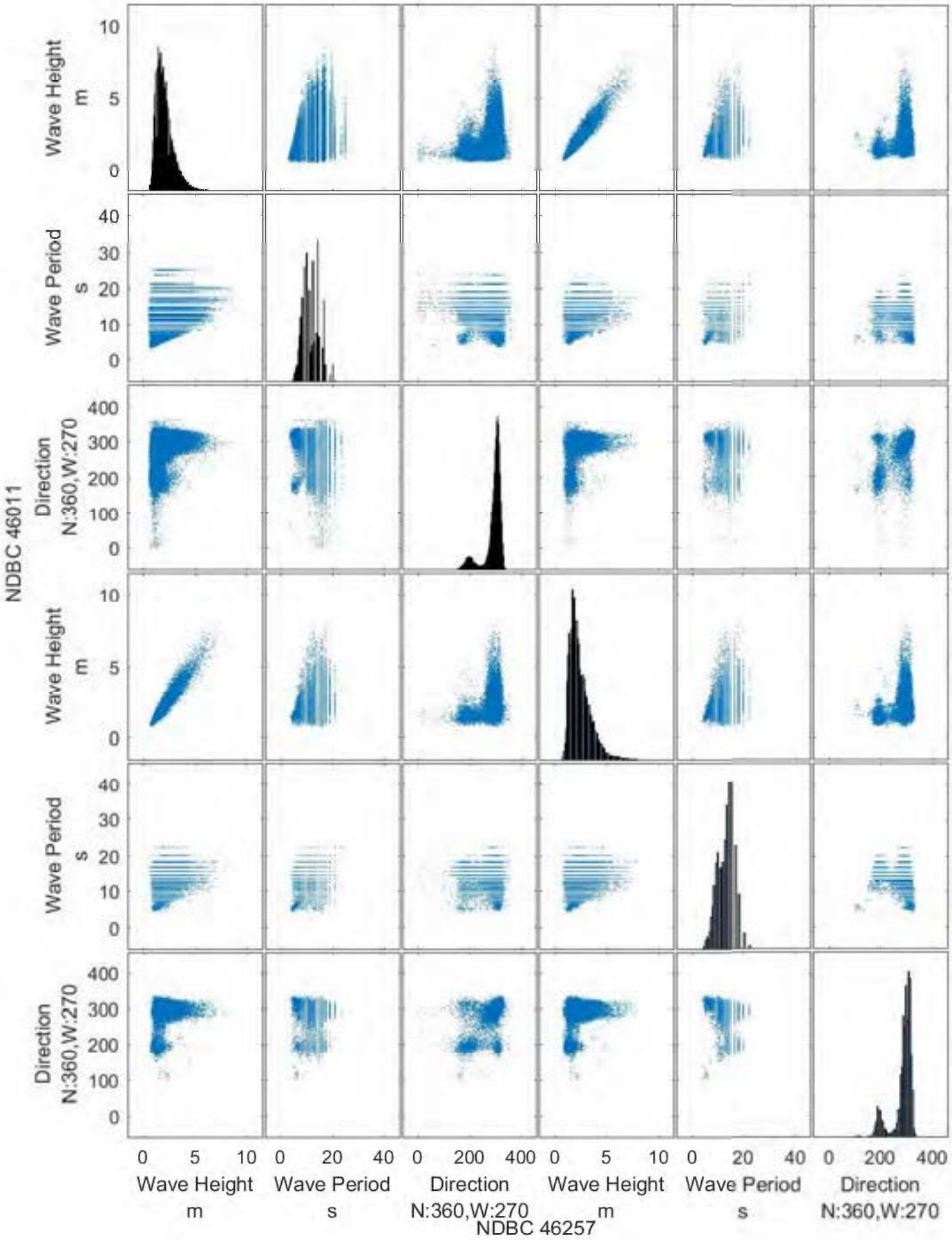


Figure B015: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46011 and NDBC 46259.

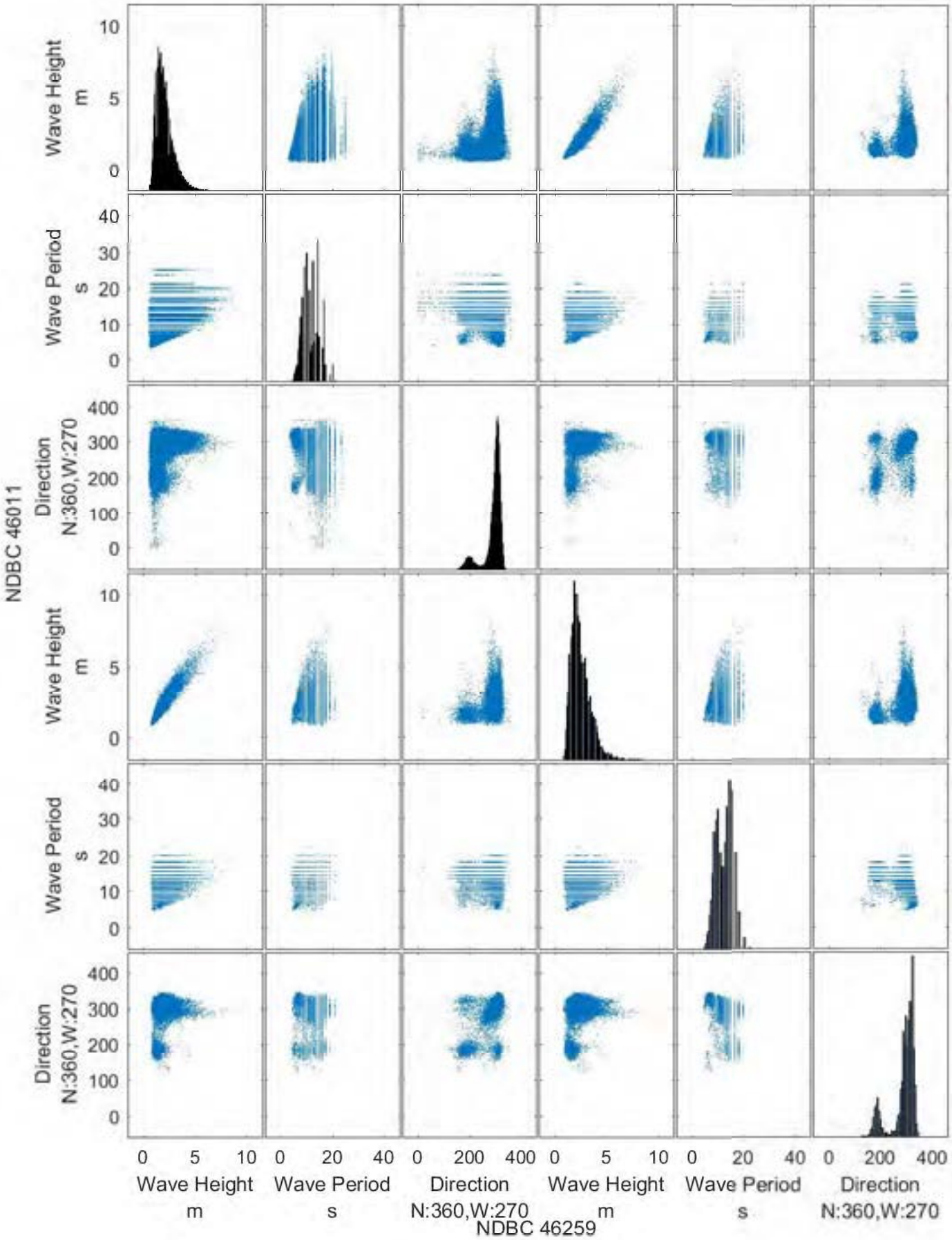


Figure B016: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46012.

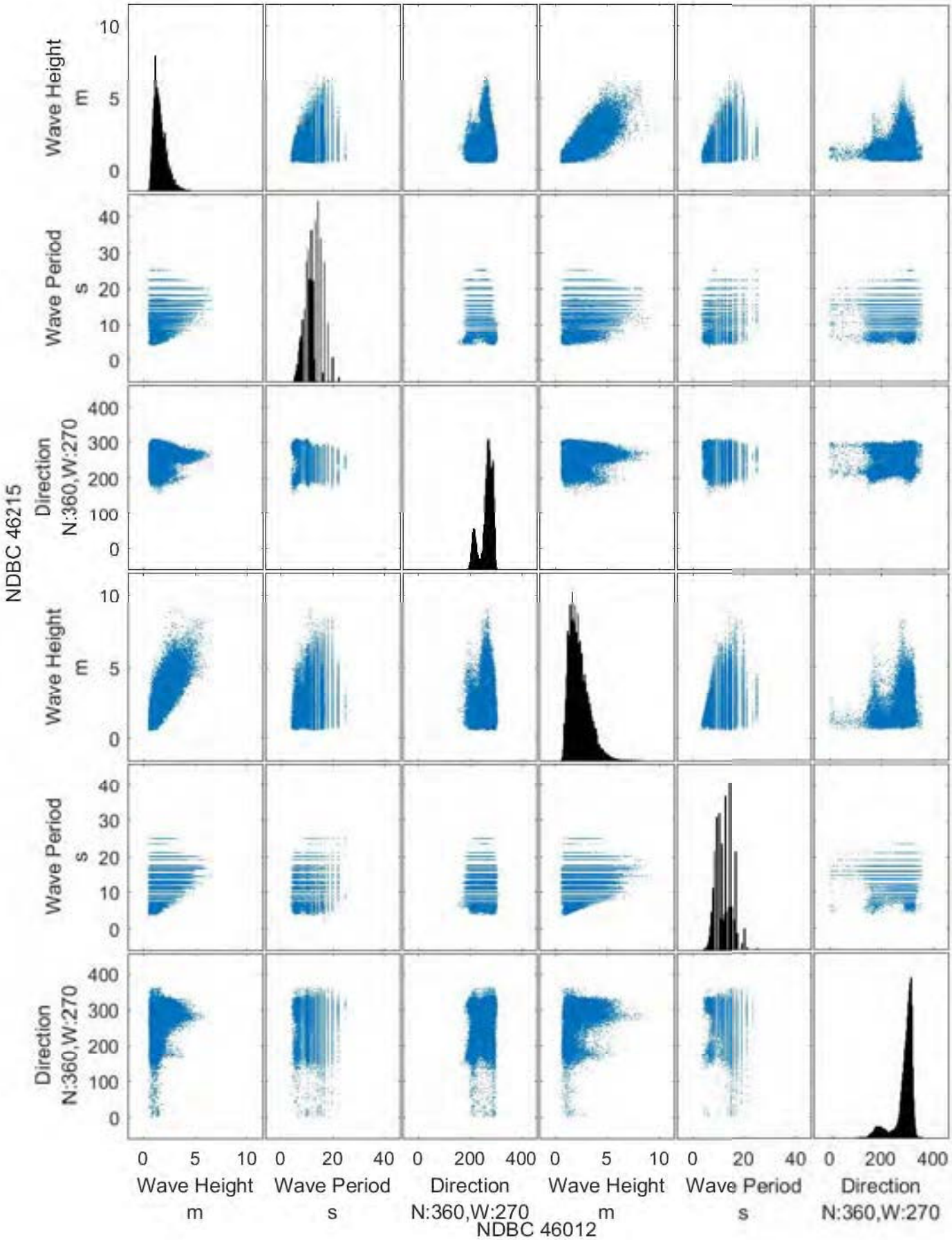


Figure B017: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46023.

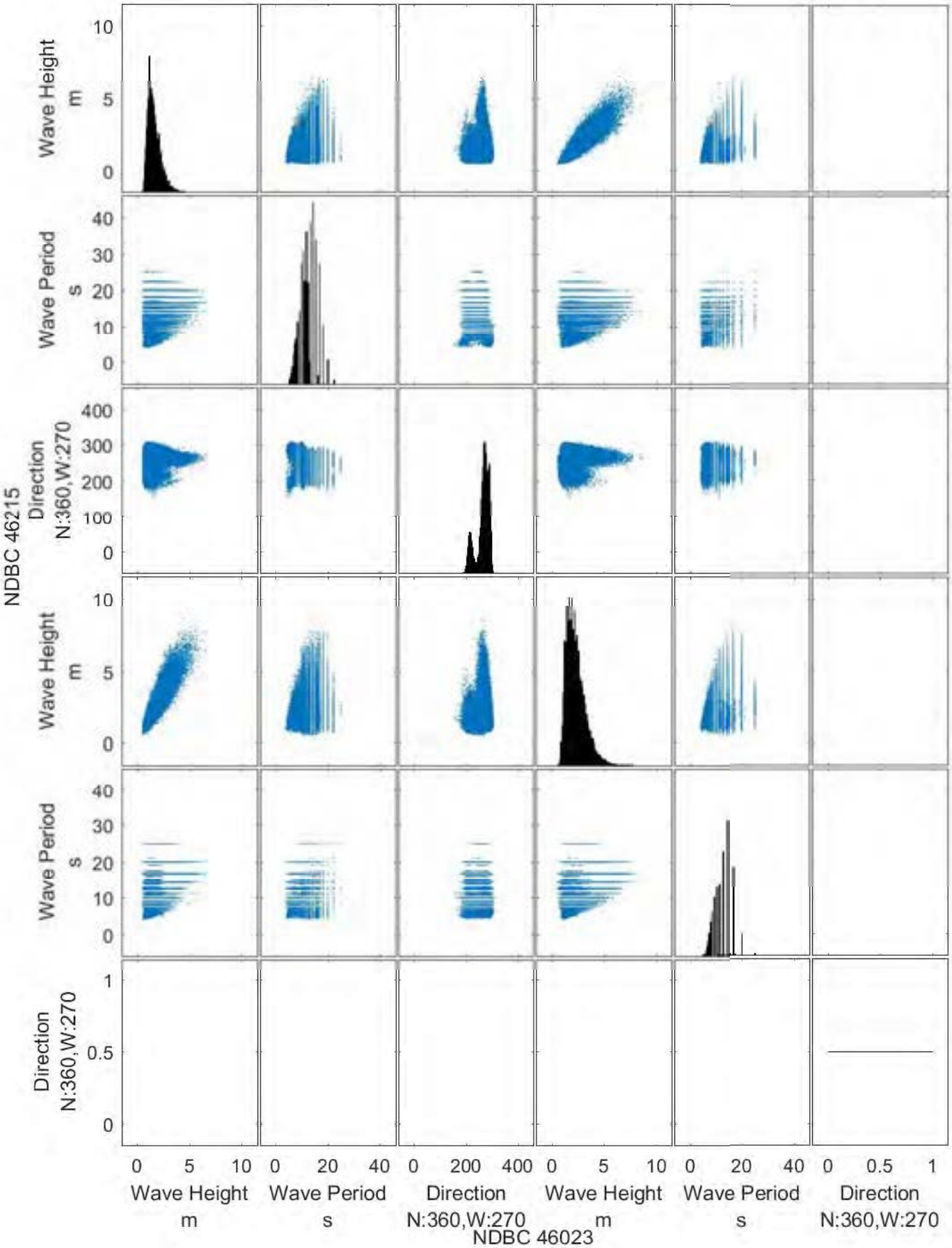


Figure B018: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46028.

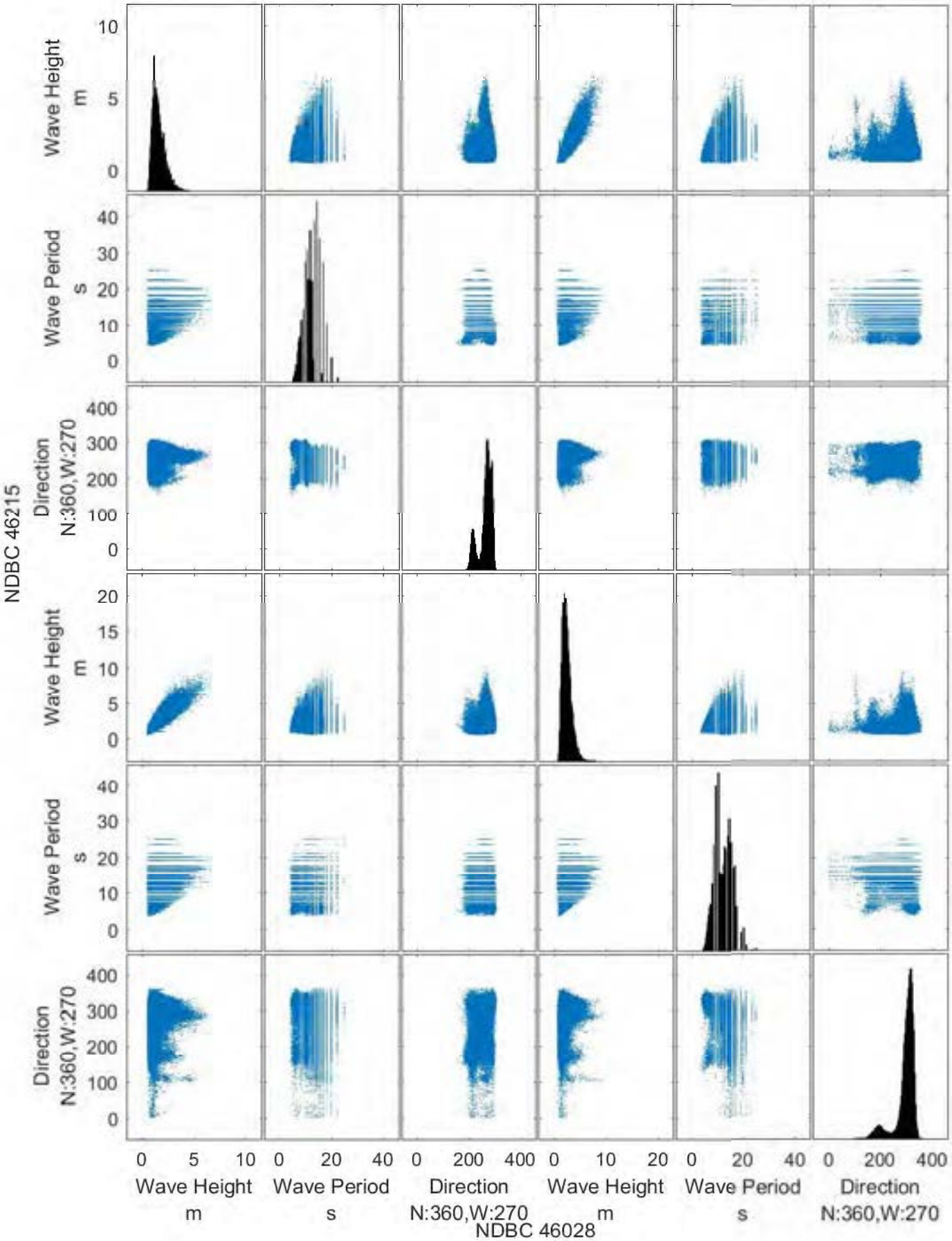


Figure B019: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46042.

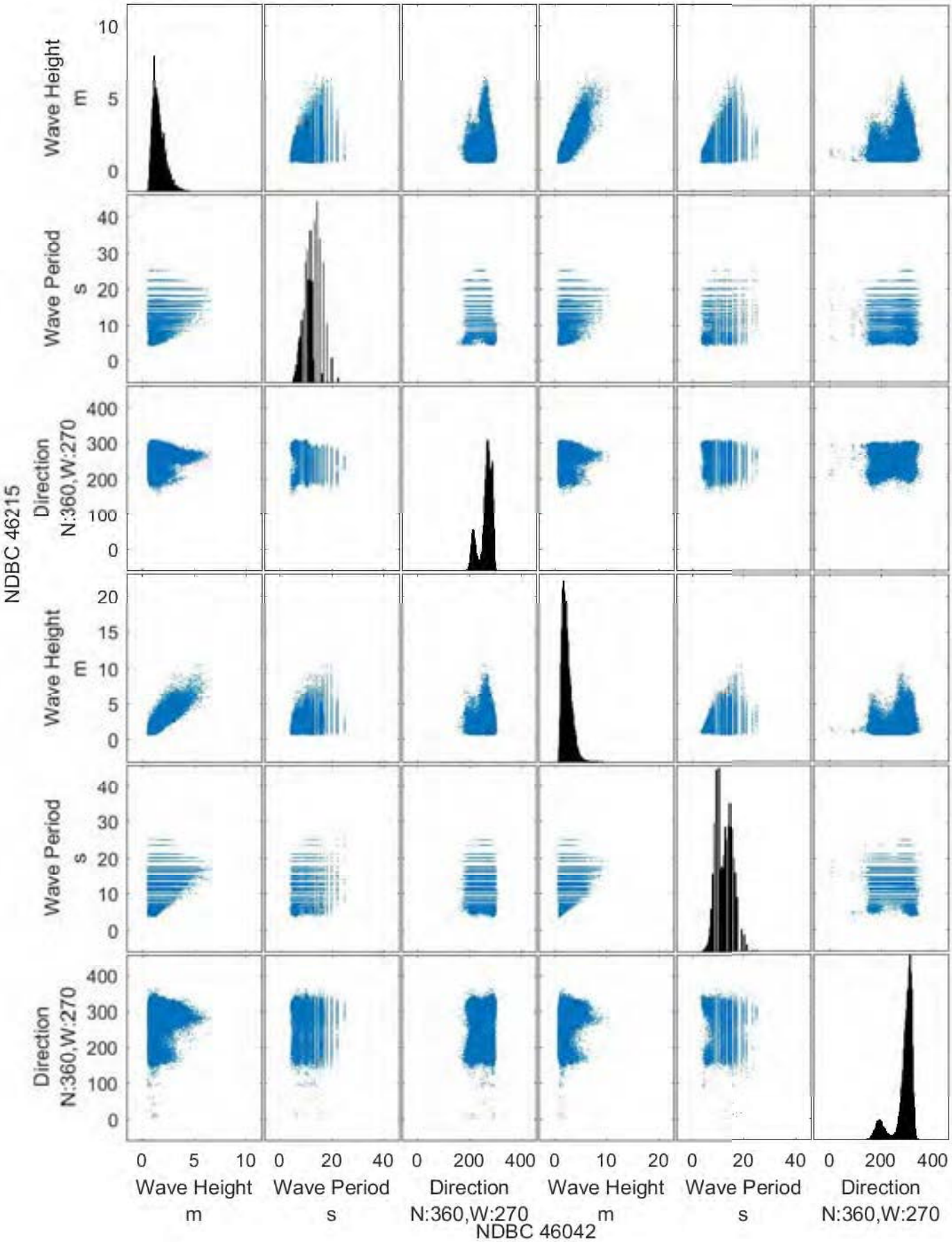


Figure B020: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46047.

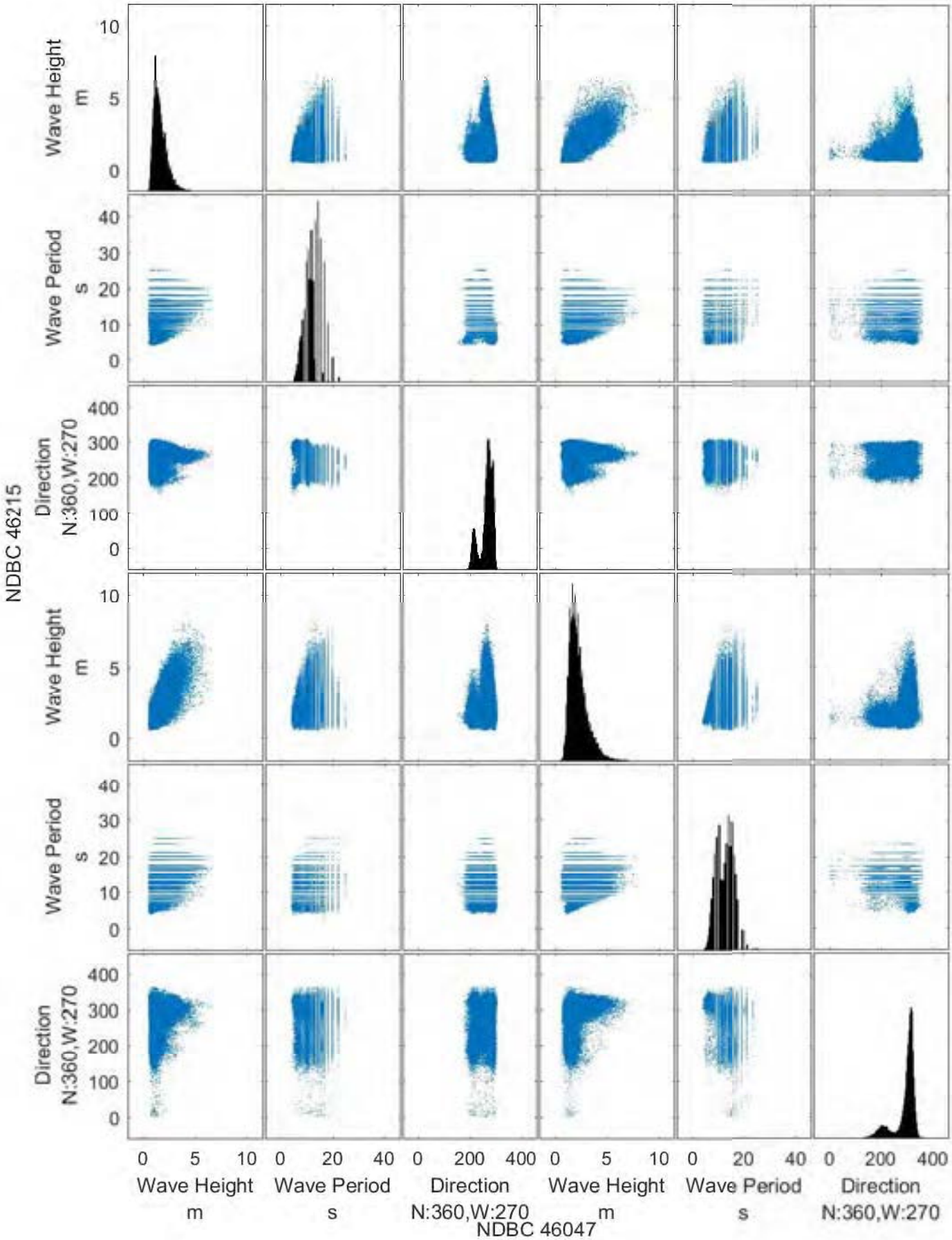


Figure B021: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46053.

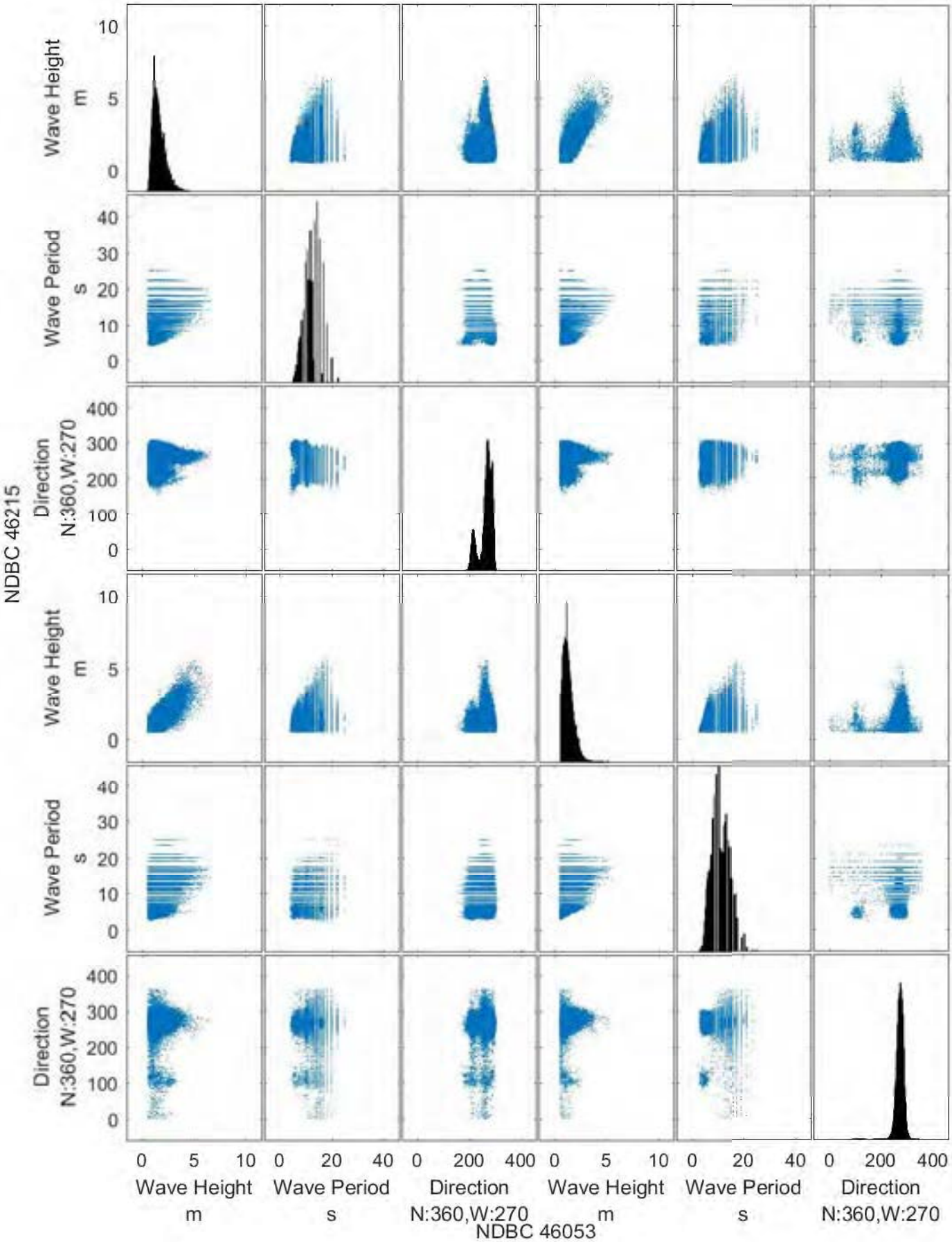


Figure B022: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46054.

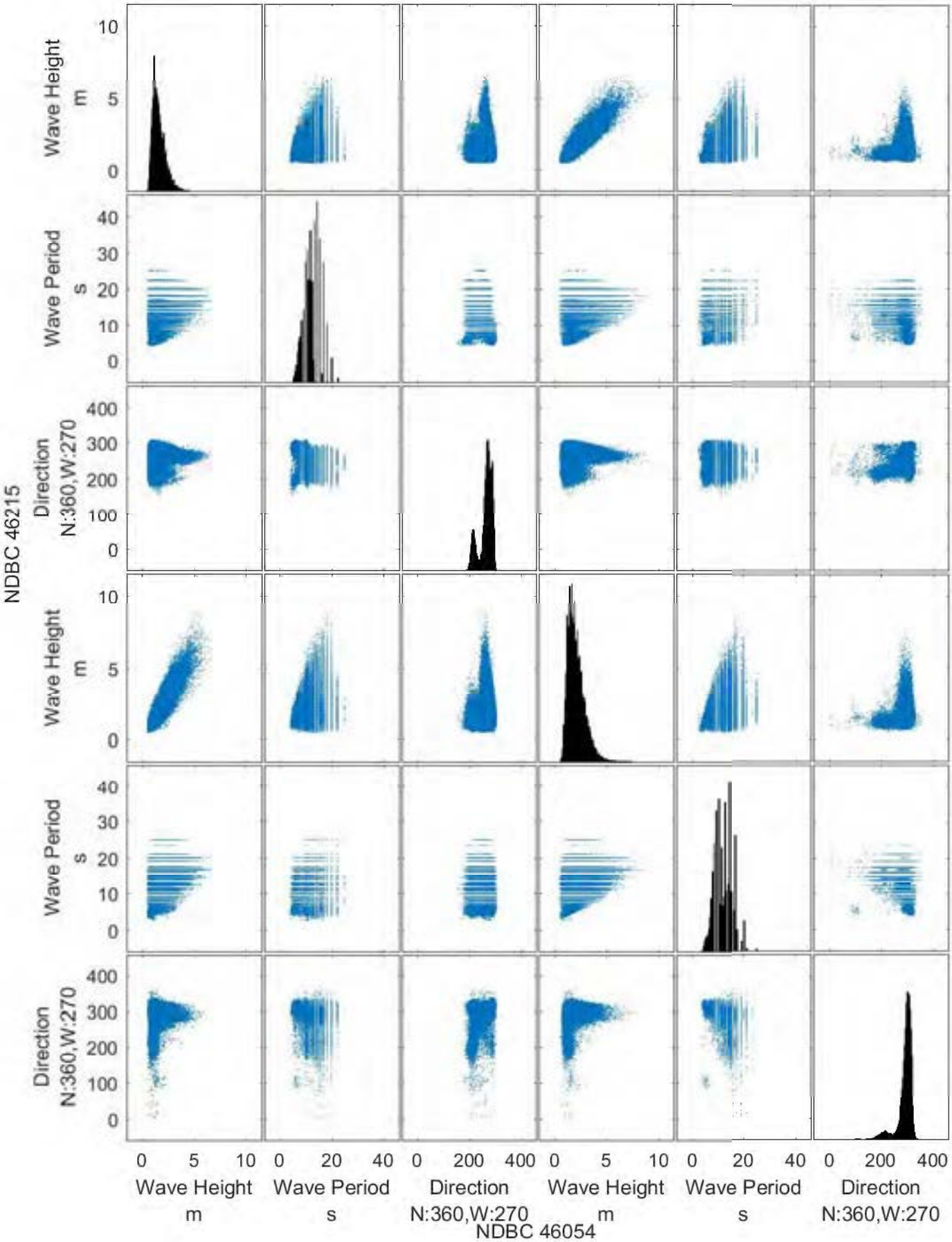


Figure B023: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46069.

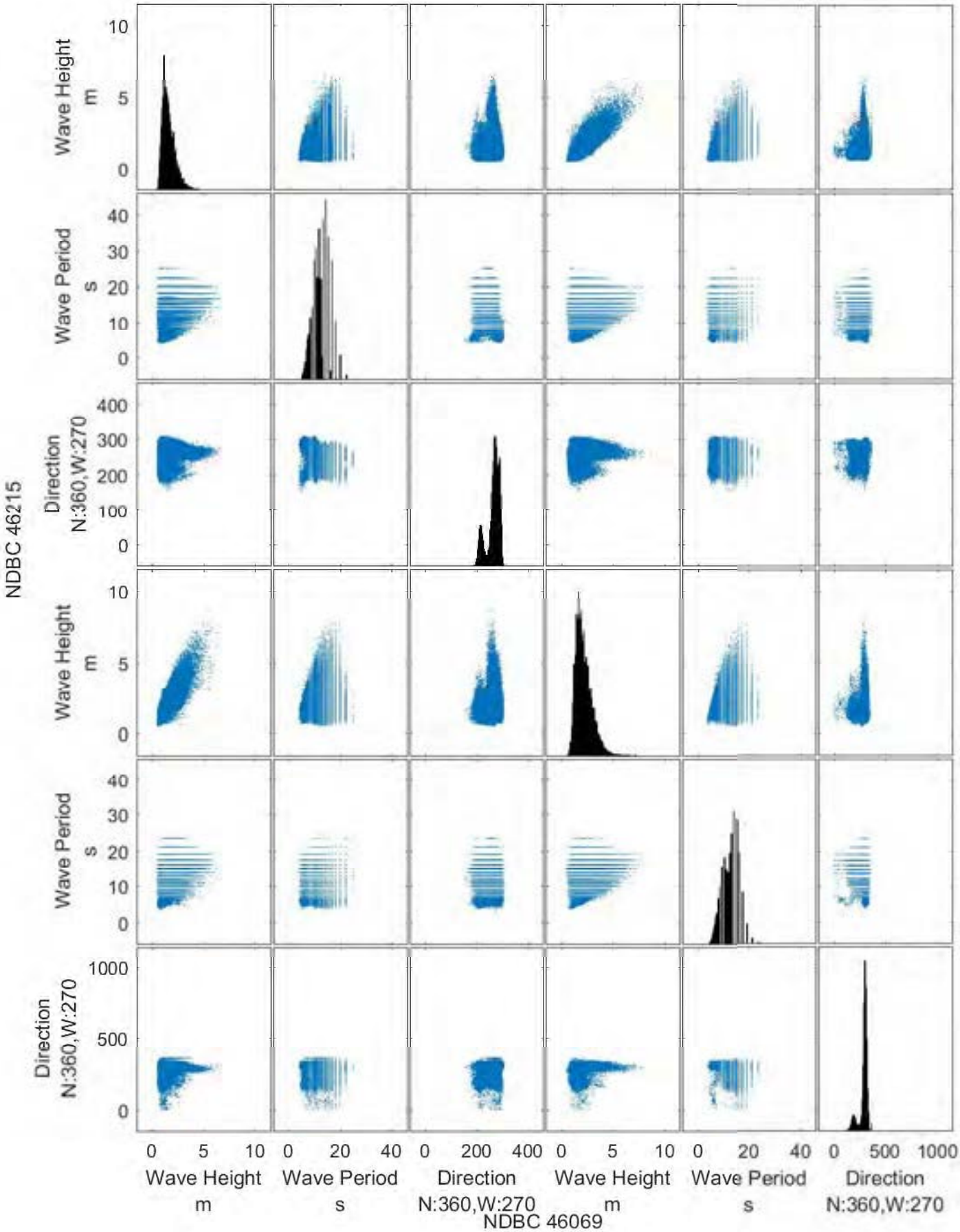


Figure B024: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46114.

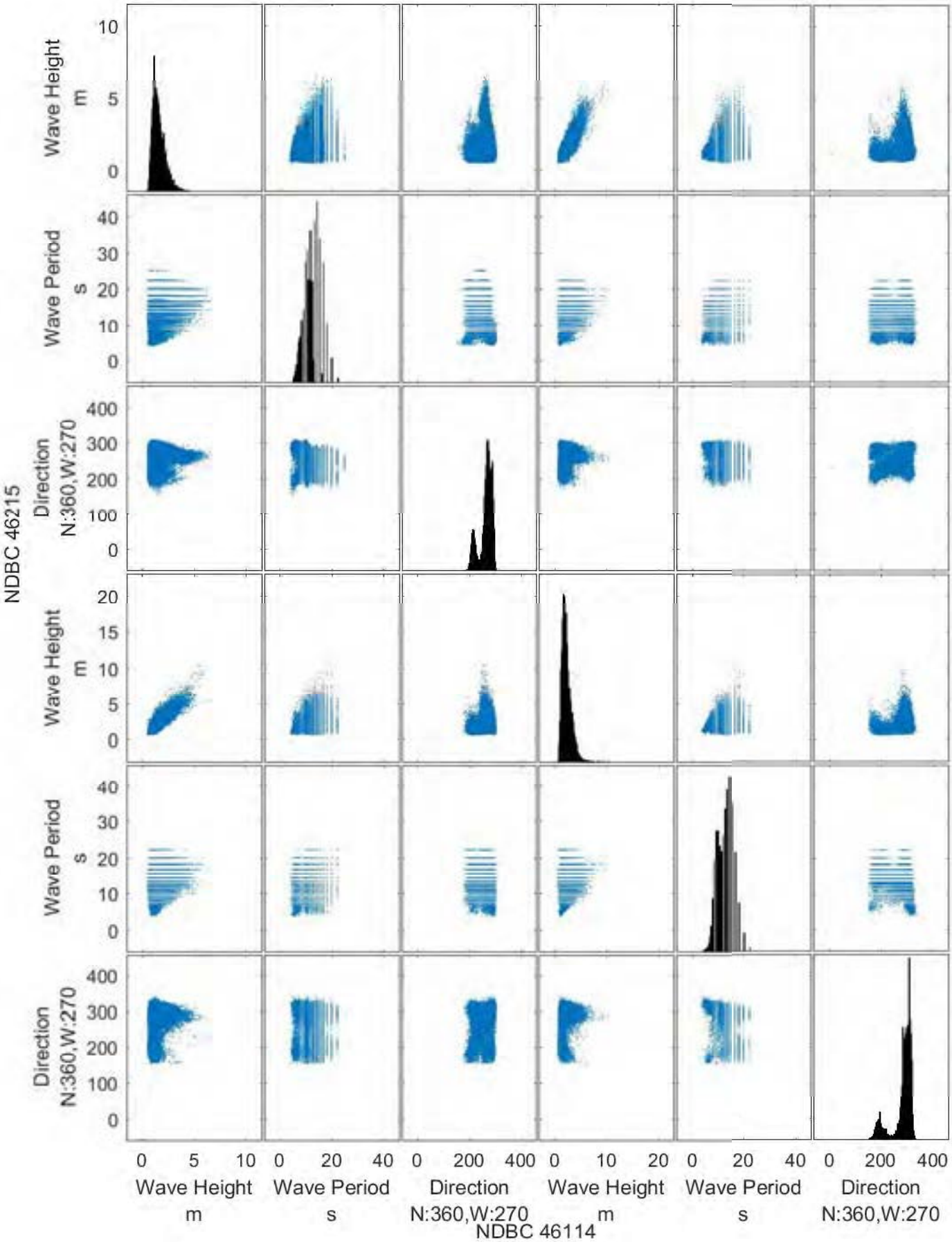


Figure B025: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46218.

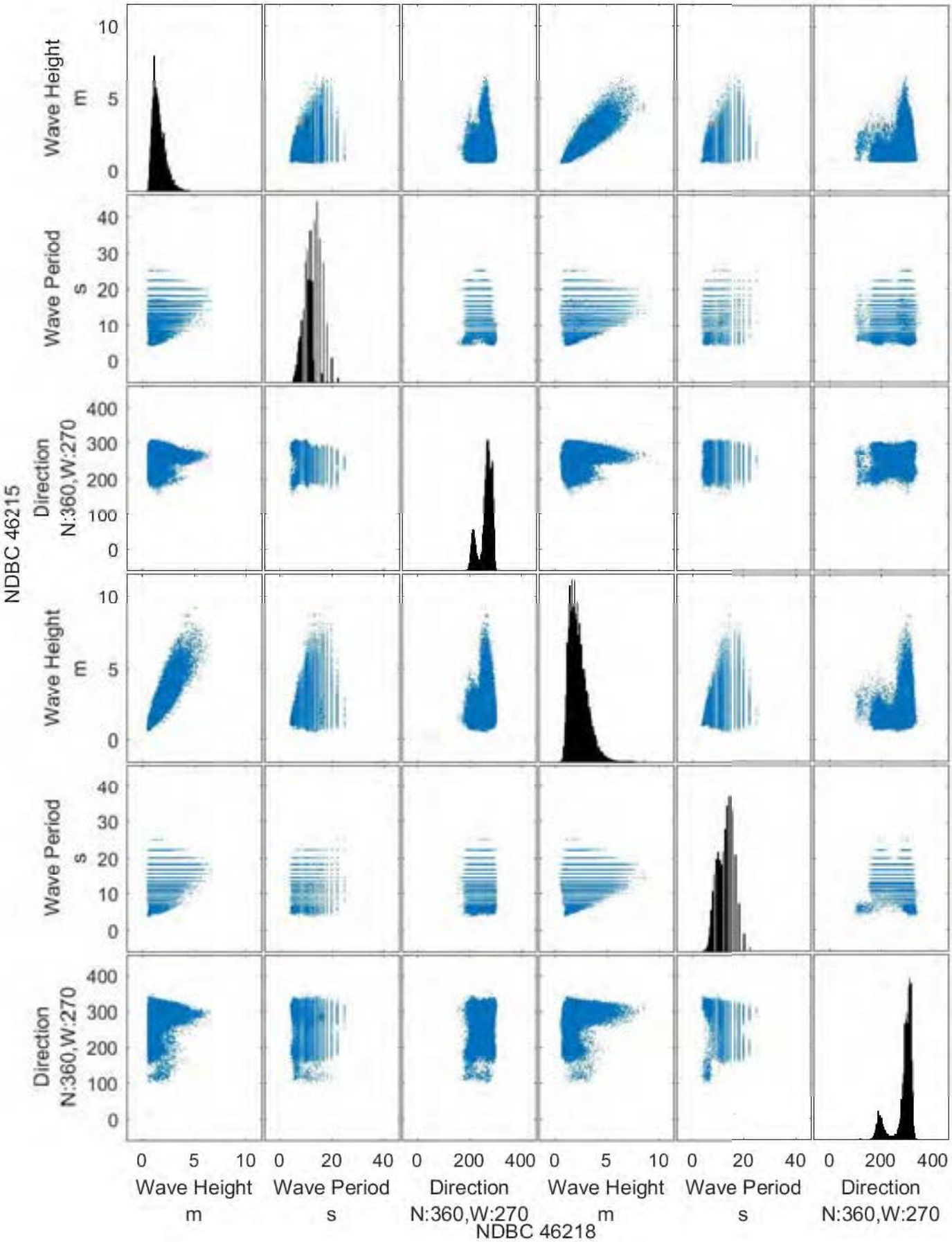


Figure B026: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46219.

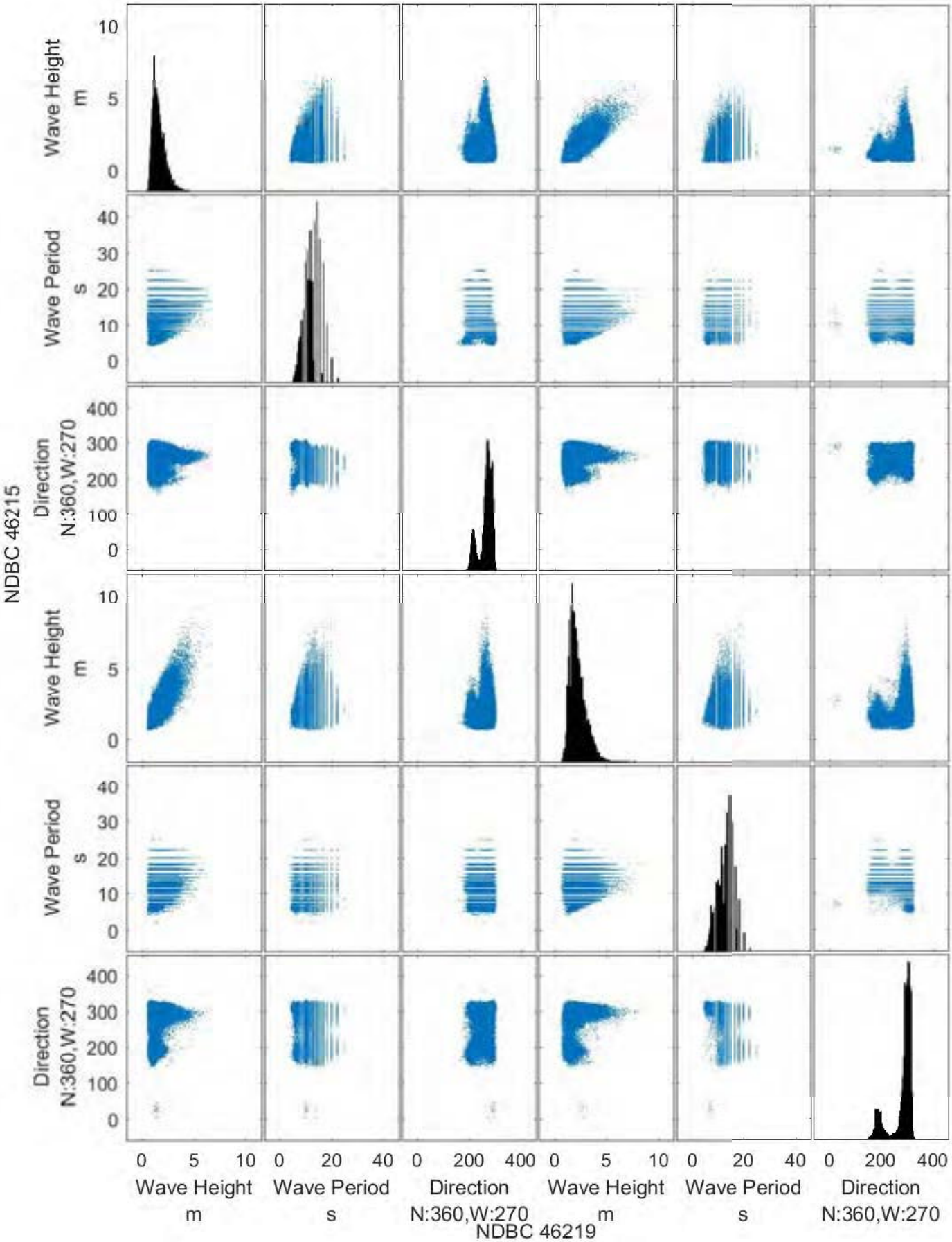


Figure B027: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46239.

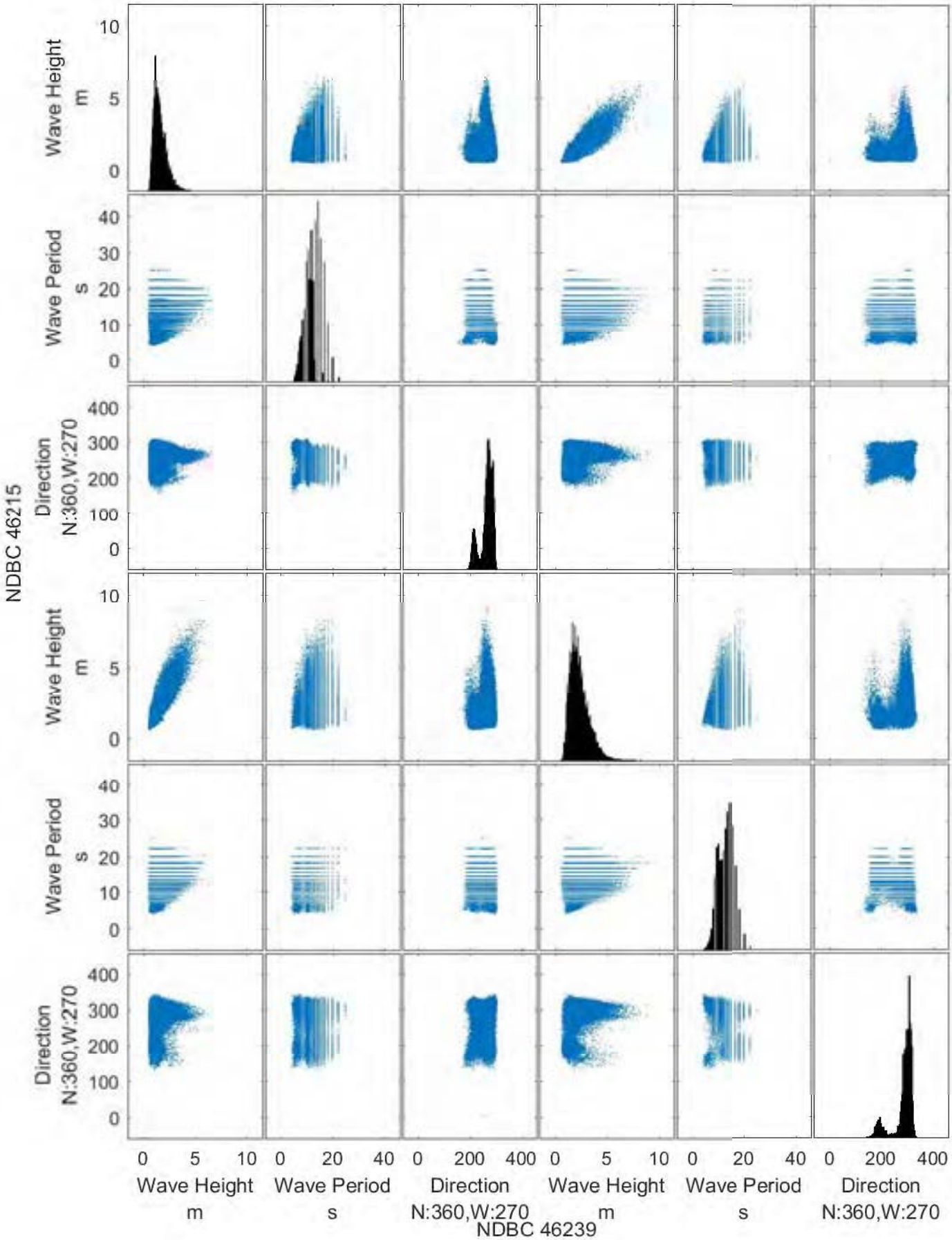


Figure B028: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46257.

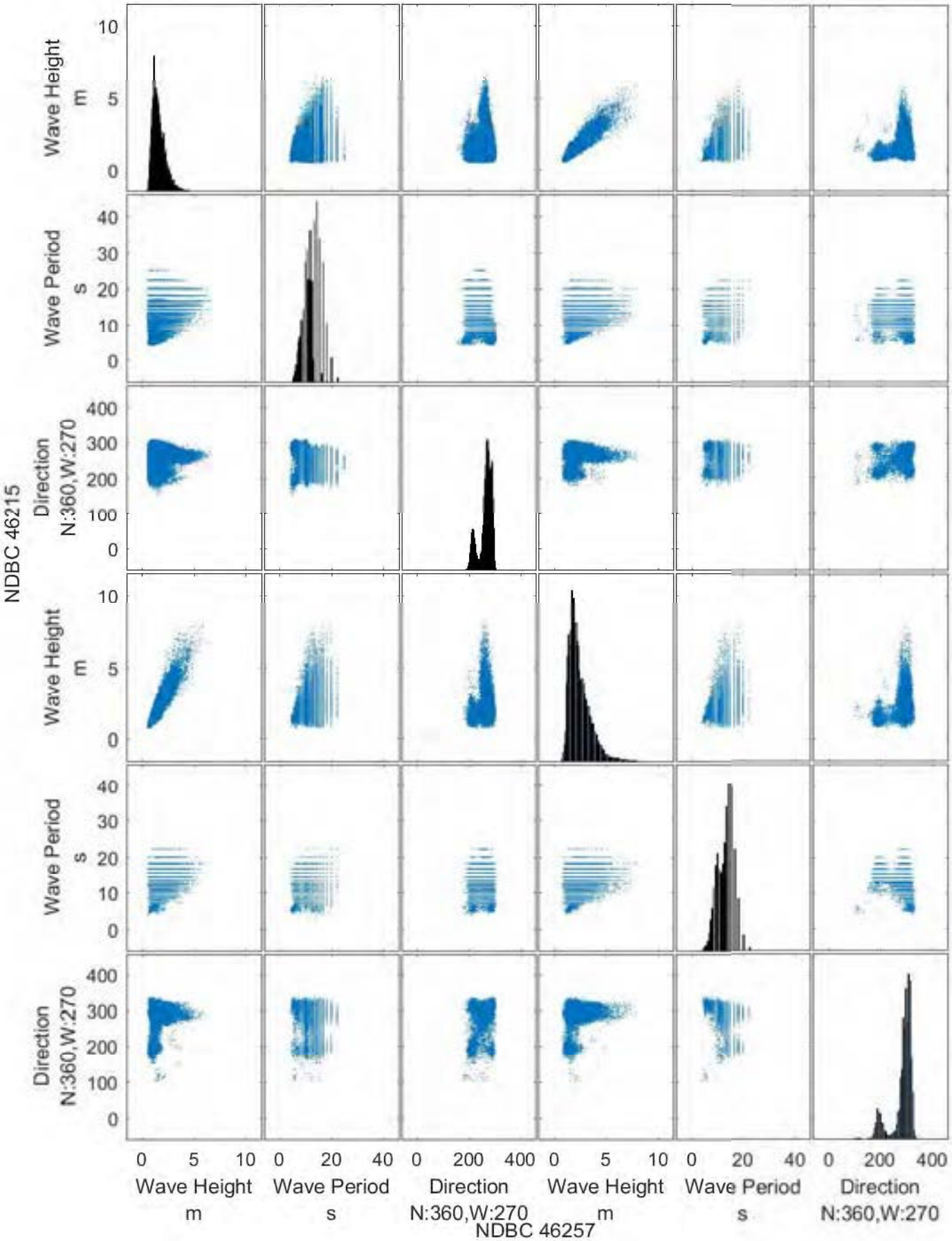


Figure B029: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46215 and NDBC 46259.

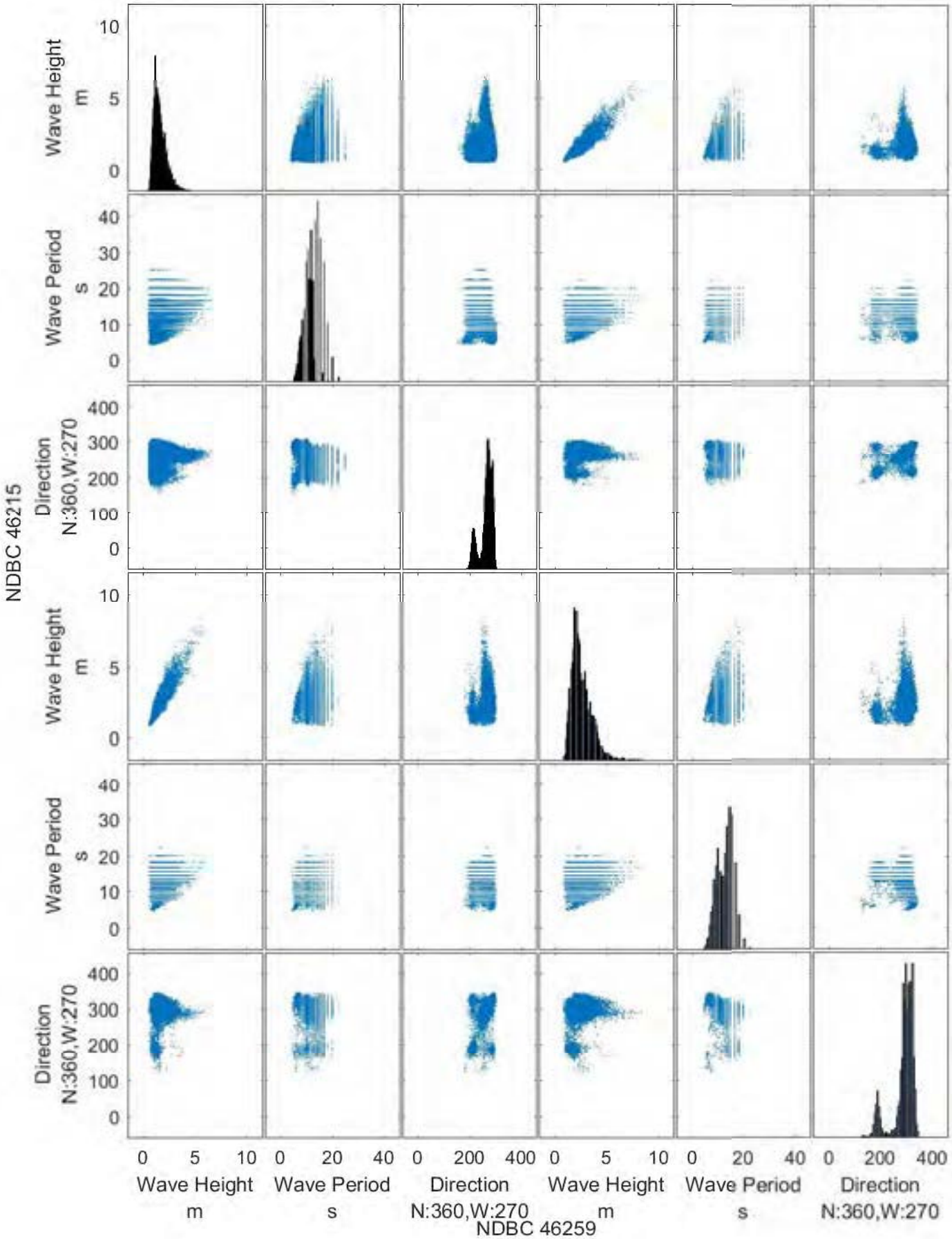


Figure B030: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46023.

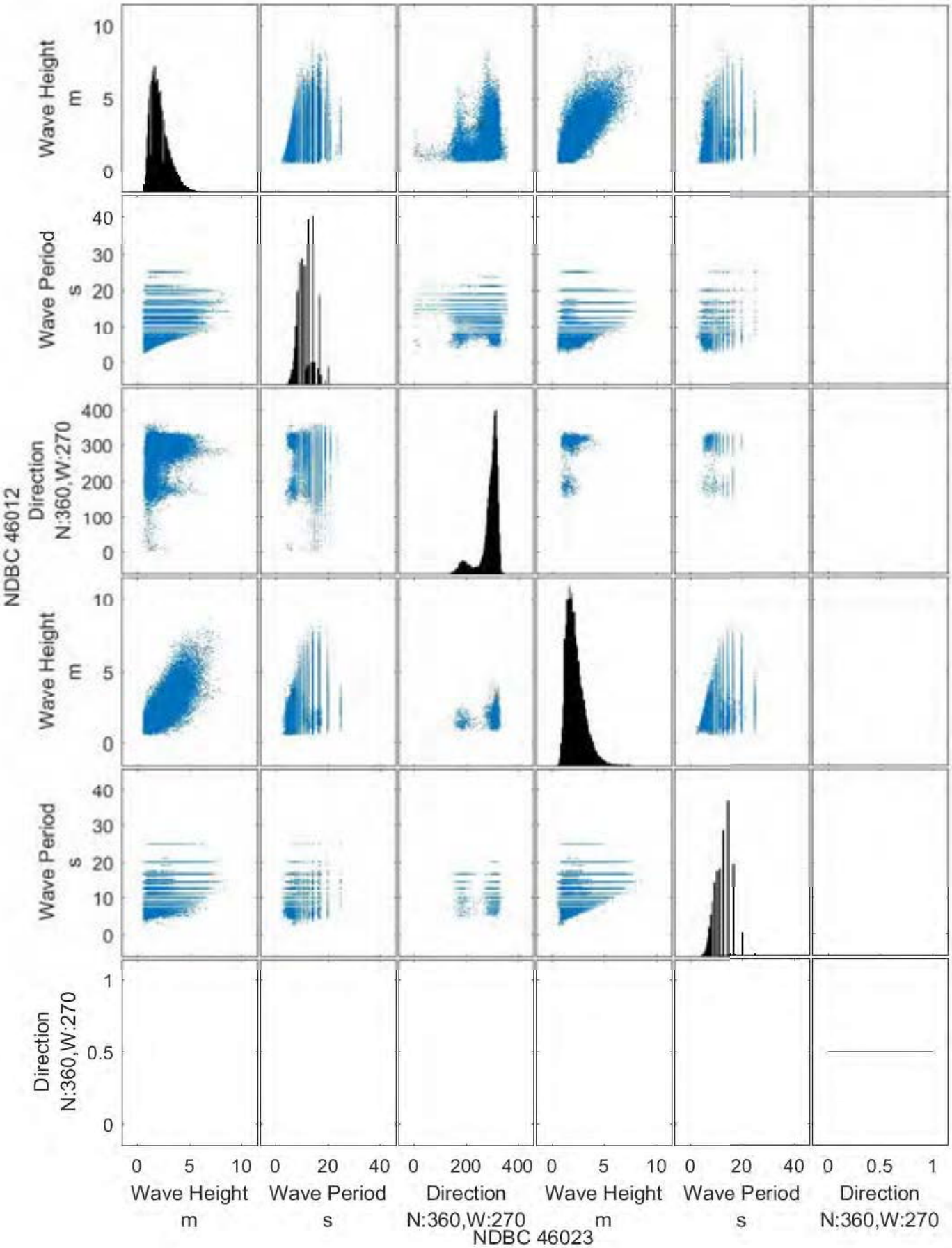


Figure B031: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46028.

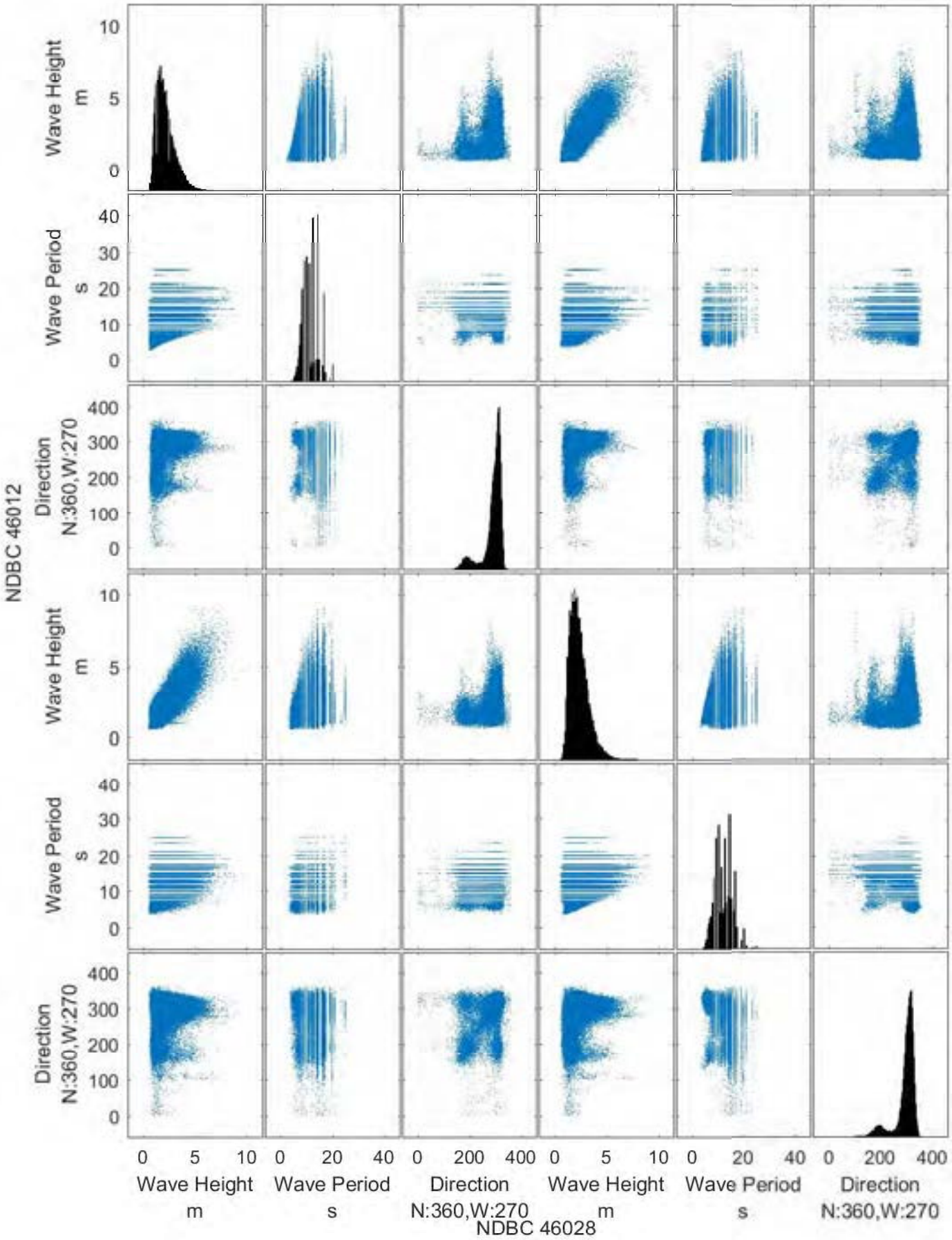


Figure B032: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46042.

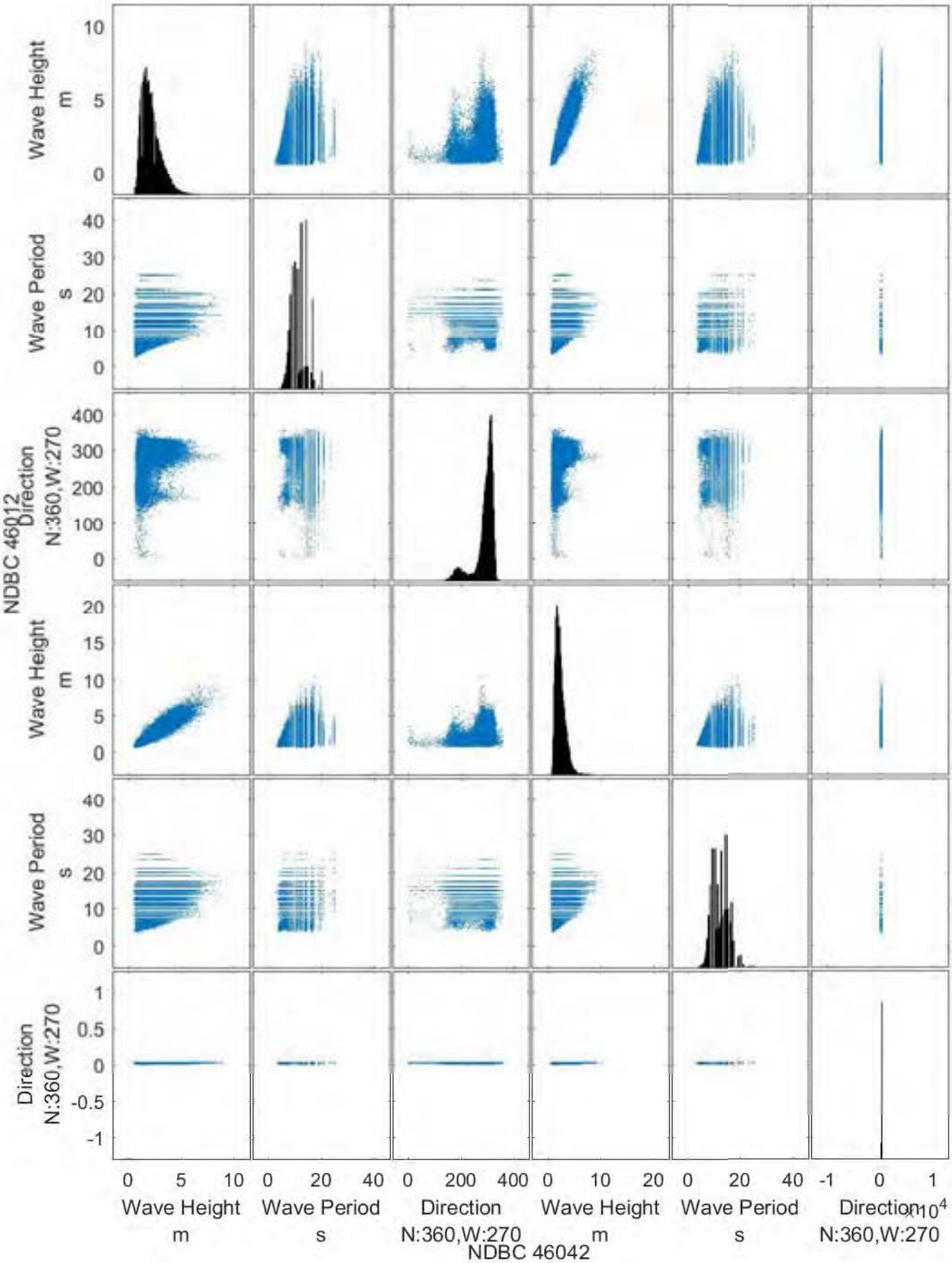


Figure B033: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46047.

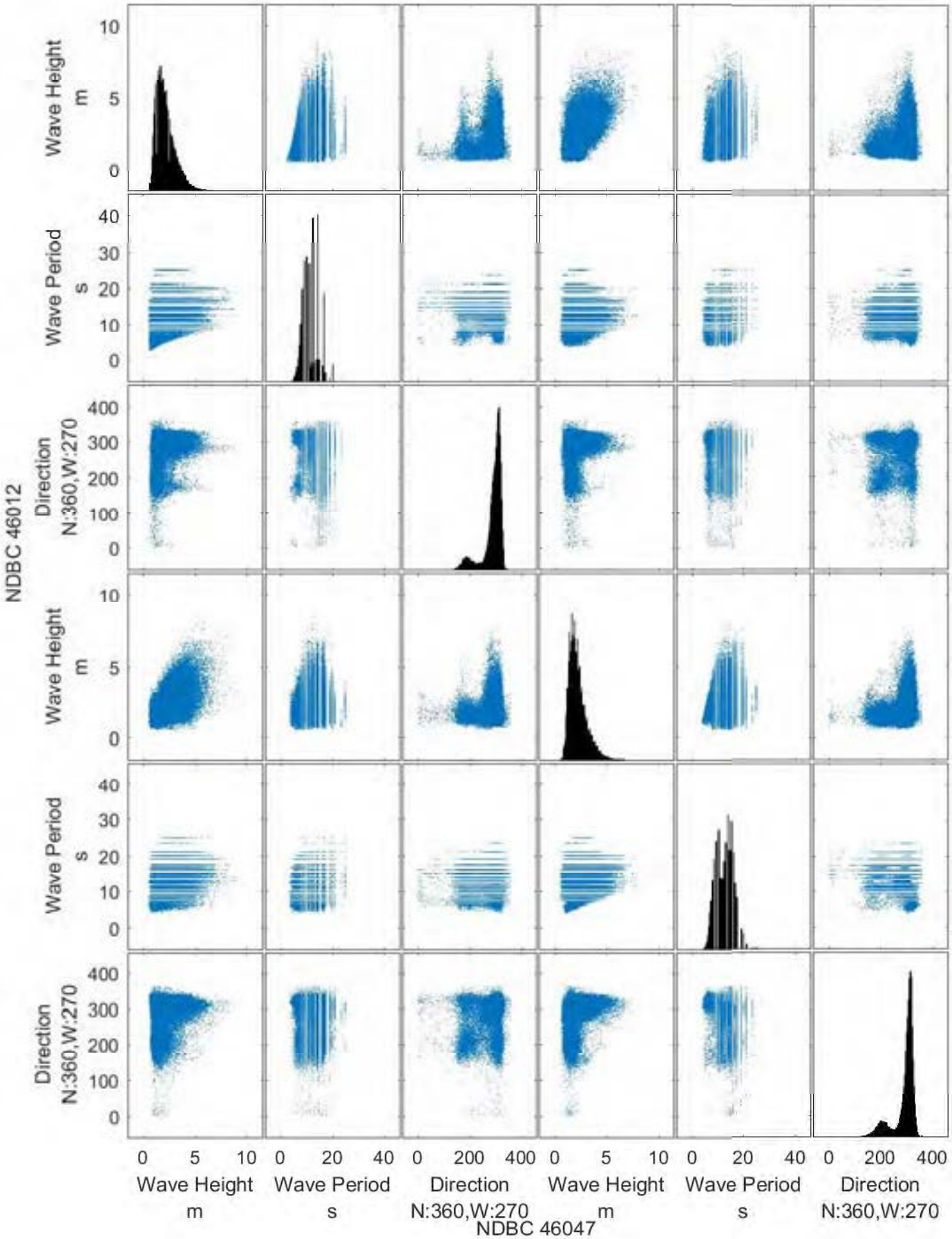


Figure B034: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46053.

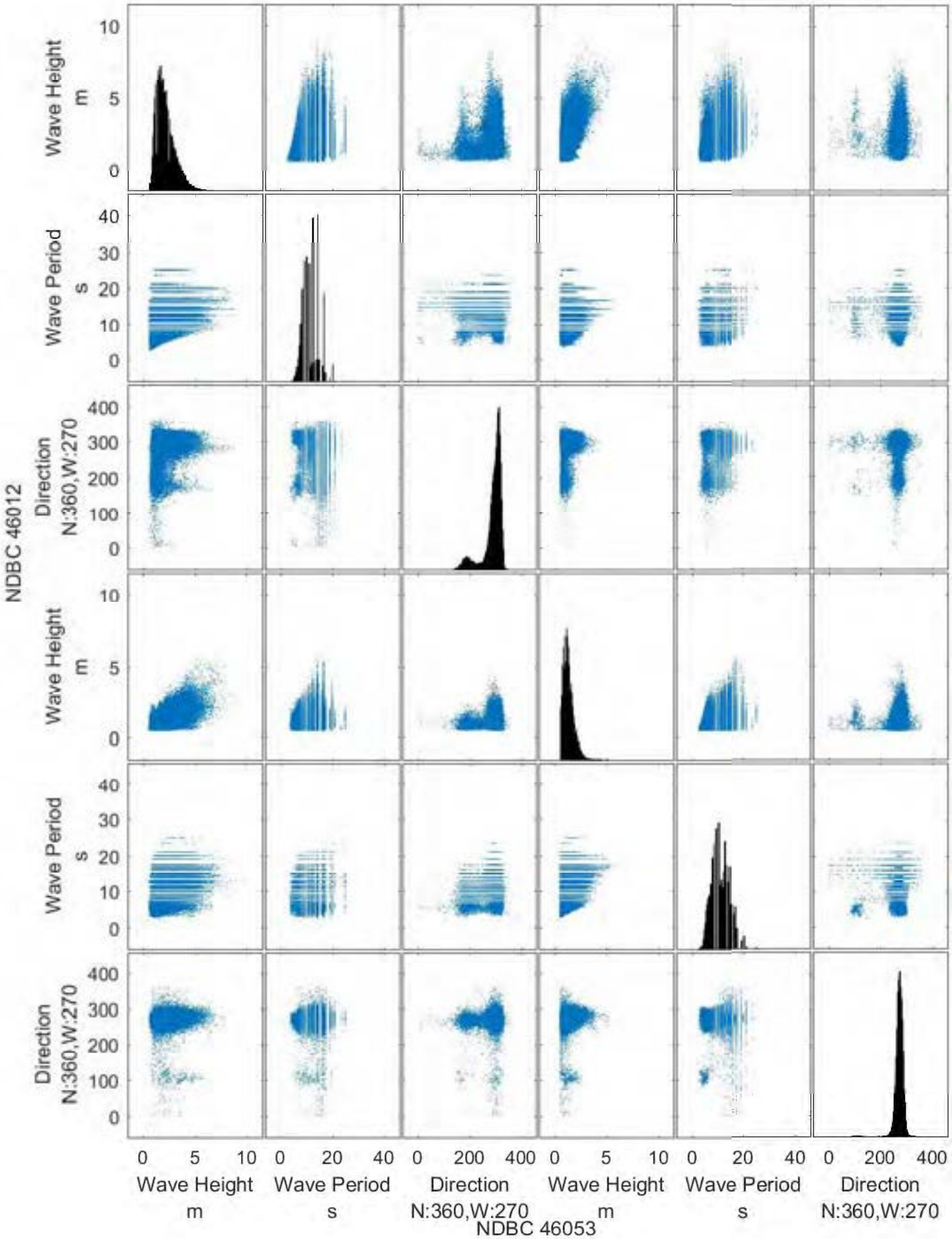


Figure B035: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46054.

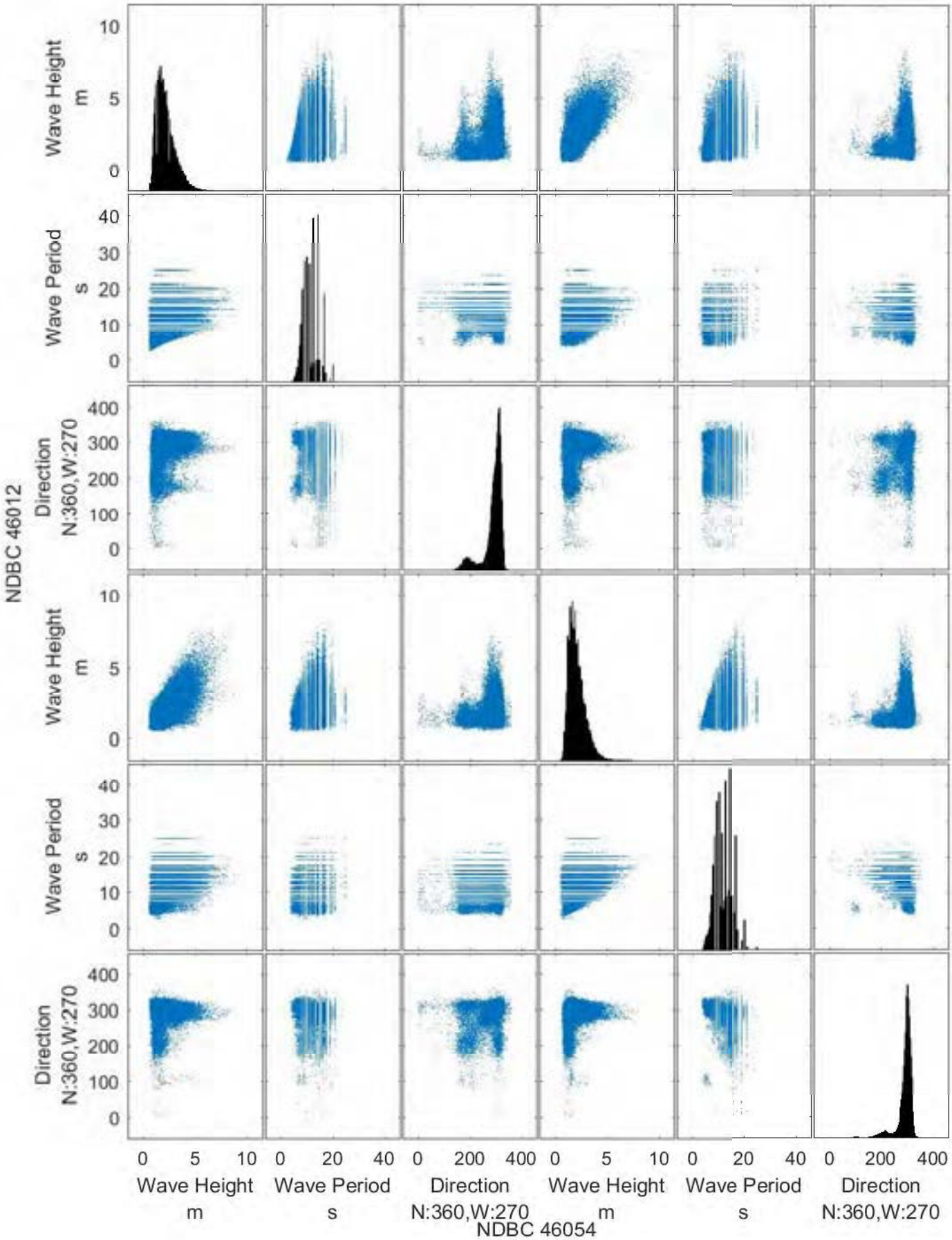


Figure B036: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46069.

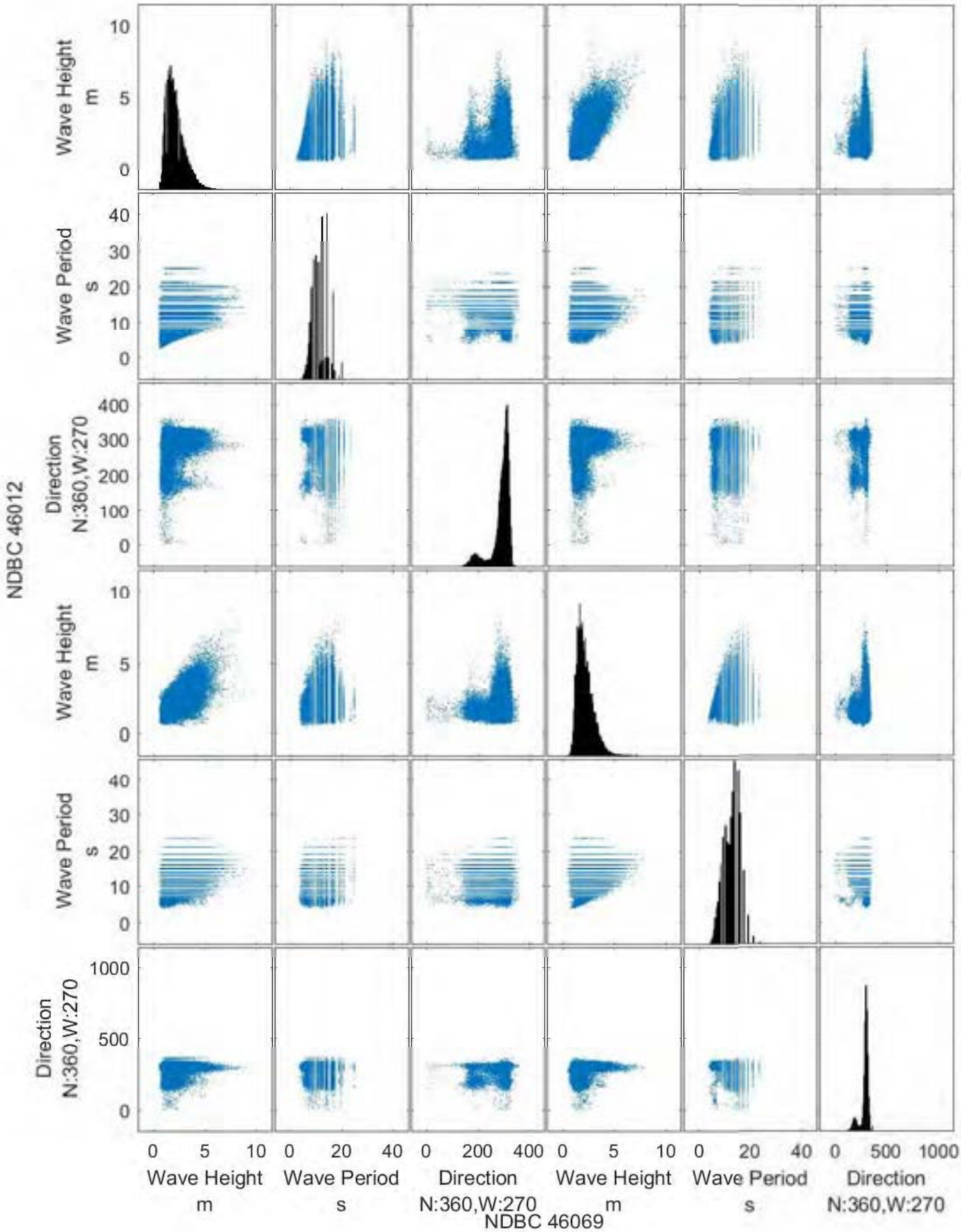


Figure B037: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46114.

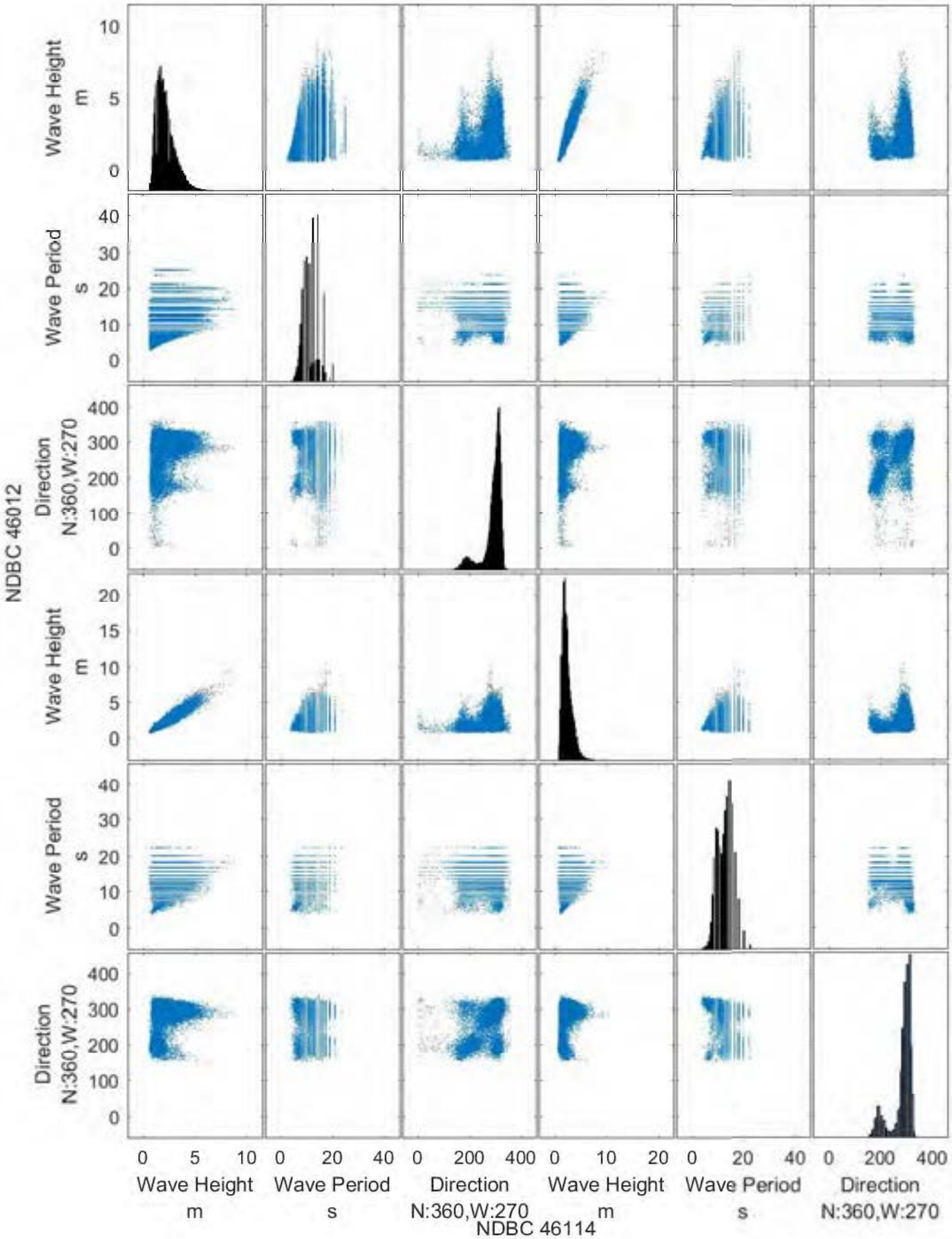


Figure B038: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46218.

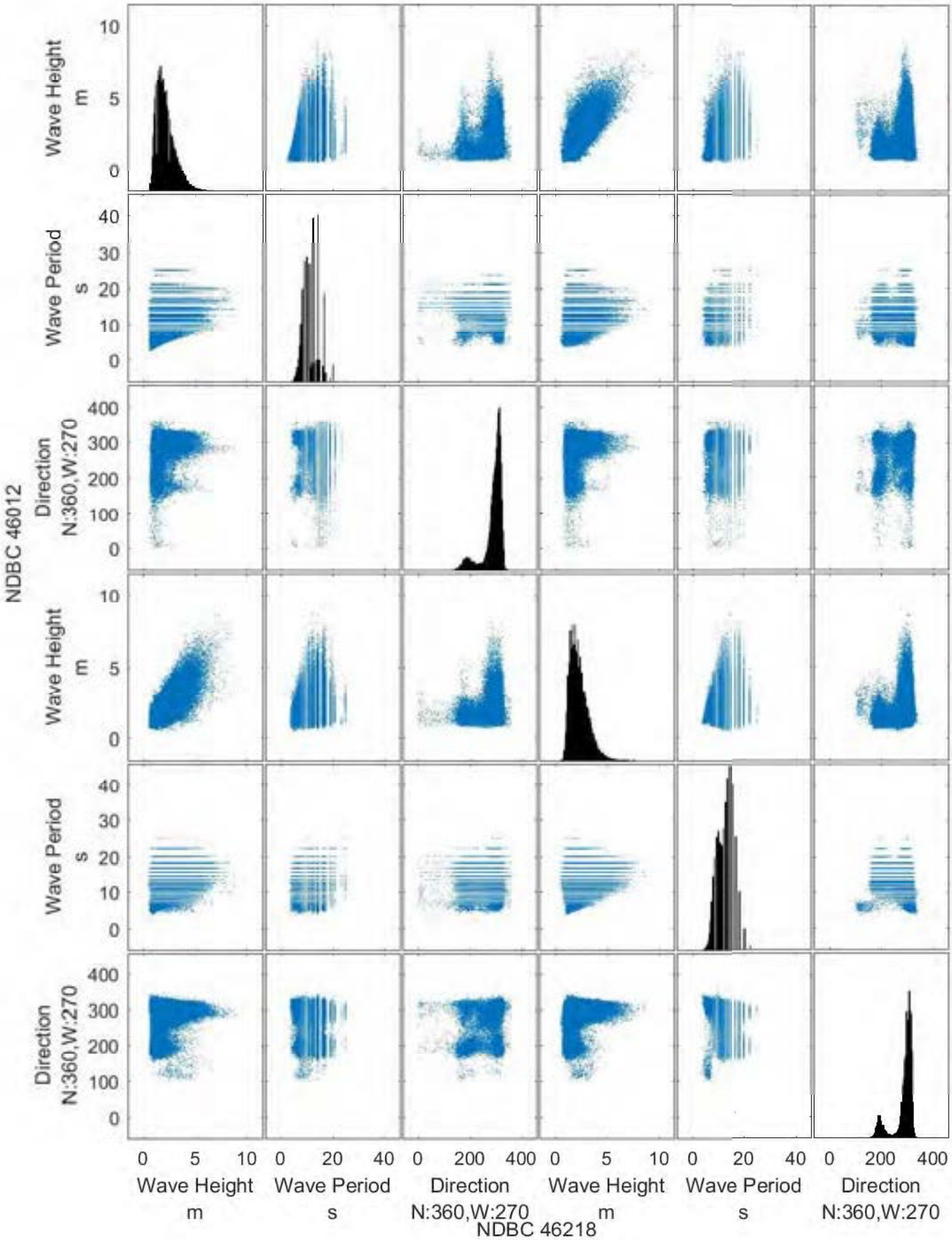


Figure B039: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46219.

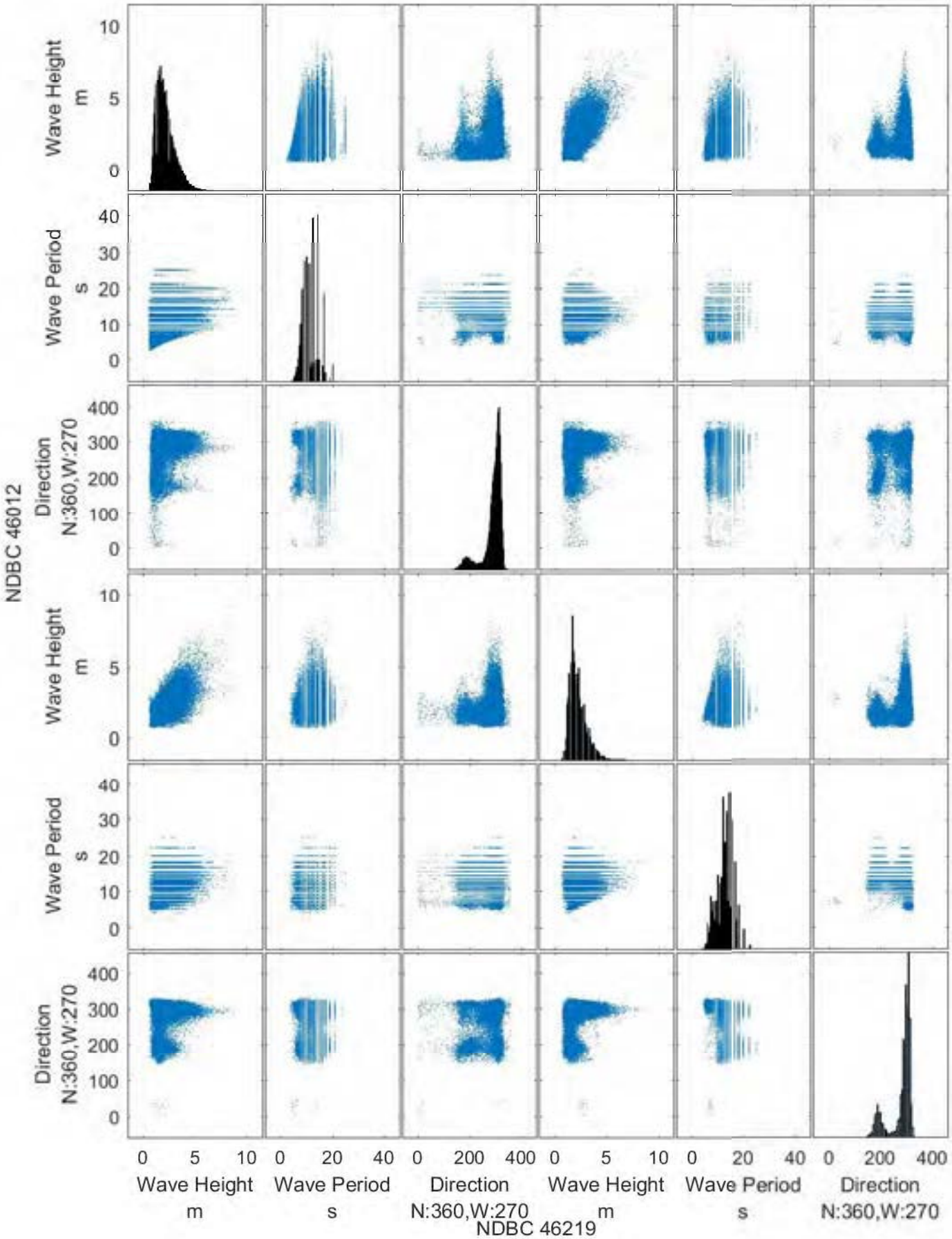


Figure B040: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46239.

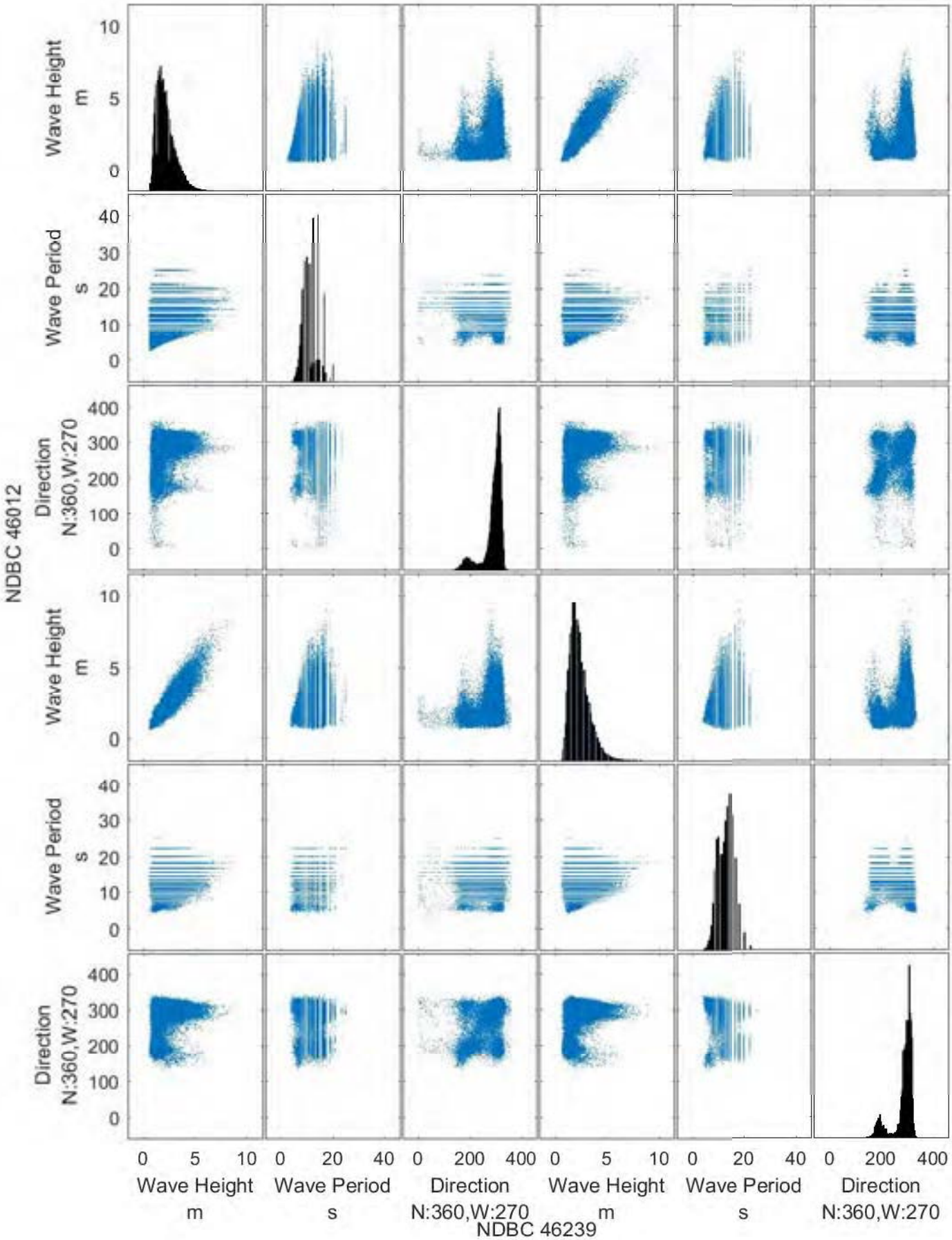


Figure B041: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46257.

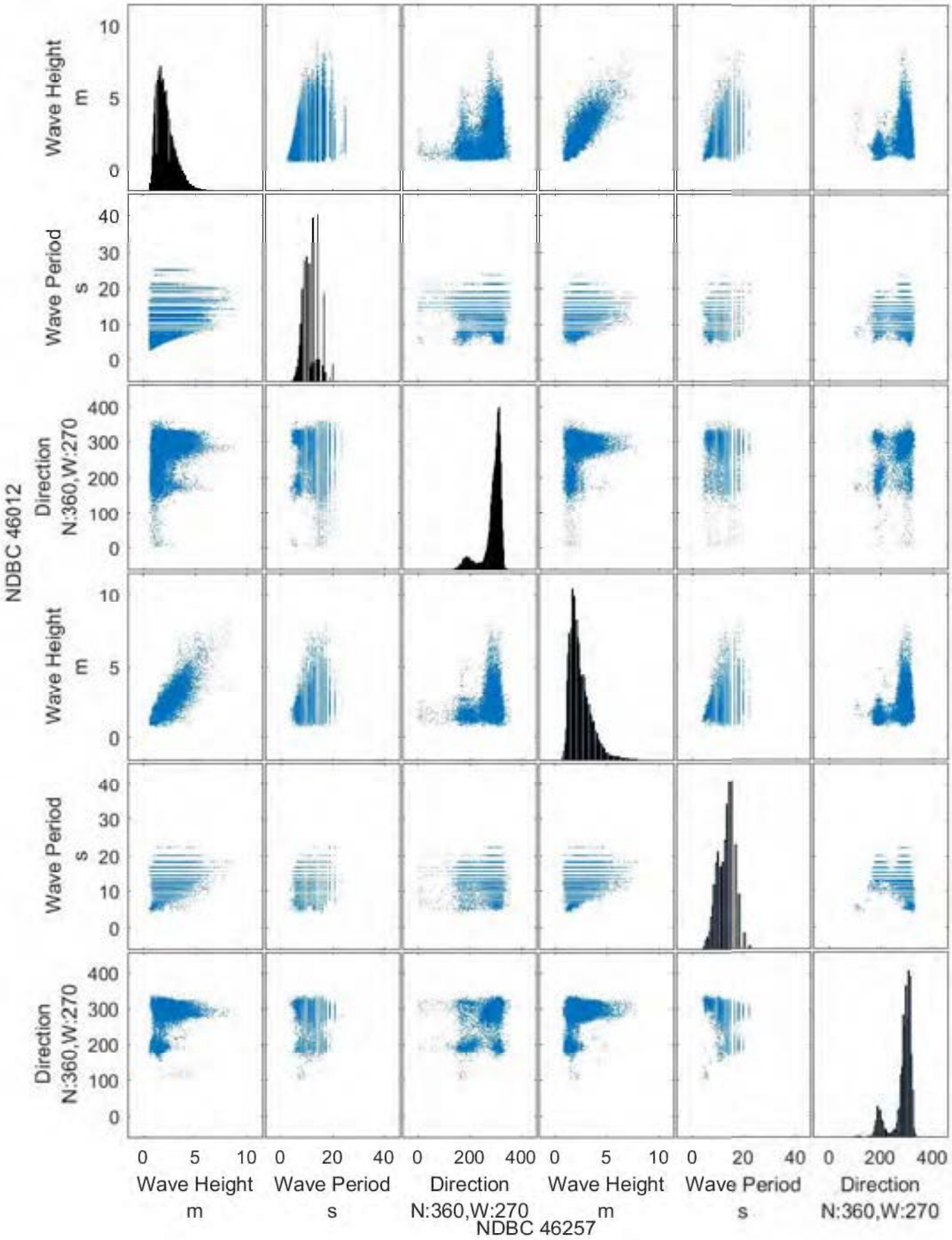


Figure B042: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46012 and NDBC 46259.

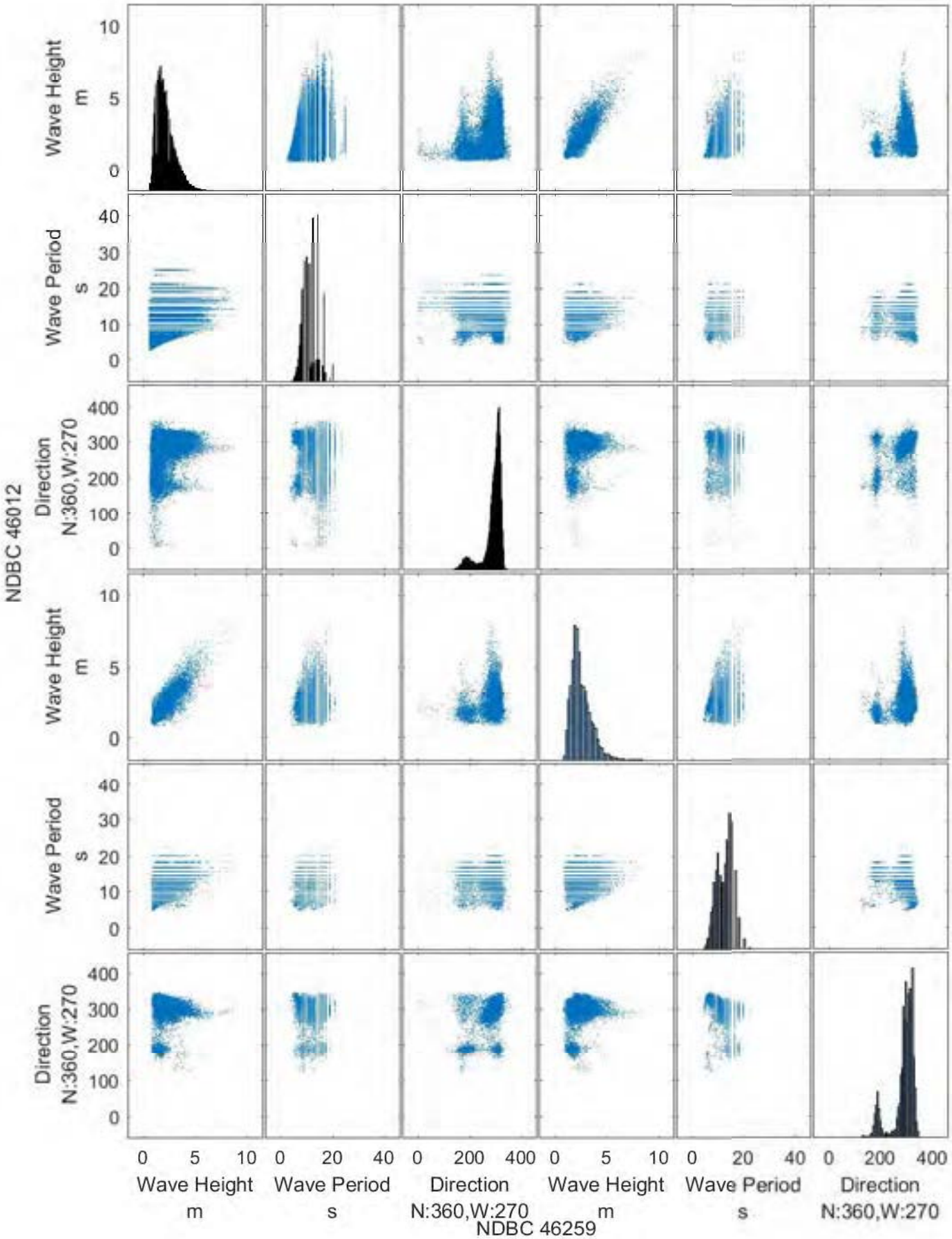


Figure B043: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46028.

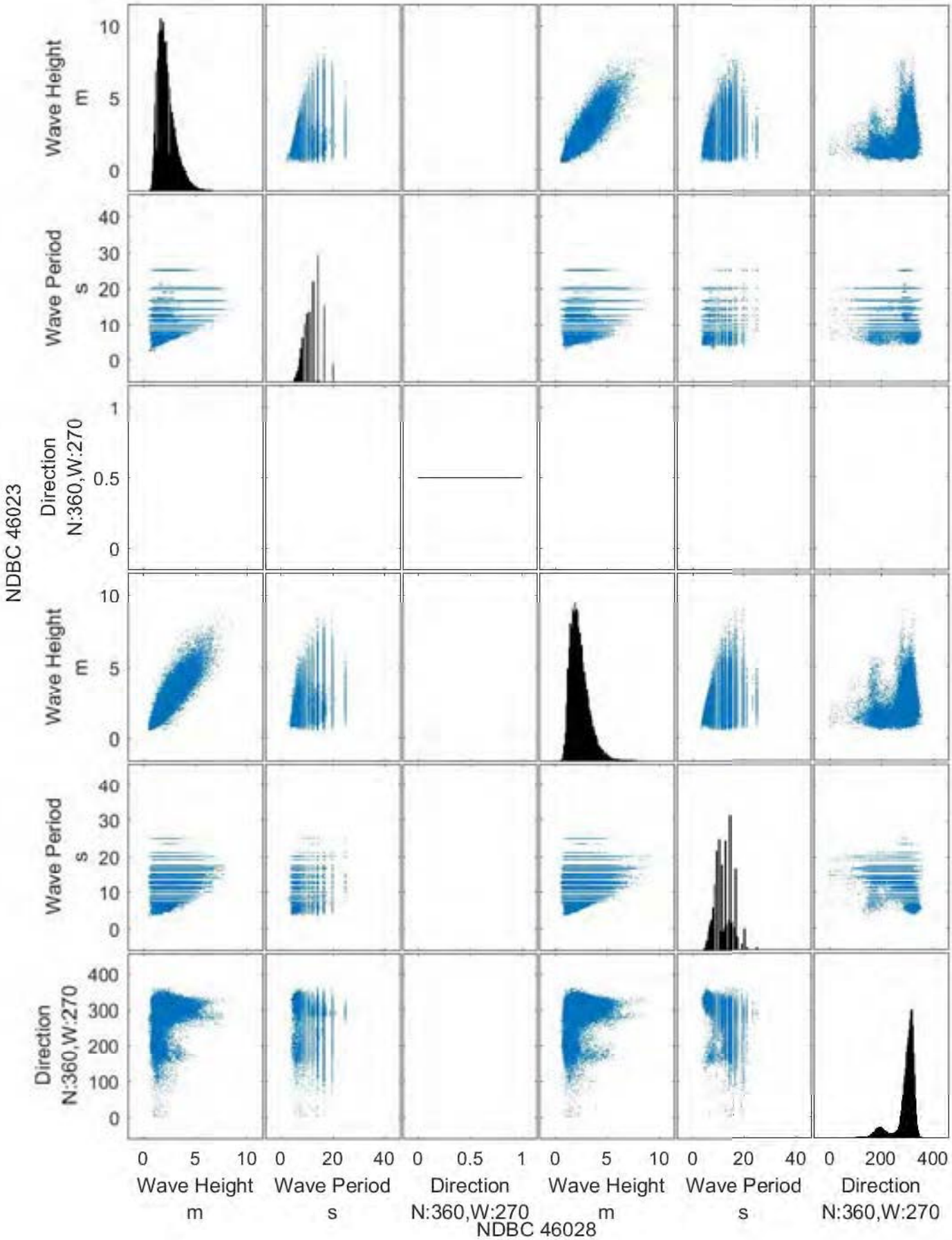


Figure B044: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46042.

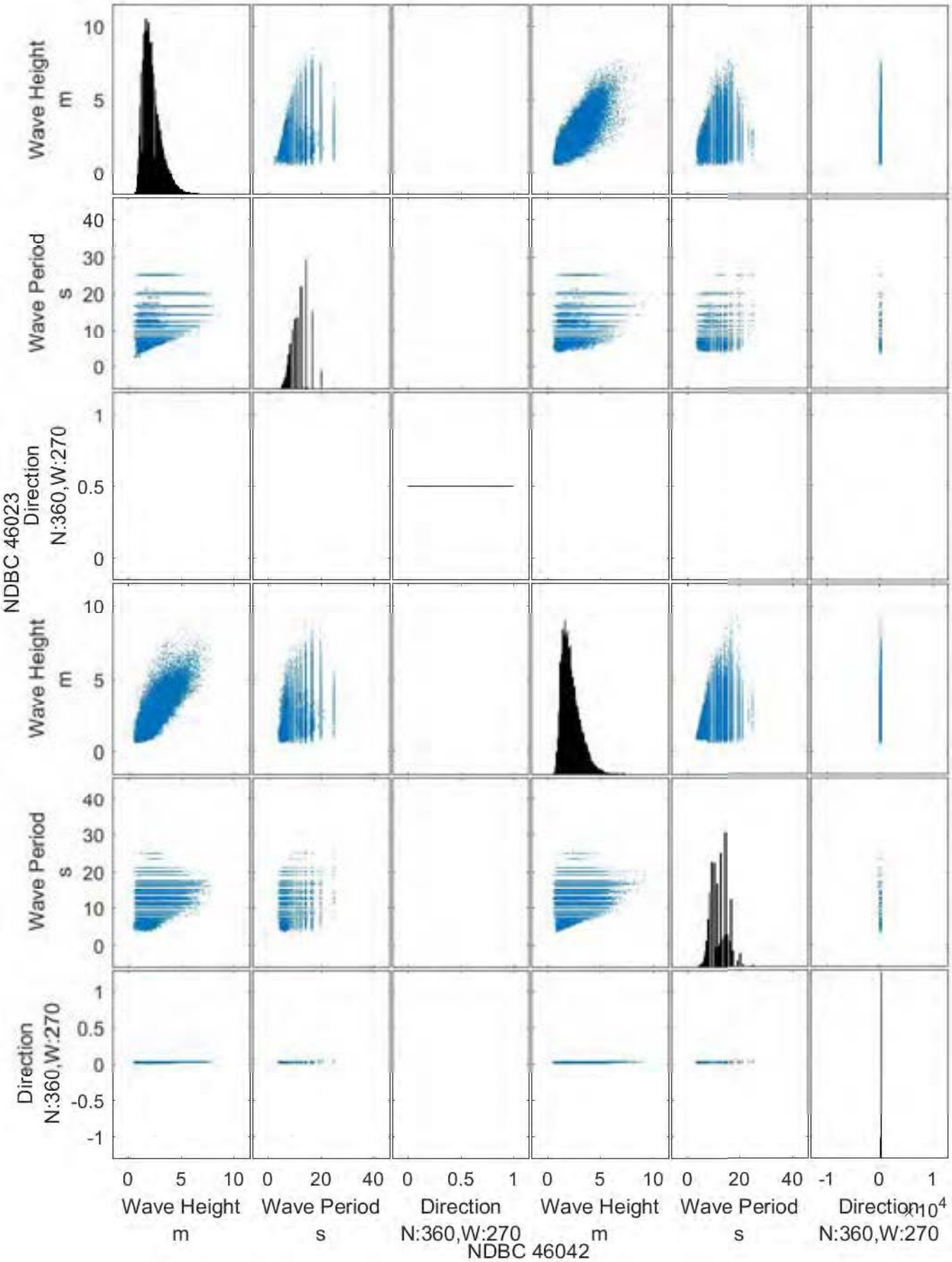


Figure B045: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46047.

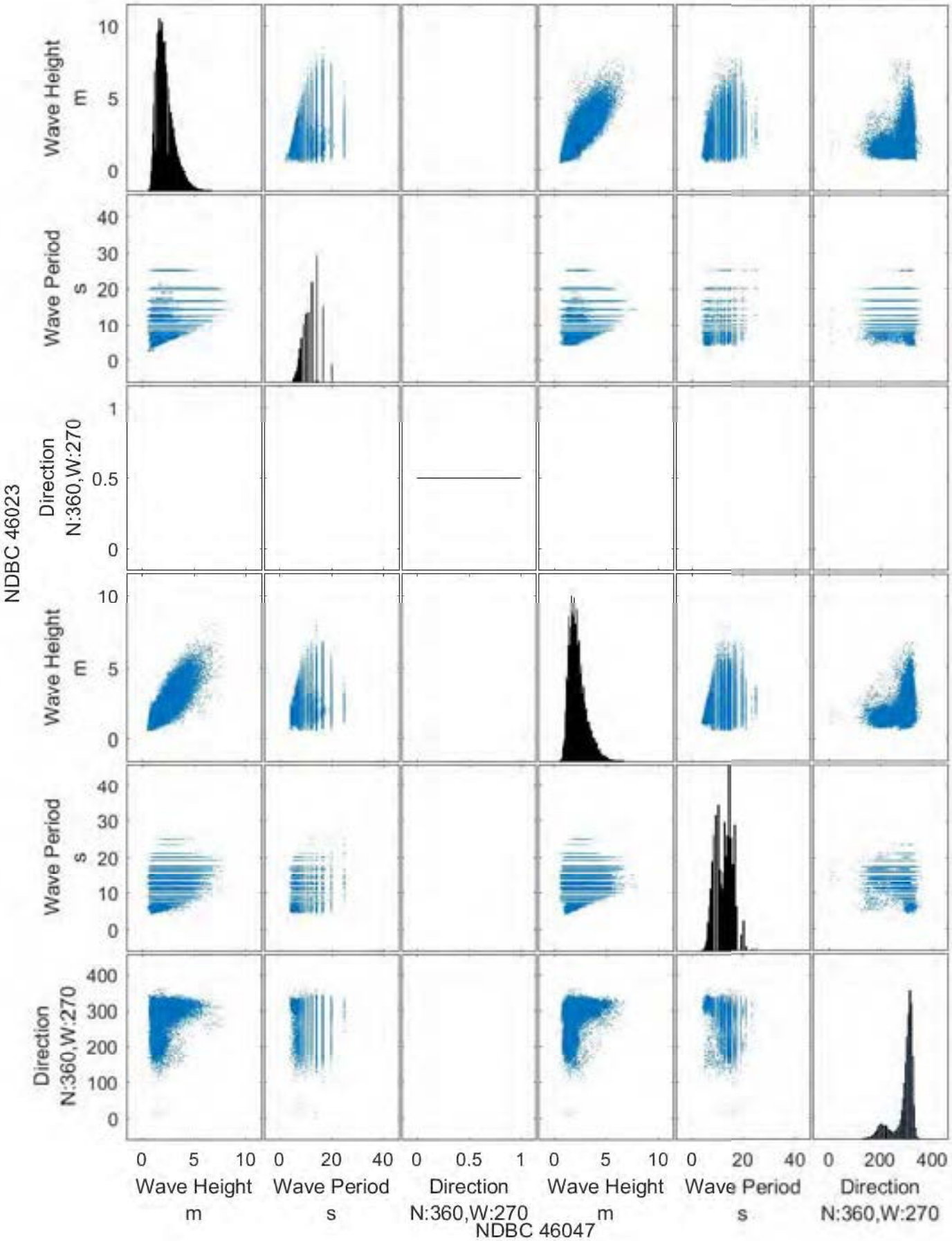


Figure B046: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46053.

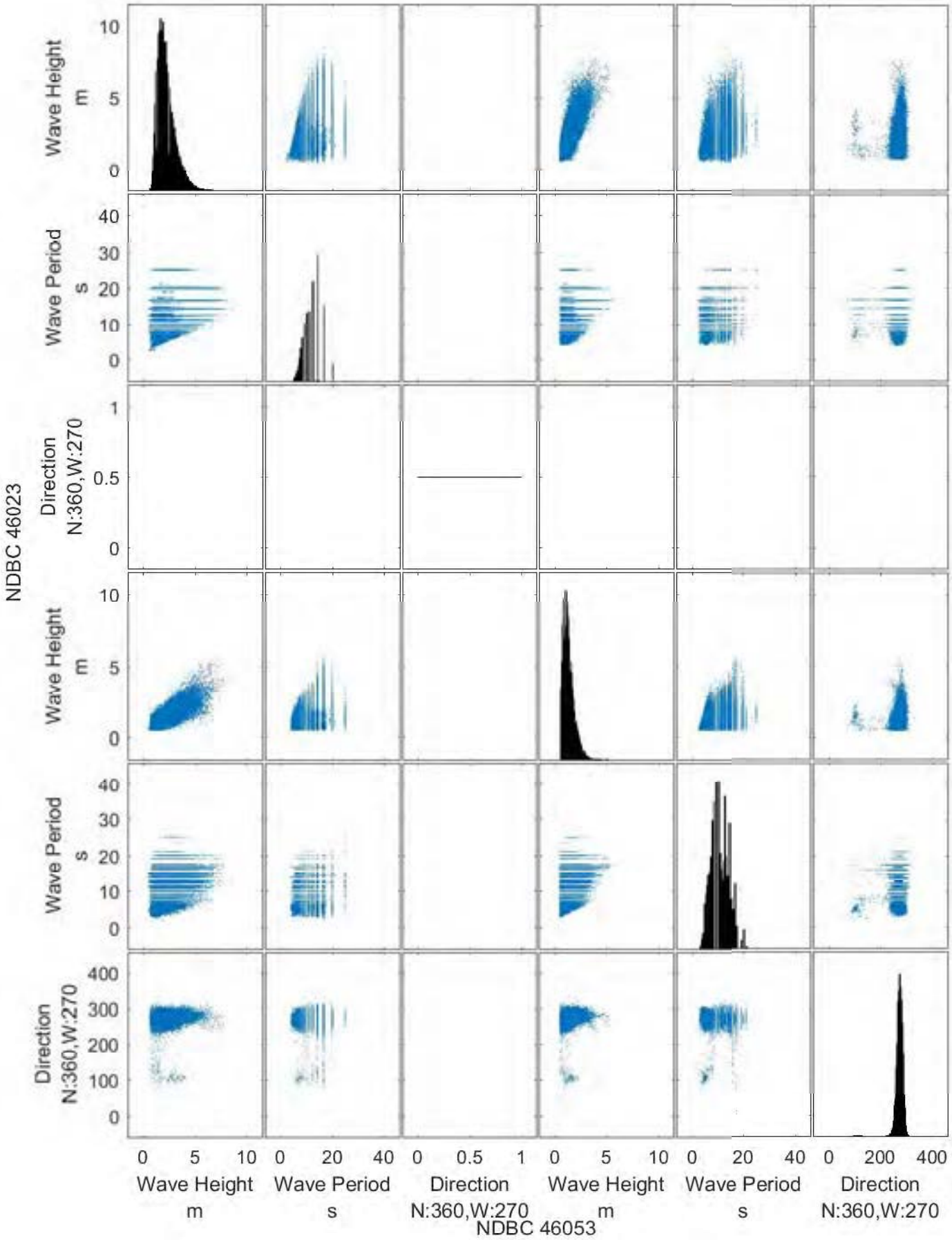


Figure B047: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46054.

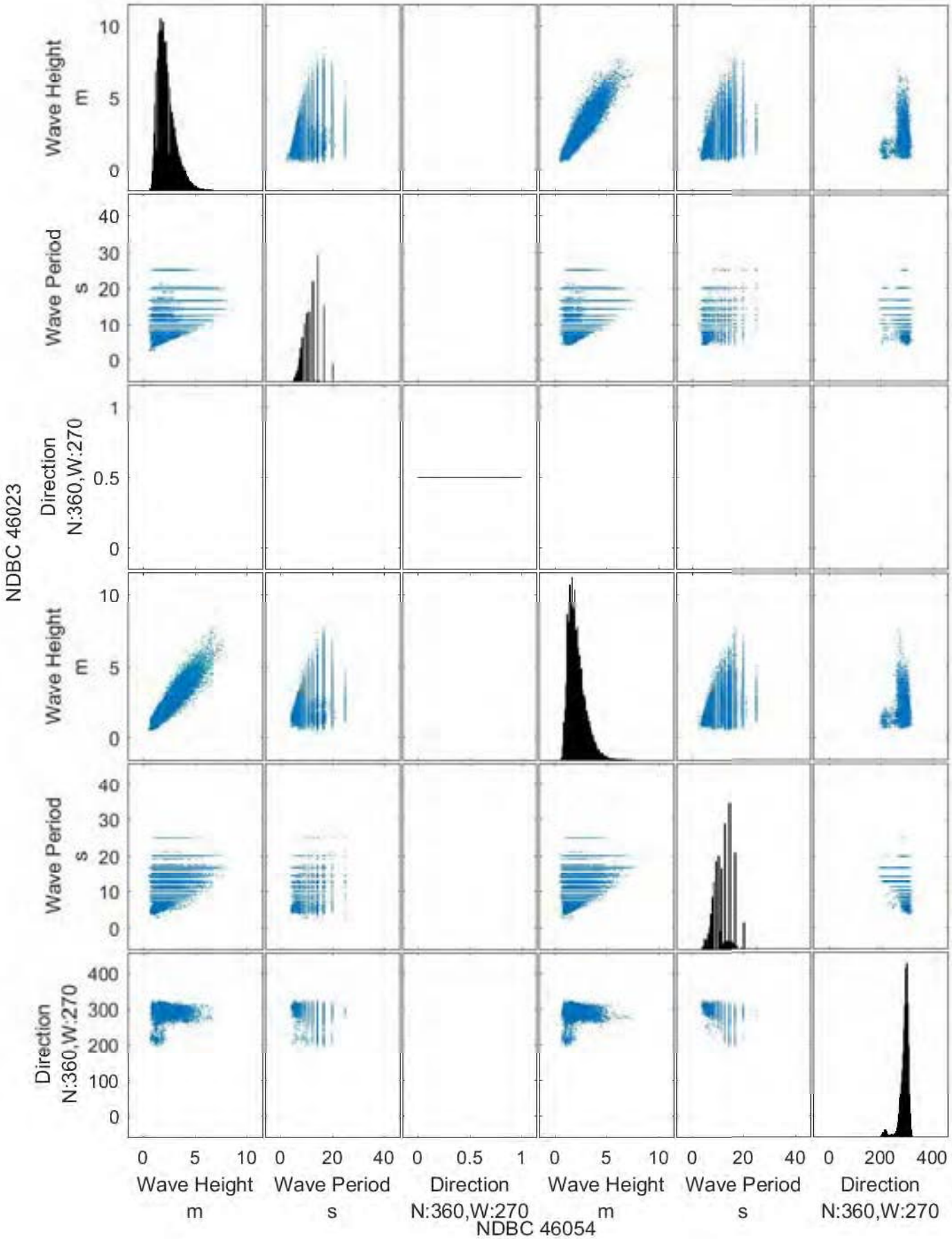


Figure B048: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46069.

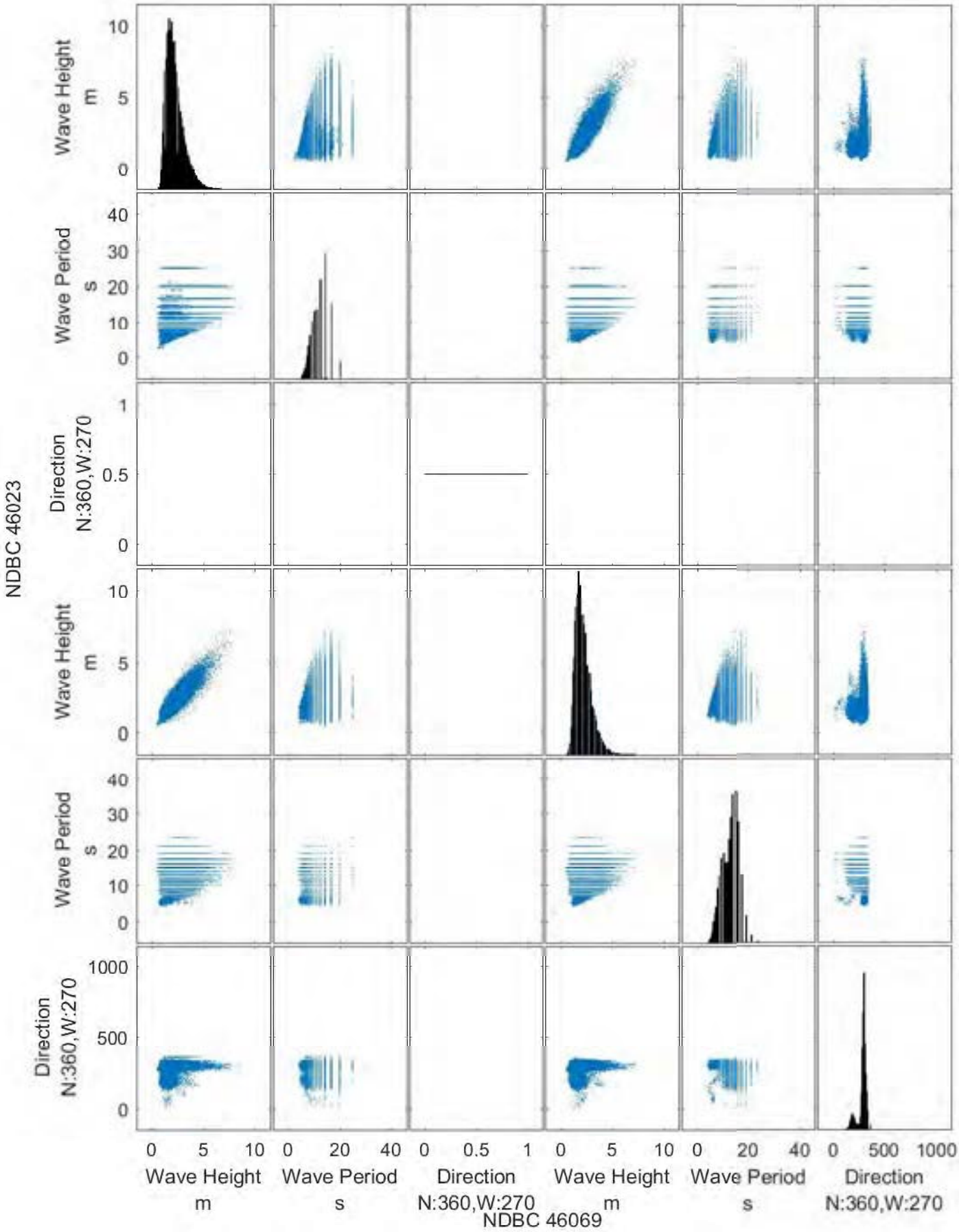


Figure B049: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46114.

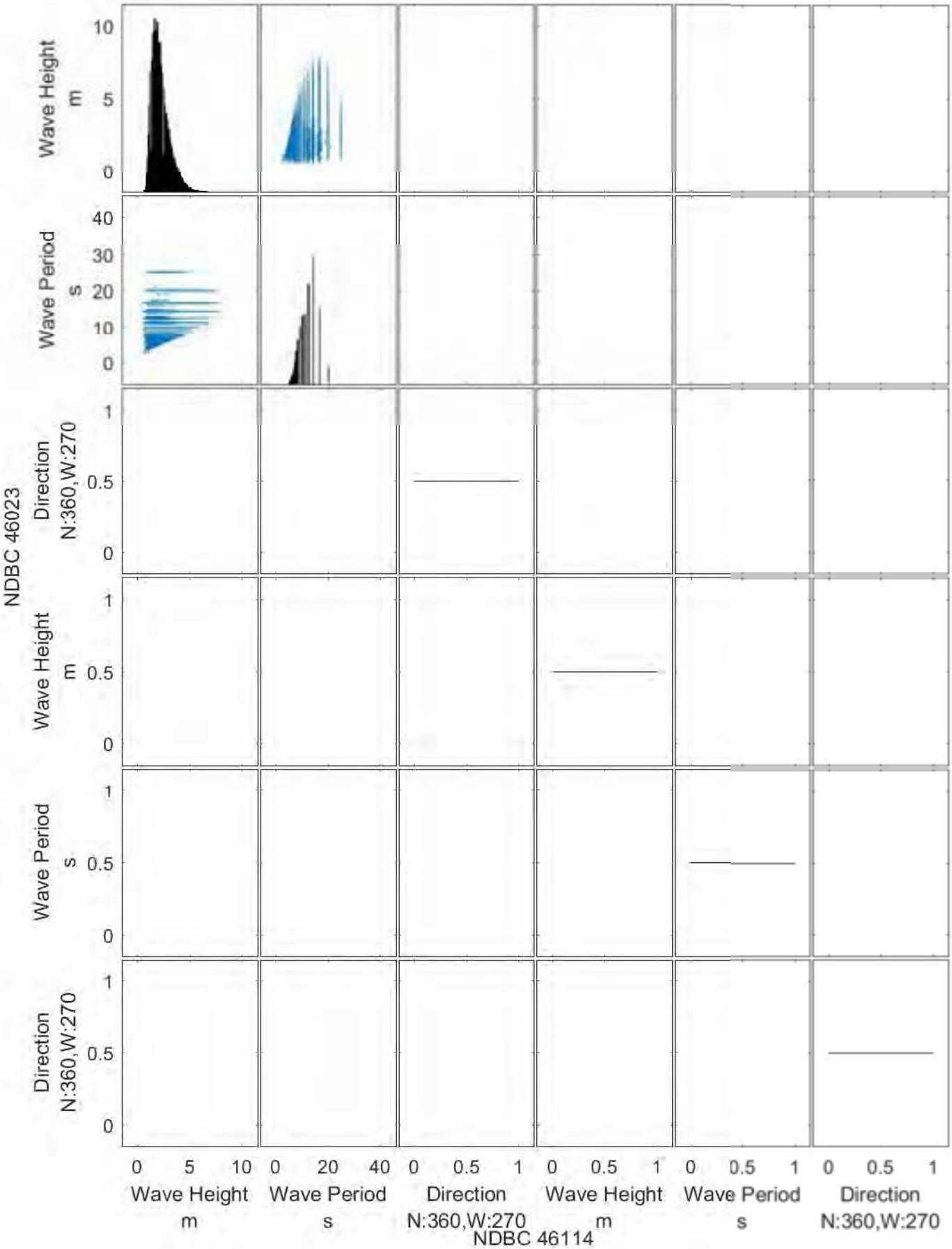


Figure B050: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46218.

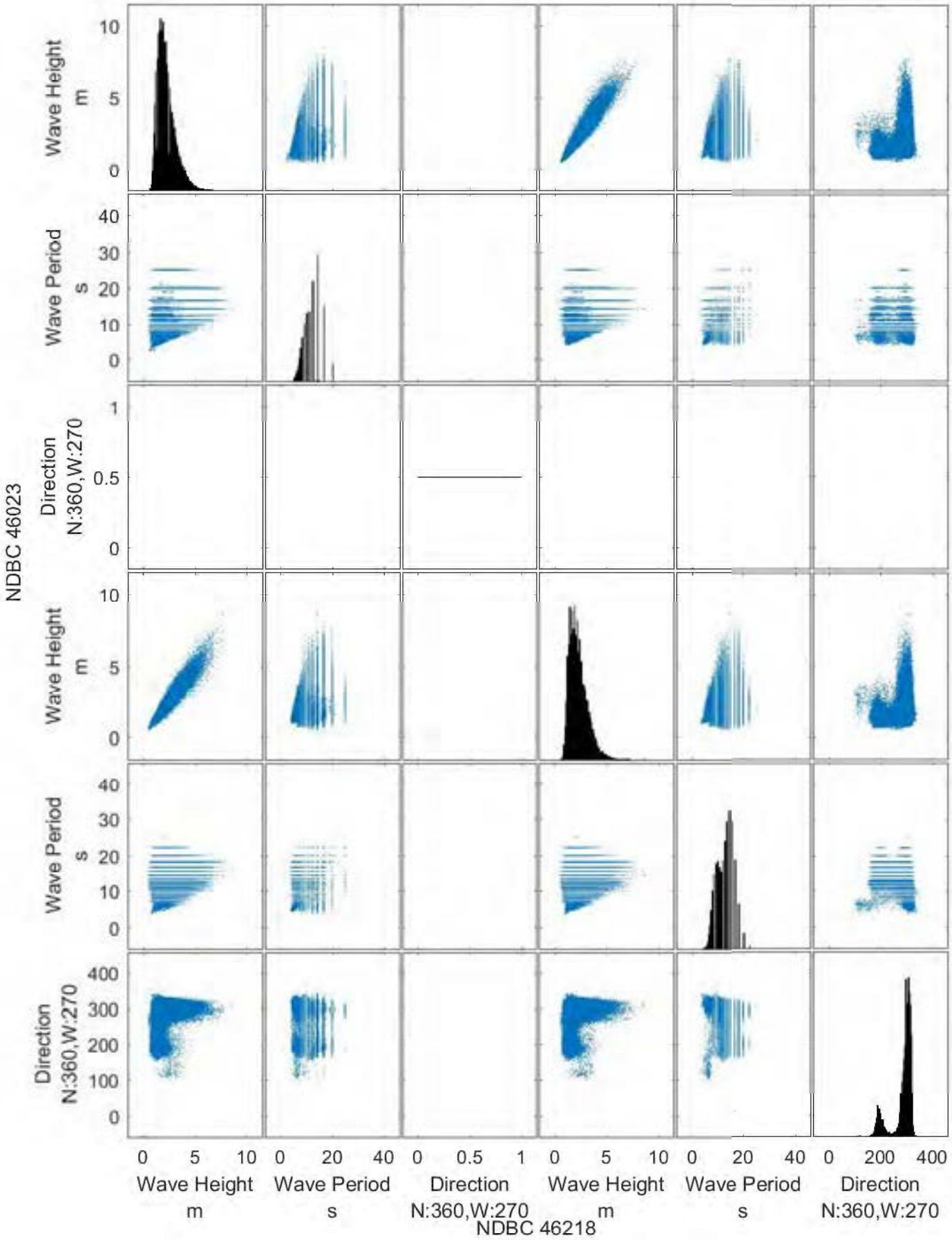


Figure B051: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46219.

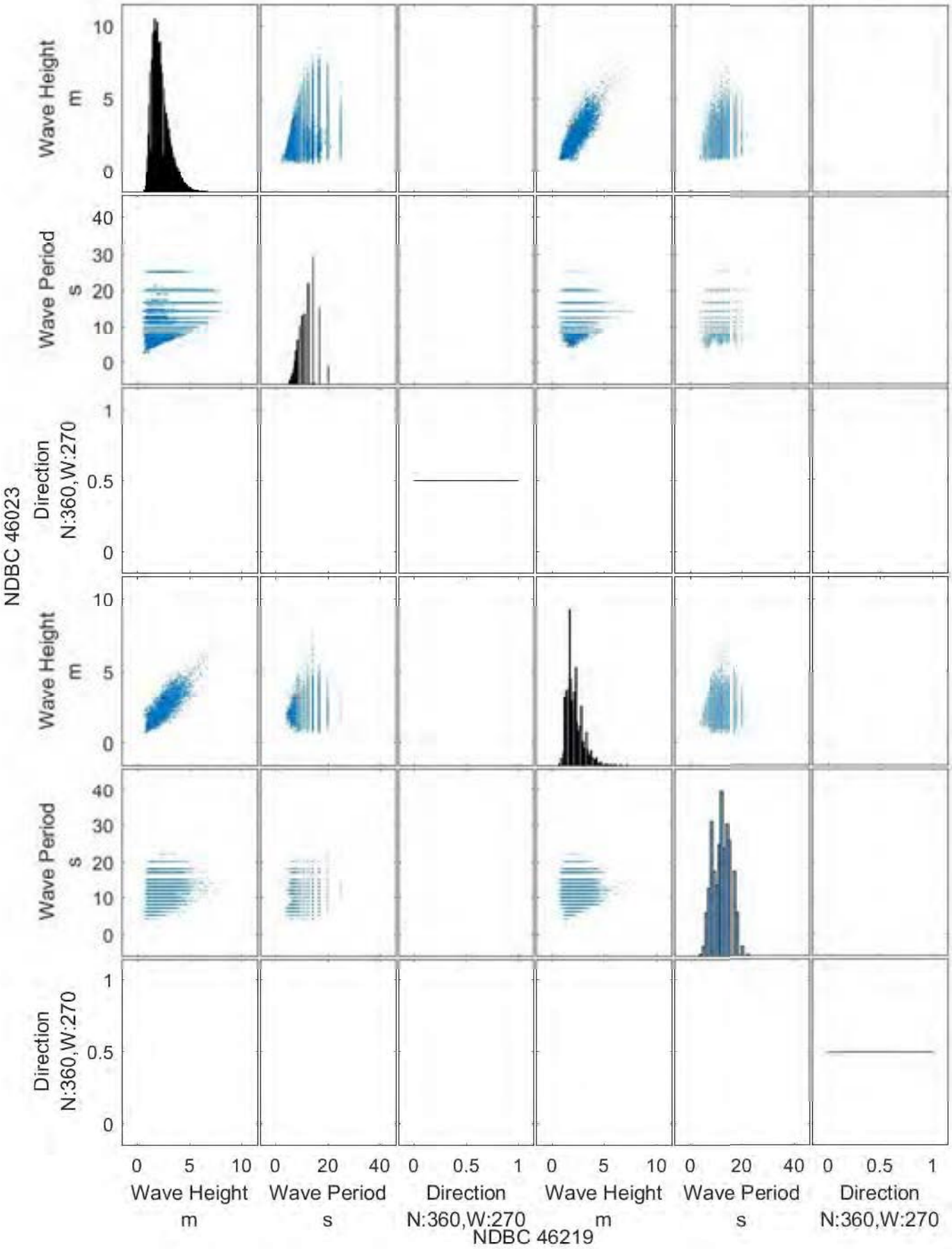


Figure B052: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46239.

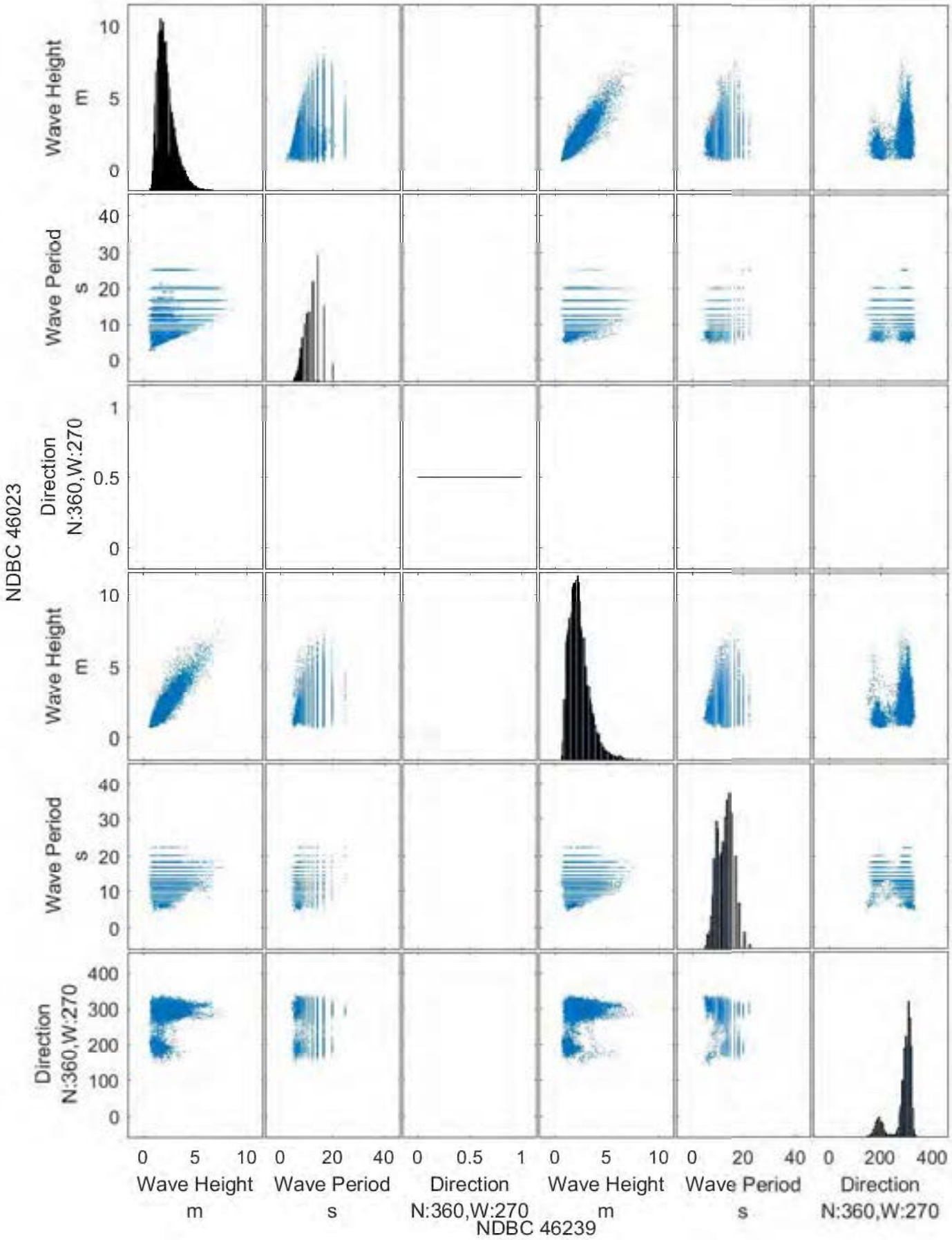


Figure B053: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46257.

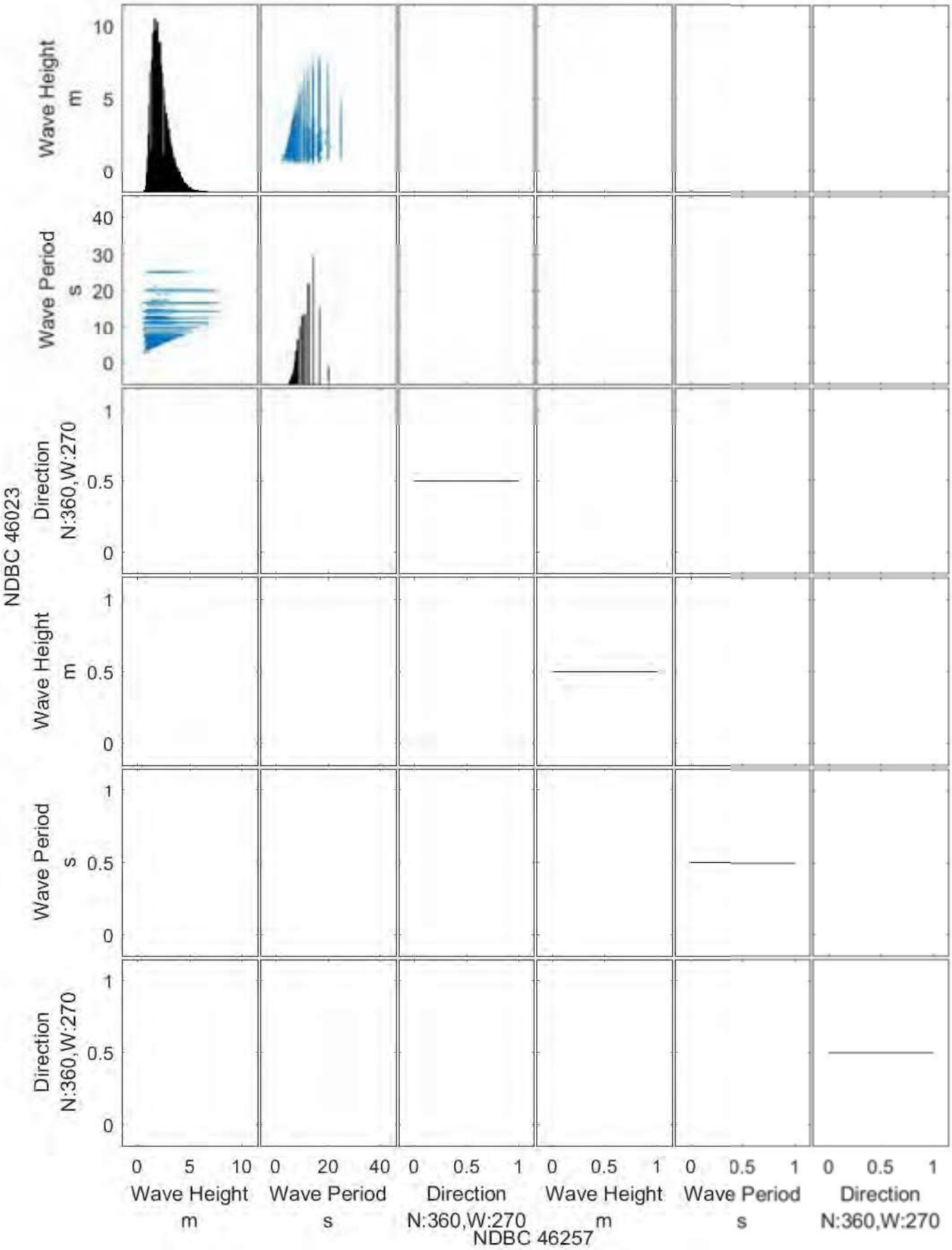


Figure B054: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46023 and NDBC 46259.

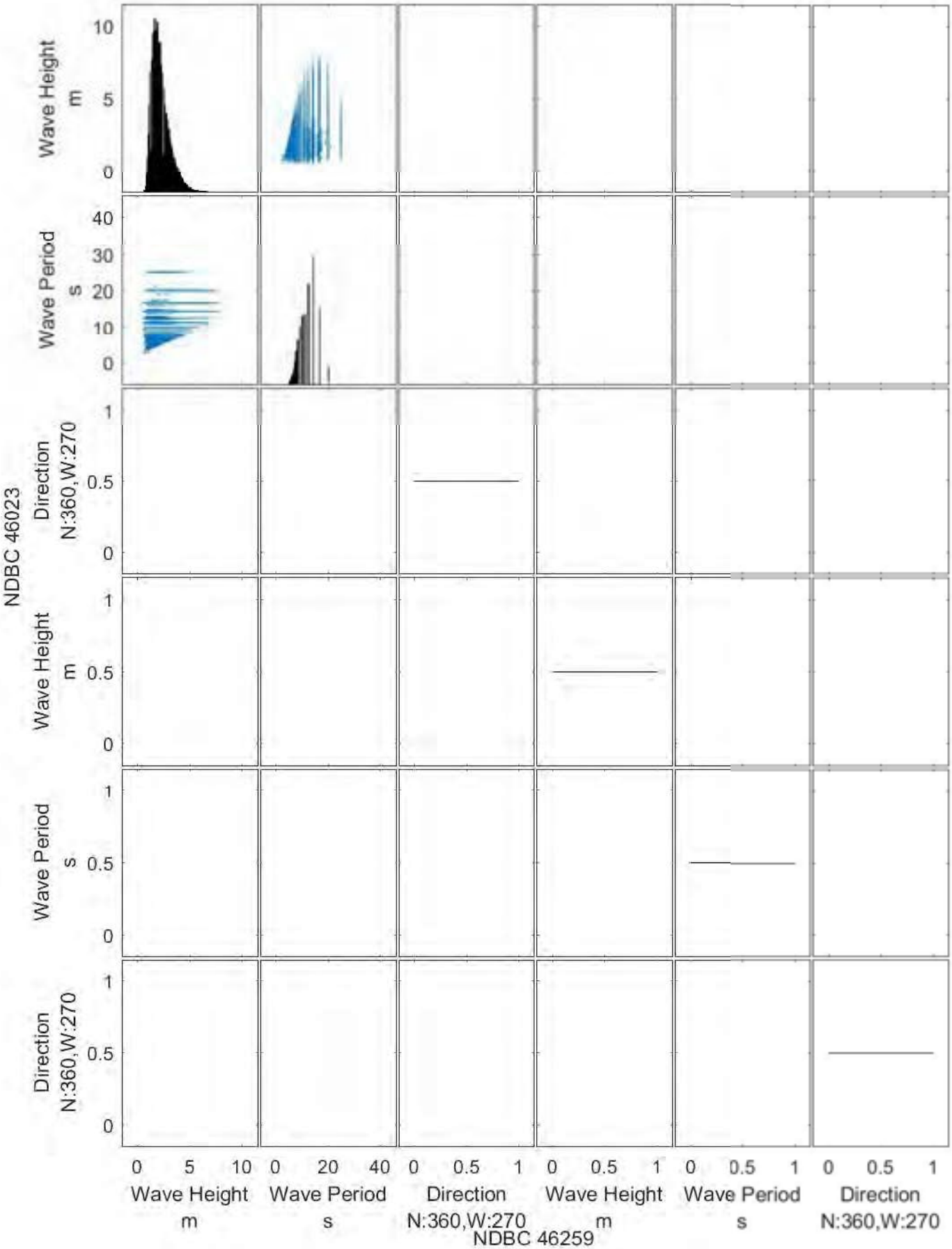


Figure B055: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46042.

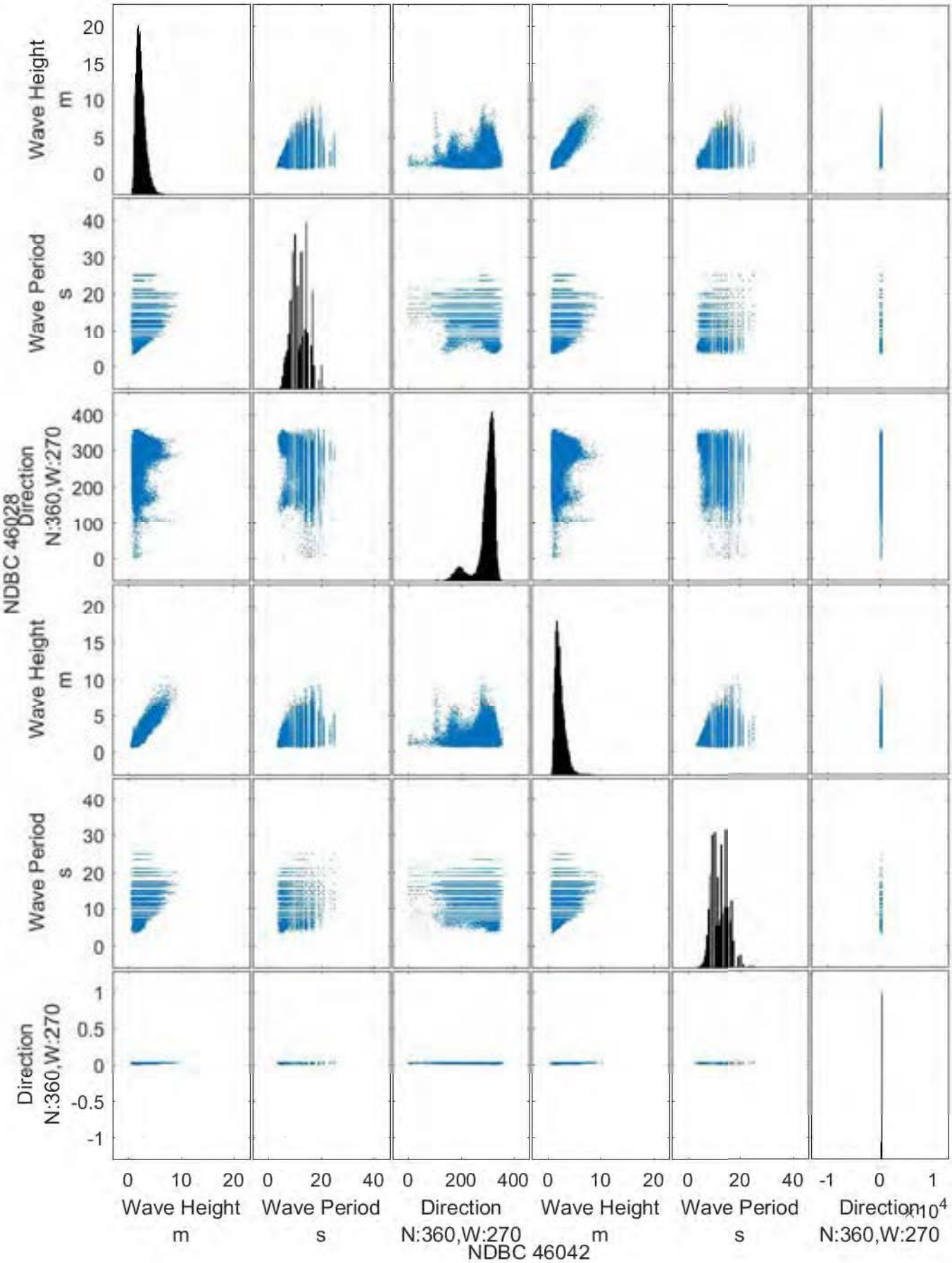


Figure B056: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46047.

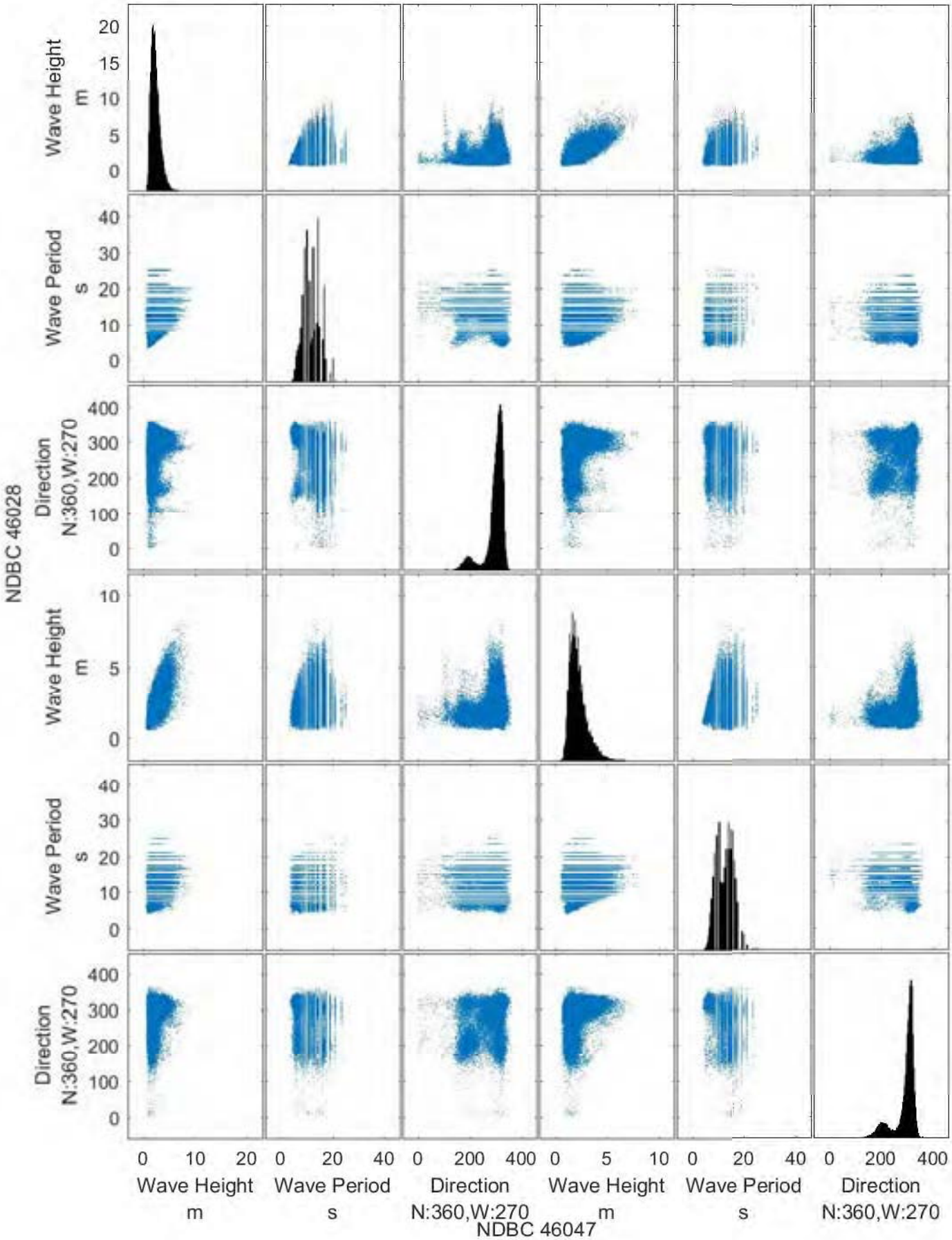


Figure B057: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46053.

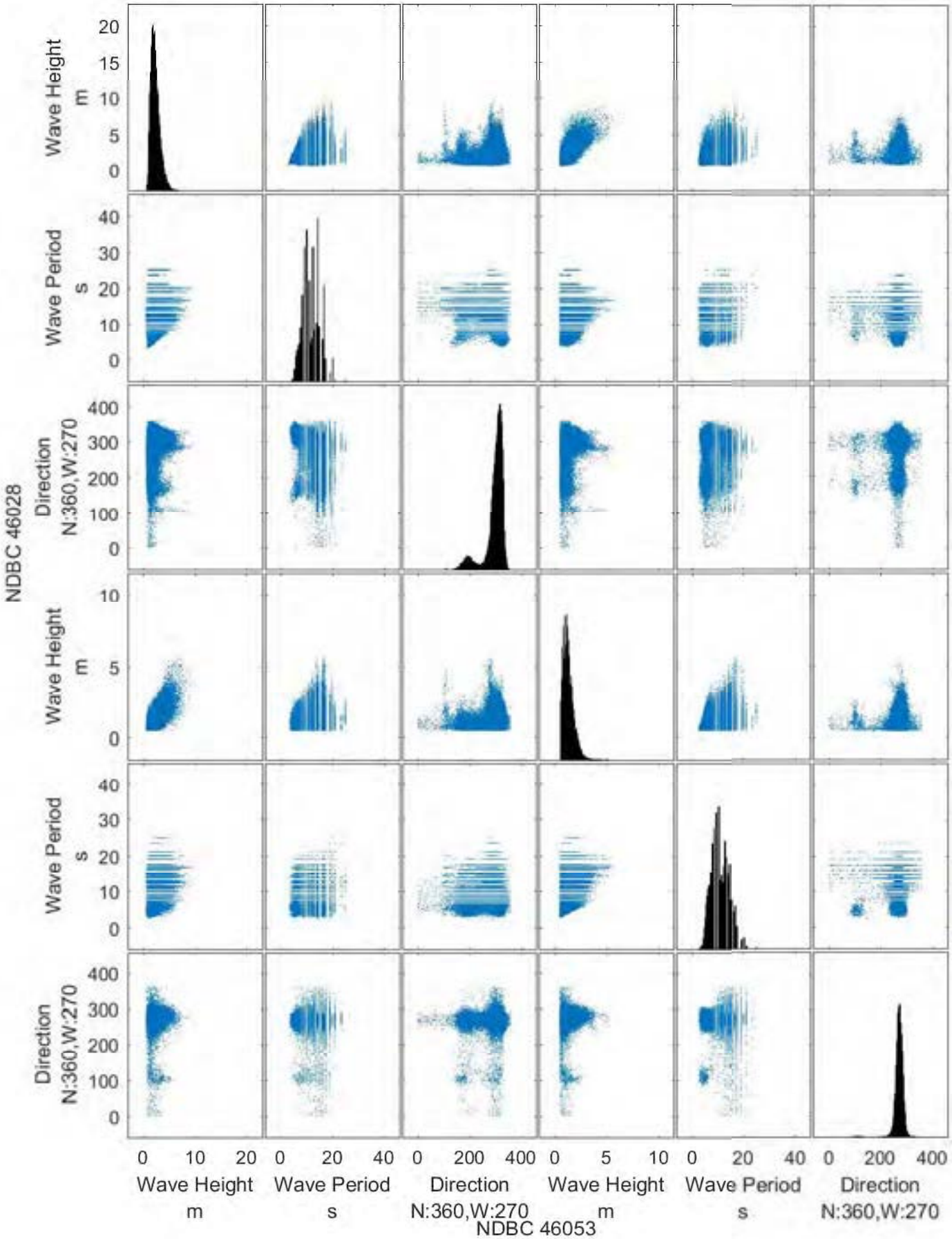


Figure B058: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46054.

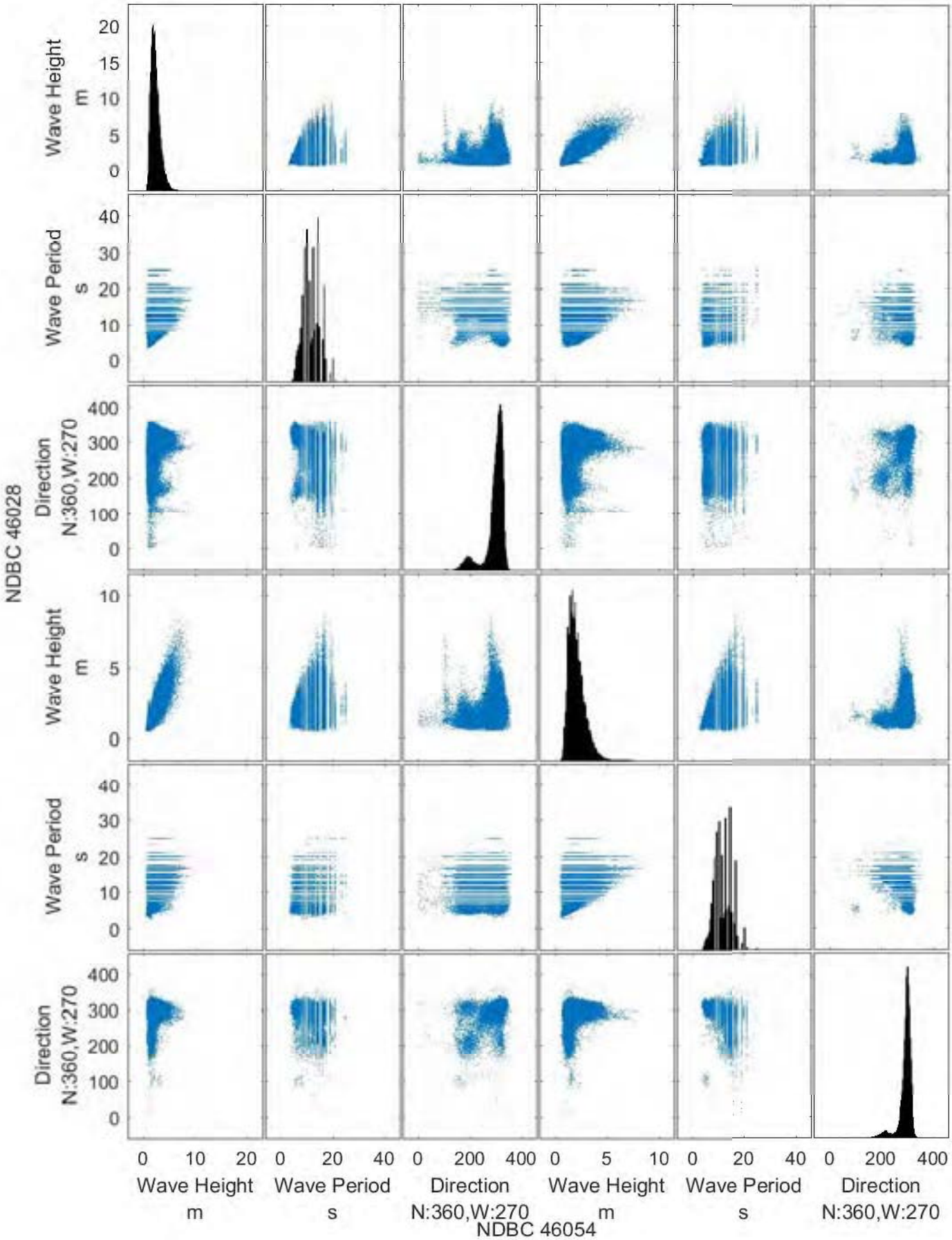


Figure B059: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46069.

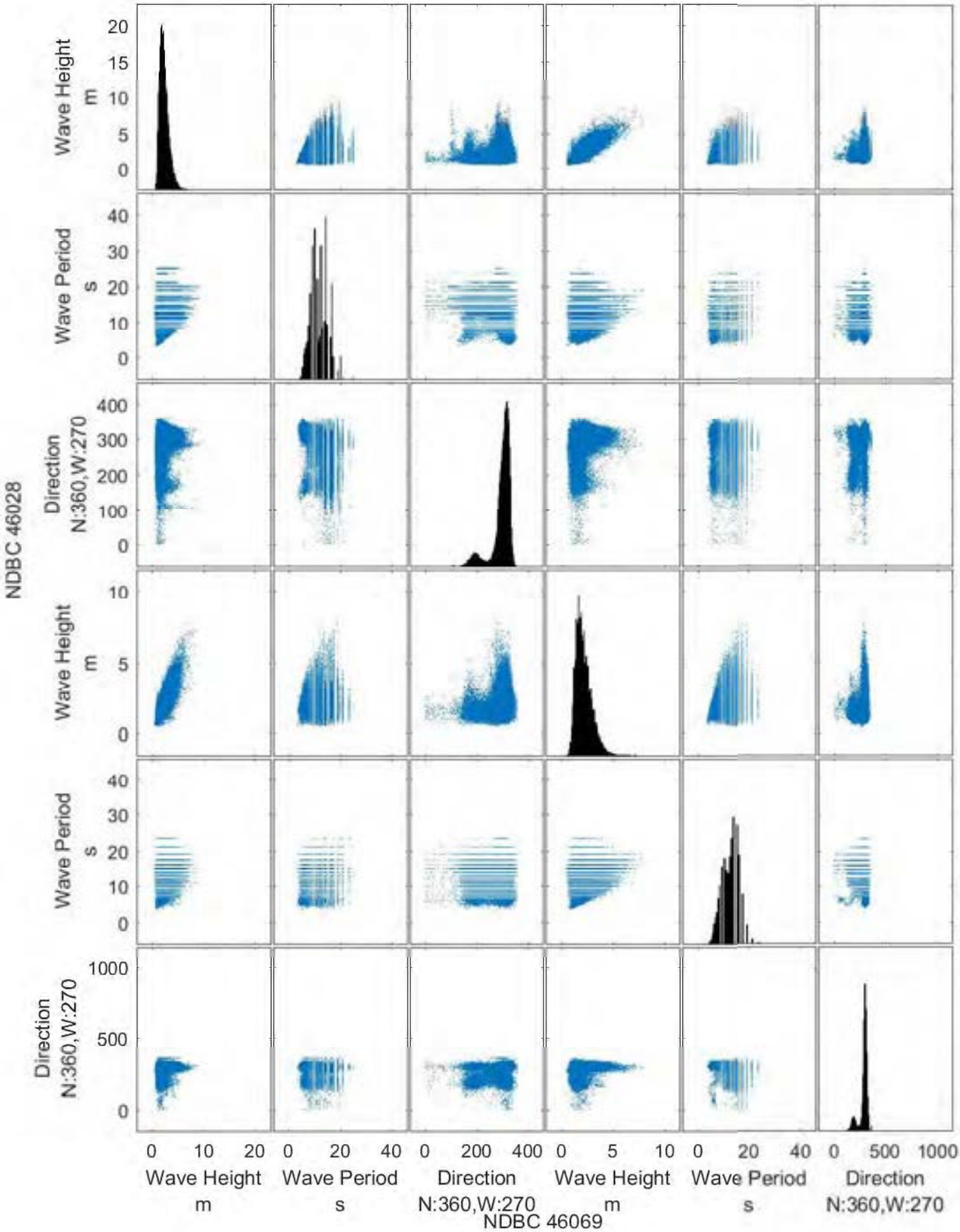


Figure B060: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46114.

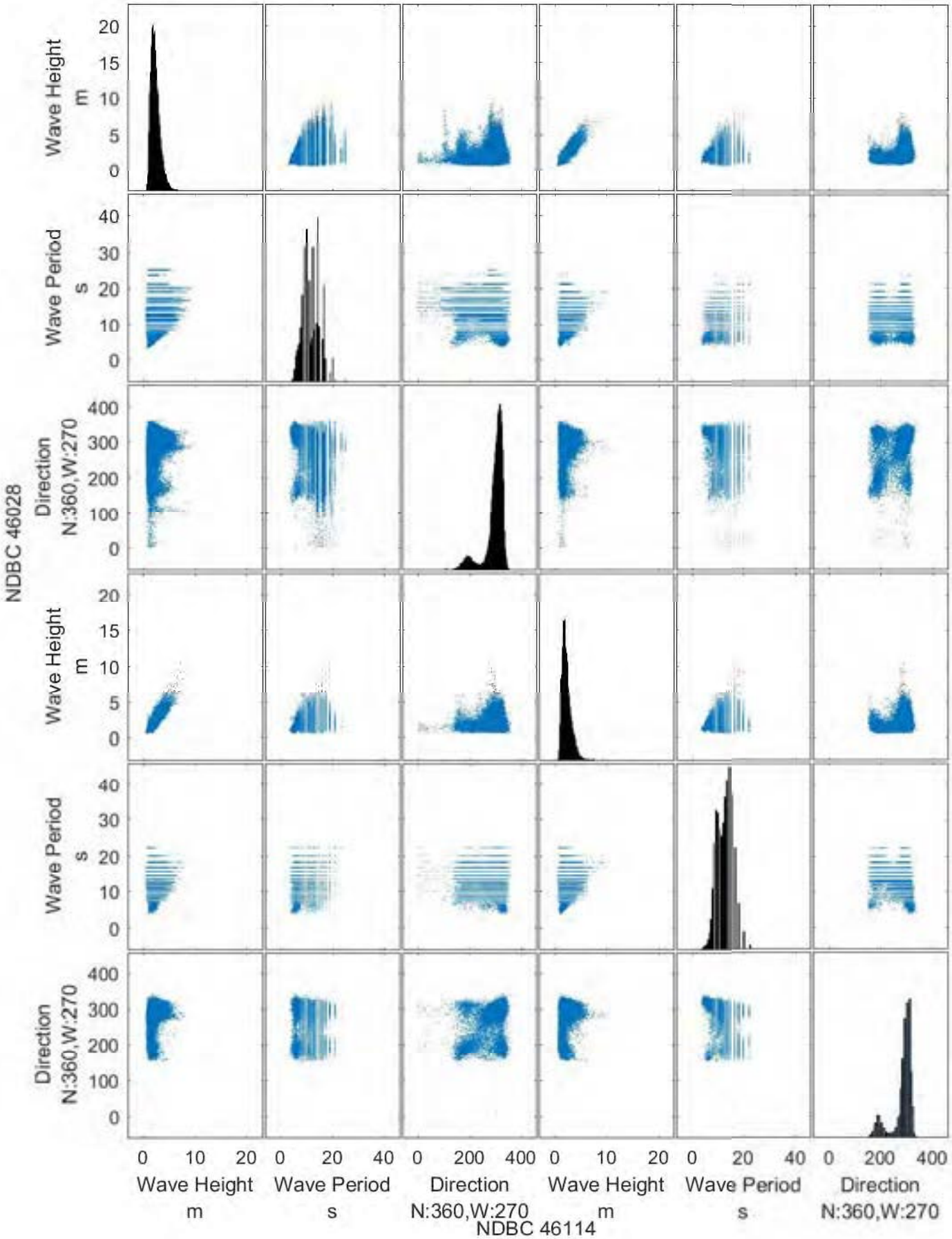


Figure B061: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46218.

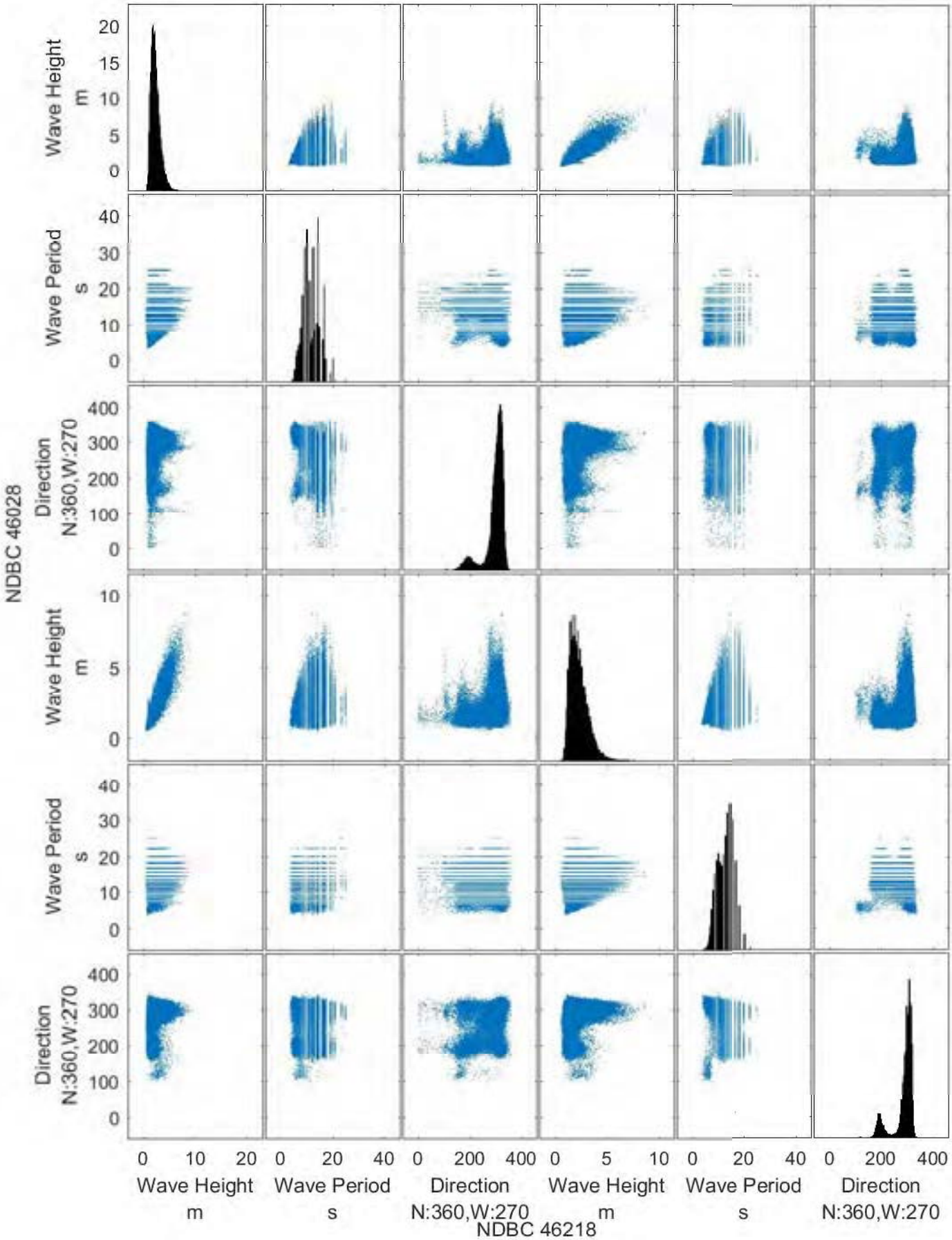


Figure B062: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46219.

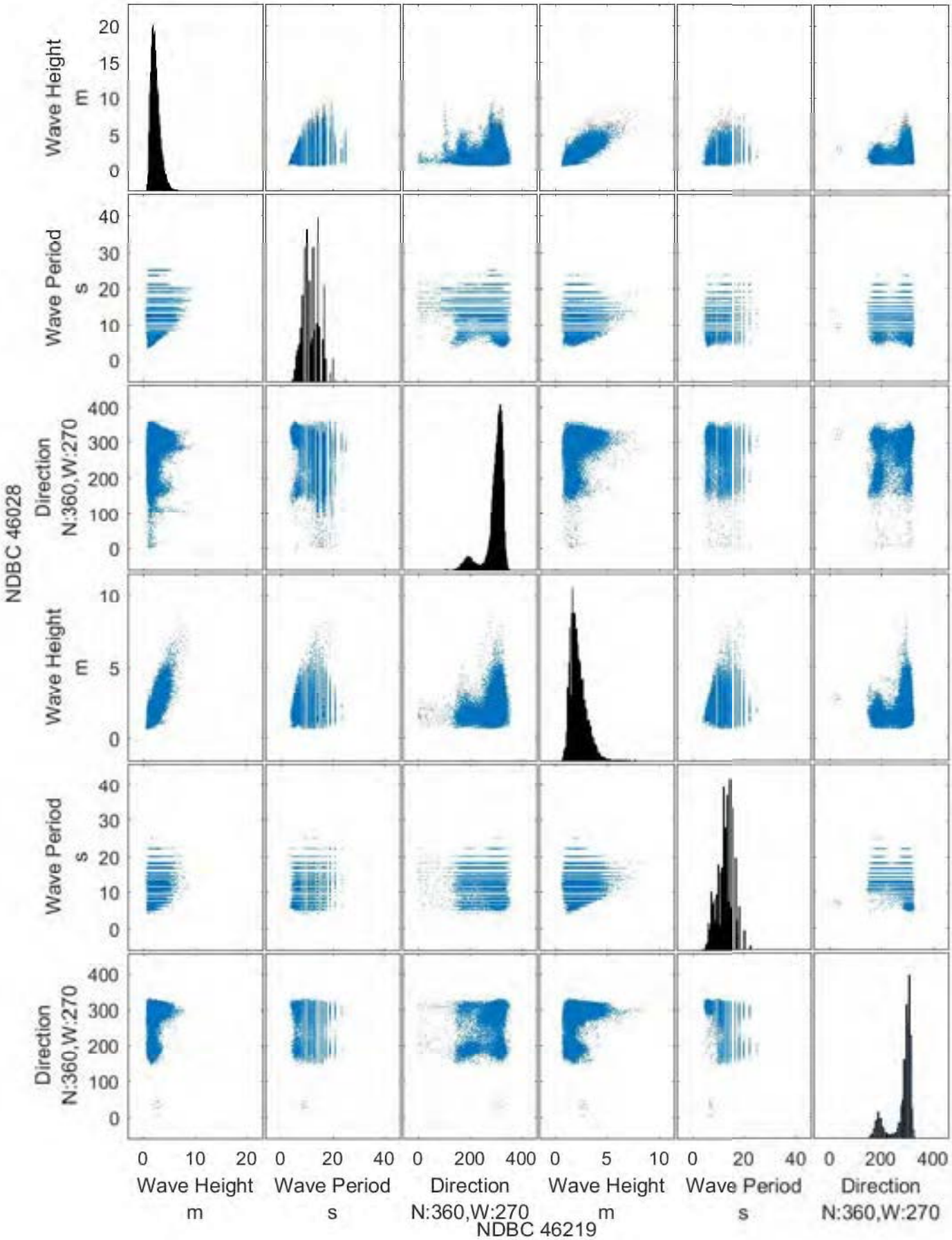


Figure B063: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46239.

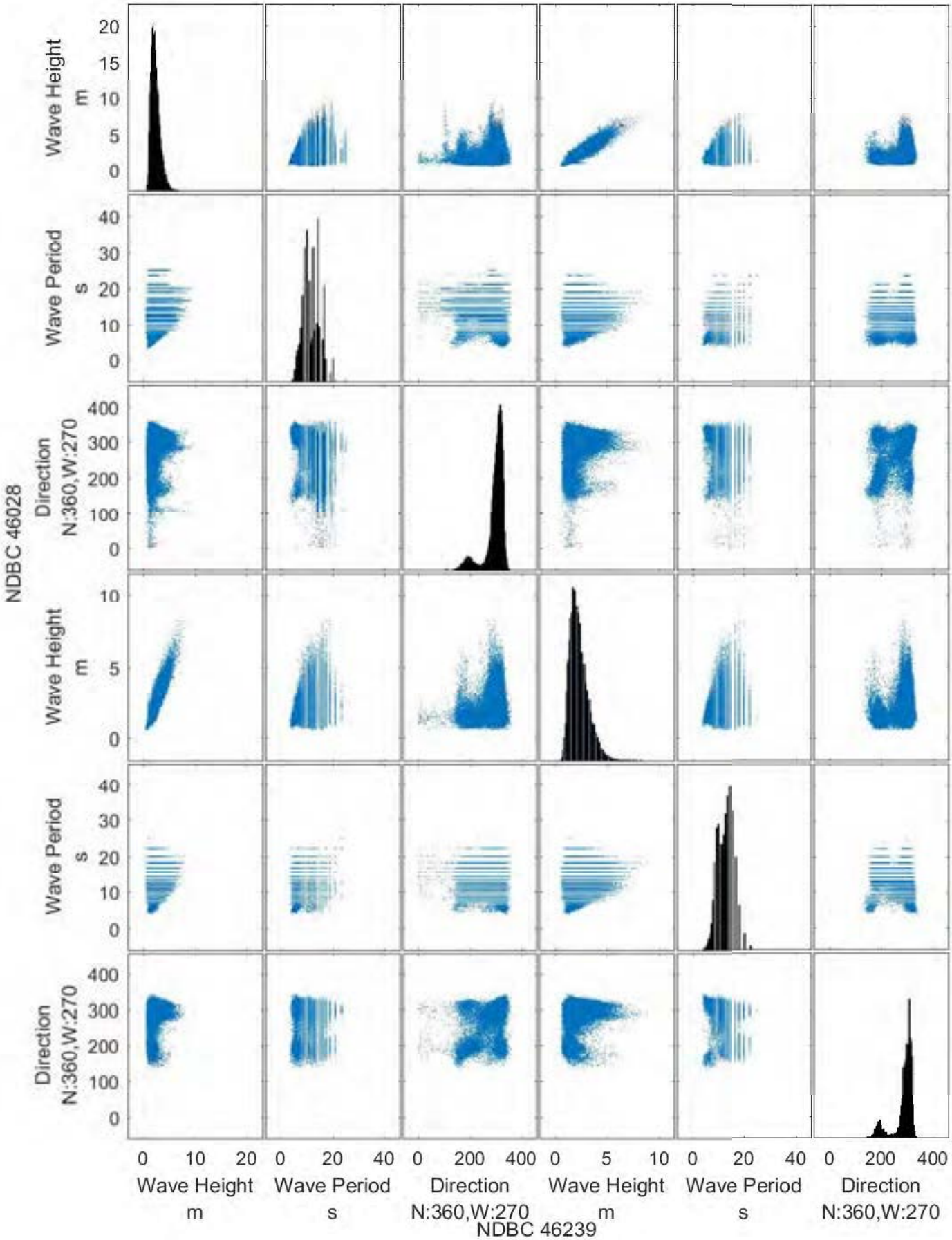


Figure B064: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46257.

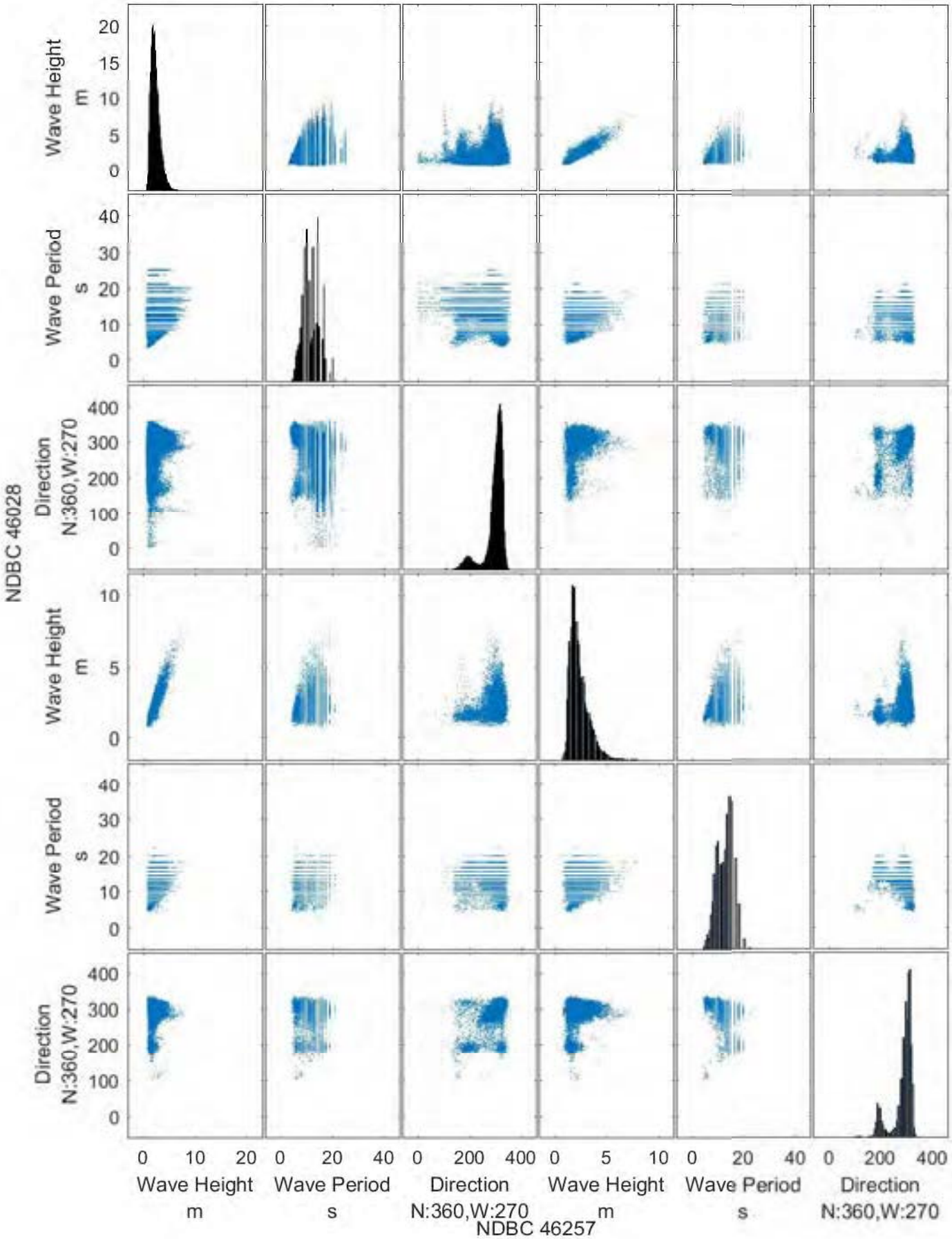


Figure B065: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46259.

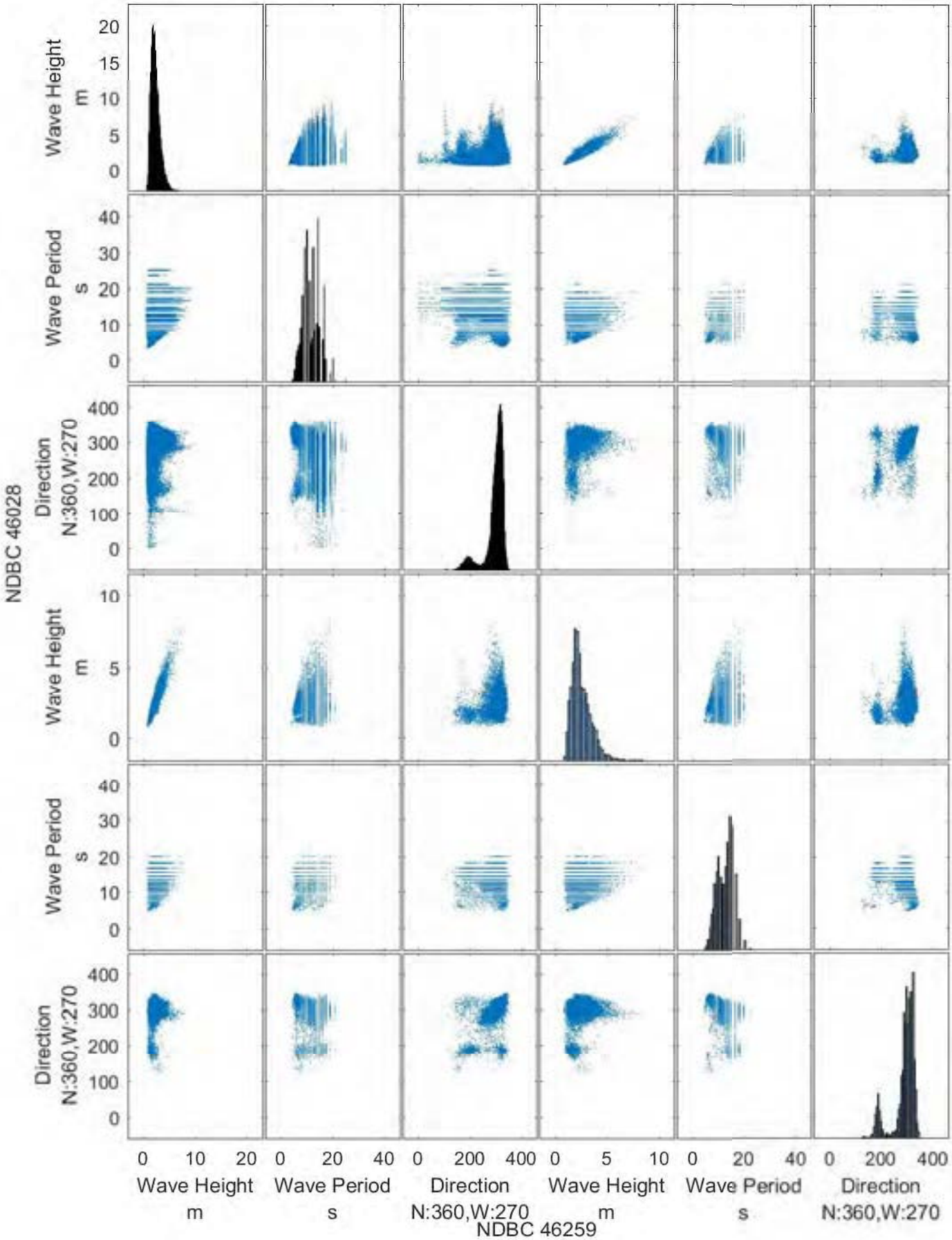


Figure B066: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46028 and NDBC 46028.

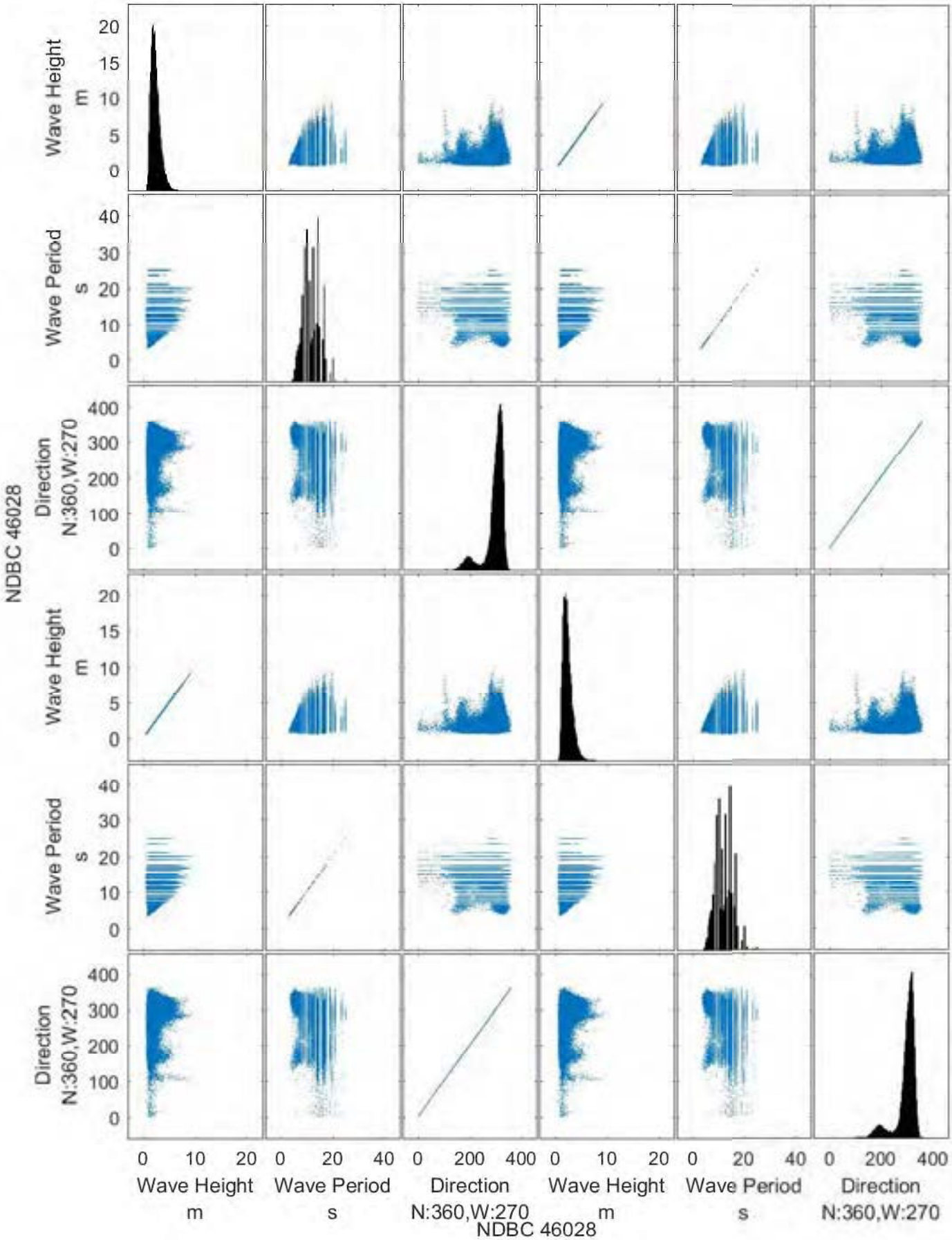


Figure B067: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46047.

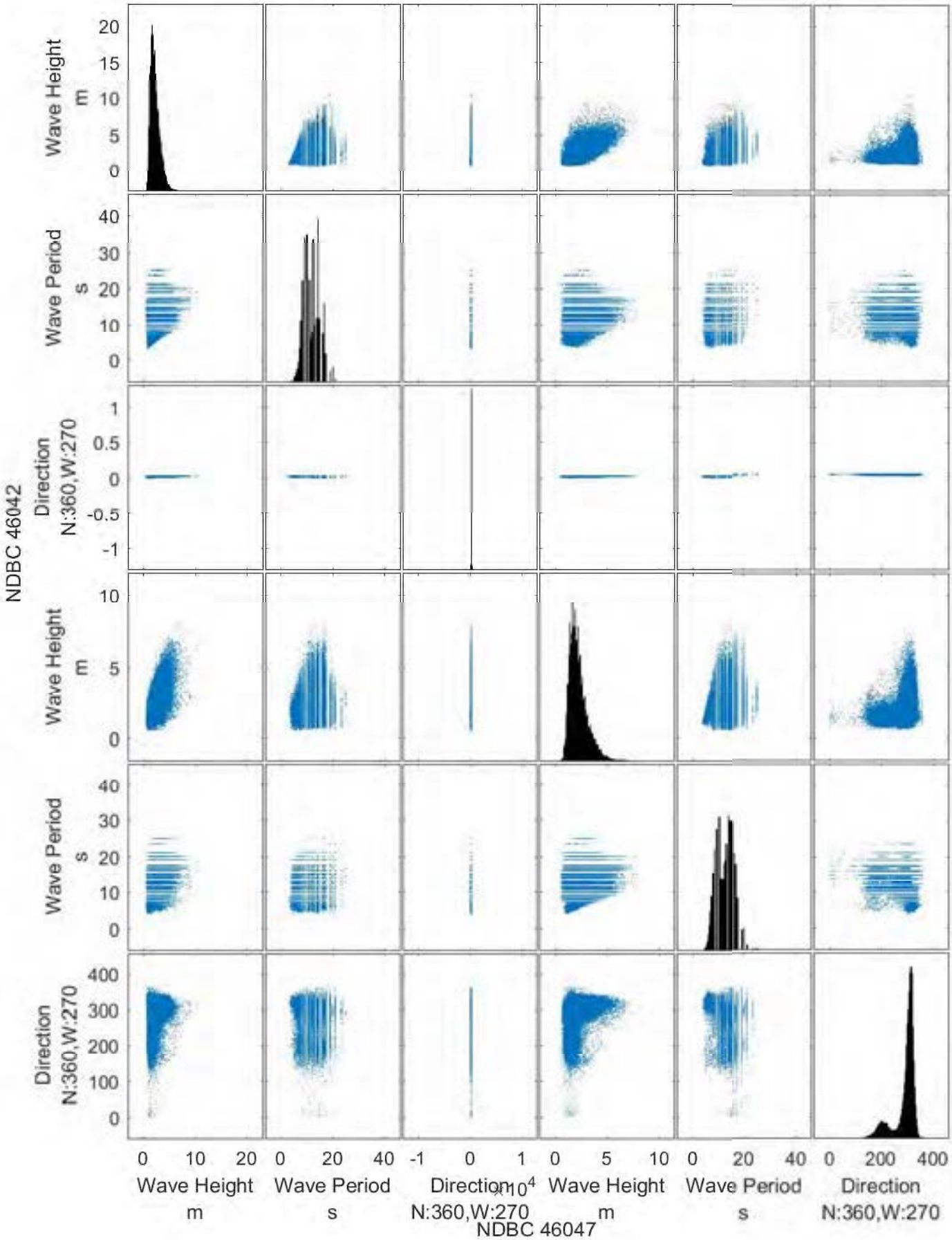


Figure B068: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46053.

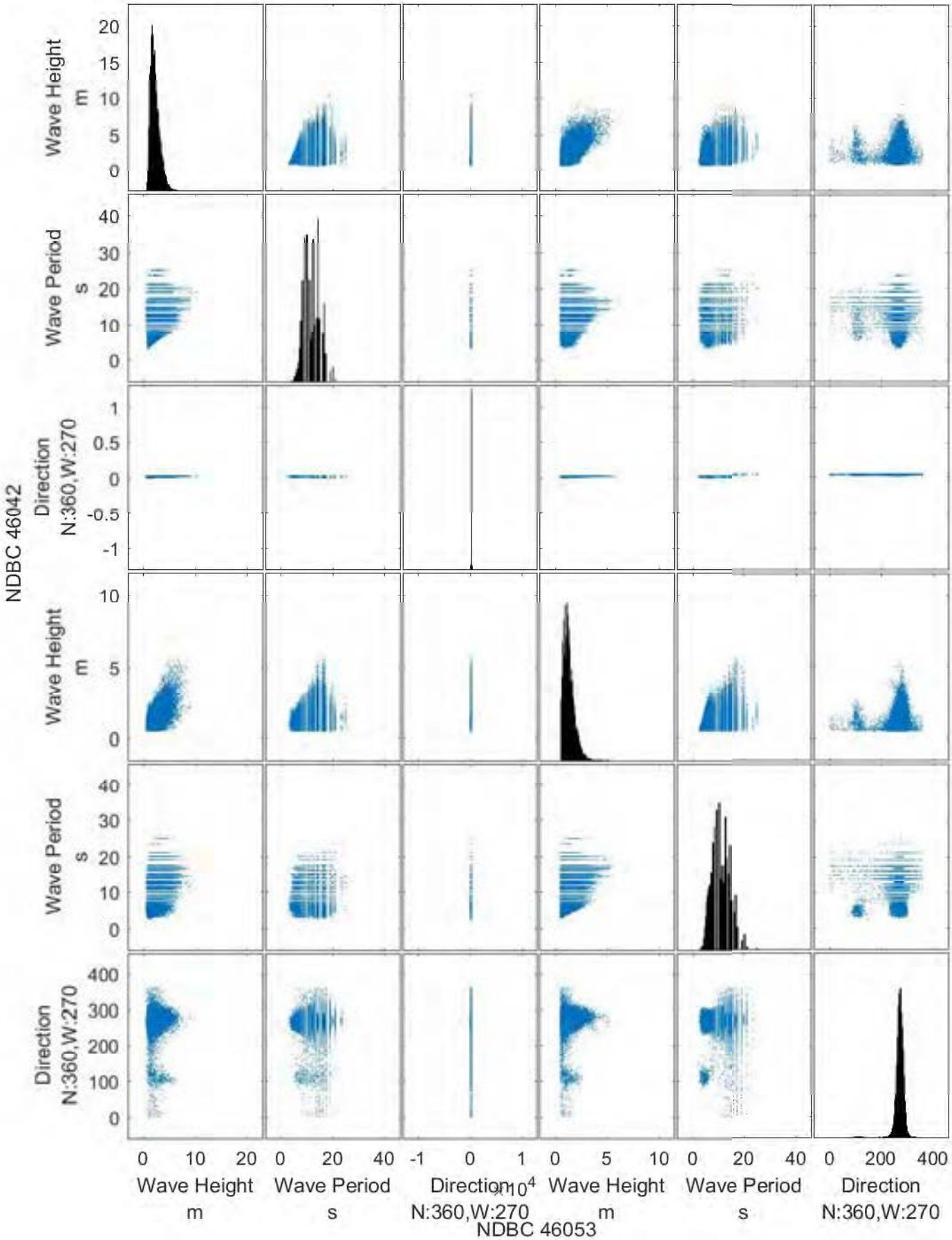


Figure B069: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46054.

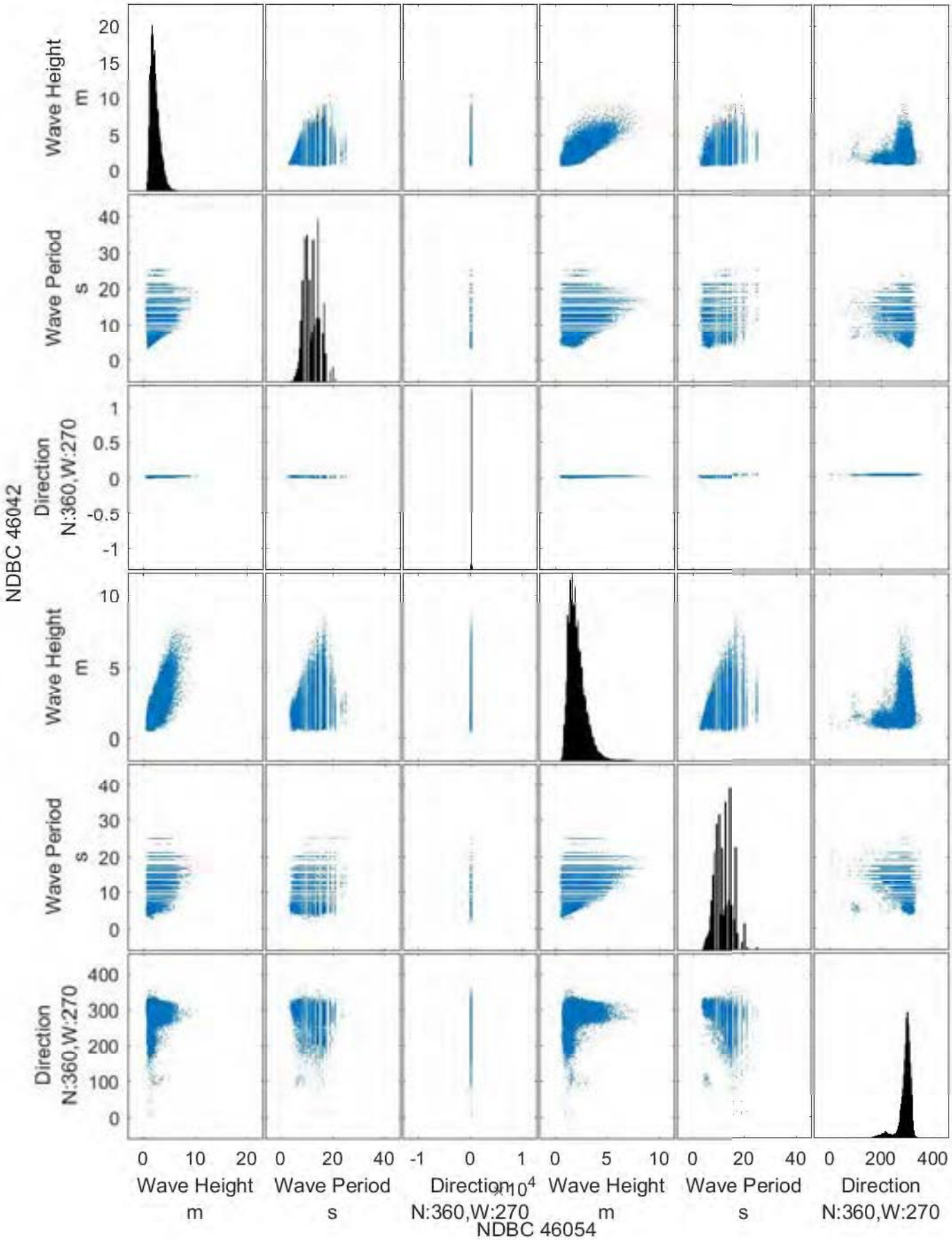


Figure B070: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46069.

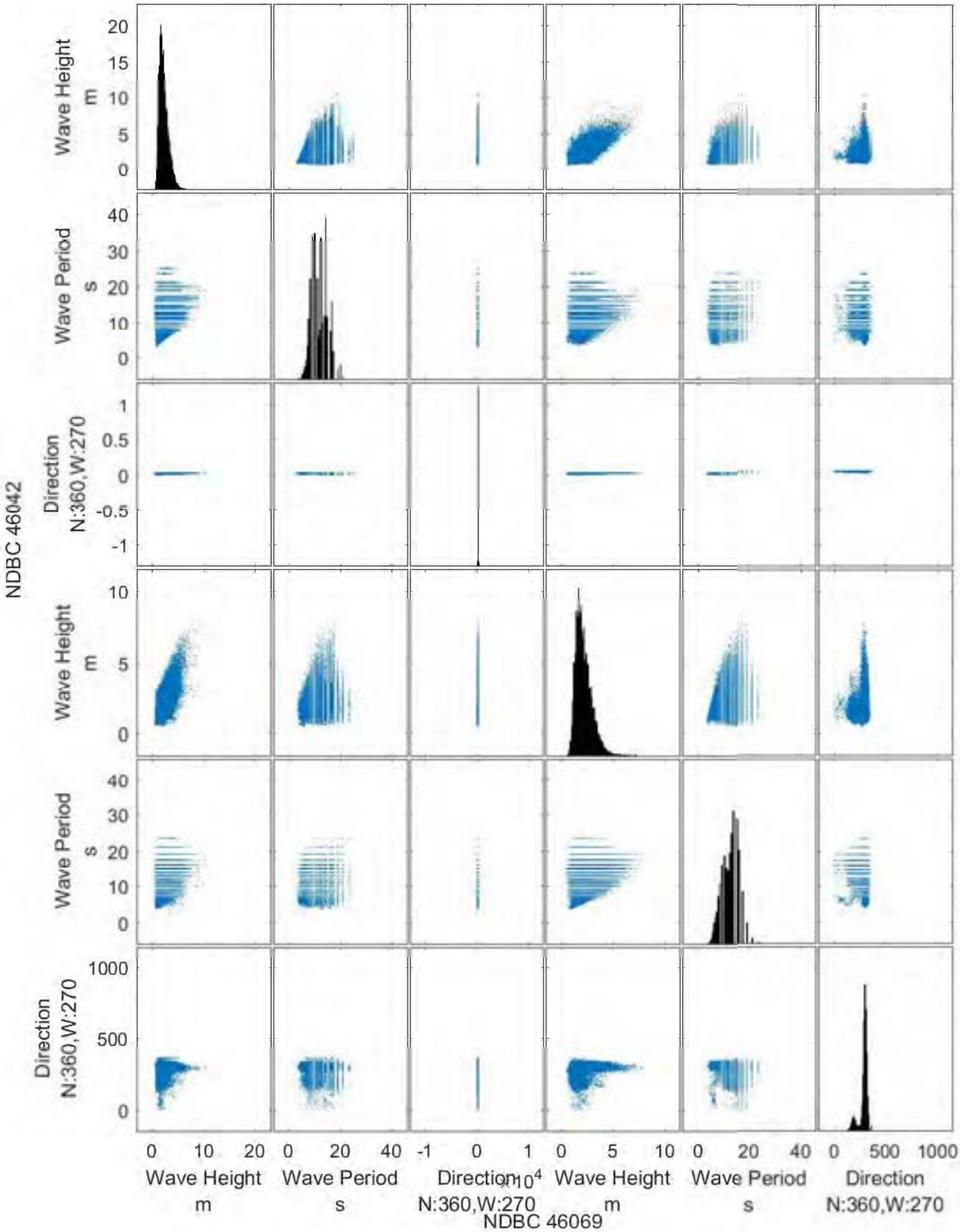


Figure B071: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46114.

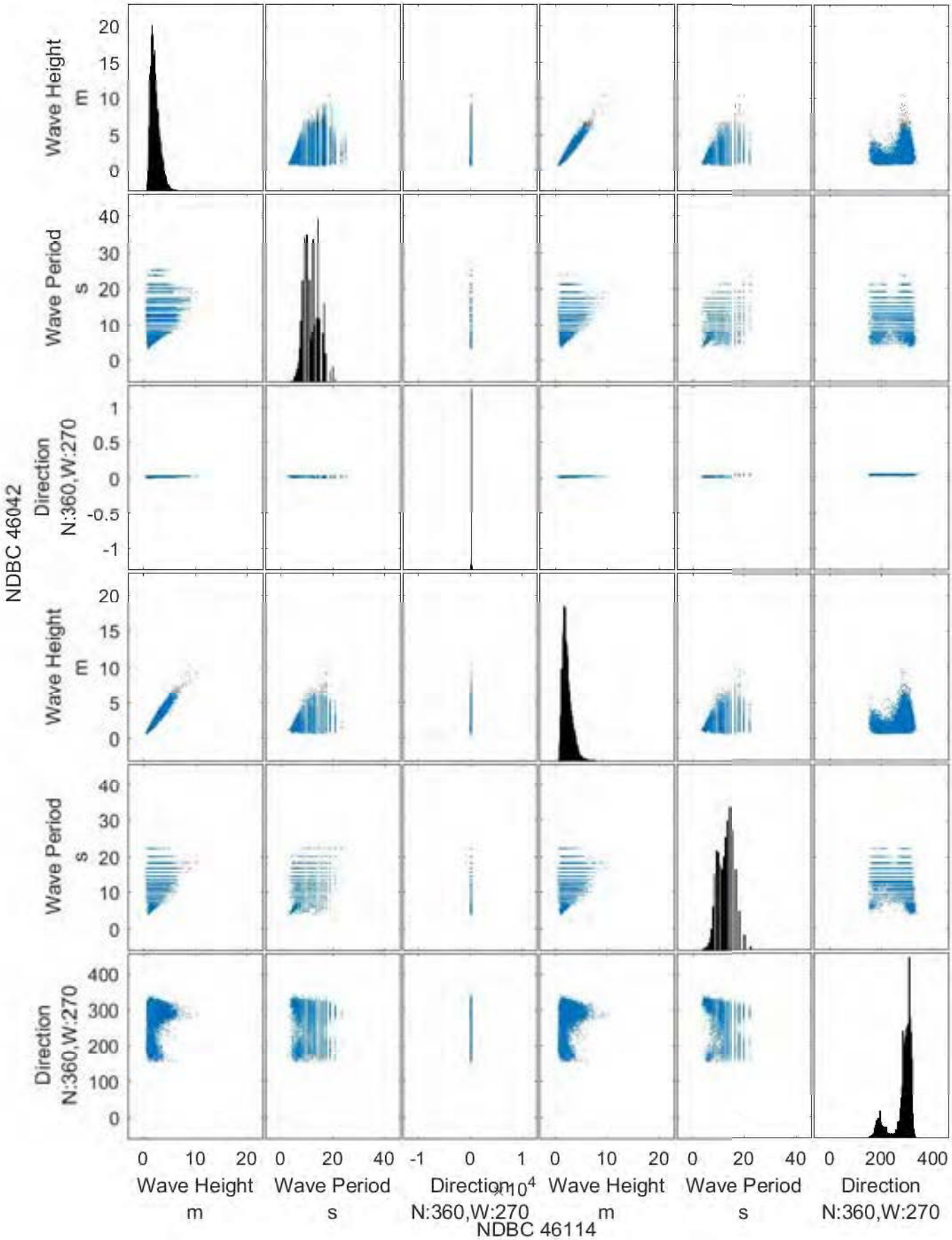


Figure B072: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46218.

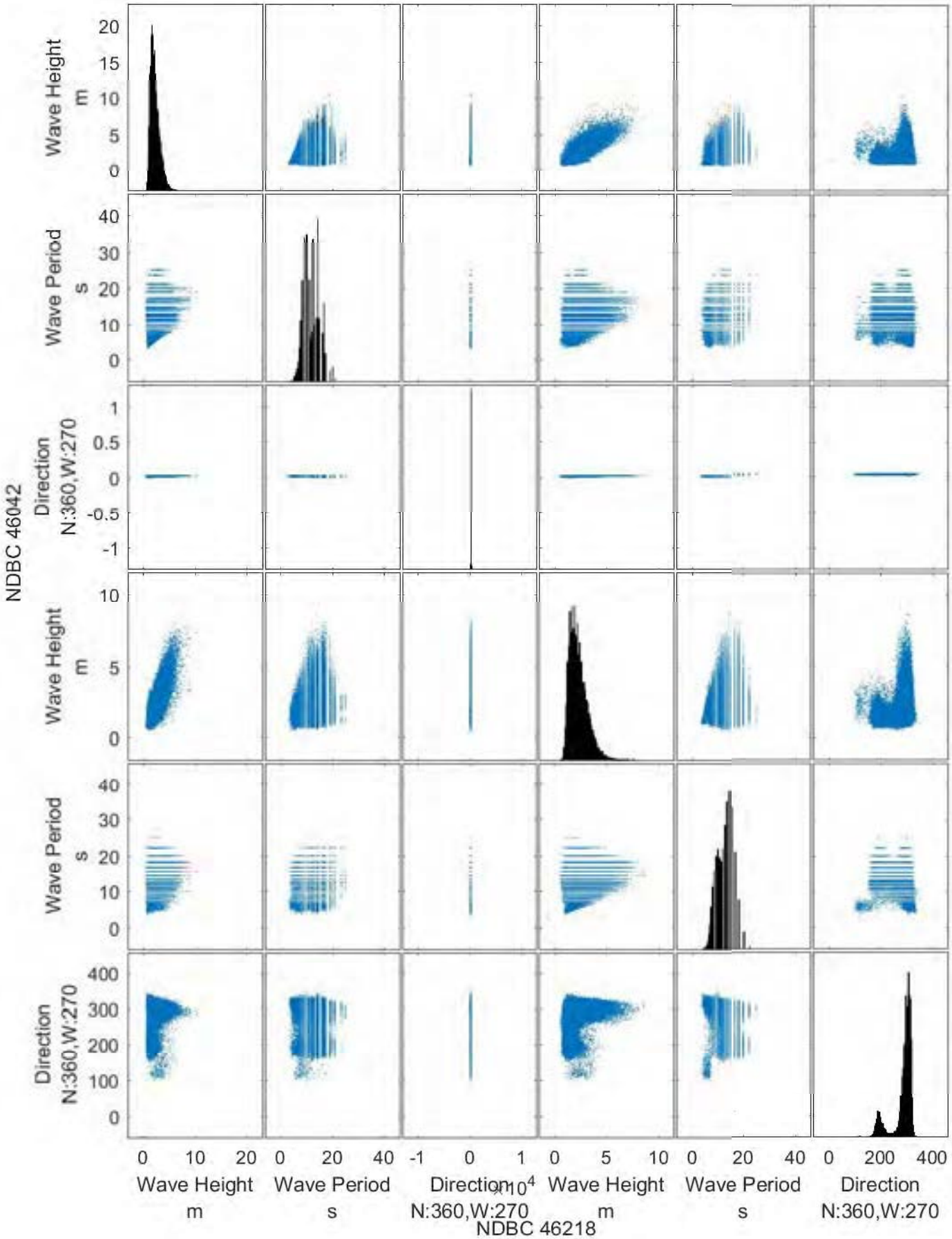


Figure B073: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46219.

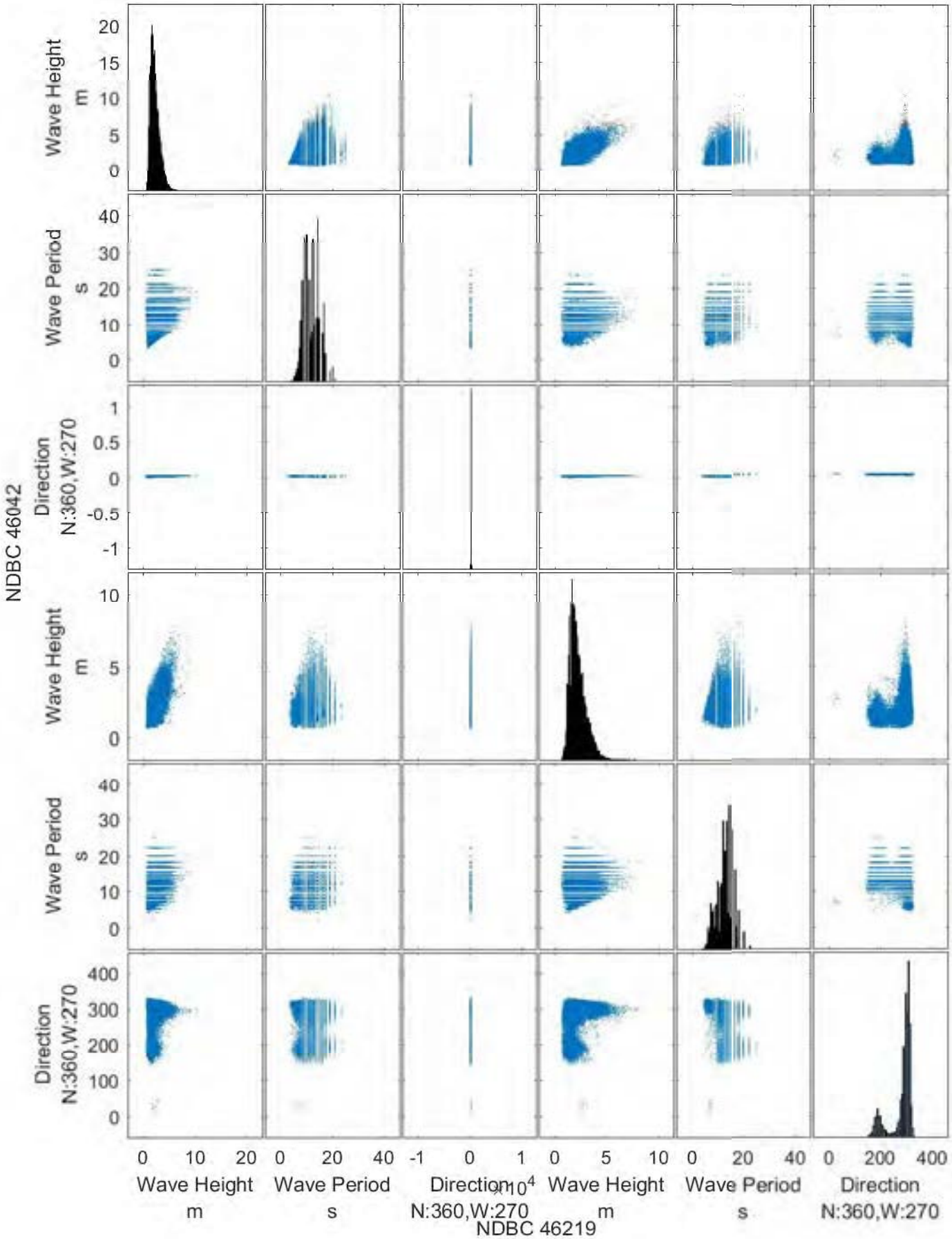


Figure B074: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46239.

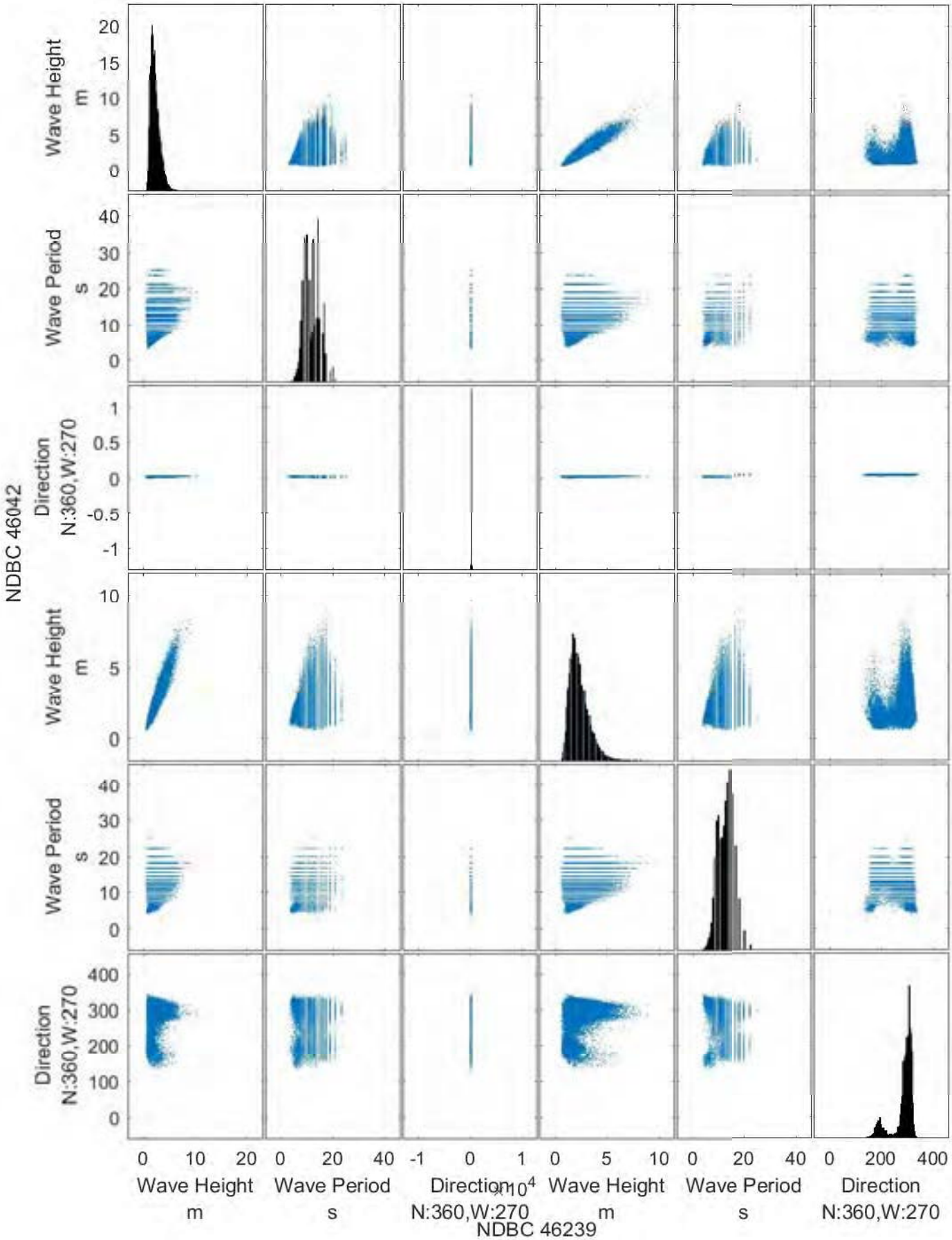


Figure B075: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46257.

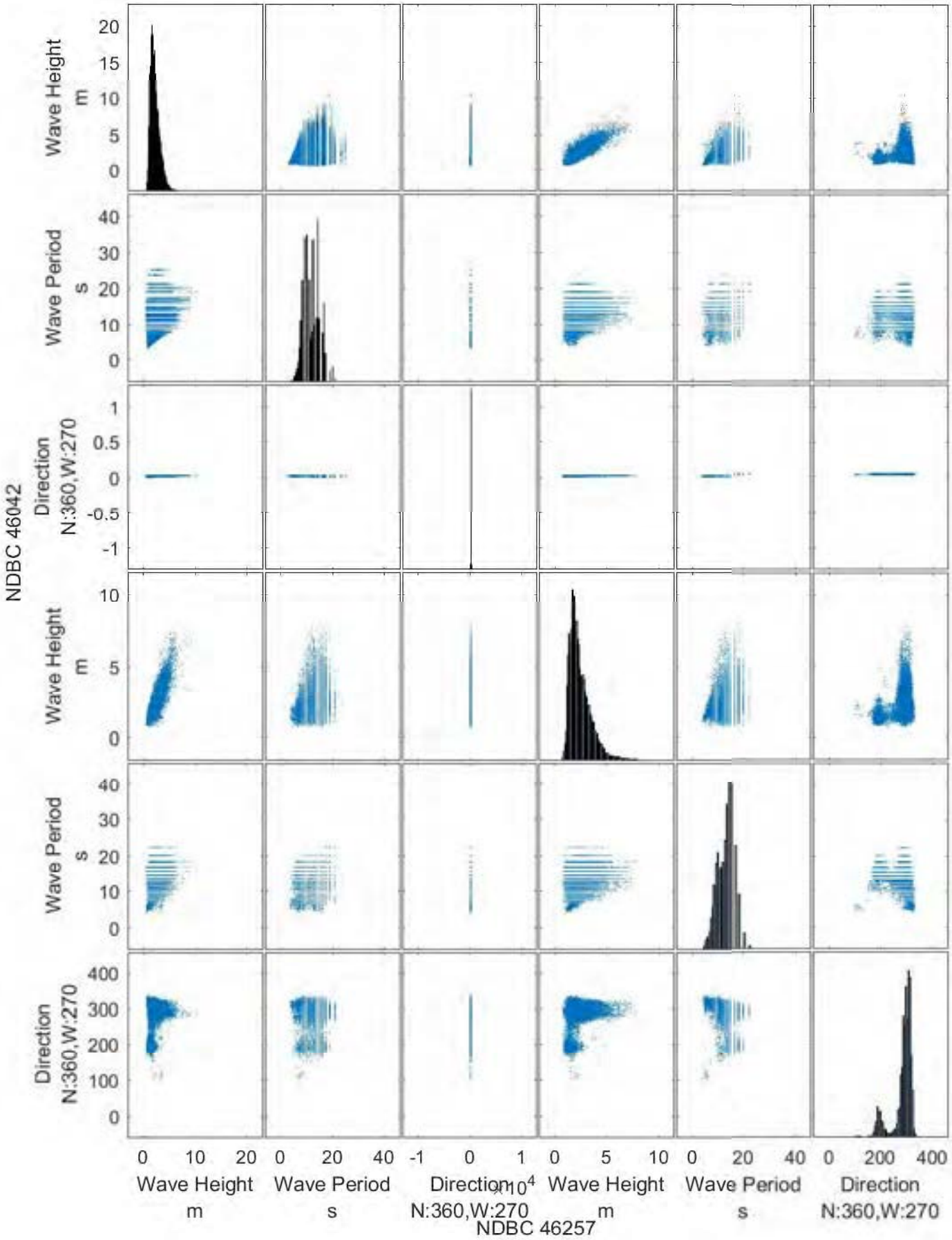


Figure B076: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46042 and NDBC 46259.

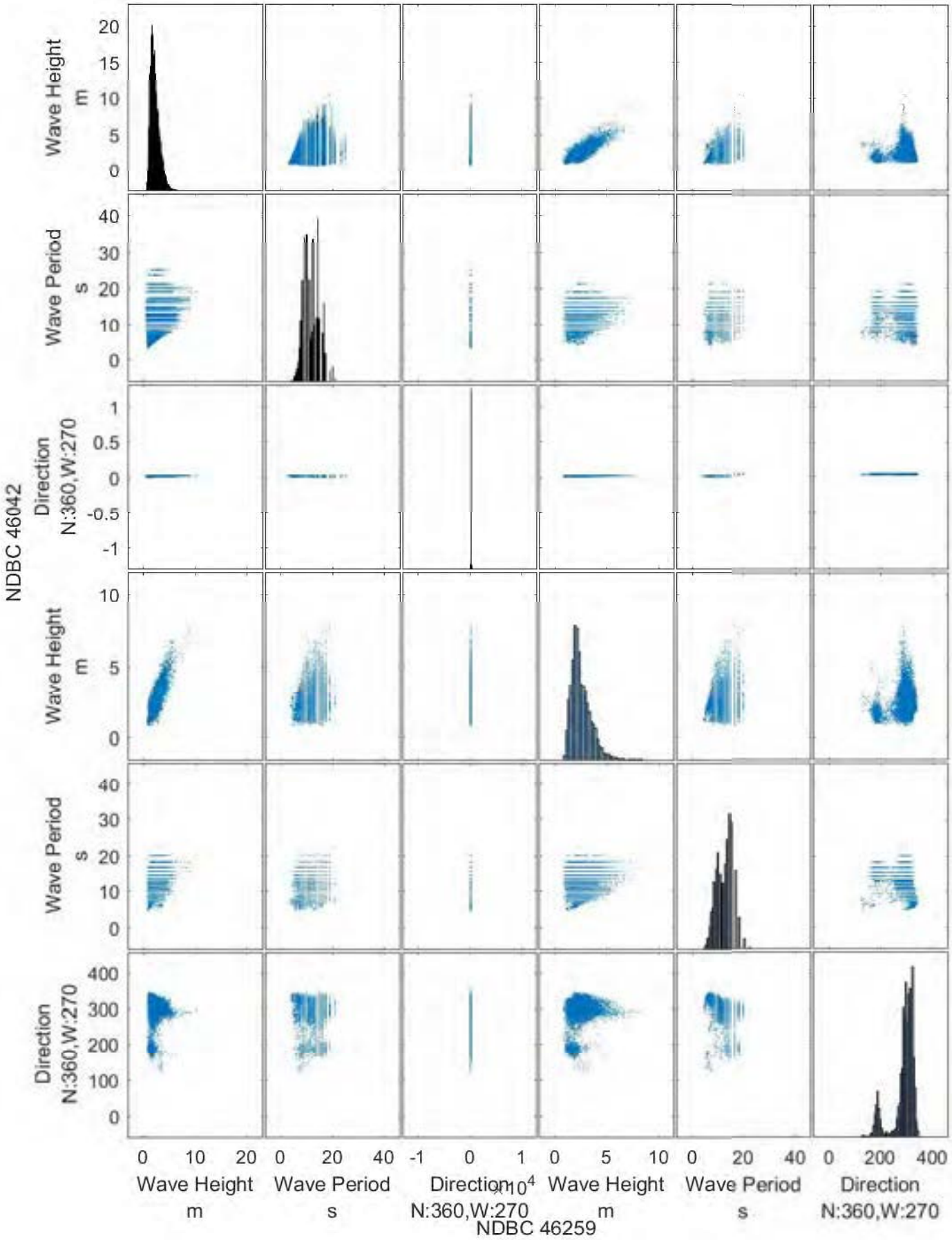


Figure B077: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46053.

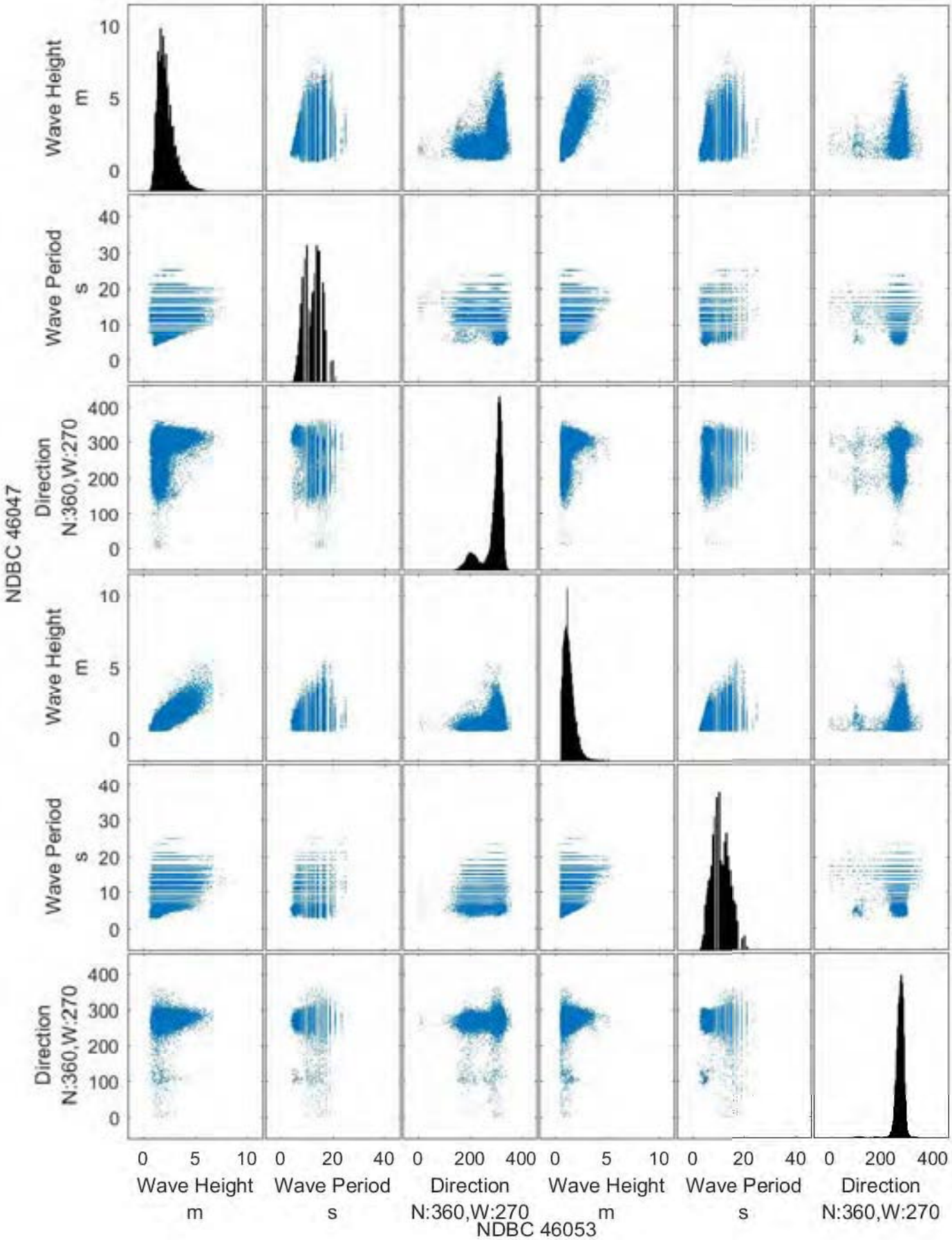


Figure B078: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46054.

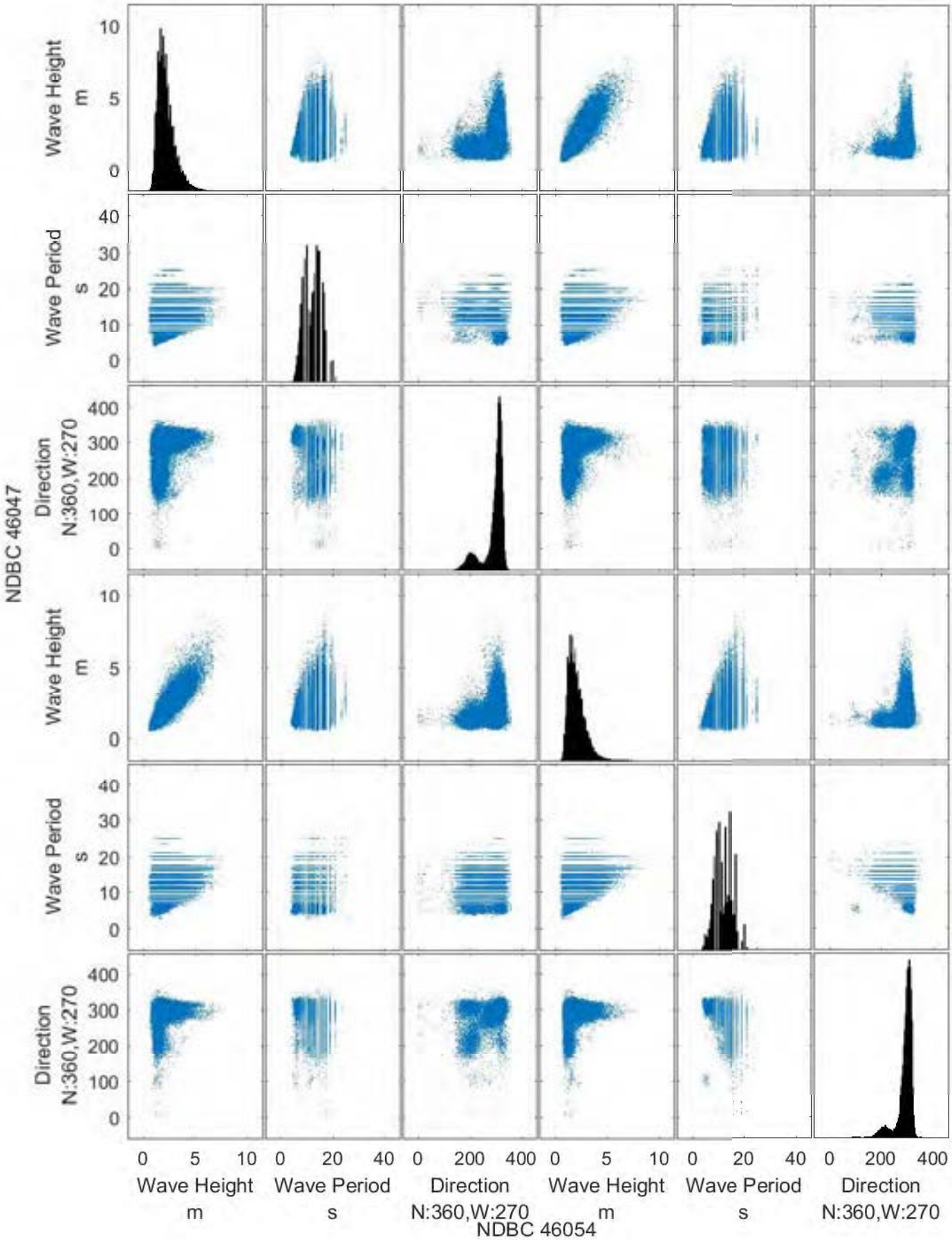


Figure B079: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46069.

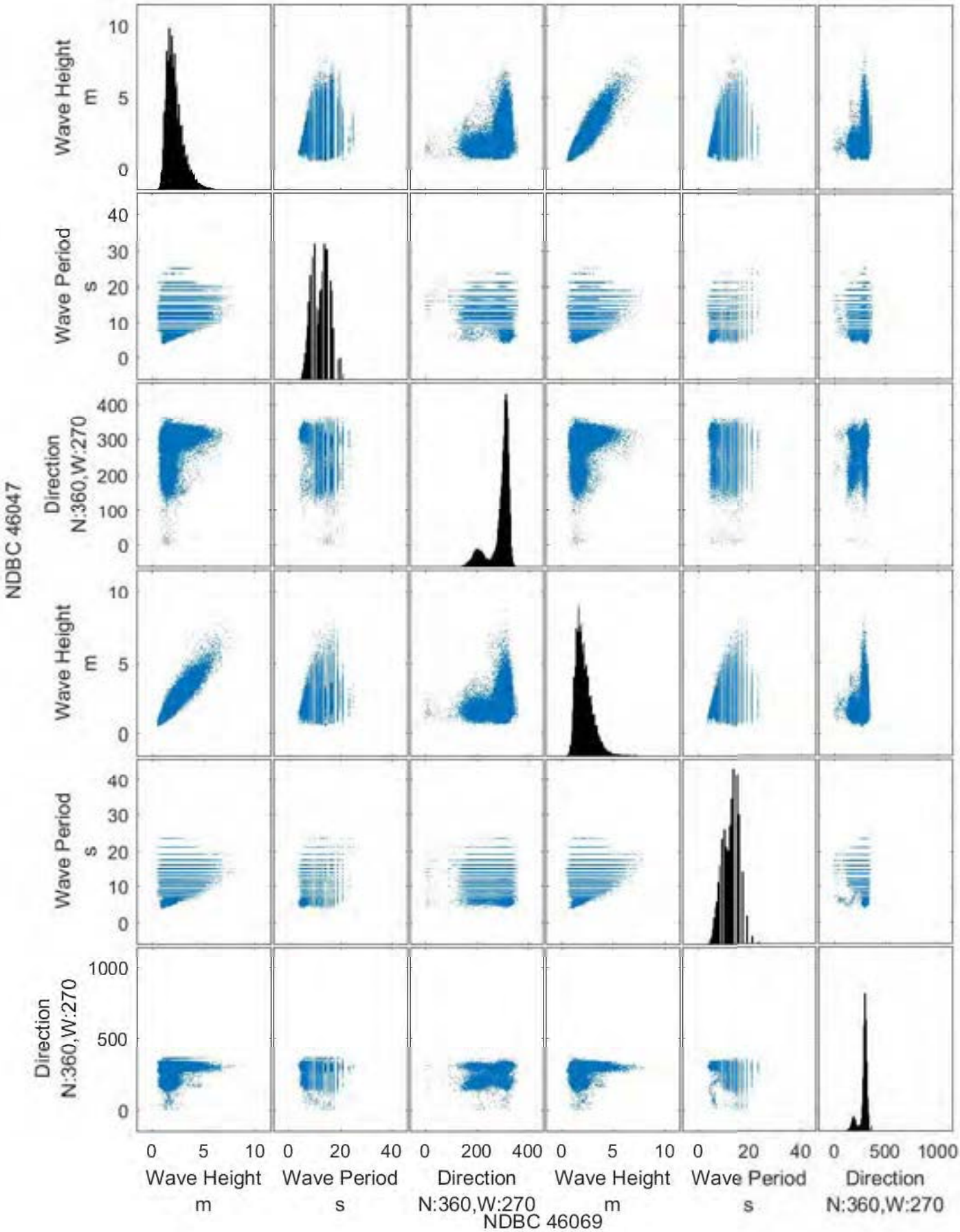


Figure B080: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46114.

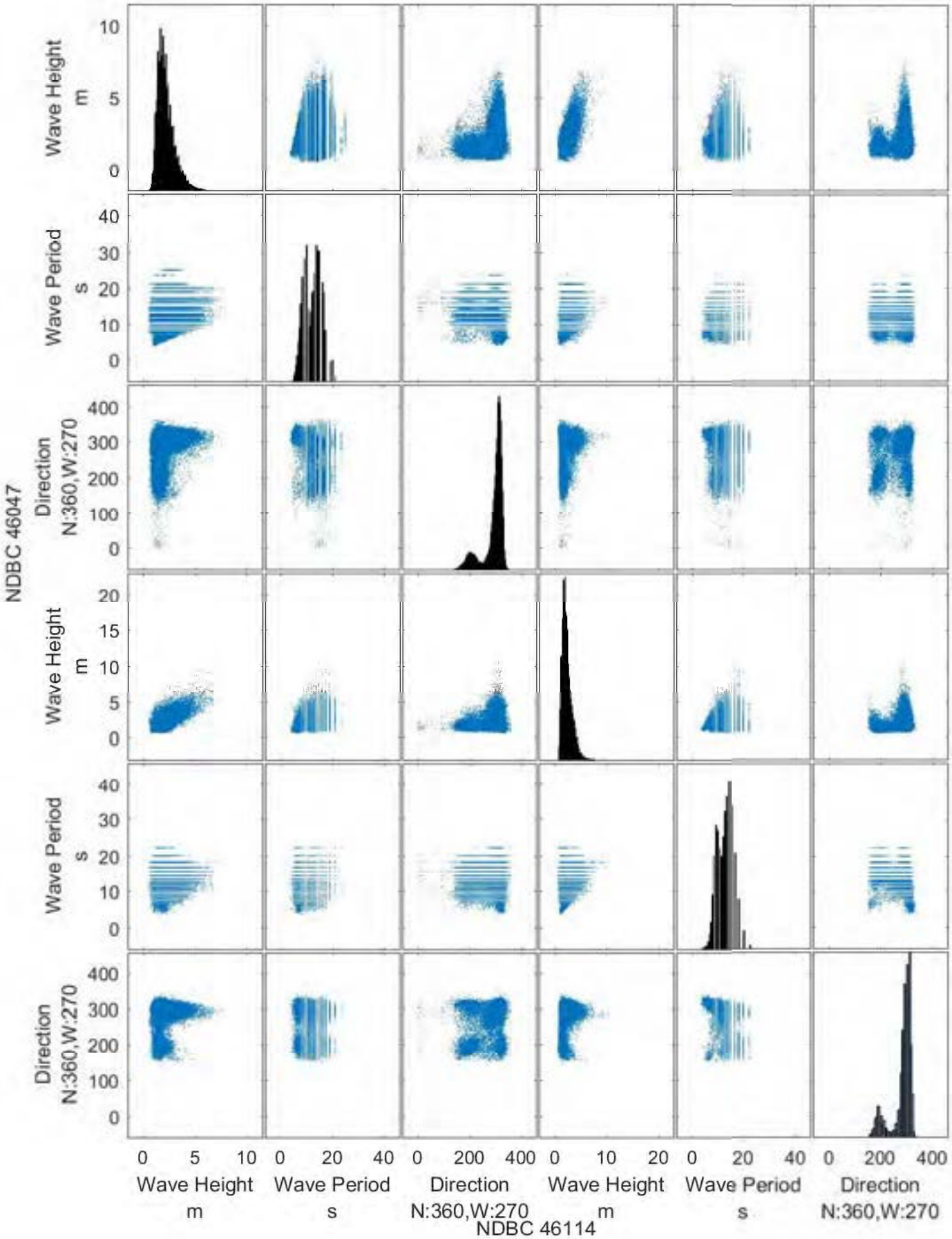


Figure B081: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46218.

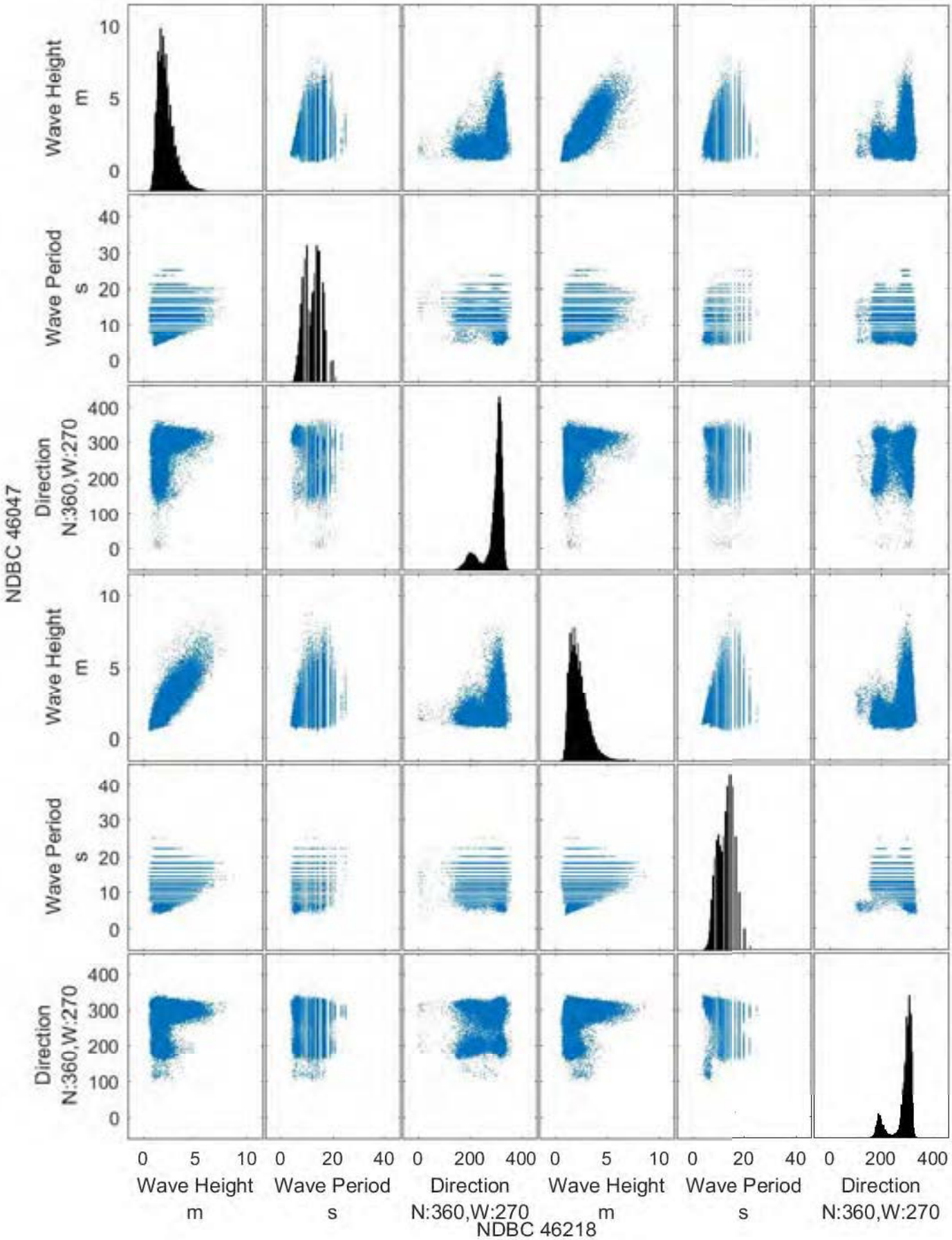


Figure B082: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46219.

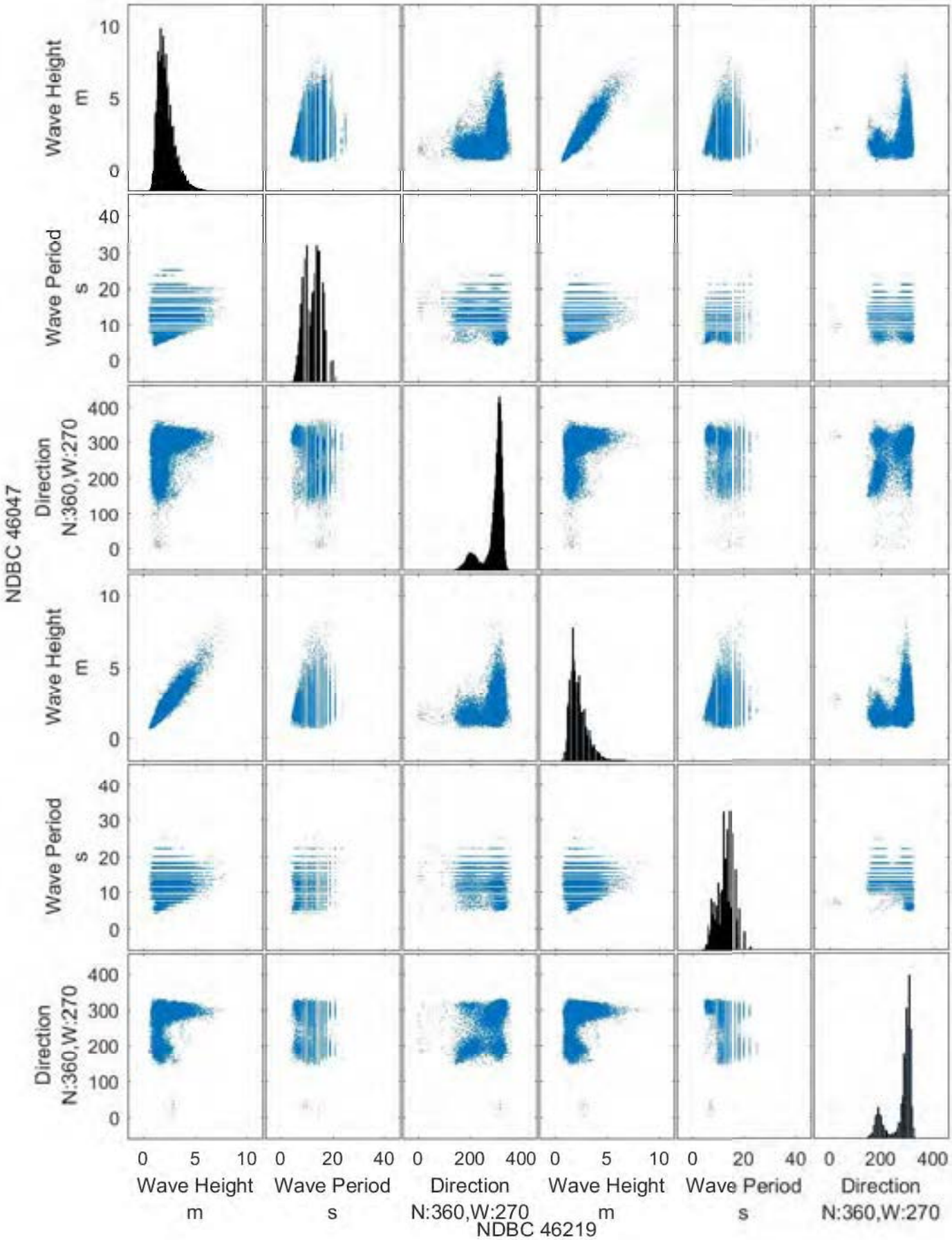


Figure B083: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46239.

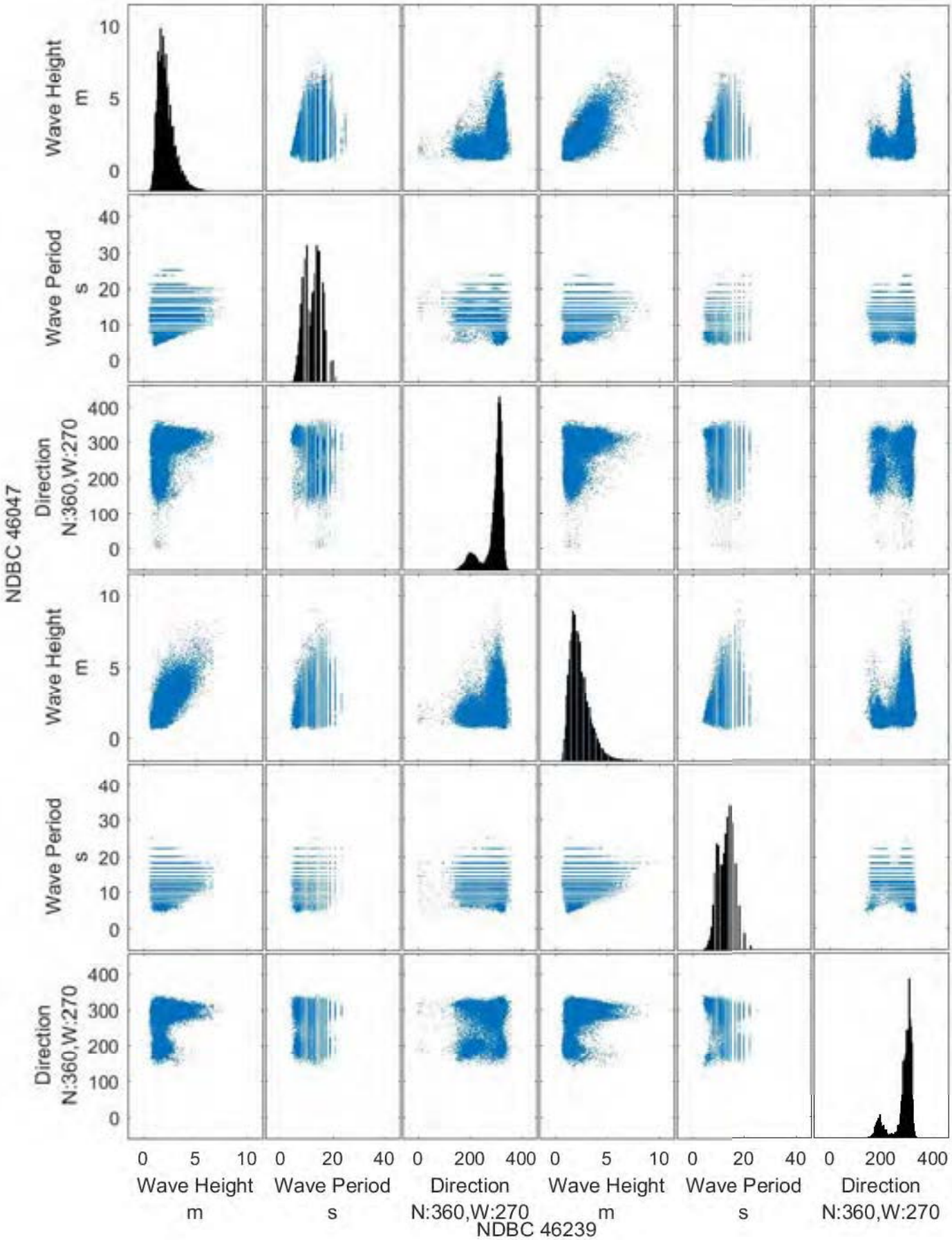


Figure B084: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46257.

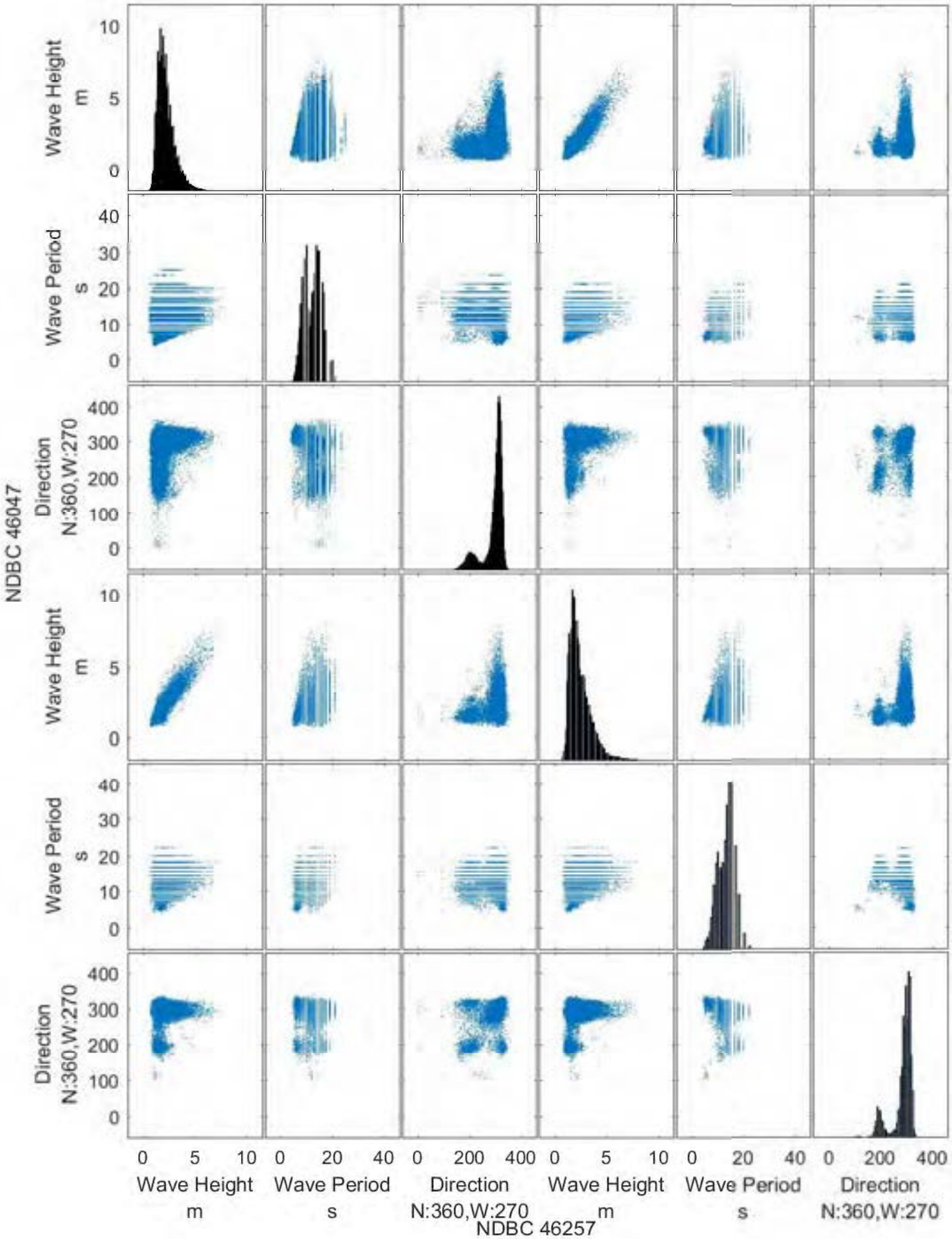


Figure B085: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46047 and NDBC 46259.

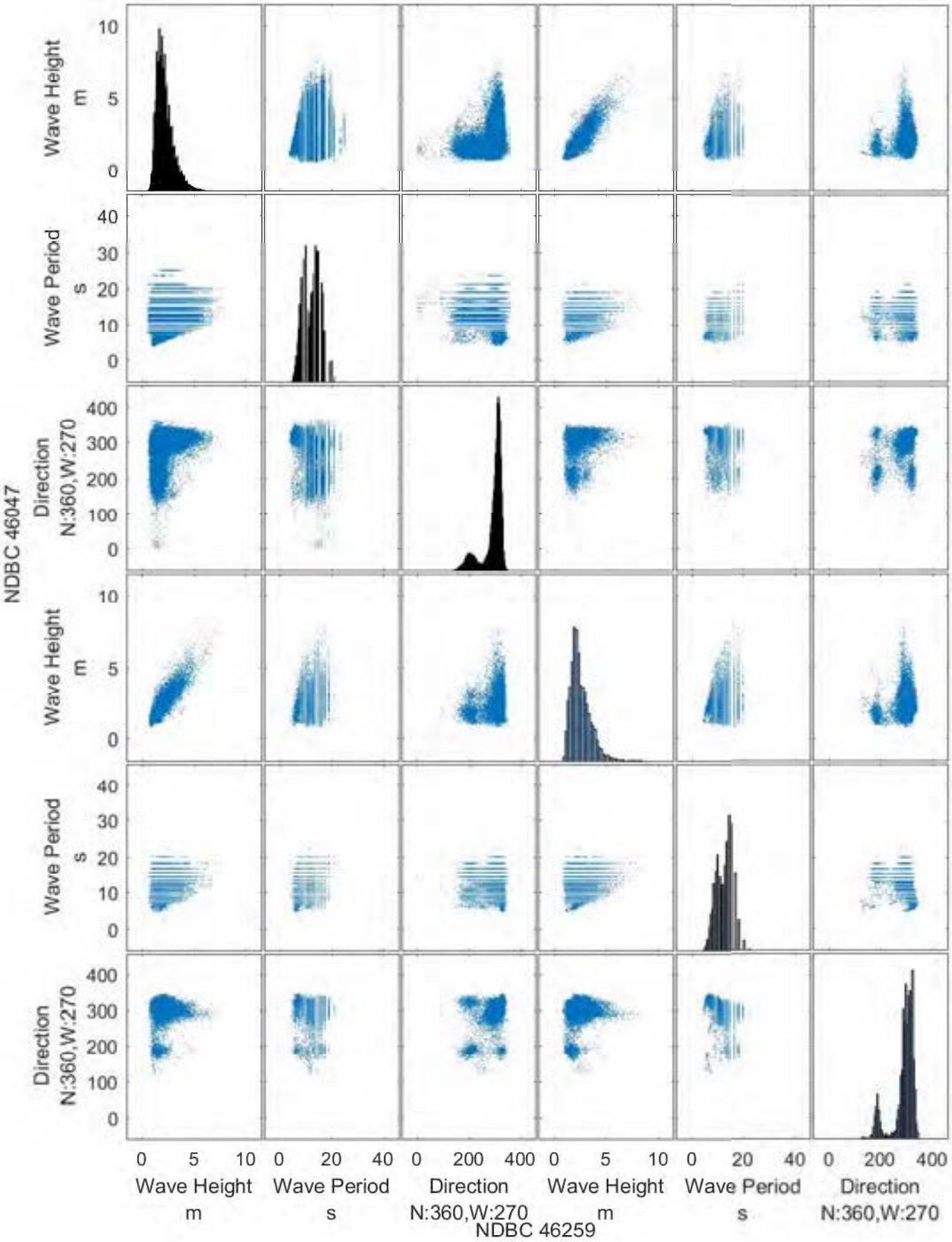


Figure B086: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46054.

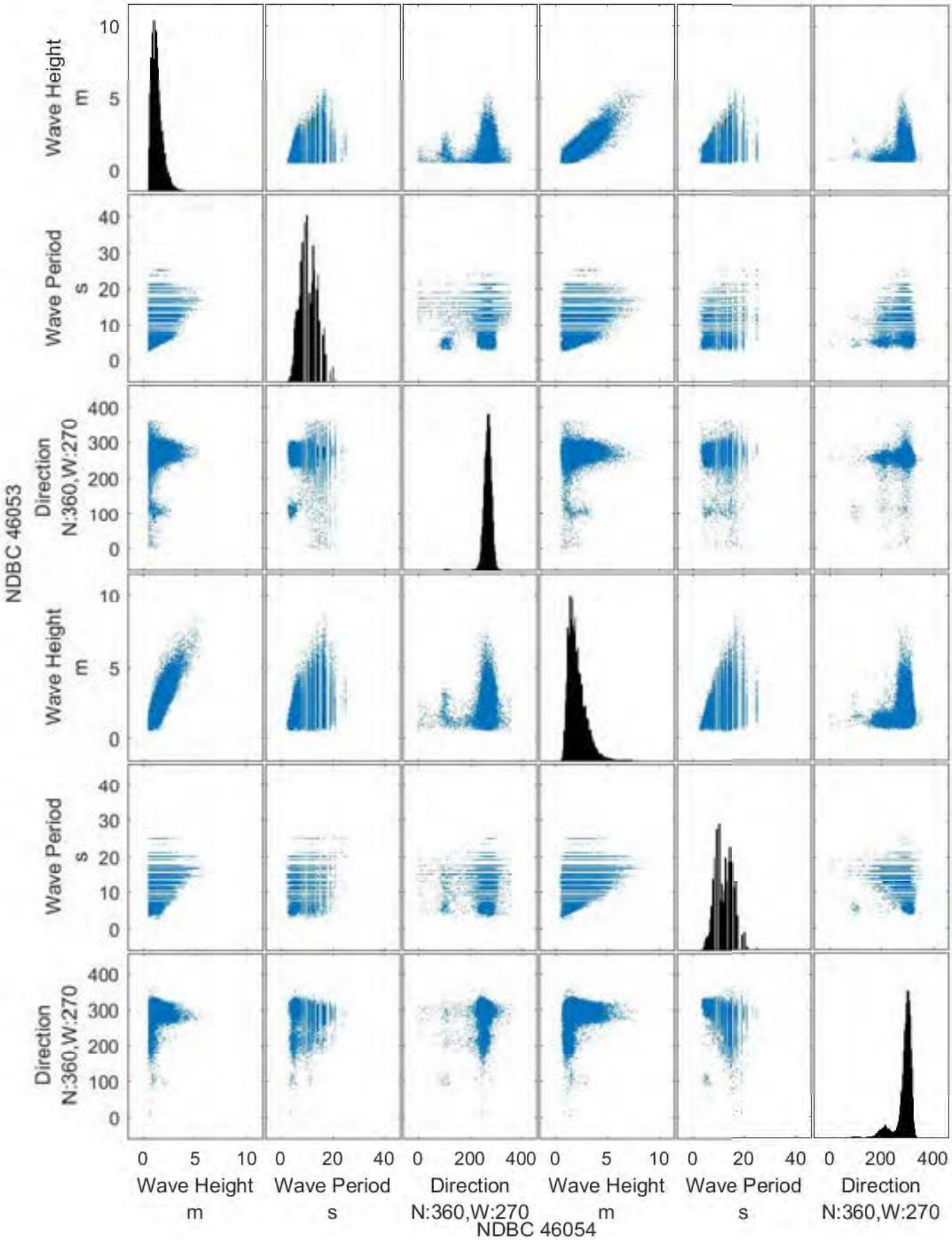


Figure B087: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46069.

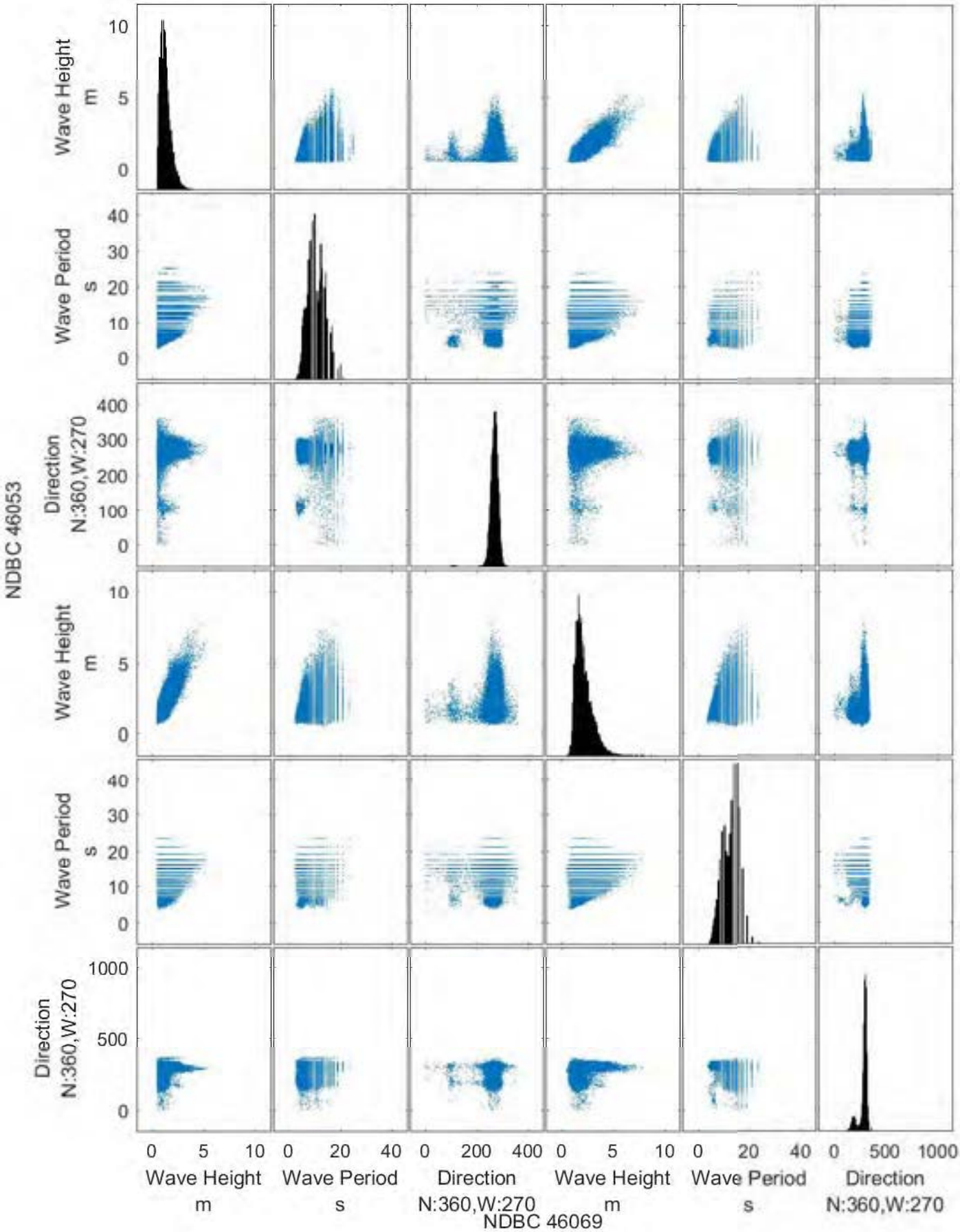


Figure B088: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46114.

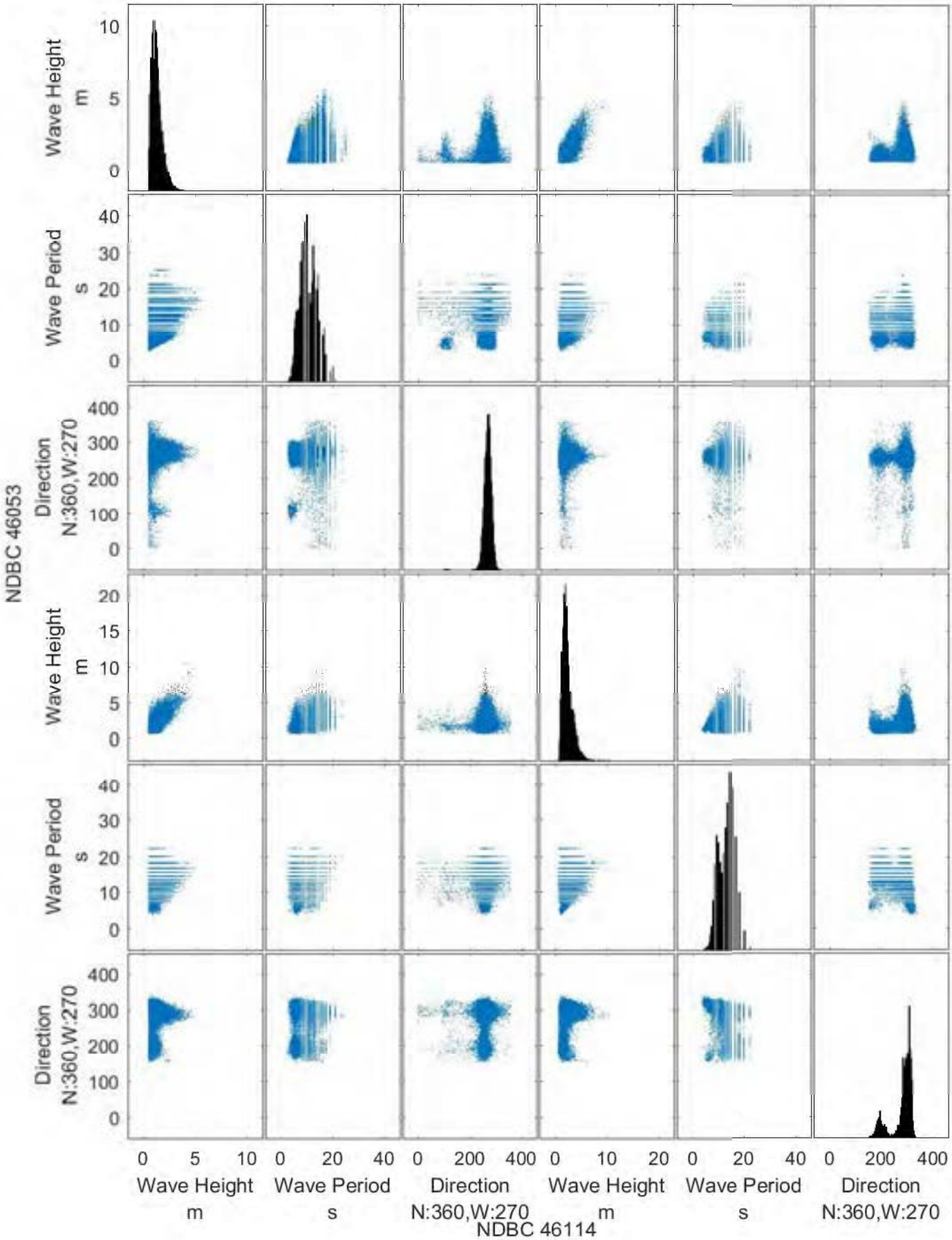


Figure B089: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46218.

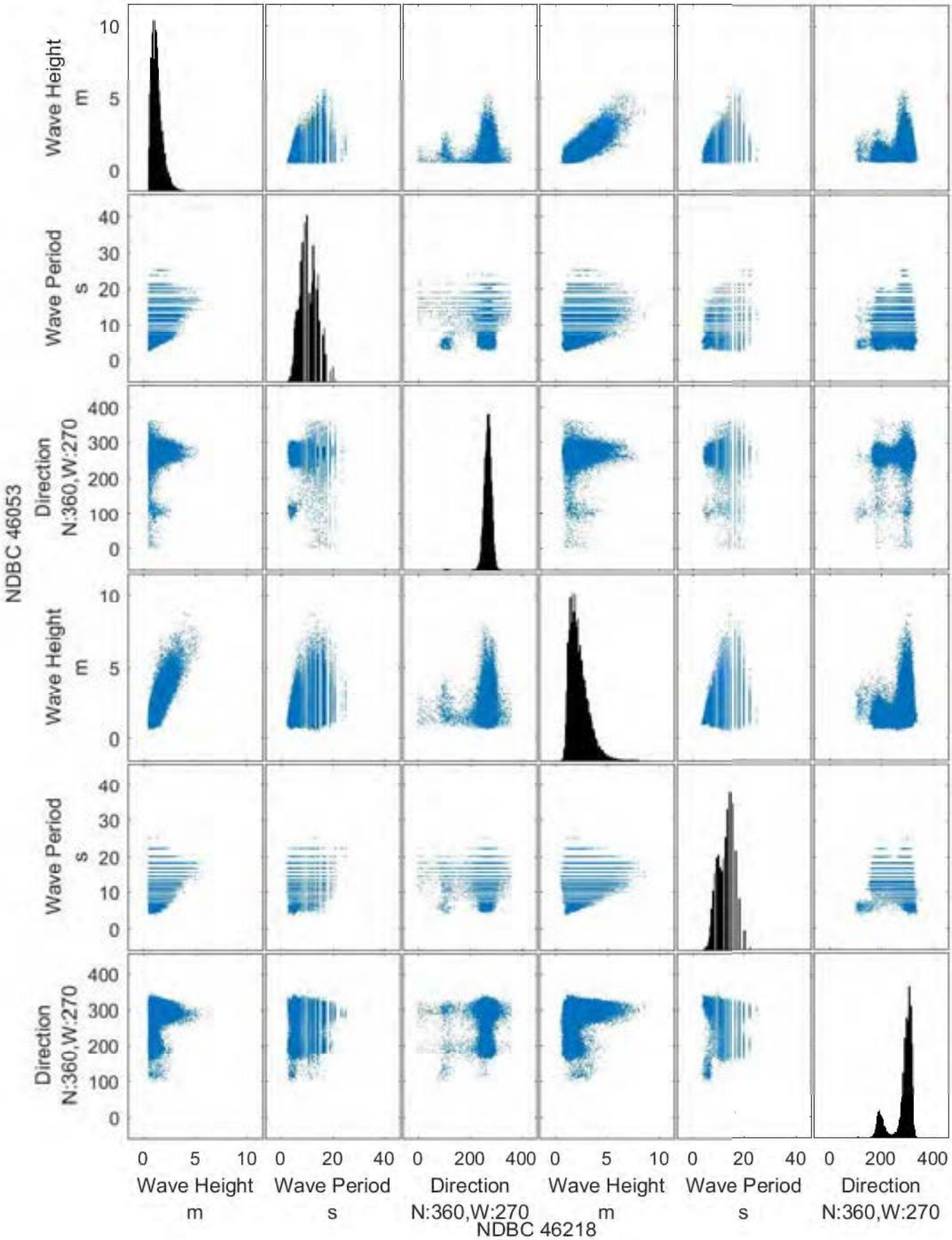


Figure B090: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46219.

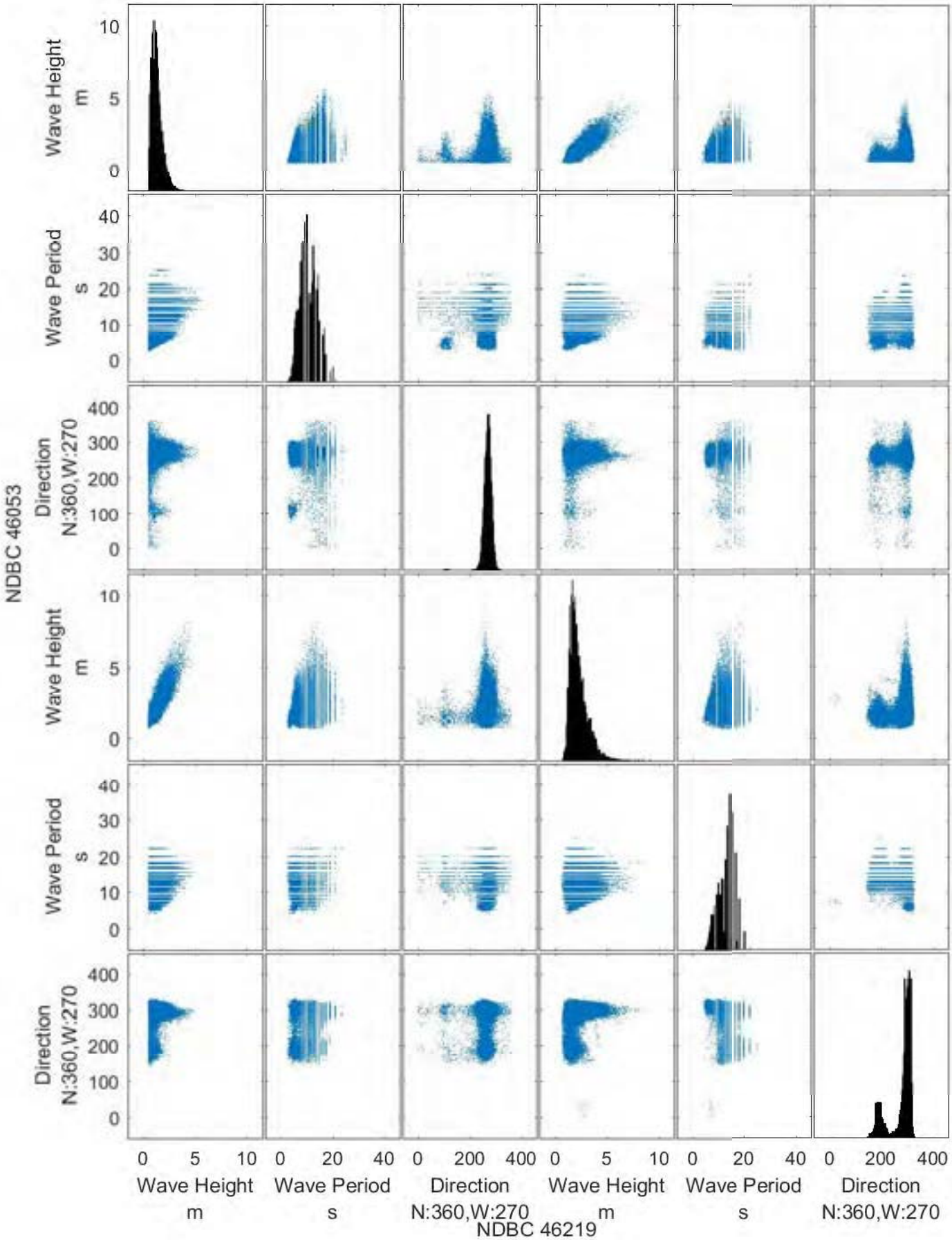


Figure B091: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46239.

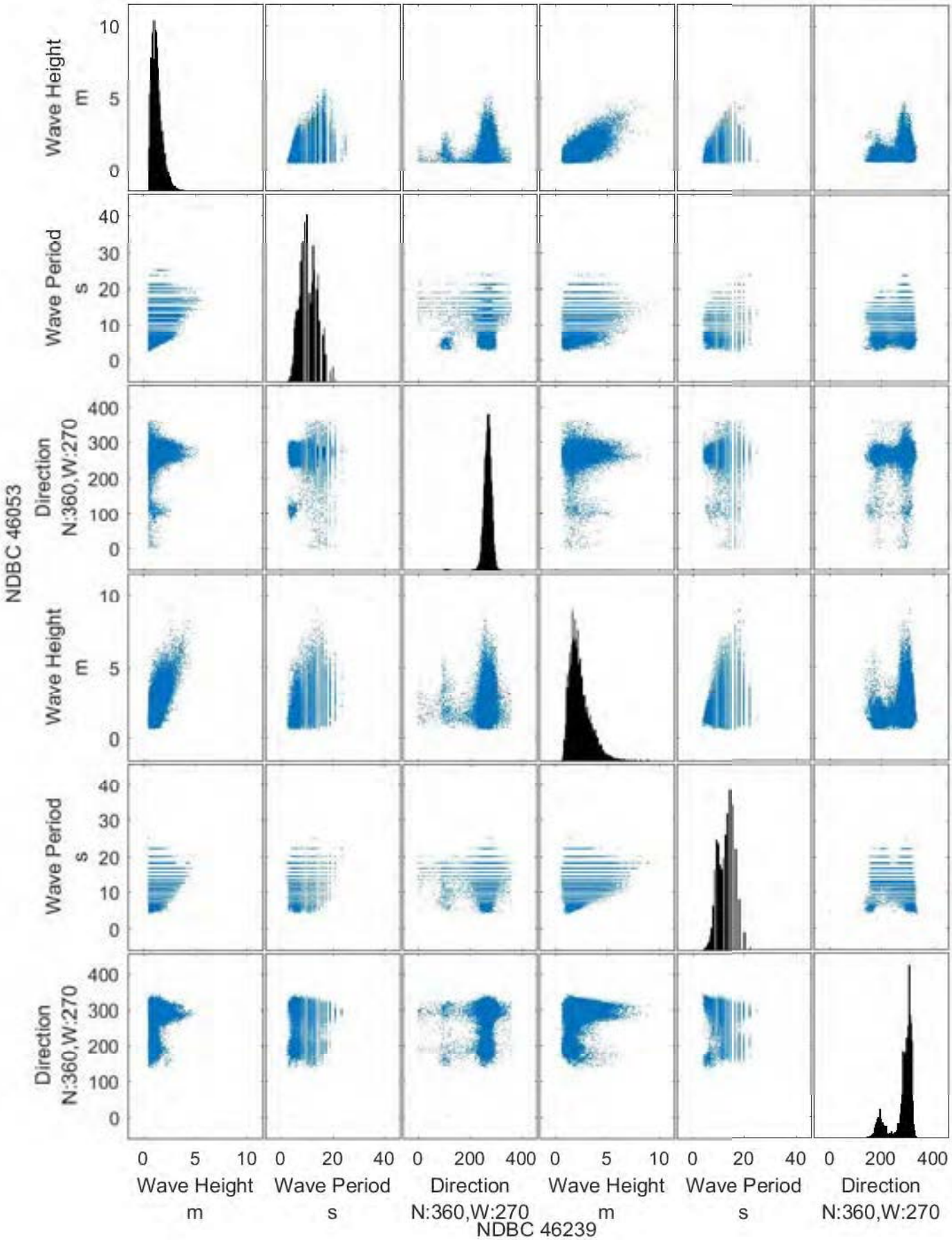


Figure B092: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46257.

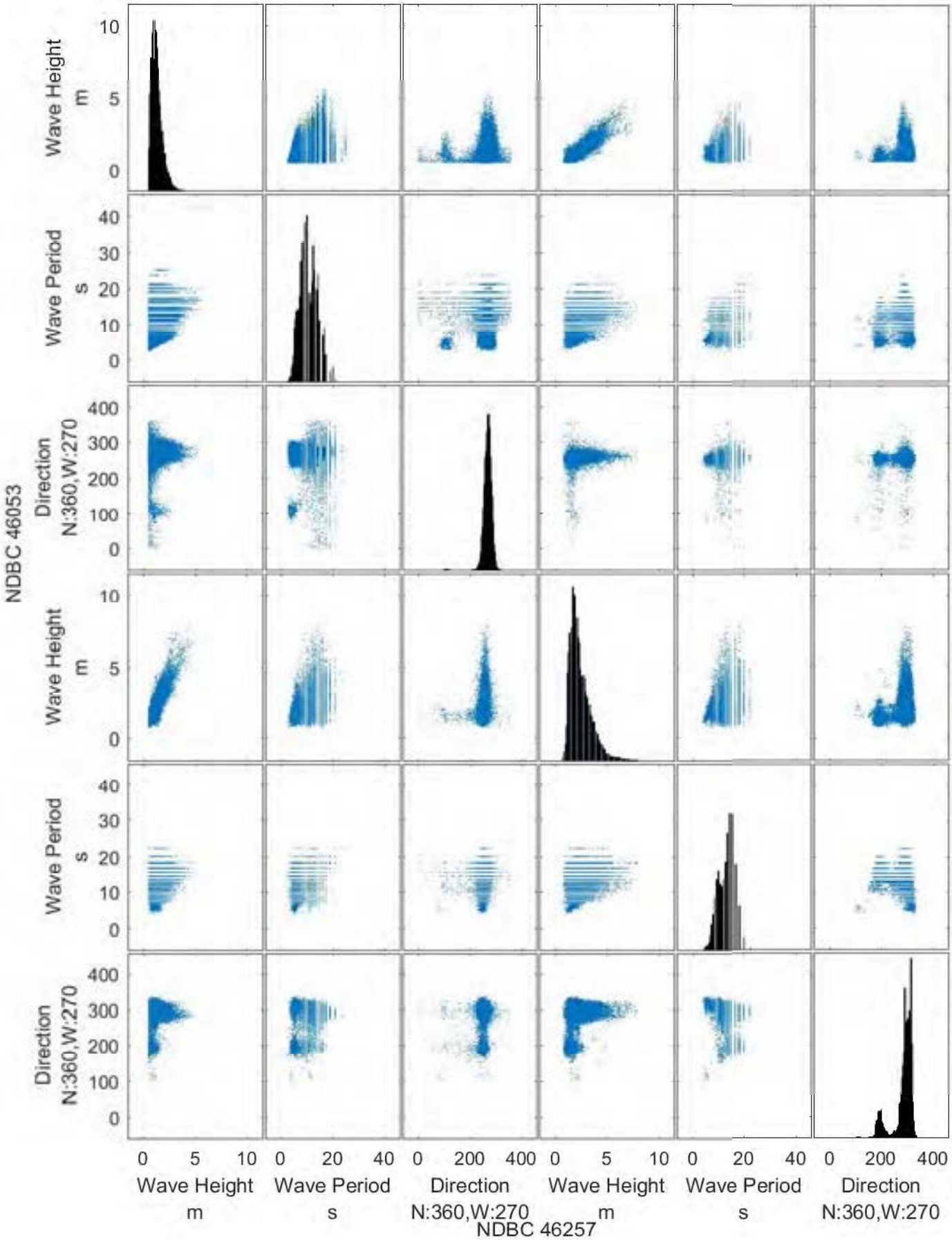


Figure B093: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46259.

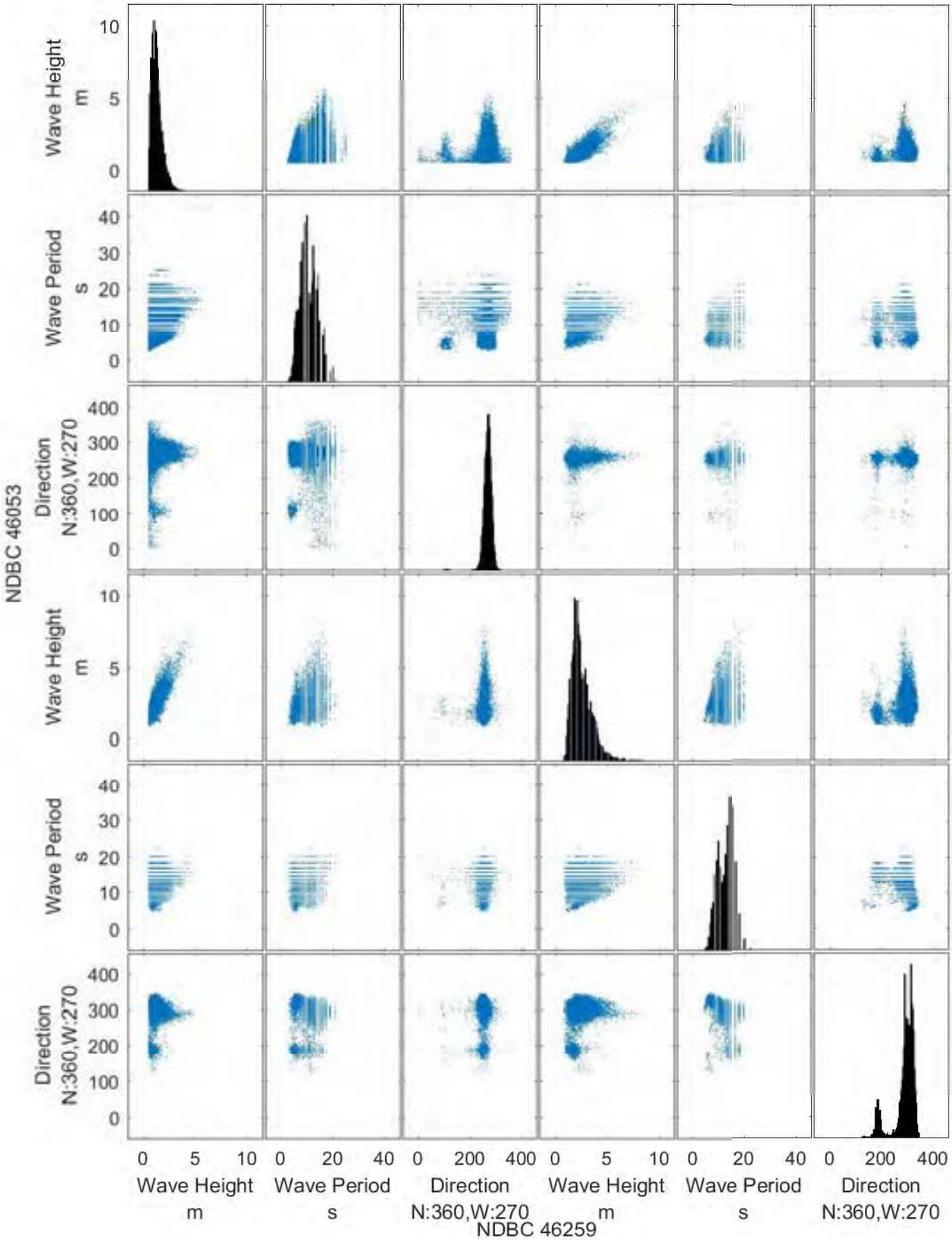


Figure B094: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46053 and NDBC 46259.

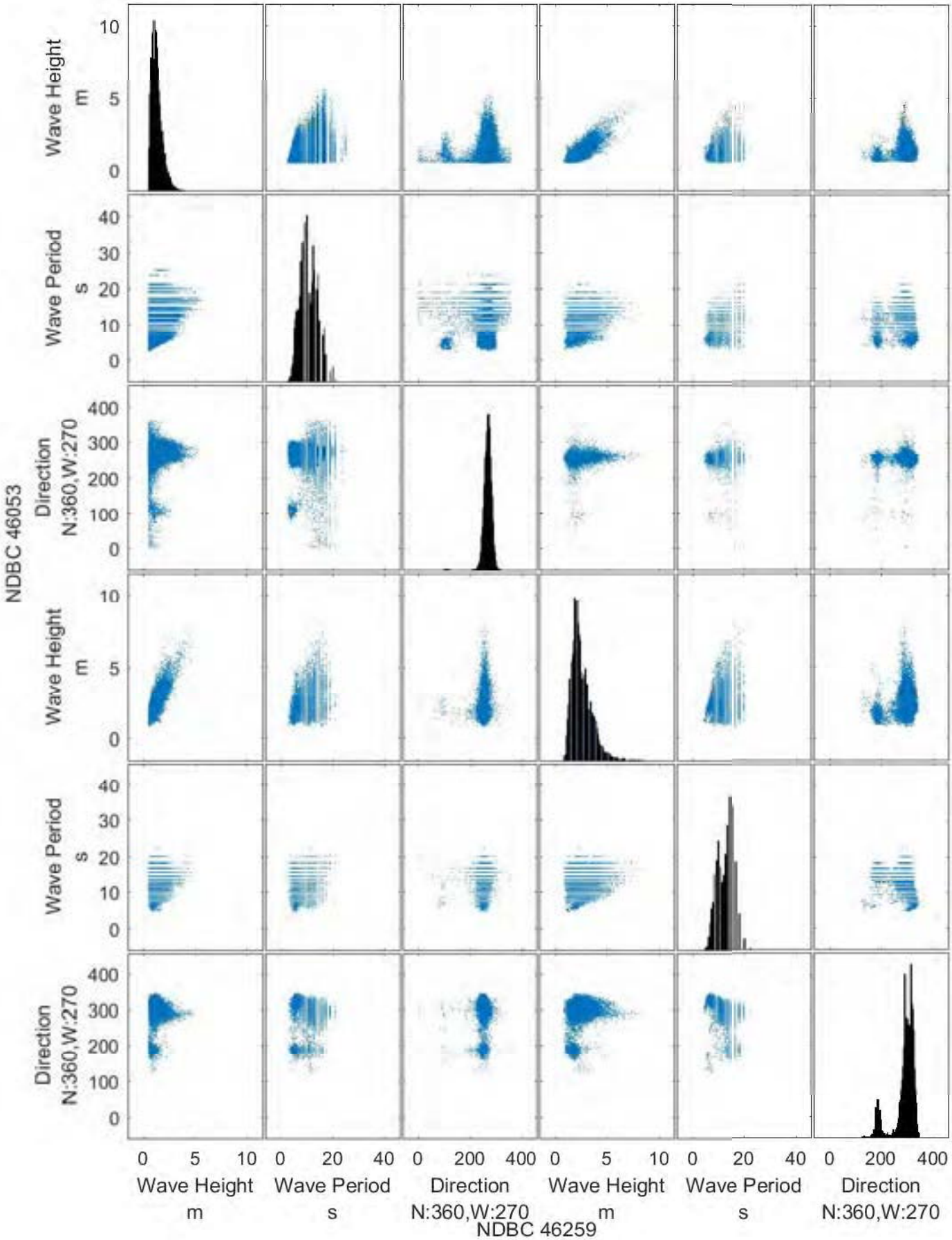


Figure B095: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46069 and NDBC 46114.

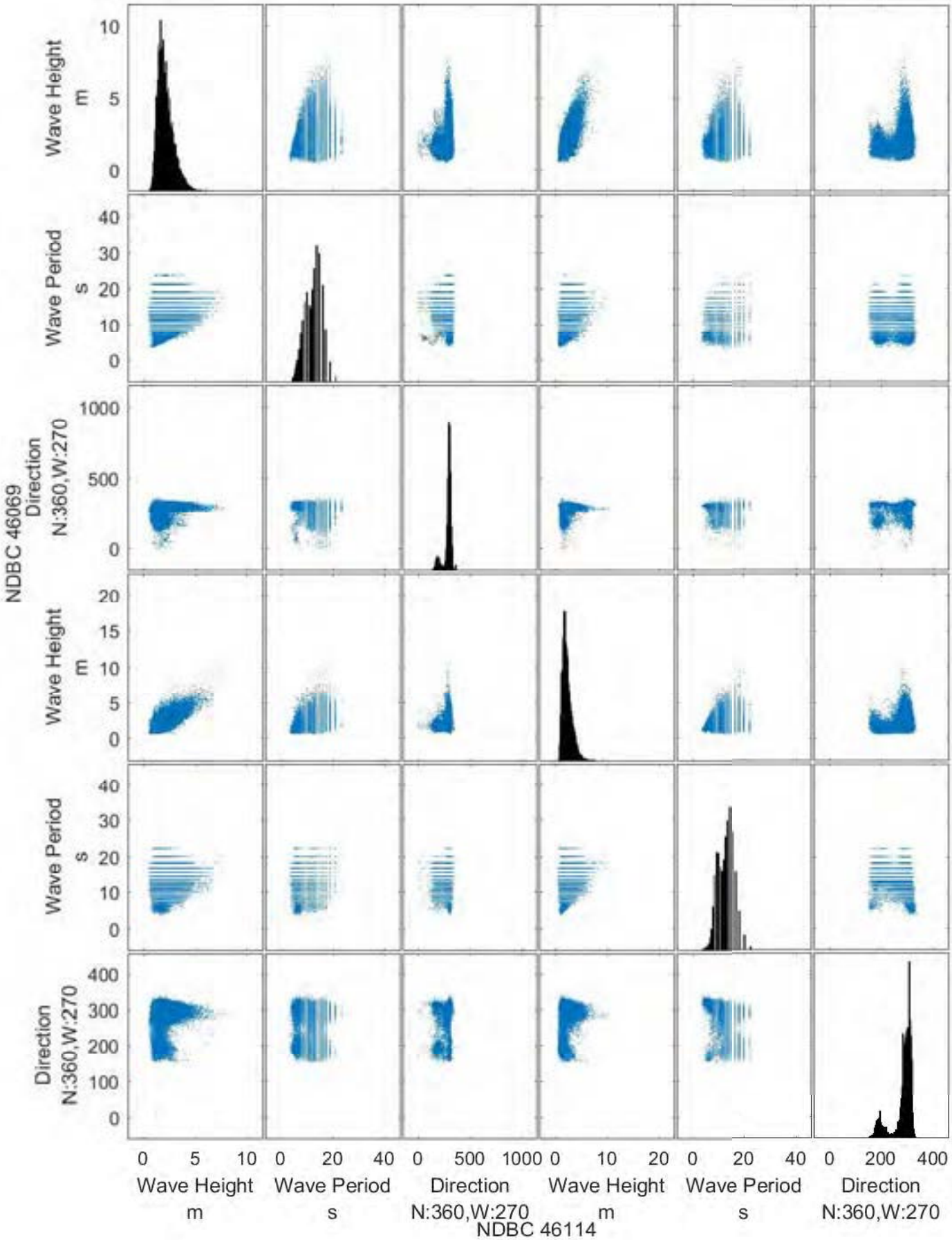


Figure B096: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46069 and NDBC 46218.

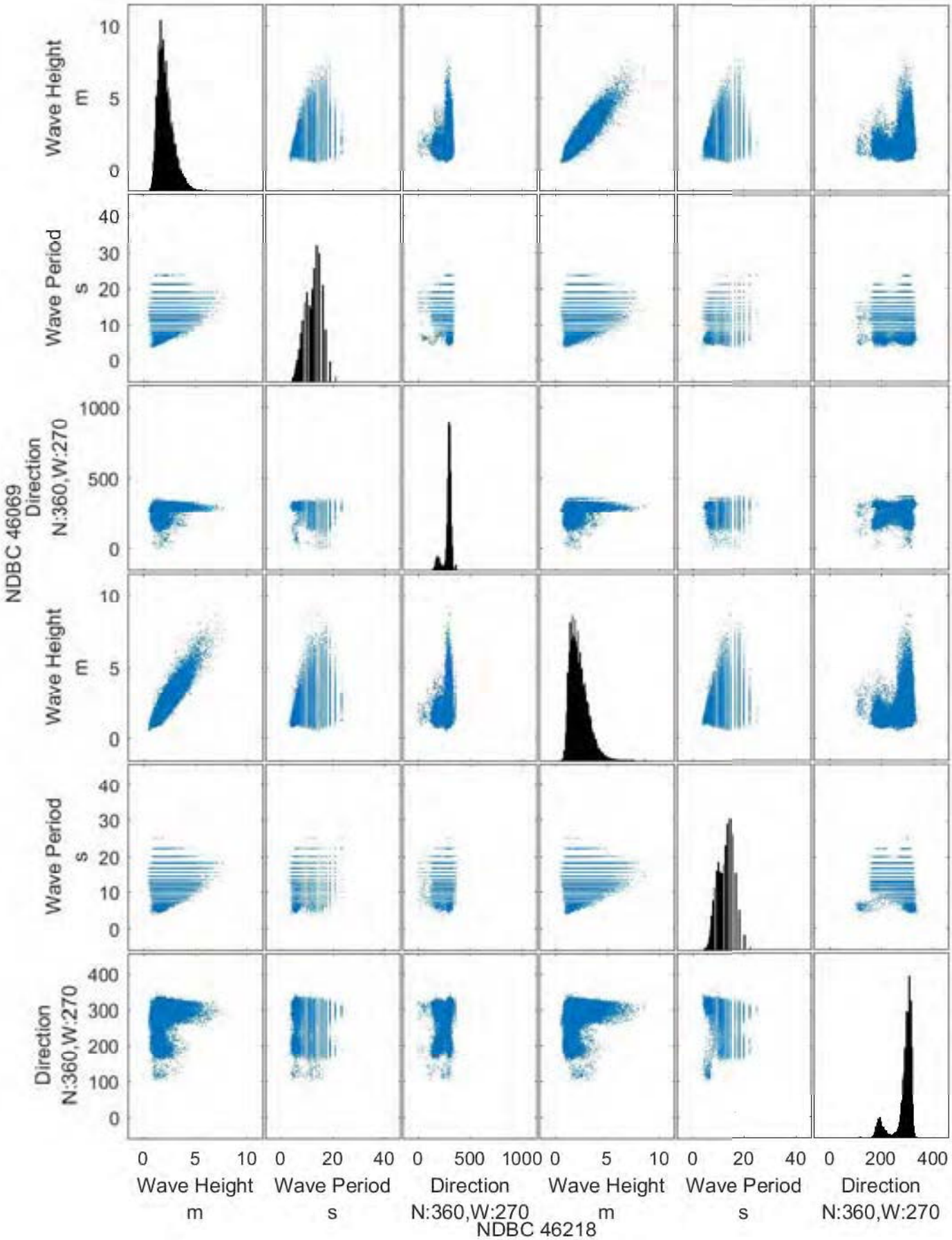


Figure B097: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46069 and NDBC 46219.

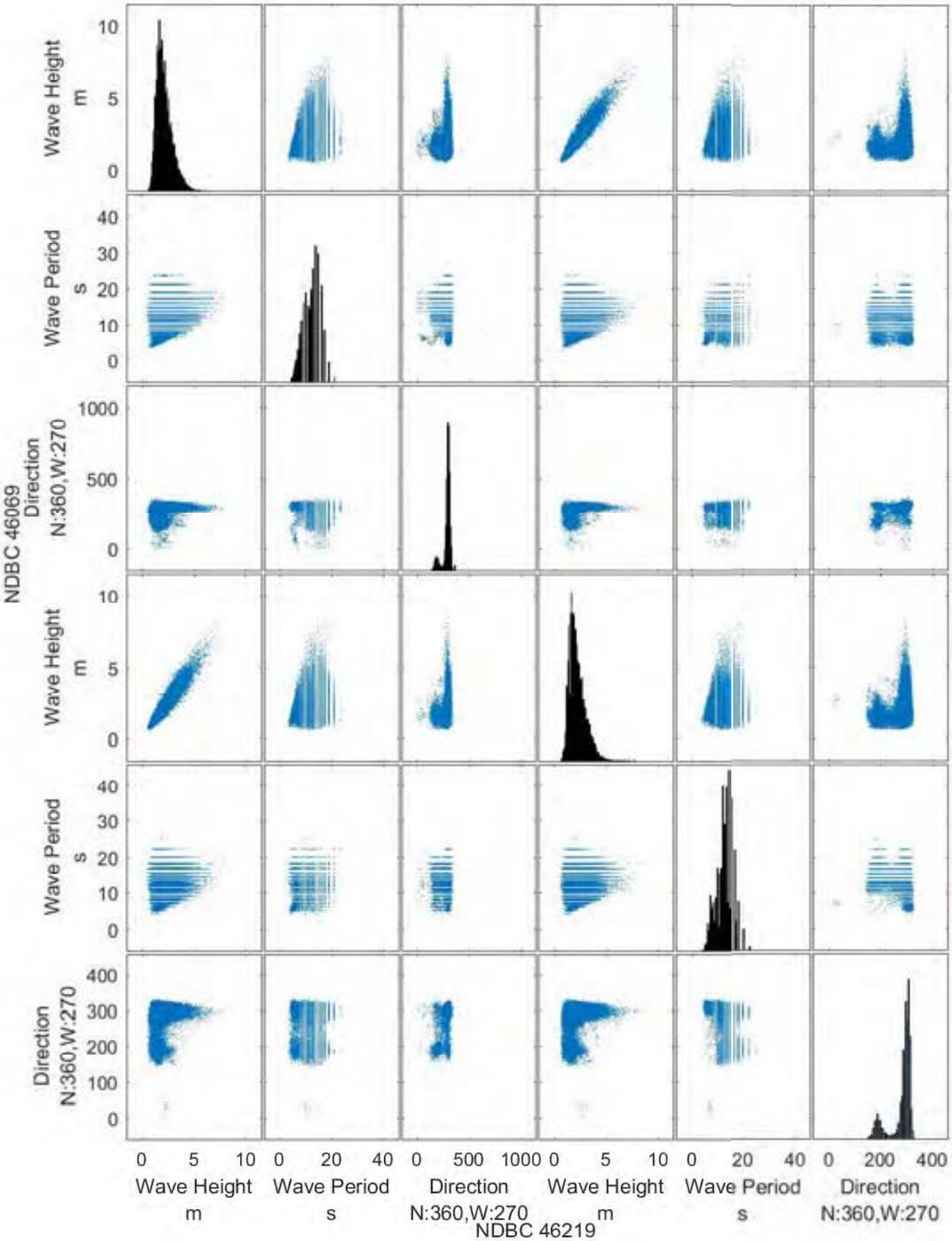


Figure B098: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46069 and NDBC 46239.

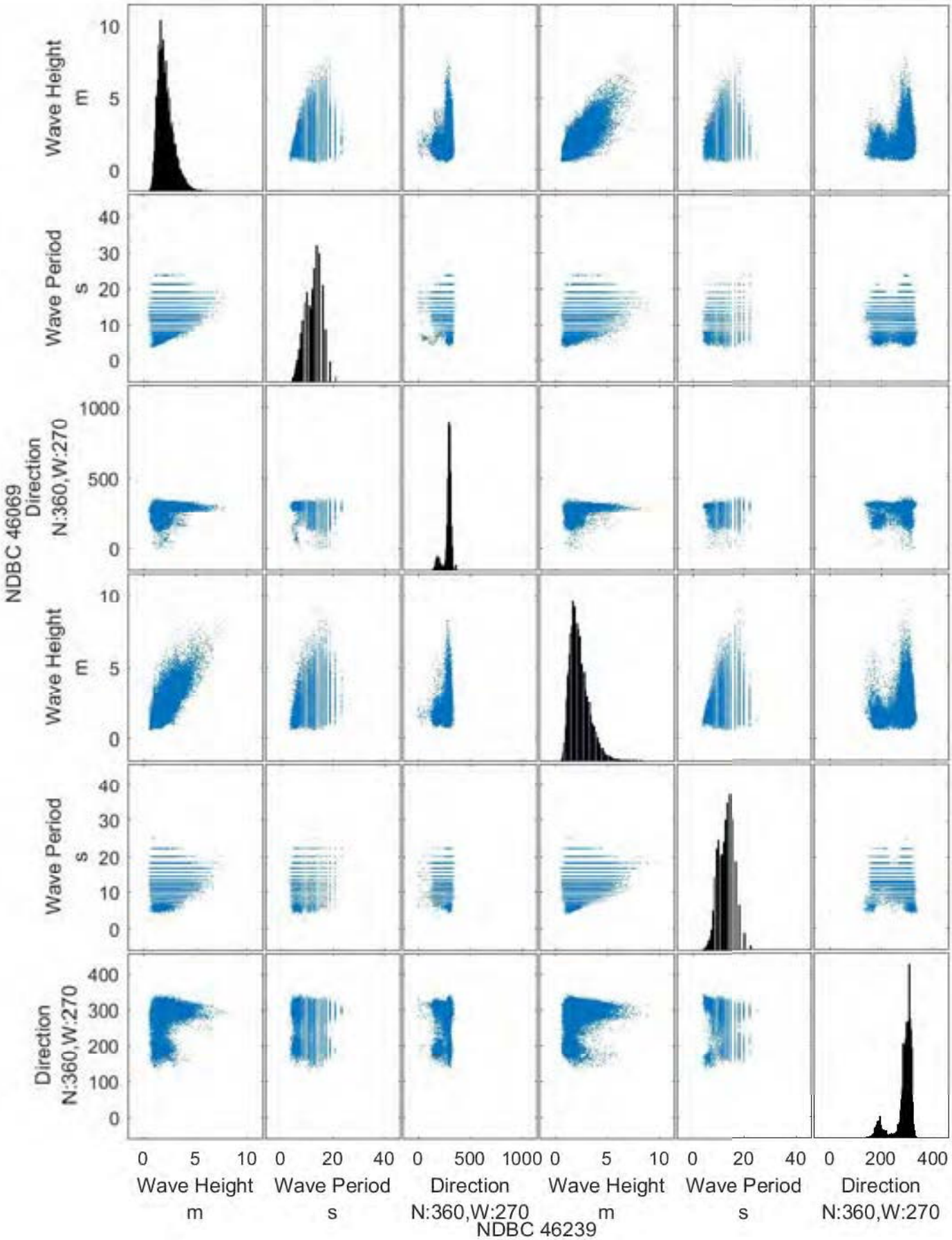


Figure B099: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46069 and NDBC 46257.

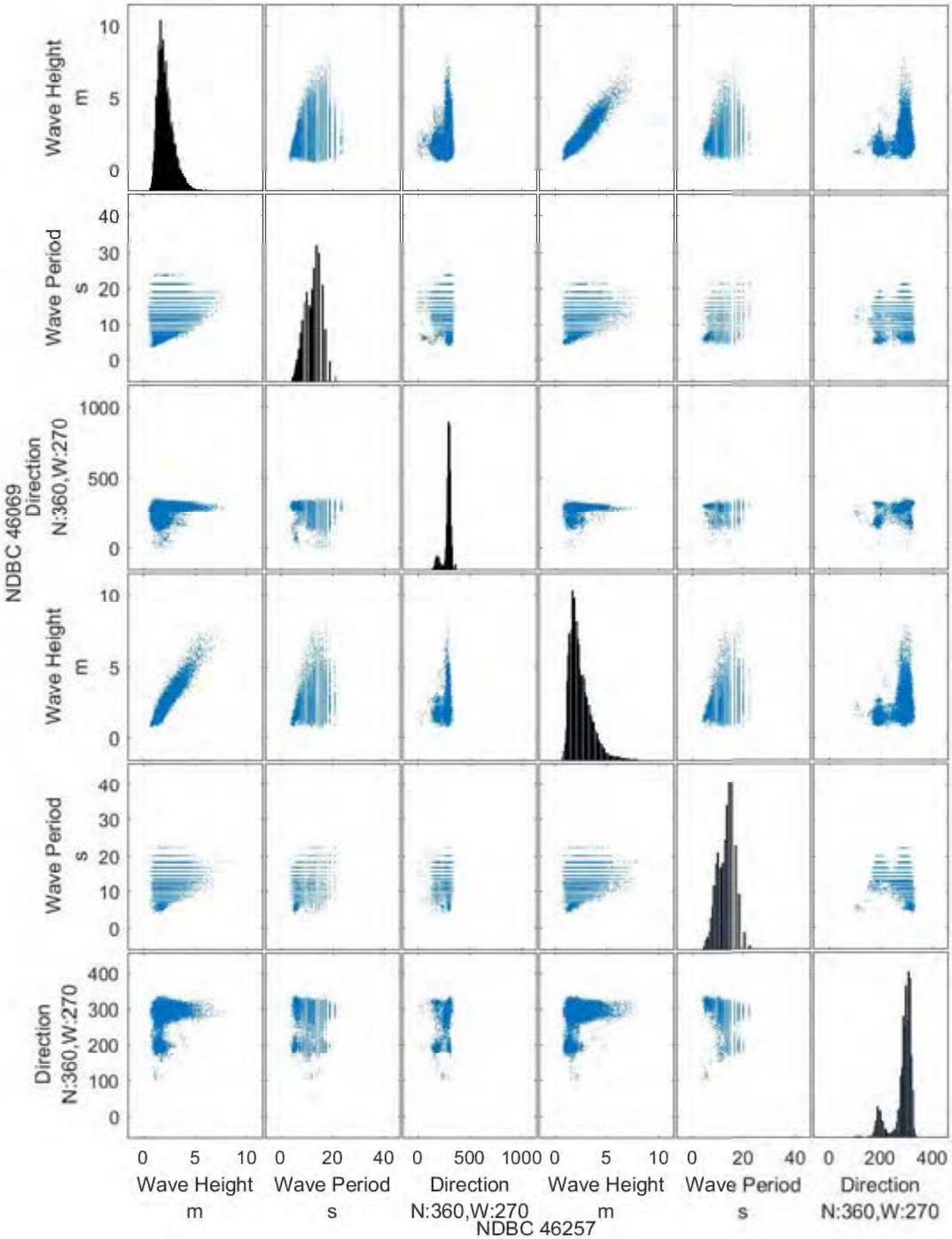


Figure B100: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46069 and NDBC 46259.

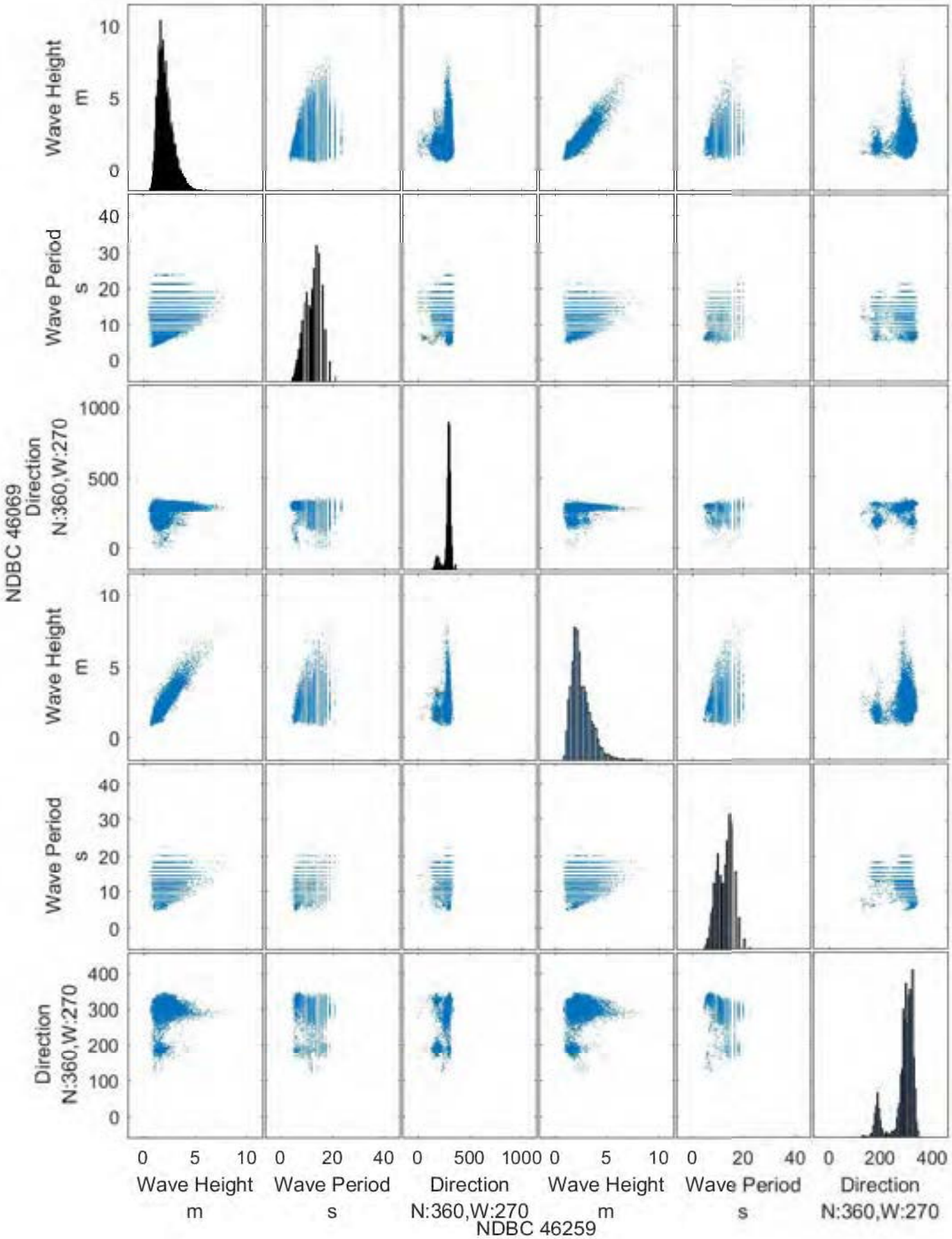


Figure B101: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46069 and NDBC 46259.

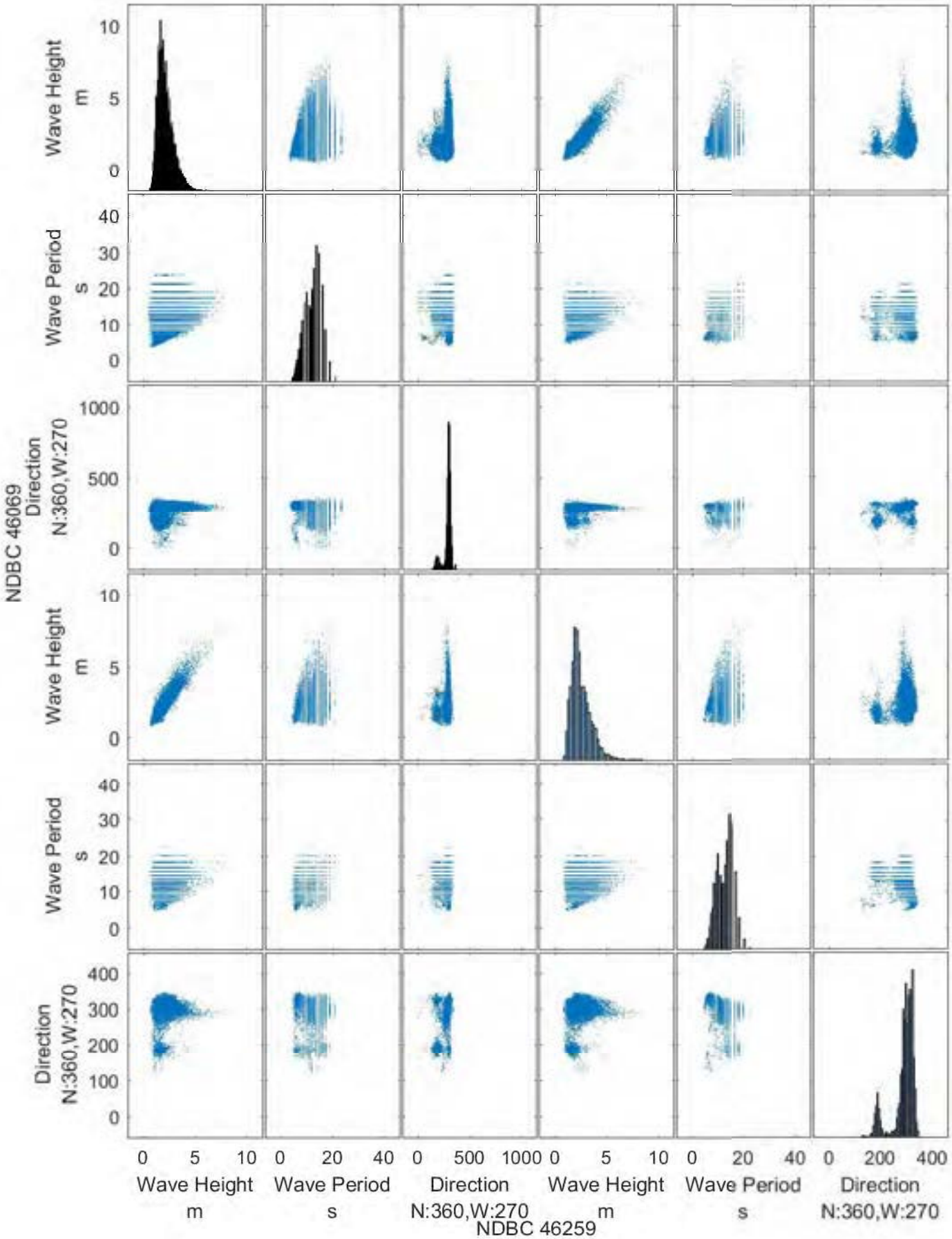


Figure B102: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46114 and NDBC 46218.

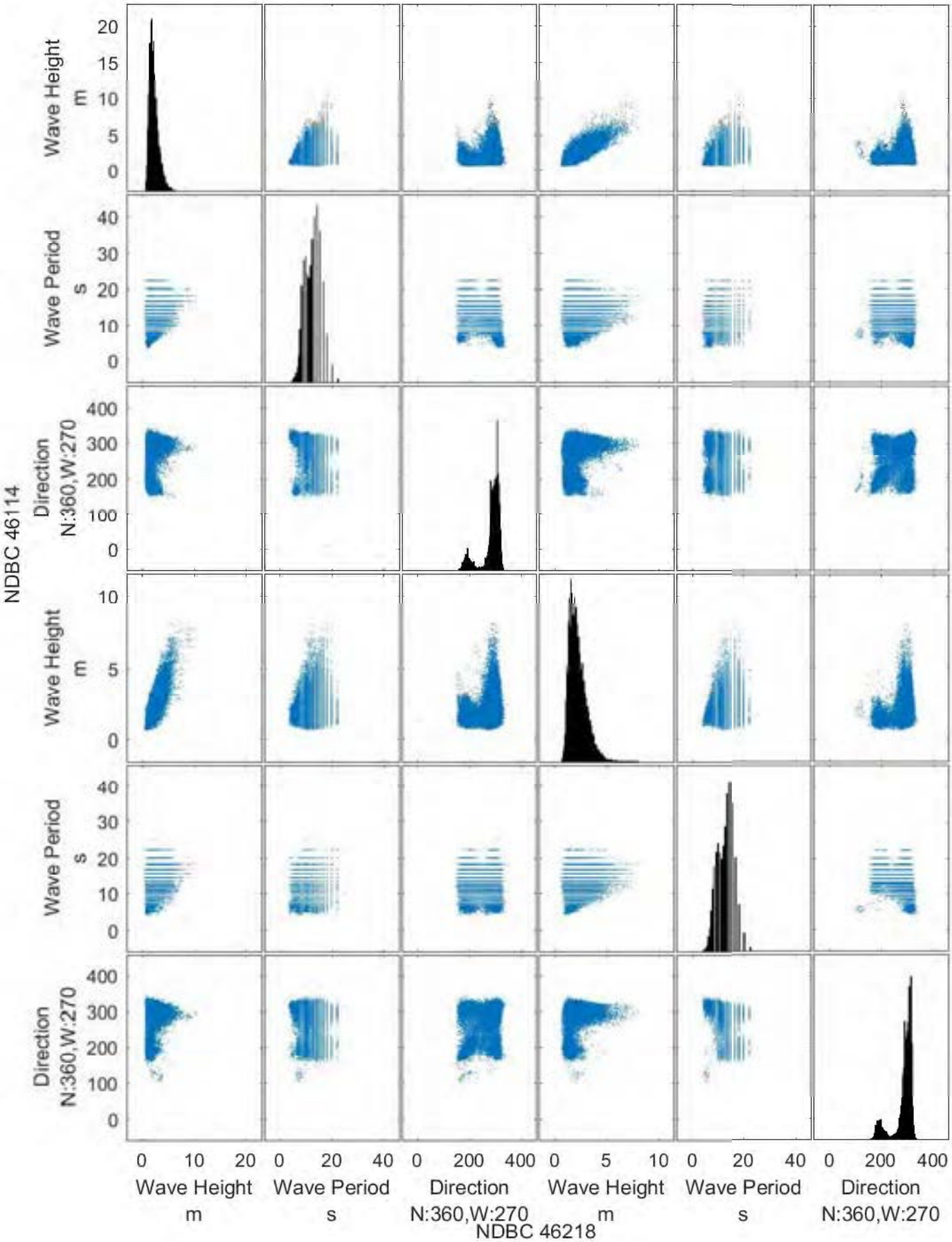


Figure B103: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46114 and NDBC 46219.

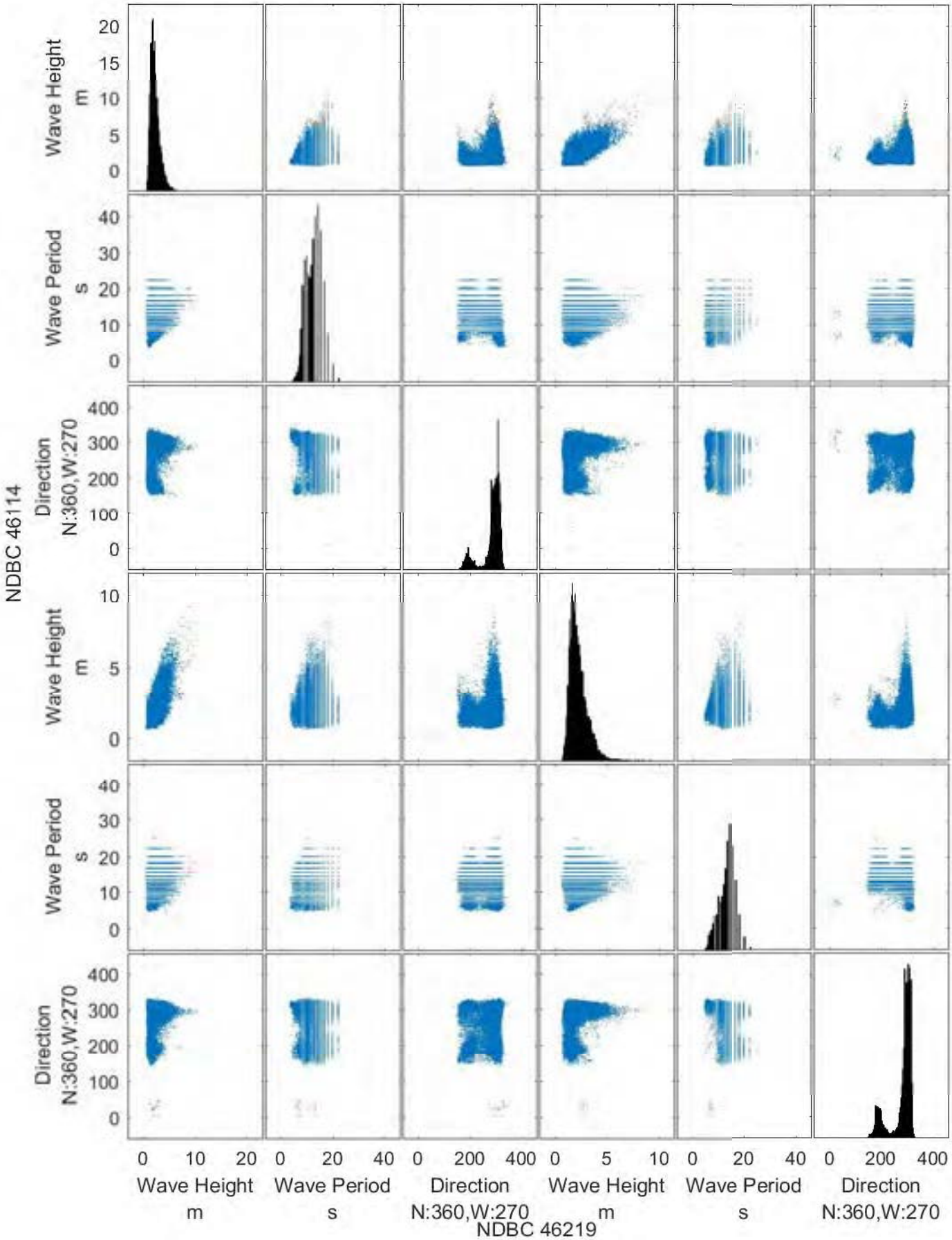


Figure B104: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46114 and NDBC 46239.

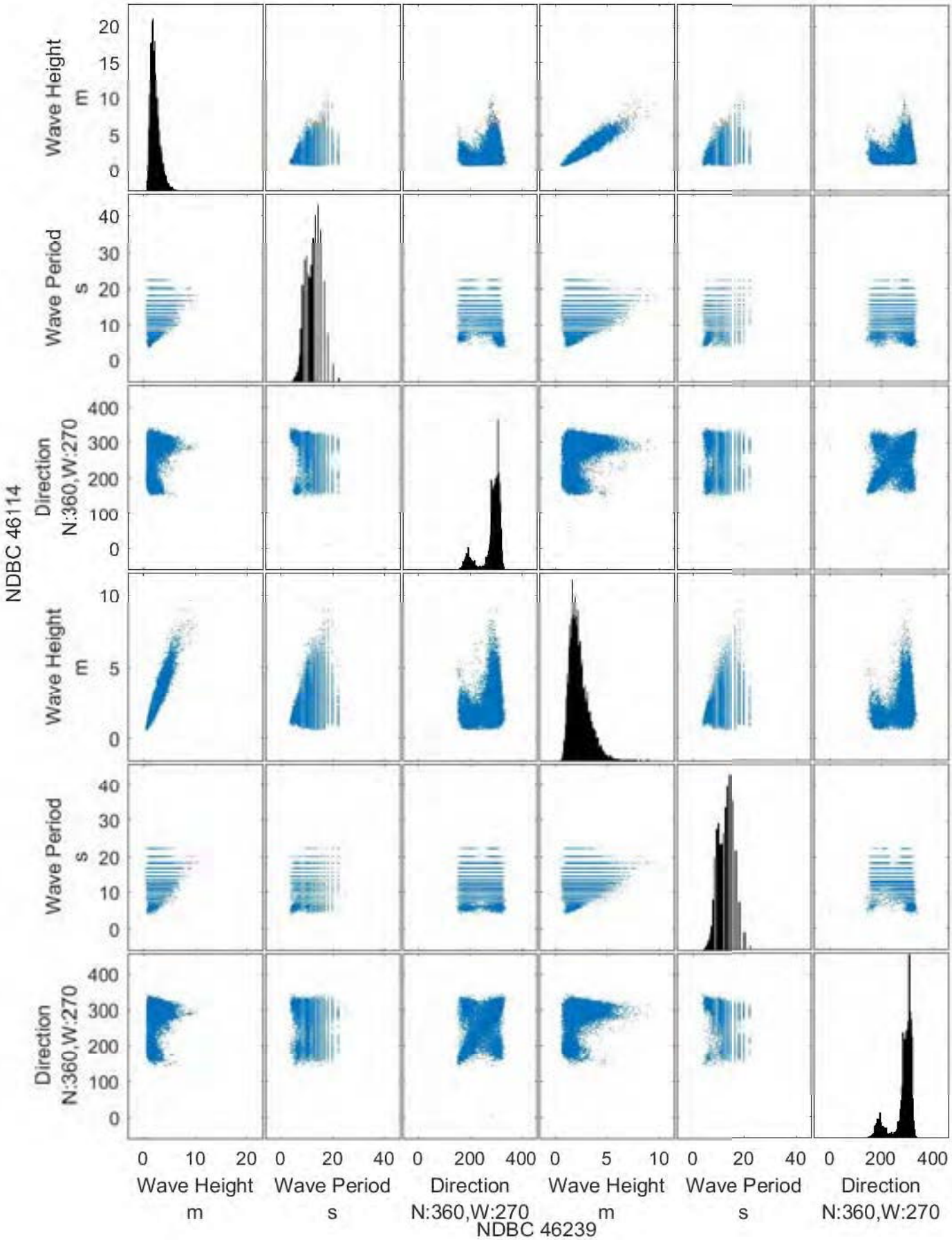


Figure B105: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46114 and NDBC 46257.

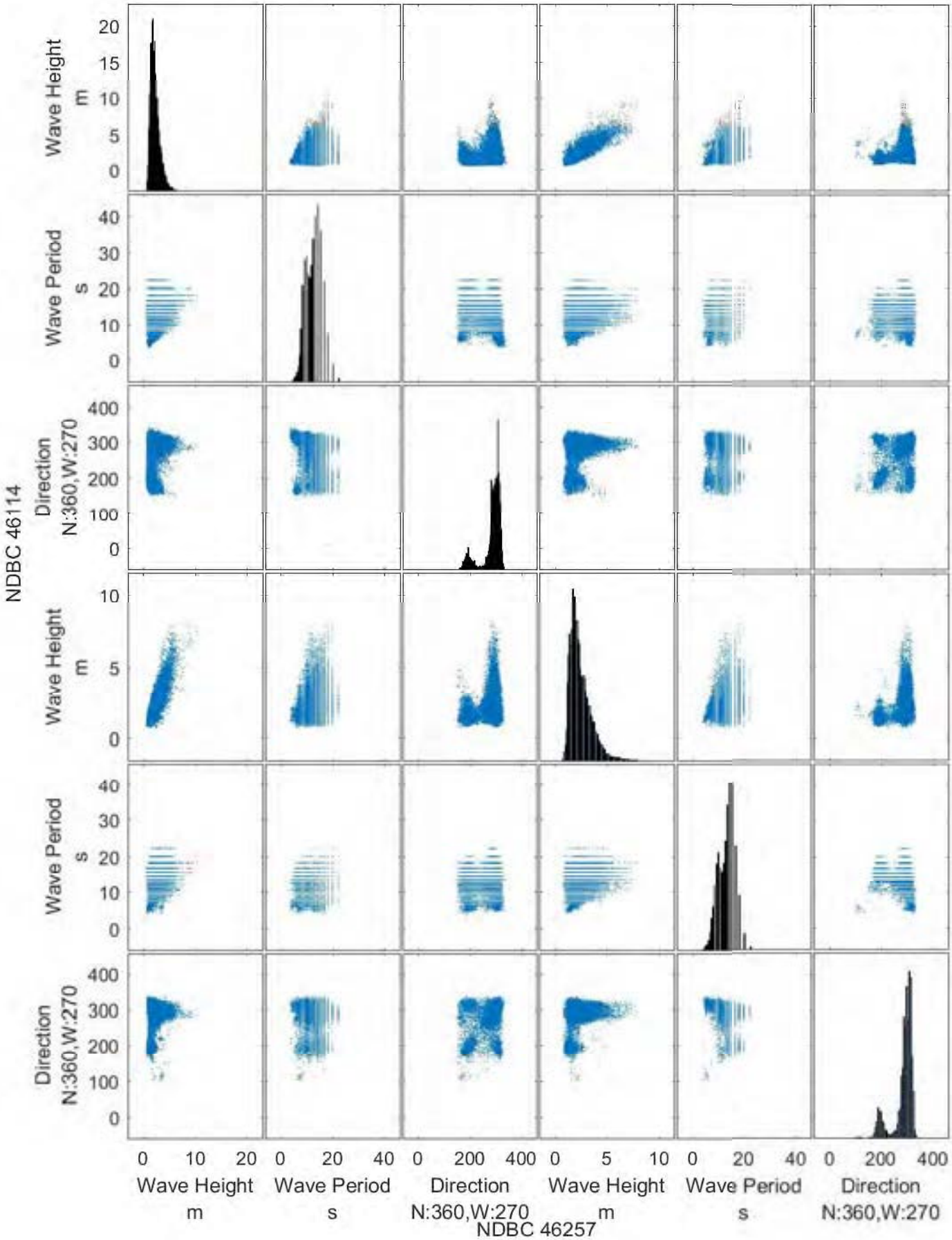


Figure B106: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46114 and NDBC 46259.

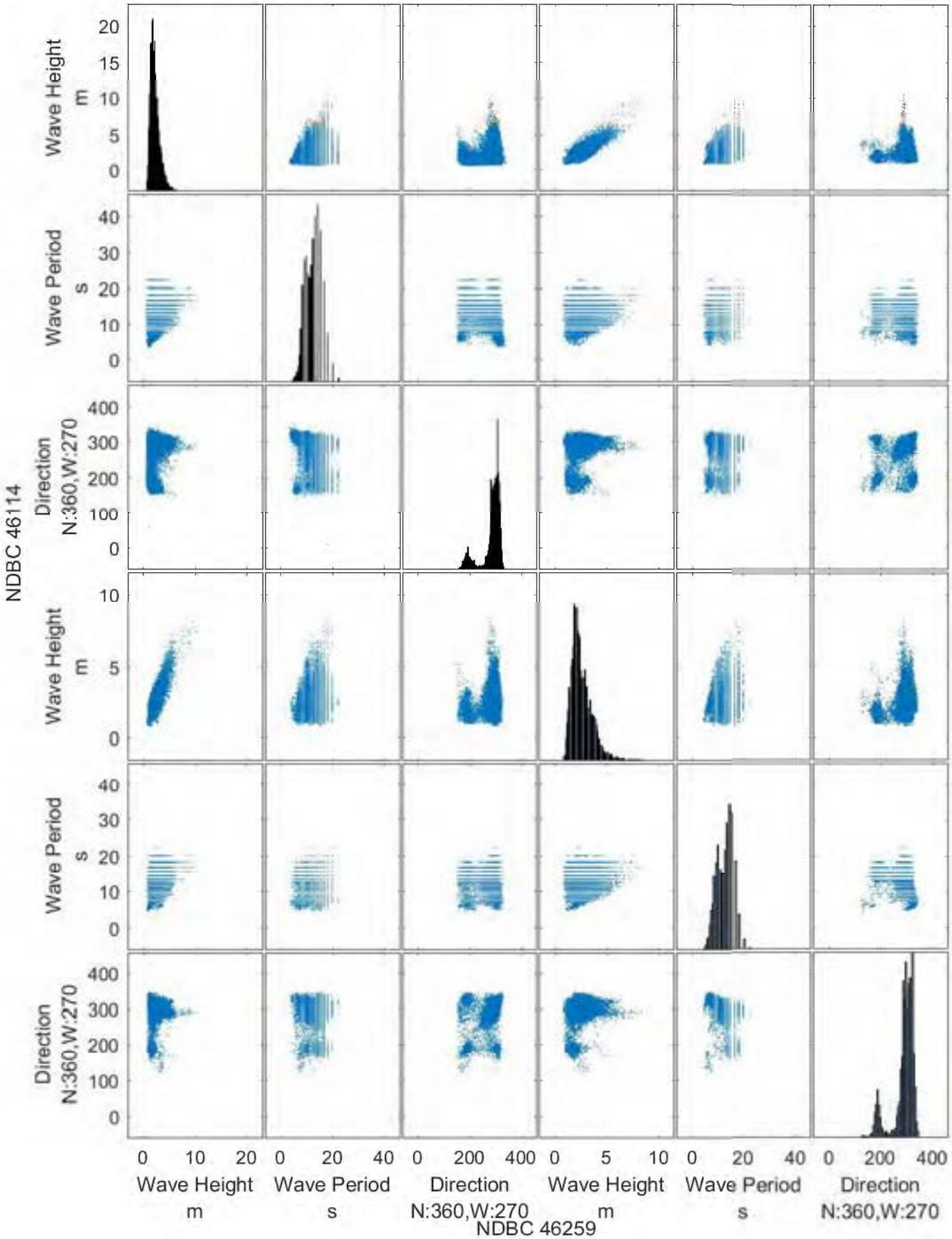


Figure B107: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46114 and NDBC 46259.

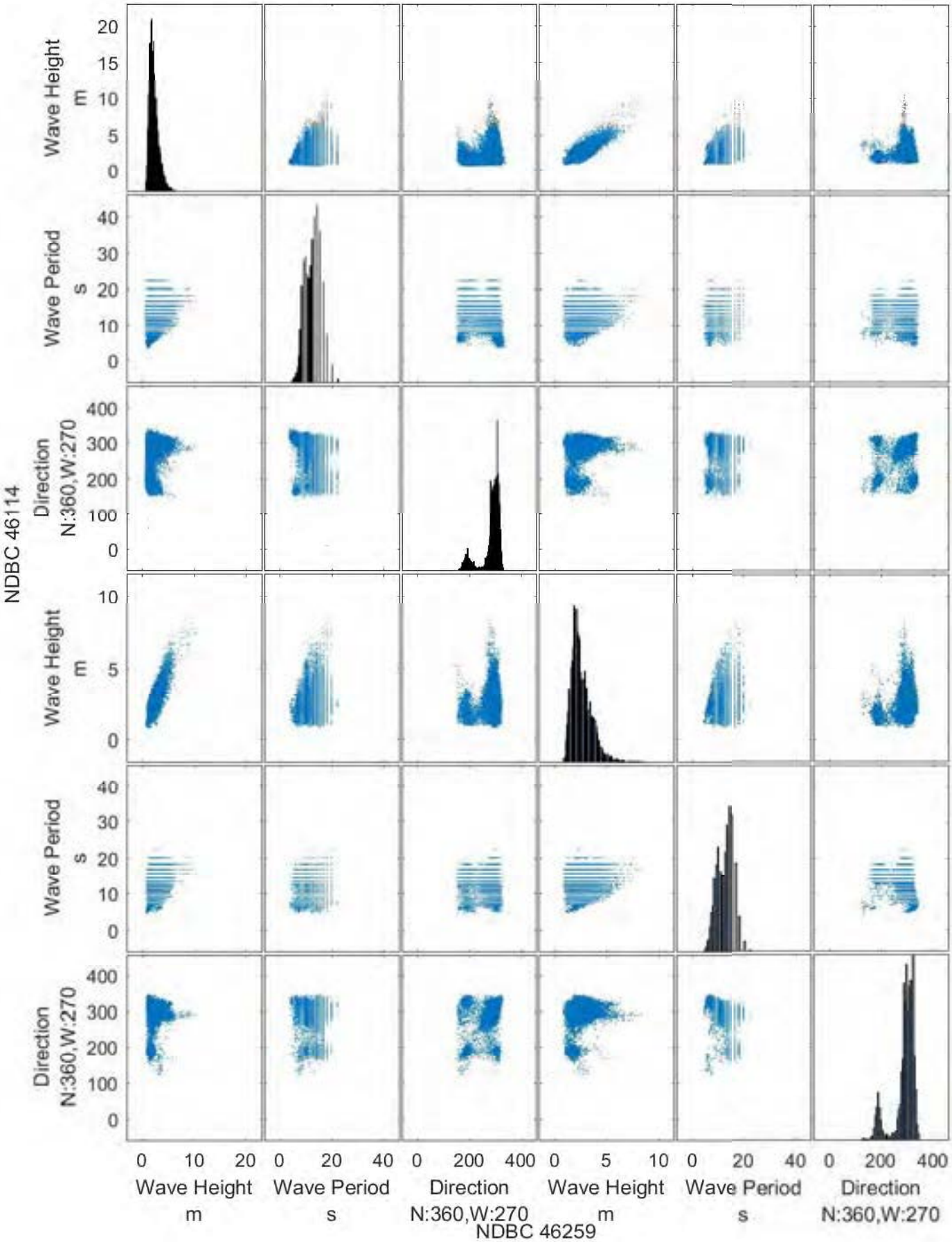


Figure B108: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46114 and NDBC 46259.

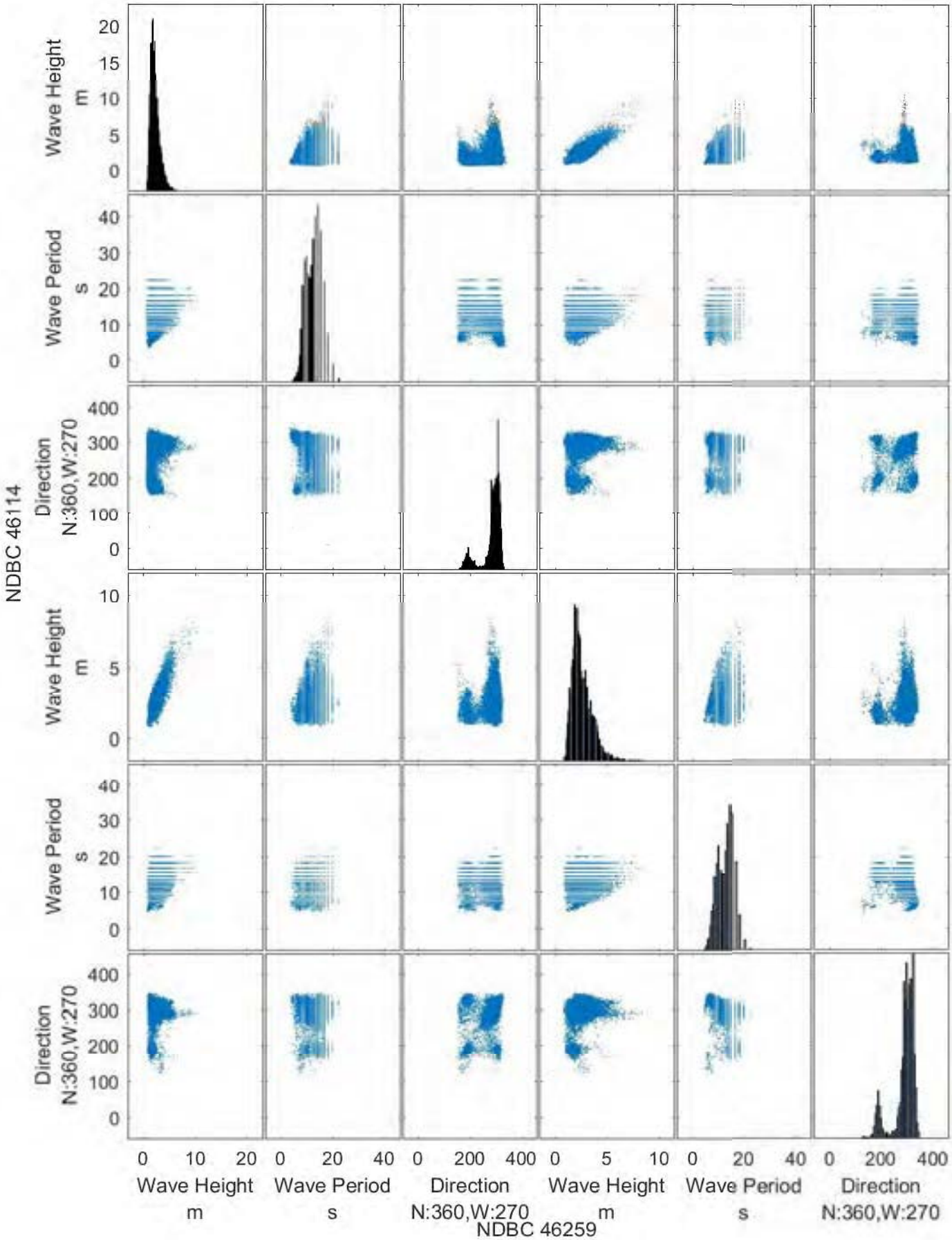


Figure B109: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46218 and NDBC 46219.

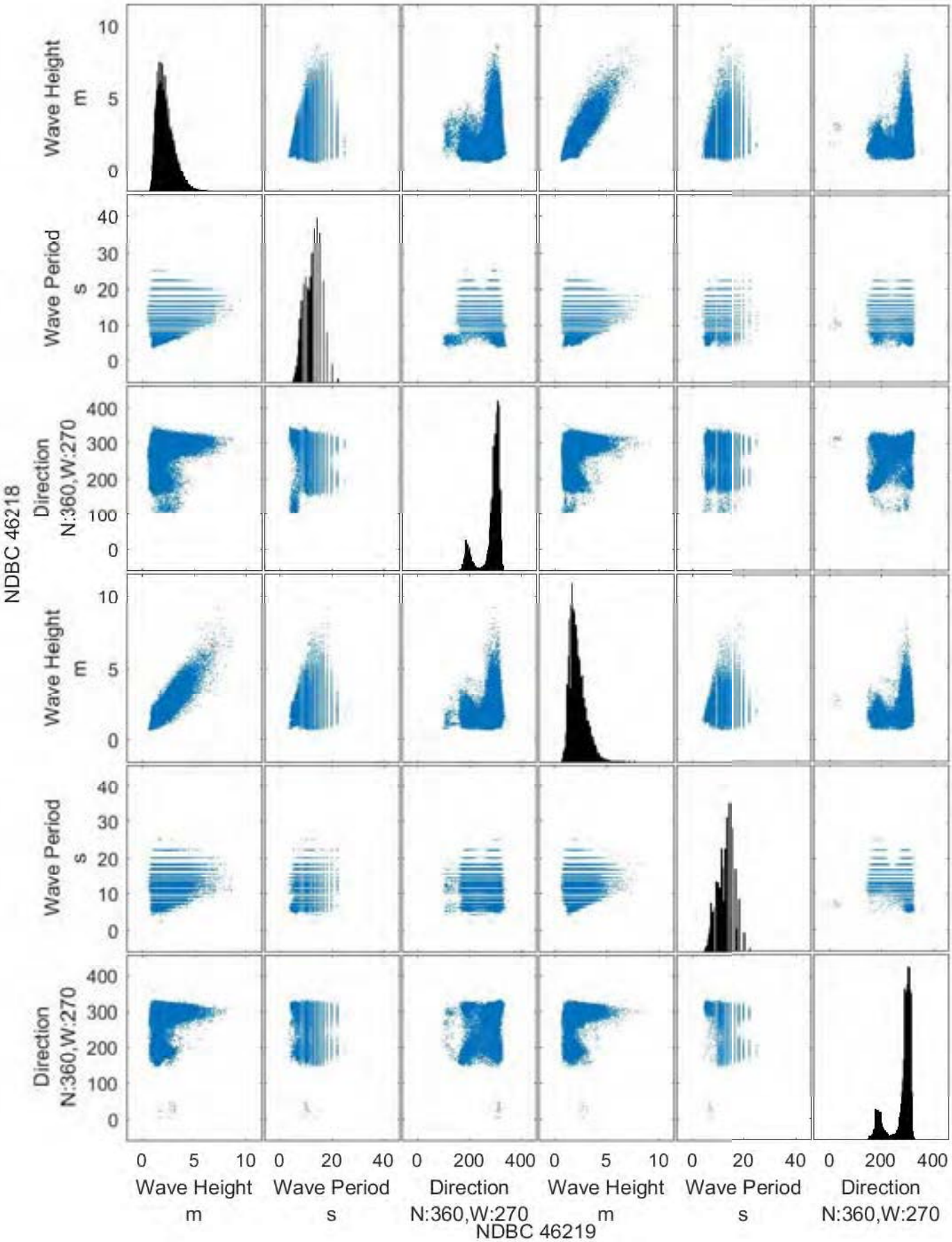


Figure B110: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46218 and NDBC 46239.

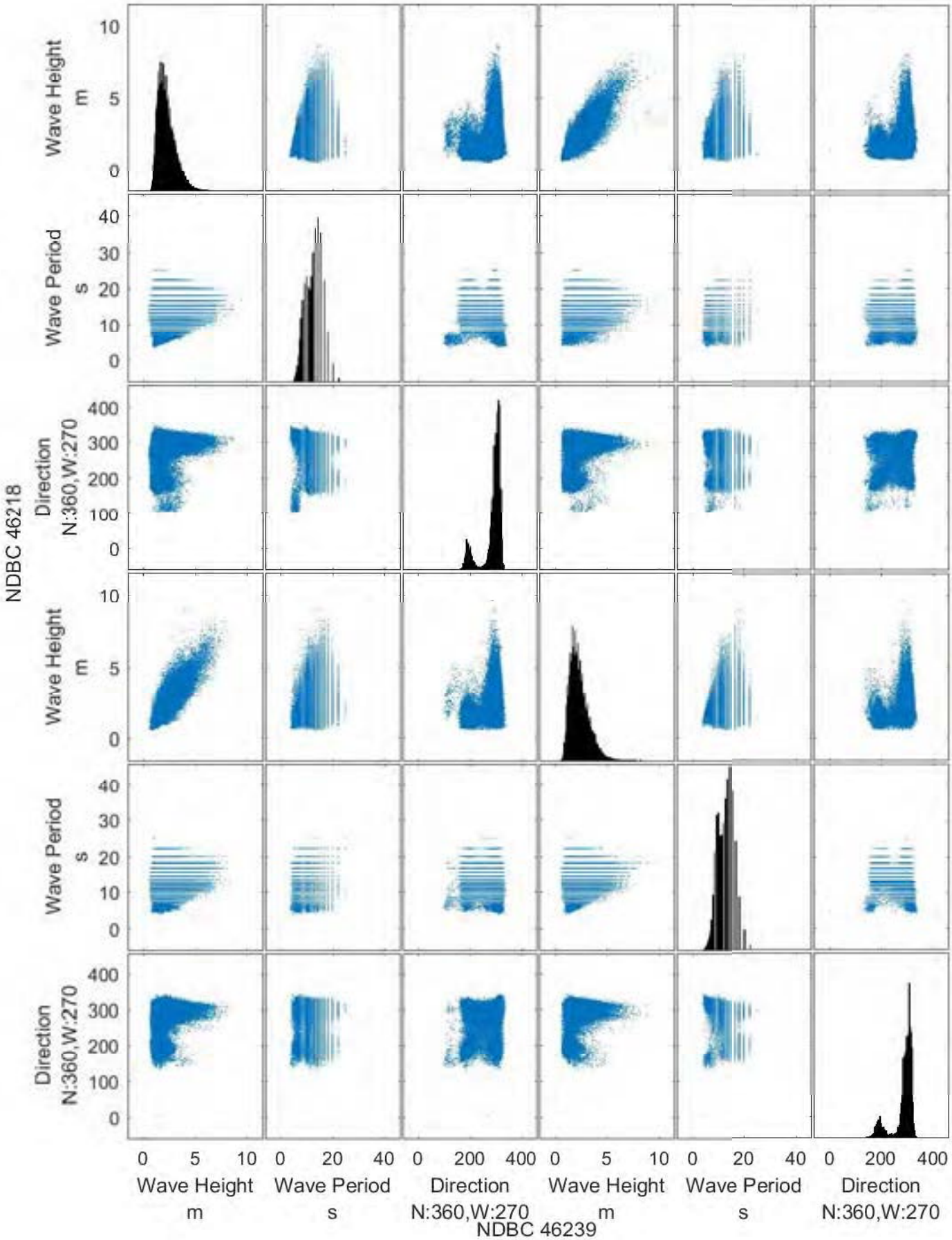


Figure B111: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46218 and NDBC 46257.

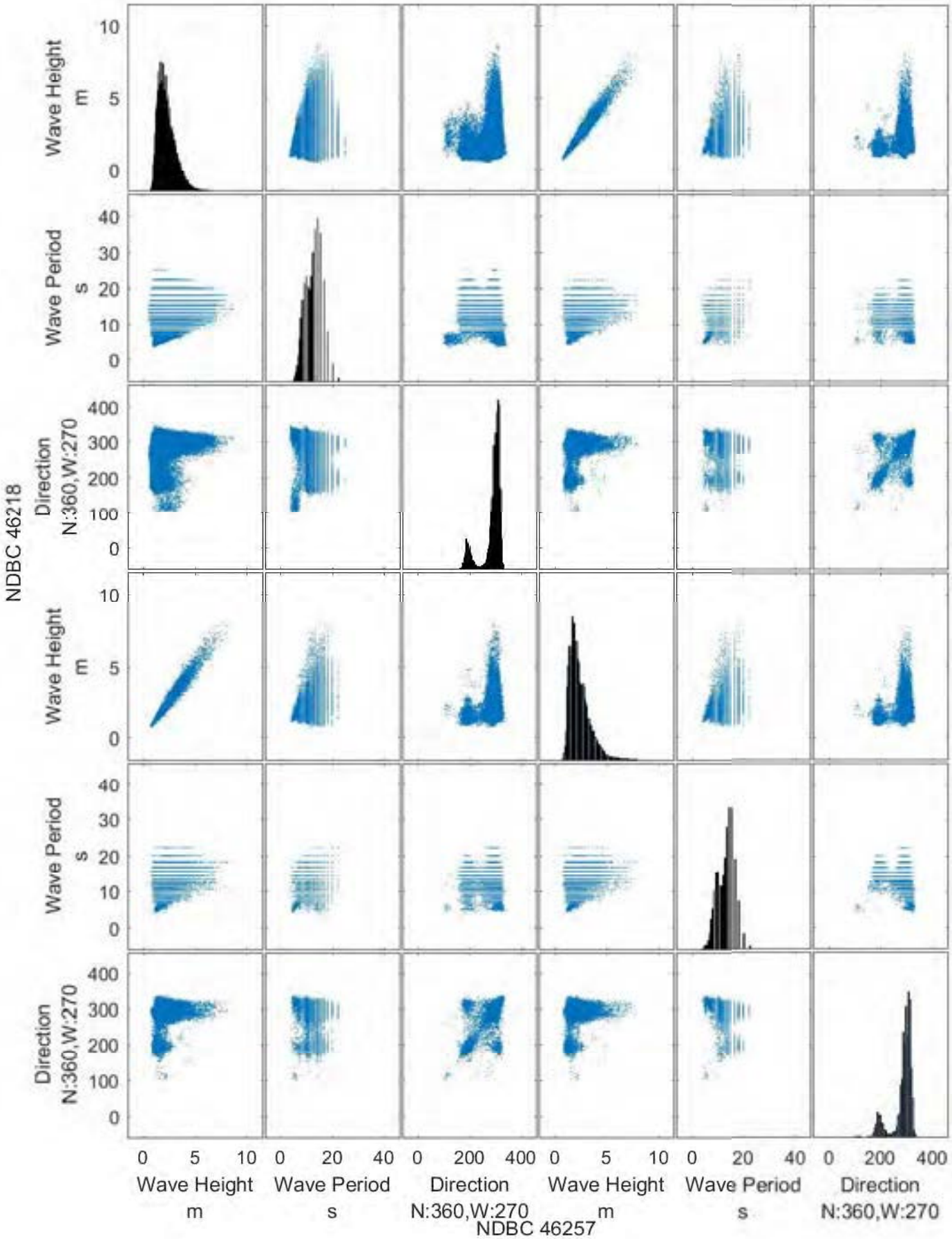


Figure B112: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46218 and NDBC 46259.

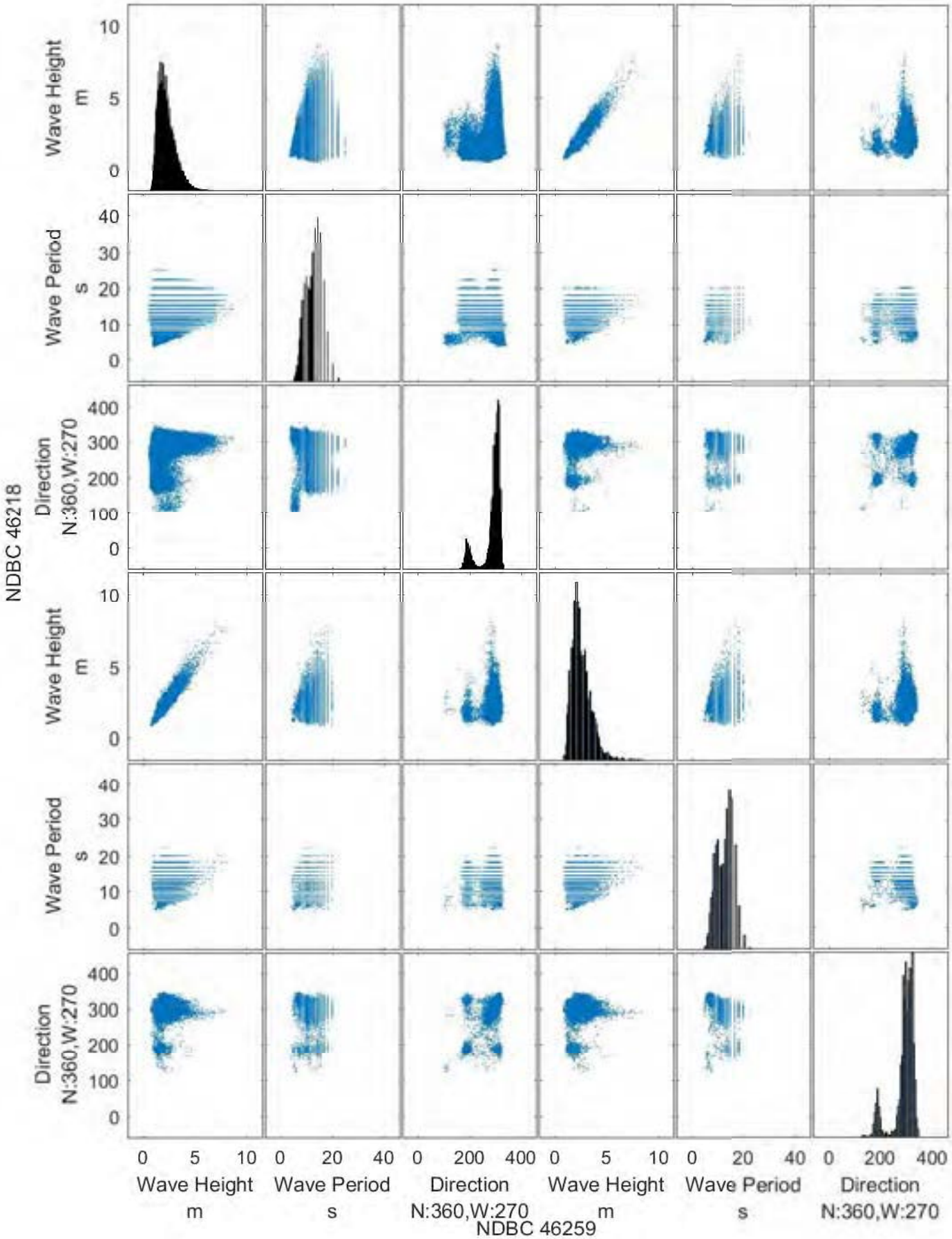


Figure B113: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46218 and NDBC 46259.

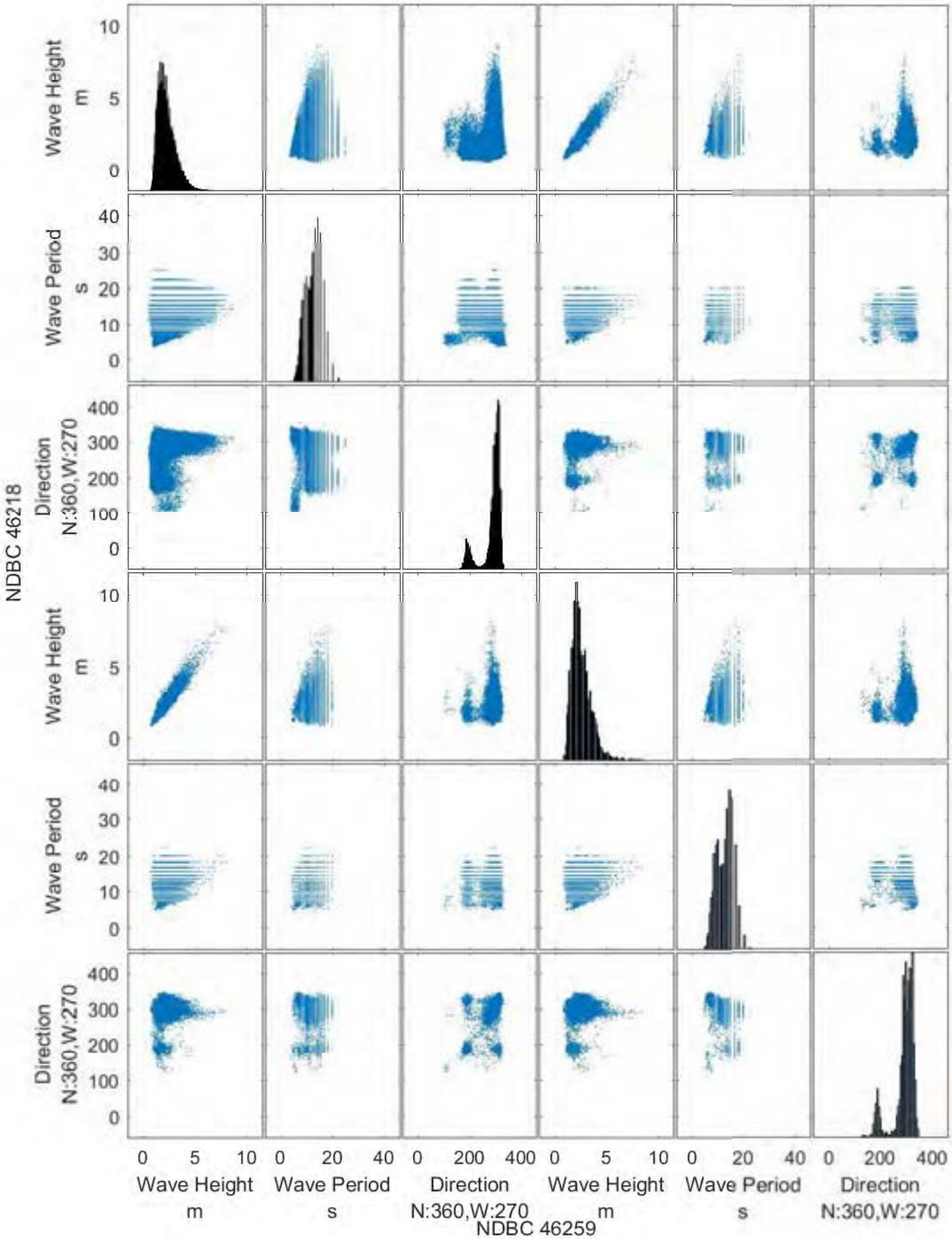


Figure B114: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46218 and NDBC 46259.

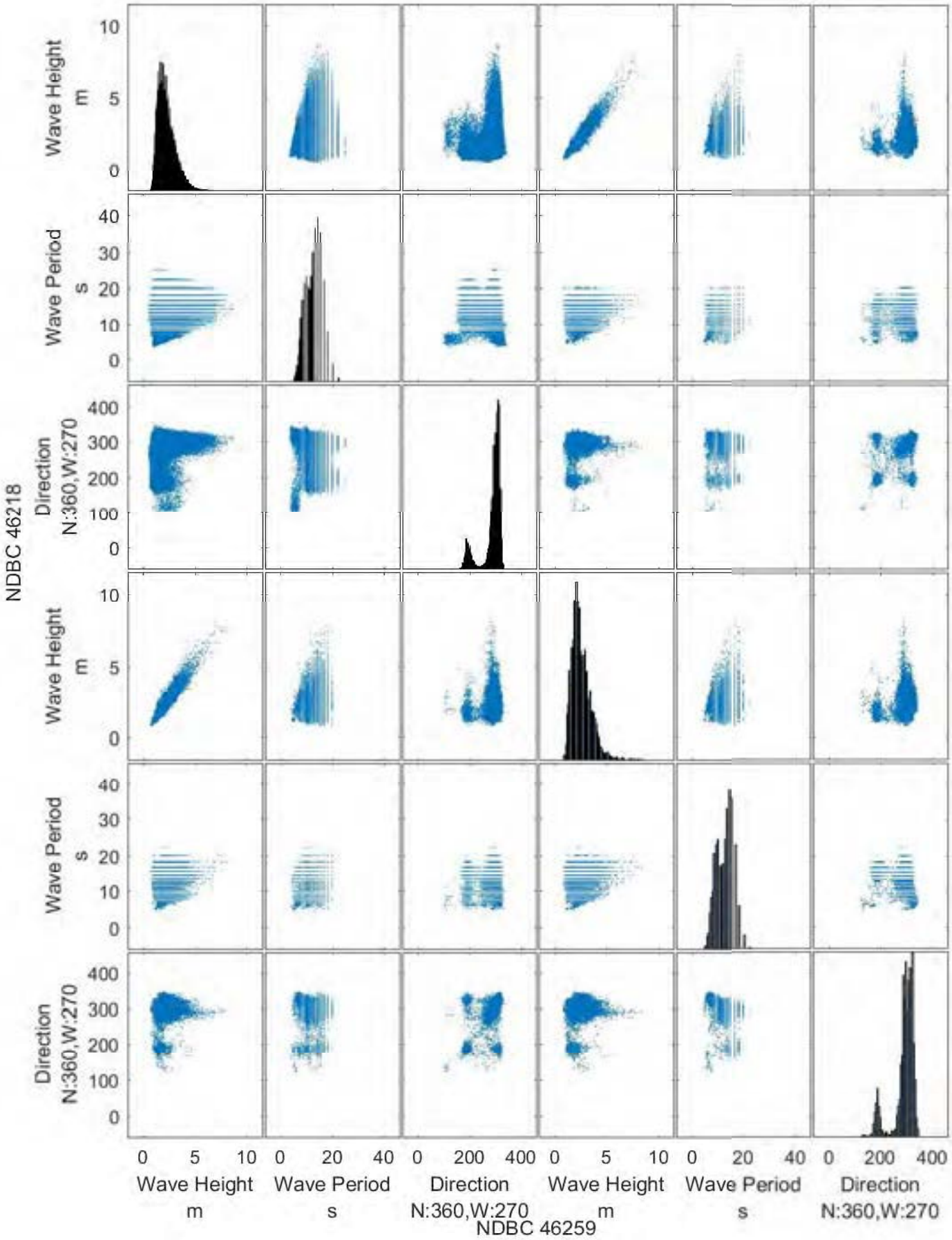


Figure B115: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46219 and NDBC 46239.

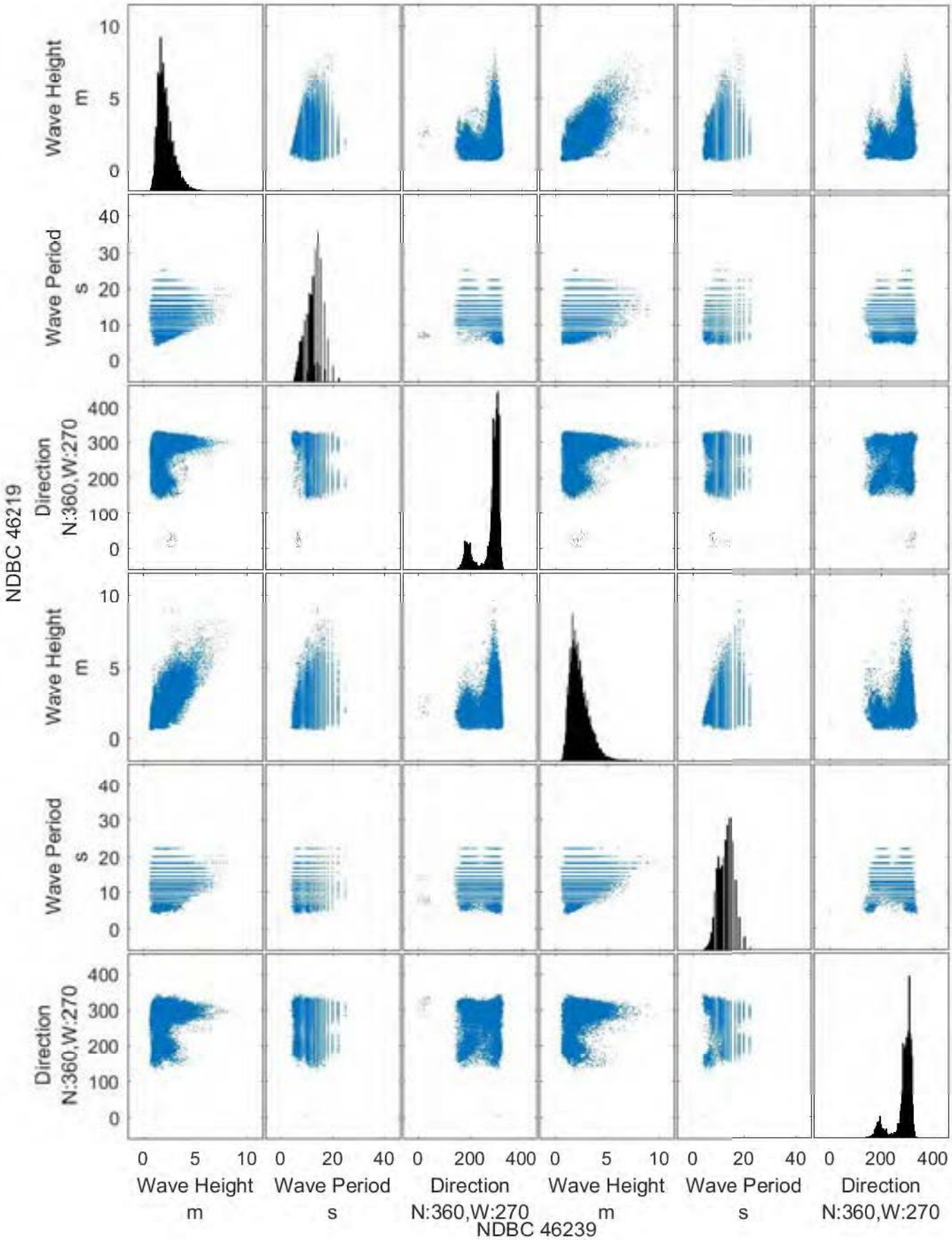


Figure B116: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46219 and NDBC 46257.

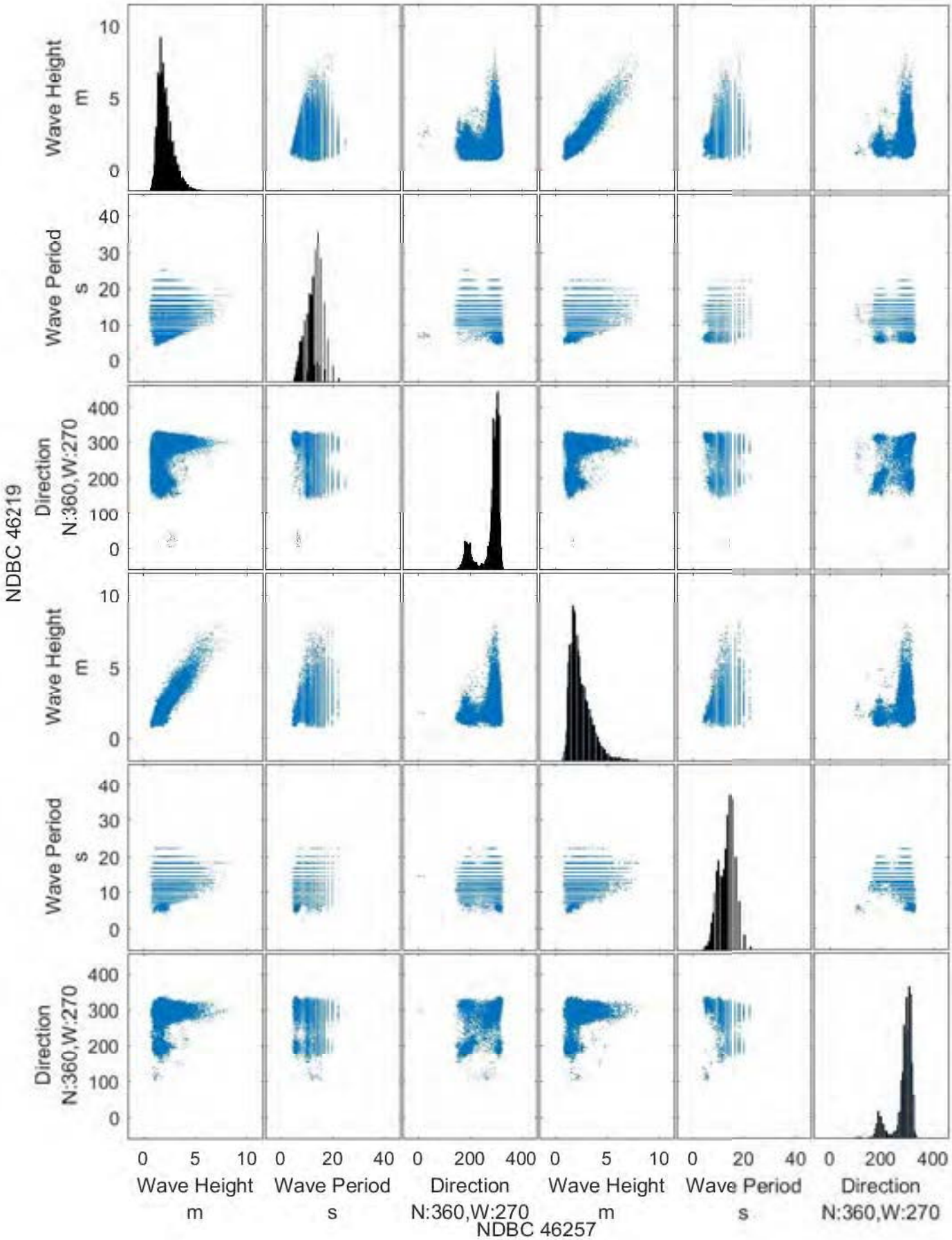


Figure B117: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46219 and NDBC 46259.

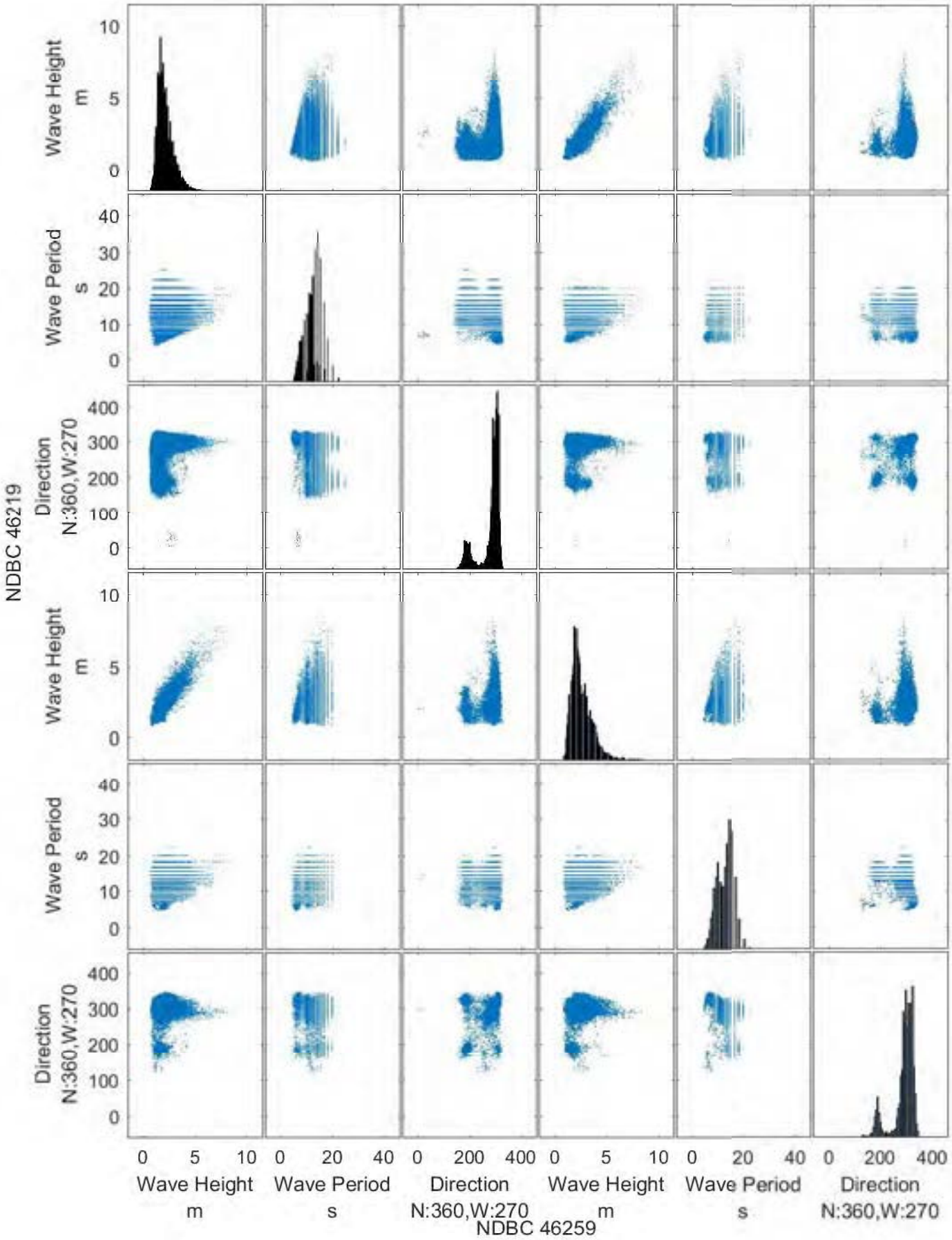


Figure B118: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46219 and NDBC 46259.

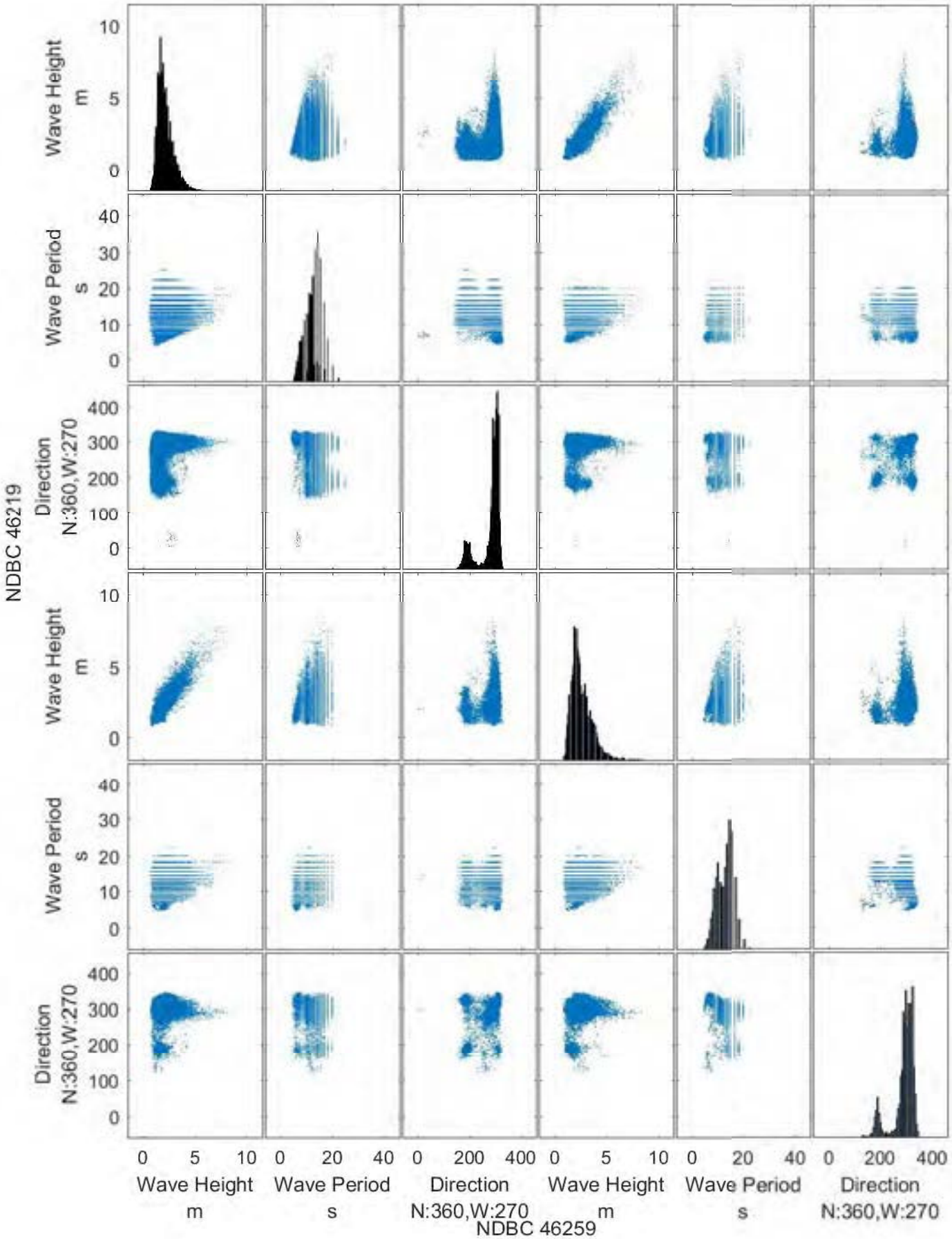


Figure B119: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46219 and NDBC 46259.

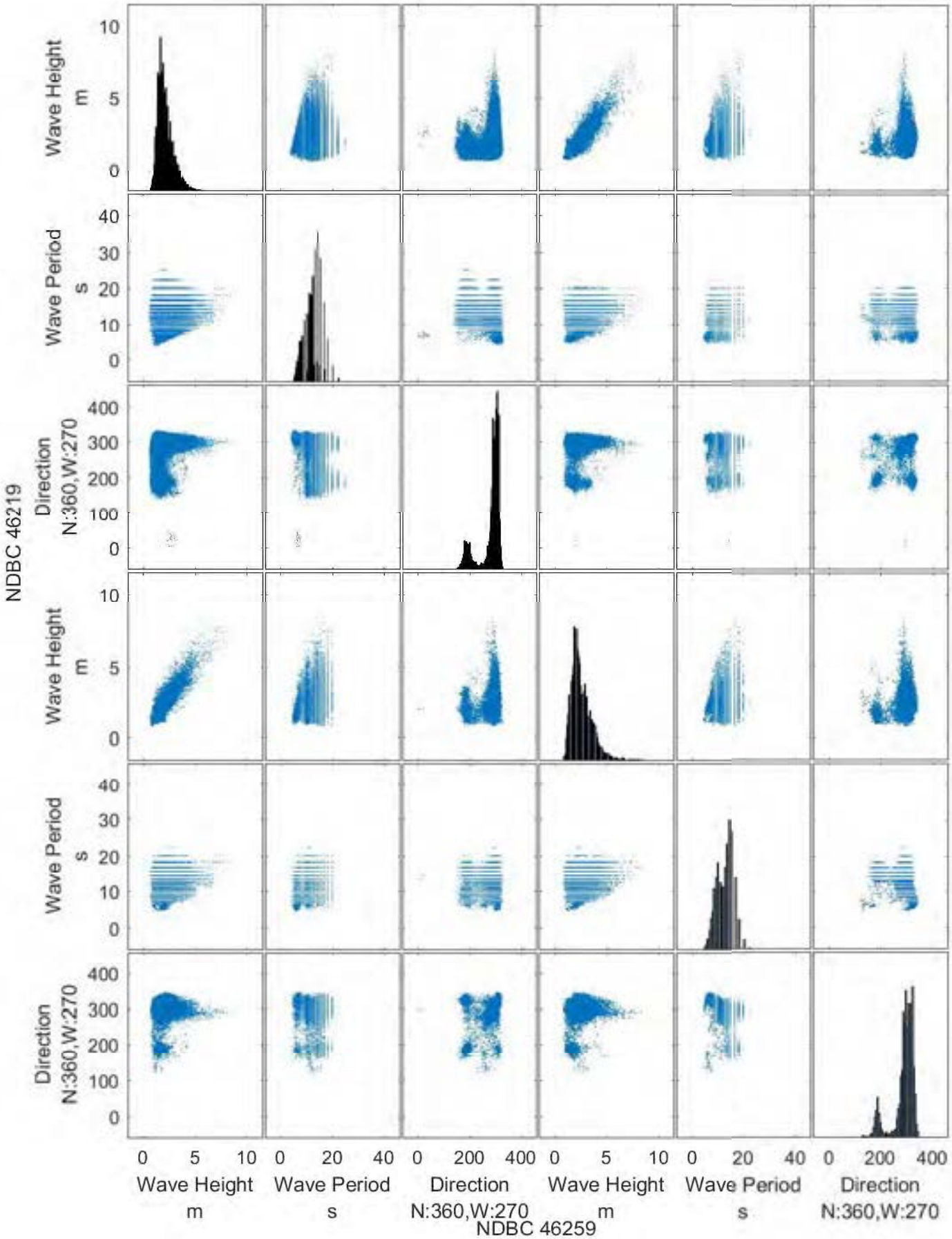


Figure B120: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46239 and NDBC 46257.

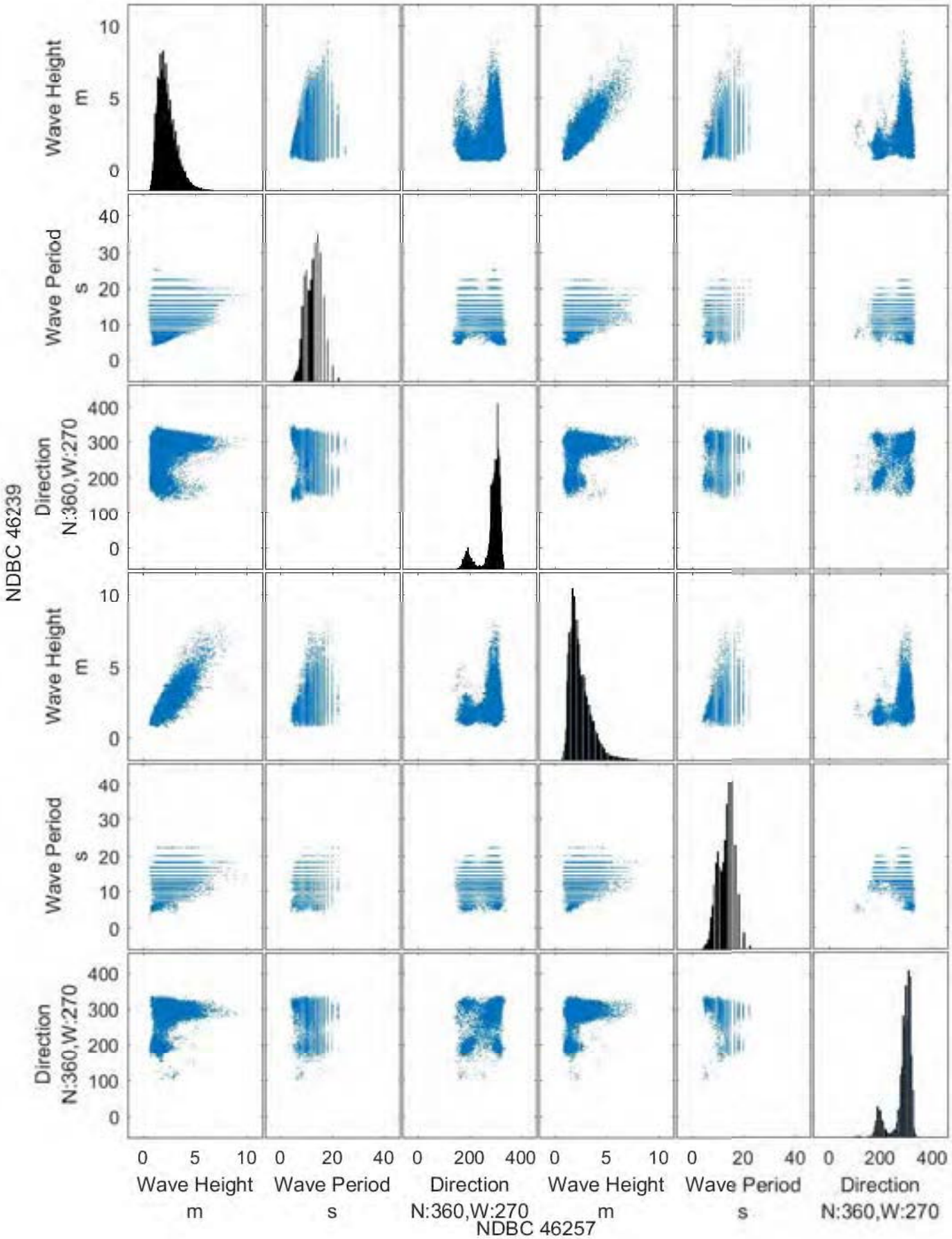


Figure B121: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46239 and NDBC 46259.

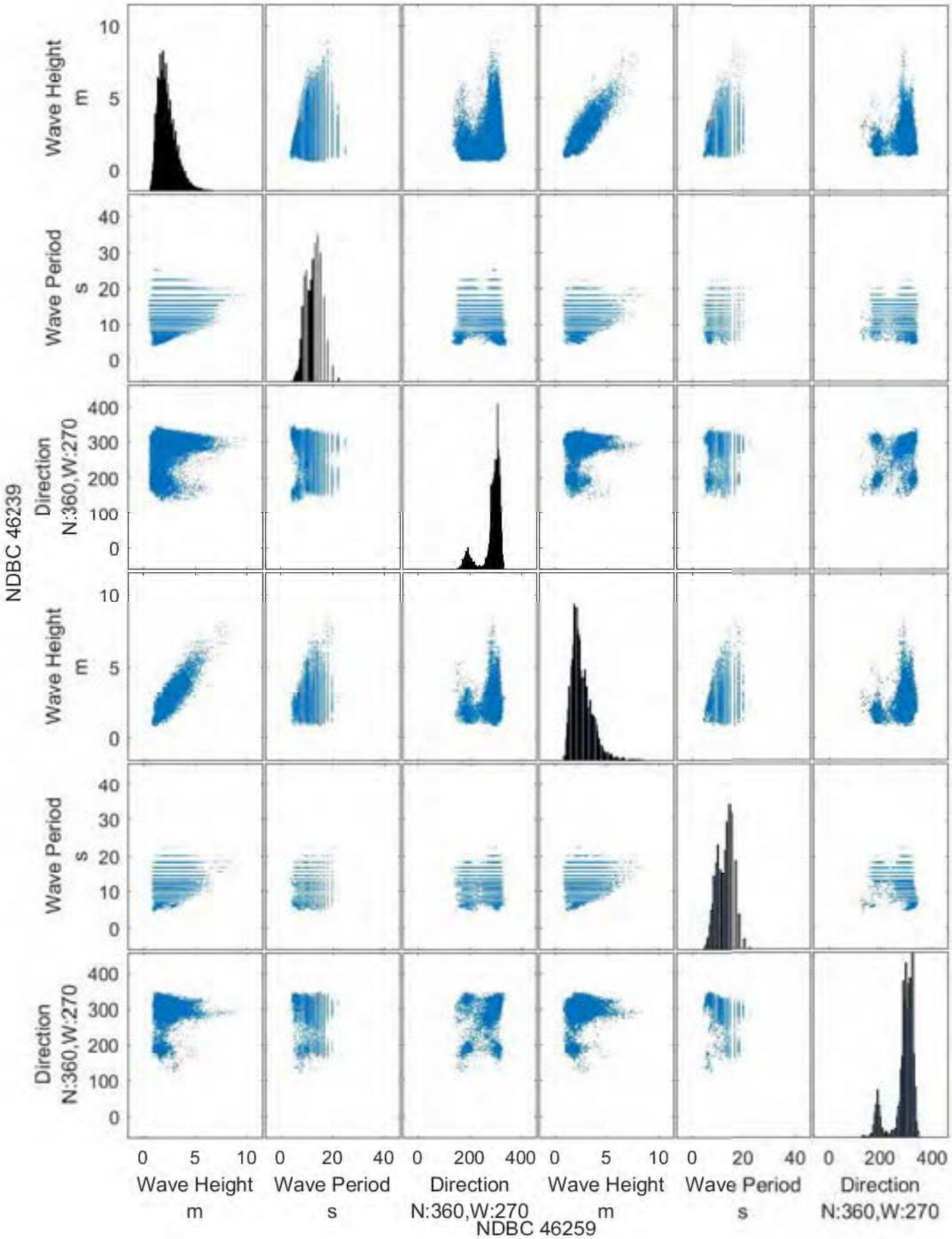


Figure B122: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46239 and NDBC 46259.

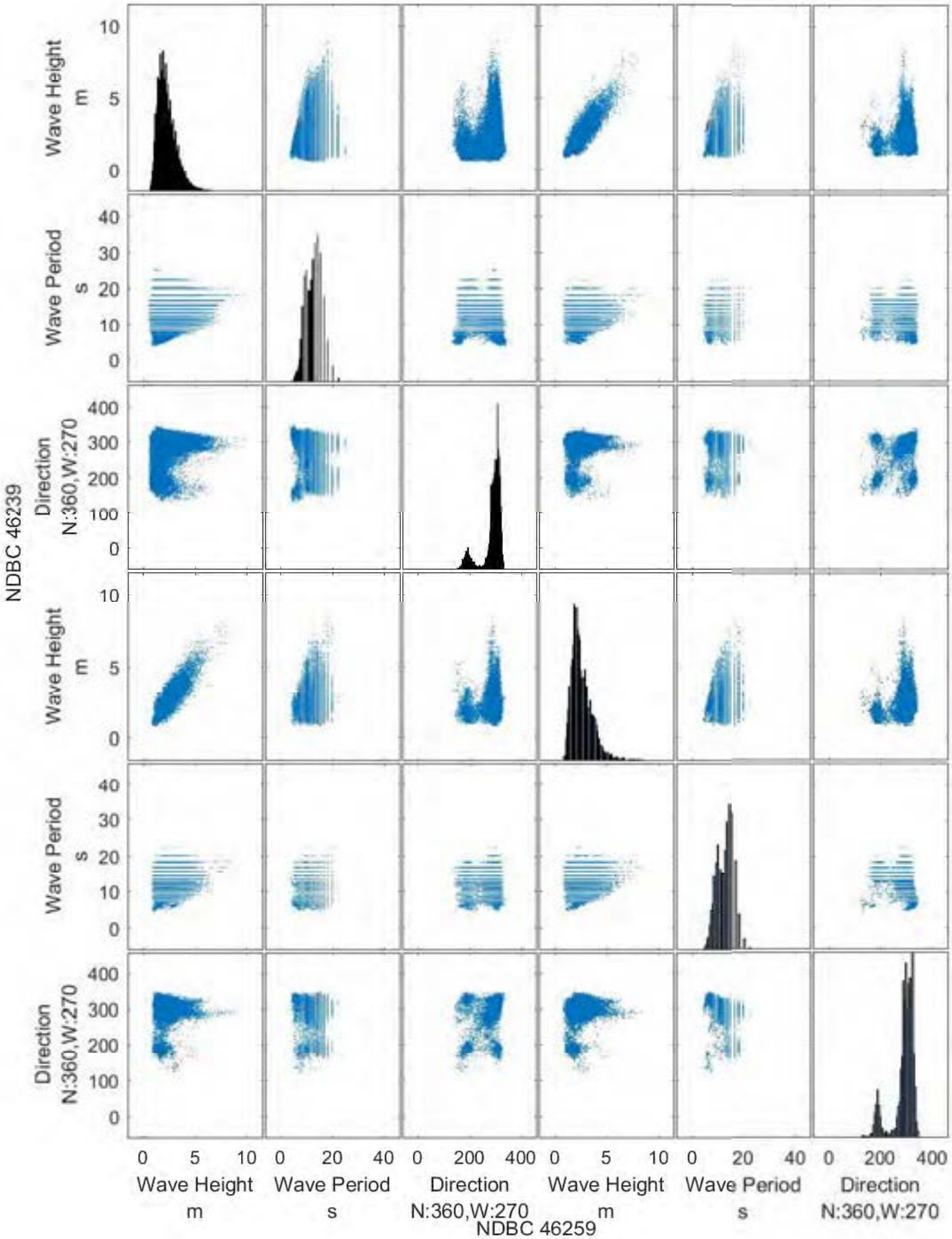
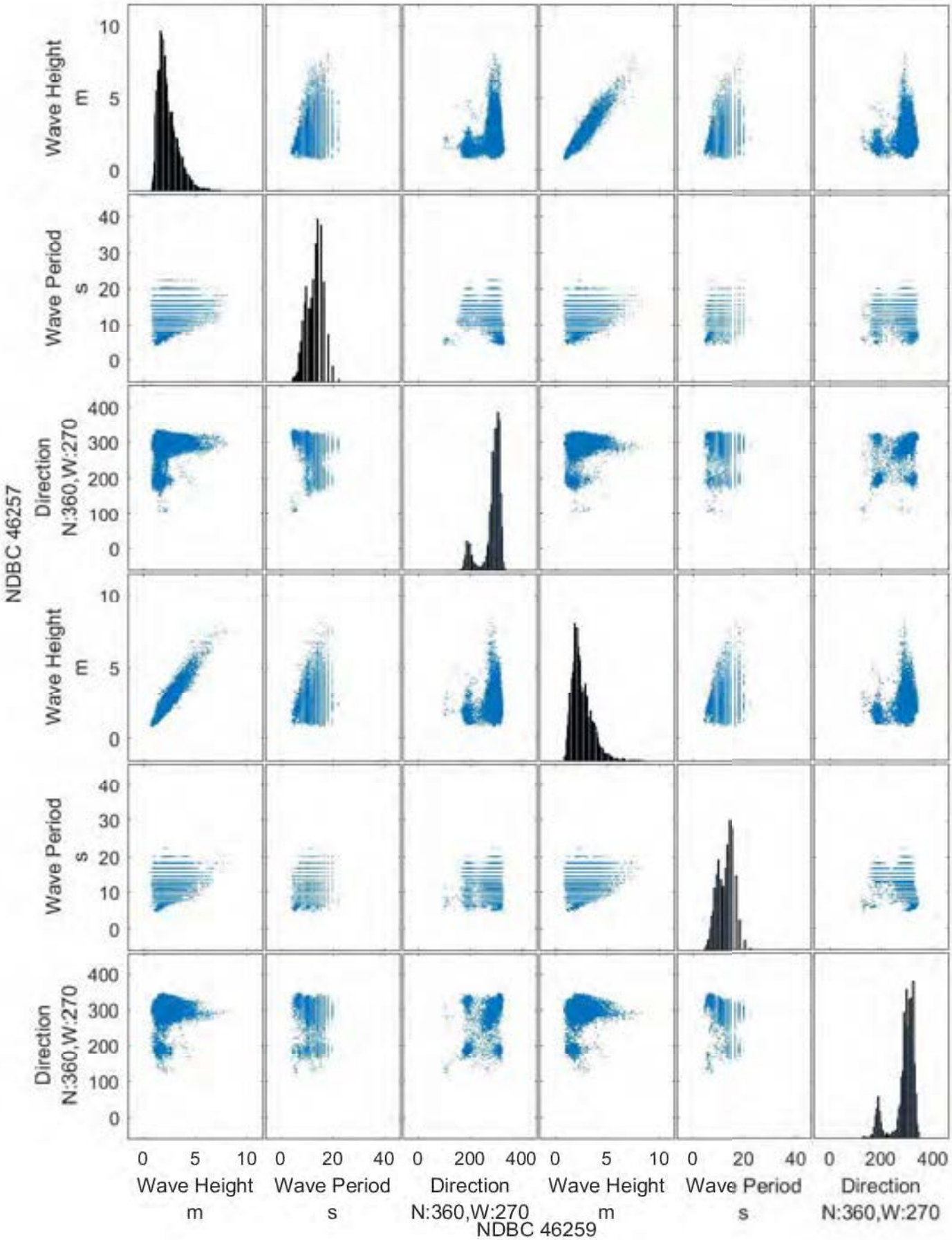


Figure B123: Cross Correlations for Wave Height, Wave Period, and Wave Direction for NDBC 46257 and NDBC 46259.



APPENDIX C: Cross Correlated Data for Wave Energy, and Direction, by Buoy

(Appendix C is included as a separate file due to size)

Figure C001: Cross Correlations for Wave Energy and Direction for NDBC 46011 and NDBC 46012.

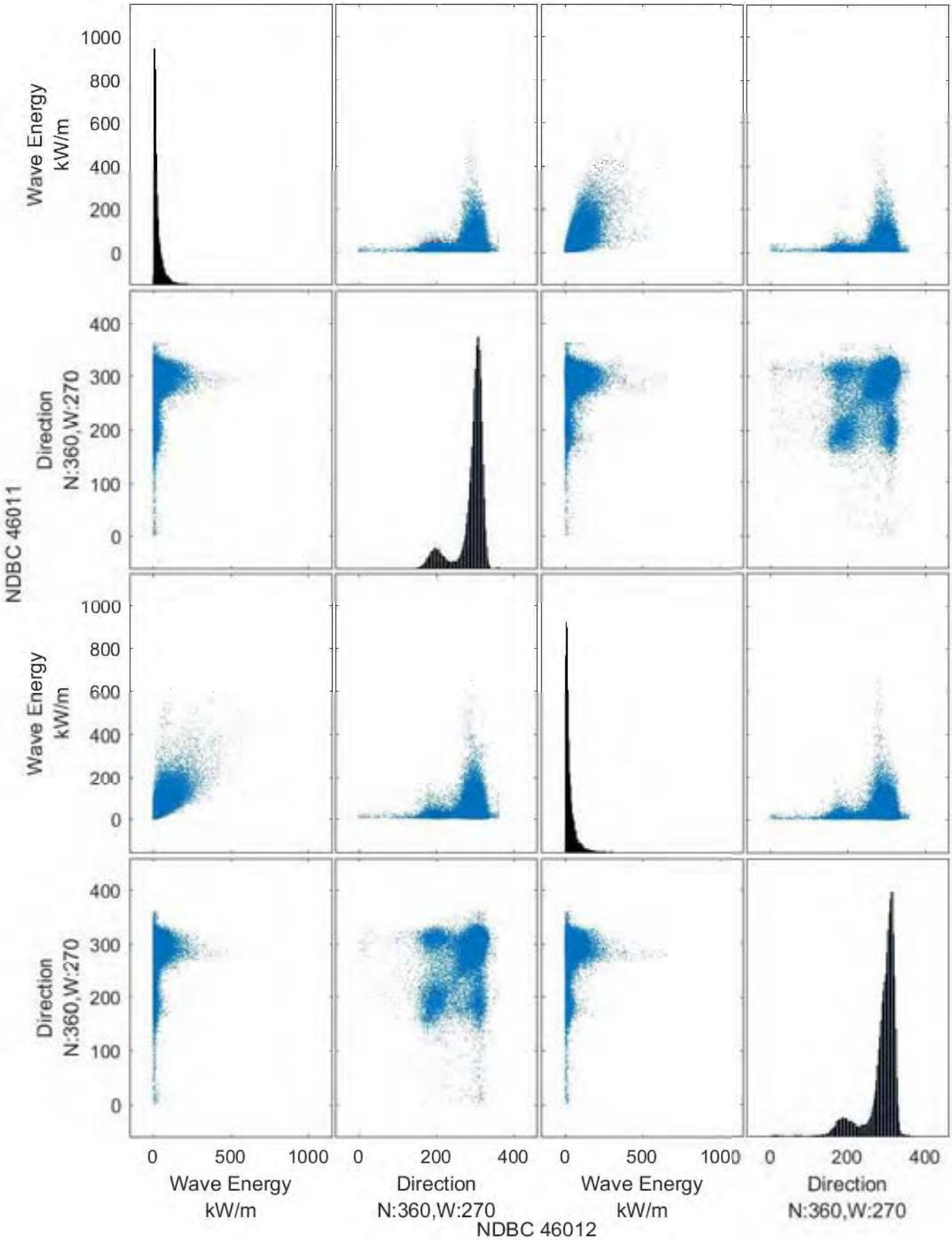


Figure C002: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46023.

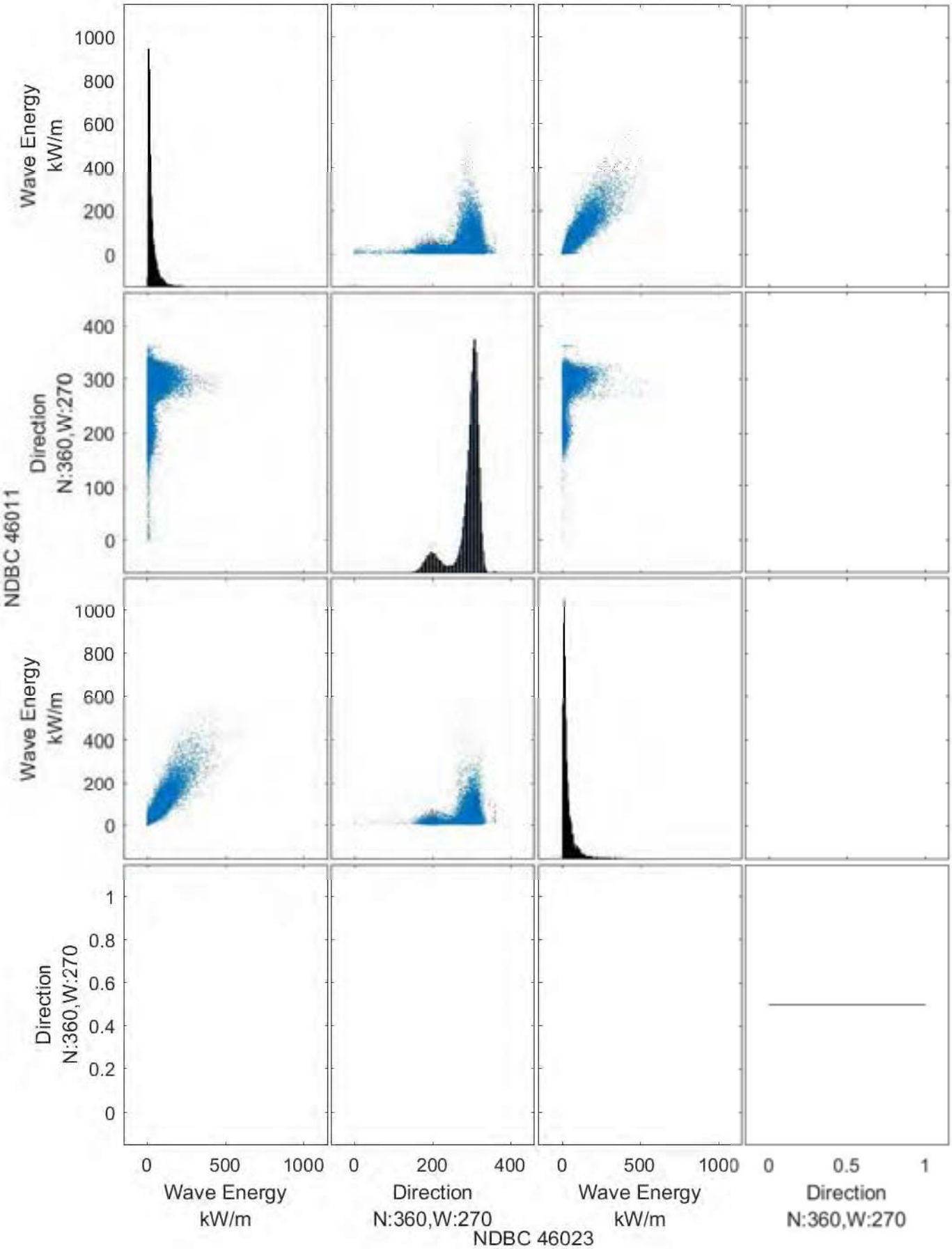


Figure C003: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46028.

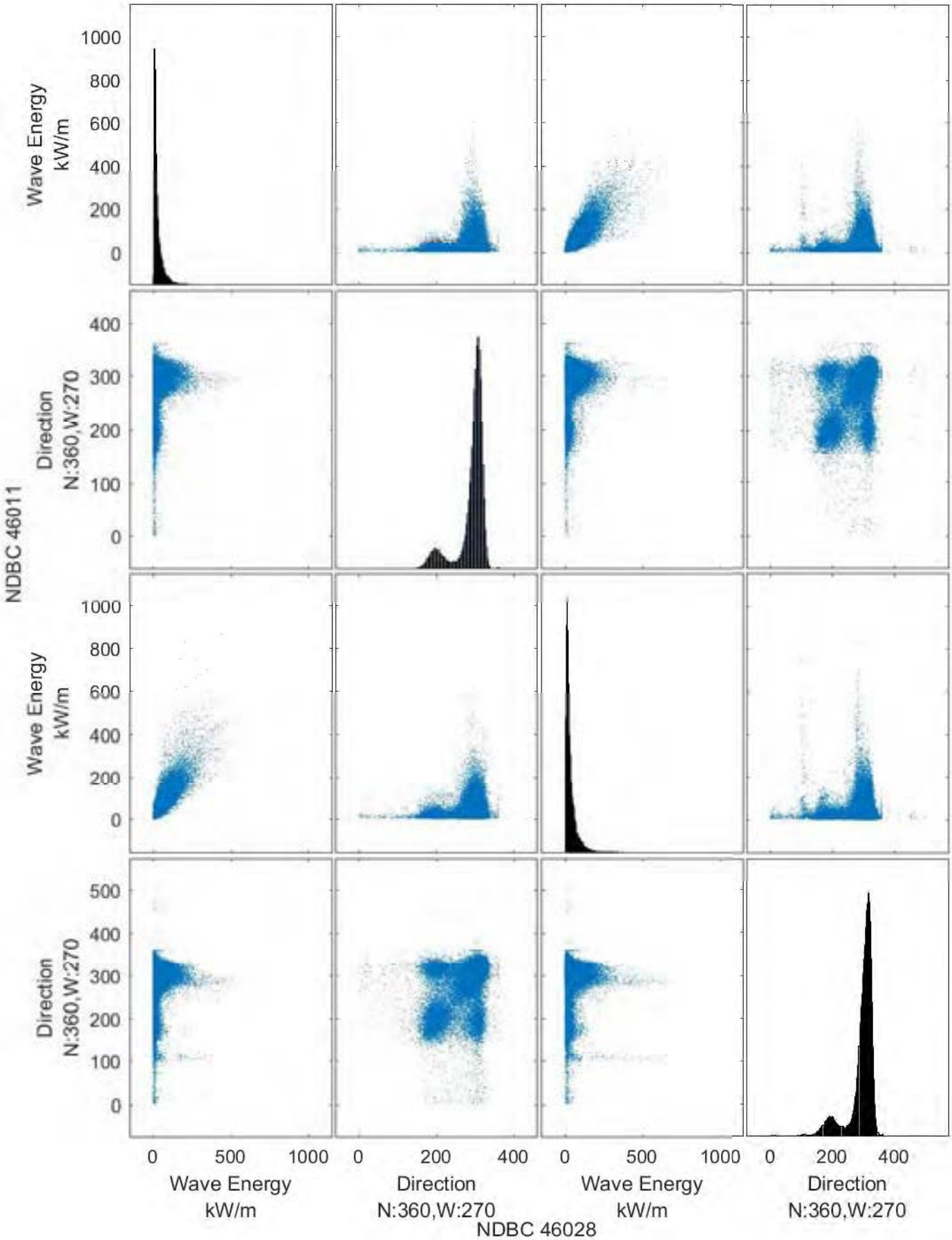


Figure C004: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46042.

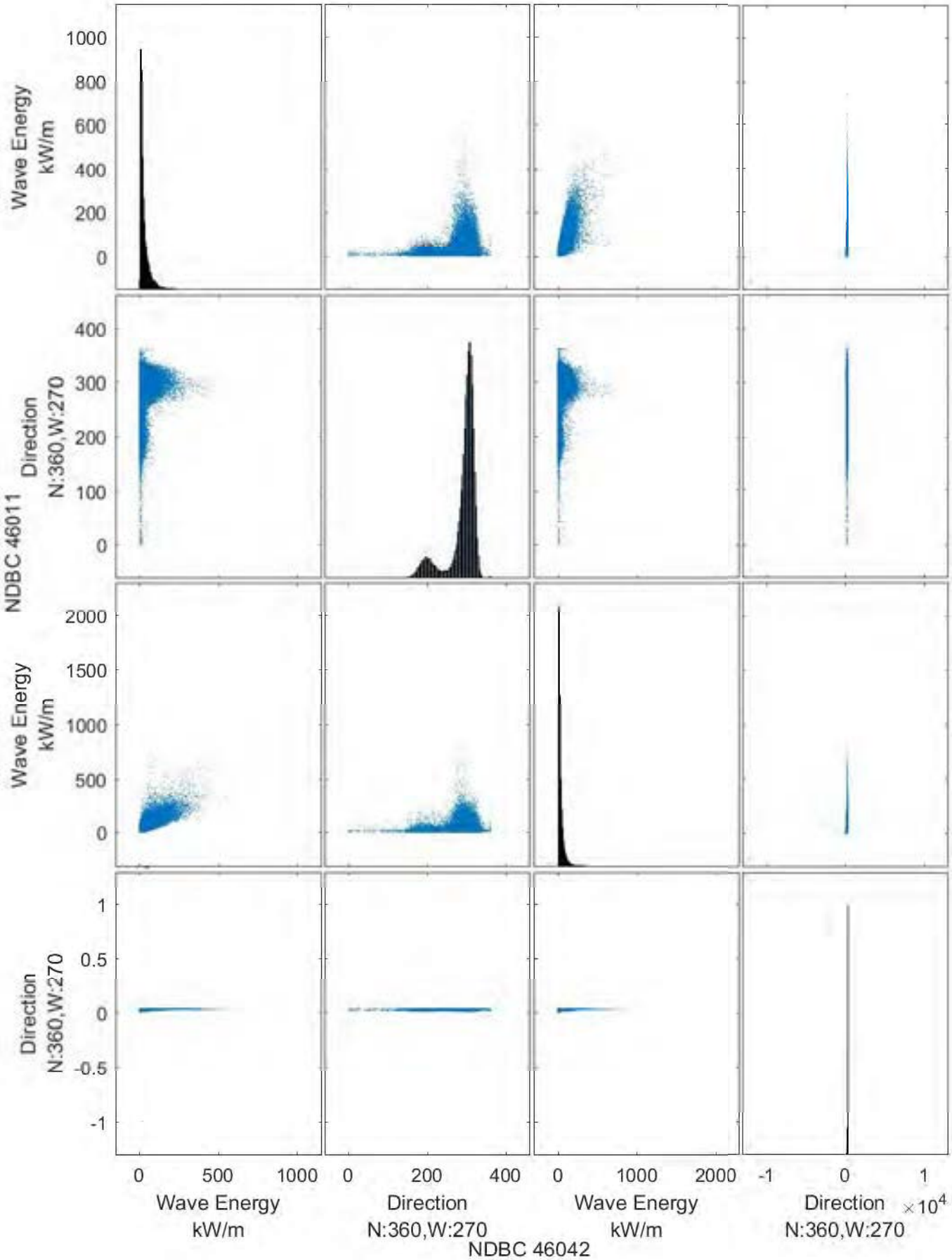


Figure C005: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46047.

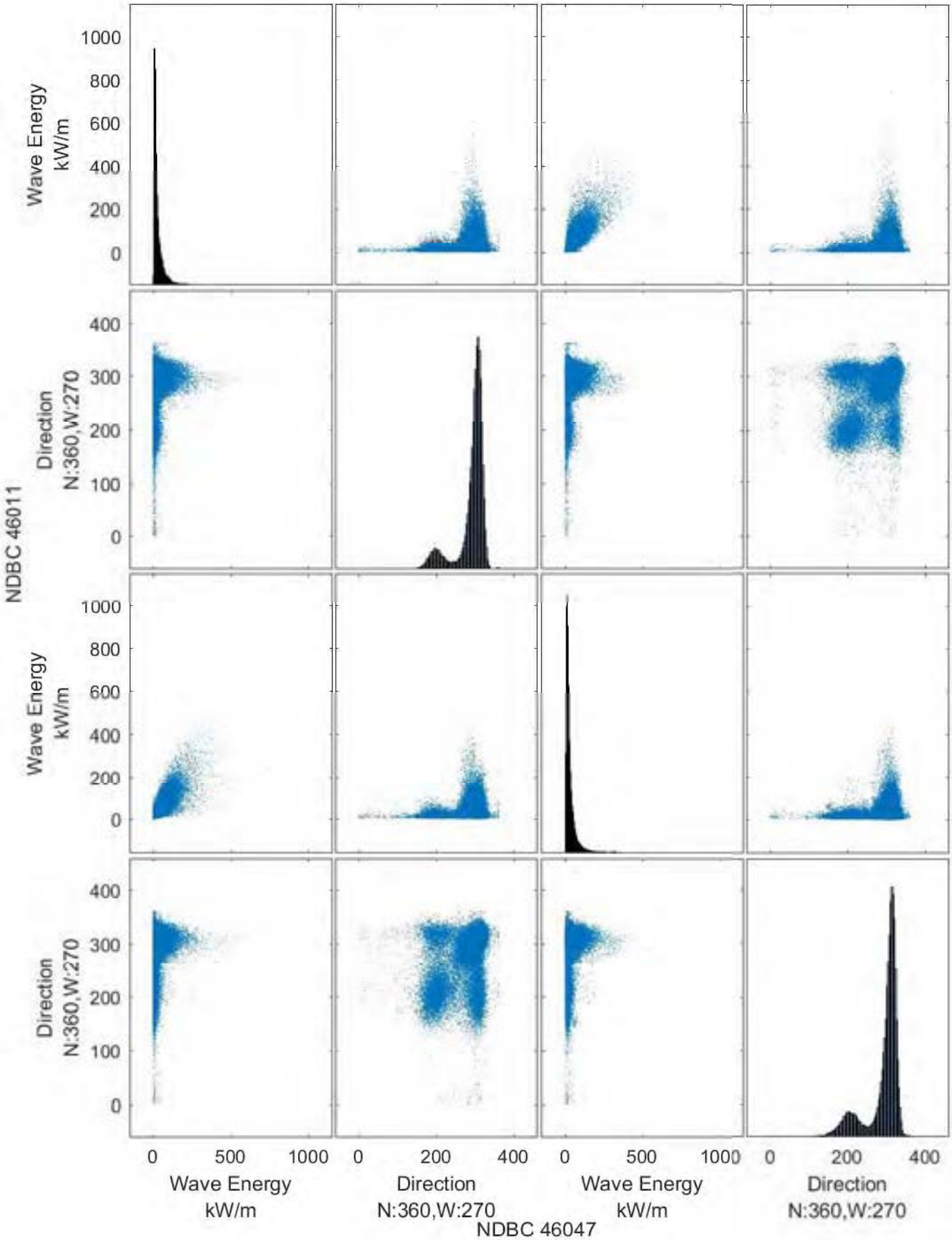


Figure C006: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46053.

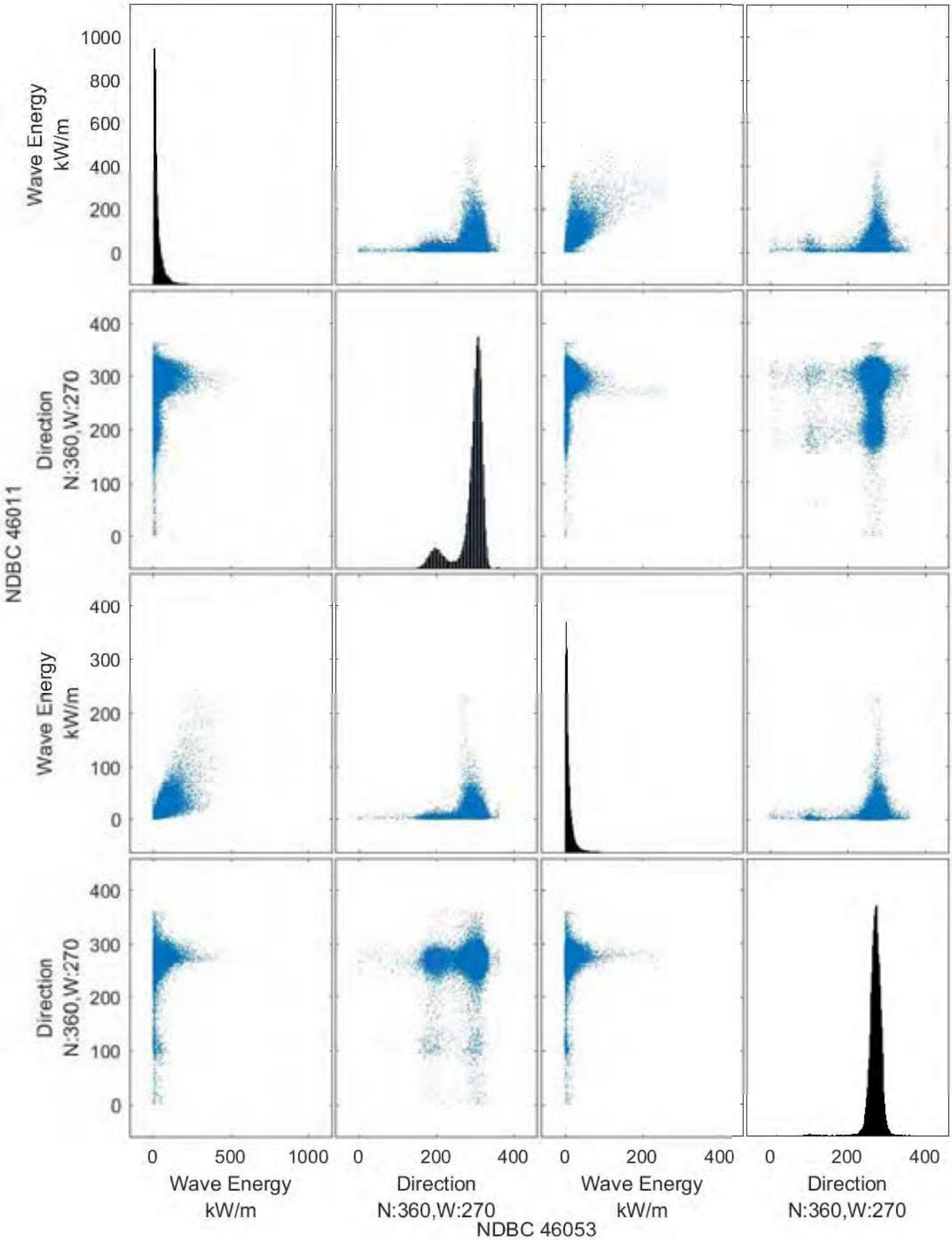


Figure C007: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46054.

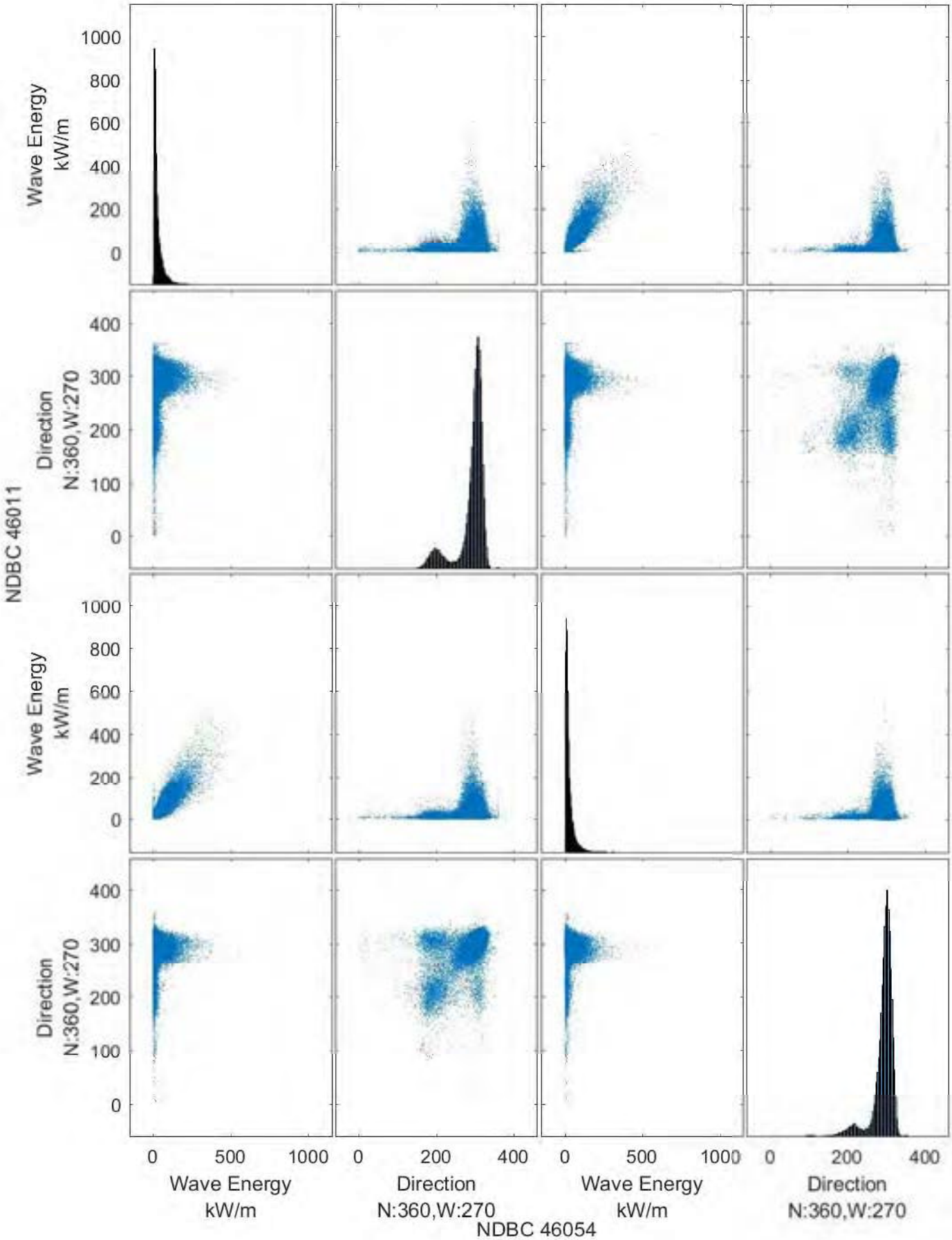


Figure C008: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46069.

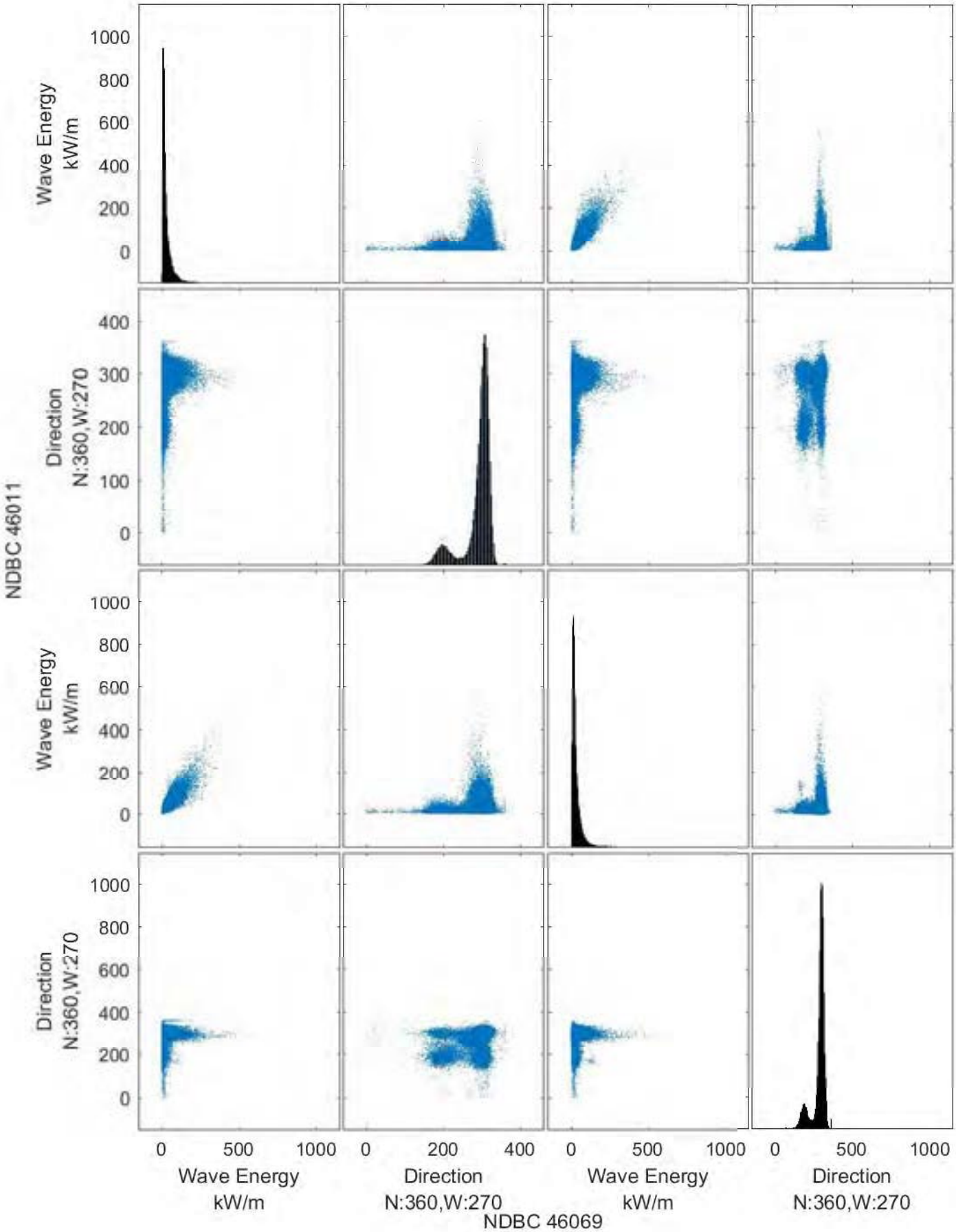


Figure C009: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46114.

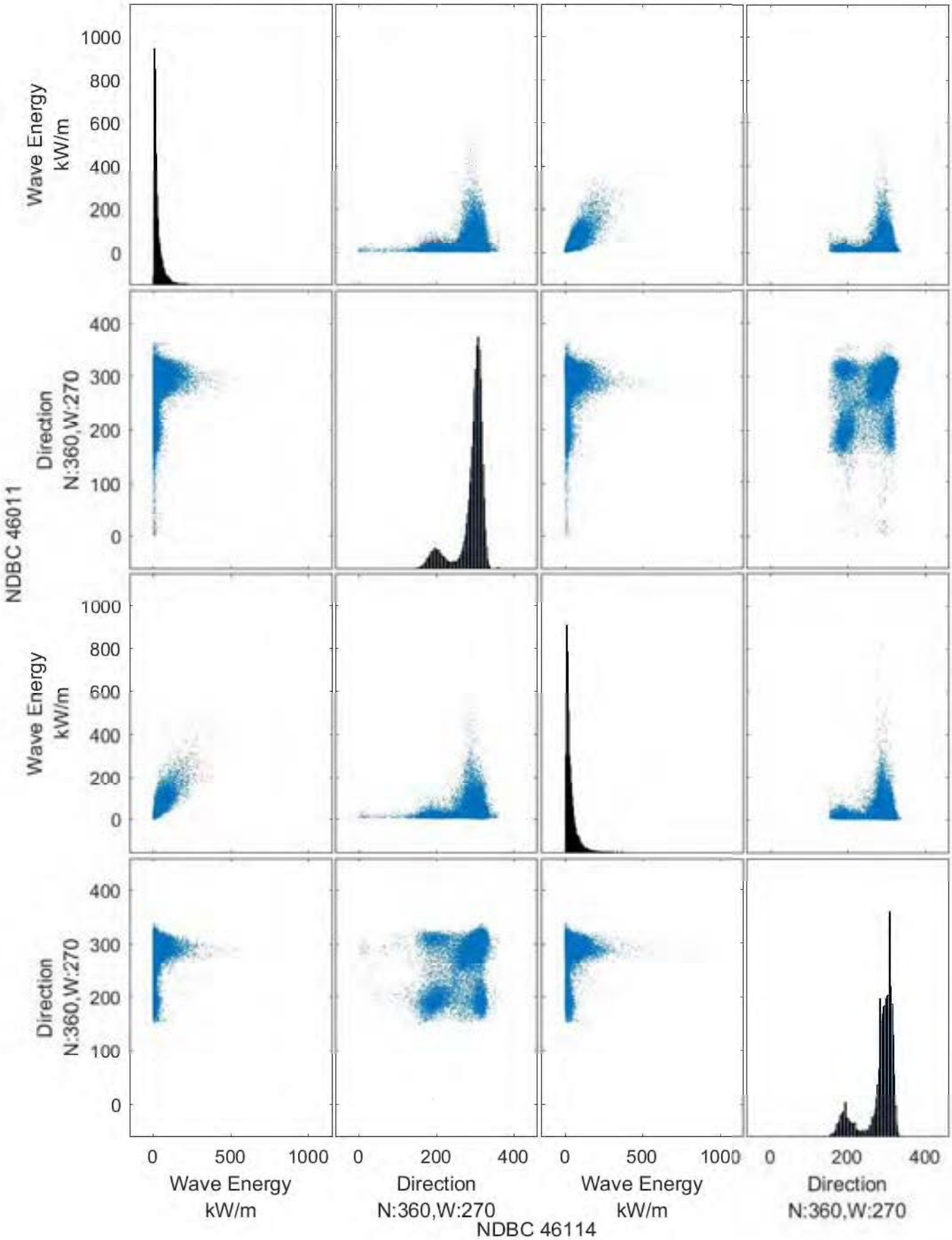


Figure C010: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46215.

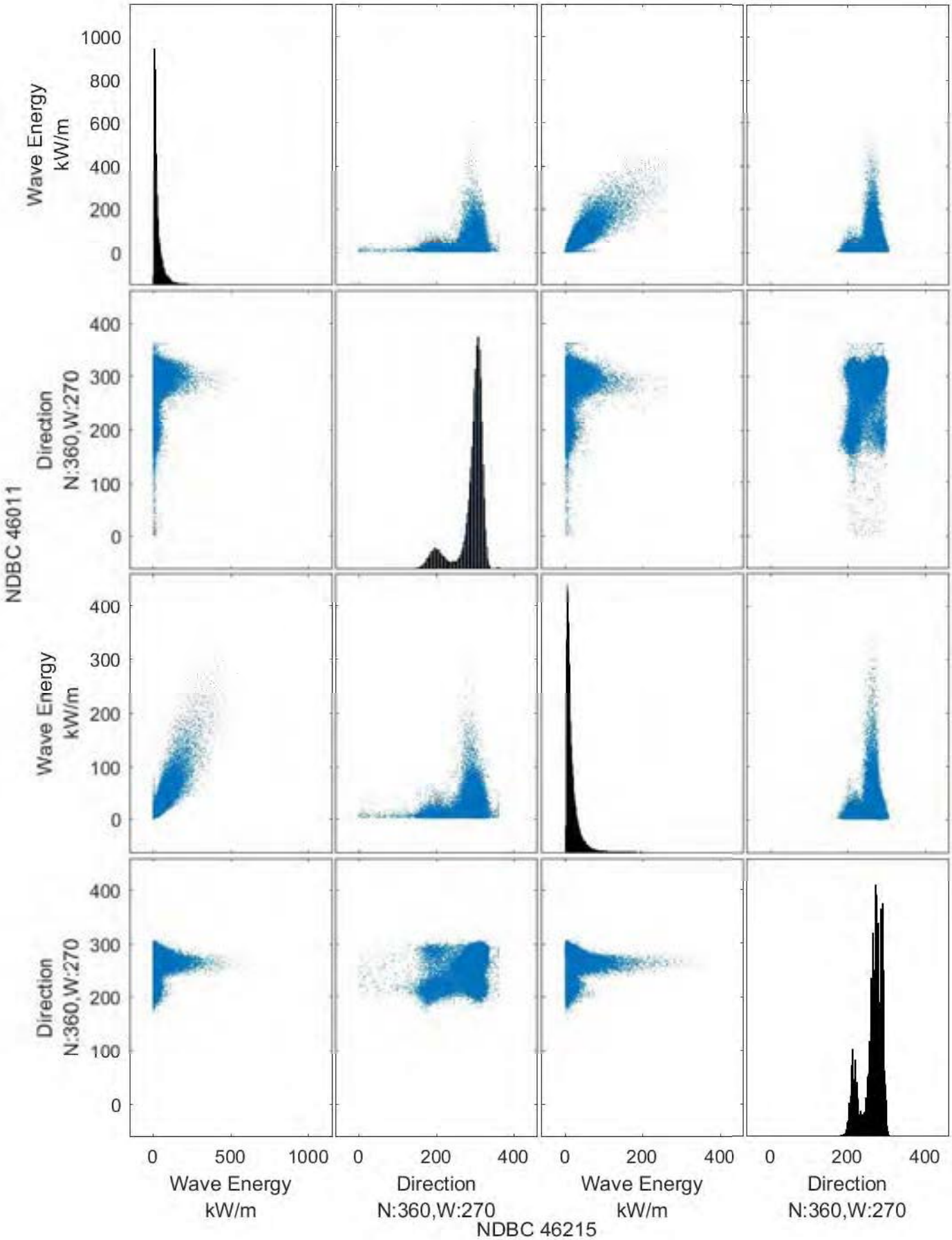


Figure C011: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46218.

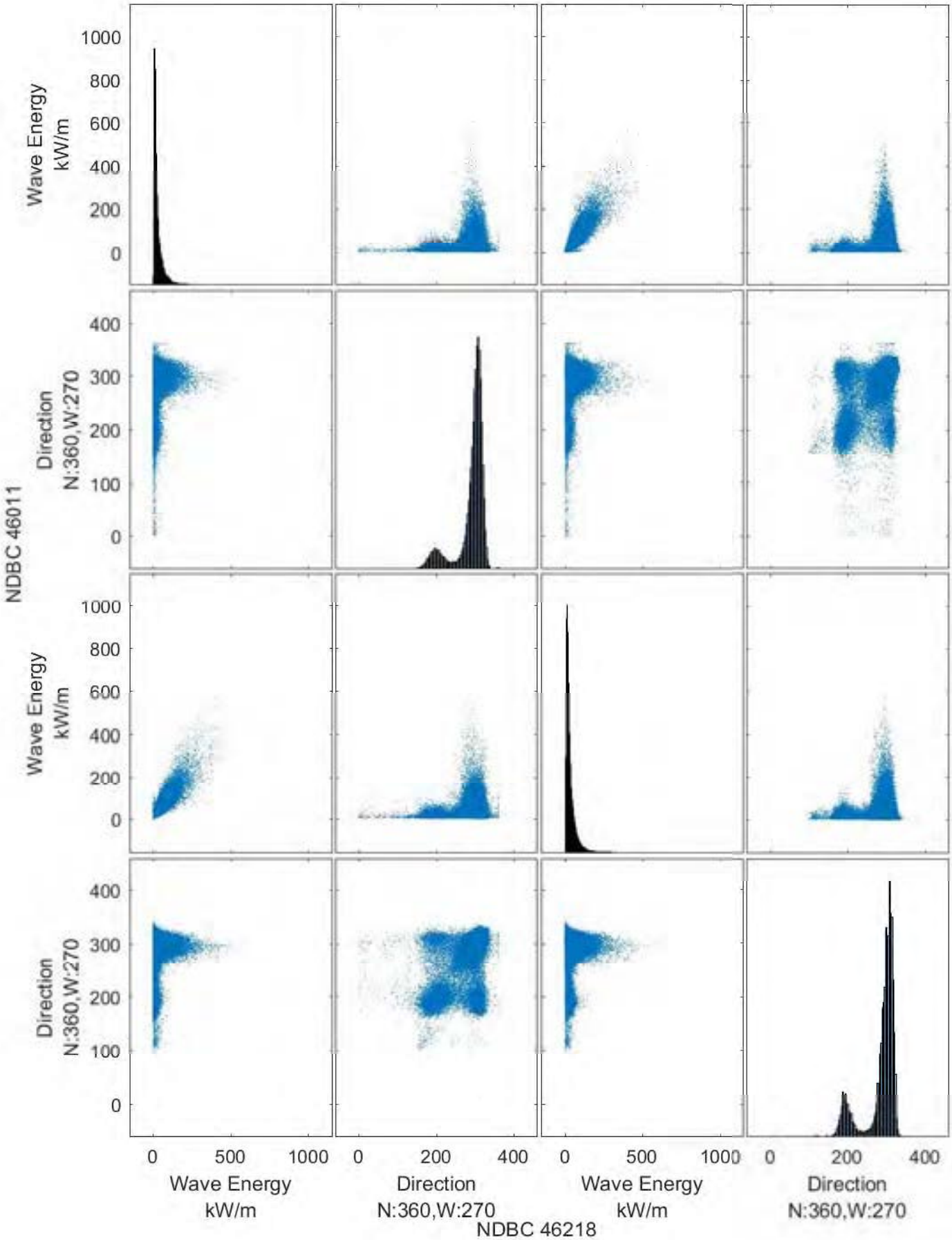


Figure C012: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46219.

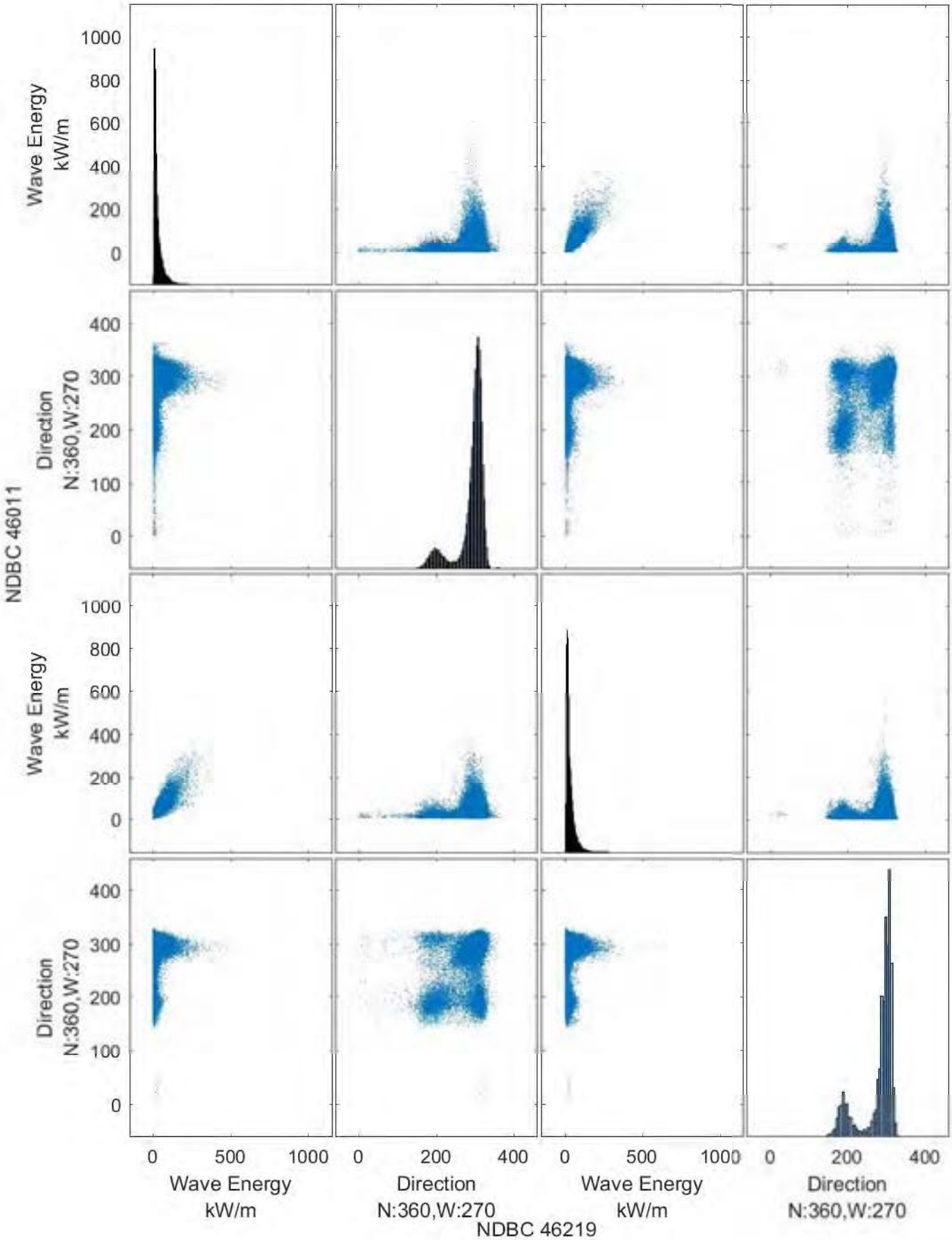


Figure C013: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46239.

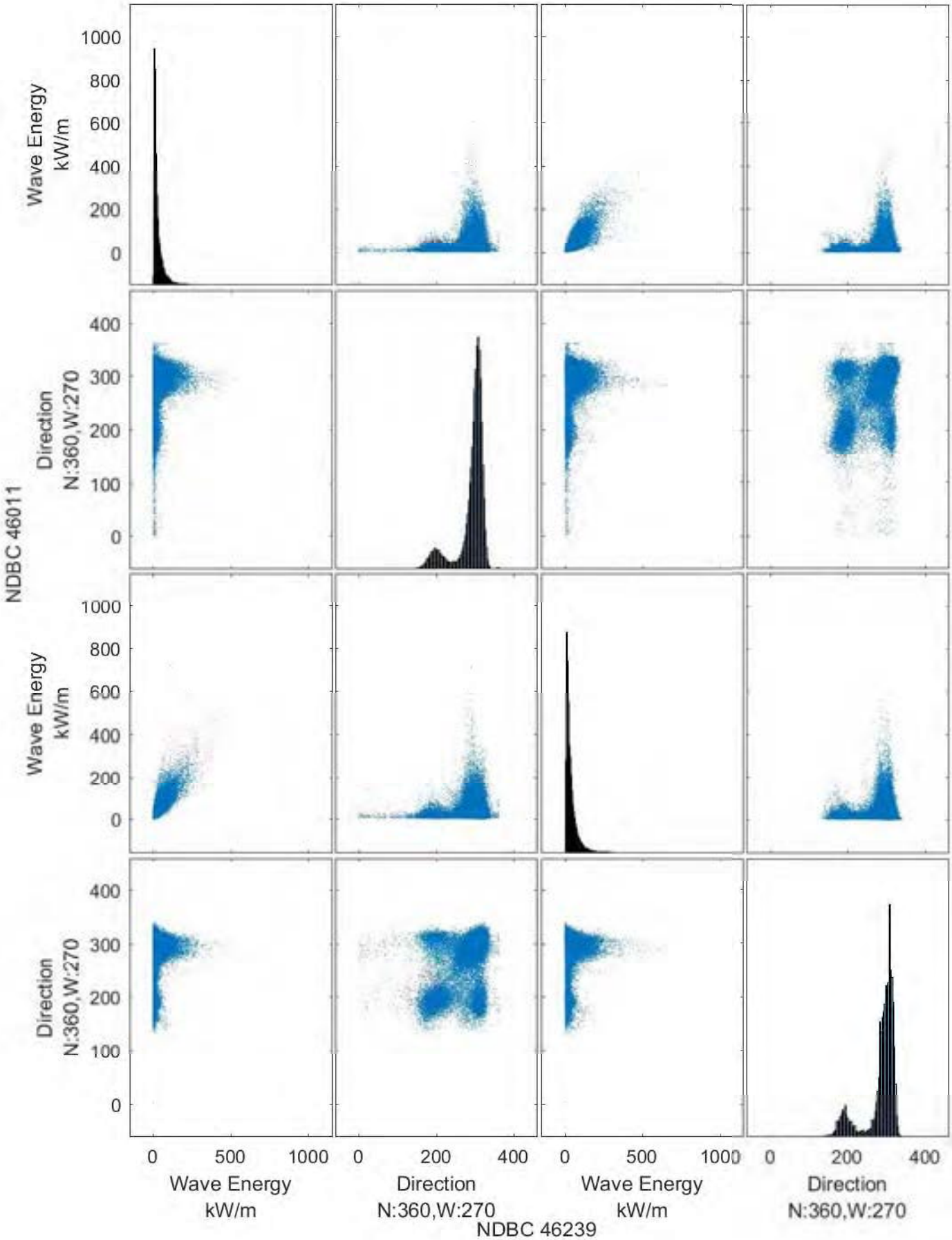


Figure C014: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46257.

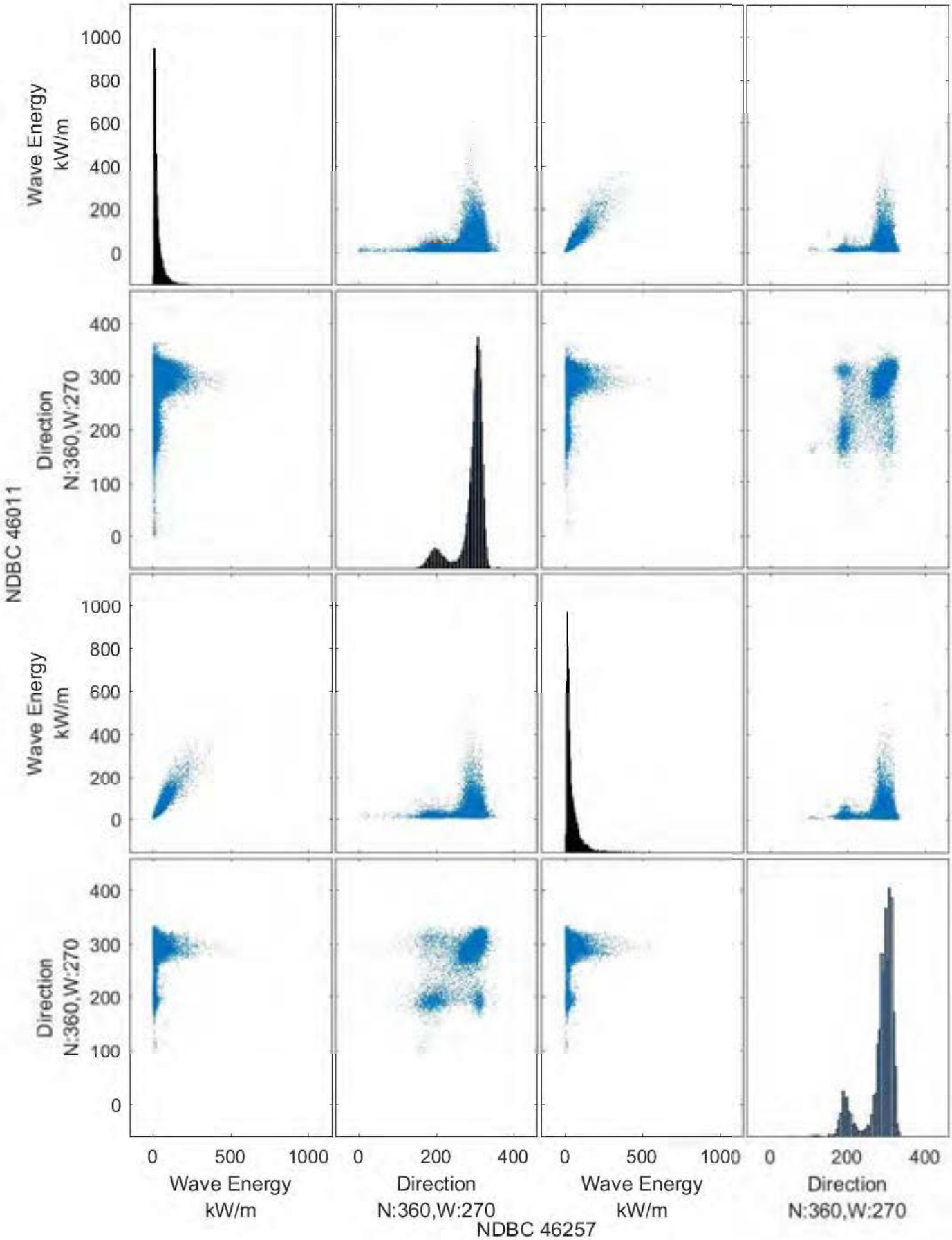


Figure C015: Cross Correlations for Wave Energyand Wave Direction for NDBC 46011 and NDBC 46259.

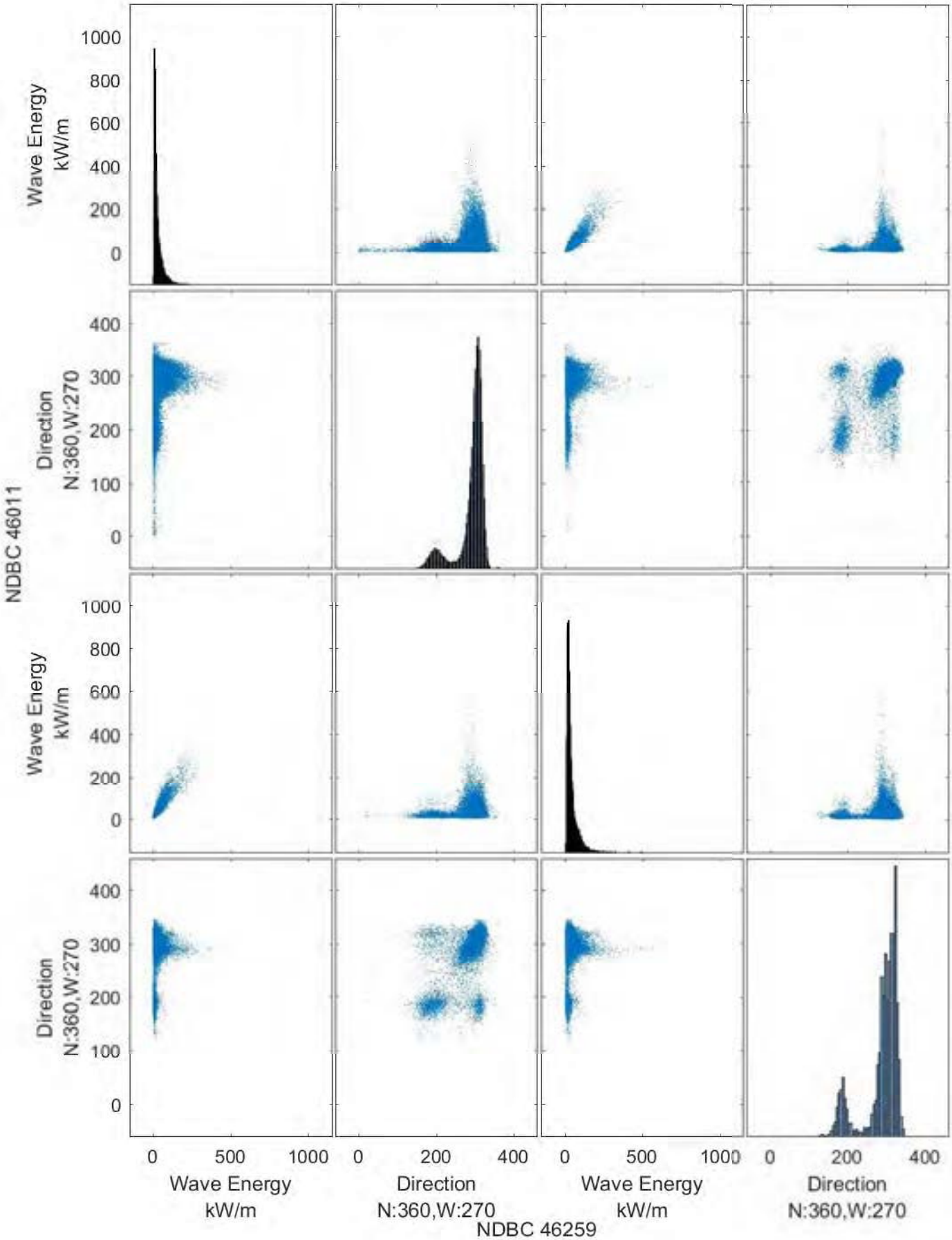


Figure C016: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46012.

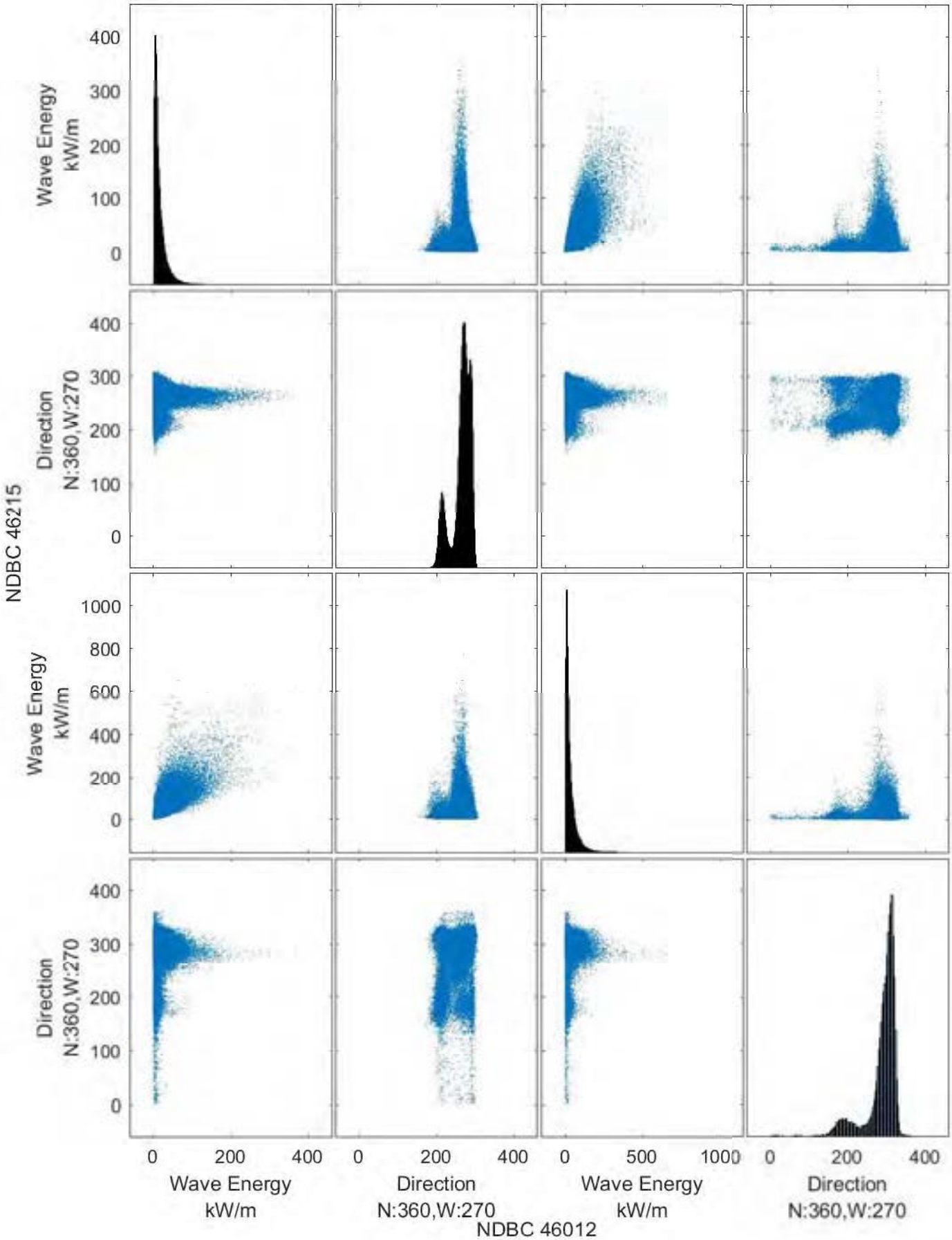


Figure C017: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46023.

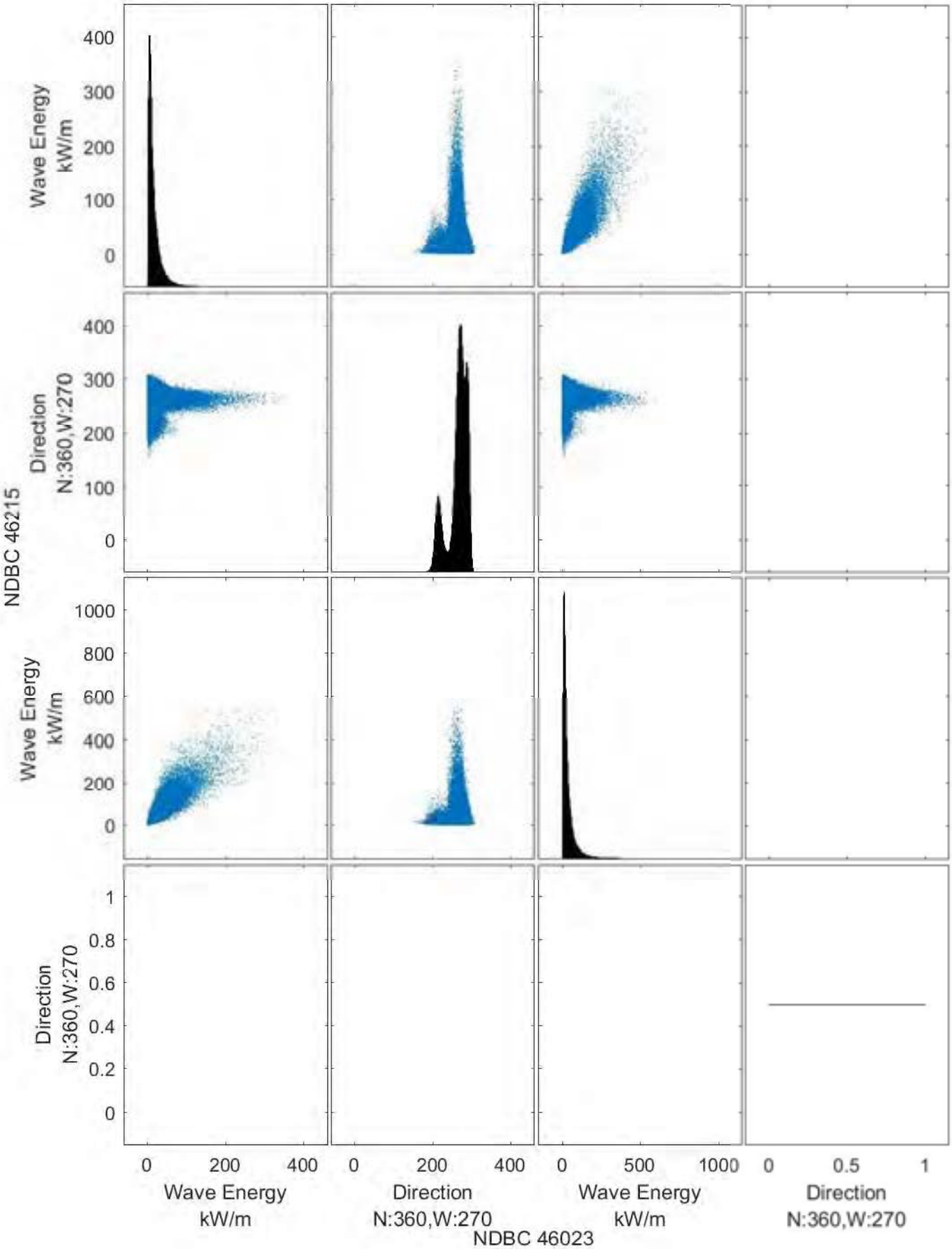


Figure C018: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46028.

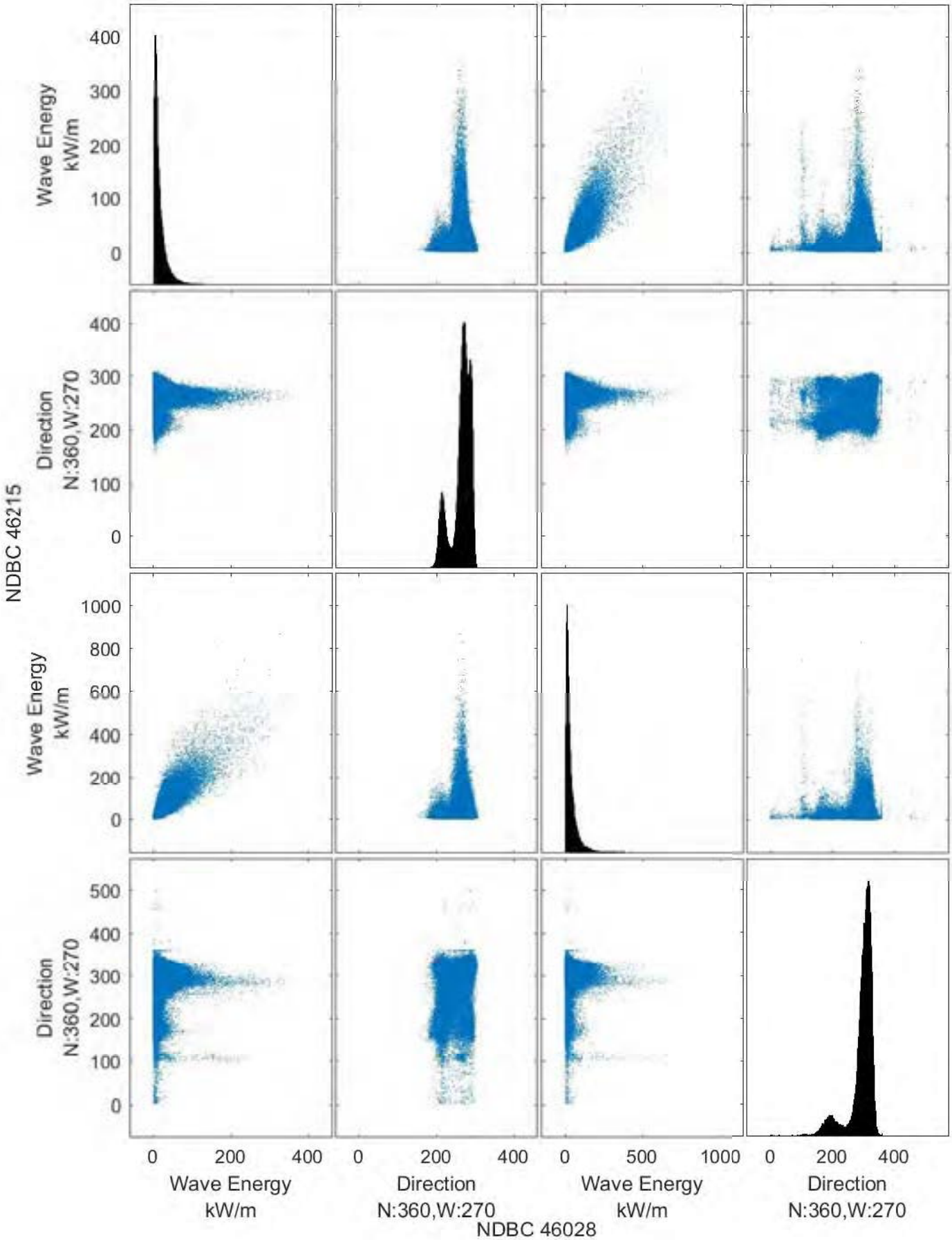


Figure C019: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46042.

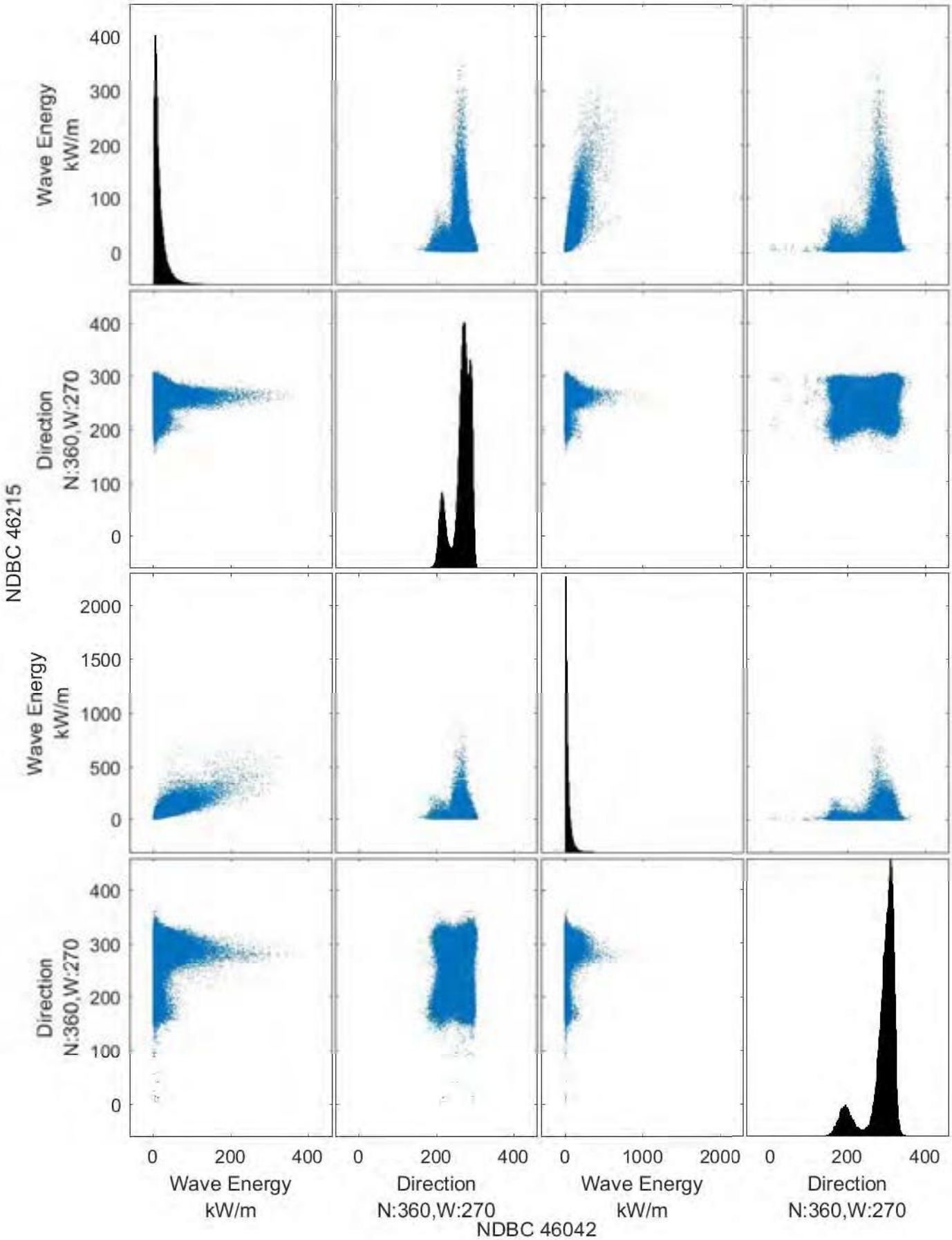


Figure C020: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46047.

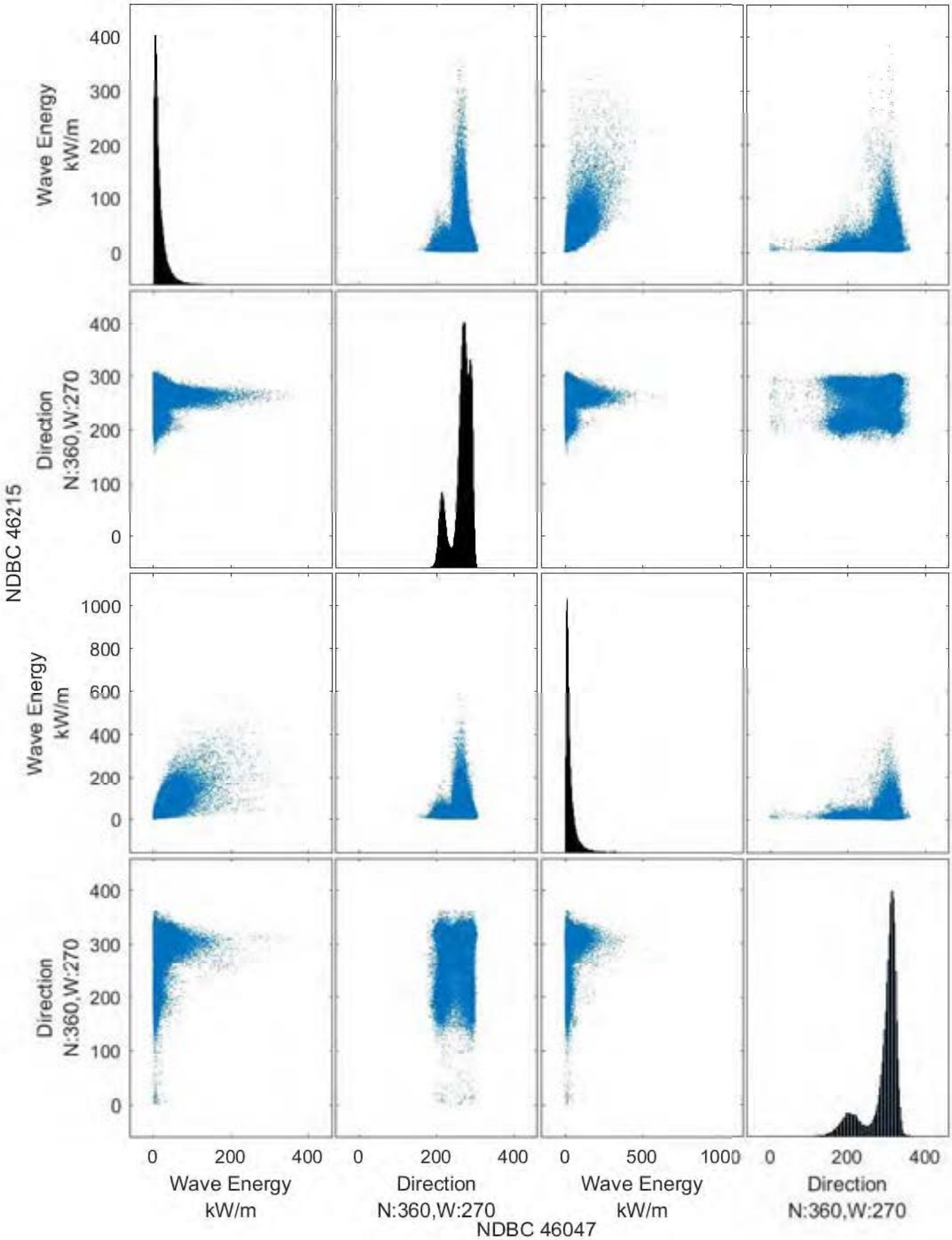


Figure C021: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46053.

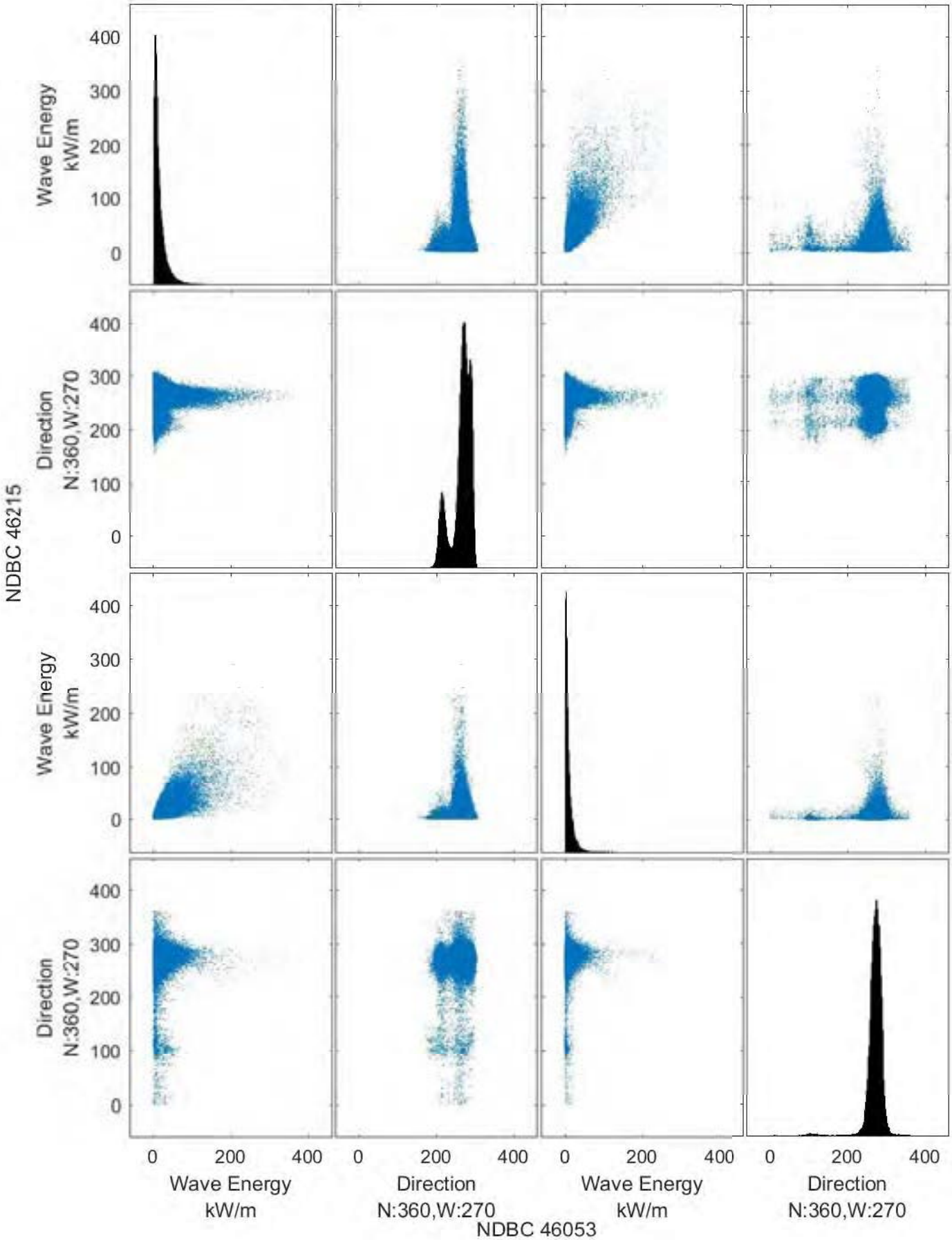


Figure C022: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46054.

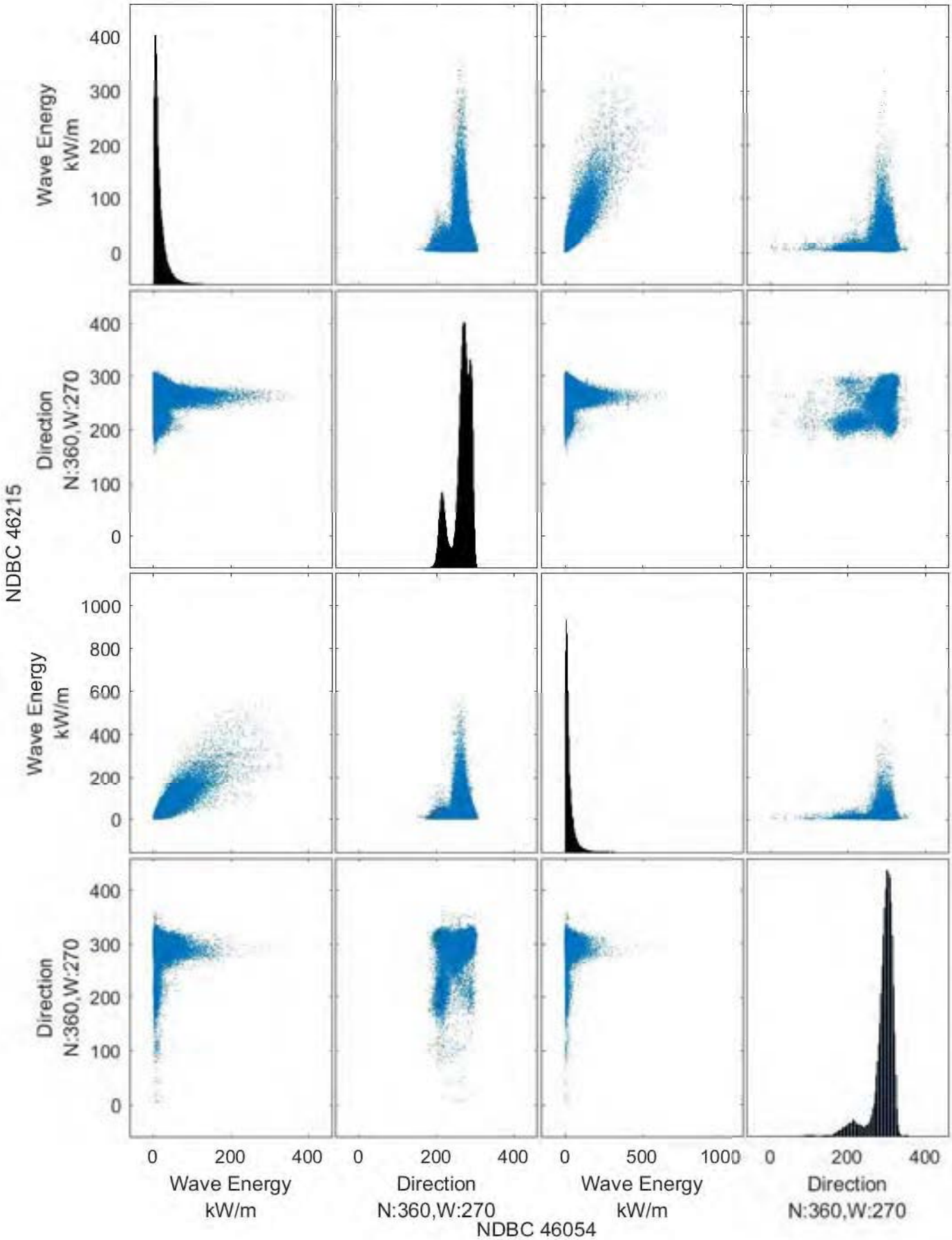


Figure C023: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46069.

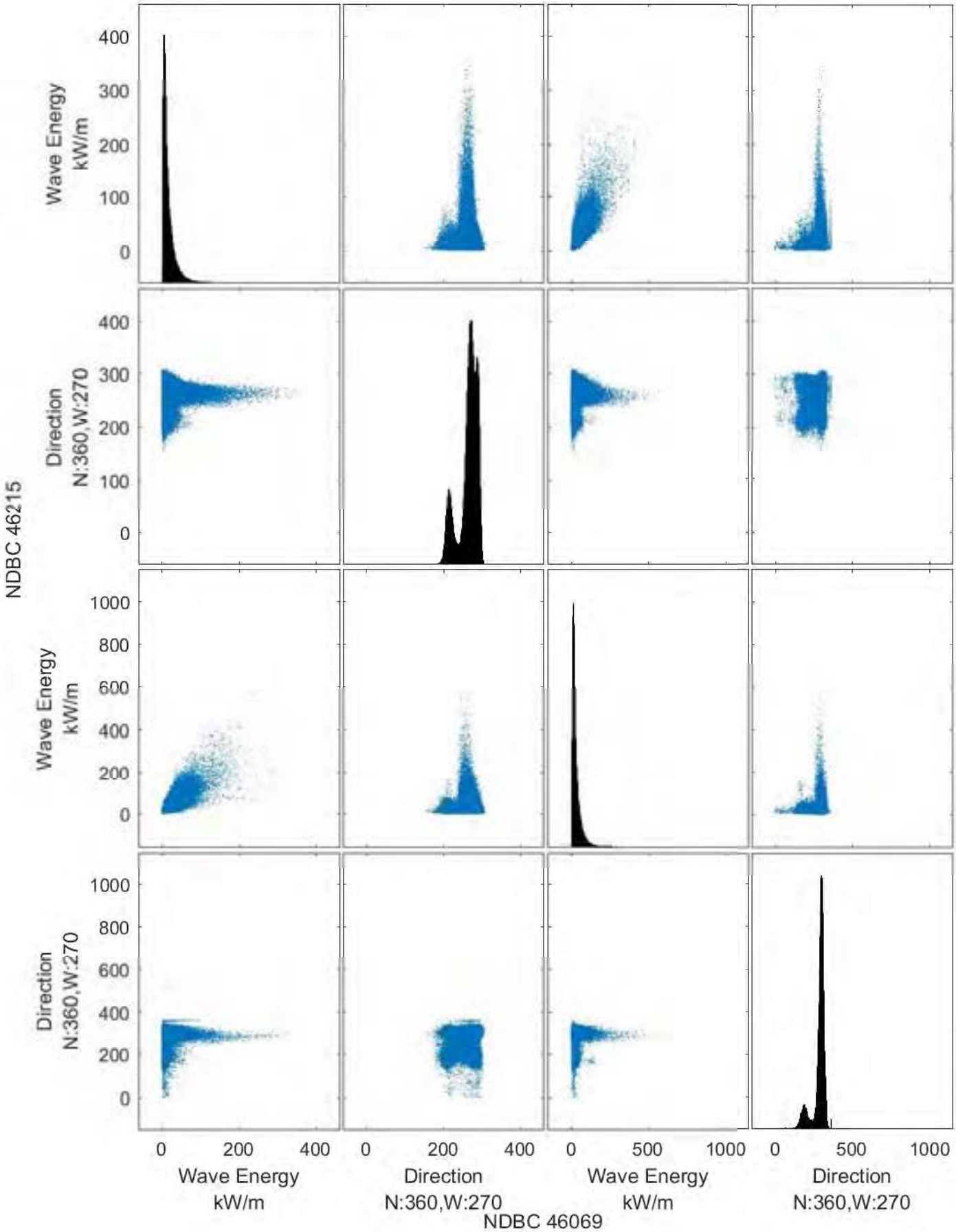


Figure C024: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46114.

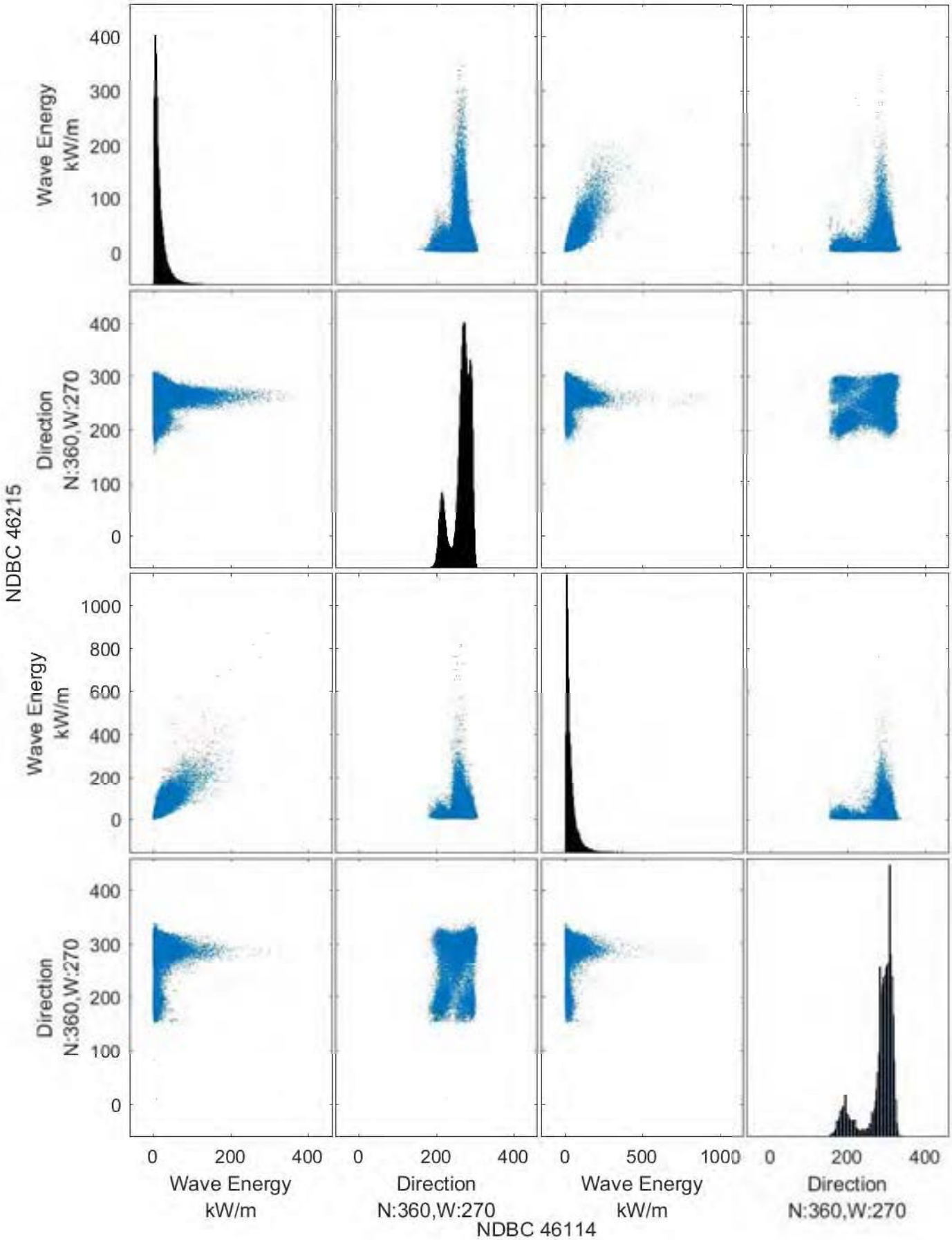


Figure C025: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46218.

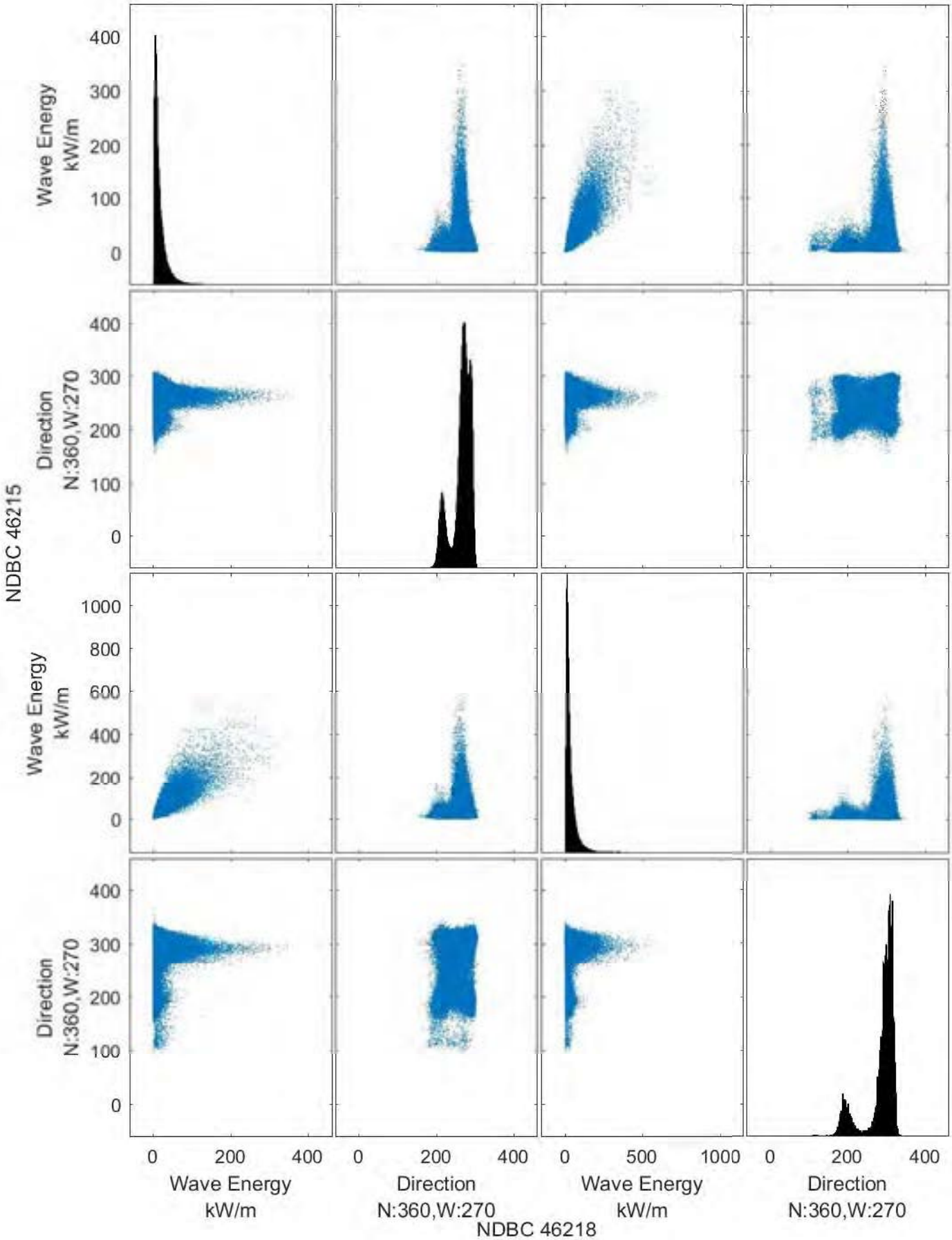


Figure C026: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46219.

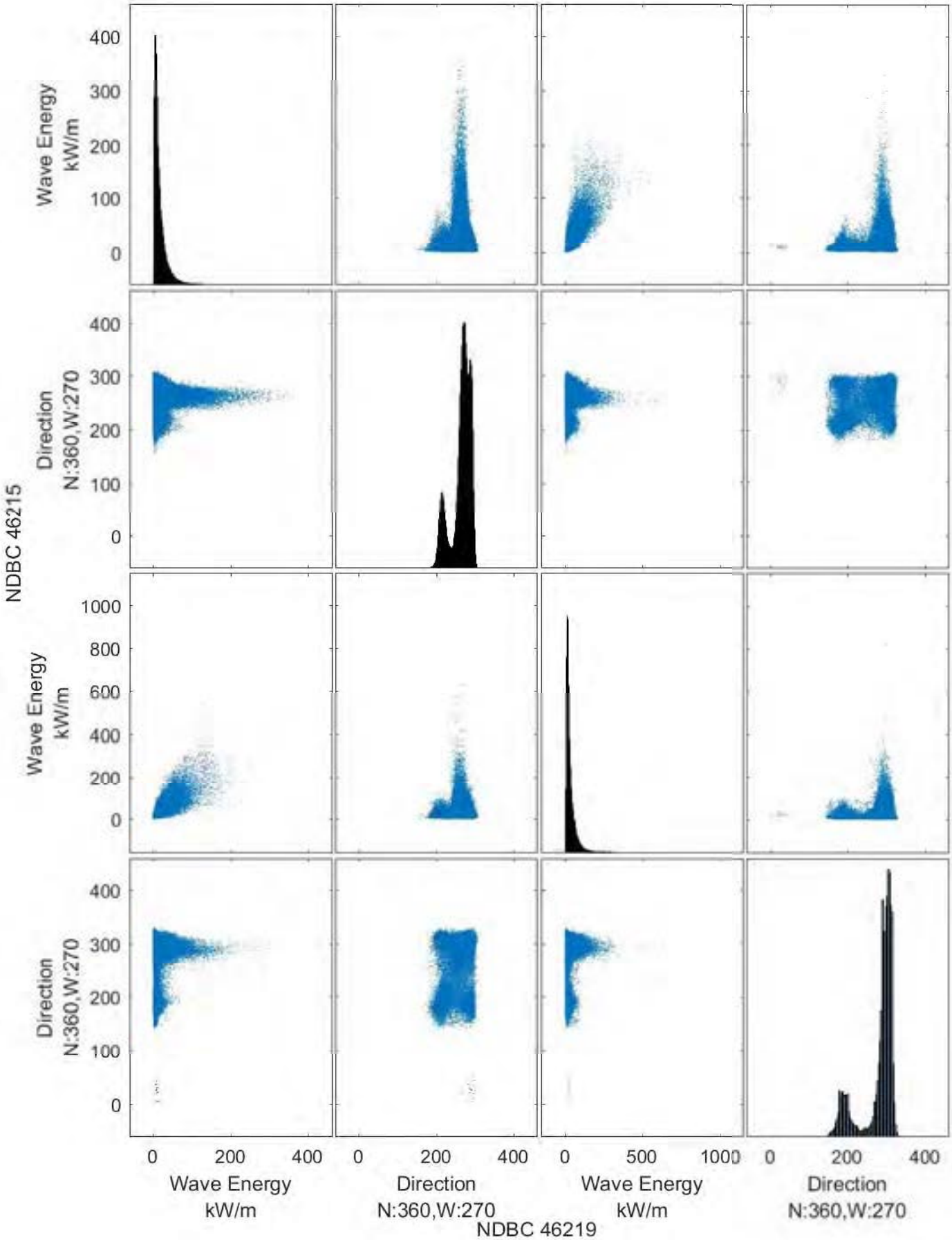


Figure C027: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46239.

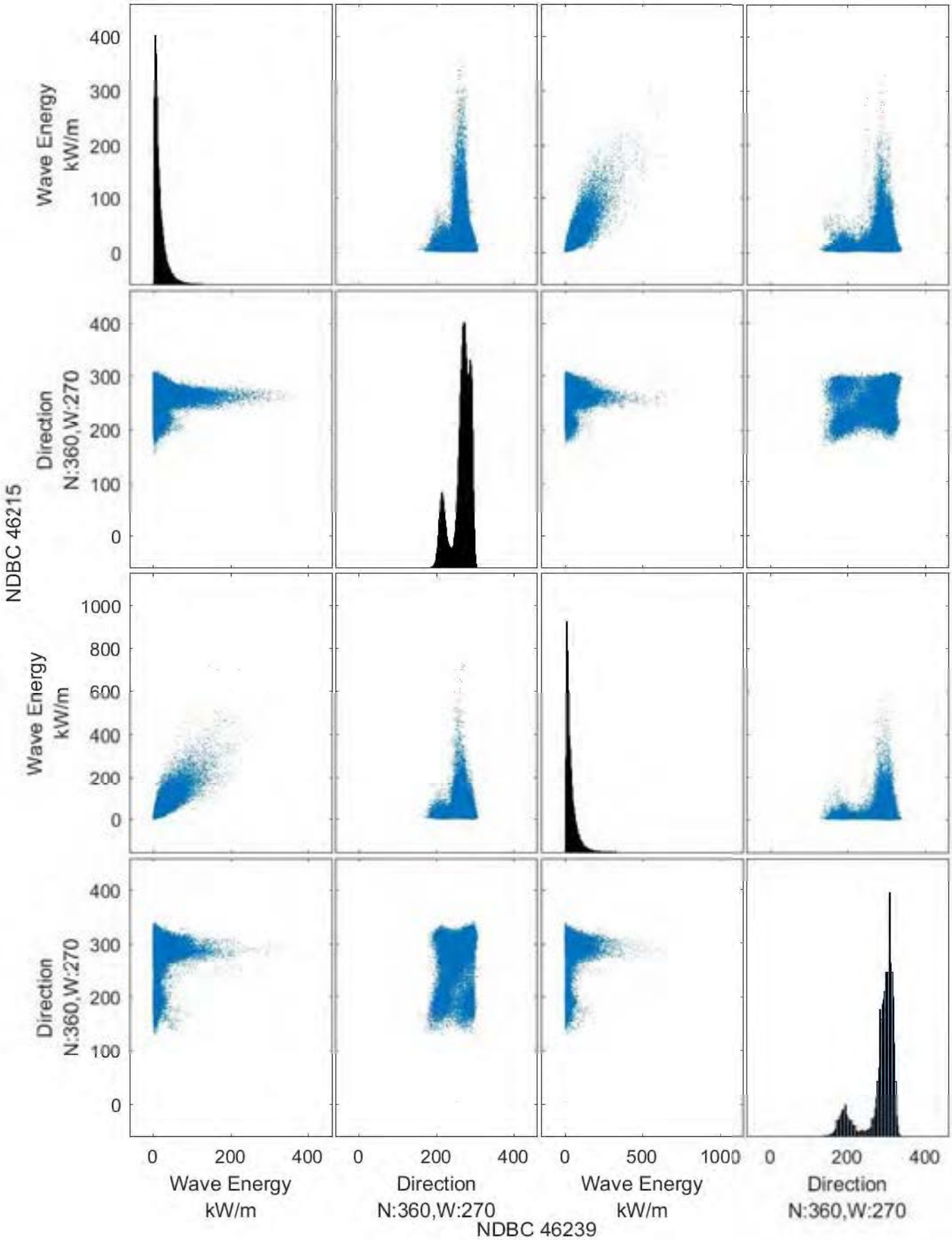


Figure C028: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46257.

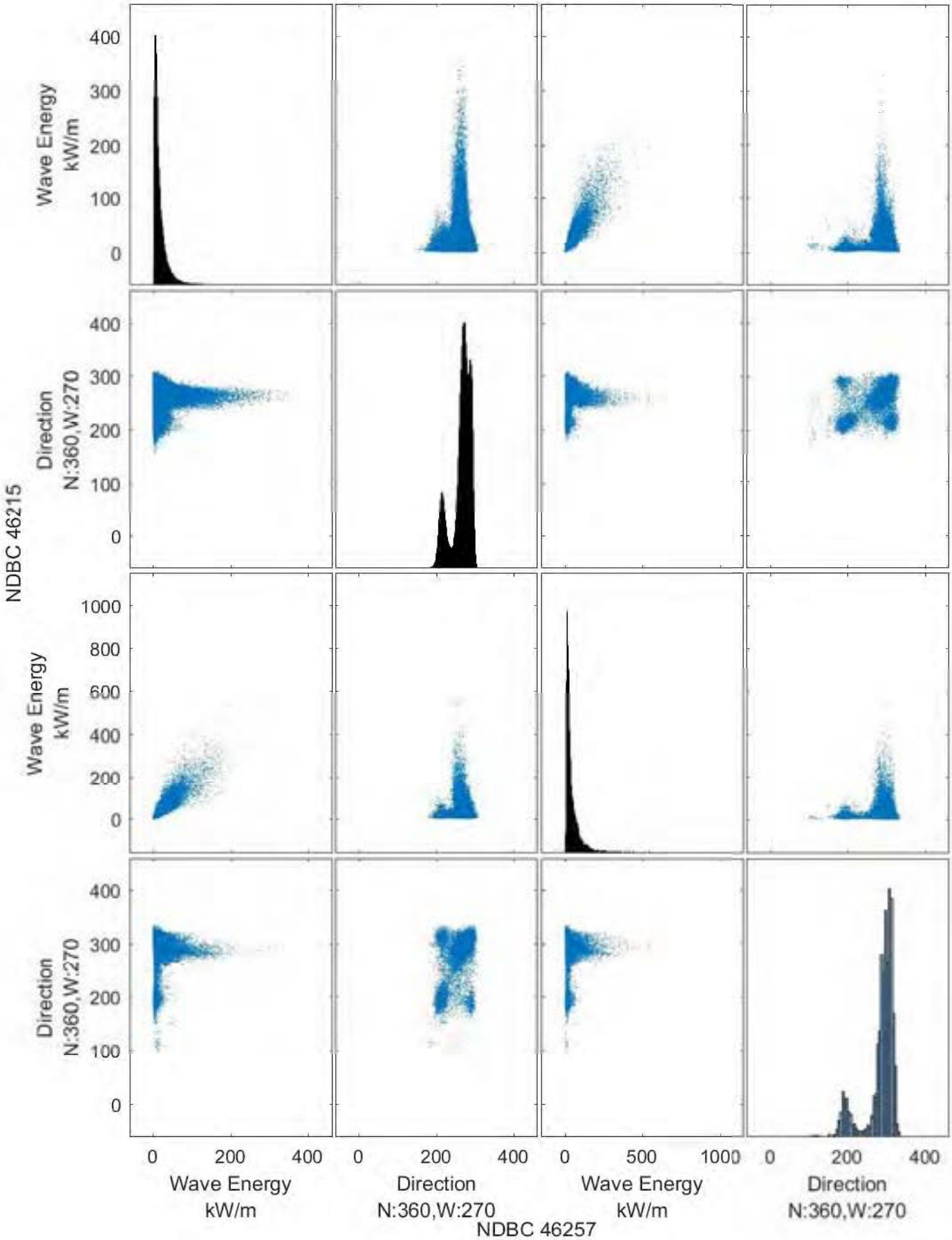


Figure C029: Cross Correlations for Wave Energyand Wave Direction for NDBC 46215 and NDBC 46259.

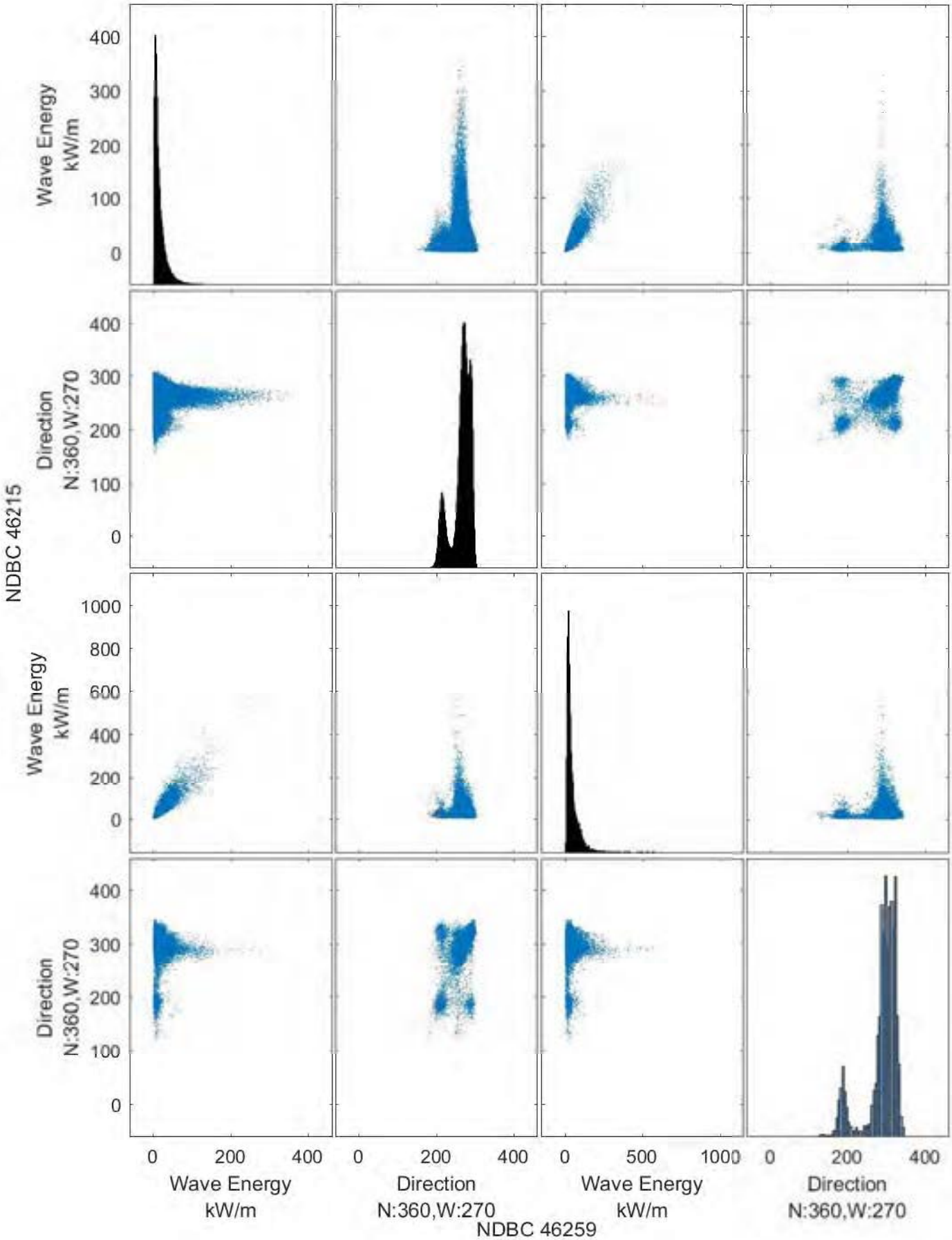


Figure C030: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46023.

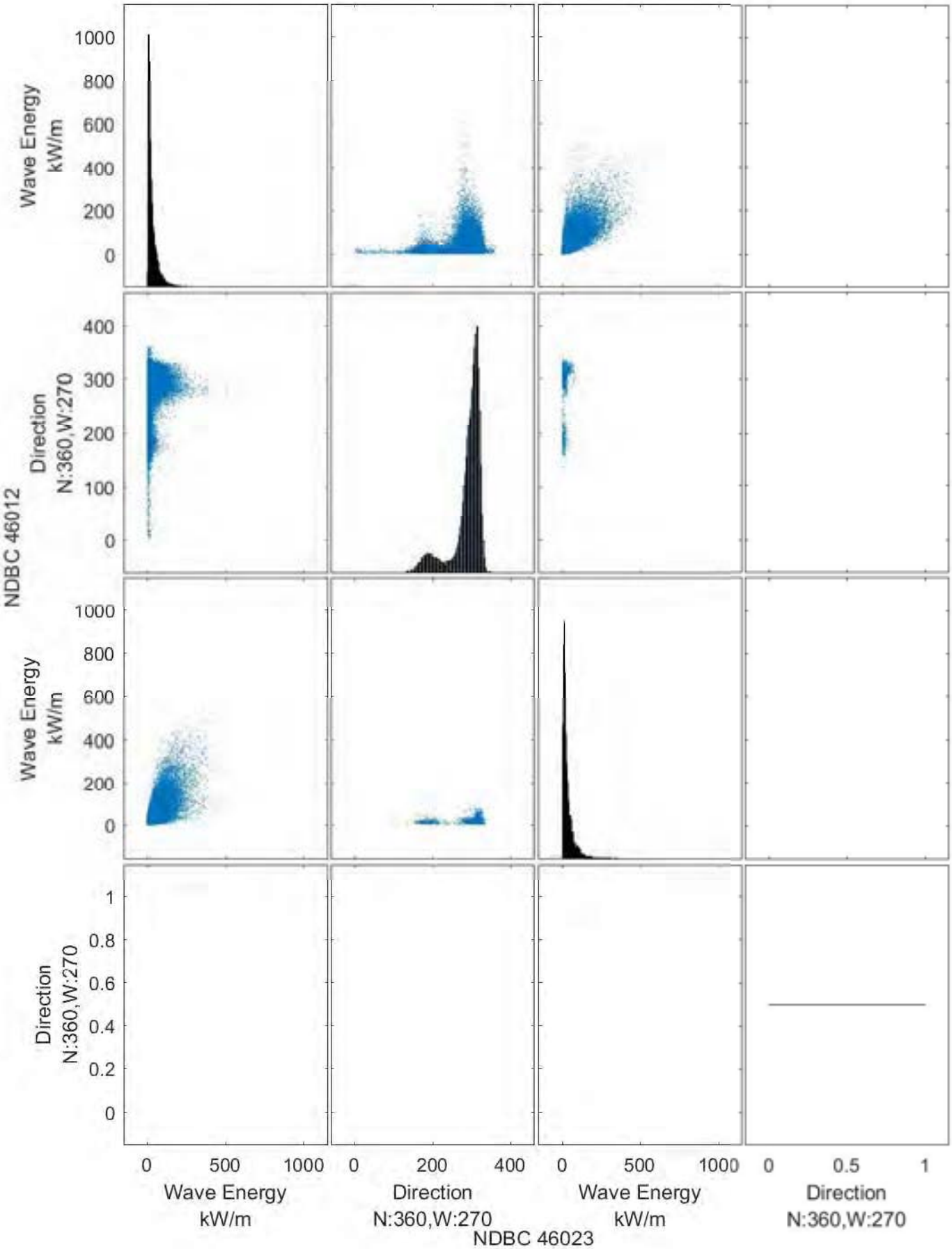


Figure C031: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46028.

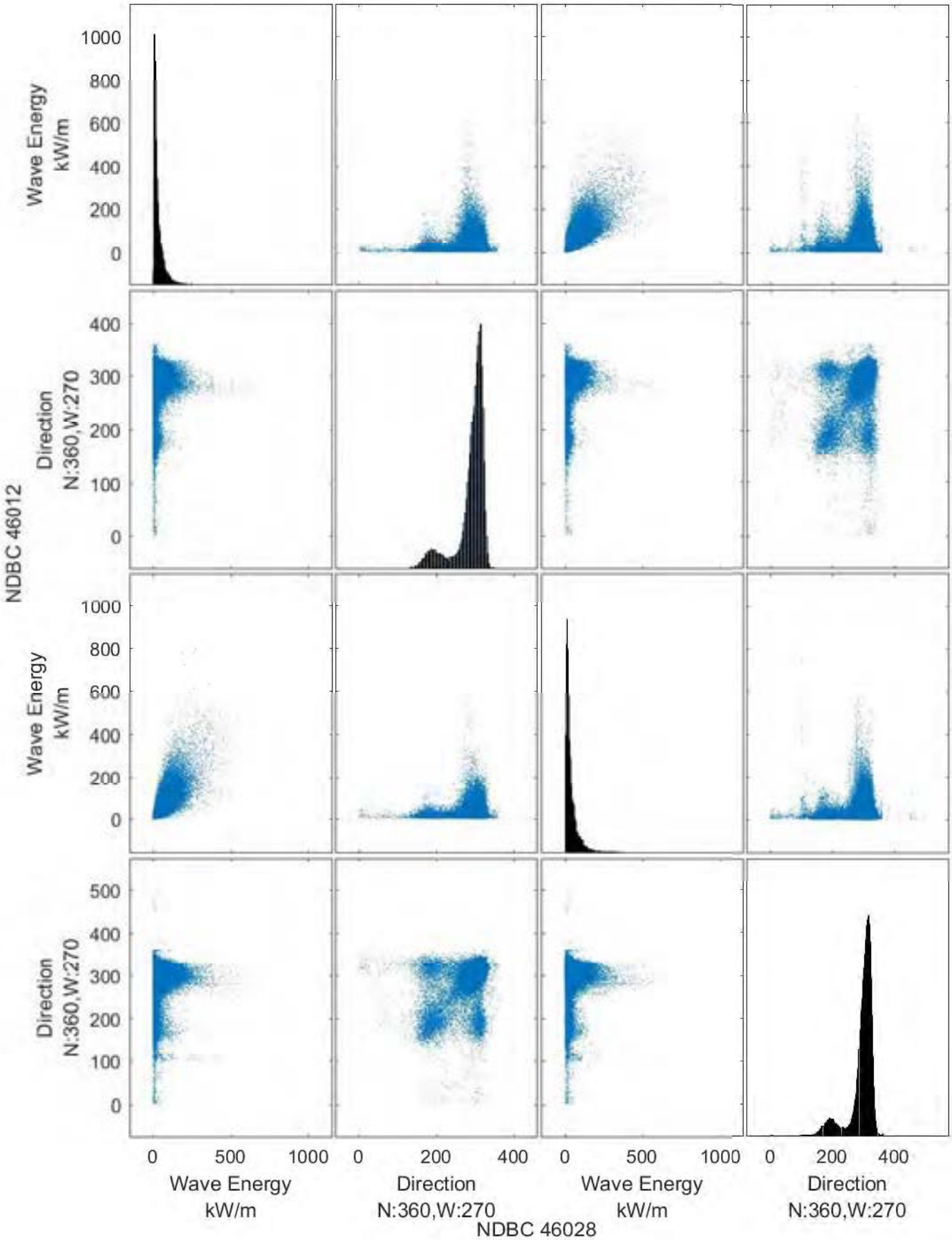


Figure C032: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46042.

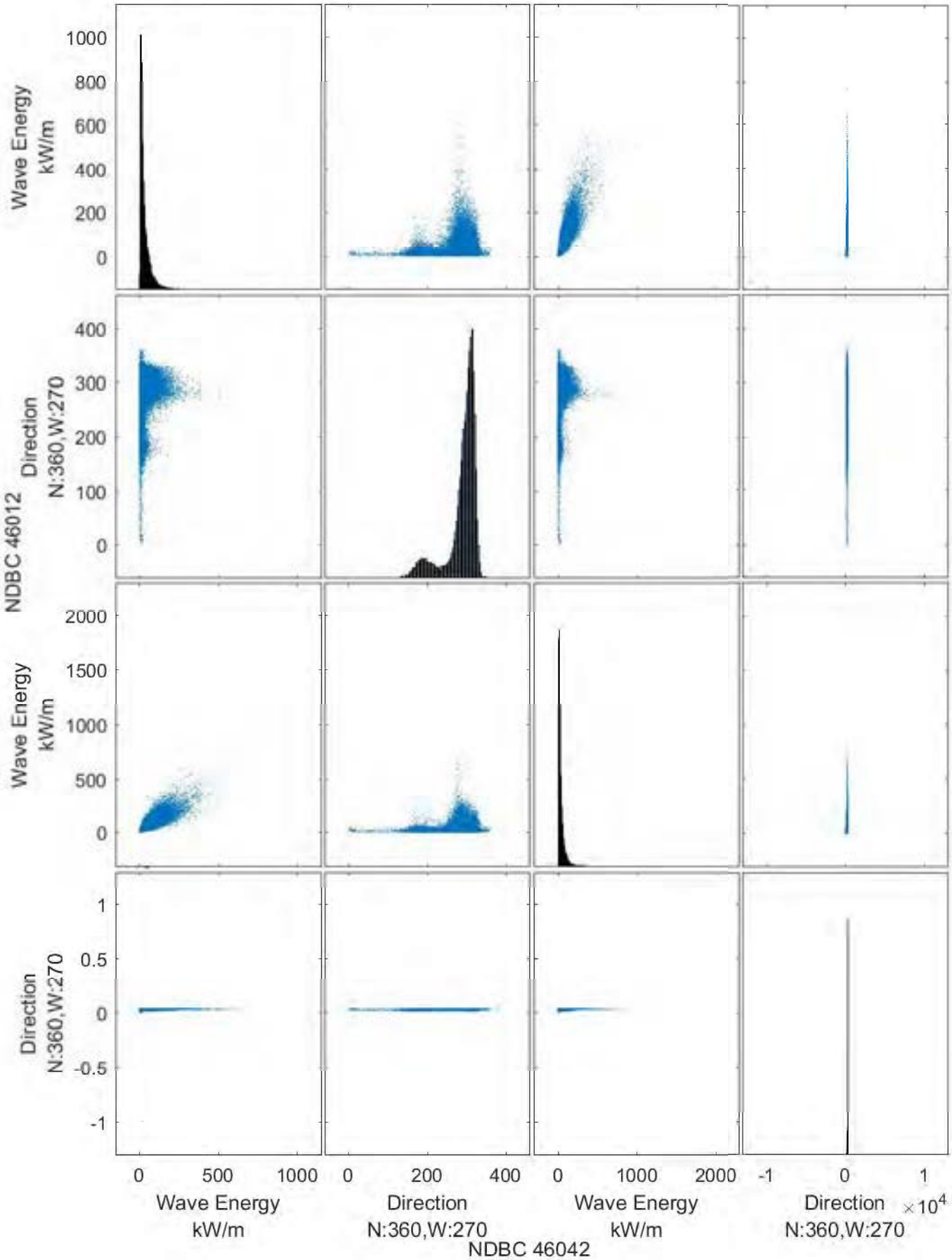


Figure C033: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46047.

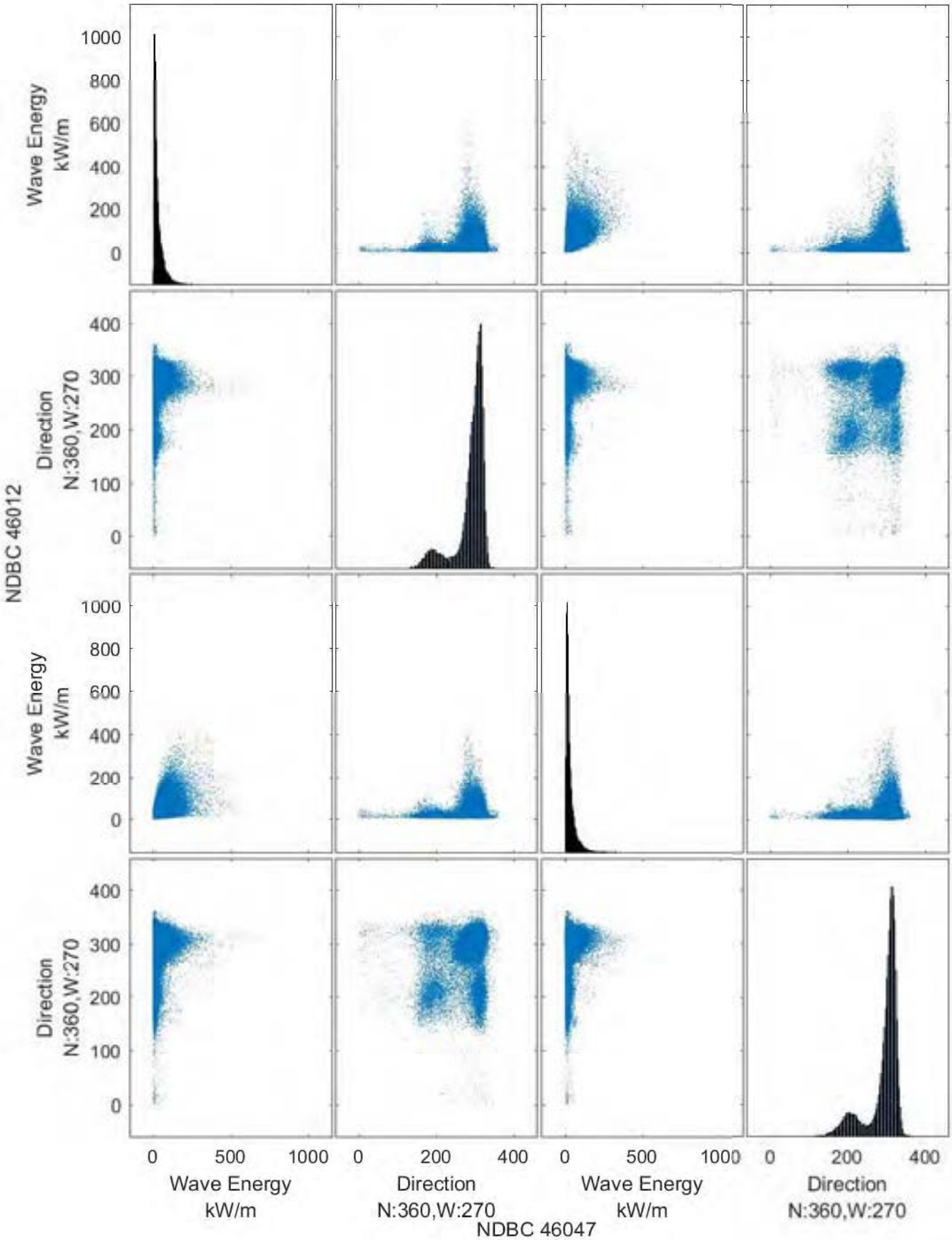


Figure C034: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46053.

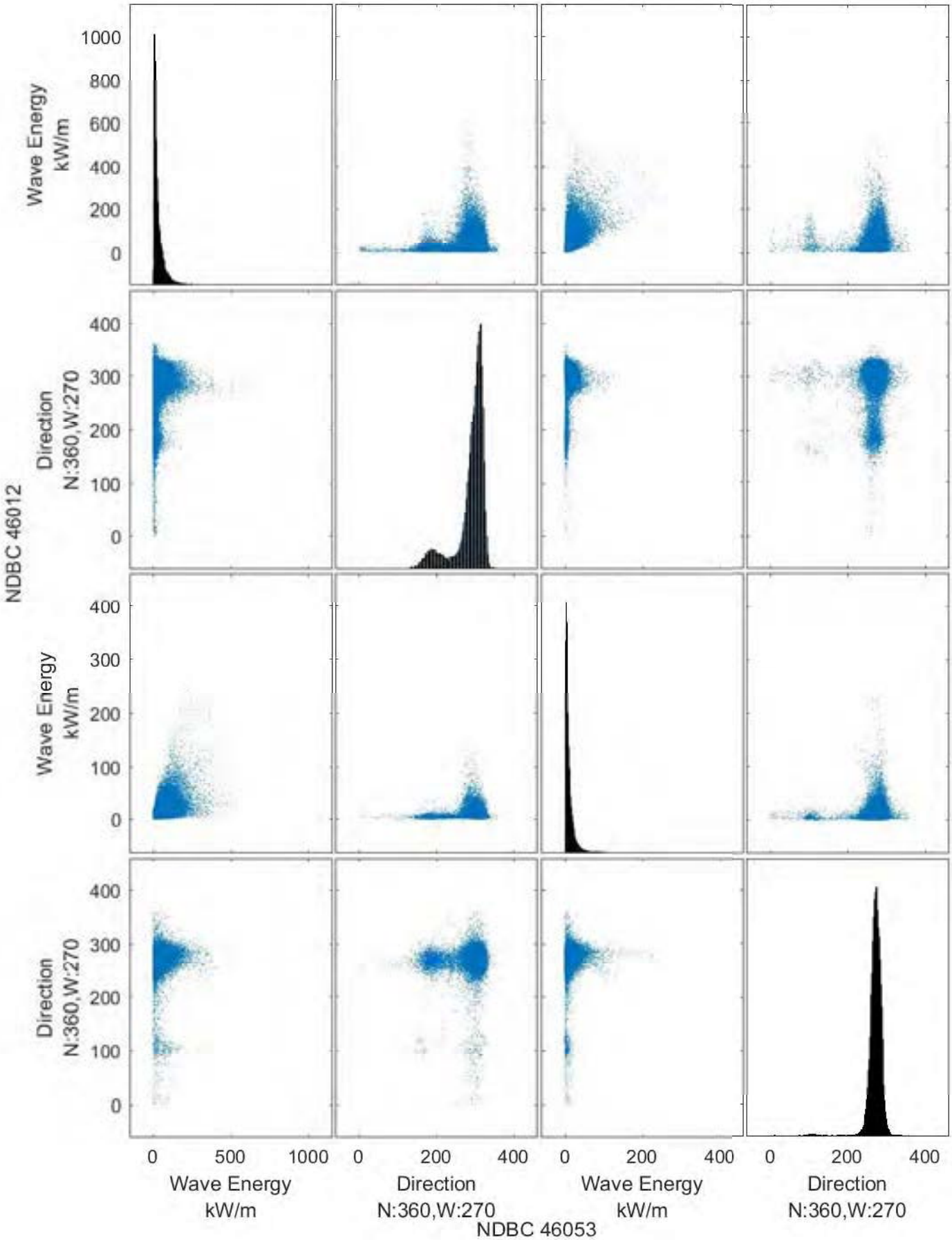


Figure C035: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46054.

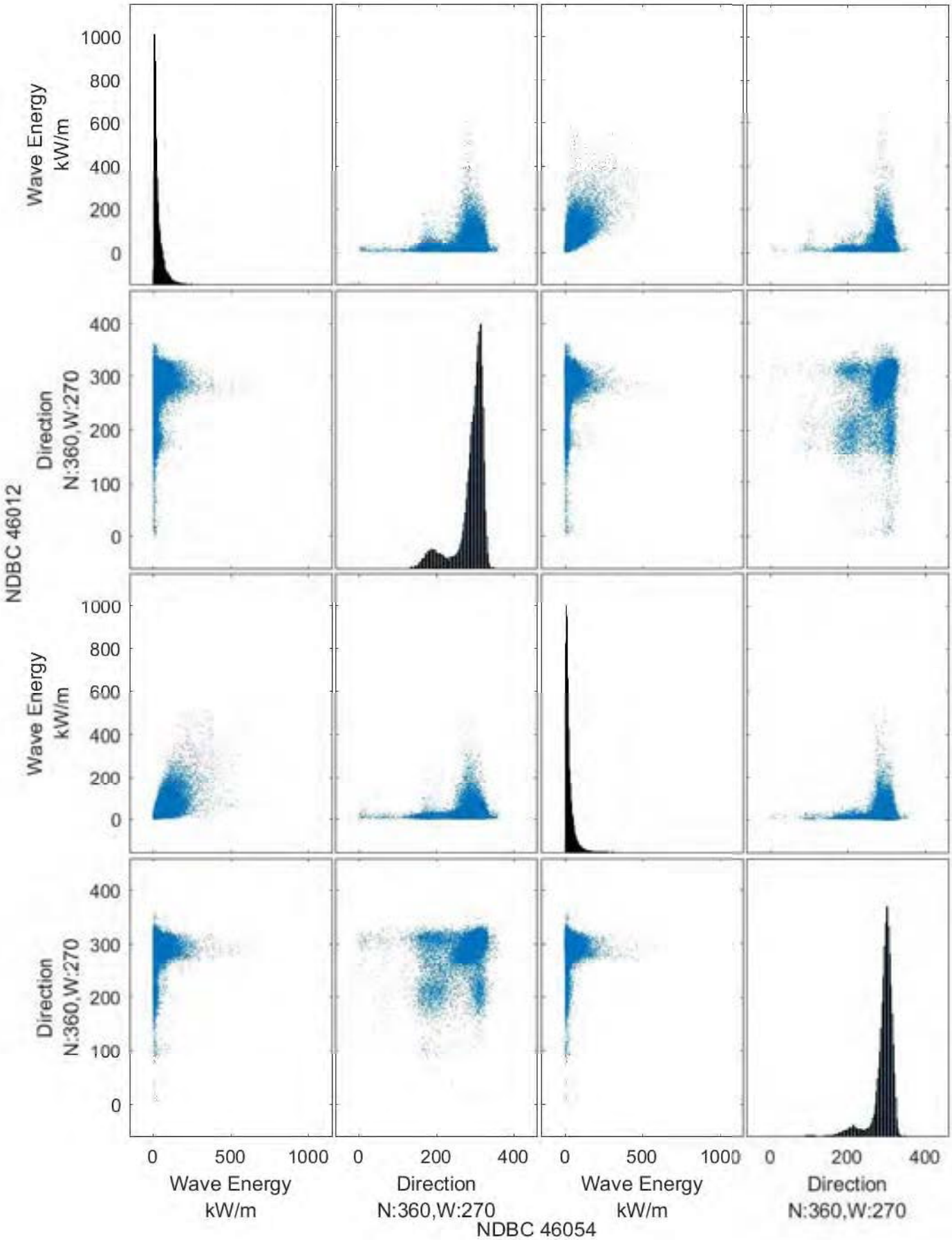


Figure C036: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46069.

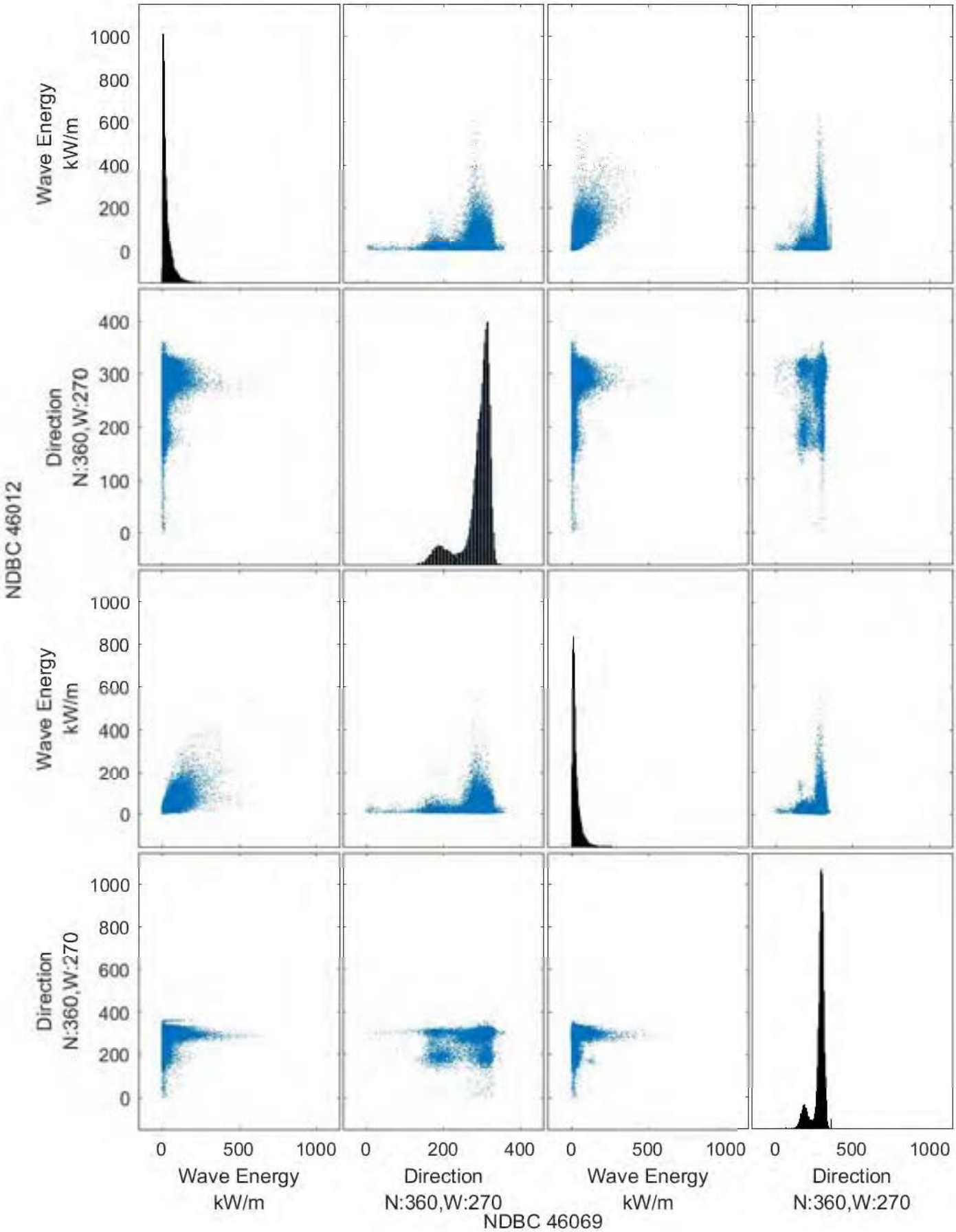


Figure C037: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46114.

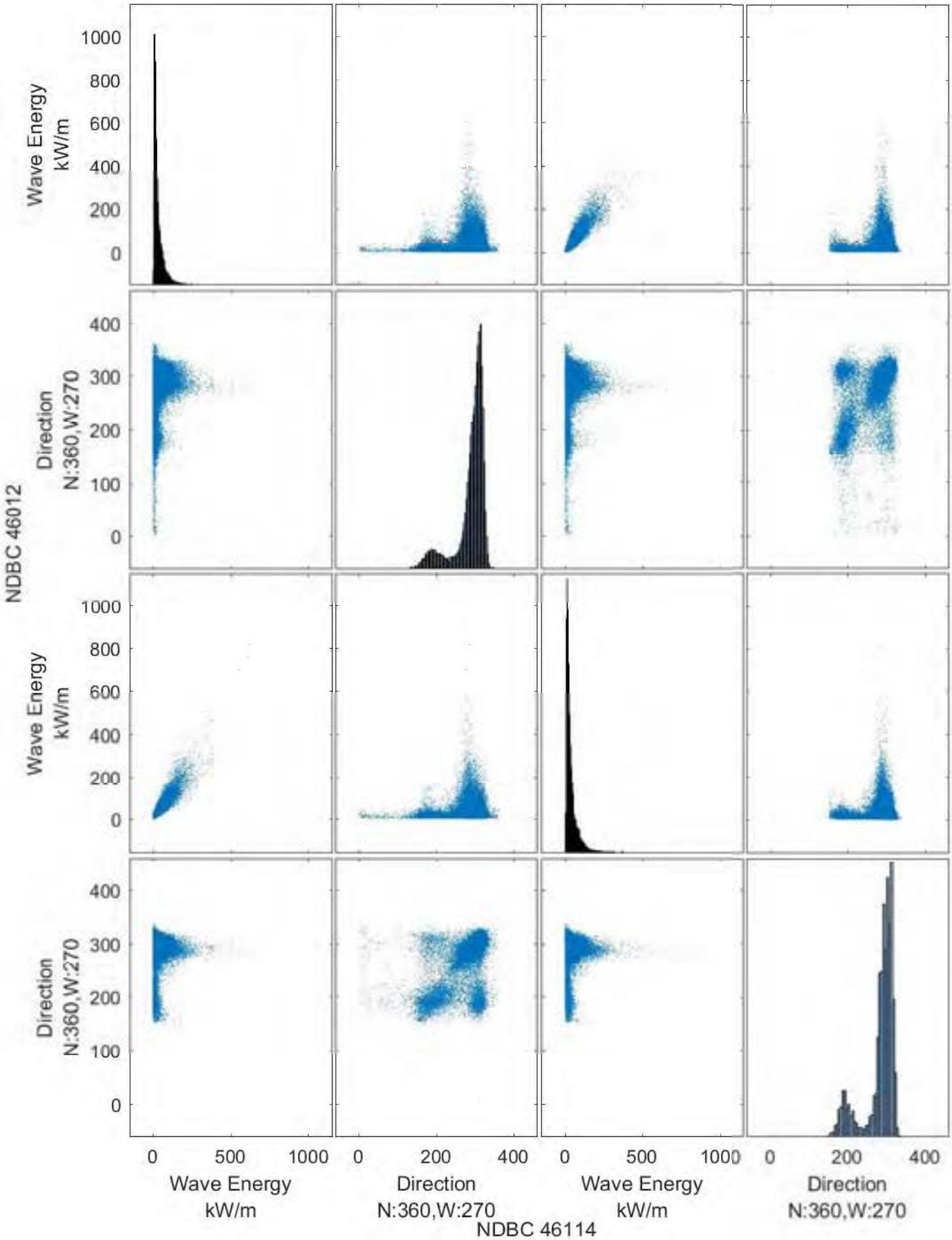


Figure C038: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46218.

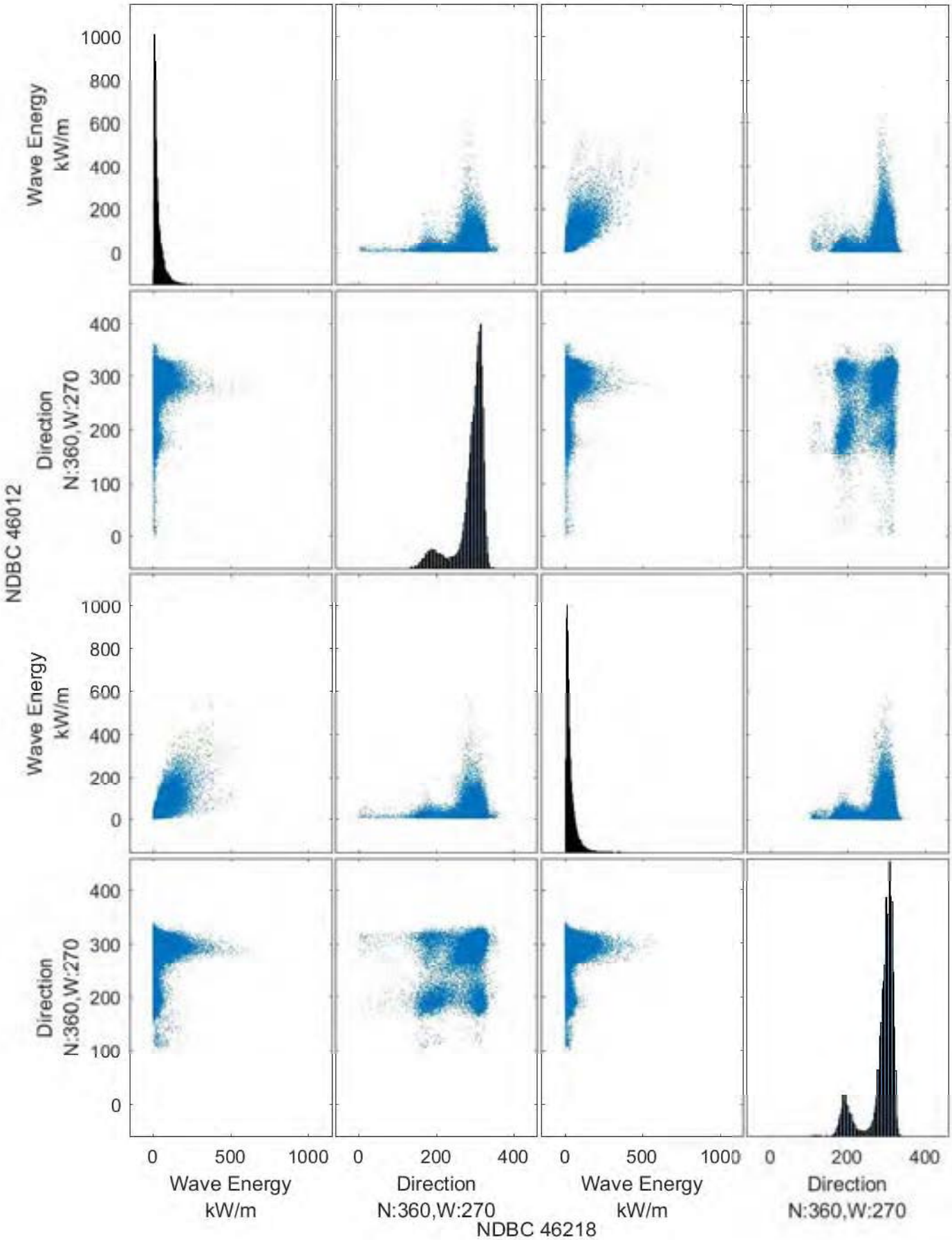


Figure C039: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46219.

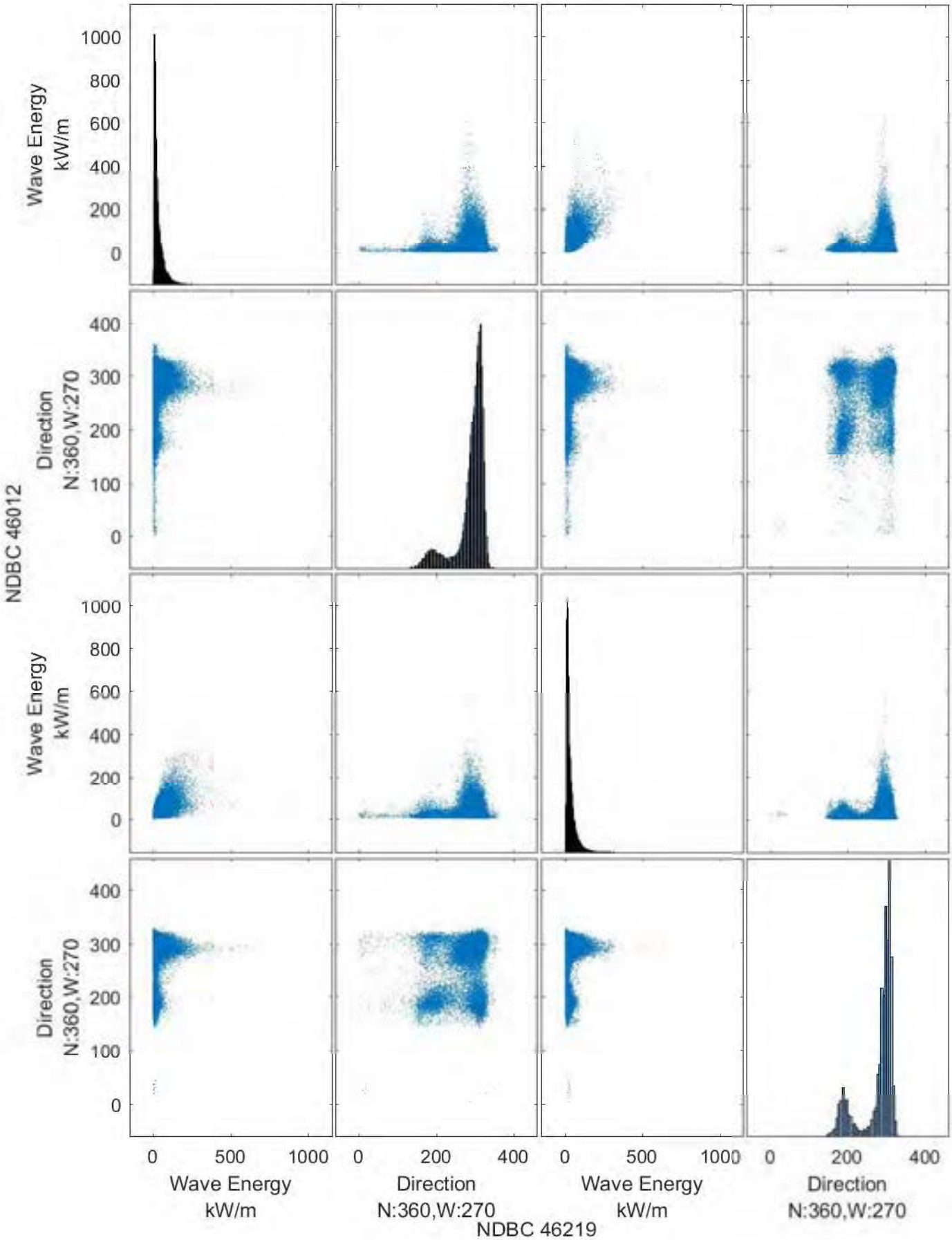


Figure C040: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46239.

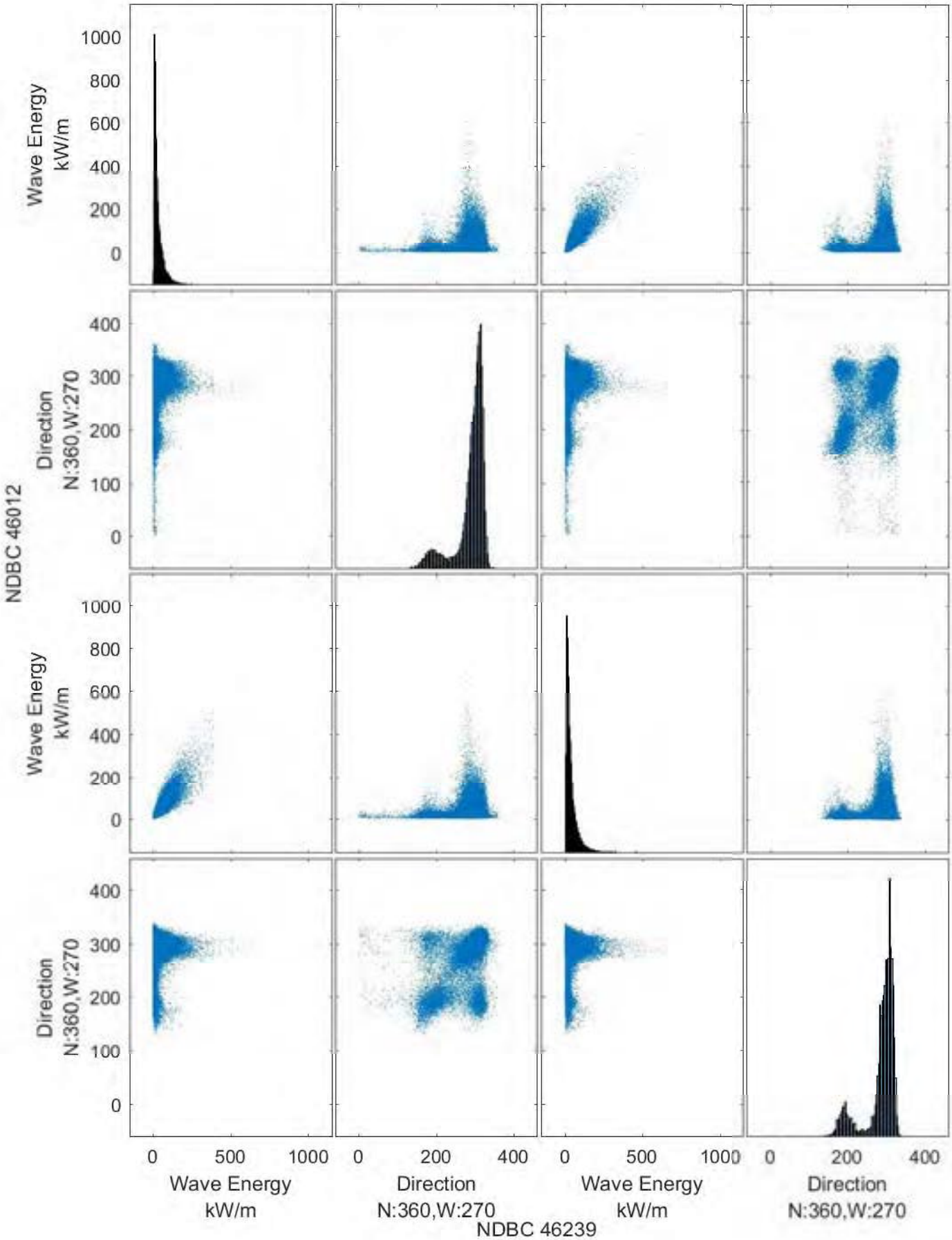


Figure C041: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46257.

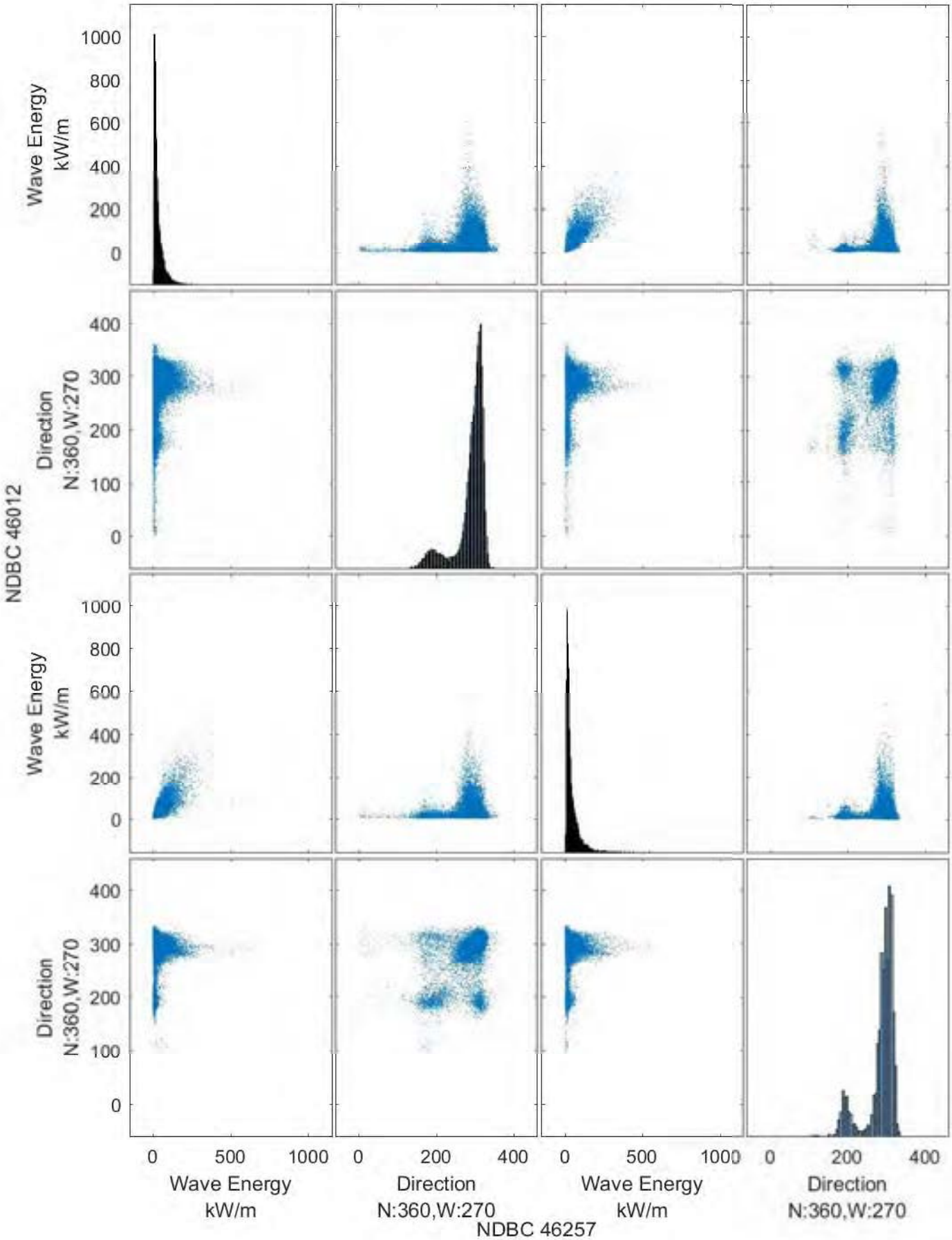


Figure C042: Cross Correlations for Wave Energyand Wave Direction for NDBC 46012 and NDBC 46259.

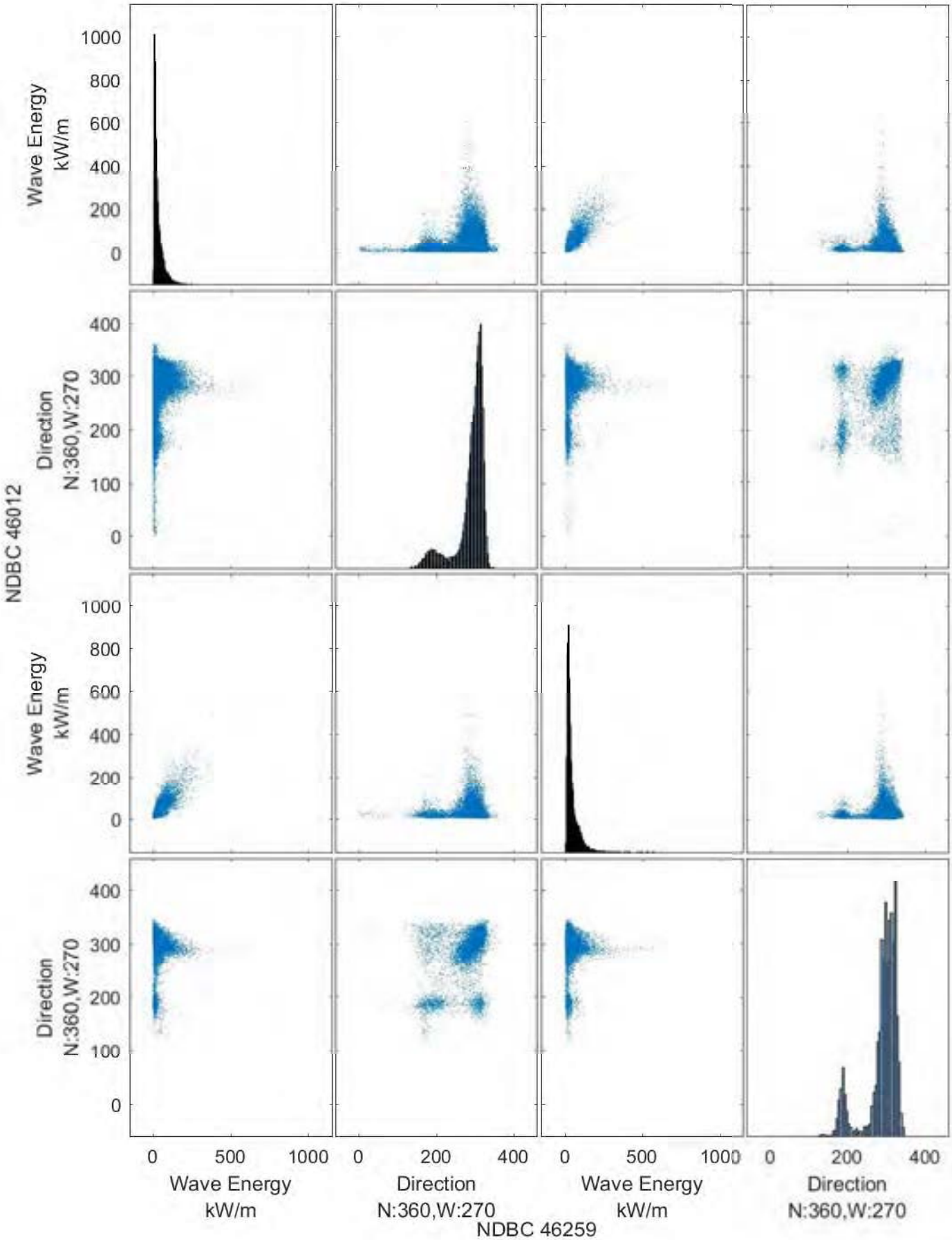


Figure C043: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46028.

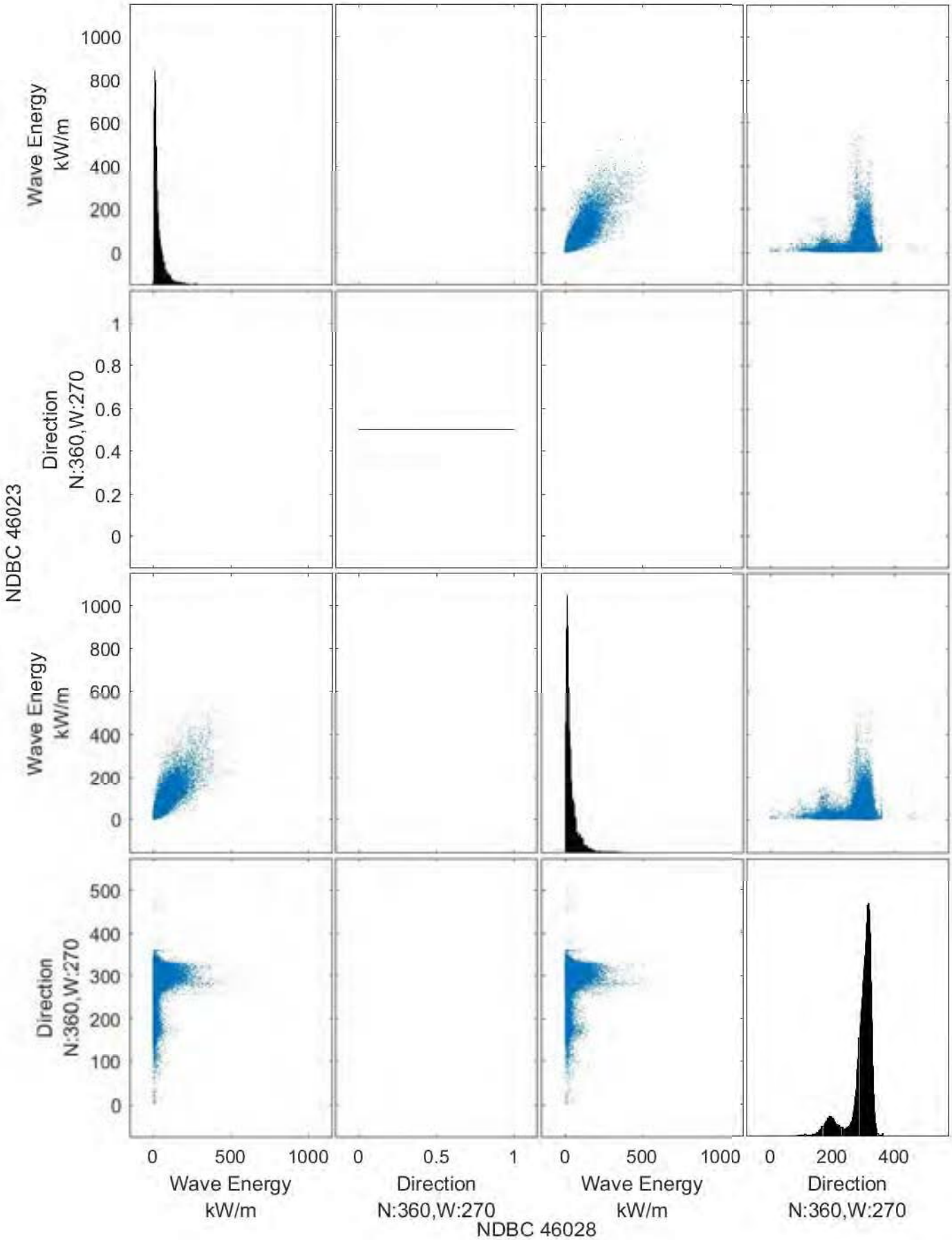


Figure C044: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46042.

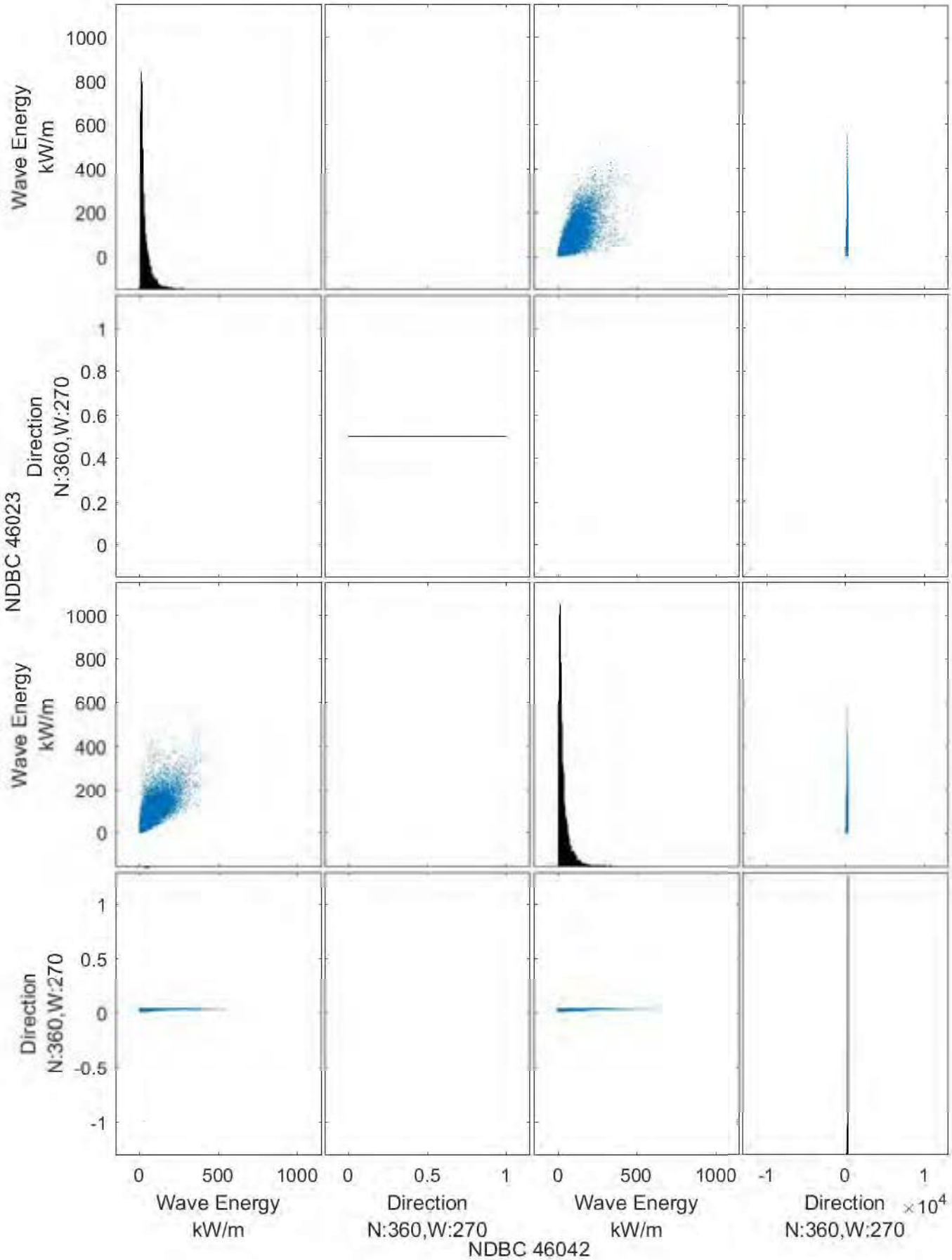


Figure C045: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46047.

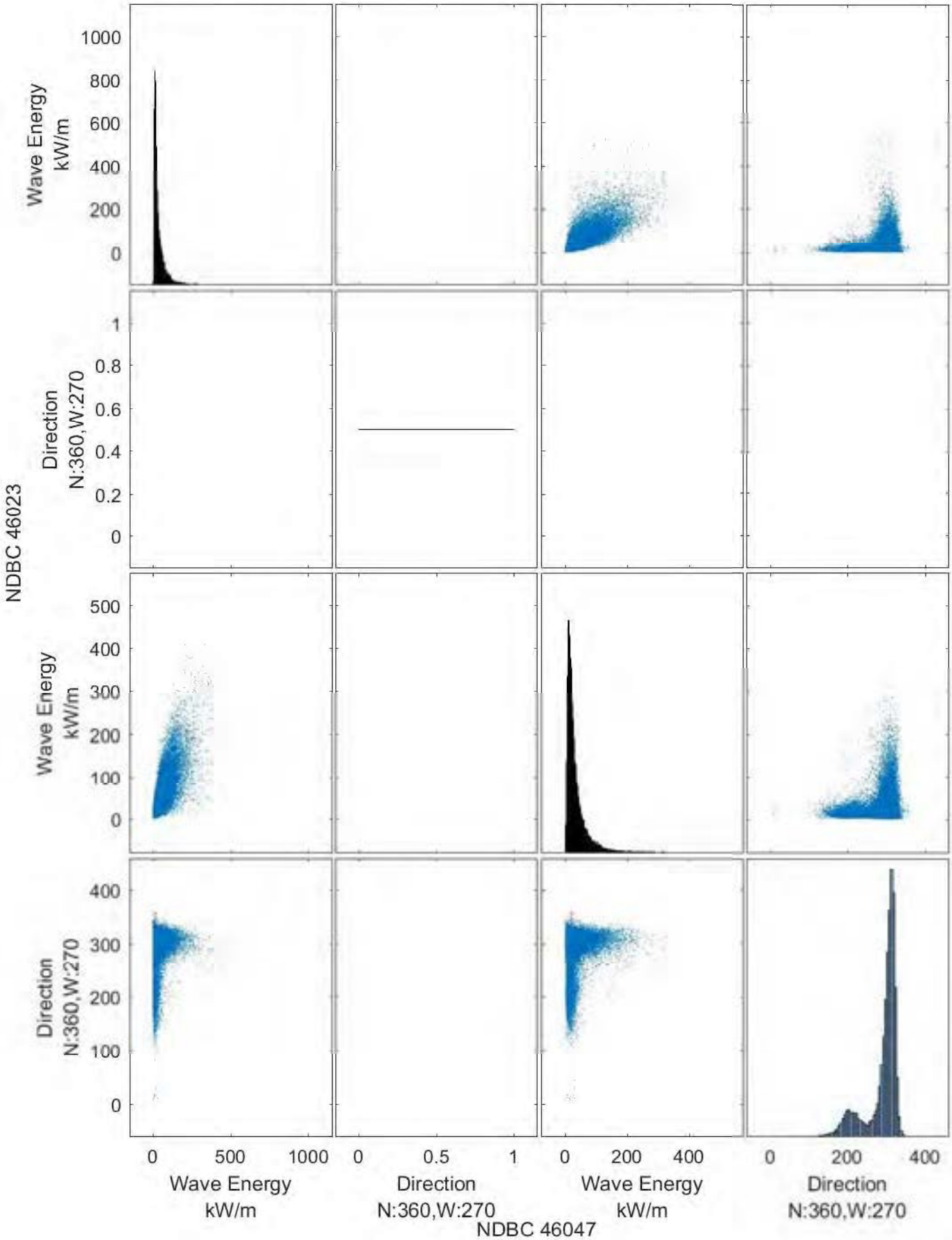


Figure C046: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46053.

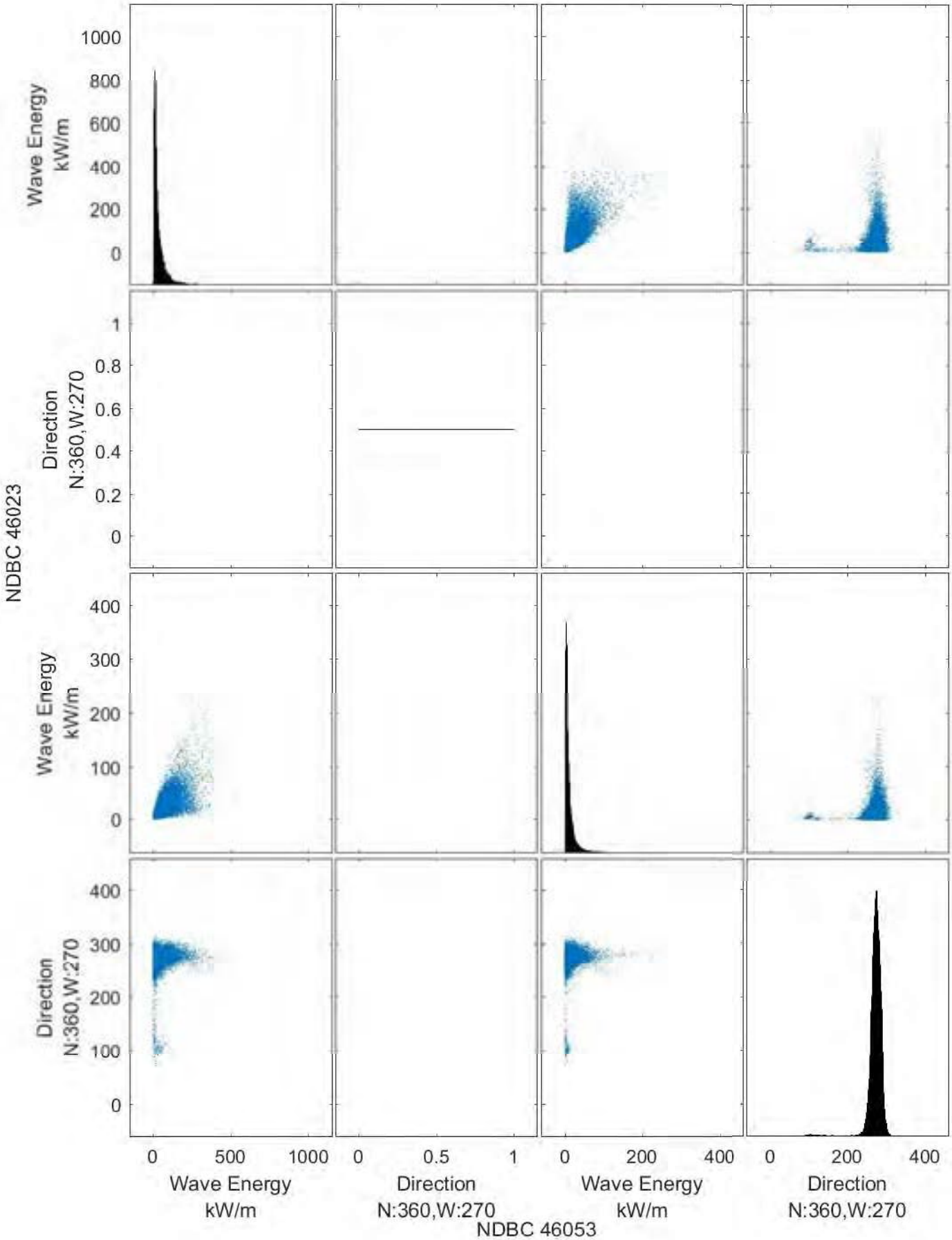


Figure C047: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46054.

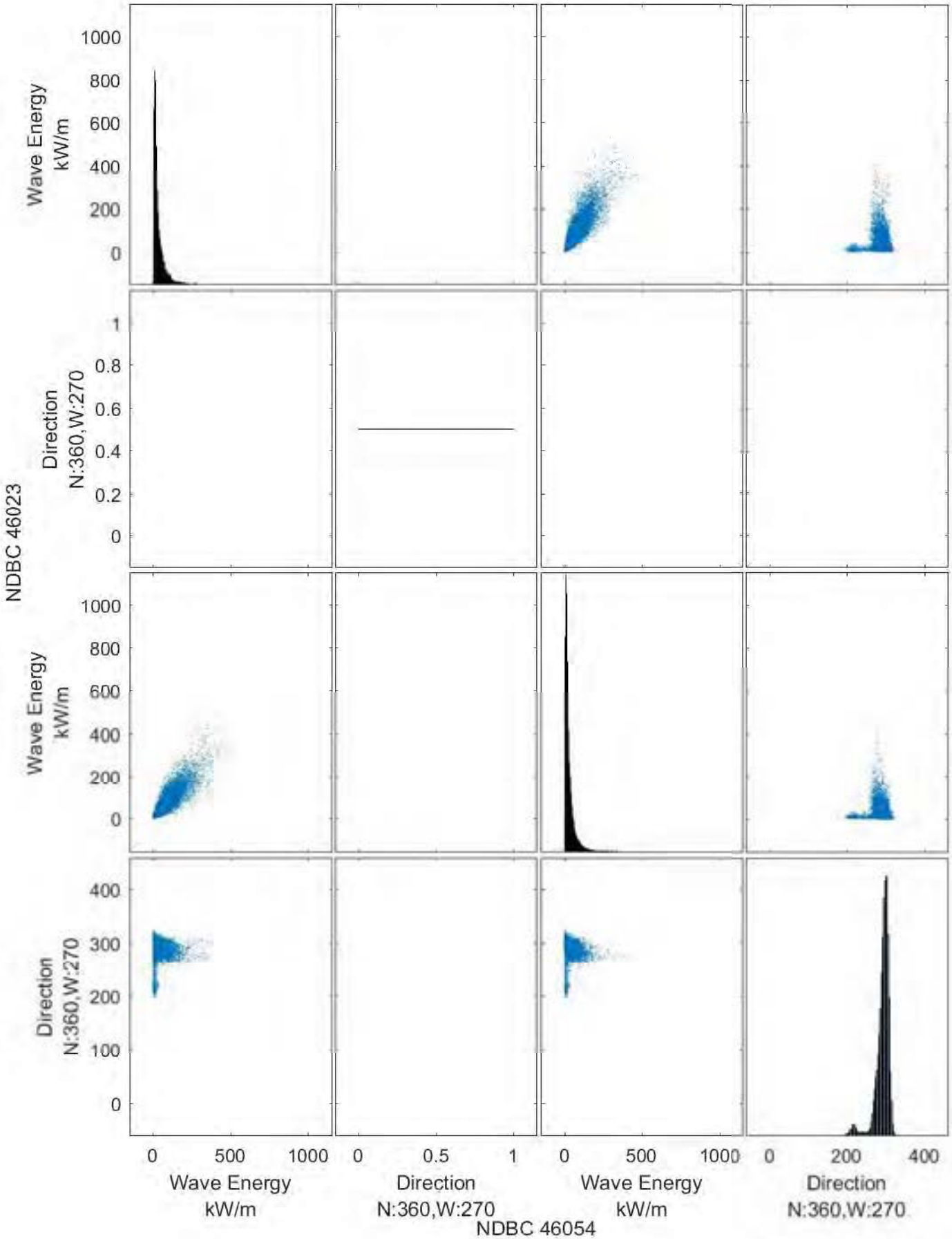


Figure C048: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46069.

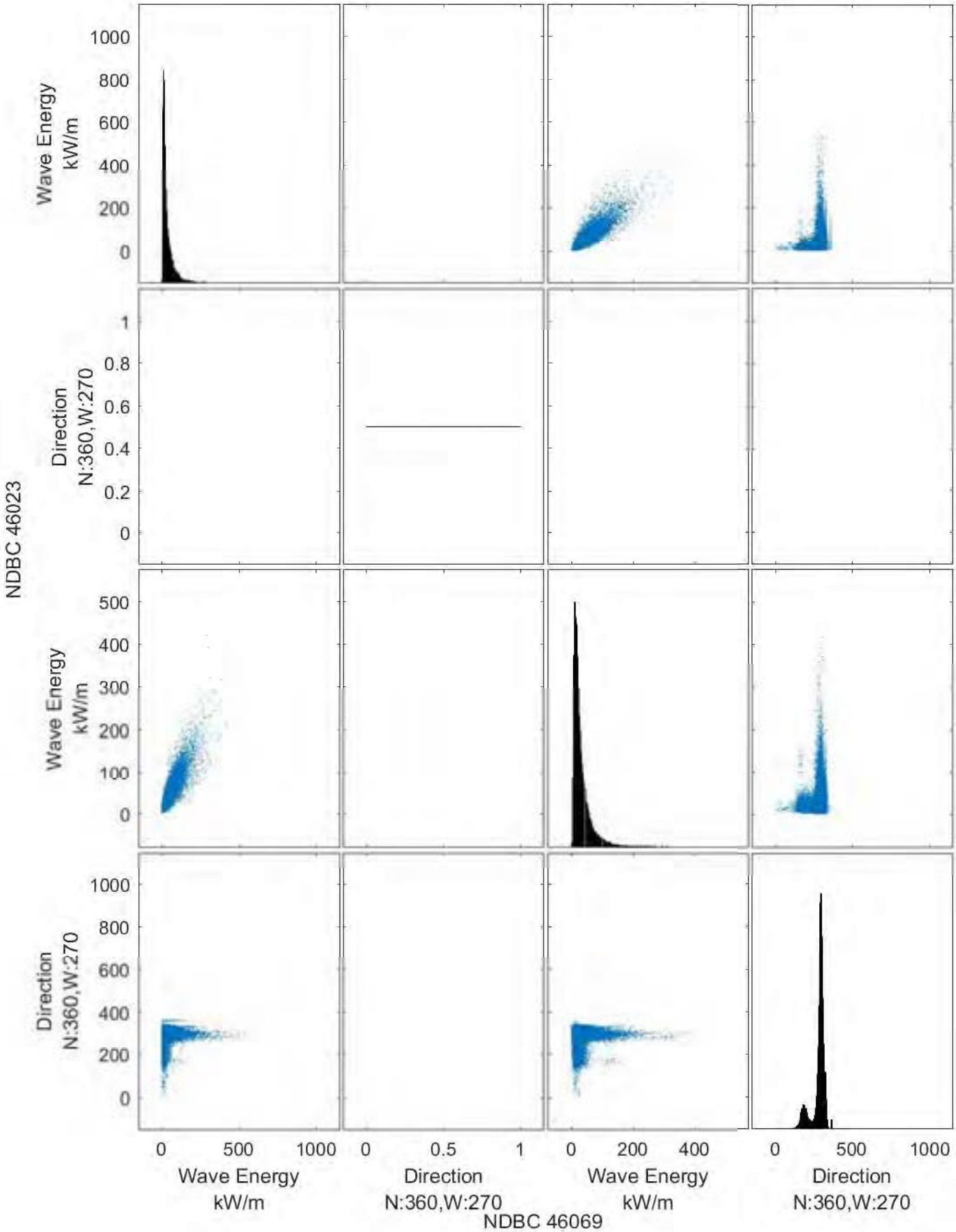


Figure C049: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46114.

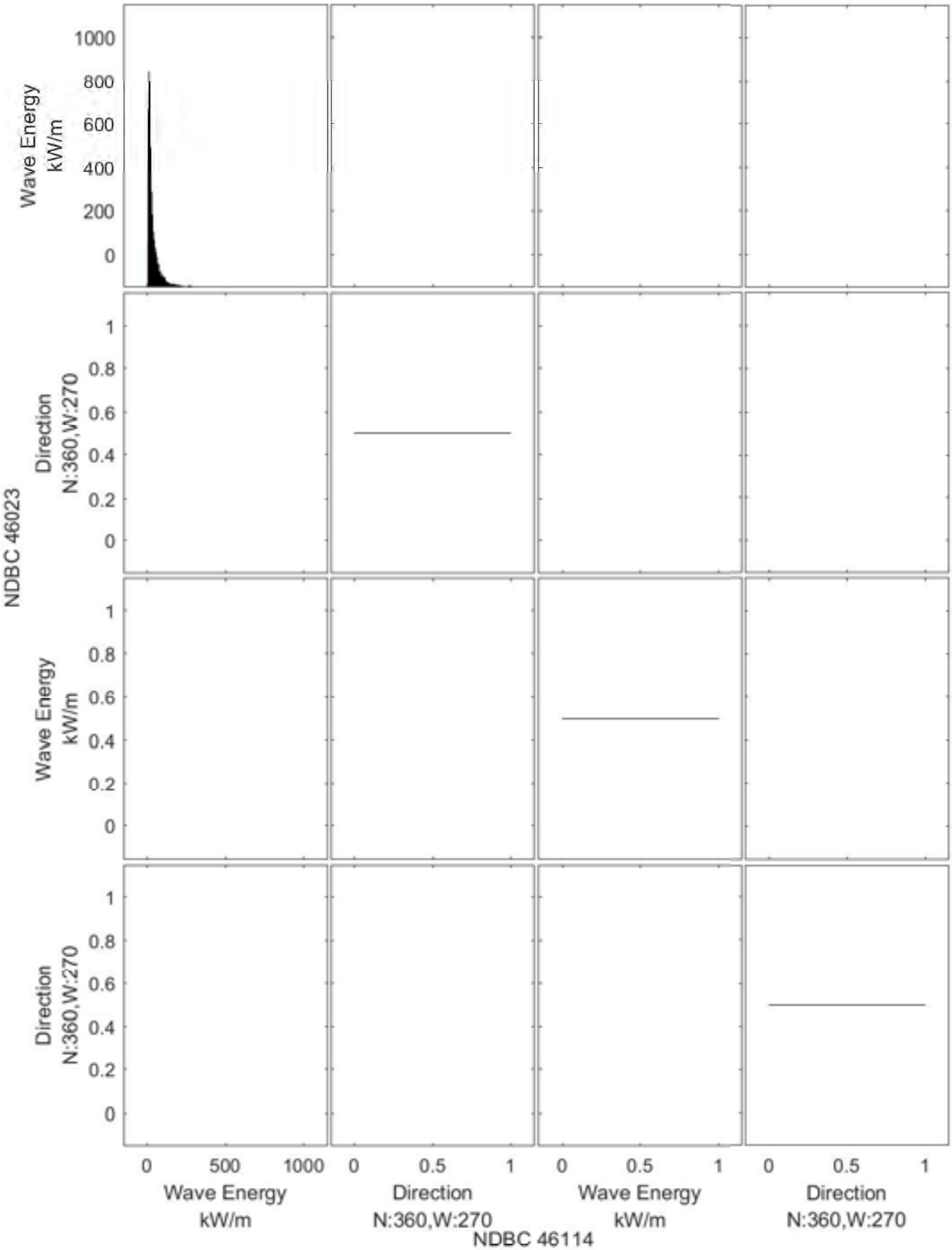


Figure C050: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46218.

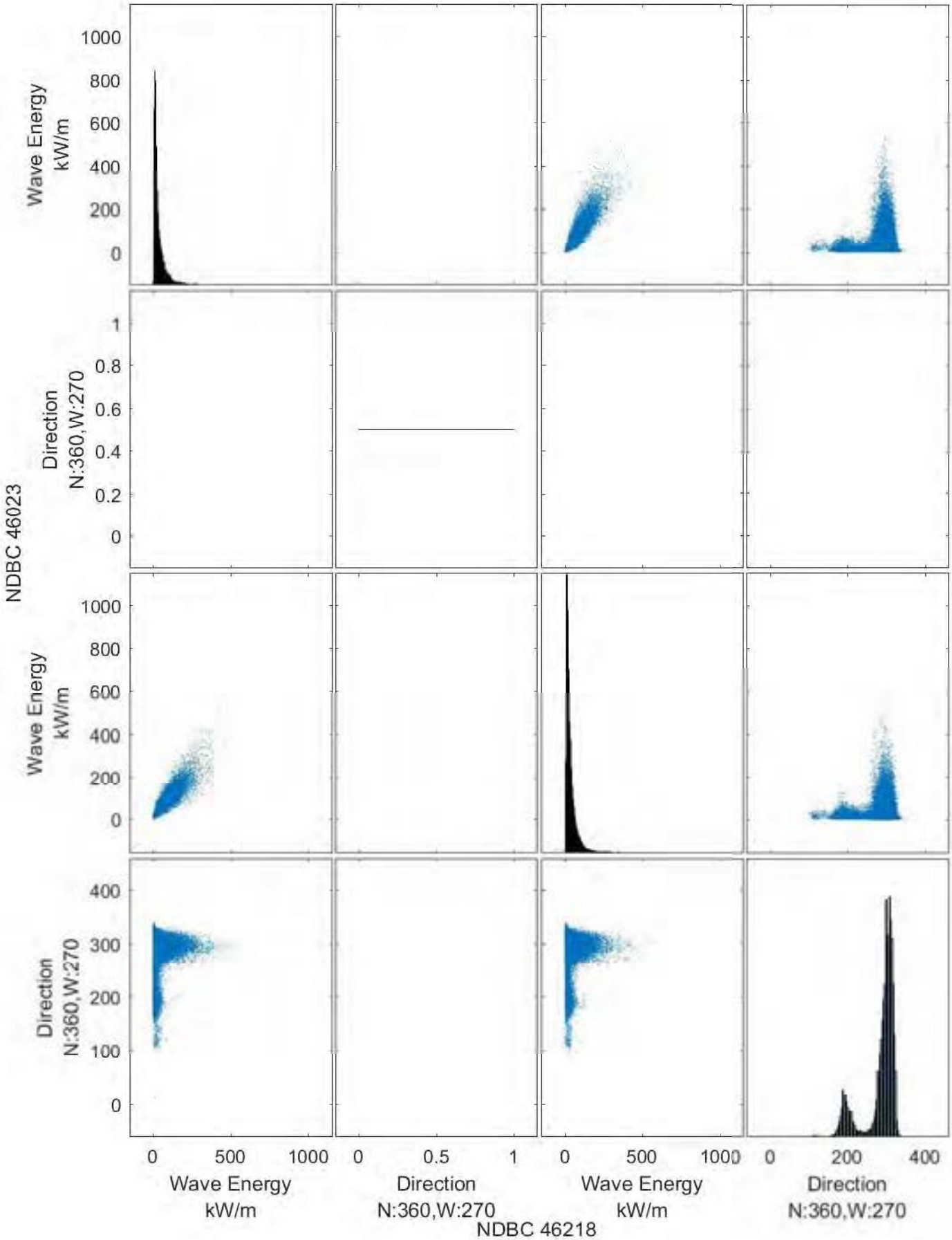


Figure C051: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46219.

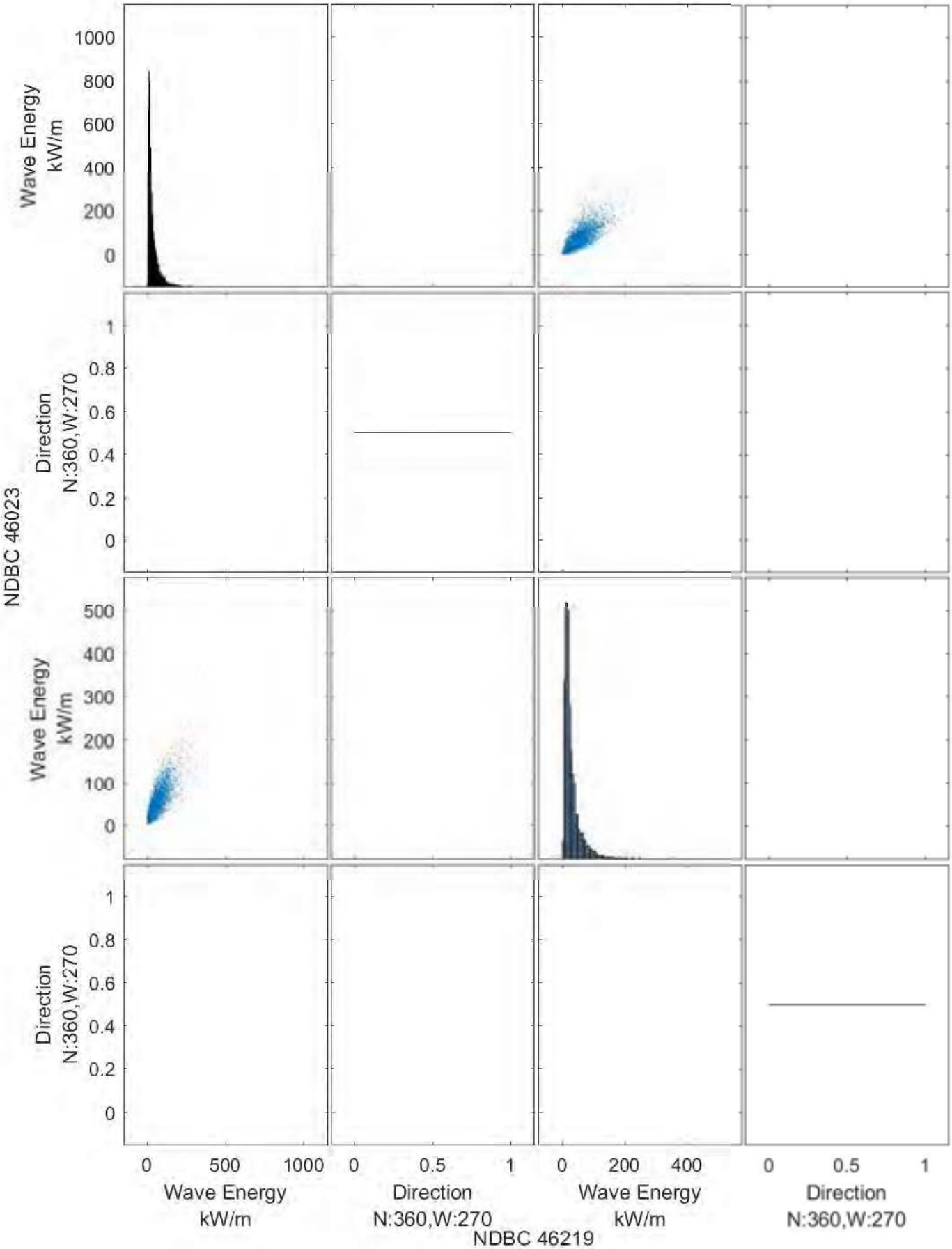


Figure C052: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46239.

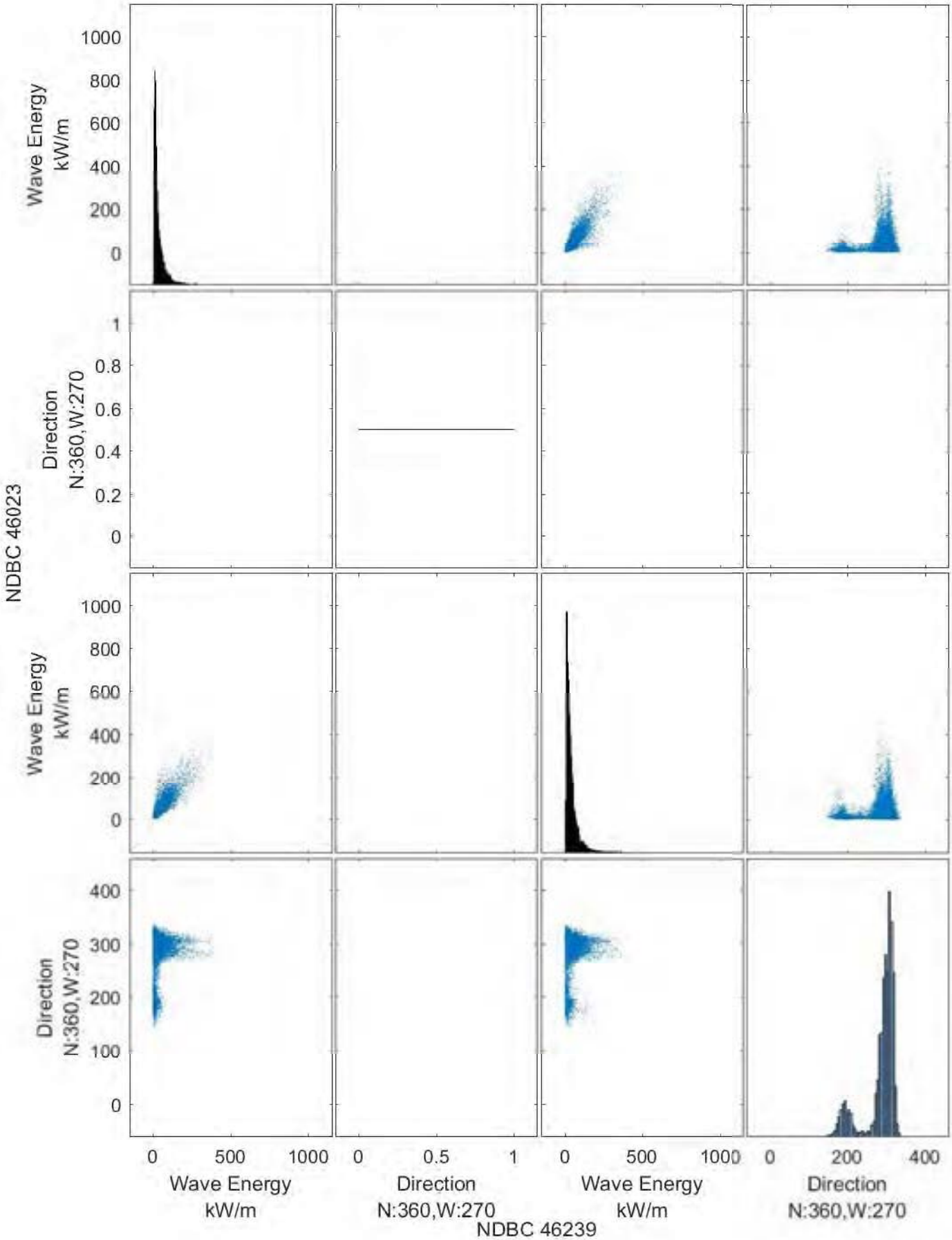


Figure C053: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46257.

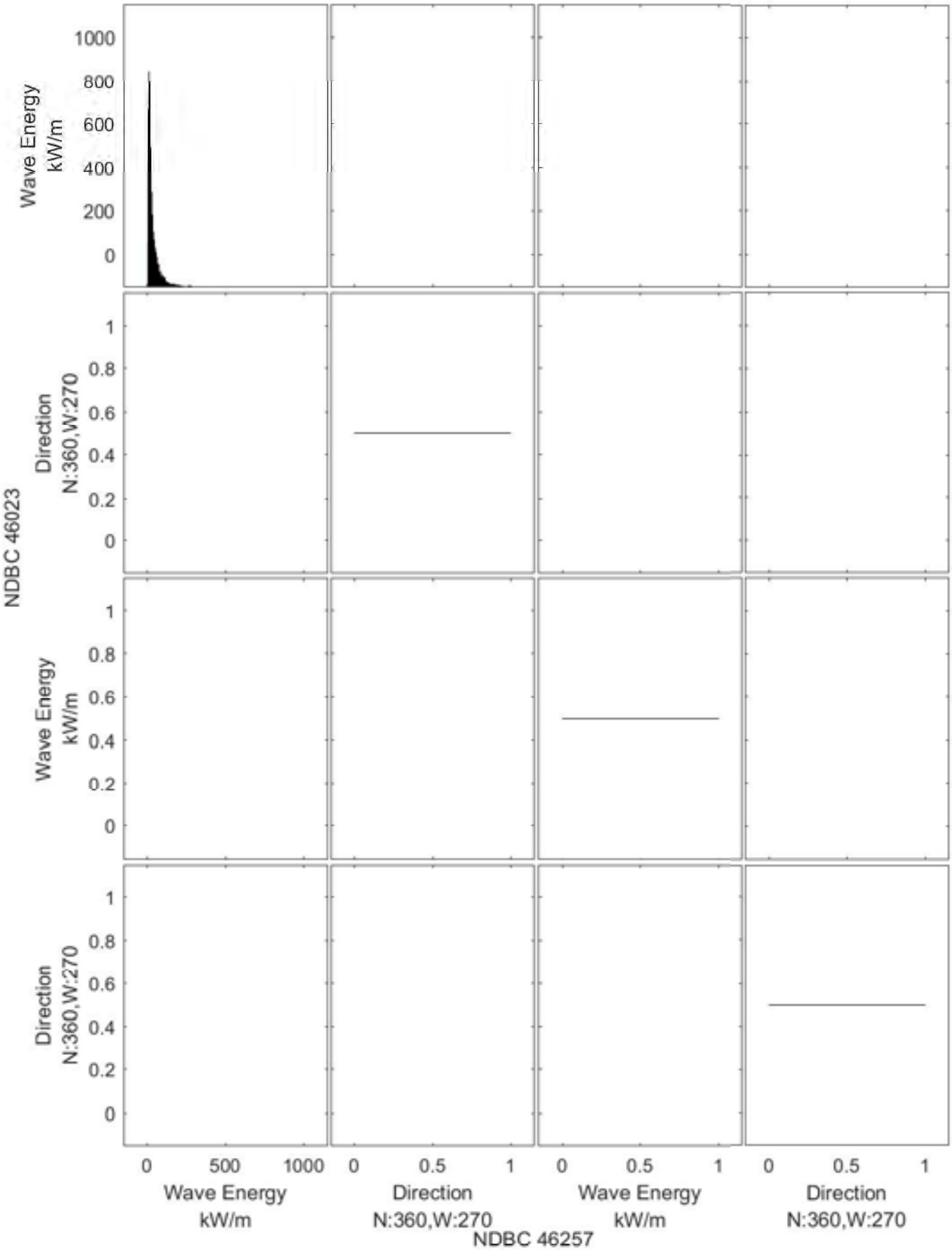


Figure C054: Cross Correlations for Wave Energyand Wave Direction for NDBC 46023 and NDBC 46259.

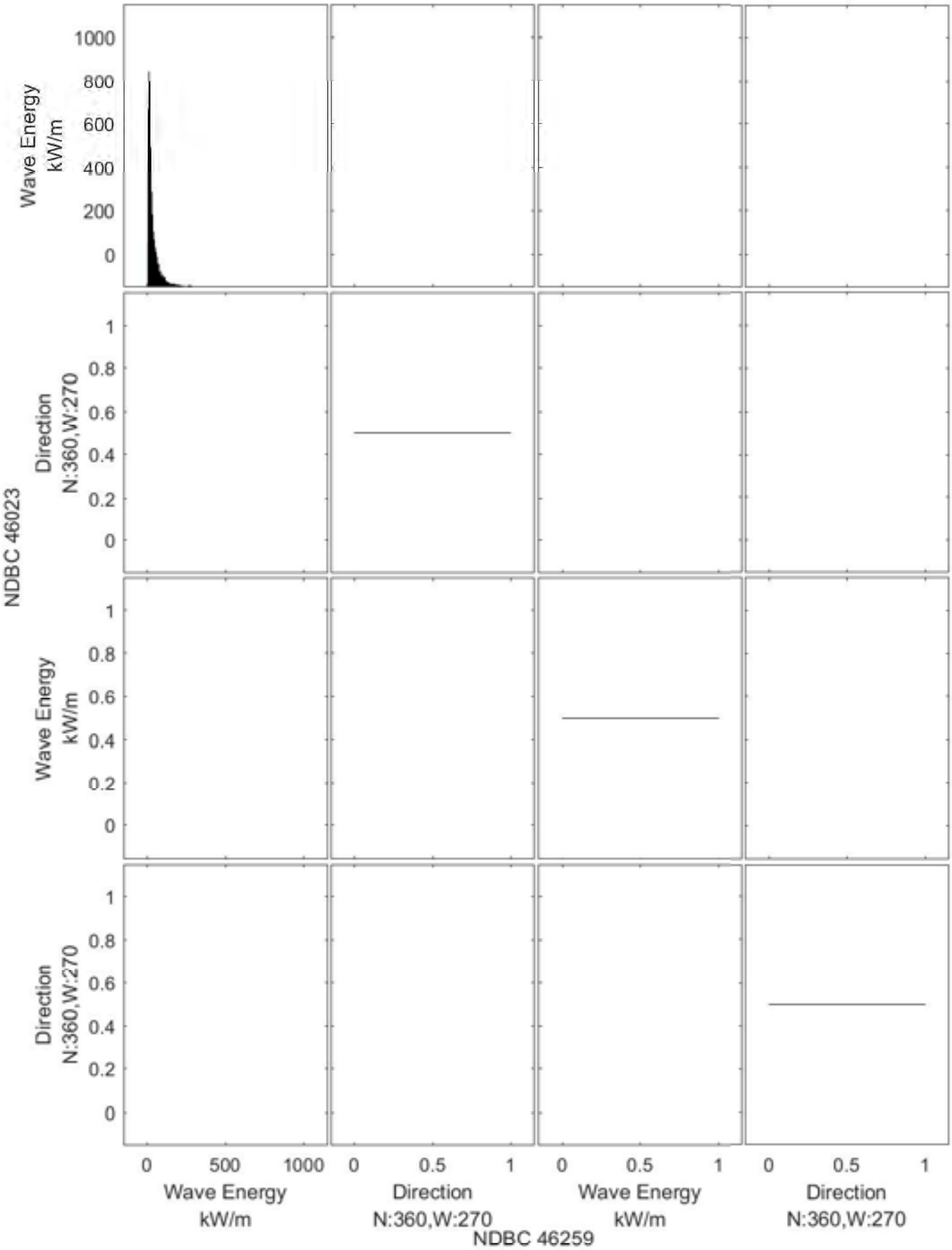


Figure C055: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46042.

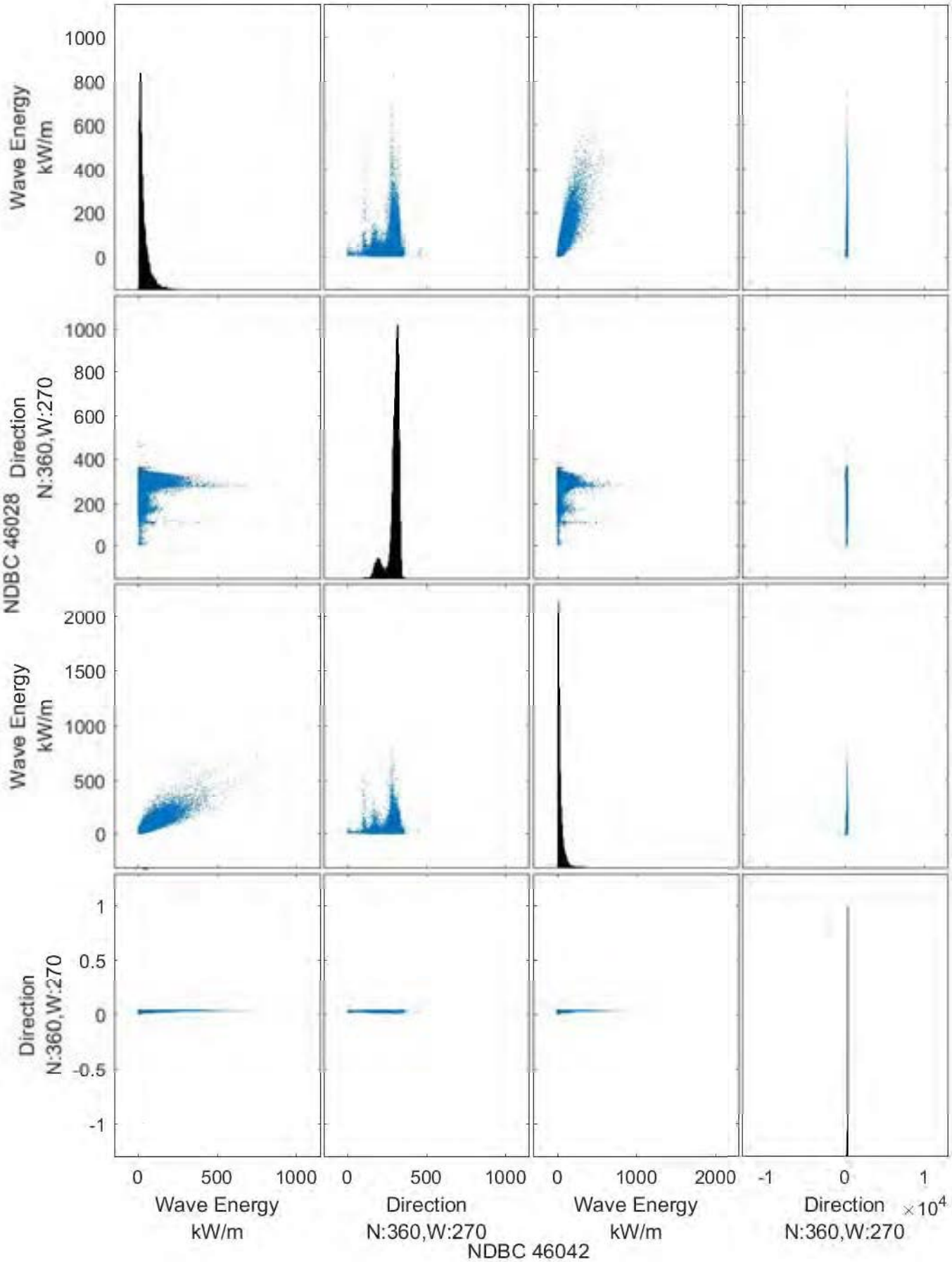


Figure C056: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46047.

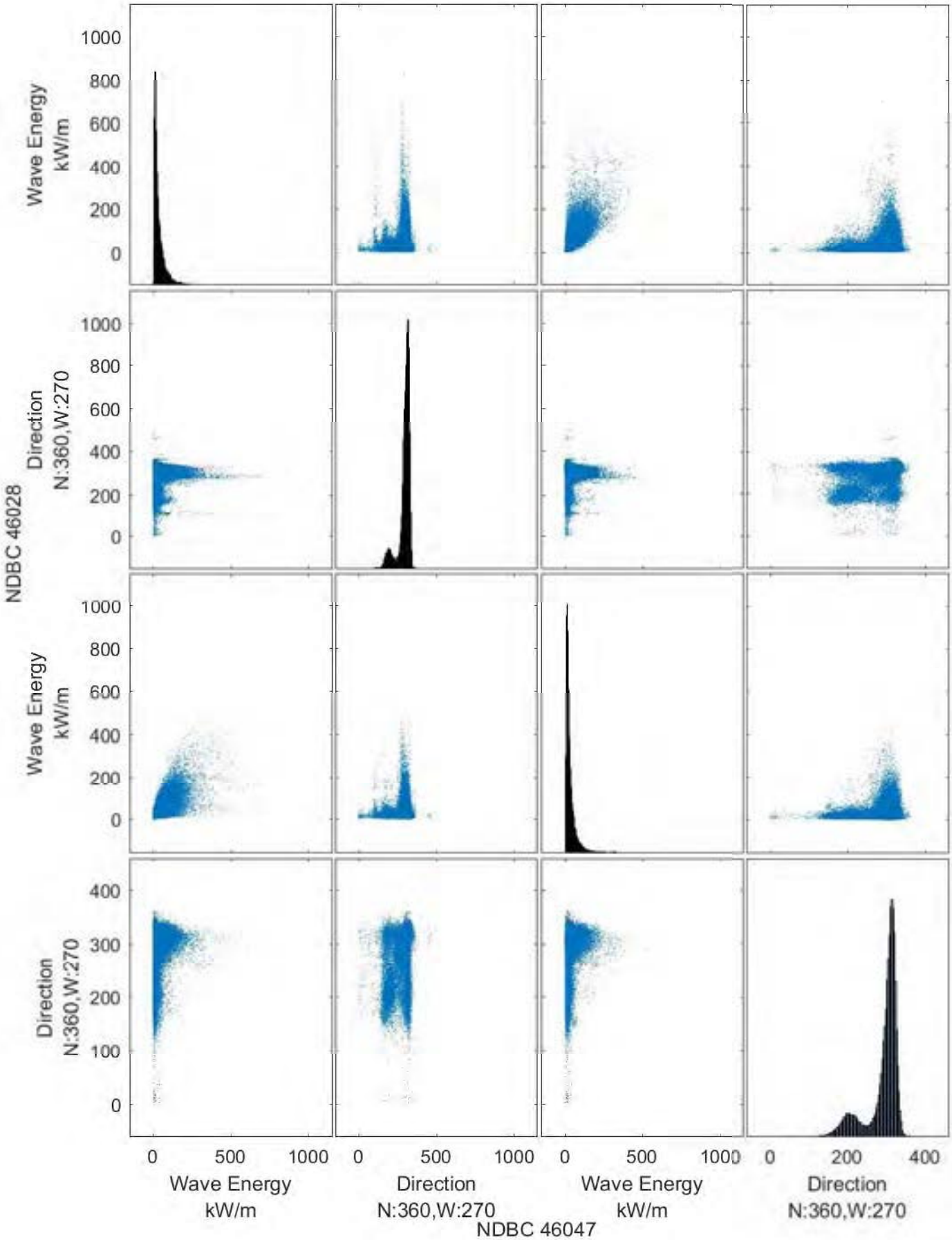


Figure C057: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46053.

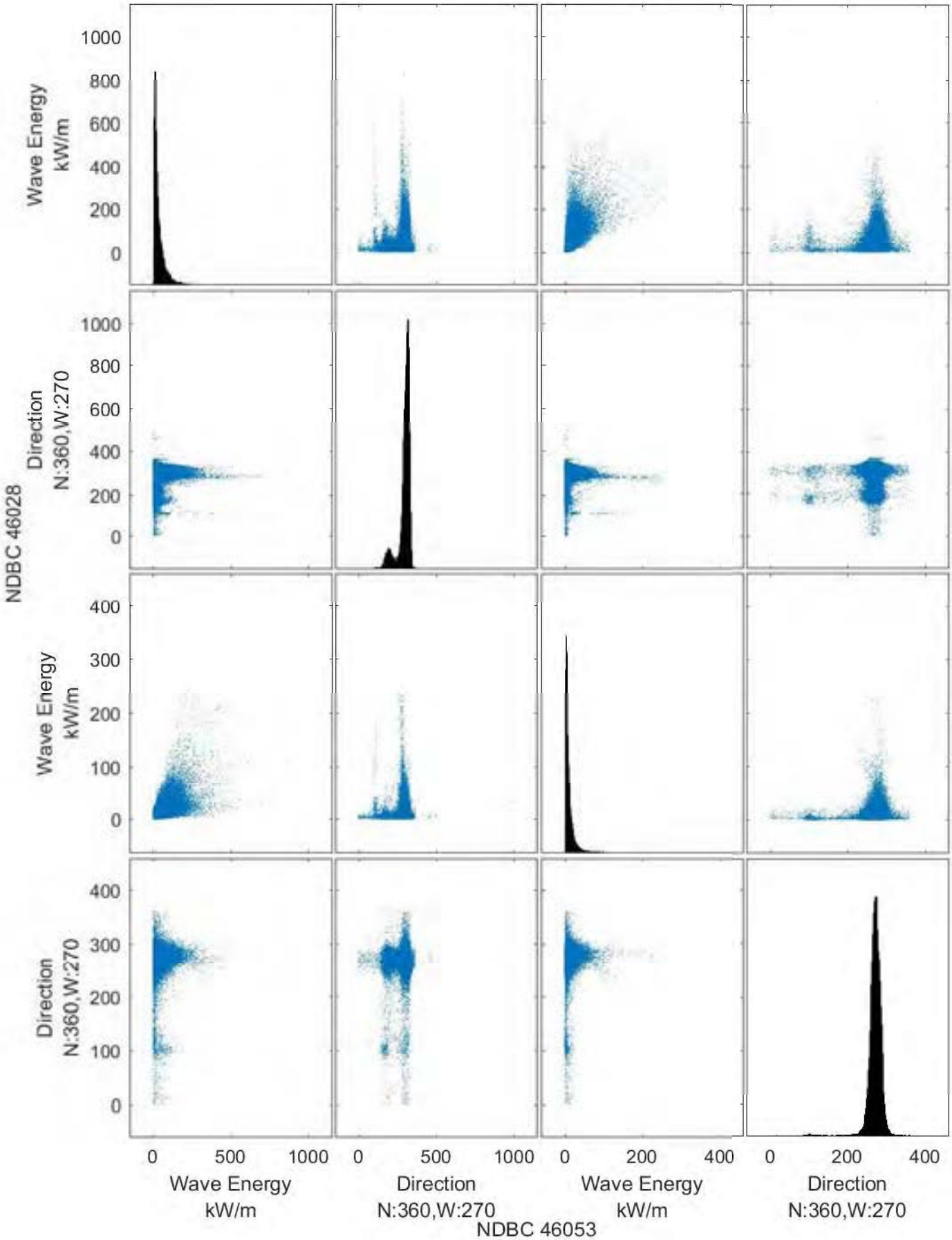


Figure C058: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46054.

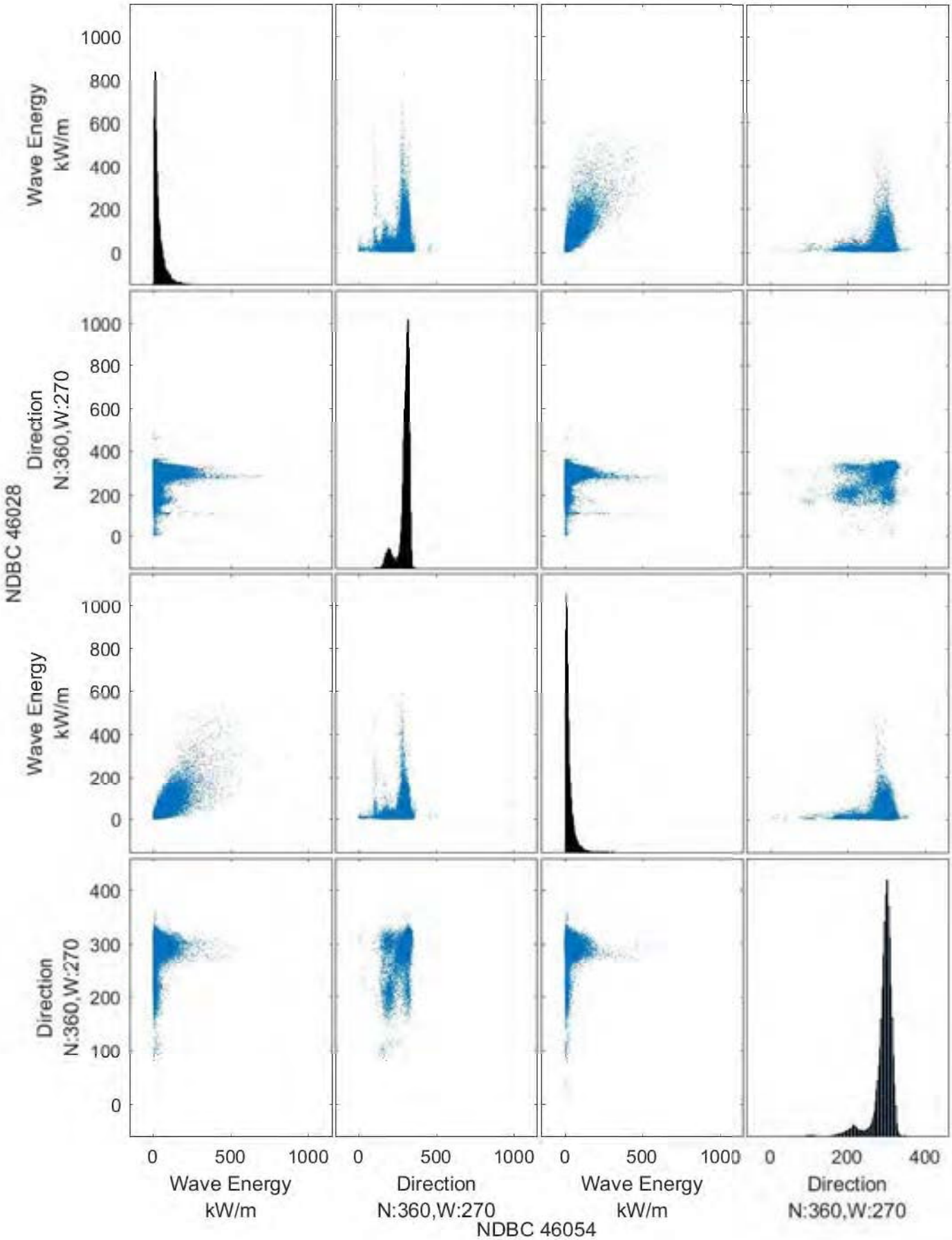


Figure C059: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46069.

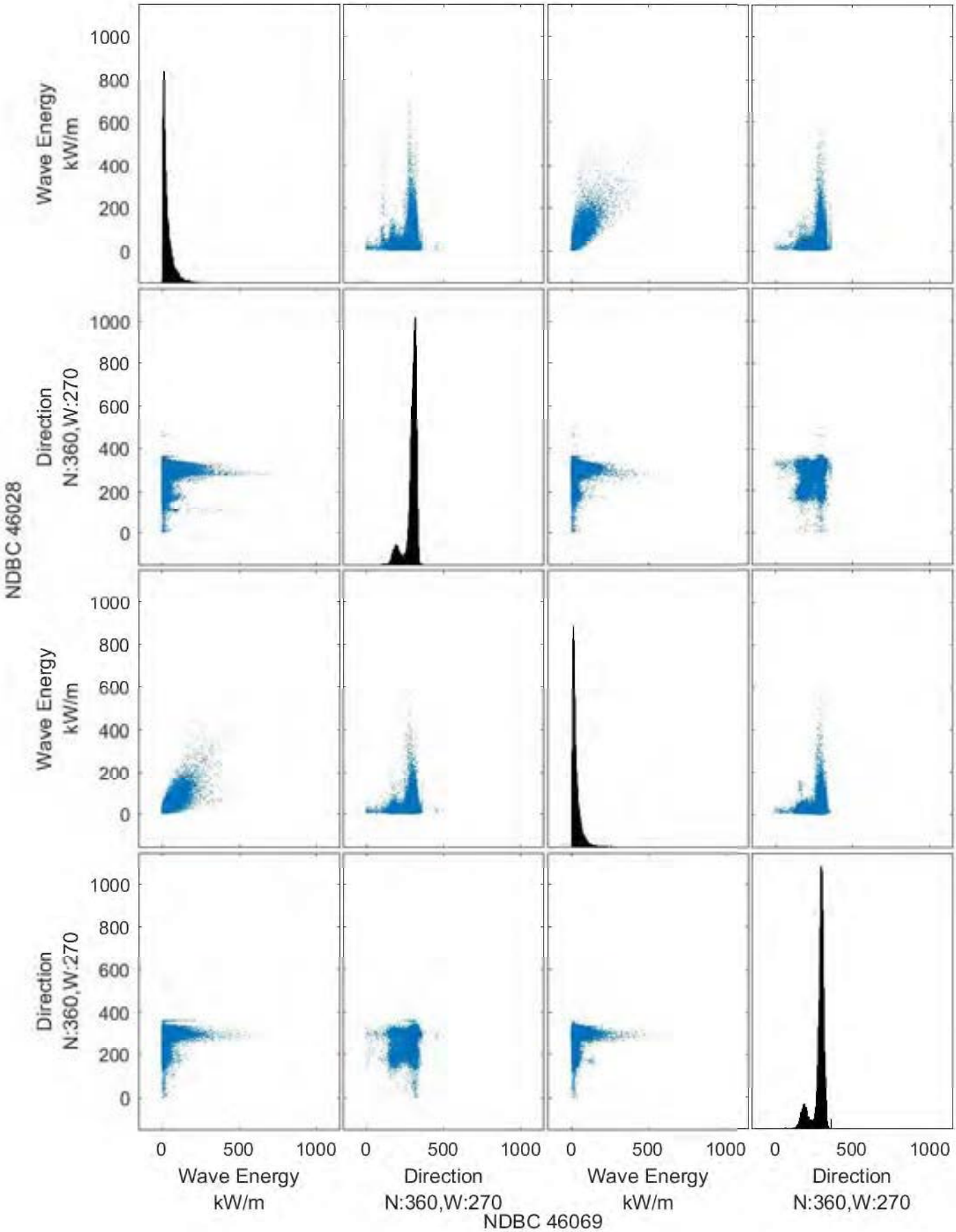


Figure C060: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46114.

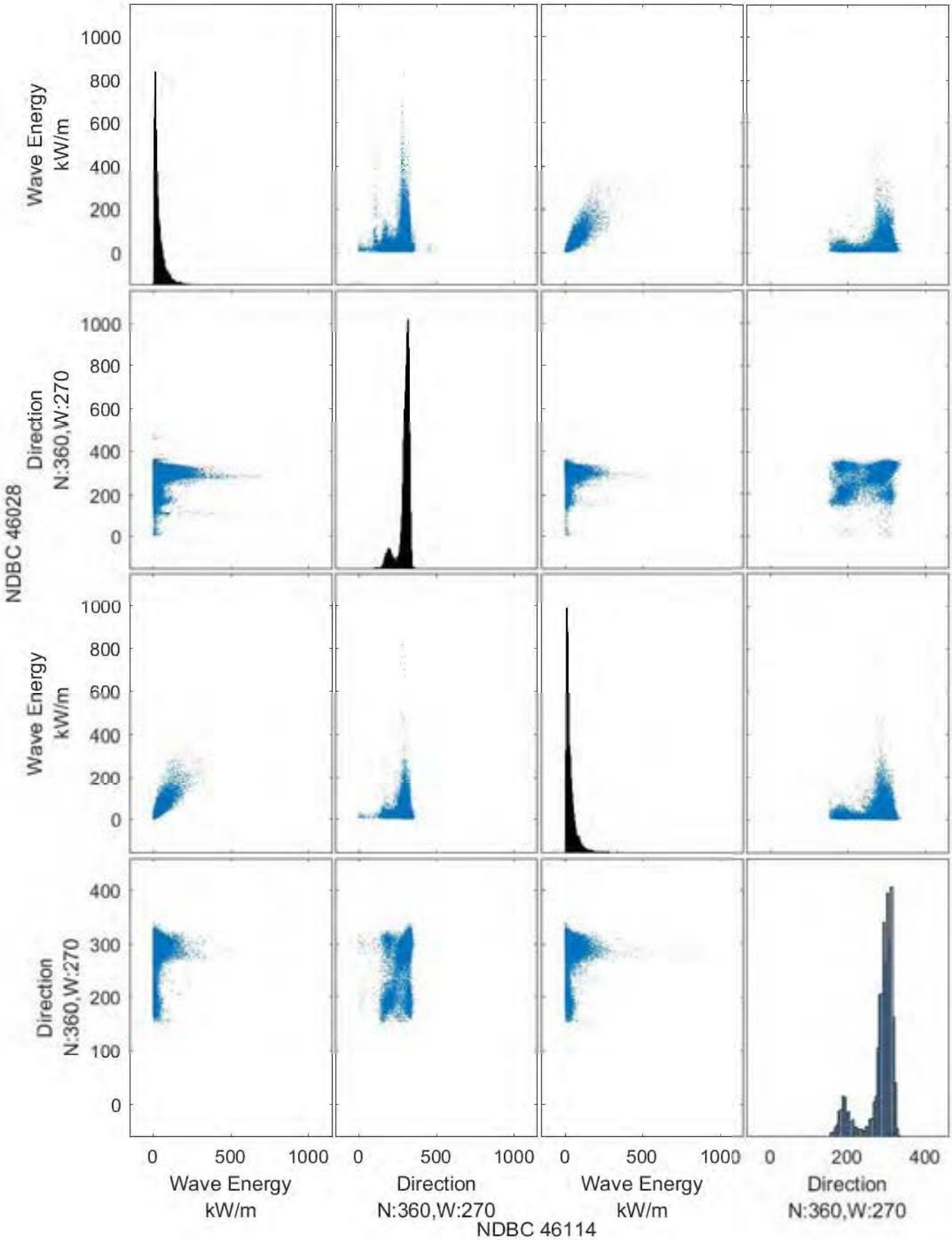


Figure C061: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46218.

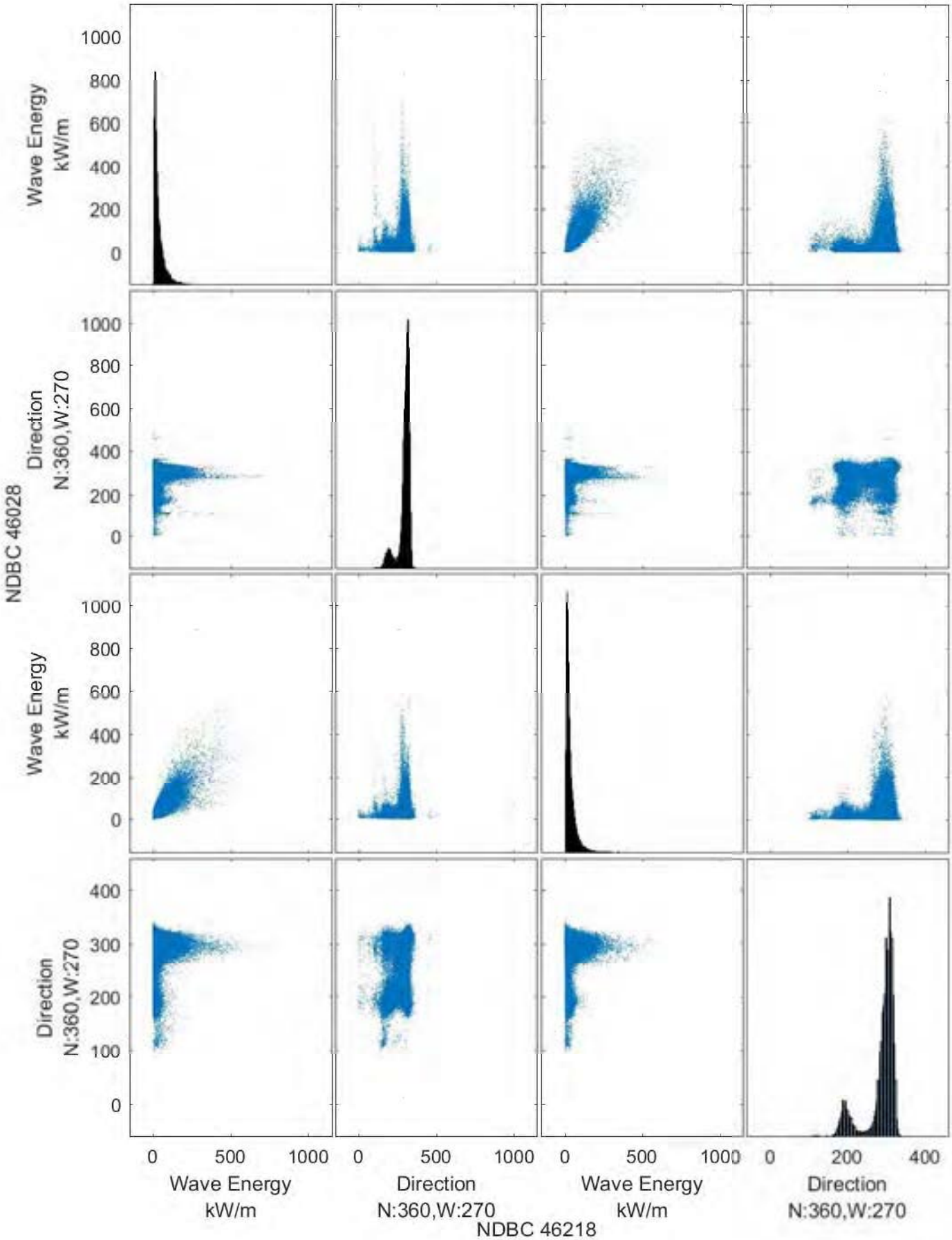


Figure C062: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46219.

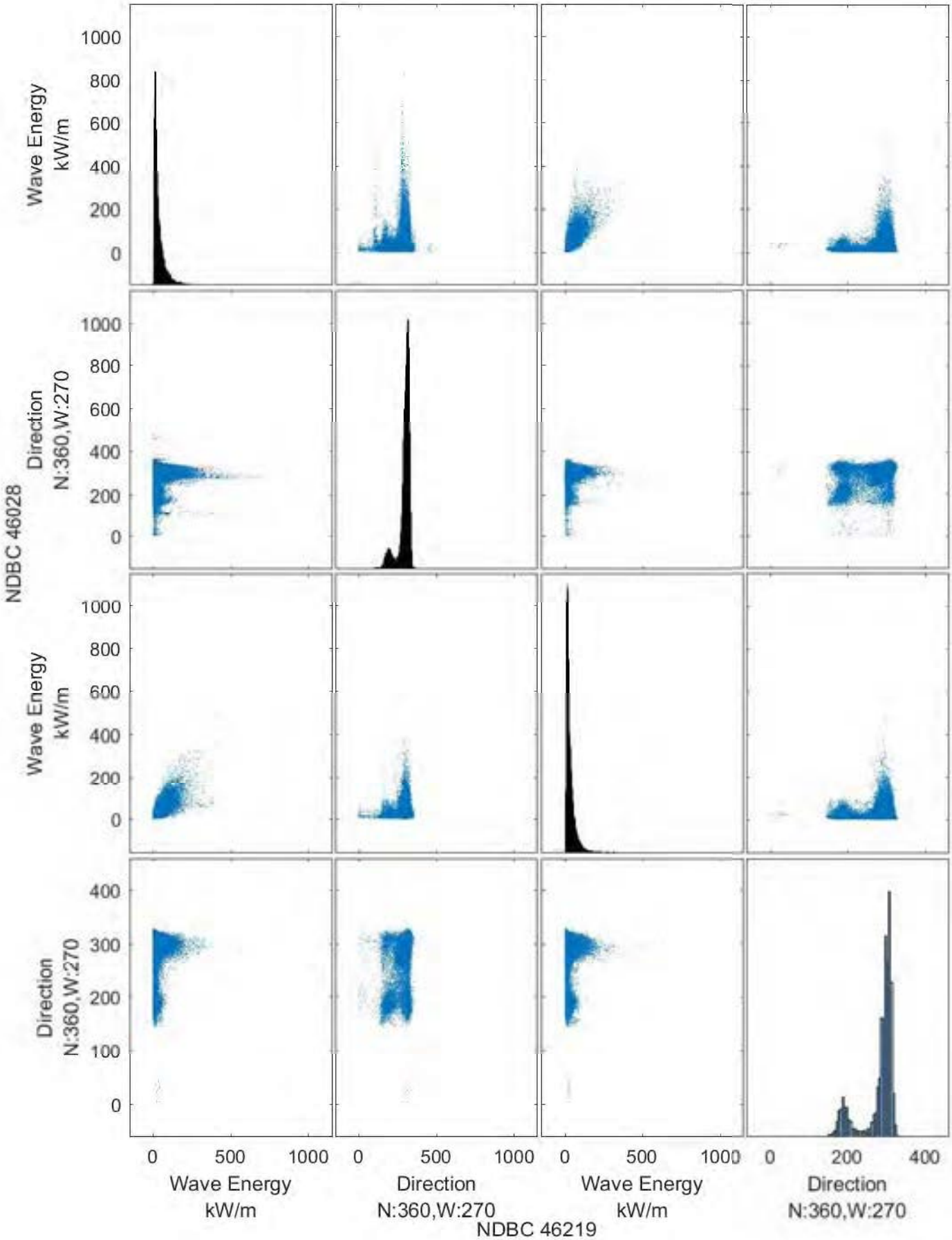


Figure C063: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46239.

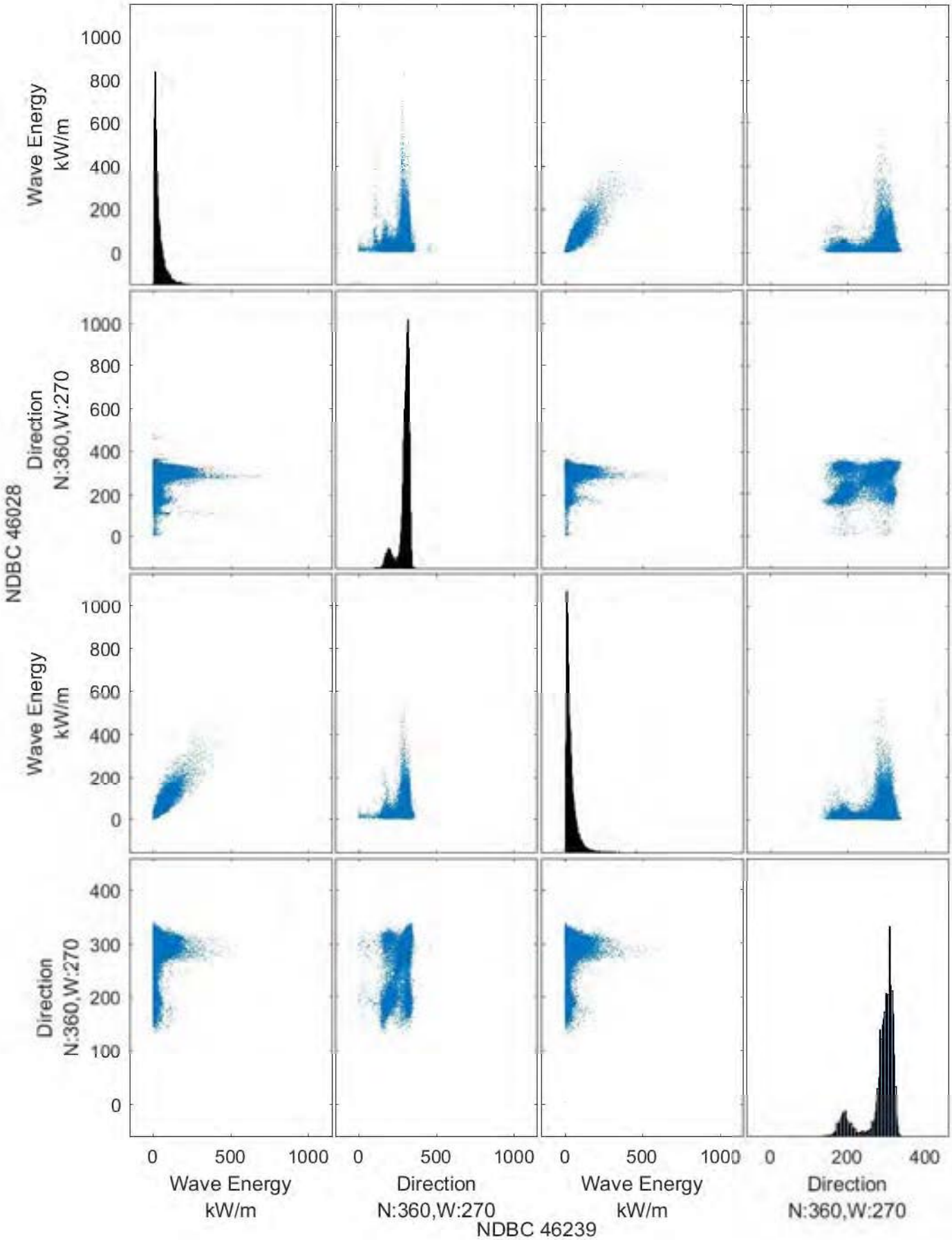


Figure C064: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46257.

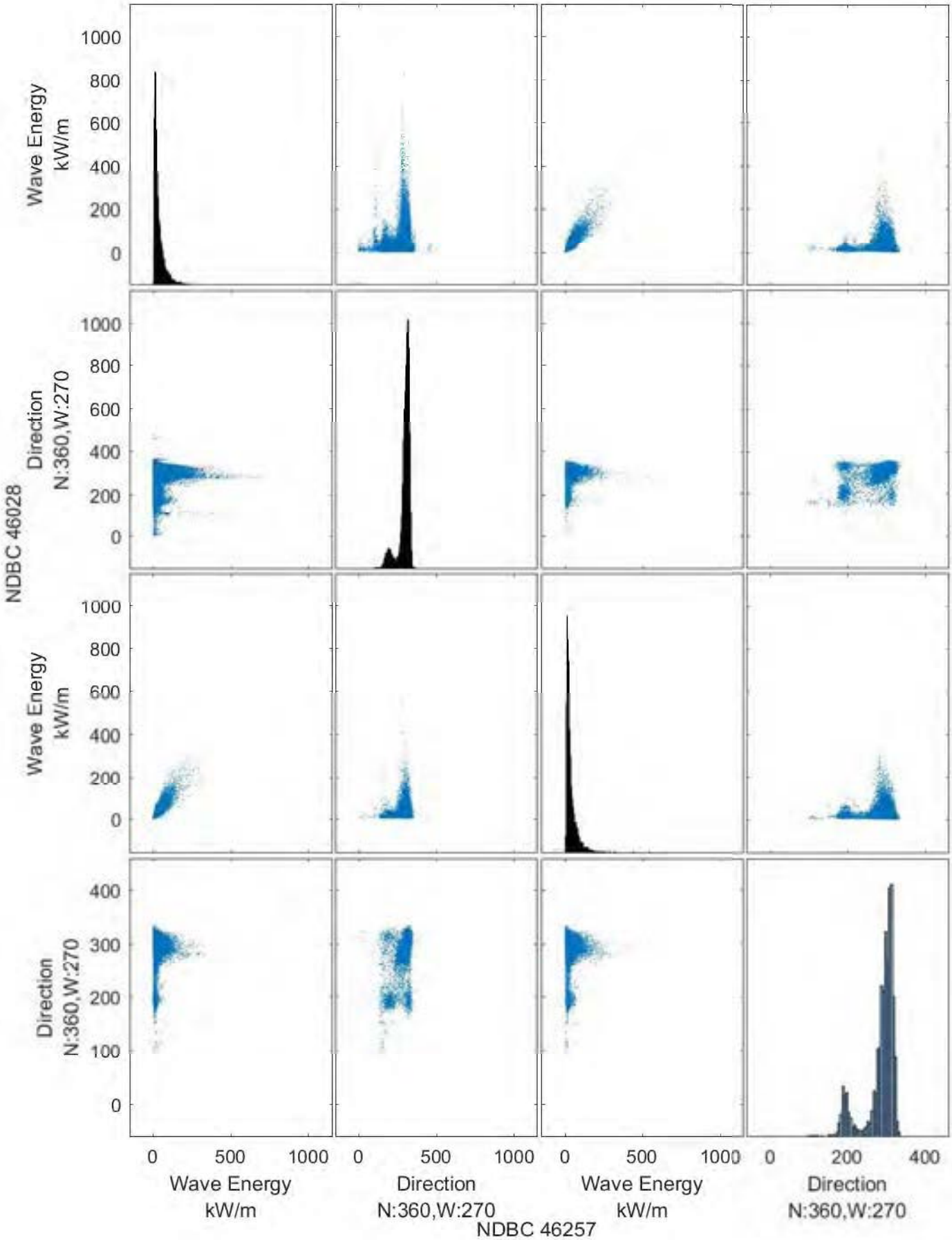


Figure C065: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46259.

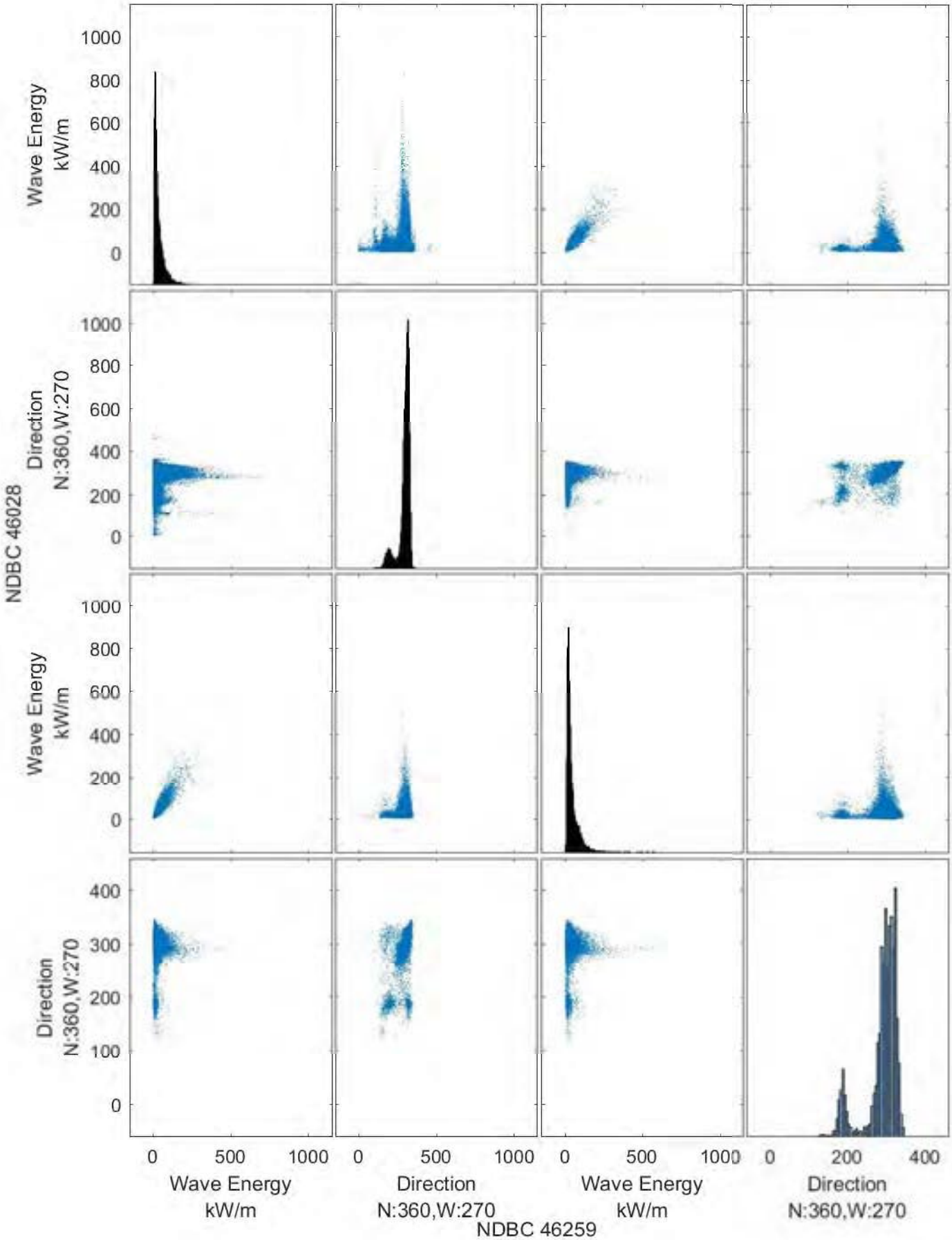


Figure C066: Cross Correlations for Wave Energyand Wave Direction for NDBC 46028 and NDBC 46028.

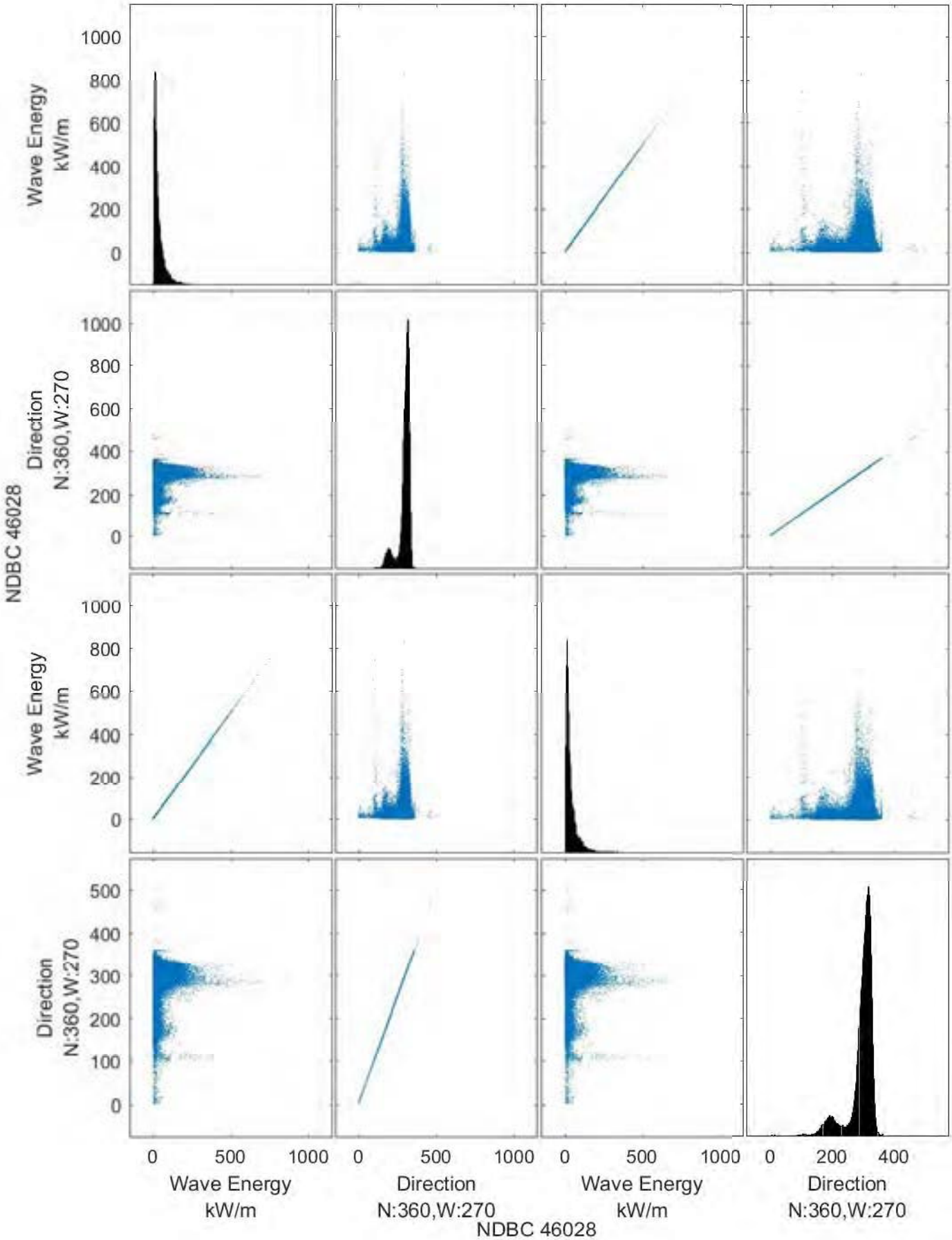


Figure C067: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46047.

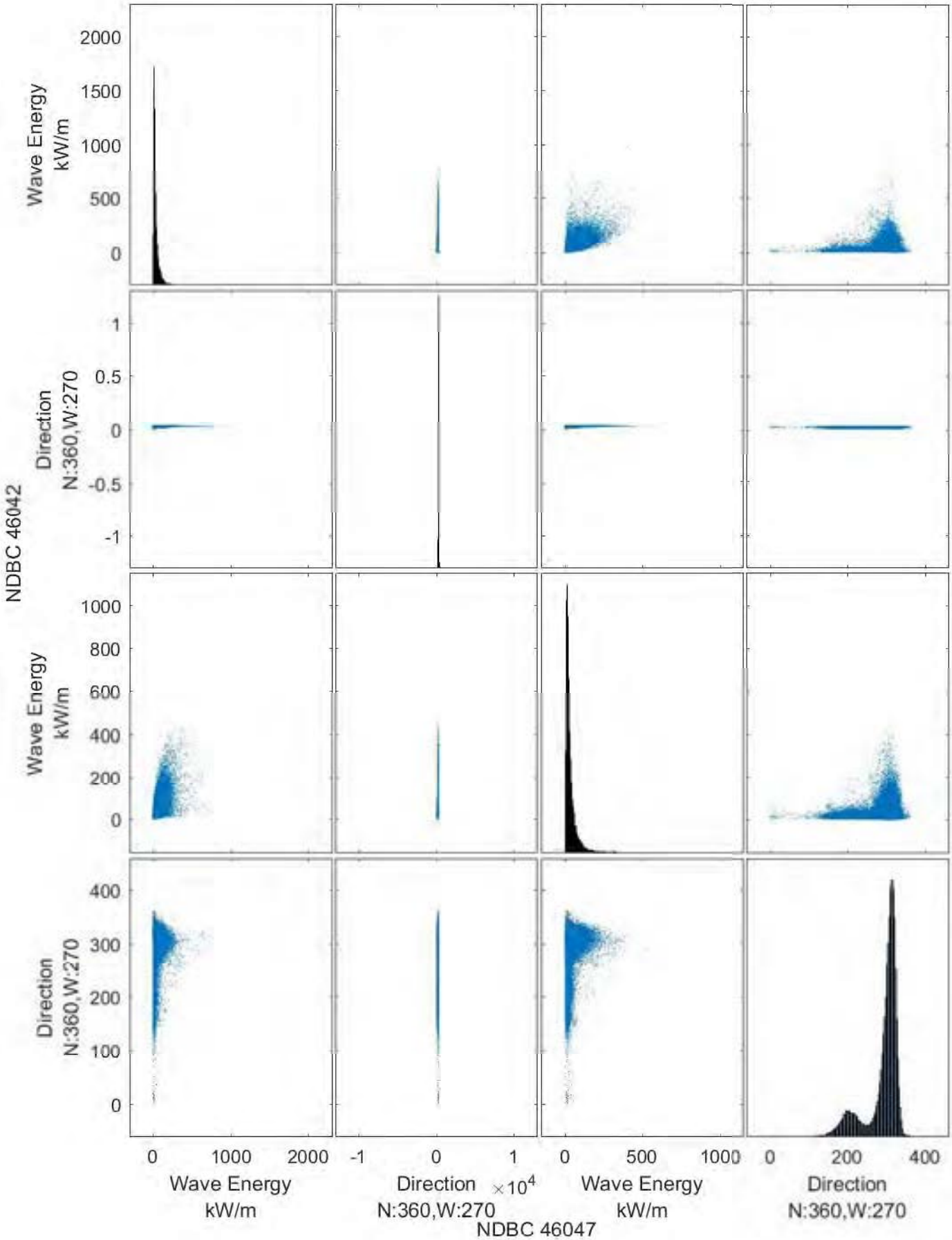


Figure C068: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46053.

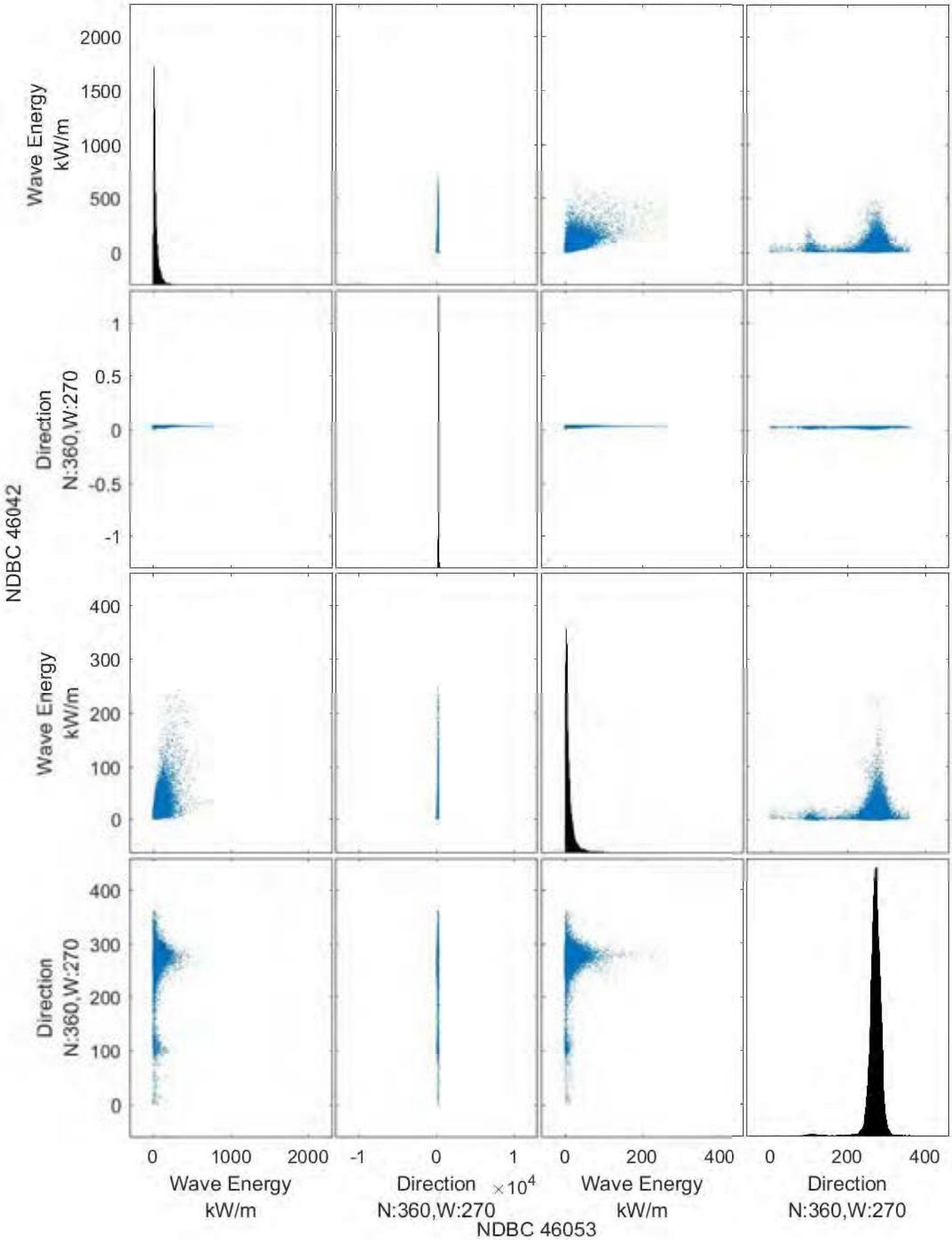


Figure C069: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46054.

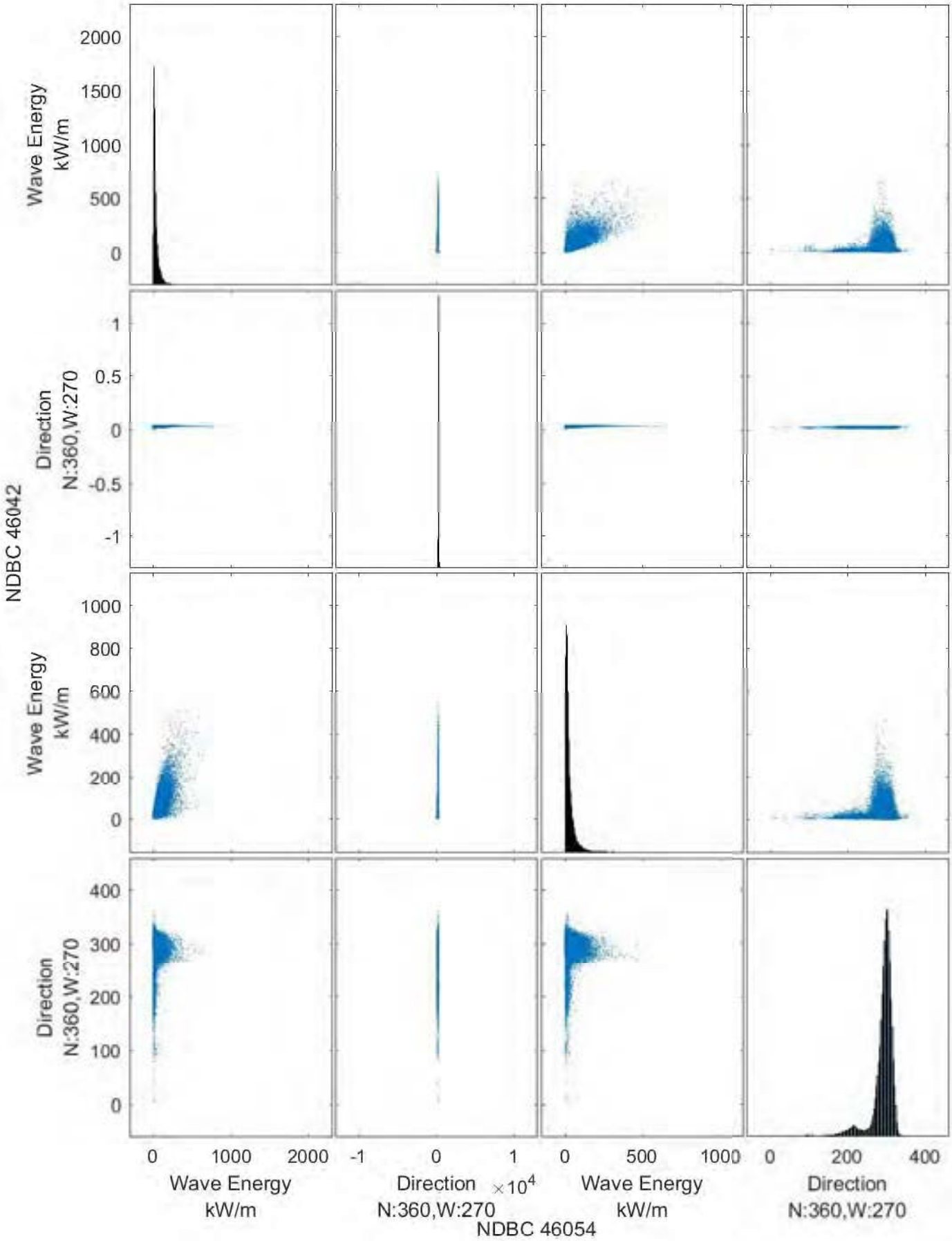


Figure C070: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46069.

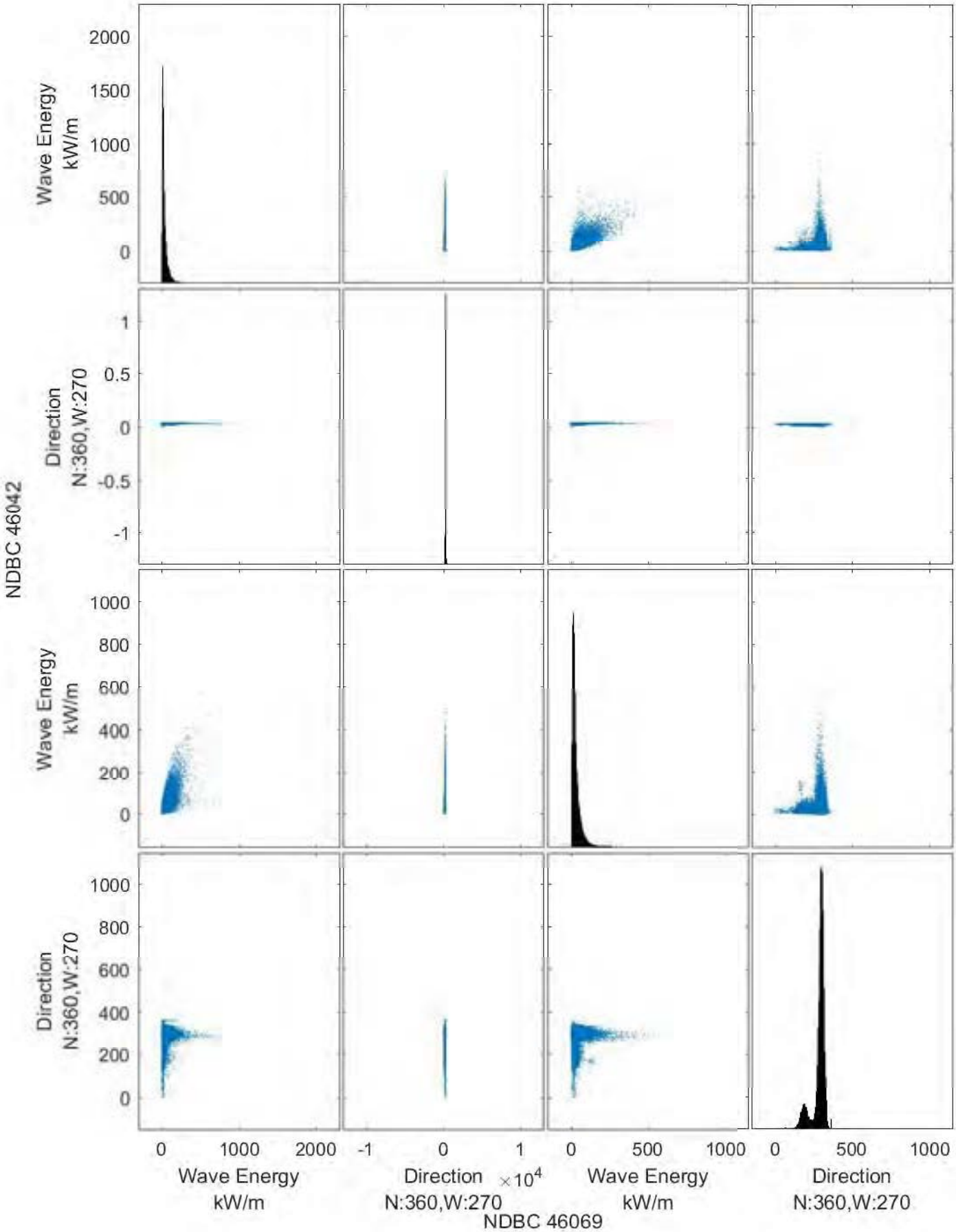


Figure C071: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46114.

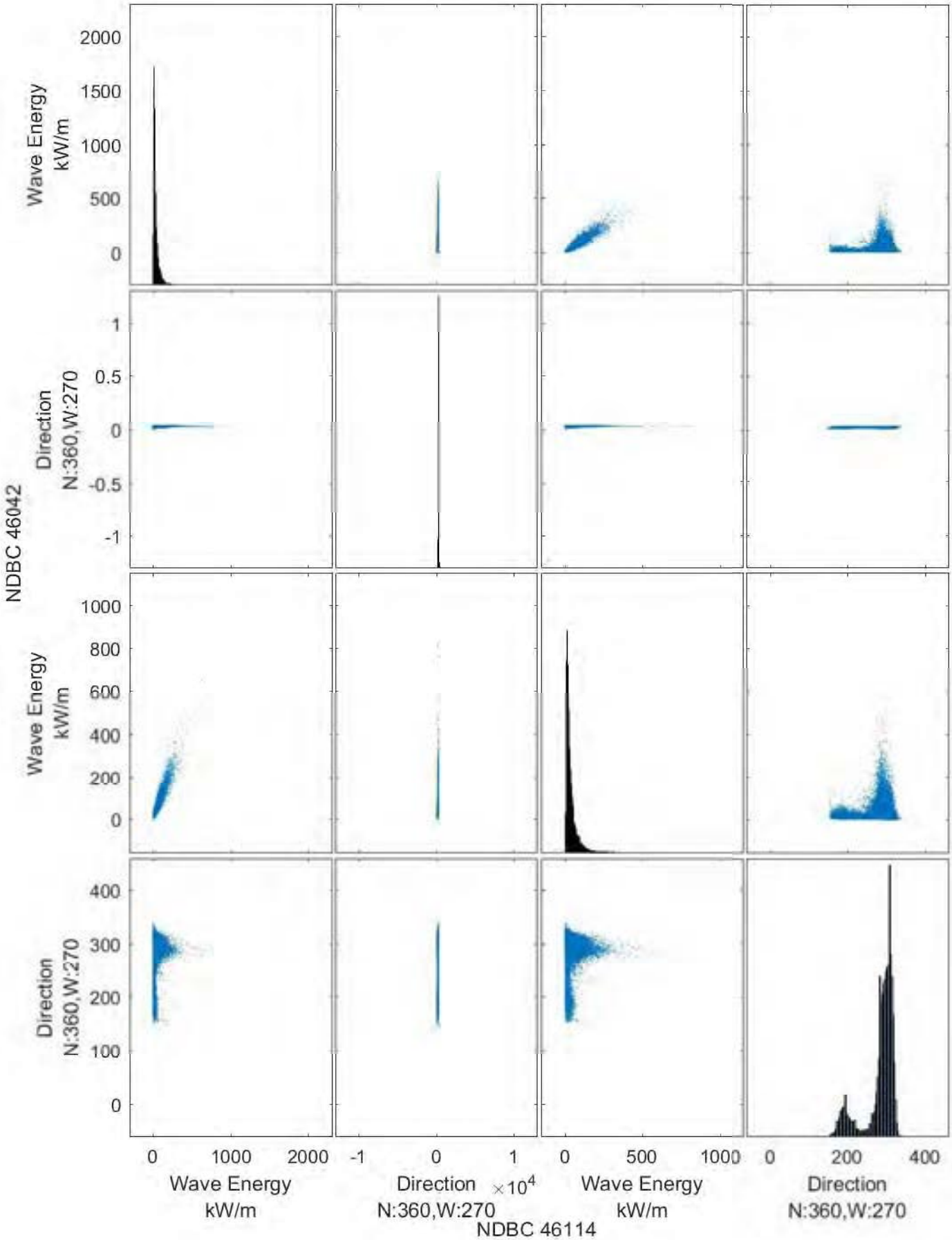


Figure C072: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46218.

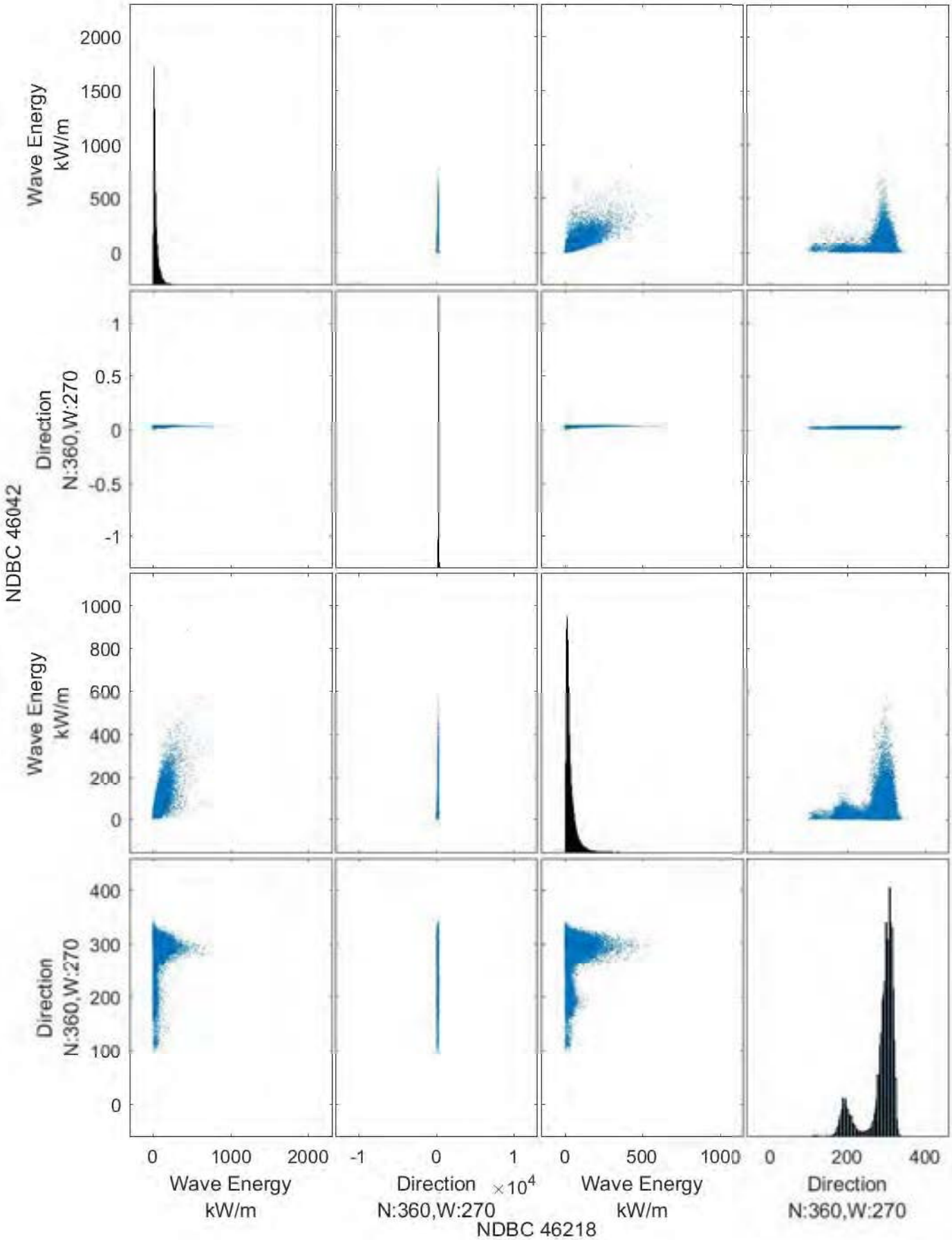


Figure C073: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46219.

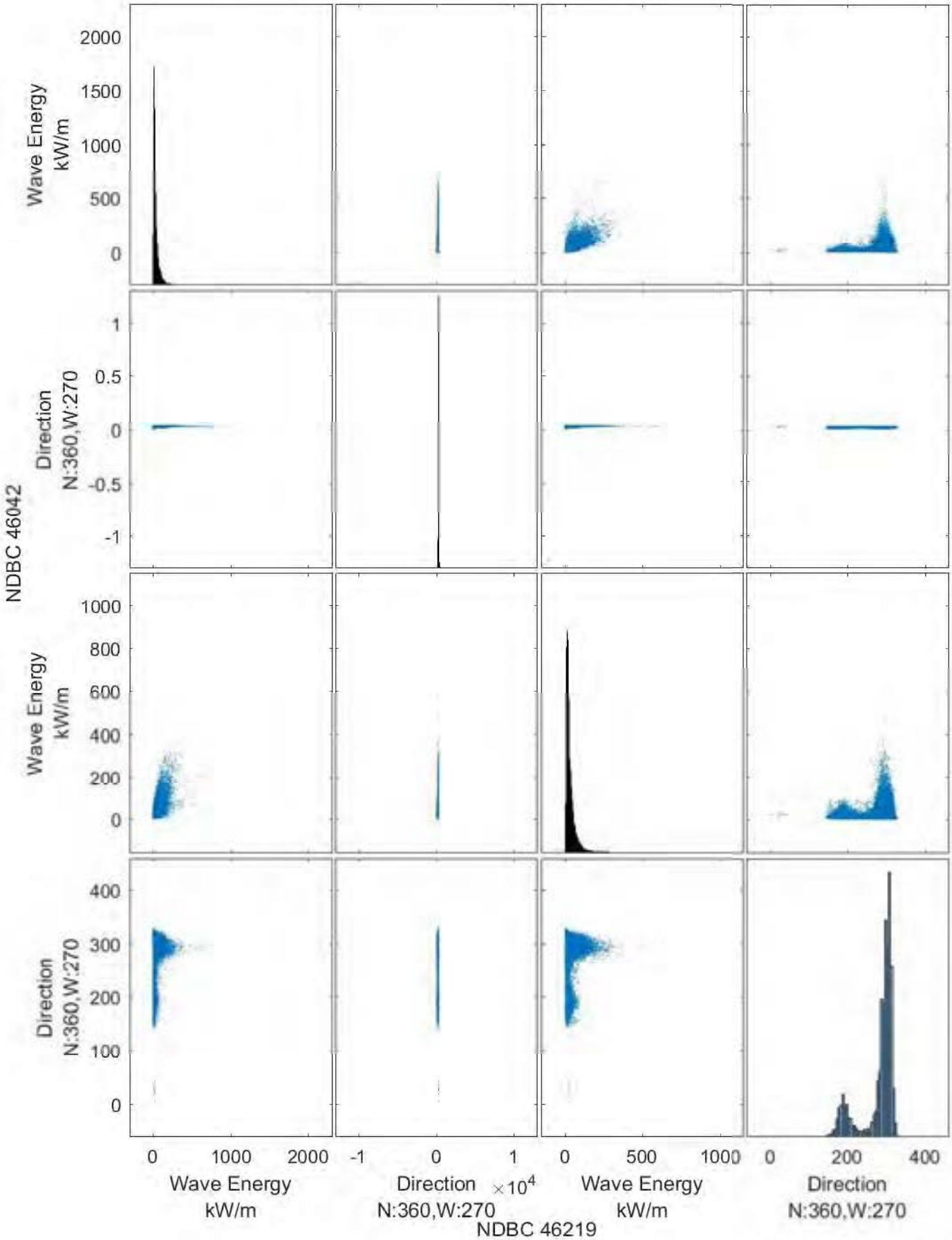


Figure C074: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46239.

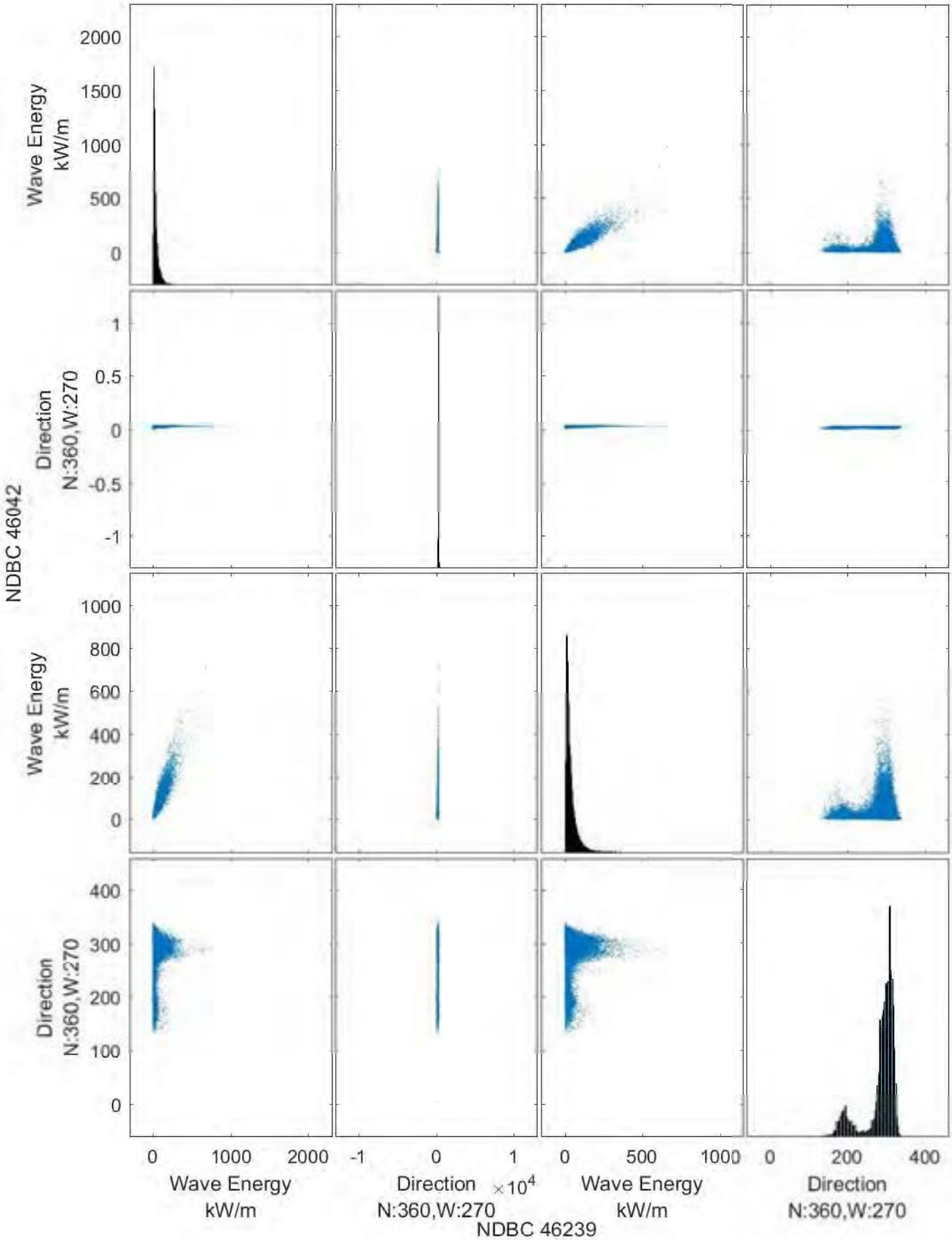


Figure C075: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46257.

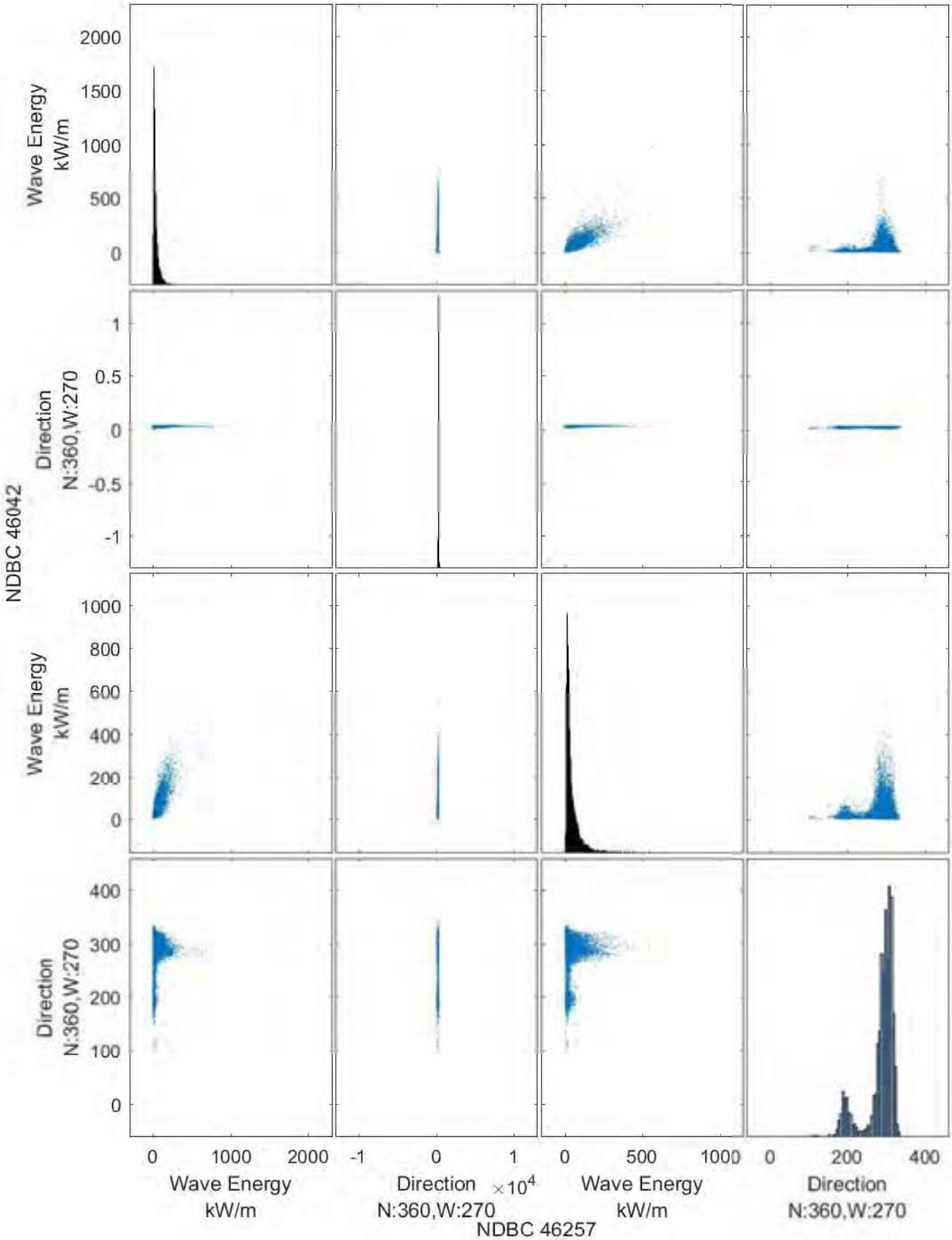


Figure C076: Cross Correlations for Wave Energyand Wave Direction for NDBC 46042 and NDBC 46259.

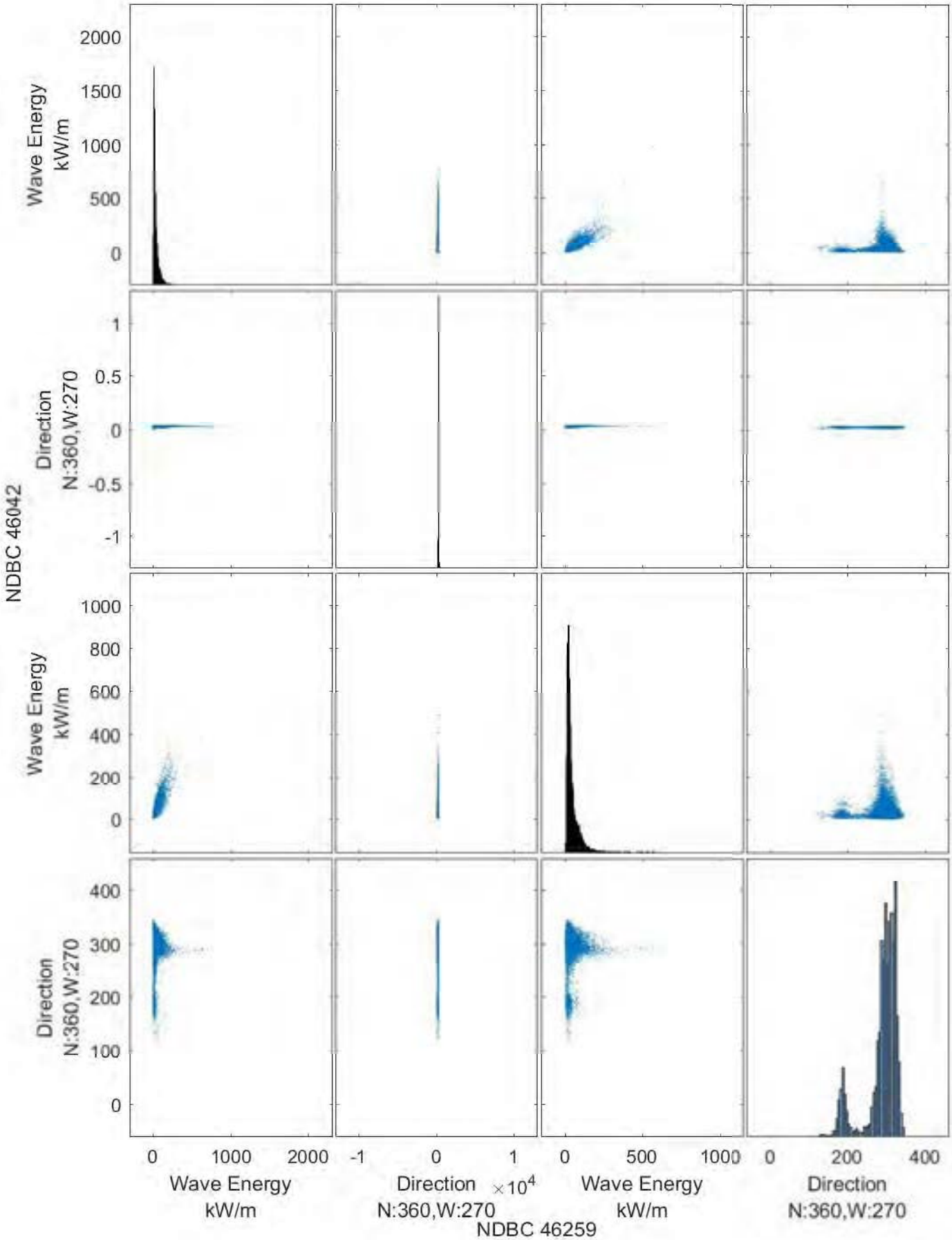


Figure C077: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46053.

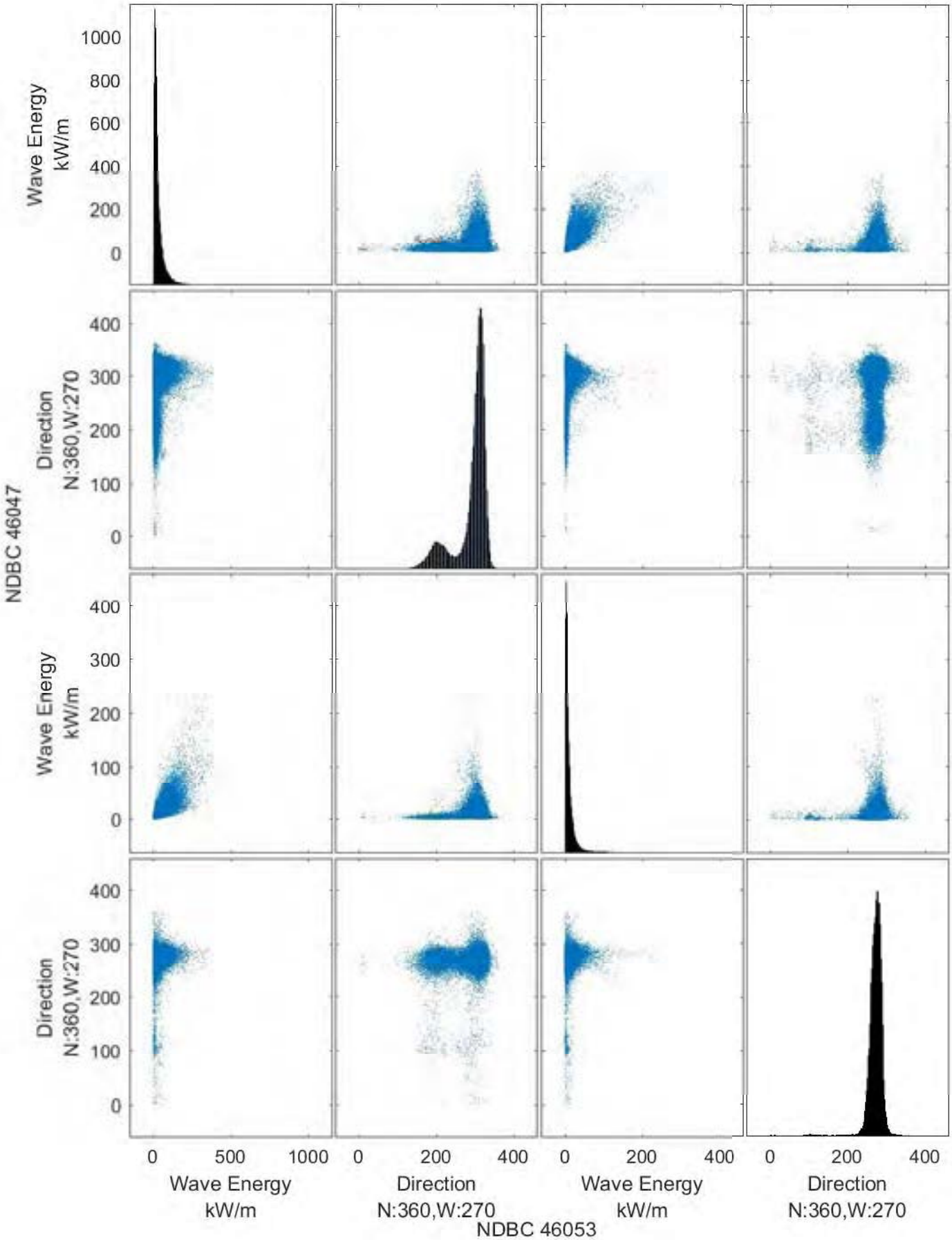


Figure C078: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46054.

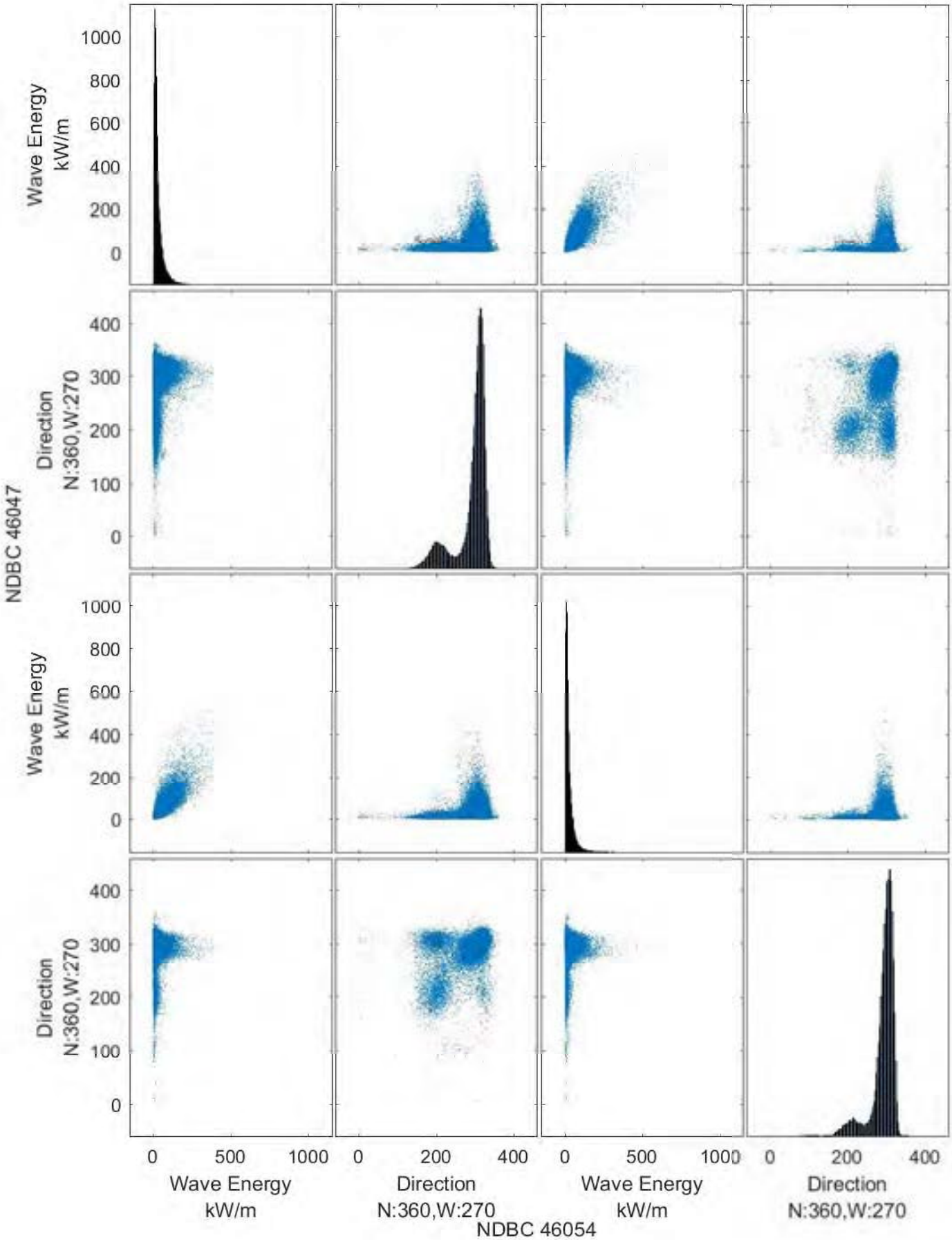


Figure C079: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46069.

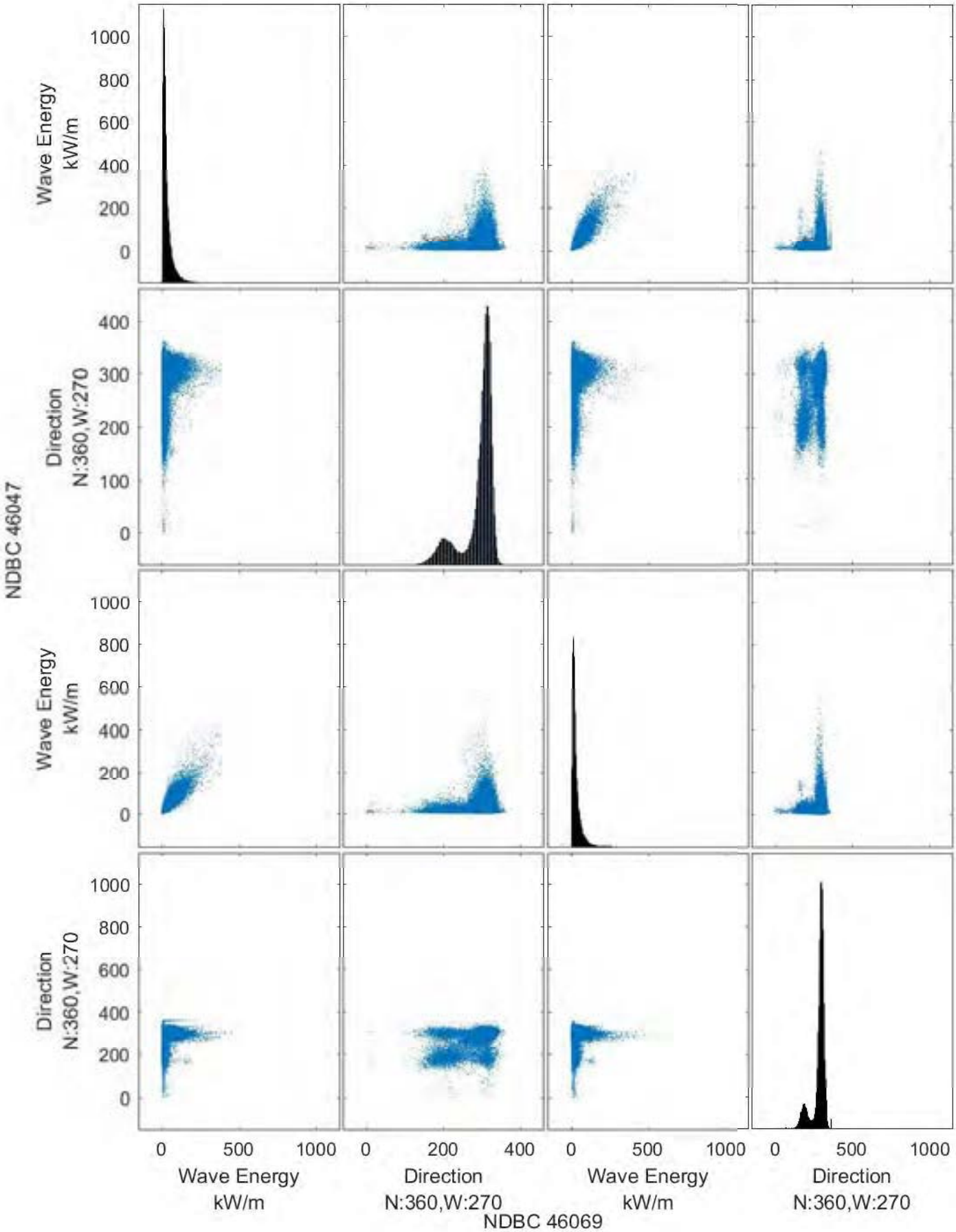


Figure C080: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46114.

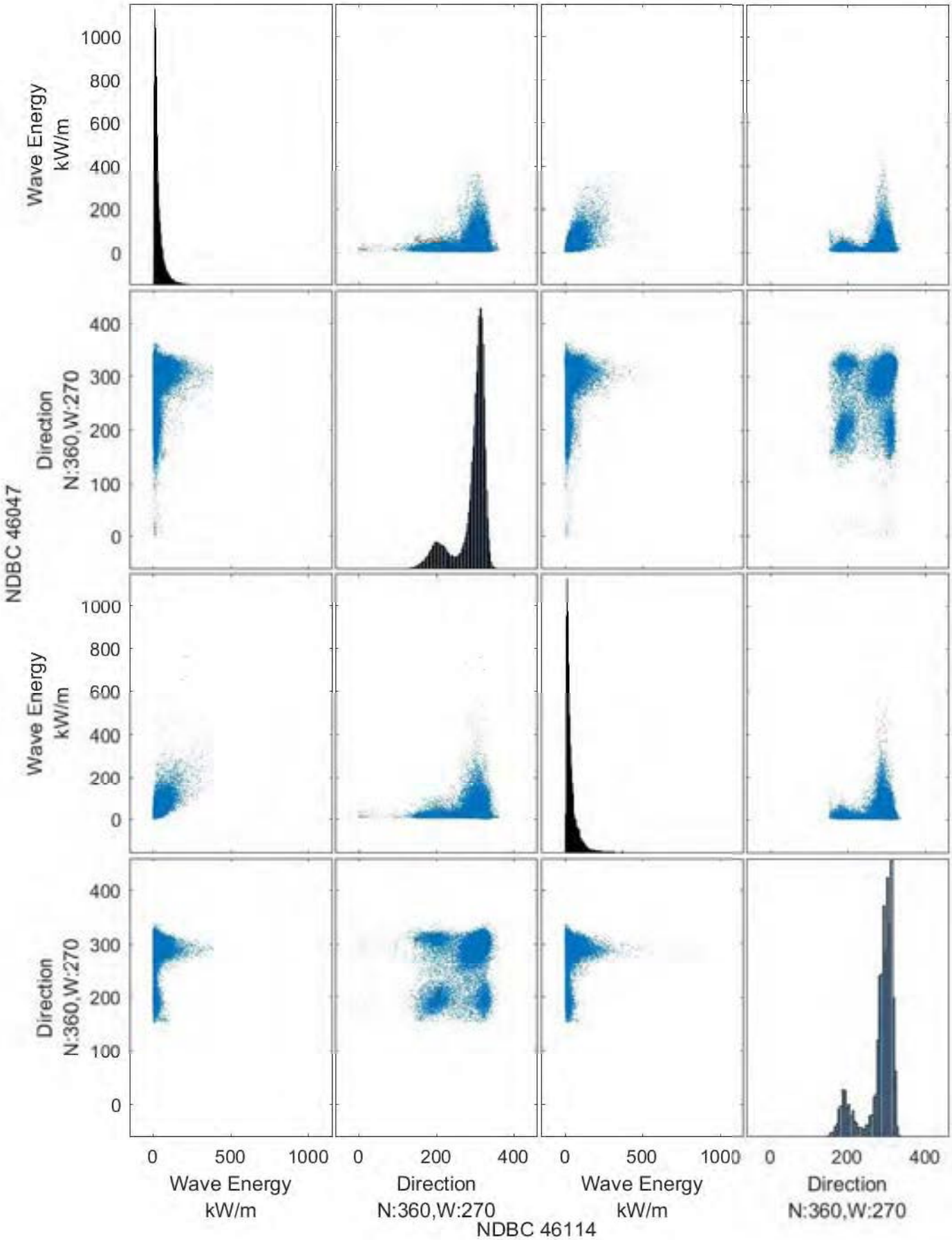


Figure C081: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46218.

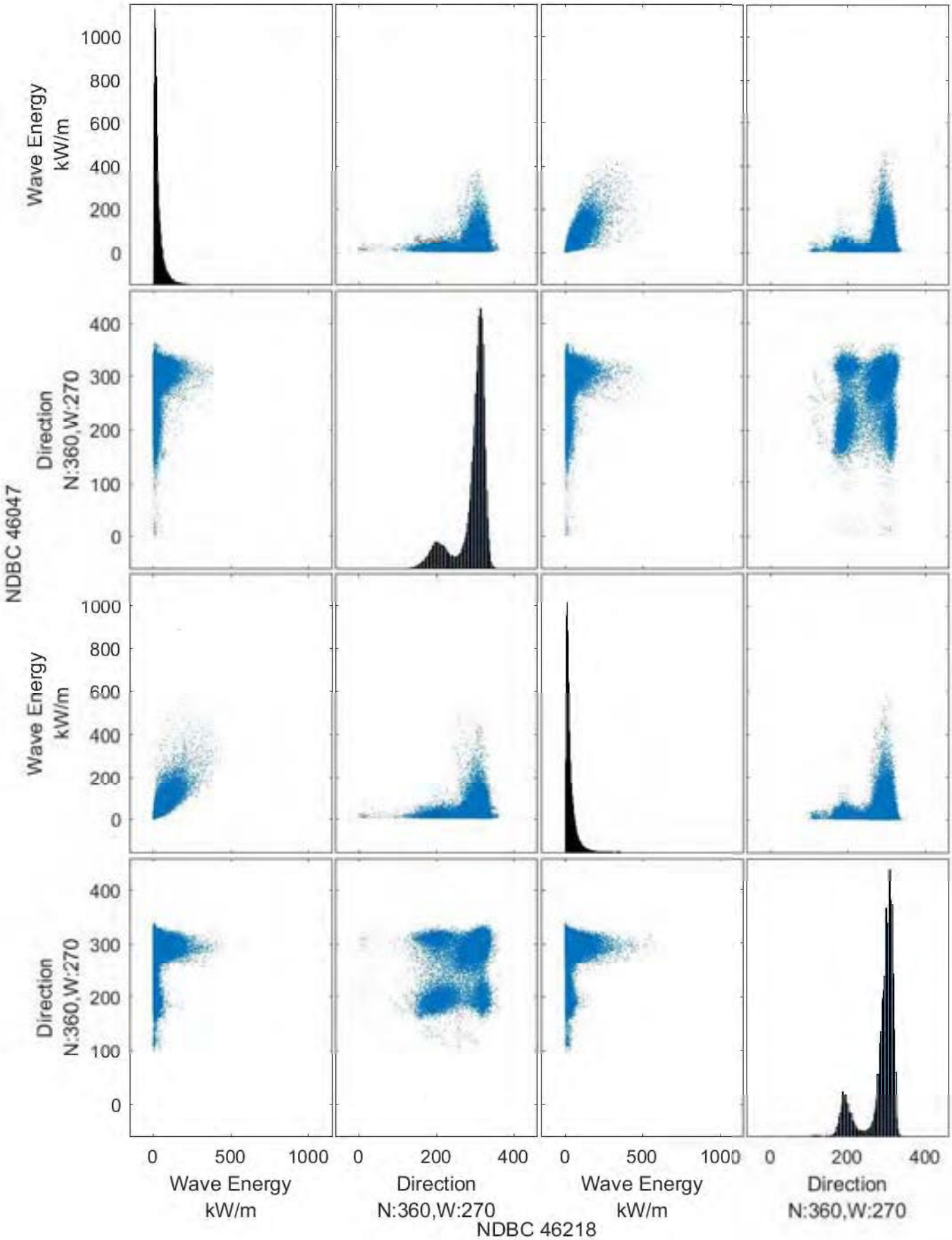


Figure C082: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46219.

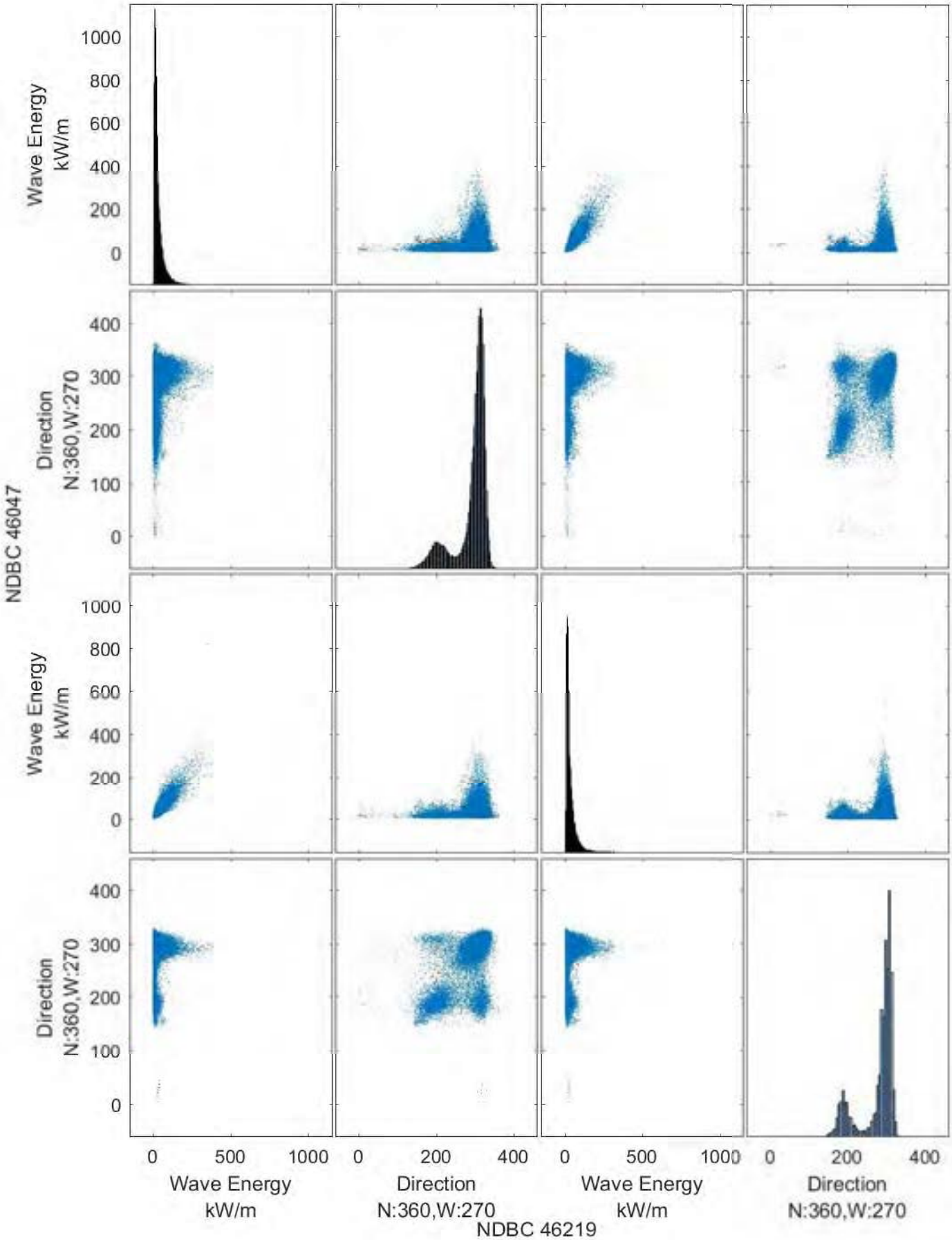


Figure C083: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46239.

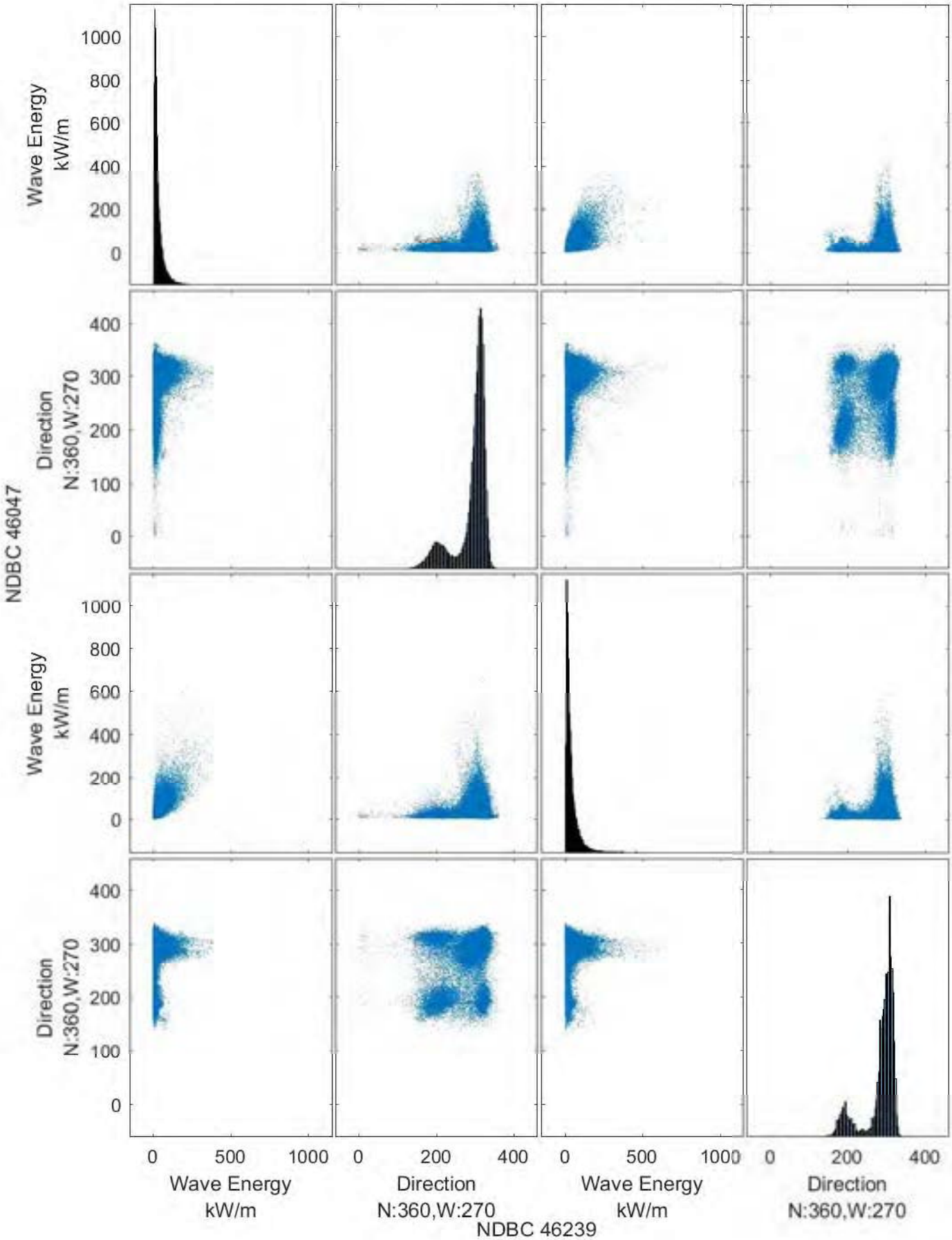
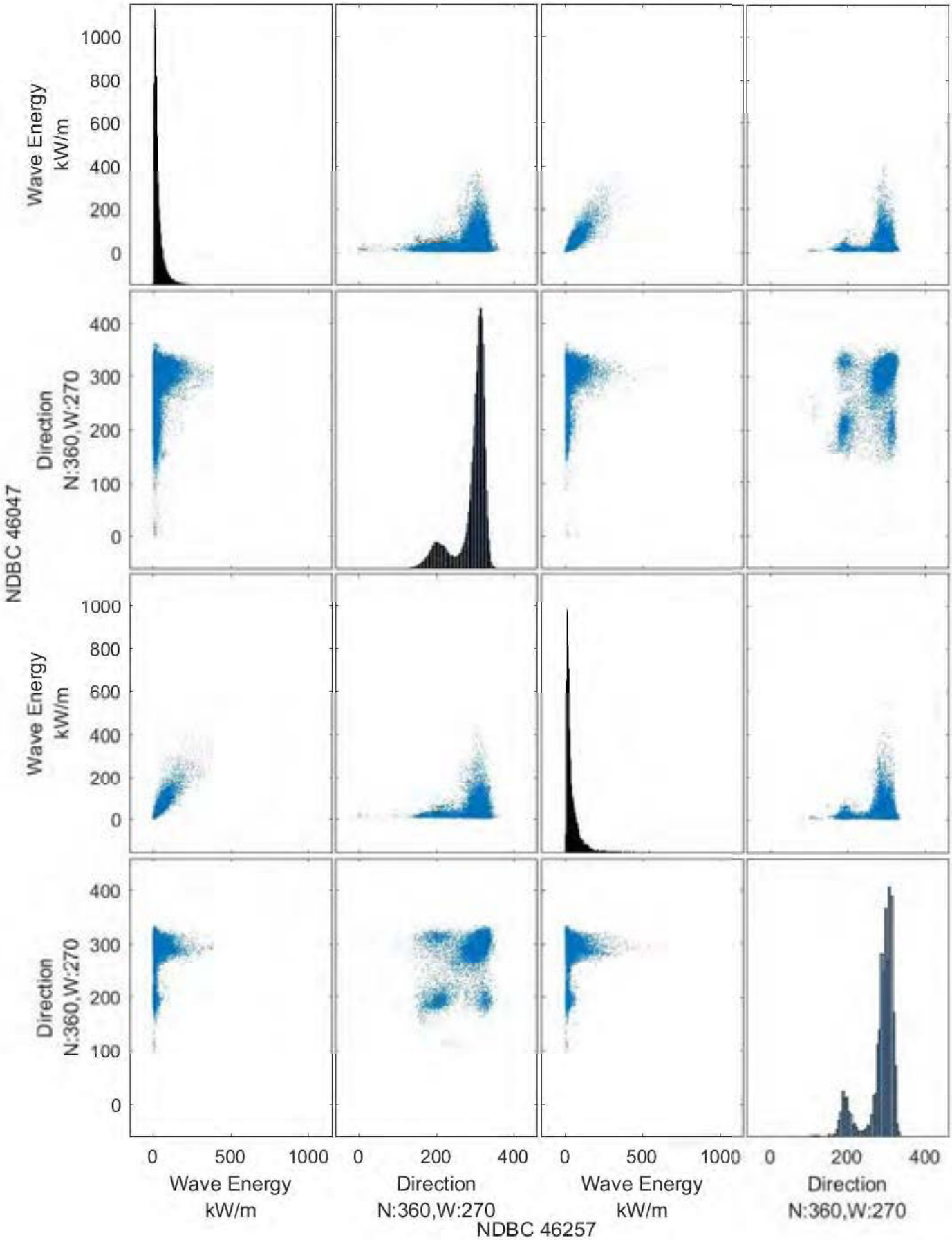


Figure C084: Cross Correlations for Wave Energyand Wave Direction for NDBC 46047 and NDBC 46257.



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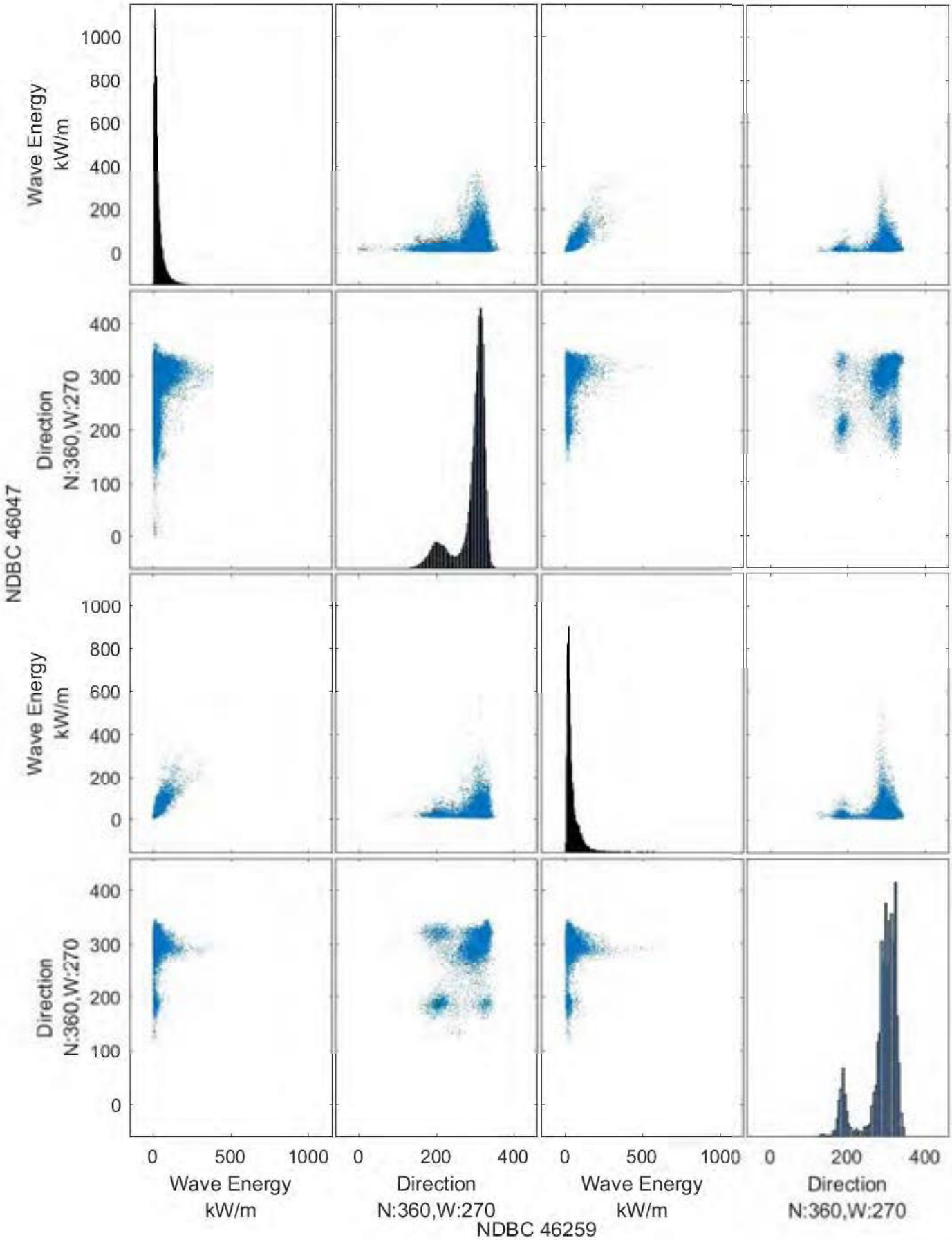
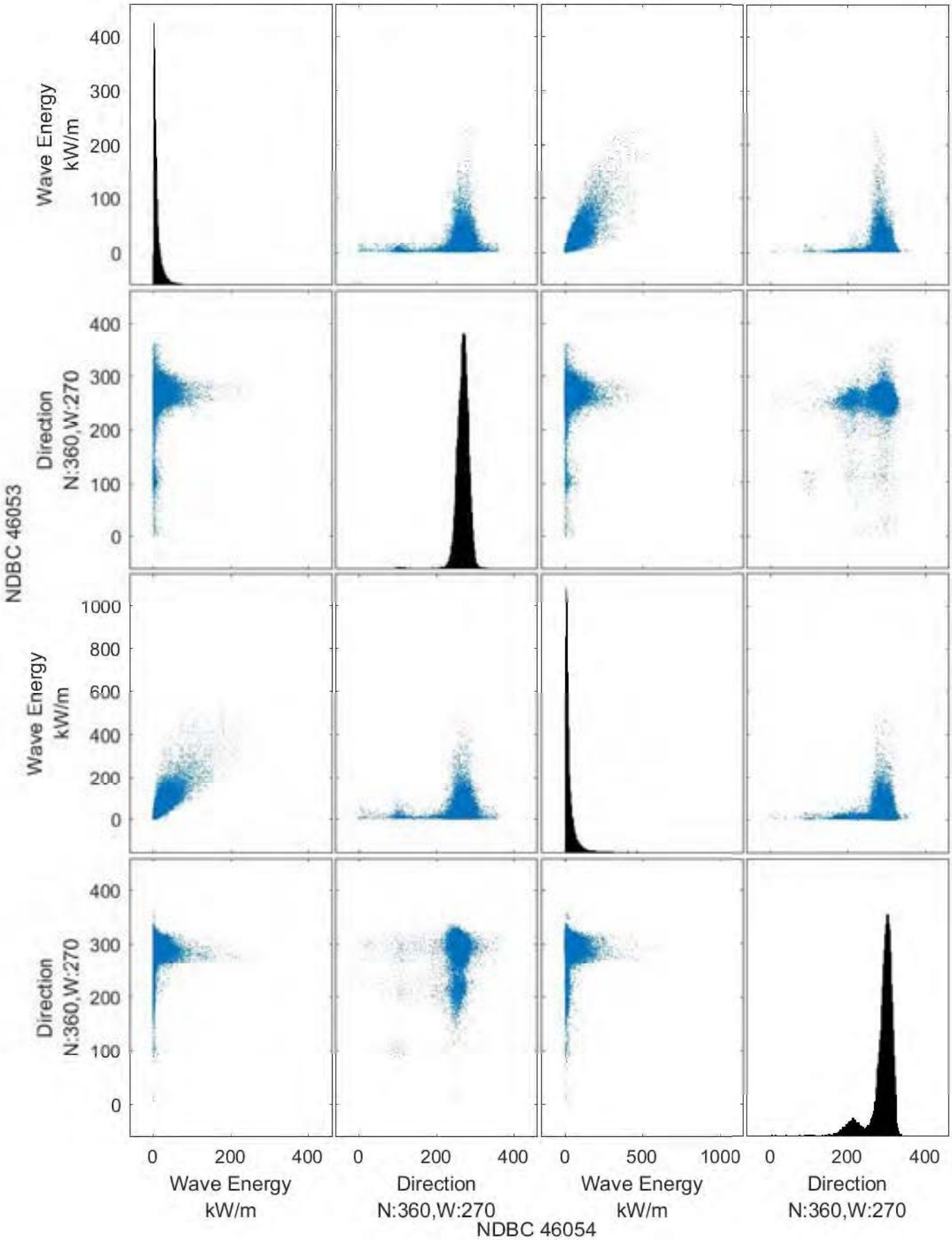


Figure C086: Cross Correlations for Wave Energyand Wave Direction for NDBC 46053 and NDBC 46054.



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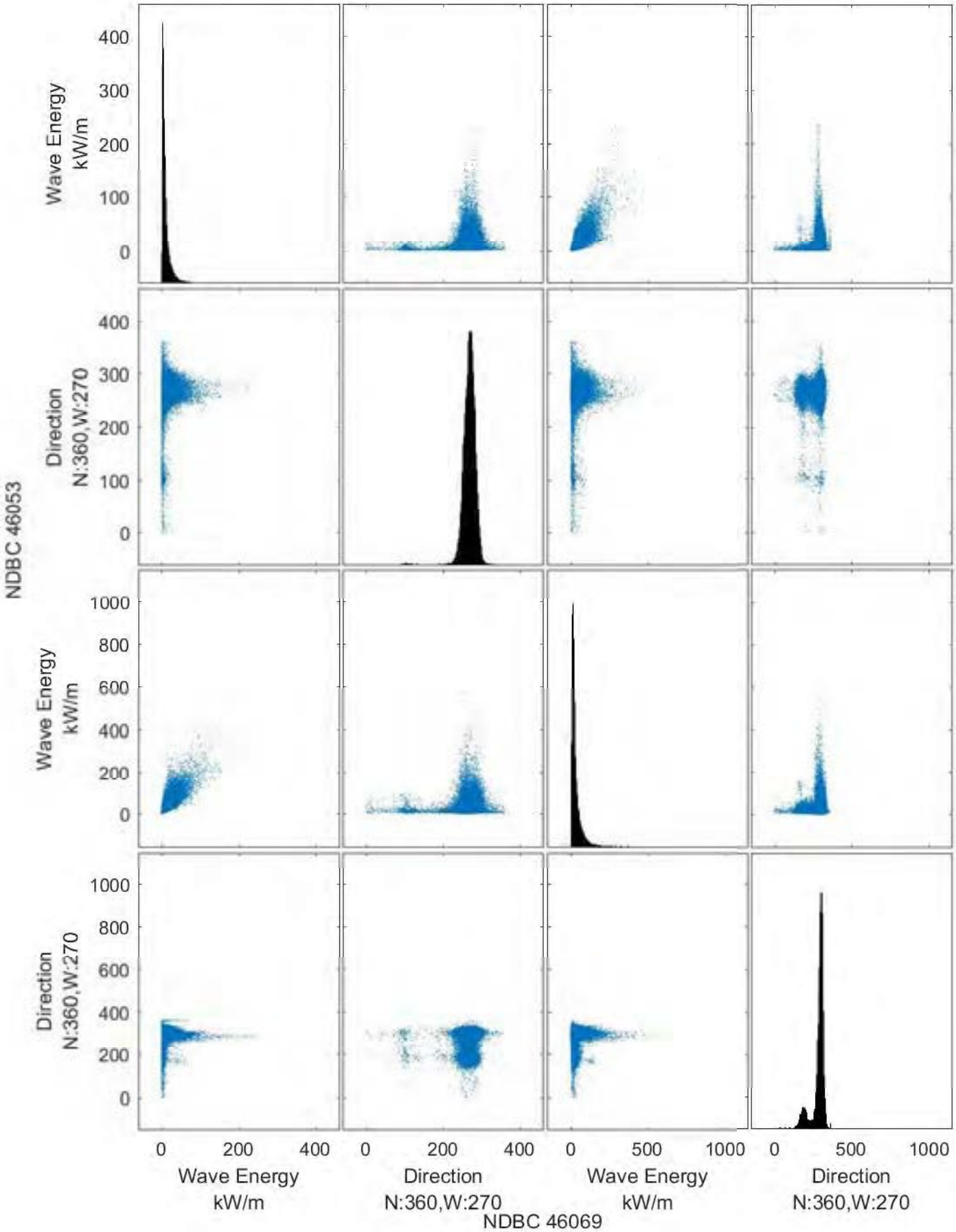


Figure C088: Cross Correlations for Wave Energyand Wave Direction for NDBC 46053 and NDBC 46114.

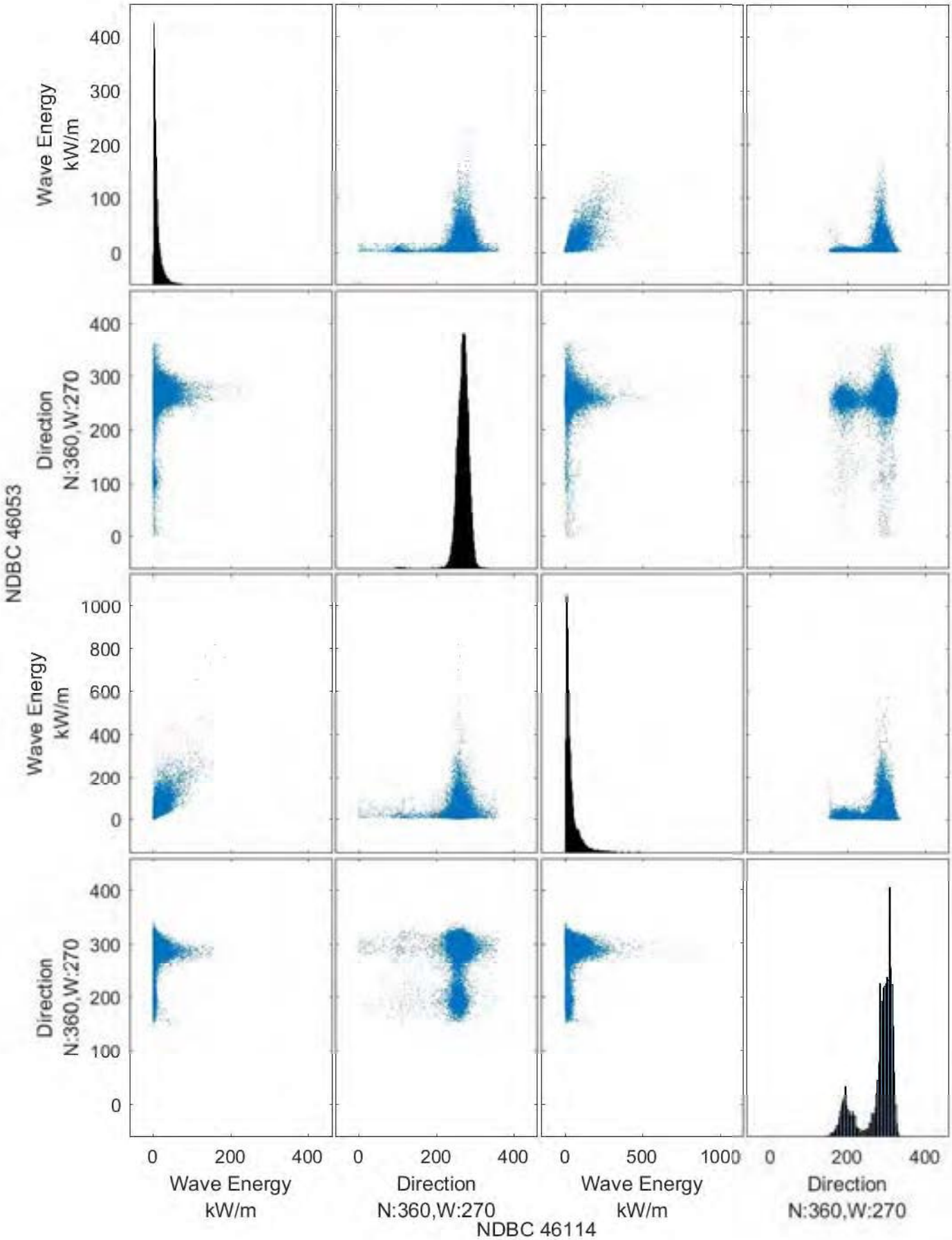


Figure C089: Cross Correlations for Wave Energyand Wave Direction for NDBC 46053 and NDBC 46218.

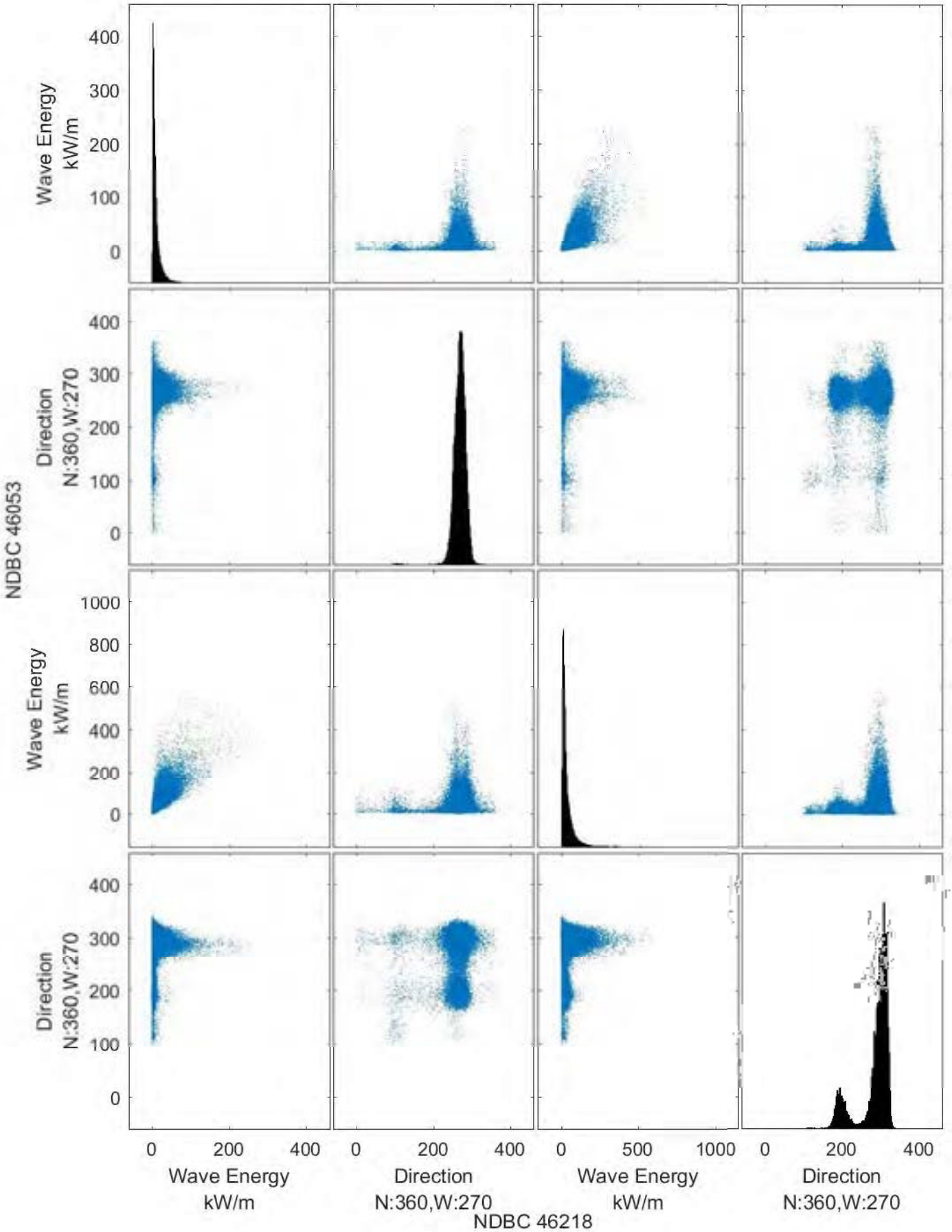
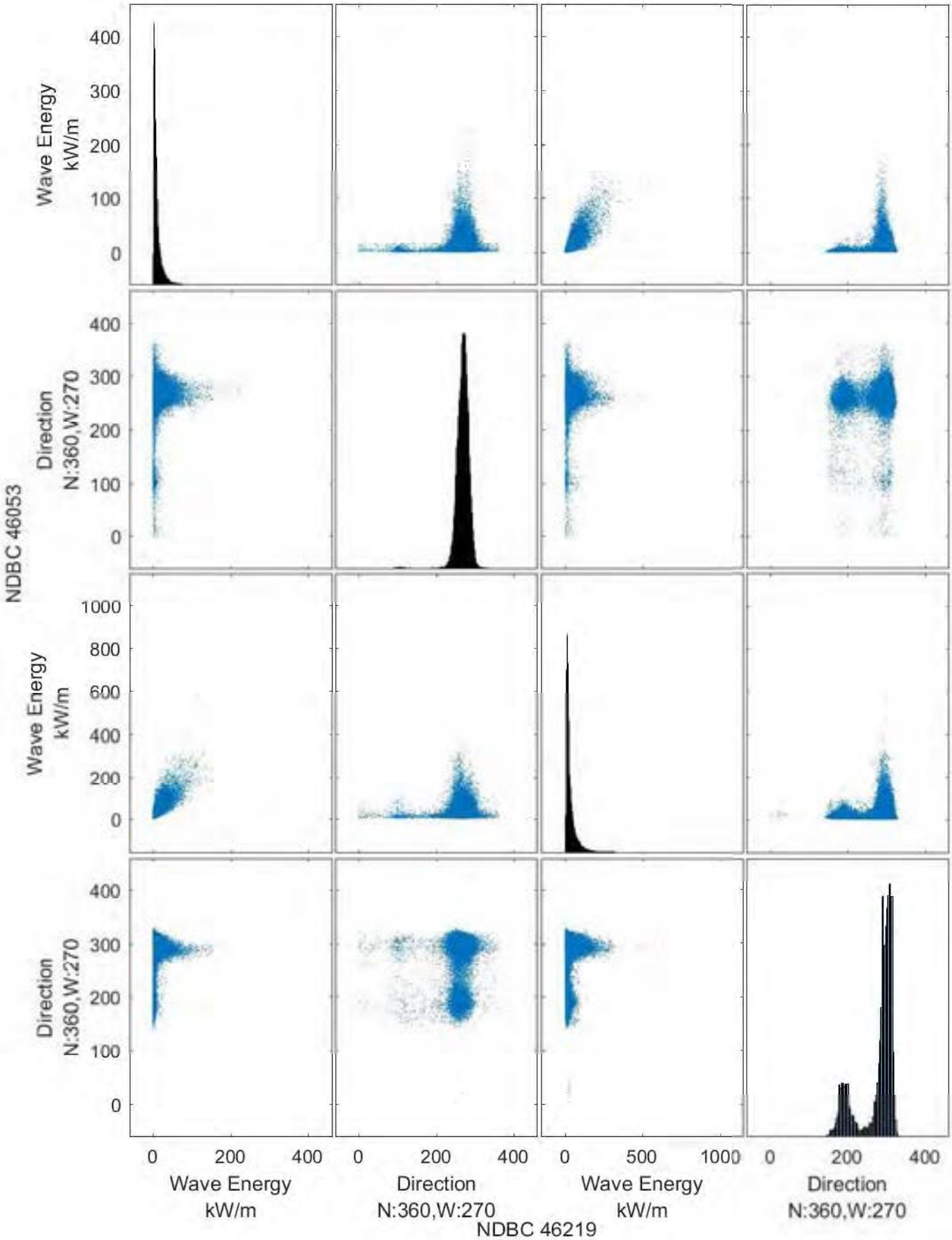


Figure C090: Cross Correlations for Wave Energyand Wave Direction for NDBC 46053 and NDBC 46219.



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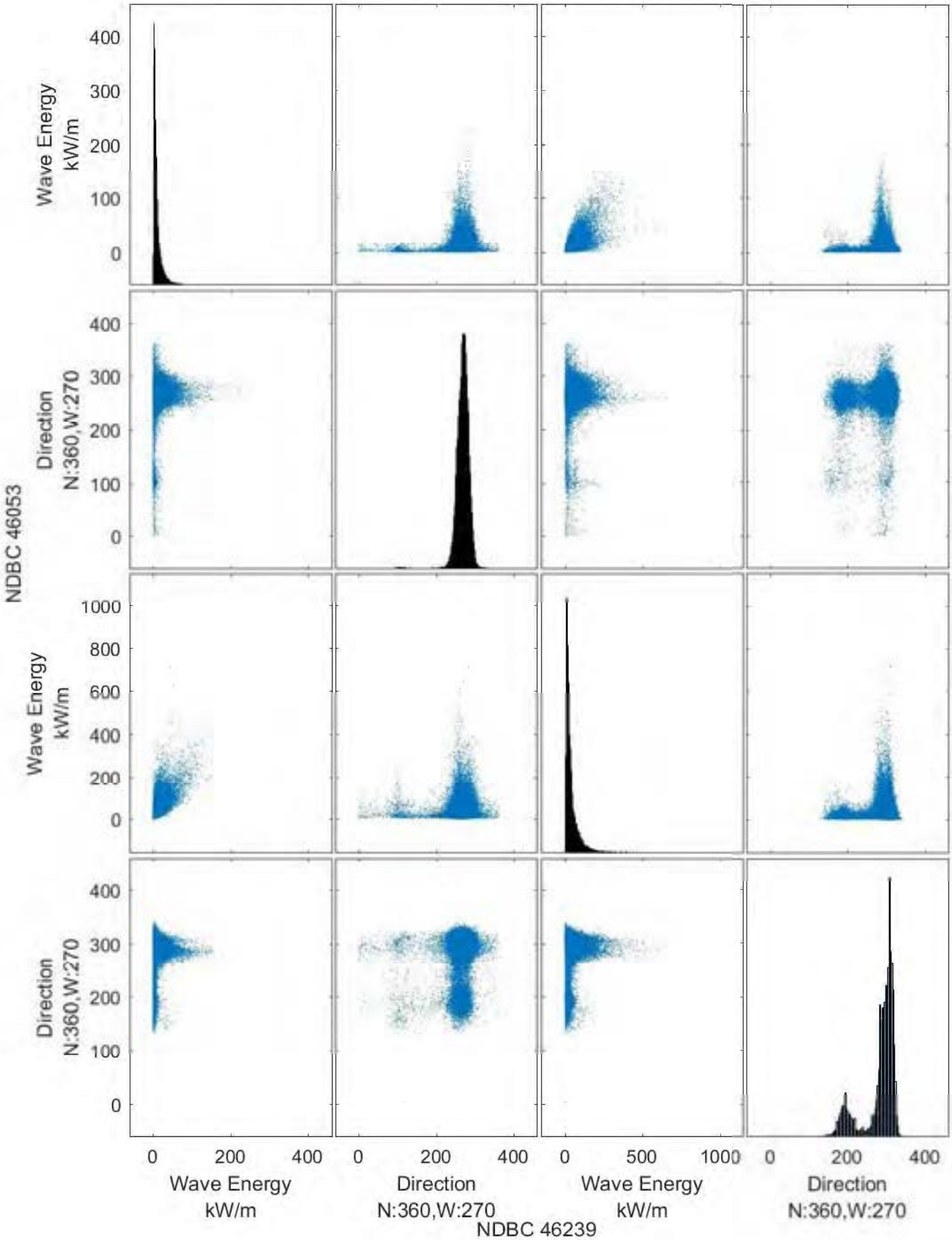


Figure C092: Cross Correlations for Wave Energyand Wave Direction for NDBC 46053 and NDBC 46257.

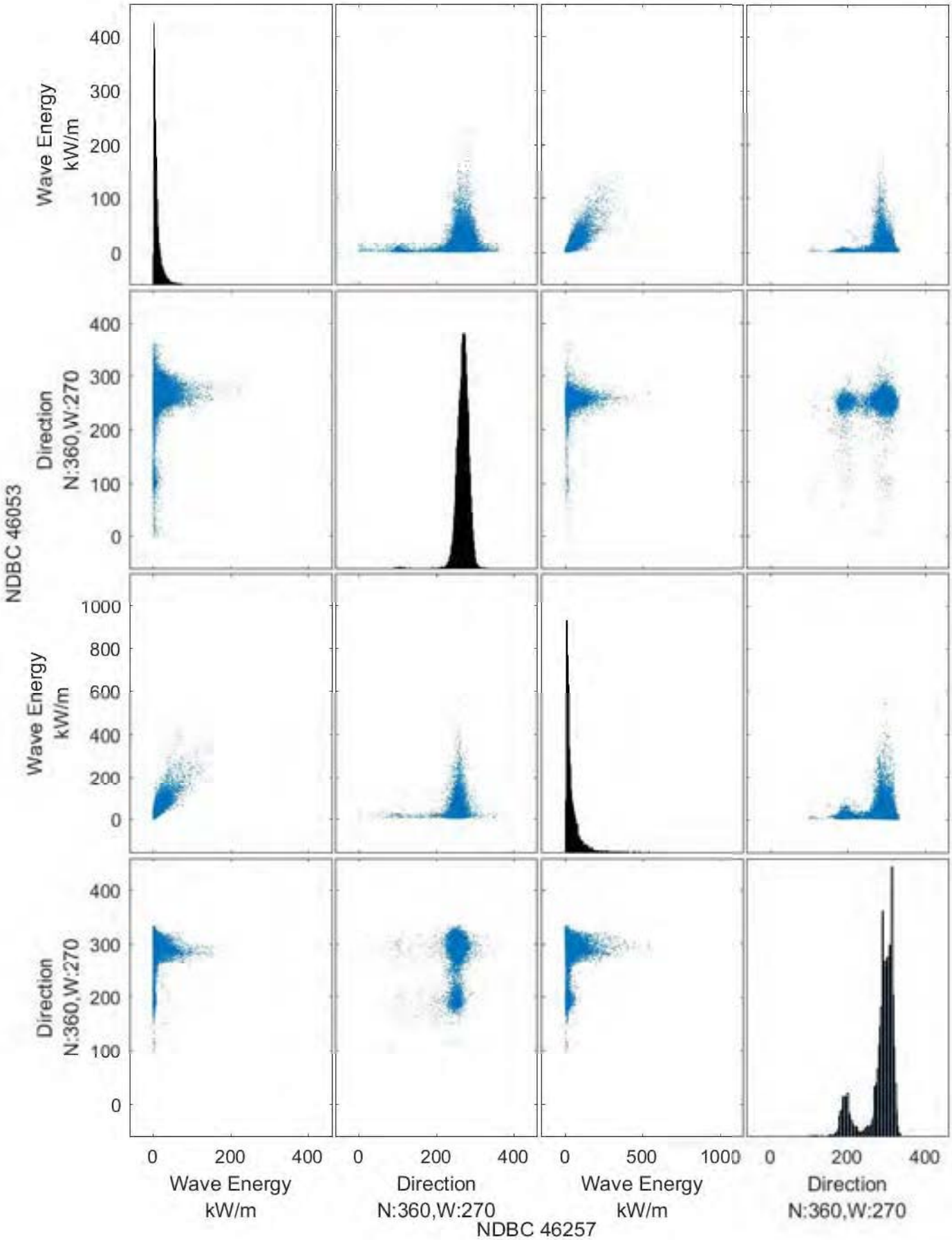


Figure C093: Cross Correlations for Wave Energyand Wave Direction for NDBC 46053 and NDBC 46259.

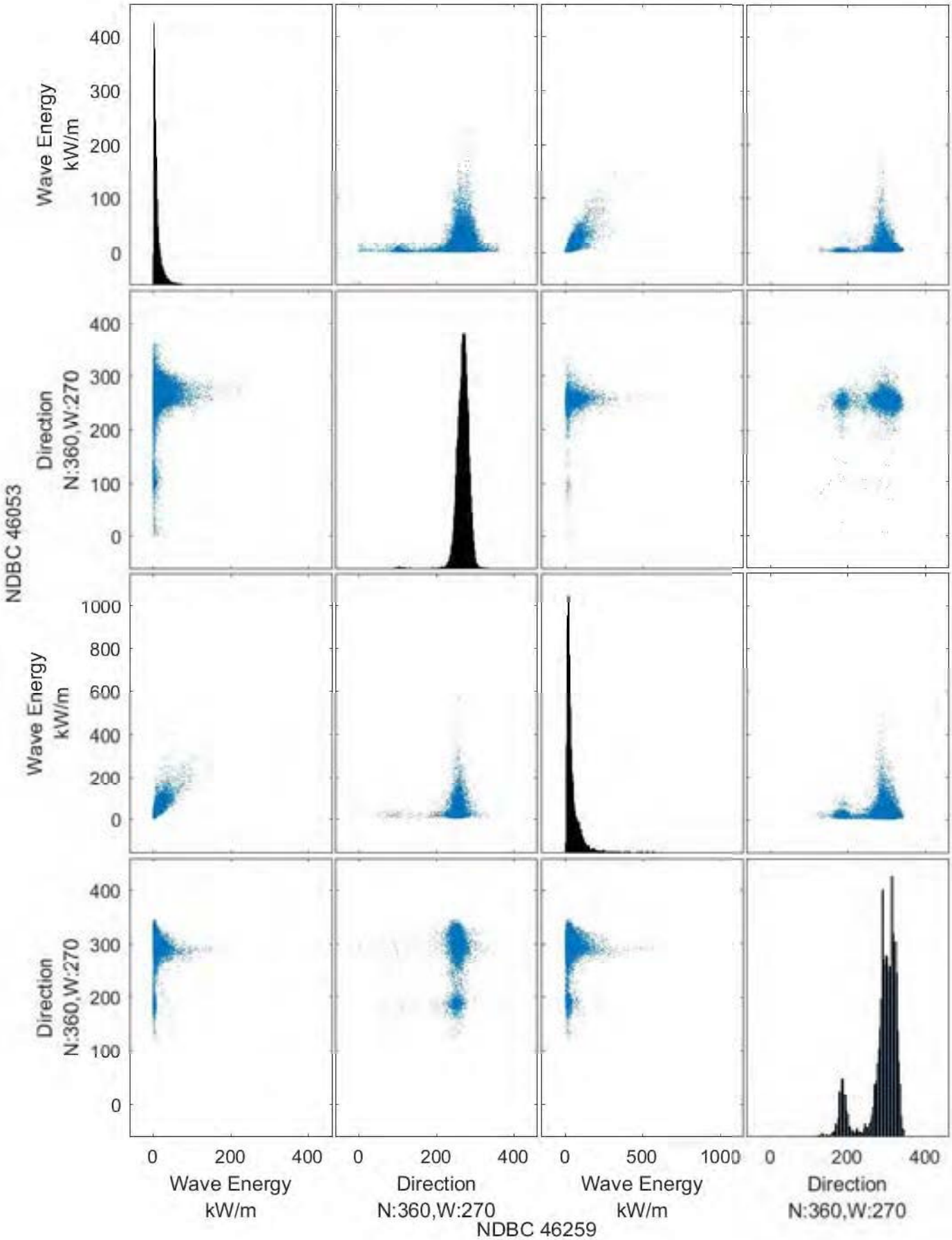


Figure C094: Cross Correlations for Wave Energyand Wave Direction for NDBC 46053 and NDBC 46259.

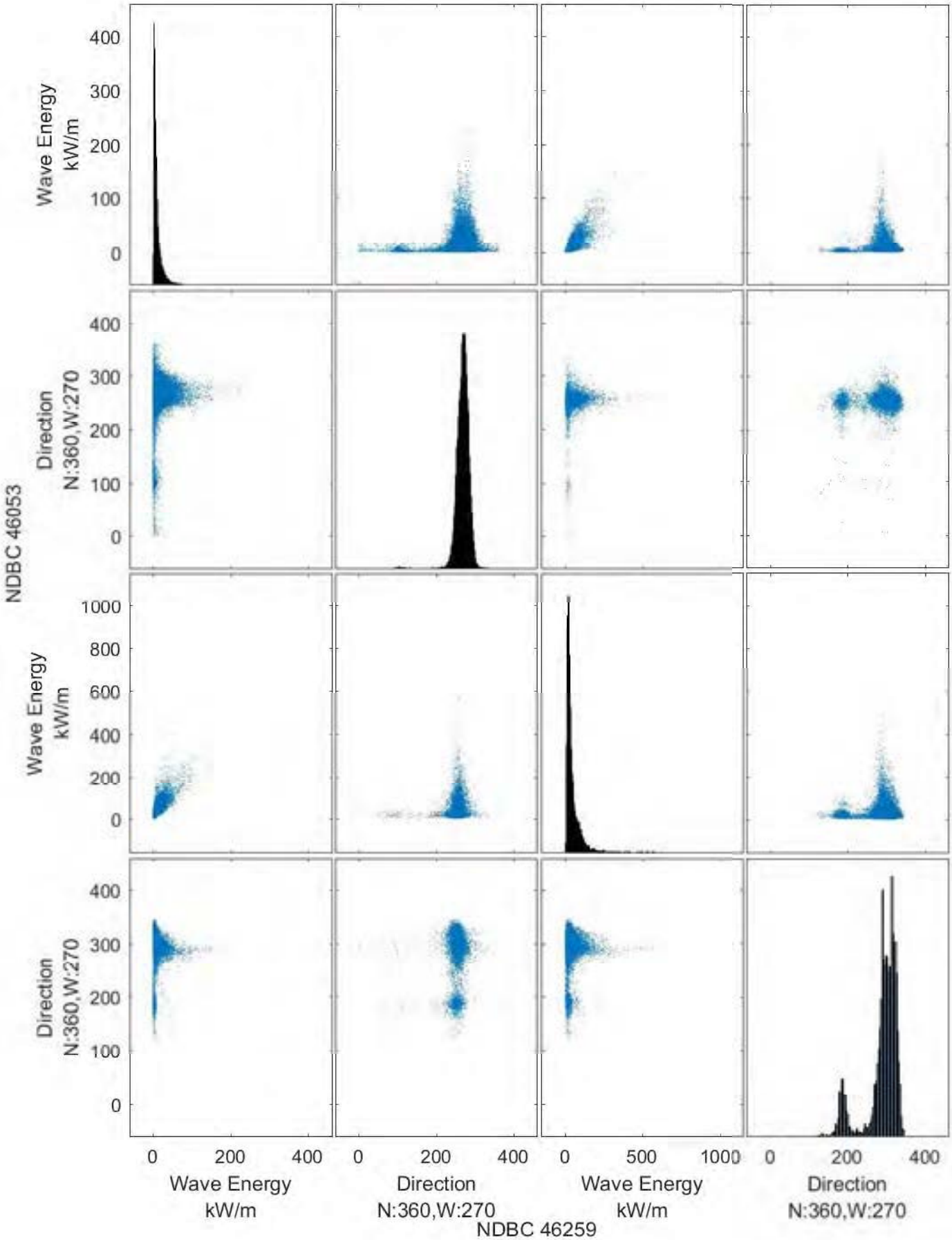
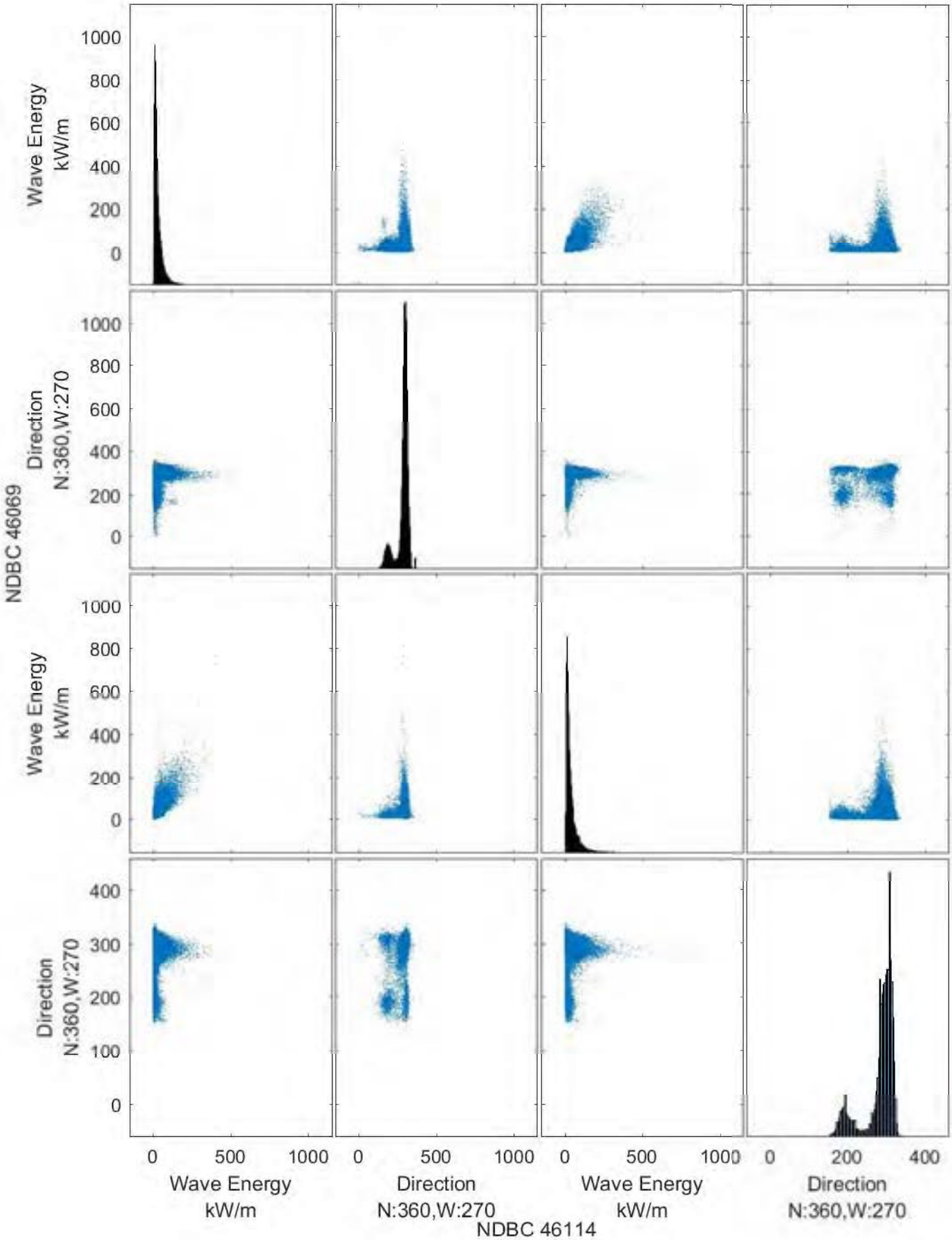


Figure C095: Cross Correlations for Wave Energyand Wave Direction for NDBC 46069 and NDBC 46114.



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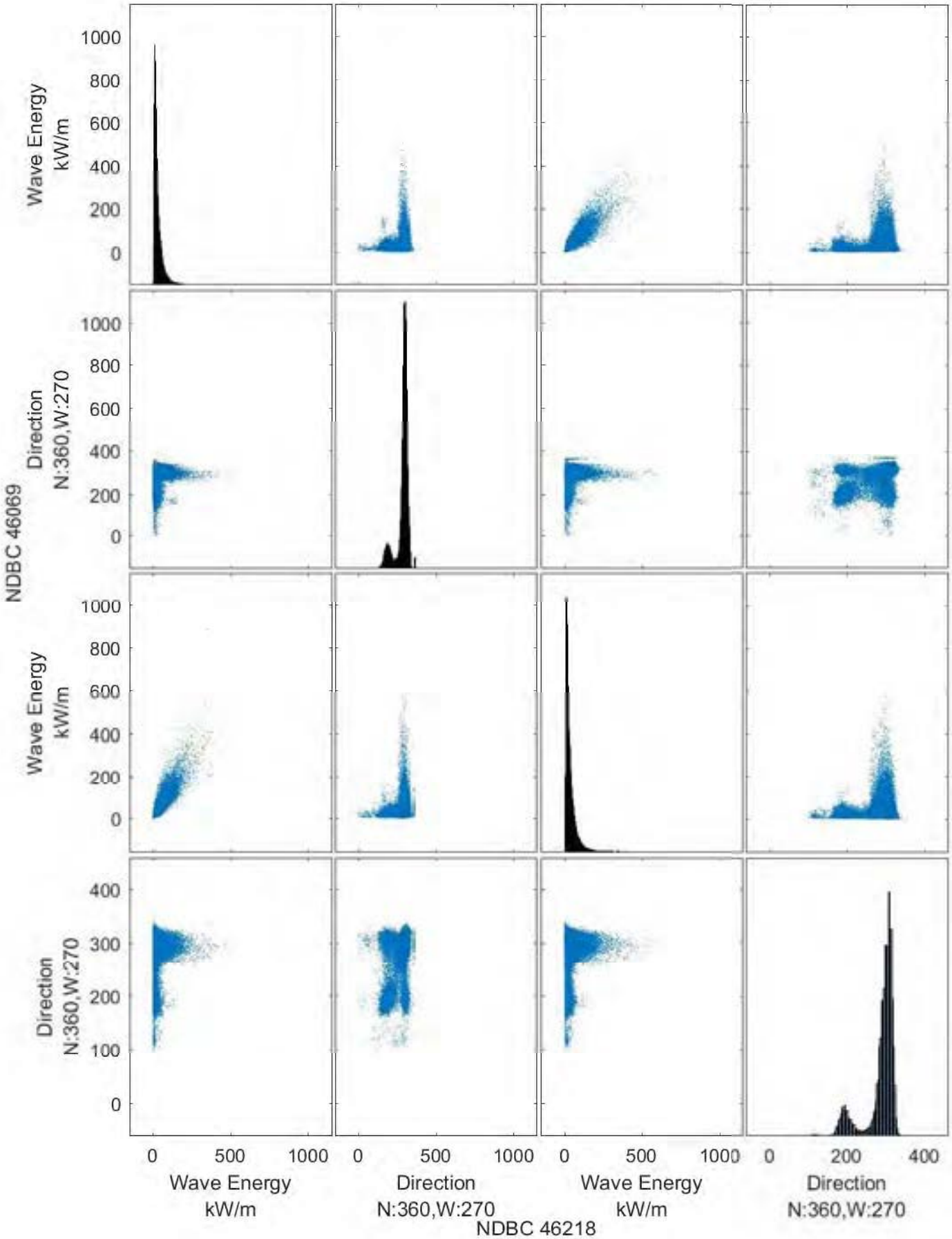


Figure C097: Cross Correlations for Wave Energyand Wave Direction for NDBC 46069 and NDBC 46219.

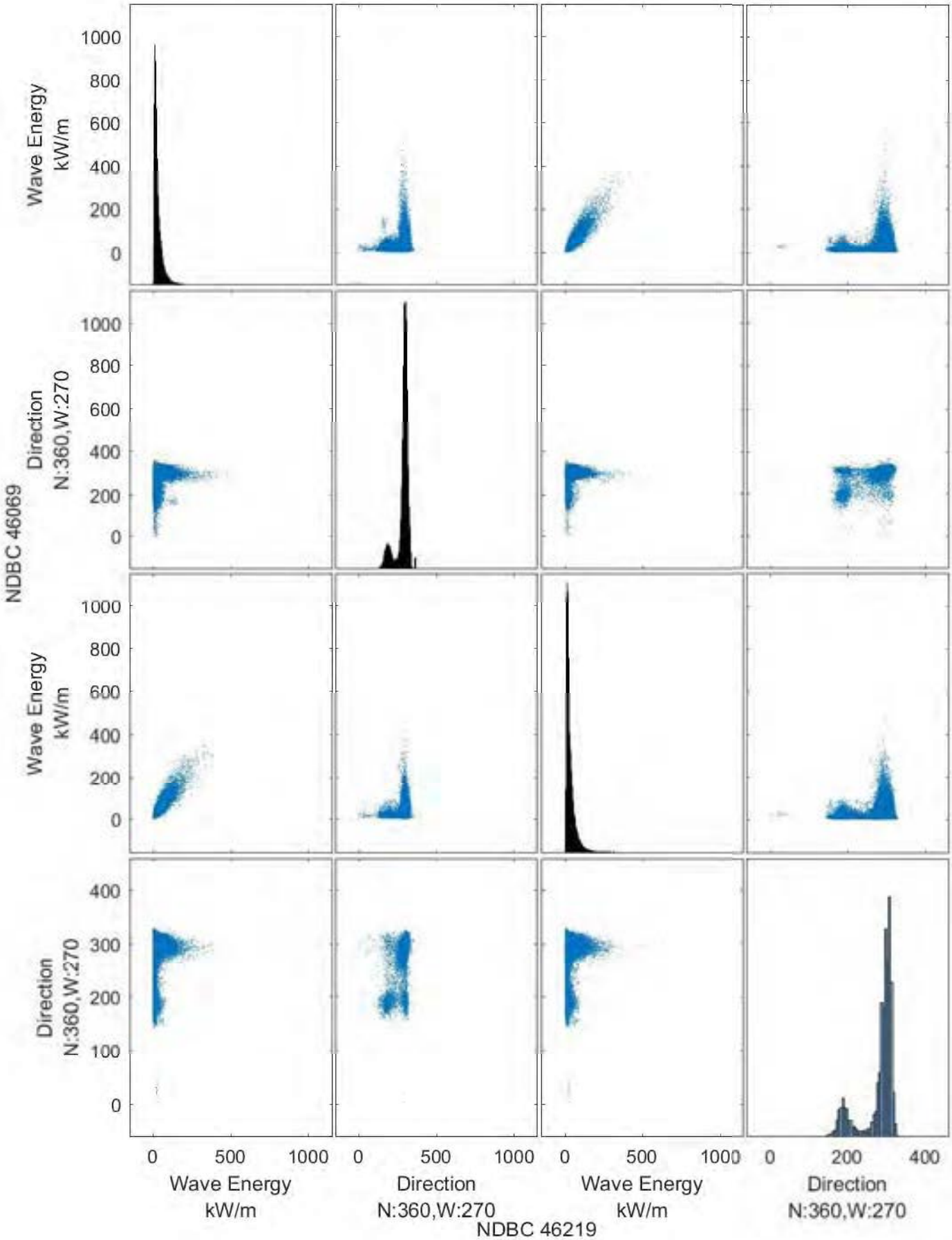
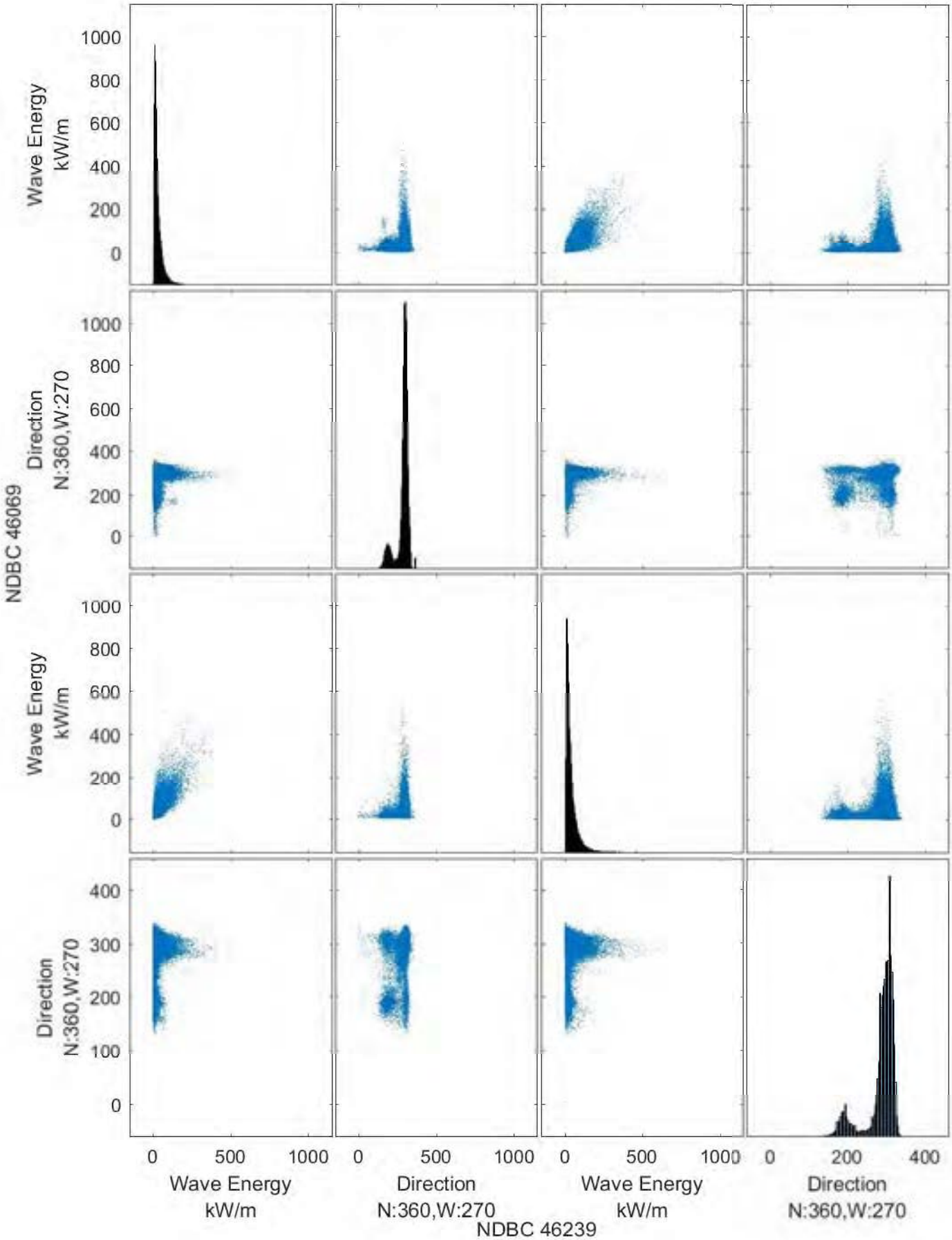


Figure C098: Cross Correlations for Wave Energyand Wave Direction for NDBC 46069 and NDBC 46239.



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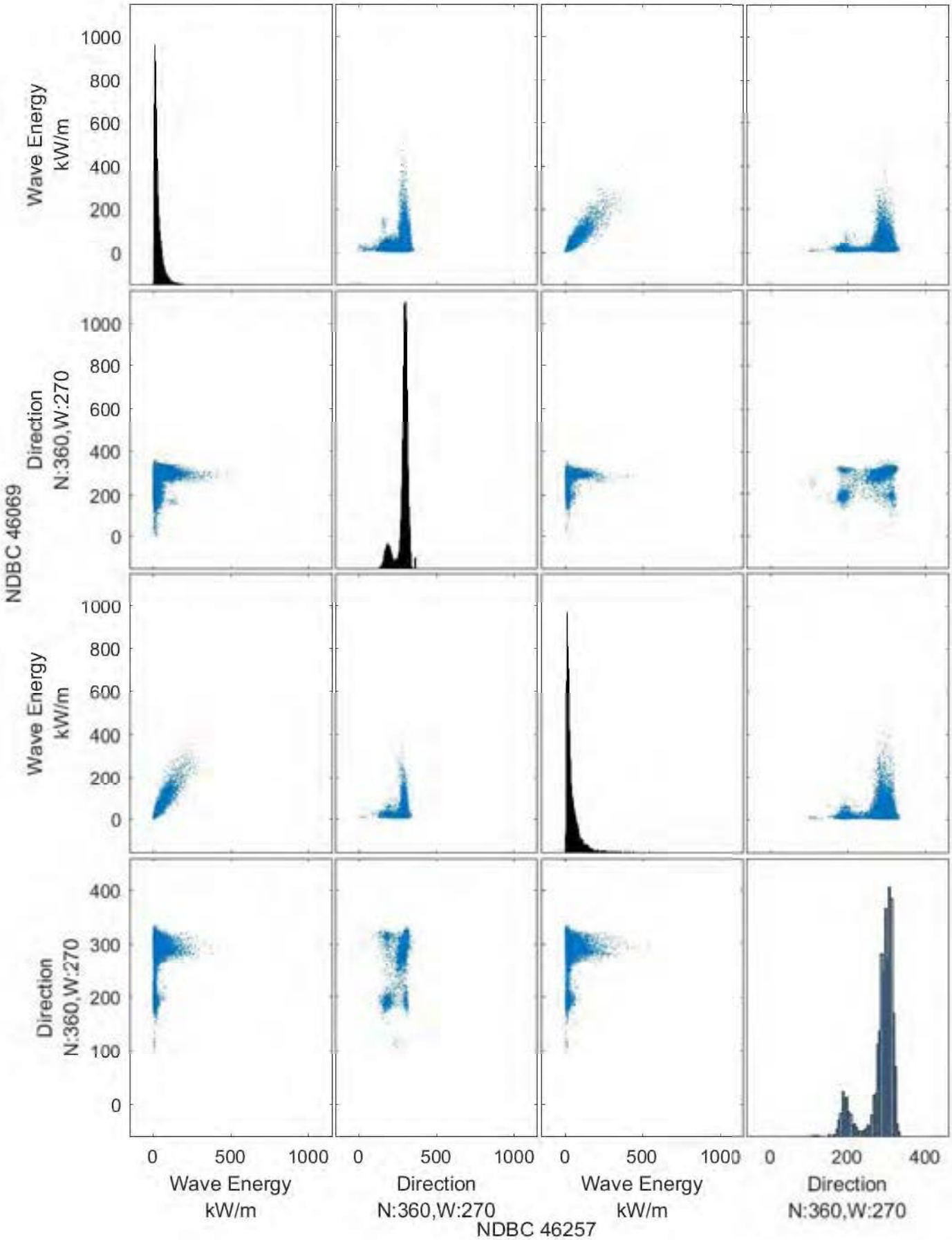

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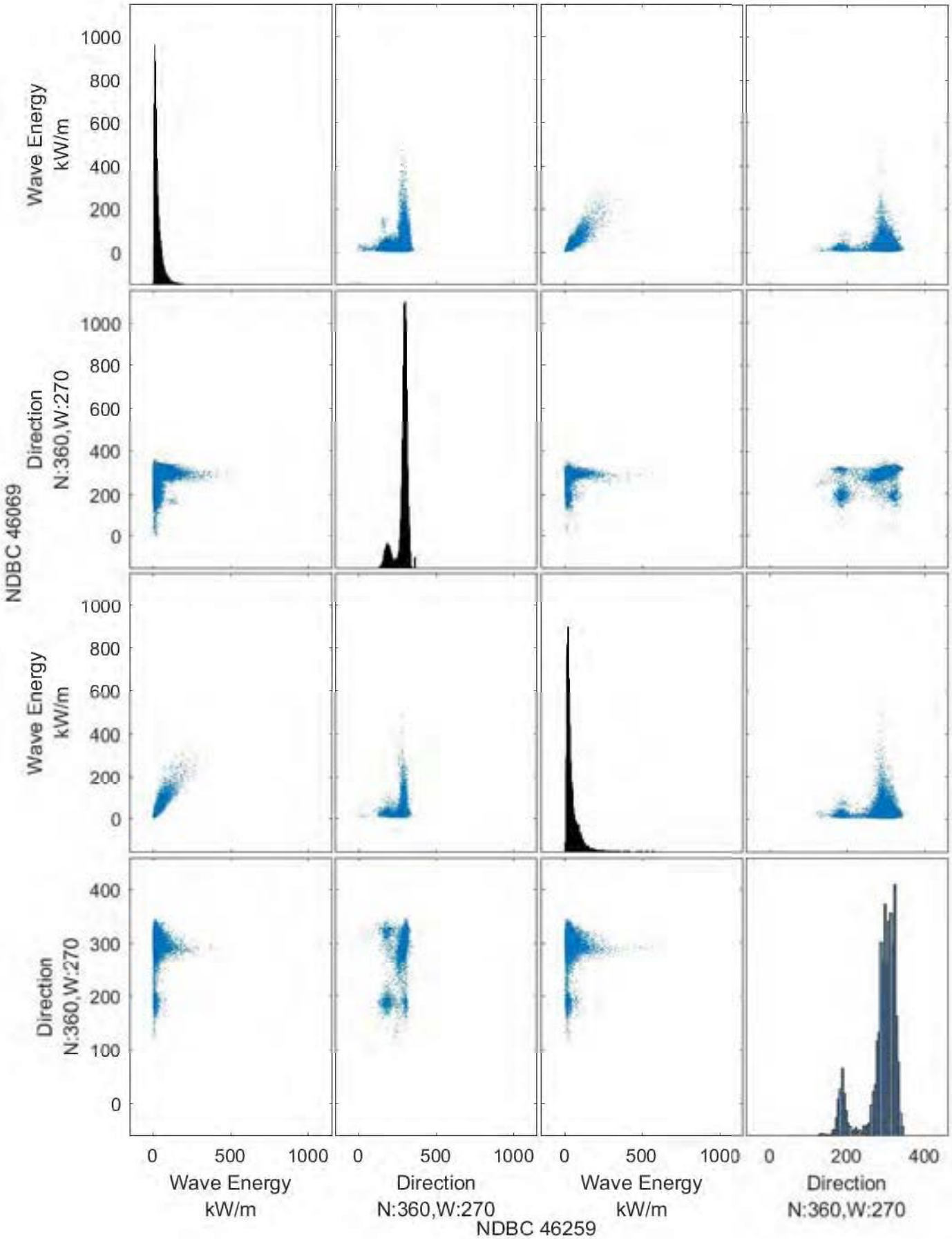

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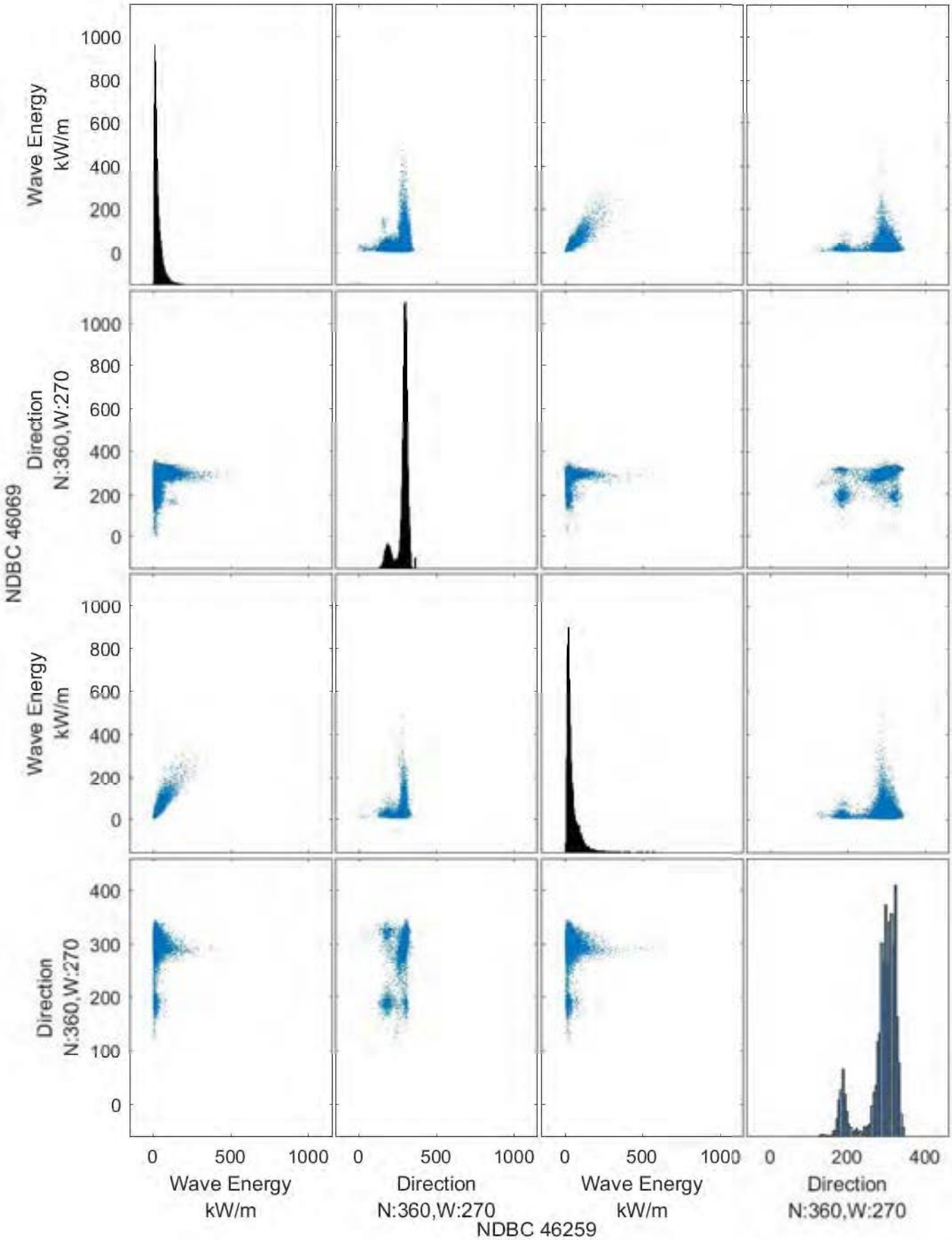


Figure C102: Cross Correlations for Wave Energyand Wave Direction for NDBC 46114 and NDBC 46218.

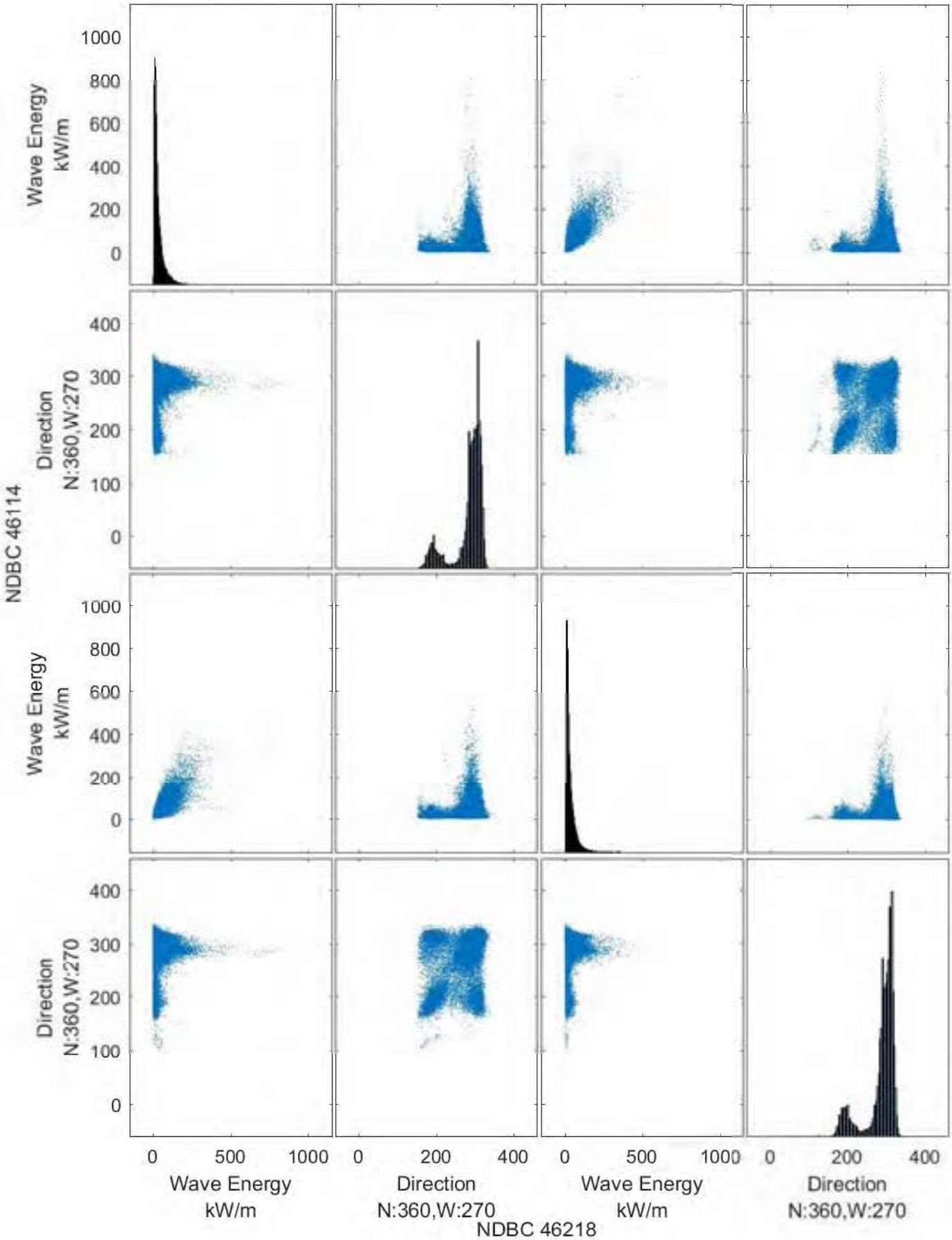


Figure C103: Cross Correlations for Wave Energyand Wave Direction for NDBC 46114 and NDBC 46219.

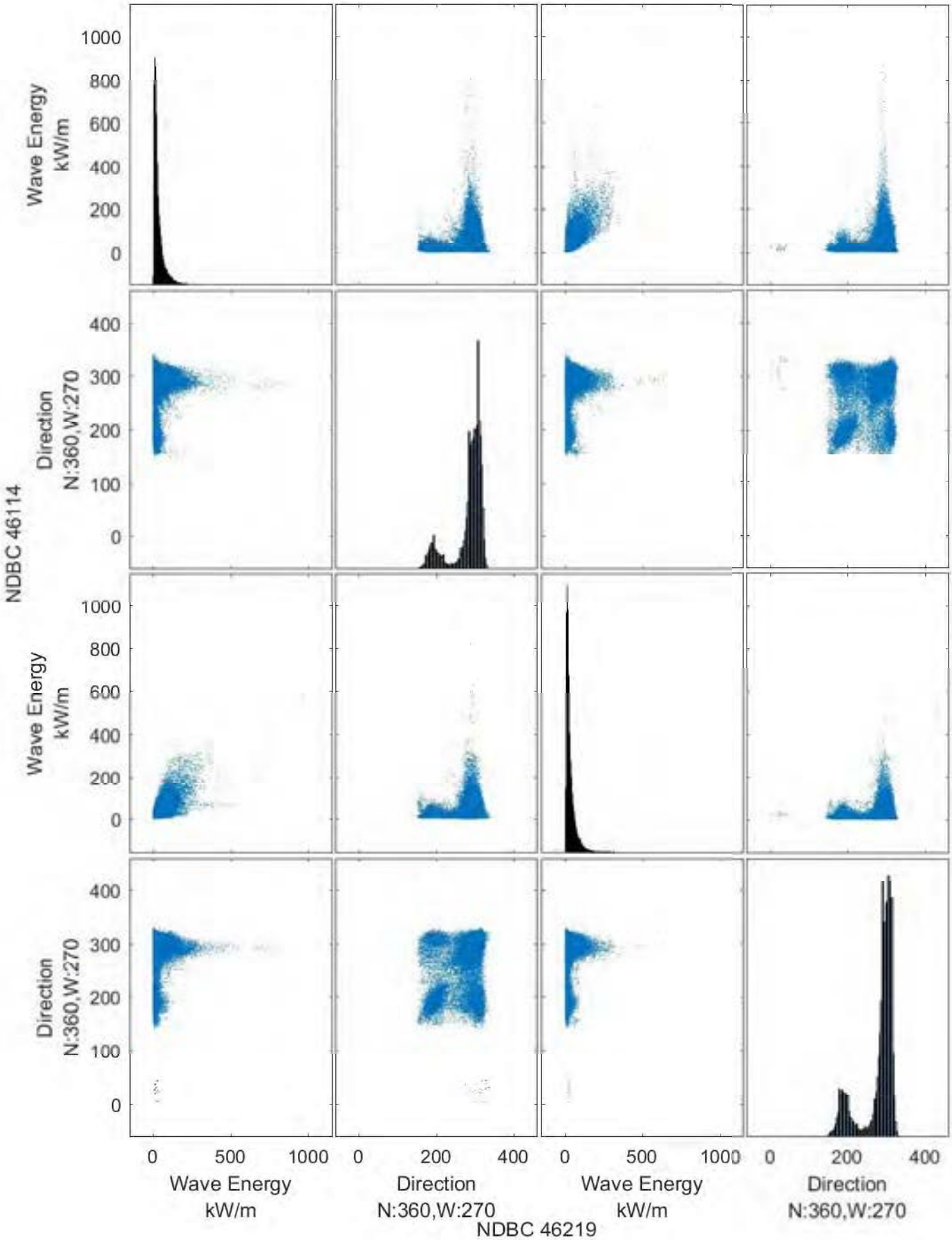


Figure C104: Cross Correlations for Wave Energyand Wave Direction for NDBC 46114 and NDBC 46239.

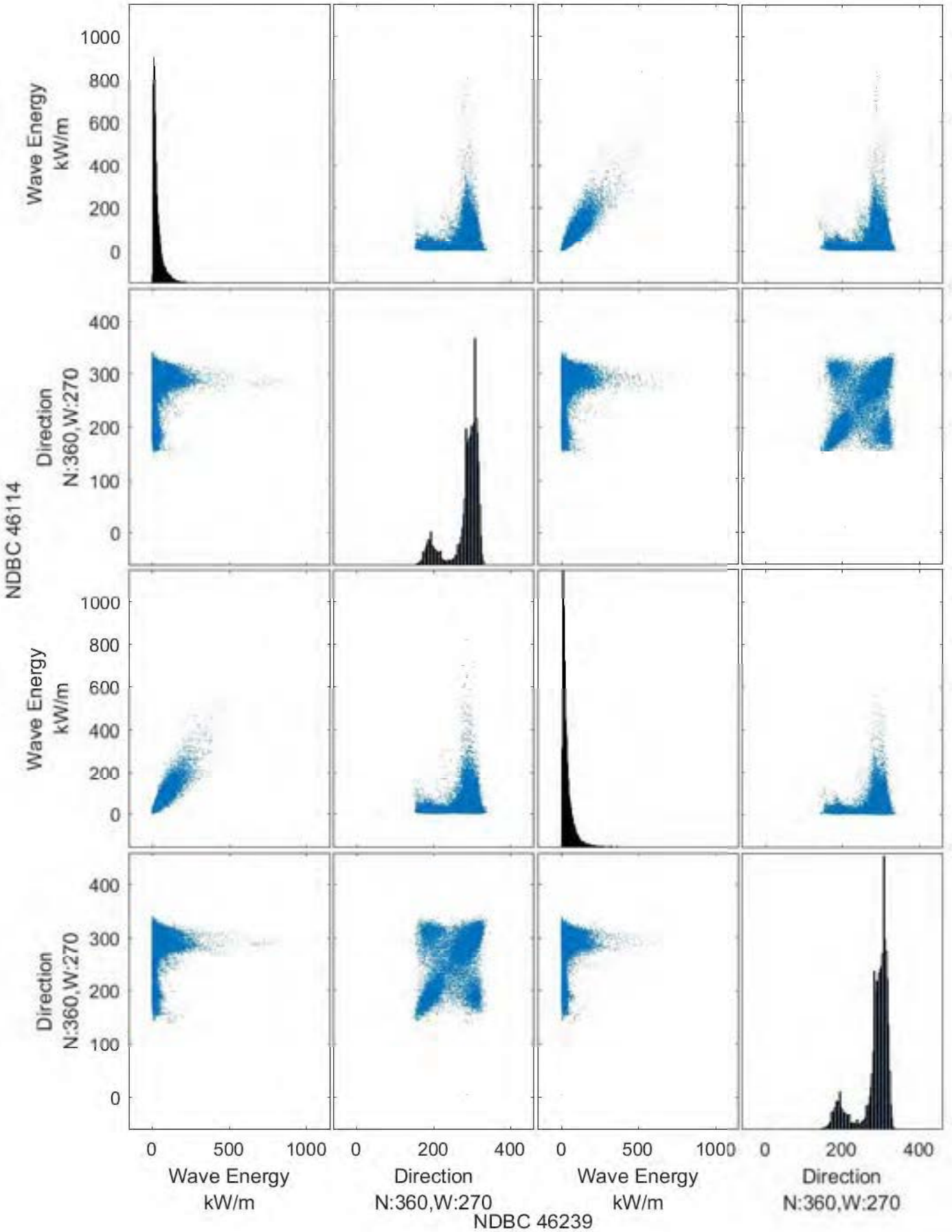
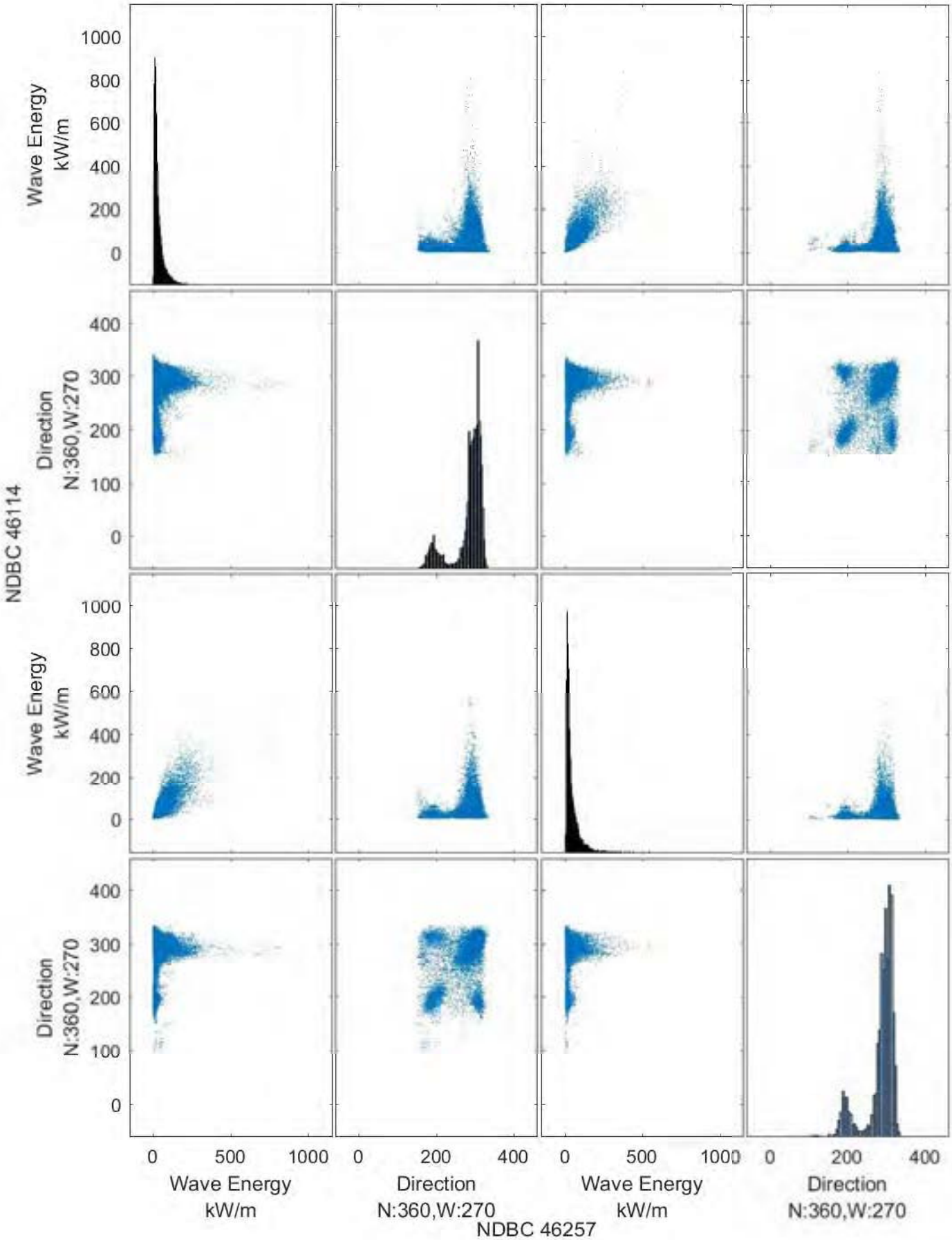


Figure C105: Cross Correlations for Wave Energyand Wave Direction for NDBC 46114 and NDBC 46257.



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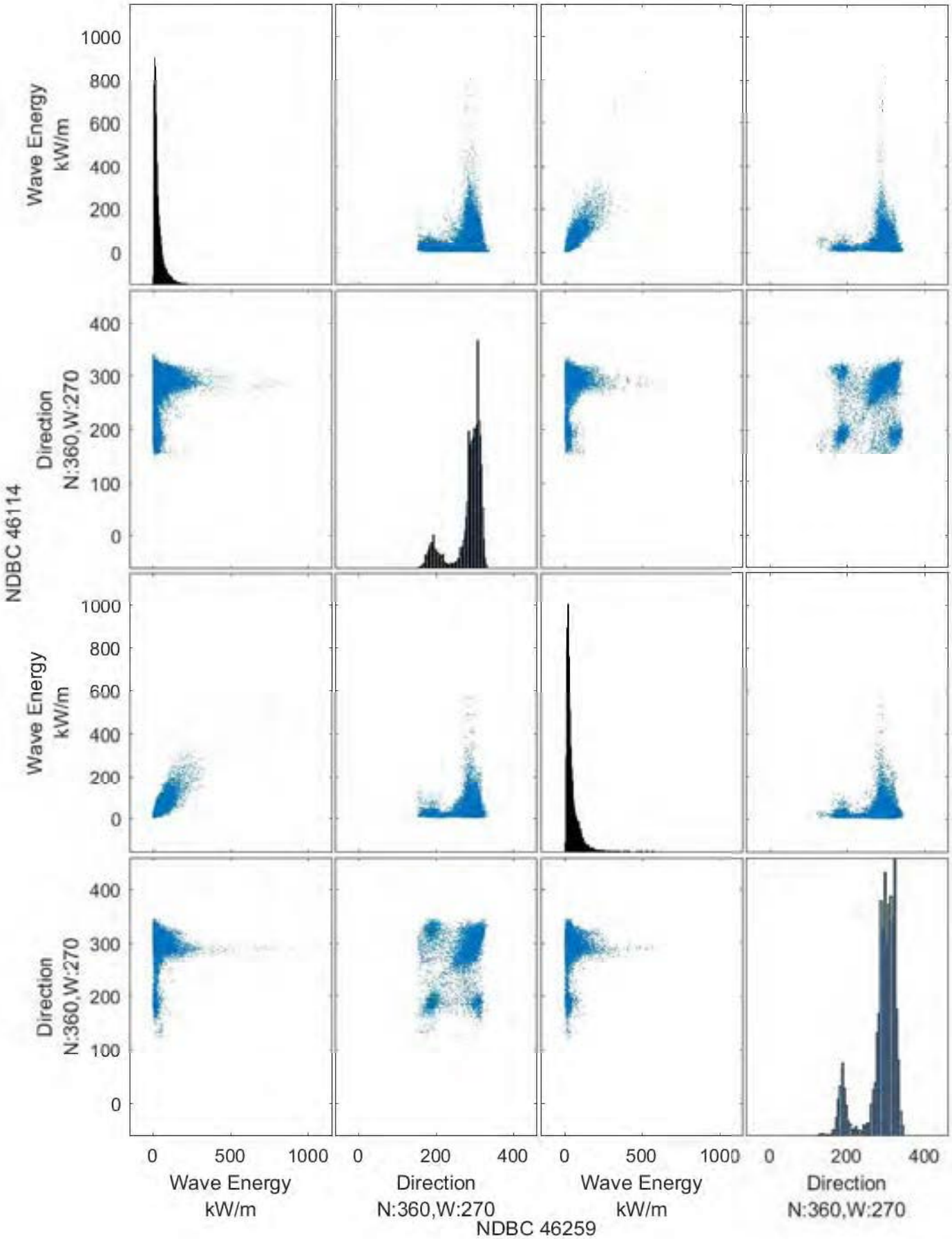

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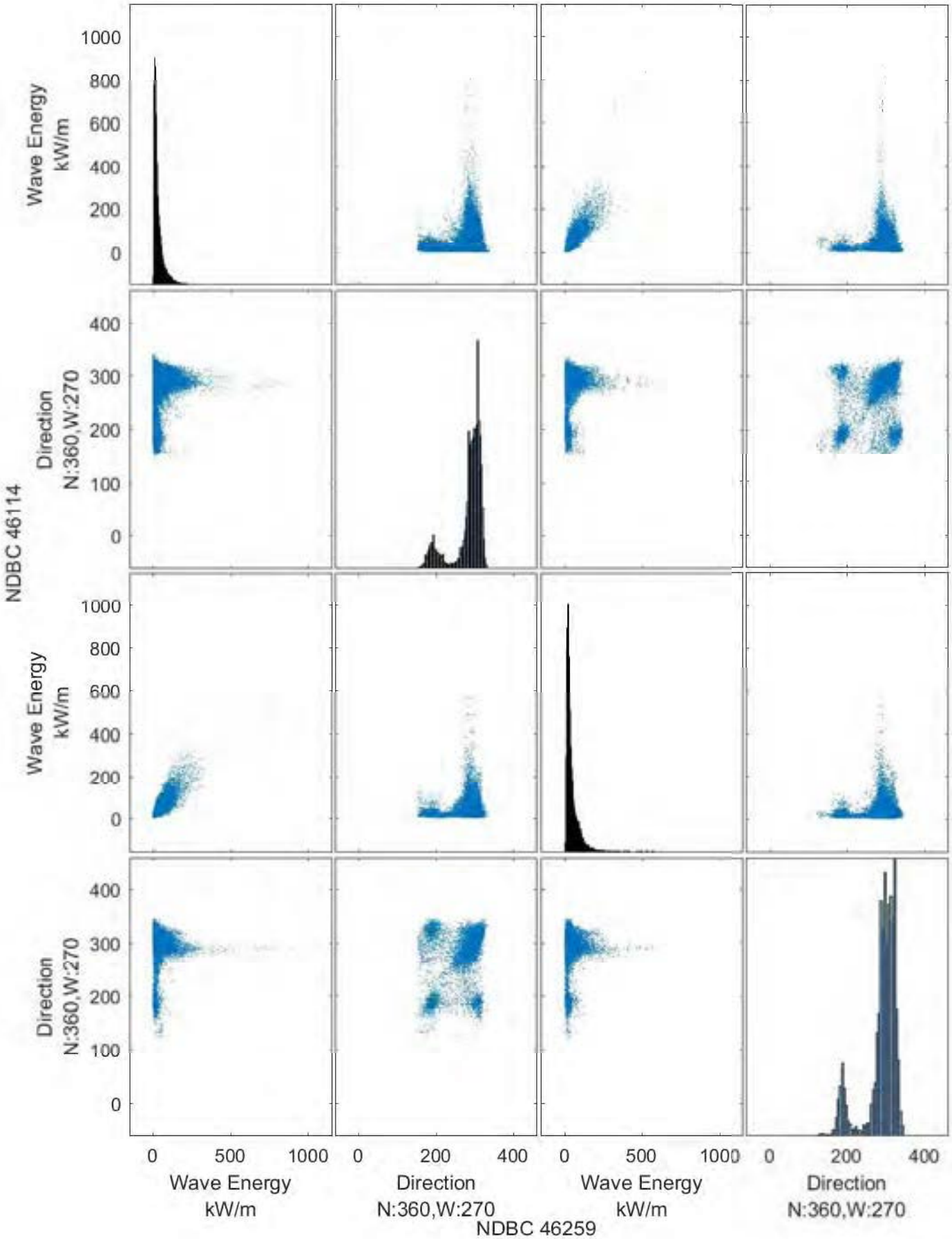

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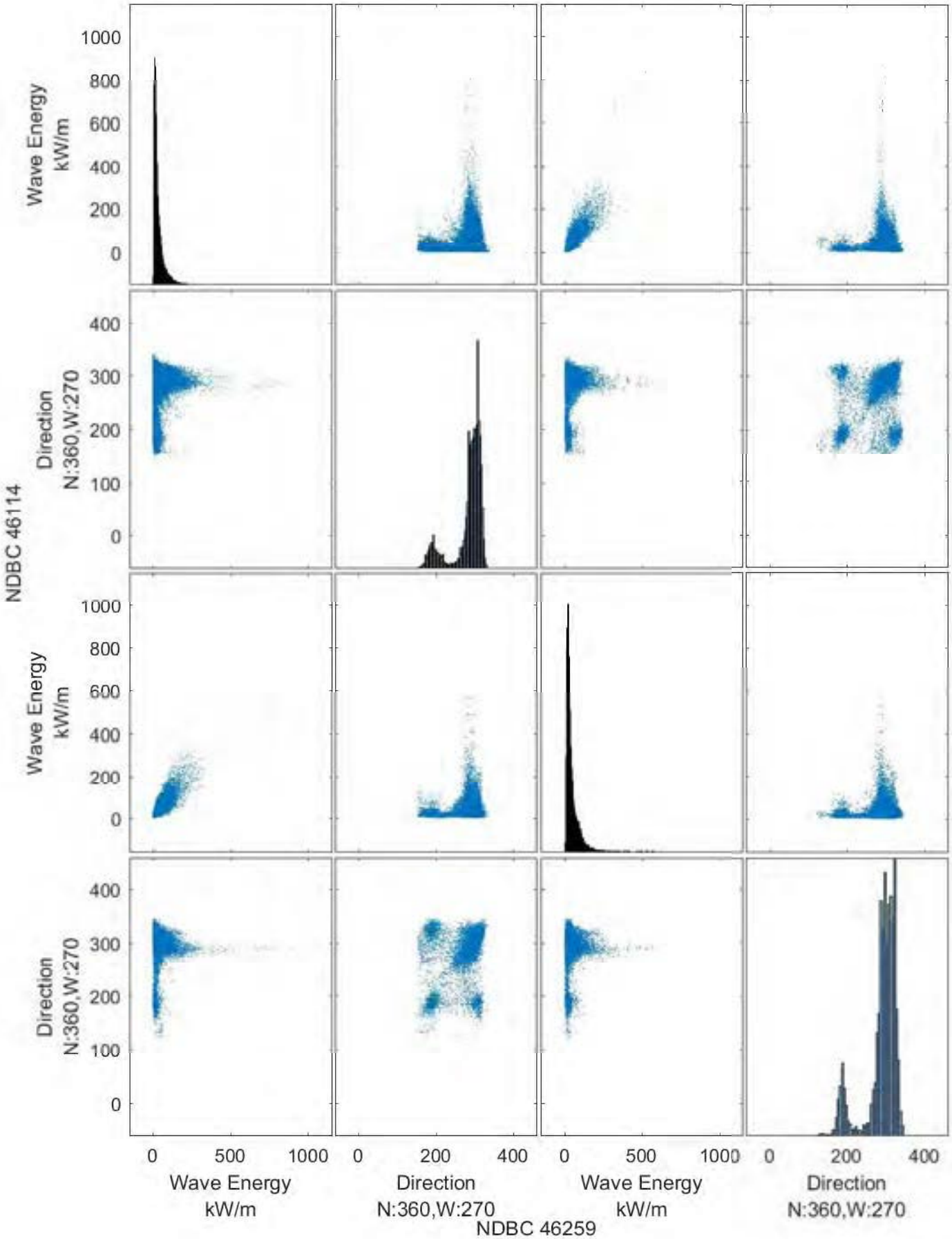


Figure C109: Cross Correlations for Wave Energyand Wave Direction for NDBC 46218 and NDBC 46219.

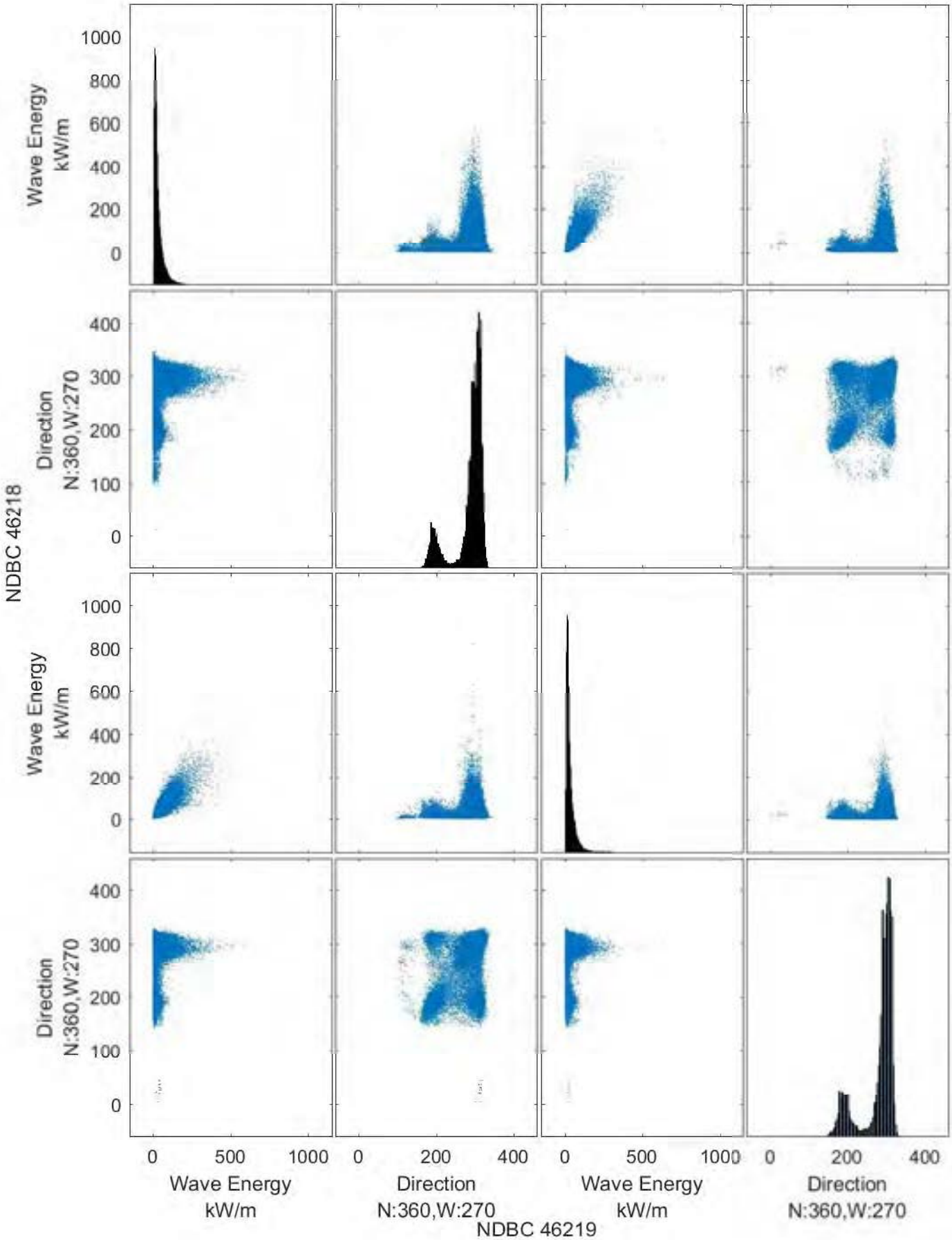


Figure C110: Cross Correlations for Wave Energyand Wave Direction for NDBC 46218 and NDBC 46239.

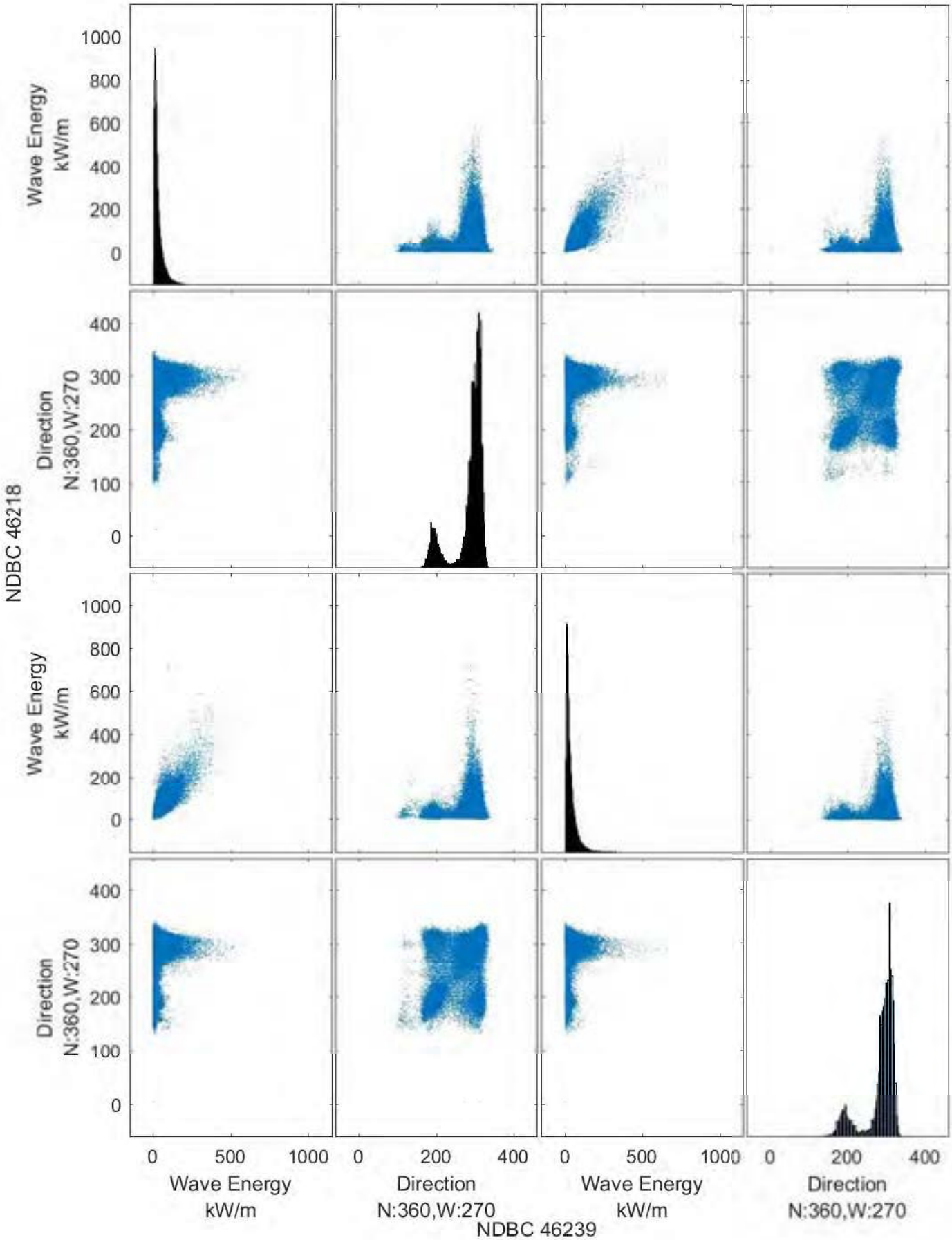
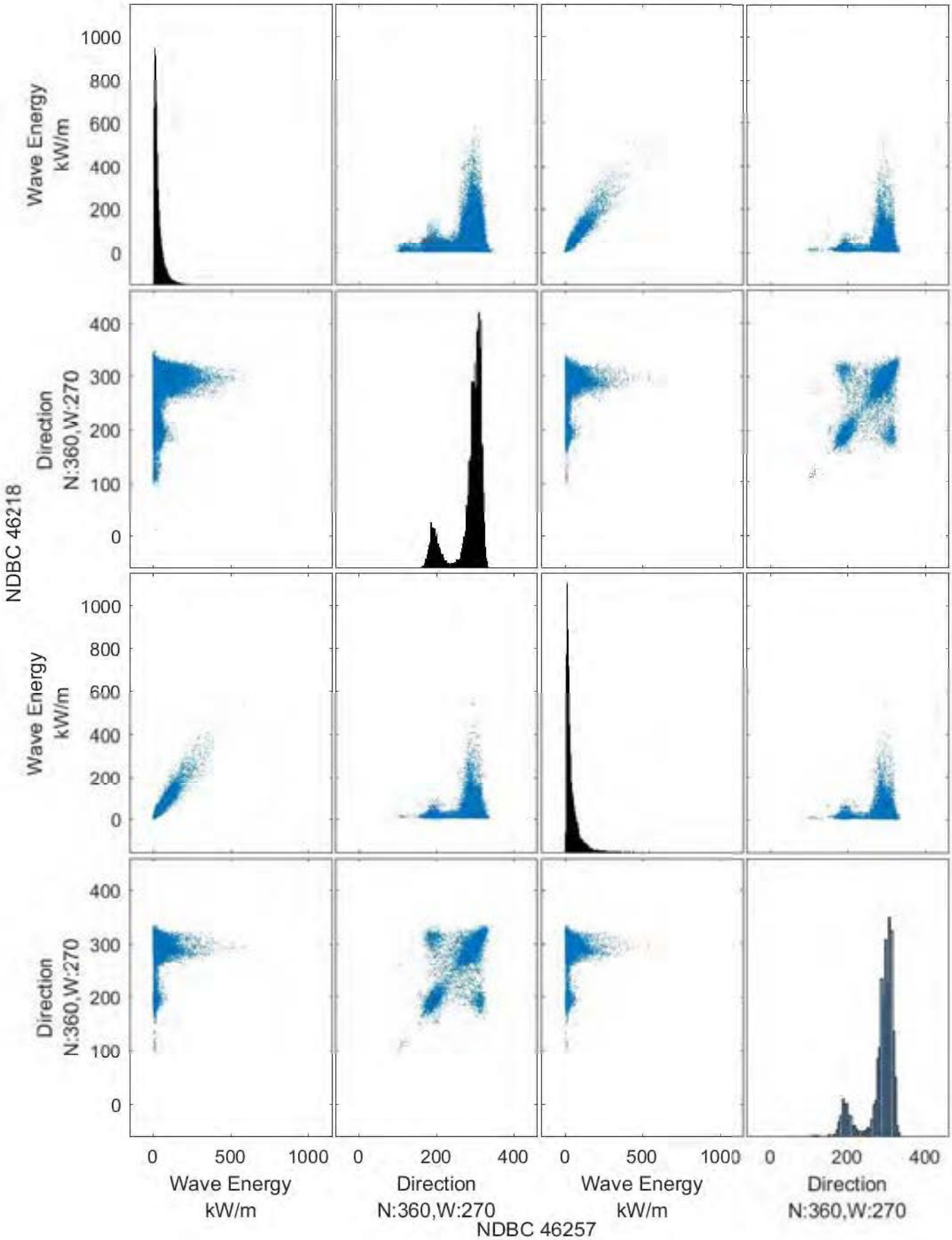


Figure C111: Cross Correlations for Wave Energyand Wave Direction for NDBC 46218 and NDBC 46257.



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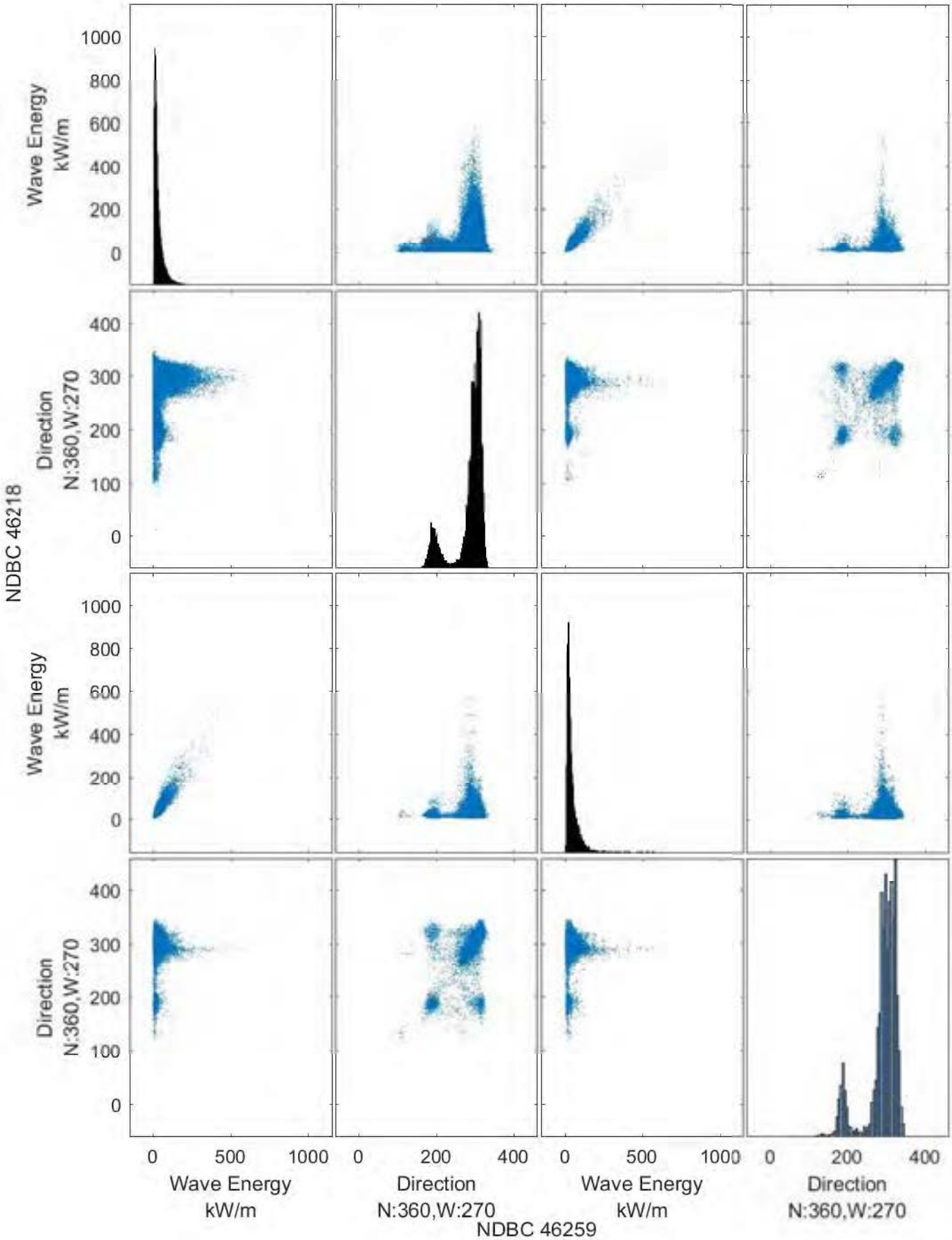

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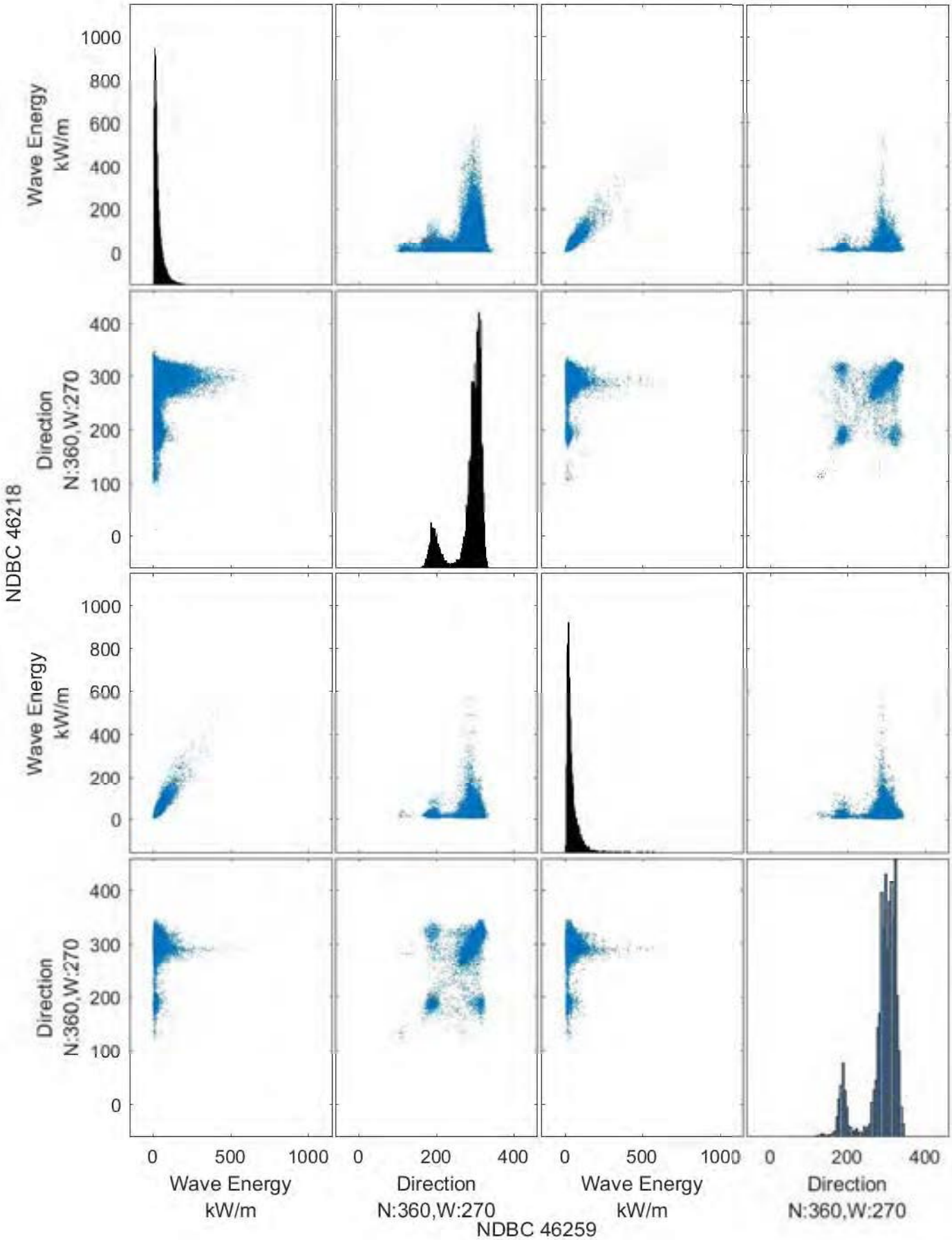


Figure C114: Cross Correlations for Wave Energyand Wave Direction for NDBC 46218 and NDBC 46259.

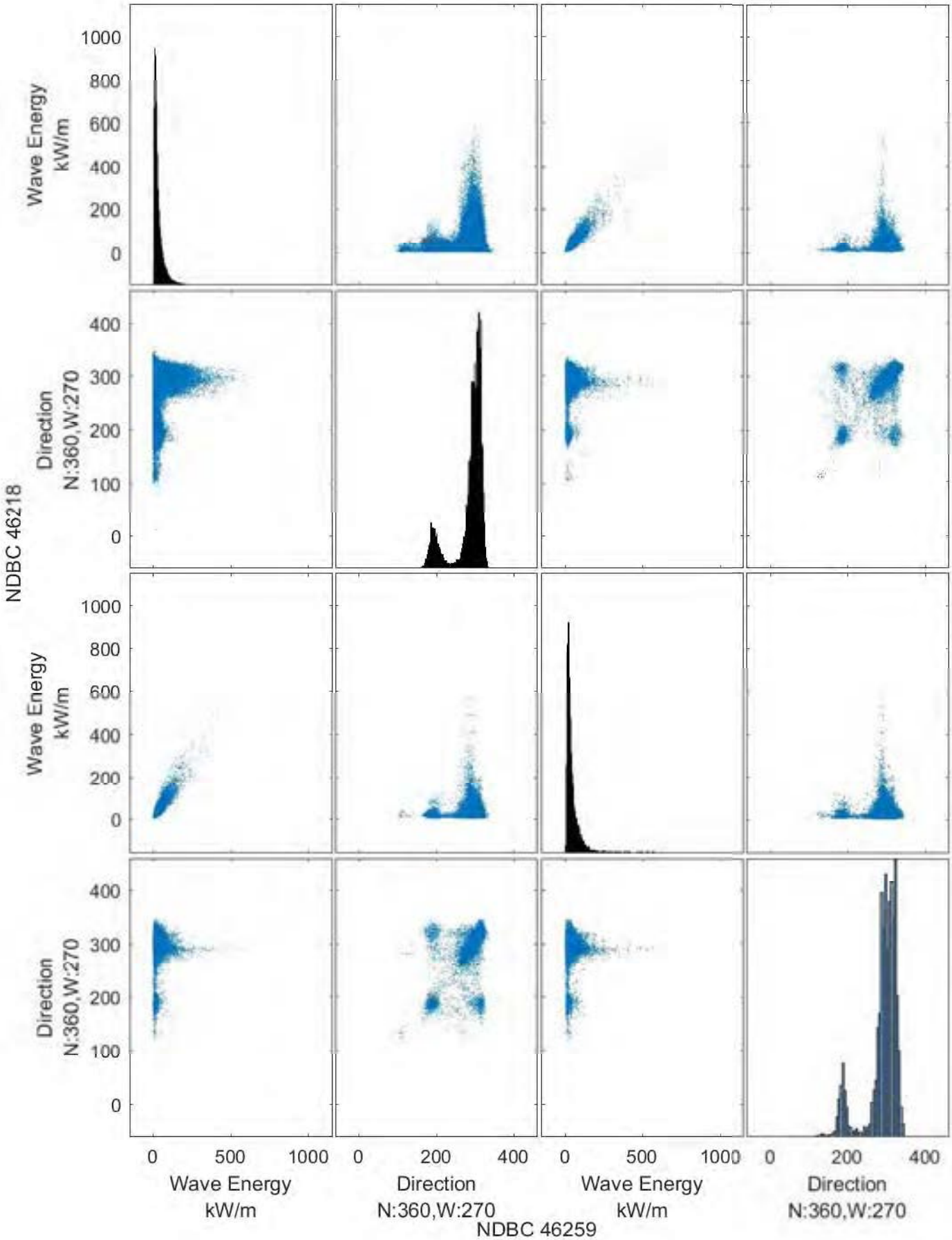


Figure C115: Cross Correlations for Wave Energyand Wave Direction for NDBC 46219 and NDBC 46239.

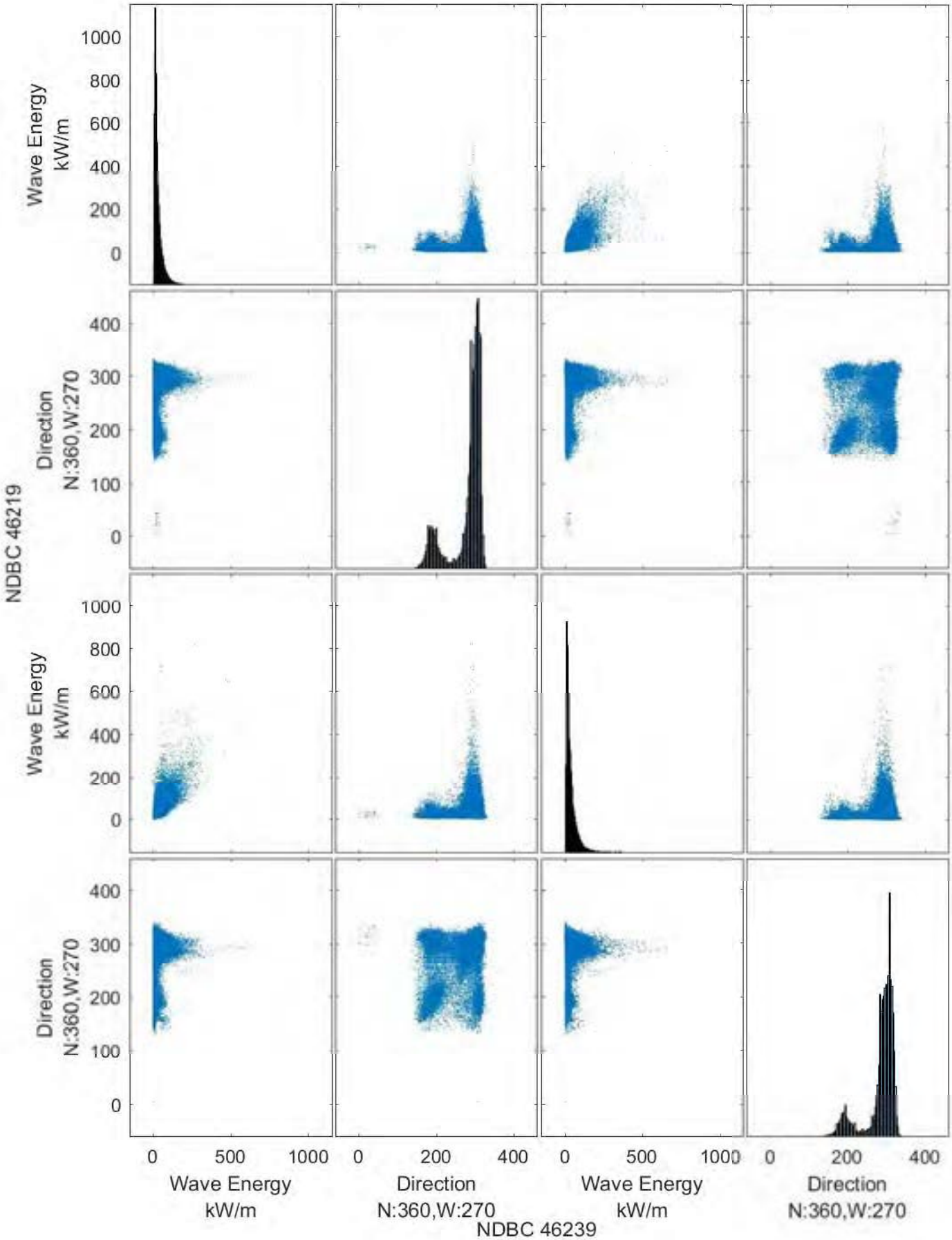


Figure C116: Cross Correlations for Wave Energyand Wave Direction for NDBC 46219 and NDBC 46257.

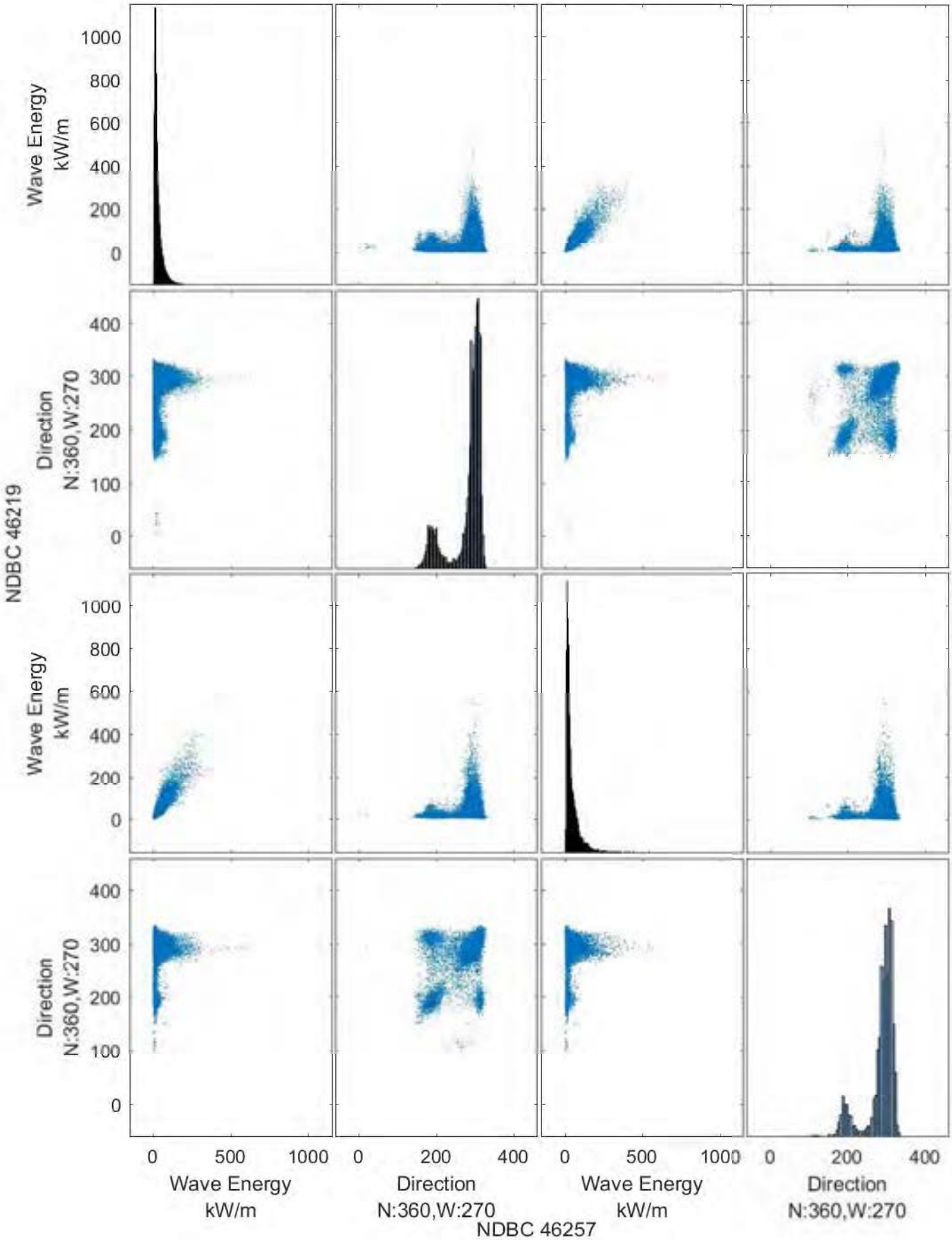
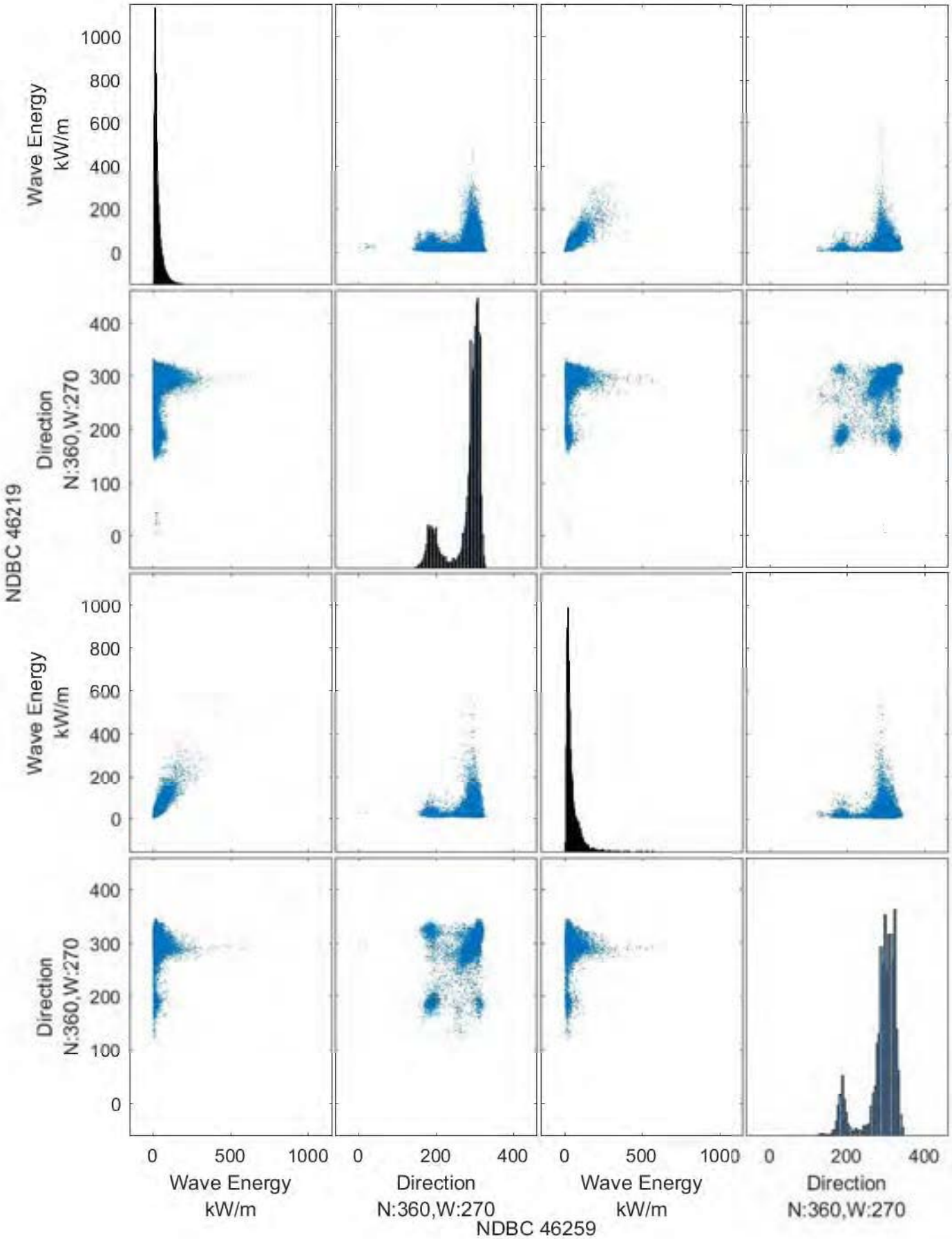


Figure C117: Cross Correlations for Wave Energyand Wave Direction for NDBC 46219 and NDBC 46259.



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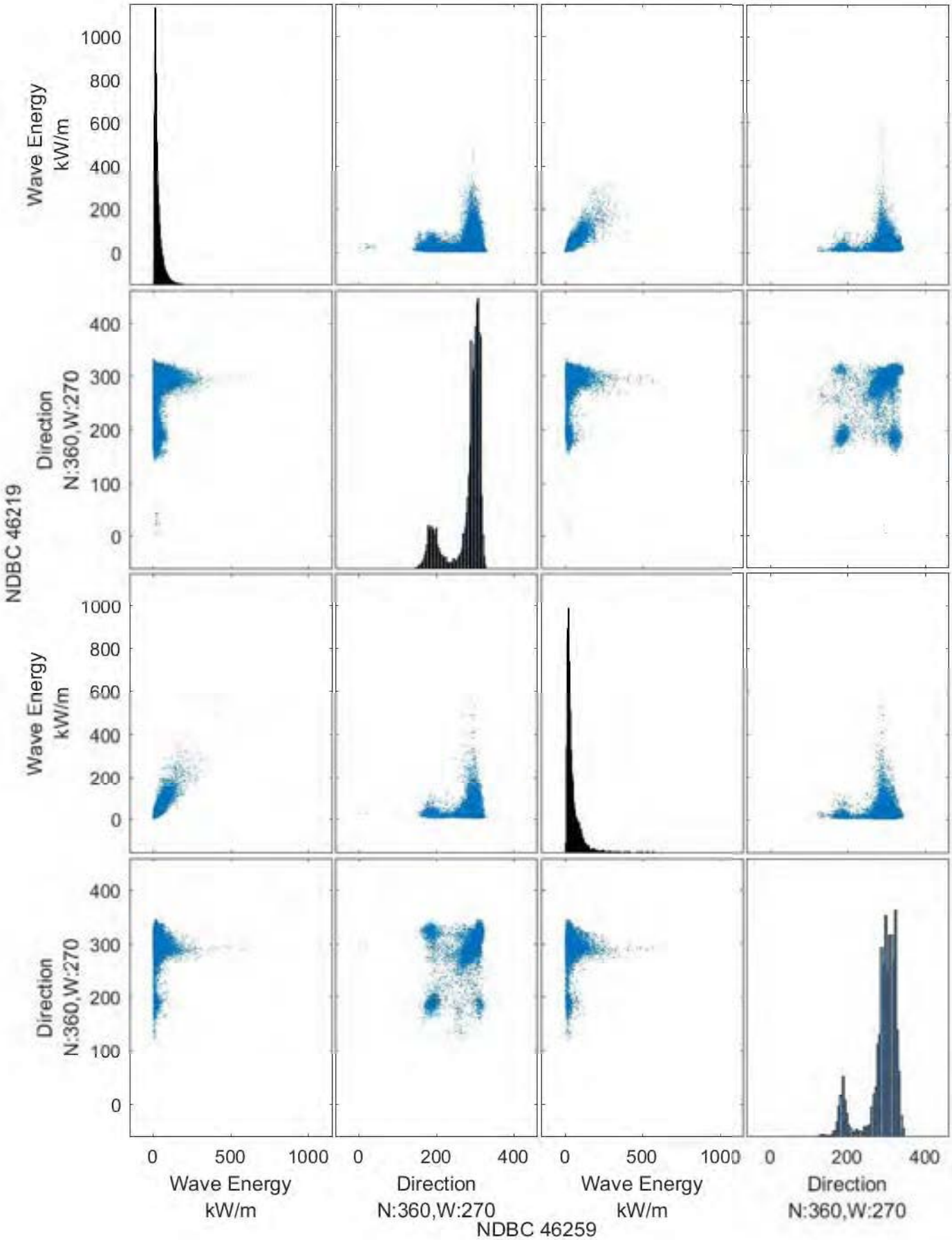


Figure C119: Cross Correlations for Wave Energyand Wave Direction for NDBC 46219 and NDBC 46259.

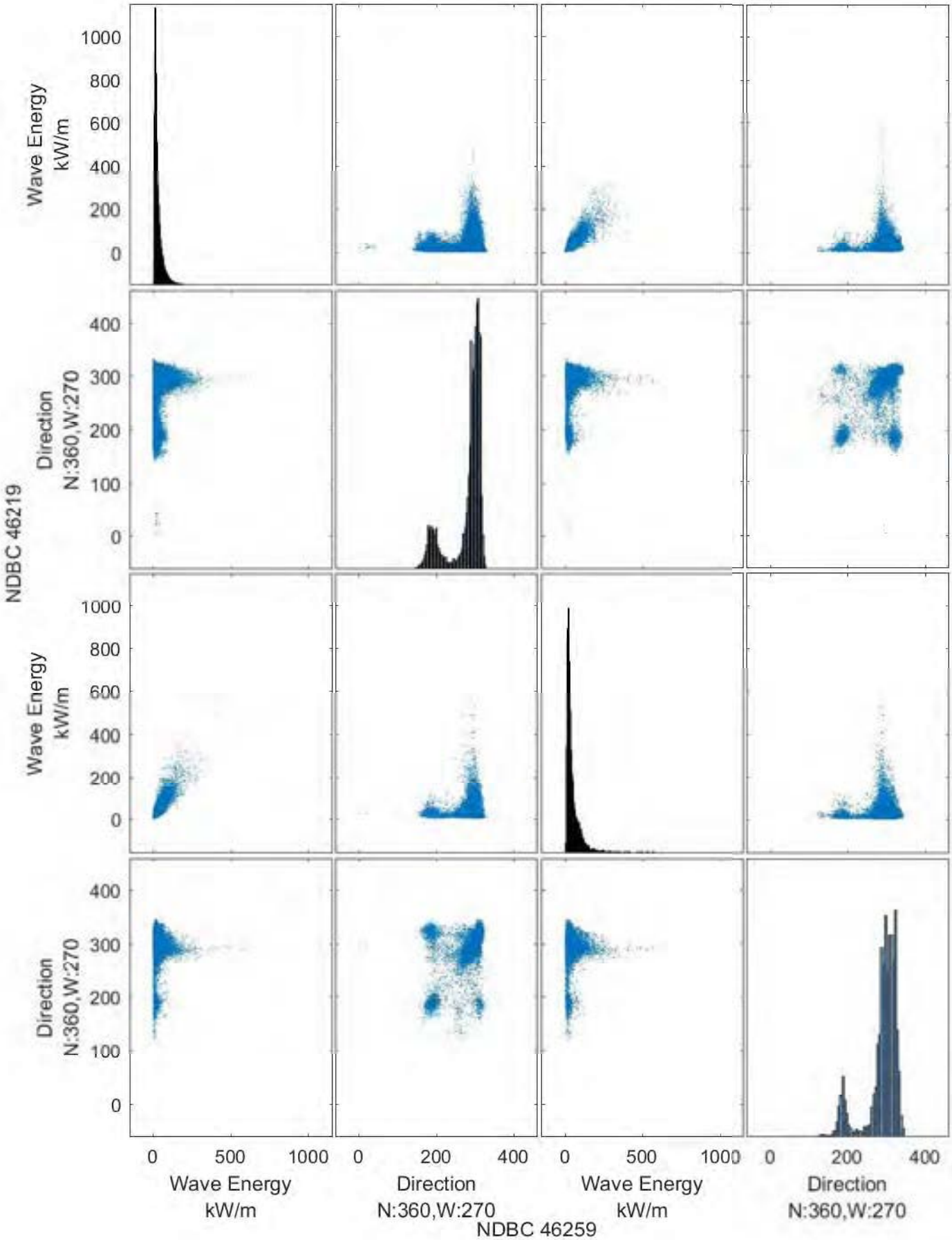
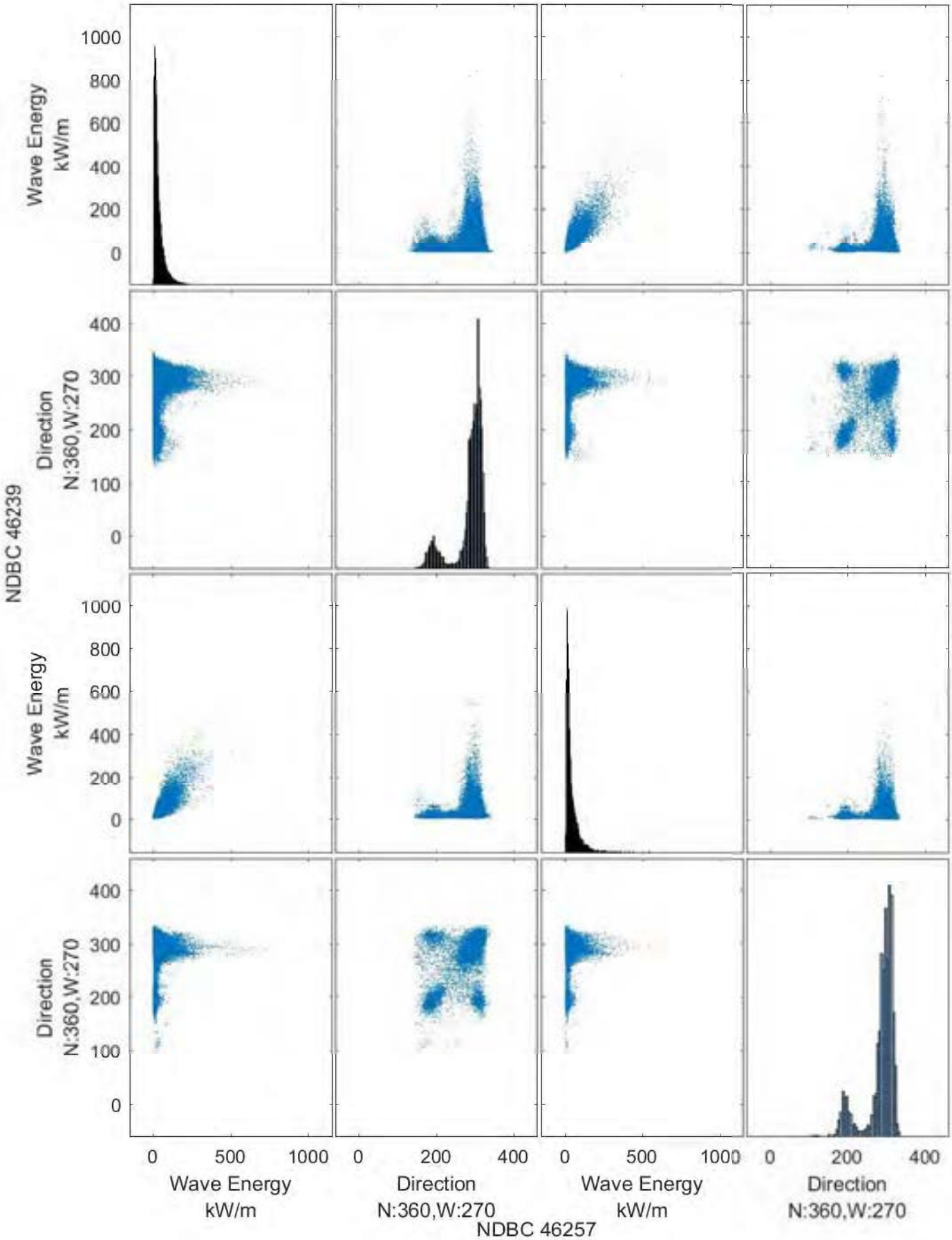


Figure C120: Cross Correlations for Wave Energyand Wave Direction for NDBC 46239 and NDBC 46257.



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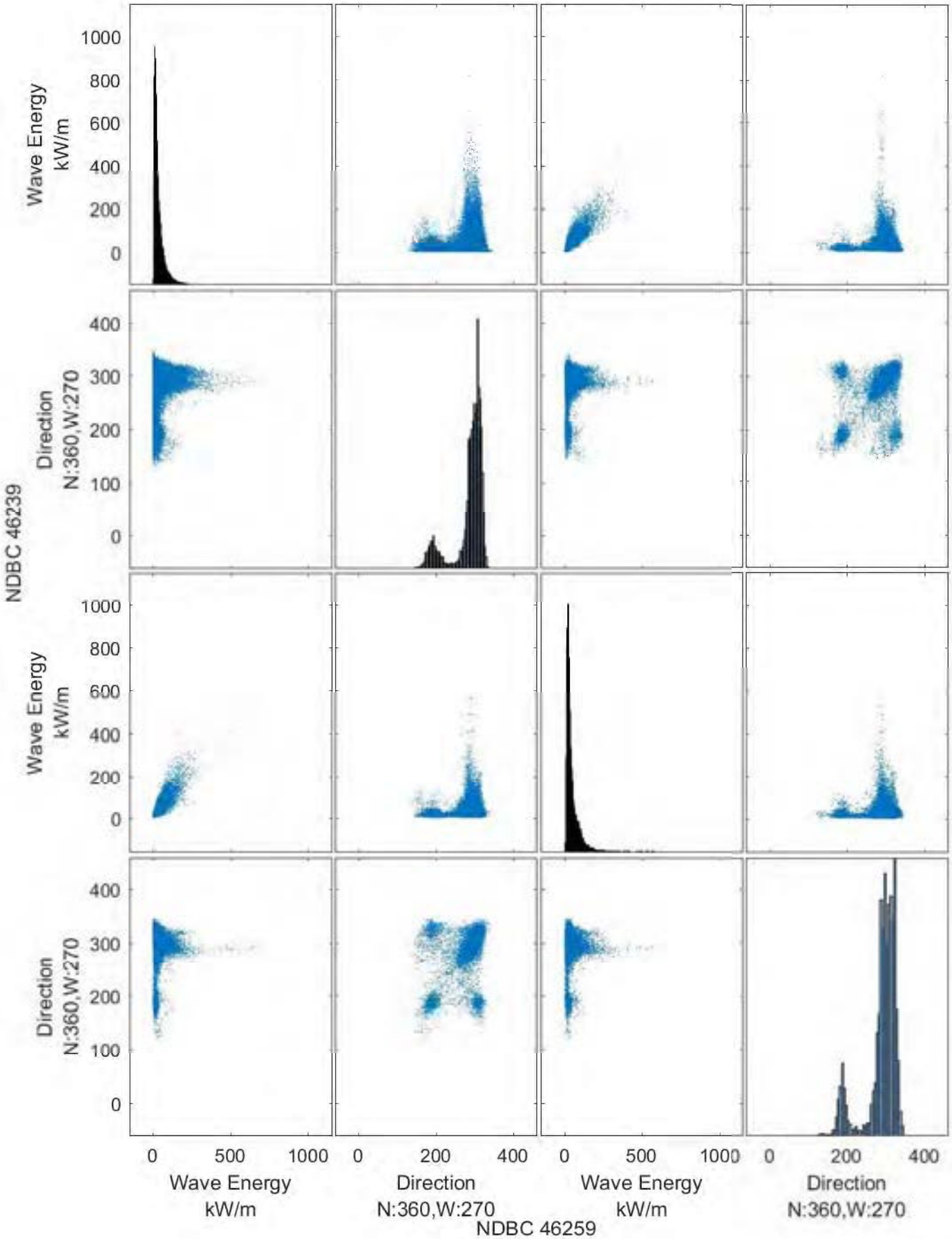
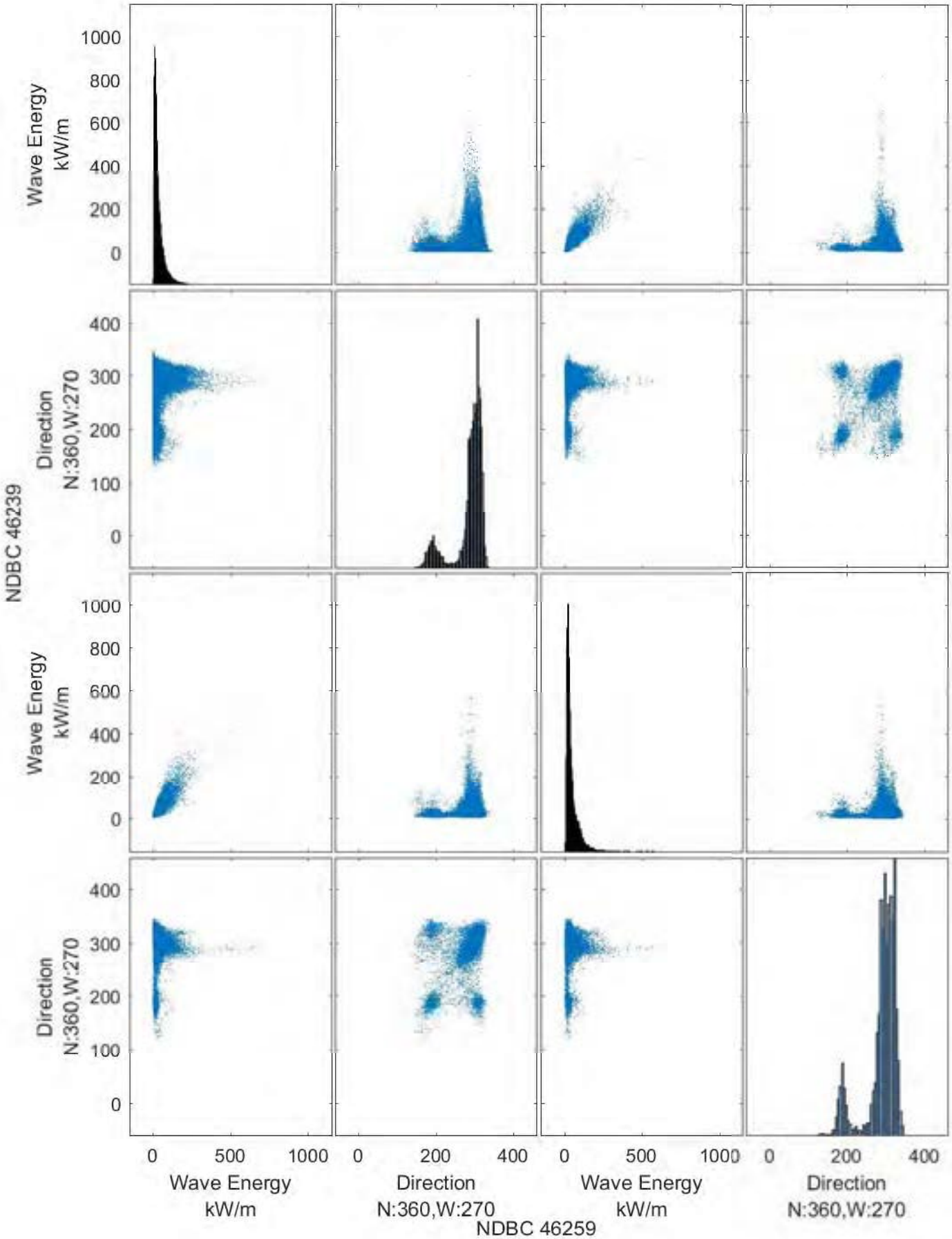


Figure C122: Cross Correlations for Wave Energyand Wave Direction for NDBC 46239 and NDBC 46259.



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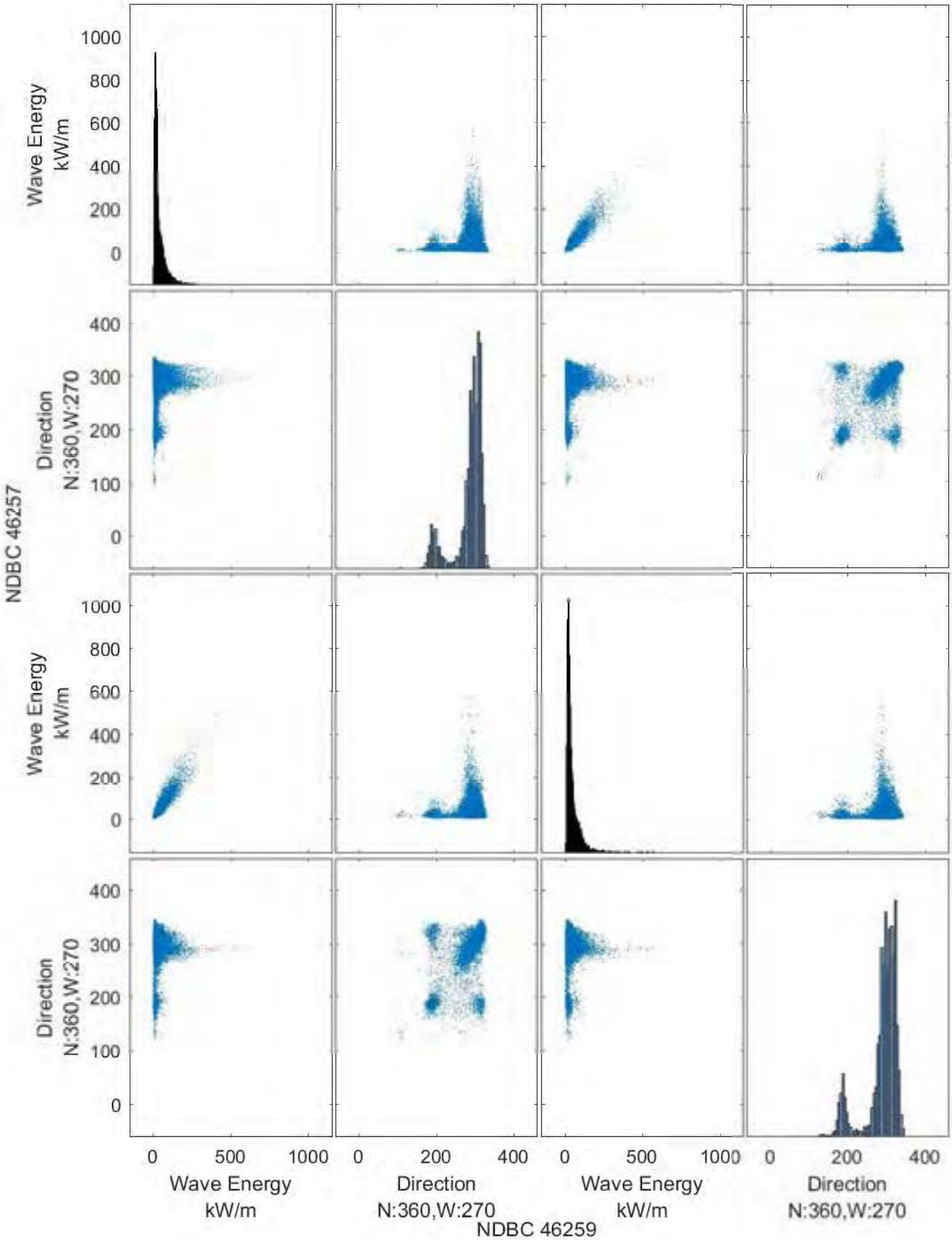

ATTACHMENT C TO SOPO TASK 12 (PERMITTING) FINAL REPORT

Task 12.4 Regulatory Roadmap

For the

California Wave Energy Test Center (CalWave[sm])

DOE Award Number: DE-EE0006517.0005

Prepared for:

Cal Poly Corporation
Institute of Advanced Technology and Public Policy
California Polytechnic State University
San Luis Obispo, California

Prepared by:

CH2M Hill Engineers, Inc.
2485 Natomas Park Drive, Suite 600
Sacramento, CA 95833

February 2017

Department of Energy Award Number: DE-EE0006517.0005

Principal Investigator:

Sam N. Blakeslee, Institute of Advanced Technology and Public Policy, California Polytechnic State University (Cal Poly), San Luis Obispo

Project Manager:

William I. Toman, Institute of Advanced Technology and Public Policy, Cal Poly, San Luis Obispo

Citation:

D.M. Davy. 2017. Attachment C to SOPO Task 12 (Permitting) Final Report, Task 12.4 Regulatory Roadmap for the California Wave Energy Test Center (CalWave^{sm}). DOE Contract DE-EE0006517.0005. Cal Poly Corporation, Institute of Advanced Technology and Public Policy, California Polytechnic University, San Luis Obispo, California. February 2017.

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Acronyms and Abbreviations

AFB	Air Force Base
BA	Biological Assessment
BLM	United States Bureau of Land Management
BO	Biological Opinion
BOEM	Bureau of Ocean Energy Management
CA	California
Cal Poly	California Polytechnic State University, San Luis Obispo
CalWave^{sm}	California Wave Energy Test Center
CCC	California Coastal Commission
CCRWQCB	Central Coast Regional Water Quality Control Board
CDFW	California Department of Fish and Wildlife
CDP	Coastal Development Permit
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CFR	Code of Federal Regulations
CSLC	California State Lands Commission
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
DOE	Department Energy
EFH	Essential Fish Habitat
EA	Environmental Assessment
EERE	Energy Efficiency and Renewable Energy
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FONSI	Finding of No Significant Impact
HAPC	Habitat Area of Particular Concern
HDD	horizontal directional drill
MBTA	Migratory Bird Treaty Act
MHK	marine hydrokinetic
MM	marine mammal
MMPA	Marine Mammal Protection Act
MOU	Memorandum of Understanding
nm	nautical mile
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NNMREC	Northwest National Marine Renewable Energy Center
NOAA	National Oceanic and Atmospheric Administration

NOAA-NMFS	National Oceanic and Atmospheric Administration-National Marine Fisheries Service
NOI	Notice of Intent
NOI/PAD	Notice of Intent/Pre-Application Document
NREL	National Renewable Energy Laboratory
OCS	Outer Continental Shelf
OEERE	Office of Energy Efficiency and Renewable Energy
PAD	Pre-Application Document
PG&E	Pacific Gas and Electric Company
PNNL	Pacific Northwest National Laboratory
RFI	Request for Interest
ROD	Record of Decision
ROM	Rough Order-of-Magnitude
ROV	Remotely Operated Vehicle
RWQCB	Regional Water Quality Control Board
SOPO	Statement of Project Objectives
SWRCB	State Water Resources Control Board
USACE	United States Army Corps of Engineers
USC	United States Code
USGC	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VAFB	Vandenberg Air Force Base
WEC	wave energy converter
WQC	Water Quality Certification

SECTION 1

Permits and Authorizations

This document is part of the Final Report for the California Wave Energy Test Center (CalWave^{sm}) project, Phase II; an attachment to the report for the Permitting Element (Task 12) of the CalWave^{sm} Statement of Program Objectives (SOPO). CalWave^{sm} is funded by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) and cost-share partners and is part of an effort to advance the development of marine hydrokinetic energy (MHK) technology. This phase of work, called CalWave^{sm} Phase II, involves developing conceptual designs, a stakeholder engagement program, and regulatory roadmap for the project. It is funded as a continuation of the DOE Feasibility Study grant (DE-EE0006517.0005).

SOPO Task 12 involves permitting CalWave^{sm}. Subtasks are to evaluate environmental baseline information, participate in stakeholder engagement activities, and prepare the regulatory roadmap for permitting the project. This report is intended to satisfy SOPO subtask 12.4, Regulatory Roadmap. As is stated in the SOPO for Task 12.4

> *CalWave^{sm} will identify the regulatory agencies with permitting authority and the permits and authorizations that will be needed before construction of the test center can begin. After consultation with regulatory agencies that has taken place during the Feasibility Study and that will continue through FY2015 funded work, CalWave^{sm} will prepare a detailed permitting roadmap and schedule that identifies timing and key linkages between authorizations of different agencies and that considers subsequent pre-construction permitting phases.*

There are two major types of authorizations needed for CalWave^{sm} to begin construction: land/seafloor use leases or agreements, and environmental/regulatory permits. Leases include the agreement with the U.S. Air Force for the use of facilities at Vandenberg Air Force Base, Bureau of Ocean Energy Management (BOEM) marine energy research lease of the project test site, the California State Lands Commission (CSLC) submerged lands lease for the portion of the subsea cable run that is located in state waters. Table 1-1 lists the major permits and authorizations, responsible agencies, and legal authorities.

1.1 Lease Agreements

1.1.1 Vandenberg Air Force Base Agreement

The project will require an agreement to lease the on-shore facilities site from Vandenberg AFB and to interconnect with the Vandenberg electrical grid. Onshore facilities include the subsurface cable run from the test berths onshore to the shore facilities, horizontal directional drill (HDD) bore site, shore station, and Vandenberg Dock. CalWave^{sm} will at some point upgrade the existing 12 kV distribution cables from Vandenberg Dock to Substation 'N', and add 70 kV cables capability on the existing poles for approximately six miles between the shore site and Substation 'N'.

1.1.2 CSLC Submerged Lands Lease (Cal. Pub. Res. Code § 6501 et seq)

Submerged lands below the mean high tide line within the California territorial sea (to 3 nm from shore) are sovereign lands of the State of California and managed by the CSLC. Use of these lands for submerged cable installation will require a Submerged Lands Lease, issued by the CSLC. As the trustee of California's sovereign lands, CSLC reviews lease and permit applications for consistency with its responsibilities under the Public Trust Doctrine, and to ensure that proposed activities and projects are in the best interests of the state. Approval of applications may also be contingent upon other criteria and conditions, including but not limited to environmental review documentation and compliance pursuant to the California Environmental

Quality Act (CEQA) and authorizations and permits from other local, state, and federal agencies. CSLC may act as the lead, responsible, or trustee agency for the CEQA process, depending on the type of activity or project. The State CEQA Guidelines direct state lead agencies to coordinate environmental review with federal lead agency counterparts conducting review pursuant to the National Environmental Policy Act (NEPA) for projects that encompass both state and federal jurisdictions, when feasible (Cal Code Regs. tit. 14, § 15222). Preparation of a joint CEQA/NEPA document would require the federal lead agency's cooperation, and the document would need to provide information sufficient to comply with both CEQA and NEPA requirements.

1.1.3 BOEM Research Lease (30 CFR 585.238)

BOEM is the federal agency with responsibility for issuing leases to entities wishing to develop energy projects on the Outer Continental Shelf (OCS). For oil and gas leases or commercial offshore energy (wind, MHK) leases, BOEM may define lease blocks (seafloor lease areas) and hold auctions allowing multiple parties to bid on the areas for energy resources development. Under the provisions of 30 Code of Federal Regulations (CFR) §585.238, BOEM may also issue leases to certain public entities for research purposes.

> The Director may issue OCS leases, ROW grants, and RUE grants to a Federal agency or a State for renewable energy research activities that support the future production, transportation, or transmission of renewable energy (30 CFR 585.238[a]).

Before issuing a Research Lease, BOEM must make a Determination of No Competitive Interest by advertising the proposed research lease. If there is no competitive interest in the lease area, BOEM may issue the Research Lease. For the CalWave^{sm} project, it is likely that the Research Lease holding entity will be the State of California, either through Cal Poly or the California Resources Agency. If there were competitive interest in the lease area, BOEM would hold an auction to determine the best value to the government of issuing the lease.

If, for some reason, the lease holding entity were a private entity, then CalWave^{sm} would obtain a commercial lease. In this case, the same requirements for BOEM to make a determination of competitive interest would apply.

BOEM and FERC signed a Memorandum of Understanding (MOU) on April 9, 2009 to establish their respective jurisdictions and roles in authorizing renewable energy development on the OCS. This document established the exclusive jurisdiction of BOEM to issue renewable energy leases on the OCS and FERC to issue licenses for renewable energy projects using MHK technologies (BOEM maintains jurisdiction to license offshore wind projects). In July of 2012, FERC and BOEM released a document titled "BOEM / FERC Guidelines on Regulation of Marine and Hydrokinetic Energy Projects on the OCS" outlining procedures for licensing MHK projects on the OCS. Most importantly, this document simplifies permitting for MHK projects by combining what would otherwise be the separate processes of BOEM and FERC into a single process.

In the standard BOEM renewable energy permitting process for offshore wind development, an applicant would prepare a series of activities plans (Site Assessment Plan [or Research Activities Plan], General Activities Plan, and Construction and Operation Plan) and BOEM's environmental review process would be based on environmental information gathered in conjunction with preparing these plans/project description documents. In the standard FERC licensing process, by contrast, an applicant prepares a Pre-Application Document (PAD) that serves as a draft project description and also contains initial baseline environmental information about the project area. The applicant then consults with regulatory agencies to prepare environmental study plans and, once these are accepted, prepares a final application and

environmental effects analyses. FERC then issues an Environmental Assessment or Environmental Impact Statement. Under the new BOEM/FERC agreement, licensing will follow the FERC process. BOEM will be a consulting/cooperating agency, but once the Determination of No Competitive Interest has been made, the FERC will be the lead agency for environmental review and permitting that will take place mainly under FERC licensing procedures.

1.2 Licenses, Permits, and Authorizations

To authorize the start of construction, CalWave[sm] will require a number of separate permits from various agencies (Table 1-1). These are discussed briefly below.

Table 1-1. Permits and authorizations needed to begin construction

Agency	Permit/Authorization	Project Purpose	Regulatory Authority
Federal Agencies			
United States Air Force (USAF), Vandenberg Air Force Base (VAFB)	Onshore lease agreement, utility sale agreement	Project host, interconnection with VAFB grid	Federal land manager/property owner
Bureau of Ocean Energy Management	Offshore Research Lease	Sole authority to lease areas in the Outer Continental Shelf (OCS) for energy development	Federal Power Act (16 USC 791-828c as amended), 30 Code of Federal Regulations (CFR) 585.238
Federal Energy Regulatory Commission	Hydrokinetic Project License National Environmental Policy Act (NEPA) review Lead Agency	Responsible for siting and operation of grid-connected hydrokinetic power facilities. Lead NEPA agency.	-Federal Power Act (16 USC 791-828c as amended) -National Environmental Policy Act (42 USC 4321)
U.S. Fish and Wildlife Service (USFWS)	Incidental Take Authorization (terrestrial species)	Protection and recovery of threatened and endangered species Protection of migratory birds	-Federal Endangered Species Act (16 USC 35) -Migratory Bird Treaty Act (16 USC 703-712)
National Oceanographic and Atmospheric Administration National Marine Fisheries Service (NOAA-NMFS)	- Incidental Take Authorization - Marine Mammal Incidental Harassment or Take Authorization (marine mammals) -Essential Fish Habitat Analysis	Protection and of threatened and endangered species and marine mammals and Essential Fish Habitat	- Federal Endangered Species Act - Marine Mammal Protection Act (16 USC 31) - Magnuson-Stevens Fishery Conservation and Management Act (16 USC 38)
U.S. Army Corps of Engineers (USACE)	- Section 10 RHA Permit - Section 404 CWA permit	- Responsible for use of navigable waterways - Protect water quality and wetlands	- Rivers and Harbors Act - Clean Water Act (33 USC 1251-1387)
U.S. Coast Guard (USCG)	Private Aids to Navigation	Responsible for siting of navigation aids in coastal waters	33 CFR 66

Agency	Permit/Authorization	Project Purpose	Regulatory Authority
U.S. Bureau of Land Management (BLM)	Consulting Agency under NEPA	Construction near offshore rocks that are part of the California Coastal National Monument	National Environmental Policy Act
State Agencies			
California Coastal Commission	- Coastal Zone Consistency Determination - Coastal Development Permit	Responsible for development in the Coastal Zone; ensures public access to the Coastal Zone	- Coastal Zone Management Act (16 USC 33) - California Coastal Act (CA PRC 3413)
California State Lands Commission	- Submerged Lands Lease - Geologic or Geophysical Survey Permit - California Environmental Quality Act Compliance	- Leasing of state-owned submerged lands for public benefit - permission to conduct geologic and geophysical studies to obtain technical information - Public Trust consistent development of projects on state submerged lands	CA PRC 6301 et seq, 6501 et seq-CA PRC 6212.3 - California Environmental Quality Act (CA PRC 21000)
California Department of Fish and Wildlife	- Incidental Take Authorization - Streambed Alteration Agreement (if stream crossing)	Protection of threatened and endangered species	- California Endangered Species Act incidental take permit (CA Fish & G. Code 2081(b)) - California Fish and Game Code, Section 1602
Central Coast Regional Water Quality Control Board	- Section 401 Water Quality Certification Waste discharge requirements (if waters of the state) - General National Pollution Discharge Elimination System Permits for construction and operation	Protect and manage water quality	- Federal Clean Water Act - Porter-Cologne Water Quality Control Act (CA PRC 4629)
California Office of Historic Preservation	-Section 106 compliance review -State Historic Preservation Officer consultation	Protect and manage historic properties and other cultural resources	-National Historic Preservation Act -CA PRC 5024, 5024.5

1.2.1 Federal Authorizations

Federal authorizations include the FERC License and ancillary authorizations such as permits or authorizations that would be issued under NEPA, the Endangered Species Act, Marine Mammal Protection Act, Rivers and Harbors Act, Clean Water Act, and other laws and regulations.

1.2.1.1 FERC License (18 CFR 5)

The FERC license serves as a kind of master environmental permit for CalWave^{sm}. It is through the FERC licensing process and through the FERC acting in the capacity as lead Federal agency for compliance with the NEPA that other agencies will have their most important opportunity to comment on the project and its potential effects on the environment. It is also through the FERC licensing authority that consultations with key sister agencies will take place, leading to authorizations under the Endangered Species Act, Marine Mammal Protection Act, Magnuson-Stevens Act, and National Historic Preservation Act that are separate from, but closely linked with, the FERC license.

FERC has three variations on its licensing processes (Integrated, Traditional, and Alternative) that vary in terms of the timing and means of working with agencies and stakeholder groups and it is premature to decide which path is best for CalWave^{sm}. Nevertheless, a characteristic of all three processes is early consultation with regulatory agencies and development of study plans before implementing the plans and entering the environmental analysis phase.

Using the Alternative process as an example, the applicant would form a stakeholder working group to discuss key permitting issues and provide input to study plan development. The applicant then submits a Pre-Application Document and draft study plans. FERC begins the scoping process and, after agreement on the Study Plans, carries out the studies. The applicant can then file the formal application document along with a draft NEPA Environmental Assessment. The Traditional and Integrated processes differ in the organization and timing of stakeholder involvement and study plan submittal. One advantage of the Alternative Process is that it allows the Applicant to prepare the draft NEPA EA. If the project requires an EIS, the Applicant can participate in selecting a third-party contractor to prepare the document. Under these circumstances, the Applicant may have better control of the permitting schedule during this phase of work.

1.2.1.2 Consultations with Federal Agencies

As lead permitting agency and lead NEPA agency, FERC is required to consult with sister agencies to confirm that CalWave^{sm} would comply with laws and regulations for which those agencies are responsible (such as the Endangered Species Act, Marine Mammal Protection Act, National Historic Preservation Act). These agencies have promulgated regulations for coordinating with other federal agencies to carry out this responsibility.

Endangered Species Act (16 USC § 1531 et seq.)

FERC, as the federal action agency, is required under Section 7 of the ESA to consult with the US Fish and Wildlife Service (USFWS) for terrestrial species and marine birds and NOAA-NMFS for marine species if a project may affect species listed under the Federal Endangered Species Act or their critical habitat. This may take the form of an informal consultation, if the USFWS or NOAA-NMFS determines that adverse effects are not likely, or more consultation, if the USFWS or NOAA-NMFS determines the project is likely to adversely affect a listed species. After completion of formal consultation, the USFWS or NOAA-NMFS issues a Biological Opinion (BO) regarding the effects of the project on listed species, and whether the project would jeopardize the continued existence of the species. If the species would not be jeopardized, the USFWS or NOAA-NMFS includes an Incidental Take Statement at the end of the BO that specifies the amount or level of take that will be allowed that is incidental to the activity permitted, and any reasonable and prudent measures that would be required to minimize the take of the species. The BO is partly based on the applicant's/FERC's analysis of project effects and proposed measures to avoid and minimize them provided in a Biological Assessment (BA) document.

Marine Mammal Protection Act (16 USC § 31)

Marine mammals are protected from harm and harassment under the Marine Mammal Protection Act. Because of the potential for the project to affect marine mammals, the FERC will consult with NOAA-NMFS regarding the potential effects of the project on marine mammals and type of authorization needed. If the effects would be limited to short-term harassment (injury or disturbance), NOAA-NMFS can issue an Incidental Harassment Authorization (IHA); however, if the effects would include serious injury or mortality, or cause harassment over multiple years, NOAA-NMFS can issue a Letter of Authorization (LOA). For NOAA-NMFS to issue an LOA for incidental take of marine mammals, the take must be of small numbers, and have no more than a negligible impact on species or stocks. These authorizations are similar to an Incidental Take Permit under the US Endangered Species Act and allow a clearly defined level or amount of harassment or take per annum to marine mammals.

Magnuson-Stevens Fishery Conservation and Management Act (16 USC §§ 1801-1884)

The FERC is also required to consult with NOAA-NMFS regarding a project's possible effects on the viability of commercial fisheries. NOAA-NMFS has designated certain areas as essential fish habitat (EFH) and carefully reviews proposed actions that would affect EFH in a way that could damage the productivity of commercial fisheries. In the project area, the defined EFH mostly has to do with eelgrass, kelp forests, and rocky seafloor bottom and CalWave^{sm} proposes to route the cable to avoid these habitats.

National Historic Preservation Act (16 USC § 470 et seq. and 36 CFR 800)

Under Section 106 of the National Historic Preservation Act, federal agencies must consider the effects of their actions on historic properties (those meeting the criteria for listing in the National Register of Historic Places). FERC would issue this request to the California Office of Historic Preservation, along with a copy of CalWave's report of surveys of archaeological and historic properties that could be affected by the project. Historic properties could include shipwrecks along the submarine cable lay or in mooring areas.

Migratory Bird Treaty Act (16 USC § 703 et seq)— Under the Migratory Bird Treaty Act (MBTA), it is illegal to take, possess, import, export, transport, sell, purchase, barter, or offer for sale, purchase, or barter, any migratory bird, or the parts, nests, or eggs of such a bird except under the terms of a valid permit issued pursuant to Federal regulations. As part of its responsibilities as lead agency under NEPA, FERC would consult with the USFWS under the MBTA and the USFWS would provide comments to FERC regarding the project's potential effects to migratory birds, particularly those nesting in or near the project area.

California Coastal National Monument–Also as lead NEPA agency, FERC will consult the BLM regarding their management responsibility for offshore rocks that are part of the California Coastal National Monument. All offshore rocks not otherwise owned or managed by other entities are part of this National Monument. The BLM would provide comments on the project's potential effects on natural resources of the offshore rocks, such as seabirds and marine mammals.

1.2.1.3 Other Federal Permits and Authorizations

U.S. Army Corps of Engineers Section 10 and 404 Permits—Under Section 10 the Rivers and Harbors Act (330 USC §§ 407) the USACE has the authority to permit development in navigable Waters of the United States and under Section 404 Clean Water Act (30 USC §§ 1251-1387), the USACE has the authority to regulate dredge and fill (construction activities) in Waters of the United States. The agencies would require a detailed project description and analyses of the potential impacts on navigation and on water quality. These permits are at times issued in tandem. USACE would rely on FERC to be the lead NEPA agency for the overall analysis of environmental impacts associated with the project.

1.2.1.4 U.S. Coast Guard Aids to Navigation, 33 CFR 66

CalWave[sm] has begun coordinating procedures for the U.S. Coast Guard's review and comment on private aids to navigation, in this case, WEC lighting and marking, per Coast Guard regulations at 33 CFR 66.

1.2.1.5 Federal Authorizations Delegated to State Agency for Administration

California Water Resources Control Board Section 401 Water Quality Certification—Under the Federal Clean Water Act, the USACE's issuance of a Section 404 permit automatically requires a Water Quality Certification (WQC) under Section 401 of this law. Responsibility for implementing Section 401 has been delegated by the federal government in California to the State Water Resources Control Board and Regional Water Quality Control Boards, in this case, the Central California Regional Water Quality Control Board, located in San Luis Obispo. The WQC will dictate conditions for the preservation/control of water quality associated with construction and operation of the project.

California Coastal Commission CZMA Consistency Determination—The FERC requires a determination that the project is consistent with the federal Coastal Zone Management Act (16 USC §§ 1451–1464). In California's coastal areas, this determination is made by the California Coastal Commission (CCC), which also issues Coastal Development Permits (CDP) (see discussion, below, under State Authorizations.

1.2.2 State of California Authorizations

State of California authorizations include review and certification under the California Environmental Quality Act (CEQA), which is generally completed prior to the CSLC's discretionary review of CalWave's Submerged Lands Lease Application and the Coastal Commission's Coastal Development Permit review under the California Coastal Act.

1.2.2.1 California Environmental Quality Act Review

The California Environmental Quality Act (CEQA) requires that state and local agencies in California disclose and analyze the environmental effects of a project subject to their discretionary decision-making. While there are a number of parallels between the NEPA and CEQA requirements and processes, while NEPA is ultimately a disclosure document, CEQA includes a mandate that prohibits lead agencies from approving projects that result in significant effects on the environment unless those effects are minimized and mitigated to the extent feasible and the lead agency finds that certain economic, legal, technological, social, or other benefits outweigh the adverse environmental consequences. If the lead agency determines the project could not result in a significant effect on the environment, it may prepare and adopt a Negative Declaration, or Mitigated Negative Declaration if project changes or measures are incorporated to ensure significant impacts are avoided. If the project may result in significant impacts, the lead agency will prepare an Environmental Impact Report, which contains an explanation and analysis of the potentially significant impacts of the proposed project, introduces and discusses a range of alternatives to the project, examines cumulative impacts, and imposes mitigation measures that would reduce the significance of the impact to the extent feasible.

The lead agency for CEQA would most likely be the CSLC, because it is the state trustee land manager of tide and submerged lands which will be leased for project infrastructure such as seafloor cables. As the lead agency, CSLC would organize and lead the environmental review process, including public engagement, as well as coordinate with Federal agencies on a possible joint EIR/EIS document. Other state agencies, such as the California Coastal Commission (CCC) and the Department of Water Resources, will participate as responsible agencies, based on their regulatory authorities managing coastal resources and ensuring the project's conformity to relevant state permit requirements.

As CEQA and NEPA processes examine many of the same topics within a similar analytical framework and with similar requirements for stakeholder engagement and public information, it is possible to combine the

processes, as long as the state and federal lead agencies agree do to so. Guidelines for this joint coordination and review processes are available through the California Governor's Office of Planning and Research.

1.2.2.2 Coastal Development Permit

The CCC has authority under the California Coastal Act to issue discretionary CDPs for developments within the coastal zone. The width of the coastal zone varies from place to place, but is generally no less than 1,000 feet from the mean high tide line on land. To comply with the Coastal Act, local planning agencies prepare a Local Coastal Plan (LCP). The CCC reviews the LCP and, once approved, the local (City or County) planning agency has jurisdiction to review and approve CDPs, consistent with the LCP, within the area the LCP covers. In areas with no LCP, the CCC retains jurisdiction. Non-federal activities, such as CalWave^{sm}, that occur on lands leased from the federal government will generally require a CDP from the CCC.

The CCC also retains jurisdiction within submerged lands of the territorial sea, including submerged lands adjacent to federal property at VAFB. To obtain the CDP, CalWave^{sm} will submit a Coastal Resources Assessment and CDP application to the CCC. In its determination as to whether to approve a CDP, the CCC will assess the potential effects of the project on coastal resources and consider issuance of a CDP. Topics of particular interest to the CCC in CDP review include public access to the coastal zone, recreation, biological resources, and effects on geomorphology and potential geological hazards. In considering and issuing proposed CDPs, the CCC complies with CEQA pursuant to its Certified Regulatory Program (Pub. Resources Code § 21080.5; Cal Code Regs. § 15251(c))

1.2.2.3 California Department of Fish and Wildlife CESA Consultation, Section 2081 Permit

Consultation with the CDFW regarding the project's potential effects on species listed under the California Endangered Species Act (CESA) will take place through the CEQA process with CSLC as lead agency. In some cases, a combined state/federal listed species process, coordinated through the FERC license, is possible. If the project could result in the incidental take of a species listed under the CESA, CalWave^{sm} would need to apply for an incidental take permit from the CDFW pursuant to Fish and Game Code section 2081(b). The CDFW issues incidental take permits when the applicant can demonstrate that the impacts of the taking are minimized and fully mitigated, that funding to ensure the success of any mitigation measures has been provided, and that the project would not jeopardize the continued existence of the species.

1.2.2.4 CDFW Lake and Streambed Alteration, Section 1602 Agreement

CalWave^{sm} may also need a Lake and Streambed Alteration Agreement (Section 1602 of the California Fish and Game Code) if it will involve construction within the bed and bank of a stream or lake. It is possible, but unlikely, that this would be required for the generator tie-line pole upgrade between the shore site and substation. Final routing and pole placement will determine whether this is needed.

1.2.2.5 CSLC Geological or Geophysical Permit

The CSLC issues permits for geologic and geophysical surveys conducted within state waters, and administers a specific program for offshore low energy geophysical permits pursuant to California Public Resources Code section 6212.3. These permits are designed to ensure the acoustic effects of geophysical survey devices do not cause disturbance or harm to trust wildlife, fishers, or recreators. CalWave^{sm} is likely to need to conduct, or contract with a permitted operator to conduct, geological and low energy geophysical surveys as part of preliminary site evaluation to determine the seafloor substructure and other factors important to engineering and site design considerations.

1.2.2 Local Government Authorizations

All of the components of the CalWave^{sm} project are on federally owned and managed land or in submerged lands. For this reason, the project will not require authorization from Santa Barbara County (for example, a CDP).

SECTION 2

Permitting Schedule and Process

The time that it will take to secure permits and authorizations needed for CalWave^{sm} to begin construction will depend on a number of factors, including whether there are changes to the project design or siting during permitting, the level of controversy over the project among the public and agencies, and the kinds of studies that agencies require in order to resolve environmental permitting issues. Figure 2-1 is a hypothetical scheduling scenario that assumes that there is a relatively mature project description to begin permitting at the initial stages depicted on the bar chart.

2.1 BOEM Lease Application

Submitting an application to BOEM for a marine renewable energy lease on the OCS is a precursor to other major permitting activities. CalWave^{sm} will submit an unsolicited application for an outer continental shelf marine renewable energy research (or commercial) lease under 36 CFR 585.230 for BOEM's data adequacy review. The application will identify the applicant and the marine renewable energy aliquots (locations) CalWave^{sm} is seeking to lease. Aliquots are square grid units that are 1200 meters on a side that are organized in block units that are 4800 meters on a side. CalWave^{sm} will request a number of aliquots situated both north and east of the existing oil and gas lease P00451. These aliquots will most likely be located in the following aliquot block units: 6474, 6575 (north of P00451), and 6526 (east of P00451). Portions of oil and gas lease P00451 could also be requested from BOEM and use could be granted with consultation from the existing oil and gas lease holder. Oil Platforms Hidalgo, Harvest, and Hermosa are located in adjacent oil and gas blocks to P00451.

Once BOEM determines that the application contains sufficient information, BOEM will issue a public notice of an unsolicited request for a marine renewable energy lease, request for interest (RFI), and request for public comment. If other parties indicate competitive interest in the lease area, BOEM procedures require a competitive auction to determine which party will lease the aliquots in question. If competing parties do not come forward indicating competitive interest within a set period of time (30 days), then BOEM will issue a Determination of No Competitive Interest, and negotiation the lease with CalWave^{sm}. This process, including review of the draft application, can take several months.

2.2 FERC NOI/PAD

Execution of the BOEM lease is a prerequisite to filing application documents with FERC to start the licensing process. To start this process, CalWave^{sm} will submit a Notice of Intent (NOI) to file an application and a Pre-Application Document (PAD) to FERC. The NOI/PAD will contain a detailed description of the project site location, a description of the project design, and general information about the environmental baseline that will allow agencies, stakeholders, and interested parties to understand the scope of the project. The PAD will include sufficient baseline information that is publically available without field studies to identify key issues for permitting and to develop study plans to address the issues.

FERC will then hold scoping meetings and prepare scoping documents that identify key regulatory and public interest issues. In consultation with FERC and the regulatory agencies and the collaborative working group established through the stakeholder involvement program, CalWave^{sm} will prepare draft study plans for review. These study plans will identify data that will need to be collected to address the key regulatory issues. Preparation of study plans is CalWave^{sm}'s opportunity to focus the study effort on substantive issues

having a clear nexus to the project. It is the opportunity of the regulatory agencies to request data they feel is necessary to address key issues.

CalWave^{sm} will implement the study plans and begin collecting the data that will be necessary to permit the project. After this phase of initial encounter with FERC, the public, and regulatory agencies, issues may arise that lead to minor changes to the project design.

2.3 FERC License Application and Environmental Analysis

CalWave^{sm} can begin preparing the FERC license application based on the initial project design and the results of scoping studies and discussions with regulatory agencies, and the public. The actual time it will take to complete this phase of the schedule is undetermined at this early stage because it is not clear whether the study plans will require data from more than one season or even more than one year. If long-term studies will not be needed to resolve environmental resources issues (for example, potential effects on listed species or marine mammals), then less time may be needed for field studies and the schedule might possibly be shortened. Stand-alone study reports would likely include, among others:

- Biological Assessment (Endangered Species act)
- Biological Assessment (Marine Mammal Protection Act)
- Biological Assessment (California Endangered Species Act)
- Cultural Resources Inventory and Evaluation (National Historic Protection Act)

Topics required to be included in the environmental analysis and application are as follows:

- Geology, Topography, and Soils
- Water Resources
- Fish and Aquatic Resources
- Wildlife and Botanical Resources
- Floodplains, Wetlands, Riparian, and Littoral Habitat
- Rare, Threatened and Endangered Species
- Recreation and Land Use
- Aesthetic Resources
- Cultural Resources
- Socio-economic Resources
- Tribal Resources

CalWave^{sm} will prepare the final license application and file the document with FERC. The license application will contain a detailed project description suitable for permitting, environmental baseline analyses of the key environmental resources disciplines of interest to FERC, and analysis of CalWave^{sm}'s potential effects on environmental resources. Under the Alternative Licensing Process, CalWave^{sm} could also submit a preliminary draft NEPA EA document at or shortly after this time which, after acceptance by FERC, would serve as FERC's NEPA compliance document if an Environmental Impact Statement (EIS) is not necessary. In the latter case, the EIS would be prepared by a third-party, paid for by CalWave^{sm}, instead of by FERC staff.

2.4 Ancillary Permit Applications

During this phase also, CalWave^{sm} will prepare the following application documents and submit them to the applicable regulatory agencies:

- Clean Water Act Section 404/Rivers and Harbors Act Section 10 Permit – USACE
- Submerged Lands Lease – CSLC
- Coastal Development Permit and CZMA Consistency Determination – CCC
- Clean Water Act Section 401 Water Quality Certification – SWRCB/CCRWQCB

After acceptance of the application and CalWave^{sm}'s Biological Assessment as complete, FERC will initiate the required consultations with sister agencies (NOAA-NMFS, USFWS, California Office of Historic Preservation), work with the applicant or third-party consultant to finalize the NEPA document and then issue the document to the public and agencies for comment. After receiving comments, FERC, with CalWave^{sm}'s help and that of the third-party consultant, will respond to the public and agency comments and issue the final NEPA document. After consultations with sister-agencies are completed, FERC will issue the final NEPA document and its own findings.

2.5 Permit and Lease Issuance

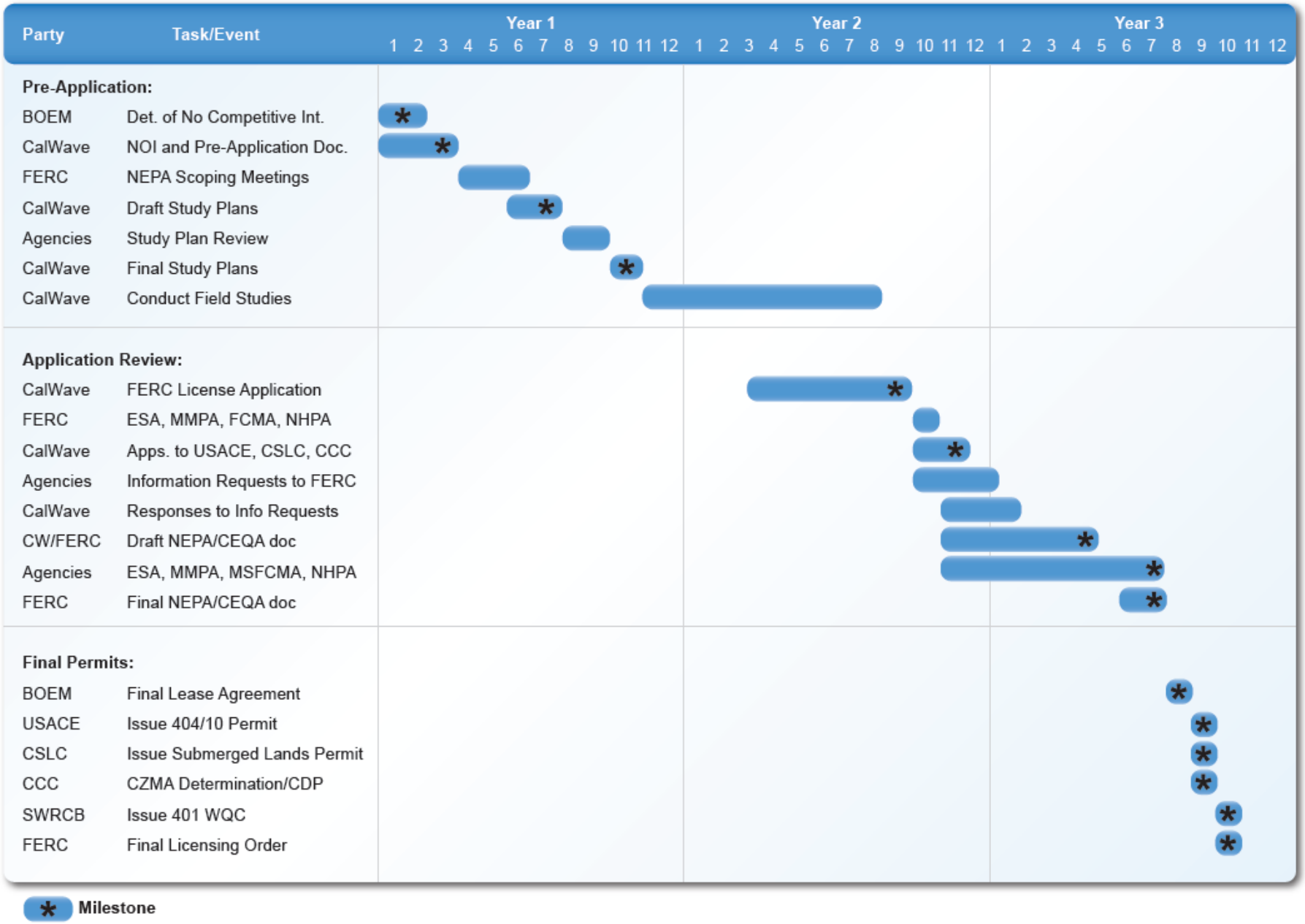
Once the final NEPA/CEQA document is certified BOEM can issue the Research Lease, contingent on obtaining all authorizations needed from other agencies. Once the federal and state agencies have issued the ancillary permits and their comments to FERC with proposed licensing conditions for resources under their responsibility, FERC can issue the final licensing order and CalWave^{sm} can enter the construction phase.

2.6 Key Linkages and Sequencing Summary

The following are some of the key linkages/permitting sequences that will determine the critical path schedule:

- **BOEM Lease Application process before Filing the FERC PAD** – FERC will not accept the NOI/PAD without certainty from BOEM that the OCS lease is in place or very likely to occur.
- **Completion of field studies before filing FERC Application and Environmental Analysis**—Field studies and their results must be fully reflected in the Application and Environmental Analysis and study reports must be appended to the Application.
- **FERC application filed before starting formal consultations under the Endangered Species Act, Marine Mammal Protection Act, or National Historic Preservation Act**—To begin formal consultation, FERC must have a completed application and Biological Assessment (Endangered Species Act) and Historic Properties Survey Report (National Historic Preservation Act).
- **Consulting agency findings/permits before NEPA EA Finding of no Significant Impact (FONSI) or EIS Record of Decision (ROD)**—FERC prefers to have the findings of or necessary authorizations from consulting agencies before issuing a formal Record of Decision under NEPA. For example, the Biological Opinion or a Memorandum of Agreement to resolve adverse effect under the National Historic Preservation Act should be in place before FERC issues the NEPA EA FONSI or EIS ROD.
- **NEPA FONSI or ROD before the FERC License**—FERC cannot issue a final licensing order before NEPA is concluded.
- **CEQA EA Negative Declaration or EIR Notice of Determination before CSLC lease and CDP**—Similarly, CSLC cannot issue its lease and CCC cannot issue a CDP before CEQA is concluded.
- **Ancillary Permits before FERC License**— FERC does not issue a final licensing order before ancillary permits are granted, such as Water Quality Certification and the Section 10 Rivers and Harbors Permit and the Coastal Zone Consistency Determination is made through the CCC's CDP process.

Figure 2-1. CalWave℠ Hypothetical Permitting Process Schedule



Cost Estimate[1]

The cost of licensing and permitting CalWave[sm] has the following essential components:

- Gather baseline data/literature search
- Gather site-specific field data
- Prepare and file application documents
- Respond to information requests and comments on the license and permit applications
- Prepare construction monitoring and compliance plans
- Monitor construction
- Monitor post construction

Costs in each of these phases will also include costs of coordination with the CalWave[sm] project development team and of participating in the public involvement and stakeholder engagement program (meetings with regulatory agencies, etc.).

At this stage of development (before filing the PAD), costs of two components in particular are especially difficult to predict. These are the site-specific data gathering and the post-construction monitoring components. Costs of site-specific data gathering will depend to a large extent on the outcomes of the outcome of negotiations with regulatory agencies regarding which issues will require site-specific data gathering and the extent of data needed to address regulatory issues. Costs of post-construction monitoring will depend largely on the level of uncertainty that remains regarding potential project effects after construction as determined through the permitting process.

3.1 PNNL Permitting Cost Studies

The DOE Pacific Northwest National Laboratory (PNNL) has conducted several studies to estimate the potential contribution of licensing and permitting to the development of MHK power projects. These studies established several reference models (tidal, ocean current, point absorber, oscillating water column, nearshore flap, etc.) and prepared generic estimates of potential licensing costs for each reference model. Copping and Geerlofs, 2011; Copping, Geerlofs, and Hanna, 2013, 2014).

The PNNL studies assumed that the following biological field data collection efforts would be needed to license an MHK wave farm (point absorber, oscillating water column), among other studies needed:

- **Marine Mammals—**Large vessel for gray whale surveys in spring and winter; small vessel surveys for resident gray and humpback whales in summer and fall; acoustic monitoring with autonomous recorders for other species
- **Fish and Invertebrates**—Grab sampling to assess benthic invertebrates, trawling to assess demersal fish and benthic invertebrates
- **Birds**—Small boat surveys and line transects, some of which can be done in conjunction with marine mammal surveys
- **Sea turtles**—Surveys done in conjunction with marine mammal and seabird boat surveys or by aircraft.

[1] The cost estimates found here are minor updates of those found in the Phase I Feasibility Study for CalWave[sm]. Cost estimating is not in the Task 12 Scope of Service, but is provided here for convenience.

These studies are recommended to continue for a year (marine mammals, sea turtles) or more (fish and invertebrates) for sites where baseline data is not available, and for CalWave[sm] would commence later in Year 1 (see schedule, above) after study plans are approved.

The PNNL studies developed low and high cost range estimates for three scenarios: (1) pilot project, <5 M for 5 years, (2) small-scale commercial (10 to 50 devices), and (3) large-scale commercial (> 50 devices). The scenario that best fits CalWave is the small-scale commercial model. Differences are that CalWave[sm] may host fewer than 50 devices. It will operated for more than 5 years, but possibly less than the 30-year presumed lifetime of a large commercial wave farm (assume 25 to 30 years). Table 3-1 reproduces the PNNL cost estimates (adjusted for inflation), for Reference Model #3, point absorber buoy with a reaction plate, anchored to the seafloor, assuming northern California location, and Reference Model #6, Oscillating Water Column devices sited in 50 m of water in Northern California. Copping and Geerlofs note that these costs estimates do not include possible costs of mitigation, which would be specific to a particular project and which, for some projects, could be substantial.

Table 3-1. PNNL Permitting Cost Estimates, Point Absorber and, Oscillating Water Column Reference Models

Reference Model	RM#3, Point Absorber		RM#6, Oscillating Water Column	
Project Phase	**Low Estimate***	**High Estimate***	**Low Estimate**	**High Estimate**
Siting & Scoping	$341,794	$538,585	$330,000	$530,000
Pre-Installation Studies	$2,055,944	$3,847,774	$1,753,000	$3,452,000
NEPA & Process	$937,345	$1,786,652	$1,100,000	$2,300,000
Subtotal	$3,335,083	$6,173,010	$3,183,000	$6,282,000
Post-Installation Monitoring	$7,493,579	$18,068,484	$9,355,000	$19,800,000
Grand Total	$10,828,662	$24,241,495	$12,538,000	$26,082,000

Source: Copping and Geerlofs, 2011; Copping, Geerlofs, and Hanna, 2014
* These costs have been adjusted upward from those provided by Copping and Geerlofs by 3.5 percent to account for price inflation between 2011 and 2013.

The PNNL reference models indicate that, not surprisingly, the largest costs will be for pre-installation data gathering and post-installation monitoring. PNNL estimates costs to permit an oscillating water column as higher than point absorber, partly due to the size and deck area required for an oscillating water column. This leads to more potential conflicts with marine mammals and sea birds.

These costs are relatively high compared with energy facilities on land, but this is partly due to the high cost of collecting data in the ocean and also the scale of the facilities. Costs for large-scale solar farms requiring large amounts of land have reached, and exceeded, these levels routinely for initial permitting.

The post-construction monitoring cost estimates seem particularly high, although less so when placed in the context of a 30-year project life. The standard approach for environmental permitting is that applicants and regulatory agencies, working together, should be able to predict or foresee what impacts to public resources will be significant and adverse, and prepare plans or mitigation measures to avoid or compensate for adverse impacts before construction takes place. In reality, however, some impacts of MHK projects implemented in the marine environment are still uncertain and agencies are likely to require post-construction monitoring to determine whether or not unforeseen impacts are taking place. Copping and Geerlofs put it this way:

> Until sufficient data exist to anticipate interactions of MHK devices with marine animals and habitats, extensive monitoring is likely to be required during the initial years of deployment at the commercial scale, resulting in front-loading of costs in the first five years (2011:3.13)

Once the MHK industry is well established, it is expected that post-construction monitoring will be required only for a few particularly intractable issues for which additional information needs to be gathered to resolve issues.

3.2 CalWave^{sm} Permitting Cost Estimate

The PNNL reference model cost estimates are very helpful in estimating MHK project permitting costs and were intended as reference models for developing site-specific cost estimates for proposed facilities. Each location will have special data-collection needs that will drive permitting costs at that location.

The cost estimate included here in Table 3-2 for CalWave^{sm} is based on the PNNL cost models and also assumes the following:

- It will take approximately three years to permit the project
- One year of field studies (or less) will be sufficient to gather baseline data needed to permit the project
- These permitting costs do not include bathymetry and wave resource assessment, turbulence, and other oceanographic site characterization tasks, which are done to support engineering design
- CalWave^{sm} will host up to 40 WECs and will operate for 25 to 30 years
- Post-construction monitoring can be significantly reduced after 5 years
- These permitting costs do not include the costs of stakeholder participation and public involvement (those are estimated separately – see Section 5.0)
- This cost estimate is preliminary and Rough Order-of-Magnitude (ROM) estimate only and is based on current information (feasibility study).

Table 3-2. CalWave^{sm} Permitting Preliminary Cost Estimate*

Task	Low	High	Notes
Gather Baseline Data	$40,000	$80,000	Additional lit search for environ. disciplines
Field Studies:			
Marine Mammals	$300,000	$800,000	Vessel, airplane, or sonar-buoy
Fish and Invertebrates	$200,000	$750,000	Trapping, netting, trawling
Seabirds	$50,000	$100,000	Combine with MM survey
Habitat mapping (from bathymetry)	$20,000	$30,000	Assumes bathymetry available
Terrestrial Biology	$40,000	$80,000	Survey shore site, gen-tie line
Cultural Resources	$35,000	$60,000	Survey shore site, gen-tie line, assume historic shipwrecks avoided
Commercial Fishing Assessment	$35,000	$120,000	LOE depends on fisher concern
Visual Resources, Recreation, etc.	$25,000	$50,000	Prepare visual simulations

Task	Low	High	Notes
Water Quality modeling	$100,000	$200,000	Deploy conductivity, temperature, depth instrument, combine with other surveys
Noise modeling	$20,000	$50,000	Estimates of project noise levels
Air emissions modeling	$30,000	$50,000	Model construction and operation emissions for NEPA/CEQA analysis
Sediment transport modeling	$30,000	$50,000	Model effects of wave energy removal on sediment, recreational surfing
Ship navigation transponder	$5,000	$10,000	Deploy AIS transponder to record ship tracks (if not available from VAFB)
Subtotal field studies	**$890,000**	**$2,350,000**	
Applications (FERC, USACE, CSLC, CCC)	$250,000	$300,000	Applicant-prepared documents
NEPA/CEQA document	$250,000	$850,000	If EIS/EIR, consultant-prepared (high)
Information Request Responses	$150,000	$250,000	Applicant and 3rd party consultant
Subtotal Application process	**$500,000**	**$1,200,000**	
Total Permitting Costs	**$1,430,000**	**$3,630,000**	**Cost to authorize construction**
Post-Licensing Compliance Plans	$60,000	$80,000	Plans required by permit for construction compliance
Construction Monitoring	$150,000	$350,000	Whale monitors, etc. for construction
Post-Construction Monitoring	$3,463,333	$8,710,000	Most in first five years, 20-year project
Total Post-permitting costs	**$3,673,333**	**$9,140,000**	
Grand Total, permitting and operation	**$5,103,333**	**$12,770,000**	
*Estimates based roughly on PNNL reference models for a site with no previous pilot project to establish baseline data.			

3.3 References Cited

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