# South West of England Regional Development Agency

# Wave Hub Development and Design Phase Coastal Processes Study Report

June 2006

Halcrow

South West *of* England
Regional Development Agency

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## Contents Amendment Record

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# Executive Summary

The South West of England Regional Development Agency (SWRDA) is undertaking the technical development of the Wave Hub which is an underwater offshore plug-in facility to enable wave energy converter device developers to connect their devices to the National Grid for pre-commercial testing.

This report considers the impact of the Wave Hub sub-sea facilities (cable termination and distribution unit, transformers and connection points), interconnecting cables, onshore cable and alternative wave energy converter (WEC) device layouts on coastal processes (wave climate, tidal streams and currents and sediment regime) and geomorphological processes.

Two alternative WEC device layouts have been considered:

- WEC device layout no.1 included four west-facing Wave Dragons;
- WEC device layout no.2 comprised one Wave Dragon, two Fred Olsen FO$^3$; thirty Power Buoy PB150 and six Pelamis.

To provide baseline conditions, latest available data has been presented on; water levels (typical and extreme); offshore wave conditions (including desktop review of available data, recorded wave data between 30 Jan 2005 and 12 April 2006, Met Office wave model data, joint probability and extremes analysis); tidal streams and currents; and sediment regimes in the offshore, transitional and nearshore zones.

| **Typical Water Levels** | **Water Level (mODN)** |
|---|---|
| Mean Low Water Spring (MLWS) | -2.6 |
| Mean High Water Spring (MHWS) | +3.2 |
| **Extreme Water Levels** | |
| 1 in 2 year return period | +3.6 |
| 1 in 50 year return period | +3.7 |
| 1 in 100 year return period | +3.8 |
| Figures above exclude sea level rise = 5mm/yr (Defra, 2004)<br>and exclude surge 1 in 50 yr return period surge at St Ives = 1.0m (Pugh, 1987)<br>(mODN) metres above Ordnance Datum Newlyn | |

| **Typical Offshore Wave Conditions** | **Hs (m)** | **T (s)** |
|---|---|---|
| Typical “small” surf wave conditions (38% prob of occurrence between 1 May and 31 Aug, 45 days/ 122 days. 28% prob. of occurrence throughout the year 100 days/ 365 days) | 1.0 | 7.0 |
| Mean wave climate | 1.6 | 5.4 |
| “Big” surf wave conditions (0.3% prob of occurrence, approx 1 day per year) | 4.0 | 16.0 |
| **Extreme Offshore Wave Conditions (all directions)** | | |
| 1 in 1 year return period | 10.4 | 12.1 |
| 1 in 50 year return period | 13.8 | 13.9 |
| 1 in 100 year return period | 14.4 | 14.1 |

| **Typical Tidal Current** (typically parallel to the coast) | 1.0m/s to 1.2m/s |
|---|---|
| **Extreme Tidal Current**: 1 in 50 year return period surface current | 1.6m/s |

Sediments in the offshore and transition zone (60mCD to 10mCD) are comprised of patchy and thin, typically less than 1m, layers of sands and gravels which overlie mudstone/ shale bedrock and which become increasingly intermittent towards the offshore zone (40mCD). Since no major features have been observed it is speculated that little change has occurred on the seabed over the last 100 years. Due to the depth of water sediment movement is limited except during storm conditions.

St Ives Bay is believed to be a sediment sink. However since sediment inputs from the River Hayle and from offshore are limited the system can be considered as a ‘closed’ sediment system. The beaches are comprised mainly of sand. The beach profile demonstrates typical seasonal changes with lowering of beach levels and the creation of an inter-tidal bar during winter. Limited beach profile data is available, but it has been suggested that beach levels can reduce by up to 1.8m (6ft) following storms. The plan shape of the beach suggests longshore drift in the estuary mouth from both the west and east. The dunes to the west of the proposed cable landfall are eroding and this could potentially extend eastwards in future. Rapid accretion occurs in the channel at the mouth of the estuary, which was previously dredged and sluiced to maintain a shipping channel. The alignment of the channel appears to be stable. Development proposals are currently being considered to redevelop the harbour into a marina and possibly to re-establish sluicing of the channel.

The Wave Hub sub-sea facilities and cables will have minor to negligible impacts on local sediments, with the main impacts occurring during installation.

WEC device layouts considered will result in up to a 5% reduction in wave heights at the coast during a 1 in 1 year return period storm (based on spectral wave modelling which considers a typical sea state which is comprised of many different waves approaching from different directions) and up to a 13% reduction in the height of typical surfing waves at the coast (based on monochromatic wave modelling which considers the impact of a single wave approaching from a single direction, to simulate a long period swell wave approaching from the North Atlantic).

WEC device layouts considered will lead to a change in tidal currents of up to -0.8m/s to +0.6m/s within a 15km x 15km area surrounding the WEC deployment area, which does not extend to the coast.

WEC device layouts considered will not have a discernable impact on sediment transport and beach levels along the north Cornish coast, change of less than 0.2m in beach levels during extreme events, which is minimal when compared to the current typical seasonal changes to the beach which can reduce levels by up to 1.8m following a storm.

# Contents

# 1 Introduction

The South West of England Regional Development Agency (SWRDA) is undertaking the technical development of the Wave Hub which is an underwater offshore plug-in facility, see Figures 1.1 and 1.2, to enable wave energy converter device developers to connect their devices to the National Grid for pre-commercial testing. A 24kV cable will run from the Wave Hub to a new sub-station located on the north Cornish coast at Hayle, see Figure 1.3. It is proposed that the offshore section of the cable will be laid on the seabed, whilst the section within St Ives Bay will be buried beneath the sand.

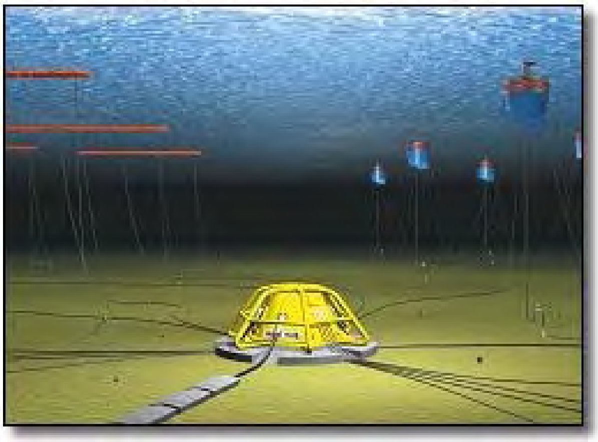


*Figure 1.1: Artist's Impression of the Wave Hub*

To determine site conditions, technical feasibility and economical design, a series of investigations have been conducted. This report addresses the coastal processes study which includes: a review of existing offshore and coastal conditions and the potential impact of the Wave Hub on offshore, coastal and geomorphological processes.

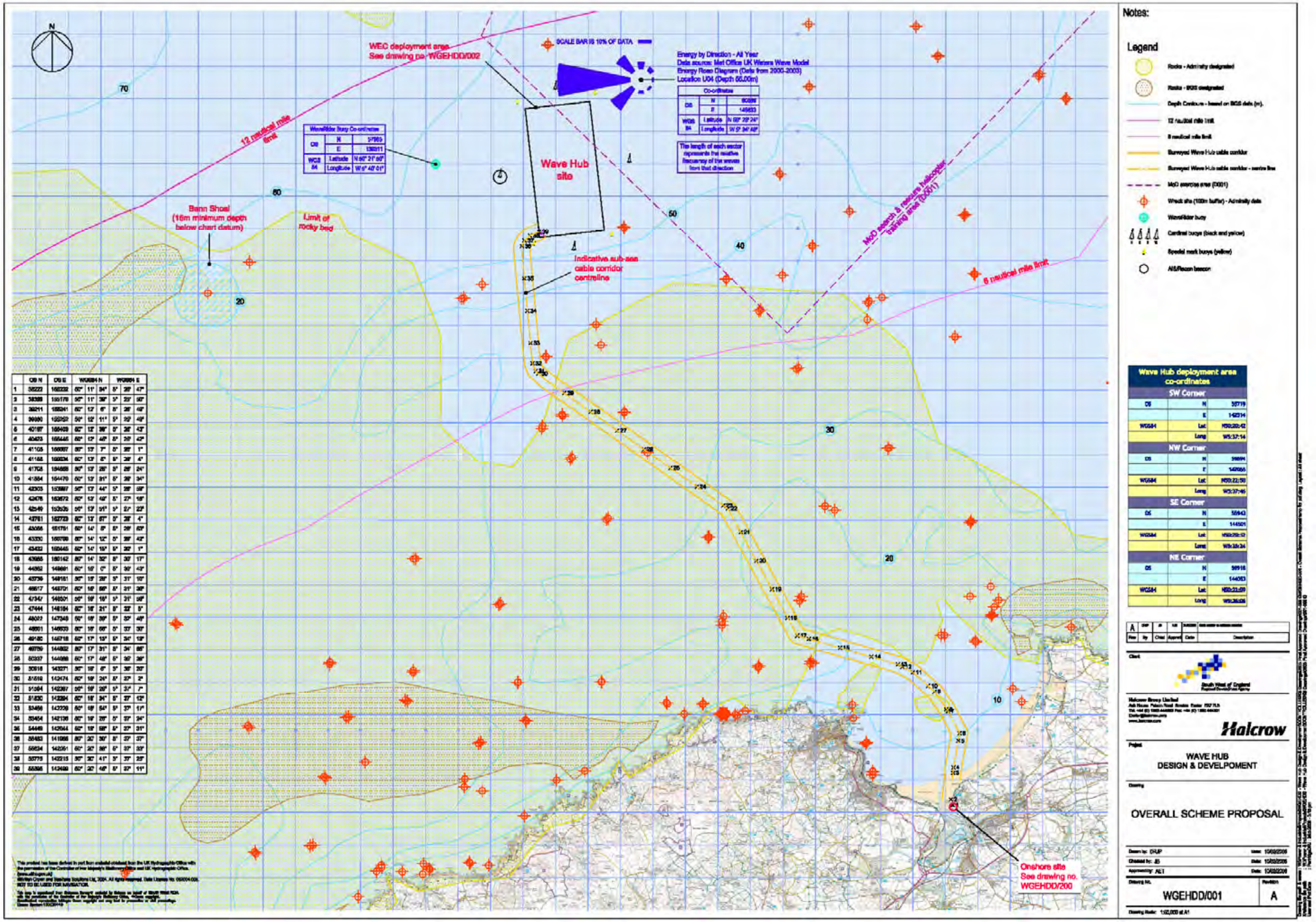


Figure 1.2: Overall Scheme Proposal

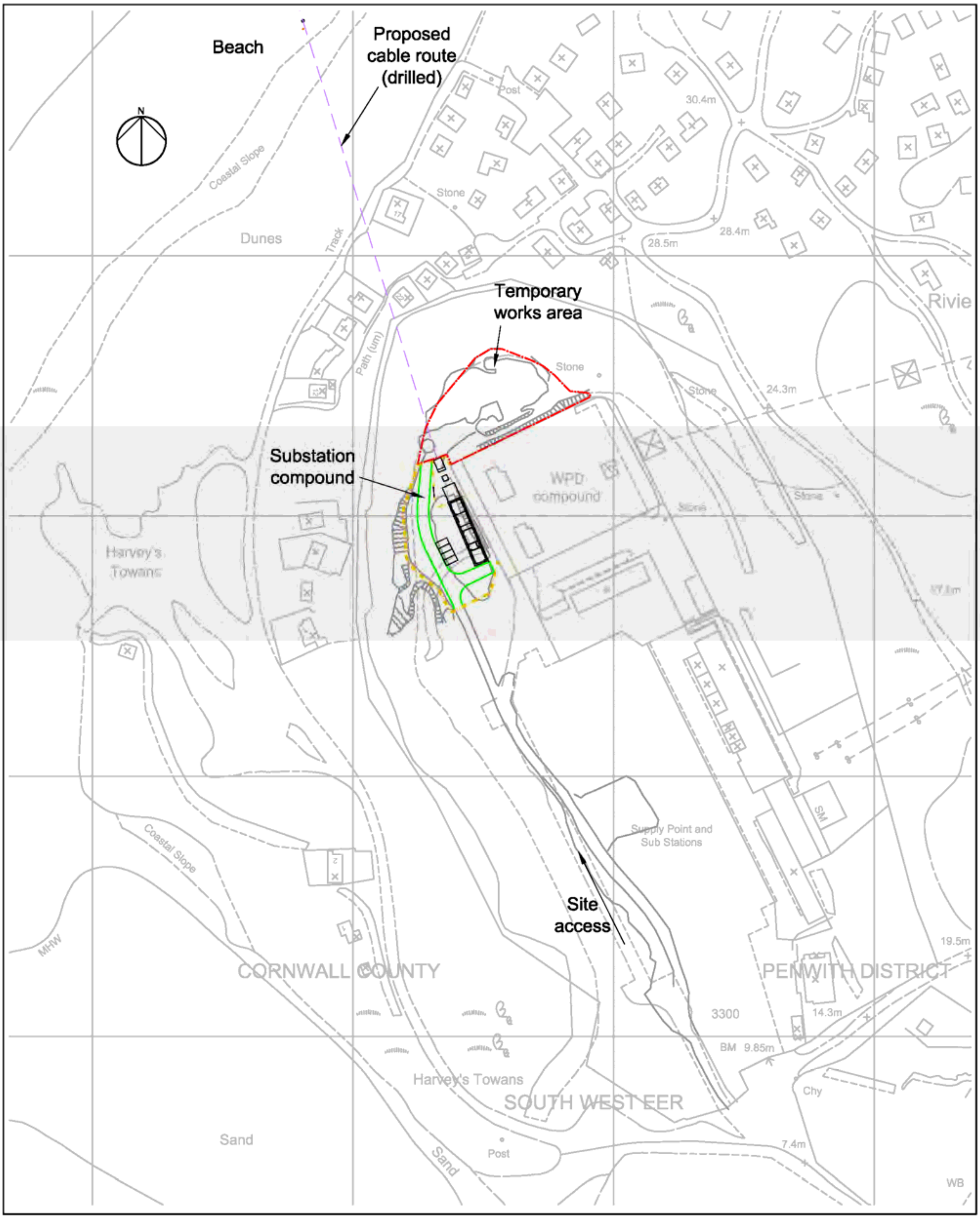


*Figure 1.3: Proposed Onshore Site Layout*

The impacts of two alternative arrays of wave energy converter (WEC) devices based at the Wave Hub were considered:

- Four west-facing Wave Dragons aligned perpendicular to the predominant westerly wave direction, see Plate 1.1 and Figure 1.4.
- An array of various devices which may be deployed at the Wave Hub, based on the recent submission to DTI. This array is comprised of one Wave Dragon; two Fred Olsen FO$^3$; thirty Power Buoy PB150 and six Pelamis, see Plate 1.1 and Figure 1.5.

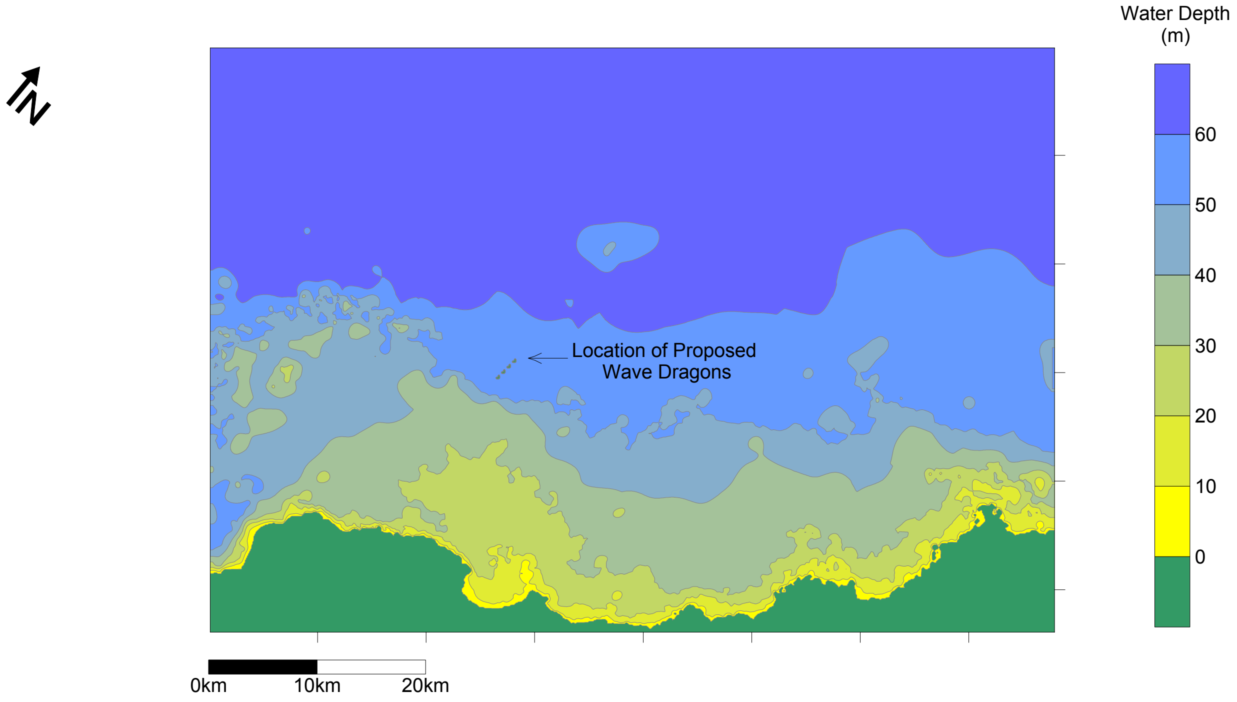
***Plate 1.1: WEC Devices***
***(top to bottom: Wave Dragon, FO$^3$, Pelamis and PowerBuoy PB150)***

Wave Dragon is a floating, slack moored overtopping device. Two wave reflector arms focus waves towards a ramp. Behind the ramp is a large reservoir where the water that runs up the ramp is collected and temporarily stored, the water leaves the reservoir through a series of low-head turbines which utilise the head between the level of the reservoir and sea level. The potential energy in the stored water is in this way converted into power (www.wavedragon.net).

Fred Olsen FO$^3$ is a floating semi-submersible platform onto which several point absorbers are mounted on vertical hydraulic cylinders. The vertical movements of the point absorbers are transformed to hydraulic pressure which is utilised to drive generators (no company web-site is provided, further information from ToreGulli@fredolsen.no).

PowerBuoy has been developed by Ocean Power Technologies. The WEC device is submerged more than metre below the water's surface. Inside a piston-like structure moves as the PowerBuoy rises and falls with the waves. The movement drives a generator (www.oceanpowertechnologies.com).

Pelamis is named after a sea-snake and has been developed by Ocean Power Delivery Ltd. The device is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. The wave induced motion of the joints is resisted by hydraulic rams which pump high pressure fluid through hydraulic motors which drive generators to produce electricity (www.oceanpd.com).



**Application of FLOW3D Model**

**Model Bathymetry**

**4 Wave Dragons**

*Figure 1.4: WEC Device Array Layout No.1 – 4 nr. Wave Dragons (west-facing)*

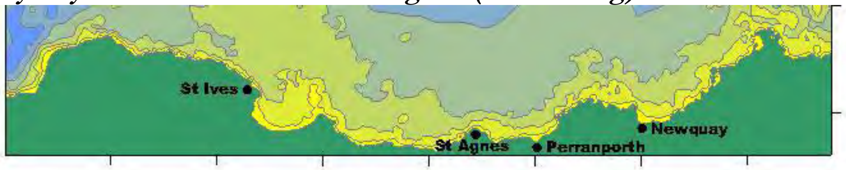
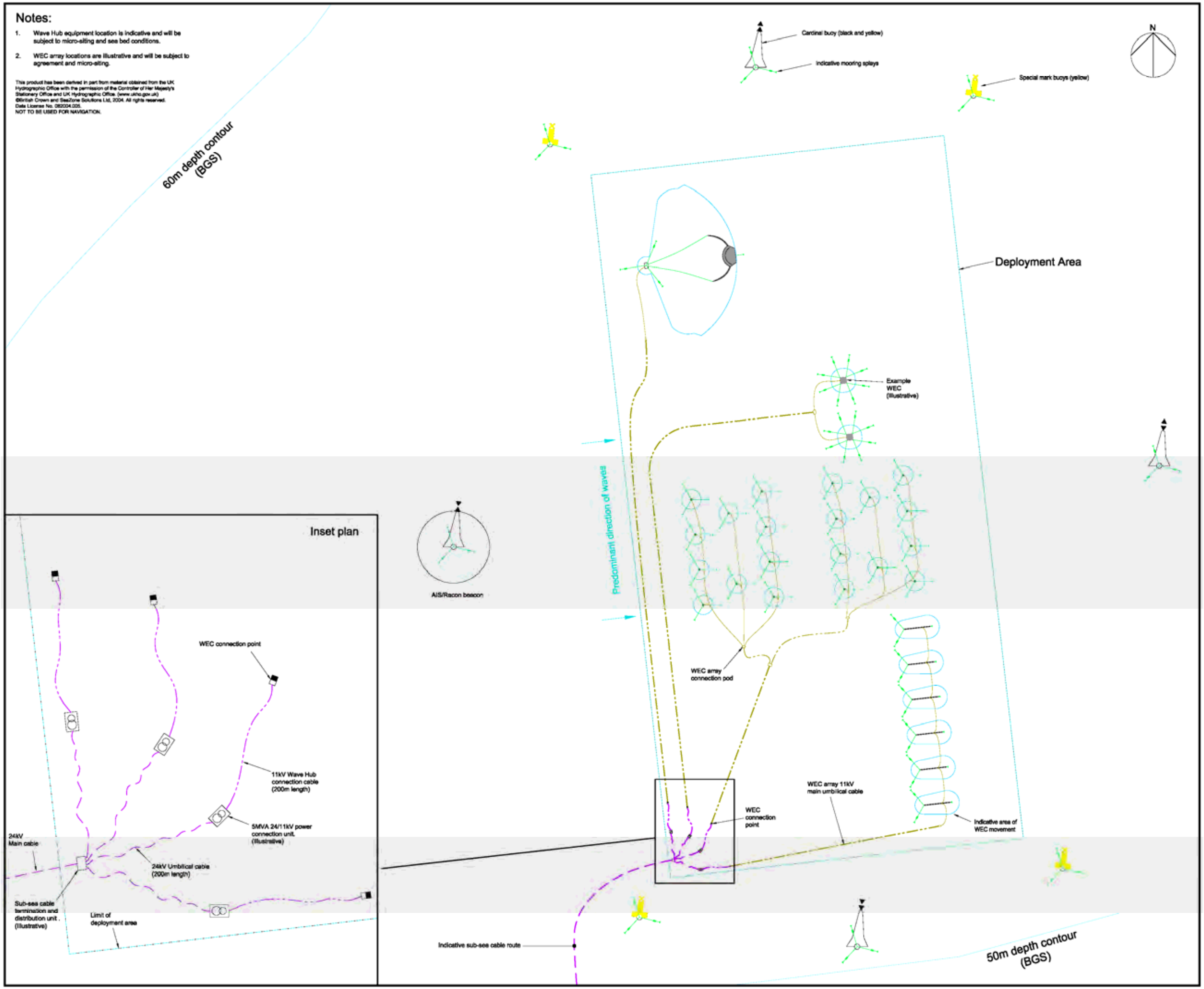


*Figure 1.4a: Location Plan*



Notes:

1. Wave Hub equipment location is indicative and will be subject to micro-siting and sea bed conditions.
2. WEC array locations are illustrative and will be subject to agreement and micro-siting.

This product has been derived in part from material obtained from the UK Hydrographic Office with the permission of the Controller of Her Majesty's Stationery Office and UK Hydrographic Office. (www.ukho.gov.uk)

Data License No. 082004.005.
NOT TO BE USED FOR NAVIGATION.

*Figure 1.5: WEC Device Array Layout No.2 – Various Devices*

# 2 Water Levels

Typical and extreme water levels at the proposed deployment site are provided in the Tables 2.1 and 2.2 below.

| Tidal State | Water Level (mODN) |
|---|---|
| Mean High Water Spring (MHWS) | +3.2 |
| Mean High Water Neap (MHWN) | +1.5 |
| Mean Low Water Neap (MLWN) | -1.0 |
| Mean Low Water Spring (MLWS) | -2.6 |
| (mODN) metres above Ordnance Datum Newlyn | |

***Table 2.1: Typical Tide Levels at St Ives***

| Return period (years) | Water Level (mODN) |
|---|---|
| 1 in 2 | 3.55 |
| 1 in 5 | 3.63 |
| 1 in 10 | 3.66 |
| 1 in 20 | 3.69 |
| 1 in 50 | 3.72 |
| 1 in 100 | 3.75 |
| 1 in 200 | 3.76 |
| Notes:<br>1. Figures above exclude surge or long term sea level rise<br>2. (mODN) metres above Ordnance Datum Newlyn | |

***Table 2.2: Extreme Tide Levels at St Ives***

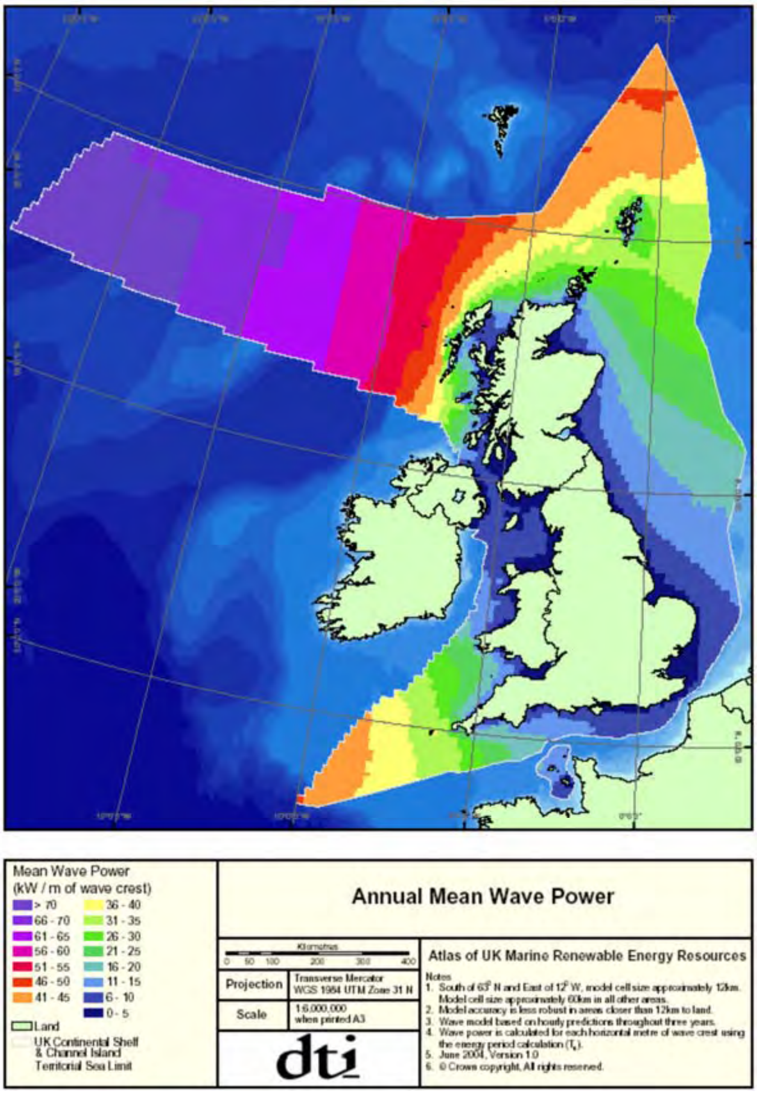
The 50 year return period predicted storm surge at St Ives is 1.0m (Pugh, 1987).

The recommended rate of sea level rise for SW England is 5mm/yr (Defra/ EA, 2004).

# 3 Offshore Wave Conditions

## 3.1 *Desktop Review of Existing Data*

The annual mean wave power at the Wave Hub has been estimated as between 21kW/m and 25kW/m (DTI, 2004 and SWRDA, 2004), see Figure 3.1, which is understood to be a reasonable wave climate for WECs. Further details of the desk top review of existing data is provided in the Wave Hub Technical Feasibility Study (Halcrow, 2005).



Notes
1. South of 63° N and East of 12° W, model cell size approximately 12km. Model cell size approximately 60km in all other areas.
2. Model accuracy is less robust in areas closer than 12km to land.
3. Wave model based on hourly predictions throughout three years.
4. Wave power is calculated for each horizontal metre of wave crest using the energy period calculation ($T_e$).
5. June 2004, Version 1.0
6. © Crown copyright, All rights reserved.

*Figure 3.1: UK Annual Mean Wave Power (DTI, 2004)*

## 3.2 Recorded Wave Data

A wave buoy was deployed close to the proposed location of the Wave Hub (Offshore point, 50º21'30" N, 5º40'0" W, depth 52m Chart Datum) between 30 Jan 2005 and 10 April 2006, see Plate 3.1. The recorded wave data, see Figure 3.2, was compared against coincident data from the Met Office Wave Model UK waters grid point U04 which is close to the location of the wave buoy, see Figure 3.3.

A summary of wave data and spectral wave data has been provided in Appendix A.

*Plate 3.1: Wave Buoy*

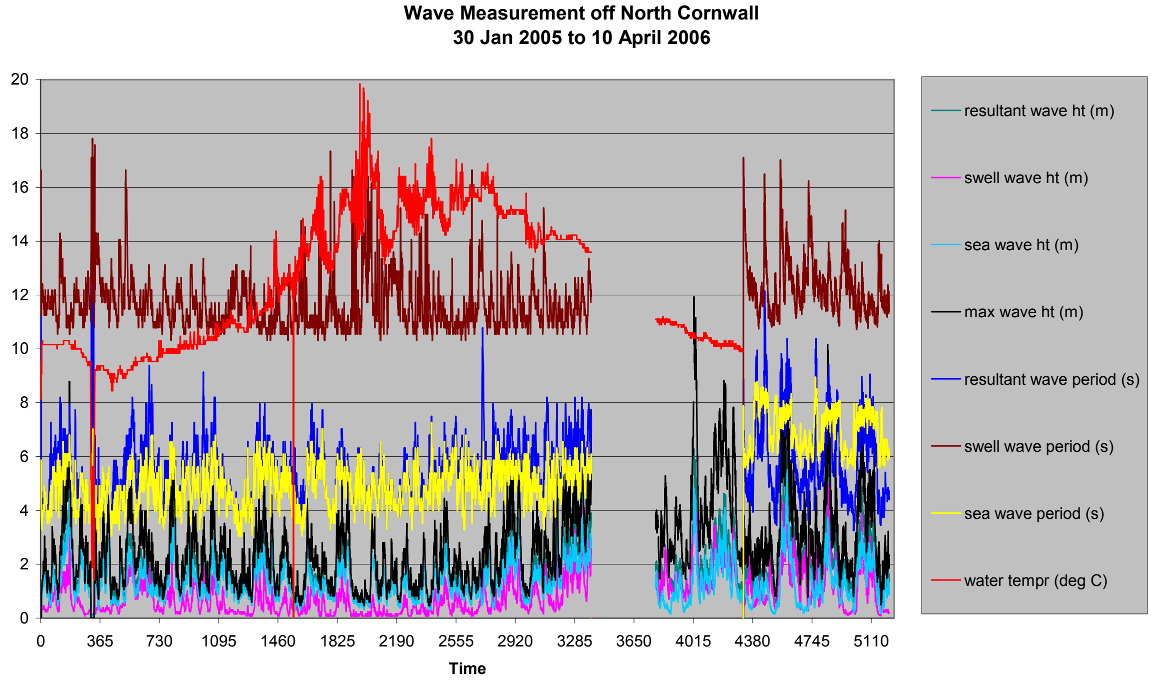
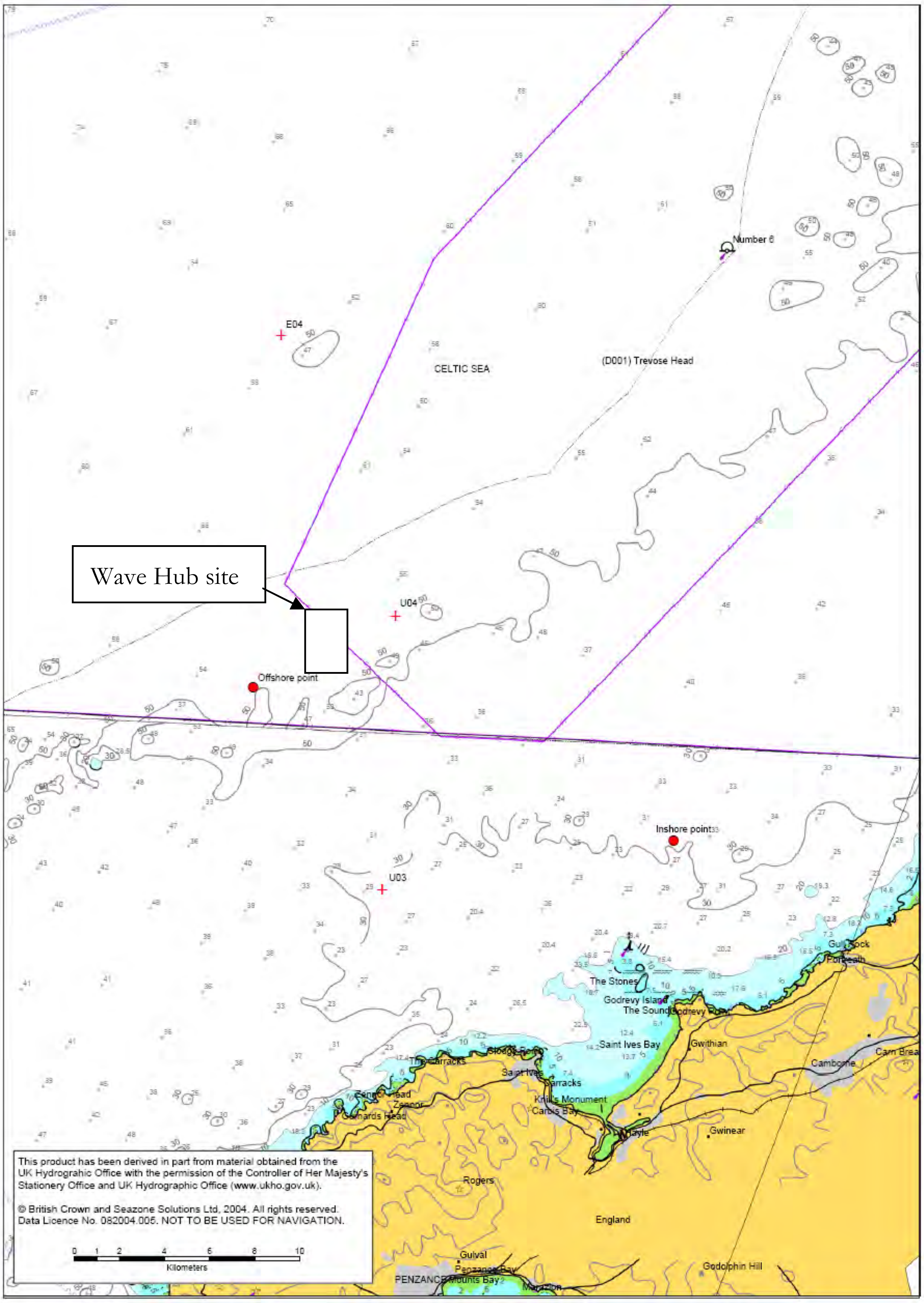


*Figure 3.2: Summary Plot of Recorded Wave Data (30 Jan 2005 to 10 April 2006)*



**Extract from Admiralty Chart No. 1149**

*Figure 3.3: Admiralty Chart Extract*
*E04 – Met Office European waters wave model grid point*
*U03/ U04 – Met Office UK inshore wave model grid points*
*Offshore point – Wave buoy deployment location*

## 3.3 *Meteorological Office (Met Office) Wave Model Data*

For many years the Met Office has run second-generation global and regional wave models to provide forecasts of sea state, supporting a range of user applications. The sea state at any point may be thought of as the sum of many individual waves, each of a particular direction and frequency. This can be represented as the wave energy spectrum, where the wave energy in each frequency and each direction is known. The Met Office wave model divides the wave energy spectrum at each grid point into 13 frequency components and 16 direction components. The lowest model frequency is at 0.04 Hz (25 seconds period or 975 m wavelength), and the highest frequency resolved by the model is 0.324 Hz (three seconds period or 15 m wavelength). The effect of waves at higher frequencies is included in the calculation of source terms.

The wave models account for growth of waves due to wind input, dissipation of energy by breaking waves, and transfer of energy between spectral components by non-linear interactions. Wave energy is advected from one grid point to the next at the group velocity. The wave models are run using hourly surface winds from our global and mesoscale numerical weather prediction (NWP) models and there are three operational wave model configurations, with different areas and resolutions, currently in use (global, European and for UK waters). All the models include shallow-water physics, namely bottom friction, refraction and shoaling. The UK waters model additionally includes the effects of time-varying currents on the waves. The global wave model assimilates wave height data from the radar altimeter on the ERS-2 satellite.

The UK waters wave model covers the north-west European continental shelf from 12°W, between 48°N and 63°N at a resolution of 1/9° longitude by 1/6° latitude (approximately 12 km). The UK waters model has a much better resolution of the coastline than the European wave model, and includes the effect of time-varying currents on the waves, using currents forecast by the operational storm-surge model. The model was introduced into the operational suite on 28 March 2000 and runs four times daily from 00, 06, 12 and 18 UTC, taking hourly surface winds from mesoscale NWP to give a 48-hour forecast.

Waves in the tidal waters around the UK can be a combination of locally generated wind waves and remotely generated swell, both can be modified by tidal or storm-surge currents which affect both wave height and wave period.

The maximum amount of data which is currently available, 17 years of data, was obtained from the Met Office wave model grid points E04 and U04. The data was analysed to provide: offshore wave rose, time-series plots of typical resultant and swell wave heights and periods, extreme wave conditions and joint probability analysis scatter plots, see Figures 3.4 to 3.8 and Tables 3.1 to 3.5.

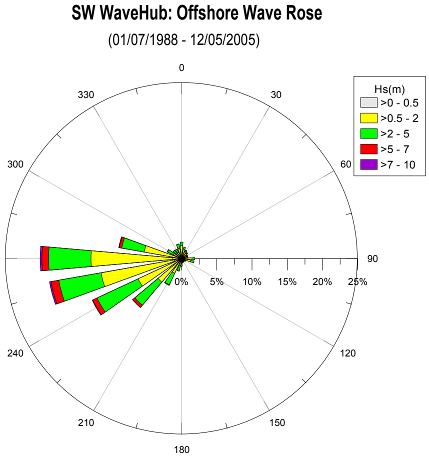


***Figure 3.4: Offshore wave rose (Met Office wave data)***

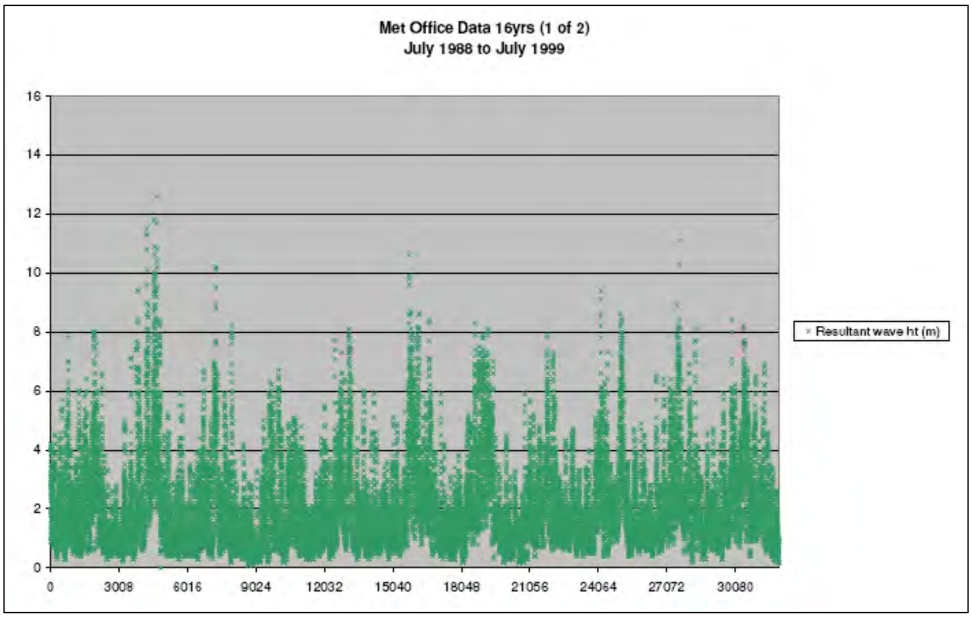


*Figure 3.5: Variation in Resultant Wave Height over 10 years (Met Office wave data)*

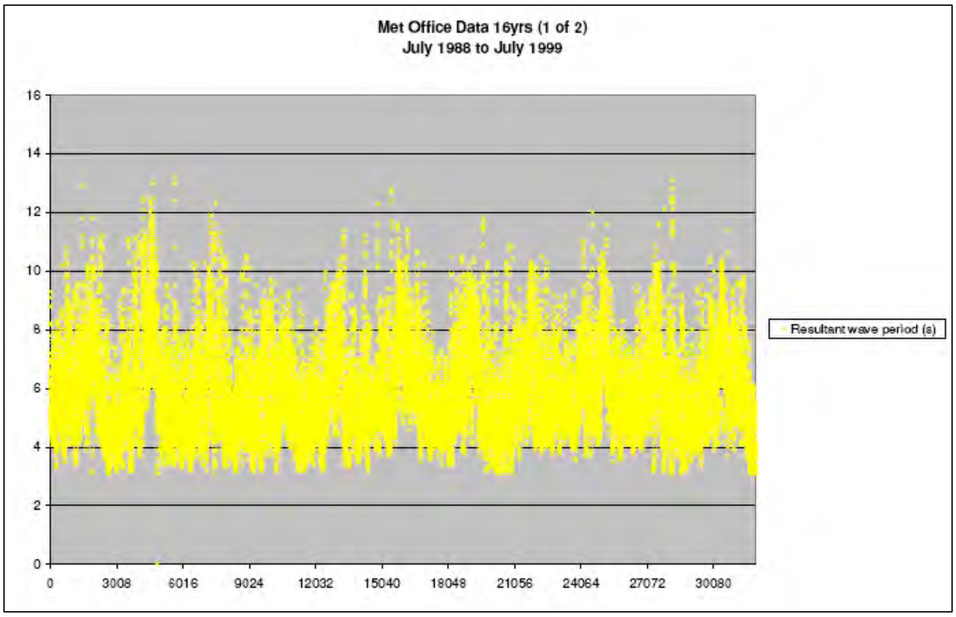


*Figure 3.6: Variation in Resultant Wave Period over 10 years (Met Office wave data)*

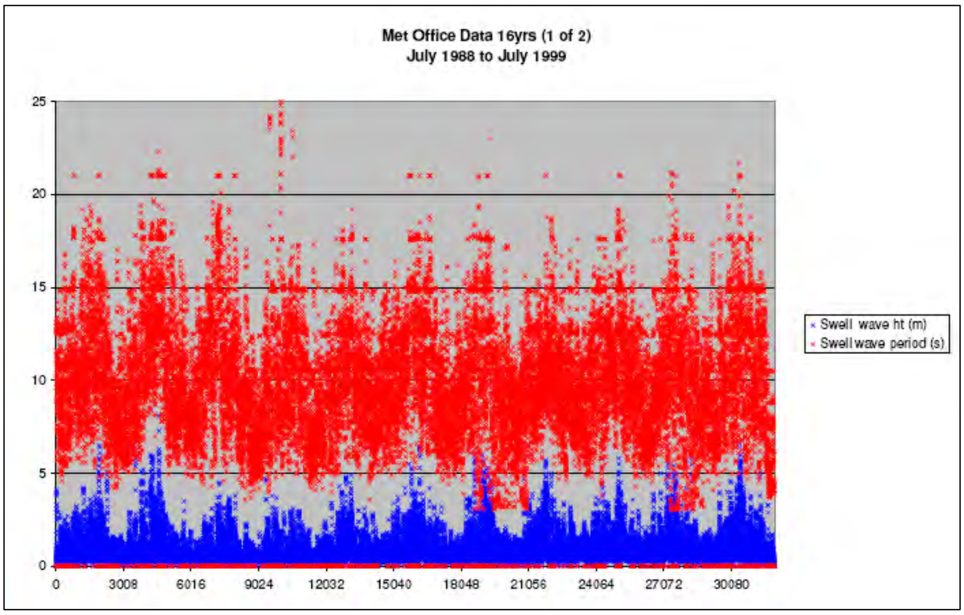


*Figure 3.7: Variation in Swell Wave Height and Period over 10 years (Met Office wave data)*

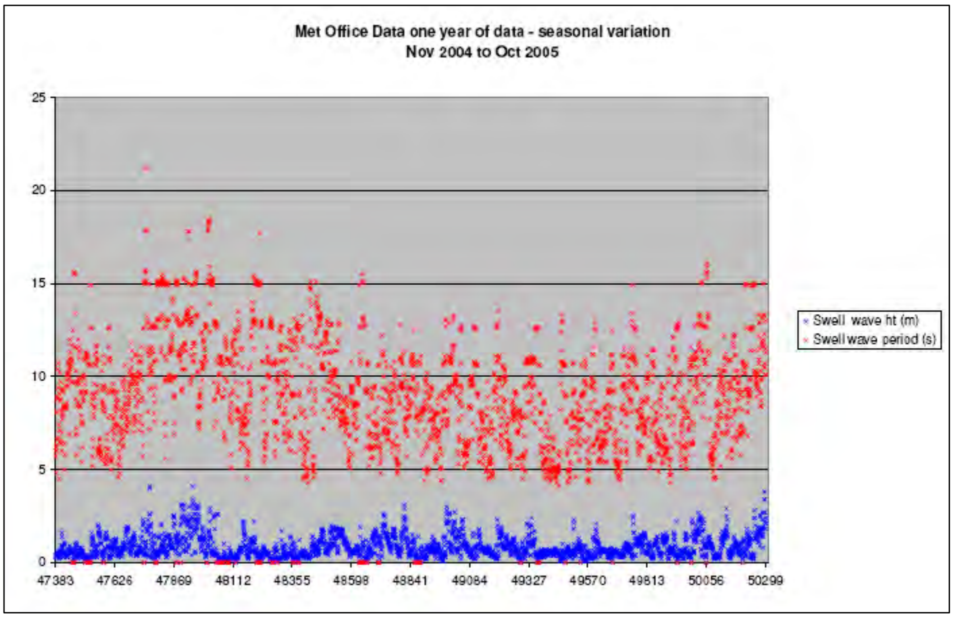
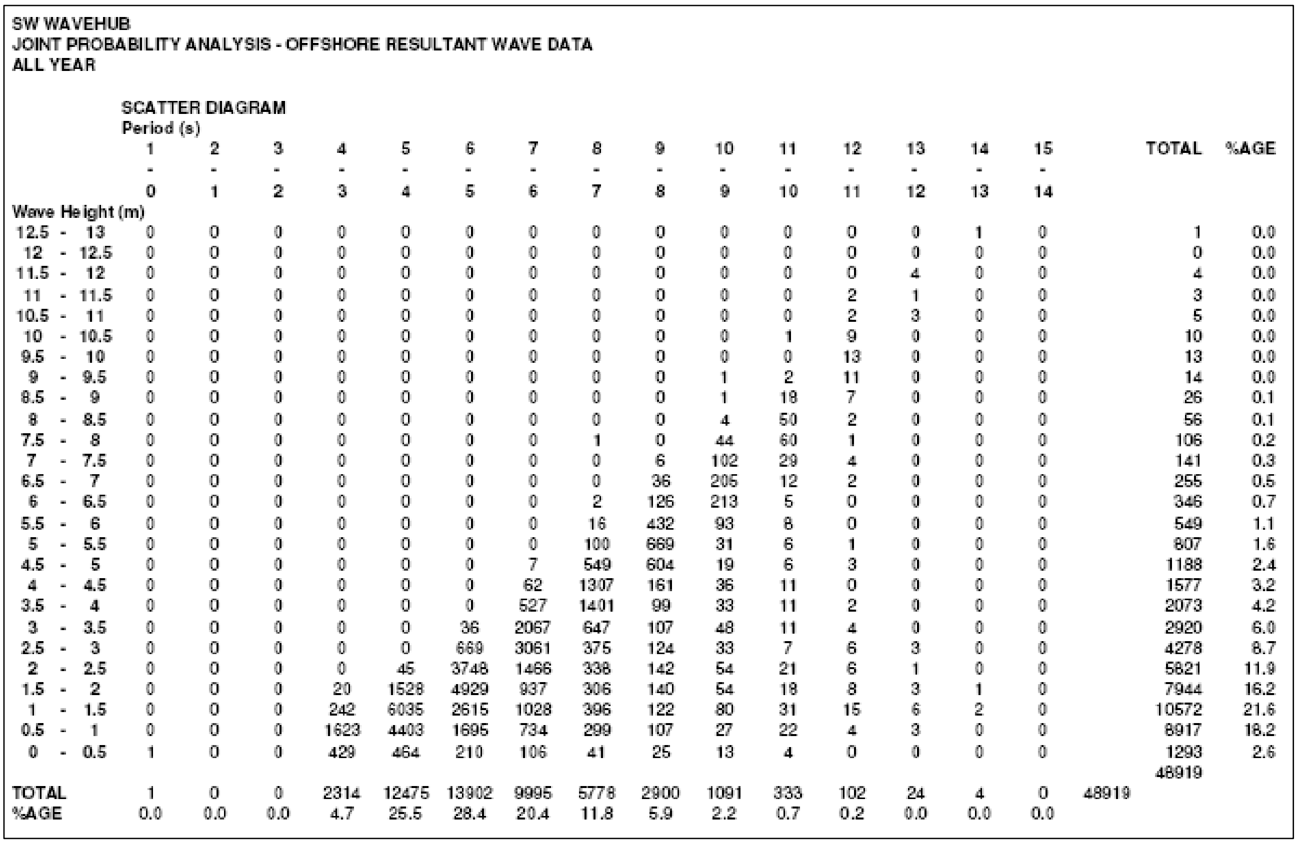


*Figure 3.8: Seasonal Variation in Swell Wave Height and Period over One Year – Nov 2004 to Oct 2005 (Met Office wave data)*

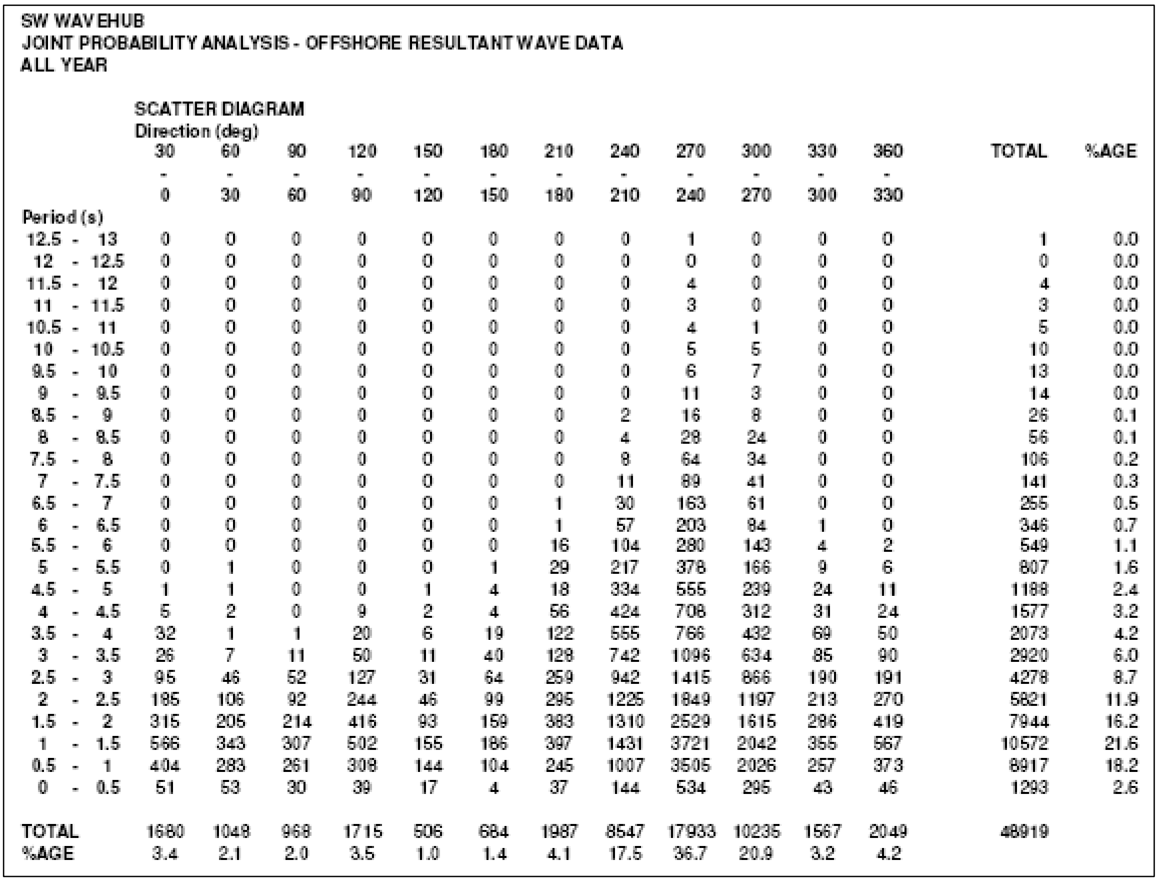


SW WAVEHUB
JOINT PROBABILITY ANALYSIS - OFFSHORE RESULTANT WAVE DATA
ALL YEAR

SCATTER DIAGRAM
Period (s)

| Wave Height (m) | 1 - 0 | 2 - 1 | 3 - 2 | 4 - 3 | 5 - 4 | 6 - 5 | 7 - 6 | 8 - 7 | 9 - 8 | 10 - 9 | 11 - 10 | 12 - 11 | 13 - 12 | 14 - 13 | 15 - 14 | | TOTAL | %AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.5 - 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | | 1 | 0.0 |
| 12 - 12.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 11.5 - 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | | 4 | 0.0 |
| 11 - 11.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | | 3 | 0.0 |
| 10.5 - 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | | 5 | 0.0 |
| 10 - 10.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 9 | 0 | 0 | 0 | | 10 | 0.0 |
| 9.5 - 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | | 13 | 0.0 |
| 9 - 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 11 | 0 | 0 | 0 | | 14 | 0.0 |
| 8.5 - 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 18 | 7 | 0 | 0 | 0 | | 26 | 0.1 |
| 8 - 8.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 50 | 2 | 0 | 0 | 0 | | 56 | 0.1 |
| 7.5 - 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 44 | 60 | 1 | 0 | 0 | 0 | | 106 | 0.2 |
| 7 - 7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 102 | 29 | 4 | 0 | 0 | 0 | | 141 | 0.3 |
| 6.5 - 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36 | 205 | 12 | 2 | 0 | 0 | 0 | | 255 | 0.5 |
| 6 - 6.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 126 | 213 | 5 | 0 | 0 | 0 | 0 | | 346 | 0.7 |
| 5.5 - 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 432 | 93 | 8 | 0 | 0 | 0 | 0 | | 549 | 1.1 |
| 5 - 5.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 669 | 31 | 6 | 1 | 0 | 0 | 0 | | 807 | 1.6 |
| 4.5 - 5 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 549 | 604 | 19 | 6 | 3 | 0 | 0 | 0 | | 1188 | 2.4 |
| 4 - 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 62 | 1307 | 161 | 36 | 11 | 0 | 0 | 0 | 0 | | 1577 | 3.2 |
| 3.5 - 4 | 0 | 0 | 0 | 0 | 0 | 0 | 527 | 1401 | 99 | 33 | 11 | 2 | 0 | 0 | 0 | | 2073 | 4.2 |
| 3 - 3.5 | 0 | 0 | 0 | 0 | 0 | 36 | 2067 | 647 | 107 | 48 | 11 | 4 | 0 | 0 | 0 | | 2920 | 6.0 |
| 2.5 - 3 | 0 | 0 | 0 | 0 | 0 | 669 | 3061 | 375 | 124 | 33 | 7 | 6 | 3 | 0 | 0 | | 4278 | 8.7 |
| 2 - 2.5 | 0 | 0 | 0 | 0 | 45 | 3748 | 1466 | 338 | 142 | 54 | 21 | 6 | 1 | 0 | 0 | | 5821 | 11.9 |
| 1.5 - 2 | 0 | 0 | 0 | 20 | 1528 | 4929 | 937 | 306 | 140 | 54 | 18 | 8 | 3 | 1 | 0 | | 7944 | 16.2 |
| 1 - 1.5 | 0 | 0 | 0 | 242 | 6035 | 2615 | 1028 | 396 | 122 | 80 | 31 | 15 | 6 | 2 | 0 | | 10572 | 21.6 |
| 0.5 - 1 | 0 | 0 | 0 | 1623 | 4403 | 1695 | 734 | 299 | 107 | 27 | 22 | 4 | 3 | 0 | 0 | | 8917 | 18.2 |
| 0 - 0.5 | 1 | 0 | 0 | 429 | 464 | 210 | 106 | 41 | 25 | 13 | 4 | 0 | 0 | 0 | 0 | | 1293 | 2.6 |
| | | | | | | | | | | | | | | | | | 48919 | |
| TOTAL | 1 | 0 | 0 | 2314 | 12475 | 13902 | 9995 | 5778 | 2900 | 1091 | 333 | 102 | 24 | 4 | 0 | 48919 | | |
| %AGE | 0.0 | 0.0 | 0.0 | 4.7 | 25.5 | 28.4 | 20.4 | 11.8 | 5.9 | 2.2 | 0.7 | 0.2 | 0.0 | 0.0 | 0.0 | | | |

*Table 3.1: Joint probability scatter plot (wave ht vs wave period)*
*All year – offshore resultant waves*

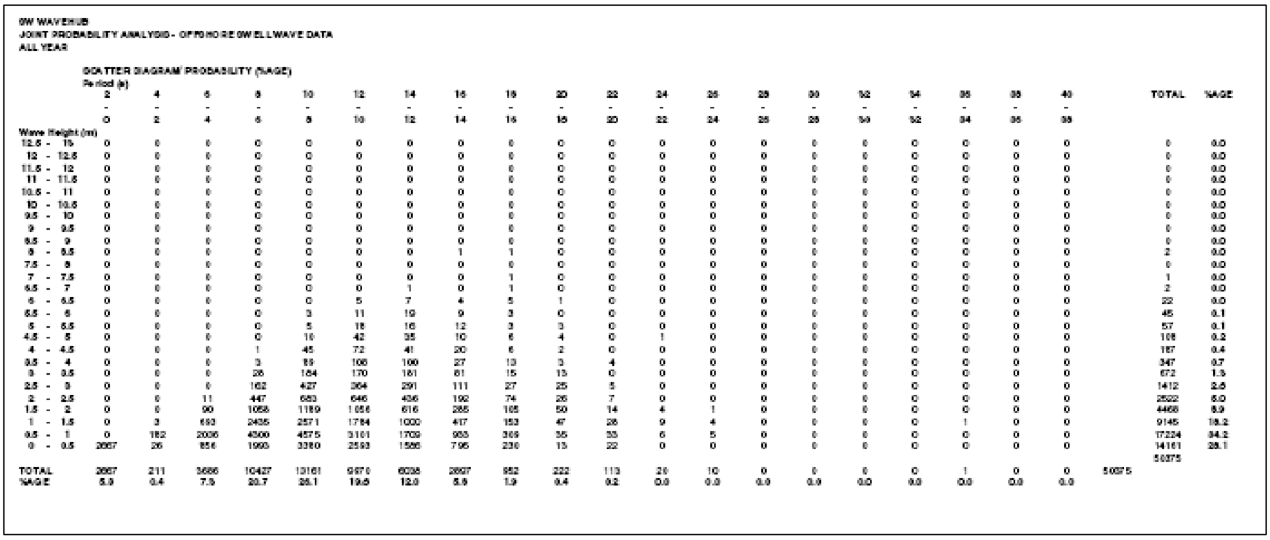


SW WAVEHUB
JOINT PROBABILITY ANALYSIS - OFFSHORE RESULTANT WAVE DATA
ALL YEAR

SCATTER DIAGRAM

| Period (s) | Direction (deg)<br>30 - 0 | 60 - 30 | 90 - 60 | 120 - 90 | 150 - 120 | 180 - 150 | 210 - 180 | 240 - 210 | 270 - 240 | 300 - 270 | 330 - 300 | 360 - 330 | TOTAL | %AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.5 - 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0.0 |
| 12 - 12.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 11.5 - 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 0.0 |
| 11 - 11.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0.0 |
| 10.5 - 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 0 | 5 | 0.0 |
| 10 - 10.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 0 | 10 | 0.0 |
| 9.5 - 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 7 | 0 | 0 | 13 | 0.0 |
| 9 - 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 3 | 0 | 0 | 14 | 0.0 |
| 8.5 - 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 16 | 8 | 0 | 0 | 26 | 0.1 |
| 8 - 8.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 28 | 24 | 0 | 0 | 56 | 0.1 |
| 7.5 - 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 64 | 34 | 0 | 0 | 106 | 0.2 |
| 7 - 7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 89 | 41 | 0 | 0 | 141 | 0.3 |
| 6.5 - 7 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 30 | 163 | 61 | 0 | 0 | 255 | 0.5 |
| 6 - 6.5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 57 | 203 | 84 | 1 | 0 | 346 | 0.7 |
| 5.5 - 6 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 104 | 280 | 143 | 4 | 2 | 549 | 1.1 |
| 5 - 5.5 | 0 | 1 | 0 | 0 | 0 | 1 | 29 | 217 | 378 | 166 | 9 | 6 | 807 | 1.6 |
| 4.5 - 5 | 1 | 1 | 0 | 0 | 1 | 4 | 18 | 334 | 555 | 239 | 24 | 11 | 1188 | 2.4 |
| 4 - 4.5 | 5 | 2 | 0 | 9 | 2 | 4 | 56 | 424 | 708 | 312 | 31 | 24 | 1577 | 3.2 |
| 3.5 - 4 | 32 | 1 | 1 | 20 | 6 | 19 | 122 | 555 | 766 | 432 | 69 | 50 | 2073 | 4.2 |
| 3 - 3.5 | 26 | 7 | 11 | 50 | 11 | 40 | 128 | 742 | 1096 | 634 | 85 | 90 | 2920 | 6.0 |
| 2.5 - 3 | 95 | 46 | 52 | 127 | 31 | 64 | 259 | 942 | 1415 | 866 | 190 | 191 | 4278 | 8.7 |
| 2 - 2.5 | 185 | 106 | 92 | 244 | 46 | 99 | 295 | 1225 | 1849 | 1197 | 213 | 270 | 5821 | 11.9 |
| 1.5 - 2 | 315 | 205 | 214 | 416 | 93 | 159 | 383 | 1310 | 2529 | 1615 | 286 | 419 | 7944 | 16.2 |
| 1 - 1.5 | 566 | 343 | 307 | 502 | 155 | 186 | 397 | 1431 | 3721 | 2042 | 355 | 567 | 10572 | 21.6 |
| 0.5 - 1 | 404 | 283 | 261 | 308 | 144 | 104 | 245 | 1007 | 3505 | 2026 | 257 | 373 | 8917 | 18.2 |
| 0 - 0.5 | 51 | 53 | 30 | 39 | 17 | 4 | 37 | 144 | 534 | 295 | 43 | 46 | 1293 | 2.6 |
| TOTAL | 1680 | 1048 | 968 | 1715 | 506 | 684 | 1987 | 8547 | 17933 | 10235 | 1567 | 2049 | 48919 | |
| %AGE | 3.4 | 2.1 | 2.0 | 3.5 | 1.0 | 1.4 | 4.1 | 17.5 | 36.7 | 20.9 | 3.2 | 4.2 | | |

***Table 3.2: Joint probability scatter plot (wave period vs direction)***
***All year – offshore resultant waves***

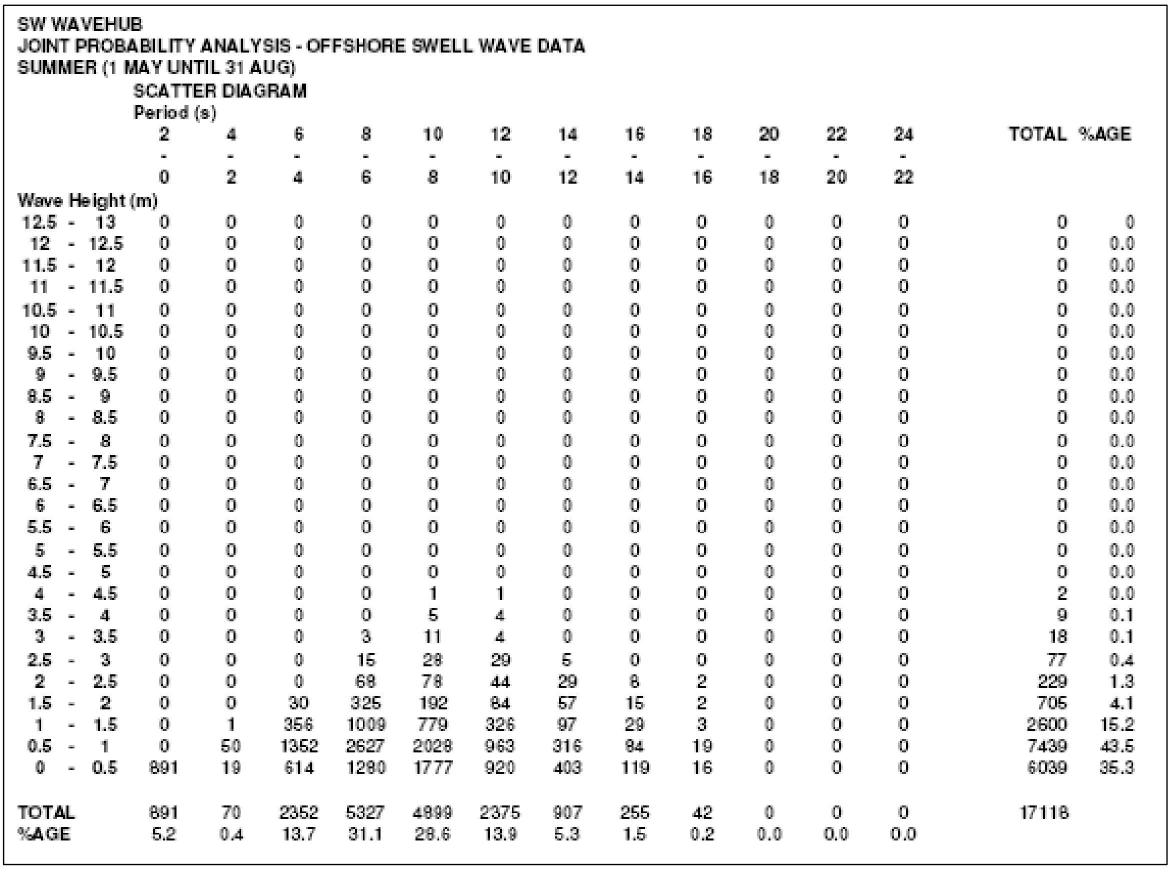


SW WAVEHUB
JOINT PROBABILITY ANALYSIS - OFFSHORE SWELL WAVE DATA
ALL YEAR

SCATTER DIAGRAM/ PROBABILITY (%AGE)
Period (s)

| Wave Height (m) | 2 - 0 | 4 - 2 | 6 - 4 | 8 - 6 | 10 - 8 | 12 - 10 | 14 - 12 | 16 - 14 | 18 - 16 | 20 - 18 | 22 - 20 | 24 - 22 | 26 - 24 | 28 - 26 | 30 - 28 | 32 - 30 | 34 - 32 | 36 - 34 | 38 - 36 | 40 - 38 | | TOTAL | %AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.5 - 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 12 - 12.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 11.5 - 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 11 - 11.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 10.5 - 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 10 - 10.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 9.5 - 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 9 - 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 8.5 - 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 8 - 8.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 2 | 0.0 |
| 7.5 - 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.0 |
| 7 - 7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | 0.0 |
| 6.5 - 7 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 2 | 0.0 |
| 6 - 6.5 | 0 | 0 | 0 | 0 | 0 | 5 | 7 | 4 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 22 | 0.0 |
| 5.5 - 6 | 0 | 0 | 0 | 0 | 3 | 11 | 19 | 9 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 45 | 0.1 |
| 5 - 5.5 | 0 | 0 | 0 | 0 | 5 | 18 | 16 | 12 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 57 | 0.1 |
| 4.5 - 5 | 0 | 0 | 0 | 0 | 10 | 42 | 35 | 10 | 6 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 108 | 0.2 |
| 4 - 4.5 | 0 | 0 | 0 | 1 | 45 | 72 | 41 | 20 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 187 | 0.4 |
| 3.5 - 4 | 0 | 0 | 0 | 3 | 89 | 108 | 100 | 27 | 13 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 347 | 0.7 |
| 3 - 3.5 | 0 | 0 | 0 | 28 | 184 | 170 | 181 | 81 | 15 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 672 | 1.3 |
| 2.5 - 3 | 0 | 0 | 0 | 162 | 427 | 364 | 291 | 111 | 27 | 25 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 1412 | 2.8 |
| 2 - 2.5 | 0 | 0 | 11 | 447 | 683 | 646 | 436 | 192 | 74 | 26 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 2522 | 5.0 |
| 1.5 - 2 | 0 | 0 | 90 | 1058 | 1189 | 1056 | 616 | 285 | 105 | 50 | 14 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 4468 | 8.9 |
| 1 - 1.5 | 0 | 3 | 693 | 2435 | 2571 | 1784 | 1000 | 417 | 153 | 47 | 28 | 9 | 4 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | | 9145 | 18.2 |
| 0.5 - 1 | 0 | 182 | 2036 | 4300 | 4575 | 3101 | 1709 | 933 | 309 | 35 | 33 | 6 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 17224 | 34.4 |
| 0 - 0.5 | 2667 | 26 | 856 | 1993 | 3380 | 2593 | 1586 | 795 | 230 | 13 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 14161 | 28.2 |
| | | | | | | | | | | | | | | | | | | | | | | 50075 | |
| TOTAL | 2667 | 211 | 3686 | 10427 | 13161 | 9970 | 6038 | 2897 | 952 | 222 | 113 | 20 | 10 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 50075 | | |
| %AGE | 5.3 | 0.4 | 7.3 | 20.8 | 26.3 | 19.9 | 12.0 | 5.8 | 1.9 | 0.4 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |

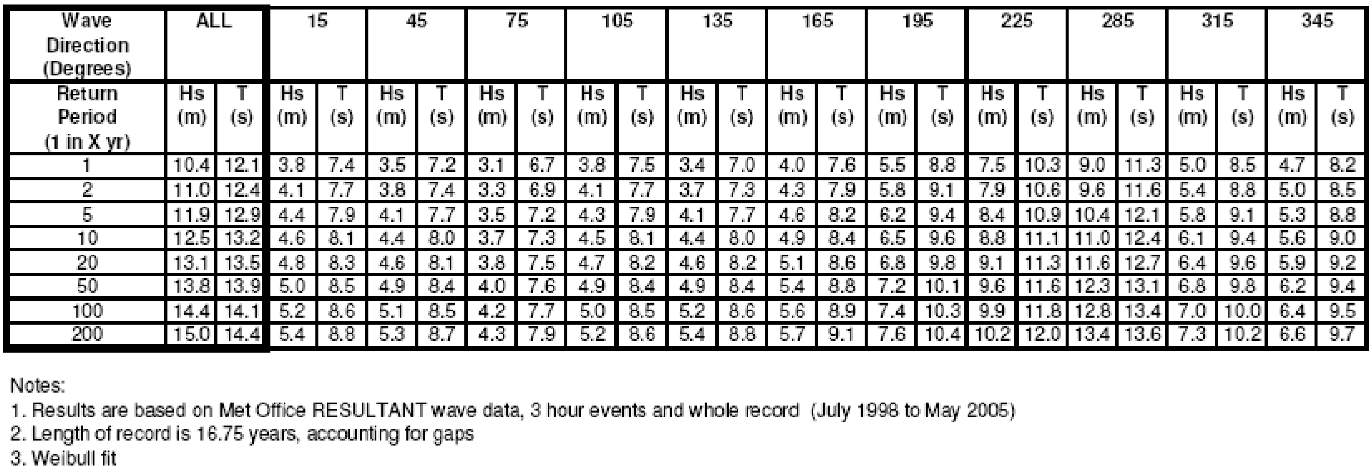
*Table 3.3: Joint probability scatter plot (wave ht vs wave period)*
*All year – offshore swell waves*



SW WAVEHUB
JOINT PROBABILITY ANALYSIS - OFFSHORE SWELL WAVE DATA
SUMMER (1 MAY UNTIL 31 AUG)
SCATTER DIAGRAM
Period (s)

| Wave Height (m) | 2 - 0 | 4 - 2 | 6 - 4 | 8 - 6 | 10 - 8 | 12 - 10 | 14 - 12 | 16 - 14 | 18 - 16 | 20 - 18 | 22 - 20 | 24 - 22 | TOTAL | %AGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.5 - 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 - 12.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 11.5 - 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 11 - 11.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 10.5 - 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 10 - 10.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 9.5 - 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 9 - 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 8.5 - 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 8 - 8.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 7.5 - 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 7 - 7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 6.5 - 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 6 - 6.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 5.5 - 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 5 - 5.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 4.5 - 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| 4 - 4.5 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.0 |
| 3.5 - 4 | 0 | 0 | 0 | 0 | 5 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0.1 |
| 3 - 3.5 | 0 | 0 | 0 | 3 | 11 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0.1 |
| 2.5 - 3 | 0 | 0 | 0 | 15 | 28 | 29 | 5 | 0 | 0 | 0 | 0 | 0 | 77 | 0.4 |
| 2 - 2.5 | 0 | 0 | 0 | 68 | 78 | 44 | 29 | 8 | 2 | 0 | 0 | 0 | 229 | 1.3 |
| 1.5 - 2 | 0 | 0 | 30 | 325 | 192 | 84 | 57 | 15 | 2 | 0 | 0 | 0 | 705 | 4.1 |
| 1 - 1.5 | 0 | 1 | 356 | 1009 | 779 | 326 | 97 | 29 | 3 | 0 | 0 | 0 | 2600 | 15.2 |
| 0.5 - 1 | 0 | 50 | 1352 | 2627 | 2028 | 963 | 316 | 84 | 19 | 0 | 0 | 0 | 7439 | 43.5 |
| 0 - 0.5 | 891 | 19 | 614 | 1280 | 1777 | 920 | 403 | 119 | 16 | 0 | 0 | 0 | 6039 | 35.3 |
| TOTAL | 891 | 70 | 2352 | 5327 | 4899 | 2375 | 907 | 255 | 42 | 0 | 0 | 0 | 17118 | |
| %AGE | 5.2 | 0.4 | 13.7 | 31.1 | 28.6 | 13.9 | 5.3 | 1.5 | 0.2 | 0.0 | 0.0 | 0.0 | | |

*Table 3.4: Joint probability scatter plot (wave ht vs wave period)*
*Summer (1 May until 31 August) – offshore swell waves*



| Wave Direction (Degrees) | ALL | | 15 | | 45 | | 75 | | 105 | | 135 | | 165 | | 195 | | 225 | | 285 | | 315 | | 345 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Return Period (1 in X yr) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) | Hs (m) | T (s) |
| 1 | 10.4 | 12.1 | 3.8 | 7.4 | 3.5 | 7.2 | 3.1 | 6.7 | 3.8 | 7.5 | 3.4 | 7.0 | 4.0 | 7.6 | 5.5 | 8.8 | 7.5 | 10.3 | 9.0 | 11.3 | 5.0 | 8.5 | 4.7 | 8.2 |
| 2 | 11.0 | 12.4 | 4.1 | 7.7 | 3.8 | 7.4 | 3.3 | 6.9 | 4.1 | 7.7 | 3.7 | 7.3 | 4.3 | 7.9 | 5.8 | 9.1 | 7.9 | 10.6 | 9.6 | 11.6 | 5.4 | 8.8 | 5.0 | 8.5 |
| 5 | 11.9 | 12.9 | 4.4 | 7.9 | 4.1 | 7.7 | 3.5 | 7.2 | 4.3 | 7.9 | 4.1 | 7.7 | 4.6 | 8.2 | 6.2 | 9.4 | 8.4 | 10.9 | 10.4 | 12.1 | 5.8 | 9.1 | 5.3 | 8.8 |
| 10 | 12.5 | 13.2 | 4.6 | 8.1 | 4.4 | 8.0 | 3.7 | 7.3 | 4.5 | 8.1 | 4.4 | 8.0 | 4.9 | 8.4 | 6.5 | 9.6 | 8.8 | 11.1 | 11.0 | 12.4 | 6.1 | 9.4 | 5.6 | 9.0 |
| 20 | 13.1 | 13.5 | 4.8 | 8.3 | 4.6 | 8.1 | 3.8 | 7.5 | 4.7 | 8.2 | 4.6 | 8.2 | 5.1 | 8.6 | 6.8 | 9.8 | 9.1 | 11.3 | 11.6 | 12.7 | 6.4 | 9.6 | 5.9 | 9.2 |
| 50 | 13.8 | 13.9 | 5.0 | 8.5 | 4.9 | 8.4 | 4.0 | 7.6 | 4.9 | 8.4 | 4.9 | 8.4 | 5.4 | 8.8 | 7.2 | 10.1 | 9.6 | 11.6 | 12.3 | 13.1 | 6.8 | 9.8 | 6.2 | 9.4 |
| 100 | 14.4 | 14.1 | 5.2 | 8.6 | 5.1 | 8.5 | 4.2 | 7.7 | 5.0 | 8.5 | 5.2 | 8.6 | 5.6 | 8.9 | 7.4 | 10.3 | 9.9 | 11.8 | 12.8 | 13.4 | 7.0 | 10.0 | 6.4 | 9.5 |
| 200 | 15.0 | 14.4 | 5.4 | 8.8 | 5.3 | 8.7 | 4.3 | 7.9 | 5.2 | 8.6 | 5.4 | 8.8 | 5.7 | 9.1 | 7.6 | 10.4 | 10.2 | 12.0 | 13.4 | 13.6 | 7.3 | 10.2 | 6.6 | 9.7 |

Notes:
1. Results are based on Met Office RESULTANT wave data, 3 hour events and whole record (July 1998 to May 2005)
2. Length of record is 16.75 years, accounting for gaps
3. Weibull fit

*Table 3.5: Extreme Wave Conditions*

Following joint probability analysis of the Met Office data and discussions with BSA (British Surfing Association) and SAS (Surfers Against Sewage) the following offshore wave conditions were defined and used to assess the impact of the SW Wave Hub on wave conditions at the shore:

1. **Hs=1m, T=7s** has an average probability of occurrence of 38% in a particular summer. 45 days/122 days, assumed between 1 May and 31 Aug. The average probability of occurrence of wave conditions in two wide envelopes of data: Hs=1m to 1.5m and T=6s to 10s and Hs=0.5m to 1m, T=6s to 10s have been considered. Similar assumptions have been made below. Lower wave heights have been considered to take account of breaking wave heights at the shore which have the potential to be up to 50% greater than offshore wave heights.
2. **Hs=2m, T=10s** has an average probability of occurrence of 8% in a particular summer (10 days/ 122 days) or a 13% probability of occurrence in any particular year (48 days per year).
3. **Hs=3m, T=12s** has an average probability of occurrence of 3% in any particular year (13 days per yr).
4. **Hs=4m, T=14s** has an average probability of occurrence of approx 1% in any particular year (approx 3 days per yr).
5. **Hs=4m, T=16s** has an average probability of occurrence of 0.3% in any particular year (approximately 1 day per yr).

Although long period swells have been recorded by the wave buoy the largest wave height and period combination is Hs=0.5m, T=15s which has a probability of occurrence of 1.3% in any particular year (5 days per year). Conditions with greater wave periods and wave heights are either: quite extreme (probability of occurrence in any one year of 0.03%, 0.1 days per year); or have low wave heights, less than 0.5m.

Therefore the above five wave conditions provide a reasonable summary of the existing wave climate and were used in the wave model to assess the impacts of the Wave Hub on offshore and inshore/ surfing waves.

## 3.4 *Wave Power*

The wave power at sites closest to Wave Hub site are as follows, see Figures 3.3 (location plan) and Figures 3.9, 3.10 and 3.11 below:

Annual average wave power at E04 between 1989 and 1989 was 29.9kW/m (cf 30.5kW/m, based on analysis of data between 1991 and 2003 (SWRDA, 2004))

Annual average wave power at U04 between 2001 and 2005 was 19.6kW/m (cf 21.8kW/m, based on analysis of data between 2000 and 2003 (SWRDA, 2004))

The comparison between Met Office wave model data and recorded wave data during 2005 shows that there is good agreement between the two sets of data, although recorded wave data provides slightly less power than the Met Office wave model data, see Figure 3.11.

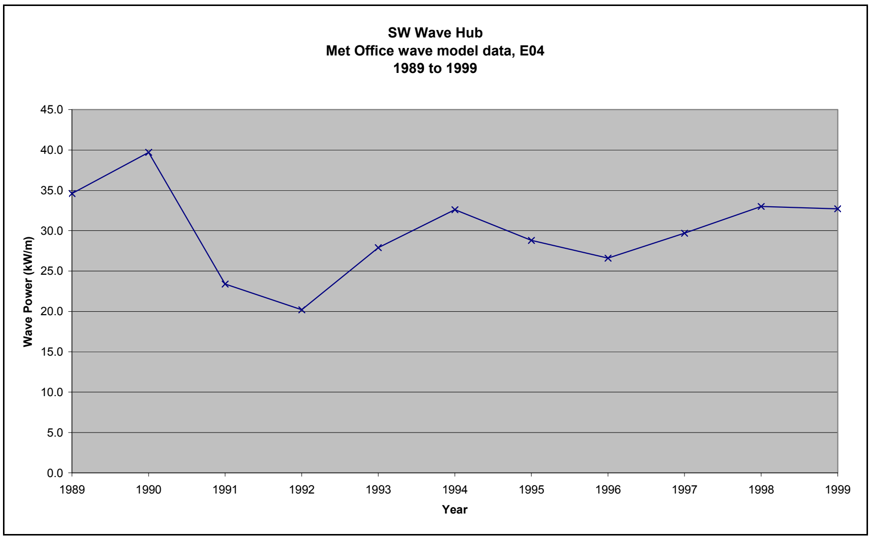


***Figure 3.9: Annual mean wave power at Met Office wave model point E04 (1989 to 1999)***

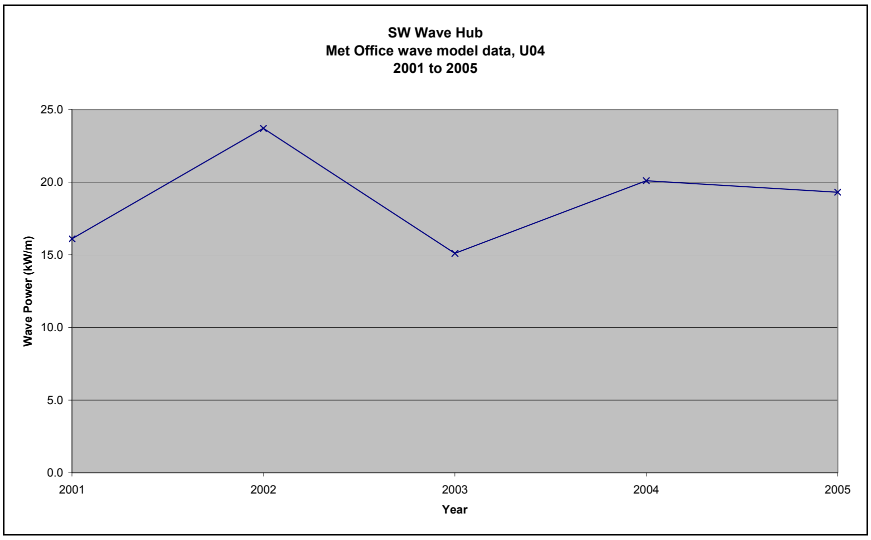


*Figure 3.10: Annual mean wave power at Met Office wave model point U04 (2000 to 2005)*

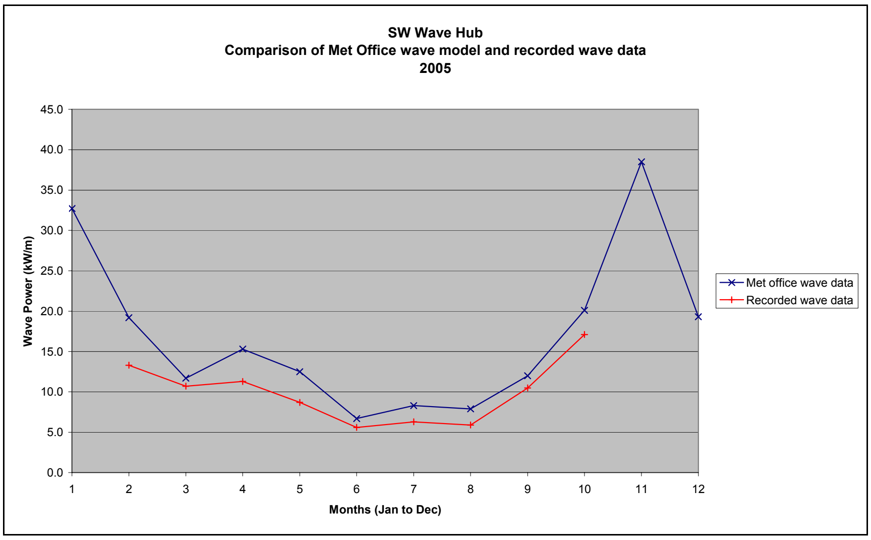


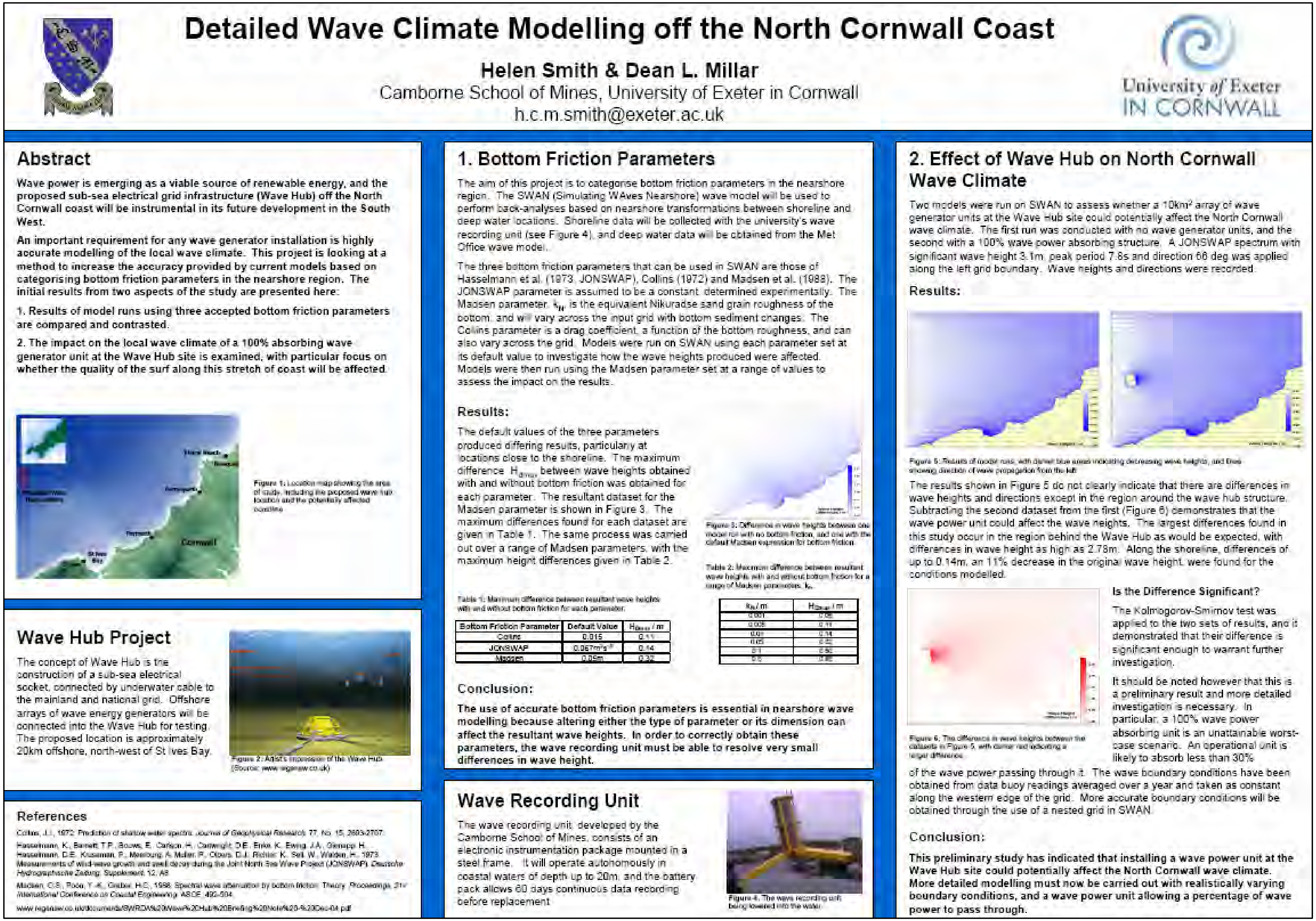
*Figure 3.11: Seasonal variation in wave power 2005 (Met Office wave model data point U04 compared to recorded wave data)*

# 4 Impacts of Wave Hub on Wave Climate

## *4.1 Wave Modelling by Others*

### *4.1.1 Exeter University*

Exeter University has undertaken SWAN modelling work which assumes 100% wave absorption over a 10km$^2$ array of WEC devices sited near to the proposed Wave Hub site for a single spectral wave climate (Hs=3.1m, T=7.8s, JONSWAP spectrum from 66 deg), which results in a 11% decrease in wave height at the shoreline, see Figure 4.1.



# Detailed Wave Climate Modelling off the North Cornwall Coast

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## Abstract

**Wave power is emerging as a viable source of renewable energy, and the proposed sub-sea electrical grid infrastructure (Wave Hub) off the North Cornwall coast will be instrumental in its future development in the South West.**

**An important requirement for any wave generator installation is highly accurate modelling of the local wave climate. This project is looking at a method to increase the accuracy provided by current models based on categorising bottom friction parameters in the nearshore region. The initial results from two aspects of the study are presented here:**

**1. Results of model runs using three accepted bottom friction parameters are compared and contrasted.**

**2. The impact on the local wave climate of a 100% absorbing wave generator unit at the Wave Hub site is examined, with particular focus on whether the quality of the surf along this stretch of coast will be affected.**

Figure 1: Location map showing the area of study, including the proposed wave hub location and the potentially affected coastline.

## Wave Hub Project

The concept of Wave Hub is the construction of a sub-sea electrical socket, connected by underwater cable to the mainland and national grid. Offshore arrays of wave energy generators will be connected into the Wave Hub for testing. The proposed location is approximately 20km offshore, north-west of St Ives Bay.

Figure 2: Artist's impression of the Wave Hub (Source: www.regensw.co.uk)

## References

Collins, J.I., 1972. Prediction of shallow water spectra. *Journal of Geophysical Research*, 77, No. 15, 2693-2707.

Hasselmann, K., Barnett, T.P., Bouws, E., Carlson, H., Cartwright, D.E., Enke, K., Ewing, J.A., Gienapp, H., Hasselmann, D.E., Kruseman, P., Meerburg, A., Muller, P., Olbers, D.J., Richter, K., Sell, W., Walden, H., 1973. Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). *Deutsche Hydrographische Zeitung*, Supplement 12, A8.

Madsen, O.S., Poon, Y.-K., Graber, H.C., 1988. Spectral wave attenuation by bottom friction: Theory. *Proceedings, 21st International Conference on Coastal Engineering*, ASCE, 492-504.

www.regensw.co.uk/documents/SWRDA%20Wave%20Hub%20Briefing%20Note%20-%20Dec-04.pdf

## 1. Bottom Friction Parameters

The aim of this project is to categorise bottom friction parameters in the nearshore region. The SWAN (Simulating WAves Nearshore) wave model will be used to perform back-analyses based on nearshore transformations between shoreline and deep water locations. Shoreline data will be collected with the university's wave recording unit (see Figure 4), and deep water data will be obtained from the Met Office wave model.

The three bottom friction parameters that can be used in SWAN are those of Hasselmann et al. (1973, JONSWAP), Collins (1972) and Madsen et al. (1988). The JONSWAP parameter is assumed to be a constant, determined experimentally. The Madsen parameter, $k_N$, is the equivalent Nikuradse sand grain roughness of the bottom, and will vary across the input grid with bottom sediment changes. The Collins parameter is a drag coefficient, a function of the bottom roughness, and can also vary across the grid. Models were run on SWAN using each parameter set at its default value to investigate how the wave heights produced were affected. Models were then run using the Madsen parameter set at a range of values to assess the impact on the results.

### Results:

The default values of the three parameters produced differing results, particularly at locations close to the shoreline. The maximum difference $H_{dmax}$ between wave heights obtained with and without bottom friction was obtained for each parameter. The resultant dataset for the Madsen parameter is shown in Figure 3. The maximum differences found for each dataset are given in Table 1. The same process was carried out over a range of Madsen parameters, with the maximum height differences given in Table 2.

Figure 3: Difference in wave heights between one model run with no bottom friction, and one with the default Madsen expression for bottom friction.

Table 1: Maximum difference between resultant wave heights with and without bottom friction for each parameter.

| Bottom Friction Parameter | Default Value | $H_{dmax}$ / m |
|---|---|---|
| Collins | 0.015 | 0.11 |
| JONSWAP | $0.067m^2s^{-3}$ | 0.14 |
| Madsen | 0.05m | 0.32 |

Table 2: Maximum difference between resultant wave heights with and without bottom friction for a range of Madsen parameters, $k_N$.

| $k_N$ / m | $H_{dmax}$ / m |
|---|---|
| 0.001 | 0.08 |
| 0.005 | 0.11 |
| 0.01 | 0.14 |
| 0.05 | 0.32 |
| 0.1 | 0.50 |
| 0.5 | 0.86 |

### Conclusion:

**The use of accurate bottom friction parameters is essential in nearshore wave modelling because altering either the type of parameter or its dimension can affect the resultant wave heights. In order to correctly obtain these parameters, the wave recording unit must be able to resolve very small differences in wave height.**

## Wave Recording Unit

The wave recording unit, developed by the Camborne School of Mines, consists of an electronic instrumentation package mounted in a steel frame. It will operate autonomously in coastal waters of depth up to 20m, and the battery pack allows 60 days continuous data recording before replacement.

Figure 4. The wave recording unit being lowered into the water.

## 2. Effect of Wave Hub on North Cornwall Wave Climate

Two models were run on SWAN to assess whether a 10km² array of wave generator units at the Wave Hub site could potentially affect the North Cornwall wave climate. The first run was conducted with no wave generator units, and the second with a 100% wave power absorbing structure. A JONSWAP spectrum with significant wave height 3.1m, peak period 7.8s and direction 66 deg was applied along the left grid boundary. Wave heights and directions were recorded.

### Results:

Figure 5: Results of model runs, with darker blue areas indicating decreasing wave heights, and lines showing direction of wave propagation from the left

The results shown in Figure 5 do not clearly indicate that there are differences in wave heights and directions except in the region around the wave hub structure. Subtracting the second dataset from the first (Figure 6) demonstrates that the wave power unit could affect the wave heights. The largest differences found in this study occur in the region behind the Wave Hub as would be expected, with differences in wave height as high as 2.78m. Along the shoreline, differences of up to 0.14m, an 11% decrease in the original wave height, were found for the conditions modelled.

Figure 6: The difference in wave heights between the datasets in Figure 5, with darker red indicating a larger difference

**Is the Difference Significant?**

The Kolmogorov-Smirnov test was applied to the two sets of results, and it demonstrated that their difference is significant enough to warrant further investigation.

It should be noted however that this is a preliminary result and more detailed investigation is necessary. In particular, a 100% wave power absorbing unit is an unattainable worst-case scenario. An operational unit is likely to absorb less than 30% of the wave power passing through it. The wave boundary conditions have been obtained from data buoy readings averaged over a year and taken as constant along the western edge of the grid. More accurate boundary conditions will be obtained through the use of a nested grid in SWAN.

### Conclusion:

**This preliminary study has indicated that installing a wave power unit at the Wave Hub site could potentially affect the North Cornwall wave climate. More detailed modelling must now be carried out with realistically varying boundary conditions, and a wave power unit allowing a percentage of wave power to pass through.**

*Figure 4.1: Results from Exeter University (Dean Millar) modelling work*

### 4.1.2 *Heriot Watt Surf Modelling Study*

A surf modelling study is currently being carried out by Heriot Watt University. Professor Julian Wolfram of the university's School of the Built Environment is involved in research with people in south-west England who fear that capturing the power of the waves for electricity might jeopardise surfing tourism: "They want big waves and are concerned that wave energy farms will pinch all the big waves at their surfing beaches." *Author: Heriot Watt Press and Public Relations Office, Date Published: 21 December 2004*

No further information is currently available

## 4.2 *Halcrow MWAVE Regional Wave Model*

In order to predict wave heights in the nearshore coastal zone it is necessary to consider the shallow water wave effects of wave refraction, diffraction and breaking as waves are transformed from offshore to inshore.

Wave transformation models have undergone rapid development during the past decade. Early models were generally based on wave ray techniques, which could only account for wave refraction processes. Halcrow have maintained their position at the forefront of this technology and have developed some of the most advanced models available today. Halcrow's regional wave model MWAVE is based on the so-called evolution solution of the mild slope wave equation for a regular bathymetry grid. Due to its clever solution and its ability to operate on a grid size that can be of the same order of magnitude as the wavelength, it is at least an order of magnitude faster than other mild slope equation solutions and this enables much larger areas to be modelled. It also takes into account the combined shallow water effects of wave breaking, refraction and diffraction. It has been proven against measured prototype wave data, other mathematical models, and published results of accurate wave basin experiments (Li, 1994). A post-processing module was used to consider wave spectra using the method of Goda, which essentially sums all of the components of the spectrum for a given spectral definition.

MWAVE was applied to investigate wave climate in the vicinity of proposed project and on waves along the Cornish coast. MWAV_REG was used to transform wave climates from offshore to inshore. Results from MWAV_REG were used to evaluate the impact of proposed project on the larger area, and were also used in further sediment modelling. MWAV_LOC was applied to evaluate wave climate near the project area. Various wave deformations including wave diffraction and reflection were simulated using MWAV_LOC. MWAVE_LOC requires fine grid spacing such that there are typically 8 nodes per wavelength.

To simulate wave transmission through the floating WEC devices a practical guide for design and construction of the floating structures (PIANC 1994) was applied to estimate wave transmission factor. According to the guide, the transmission coefficient for Wave Dragon is 0.68. The other wave energy devices are very different from the Wave Dragon. For devices of Power Buoy and Fred Olsen, it is reasonable to assume that the transmitted waves are very low immediately after the solid structures. Thus the transmission coefficients for both Power Buoy and Fred Olsen are taken as 0. On the other hand, the waves propagate along the Pelamis for 150m. The transmitted waves immediately after the Pelamis should be low as well. Therefore it was reasonable to assume that the wave transmission coefficient for Pelamis is 0.

Model bathymetry was constructed from the Admiralty Chart (No. 1149 & No.1178). The final bathymetry and model area are shown in Figure 4.2. This bathy has been used in MWAVE and FLOW3D models. The grid spacing used was 100m and the model area was about 78km x 45km.

For the local wave model MWAVE_LOC a smaller grid (800x600 grid points) and 5m grid spacing was used.

The transmission coefficients used in the larger wave model were obtained from the local wave modelling results.

For the 1 in 1 year return period storm simulated in this study, seven wave directions from south-west to north-west representing the most frequent wave directions (see Figure 3.4 for offshore wave rose), have been tested.

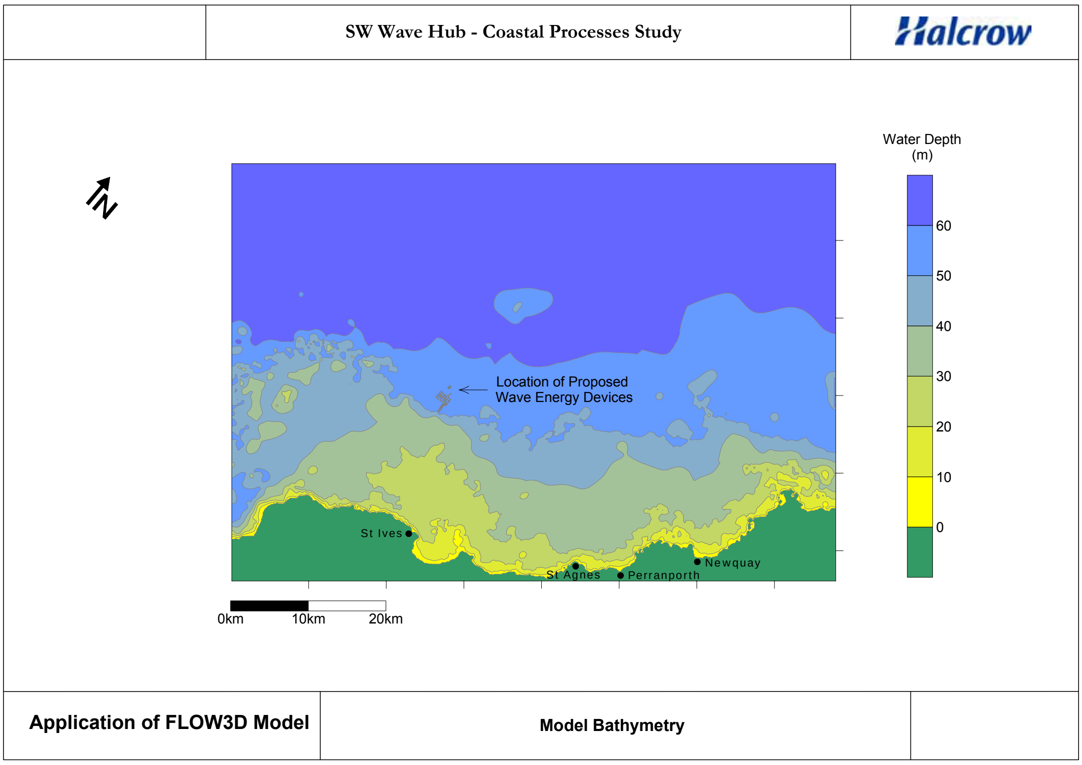


*Figure 4.2: Model Bathymetry*

Although a range of wave conditions occur at the site a summary of the "snap-shot" representative wave conditions, which were used during modelling to define typical and extreme wave conditions at the site, has been provided in Table 4.1.

| Hs (m) | T (s) | Description | Probability of occurrence |
|---|---|---|---|
| 1 | 7 | "Small" surf wave conditions | Average probability of occurrence of 38% in a particular summer (1 May until 31 August). 45 days/122 days.<br>Average probability of occurrence of 28% in any particular year. 100 days/365 days. |
| 1.6 | 5.4 | | Mean wave conditions over the whole year |
| 2 | 10 | | Average probability of occurrence of 8% in a particular summer. 10 days/ 122 days<br>Average probability of occurrence of 13% in any particular year. 48 days per year. |
| 3 | 12 | | Average probability of occurrence of 3% in any particular year. 13 days per year. |
| 4 | 14 | | Average probability of occurrence of approx 1% in any particular year. Approx 3 days per year. |
| 4 | 16 | "Big" surf wave conditions | Average probability of occurrence of 0.3% in any particular year. Approximately 1 day per year. |
| 10 | 12 | | 1 in 1 year return period wave conditions |

***Table 4.1: Wave scenarios considered during modelling***

## 4.3 WEC Device Array Layout No.1 – 4nr. Wave Dragons

Spectral wave modelling results consider a typical sea state which is comprised of many different waves approaching from many different directions.

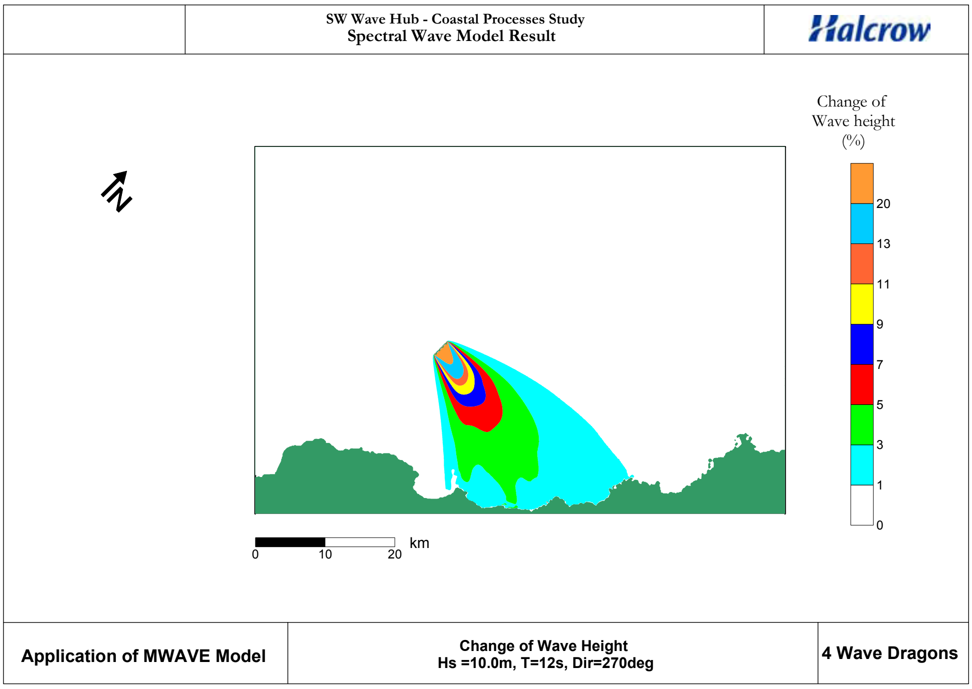


*Figure 4.3: WEC Device Layout No.1: 4 nr. Wave Dragons (west-facing)*
*Spectral wave modelling results: Hs=10m, T=12s*
*1 in 1 year return period wave conditions*
*(up to 5% reduction in wave heights at the shore)*

*Figure 4.3a: Location Plan*

Wave modelling was undertaken using monochromatic waves to demonstrate the impact of WEC devices on surfing waves at the coast, since surfers are primarily concerned with long period swell waves. Monochromatic wave modelling results are as follows:

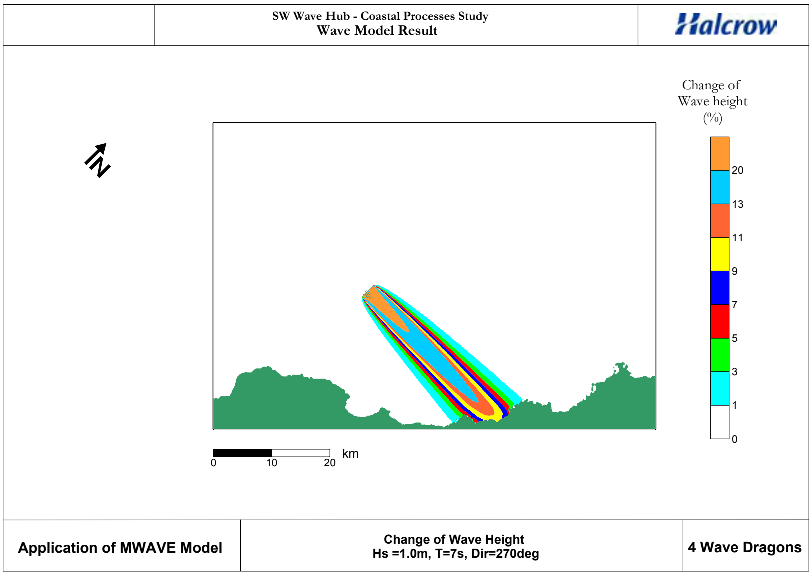


*Figure 4.4: WEC Device Layout No.1: 4 nr. Wave Dragons (west-facing) Impacts of monochromatic typical "small" surf wave conditions (Hs=1m, T=7s, Dir=270deg) (up to 11% redn. in wave height at shore)*

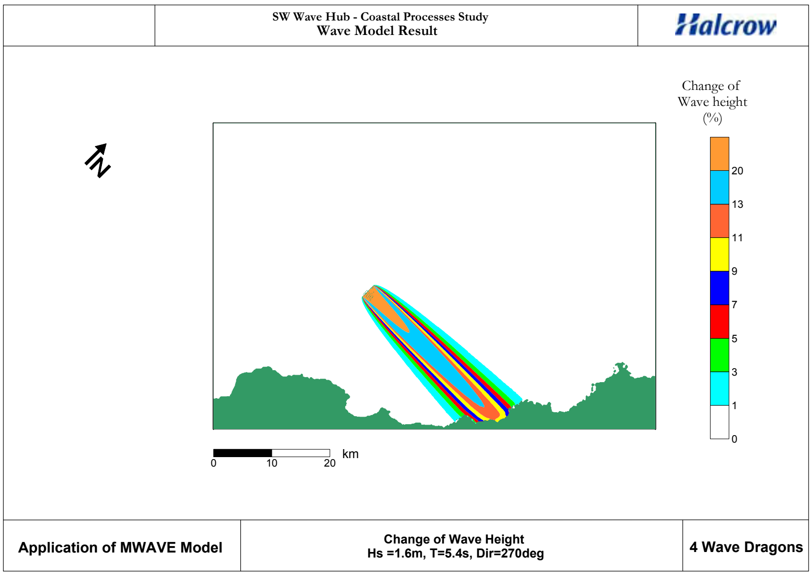


*Figure 4.5: WEC Device Layout No.1: 4 nr. Wave Dragons (west-facing) Impacts of monochromatic mean wave conditions (Hs=1.6m, T=5.4s, Dir=270deg) (up to 13% redn. in wave height at shore)*

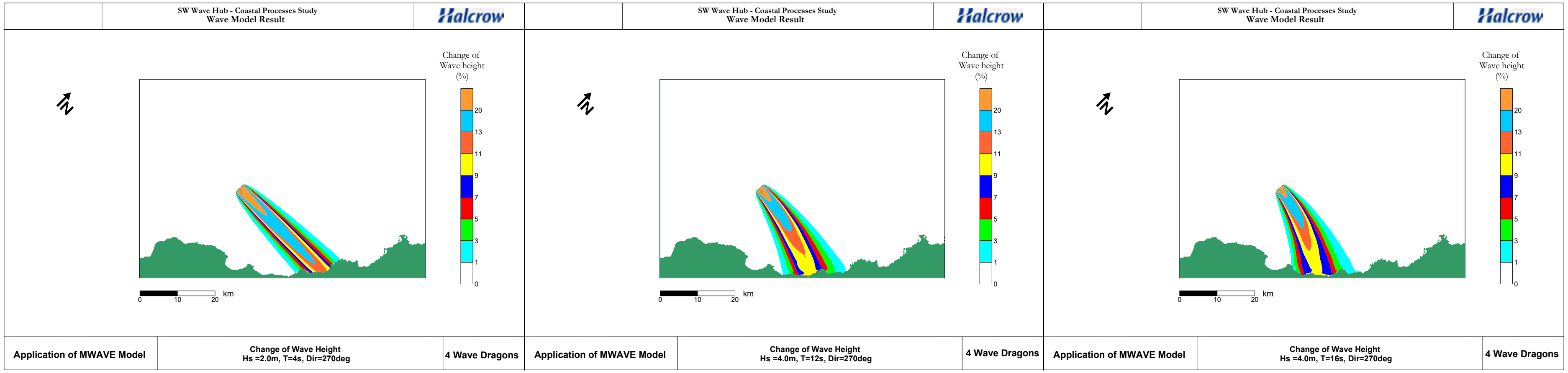


*Figure 4.6: WEC Layout No.1: 4 nr. Wave Dragons (west-facing)*
*Comparison of impacts of various monochromatic wave conditions to simulate alternative swell (surfing) wave conditions (Hs=2m to 4m, T=4s to 16s) (up to 13% reduction in swell wave height at the shore, shorter period waves, larger %age reduction, also demonstrates refraction of longer period waves)*

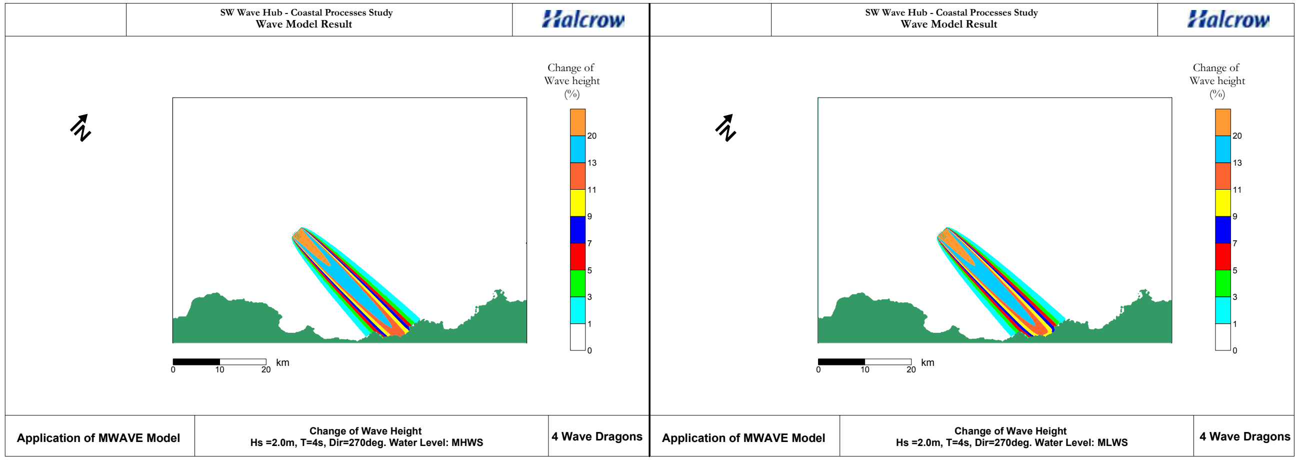
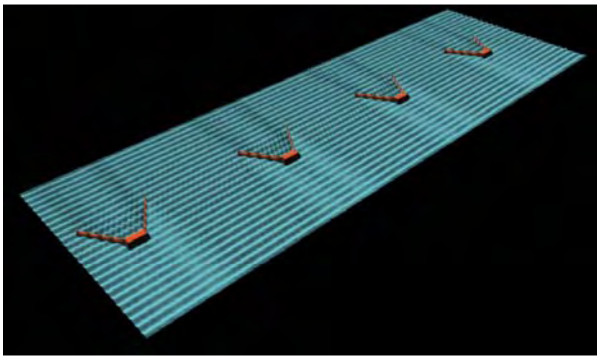


*Figure 4.7: WEC Layout No.1: 4 nr. Wave Dragons (west-facing)*
*Comparison of impact of different tide levels (MHWS and MLWS – left and right respectively) on monochromatic wave conditions Hs= 2m, T=4s (up to 13% localised reduction in swell wave height at the shore for all options)*

SW Wave Hub - Coastal Processes Study
Wave Model Result

Halcrow

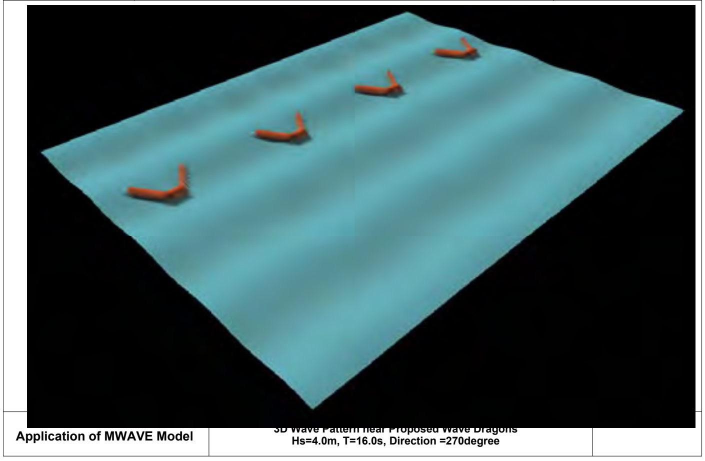


Application of MWAVE Model

3D Wave Pattern near Proposed Wave Dragons
Hs=2m, T=4s, Direction =270degree

SW Wave Hub - Coastal Processes Study
Wave Model Result

Halcrow



Application of MWAVE Model

3D Wave Pattern near Proposed Wave Dragons
Hs=4.0m, T=16.0s, Direction =270degree

***Figure 4.8: WEC Layout No.1: 4 nr. Wave Dragons (west-facing)***
***3D plots of wave modelling results***
***Demonstrates that WEC have greatest impact on shorter period waves, large WECs, such as Wave Dragon, tend to 'ride' longer period waves, much like a large ship***

WEC Device Layout No.1 (4nr. Wave Dragons) will result in up to 5% reduction in wave heights at the coast during a 1 in 1 year return period storm, based on spectral wave modelling results which consider a typical sea state comprised of many different waves approaching from many different directions.

WEC Device Layout No.1 (4 nr. Wave Dragons), during typical "small" and "big" surf wave conditions - see Table 4.1, will result in a reduction in swell wave heights at the coast of up to 13%, based on monochromatic wave modelling results which consider the impact of a single wave condition approaching from a single direction to simulate a long period swell wave (surfing wave) approaching from the North Atlantic.

## 4.4 *WEC Device Layout No.2 – Various Devices*

Spectral wave modelling results consider a typical sea state which is comprised of many different waves approaching from many different directions.

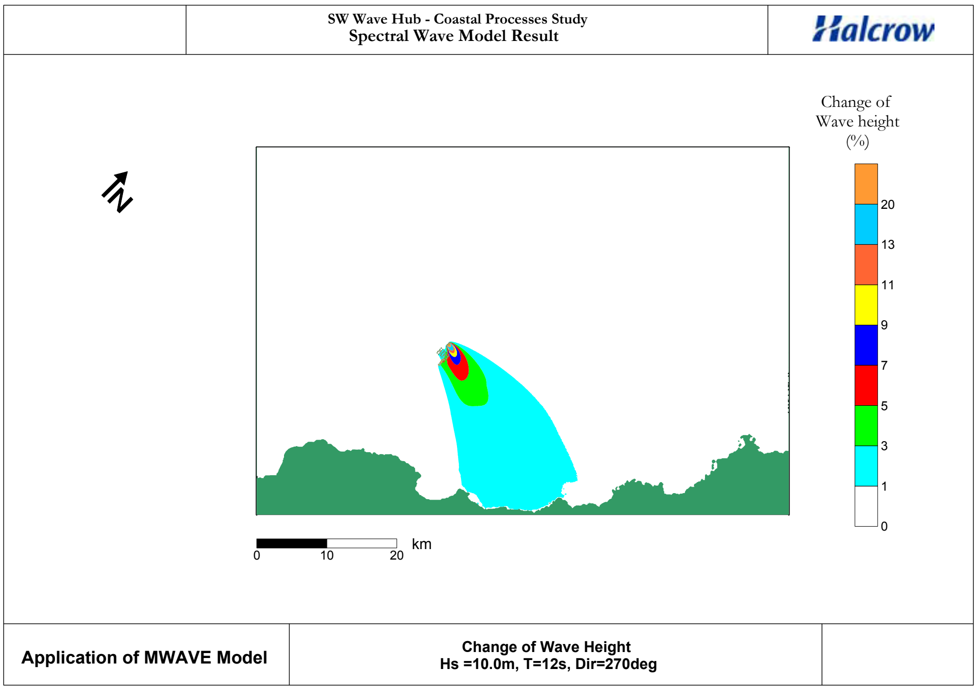


***Figure 4.9: WEC Device Layout No.2***
***Spectral wave model results: Hs=10m, T=12s***
**1 in 1 year return period wave conditions**
***(up to 3% reduction in wave heights at the shore)***

***Figure 4.9a: Location Plan***

Wave modelling was undertaken using monochromatic waves to demonstrate the impact of WEC devices on surfing waves at the coast, since surfers are primarily concerned with long period swell waves. Monochromatic wave modelling results are as follows:

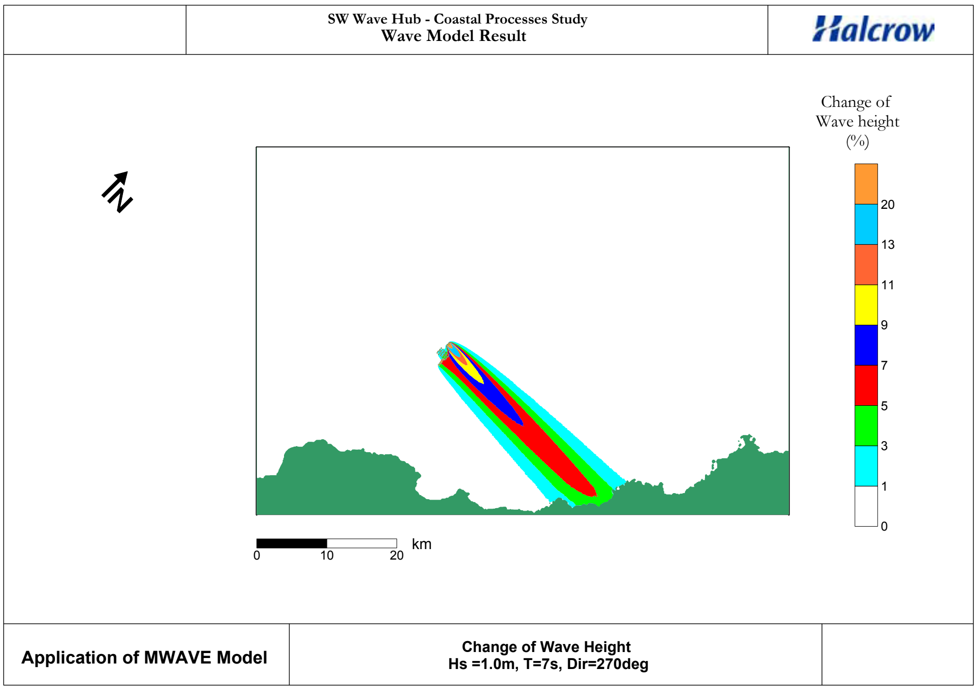


*Figure 4.10: WEC Device Layout No.2*
*Impacts of monochromatic typical "small" surf wave conditions*
*(Hs=1m, T=7s, Dir=270deg) (up to 5% reduction in swell wave height at the shore)*

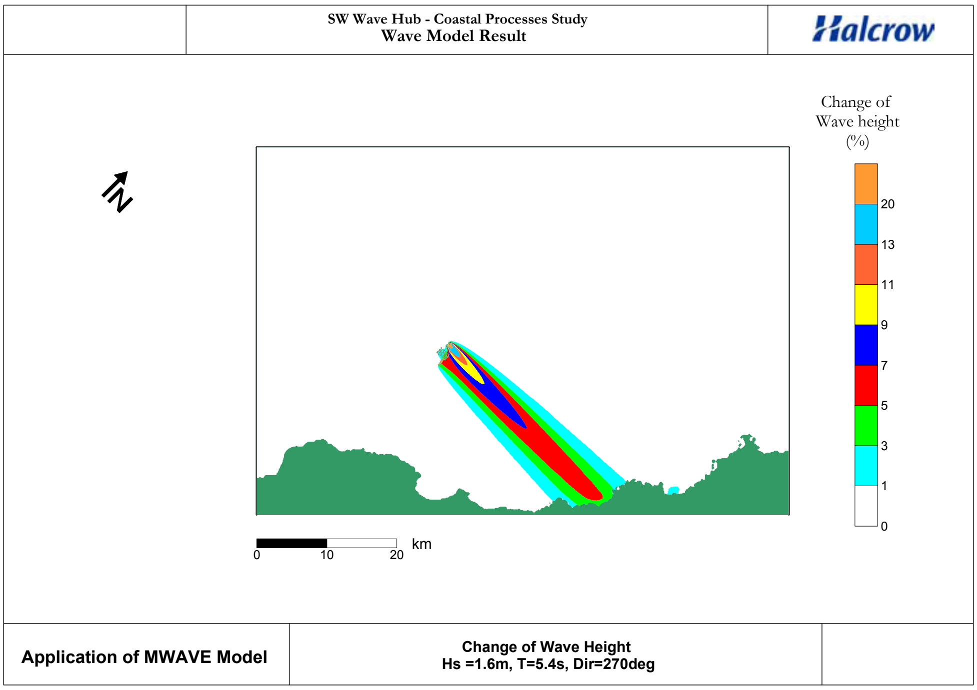


*Figure 4.11: WEC Device Layout No.2*
*Impacts of monochromatic mean wave conditions*
*(Hs=1.6m, T=5.4s, Dir=270deg) (up to 5% reduction in swell wave height at the shore)*

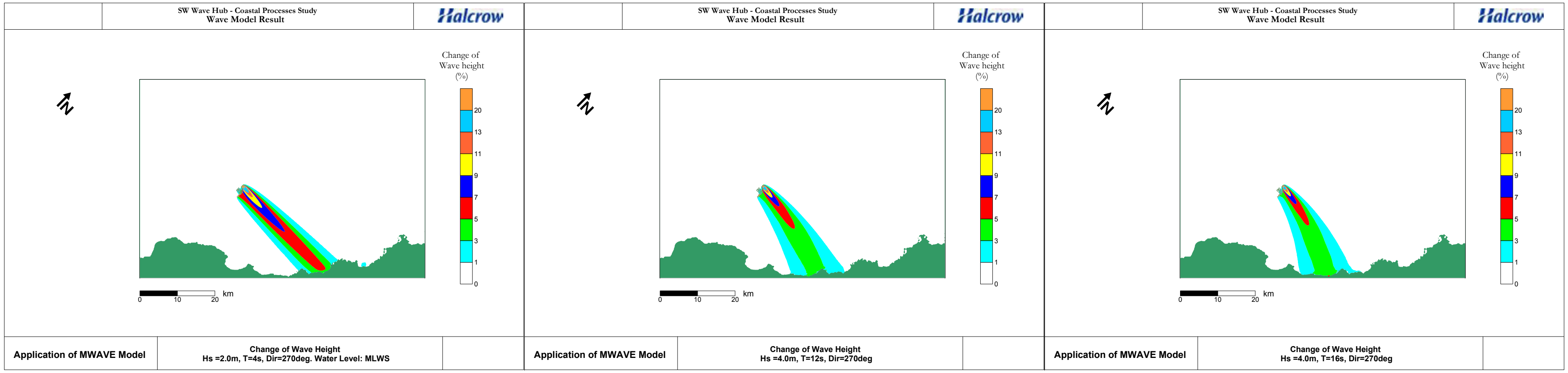


*Figure 4.12: WEC Device Layout No.2*

*Comparison of impacts of various monochromatic wave conditions – to simulate alternative swell (surfing) wave conditions*

*(Hs=2m to 4m, T=4s to 16s)*

*(up to 5% reduction in swell wave height at the shore, shorter period waves, larger %age reduction, also demonstrates refraction of longer period waves)*

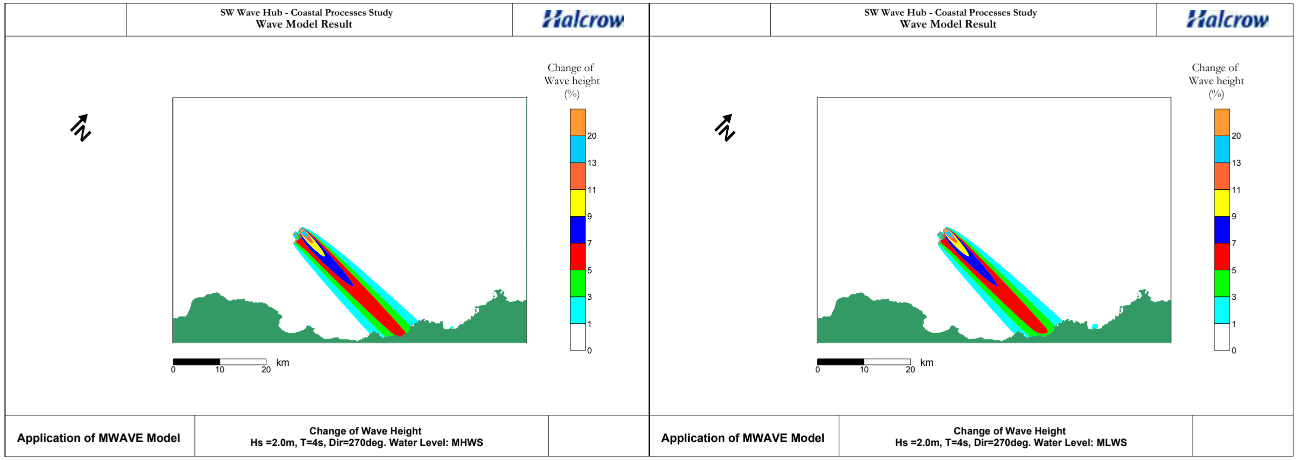


*Figure 4.13: WEC Device Layout No.2*

*Comparison of impact of different tide levels (MHWS and MLWS – left and right respectively) on monochromatic wave conditions*

*Hs= 2m, T=4s (up to 7% localised reduction in swell wave height at the shore for all options)*

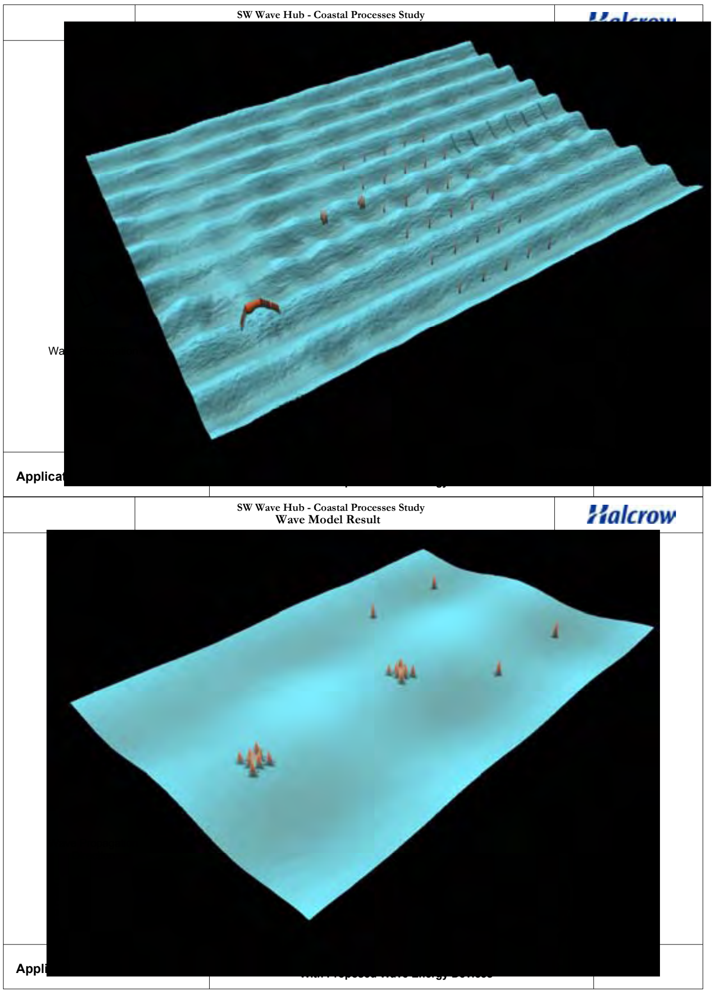


***Figure 4.14: Impact of WEC Device Layout No.2 on waves***
***3D plots of wave modelling results***

WEC Device Layout No.2 will result in up to 3% reduction in wave heights at the coast during a 1 in 1 year return period storm, based on spectral wave modelling results which consider a typical sea state comprised of many different waves approaching from many different directions.

WEC Device Layout No.2 will result in up to 7% reduction in surfing wave heights at the coast, based on monochromatic wave modelling results which consider the impact of a single wave condition approaching from a single direction to simulate a long period swell wave (surfing wave) approaching from the North Atlantic.

# 5 Tidal Streams and Currents

A distinction needs to be drawn between tidal streams, which are astronomical in origin, and currents, which are not dependent upon astronomic conditions and which, in the waters around the British Isles, are mainly of meteorological origin. Non-tidal currents are not included in the tidal stream prediction tables. With strong or prolonged winds these currents may nevertheless be considerable and they must be assessed separately.

The Admiralty Pilot reports that tidal streams on the north coast of Cornwall run mainly parallel to the shore at a spring rate of 1 to 2 knots (0.5 to 1.0m/s), being stronger off Cape Cornwall, Hartland Point and other salient points, but weaker in the bays between. More detailed information is provided in the Tidal Stream Atlas of the Cornish Coast, produced by the Institute of Marine Studies at Plymouth University which was produced by simulating the tidal dynamics using a numerical model with a mesh size of 0.8 nautical miles (approximately 1.5km) which confirms a maximum tidal stream of 1m/s in the vicinity of the Wave Hub, see Figure 5.1. Refer to Appendix C for further details.

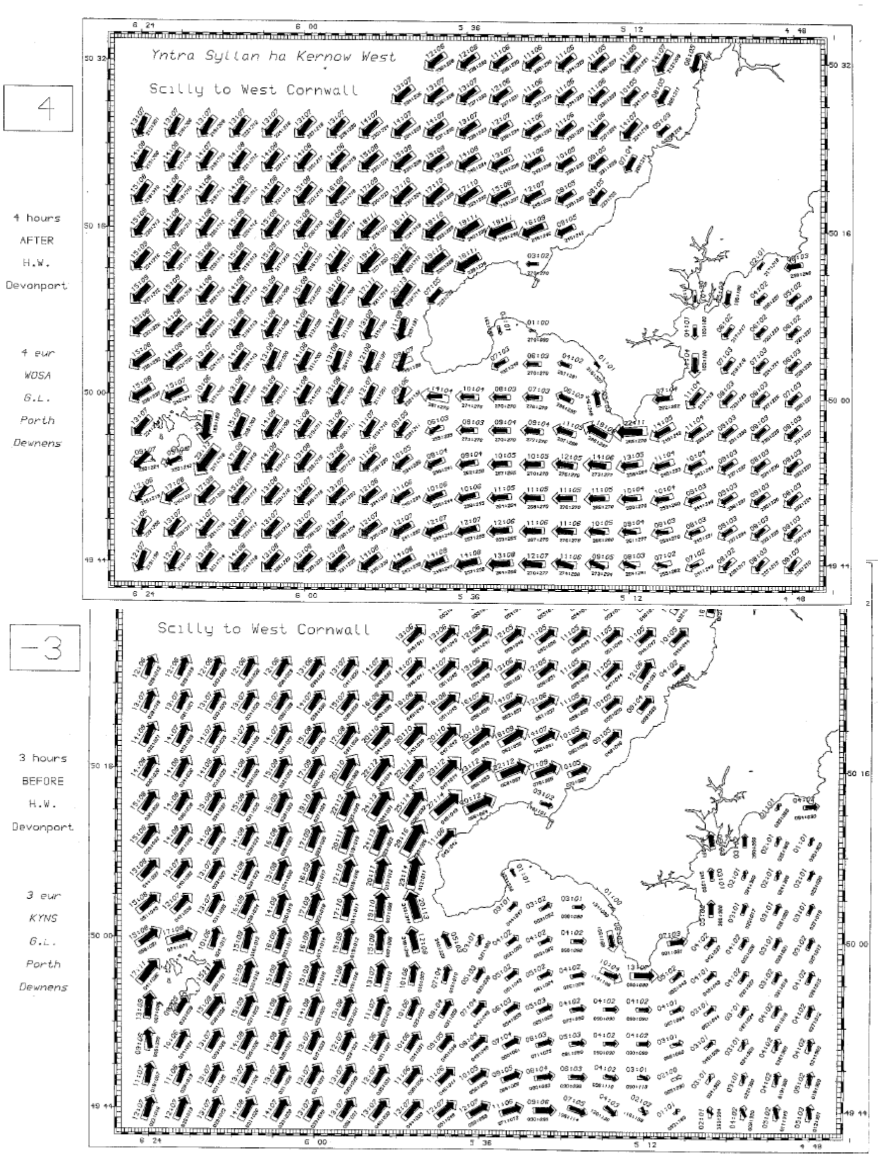


*Figure 5.1: Tidal Stream Atlas*

A summary of surface tidal currents recorded during the deployment of the wave buoy has been provided in Figure 5.2. Between 30 Jan 2005 and 8 November 2005 the maximum recorded surface tidal current recorded was 1.2m/s.

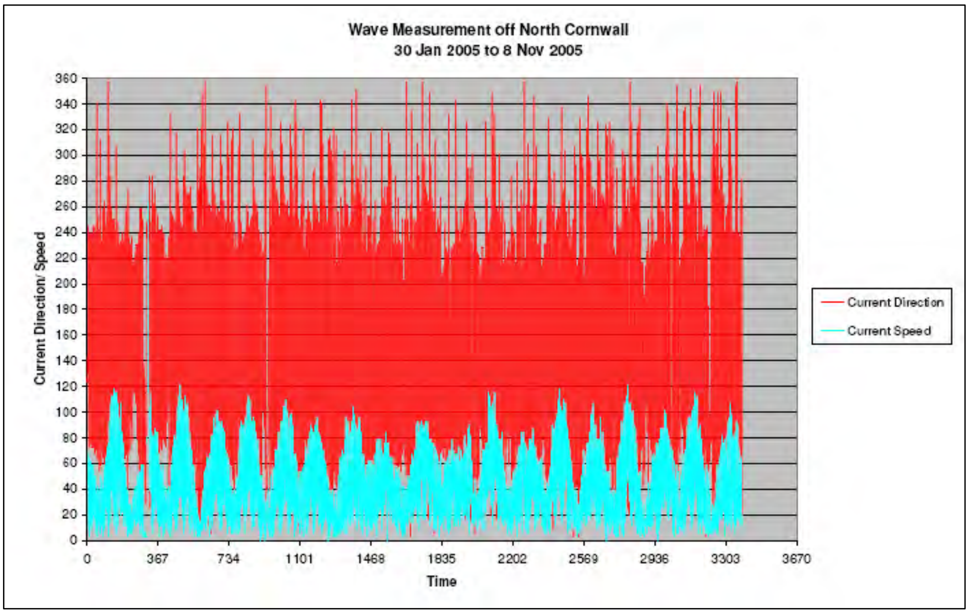


*Figure 5.2: Recorded Tidal Currents*

The estimated 1 in 50 year return period extreme total surface current is 1.6m/s, which is based on a vector sum of all components co-linear with the downwind direction of the 1 in 50 year extreme wind, averaged from the surface to a depth of 10 metres (UK Department of Energy, 1983).

# 6 Impacts of Wave Hub on Tidal Streams and Currents

## 6.1 *FLOW3D*

Halcrow's newly developed 3D model FLOW3D is a three-dimensional mathematical model for free surface flow based on the Reynolds-averaged Navier-Stokes equations. This model is developed in a sigma co-ordinate system. The time-splitting method is used to separate advection and diffusion terms from the pressure terms in the governing equations. The pressure variable is further separated into hydrostatic and hydrodynamic pressures so that the computer rounding errors can be largely avoided. The resulting hydrodynamic pressure equation is solved by a multigrid method, while the hydrostatic pressure equations are solved very efficiently by an Alternating Direction Implicit (ADI) scheme. The convection terms are discretized by the Roe's scheme of second-order accuracy. A staggered mesh is used. The model has been tested against available analytical solutions and experimental data. Good agreement has been achieved.

FLOW3D was used to model the impact of WEC Device Layouts No.1 and No.2 on tidal currents and sediment regime.

## 6.2 *Model Bathymetry*

Model bathymetry was constructed from the Admiralty Chart (No. 1149 & No.1178) and was used in the FLOW3D models, see Figure 4.2. The grid spacing used was 100m and the model area is about 78km x 45km.

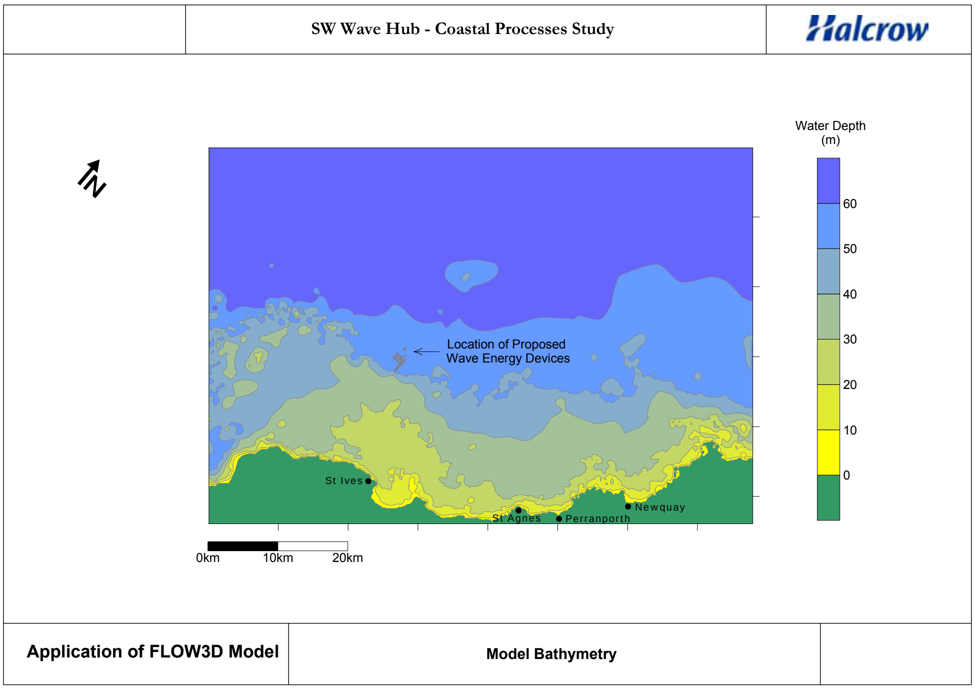


*Figure 6.1: Model bathymetry*

## 6.3 *Calibration*

Before any production modelling runs were undertaken, calibration tests were carried out. Tidal harmonic constituents were used to set up the model boundary conditions.

Calibration was an important step in the development of the hydrodynamic model. With calibrated boundary conditions, the model then can correctly simulate realistic scenarios. In this study, there was measured flow data available at offshore point from 28/02/2005- 08/05/2005, but only a short period was used in calibration. This is from 03/02/2005 -14/02/2005, which include both spring and neap tide. Various boundary conditions were tested in order to provide good agreement between model and measured flow data.

The only available data for the model boundary conditions were tidal constituents from tidal stations in the area. After a series of tests, boundary conditions based on tidal constituents from St Ives (50º13'N, 5º 28'W) and Padstow Bay (50º 33'N, 4º 56'W) were used in the model, since they provide a reliable simulation of the real scenario. Figure 6.2 shows tidal level, and Figure 6.3 and 6.4 present the calibrated results (flow speed and phase). The graphs show that the flow speed matches well and tidal phase agrees very well, therefore the model based on this calibration can provide reliable results.

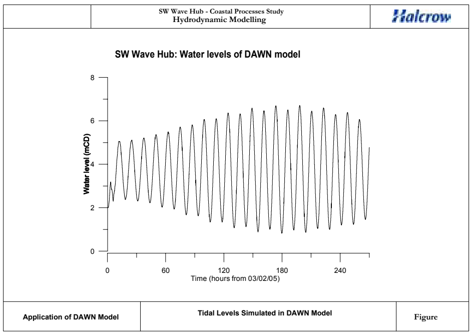


*Figure 6.2: Water level of hydrodynamic model (offshore point)*

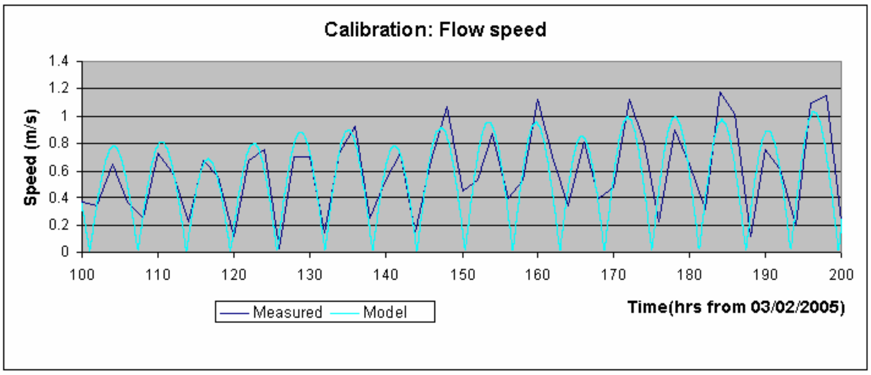


*Figure 6.3: Calibration of flow speed*

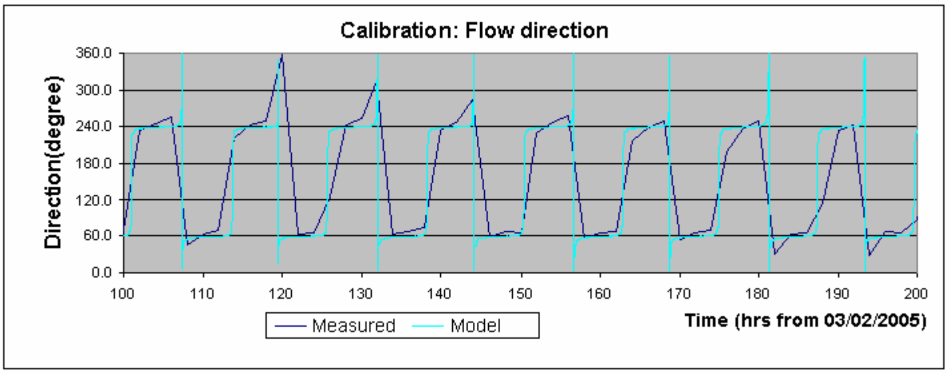


*Figure 6.4: Calibration of flow direction (tidal phase)*

## 6.4 WEC Device Layout No.1 - 4 nr. Wave Dragons

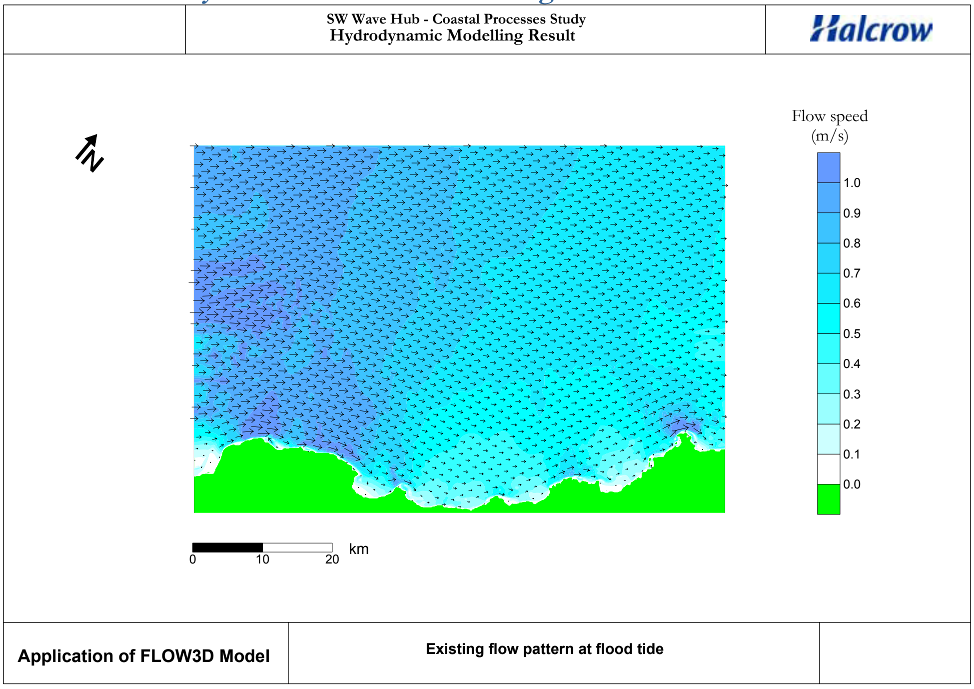


*Figure 6.5: Existing flood flow*

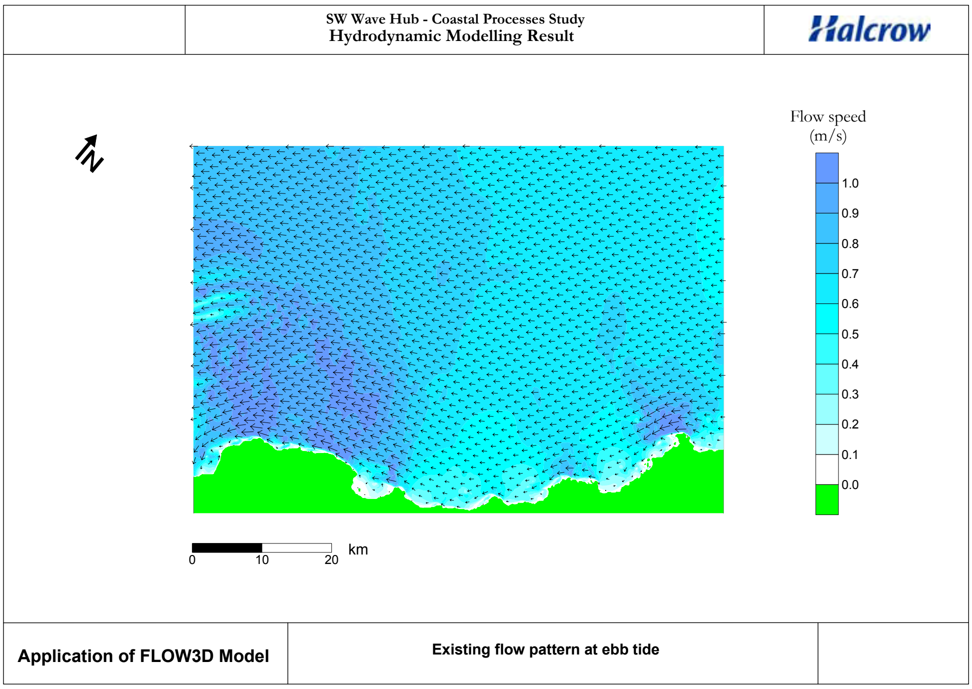
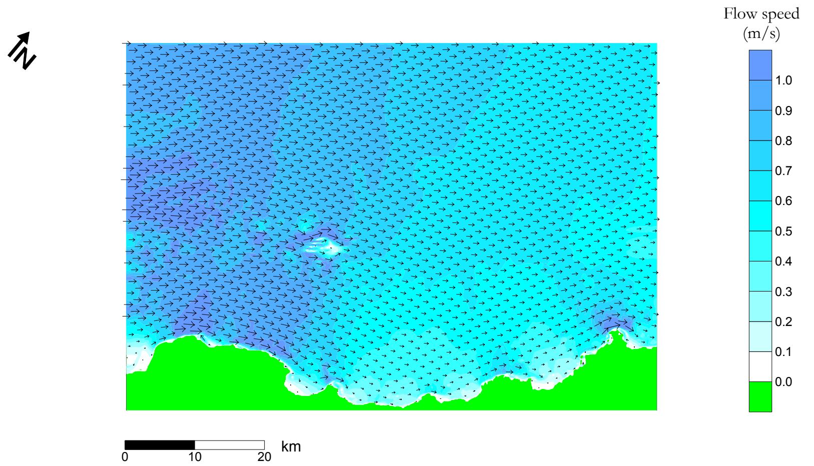


*Figure 6.6: Existing ebb flow*

SW Wave Hub - Coastal Processes Study
Hydrodynamic Modelling Result

Halcrow



**Application of FLOW3D Model**

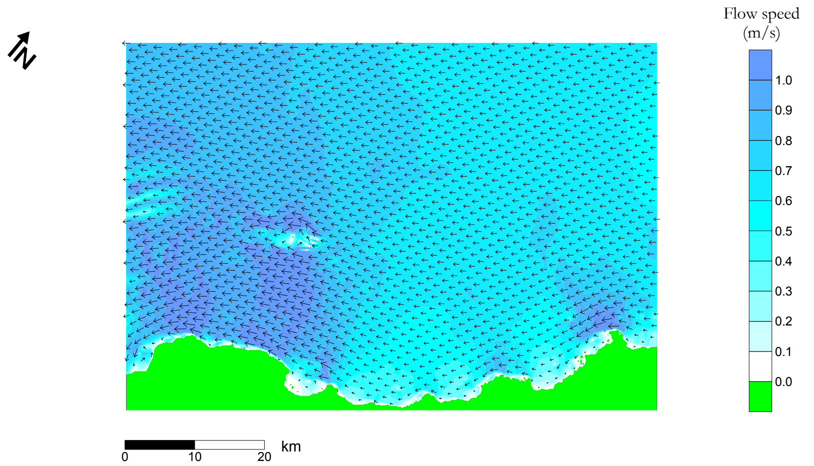
**Flow pattern at flood tide**
**with proposed wave energy devices**

**4 Wave Dragons**

*Figure 6.7: WEC Layout No.1: 4 nr. Wave Dragons (west-facing) Impact on flood tidal flow*

SW Wave Hub - Coastal Processes Study
Hydrodynamic Modelling Result

Halcrow



**Application of FLOW3D Model**

**Flow pattern at ebb tide**
**with proposed wave energy devices**

**4 Wave Dragons**

*Figure 6.8: WEC Layout No.1: 4 nr. Wave Dragons (west-facing) Impact on ebb tidal flow*

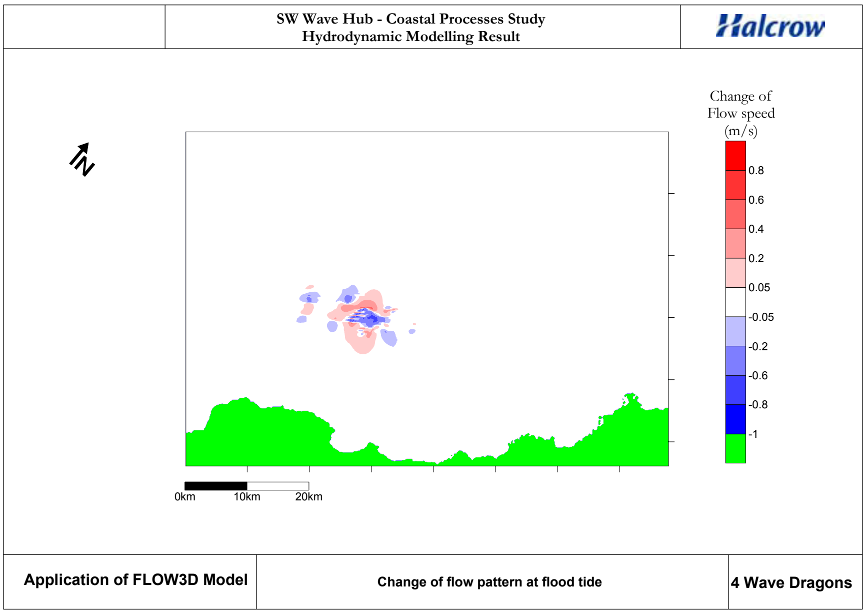


*Figure 6.9: WEC Layout No.1: 4 nr. Wave Dragons (west-facing) Change of flow speed at flood tide*

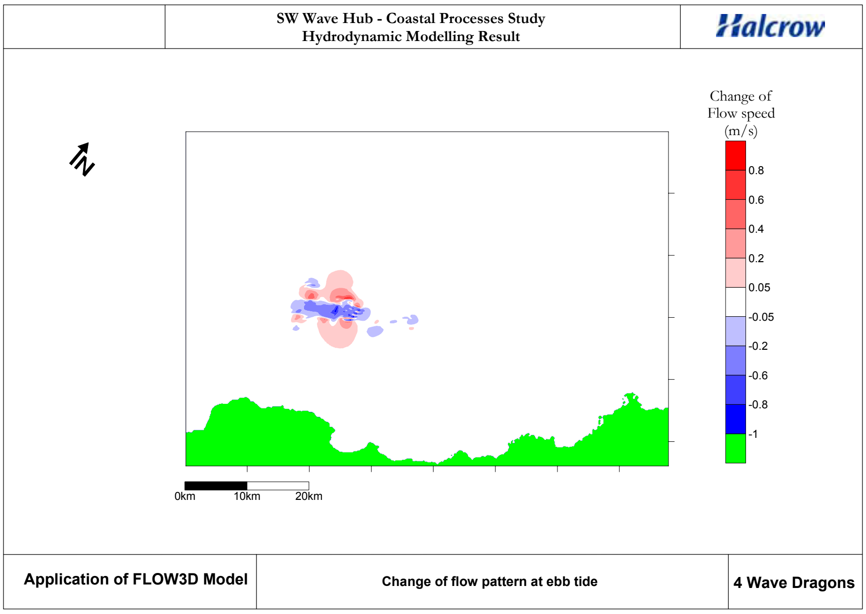


*Figure 6.10: WEC Layout No.1: 4 nr. Wave Dragons (west-facing) Change of flow speed change at ebb tide*

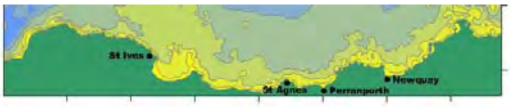


*Figure 6.10a: Location Plan*

The impact of WEC Device Array Layout No.1 (4 nr. west facing Wave Dragons, worst case scenario) on surface currents will be a change of up to -0.8m/s and +0.6m/s within a 15km x 15km area surrounding the WEC deployment area, see Figures 6.8 and 6.9, which does not extend to the coast.

## 6.5 WEC Device Layout No.2 – Various Devices

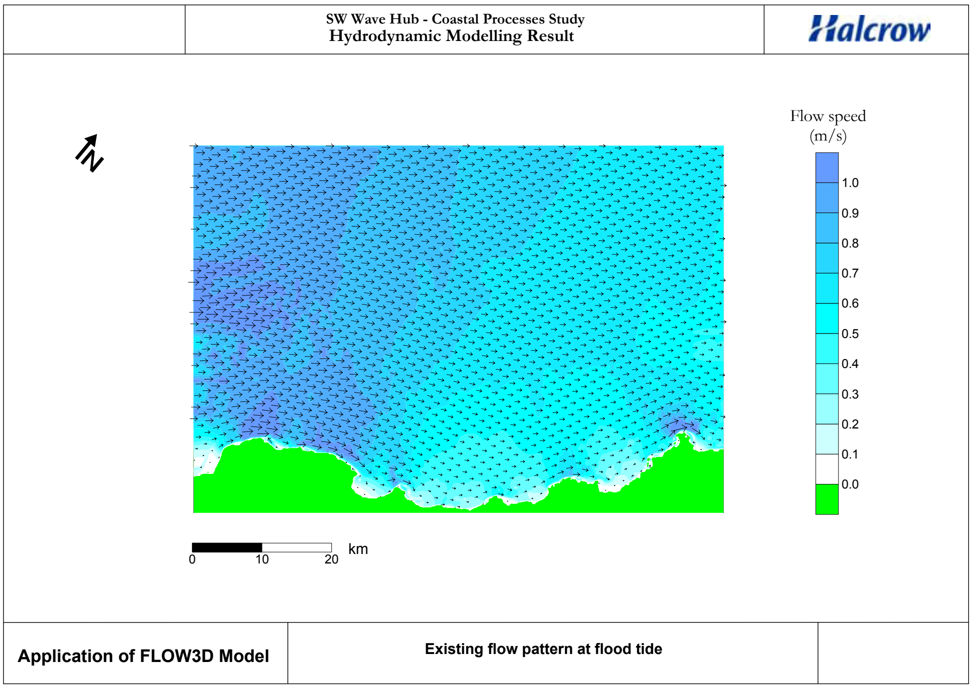


*Figure 6.11: Existing flood flow*

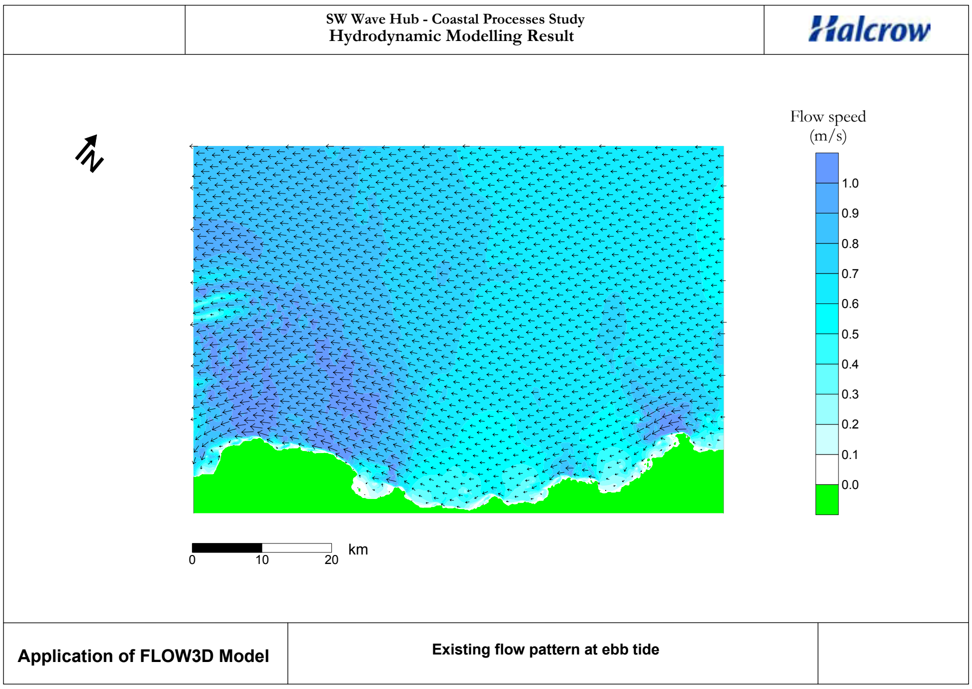
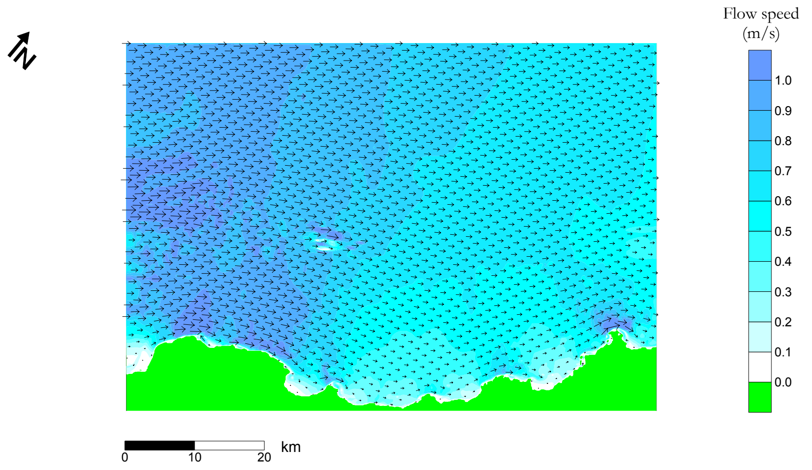


*Figure 6.12: Existing ebb flow*

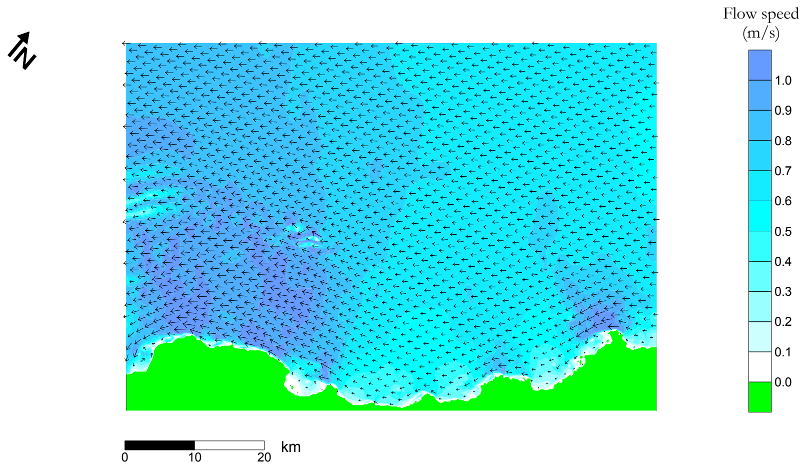
| | | |
|---|---|---|
| | SW Wave Hub - Coastal Processes Study<br>Hydrodynamic Modelling Result | Halcrow |



| | | |
|---|---|---|
| **Application of FLOW3D Model** | **Flow pattern at flood tide<br>with proposed wave energy devices** | |

*Figure 6.13: WEC Layout No.2: Various Devices Impact on flood tidal flow*

| | | |
|---|---|---|
| | SW Wave Hub - Coastal Processes Study<br>Hydrodynamic Modelling Result | Halcrow |



| | | |
|---|---|---|
| **Application of FLOW3D Model** | **Flow pattern at ebb tide<br>with proposed wave energy devices** | |

*Figure 6.14: WEC Layout No.2: Various Devices Impact on ebb tidal flow*

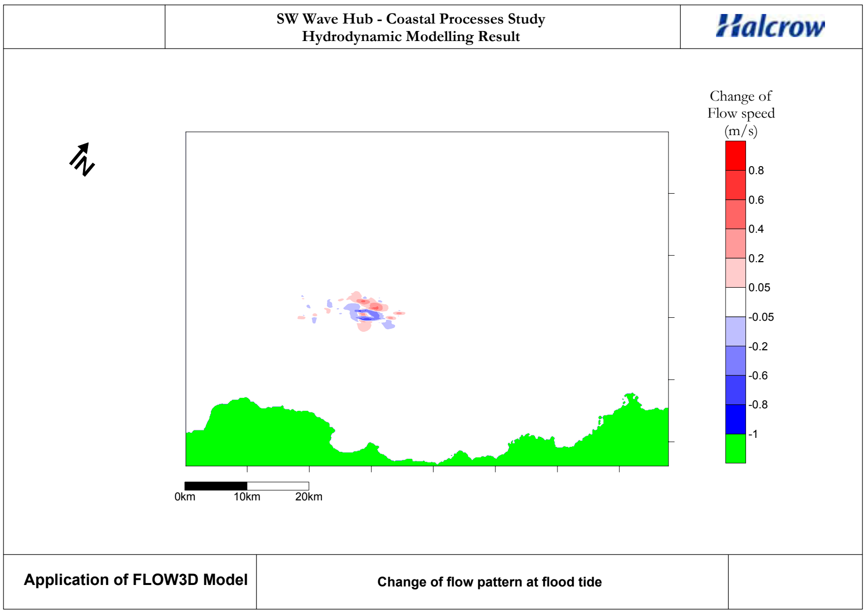


*Figure 6.15: WEC Layout No.2: Various Devices Change in flow speed at flood tide*

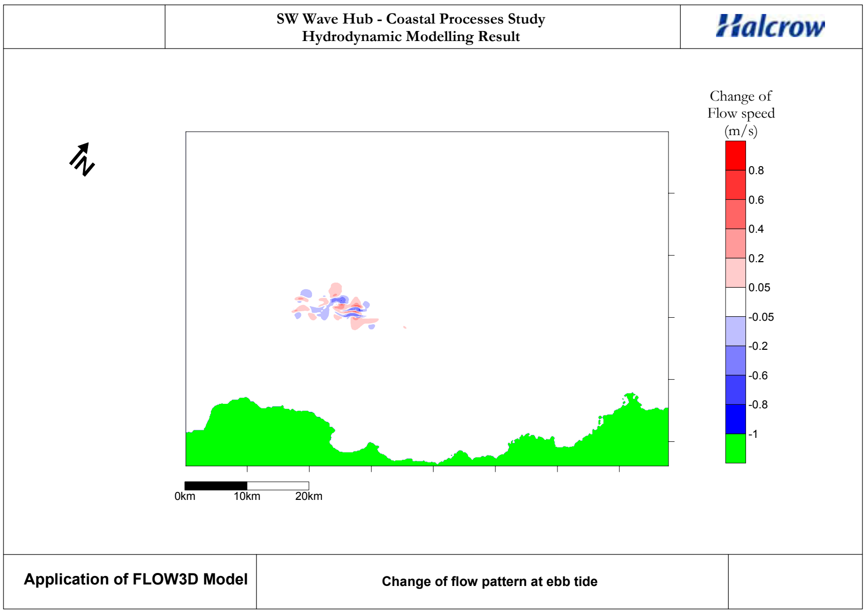


*Figure 6.16: WEC Layout No.2: Various Devices Change in flow speed at ebb tide*

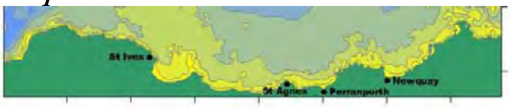


*Figure 6.16a: Location Plan*

The impact of WEC Device Array Layout No.2 (Various Devices) on surface currents will be a change of up to -0.8m/s to +0.6m/s within a 15km x 15km area surrounding the WEC deployment area, see Figures 6.14 and 6.15, which does not extend to the coast

# 7 Sediment Regime

## *7.1 Offshore zone (40mCD to 60mCD)*

***Figure 7.1: Regional Seabed Sediments (Source: Halcrow, 2005)***

Sediments in the offshore zone are thin (approx 1m depth) and patchy, predominantly medium to coarse grained sand and fine to coarse grained gravel. The predominant offshore sediments are gravelly sand and sandy gravel which overlie, in layers typically less than one metre thick, the mudstone/shale bedrock.

It is speculated that very little change has occurred on the seabed over the past 100 years since no major features, in response to construction/ destructive forces, have been recorded by BGS (1983, 1987); Poulton et al (2002); English Nature (2004) and Halcrow (2005).

As water depth exceeds 40m the opportunity for sediment movement is unfavourable, but may occur during storm conditions.

## 7.2 *Transitional Zone (10mCD to 40mCD)*

Sediments in the transitional zone were typically dense olive grey coloured sand and gravel as well as shelly-sandy gravel, which are typically 0.2m thick overlying the mudstone/ shale bedrock. The thin superficial sediment cover becomes increasingly intermittent towards the offshore zone, which suggests that there may be an exchange of sediment between the nearshore and the offshore zone.

Transport in deep water is mainly related to currents as the influence of waves are limited to shallow depths ie. less than 10m. As water depth exceeds 10m and sediment on the seabed is limited and predominantly coarse the opportunity for sediment movement is unfavourable, but may occur during storm conditions.

## 7.3 *Nearshore Zone (less than 10mCD)*

St Ives Bay is believed to be a sediment sink supplied by the River Hayle and offshore sediments, see Figure 7.2. There are unlikely to be significant sediment inputs from the River Hayle since freshwater flows are generally small except during times of fluvial flooding, also the entrance channel has historically required dredging suggesting that this area is a sediment sink. There are no significant quantities of sand offshore, sediments are thin (approx 1m depth) and patchy, predominantly medium to coarse grained sand and fine to coarse grained gravel. Under contemporary conditions the offshore sediments are believed to be largely immobile. There is limited input or export of sediment to St Ives Bay which can be considered as a ‘closed’ sediment system.

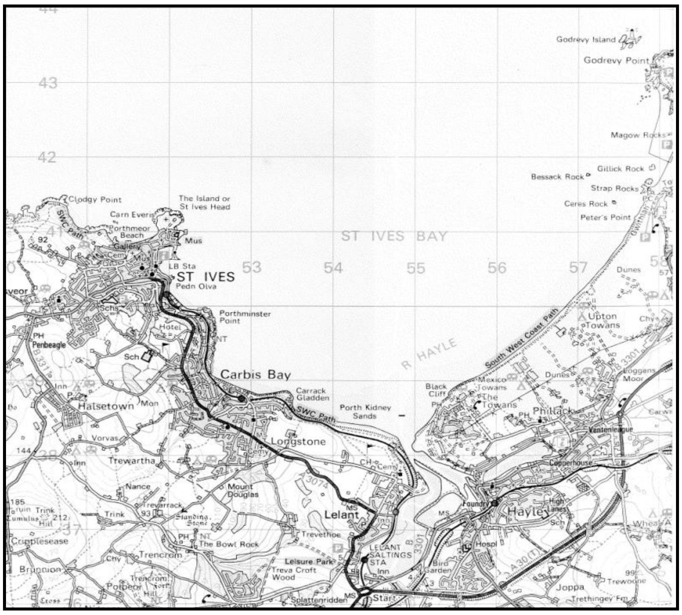


*Figure 7.2: Overall Layout Map of St Ives Bay*

The plan shape of the adjacent beaches suggests that longshore drift of beach sand appears to be occurring into the mouth of the estuary from Black Cliff and the beaches to the east and from Porth Kidney Sands to the west, see Figure 7.3.

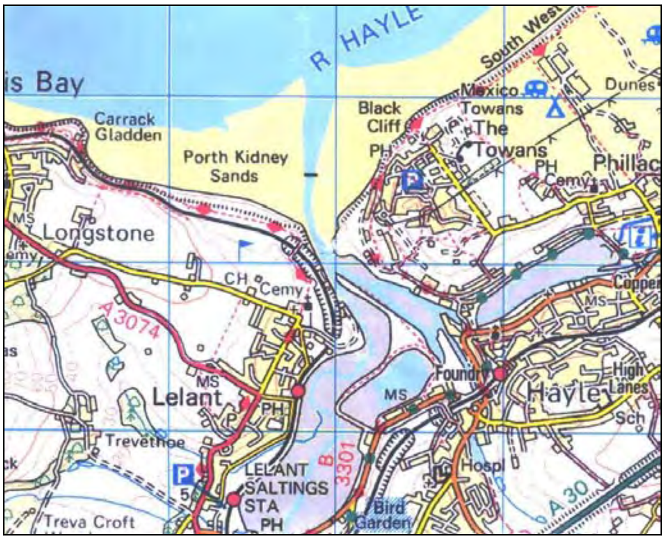
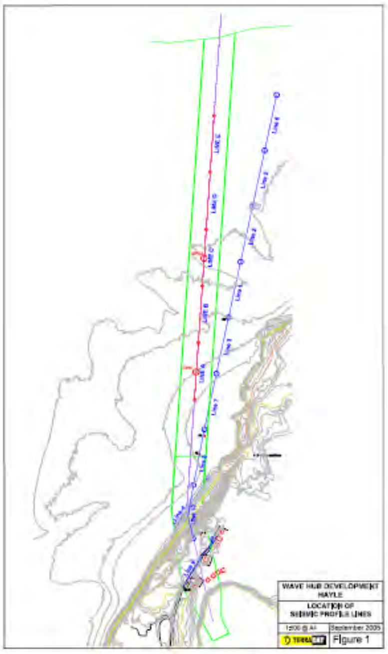


*Figure 7.3: Detail map at mouth of Hayle Estuary*

The beaches are comprised of mainly sand, occasionally gravely sand with a typical depth 5m to 6m, up to 8m in places, see Figure 7.4.



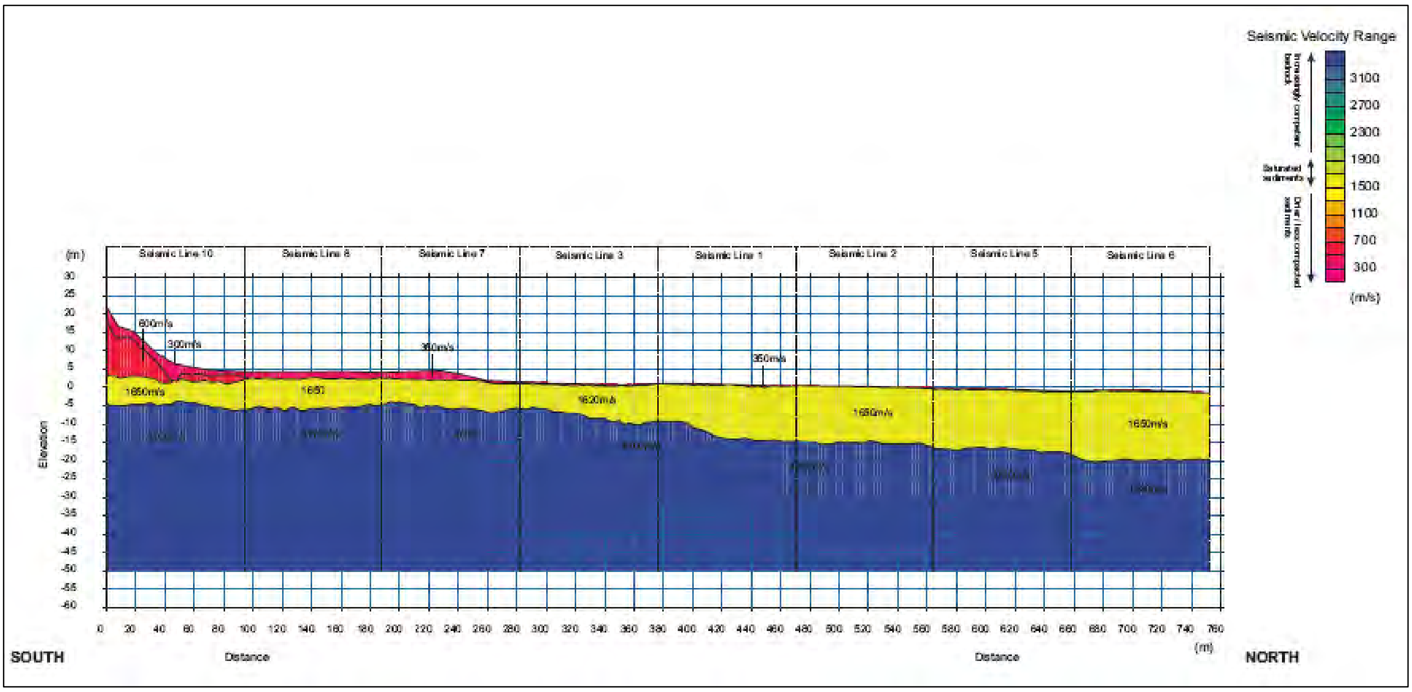


*Figure 7.4: Geophysical survey results along alignment of proposed cable route*

Red – dry loose sand (weak near surface material/ compact dry sediment)

Yellow – wet sand (saturated unconsolidated sediment)

Blue – competent bedrock

Wind-blown sand from the exposed foreshore feeds the dune systems on both sides of the estuary mouth. Reduction in the width of beach exposed at low tide will reduce the amount of sediment feeding the dunes. Wave action erodes the dunes and returns the sand to the beach during storms. Harvey's Towans (dunes) to the east and immediately adjacent to the entrance channel appear to be eroding, exposing former areas of fill which were tipped in this area during the late 1940s and early 1950s, see Plates 7.1 and 7.4. This also occurred in 1983 (Babtie, 2002). It is important to note that the current line of the dunes at Harvey's Towans is artificial and this may be contributing to their erosion, whilst adjacent dunes further to the east and to the west of the harbour entrance appear to be more stable. It is important that sand is allowed to pass from the beach to the dunes and vice versa to provide a sustainable system, see Figure 7.5

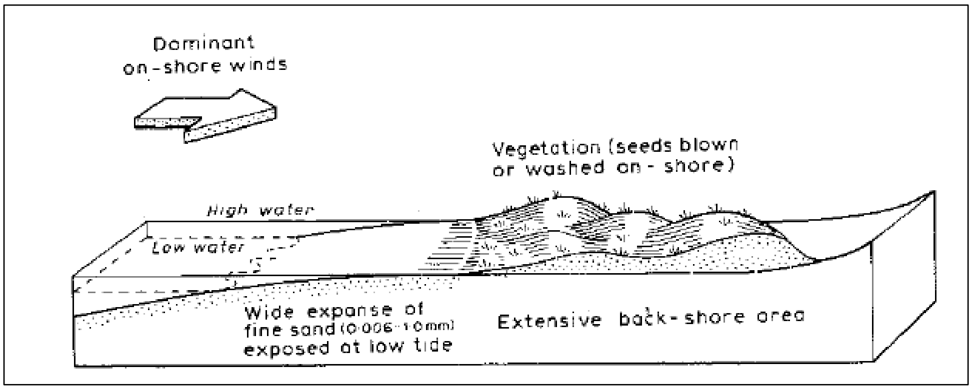


***Figure 7.5: Conditions necessary for dune growth/ development (Pethick, 1984)***

The presence of the exposed former tipped material immediately adjacent to the harbour entrance, see Plate 7.8, may currently be preventing the transfer of sand between the dune and beach and may be resulting in lowering of the beach, whilst to the east a more natural beach and dune system is in place, see Plate 7.1. An area in front of the dunes along the proposed cable route was infilled in the late 1940s and early 1950s, see Plates 7.2 to 7.5, which advanced the line by some 130m between 1848 and 1946. Between 1946 and 1985 dune erosion led to 70m erosion, whilst the plan alignment of the dunes remained fairly stable between 1985 and 1995, possibly as a result of dune management measures, which included restricting public access to the dunes by the fencing.

*Plate 7.1: Looking towards Harvey's Towans dunes and the mouth of the Hayle Estuary from offshore (Halcrow, 2005)*

*Plate 7.2: 1848 – Navigation chart*

*Plate 7.3: May 1946 – aerial photograph*

*Plate 7.4: July 1985 – aerial photograph*

*Plate 7.5: June 1996 – aerial photograph*

*Plate 7.6: Looking towards the mouth of Hayle Estuary from Black Cliff (January 2006)*

***Plate 7.7: Looking towards the dunes along the proposed cable route, note erosion caused by use of beach access track (January 2006)***

***Plate 7.8: Looking towards Harvey's Towans dunes and Hayle Estuary mouth from the beach. Note rock revetment at the toe of the dunes in the distance and the exposed tipped material (January 2006)***

The beach profiles demonstrate typical seasonal changes. Beach levels can reduce by up to 1.8m (6ft) following severe storms (anecdotal evidence), removing material from the beach to create an inter-tidal bar some distance offshore. During less severe wave conditions this material is returned to the beach from the inter-tidal bar. Limited beach profile/ topographic information is available for this area, it is therefore not possible to confirm fluctuation in beach levels simply by analysis of historic profile data, see Figures 7.6 to 7.8.

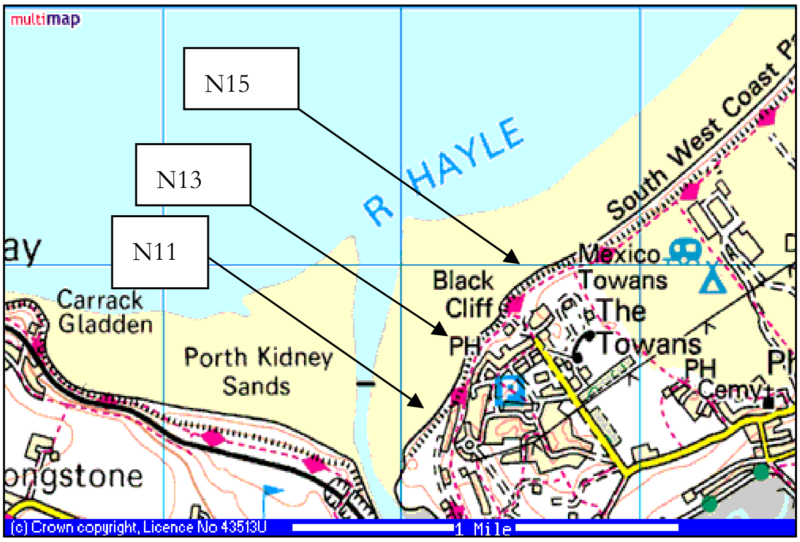


*Figure 7.6: Beach Profile Alignments*

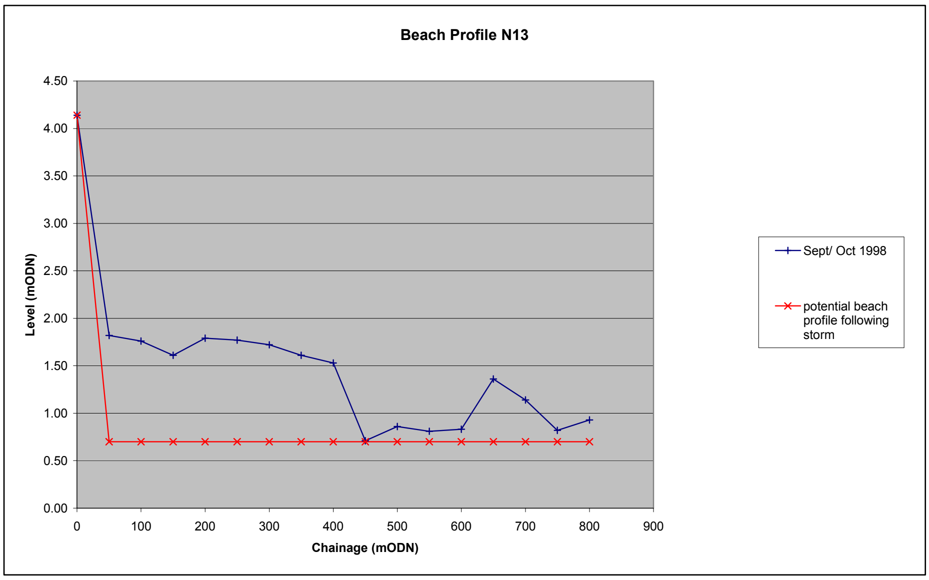


*Figure 7.7: Beach profile N13, surveyed in Sept/ Oct 1998, along approximate alignment of proposed cable route*

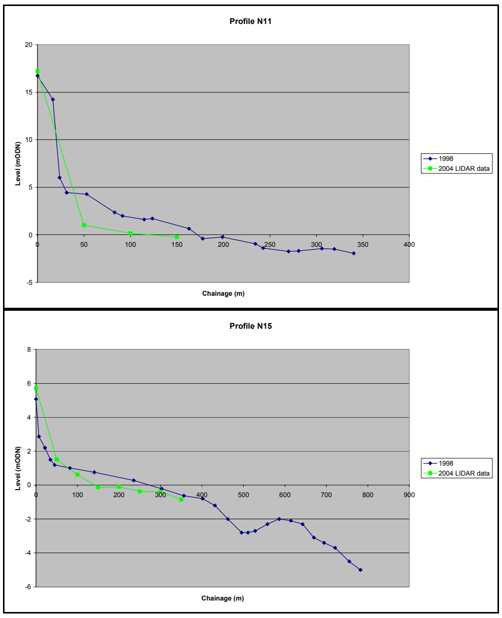


***Figure 7.8: Fluctuation in beach levels on adjacent beach profiles N11 and N15 between 1998 (blue) and 2004 (green)***

Rapid accretion of sediment occurs in Hayle Harbour and approach channel. The entrance channel was dredged from the late 1700's until the latter half of the 1970s, primarily to maintain a navigable channel for shipping, although sand extract continued at the estuary mouth until July 2004. 20,000 tonnes to 30,000 tonnes were dredged per annum between 1973 and 2001 and approximately 18,000 tonnes between October 2001 and February 2002. The cessation of dredging alone will not in itself arrest the erosion of Hayle Beach or dunes (Babtie, 2002).

Sand transport modelling (HR Wallingford) indicated infilling of the inner harbour and also that sluicing removes sand from the channel as far as the bar. Information provided by the harbour master indicated that whilst there are changes to the bed level at the entrance and the navigation channel migrates, the channel at the entrance to the estuary does not migrate (HR Wallingford). There are development plans to develop the harbour into a marina and possibly to re-establish sluicing of the entrance channel to ensure that it is navigable to vessels which will use the marina. Development details are unknown at present, however if sluicing of the channel is re-established this is likely to return sand to the beach.

Further details are provided in Appendix D: Geomorphological Report.

# 8 Impacts of Wave Hub on Sediment Regime

## 8.1 *Sediment Modelling*

Using the same tidal condition, and bathymetric conditions representing existing and future conditions, the model was run for 48 hours with 1 in 1 year storm event wave condition. These model runs were carried out for sand sediment type. Sediment transport model results illustrate impacts on the general patterns of sedimentation which are shown as depths of erosion and accretion over a period of 48 hours. Contour maps are presented showing both the computed values for existing and future conditions.

Results of sediment pattern for the existing case and WEC device layouts no.1 and no.2 are shown in Figures 8.1 to 8.4. The results with and without proposed WEC arrays are quite similar. The impact of WEC device layouts no.1 and no.2 are not significant and are limited to a small area, close to the wave devices. This is because: the flow pattern with or without WEC arrays are almost the same; and the proposed WEC device arrays have an impact on wave patterns but this does have a significant impact on sediment transport at the seabed, in water depth of more than 50m.

## 8.2 WEC Device Layout No.1 - 4 nr. Wave Dragons

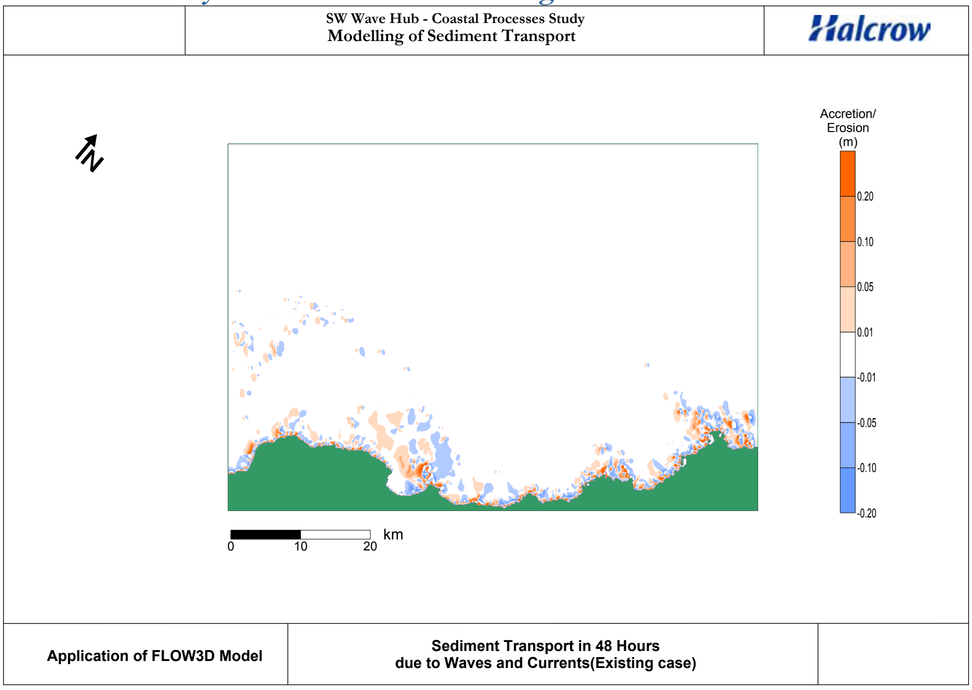


*Figure 8.1: Existing Sediment Transport Regime*

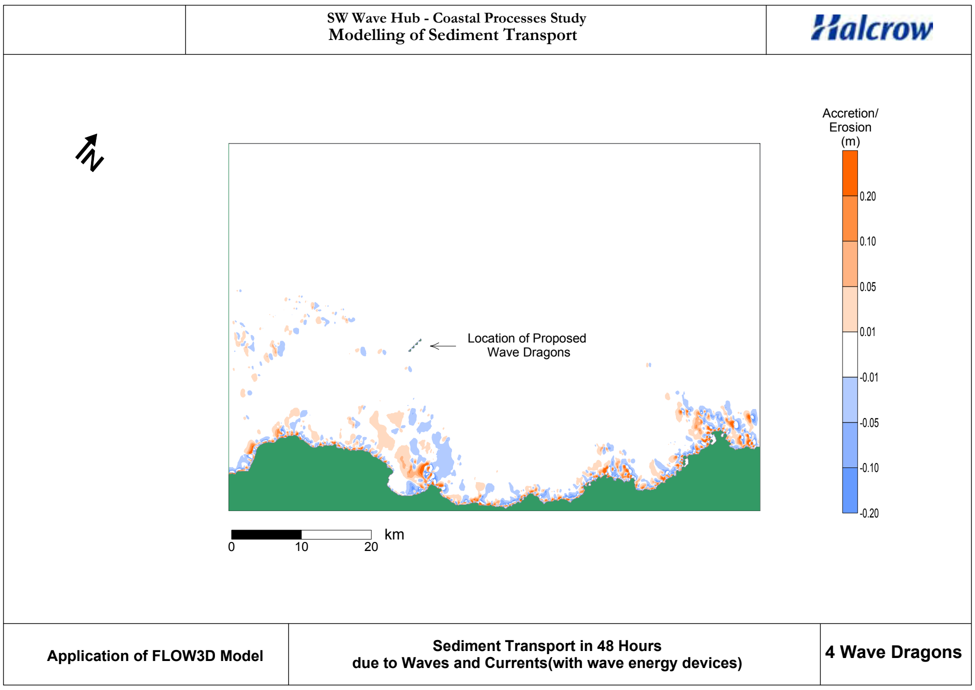


*Figure 8.2: Sediment Transport Regime with WEC Device Layout No.1*

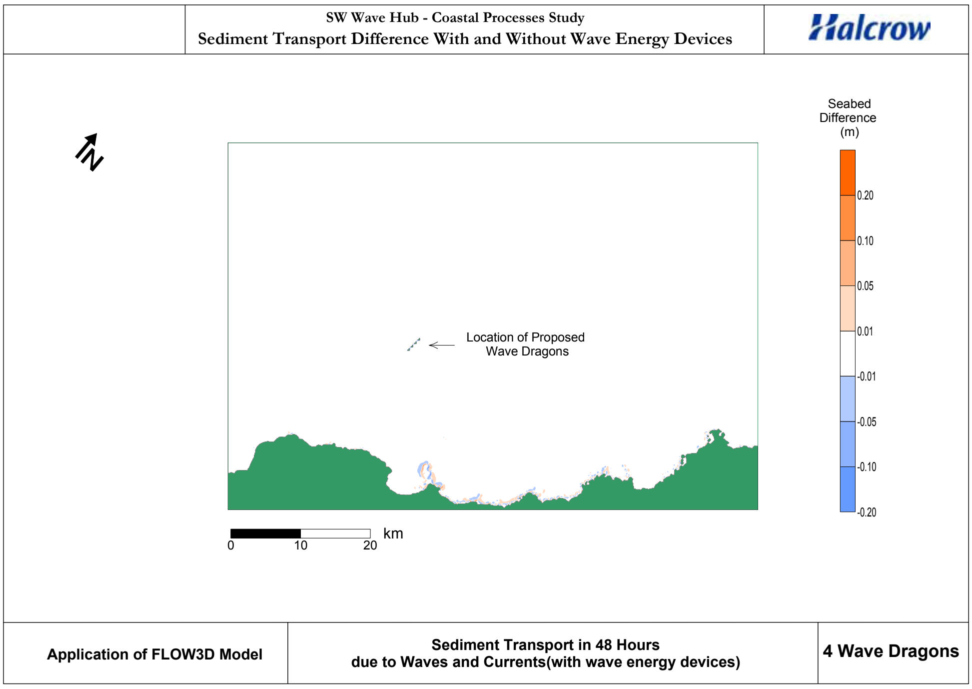


*Figure 8.3: Sediment Transport Regime with WEC Device Layout No.1 Difference Plot*

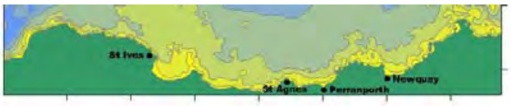


*Figure 8.3a: Location Plan*

## 8.3 WEC Device Layout No.2 – Various Devices

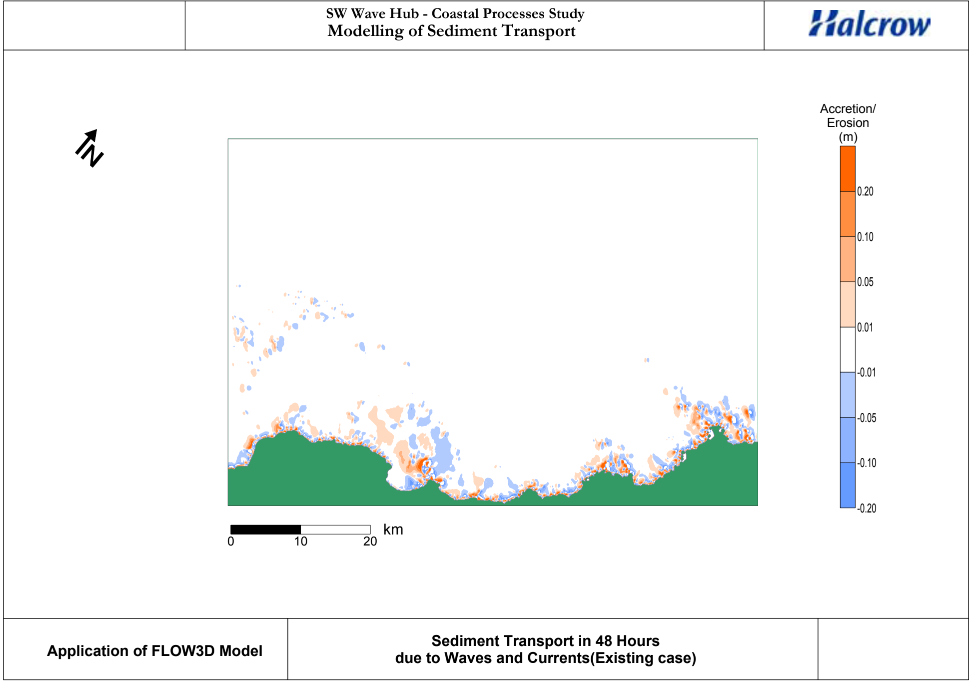


*Figure 8.4: Existing Sediment Transport Regime*

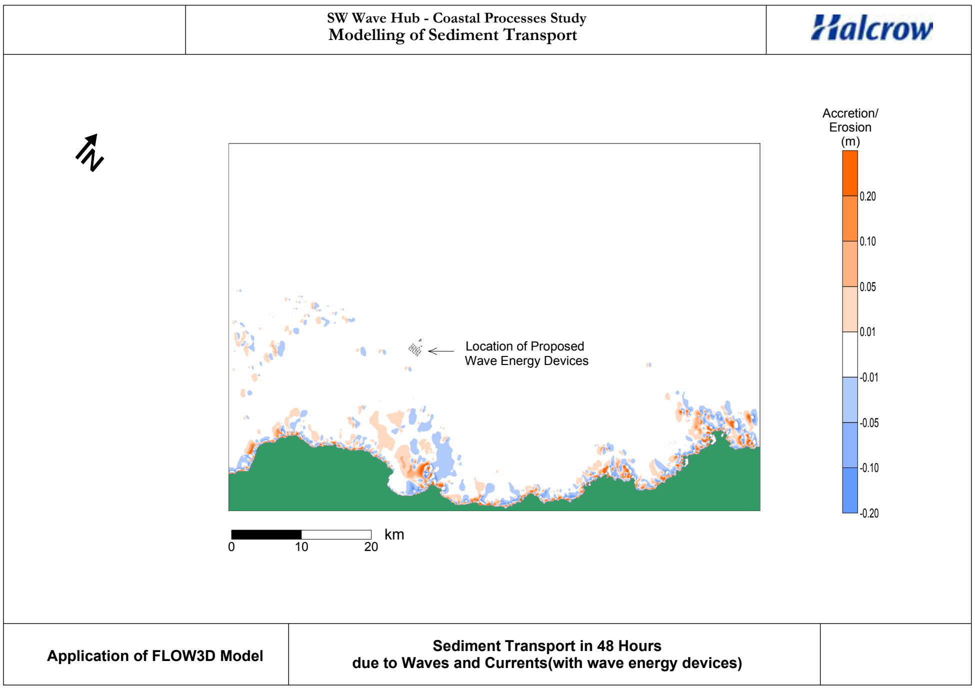


*Figure 8.5: Sediment Transport Regime with WEC Device Layout No.2*

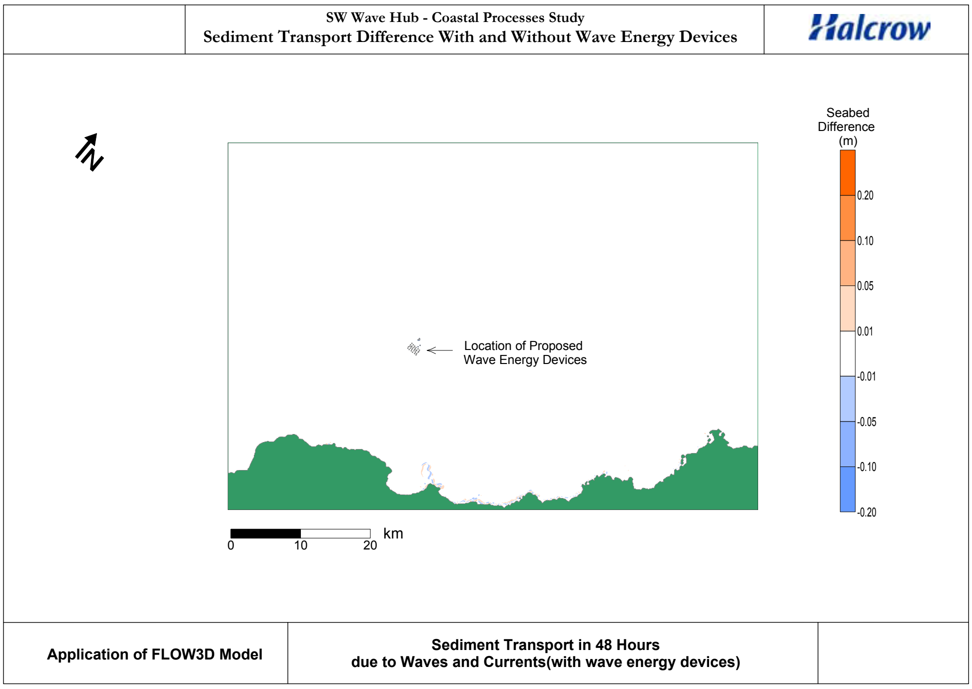


*Figure 8.6: Sediment Transport Regime with WEC Device Layout No.2 Difference Plot*

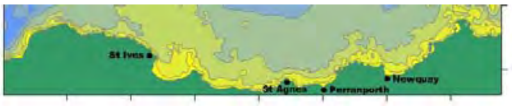


*Figure 8.6a: Location Plan*

## 8.4 *Impacts of the Wave Hub sub-sea facilities and cables*

### 8.4.1 *Offshore/ Transitional Zone (40mCD to 10mCD)*

The Wave Hub project is likely to have a minor localised impact in the immediate vicinity of the sub-sea facilities (cable termination and distribution unit, transformers and connection points), connecting cables and the onshore cable route where it is laid on the seabed. These impacts can be summarised as follows:

- Disturbance of seabed sediments during installation of the sub-sea facilities and cables;
- Disruption of existing sediment movement due to the presence of the sub-sea facilities and cables. There is limited potential for this since little change has occurred on the seabed over the past 100 years;
- Localised scour and potential burial of the sub-sea facilities and cables. Since offshore sediments typically occur in layers less than one metre thick this is unlikely to cause a significant problem. However sub-sea facilities should be founded on bedrock to prevent undermining/overturning and cables should be placed on bedrock on the seabed to prevent the creation of a free span following scour of sediment during storm conditions;
- Movement of offshore sediments following storm conditions which may lead to localised burial of sub-sea facilities/ cables;
- Abrasion of the mudstone/ shale on the seabed if sub-sea facilities and cables are not anchored sufficiently;
- Sub-sea facilities and cables should be anchored or weighed down to prevent flow induced vibration which could lead to damage and/or severance;
- Potential abrasion of cables where they pass over jagged outcrops of rock on the seabed;
- Marine growth and associated impacts on sub-sea facilities and cables;
- The sub-sea facilities and cables need to be protected against trawl board or anchor loading.

Offshore cables will need to be weighted or anchored to prevent uplift and abrasion against exposed rock outcrops during storm conditions and will be buried in seabed sediments inshore of 20mCD.

### 8.4.2 *Nearshore Zone (less than 10mCD)*

For both WEC device layouts the resultant change to the wave climate and currents will not have a discernable effect on sediment transport and beach levels along the north Cornish coast, a change of less than 0.2m in beach levels during extreme storm events. This change is minimal when compared to current typical seasonal and temporal changes to the level of the beach, which can reduce by up to 1.8m (6ft) in places following severe storms, removing material from the upper beach to create an inter-tidal bar some distance offshore. During less severe wave conditions this material is returned to the beach from the inter-tidal bar.

Limited disturbance of sediment in the nearshore zone would occur when burying the cable beneath the beach. A plough would be used to bury the cable across the beach, whilst drilling would be utilised to install the cable beneath the dunes. Impacts would be limited to: disturbance on the beach during installation (summer tourist season to be avoided if possible to minimise disruption); excavation of sand along cable route and possible deposition of gravel/ sand/ silt/ mudstone following burial of cable. Background levels of suspended sediment in the area are naturally high, therefore sediment plumes arising from the cable burial process are not likely to be significant.

No long term impacts would result from cable burial, provided the cable is buried to a sufficient depth to prevent future exposure.

The potential for further erosion of the beach must be considered and the suggested buried level for the cable in the nearshore zone is as follows:

- Minimum burial level for cable = -2.0mODN (metres above Ordnance Datum Newlyn), which includes:
  - potential beach fluctuation during storms, 1.8m (based on anecdotal evidence since limited beach profile data is available at the site);
  - additional allowance for future beach lowering due to future sea level rise and an allowance for beach erosion during the height of storm, 1.0m;
- Maximum burial level = -5.0mODN, just above competent bedrock (Ch 0m to Ch 300m), varies -5mODN to -20mODN (Ch 300m to Ch 750m).

The depth of burial will need to be continued 100m inshore beyond the existing toe of the dunes to allow for future erosion of the dunes, see Figure 8.7.

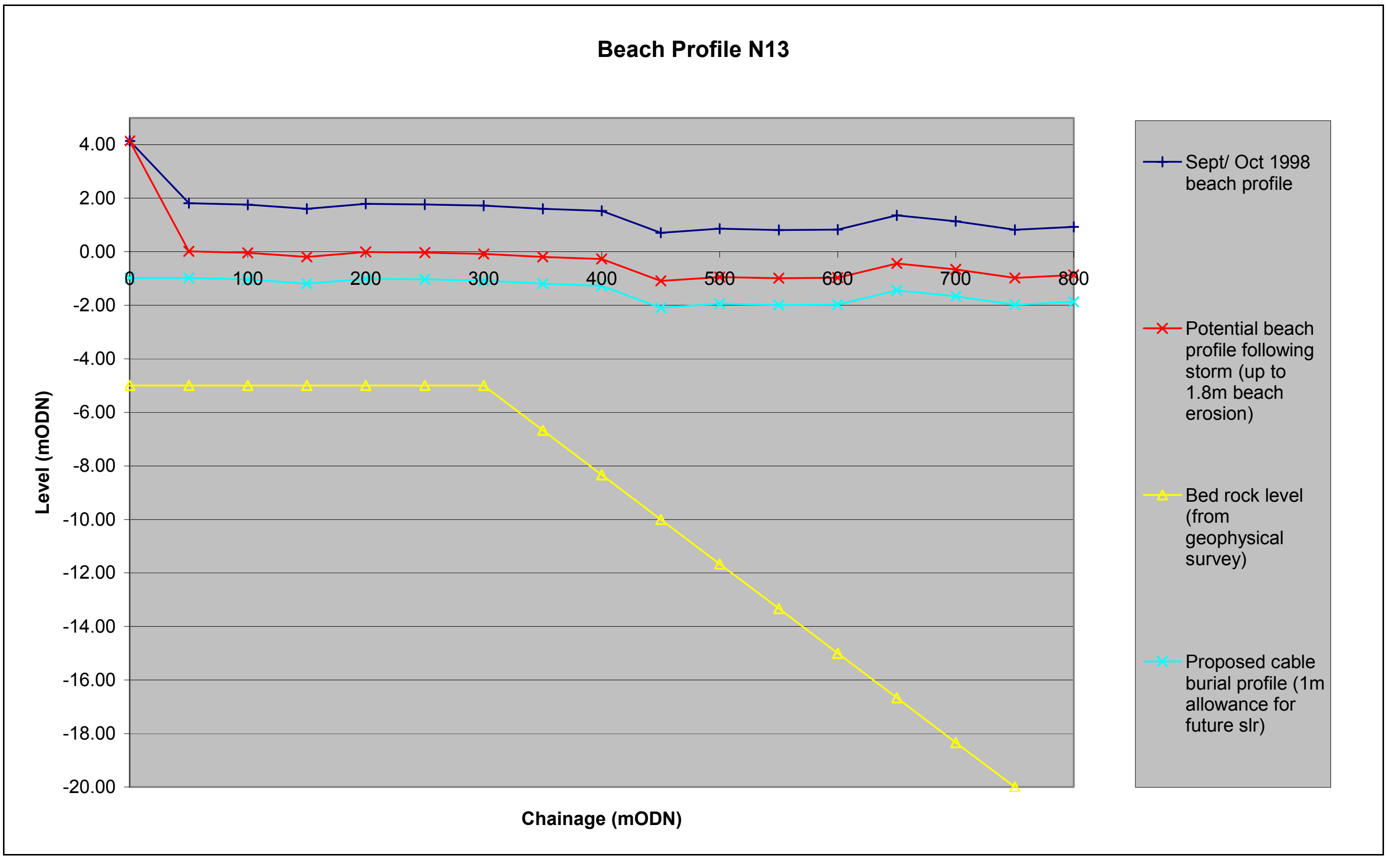


*Figure 8.7: Proposed cable burial profile*

## 8.5 Onshore Zone

There will be minimal impact on the sediment regime at the onshore sub-station or in the surrounding area, since the sub-station is already in place.

## 8.6 Overall

Overall a **minor adverse** to **negligible** effect is predicted for the Wave Hub.

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# Appendix A – Wave Data

**HALCROW GROUP LIMITED**

# Wave and Current Measurements St. Ives Cornwall
**30 January 2005 to 10 April 2006**

**Fugro GEOS Reference No: C10644/4056/R1**
**June 2006**

**Fugro GEOS Ltd**
**Fugro House, Hithercroft Road**
**Wallingford, Oxfordshire OX10 9RB, UK**
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## Wave And Current Measurements, St Ives, Cornwall: C10644/4056

| Rev | Date | Originator | Checked & Approved | Issue Purpose |
|---|---|---|---|---|
| 0 | 5 June 2006 | Donald Brockie<br>Data Analyst | Karen Stapleton<br>Technical Reviewer | Interim Report for Client comments |
| 1 | 16 June 2006 | Donald Brockie<br>Data Analyst | Andrew N Moore<br>Technical Manager | Final report approved by client |

| Rev R1 – 16 June 2006 | Originator | Checked & Approved |
|---|---|---|
| Signed: | *Donald Brockie* | *Andrew N Moore* |

This report is not to be used for contractual or engineering purposes unless the above is signed where indicated by both the originator of the report and the checker/approver and the report is designated ‘FINAL’.

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## TABLES

Included in the text are tables

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| 1.1a | Heave parameter definitions from zero-crossing analysis |
| 1.1b | Heave parameter computed from spectral analysis |
| 1.2 | Directional wave parameters computed by Neptun-8 |

## FIGURES

Figures included at the end of this report contain time series of wave parameters including:

Hm0, Hmax, Hm0a, Tm02, Tp, mdir, mdira, ThTp, and mdirb for the period 30 January 2005 to 10 April 2006.

In previous reports, Thlf has been plotted, this parameter is not readily available from the Datawell buoy, so has been omitted.

Time series of current speed and direction and seawater temperature from 30 January 2005 to 8 November 2005, are also included.

# 1. INTRODUCTION

## 1.1 Background

Seawatch Mini Wave Buoys and Datawell Directional Waveriders have recorded wave measurements off St. Ives, Cornwall in six time periods:

| INSTRUMENT TYPE | START DATE | END DATE |
|---|---|---|
| Seawatch Mini | 30 January 2005 | 23 February 2005 |
| Seawatch Mini | 26 February 2005 | 8 June 2005 |
| Seawatch Mini | 8 June 2005 | 5 October 2005 |
| Seawatch Mini | 5 October 2005 | 8 November 2005 |
| Datawell DWR | 11 December 2005 | 25 January 2006 |
| Datawell DWR | 25 January 2006 | 10 April 2006 |

The Seawatch Mini buoys recorded wave height and wave direction at 2-hourly intervals, each record containing 1024 samples of Heave (H), position east (E) and position north (N) sampled at a rate of 1 Hertz. East and north are defined according to True North. The Datawell buoys recorded similar datasets but at hourly intervals at 2Hz.

## 1.2 Raw Data Files

The raw data are listed in two sub folders, named SWM and DWR. The Seawatch Mini data files are in machine raw files (.PFF). The Directional Waverider files are Datawell Mode 0 raw Binary format

## 1.3 QC Time Series Data Files

The wave time series data are listed in two files, named CORNWALL_SWM_WAVES.txt, and CORNWALL_DWR_WAVES.txt. CORNWALL_SWM_CURRENTS.txt contains surface current data. In each data record there is first a time stamp followed by the parameters. The <tab> character separates the fields within a record.

## 1.4 Parameter Data Files

Computed wave parameters are listed in two files:

Swm_cornwall_zeroup_par.txt containing parameters computed from the zero-upcrossing analysis.
Swm_cornwall_nep_dir_par.txt containing parameters computed from the directional spectrum.

These are tab-separated ASCII files suitable for import to Excel. The file header gives a description of the parameters in each field of data records. The records contain the recorded data and the time stamp at the beginning of the recorded time series, followed by the parameters listed in Fortran's E13.5 format. Parameter Definitions are listed in the tables below.

| TIME DOMAIN | |
|---|---|
| H | Individual wave height (not presented) |
| Hs | Average of the third highest waves |
| Hmax | Height of highest wave |
| Hmean | Average height of individual waves |
| HS1max | Height of steepest wave |
| T | Individual wave period (not presented) |
| Ts | Average period of the one third highest waves |
| Tz | Average period of individual waves |
| THmax | Period of the highest wave |
| S1 | Steepness of individual wave: S1 = $H/(1.56T^2)$ (not presented) |
| S1mean | Average wave steepness |
| S1max | Steepness of steepest wave |
| SIGS1 | Standard deviation of individual steepness |
| S1Hmax | Steepness of highest wave |
| S2 | Steepness based on Hs and Tz: S2 = $Hs/(1.56Tz^2)$ |
| S3 | Steepness based on Hs and Ts: S3 = $Hs/(1.56Ts^2)$ |
| NZ | Number of waves in the time series |

**Table 1.1a Heave Parameter Definitions from Zero-Crossing Analysis**

| **FREQUENCY DOMAIN** | |
|---|---|
| $m_0$, $m_1$, $m_2$, $m_4$, $m_{-1}$, $m_{-2}$ | Moments of the spectrum about the origin: $m_k = \int_{f=0.04Hz}^{0.5Hz} f^k S(f)df$ where $S(f)$ is the spectral density and $f$ is the wave frequency. |
| $m_{0a}$, $m_{0b}$, $m_{2a}$, $m_{2b}$ | Spectral moments calculated as above for two frequency bands:<br>Low frequency (“swell”): Band a: $f$ in the range 0.04 – 0.10 Hz<br>High frequency (“wind sea”): Band b: $f$ in the range 0.10 – 0.50 Hz |
| Hm0 | Estimate of Hs, $Hm0 = 4\sqrt{m_0}$ |
| Hm0a, Hm0b | Estimate of Hs for frequency bands a and b.<br>$Hm0a = 4\sqrt{m_{0a}}$ and $Hm0b = 4\sqrt{m_{0b}}$ |
| Hm0lf | Significant Wave Height, Low Frequency Band |
| Tp | Period of spectral peak Tp = $1/f_p$ where $f_p$ is the frequency corresponding to the spectral component with the highest energy density. |
| TL | Lower wave period of significance; 5% of the energy has longer periods |
| TU | Upper wave period of significance; 5% of the energy has higher periods |
| SFP | Maximum spectral density SFP = $S(f_p)$ |
| Tpc | Estimate of Tp from spectral moments, $Tpc = \frac{m_{-2}m_1}{m_0{}^2}$ |
| Tm-20 | Estimate of Ts, $Tm_{-20} = \sqrt{\frac{m_{-2}}{m_0}}$ |
| Tm-10 | Estimate of Ts, $Tm_{-10} = \frac{m_{-1}}{m_0}$ |
| Tm01 | Estimate of Tz, $Tm_{01} = \frac{m_0}{m_1}$ |
| Tm02 | Estimate of Tz, $Tm_{02} = \sqrt{\frac{m_0}{m_2}}$ |
| Tm02a, Tm02b | Estimate of Tz for the frequency bands a and b defined above, calculated as<br>$Tm_{02a} = \sqrt{\frac{m_{0a}}{m_{2a}}}$, $Tm_{02b} = \sqrt{\frac{m_{0b}}{m_{2b}}}$. |
| Tm24 | Estimate of Tc (the duration of recorded time series divided by number of crests):<br>$Tm_{24} = \sqrt{\frac{m_2}{m_4}}$ |
| Sm02 | Estimate of S2, $Sm02 = Hm0/(1.56Tm02^2)$ |
| Qp | Spectrum width parameter $Qp = \frac{2}{m_0{}^2} \int_{0.04Hz}^{0.5Hz} S(f)^2 df$ |

**Table 1.1b Heave Parameter Computed from Spectral Analysis**

| | |
|---|---|
| Rb | Width of spectrum peak, *Rb = f1 - f2, S(f1) = S(f2) = 0.10 S(1/Tp)* |
| ThTp | Mean wave direction at the spectral peak period. |
| ThHf | High frequency mean wave direction. Frequency band between 0.4 and 0.44 Hz |
| ThLf | Low frequency mean wave direction. Frequency band between 0.05 and 0.07 Hz |
| Mdir | Mean spectral wave direction |
| Mdira, Mdirb | Mean spectral wave direction over frequency bands "a" and "b", respectively |
| SprTp | Wave spreading at spectral peak period |
| UI | Unidirectivity index |

**Table 1.2 Directional Wave Parameters Computed by Neptun-8**

The definitions of parameters Mdir and UI are, following Tucker (1991):

$$Mdir = \arctan(b/a)$$
$$UI = \sqrt{a^2 + b^2}$$

where

$$a = \frac{\int S(f)\cos[\theta_M(f)]df}{\int S(f)df}$$
$$b = \frac{\int S(f)\sin[\theta_M(f)]df}{\int S(f)df}$$

and $\theta_M(f)$ is the mean direction for each frequency band. Now, if $\theta_M(f)$ is constant through the spectrum, then $Mdir = \theta_M$ and $UI = 1$, otherwise $0 \le UI < 1$.

**MRU transfer function**

**Channel dependent constants**

For heave:

$$f_c = 0.01Hz$$
$$e = 1.0$$

For east and north displacement:

$$f_c = 0.04Hz$$
$$e = 0.6$$

**The transfer functions for all three channels**

$f$ is the frequency of the spectral component in Hz.

The correction of the amplitude, $A$, is

$$C_A = \frac{1}{\sqrt{re^2 + im^2}}$$

The correction of the phase angle, θ, is

$$C_\theta = \tan^{-1}\left(\frac{im}{re}\right)$$

where

$$re = \frac{x^4\left\{1 + x^2\left[x^2 - 2\left(1 + 2e^2\right)\right]\right\}}{\eta}$$

$$im = \frac{4ex^5\left(x^2 - 1\right)}{\eta}$$

$$\eta = 1 + 4x^2\left(2e^2 - 1\right) + x^4\left[6 + 16\left(e^2 - 1\right)\right] + 4x^6\left(2e^2 - 1\right) + x^8$$

and

$$x = \frac{f}{f_c}$$

The Datawell Directional Waverider uses the translational principal to resolve wave direction. From the accelerations measured in the x and y directions of the moving “buoy reference frame” the accelerations along the fixed, horizontal, north and west axes are calculated. All three accelerations (vertical, north and west) are digitally integrated to get filtered displacements with a high frequency cut-off at 0.6Hz. Finally, Fast Fourier Transforms of eight series of 256 data points (200s) are summed to give 16 degrees of freedom on 1600 seconds of data. Data are automatically pre-processed onboard the buoy and recorded to an internal data logger. The system was configured to log at 2Hz for a period of 34 minutes (4096 samples at 2Hz) once an hour. The wave buoy was fitted with an Argos transmitter to enable basic wave spectra and sea temperature to be monitored in Fugro GEOS’ office, via the CLS ARGOS network. The buoy’s position was monitored, such that it could be tracked if it moved from location.

Data, in the final period of deployment, was transmitted to the St. Ives Coastguard Station in real-time, via HF radio link, where a Warec receiver relayed data to a display/logging-PC running Fugro GEOS’ display software. Basic wave parameters were updated at a minimum interval of 10-minutes.

## 2. DIRECTIONAL SPECTRA FILES

The wave spectra data from the Seawatch Mini have been exported to ASCII files in a format with three files containing the complete directional wave spectrum for the deployment period. For each Spectrum is given:

| | |
|---|---|
| Record 1: | Time stamp |
| Record 2-6: | One parameter per record: Hm0, Tm02, Tp, Mdir, ThTp |
| Record 7: | Blank |
| Record 8: | The Text "WAVE SPECTRUM" |
| Record 9: | Column headers for the spectrum data |
| Record 10-56: | One record for each spectral band of width 0.01Hz: Frequency, spectral density, direction, directional spreading, a1, b1, a2, b2 (the first and second order Fourier components of the directional distribution) |
| Record 57: | Blank |

The wave spectra data from the Datawell DWR have been exported to ASCII files in a format with two files containing the complete directional wave spectrum for the deployment period. For each Spectrum is given:

| | |
|---|---|
| Record 1: | Time stamp, 7 Spectral Moments, Errors |
| Record 2: | Column headers for the spectrum data |
| Record 3-67: | One record for each spectral band of width 0.01Hz: Frequency, spectral density, direction, directional spreading, a1, b1, a2, b2 (the first and second order Fourier components of the directional distribution) |

## 3. PRESENTATION OF RESULTS

Presented in this report are time series of wave parameters including the following parameters: Hm0, Hmax, Hm0a, Tm02, Tp, mdir, mdira, ThTp, and Thhf for the period 30 January 2005 to 10 April 2006.

Also presented are time series of surface current speed, direction and temperature for the period 30 January 2005 to 8 November 2005

## 4. REFERENCES

Tucker, M.J., 1991: "Waves in Ocean Engineering. Measurement, Analysis, Interpretation." Ellis Horwood Publishing Ltd. ISBN 0-13-932955-2.

# FIGURES

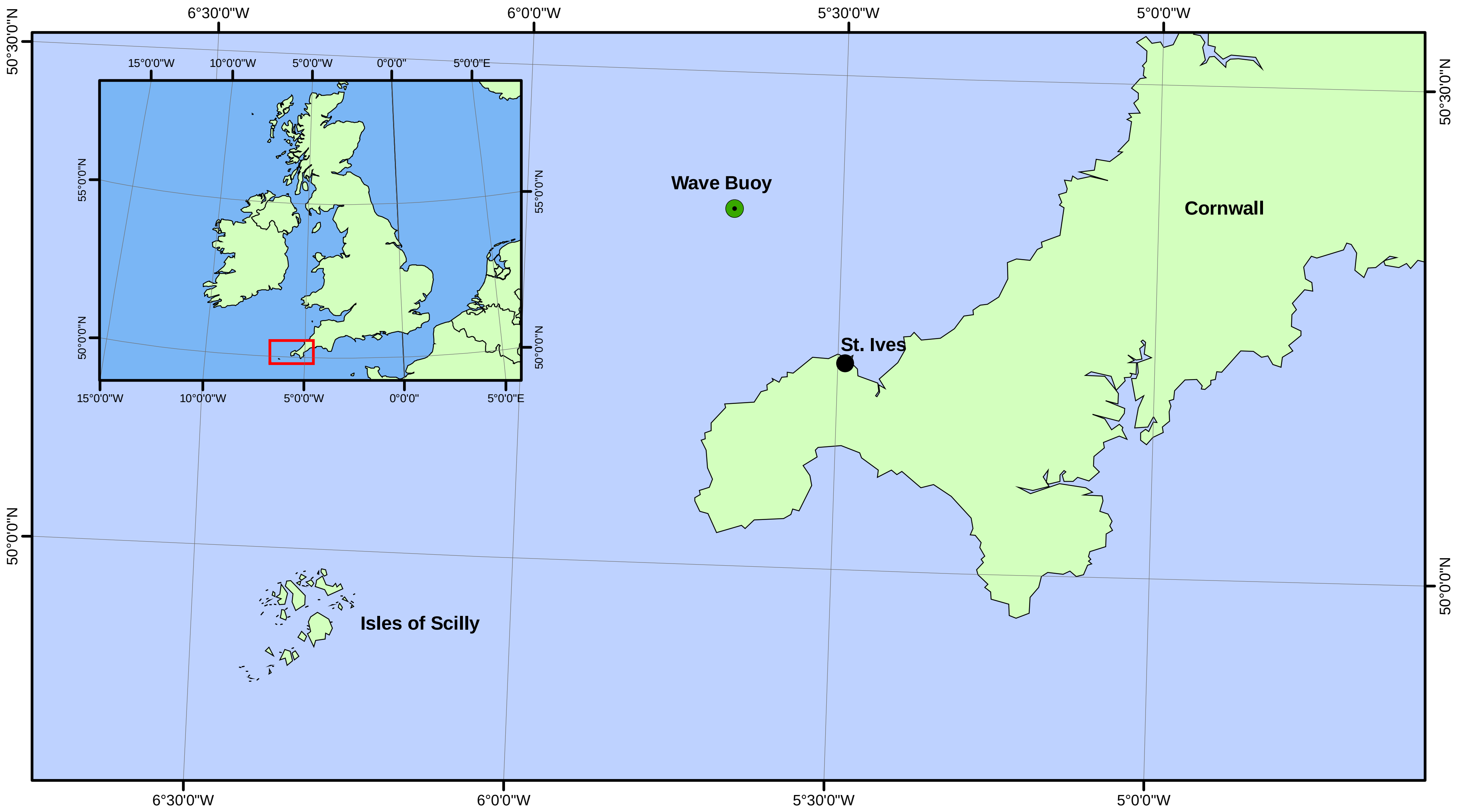
# LIST OF FIGURES

**Location Map**

**System Configuration**

**Time Series of Observed Wave Parameters**

**Time Series of Observed Surface Current Parameters**



# Wave and Current Measurements, St. Ives, Cornwall
# Location Map

Legend ⊙ Wave Buoy

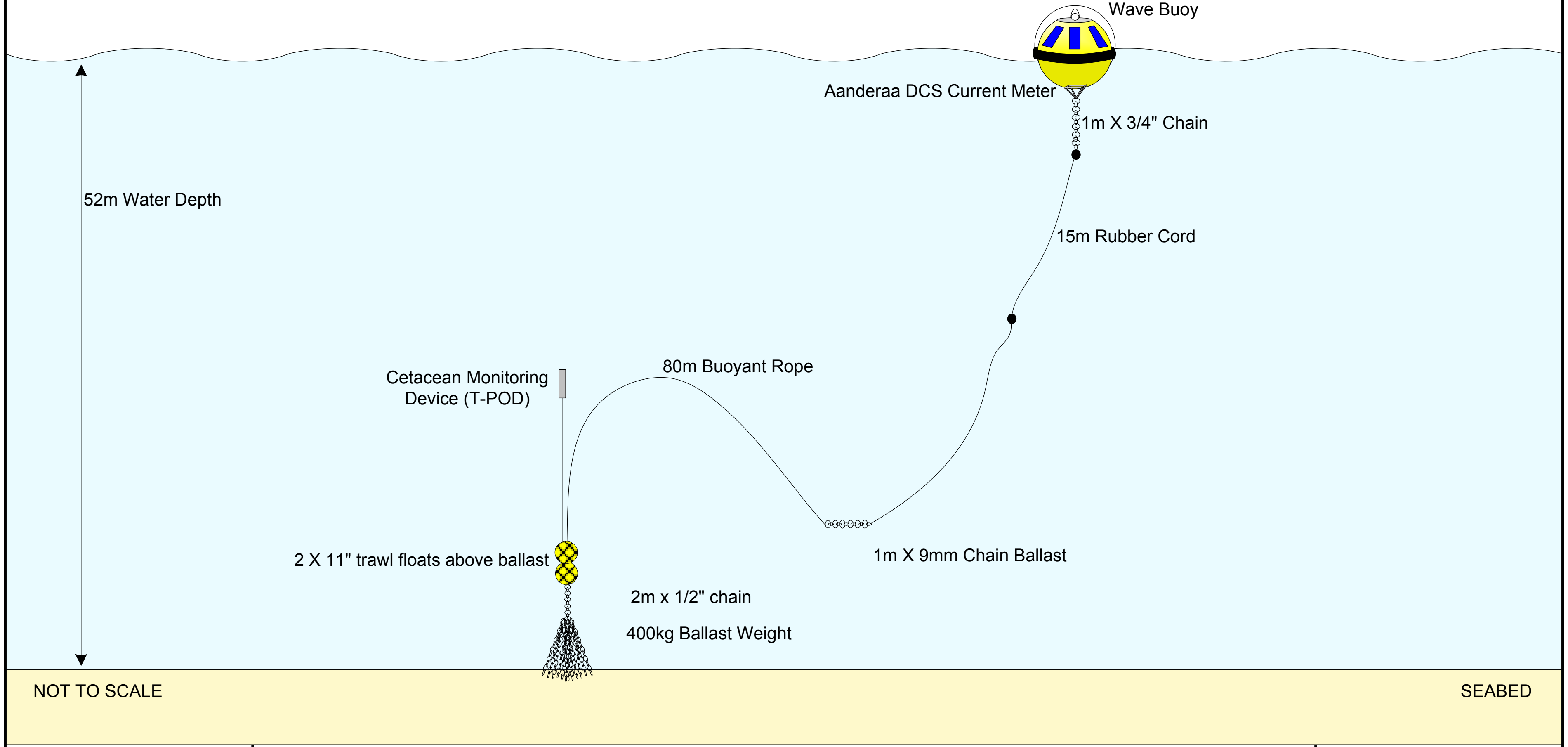
Ref No. C10644/4056

Figure No. 1

Updated: 01-JUN-06

Halcrow Group Limited

C10644/4056/R1/4056.MXD



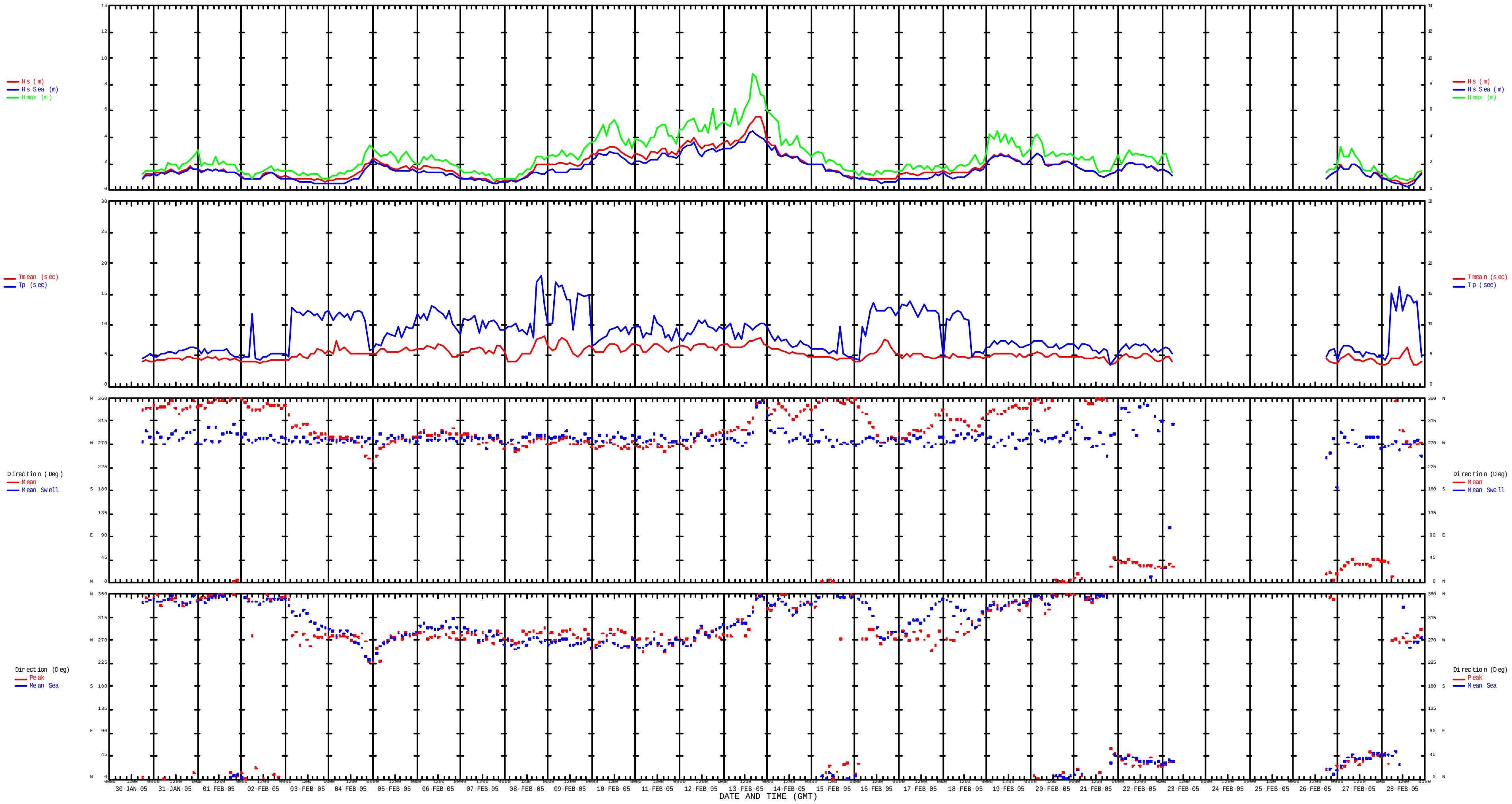
FUGRO

## Wave and Current Measurements - St . Ives, Cornwall

## Standard Wave Buoy Mooring

Ref: C10644/4056

Fig: 2



## NOTES:

| | |
|---|---|
| INSTRUMENT TYPE: | OCEANOR SEAWATCH MINI |
| LOCATION: | ST.IVES, CORNWALL |
| POSITION: | 50 21.78'N, 005 40.28'W |
| WATER DEPTH: | 52.0m |
| INSTRUMENT DEPTH: | 0.0m |
| SAMPLING INTERVAL: | 120 MINS |

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

## OBSERVED WAVE PARAMETERS

SEAWATCH MINI

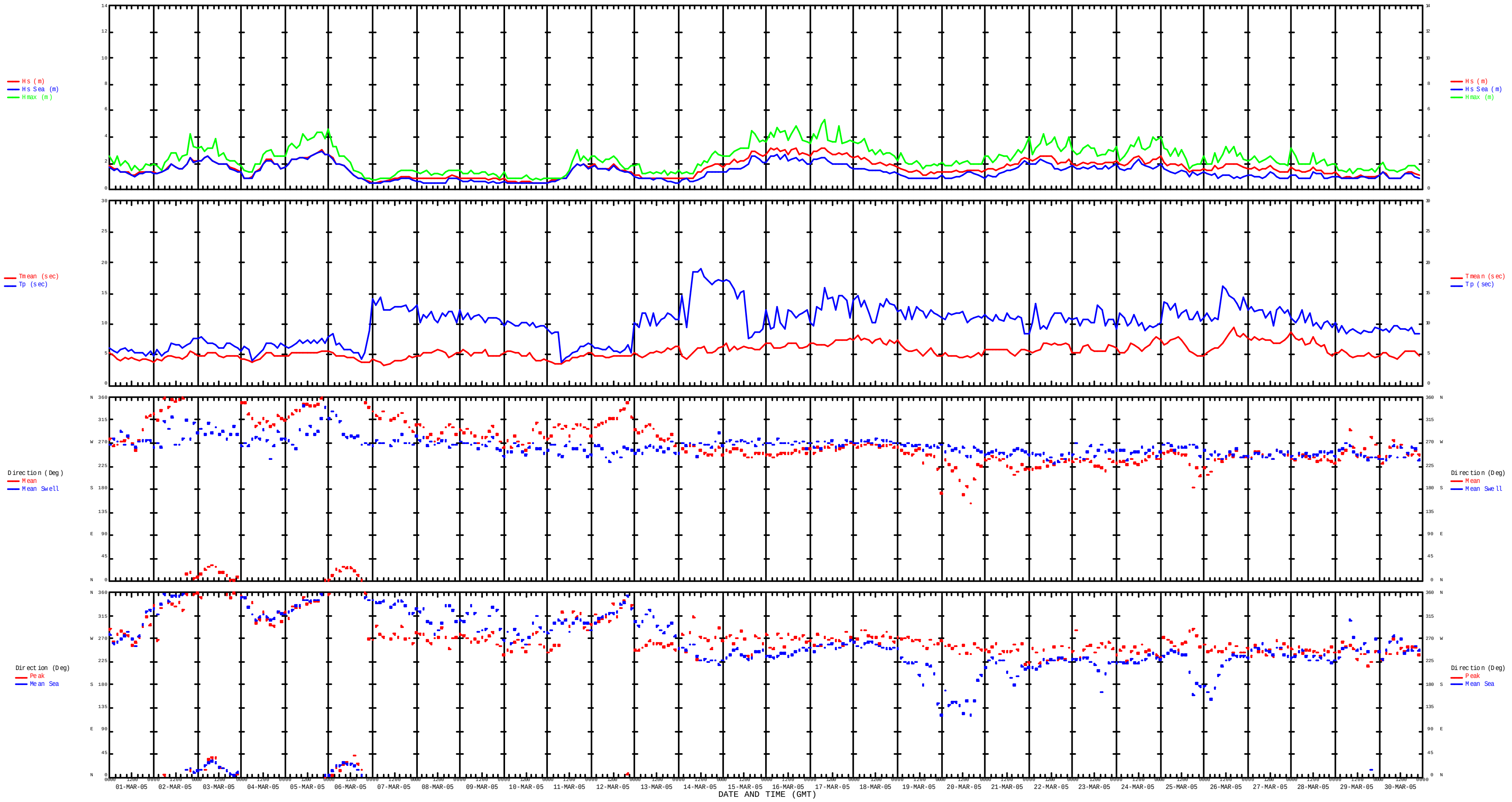
30-JAN-05 TO 28-FEB-05

REF. NO: 10644/4056

FIGURE NO: 3.1

PLOT DATE: 2-JUN-06

FILE: F3P01



NOTES:

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|---|---|
| INSTRUMENT TYPE: | OCEANOR SEAWATCH MINI |
| LOCATION: | ST.IVES, CORNWALL |
| POSITION: | 50 21.78'N, 005 40.28'W |
| WATER DEPTH: | 52.0m |
| INSTRUMENT DEPTH: | 0.0m |
| SAMPLING INTERVAL: | 120 MINS |

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

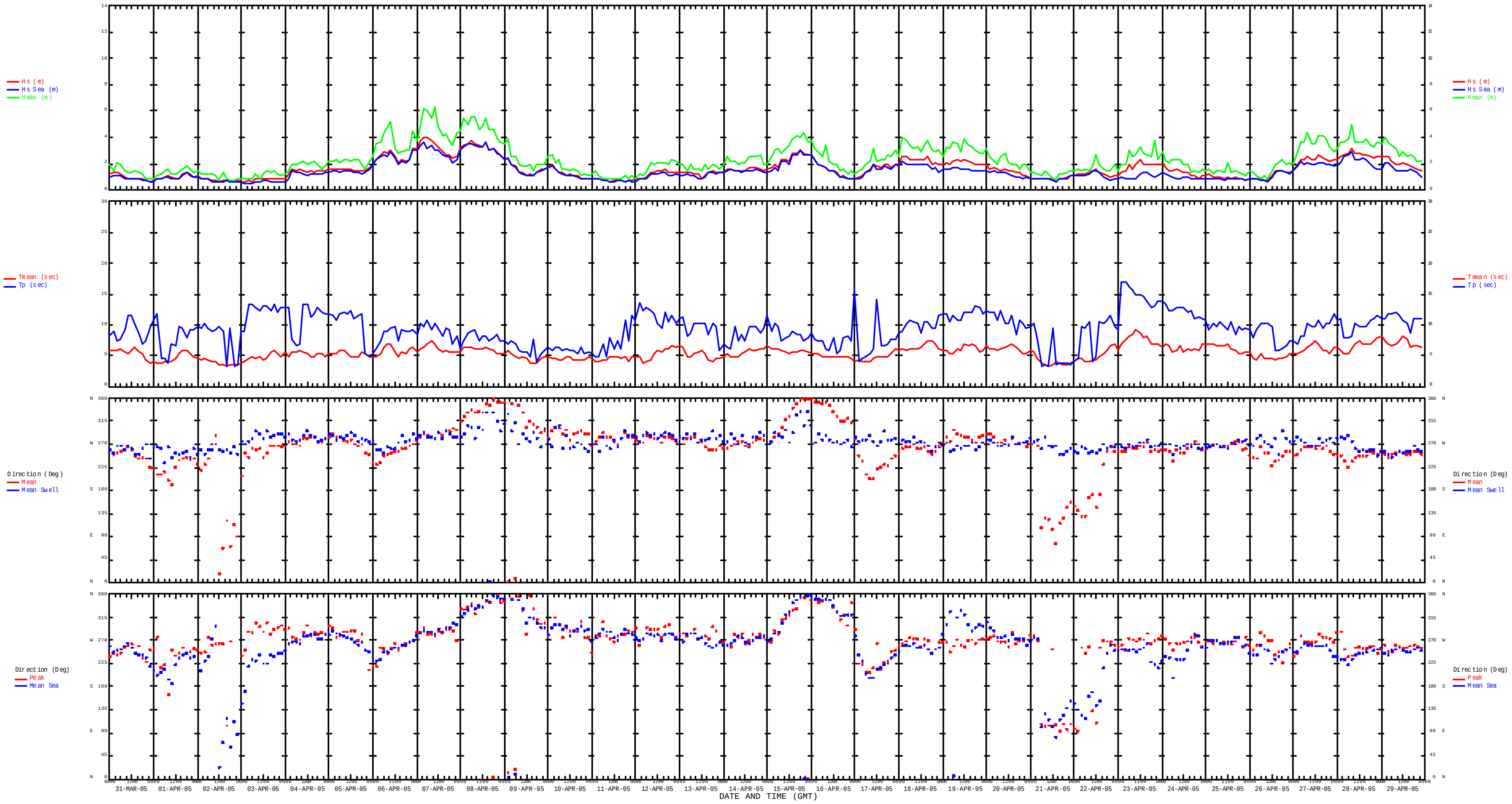
SEAWATCH MINI

01-MAR-05 TO 30-MAR-05

| | |
|---|---|
| REF. NO: | 10644/4056 |
| FIGURE NO: | 3.2 |

PLOT DATE: 2-JUN-06

FILE: F3P02



NOTES:

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LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

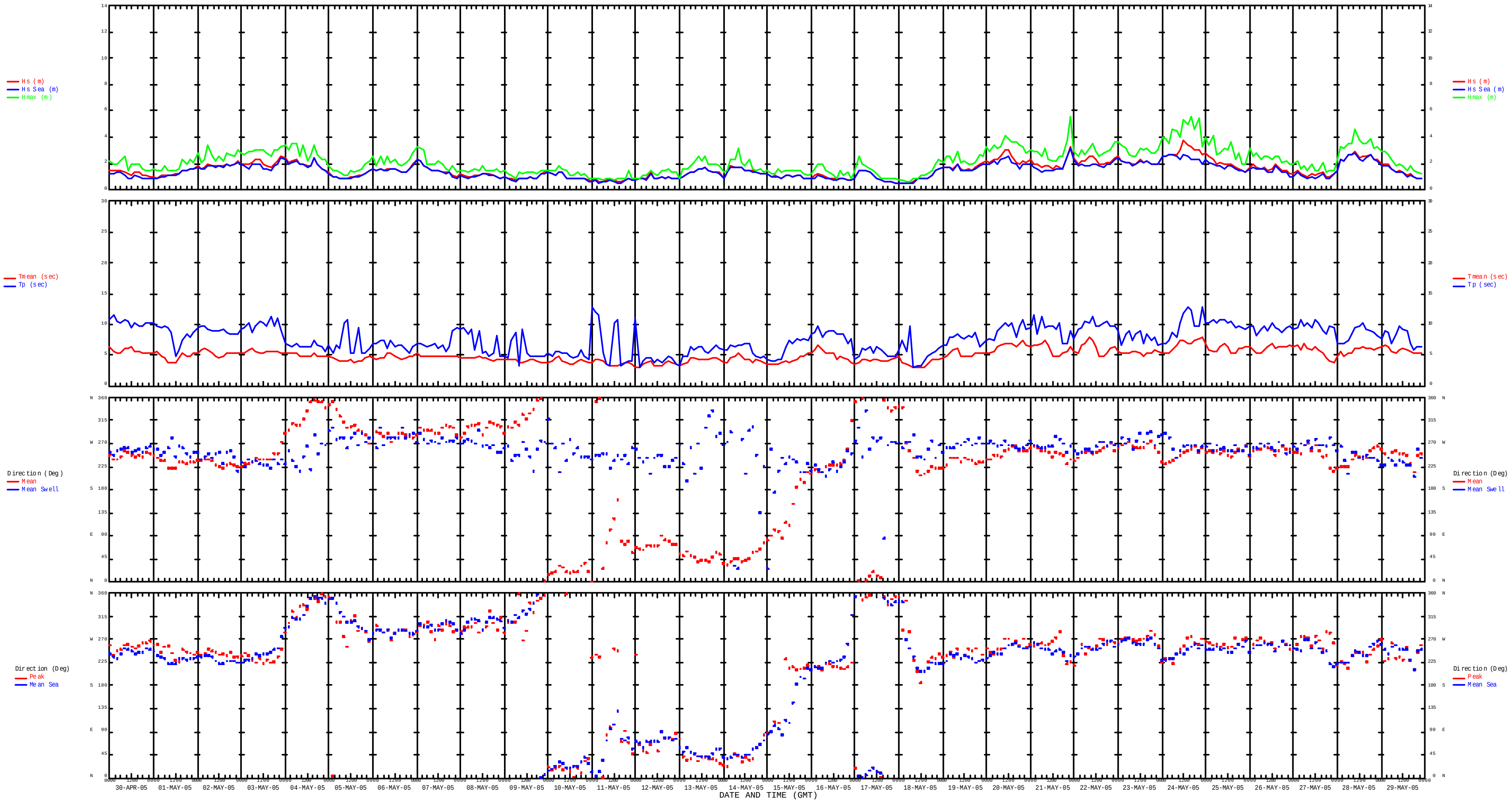
SEAWATCH MINI

31-MAR-05 TO 29-APR-05

| | |
|---|---|
| REF. NO: | 10644/4056 |
| FIGURE NO: | 3.3 |

PLOT DATE: 2-JUN-06

FILE: F3P03



NOTES:

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LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

SEAWATCH MINI

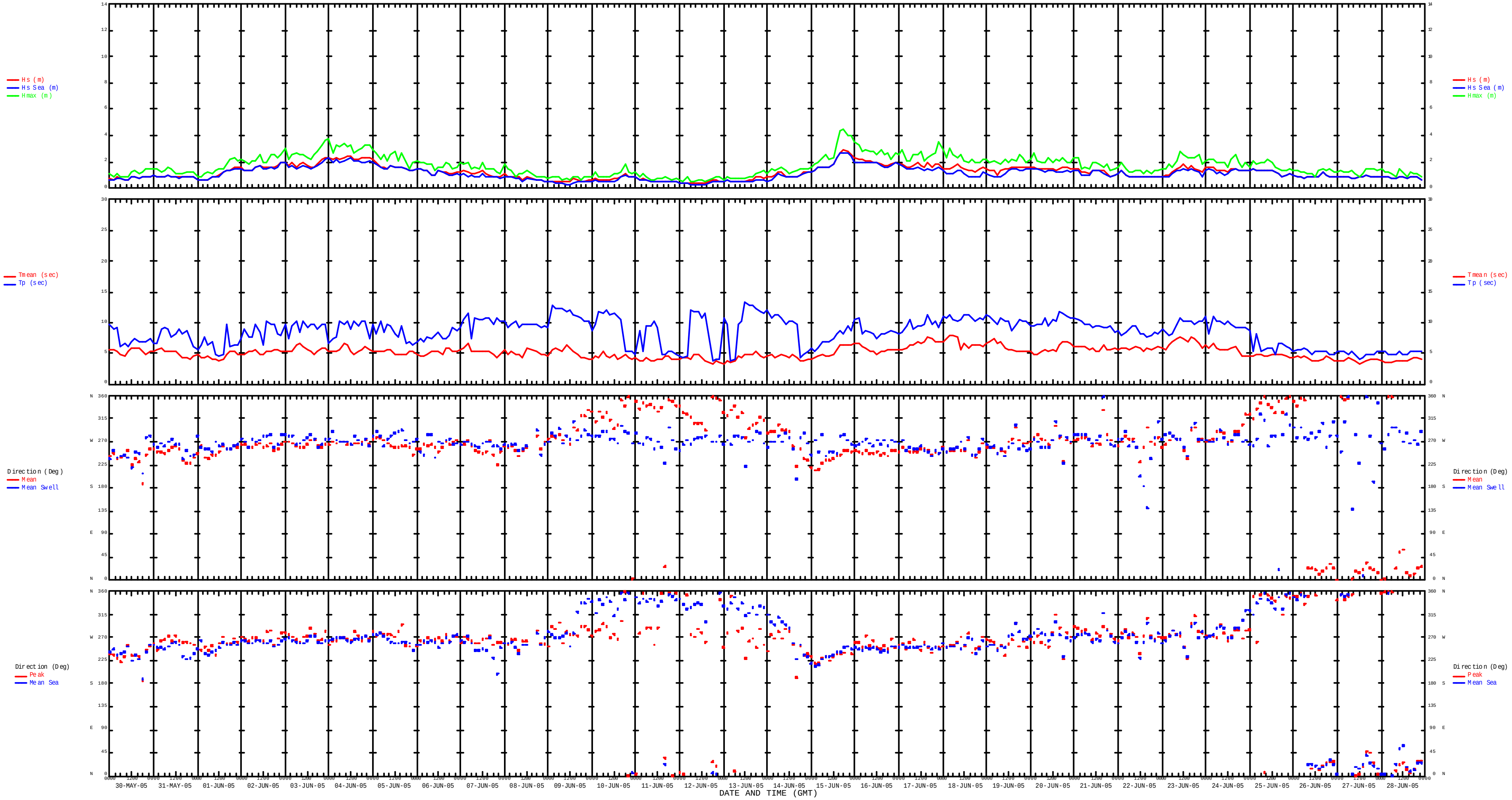
30-APR-05 TO 29-MAY-05

REF. NO: 10644/4056

FIGURE NO: 3.4

PLOT DATE: 2-JUN-06

FILE: F3P04



## NOTES:

| | |
|---|---|
| INSTRUMENT TYPE: | OCEANOR SEAWATCH MINI |
| LOCATION: | ST.IVES, CORNWALL |
| POSITION: | 50 21.78'N, 005 40.28'W |
| WATER DEPTH: | 52.0m |
| INSTRUMENT DEPTH: | 0.0m |
| SAMPLING INTERVAL: | 120 MINS |

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

# OBSERVED WAVE PARAMETERS

SEAWATCH MINI

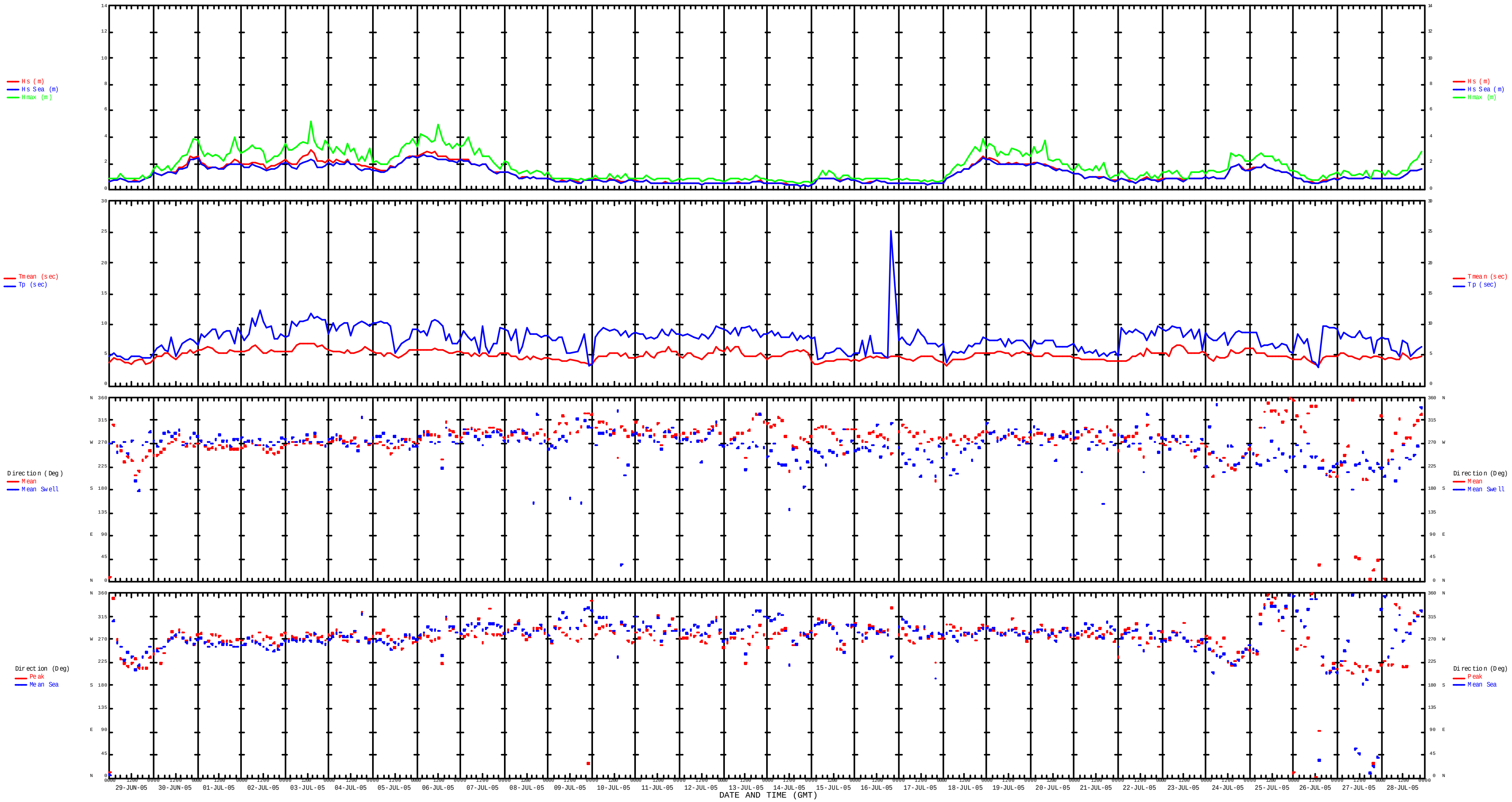
30-MAY-05 TO 28-JUN-05

REF. NO: 10644/4056

FIGURE NO: 3.5

PLOT DATE: 2-JUN-06

FILE: F3P05



NOTES:

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LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

SEAWATCH MINI

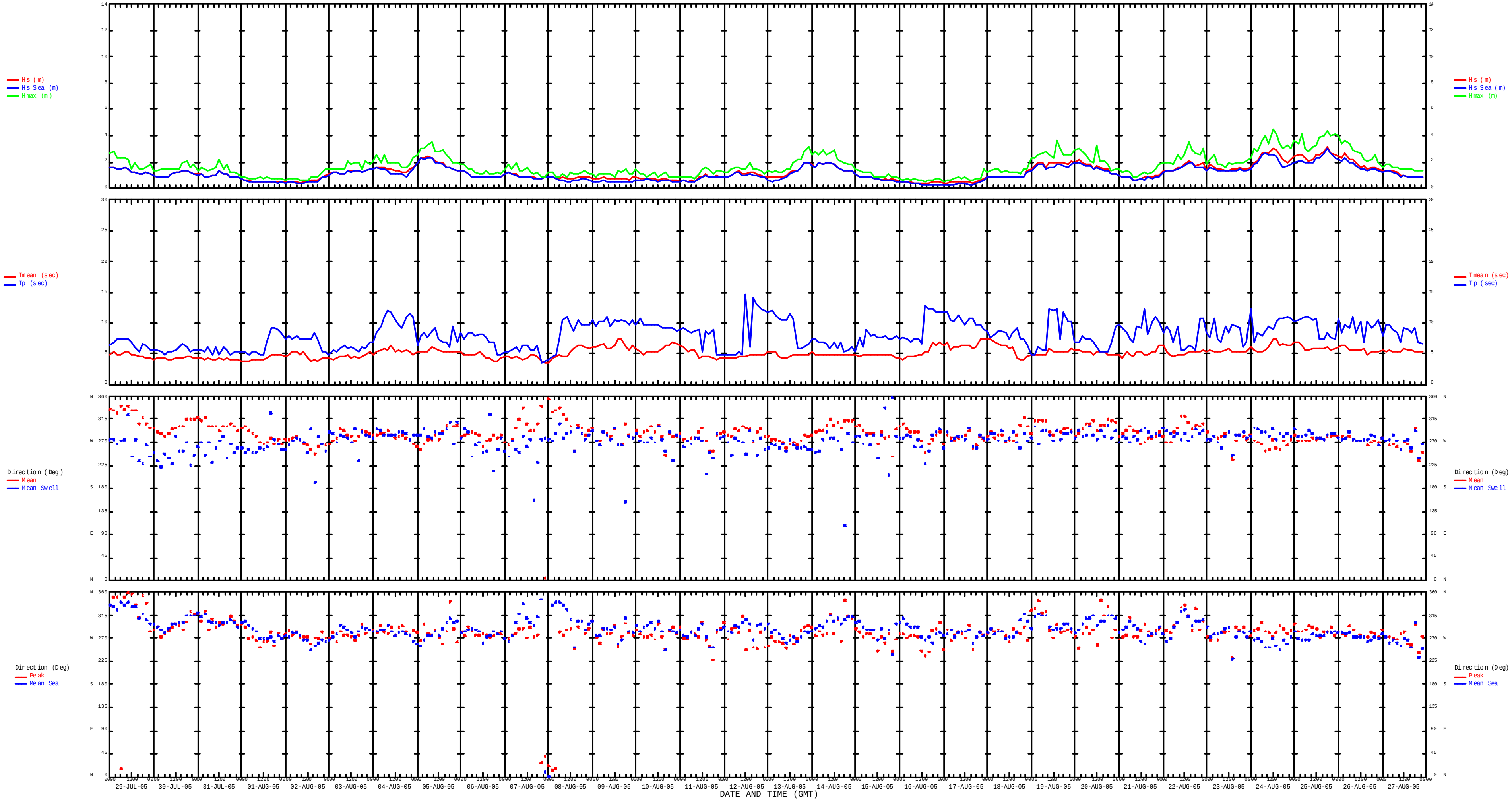
29-JUN-05 TO 28-JUL-05

REF. NO: 10644/4056

FIGURE NO: 3.6

PLOT DATE: 2-JUN-06

FILE: F3P06



NOTES:

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POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

SEAWATCH MINI

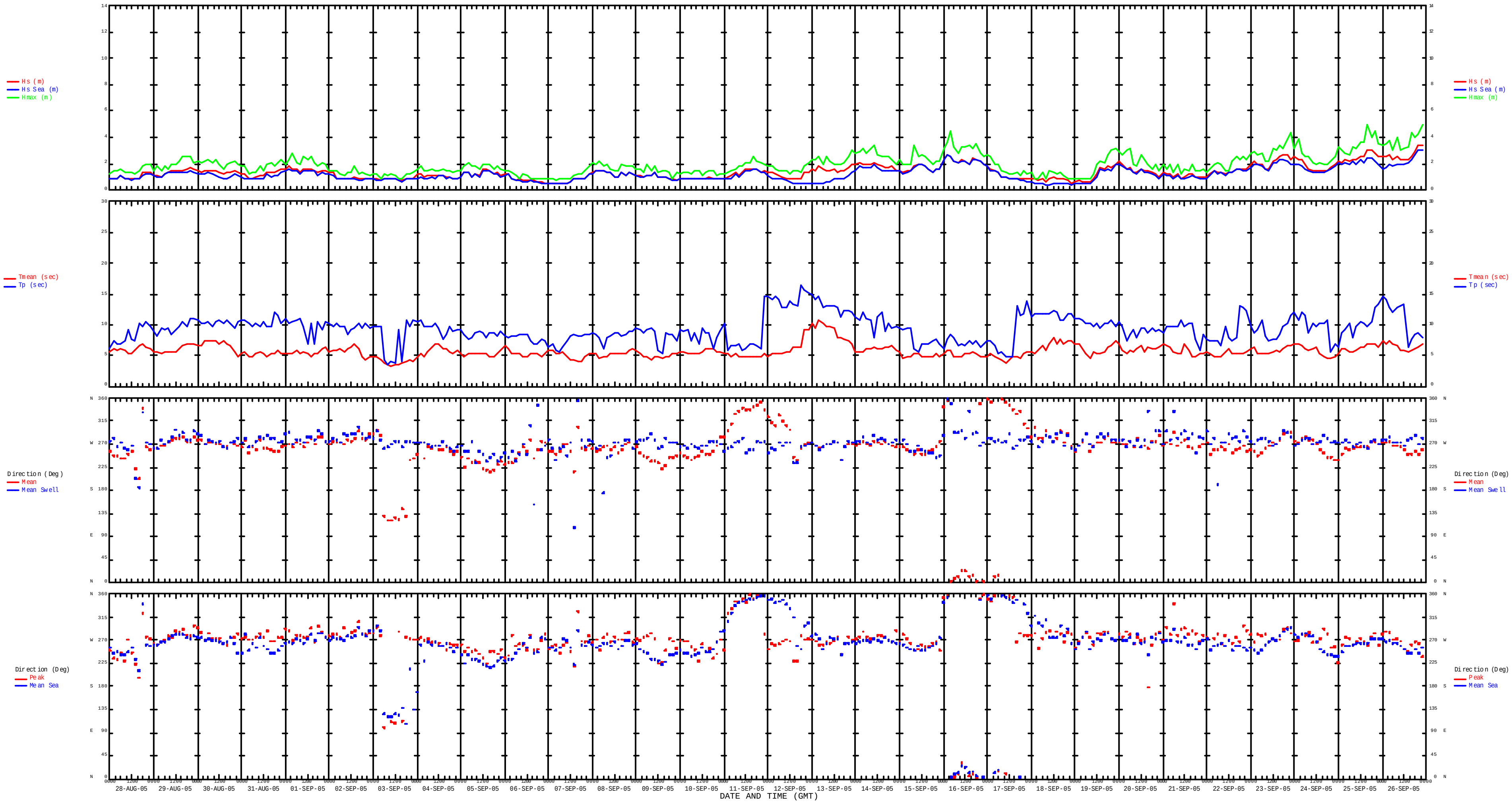
29-JUL-05 TO 27-AUG-05

REF. NO: 10644/4056

FIGURE NO: 3.7

PLOT DATE: 2-JUN-06

FILE: F3P07



NOTES:

| | |
|---|---|
| INSTRUMENT TYPE: | OCEANOR SEAWATCH MINI |
| LOCATION: | ST.IVES, CORNWALL |
| POSITION: | 50 21.78'N, 005 40.28'W |
| WATER DEPTH: | 52.0m |
| INSTRUMENT DEPTH: | 0.0m |
| SAMPLING INTERVAL: | 120 MINS |

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

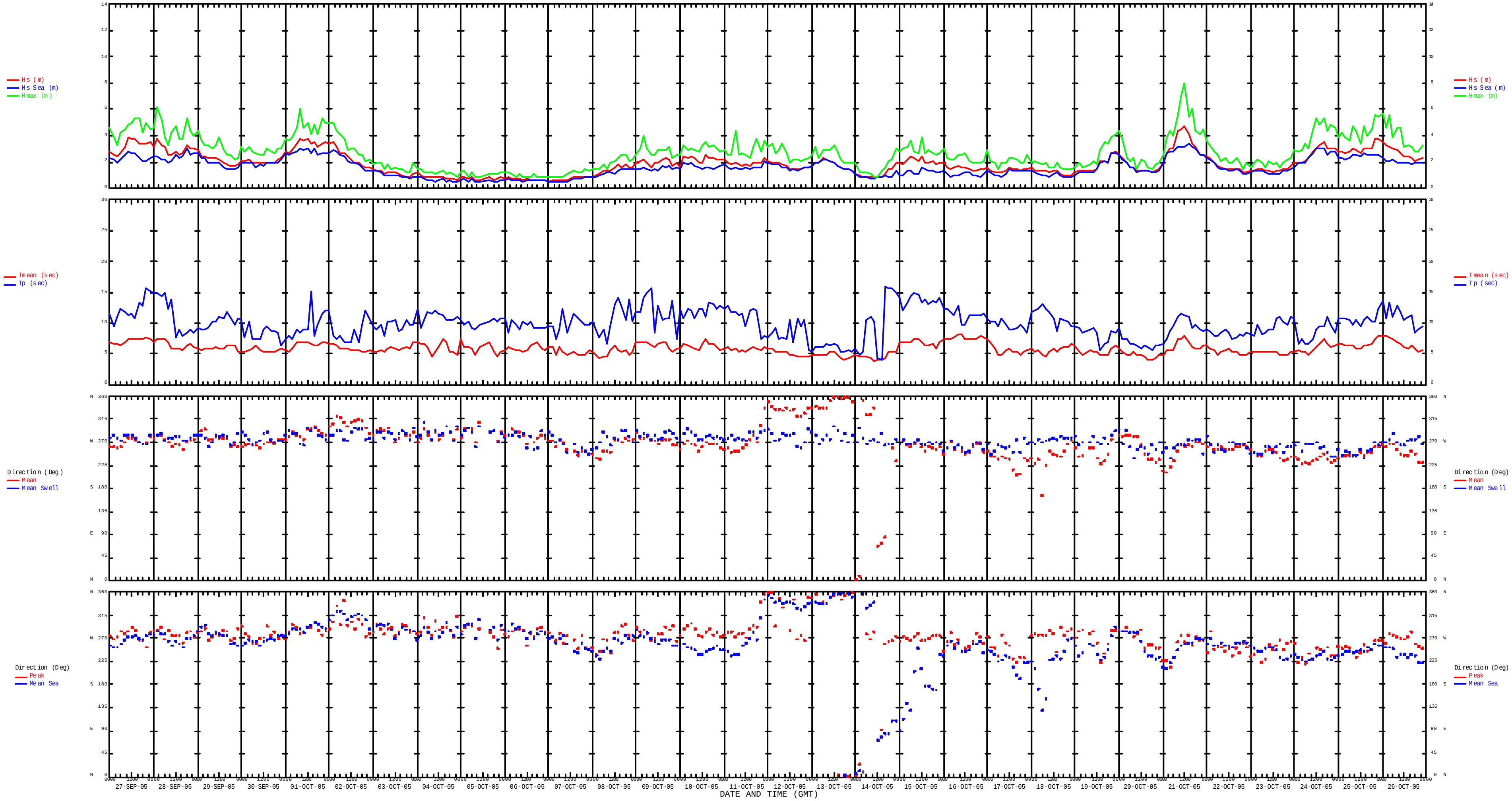
SEAWATCH MINI

28-AUG-05 TO 26-SEP-05

| | |
|---|---|
| REF. NO: | 10644/4056 |
| FIGURE NO: | 3.8 |

PLOT DATE: 2-JUN-06

FILE: F3P08



NOTES:

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LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

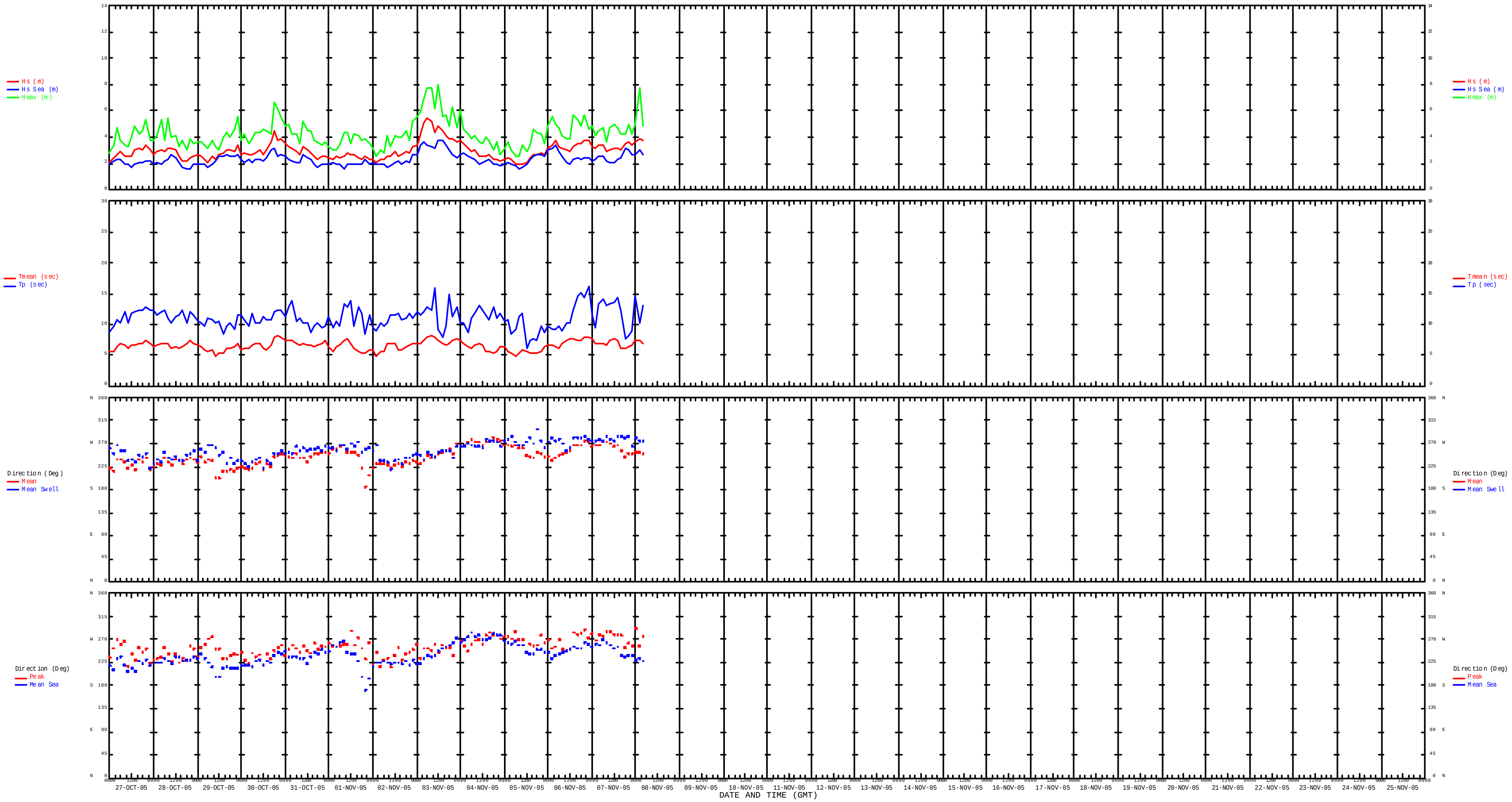
SEAWATCH MINI

27-SEP-05 TO 26-OCT-05

| | |
|---|---|
| REF. NO: | 10644/4056 |
| FIGURE NO: | 3.9 |

PLOT DATE: 2-JUN-06

FILE: F3P09



NOTES:

INSTRUMENT TYPE: OCEANOR SEAWATCH MINI
LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

SEAWATCH MINI

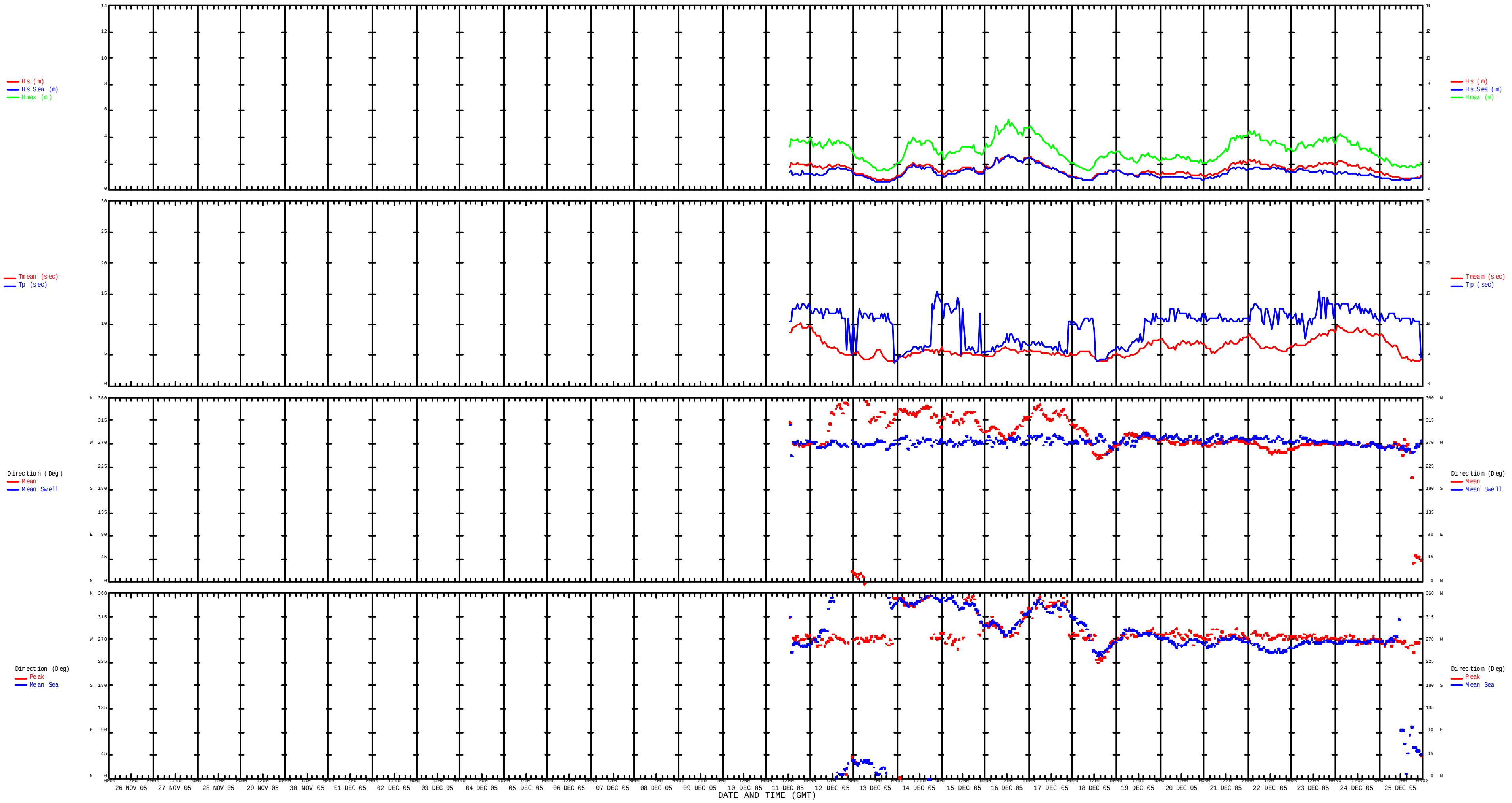
27-OCT-05 TO 25-NOV-05

REF. NO: 10644/4056

FIGURE NO: 3.10

PLOT DATE: 2-JUN-06

FILE: F3P10



NOTES:

INSTRUMENT TYPE: DATAWELL WAVERIDER
LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

WAVERIDER

26-NOV-05 TO 25-DEC-05

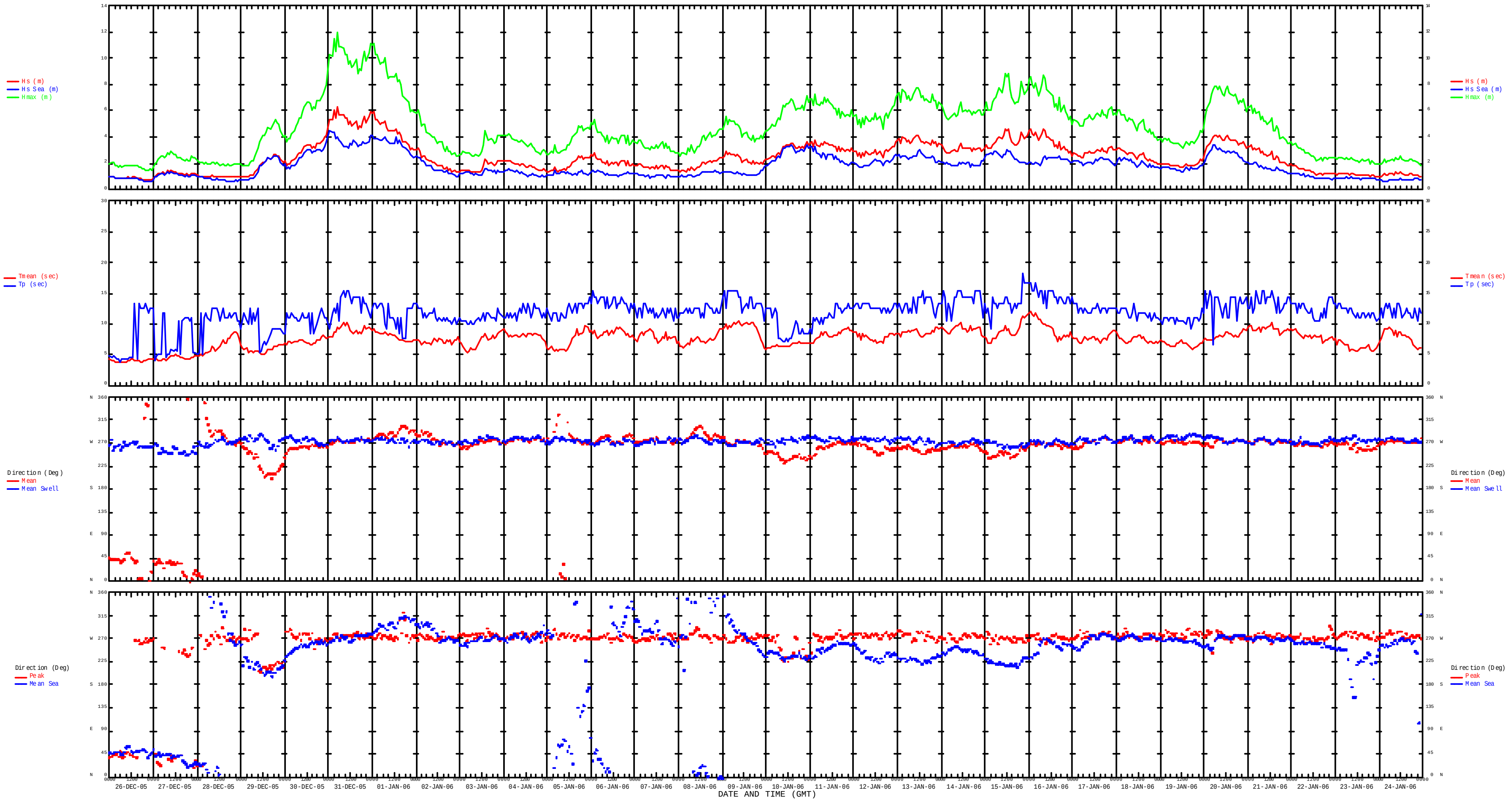
FUGRO GEOS

REF. NO: 10644/4056

FIGURE NO: 3.11

PLOT DATE: 2-JUN-06

FILE: F3P11



NOTES:

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LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

WAVERIDER

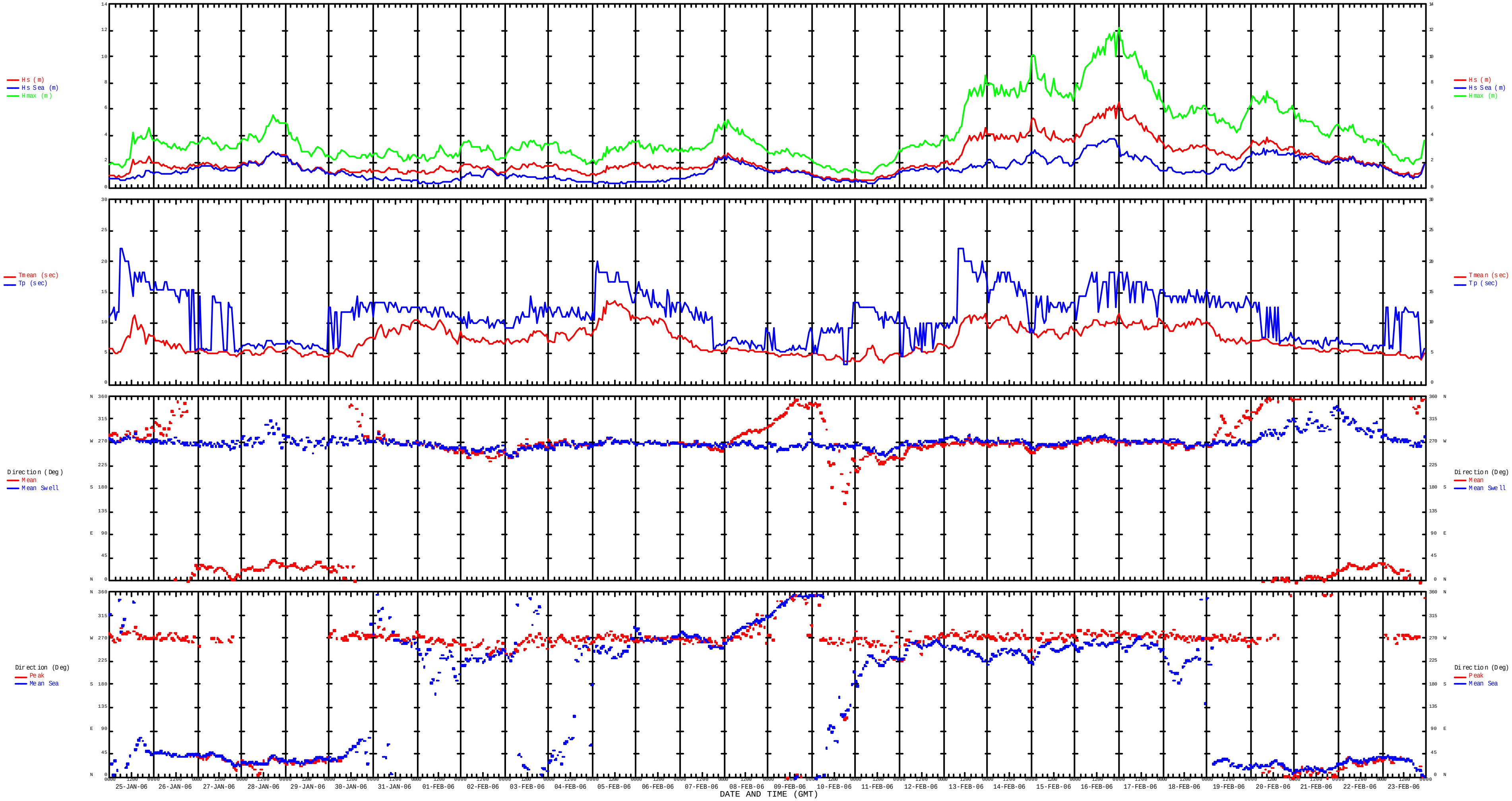
26-DEC-05 TO 24-JAN-06

REF. NO: 10644/4056

FIGURE NO: 3.12

PLOT DATE: 2-JUN-06

FILE: F3P12



NOTES:

INSTRUMENT TYPE: DATAWELL WAVERIDER
LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

WAVERIDER

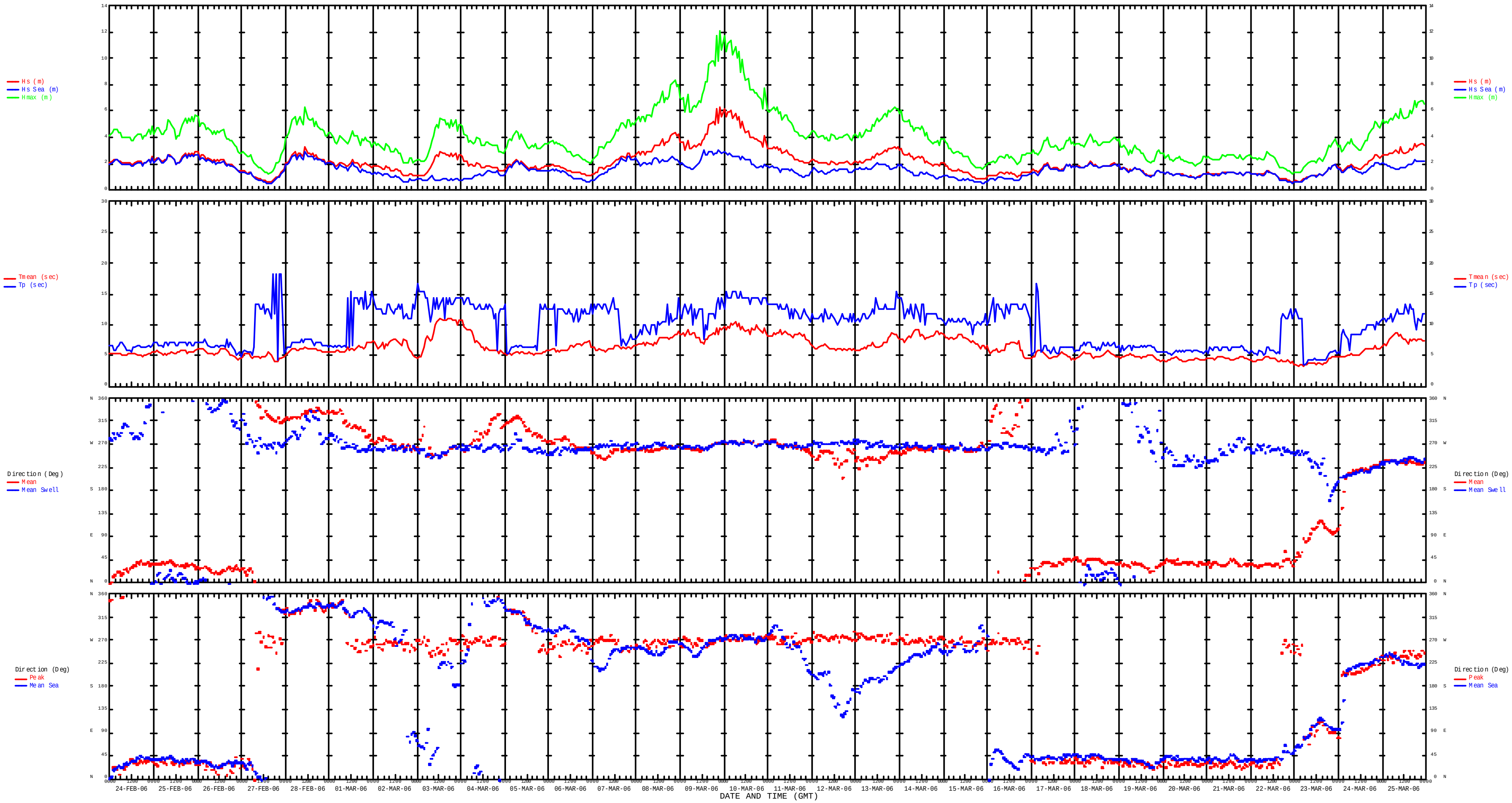
25-JAN-06 TO 23-FEB-06

REF. NO: 10644/4056

FIGURE NO: 3.13

PLOT DATE: 2-JUN-06

FILE: F3P13



NOTES:

INSTRUMENT TYPE: DATAWELL WAVERIDER
LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 0.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

WAVERIDER

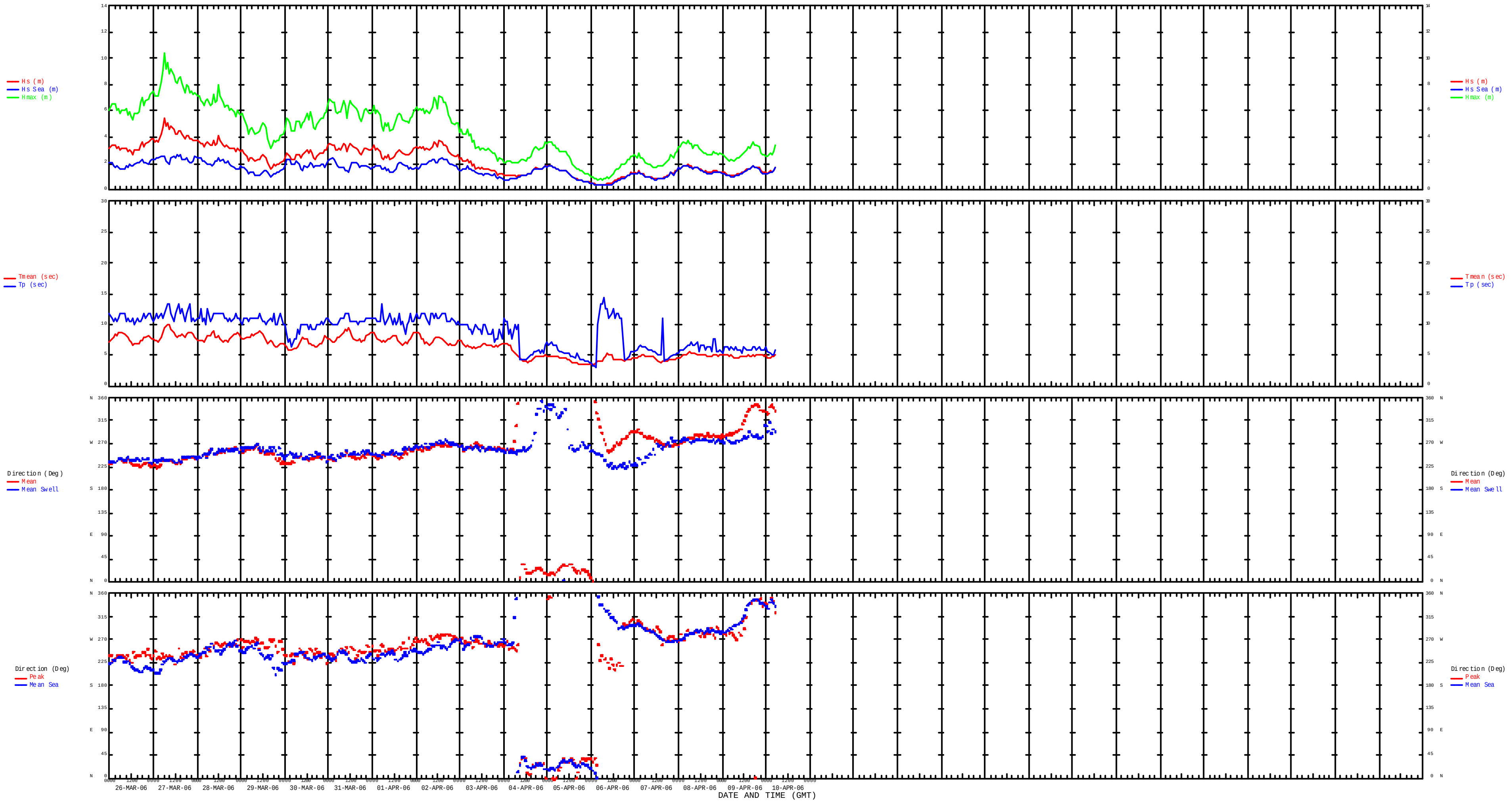
24-FEB-06 TO 25-MAR-06

REF. NO: 10644/4056

FIGURE NO: 3.14

PLOT DATE: 2-JUN-06

FILE: F3P14



NOTES:

INSTRUMENT TYPE:    DATAWELL WAVERIDER
LOCATION:    ST.IVES, CORNWALL
POSITION:    50 21.78'N, 005 40.28'W
WATER DEPTH:    52.0m
INSTRUMENT DEPTH:    0.0m
SAMPLING INTERVAL:    120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED WAVE PARAMETERS

WAVERIDER

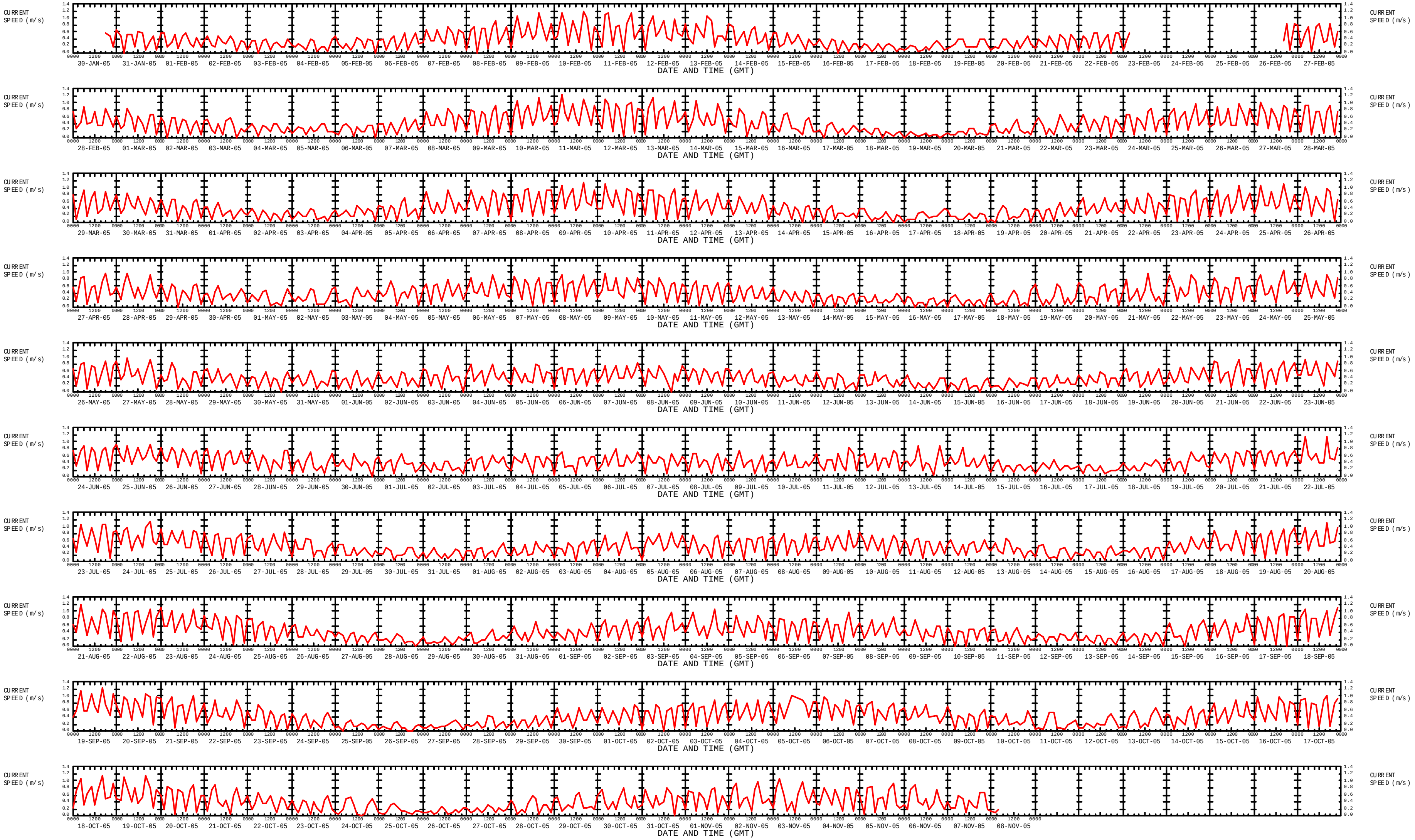
26-MAR-06 TO 10-APR-06

REF. NO: 10644/4056

FIGURE NO: 3.15

PLOT DATE: 2-JUN-06

FILE: F3P15



NOTES:

INSTRUMENT TYPE: AANDERAA DCS
LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 2.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

OBSERVED CURRENT SPEED

OCEANOR SEAWATCH MINI

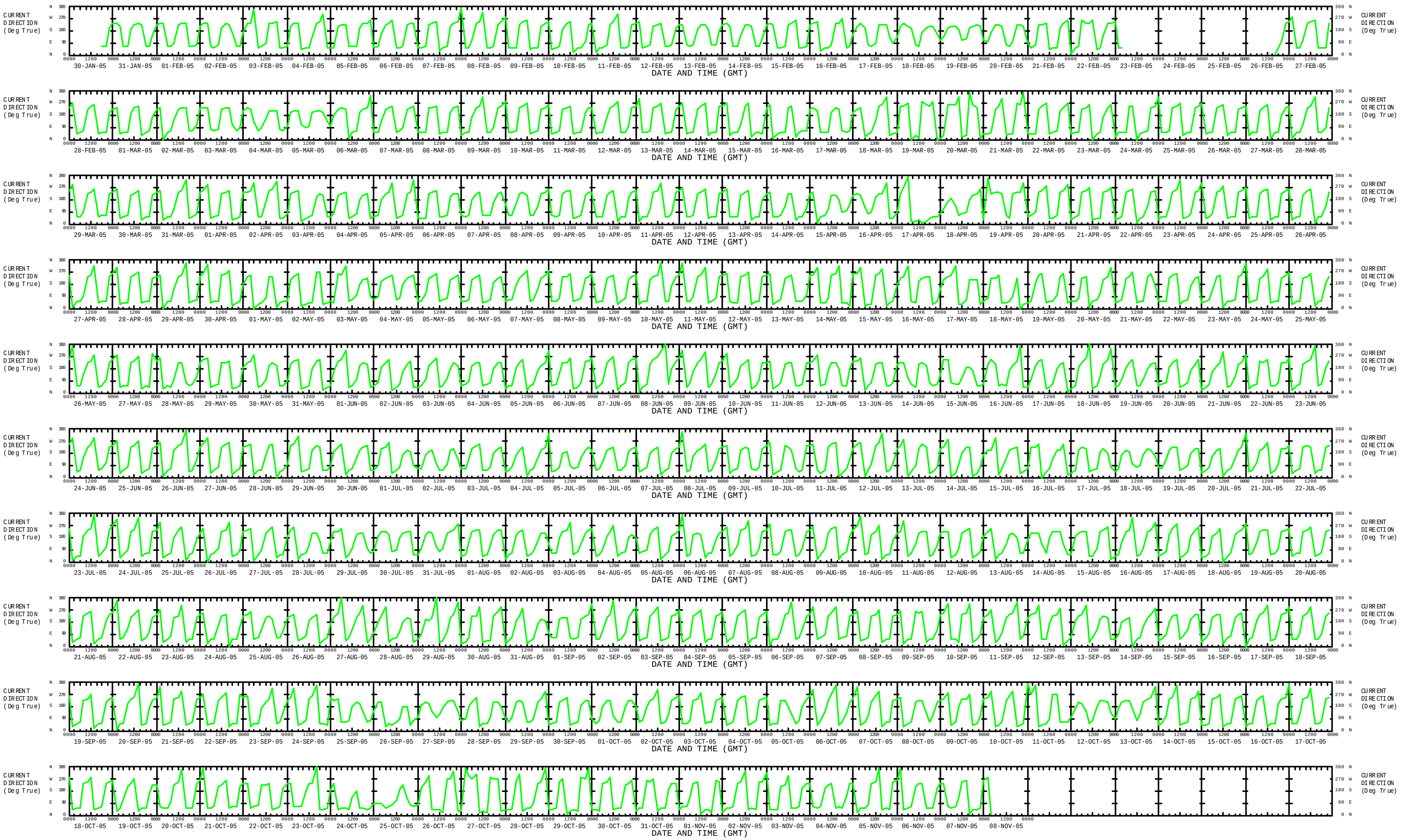
30-JAN-05 TO 08-NOV-05

REF. NO: 10644/4056

FIGURE NO: 4.1

PLOT DATE: 5-JUN-06

FILE: F4P1



NOTES:

INSTRUMENT TYPE: AANDERAA DCS
LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 2.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

## OBSERVED CURRENT DIRECTION

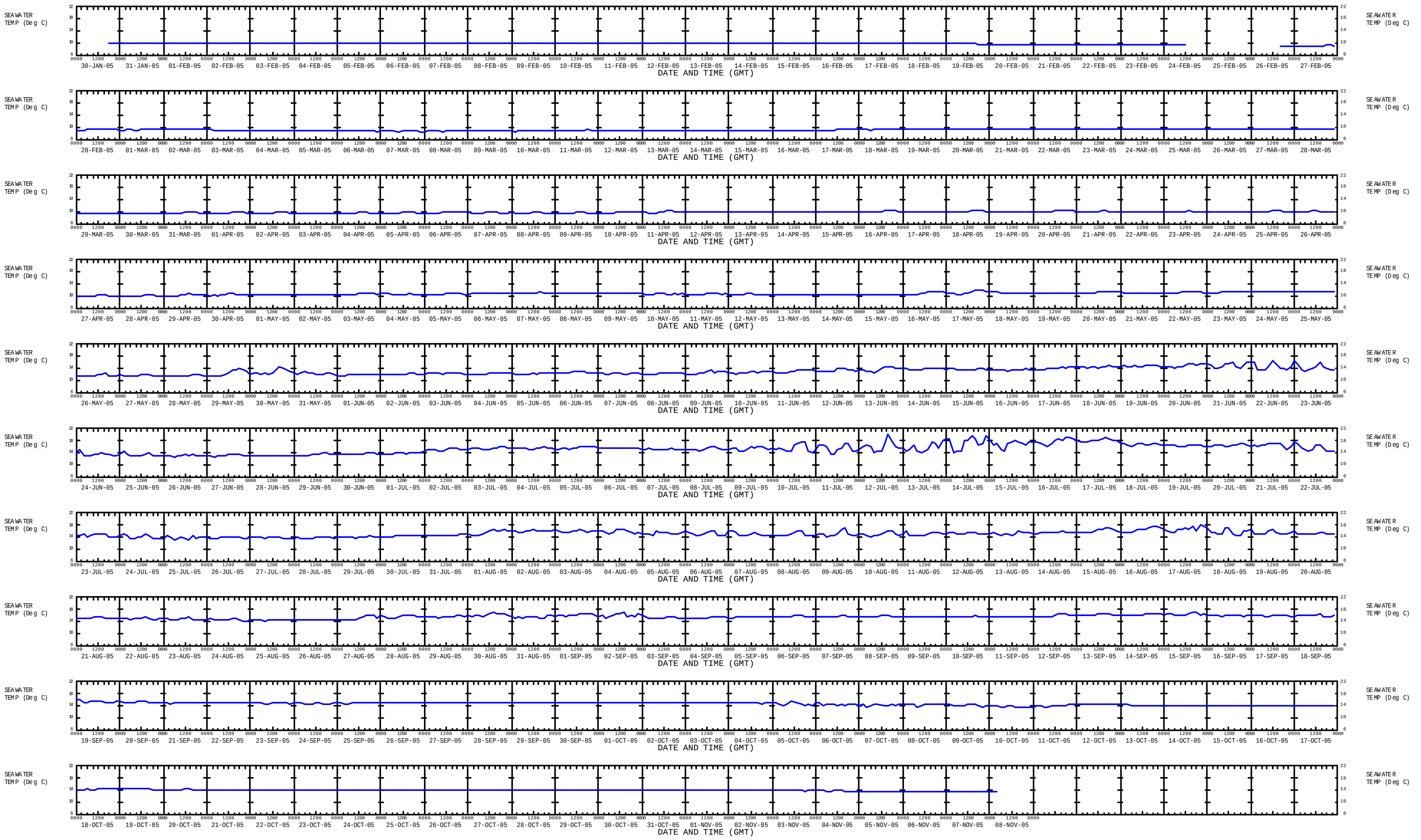
## OCEANOR SEAWATCH MINI

## 30-JAN-05 TO 08-NOV-05

| | |
|---|---|
| REF. NO: | 10644/4056 |
| FIGURE NO: | 4.2 |

PLOT DATE: 5-JUN-06

FILE: F4P2



NOTES:

INSTRUMENT TYPE: AANDERAA DCS
LOCATION: ST.IVES, CORNWALL
POSITION: 50 21.78'N, 005 40.28'W
WATER DEPTH: 52.0m
INSTRUMENT DEPTH: 2.0m
SAMPLING INTERVAL: 120 MINS

WAVE AND CURRENT MEASUREMENTS, ST. IVES CORNWALL

SEAWATER TEMPERATURE

OCEANOR SEAWATCH MINI

30-JAN-05 TO 08-NOV-05

FUGRO GEOS

REF. NO: 10644/4056

FIGURE NO: 4.3

PLOT DATE: 5-JUN-06

FILE: F4P3

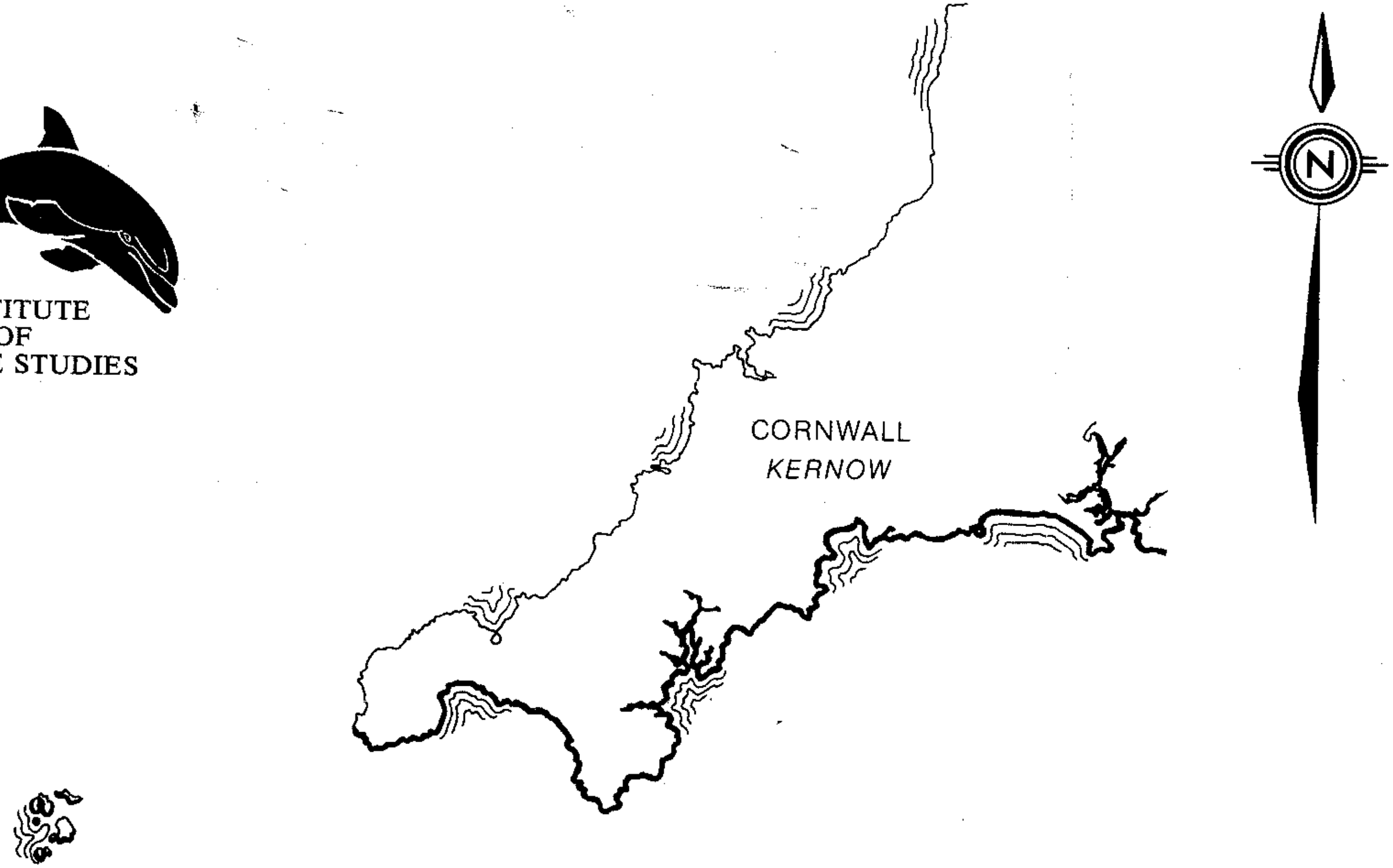
# Appendix B – IOMS Tidal Stream Atlas

POLYTECHNIC SOUTH WEST

# TIDAL STREAM ATLAS OF THE CORNISH COAST
# FROSOW A-DRO DHE'N ARVOR KERNEWEK

DR. K.J. GEORGE

INSTITUTE
OF
MARINE STUDIES



## EXPLANATION

### What do the arrows mean?

The atlas has been produced using a traditional format for a semi-diurnal regime, viz. thirteen charts, one for each hour of tidal time (i.e. time measured from high water (H.W.) at the standard port). Arrows depict the **set** of the stream (i.e. the direction towards which it is running), and the **rate** of the stream (i.e. its magnitude). The area of each arrow is proportional to the rate.

The figures above each arrow are:
(a) the mean spring rate in tenths of a knot, before the colon;
(b) the mean neap rate in tenths of a knot, *in italics* after the colon.
The figures below each arrow are:
(c) the set at mean springs in degrees true, before the colon;
(d) the set at mean neaps in degrees true, *in italics* after the colon.

### Where do the data come from?

The data for the atlas have been obtained by simulating the tidal dynamics using a numerical model with a mesh size of 0.8 nautical mile (about 1.5 km). This involves specifying the rise and fall of the tide at the boundary of the model, and calculating the tide at all points within the model.

Although two-dimensional numerical models of tidal propagation were first developed some twenty years ago, it is only recently that their output has been used to produce tidal stream atlases. Notable among these are:

DeWOLFE, D.L. (1981) *Atlas of tidal currents - Bay of Fundy and Gulf of Maine.* Canadian Hydrographic Service, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.

CREAN, P.B. and HUGGETT, W.S. (1987) *Current Atlas - Juan de Fuca Strait to Strait of Georgia.* Canadian Hydrographic Service, Institute of Ocean Sciences, Sidney, British Columbia, Canada.

COMOLET-TIRMAN (1988) *Courants de marée dans le Pas de Calais.* Service Hydrographique et Océanographique de la Marine, Paris.

Like the last two books, this publication is bilingual, but in Cornish and English rather than English and French.

## DISPLEGYANS

### Pana styr eus dhe'n sethow?

An lyver ma re beu gwrys herwydh gis hengovek lowr rag gwarthevyans hanterdydhyek, gans trydhek mappa, onyn rag pub eur a dermyn lanwek (hemm yw, termyn musurys a-dhiworth an gorlanow (G.L.) y'n pennporth). Sethow a dhiskwa tu ha toth an fros. Efander pub seth a dyv herwydh an toth.

An rivow a-ugh pub seth yw:
(a) toth an reverthi kres yn degvesow kolm, a-rag an dhewboynt;
(b) toth an marvor kres yn degvesow kolm, *yn lytherennow italek* warlergh an dhewboynt;
An rivow yn-dann pub seth yw:
(c) tu an reverthi kres yn gradhow gwir, a-rag an dhewboynt;
(d) tu an marvor kres yn gradhow gwir, *yn lytherennow italek* warlergh an dhewboynt.

### A-ble y teu an derivadow?

An derivadow rag an lyver re beu kevys dre wul hevelepter gwayans an mortid gans gweres patron niverek, neb a'n jeves maglenn 0.8 mildir morek (a-dro dhe 1.5 km) hy braster. Res yw derivas lenwel ha bassya an mortid war oryon an patron, ha kalkya an mortid dhe bup poynt a-berth y'n patron.

Kynth yw lemmyn neb ugens blydhen a-ban veu displegys yn-kynsa patronyow niverek dewvynsek a argerdh an lanow, nyns yw saw soladhydh may fedha aga derivadow devnydhys dhe wul lyvrow-mappow frosow mor. Dhe vos notys yntredha yw:

DeWOLFE, D.L. (1981) *Atlas of tidal currents - Bay of Fundy and Gulf of Maine.* Canadian Hydrographic Service, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.

CREAN, P.B. and HUGGETT, W.S. (1987) *Current Atlas - Juan de Fuca Strait to Strait of Georgia.* Canadian Hydrographic Service, Institute of Ocean Sciences, Sidney, British Columbia, Canada.

COMOLET-TIRMAN (1988) *Courants de marée dans le Pas de Calais.* Service Hydrographique et Océanographique de la Marine, Paris.

Avel an dhew lyver diwettha, diwyethek yw an dyllans ma, mes yn Kernewek ha Sowsnek kynses Sowsnek ha Frynkek.

### Why are there arrows for both springs and neaps ?

It has been customary, at least in British hydrographic publications, to assume that the tidal streams at different ranges of tide are related by the following rules:

(i) The rate is a function of tidal time, and is directly proportional to the range at the standard port.

(ii) The set is a function of tidal time, and is independent of the range at the standard port.

These assumptions are made because short-period observations, lasting for 25 hours, are carried out only at springs. With numerical models, any range of the tide may be simulated.

Results from the models show that these rules are incorrect, especially around salient points. The set of the stream is often significantly different at springs and at neaps. For this reason, arrows are shown for both ranges, in outline for springs and in black for neaps. In order to save space, they are plotted on the same chart.

### How accurate are the data ?

The model gives a detailed qualitative picture of the tidal streams throughout the tidal cycle. By looking at consecutive pages, the development and decay of main streams and of eddies can be followed. It is more difficult to make quantitative comparisons with data published on navigational charts, since these (in the form of tidal stream diamond tables) are generally based on observations lasting for only 25 hours. On the whole, there is reasonable agreement.

The model has difficulty in producing realistic pictures:

(a) when there are weak streams over an extended area (e.g. as shown on the chartlet *Dodman Point to Seaton* for hour -3);

(b) when the scale of coastal features is the same or smaller than the mesh-size.

It must be remembered that tidal streams are more perturbed by the weather than the vertical tide.

### *ALL PREDICTIONS MADE WITH THE AID OF THE ATLAS ARE TO REGARDED AS APPROXIMATE*

***Although every effort has been made to make this atlas as accurate as possible, neither the author nor the publisher take any responsibility for any differences between predictions made using the atlas and tidal streams actually experienced in the sea.***

### Prag yma sethow keffrys rag an reverthi ha'n mar'vor ?

Re beu an gis, dhe'n liha yn dyllansow morydhiethek predennek, dhe dhesevos bos an frosow orth hysyow dihaval an lanow kelmys dre an rewlys a syw:

(i) Toth an fros a greg war dermyn lanwek, hag a dyv orth hys an lanow y'n pennporth.

(ii) Tu an fros a greg war dermyn lanwek, mes ny sergh orth hys an lanow y'n pennporth.

Desevos a wrer yndella awos na vydh gwrys musuryansow berr aga durya a 25 our saw orth an reverthi. Pan wrer devnydh a batronyow niverek, y hyllir gul hevelepter a bup hys an lanow.

Sywyansow an patronyow a dhiskwa bos fals an rewlys ma, dres oll a-dro dhe bennow tir. Menowgh yth yw tu an frosow dihaval orth an reverthi hag orth an mar'vor. Raghenna, y fydh sethow diskwedhys rag an dhew hys, avel fram rag an reverthi ha du rag an mar'vor. Rag erbysi spas, yth yns delinys war an keth mappa.

### Py par kewarder eus dhe'n derivadow ?

Avel desskrifans, an patron a ro skeusenn vunys a'n frosow dres kylgh an mortid. Dre vires orth folennow a omsyw, y hyllir gweles tevi ha gwedhra an frosow meur ha'n gorthfrosow. Kalessa yw keheveli mynsow gans an derivadow war vappow lywya dyllys, drefenn an re ma (yn-dann furv towlennow an fros) dhe vos selys war vusuryansow hag a dhur, dell yw usys, dre 25 our hepken. Dre vras, yth yns unnver.

Kales yw dhe'n patron gul hevelepter da pan vo:

(a) pur wann an frosow dre efander bras (rag ensampel, dell yw diskwedhys dre vappa *Yntra Pennardh Powder ha Seythyn* rag eur -3)

(c) braster tremynnow an arvor an keth myns po byghanna es myns an vaglenn.

Res yw perthi kov bos an frosow moy distemprys gans an gewer ages an lanow.

### *RES YW MIRES ORTH PUB DARGAN GWRYS DIWORTH AN LYVER MA AVEL TRA OGAS*

***Kyn feu gwrys pub strivyans dhe wul an lyver ma an kewarra gyllir, nyns eus omgemmeryans na dhe'n skrifer na dhe'n dyllor rag sywyansow a dhyffransow yntra frosow dargenys a'n lyver ma ha'n re kevys yn hwir y'n mor.***

**What does the atlas contain ?**

The atlas contains twelve series each of thirteen chartlets. Coverage of the entire Cornish coast is provided by three series, with data displayed on a mesh-size of 3.2 nautical miles.

*Lizard Head to Bolt Head*
*Scilly to West Cornwall*
*St Ives to Hartland Point*

More detailed coverage of the whole of the south coast and part of the north coast is provided by the other nine series, with data displayed on a grid with the same mesh-size as the model, i.e. 0.8 nautical mile:

*Seaton to the Yealm*
*Dodman Point to Seaton*
*Nare Point to Dodman Point*
*Around Lizard Head*
*Tater Du to Lizard Head*
*Around Land's End*
*Around Cape Cornwall*
*Gurnard's Head to St Agnes' Head*
*Around Trevose Head*

**Pyth yw hys an lyver-mappow ?**

Yma dhe'n lyver dewdhek kevres a drydhek mappa. Kwethys yn tien yw an arvor Kernewek dre dri hevres, gans derivadow war vaglenn 3.2 mildir morek hy braster.

*Yntra Lysardh ha Penntir Ebil*
*Yntra Syllan ha Kernow West*
*Yntra Porth Ia ha Penntir Hartland*

Kwethys yw yn funyssa an arvor deghow ha rann an arvor kledh dre an naw kevres arall, gans derivadow war vaglenn a's teves an keth braster dell yw myns maglenn an patron, hemm yw 0.8 mildir morek:

*Yntra Seythyn ha'n Yam*
*Yntra Pennardh Powder ha Seythyn*
*Yntra Pennardh Menek ha Pennardh Powder*
*A-dro dhe Lysardh*
*Yntra Torthell Du ha Lysardh*
*Penn an Wlas*
*Penntir Kernow*
*Yntra Enyal ha Penntir Brevannek*
*A-dro dhe Benntir Trefos*

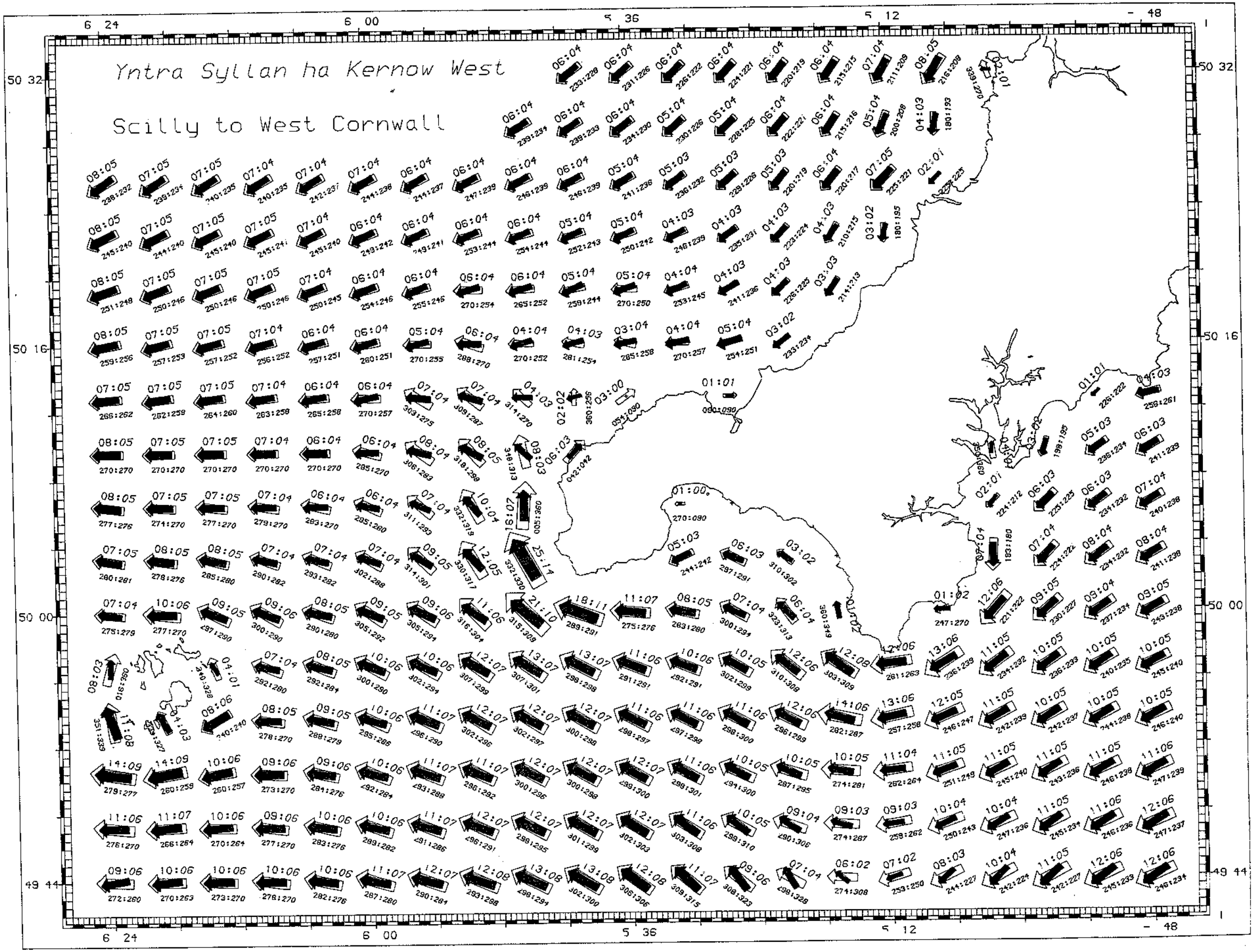
−6

6 hours
BEFORE
H.W.
Devonport

*6 eur*
*KYNS*
*G.L.*
*Porth*
*Dewnens*

## *Yntra Syllan ha Kernow West*

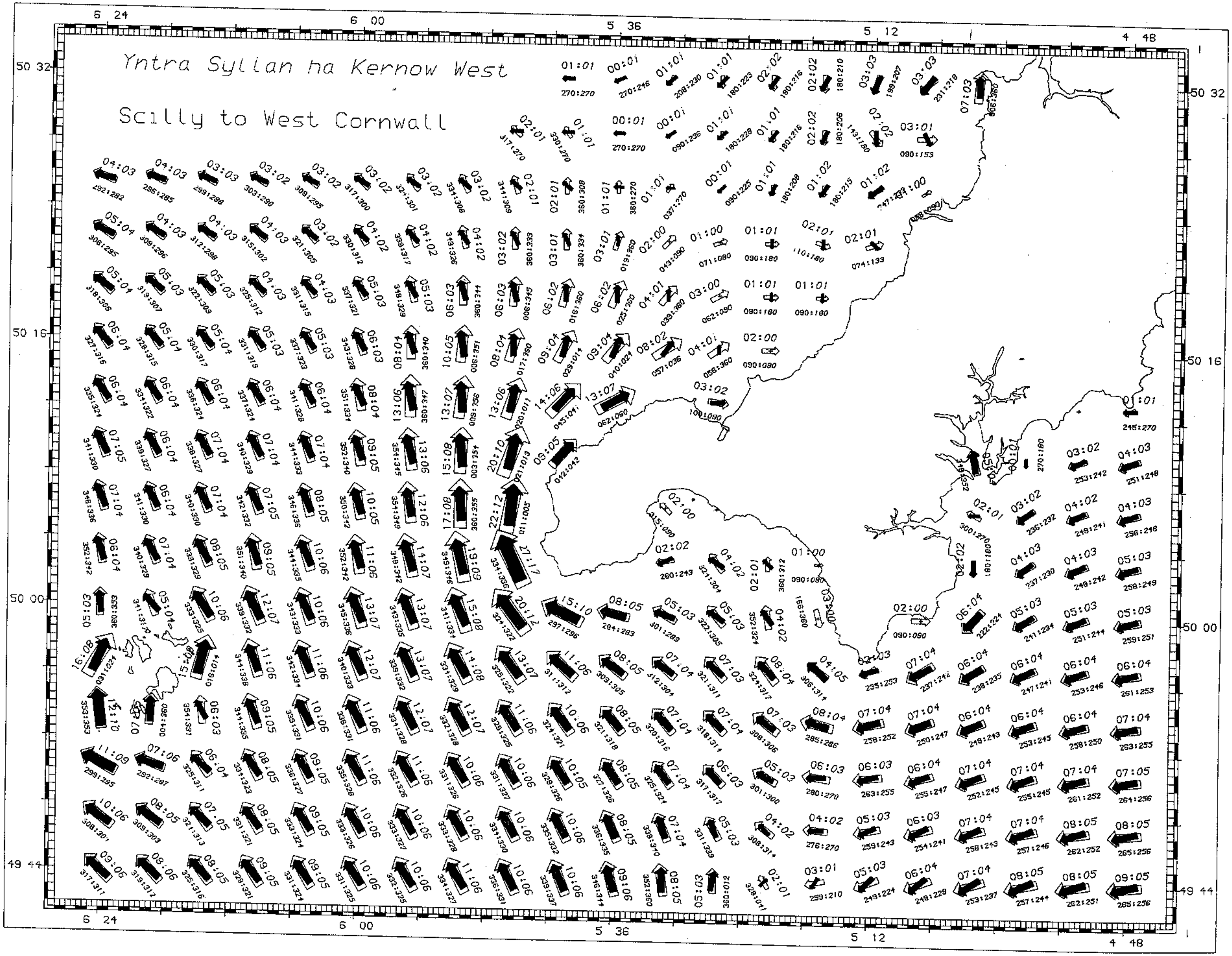
## Scilly to West Cornwall



−5

5 hours
BEFORE
H.W.
Devonport

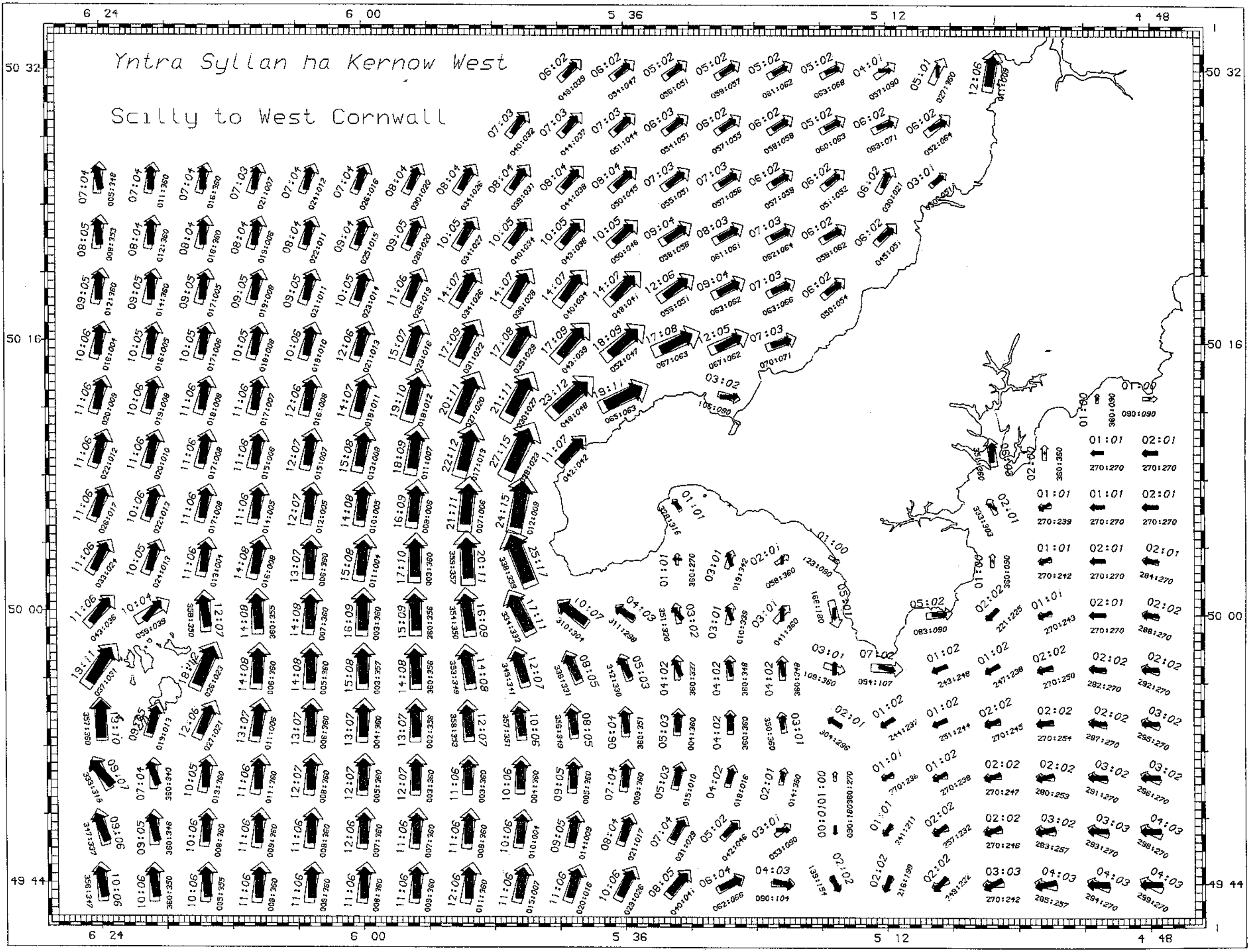
5 eur
KYNS
G.L.
Porth
Dewnens



-4

4 hours
BEFORE
H.W.
Devonport

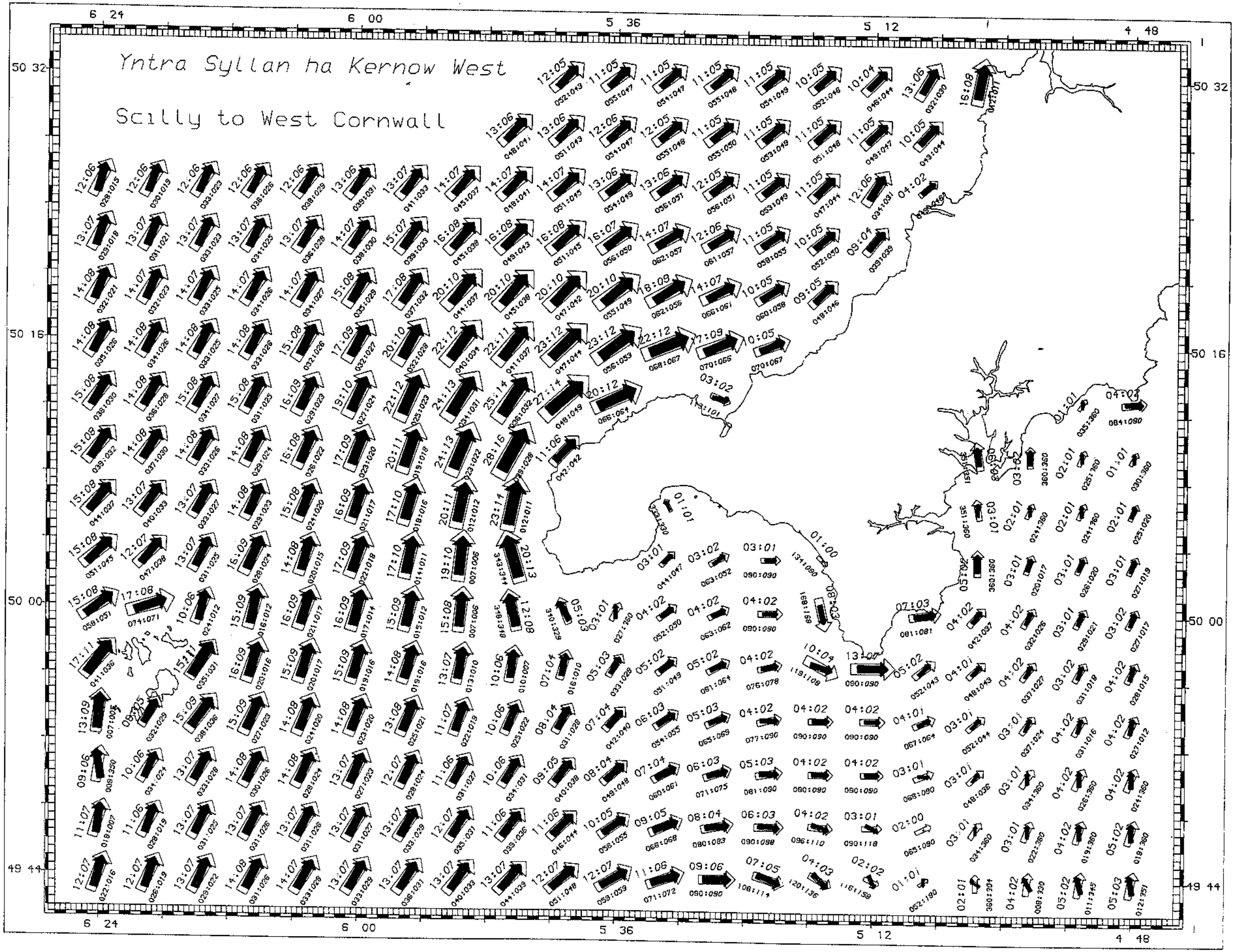
*4 eur*
*KYNS*
*G.L.*
*Porth*
*Dewnens*



-3

3 hours
BEFORE
H.W.
Devonport

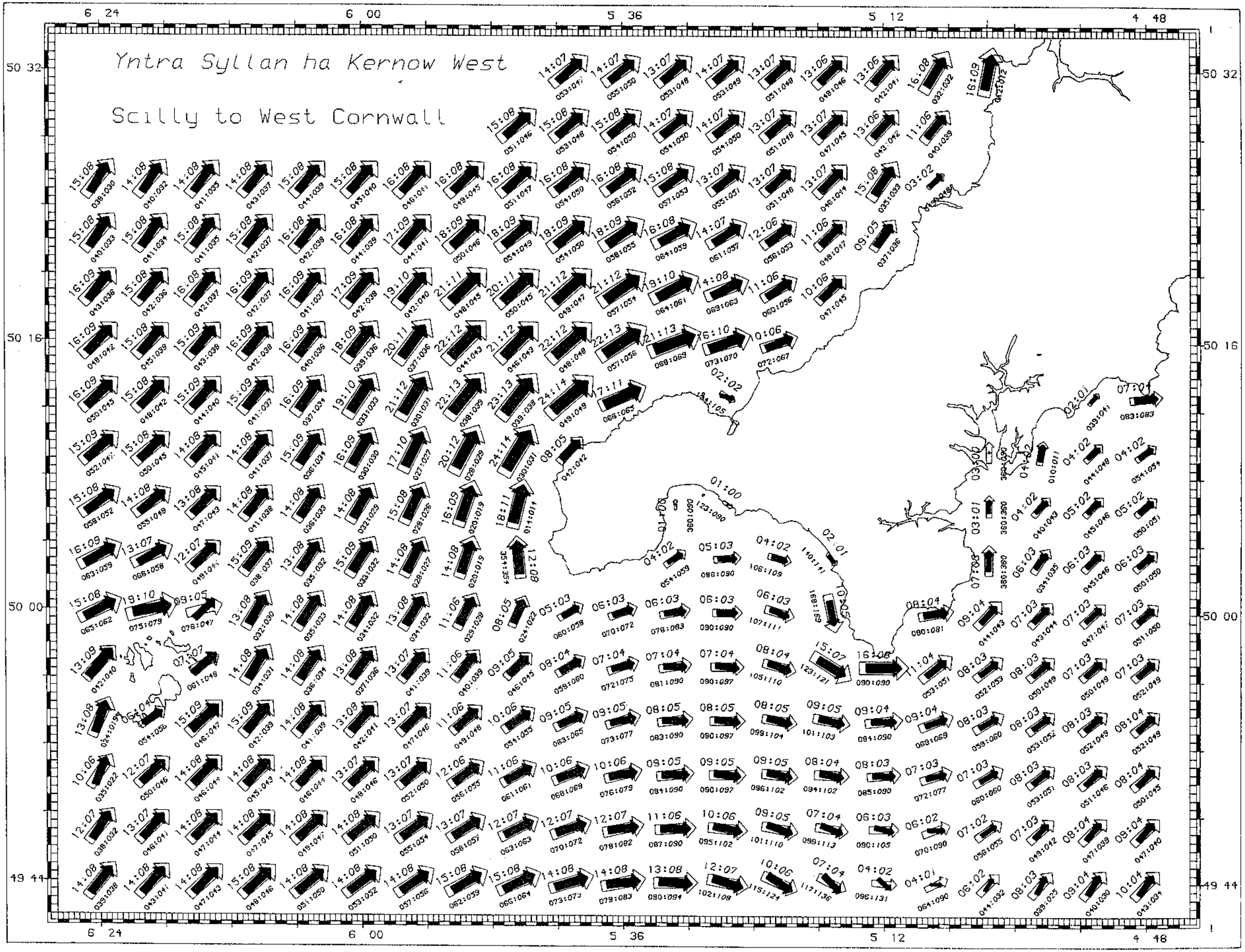
*3 eur*
*KYNS*
*G.L.*
*Porth*
*Dewnens*



# −2

2 hours
BEFORE
H.W.
Devonport

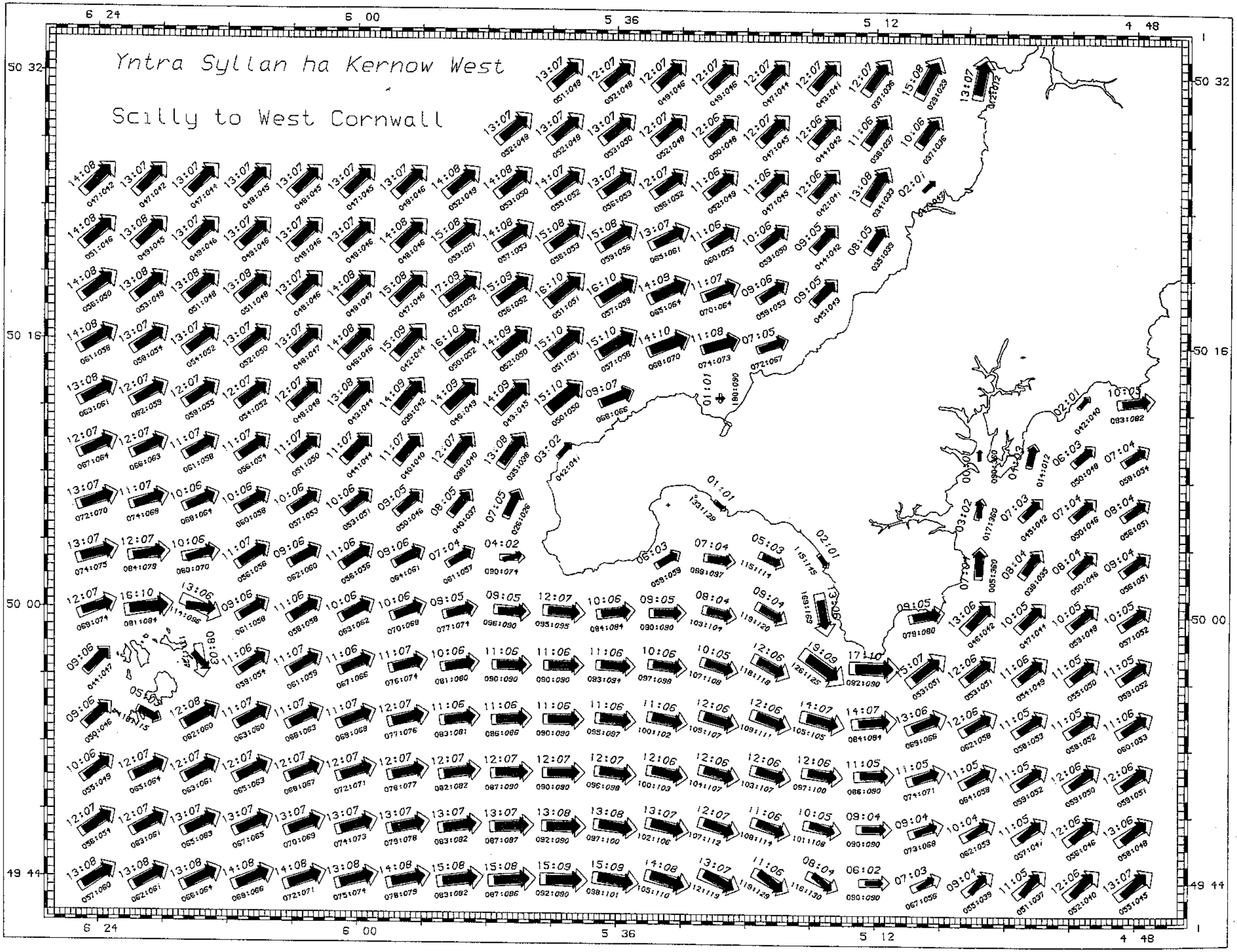
*2 eur*
*KYNS*
*G.L.*
*Porth*
*Dewnens*

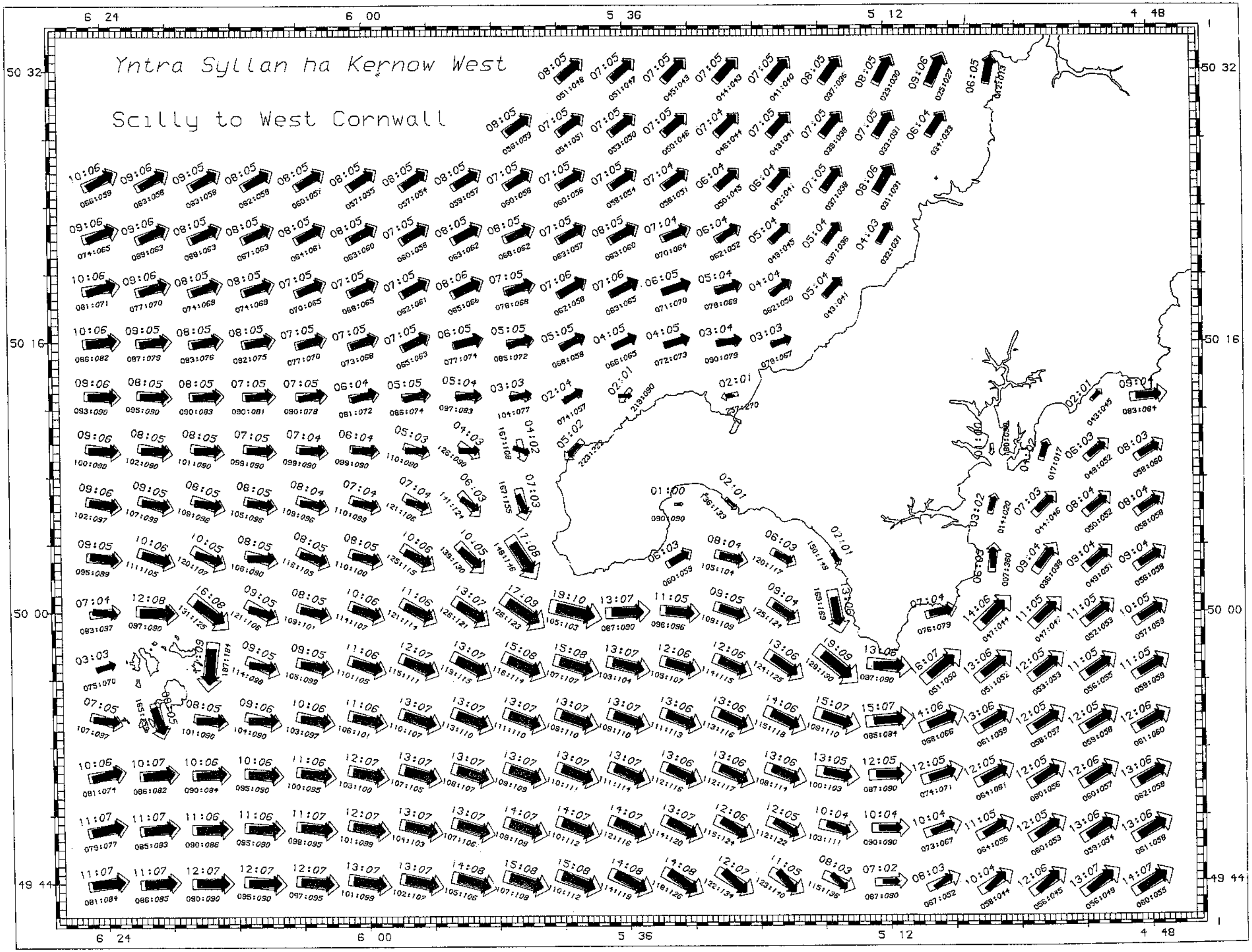


−1

1 hour
BEFORE
H.W.
Devonport

1 eur
KYNS
G.L.
Porth
Dewnens





H.W.

Devonport

G.L.

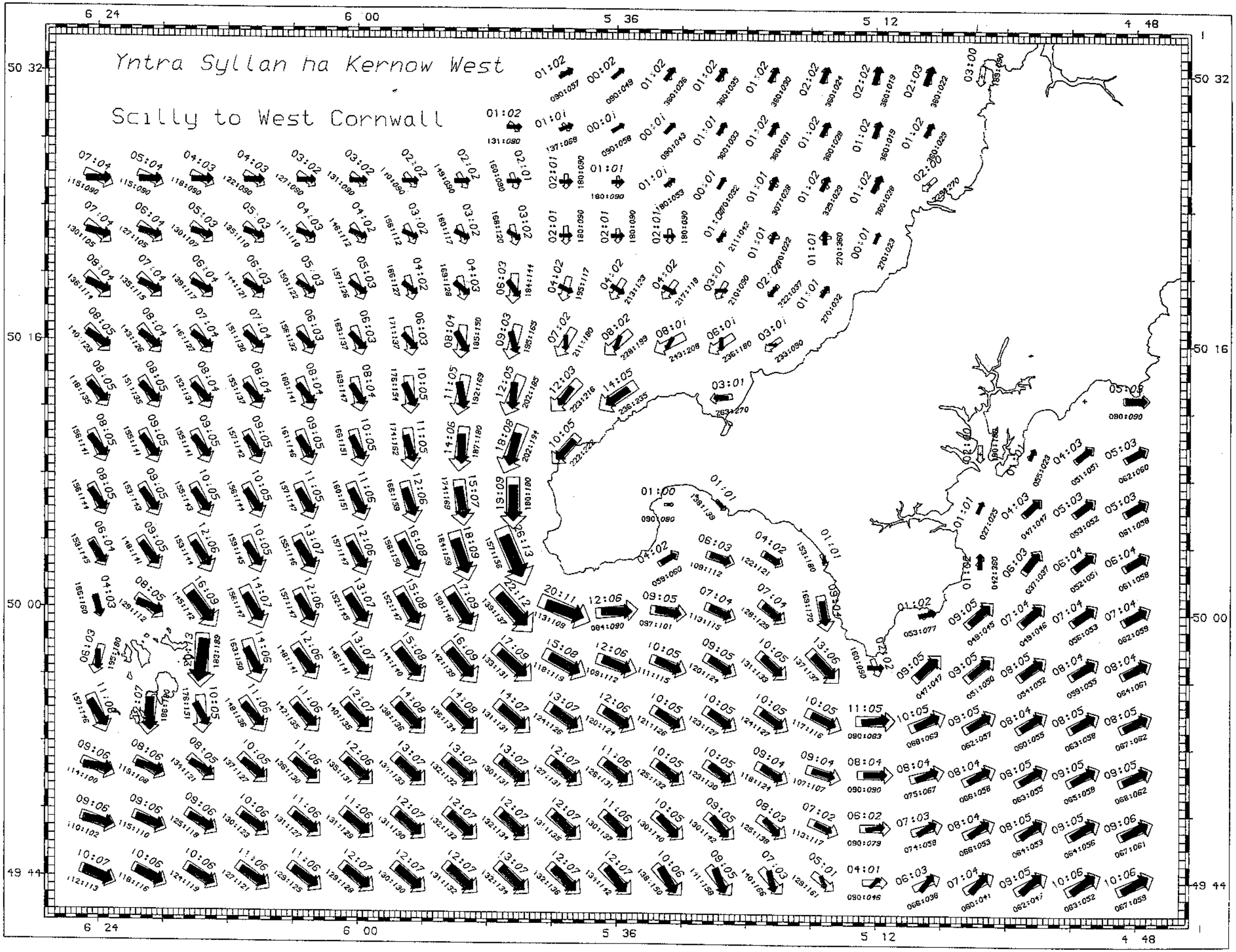
Porth

Dewnens

1

1 hour
AFTER
H.W.
Devonport

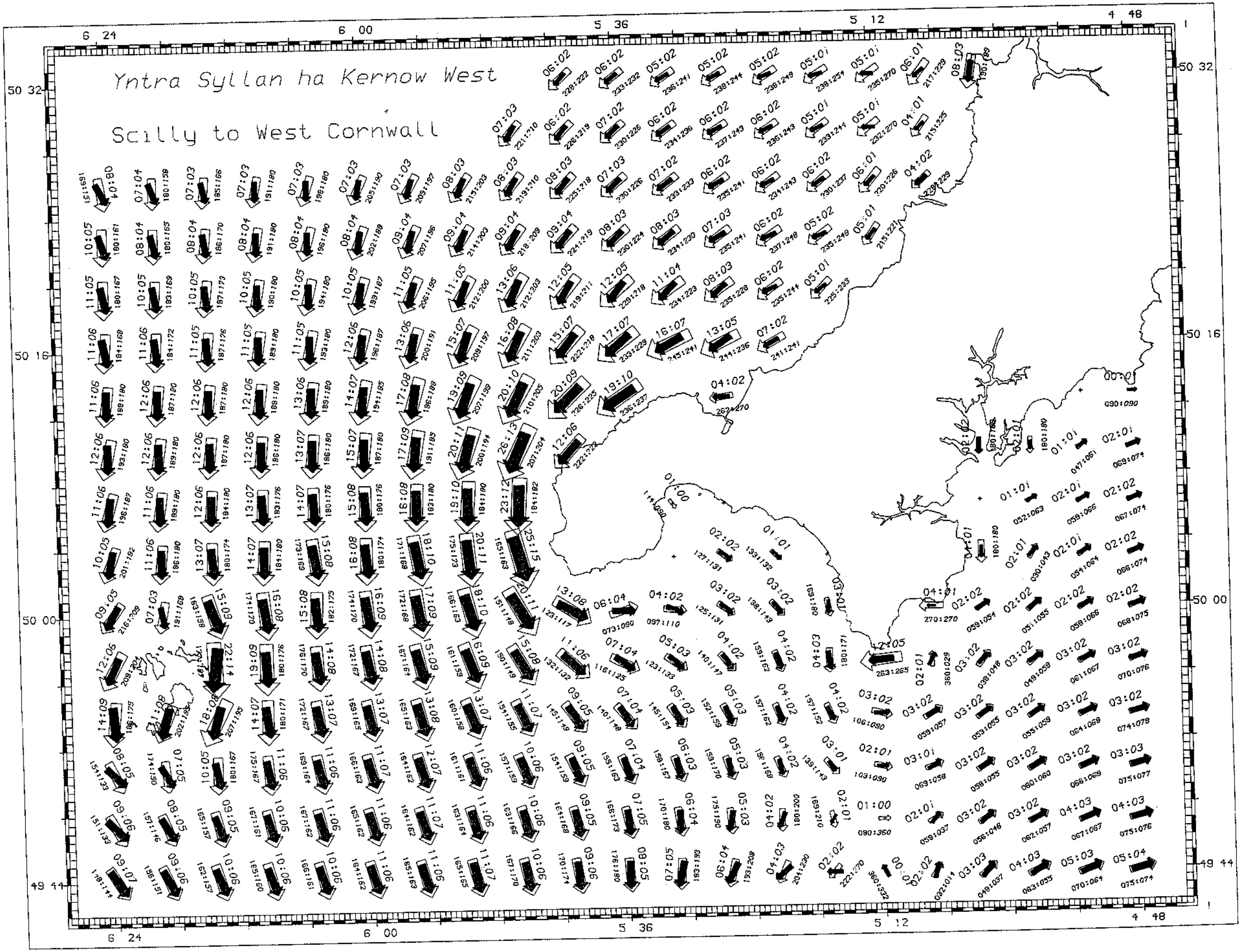
1 eur
WOSA
G.L.
Porth
Dewnens



2

2 hours
AFTER
H.W.
Devonport

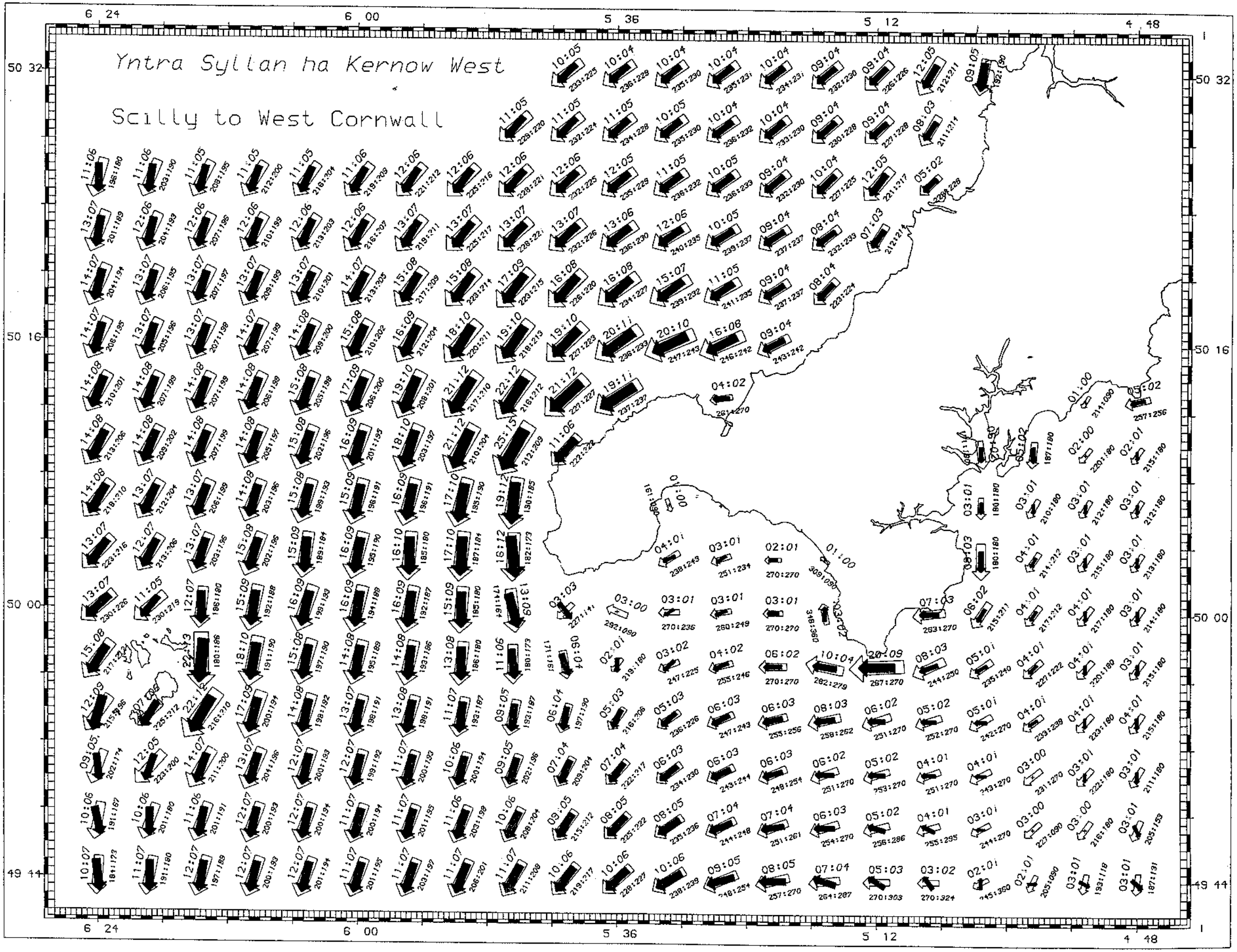
*2 eur*
*WOSA*
*G.L.*
*Porth*
*Dewnens*



3

3 hours
AFTER
H.W.
Devonport

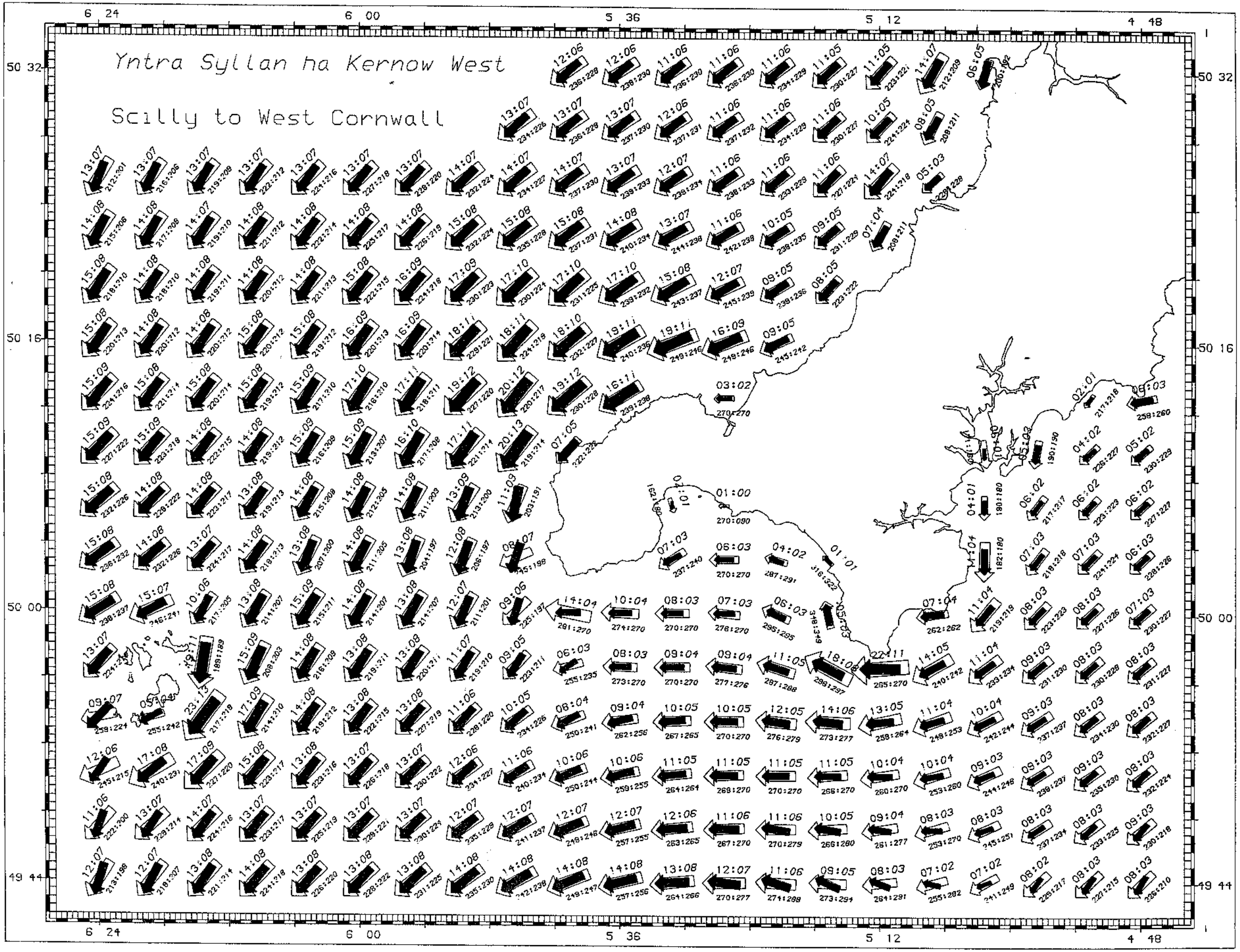
*3 eur*
*WOSA*
*G.L.*
*Porth*
*Dewnens*



4

4 hours
AFTER
H.W.
Devonport

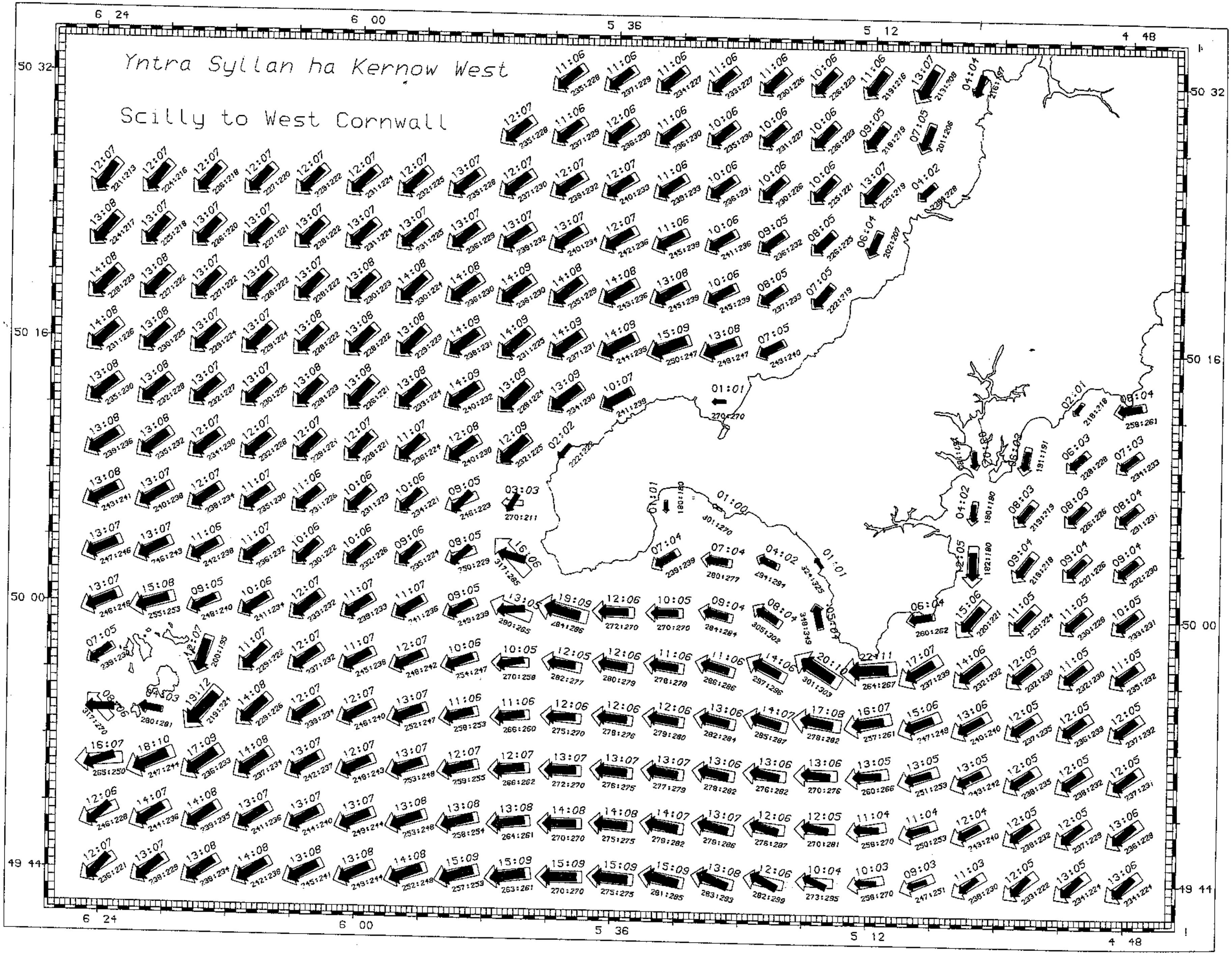
*4 eur*
*WOSA*
*G.L.*
*Porth*
*Dewnens*



5

5 hours
AFTER
H.W.
Devonport

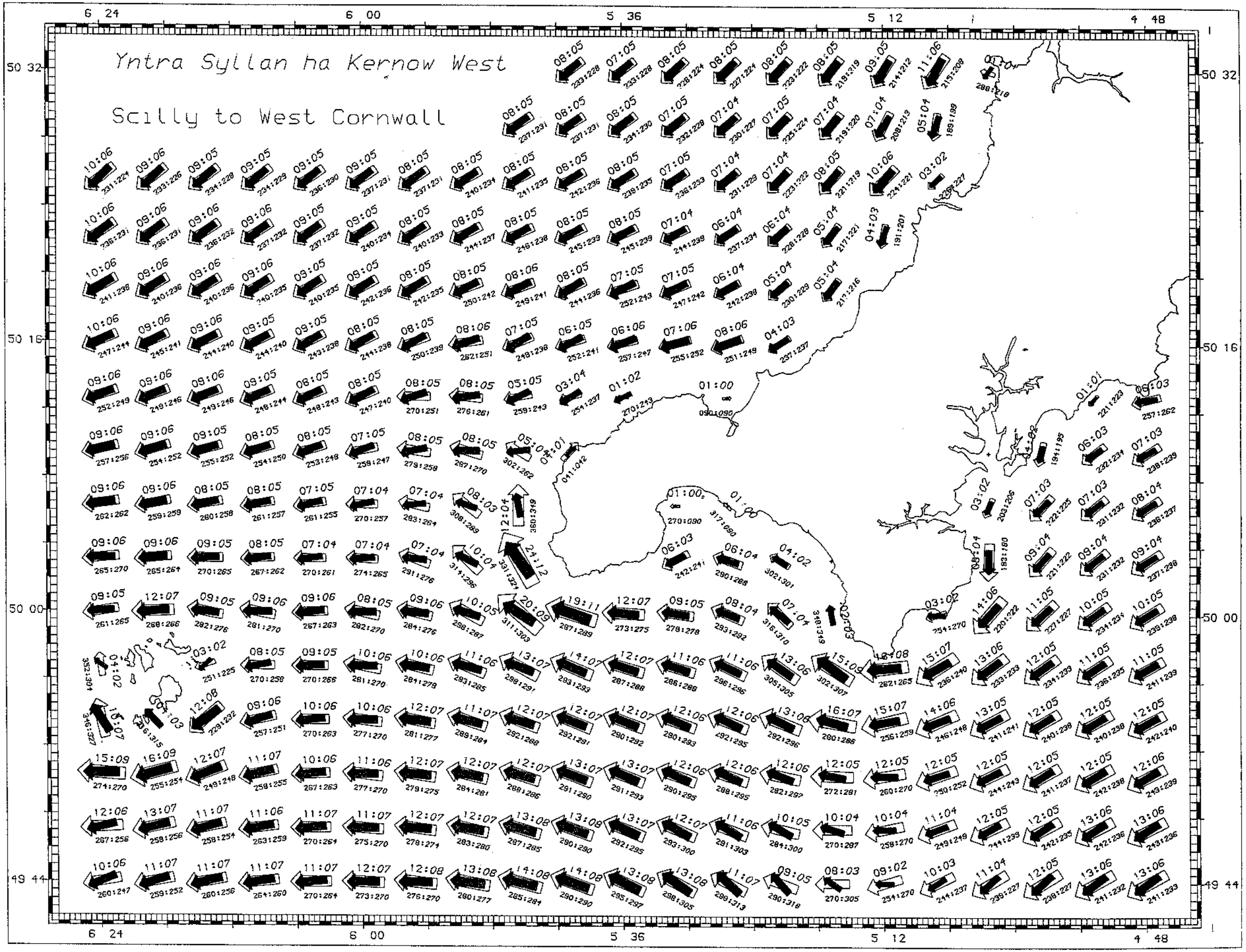
*5 eur*
*WOSA*
*G.L.*
*Porth*
*Dewnens*



6

6 hours
AFTER
H.W.
Devonport

*6 eur*
*WOSA*
*G.L.*
*Porth*
*Dewnens*



# Appendix C – METOC Wave Data

## LOCATION E04

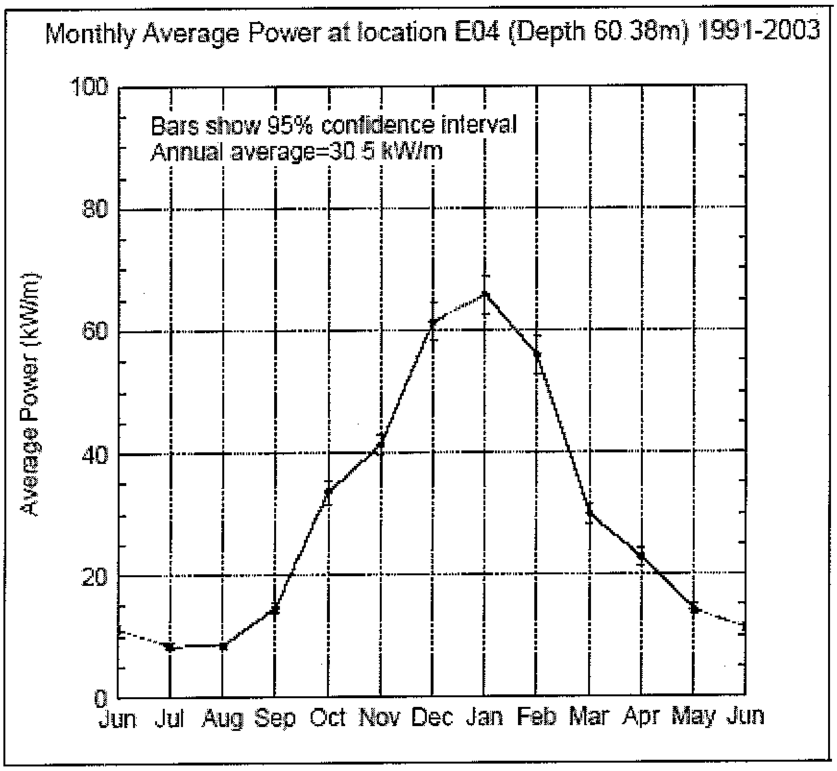
**Data source:** Met Office European Wave Model

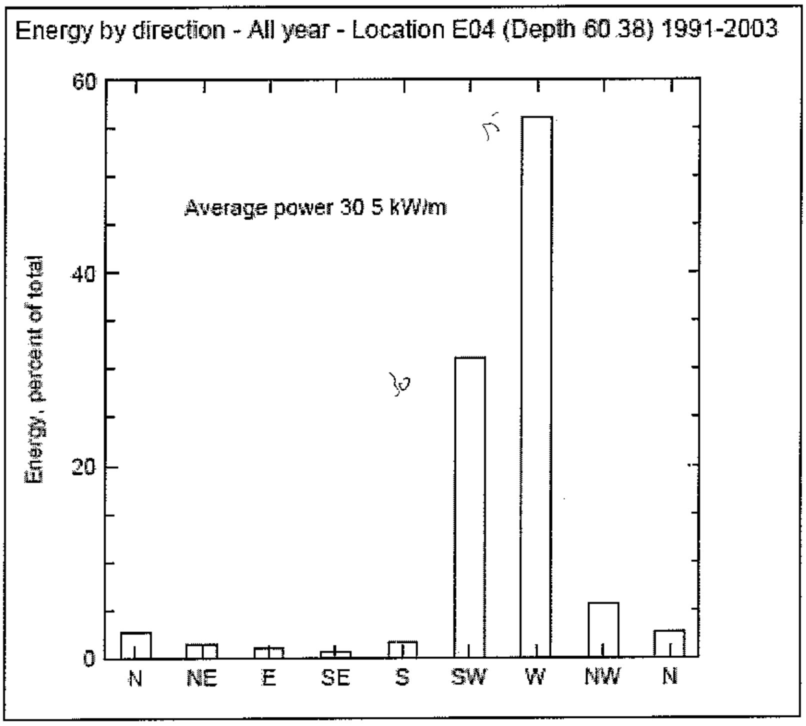
**Gridpoint position:** 50.50°N, 5.66°W

**Depth:** 60.4m

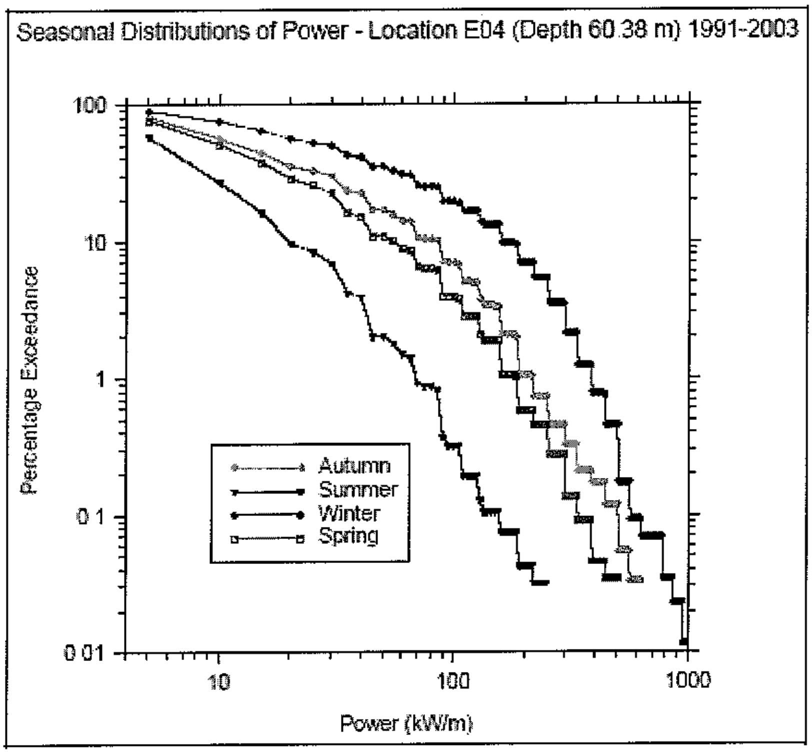
Presentations:

- Monthly Average Power;
- Energy By Direction - All Year;
- Seasonal Distributions of Power;
- Hs:Tz Scatter Diagram – All Year;
- Distribution of Energy with Hs & Tz (All year and 4 seasons).





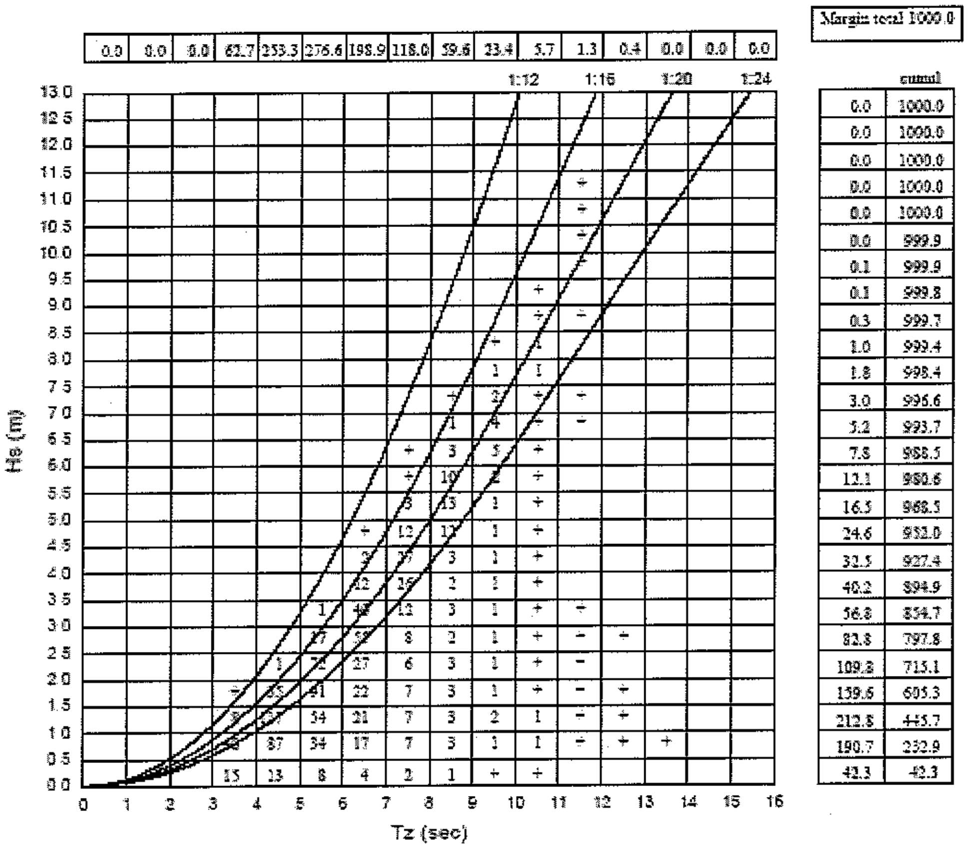
Energy by direction - All year - Location E04 (Depth 60.38) 1991-2003



Seasonal Distributions of Power - Location E04 (Depth 60.38 m) 1991-2003

# SOUTH WEST REGION SEAPOWER REVIEW

## Joint Probability (ppt) of Hs and Tz



- Number of data used (normalised to 12 whole years): 35068   Data interval: 3.0 hours
- Met Office European Wave Model - All year 1991 to 2003
- Position: 50.50° N 5.66° W   Depth: 60.4 m   Designation: E04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 30.5 kW/m

HS:TZ SCATTER DIAGRAM - LOCATION E04 - ALL YEAR

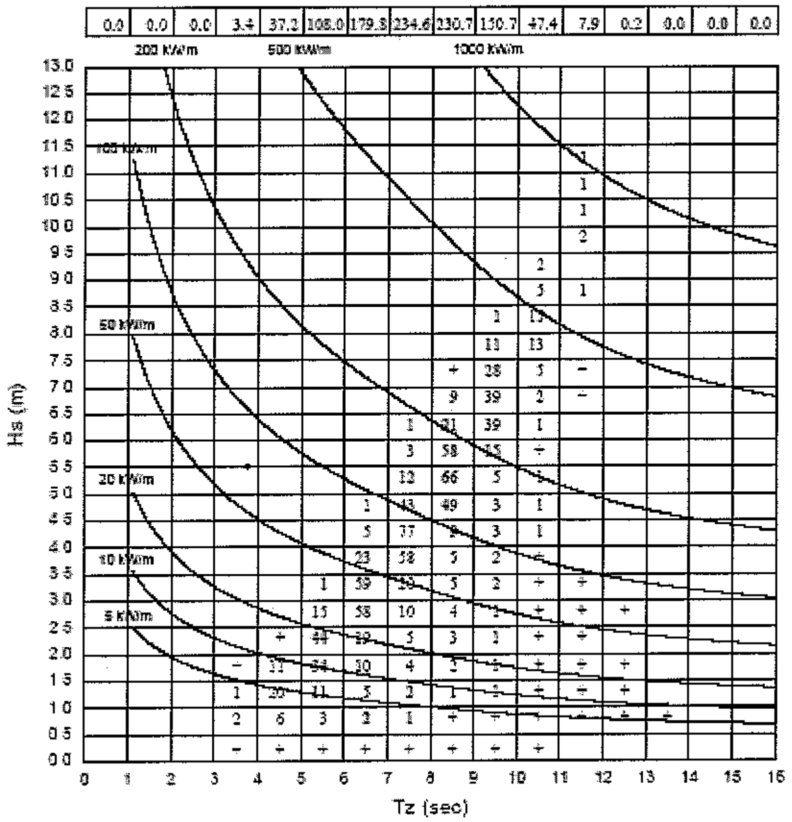
Input file: (AWR-2) D:\Wave Energy\Reges\SWDATA\E04200501200.PTF

Plotted on 9 Jan 2004 at 1522

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz

Margin total 1000.0



| | cumul |
|---|---|
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 1.0 | 1000.0 |
| 0.9 | 999.0 |
| 0.8 | 998.1 |
| 2.2 | 997.3 |
| 1.8 | 995.2 |
| 5.9 | 993.4 |
| 16.7 | 987.5 |
| 24.0 | 970.8 |
| 33.7 | 946.8 |
| 49.3 | 913.0 |
| 61.5 | 863.7 |
| 75.5 | 802.2 |
| 82.9 | 726.8 |
| 95.8 | 643.9 |
| 94.7 | 548.1 |
| 87.8 | 453.4 |
| 87.8 | 365.6 |
| 87.7 | 277.8 |
| 73.1 | 190.1 |
| 61.8 | 117.0 |
| 40.7 | 55.1 |
| 14.0 | 14.4 |
| 0.3 | 0.3 |

- Number of data used (normalised to 12 whole years): 36068 Data interval: 3.0 hours
- Met Office European Wave Model - All year 1991 to 2003
- Position: 50.50° N 5.66° W Depth: 60.4 m Designation: E04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 30.5 kW/m

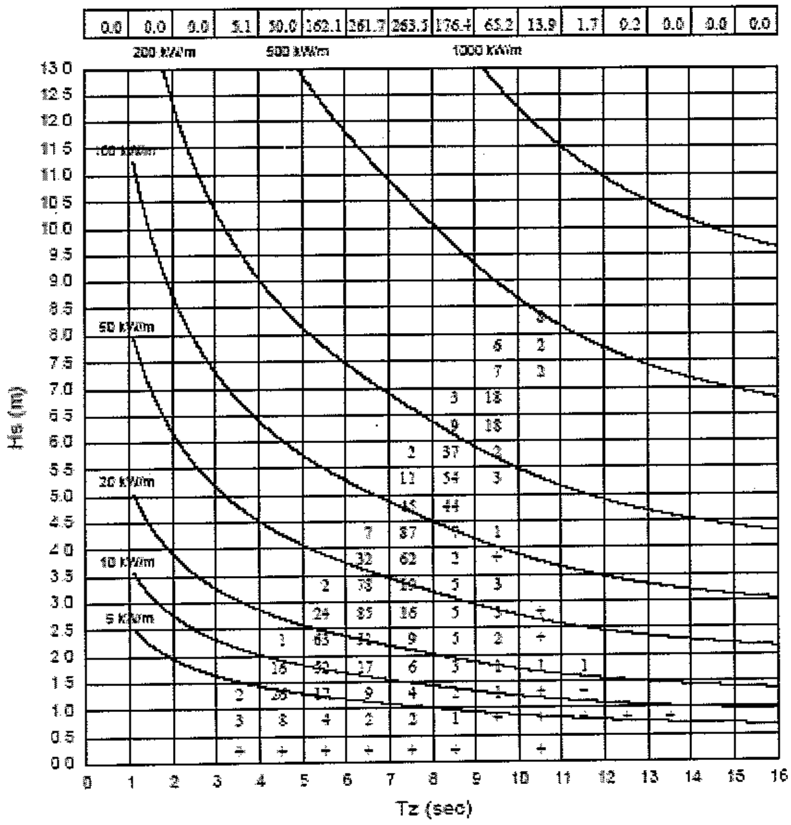
## DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION E04 - ALL YEAR

Input file: (AWR-3) D:\Wave Energy\Roger SW\DATA\E04\3050050205.PTF

Plotted on 8 Jan 2004 at 1621

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



Margin total 1000 0

| | cumul |
|---|---|
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 7.7 | 1000.0 |
| 8.2 | 992.3 |
| 9.0 | 984.1 |
| 20.7 | 975.1 |
| 27.1 | 954.4 |
| 41.7 | 927.2 |
| 67.6 | 885.6 |
| 89.5 | 818.0 |
| 101.4 | 728.4 |
| 97.6 | 627.0 |
| 106.8 | 529.4 |
| 132.6 | 422.6 |
| 111.7 | 290.0 |
| 96.9 | 178.4 |
| 60.6 | 81.4 |
| 20.4 | 20.8 |
| 0.4 | 0.4 |

- Number of data used: 8758 Data interval: 3 0 hours
- Met Office European Wave Model - Spring 1991 to 2003
- Position: 50 50° N 5.66° W Depth: 80.4 m Designation: E04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 22.3 kW/m

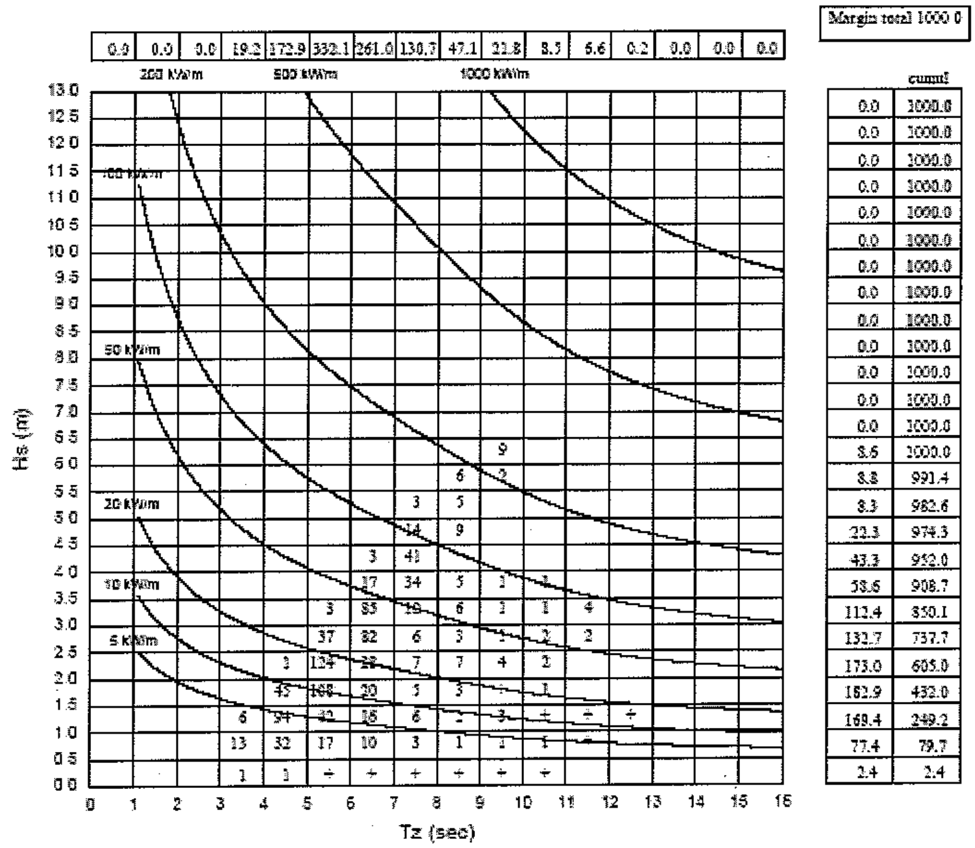
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION E04 - SPRING

Input file: (AWB-2) D:\Wave Energy\Roger\SWDATA\E0413501 2003.PTF

Plotted on 9 Jan 2004 at 1510

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



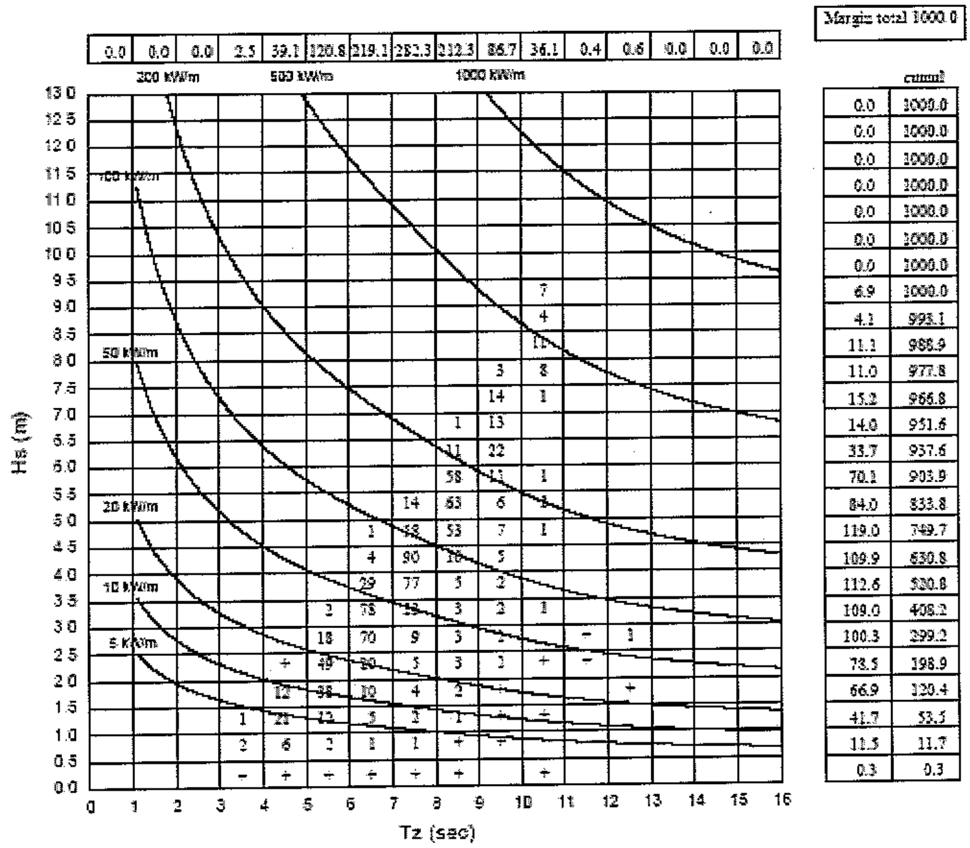
- Number of data used: 9437 Data interval: 3.0 hours
- Met Office European Wave Model - Summer 1991 to 2003
- Position: 50.50° N 5.66° W Depth: 60.4 m Designation: E04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 9.3 kW/m

DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION E04 - SUMMER

Input file: (AWR-3) D:\Wave Energy\Region\SWDATA\[illegible].PTF Plotted on 8 Jan 2004 at [illegible]

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



- Number of data used: 9184 Data interval: 3.0 hours
- Met Office European Wave Model - Autumn 1991 to 2003
- Position: 50.50° N 5.66° W Depth: 60.4 m Designation: E04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 29.5 kW/m

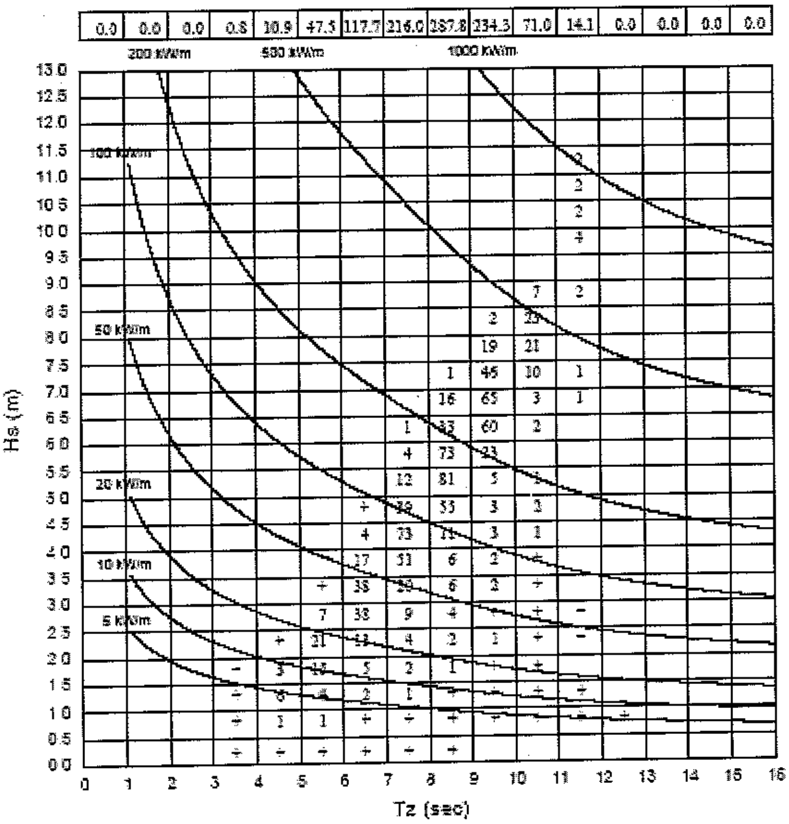
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION E04 - AUTUMN

Input file: (AWR-2) [illegible]

Plotted on [illegible]

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



Margin total 1000.0

| | cumul |
|---|---|
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 2.0 | 1000.0 |
| 1.8 | 998.0 |
| 1.6 | 996.3 |
| 4.4 | 994.6 |
| 0.0 | 990.2 |
| 9.8 | 990.2 |
| 25.3 | 980.4 |
| 40.0 | 955.1 |
| 57.2 | 915.1 |
| 85.1 | 857.8 |
| 96.3 | 772.8 |
| 100.4 | 676.5 |
| 99.4 | 576.1 |
| 98.4 | 476.7 |
| 92.3 | 378.4 |
| 76.2 | 286.1 |
| 66.5 | 209.8 |
| 58.0 | 143.3 |
| 40.8 | 85.2 |
| 27.9 | 44.5 |
| 13.3 | 16.5 |
| 3.2 | 3.3 |
| 0.1 | 0.1 |

- Number of data used: 8642 Data interval: 3.0 hours
- Met Office European Wave Model - Winter 1991 to 2003
- Position: 50.50° N 5.66° W Depth: 60.4 m Designation: E04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 61.2 kW/m

DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION E04 - WINTER

Input file: (AWR-2) D:\Wave Energy\[illegible] Plotted on [illegible] Jan 2004 at [illegible]

## LOCATION U03

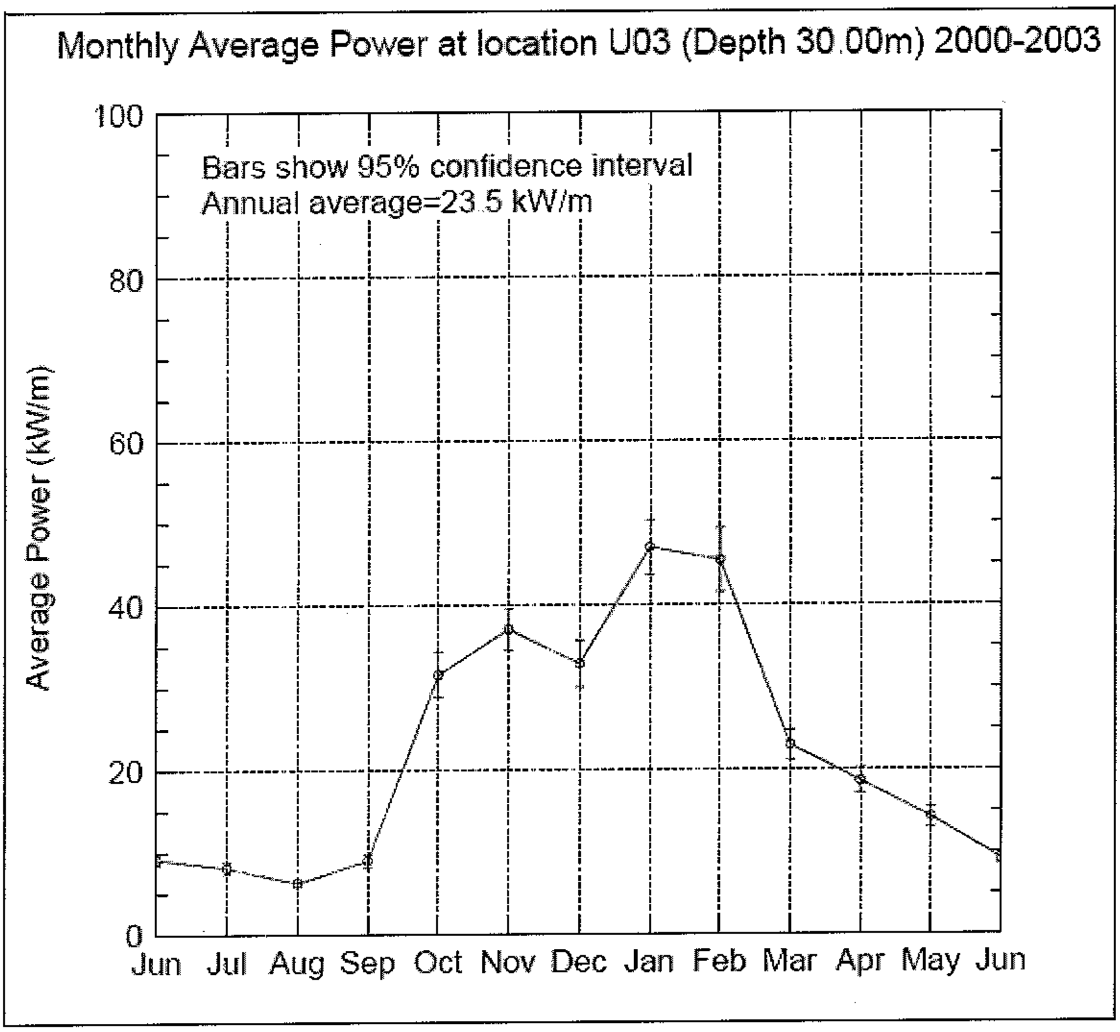
**Data source:** Met Office UK Waters Wave Model

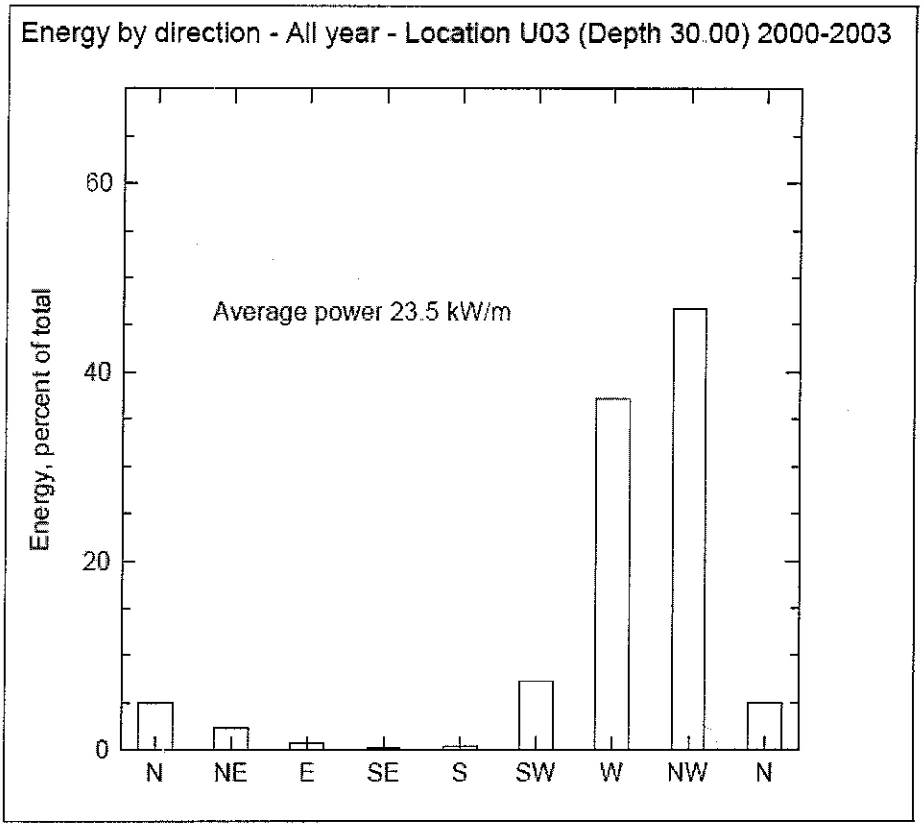
**Gridpoint position:** 50.28°N, 5.58°W

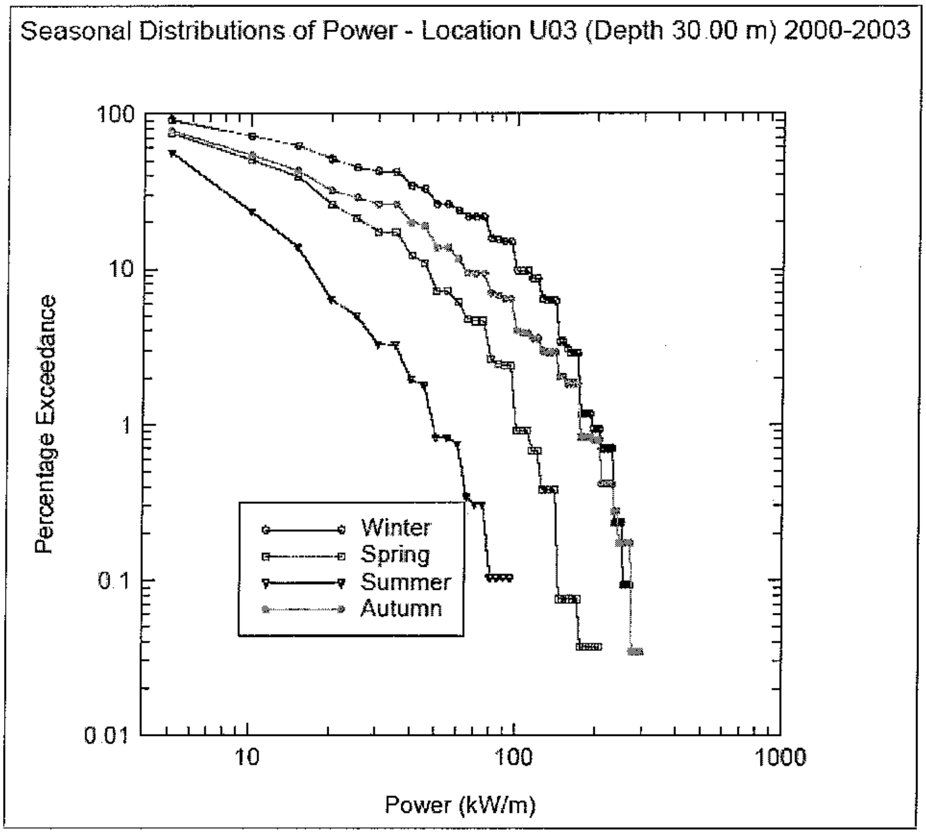
**Depth:** 30.0m

Presentations:

- Monthly Average Power;
- Energy By Direction - All Year;
- Seasonal Distributions of Power;
- Hs:Tz Scatter Diagram – All Year;
- Distribution of Energy with Hs & Tz (All year and 4 seasons).

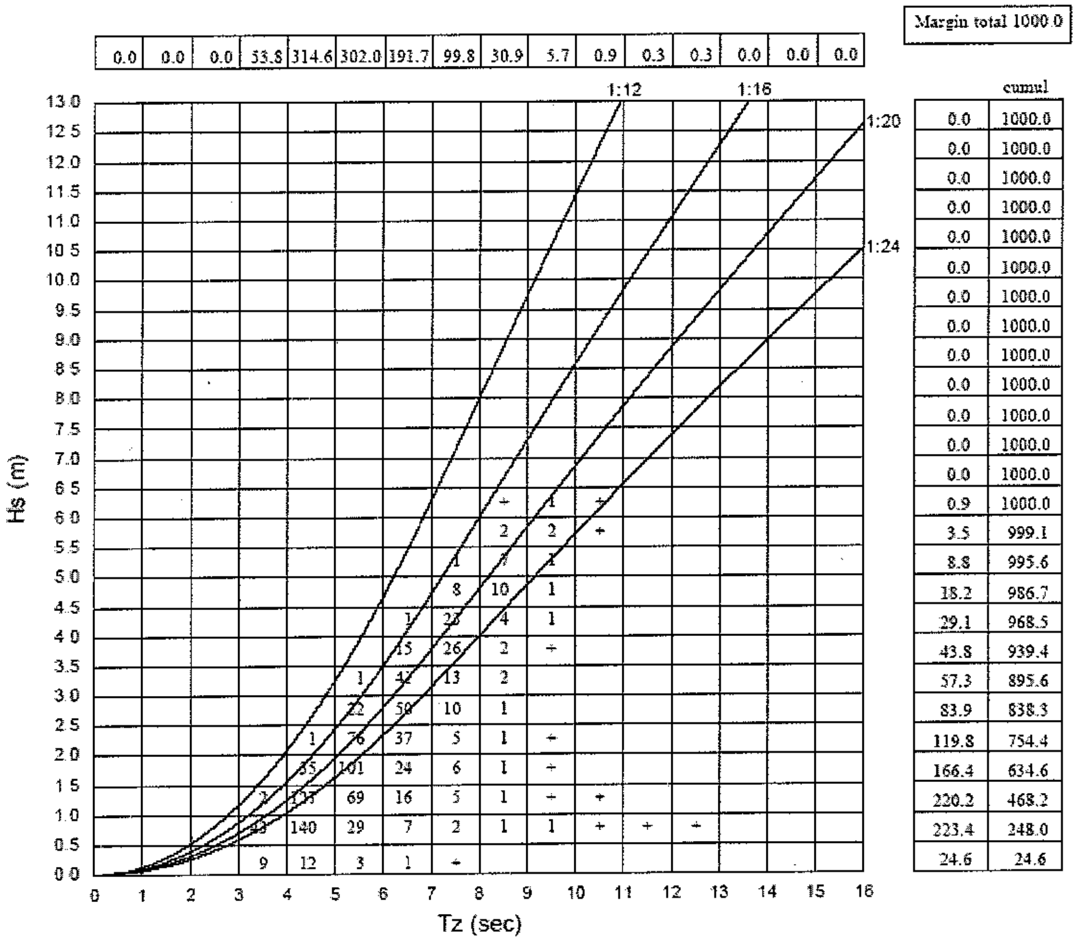



Energy by direction - All year - Location U03 (Depth 30.00) 2000-2003


Seasonal Distributions of Power - Location U03 (Depth 30.00 m) 2000-2003

# SOUTH WEST REGION SEAPOWER REVIEW

## Joint Probability (ppt) of Hs and Tz



Margin total 1000.0

| Hs (m) | 0–1 | 1–2 | 2–3 | 3–4 | 4–5 | 5–6 | 6–7 | 7–8 | 8–9 | 9–10 | 10–11 | 11–12 | 12–13 | 13–14 | 14–15 | 15–16 | | cumul |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | 0.0 | 0.0 | 53.8 | 314.6 | 302.0 | 191.7 | 99.8 | 30.9 | 5.7 | 0.9 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | | |
| 12.5–13.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 12.0–12.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 11.5–12.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 11.0–11.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 10.5–11.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 10.0–10.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 9.5–10.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 9.0–9.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 8.5–9.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 8.0–8.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 7.5–8.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 7.0–7.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 6.5–7.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 6.0–6.5 | | | | | | | | | + | 1 | + | | | | | | 0.9 | 1000.0 |
| 5.5–6.0 | | | | | | | | | 2 | 2 | + | | | | | | 3.5 | 999.1 |
| 5.0–5.5 | | | | | | | | 1 | 7 | 1 | | | | | | | 8.8 | 995.6 |
| 4.5–5.0 | | | | | | | | 8 | 10 | 1 | | | | | | | 18.2 | 986.7 |
| 4.0–4.5 | | | | | | | 1 | 23 | 4 | 1 | | | | | | | 29.1 | 968.5 |
| 3.5–4.0 | | | | | | | 15 | 26 | 2 | + | | | | | | | 43.8 | 939.4 |
| 3.0–3.5 | | | | | | 1 | 42 | 13 | 2 | | | | | | | | 57.3 | 895.6 |
| 2.5–3.0 | | | | | | 22 | 50 | 10 | 1 | | | | | | | | 83.9 | 838.3 |
| 2.0–2.5 | | | | | 1 | 76 | 37 | 5 | 1 | + | | | | | | | 119.8 | 754.4 |
| 1.5–2.0 | | | | | 35 | 101 | 24 | 6 | 1 | + | | | | | | | 166.4 | 634.6 |
| 1.0–1.5 | | | | 2 | 127 | 69 | 16 | 5 | 1 | + | + | | | | | | 220.2 | 468.2 |
| 0.5–1.0 | | | | 43 | 140 | 29 | 7 | 2 | 1 | 1 | + | + | + | | | | 223.4 | 248.0 |
| 0.0–0.5 | | | | 9 | 12 | 3 | 1 | + | | | | | | | | | 24.6 | 24.6 |

- Number of data used (normalised to 4 whole years): 11690     Data interval: 3.0 hours
- Met Office UK Waters Wave Model - All year 2000 to 2003
- Position: 50.28° N 5.58° W     Depth: 30.0 m     Designation: U03
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 23.5 kW/m

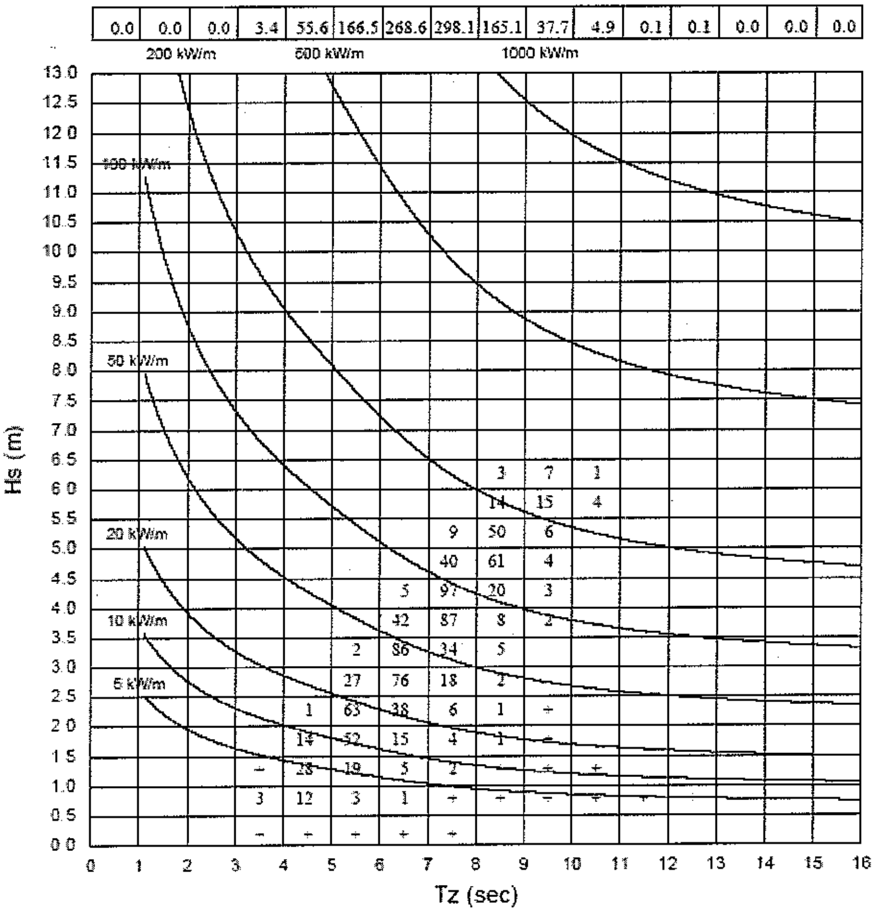
HS:TZ SCATTER DIAGRAM - LOCATION U03 - ALL YEAR

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\W032009010200.PTF

Plotted on 13 Jan 2004 at 1239

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



Margin total 1000.0

| | cumul |
|---|---|
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 10.7 | 1000.0 |
| 33.2 | 989.3 |
| 64.4 | 956.1 |
| 105.0 | 891.7 |
| 125.5 | 786.7 |
| 138.4 | 661.1 |
| 126.3 | 522.8 |
| 124.1 | 396.5 |
| 109.3 | 272.4 |
| 86.9 | 163.1 |
| 55.4 | 76.2 |
| 20.5 | 20.8 |
| 0.2 | 0.2 |

- Number of data used (normalised to 4 whole years): 11690     Data interval: 3.0 hours
- Met Office UK Waters Wave Model - All year 2000 to 2003
- Position: 50.28° N  5.58° W     Depth: 30.0 m     Designation: U03
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 23.5 kW/m

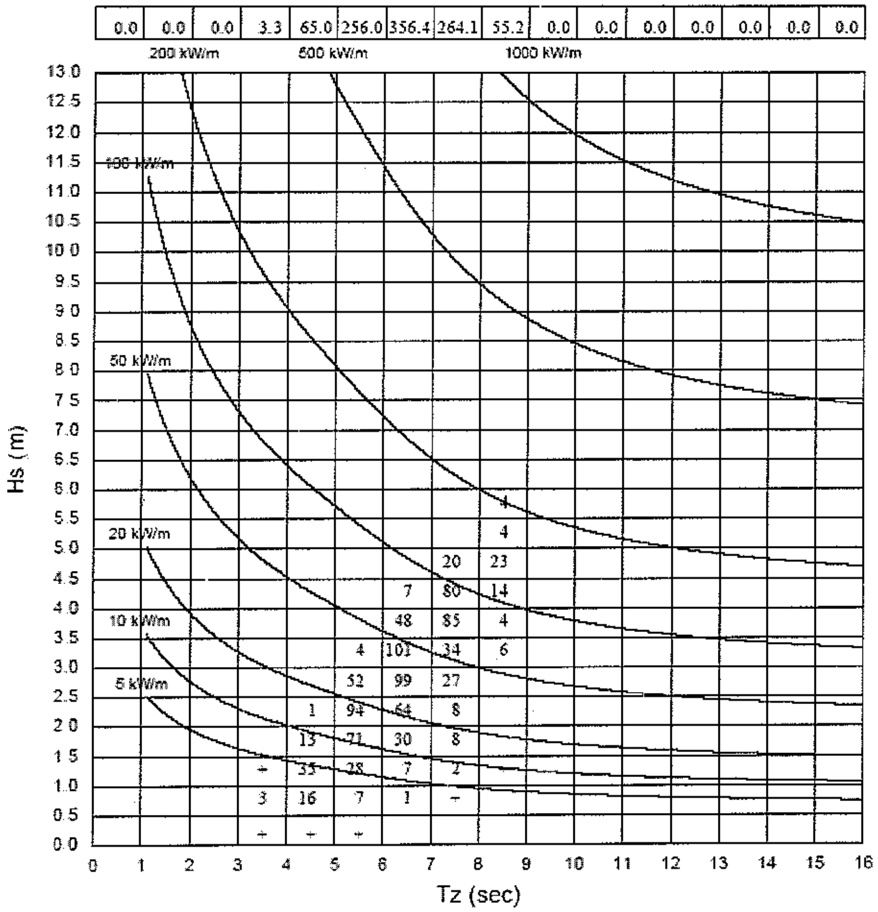
## DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U03 - ALL YEAR

Input file: (AWR-2) D:\Wave Energy\Regen\SW\DATA\U034009010255.PTF

Plotted on 13 Jan 2004 at 1327

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



Margin total 1000 0

| | cumul |
|---|---|
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 4.3 | 1000.0 |
| 3.6 | 995.7 |
| 43.8 | 992.2 |
| 100.6 | 948.4 |
| 136.4 | 847.8 |
| 144.4 | 711.3 |
| 178.0 | 567.0 |
| 167.0 | 389.0 |
| 122.2 | 222.0 |
| 72.2 | 99.7 |
| 27.3 | 27.6 |
| 0.3 | 0.3 |

- Number of data used: 2663 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Spring 2000 to 2003
- Position: 50 28° N 5.58° W Depth: 30.0 m Designation: U03
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 18.3 kW/m

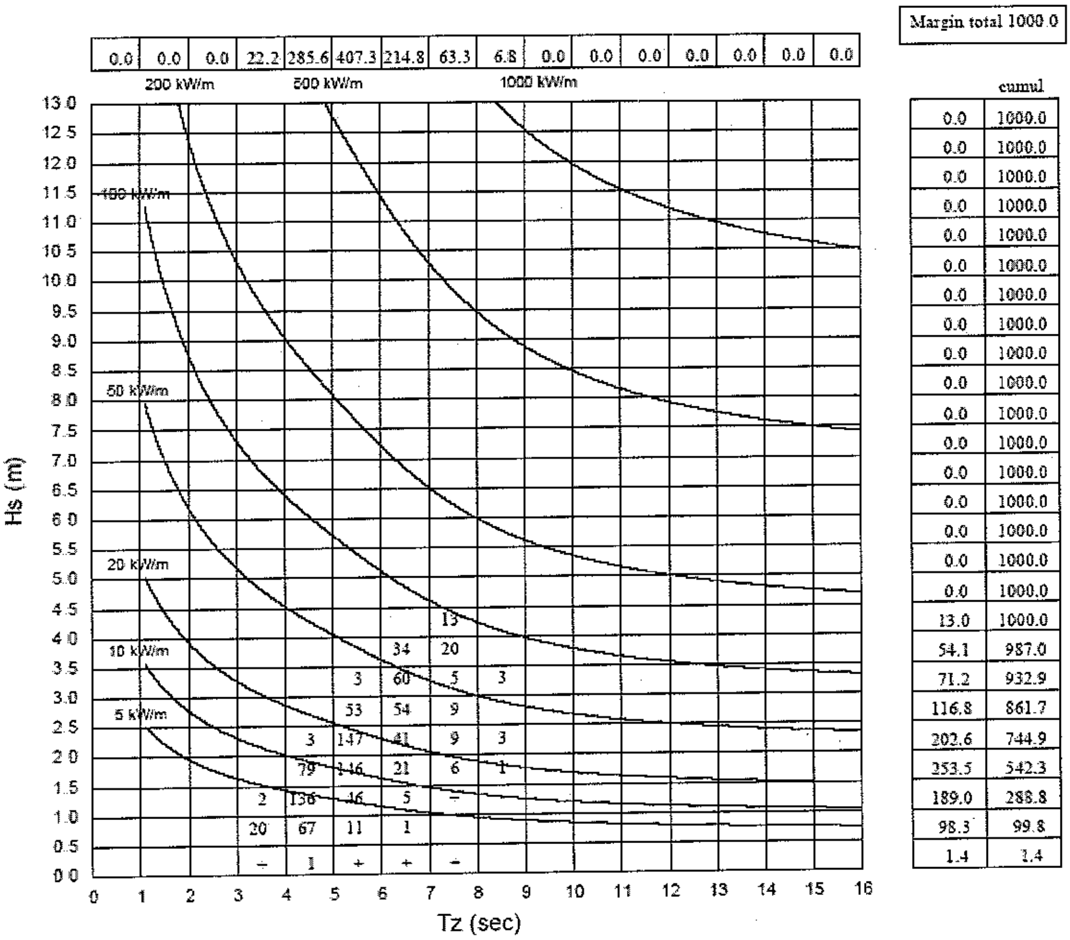
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U03 - SPRING

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\V034139010205.PTF

Plotted on 13 Jan 2004 at 1325

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



- Number of data used: 2924 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Summer 2000 to 2003
- Position: 50.28° N 5.58° W Depth: 30.0 m Designation: U03
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 7.9 kW/m

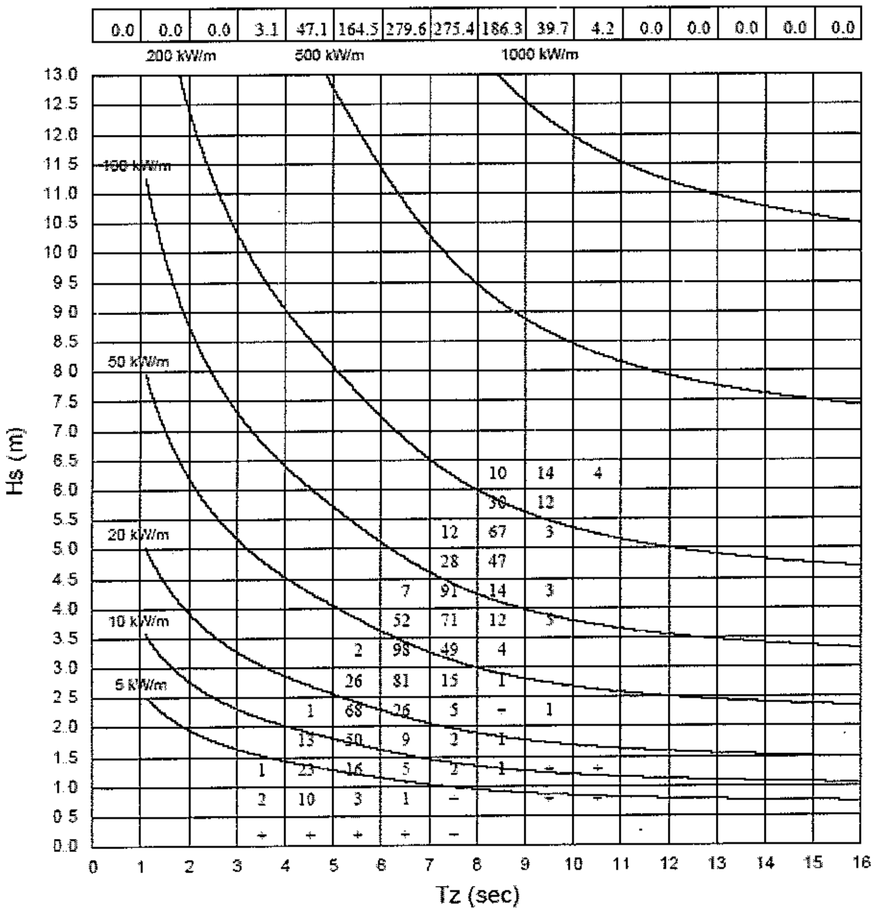
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U03 - SUMMER

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\W034149010205.PTF

Plotted on 13 Jan 2004 at 1327

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 3.1 | 47.1 | 164.5 | 279.6 | 275.4 | 186.3 | 39.7 | 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Margin total 1000.0 | cumul |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| | | | | | | | | 10 | 14 | 4 | | | | | | 28.1 | 1000.0 |
| | | | | | | | | 30 | 12 | | | | | | | 42.6 | 971.9 |
| | | | | | | | 12 | 67 | 3 | | | | | | | 81.3 | 929.3 |
| | | | | | | | 28 | 47 | | | | | | | | 75.2 | 848.0 |
| | | | | | | 7 | 91 | 14 | 3 | | | | | | | 114.7 | 772.8 |
| | | | | | | 52 | 71 | 12 | 3 | | | | | | | 140.9 | 658.1 |
| | | | | | 2 | 98 | 49 | 4 | | | | | | | | 151.9 | 517.2 |
| | | | | | 26 | 81 | 15 | 1 | | | | | | | | 123.2 | 365.2 |
| | | | | 1 | 68 | 26 | 5 | - | 1 | | | | | | | 101.1 | 242.0 |
| | | | | 13 | 30 | 9 | 2 | 1 | | | | | | | | 75.6 | 140.9 |
| | | | 1 | 23 | 16 | 5 | 2 | 1 | + | + | | | | | | 48.9 | 65.4 |
| | | | 2 | 10 | 3 | 1 | - | | + | + | | | | | | 16.2 | 16.4 |
| | | | + | + | + | + | - | | | | | | | | | 0.2 | 0.2 |

- Number of data used: 2902 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Autumn 2000 to 2003
- Position: 50.28° N 5.58° W Depth: 30.0 m Designation: U03
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 26.0 kW/m

DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U03 - AUTUMN

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\W034169010203.PTF

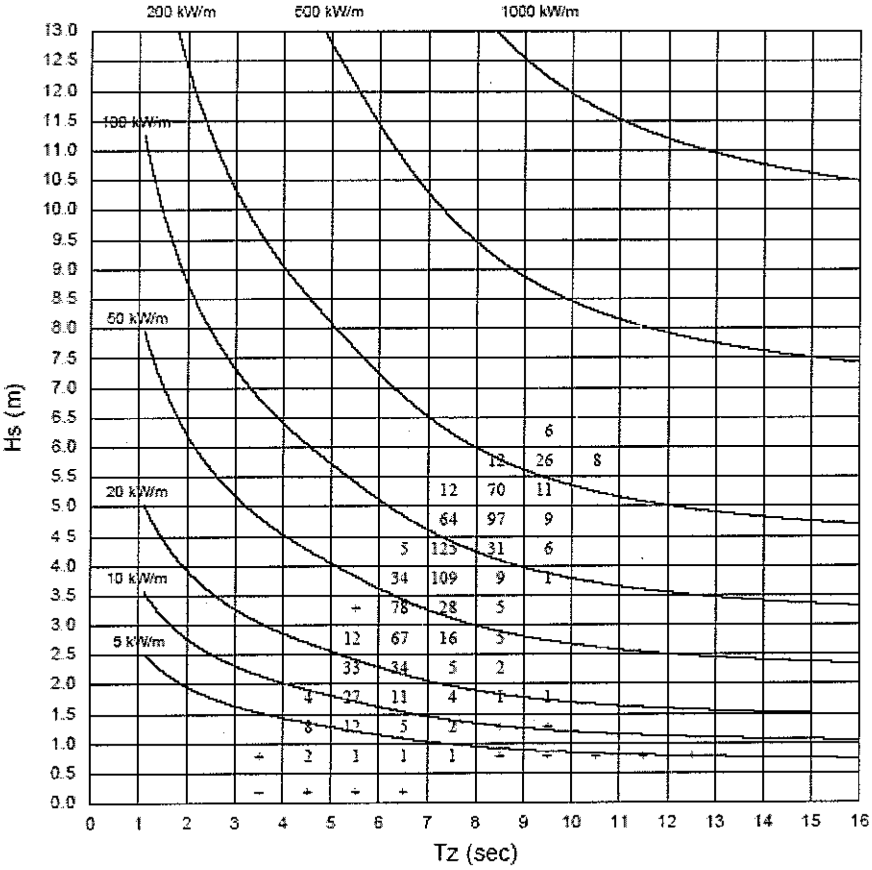
Plotted on 13 Jan 2004 at 1327

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz

Margin total 1000 0

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.3 | 14.1 | 85.9 | 234.2 | 365.3 | 232.1 | 59.4 | 8.6 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |



| | cumul |
|---|---|
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 6.1 | 1000.0 |
| 46.0 | 993.9 |
| 92.6 | 947.9 |
| 170.0 | 855.3 |
| 165.9 | 685.3 |
| 153.3 | 519.3 |
| 111.4 | 366.0 |
| 100.5 | 254.6 |
| 74.0 | 154.1 |
| 47.7 | 80.2 |
| 27.1 | 32.5 |
| 5.4 | 5.4 |
| 0.0 | 0.0 |

- Number of data used: 2151 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Winter 2000 to 2003
- Position: 50.28° N 5.58° W Depth: 30.0 m Designation: U03
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 41.5 kW/m

DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U03 - WINTER

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\W034179010208.PTF

Plotted on 13 Jan 2004 at 1324

## LOCATION U04

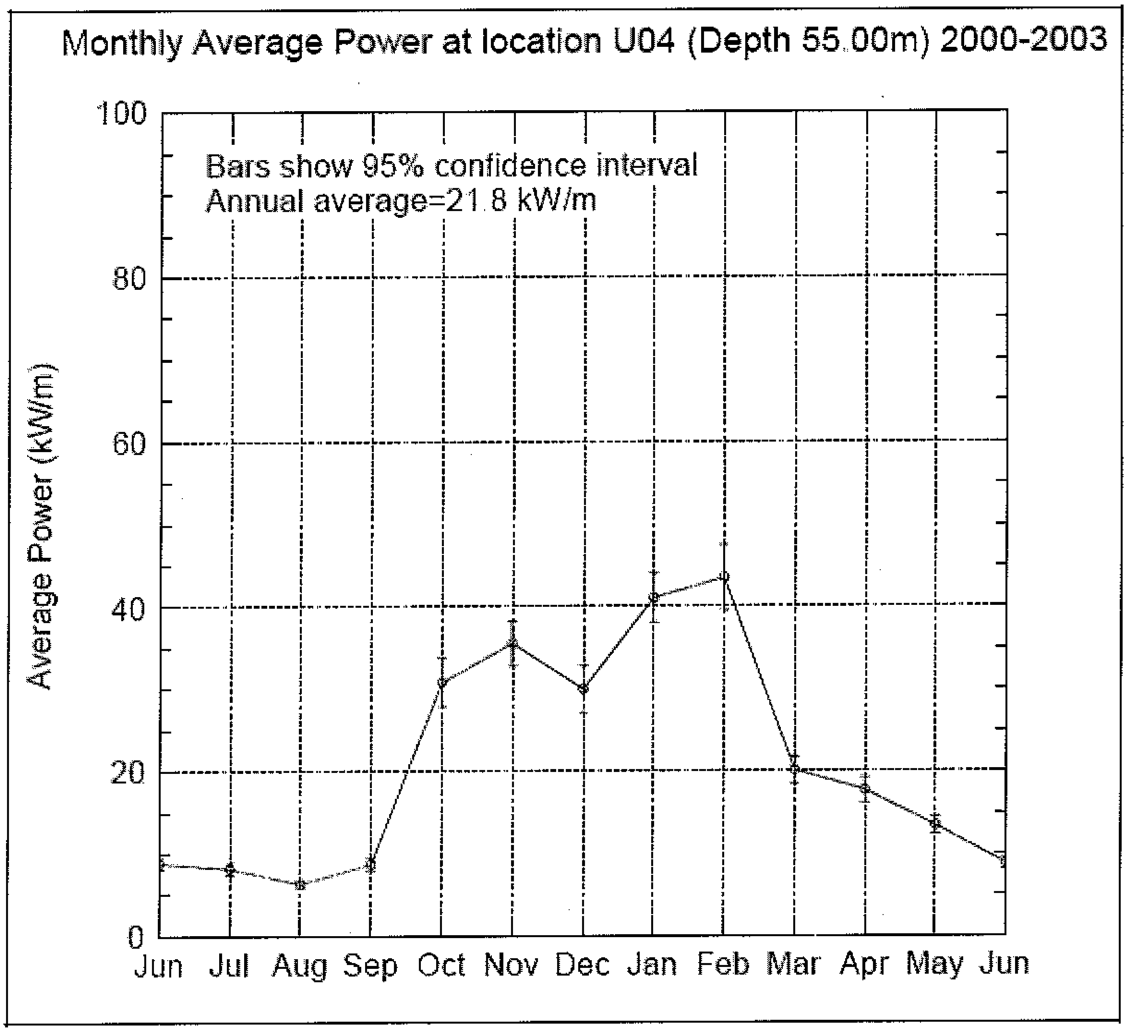
**Data source:** Met Office UK Waters Wave Model

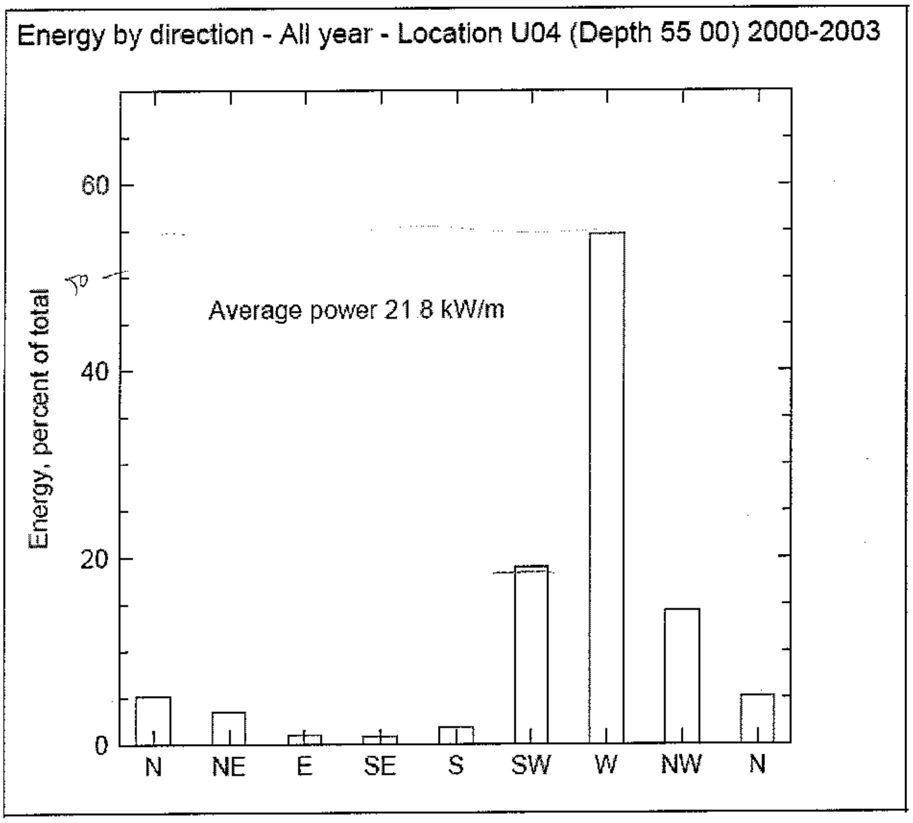
**Gridpoint position:** 50 39°N, 5.58°W

**Depth:** 55.0m

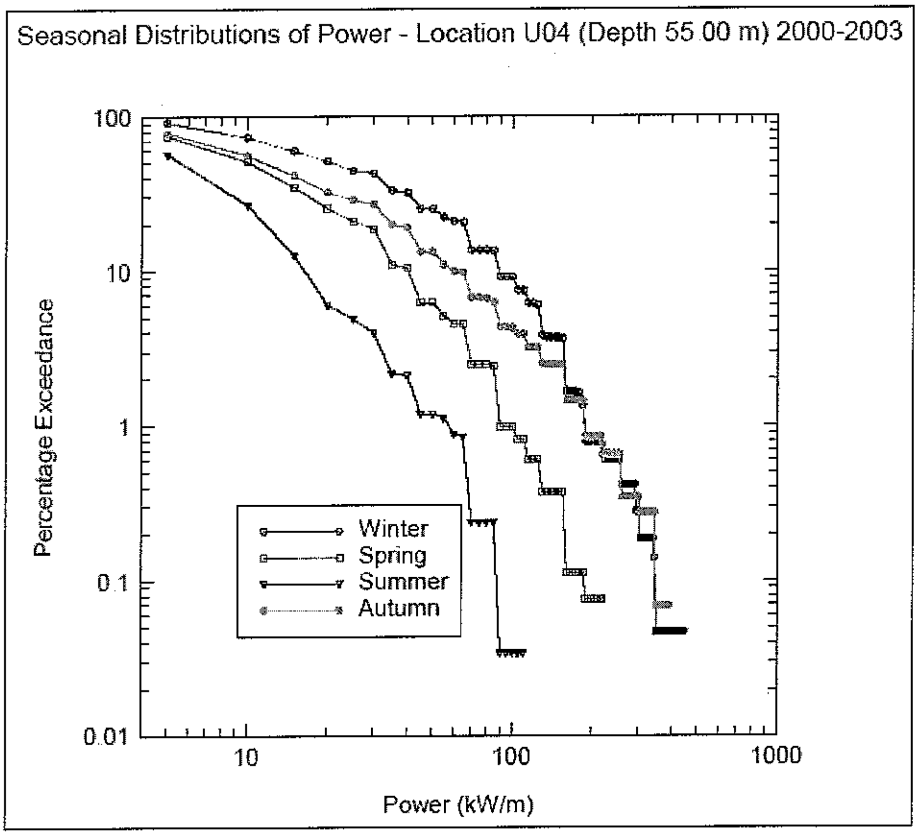
Presentations:

- Monthly Average Power;
- Energy By Direction - All Year;
- Seasonal Distributions of Power;
- Hs:Tz Scatter Diagram – All Year;
- Distribution of Energy with Hs & Tz (All year and 4 seasons)





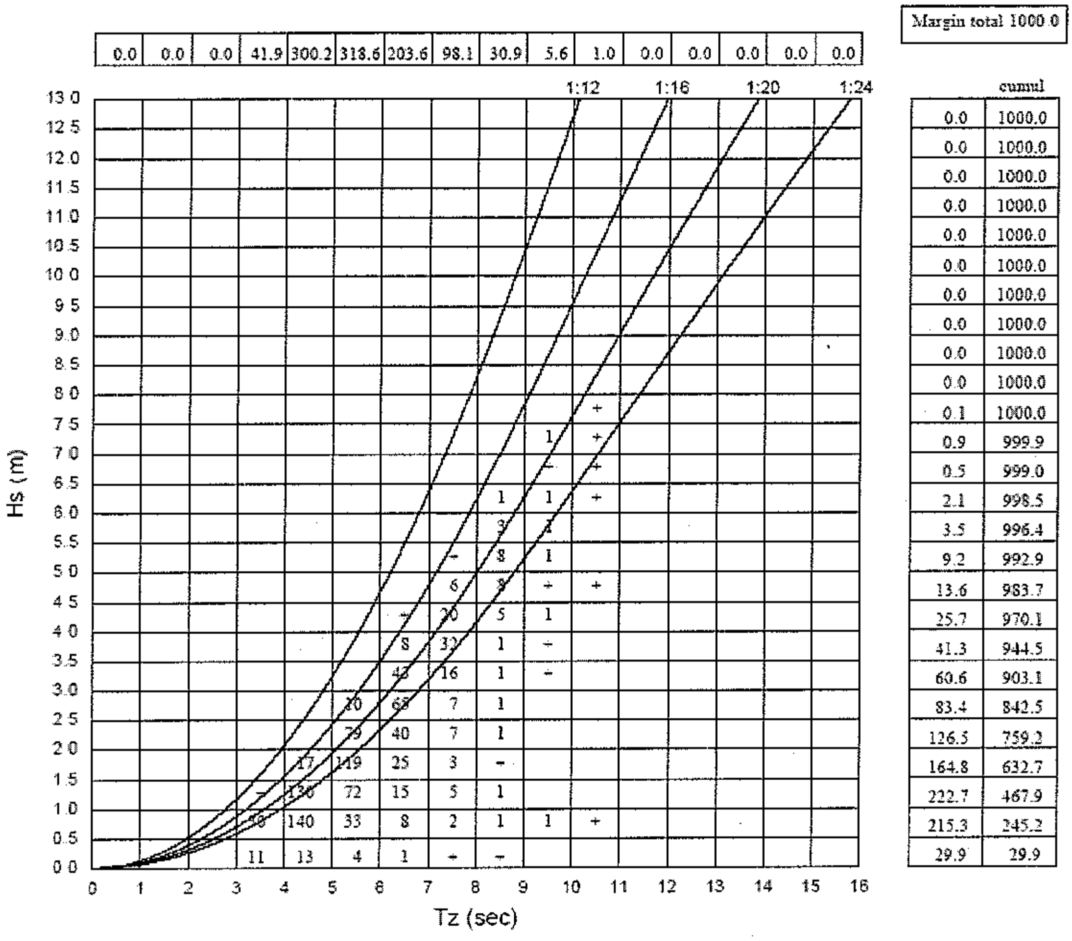
Energy by direction - All year - Location U04 (Depth 55 00) 2000-2003



Seasonal Distributions of Power - Location U04 (Depth 55 00 m) 2000-2003

# SOUTH WEST REGION SEAPOWER REVIEW

## Joint Probability (ppt) of Hs and Tz



- Number of data used (normalised to 4 whole years): 11684 Data interval: 3 0 hours
- Met Office UK Waters Wave Model - All year 2000 to 2003
- Position: 50 39° N 5 58° W Depth: 55 0 m Designation: U04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 21 8 kW/m

HS:TZ SCATTER DIAGRAM - LOCATION U04 - ALL YEAR

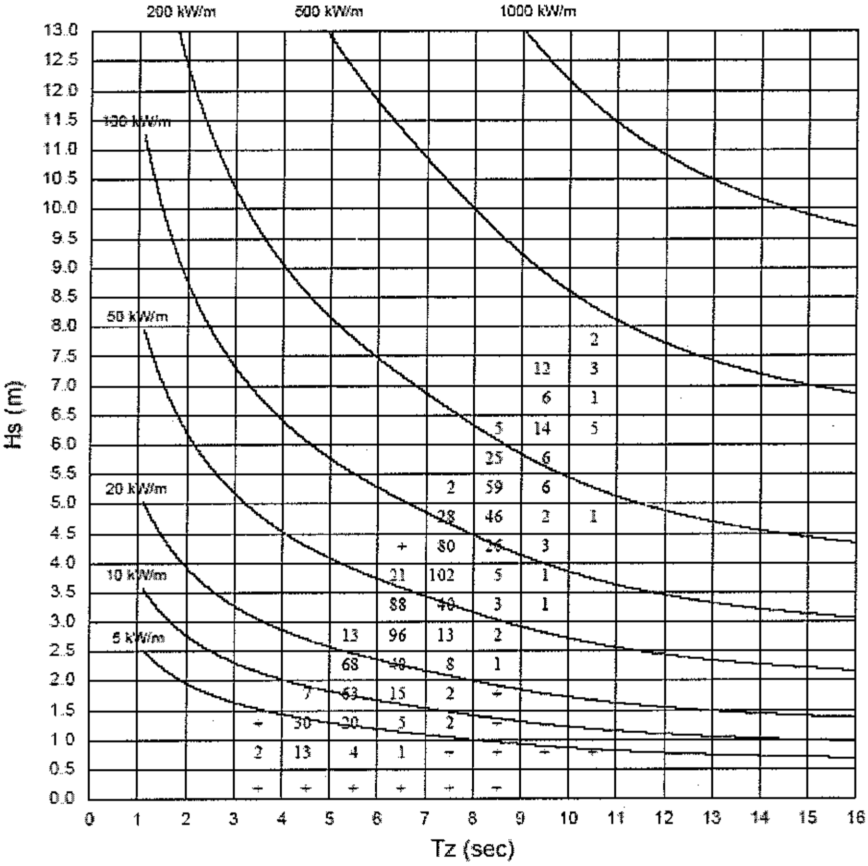
Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\U042000010220.PTF Plotted on 13 Jan 2004 at 1240

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 2.4 | 51.4 | 168.0 | 266.8 | 276.7 | 172.8 | 50.4 | 11.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Margin total 1000.0



| | cumul |
|---|---|
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 0.0 | 1000.0 |
| 1.8 | 1000.0 |
| 15.3 | 998.2 |
| 7.2 | 982.9 |
| 24.0 | 975.7 |
| 31.2 | 951.7 |
| 66.7 | 920.5 |
| 76.3 | 853.9 |
| 108.9 | 777.5 |
| 128.7 | 668.7 |
| 131.0 | 539.9 |
| 123.6 | 408.9 |
| 116.7 | 285.3 |
| 88.9 | 168.6 |
| 58.3 | 79.7 |
| 21.1 | 21.4 |
| 0.3 | 0.3 |

- Number of data used (normalised to 4 whole years): 11684     Data interval: 3.0 hours
- Met Office UK Waters Wave Model - All year 2000 to 2003
- Position: 50.39° N 5.58° W     Depth: 55.0 m     Designation: U04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 21.8 kW/m

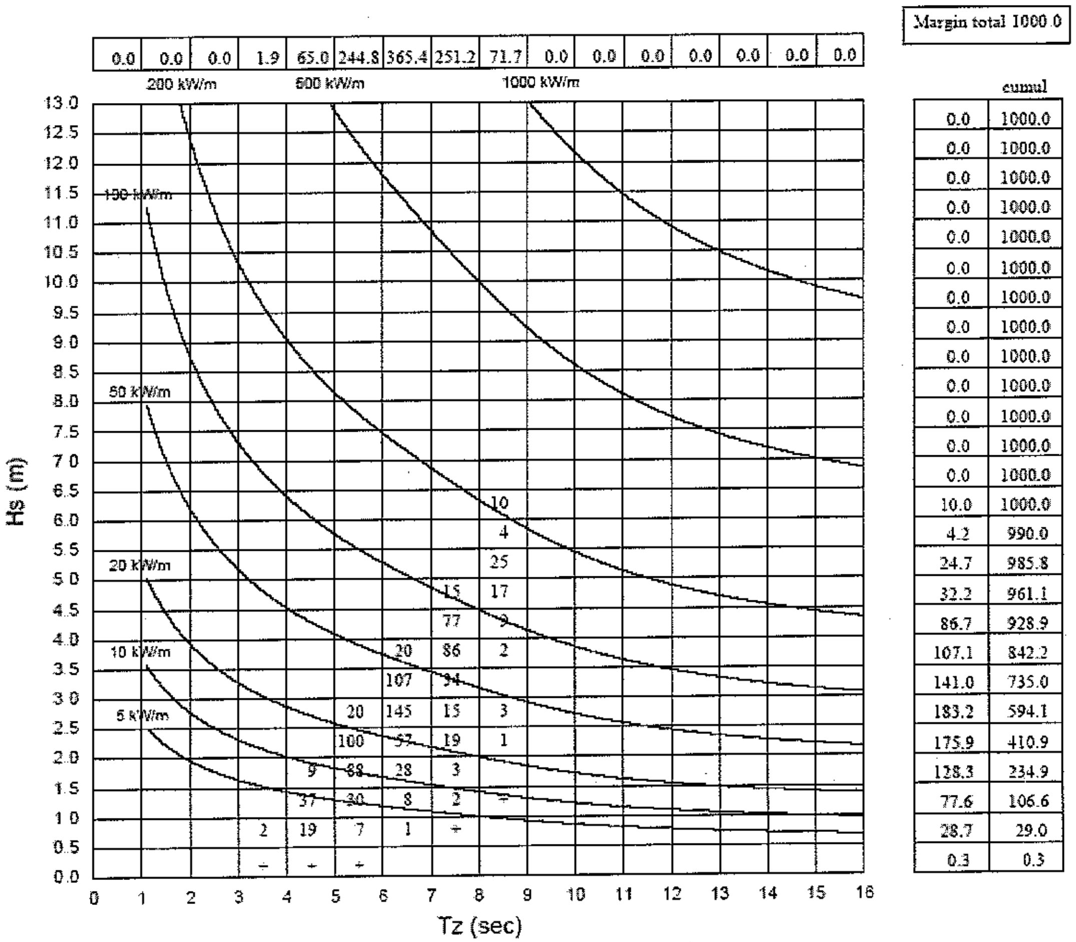
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U04 - ALL YEAR

Input file: (AWR-3) D:\Wave Energy\RegenSW\DATA\W044009010205.PTF

Plotted on 13 Jan 2004 at 1243

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



- Number of data used: 2663 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Spring 2000 to 2003
- Position: 50.39° N 5.58° W Depth: 55.0 m Designation: U04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 16.8 kW/m

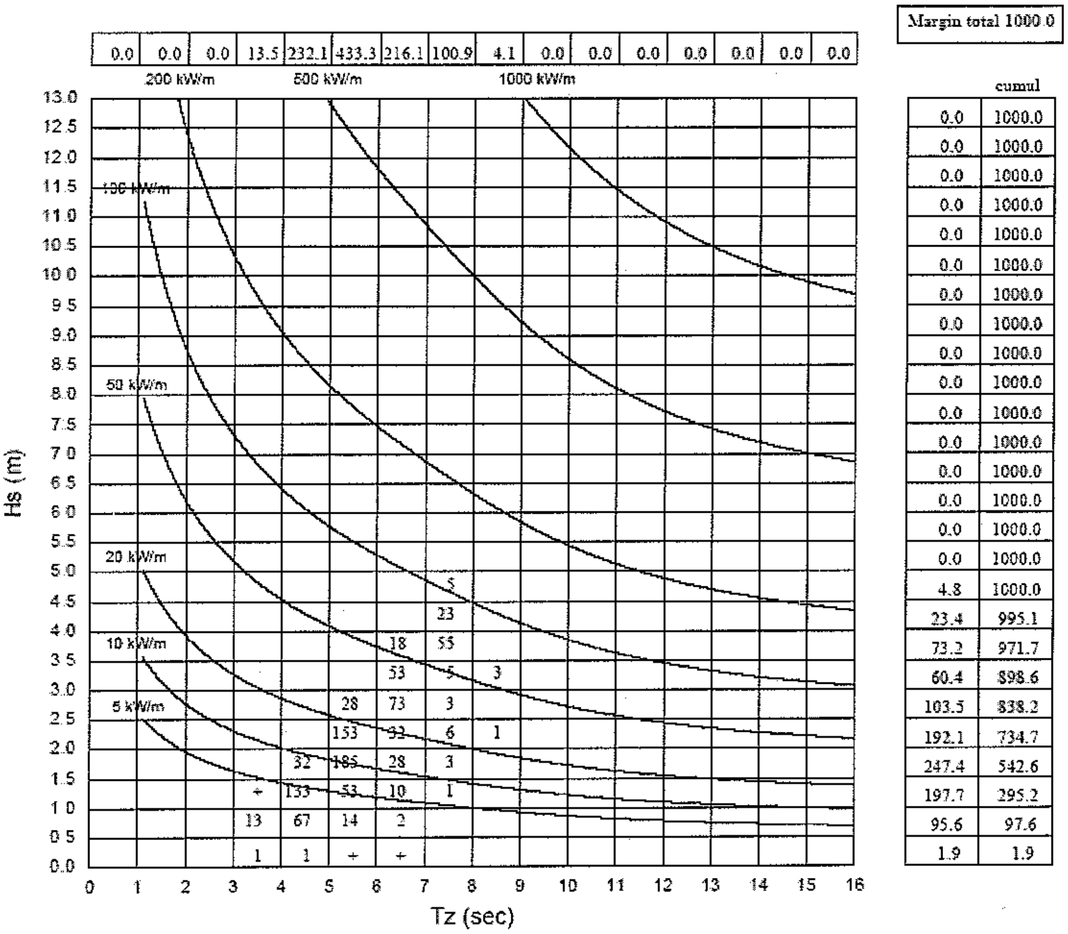
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U04 - SPRING

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\V044139010206.PTF

Plotted on 13 Jan 2004 at 1241

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



| Hs (m) | 0–1 | 1–2 | 2–3 | 3–4 | 4–5 | 5–6 | 6–7 | 7–8 | 8–9 | 9–10 | 10–11 | 11–12 | 12–13 | 13–14 | 14–15 | 15–16 | | cumul |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12.5–13.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 12.0–12.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 11.5–12.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 11.0–11.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 10.5–11.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 10.0–10.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 9.5–10.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 9.0–9.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 8.5–9.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 8.0–8.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 7.5–8.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 7.0–7.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 6.5–7.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 6.0–6.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 5.5–6.0 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 5.0–5.5 | | | | | | | | | | | | | | | | | 0.0 | 1000.0 |
| 4.5–5.0 | | | | | | | | 5 | | | | | | | | | 4.8 | 1000.0 |
| 4.0–4.5 | | | | | | | | 23 | | | | | | | | | 23.4 | 995.1 |
| 3.5–4.0 | | | | | | | 18 | 55 | | | | | | | | | 73.2 | 971.7 |
| 3.0–3.5 | | | | | | | 53 | 5 | 3 | | | | | | | | 60.4 | 898.6 |
| 2.5–3.0 | | | | | | 28 | 73 | 3 | | | | | | | | | 103.5 | 838.2 |
| 2.0–2.5 | | | | | | 153 | 32 | 6 | 1 | | | | | | | | 192.1 | 734.7 |
| 1.5–2.0 | | | | | 32 | 185 | 28 | 3 | | | | | | | | | 247.4 | 542.6 |
| 1.0–1.5 | | | | + | 133 | 53 | 10 | 1 | | | | | | | | | 197.7 | 295.2 |
| 0.5–1.0 | | | | 13 | 67 | 14 | 2 | | | | | | | | | | 95.6 | 97.6 |
| 0.0–0.5 | | | | 1 | 1 | + | + | | | | | | | | | | 1.9 | 1.9 |
| | 0.0 | 0.0 | 0.0 | 13.5 | 232.1 | 433.3 | 216.1 | 100.9 | 4.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |

- Number of data used: 2924 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Summer 2000 to 2003
- Position: 50 39° N 5 58° W Depth: 55.0 m Designation: U04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 7.8 kW/m

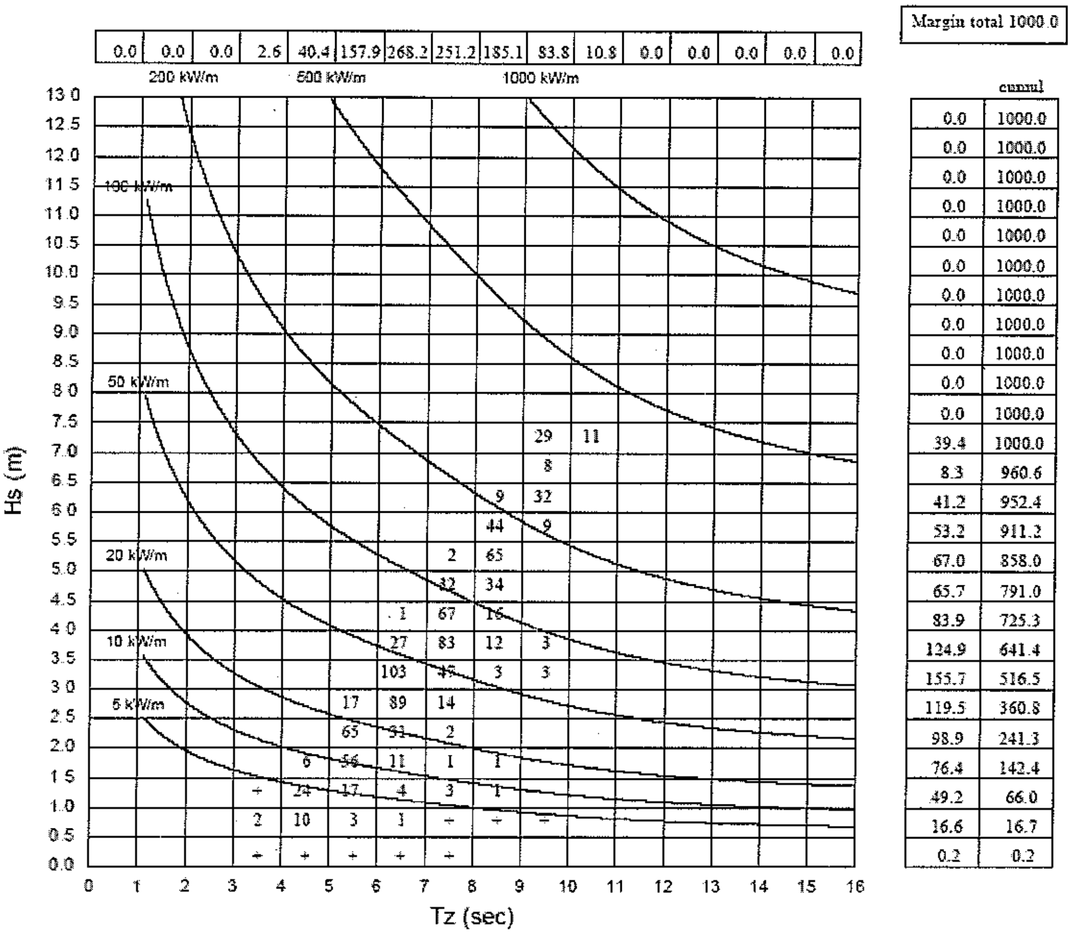
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U04 - SUMMER

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\W044149010205.PTF

Plotted on 13 Jan 2004 at 1242

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



- Number of data used: 2902 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Autumn 2000 to 2003
- Position: 50.39° N 5.58° W Depth: 55.0 m Designation: U04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 25.1 kW/m

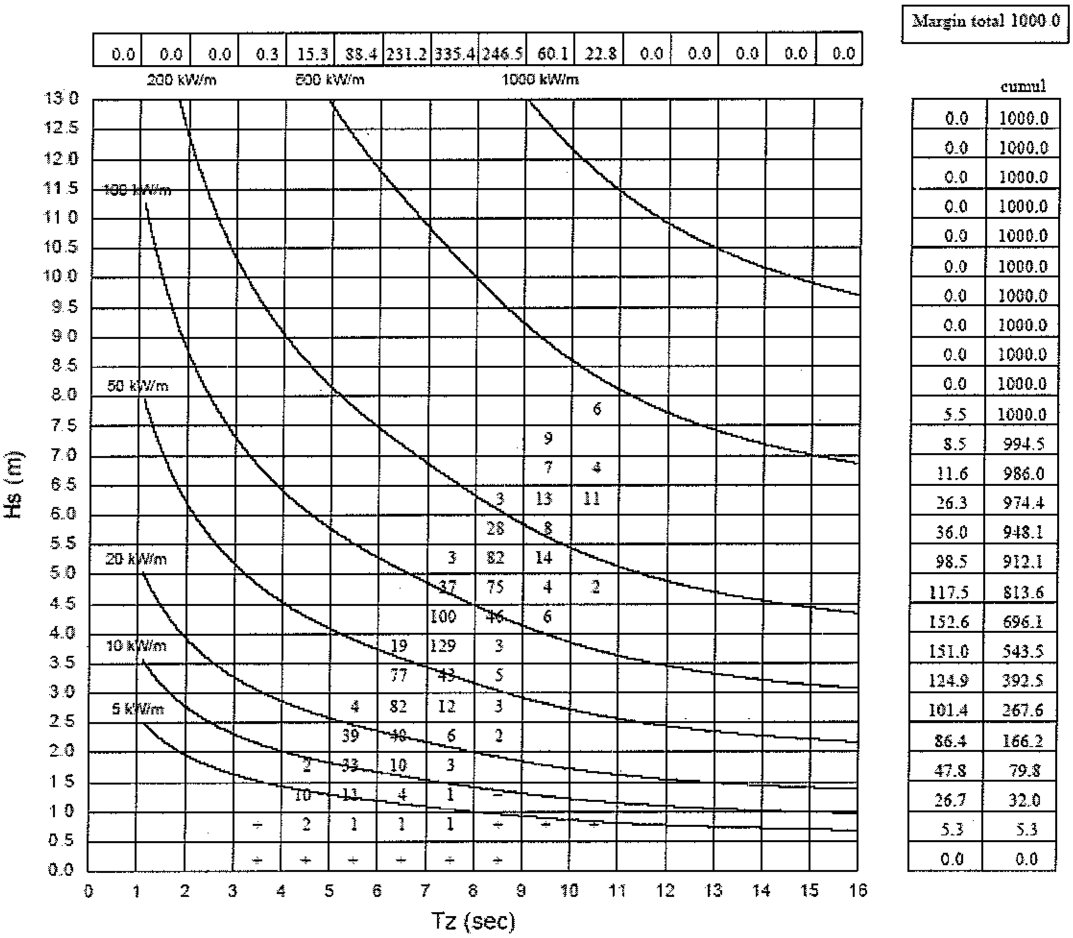
DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U04 - AUTUMN

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\V044169010205.PTF

Plotted on 13 Jan 2004 at 1242

# SOUTH WEST REGION SEAPOWER REVIEW

## Proportion (ppt) of Energy in ranges of Hs and Tz



- Number of data used: 2151 Data interval: 3.0 hours
- Met Office UK Waters Wave Model - Winter 2000 to 2003
- Position: 50.39° N 5.58° W Depth: 55.0 m Designation: U04
- Data obtained from UKMO under licence for use on behalf of SWRDA
- Mean power: 37.8 kW/m

DISTRIBUTION OF ENERGY WITH HS & TZ - LOCATION U04 - WINTER

Input file: (AWR-2) D:\Wave Energy\RegenSW\DATA\W044179010205.PTF Plotted on 13 Jan 2004 at 1241

# Appendix D – Geomorphological Report

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# South West of England Regional Development Agency

## Wave Hub Development and Design Phase

## Coastal Processes Study
## Geomorphological Appendix

May 2006

Halcrow

South West of England
Regional Development Agency

# South West of England Development Agency

## Wave Hub Development and Design Phase
## Interim Coastal Processes Report

## May 2006

## Contents Amendment Record

This report has been issued and amended as follows:

| Issue | Revision | Description | Date | Signed |
|---|---|---|---|---|
| 1 | 1 | Draft | May 2006 | A Richmond |

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# Contents

# 1 Introduction

This appendix addresses geomorphological and sedimentological issues relating to the sub-sea facilities at the Wave Hub and the routing of the 24kV cable to the onshore sub-station at the mouth of the River Hayle.

The aims of this appendix are:

- To provide an overview of the key features and process controls in St Ives Bay;
- To assess the geomorphological variability of the dune and foreshore areas;
- To summarise the mobility / stability of foreshore cover and historic trends through literature review;
- To provide an overview of the River Hayle and its estuary including present trends and future behaviour.

# 2 Coastal Setting

## 2.1 *St Ives Bay*

Situated on the south-west coast of England, St Ives Bay (Figure 2.1 below) is a large bay, approximately 8km long, 3.5km deep. Contained by the headlands of St Ives Head, in the south, and Godrevy Point to the north, the majority of the bay orientates to the north and north-west. Extensive sand dune areas, known locally as 'Towans', stretch along the majority of the frontage. In the centre of the bay lies Hayle Estuary, a 'bar built', multi-branched drowned valley, Table 2.1 (Futurecoast, 2002).

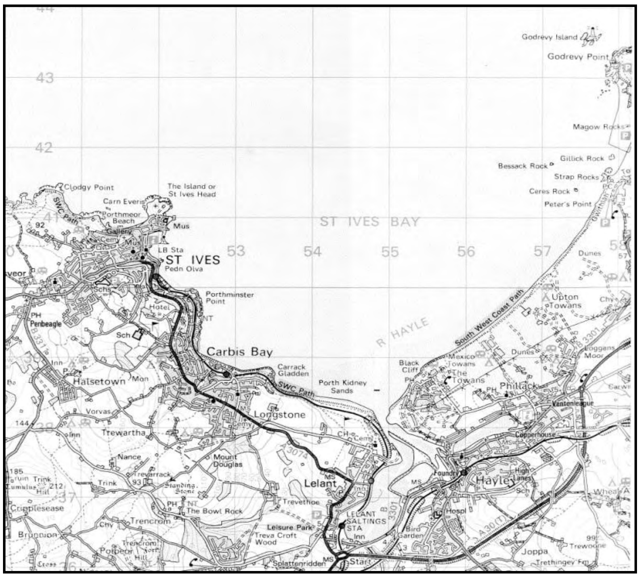

*Figure 2.1 – Location of the study area, St Ives Bay, Cornwall, UK.*

| Total Area (ha) | Inter-tidal Area (ha) | Shore Length (km) | Channel Length (km) | Tidal Range (m) | Geomorphic Type | Human Population |
|---|---|---|---|---|---|---|
| 358 | 321 | 19.5 | 2.4 | 5.0 | Bar built | 15,000 |

*Table 2.1 Summary Statistics of Hayle Estuary (Source: JNCC, 1997)*

Hydraulics Research (1976) noted that there have been considerable fluctuations in the depth of the entrance channel since 1848. This is attributed to numerous unconsolidated sand bars on the estuary bed which are believed to migrate up and down the channel. The estuary was dredged from the late 1700's until the latter half of the 1970's (20,000 tonnes to 30,000 tonnes per annum between 1973 and 2001) primarily to maintain a navigable channel for shipping. Sand extraction continued at the mouth of the estuary until July 2004.

# 3 Historic Geomorphological Behaviour

## *3.1 Offshore*

It is believed that the majority of the sea bed sediments in the study area represent material reworked under rising sea levels that followed the Pleistocene glaciation (125,000 yrs/Before Present (BP) to 12,000 yrs/BP). As sea levels rose (during the Holocene Marine Transgression) the shoreline transgressed landwards and wave action transported sand and gravel material onshore to form the present beaches and dunes. Some sediment was however left in its former position and it is this sediment, which is predominantly medium to coarse grained sand and fine to coarse grained gravel that forms the thin (<1 metre) and patchy distribution of sediment in the offshore zone today. Figures 5.1 and 5.2 illustrate seabed sediment distribution. Under contemporary conditions these sediments are believed to be largely immobile (BGS, 1992 and Halcrow, 2005) and as such it is assumed that there is little movement of these sediments onshore.

## *3.2 Shoreline*

### *3.2.1 St Ives Bay*

It is believed that the beach, fronting this section of the coast, was probably formed predominantly from glacial outwash material, although small quantities of 'raised beach' (from previous marine high stands) may contribute to the store.

Over the recent historic past (<100 years) St Ives Bay has been relatively stable. The rate of cliff erosion, in the western part of the bay, has been gradual and low whilst the backing dunes, which dominate the majority of the study area, show varying patterns of erosion and accretion.

The Hayle Estuary is believed to be a sink rather than sediment source (Futurecoast, 2002) and as such it is unlikely that sediment from the estuary is feeding the peripheral beaches.

Beaches within the bay are believed to have maintained a similar form over the recent historic past (<100 years) albeit with cyclic, localised change.

- The SMP (1999) states that at its time of write-up the *"sand was blocking the mouth of Hayle Estuary, erosion of the dunes directly east of the estuary mouth was also taking place whilst sand accumulations elsewhere were reported to be increasing rapidly."*

- Anecdotal evidence suggests that there is storm erosion and fair weather cycle; whereby material eroded, typically in storms, is re-deposited onto the fronting beach during fair weather / shore normal conditions.

### *3.2.2* *Harvey's Towans*

Babtie (2002) acknowledge that *"natural processes and human intervention have, over time, influenced the Hayle Towans to the east of the estuary mouth."* The tipping of man made material began during the late 1940's and early 1950's has, along with wind blown beach sand, assisted the development of dunes. Recently however there has been concern that the Towans are eroding. Both Sea Sediments (1983) and Babtie (2002) highlight that *"In more recent years, it has been noted that the dune system has retreated exposing previously tipped material."*

A review of historic chart (1848) and aerial photographs (1946, 1985 and 1996) determined the following. An area in front of the dunes along the proposed cable route was infilled in the late 1940s and early 1950s, see Plates 3.1 to 3.4, which advanced the line by some 130m between 1848 and 1946. Dune erosion between 1946 and 1985 led to 70m erosion, whilst the plan alignment of the dunes remained fairly stable between 1985 and 1995, possibly as a result of dune management measures, which include restricting public access to the dunes. The plan shape in front of the dunes appears to have been reasonably stable between 1946 and 1995.

*Plate 3.1: 1848 – Navigation chart*

*Plate 3.2: May 1946 – aerial photograph*

*Plate 3.3: July 1985 – aerial photograph*

*Plate 3.4: June 1996 – aerial photograph*

# 4 Present Day Geomorphological Behaviour

*Plate 4.1 From Harvey's Towans looking west towards Hayle Estuary Mouth (Source: Halcrow)*

Previous reports (SMP[1], 1999; Babtie, 2002; Futurecoast, 2002) have stated that the study area is characterised by:

- Limited input or export of sediment into and out of St Ives Bay i.e. it is a 'closed' sediment system.

- From the perspective of the effect on the coast, the tidal control on sand transport is weak and regionally uncertain, and the volumes of sand involved are limited in comparison with other sectors of the English coast. Wave induced currents are more important in controlling sediment movement. The prevailing winds are from the south and west, but winds with an easterly component can produce significant movement of sediment. Storm events

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[1] *Lands End to Hartland Point Shoreline Management Plan, 1999*

cause movement of sand on the inner shelf but the effects are greatest in the narrow, shallower nearshore zone (Futurecoast, 2002).

- Cross-shore sediment transport takes place.
- There is a clock-wise circulation of sediment. It is transported alongshore from the east to Hayle Beach, where it may settle in Hayle Estuary or be transported alongshore on an ebb tide to Porth Kidney Sands and Carbis Bay. Once in the vicinity of St Ives Headland, offshore currents transport the sediment to Godrevy Point and the circular motion starts again (Babtie, 2002).
- There is potential for drift between Porth Kidney Sands in the west across the mouth of the estuary towards Black Cliff beach.

# 5 Morphological Issues Influencing the Cable

## *5.1 Introduction*

For sea bed cables, there are a number of morphological issues that have the potential to impact upon the choice of route and approach to sea bed installation, including:

- The type of sediment;
- The thickness of sediment;
- The amounts of transport (potential for structural damage/ cable scour);
- The variability in bed levels.

Table 5.1 explains the significance of these issues in more detail.

This chapter discusses the issues in the context of the Wave Hub project, drawing on available, existing information. Consideration is given to the offshore (Zones 6, 7, 8 and 9), transitional zone (Zones 3, 4 and 5), nearshore (Zones 1 and 2) and onshore (see Figure 5.1 and 5.2) to inform the preferred cable and cable-routing methodology versus sedimentological and geomorphological considerations.

| **Process / Sedimentological / Geomorphological Considerations** | | **Significance** |
|---|---|---|
| **Sediment Type** | | Influences grain size, which in turn influences sediment mobility.<br>Influences abrasion of cable |
| **Thickness of Sediment Cover** | | Influences burial depths and maximum depth of scour |
| **Temporal Variation in present sea bed/beach elevation**<br>Short term: e.g. mobile sand waves, storm/fair weather beach cycles<br>Long term: e.g. long term depletion of sea bed sediments, decadal progradation or recession of shorelines | | Determines whether cable could become buried or exhumed |
| **Sediment Transport** | Magnitude of sediment transport occurs<br>What is direction of transport? | Determines the potential for scour/burial |
| | Is transport driven by waves or currents? | Determines when transport occurs e.g. tides follow a predicable cycle's semi-diurnal, spring neap, autumnal and spring equinoxes.<br>Wave activity is more seasonal with larger waves occurring in the winter months |

*Table 5.1 Coastal process and Geomorphological considerations for sea bed cables*

### 5.2 *Proposed Cable Routing*

The 24kV cable will extend from the Wave Hub, some 16km offshore, to a sub-station on the mainland near to the mouth of the Hayle estuary. In the offshore zone it is proposed that the cable will be laid on the seabed. At a depth of approximately 20mCD, the cable will be buried into the superficial sediments to the Mean Low Water Mark (MLWM). Thereafter the cable will be buried in the beach sands. It will then run beneath the foreshore, a distance of approximately 800m, to the toe of the high sand dunes.

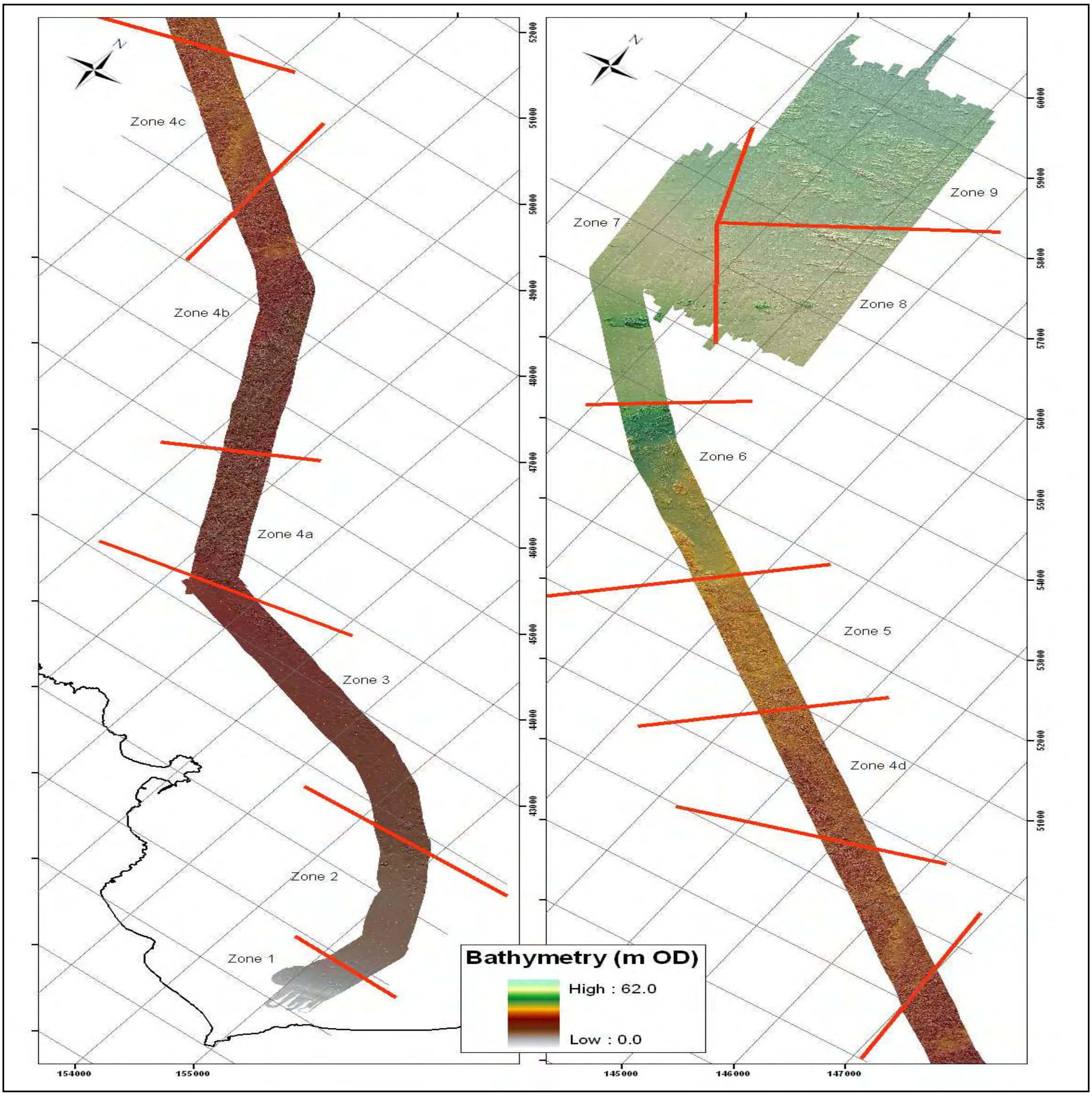


*Figure 5.1 Zones and Bathymetry of the Proposed Site and Cable Route (Halcrow, 2005)*

## *5.3 Offshore factors affecting the cable*

Offshore the cable will 'rest' on the seabed rather than of being buried with superficial sediments, due to the apparent lack of superficial seabed sediments in the offshore.

### *5.3.1 Sediment Type*

The type of sediment influences the choice and depth of cable covering i.e. if the sediment is coarse a more rugged casing of the cable is required, if however the sediment is fine and well rounded then the sediment is less abrasive and therefore the cable casing will not need to be as durable.

The British Geological Survey (Maps: Institute of Geological Sciences (IGS) (1983a & b), and British Geological Survey, 1987) concludes that the study area comprises mainly sand, sandy gravel, gravely sand, gravel and rock (Figure 5.2). In the offshore zone (<-20mCD) gravely sand is the predominant sediment type. These overlie undivided Devonian to Carboniferous rocks. Futurecoast (2002) concurs with this, stating that throughout the study site there is a predominance of Holocene (10,000 years BP to present) seabed sediments; consisting of granular soils: composed of generally medium to coarse grained sand and fine to coarse grained gravel (sub-rounded), with the occasional cobble sized material.

English Nature (2004) also investigated offshore sediment type and concluded that the main sediment was sand mixed occasionally with shelly gravel. These sediments are believed to represent a 'lag' deposit, created by vigorous wave action as sea level rose at the end of the last glaciation. English Nature also recognises that areas of the seafloor consist of rocky outcrops, reefs, submerged cliffs and sea caves (submerged and emergent). The outcrops are formed from folded Devonian and Carboniferous rocks and igneous intrusions.

More recently Halcrow (2005) conducted an offshore geotechnical survey, samples from this survey are presented in Figure 5.3 and 5.4, from the CPT bores if is evident that gravelly sand and sandy gravel is the most predominant sea bed sediment, which overlies the bedrock composed primarily of mudstone / shale.

### *5.3.2 Thickness of sediment cover*

The resistant nature of the bedrock and the limited glacially derived sediment that seabed sediments offshore are commonly less than one metre thick (British Geological Survey, 1983; 1987, *Evans et al. (1990) and English Nature (2004)).*

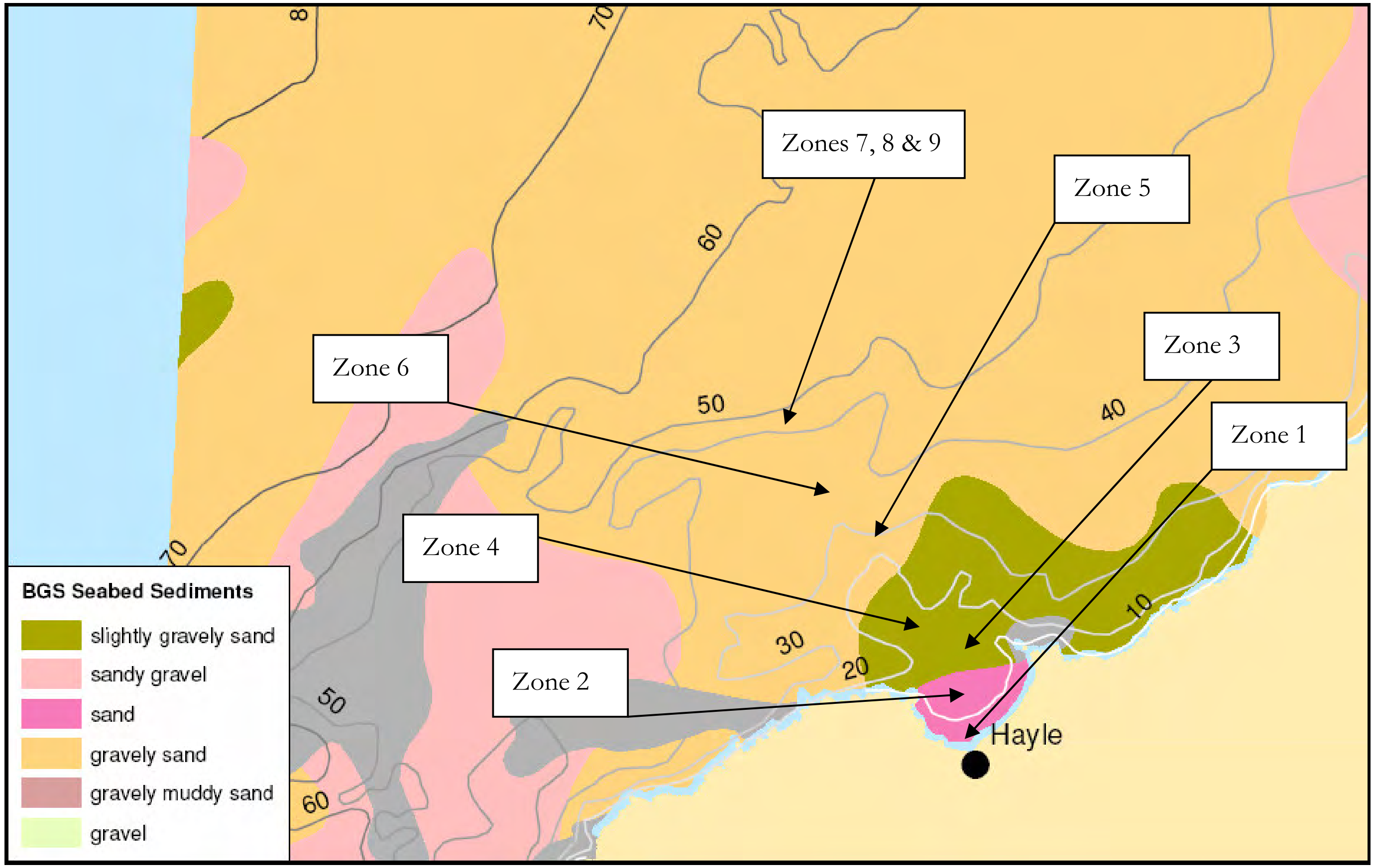
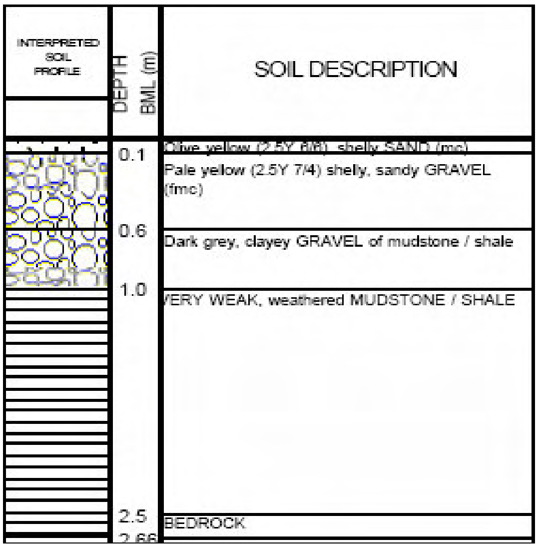


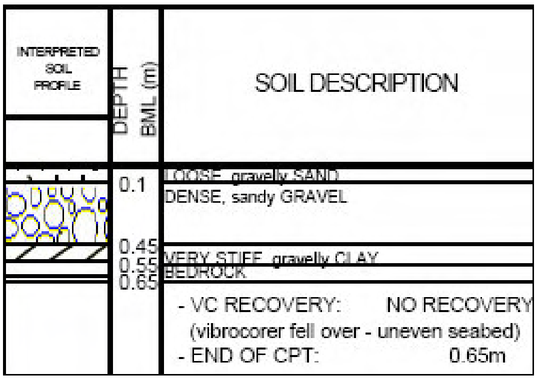
*Figure 5.2 Seabed Sediments (Source: British Geological Survey, 1987)*

*Figure 5.3* *Regional Seabed Sediments (Source: Halcrow, 2005)*

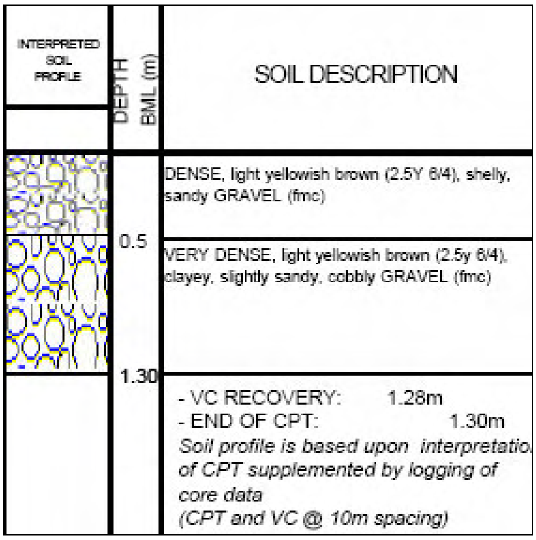
English Nature (2004) attributes the thin layer of sediment cover that is present to the recent geological past i.e. the last 10,000 years Before Present (BP). English Nature also regards this sediment as being partially mobile. To ascertain some site specific certainty Halcrow (2005) conducted an offshore survey (refer to Figure 5.4 for an indication of the results and to Geotechnic Report for further details). In essence Halcrow (2005) found that their results agree with BGS, Evans et al., (1990) and English Nature (2004).



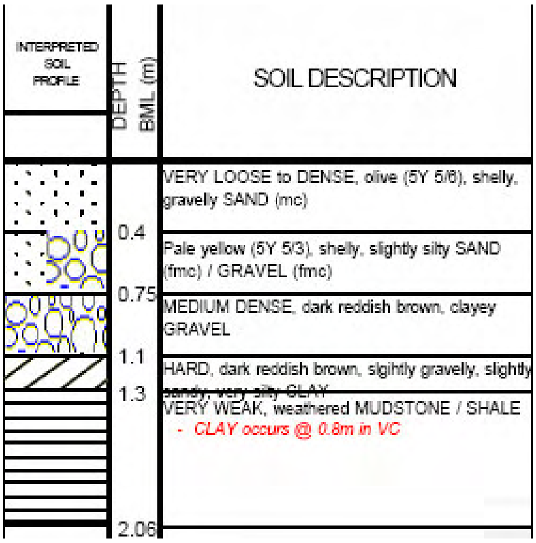
CPT 18a (138 347mE / 57 080mN)



CPT 19c (138 358mE / 57 233mN)



20a (38 419mE / 57 163mN)



22a (138 389mE / 56 928 mN)

*Figure 5.4: Offshore Sediment Samples (Halcrow, 2005):* CPT (Piezocone Penetration Test) and VC (Vibrocore)

### 5.3.3 *Sea Bed Topography*

The seabed geomorphology of the study region was initially investigated by Evans (1990) who described the seabed as a very shallow slope of the inner continental shelf. Evans (1990) noted that regional bathymetric surveys had identified that there were limited seabed features in the region, although large sand ridges were recorded further offshore, on the outer continental shelf. Halcrow updated this information in 2005, when they investigated the sea bed using bathymetry survey results and preliminary BGS side sonar data. Detailed results, from the survey, are available in the Geohazard's Report (in progress). However, in essence the report concluded that despite the seabed being vertically bedded, sea bed gradient is extremely shallow, generally around 0.5°[2] and that there does not appear to be any mobile sand waves / sand banks, which arises due to the limited amount of seabed sediment cover.

English Nature (2004) investigated the regional bathymetry of the north coast of Cornwall and concluded that *"the large-scale topography of the seabed is generally featureless"*. They also go onto state that the *"bathymetry of the north coast of the Cornish peninsula is relatively smooth, with the seabed sloping steeply out to the 50-metre contour before levelling out onto the west-sloping continental shelf"*.

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[2] *Consultation with the Hydrographic Society (www.hydrographicsociety.co.uk) advocates that a cable should not be routed if the seabed gradient is greater than 10% thus it appears that there is no cause for concern here*

### 5.3.4 *Sediment Transport*

There is very little published data on sediment transport in the study area. However some assumptions have been drawn from the location of the study site and generic offshore sediment transport.

- Being on the UK Atlantic Margin it is accepted that the South West region has a good wave and tidal stream. SWRDA propose that the South West is exposed to waves from the west and southwest, but are shielded by Ireland to some extent from waves from the northwest.

- Generally it is accepted that transport in the offshore zone is mainly related to currents as the influence of waves is limited to shallow water depths (i.e. <10m, which is not the case here). Unfortunately there is no admiralty information regarding tidal currents for St Ives Bay however there is information for the South West, for example tidal current speeds range from 0.72 metres per second off Lundy to over 3.0 metres per second in the Bristol Deep off Avonmouth (Poulton *et al* 2002, English Nature 2004).

- The lack of sediment in the offshore is either related to: 1) a lack of sediment transport generally or 2) coarse sediment is present but its critical transport threshold is not exceeded.

- In essence we believe that as depth exceeds 10m and sediment on the seabed is coarse the opportunity for sediment movement is unfavourable.

- We have assumed, as there is no data available, that sediment transport takes place during storm conditions. However as the majority of material in the offshore is coarse, clastic and located at a depth greater than 10m we speculate that this is not the case here.

- We speculate that very little change, on the sea bed, has taken place over the past 100 years as no major features, in response to constructive / destructive forces have been recorded by BGS (1983, 1987); Poulton et al, (2002); English Nature, (2004) and Halcrow (2005).

## 5.4 Transitional zone factors related to the cable

As previously stated the transitional zone lies between the offshore and the nearshore and comprises Zones 3, 4 and 5 (see Figure 5.1 and Figure 5.2).

### 5.4.1 *Sediment Type*

The BGS (1997) survey concluded that the main sediment type in nearshore / transitional zone (-15mCD to -20-35mCD) is slightly gravely sand. Halcrow (2005) surveyed the nearshore and found that sediment types in the transitional zone were typically coarse comprising dense olive grey coloured sand and gravel as well as shelly-sandy gravel. Samples from the Offshore Geotechnical Survey are presented in Figures 5.5 to 5.8 however, for further details please refer to the 'Offshore Geotechnical Report' (Halcrow, 2005).

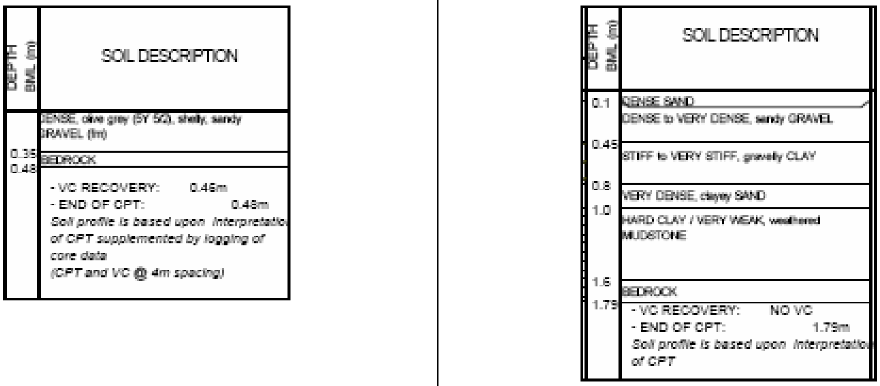
### 5.4.2 *Sediment Thickness*

BGS (1997) do not define sediment thickness in their survey; however Halcrow's Offshore Geotechnical Survey (2005) highlights that the superficial sediment is typically in the region of 0.2 metres thick, overlying mudstone and/or shale bedrock (Figures 5.5 to 5.8). Halcrow (2005) also found that the thin superficial sediment cover becomes increasingly intermittent towards the offshore zone. For example between Zones 3 and 4 there is a gradual reduction in sand cover over bedrock, which we speculate may be related to past events (i.e. the Holocene Marine Transgression), greater currents in that area due to a lack of headland protection. Conversely the sediment cover in Zone 3 is much thinner than in Zones 1 and 2 i.e. the nearshore area, which suggests:

1) Sediment is not deposited in Zone 3,

2) Sediment is transported away from Zone 3 or

3) The variation in thickness may be a legacy of past onshore movement of sediments under a scenario of sea level rise.



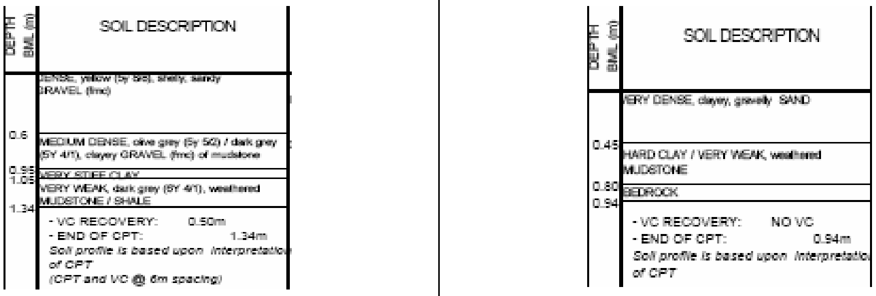
| DEPTH BML (m) | SOIL DESCRIPTION |
|---|---|
| | DENSE, olive grey (5Y 5/2), shelly, sandy GRAVEL (fm) |
| 0.35 | BEDROCK |
| 0.48 | - VC RECOVERY: 0.46m<br>- END OF CPT: 0.48m<br>*Soil profile is based upon Interpretatio*<br>*of CPT supplemented by logging of*<br>*core data*<br>*(CPT and VC @ 4m spacing)* |

5A (153462mE/42556mN)

| DEPTH BML (m) | SOIL DESCRIPTION |
|---|---|
| | DENSE SAND |
| 0.1 | DENSE to VERY DENSE, sandy GRAVEL |
| 0.45 | STIFF to VERY STIFF, gravelly CLAY |
| 0.8 | VERY DENSE, clayey SAND |
| 1.0 | HARD CLAY / VERY WEAK, weathered MUDSTONE |
| 1.6 | BEDROCK |
| 1.79 | - VC RECOVERY: NO VC<br>- END OF CPT: 1.79m<br>*Soil profile is based upon Interpretatio*<br>*of CPT* |

6A (152462mE/42743mN)

*Figure 5.5* *Transitional Zone (Zones 3) Sediment Samples (Halcrow, 2005)*



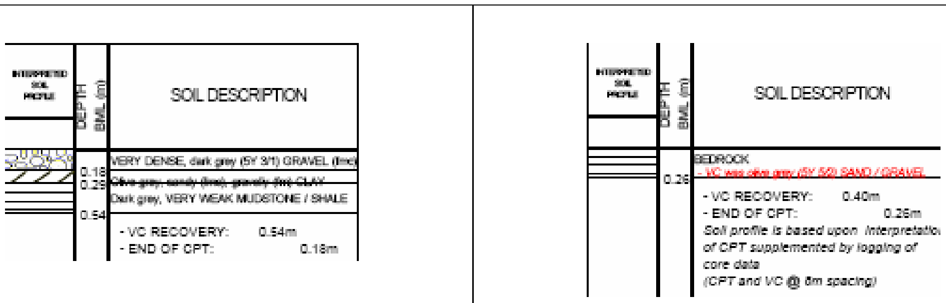
| DEPTH BML (m) | SOIL DESCRIPTION |
|---|---|
| | DENSE, yellow (5y 5/6), shelly, sandy GRAVEL (fmc) |
| 0.6 | MEDIUM DENSE, olive grey (5y 5/2) / dark grey (5Y 4/1), clayey GRAVEL (fmc) of mudstone |
| 0.95 | VERY STIFF CLAY |
| 1.05 | VERY WEAK, dark grey (5Y 4/1), weathered MUDSTONE / SHALE |
| 1.34 | - VC RECOVERY: 0.50m<br>- END OF CPT: 1.34m<br>*Soil profile is based upon Interpretatio*<br>*of CPT*<br>*(CPT and VC @ 6m spacing)* |

7A (151498mE/42952mN)

| DEPTH BML (m) | SOIL DESCRIPTION |
|---|---|
| | VERY DENSE, clayey, gravelly SAND |
| 0.45 | HARD CLAY / VERY WEAK, weathered MUDSTONE |
| 0.80 | BEDROCK |
| 0.94 | - VC RECOVERY: NO VC<br>- END OF CPT: 0.94m<br>*Soil profile is based upon Interpretatio*<br>*of CPT* |

8A (150541mE/43229mN)

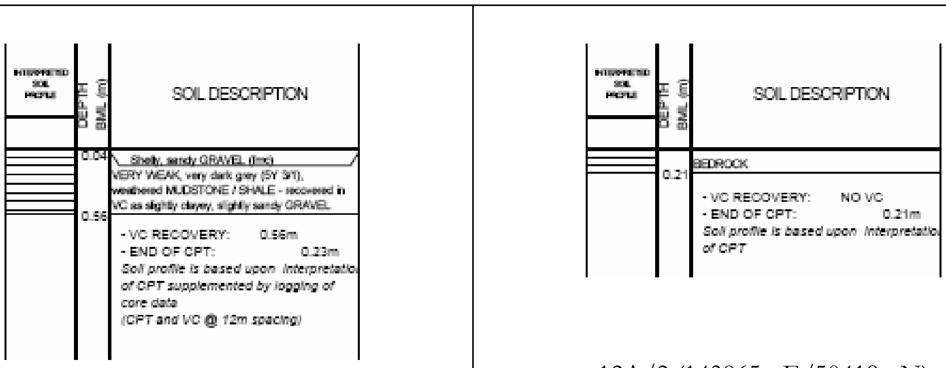
*Figure 5.6* *Transitional Zone (Zones 3) Sediment Samples (Halcrow, 2005)*



9A (149 994mE / 44 212mN)

10a (148436mE/46759mN)

*Figure 5.7 Transitional Zone (Zones 4) Sediment Samples (Halcrow, 2005)*



11A (146373mE/48802mN)

12A/2 (143865mE/50419mN)

*Figure 5.8 Transitional Zone (Zones 5) Sediment Samples (Halcrow, 2005)*

### 5.4.3 *Sea Bed Topography*

In 2005 Halcrow conducted a Geotechnic and Geohazard Survey. Generally the survey found that the sea bed topography was generally flat with small areas of variation related to the thickness of sediment cover and exposure of bedrock.

- In 'Zone 3', for example, the seabed topography slopes gently and is predominantly smooth albeit with common outcrops of rock.

- In 'Zone 4' (see Figure 5.7) the rock surface is also gently sloping but sections of the seabed are convex, concave and flat. The rock here is folded, jointed and has clearly visible steeply dipping bedding. The rock also has a very rough surface with bedding aligned in four general directions.

- In 'Zone 5' the survey found that the seabed is again of a very gently sloping gradient, often covered with a thin veneer of sediment. Zone 5 is also dominated by rock outcrop.

### 5.4.4 *Sediment Transport*

There is very little published information to date regarding sediment transport in the transitional zone therefore a modelling study is being carried out, by Halcrow, to determine a number of characteristics of the sediment transport regime. It is foreseen that the results from this study will help determine:

- The magnitude and duration of sediment transport under different events i.e. storm and normal
- The relative importance of waves and currents on sediment transport in the transitional zone
- The direction of sediment transport
- The degree of scour that the cable could experience

In the interim we have used geomorphological knowledge to assume the following:

- Transport in deep water is mainly related to currents as the influence of waves are limited to shallow depths i.e. <10m.

- The lack of sediment in the transitional zone could be related to: 1) a lack of sediment transport generally or 2) coarse sediment is present but its critical transport threshold is not exceeded.

- In essence we believe that as depth exceeds 10m and sediment on the seabed is coarse the opportunity for sediment movement is unfavourable. However in Zone 3 there appears to be an exchange of sediment between the nearshore and the offshore. Both BGS (1997) and Halcrow (2005) have identified linear hollows between the transitional boundary of Zone 3 and the nearshore boundary of Zone 2; Halcrow (2006) attributes this to current scour.

- We speculate that very little change, on the sea bed, has taken place over the past 100 years as no major features, in response to constructive / destructive forces) have been recorded by BGS (1983, 1987); Poulton et al, (2002); English Nature, (2004) and Halcrow (2005).

5.4.5 *Long term trends in sea bed change*

Unfortunately there is a general lack of offshore data thus it is difficult to ascertain spatial and temporal change. We speculate that very little change has taken place over the past 100 years as no major features, related to constructive / destructive forces were recorded by BGS (1983, 1987); Poulton et al. (2002); English Nature, (2004) and more recently Halcrow (2005).

We speculate that no significant change is initially attributed to a lack of seabed sediments, a legacy of the Holocene (10,000 yrs/BP) plus a lack of contemporary sediment being added to the system. This section of the coast also occupies a relatively sheltered position i.e. the headland at St Ives provides the transitional zone with a certain degree of shelter whilst it is also beyond the confines of the nearshore / foreshore boundary of sediment movement. In the case of the latter it is unlikely that accretional features such as sand bars would build here. Conversely the Geotechnical and Geohazard's survey identified no significant erosional features i.e. troughs and from this we conclude that there has been no significant change of the seabed over the past 100 years.

5.4.6 *Potential for cable undermining*

One future cause for concern is that the bedrock in this area is composed of mudstone and shale (Figure 5.7 and 5.8).[3] It is understood that these sedimentary rocks erode and if a heavy cable is to be laid on top of this then it may prompt a certain degree of scour, which could lead to localised undermining of the cable.

5.4.7 *Foundation issues related to changing bed levels*

The Geohazard Report (in progress) concluded that bed levels in the transitional zone vary very little thus no / little accommodation needs to be made for bed level change. However consideration needs to be given to bedrock type (i.e. mudstone and shale) which the cable could abrade and thus undermine anchoring foundations.

5.4.8 *Potential for cable burial*

The cable in the transitional zone will 'rest' on the seabed. Despite the cable being approximately 0.1m in height and the average depth of seabed sediments being

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[3] *Shale and Mudstone: is a fine-grained sedimentary rock made up of clay-to silt-sized particles (up to 0.0625 mm). Formed from relatively fine grained weathered rock material, these rocks are clearly layered and crumble easily. When consolidated and relatively massive it is known as mudstone (or claystone); if finely bedded so that it splits readily into thin layers it is called shale.*

0.2m it is unlikely that the cable will become buried due to: 1) a general lack of contemporary sediment entering the system, 2) the average sediment type being coarse and thus not particularly prone to movement and 3) a general lack of accretional features being identified in the nearshore thus the probability of accretional features forming in the future is also unlikely.

## 5.5 Specific issues related to the cable in the nearshore

### 5.5.1 *Sediment Type*

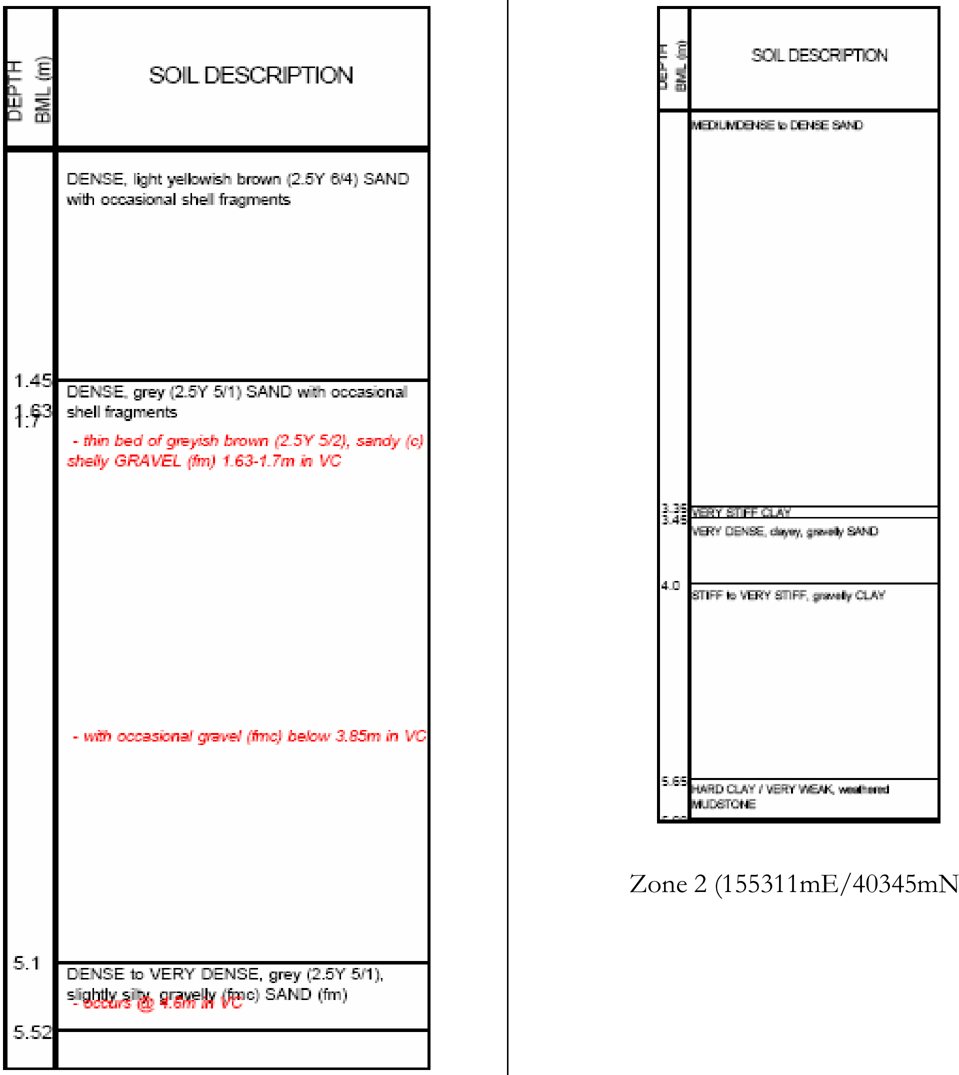
The British Geological Survey (Maps: Institute of Geological Sciences (IGS) 1983a and b, and British Geological Survey, 1987) concludes that the nearshore area comprises mainly sand. The results from Halcrow's offshore survey (2005) concurs with BGS, Halcrow state that the sediment in Zone 1 (Figure 5.9) is mainly sand and occasionally gravely sand and describe it as being light, yellow brown and containing occasional shell fragments in the upper facies. In Zone 2 (Figure 5.9) however differences are recorded; the upper facies are dominated by medium dense to dense sand, thereafter follows a very thin band of clay, which then gives way to clayey-gravelly sand that changes to a stiff, gravelly clay that finally gives way to a very stiff clay / weak mudstone, thus as one moves offshore sediment compaction appears to have taken place. The sediment in Zones 1 and 2 of the cable route are interpreted by Halcrow (2006) to have been deposited by coastal and estuary processes.

### 5.5.2 *Thickness of Sediment Cover*

BGS (1983a & b and 1987) did not define sediment depth Halcrow (2005) however do in their Geotechnical Survey. The vibrocore and CPT results indicate that sediment thickness, in and around Zone 1, is typically in the region of 5-6m (Figure 5.9) however occasionally it does reach depths of 5-8 metres. In Zone 2 similar depths were recorded despite the varying sediment layers.

### 5.5.3 *Sea bed Topography*

There appears to be limited data regarding seabed characteristics thus Halcrow conducted a Geotechnic and Geohazard Survey in 2005. In summary it was found that in Zones 1 the seabed was gently sloping and smooth sea with undulating shore-parallel ridges. This merges into Zone 2 which is also smooth and gently sloping with the occasional shallow depression (<0.5m) some of which contain low rock outcrops. There is however a marked shallow step between the outer limits of the nearshore (Zone 2) and the transitional zone (Zone 3), a step in the region of <0.5m thus this will need to be accounted for in the routing of the cable.



Zone 1 (155250mE/39364mN)

Zone 2 (155311mE/40345mN)

*Figure 5.9* *Nearshore: Zones 1and 2 Vibrocore and CPT Results (Halcrow, 2005)*

### 5.5.4 *Sediment Transport*

Zones 1 and 2 make up the sand filled embayment which we speculate is related to the Holocene marine transgression (10,000 yrs/BP to the present) when material was driven onshore. In the lee of St Ives Head and Godrevy Head medium to fine sediment was deposited.  Material has since been retained due to the headlands affording some degree of protection from offshore currents and waves and St Ives Bay being a closed sediment system.  The Geotechnical and Geohazard Survey (2005) found that a series of sand bars have formed in Zone 1 indicative that sediment transport takes place today, although the rate has yet to be quantified. In Zone 2 we speculate that sediment transport reduces as sand cover gradually thins, to expose the occasional bed rock outcrops. A separate study is in the process of investigating this and once the findings from that study are available this section will be updated.

The transition of Zone 2 to Zone 3 is identified by a marked step which corresponds with the headlands at the margins of the bay. Although this is very speculative the sand step may relate to erosion by offshore currents in an area not protected by headlands. As such the cable in this zone could experience greater stresses due to currents.

## 5.6 *Specific issues related to the cable onshore*

From the Mean Low Water Mark (MLWM) it is proposed that the cable will be buried into the beach sand and transgress landwards, over a distance of approximately 800m to the toe of the high sand dunes (Harvey's Towans). The proposed location of the onshore sub-station will be positioned in the lee of the sand dunes.

### 5.6.1 *Sediment Type*

The foreshore comprises a wide and long (c.5km) continuous beach, composed predominantly of sand, which is reported to have a high carbonate concentrate (SMP 1999). Other sediment types within the area include cobbles, to the east of the proposed cable route, at the foot of Black Cliff (BGS, 1993, 1997; Buro Happold, 2005). The sub-surface strata was examined in a recent terrestrial ground investigation seismic refraction survey (Halcrow, 2005) and generally it was found that there were four distinct layers within the subsurface sediments: (1) dry loose sand, (2) compact dry sediment, (3) saturated unconsolidated sediments and (4) competent bedrock.

Results from the recent ground investigation surveys, commissioned by Halcrow (2005), state that: located just above the Mean High Water (MHW) mark the borehole encountered 5m of slightly silty sands (to +1.2m OD), which were underlain by 2.2m of very sandy gravels (to -1.0m OD) that rested on weathered bedrock. Bedrock appears some 7.2 to 23.5m below ground level, in the form of siltstones, sandstones with the occasional quartz band and at one location (Borehole 3) as silicified sandstone.

Borehole investigations found that at the toe of the sand dunes, the upper layer comprised 2 metres of 'made ground material' (dark brown and grey, gravelly sand including fragments of brick, quartz, slate and metal)). Underlain by medium dense sands to 4.5m below ground level, giving way to very dense, slightly gravelly sand to a depth of c.8m below ground level (+5m OD) and thereafter very dense, very sandy gravels to bedrock at 10.5m below ground level (+2.5m OD).

A second borehole, located on top of the dunes (approximately 30m west of the proposed cable route) encountered loose to medium dense, occasionally gravelly sand to 17.4m below ground level (+1m OD), interrupted at 8.0m to 9.6m below ground level with a very dense horizon. Between 17.4m and 19.5m below ground level (+1.0m OD to -1.1m OD) are medium, dense gravelly sands underlain with medium dense gravelly sands to rock head at 23.5m below ground level (-5.1m OD).

5.6.2 *Thickness of sediment cover*

Halcrow carried out ground investigations in the summer 0f 2005 to determine sediment thickness. As already alluded to on the **foreshore** the sediment thickness is typically in the region of 10m. Whereas at the toe of the sand dunes sediment thickness was recorded as being typically 10.5m below ground level, whilst from the dune top sediment thickness was recorded as being typically 23.5m below ground level.

5.6.3 *Topography*

(a) Foreshore

From the base of the sand dunes (at an elevation of +6m OD) the beach reduces in elevation to around +3.8m OD over a distance of approximately 50m, to the MHWM. From here the beach remains relatively flat for a further 200m before reducing in elevation for a further 550m to the MLWM at approximately -2m OD.

(b) Backshore

The foreshore is backed largely by sand dunes, locally known as Harvey's Towans. These rise from +13m OD in the proposed site compound area to a maximum elevation of +30m OD and reduce to around +6m OD on Hayle Beach and cover a maximum distance of 200m. The dunes are well vegetated and therefore it is presumed that they are well established.

5.6.4 *Temporal variations in bed levels*

The present beach profile would be expected to vary significantly over the seasonal trends and during storm/extreme events. However it appears that data to substantiate this statement is scarce; since limited survey data is held by Penwith District Council, Cornwall County Council or the Environment Agency.

To gain an actual understanding of likely variability in beach levels one set of Annual Beach Monitoring Survey (ABMS) data was compared against two sets of Light Detection and Ranging (LiDAR) data (2001 and 2003 respectively). The ABMS was recorded at Harvey's Towans (N11) and Black Cliff (N15) respectively (refer to Figure 5.10). The LiDAR data was selected to correspond with the

ABMS spatial co-ordinates. Both sets of data were graphed in Excel (Figures 3.7 and 3.8) to investigate beach profile change.[4]

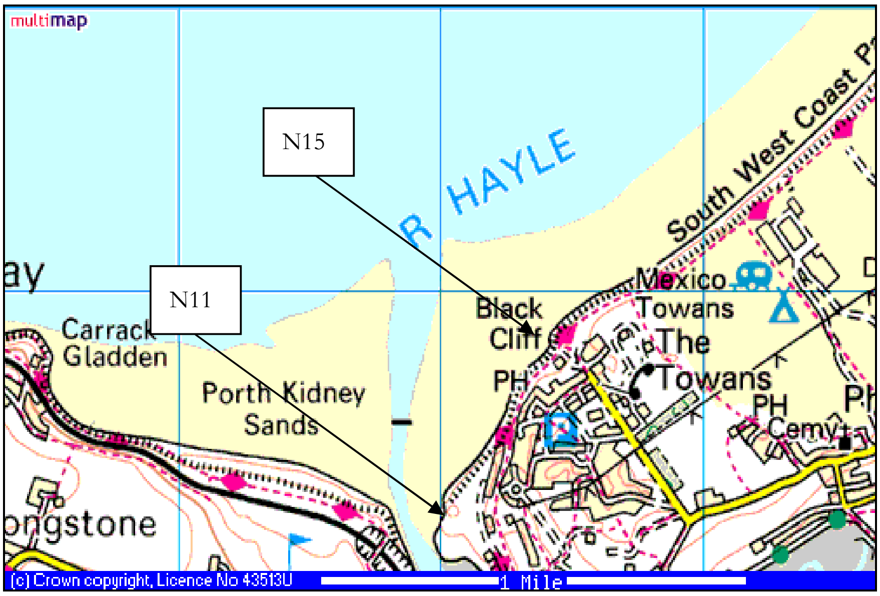


*Figure 5.10* *Beach Profile Locations*

From Figure 5.11 the presence of the sand dunes is evident and between the two datasets it appears that their shoreline position has not retreated although there has been beach profile change. In the Sept/ Oct 1998 profile erosion at the toe of the dunes is evident, however this may be related to the survey date being late in the year and the beach could be experiencing a 'winter' profile; when sediment from the upper foreshore is typically draw-down the beach and deposited in the nearshore. It is difficult to comment on the profile after 150m, as it terminates here however it is evident that between 1998 and 2004 the beach levels at the backshore have dropped to the order of 1.5m. When compared to N15 the 2004 beach at N11 appears to be relatively similar albeit for the presence of the sand dunes, the 1998 profile is however a lot different; at N11 the profile is more convex, indicative of beach build.

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[4] Please note that the LiDAR data has an error of ***

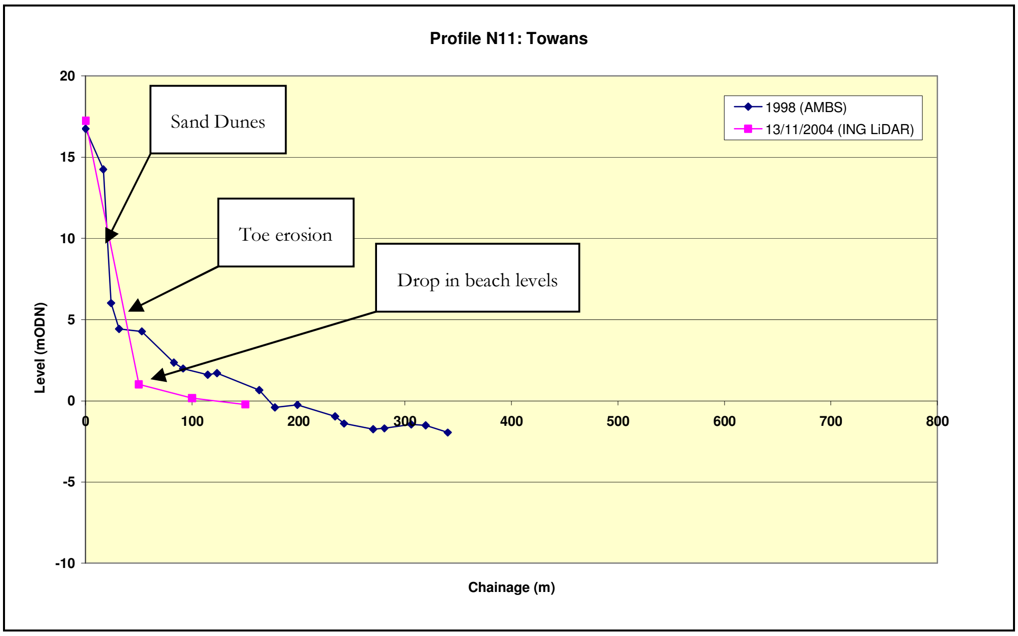

*Figure 5.111998 ABMS compared to 2004 LiDAR beach profile data at N11*

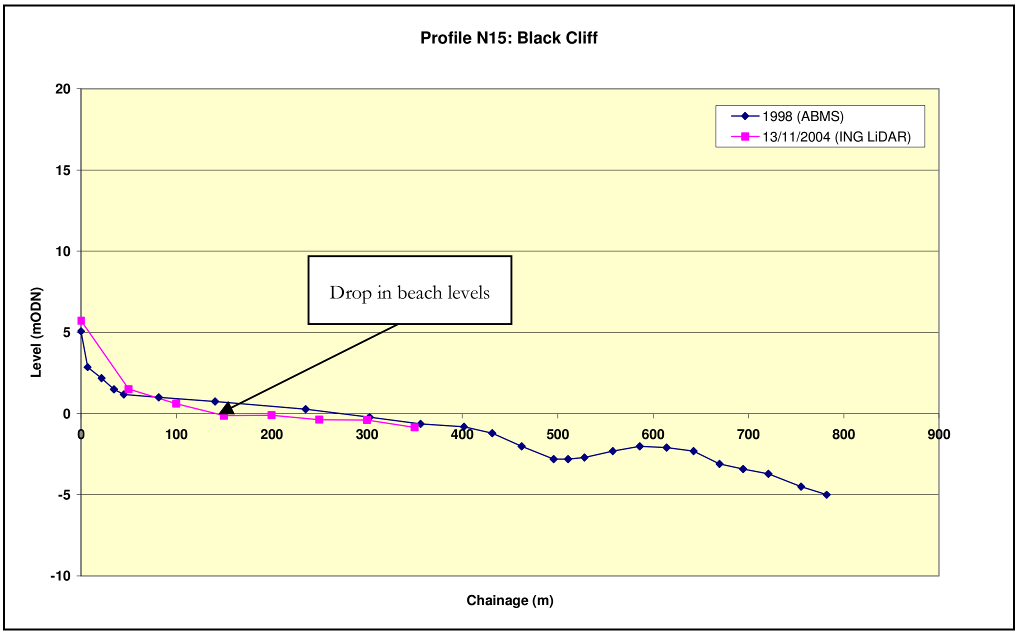

*Figure 5.121998 ABMS compared to 2004 LiDAR beach profile data at N15*

The beach survey in both 1998 and 2004 depicts a beach with a shallow gradient (Figure 5.12). Beach height for example does not exceed 5m OD, unlike Figure 3.7 where heights exceed 16m. At Black Cliff the majority of the foreshore is around 2m OD in height and slopes down to 0mOD, over a distance of 300m. In 1998 the beach gradient between 400m to 800m becomes steeper, with a convex form located around 600m out at a depth of -2mOD. It is difficult to interpret change between the two data sets, as the 1998 data set is not as abundant as the 2004 LiDAR however between 50m and 350m the beach level in 2004 is 0.5m-1m lower than 1998.

Anecdotal evidence confirms that the foreshore is capable of lowering by up to 1.8m (6ft) following storm events. This would imply that Harvey's Towans Beach is very dynamic, however as St Ives Bay is a 'closed sediment cell' material moved from the backshore / foreshore to the nearshore, under storm conditions, is returned to the foreshore/backshore under shore 'normal' conditions.

### *5.6.5* Sediment transport

In a littoral environment, sediment transport is expected to be dominated by wave action. Babtie (2002) investigated sediment transport in St Ives by modelling the effects of waves and tidal currents, in the inter-tidal area; at seven locations within St Ives Bay (Harvey's Towans and Black Cliff Beach are 2 of the 7 locations) and the potential sediment transport rate under:

- a spring tide with no wave condition,
- a spring tide with a 5 year return period wave and
- a spring tide with a moderate swell wave from the predominate wave direction (300° North) was compared.

Babtie (2002) reported that *"the impact of wave action on the potential sediment transport is significant, whereas sediment transport induced by tidal flow alone results in a net movement landward of 0.018t/m"*. A rate that Babtie (2002) consider insubstantial when compared with wave-induced transport, which they calculated as having a magnitude of 0.67t/m. Babtie (2002) also concluded that Hayle Beach is exposed to wave action from a variety of directions (30°N to 300°N) whilst the shoreline further east i.e. Gwithian Towans is exposed mostly to north-westerly waves (300°N to 340°N). This makes the Hayle frontage more susceptible to wave attack and as such there greater potential for sediment feed and shoreline erosion.

Babtie's (2002) investigations into shoreline dynamics found that the transportation of sediment takes place when:

- There is wave action: wave induced transport redistributes the sediment in the inter-tidal zone.
- There is a storm event: the potential for large quantities of material to be transported seawards, from the beaches within St Ives Bay, by waves, to an area of ebb dominated flow[5] is high.
- There is a spring tide flood: under these conditions the sediment is transported landwards.
- Waves approach the shoreline obliquely and drive the longshore transportation of material.

Thus in summary it appears that the transportation of sediment, in St Ives Bay, is mainly cross-shore unfortunately however there is no data that quantifies the transferral of material between the nearshore and onshore during storm (winter) and normal (summer) events. It is also recognised that alongshore transportation takes place within St Ives Bay (HR Wallingford, 1983); the Shoreline Management Plan, Halcrow 1999). The net movement of material appears to be west to east however there are localised 'iterations' one of which is at the beach which fronts the onshore sub-station. Along this frontage the sediment moves in a westwards (clockwise) direction, into Hayle Estuary where it has the opportunity to either settle or be transported further alongshore on an ebb tide.

Modelling conducted by Babtie (2002) suggests however that this transferal, from Black Cliff Beach into Hayle Estuary, might not be as significant as what it could be due to the tidal currents, which moves sediment in the opposite direction back towards Black Cliff. Aerial photographs used to analyse shoreline change between 1946 and 1996 illustrate this sediment transport regime, with sediment building up periodically on either side of the estuary mouth.

Taking this information together with our understanding of coastal processes a conceptual model has been devised for St Ives, see Figure 5.13. Although it should be noted that this figure provides net drift rates and there is potential for drift between Porth Kidney Sands in the west across the mouth of the estuary towards Black Cliff beach.

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[5] *Babtie (2002) do not state where the ebb dominated flow is but we assume that this may be in the vicinity of Hayle Estuary.*

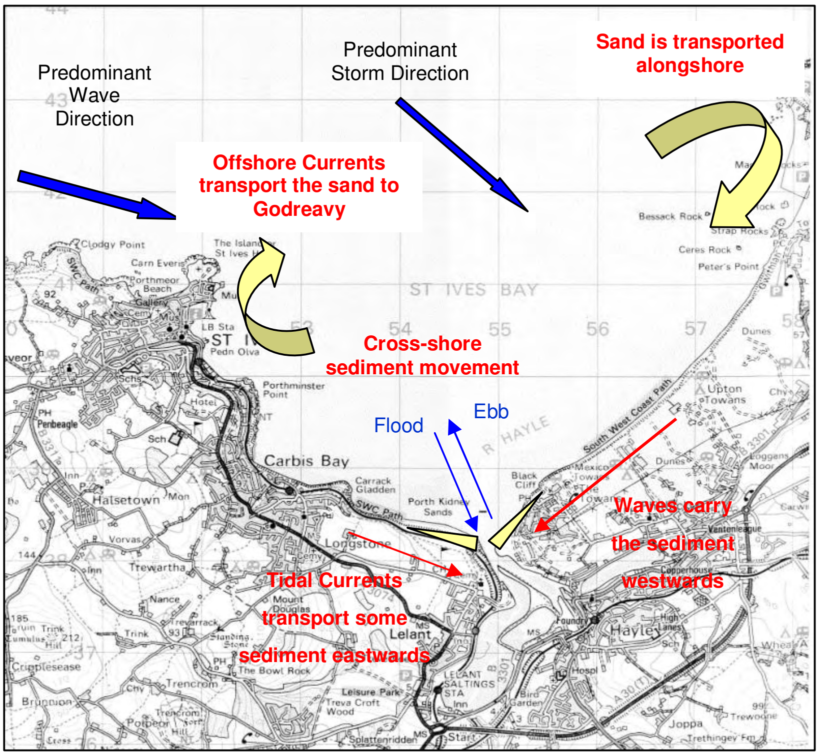

*Figure 5.13 Conceptual Sediment Transport Model for St Ives Bay*

5.6.6 *Long term trends in shoreline position*

Recently it was reported that the beach at Hayle had experienced a reduction in beach levels, to the order of approximately 1m, exposing previously covered coarse gravels and rock (Babtie, 2002). This drop is also detected in the Shoreline Management Plan (1999) following analysis of shoreline change between 1907 and the present day using OS maps; concluding that at Hayle Towans Mean High Water has retreated between the estuary mouth and into the estuary, up to a maximum of 45m, and related this to dune erosion, whereas at Hayle Harbour / Estuary the extent of the inter-tidal area had generally stayed the same. Analysis of beach profile data and LiDAR data showed up to a 1.8m difference in beach levels between Sept/ Oct 1998 survey data and Nov 2004 survey data at Harvey's Towans Beach, Profile N11, with about 1m difference in beach levels at Black Cliff, Profile N15 (Figures 5.11 and 5.12). This may be the difference between summer and winter beach profiles.

Lowering of the shoreline leads to deeper waters propagating the foreshore which leads to increased wave attack; as larger waves are now able to penetrate further up the beach and as such the frequency and intensity of dune attack is increased.

For this study we have also investigated shoreline change using aerial photography and LiDAR data. Fundamentally the study shows that between 1946 and 2003 the strandline vegetation line has retreated, however since 1985 the shoreline along this section of the beach has shown signs of stability, in obtaining a more or less similar position, see Figures 3.1 and 3.2.

# 6 Future Change

## *6.1 Offshore/ Transitional Zone (40mCD to 10mCD)*

Very little change appears to have taken place in offshore and transitional zone in the recent historic past (<100 years) and thus the probability of change in the future is limited.

## *6.2 Nearshore Zone (less than 10mCD)*

It has been noted that St Ives Bay is constantly in a state of flux, with areas of accretion and erosion occurring in close proximity (Halcrow, 1999).

The beaches are expected to retain their overall form, due to the system being sheltered, 'closed' and largely unmanaged. A summary of the potential impacts of future sea level rise has been provided below.

The shoreline will retreat and beach levels are likely to lower as a result of sea level rise, where defences are placed then the beaches will narrow. An increase in the frequency of winter storm wave activity may also lead to an increase in the rate of beach lowering and landward migration of the dunes.

There is potential for the sand dunes backing Porth Kidney Sands (to the west of the mouth of the estuary) to roll back whilst on the eastern side of the estuary dune erosion is expected.

As a result of sea level rise the tidal prism of Hayle Estuary would increase as would the tidal currents at the mouth of the estuary, which would assist natural flushing of the entrance channel, but may also result in increased erosion of the dunes, either side of the estuary, as the mouth widens.

Further drowning of the river mouth may be followed by progressive infilling of the estuary by marine and fluvial materials. Future shoreline position would depend on the relative contributions of the two sediment sources. There is potential for the estuary to regain its natural 'depositional' capacity, as its natural flushing regime may be unable to move sediment seawards.

Dunes form where there is an expanse of sand exposed at low tide, the surface of which dried in the sun and the wind, so allowing sand to be blown by the wind.

Any future changes to the dunes will be dependent on the dune type, volume of sand supply, the wind regime and the profile of the shore. Shoreline analysis conducted for this study indicates that the dunes fronting the onshore sub-station have eroded by up to 70m in the last 60 years. Therefore the cable should be buried to sufficient depth to allow for future erosion of the dune.

# 7 Impacts of the Wave Hub

## *7.1 Offshore/ Transitional Zone (40mCD to 10mCD)*

The Wave Hub project is likely to have a minor localised impact in the immediate vicinity of the sub-sea facilities (cable termination and distribution unit, transformers and connection points), connecting cables and the onshore cable route where it is laid on the seabed. These impacts can be summarised as follows:

- Disturbance of seabed sediments during installation of the sub-sea facilities and cables;
- Disruption of existing sediment movement due to the presence of the sub-sea facilities and cables. There is limited potential for this since little change has occurred on the seabed over the past 100 years;
- Localised scour around the sub-sea facilities and cables. Since offshore sediments typically occur in layers less than one metre thick this is unlikely to cause a significant problem;
- Movement of offshore sediments following storm conditions which may lead to localised burial of sub-sea facilities/ cables;
- Abrasion of the mudstone/ shale on the seabed by cables if they are not anchored correctly;
- Potential abrasion of onshore cable where it passes over jagged outcrops of rock on the seabed;
- Marine growth and associated impacts on sub-sea facilities and cables.

## *7.2 Nearshore Zone (less than 10mCD)*

Limited disturbance of sediment in the nearshore zone would occur when burying the cable beneath the beach. A plough would be used to bury the cable across the beach, whilst drilling would be utilised to install the cable beneath the dunes. Impacts would be limited to: disturbance on the beach during installation (summer tourist season to be avoided if possible to minimise disruption); excavation of sand along cable route and possible deposition of gravel/ sand/ silt/ mudstone following burial of cable.  Background levels of suspended sediment in the area are naturally high, therefore sediment plumes arising from the cable burial process are not likely to be significant.

No long term impacts would result from cable burial, provided the cable is buried to a sufficient depth to prevent future exposure.

### 7.3 *Onshore Zone*

There will be minimal impact at the onshore sub-station or in the surrounding area, since the sub-station is already in place.

### 7.4 *Overall*

Overall a **minor adverse** to **negligible** effect is predicted for the Wave Hub.

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