

Technical Webinar on Global Wind Atlas
Hosted by Clean Energy Solutions Center
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The Global Wind Atlas: The New Worldwide Microscale Wind Resource Assessment Data and Tools

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EUDP 11-II, Globalt Vind Atlas, 64011-0347

DTU Wind Energy
Department of Wind Energy

Outline

- Model chain
- Input data
- Output
- Global assessments of the technical potential

The global wind atlas objective

- provide wind resource data accounting for high resolution effects
- use microscale modelling to capture small scale wind speed variability (crucial for better estimates of total wind resource)
- use a unified methodology
- ensure transparency about the methodology
- validate the results in representative selected areas

For:

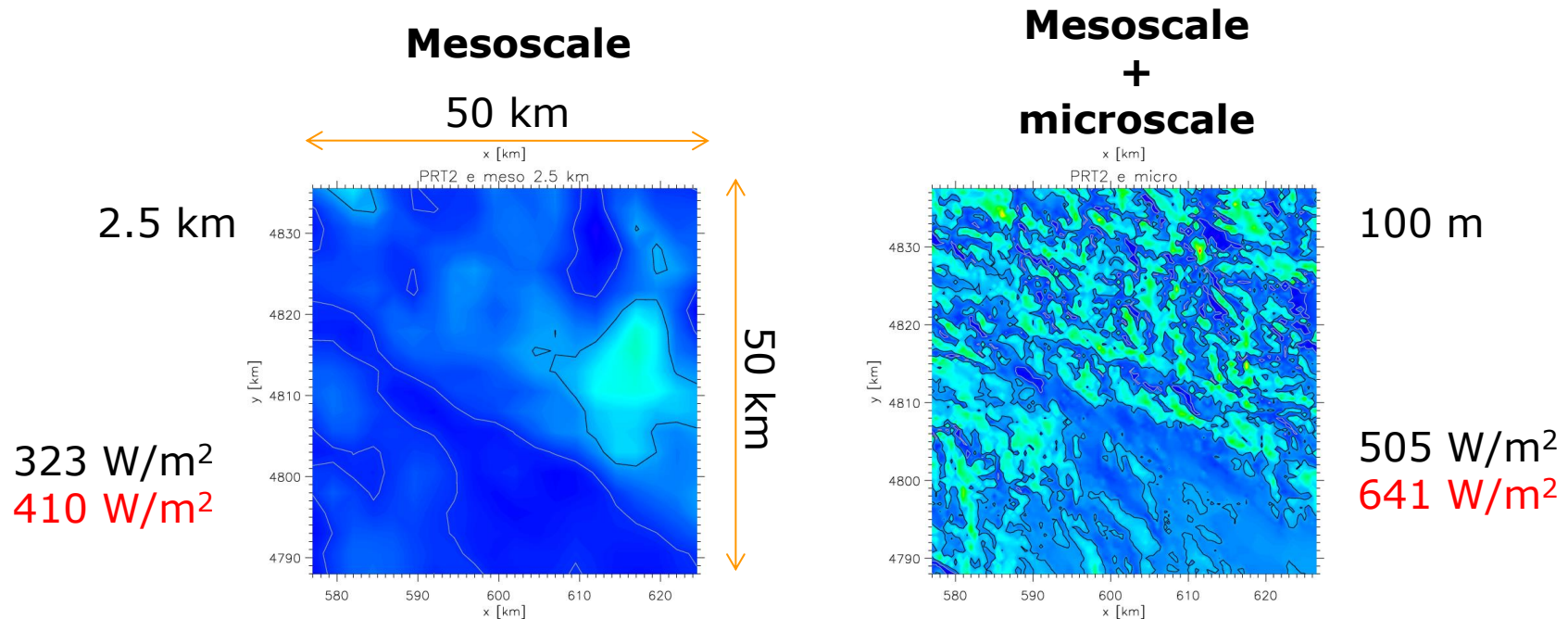
- Aggregation, upscaling analysis and energy integration modelling for energy planners and policy makers

Not for:

- Not for wind farm siting

Project context

Wind resource (power density) calculated at different resolutions

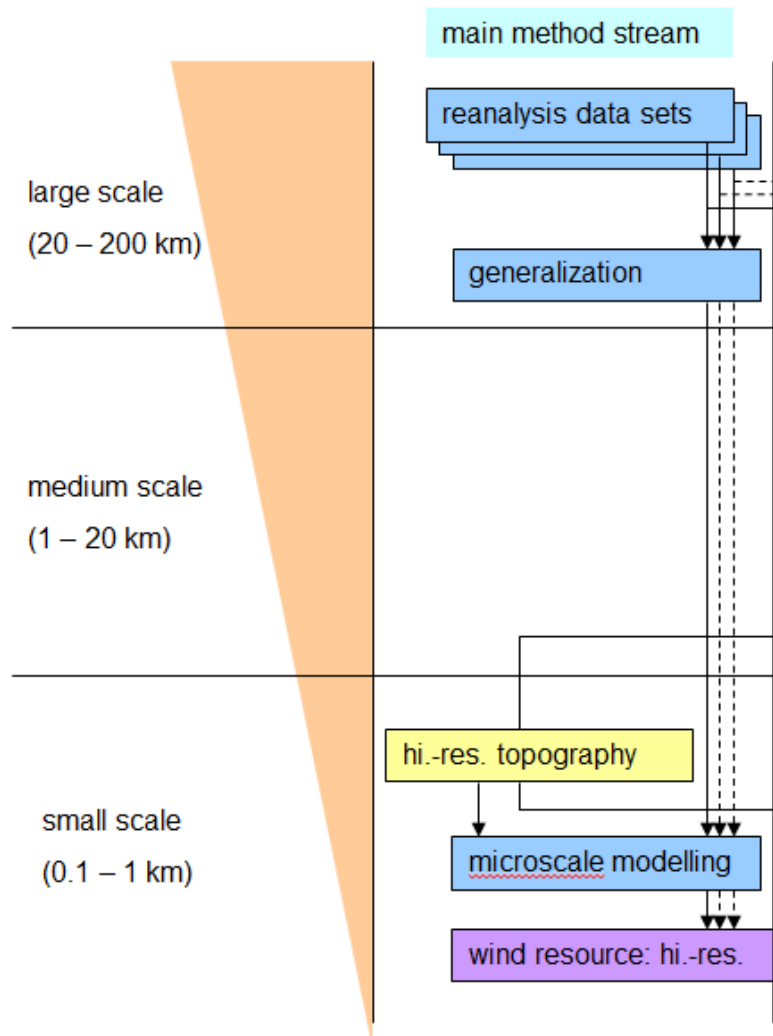


mean power density of total area mean power density for windiest 50% of area

Wind farms are not randomly located but are built on favourable areas

Model chain Downscaling

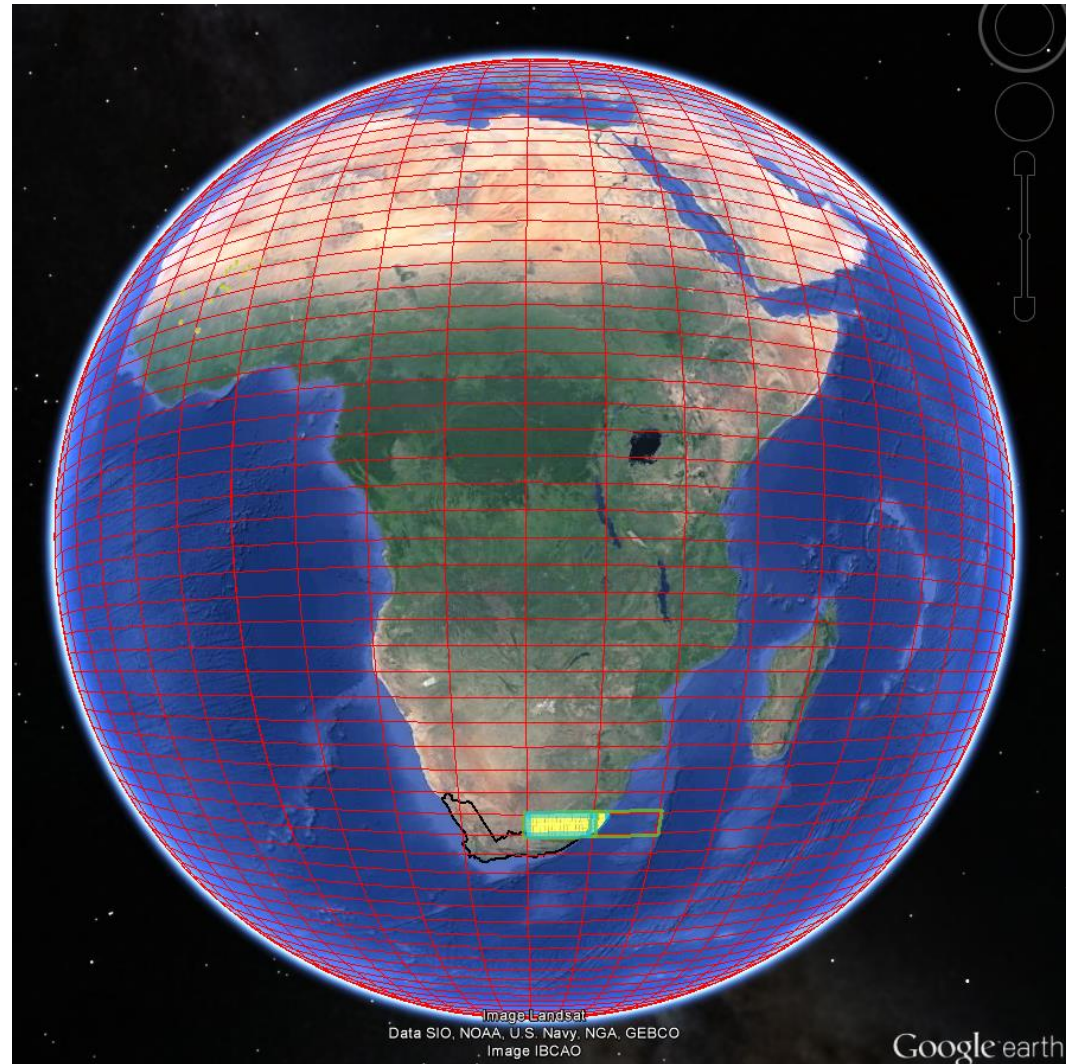
GWA



Model chain

Global Wind Atlas implementation

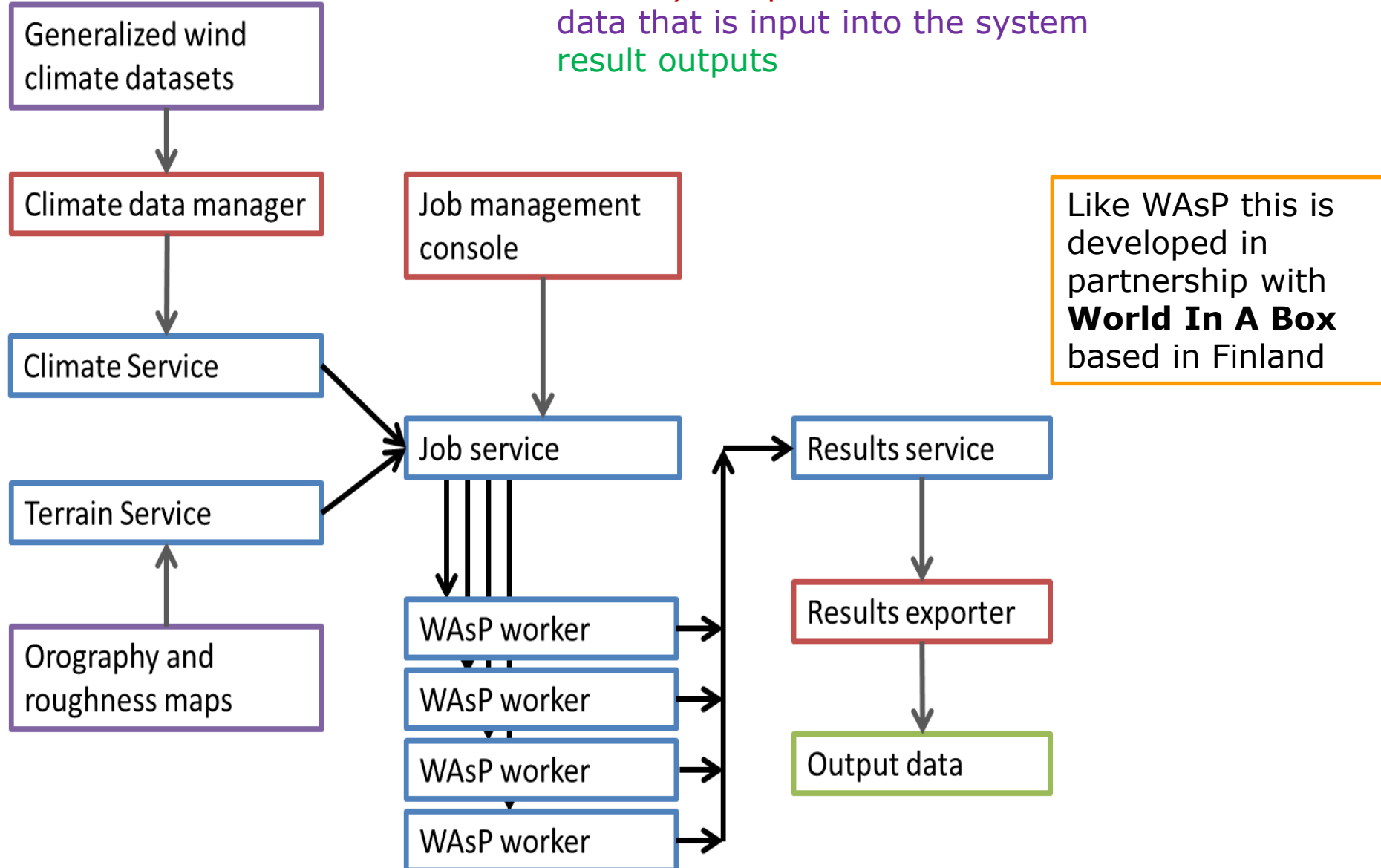
- Military Grid Reference System (MGRS) form basis of the job structure
- MGRS zones are divided into 4 pieces (total 4903)
- **2439 jobs required to cover land and 30 km offshore**
- Frogfoot system runs WAsP-like microscale modelling. Inputs
 - Generalized reanalysis winds
 - High resolution elevation and surface roughness data



Model chain

What is Frogfoot?

core Frogfoot-server components
 ancillary components run on user PC
 data that is input into the system
 result outputs



Like WAsP this is developed in partnership with **World In A Box** based in Finland

DTU

Create New Job

New job

- Maps
- Climates
- Calculation grid
- Results
- Review

NEW JOB

Name:

Comments:

Close Refresh Next

Job Management Console - connected to http://wind-ptdprod/FrogfootService/JobService.svc

View

Job Name	Priority	Tiles	Created	Status
Baseline test 1	Normal	2000	06/11/2013 09:44:06	Complete
Test_20131107_1	Normal	1880	07/11/2013 13:52:05	Complete
test2	Normal	81	26/11/2013 13:17:02	Complete

Status: Any

Priority: Any

Name:

From:

To:

Reset filter

Show

New Job

Delete

Pause

Job details

test2

Priority:

@ normal medium high

Complete

Job information

Title summary

Activity

Comments

Created at

26/11/2013 13:17

Completed at

26/11/2013 13:37

Setup

Heights

50m, 100m, 200m

Resolution

1000m

Extent

{569500, 4680500} - {661500, 4772500}

Projection

UTM WGS84 {30}

Terrain

Elevation layer

ElevationLayer

Roughness layer

RoughnessLayer

Boundary

Boundary

Allaz_boundary_inner.map

Climate

Climate dataset

ALAS_4_2_p1980_2009_nz0lib5

View in Google Earth

The screenshot shows a web browser window titled "Wasp worker - connected to http://vind-ptadpole/FrogfootService/TaskAllocationService.svc". The main area contains a table with two columns: "Activity" and "Status". The table has several rows, all of which are currently empty. At the bottom of the page, there is a status bar that says "Checking for work in 1 seconds..." followed by a link labeled "Check now". To the right of the status bar are three small icons: a square, a circle, and a vertical rectangle.

Activity	Status

Checking for work in 1 seconds... [Check now](#)

9

Model chain

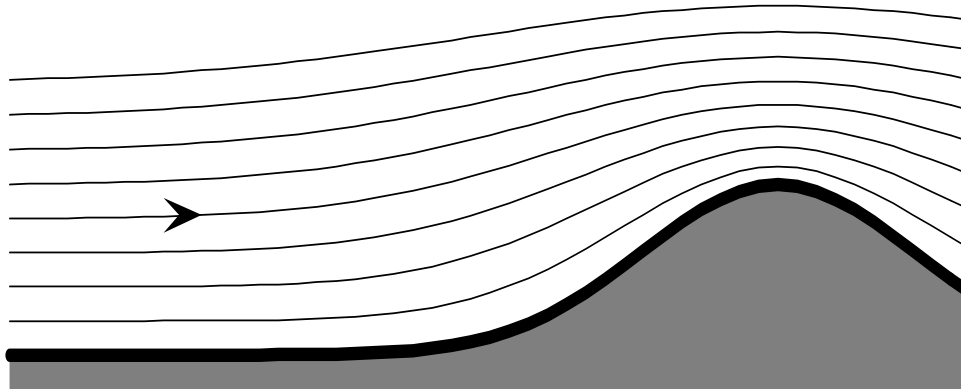
How to work with Frogfoot?

WASP Worker(s)



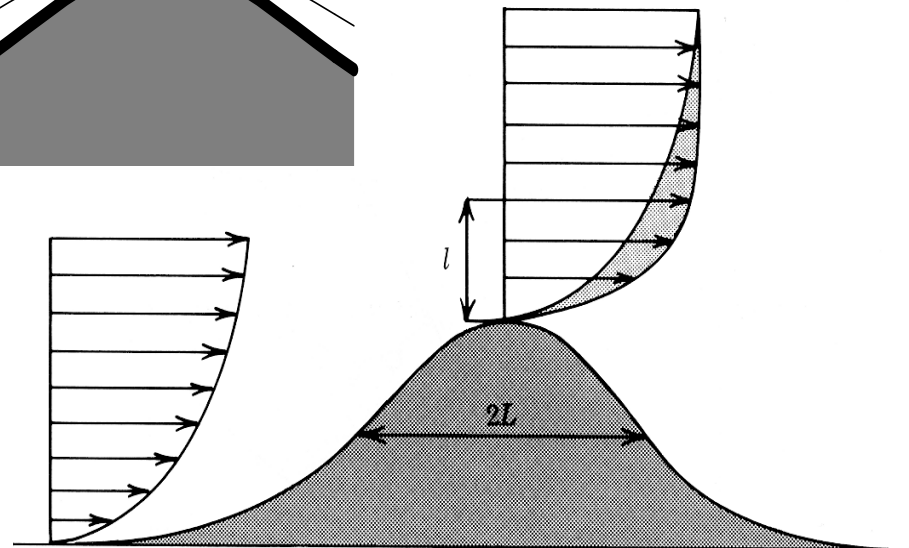
Microscale Orographic speed-up

Streamlines closer together means faster flow



Winds speed up on hills

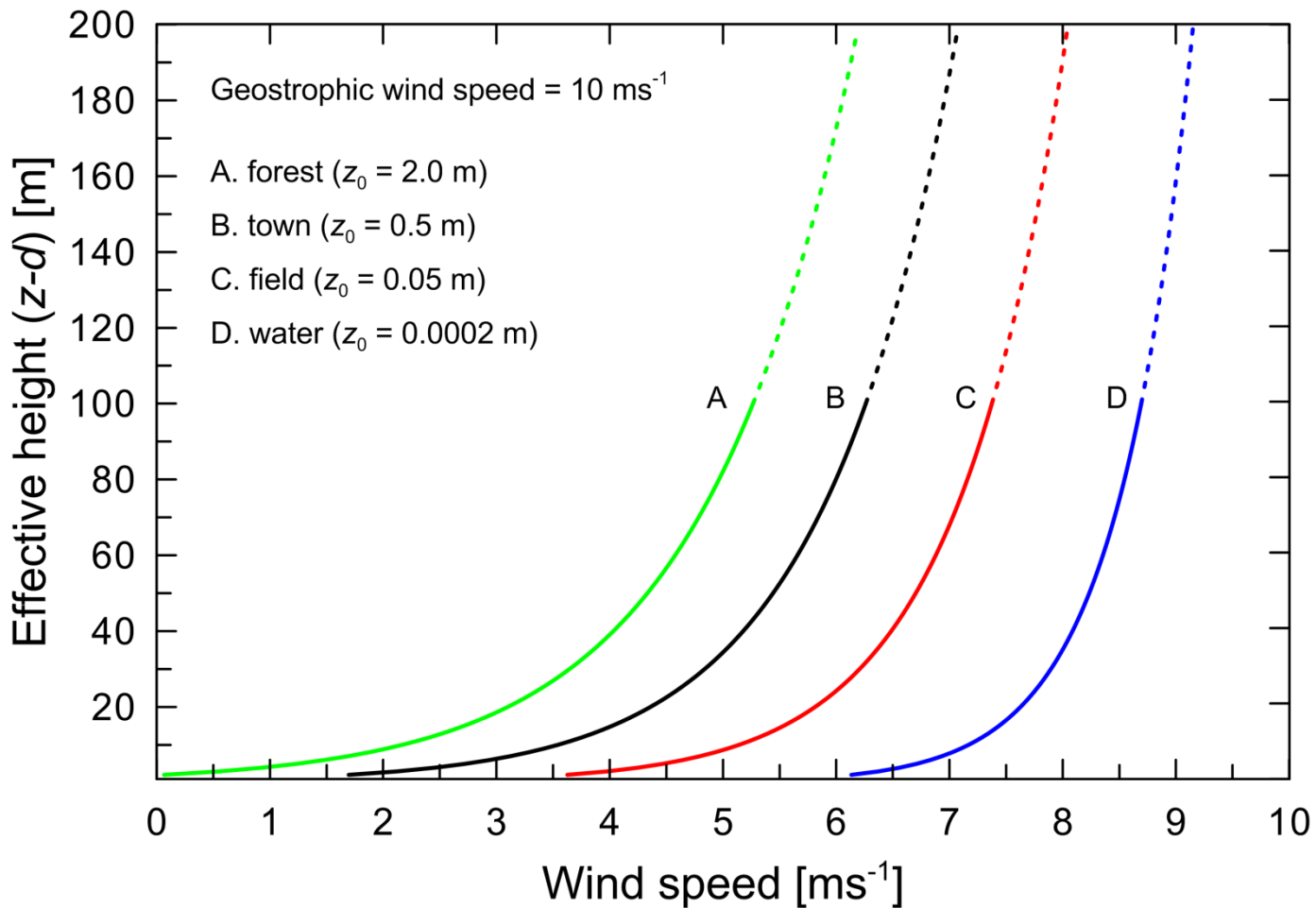
Winds slow down in valleys



Modification of the wind profile

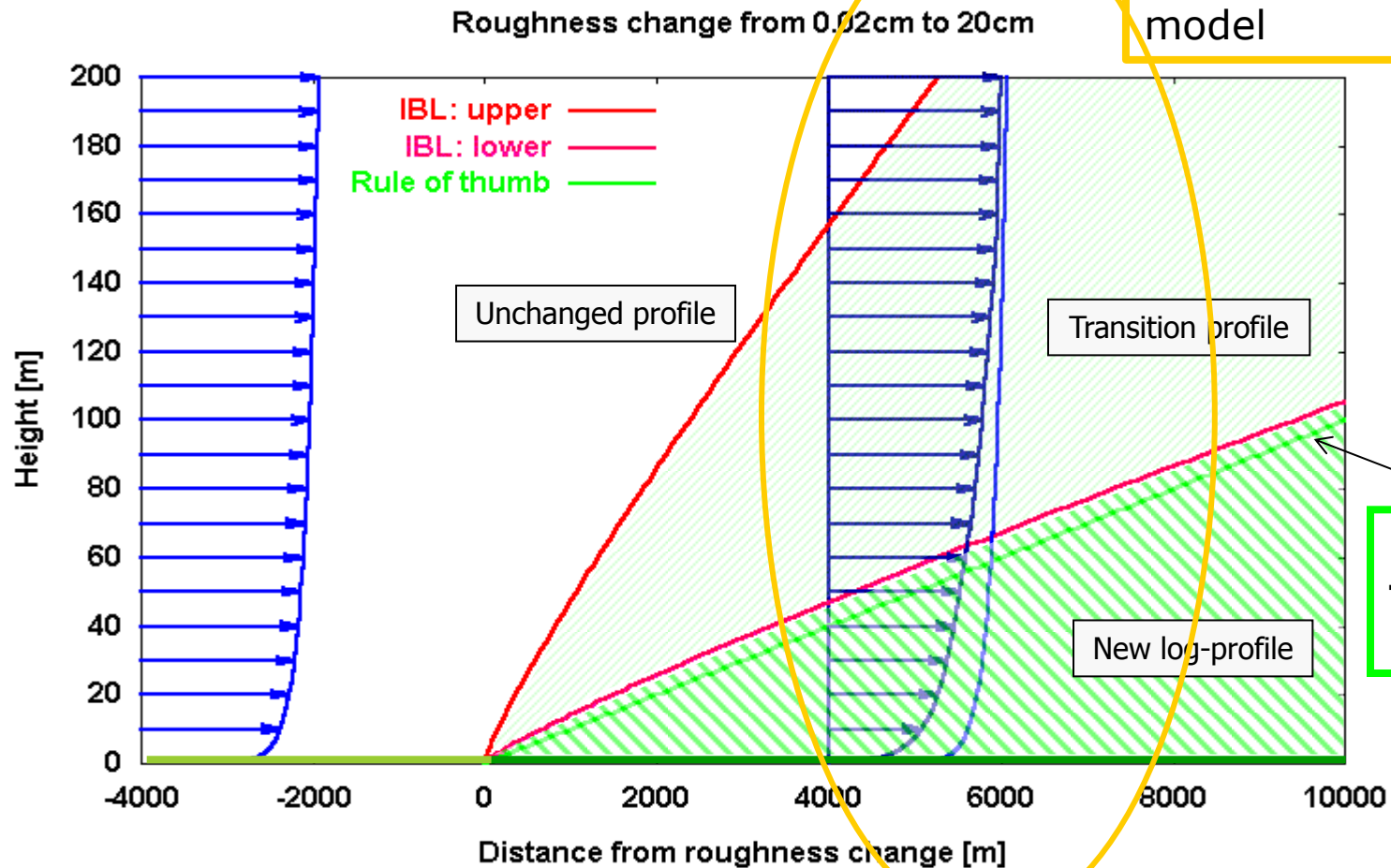
Microscale

Surface roughness length



Microscale Surface roughness change

Accounted for by roughness speed-up and meso roughness parameters from WASP flow model



Datasets: atmospheric data

Reanalysis

Product	Model system	Horizontal resolution	Period covered	Temporal resolution
ERA Interim reanalysis	T255, 60 vertical levels, 4DVar	$\sim 0.7^\circ \times 0.7^\circ$	1979-present	6-hourly
NASA – GAO/MERRA	GEOS5 data assimilation system (Incremental Analysis Updates), 72 levels	$0.5^\circ \times 0.67^\circ$	1979-present	6-hourly
NCAR CFDDA	MM5 (regional model)+ FDDA	~ 40 km	1985-2005	hourly
CFSR	NCEP GFS (global forecast system)	~ 38 km	1979-2009 (& updating)	6-hourly

Datasets terrain: elevation and roughness

Topography: surface description

Elevation

Shuttle Radar Topography Mission (SRTM) resolution 90 - 30 m

Viewfinder, compiles SRTM and other datasets resolution 90 - 30 m

ASTER Global Digital Elevation Model (ASTER GDEM) resolution 30 m

Land cover

ESA GlobCover resolution 300 m

Modis, land cover classification resolution 500 m

Challenges in determining surface roughness

GLOBCOVER

- European Space Agency initiative
- January – December 2009
- Global 300m resolution
- 22 Classes
- Data gaps near poles
 - Limited number of overpasses
 - Large number of cloudy images

Value	GlobCover global legend	
11	Post-flooding or irrigated croplands	
14	Rainfed croplands	
20	Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)	
30	Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)	
40	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)	
50	Closed (>40%) broadleaved deciduous forest (>5m)	
60	Open (15-40%) broadleaved deciduous forest (>5m)	
70	Closed (>40%) needleleaved evergreen forest (>5m)	
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	
110	Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)	
120	Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)	
130	Closed to open (>15%) shrubland (<5m)	
140	Closed to open (>15%) grassland	
150	Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)	
160	Closed (>40%) broadleaved forest regularly flooded - Fresh water	
170	Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water	
180	Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water	
190	Artificial surfaces and associated areas (urban areas >50%)	

Challenges in determining surface roughness

Roughness lengths used in the GWA

Roughne	GLOBCOVER_Class	Modis_Class
0.0	Water bodies	Water
0.0004	Permanent snow and ice	Snow / Ice
0.005	Bare areas	Baren or sparsely vegetated
0.03	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	Grasslands
0.05	Sparse (<15%) vegetation	
0.1	Post-flooding or irrigated croplands (or aquatic)	
0.1	Rainfed croplands	Croplands
0.1	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	Closed Shrublands / Open Shrublands
0.2	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	Permanent Wetland
0.3	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	
0.3	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	Cropland / Natural Vegetation Mosaic
0.5	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	
0.5	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	Savannas
0.6	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	
1.5	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	Evergreen Broadleaf Forest
1.5	Closed (>40%) broadleaved deciduous forest (>5m)	Deciduous Broadleaf Forest
1.5	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	
1.5	Closed (>40%) needleleaved evergreen forest (>5m)	Evergreen Needle Leaf Forest
1.5	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	Deciduous Needle leaf Forest
1.5	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	Mixed Forest
1.5	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	Woody Savannas
1.0	Artificial surfaces and associated areas (Urban areas >50%)	Urban and Built-Up
	No data (burnt areas, clouds,...)	

Validation

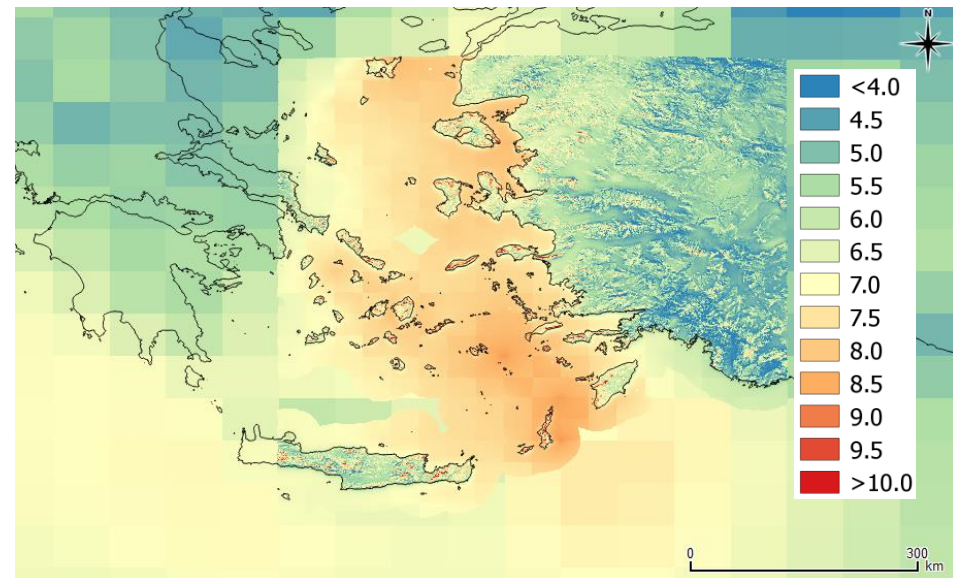
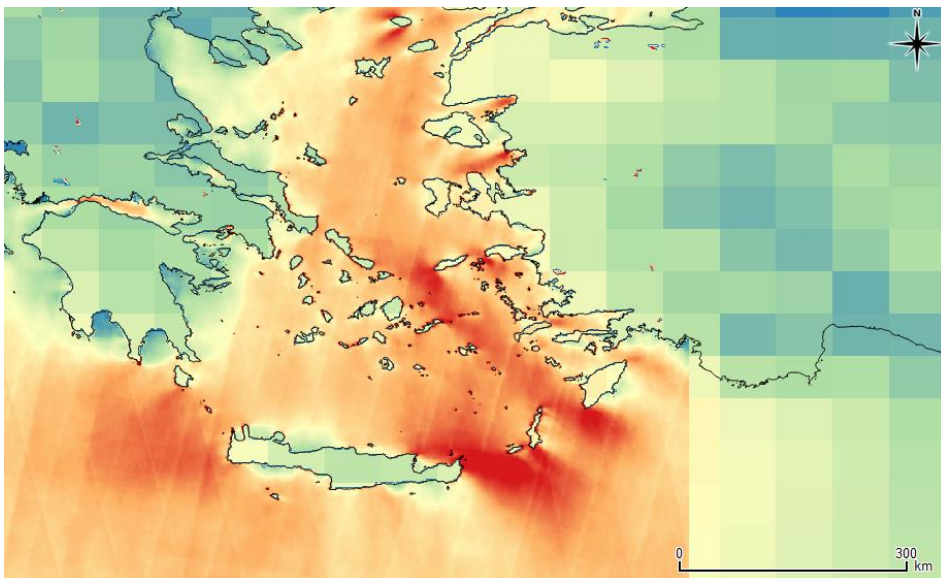
Synthetic Aperture Radar

The limitations of this method include

- that only onshore areas can be mapped
- the extrapolation of wind speeds to Global Wind Atlas heights introduces uncertainty.

Synthetic Aperture Radar S-WAsP

Global Wind Atlas

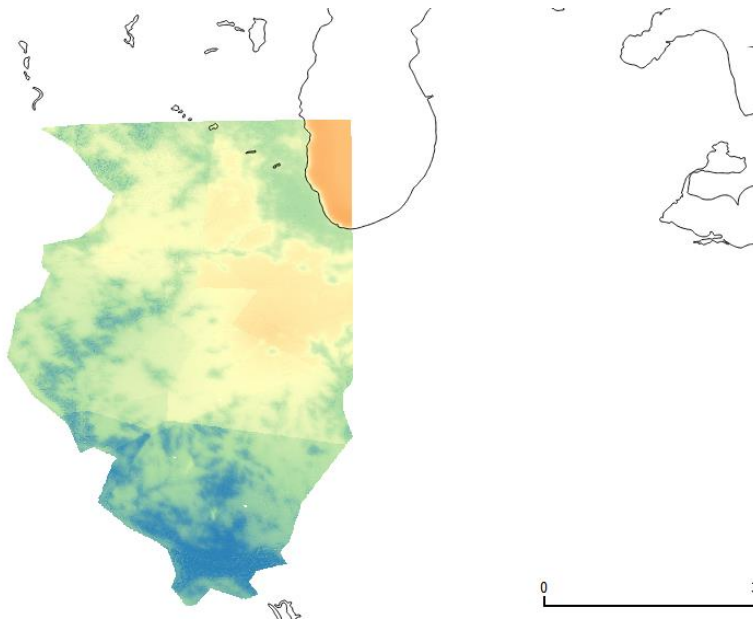


Validation

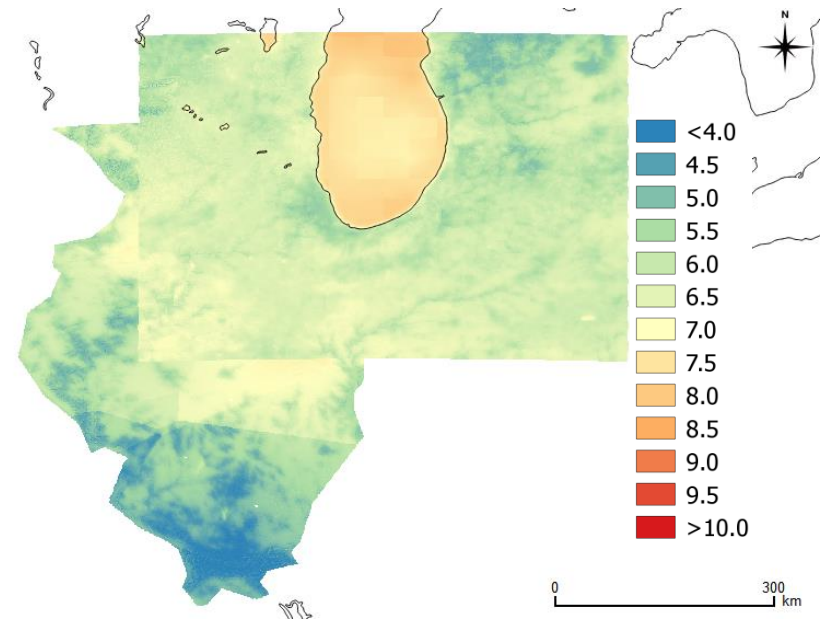
Against high resolution resource maps generated from measurement based generalized winds.

A limitation is the comparison is being made against, in part, results of modelling.

Observational Wind Atlas for Illinois
Munoz-Najar (2015)



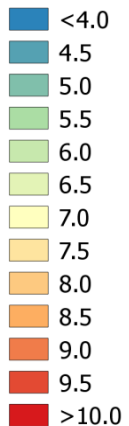
Global Wind Atlas



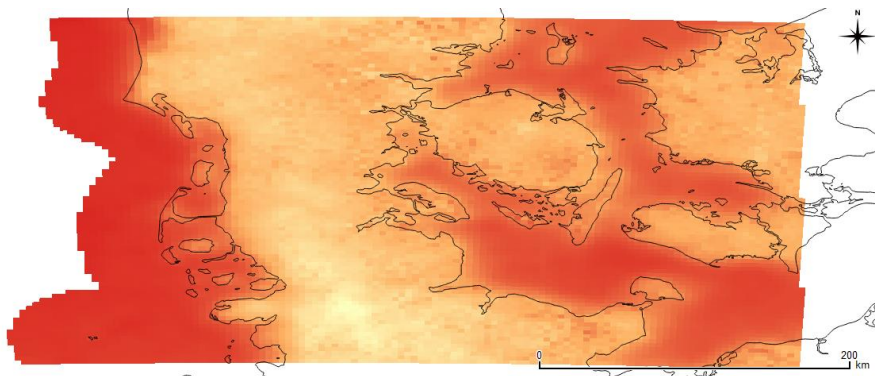
Against validated numerical wind atlas results

Advantage is that the validation can be done over land

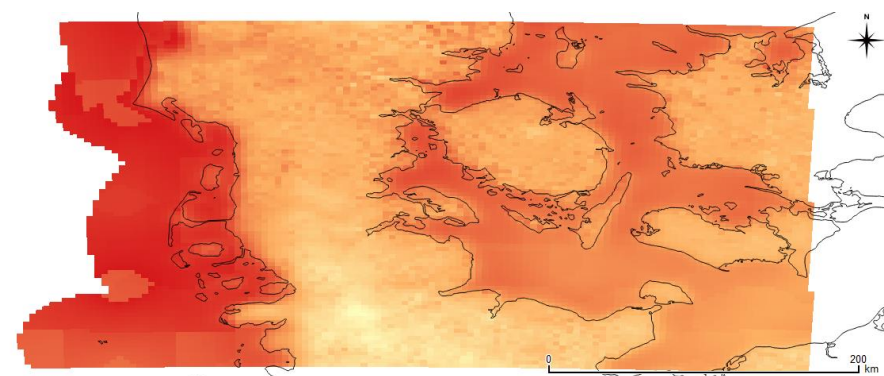
The limitation is a comparison is being made against results of modelling, so it is not a comparison against measurements.



Numerical wind atlas
KAMM / WAsP



Global Wind Atlas



Validation

Against validated numerical wind atlas results

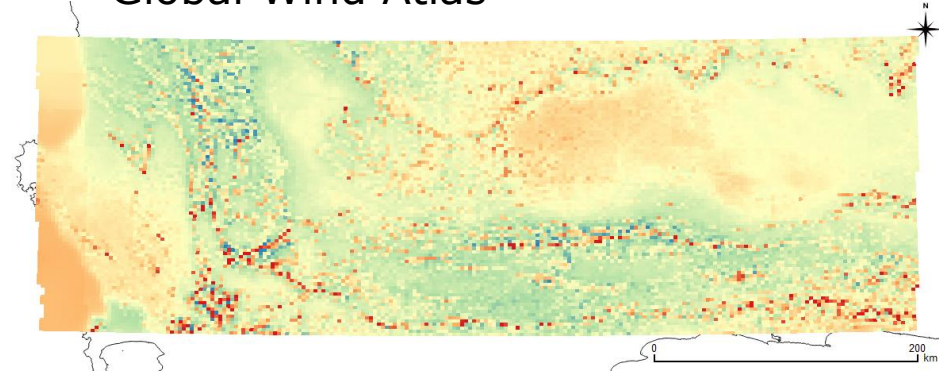
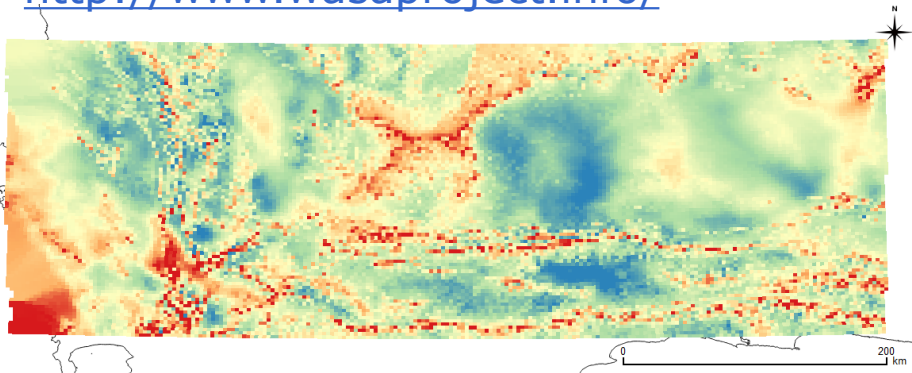
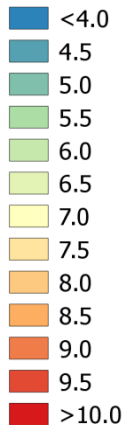
An advantage is that the validation can be done over land

A limitation is a comparison is being made against results of modelling, so it is not a comparison against measurements.

National Validated Numerical Wind Atlas
WASA project

<http://www.wasaproject.info/>

Global Wind Atlas



Global Wind Atlas at DTU

globalwindatlas.com



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Global Wind Atlas



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Supported by:
EUDP 11-II, Global Wind Atlas J.nr. 64011-0347

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Global Wind Atlas at DTU

globalwindatlas.com

Surface roughness length

Large-scale Wind Forcing

Land Use and Roughness

Globcover ☐

MODIS ☐

GWA Roughness ☒

Terrain Height

High-resolution Wind Speed

High-resolution Power Density

Roughness Effects

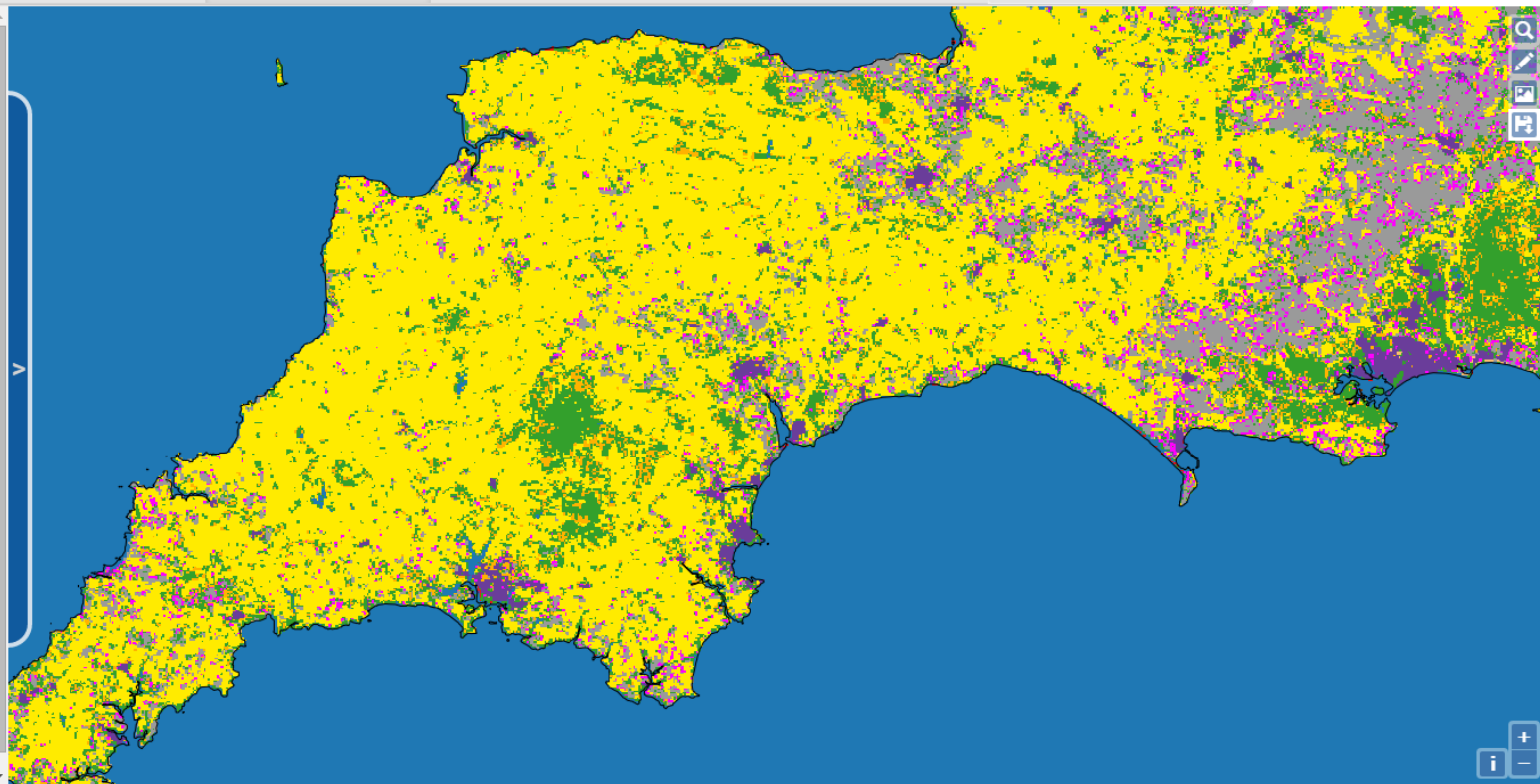
Orographic Effects

Base Layers

Coastlines

Selection Boundaries

Grids



Roughness from landuse type

Water 0.0	Snow 0.0004	Bare 0.005	Herb Veg. 0.03	Sparse 0.05	Crops 0.1	Woody Veg. 0.2	Mosaic 0.3	Shrubs 0.5	Bl Shrubs 0.6	Urban 1.0	Forest 1.5	Missing
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Global Wind Atlas at DTU

globalwindatlas.com

Orography

[Large-scale Wind Forcing](#)[Land Use and Roughness](#)[Terrain Height](#)[Viewfinder 150m](#)[High-resolution Wind Speed](#)[High-resolution Power Density](#)[Roughness Effects](#)[Orographic Effects](#)[Base Layers](#)[Coastlines](#)[Selection Boundaries](#)[Grids](#)

200km

Terrain Height

0 0m

< 10m

< 100m

< 500m

< 1000m

< 1500m

< 2000m

< 2500m

< 5000m

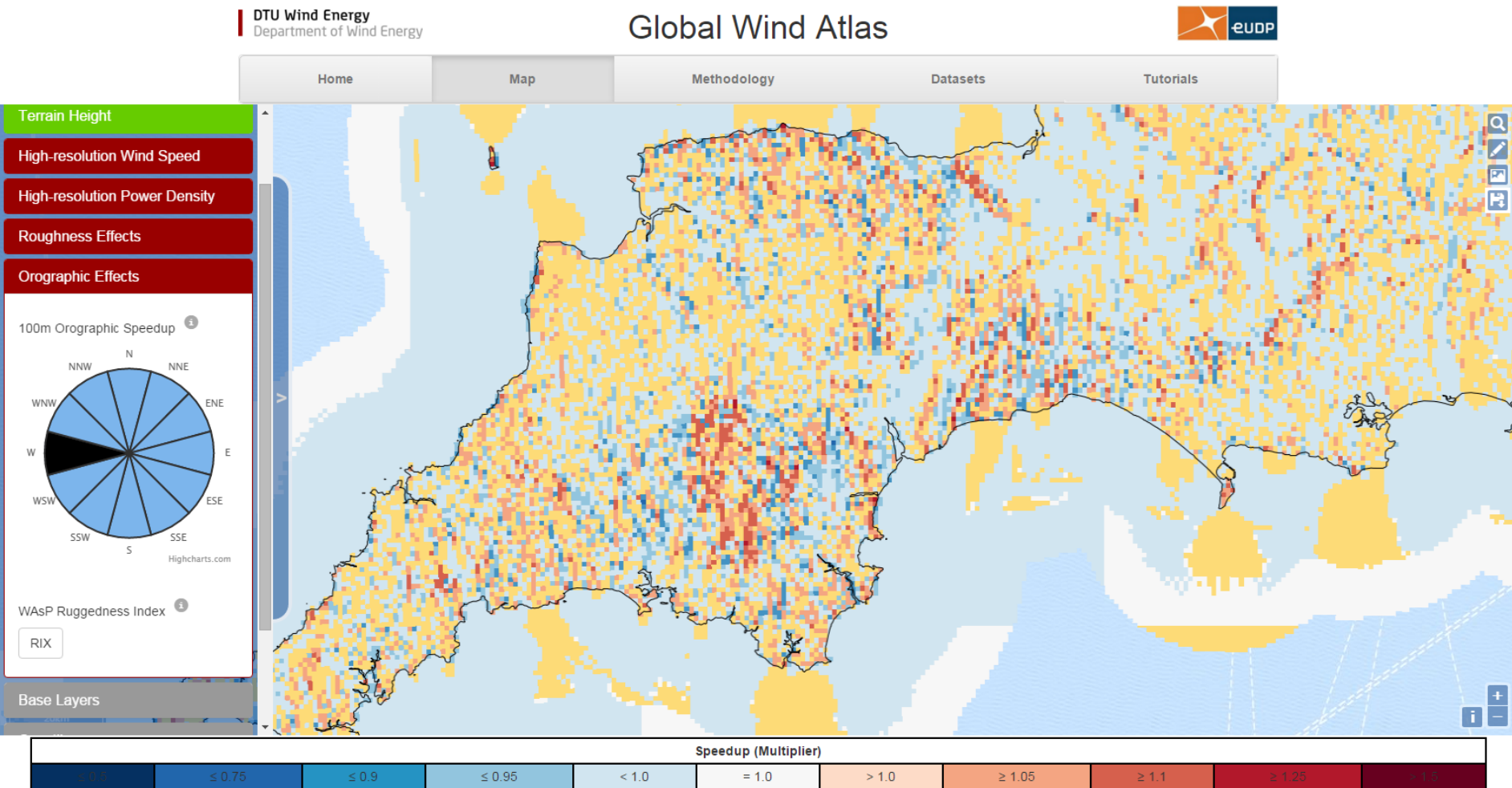
< 9000m

Global Wind Atlas at DTU

globalwindatlas.com



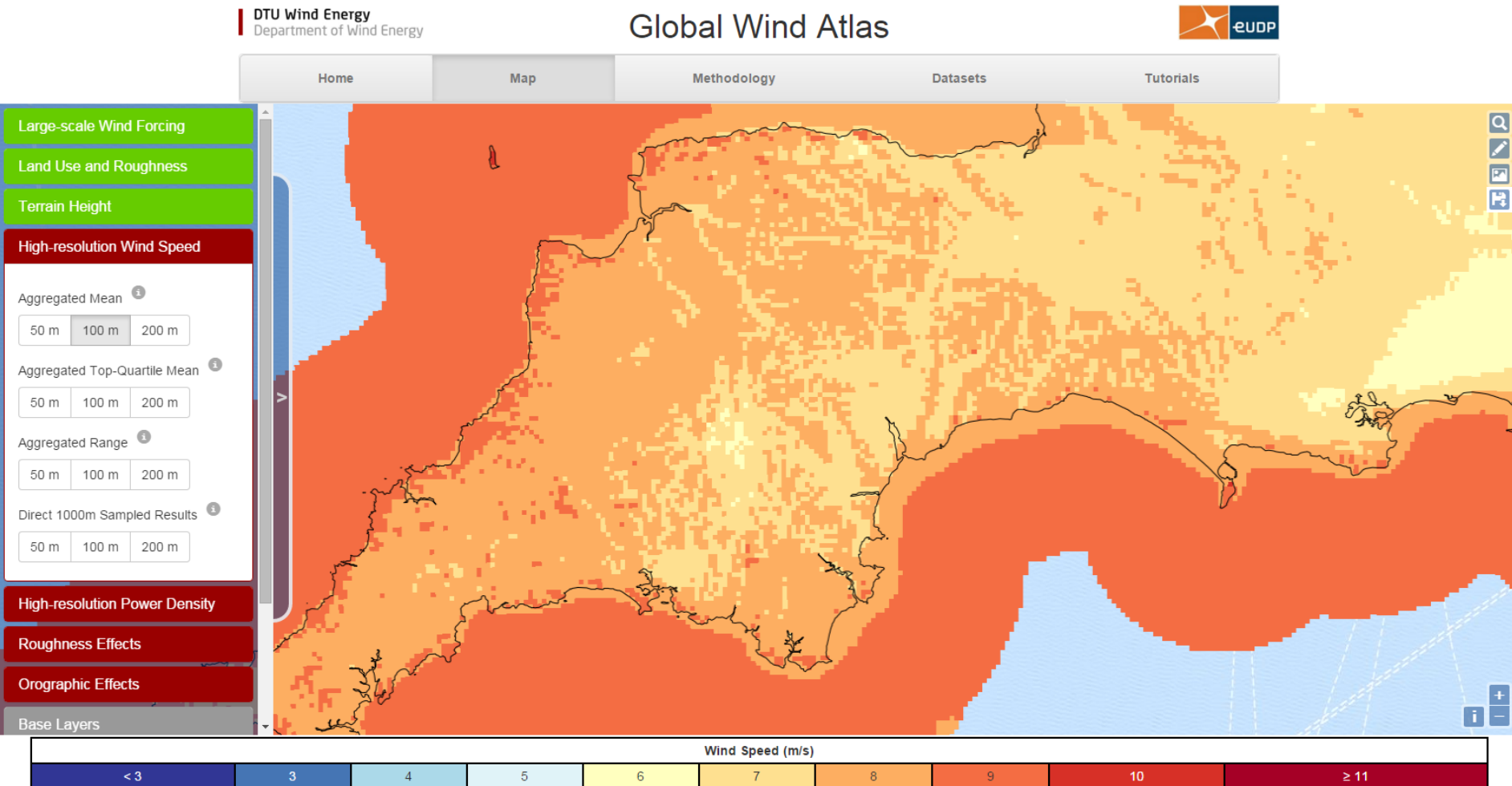
Orographic speed up for westerly winds at 100 m



Global Wind Atlas at DTU

globalwindatlas.com

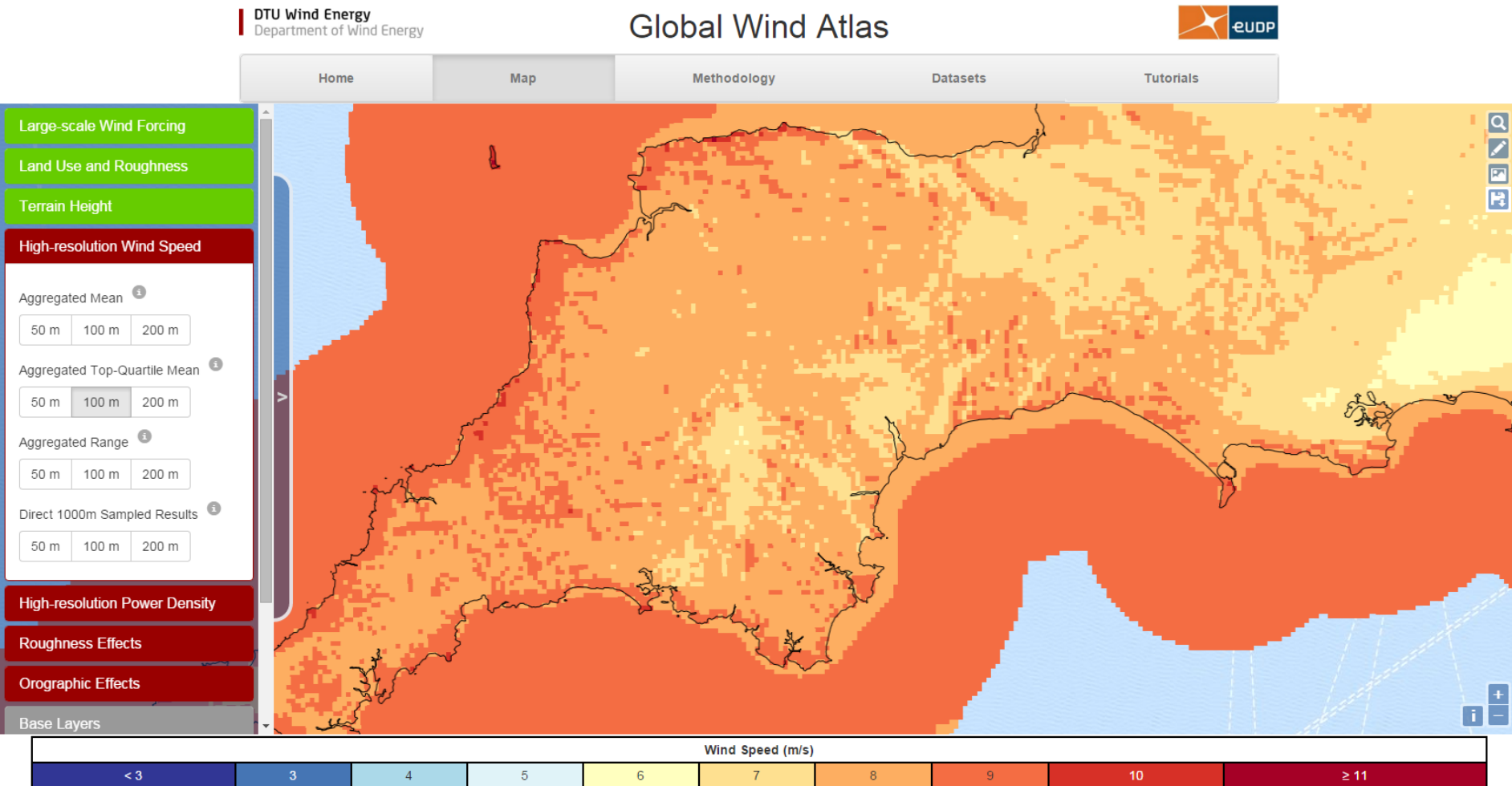
Mean wind speed at 100 m



Global Wind Atlas at DTU

globalwindatlas.com

Top-quartile mean wind speed at 100 m

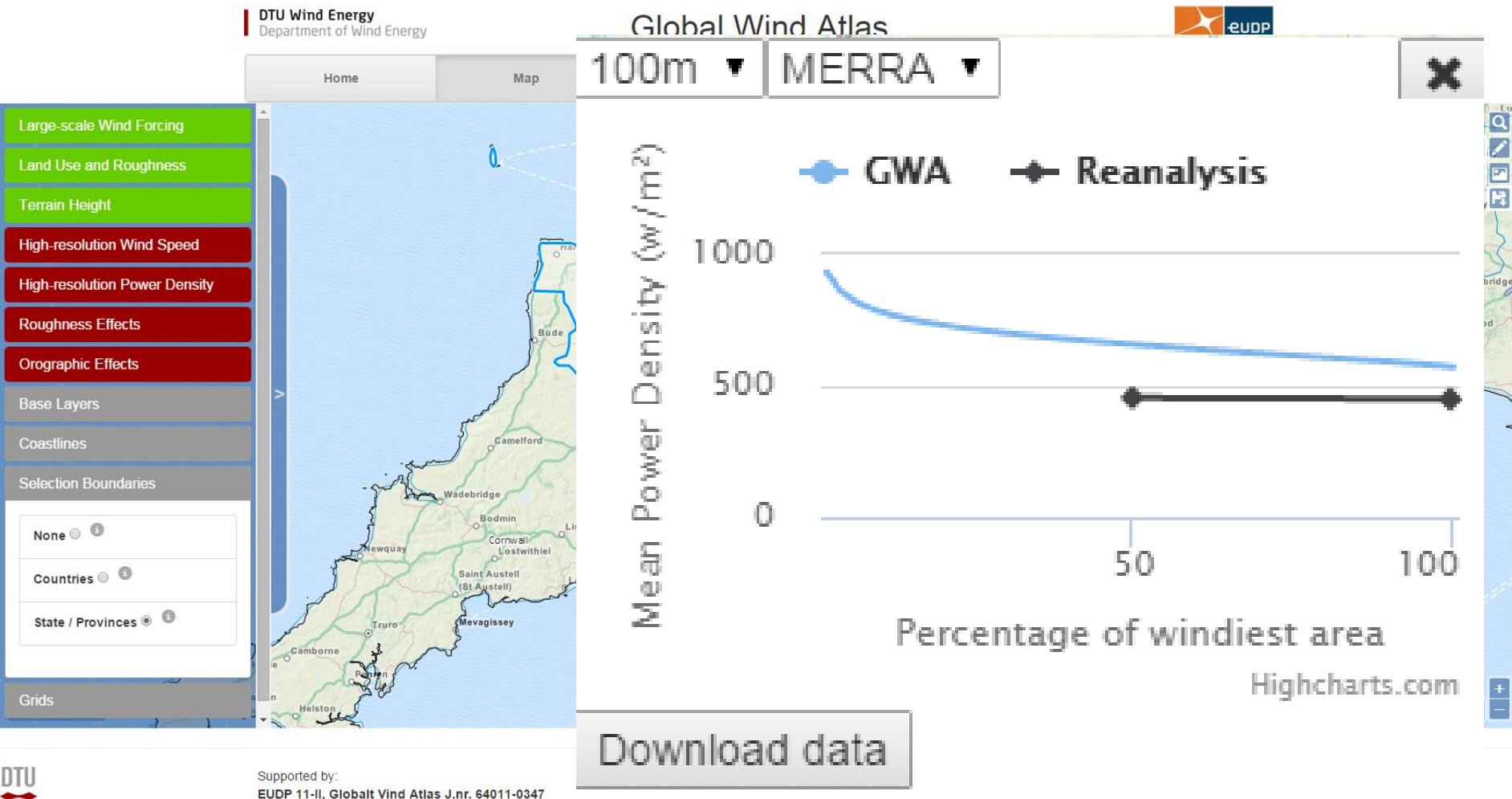


Global Wind Atlas at DTU

globalwindatlas.com



Tools, e.g. power density for windiest areas at 100 m



Global Wind Atlas at DTU

globalwindatlas.com

Mean wind speed at 100 m



DTU Wind Energy
Department of Wind Energy

Global Wind Atlas



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Large-scale Wind Forcing

Land Use and Roughness

Terrain Height

High-resolution Wind Speed

Aggregated Mean

50 m 100 m 200 m

Aggregated Top-Quartile Mean

50 m 100 m 200 m

Aggregated Range

50 m 100 m 200 m

Direct 1000m Sampled Results

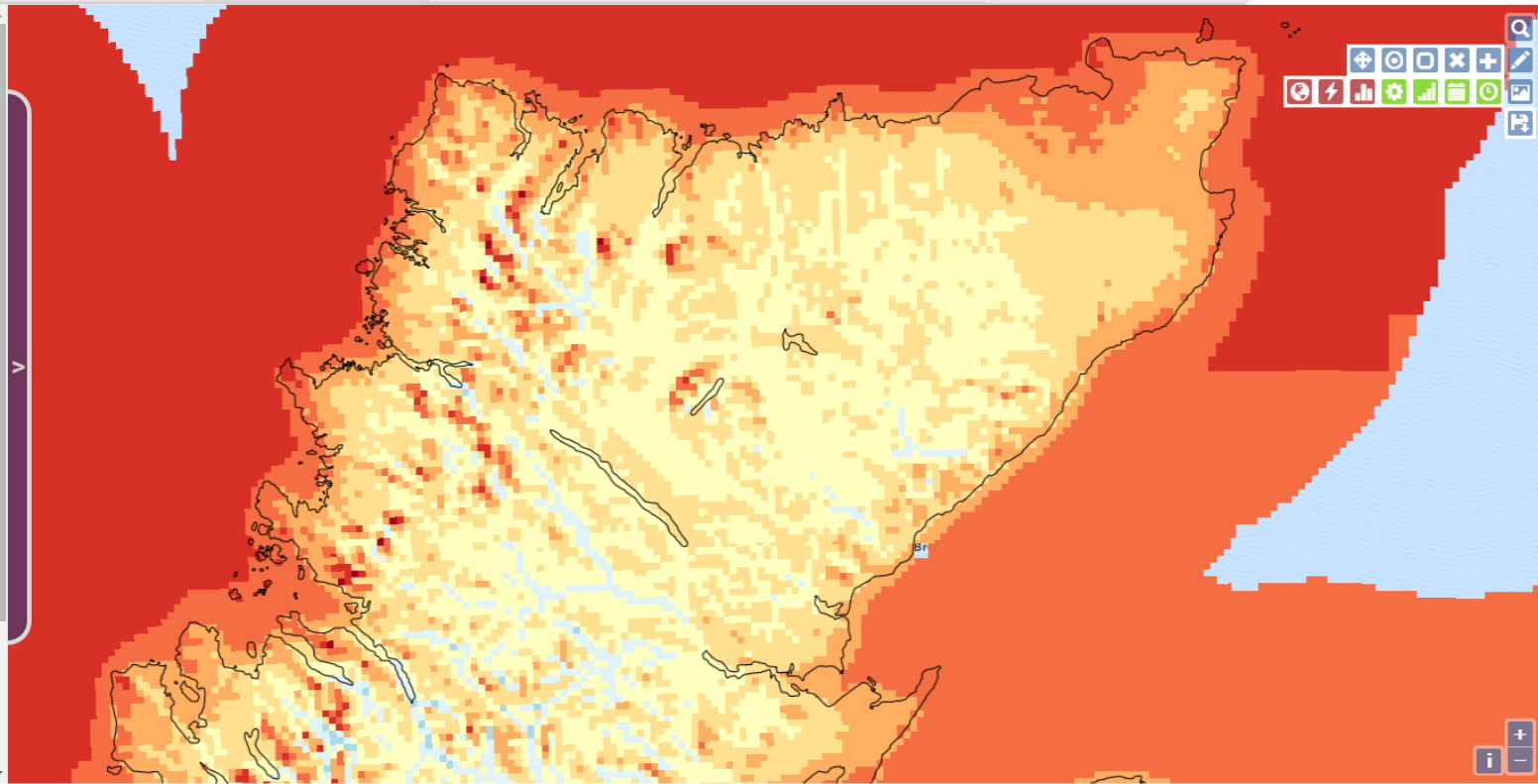
50 m 100 m 200 m

High-resolution Power Density

Roughness Effects

Orographic Effects

Base Layers



Wind Speed (m/s)

< 3

3

4

5

6

7

8

9

10

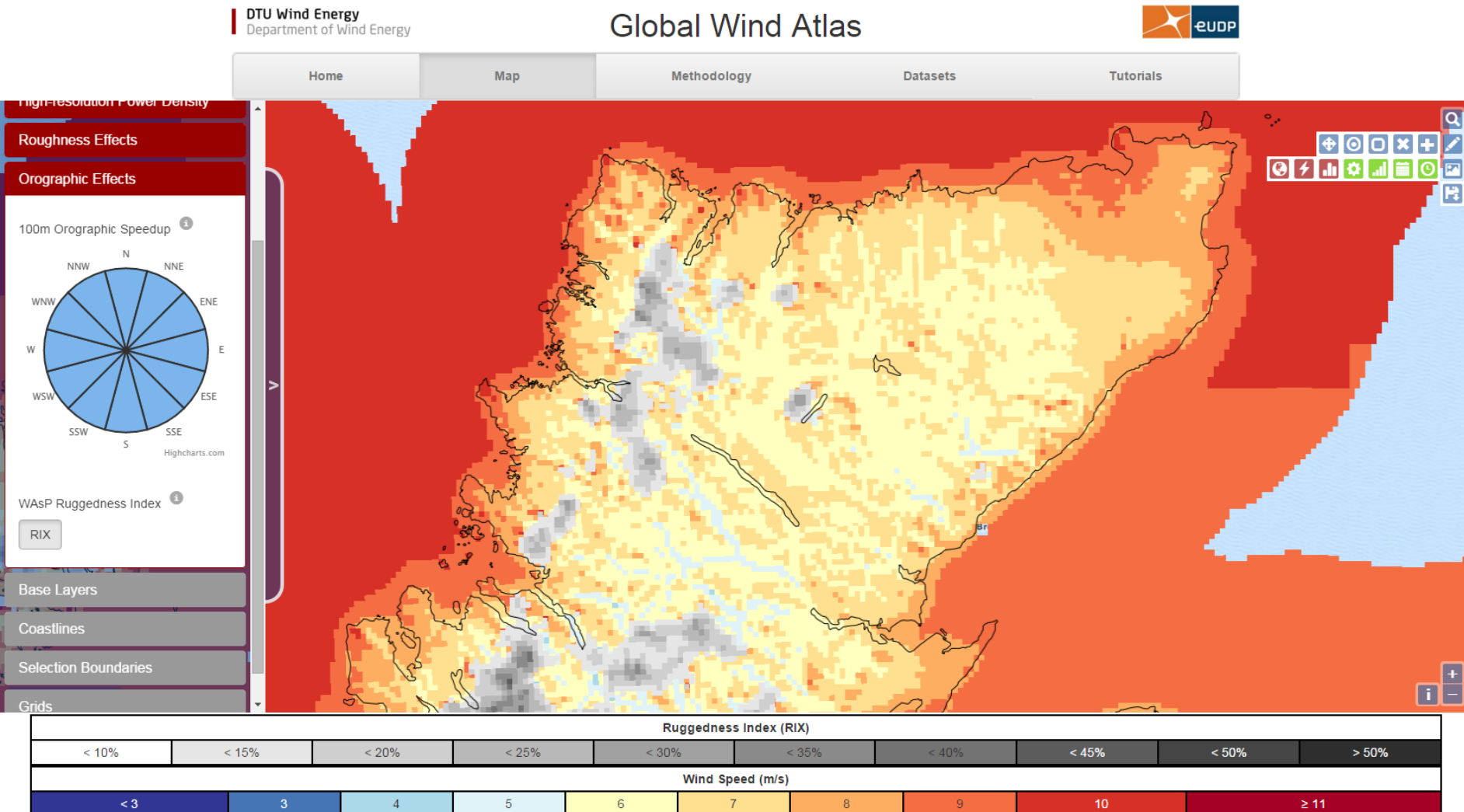
≥ 11

Global Wind Atlas at DTU

globalwindatlas.com



mean wind speed high ruggedness masked out (RIX)



Future application

Global assessment of the technical potential

We can use the EUDP Global Wind Atlas to determine global potential accounting for high resolution effects and get a better spatial breakdown.

The challenge is to create a consistent approach, with range of tested assumptions, available for the community to scrutinize.

The Global Wind Atlas makes this easier via

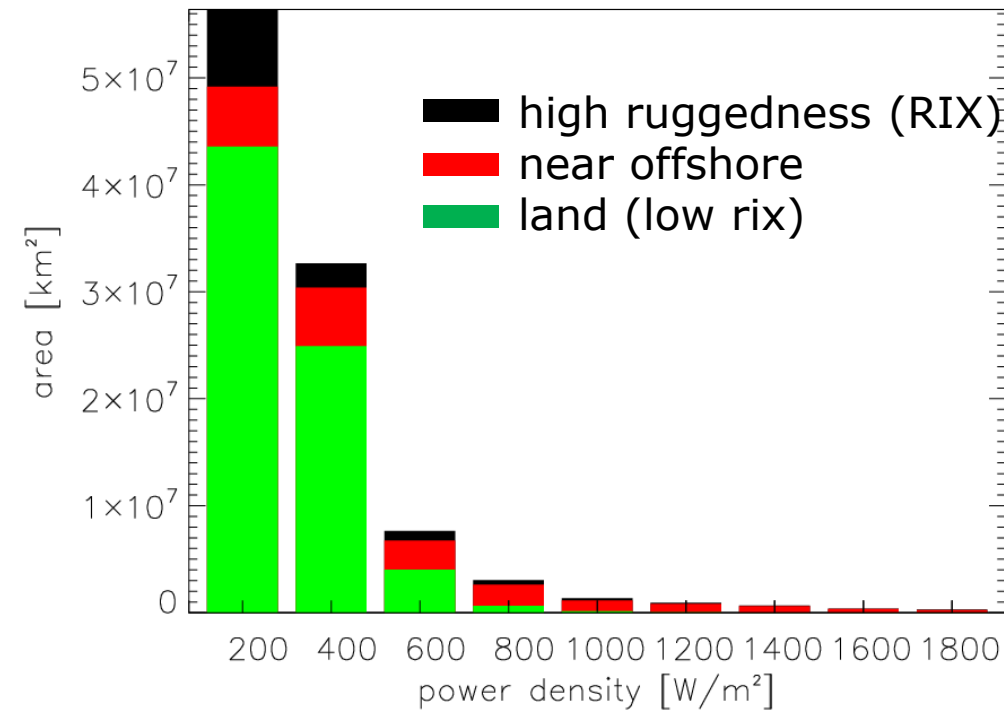
- Transparency of methodology
- Providing data to allow annual energy production calculation
- GIS integration of datasets

Global assessments of the technical potential

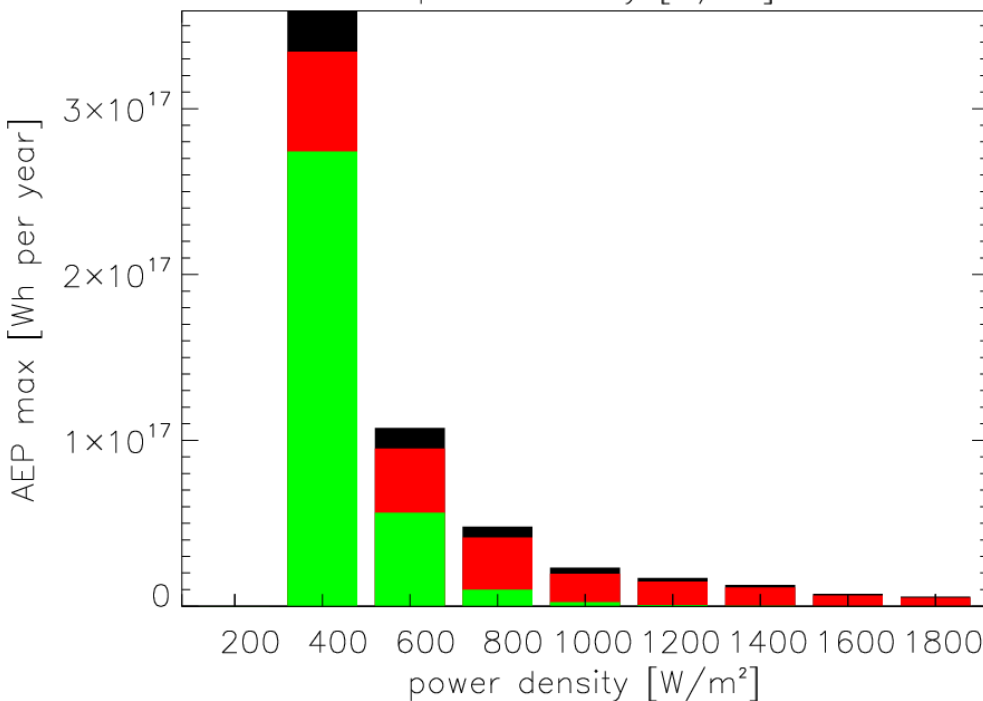
IPCC Special Report on Renewable Energy Sources and Climate Change:
range tech. pot. **19 – 125 PWh / year** (onshore and near shore)

Table 7.1 | Global assessments of the technical potential for wind energy.

Study	Scope	Methods and Assumptions ¹	Results ²
Krewitt et al. (2009)	Onshore and offshore	Updated Hoogwijk and Graus (2008), itself based on Hoogwijk et al. (2004), by revising offshore wind power plant spacing by 2050 to 16 MW/km ²	<i>Technical</i> (more constraints): 121,000 TWh/yr 440 EJ/yr
Lu et al. (2009)	Onshore and offshore	>20% capacity factor (Class 1); 100 m hub height; 9 MW/km ² spacing; based on coarse simulated model data set; exclusions for urban and developed areas, forests, inland water, permanent snow/ice; offshore assumes 100 m hub height, 6 MW/km ² , <92.6 km from shore, <200m depth, no other exclusions	<i>Technical</i> (limited constraints): 840,000 TWh/yr 3,050 EJ/yr
Hoogwijk and Graus (2008)	Onshore and offshore	Updated Hoogwijk et al. (2004) by incorporating offshore wind energy, assuming 100 m hub height for onshore, and altering cost assumptions; for offshore, study updates and adds to earlier analysis by Fellows (2000); other assumptions as listed below under Hoogwijk et al. (2004); constrained technical potential defined here in economic terms separately for onshore and offshore	<i>Technical/Economic</i> (more constraints): 110,000 TWh/yr 400 EJ/yr
Archer and Jacobson (2005)	Onshore and near-Shore	>Class 3; 80 m hub height; 9 MW/km ² spacing; 48% average capacity factor; based on wind speeds from surface stations and balloon-launch monitoring stations; near-shore wind energy effectively included because resource data includes buoys (see study for details); constrained technical potential = 20% of total technical potential	<i>Technical</i> (limited constraints): 627,000 TWh/yr 2,260 EJ/yr <i>Technical</i> (more constraints): 125,000 TWh/yr 450 EJ/yr
WBGU (2004)	Onshore and offshore	Multi-MW turbines; based on interpolation of wind speeds from meteorological towers; exclusions for urban areas, forest areas, wetlands, nature reserves, glaciers, and sand dunes; local exclusions accounted for through corrections related to population density; offshore to 40 m depth, with sea ice and minimum distance to shore considered regionally; constrained technical potential (authors define as 'sustainable' potential) = 14% of total technical potential	<i>Technical</i> (limited constraints): 278,000 TWh/yr 1,000 EJ/yr <i>Technical</i> (more constraints): 39,000 TWh/yr 140 EJ/yr



Power density	Capacity factor
200	0.00
400	0.25
600	0.32
800	0.36
1000	0.39
1200	0.42
1400	0.43
1600	0.45
1800	0.46



Assumption:
 5 MW per km² capacity density
 Annual production from wind.

all 581 PWh
 low ruggedness 528 PWh
 low ruggedness onshore 344 PWh

Note: 1 PWh = 1e15 Wh

Thank you for your attention



<http://globalwindatlas.com/map.html>

<http://globalwindatlas.com/methods.html>

<http://globalwindatlas.com/datasets.html>

<http://globalwindatlas.com/tutorials.html>

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Funding:

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