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The new worldwide microscale wind resource assessment data on IRENA's Global Atlas. The EUDP Global Wind Atlas

Badger, Jake; Davis, Neil; Hahmann, Andrea N.; Olsen, Bjarke Tobias; Larsén, Xiaoli Guo; Kelly, Mark C.; Volker, Patrick; Badger, Merete; Ahsbahs, Tobias Torben; Mortensen, Niels Gylling; Ejsing Jørgensen, Hans; Lundtang Petersen, Erik; Lange, Julia; Fichaux, Nicolas

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EWEA RESOURCE ASSESSMENT 2015

Helsinki, 2-3 June 2015

The new worldwide microscale wind resource assessment data on IRENA's Global Atlas

The EUDP Global Wind Atlas

Jake Badger, Neil Davis, Andrea Hahmann, Bjarke T. Olsen Xiaoli G. Larsén, Mark C. Kelly, Patrick Volker, Merete Badger, Tobias T. Ahsbahs, Niels Mortensen, Hans Jørgensen, Erik Lundtang Petersen, Julia Lange, DTU
Nicolas Fichaux, IRENA

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

DTU Wind Energy
Department of Wind Energy

Outline

- Project context
- Model chain
- Input data
- Output and verification
- Web user interface, walk through
- Future plans
- Global assessments of the technical potential

Project context - International collaboration

DTU

DTU Wind Energy
Department of Wind Energy

Energy Technology development and Demonstration (EUDP)
Global Wind Atlas by DTU Wind Energy

Global Atlas
FOR RENEWABLE ENERGY

Coordinated by International Renewable Energy Agency (IRENA)

Multilateral Solar and Wind Working Group

Lead countries are Denmark, Germany and Spain.+ 11 countries and EC

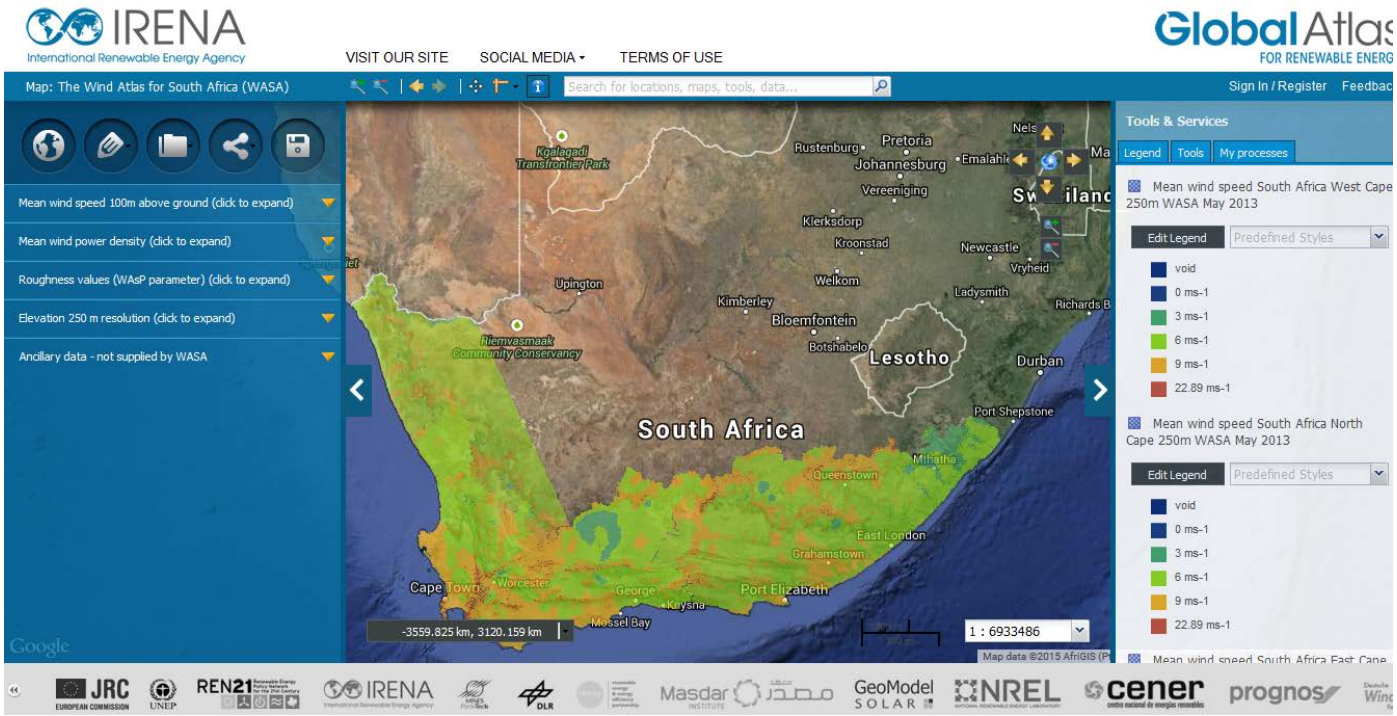
CLEAN ENERGY MINISTERIAL
Accelerating the Transition to Clean Energy Technologies

23 participating CEM governments account for 80 percent of global greenhouse gas emissions

International collaboration
What is IRENA's Global Atlas?

It is a high-level prospector for renewable energy opportunities

- builds on publicly available information
- information released by the private sector
- data released by institutions,
  - i.e. EUDP Global Wind Atlas
  - New European Wind Atlas

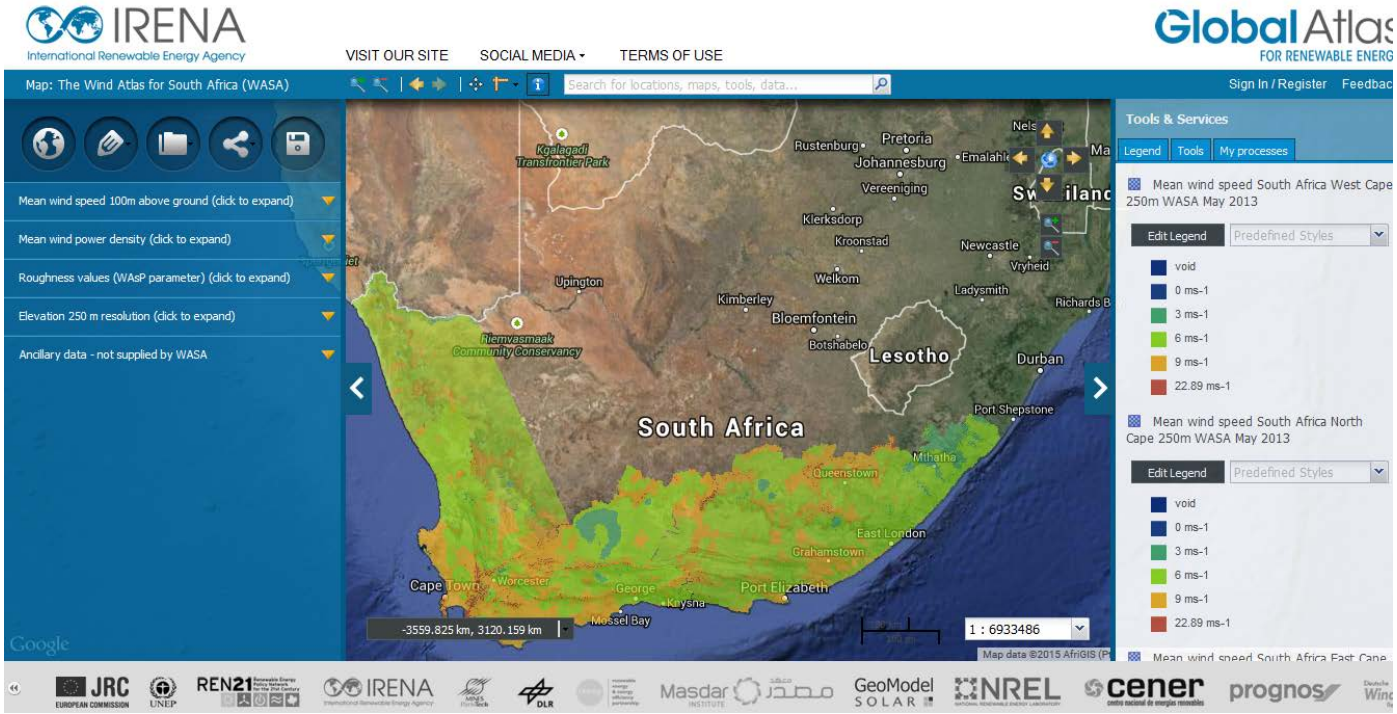


http://globalatlas.irena.org/

International collaboration
IRENA's Global Atlas

It supports

- countries in prospecting their renewable energy opportunities
- companies to approach new markets
- the general public in gaining interest in renewable energy



http://globalatlas.irena.org/

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
- verify 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

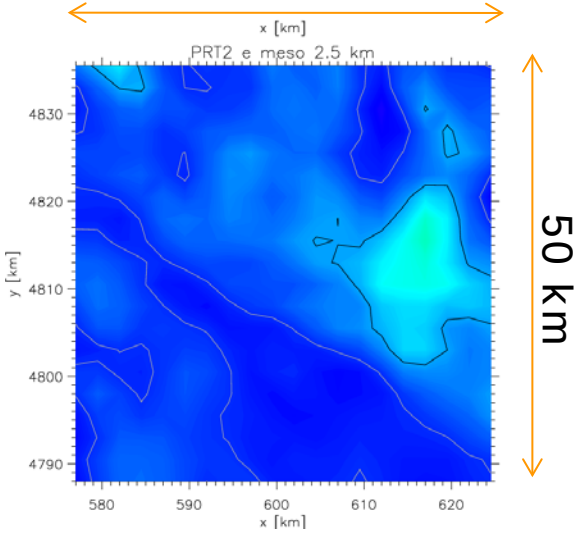
Project context

Wind resource (power density) calculated at different resolutions

Mesoscale

50 km

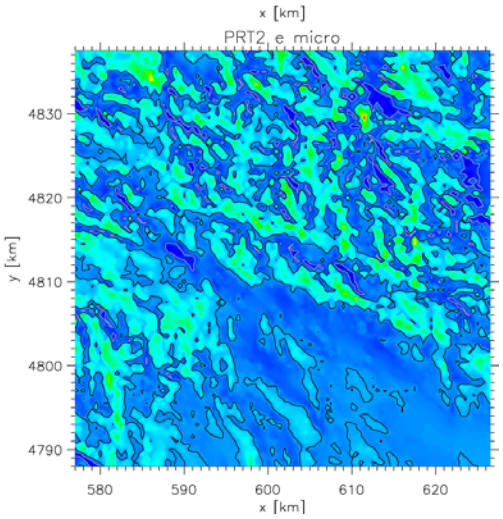
2.5 km



323 W/m²

410 W/m²

Mesoscale + microscale



100 m

505 W/m²

641 W/m²

mean power density of total area

mean power density for windiest 50% of area

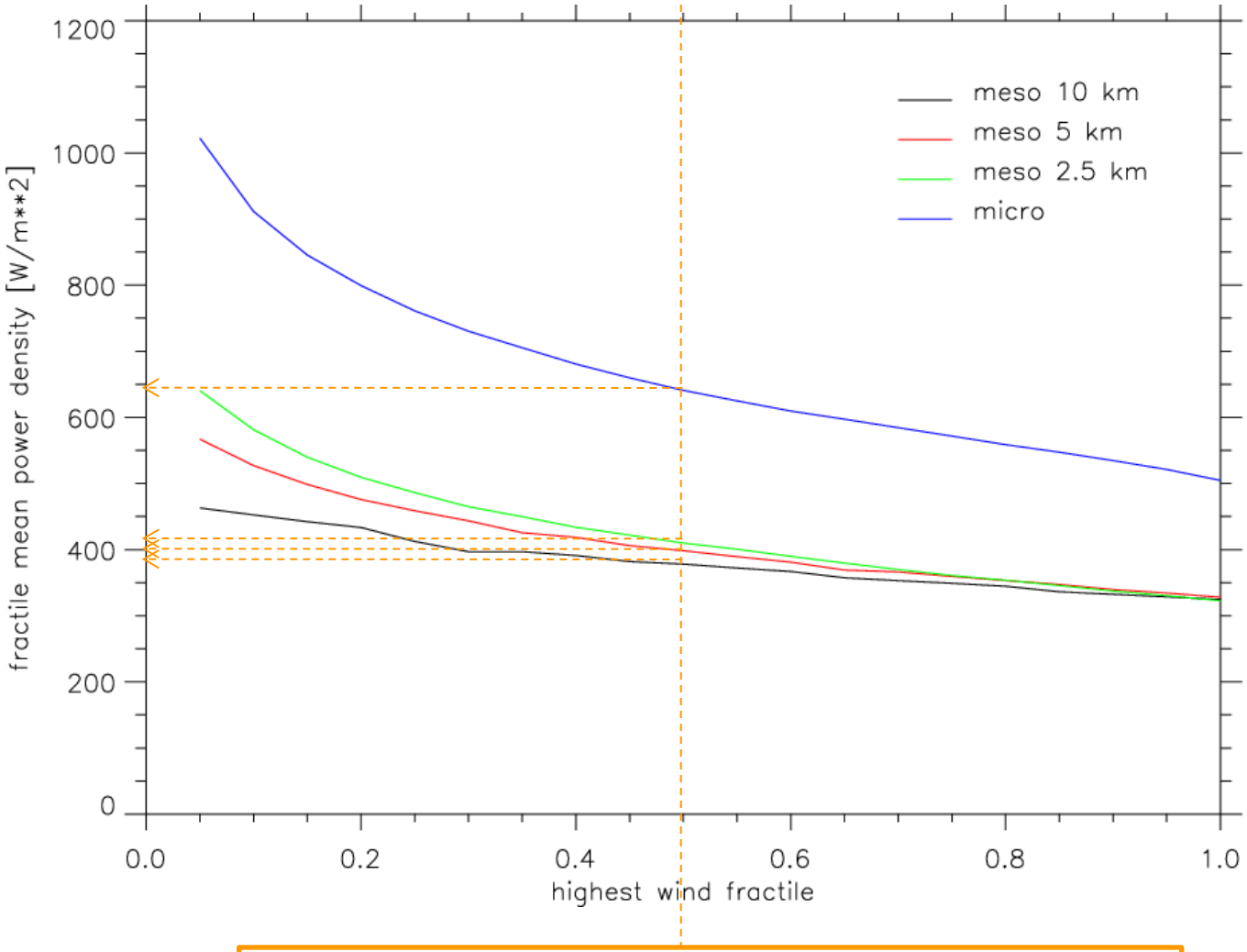
Wind farms are not randomly located but are built on favourable areas

Project context

Note:

This area exhibits large topography effects.

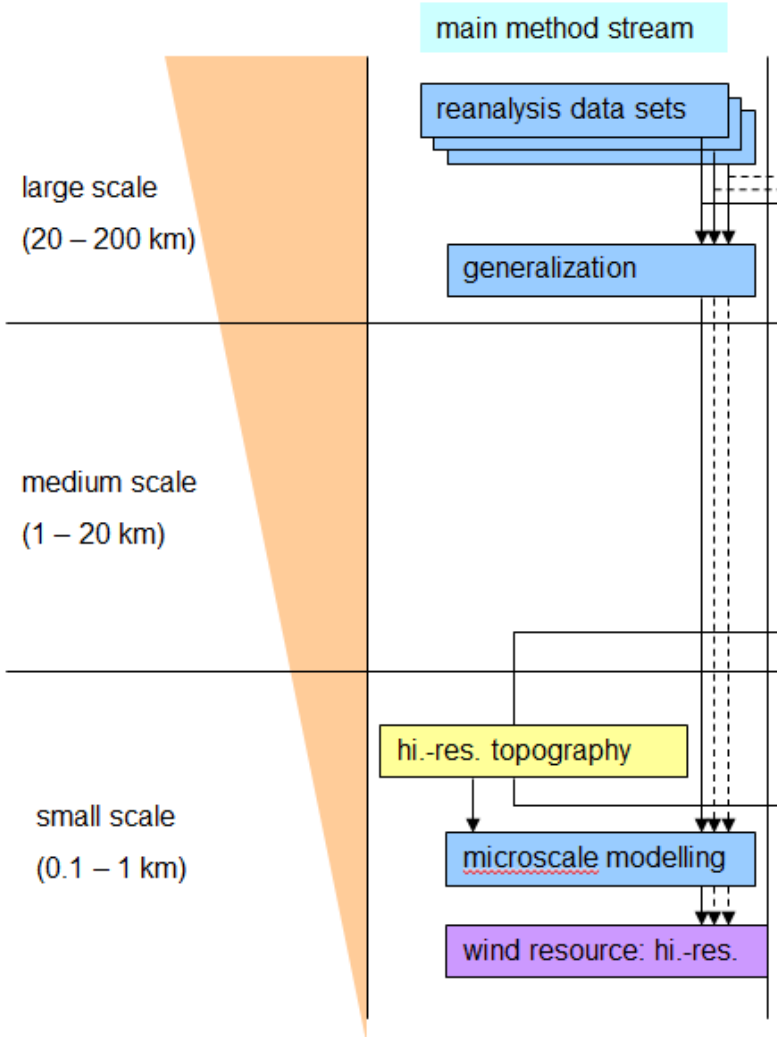
Even for Danish landscape effect can give 25 % boast in wind resource at the windiest 5 percentile.



Mean wind power density for windiest half of area

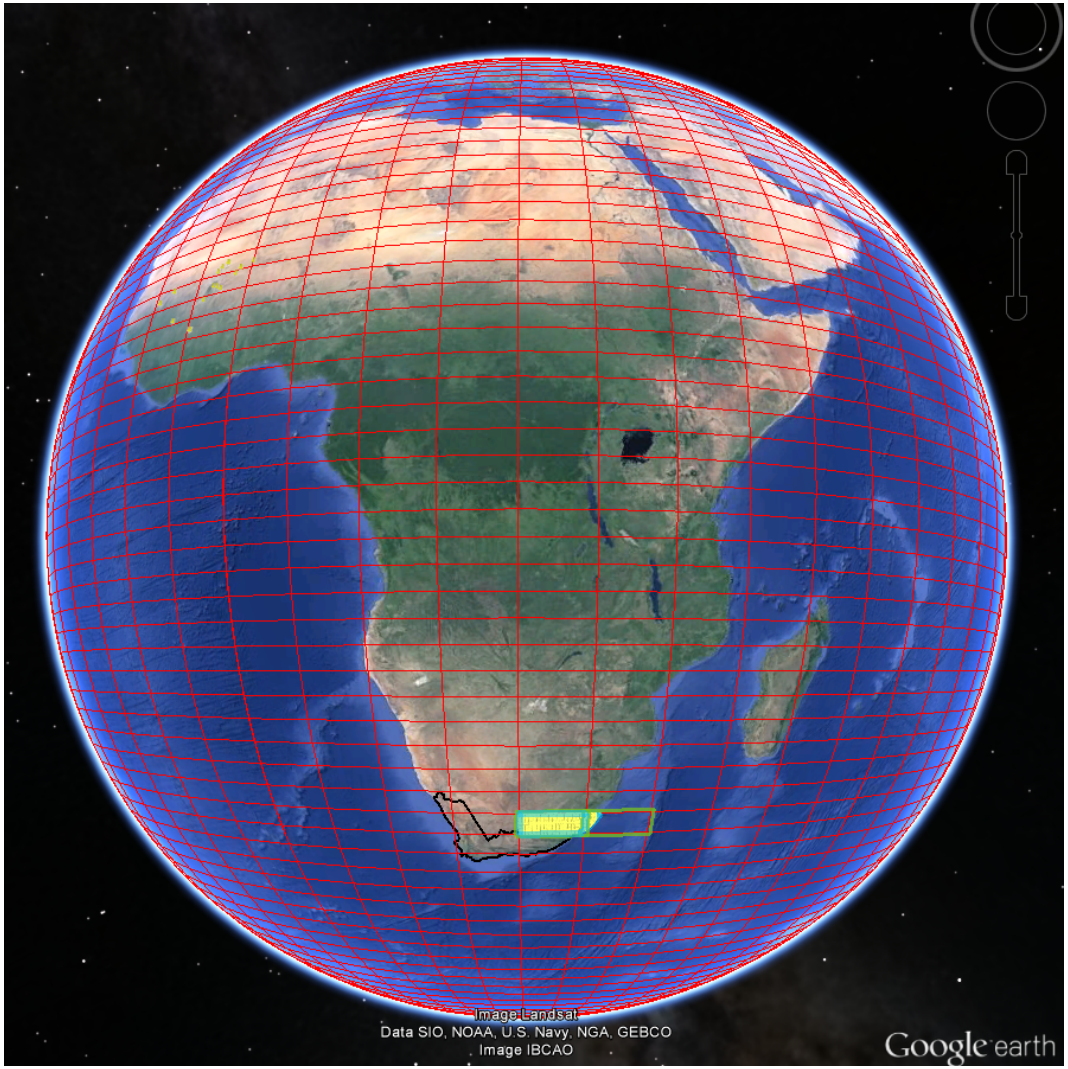
Model chain Downscaling

GWA



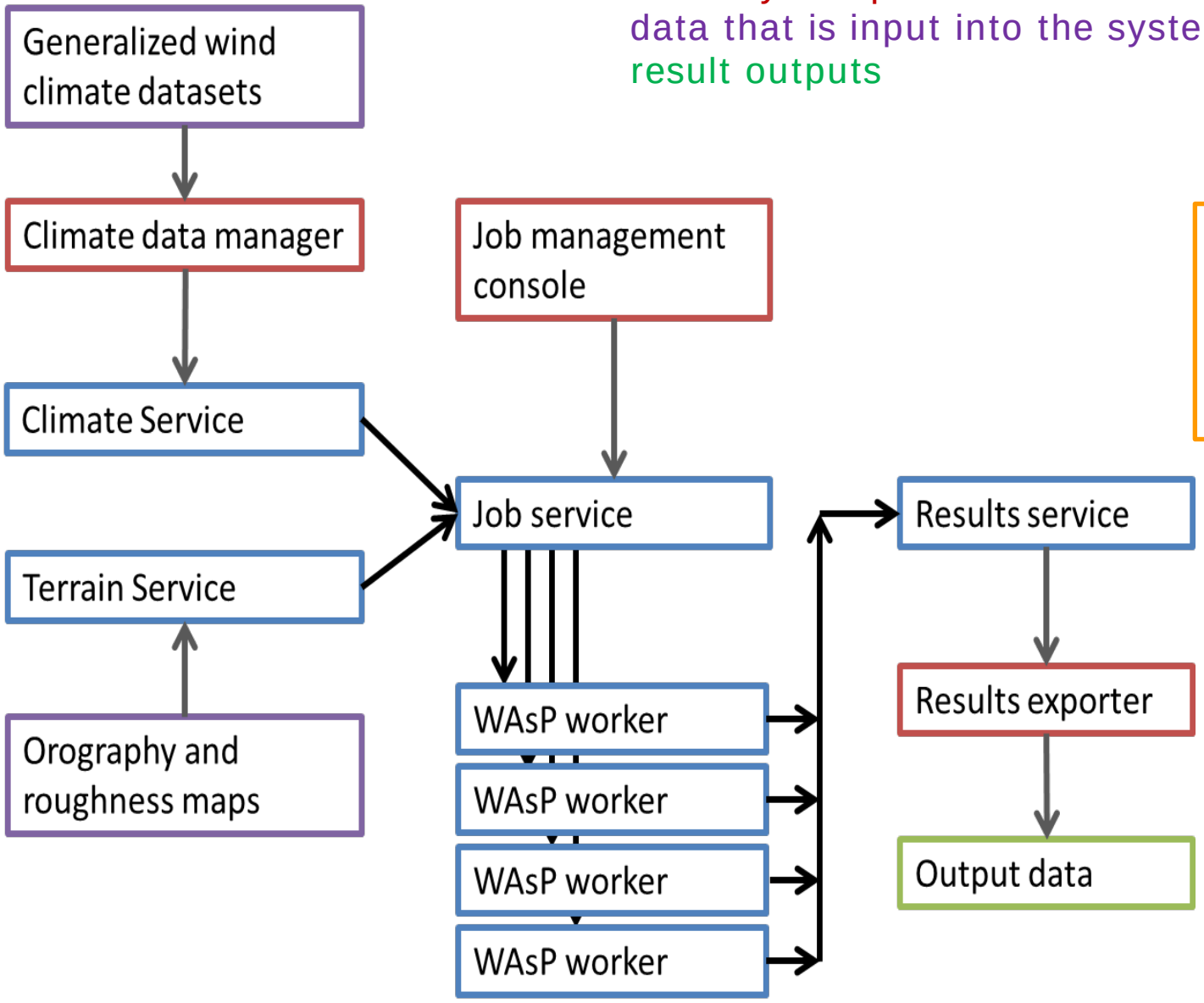
Model chain
Global Wind Atlas implementation

- Military Grid Reference System (MGRS) form basis of the job structure
- MRGS 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?

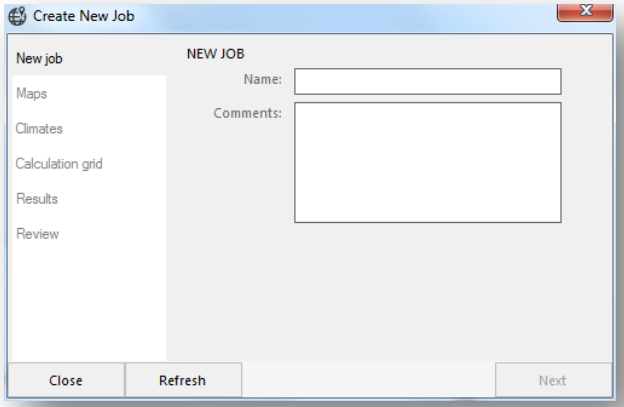
core Frogfoot-server components
ancillary components run on user PC
data that is input into the system
result outputs



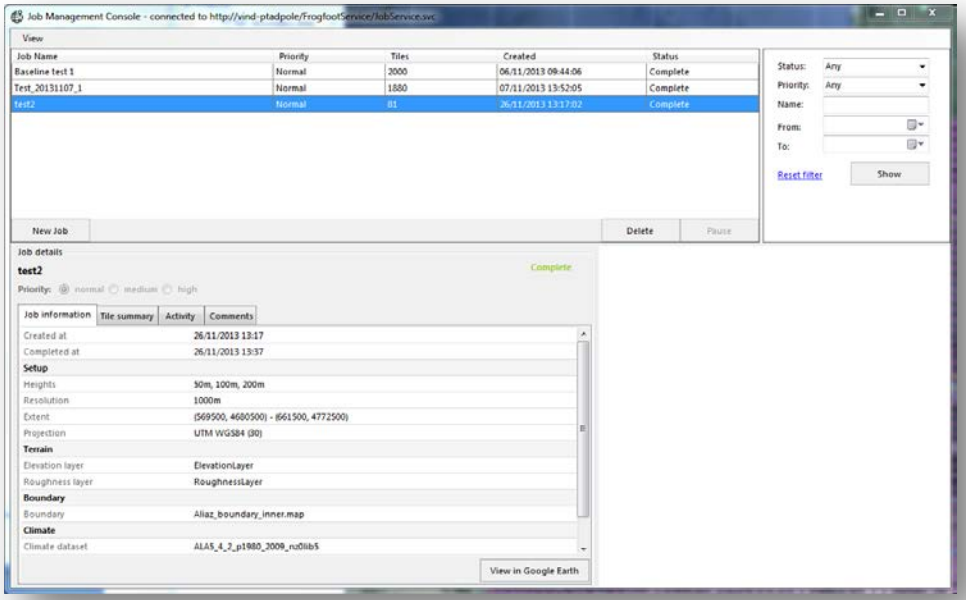
Like WAsP this is developed in partnership with **World In A Box** based in Finland

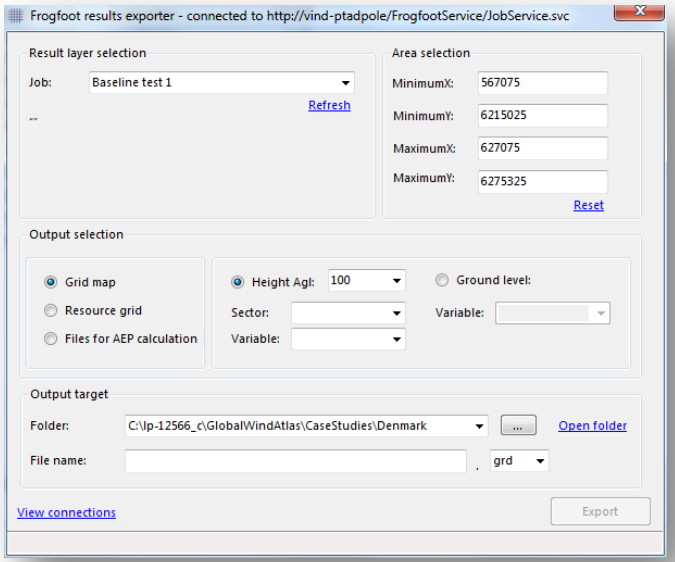
Frogfoot components

Job Creation

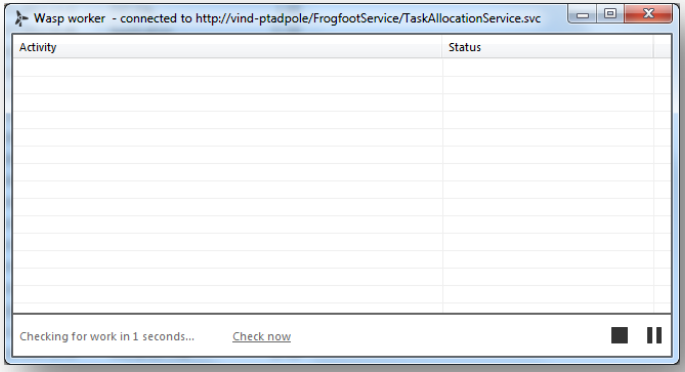


Job Management Console





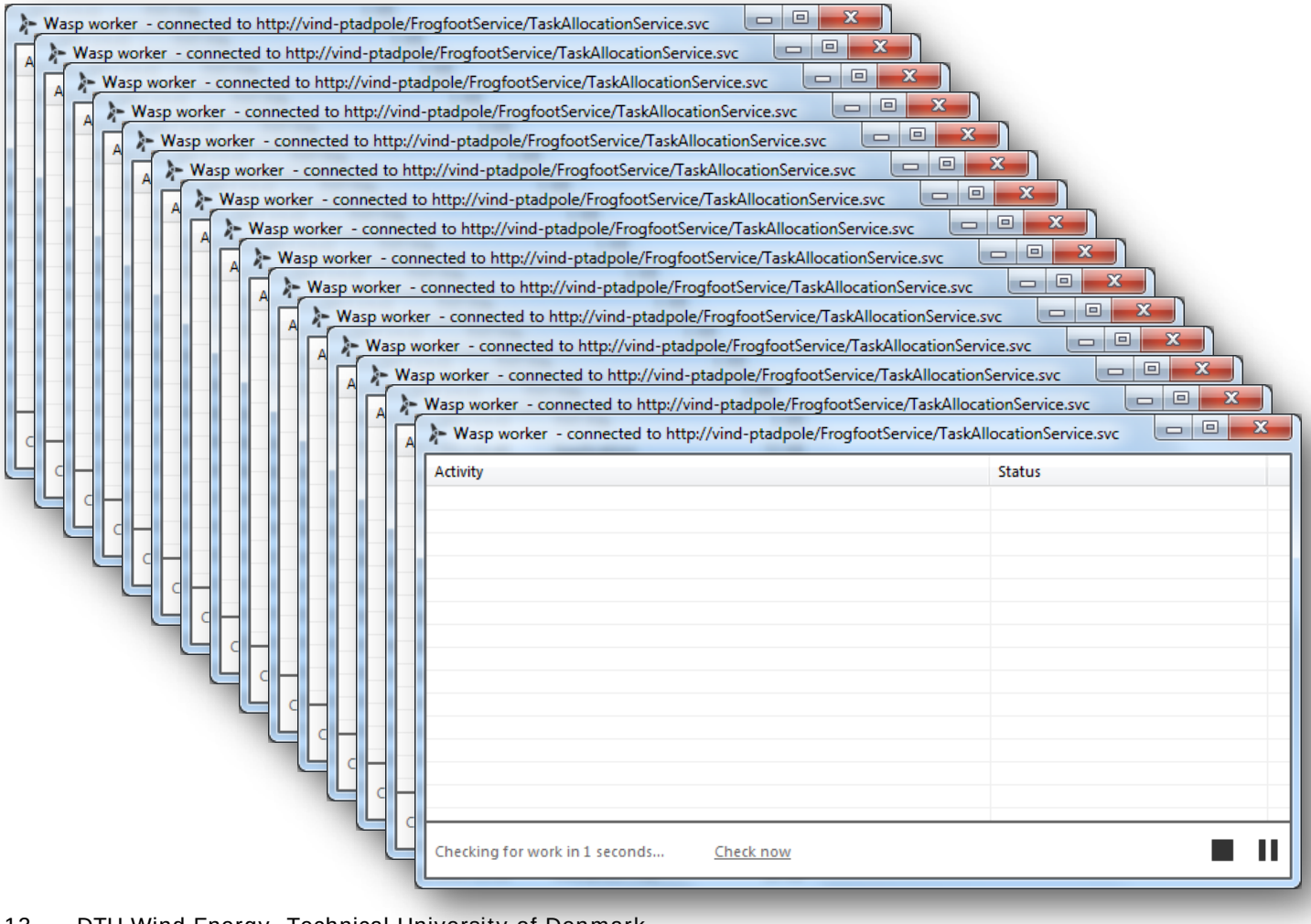
Results Exporter



WAsP Worker

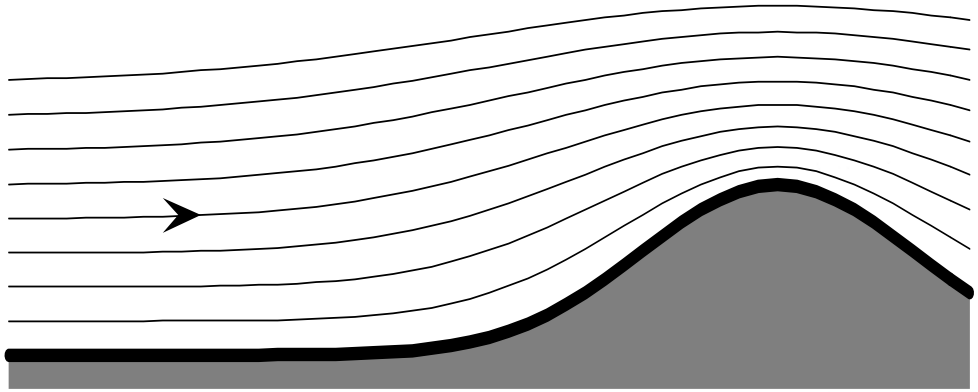
Model chain
How to work with Frogfoot?

WAsP Worker(s)



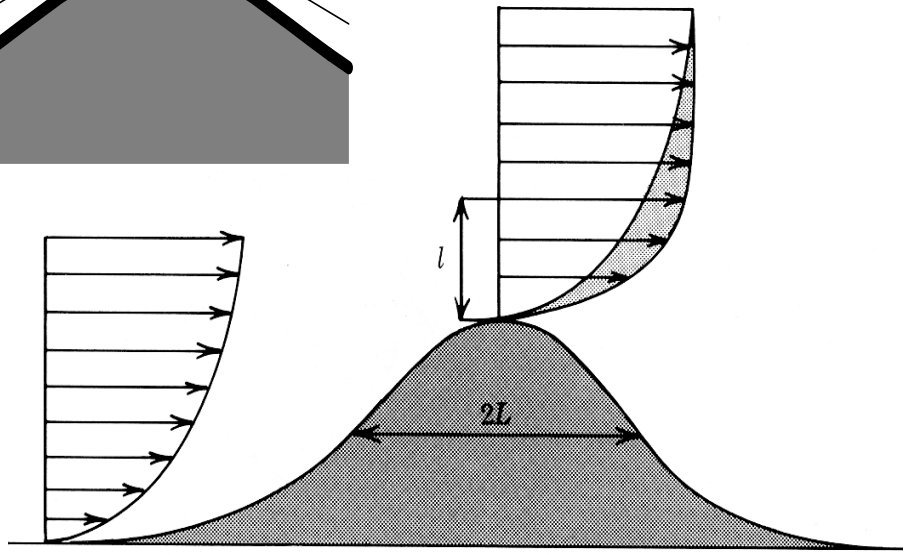
Microscale
Orographic speed-up

Streamlines closer together means faster flow



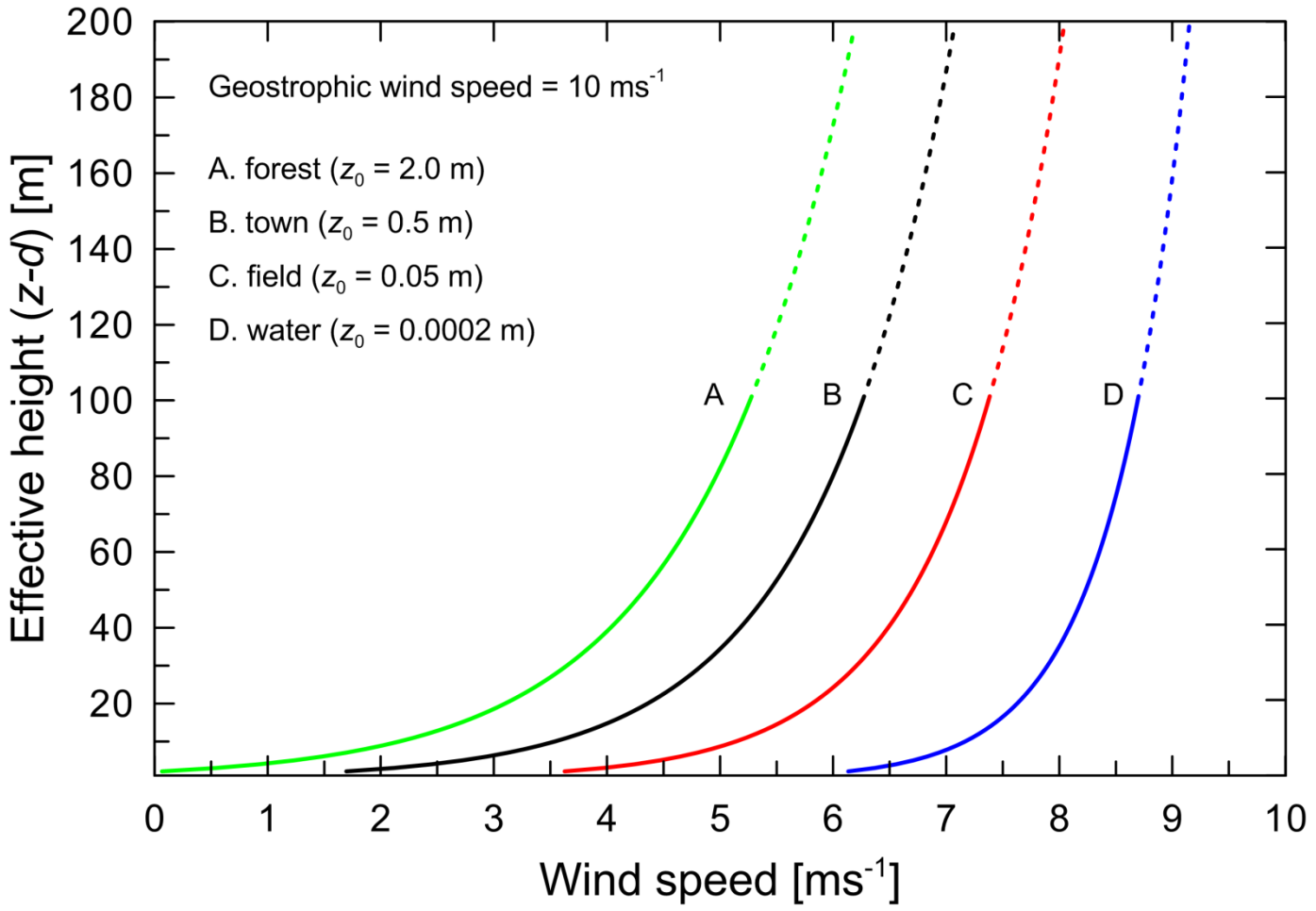
Winds speed up on hills

Winds slow down in valleys



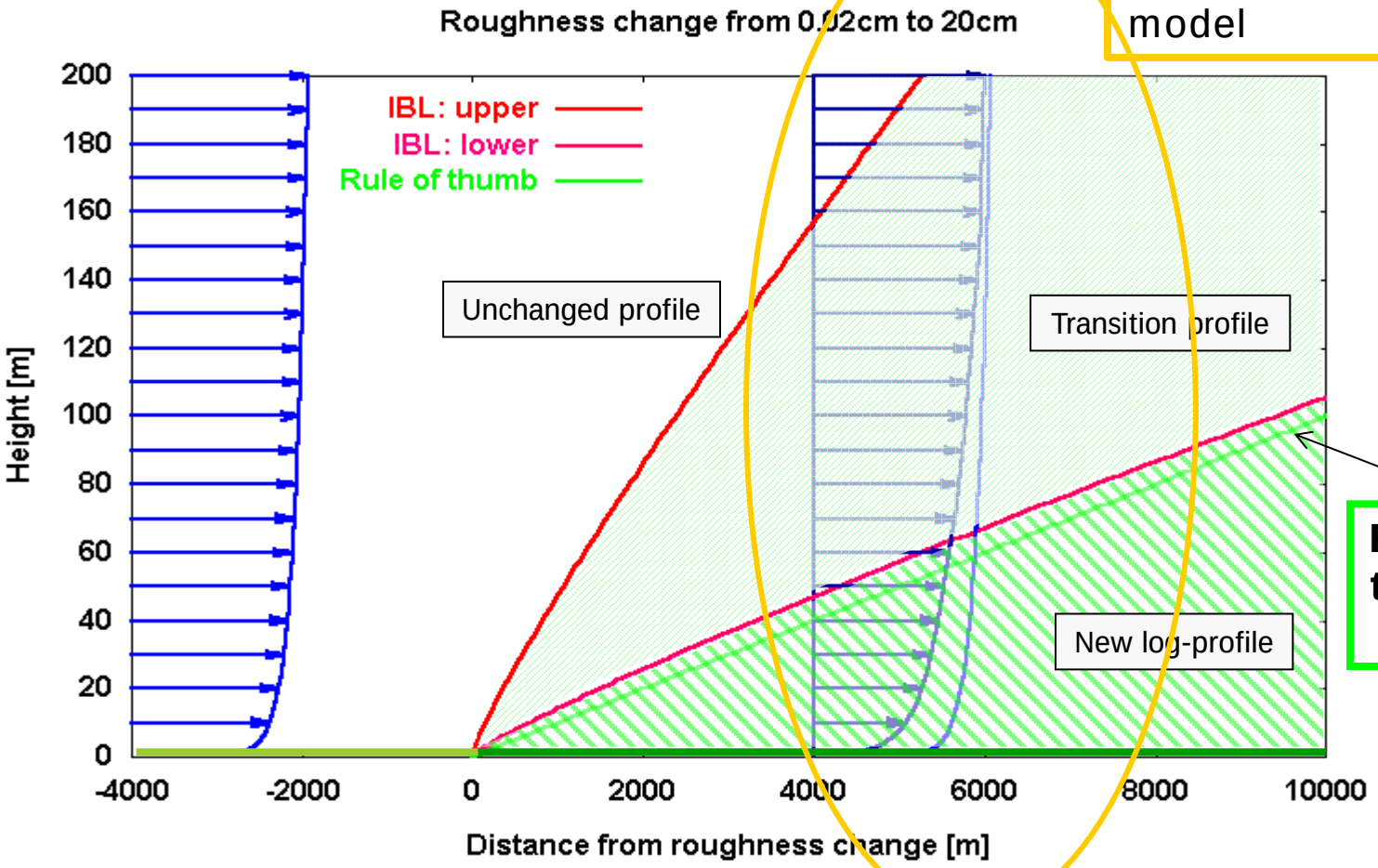
Modification of the wind profile

Microscale
Surface roughness length



Microscale
Surface roughness change

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



Rule of thumb: 1:100

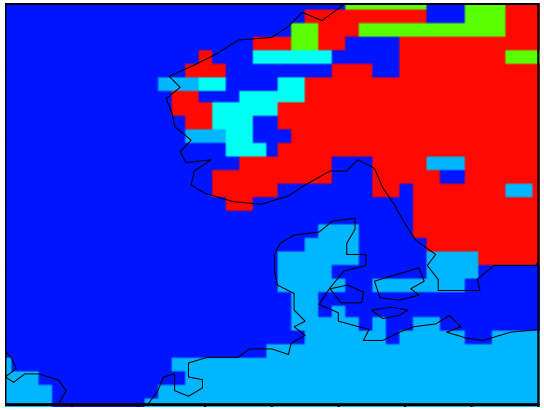
Datasets: atmospheric data

Reanalysis

Product	Model system	Horizontal resolution	Period covered	Temporal resolution
ERA Interim reanalysis	T255, 60 vertical levels, 4DVar	~0.7° × 0.7°	1979-present	3-hourly
NASA – GAO/MERRA	GEOS5 data assimilation system (Incremental Analysis Updates), 72 levels	0.5° × 0.67°	1979-present	hourly
NCAR CFDDA	MM5 (regional model)-FDDA	~40 km	1985-2005	hourly
CFSR	NCEP GFS (global forecast system)	~38 km	1979-2009 (& updating)	hourly

Challenges in generalizing wind climatologies

- Roughness length among the various reanalysis varies
- The response of the simulated wind profile to the surface roughness varies from model to model



surface roughness length (m)

0.48

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

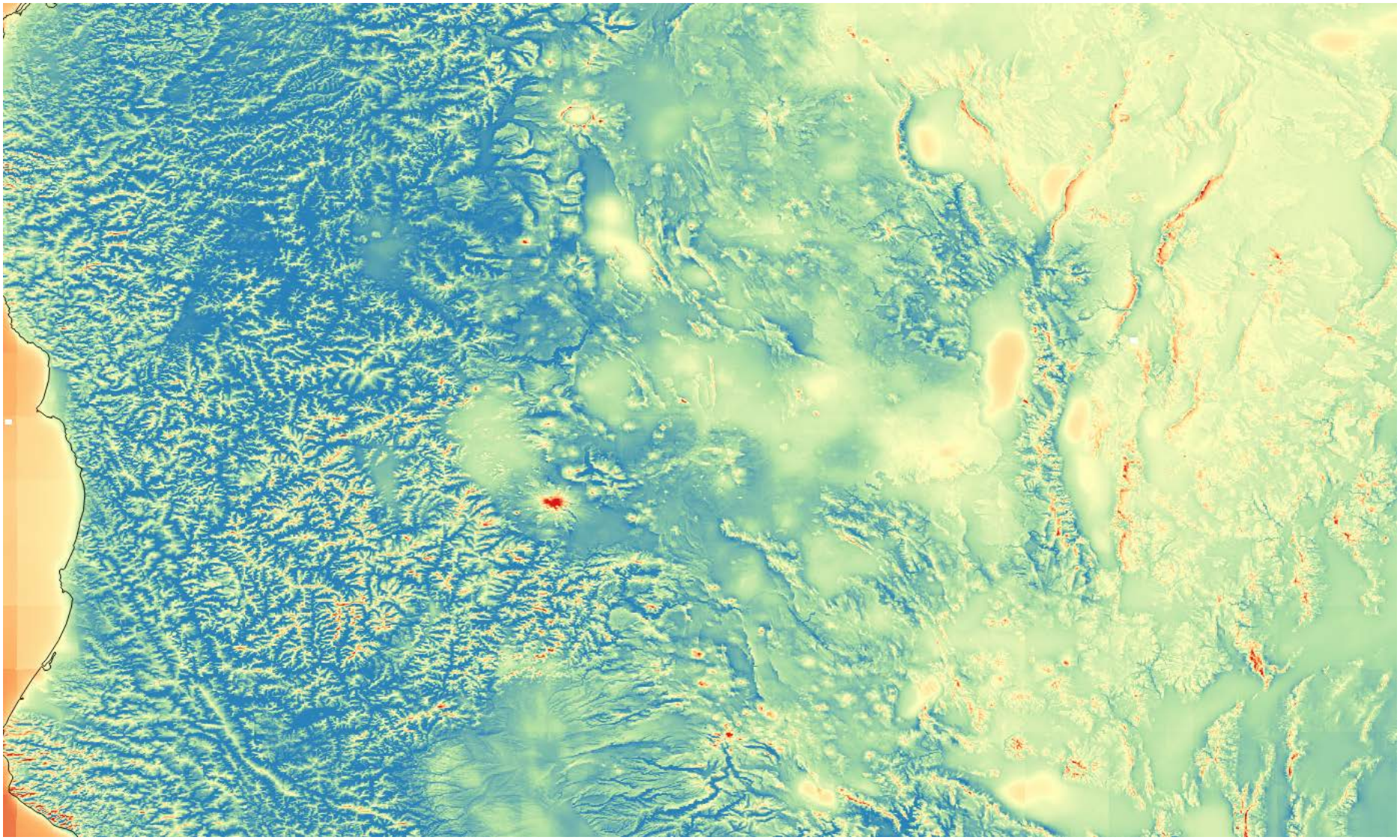
- European Space Agency initiative
- January – December 2009
- Global 300m resolution
- 22 Classes
- Data gaps near poles
  - Limited number of overpasses
  - Large number of cloudy images

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%)

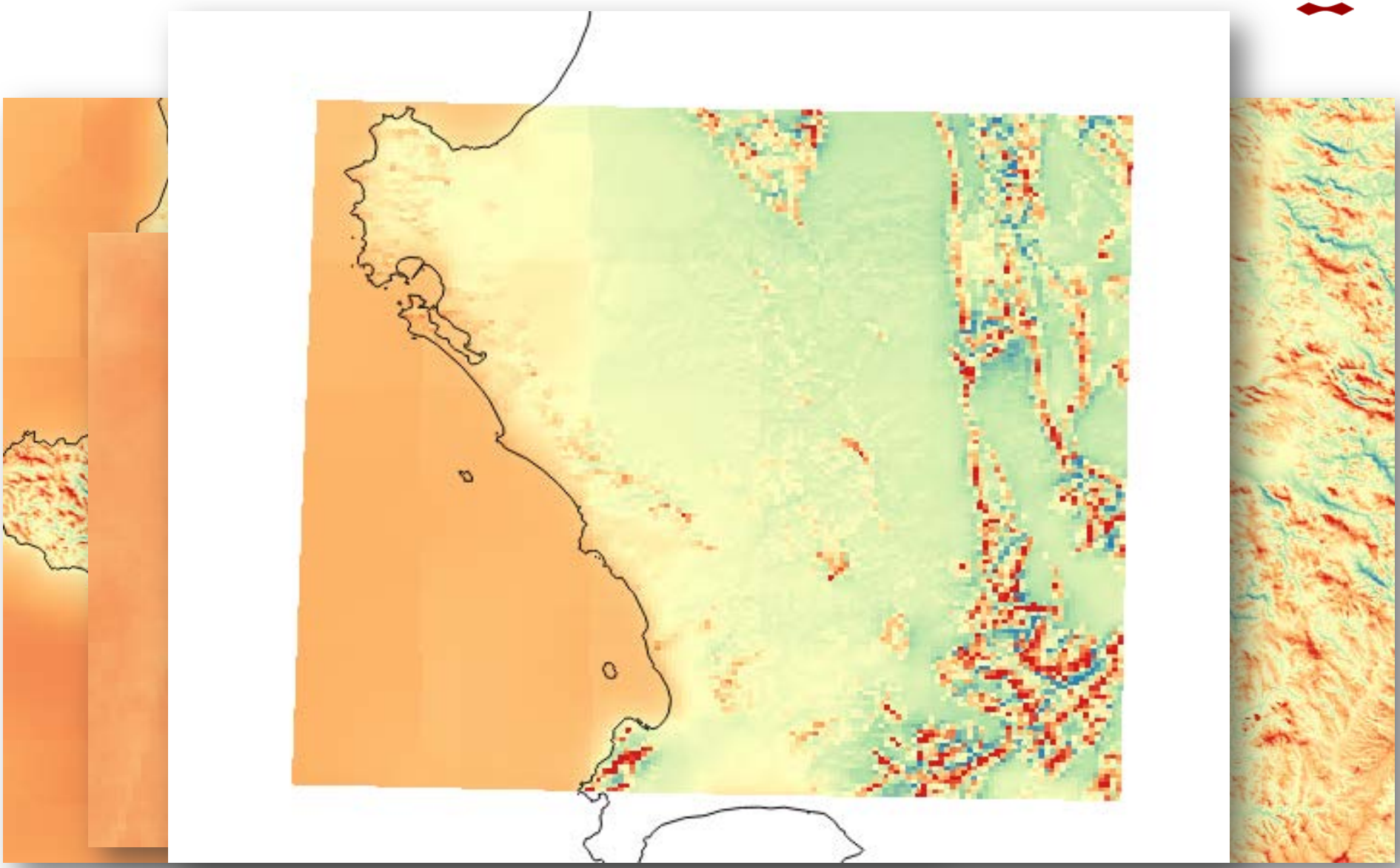
Challenges in determining surface roughness
Roughness lengths used in the GWA

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 vegatated
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 Vegatation 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,…)	

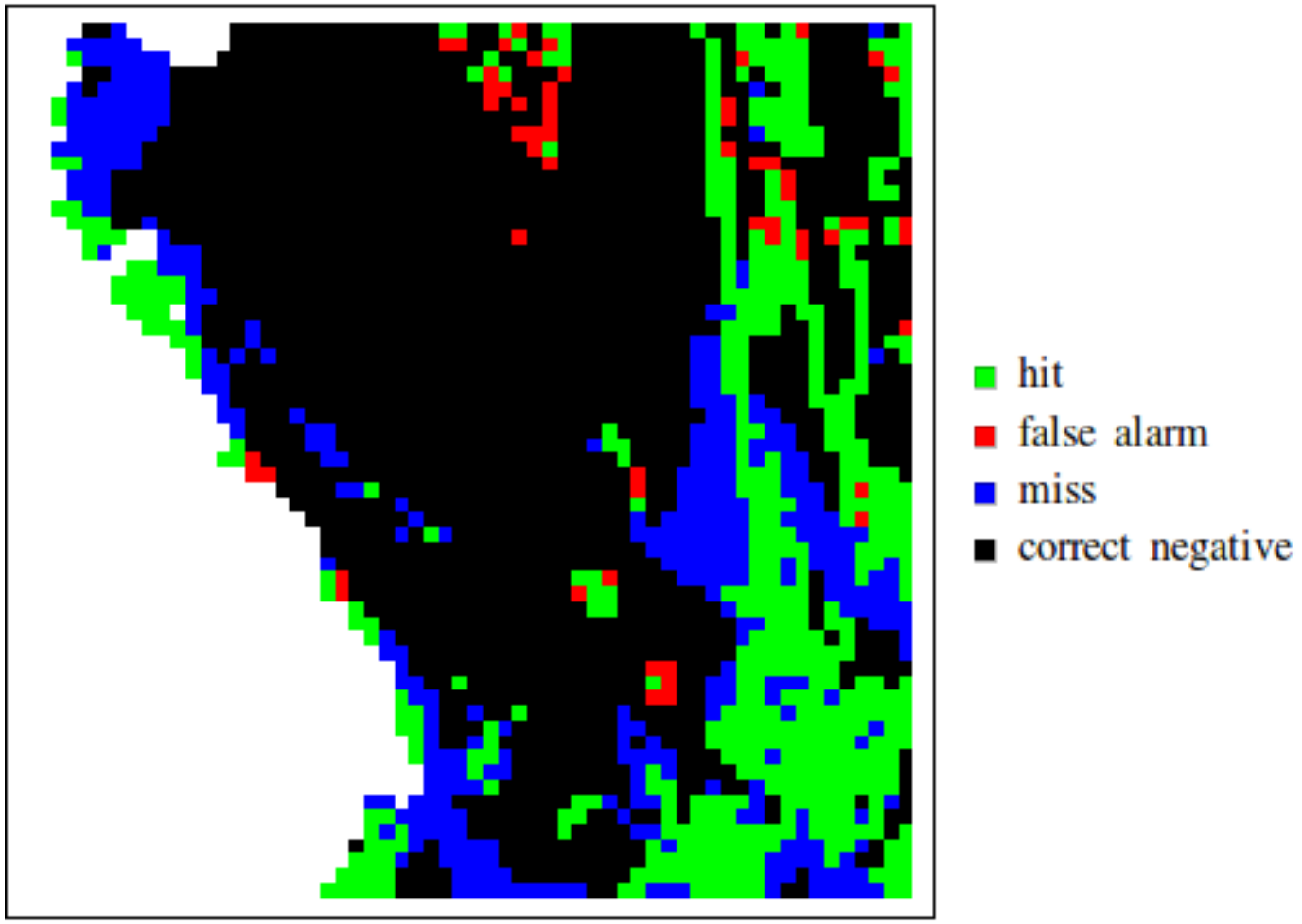
Example output
250 m calculation node spacing



Output and verification



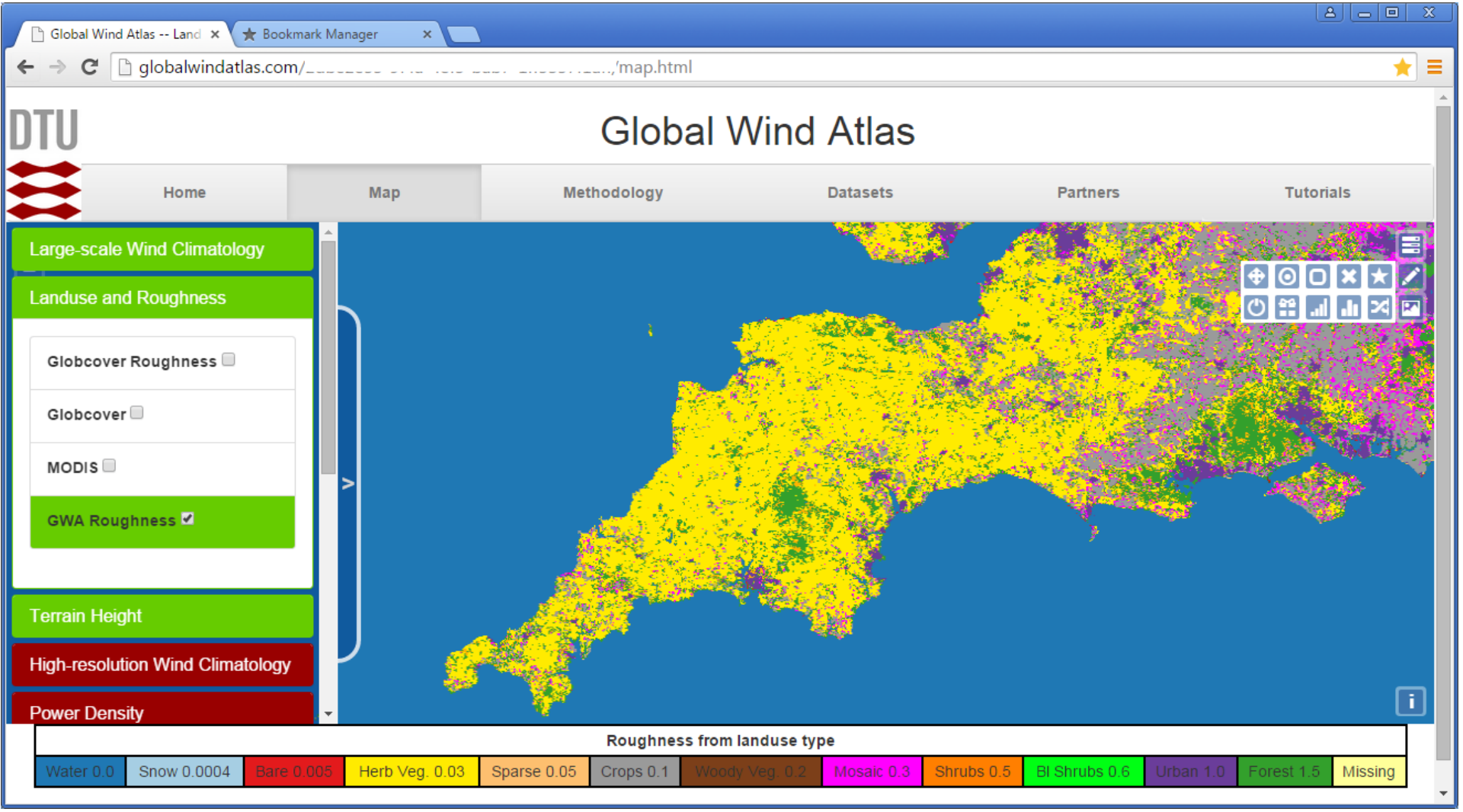
Output and verification



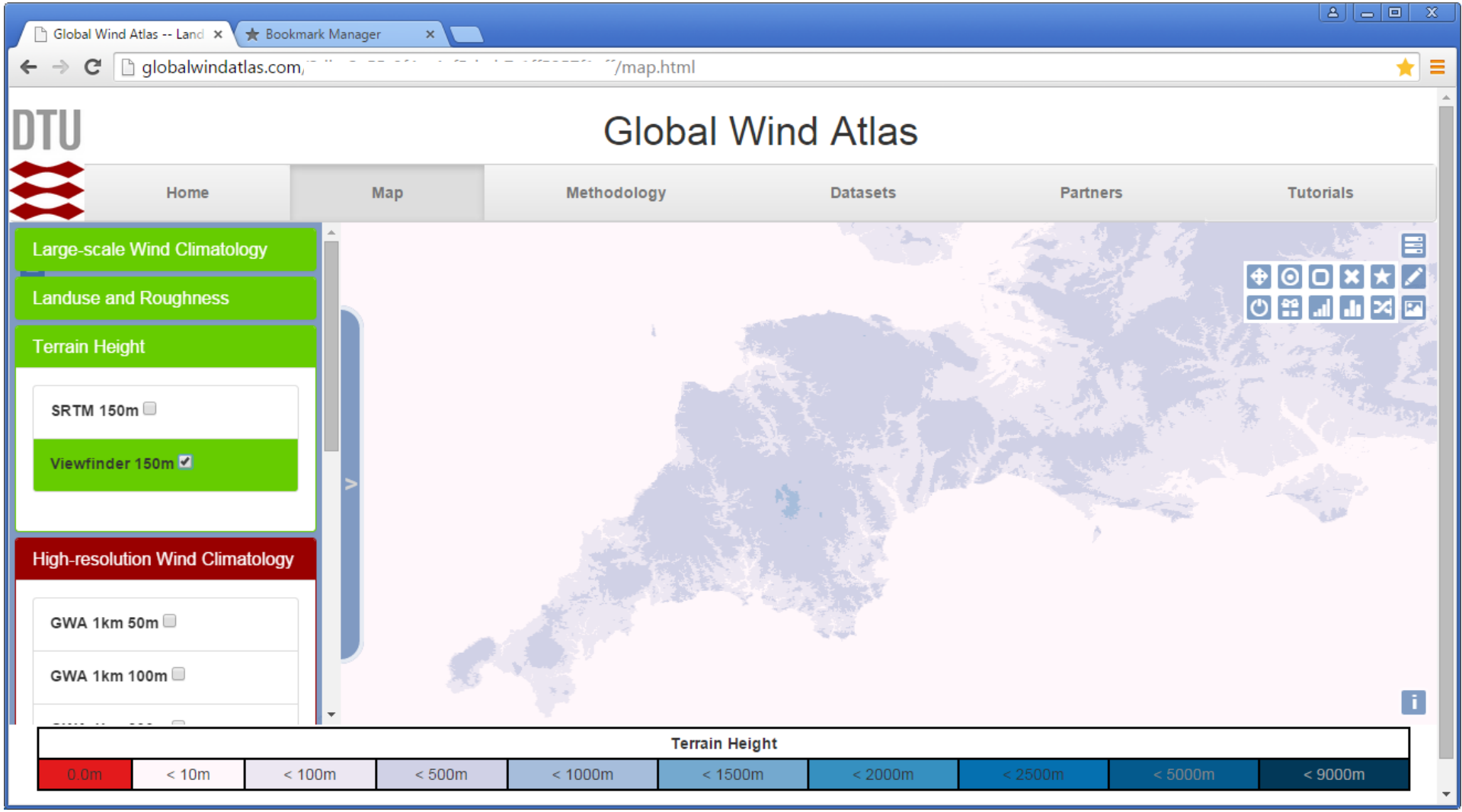
Contingency map for a power density threshold of 600W/m^2 comparing WASA and GWA, **Tobias Ahsbahs, 2015**

Web user interface, walk through

Roughness length



Orography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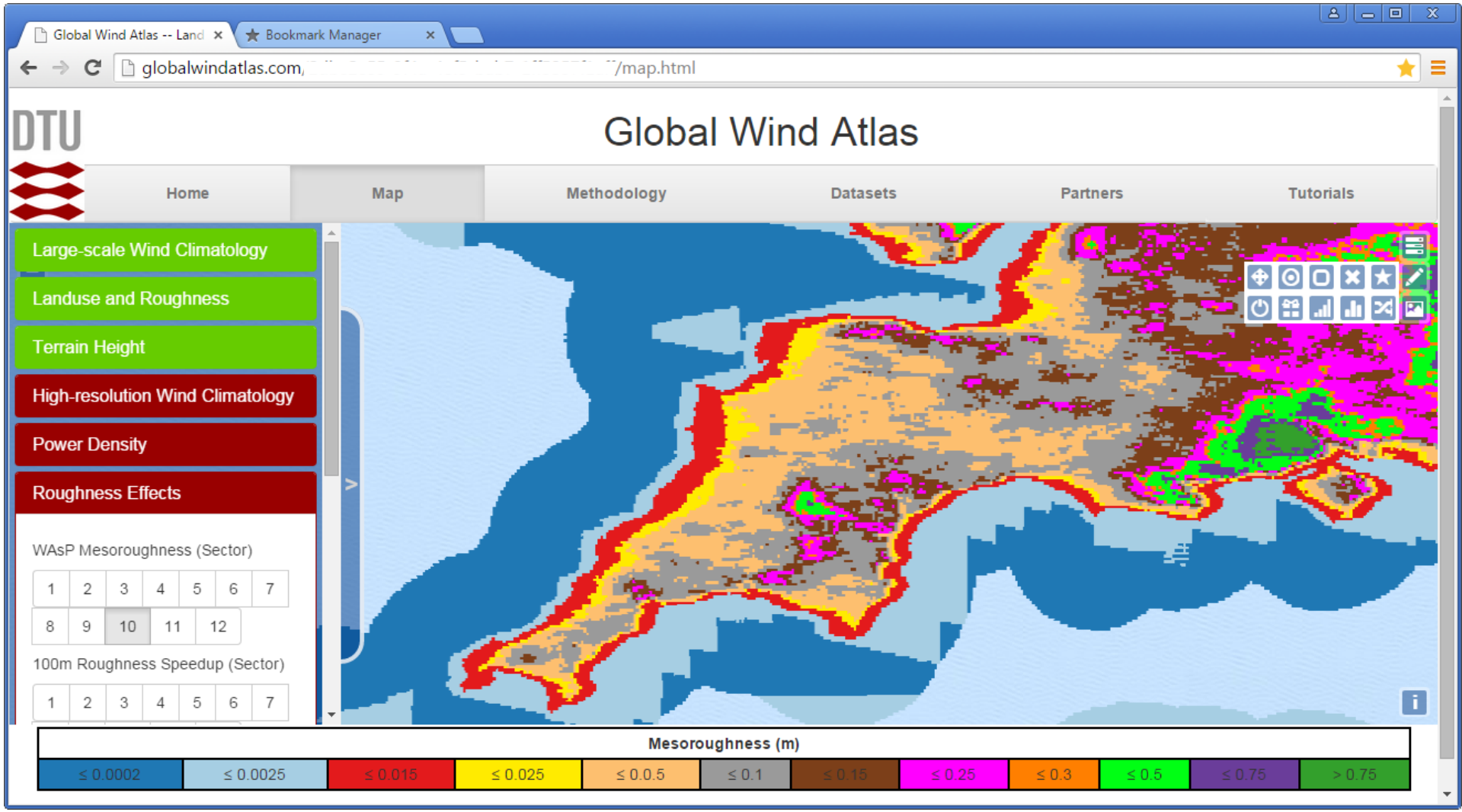
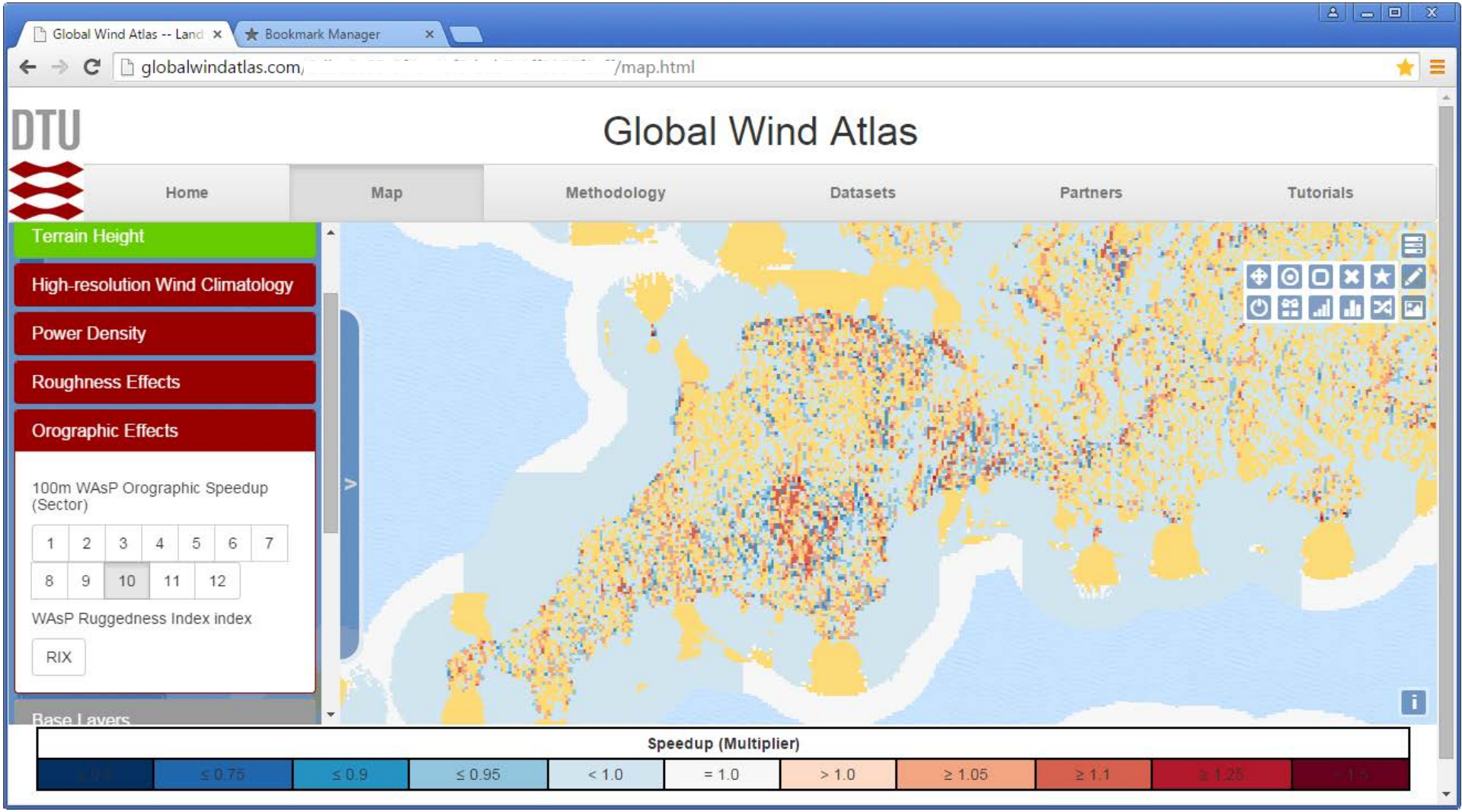
Landuse and Roughness
Terrain Height
SRTM 150m
Viewfinder 150m
High-resolution Wind Climatology
GWA 1km 50m
GWA 1km 100m
Terrain Height
0.0m
< 10m
< 100m
< 500m
< 1000m
< 1500m
< 2000m
< 2500m
< 5000m
< 9000m

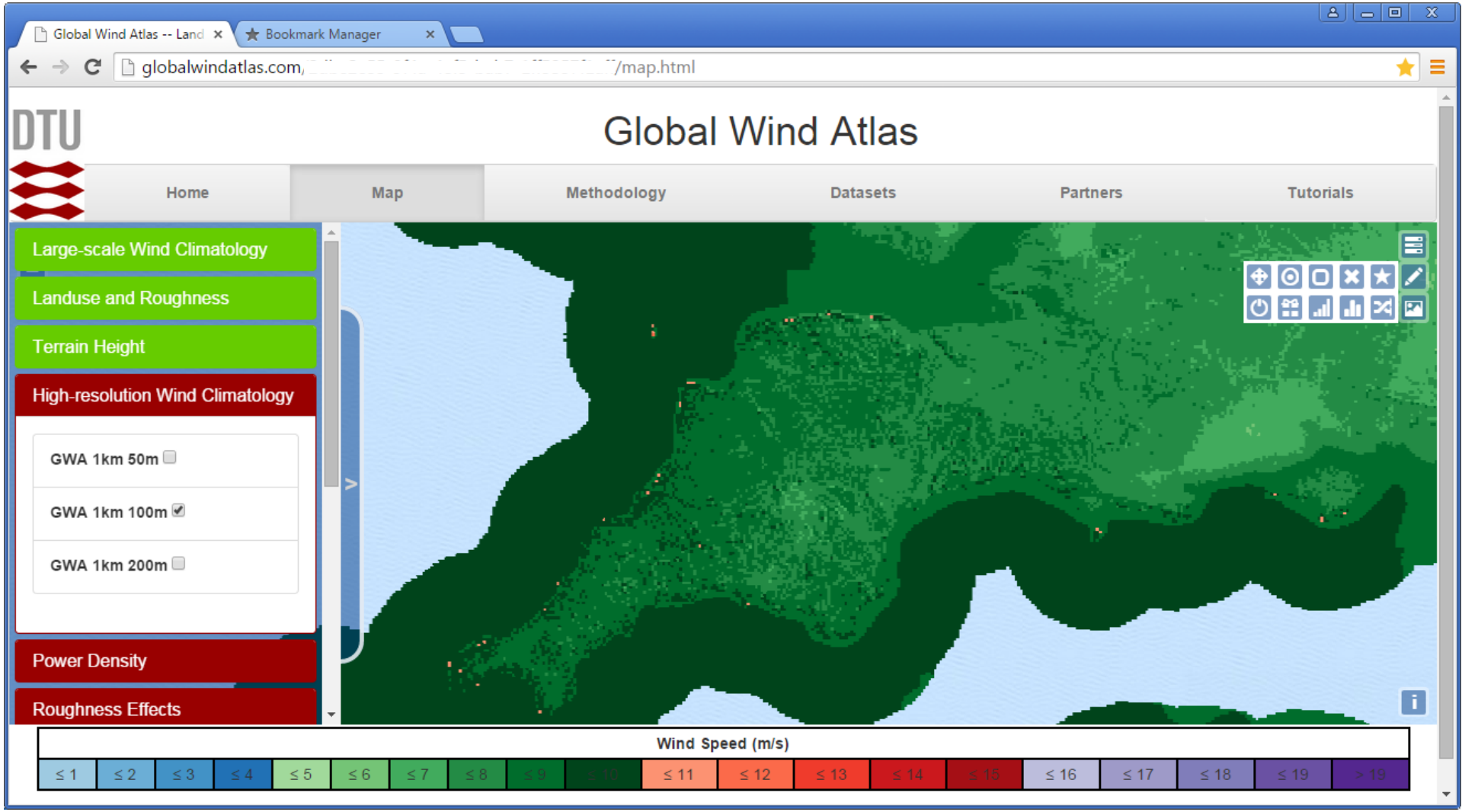
WAsP Mesoroughness per sector



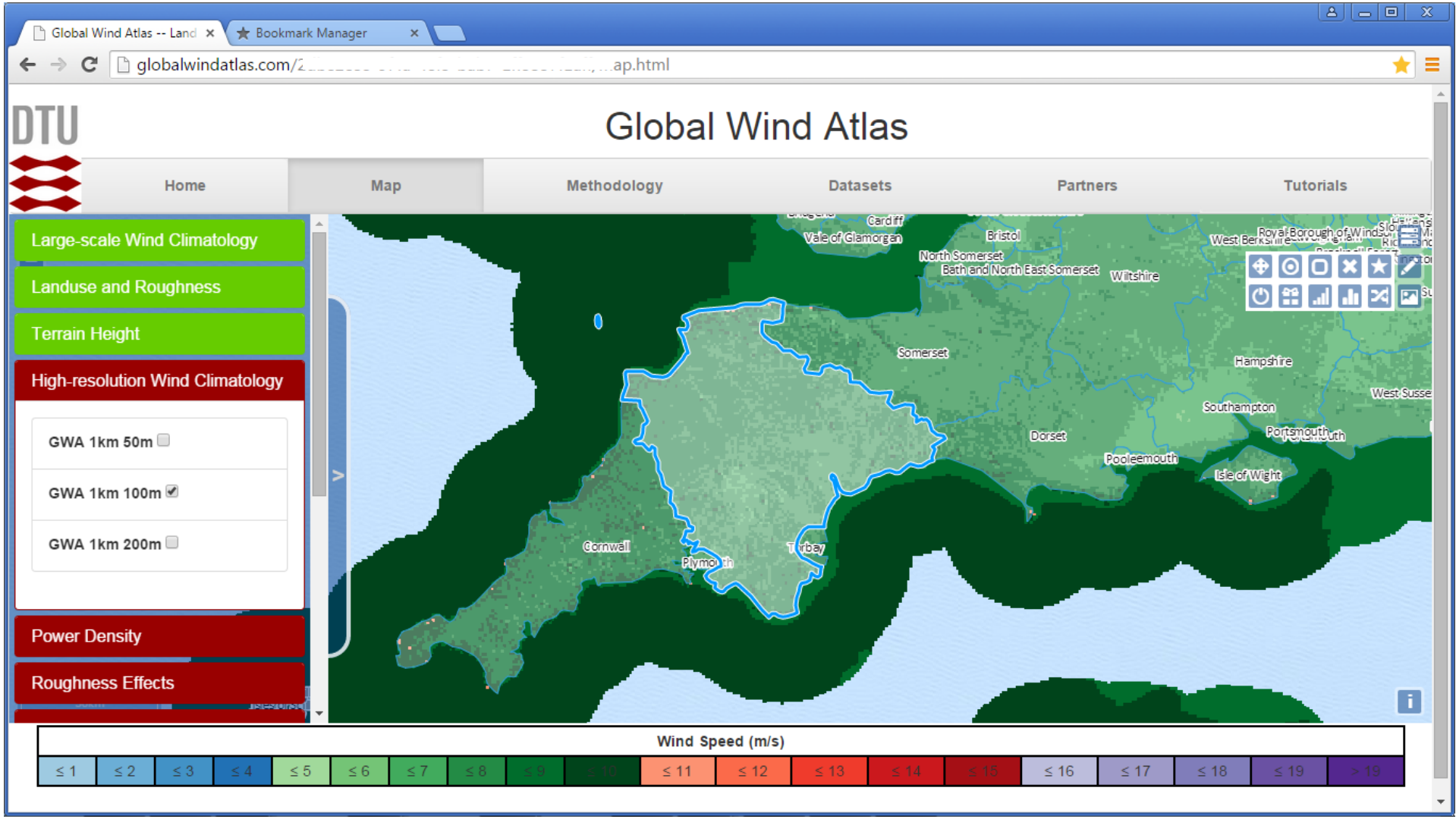
Orographic speed-up per sector



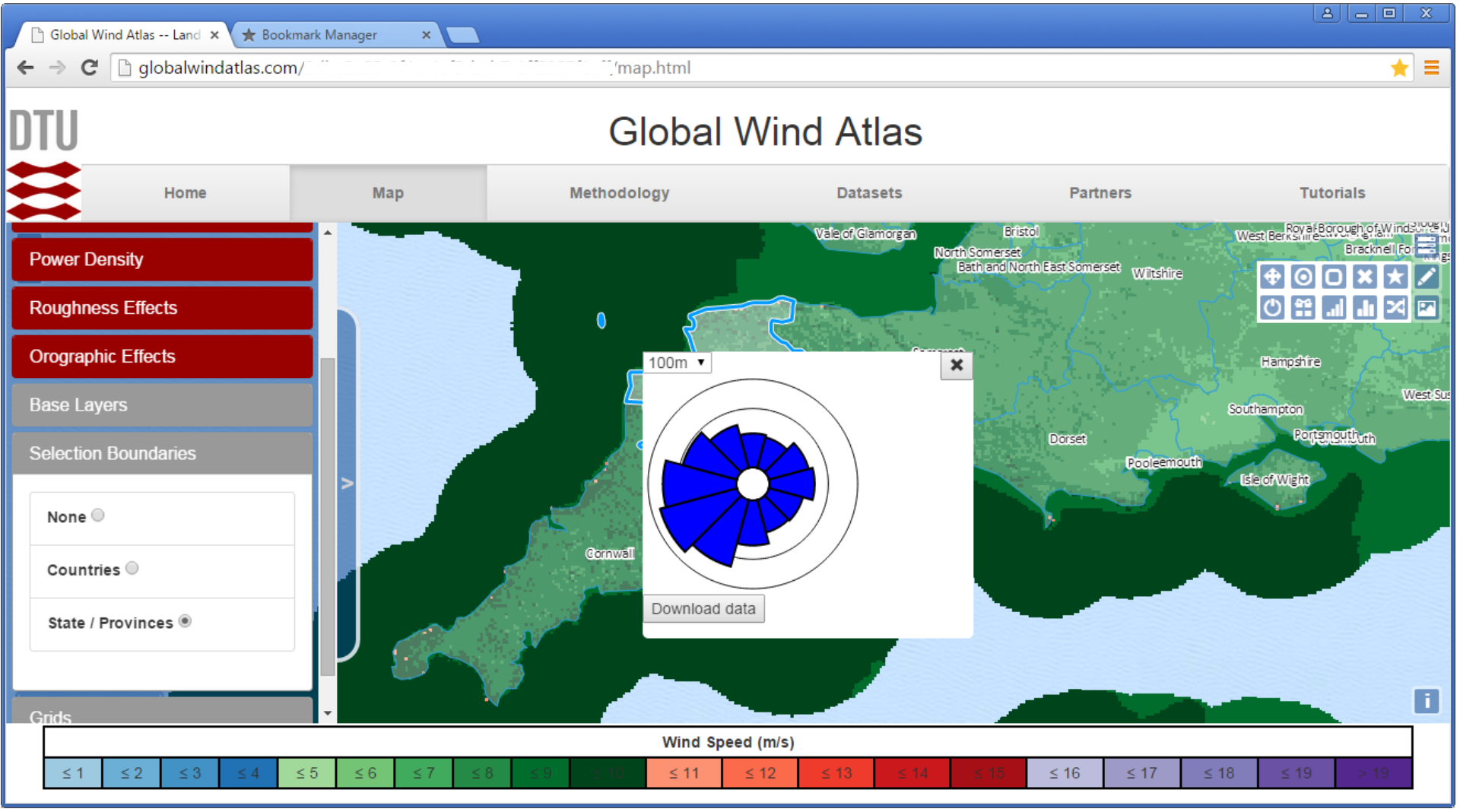
Annual mean wind climate



Selection of aggregation area



Wind rose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Roughness Effects
Orographic Effects
Base Layers
Selection Boundaries
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Grids
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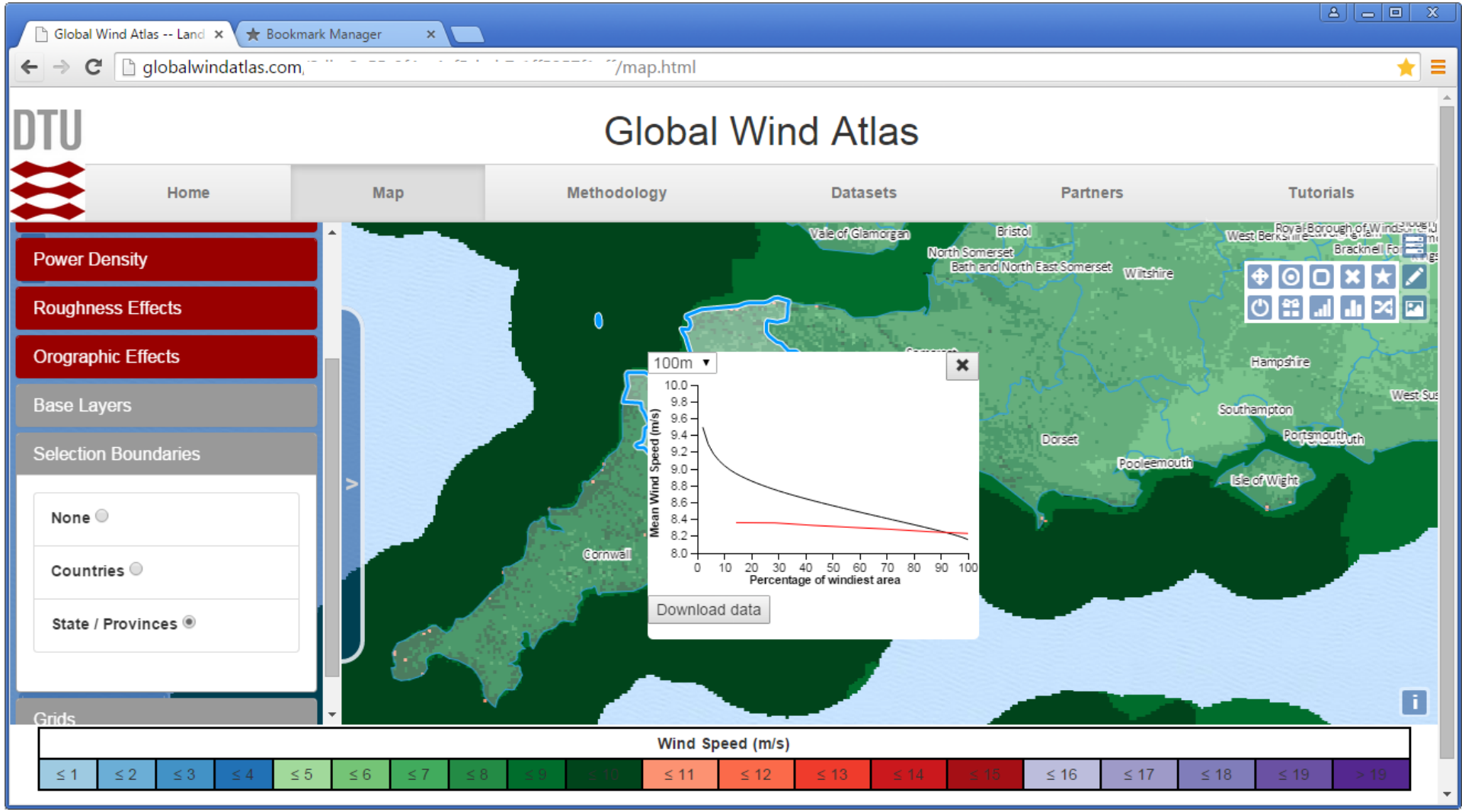
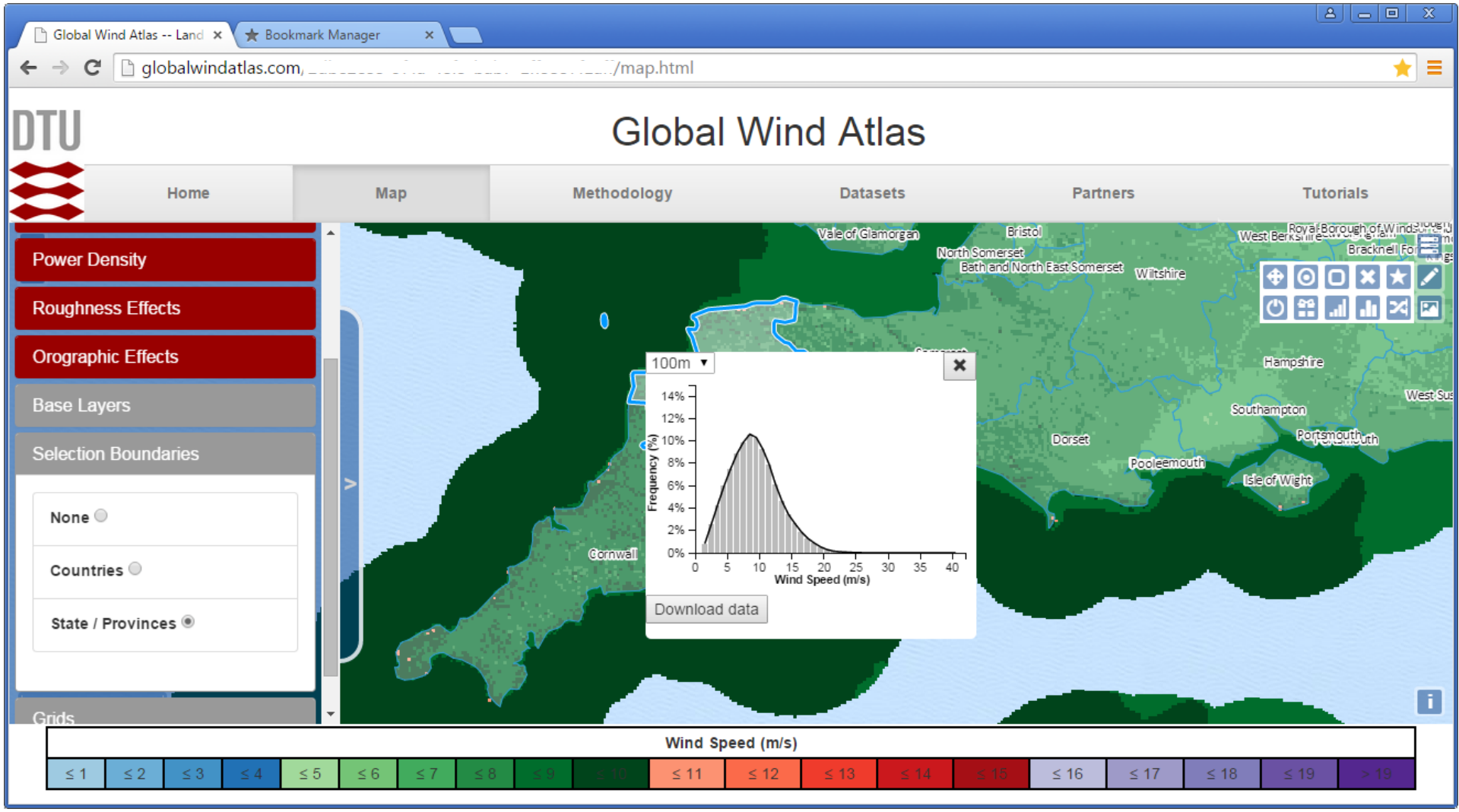
Bristol
North Somerset
Bath and North East Somerset
Wiltshire
Hampshire
Southampton
Portsmouth
Dorset
Pooleemouth
Isle of Wight
Cornwall
100m
Download data
Wind Speed (m/s)
≤ 1
≤ 2
≤ 3
≤ 4
≤ 5
≤ 6
≤ 7
≤ 8
≤ 9
≤ 10
≤ 11
≤ 12
≤ 13
≤ 14
≤ 15
≤ 16
≤ 17
≤ 18
≤ 19
> 19

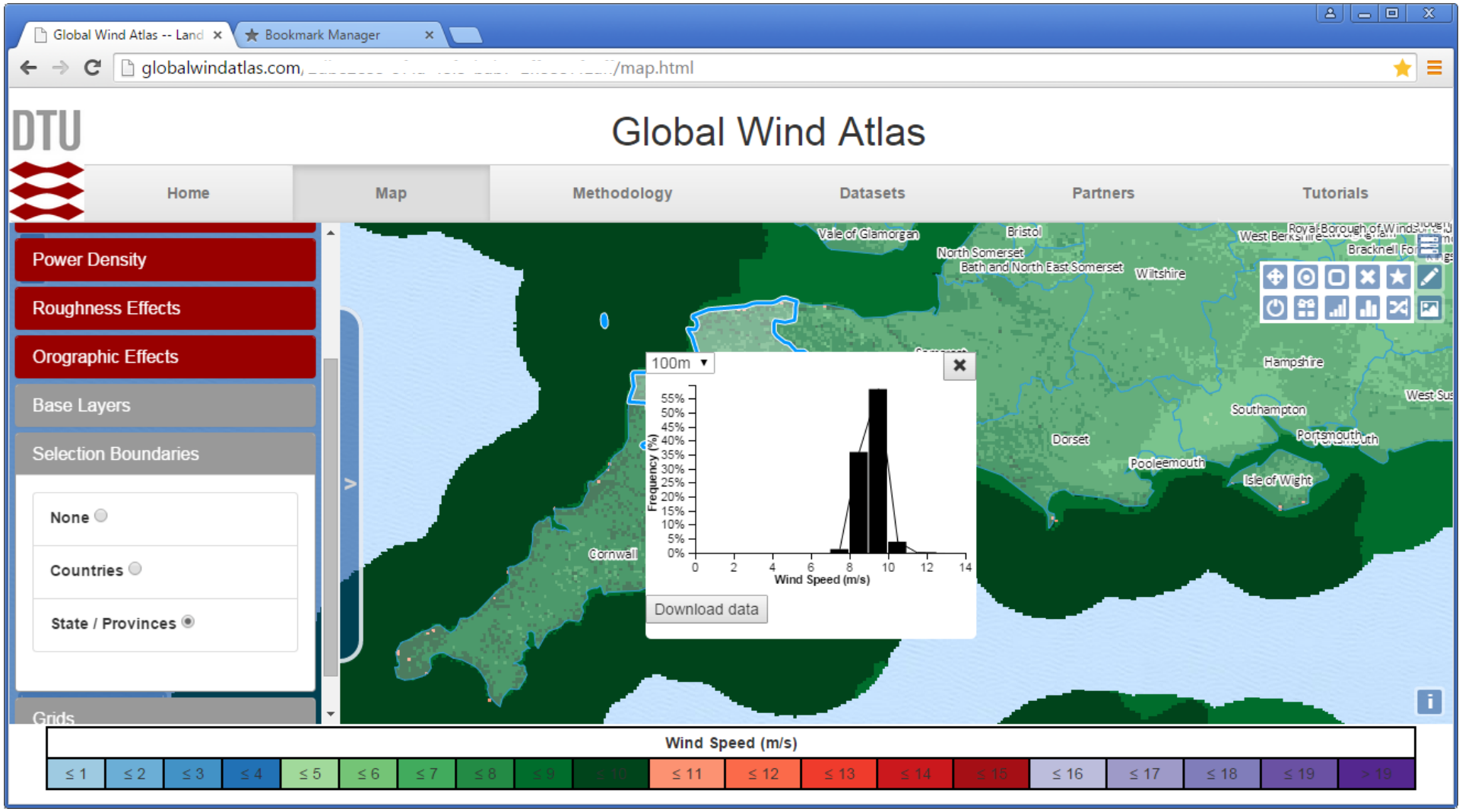
Windiest fractile plot



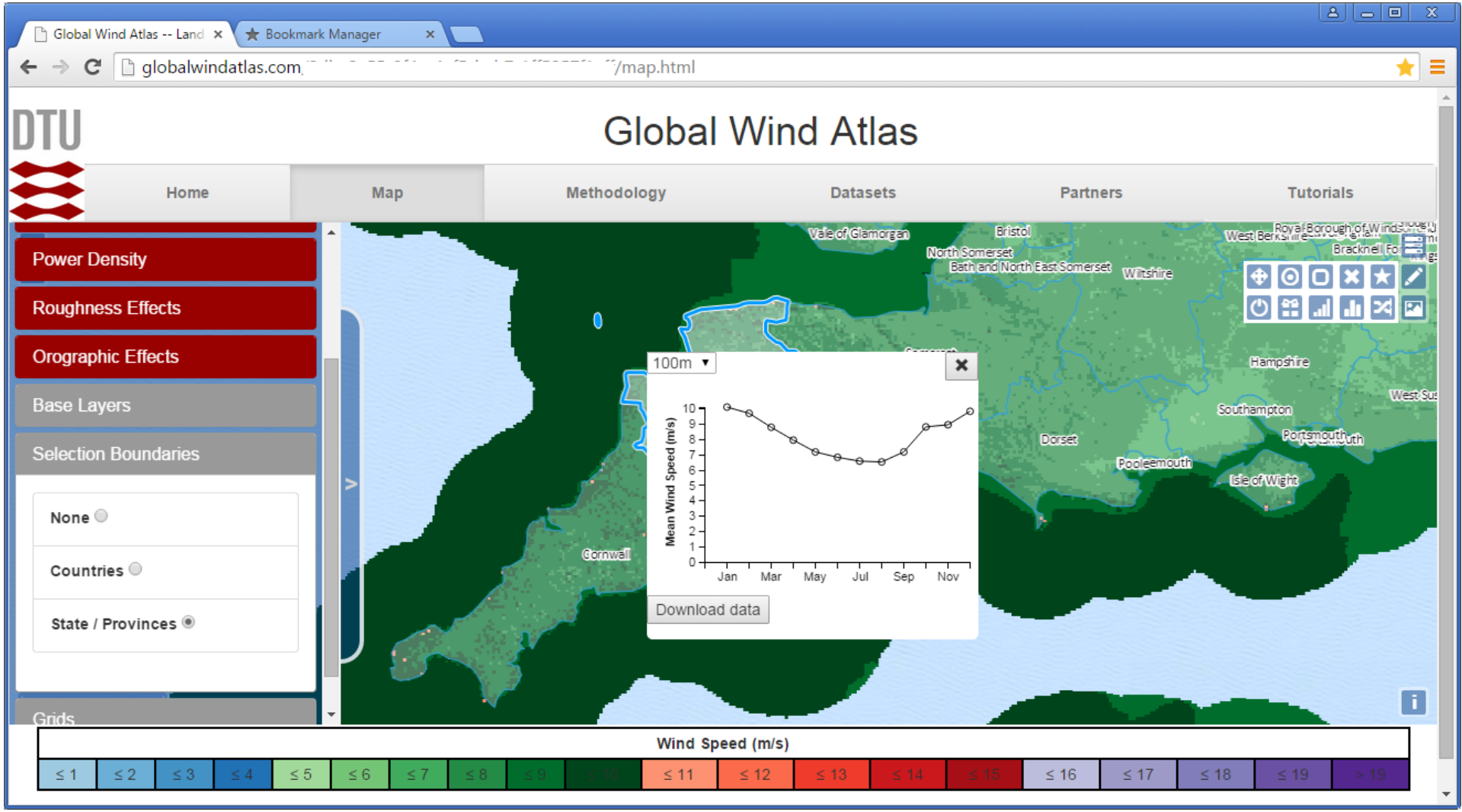
Wind speed distribution



Distribution of mean wind speed over area



Mean annual cycle over area



Still to complete

- Global runs with alternative reanalyses (1000 m)
- Complete verification
- Integration into IRENA global atlas
- Launch – IRENA-coordinated web event, September 2015

Future plans

- Following projects
  - Framework agreement led by ECN (NL) to supply renewable resource data to JRC TIMES-EU energy model.
  - Foundation for data inputs and concepts for server platform for the New European Wind Atlas
    - Roughness mapping improvements
    - Elevation data verification would be of value
    - Model chain development
  - Many possibilities for post processing of data

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	*Technical (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	*Technical (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	*Technical/Economic (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	*Technical (limited constraints):* 627,000 TWh/yr 2,260 EJ/yr *Technical (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	*Technical (limited constraints):* 278,000 TWh/yr 1,000 EJ/yr *Technical (more constraints):* 39,000 TWh/yr 140 EJ/yr

Global assessments 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.

So far “back of the envelope” calculations suggest 2 – 300 PWh / year

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

Thank you for your attention

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