The Wind Energy Potential of Iceland

A Contribution to Work Package 2 of IceWind

Nikolai Nawri, Guðrún Nína Petersen, and Halldór Björnsson
Icelandic Meteorological Office, Reykjavík
Kristján Jónasson
University of Iceland, Reykjavík
Andrea N. Hahmann
Technical University of Denmark, Roskilde

Introduction

- One goal of Work Package 2 of IceWind has been the development of a wind atlas of Iceland for the purpose of wind energy assessments (WEA)
- Previous studies have established the climatological aspects of surface wind conditions over Iceland: seasonal and elevation differences; coastal vs inland locations; exposed vs sheltered locations; temporal and spatial variability
- For WEA (wind atlas), wind statistics required at greater heights above the ground, approximately turbine hub height (here, 55 - 67 mAGL)
- Met: wind speeds; WEA: wind power density and available power
- Met: averages calculated directly from time-series; WEA: averages calculated from Weibull distributions

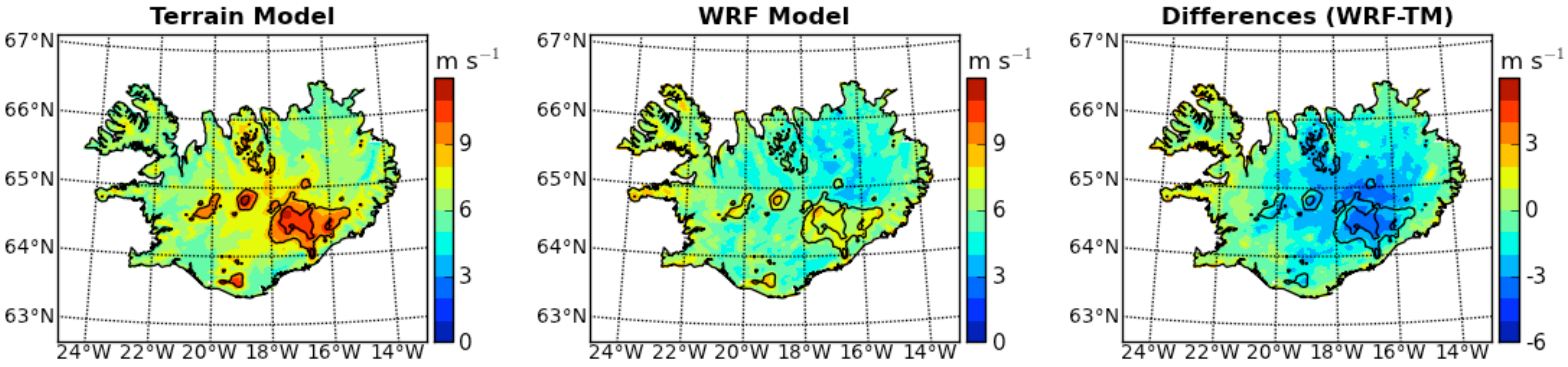
Data

- Weather Research and Forecasting (WRF) Mesoscale Model Runs:
  - Simulations produced by Reiknistofu í veðurfræði (Hálfdán Ágústsson, Ólafur Rögnvaldsson, Haraldur Ólafsson, et al.)
  - Resolution: 3-hourly fields; ~ 3 km grid-point spacing
  - Available data period: 1 Sep 1994 - 2 Nov 2009; full years 1995 - 2008
  - Calculated on sigma levels; projected to 10, 50, and 100 mAGL
- Hourly time-series from surface weather stations:
  - Quality controlled and corrected for differences in anemometer heights following WMO guidelines; either measured or projected to 10 mAGL

Data Reliability

- Neither station data nor WRF model data are absolutely reliable
- Weather stations: anemometers at 7.2 - 11.6 mAGL; heavily influenced by local terrain features and obstacles; uncertainties about projecting to higher altitudes
- WRF: limited spatial resolution, poor representation of orography; problems with terrain type, surface roughness; approximations through turbulence parameterisations near the ground

Mean Annual Wind Speeds (10 mAGL)



Terrain model: gridded surface (10 mAGL) measurements, with linear dependence on terrain elevation; residuals at mean sea level are horizontally interpolated, linearly projected back onto elevated terrain; applicable to average wind speeds (monthly or annual)

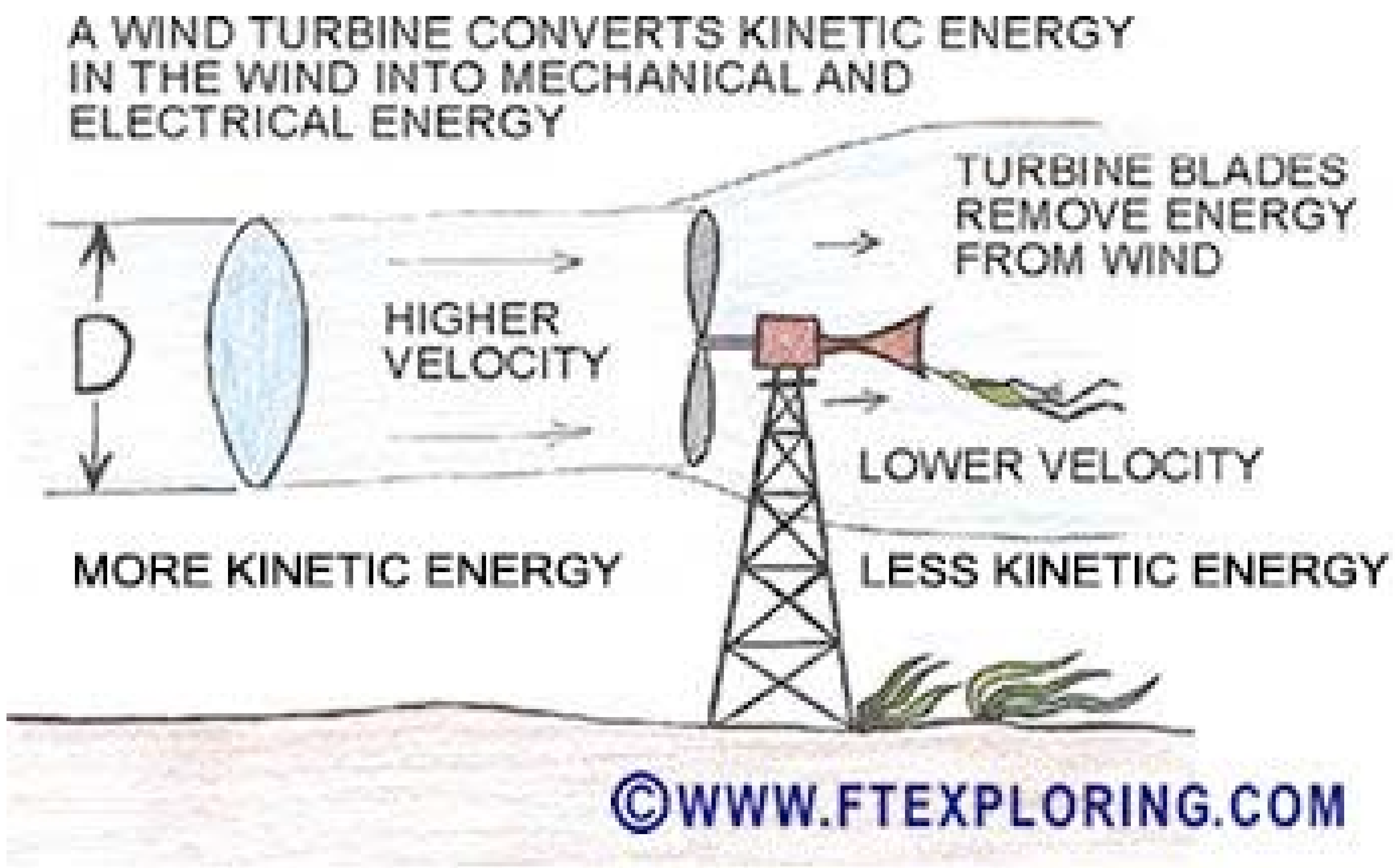
Wind Power

Upstream wind power density [W m^{-2}]

$$E = \frac{1}{2}\rho v^3$$

Air density: ρ

Upstream wind speed: v



Available wind power [kW]

$$P = \frac{1}{2}\rho_0 A C_p v^3$$

Constant air density (international standard): $\rho_0 = 1.225\ \mathrm{kg\ m^{-3}}$

Area swept by rotor blades: $A = \pi r^2$

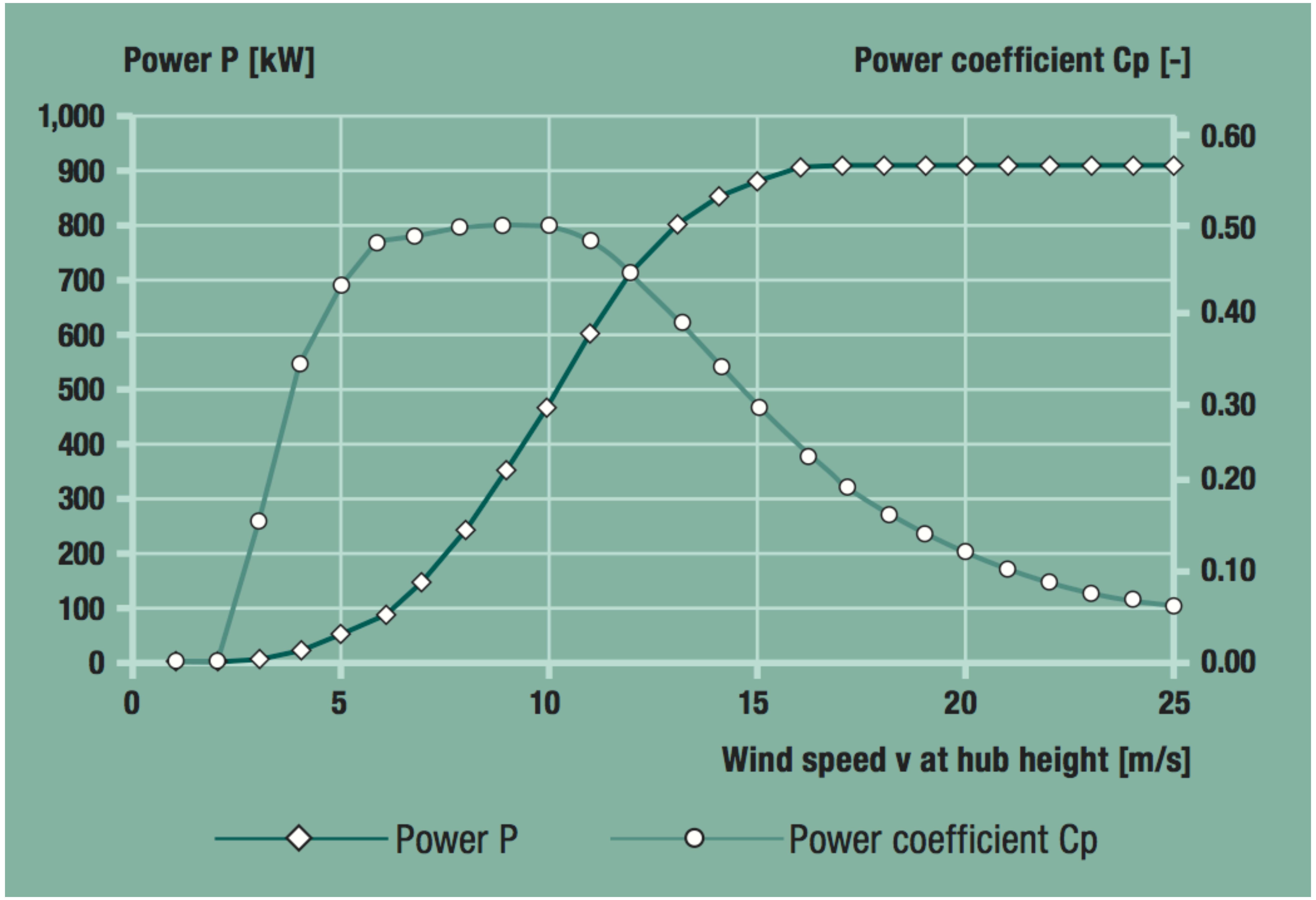
Power coefficient (dependent on wind speed): $C_p = 0 - 0.59$

Power Curves

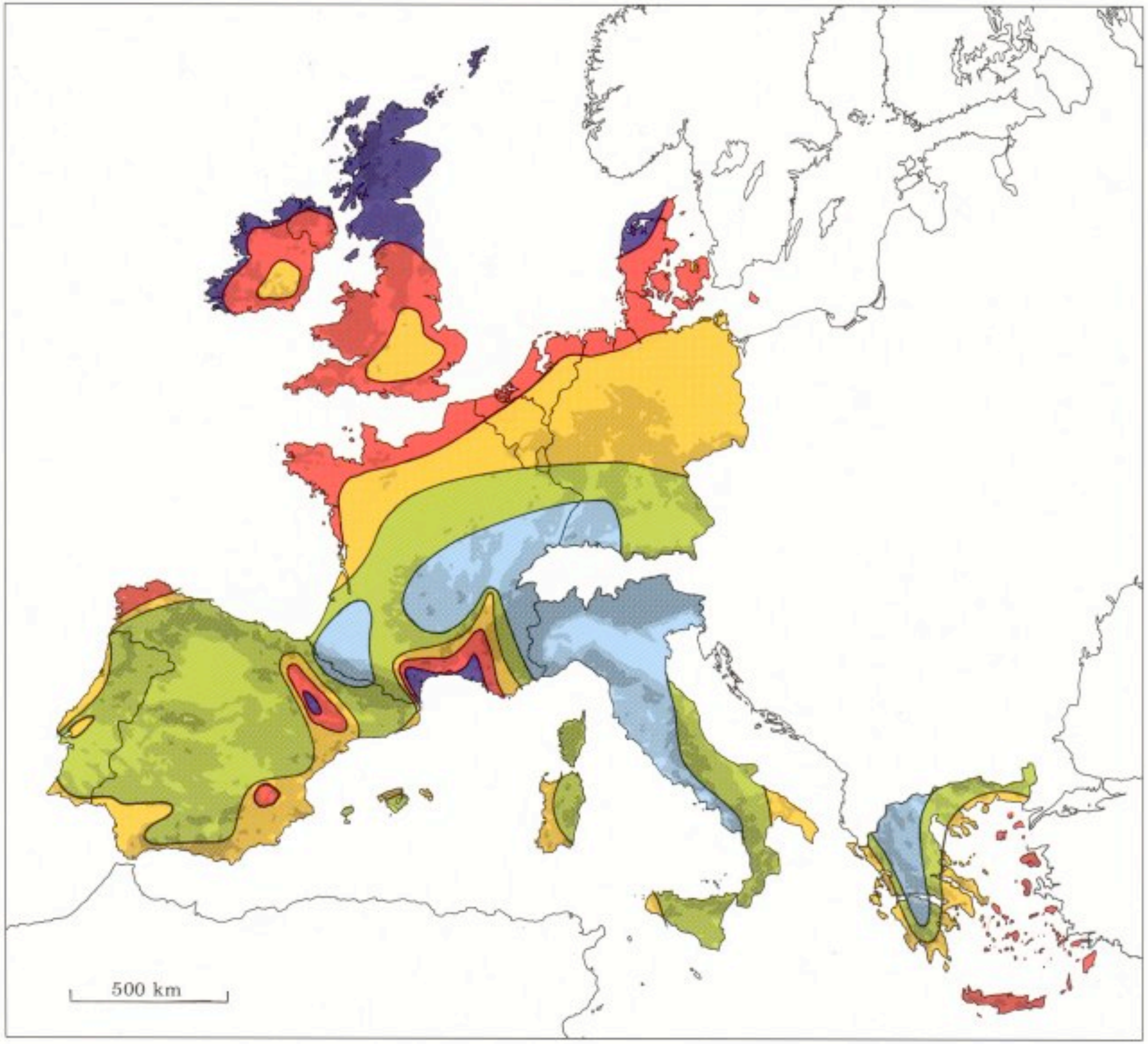
- Power coefficient typically has highest values (~ 0.50) between 5 and 10 m s^{-1}
- Effectively, available power does not increase with square of blade length (for large turbines, higher cut-in speed, lower efficiency at strong winds)
- Power density only depends on atmospheric variables; most appropriate for turbine-independent evaluations of wind energy potential (e.g., wind atlases)
- When specific turbine has been decided on, available wind power provides more accurate assessment

Enercon E44 Wind Turbine

$$\rho_0 = 1.225 \text{ kg m}^{-3}$$



1 m s^{-1} cut-in speed; 900 kW maximum power



Wind Power Density at 50 mAGL

Sheltered terrain:
> 250 W m^{-2}

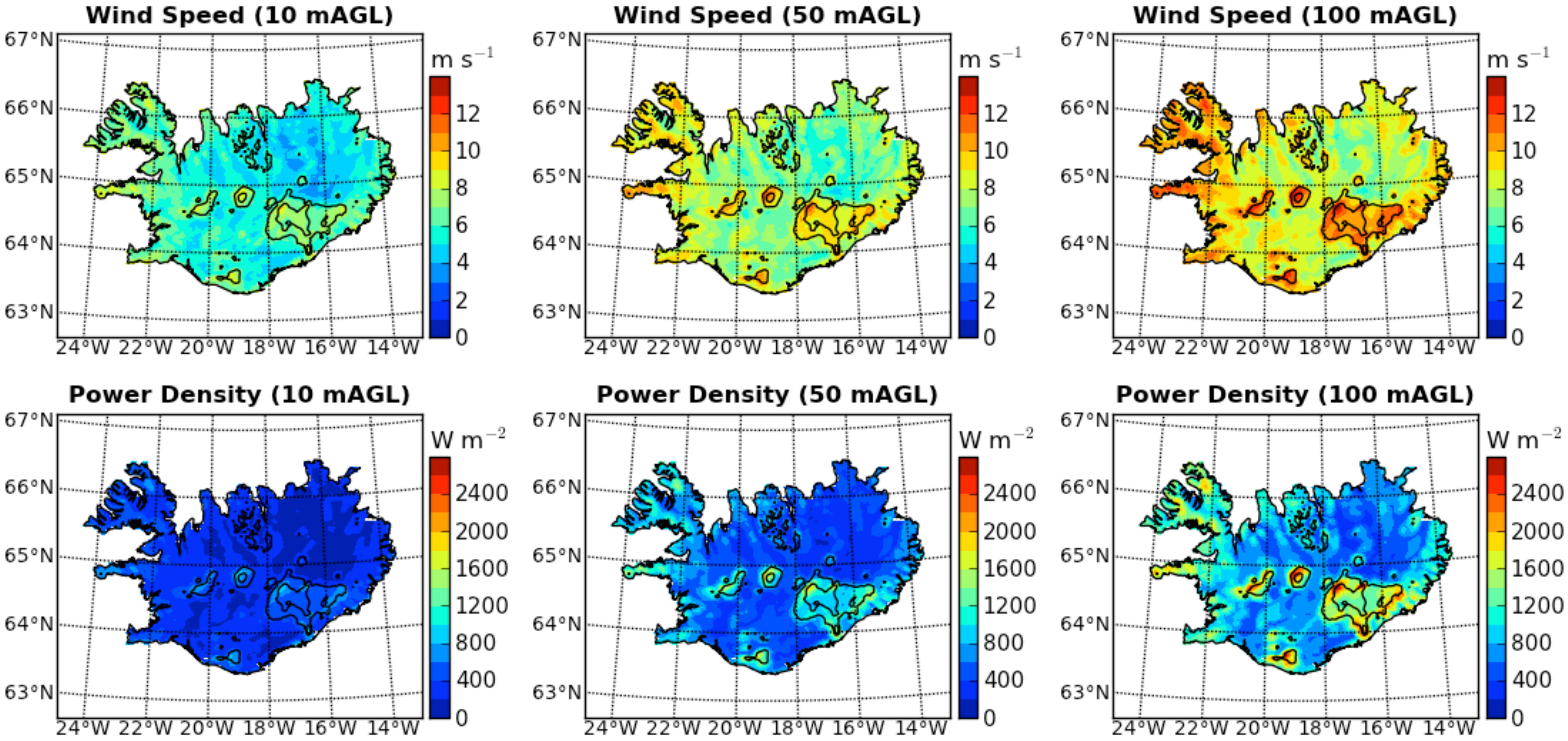
Open plain:
> 500 W m^{-2}

Open coast:
> 700 W m^{-2}

Hills and ridges:
> 1800 W m^{-2}

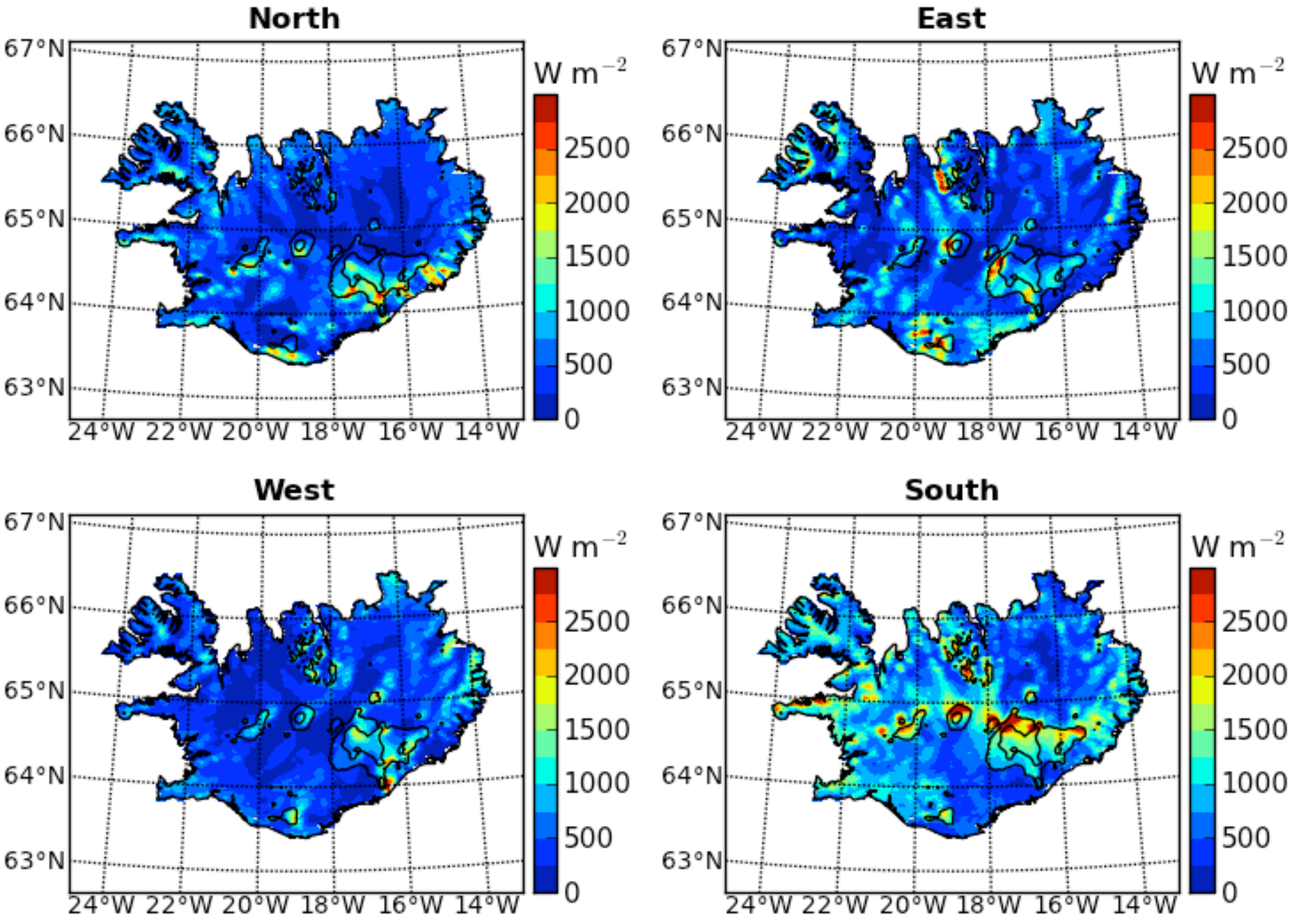
Troen, I. and E.L. Petersen (1989): European Wind Atlas, Risø National Laboratory, Roskilde

Wind Speed and Power Density (WRF Model)



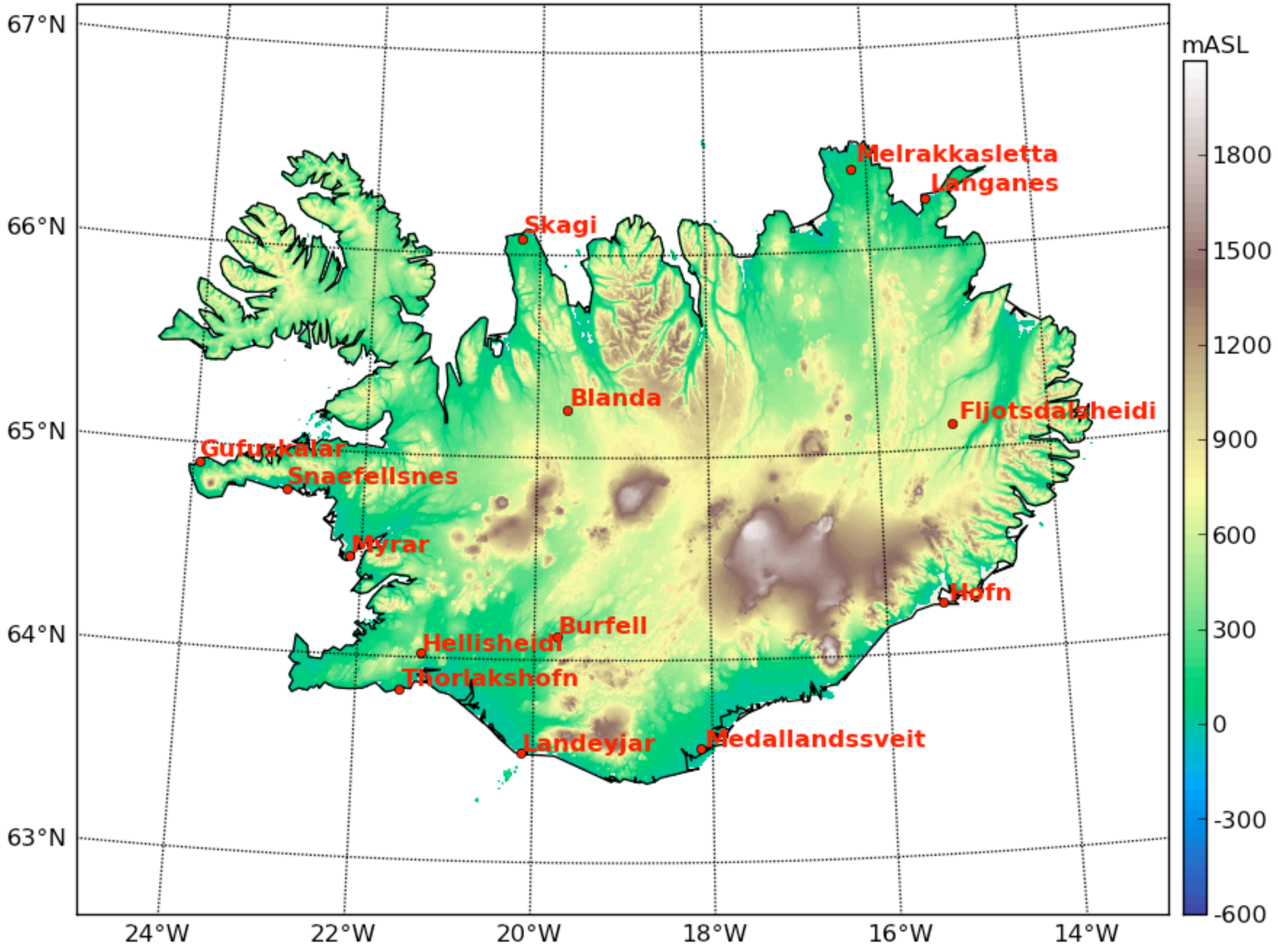
Power density at 50 mAGL: 300 - 1800 W m^{-2} (consider low bias over interior)

Mean Annual Wind Power Density (50 mAGL; Sectors)

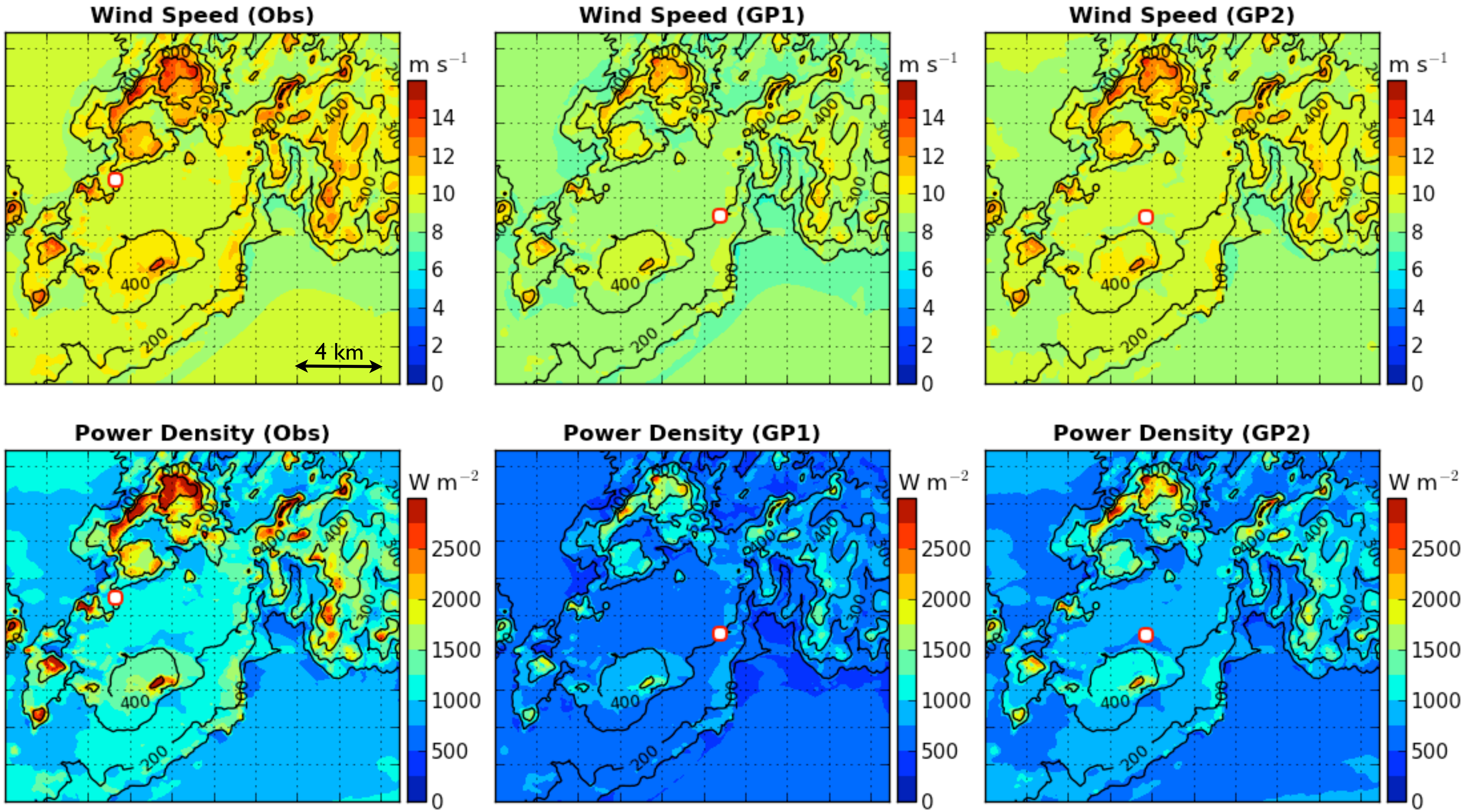


Priority Sites for Wind Farms

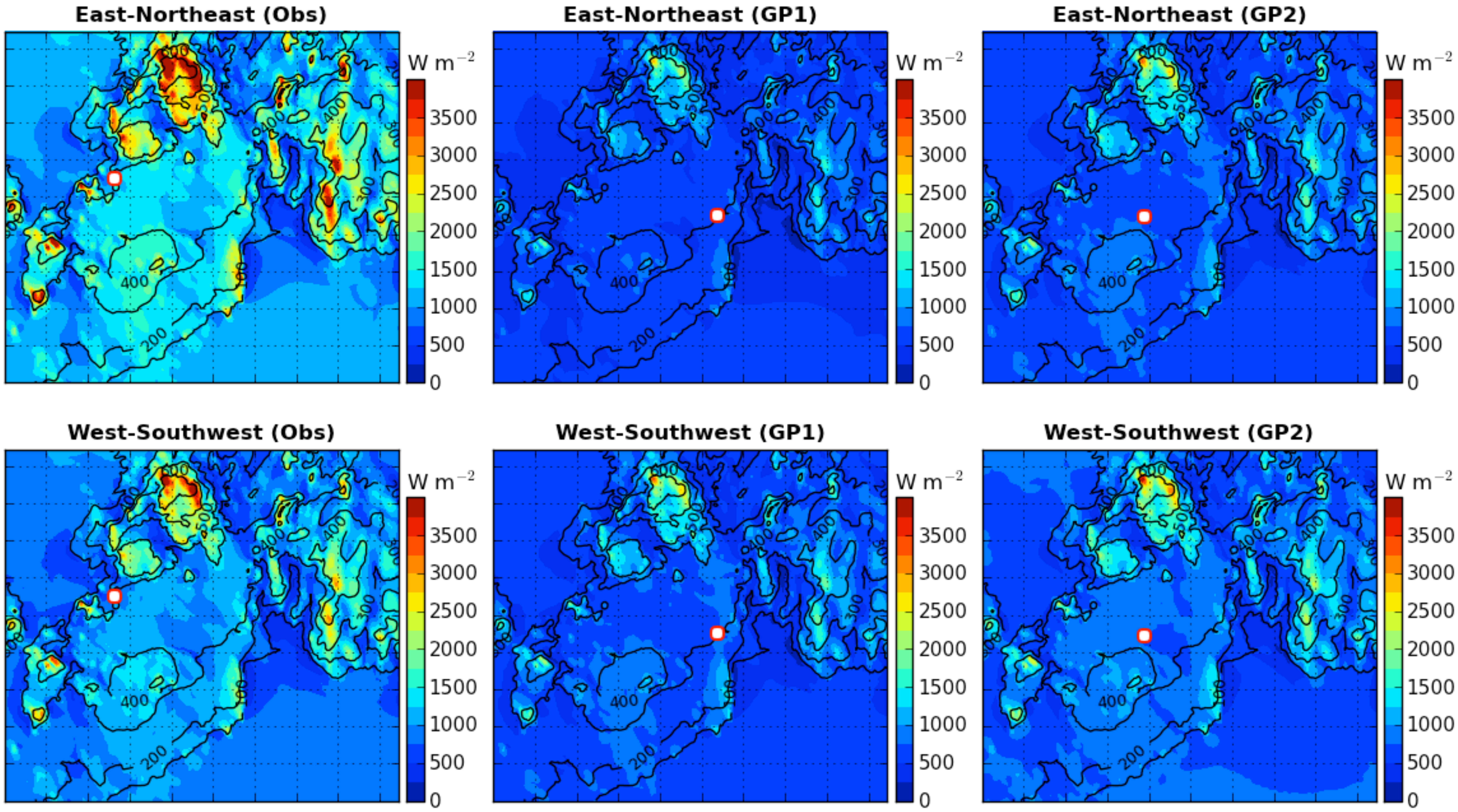
- Criteria:
  - Wind power density
  - Locally flat and solid terrain
  - Away from avalanche paths
  - Road access
  - Grid access, power lines
  - Aviation
  - Nature conservation
  - Tourism



Hellisheiði – Wind Speed and Power Density (55 mAGL)

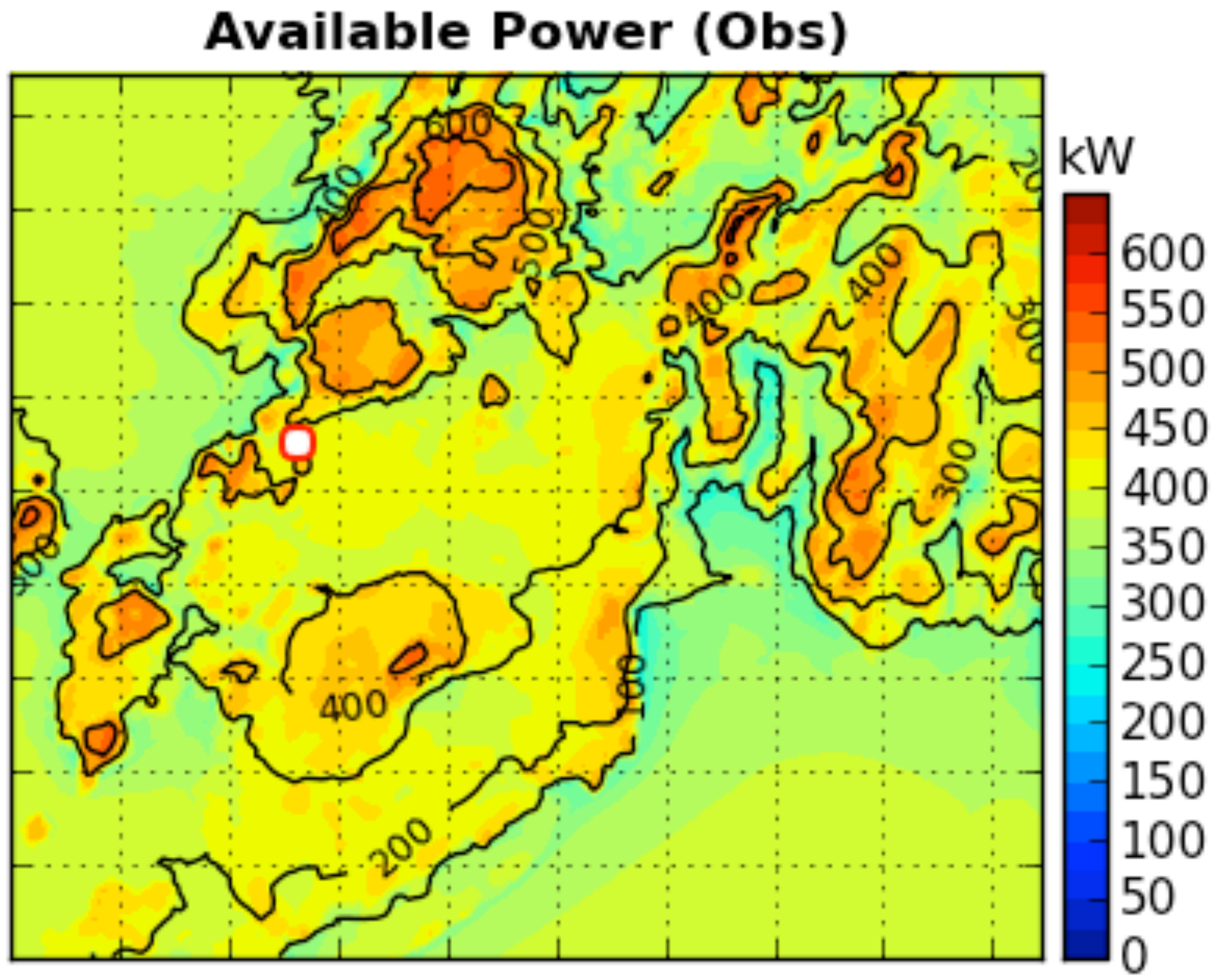


Hellisheiði – Power Density (55 mAGL; Sectors)



Hellisheiði – Average Available Power (55 mAGL)

Based on Enercon E44 (900 kW) wind turbine



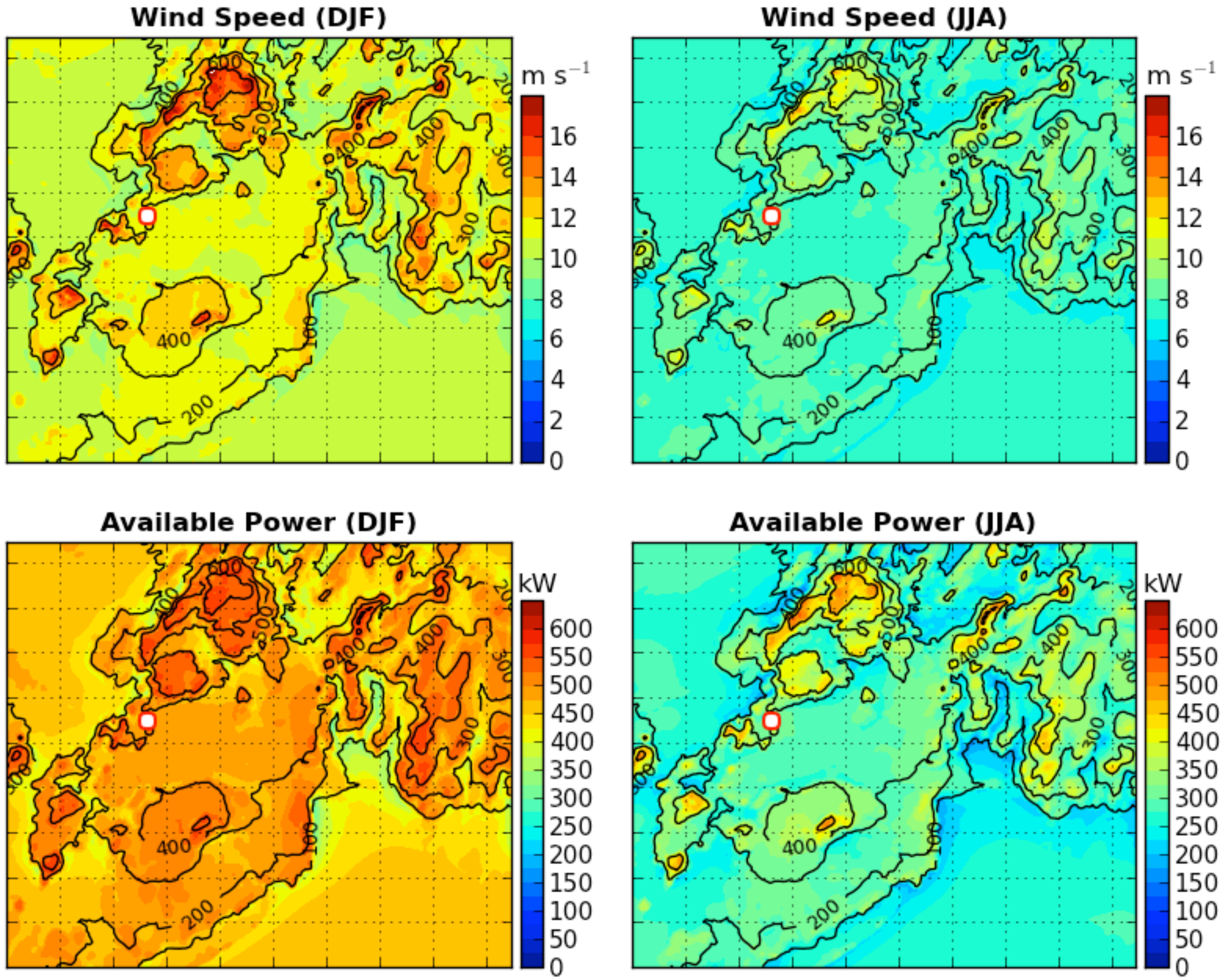
For comparison: the Hellisheiði geothermal power station has an electric capacity of 303 MW (largest in Iceland, second largest in the world)

One Enercon E44, operating at 500 kW on average, produces 1.65‰ of Hellisheiði power station

Hellisheiði – Seasonal Differences (55 mAGL)

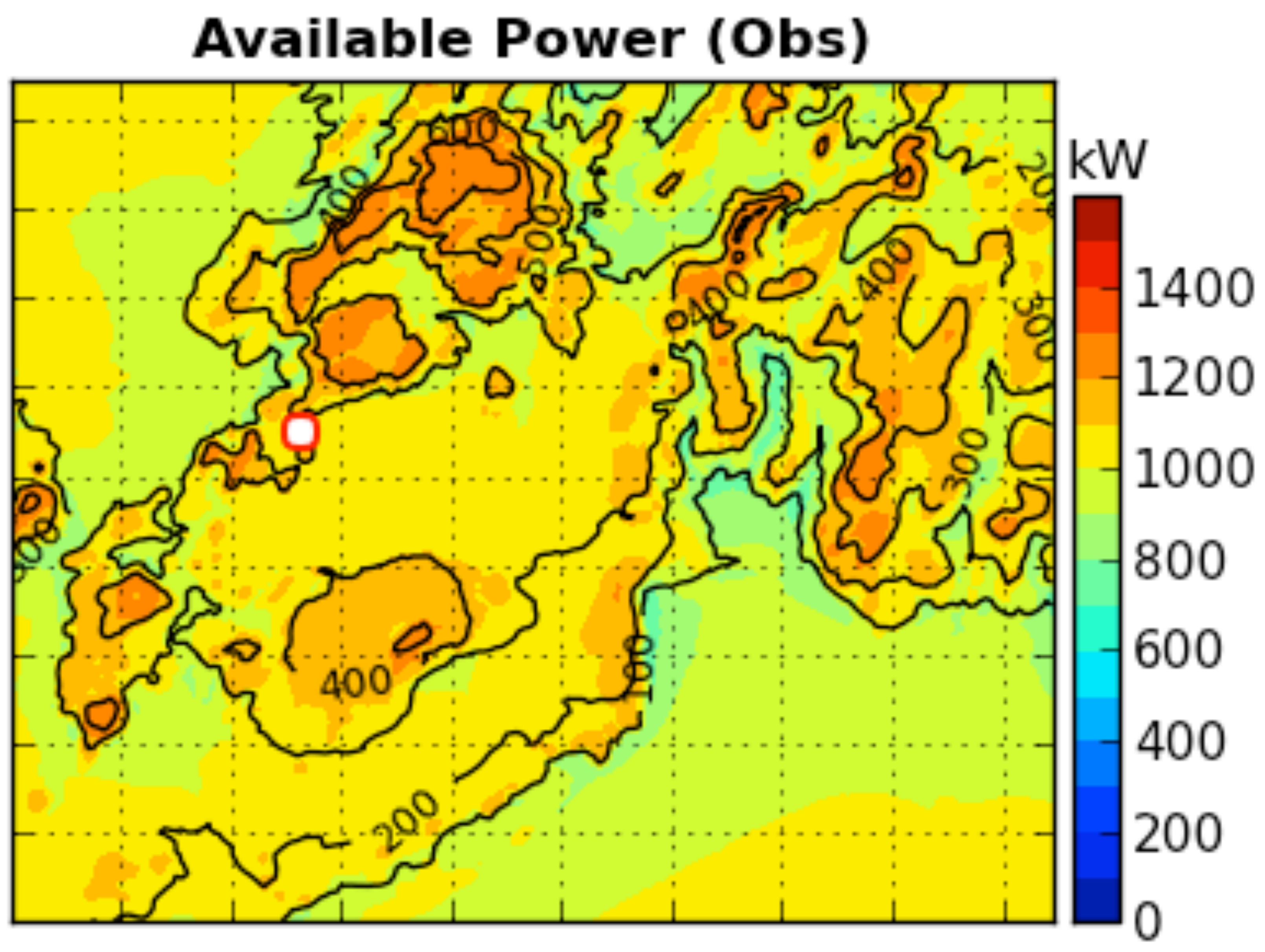
Based on Enercon E44 (900 kW) wind turbine

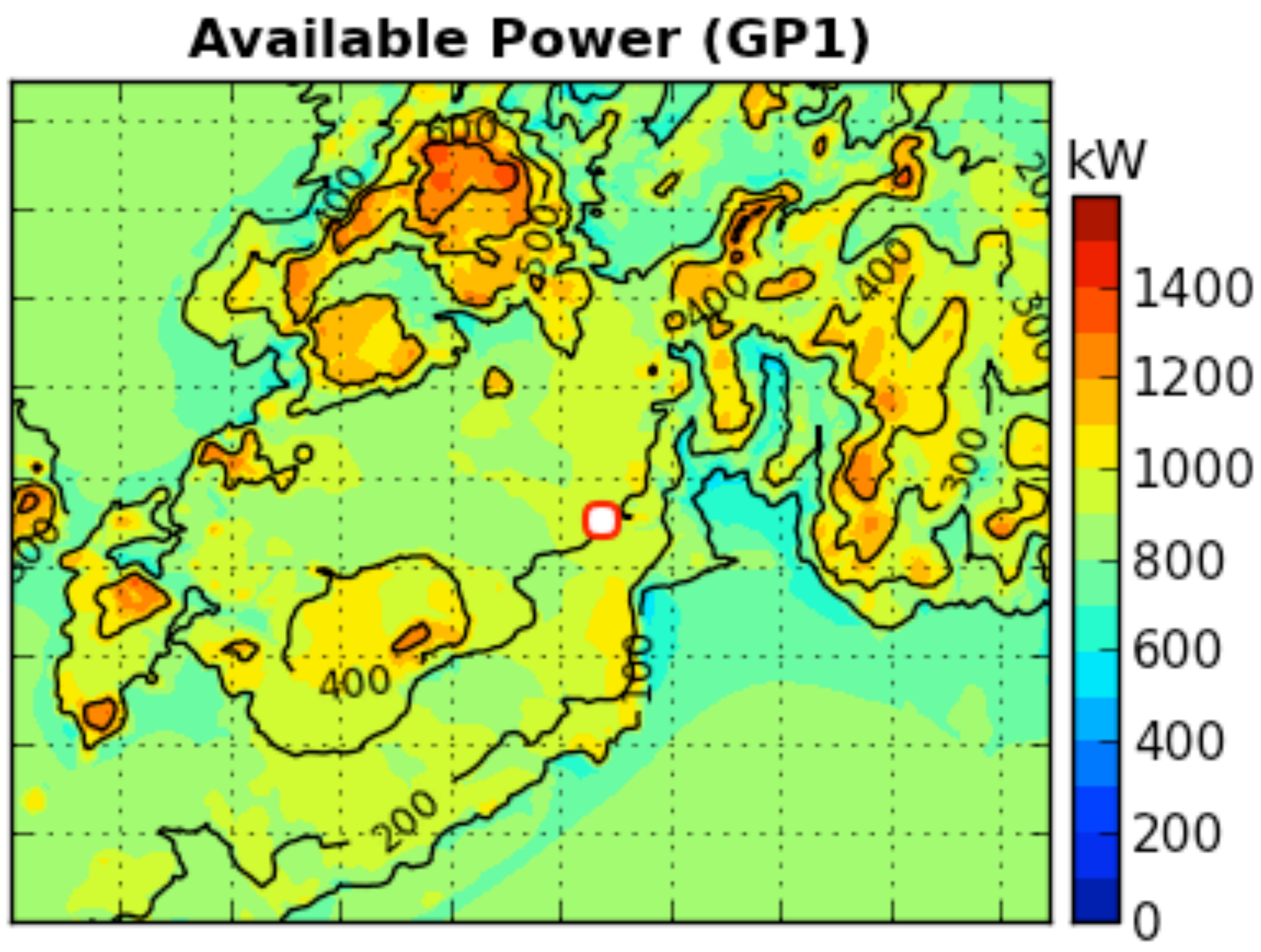
- Average wind speeds on plateau:
  - Winter: 10 - 12 m s-1
  - Summer: 7 - 9 m s-1
  - Winter / summer ratio: ~ 1.375
- Average available wind power on plateau
  - Winter: 450 - 550 kW
  - Summer: 250 - 350 kW
  - Winter / summer ratio: ~ 1.667

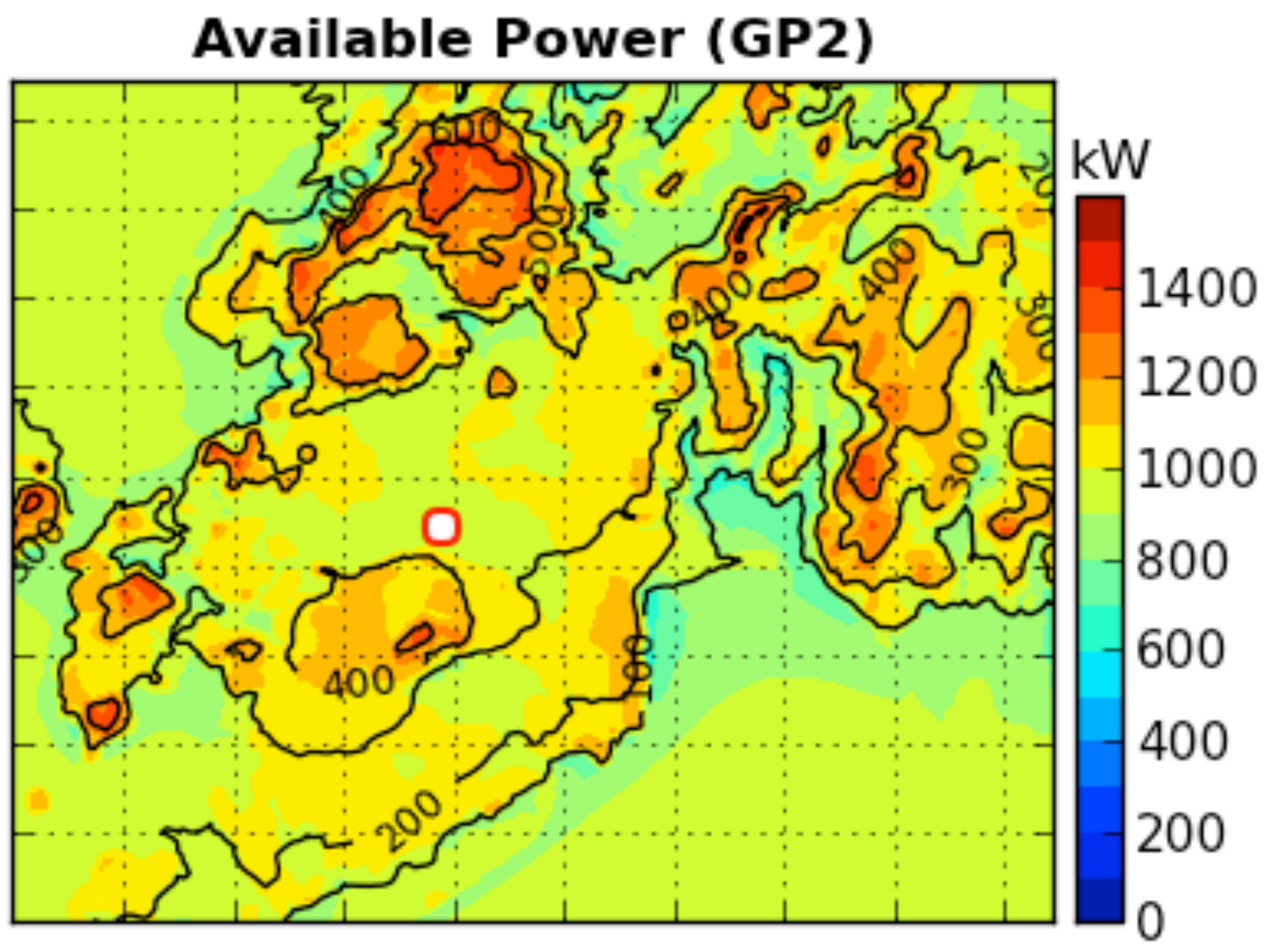


Hellisheiði – Average Available Power (67 mAGL)

Based on Vestas V80 (2 MW) wind turbine







Increase in blade length by factor 1.8, leads to increase in power by approximately factor 2.4

One Vestas V80, operating at 1.2 MW on average, produces 3.96‰ of Hellisheiði power station

Five Wind Turbines on Hellisheiði vs Power Plants

Fljótsdalur hydropower (690 MW): **0.36% E44**; **0.87% V80**

Hellisheiði geothermal (303 MW electric capacity): **0.83% E44**; **1.98% V80**

Burfell hydropower (270 MW): **0.93% E44**; **2.22% V80**

Blanda and **Sigalda** hydropower (150 MW): **1.67% E44**; **4.00% V80**

Nesjavellir geothermal (120 MW electric capacity): **2.08% E44**; **5.00% V80**

Krafla geothermal (60 MW electric capacity): **4.17% E44**; **10.00% V80**

Bjarnarflag geothermal (3 MW electric capacity): **83% E44**; **200% V80**

Summary

- Low-lying interior parts of the northeast region have the lowest wind energy potential; overall highly competitive with other Western European countries
- Annual wind conditions are not a limiting factor for wind energy production
- At 50 to 70 mAGL, the annually average available power is approximately half the maximum output of typical wind turbines (Enercon E44 ~ 400 - 500 kW; Vestas V80 ~ 1000 - 1200 kW)
- Seasonal cycle: winter wind speeds larger than in summer, leading to increased available power by about a factor of 1.6
- Under normal conditions, no considerable downtime in winter to be expected
- On summits and ridges, extreme winds can be a problem