# Wind resource identification and high resolution modelling

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Tallinn Oct 2011

# Outline & motivation

- Require: mean wind speed estimates and distributions over periods of 10-20 years, 50-100 m above the surface at sites
- Use archived and rerun Met Office weather forecast models
- Local downscaling adjustments
- “Virtual Met Mast”
- Extension to long term climatology
- Verification
- Wind atlas
- High resolution modelling to improve adjustment
- Conclusions/ Improvements

# Wind Climatology – site-screening

Typical requirement :

mean wind speed estimates and distributions over periods of 10-20 years, 50-100 m above the surface

Traditionally assessment:

Direct measurement onsite - expensive and time consuming

Measure correlate predict (MCP) using closest long term wind station (10m wind)

Archived Numerical Weather Prediction (NWP) data can offer a cheaper and more representative alternative

Very high resolution modelling to improve

# Primary Operational NWP Forecast Systems

## UK 4km/1.5km

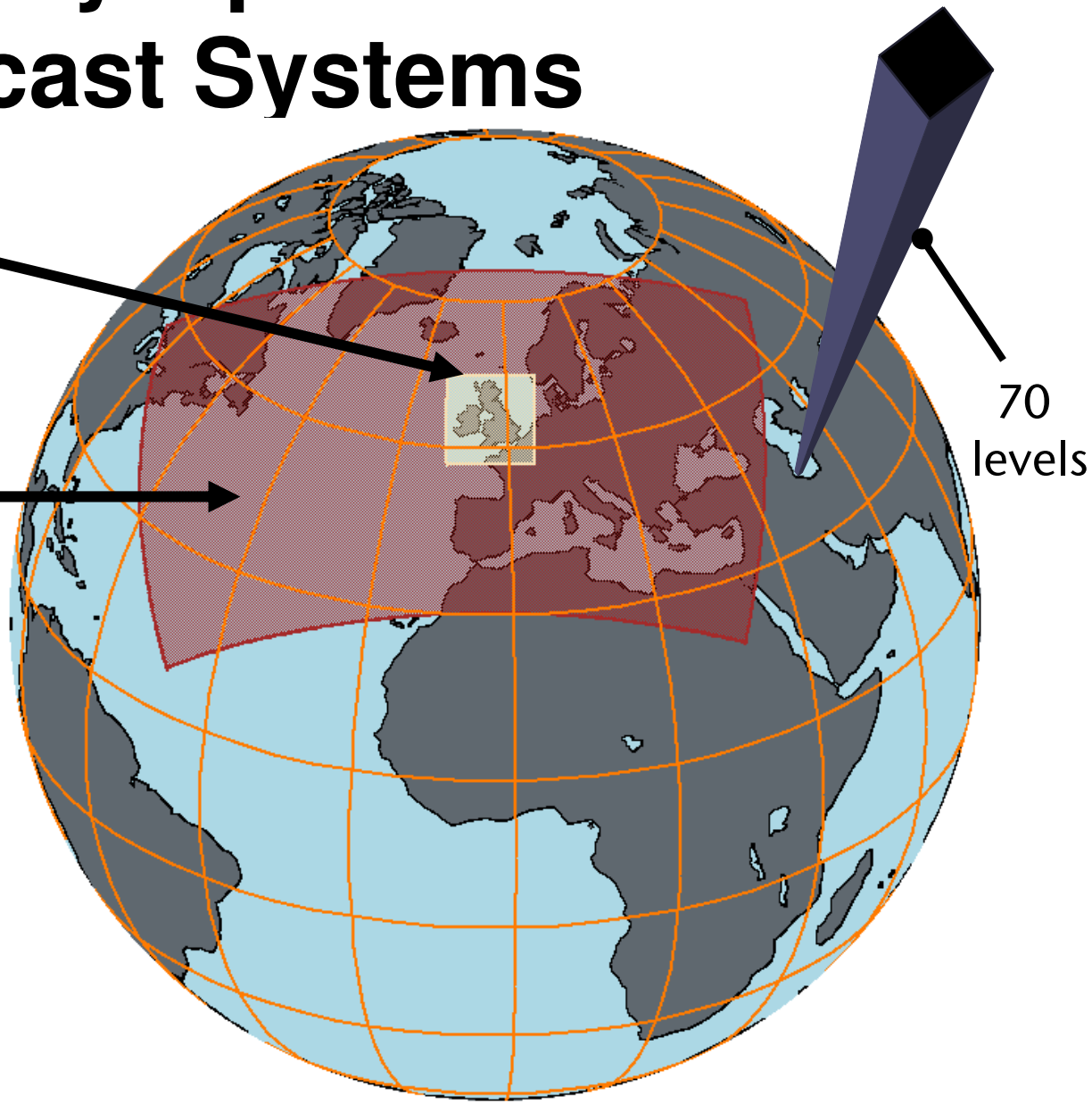
- 36 hour forecast
- 70 levels up to 40km
- 4 times per day

## Regional 12km

- 60 hour forecast
- 38 levels (70L now)
- 4 times per day
- +EPS 18km, 24member

## Global 25km

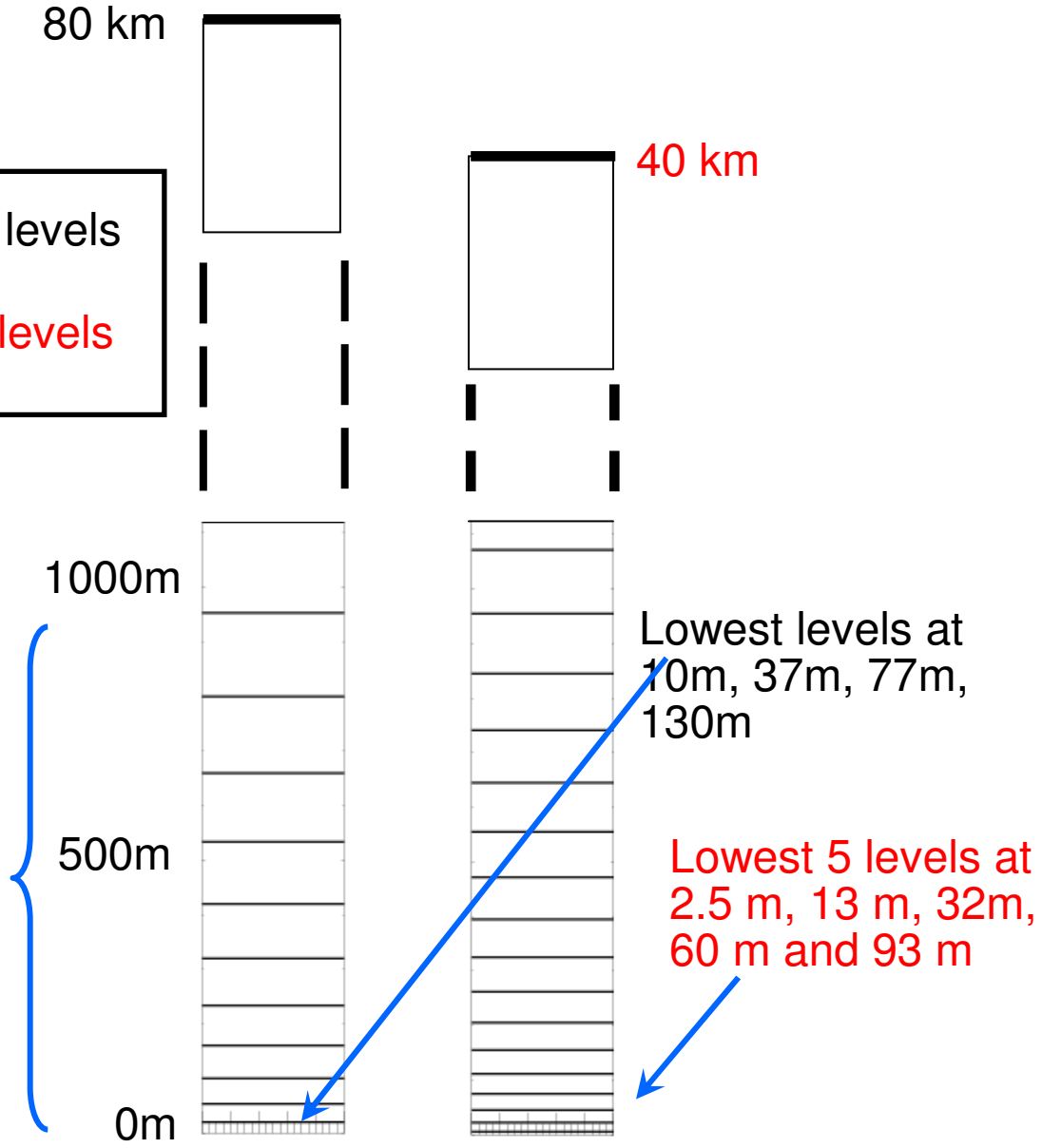
- 60 hour forecast twice/day
- 144 hour forecast twice/day
- +EPS 24member, 90km



# Model levels – focussing on the near surface

LEFT:- Global and 12 km model levels

RIGHT:- 4 km and 1.5 km model levels




**Lowest 1000m**

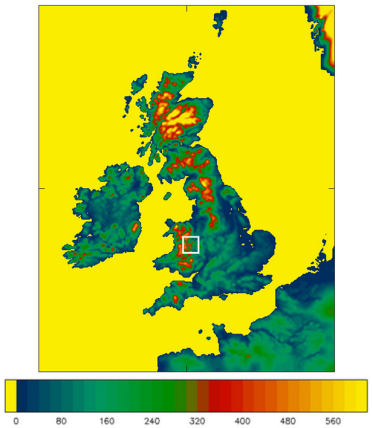
Global +12km L70: 11 levels

4km + 1.5km L70: 16 levels

# Example: orography over the COLPEX (Cold Air Pooling Expt) region

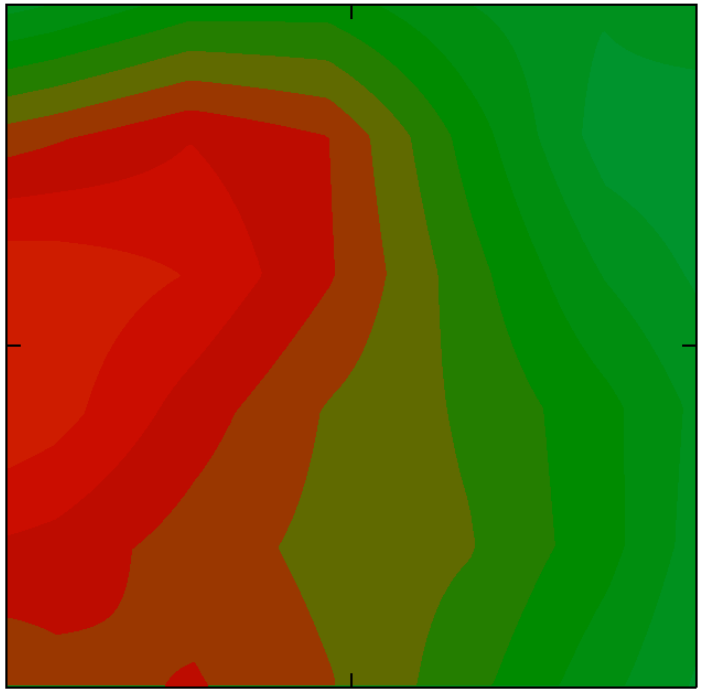
## Model=box mean from 100m data

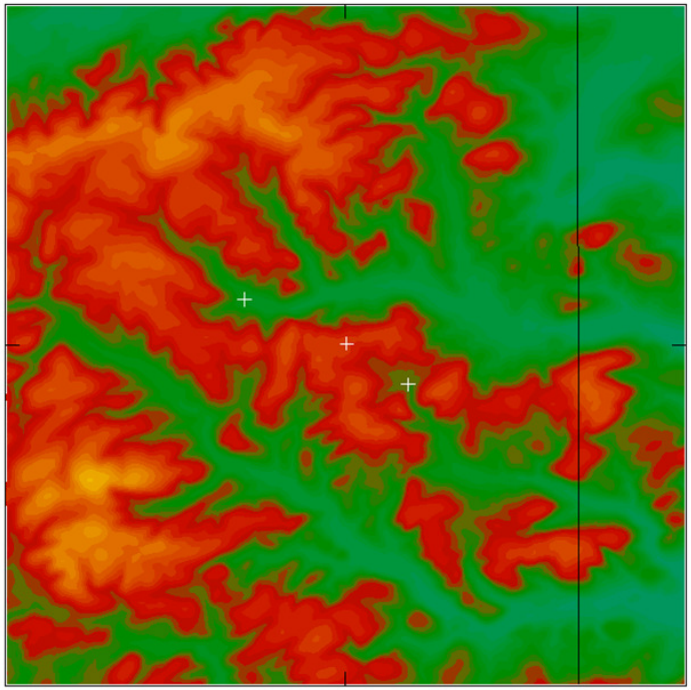
- Orographic Roughness scheme in NWP models accounts for drag due to unresolved terrain.
- Local wind predictions need to correct for this

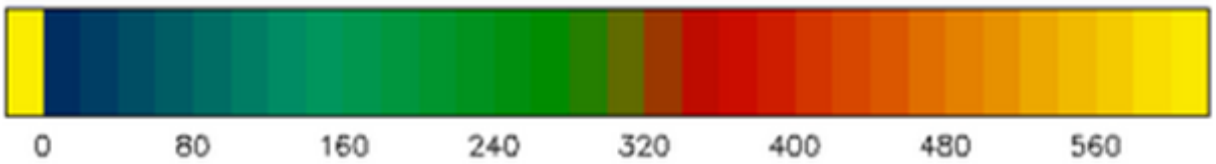



4 km model orography

Terrain at 100 m resolution



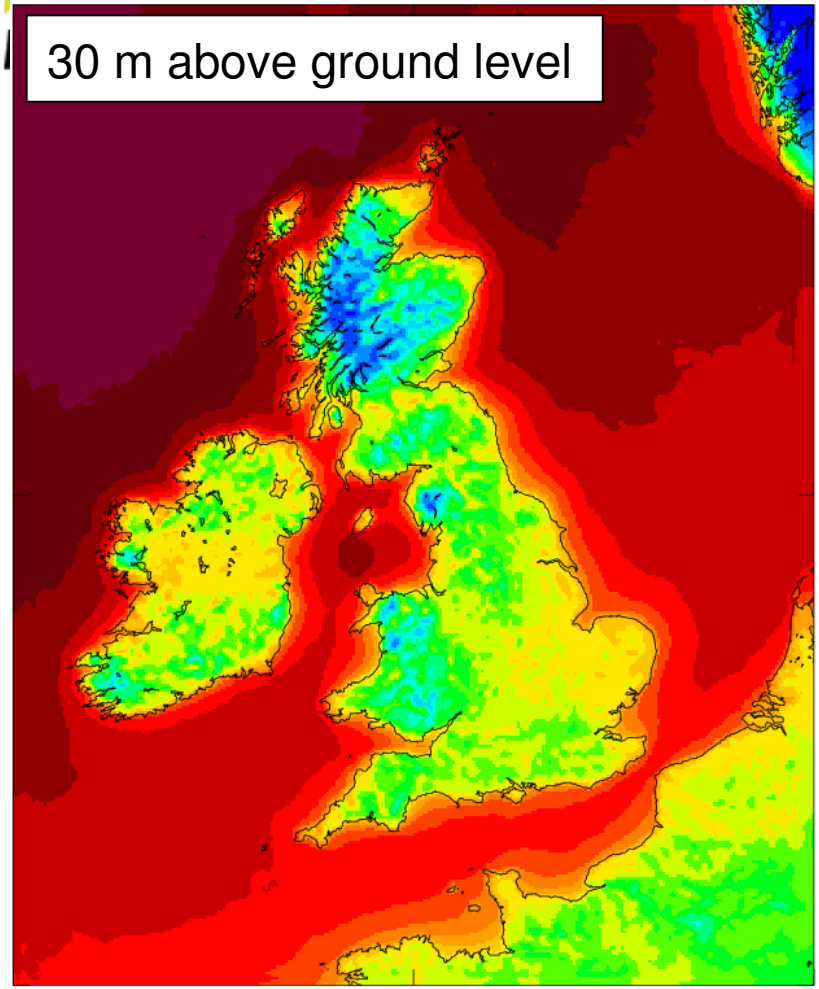


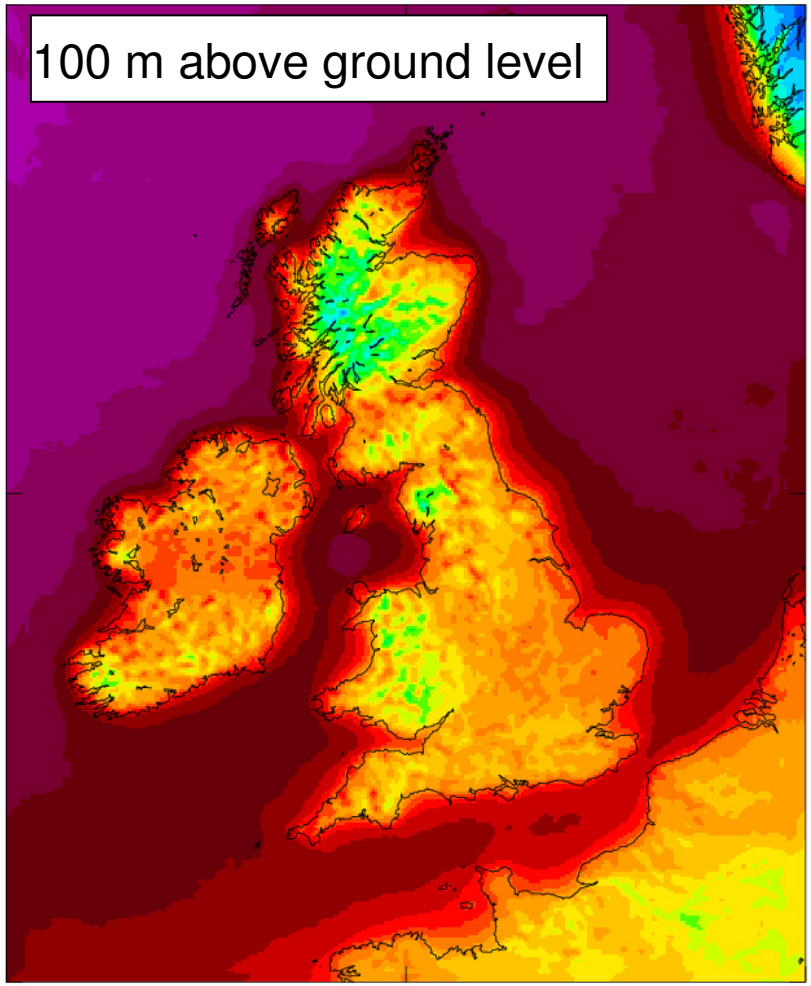



Height in Metres

# Impact of Orographic roughness in UK 4km model

(4 year) Average wind speed ($ms^{-1}$)

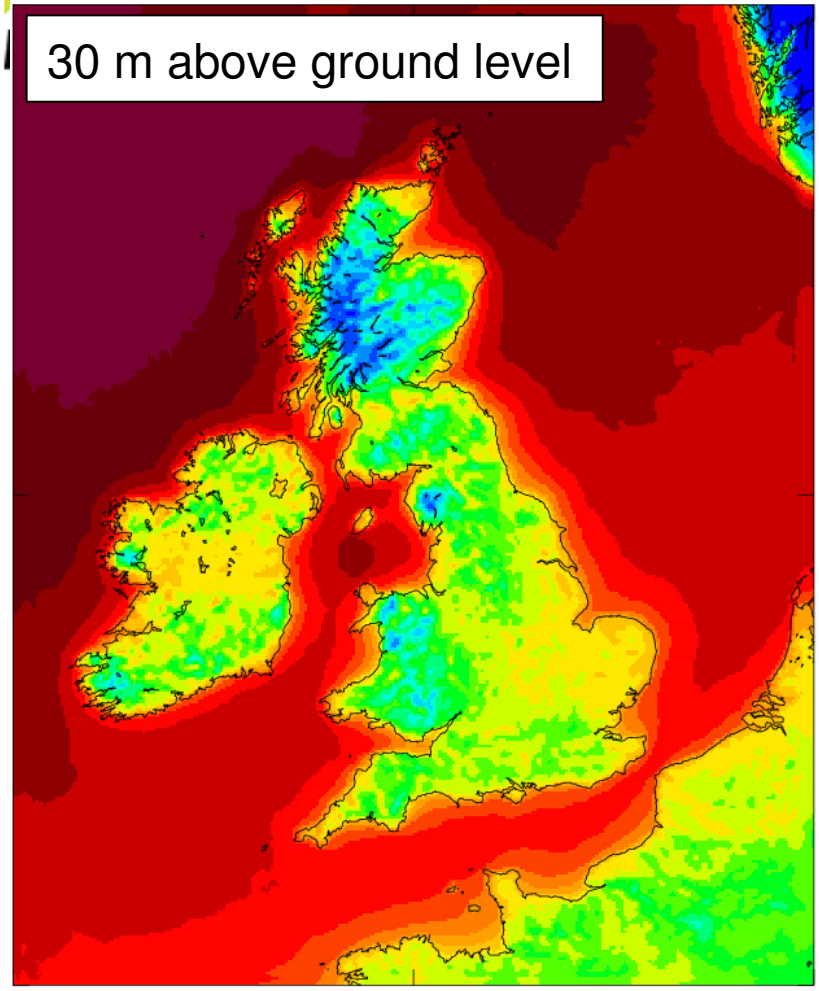




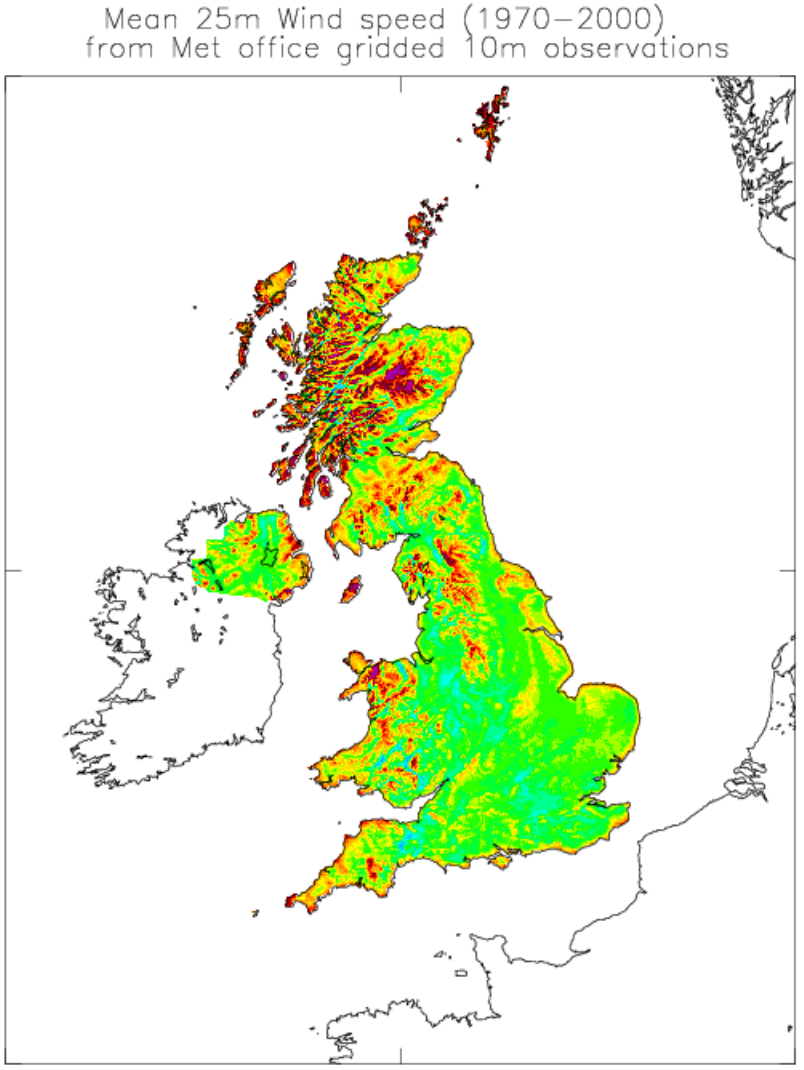
# Impact of Orographic roughness in UK 4km model

wind speed ($ms^{-1}$)



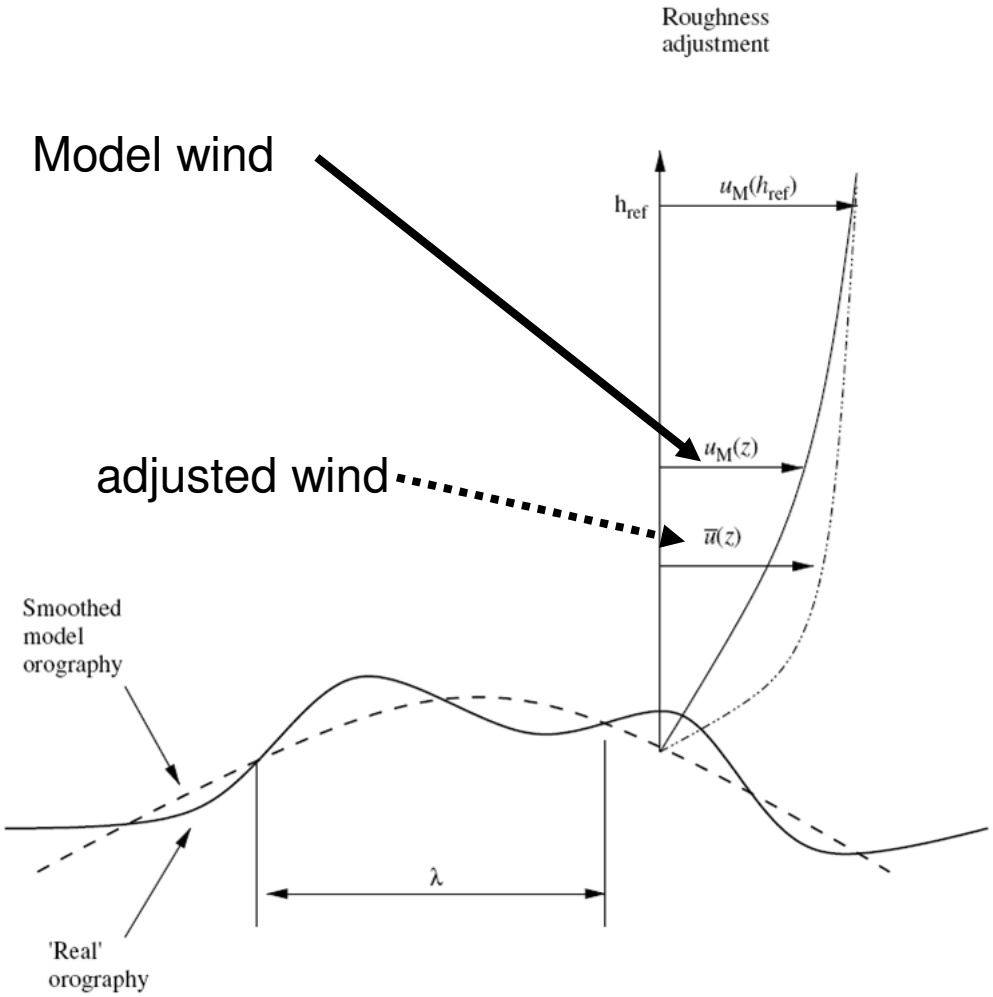







# Land adjustments, Howard and Clark(2007) - roughness correction

- $h_{ref}$ is the height above which perturbations due to sub-grid hills have decayed to some small value
- Derive wind at mast height from $u_M(h_{ref})$
- In VMM, only apply this correction i $h_{ref} > z_{hub}$
- Determination of $h_{ref}$ is therefore important
- $h_{ref}=\{\ln(kh)-\ln(\varepsilon)\}k^{-1}$
  - k=characteristic wavelength
  - h= amplitude orography
  - ε=adjustable tuning



# The ‘Virtual Met Mast’ - VMM

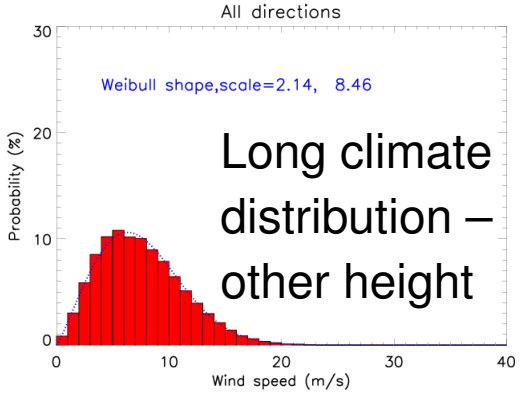
- Downscaling required
  - Orographic roughness known to reduce low-level winds
  - Effect of unresolved orography can be considerable
  - Local roughness variablity
  - Adjustment of boundary layer at coasts (roughness change)
  - Further Offshore - no adjustments
- “High”-resolution NWP archives are relatively short
  - 4km,12km 2006→today
  - Techniques to extend NWP climatology to cover longer periods
  - Extending high resolution period by hindcasts - downscaling re-analyses (ERA Interim)

# Climatology Extension

$$\underline{\mathbf{P}} \cdot \underline{\mathbf{u}}_{climate}$$

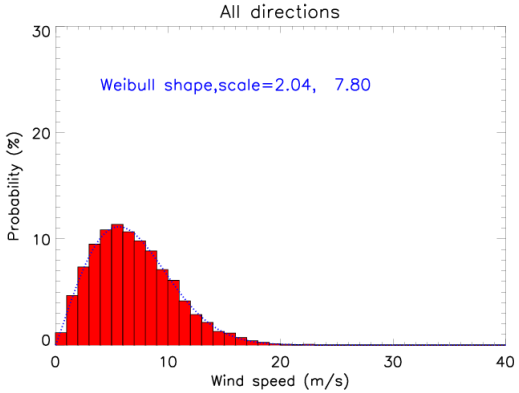
Probability matrix=

probability of downscaled wind **u** with speed (& direction) in bin k when "climate" wind $\mathbf{u_c}$ has speed (& direction) in bin l

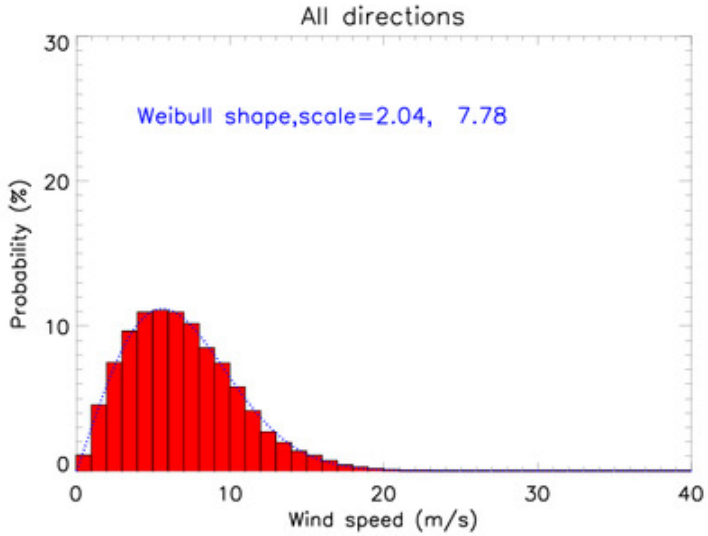


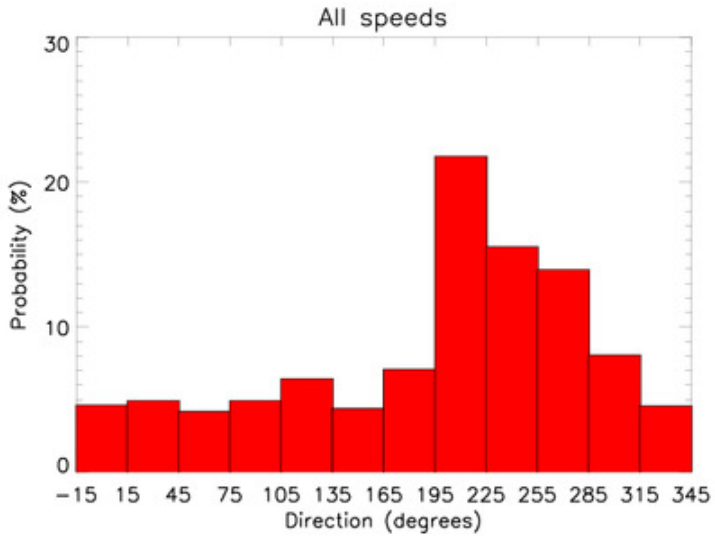

Long climate distribution – other height

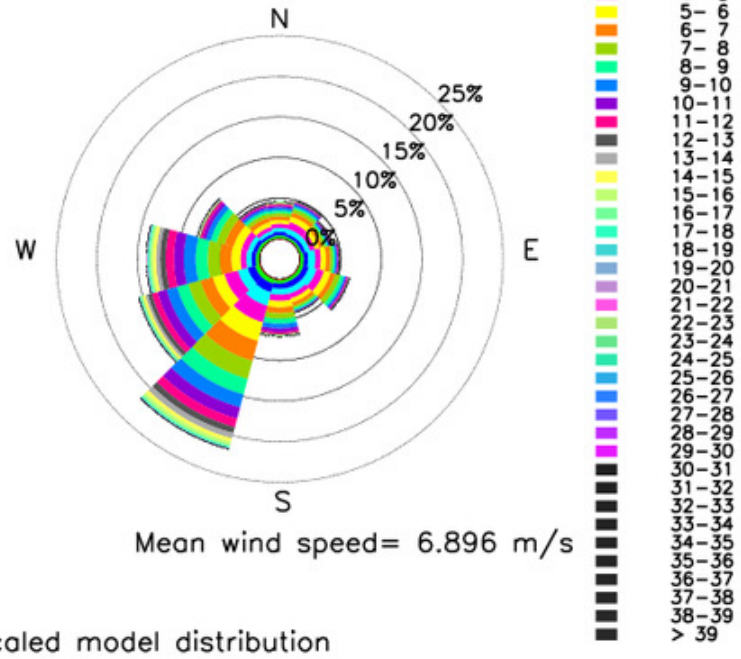
=




$$\underline{\mathbf{u}}_{mast}$$

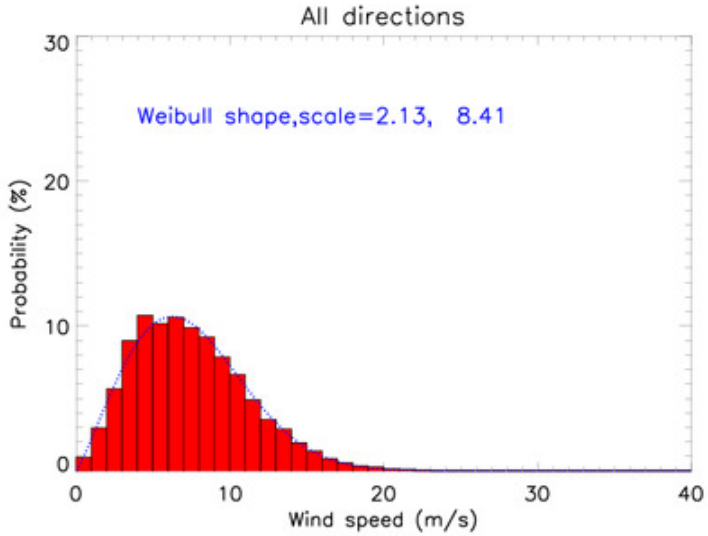


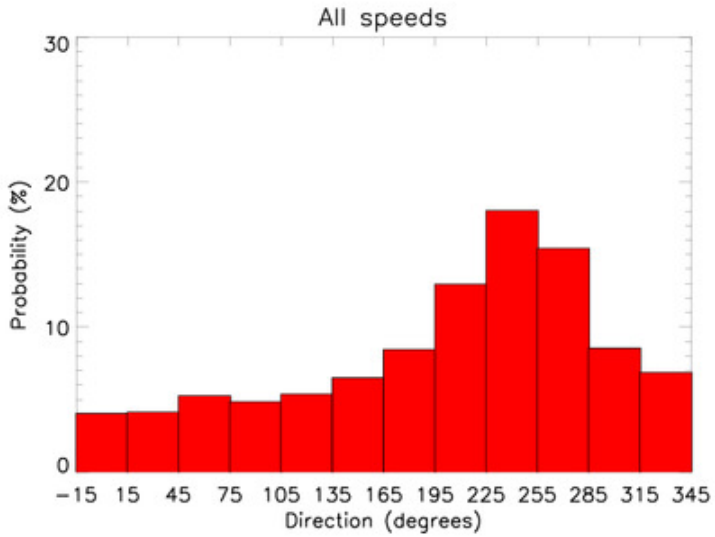



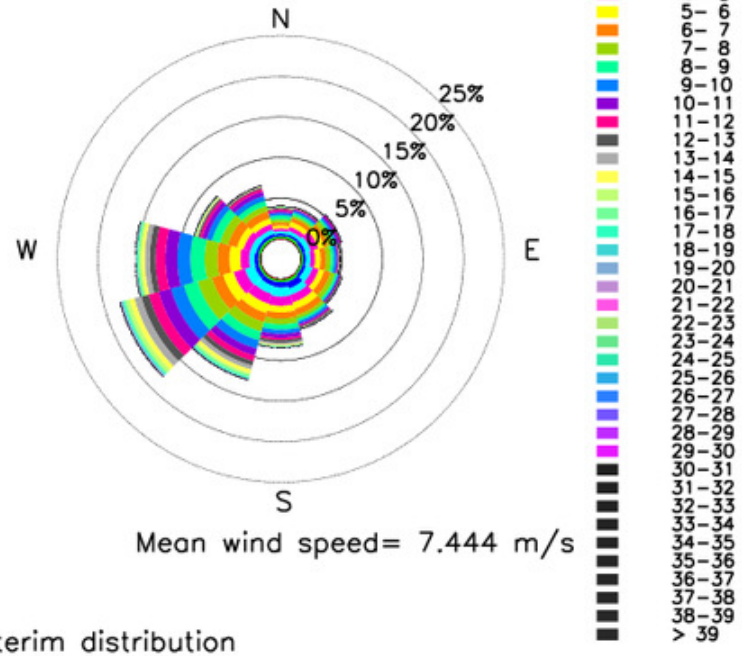




Mean wind speed= 6.896 m/s

47m downscaled model distribution

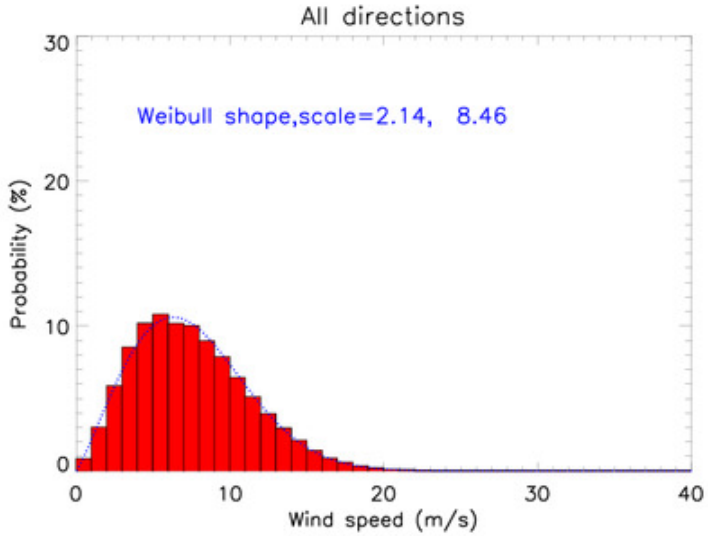


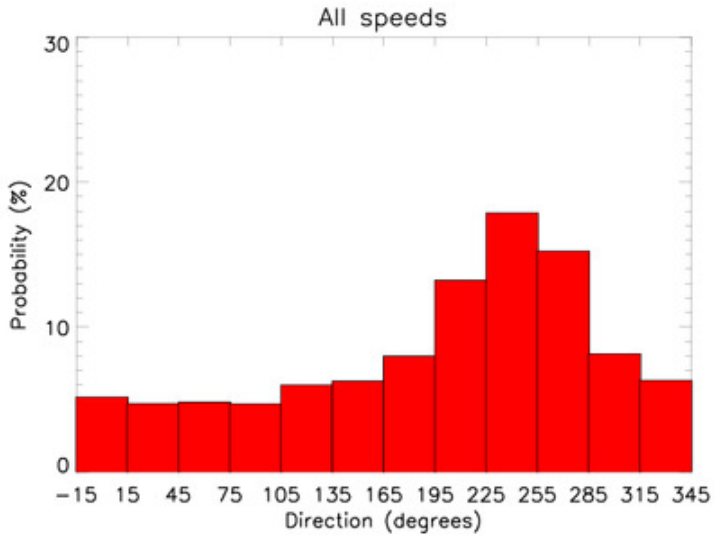



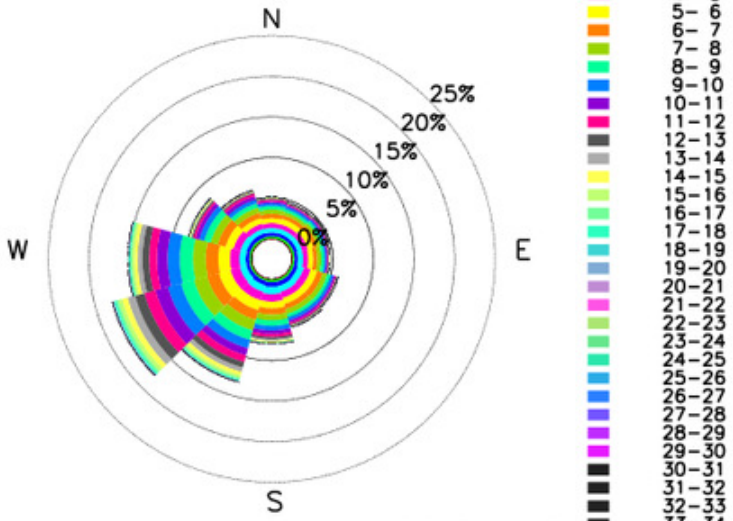




Mean wind speed= 7.444 m/s

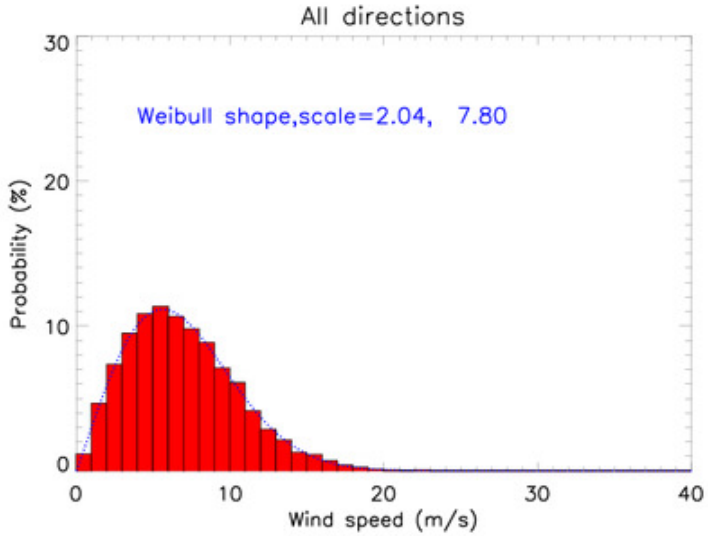
60m ERA Interim distribution

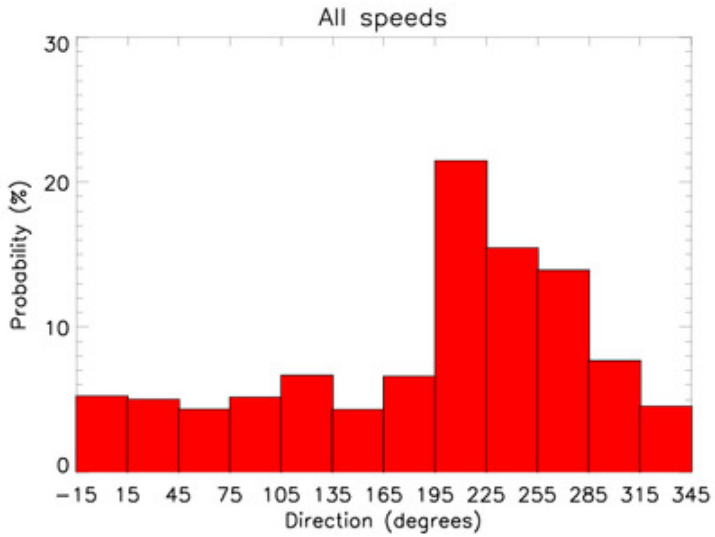


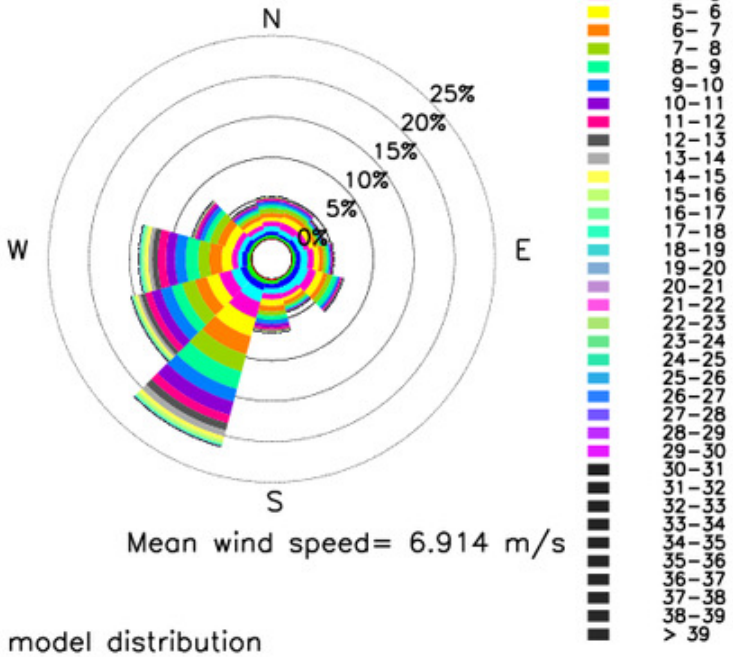




60m ERA Interim long period



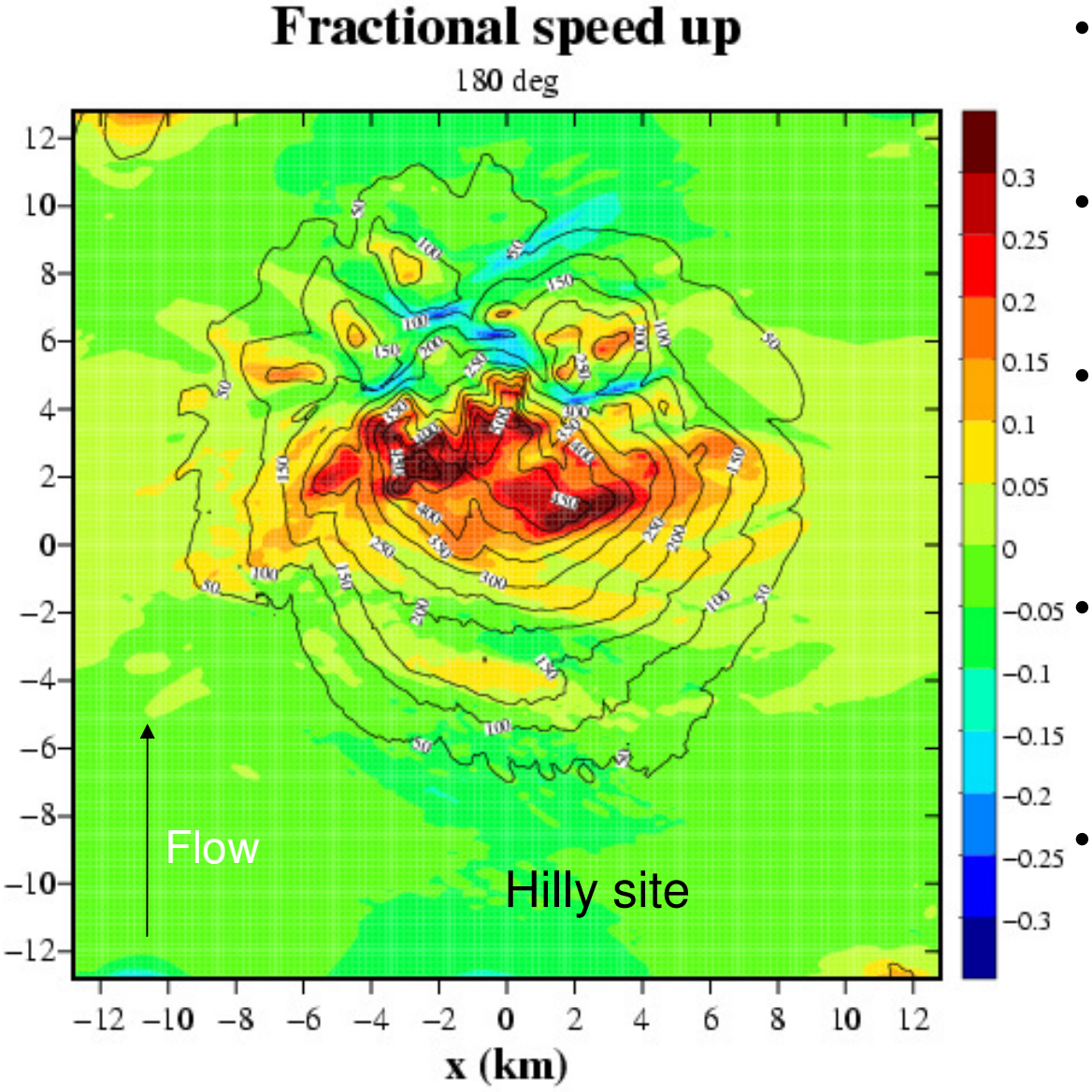




Mean wind speed= 6.914 m/s

47m derived model distribution

# Height adjustment for local orography -Linear model

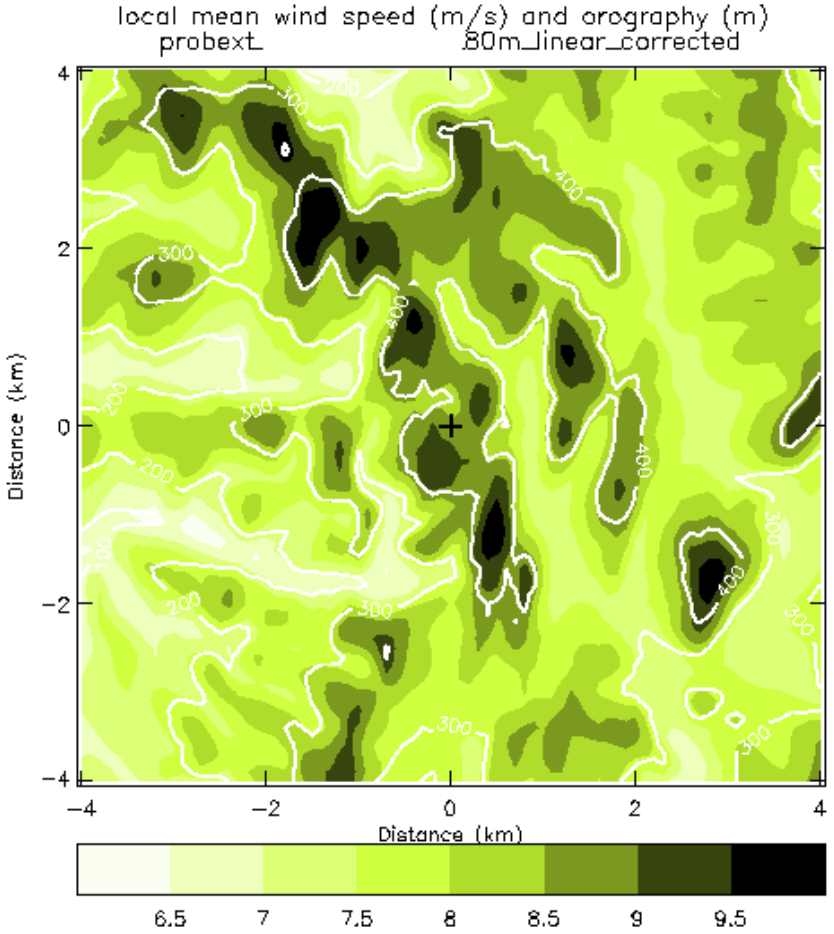



- Based on Mason & King ‘model D’
- 100 m DTED orography centred on site
- Orography tapered at edges of domain (typically 25x25 km$^2$)
- Orography filtered to remove larger scales represented in UK4
- Run for all wind directions e.g. with 5$^o$ resolution

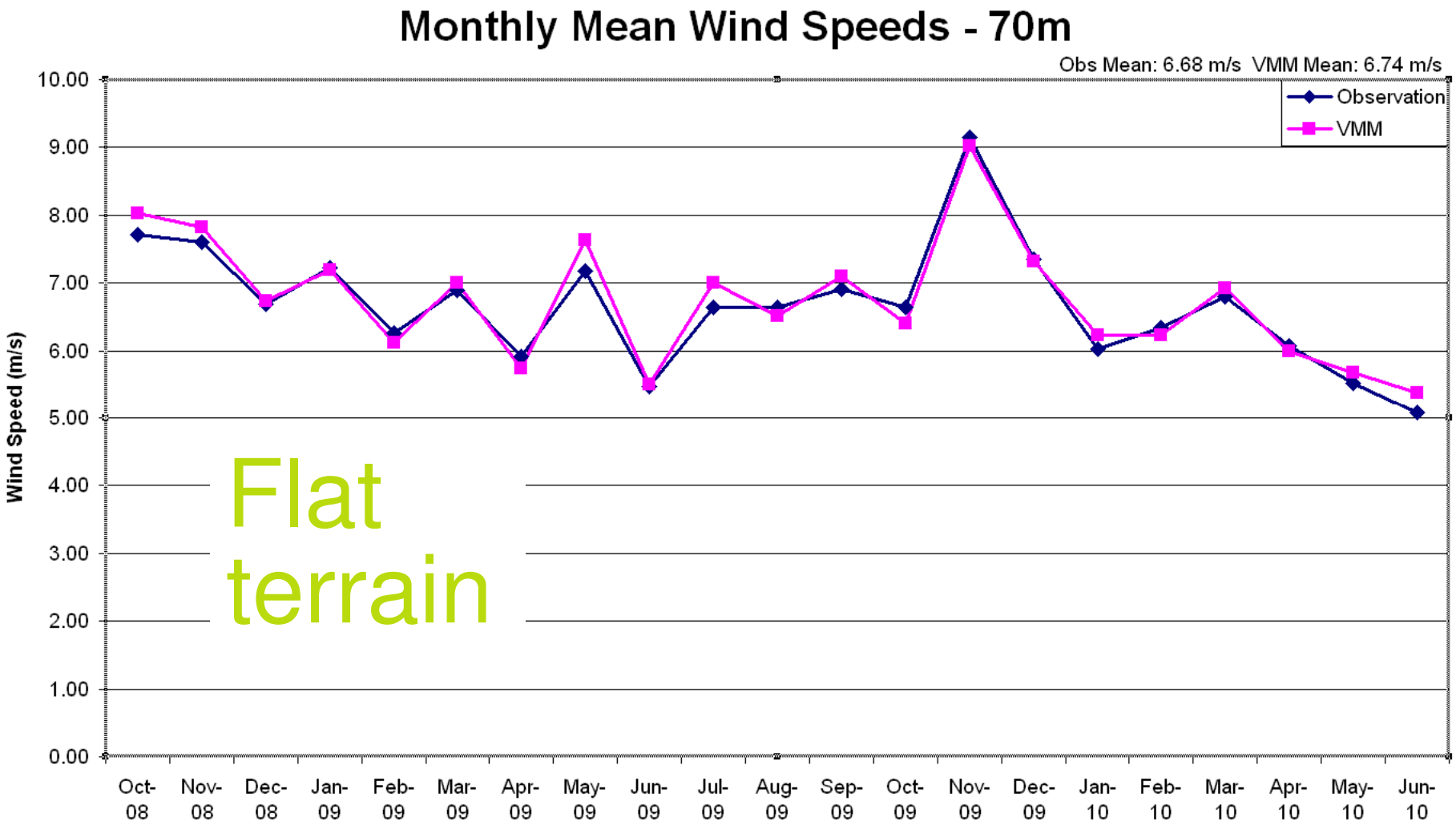
# Local wind map at location

- Combine
  - mean wind distribution
  - Fractional speed-up by direction

- Show local orographic influence



# Verification



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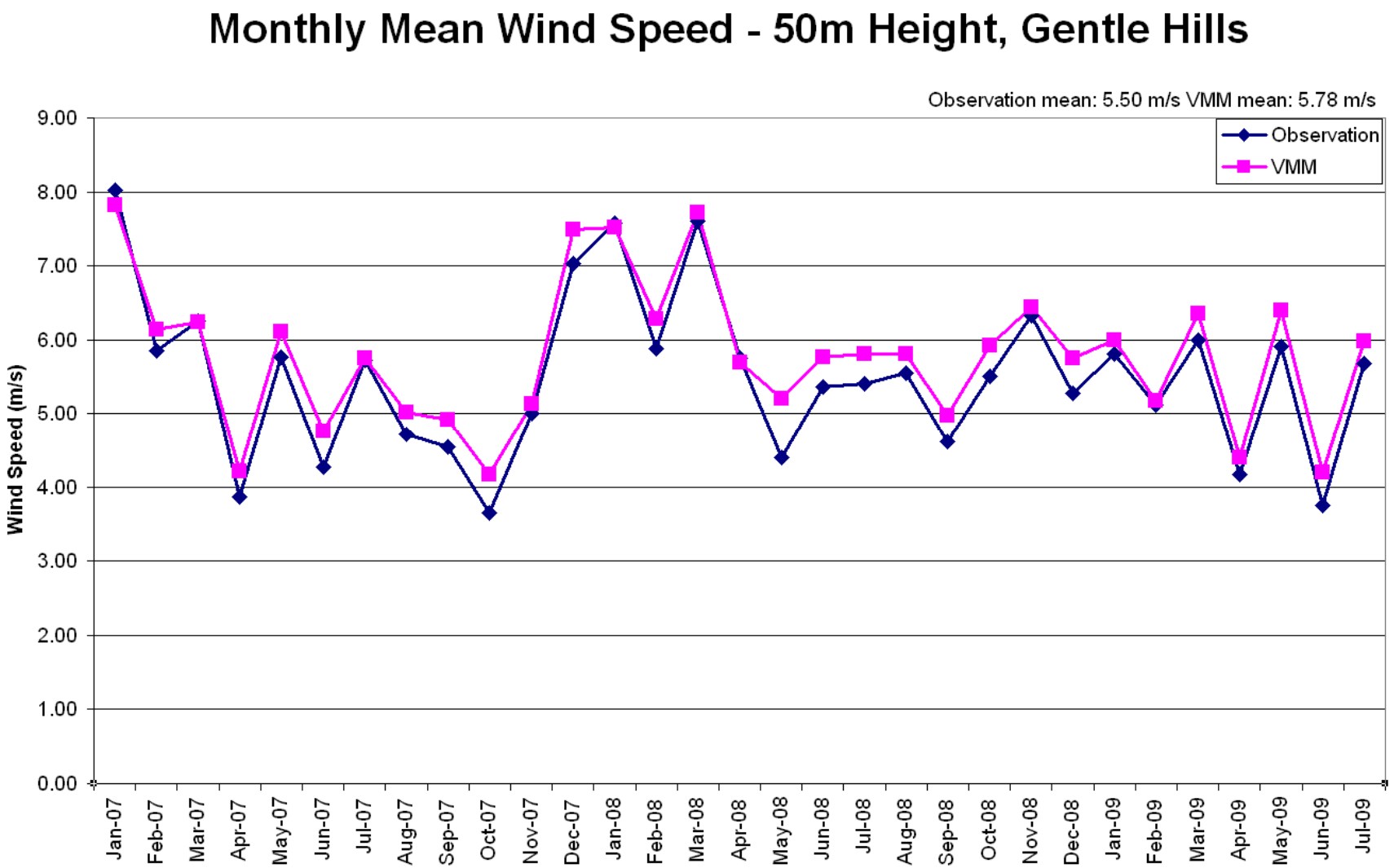

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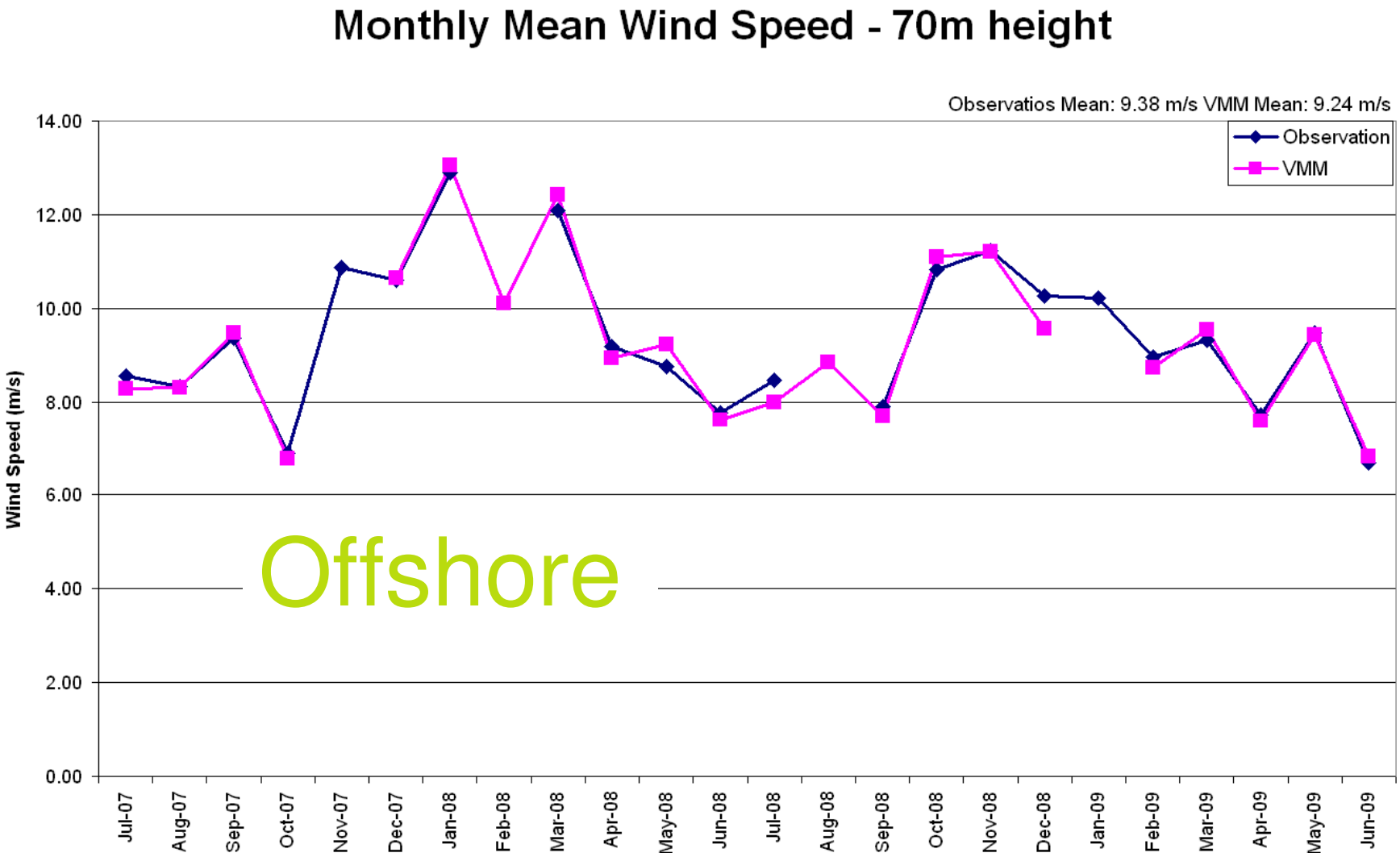

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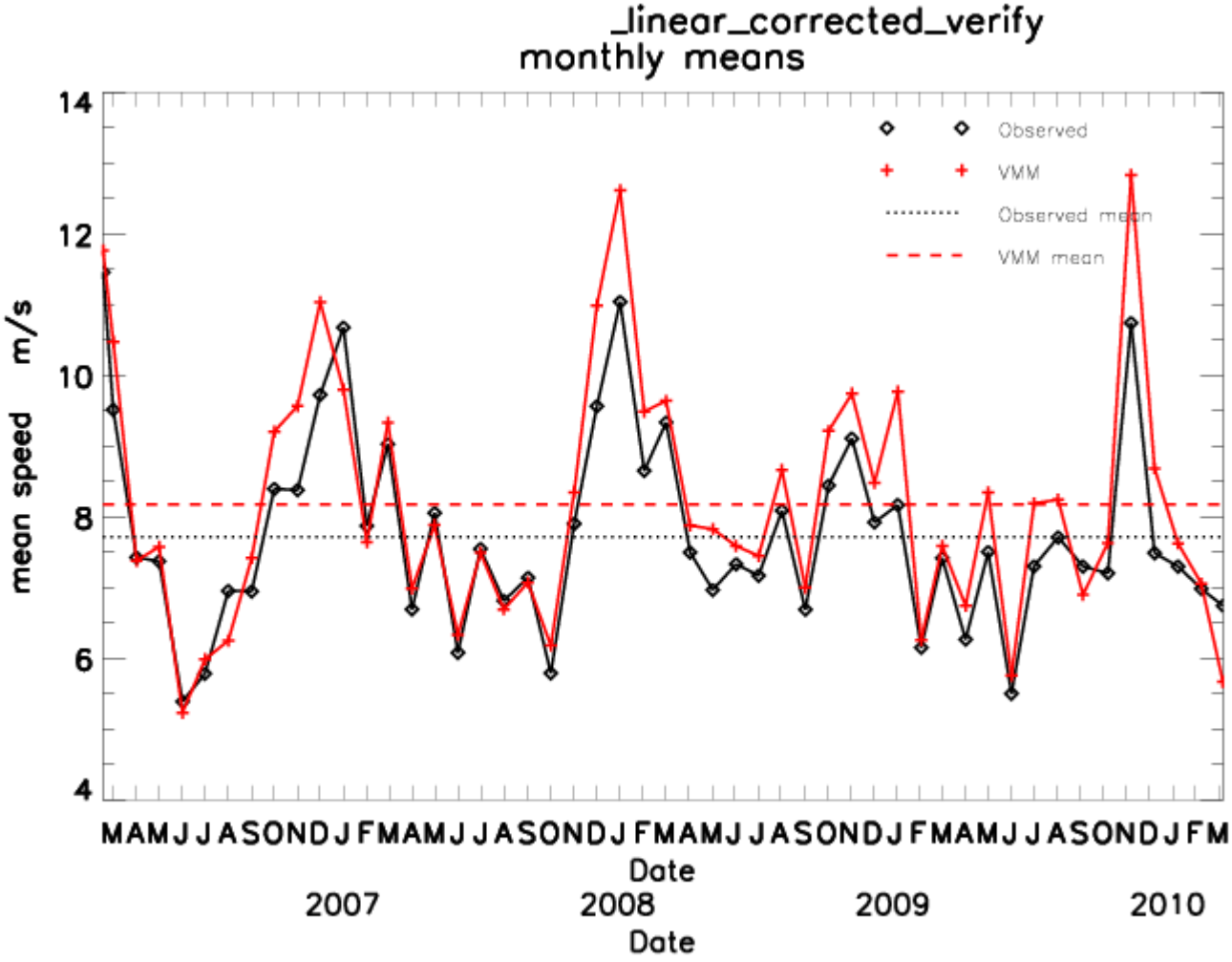


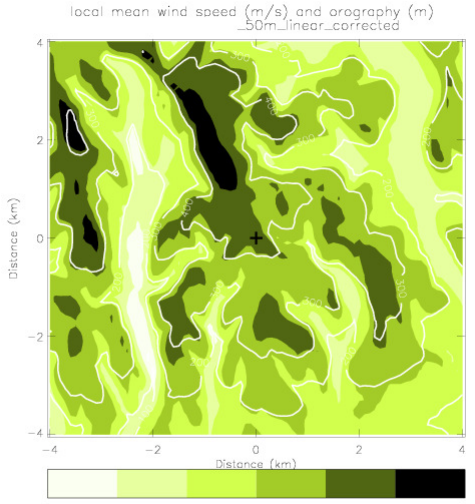

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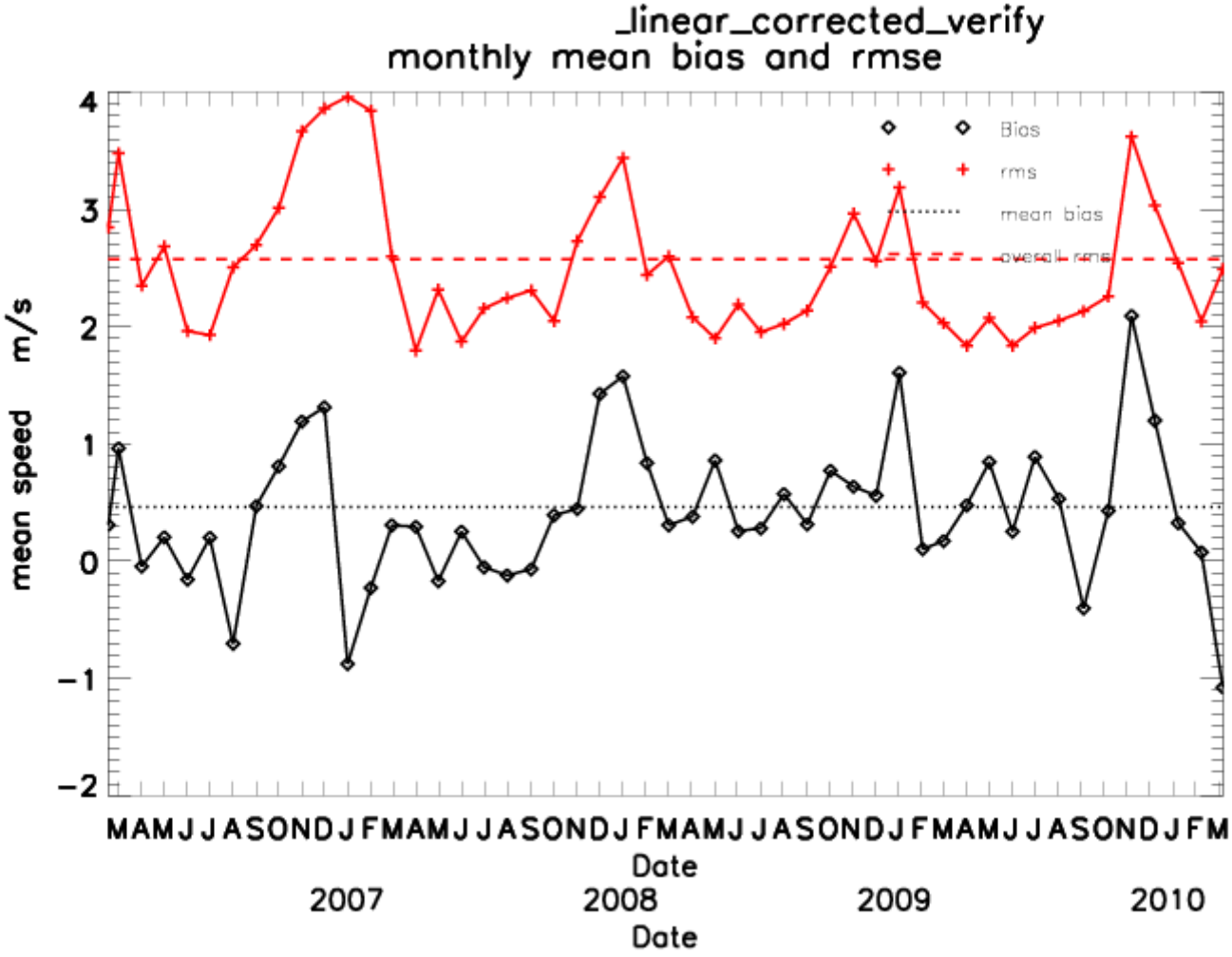
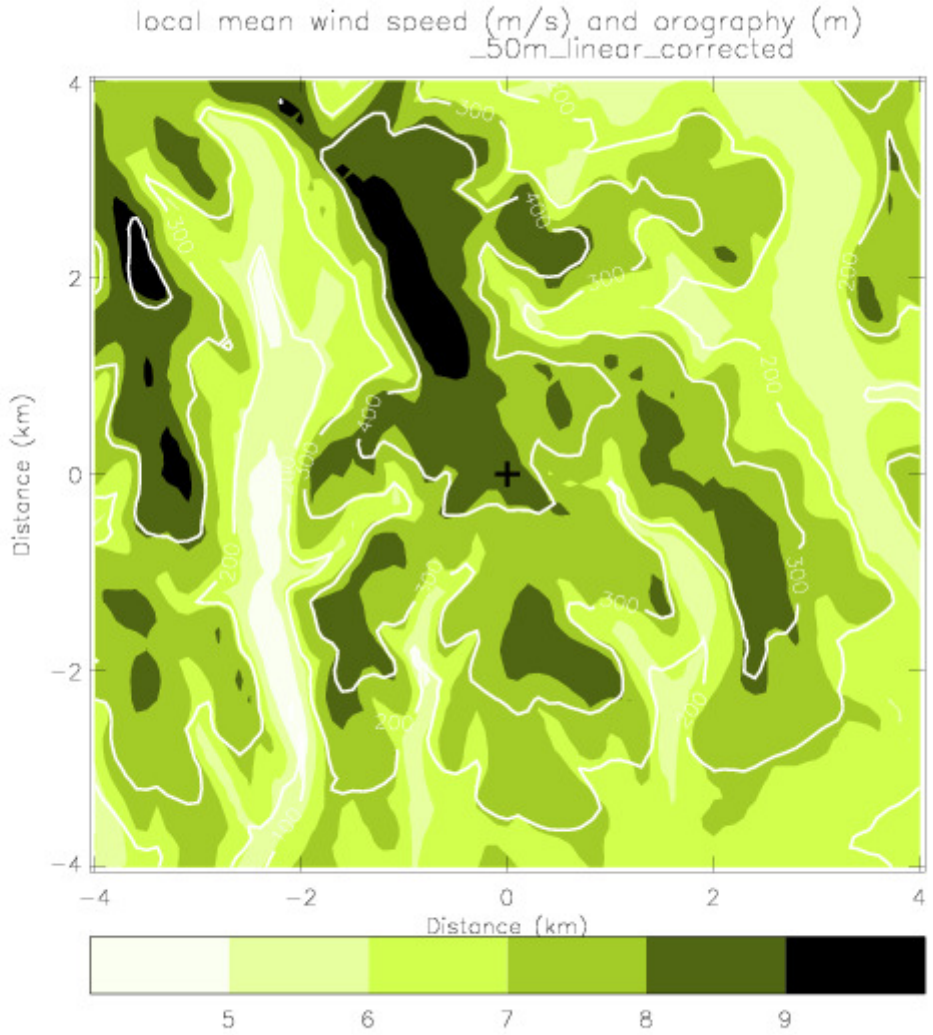
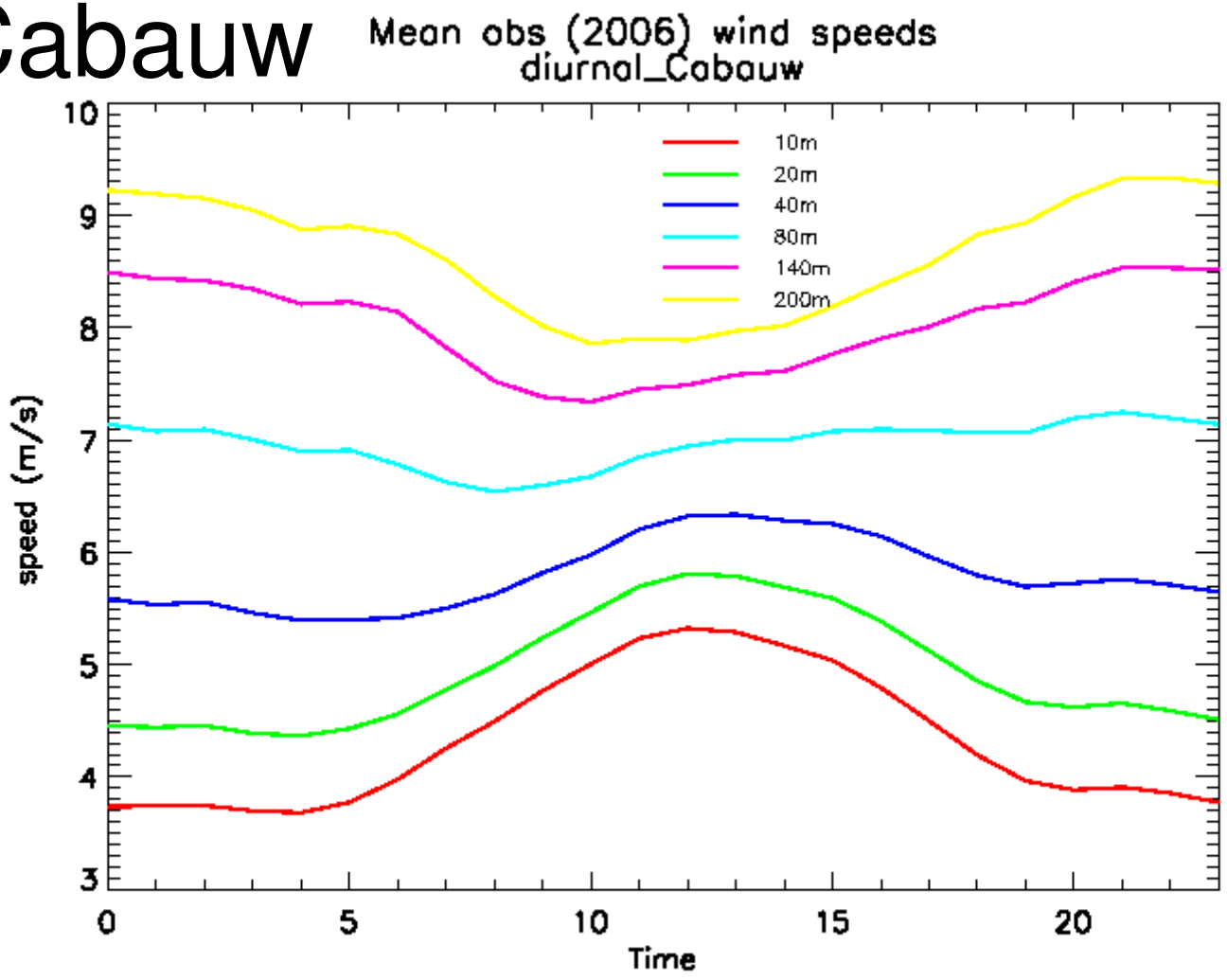
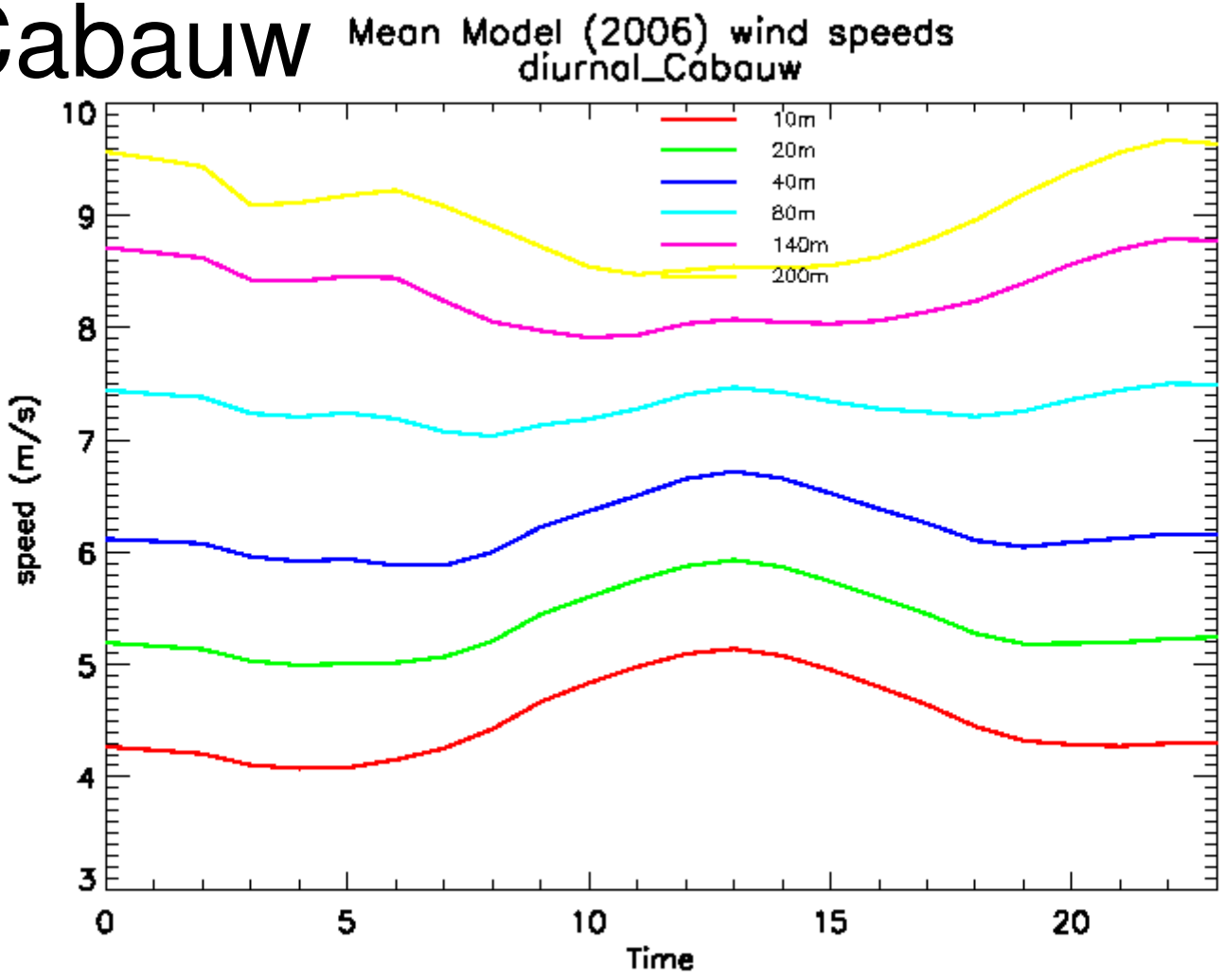




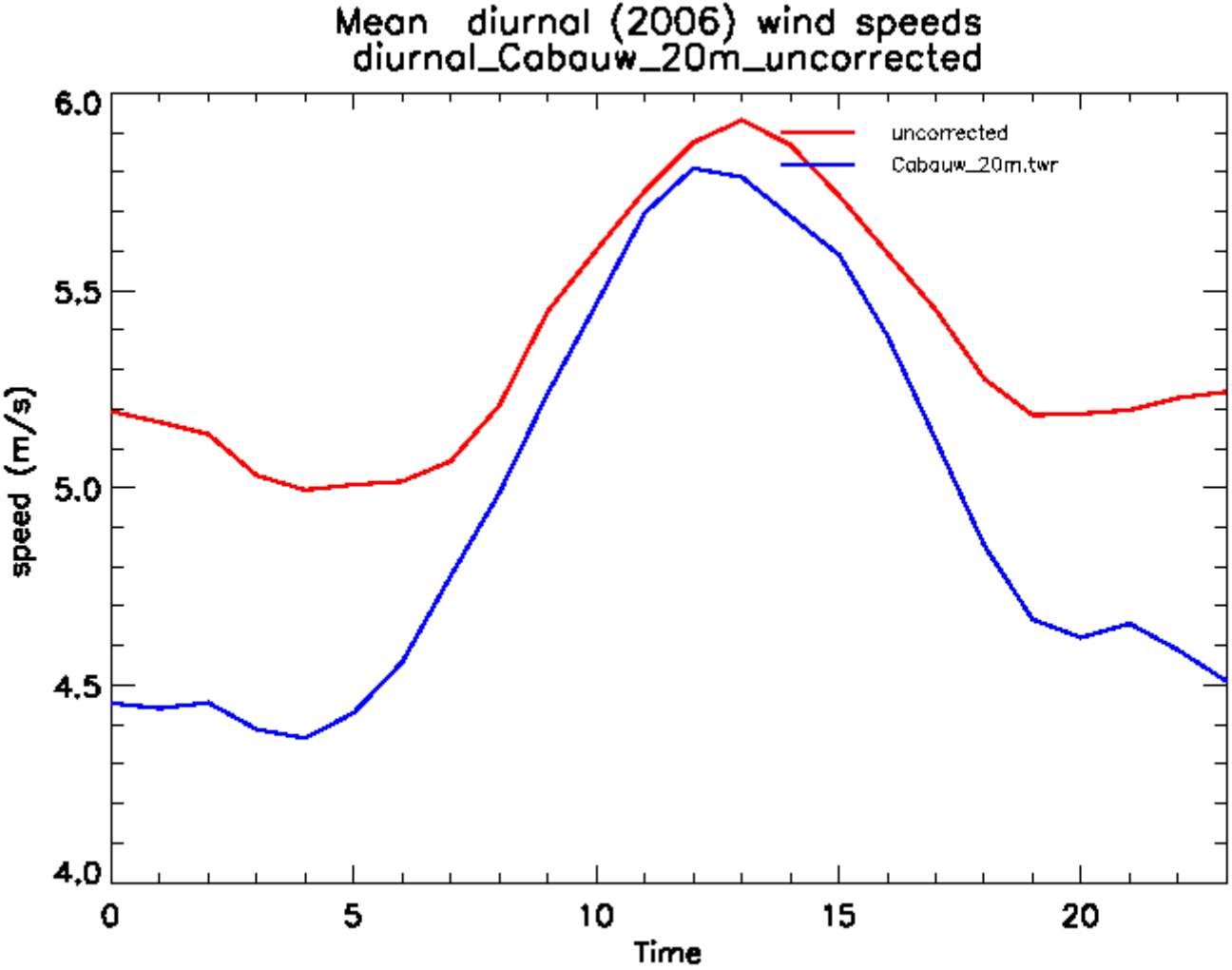
# Diurnal variation observed at Cabauw



# Diurnal variation modelled at Cabauw

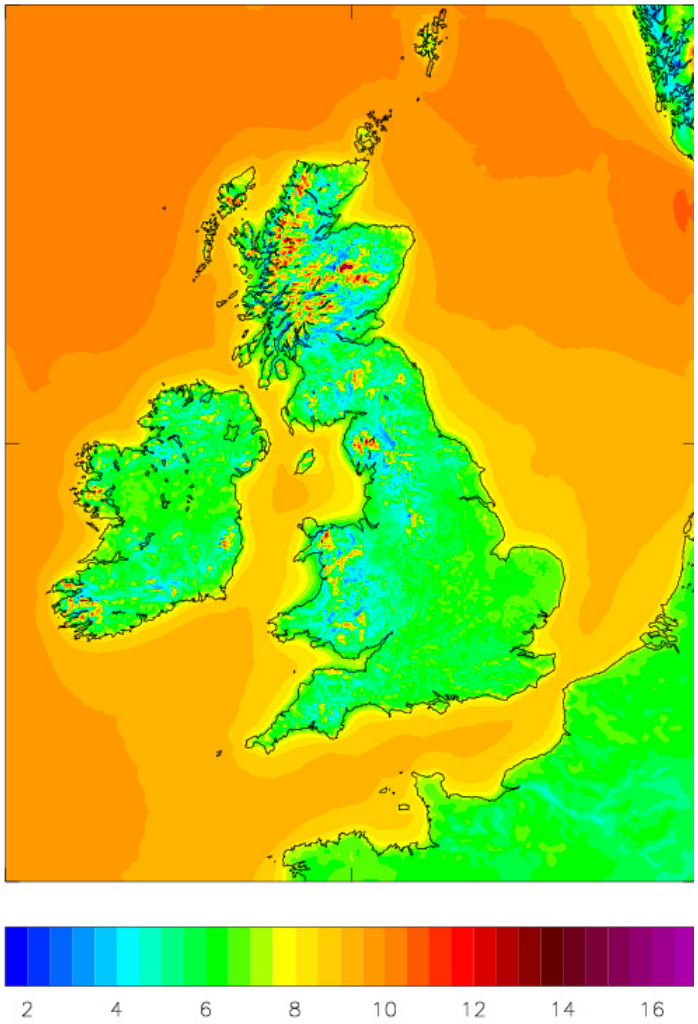


Met Office

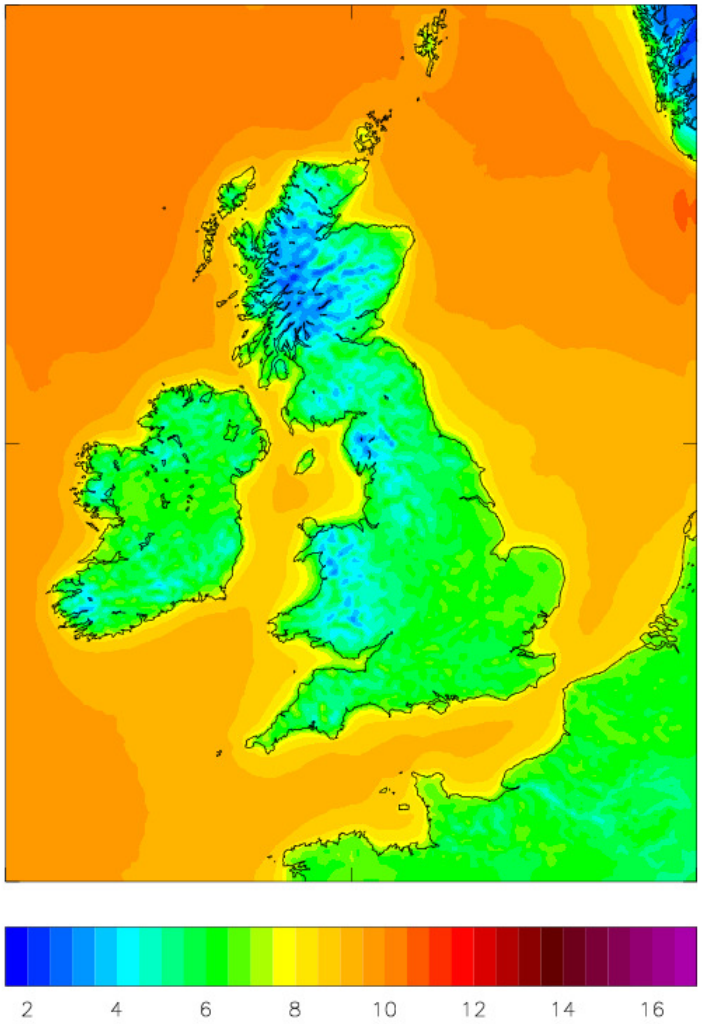

Mean diurnal (2006) wind speeds
diurnal_Cabauw_20m_uncorrected
uncorrected
Cabauw_20m.twr
6.0
5.5
5.0
4.5
4.0
speed (m/s)
0
5
10
15
20
Time

# Wind Atlas maps

70m mean speed 2010
height and orographic drag corrected




70m mean speed 2010
uncorrected



# High Resolution modelling- Colpex – Met Office masts

- COLPEX
  - Cold Air Pooling Experiment
  - Valley in Shropshire
- Chose windy period in COLPEX observational period to run UK4, 1 km, 333 m and 100 m models
  - 4km model provides LBCs for 1km model which provides LBCs for 333m model….through to the 100m model.

- All nested models (1km and finer) are free running and fixed resolution.
- 17/12/09 to 31/12/09

# Configuration of each of the models

| Horizontal Resolution (km) | Horizontal Grid-size (columns × rows) | Timestep (s) | Convection Param. | Orographic Form Drag | Sub-grid Turbulence (S-L=Smag'sky-Lilly) |
|---|---|---|---|---|---|
| 4 | 288x360 | 100 | Shallow | Effective Roughness | 1DBL + 2D S-L |
| 1 | 100×100 | 30 | None | None | As 4km + drainage |
| 0.333 | 150x150 | 10 | None | None | 3D S-L + drainage |
| 0.1 | 200×200 | 3 | None | None | 3D S-L + drainage |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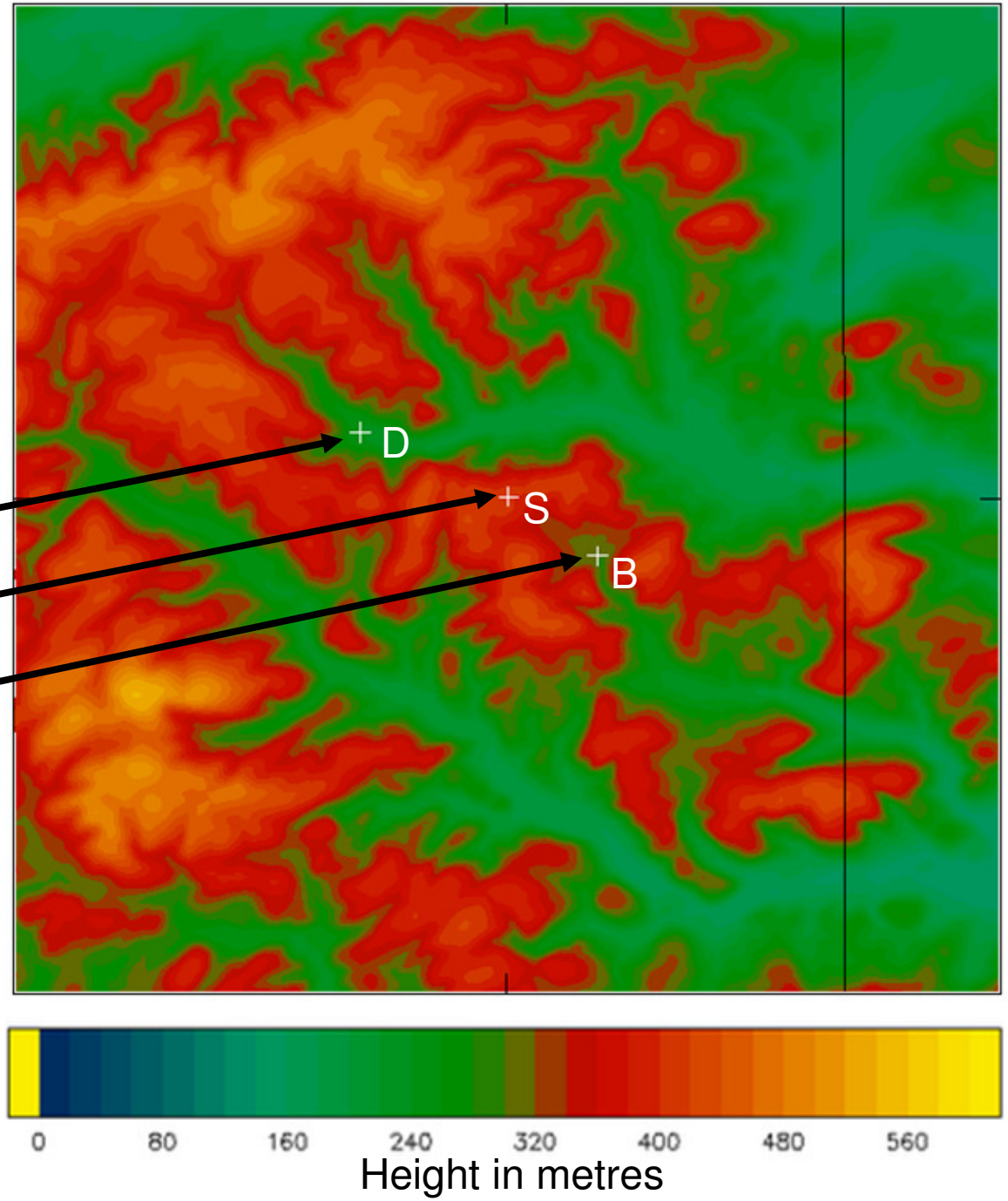
# 100 m model domain and orography

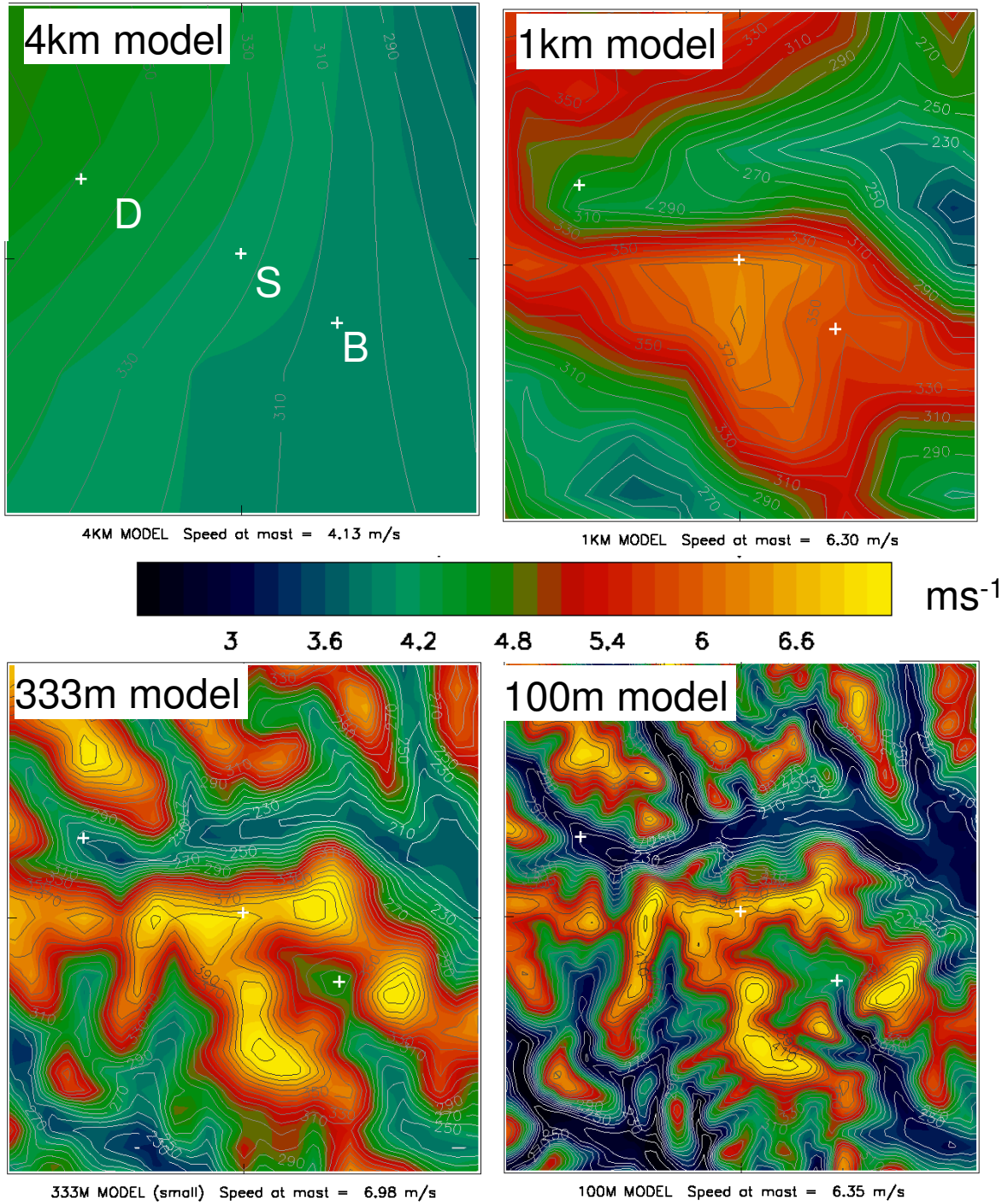
- Area = 20km x 20km centred on Springhill
- Masts at:-
  - **D**uffryn (main valley)
    - 50m
  - **S**pringhill (valley rim)
    - 30m
  - **B**urfield (adjacent valley)
    - 30m



# Time averaged wind speed at 30m above ground level

- Area = 10km x 10km centred on **S**pringhill
- Orography contours from 200m (white lines) to 600m (black lines).

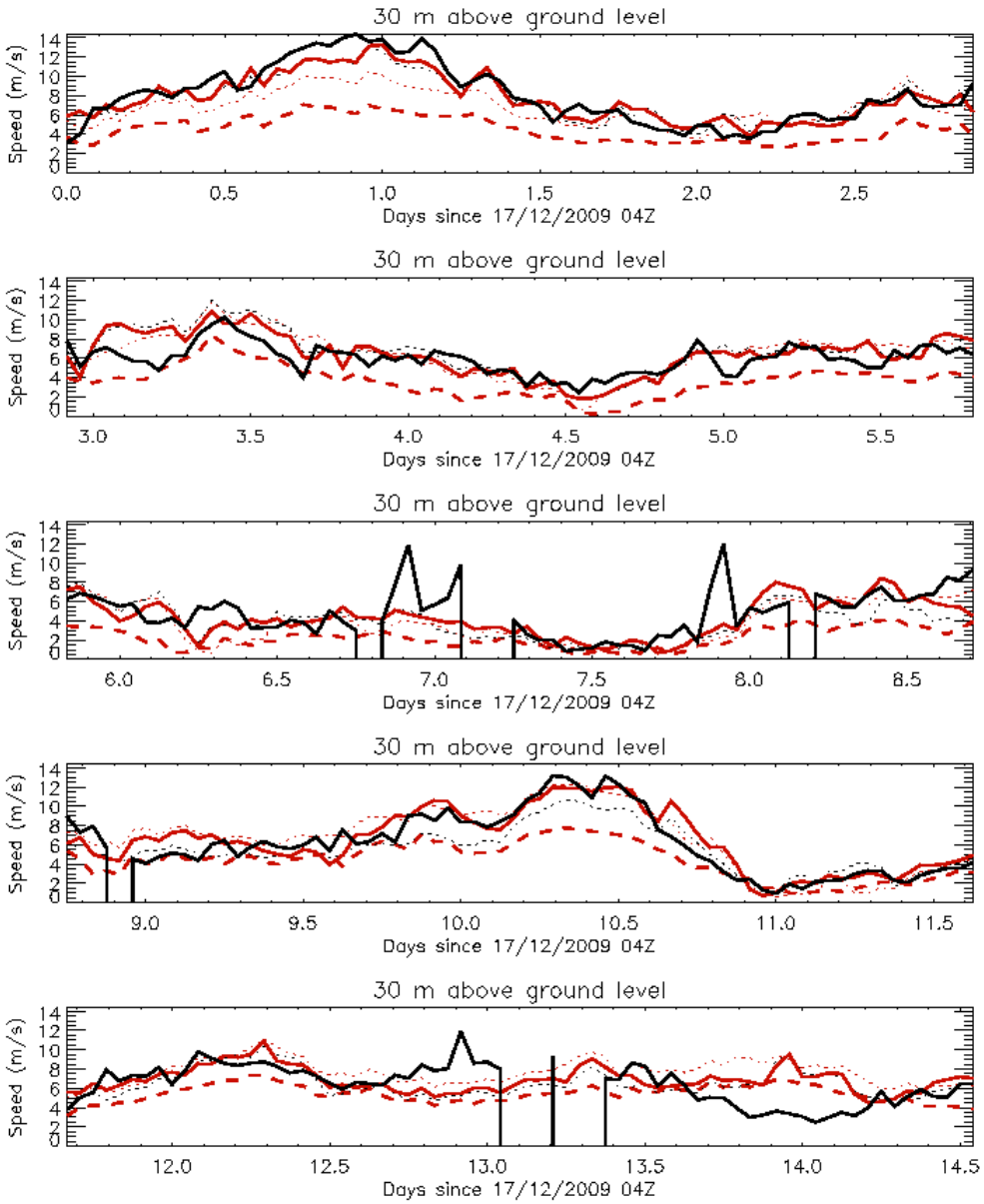
- Increased detail and larger range of winds in finer resolution simulations.
- Not surprisingly, windier over the hill tops (including **S**pringhill) and calmer in the valleys (including **D**uffryn).



# Springhill 14 Day Timeseries

| | | | |
|---|---|---|---|
| 4km model | Mean = | 4.03 m/s |
| 1km model | Mean = | 6.30 m/s |
| 333m model | Mean = | 6.08 m/s |
| 100m model | Mean = | 6.37 m/s |
| Observations | Mean = | 6.31 m/s |

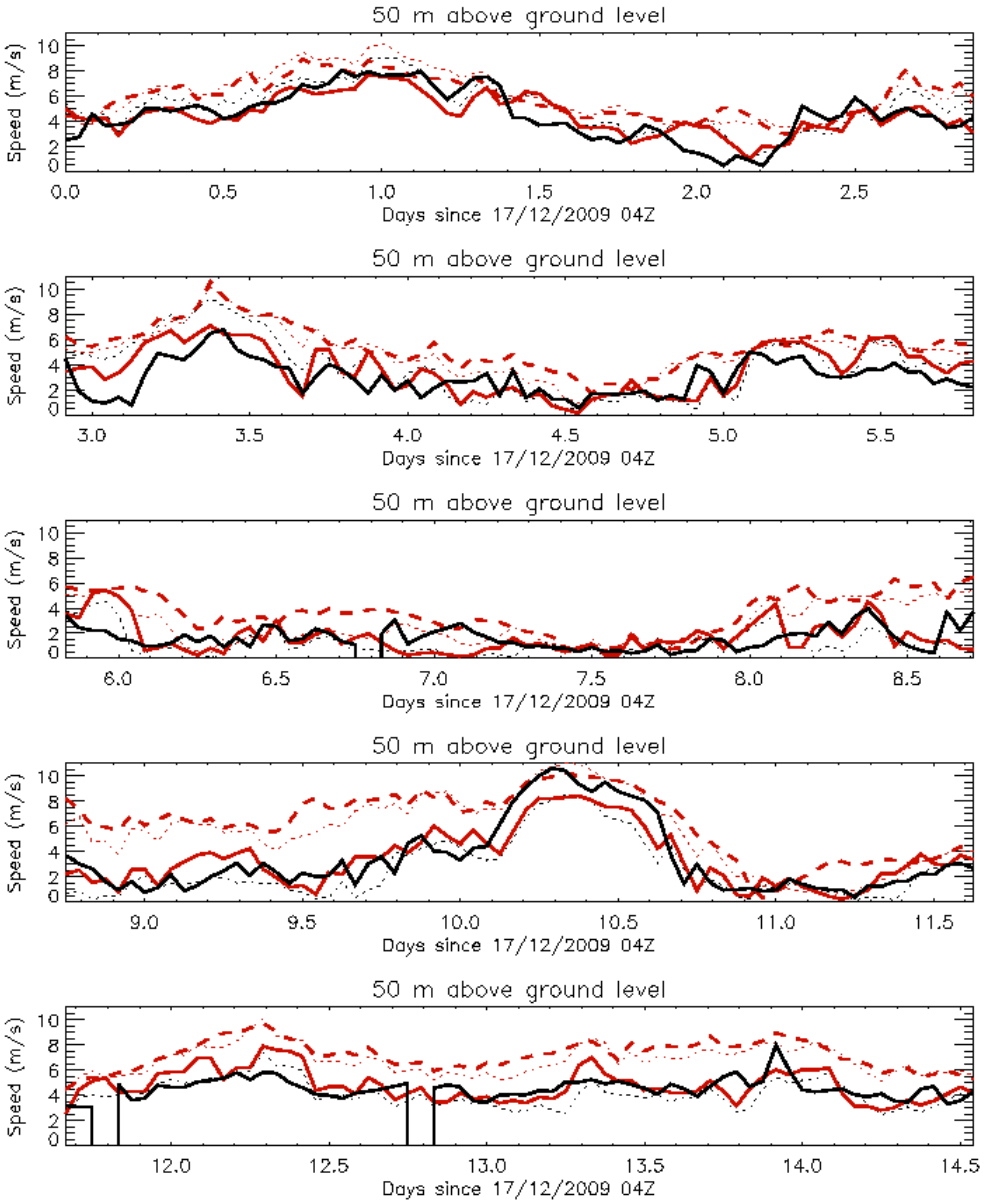
- Hill top location
- 4 km model consistently 2-3m/s slower than wind mast observations.
- Mean errors for 1 km, 333 m and 100m models all within 0.3 m/s of observations
  - 1km resolution sufficient to get winds right at this location



# Duffryn 14 day timeseries

| | | | |
|---|---|---|---|
| 4km model | Mean = | 5.67 m/s |
| 1km model | Mean = | 5.24 m/s |
| 333m model | Mean = | 3.37 m/s |
| 100m model | Mean = | 3.61 m/s |
| Observations | Mean = | 3.42 m/s |

- Located in main valley
- 4 km model consistently 2-3 m/s faster than wind mast observations.
- 1 km model consistently ~2 m/s faster than wind mast observations.
- Mean errors for 333 m and 100m models within 0.2 m/s of observations
  - 333 m resolution sufficient to get winds right at both locations



# Mean Wind Errors at the two sites:- Summary

- Remarkable agreement between finest resolution model simulations and mast observations

- Using corrections to 4km winds based on these 100m (or 333m) simulations should yield small errors in the VMM timeseries.

**14 day averaged Wind Speed Error (m/s)**

| Model | Springhill | Dyffryn |
|---|---|---|
| 4km | -2.28 | +2.25 |
| 1km | -0.01 | +1.82 |
| 333m | -0.23 | -0.05 |
| 100m | +0.06 | +0.19 |
| **Observed Speed** | **6.31** | **3.42** |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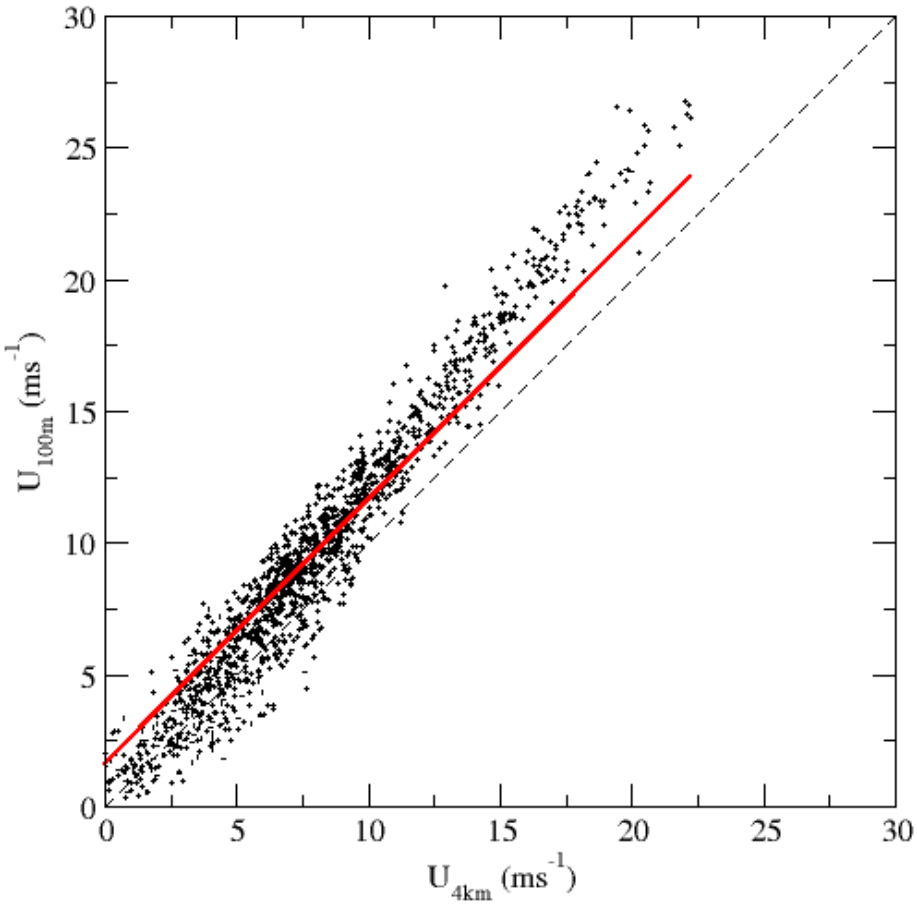
# VMM High-resolution UM corrections 2 months - 1/12/07-31/1/08

Correction techniques tested rely on relating high-resolution UM timeseries (i.e. $\Delta x$=100m or 333m) to 4km resolution timeseries

1) Ratio of time average winds ($U_{100m}/U_{4km}$)
2) Linear regression
3) Linear regression with forced zero intercept

4-6) Directionally dependent versions of 1-3



# Summary of results – 14 locations

| Δx=100m | VMM | Linear regression | Directional linear regression |
|---|---|---|---|
| **Mean \|bias\|** | **1.05** | **0.83** | **0.80** |
| **St. dev \|bias\|** | **0.60** | **0.61** | **0.61** |
| **Mean bias** | **0.054** | **-0.017** | **-0.045** |
| **St. dev bias** | **1.26** | **1.03** | **1.18** |

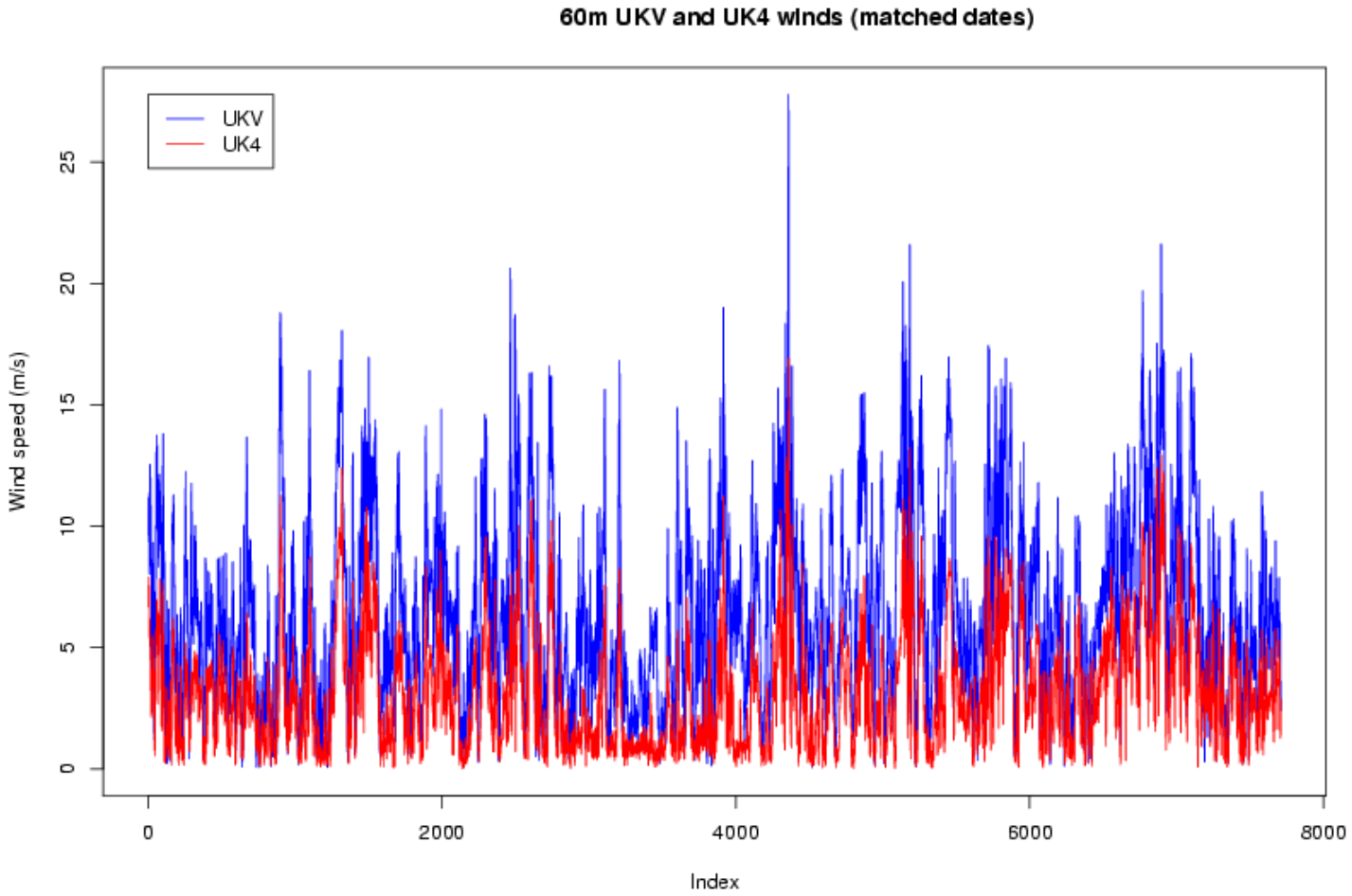
| **Δx=333m** | **VMM** | **Linear regression** | **Directional linear regression** |
|---|---|---|---|
| **Mean \|bias\|** | **1.05** | **0.87** | **0.84** |
| **St. dev \|bias\|** | **0.60** | **0.62** | **0.63** |
| **Mean bias** | **0.054** | **-0.11** | **-0.05** |
| **St. dev bias** | **1.26** | **1.07** | **1.05** |

# Conclusions

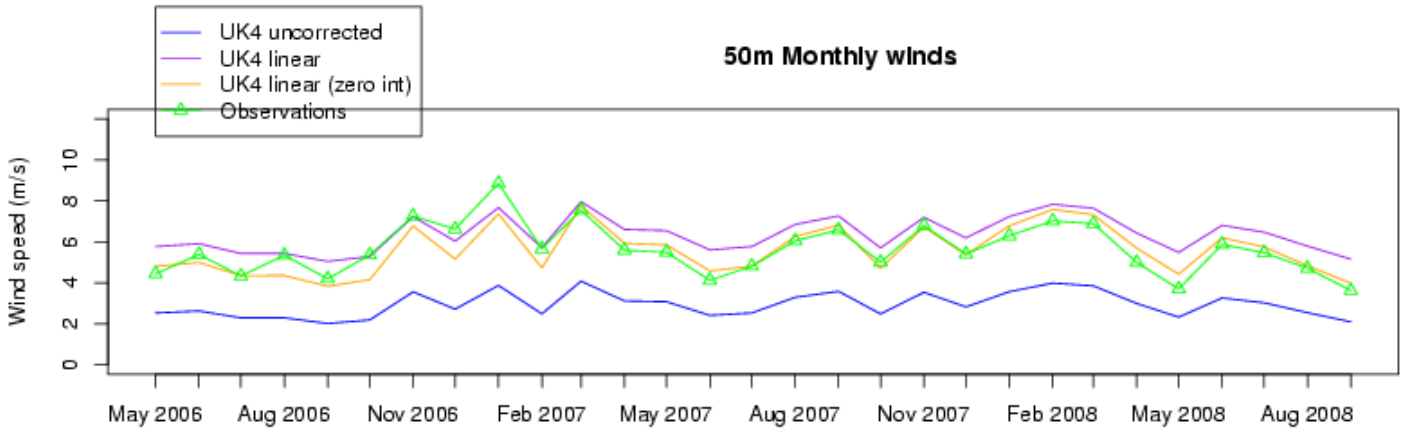
- Cost Effective site screening
- Wind maps/atlas in preparation
- Extension to long term climatology
- High resolution modelling for more local accuracy – especially in complex terrain
- Improvements
  - Ability to ingest limited period site mast observations (MCP)
  - Better orographic drag correction by scaling 1.5km/4km winds

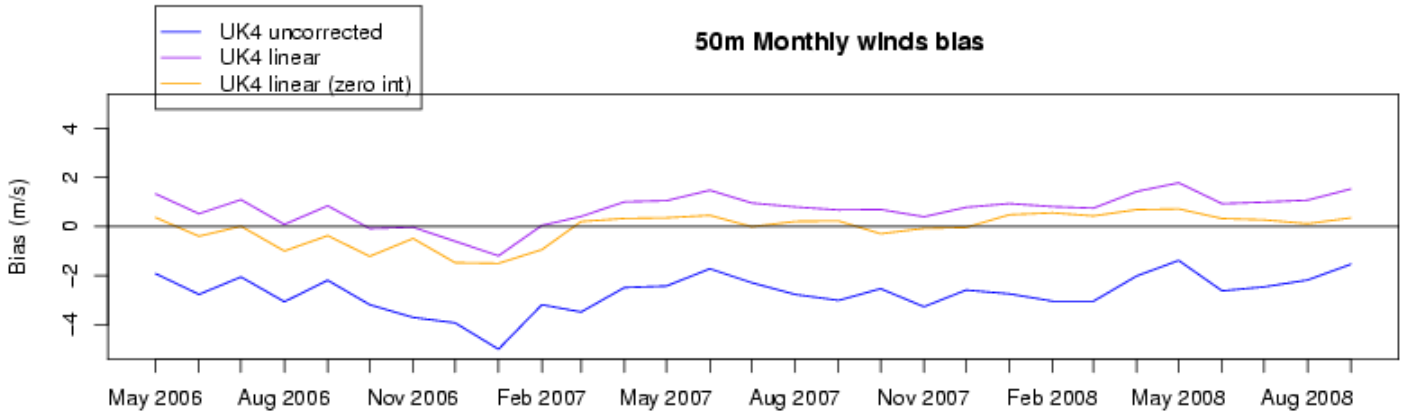
# 1.5km model ( without orographic drag) to correct 4km model

07/2010-06/2011

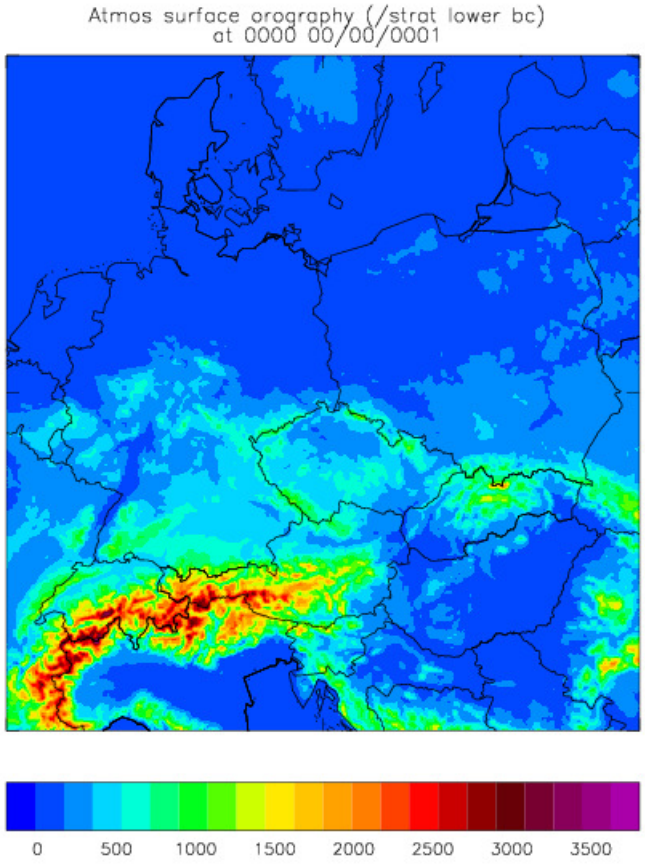


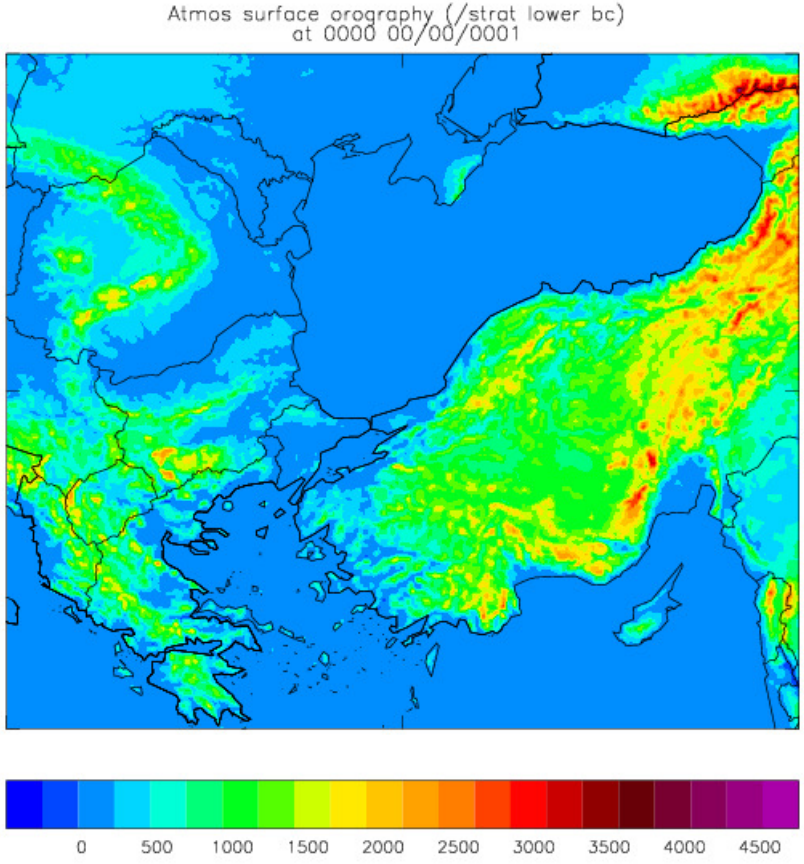
# Verification of corrected 4km model



# New domains 4km ( 2001-2010)



# Summary of results – 14 locations

## Δx=100m

| | VMM | Linear regression | Directional linear regression | Directional linear regression, zero intercept |
|---|---|---|---|---|
| Mean \|bias\| | 1.05 | 0.83 | 0.80 | 0.87 |
| St. dev \|bias\| | 0.60 | 0.61 | 0.61 | 0.77 |
| Mean bias | 0.054 | -0.017 | -0.045 | -0.20 |
| St. dev bias | 1.26 | 1.03 | 1.18 | 1.15 |

## Δx=333m

| | VMM | Linear regression | Directional linear regression | Directional linear regression, zero intercept |
|---|---|---|---|---|
| Mean \|bias\| | 1.05 | 0.87 | 0.84 | 0.90 |
| St. dev \|bias\| | 0.60 | 0.62 | 0.63 | 0.78 |
| Mean bias | 0.054 | -0.11 | -0.05 | -0.19 |
| St. dev bias | 1.26 | 1.07 | 1.05 | 1.18 |