Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Meteorologisk institutt

Met Office

State of the art of wind forecasting and planned improvements for NWP

Helmut Frank (DWD), Malte Müllller (met.no), Clive Wilson (UKMO)

thanks to S. Bauernschubert, U. Blahak, S. Declair, A. Röpnack, C. Schraff, A. Steiner

Wind power forecast errors

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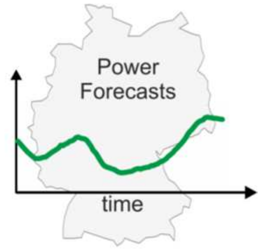
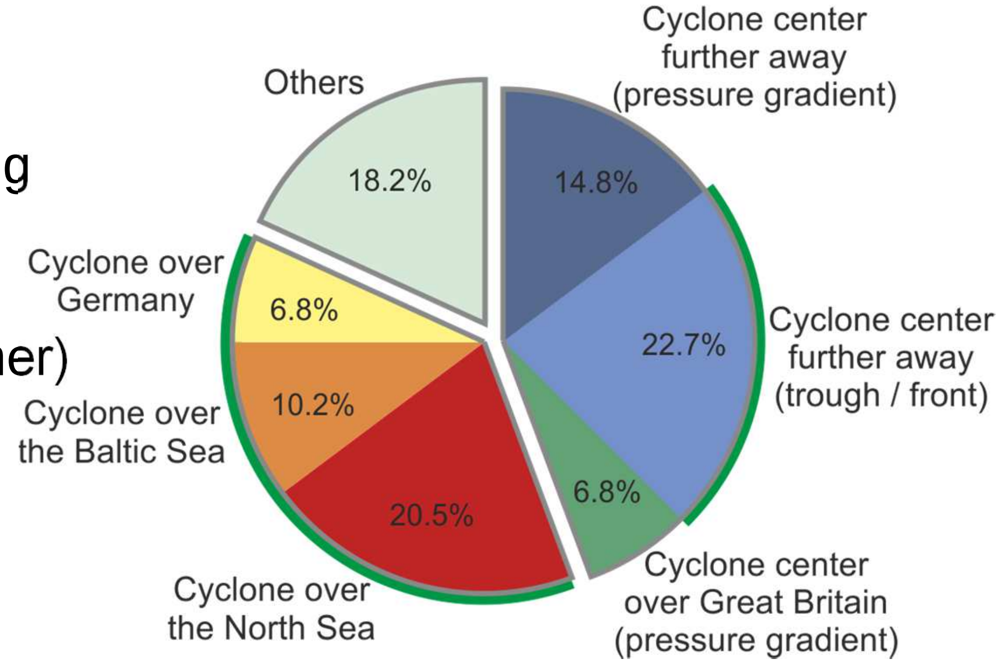
- ➔ 100 days with largest day-ahead power forecast errors (IWES):
  - 2012 – 2014: Summed, absolute wind errors within 6h-moving window
- ➔ Error analysis and correlation with underlying weather



Most critical

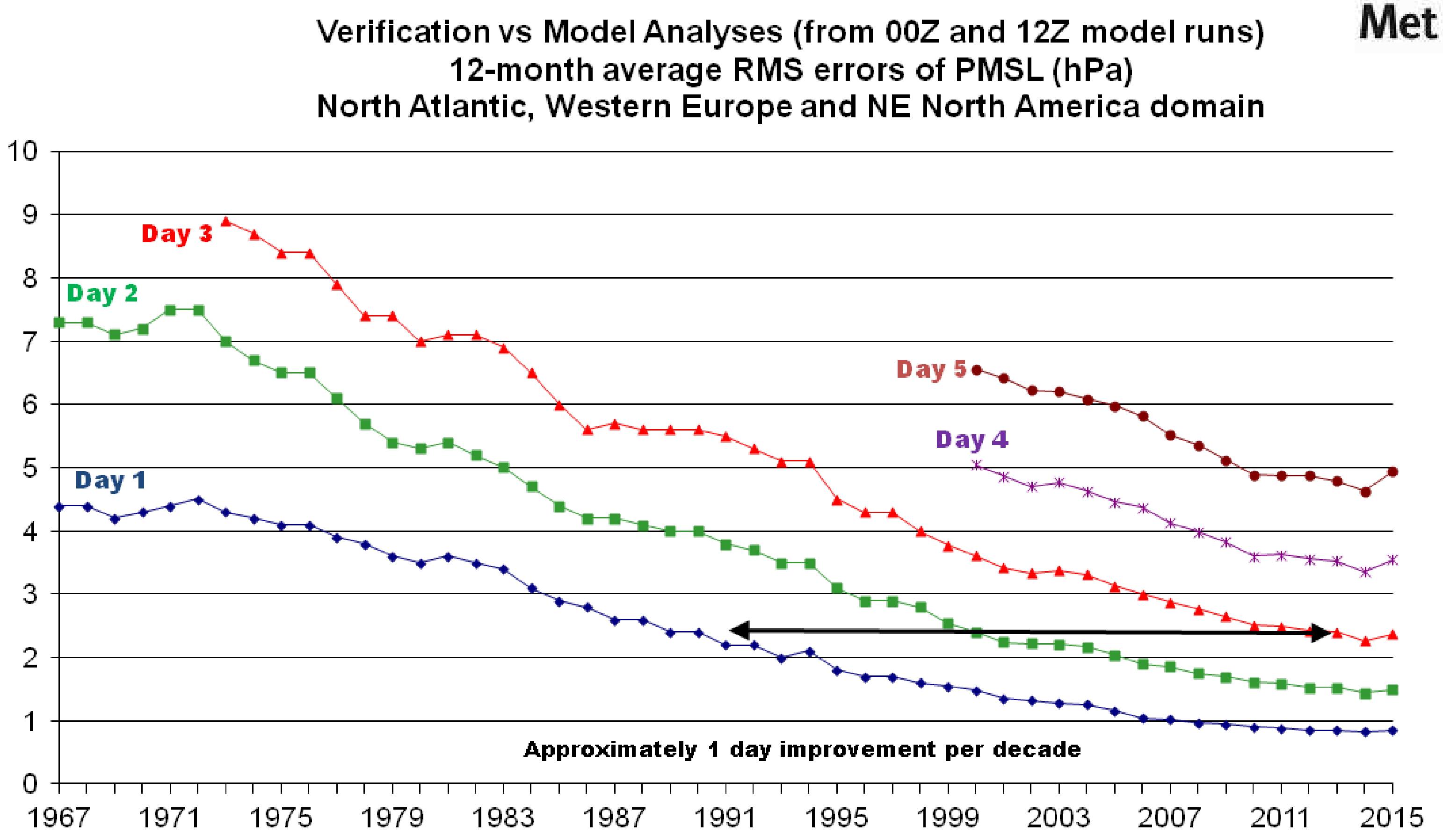
- Frontal passage: Position, Timing
- Stable stratification (winter)
- Daily cycle, low level jets (summer)



Outline

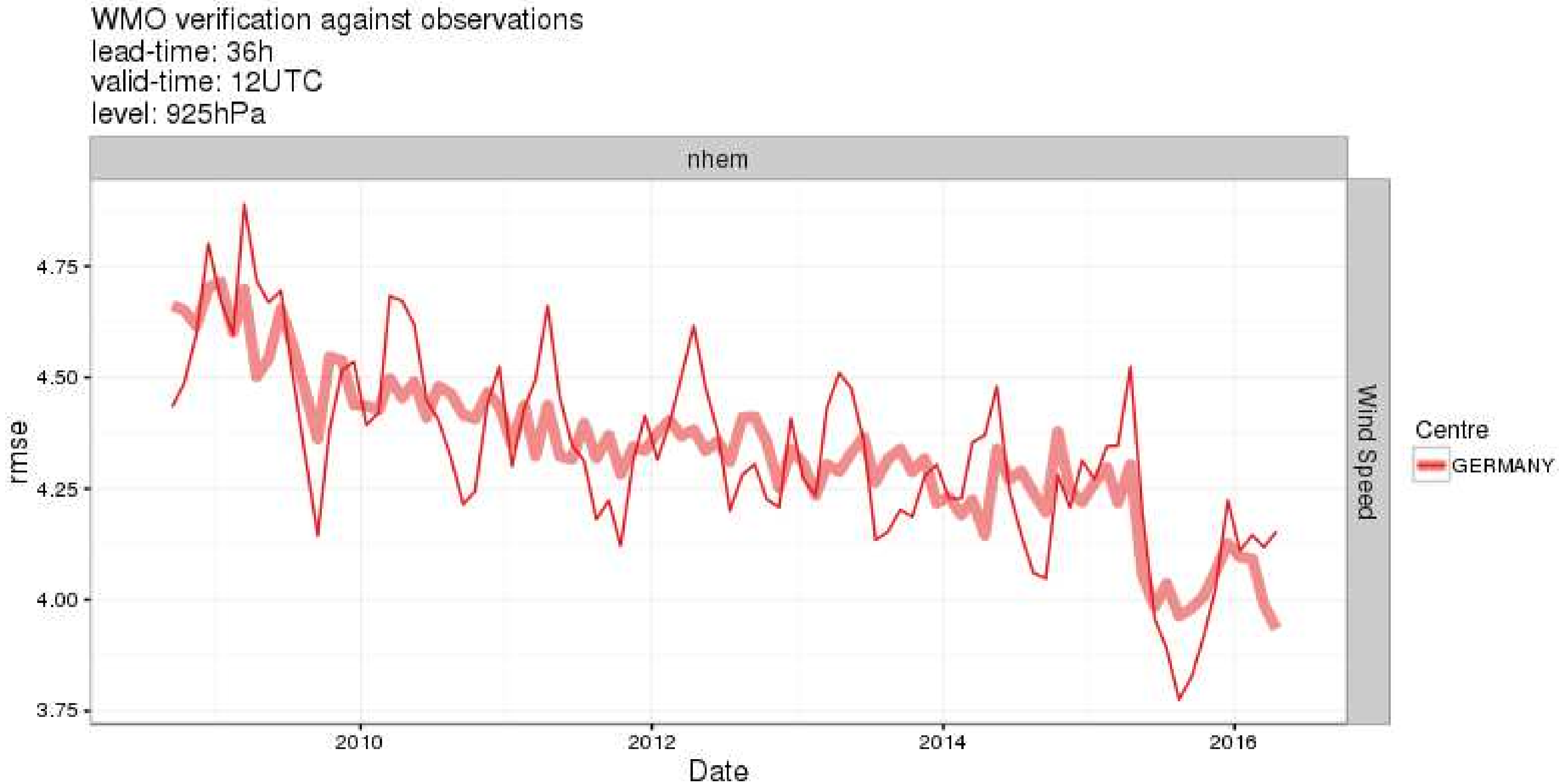
- Where are we?
  - Trend of wind forecast errors
  - Resolution increases: Non-hydrostatic, convection permitting
  - Data assimilation
- Model physics
  Turbulence and boundary layer modeling
- Ensemble prediction, calibration, MOS
- Ensemble data assimilation
- New observations: LIDAR, RADAR, GNSS Slant Total Delay
- Wind power in NWP models:
  - Assimilation of power data
  - Offshore wind farms in NWP models
- Summary

Trend of model improvement



Where are we?

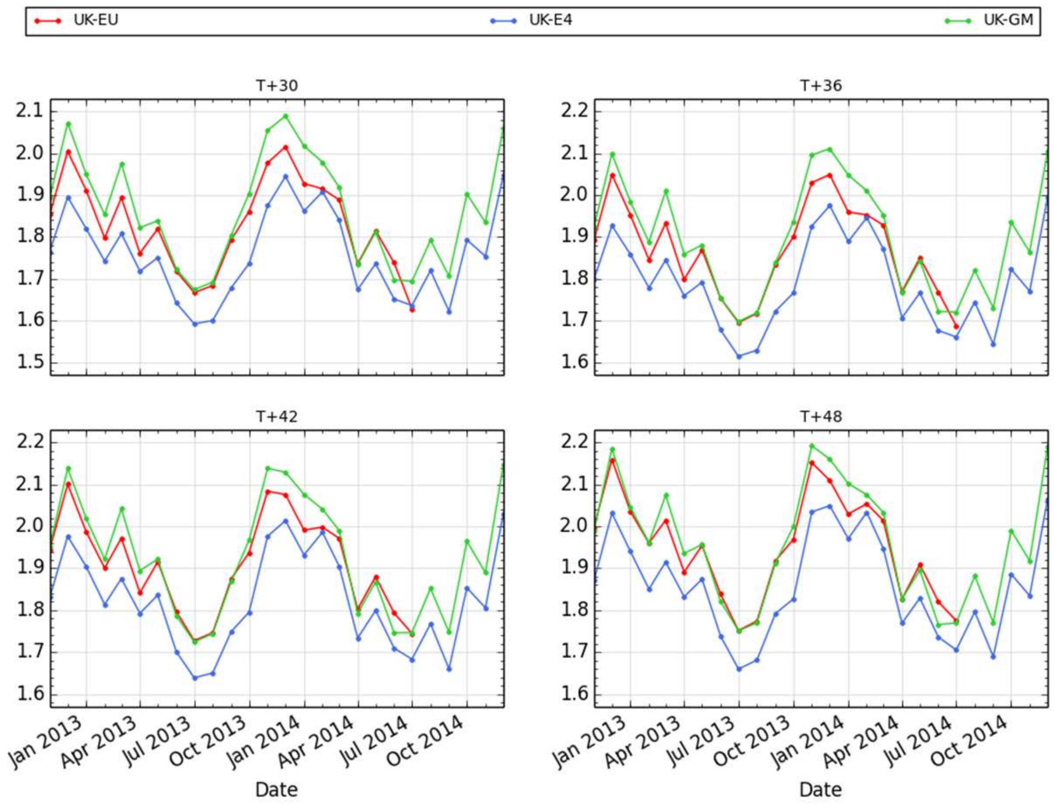
Wind speed at 925 hPa in Northern Hemisphere: GME, ICON



GME ICON

Limited area high resolution models v Global, 25km, 12km, 1.5km resolution – surface wind errors

Surface (10m) Wind Speed (m/s), Root Mean Square Error (Forecast - Observations), Combined stations, Surface Obs



Observations used by ICON (2016-05-19 00 UTC)

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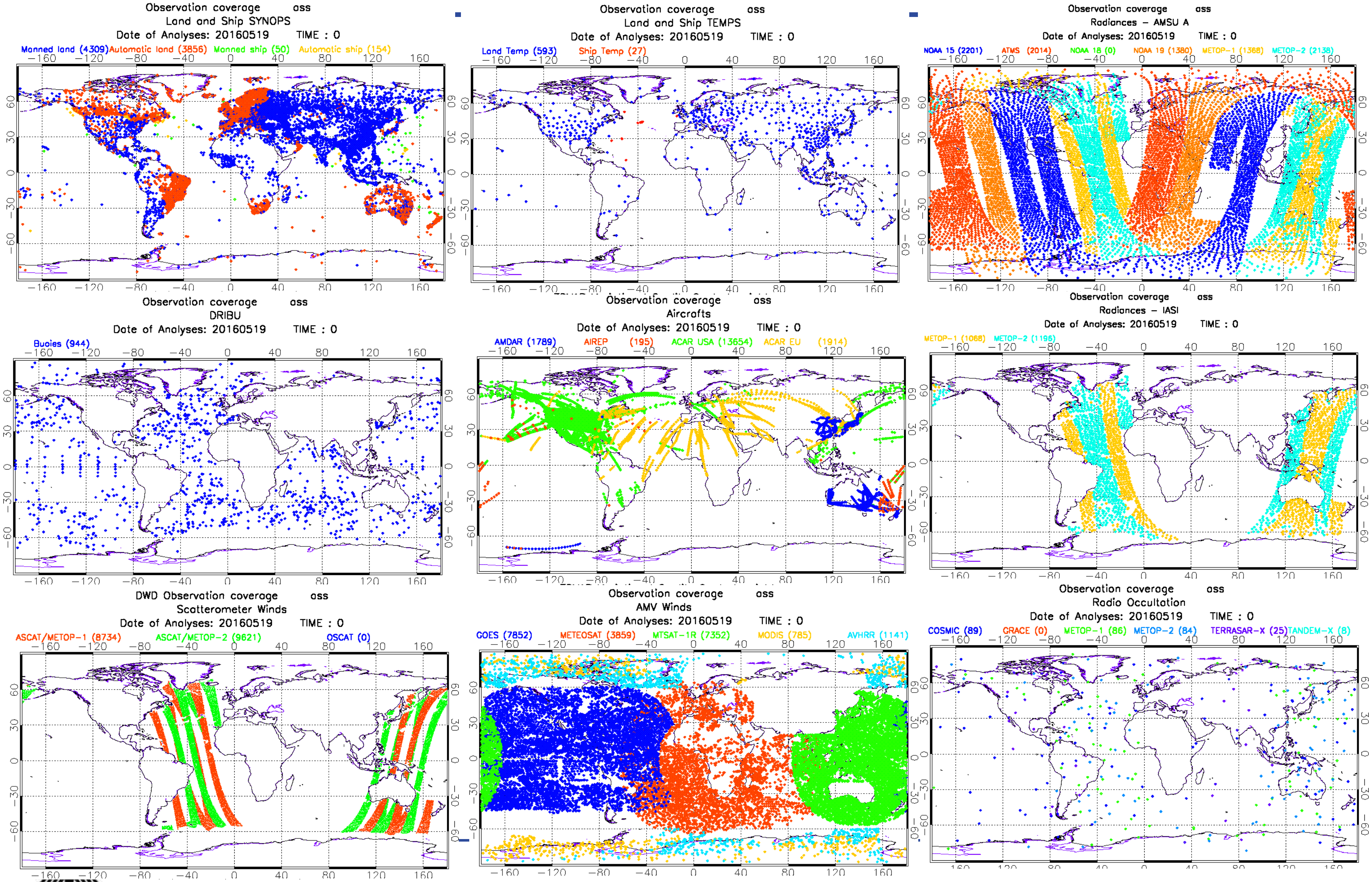
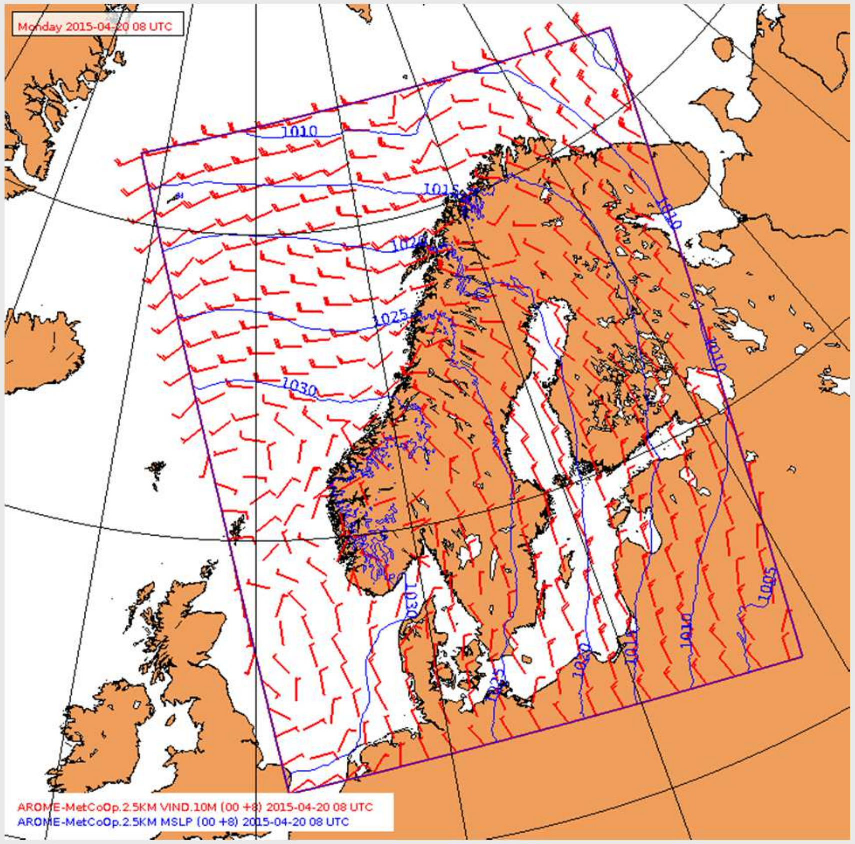


Not schown: HIRS

AROME MetCoOp

- Operational numerical weather prediction model – AROME-MetCoOp
- 2.5 km horizontal resolution
  65 layer in the vertical
- 66 hour forecasts every six hours
  (update cycle 3 hours)
- Boundaries are from ECMWF forecasts 3 - 6 hours old
- Initial conditions for each forecast is computed by including observations «3DVar - data assimilation»
- Forecasts are distributed by an efficient distribution server



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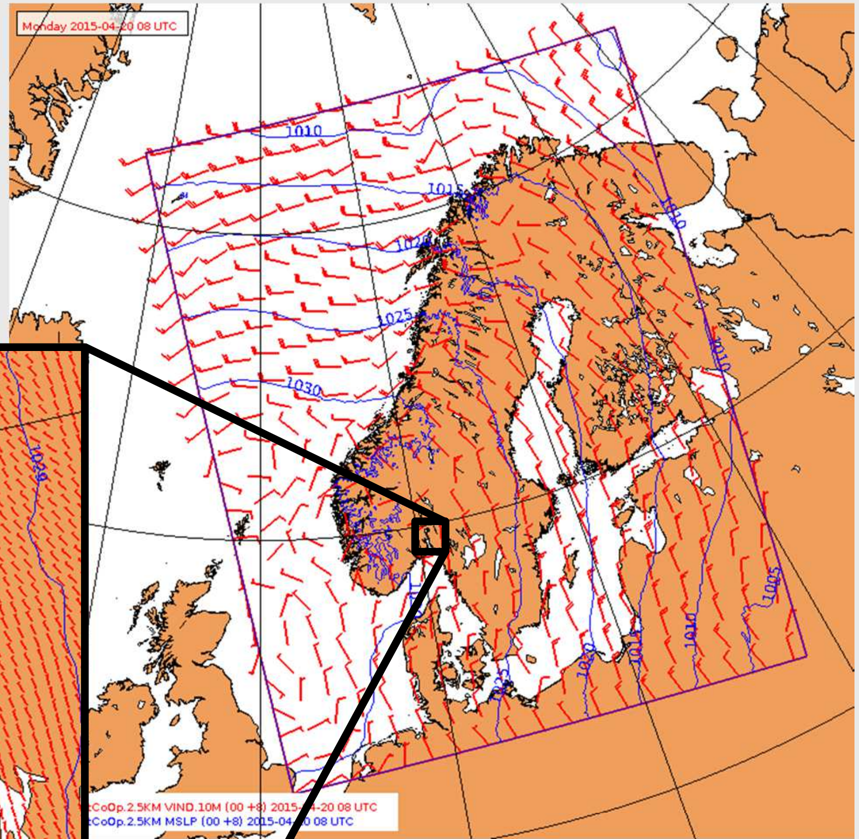

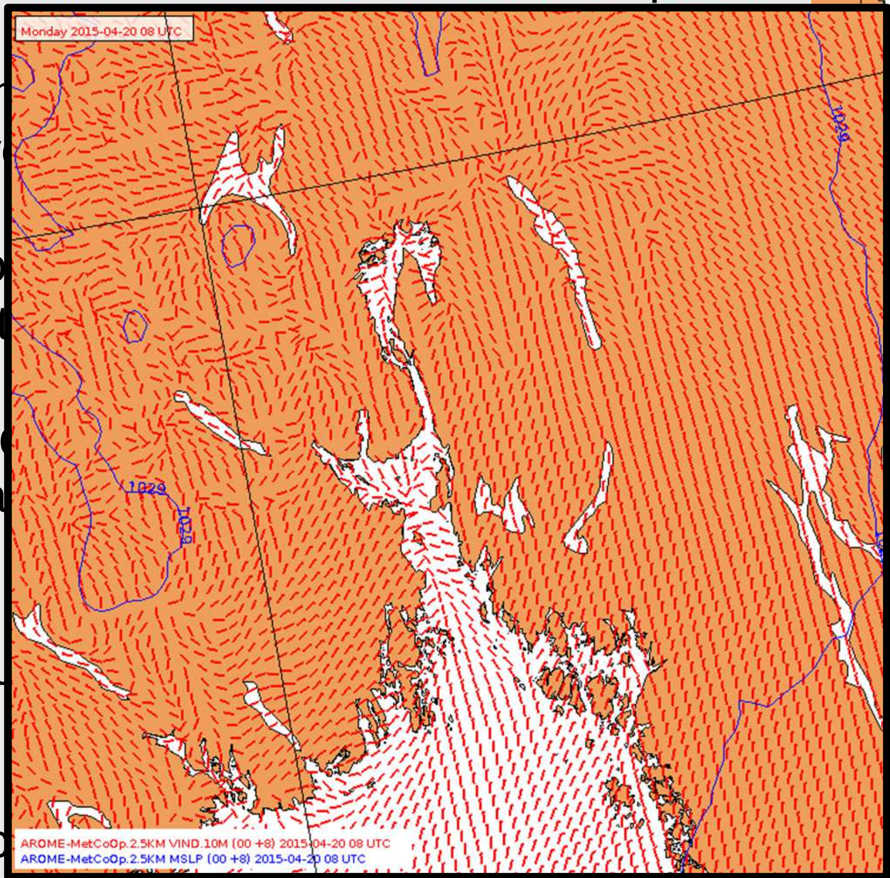

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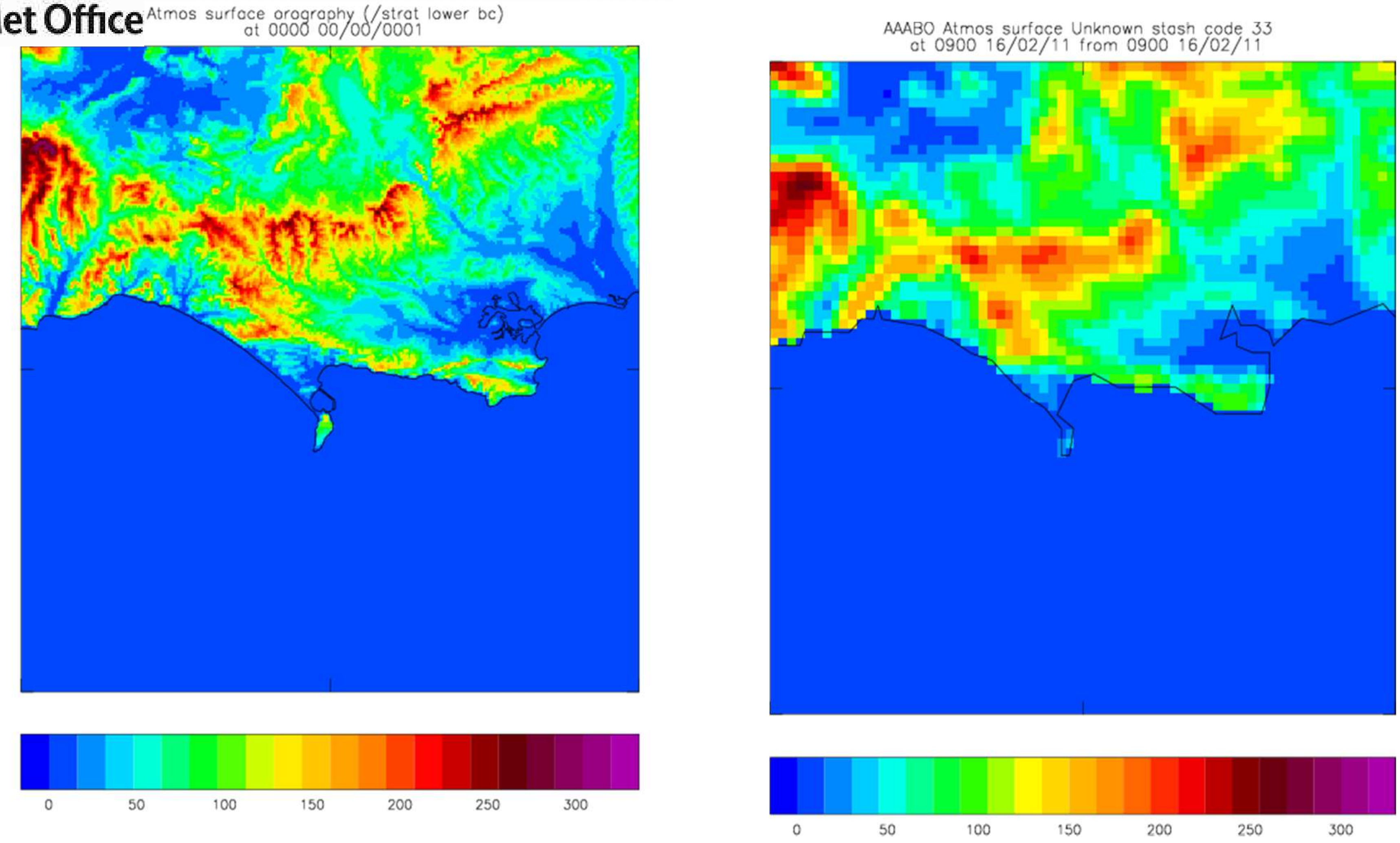
Resolution of some operational NWP models:

Global models	Mesh width [km]	Regional models	Mesh width [km]
IFS (ECMWF)	9		
ICON (DWD)	13	COSMO-DE	2.8
GFS (NCEP)	13	HIRESW	3.4
UM Global (UKMO)	17	UKV	1.5
ARPEGE (MF)	16	AROME	1.3
MetCoOp (met.no, SMHI)		AROME	2.5

Horizontal resolutions is increasing with improved realism of detailed forecasts. However this does come with the associated “double penalty” problem of small location errors of more intense features verifying worse than smoother lower resolution fields.

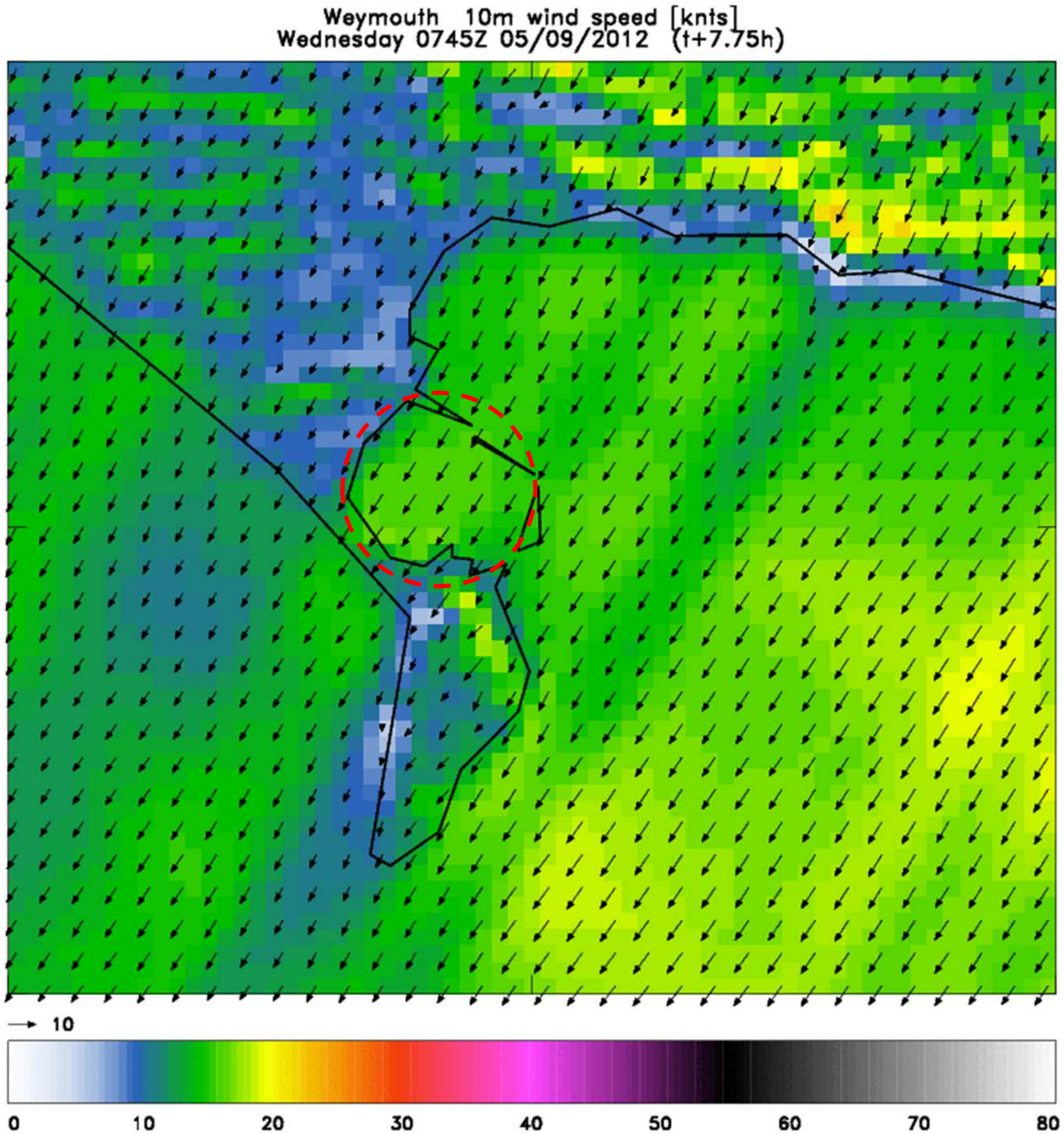
330m research model Orography



Weymouth 333m – UKV 1.5km

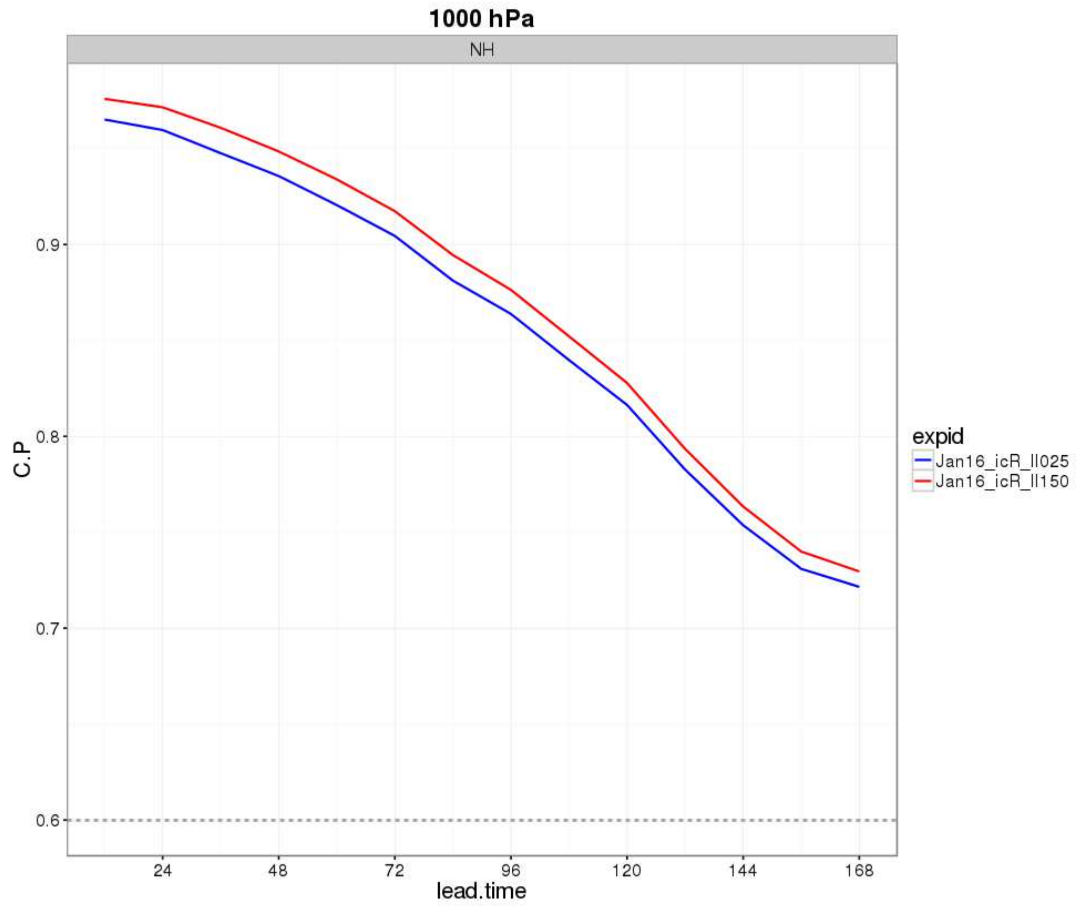
5 Sept

Variable winds



Anomaly correlation of U at 1000 hPa January 2016

Lower resolution yields smoother fields and better score!

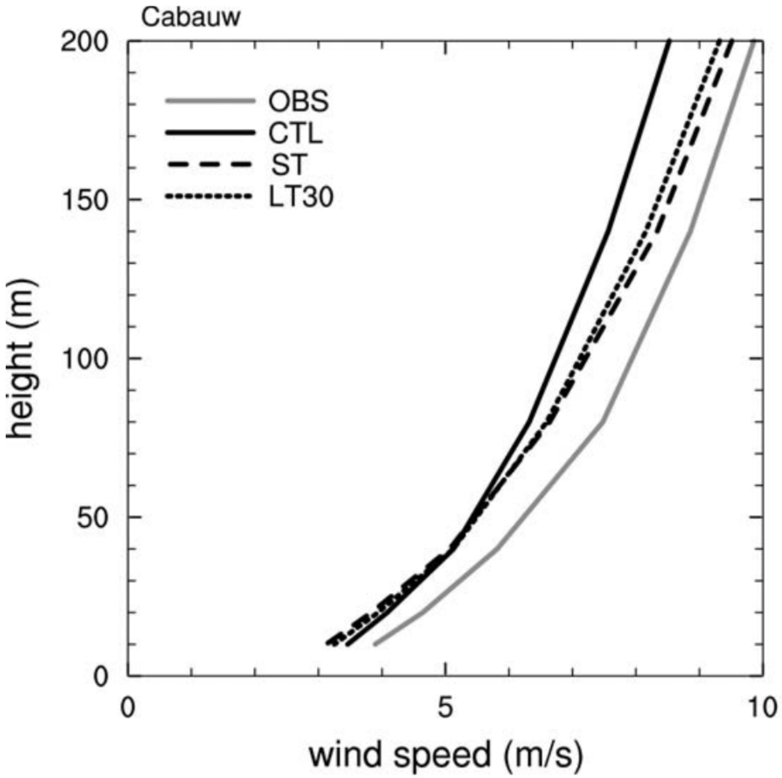


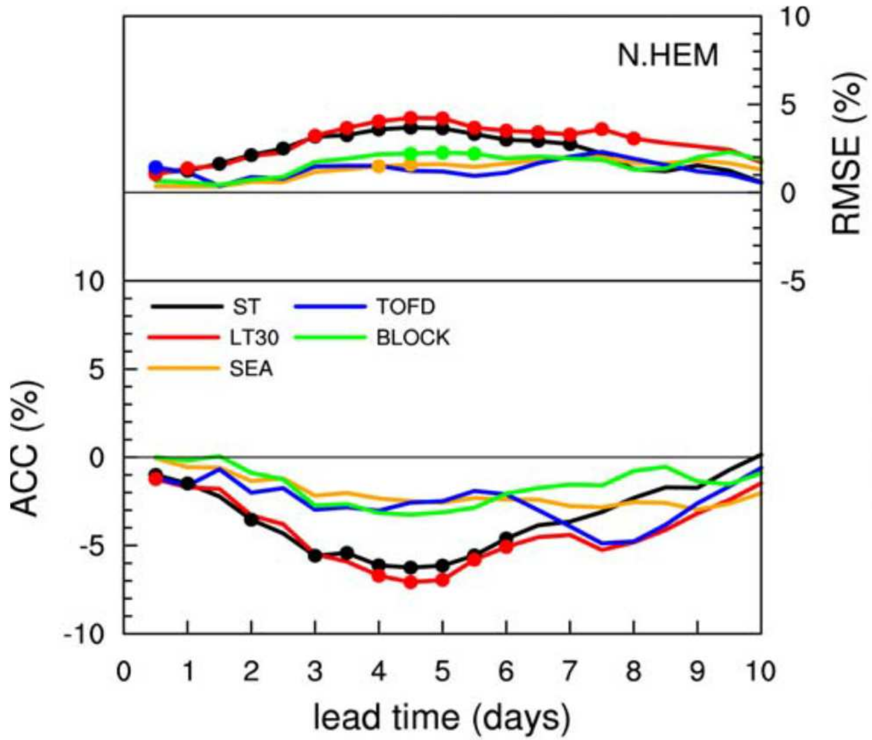
Regular Grid
1.50°
0.25°

Model physics: Improve wind without deteriorating other weather parameters

Sandu et al. (J. Adv. Mod. E. Sys. 2013)

IFS January 2011 modified turbulence scheme





Boundary layer wind improved, but forecast anomaly correlation and RMSE of 500 hPa geopotential became worse.
Vertical diffusion in stable conditions changed in combination with surface drag and heat exchange between land surface and atmosphere in cycle 40r1 in November 2013.

Modeling: Turbulence, Low-level jets

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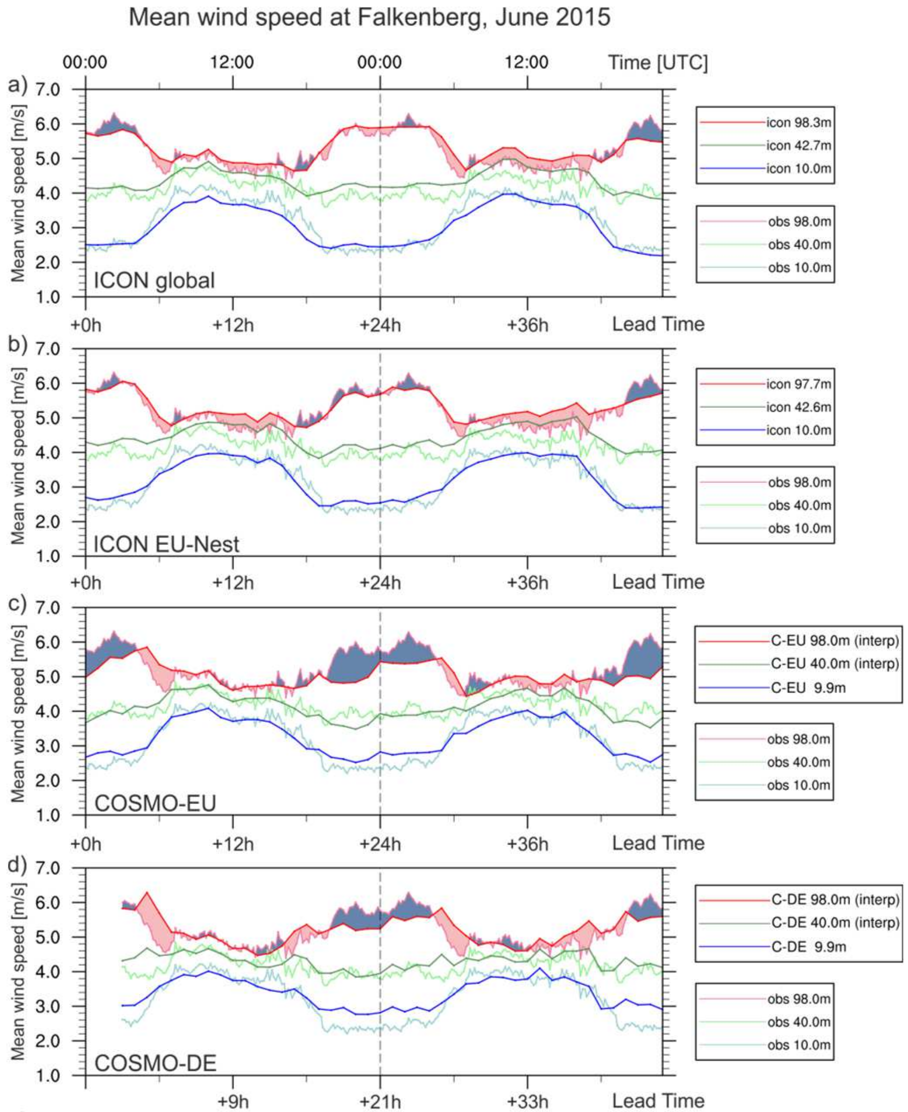
ICON global

ICON-EU

COSMO-EU

COSMO-DE

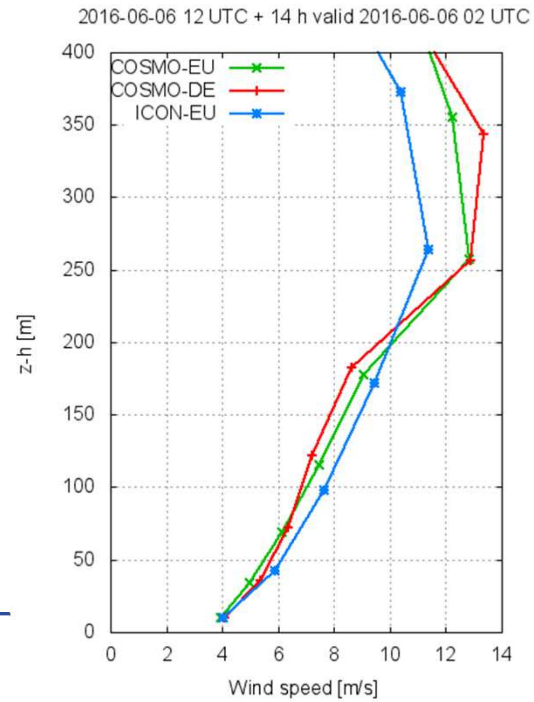


98 m

43 m (40m)

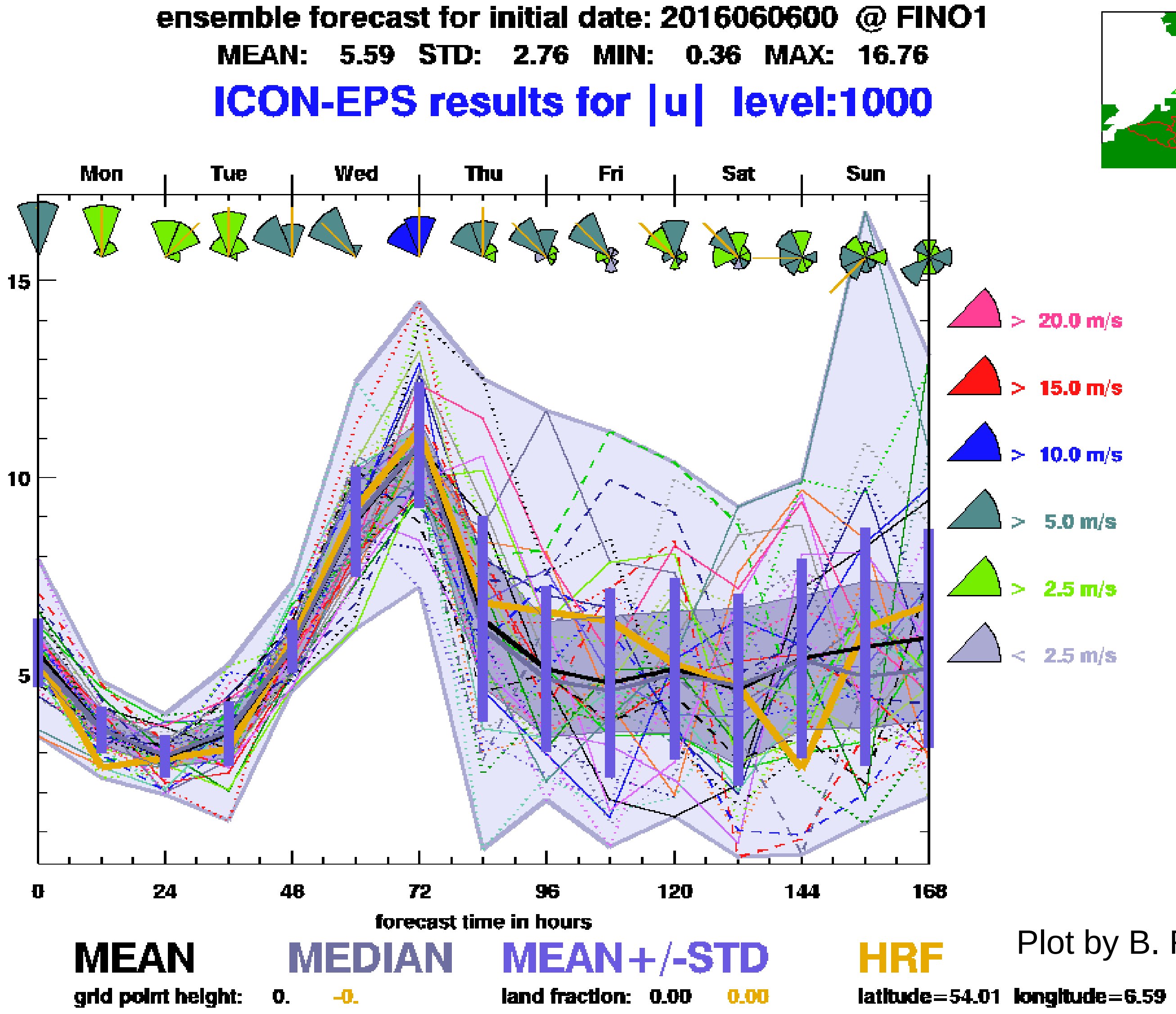
10 m

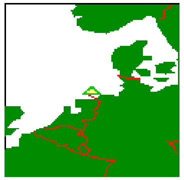
Higher vertical resolution does not necessarily mean better wind profiles



Ensemble prediction

- Ensemble generation
- Ensemble perturbation
- Boundary model for limited area models



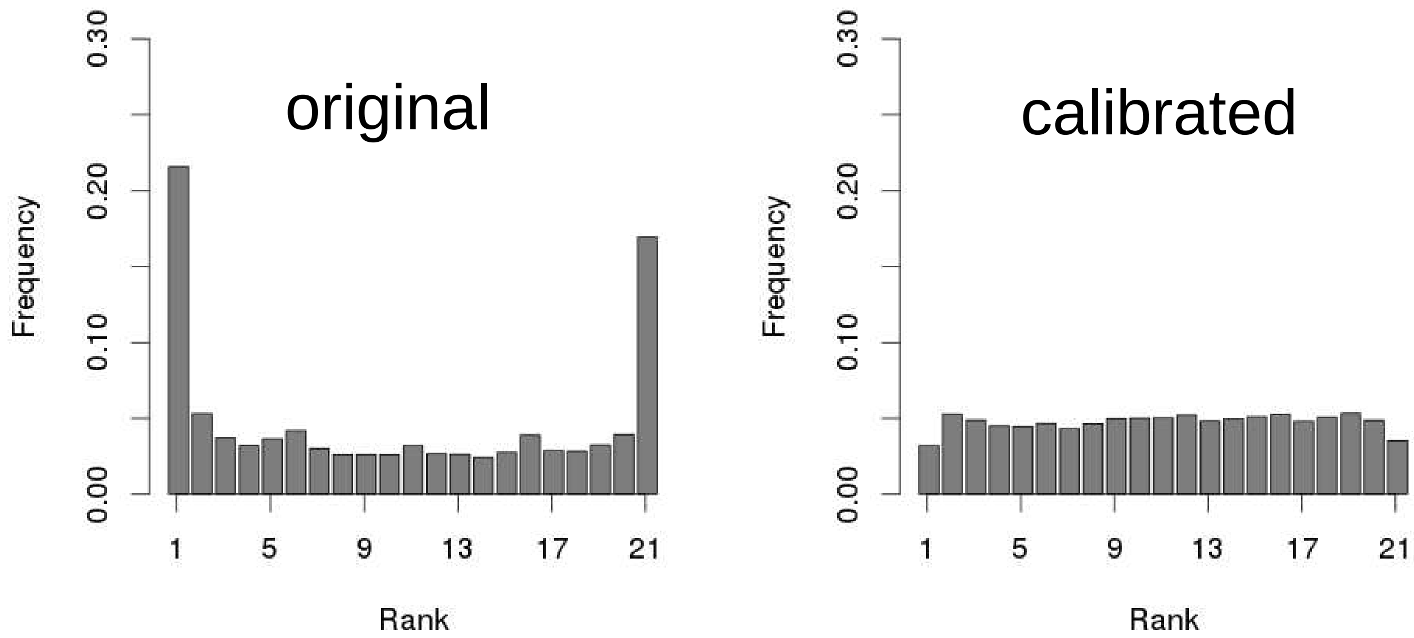


Plot by B. Ritter

Statistical postprocessing: Calibration, MOS, …

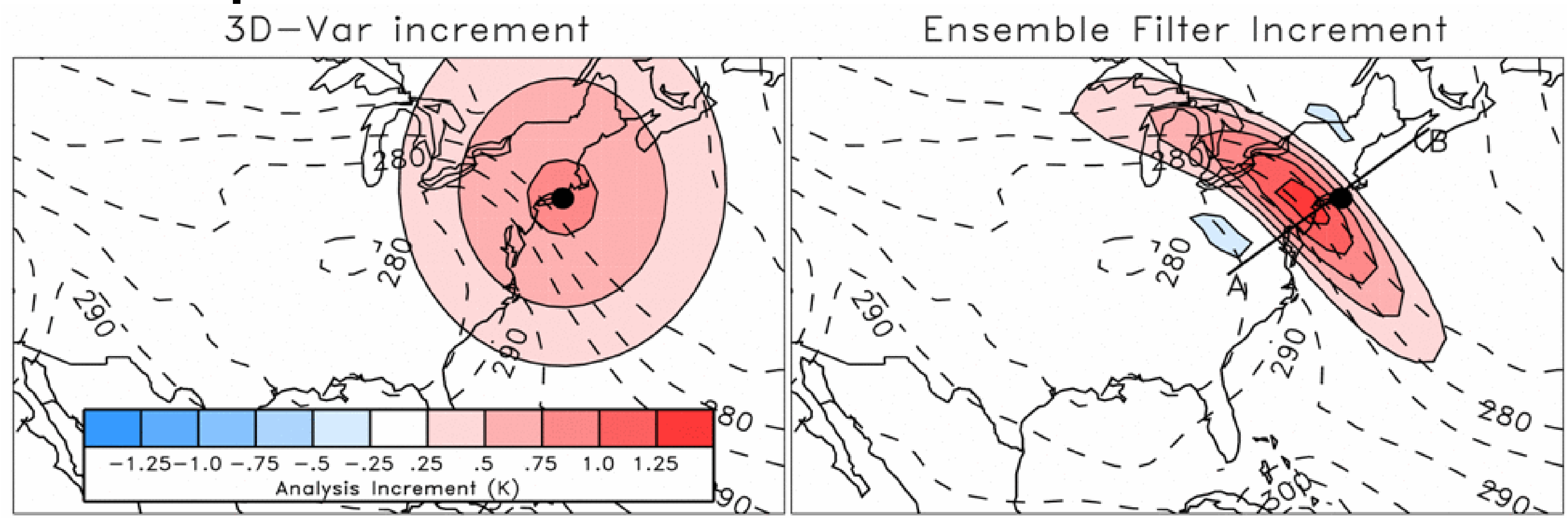
COSMO-DE-EPS: Quantil Regression

➔ **100m-Wind**



JJA 2014: 03 UTC

Improved analysis / forecast quality by use of **multi-variate, flow-dependent error covariances**



Whitaker et al. 2005

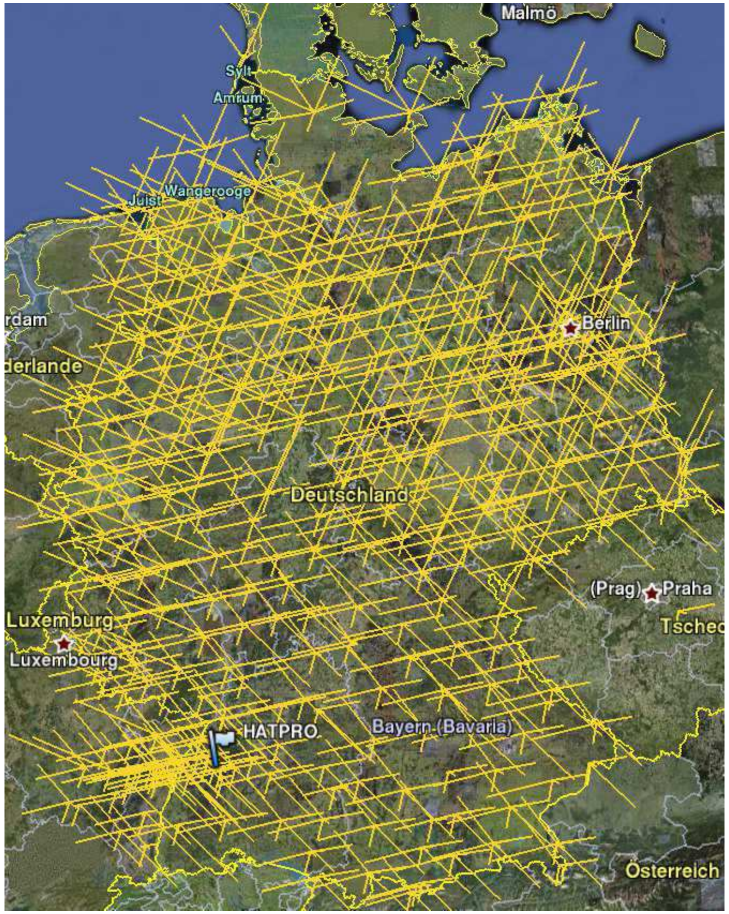
- Observations causes analysis increments over frontal area
- Advantage especially in frontal areas and on convective scales where **error covariances** are strongly **flow dependent**

New observation systems

GNSS Slant Total Delay (STD): Humidity integrated over path from ground station to GNSS (GPS) satellite, all weather obs

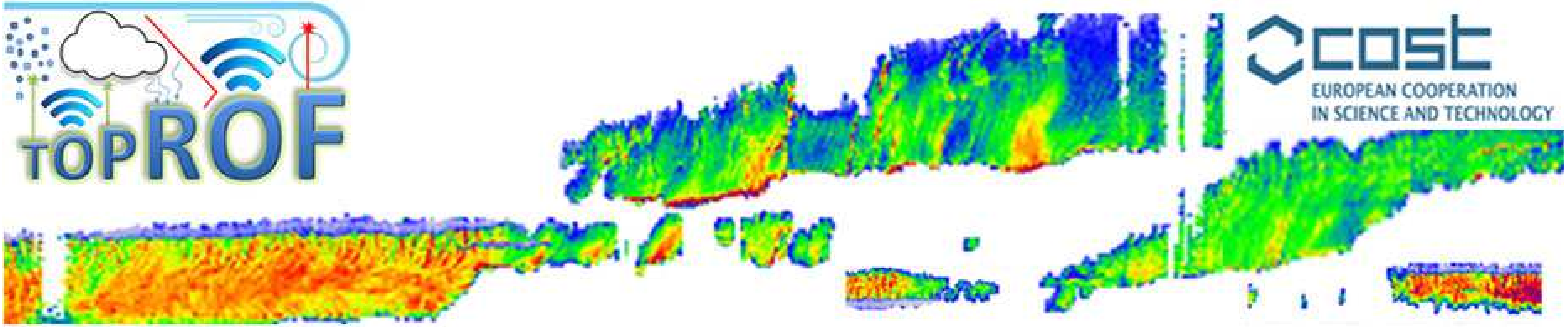
45 GPS obs. from 1 station/ 9 satellites in 15 min
Elevations angles 90° - 5°.

- Many stations → 3-D information on humidity
- At 5° (7°), path reaches height of 10 km at ~ 100 (80) km distance
- vert. + horiz. non-local obs (not point measurements)



by M. Bender (DWD)

New observations systems



TOPROF (COST Action ES1303):

Towards operational ground based profiling with ceilometers, doppler lidars and microwave radiometers for improving weather forecasts

Developing three instruments available throughout Europe:

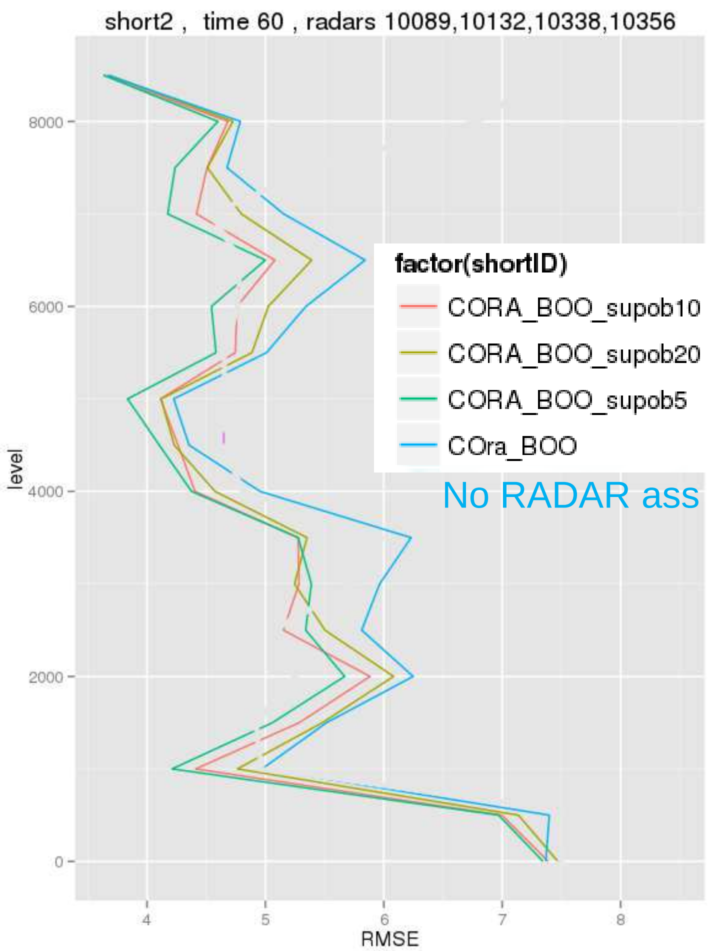
i. Several 100 **Ceilometers** providing backscatter profiles of aerosol and cloud properties with 30m vertical resolution every minute

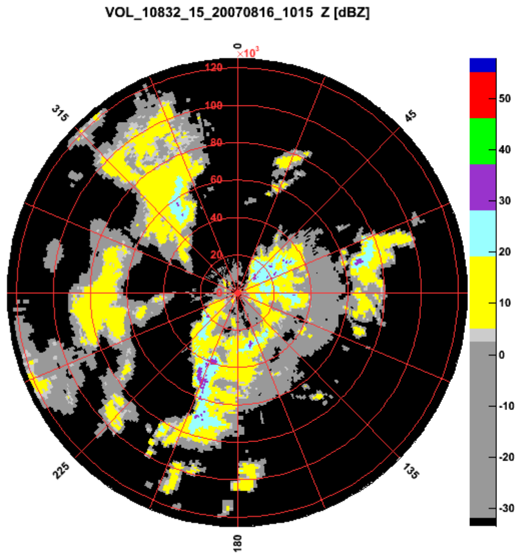
ii. >20 **Doppler lidars**, providing vertical and horizontal winds in the lower atmosphere with a resolution of 30m every 5 minutes

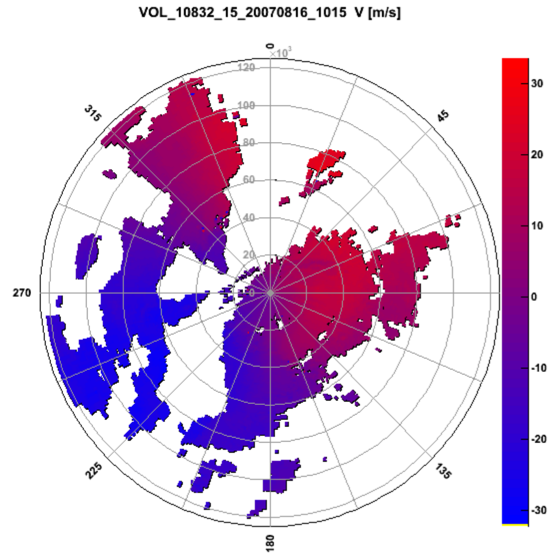
iii. ~30 **Microwave profilers** giving profiles of temperature and humidity in the lowest few km every 10 minutes.

http://www.toprof.imaa.cnr.it/index.php

RADAR: 3-D reflectivity, 3-D radial velocity







Assimilation of 1 RADAR and verification at 4 RADARs

E. Bauernschubert (DWD)

NowWind - Nowcasting for windenergy production

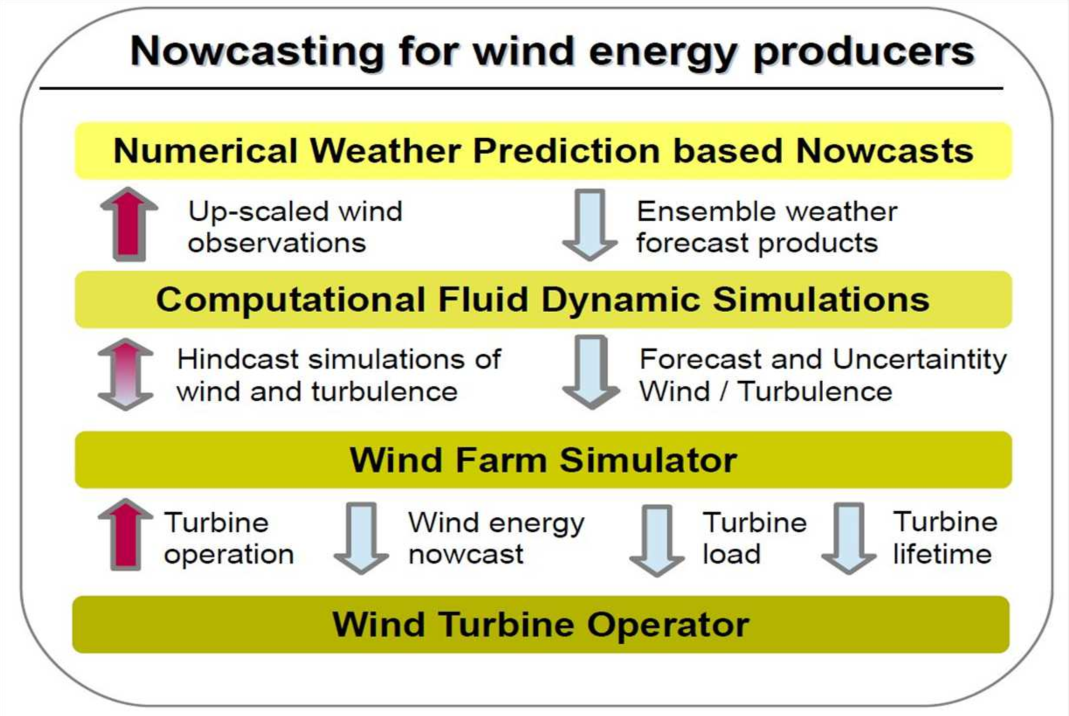
Innovation project (2016-2019)

Kjeller Vindteknikk, Norwegian Meteorological Institute, WindSim, Vestas Windsystems & TrønderEnergi Kraft

Objective: To develop an integrated nowcasting approach by coupling numerical weather prediction, computation fluid dynamics, and wind farm simulator systems in order to deliver forecast and uncertainty products tailored towards optimized economical decision making.

Innovation:

- Novel Nowcast Model System with assimilation of new wind observations
- Integration of forecasts with an operational perspective
- Improved dynamic turbine control
- Advanced opportunities for trading



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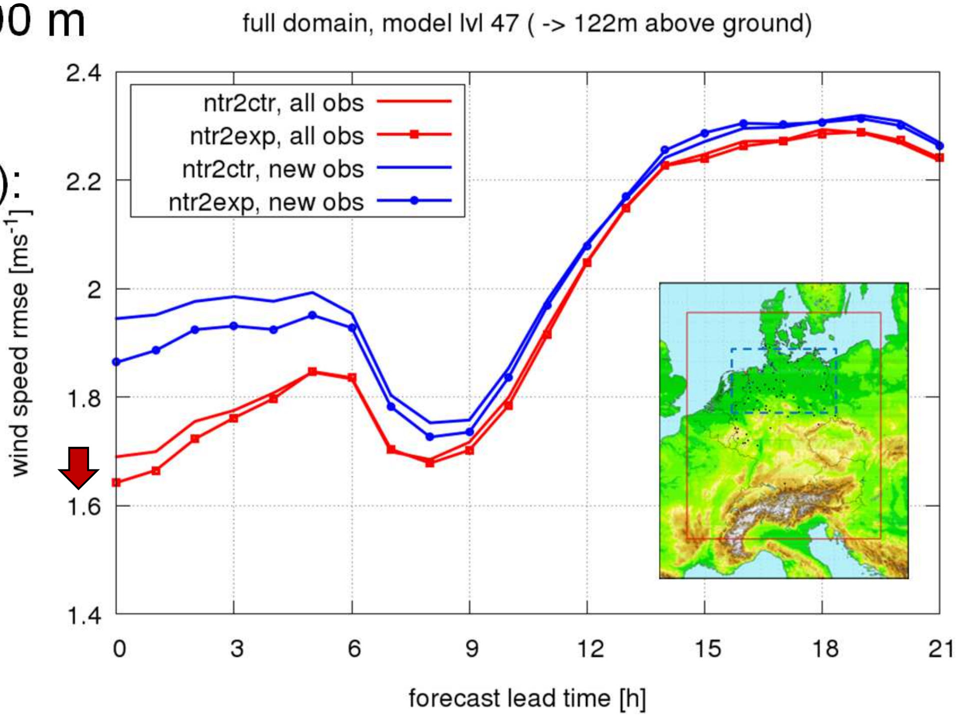
Assimilation of power (wind, solar)

OSSE (Observation System Simulation Experiment) by S. Declair (EWeLiNE):
Assimilation of artificial wind data at 100 m



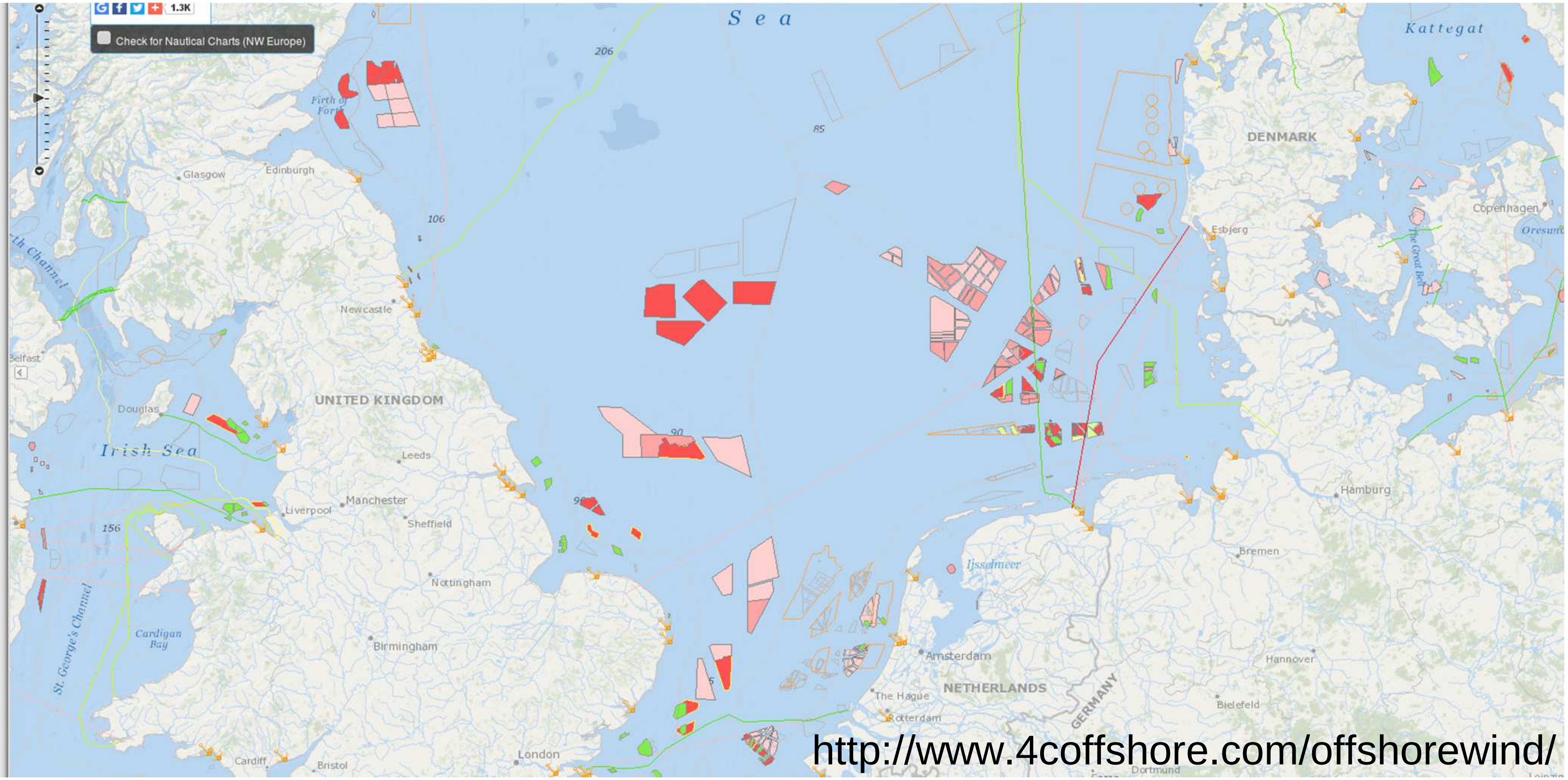
Cannot be used currently (in Germany):

- ➔ Up-to-date data not available
- ➔ Poor quality of data and meta data

Assimilation of solar power data more promissing because of more available data

Wind farms in NWP models?

Existing and planned wind farms in the North Sea



http://www.4coffshore.com/offshorewind/

Wind farms affect the flow in the boundary layer. There influence depends on many parameters and is constantly changing.

Summary and outlook

- Numerical weather prediction is constantly improving
- km-scale forecasts are made though they face the problem of small location errors
- Use ensemble precditions
- Better physics improves winds in boundary layer
- New observations and new assimilation methods improve initial condition and forecasts. Good quality control of observations is essential.
- Seamless prediction from nowcasting, short-range and medium-range to seasonal and climate prediction

- Will it be possible to assimilate power data?
- When will wind farms be included in NWP models - as momentum sinks?

- “New” output variables, e.g. wind in ~100m height (e.g. from *thredds.met.no, ECMWF)*