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

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thanks to S. Bauernschubert, U. Blahak, S. Declair, A. Röpnack, C. Schraff, A. Steiner
Wind power forecast errors

- 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

Verification vs Model Analyses (from 00Z and 12Z model runs)
12-month average RMS errors of PMSL (hPa)
North Atlantic, Western Europe and NE North America domain

Approximately 1 day improvement per decade
Wind speed at 925 hPa in Northern Hemisphere: GME, ICON

WMO verification against observations
lead-time: 36h
valid-time: 12UTC
level: 925hPa
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)

Not shown: 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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AROME MetCoOp
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.

### Where are we?

#### Resolution of some operational NWP models:

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<tr>
<th>Global models</th>
<th>Mesh width [km]</th>
<th>Regional models</th>
<th>Mesh width [km]</th>
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<td>IFS (ECMWF)</td>
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<tr>
<td>MetCoOp (met.no, SMHI)</td>
<td></td>
<td>AROME</td>
<td>2.5</td>
</tr>
</tbody>
</table>
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!
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

Higher vertical resolution does not necessarily mean better wind profiles

ICON global

ICON-EU

COSMO-EU

COSMO-DE

98 m
43 m (40m)
10 m
Ensemble prediction

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

ensemble forecast for initial date: 2016060600 @ FINO1

MEAN: 5.59  STD: 2.76  MIN: 0.36  MAX: 16.76

ICON-EPS results for |u| level:1000

Plot by B. Ritter

MEAN
MEDIAN
MEAN+/-STD

grid point height: 0.00
land fraction: 0.00 0.00

HRF
latitude=54.01 longitude=6.59
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

- Observations cause 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)*
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
New observations systems

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

Assimilation of 1 RADAR and verification at 4 RADARs

E. Bauernschubert (DWD)
NowWind - Nowcasting for wind energy 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
New observation systems

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 promising because of more available data
Wind farms affect the flow in the boundary layer. Their 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 predictions
- 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)