Overview of the Role of Ground-Based Remote Sensing during the Second Wind Forecast Improvement Project (WFIP2)

(Using observations to improve NWP model forecast skill)

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WFIP2 Study Area

Mt Rainier (4392 m)
Mt Adams (3743 m)
Columbia River Gorge
Mt Hood (3429 m)

Cold pools
Gap flows
Mountain waves
Multi-Scale Observations

- 11 wind profiling radars
- 17 sodars
- 5 wind profiling lidars
- 5 scanning lidars
- 4 microwave radiometers
- 10 microbarographs
- 1 Ceilometer
- 28 sonic anemometers
- 5 radiative flux systems
- 4 soil moisture sites
- ~200 radiosonde launches
- Wind plant data from 14 wind plants (1,569 turbines)

Field Campaign:
All 4 seasons
Oct 2015 - March 2017
(18 months)
WFIP 2 Instrumentation

Scanning lidar
Met Station
Ceilometer
GPS
MWR
Profiling lidar
915 MHz WPR RASS
Surf Rad
Sodar

Doppler lidar
Met Station
Microwave Radiometer
S-Band
915-MHz Wind Profiling Radar
RASS
Model Development within RAP and HRRR (WRF-ARW based)

RAP & HRRR 24x/day
HRRR Nest 2x/day
Model improvement process

Obs + Real time forecasts

Forecast busts (large errors)
Extreme events
Model Biases

Obs: Process-based case studies

Model case studies:
LES
1D single column
3D WFIP2 region
3D other regions

Trial parameterizations

Obs evaluation

Reforecasts:
Four 6-week blocks
cntl & exp 00&12Z, to 24h

Obs verification
Model improvement process

**Observations + Real time forecasts**

*Forecast busts (large errors)*
*Extreme events*
*Model Biases*

**Obs:** Process-based case studies

**Trial parameterizations**

**Model case studies:**
- LES
- 1D single column
- 3D WFIP2 region
- 3D other regions

**Obs evaluation**

**Reforecasts:**
- Four 6-week blocks:
  - cntl & exp 00&12Z, to 24h

**Obs verification**
Model Parameterization Development

• **Eddy diffusivity**: implemented a z-less formulation of mixing length (maintains cold pools better)

• **Mass-Flux scheme** added to the MYNN PBL scheme (allowing for a direct coupling of the subcloud convective cores and the cloud layer above)

• **Subgrid-scale (SGS) clouds** and coupling to radiation (improves the downward shortwave forcing in shallow-cumulus and stratocumulus conditions)

• **Surface drag** due to gravity waves and form drag from SGS topography (reduces wind speed bias)

• **Surface layer** scalar flux algorithm (improvements to near-surface temperatures over snow)

• **Horizontal finite differencing** in Cartesian space instead of sigma coordinates (reduces artificial diffusion in steep terrain)
Cold Pools

Models have a large wintertime positive speed bias

Aggregated equivalent wind power over 22 sodar/lidar sites
Cold Pool Mix-Out of 13 January 2016 – Sodar

Sodar (barbs+speed)
Wasco, Oregon

3-km HRRR

750m Nest

Control

New
MYNN
+Hor Diff
+GWD
Recurrent diurnal gap flows due to sea-breeze forcing

Averaged equivalent wind power over 22 sodar/lidar sites
15 min GOES satellite estimates of periodicity
Mountain Waves: Model view

- Waves can be seen propagating upstream to the west
- $\Delta U \sim 3\text{m/s}$ peak-trough matches sodar data
- WFIP2 provides first proof that mountain waves do in fact affect wind energy production
Forecast Improvement Skill (80m winds)

10 year average improvement RMSE
12h 850 mb vector winds:
NAM: 0.7% per year
GFS: 0.4% per year
Forecast Improvement Skill (Radar wind profiler wind speed)

MAE improvement

- +0.5 m/s
- 0 m/s
- -0.5 m/s

**Spring**
- Sunset
- Sunrise

**Summer**
- Sunset
- Sunrise

**Fall**
- Sunset
- Sunrise

**Winter**
- Sunset
- Sunrise
WFIP2 CONCLUSIONS

• WFIP2 has demonstrated the importance of lower tropospheric profiling observations for improving model forecast skill
  • Identify model problems
  • Understand physical processes/suggest parameterization improvements
  • Evaluate candidate model parameterization additions and revisions in an iterative process
  • Verify final set of new parameterizations
• Having instruments measuring different atmospheric parameters was essential to understand the physical processes causing model forecast errors.
Forecast Improvement Skill (PBL temperatures)

MAE improvement

SPRING

SUMMER

FALL

WINTER
Normal VAD technique
New technique – maximum of the function of accumulated spectra (MFAS)

- Work in Doppler spectrum domain
- Shift spectra with respect to azimuth direction $\Theta$, multiplying spectra by $\sin(\delta \Theta)$
- Spectra accumulate and the peak is more pronounced compared to noise
- Increase in sensitivity is $\propto \sqrt{N}$

Banakh et al. (2001)
Smalikho, 2003
Wind profile comparison

Standard VAD speed [m s$^{-1}$]

Enhanced VAD speed [m s$^{-1}$]

Height: 0 - 1000  Wind m: 0.97  b: 0.07  N: 31612  Corr Coef: 0.98  mean Diff: 0.21 m/s

Shifter speed

VAD speed [m s$^{-1}$]

Standard VAD direction

Enhanced VAD direction

Height: 0 - 1000  Dir m: 1.00  b: 0.62  N: 30003  Corr Coef: 1.00  mean Diff: -0.05°

Shifter direction

VAD direction
1. Mixed-Layer Height (MLH) comparison:

- Comparison eliminates days when either instrument had missing data, or MLH could not be estimated due to rain/virga, low clouds, low SNR.
- Mean values and standard deviation of the binned data are plotted.
Model – Obs Evaluation Webpage:

- Compares observations with models
- Used to:
  - check if instruments running correctly
  - classify weather events when models fail
  - understand physical processes
- Real-time and final QC’d data is being stored on DAP at PNNL

http://wfip.esrl.noaa.gov/psd/programs/wfip2/
Time-series of normalized aggregate wind power generation on the Bonneville Power Administration system (red curves) and the aggregate equivalent power derived from a network of 22 WFIP2 remote sensing sites that measured 80 m winds.
Sites measuring hub-height (80m) winds

- IEC Class 2 power curve
- Aggregate power

22 remote sensor sites (19 sodars, 3 lidars)
Conus-wide improvements

2-m Temperature

10-m Wind Speed

Western CONUS
Eastern CONUS
WFIP2 Field Campaign

RMS [°C]

RMS [m s⁻¹]