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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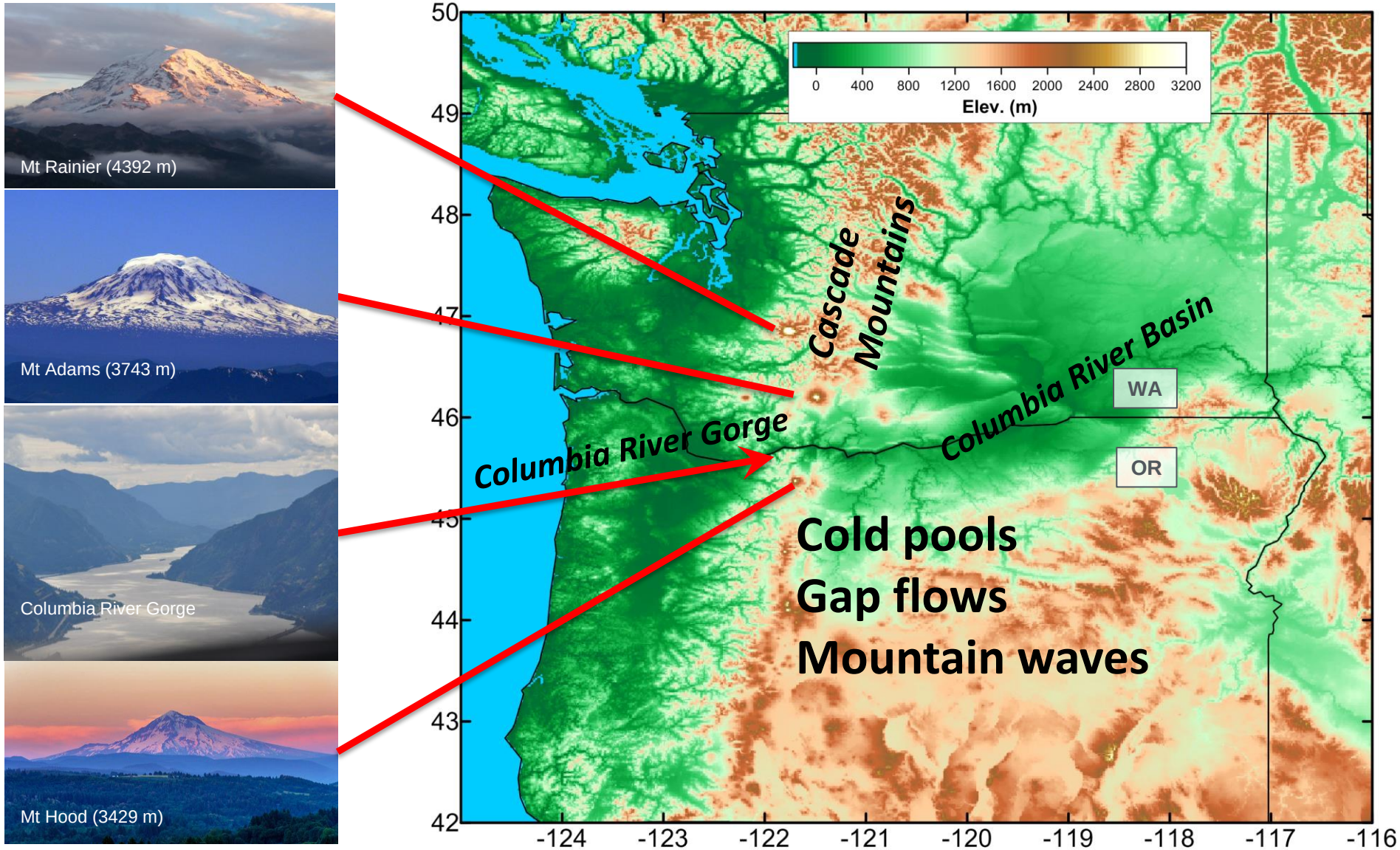
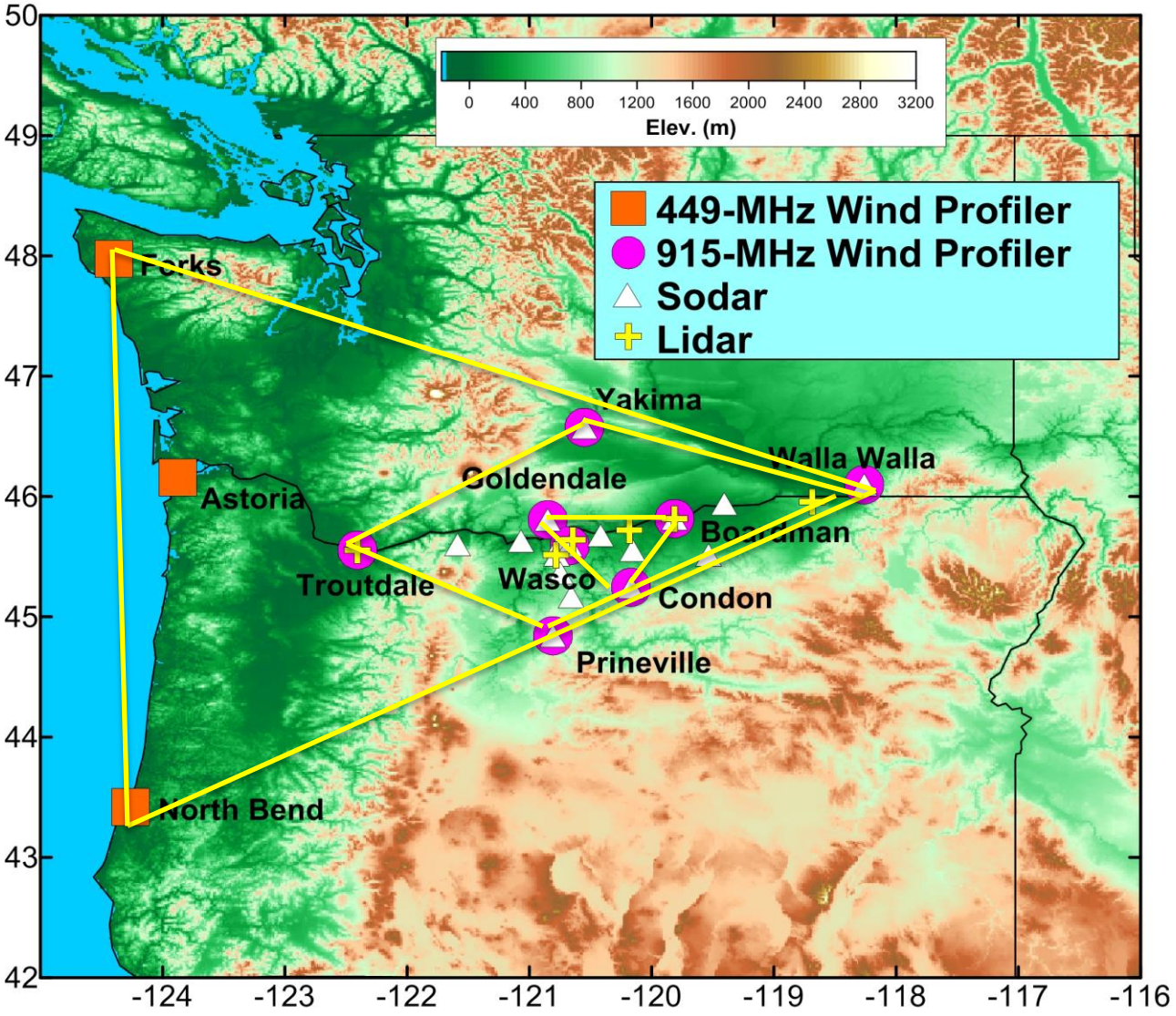
WFIP2 Study Area



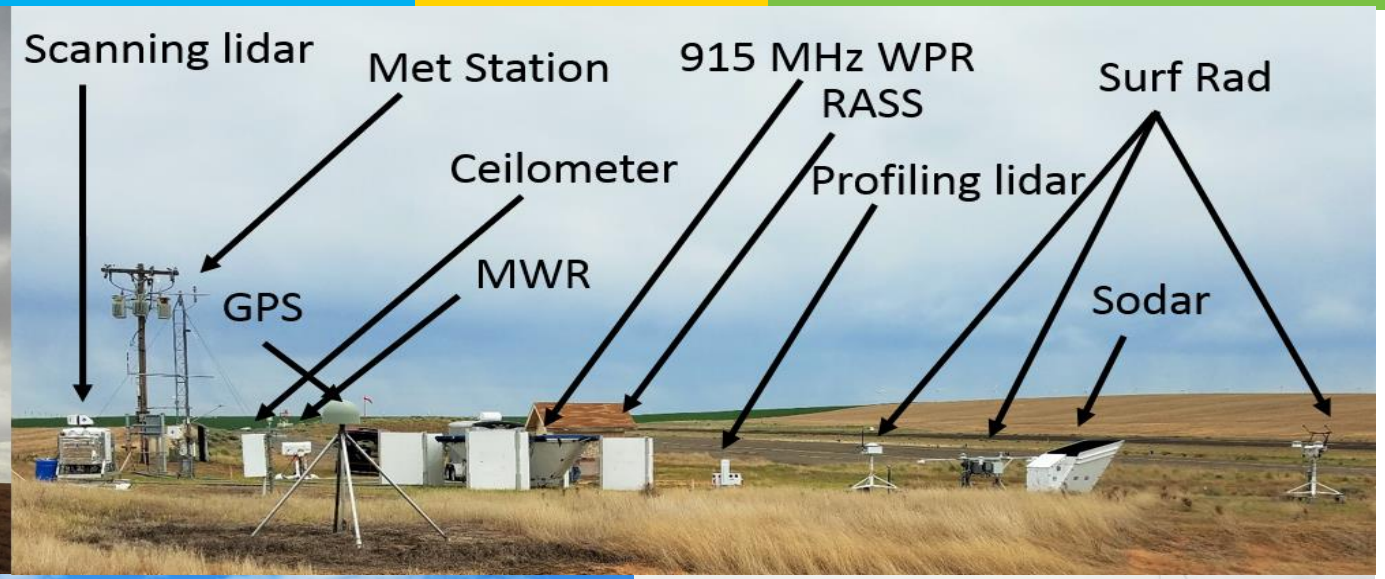
Multi-Scale Observations



- 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)

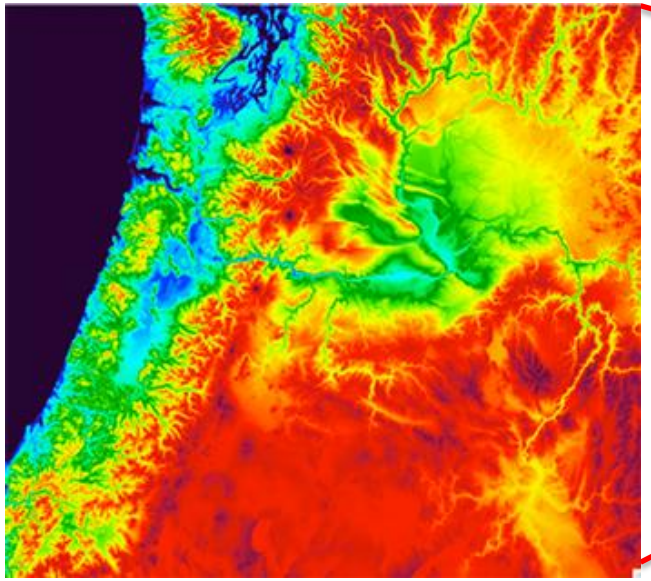
WFIP 2 Instrumentation



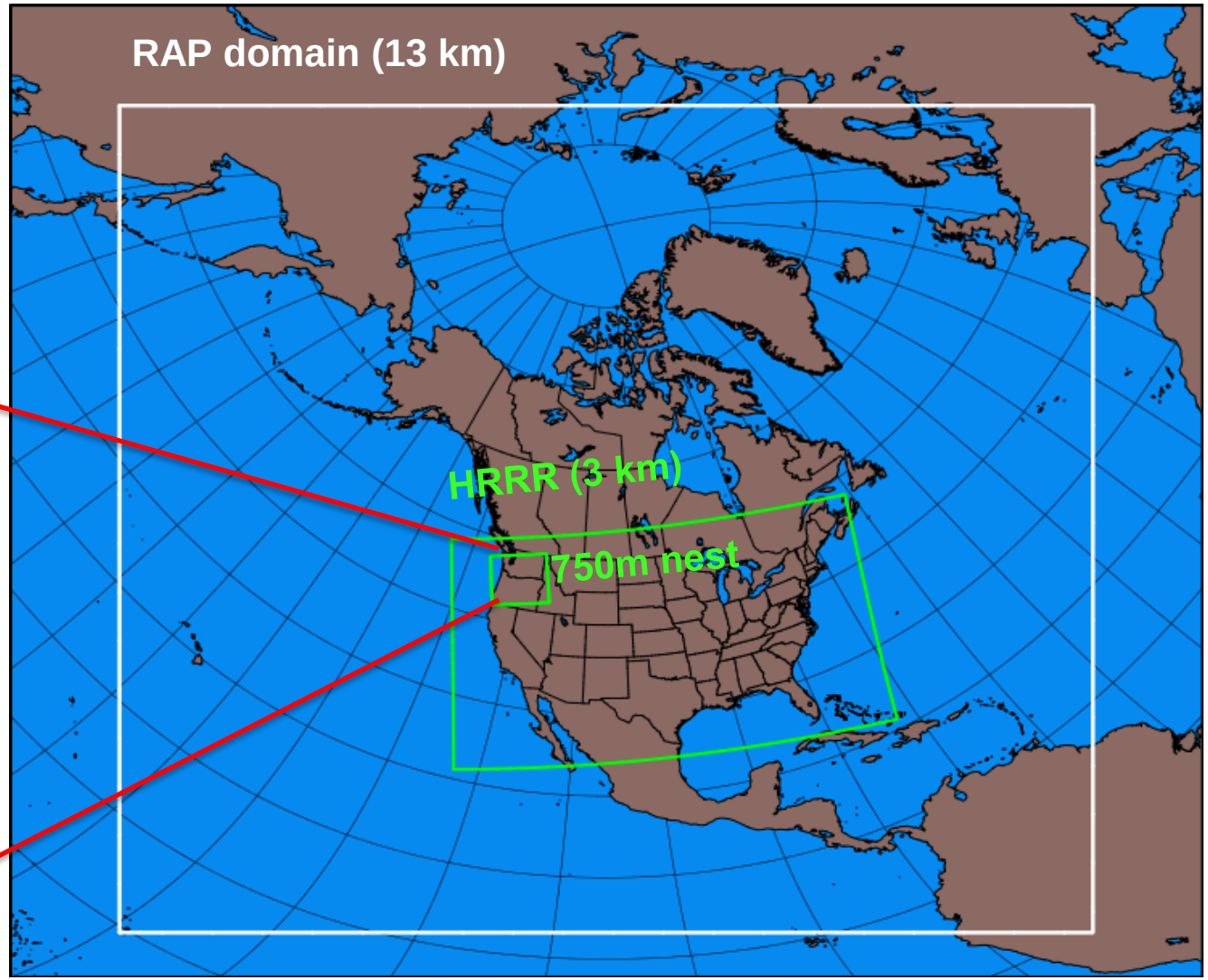
Model Development within RAP and HRRR (WRF-ARW based)

RAP & HRRR 24x/day

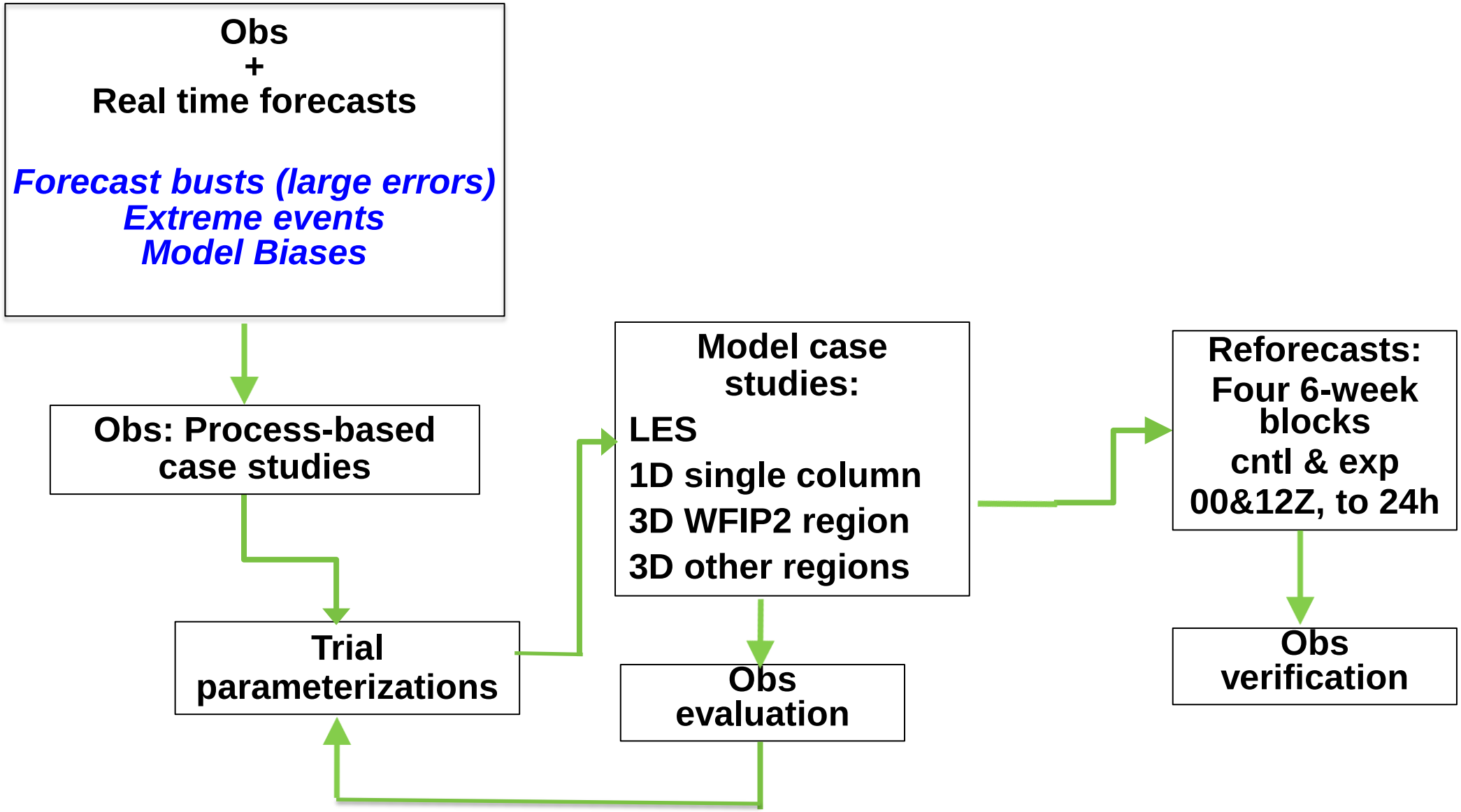
HRRR Nest 2x/day



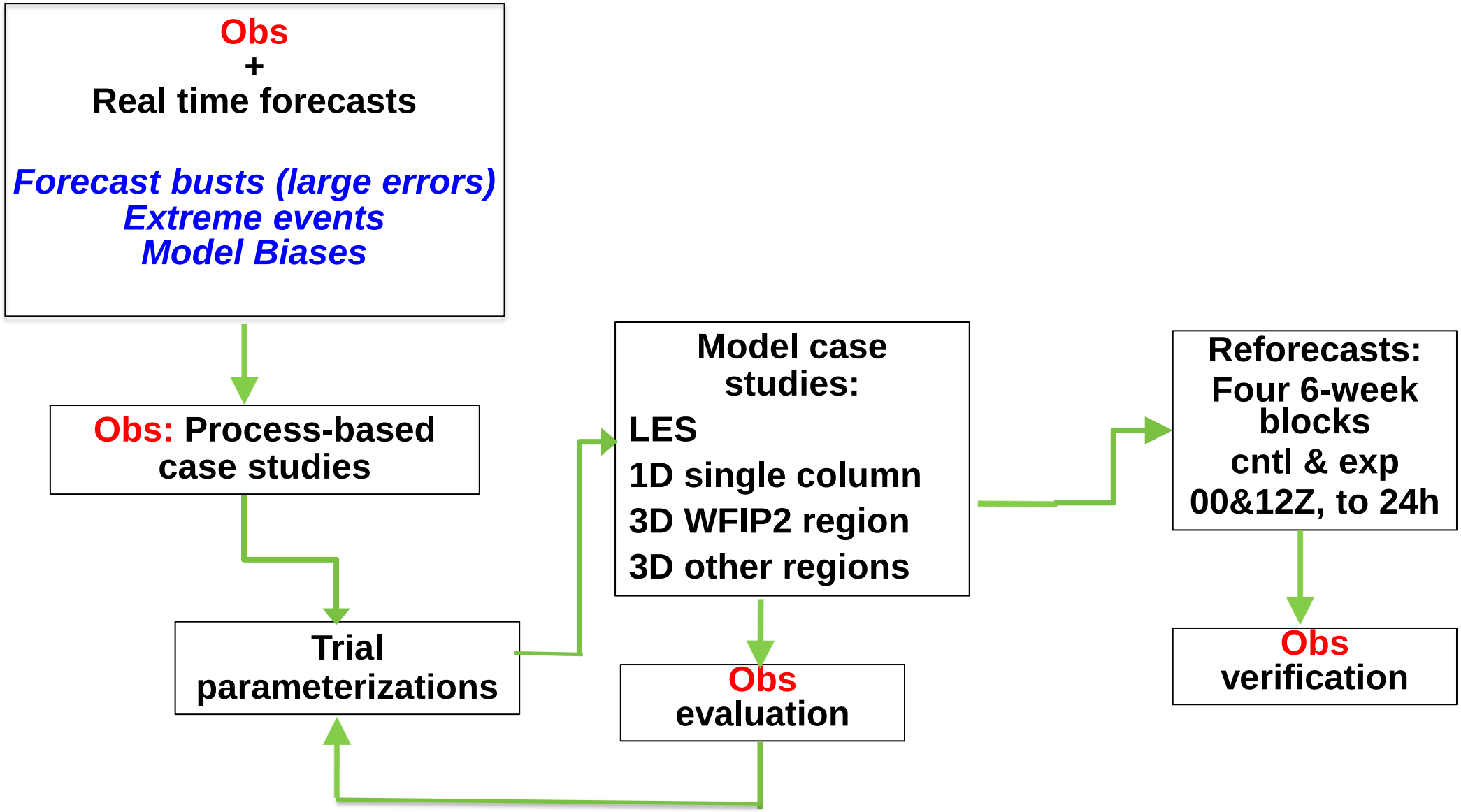
Terrain, HRRR 750m nest



Model improvement process



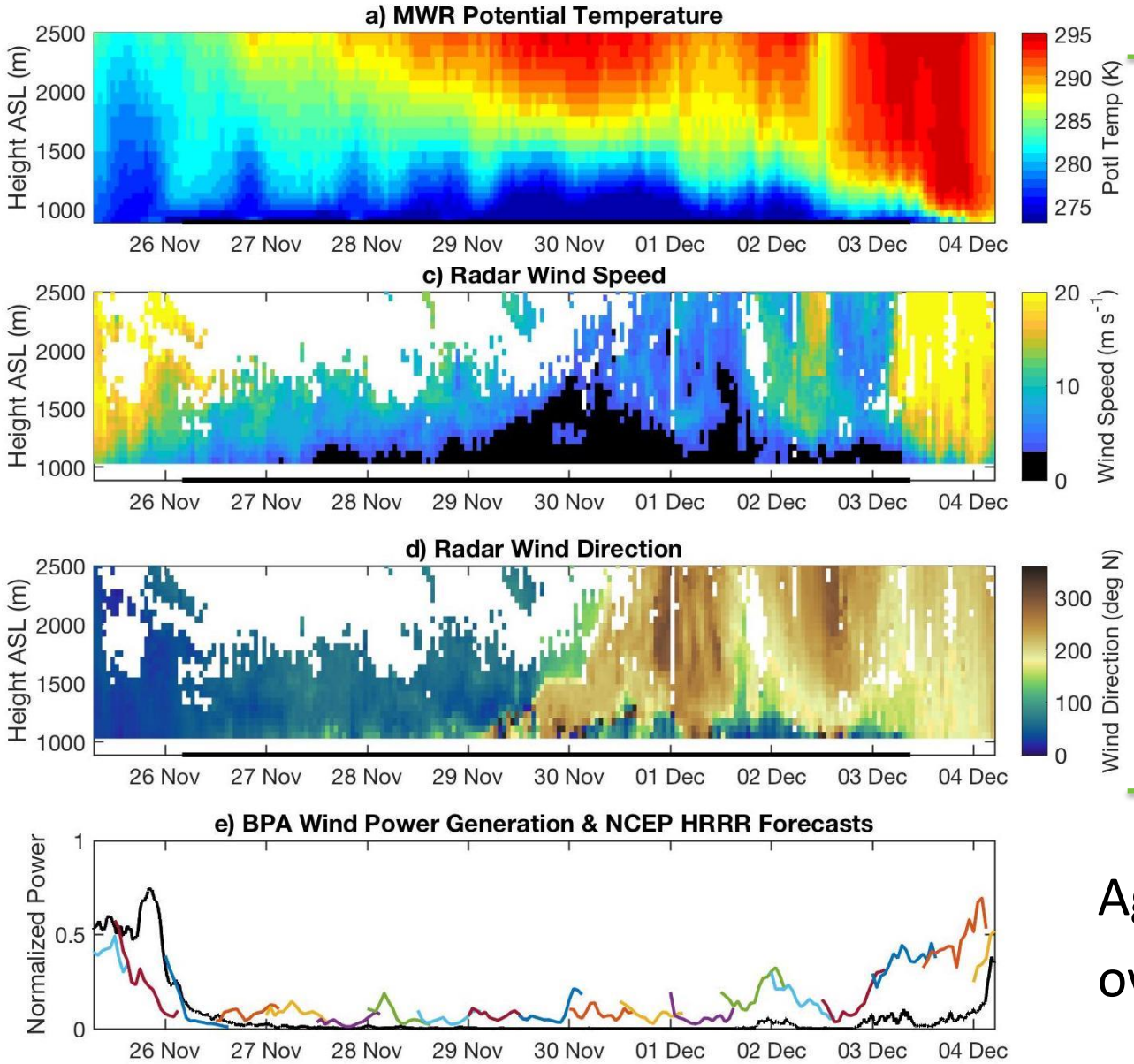
Model improvement process



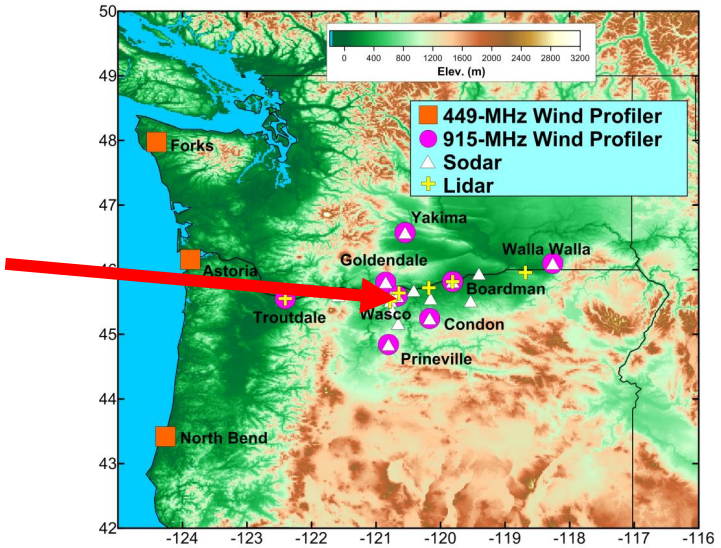
Model Parameterization Development

- **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



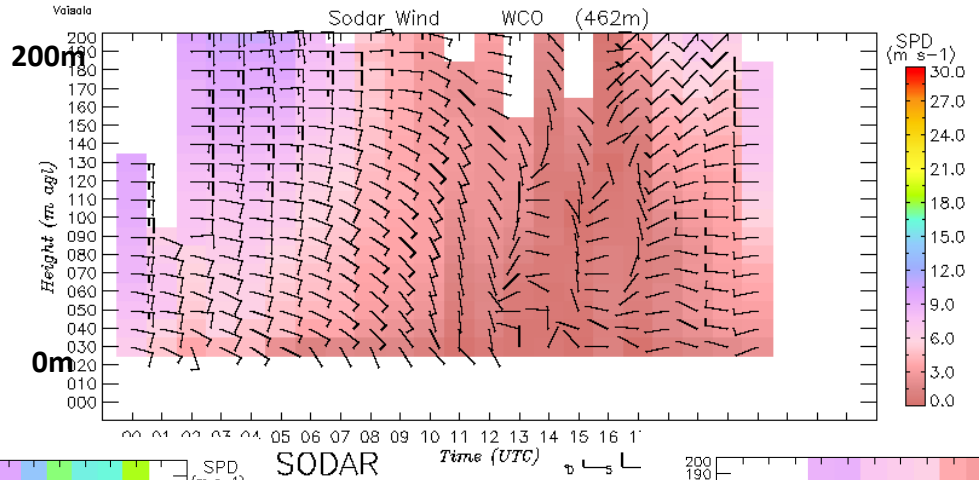
Models have a large wintertime positive speed bias



Aggregated equivalent wind power over 22 sodar/lidar sites

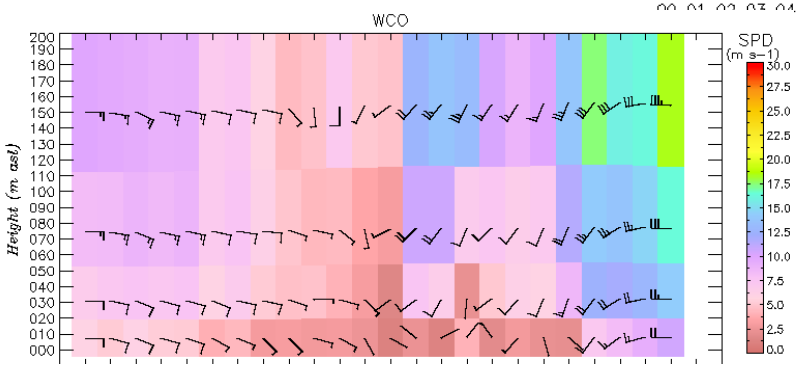
Cold Pool Mix-Out of 13 January 2016 – Sodar

Sodar (barbs+speed)
Wasco, Oregon

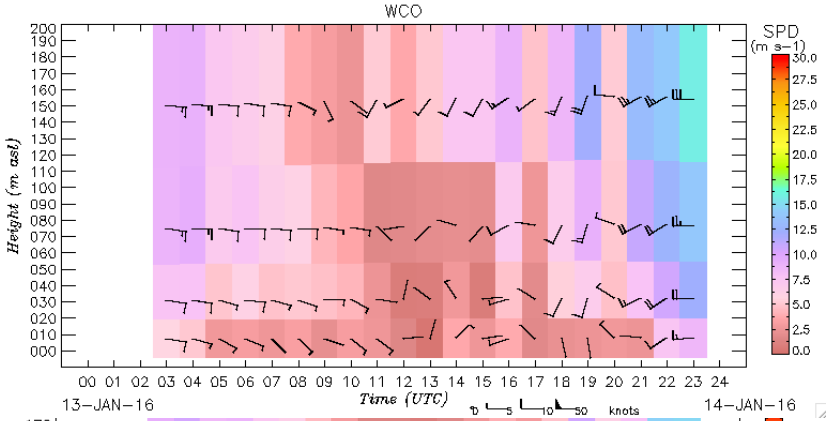


3-km HRRR

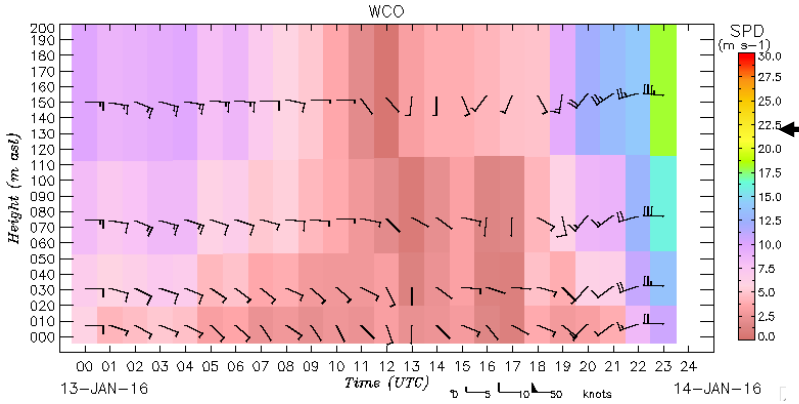
750m Nest

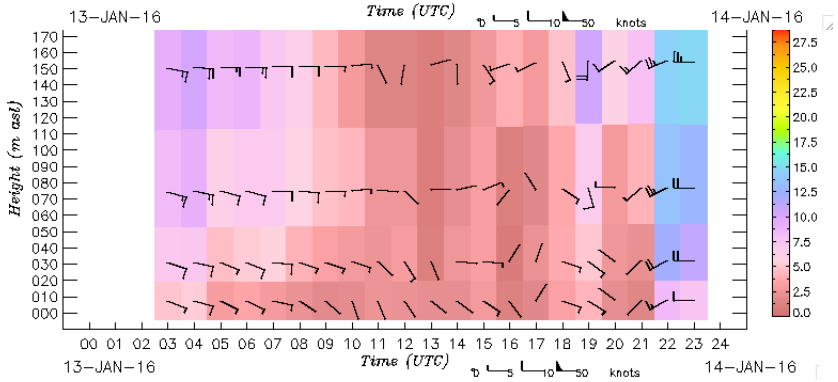


Control

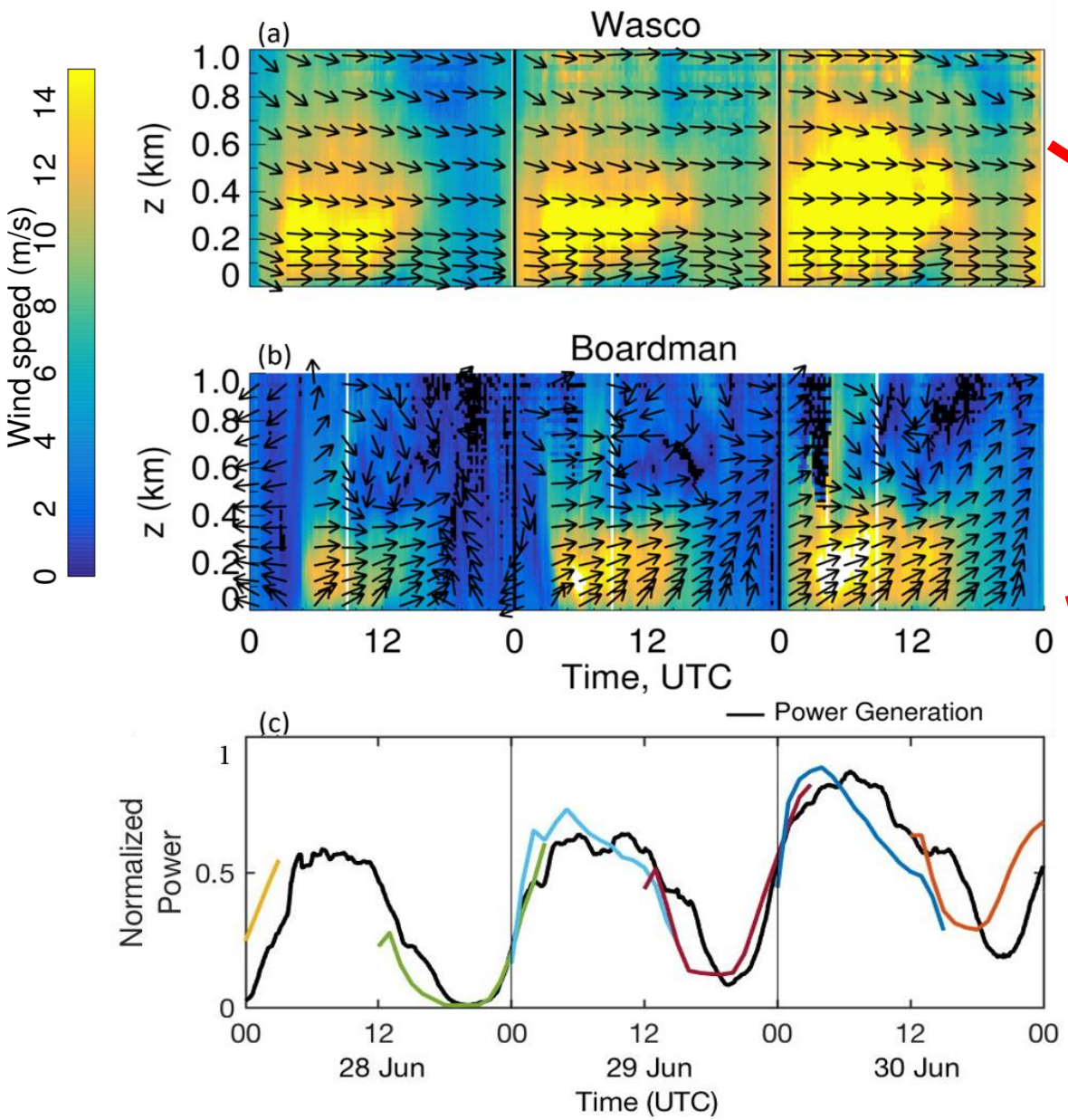


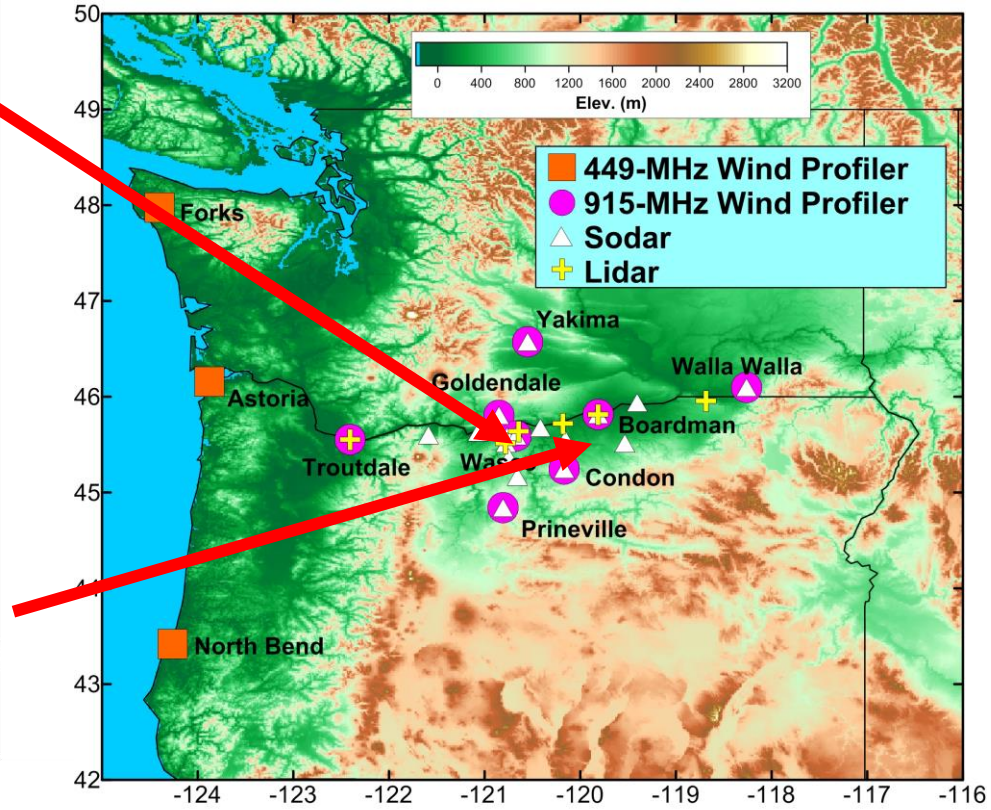
New
MYNN
+Hor Diff
+GWD





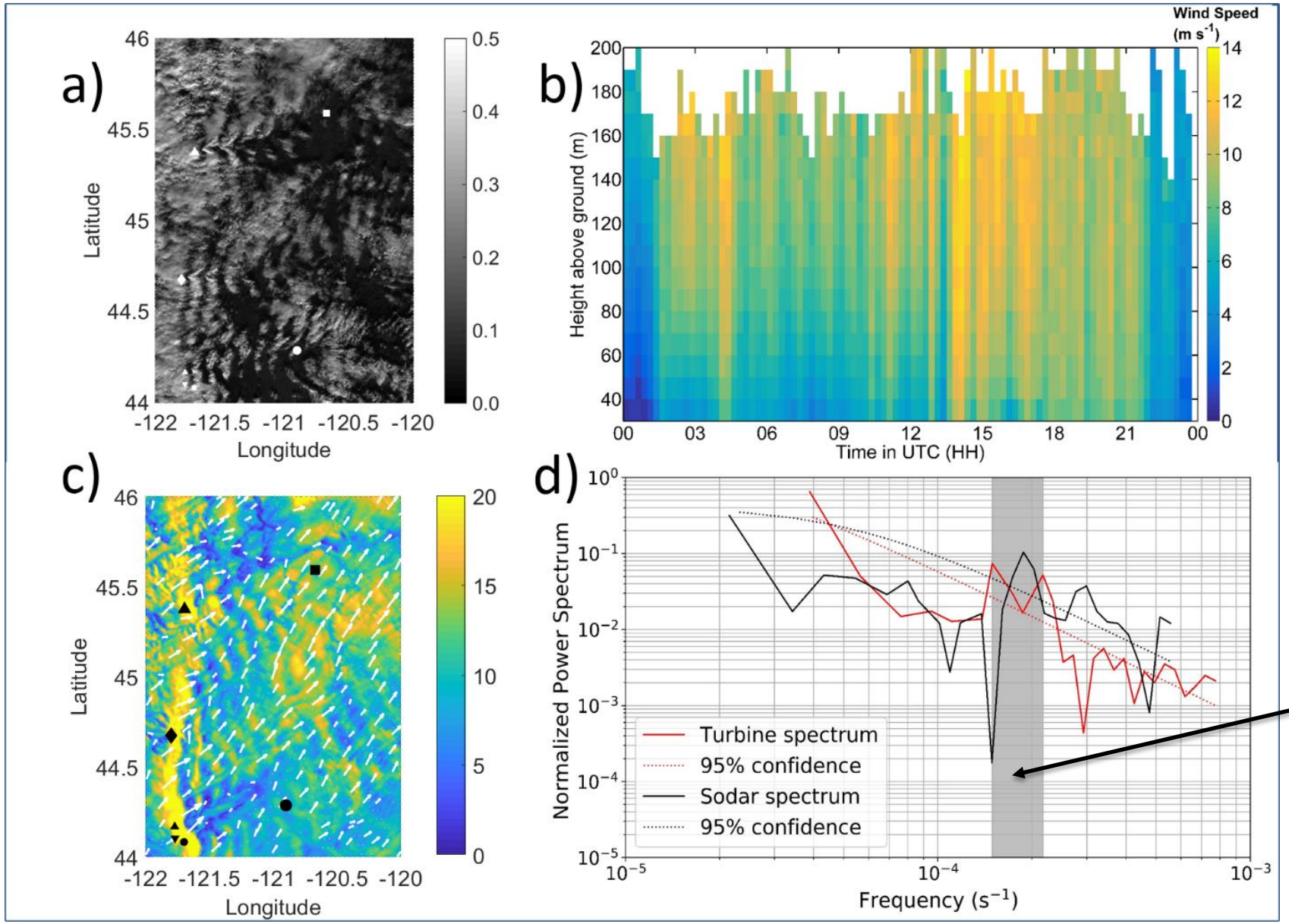
Recurrent diurnal gap flows due to sea-breeze forcing





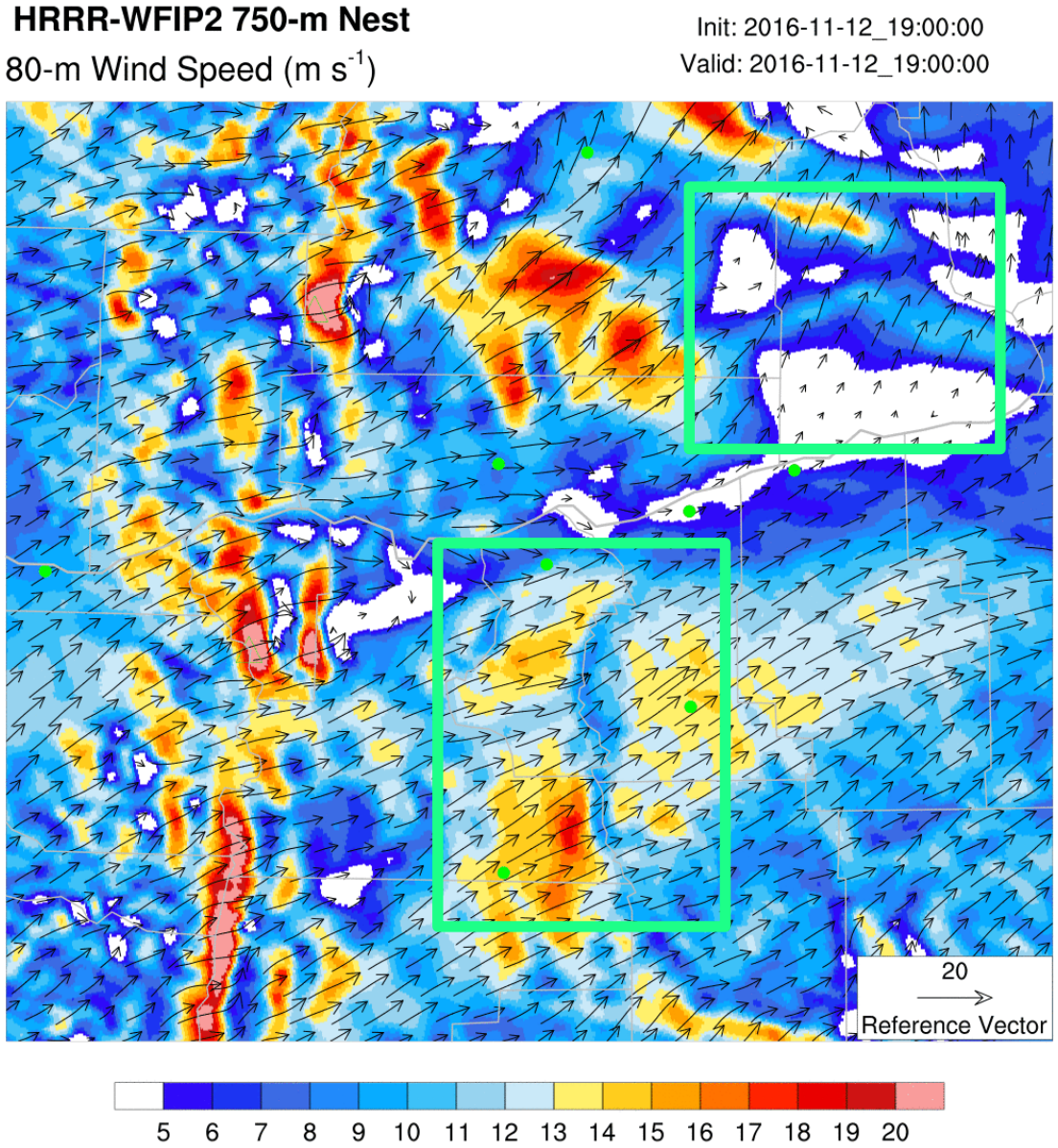
Averaged equivalent wind power over 22 sodar/lidar sites

Mountain Waves



15 min GOES satellite estimates of periodicity

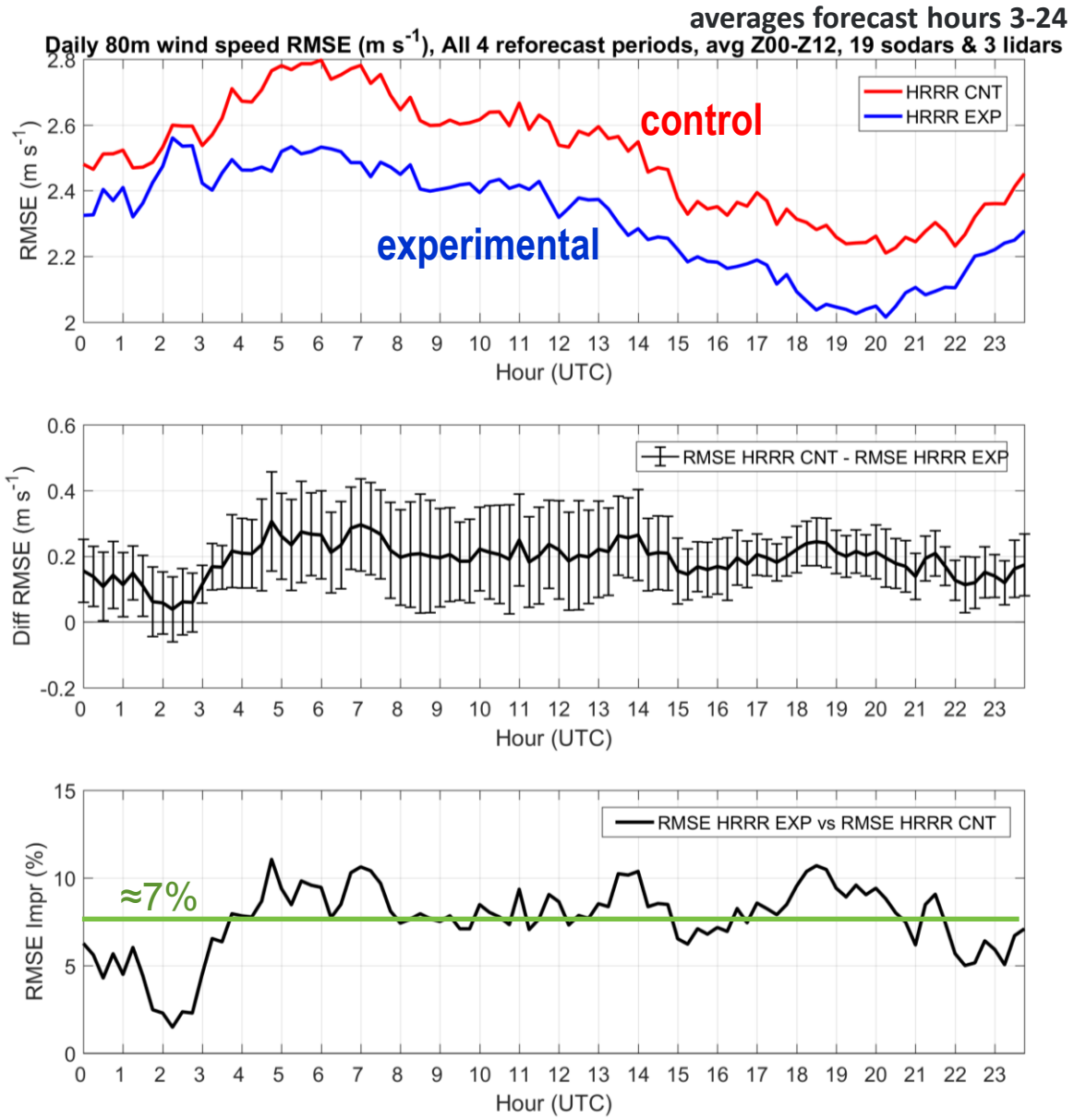
Mountain Waves: Model view



- Waves can be seen propagating upstream to the west
- ΔU ~ 3m/s peak-trough matches sodar data
- WFIP2 provides first proof that mountain waves do in fact affect wind energy production

Images: Joe Olson

Forecast Improvement Skill (80m winds)



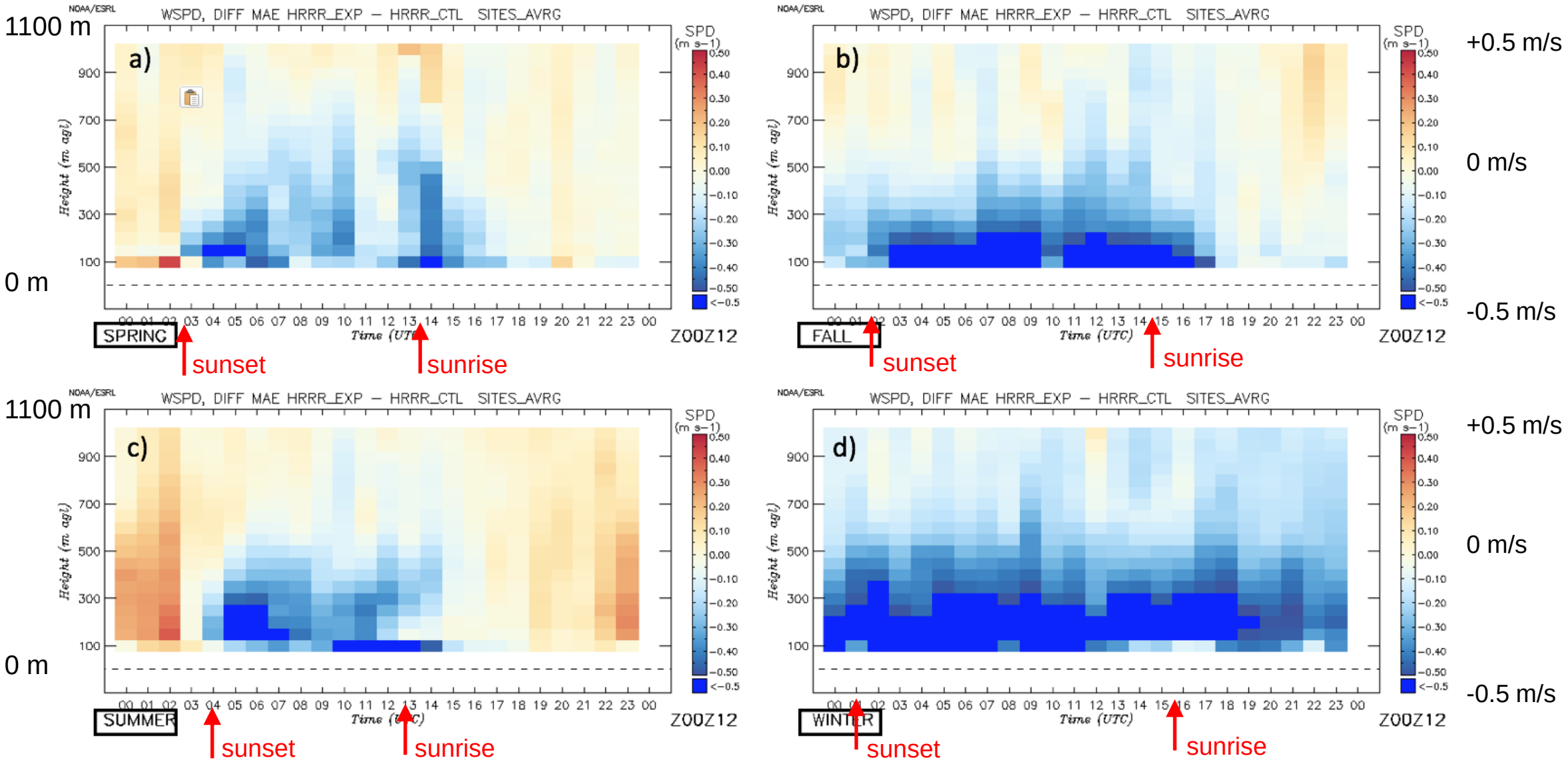
10 year average improvement RMSE 12h 850 mb vector winds:

NAM: 0.7% per year

GFS: 0.4% per year

Forecast Improvement Skill (Radar wind profiler wind speed)

MAE improvement

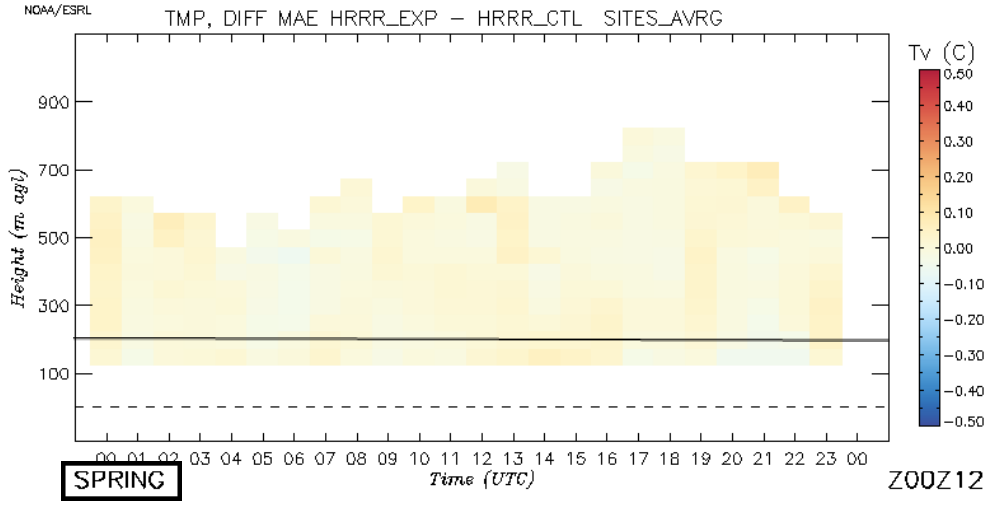


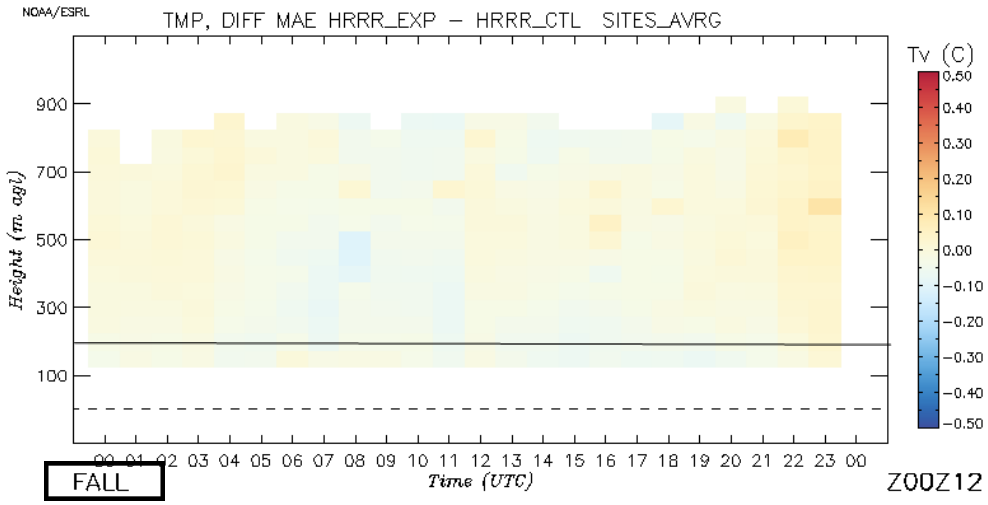
WFIP2 CONCLUSIONS

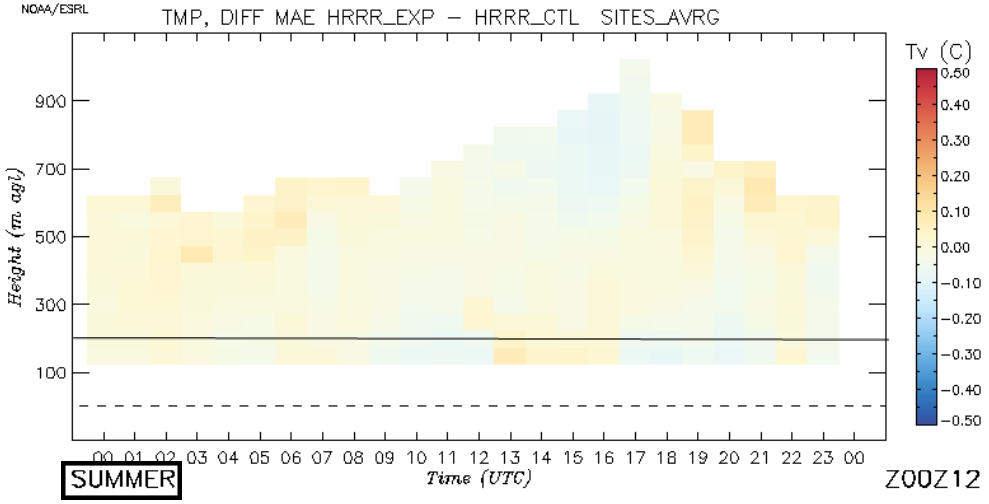
- WFIP2 has demonstrated the importance of lower tropospheric profiling observations for improving model forecast skill
  - Identify model problems
  - Understand physical processes/suggest parameterization improvements
  - Evaluate candidate model parameterization additions and revisions in an iterative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

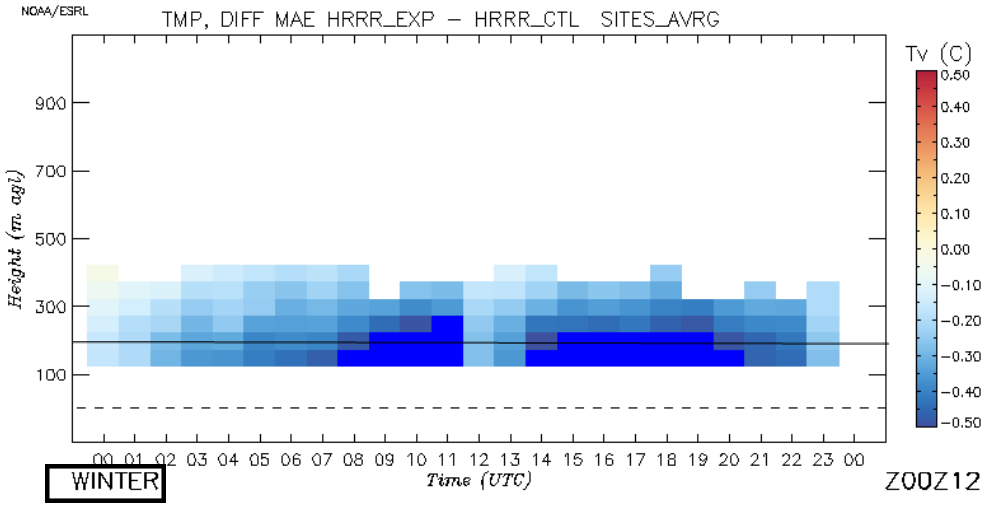
Forecast Improvement Skill (PBL temperatures)

MAE improvement

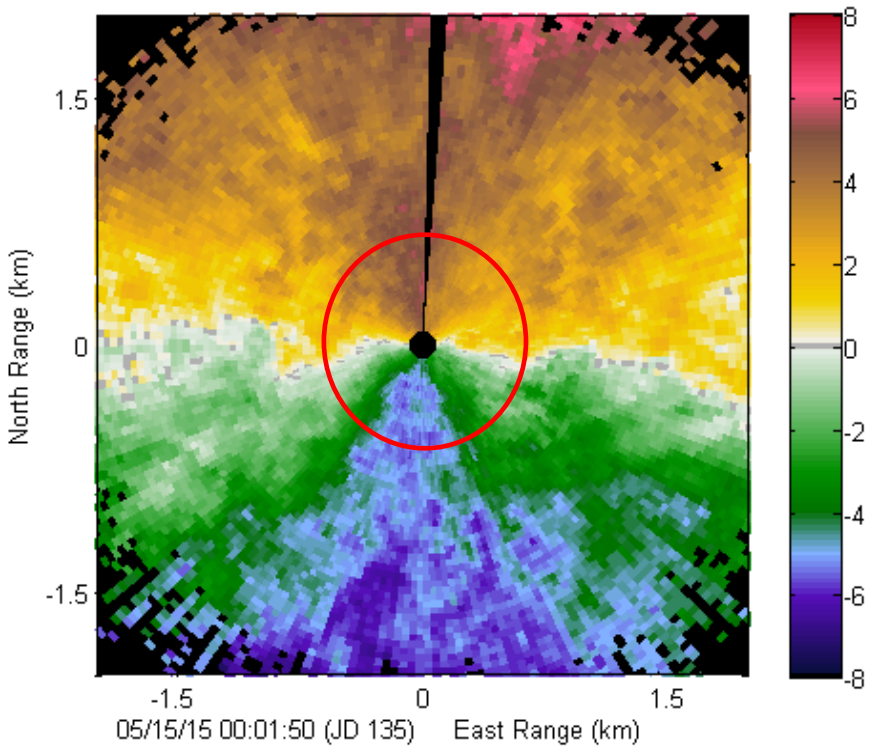


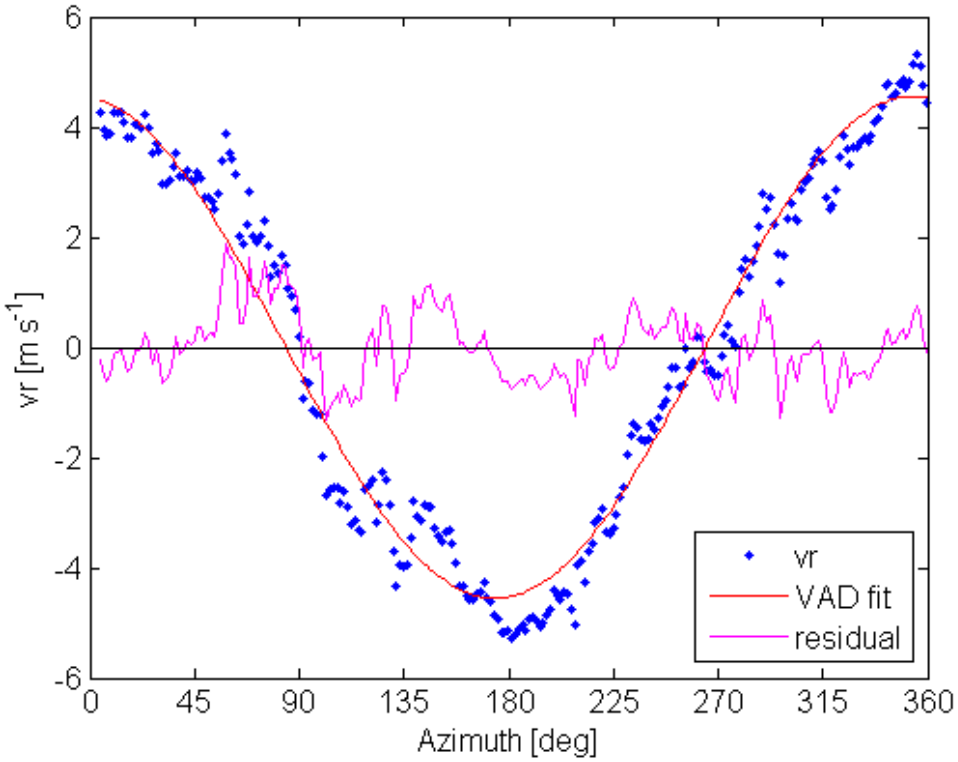




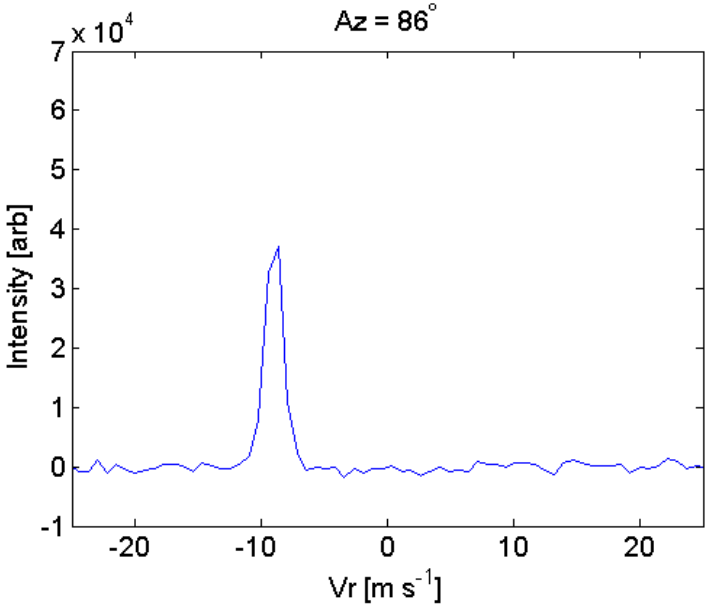


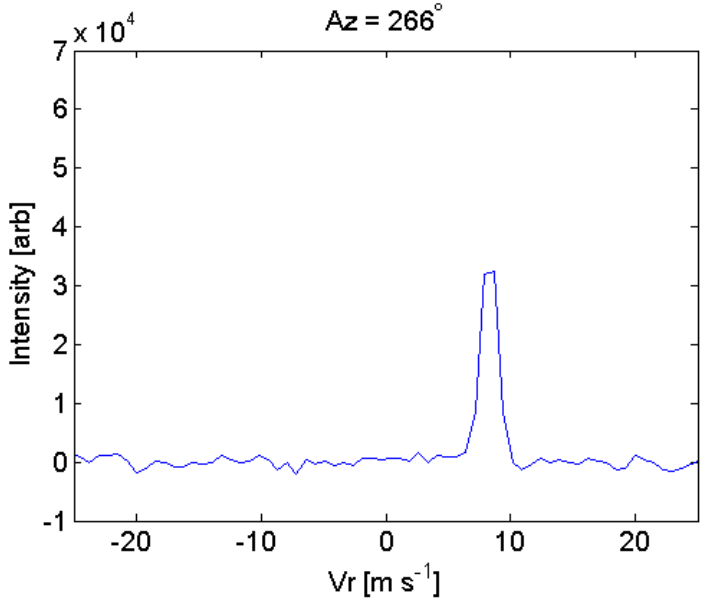
Normal VAD technique

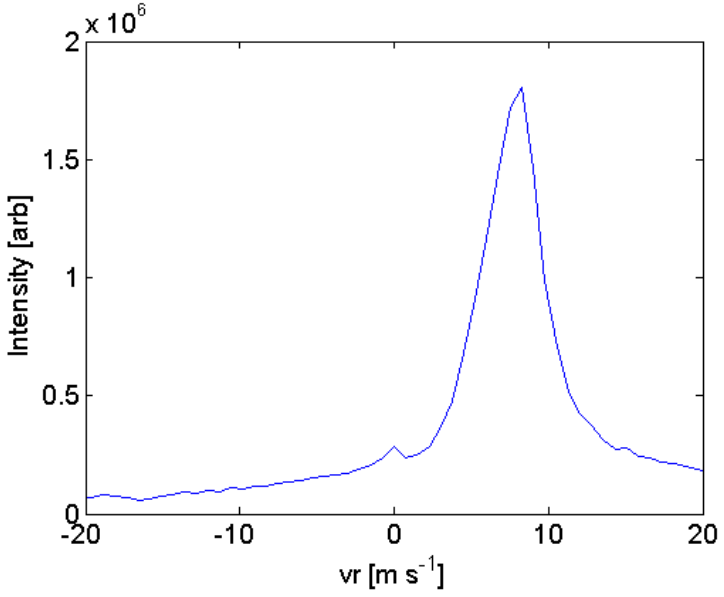




New technique – maximum of the function of accumulated spectra (MFAS)







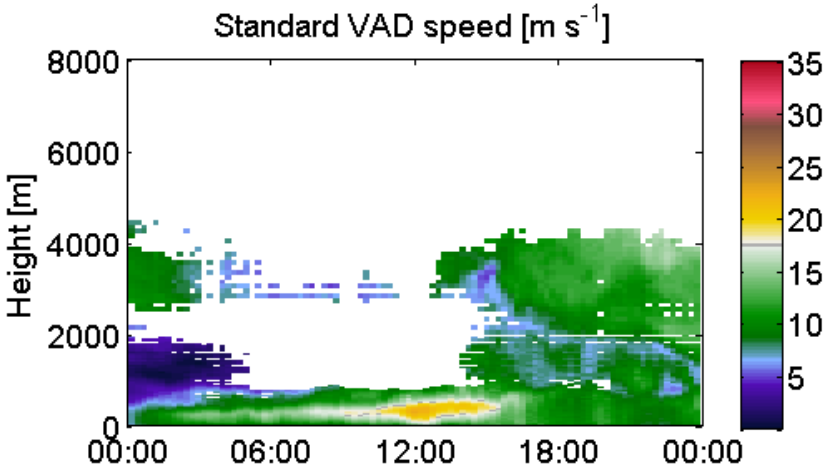
- Work in Doppler spectrum domain
- Shift spectra with respect to azimuth direction Θ, multiplying spectra by sin(δΘ)

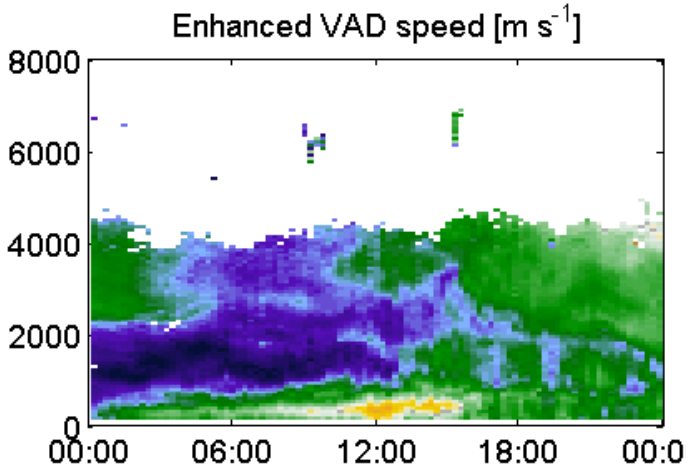
- Spectra accumulate and the peak is more pronounced compared to noise
- Increase in sensitivity is $\propto \sqrt{N}$

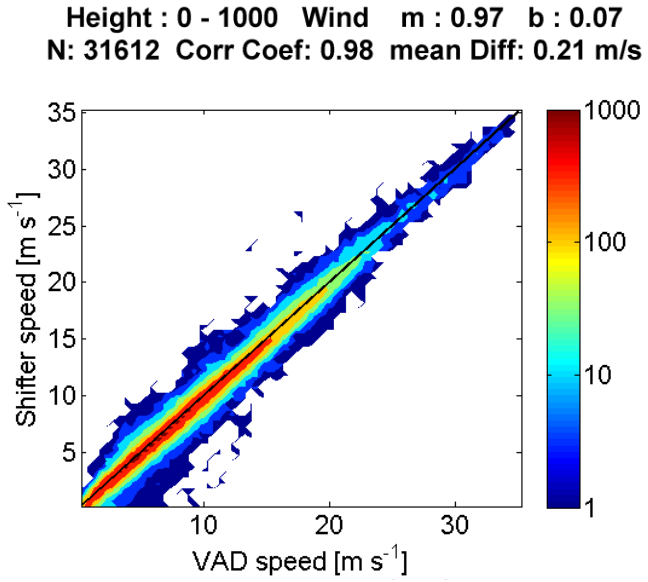
Banakh et al. (2001)

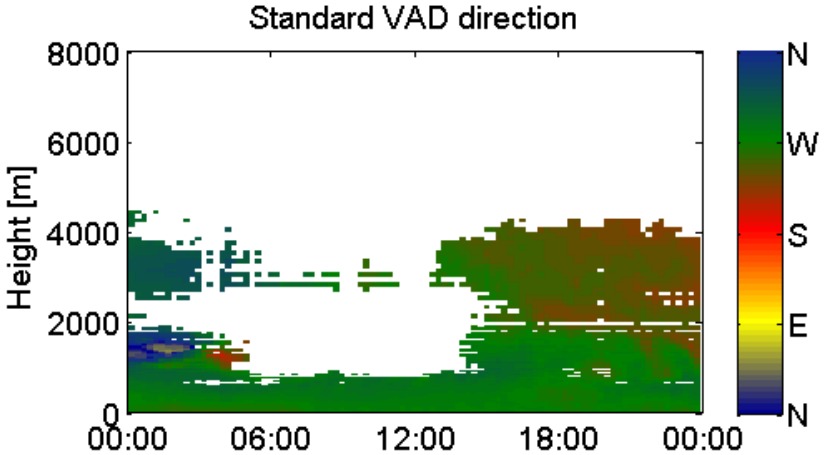
Smalikho, 2003

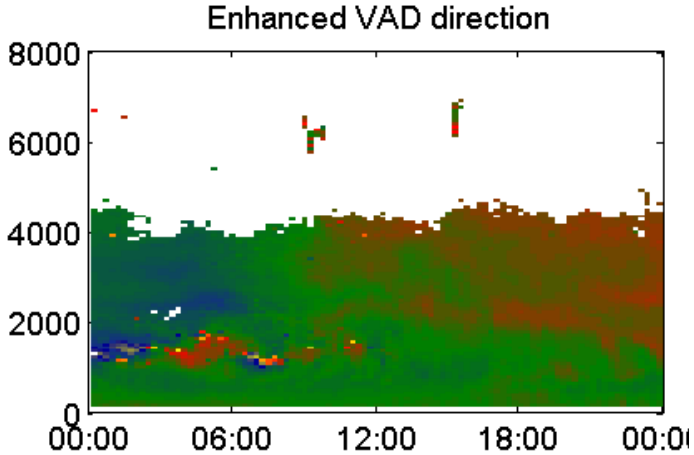
Wind profile comparison

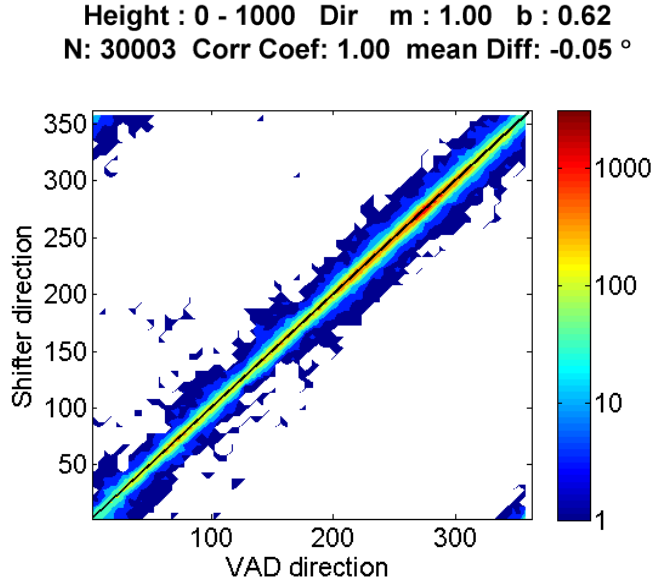


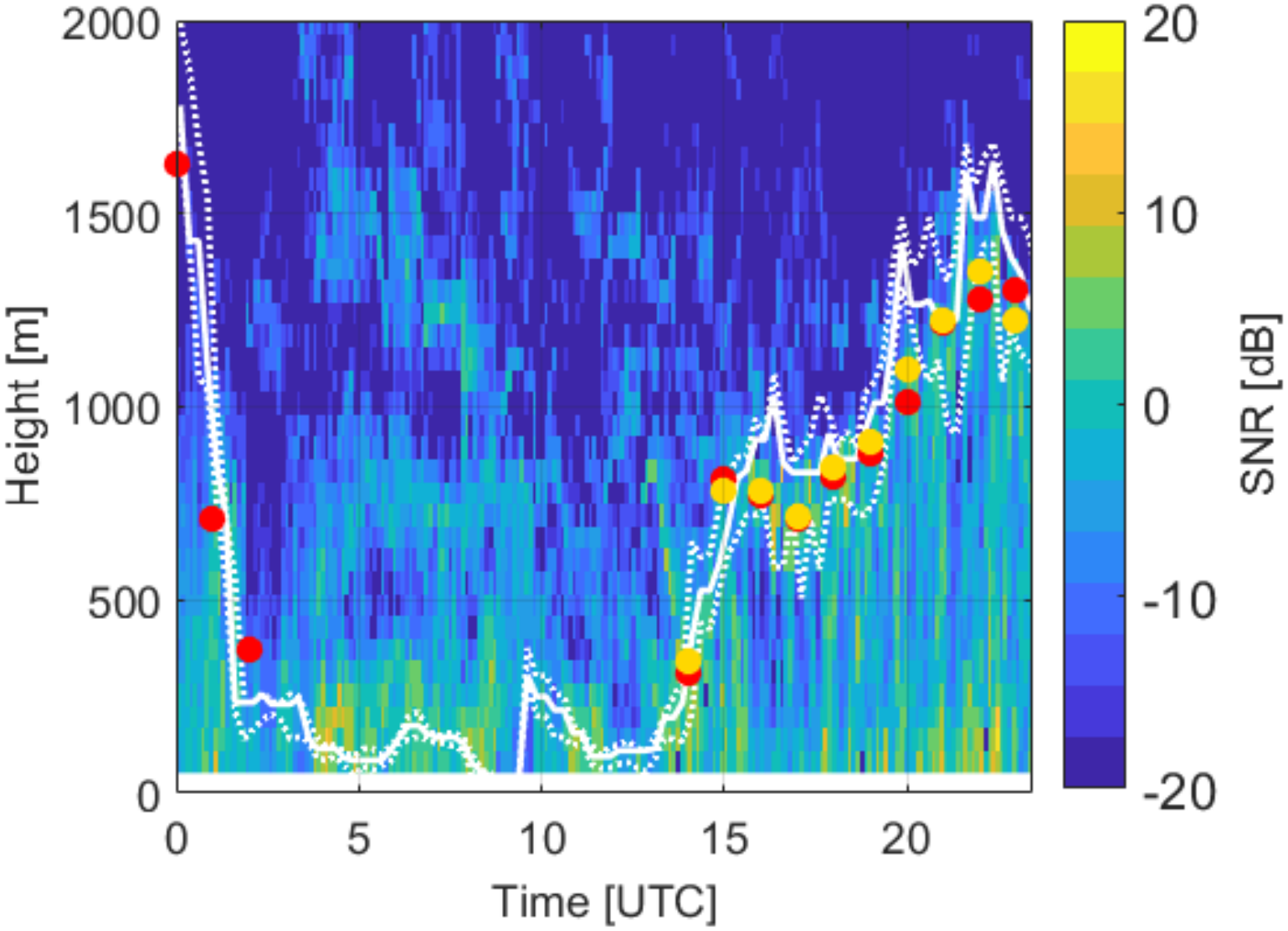




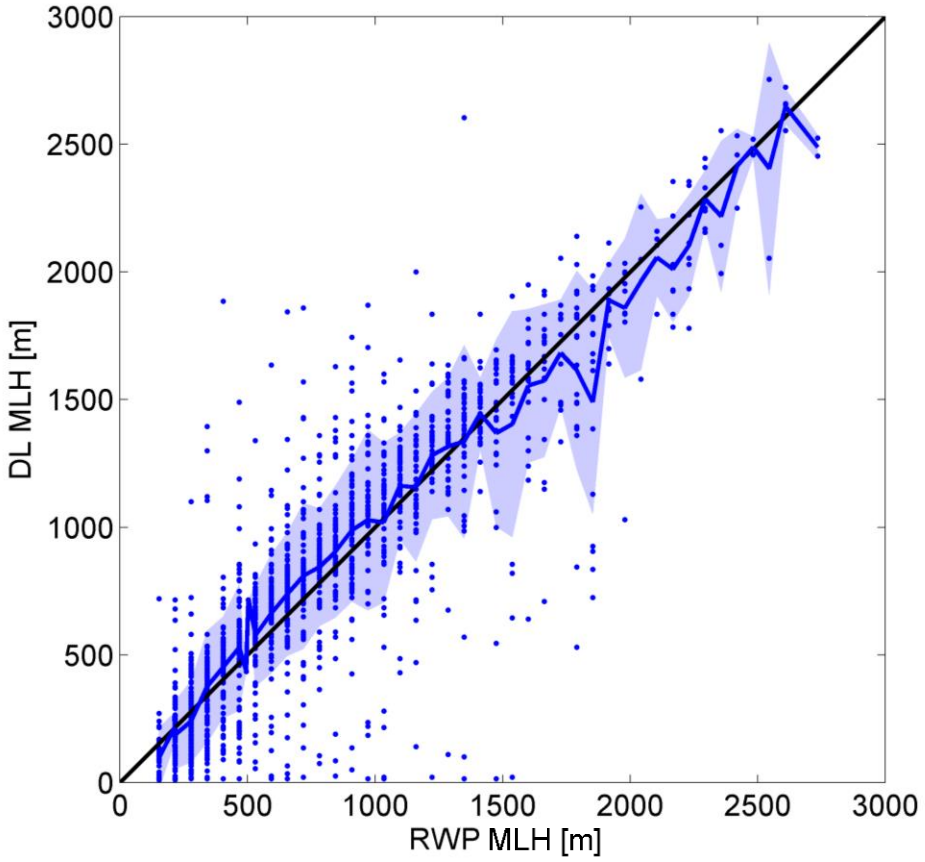


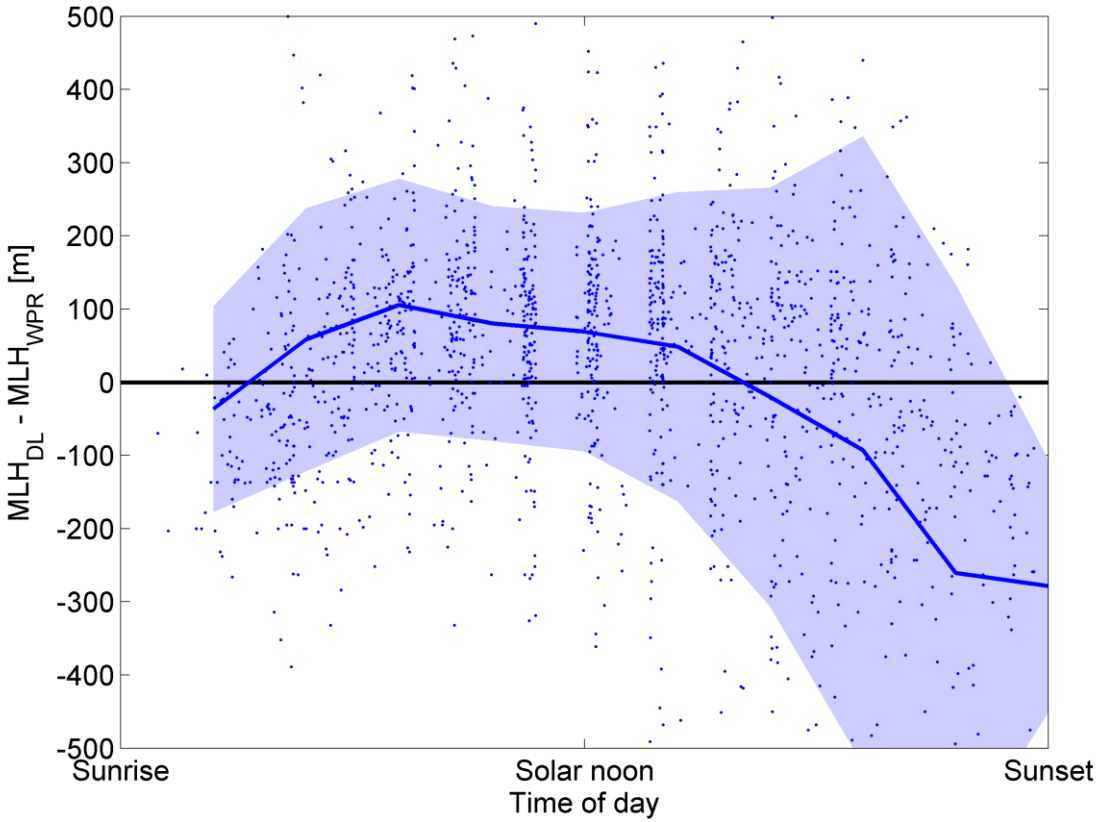





2000
1500
1000
500
0
Height [m]
0
5
10
15
20
Time [UTC]
20
10
0
-10
-20
SNR [dB]

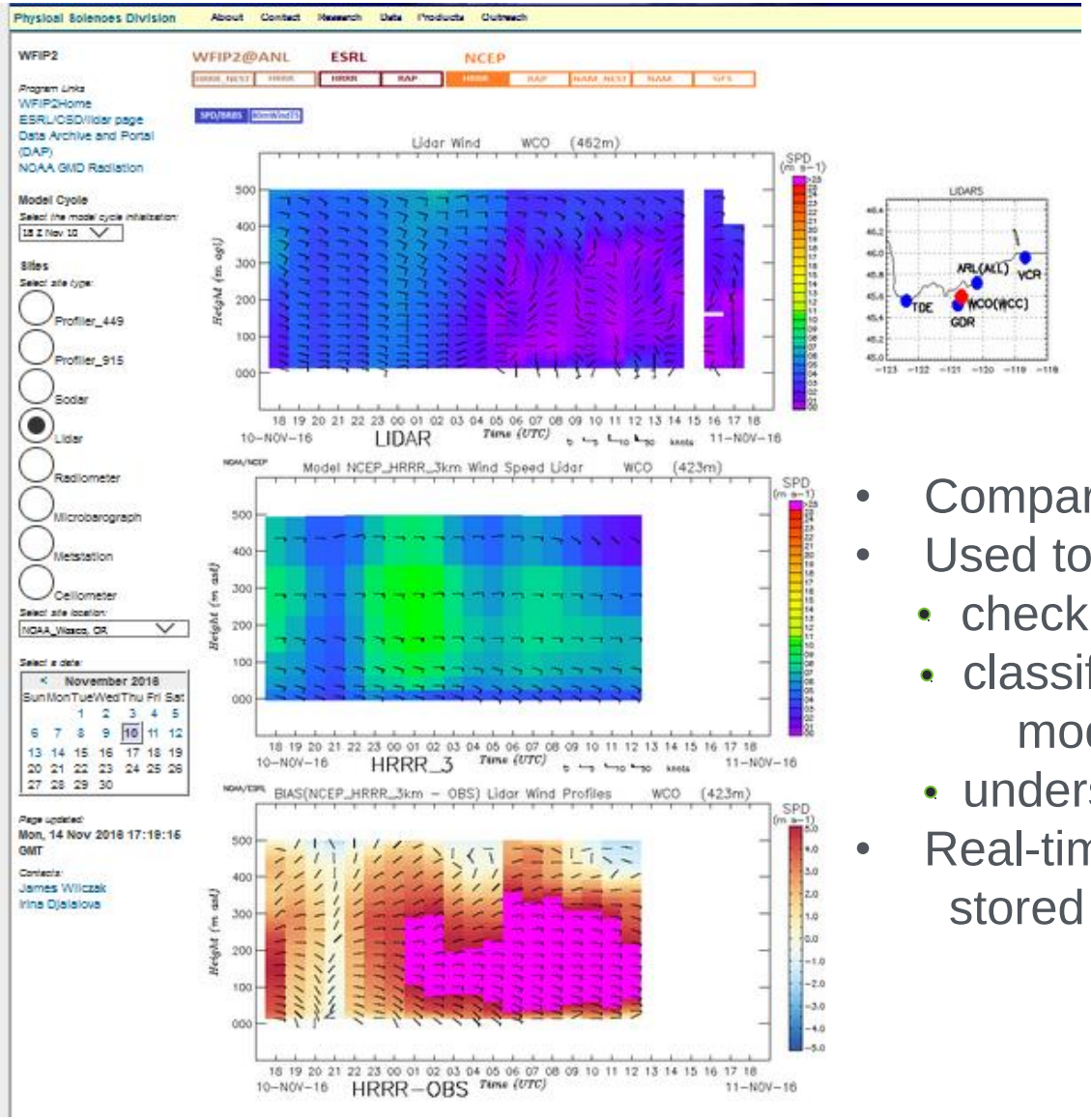
1. Mixed-Layer Height (MLH) comparison:





- 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:

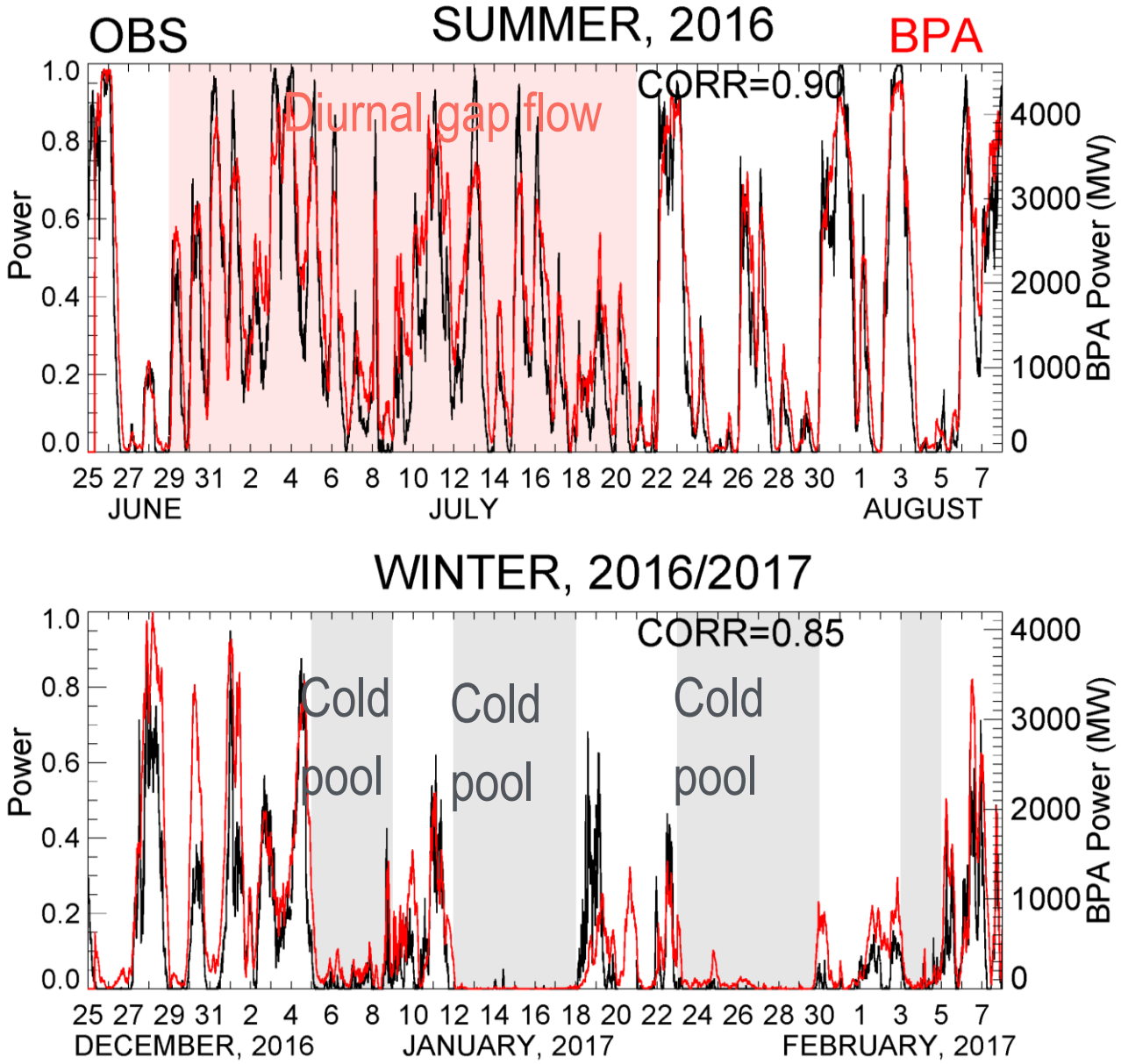


http://wfip.esrl.noaa.gov/psd/programs/wfip2/

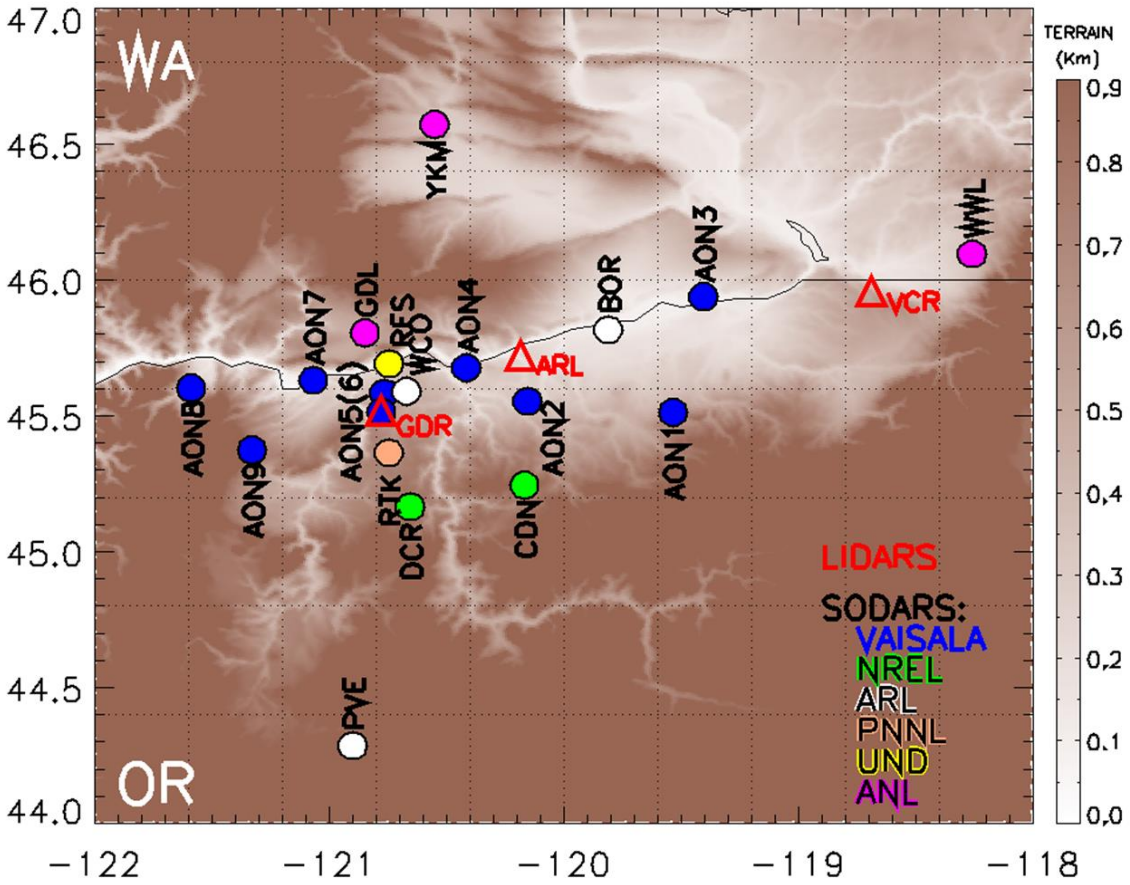
- Compares observations with models
- Used to:
  - check if instruments running correctly
  - classify weather events when models fail
  - understand physical processes
- Real-time and final QC'd data is being stored on DAP at PNNL

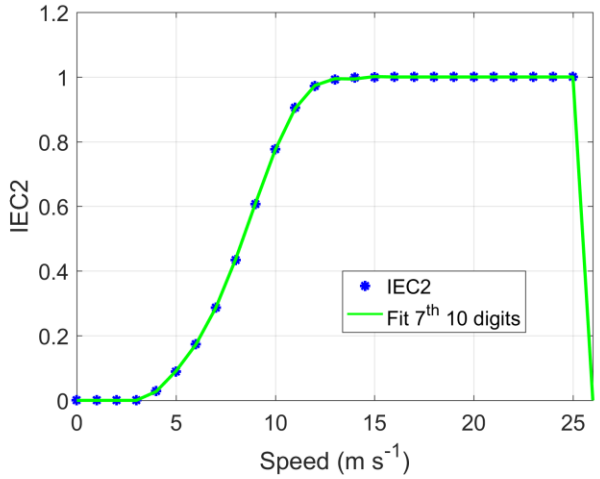
Aggregate Power on BPA System and WFIP2 Network of 22 Remote Sensors

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