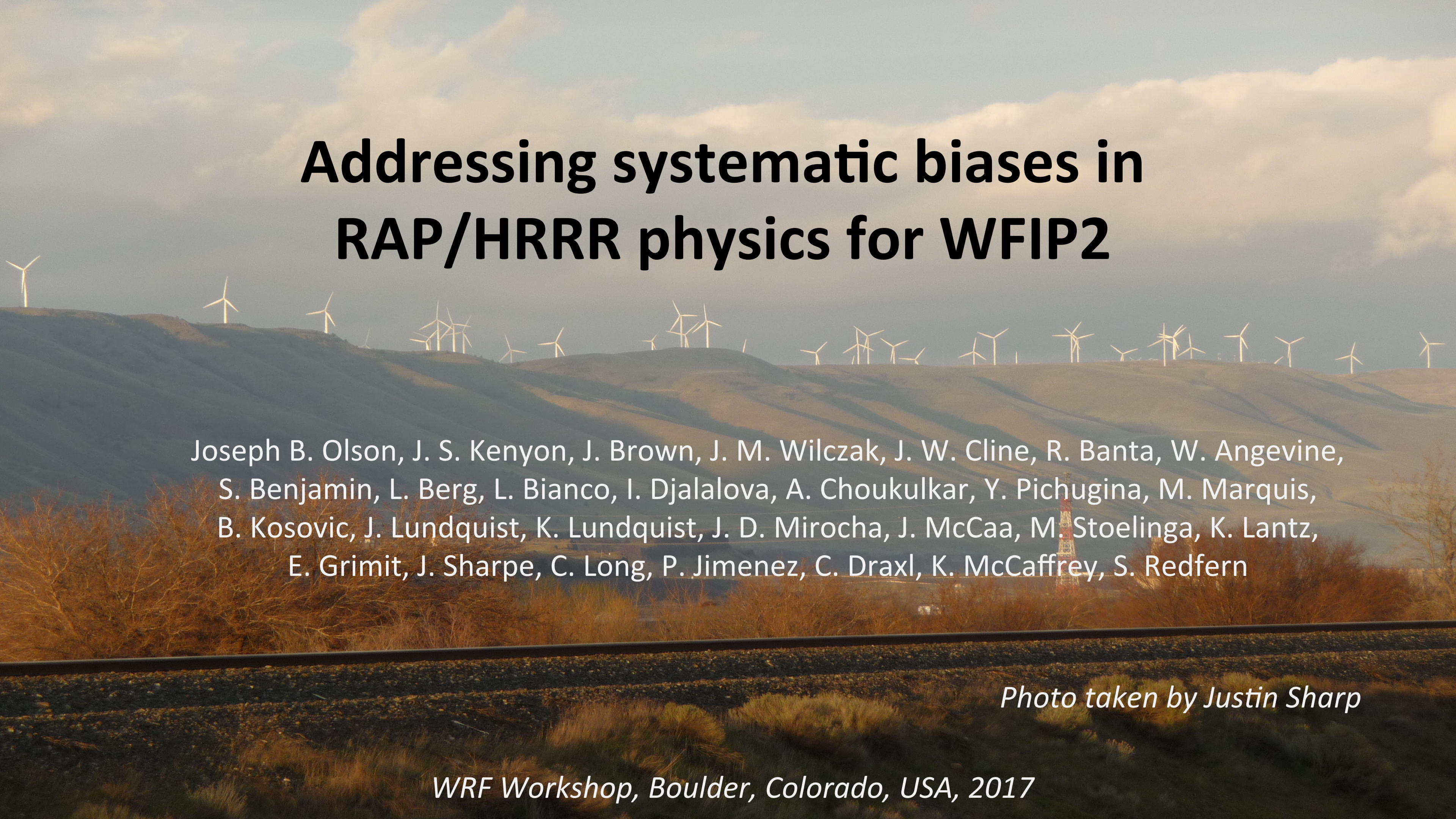


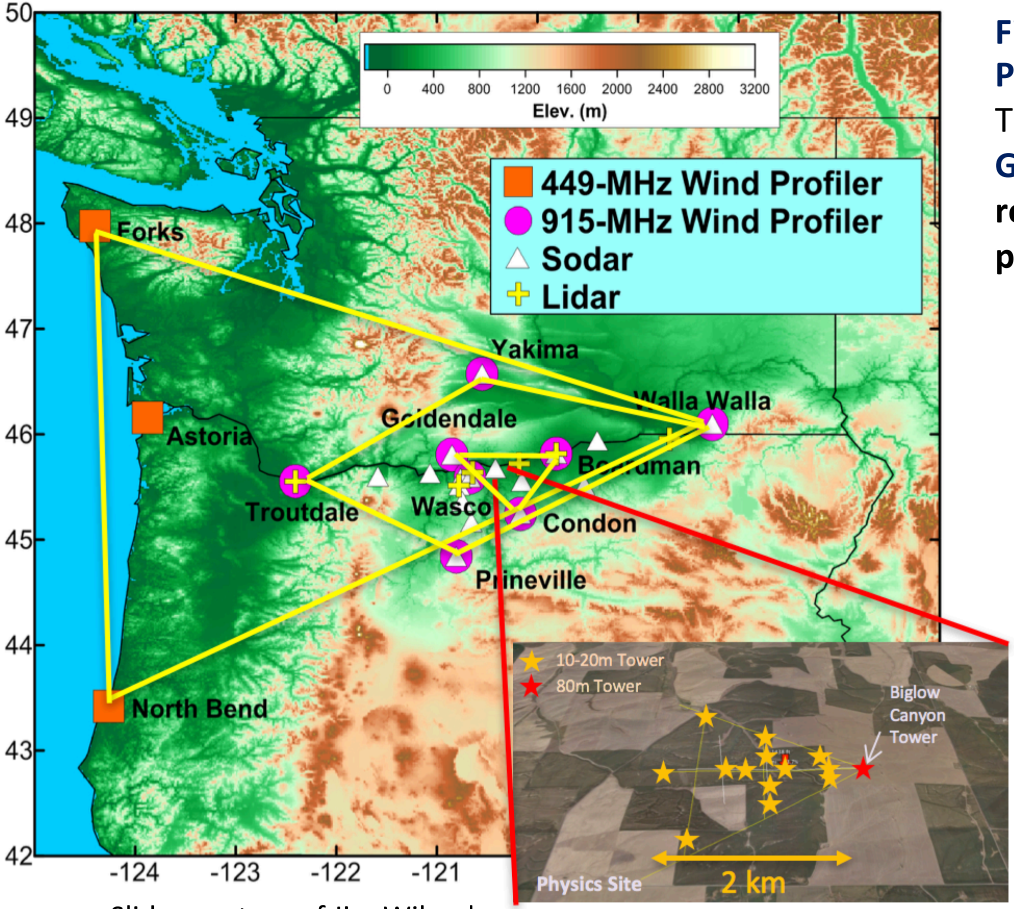
Addressing systematic biases in RAP/HRRR physics for WFIP2

Joseph B. Olson, J. S. Kenyon, J. Brown, J. M. Wilczak, J. W. Cline, R. Banta, W. Angevine, S. Benjamin, L. Berg, L. Bianco, I. Djalalova, A. Choukulkar, Y. Pichugina, M. Marquis, B. Kosovic, J. Lundquist, K. Lundquist, J. D. Mirocha, J. McCaa, M. Stoelinga, K. Lantz, E. Grimit, J. Sharpe, C. Long, P. Jimenez, C. Draxl, K. McCaffrey, S. Redfern

Photo taken by Justin Sharp

WRF Workshop, Boulder, Colorado, USA, 2017

Wind Forecast Improvement Project 2



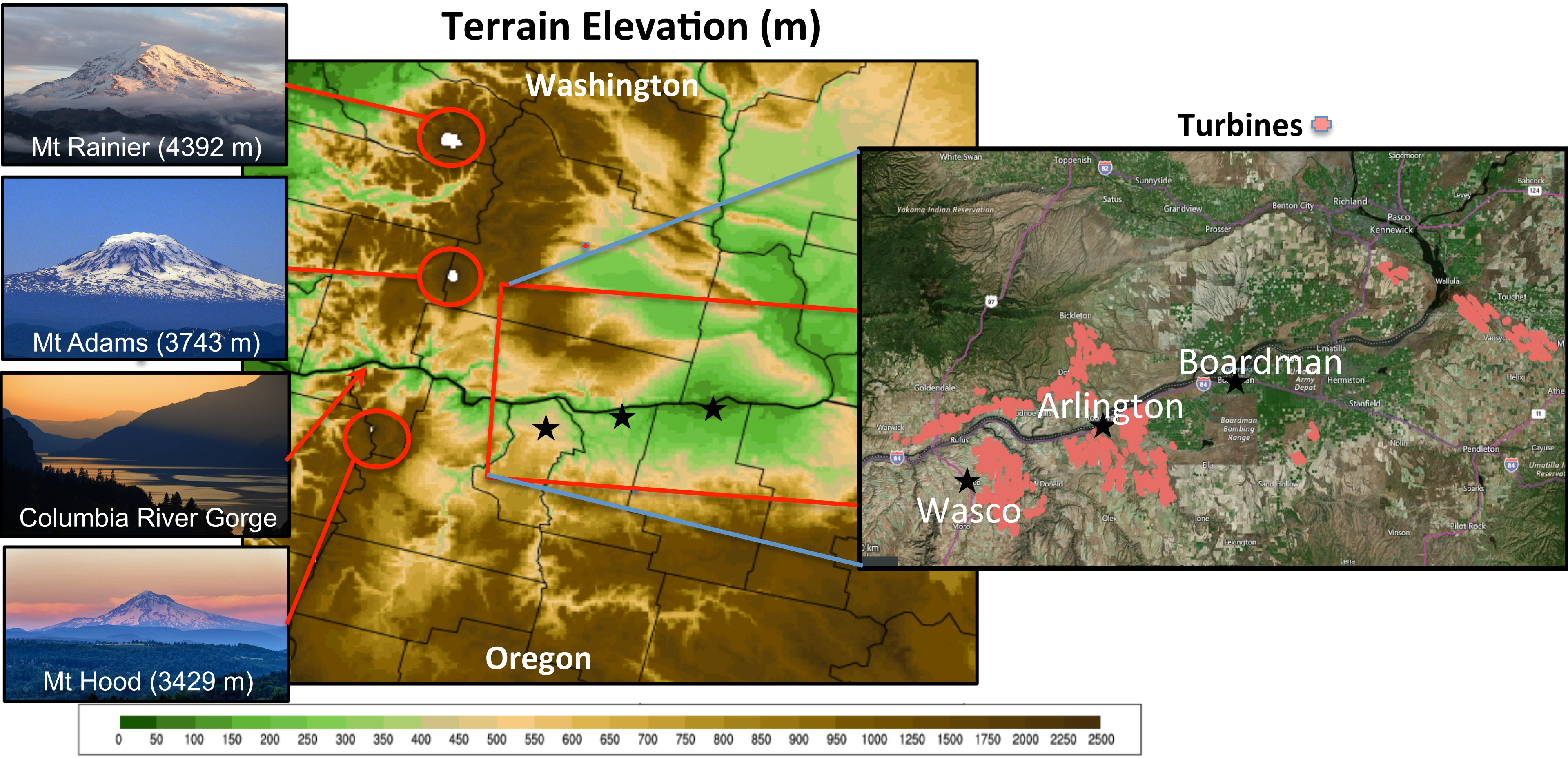
Slide courtesy of Jim Wilczak.

Field Project Dates: 01 October 2015 – 31 March 2017
Participants: DOE, NOAA, Vaisala, Sharply Focused, Texas Tech, University of Colorado, Notre Dame
Goal: **To improve wind speeds forecasts in the turbine rotor layer by improving model physical parameterizations and numerical methods.**

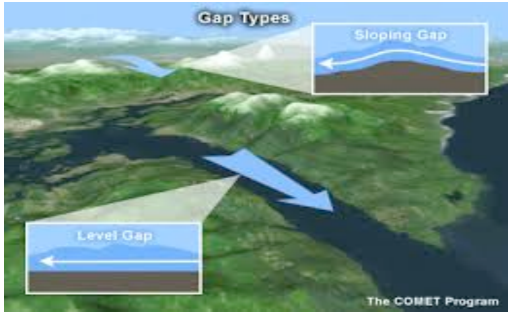
Instruments Deployed

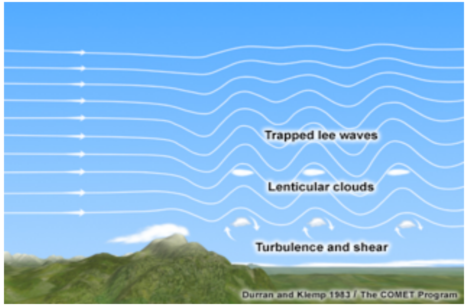
- 11 wind profiling radars
- 17 sodars
- 5 wind profiling lidars
- 4 scanning lidars
- 4 radiometers
- 10 microbarographs
- 1 ceilometer
- 2 scanning radars
- 28 sonic anemometers
- 5 surface energy balance
- 1 SurfRad
- 2 RadSys

Topography and Wind Farms in the WFIP2 Study Region

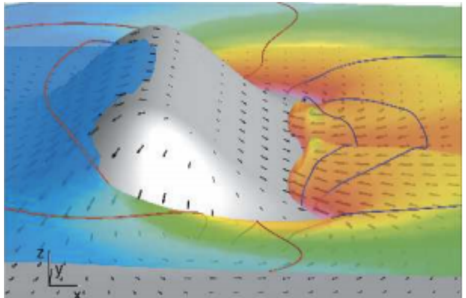


Forecast Challenges

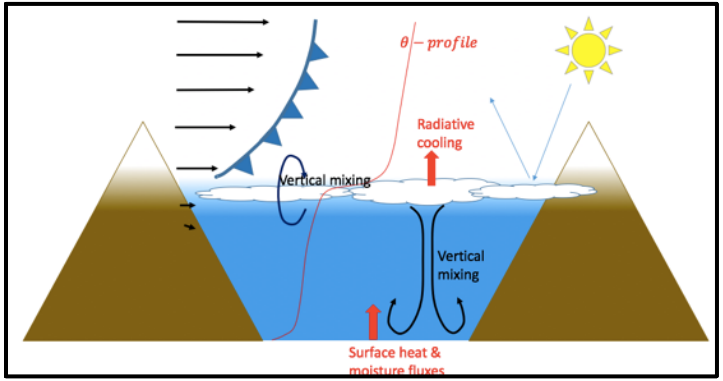




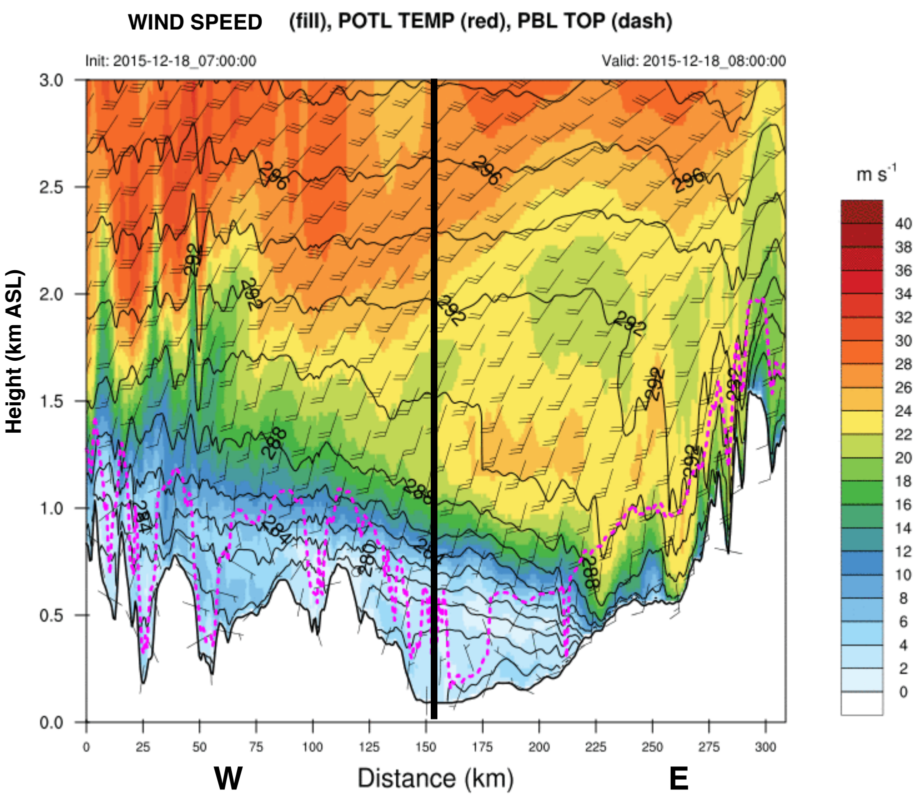
- Gap Flows
- Mountain Waves
- Topographic Wakes
- Marine Pushes/Thermal Troughs
- Cold Pool Mix-Outs
  - Cold pools shield the wind farms from wind resources aloft.
  - Models typically struggle with maintaining cold pools.

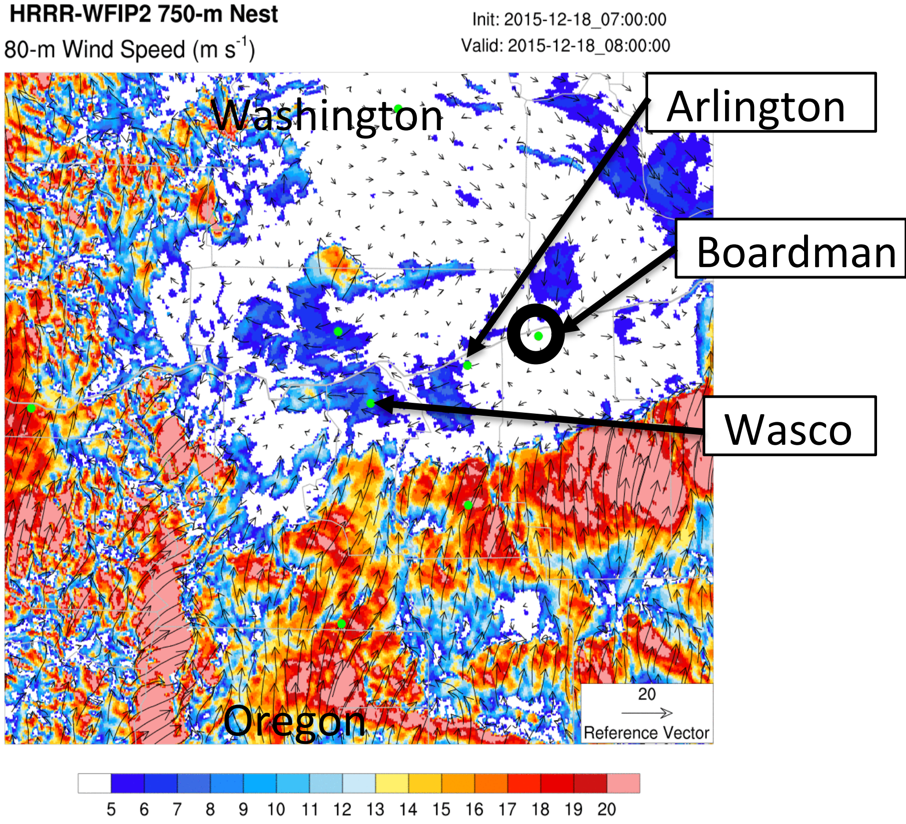


Epifanio and Rotunno (2005, JAS)



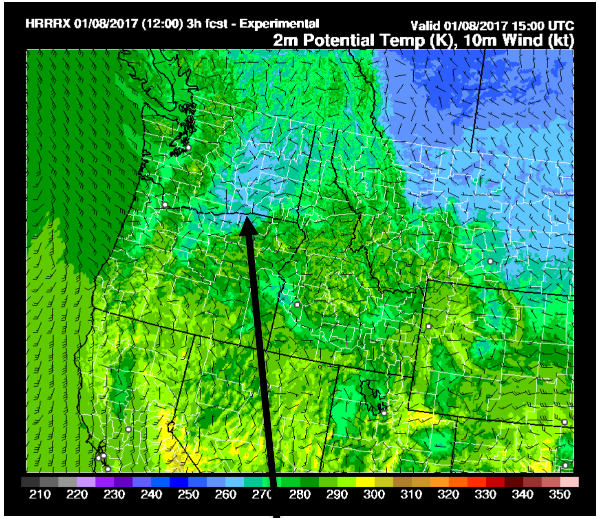
Example of Cold Pool Mix-Out





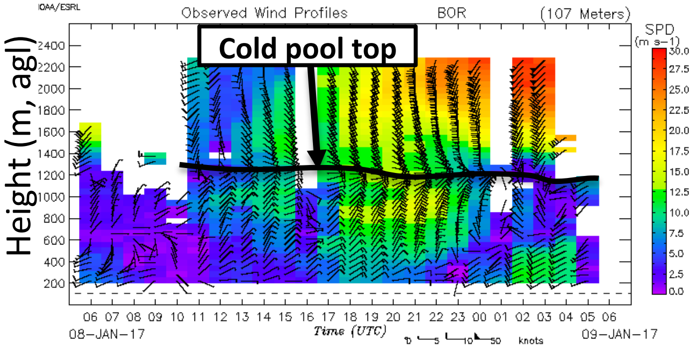
Center Point: Boardman, OR

Systematic Biases in Cold Pool Events

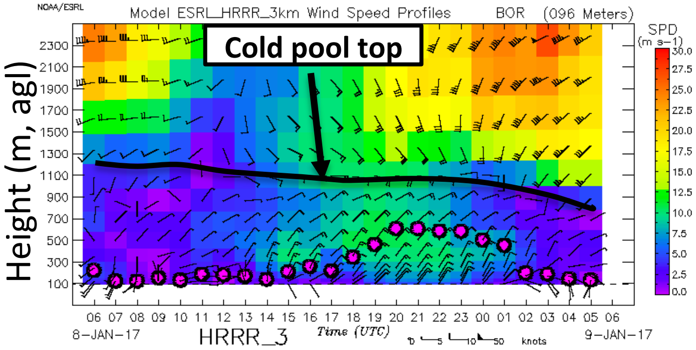


Boardman, OR

Observed Winds



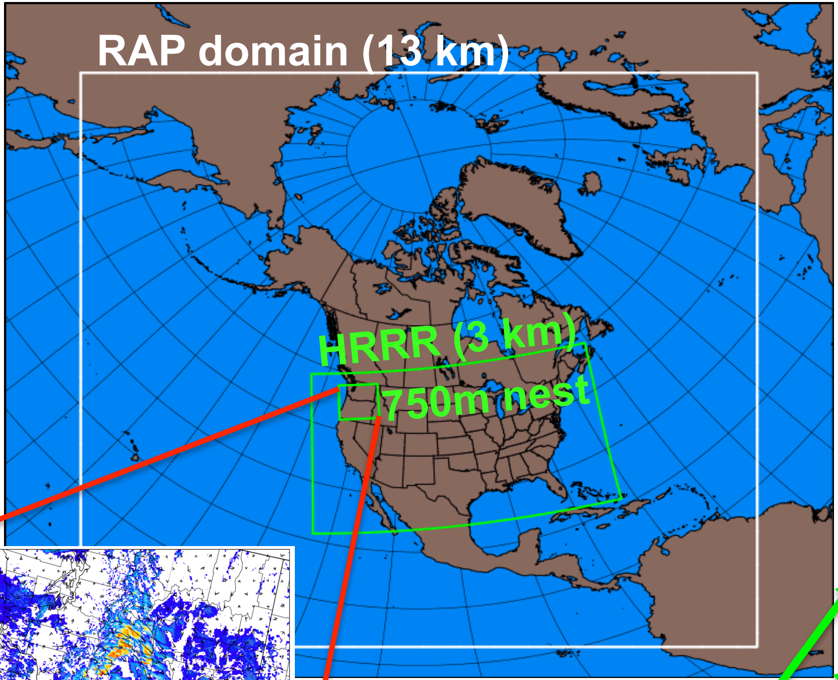
Model Winds

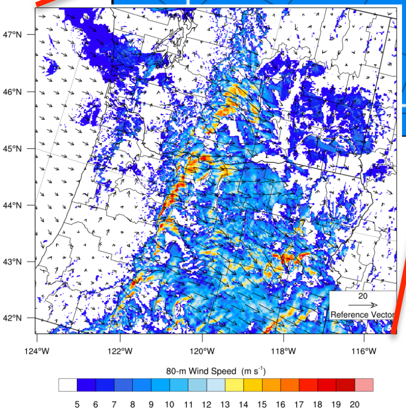


Time (UTC)

- Model is generally shallow-biased w.r.t. cold pool depths.
- Easterly current within cold pools are typically high-biased near the surface.

Model Development within RAP/HRRR





Terrain-specific modifications

Model Component	Original	New
LSM	RUC 9-level	RUC 9-level
Surface layer	MYNN-old	MYNN
PBL	MYNN level 2.5-old	MYNN-EDMF
SW Radiation	RRTMG	RRTMG
LW Radiation	RRTMG	RRTMG
Microphysics	Thompson Aero	Thompson Aero
Deep Convection	Grell-Freitas	Grell-Freitas
Shallow Convection	Grell-Freitas	---
Horizontal Diffusion	Smag on sigma	Smag on X-Y-Z
Small-Scale Gravity Wave Drag	---	Steeneveld et al. 2007 JAMC
Wind Farm Drag	---	Fitch et al. 2012 MWR
Vertical Coordinate	sigma	Hybrid sigma-P
Vertical levels	51 levels	51 levels

Notes on Model Physics Changes to Improve Cold Pools

MYNN-EDMF

1. **Mixing Length (bl_mynn_mixlength = 1 to 2):** reduced magnitude in stable conditions.
2. **Mass-Flux Scheme:** essentially inactive in cold pool situations.

Horizontal Diffusion

1. **Switching from diff_opt = 1 to 2:** mix along Cartesian coordinates.

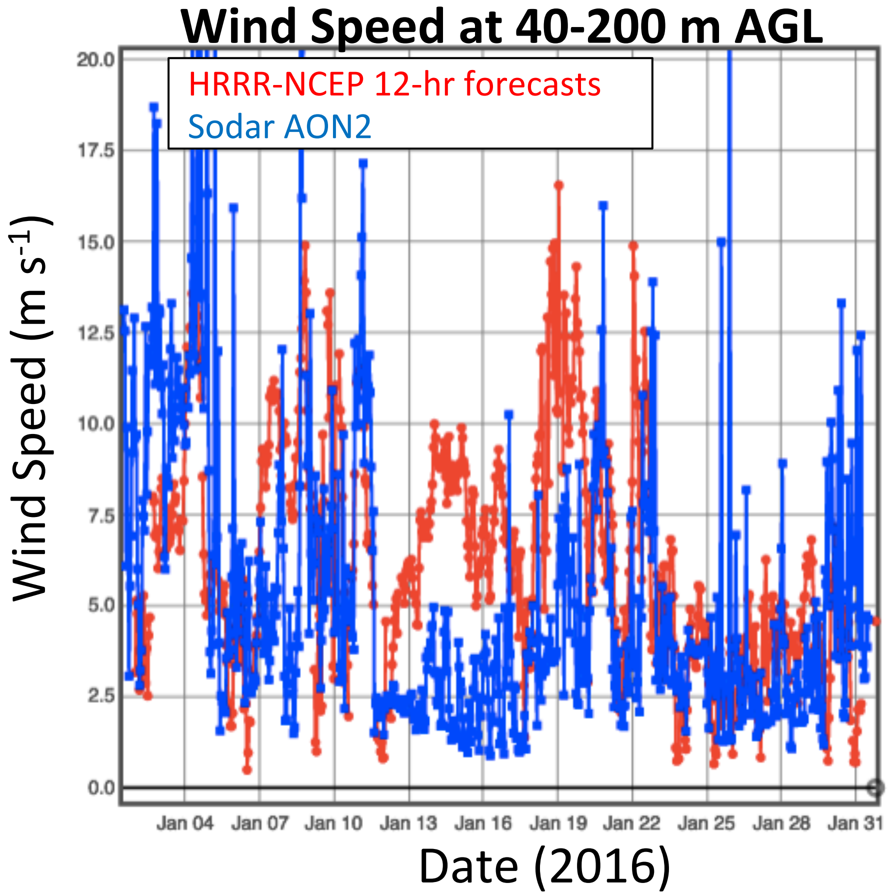
Small-Scale Gravity Wave Drag

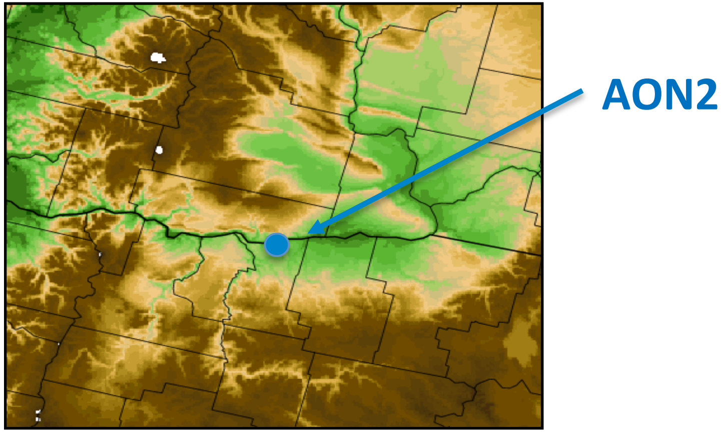
1. **Adapted from Steeneveld et al (2007, JAMC).**

$$\tau_{wave} = \begin{cases} \frac{1}{2}\rho_0 k_s H^2 NU, & \text{if } \frac{N}{U} \geq k_s \\ 0 & \text{if } \frac{N}{U} < k_s \end{cases} \qquad \tau_{wave}(z) = \tau_{wave}(0)\left(1 - \frac{z}{h}\right)^2$$

Where U has been changed from U_{PBLH} to U_1 and the drag has been made scale-aware so it can be applied down to dx=1 km, like so: $\tau\downarrow wave$ = $\tau\downarrow wave$ $f(\triangle x)$, where $f(\triangle x)$ =(1-$1000/\Delta x$).

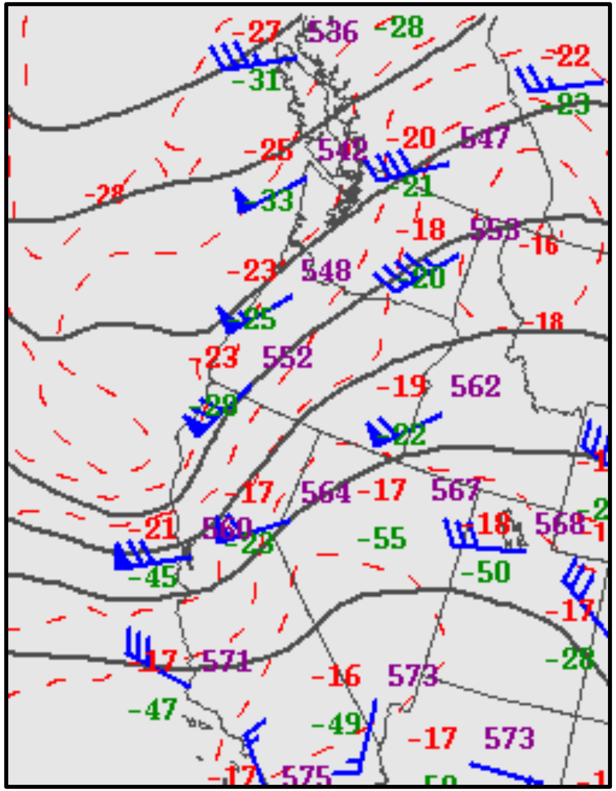
Selecting forecast busts from time series



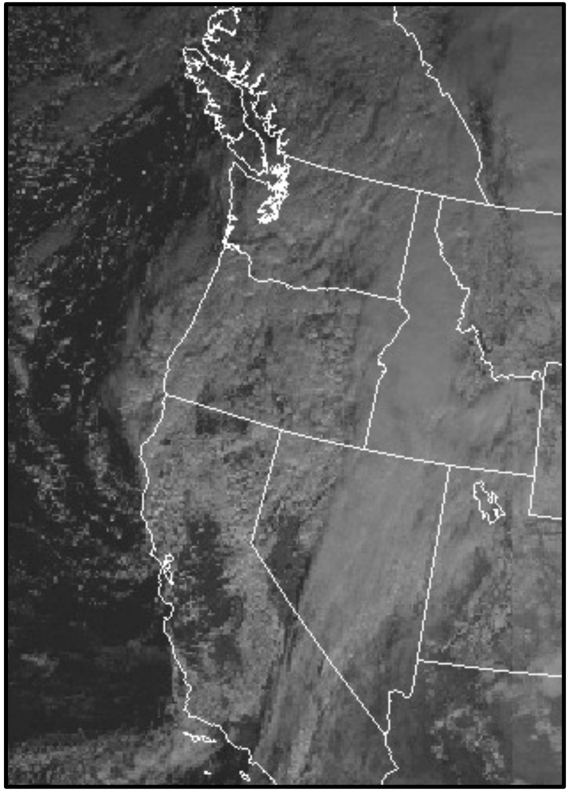


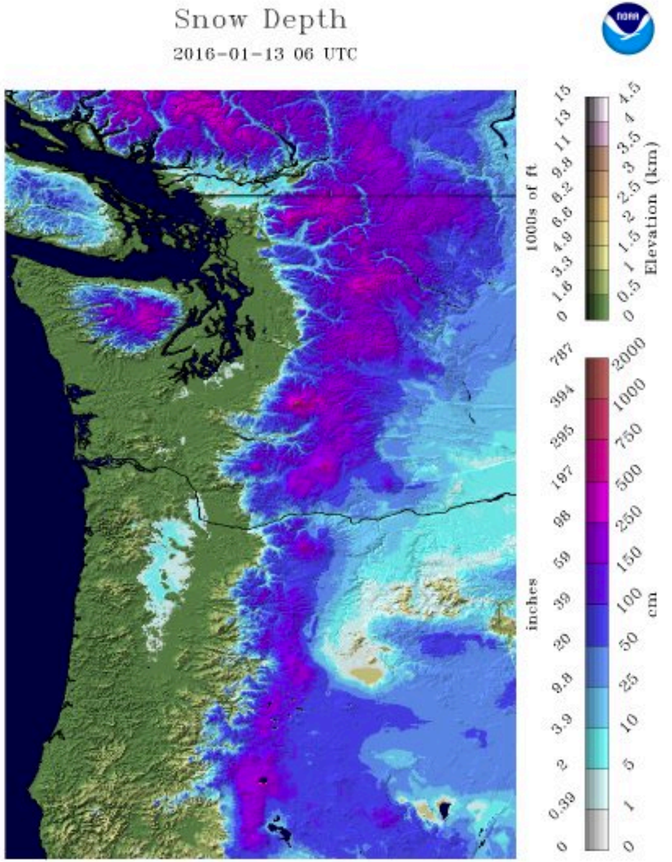
Cold Pool Mix-Out of 20160113

500 mb Height, Winds and Temp
12 UTC 13 Jan 2016

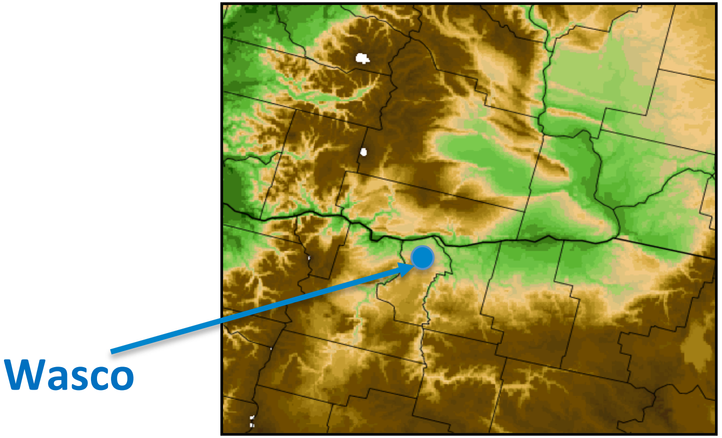


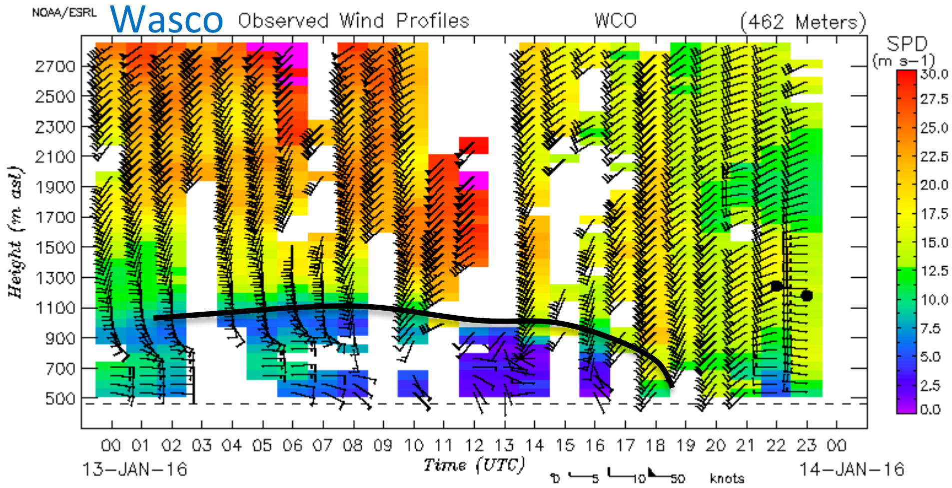
Visible Satellite
18 UTC 13 Jan 2016

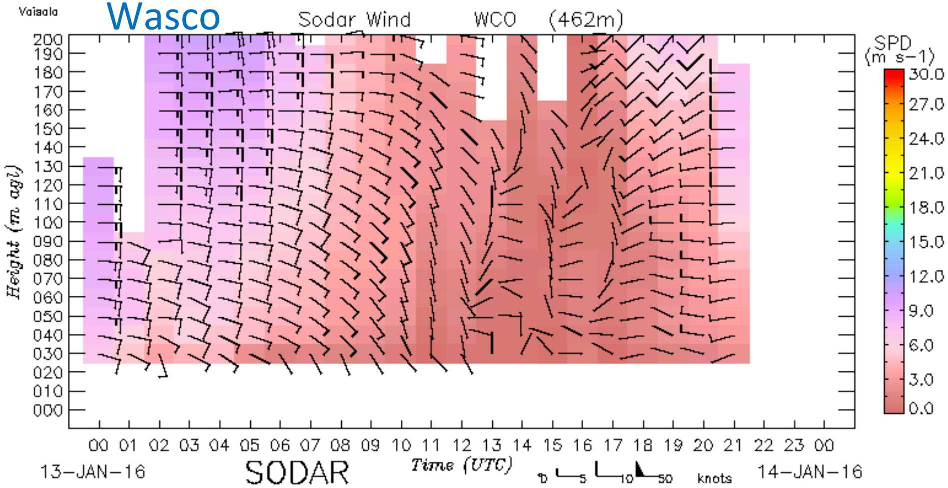




Cold Pool Mix-Out of 20160113

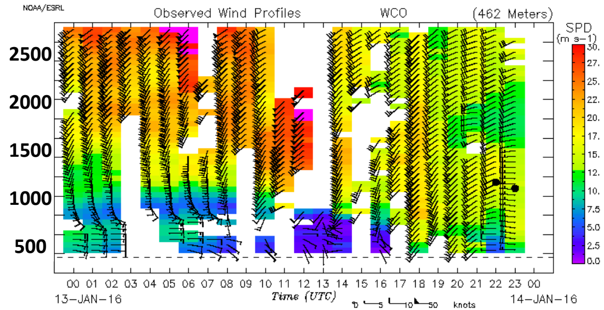




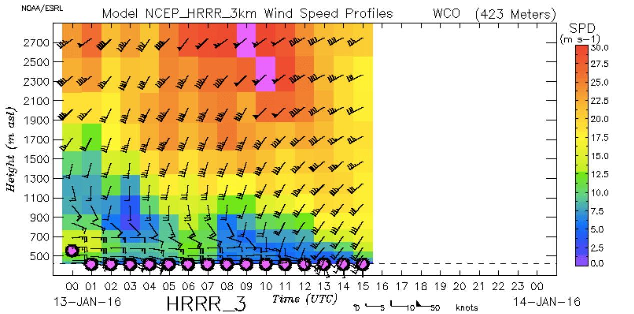


Evolution of Wind Speed Errors in the Real-time HRRR

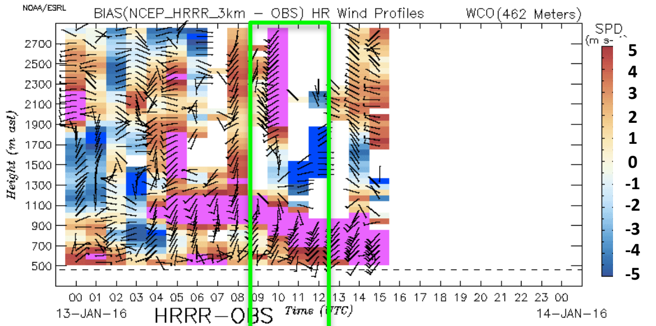
915 RWP at Wasco



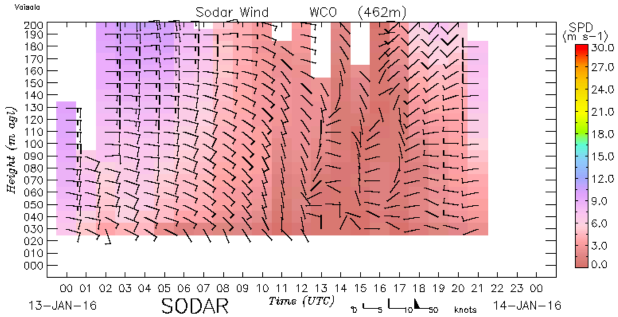
3-km Domain



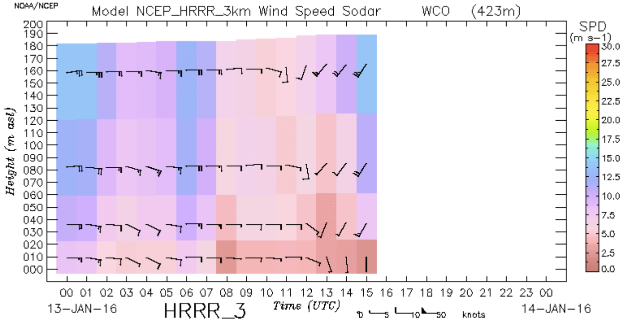
Difference



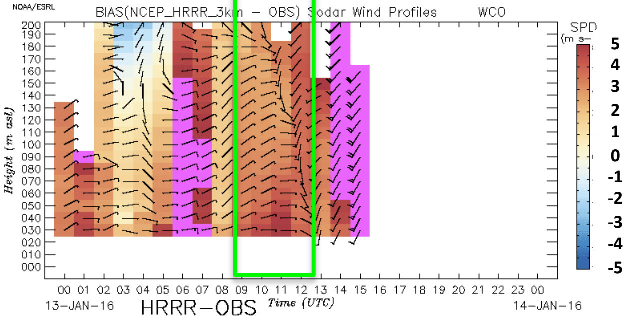
Sodar at Wasco



3-km Domain



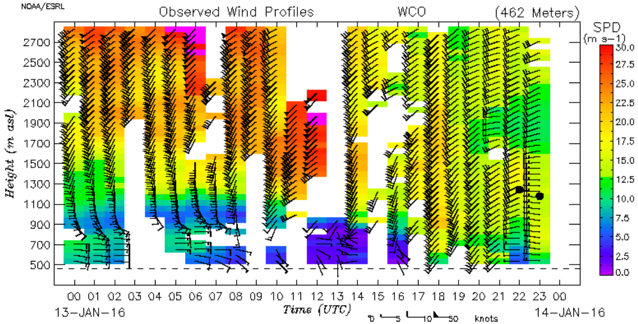
Difference

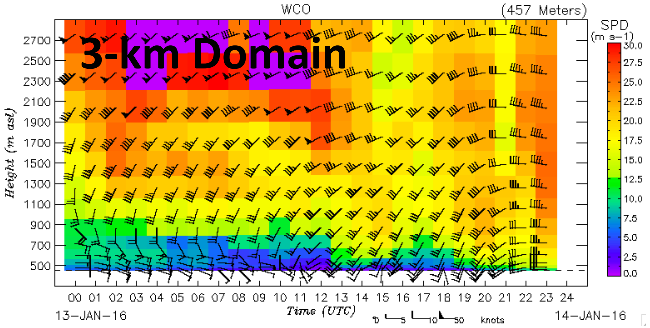


Note that the Wasco radiometer was not functioning during this event.

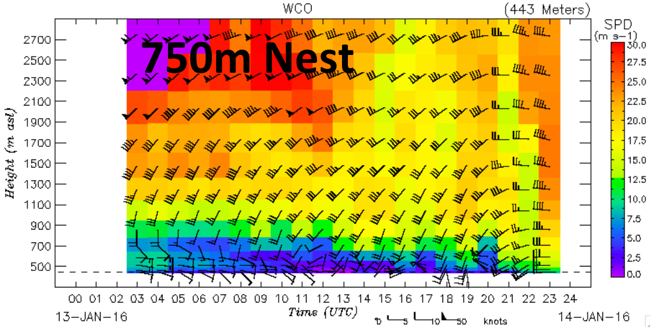
Results: Cold Pool Mix-Out of 20160113

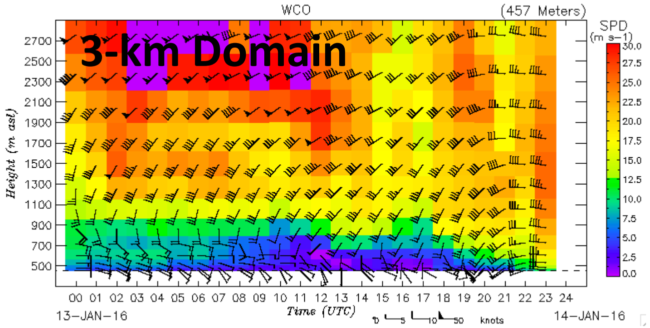
Wasco, Oregon



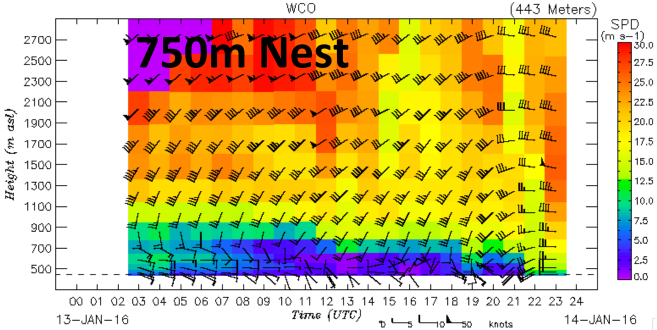


Original



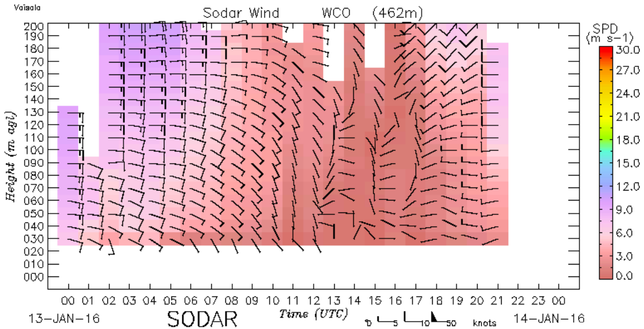


New
MYNN-EDMF
+Hor Diff
+GWD



Results: Cold Pool Mix-Out of 20160113

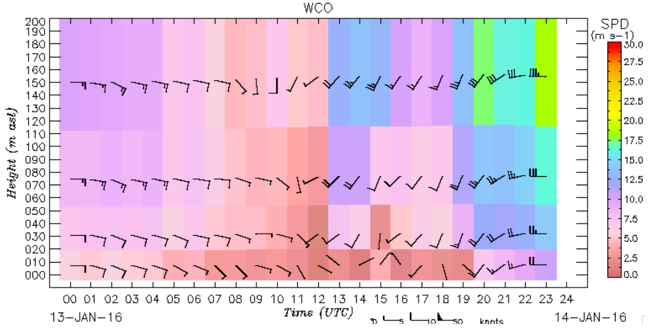
Wasco, Oregon

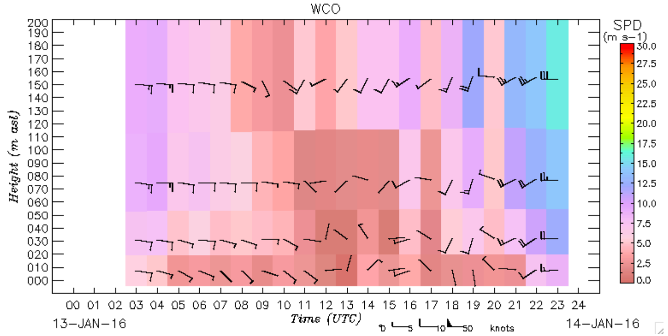


3-km Domain

750m Nest

Original



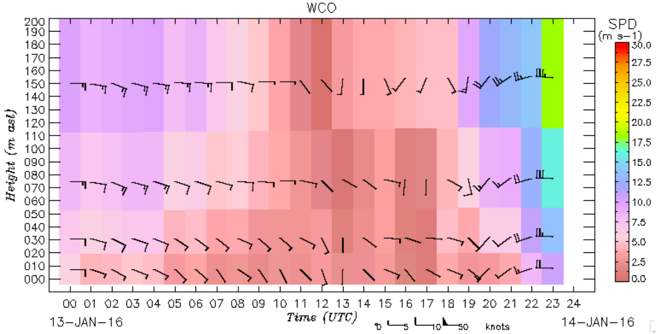


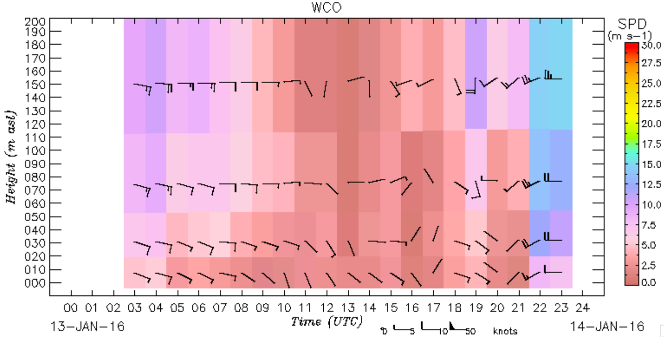
New

MYNN-EDMF

+Hor Diff

+GWD



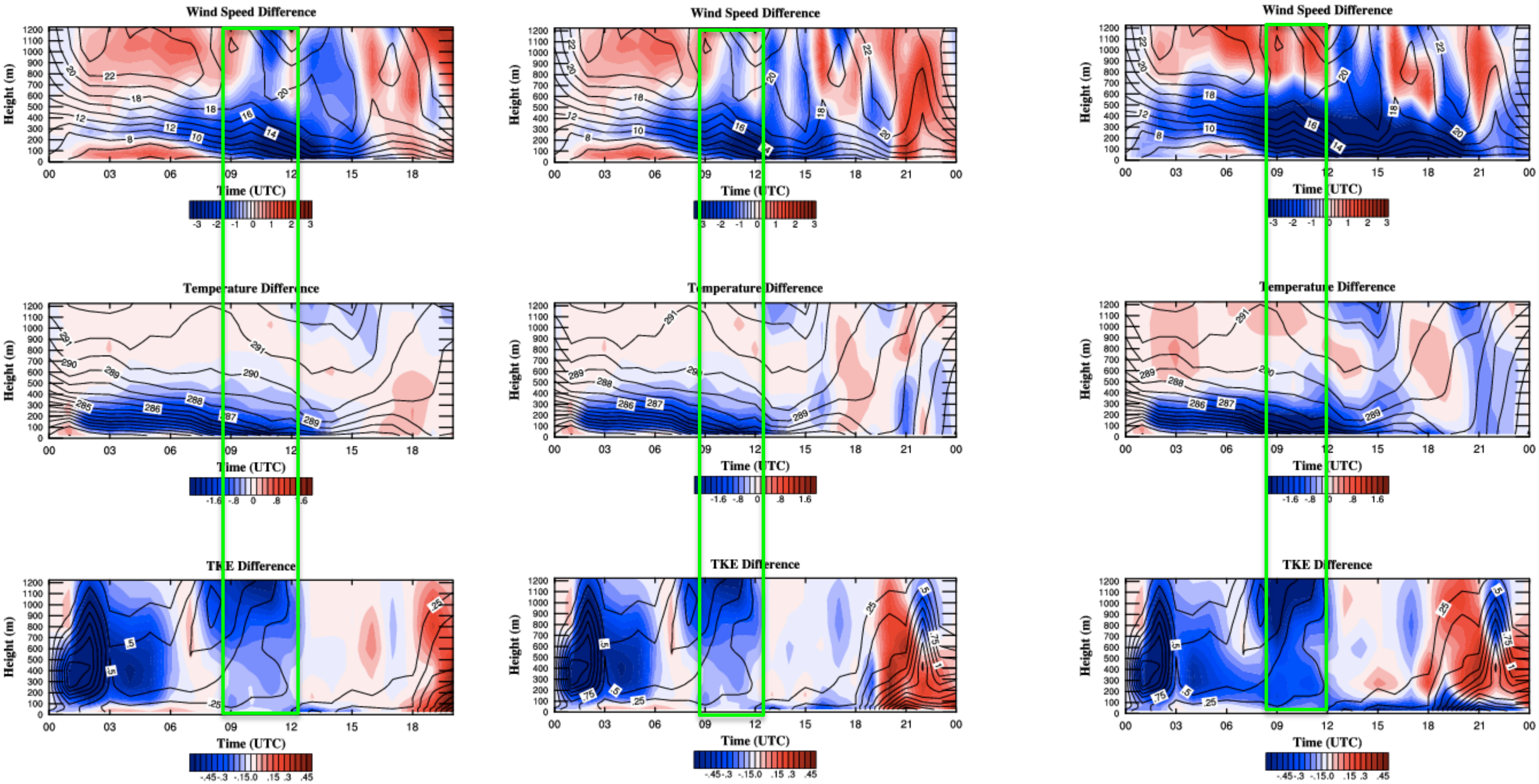


Results: Evolution of Profile Differences at Wasco

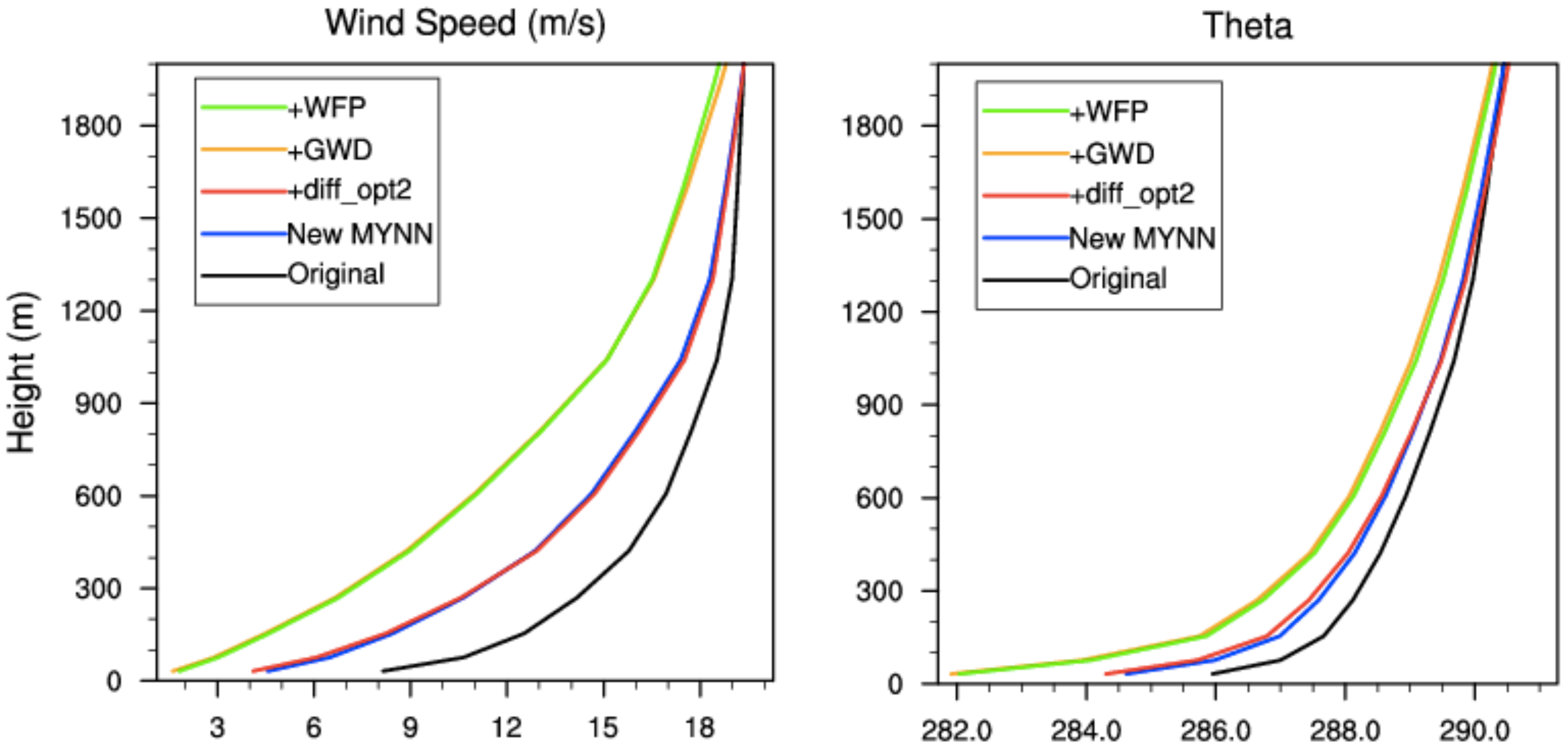
New MYNN - Original

(New MYNN + DO2) - Original

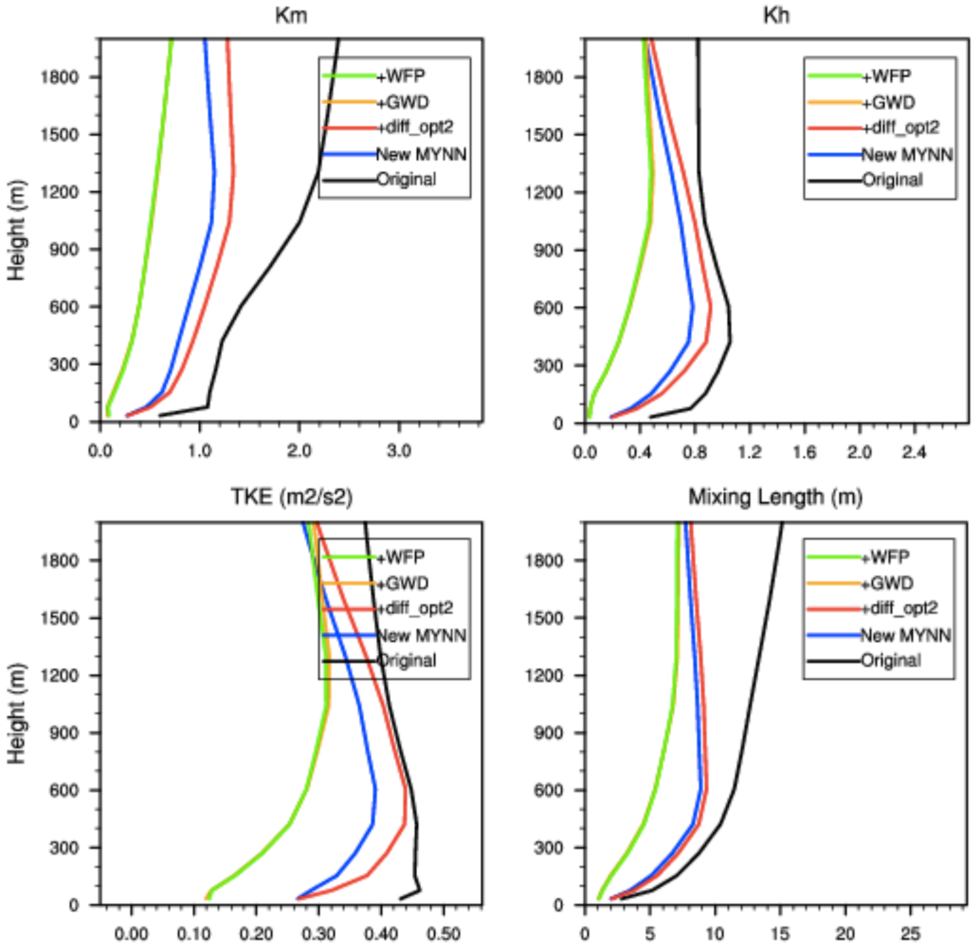
(New MYNN + DO2 + GWD) - Original



Results: Mean Profiles at Wasco at 09-12 UTC 20160113



Results: Mean Profiles at Wasco at 09-12 UTC 20160113



Summary

- **The WFIP2 Model Development Team has targeted improvements to many components of the model (both complex terrain-specific and general weather physics).**
  - Mass-Flux scheme (Wednesday Poster: Jaymes Kenyon)
  - Mixing length revision (Wednesday Poster: Jaymes Kenyon)
  - Small-Scale Gravity Wave Drag (Steeneveld et al. 2007, JAMC; NOT YET IN PUBLIC RELEASE OF WRF)
  - 3D Turbulence scheme (Tuesday's talk: Kosovic and Jimenez)
  - Hybrid vertical coordinate (Earlier this session: Jeff Beck and Sang-Hun Park)
  - Wind Farm Parameterization (Fitch et al. 2012 and Jimenez et al.)
- **The systematic biases associated with simulating cold pool mix-outs have been reduced.**
  - Cold pool at Wasco was ~4 C cooler.
    - Mixing length revision revision was responsible for ~40% of this improvement.
    - Small-scale gravity wave drag was responsible for ~60% of this improvement.
  - Improvement from horizontal diffusion on Cartesian coordinates (diff_opt=2) was only evident in narrow valleys/gorges – not in the middle of wider basins.
  - Little/no impact on low-level winds from the HVC or WFP for this event (not shown).
- **Not all cases are the same! (Not Shown)**
  - Much more subtle improvements in steady-state pools, where high-bias in easterly current is the biggest error – wind farm parameterization helps reduce that bias.
- **WFIP2 data is being QC'd and standardized.**
- **Long-term retrospective simulations are in progress to better summarize model improvements.**