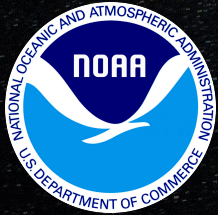


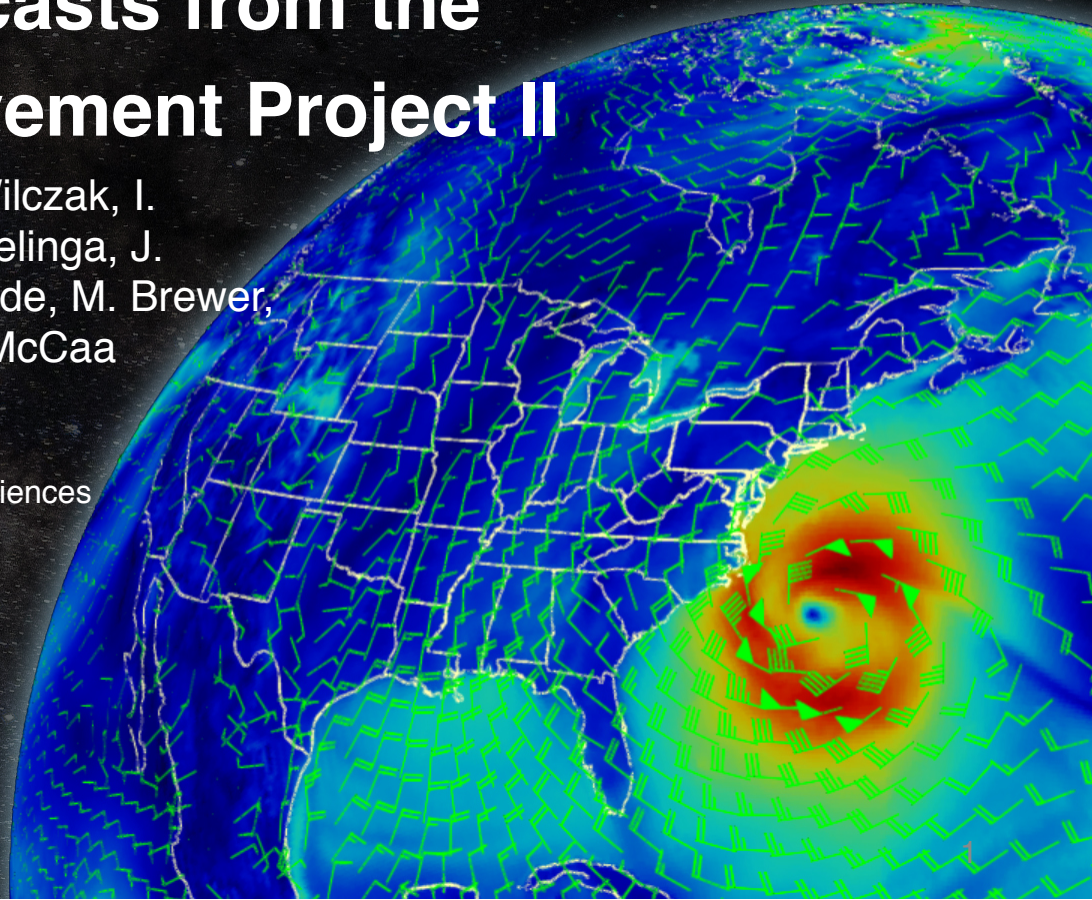
Case Studies of Improved HRRR Low-Level Wind Forecasts from the Wind Forecast Improvement Project II

Jaymes Kenyon, J. Olson, J. Brown, J. Wilczak, I.
Djalalova, W. Angevine, R. Banta, M. Stoelinga, J.
Sharp, E. Gritit, Q. Yang, L. Berg, K. Wade, M. Brewer,
R. Eckman, J. Cline, M. Marquis, and J. McCaa

NOAA / Earth System Research Laboratory, and
Cooperative Institute for Research in Environmental Sciences
Boulder, Colorado

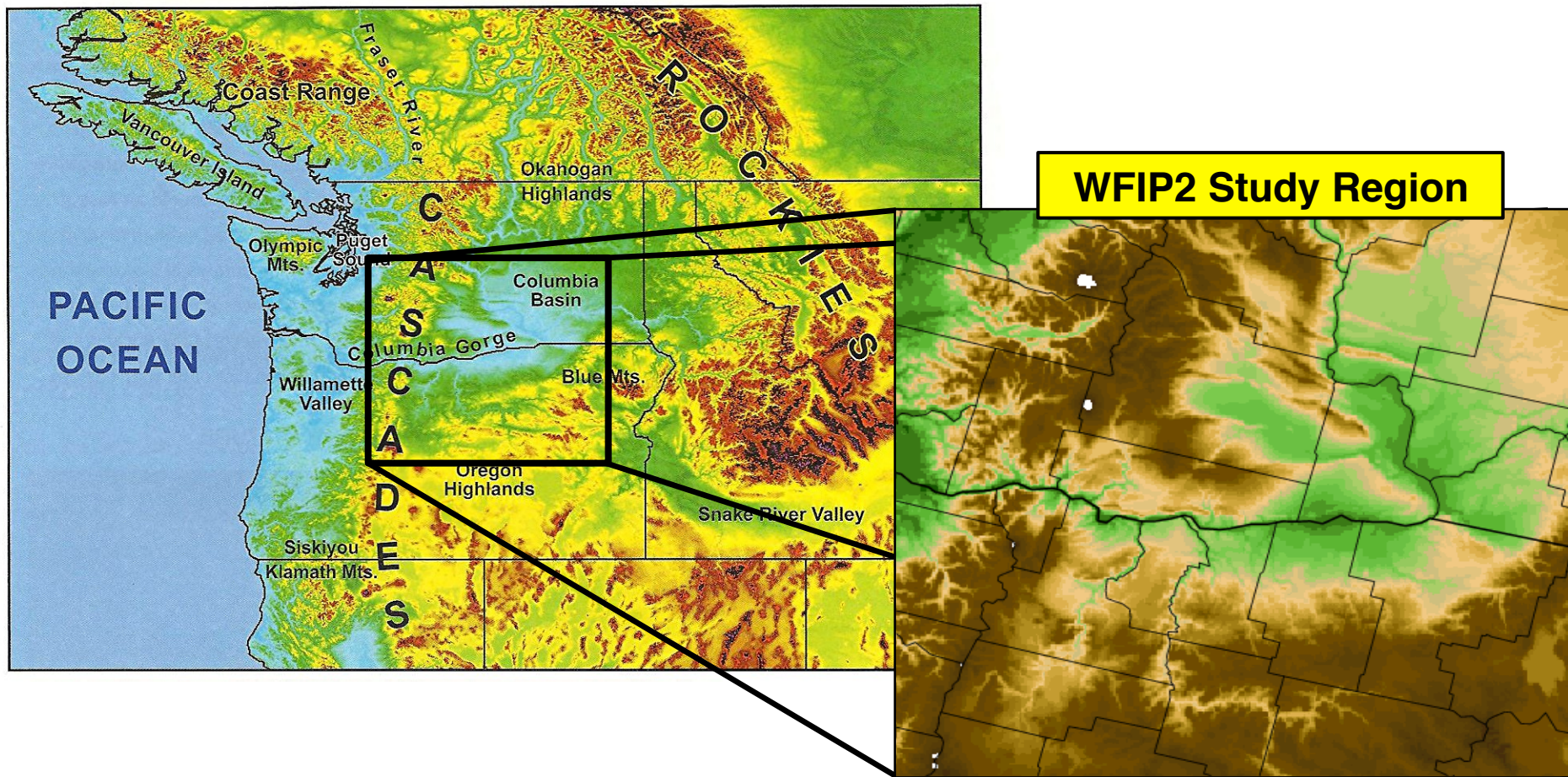


17th Annual WRF Users' Workshop
30 June 2016 | Boulder, Colorado, USA



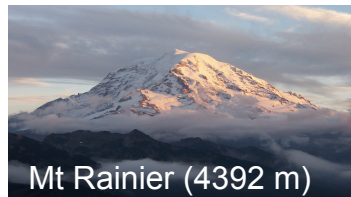


Motivation: Improve Wind Forecasts in Complex Terrain





Motivation: Improve Wind Forecasts in Complex Terrain



Mt Rainier (4392 m)



Mt Adams (3743 m)

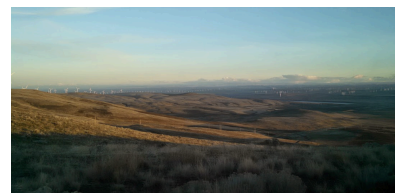
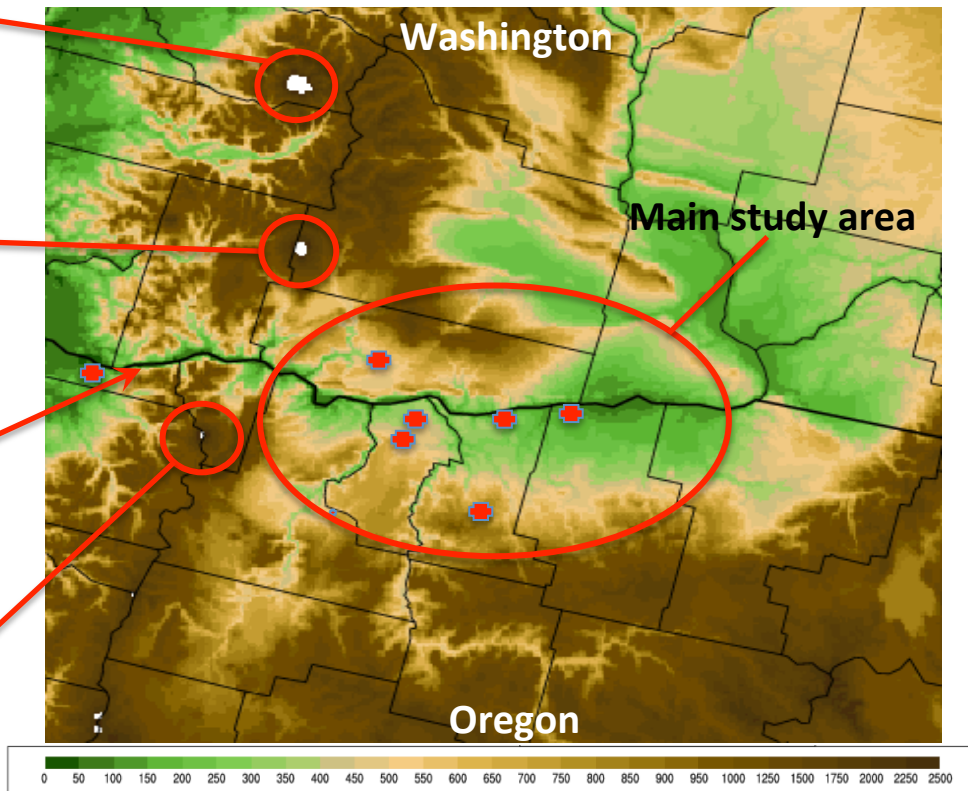


Columbia River Gorge



Mt Hood (3429 m)

Terrain Elevation (m) in HRRR-WFIP2 Nest



RAP and HRRR: Hourly-Updated Forecast Models

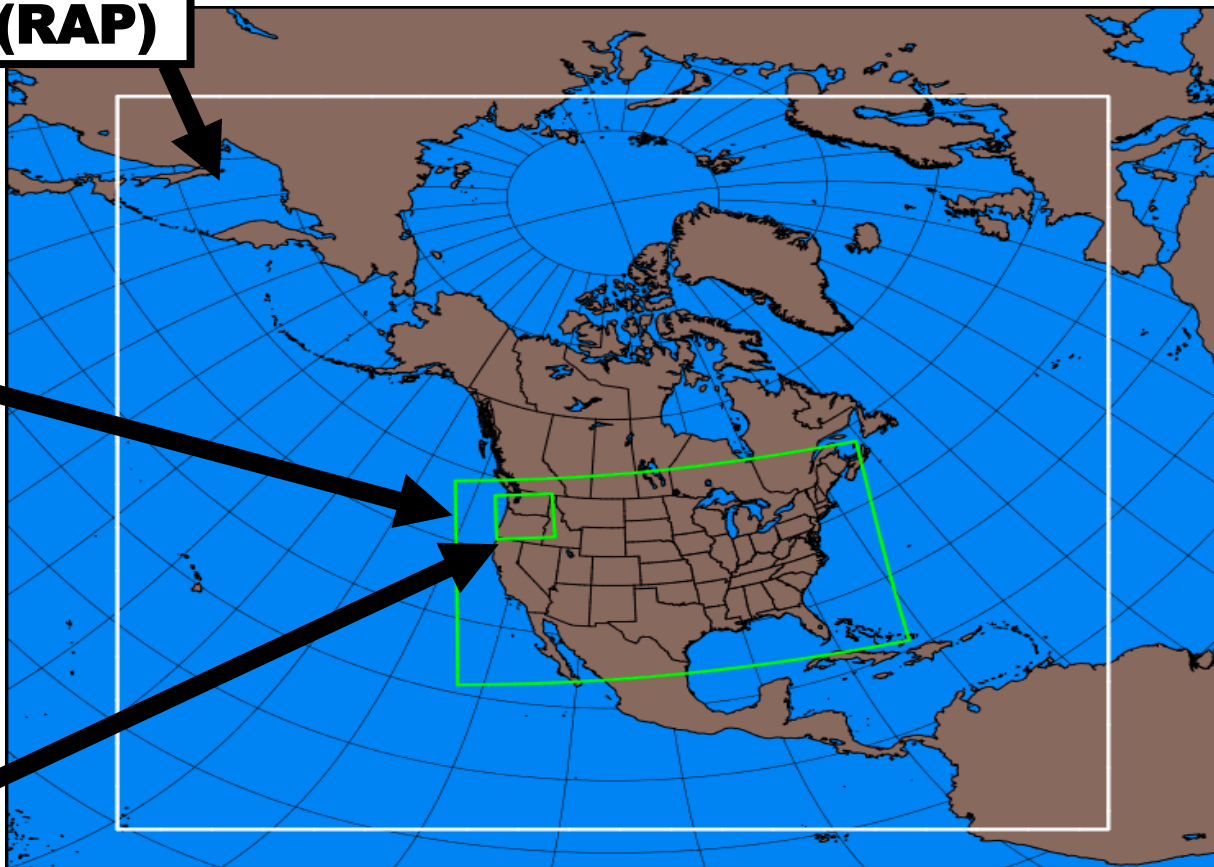
13-km Rapid Refresh (RAP)

Initial & Lateral Boundary
Conditions

3-km High-Resolution Rapid Refresh (HRRR)

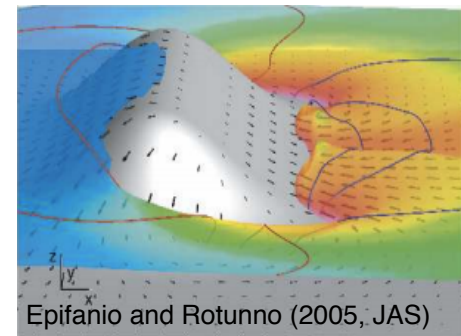
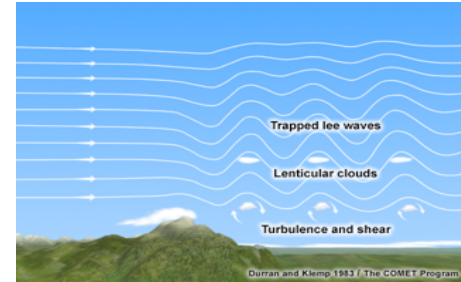
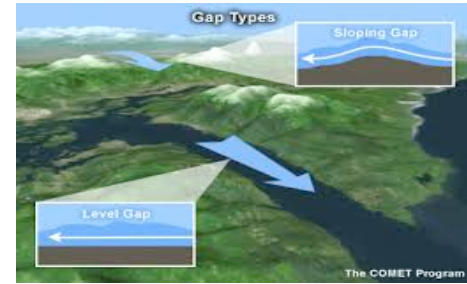
Initial & Lateral Boundary
Conditions

750-m HRRR-WFIP2 nest

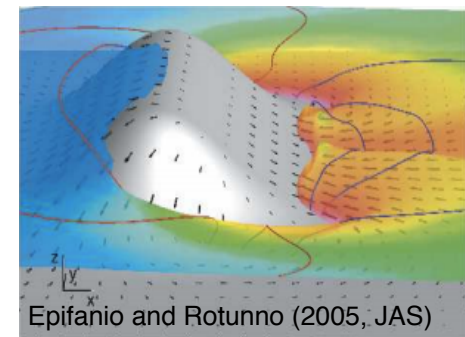
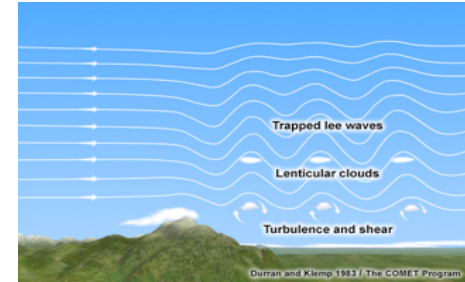
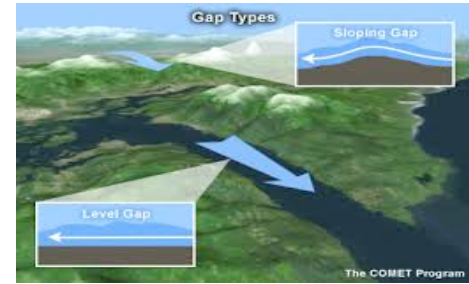


WFIP2 Meteorology

- Gap Flows
- Convective Outflows
- Mountain Waves
- Topographic Wakes
- Marine Pushes
- Frontal Passages with Stable Mix-Out



- Gap Flows
- Convective Outflows
- Mountain Waves
- Topographic Wakes
- Marine Pushes
- Frontal Passages with Stable Mix-Out
 - 18 December 2015
 - 8 December 2015



**Stable Air
Mix-Out:**

***Antecedent
Context***

WFIP2 Study Region

2 Days Prior: 1200 UTC 16 December 2015

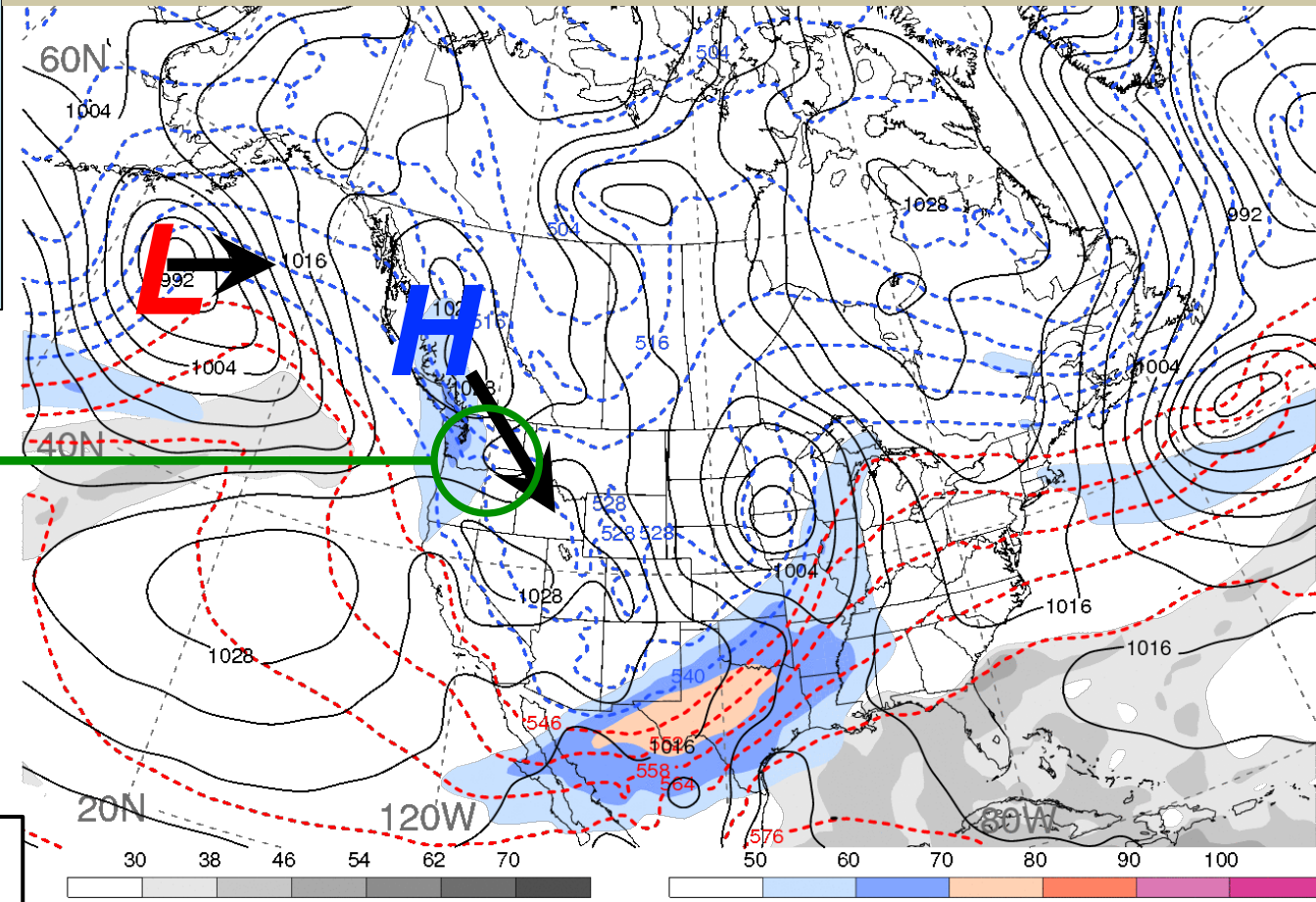


Image Source:
Heather Archambault,
www.met.nps.edu/~hmarcham/

1000–500 hPa Thick, PW, SLP, 250 hPa Wnd at 151216/1200

**Stable Air
Mix-Out:**

***Antecedent
Context***

1 Day Prior: 1200 UTC 17 December 2015

WFIP2 Study Region

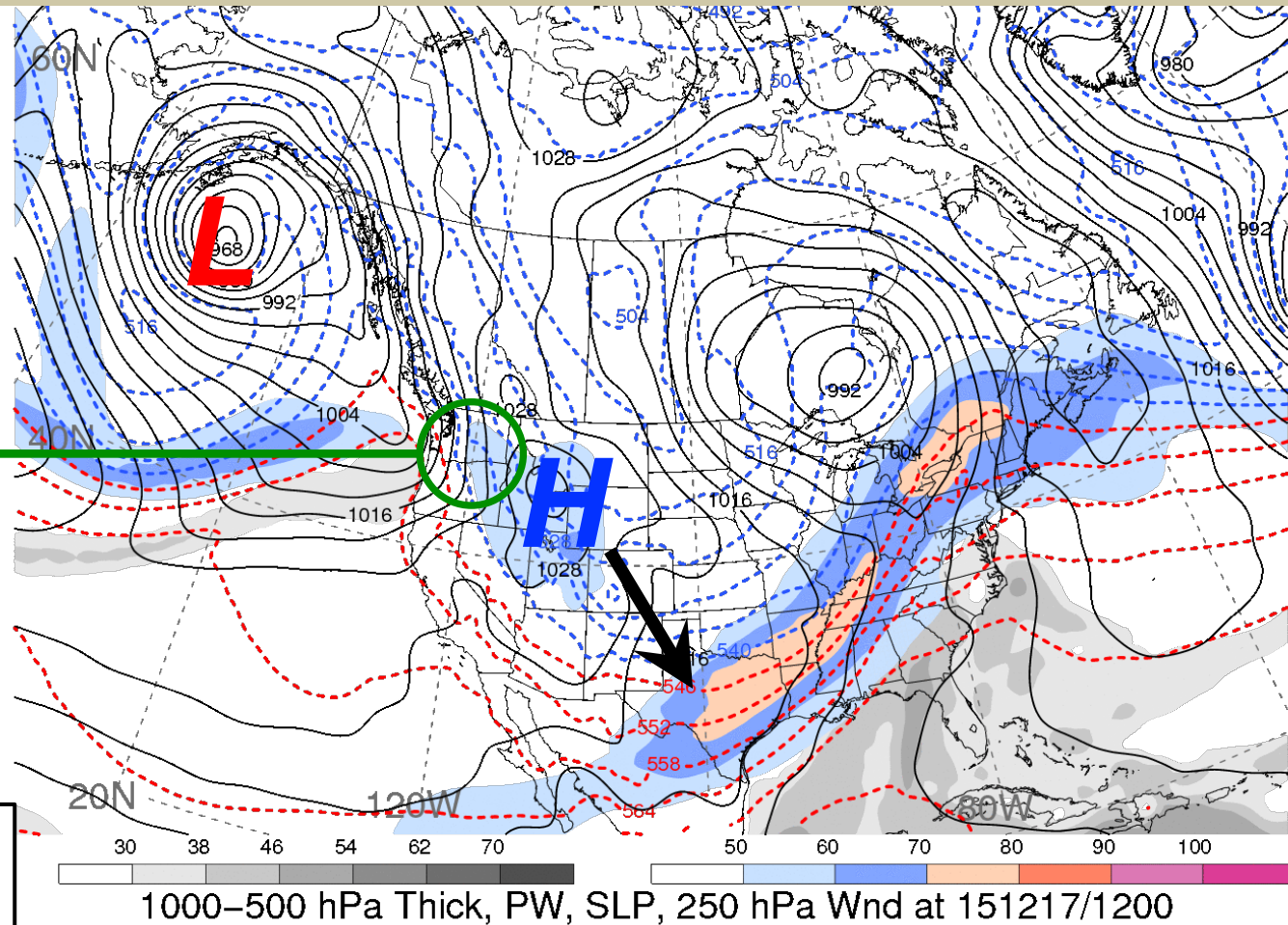


Image Source:
Heather Archambault,
www.met.nps.edu/~hmarcham/

**Stable Air
Mix-Out:**

***Antecedent
Context***

WFIP2 Study Region

Hours Prior: 1200 UTC 18 December 2015

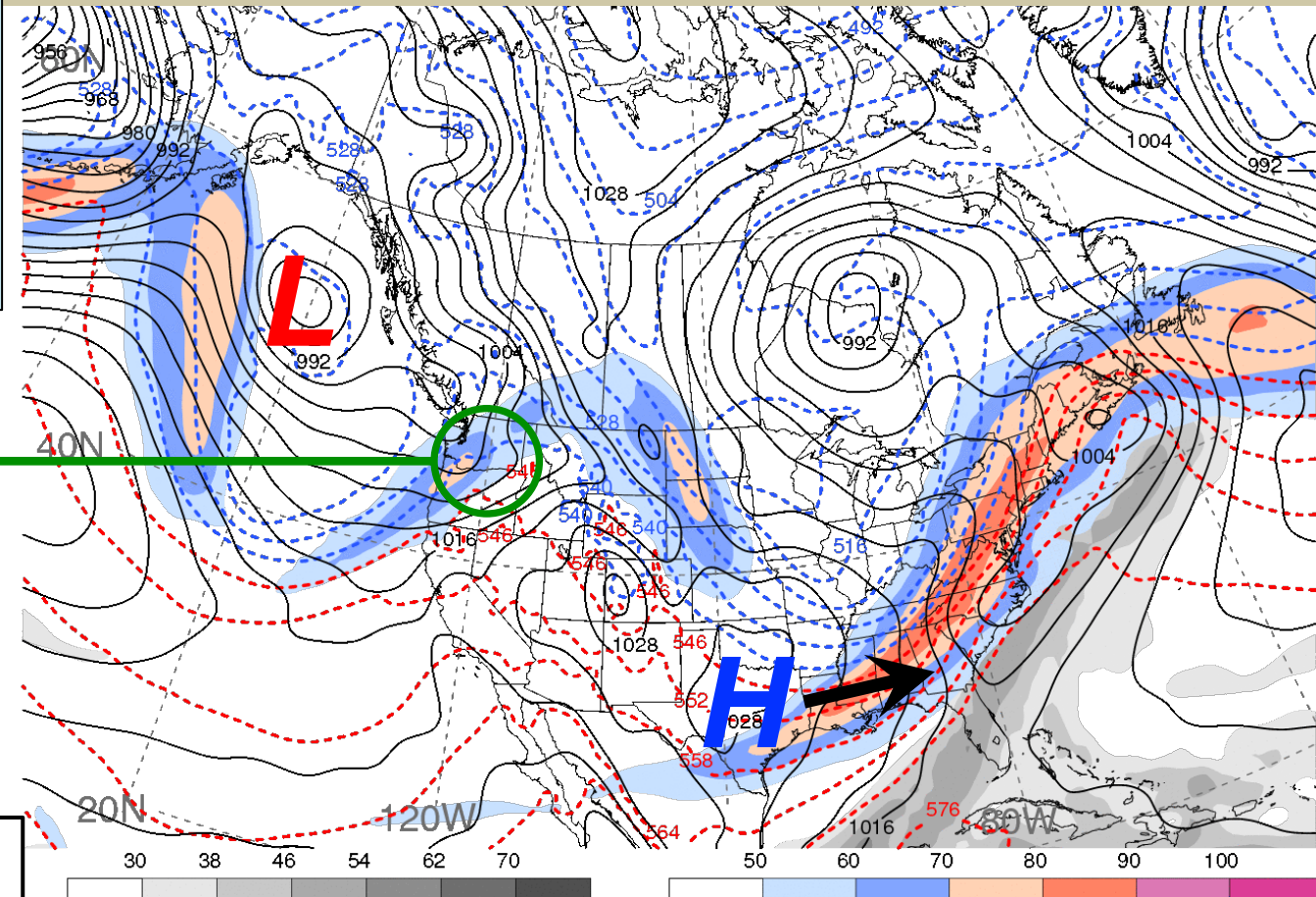


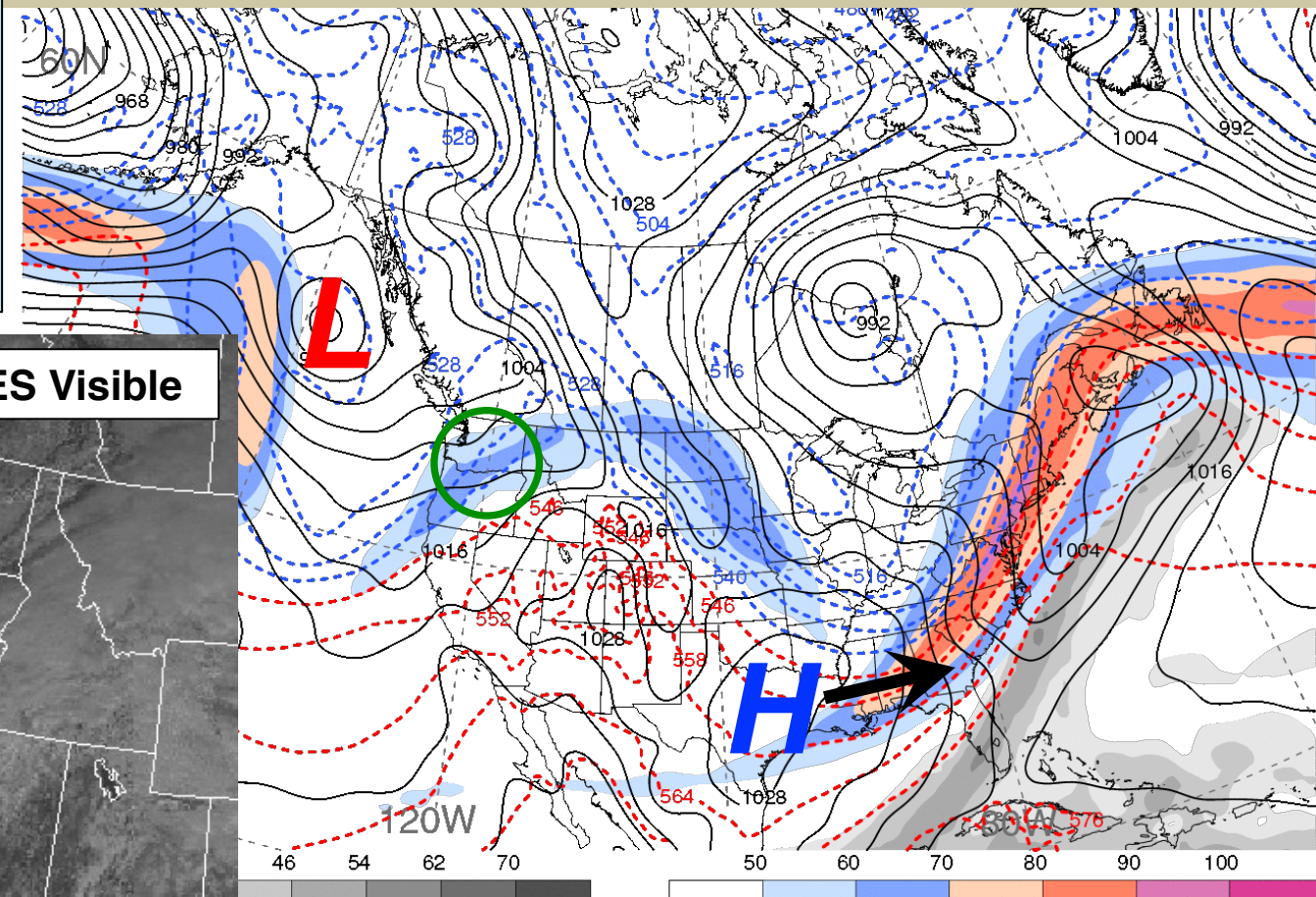
Image Source:
Heather Archambault,
www.met.nps.edu/~hmarcham/

1000–500 hPa Thick, PW, SLP, 250 hPa Wnd at 151218/1200

**Stable Air
Mix-Out:**

***Antecedent
Context***

1800 UTC 18 December 2015



GOES Visible

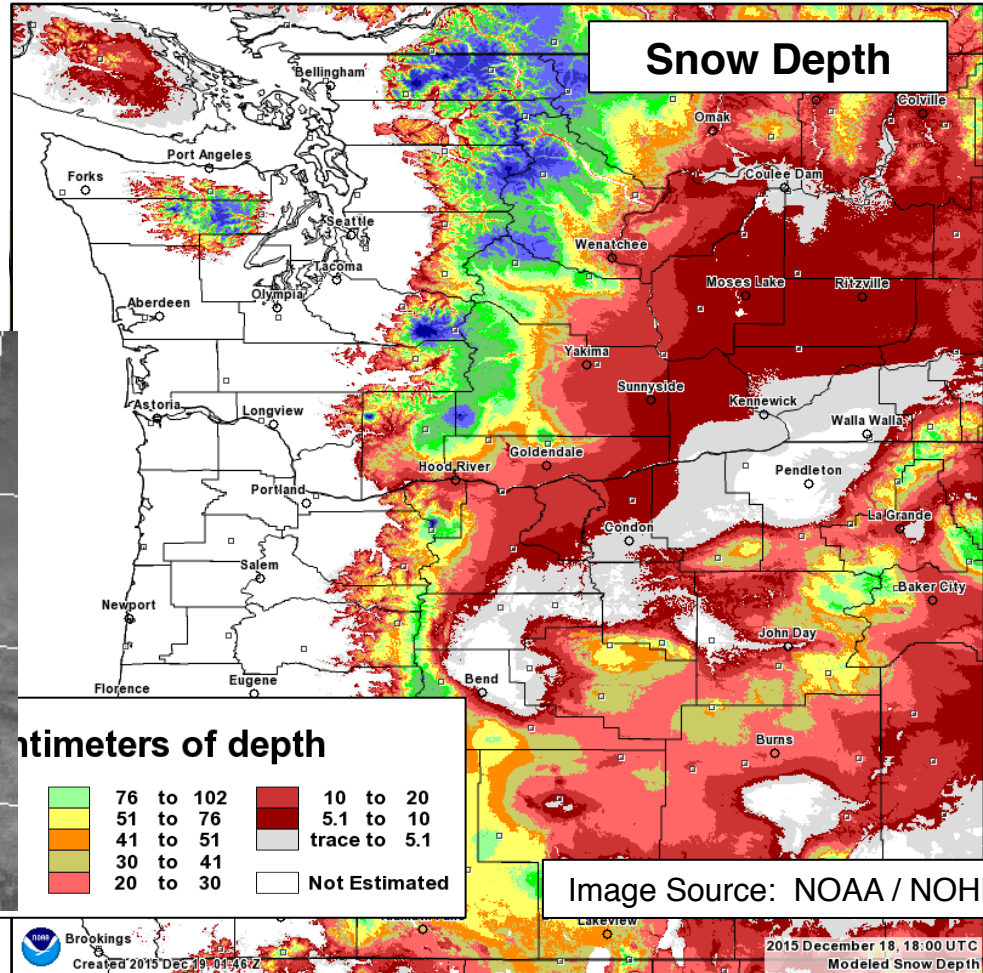
Image Source: UCAR

1000–500 hPa Thick, PW, SLP, 250 hPa Wnd at 151218/1800

**Stable Air
Mix-Out:**

***Antecedent
Context***

1800 UTC 18 December 2015

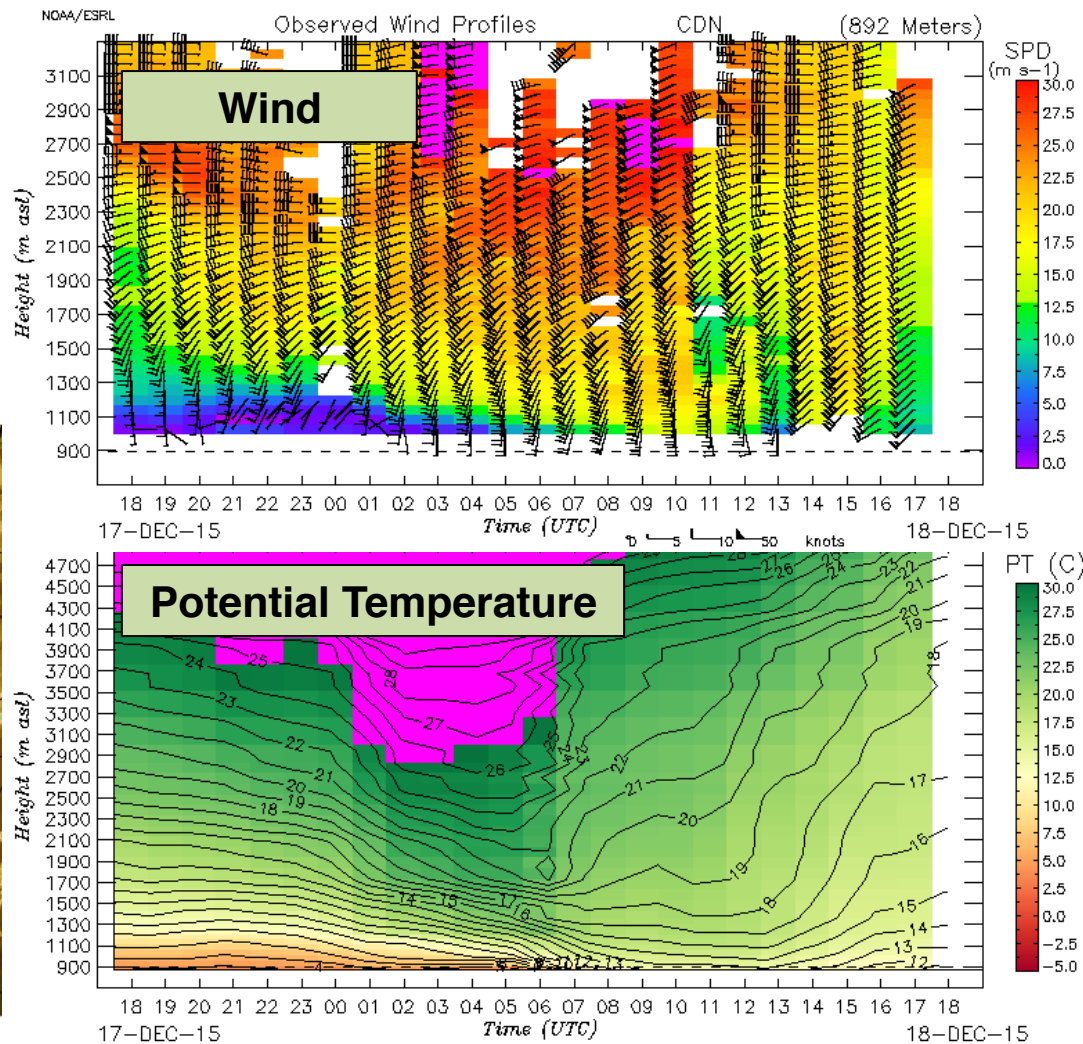
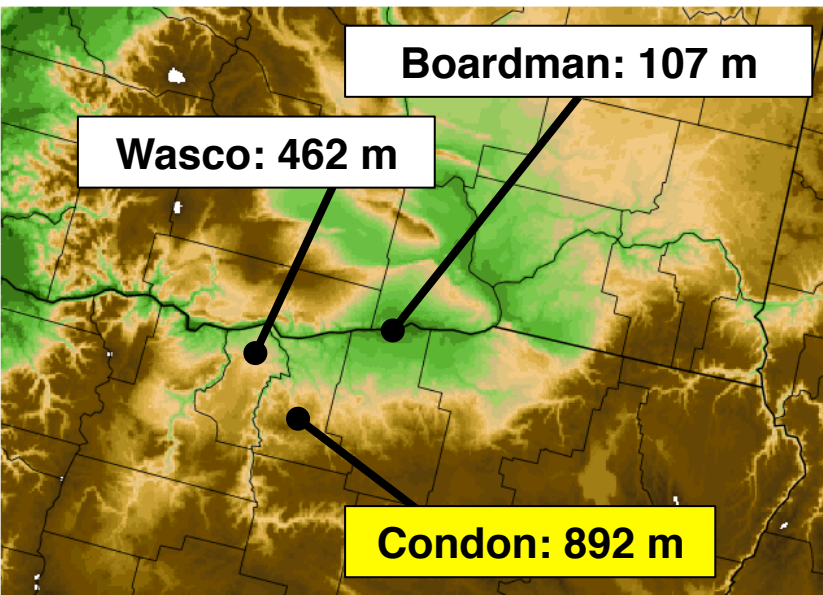


GOES Visible

Image Source: UCAR

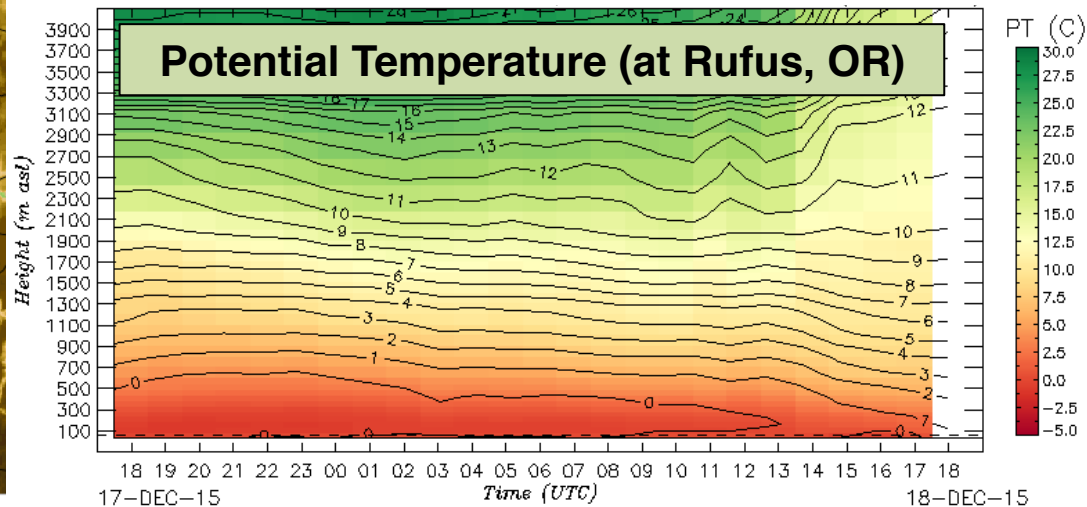
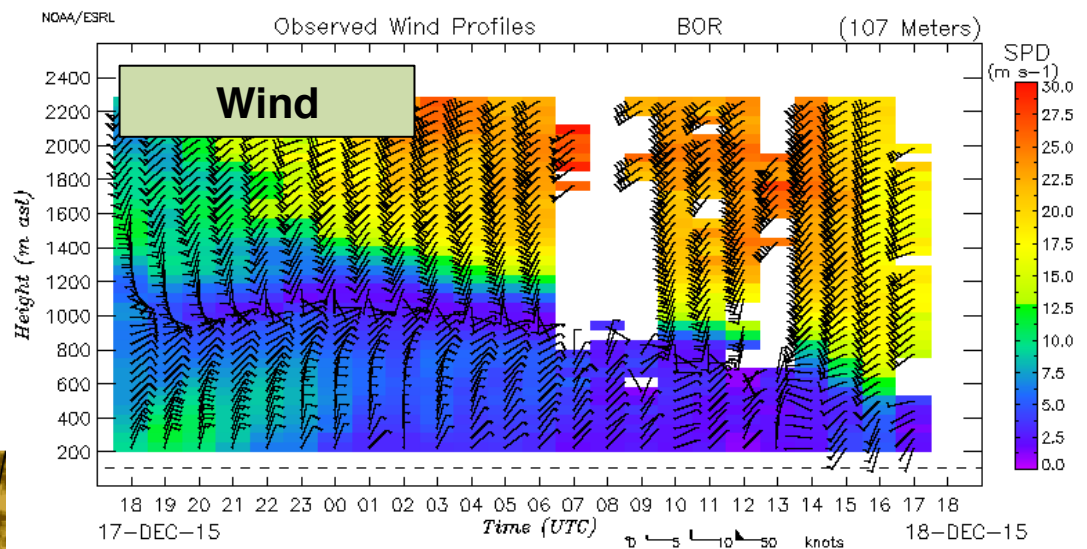
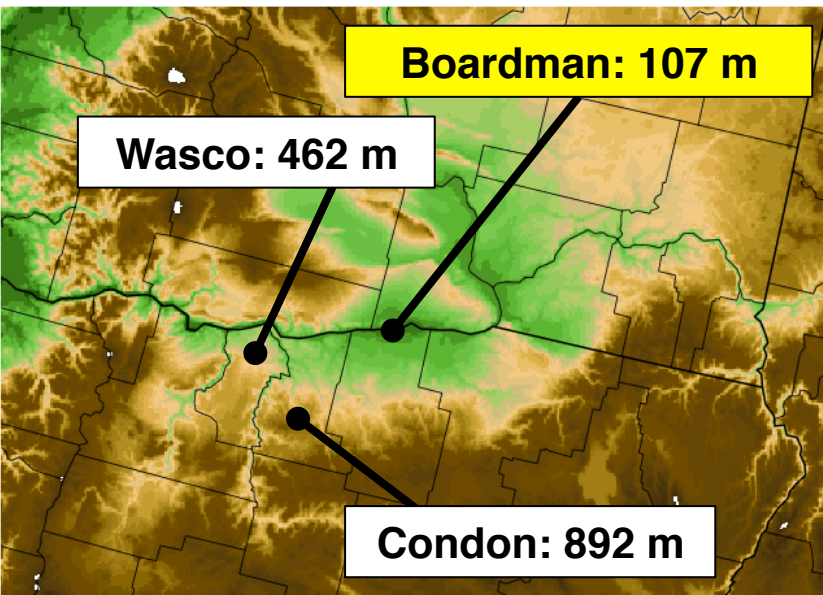
Stable Air Mix-Out:

In-Situ Measurements



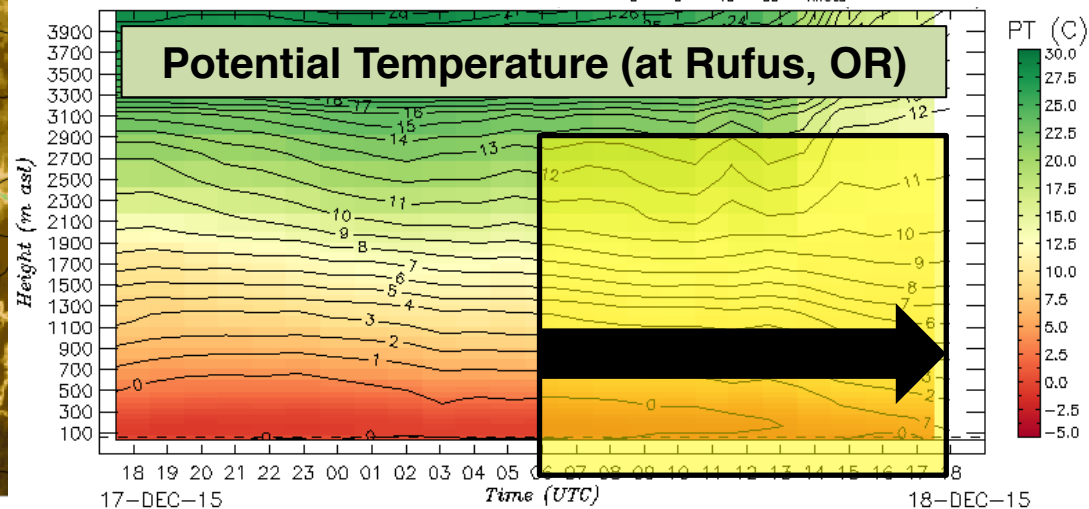
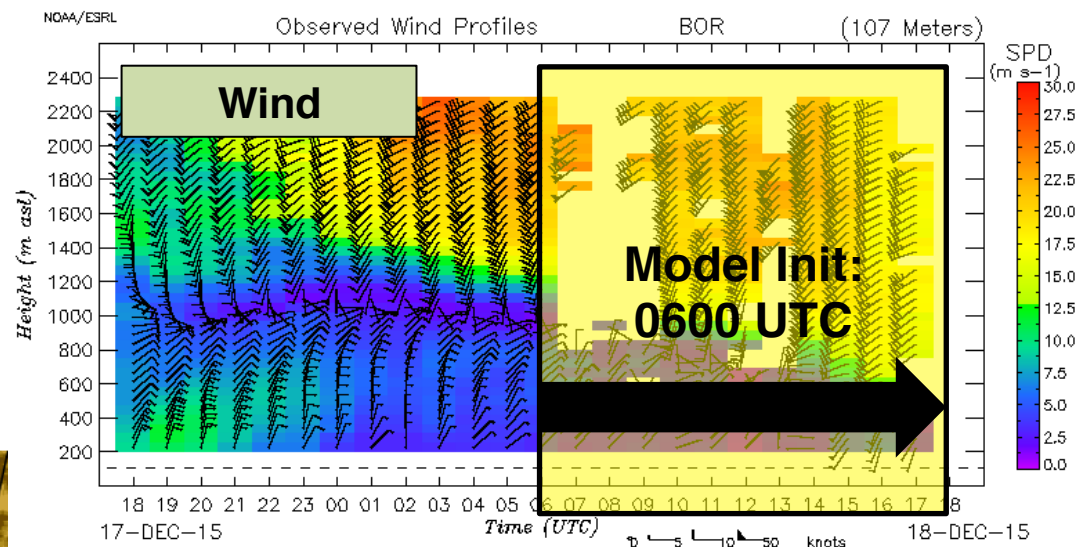
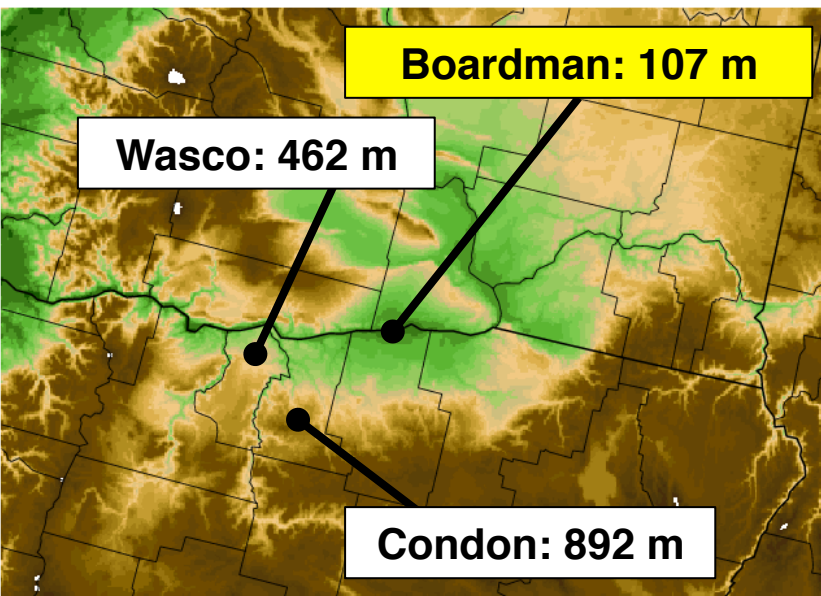
Stable Air Mix-Out:

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Stable Air Mix-Out:

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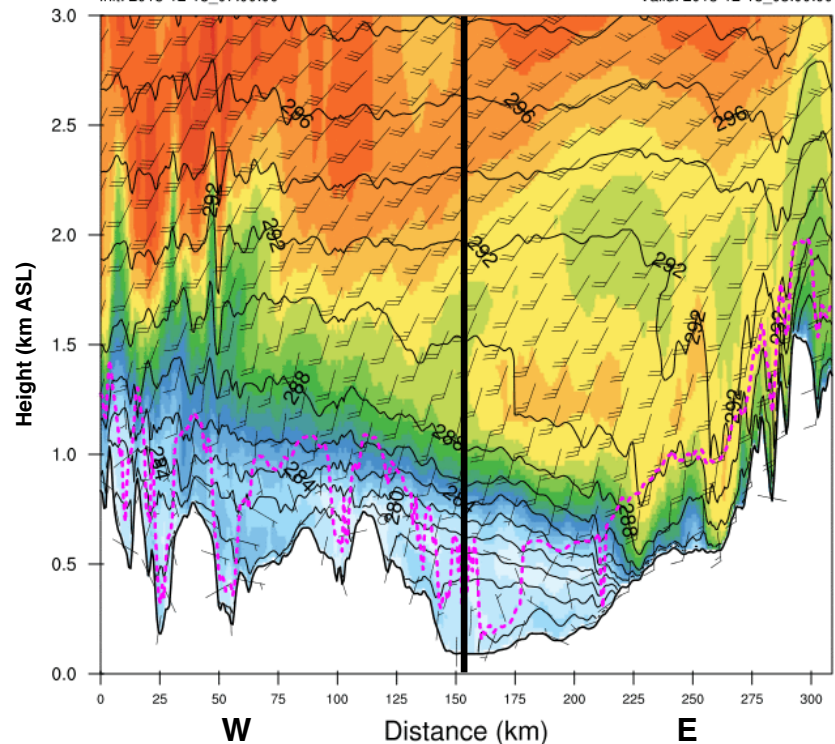


HRRR-WFIP2 750-m Nest Forecast

WIND SPEED (fill), POTL TEMP (red), PBL TOP (dash)

Init: 2015-12-18_07:00:00

Valid: 2015-12-18_08:00:00



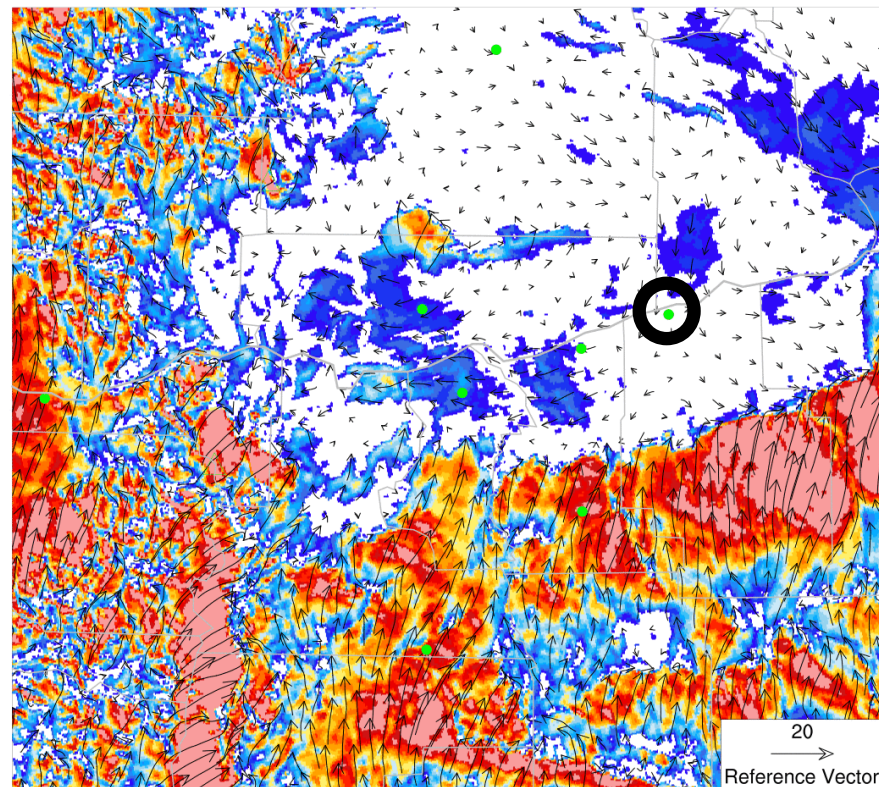
Center Point: Boardman, OR

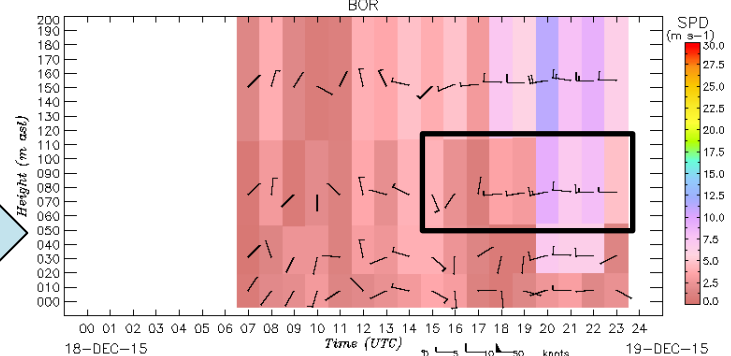
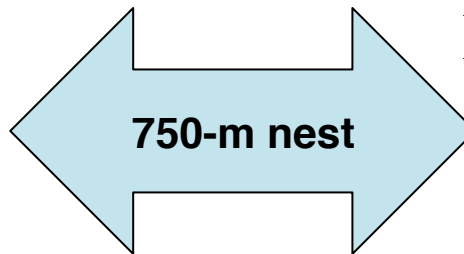
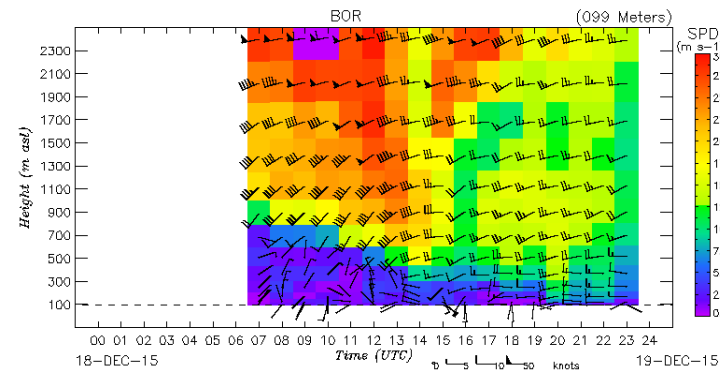
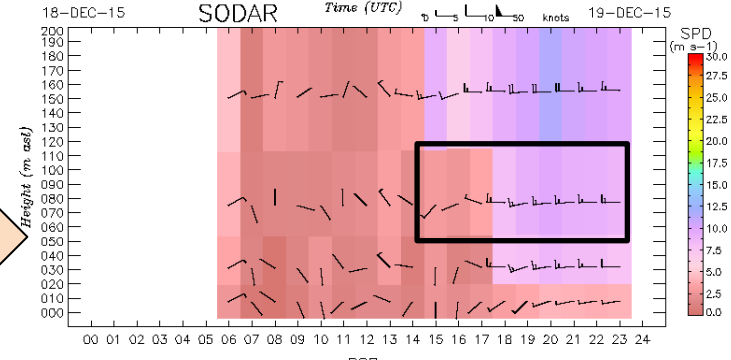
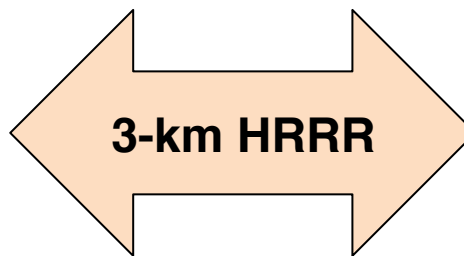
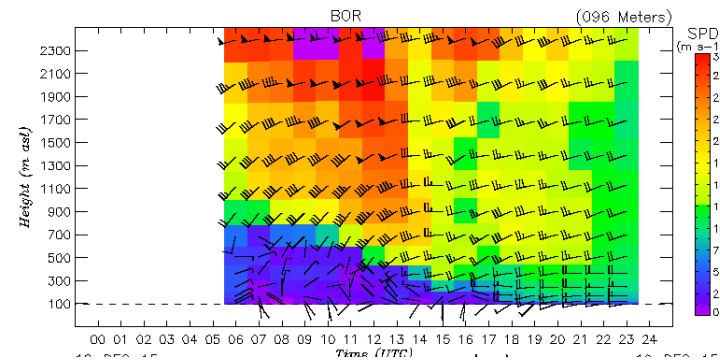
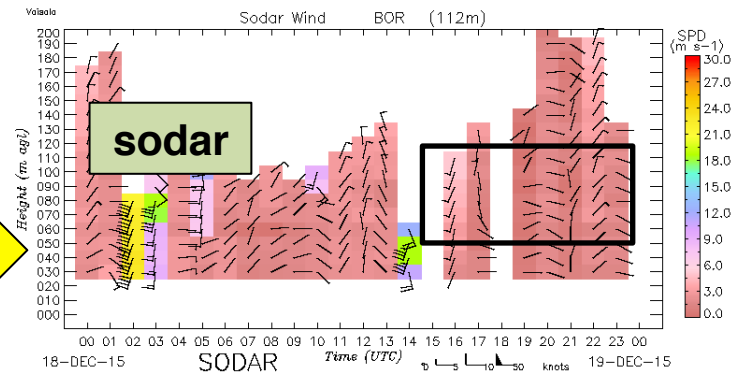
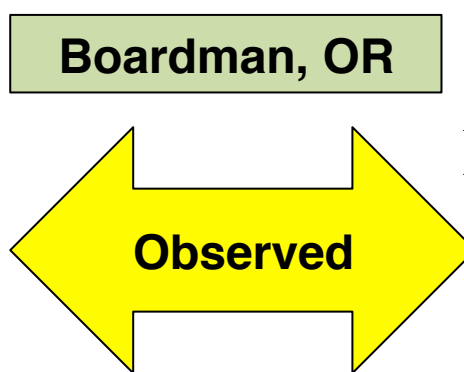
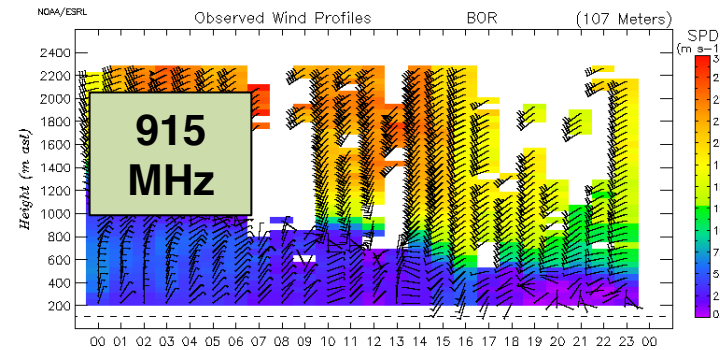
HRRR-WFIP2 750-m Nest

80-m Wind Speed (m s^{-1})

Init: 2015-12-18_07:00:00

Valid: 2015-12-18_08:00:00





The MYNN Length Scale: *Operational RAP & HRRR*

$$\frac{1}{l_m} = \frac{1}{l_s} + \frac{1}{l_t} + \frac{1}{l_b}$$

Surface Layer

$$l_s = \begin{cases} kz(1 + \text{cns}\xi)^{-1} & \text{if } 0 \leq \zeta \leq 1 \\ kz(1 - 100\xi)^{0.2} & \text{if } \zeta < 0 \end{cases}$$

Buoyancy

$$l_b = \alpha_2 \frac{q}{N} \left[1 + \alpha_3 \left(\frac{q_c}{l_t N} \right)^{1/2} \right]$$

Turbulence

$$l_t = \alpha_1 \frac{\int_{z=0}^{PBLH} zq \, dz}{\int_{z=0}^{PBLH} q \, dz}$$

buoyancy
enhancement
factor

The MYNN Length Scale: *Operational RAP & HRRR*

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Buoyancy

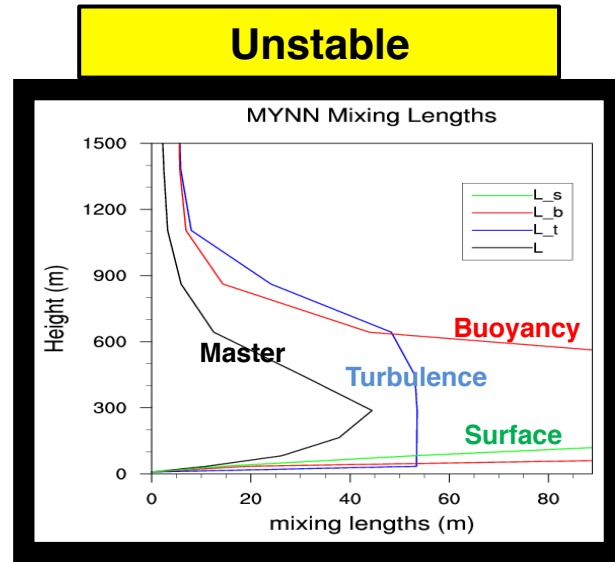
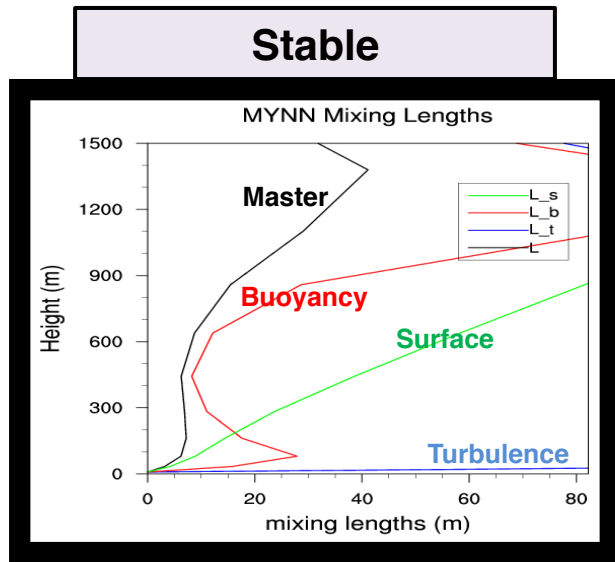
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buoyancy
enhancement
factor

The MYNN Length Scale: *Operational RAP & HRRR*



Known Problems...

- Harmonic averaging makes length specification difficult
- Surface-layer length scale (z-dependent) is influential everywhere
- Buoyancy enhancement factor may make L_B too large in the upper PBL



The MYNN Length Scale: *Experimental Revisions*

$$l_m = (1 - w)l_{PBL} + wl_{FREE}$$

PBL

$$l_{PBL} = \text{MIN}(l_{STABLE}, l_{UNSTABLE})$$

Unstable

$$\frac{1}{l_{UNSTABLE}} = \frac{1}{l_S} + \frac{1}{l_T}$$

Stable

$$l_{STABLE} = (1 - x)l_S + xl_B$$

Free Atmosphere

$$l_{FREE} = \begin{cases} l_B, & \text{if } l_B \leq 500 \text{ m} \\ l_{BOULAC}, & \text{if } l_B > 500 \text{ m} \end{cases}$$

Buoyancy

- (1) eliminate buoyancy enhancement factor in L_B
- (2) use a cloud-specific L_B following Teixeira and Cheinet (2003); blend with cloud-free L_B according to cloud fraction
- (3) adjust time-invariant parameters



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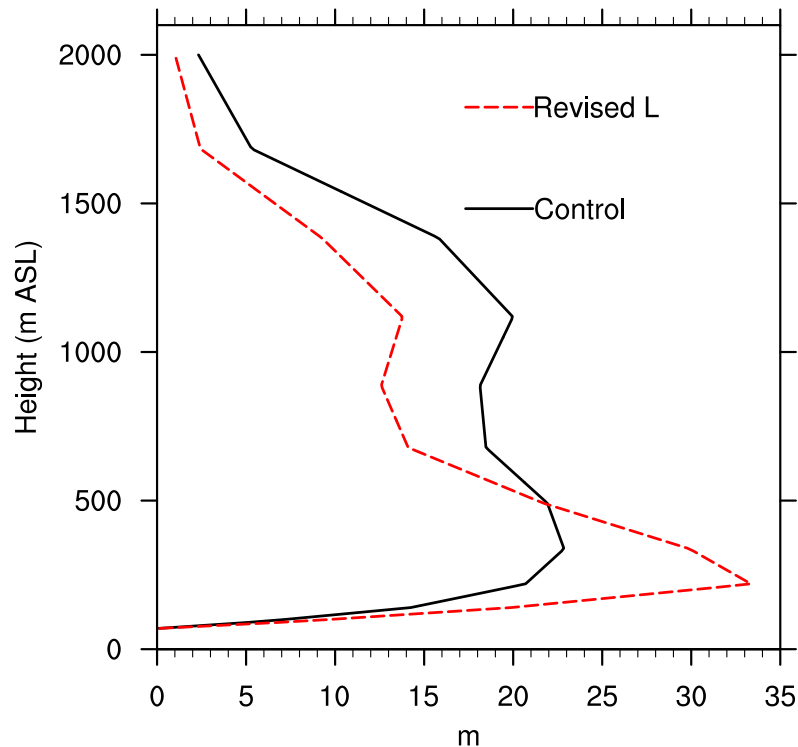
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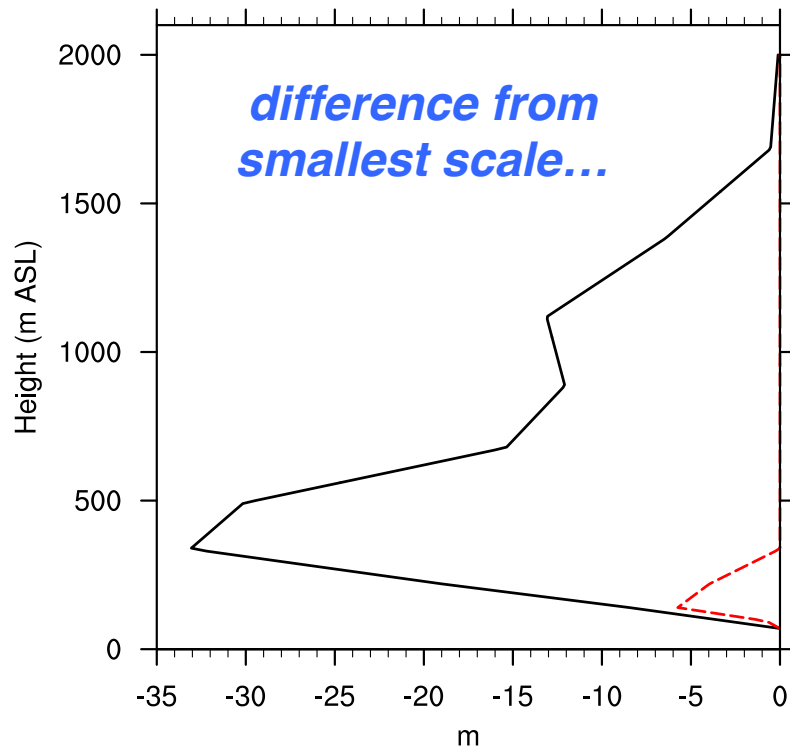
The MYNN Length Scale: *Experimental Revisions*

Stable

Master Length Scale (L_m)



$L_m - \min(L_s, L_t, L_b)$

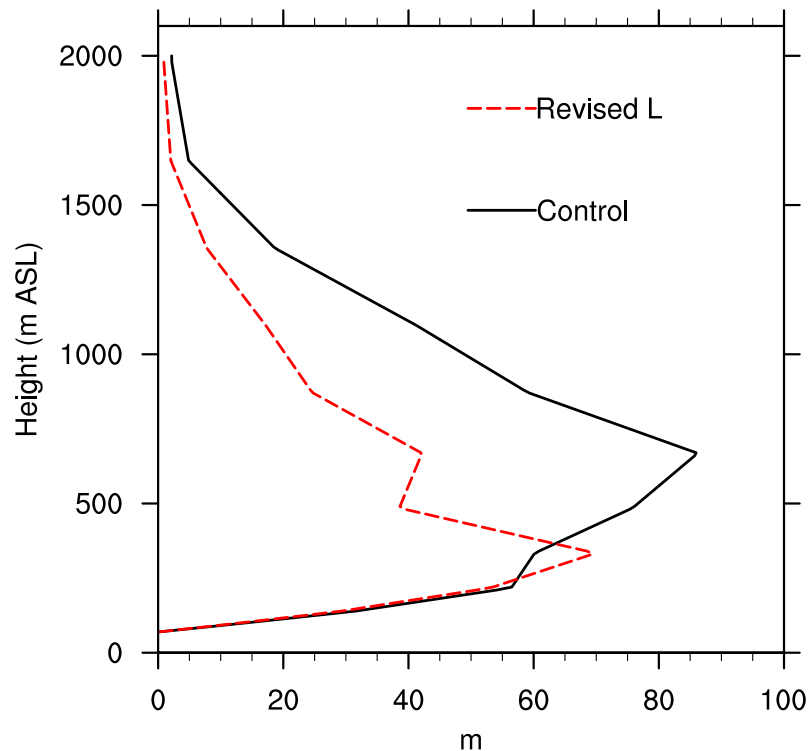




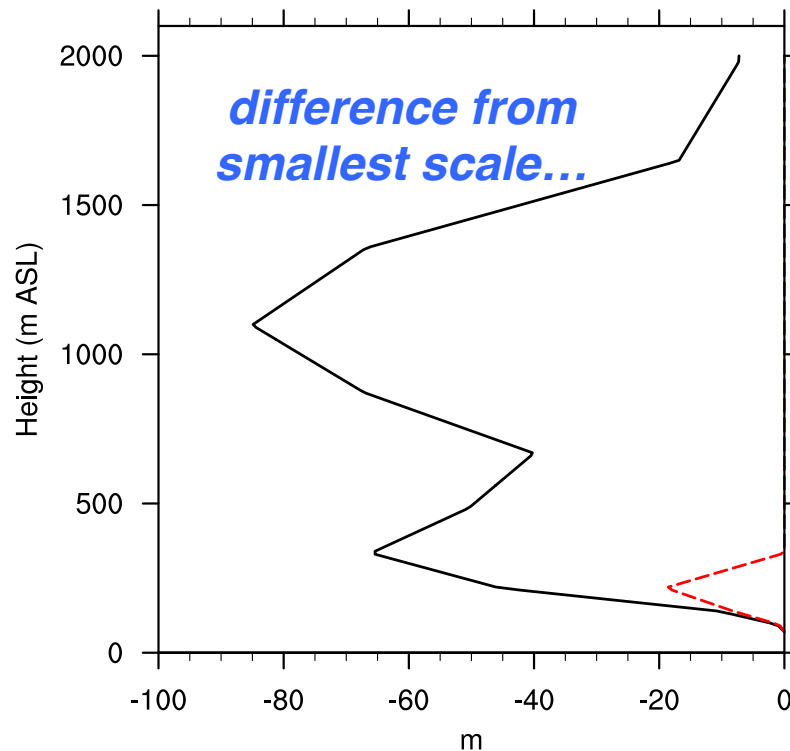
The MYNN Length Scale: *Experimental Revisions*

Unstable

Master Length Scale (L_m)

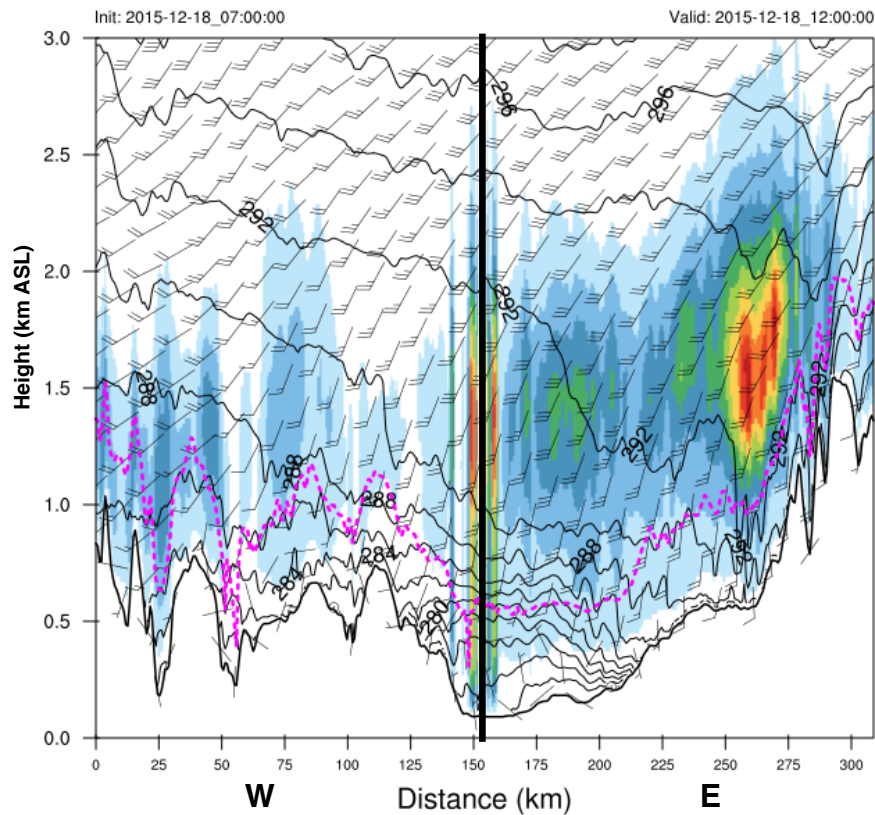


$L_m - \min(L_s, L_t, L_b)$

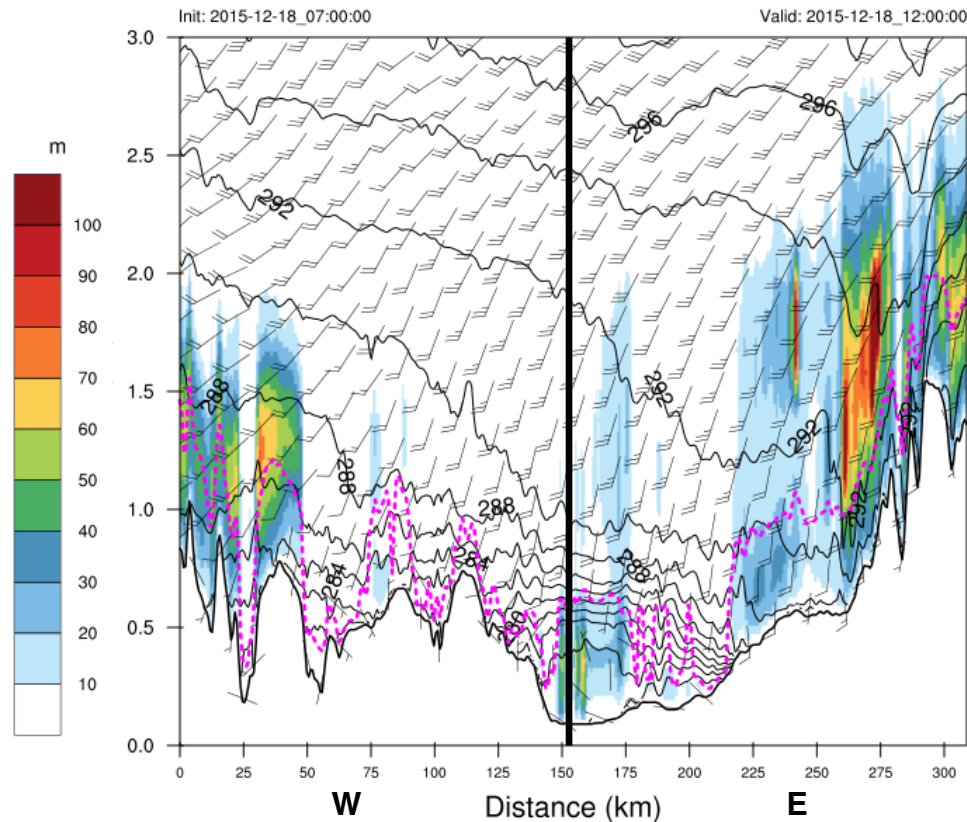


Mixing Length in 750-m Nest: 6-h Forecast Comparison

Control



w/ New Mixing Lengths



Center Location: Boardman, OR

Valid 1200 UTC 18 December 2015

MYNN Mixing-Length Revision:

Model Results...

18 December 2015

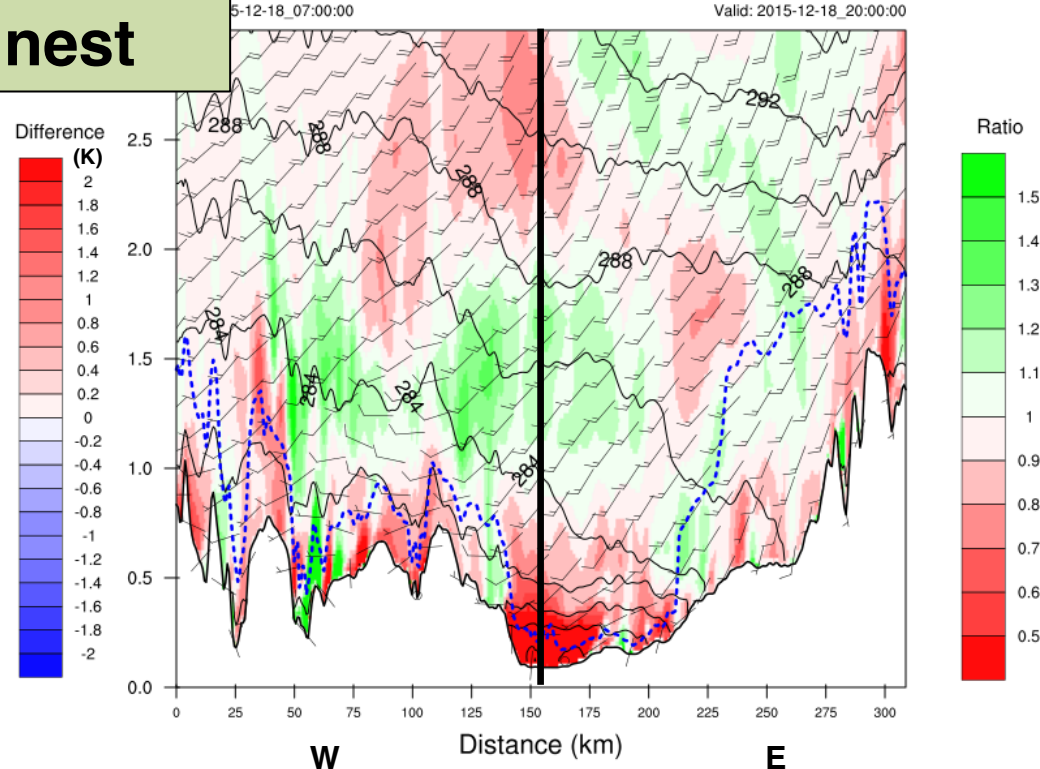
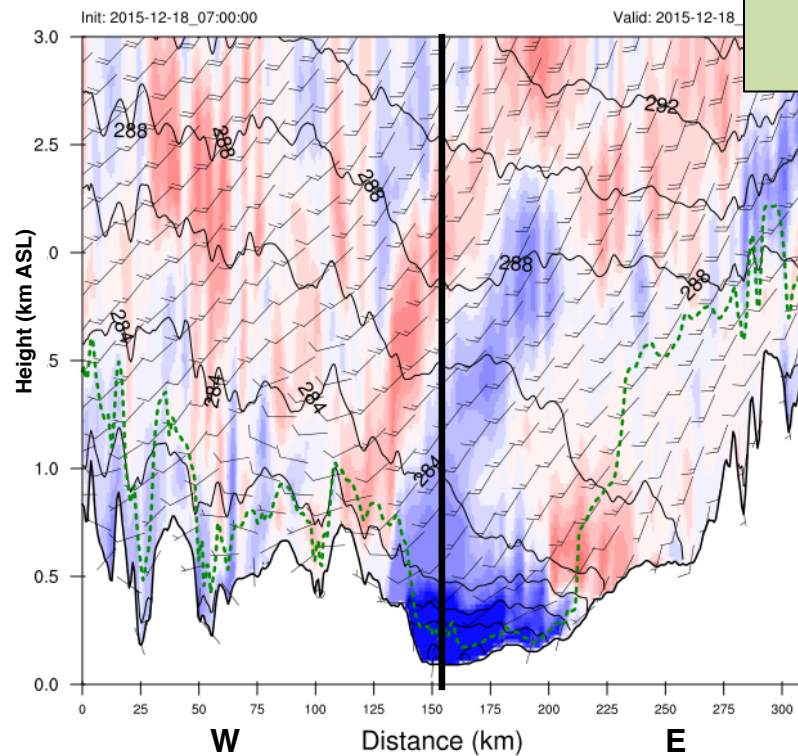
8 December 2015

Mixing-Length Revision: 14-h Forecast Difference

Temperature Difference

750-m
nest

Wind-Speed Ratio



Center Location: Boardman, OR

Valid 2000 UTC 18 December 2015

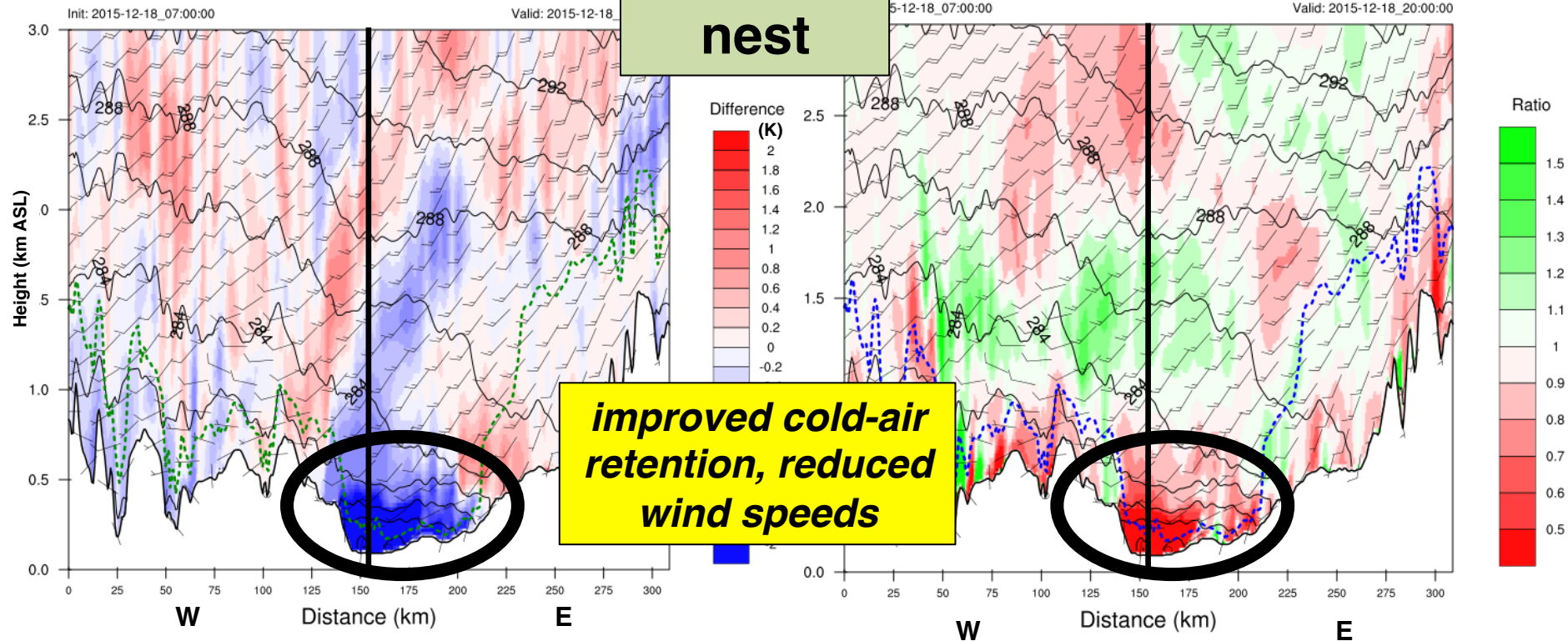
Mixing-Length Revision: 14-h Forecast Difference

Temperature Difference

750-m
nest

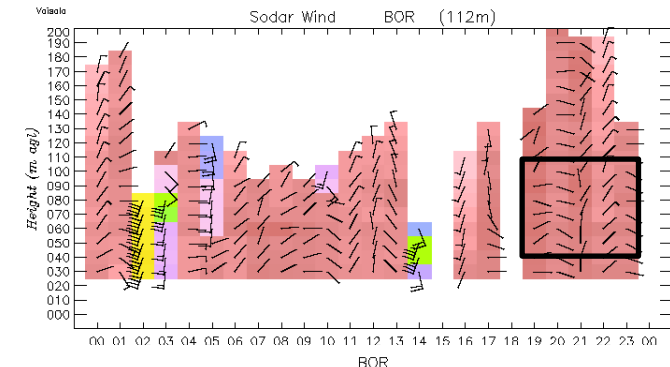
Wind-Speed Ratio

*improved cold-air
retention, reduced
wind speeds*



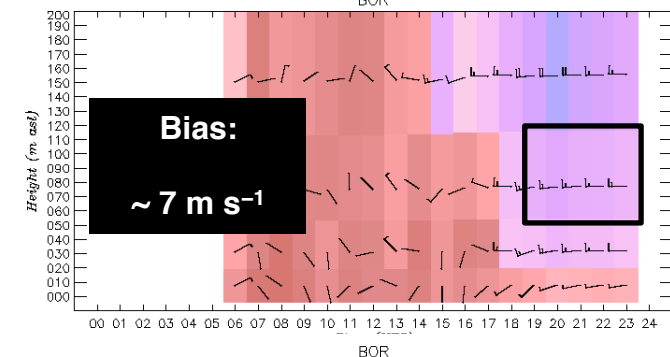
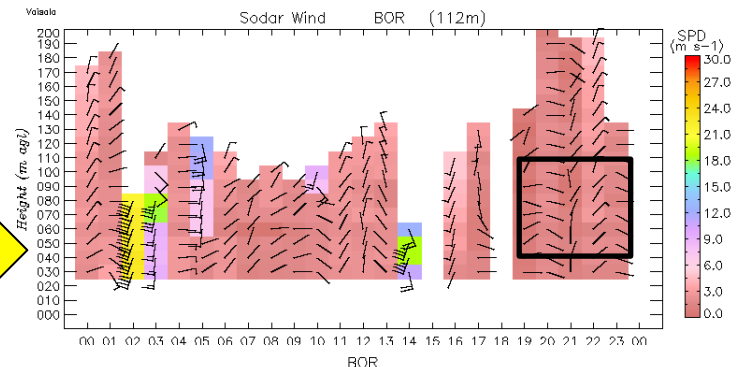
Center Location: Boardman, OR

Valid 2000 UTC 18 December 2015

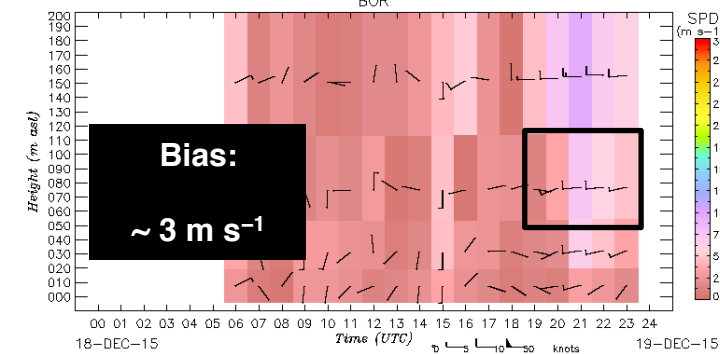
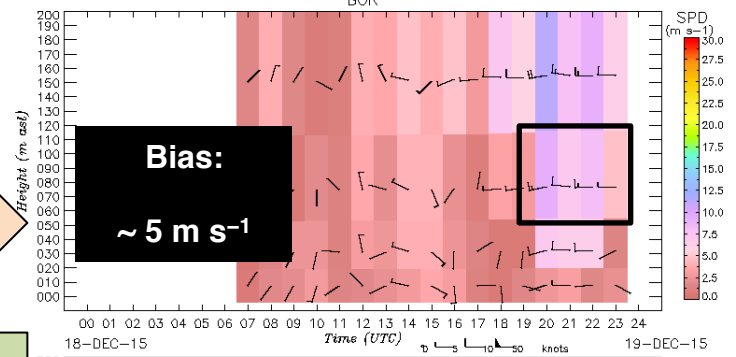


Boardman, OR

Observed
(plots identical)



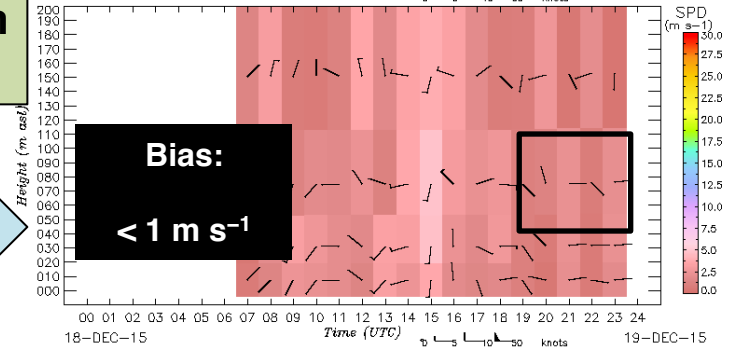
Control

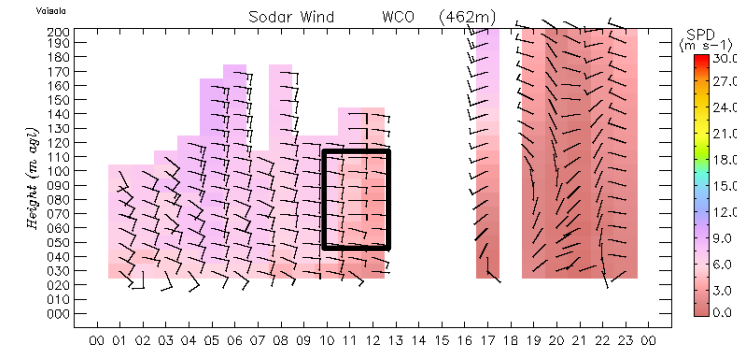


3-km
HRRR

750-m
nest

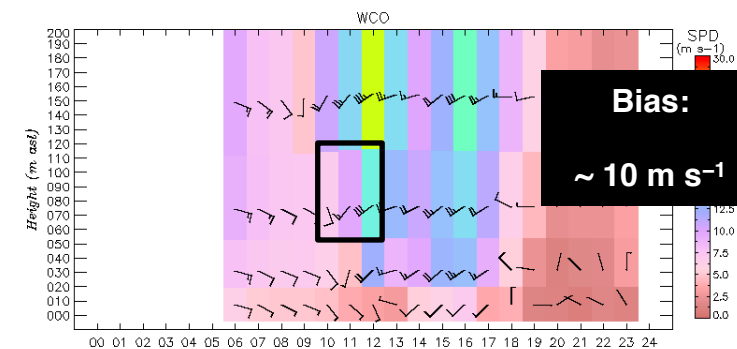
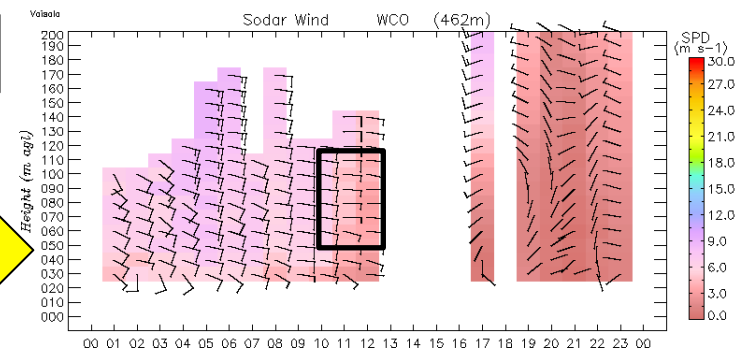
w/ New Mixing
Lengths



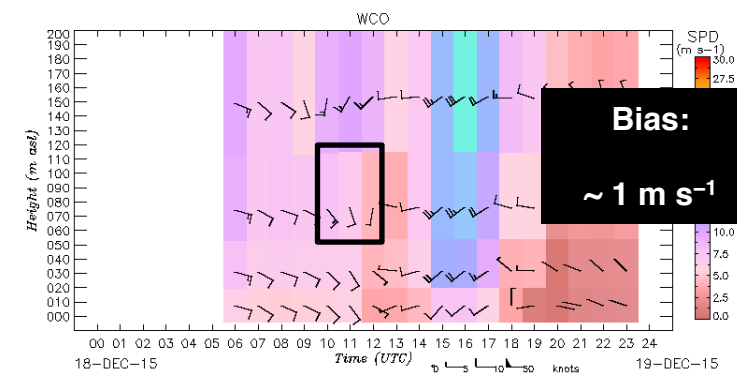
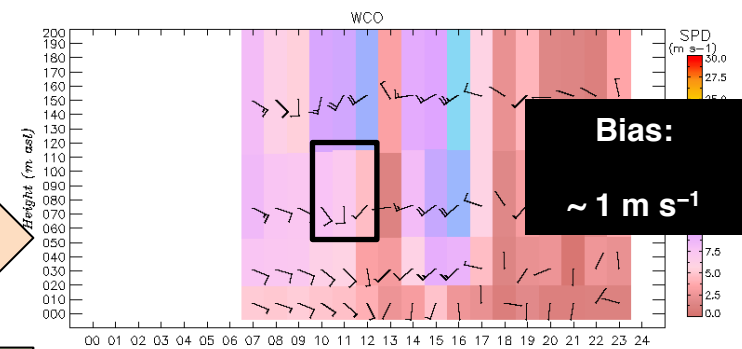


Wasco, OR

Observed
(plots identical)



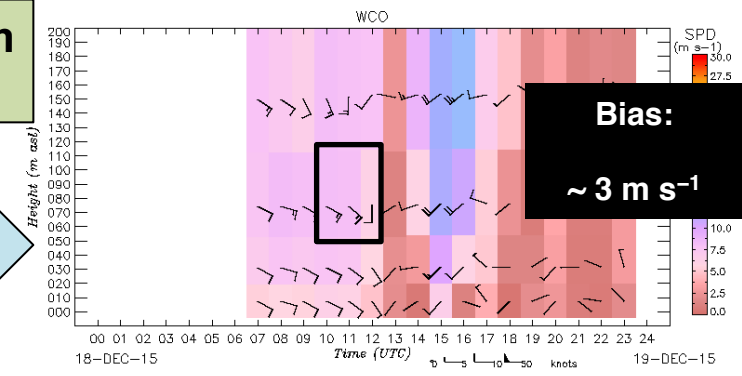
Control

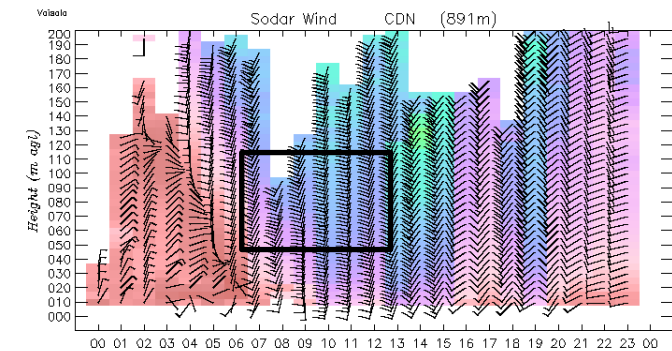


3-km
HRRR

750-m
nest

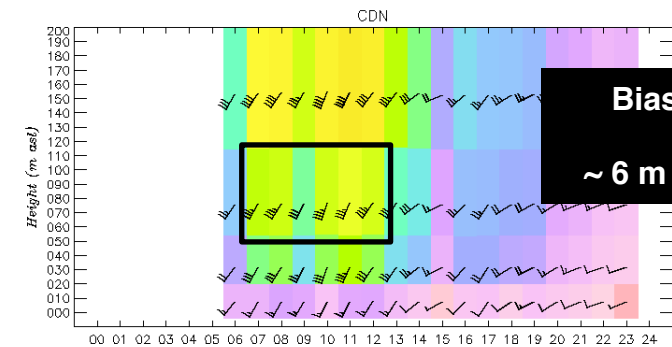
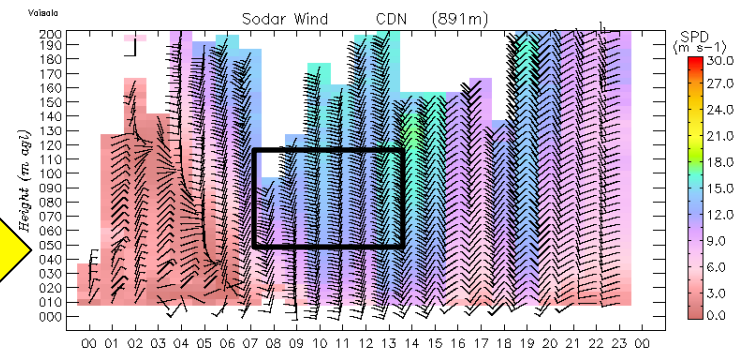
w/ New Mixing
Lengths



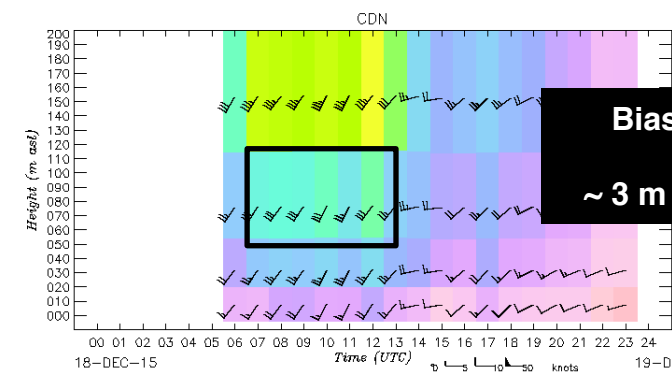
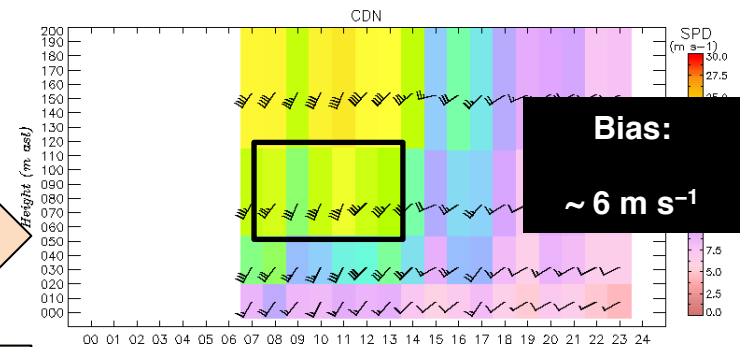


Condon, OR

Observed
(plots identical)



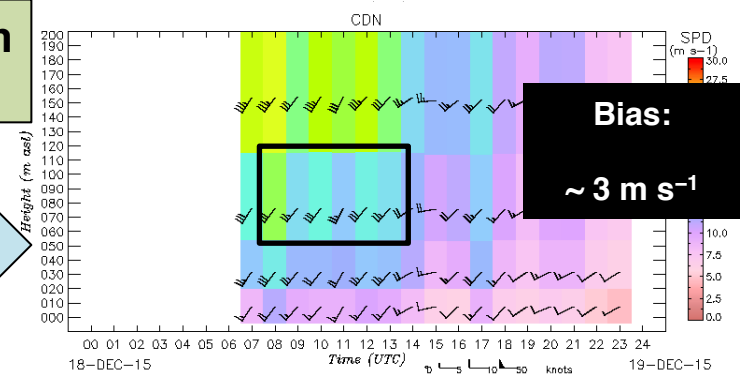
Control



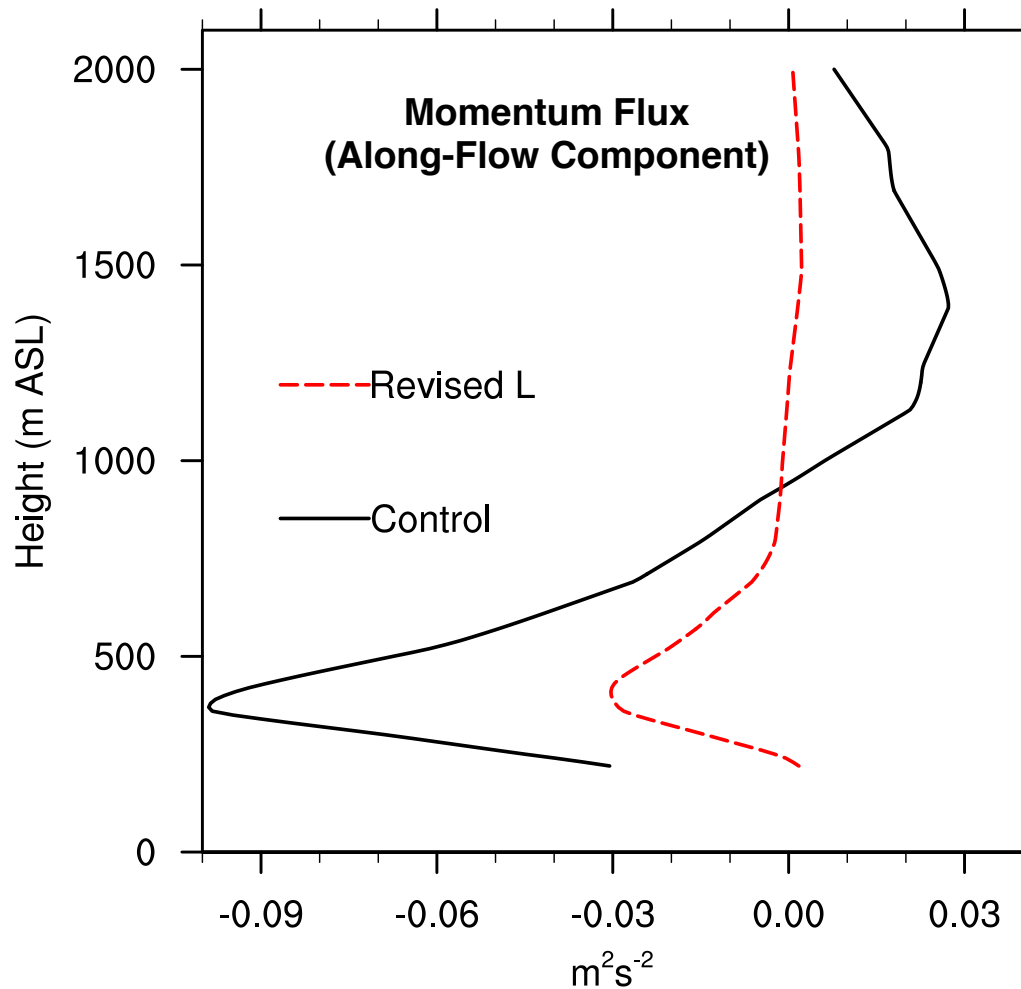
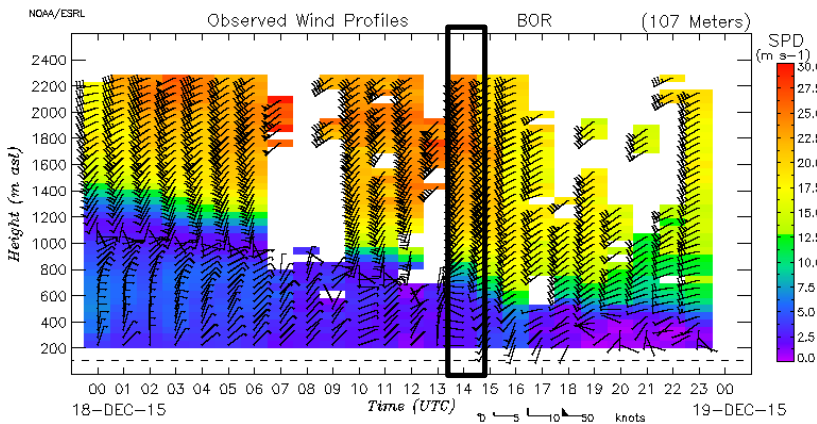
3-km HRRR

750-m nest

w/ New Mixing Lengths



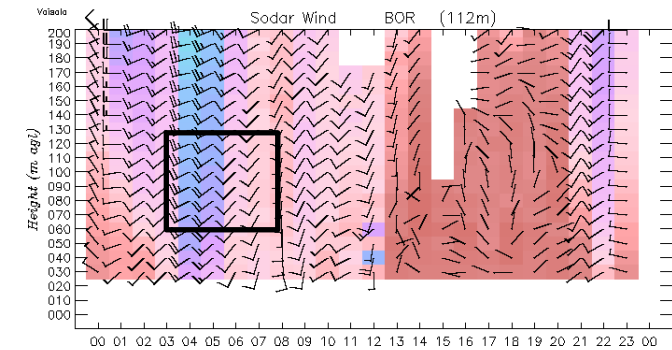
Parameterized Fluxes



**Composite of 490 Grid Columns
(750-m nest)**

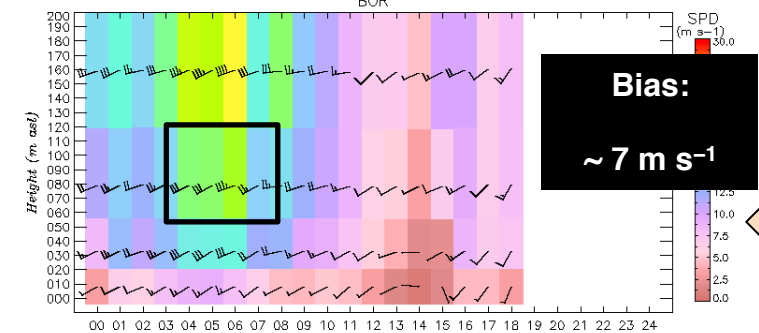
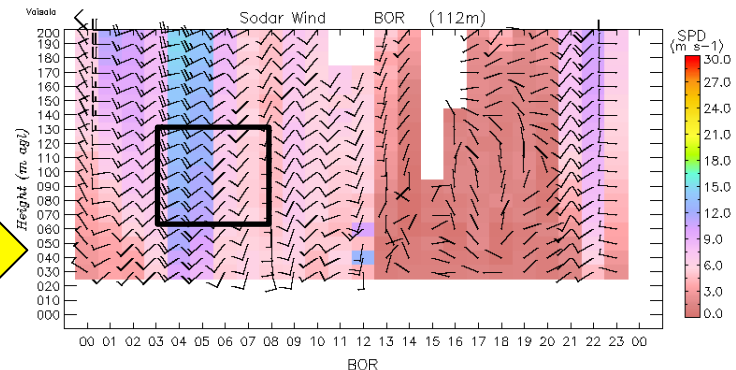
Center Location: Boardman, OR

Valid 1400 UTC 18 December 2015



Boardman, OR

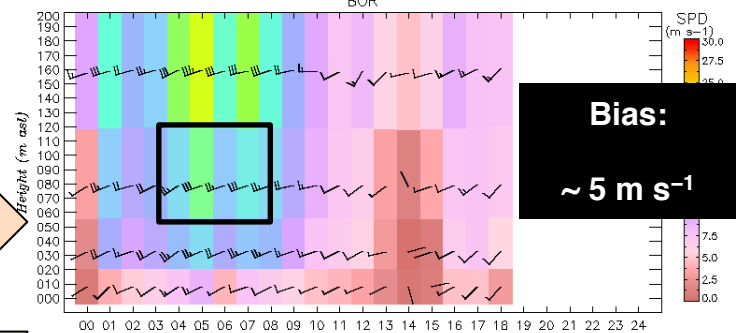
**Observed
(plots identical)**



Bias:

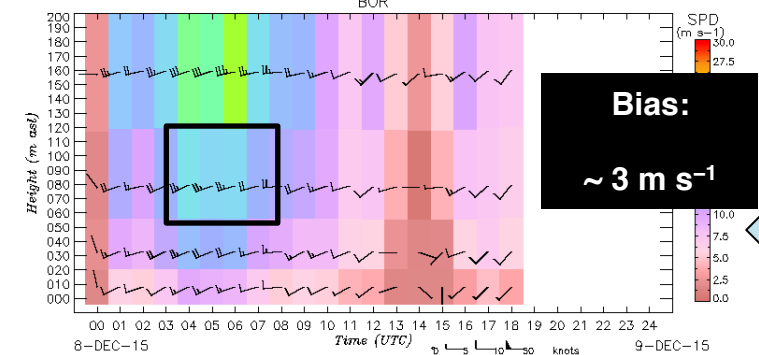
~ 7 m s⁻¹

Control



Bias:

~ 5 m s⁻¹



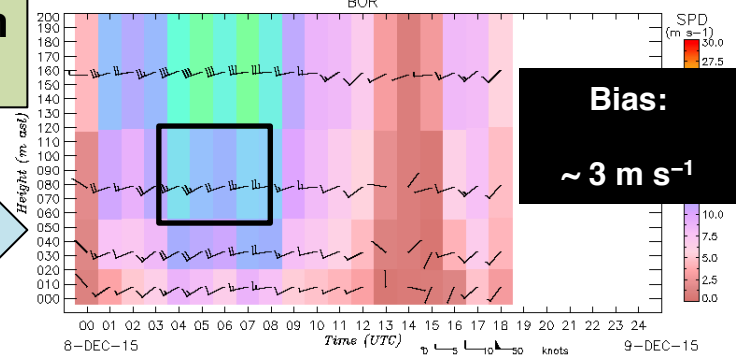
Bias:

~ 3 m s⁻¹

**3-km
HRRR**

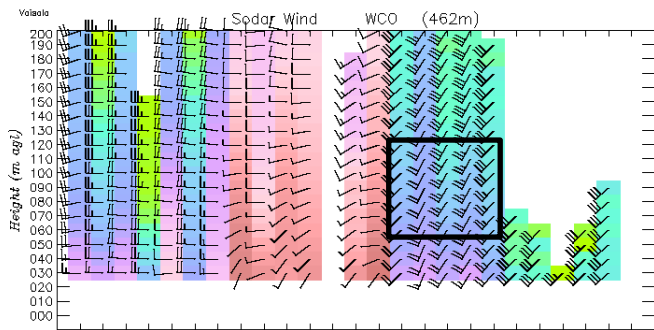
**750-m
nest**

**w/ New Mixing
Lengths**



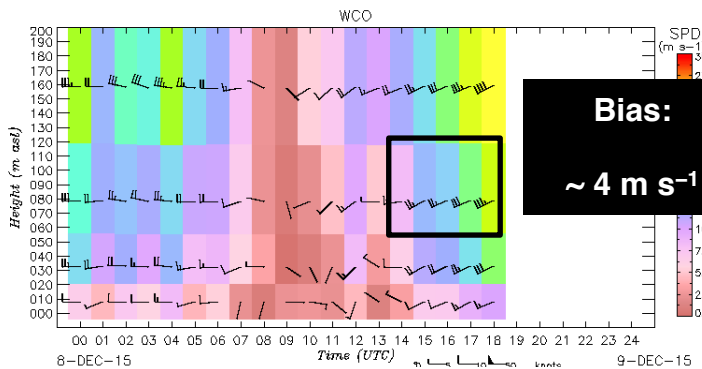
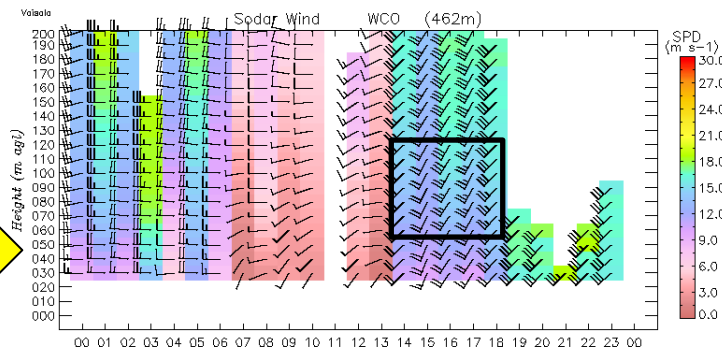
Bias:

~ 3 m s⁻¹



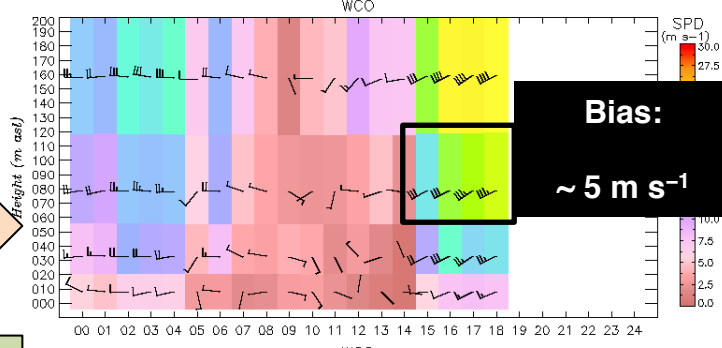
Wasco, OR

**Observed
(plots identical)**

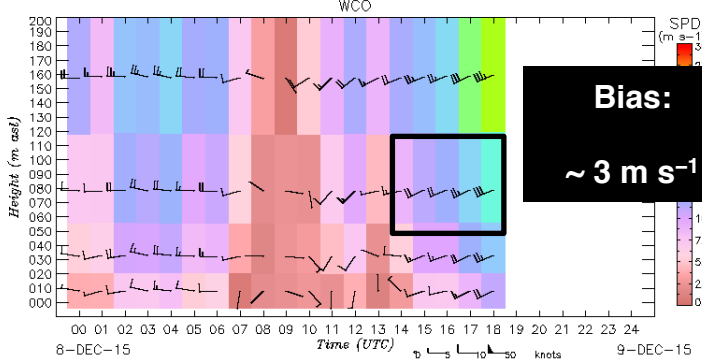


**Bias:
~ 4 m s⁻¹**

Control



**Bias:
~ 5 m s⁻¹**

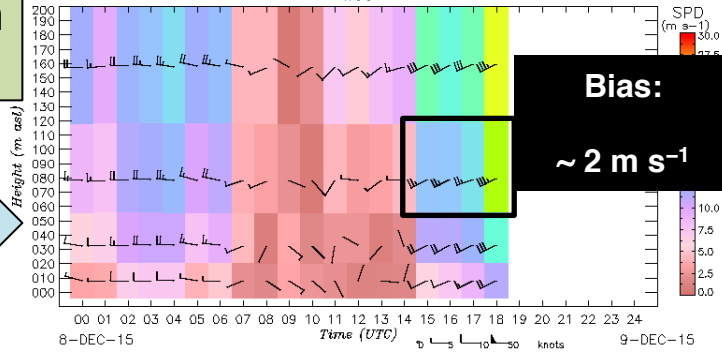


**Bias:
~ 3 m s⁻¹**

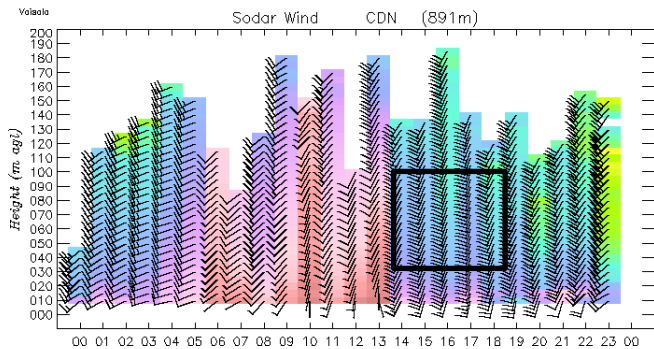
**3-km
HRRR**

**750-m
nest**

**w/ New Mixing
Lengths**

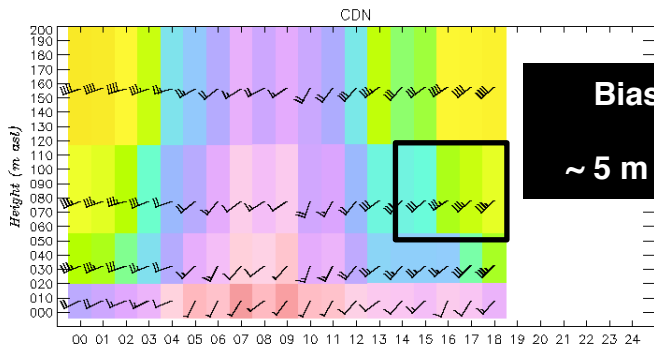
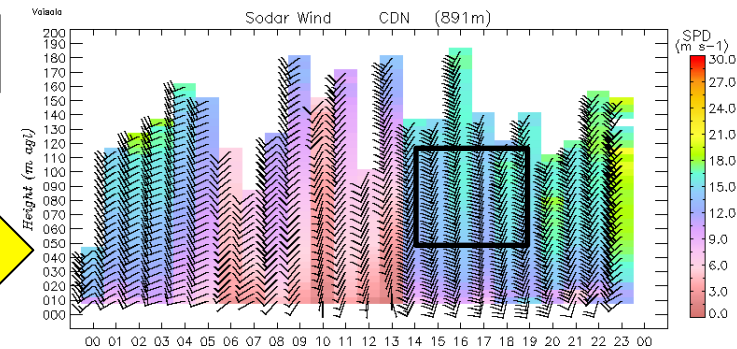


**Bias:
~ 2 m s⁻¹**

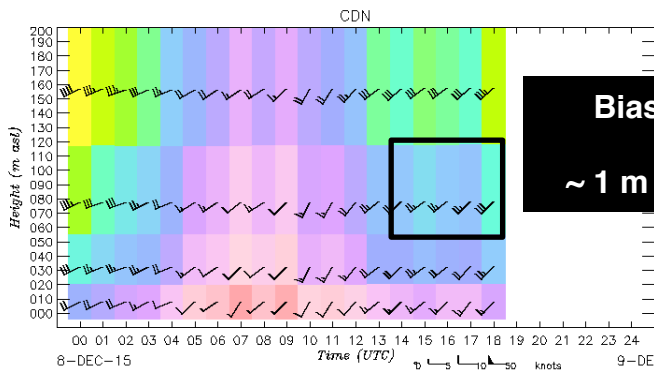
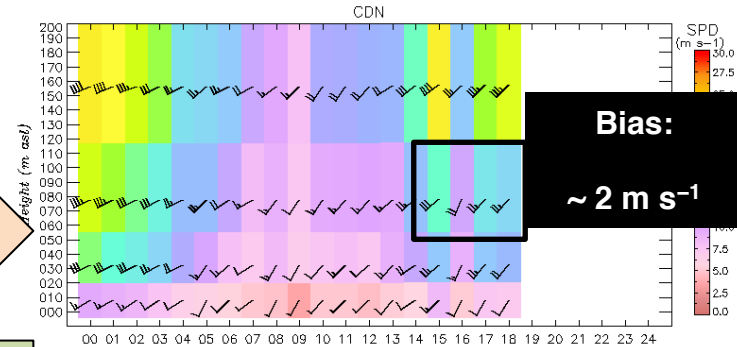


Condon, OR

**Observed
(plots identical)**



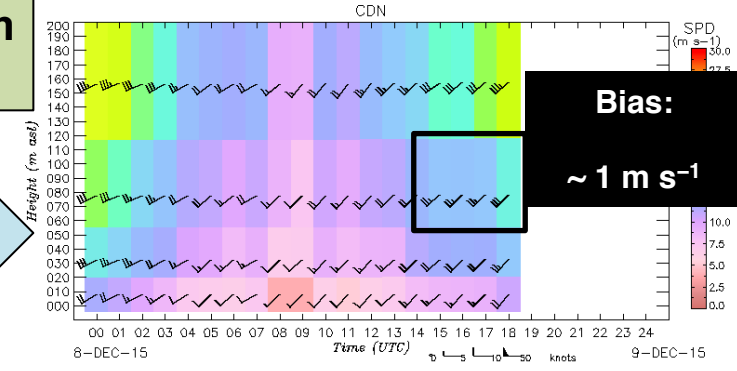
Control



**3-km
HRRR**

**750-m
nest**

**w/ New Mixing
Lengths**



Summary

- Common model failure mode...
*poor representation of stable-air
“mix out”*
 - Better representation of free-atmosphere & PBL turbulence



- For MYNN applications in 3-km HRRR and 750-m nest, reformulating the mixing-length scale appears to improve wind-forecast accuracy.
 - (1) invoke component length scales where they are physically applicable
 - (2) modify the buoyancy length scale (generally more restrictive)

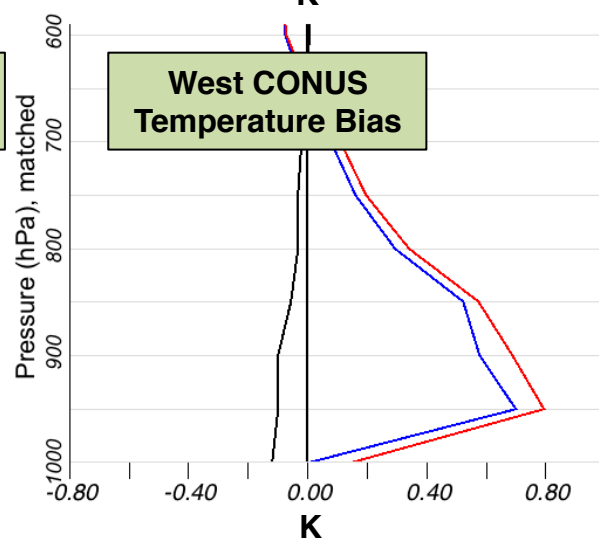
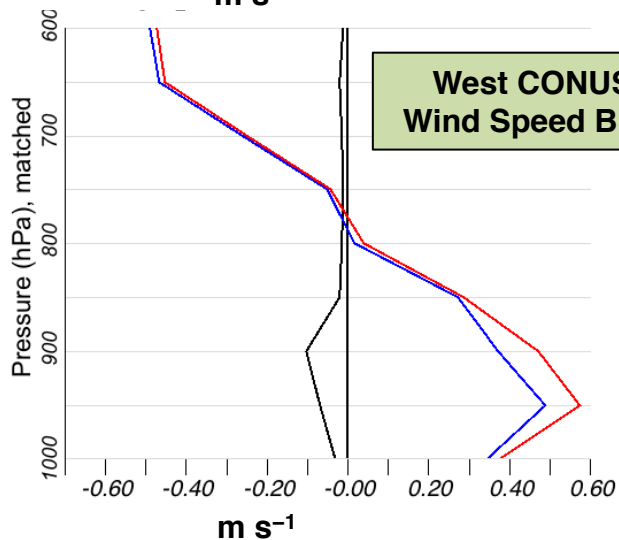
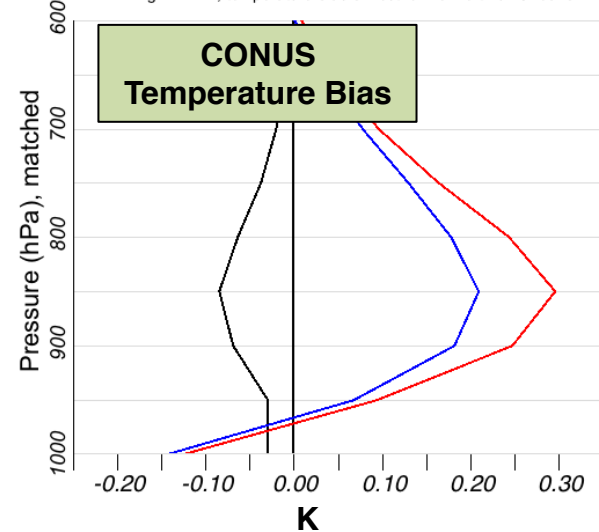
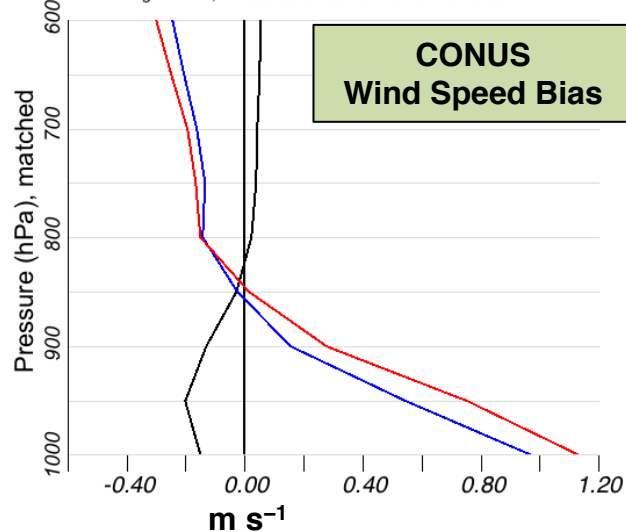
HRRR Upper-Air Verification

**6-h
Forecasts:
Nov 2015 to
Feb 2016**

HRRR-ESRL

HRRR-WFIP2

Difference





RAPv3/HRRRv2 Summary of Changes

Implementation RAPv3/HRRRv2

Larger RAP Domain

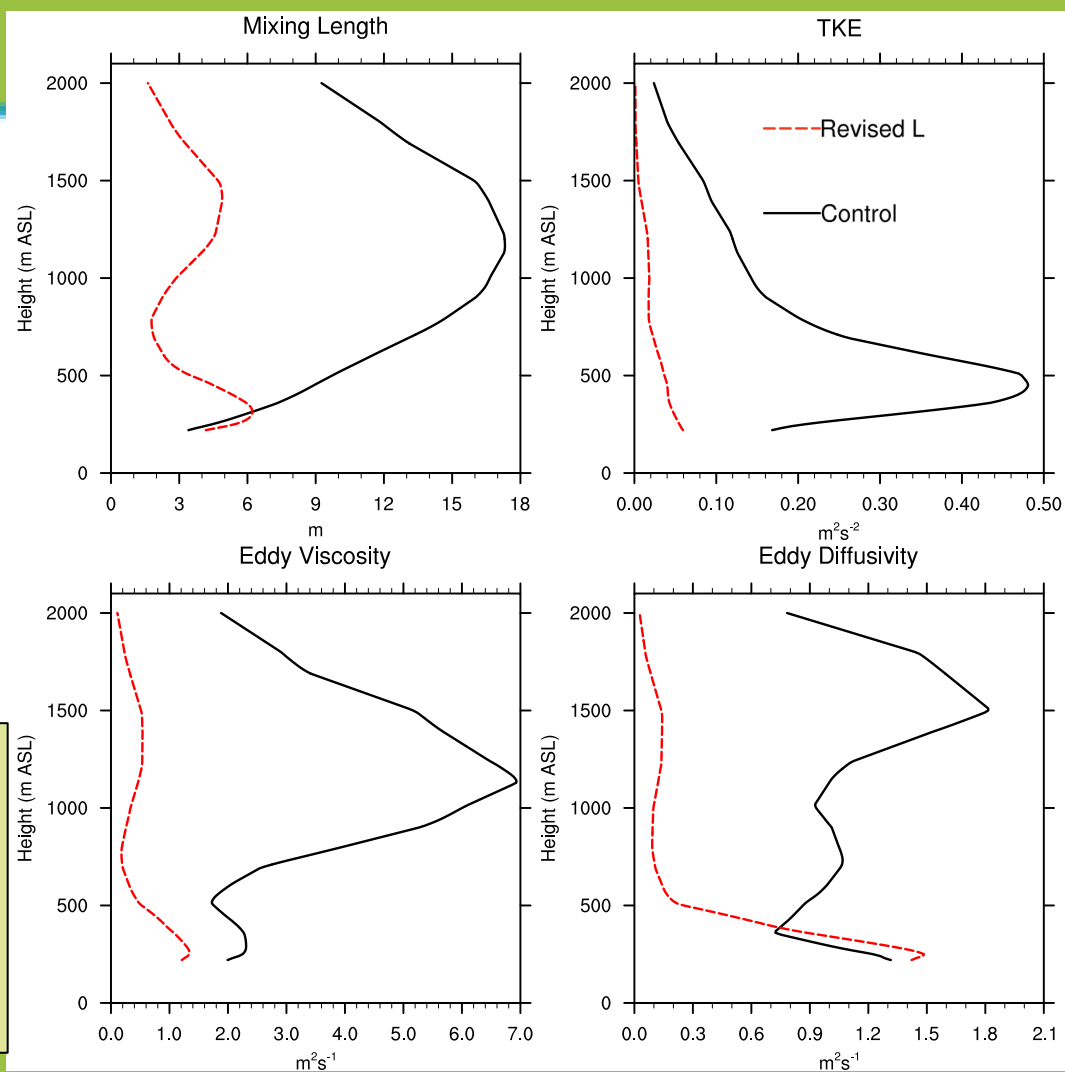
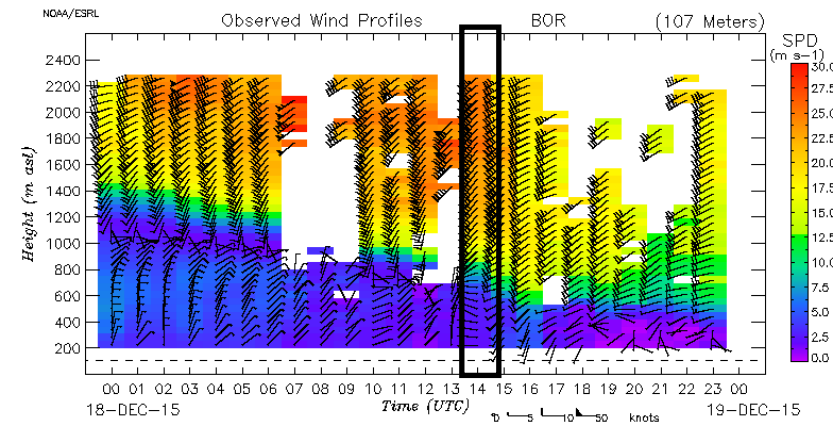
Newer Model Version
More Ensemble Weight
Advanced Physics

Seasonal Vegetation
Fraction/Leaf Area Index

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle)
Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	13-km DFI	RRTMG/ RRTMG	Thompson Aerosol v3.6	GF + Shallow	MYNN v3.6	RUC v3.6
HRRR	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.6	None	MYNN v3.6	RUC v3.6
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6 th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5 th /5 th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	5 th /5 th	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

Composite Profiles

GLOBAL SYSTEMS DIVISION



**Composite of 490 Grid Columns
(750-m nest)**

Center Location: Boardman, OR

Valid 1400 UTC 18 December 2015