WRF Diffusion in Complex Terrain

Dealing with Overmixing Near Steep Terrain

Cliff Mass and David Ovens

University of Washington

WRF Workshop, June 2017

With standard diffusion settings, WRF can produce too much vertical mixing near steep terrain

- A particular problem for stable lower tropospheres
- Can produce unphysical vertical mixing near:
  - Gaps
  - Valleys
  - Near steep slopes

Not the first to talk about these issues….

Modeling Cold Pools in California's Central Valley

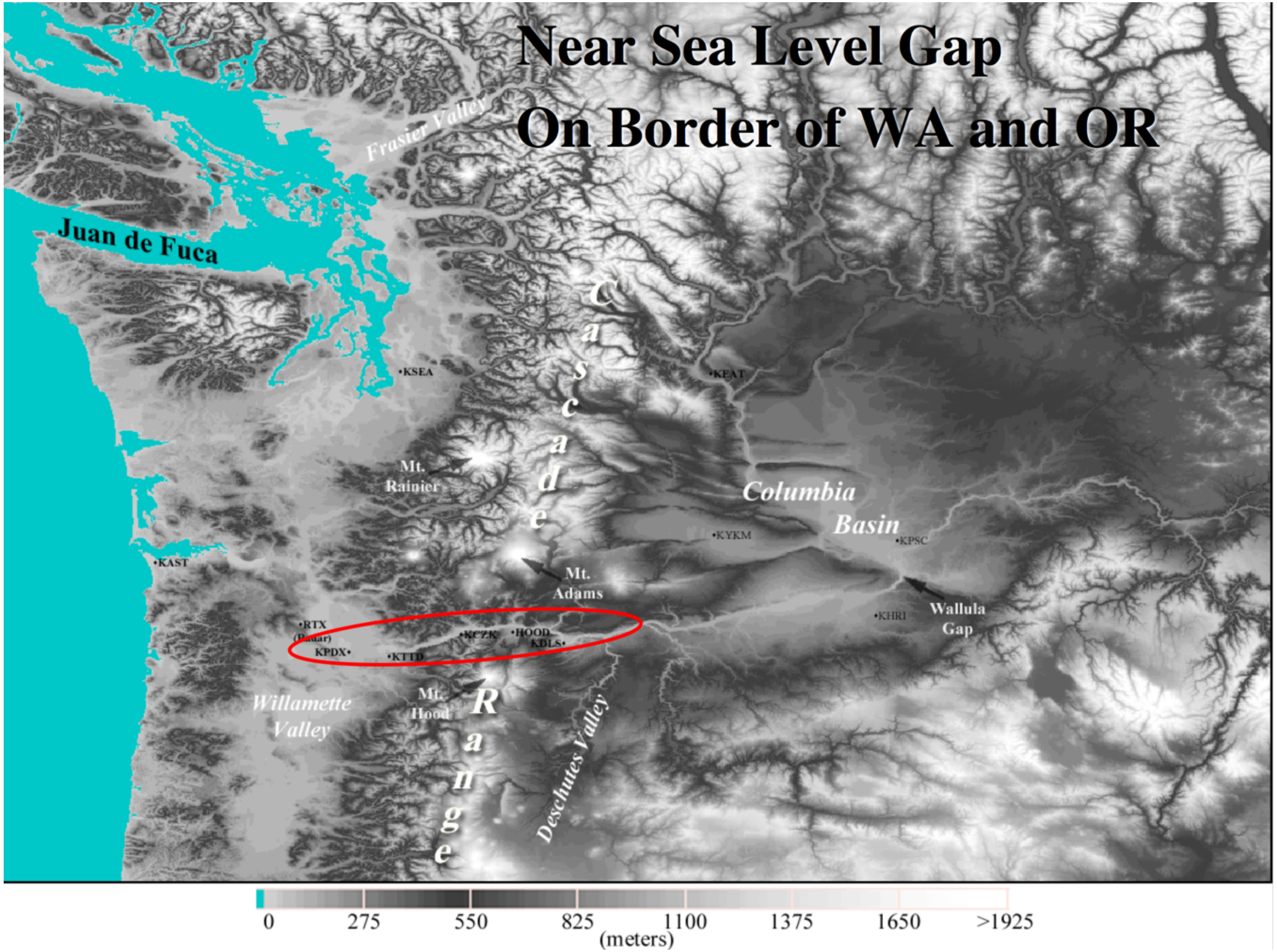
TRAVIS WILSON * AND ROBERT FOVELL

Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles

ABSTRACT

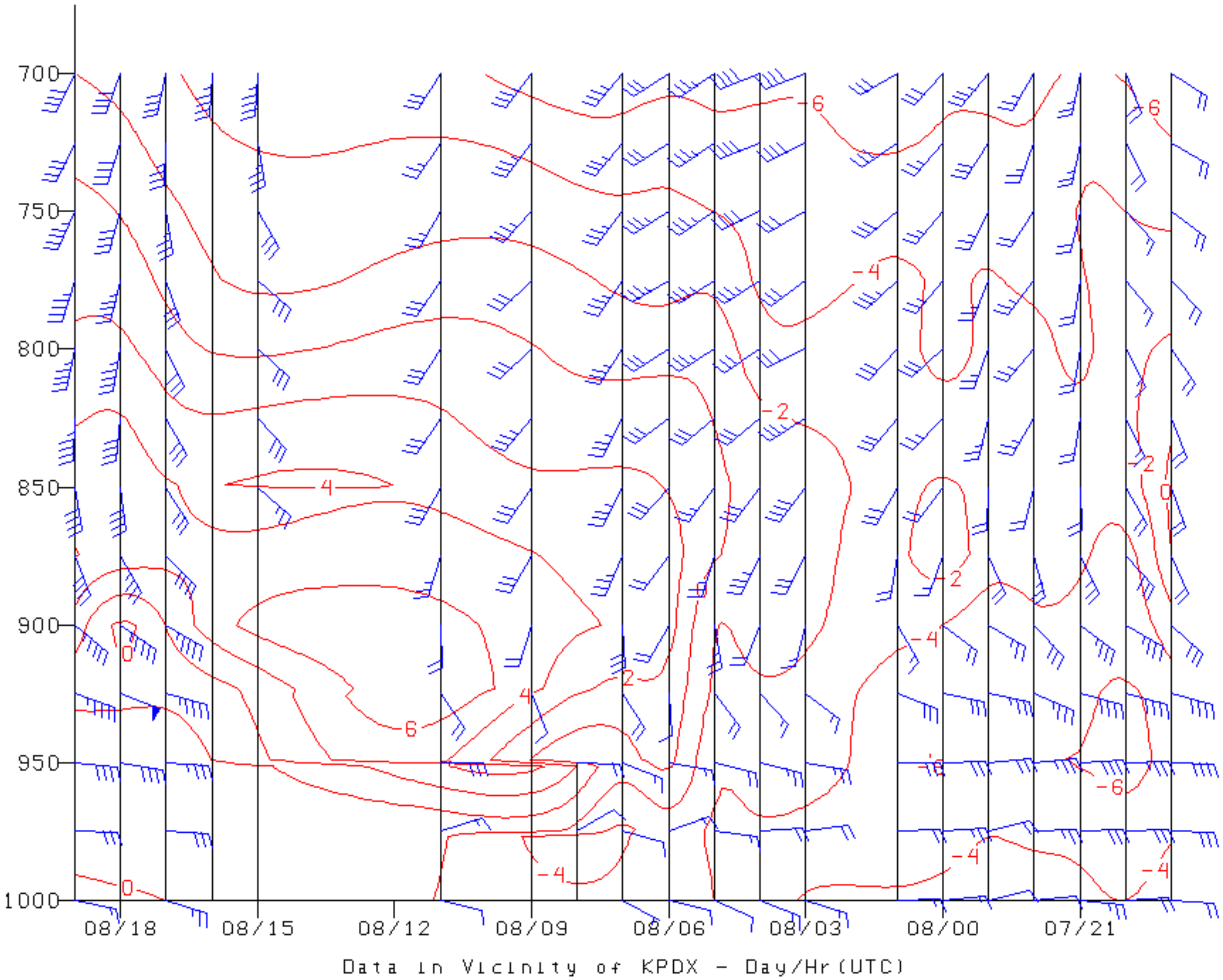
Despite our increased understanding in the relevant physical processes, forecasting radiative cold pools and their associated meteorological phenomena (e.g., fog and freezing rain) remains a challenging problem in mesoscale models. The present study is focused on California's Tule fog where the Weather Research and Forecasting (WRF) model's inability to forecast the event is addressed and substantially improved. An intra-model physics ensemble reveals that no current physics is able to properly capture the Tule fog and that model revisions are necessary. It has been found that revisions to the height of the lowest model level in addition to reconsideration of horizontal diffusion and surface-atmospheric coupling are critical for accurately forecasting the onset and duration of these events.

Consider the Columbia River Gorge

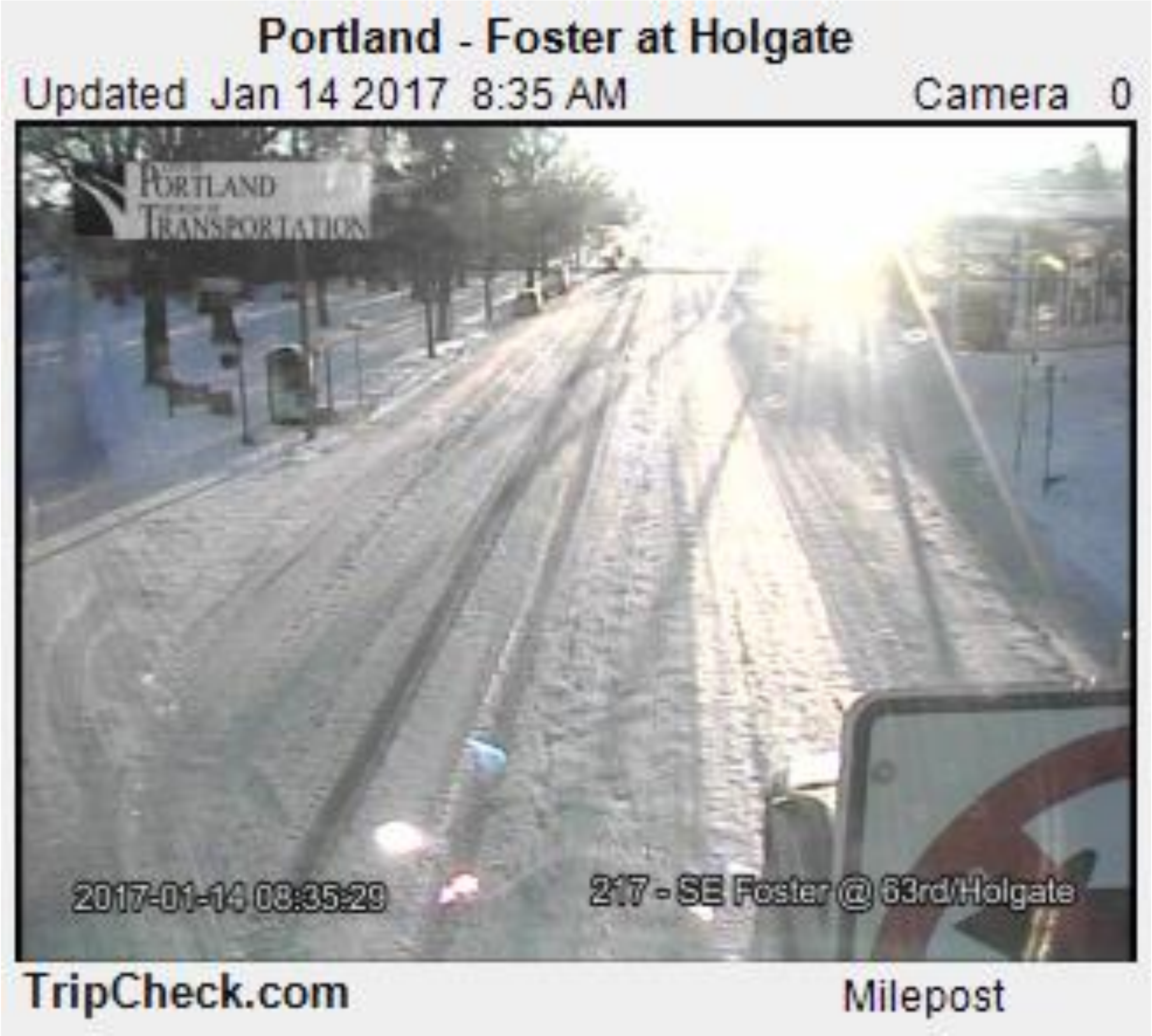


Near Sea Level Gap
On Border of WA and OR
Juan de Fuca
Frasier Valley
Cascade
Range
•KSEA
•KEAT
Mt. Rainier
Columbia Basin
•KYKM
•KPSC
•KAST
Mt. Adams
Wallula Gap
•KHRI
•RTX (Radar)
KPDX•
•KTTD
•KCZK
•HOOD
KDLS•
Mt. Hood
Willamette Valley
Deschutes Valley
0
275
550
825
1100
1375
1650
>1925
(meters)

January 8, 2017, Portland (PDX)

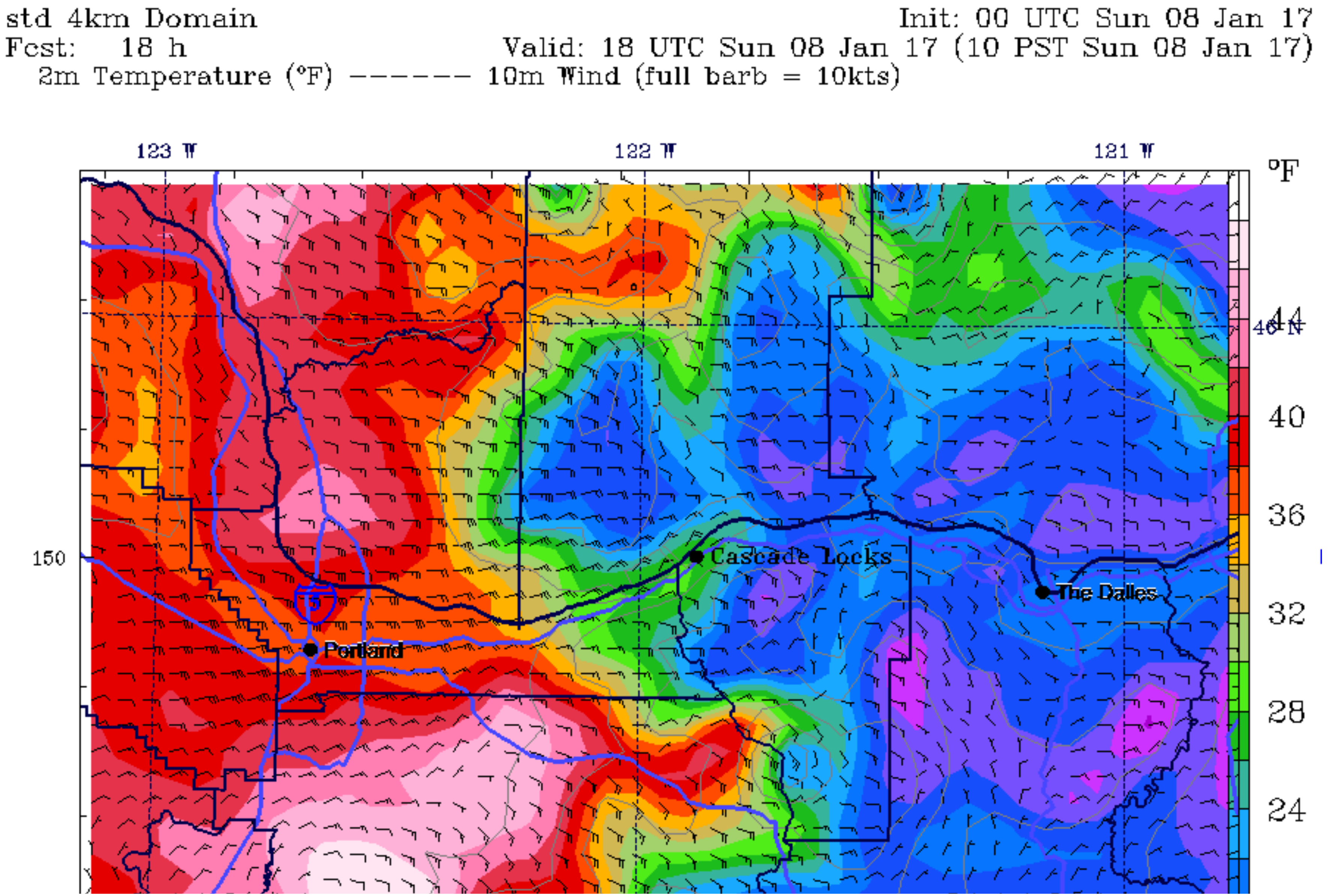


January 2017: UW WRF was consistently too warm in the Gorge (and immediately downstream) with too little snow



Observations at 1800 UTC 08 January

UW WRF Too Warm



Diagnosis: Too Much Mixing in the Model

- The WRF model had much too much mixing between the cold air below and warm air above
- The problem was particularly large in and immediately downstream of the Gorge
- Could excessive model diffusion contribute?

WRF Diffusion 101

Three types of diffusion in WRF:

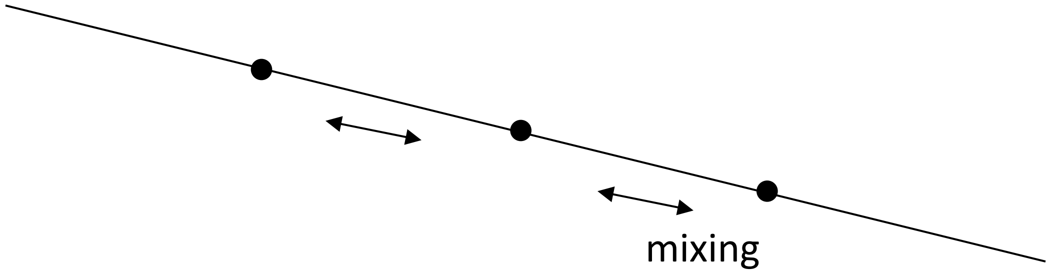
1. Diffusion inherent in finite differencing (can’t remove)
2. Diffusion used to deal with horizontal variations in PBL (second order diffusion): diff_opt in namelist
3. Sixth order diffusion used to take out fine-scale noise (available starting in 2007)

diff_opt ---second order diffusion

diff_opt=0 No second order diffusion
diff_opt=1 Diffusion along model surface
diff_opt=2 Horizontal diffusion

Default is 1 and we had been using that based on stability issues that have now been fixed.

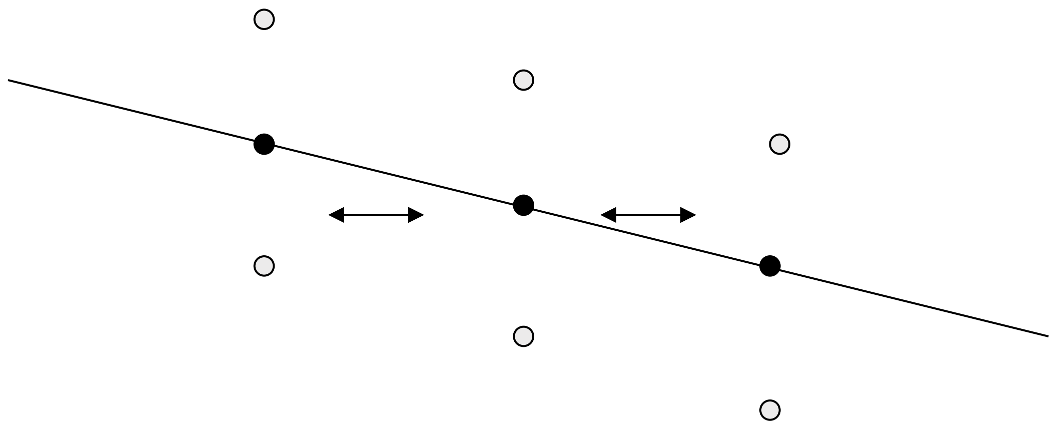
Difference between diff_opt 1 and 2



diff_opt=1

Horizontal diffusion acts along model levels
Simpler numerical method with only neighboring points on the same model level

Difference between diff_opt 1 and 2

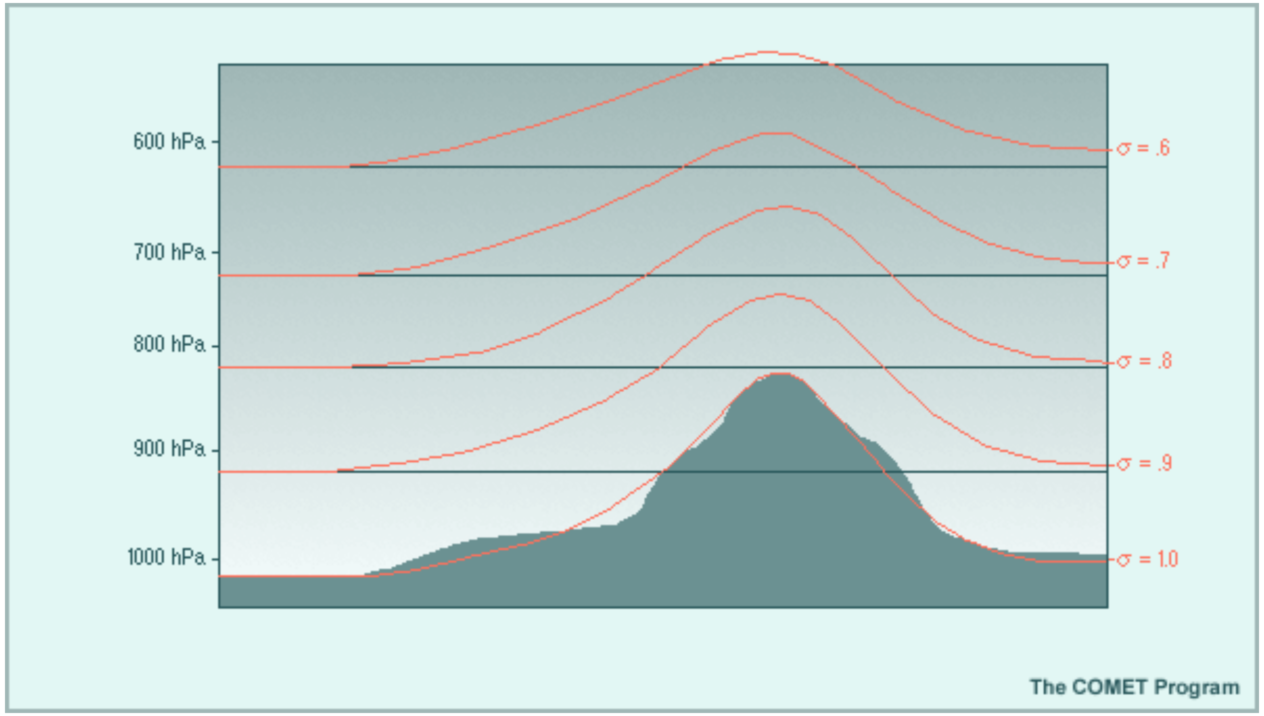


diff_opt=2

Horizontal diffusion acts along quasi-horizontal surfaces
Numerical method includes vertical correction term using more grid points

Mixing along model surfaces can mix in the VERTICAL when model surface are tilted…as they are in and near terrain

- Worse at high resolution
- Worse in gaps and valleys
- Steeper the terrain, the more serious the problem



WRF 6th Order Diffusion

6th order option adds horizontal diffusion **on model levels**

- Used as a numerical filter for 2*dx noise
- Suitable for idealized and real-data cases
- Affects all advected variables including scalars

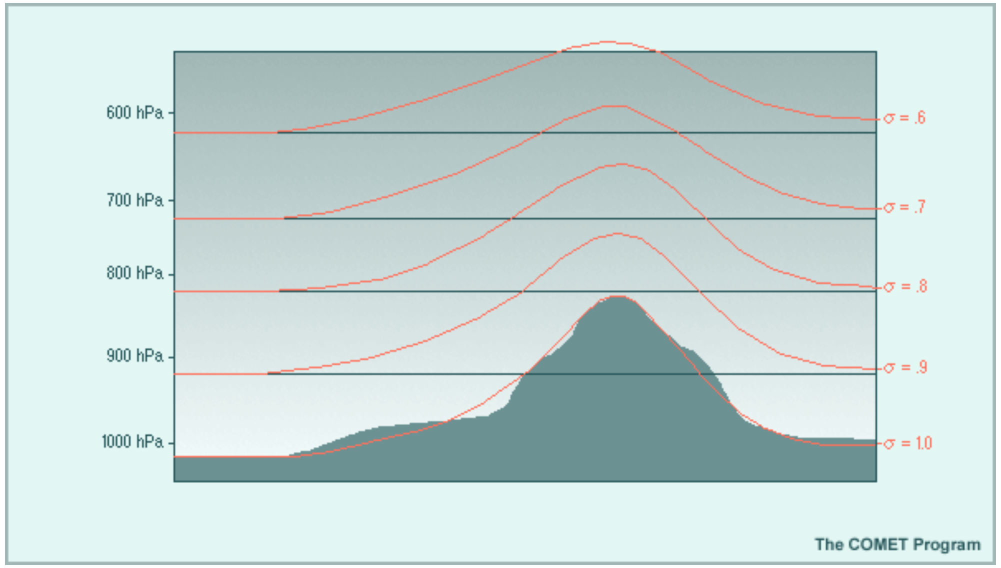
$$\frac{\partial \phi}{\partial t} = S + \alpha \nabla_{\eta}^{6} \phi,$$

diff_6th_opt

- **diff_6th_opt**
  - 0: none (default)
  - 1: on (can produce negative water)
  - 2: on and prohibit up-gradient diffusion (better for water conservation)
- **diff_6th_factor**
  - Non-dimensional strength (typical value 0.12, 1.0 corresponds to complete removal of 2*dx wave in a time-step)

AGAIN, the default is mixing along model surfaces

But that can mix in the VERTICAL when model surfaces are tilted…as they are in and near terrain

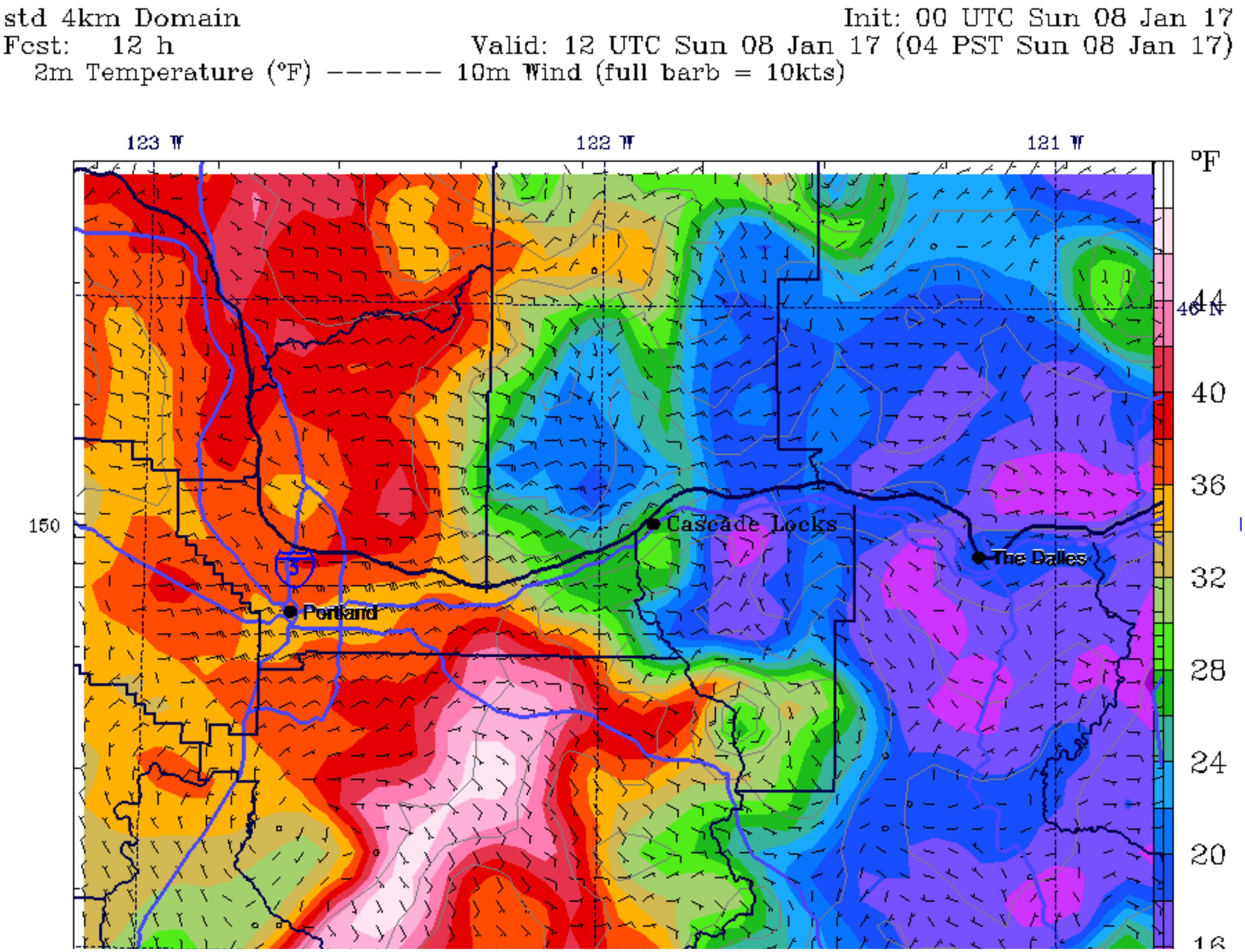


The University of Washington real-time modeling system included second order diffusion along model surfaces and 6th order diffusion

Could that have been a problem in the Columbia Gorge?

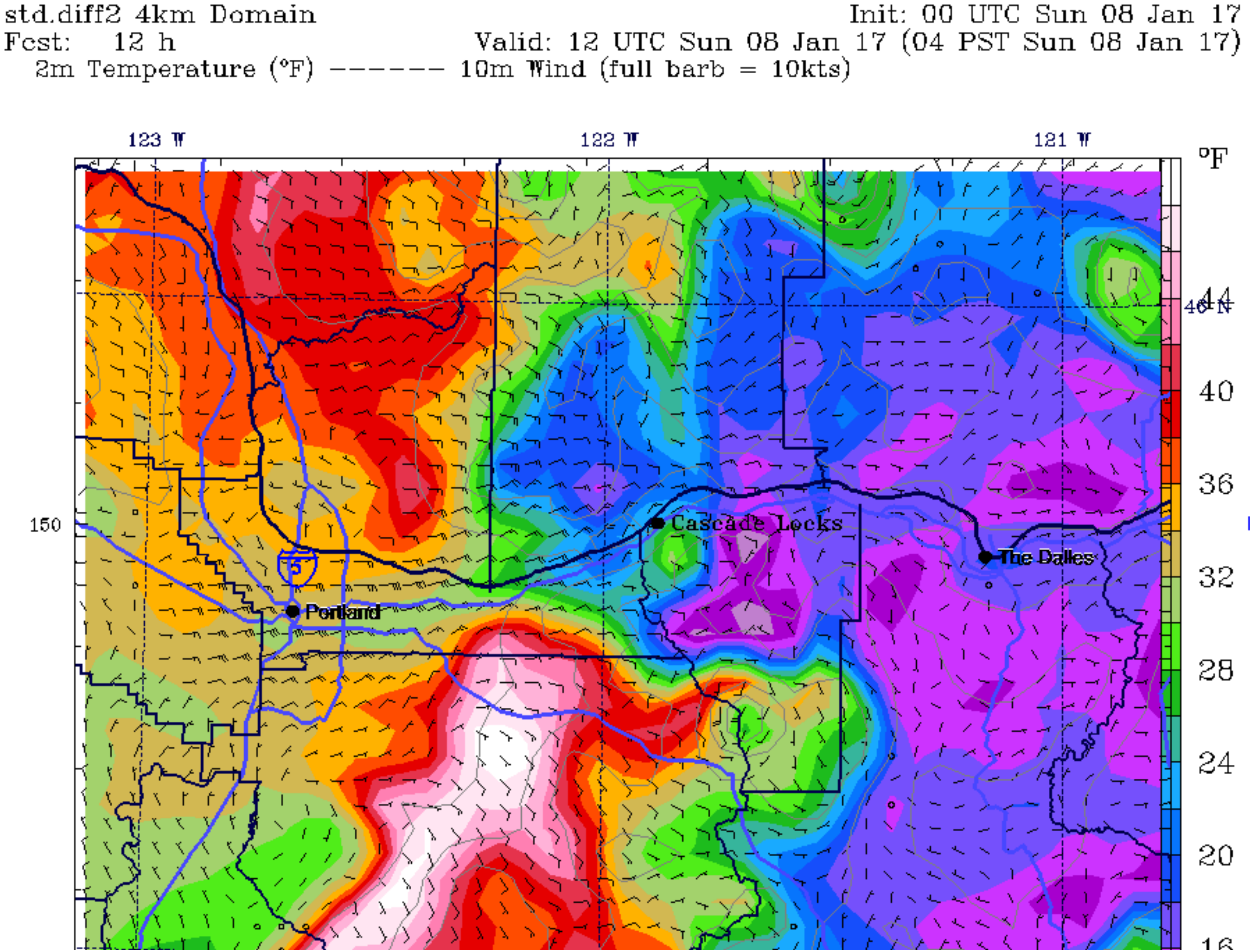
Let’s find out!

Original

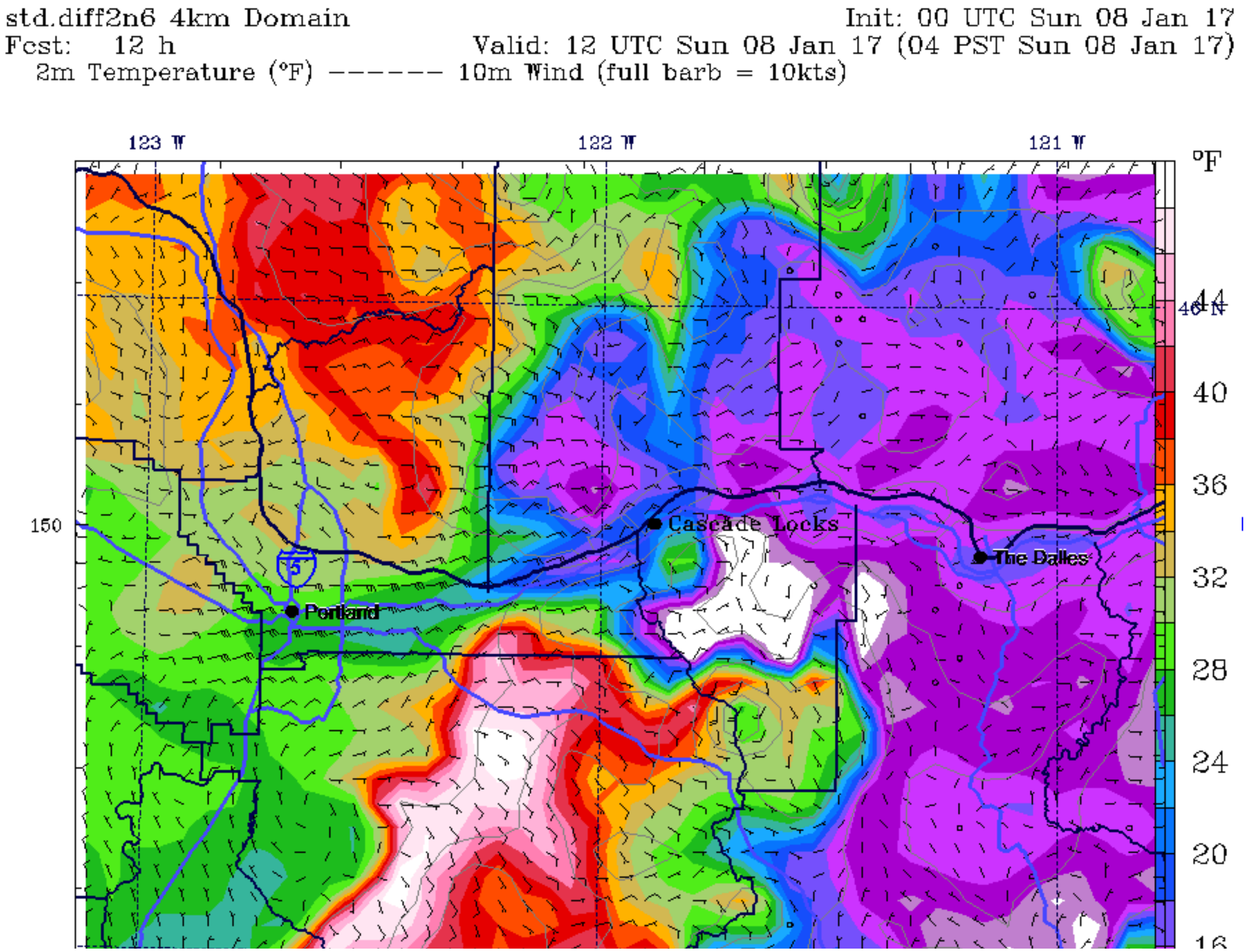


std 4km Domain
Fcst: 12 h
Init: 00 UTC Sun 08 Jan 17
Valid: 12 UTC Sun 08 Jan 17 (04 PST Sun 08 Jan 17)
2m Temperature (°F) ------- 10m Wind (full barb = 10kts)
123 W
122 W
121 W
46 N
150
Cascade Locks
The Dalles
Portland
5
°F
44
40
36
32
28
24
20
16

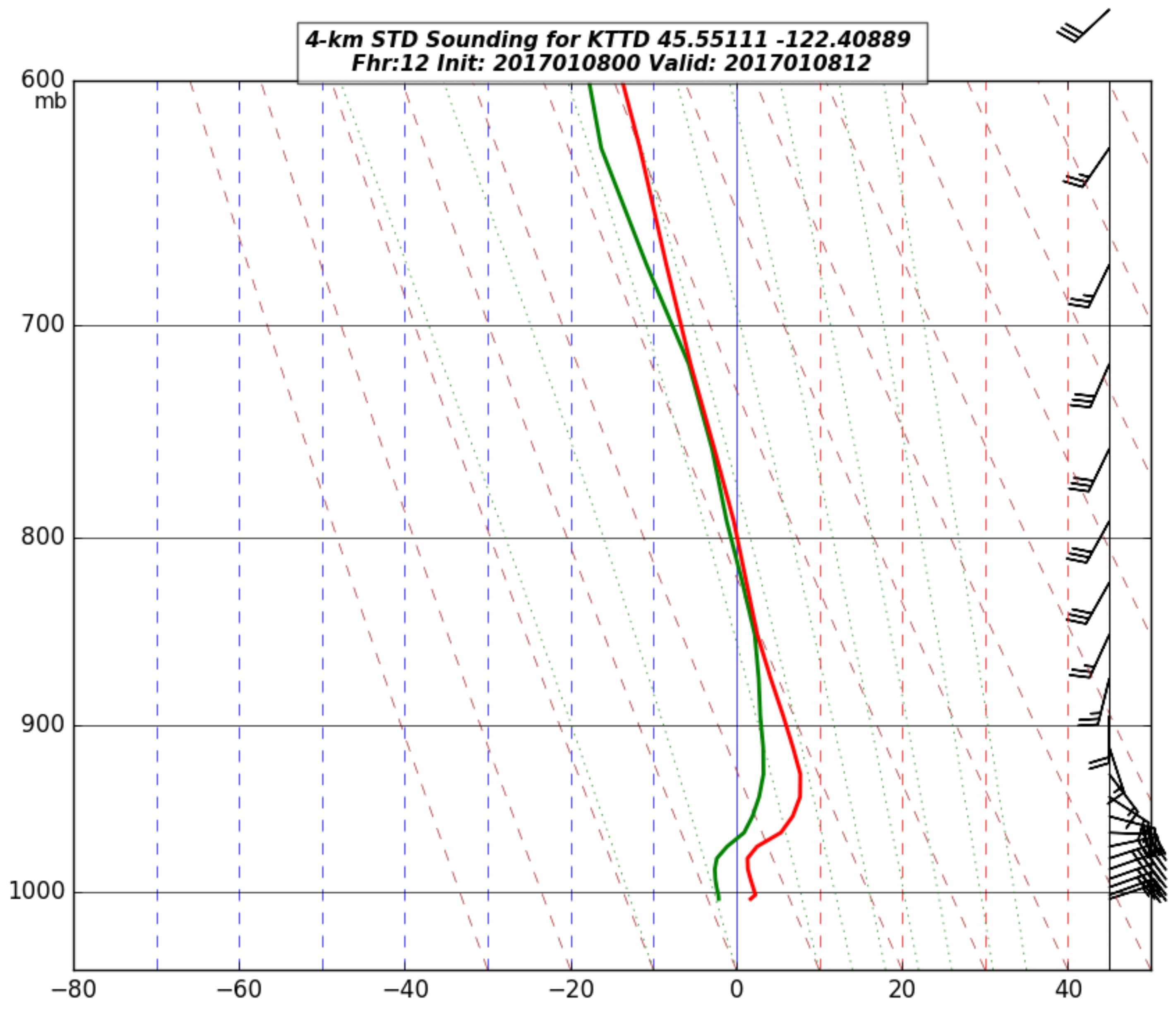
Changing 2nd order to diffusion to horizontal

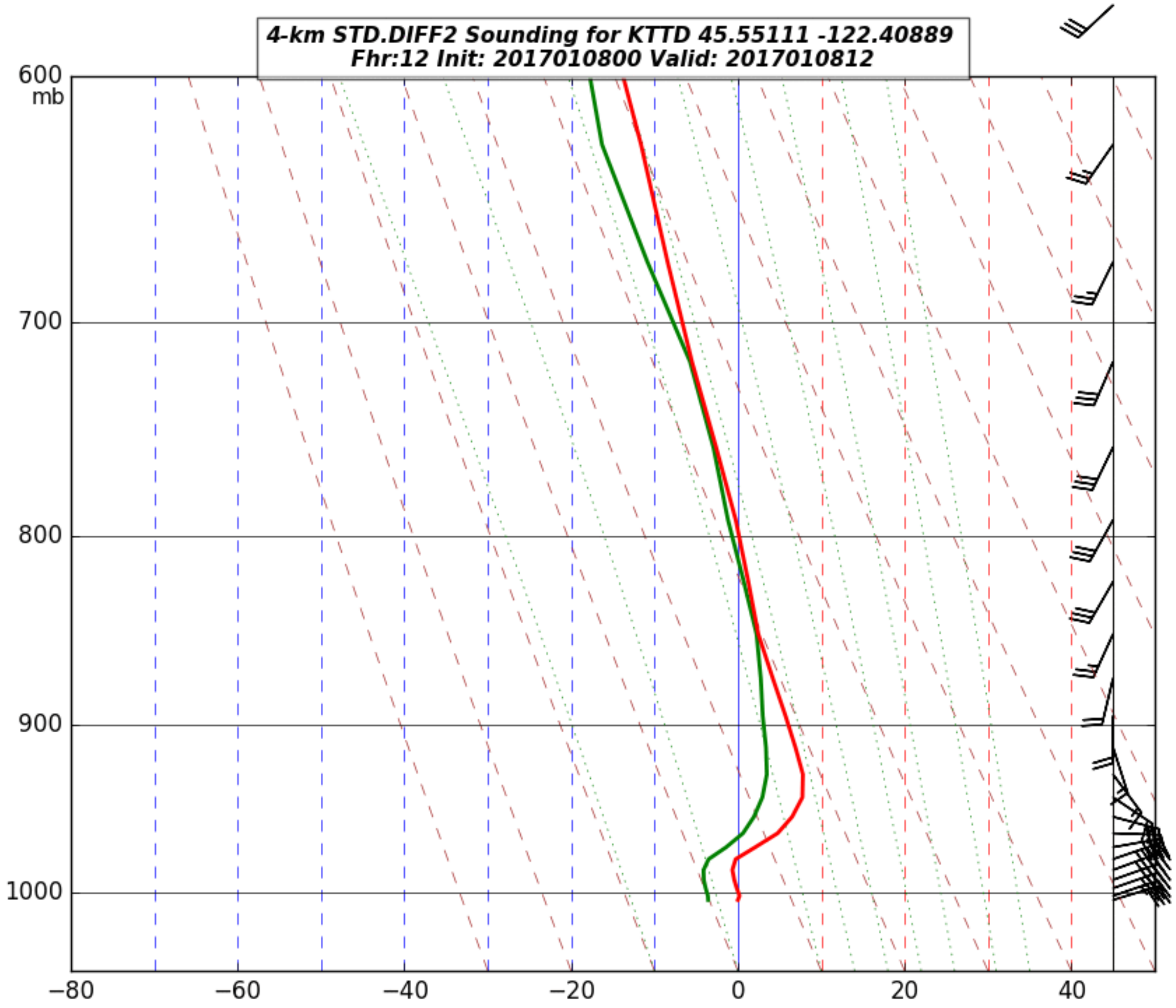


Plus Remove 6th Order Diffusion!

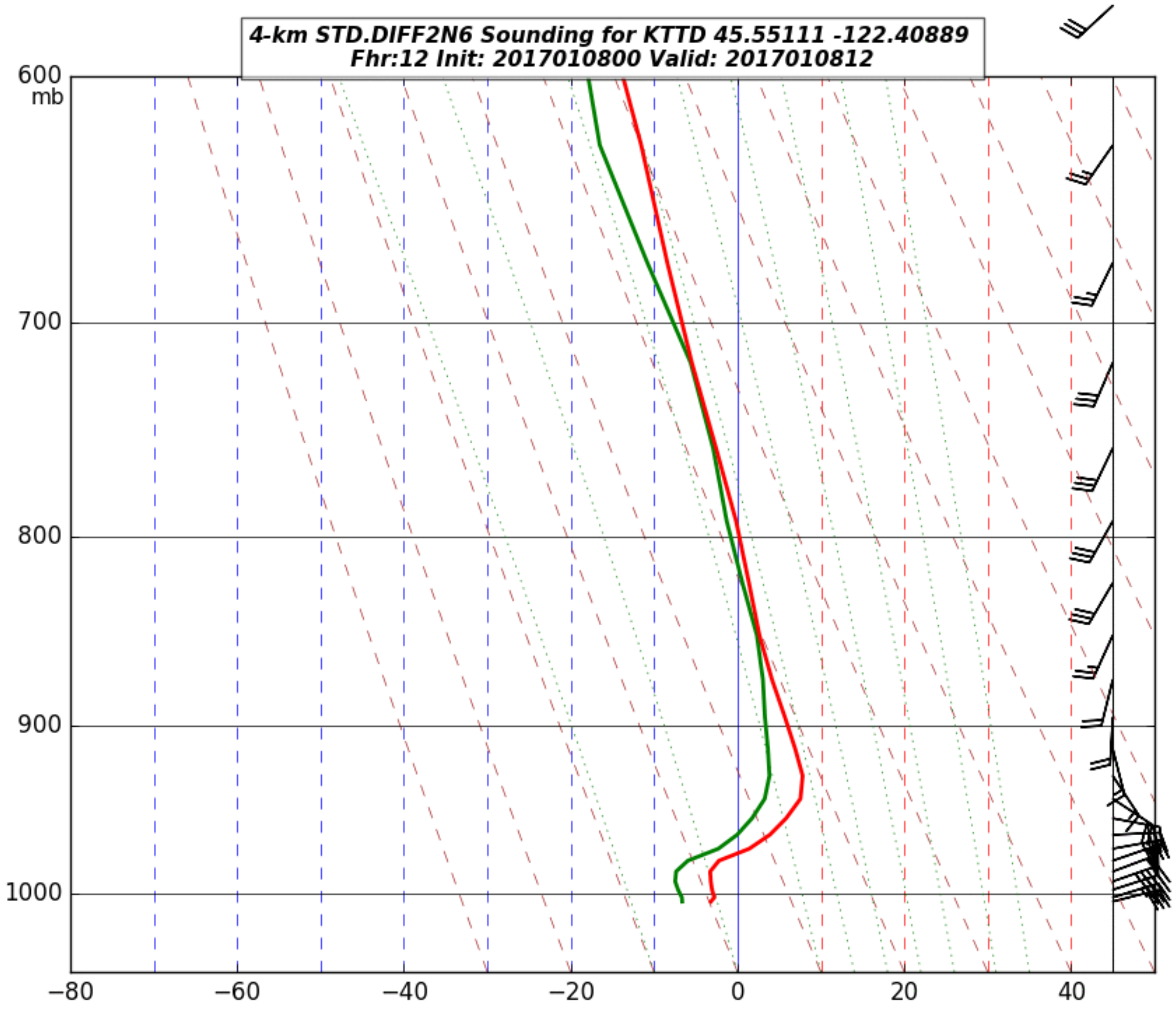


Model sounding in the western Gorge at Troutdale, OR

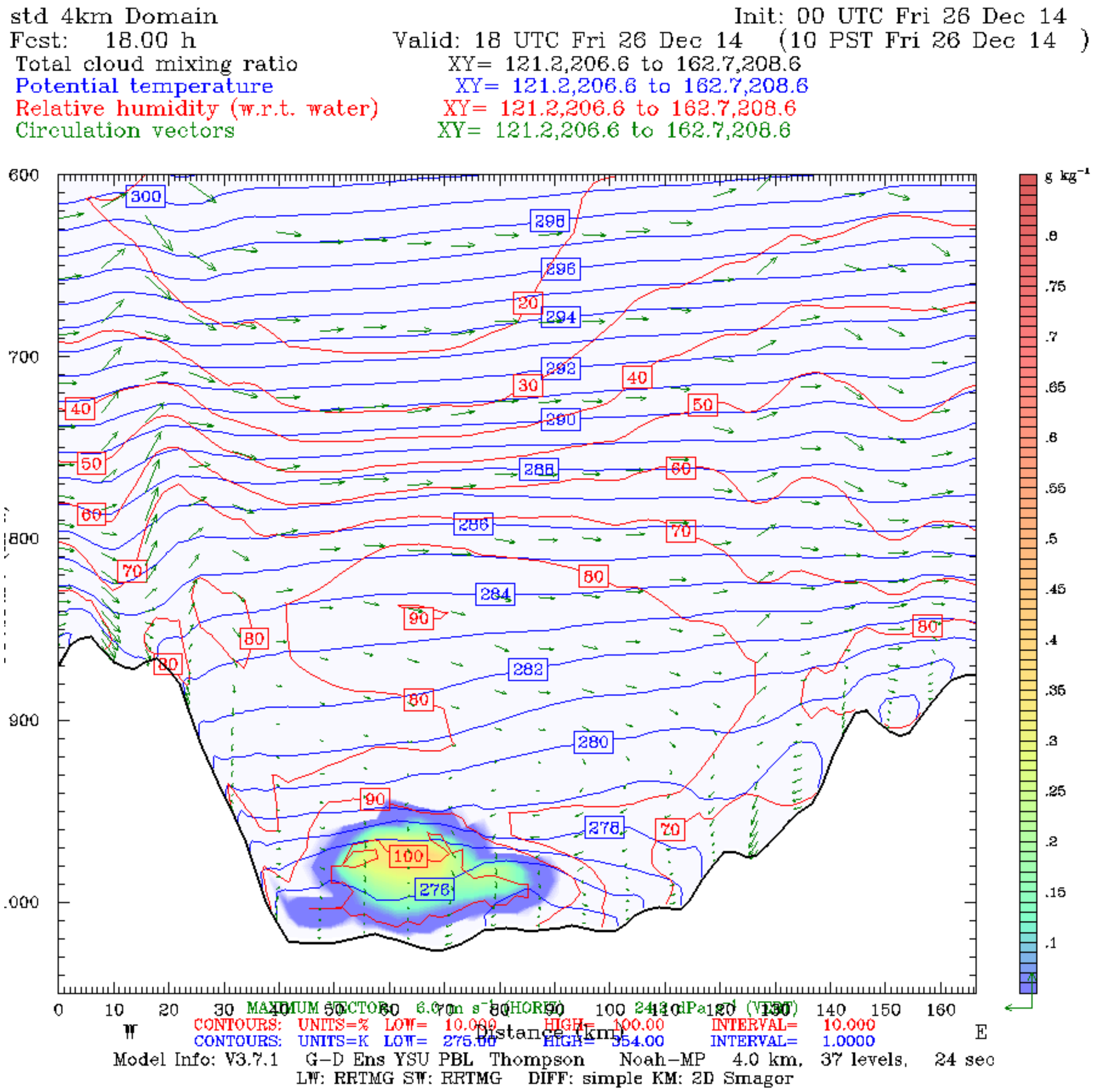




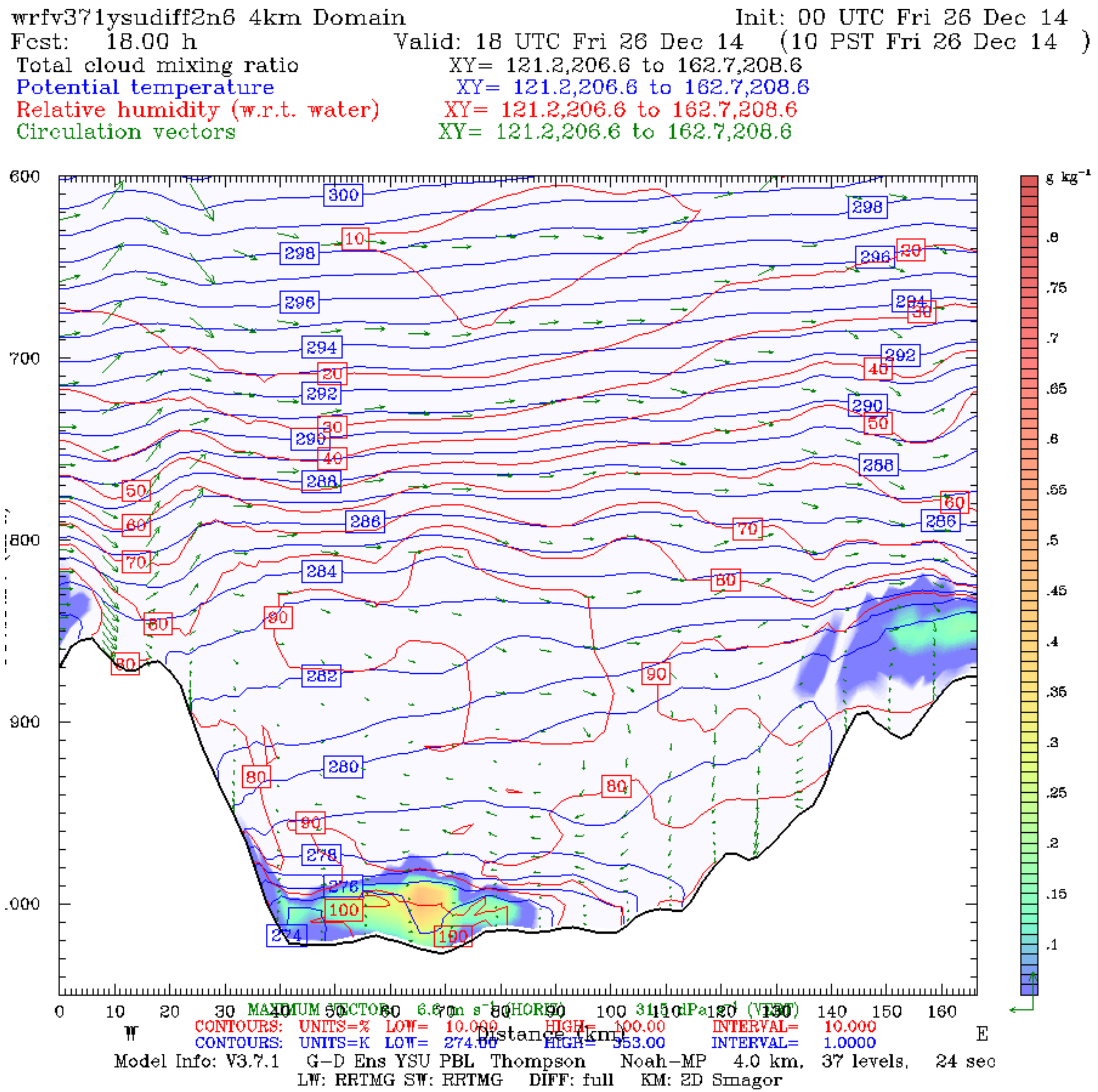
4-km STD.DIFF2 Sounding for KTTD 45.55111 -122.40889
Fhr:12 Init: 2017010800 Valid: 2017010812
600
mb
700
800
900
1000
−80
−60
−40
−20
0
20
40


4-km STD.DIFF2N6 Sounding for KTTD 45.55111 -122.40889
Fhr:12 Init: 2017010800 Valid: 2017010812
600
mb
700
800
900
1000
−80
−60
−40
−20
0
20
40

Better Fog

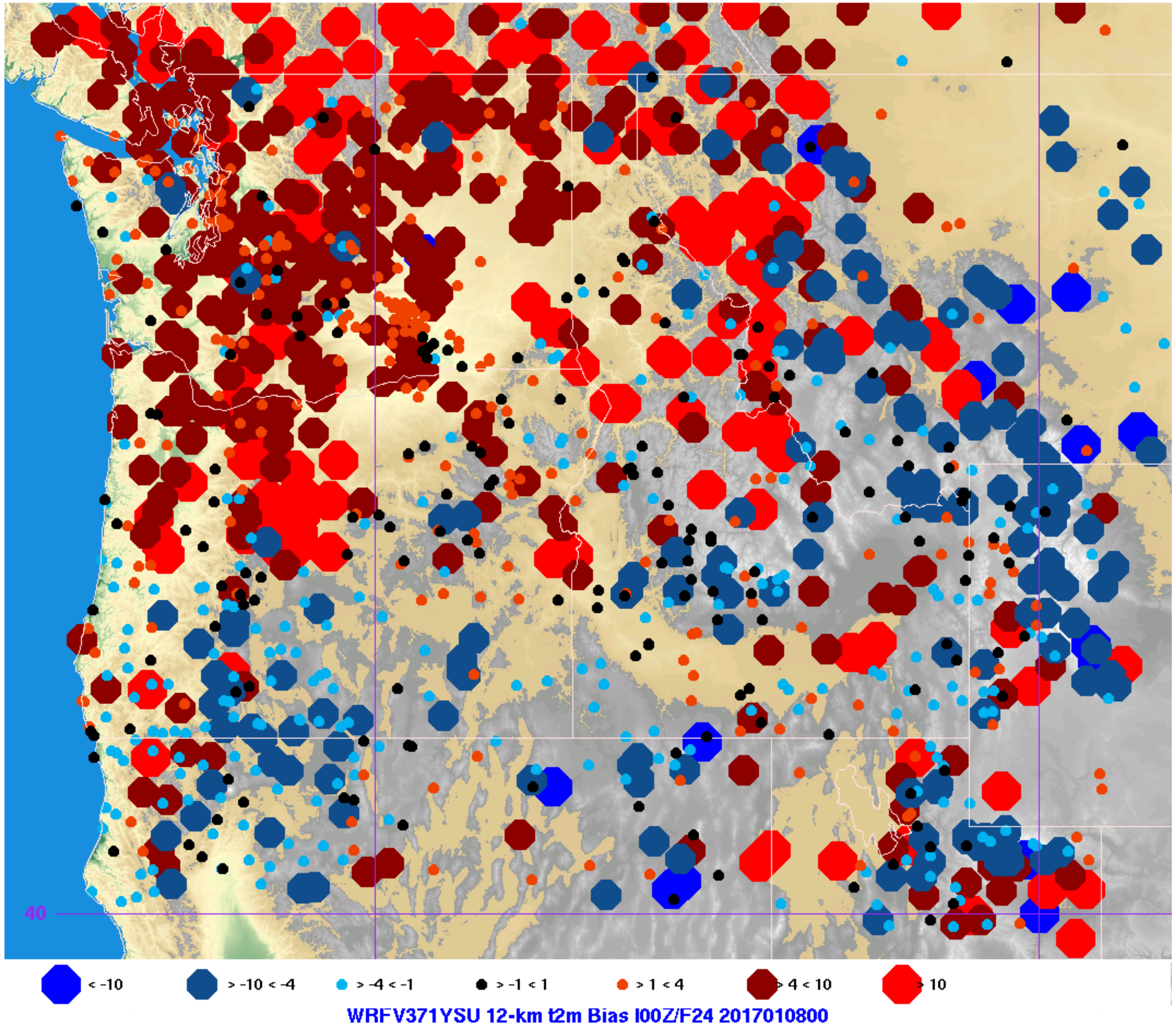


std 4km Domain
Init: 00 UTC Fri 26 Dec 14
Fcst: 18.00 h
Valid: 18 UTC Fri 26 Dec 14 (10 PST Fri 26 Dec 14)
Total cloud mixing ratio XY= 121.2,206.6 to 162.7,208.6
Potential temperature XY= 121.2,206.6 to 162.7,208.6
Relative humidity (w.r.t. water) XY= 121.2,206.6 to 162.7,208.6
Circulation vectors XY= 121.2,206.6 to 162.7,208.6
g kg⁻¹
W
E
Distance (km)
CONTOURS: UNITS=% LOW= 10.000 HIGH= 100.00 INTERVAL= 10.000
CONTOURS: UNITS=K LOW= 275.00 HIGH= 354.00 INTERVAL= 1.0000
Model Info: V3.7.1 G-D Ens YSU PBL Thompson Noah-MP 4.0 km, 37 levels, 24 sec
LW: RRTMG SW: RRTMG DIFF: simple KM: 2D Smagor

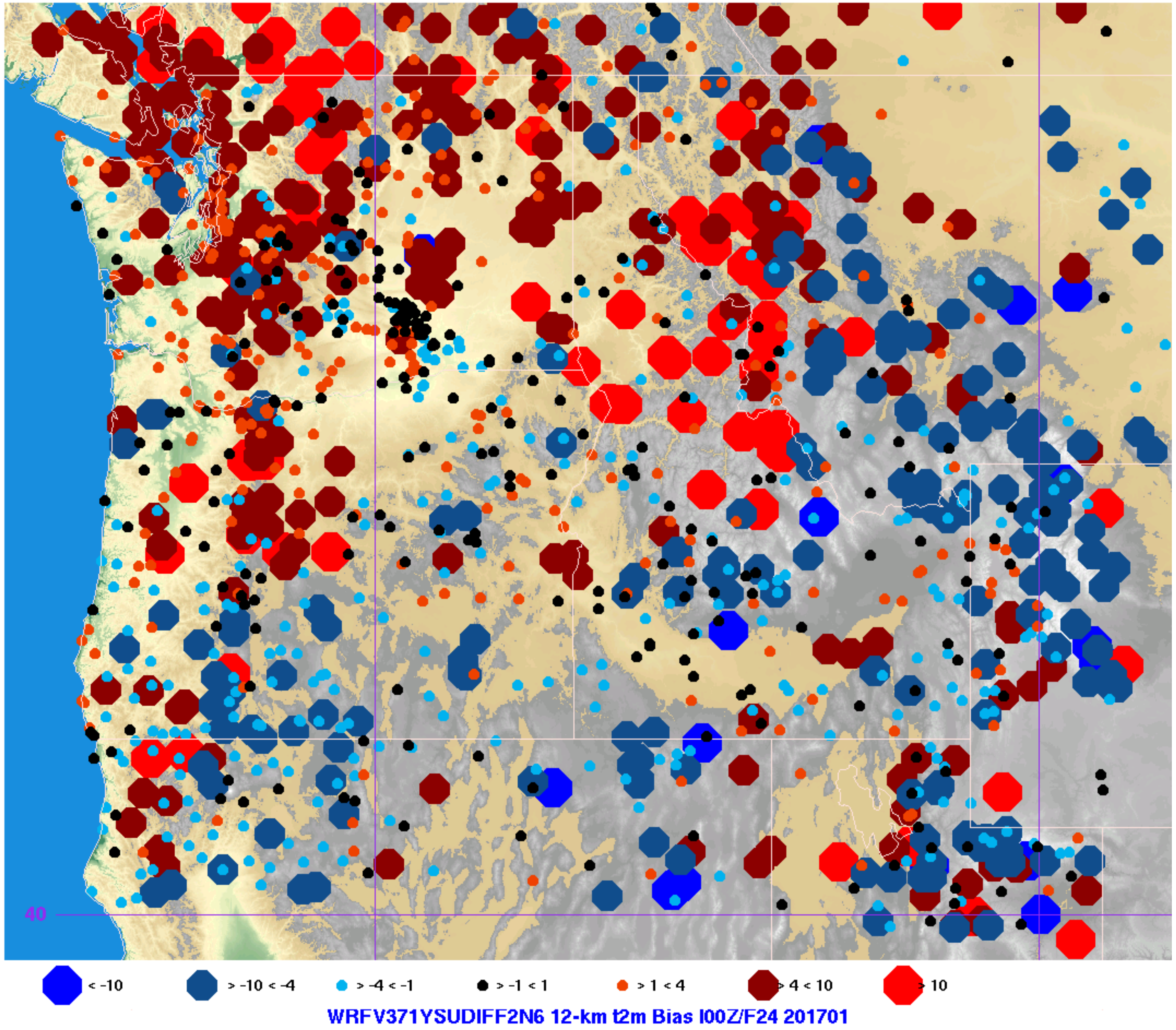

wrfv371ysudiff2n6 4km Domain
Init: 00 UTC Fri 26 Dec 14
Fcst: 18.00 h
Valid: 18 UTC Fri 26 Dec 14 (10 PST Fri 26 Dec 14)
Total cloud mixing ratio
XY= 121.2,206.6 to 162.7,208.6
Potential temperature
XY= 121.2,206.6 to 162.7,208.6
Relative humidity (w.r.t. water)
XY= 121.2,206.6 to 162.7,208.6
Circulation vectors
XY= 121.2,206.6 to 162.7,208.6
g kg-1
Distance (km)
W
E
CONTOURS: UNITS=% LOW= 10.000 HIGH= 100.00 INTERVAL= 10.000
CONTOURS: UNITS=K LOW= 274.00 HIGH= 353.00 INTERVAL= 1.0000
Model Info: V3.7.1 G-D Ens YSU PBL Thompson Noah-MP 4.0 km, 37 levels, 24 sec
LW: RRTMG SW: RRTMG DIFF: full KM: 2D Smagor

Surface Temperature Bias for 24h forecast valid January 08, 00 UTC

Original diffusion

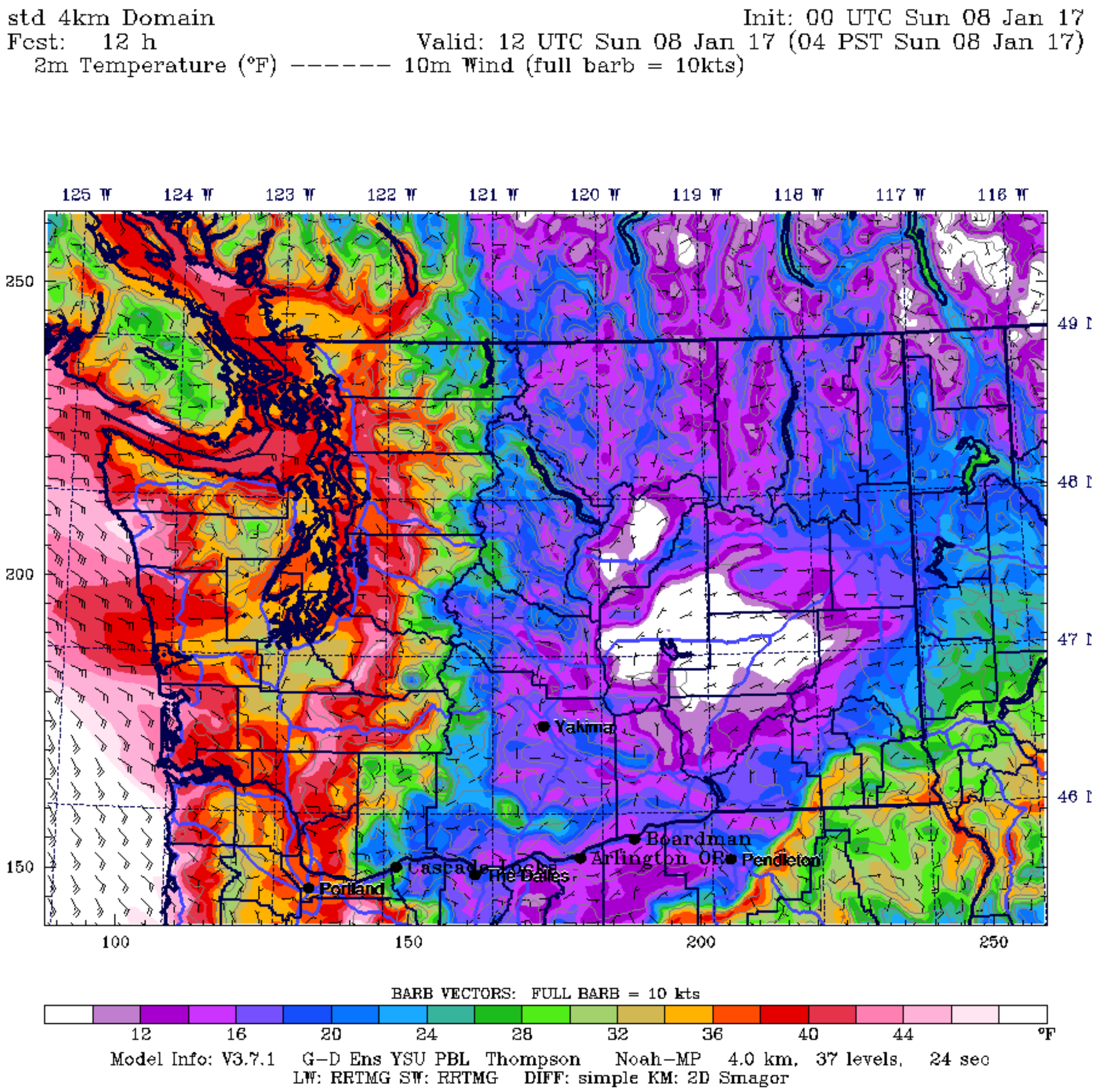


After changing 2^{nd} order and eliminating 6^{th} order

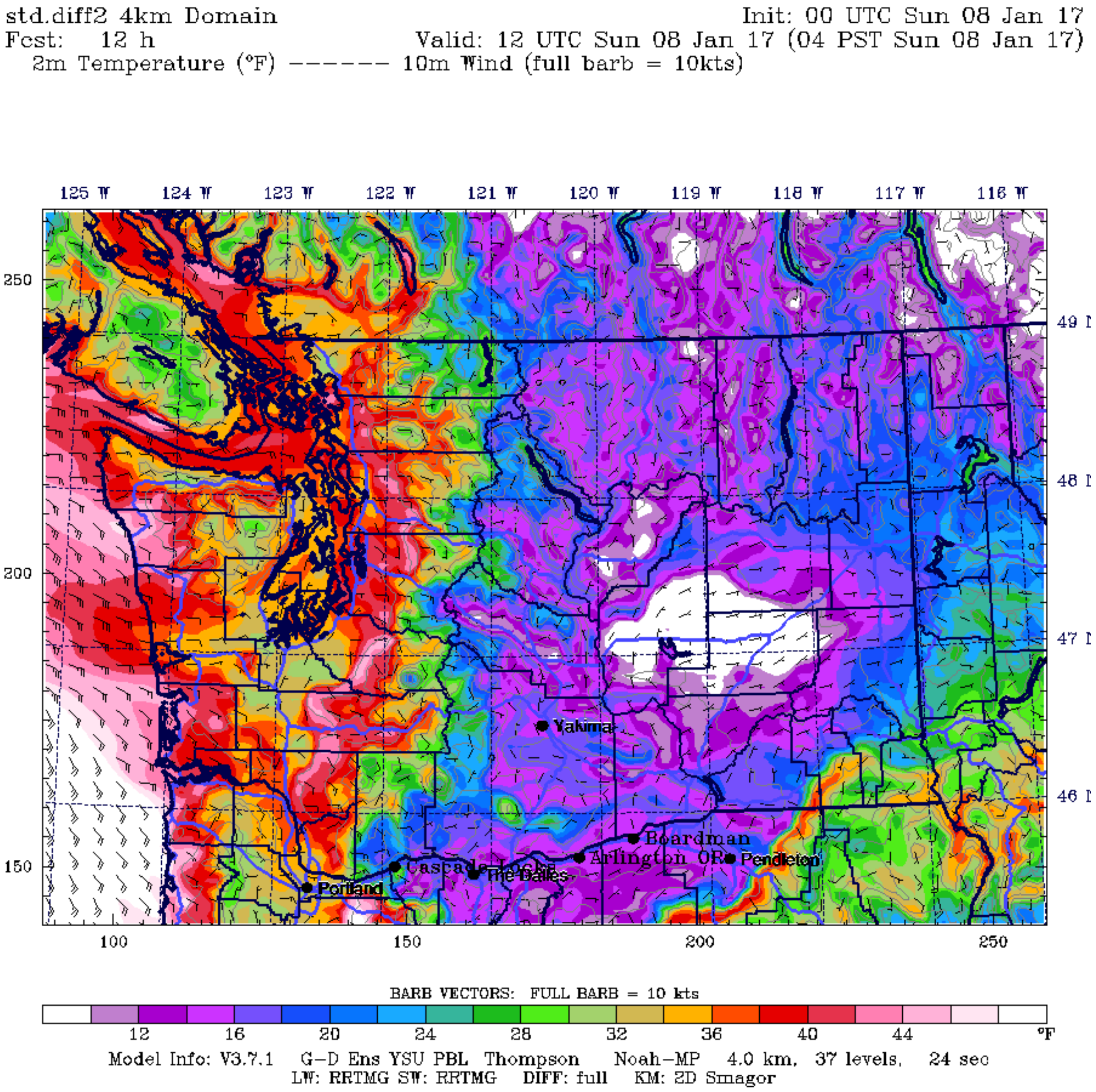


Regional surface temperature changes

Original

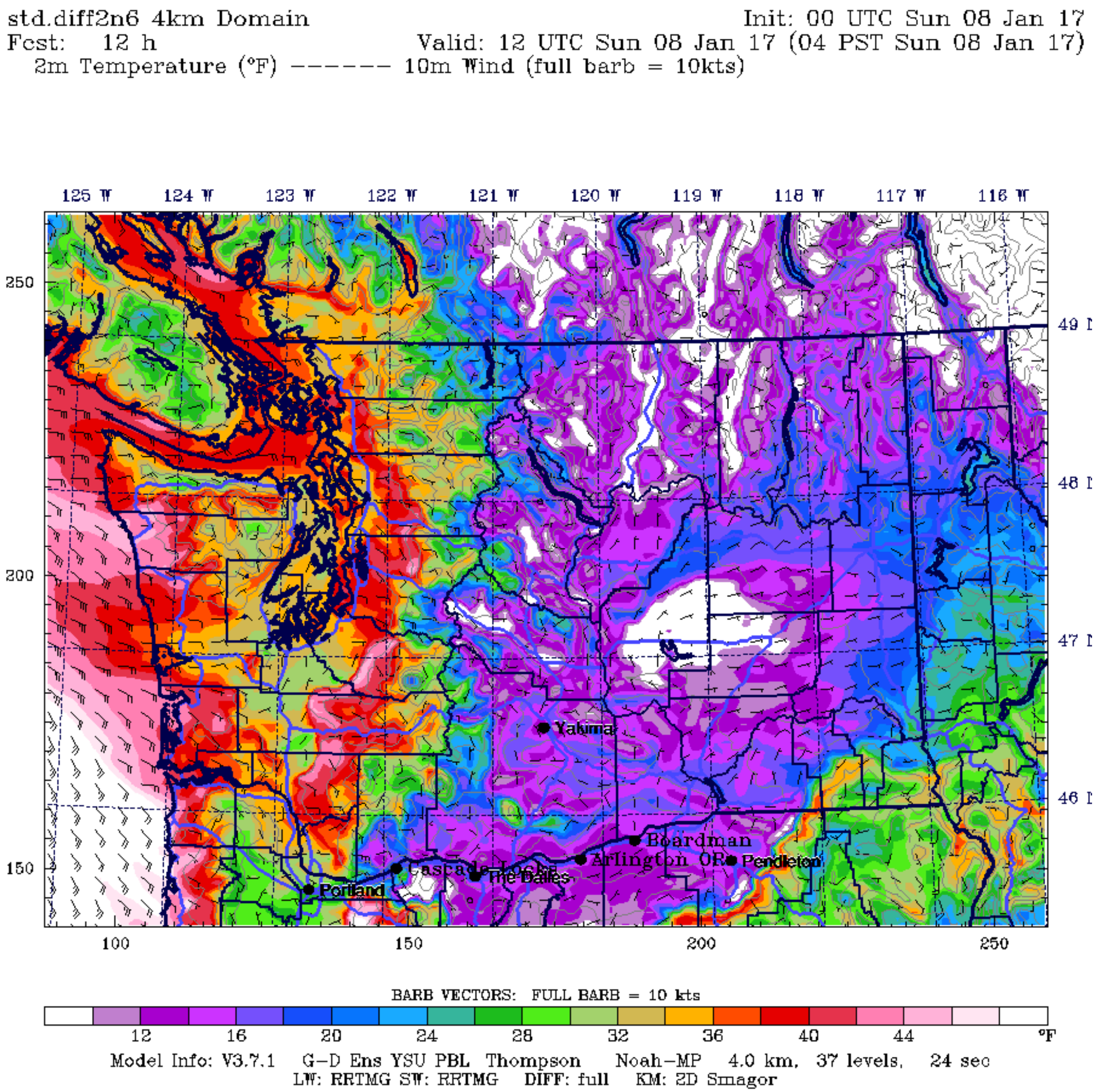


2^{nd} order horizontal (subtle)



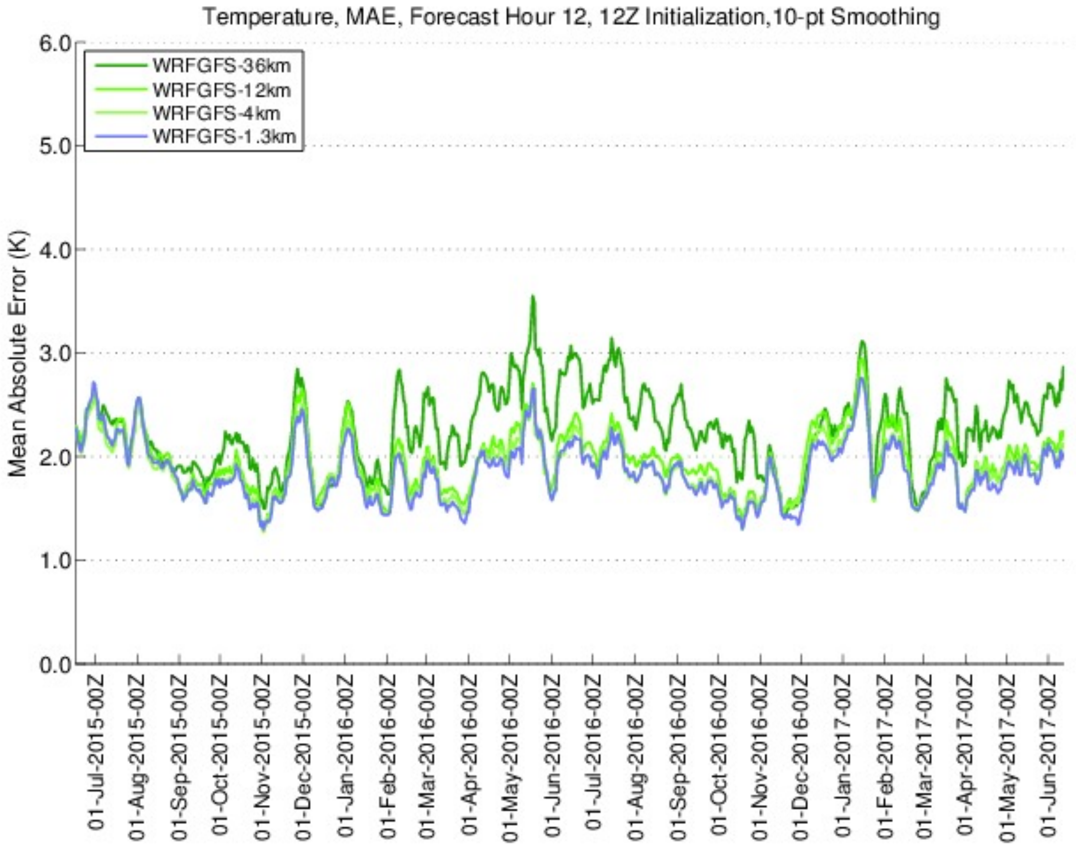
Plus no 6th order

Note: cold air in narrow valleys



Horizontal 2nd order and no 6th order diffusion is now operational in the UW real time system

- No negative impacts on reliability
- No negative impacts on general verification
- Clear improvements near and in terrain for stable conditions



Bottom line:

Diffusion of both kinds (2nd order and 6th order) along model surfaces caused substantial and unrealistic vertical mixing in stable PBL situations.

In areas of terrain it is useful to use horizontal second order diffusion and to turn off 6th order diffusion.

The END