WRF Model Physics: Progress, Problems, and Perhaps Some Solutions

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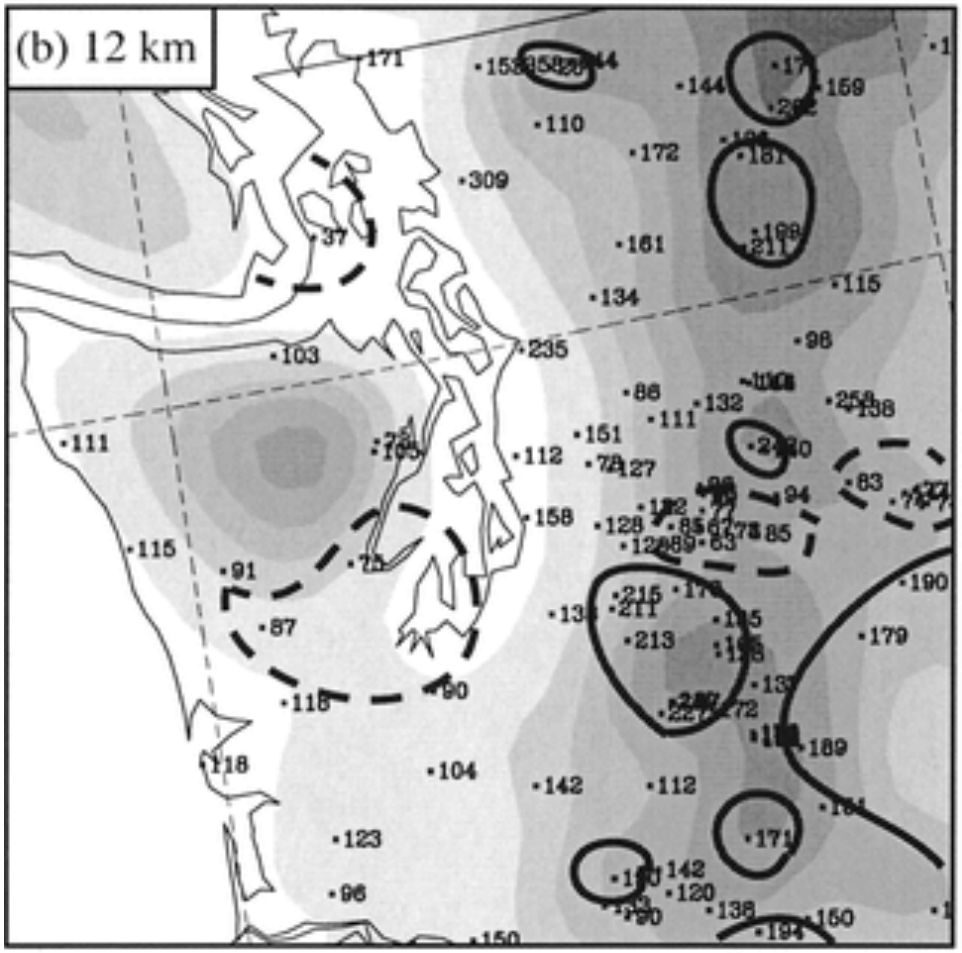
For Several Basic Parameters We Have Made Substantial Progress With the Transition from MM5 to WRF and From Improvements in WRF

Case in Point: Precipitation

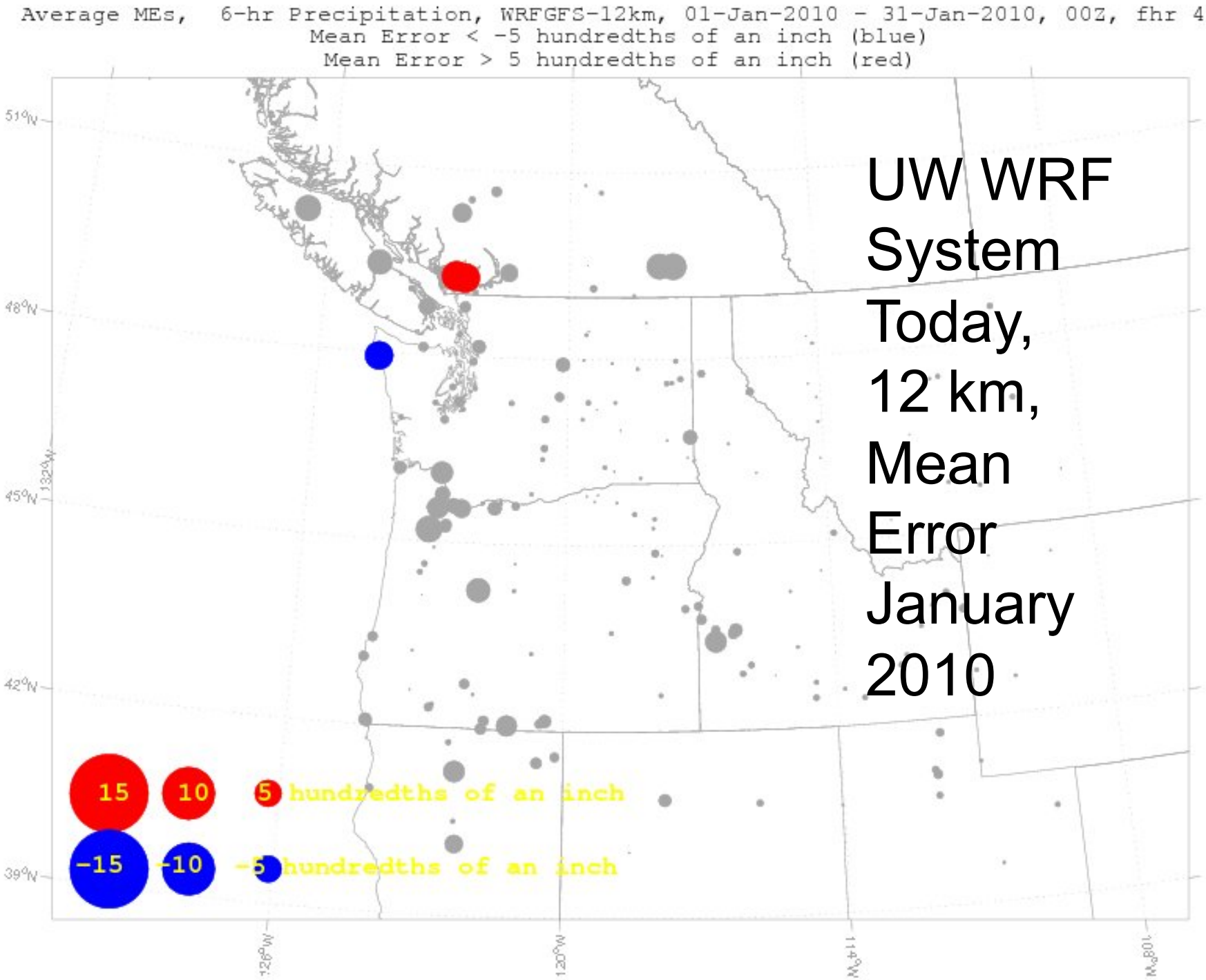
MM5 and Early WRF had large systematic errors

MM5 Precip Bias for 24-h: overprediction on windward slopes



90% and 160% lines are contoured with dashed and solid lines

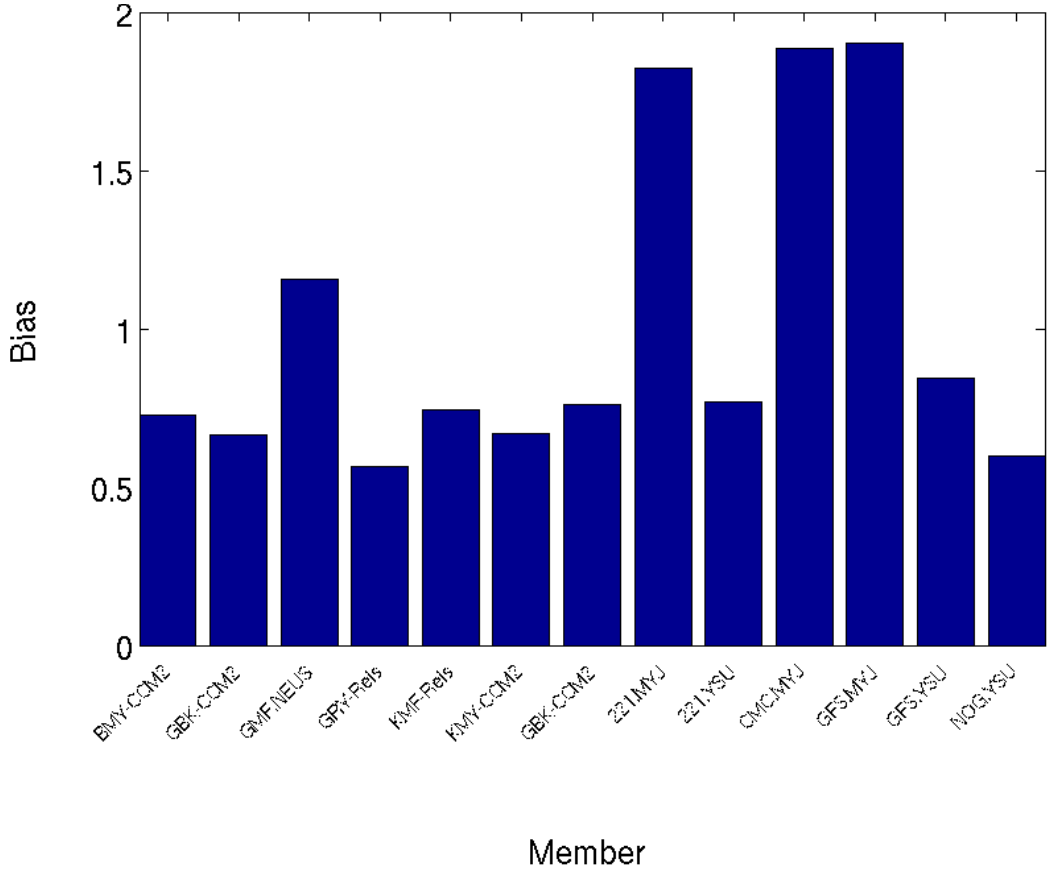
For an entire winter season: 98-99


Average MEs, 6-hr Precipitation, WRFGFS-12km, 01-Jan-2010 - 31-Jan-2010, 00Z, fhr 48
Mean Error < -5 hundredths of an inch (blue)
Mean Error > 5 hundredths of an inch (red)
51°N
48°N
45°N
42°N
39°N
132°W
126°W
120°W
114°W
108°W
15
10
5 hundredths of an inch
-15
-10
-5 hundredths of an inch
UW WRF System Today, 12 km, Mean Error January 2010

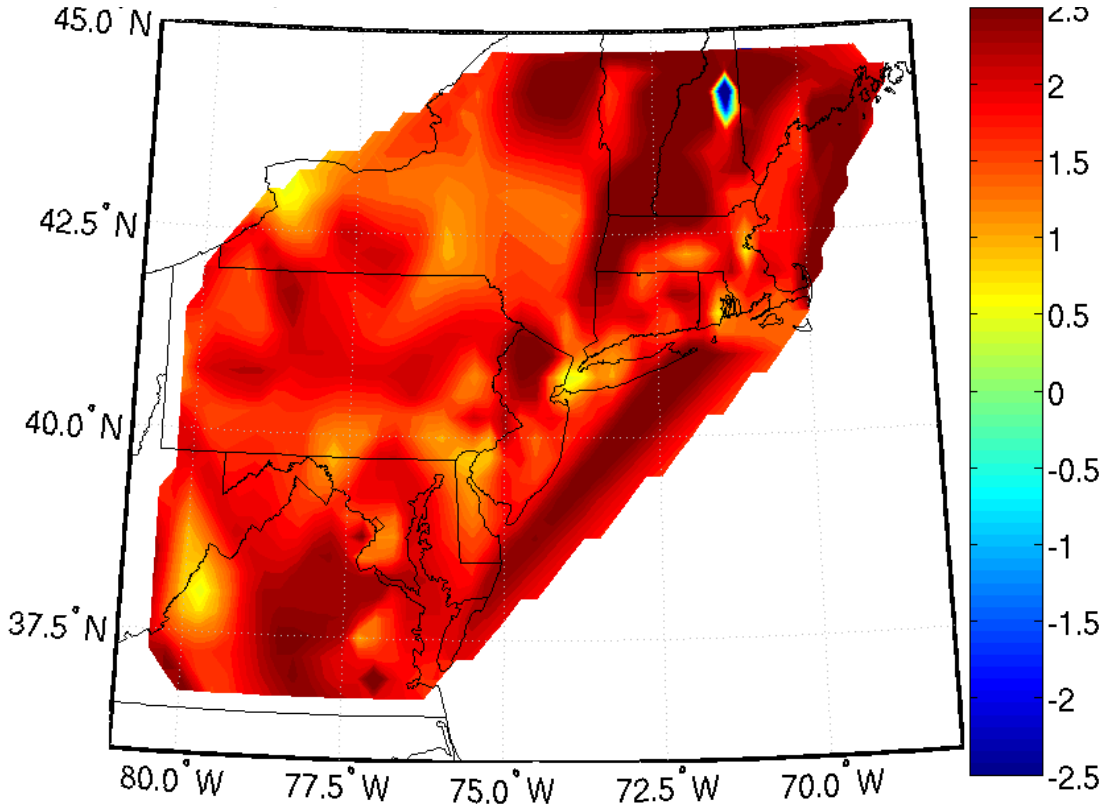
But some parameters are still a problem: wind speed and wind direction

- WRF generally has a substantial overprediction bias at low to moderate wind speeds
- Winds are generally too geostrophic.
- Not enough contrast between winds over land and water.
- This problem is evident virtually everywhere

Northeast U.S. from SUNY Stony Brook (Courtesy of Brian Colle): 12-36 hr wind bias for NE US: additive bias (F-O)



SUNY Stony Brook:
Wind Bias over Extended Period for One Ensemble Member



U.S. Army WRF over Utah

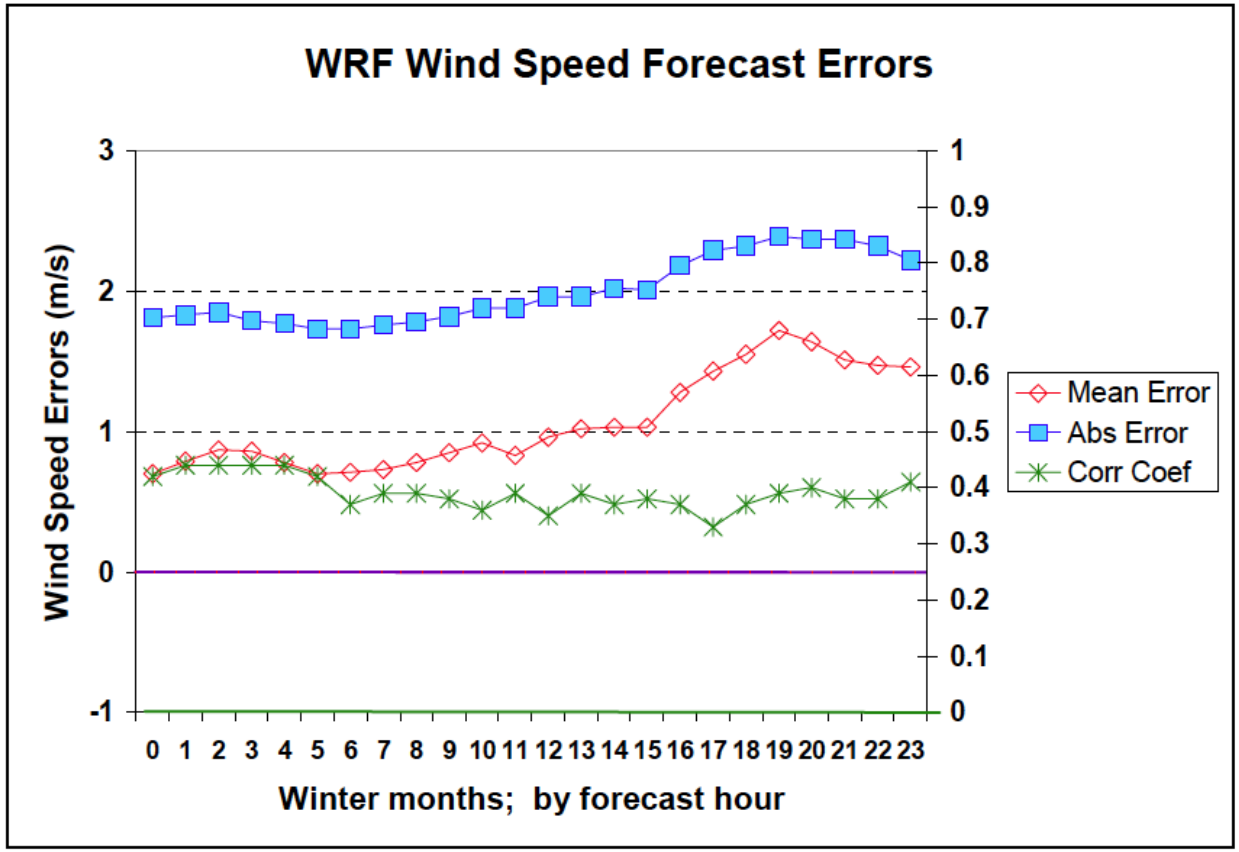


Figure 9. WRF wind speed forecast errors (left axis) and correlation coefficients (right axis) by forecast hour for the winter model runs.

Cheng and Steenburgh 2005 (circles are WRF)

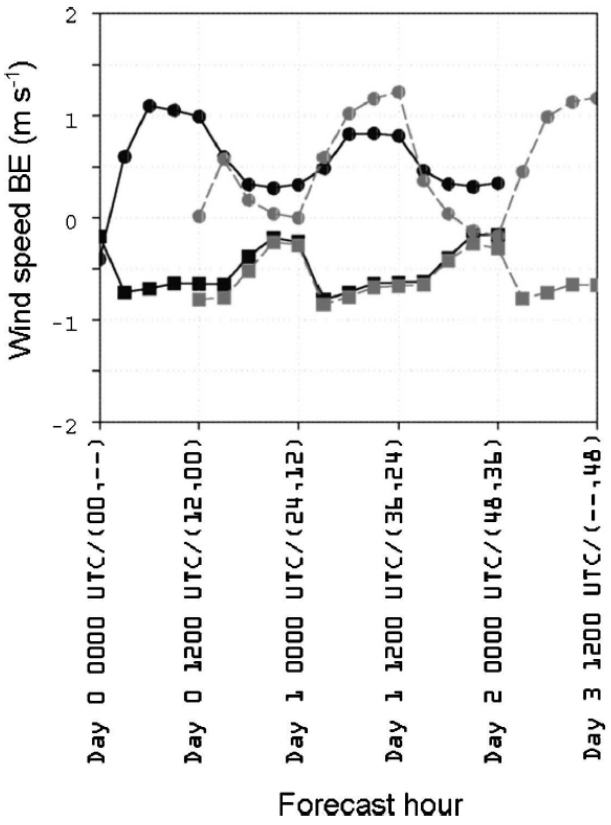
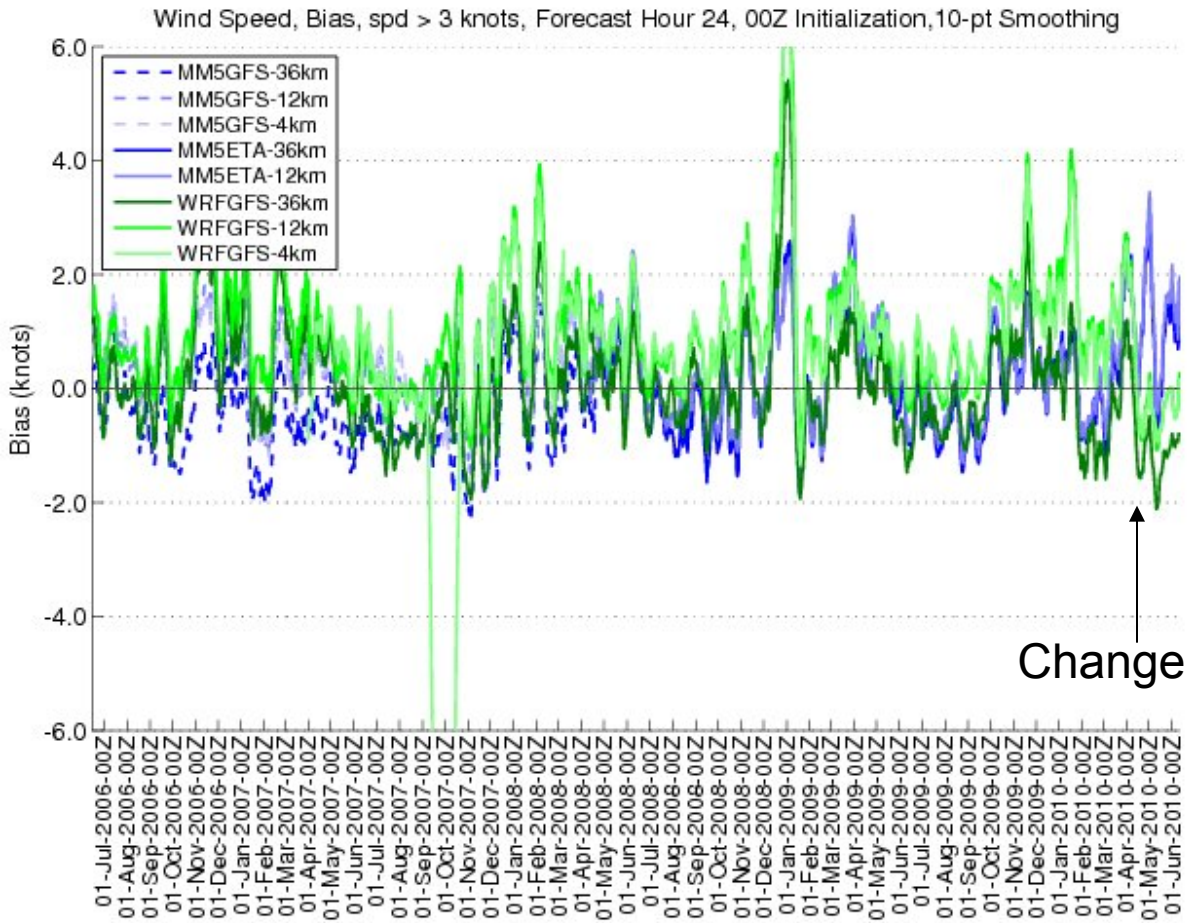
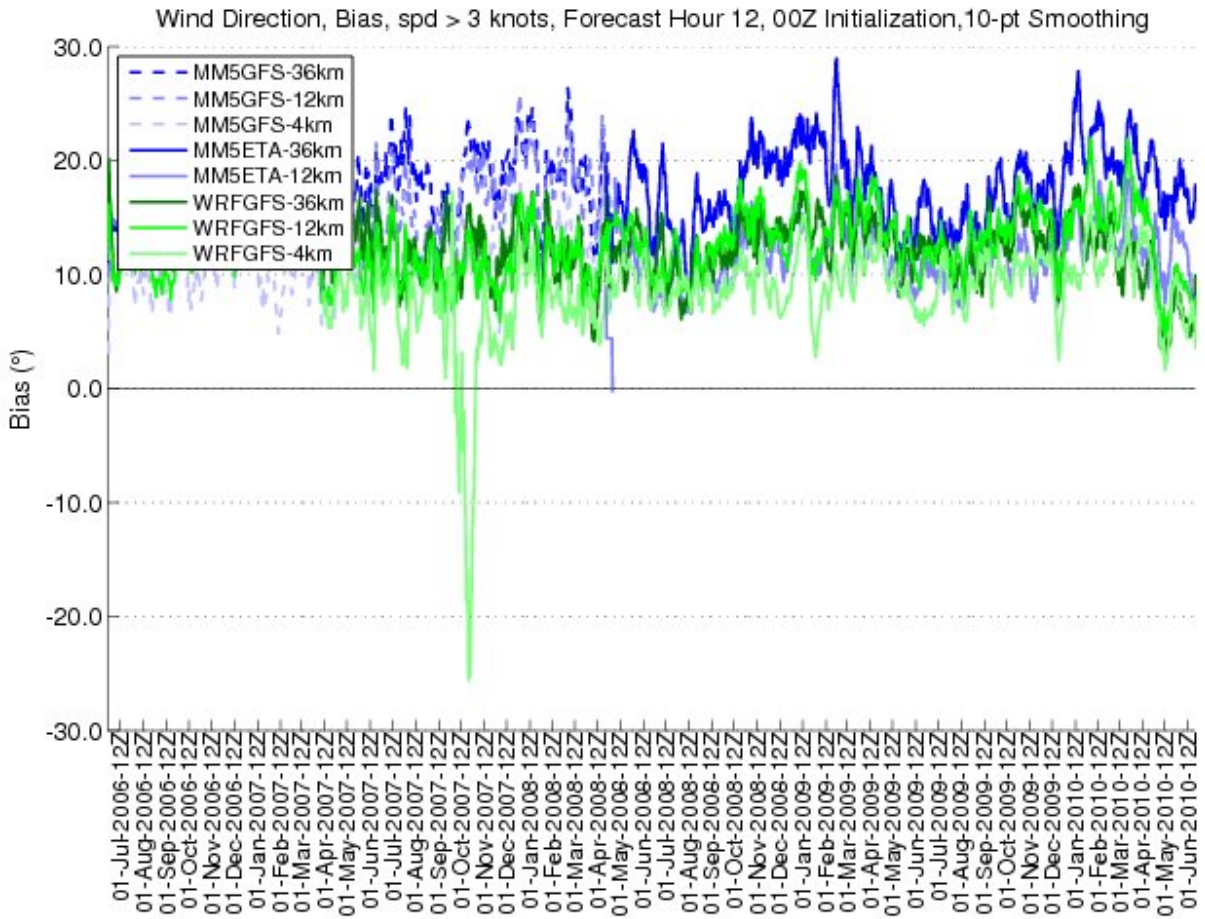


FIG. 7. Average wind speed BE (m s^{-1}) as a function of forecast hour (UTC) for the 0000 (black curves) and 1200 UTC (gray curves) cycles. Circles (squares) represent results from CIRP WRF (the Eta).

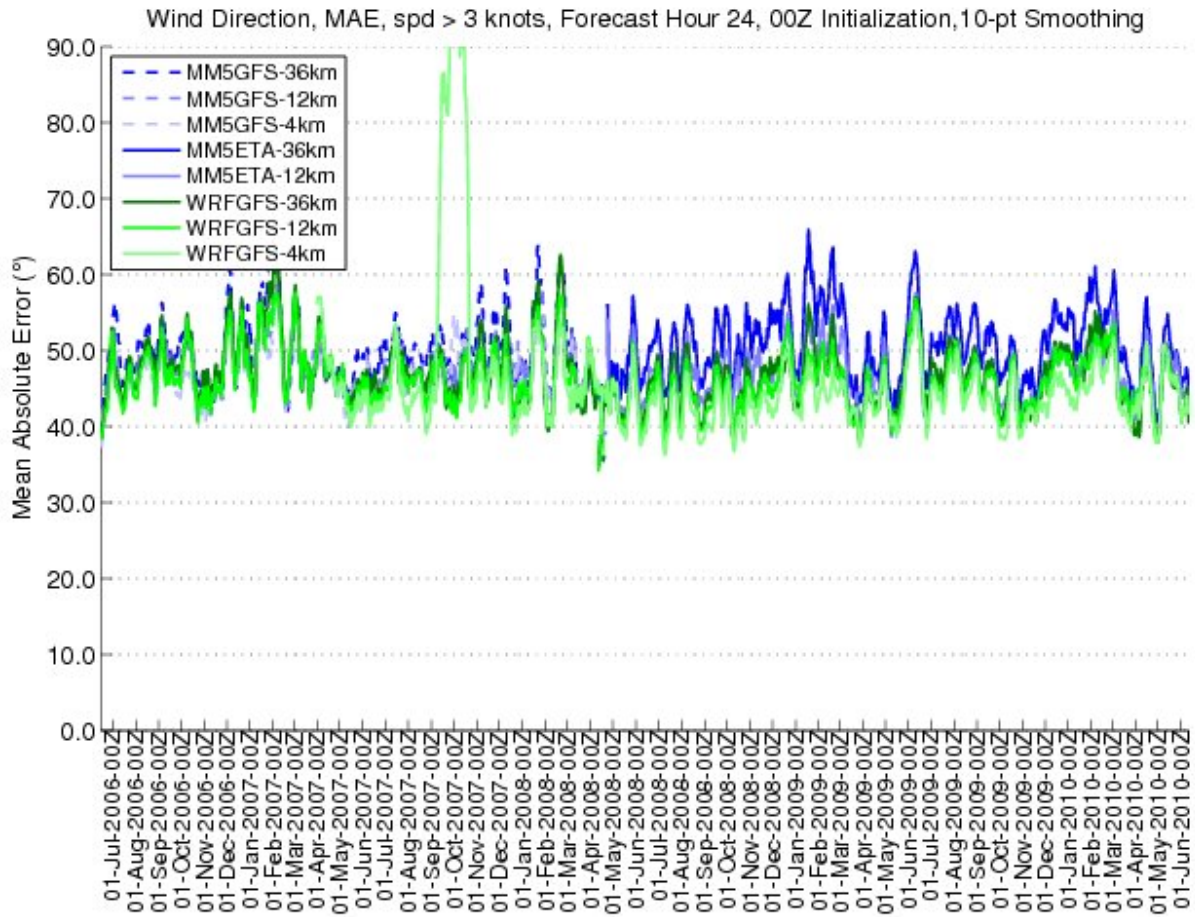
UW WRF 36-12-4km: Positive Bias



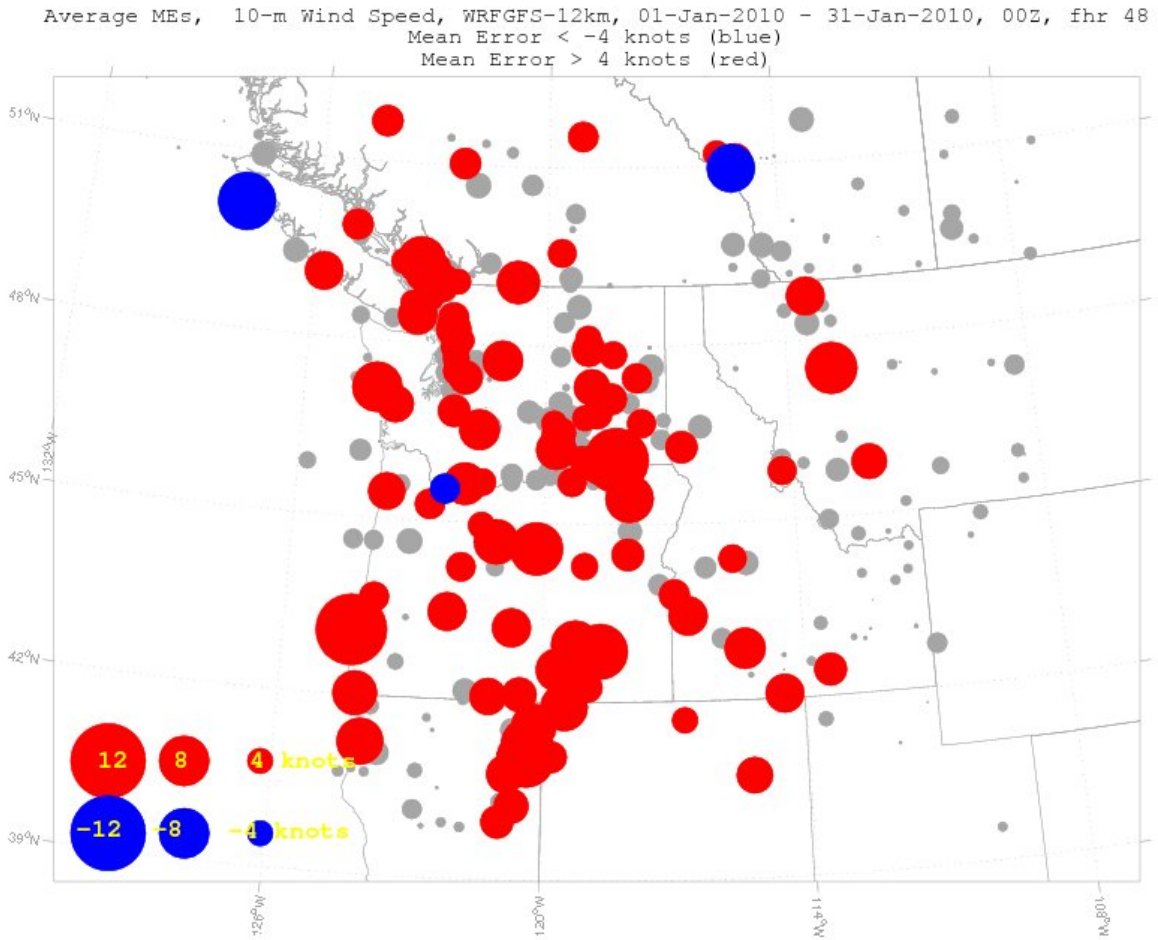
Wind Direction Bias: Too Geostrophic



MAE is something we like to forget…



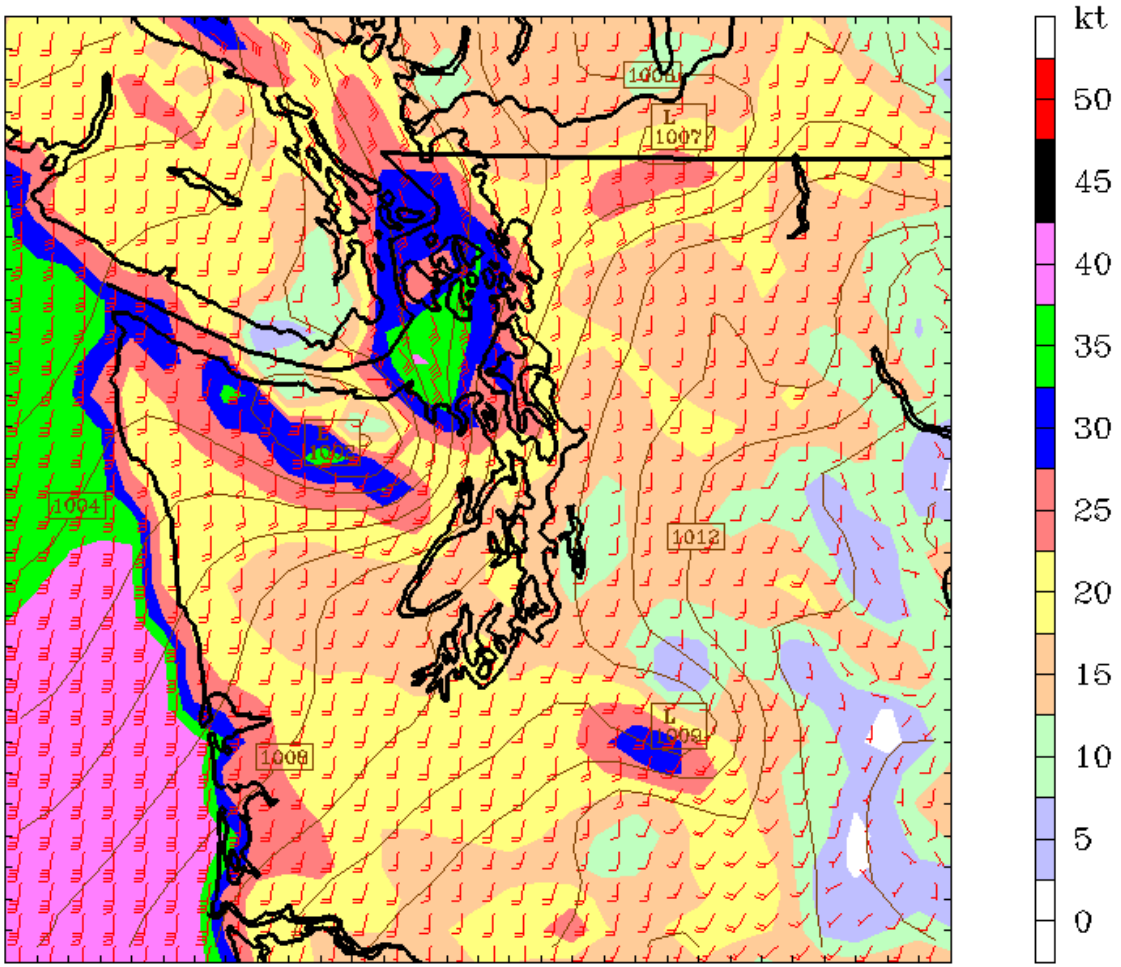
Spatially Extensive: Jan 2010: 10m Wind Speed Bias

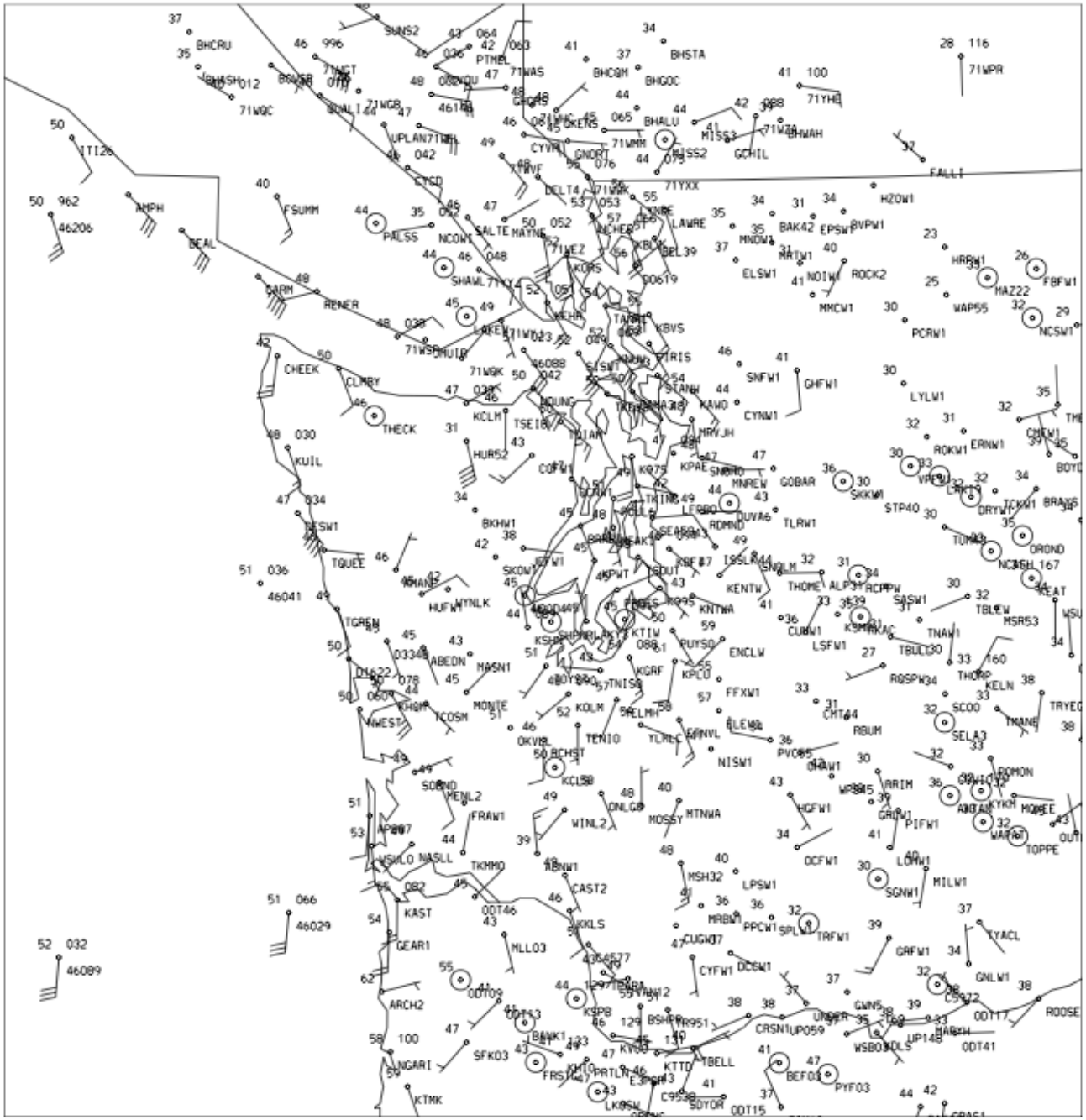


Case Study

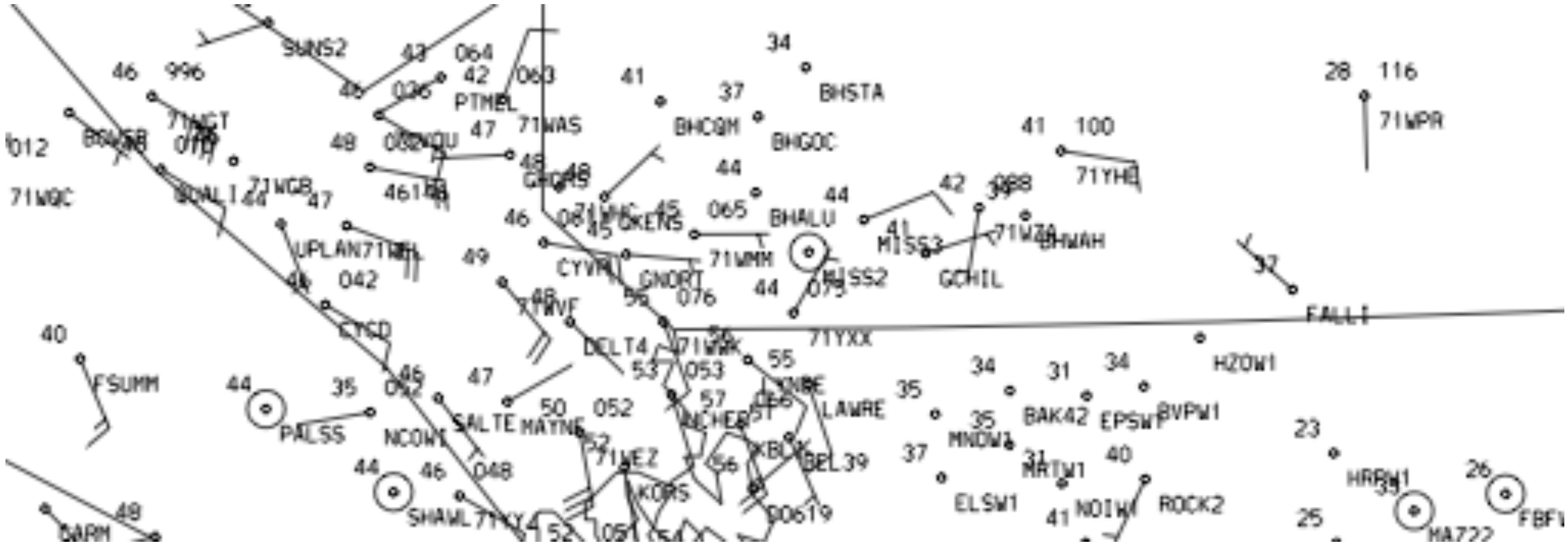
std 12km Domain
Fcst: 12 h
10m Wind Speed (knots)
Wind at 10m (full barb = 10kts)
Sea Level Pressure (hPa)

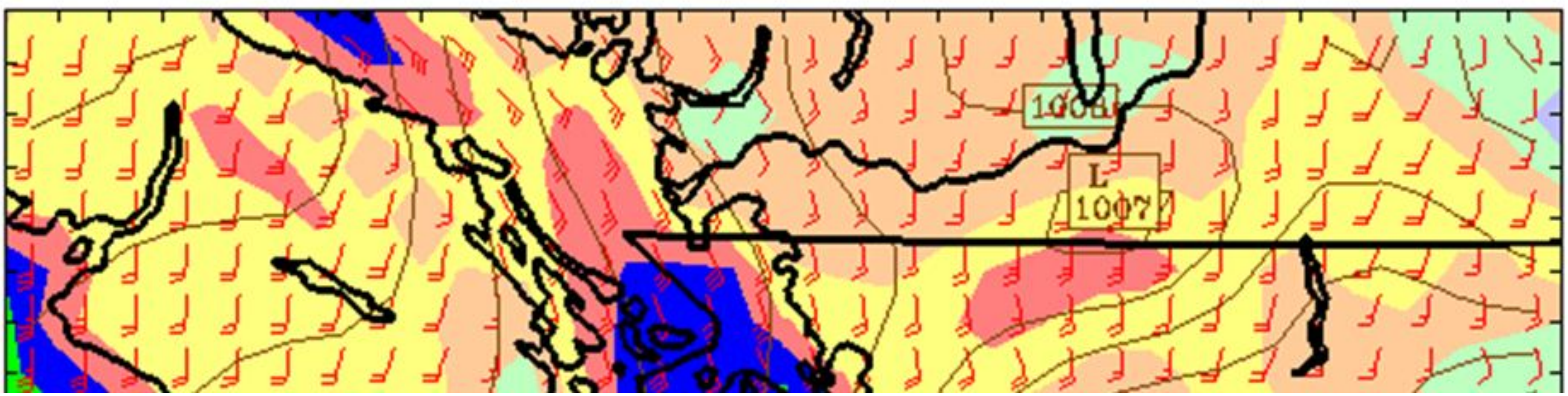
Init: 00 UTC Fri 15 Jan 10
Valid: 12 UTC Fri 15 Jan 10 (04 PST Fri 15 Jan 10)





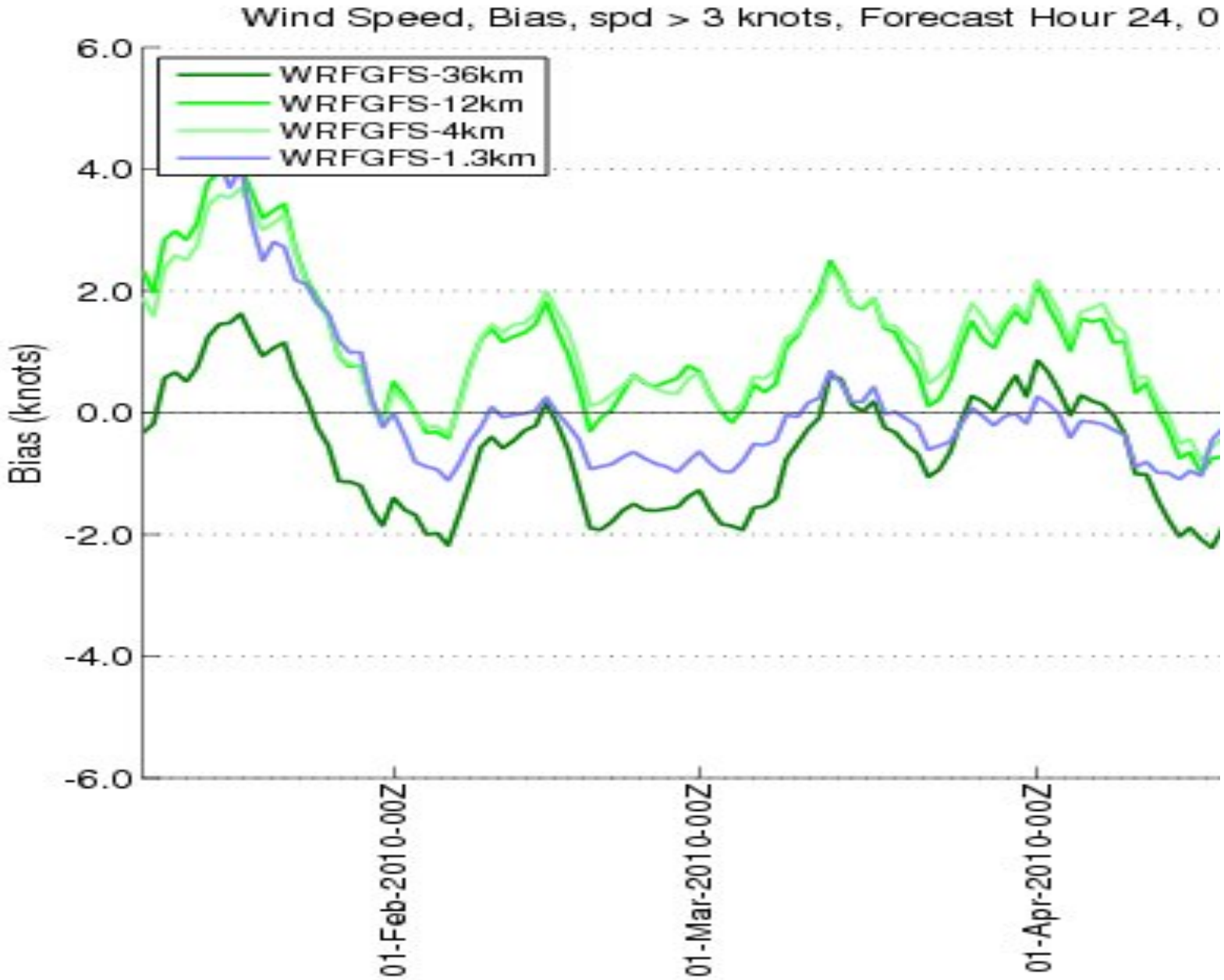
15 JAN 10 1200Z


BHSTA
71WPR
71YHE
BHALU
GCHIL
BHWAH
FALLI
71YXX
HZOW1
FSUMM
PALSS
NCOWI
SALTE
MAYNE
DELT4
LAWRE
BAK42
EPSWT
BVPW1
ELSW1
ROCK2
MA722


1008
L
1007

Dealing with surface wind biases

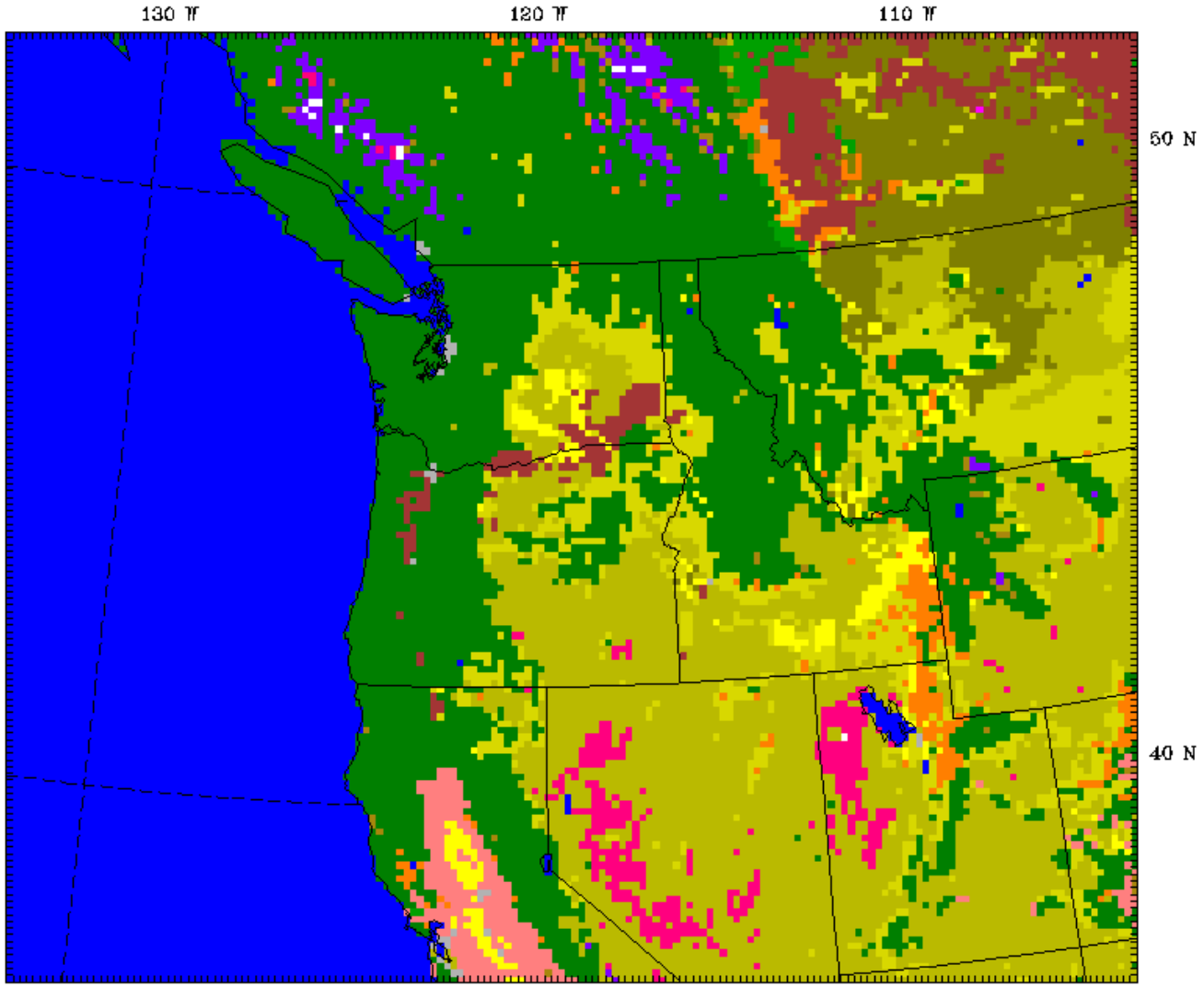
- Last year we experimented with all available planetary boundary layer schemes (including a number of new ones) and played around with varying vertical diffusion.
- None solved this problem.
- Earlier this year we started running at 1.3 km grid spacing over western WA and the problem was lessened.


Wind Speed, Bias, spd > 3 knots, Forecast Hour 24, 0
WRFGFS-36km
WRFGFS-12km
WRFGFS-4km
WRFGFS-1.3km
Bias (knots)
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
01-Feb-2010-00Z
01-Mar-2010-00Z
01-Apr-2010-00Z

Dealing with Wind Biases

- This led to a hypothesis that the problem is that WRF is not resolving subgrid scale roughness elements at the surface for 12km or even 4-km grid spacing.

UW Dec09 WRF Landuse 12km Domain
Init: 00 UTC Fri 31 Dec 99
Fcst: 0 h
Valid: 00 UTC Fri 31 Dec 99 (16 PST Thu 30 Dec 99)
Land use category



OUTPUT FROM GEOGRID V3.1.1 x = 169, y = 142, 12 km


Blaine
Lynden
Cowichan River
Ferndale
Sudden Valley
Bellingham
Anacortes
Sedro-Woolley
Neah Bay
Victoria
Mt Vernon
Rainy Lake Falls
Twisp
Hall Slough
Asbestos Creek Falls
Port Angeles
Marysville
Forks
Everett
Chelan
Shoreline
Bothell
Sunset Falls
Entiat
Kanim Falls
Seattle
Bellevue
Queets River
Cashmere
Wenatchee
Skokomish River
Renton
Burien
Kent
Washington
Tacoma
Puyallup
Olympia
Spanaway
Aberdeen
Ocean Shores
Ellensburg
Westport
Mattawa
Raymond
Centralia
Yakima

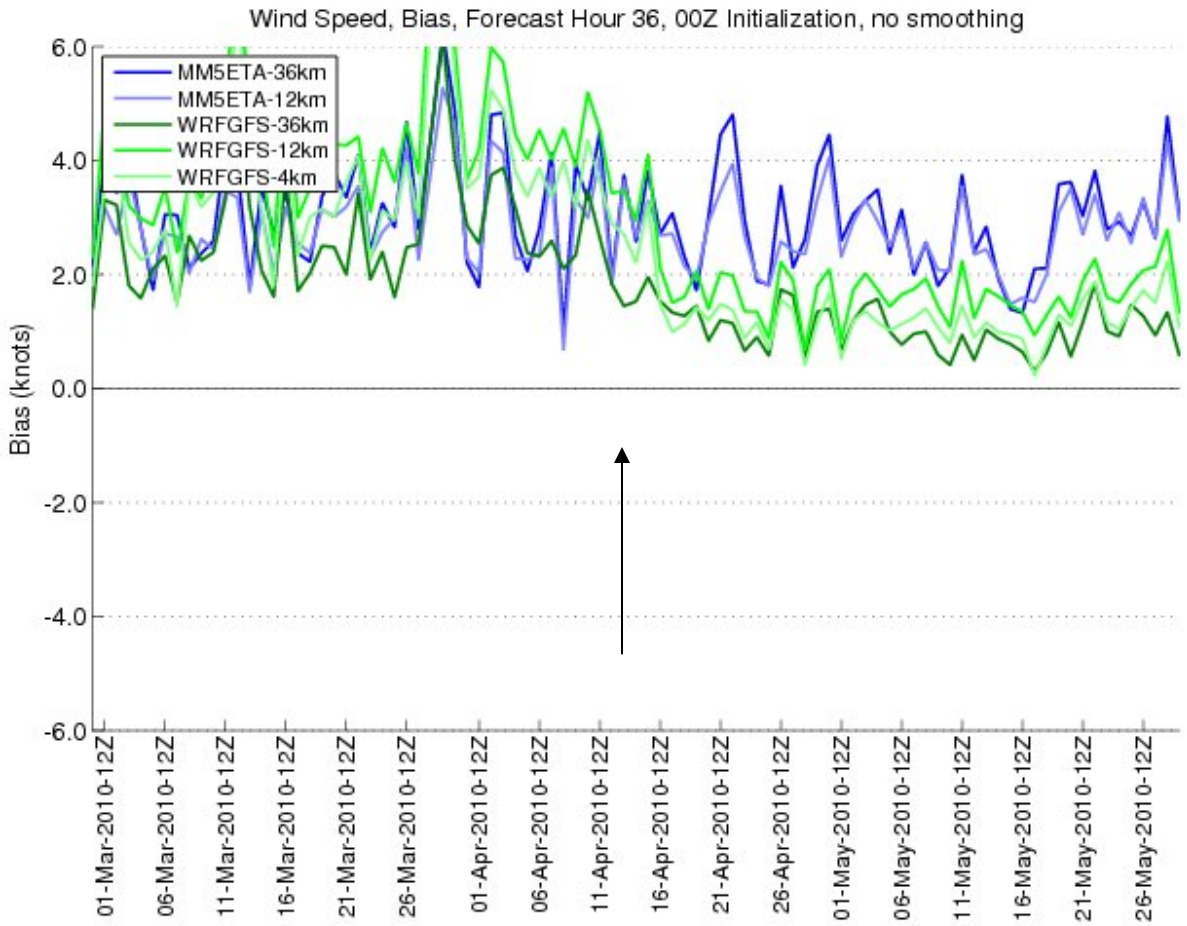

Esperance
Mountlake Terrace
Manor
522
Echo Lake
Shoreline
Bothell
Woodinville
Cottage Lake
Duvall
Kingsgate
5
Lake Marcel-Stillwater
Kirkland
Redmond
Union Hill-Novelty Hill
Mound BM
Union Hill
Montlake Cut
Yarrow Point
Carnation
Sammamish
Ames Lake
Clyde H
Medina
Seattle
Bellevue
Lake Sammamish
90
Mercer Island
Eastgate
West Lake Sammamish
Fall City
Snoqualmie Falls
Ernie's Grove
Fantastic Falls
Newcastle
Issaquah
Snoqualmie
White Center
5
405
90
Bryn Mawr-Skyway
Renton
East Renton Highlands
North Bend
Tanner

Attempting to deal with true roughness

- We have tried two approaches in increasing surface drag to simulate the real roughness
  - Increasing u_*
  - Increasing z_0

- Early experiments in increasing u_* were very suggestive—it decreased the wind and directional biases significantly.

1.5 times ustar!

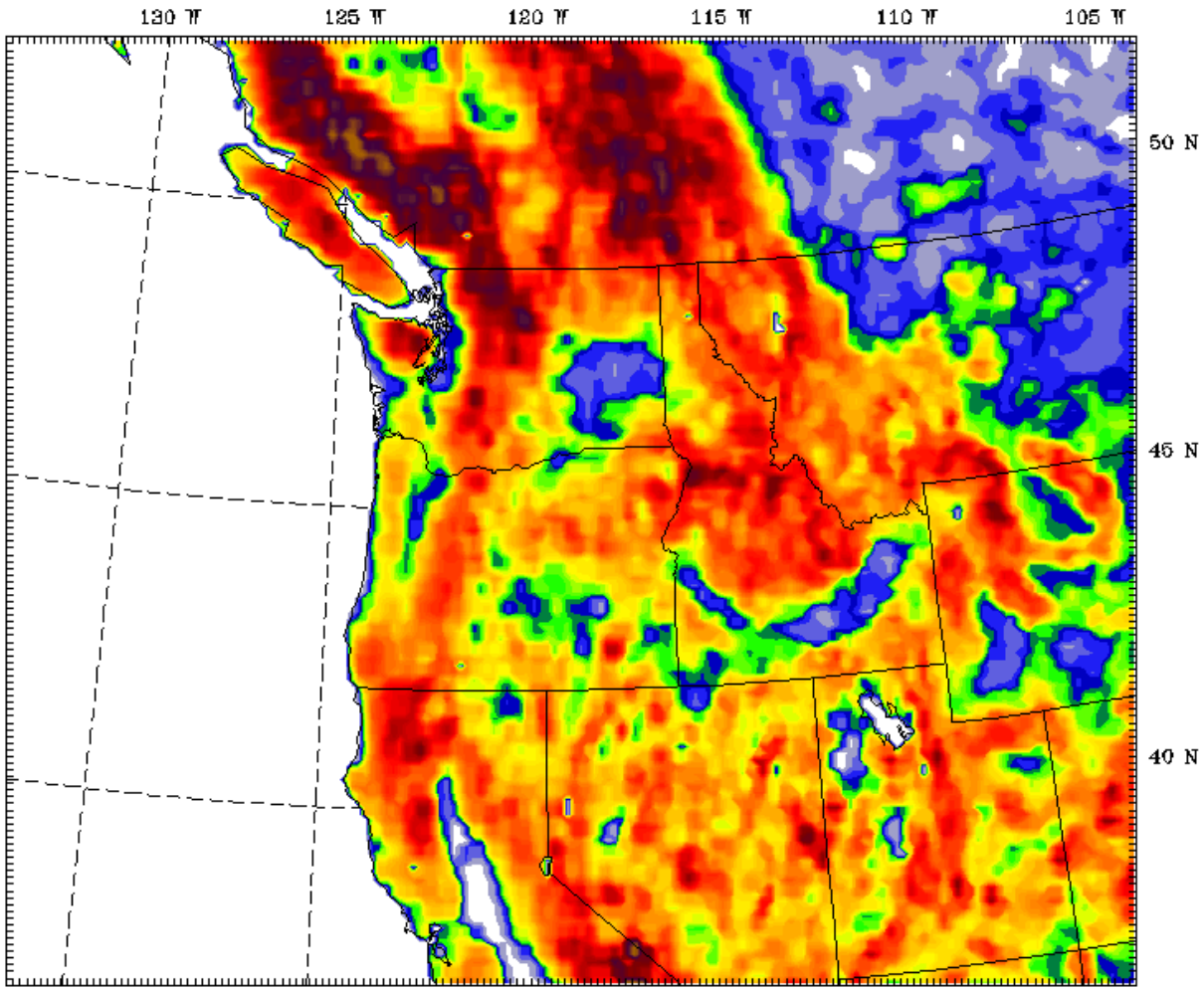


Dealing with Bias

- More recently we (Dave Ovens!) have experimented with enhancing the surface roughness length (z_0), based on the sub-grid scale terrain variance.
- Note--using WRF 3.1.1 with YSU PBL

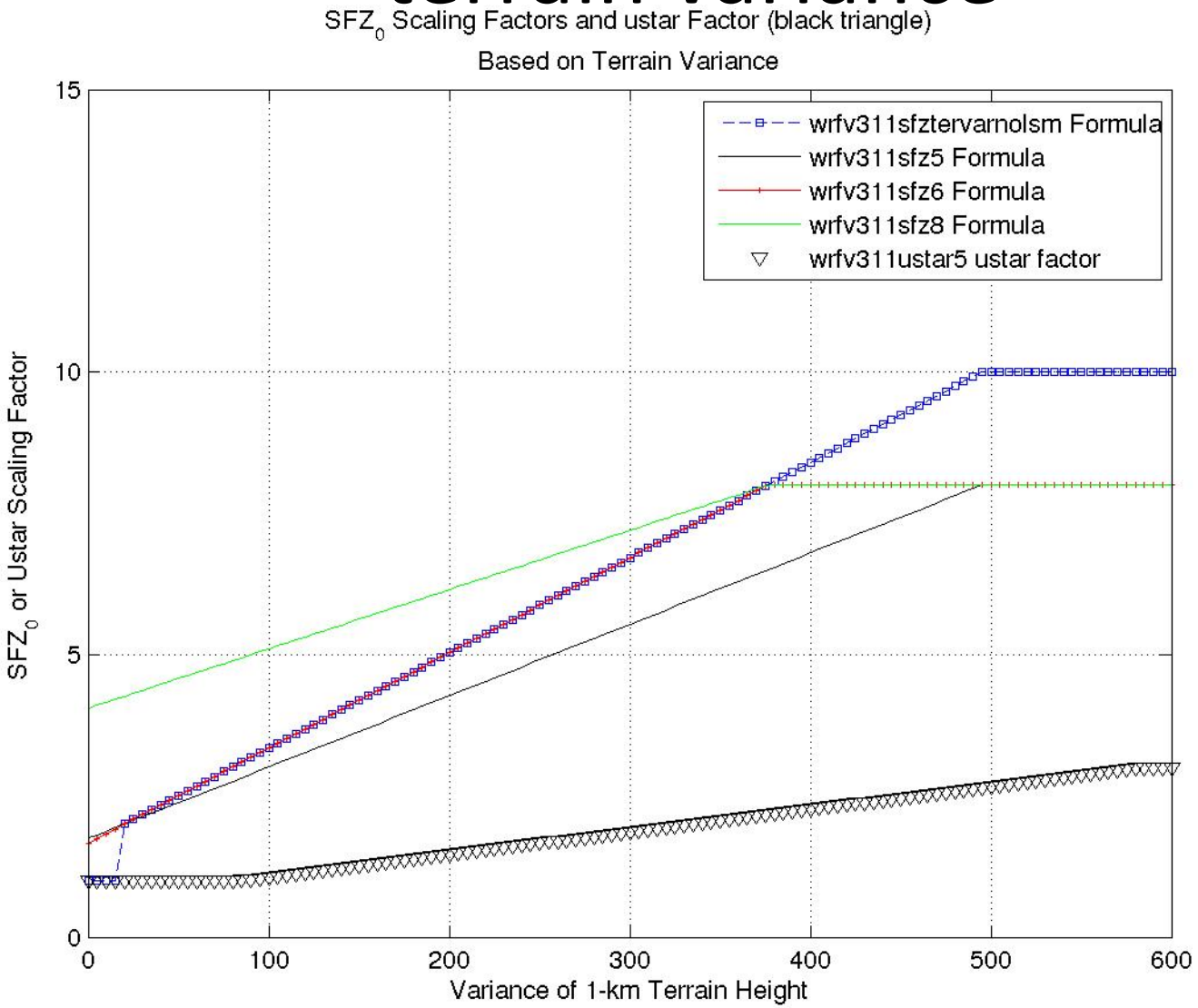
UW WRF-GFS 12km Domain
Fcst: 0 h
OROGRAPHIC VARIANCE

Init: 12 UTC Sun 02 Dec 07
Valid: 12 UTC Sun 02 Dec 07 (04 PST Sun 02 Dec 07)

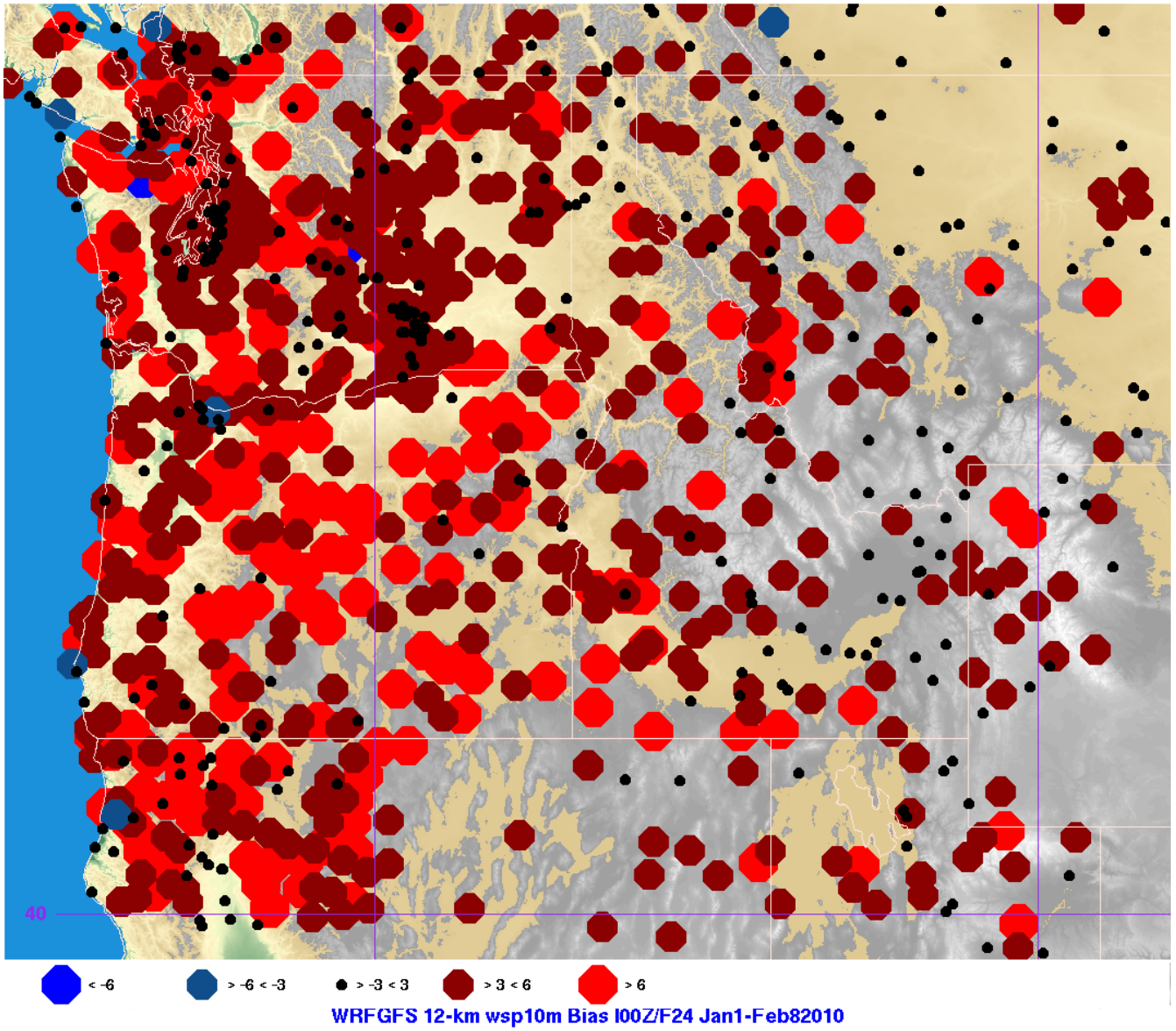


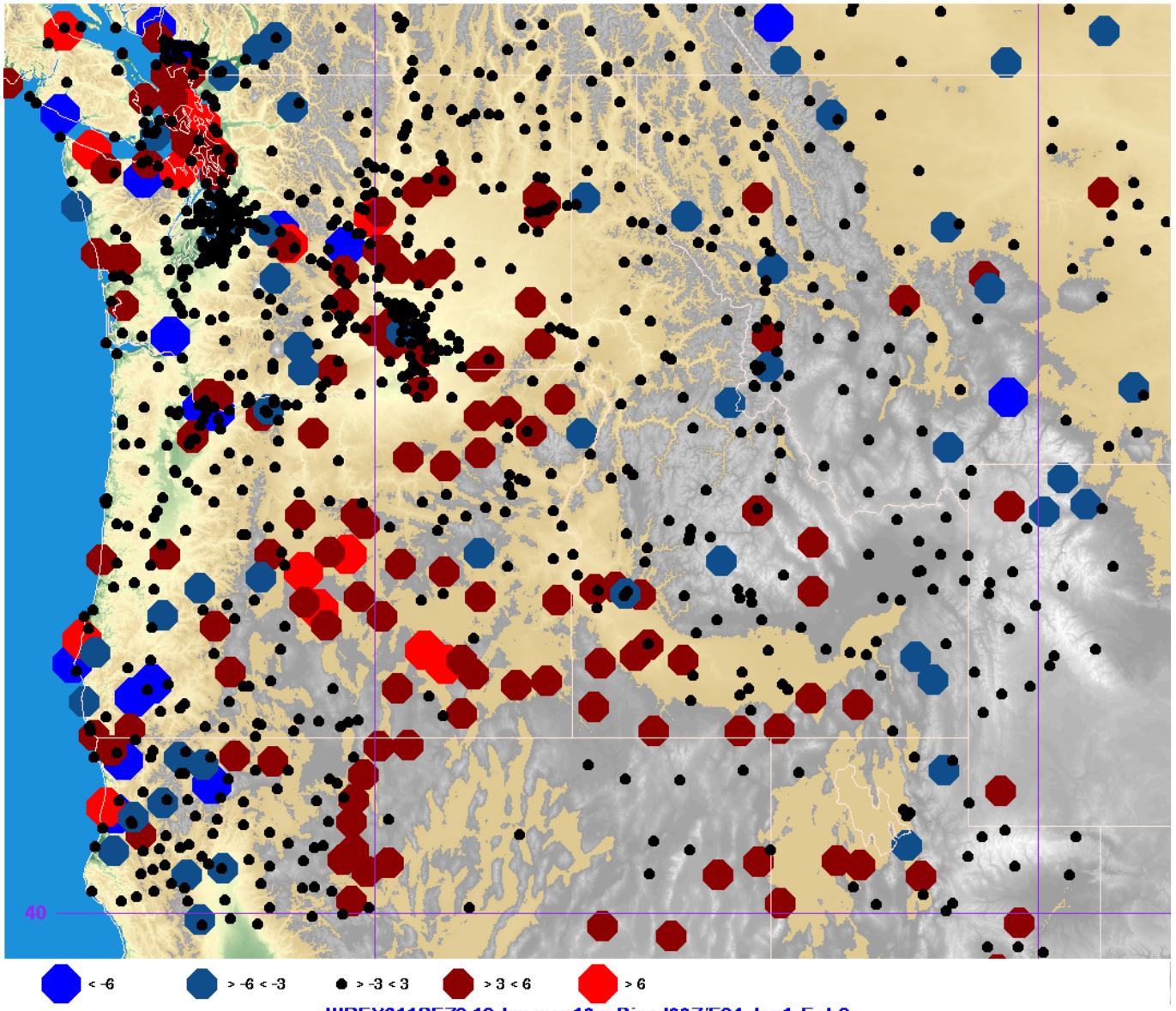
Model Info: V3.1.1 KF YSU PBL Thompson Noah LSM 12 km, 37 levels, 72 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Roughness enhancement versus terrain variance

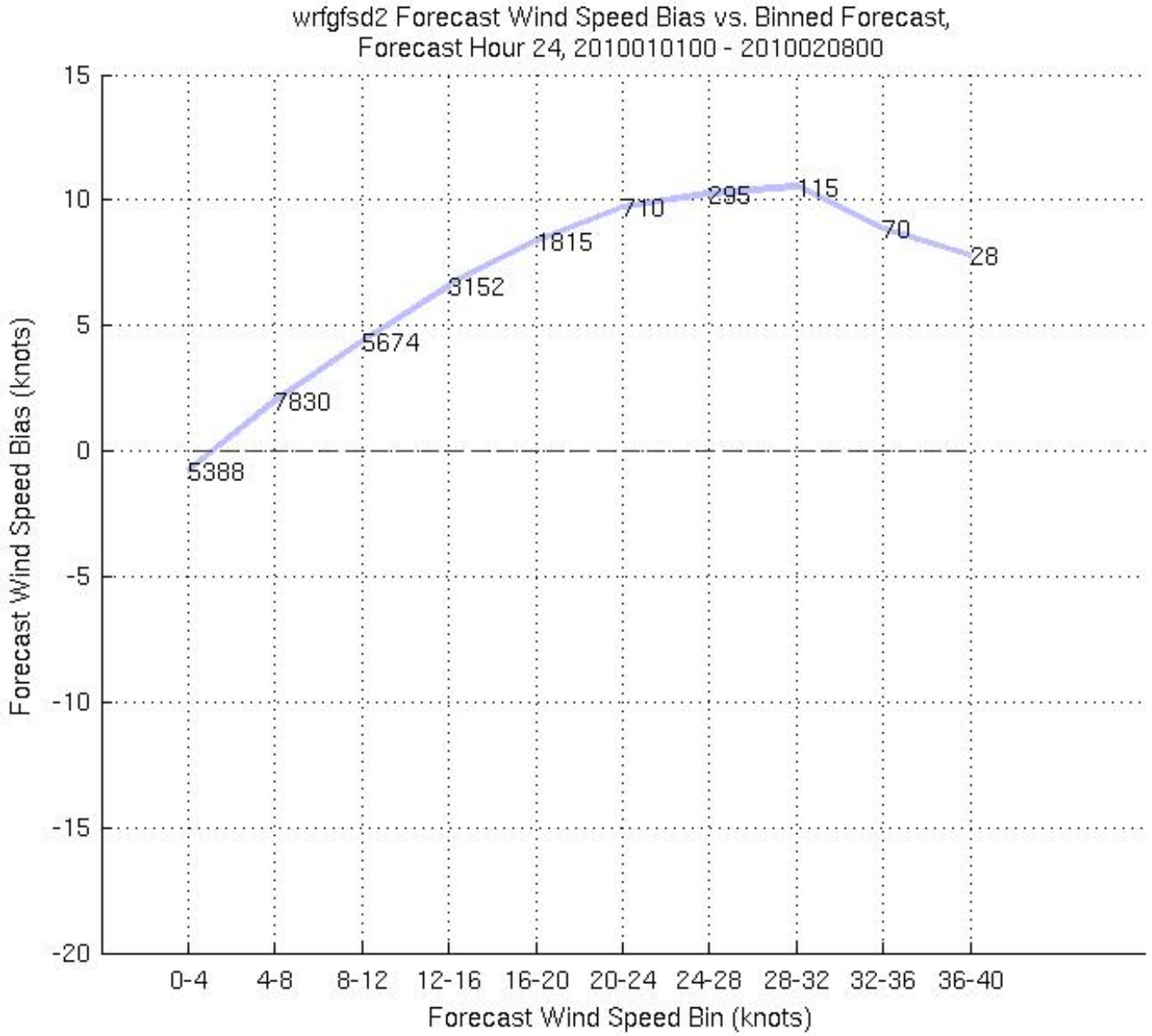


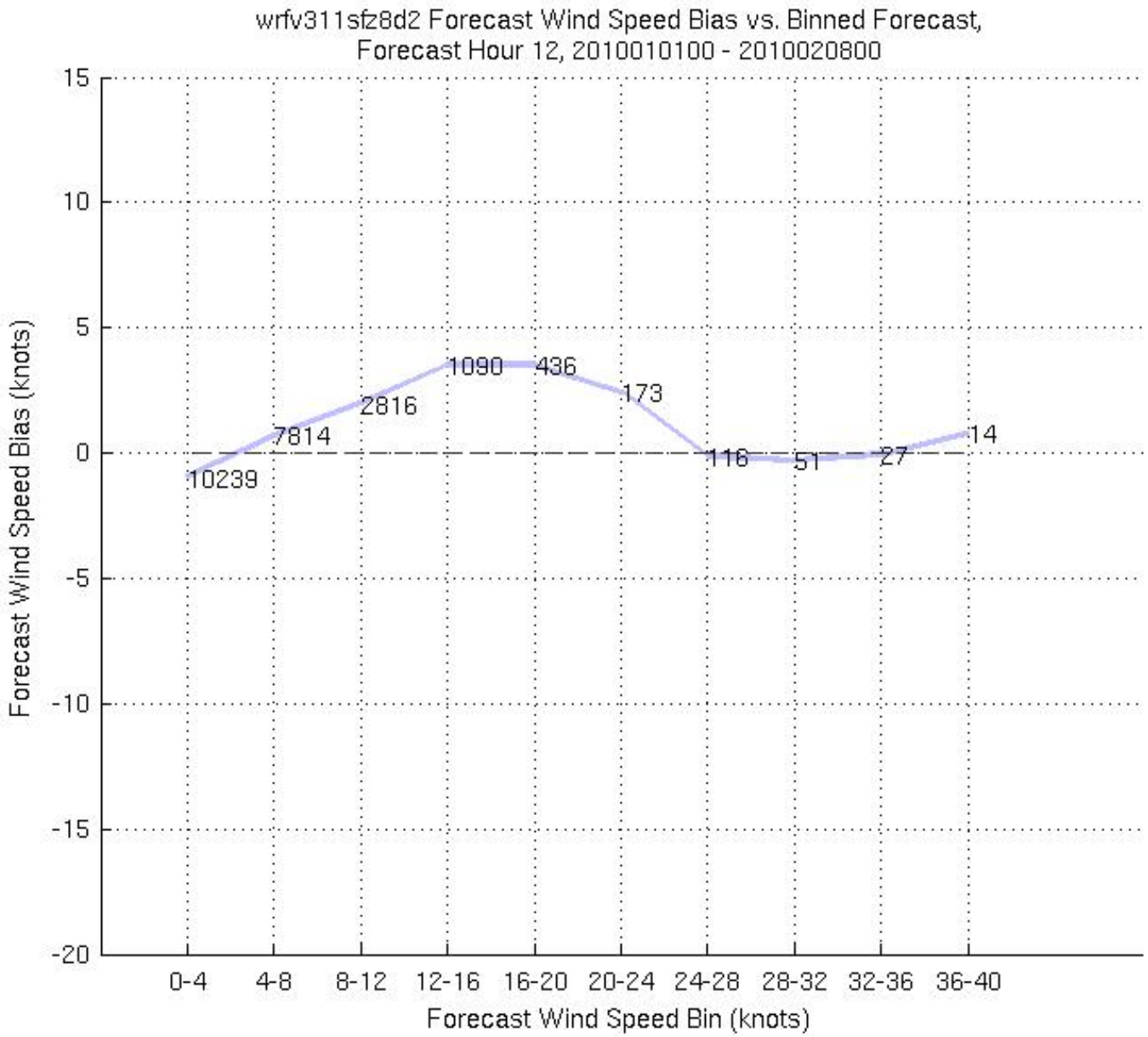
Old Wind Bias-00 UTC-24h forecast-Jan1-Feb 8 2010




40
< -6
> -6 < -3
> -3 < 3
> 3 < 6
> 6
WRFV311SFZ8 12-km wsp10m Bias I00Z/F24 Jan1-Feb8

Standard WRF

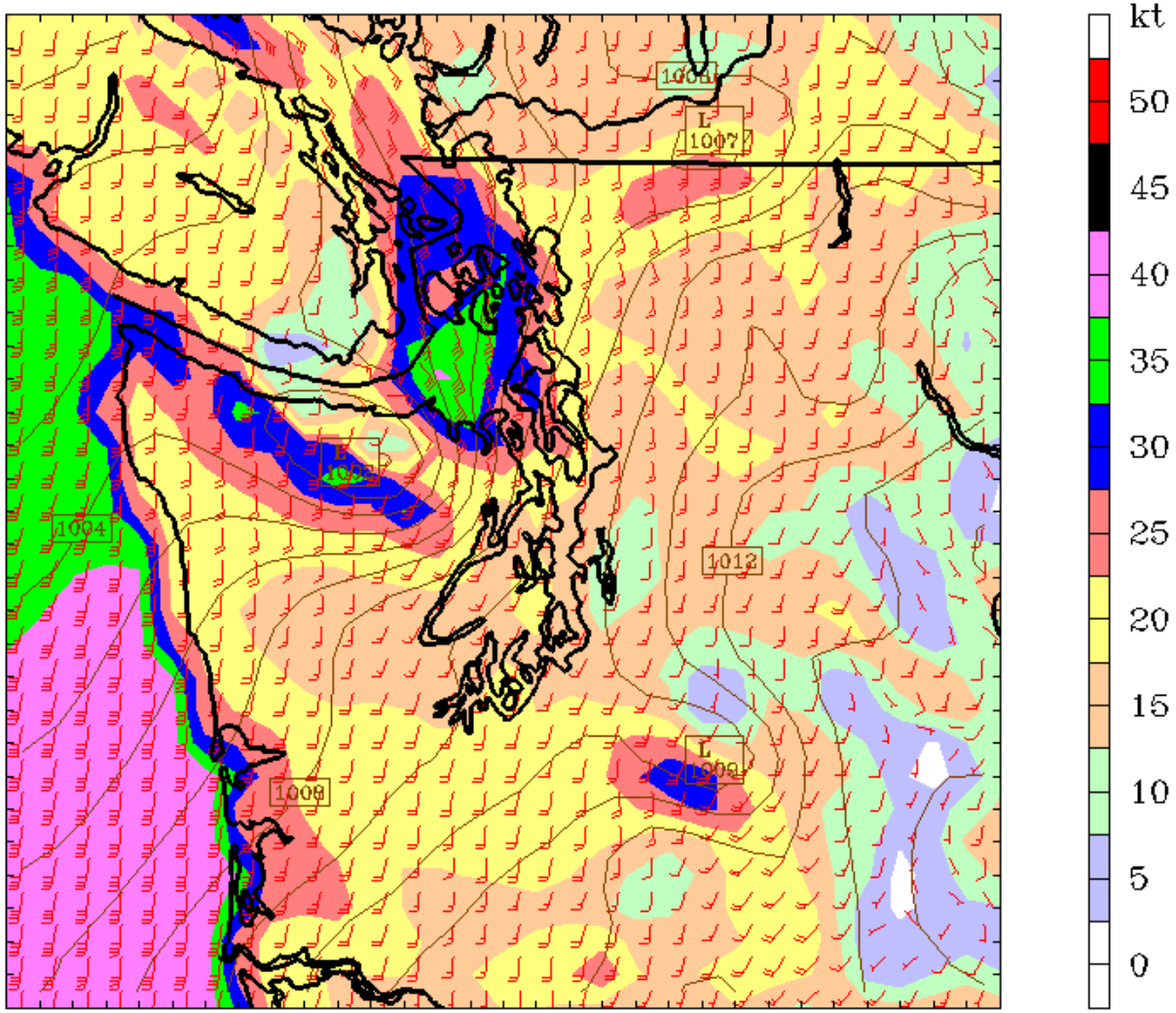



wrfv311sfz8d2 Forecast Wind Speed Bias vs. Binned Forecast,
Forecast Hour 12, 2010010100 - 2010020800
Forecast Wind Speed Bias (knots)
15
10
5
0
-5
-10
-15
-20
10239
7814
2816
1090
436
173
116
51
27
14
0-4
4-8
8-12
12-16
16-20
20-24
24-28
28-32
32-36
36-40
Forecast Wind Speed Bin (knots)

std 12km Domain
Fcst: 12 h
10m Wind Speed (knots)
Wind at 10m (full barb = 10kts)
Sea Level Pressure (hPa)

Init: 00 UTC Fri 15 Jan 10
Valid: 12 UTC Fri 15 Jan 10 (04 PST Fri 15 Jan 10)

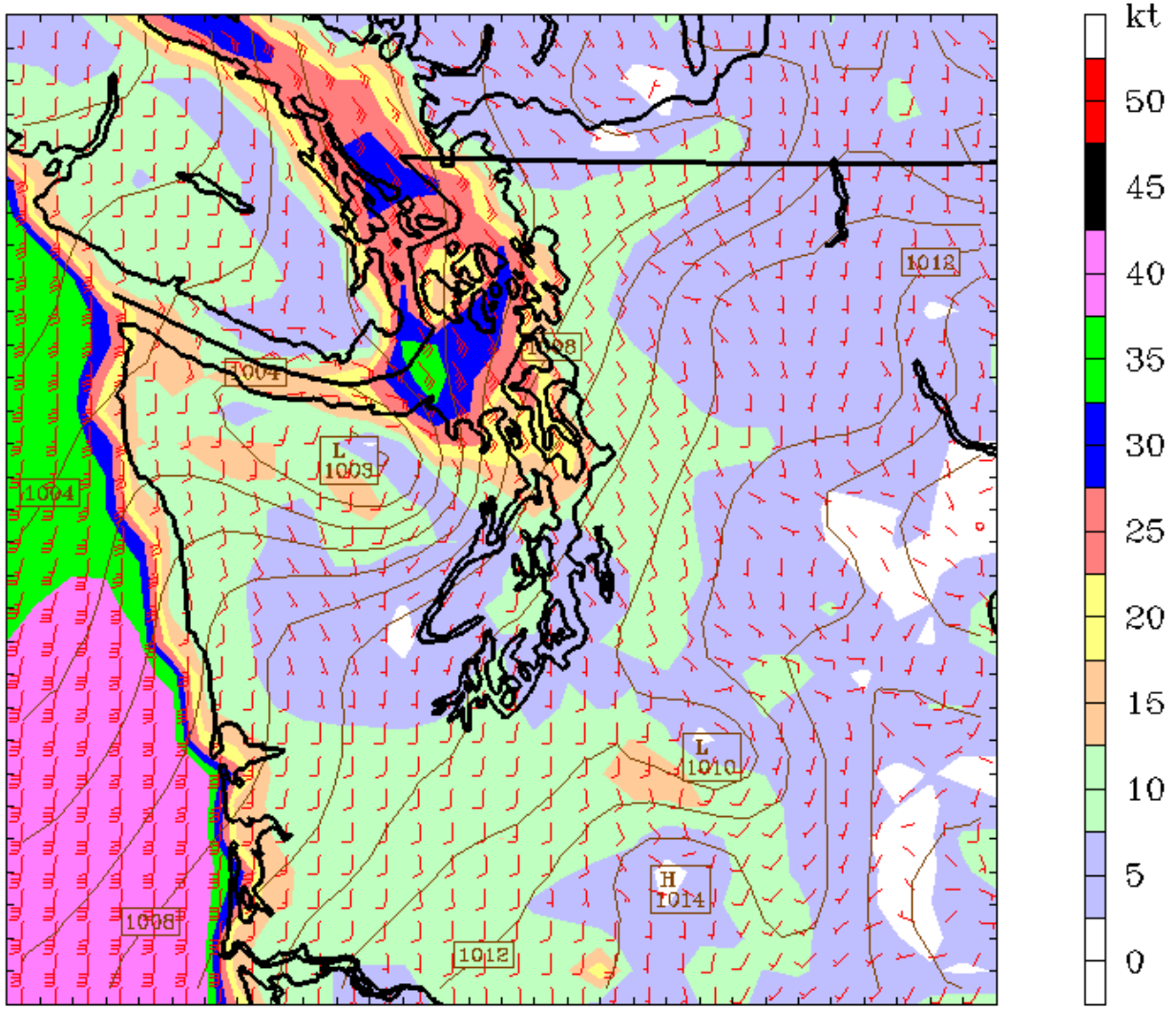
Standard
WRF
YSU PBL
V 3.1.1



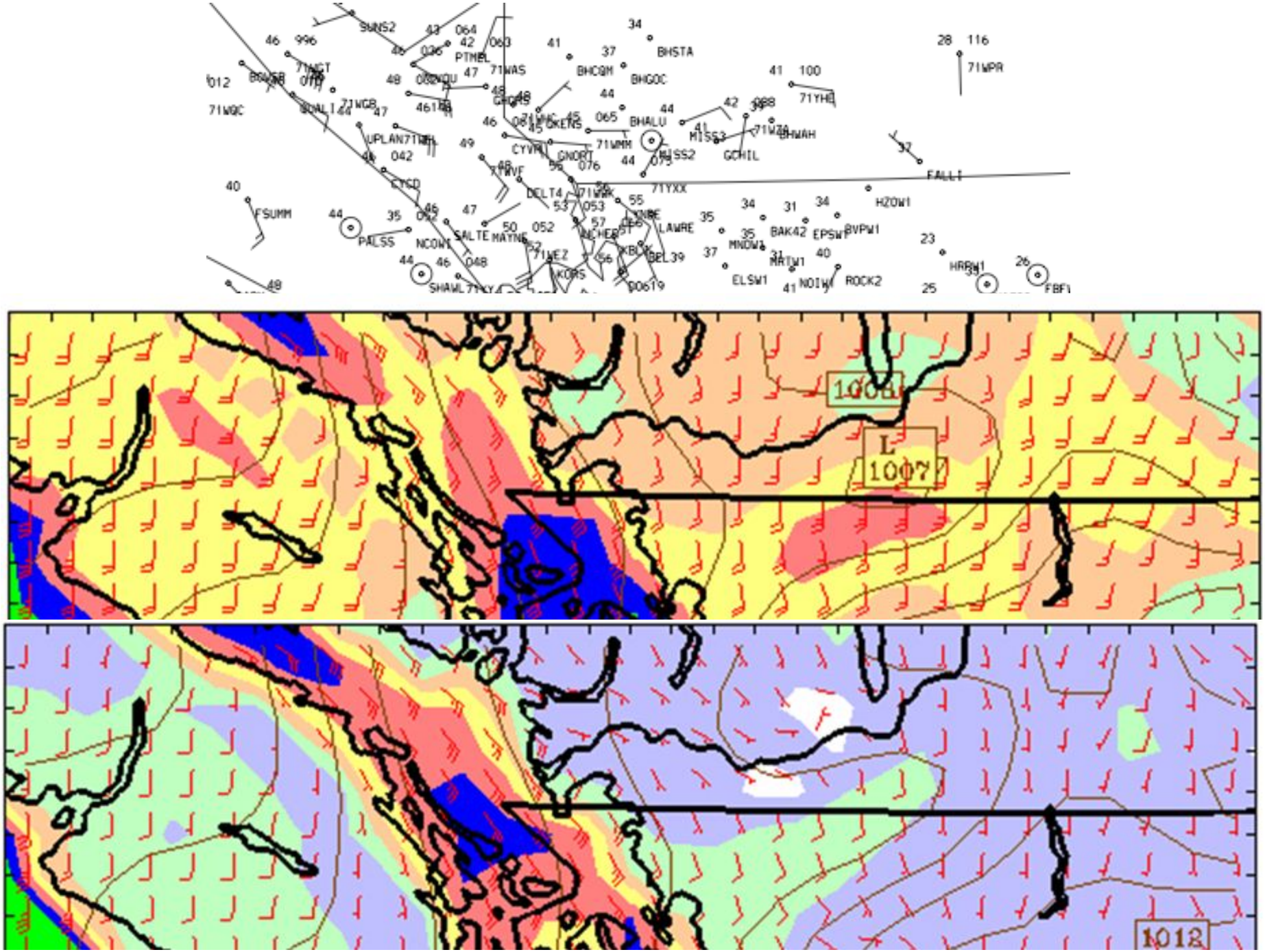
CONTOURS: UNITS=hPa LOW= 1001.0 HIGH= 1014.0 INTERVAL= 1.0000
Model Info: V3.1.1 KF YSU PBL Thompson Noah LSM 12 km, 37 levels, 72 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

wrfv311sfz8 12km Domain
Fcst: 12 h
10m Wind Speed (knots)
Wind at 10m (full barb = 10kts)
Sea Level Pressure (hPa)

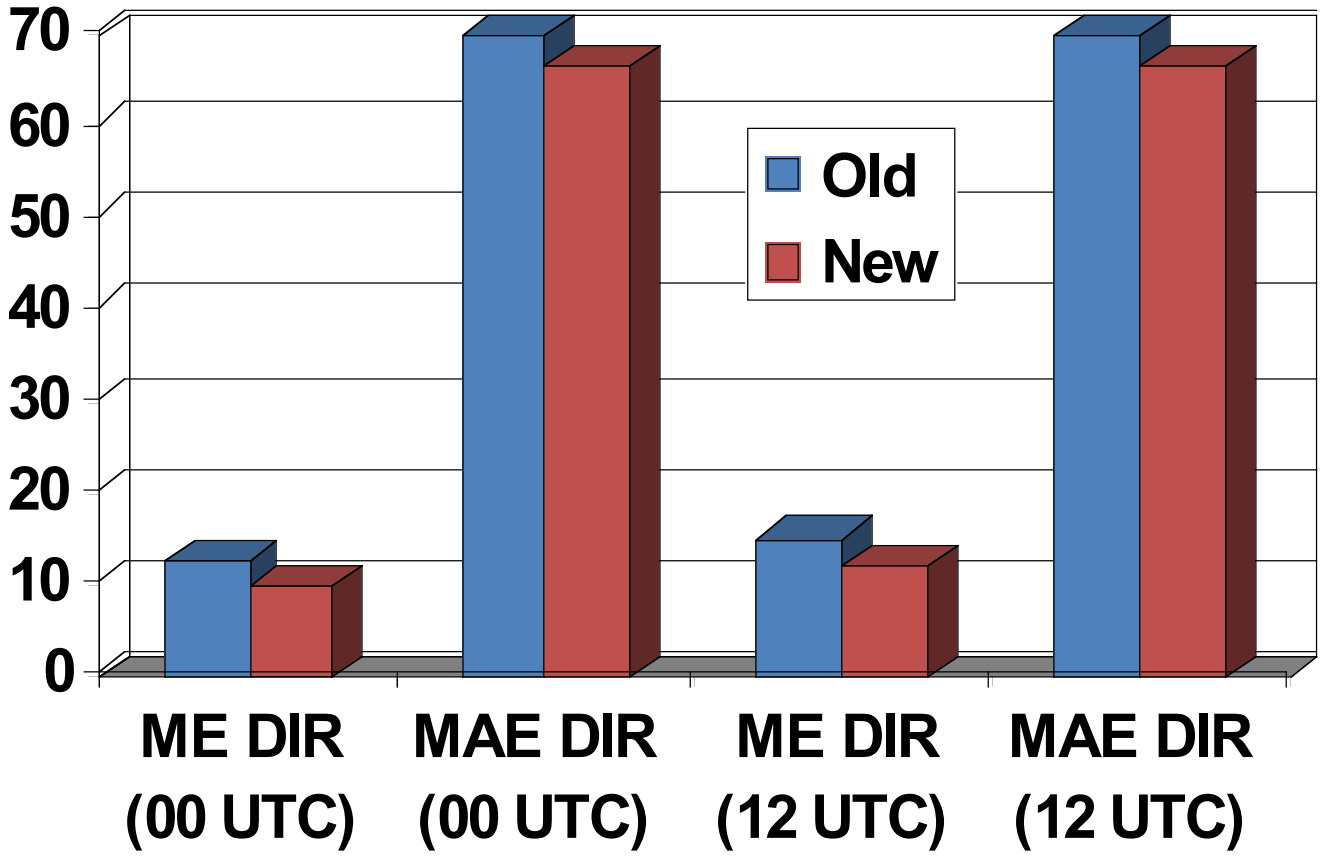
Init: 00 UTC Fri 15 Jan 10
Valid: 12 UTC Fri 15 Jan 10 (04 PST Fri 15 Jan 10)



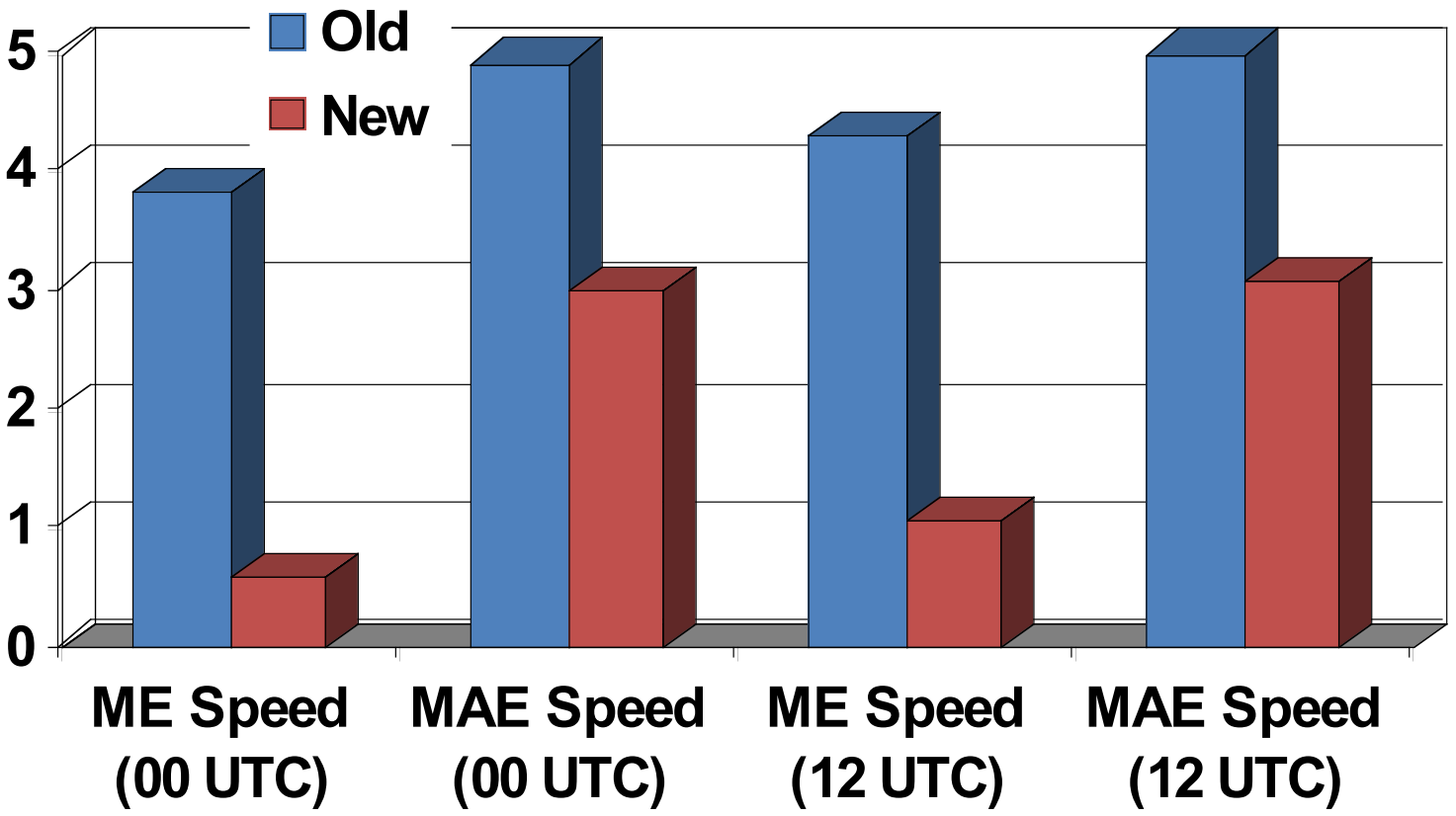
CONTOURS: UNITS=hPa LOW= 1002.0 HIGH= 1015.0 INTERVAL= 1.0000
Model Info: V3.1.1 KF YSU PBL Thompson Ther-Diff 12 km, 37 levels, 72 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor


L
1007
1012

Direction Errors (All Stations and Speeds)

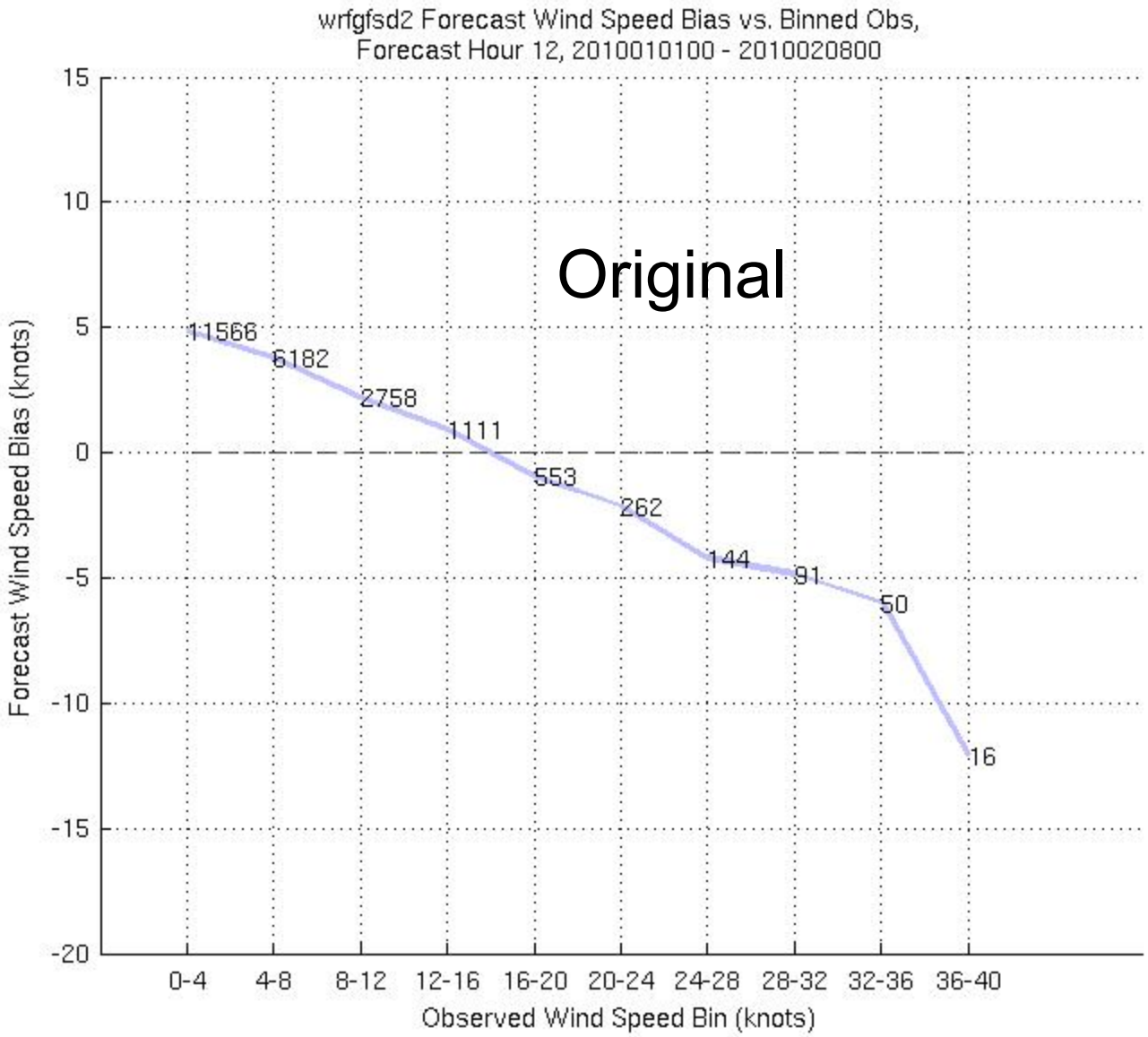


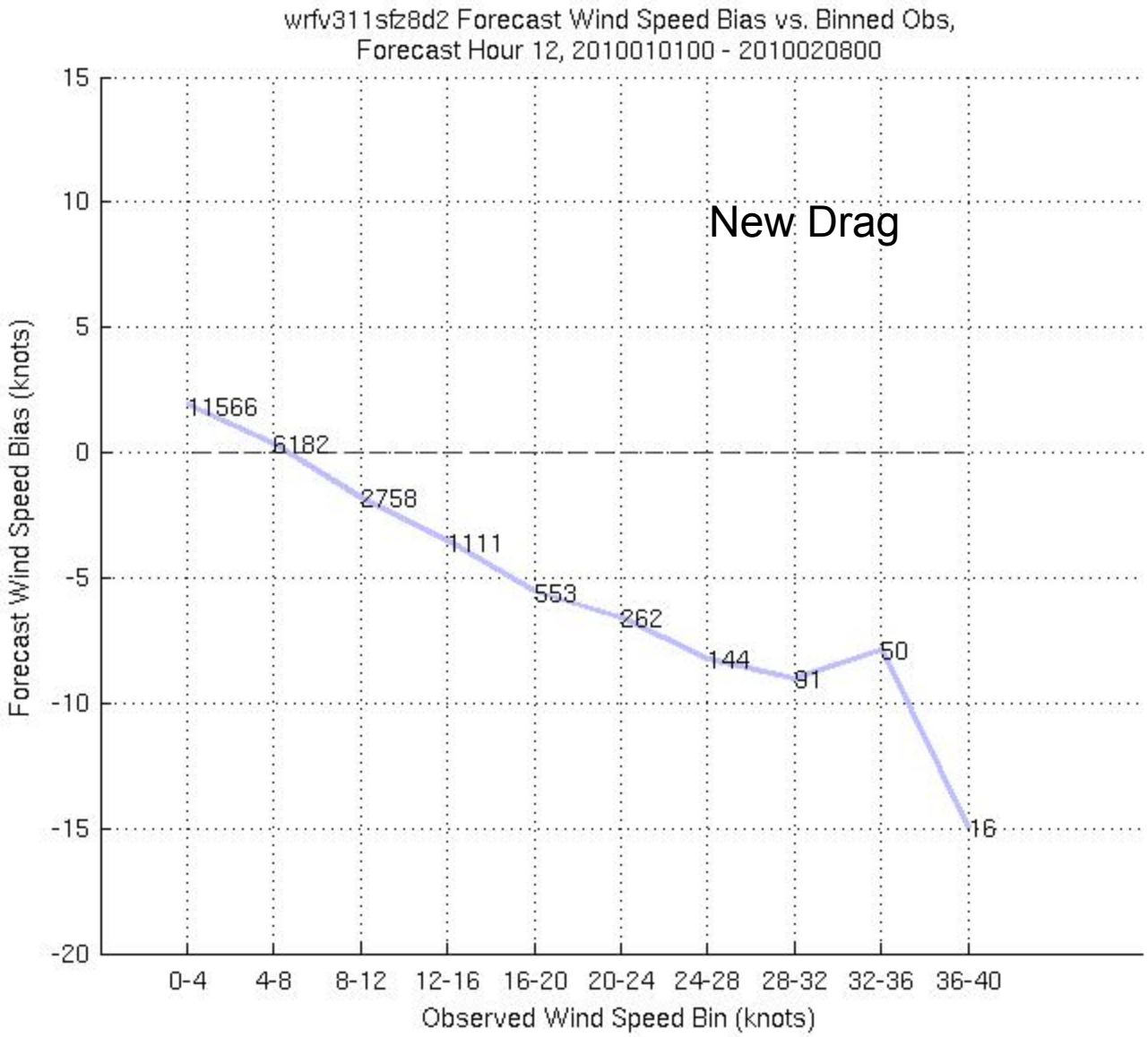
Speed Error (All Stations and Speeds)



But the problem…

- Although such an approach helps substantially overall, it hurts speed (but not direction) at higher wind speeds (greater than roughly 10-15 kts)


wrfgfsd2 Forecast Wind Speed Bias vs. Binned Obs,
Forecast Hour 12, 2010010100 - 2010020800
Original
Forecast Wind Speed Bias (knots)
15
10
5
0
-5
-10
-15
-20
11566
6182
2758
1111
553
262
144
91
50
16
0-4
4-8
8-12
12-16
16-20
20-24
24-28
28-32
32-36
36-40
Observed Wind Speed Bin (knots)


wrfv311sfz8d2 Forecast Wind Speed Bias vs. Binned Obs,
Forecast Hour 12, 2010010100 - 2010020800
New Drag
Forecast Wind Speed Bias (knots)
15
10
5
0
-5
-10
-15
-20
11566
6182
2758
1111
553
262
144
91
50
16
0-4
4-8
8-12
12-16
16-20
20-24
24-28
28-32
32-36
36-40
Observed Wind Speed Bin (knots)

Not Done Yet

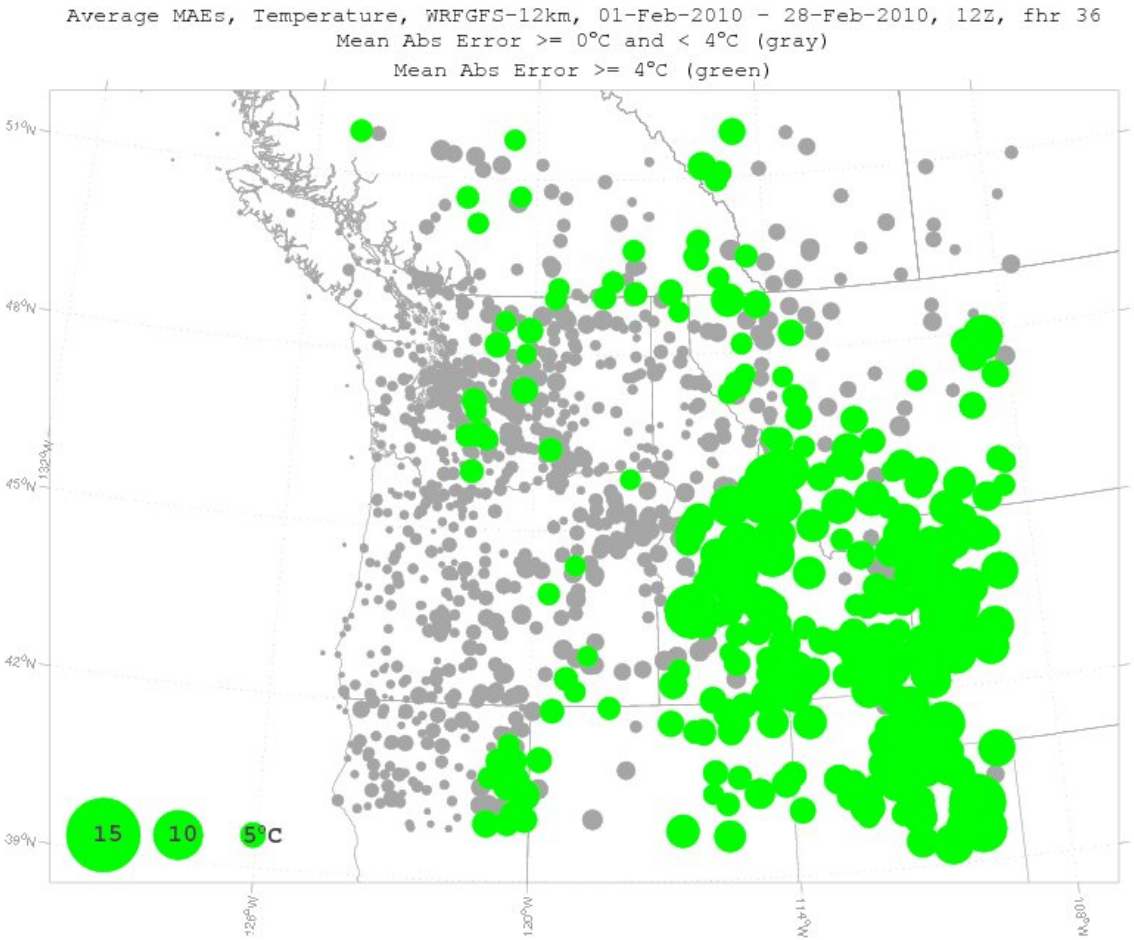
- Now experimenting with having this drag parameterization fade out at higher wind speeds.
- Also experimenting more with the enhancement of the ustar approach
- Any suggestions?

Sometimes When We Add Complexity We Mess Things Up

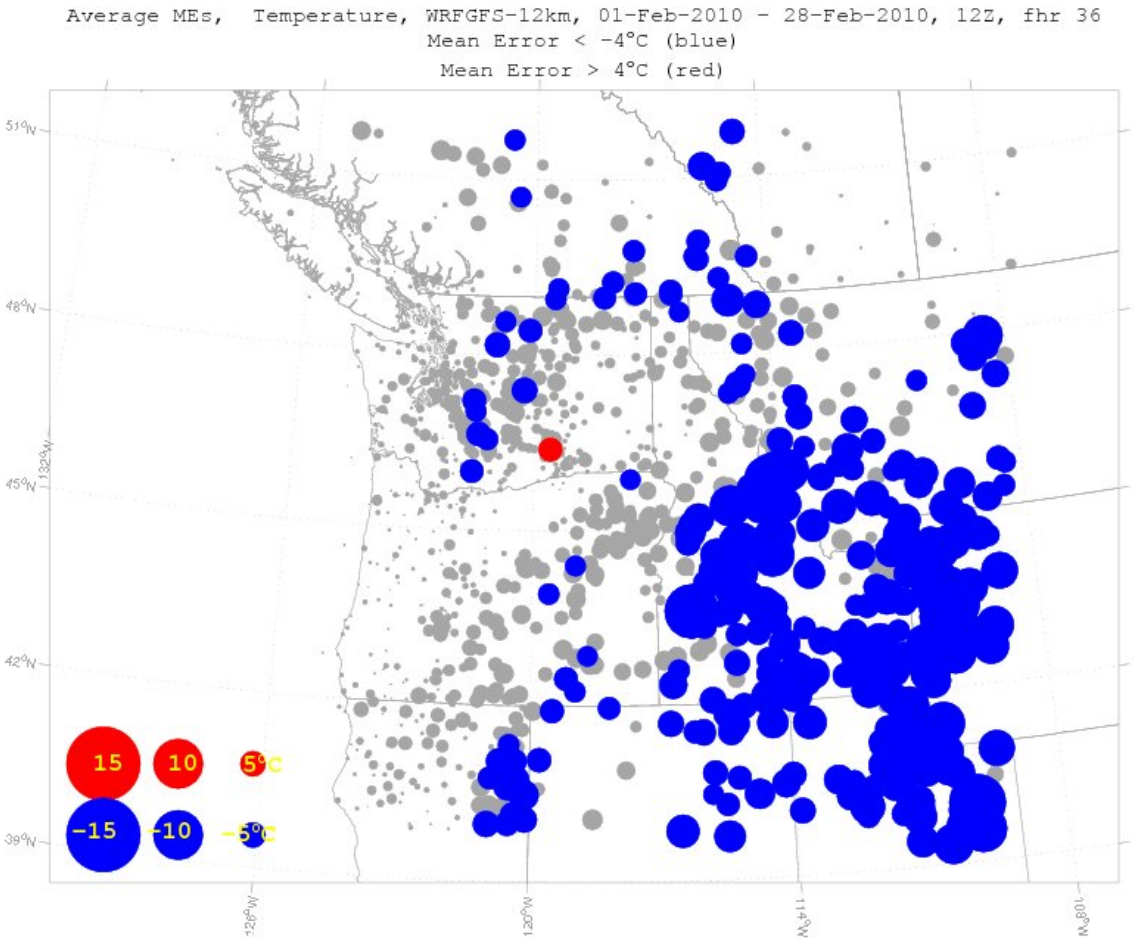
LSM Change

The Noah LSM in the WRF 3.1.1 and 3.2 codes has a strong cold bias in max temp over the elevated terrain of the Intermountain West.

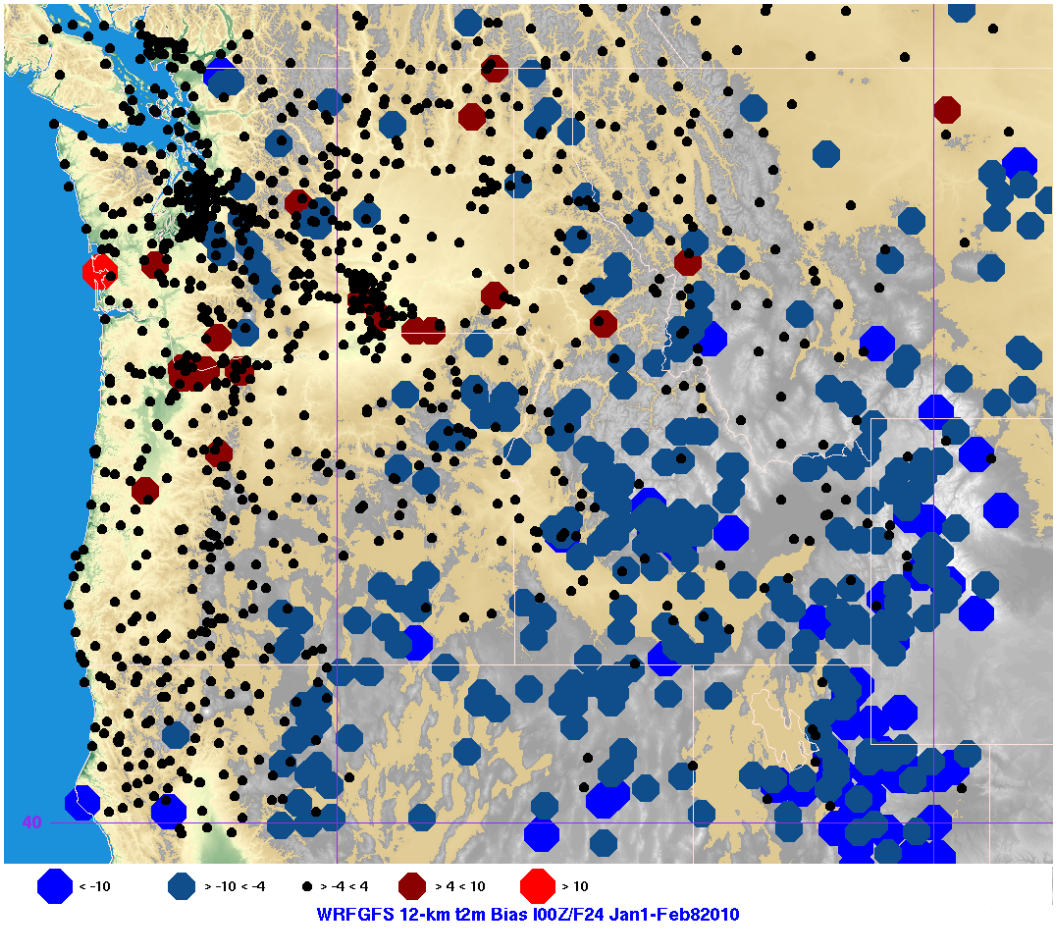
Feb 2-m temp MAE, 00Z



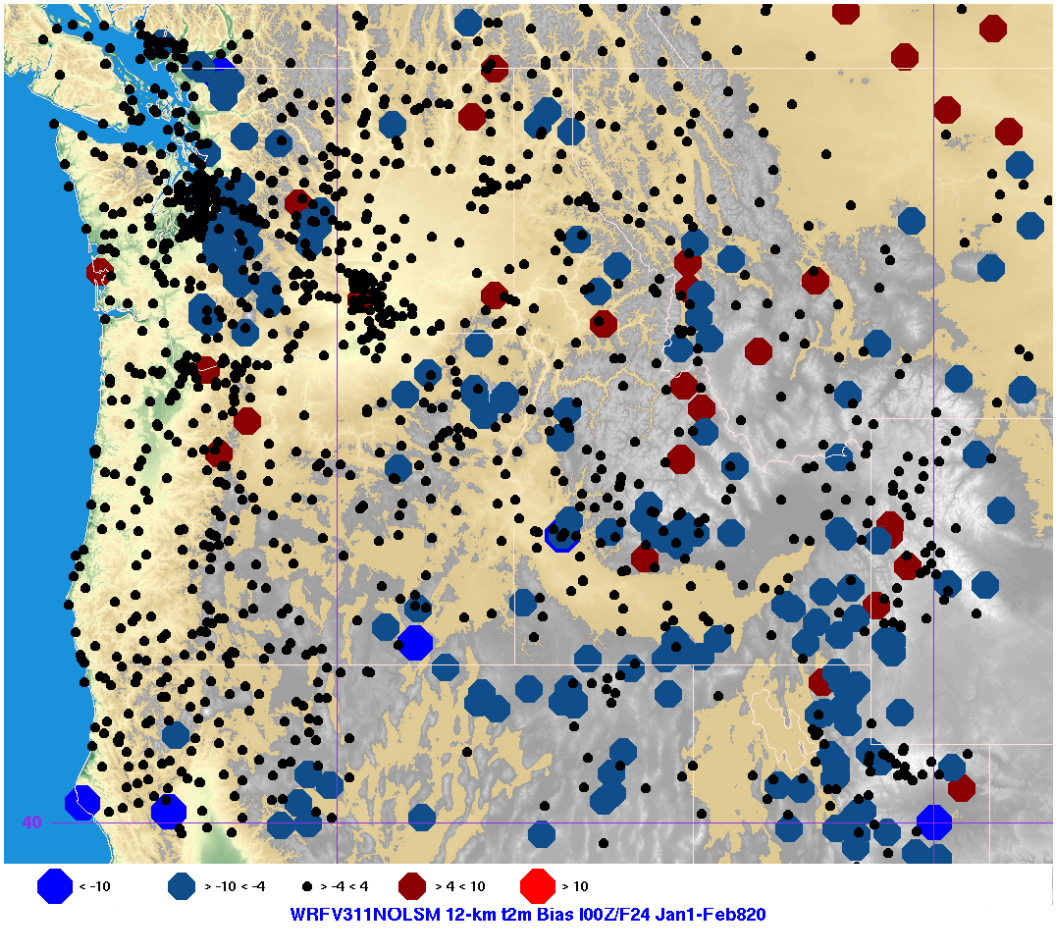
Corresponding Bias



LSM


40
< -10
> -10 < -4
> -4 < 4
> 4 < 10
> 10
WRFGFS 12-km t2m Bias I00Z/F24 Jan1-Feb82010

No LSM


40
< -10
> -10 < -4
> -4 < 4
> 4 < 10
> 10
WRFV311NOLSM 12-km t2m Bias I00Z/F24 Jan1-Feb820

Final Thoughts

- We have made improvements in some parameters and not others.
- A far more organized effort to deal with physics problems---informed by detailed extended period runs and verification--is required. Role for the DTC?
- Adding complexity and more detailed physics does not always improve verification of key parameters.

The End