Addressing Diurnal Temperature Biases in the WRF Model

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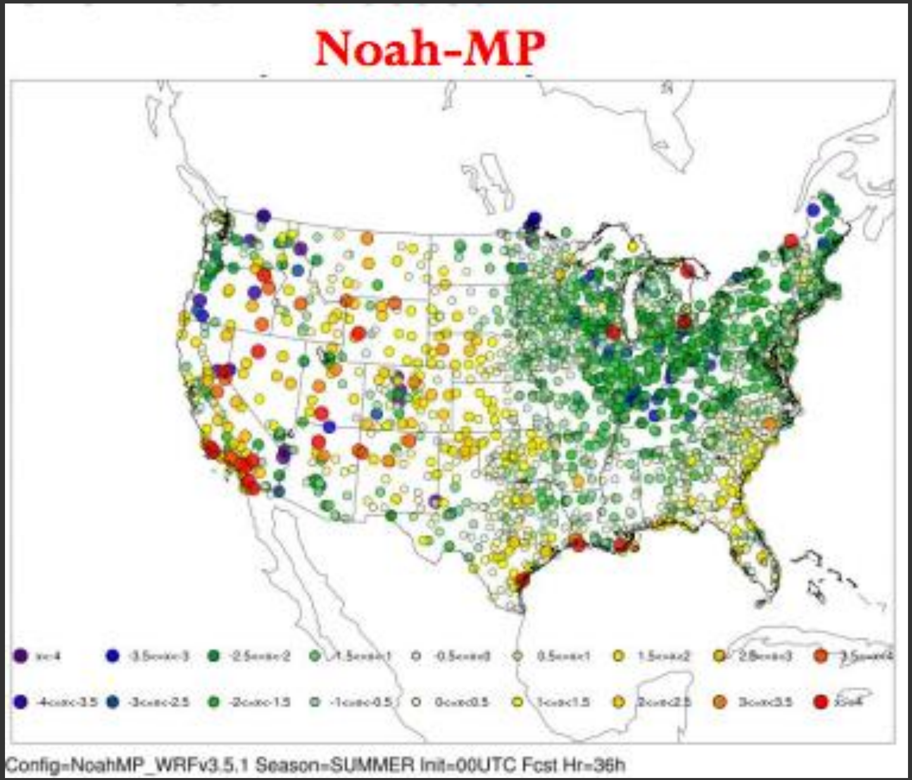
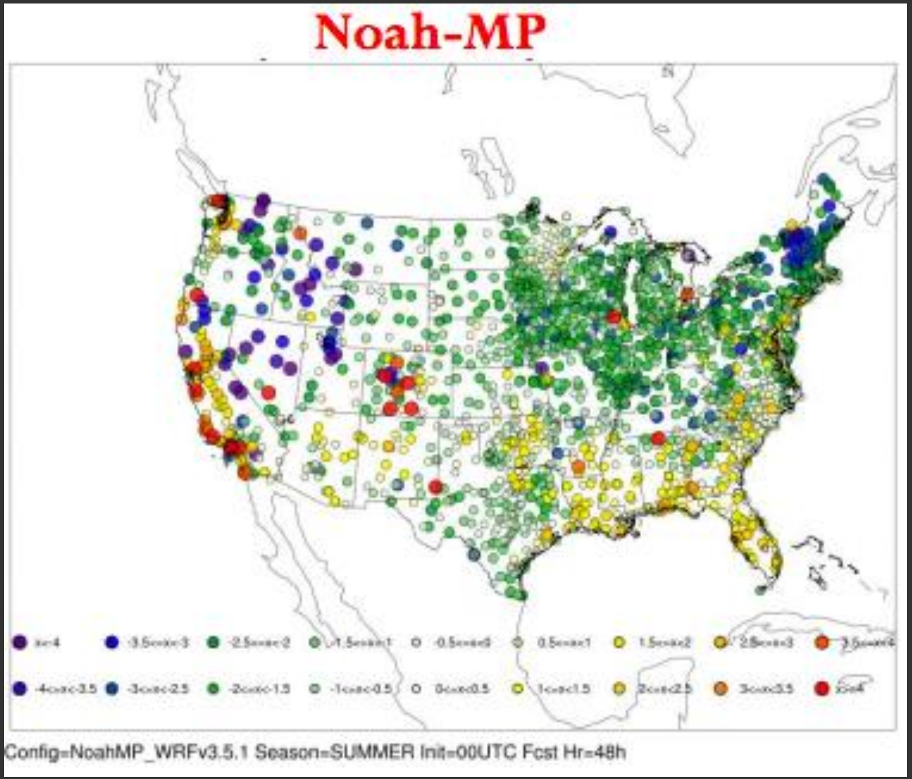
Long term 2-m temperature verification studies

12 UTC



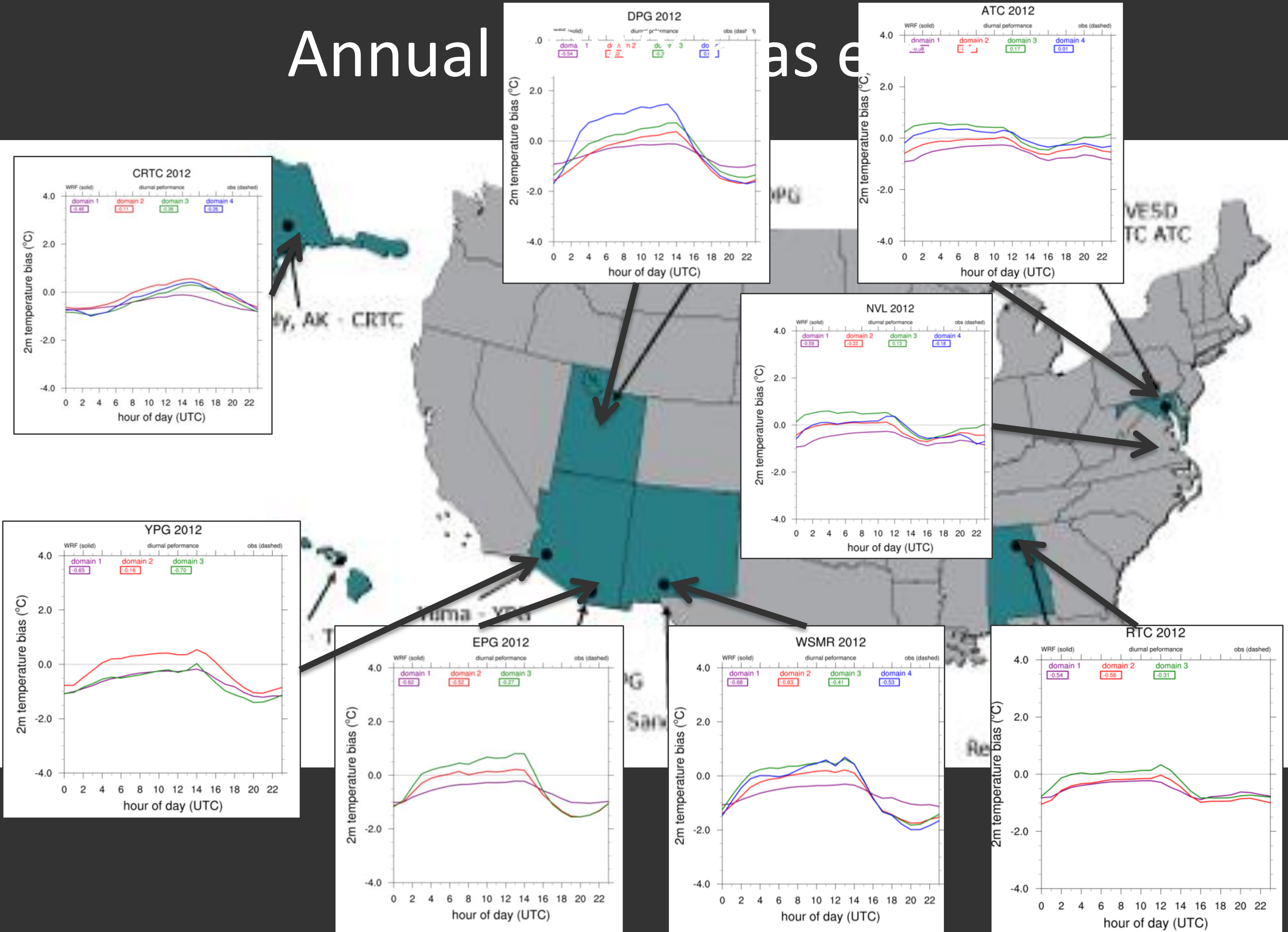
00 UTC



Western Conus has morning warm bias and afternoon cold bias

Source: Development Testbed Center: Michelle Harrold, Jamie Wolff, and Mei Xu 2014 AMS presentation

Annual

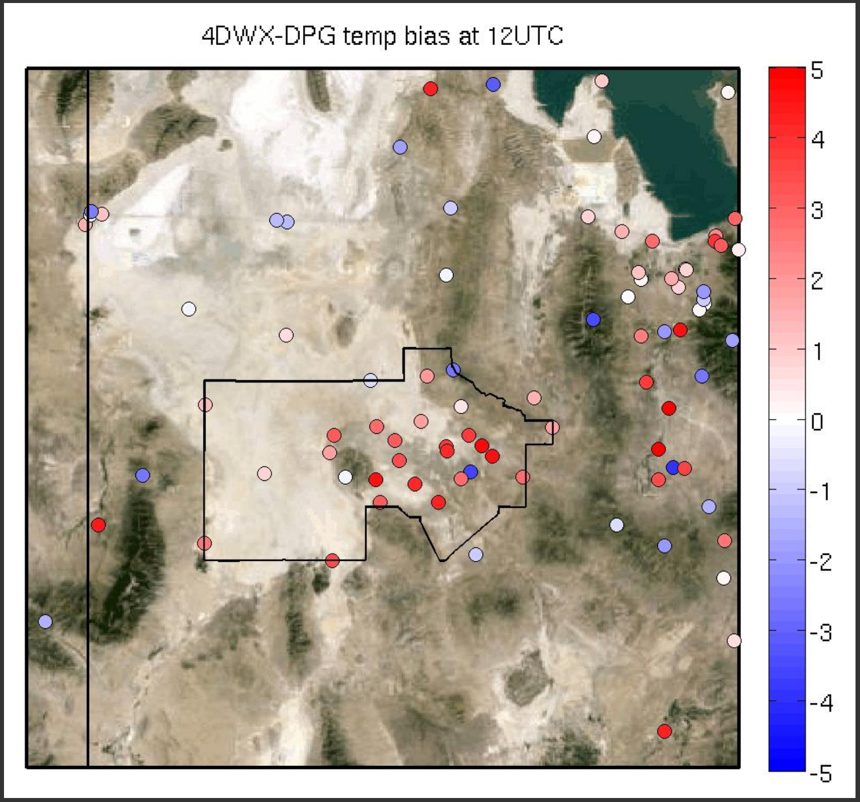


CRTC 2012
DPG 2012
ATC 2012
NVL 2012
YPG 2012
EPG 2012
WSMR 2012
RTC 2012
WRF (solid)
diurnal peformance
obs (dashed)
domain 1
domain 2
domain 3
domain 4
2m temperature bias (°C)
hour of day (UTC)
AK - CRTC
DPG
VESD
TC ATC
Yuma - YPG

WRF 2-m Temperature Biases

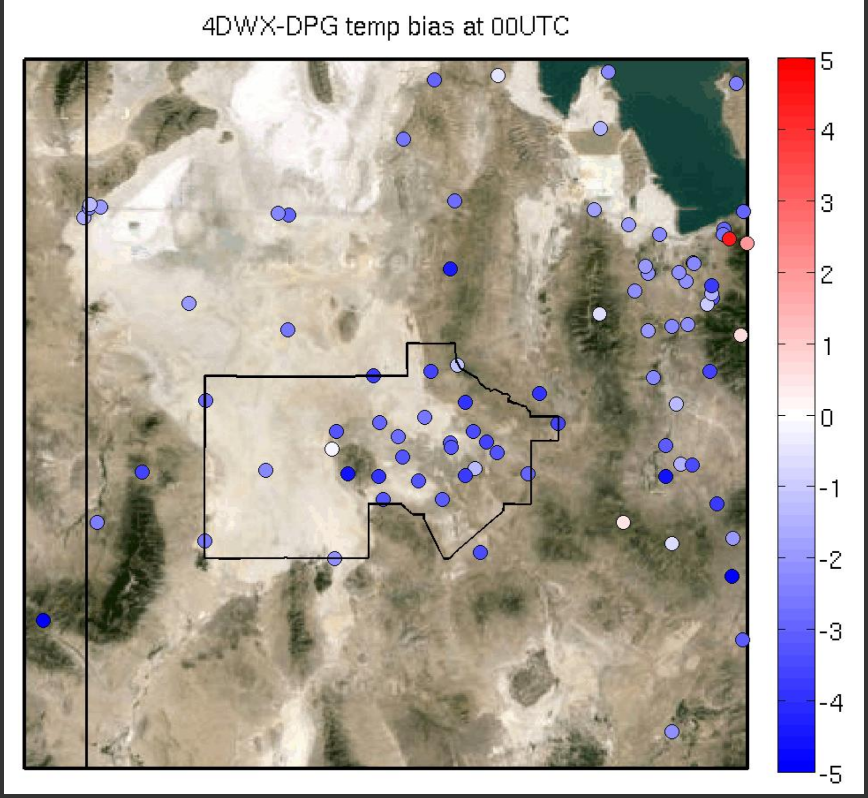
12 UTC Mean Bias Errors

Strong cold bias over certain land surfaces and little bias elsewhere

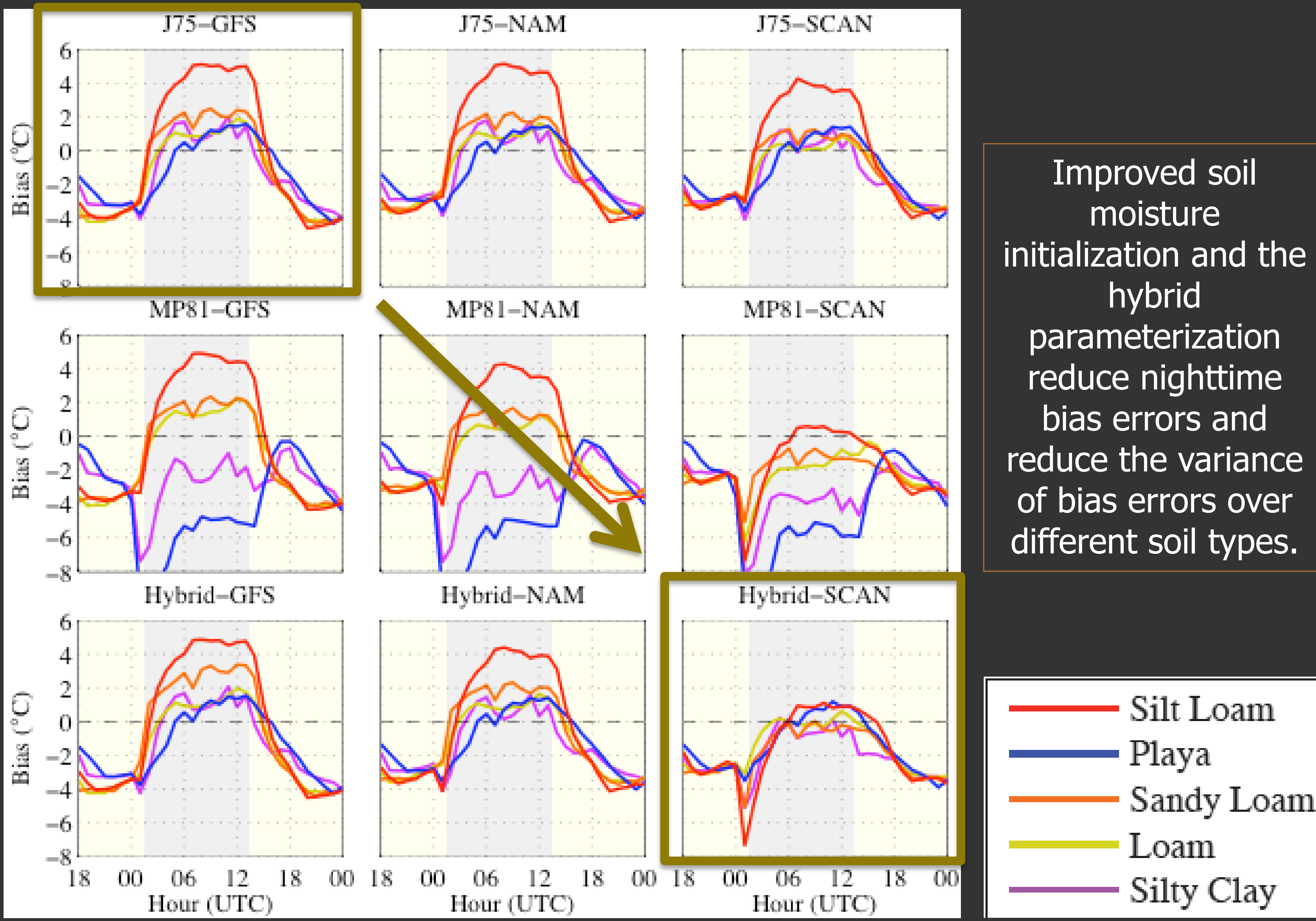


00 UTC Mean Bias Errors

Domain wide cold bias independent of the land surface

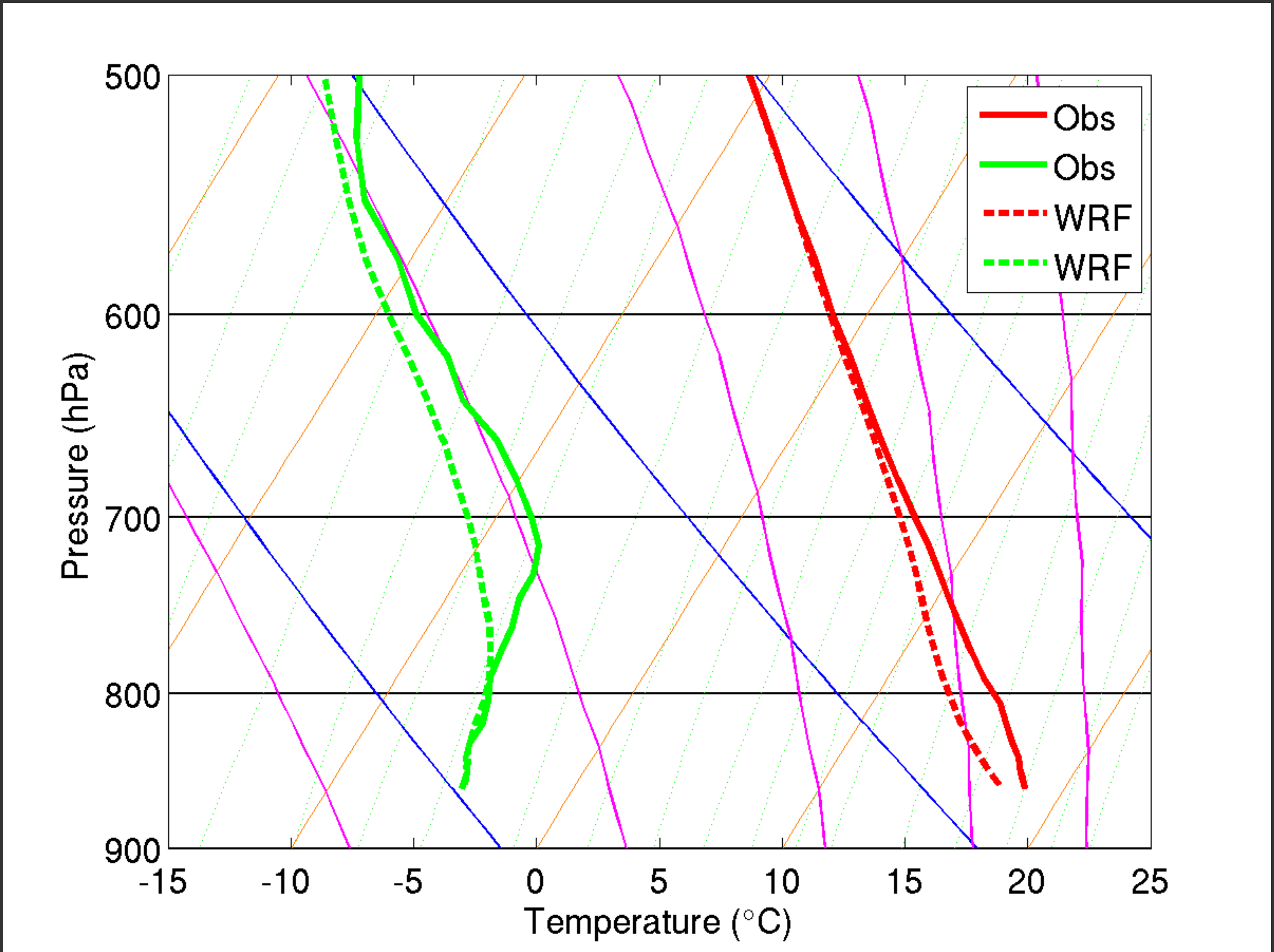


Near-Surface Temperature Bias Errors

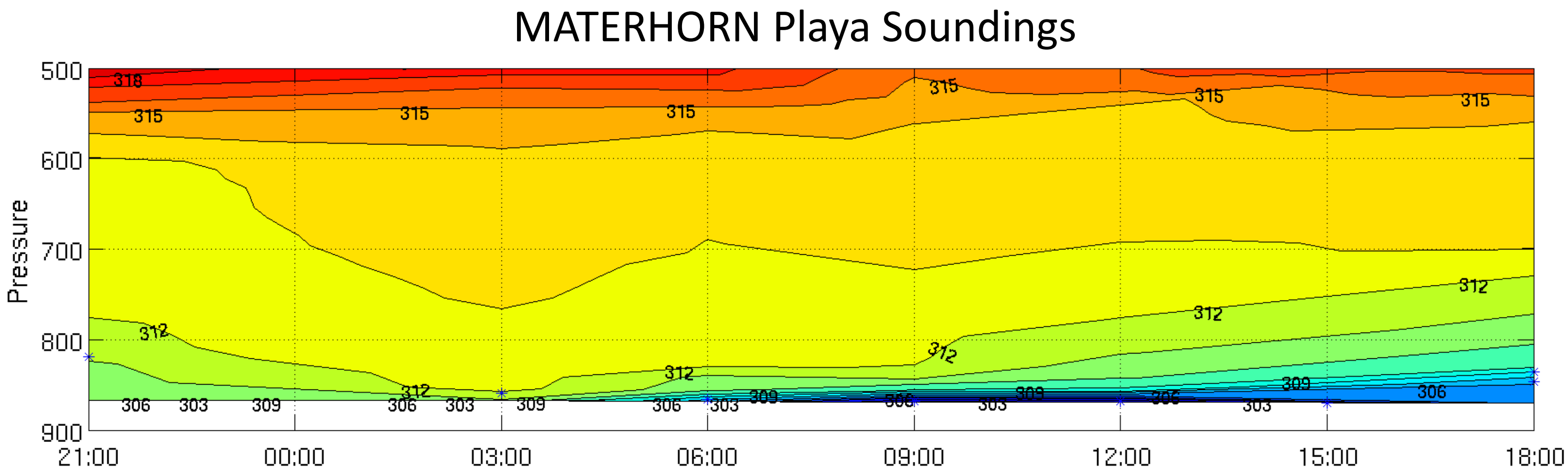


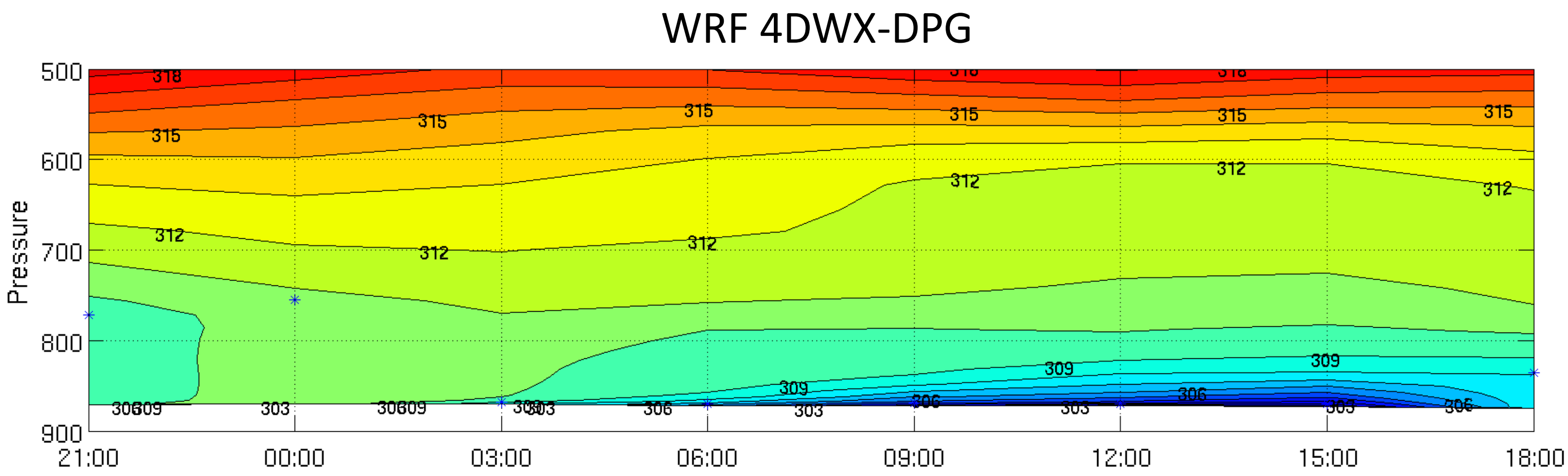
Improved soil moisture initialization and the hybrid parameterization reduce nighttime bias errors and reduce the variance of bias errors over different soil types.

Average MATERHORN Fall 2012 Afternoon Soundings



MATERHORN Fall IOP01 (21 UTC 28 Sep 2012 – 18 UTC 29 Sep 2012)





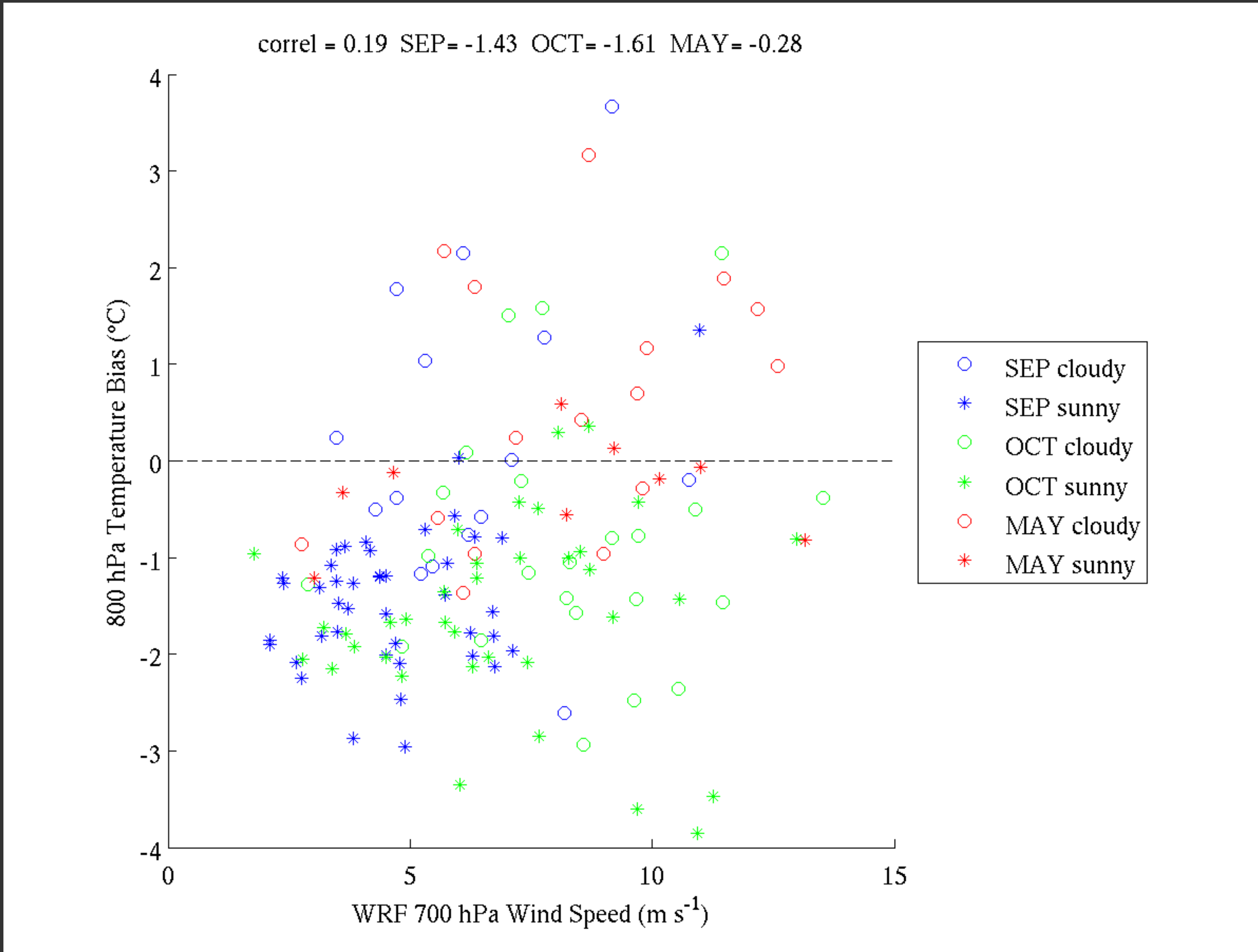
Possible Temperature Bias Sources

1. PBL parameterization errors
   - Underestimation of vertical mixing, entrainment, and/or PBL height
2. Radiation errors
   - Surface radiation budget errors, especially sensible heat flux, and radiation divergence.
   - Sky view restriction and topographic amplification factor (TAF)
3. Landuse errors
   - Inaccurate landuse and terrain classification and initialization
4. Cloud and/or precipitation errors
5. Initial, lateral boundary condition, or resolution errors
6. Numerical errors
   - Calculating derivatives in sloping sigma coordinates
   - Advection

Recent studies with a daytime cold bias in complex terrain citing one or more of these reasons:

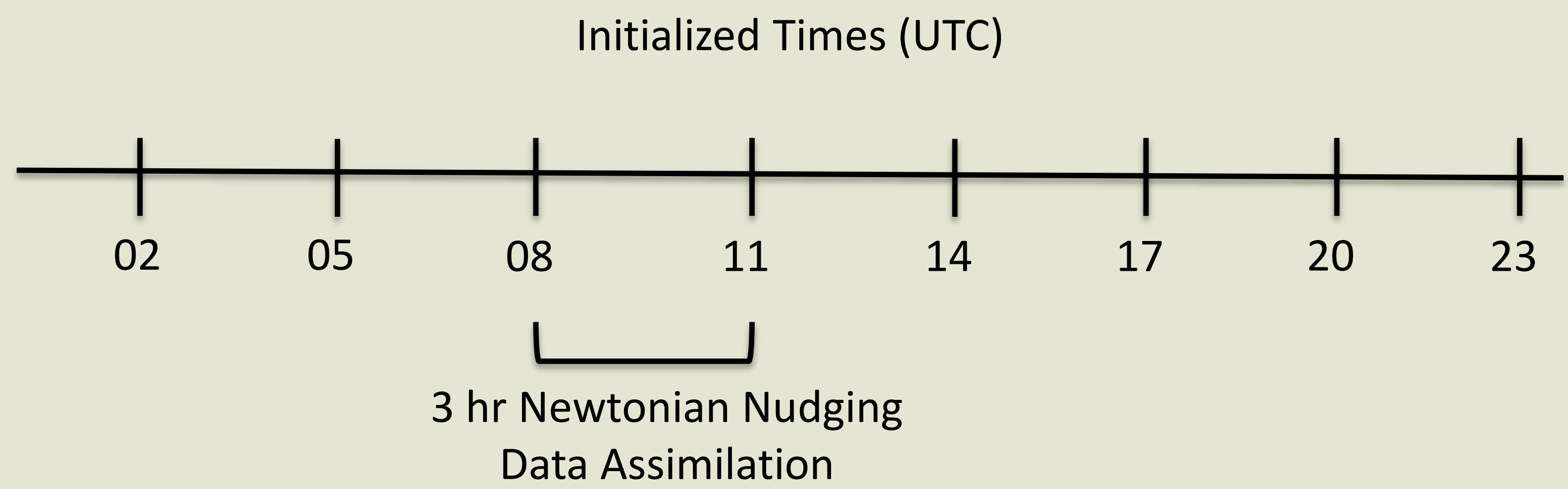
Hanna and Yang 2001
Coniglio et al 2013
Reeves et al 2011
Zhong and Fast 2005
Garcia-Diez et al 2012
Muller and Scherer 2005
Steeneveld et al 2011
Svenssen et al 2011
Wyszogrodzki et al 2013
Cheng and Steenburgh 2005
Massey et al 2014

4DWX-DPG 00 UTC Cold Bias



4DWX-DPG

NCAR's operational four-dimensional weather system developed for Dugway Proving Ground



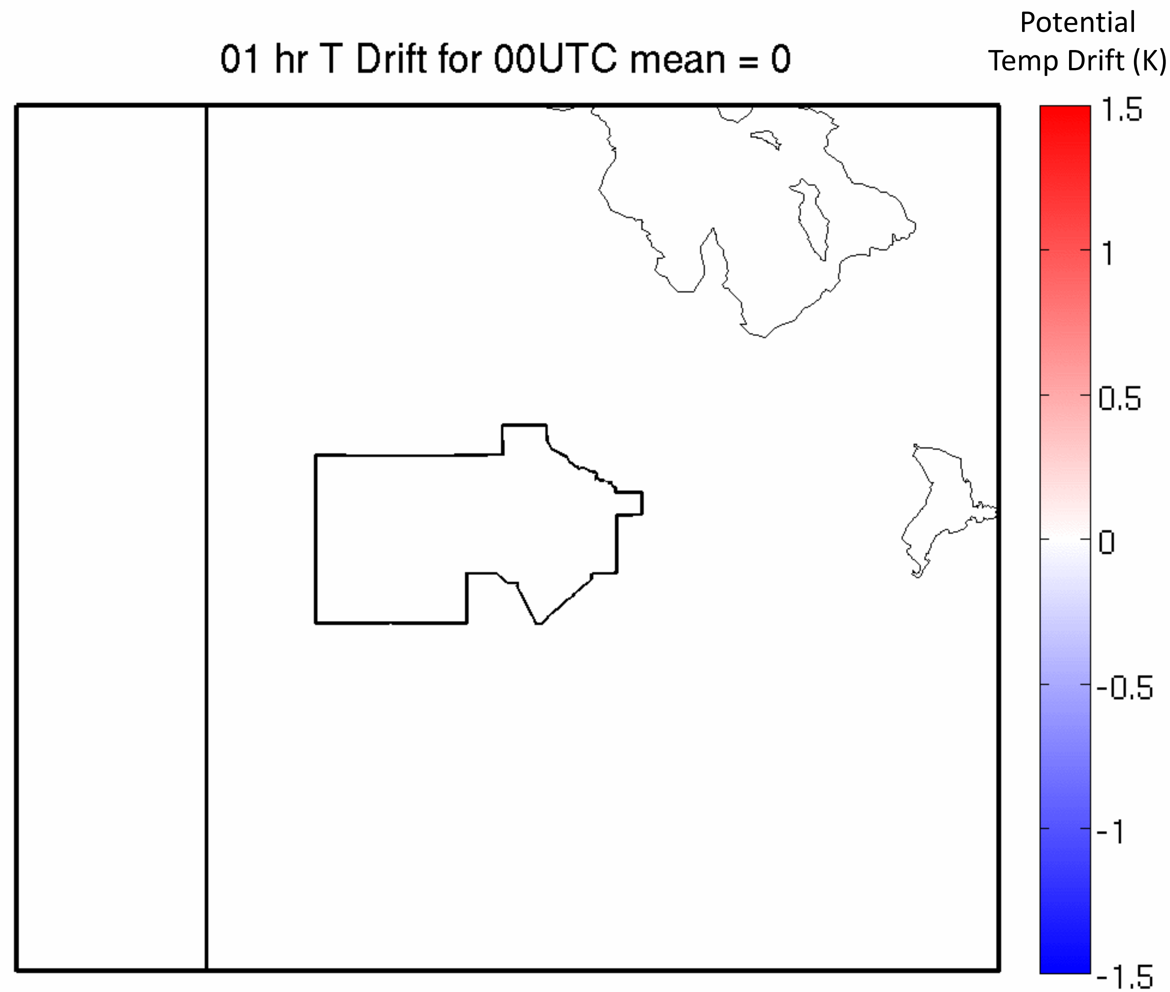
Data Assimilation

1. Surface Stations
2. Rawinsondes
3. Profilers
4. Buoys
5. Aircraft
6. Satellite

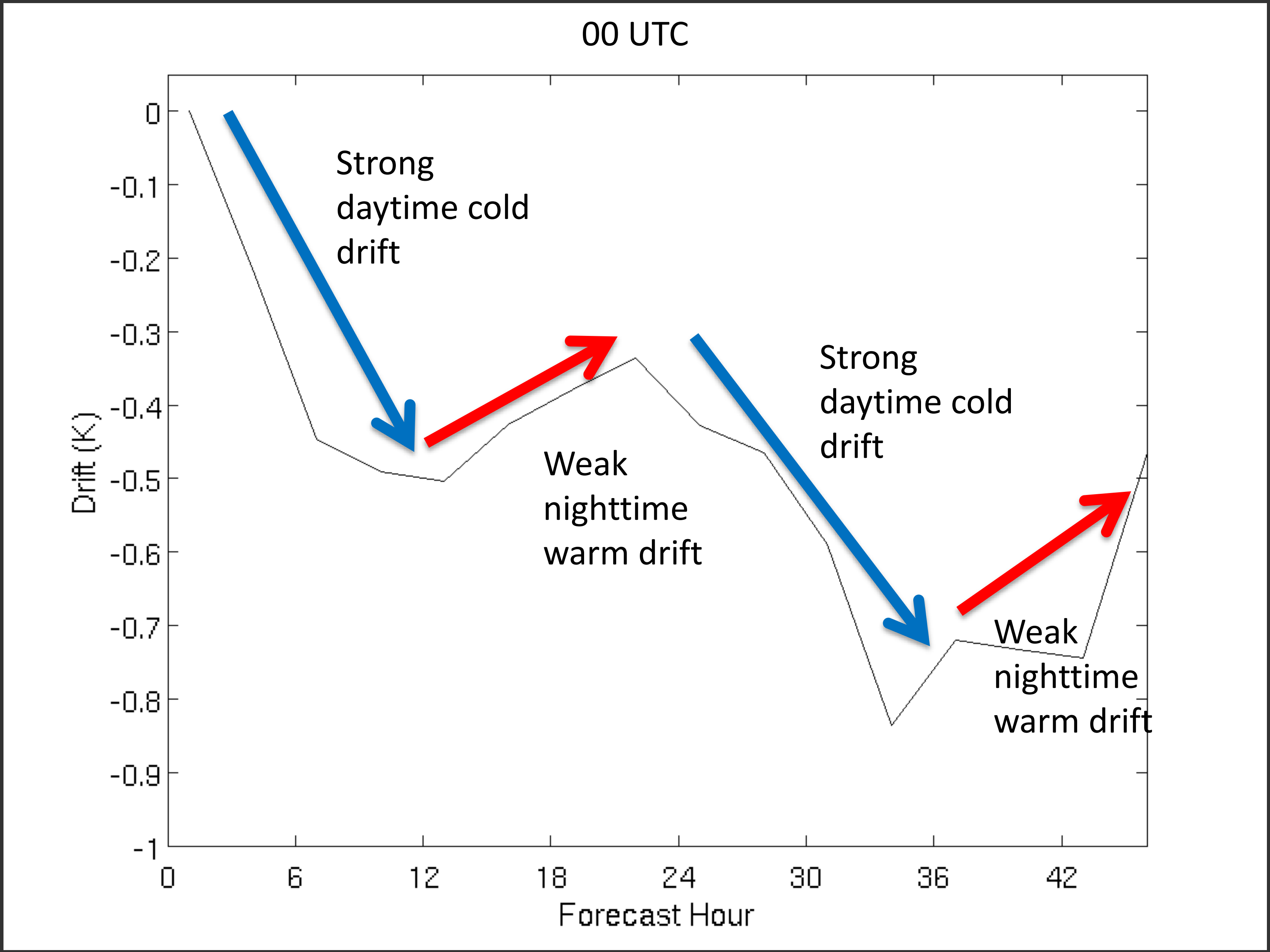
- Each run's warm start initialization is nudged towards observations

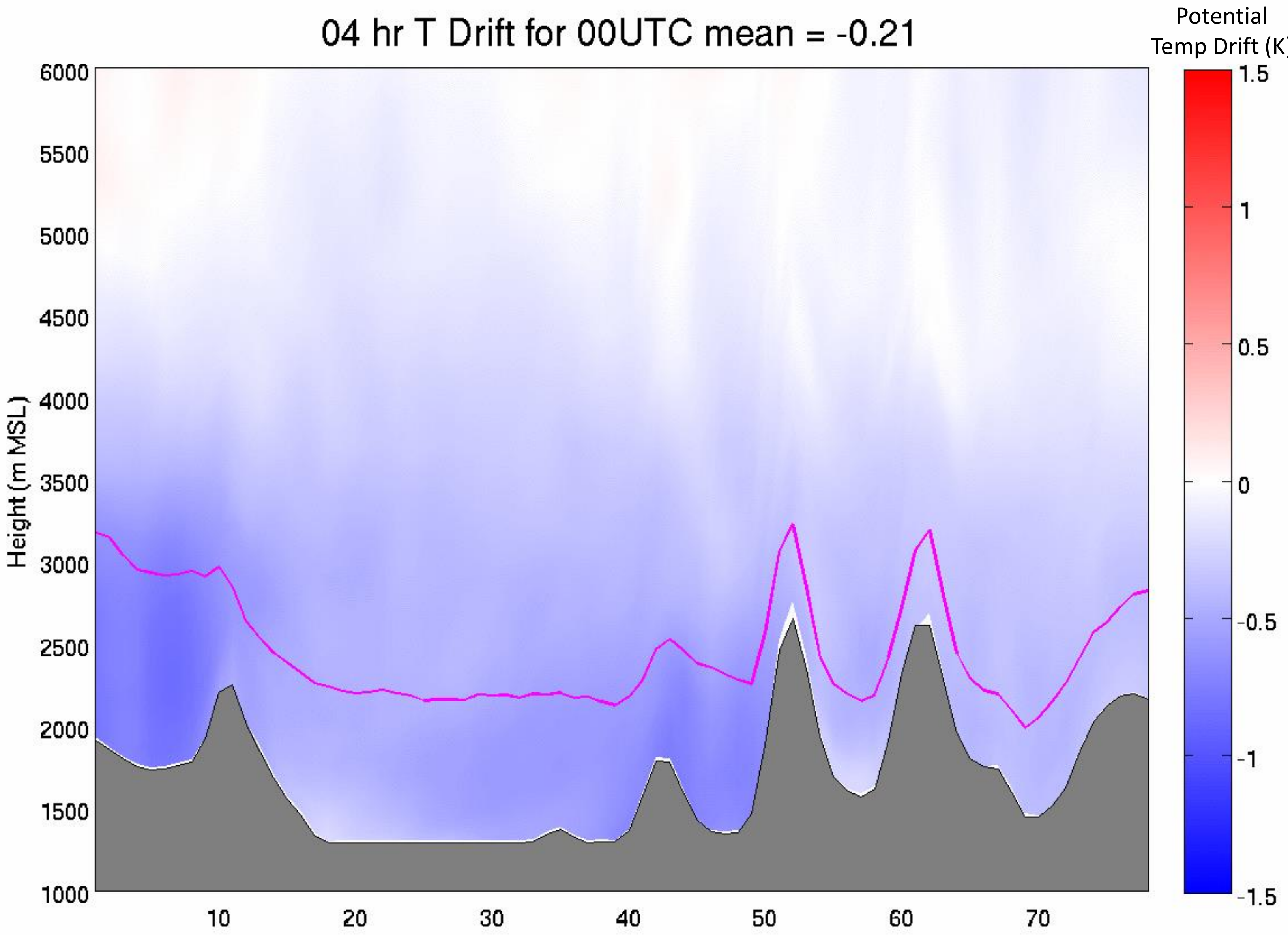
Mean Vertically Averaged Temperature Drift in 4DWX

(X hr forecast ending at 00 UTC) – (1 hr forecast ending at 00 UTC)



Horizontally and Vertically Averaged Drift



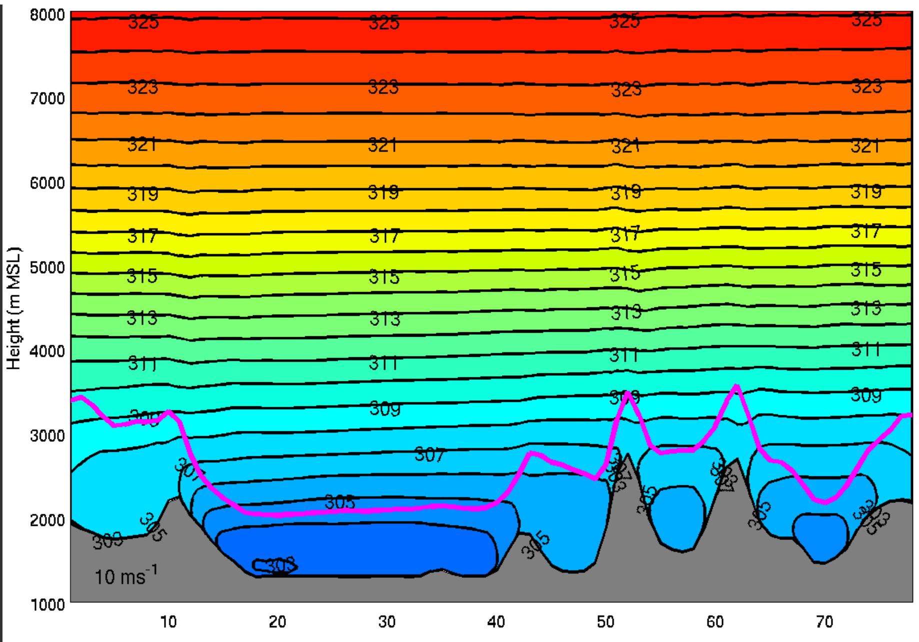

04 hr T Drift for 00UTC mean = -0.21
Potential Temp Drift (K)
1.5
1
0.5
0
-0.5
-1
-1.5
Height (m MSL)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
10
20
30
40
50
60
70

Can these biases be replicated?

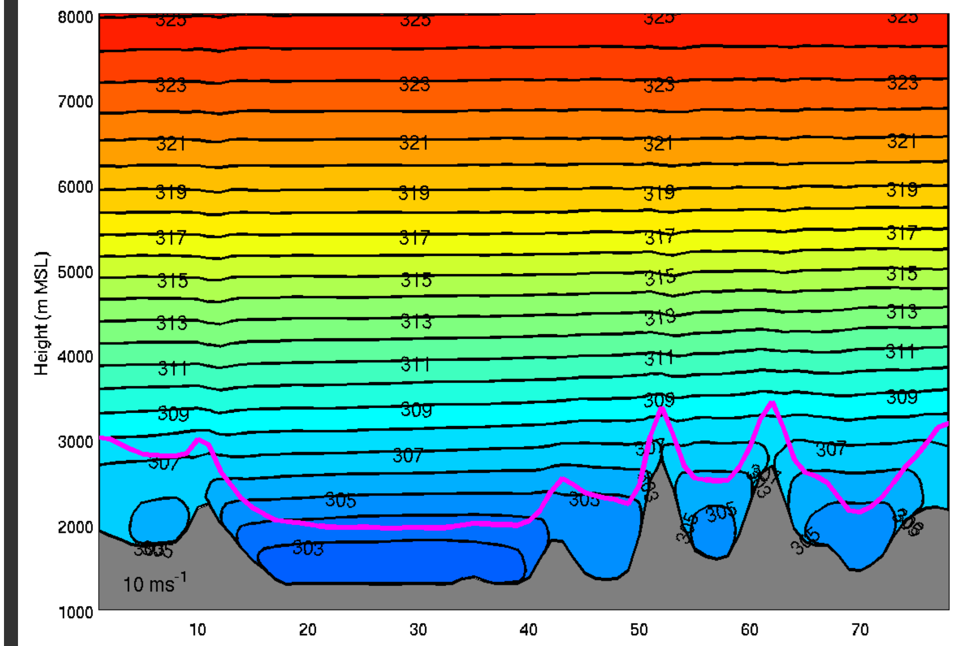
Modeling framework:

1. 3 km domain, which is the same as domain 3 in 4DWX-DPG
2. 8 6-hr simulations were initialized with mean 4DWX analysis fields from 81 sunny days
3. Forced with 3 hourly mean 4dwx analysis fields or mean 4dwx forecasts
4. Same physics and dynamics packages as 4dwx
5. Simulation was run for October 7 - 8 since radiation forcing for the 7th matches up well with the radiation mean

Mean 4DWX Analysis at 20:00 UTC



Mean 4DWX 3 hour forecast at 20:00 UTC



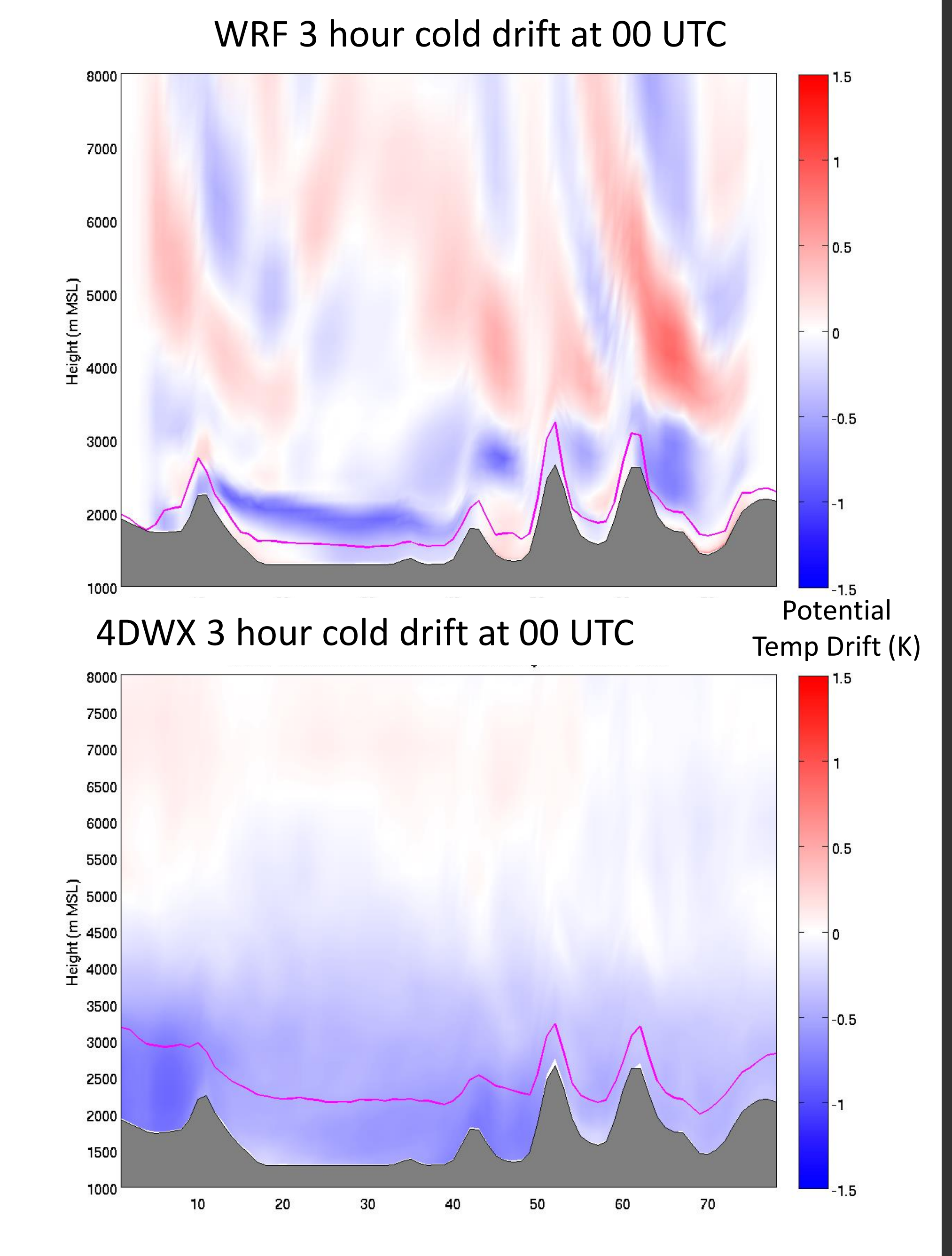
Forcing by 4DWX Analyses

Results:

1. Cold drift is not replicated!
2. Full domain mean difference is -0.03 K in WRF and -0.21 K in 4DWX

A 4 h forecast minus a 1 h forecast ending at 00Z for WRF forced with mean 4DWX-DPG analyses

The mean 4 h forecast minus the mean 1 h forecast ending at 00Z for 4DWX-DPG



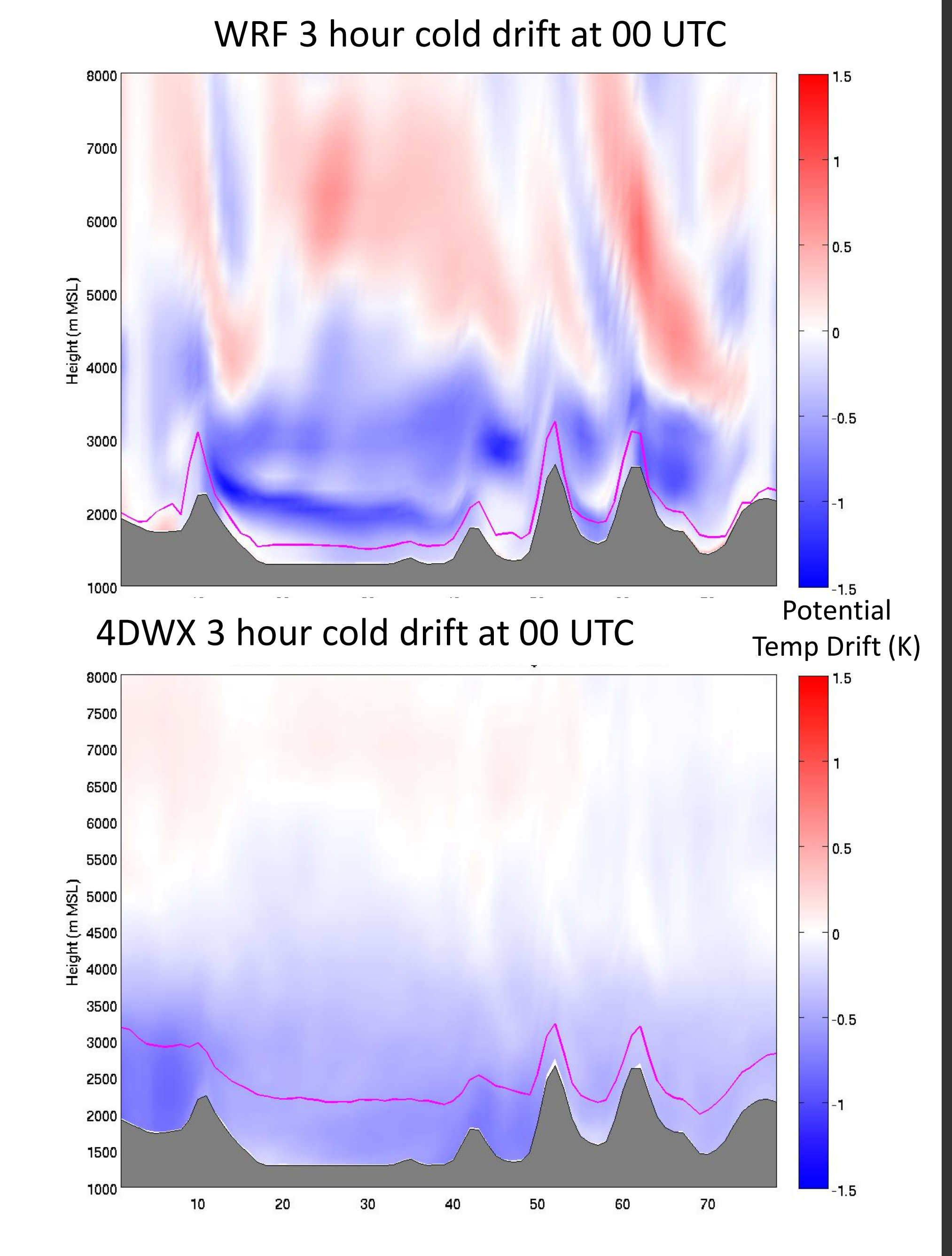
Forcing by 4DWX Forecasts

Results:

- Much more cooling, especially aloft
- Full domain mean difference is -0.15 K in WRF and -0.21 K in 4DWX
- Cooling appears to be coming from boundary conditions

A 4 h forecast minus a 1 h forecast ending at 00Z for WRF forced with mean 4DWX-DPG forecasts

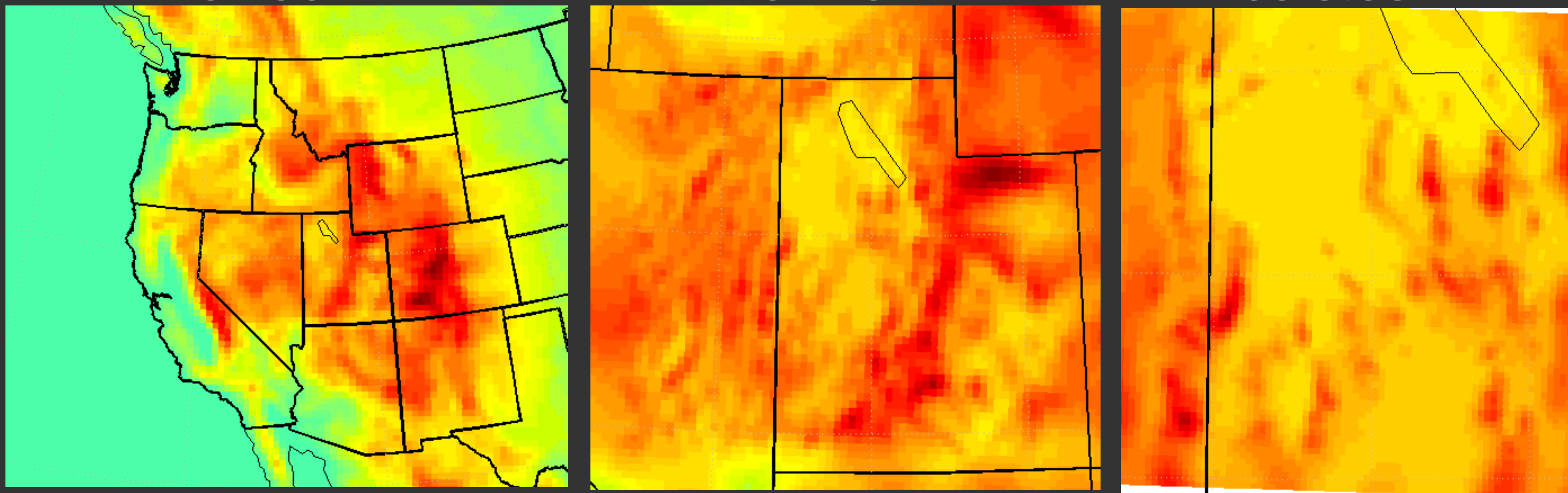
The mean 4 h forecast minus the mean 1 h forecast ending at 00Z for 4DWX-DPG



Real Case WRF Setup

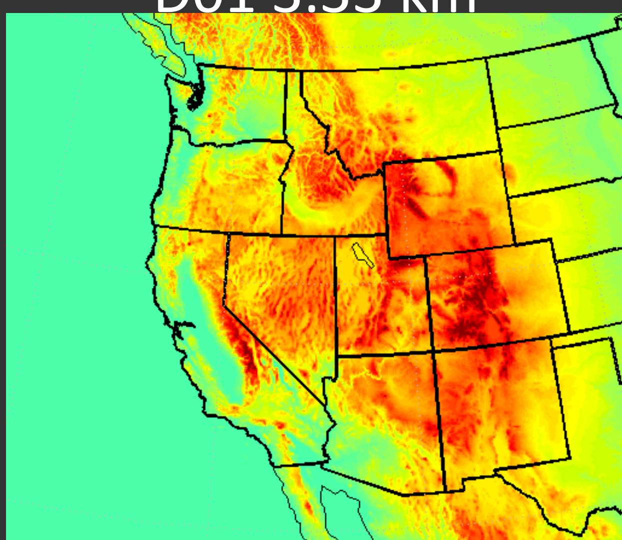
4DWX

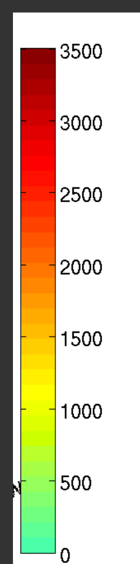
D01 30 km | D02 10 km | D03 3.33 km



Hires

D01 3.33 km

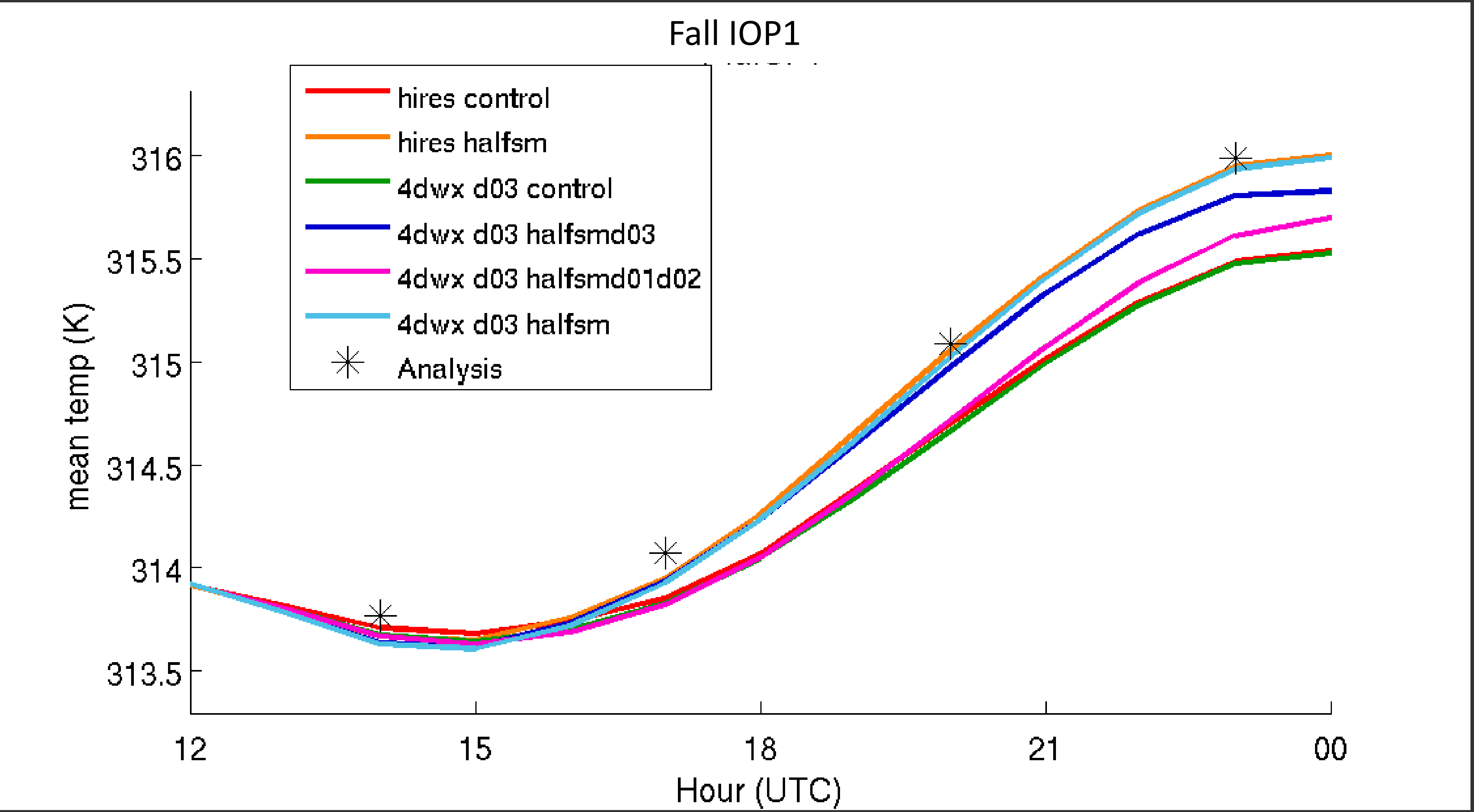


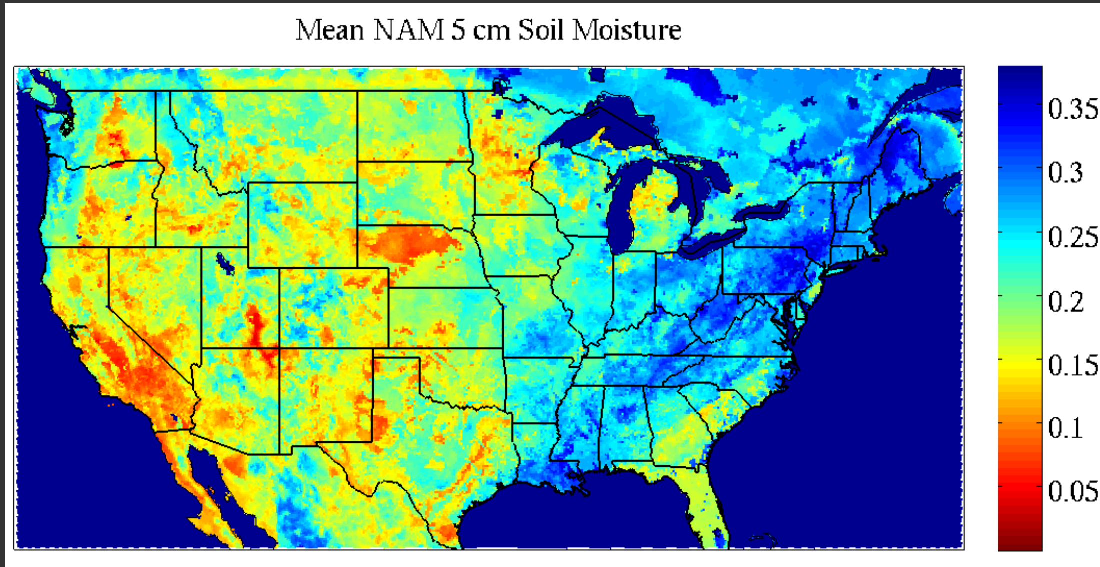


- 4dwx runs use same resolution and physics as 4DWX-DPG
- Hires runs use same static fields as 4dwx and same physics
- Hires runs take ~10x longer

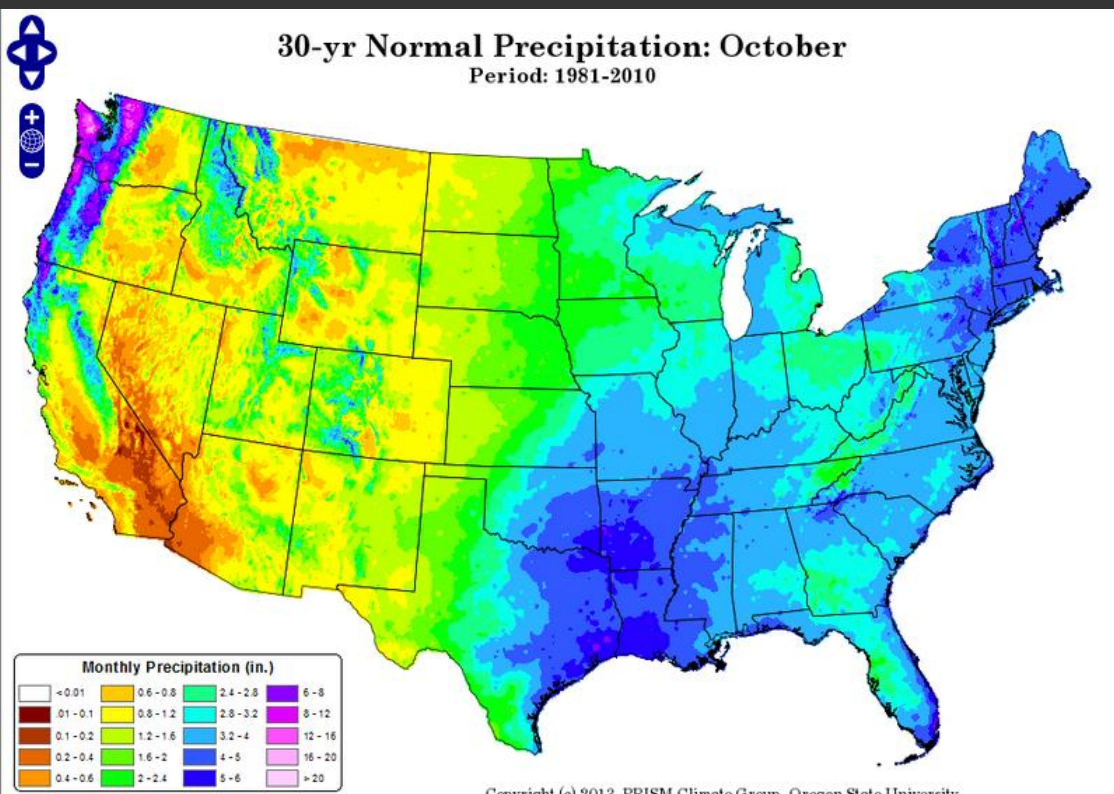
Horizontally and Vertically Averaged Potential Temperature

- Relatively weak sensitivity to resolution compared to soil moisture.
- Decreasing the soil moisture in the outer domains has a significant impact on temperatures in inner domain





Is soil moisture greatly over-estimated over the western CONUS?



Should Great Basin have similar soil moisture as Midwest?

Very few soil moisture observing stations in west.

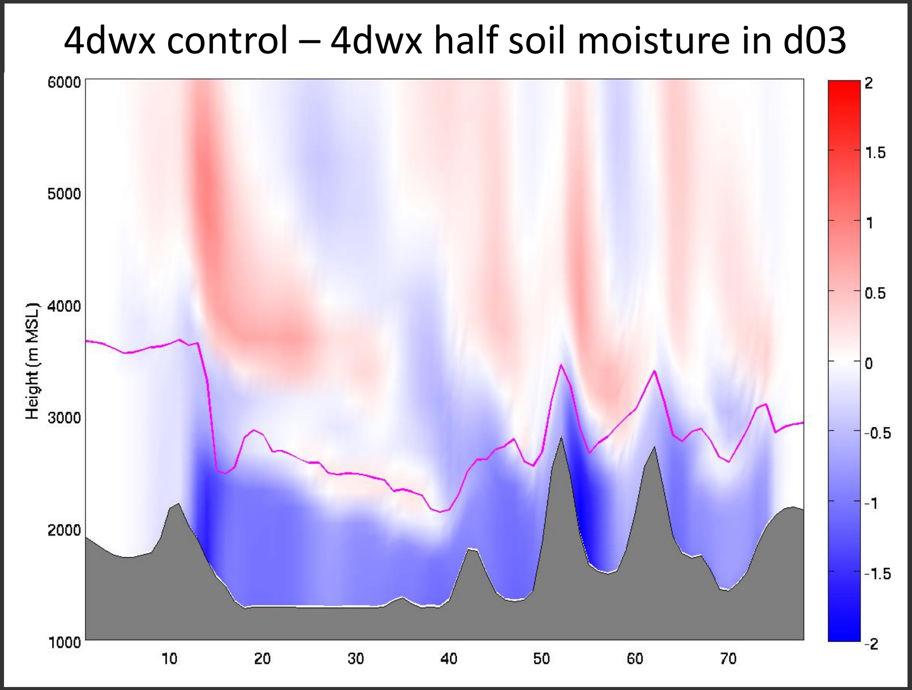
Perhaps another variable is affecting surface heat flux on a large scale?

Source: PRISM Climate Group, Oregon State University

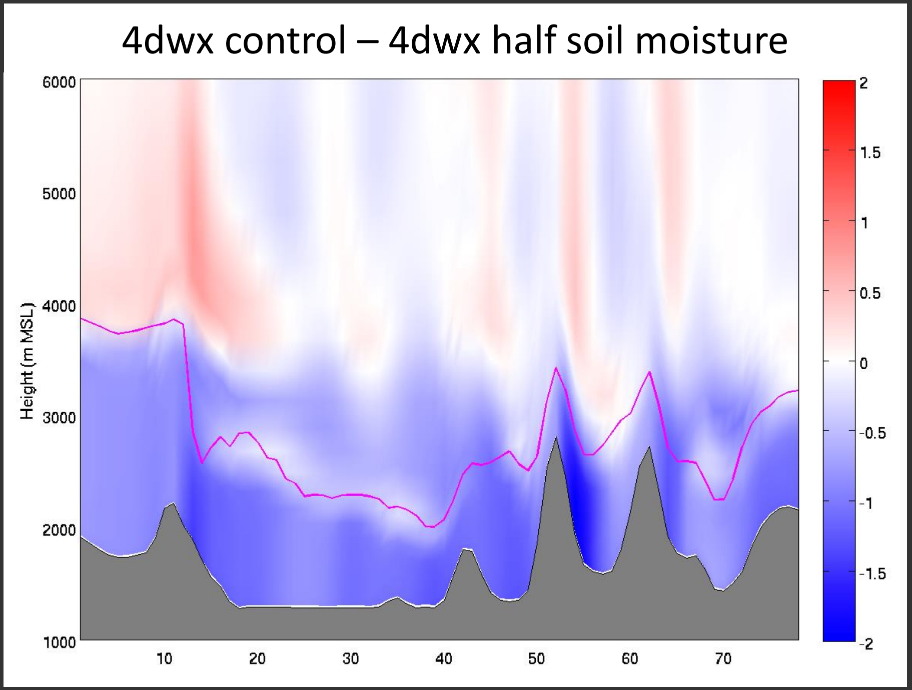
Conclusions

- WRF simulations of DPG and the surrounding area have a nighttime warm bias and daytime cold bias that is stronger in magnitude
- The nighttime warm bias is soil type dependent and can be remedied through the use of SCAN soil moisture and a hybrid soil thermal conductivity parameterization.
- The cold bias is present above and below the boundary layer is at least partially driven by lateral boundary conditions errors.
- A reduction of soil moisture in the outer domains appears to greatly reduce the cold bias, but other sources of error are possible

How does decreasing soil moisture affect the temperature structure?



Domain wide average difference = -0.23



Domain wide average difference = -0.37

Decreasing soil moisture in innermost domain mainly affects temperatures within boundary layer

Decreasing soil moisture in all domains affects temperatures above and below boundary layer

MATERHORN Sagebrush Observations