MATERHORN-M Progress (NPS, U. Utah) Summaries and notes from recent work

Project Scientific Issues – Barriers/Challenges

- Atmospheric Predictability in complex terrain – poor
- Accurate measurement of model-relevant soil properties and the surface energy balance over extended periods – difficult
- Model deficiencies – structural and physical – insufficiently understood

MURI Topic #7 presented to OSD 2013

Evaluate WRF Surface Forecasts

Hailing Zhang and Zhaoxia Pu, U. Utah

- Warm biases at night time and cold biases at day time are found in WRF forecasts.
- Under weak synoptic forcing, errors in near surface temperature and winds depend on the diurnal cycle. Flow-dependent forecast errors are seen in stronger synoptic forcing cases, as the errors do not follow the diurnal pattern.
- Errors are present in near surface wind and temperature even when the WRF is skillful at synoptic scales.

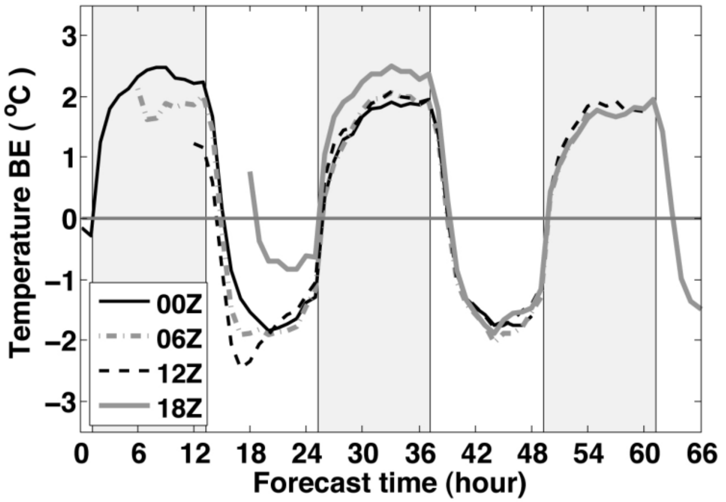


FIG. Bias of simulated 2-m temperature from the 1.11-km domain over DPG with various initialization times. The forecasting period for all forecasts is 48 h. Statistics are based a month-long WRF real-time forecasts.

Related Publication: Zhang, H., Z. Pu and X. Zhang, 2013: Examination of errors in near-surface temperature and wind from WRF numerical simulations in regions of complex terrain. *Wea. Forecasting.* 28, 893-914.

Data Assimilation and Predictability

Zhaoxia Pu and Hailing Zhang, U. Utah

Objectives:

- Evaluate the impact of data assimilation on the predictability of atmospheric conditions over complex terrain
- Compare different data assimilation methods, such as ensemble Kalman filter (EnKF) and 3-dimensional variational data assimilation (3DVAR).

Major findings so far:

- EnKF outperforms 3DVAR over complex terrain
- Assimilation of surface mesonet observations results in positive impact on short-range forecasts.

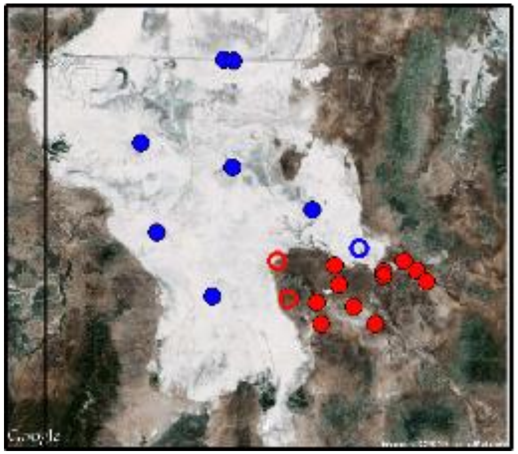
On-going work and recent progress:

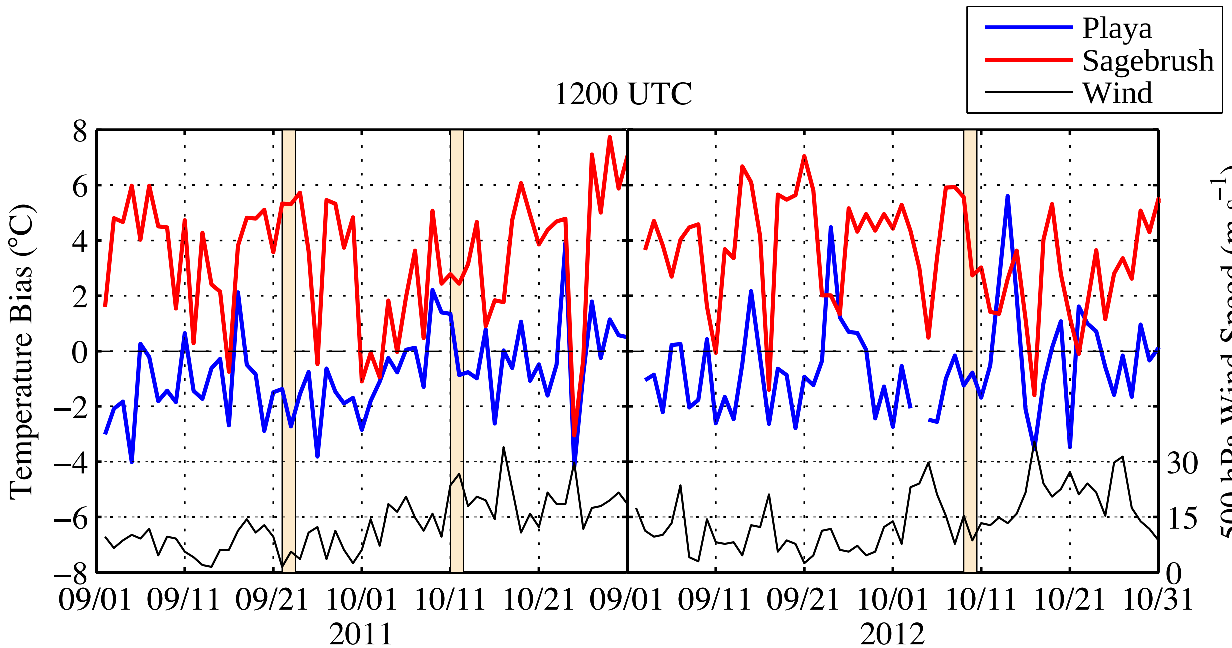
- Study the predictability with ensemble Kalman filter assimilation of available surface mesonet observations along with the special data collected during Materhorn filed experiments. ***See Pu's talk for details.***

Related publication: Pu, Z., H. Zhang, and J. A. Anderson, 2013: Ensemble Kalman filter assimilation of near-surface observations over complex terrain: Comparison with 3DVAR for short-range forecasts. *Tellus A,* 65,19620.

Improving Surface Forecasts

Massey et al., U. Utah



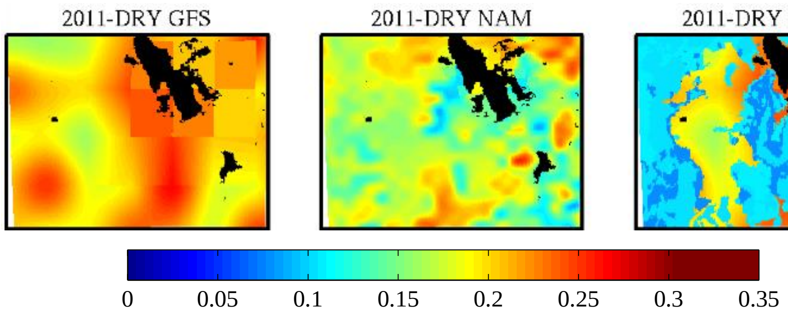


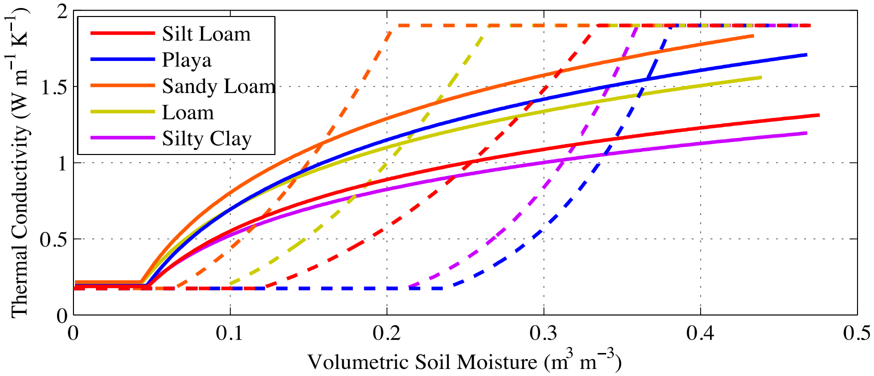
<u>Issue</u>: Mesoscale atmospheric models (e.g., WRF) too warm at night over sagebrush
Documented at DPG during MATERHORN and in other mountainous regions
(Mass et al. 2002, Cheng and Steenburgh 2005, Hart et al. 2005)

<u>Implications</u>: Poorly simulated nocturnal boundary layer, errors in the prediction of near-surface winds and turbulence, dust emissions and transport, etc.

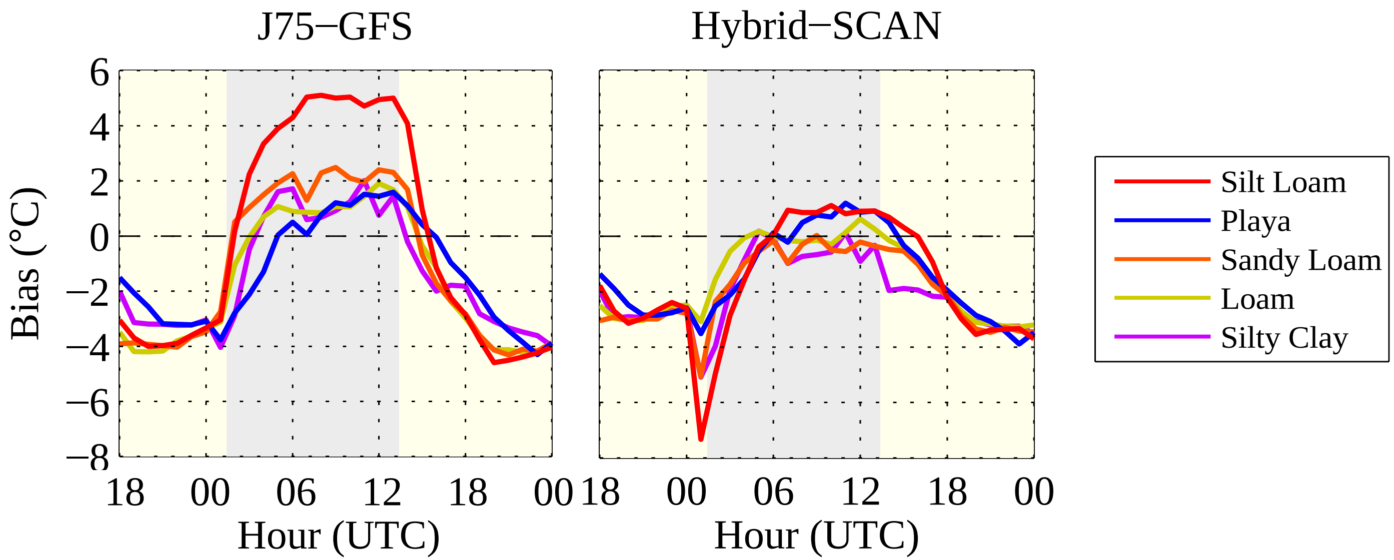
Findings and Advances

Massey et al., U. Utah





Error Sources: Initialization of soil moisture; Parameterization of soil thermal conductivity



Advances: Improved LSM initialization and parameterization (Massey et al., submitted)

Remaining Challenge: Improving soil moisture analyses in data sparse regions

Ensemble sensitivity

Hacker, Chilcoat, Wile, Homan, NPS

How does the change in a set of initial state variables x_s change a forecast metric J?

$$\frac{\partial J_e}{\partial x^a}$$

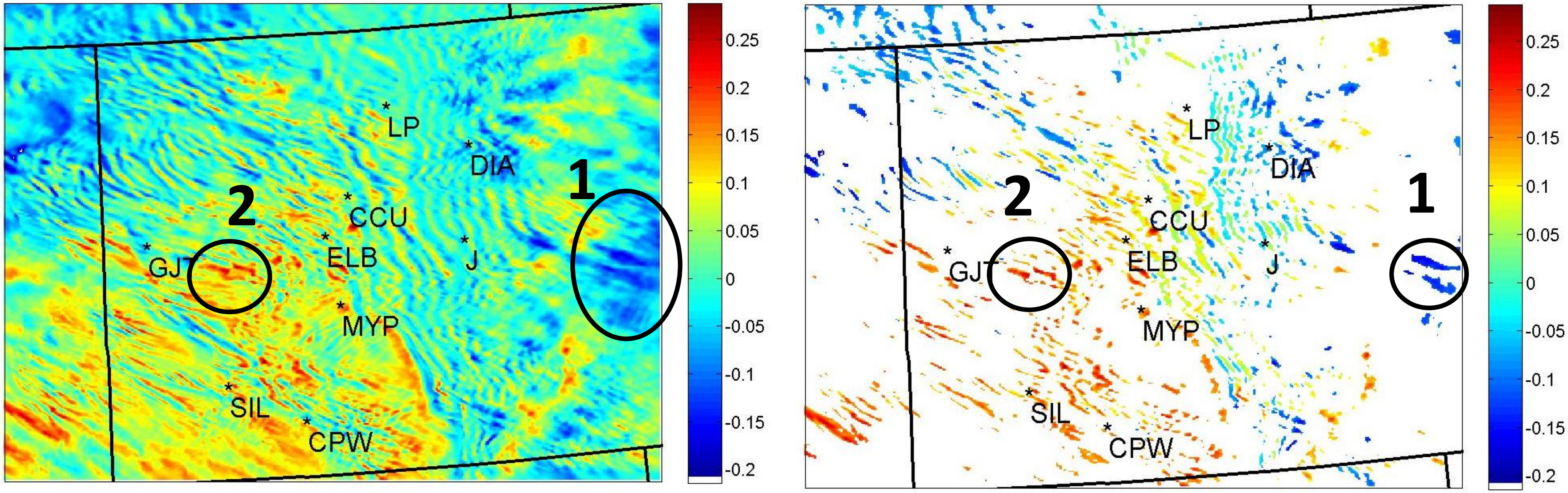
- Identify dynamically relevant covariance structures in space and time, and over complex terrain
- Propose observing strategies for mesoscale, short-range forecasts in complex terrain
- Sensitivity scales (time and space) to infer predictability scales
- Predictability of specific phenomena

Open issues we are addressing under MATERHORN:

- Linearity assumptions in complex terrain
- Linearity assumptions at fine scales
- Sampling error

Ensemble sensitivity

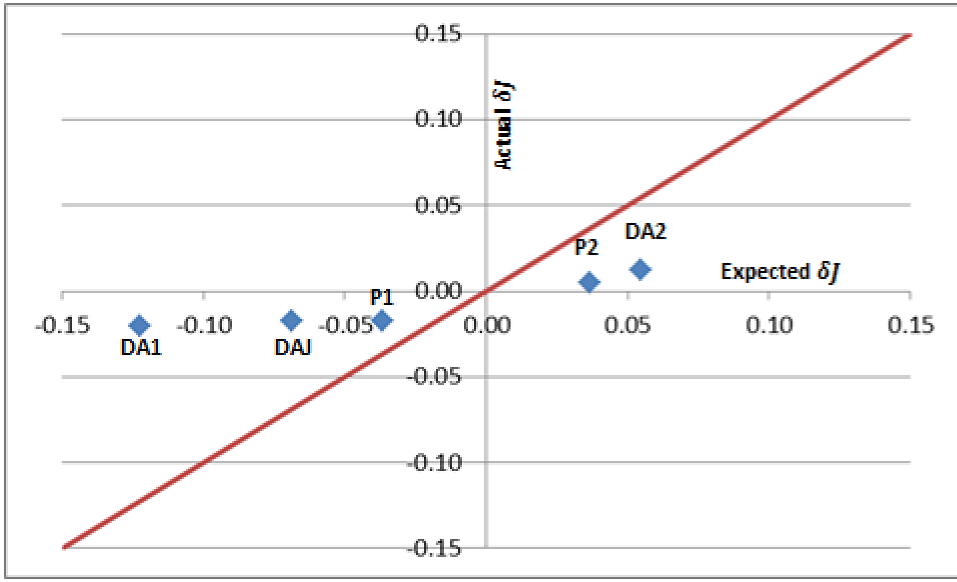
Homan and Hacker, NPS

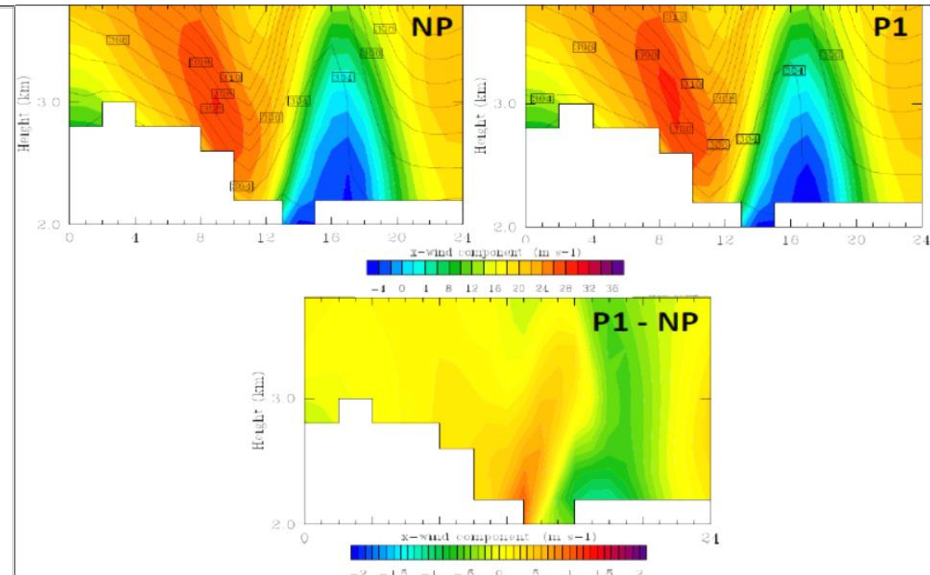


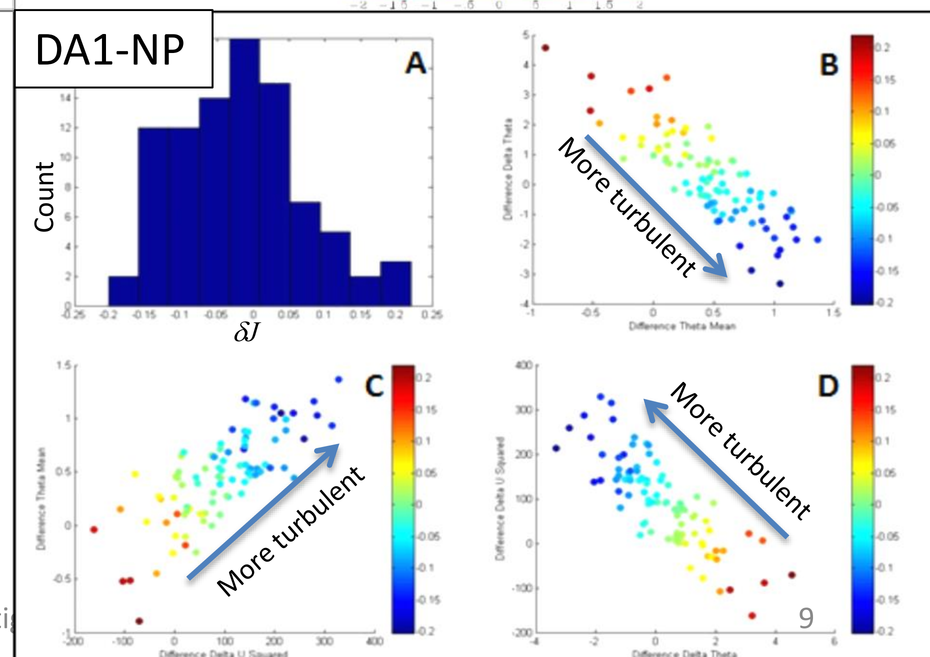
- Metric J_e based on flow stability near USAFA airfield
- Sensitivity $(\partial J_e / \partial x)$ at model level 13 for 3-hr forecast of Potential Temp (left) and filtered for confidence test at 95% confidence interval (right)
- At region 1 – Decrease in Temp predicted to increase J_e
- At region 2 – Increase in Temp predicted to decrease J_e
- Good candidates for perturbations of IC's for new ensemble runs to verify sensitivity

A few results

Homan and Hacker, NPS







- ESA shows skill in identifying regions of IC sensitivity for a down slope wind storm
- All runs move the ensemble mean for *J* in the direction predicted
- ESA successfully identifies importance of vertical structure of atmospheric stability both upstream and downstream
- Success of ESA can be attributed to the Bulk Richardson # being appropriate metric to sample features

Errors in surface-layer parameterization: Zilitinkevich constant (CZIL)

Lee and Hacker, NPS

$$\frac{z_{0m}}{z_{0t}} = \exp\left(kC_{Zil}\sqrt{\frac{u_* z_{0m}}{u}} \right)$$

- CZIL controls land-atmosphere coupling strength
  - Larger CZIL: smaller sensible heat flux, less coupling
  - Smaller CZIL: larger sensible heat flux, more coupling
- Changing CZIL directly impacts low-level atmospheric variables, especially temperature
- No direct measurements of CZIL
- In WRF, only used with MYJ and RUC surface-layer schemes
  - By default a global constant in WRF (CZIL=0.1)
  - Built-in option to set CZIL by vegetation category (iz0tlnd=1)

Optimize CZIL in space and time via state augmentation in an ensemble filter

Lee and Hacker, NPS

Traditional Bayes problem solved via an ensemble filter:

$$P(x \mid y) = \frac{P(y \mid x)P(x)}{\text{normalization}}$$

Augment state with unknown parameters:

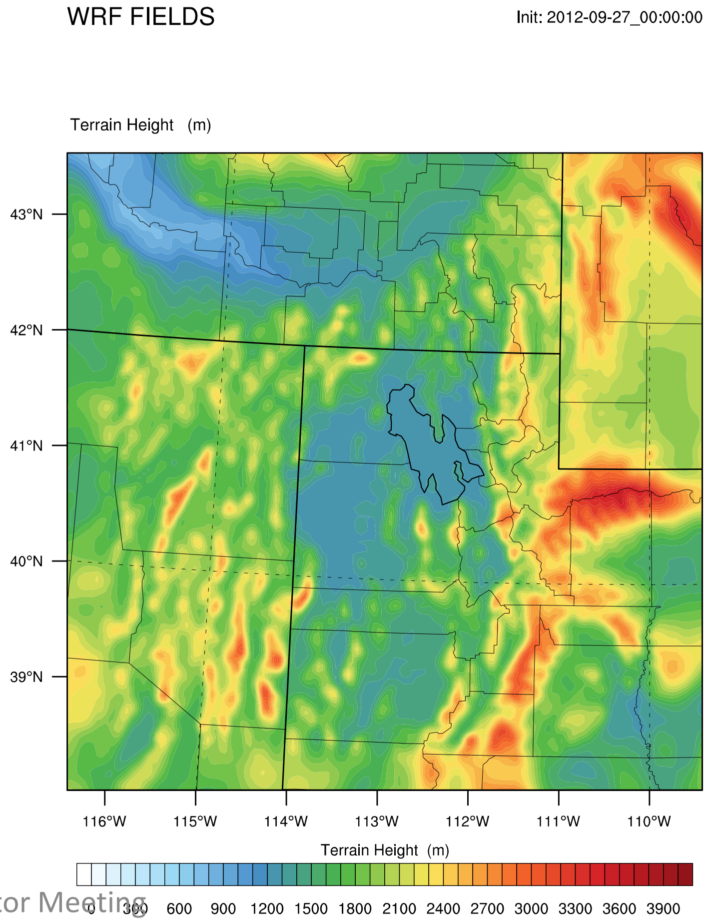
$$P(z \mid y) = \frac{P(y \mid z)P(z)}{\text{normalization}}, \quad z = [x, p] \text{ with parameters } p$$

Challenges: weak correlations between p and x, variability in complex terrain is unknown

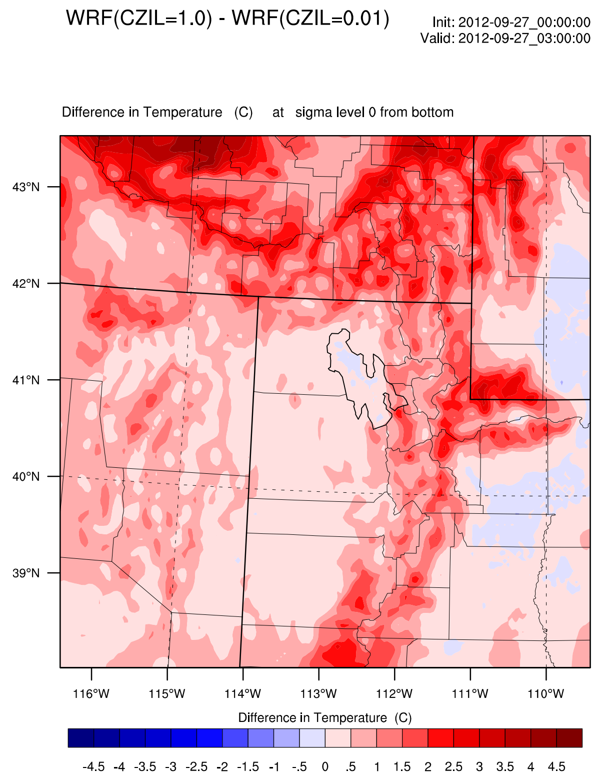
Benefit: some model error accommodated, residual error distributions analyzed to infer structural or other linear sources of error in complex terrain

Impact of CZIL on low-level T
Quick test with WRF

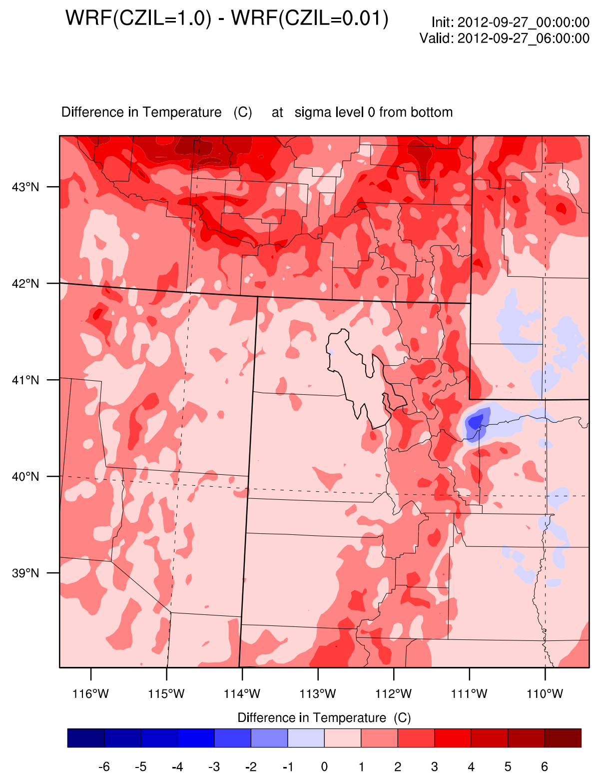
d01 = 12-km res, d02 = 4-km res
Difference fields shown for d02



Impact of CZIL on low-level T



27 Sep 2012, 03 UTC (f+03h)



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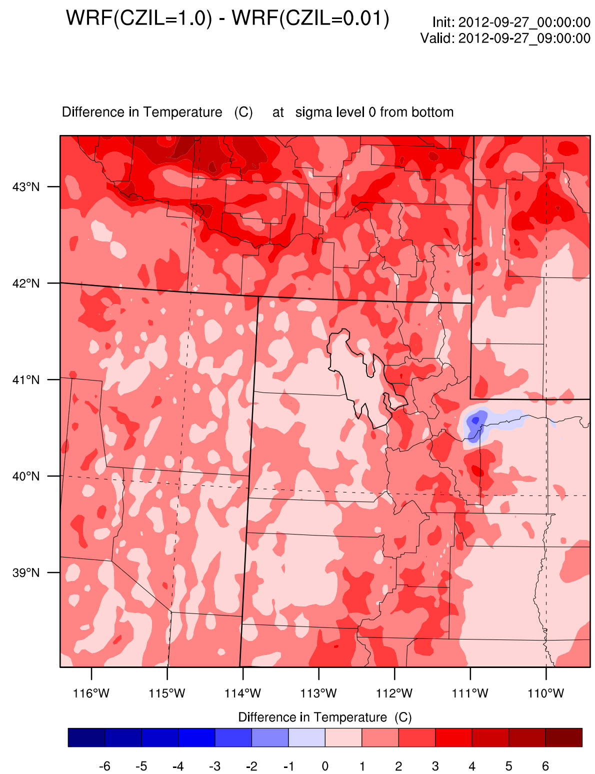
Impact of CZIL on low-level T



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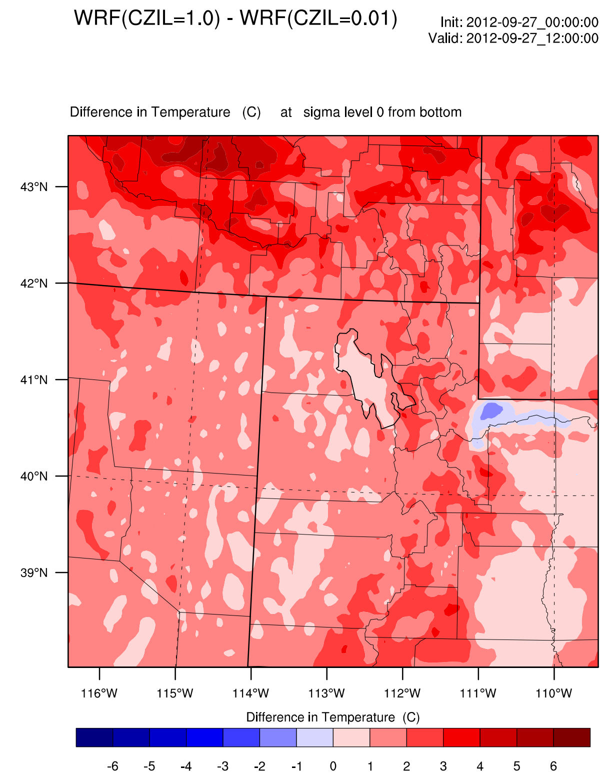

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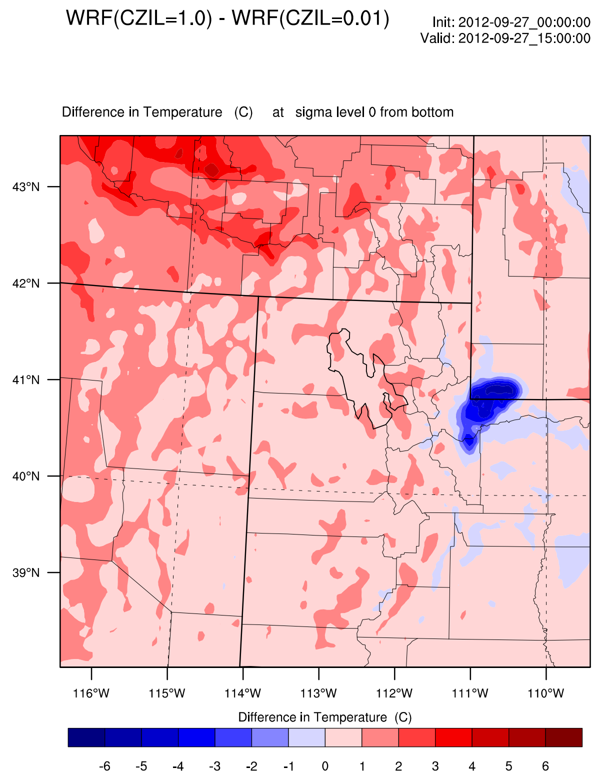
Impact of CZIL on low-level T



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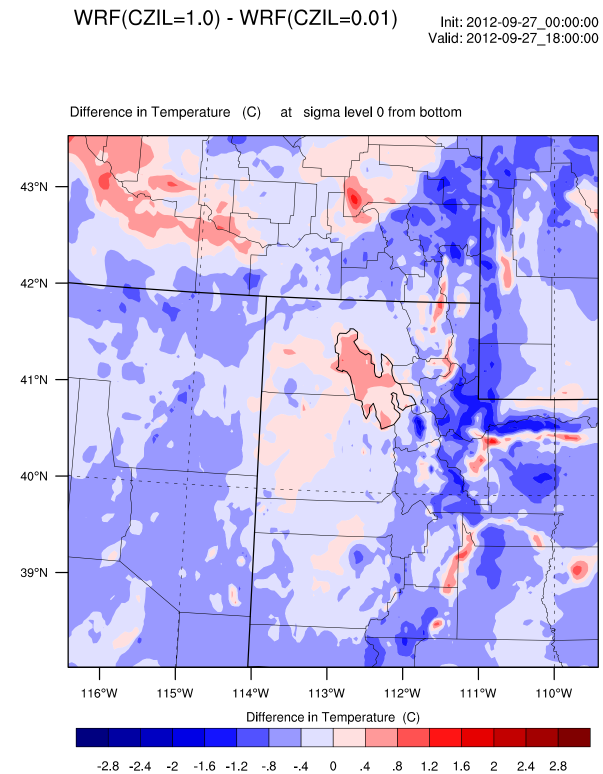

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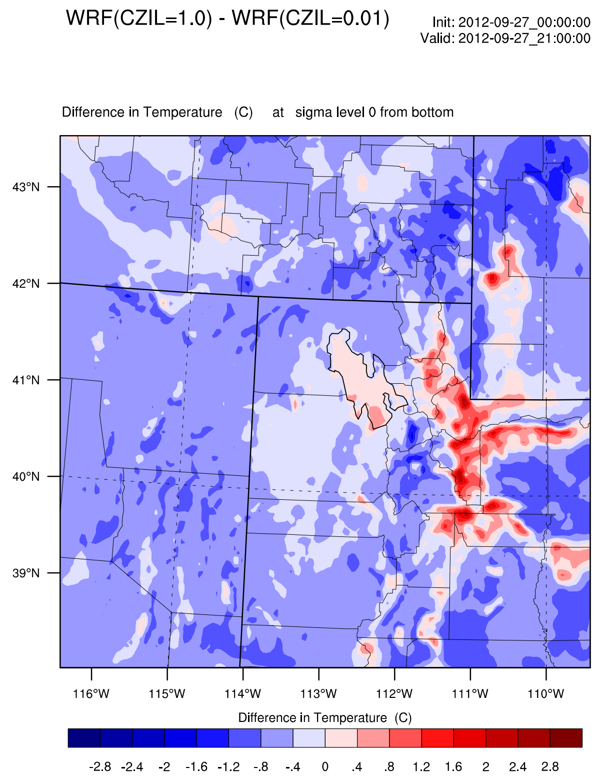
Impact of CZIL on low-level T



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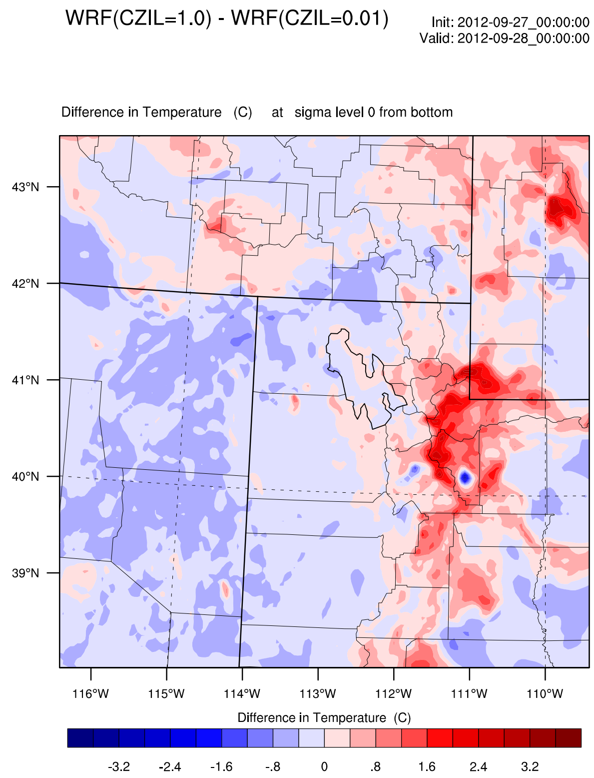

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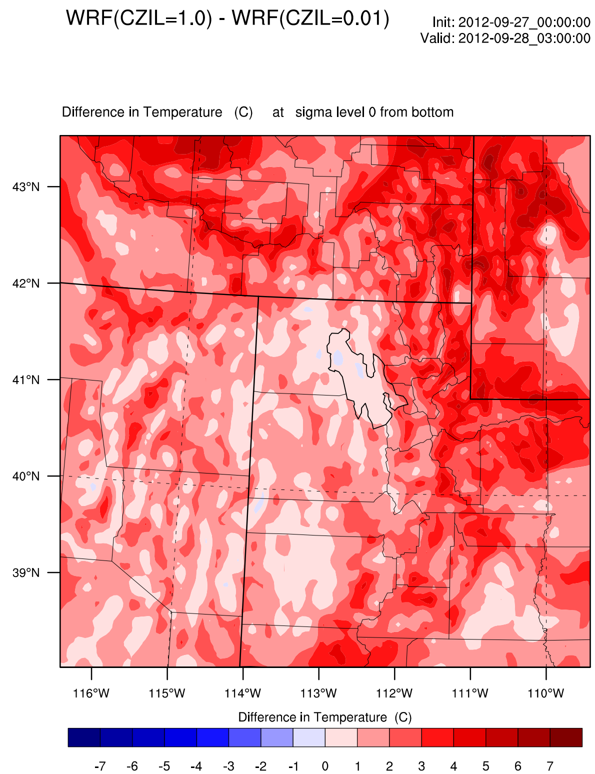
Impact of CZIL on low-level T



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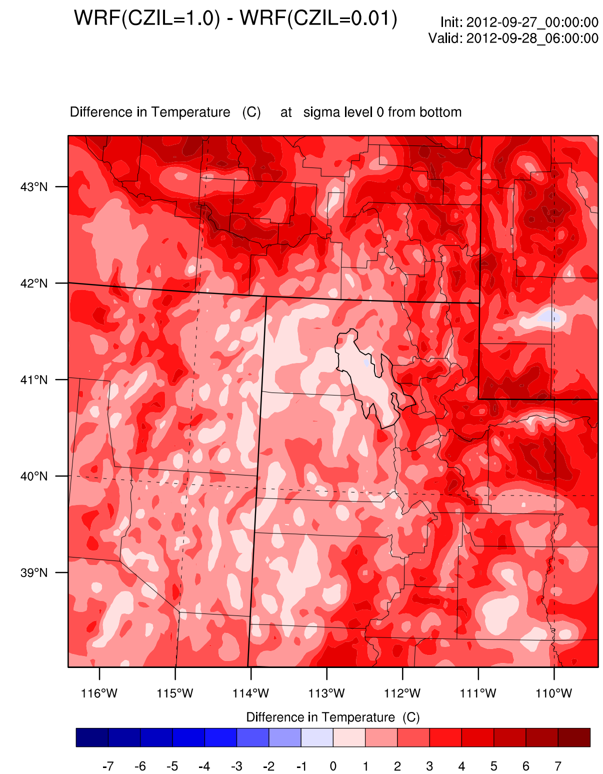
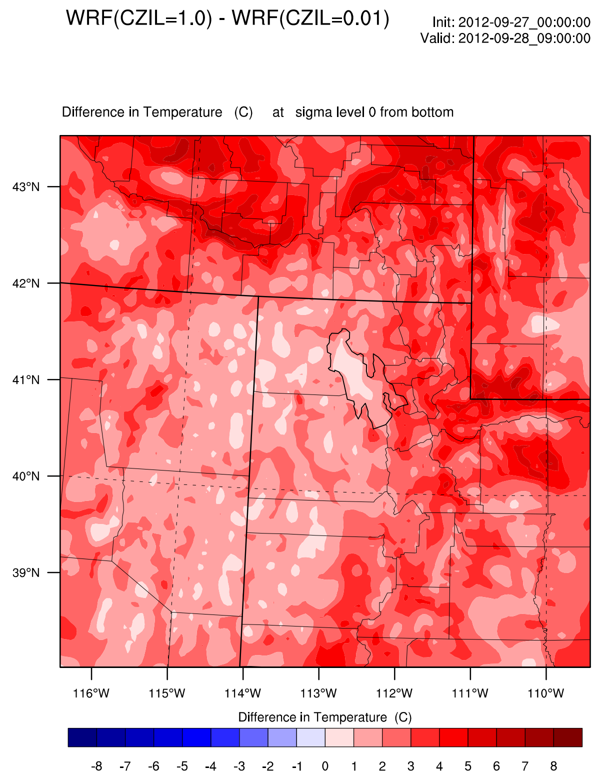


28 Sep 2012, 06 UTC (f+30h)

Impact of CZIL on low-level T



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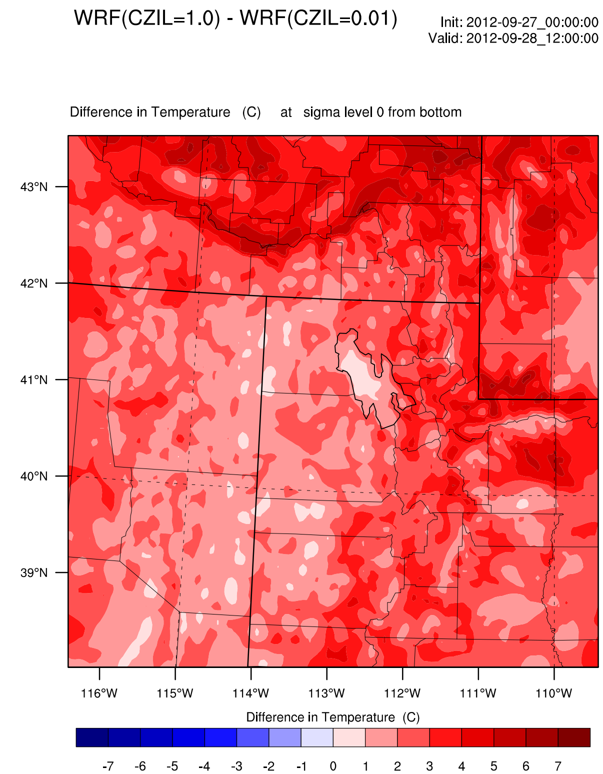

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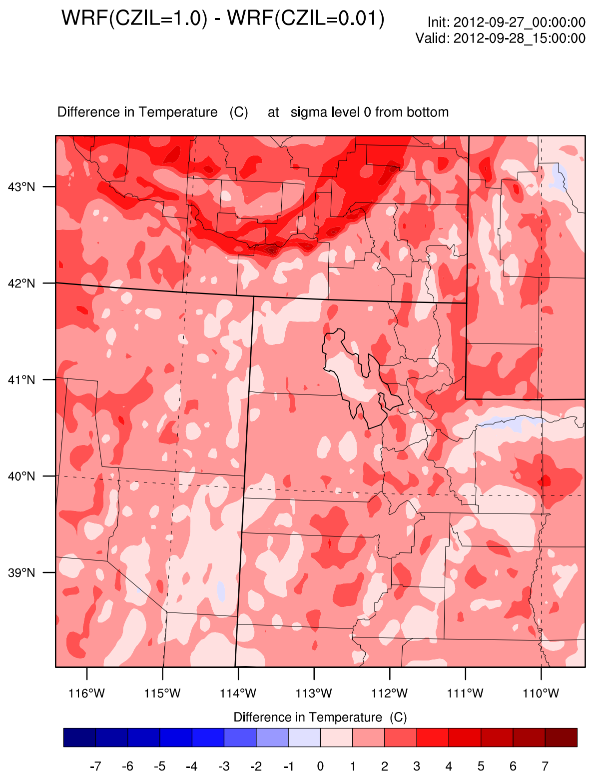
Impact of CZIL on low-level T



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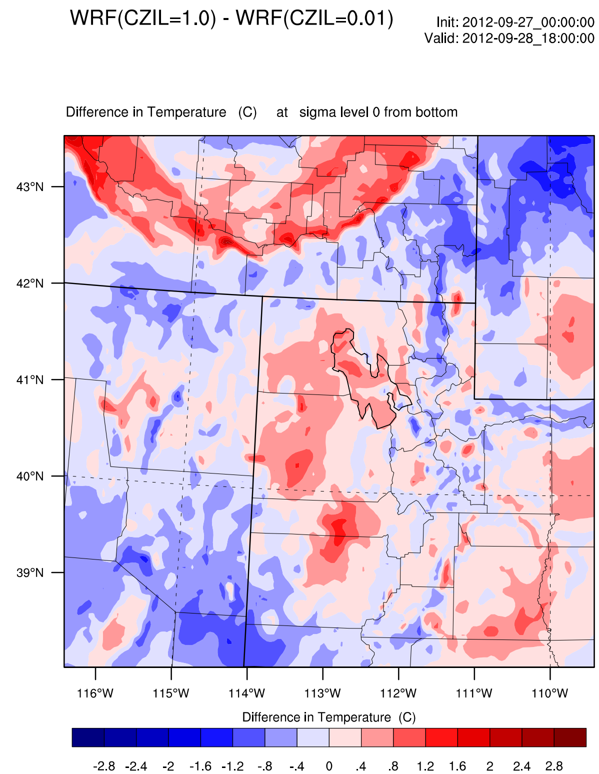

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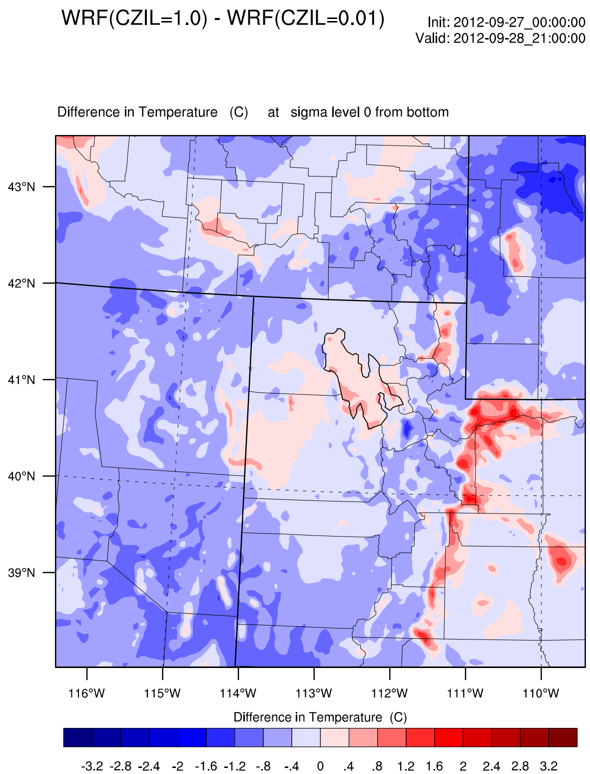
Impact of CZIL on low-level T



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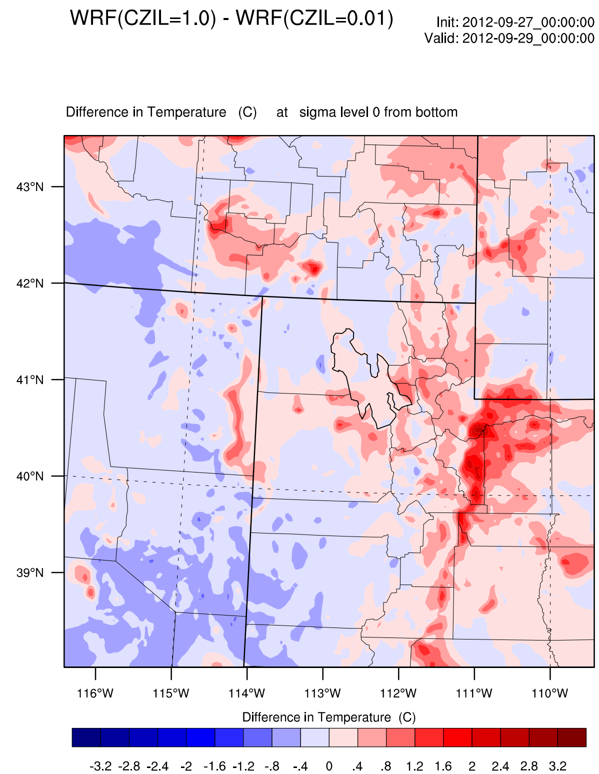


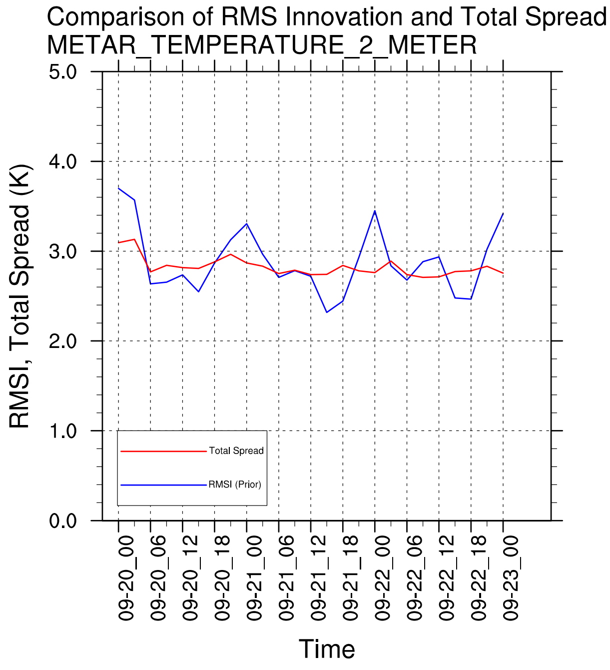
29 Sep 2012, 00 UTC (f+48h)

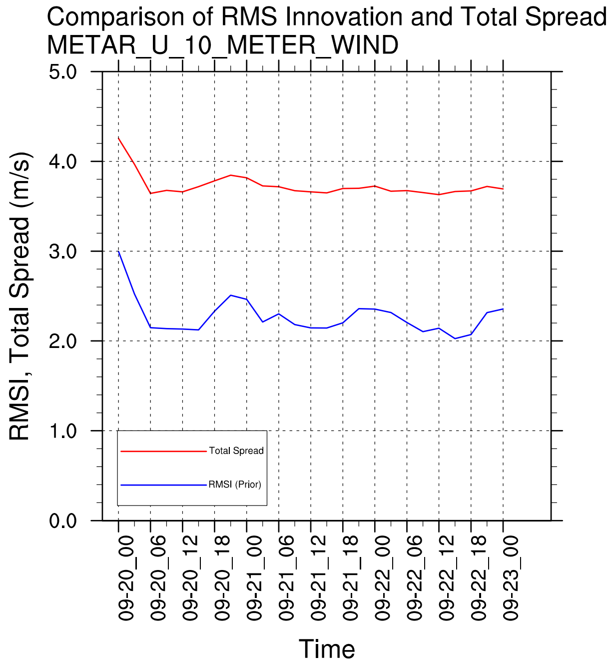
Initial Testing

96-member ensemble, 72 hours, d01 & d02 only

Total Spread and RMS Innovations versus Time

CZIL = 0.1 globally





Current status & Future work

- Ironing out CZIL modifications in WRF & DART
- Two WRF-DART ensembles, 20 Sep-25 Oct 2012
  - 1) Global CZIL=0.1
  - 2) Variable CZIL=[0.01,0.99]
- Currently just d01 & d02 for testing, add d03 & d04
- By how much does DART-estimated CZIL improve statistics for low-level/surface variables, especially in complex terrain?
- Examine prior/posterior correlations between CZIL and atmospheric variables – which have the greatest impact?