Sensitivity of Near-Surface Temperature Forecasts to Soil Properties over Dugway Proving Ground

Jeff Massey

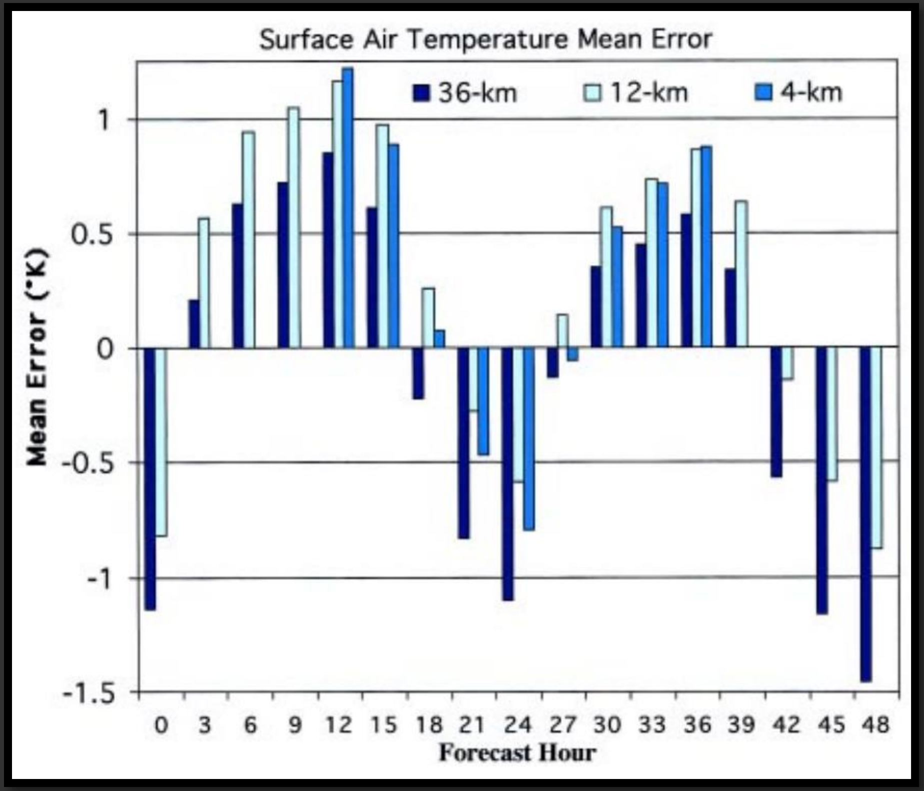
Co-authors: Jim Steenburgh, Sebastian Hoch, and Jason Knievel

Introduction

• Near-surface weather forecasts remain a major challenge for numerical weather prediction and large errors and biases still exist.

• Near-surface weather prediction is a multi-scale problem with many possible error sources.

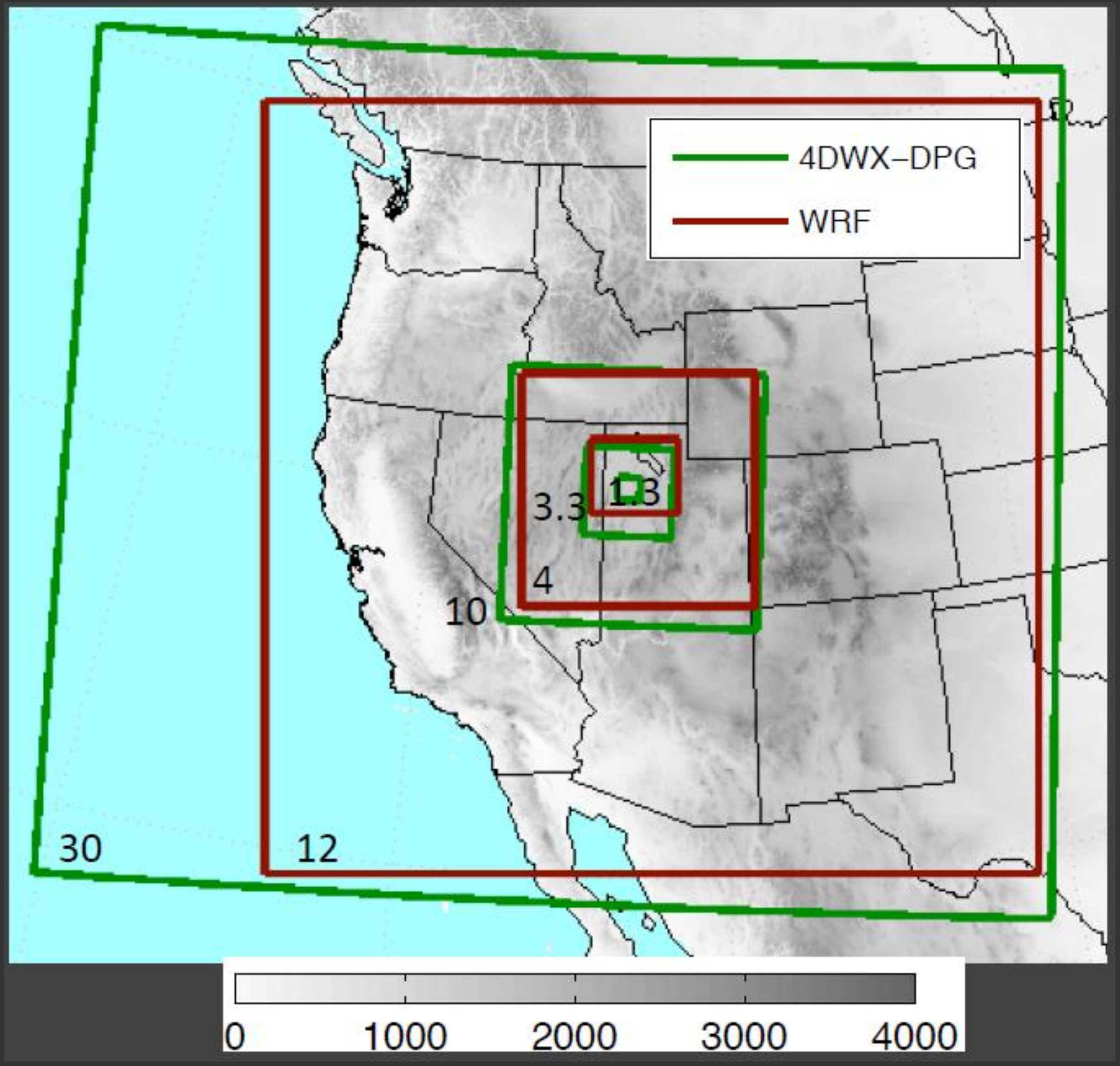
• We focus on error sources relating to the land surface



Mass et al. (2002). Plot starts at 0000 UTC

4DWX-DPG and WRF configuration

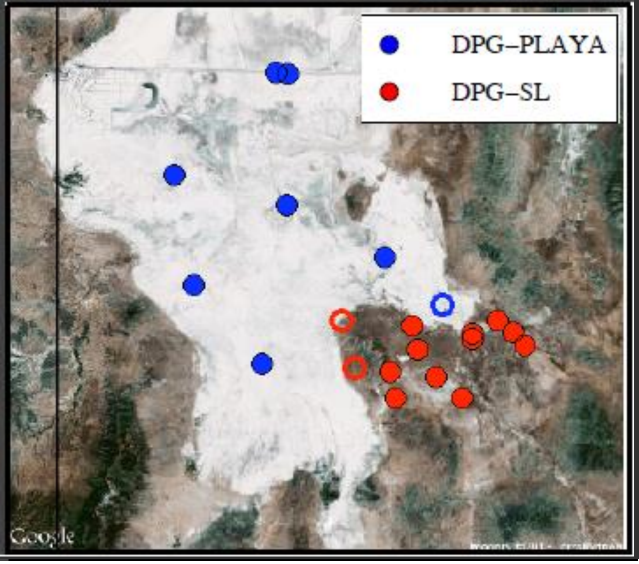
Domains	30, 10, 3.3, 1.1 km	12, 4, 1.3 km
Shortwave radiation	Dudhia	
Longwave radiation	Rapid radiation transfer model	
Boundary Layer	YSU	
Surface Layer	Monin-Obukhov	
Land Surface	Noah Model	
Cumulus convection	Kain-Fritsch on domains 1 & 2	
Microphysics	Lin	
Vertical Levels	37	
Initial Conditions	GFS	

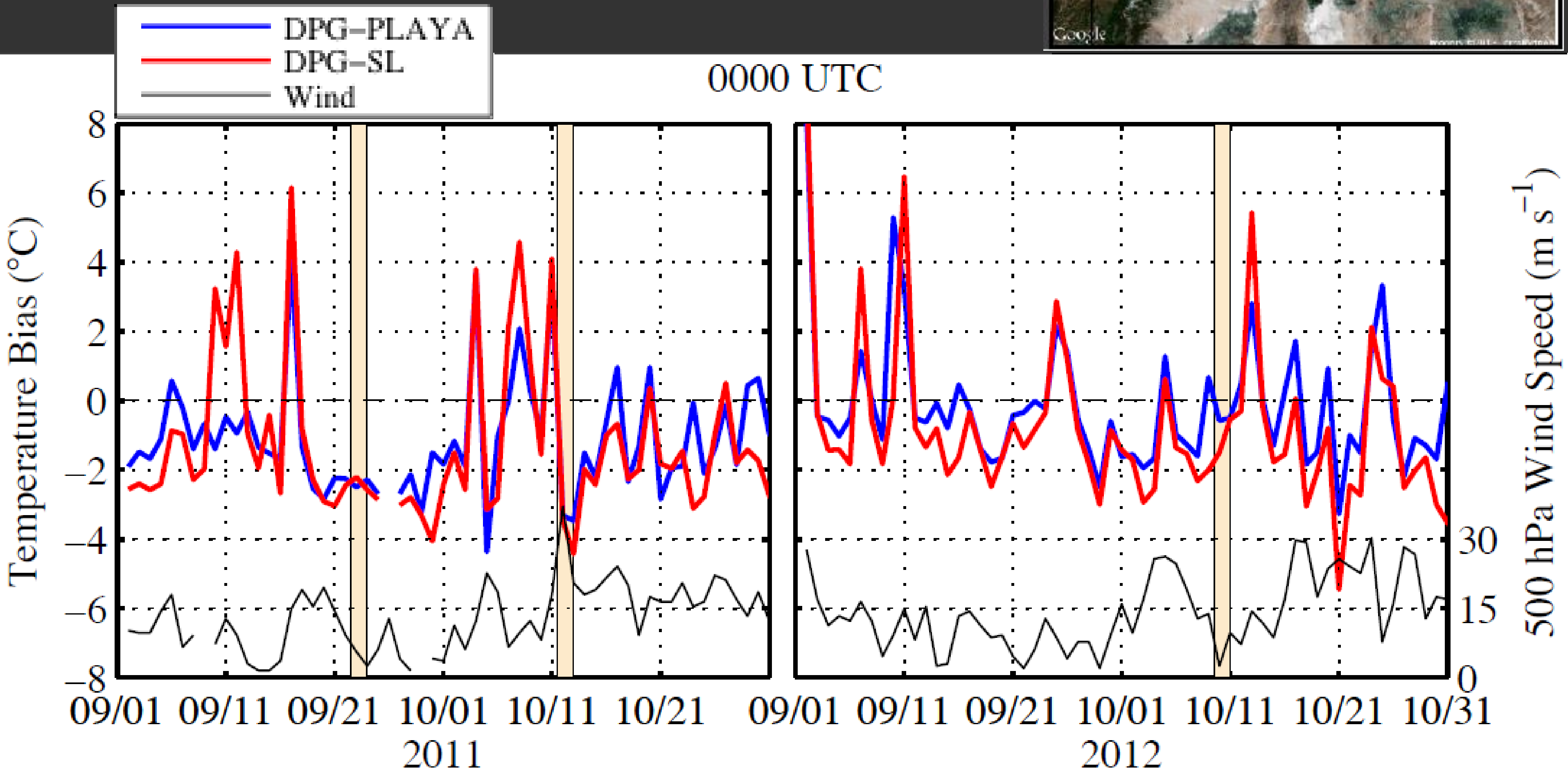


4DWX-DPG mean temperature biases at 00 UTC, or 6 pm local time

Mean over sagebrush: -1.0°C

Mean over playa: -0.6°C

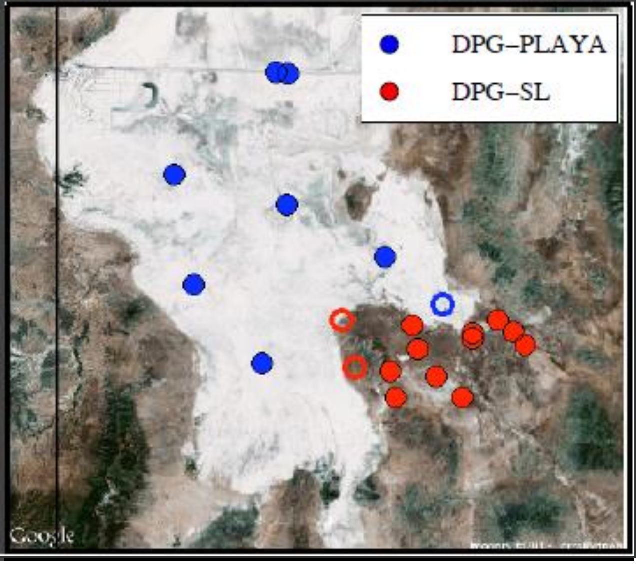


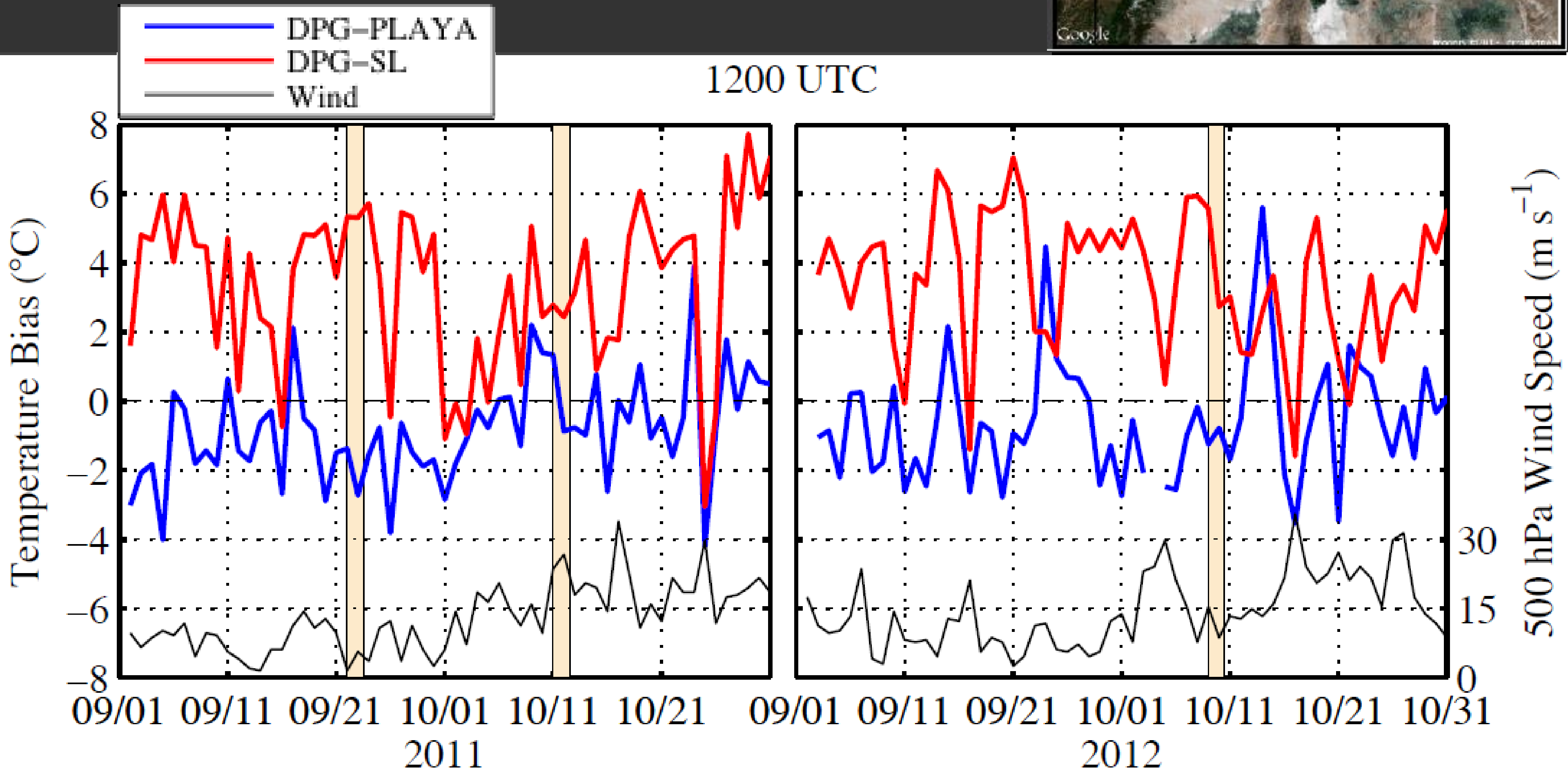


4DWX-DPG mean temperature biases at 00 UTC, or 6 pm local time

Mean over sagebrush: 3.4°C

Mean over playa: -0.7°C

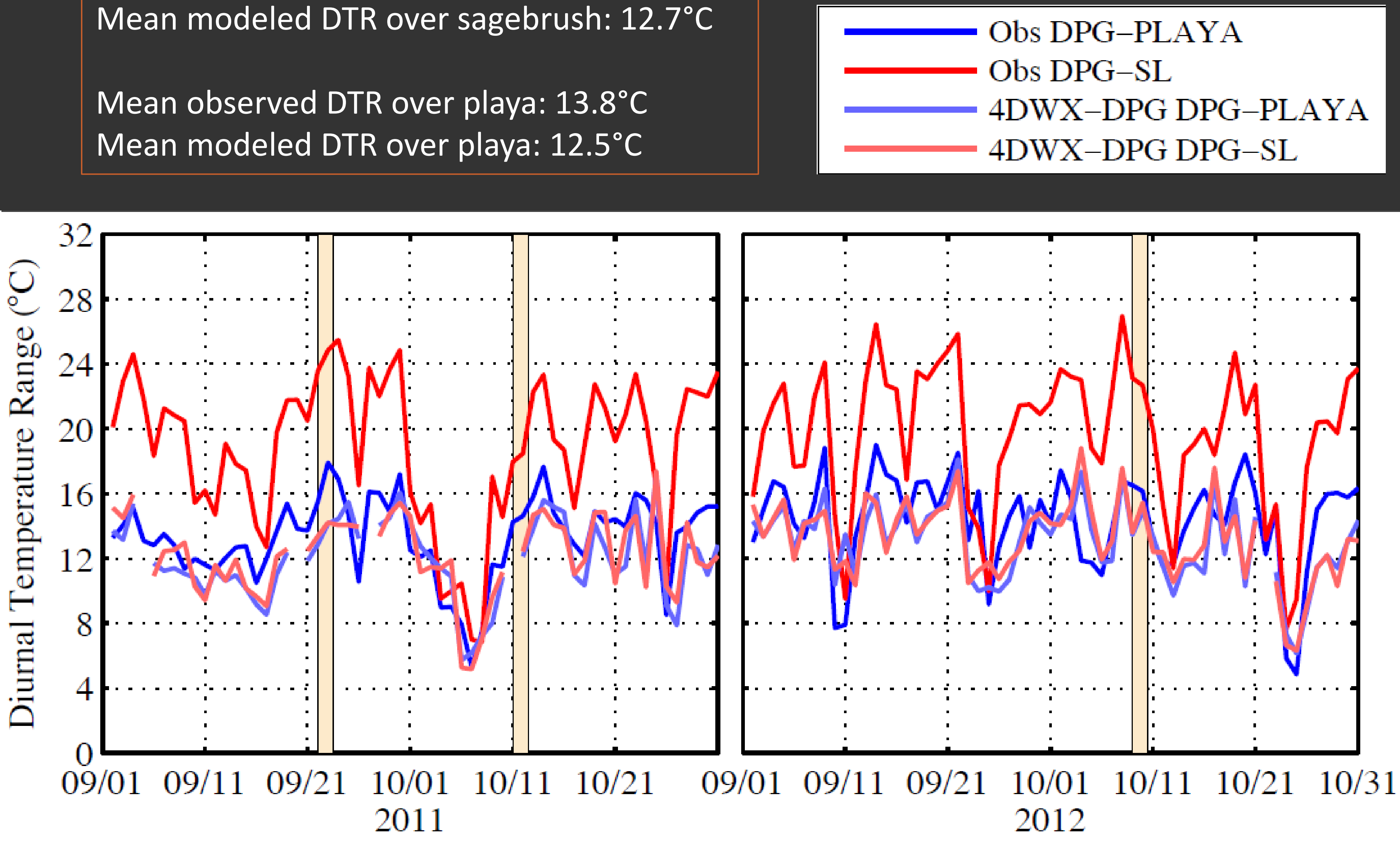




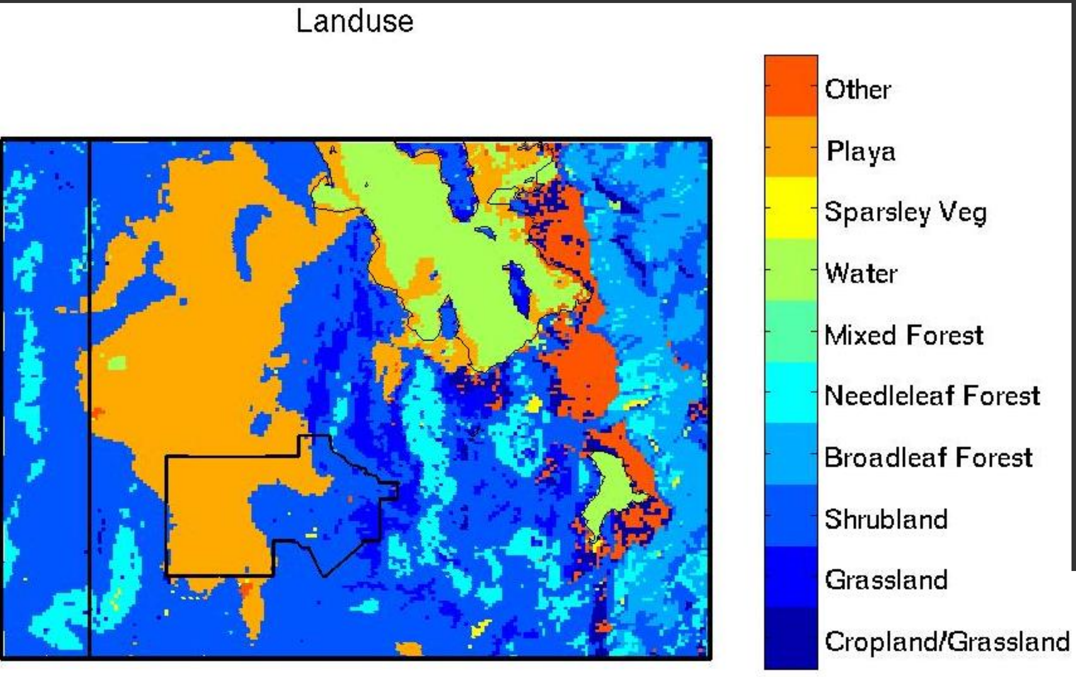
Diurnal Temperature Range

Mean observed DTR over sagebrush: 19.2°C
Mean modeled DTR over sagebrush: 12.7°C

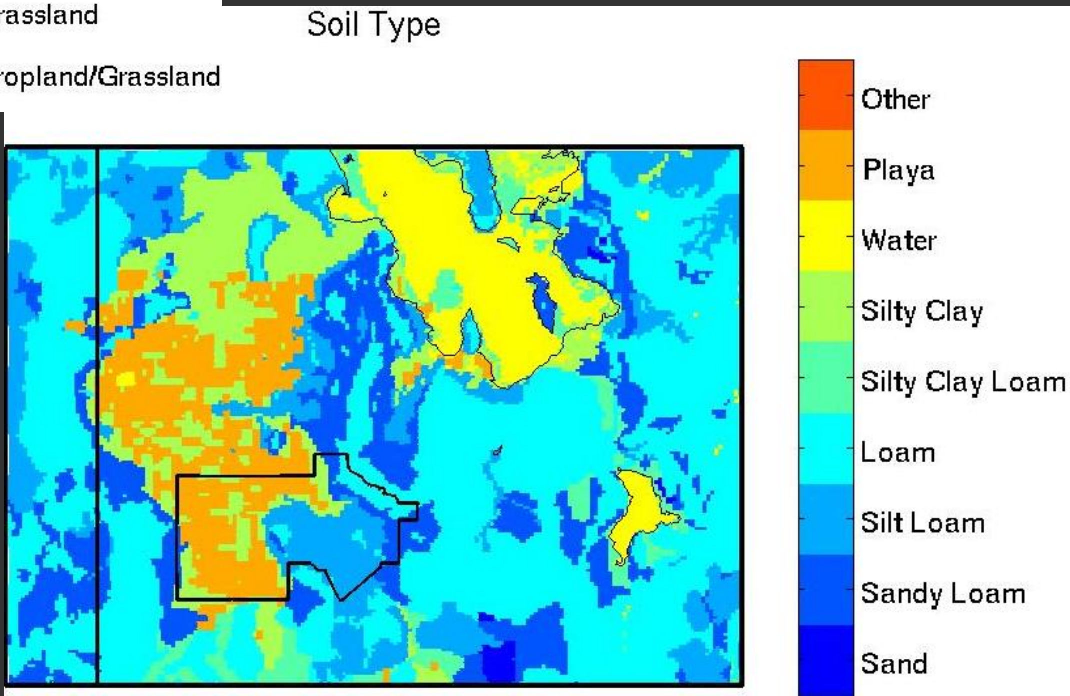
Mean observed DTR over playa: 13.8°C
Mean modeled DTR over playa: 12.5°C



Land and Soil Types



Shrubland surrounds the playa



- Silt loam and playa are dominant soil types at DPG

- Rest of region surrounding playa is characterized by loam, sandy loam, silty clay loam, and silt loam

Playa vs. Surrounding Desert

Differences between the playa and surrounding desert (Rife et al. 2002):

1. **Albedo** – Playa has a higher albedo than the surrounding desert

2. **Vegetation** – Playa has less vegetation than surrounding desert

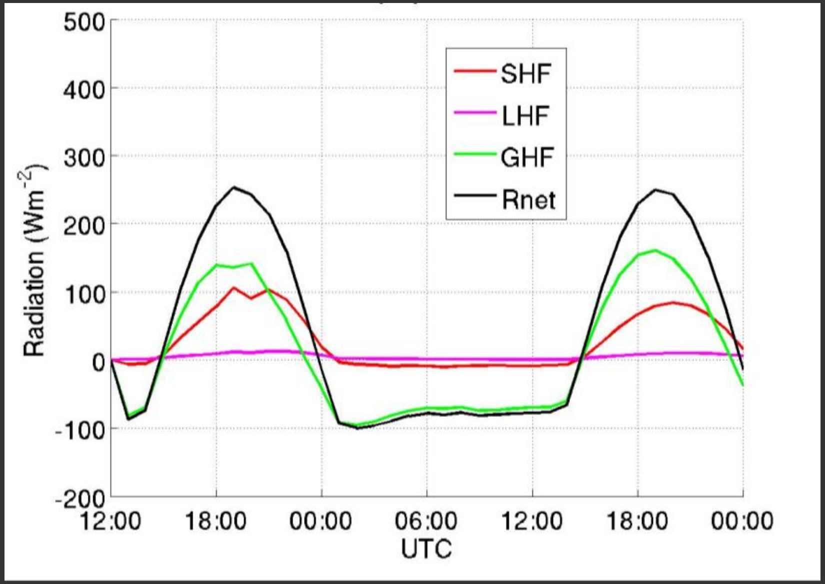
3. **Latent heat flux** – Playa is often moist so it has a higher latent heat flux

4. **Soil thermal conductivity** – Playa has a higher soil thermal conductivity compared to surrounding desert

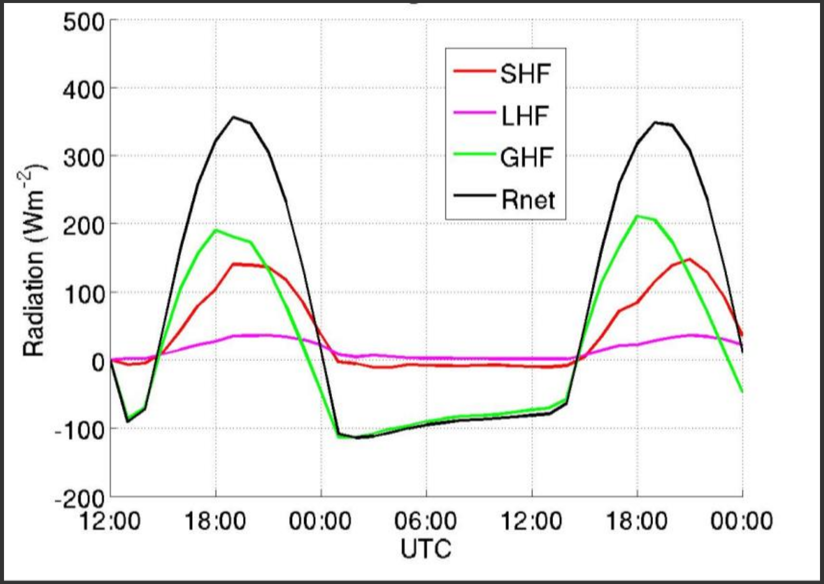
Are these differences properly represented in the Noah LSM?

Playa vs. Silt Loam

Playa 9/22/2011 – 9/24/2011



Silt Loam 9/22/2011 – 9/24/2011



- Net radiation higher over silt loam due to lower albedo.

- Latent heat flux low over both locations.

- Ratio of sensible heat flux to ground heat flux is similar suggesting that the soil thermal conductivity may be too similar between the land surfaces.

Soil Thermal Conductivity

Hypothesis: Errors relating to the soil thermal conductivity parameterization are driving the warm bias and under prediction of the DTR over the silt loam area

Soil thermal conductivity is used in the Noah LSM to calculate the ground heat flux and soil temperature tendency

$$GHF = K\frac{\partial T_s}{\partial z} \text{ at z=0}$$

$$\frac{\partial T_s}{\partial t} = \frac{K\frac{\partial T_s}{\partial z} - GHF}{C\Delta z}$$

K = soil thermal conductivity
T_s = soil temperature
C = soil heat capacity
GHF = ground heat flux

Soil Thermal Conductivity Parameterizations

Soil thermal conductivity parameterizations in the literature:

1. Kersten (1949)
2. De Vries (1963)
3. Johansen (J75; 1975)
4. McCumber and Pielke (MP81; 1981)
5. McInnes (1981)
6. Campbell (1985)
7. Ballard and Arp (2005)
8. Cote and Konrad (2005)
9. Lu et al. (2007)

Added to the Noah LSM in 2001 after verification by Peters-Lidard et al. (1998).

Used in many early land surface models, including the Noah LSM

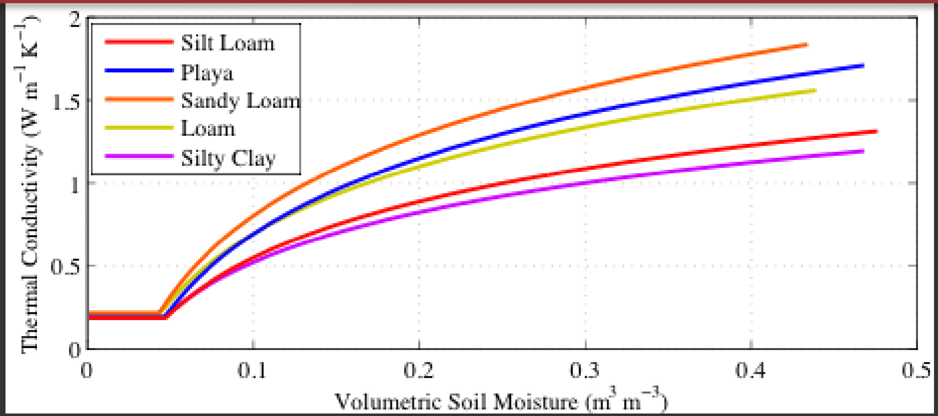
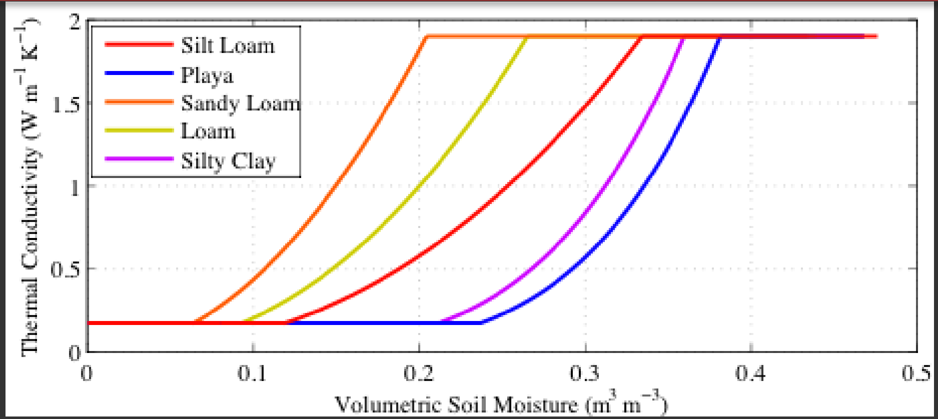
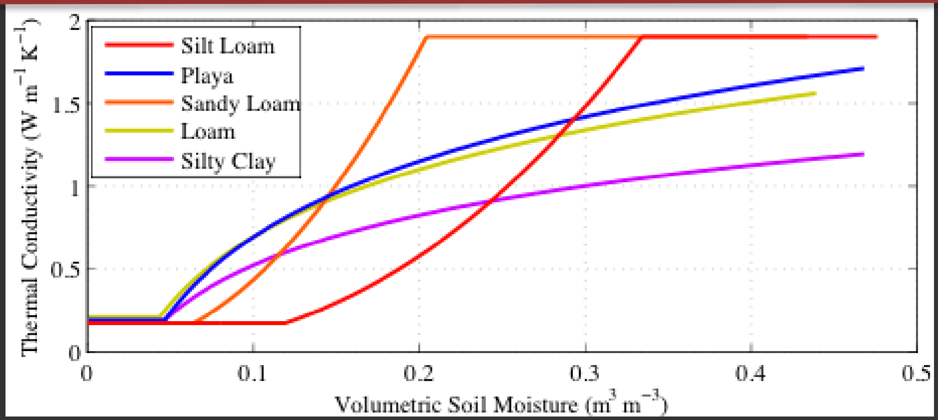
Recent parameterizations that only build off of J75 to incorporate more soil types and materials

All are a function of soil moisture

9-member ensemble setup

J75 GFS soil moisture	J75 NAM soil moisture	J75 SCAN soil moisture
MP81 GFS soil moisture	MP81 NAM soil moisture	MP81 SCAN soil moisture
Hybrid GFS soil moisture	Hybrid NAM soil moisture	Hybrid SCAN soil moisture

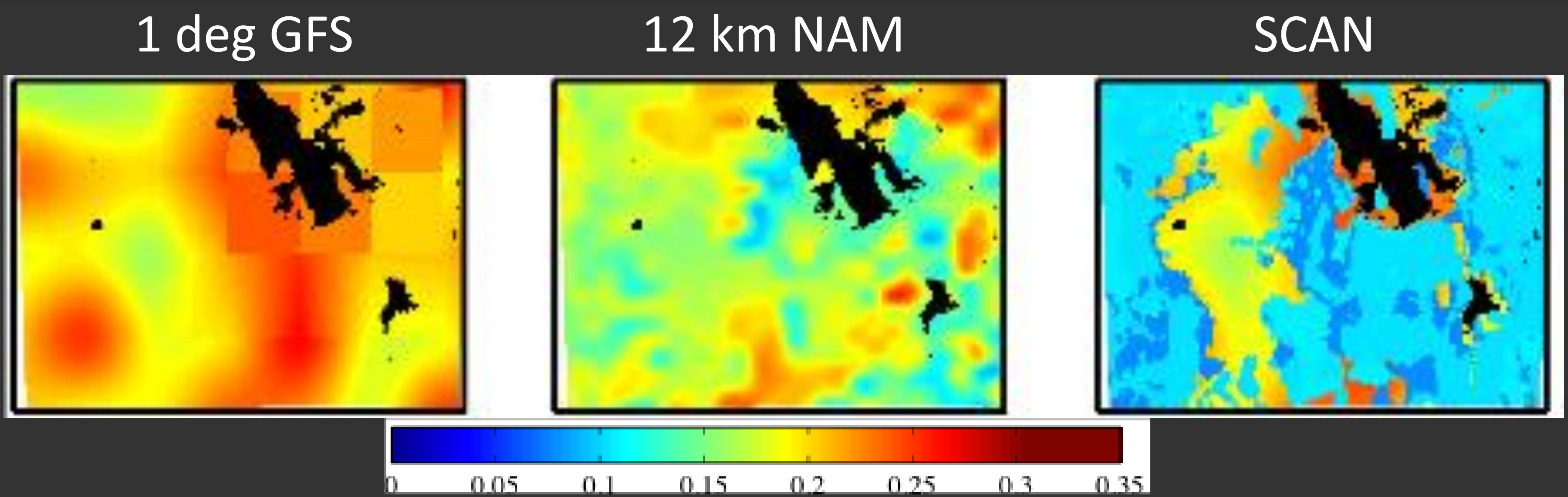
9-member ensemble setup: Thermal Conductivity

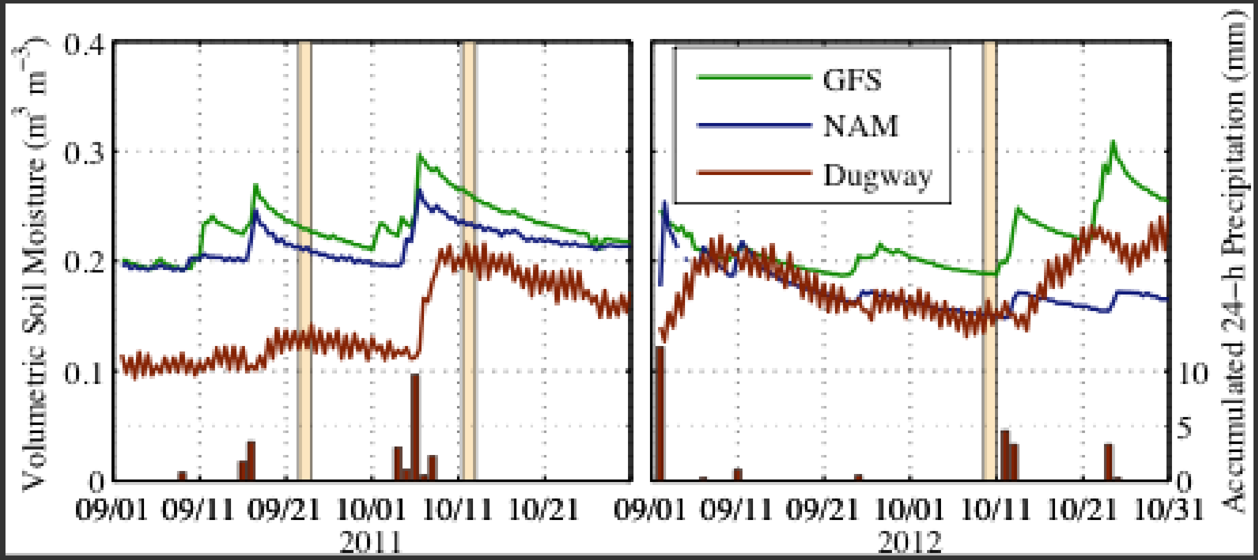
Johansen 1975 (J75) – less spread among soils and less sensitivity to soil moisture.	J75	
McCumber and Pielke 1981 (MP81) – greater spread among soil types and greater sensitivity to soil moisture.	MP81	
Hybrid – Uses MP81 for silt loam and sandy loam, and J75 for all other soil types.	Hybrid	

Soil Climate Analysis Network (SCAN)

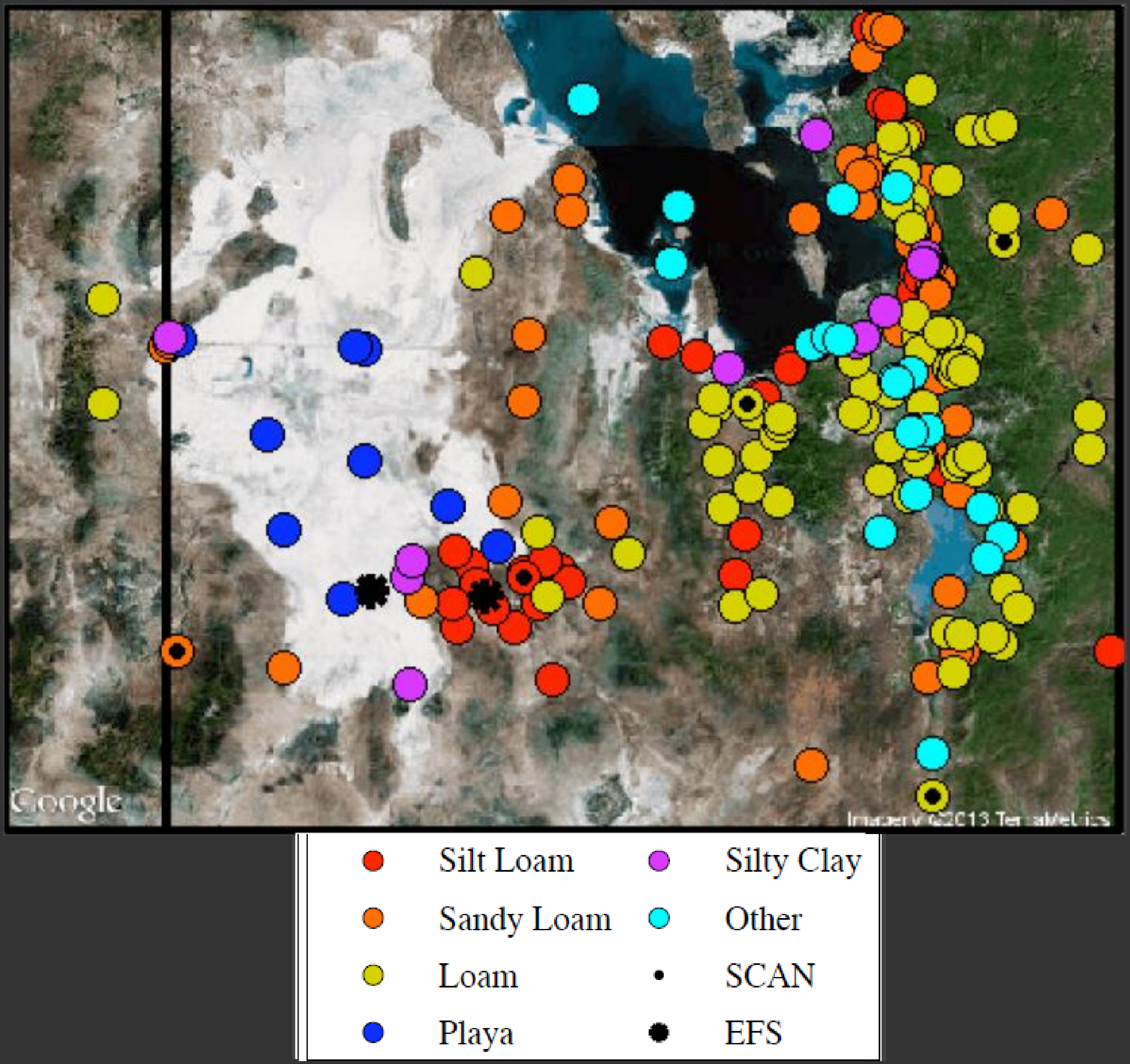
- Station in silt loam area
- Soil temperature and moisture at 2, 4, 8, 20, and 40 inches
- Only 2 inch observations can be used in Noah LSM

9-member ensemble setup: 5-cm soil moisture

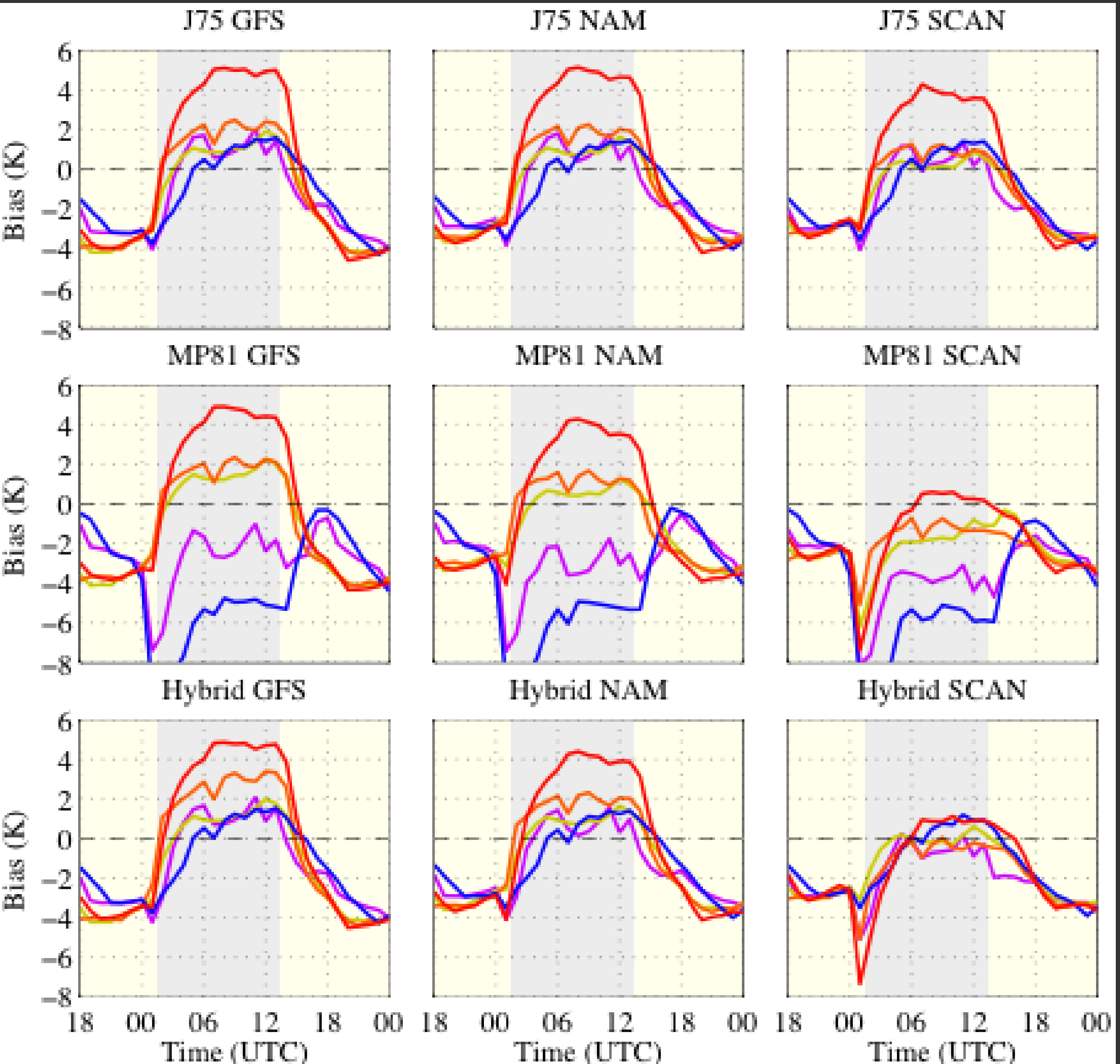




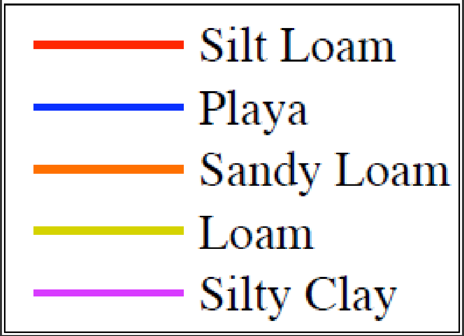
9-member ensemble setup: Verification



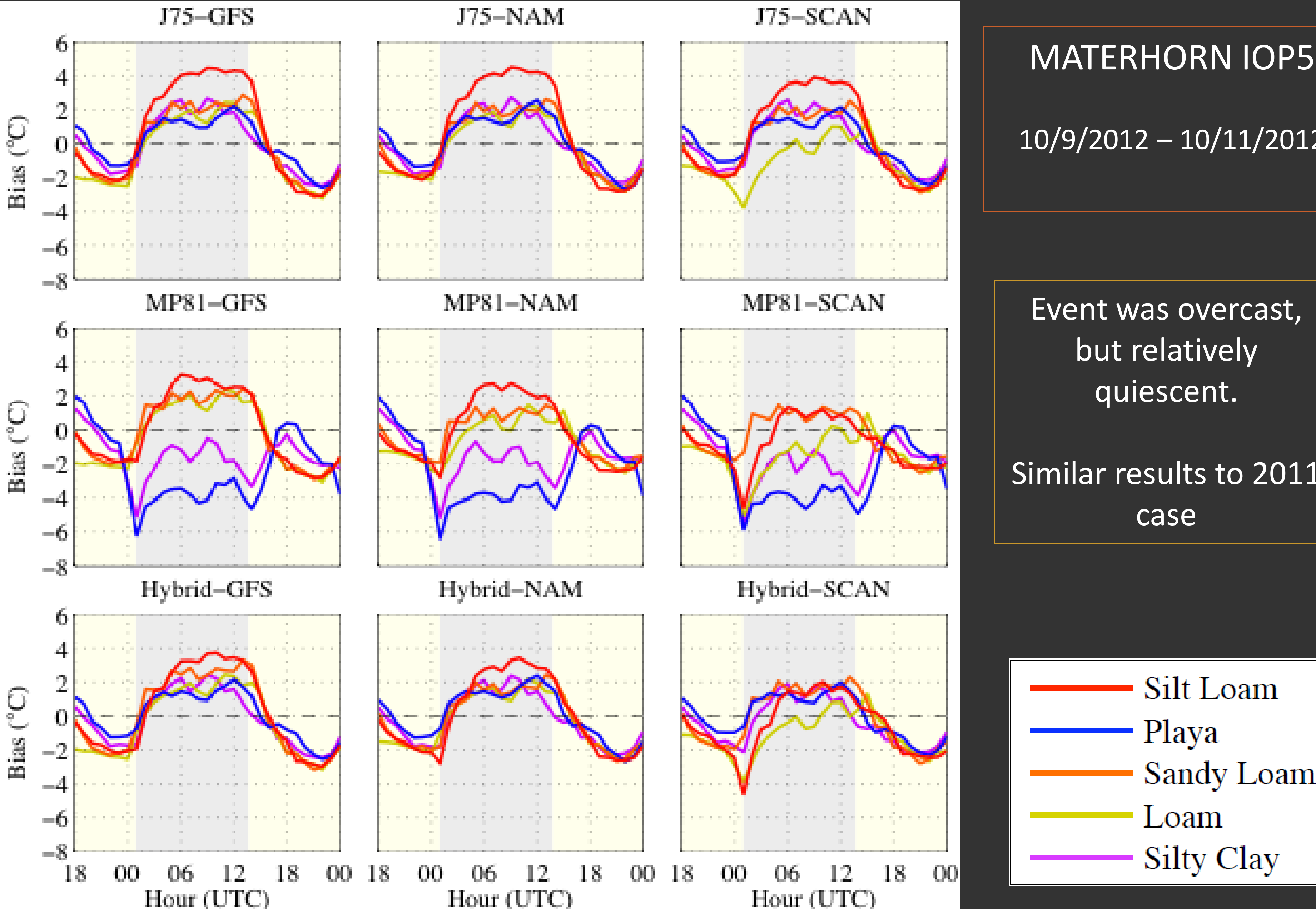
9-Member Ensemble: Results



Improved soil moisture initialization along with the hybrid parameterization reduced nighttime NST biases and reduced the variance over different soil types.



9-Member Ensemble: Results



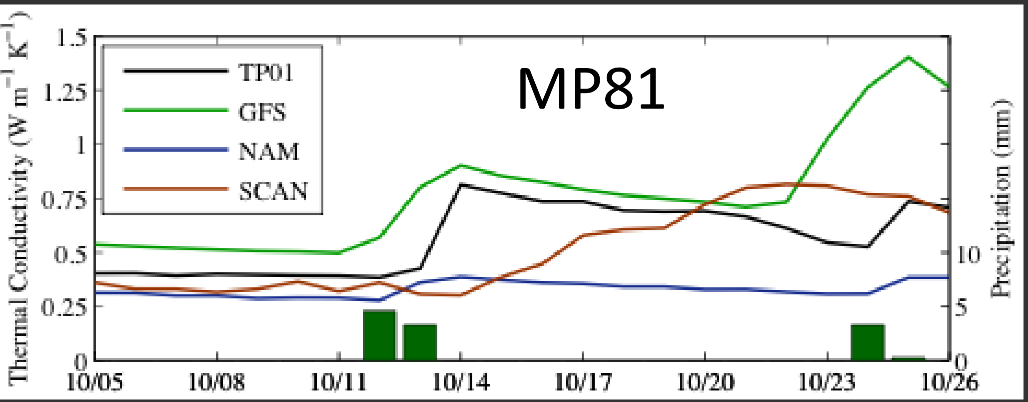
MATERHORN IOP5

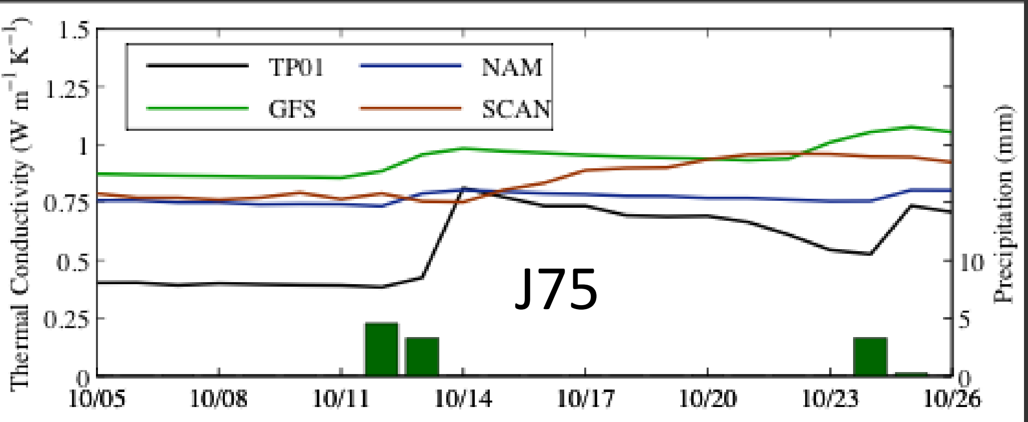
10/9/2012 – 10/11/2012

Event was overcast, but relatively quiescent.

Similar results to 2011 case

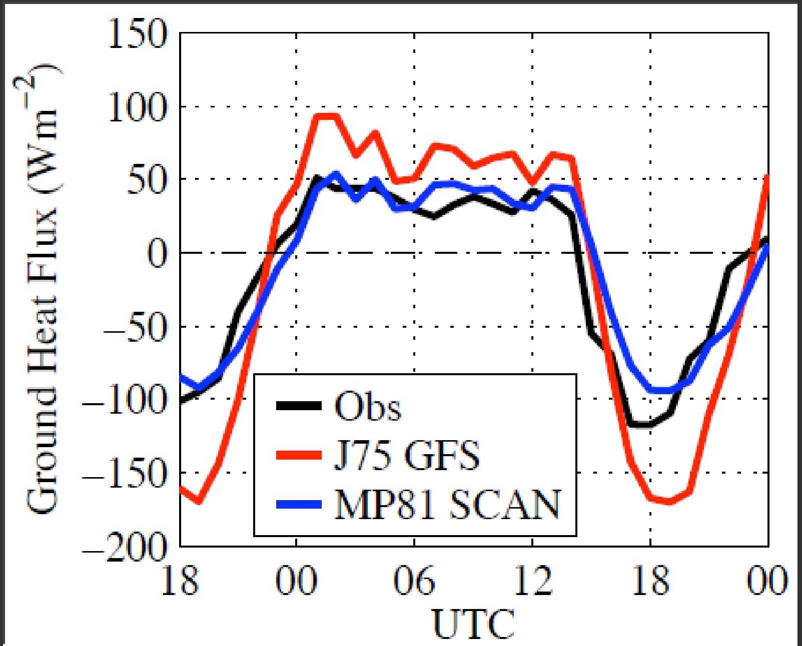
Observed Thermal Conductivity





- MP81 over silt loam more closely matched the observations from EFS-sage, especially during the dry period

Ground Heat Flux

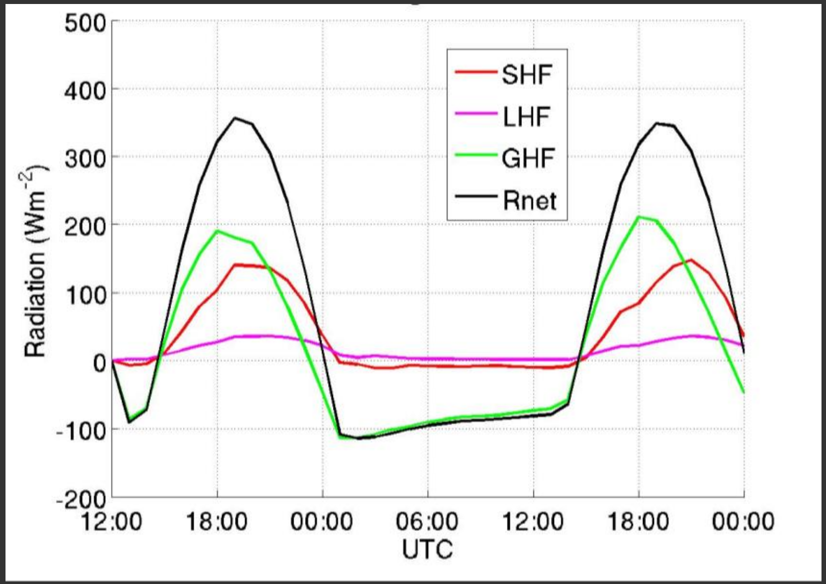


- MP81 SCAN is much closer to observations, especially at night.

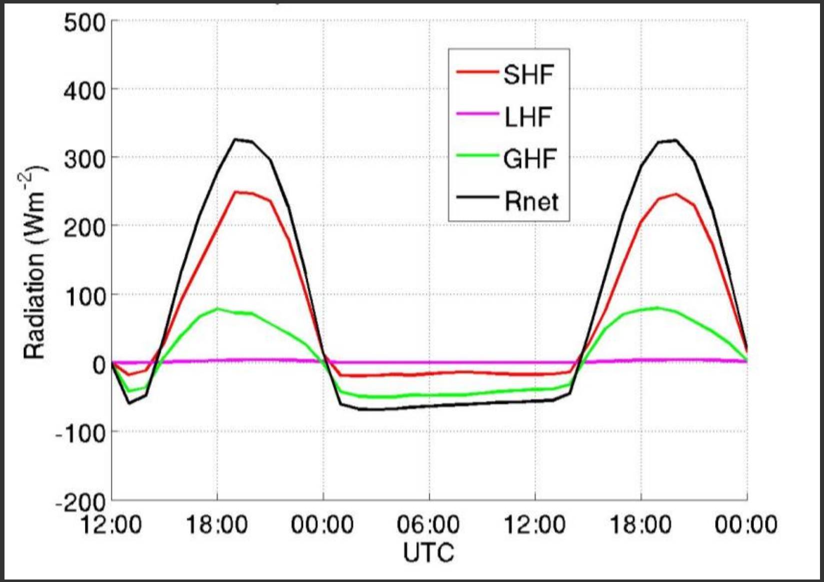
- J75 GFS overpredicts magnitude of GHF suggesting an overprediction of the soil thermal conductivity.

Surface Energy Balance Changes

J75-GFS 9/22/2011 – 9/24/2011



Hybrid-SCAN 9/22/2011 – 9/24/2011



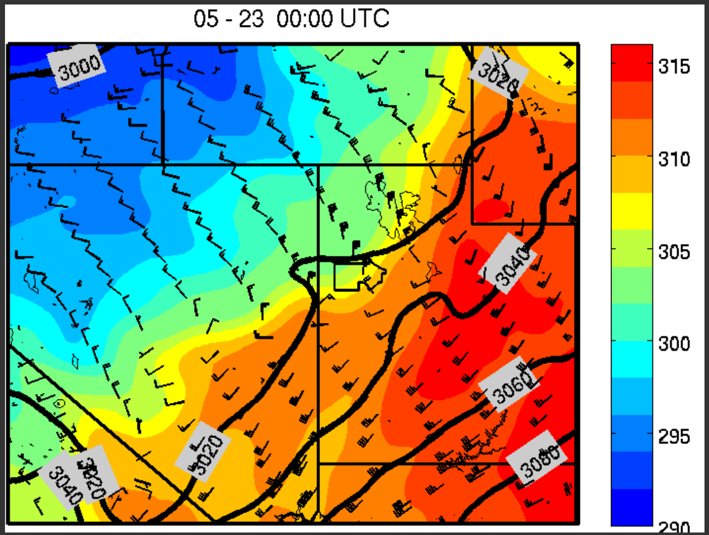
- Magnitude of GHF decreases and magnitude of SHF increases in Hybrid-SCAN.

- Latent heat flux goes to near zero

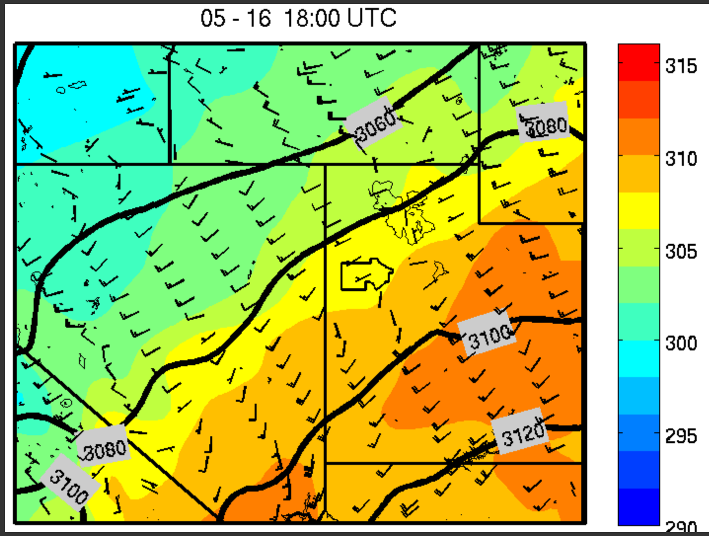
Future Work

- How does land-surface uncertainty affect mesoscale predictability in complex terrain under time-varying synoptic conditions?

- We will concentrate on IOPs with transient airmass boundaries



Cold front during spring IOP8



Baroclinic trough during spring IOP6

Conclusions

- There is a pronounced nighttime warm bias and underprediction of the diurnal temperature range over the silt loam area of Dugway Proving Ground.

- Predicted 2-m temperatures and ground heat flux values more closely matched observations over silt loam soil when observed soil moisture is initialized and the MP81 soil thermal conductivity parameterization is used.

- Future work will examine how land surface uncertainty affects the predictability of transient airmass boundaries, which will hopefully lead to more model improvements.