An Indirect Data Assimilation Scheme for Deep Soil Temperature in the Pleim-Xiu Land Surface Model

Jonathan E. Pleim and Robert Gilliam
National Exposure Research Laboratory
U.S. Environmental Protection Agency

Problem

- We noticed large cold biases in January 2006 that seem to be related to soil temperature.
- The PX LSM uses Force-Restore for soil temperature
  - Questions:
    1. Is the Force-Restore soil model good enough for all seasons and conditions?
    2. Can results be improved by better deep soil temperature initialization?
    3. How to do that?

Force-Restore soil model

- FR scheme is derived by analytical integration of the soil thermal diffusion equations with sinusoidal forcing
  - Very accurate for idealized (sinusoidal) forcing
  - Many questions for practical application:
    1. Realistic surface forcing?
    2. How to incorporate Vegetation coverage?
    3. How to incorporate the effects of snow coverage?
    4. Should deep soil temperature be close to equilibrium value (zero net energy exchange)?
    5. On what time scale should deep soil temperature vary?

- Force-Restore:

$$\frac{\partial T_g}{\partial t} = C_1 G(t) - C_2 (T_g - T_2)$$

$$\frac{\partial T_2}{\partial t} = \frac{1}{\tau_2}\left(T_g - T_2\right)$$

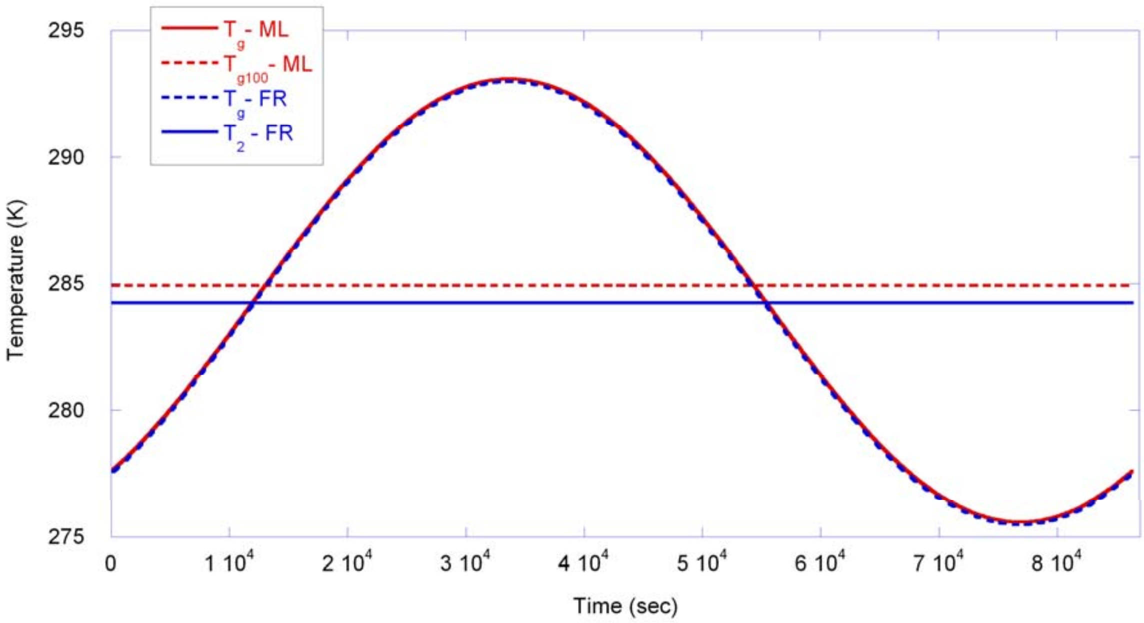
$$C_1 = \frac{2}{cd\alpha}, \quad \alpha = 1 + \frac{\delta}{d}$$

$$C_2 = \frac{\omega}{\alpha} \qquad d = \left(\frac{2\lambda}{c\omega}\right)^{1/2}$$

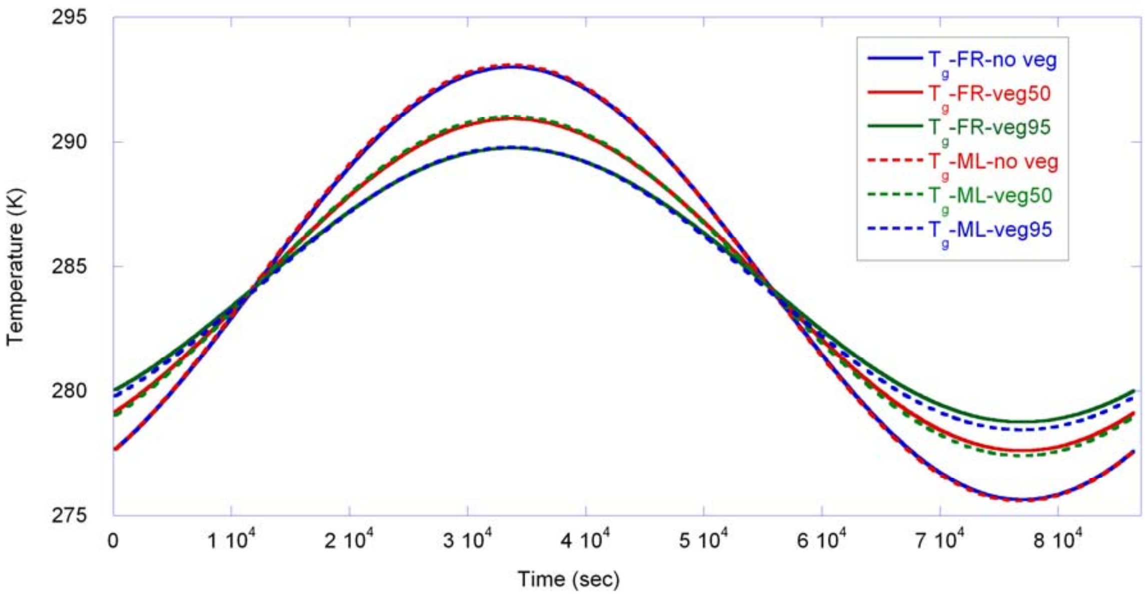
Noilhan and Planton (1989) set τ_2 = 1 day

- Multi-layer thermal diffusion

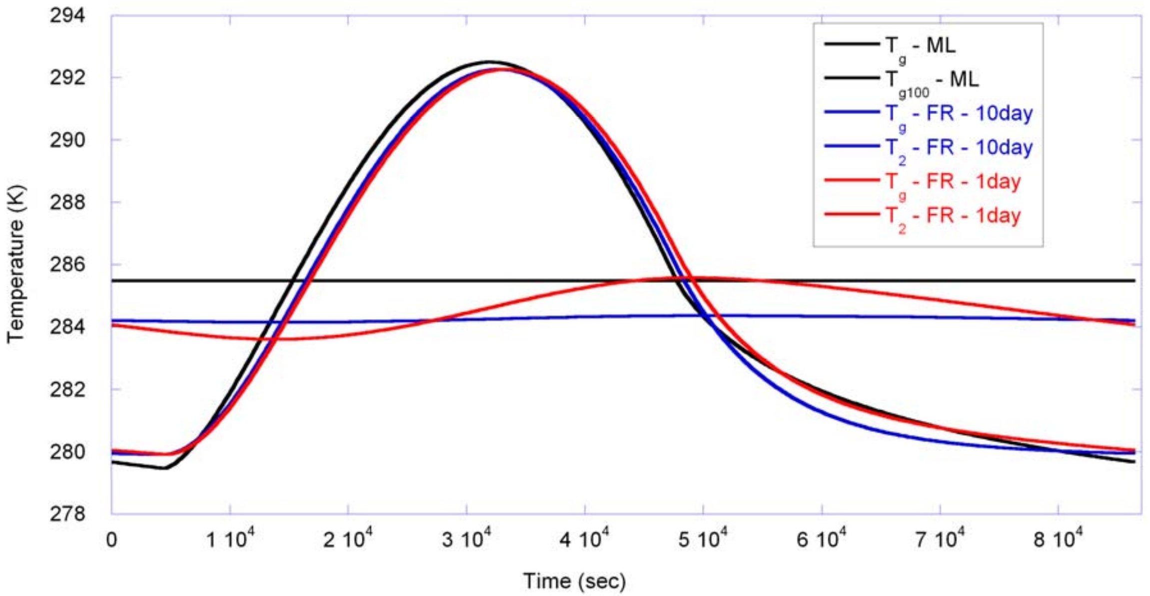
$$\frac{\partial T}{\partial z} = \left(\frac{\lambda}{c}\right)\frac{\partial^2 T}{\partial z^2} \qquad \left[-\frac{\lambda}{c}\frac{\partial T}{\partial z}\right]_{z=0} = \frac{G(t)}{c}$$



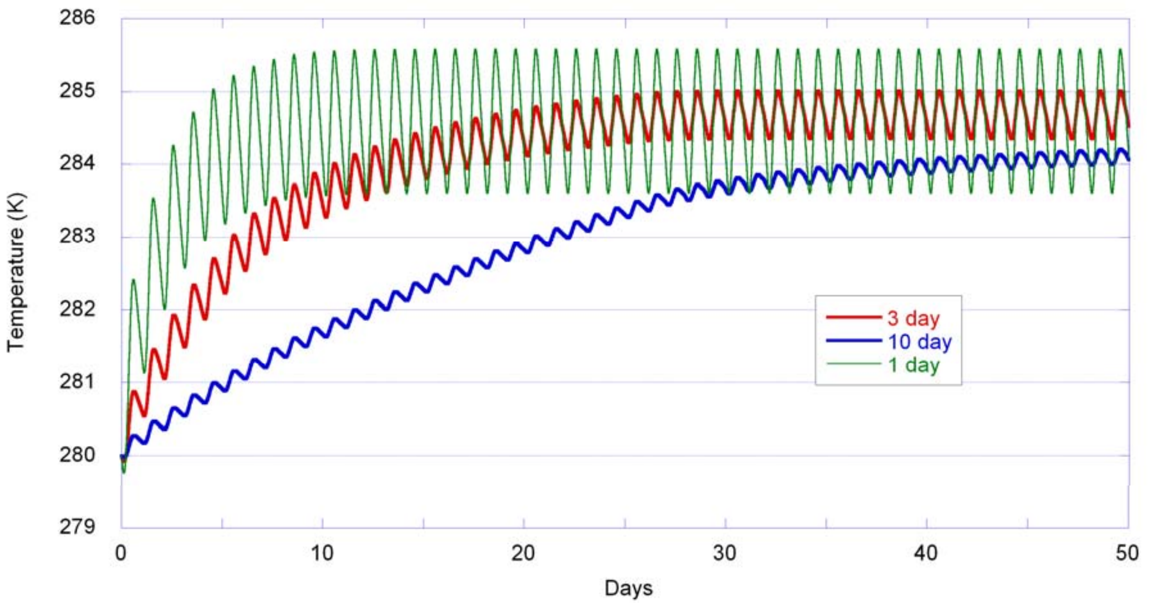
Force-Restore vs 100-layer model for sinusoidal surface forcing



For various fractions of vegetation coverages



Force-Restore vs 100-layer model for realistic surface forcing



Deep soil temperature response to different deep soil timescales

Deep Soil Temperature initialization

- The original authors of the FR technique (Bhumralkar 1975 and Blackadar 1976) suggested setting T2 to the diurnal average of the previous day's air temperature
- In MM5: T2 is set to next day diurnal average of T-2m (from analysis)
- This assumes T2 should be close to equilibrium temperature (net energy soil exchange ~ 0)
- However there could be net source/sink to/from deep soil layers (e.g. Jan 2006)
- Longer deep soil temperature timescales (e.g. τ_2 ~ 10 days) allow seasonal adjustment without requiring equilibrium

Deep soil temperature nudging

- Nudge during nighttime at constant strength : *G* = 1.0x10^{-5} s^{-1}

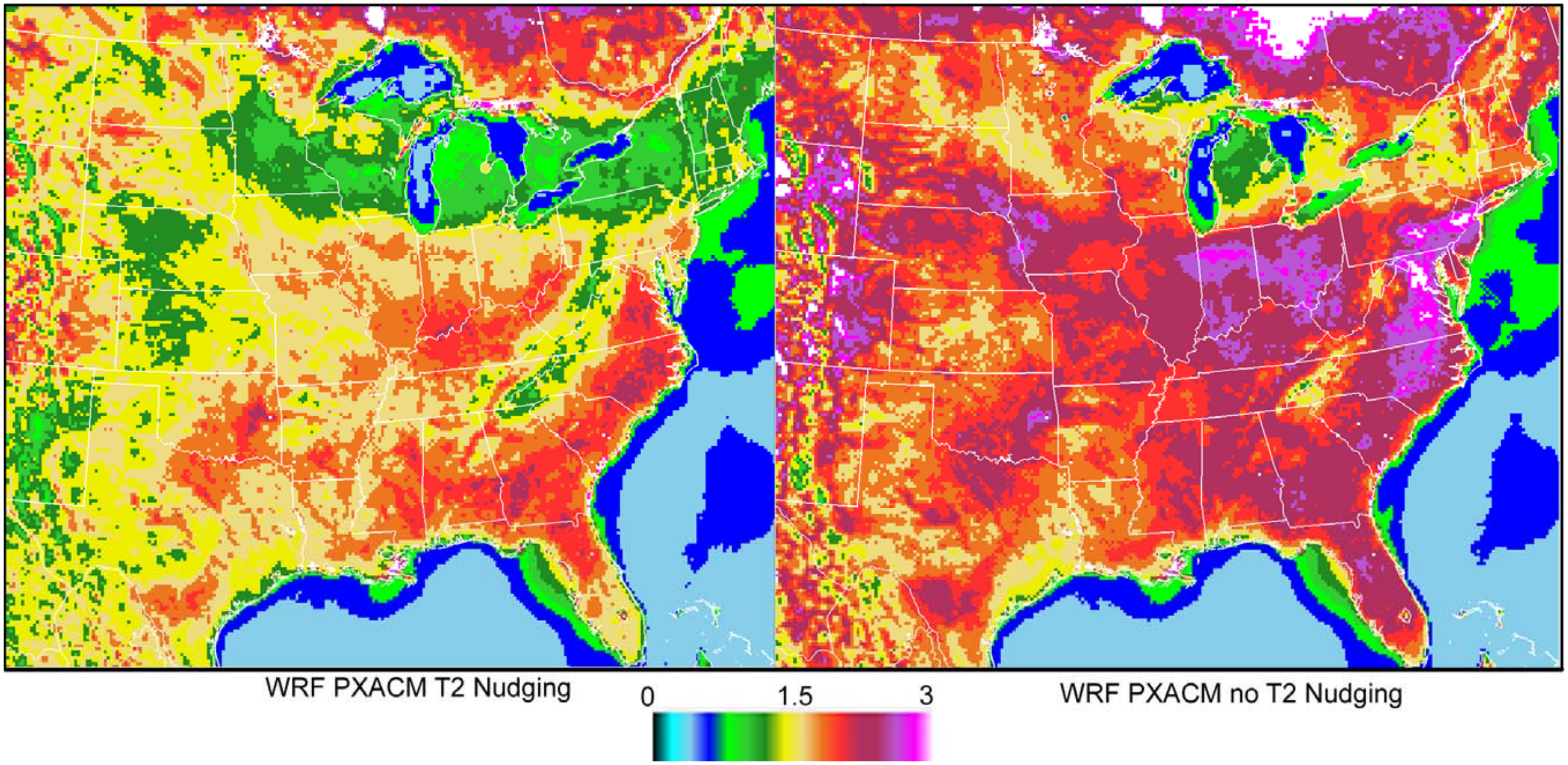
$$N_{T2} = G\left(1 - 5\frac{R_g}{1370}\right) \qquad \textit{where } N_{T2} > 0$$

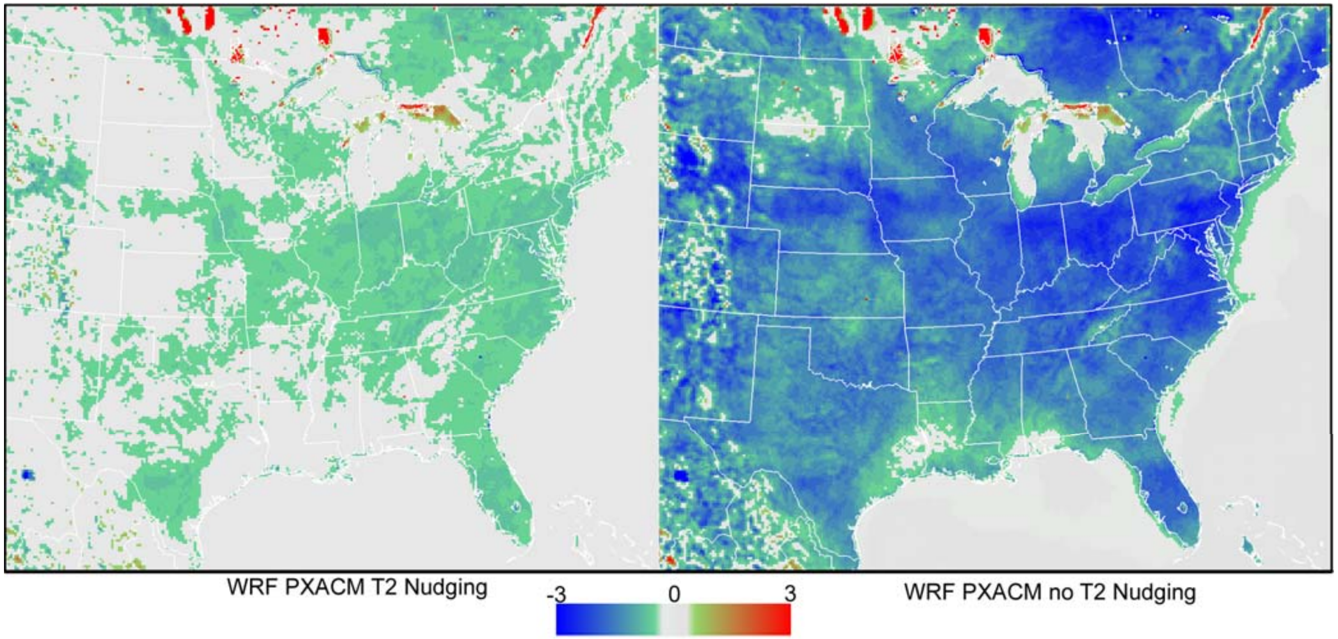
Nudging ramps linearly to zero at R_g=274 W/m^2

$$\frac{\partial T_2}{dt} = N_{T2}\left(T_{2m} - T_{obs}\right)$$

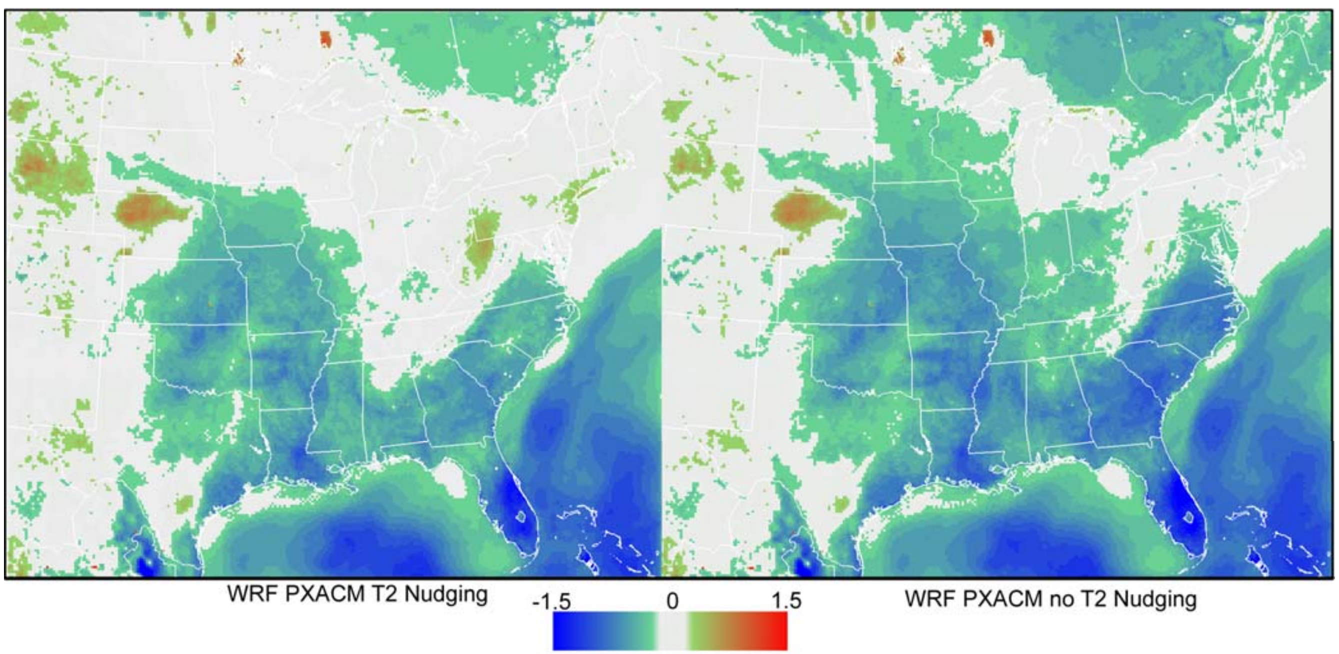
Deep soil temperature time scale is set to 10 days so the nudging can have some lasting effect

T-2m mean absolute error relative to analysis for January 2006



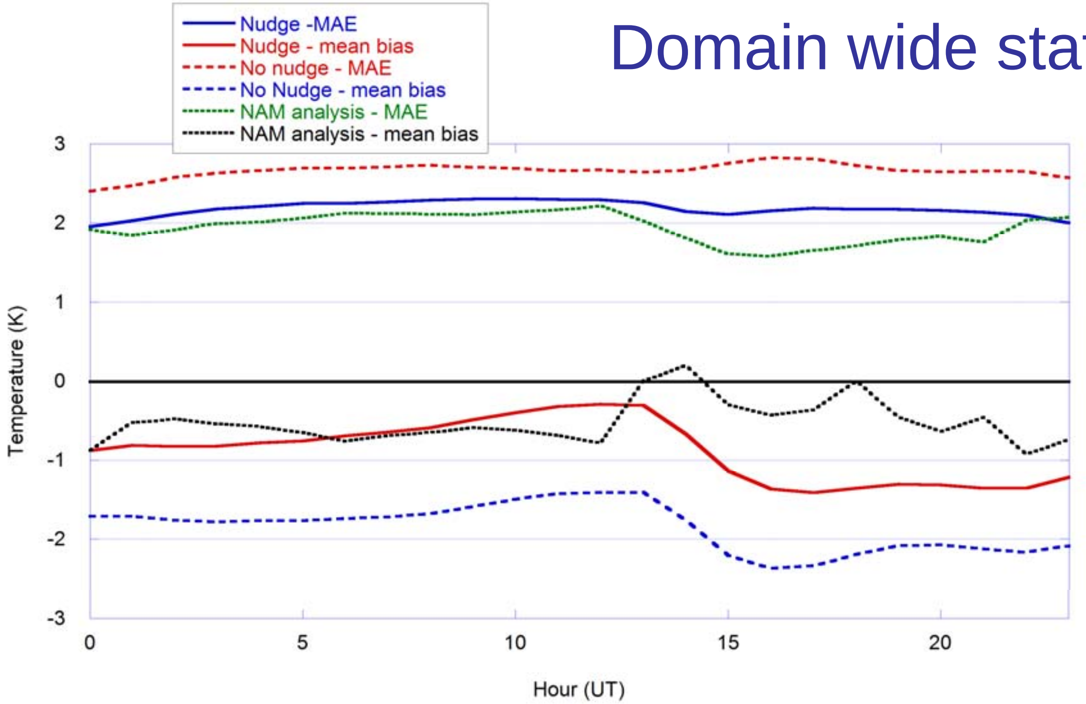


T-2m bias relative to analysis for January 2006

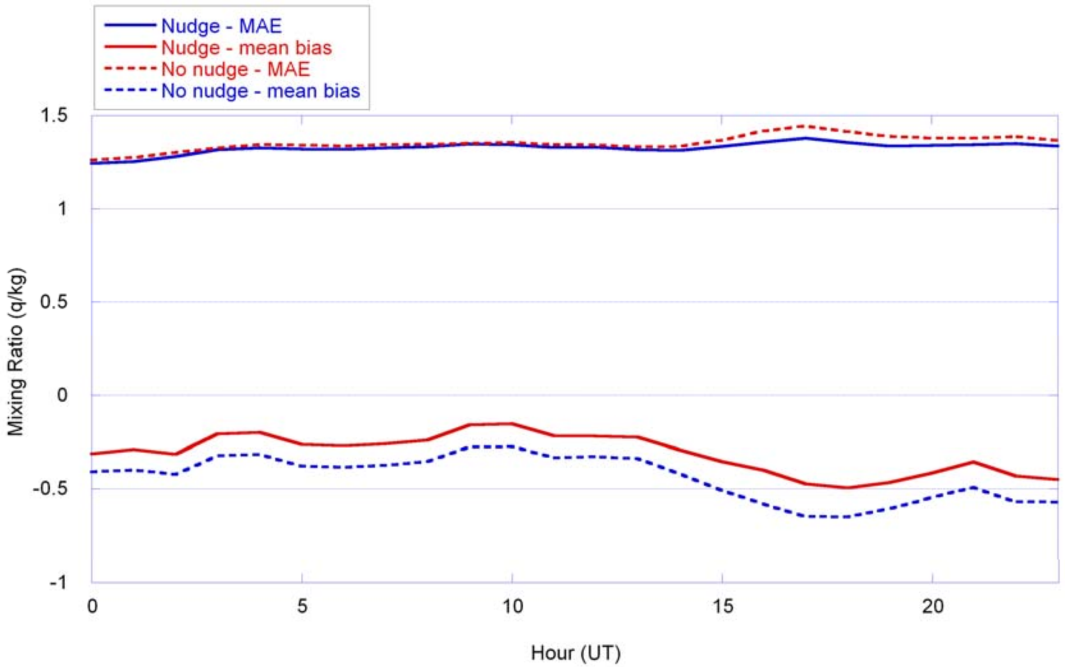


Q_v-2m bias relative to analysis for January 2006

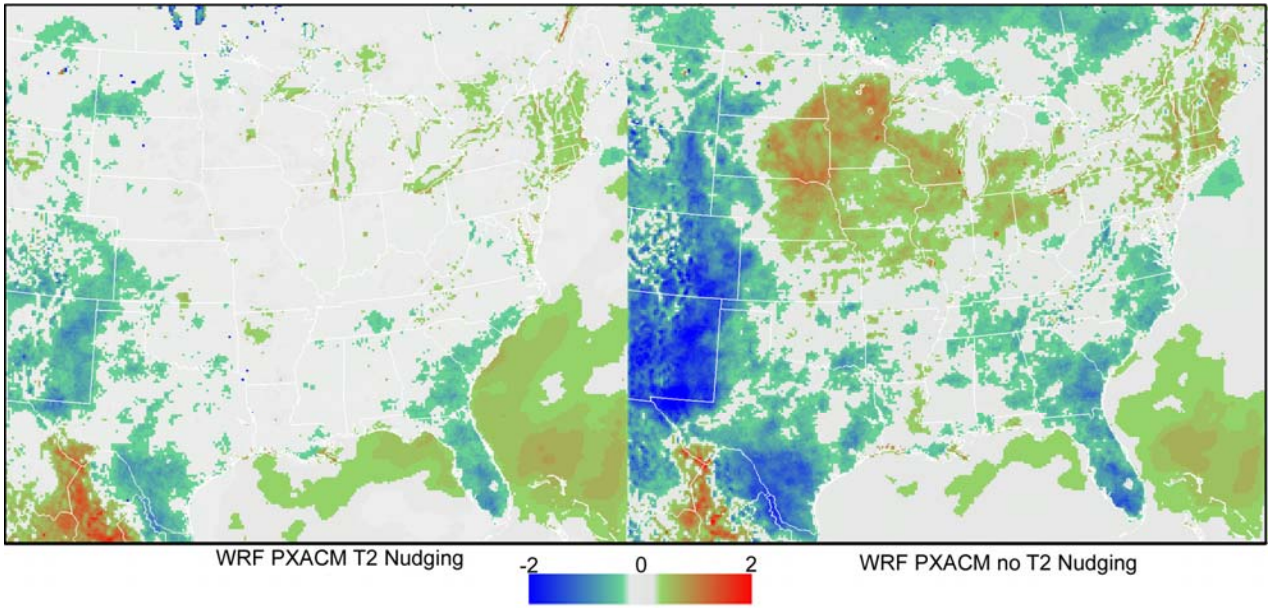
Domain wide statistics compared to NWS/FAA observations for January 2006



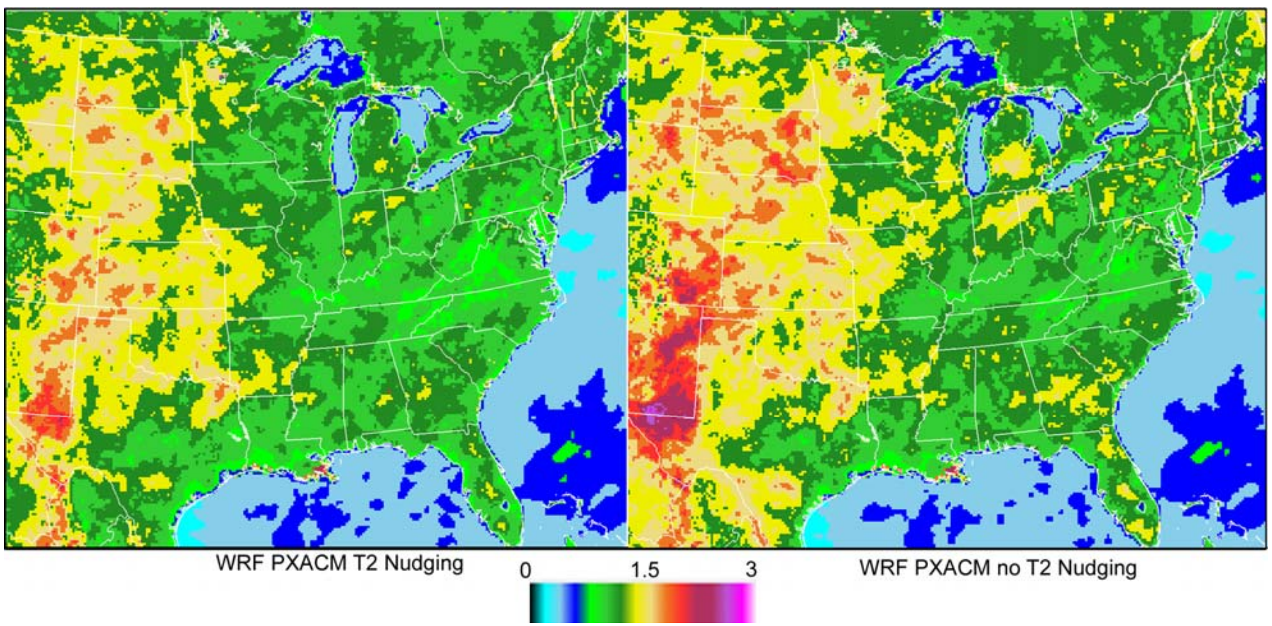
T-2m



q_v – 2m

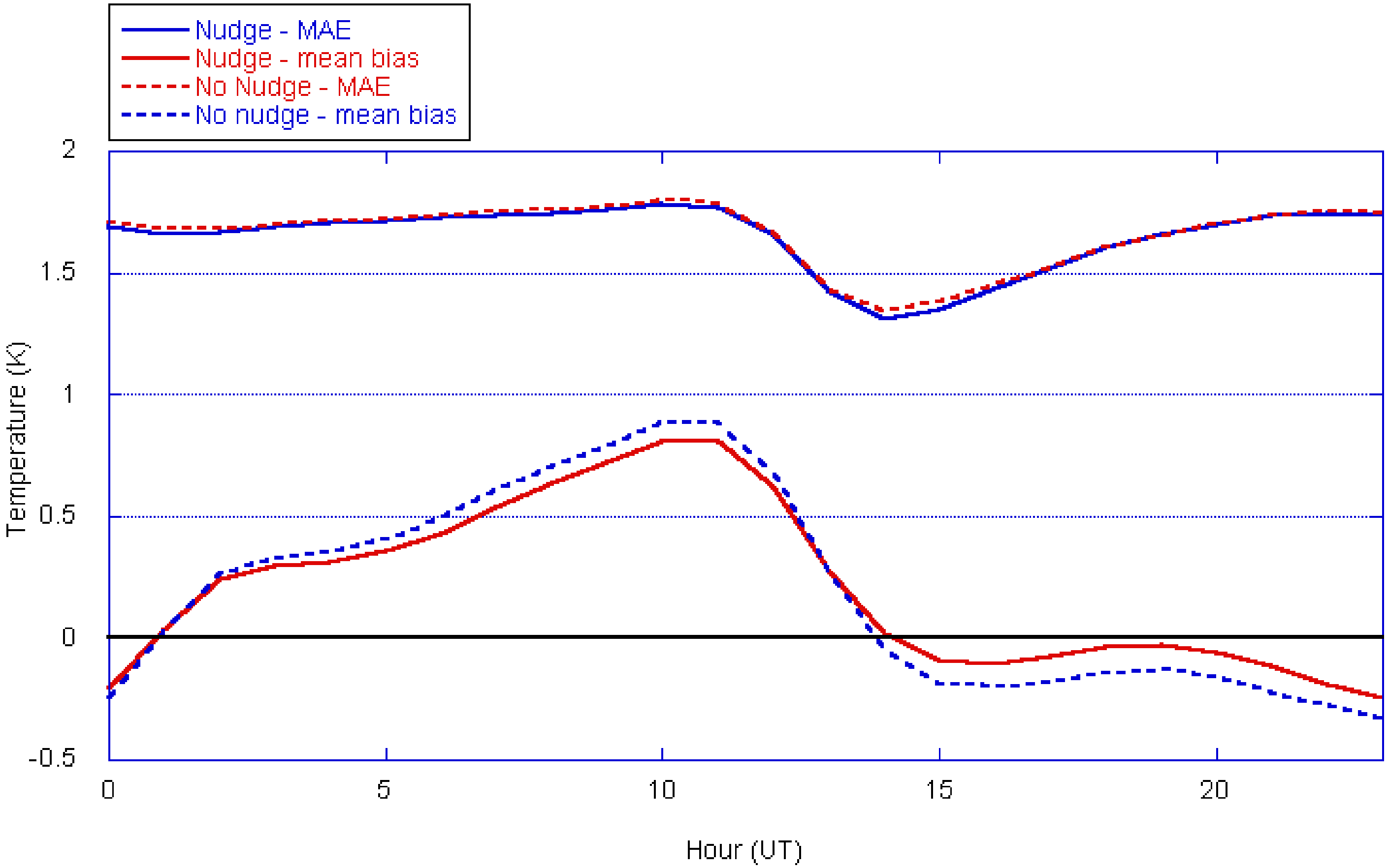


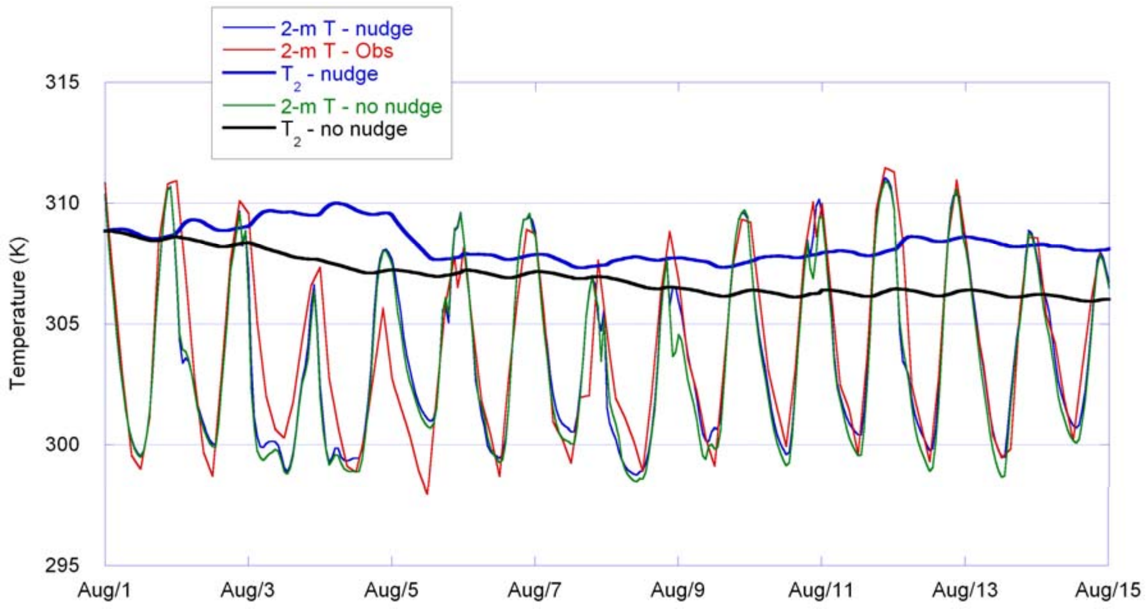
T-2m bias relative to analysis for August 2006



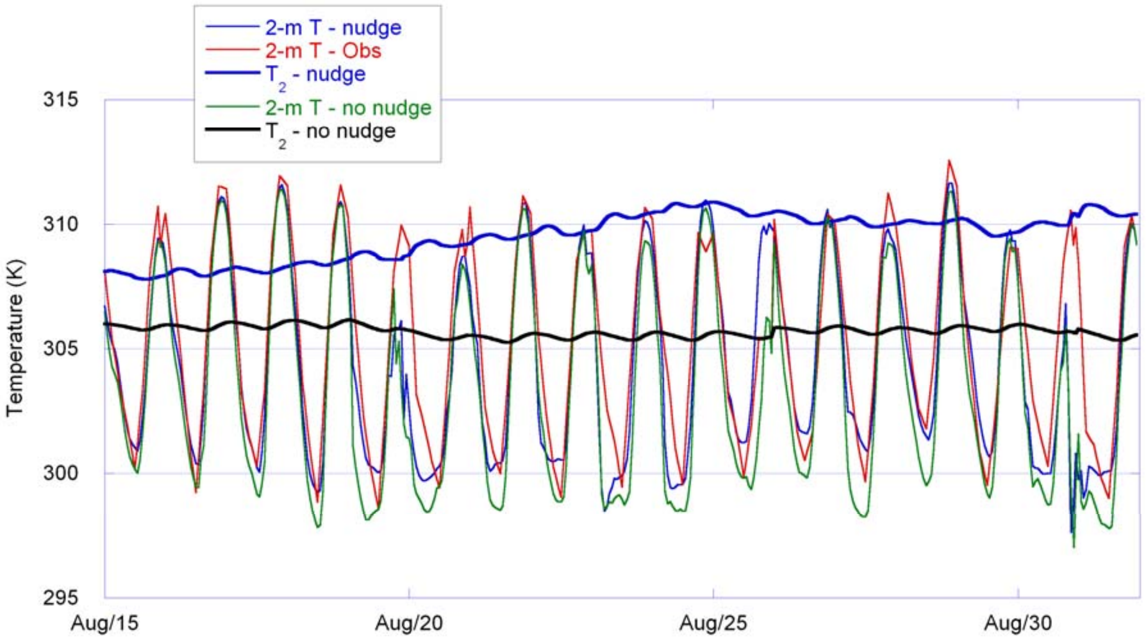
Mean absolute error relative to analysis for August 2006

Domain wide T-2m statistics compared to NWS/FAA observations

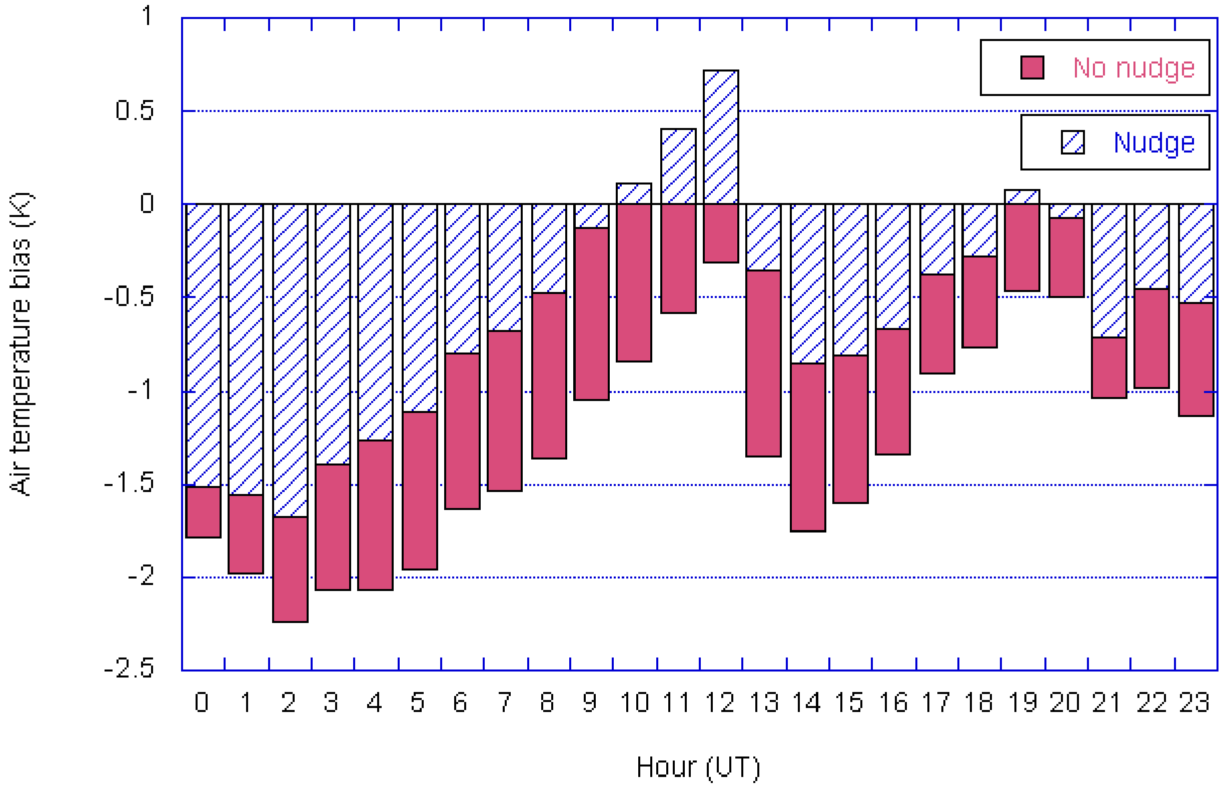




Comparison of T-2m and deep soil T with and without deep soil temperature nudging for a single grid cell in south Texas



T-2m diurnal mean bias for August 2006



Conclusions

- A simple deep soil temperature nudging technique is implemented to compensate for inherent limitations in the force-restore soil temperature model.
- The new nudging technique greatly reduces winter cold bias.
- Also improves summer temperature