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

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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:

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

\[ \frac{\partial T_2}{\partial t} = \frac{1}{\tau_2} (T_g - T_2) \]

\[ C_1 = \frac{2}{c d \alpha}, \quad \alpha = 1 + \frac{\delta}{d} \]

\[ C_2 = \frac{\omega}{\alpha} \quad d = \left( \frac{2 \lambda}{c \omega} \right)^{1/2} \]

Noilhan and Planton (1989) set \( \tau_2 = 1 \) day

• Multi-layer thermal diffusion

\[ \frac{\partial T}{\partial z} = \left( \frac{\lambda}{c} \right) \frac{\partial^2 T}{\partial z^2} \]

\[ \left[ -\frac{\lambda}{c} \frac{\partial T}{\partial z} \right]_{z=0} = \frac{G(t)}{c} \]
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. \( \tau_2 \sim 10 \) days) allow seasonal adjustment without requiring equilibrium.
Deep soil temperature nudging

• Nudge during nighttime at constant strength : \( G = 1.0 \times 10^{-5} \text{ s}^{-1} \)

\[
N_{T2} = G \left( 1 - 5 \frac{R_g}{1370} \right) \quad \text{where } N_{T2} > 0
\]

Nudging ramps linearly to zero at \( R_g = 274 \text{ W/m}^2 \)

\[
\frac{\partial T_2}{\partial t} = N_{T2} (T_{2m} - T_{\text{obs}})
\]

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