Assimilation of Geostationary Satellite Land Surface Skin Temperature Observations into the GEOS-5 Global Atmospheric Modeling and Assimilation System

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Project outline

- Aim: assimilate geostationary $T_{\text{skin}}$ observations into the land surface of the GEOS-5 GCM/Atmospheric DA system
  - Enhance assimilation of surface-sensitive atmospheric radiances
  - Improve land surface flux forecasts
- Coupled GMAO’s EnKF-based land data assimilation system to the GEOS-5 GCM/ADAS
**$T_{surf}$ in GEOS-5 Catchment land surface model**

- Catchment $T_{surf}$ is the average temperature of the canopy and soil surface (represented by an arbitrarily thin layer with minimal heat capacity)

\[
\frac{dT_{surf}}{dt} = \frac{1}{shc}(R_N - LH - SH - G)
\]

- **Diffusive heat flux** between soil layers:

\[
R_N = (1 - \alpha) R_{S\downarrow} + \ldots \\
\epsilon(R_L \downarrow - \sigma_s(T_{surf})^4)
\]

- **LH**:

\[
LH = r_L(e_{sat}(T_{surf}) - e_{air})
\]

- **SH**:

\[
SH = r_H(T_{surf} - T_{air})
\]

- Surface specific heat capacity (shc):

200 J/K

(70,000 J/K for broad-leaf e’green)
Geostationary $T_{\text{skin}}$ data

- Near-real time geostationary $T_{\text{skin}}$ data set from NASA Langley Research Center (LaRC)
- TIR clear sky observation of the effective radiative temperature of the land surface
  - GOES-E, GOES-W, Meteosat-9, MTSAT-2, FengYun-2E
  - Comparable accuracy to MODIS (vs. in situ $T_{\text{skin}}$)
  - Currently 3-hourly (clear sky) at 0.25° resolution

Correcting forecast-observation biases in coupled LA-DAS
Large forecast-observation biases (ubiquitous in land DA)
Unknown if bias is in forecasts and/or observations (likely both)
Common in land DA to assign f’cast-obs bias to observations
  At least ensures that the f’cast and obs are not biased relative to each other
  Usual methods require long data record to estimate forecast and observed climatological statistics
  For assimilation into an atmospheric system (frequent model updates!), do not have a long data record
Observation bias and state estimation

- Similar to forecast bias correction of Dee and Todling [2000]
- State forecast and update:
  \[ x^-_{k,i} = f(x^+_{k-1,i}, q_{k,i}) \]
  \[ x^+_{k,i} = x^-_{k,i} + K_k(\tilde{y}^o_k - b^+_k - H_kx^-_{k,i}) \]
  \( (K \text{ is unchanged by inclusion of bias estimate}) \)
- Bias forecast and update:
  \[ b^-_k = b^+_k \]
  \[ b^+_k = b^-_k + L_k(\tilde{y}^o_k - b^-_k - < H_kx^-_k >) \]
- Simplify by replacing \( L \) with empirical \( \Lambda \), designed to update bias more aggressively when observations are available less frequently
The estimated bias

Estimated f’cast-obs bias (K) after one month (30 June 2012)
Offline assimilation results
Comparison to in situ observations

- Assimilated 1 year of GOES-E/W over North America into GEOS-5 land surface model, forced with MERRA atmospheric analyses
Comparison to MODIS $T_{\text{skin}}$: Aqua asc. (∼18UTC)

Anomaly RMSD (K) over JJA 2012

a) Offline GEOS-5 (mean: 2.9 K)

b) GOES-E/W (mean: 2.5 K)

c) GOES-E/W bias corrected to GEOS-5 (mean: 3.5 K)

Improvement from assimilation of bias-corrected GOES (mean: 0.15 K, 65% +ve)
Comparison to MODIS $T_{skin}$: Aqua dsc. (∼06UTC)

Anomaly RMSD (K) over JJA 2012

a) Offline GEOS-5 (mean: 1.6 K)

b) GOES-E/W (mean: 1.3 K)

c) GOES-E/W bias corrected to GEOS-5 (mean: 1.8 K)

Improvement from assimilation of bias-corrected GOES (mean: 0.14 K, 78% +ve)
Assimilation into the GEOS-5 atmospheric system
Summary/conclusions

- Assimilated TIR skin temperature observations into GEOS-5 land surface model
- Introduced a simple observation bias and state estimation scheme for use with atmospheric system (does not require long data record)
- Offline assimilation of GOES TIR $T_{skin}$, with f’cast-obs bias correction, shows consistent small improvement in model short-term variability
  - Is correction of short-term variability enough to enhance atmospheric assimilation / improve land surface fluxes ????
- Results with GEOS-5 GCM/ADAS pending...
THANK YOU FOR LISTENING.
Catchment surface energy states and fluxes

\[ \frac{dW}{dt} = R_N - LH - SH - G \]

\[ R_N = (1 - \alpha)R_{S\downarrow} + \epsilon(R_L \downarrow - \sigma_s(T_C^X)^4) \]

\[ LH = RESIST_L(e_{sat}(T_C^X) - e_{air}) \]

\[ SH = RESIST_H(T_C^X - T_{air}) \]

\[ T_{SURF} = w(T_C^{SAT}, T_C^{TRANS}, T_C^{WILT}) \]

\[ \Delta(T_C^X) = \frac{\Delta(W^X)}{shc(sfc)} \]

shc = 200 J/K, or 70,000 J/K for b-l e’green

\[ TP_n = \frac{ghtcnt_n + icehct_n}{shc(rck) + shc(wtr) + shc(ice)} \]

Water assumed 0.5\( \phi \). If no ice:

\[ TP_n = ghtcnt / (2269050\Delta Z_n) \]
Two-stage observation bias and state estimation: simplified

- Replace $L$ with empirical $\Lambda$:

$$
\begin{pmatrix}
\lambda_1 & 0 & 0 \\
0 & \lambda_2 & 0 \\
0 & \ldots & \lambda_{n-1} & 0 \\
0 & 0 & \cdots & \lambda_n
\end{pmatrix}
$$

where $\lambda_j = 1 - e^{-\Delta t_j/\tau_j}$

- $\Delta t$ is time since last observation
- $\tau$ is time scale of bias memory (10 days for $T_{\text{skin}}$ assim.)
Enhance impact by relaxing ‘clear-sky’ cloud fraction for TIR $T_{\text{skin}}$?