Implementation of Coupled Skin Temperature Analysis and Bias Correction in a Global Atmospheric Data Assimilation System

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Introduction

- **Motivation:**
  - surface skin temperature (Ts) is a critical state because it reflects the surface radiative properties and energy budget and can dictate convective initiation.
  - Reliable Ts field from the operational GMAO DAS (Global Modeling and Assimilation Office Data Assimilation System) is a key requirement from scientific instrument team users.
- **Method:**
  - integration of the state-of-the-art NCAR Community Land Model (CLM) version 2.0 land-surface model (Dai et al. 2002; Zeng et al. 2002; Bonan et al. 2002) into GEOS4.
  - Ts analysis and coupled bias correction

Models & Assimilation System

- **The Finite-Volume GCM (fvGCM)**
  - Capable of resolving atmospheric motions from meso- to planetary-scale with a terrain-following Lagrangian control-volume vertical coordinate system (Lin and Rood 1999).
  - NCAR CAM2 physical parameterizations

- **The Goddard Earth Observing System (GEOS4)**
  - The fvDAS first utilizes a Statistical Quality Control (SQC) system to screen the observational data. The analysis is then performed by the Physical-Space Statistical Analysis System (PSAS; Cohn et al. 1998).

Models & Assimilation System

- **The Community Land Model (CLM v2)**
  - One-dimensional point model that uses sub-grid scale tiles.
  - One vegetation layer with a photosynthesis-conductance model to realistically depict evapotranspiration (Bonan 1996).
  - 10-uneven vertical soil layers with water, ice, and temperature states in each layer.
  - Up to five snow layers depending on the snow depth with water flow, refreezing, compaction and aging allowed.
  - Utilizes two-stream canopy radiative transfer, the Bonan lake model (1996), topographic enhanced streamflow based on TOPMODEL (Beven and Kirkby 1979), and turbulence is considered above, within, and below the canopy.

Skin Temperature Assimilation and Coupled Bias Correction

- **Incremental Bias Correction (Daily):**
  - A variant of the Dee and da Silva (1998) BC scheme was implemented where, a running estimate of the bias is calculated based on Ts observations and added to the energy balance at every timestep to counteract the subsequent forcing of the analyzed Ts back to the initial state.

$$\delta w^a = K(w^o - Hw^f + b^f)$$

$$w^a = w^f - b_{k-1}{}^f + \delta w^a$$

$$b_k{}^f = b_{k-1}{}^f - \gamma \cdot \delta w^a$$

$$f_b = \frac{b^f}{\tau}$$

  - f_b was added to the energy balance for the canopy and for the top layer soil/snow surface, and then updated at the analysis times.

Skin Temperature Assimilation and Coupled Bias Correction

- **Diurnal Bias Correction (Diurnal, DBC)**
  - IBC removed the time mean bias, but not the bias in the mean diurnal cycle thus DBC was implemented.
  - Time-dependent bias modeled with a sine wave parameterization:

$$b^f(t) = \sum_j (a_j \cos \omega_j t + b_j \sin \omega_j)$$

$$a_j = a_j - \gamma \delta w^a \cos \omega_j t$$

$$b_j = b_j - \gamma \delta w^a \sin \omega_j t$$

where $\omega_1 = \frac{2\pi}{24h}$ is the diurnal harmonic

Summary of Experiments

- Coupled Ts technique was tested in the fvDAS CLM2 framework and run at 1 x 1.25° horizontal resolution with 55 vertical levels from May through September 2001.

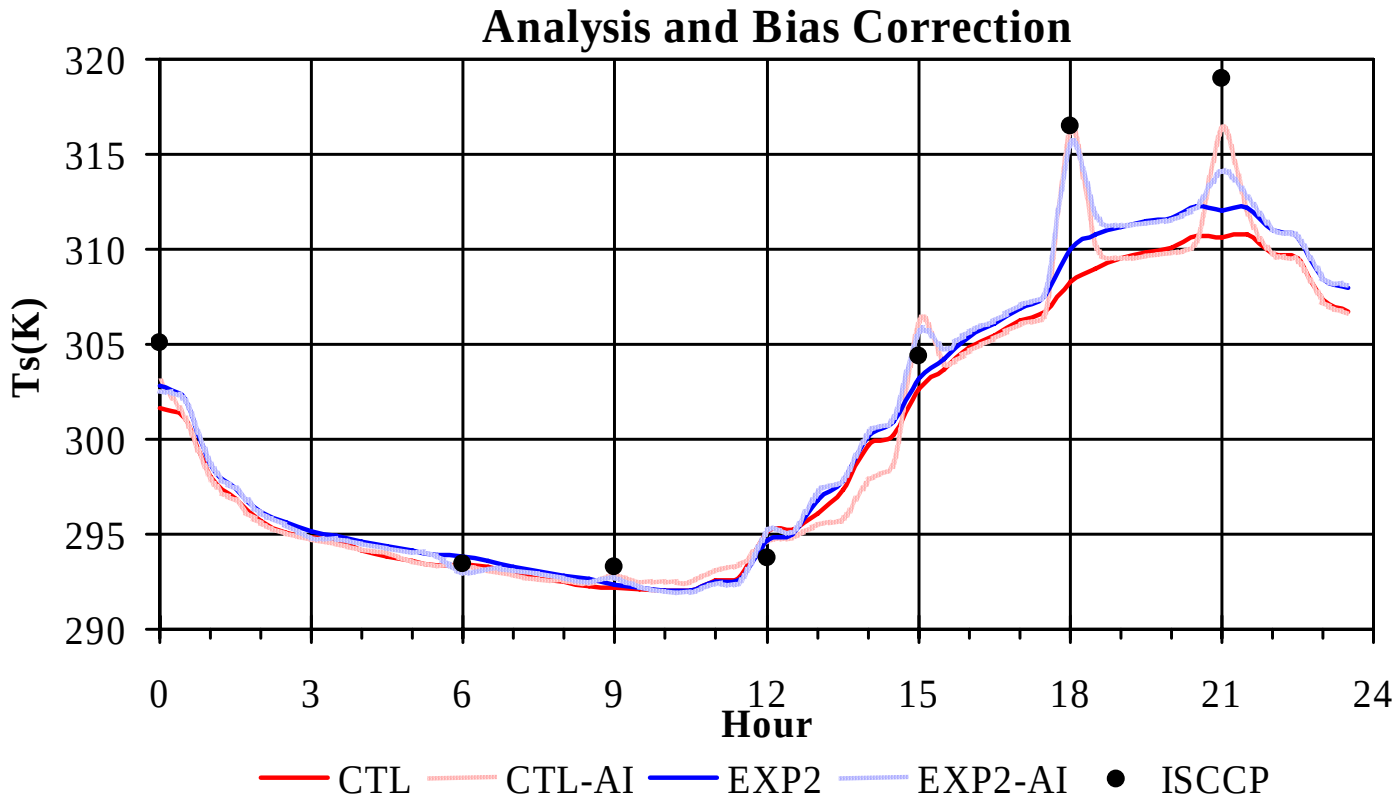
- The atmospheric analysis is performed every 6 hours, while the Ts analysis is done every 3 hours. The bias estimate is updated at the analysis time.

- ISCCP (International Satellite Cloud Climatology Project; Rossow and Schiffer, 1991) 3-hourly Ts observations were used for the surface analysis and BC.

Summary of Experiments

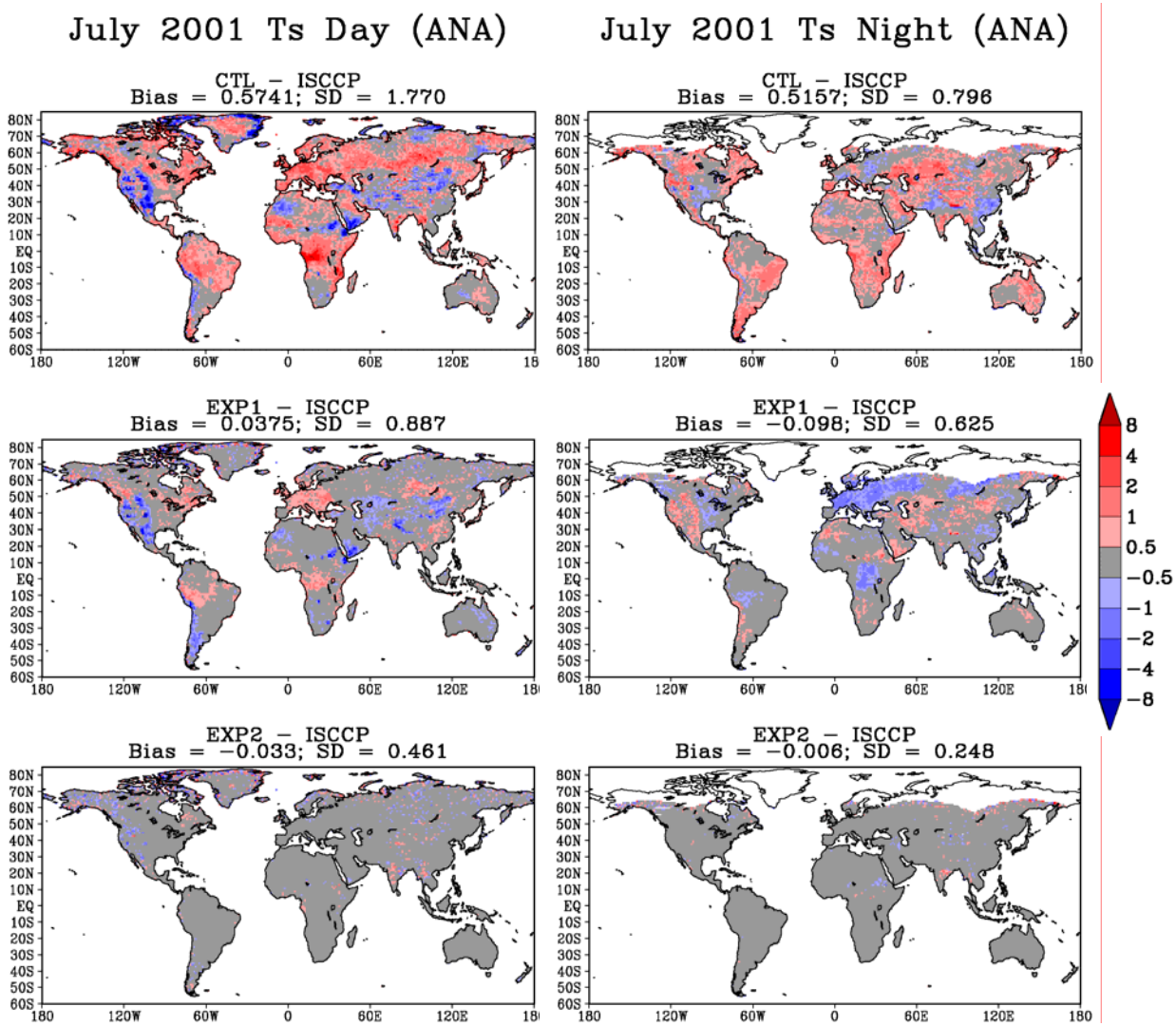
- Control (**CTL**) July-September 2001
- Daily Bias Correction (**EXP1**) – Includes a single bias at each grid point
- Diurnal Bias Correction (**EXP2**) – Includes 3 hourly (8) biases at each grid point
- **ANA** – Analysis cycle
- **BKG** – Background (model)
- CTL-AI, EXP1-AI, EXP2-AI add the analysis increment into the surface energy budget

Analysis and Bias Correction



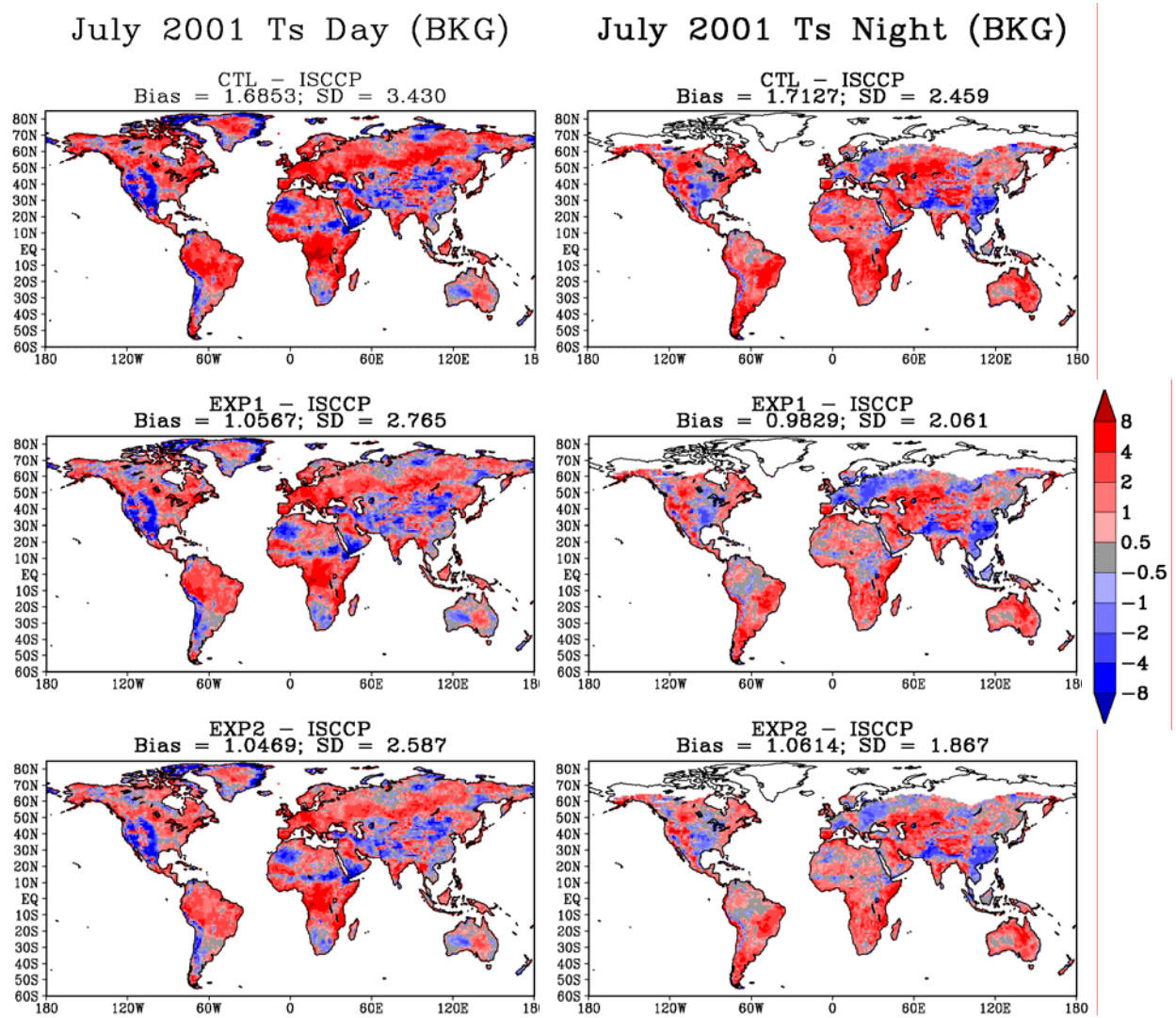
- The analysis increments immediate impact, not long lasting, bias correction is applied at every time step

Analysis Skin Temperature Differences (July 2001Day and Night)



- Analysis compared back to ISCCP
- Daily bias corrections remove of many of the regional biases
- Diurnal bias corrections address most bias

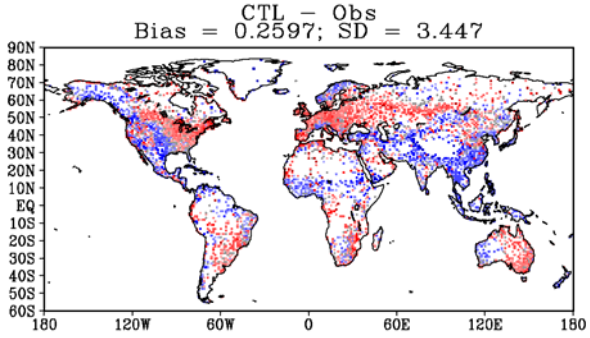
Background Skin Temperature Differences (July 2001 Day and Night)

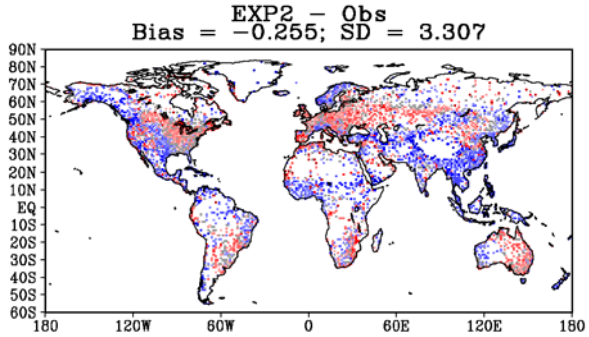


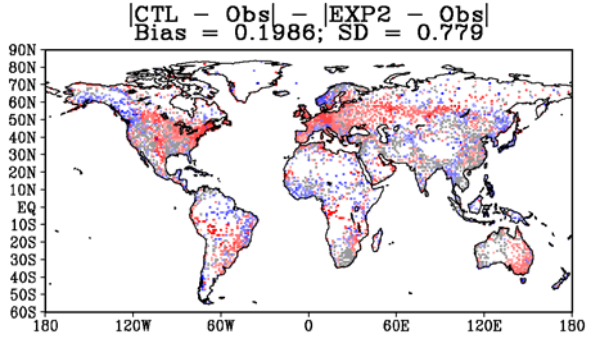
- Most improvement in skin temperature occurs with daily bias correction
- Only slight improvement in global bias, some improvement in regions

July 2001 T2m Station Observation Differences & Improvement

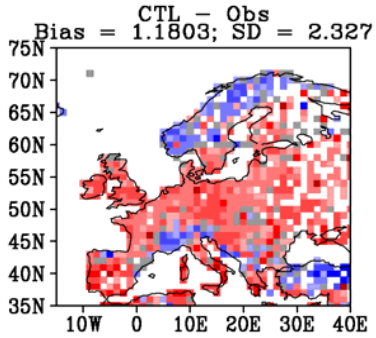
July 2001 T2m (BKG)

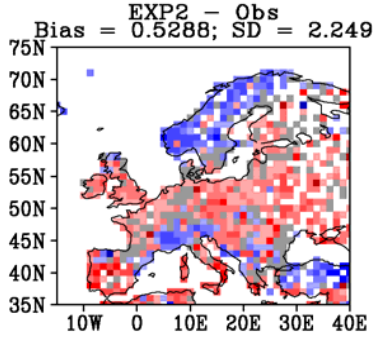


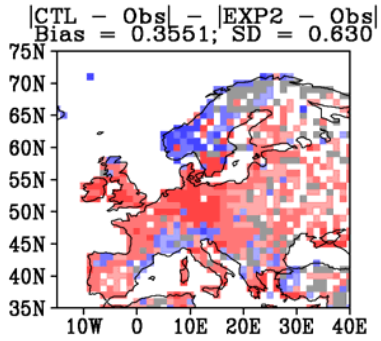




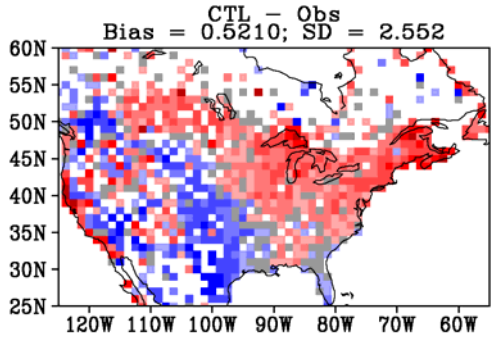
July 2001 T2m (BKG)

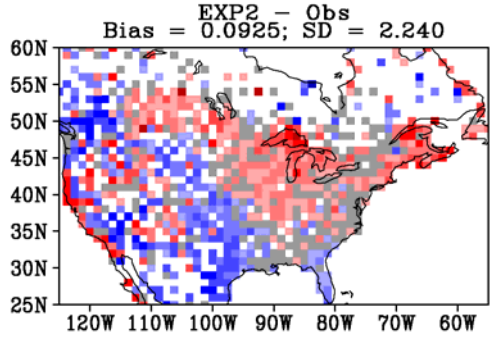


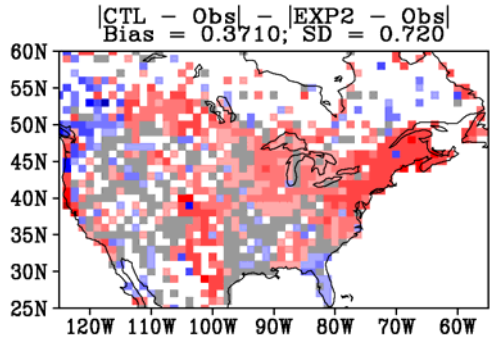


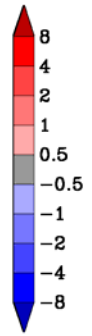


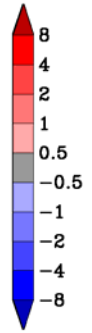
July 2001 T2m (BKG)

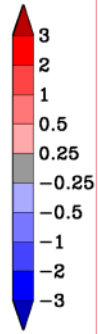




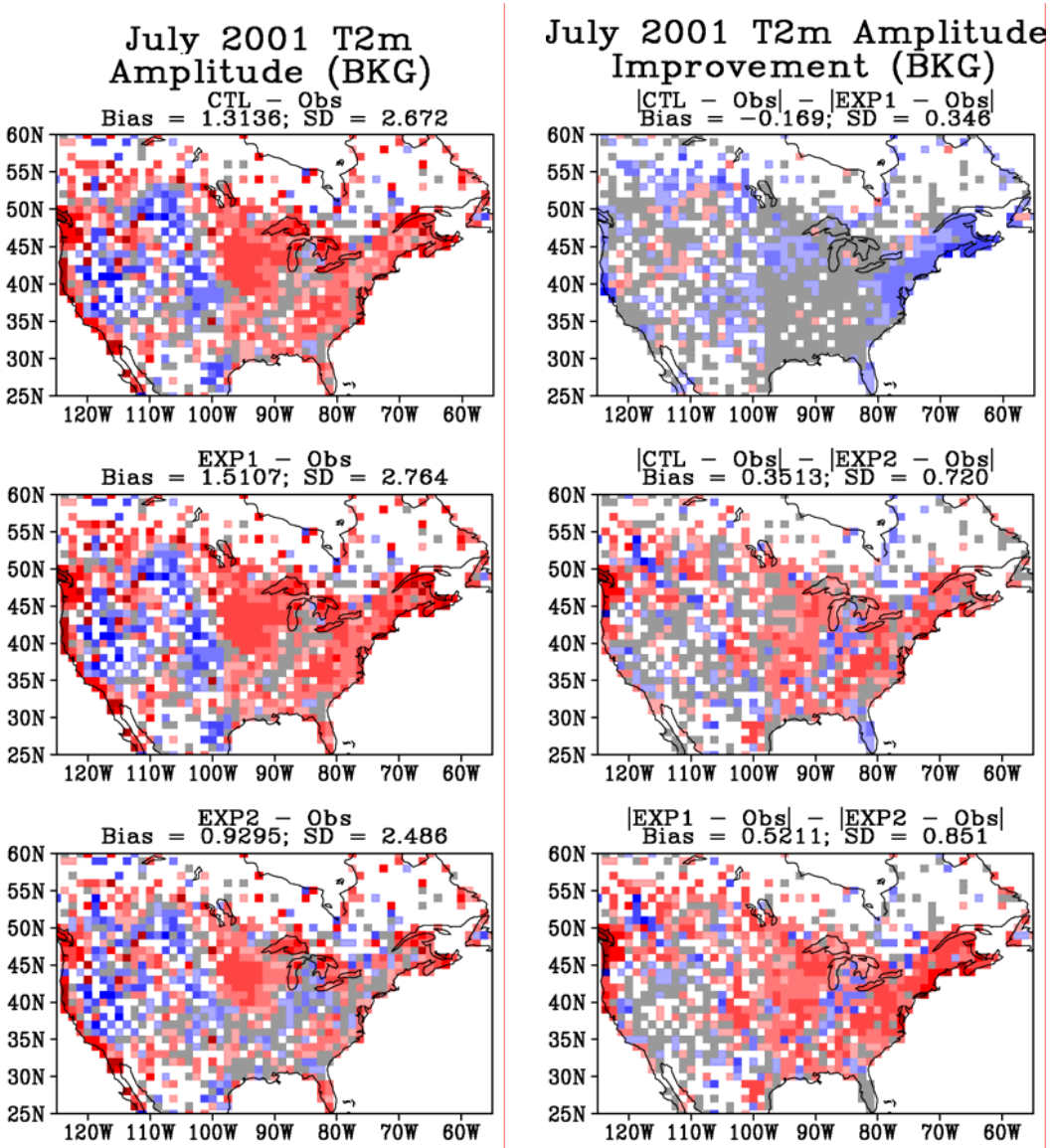






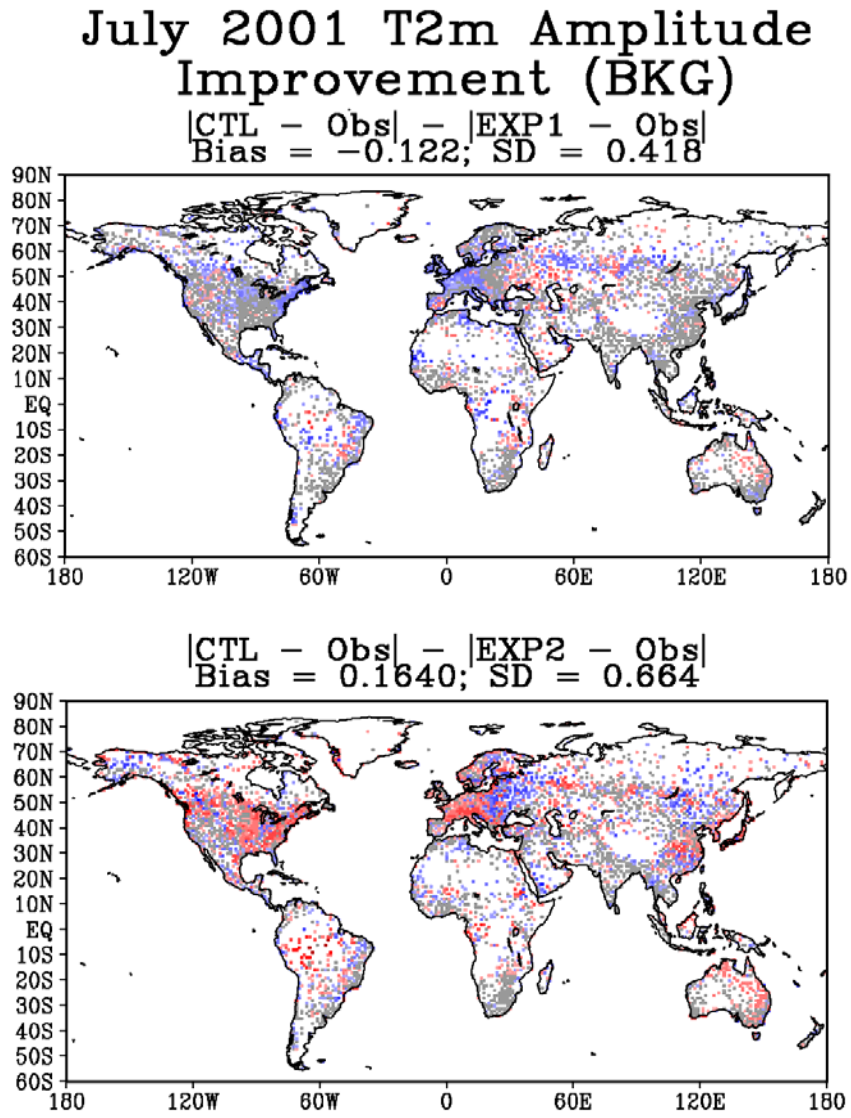


July 2001 T2m Station Observation Amplitude Differences & Improvement



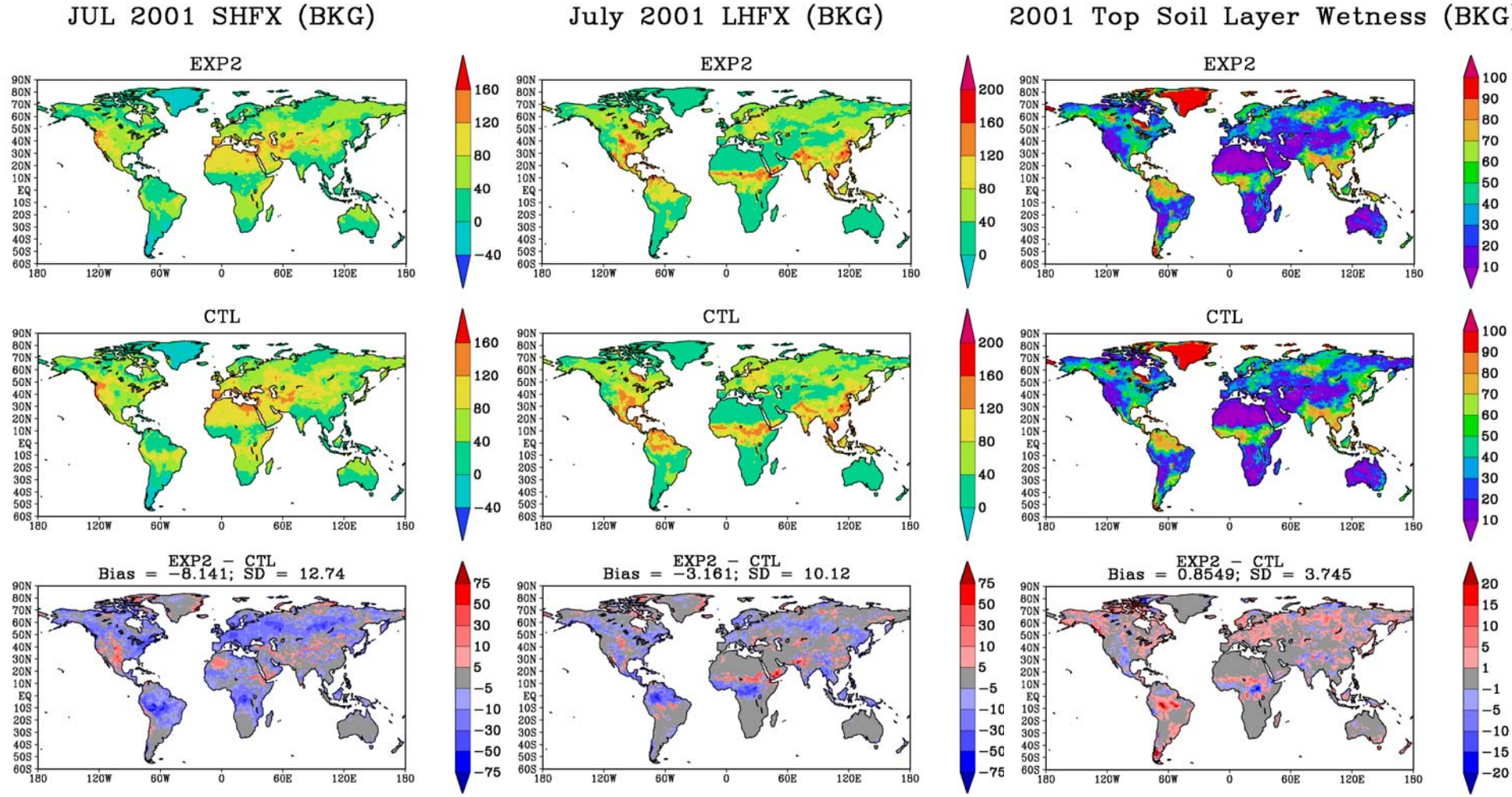
- Amplitude of the monthly mean diurnal cycle
- The daily bias correction has little or negative affect on amplitude
- The diurnal bias correction makes a positive impact for many of the largest biases

July 2001 T2m Station Observation Amplitude Differences & Improvement



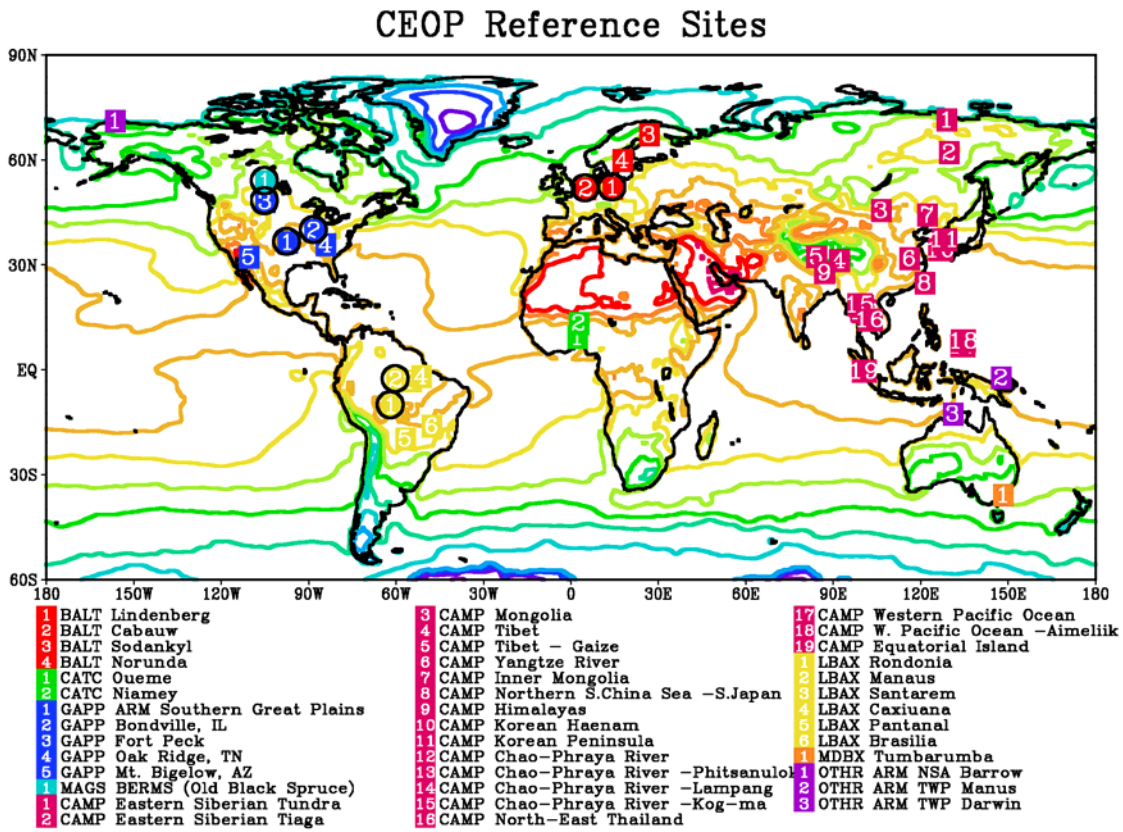
- Most regions are improved, though to varying degrees
- Eastern Europe is a region where the diurnal amplitude is not improved by diurnal bias correction
- Daily correction seems to improve the amplitude in Eastern Europe

Fluxes & Soil Moisture



CEOP In-situ Observations

- EOP-1 July – Sept, 2001
- Reference Sites mostly in GEWEX CSEs
- 40 stations in total
- 8 with complete energy/radiation observations (Circled)



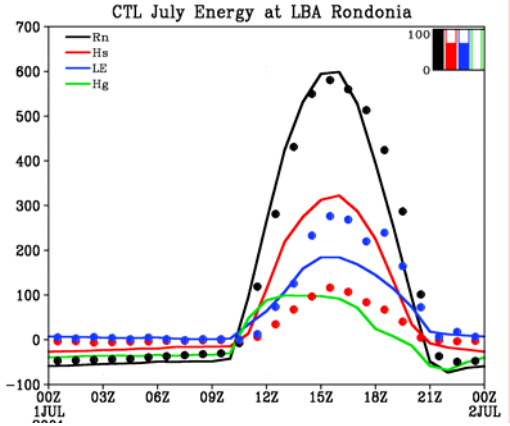
CEOP July 2001 In-situ mean Biases

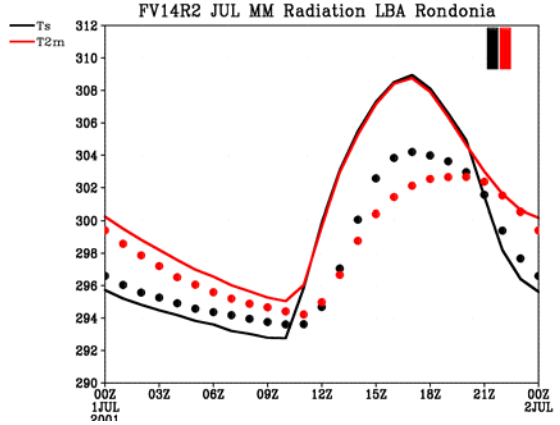
Station	Q2m	T2m	Ts	Rn	Hs	LE	Hg	Rsd	Rsu	Rld	Rlu	B
BALTEX Cabauw	**-1.94**	**3.10**		**24.3**	**59.7**	**-48.0**		**62.7**	7.8	**-18.8**	**14.8**	-47.9
BALTEX Lindenberg	**-0.56**	**0.14**		**45.9**	**34.9**	**-14.6**	0.9	52.6	10.7	**-5.8**	**-0.9**	-41.2
MAGS BERMS	**-1.38**	**0.31**		**5.5**	**8.1**	**-25.6**	6.0	39.3	19.5	-2.1	**12.1**	-31.4
LBA Manaus	**-0.91**	**-1.15**		**2.8**	-2.3	**-14.3**		**3.0**	8.4	**-4.5**	-4.6	-17.4
LBA Rondonia	**-1.99**	**0.31**	**-0.74**	**2.9**	**5.6**	4.5		**25.8**	9.3	-20.4	-6.0	-33.2
GAPP Bondville	**-1.05**	**1.88**	**1.65**	30.1	**13.7**	**-17.9**	-1.2	**18.0**	-1.4	11.1	**20.4**	-30.2
GAPP Ft_Peck	**-1.75**	**-1.26**	**-4.05**	25.8	**19.9**		-4.6	**28.9**	15.0	13.5	-13.2	-2.9
GAPP ARMSGP (E15)	**1.76**	-1.32	-2.68	30.5	8.9	**37.2**	2.4	11.4	-13.7	-10.6	-16.6	4.0
ARM NSA Atqasuk	-0.73	**-1.15**	**-0.94**	**15.8**								-40.4
ARM NSA Barrow	**0.37**	**4.42**	**2.07**	**-30.5**								-40.4
CAMP Mongolia (230)	**-0.24**	**0.41**	**-0.31**	18.2								8.2
	g/kg	K		W m^{-2}								

- Mean biases of the diurnal bias correction
- Red shows improvement of the mean bias (Blue shows degradation)

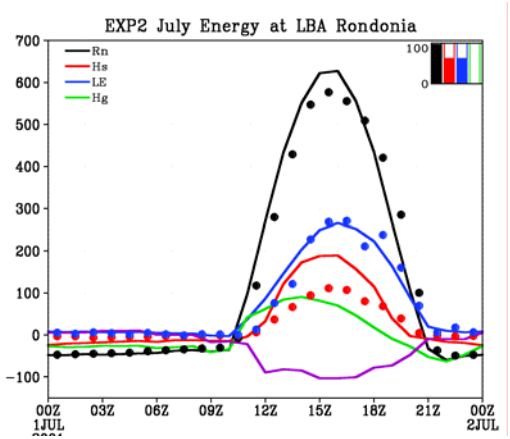
July 2001 CEOP Comparisons

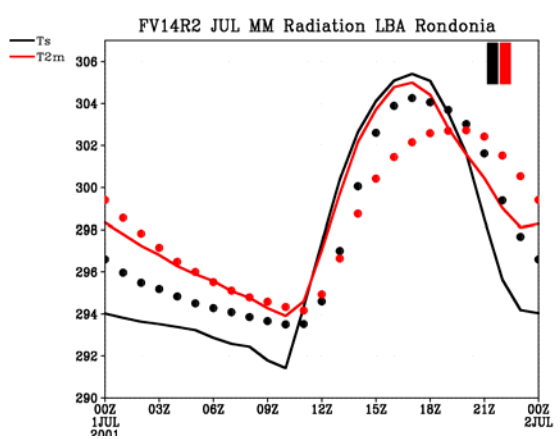
CTL





EXP2



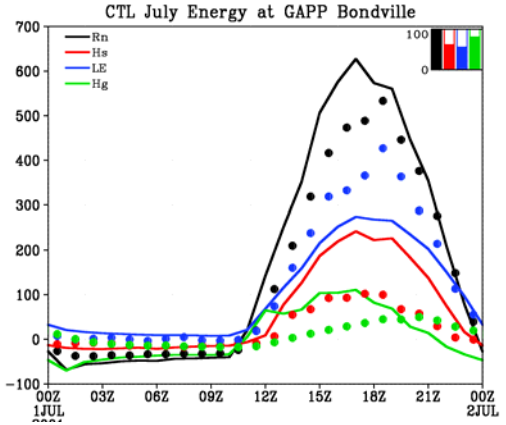


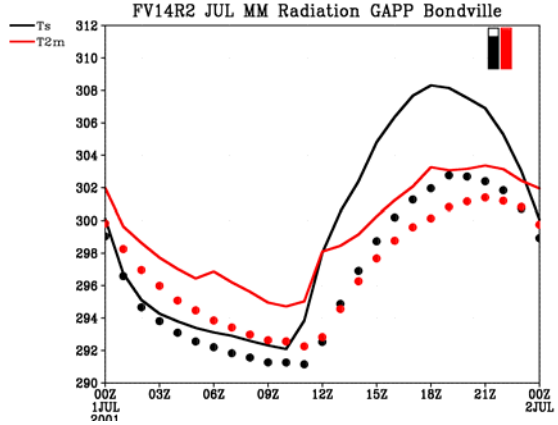
LBA Rondonia Site
(-10.08˚ , -61.93º)

- Observations are dotted lines
- Improvement in the sensible & latent heat flux due to the DBC
- Significant reduction in the daytime warm bias in the skin temperature and 2 m temperature with inclusion of DBC.
- Ground heat flux is the residual from the energy balance and thus includes the energy flux from the bias term.

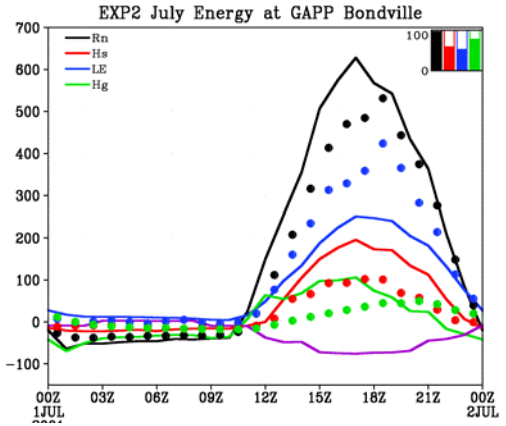
July 2001 CEOP Comparisons

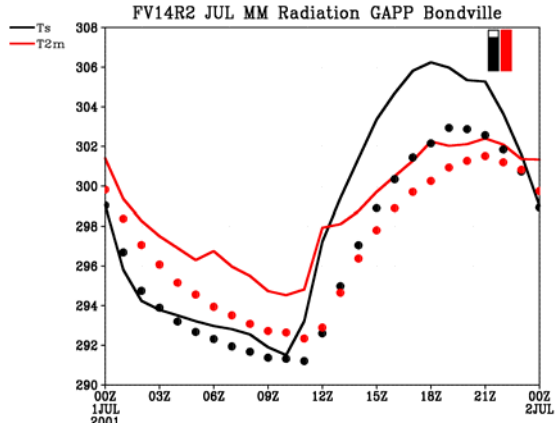
CTL





EXP2





GAPP Bondville Site
(40.01˚ , -88.29º)

- Observations are dotted lines
- Slight improvement shown in the sensible heat flux, but not the latent heat flux.
- With reduced sensible heat there is a compensating increase in the residual ground heat flux, but this is likely attributable to the bias flux which was not removed from the residual.
- Only small improvement in the TSKIN and T2m resulting from the DBC.

Conclusions

- Preliminary results show that the coupled skin temperature assimilation and bias correction was for the most part a success
- The analysis closely draws to the observations, and the effect of the coupling reduces the bias in the background skin temperature by ~ 1 K
- While diurnal bias correction does not improve the mean temperature much over daily, but the amplitude is generally improved
- Having coordinated flux stations at many different climate regimes greatly improves the validation of the surface energy budgets

Future Work

- Long term assimilation desired for CEOP EOP3 and EOP4
- The degradation of latent heat flux was ~10Wm-2 at two CEOP stations, currently looking at the relationships between Ts bias and soil moisture bias (nonlinear and less than ideal)
- There are ongoing experiments in the GMAO to assimilate clouds and also soil moisture, a multi-variate assimilation would be more desirable
- ISCCP presently does not extend past Sept 2001, MODIS is available for Aqua and Terra, but only 4 times/day