Evaluation of the Tropical TOA flux diurnal cycle in Reanalysis

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Why Study Diurnal Cycle?

(1) Diurnal cycle influences the time mean energy budget.

- Bergman and Salby (1997) attribute a 1-5 W m\(^{-2}\) and 5-20 W m\(^{-2}\) to the cloud diurnal cycle in the time mean OLR and RSW.
- Loeb et al. (2009) indicate up to a 30 W m\(^{-2}\) biases in MSc and tropical land convective regions in time mean RSW.
Why Study Diurnal Cycle?

(2) Diurnal cycle influences variability of the TOA energy budget terms.

– Taylor and Loeb (J. Climate 2013) and Taylor (J. Atmos. Sci. 2014) indicate that diurnal cycle variability accounts for up to 50% of TOA flux variability at 1°x1° scales.

Units: %
Why Study Diurnal Cycle?

(3) GCMs and NWP models poorly simulate the diurnal cycle.

CERES LWCF Anomaly (W m\(^{-2}\))
Central South America (0–15S; 50–70W)

MERRA LWCF Anomaly (W m\(^{-2}\))
Central South America (0–15S; 50–70W)

ERA-Interim LWCF Anomaly (W m\(^{-2}\))
Central South America (0–15S; 50–70W)

Itterly and Taylor
(J. Climate 2014; accepted)
Takeaway Messages

1) Diurnal cycle errors are largest in convective regions over both ocean and land; errors are 5-10 times larger than in non-convective regions.

2) Diurnally forced propagating convection is missing from both reanalysis models.

3) MERRA represents the “stationary” convective diurnal cycle much better than ERA-Interim.

4) Cloud diurnal cycle errors in a GCM contribute up to 20 W m$^{-2}$ to the time mean RSW flux.
Data and Model

- CERES Ed3 SYN Data (2002-2012; 3-hourly; Doelling et al. 2013)
  (1) calibration of each GEO instrument against MODIS
  (2) a narrowband to broadband radiance conversion
  (3) GEO broadband radiance to irradiance integration
  (4) normalization of GEO derived flux to CERES

- Reanalysis models were regridded to $1^\circ \times 1^\circ$ and 3-hourly temporal resolution for comparison with CERES
  - MERRA
  - ERA-Interim
Diurnal Cycle Error Metric

The error in the climatological TOA flux diurnal cycles was quantified using a root mean square error metric.

\[
RMSE_{\text{Var, model}} = \sqrt{\frac{1}{N} \sum_{h=1}^{N} (\text{Var}_{\text{model}}(h) - \text{Var}_{\text{CERES}}(h))^2}
\]

\[
\sigma_{\text{Var, DC}} = \sqrt{\frac{1}{N} \sum_{h=1}^{N} (\text{Var}_{\text{CERES}}(h))^2}
\]
RMS errors are given in percent relative to the standard deviation across the CERES observed OLR diurnal cycle.

Longwave TOA flux diurnal cycle simulation errors are primarily attributed to errors in the diurnal evolution of clouds.
Shortwave Diurnal Cycle

Evaluation

RMS errors are given in percent relative to the standard deviation across the CERES observed RSW diurnal cycle.

Reflected shortwave TOA flux diurnal cycle simulation errors show significant contributions from both clear and cloudy sky.
Diurnal Cycle Error Attribution: OLR Amplitude

OLR diurnal cycle amplitude is simulated too weak over land in both reanalysis models.

Amplitude errors are computed (Model minus CERES)
Diurnal Cycle Error Attribution: LWCF Amplitude

LWCF diurnal cycle amplitude is simulated too weak over land convective regions in both reanalysis models.

Amplitude errors are computed (Model minus CERES)
Diurnal Cycle Error Attribution: LWCF Phase

LWCF phase errors are due to missing diurnally forced propagating convection (e.g., Indian Ocean; Mexican coast).

Phase errors are computed (Model minus CERES)
The MERRA TOA LWCF diurnal cycle in Central South America simulate the correct phase but a slightly weaker amplitude. ERA-Interim simulated a slightly weaker amplitude but exhibits a ~6 hour phase shift.
Diurnal Cycle Error Attribution: Albedo

Albedo diurnal range amplitude is simulated too weak over ocean non-convective regions in both reanalysis models.

Albedo diurnal range errors are computed (Model minus CERES)
Diurnal Cycle Evolution Histogram
Peruvian MSc

MERRA better reproduces the dissipation of Peruvian MSc diurnal cycle.

(Iterly and Taylor 2014, accepted)
Diurnal cycle impact on time mean TOA flux
Diurnal Cycle Contributions to Time Mean TOA flux

Let’s consider that the TOA flux is the sum of two components.

\[ \text{Total Flux} = \text{Diurnally uniform contribution} + \text{Diurnal cycle contribution} \]

\[ \text{OLR} = \text{OLR}_\text{mon} + \text{OLR}_\text{dc} \]

A similar expression can be written for RSW.

Total flux => observed or modeled monthly mean

Diurnally uniform => computed using a radiative transfer model with monthly mean, diurnally uniform inputs (e.g., temperature, atmospheric transmittance, column albedo)

Diurnal cycle => Total flux minus Diurnally uniform

\[ \text{OLR}_\text{mon} = \tau_{\text{eff}} \sigma T_s^4 \]

\[ \text{RSW}_\text{mon} = \alpha_{\text{mon}} S_{\text{ins}} \]

Taylor et al. (In prep)
Shown are the contributions of the LW cloud diurnal cycle to the (a) CERES and (b) CanAM4 OLR mean state.

CanAM4 LW cloud diurnal cycle contributions to mean state OLR are the same sign as CERES but are too weak.

Taylor et al. (2014; in prep)
Mean State: SWCF_DC Contributions

Shown are the contributions of the SW cloud diurnal cycle to the (a) CERES and (b) CanAM4 RSW mean state.

CanAM4 SW cloud diurnal cycle contributions to time mean RSW exhibit the largest errors in land convective regions.

Taylor et al. (2014; in prep)
CanAM4 minus CERES

Units: W m$^{-2}$

CanAM4 SW cloud diurnal cycle contribution differences to time mean RSW are +8 to -16 W m$^{-2}$.

Taylor et al. (2014; in prep)

Shown are the differences between the the SW cloud diurnal cycle to the time mean energy budget differences CanAM4 minus CERES.
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2) Diurnally forced propagating convection is missing from both reanalysis models.

3) MERRA represents the “stationary” convective diurnal cycle much better than ERA-Interim.

4) Cloud diurnal cycle errors in a GCM contribute up to 20 W m\(^{-2}\) to the time mean RSW flux.
The Peruvian MSc diurnal cycle in cloud albedo is too weak.

(Itterly and Taylor 2014, accepted)
CERES LWCF diurnal cycle phase in the Indian Ocean is shifted 3-5 hours later in the day due to the missing diurnally-forced propagating convection. (Itterly and Taylor 2014, accepted).
Both reanalysis models simulate a cloud albedo diurnal cycle that is too strong over the central Pacific and central Atlantic Ocean. (Itterly and Taylor 2014, accepted)
Interpretation

• Longwave Cloud:
  – OLR\_dc > 0 occurs when cloud preferentially form at night when $T_s$ is lower.
  – OLR\_dc < 0 occurs when cloud preferentially form during the day when $T_s$ is higher.

• Shortwave Cloud:
  – RSW\_dc > 0 occurs when cloud preferentially form in the afternoon when Solar insolation is high.
  – RSW\_dc < 0 occurs when cloud preferentially form in the morning or evening when Solar insolation is low.