Variability of Regional TOA Flux Diurnal Cycle Composites at the Monthly Timescale

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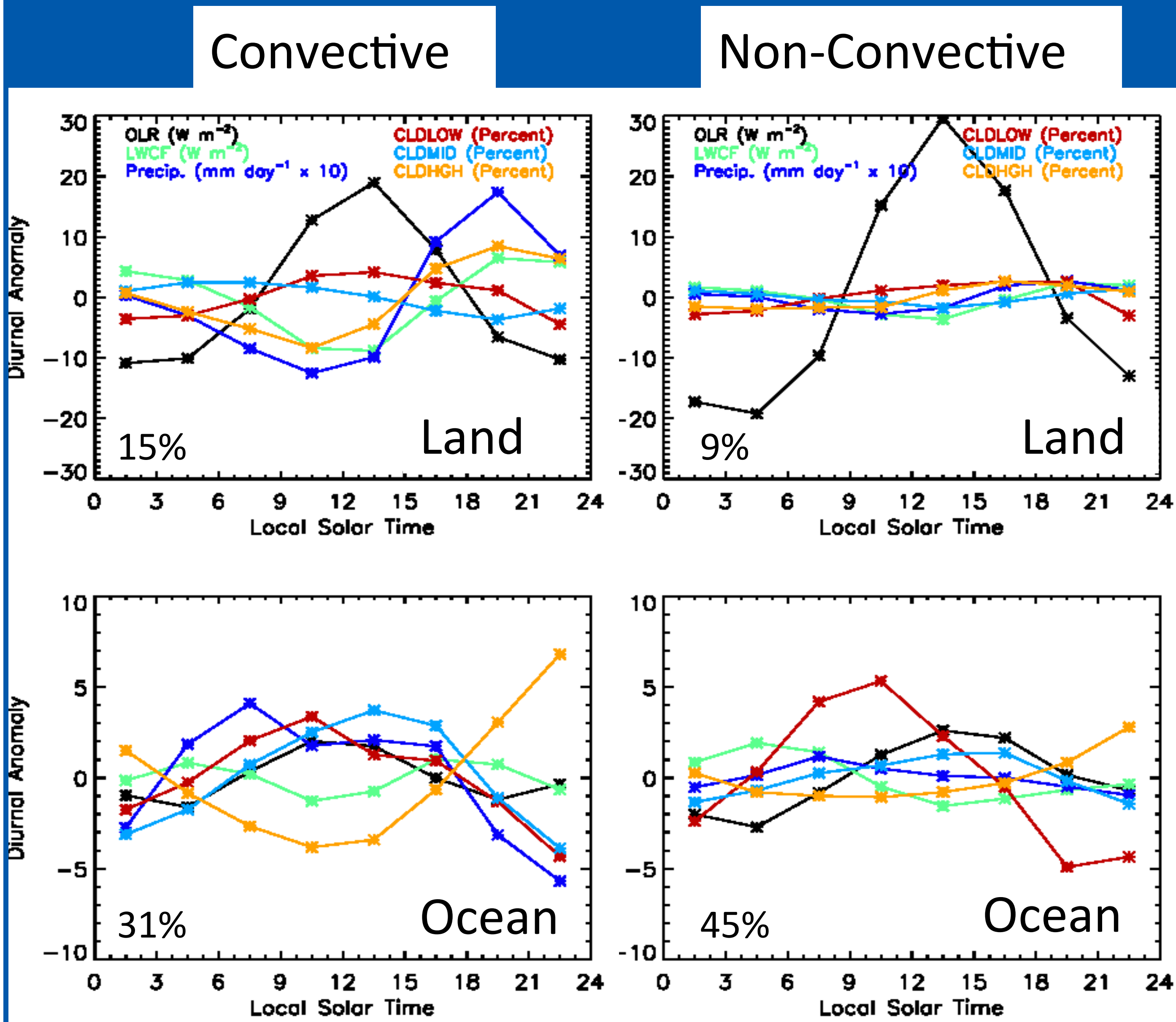
Motivation

- The diurnal cycle is a fundamental earth system variability.
- Significant diurnal cycle signals are evident in many geophysical datasets, including temperature, water vapor, clouds, radiation, and convective precipitation (e.g., Minnis and Harrison 1984a,b,c; Randall et al. 1991; Janowiak et al. 1994; Bergman and Salby 1996; Lin et al. 2000; Soden 2000; Yang and Slingo 2001).
- The diurnal cycle is traditionally thought to be the result of a long time average removing "weather noise."

Background: Diurnal Cycle Regimes

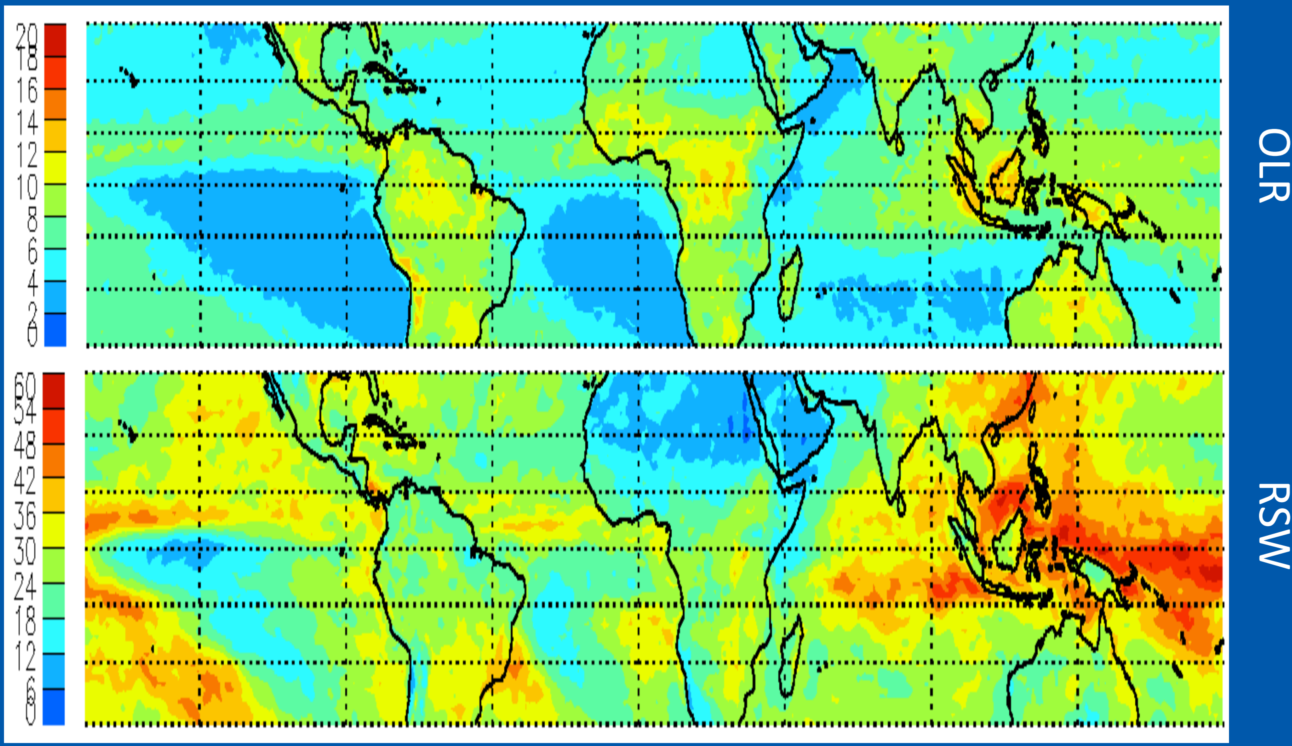


- Convective and non-convective regimes are determined using climatological High Cloud amount (e.g., Bergman and Salby 1996).

- Convective:
  High cloud > 10 %
- Non-Convective:
  High cloud < 10 %

Traditional diurnal cycle regimes provide a statistically robust categorization.

New thinking on diurnal cycle Taylor (2013)

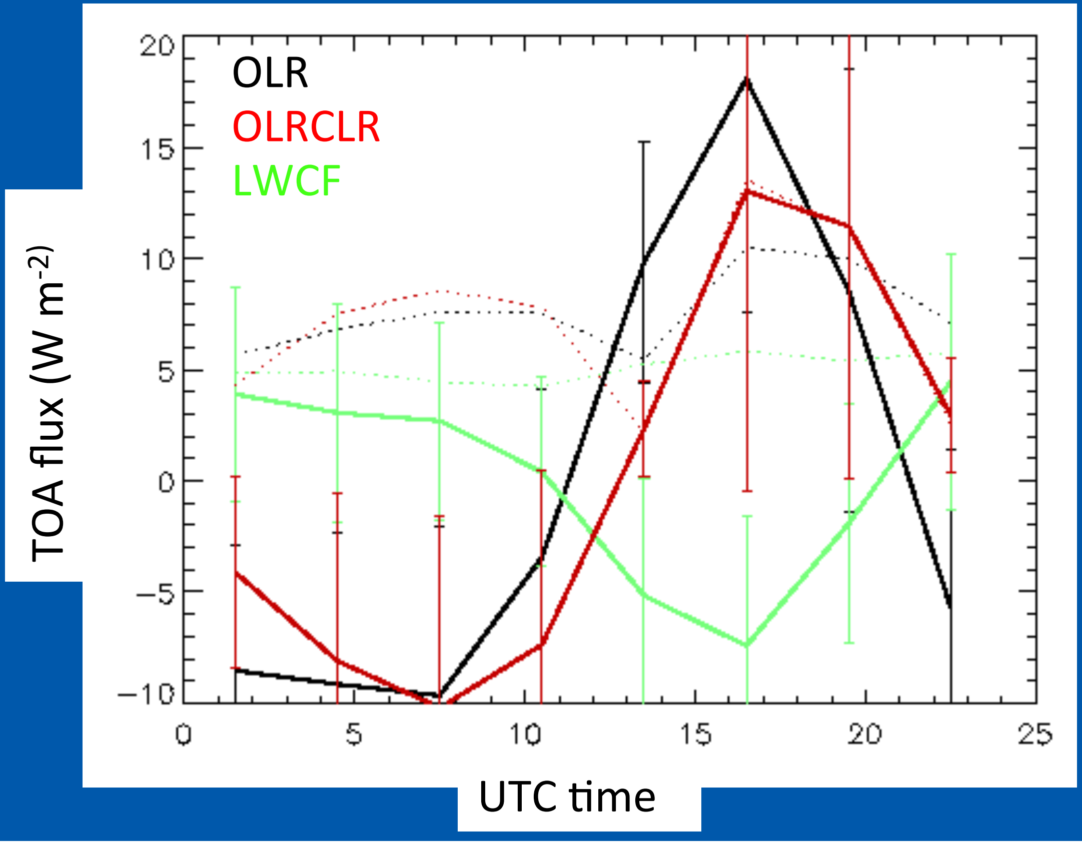


- The TOA flux diurnal cycle is highly variable in regions of oceanic convection and moderately variable over land convective and ocean non-convective regions.
- The variability is very small over land non-convective regions.
- The TOA flux diurnal cycle variability in the RSW diurnal cycle is strongly regulated by the diurnal evolution of clouds.

The monthly mean TOA Flux diurnal cycle composite varies in a statistically significant manner.

Diurnal cycle variability defined

The monthly, 3-hour composite of a variable differs from month-to-month outside of the random, statistical variations.



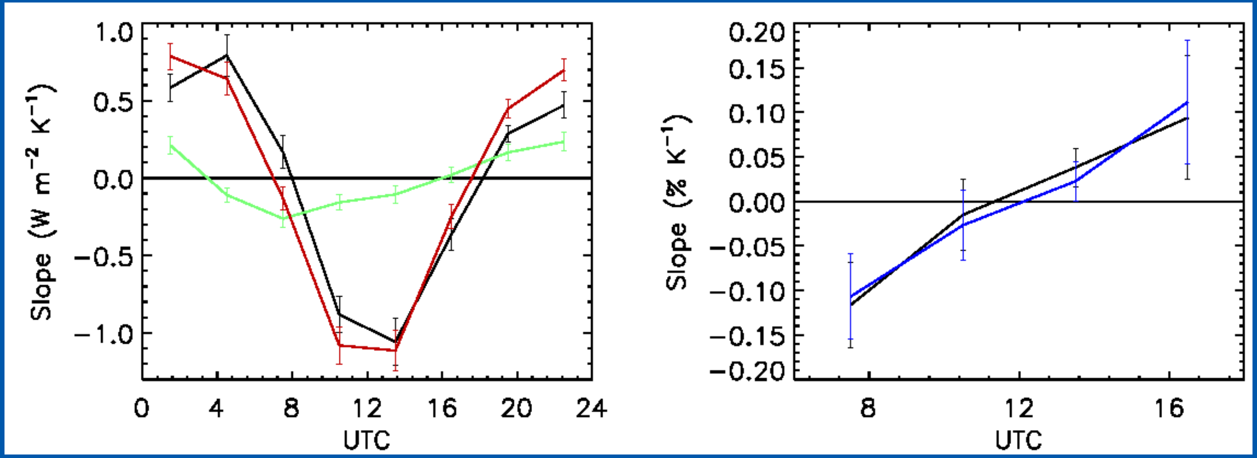
What causes the observed variability in the TOA flux diurnal cycle?

Hypothesis

Monthly mean diurnal cycle variability arises from changes in the prevailing cloud types in response to monthly anomalies in the dynamic and thermodynamic state (Taylor 2013).

Methodology

- A regression analysis is applied to the monthly, 3-hourly CERES SYN Ed3 data, ERA-Interim atmospheric dynamic and thermodynamic state diagnostics, and CERES ISCCP-D2-like to test this hypothesis.



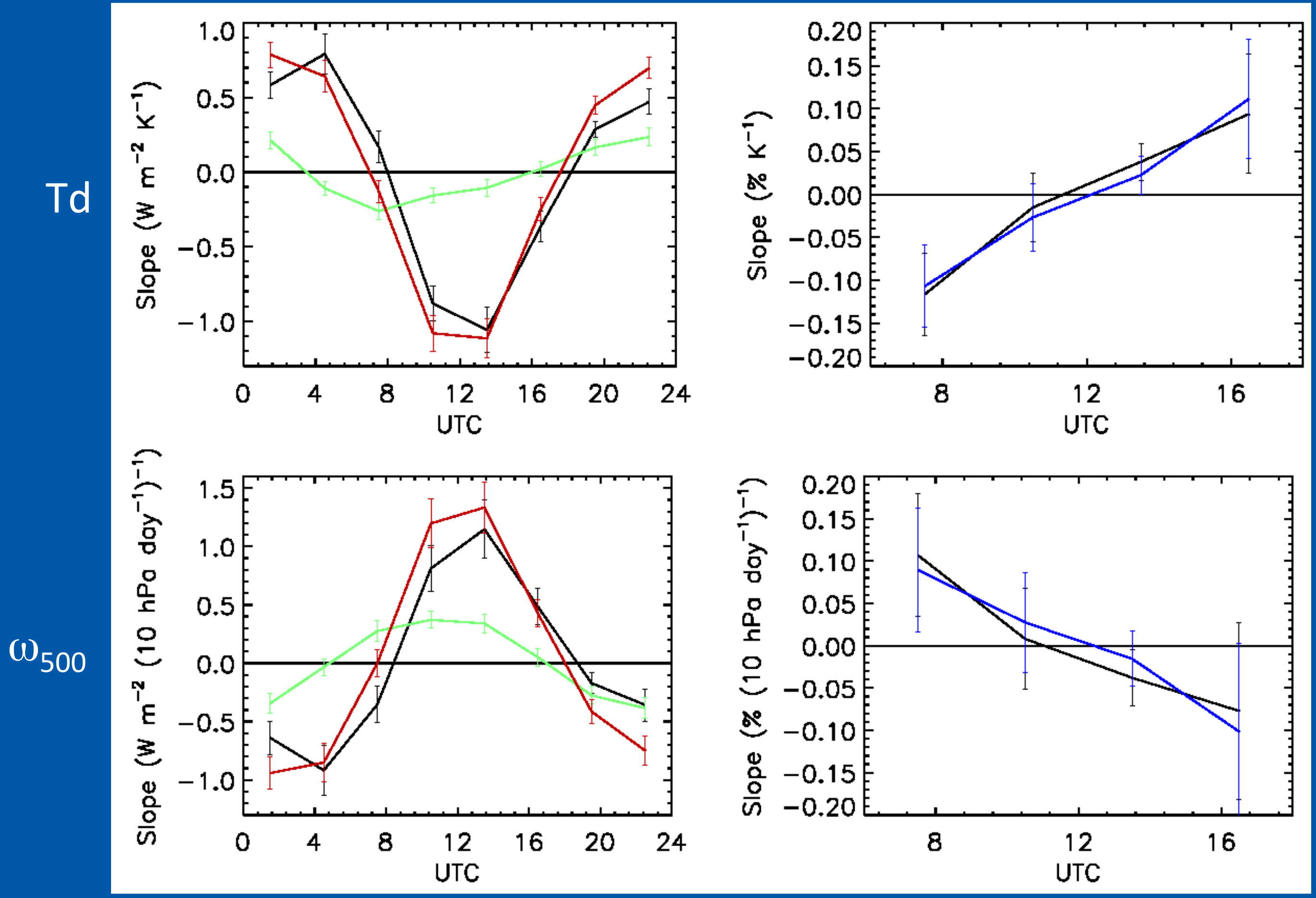
- A diurnal cycle shape is determined to occur in response to a dynamic or thermodynamic diagnostic if statistically significant differences are found between the regression slopes at two or more 3-hourly intervals .
  - Flat line (diurnally invariant regression relationship) => no diurnal cycle shape change
  - Curve line (diurnally varying regression relationship) => diurnal cycle shape change

Data

- CERES SYN Ed3
  - Synergistically combines CERES and GEO observations to create a 3-hourly data product by using GEO radiances to obtain diurnal shape and CERES for radiometric accuracy.
- CERES ISCCP D2-like
  - Combines radiance observations from Geostationary (GEO), Terra-MODIS, and Aqua-MODIS
  - Merging process normalizes the GEO retrievals to the MODIS retrievals providing a consistent set of daytime cloud properties
- ERA-Interim
  - Provides dynamic and thermodynamic state information (e.g., Ts, Td, CAPE, ω_{500}, $\theta_{E,SFC}$, $\theta_{E,850}$, and $\theta_{E,700}$)

Results

North Africa (land non-convective)

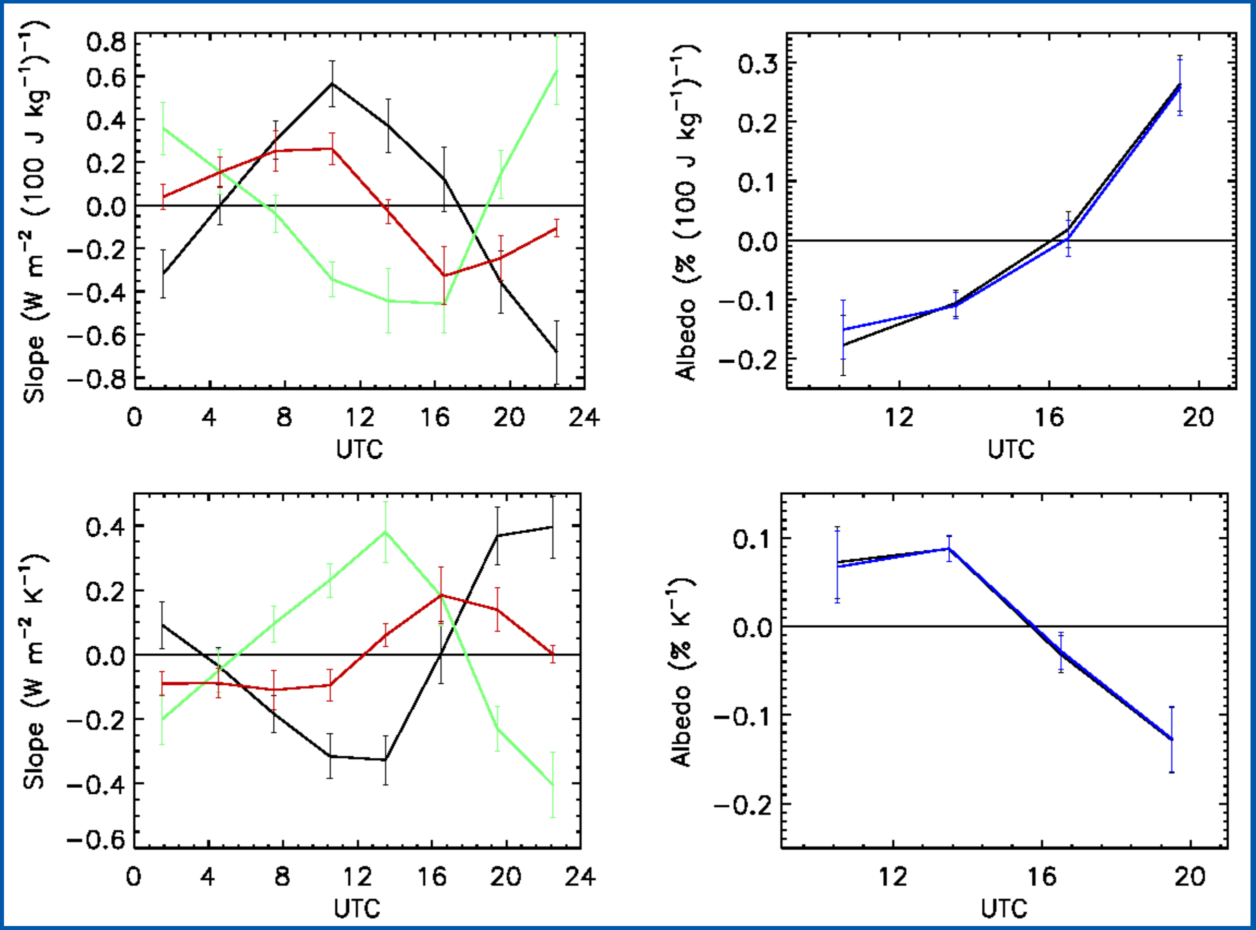


The results indicate that the monthly mean diurnal cycle in North Africa is sensitive to changes in T_d and ω_{500}.

Central South America (land convective)

CAPE

LTS

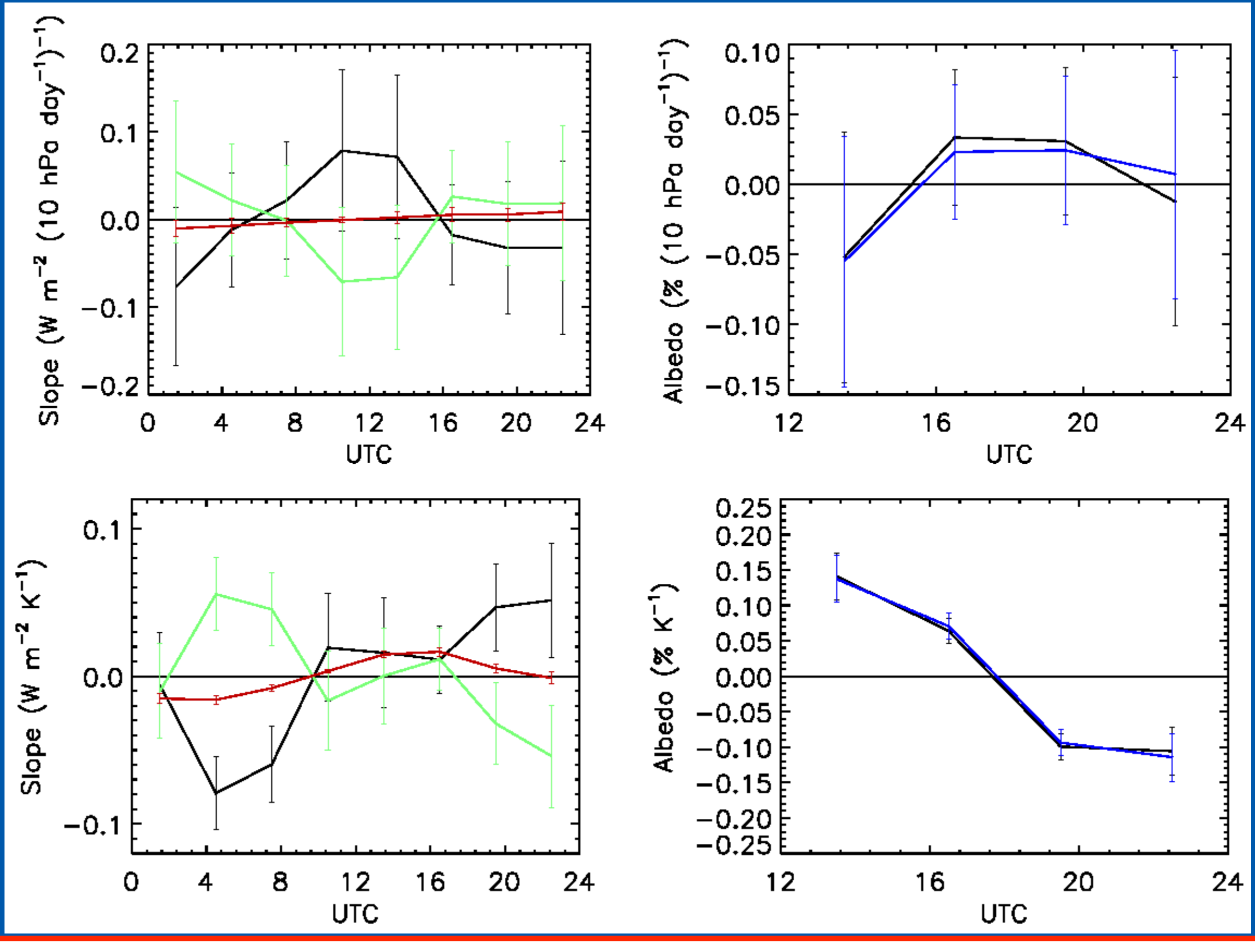


The monthly mean diurnal cycle shape for all flux variables exhibits statistically significant dependence on CAPE and LTS.

Peruvian Marine Stratocumulus (ocean non-convective)

ω_{500}

LTS

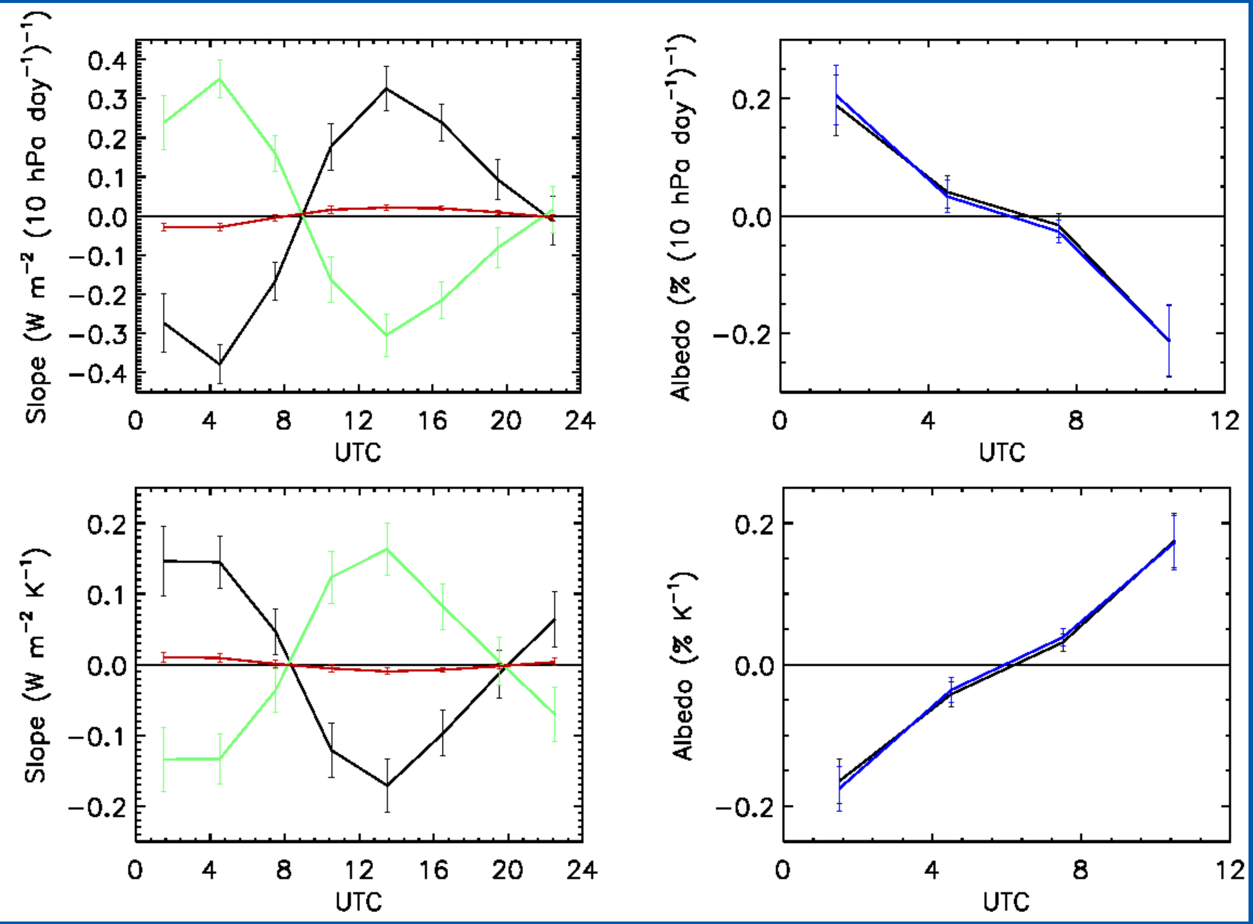


The results indicate that the monthly mean diurnal cycle in Peruvian Marine Stratocumulus is sensitive to changes in LTS.

Indian Ocean (ocean convective)

ω_{500}

$\theta_{E,850}$



The results indicate that the monthly mean diurnal cycle in Indian Ocean region is sensitive to changes ω_{500} and $\theta_{E,850}$.

Cloud population changes

		Cloud Optical Depth (τ)		
	CSA (CAPE)	Thin ($\tau < 3.6$)	Medium-thick ($3.6 < \tau < 23$)	Thick ($23 < \tau < 380$)
Cloud Top Pressure (p_c)	High ($10 < p_c < 440$ hPa)	0.59±0.13	0.31±0.08	0.17±0.03
	Middle ($440 < p_c < 680$ hPa)	0.05±0.01	0.19±0.04	0.04±0.01
	Low ($p_c > 680$ hPa),	0.23±0.11	0.07±0.05	0.01±0.01

	PMSc (LTS)	Thin ($\tau < 3.6$)	Medium-thick ($3.6 < \tau < 23$)	Thick ($23 < \tau < 380$)
Cloud Top Pressure (p_c)	High ($10 < p_c < 440$ hPa)	-0.03±0.07	0.05±0.03	0.01±0.01
	Middle ($440 < p_c < 680$ hPa)	0.00±0.01	0.05±0.03	0.01±0.01
	Low ($p_c > 680$ hPa),	-0.02±0.09	1.81±0.31	0.39±0.09

	InO (ω_{500})	Thin ($\tau < 3.6$)	Medium-thick ($3.6 < \tau < 23$)	Thick ($23 < \tau < 380$)
Cloud Top Pressure (p_c)	High ($10 < p_c < 440$ hPa)	-2.58±0.28	-2.37±0.17	-1.18±0.08
	Middle ($440 < p_c < 680$ hPa)	-0.16±0.03	-0.44±0.04	-0.04±0.01
	Low ($p_c > 680$ hPa),	0.44±0.32	0.26±0.14	0.01±0.01

The results indicate that a statistically significant change in cloud populations is found in the CSA, PMSc, and InO regions.

Main Points

- Point 1: Monthly anomalies in atmospheric dynamic and thermodynamic state contribute to TOA flux diurnal cycle variability.
- Point 2: This result corroborates the hypothesis that the sensitivity of the monthly mean TOA flux diurnal cycle to atmospheric conditions is related to a change in the cloud type distribution.
- Point 3: The proposed hypothesis, therefore, contributes to diurnal cycle variability, but explains only 10-20% of the total monthly mean diurnal cycle variability. Land-surface interaction processes are likely more important than atmospheric dynamic and thermodynamic forcing for explaining the variability.
- Point 4: One takeaway message is that the under a given monthly TOA flux or atmospheric state anomaly the monthly mean diurnal cycle shape is not free to vary randomly, but rather has a preferred diurnal cycle shape.

Monthly Mean Regression

NAf	OLR' ($W\ m^{-2}$)	OLRCLR' ($W\ m^{-2}$)	LWCF' ($W\ m^{-2}$)	α' (%)	α_{cld}'(%)
T_d (K^{-1})	-1.84±0.34	-0.71±0.21	1.14±0.20	0.05±0.04	0.20±0.04
ω_{500} (10 hPa day^{-1})	2.69±0.52	0.59±0.33	-2.10±0.27	-0.12±0.05	-0.28±0.06
CSA					
CAPE (100 J kg^{-1})	-2.07±0.58	-0.76±0.25	1.36±0.52	0.01±0.12	0.06±0.13
LTS (K^{-1})	-0.31±0.38	-0.43±0.16	-0.17±0.34	0.31±0.08	0.29±0.08
PMSc					
LTS (K^{-1})	-0.80±0.21	-0.38±0.13	0.36±0.11	0.76±0.09	0.75±0.09
ω_{500} (10 hPa day^{-1})	0.17±0.05	0.07±0.03	-0.10±0.03	-0.02±0.03	-0.02±0.03
InO					
ω_{500} (10 hPa day^{-1})	7.92±0.47	1.83±0.16	-6.05±0.42	-3.88±0.26	-3.82±0.26
$\theta_{E,850}$ (K^{-1})	-3.28±0.47	-1.00±0.12	2.29±0.39	1.46±0.25	1.41±0.25

Application of Regression model

	OLR	OLR_{CLR}	LWCF	α_{DC}	$\alpha_{cld, DC}$
NAf (T_D)	12%	18%	4%	1%	1%
CSA (CAPE)	4%	2%	4%	7%	7%
InO (ω_{500})	6%	2%	6%	4%	4%
Peru (LTS)	1%	6%	1%	6%	6%