Quantifying Diurnal Cloud Radiative Effects in the Tropical Western Pacific

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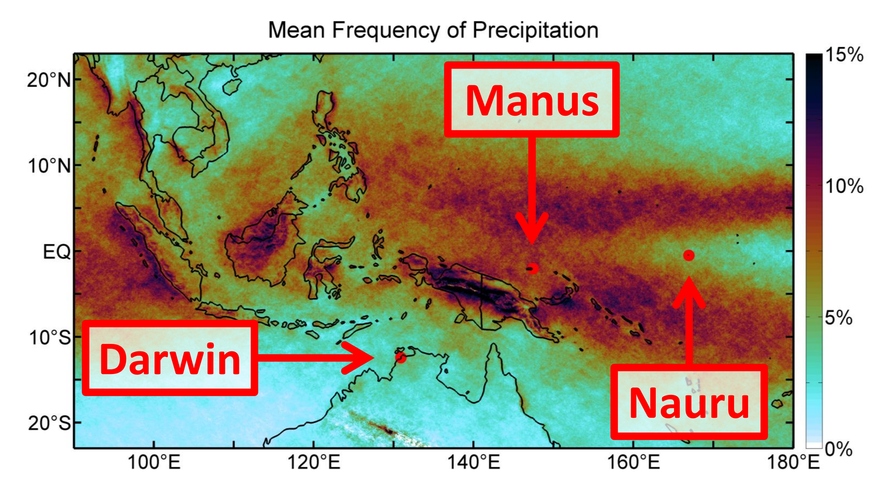
Motivation and Goals

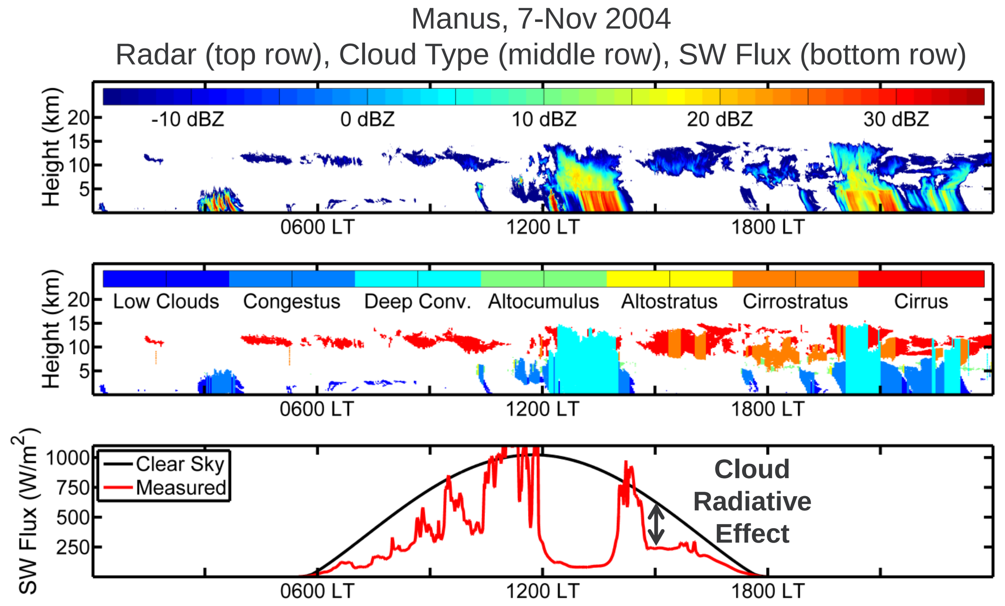
Shortwave (SW) and longwave (LW) cloud radiative effects (CREs) modify the surface energy budget and climate models often struggle to replicate observed patterns in cloud frequency and CREs. We utilize long-term datasets from the three U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) sites --- Manus, Nauru, and Darwin --- in the tropical western Pacific (TWP) to establish clear observational targets that models can be tested against and to investigate the following science questions:

1) What are the primary sources of variability in cloud frequency and SW and LW CREs for tropical clouds?
2) What types of tropical clouds have the largest impact on the surface energy budget?
3) How much would small model errors in tropical cloud frequency bias their total SW CRE?



Data and Methods

By applying a simple cloud classification scheme to the ARM radar/lidar cloud mask product we are able to attribute CREs in the surface radiative flux data to specific types of clouds. In the case of multilayer clouds, only the lowest clouds in the column are considered since their impact on the surface energy budget is most direct. Periods when the surface rainrate is >1 mm hr^{-1} are removed to limit attenuation effects.



Cloud Type Classification Scheme

Type	Base	Top	Thickness
Low	< 4 km	< 4 km	< 4 km
Congestus	< 4 km	4-8 km	≥ 1.5 km
Deep Convection	< 4 km	> 8 km	≥ 1.5 km
Altocumulus	4-8 km	4-8 km	< 1.5 km
Altostratus	4-8 km	4-8 km	≥ 1.5 km
Cirrostratus	4-8 km	> 8 km	≥ 1.5 km
Cirrus	> 8 km	> 8 km	N/A

Publications

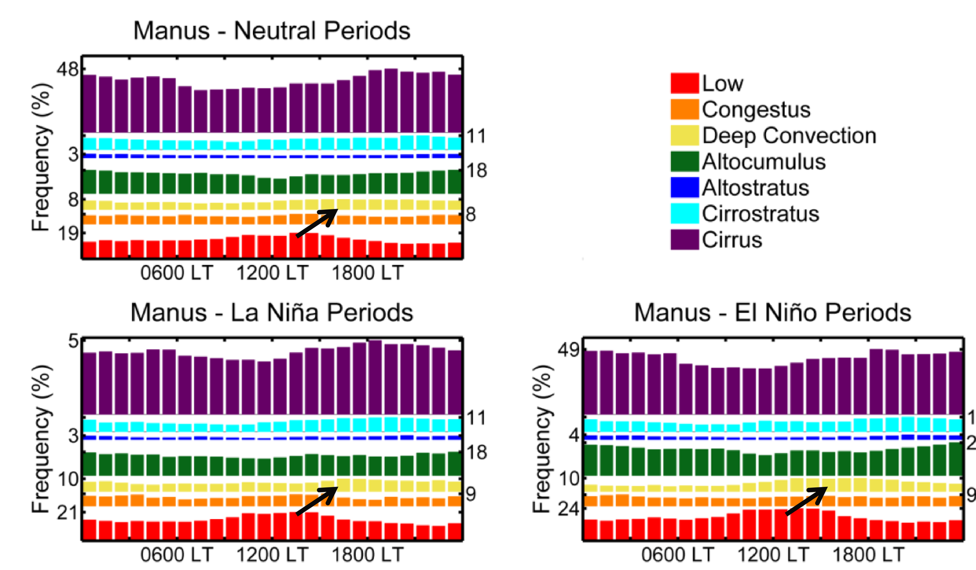
Burleyson, C. D., C. N. Long, and J. M. Comstock, 2015: Quantifying diurnal cloud radiative effects by cloud type in the tropical western Pacific. *J. Appl. Meteor. Climatol.*, **54**, 1297-1312.

Diurnal Cycles of Cloud Frequency

1) All three sites have significant diurnal cycles in cloud frequency.
2) Each responds in a different way to El Niño/Southern Oscillation (ENSO) or monsoon-related variations in large-scale conditions.
3) There is evidence of an afternoon transition from shallow to deep convective clouds (see arrows below), although more work is needed to verify this.

Manus

- Largest mean SW CREs due to high cloud frequency in all conditions

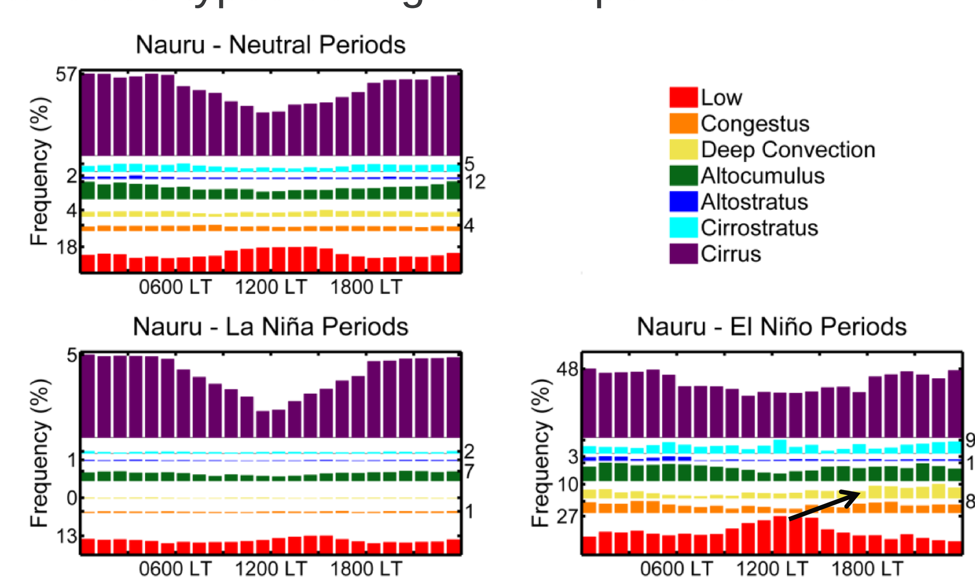


	SW CRE (W m^{-2})	LW CRE (W m^{-2})
Neutral Periods	-94.4	15.5
La Niña Periods	-90.2	14.5
El Niño Periods	-102.4	16.3

Nauru

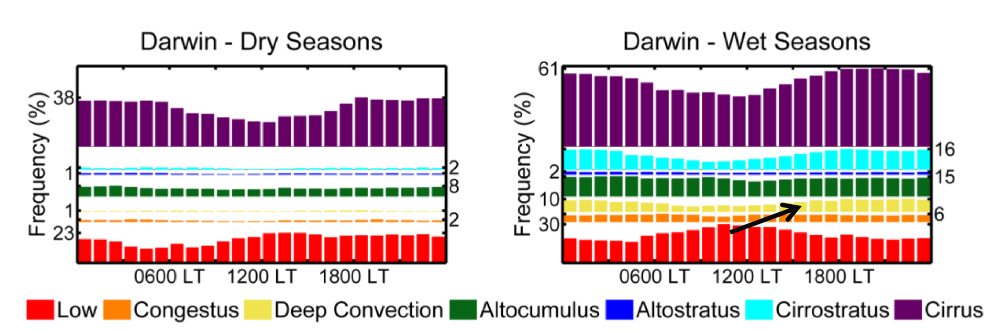
- Cloud frequency and mean CREs are most sensitive to ENSO phase
- Suppression of deeper convective clouds during La Niña periods
- Enhanced frequency of all cloud types during El Niño periods

	SW CRE (W m^{-2})	LW CRE (W m^{-2})
Neutral Periods	-68.7	12.9
La Niña Periods	-45.9	10.0
El Niño Periods	-92.3	15.0



Darwin

- Strong monsoon-related variability in cloud frequency and mean CREs
- All cloud types are suppressed during the dry seasons and deeper convective clouds are almost entirely absent
- Frequent cirrus and cirrostratus/anvil clouds during the wet seasons



	SW CRE (W m^{-2})	LW CRE (W m^{-2})
Dry Seasons	-23.5	7.8
Wet Seasons	-95.0	16.4

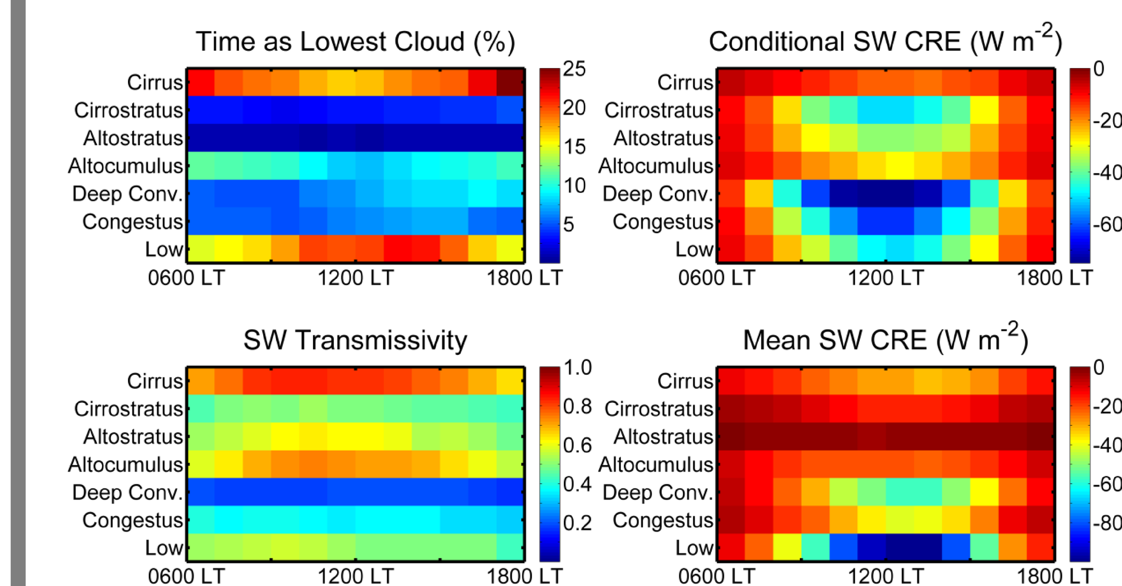
Conclusions

1) Most of the variability in SW and LW CREs is driven by changes in the absolute frequency of clouds.
2) Low clouds have the largest mean SW CRE. This is largely due to how often they are present as the lowest cloud in the column.
3) Small errors in the absolute frequency of deeper convective clouds can lead to large biases the total SW CRE at the surface.

Cloud Radiative Effects by Cloud Type

We examine the diurnal cycle of SW CREs by cloud type to see which cloud types have the largest impact on the surface energy budget.

- SW transmissivity for a given cloud type is roughly constant; as such, conditional SW CREs peak with the largest clear-sky SW fluxes
- While deep convection and cumulus congestus have larger conditional SW CREs, low clouds have the largest mean SW CRE because they are often present as the lowest cloud in the column

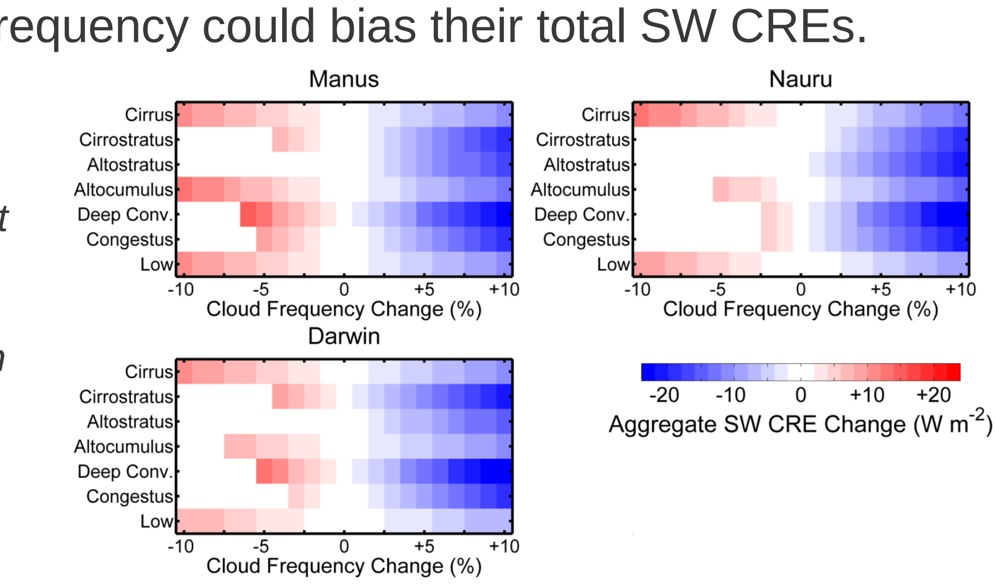


The diurnal cycle of cloud frequencies and SW CREs for Manus. Results for the other two sites are similar (not shown).

Sensitivity to Frequency Errors

We use observations of SW CREs to quantify to what degree model errors in absolute cloud frequency could bias their total SW CREs.

Change in the total SW CRE at the surface that would result from small (+/-10%) errors in the absolute frequency of each type of cloud.



- Errors as small as +/-10% in the frequency of cumulus congestus or deep convection would change the total SW CRE at the surface by up to 20 W m^{-2}, or roughly 20% of the mean value
- Errors in cloud frequency produce larger biases compared to errors in the timing of cloud formation across the diurnal cycle (not shown)

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