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Quantifying Cloud Radiative Effects in the Tropical Western Pacific

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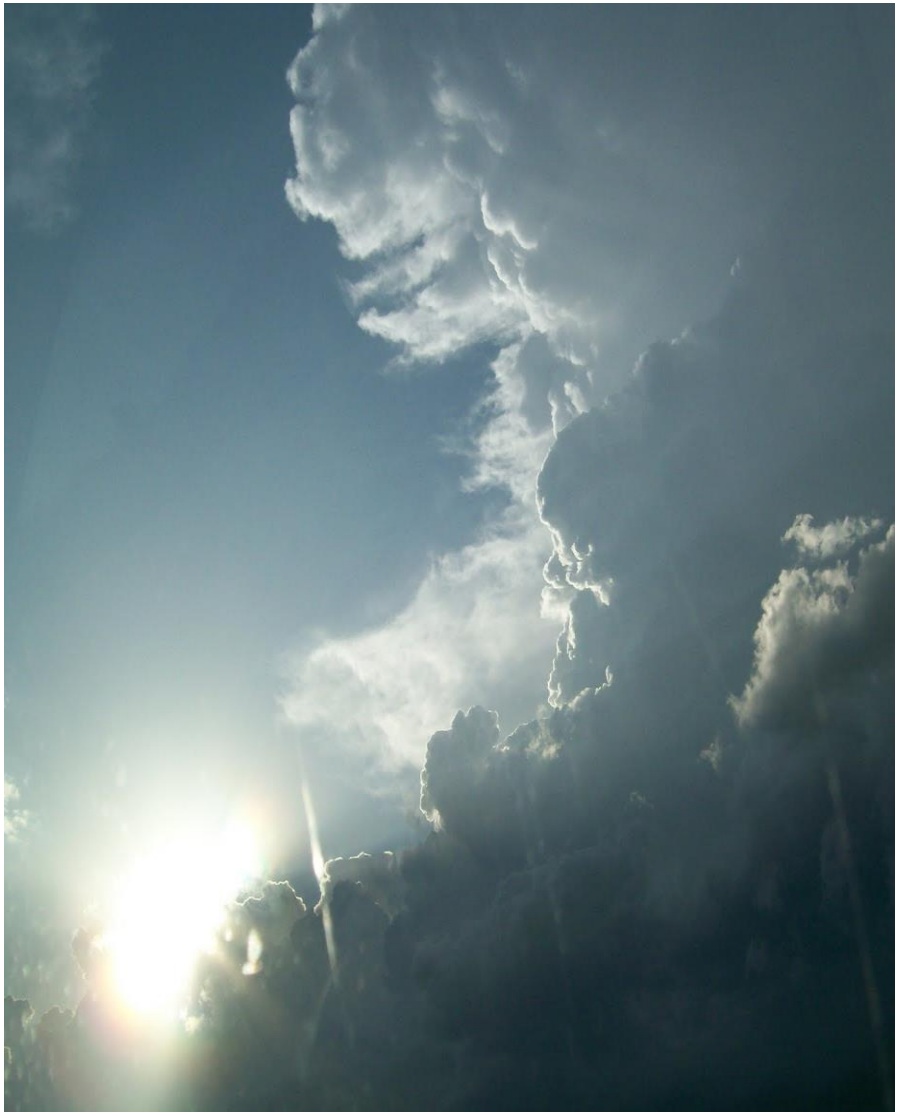
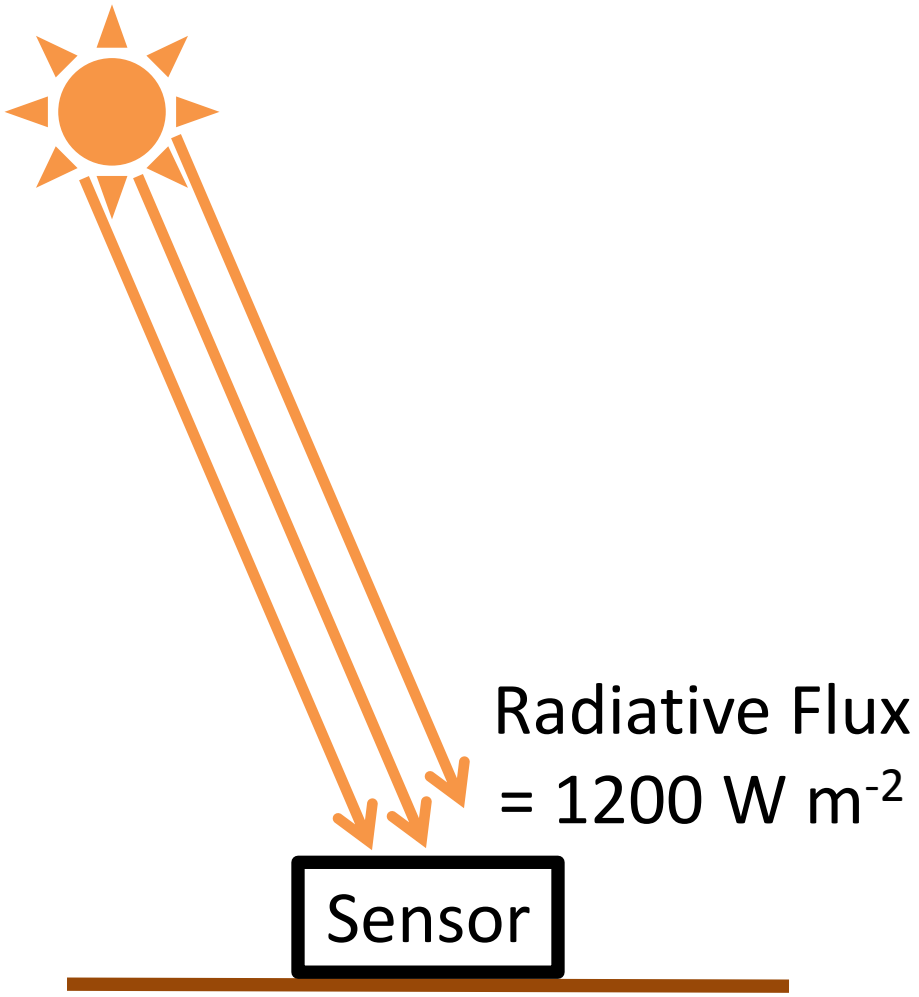
What Are Cloud Radiative Effects?





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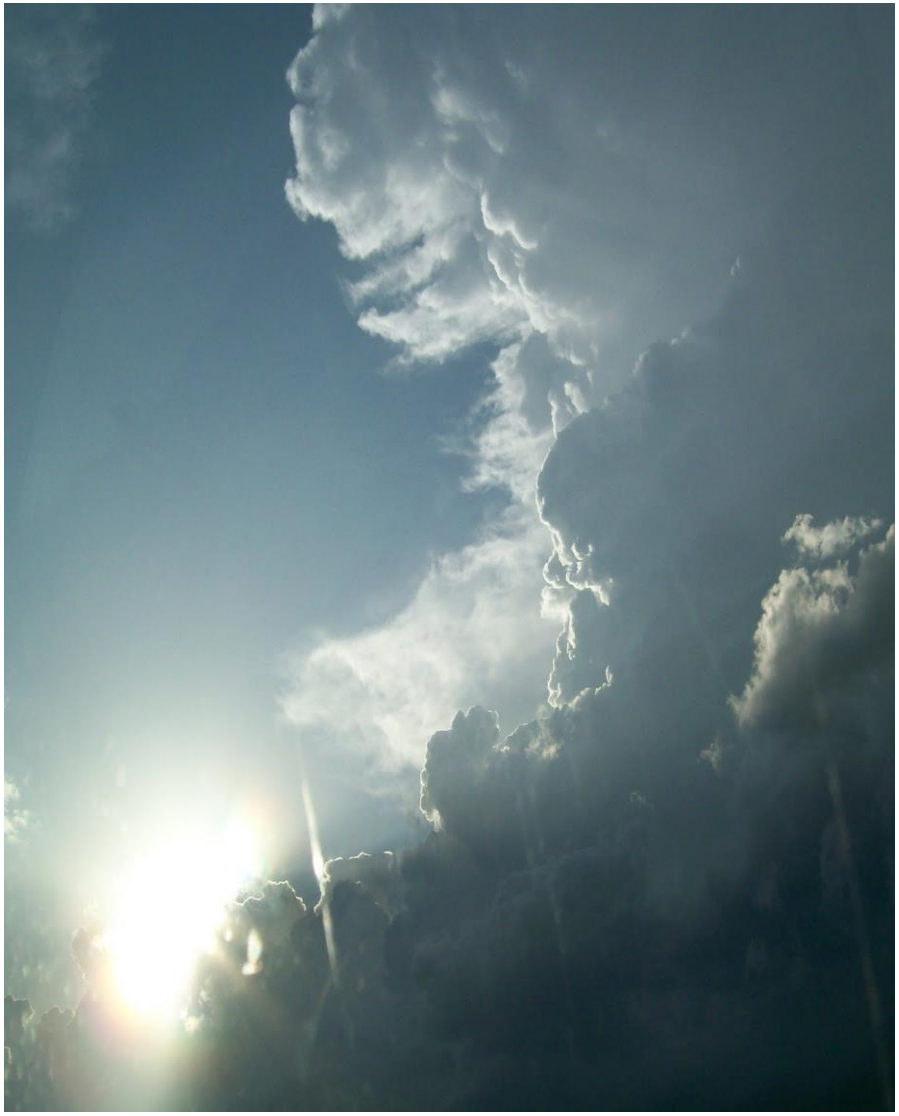
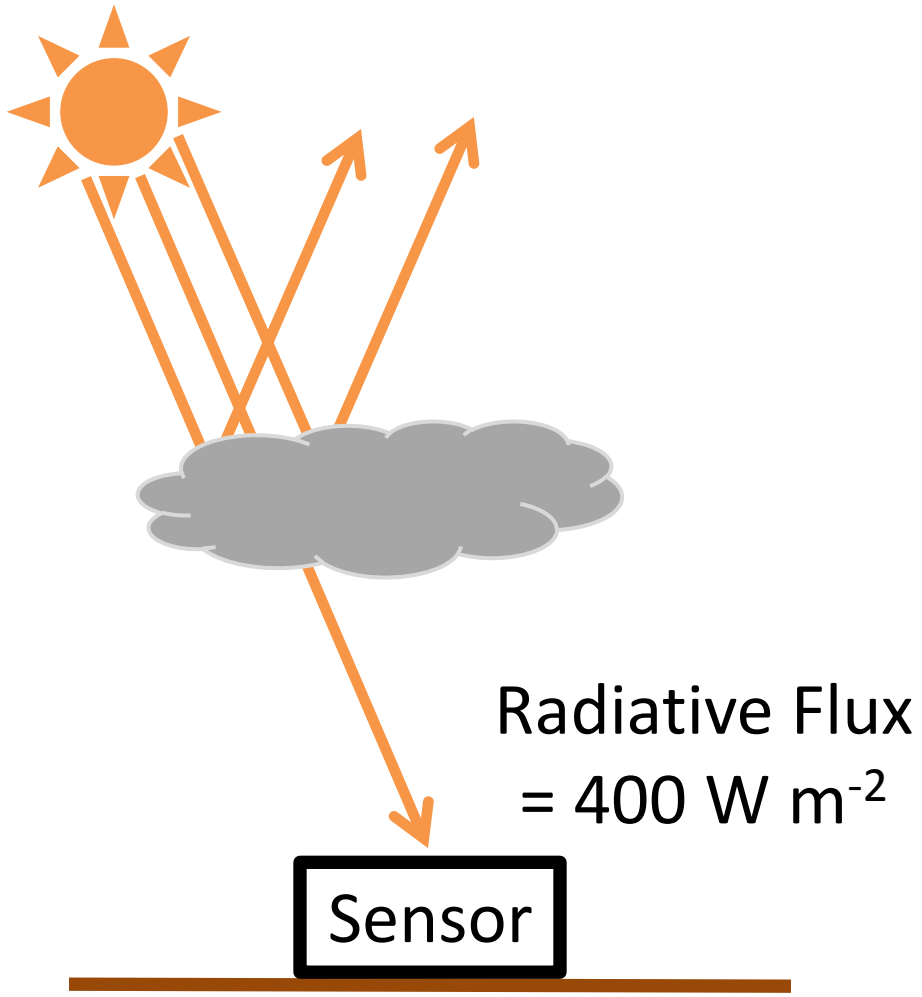
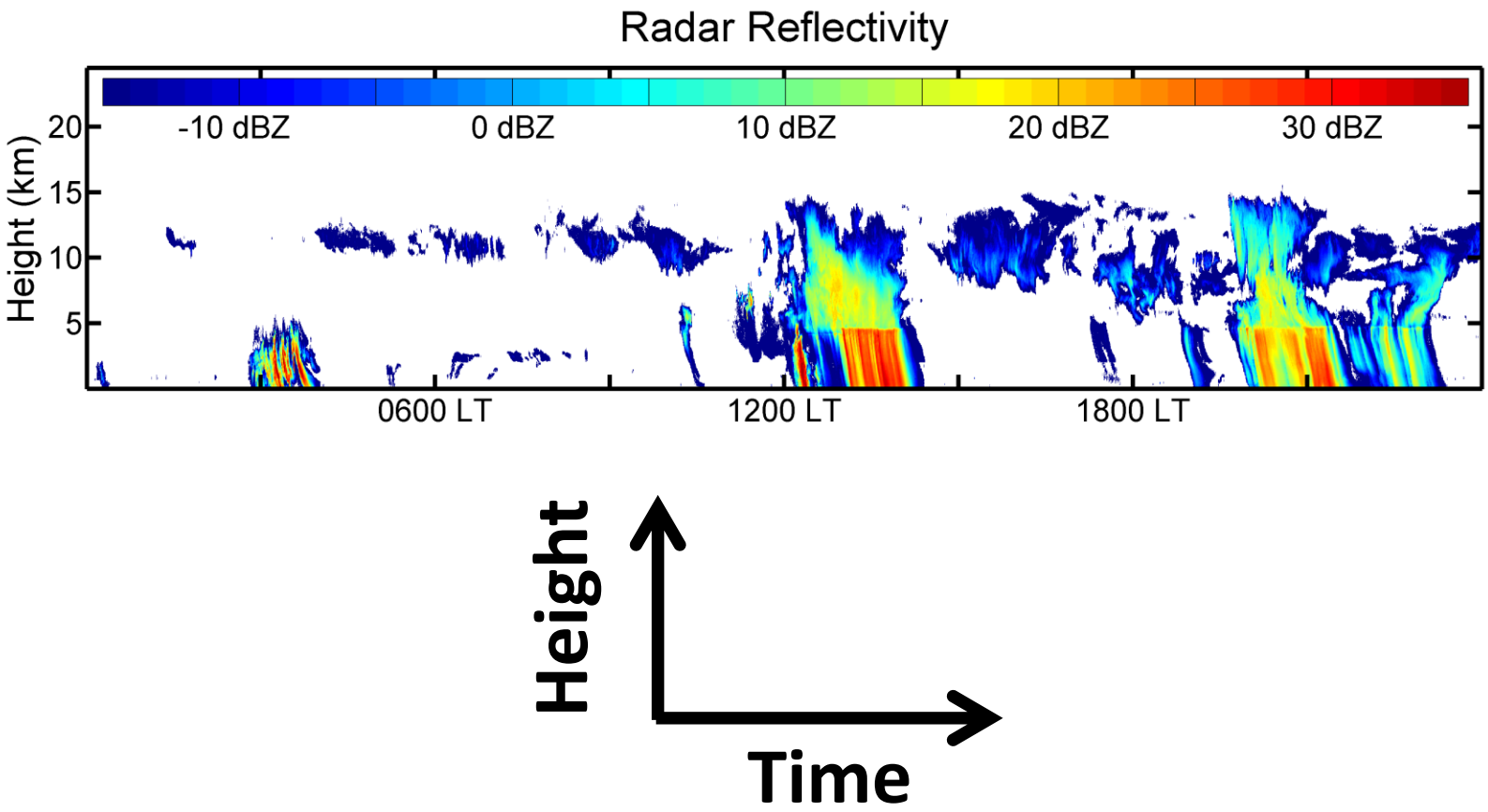




CRE = 1200 W m^{-2} - 400 W m^{-2}

What Are Cloud Radiative Effects?

An example from the tropical western Pacific region…



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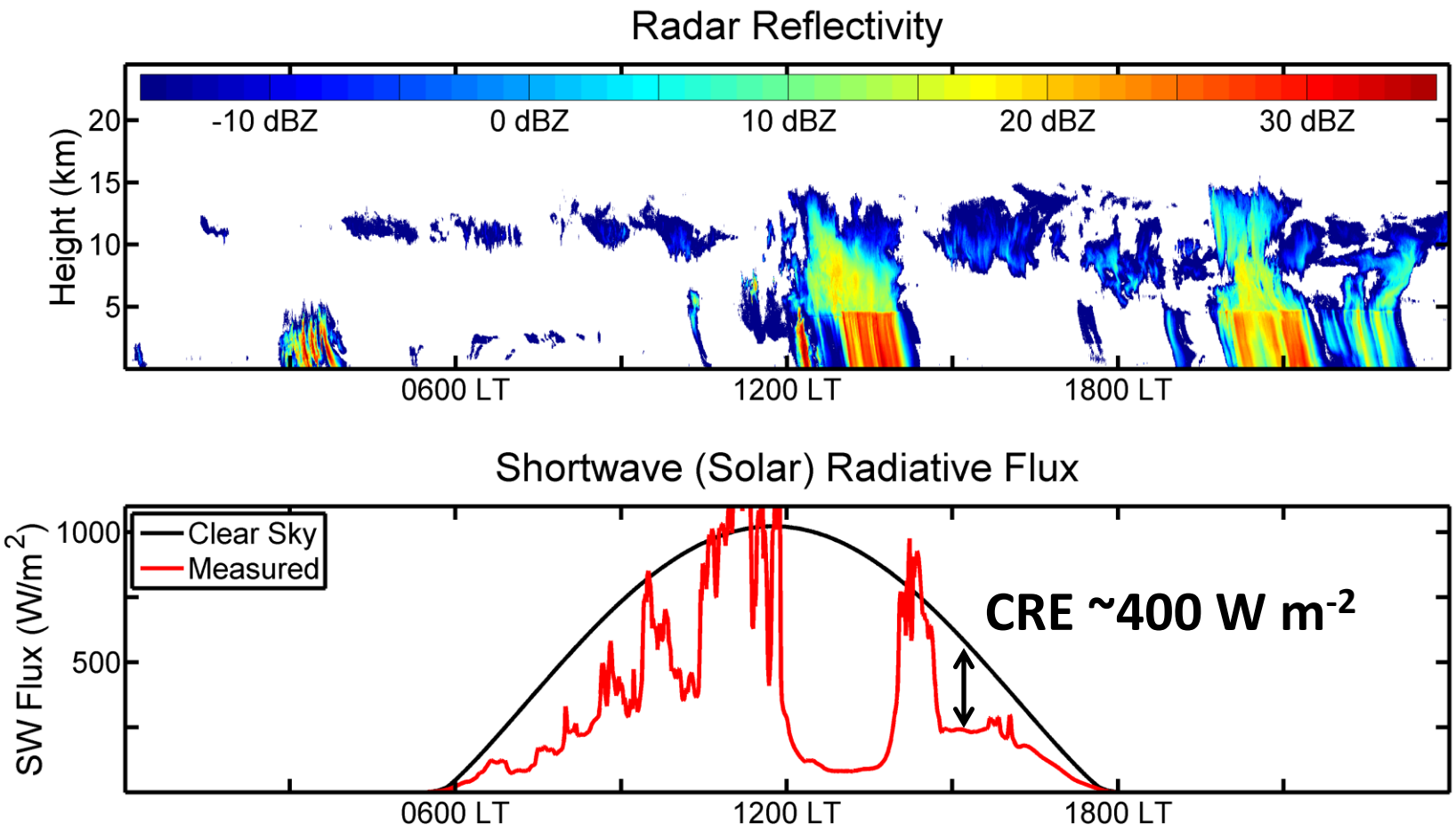
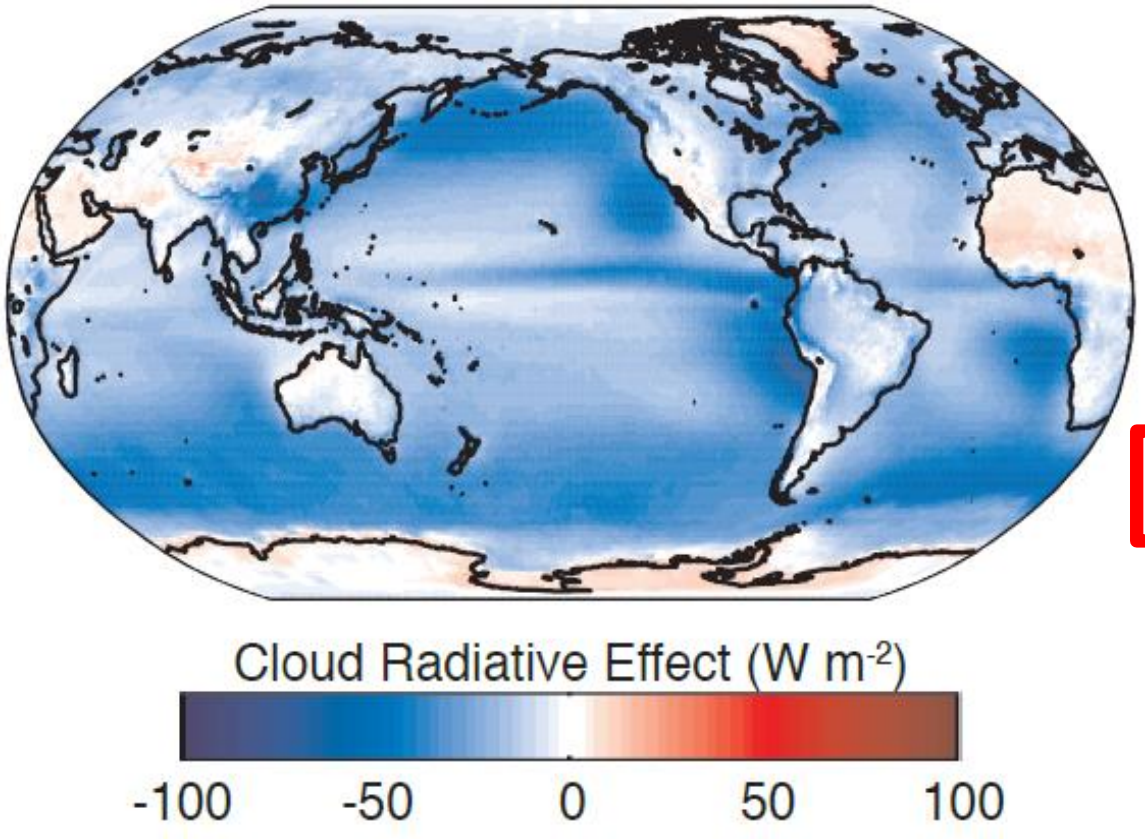


Why Do Cloud Radiative Effects Matter?



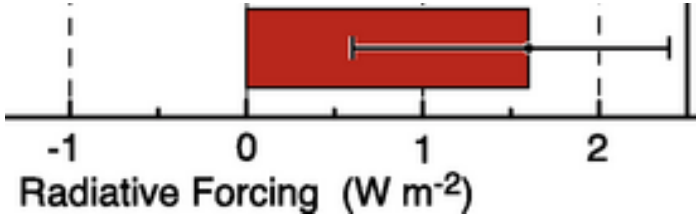
Annual mean total cloud radiative effect (data and images are from the 5th Assessment Report of the Intergovernmental Panel on Climate Change).

Annual Global Mean = -21.1 W m^{-2} ± 2 W m^{-2}

Cloud Feedback= +0.6 W m^{-2} °C^{-1}

-0.2 to +2.0 W m^{-2} °C^{-1}

Total Anthropogenic Radiative Forcing



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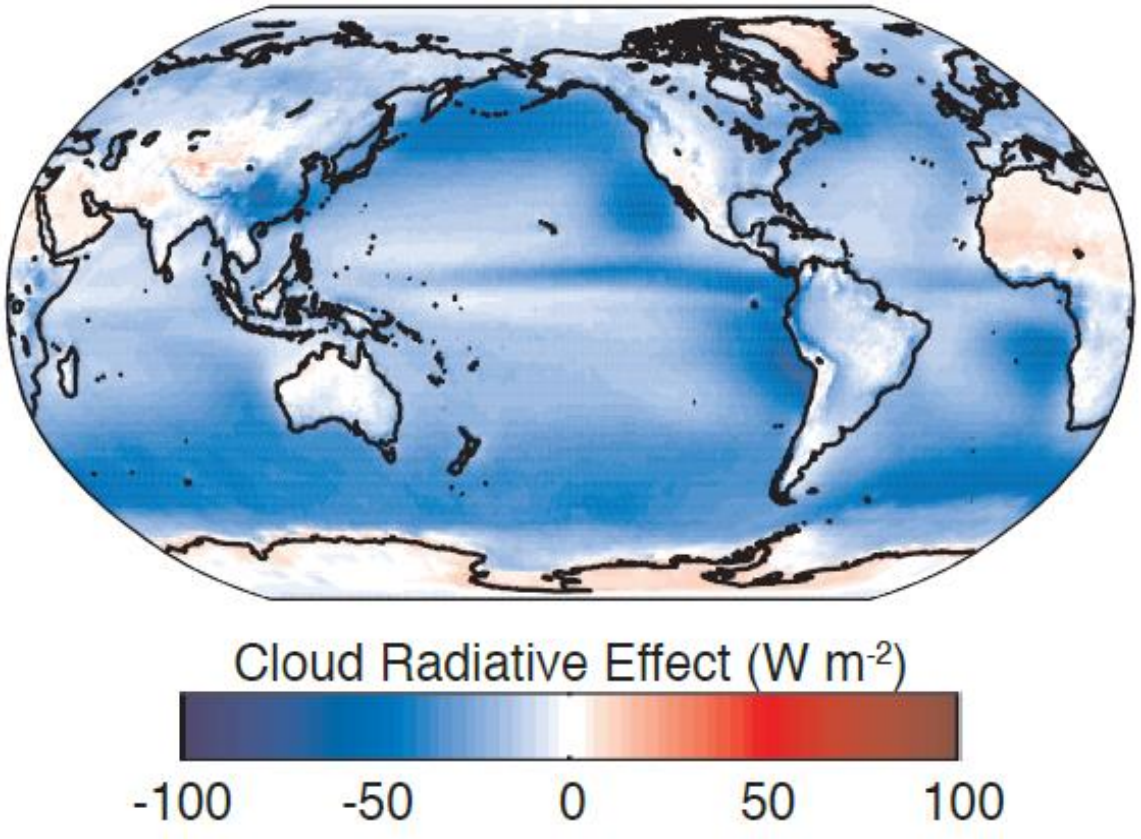

Annual mean total cloud radiative effect (data and images are from the 5th Assessment Report of the Intergovernmental Panel on Climate Change).

Clouds are one of the largest remaining sources of uncertainty and cause of intermodel spread in climate sensitivity and feedbacks (e.g. Dufresne and Bony 2008)

Research Questions

1) What are the primary sources of variability in cloud radiative effects for tropical clouds?

2) What type of tropical clouds have the largest impact on the net cloud radiative effect?

3) How much do small errors in tropical cloud frequency or the timing of cloud formation matter to the net cloud radiative effect?

DOE Atmospheric Radiation Measurements

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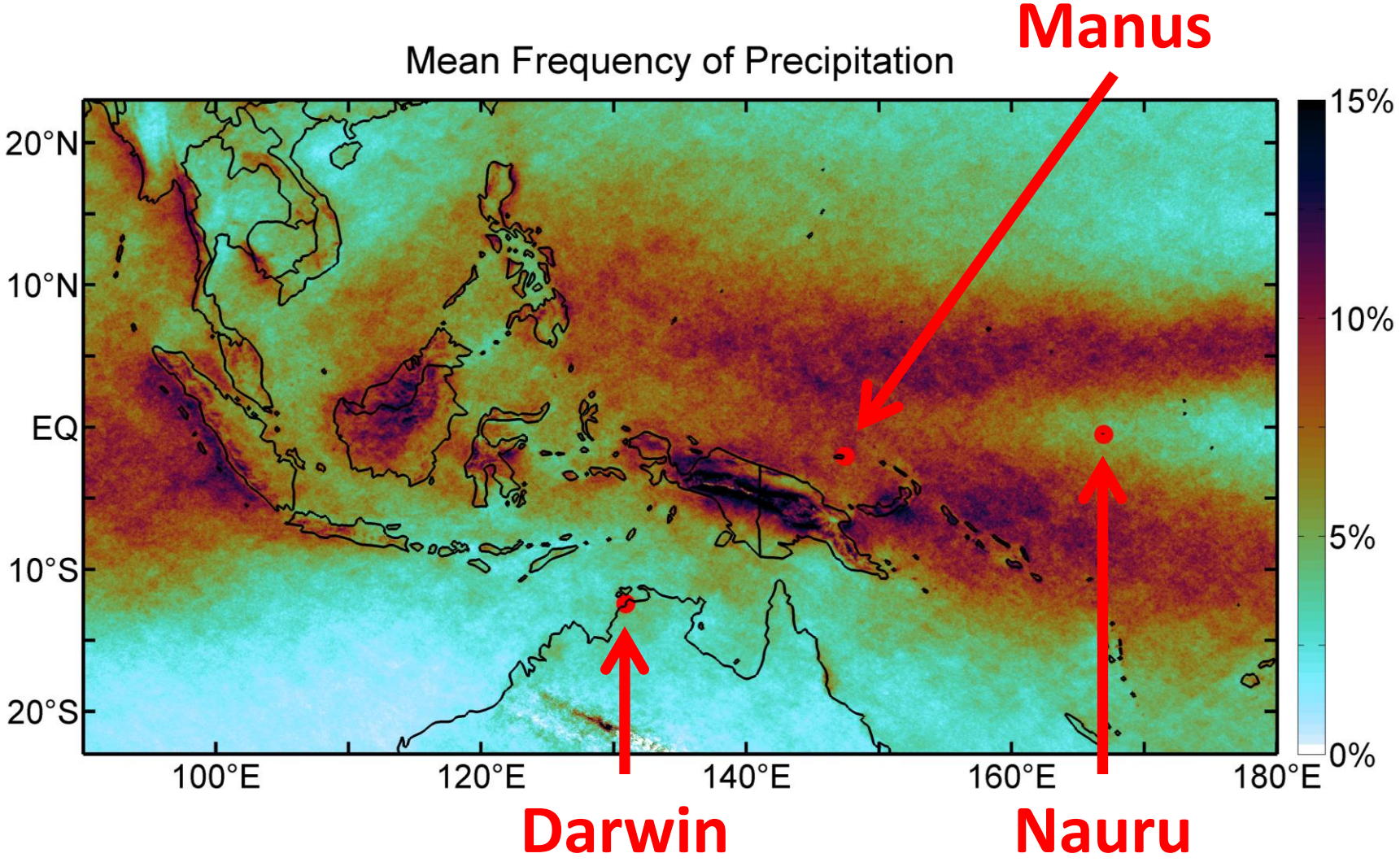
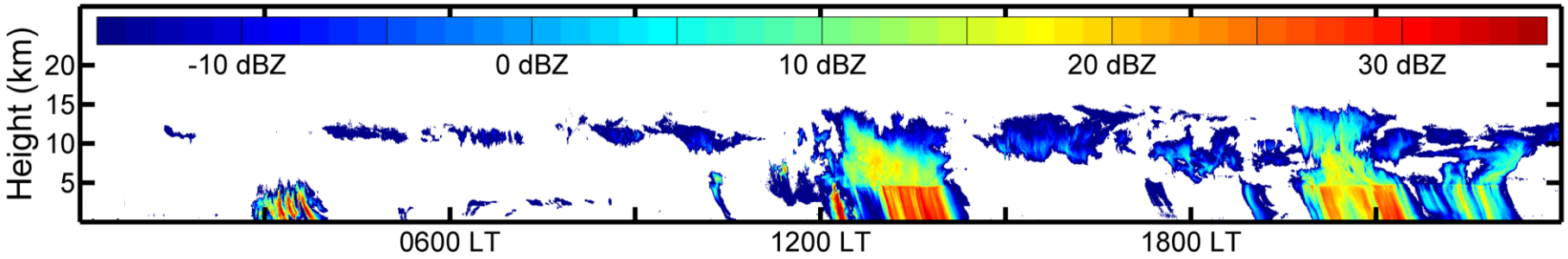
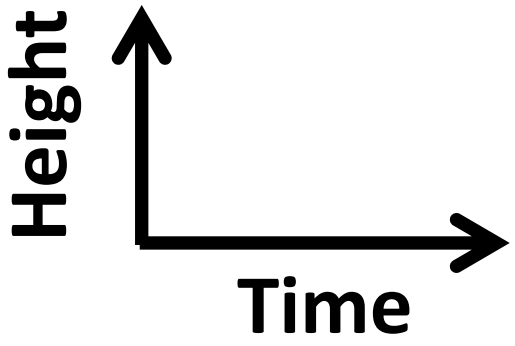
Three sites have been collecting long-term measurements…



Processing Cloud Types

An example from the tropical western Pacific region…





Cloud type	Cloud base	Cloud top	Cloud thickness
Low clouds	<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/anvil	4–8 km	>8 km	≥1.5 km
Cirrus	>8 km	>8 km	No restriction

Low (Cumulus)

Deep Convection

Cirrus

Processing Cloud Types

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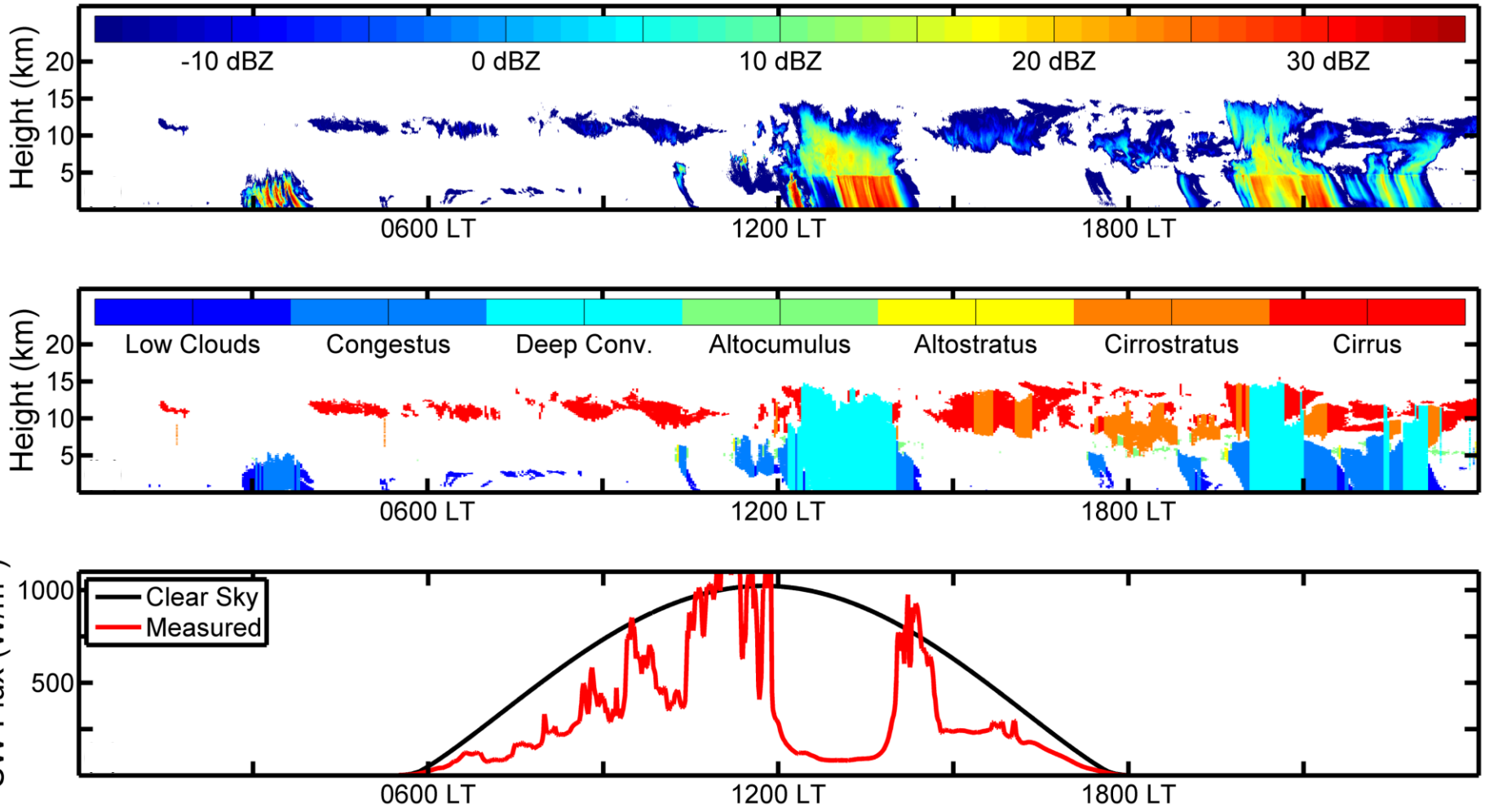

Diurnal Cycles in Cloud Frequency

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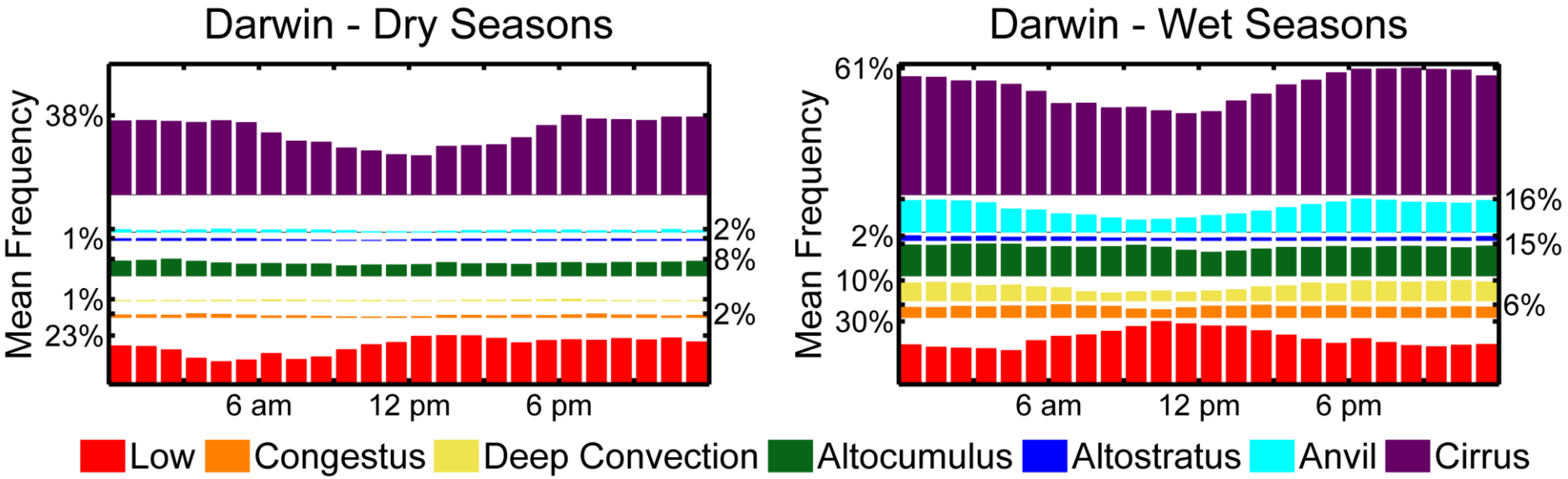
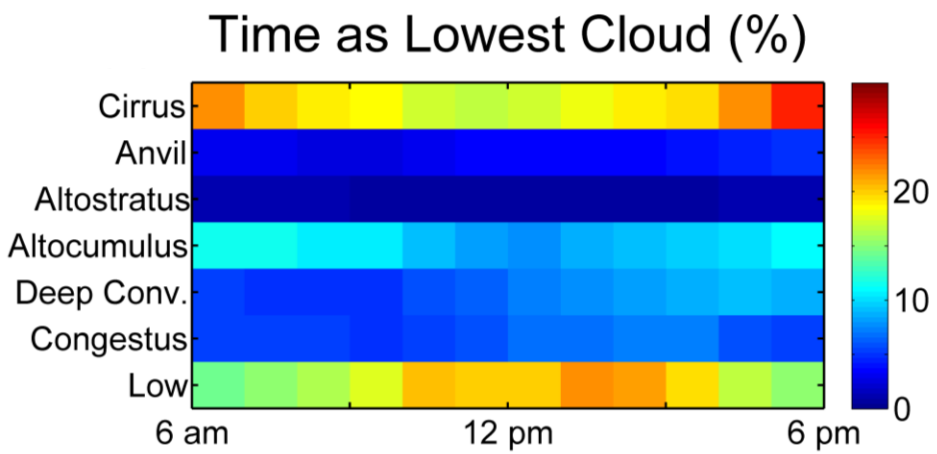
Data from Darwin

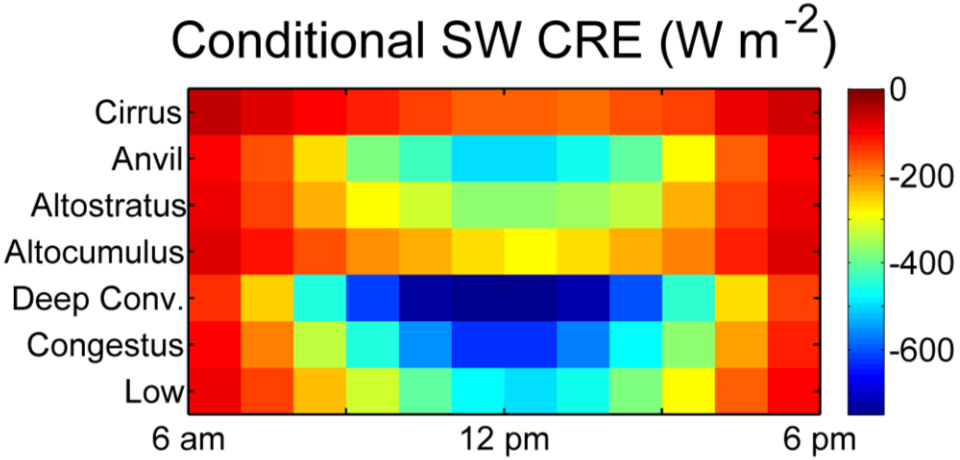


All three sites have significant diurnal and seasonal cycles in total cloud fraction and the relative frequency of each cloud type.

Shortwave (Solar) Cloud Radiative Effects

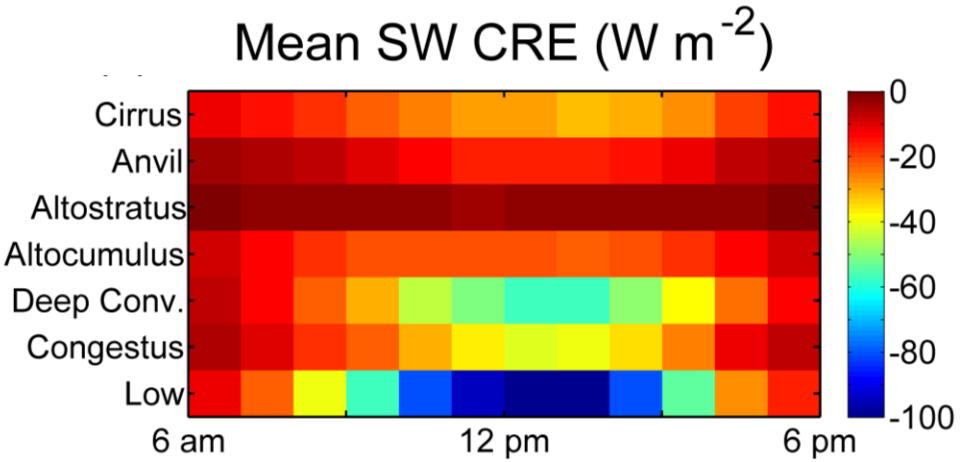
Data from Manus





1) Only concerned with the lowest cloud in the column (most direct radiative impact).

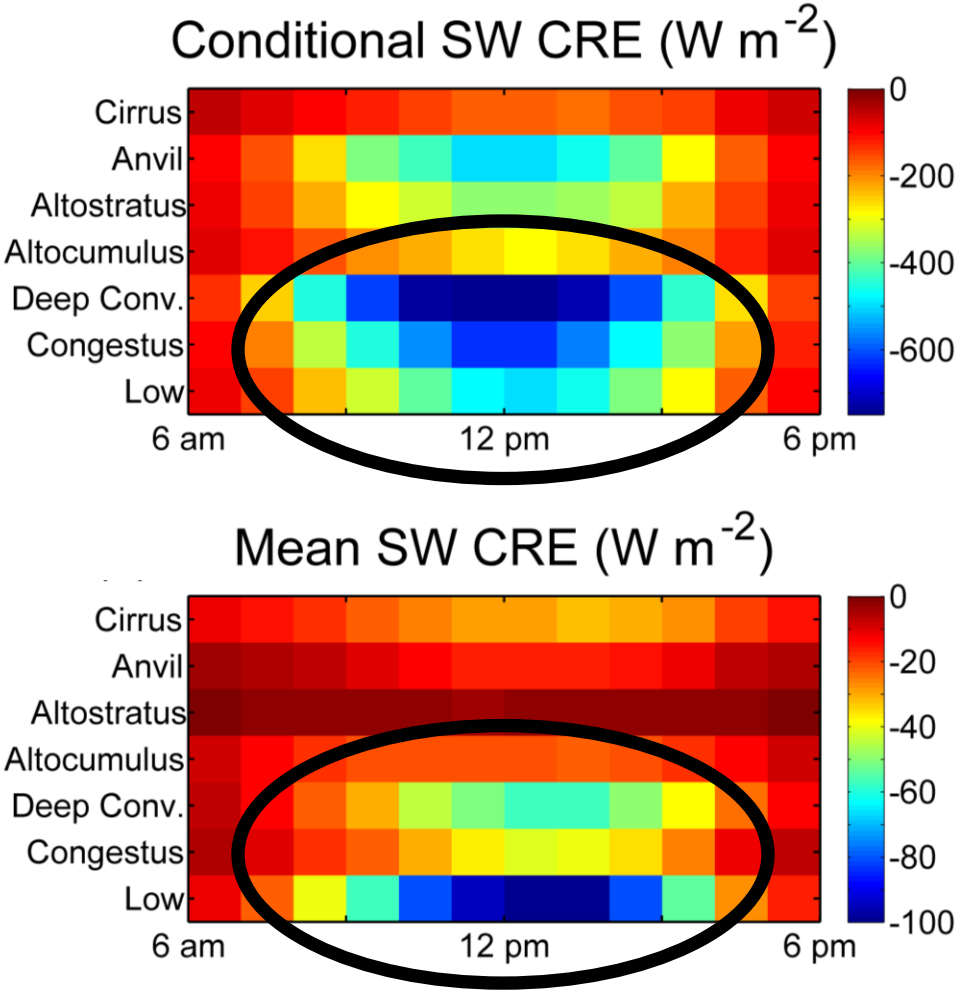
2) Only concerned with daylight hours when the sun is up.



Shortwave (Solar) Cloud Radiative Effects

Data from Manus

Although deeper clouds (cumulus congestus & deep convection) have a larger conditional shortwave cloud radiative effect, they have a smaller impact on the total cloud radiative effect compared to low clouds because they occur only infrequently.



What are the Impacts of Errors in the Frequency of Each Cloud Type?

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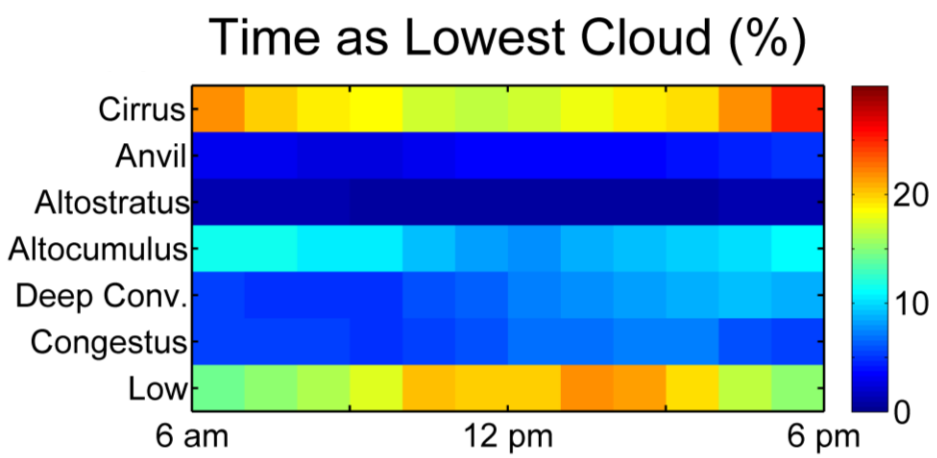
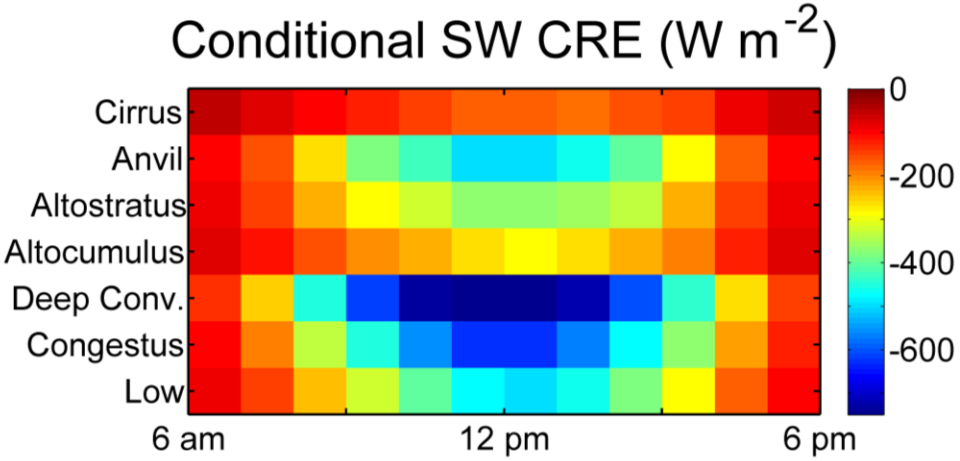
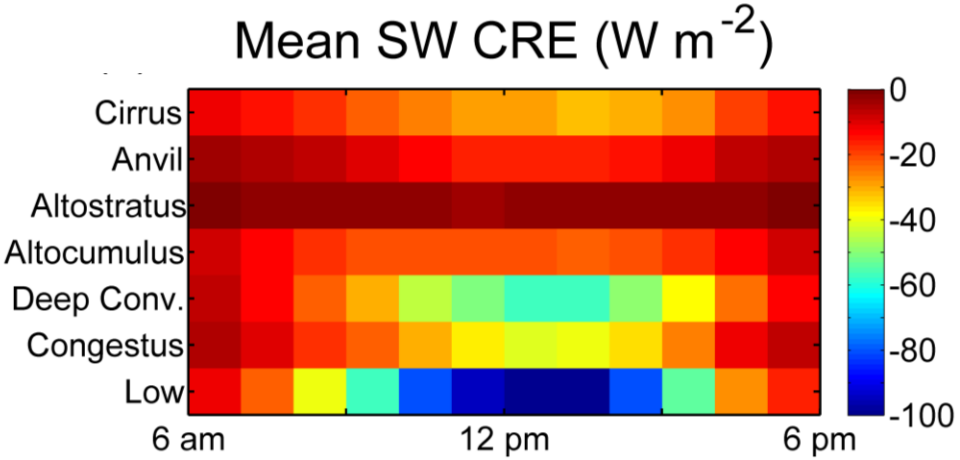
Data from Manus







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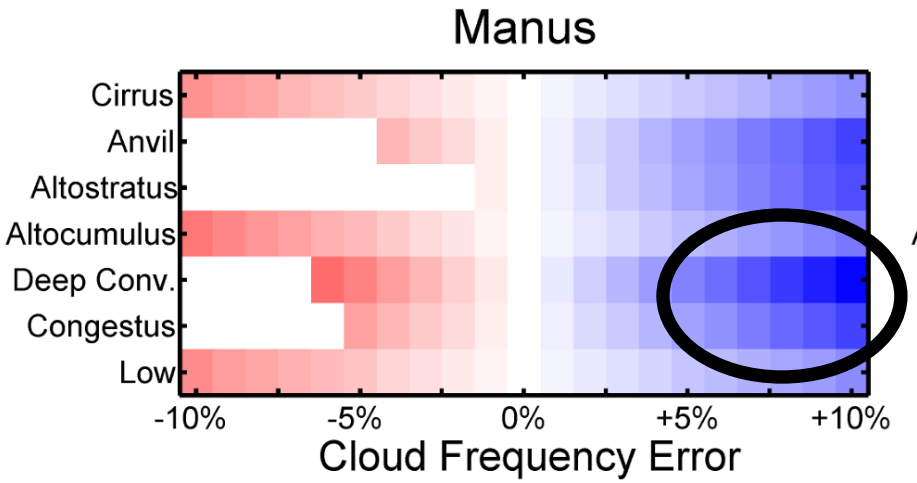

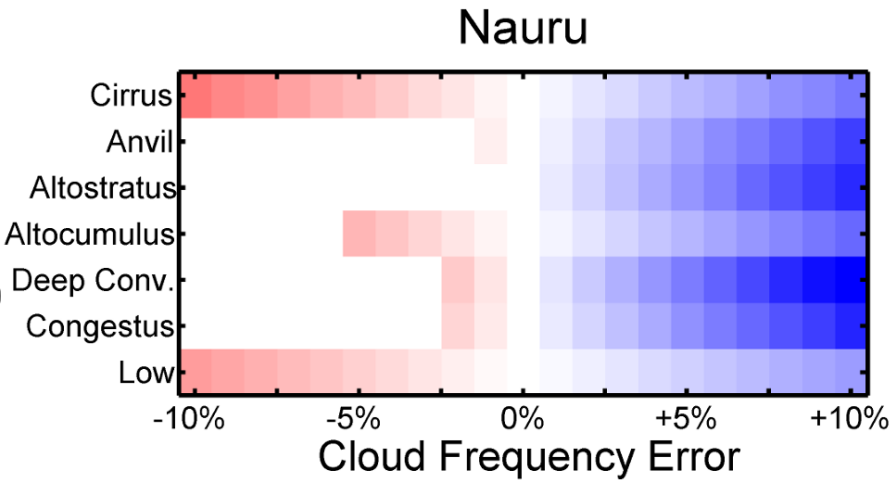

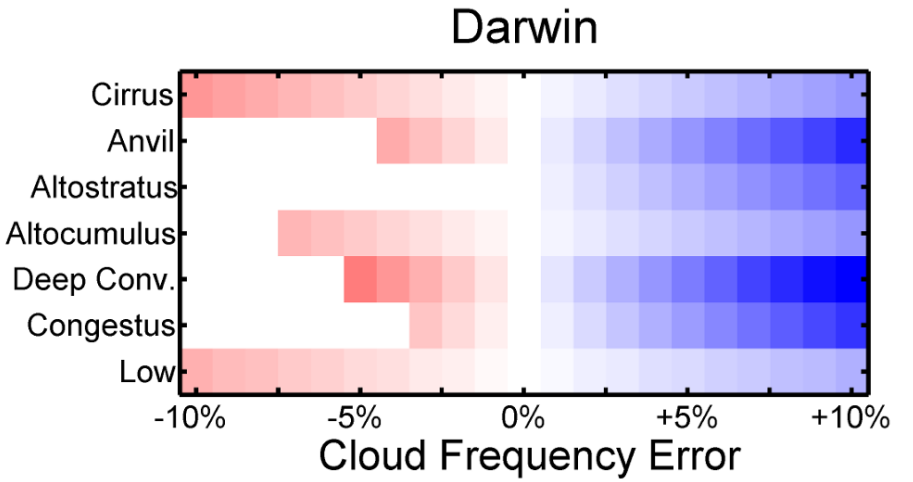

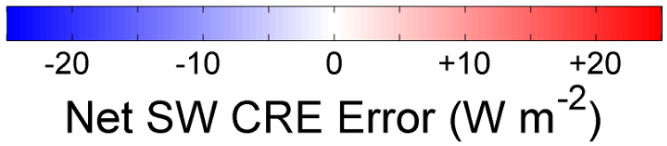

Small errors in the frequency of deep clouds can impact the total cloud radiative effect by up to -20 W m^{-2} (~20% of the mean).

What are the Impacts of Errors in the Timing of Each Cloud Type?

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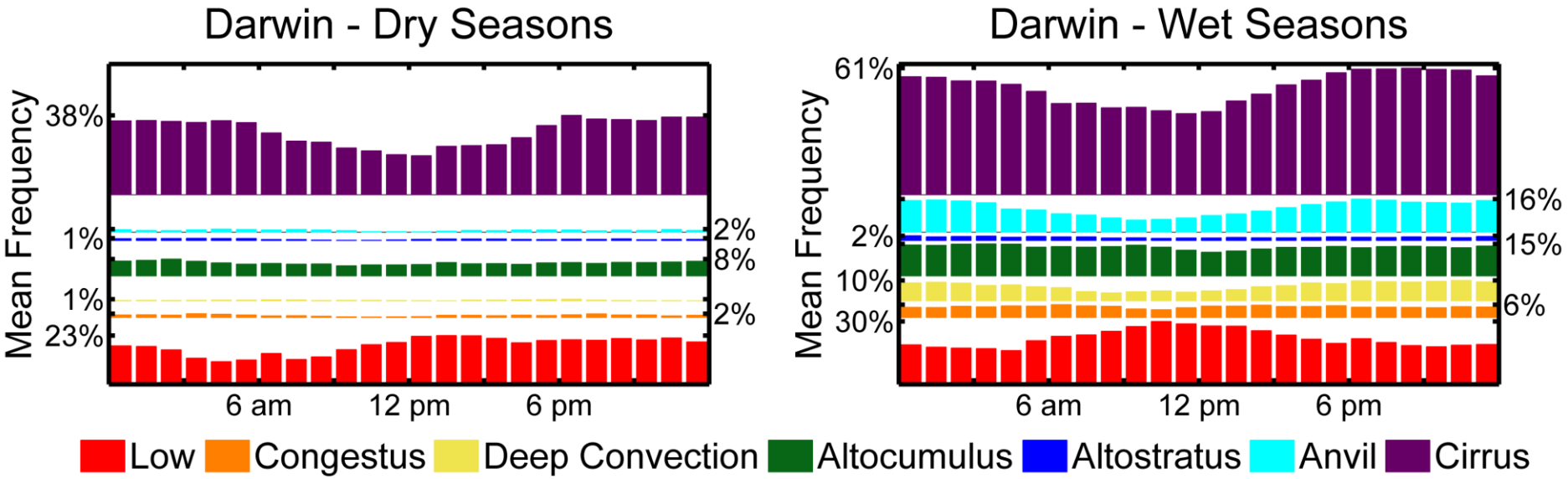
Data from Darwin



All three sites have significant diurnal cycles in total cloud fraction and the changes in the relative frequency of each cloud type as a function of time. Models sometimes phase shift the diurnal cycle by several hours.

What are the Impacts of Errors in the Timing of Each Cloud Type?

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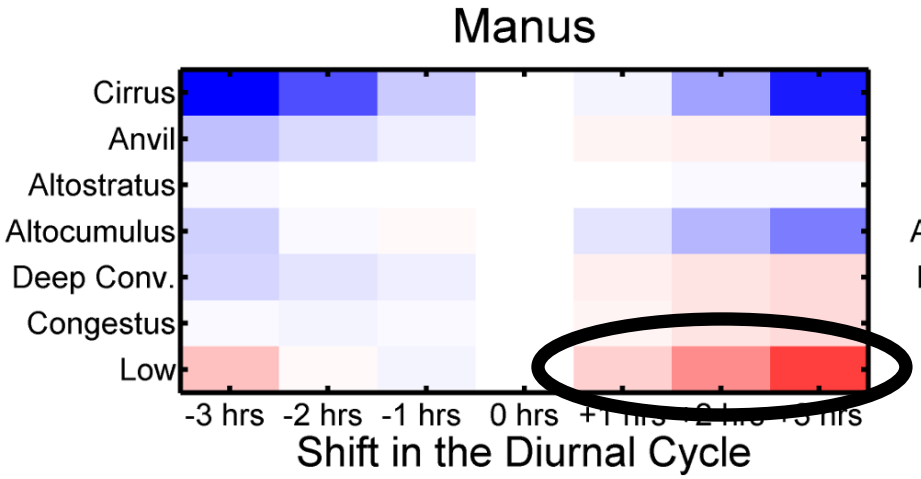

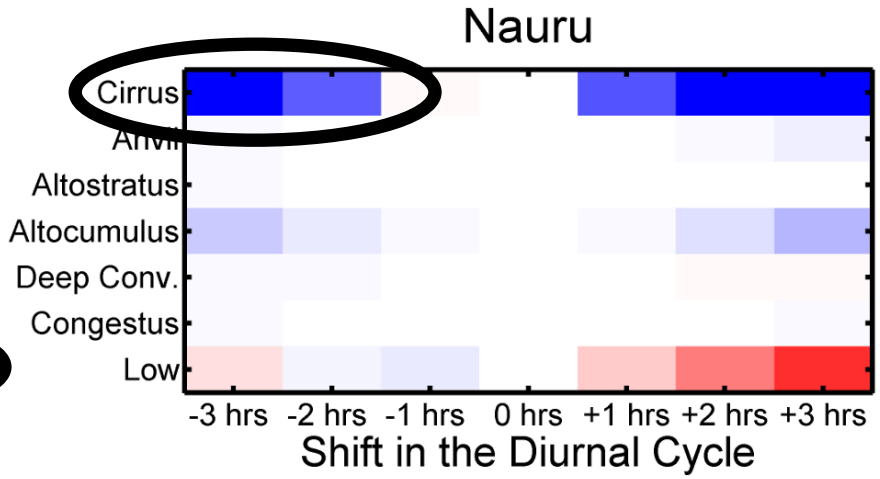

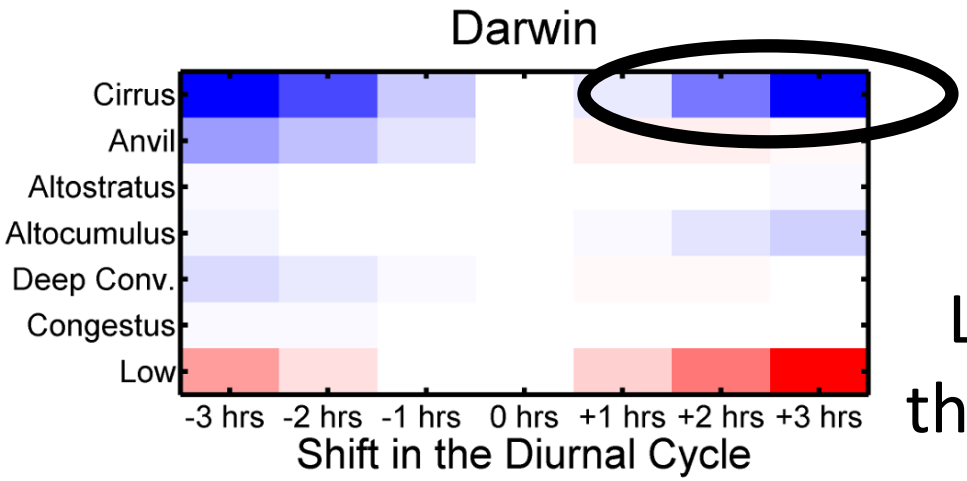

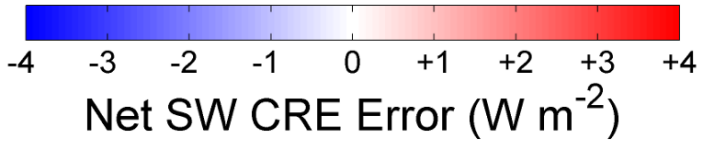

Largest impacts can change the total cloud radiative effect by +/-4 W m^{-2} (~5% of the mean).

Conclusions

1) Most of the variability in total solar cloud radiative effects between the 3 sites and between ENSO/monsoon phases at any given site is driven by changes in the relative and absolute frequency of each cloud type.

2) Although deeper clouds (congestus & deep convection) have a larger conditional cloud radiative effect they have a smaller influence on the total cloud radiative effect compared to low clouds because they occur only infrequently.

3) Missing the absolute frequency of deeper clouds by only +10% can lead to errors in the total cloud radiative effect of up to -20 W m^{-2} (20% of the mean).

4) Errors in the amplitude of the diurnal cycle and mean cloud frequency lead to larger changes (+/-20%) in the total cloud radiative effect compared to errors in the timing of the diurnal cycle of cloud frequency (+/-5%).