Quantifying Global Convective Cloud Radiative Effects with A-Train Observations

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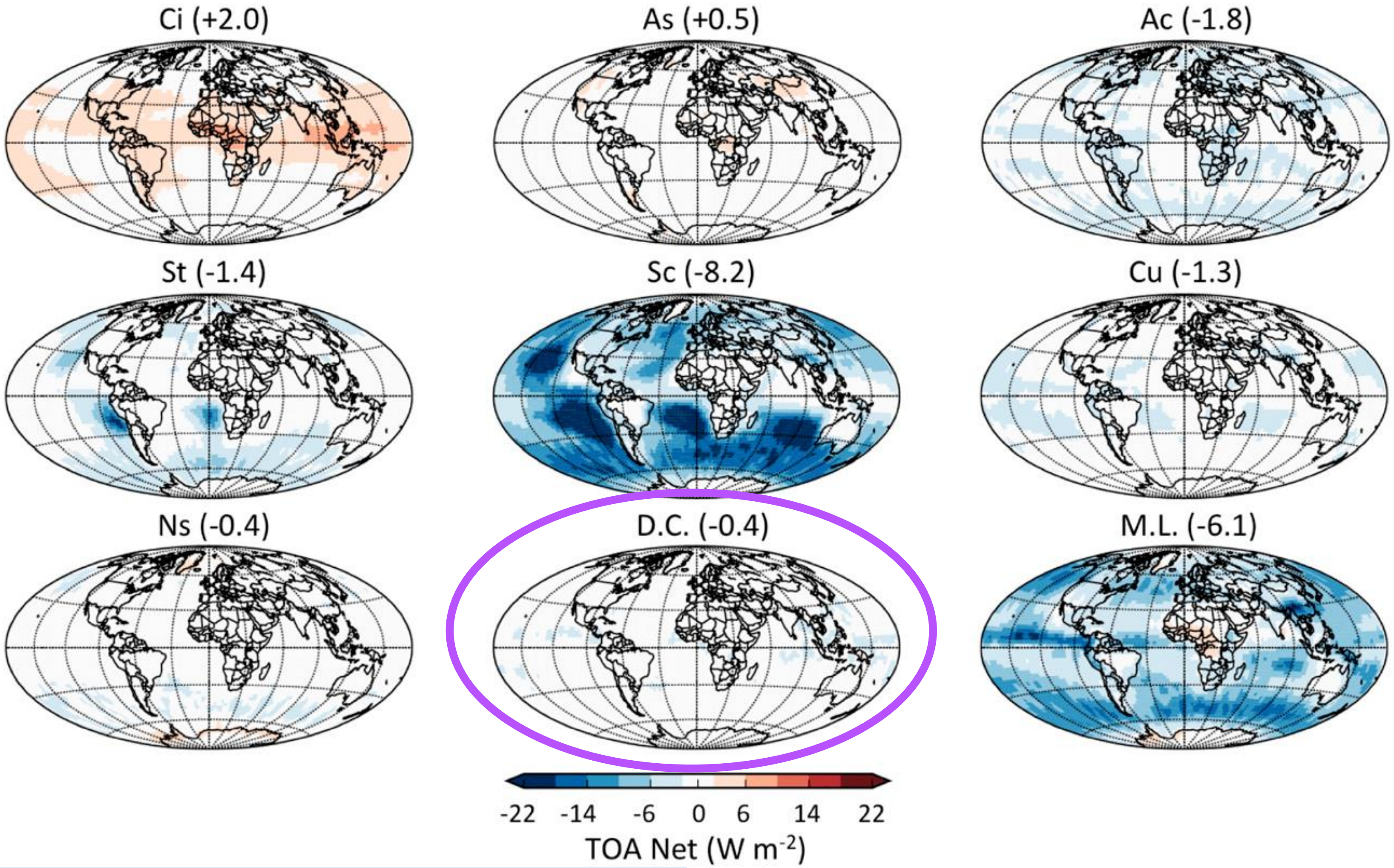
Role of Cloud Type in Earth's Energy Budget

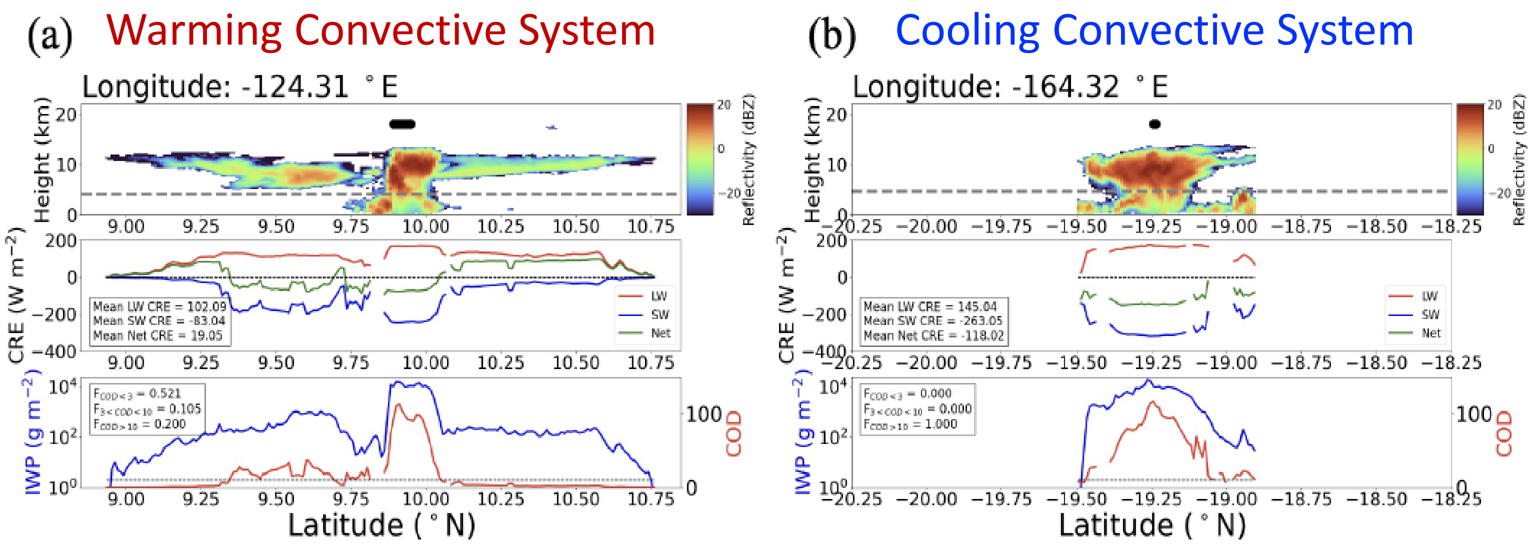


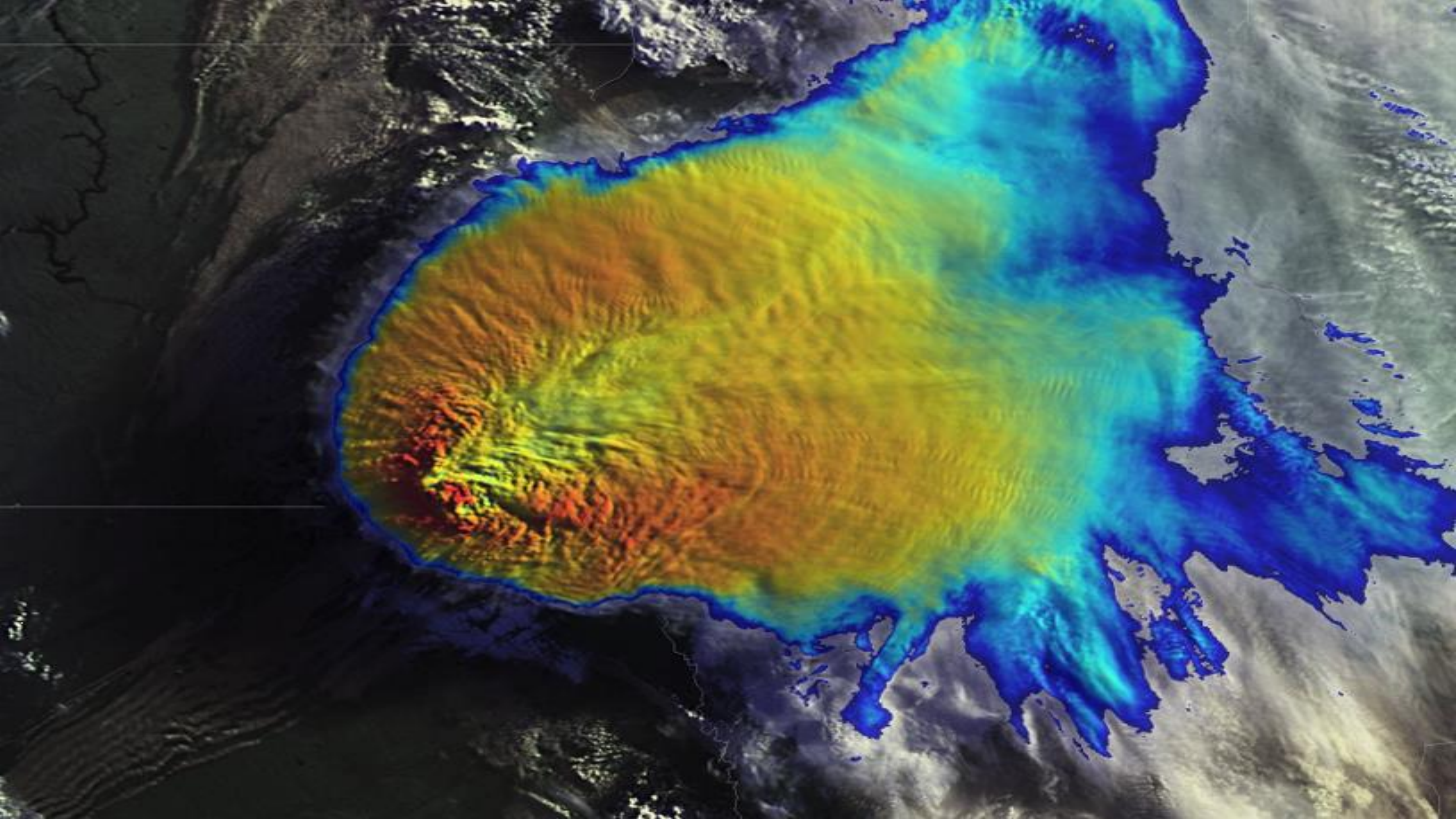
Do the radiative effects of convection matter?

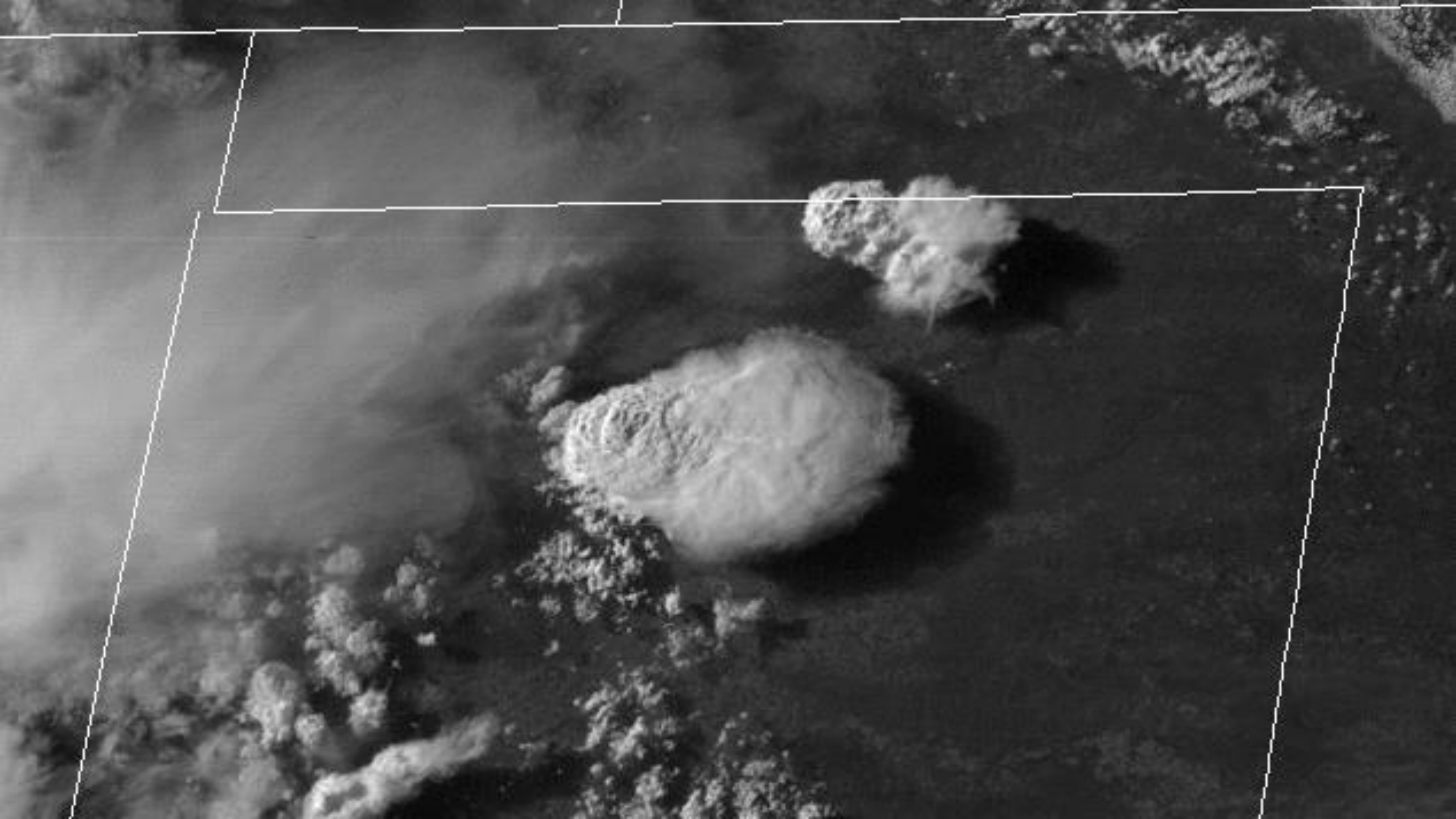
L'Ecuyer et al, *J. Climate* (2019) and Hang et al, *J. Climate* (2019)

Flaws in Interpreting Net Effect

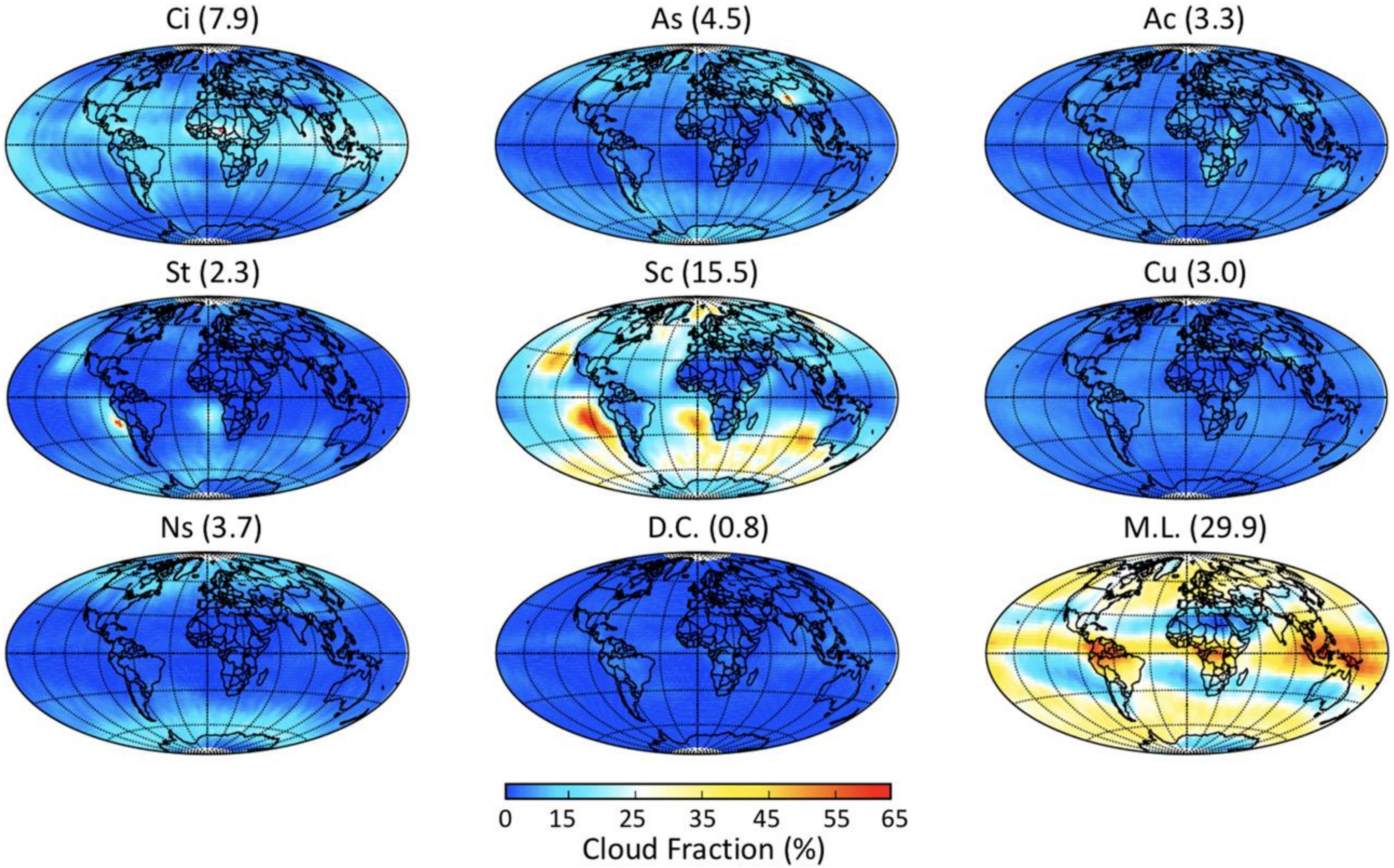
- Convection **substantially** influences both SW and LW radiation
  - The radiative effects of individual deep convective systems are much larger than any other cloud type
- SW and LW radiative effects influence the partitioning of energy between the atmosphere and ocean
- Pixel-based definitions of deep convection likely undercount clouds linked to convection





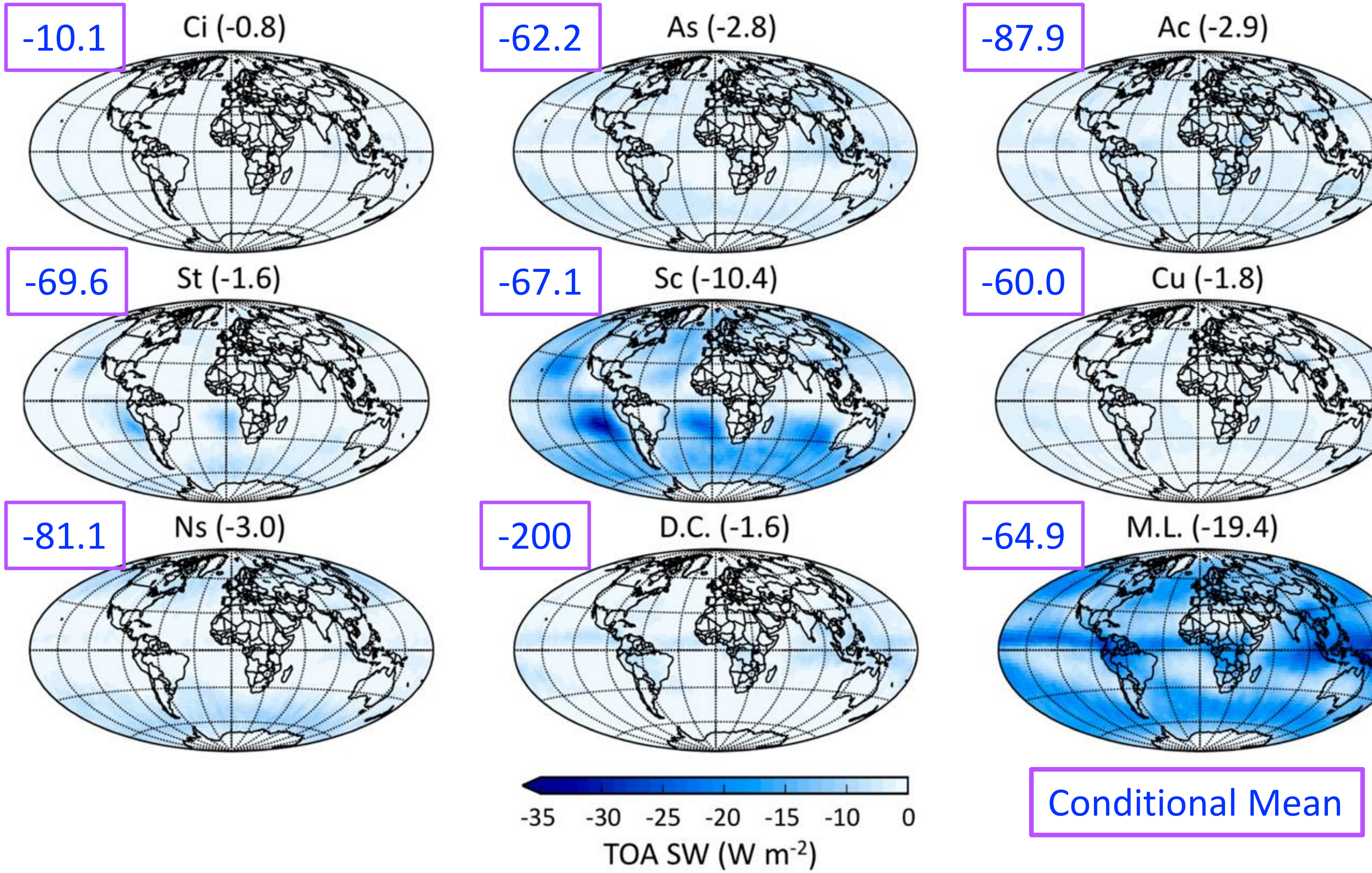


Cloud Fraction



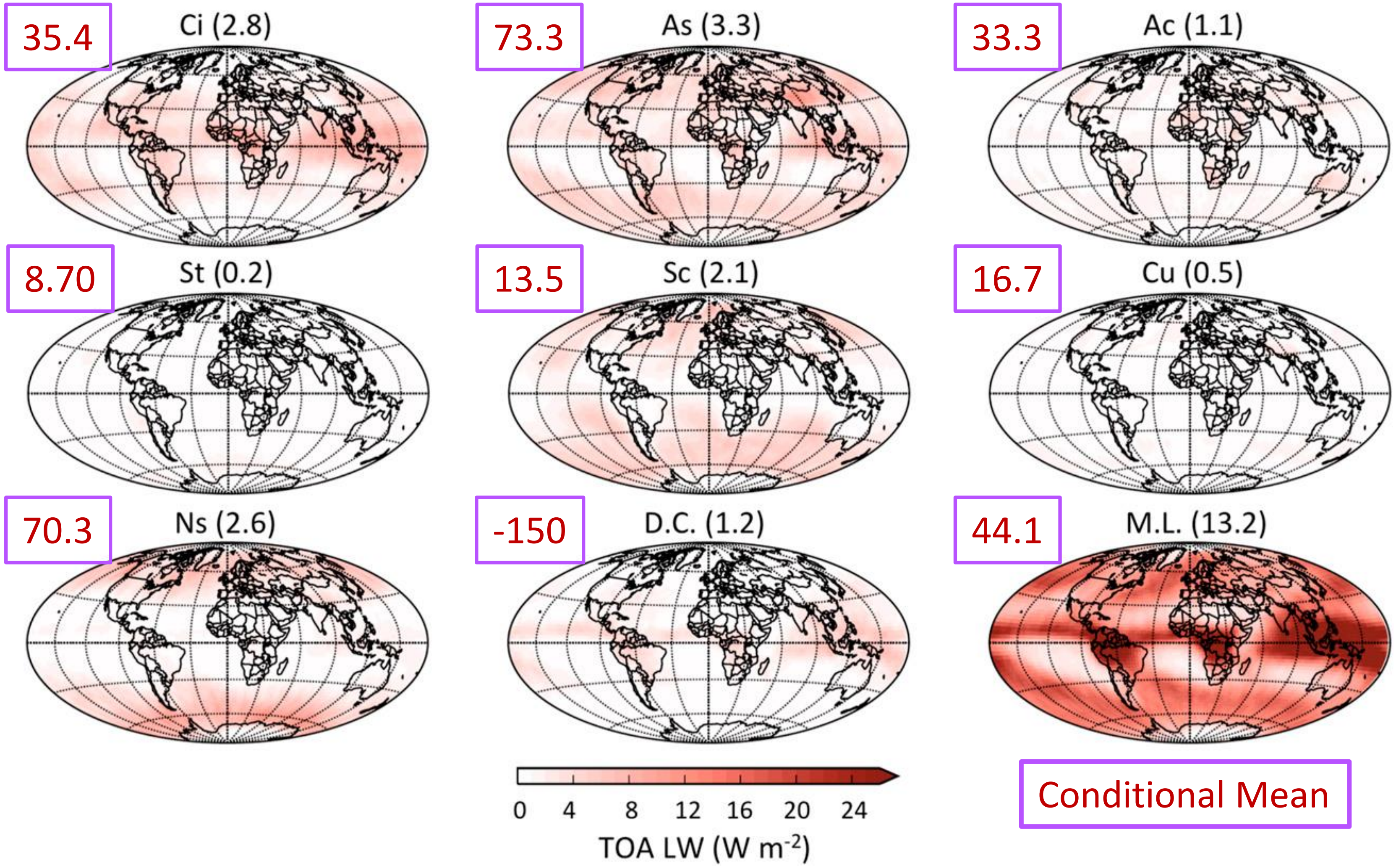
Some Ci and M.L. clouds are likely attributed to convection

Shortwave Effects



L'Ecuyer et al, *J. Climate* (2019) and Hang et al, *J. Climate* (2019)

Longwave Effects



L'Ecuyer et al, *J. Climate* (2019) and Hang et al, *J. Climate* (2019)

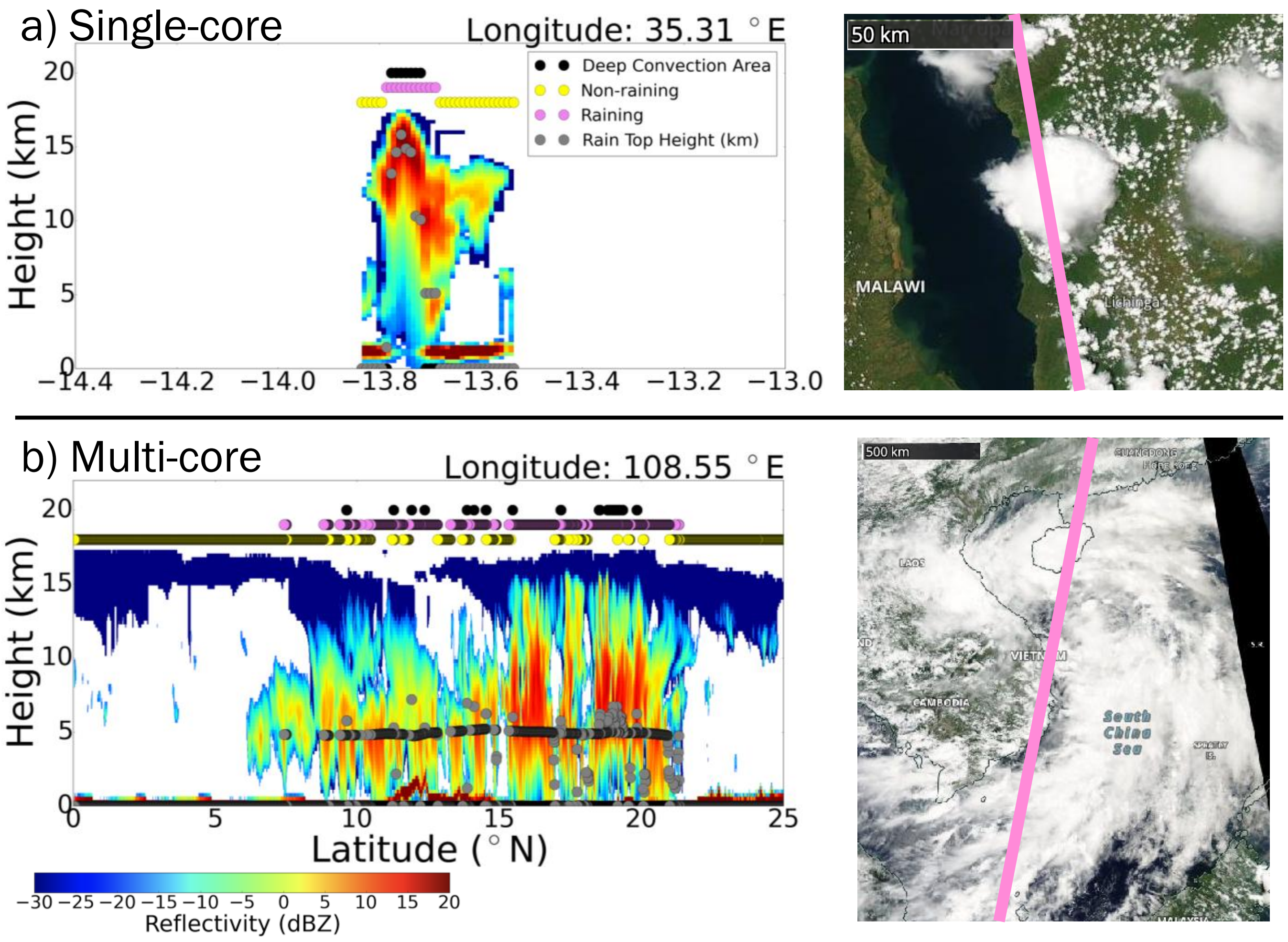
A More Complete Definition: Convective Objects

Motivating Question:

How do the radiative effects of present day convection vary with intensity?

Group connecting "cloudy" pixels surrounding convective core

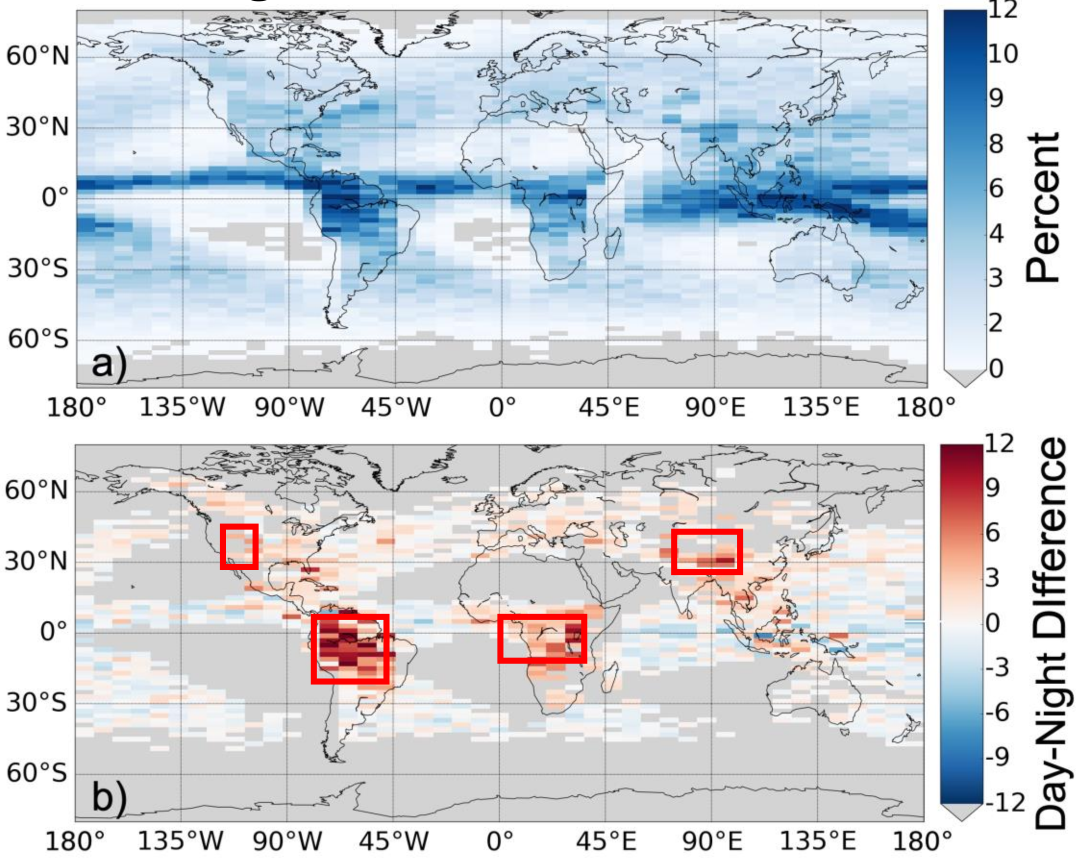
- Combined measurements from CloudSat and CALIPSO
- Object identification with Python's scikit-image package
- Conditions: -28 dbZ & cloud top height gradient < 1 km



Pilewskie and L'Ecuyer, *J. Geophys. Res.* (2022)

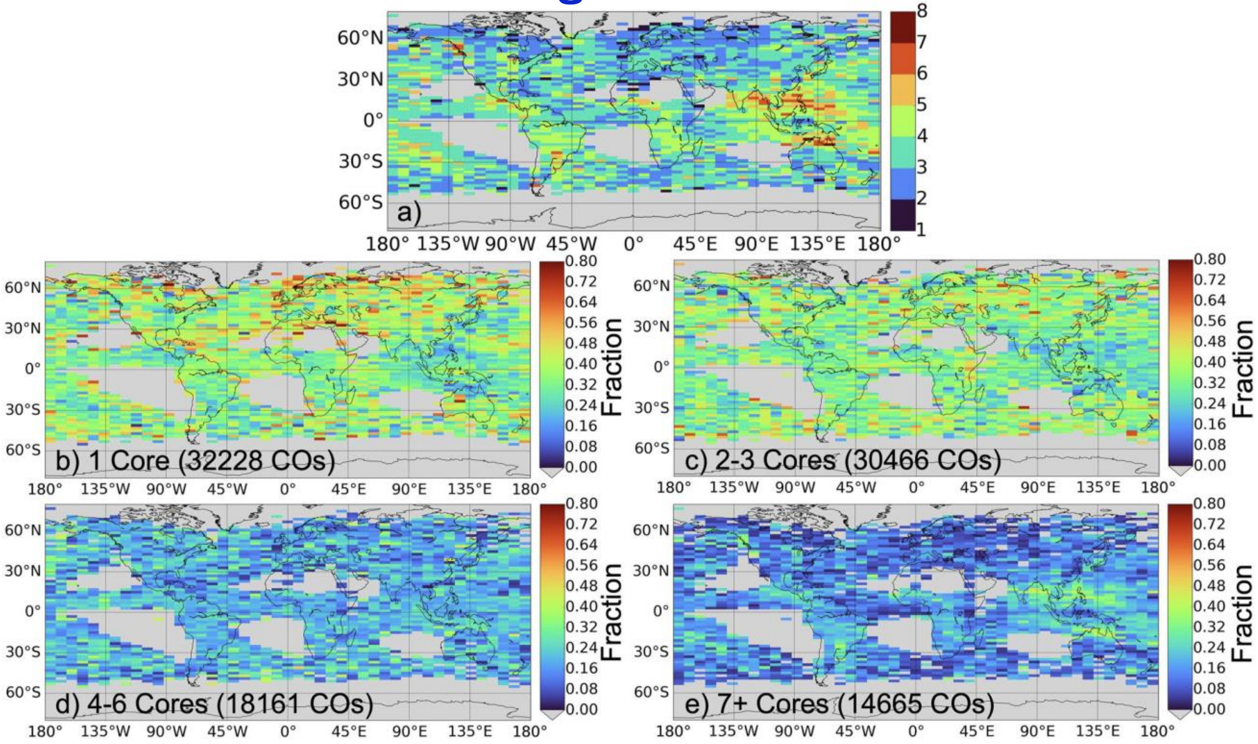
Global Distribution of Convective Objects

August 2006 – December 2010



Pilewskie and L'Ecuyer, *J. Geophys. Res.* (2022)

Average # of Cores

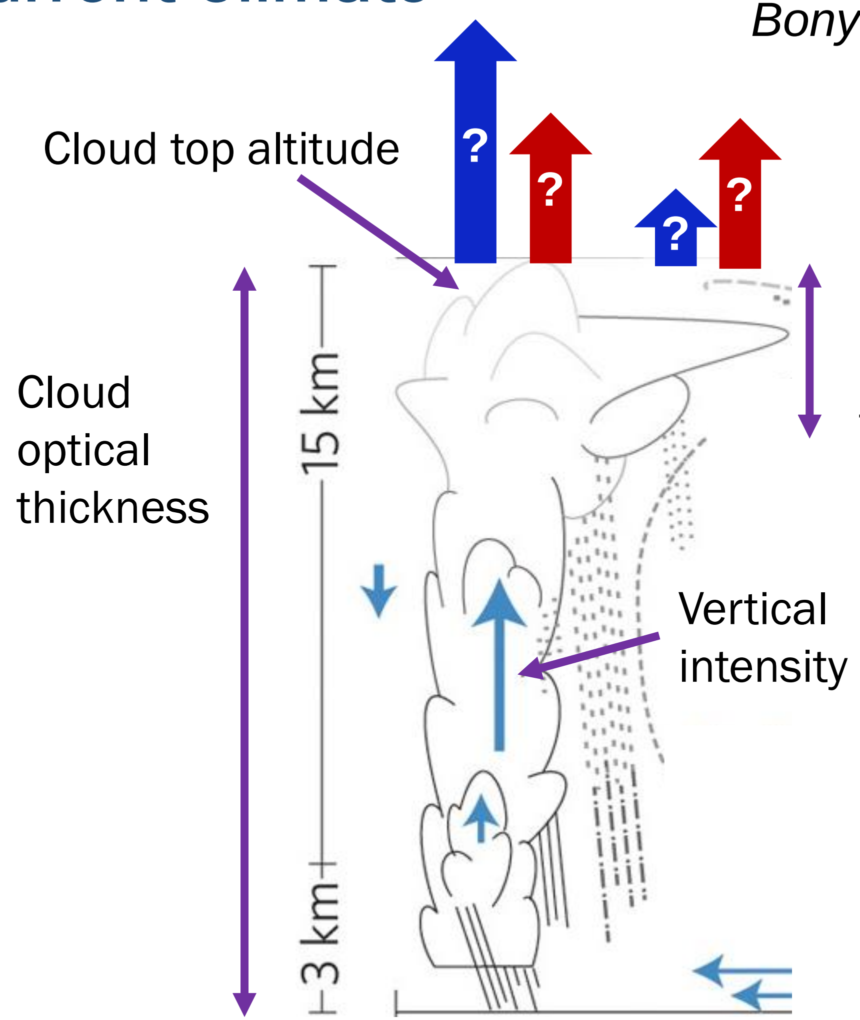


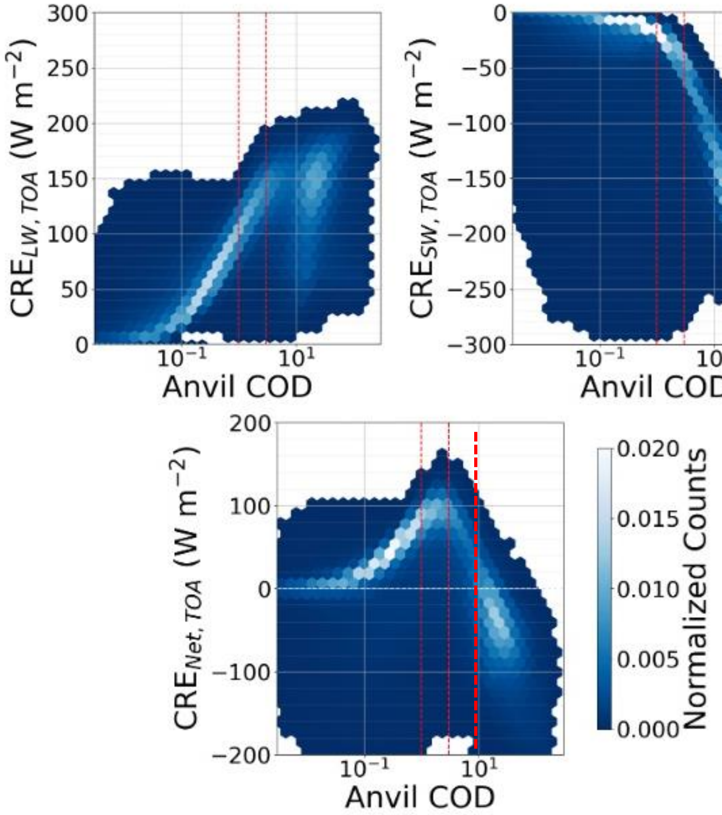
- > 95,000 COs observed in ~4 years
- Evidence of diurnal cycle limitations: more frequent convection at 1:30 pm than late at night (1:30 am); other local times not sampled by CloudSat

Observed Radiative Effects of Convective Objects

Current Climate

Adapted from Bony et al. (2015)



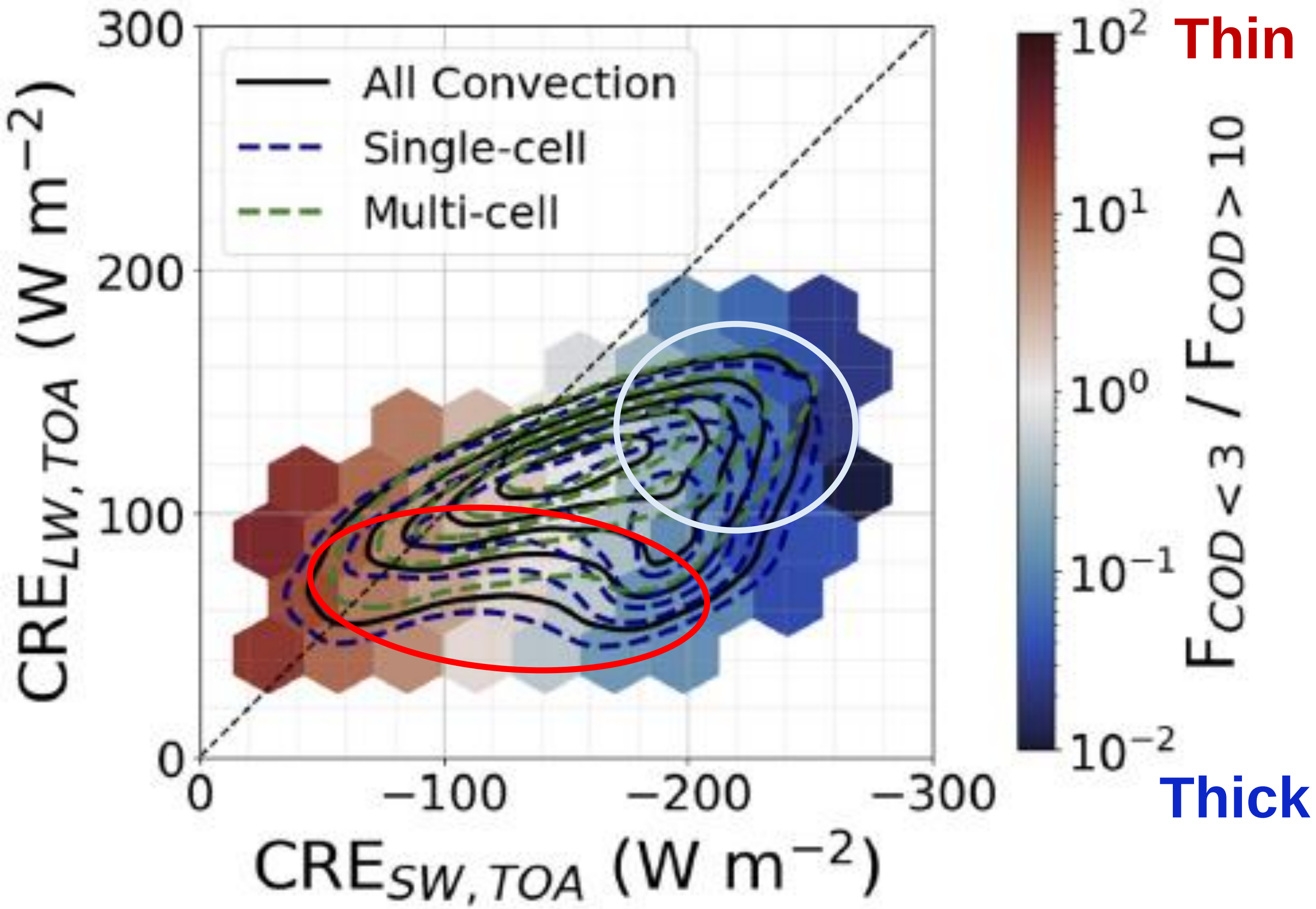


First Order Questions

- How do the areas of ‘thick’ and ‘thin’ cloud vary with intensity?
- How do the radiative effects of ‘thick’ and ‘thin’ cloud vary with intensity?

CRE is Modulated by Cloud Thickness

All Tropical Oceanic Deep Convective Objects



- **“Thick cloud” COs** ($F_{COD<3}/F_{COD<10} < 1$) primarily contribute a cooling
- **“Thin cloud” COs** ($F_{COD<3}/F_{COD<10} > 1$) usually contribute a warming

Pilewskie and L’Ecuyer, *J. Climate* (2025)

Sorting By Intensity: Relative Center of Gravity

Calculation:

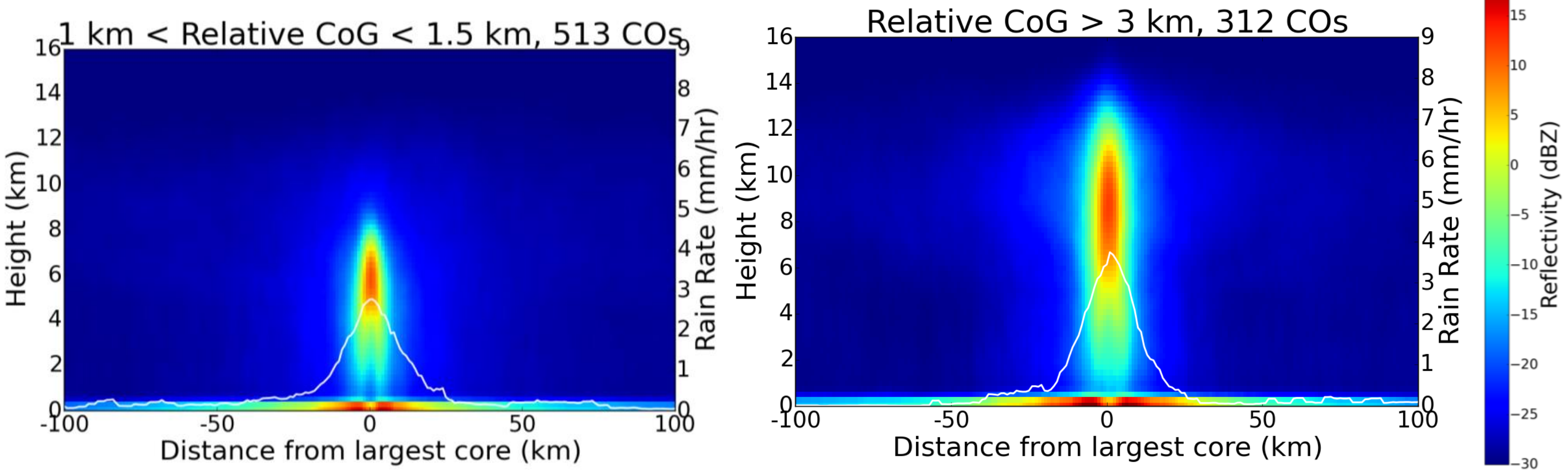
- **CoG**: Average height of the convective core weighted by reflectivity (*Storer et al., 2014*)

$$CoG = \frac{\sum_i Z_i H_i}{\sum_i Z_i}$$

Z: measured reflectivity at level *i*
H: height of each level *i*

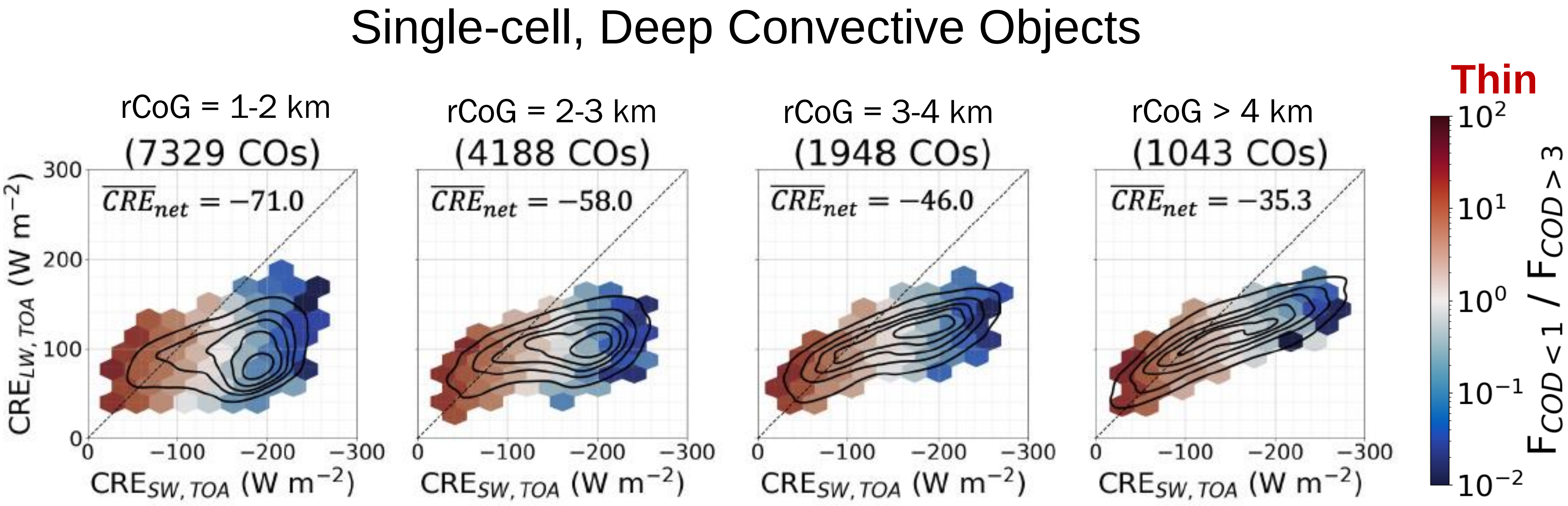
- **Relative CoG (rCoG) =** CoG – freezing level height

Composited Single-core CO Reflectivity Profiles over tropical (30°N/S) ocean in 2010



The height of the convective core rCoG reflects how high large hydrometeors are lofted into the atmosphere

CRE Changes with Intensity (single cell)

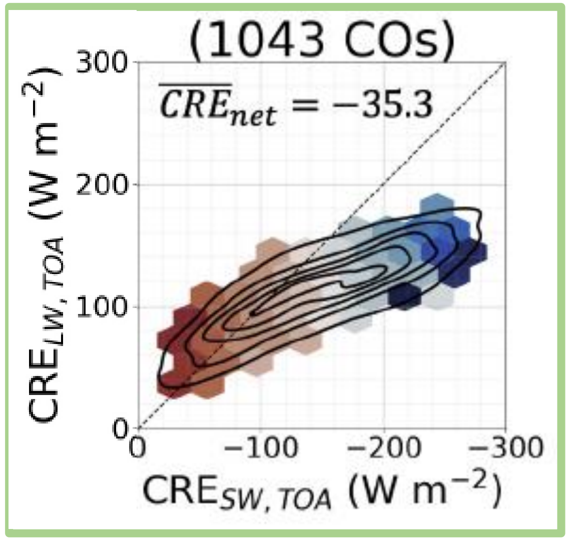


Increasing vertical intensity

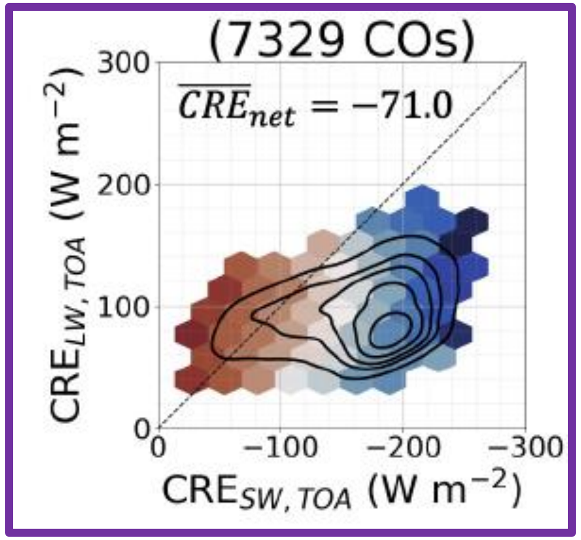
Pilewskie and L'Ecuyer, *J. Climate* (2025)

CRE Changes with Intensity (single cell)

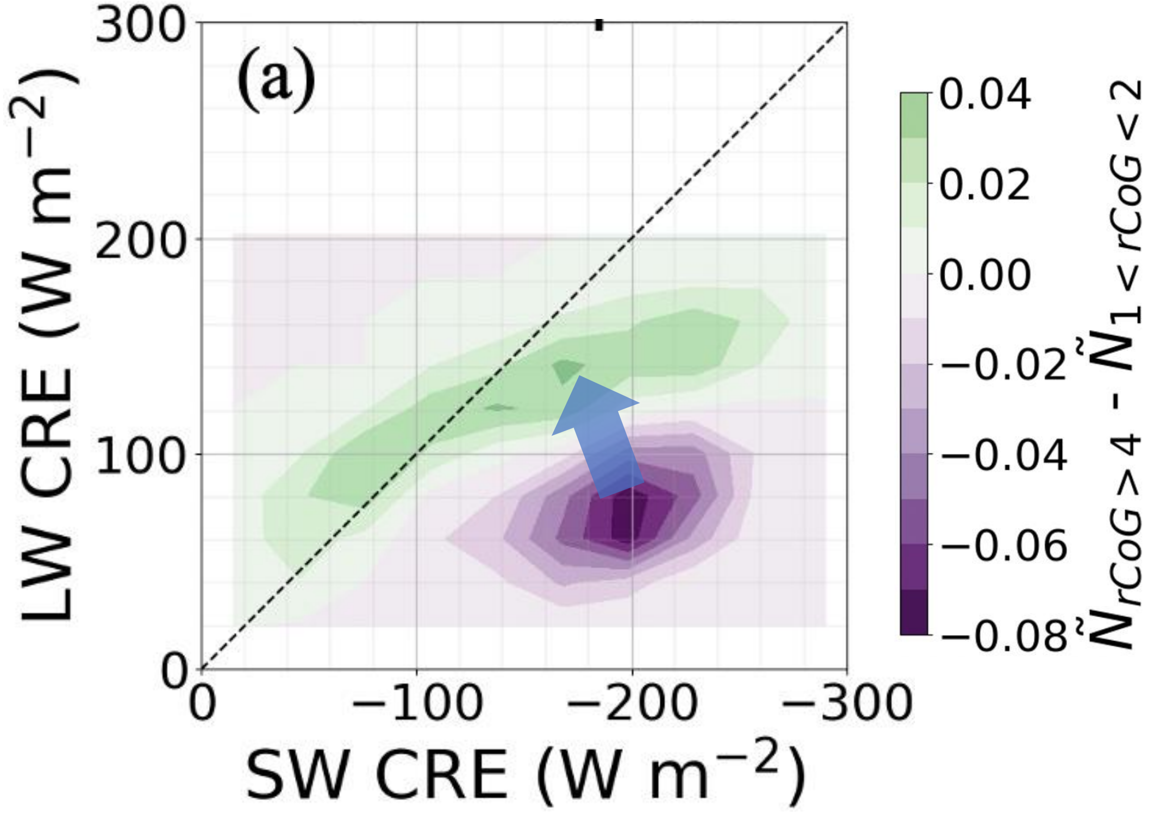
rCoG > 4 km



rCoG = 1-2 km



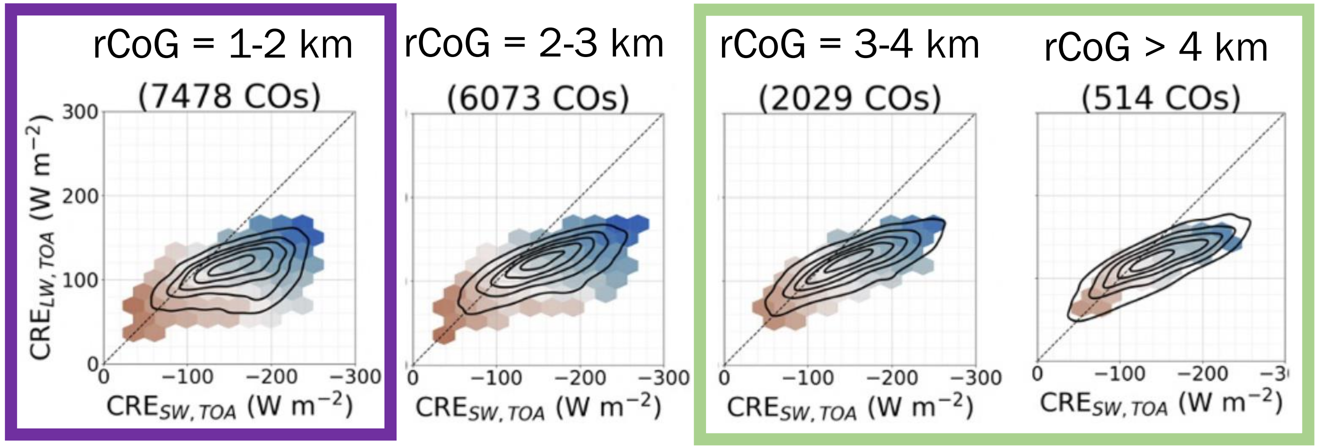
Change with Intensity



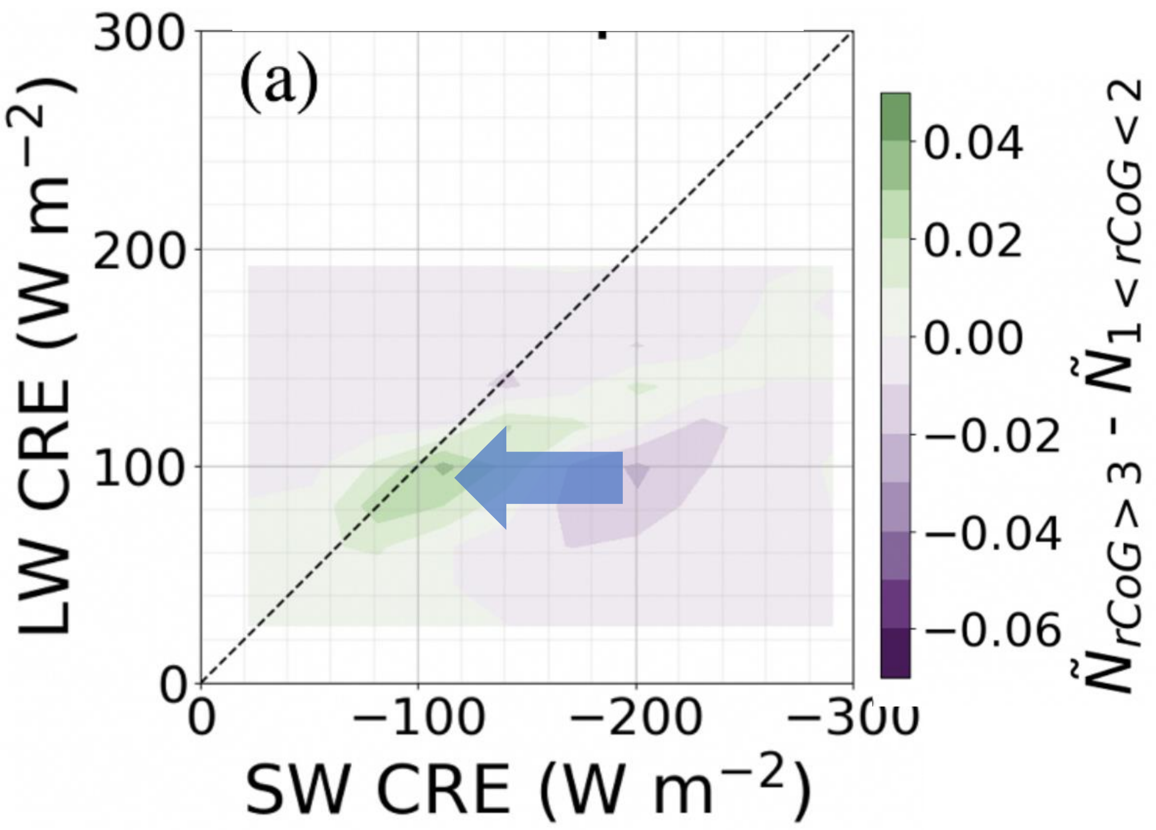
As convective intensity increases, net CRE shifts toward a more neutral effect due to higher cloud tops and a slight shift to thinner clouds

Pilewskie and L'Ecuyer, *J. Climate* (2025)

CRE Changes with Intensity (multi-cell)



Change with Intensity



Multi-cell COs exhibit a stronger reduced cooling as intensity increases

- SW CRE **<u>decreases</u>** from increased thin cloud at the expense of thick cloud
- LW CRE already resembles that of strong single-cell COs and is insensitive to intensity changes

Conclusions

- Despite diurnal sampling limitations, the A-Train (especially its active sensors) provides a unique multi-sensor perspective on the structures and radiative effects of complex convective objects.

- Active convection exerts the strongest impacts on SW and LW radiation of any cloud type, resulting in a net global cooling effect, primarily from multi-cell storms.

- Convection cools less with increasing intensity. This is particularly pronounced for multi-cell storms due to an increase in optically thin cloud area at the expense of thicker anvil.

New Dimensions (ongoing)

- time: How does the relationship between convective intensity and radiative effects vary over the convective lifecycle?

- environment: How do CO intensity and radiative effects vary as a function of the environment in which it forms?

- spectral: What additional insights can be gleaned by adding a spectral dimension?

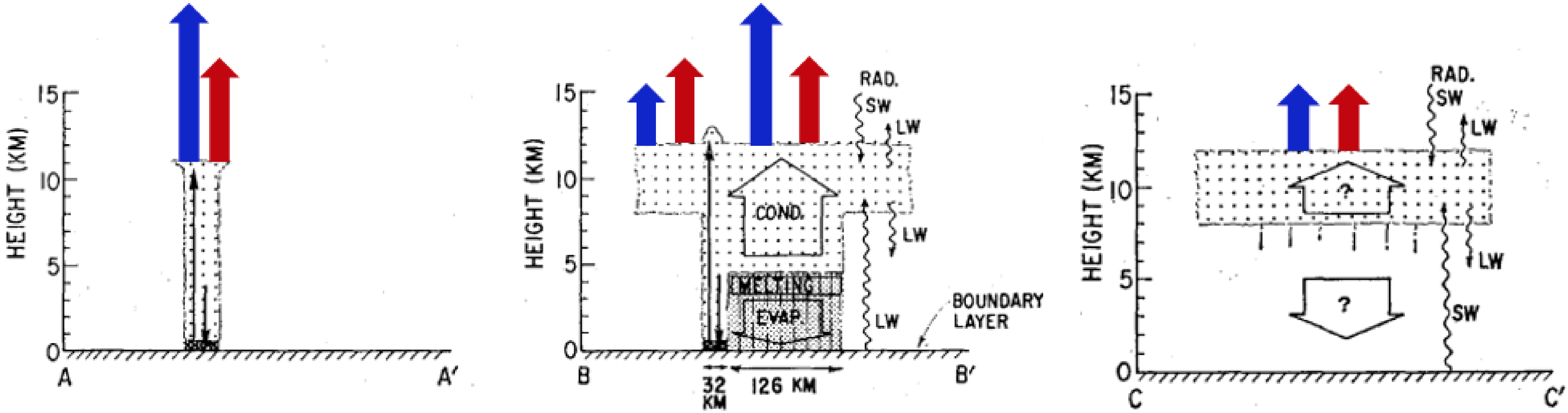
CRE Evolution over the Convective Lifecycle

TOA Cloud Radiative Effect (CRE) $= (F_{\downarrow} - F_{\uparrow})_{all\ sky,TOA} - (F_{\downarrow} - F_{\uparrow})_{clear\ sky,TOA}$

Initiation: cooling

Mature: neutral?

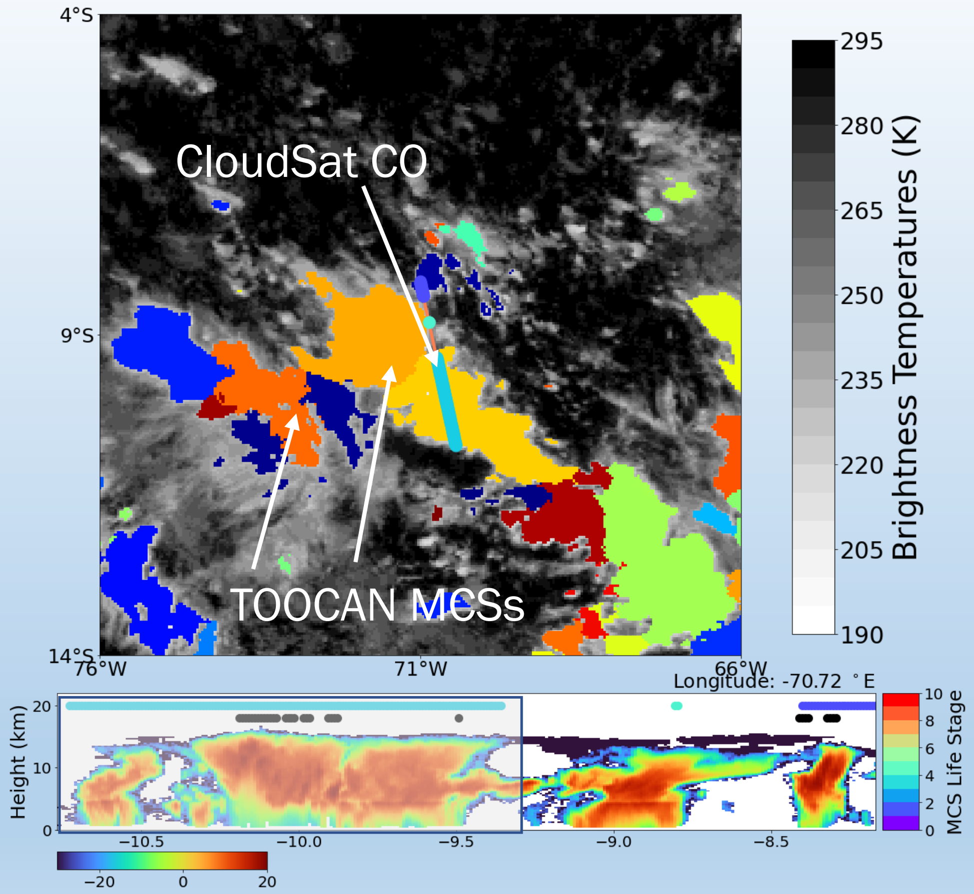
Dissipation: warming



Adapted from Houze (1981)

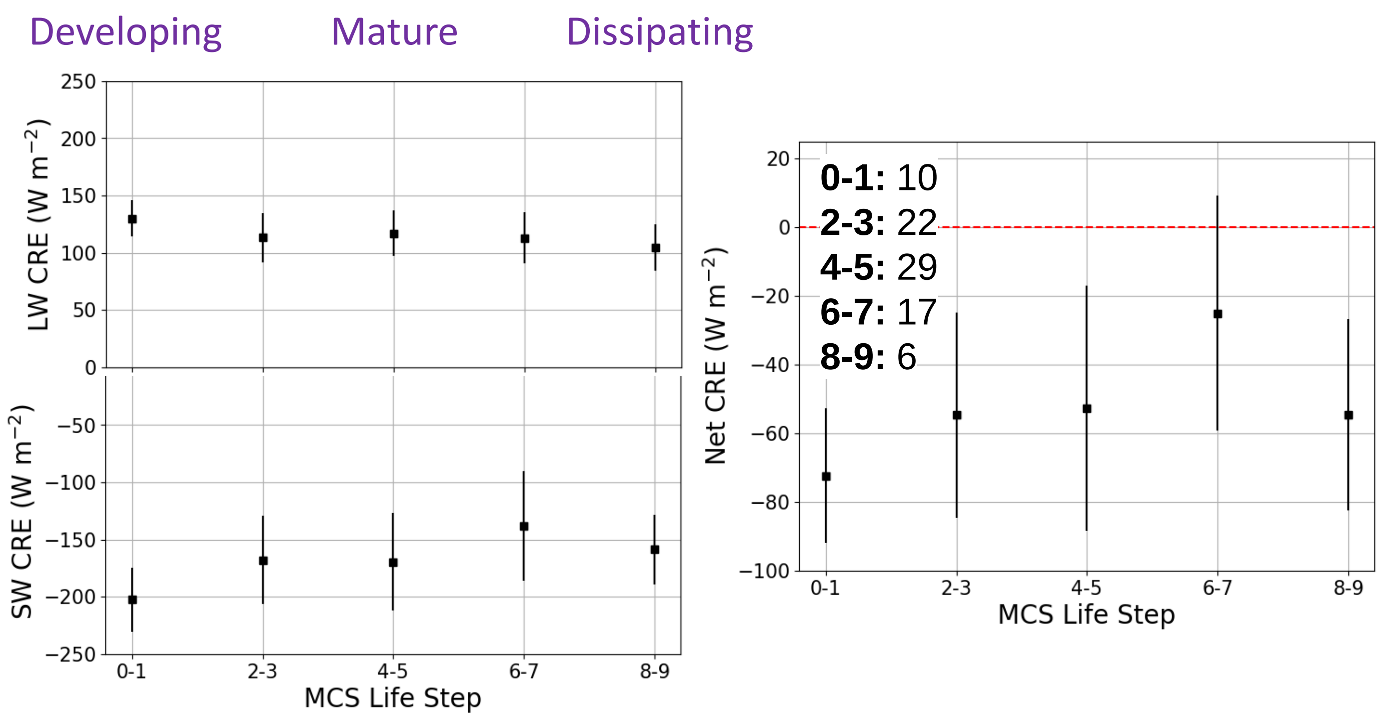
How Do MCS CREs Vary Over Their Lifecycle?

E.g. Bouniol et al., *J. Climate* (2016)
Bouniol et al., *J. Climate* (2021)
Jones et al., *ACP* (2024)



CloudSat COs mapped to TOOCAN MCS life stages

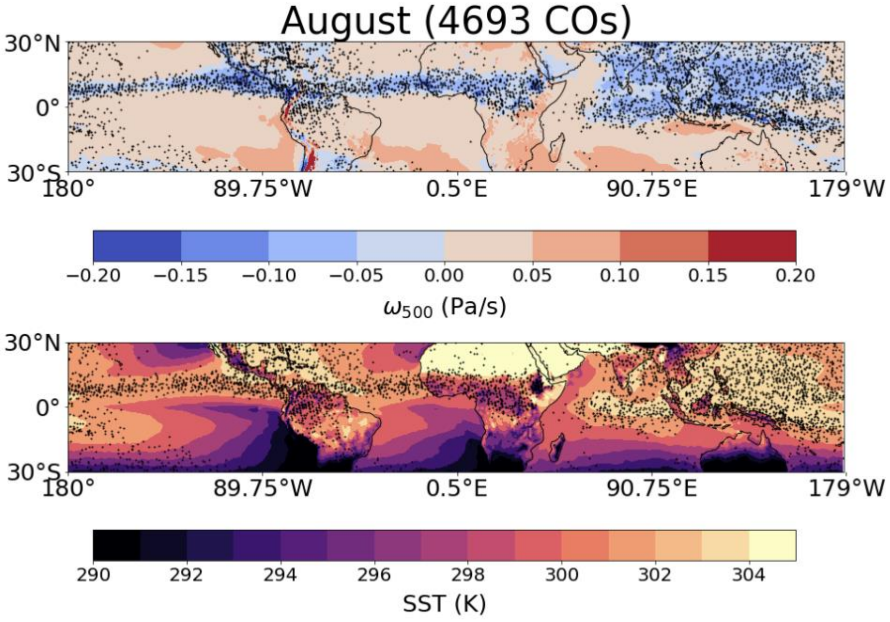
Fiolleau and Roca, *ITGRS* (2013)



Net CRE is most neutral (weakest cooling) during later stages of the MCS lifecycle

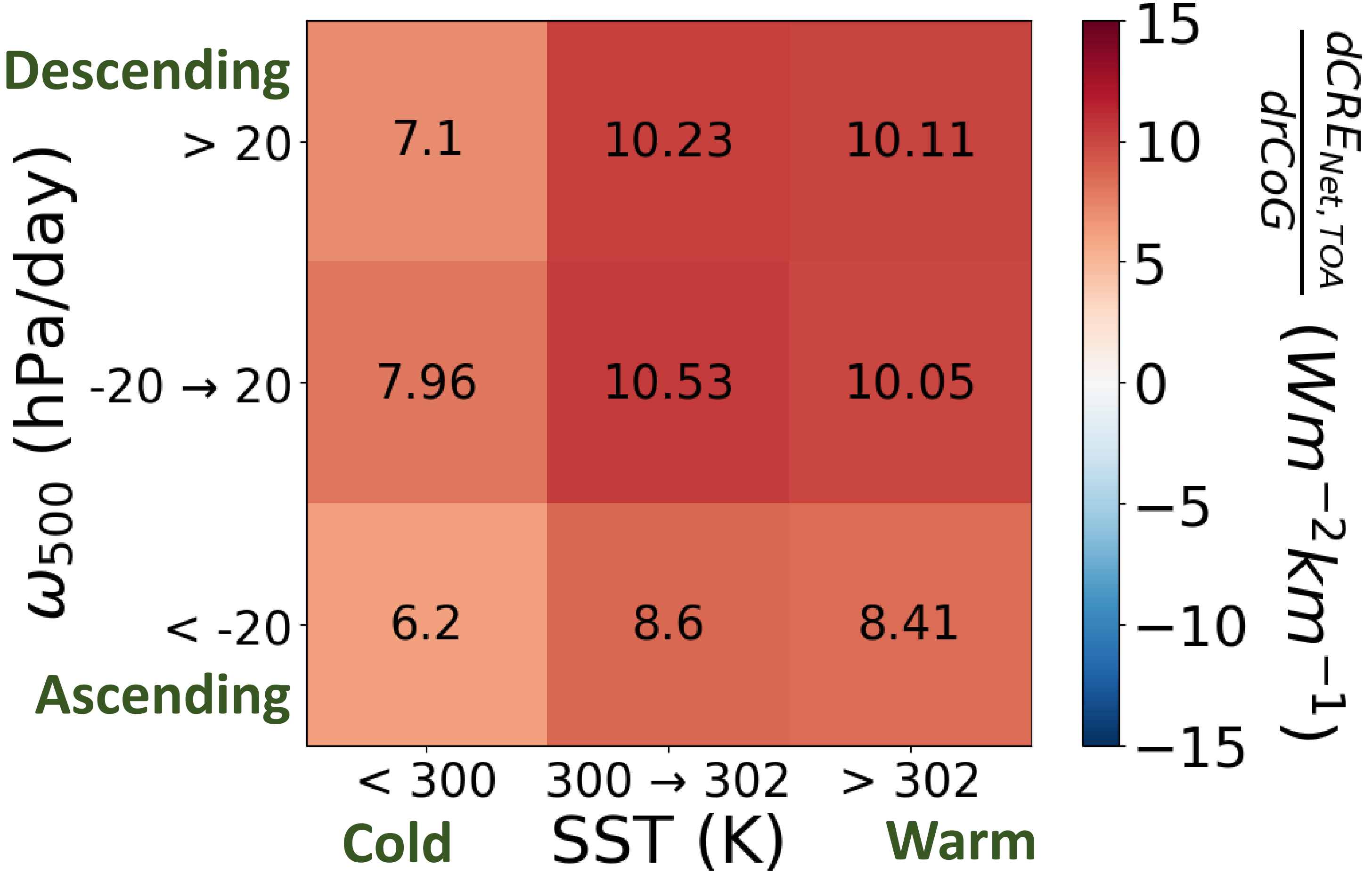
Establishing Controlling Factors

MERRA-2 monthly mean 500 hPa vertical motion (ω_{500}) and sea surface temperatures (SSTs)



net CRE shifts toward less cooling with increasing intensity in all ω_{500} – SST states but the effect is weaker for colder SSTs and strong ascent

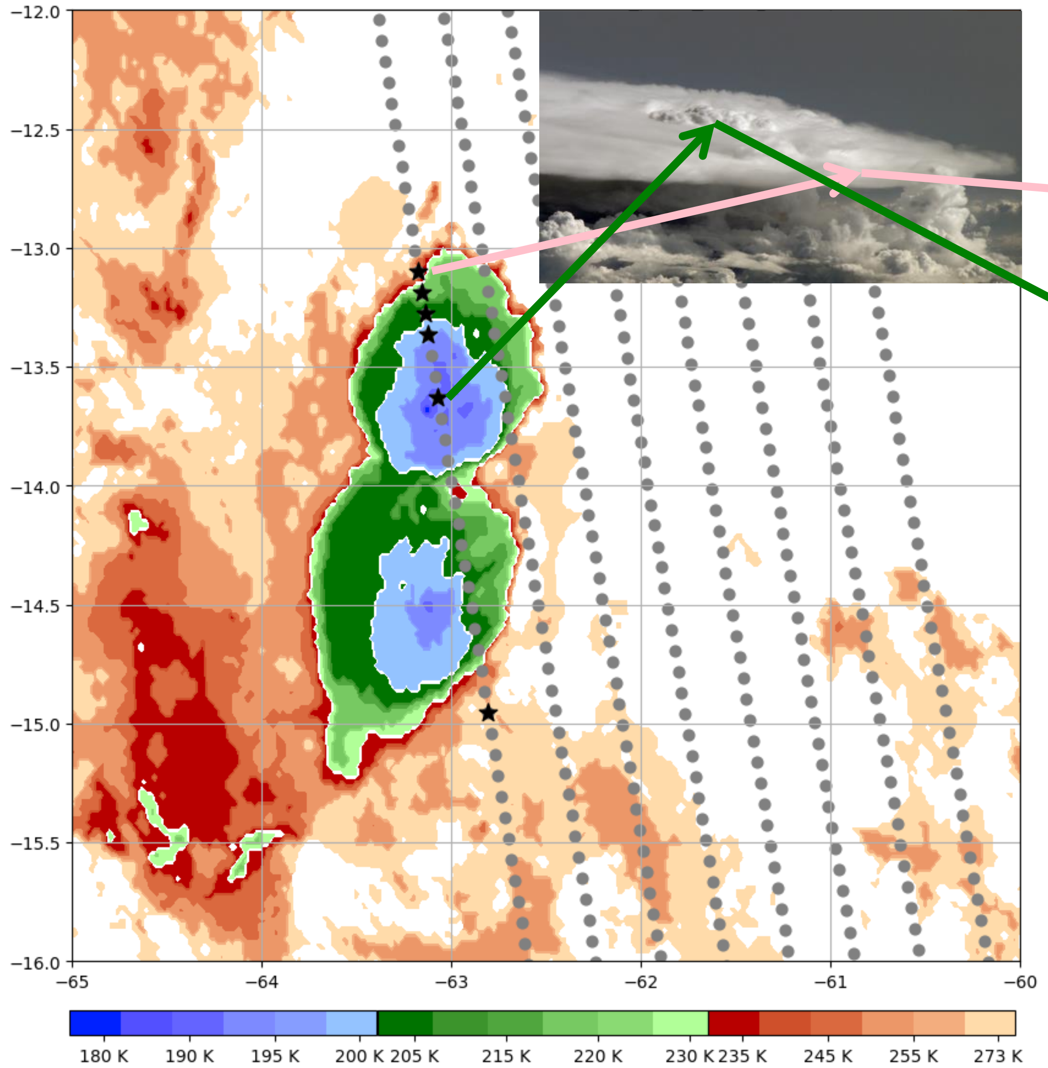
Change in $CRE_{Net,TOA}$ with Increasing Intensity



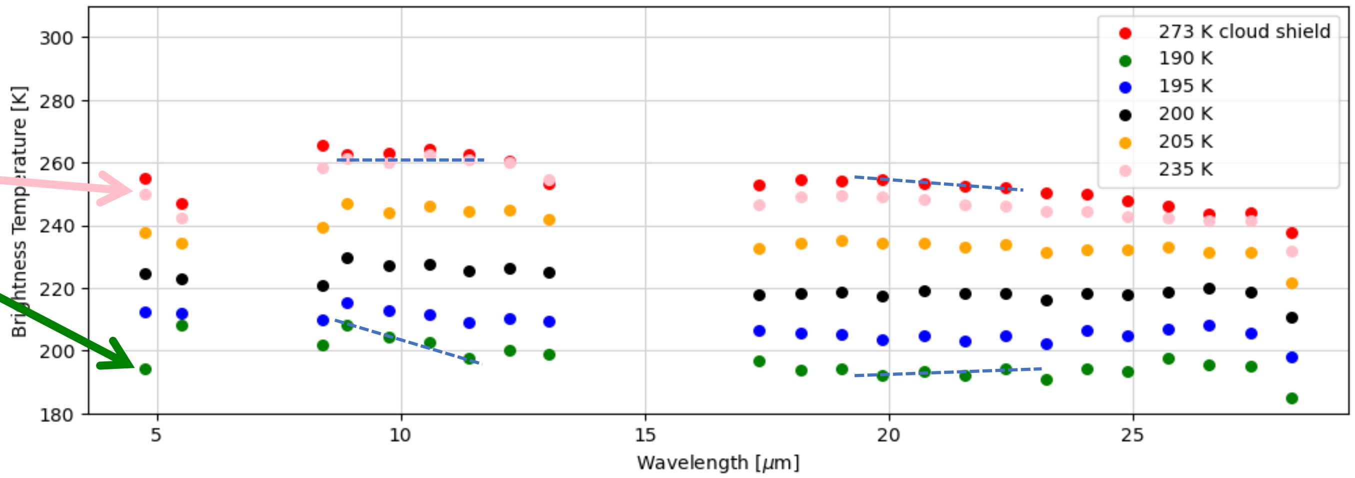
Adding the Spectral Dimension with PREFIRE

Courtesy: Carolyn Bean

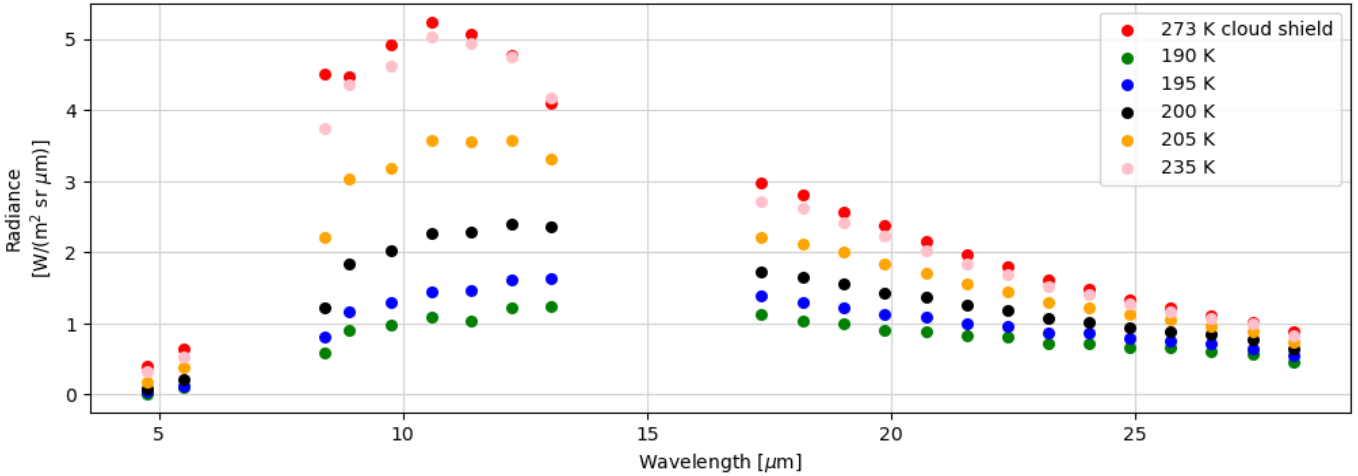
GOES-16 ABI 11.2 µm Brightness Temperature
2025-03-12 7:45 UTC (southeast Brazil)



PREFIRE Brightness Temperature Spectra



PREFIRE Radiance Spectra



The Spectral Dimension: Typhoon Yagi