Influence of the organization of deep convection on the radiation budget and precipitation extremes in the tropics

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Addis Ababa University
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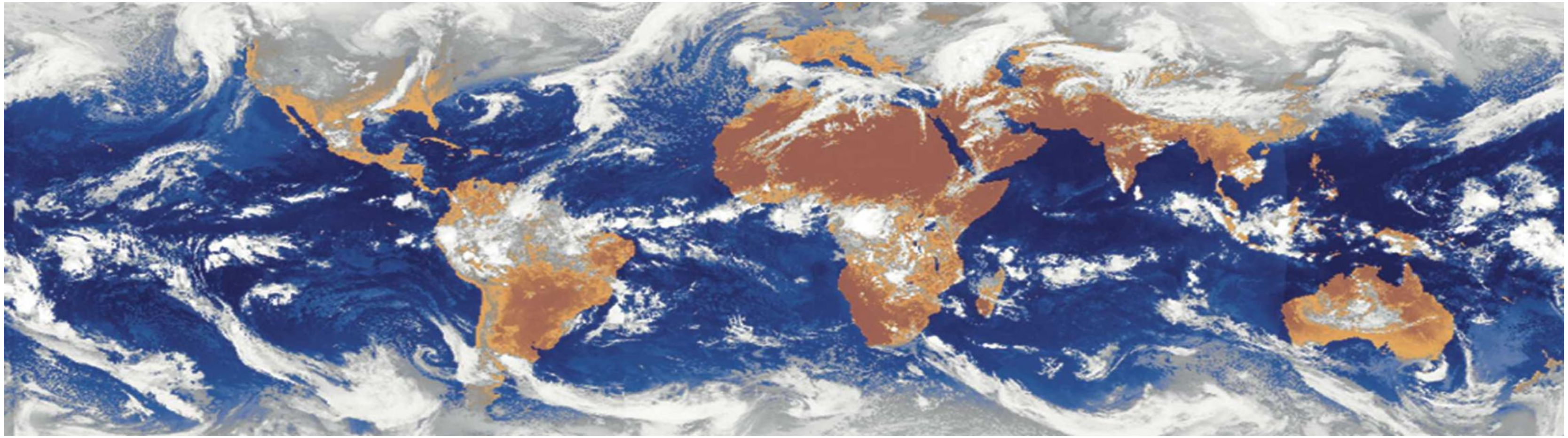
Organization of Deep Convection

- Occurs over a wide range of spatial and temporal scales.
- Are associated to regional increase in tropical precipitation Tan. et al 2015
- Could influence the radiation balance of the Earth, according to modeling studies (Khairoutdinov & Emanuel, 2010, Mauritsen & Stevens, 2015)
    - How is organization of convection related to radiation budget and precipitation extremes in the tropics?



Geostationary satellites (METEO-FRANCE and Japan Meteorological Agency)

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL086927

Relationship Between Precipitation Extremes and Convective Organization Inferred From Satellite Observations

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Key Points:
- The link between tropical precipitation extremes and the mesoscale organization of deep convection is investigated using satellite data
- The strength of local precipitation extremes exhibits a strong dependence on convective organization
- Local precipitation extremes primarily result from changes in the fractional area of heavy precipitation

Supporting Information:
- Supporting Information S1

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Abstract Convective organization has the potential to impact the strength of precipitation extremes, but numerical models disagree about this influence. This study uses satellite observations to investigate the link between the mesoscale organization of deep convection and precipitation extremes in the Tropics. Extremes in domain-averaged precipitation are found mostly over the western Pacific and Indian Ocean warm pools, and they primarily depend on the number of deep convective entities within the domain. On the other hand, extremes in local precipitation are found primarily over land, and they increase with the degree of convective organization. Therefore, this observational study shows evidence for a modulation of the strength of tropical precipitation extremes by the spatial organization of deep convection, especially over land.

Plain Language Summary Events of extreme precipitation represent huge threats to ecosystems and society. It is therefore important to understand the conditions that might promote their occurrence. Recent modeling studies have suggested that extreme precipitation events could depend on the spatial organization of deep convection, but there is no consensus among the models. In this study, we use satellite observations to investigate this issue, and we show strong evidence that the occurrence of extreme precipitation over tropical land depends on the degree of mesoscale organization of deep convection.

1. Introduction

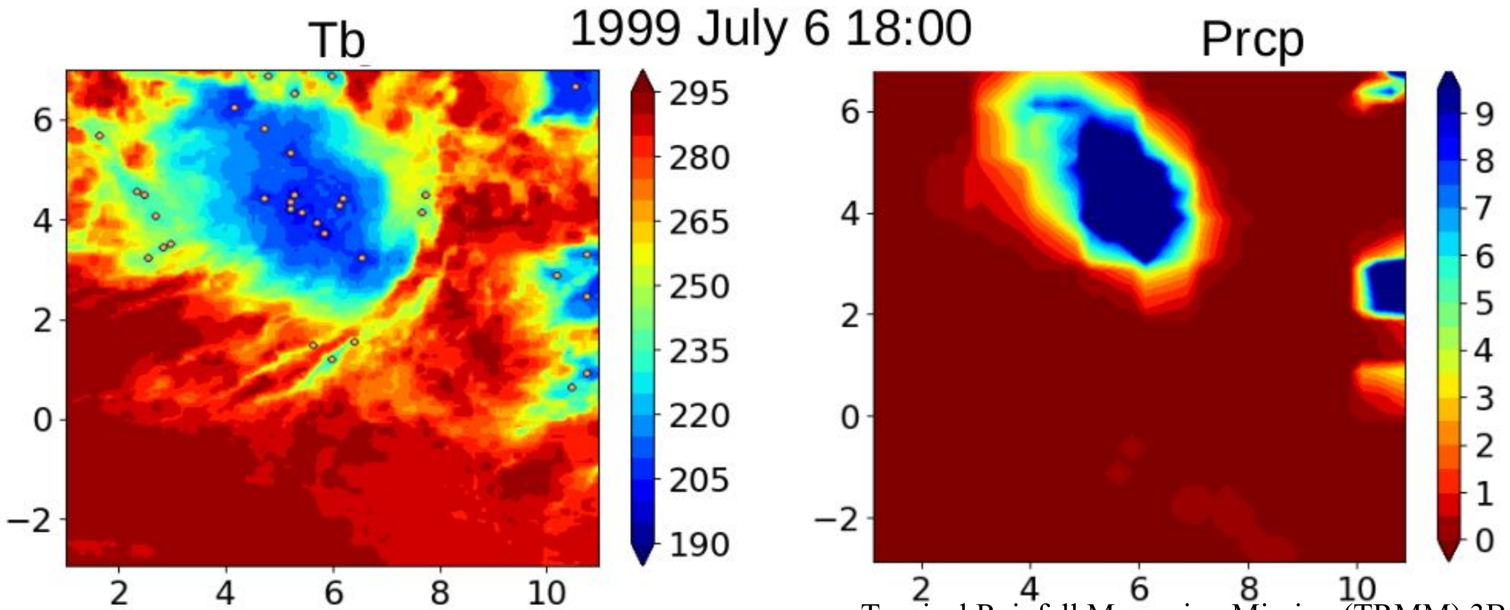
How is organization of convection related to precipitation extremes?

- No consensus among modeling studies:
  - Enhancement in extreme precipitation when convection becomes more organized *Pendegrass et al 2016 and Singleton and Toumi, 2013* .
  - Simulations didn't indicate an increase in precipitation extremes with organization *Bao and Sherwood, 2019* .

Here we use satellite observations of the tropical region and apply I_{org} to investigate the link between convective aggregation and extreme precipitation.

Mesoscale domains

- Longitude-latitude domains of 10º x 10º considered to represent Mesoscale domains Tobin. et al 2012, Stein et al. 2017
- Comparable to the domains of most cloud-resolving model simulation studies of convective aggregation

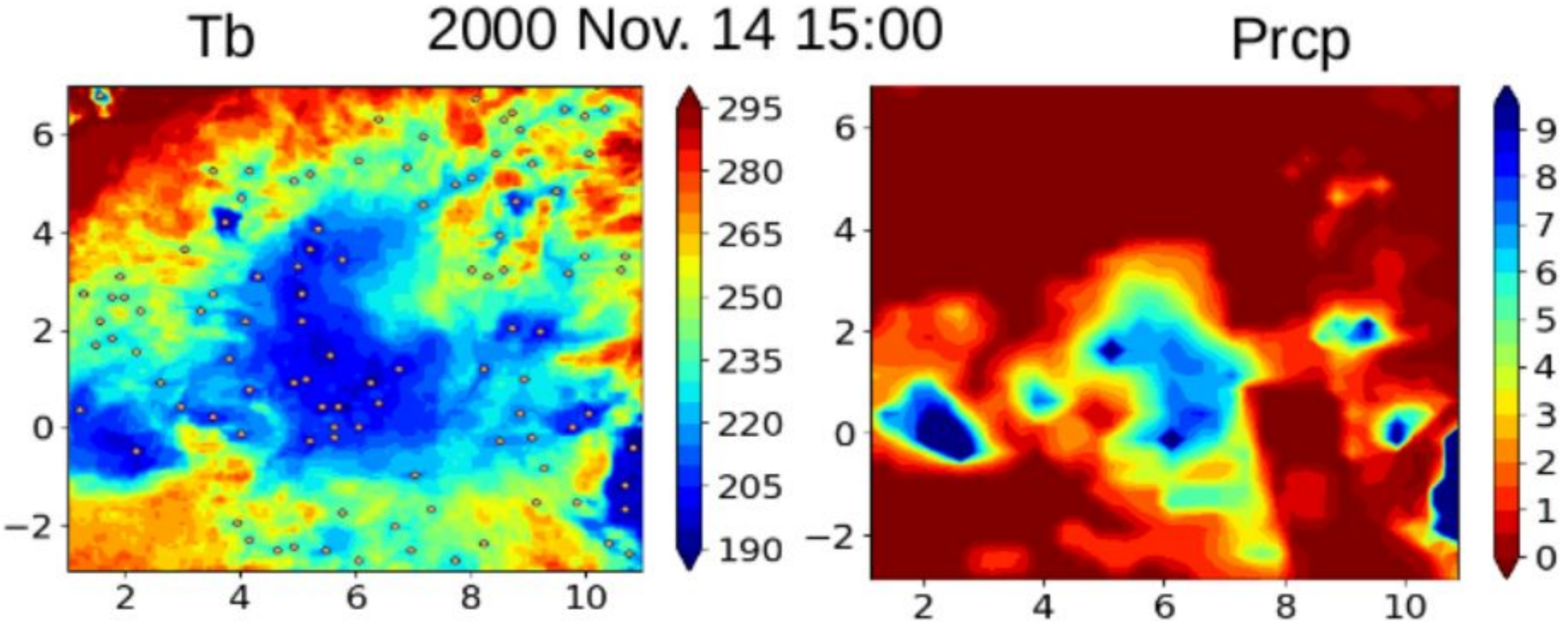


Geostationary satellites GridSat-B1 dataset (Knapp et al., 2011).

Tropical Rainfall Measuring Mission (TRMM) 3B42 product for the period 1998 to 2010 (Huffman et al., 2007)

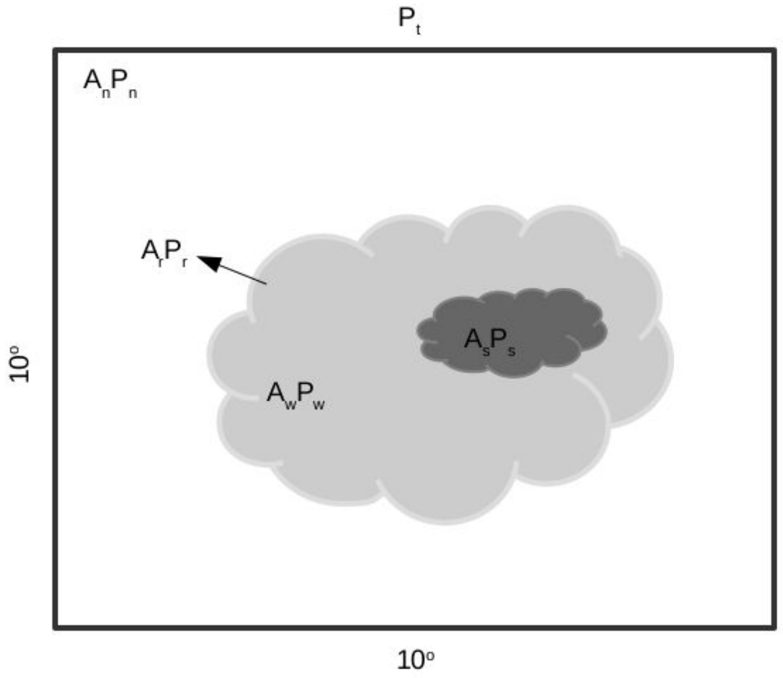
Mesoscale domains

- Within the 20º S - 20º N tropical belt, we consider every 1º degree a moving box of 10º x 10º , thus totaling 14,400 (360x40) 10º x 10º domains .



Characterization of the precipitation field

- Precipitation data are derived from TRMM 3B42 product, it has a spatial resolution of $0.25^{\circ} \times 0.25^{\circ}$.
- Precipitation field within each $10^{\circ} \times 10^{\circ}$ domain is represented by the following schematic diagram.



Characterization of the precipitation field

- P_t and P_r are domain-scale and local-scale precipitation, respectively.

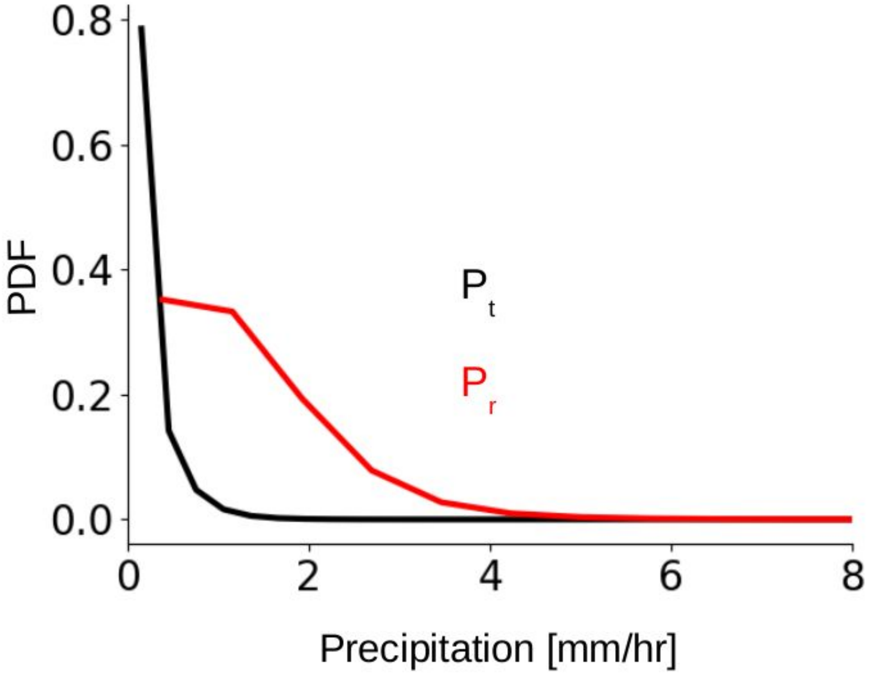
$$P_t = A_r P_r \quad with$$

$$P_r = a_w P_w + a_s P_s \quad with$$

$$A_r = A_w + A_s, a_w = \frac{A_w}{A_r} \; and \; a_s = \frac{A_s}{A_r}$$

Characterization of the precipitation field

- There are about 546,868,800 10º x10º domains when we consider all 3-hourly data over a period of 1998-2010
- We remove all the domains for which more than 1% of the area is covered by undefined precipitation data
- This reduces the total number of 10º x10º domains by 27%

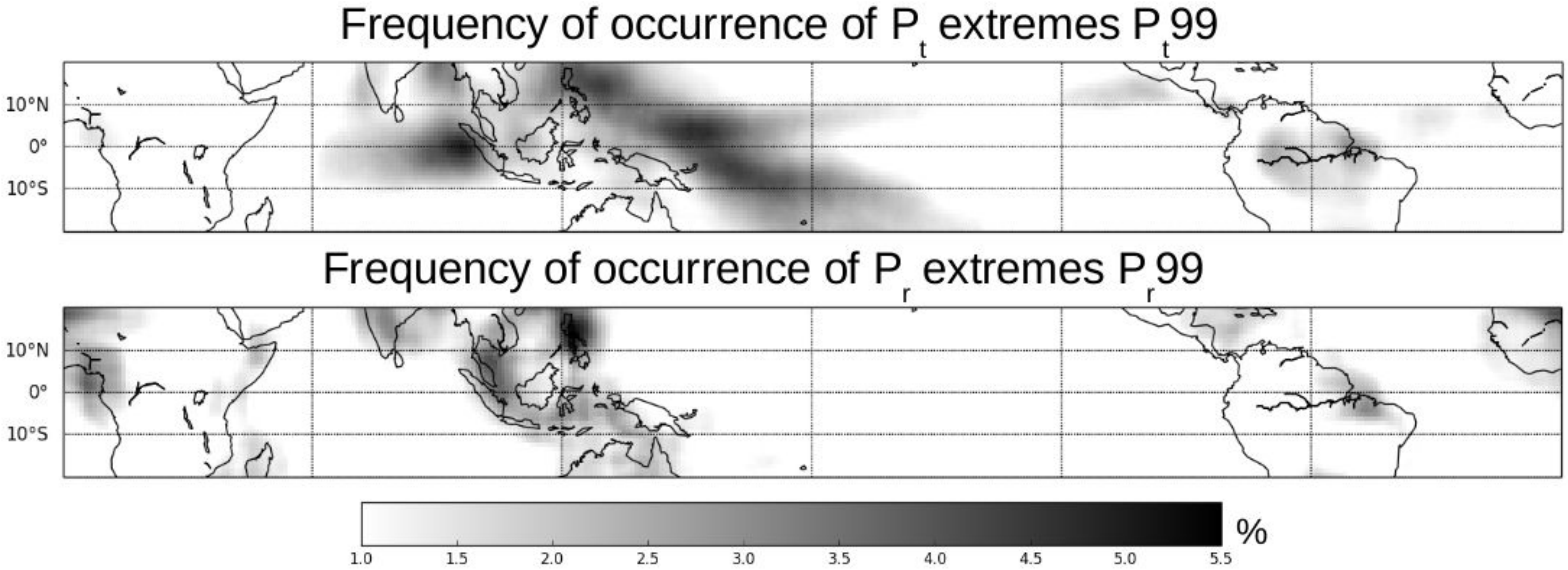


Precipitation extremes

- The 99th percentile values of P_t and P_r , referred to as P_t^o99 (1.18 mm.h−1) and P_r^o99 (4.25 mm.h−1) respectively.
- All cases corresponding to $P_t \geq P_t^o99$ (or $P_r \geq P_r^o99$) are considered as extremes of domain-scale precipitation (or local-scale precipitation), and they are referred to as P_t99 and P_r99, respectively.

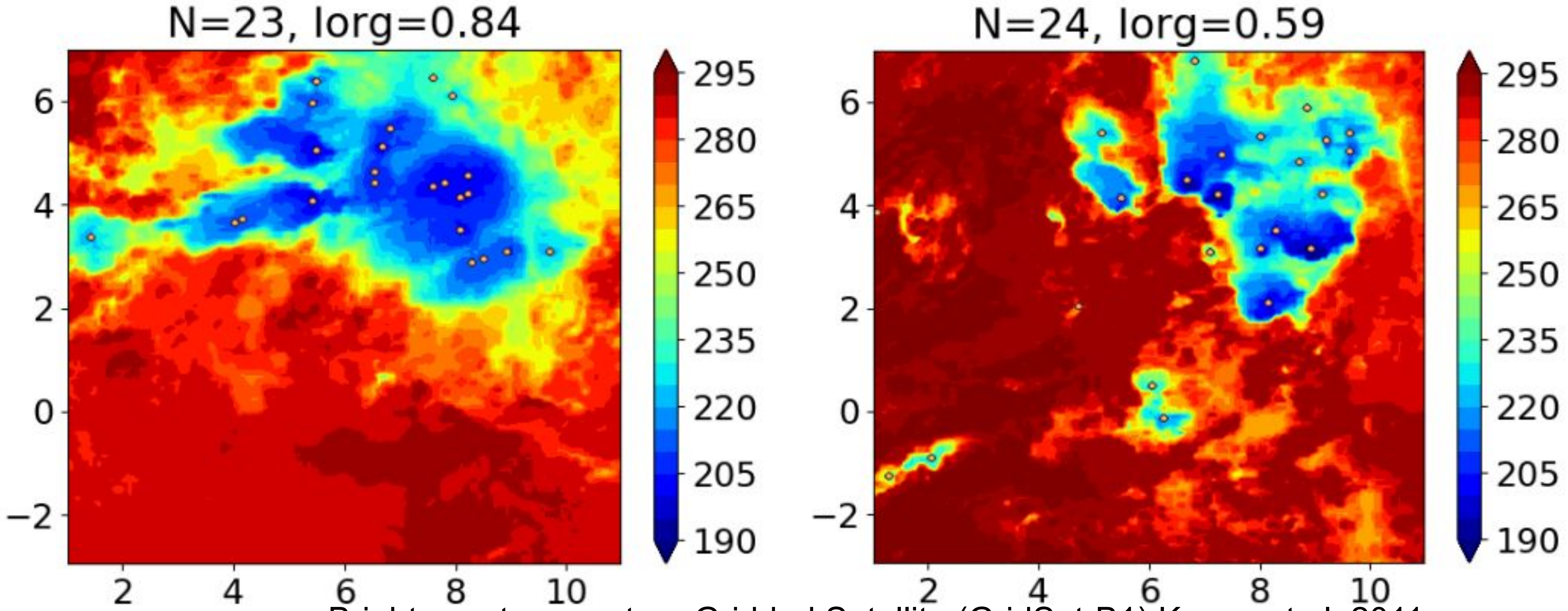
Precipitation extremes

- Most of the P_t 99 events occur over the warm pools of the tropical western Pacific and Indian oceans.
- P_r99 events occur mostly over tropical land.



Number of convective centroids, N

- Identify all the pixels having T_b less than 240 K as being associated with deep convection.
- Within each 3x3 GridSat pixels, the deep convective pixel (if any) having the lowest T_b value is considered as a deep convective centroid (N).



Brightness temperature Gridded Satellite (GridSat-B1) Knapp et al. 2011

Number of convective centroids, N

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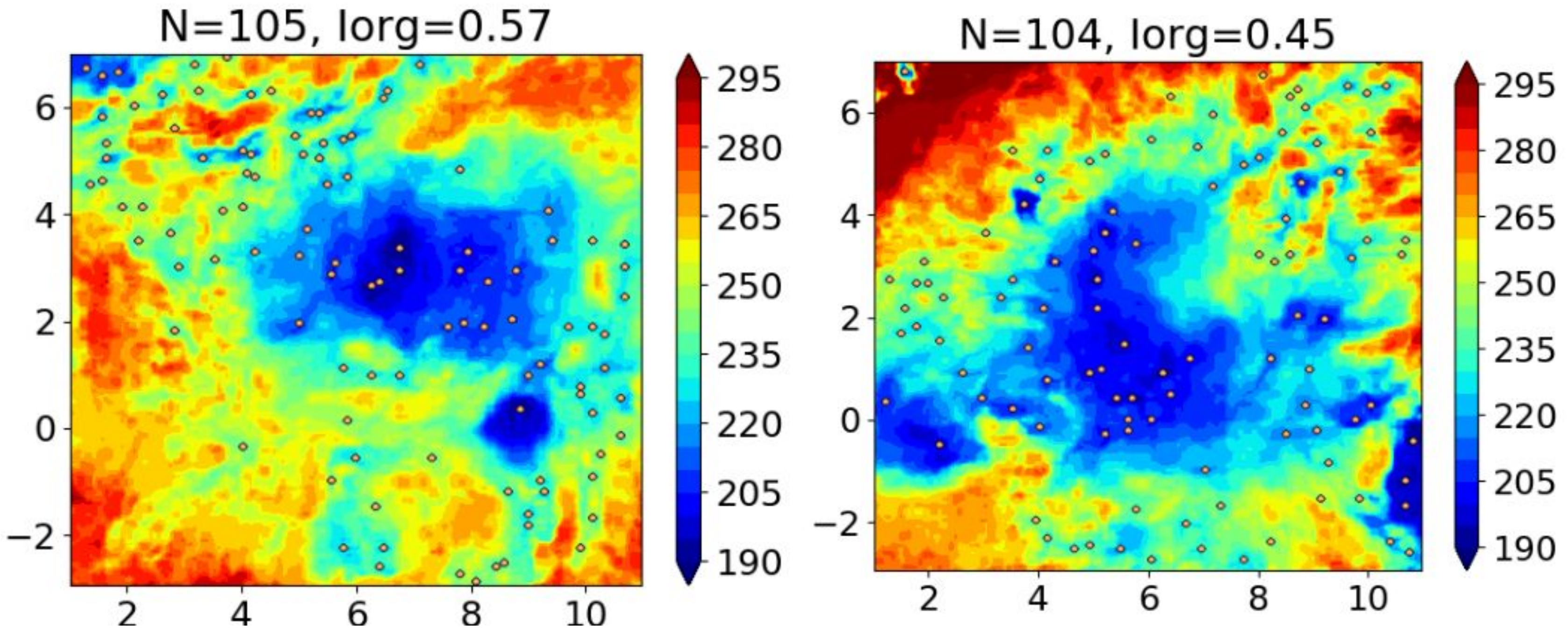
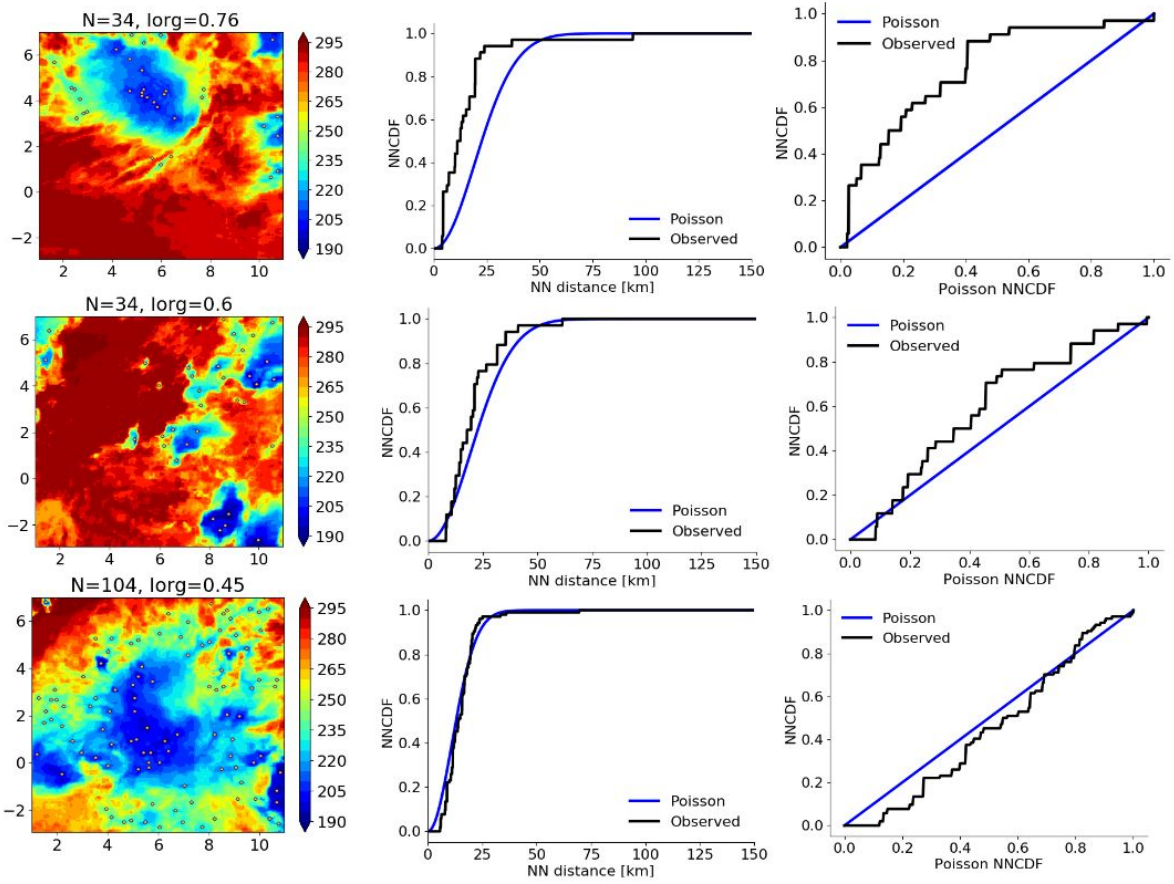
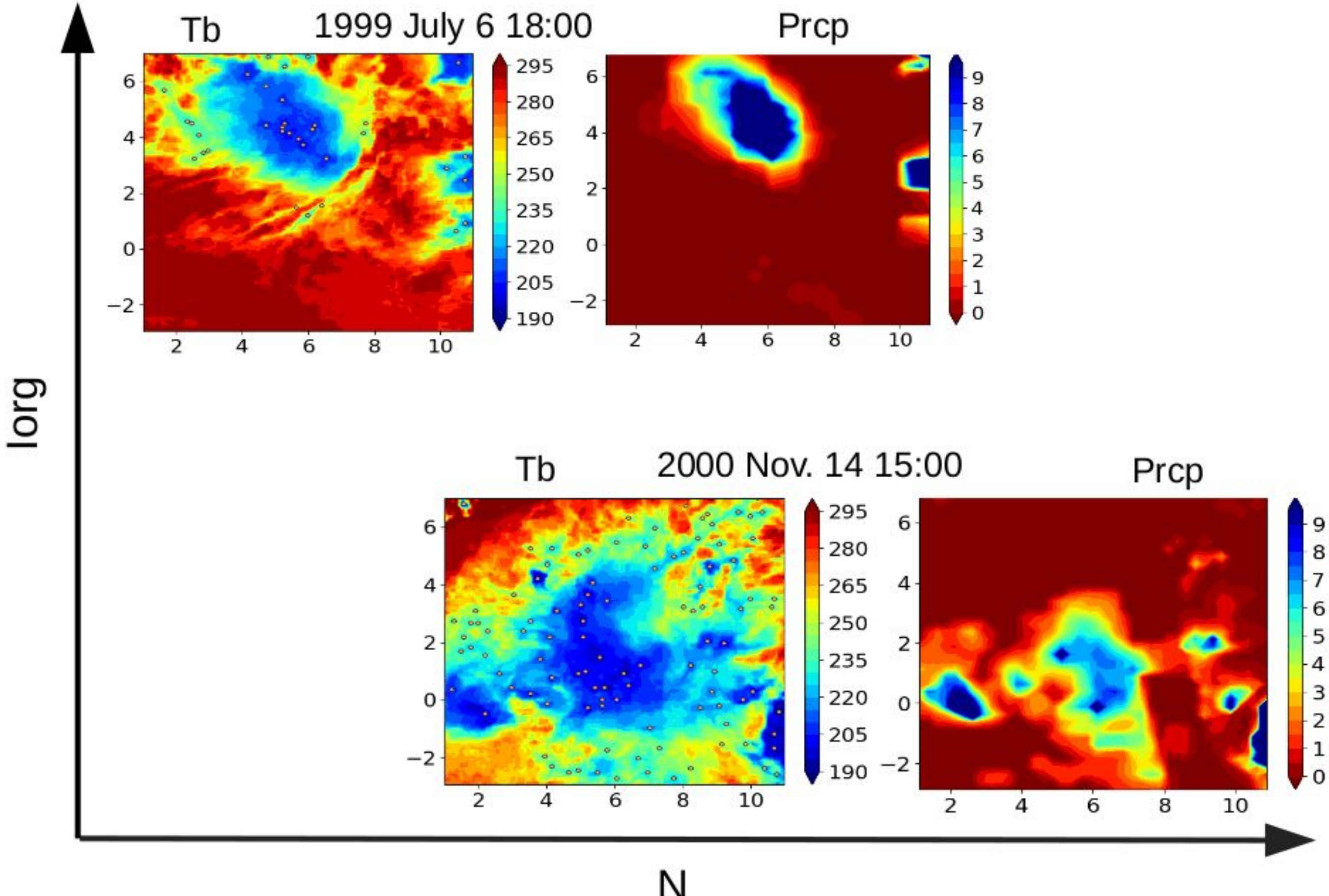


An organization index: I_{org}

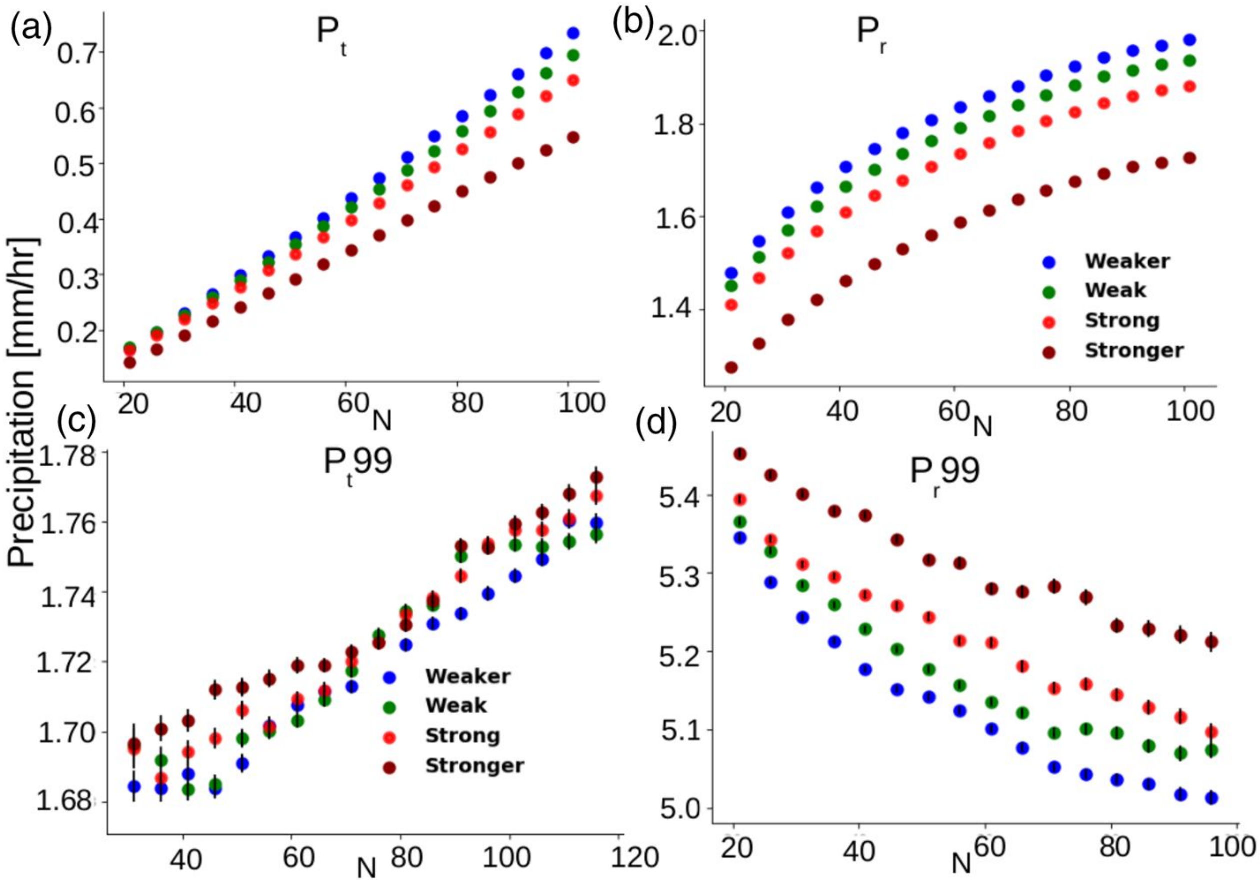


I_{org} is the area under NNCDF - Poisson NNCDF curve

Prcp and Tb in I_{org} - N space



Link between precipitation and convective organization

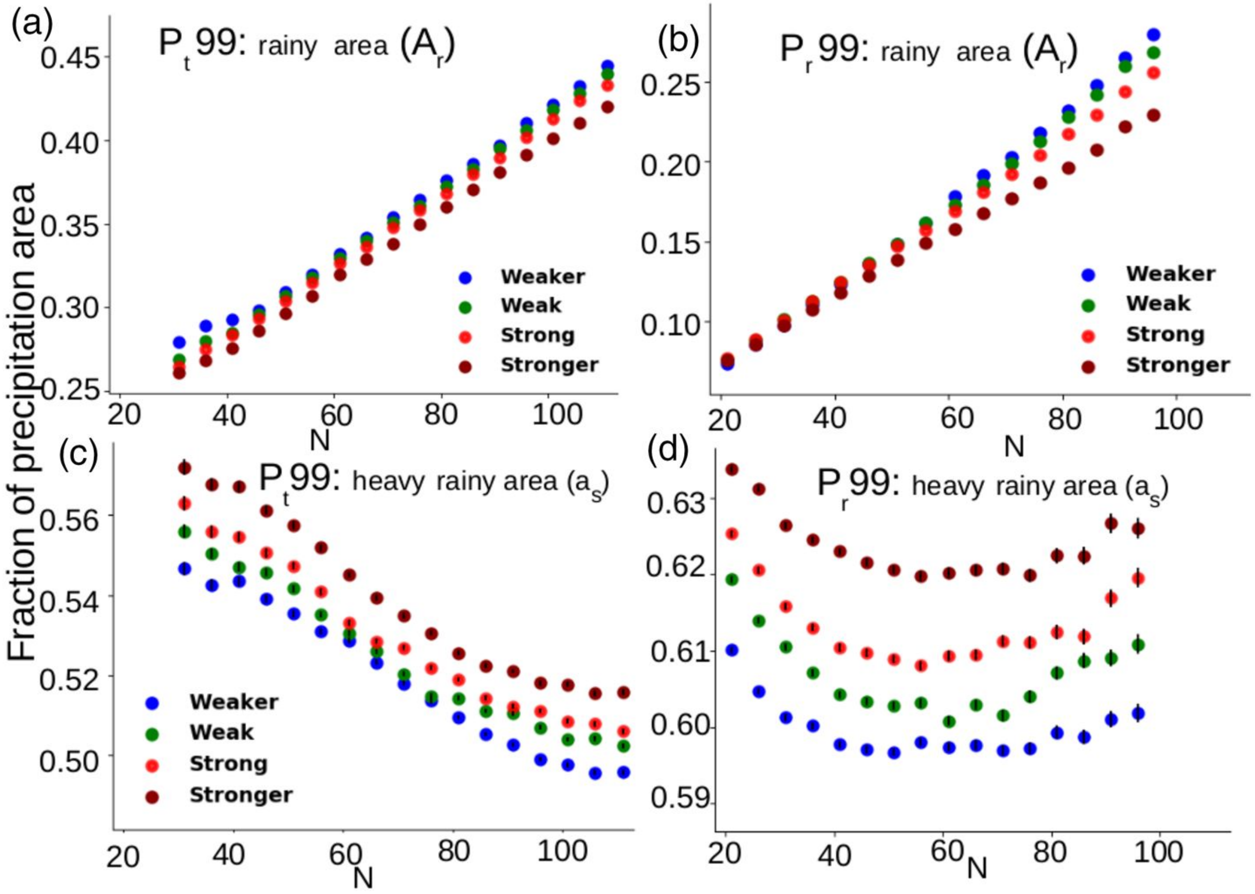


- Stronger clustering is associated with a weaker mean precipitation.

For a given N:

- There is no systematic relationship between P_t99 and I_{org}
- P_r99 increases systematical with the degree of convective clustering

Link between precipitation extremes and convective



- Non-precipitating area ($A_n = 1 - A_r$) has a stronger weight in P_t than the small portion of the domain covered by intensive rain-rate

- The fractional area covered by heavy precipitation increases with I_{org} in all the 10^o x 10^o domains where extreme events occur.

Conclusions

- Extremes in domain-scale precipitation (P_t99), which occur mostly over the ocean warm pools, primarily depend on the total number of convective centroids within the domain.
- Extremes in local precipitation (P_r99), which occur mostly over land, depends on the degree of convective clustering.
- Observations suggest a strong link between the intensity of extreme rainfall at the local scale and the organization of deep convection, especially over land.

AGU Advances

RESEARCH ARTICLE
10.1029/2019AV000155

Key Points:
- The monthly variability of deep convective organization in the tropics is investigated using satellite observations
- An enhanced organization of deep convection is associated with a drier troposphere, fewer high clouds, and a radiative cooling of the tropics
- Observations suggest equal and complementary modulations of the tropical radiation budget by convective organization and low-level stability

Supporting Information:
- Supporting Information S1
- Original Version of Manuscript
- Peer Review History
- Authors' Response to Peer Review Comments
- First Revision of Manuscript
- Authors' Response to Peer Review Comments
- Second Revision of Manuscript [Accepted]

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Observed Modulation of the Tropical Radiation Budget by Deep Convective Organization and Lower-Tropospheric Stability

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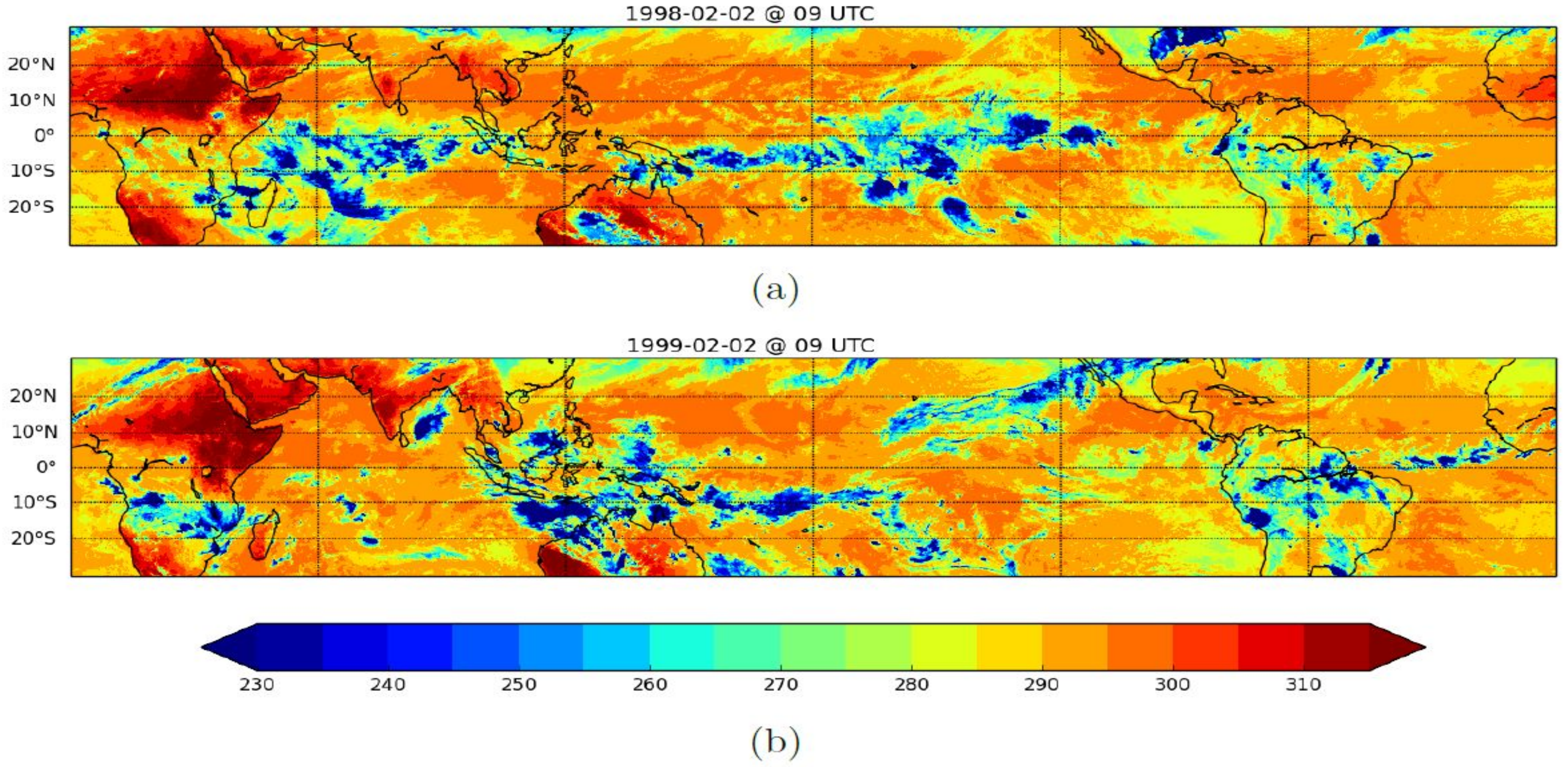
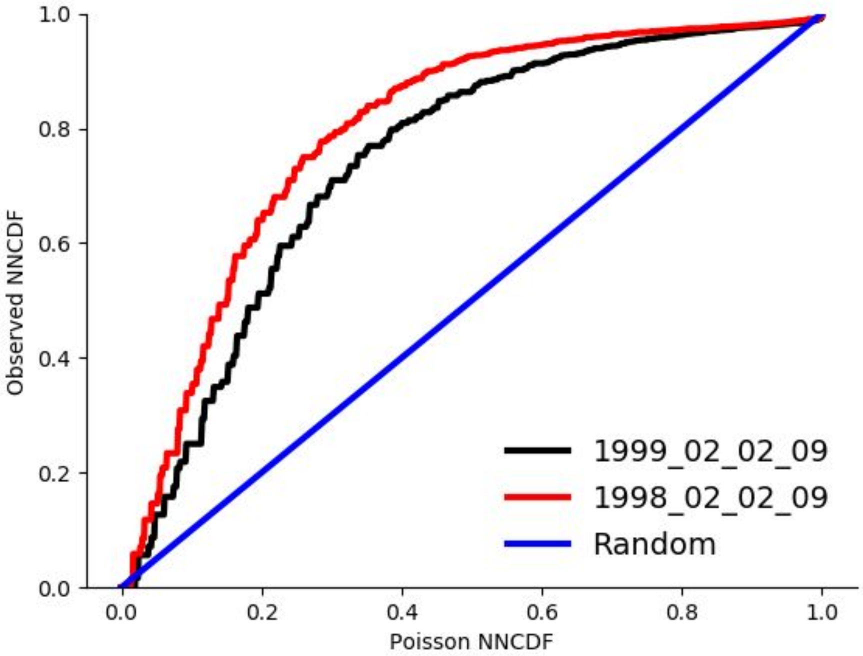
This study analyzes the observed monthly deseasonalized and detrended variability of the tropical radiation budget and suggests that variations of the lower-tropospheric stability and of the spatial organization of deep convection both strongly contribute to this variability. Satellite observations show that on average over the tropical belt, when deep convection is more aggregated, the free troposphere is drier, the deep convective cloud coverage is less extensive, and the emission of heat to space is increased; an enhanced aggregation of deep convection is thus associated with a radiative cooling of the tropics. An increase of the tropical-mean lower-tropospheric stability is also coincident with a radiative cooling of the tropics, primarily because it is associated with more marine low clouds and an enhanced reflection of solar radiation, although the free-tropospheric drying also contributes to the cooling. The contributions of convective aggregation and lower-tropospheric stability to the modulation of the radiation budget are complementary, largely independent of each other, and equally strong. Together, they account for more than sixty percent of the variance of the tropical radiation budget. Satellite observations are thus consistent with the suggestion from modeling studies that the spatial organization of deep convection substantially influences the radiative balance of the Earth. This emphasizes the importance of understanding the factors that control convective organization and lower-tropospheric stability variations, and the need to monitor their changes as the climate warms.

What role does convective aggregation play in climate on larger scale?

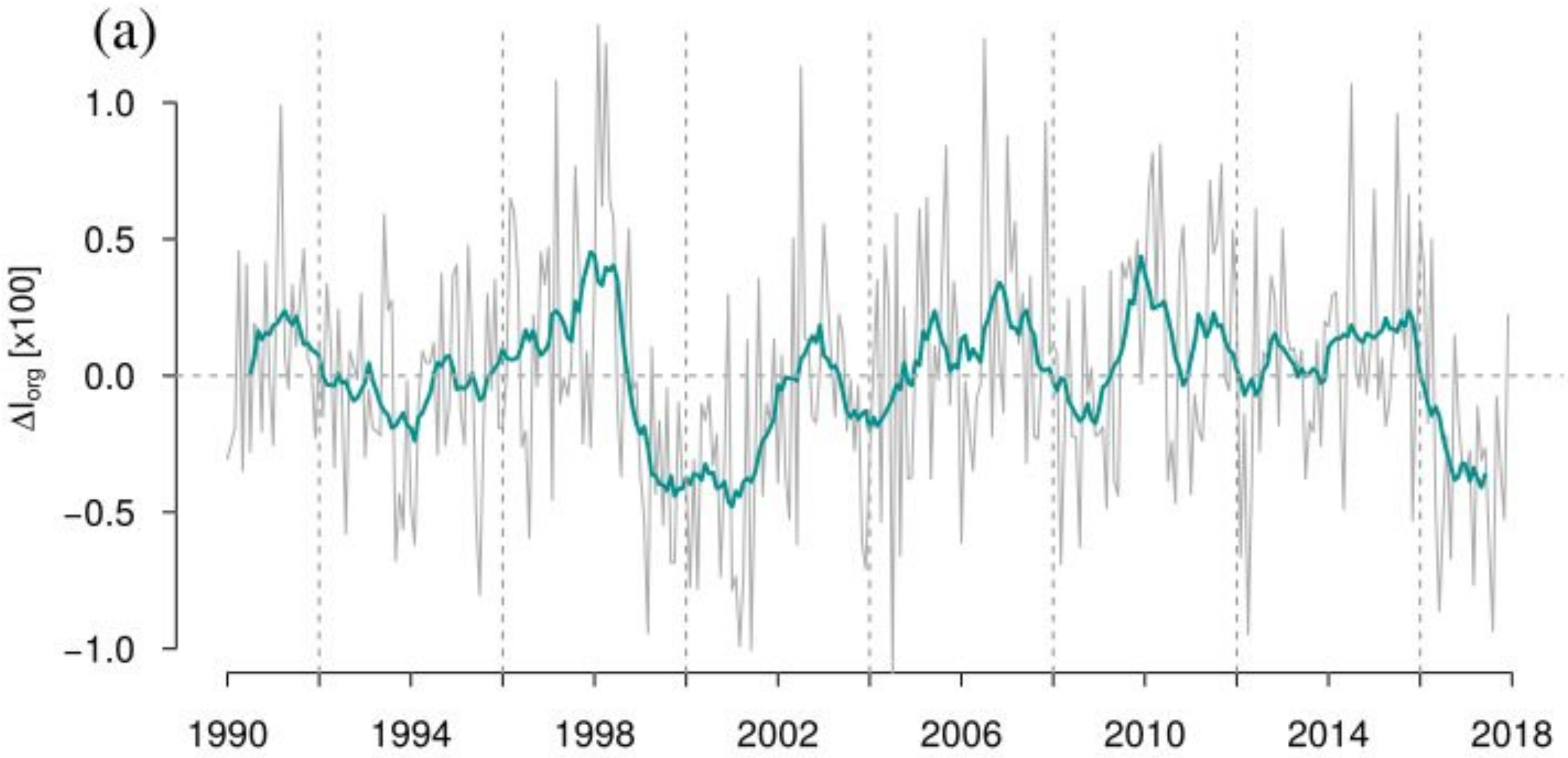


An organization index: I_{org}

- Plot normalized NNCDF against theoretical (Poisson) CDF for random distribution
- I_{org} is the area under this curve
- Random convection will have I_{org} = 0.5, and clustered (regular) states will have values that exceed (are less than) this
- Applied on three hourly brightness temperature of gridded geostationary GridSat for a period of 1990 to 2017



Time series of monthly deseasonalized and detrended anomalies of the deep convective organization index I_{org} (ΔI_{org})



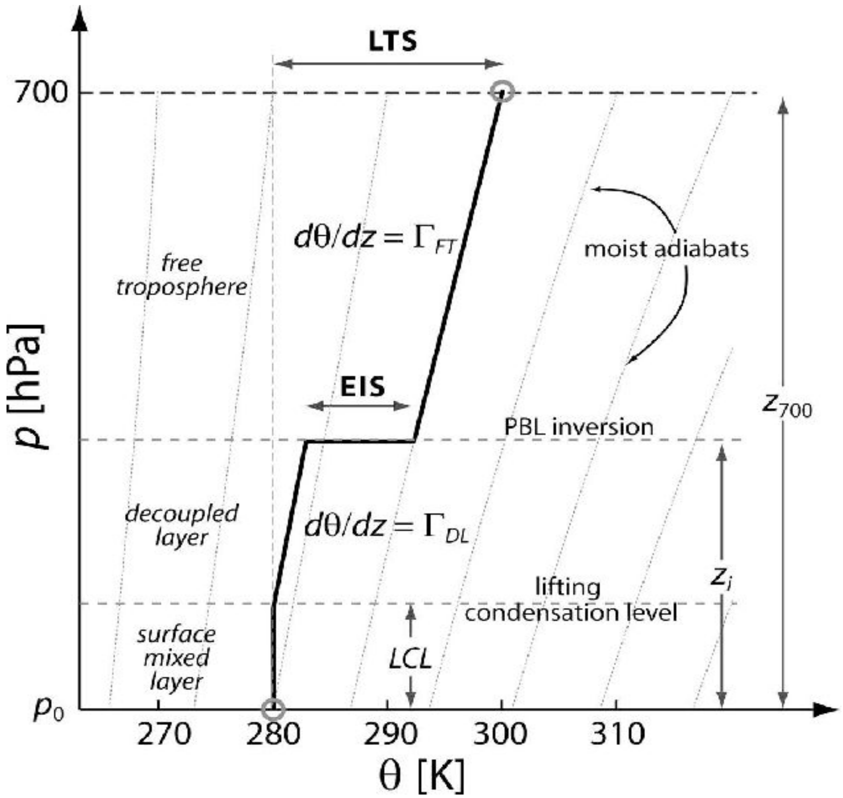
Gray lines show monthly anomalies, and green lines show 12-month running mean anomalies.

Estimated inversion strength (EIS).

$EIS = LTS - \Gamma_m^{850}(z_{700} - LCL)$

- $LTS = \theta_{700} - \theta_{1000}$, where θ_{700} and θ_{1000} are potential temperatures at 700 and 1,000 hPa levels - lower‐tropospheric stability
- where Γ_m^{850} is the moist‐adiabatic potential temperature gradient at 850 hPa
- z_{700} is the height of the 700 hPa level
- LCL is the height of the lifting condensation level assuming a surface relative humidity of 80%

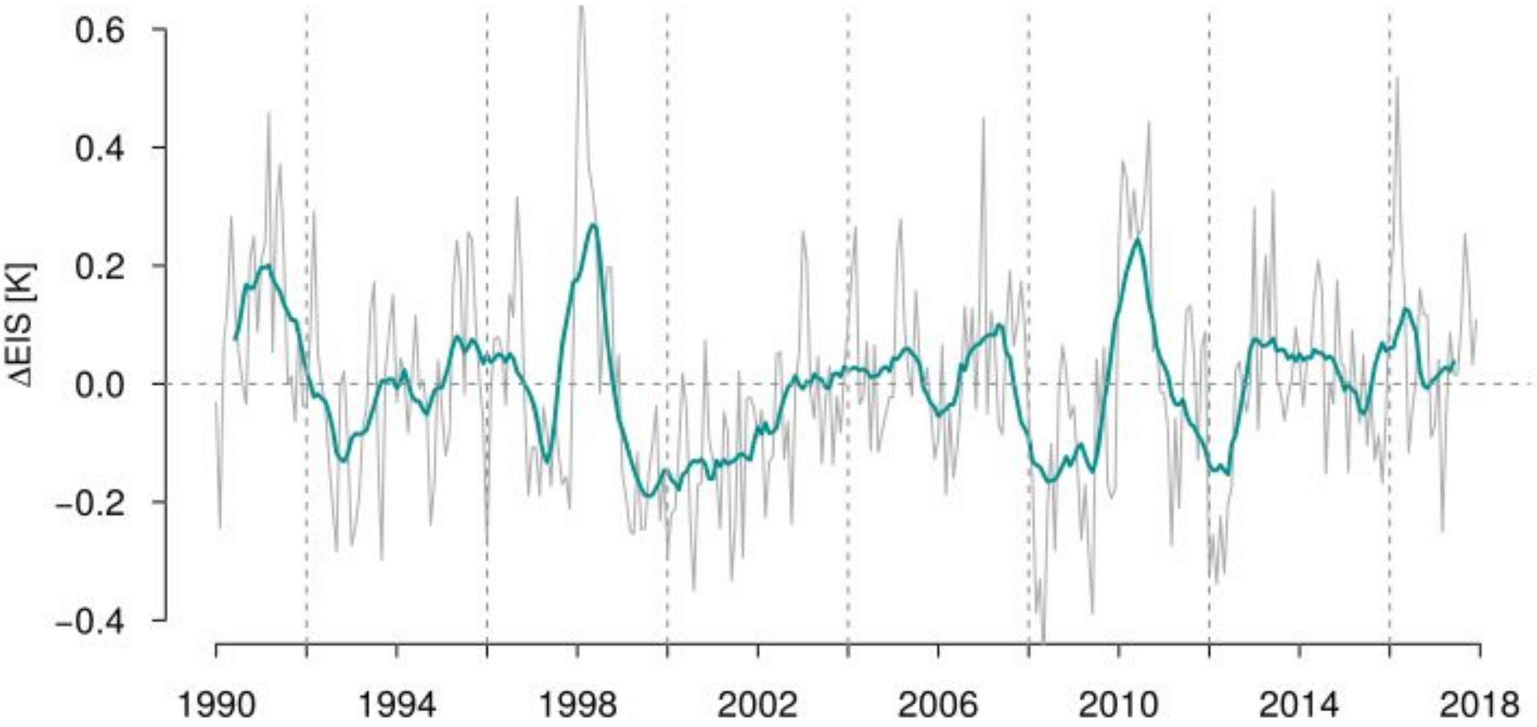
We compute EIS over each ocean region and compute the tropical‐mean EIS as the spatial average over all tropical oceans (30°S to 30°)



ERA‐interim reanalyses at a spatial resolution of 0.75°

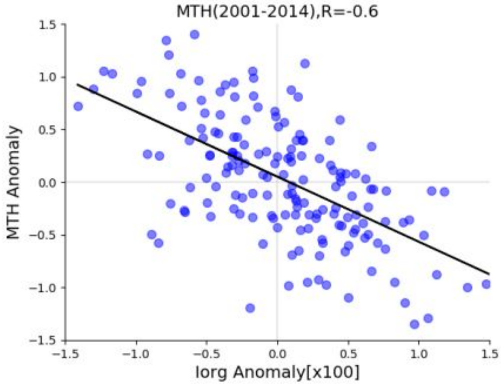
Wood & Bretherton, 2006

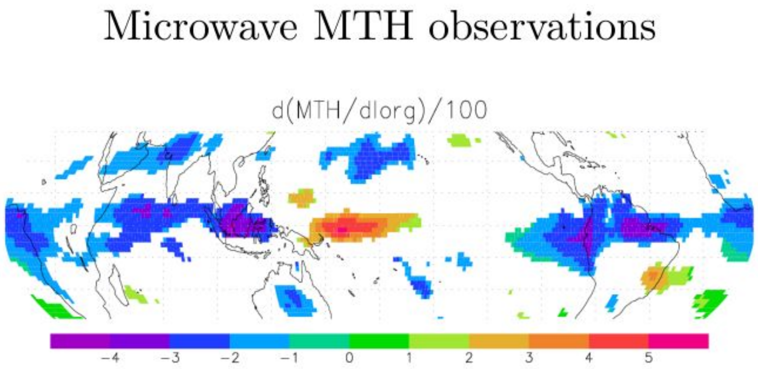
Time series of monthly deseasonalized and detrended anomalies of he tropical‑mean lower‑tropospheric stability EIS (ΔEIS)



Gray lines show monthly anomalies, and green lines show 12‑month running mean anomalies.

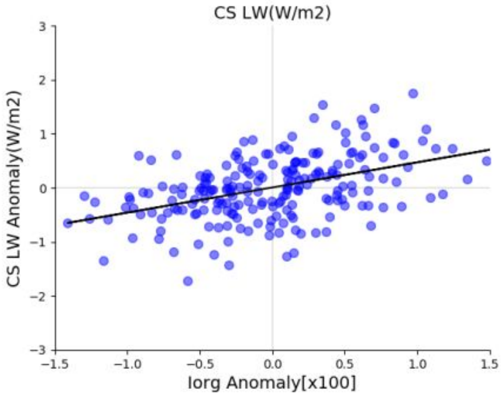
How does convective aggregation related to humidity and clear sky OLR?

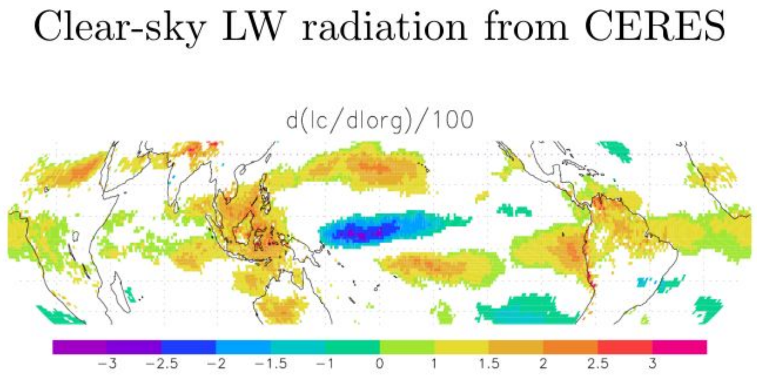




Strong aggregation is associated with

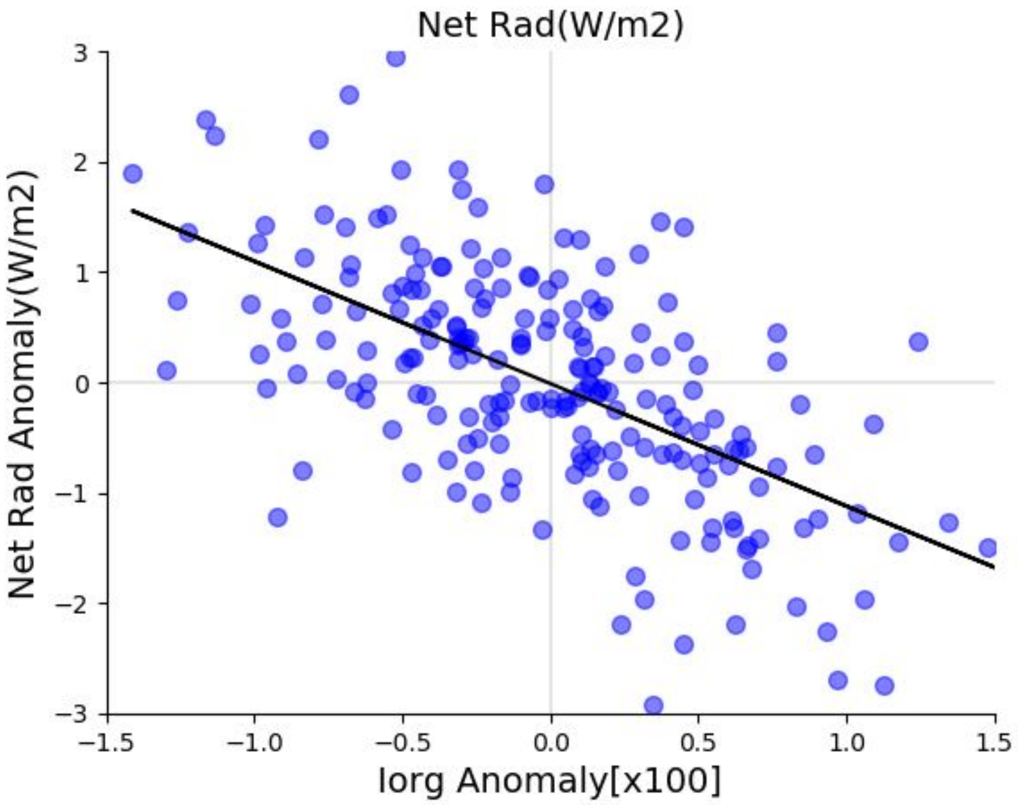
- Dry tropical atmosphere





- Enhanced emission of OLR

Radiative cooling of the tropics associated with convective aggregation

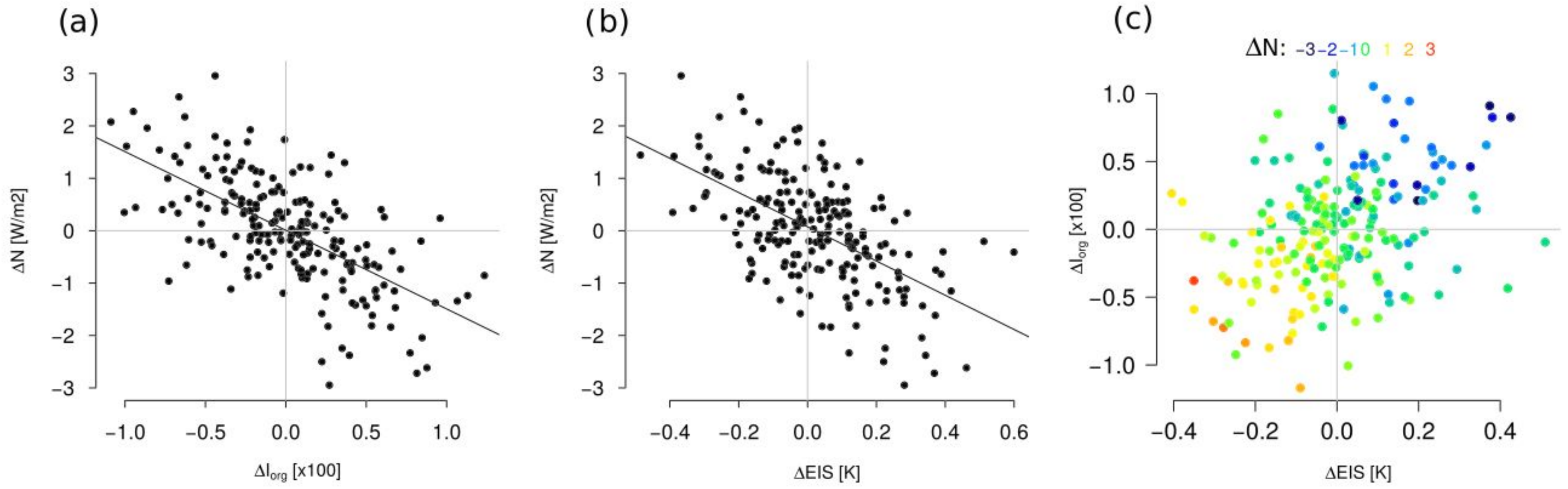


Convective Organization Versus Lower‐Tropospheric Stability

	N	N_{cs}	CRE	N_{lw}	N_{sw}	$N_{cs,lw}$	$N_{cs,sw}$	CRE_{lw}	CRE_{sw}
I_{org}	−0.65	−0.54	−0.43	−0.53	−0.22	−0.47	−0.33	−0.39	(−0.13)
EIS	−0.66	−0.44	−0.55	−0.36	−0.41	−0.47	(−0.10)	(−0.09)	−0.41

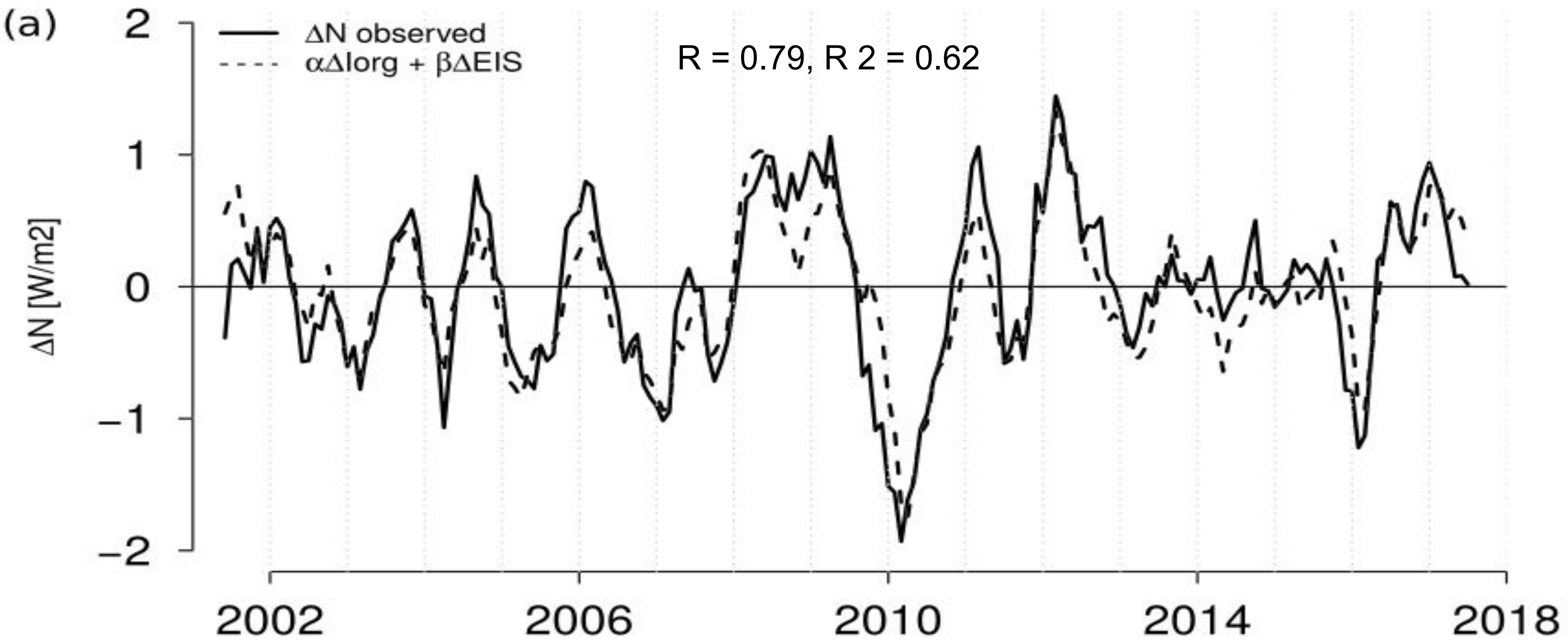
- I_{org} primarily affecting the clear‐sky component and EIS primarily the cloudy component (marine low clouds)
- I_{org} and EIS exert complementary influences on N

Convective Organization Versus Lower-Tropospheric Stability



- Negative ΔN tend to be associated with both positive ΔI_{org} and positive ΔEIS
- The anticorrelation between ΔI_{org} and ΔN remains for a given ΔEIS
- The anticorrelation between ΔEIS and ΔN remains for a given ΔI_{org} .

Net radiation as a function of Iorg and EIS



- $\Delta N = \alpha\Delta I_{org} + \beta\Delta EIS$ with $(\alpha, \beta) = (-111.41\ Wm\ 2\ , -3.14\ Wm\ 2\ K\ -1\ )$
- Explains more than 60% of the variance of monthly N anomalies

Summary

- An enhanced organization of deep convection is associated with a drier troposphere, fewer high clouds, and a radiative cooling of the tropics.
- Enhanced Lower-tropospheric stability linked with formation of low-level clouds, and thus the cooling of the tropics through the enhanced reflection of solar radiation.
- Organization of convection and atmospheric stability complement each other to modulate significant fraction of monthly interannual variance of the net tropical radiation budget.

Thank you!

Questions?