Changing Rainfall Characteristics in a Warmer Climate

William K.-M. Lau
Laboratory for Atmospheres
NASA/Goddard Space Flight Center

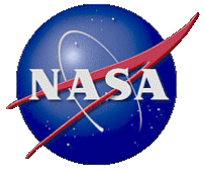
Coauthors: H. T. Wu and Y. P. Zhou

Outline of talk

- Rainfall trends analysis: physical controls, methodology
- Characterization of rain systems : rain and cloud types
- Sensitivity to tropical mean SST
- Responses of rain systems to ENSO (see Poster, Wu and Lau)
- Long-term trends in tropical cyclone rain (see Poster, Zhou and Lau)

Lau and Wu (2011): Climatology and changes in rainfall characteristics inferred from TRMM, 1998-2009, JGR, VOL. 116, D17111, doi:10.1029/2011JD015827

Lau and Zhou (2011): Recent changes in tropical cyclone rain over N. Atlantic and n. Pacific. JGR, (under review)



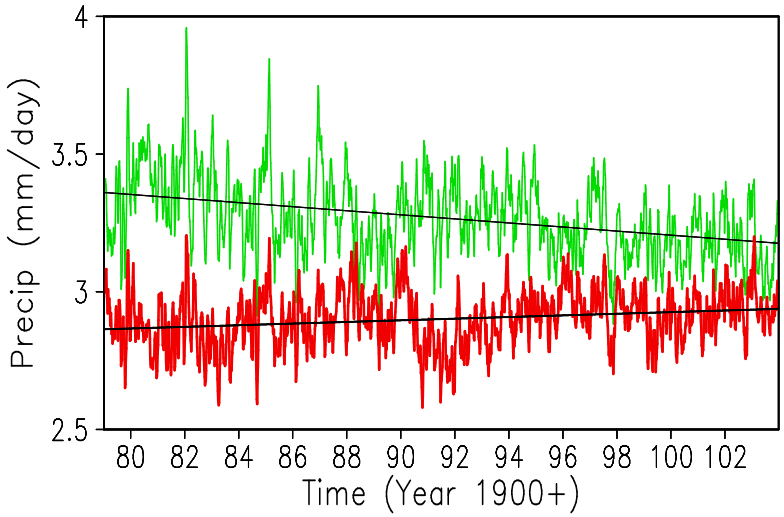
Physical factors affecting long-term changes in global precipitation:

- Clausius Clapeyron relationship governing temperature and saturated water vapor (+7% per degree C)
- Energy balance (radiative vs. latent heating)
- Mass balance (Div **V**q = E-P +R)
- Sea Surface temperature
- Moist Adiabatic Lapse Rate
- Atmospheric Large Scale Circulation: wind shear, thermal direct overturnings

Detecting long-term trends in global rainfall is challenging:

- small signal-to-noise,
- data uncertainties: sampling, inhomogeneities in historical gauge data, satellite retrieval algorithms bias…
- global merged gauge and satellite GPCP, CMAP (30+ year record), most widely used by climate modelers
- TRMM rainfall products (13+ years), extremely useful for process studies, extremes, but far too short for climate trend detection

All results on rainfall trend analyses of rainfall are highly sensitive to data set and time period used.



The right questions to ask:

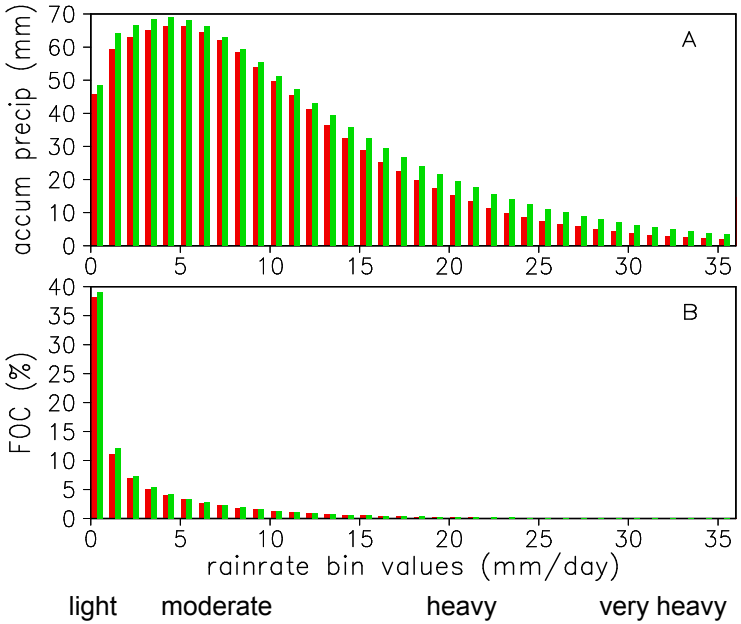
Are there detectable trends in rainfall characteristics from current global rainfall dataset?

How can we use TRMM data to learn more about characteristics and their physical controls?

— CMAP

— GPCP

Satellite-derived rainfall Probability Distribution Functions (PDF) for the tropics



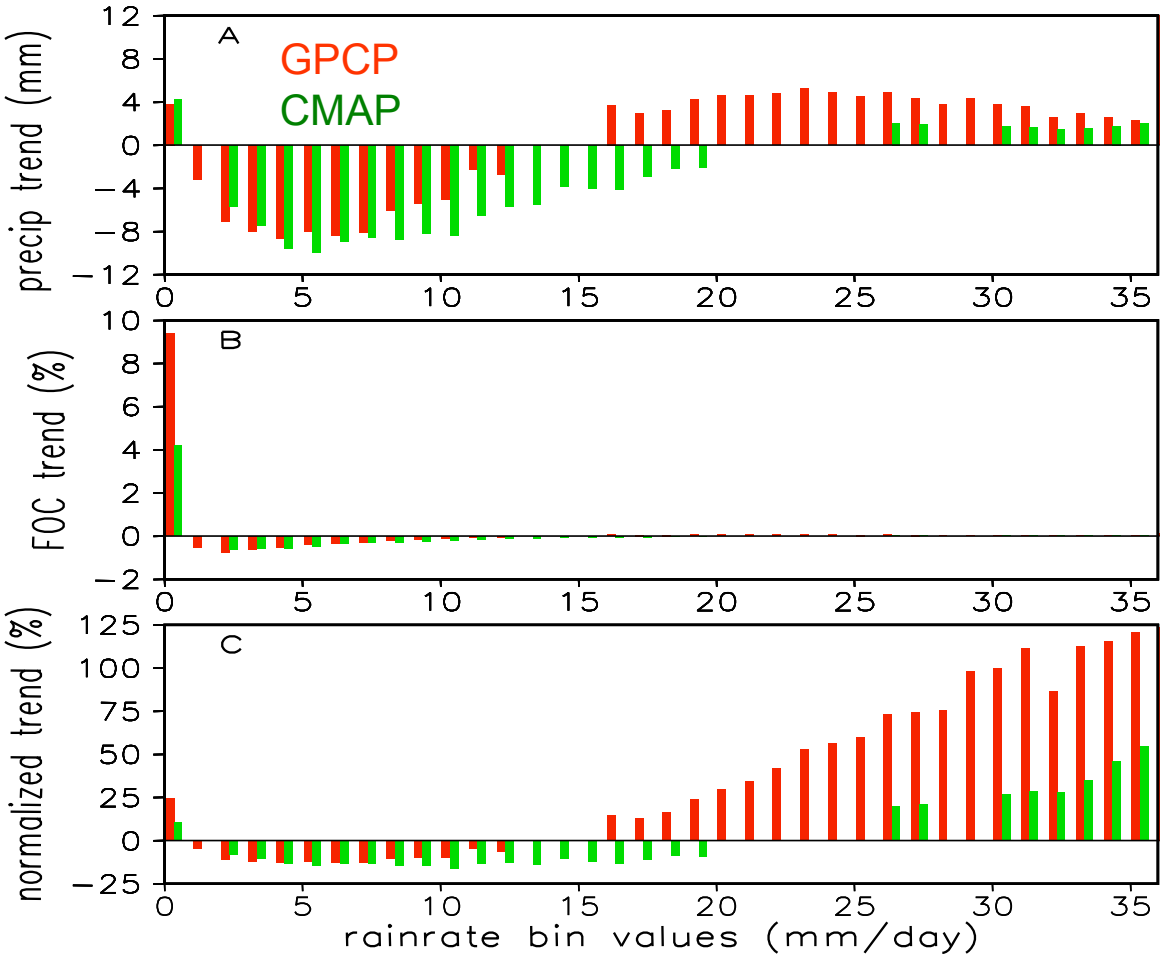
Rain amount PDF

Frequency of Occurrence PDF

A trend is defined as a monotonic increase/decrease over a multi-decade period. The "trend" could be part of a longer term (inter-decadal) variation, outside the data window.

Lau and Wu, 2007: Detecting trends in tropical rainfall characteristics, 1979-2003, Int. J. Climatology

Significant linear trends in all-tropics monthly rainfall by rainrate (1979-2003)

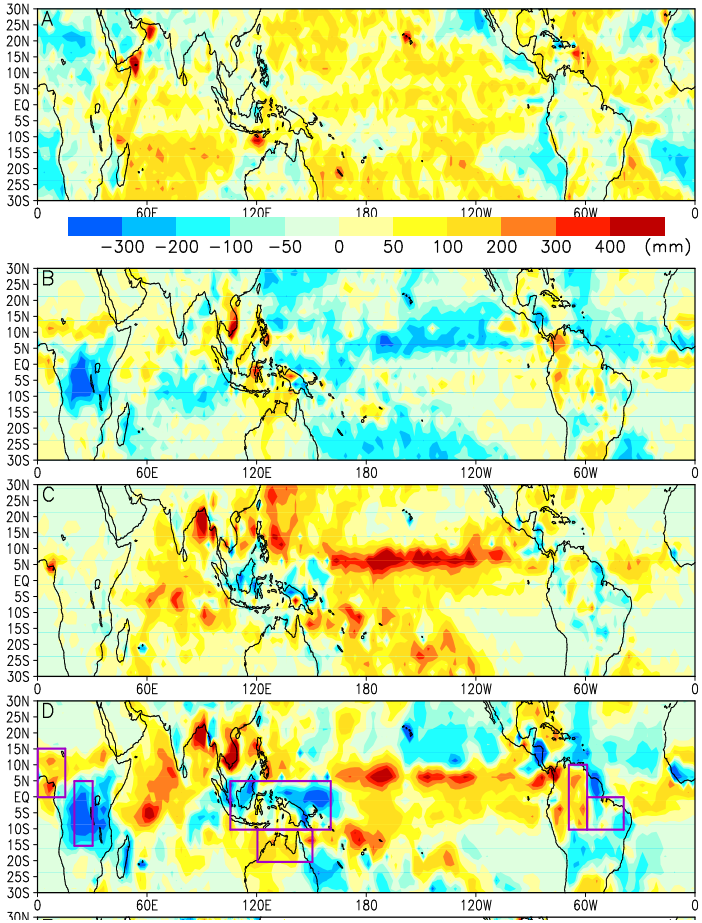


Light moderate heavy very heavy

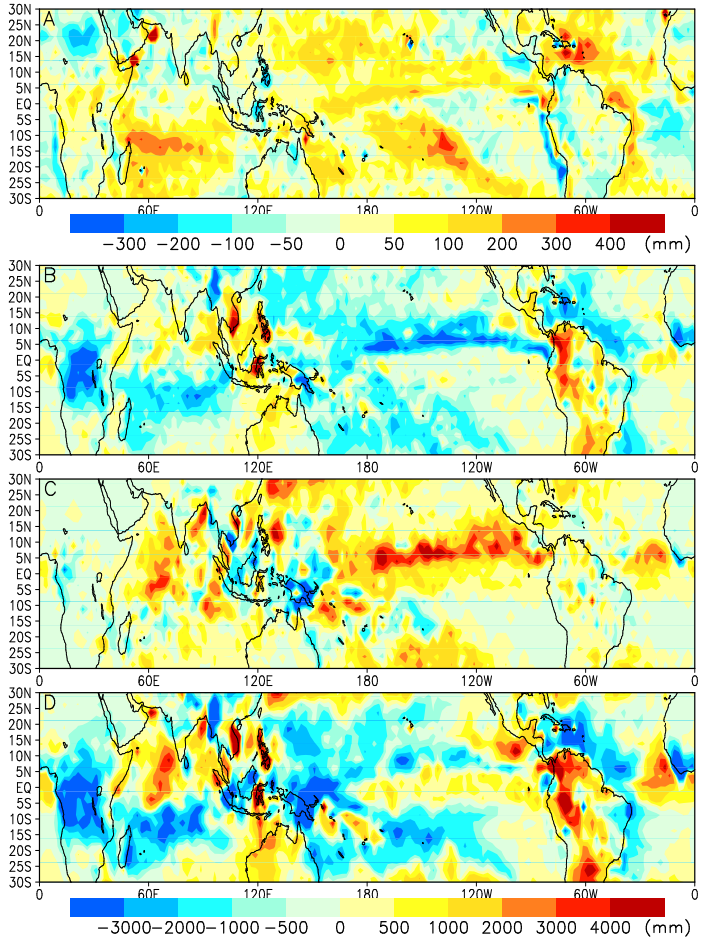
Lau and Wu, 2007

Trend patterns of annual rainfall by types

GPCP



CMAP



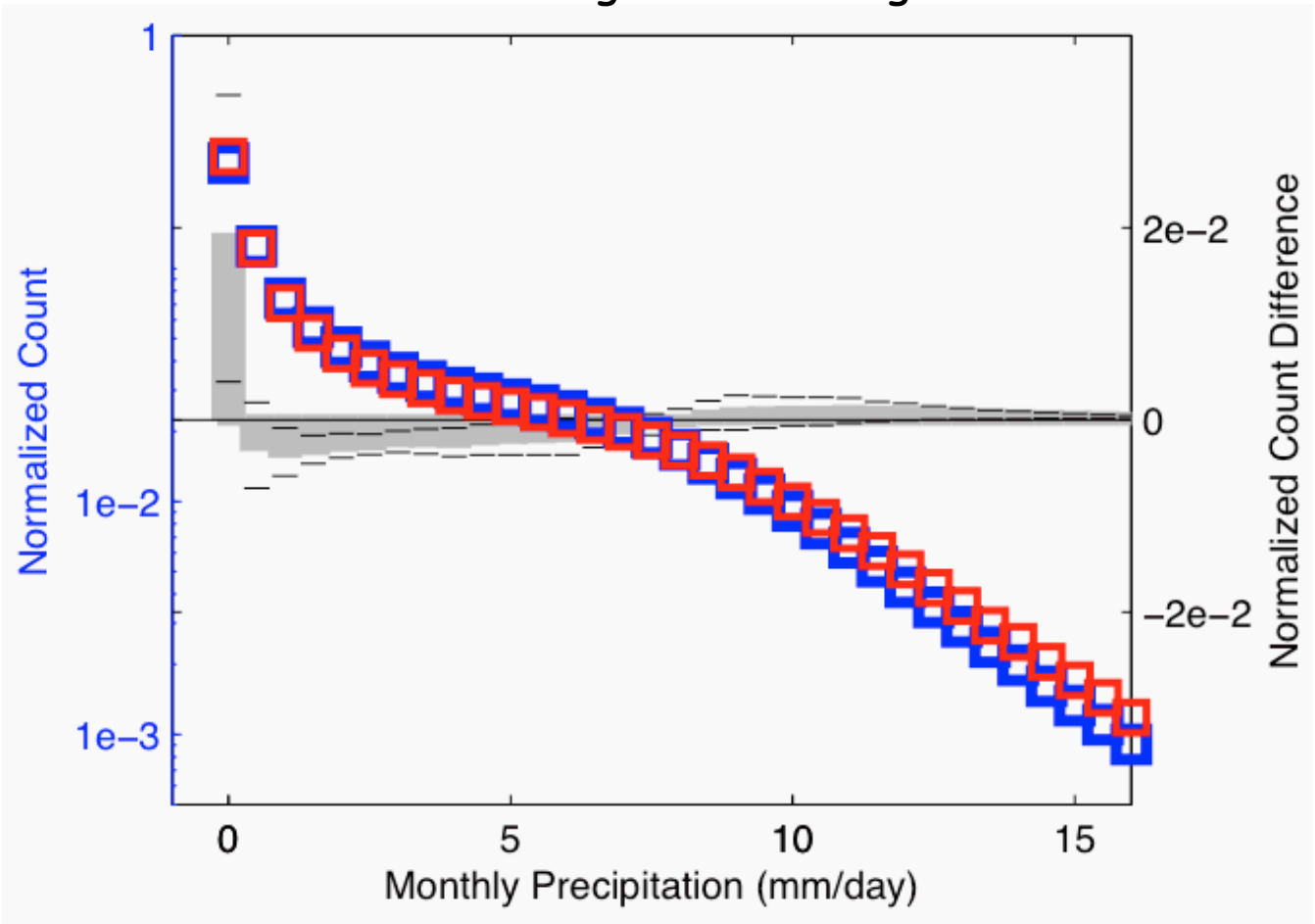
Light rain
(5 percentile, B5)

Moderate
(25-75 percentile, I25)

Heavy
90 percentile, T10

Total

24 CMIP3 (AR4) models show consistent changes in monthly rainfall distribution due to global warming



Lintner et al. 2011

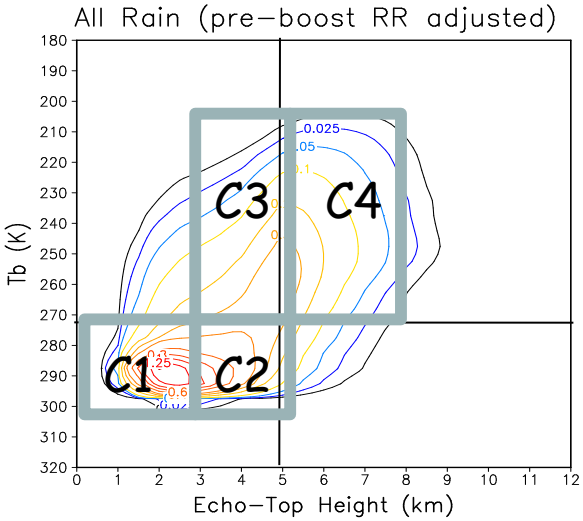
Quantile Regression

- Quantile regression is a natural analogue in regression analysis of mean values, to the practice of using different measures of central tendency and statistical dispersion to obtain a more comprehensive and robust analysis.
- In rain-system studies, quantile regression has been used as a way to discover more useful predictive relationships between variables in cases where there is no relationship or only a weak relationship in the means of such variables to the predictor. The need for and success of quantile regression in rain-system studies has been attributed to the complexity of interactions among different scales in response to external driving factors.[2]

- Koenker, R. and Hallock, K. (2001), Hao L. and Naiman D. Q.(2007)

Characterizing rainfall types with TRMM products

All Rain

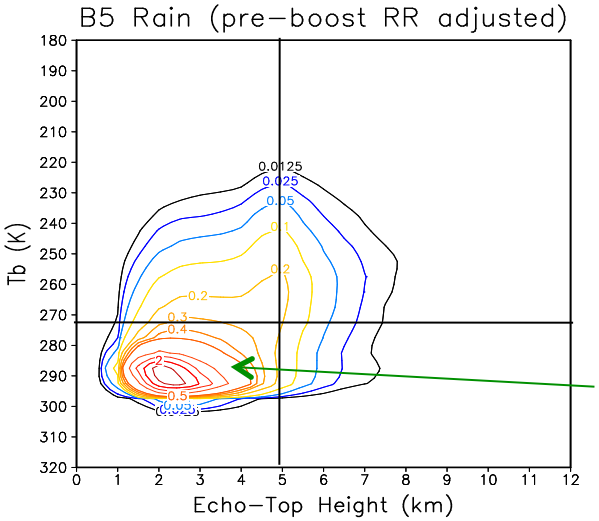


cold

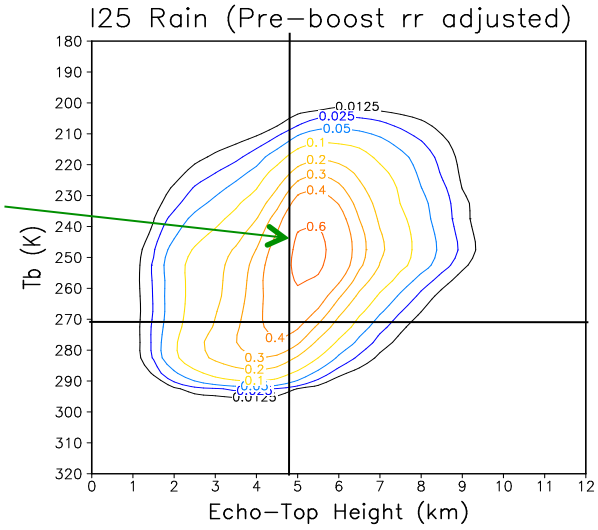
↑

warm

Light Rain

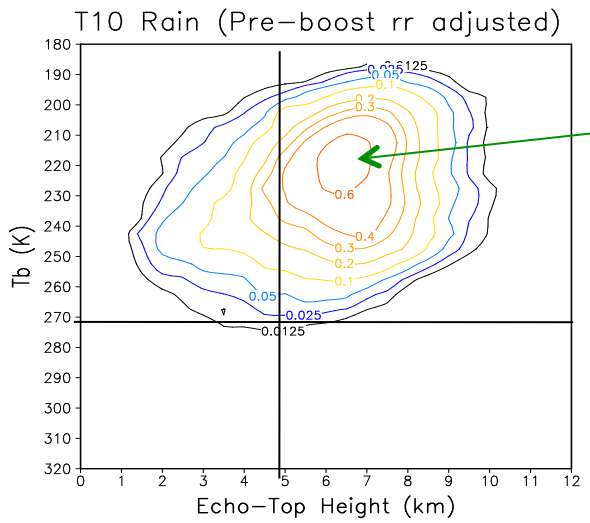


Warm rain,
Low clouds



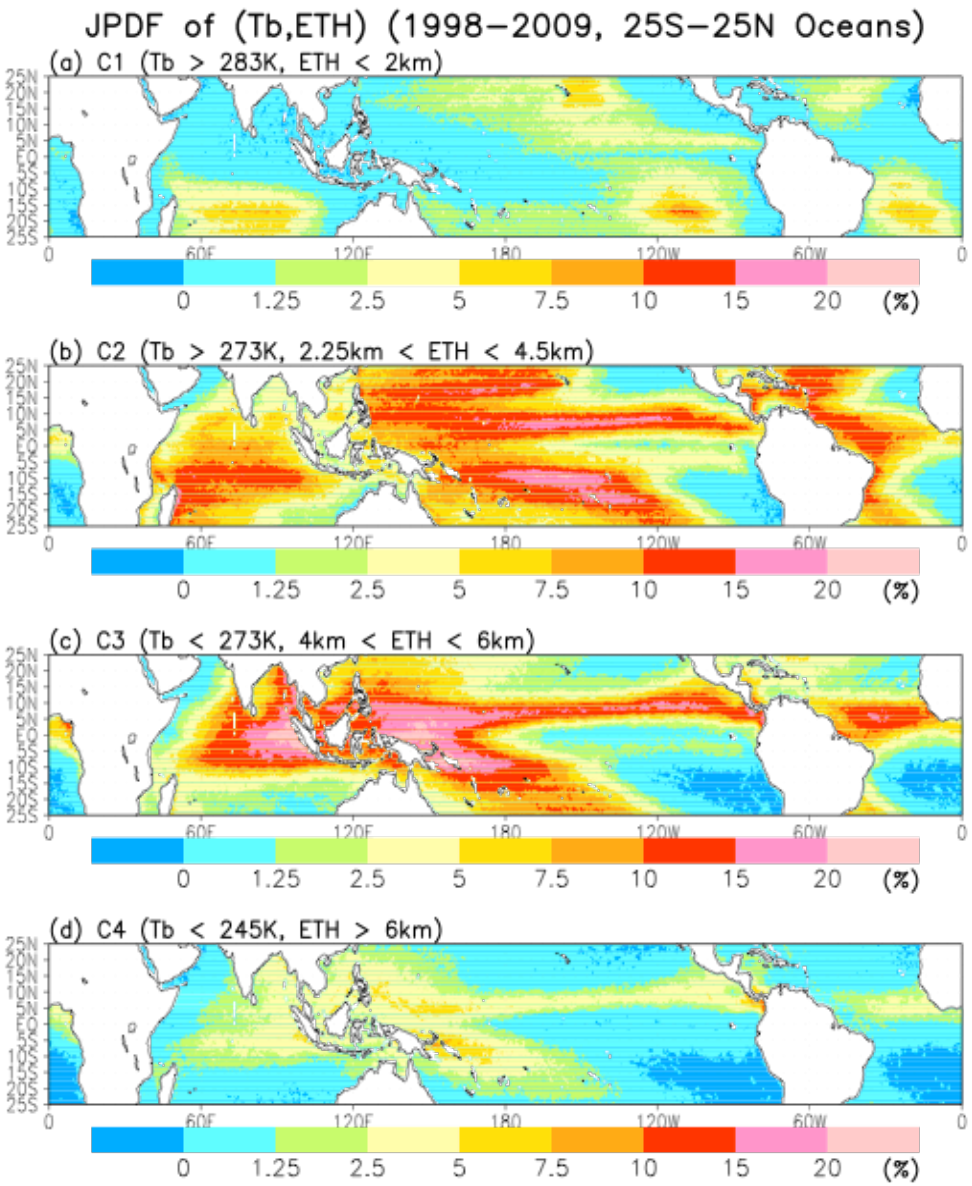
Mixed
Phase
Rain

Moderate Rain



Cold rain,
Deep Clouds

Heavy Rain

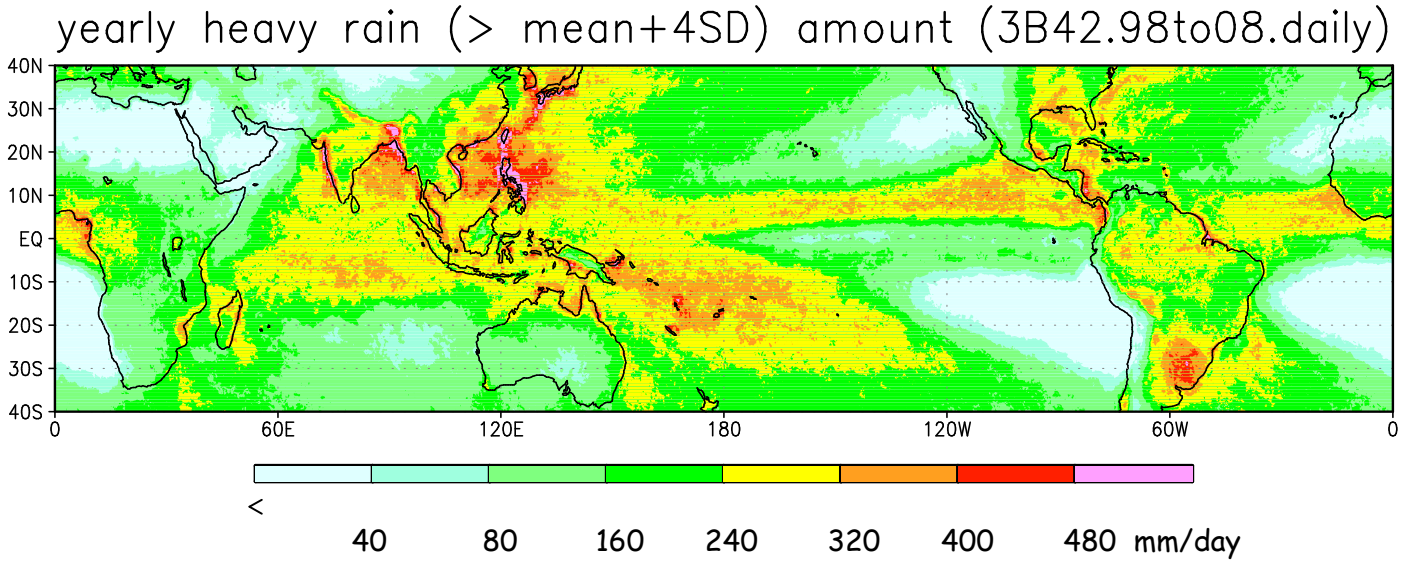


Marine PBL rain clouds

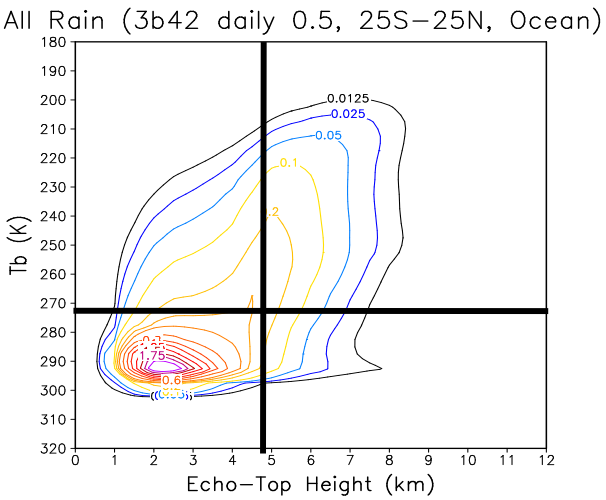
Warm rain, congestus

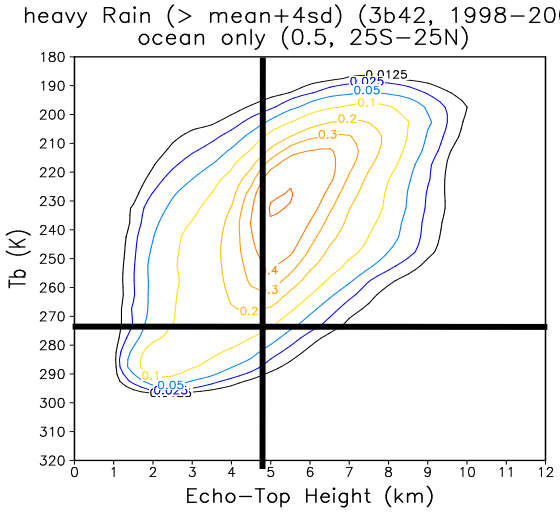
Mixed phase rain

Ice-Phase rain, deep clouds

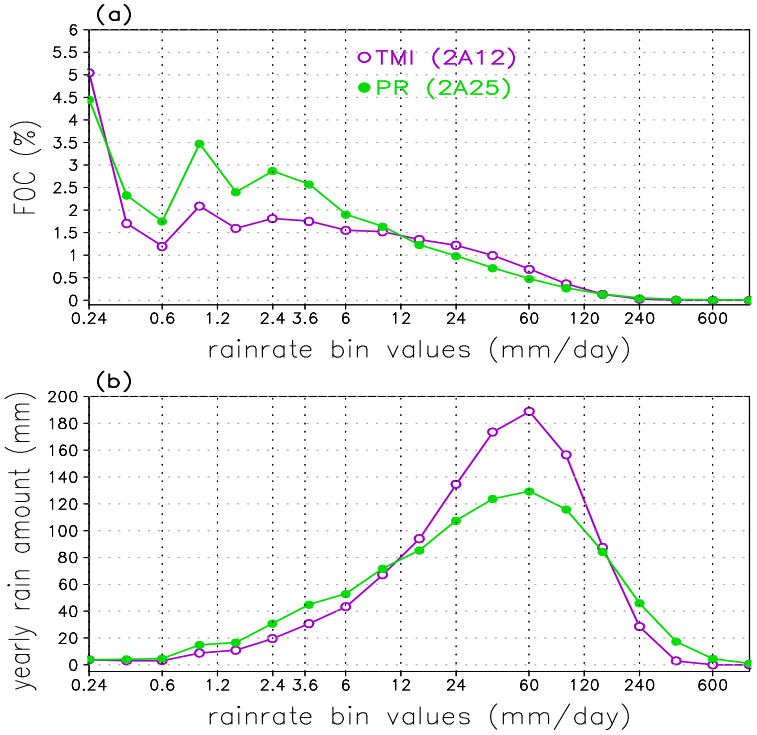


All rain

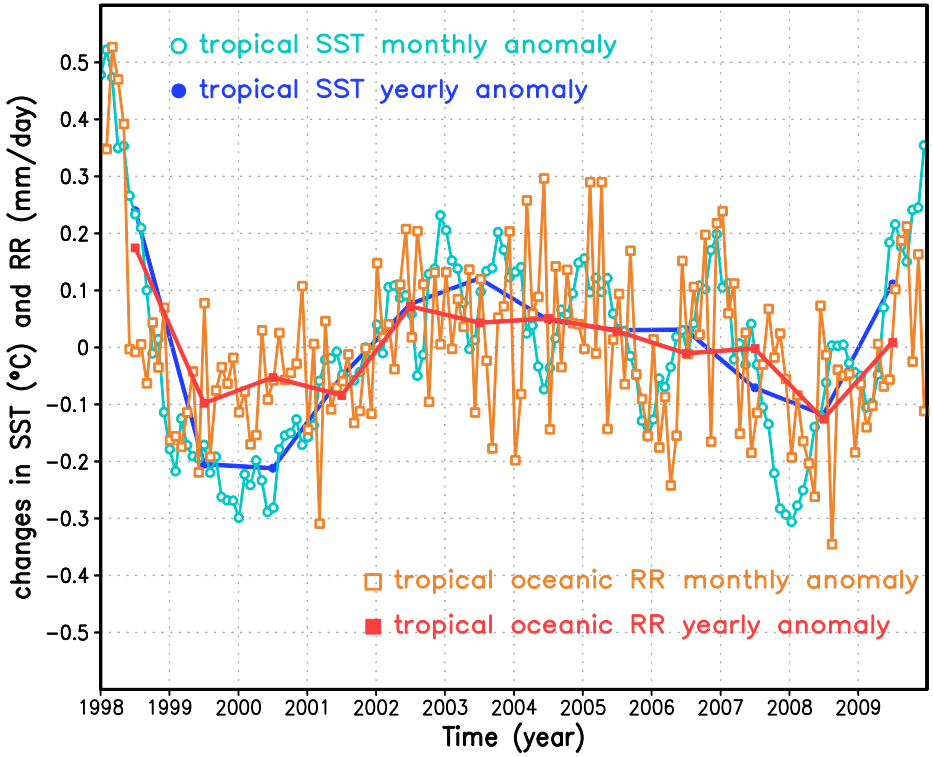




Extreme Heavy rain

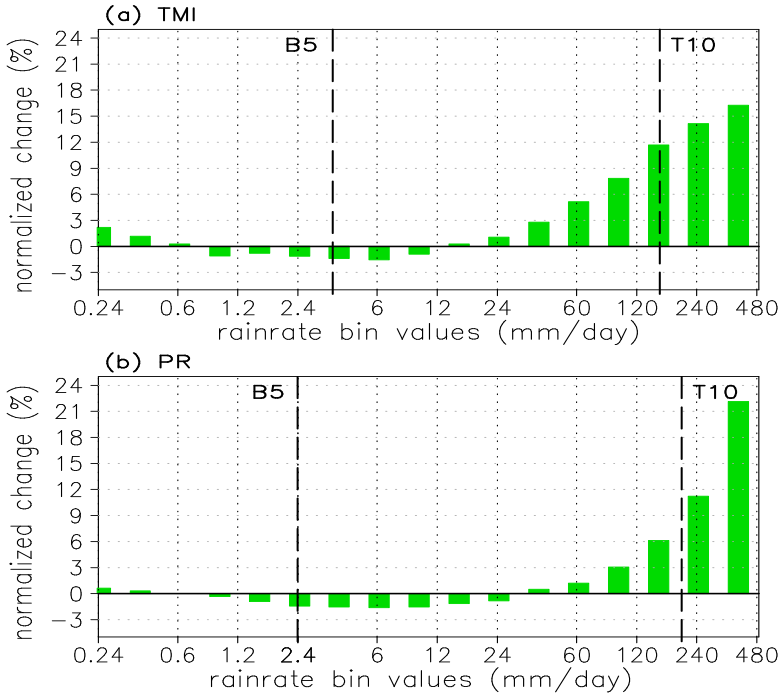


TMI and PR annual daily rainfall distributions with rain-rate dependent corrections due to orbit boost (Lau and Wu, JGR, 2011)

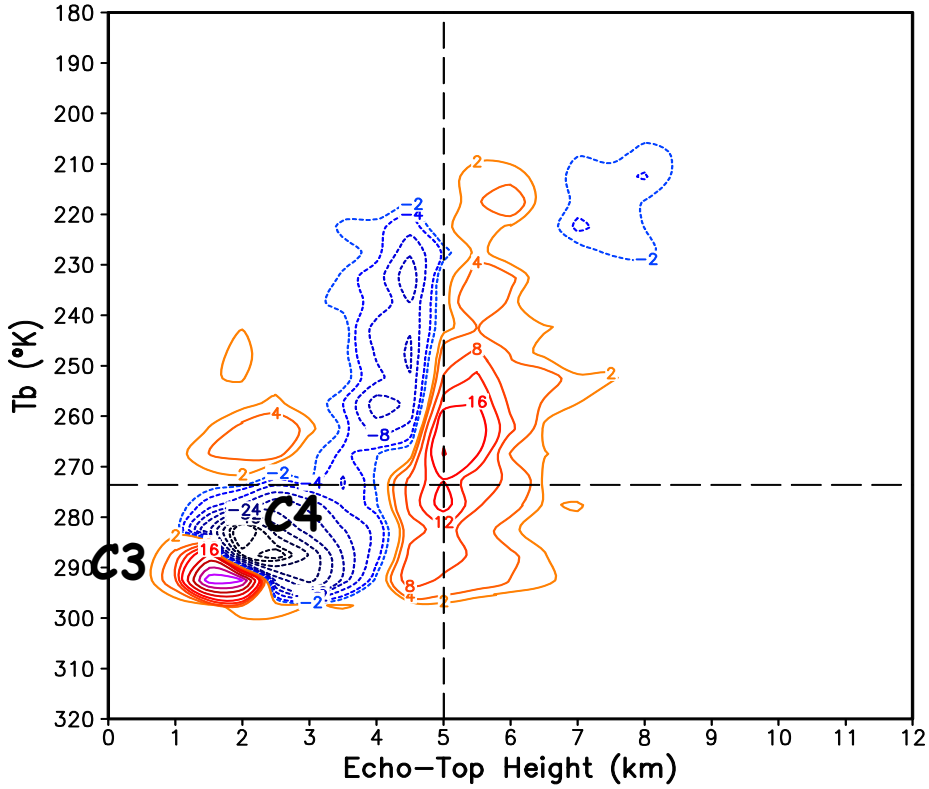

tropical SST monthly anomaly
tropical SST yearly anomaly
tropical oceanic RR monthly anomaly
tropical oceanic RR yearly anomaly
changes in SST (°C) and RR (mm/day)
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Time (year)

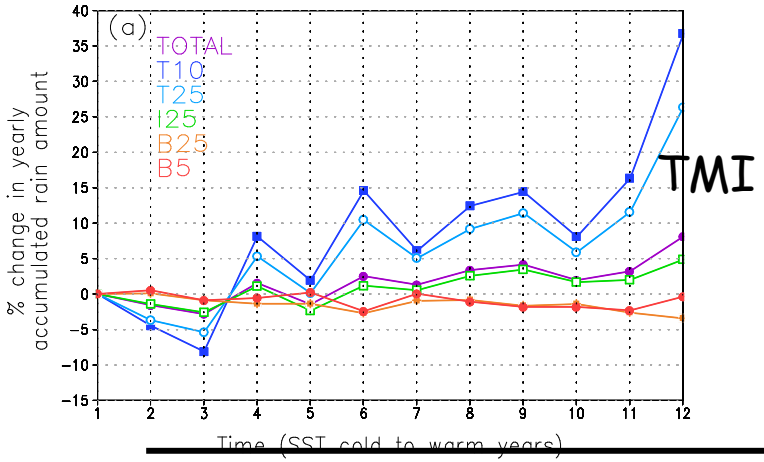
TMI

Warm-minus-Cold tropical SST year

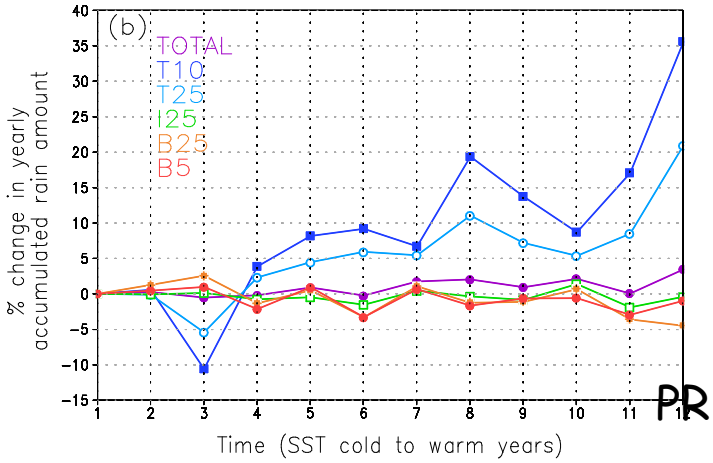


Warm-minus-cold SST changes in Tb_H_{ET} space

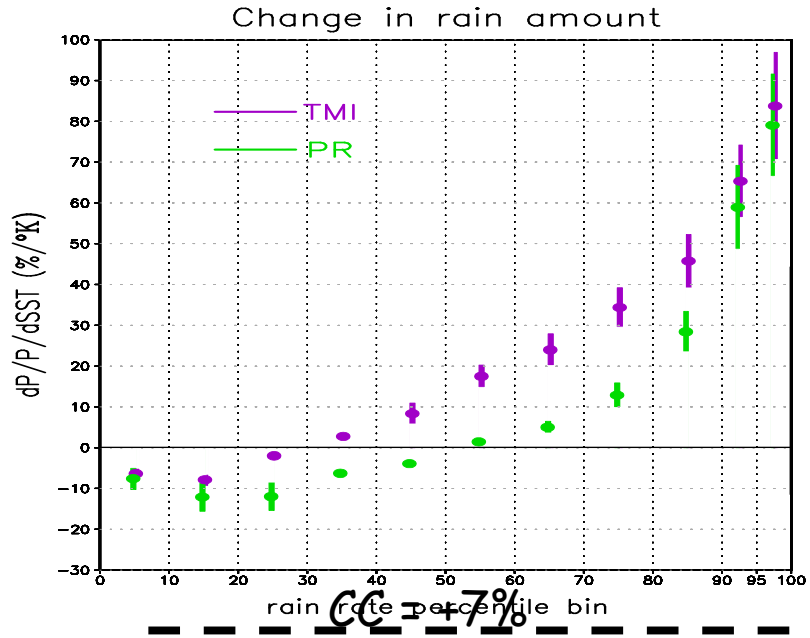



(a)
TOTAL
T10
T25
I25
B25
B5
% change in yearly accumulated rain amount
Time (SST cold to warm years)

TMI


(b)
TOTAL
T10
T25
I25
B25
B5
% change in yearly accumulated rain amount
Time (SST cold to warm years)

PR



mean sensitivity for all rain ~ 18% (TMI) and 6% (PR) per degree SST

Conclusions

- In a warmer climate, tropical rain show strong scale interactions among highly structured convective subsystems, generally with more rain coming from deeper rain system, specifically:
  - C1: marine boundary rain clouds
  - C2: warm rain, low-middle clouds
  - C3: mixed phase, congestus within warm pool
  - C4: ice-phase, deep convection core
- Heavy rain (>90 percentile) shows a super-CC sensitivity to mean SST forcing (80-90% increase per degree rise in tropical mean SST)
- Moderate (30-50 percentile) rain have near neutral sensitivity
- Light rain (< 20 percentile) negative sensitivity (-10% per degree)
- Both PR and TMI rain products show consistent sensitivity, but differs in absolute magnitudes.