Convective observations over the tropical oceans

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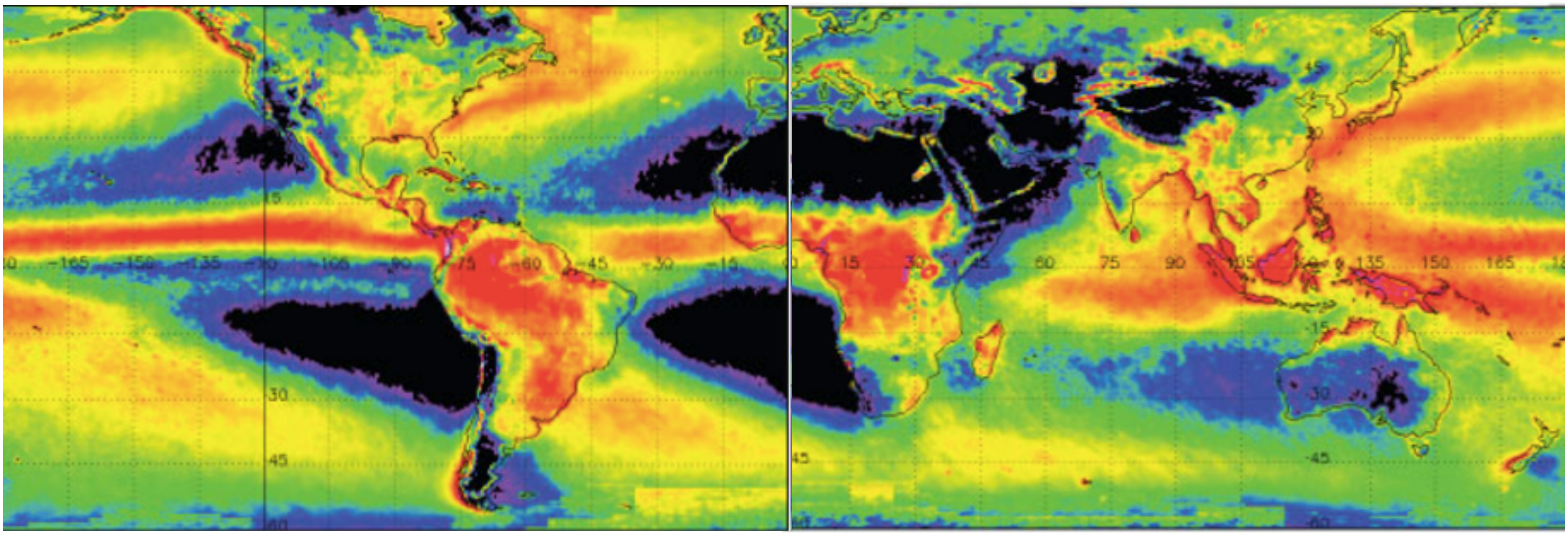
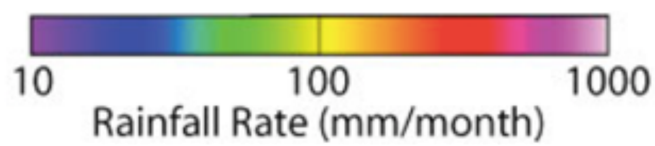
SSM/I annual rain 1987-2003

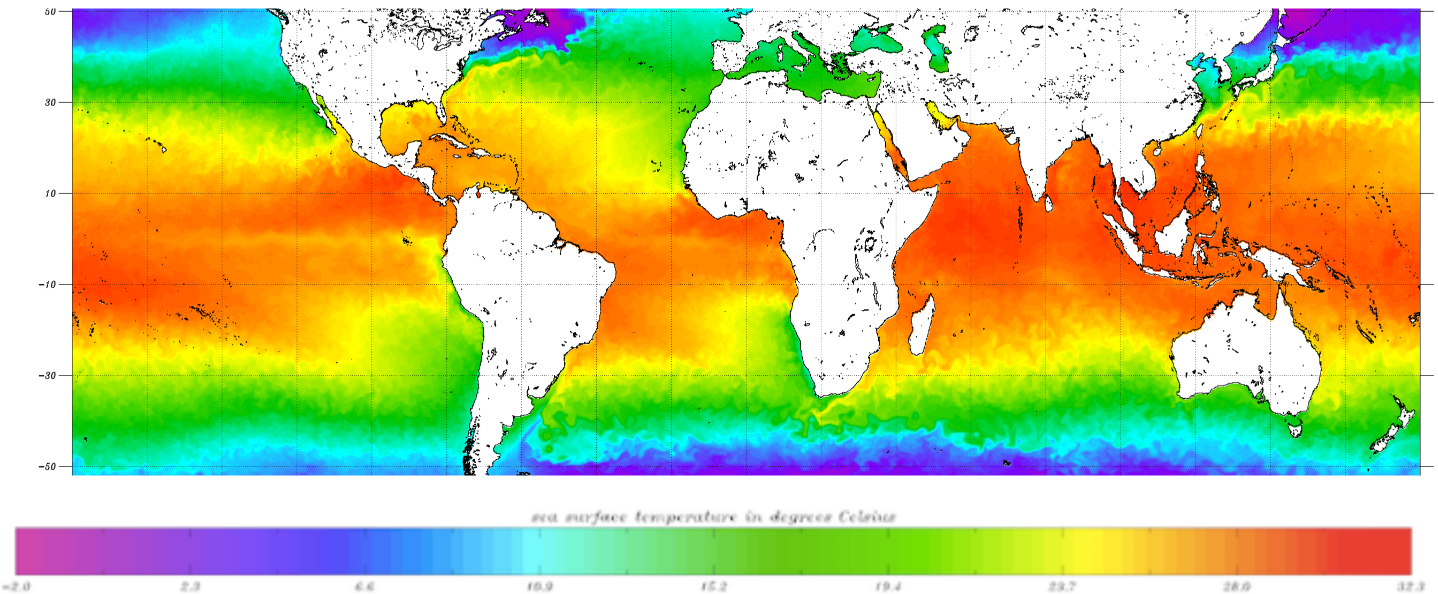


Negri et al. (2004)

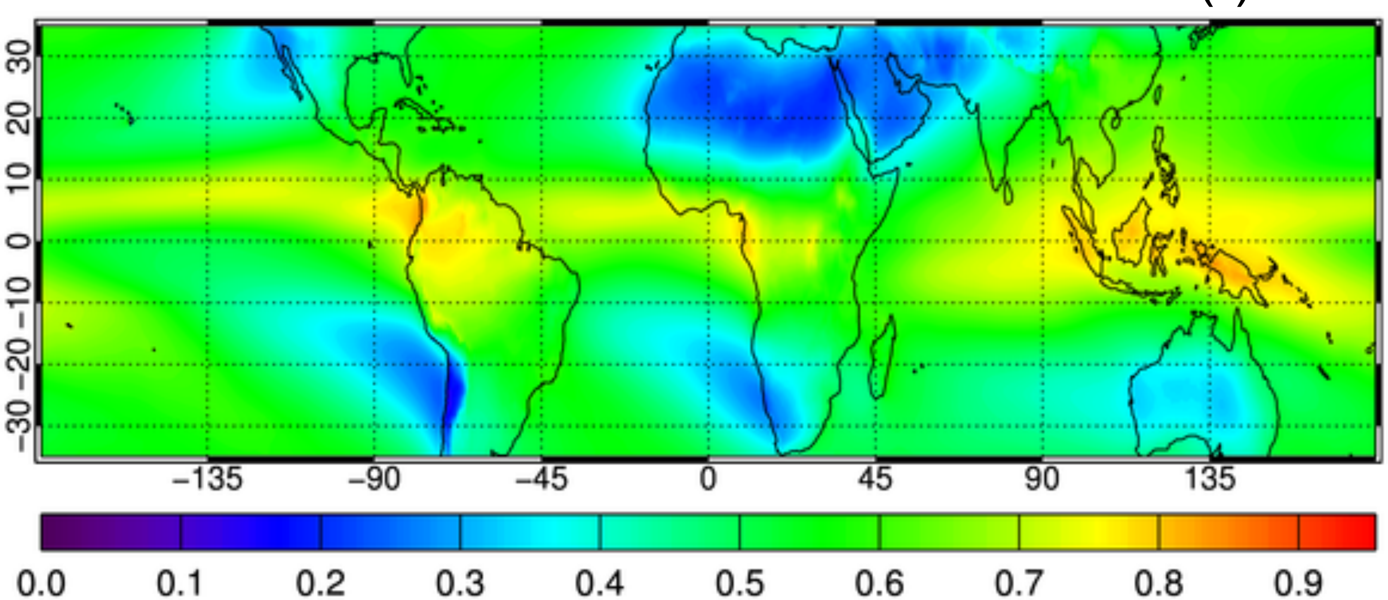


The tropical rain pattern is rich and a range of convective processes need to be considered when describing it.

NOAA/NESDIS SST



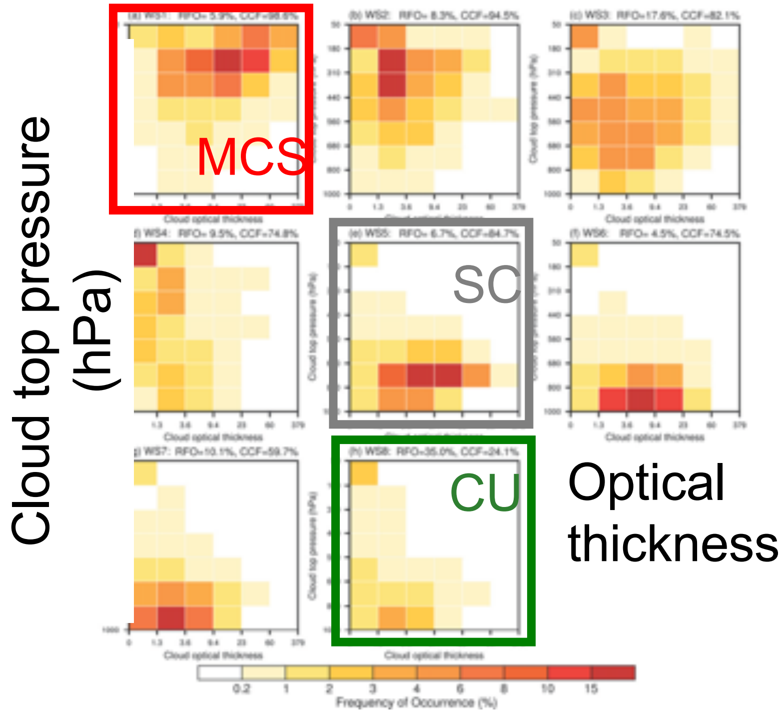
MERRA-2 column saturation fraction (r)



Environmental variables like SST and column saturation fraction (analogous to column water vapor) help dictate type of convection that feeds into tropical rain pattern:

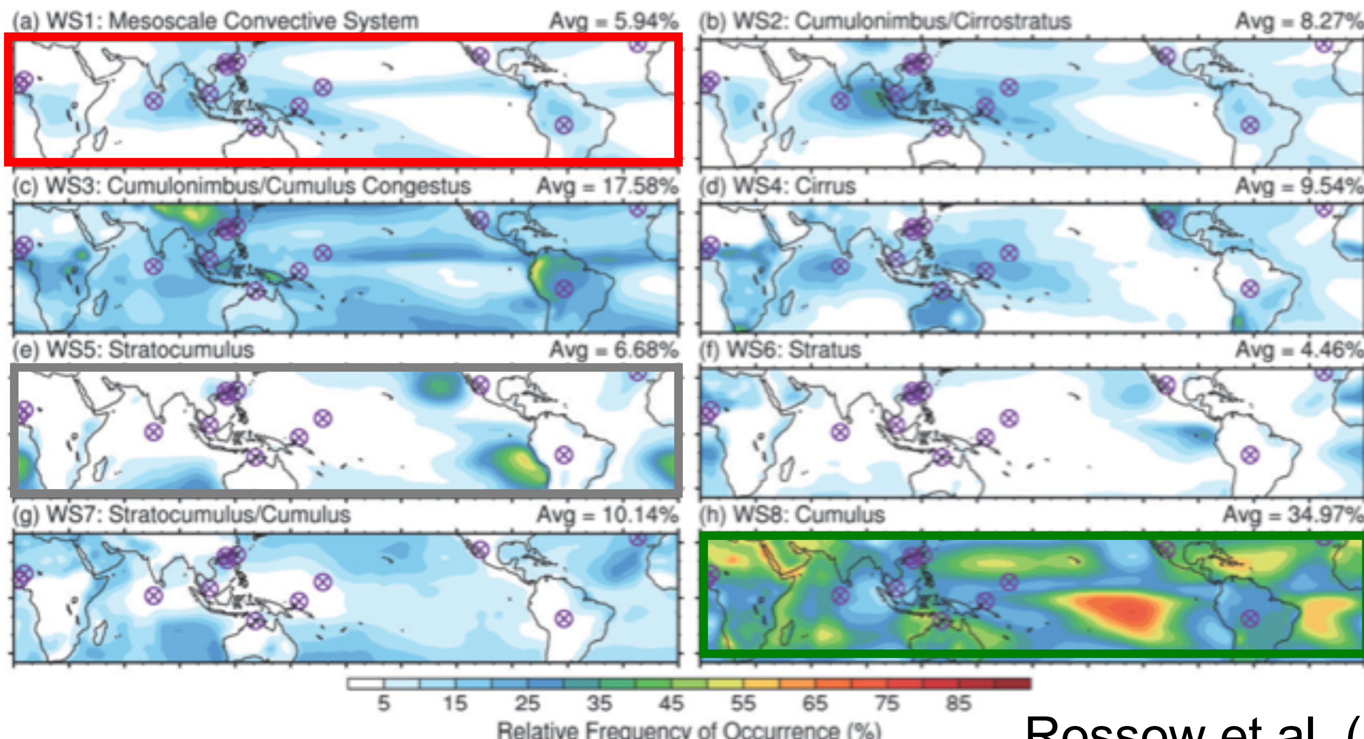
- warm + moist = more rainy
- cool + dry = less rain
- regions of gradients = sort of rainy

ISCCP weather states



ISCCP optical properties can delineate cloud populations with distinct characteristics and areal distributions:

- WS1 = cold, thick clouds (mesoscale convective systems)
- WS5 = warm, thick clouds (stratocumulus)
- WS8 = warm, less thick (cumulus)

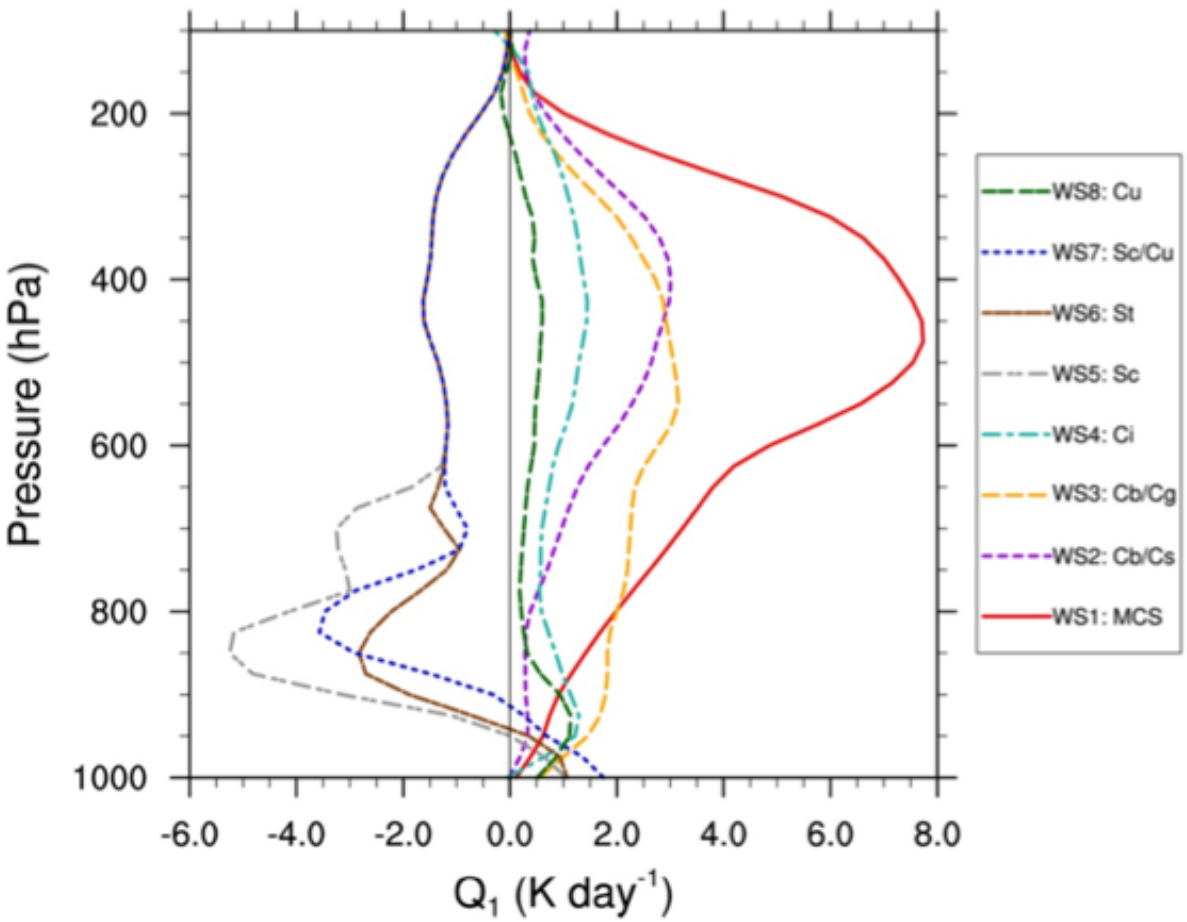


WS1 (MCSs) occurs mostly in the ITCZ, while WS5 (sc) occurs along coasts. WS8 (cu) is ubiquitous but maximizes in the trade wind regions. Symbol is for field campaigns with sounding arrays.

Rossow et al. (2005), Stachnik et al. (2013)

ISCCP weather state heating profiles

Sounding budgets from across the tropics and subtropics were used to assign heating profiles to each weather state.



- WS1 (MCSs) – strong upper level heating
- WS5 (sc) – moderate low-level cooling
- WS8 (cu) – weak low-level heating

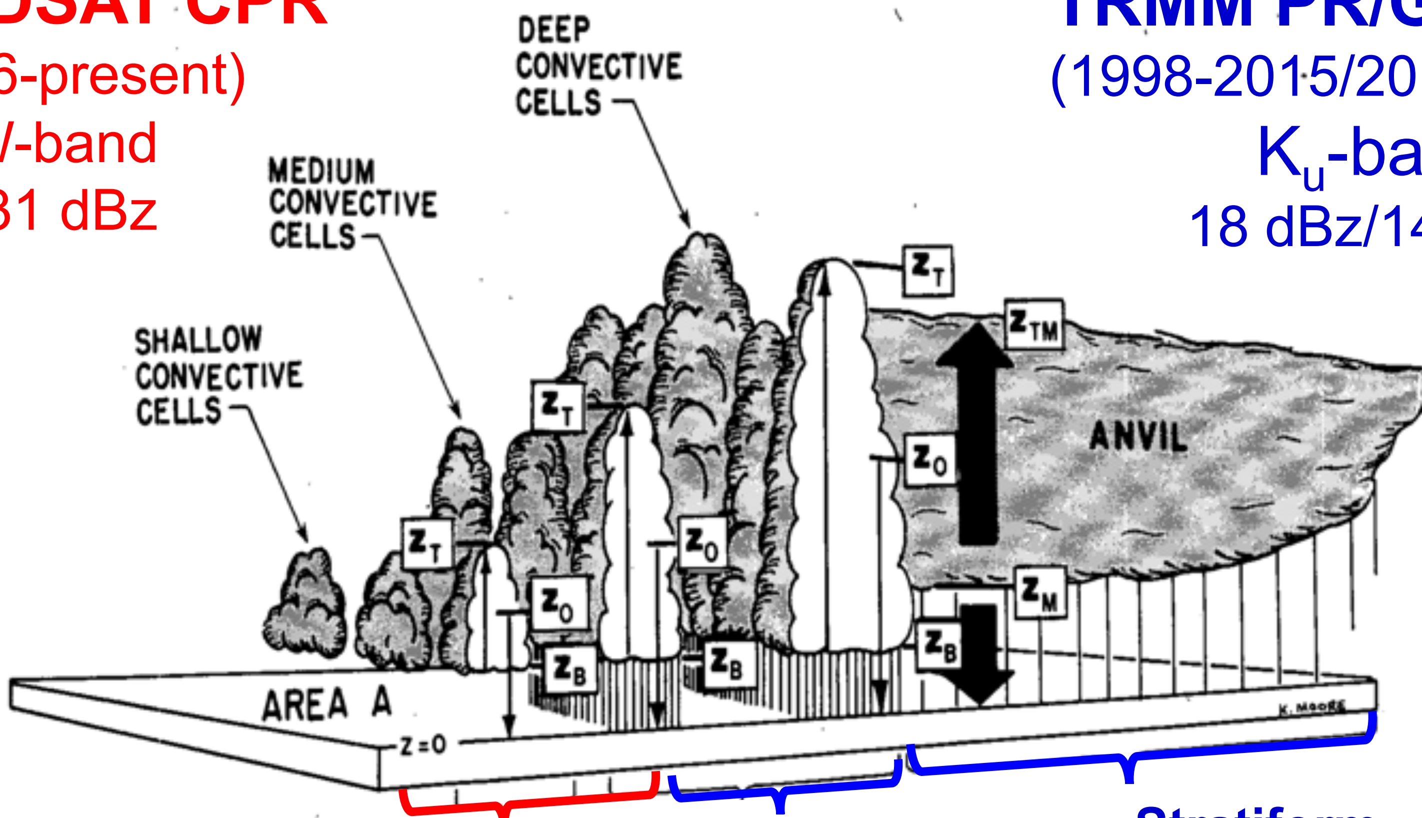
Different convective cloud types have distinct contributions to tropical rainfall and the heating or cooling profile of the tropical atmosphere.

Stachnik et al. (2013)

NASA satellite radars

CLOUDSAT CPR
(2006-present)
W-band
-31 dBz

TRMM PR/GPM DPR
(1998-2015/2014-present)
K_u-band
18 dBz/14 dBz

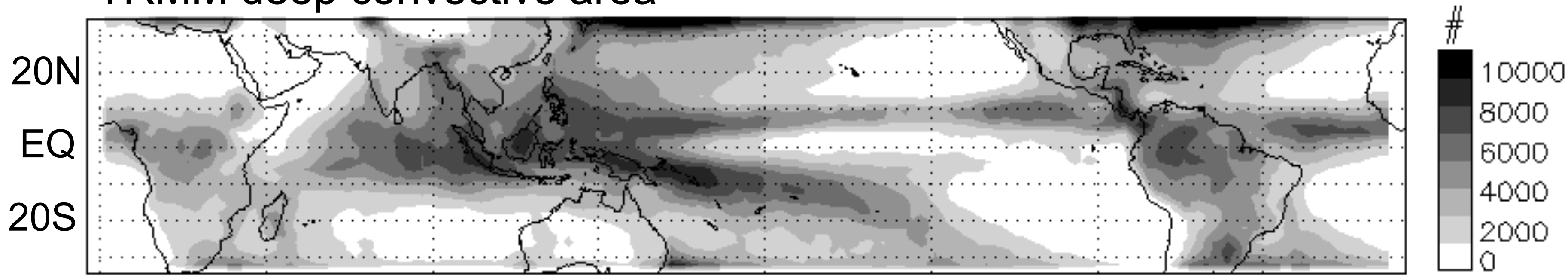


Houze et al. (1980)

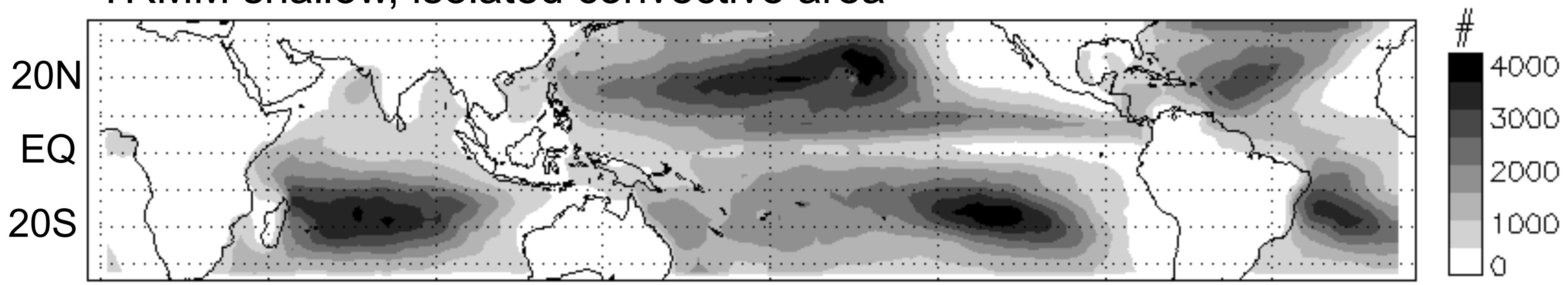
Next major NASA convection mission motivated by 2017 decadal survey: Aerosol and Cloud, Convection, and Precipitation (A-CCP)

Complementary nature of TRMM and CloudSat

TRMM deep convective area

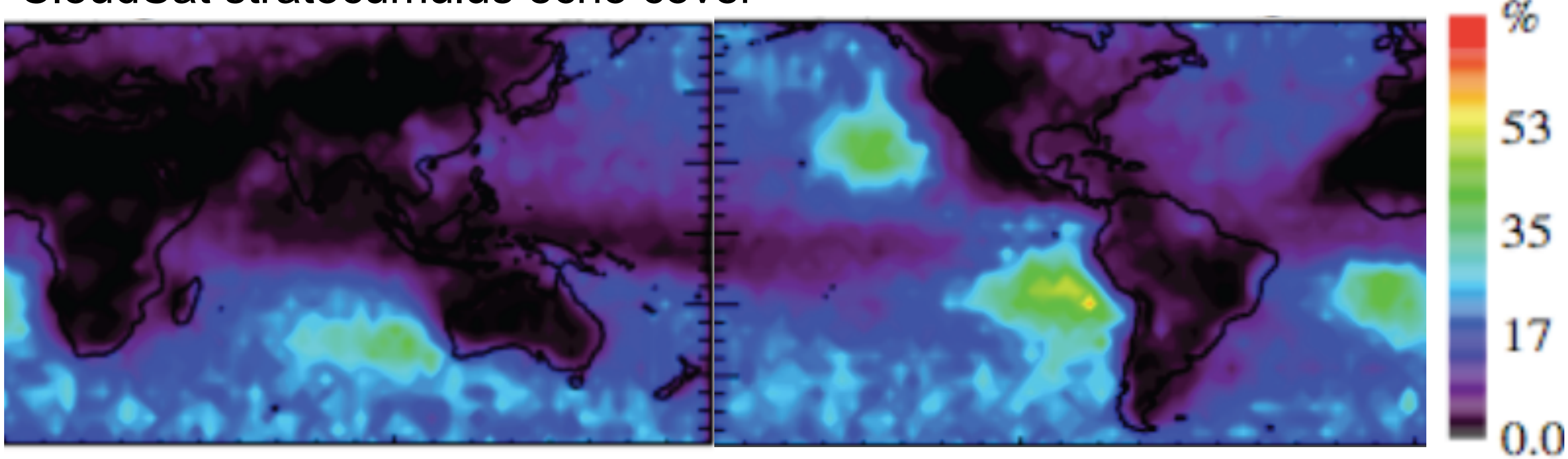


TRMM shallow, isolated convective area



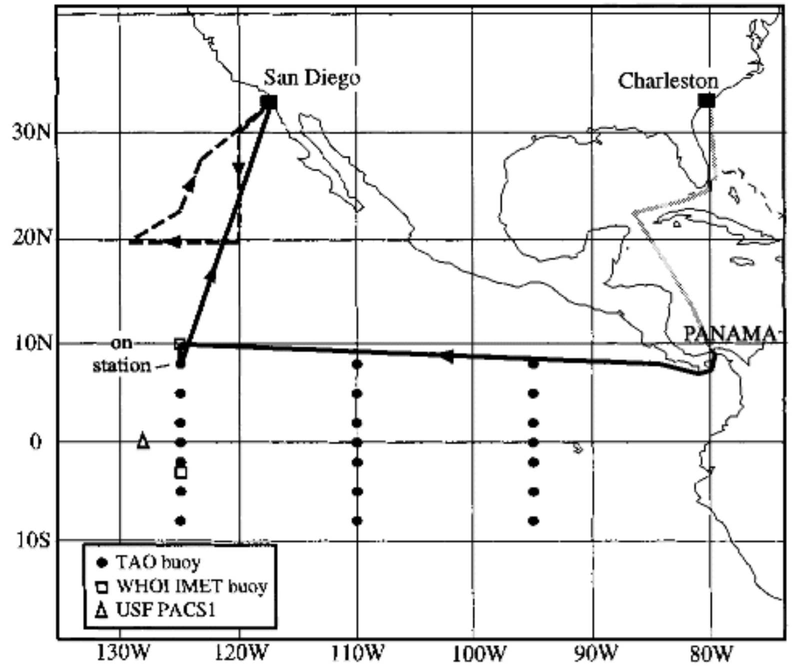
Schumacher and Houze (2003)

CloudSat stratocumulus echo cover

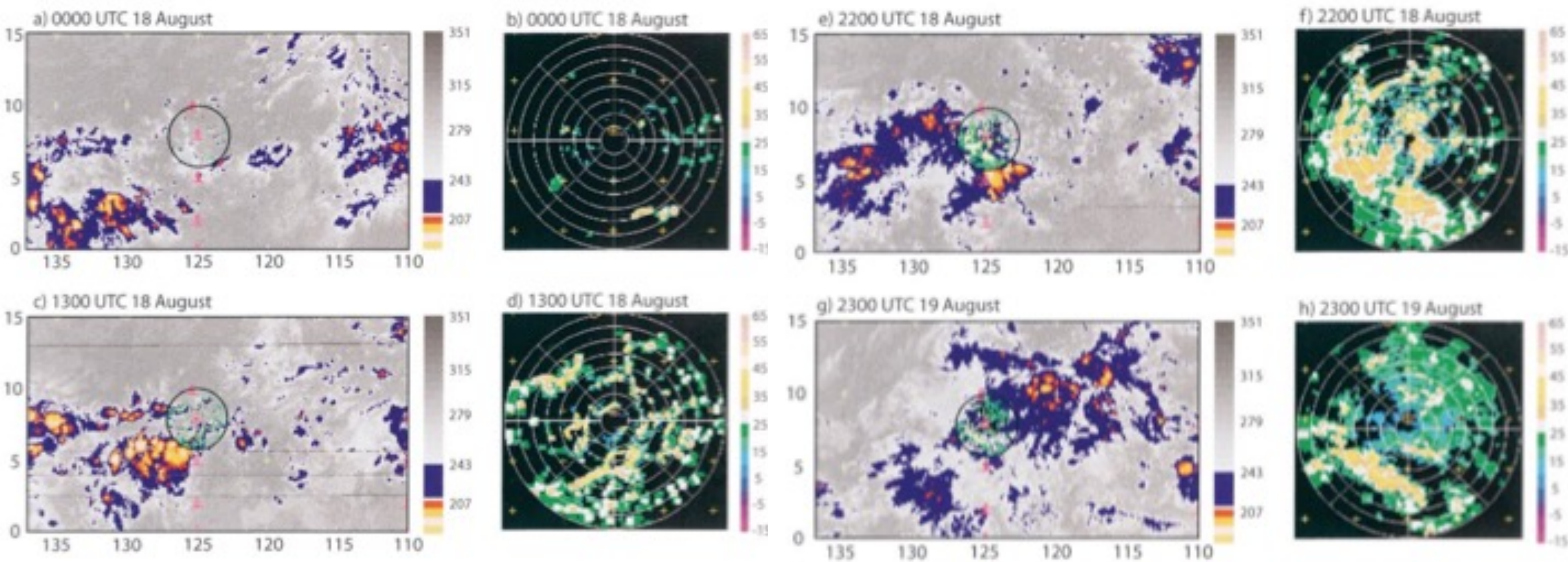


Courtesy of E. Riley Dellaripa

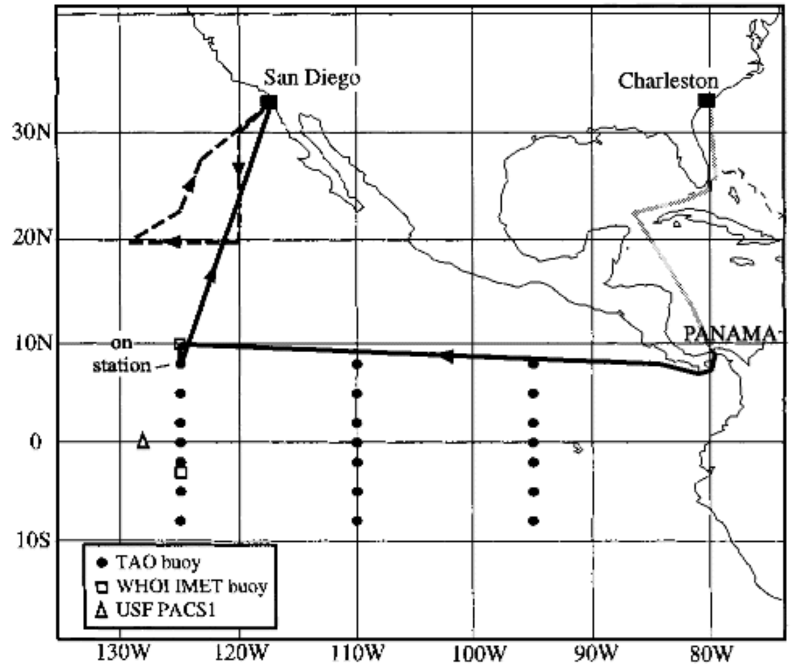
TEPPS 1997



Seven-week cruise of the RH Brown to study convective rain processes in the East Pacific (like the Kelvin wave passage below in the ITCZ).

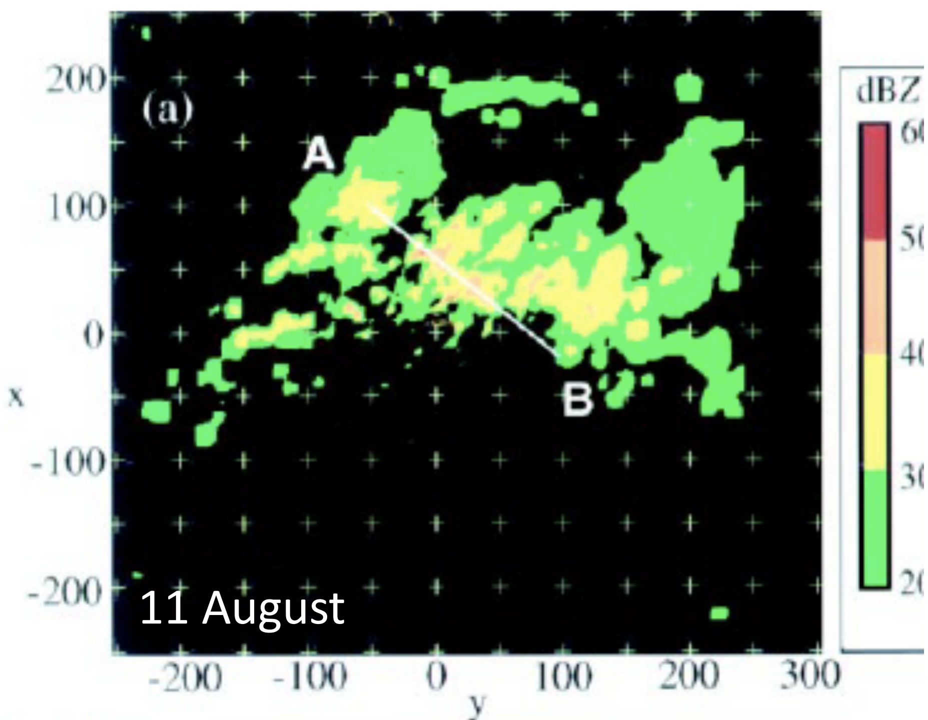


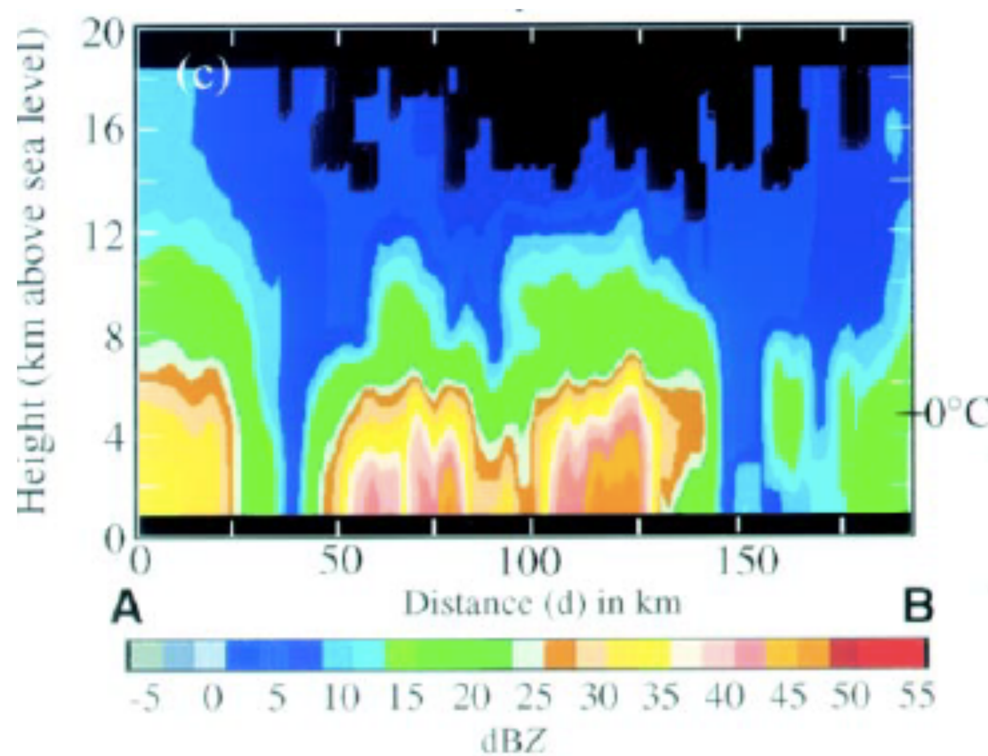
Straub and Kiladis (2002)



TEPPS 1997

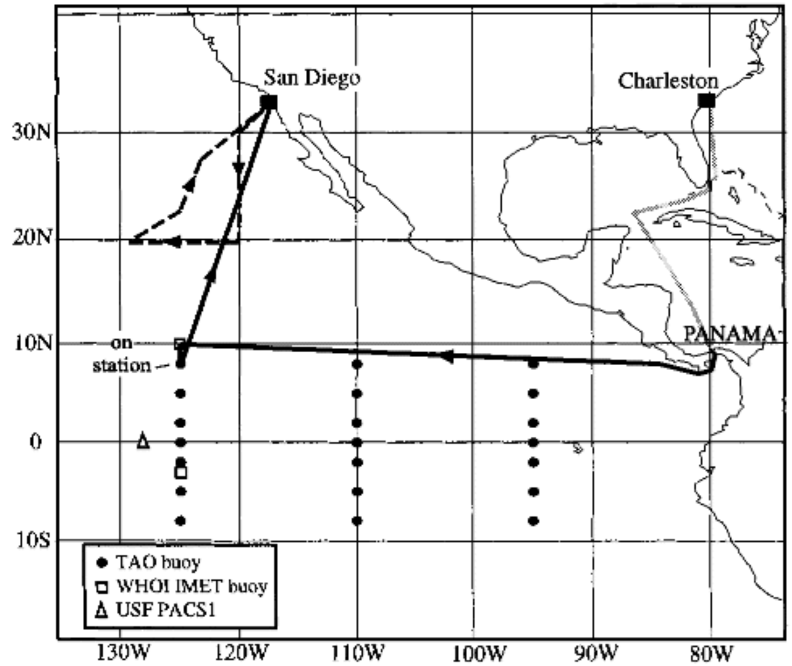
Convection over the ocean often doesn't look/act like a canonical fast-moving leading-line/trailing stratiform MCS. Houze et al. (2015) termed this rain "widespread cellular stratiform".



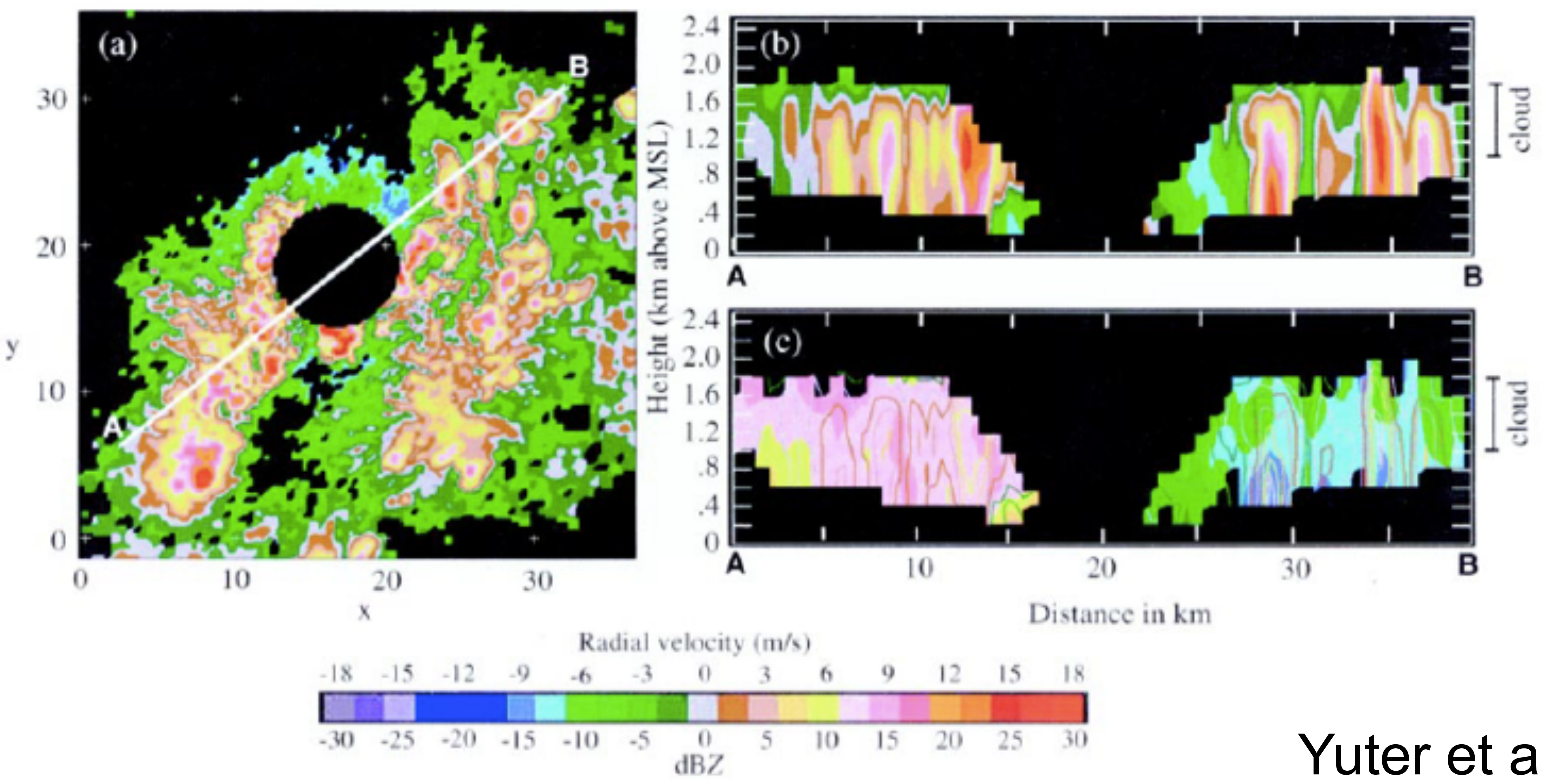


Yuter et al. (2000a)

TEPPS 1997



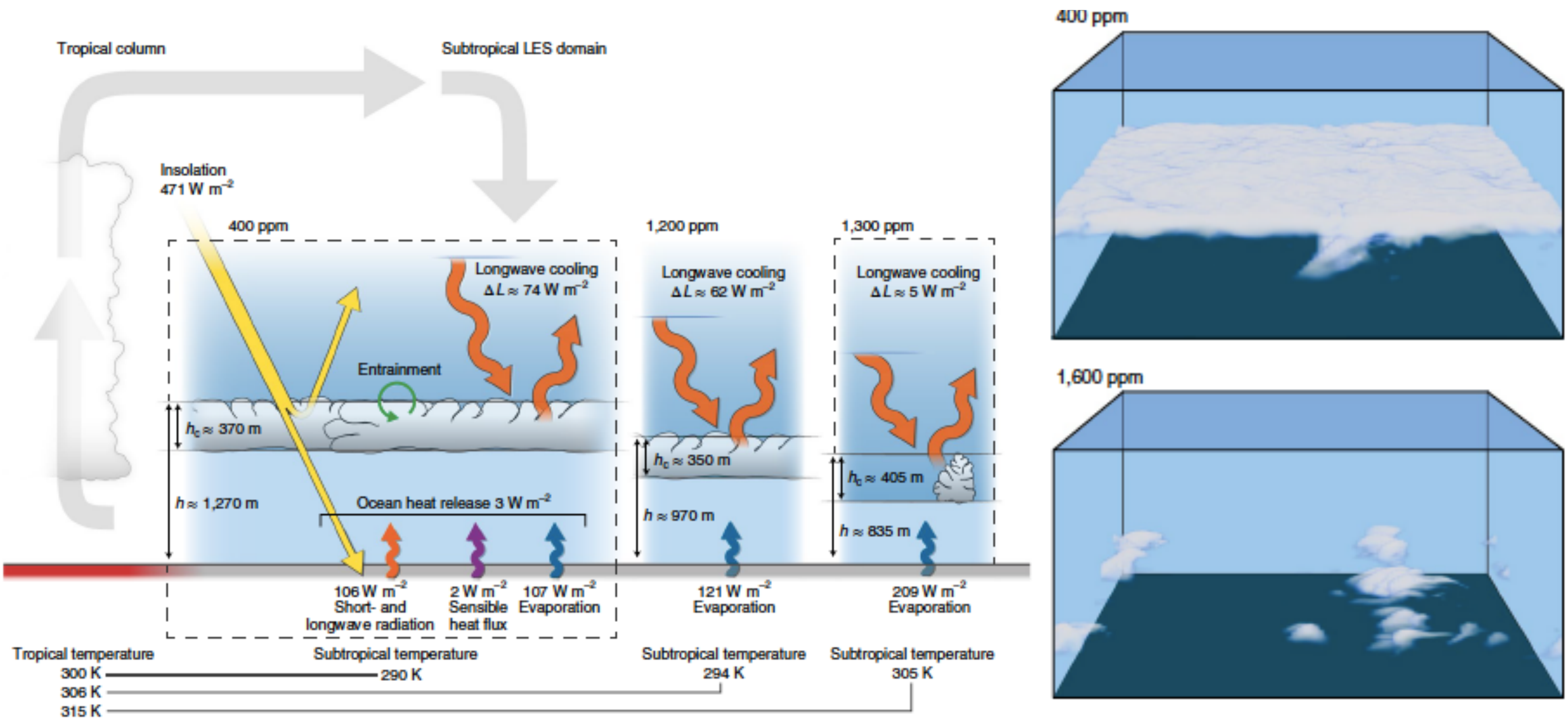
The C-band radar on the ship was also able to capture cellular structure in the stratocumulus west of Mexico.



Yuter et al. (2000b)

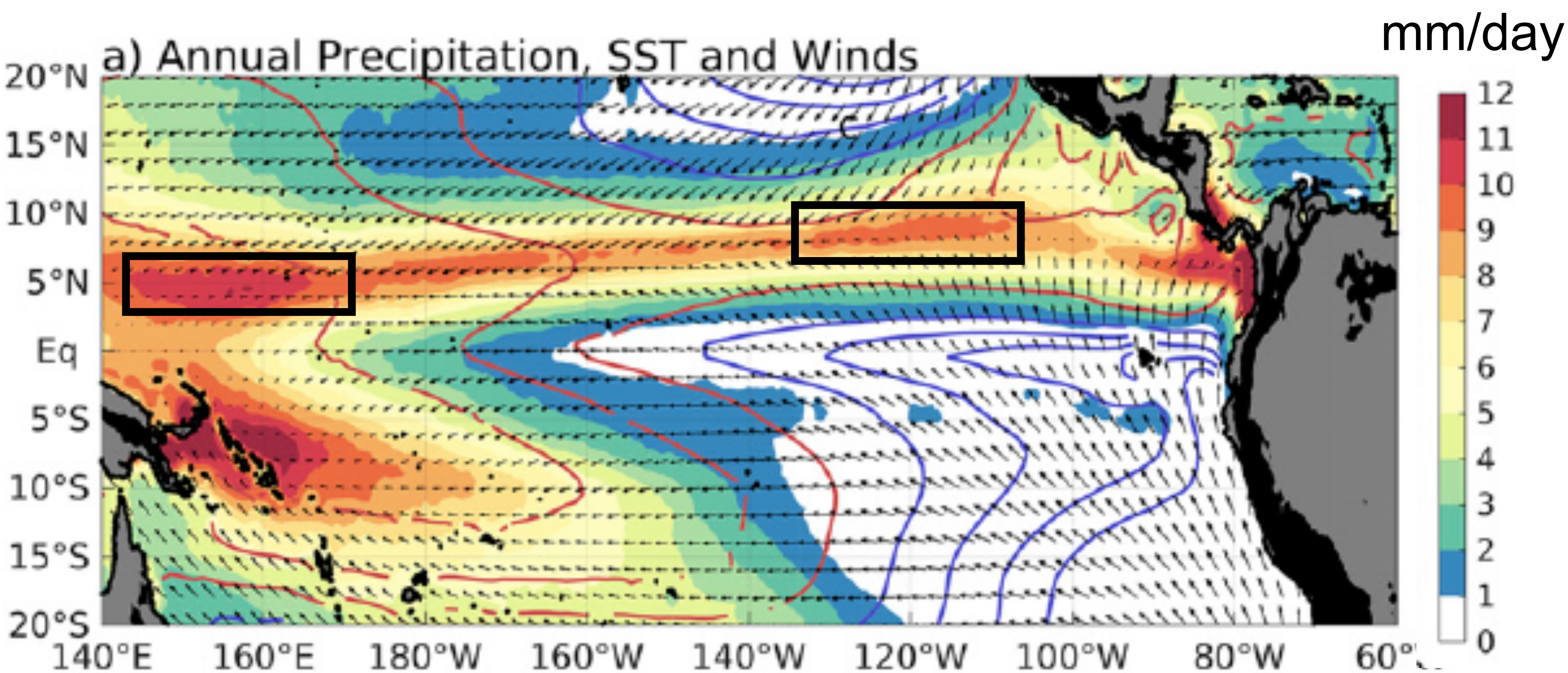
Possible climate transitions from breakup of stratocumulus decks under greenhouse warming

Tapio Schneider[1,2]*, Colleen M. Kaul[1] and Kyle G. Pressel[1]



Based on LES model simulations, the authors postulate that sc decks could break-up at high CO_2 levels, causing a surface warming of 10 K. Observations of stratocumulus decks and their interactions with the large-scale environment could better inform/constrain these types of LES runs.

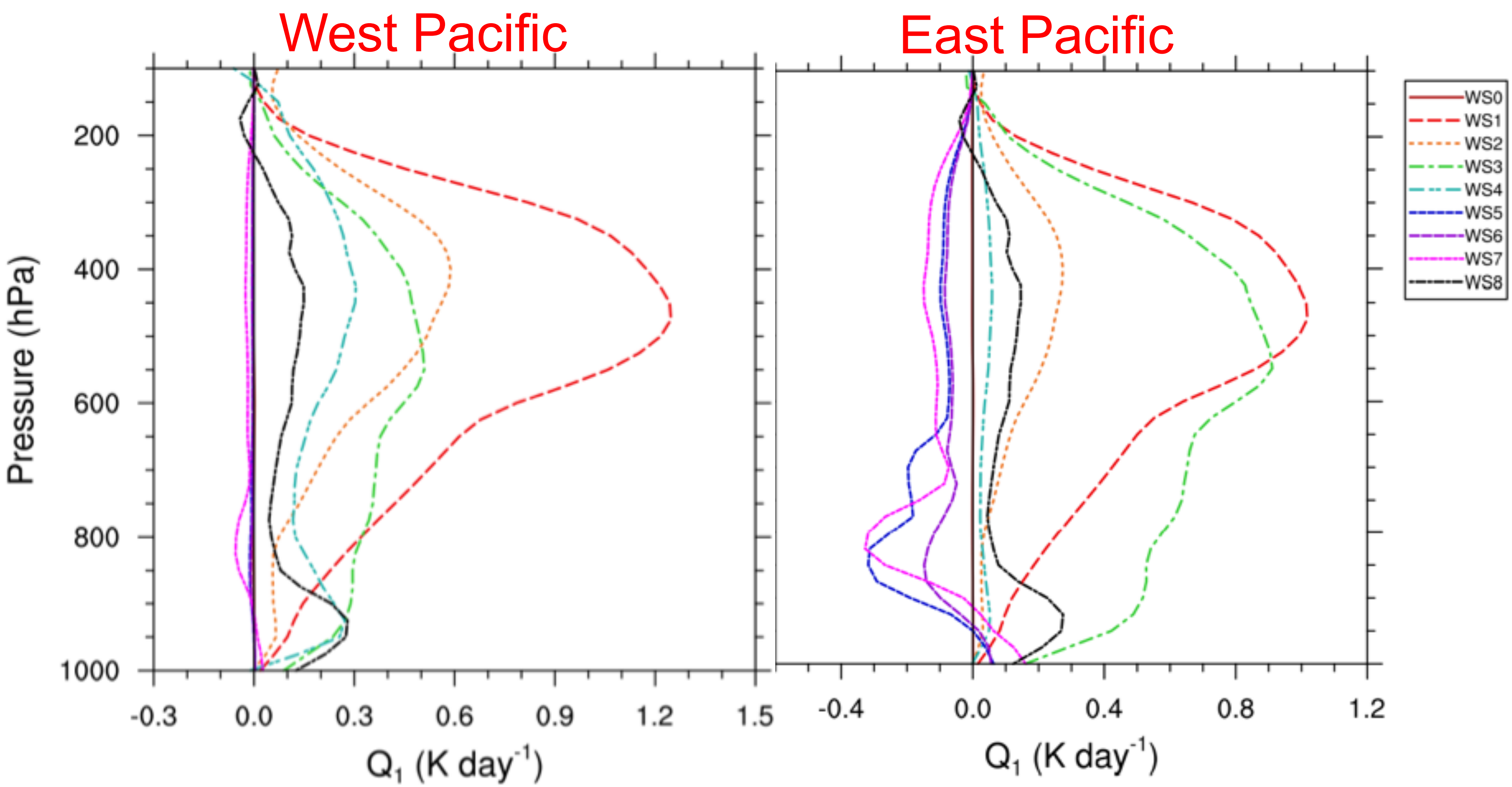
Large-scale circulations in the Pacific



Rain amounts > 9 mm/day are observed over the West Pacific warm pool and East Pacific ITCZ even though the large-scale environments are quite different.

Huaman and Schumacher (2018)

Heating in ISCCP weather states

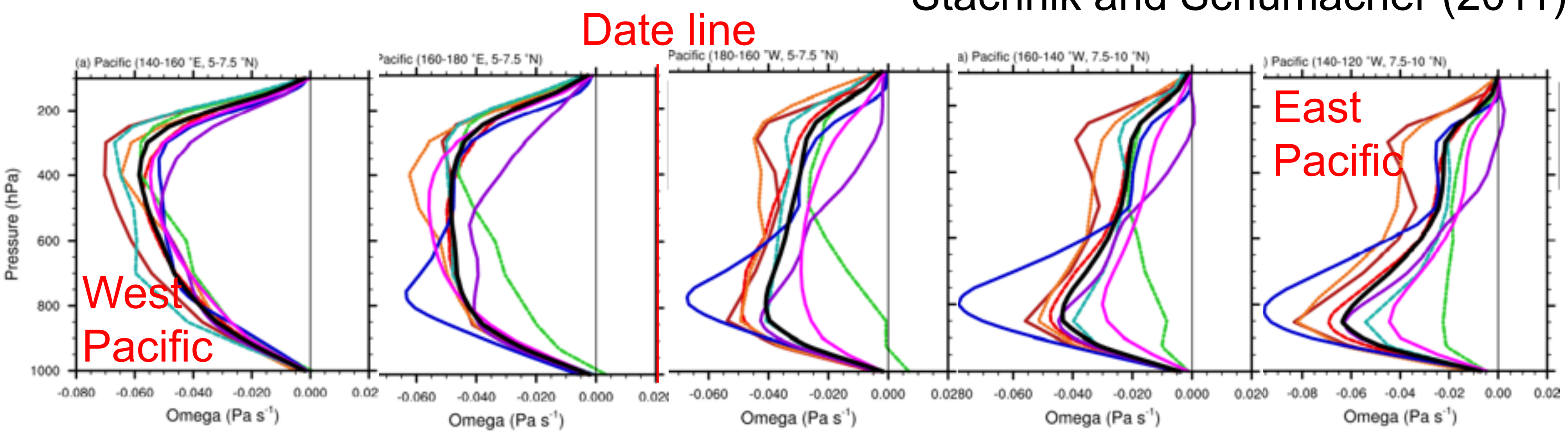


While WS3 (mixed convective heights) is more prevalent in the East Pacific, the heating remains top heavy overall – consistent with the TRMM/GPM radar observations of significant stratiform rain across the Pacific ITCZ.

Tropical Pacific vertical motion from reanalyses

Data Set	Source	Data Range	Resolution	Horizontal	Pressure	Temporal
JRA	JMA	1979–2007	T106L40	1.125° × 1.125°	23 levels	6-hourly
ERAINT	ECMWF	1989–present	T255L60	1.5° × 1.5°	37 levels	6-hourly
ERA40	ECMWF	1957–2002	T159L60	2.5° × 2.5°	23 levels	6-hourly
NNRP	NCEP/NCAR	1958–present	T62L28	2.5° × 2.5°[b]	17 levels	6-hourly
NDRP	NCEP/DOE	1979–2008	T62L28	2.5° × 2.5°[b]	17 levels	6-hourly
CFSR	NCEP	1979–present	T382L64	0.5° × 0.5°	37 levels	1-hourly
MERRA	NASA	1979–present	2/3° × 1/2°, L60	2/3° × 1/2°[c]	42 levels	3-hourly[d]
20CR	NOAA/CIRES	1871–2008	T62L28	2.0° × 2.0°[b]	24 levels	6-hourly

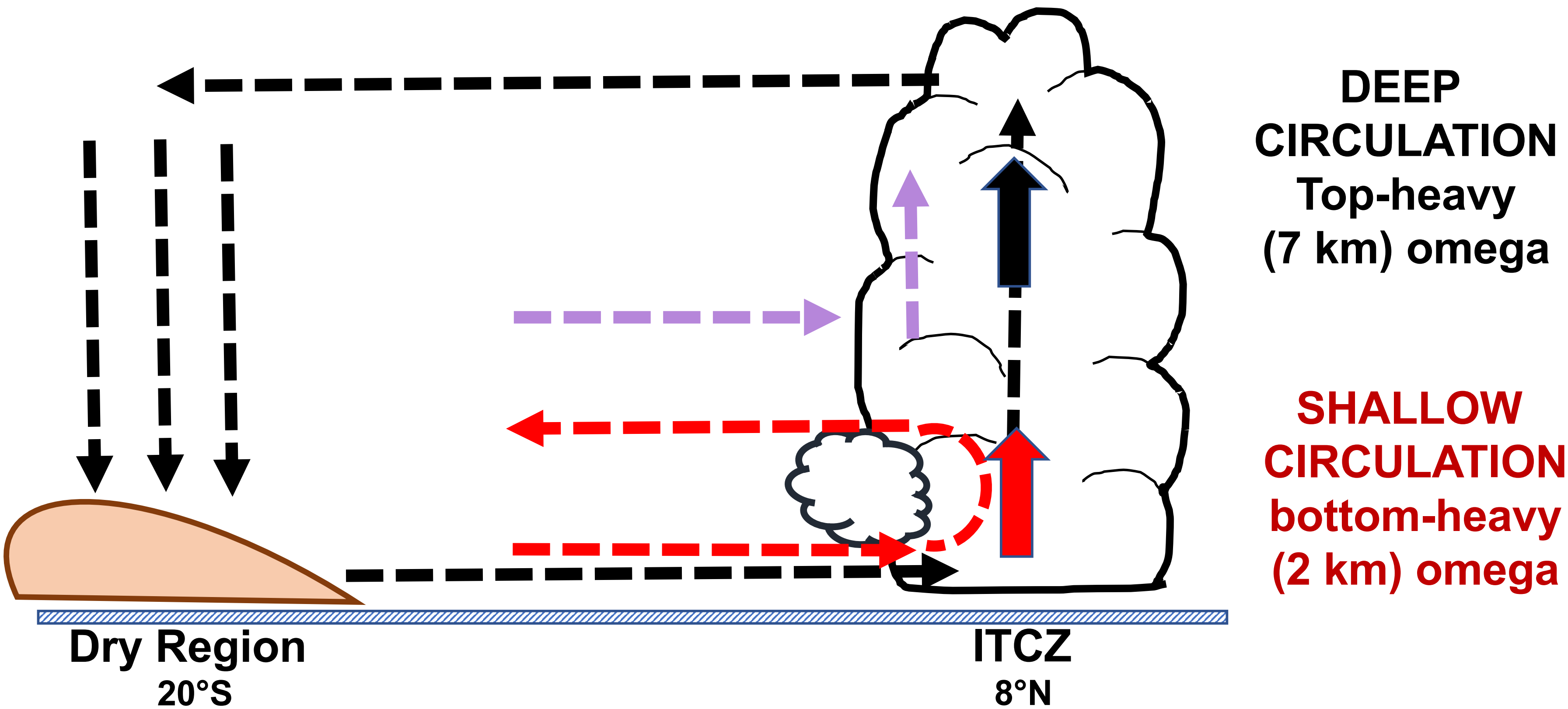
Stachnik and Schumacher (2011)



Reanalyses show general trend from top-heavy in WP to bottom-heavy in EP, which is inconsistent with satellite observations (see also Hagos et al. 2010).

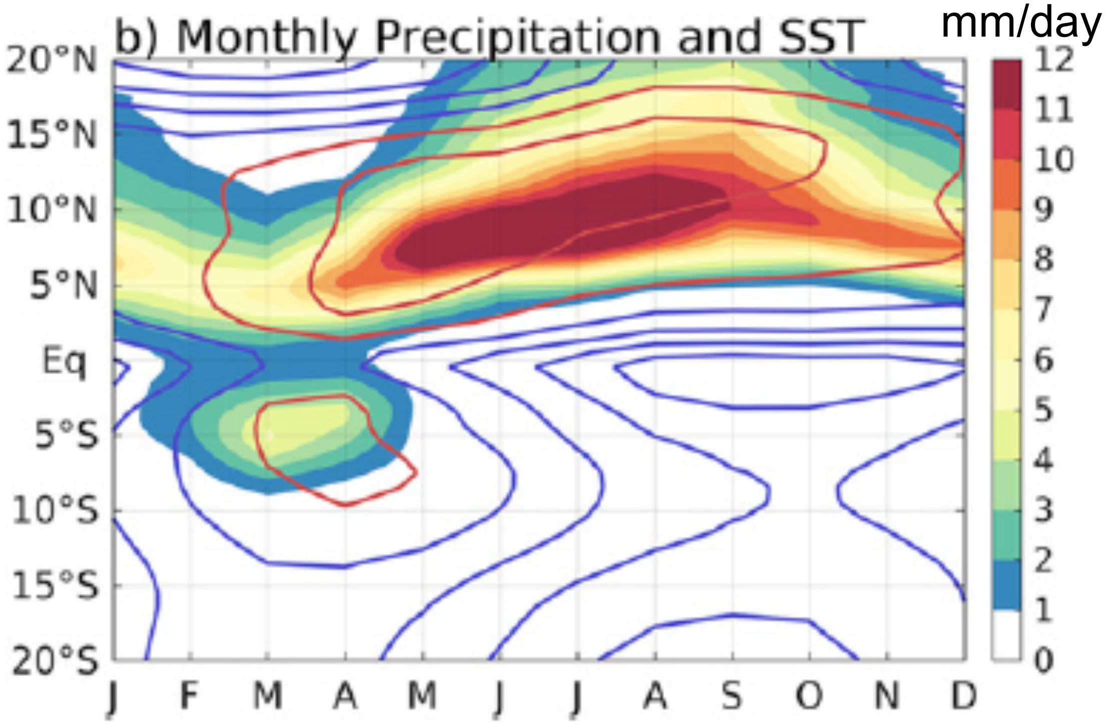
Shallow vs deep meridional overturning

1. Deep circulation (Hack et al. 1989)
2. Shallow ciculation (Zhang, 2004)
3. Mid-level inflow (Nolan et al., 2010; Huaman and Takahashi 2016)

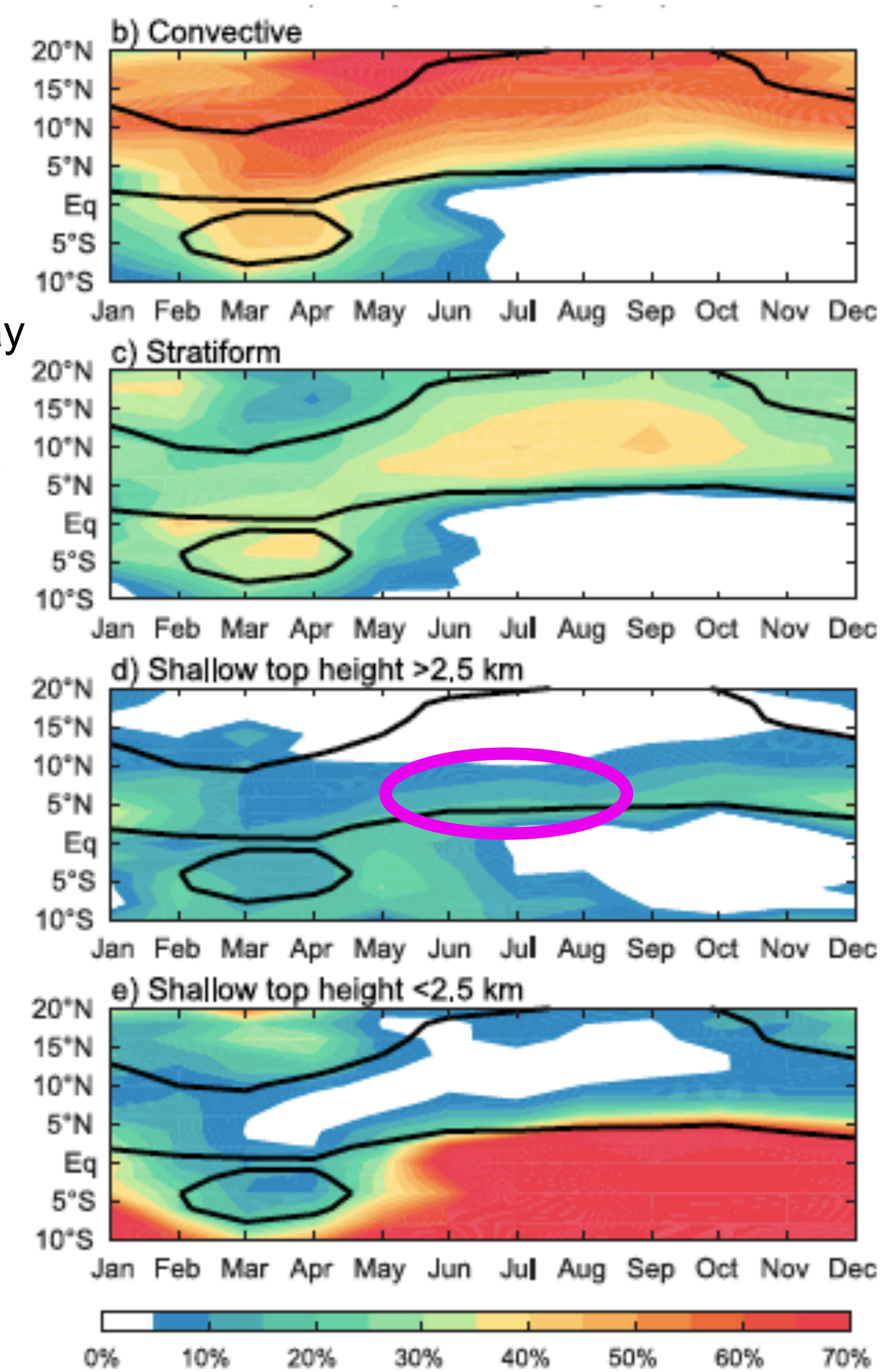


Courtesy of L. Huaman

TRMM + Cloudsat in the East Pacific
(130°W-90°W)

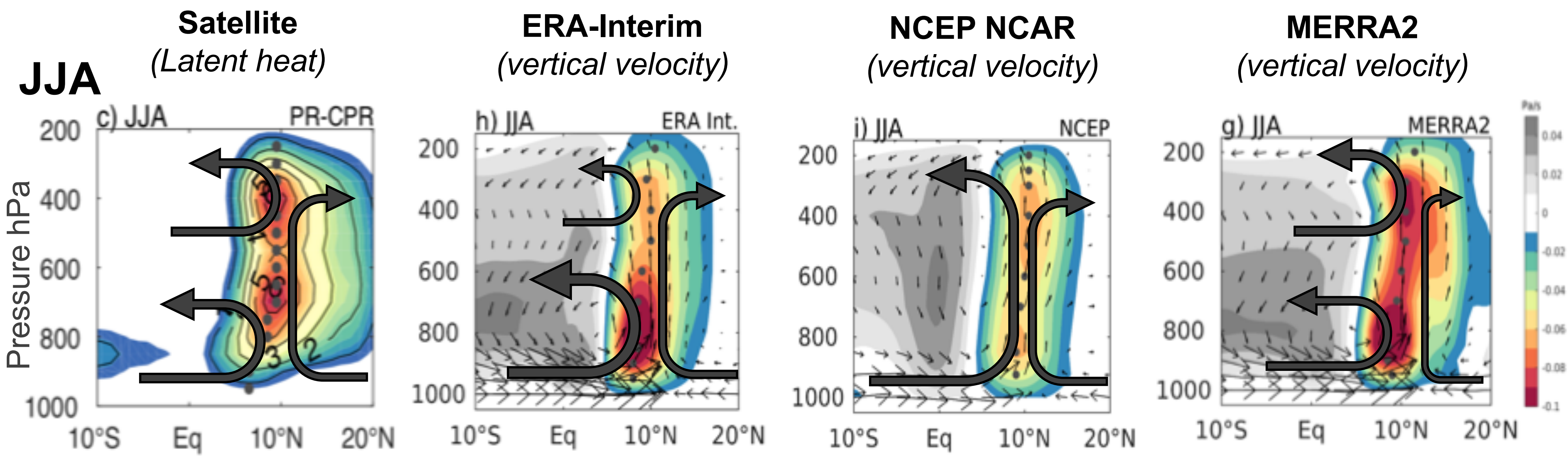


Throughout the year, rain from shallow convection dominates south of the ITCZ, while deep convective rain dominates in the northern portion. Stratiform rain associated with MCSs maximizes in the center of the ITCZ.



Huaman and Schumacher (2018)

Meridional circulation in the East Pacific



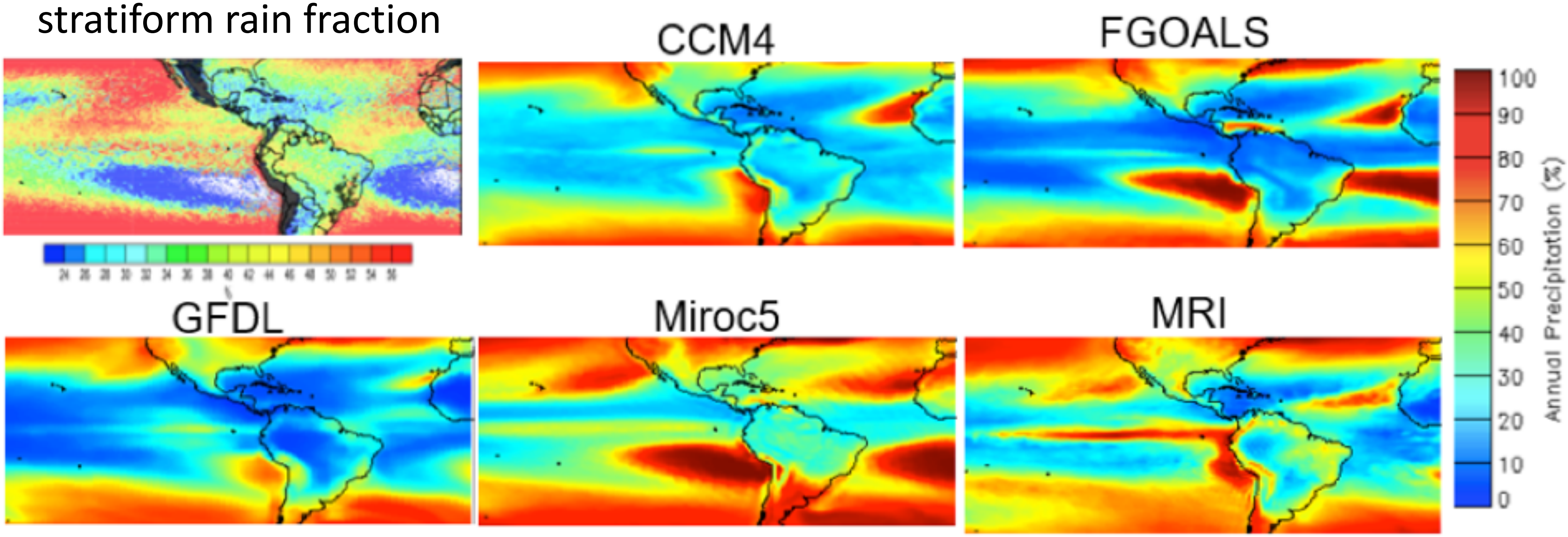
- A meridional slope is evident in the latent heating derived from the TRMM and CloudSat radars due to evolution of cloud types from shallow to deep going north into the ITCZ
- Reanalyses disagree on the magnitude and relative importance of the shallow and deep meriodional overturning cells in the East Pacfic
- Would a true coupled reanalysis help this representation?
- Future field campaigns such as OTREC will help shed light on the convection and circulations in this region

Huaman and Schumacher (2018)

Large-scale rain in climate models

TRMM
stratiform rain fraction

Large-scale rain fraction in CMIP5



Courtesy of T. Aydell

CMIP5 models vary widely in large-scale rain (i.e., the rain that doesn't come from the convective parameterization), with little convergence since Dai (2006).

Conclusions

- Convective cloud structures over the tropical oceans can be messy and are highly sensitive to their environment – marginal environments are more likely to produce a mix of convective cloud types and are harder for models to simulate
- Combined satellite observations (with careful vetting by ground measurements…) allows us to observe the full spectrum of convection and infer important aspects of its vertical structure and contribution to large-scale circulation and climate