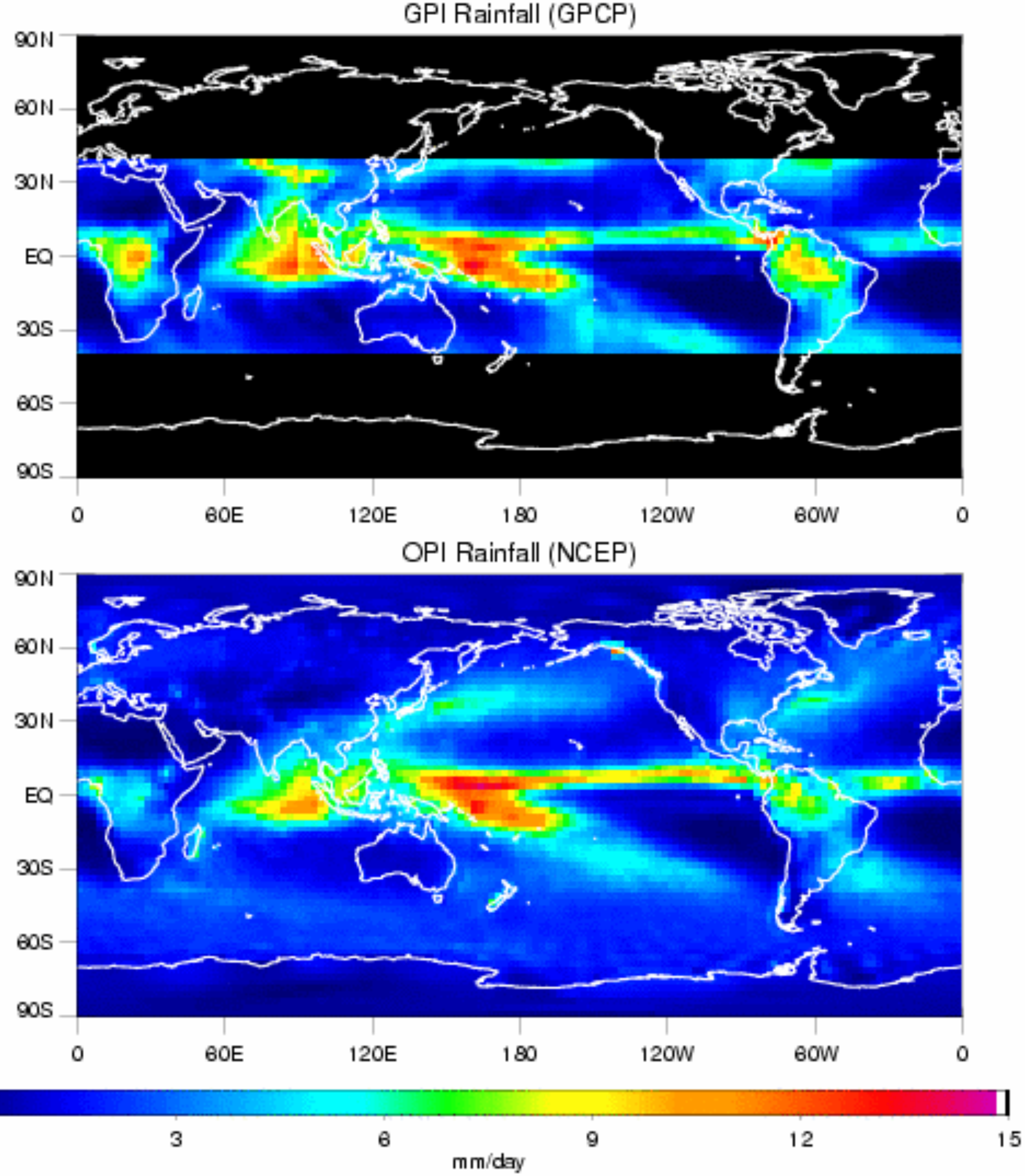
Clouds and Precipitation

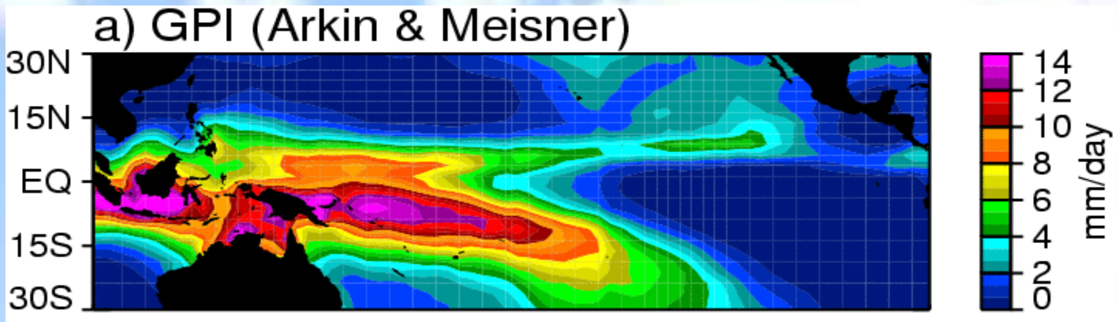
Christian Kummerow
Colorado State University

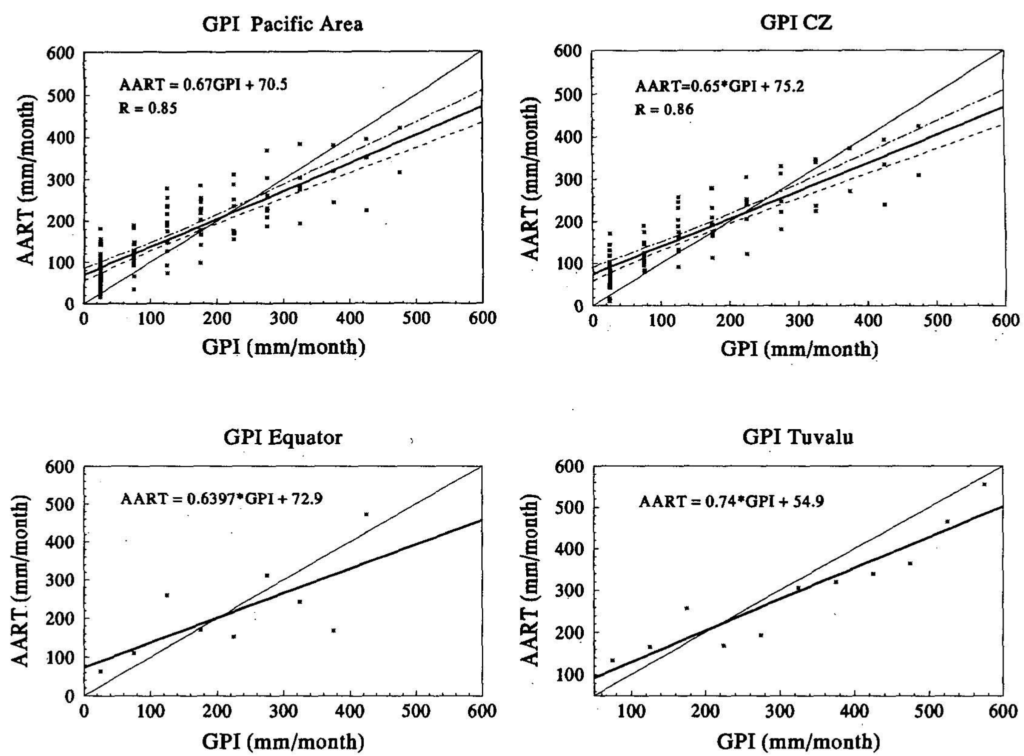
ISCCP 25 Year Anniversary
New York, NY
25 July 2008

Mean Climate Rainfall Comparison for January 1993 - December 1993

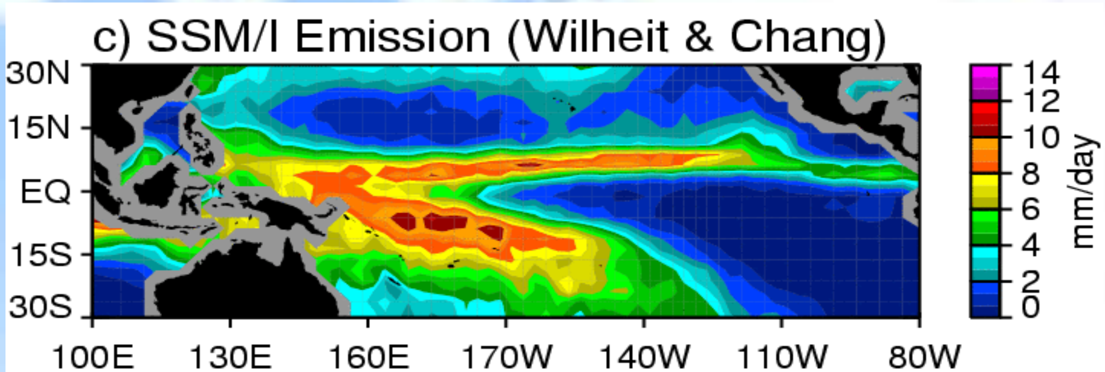


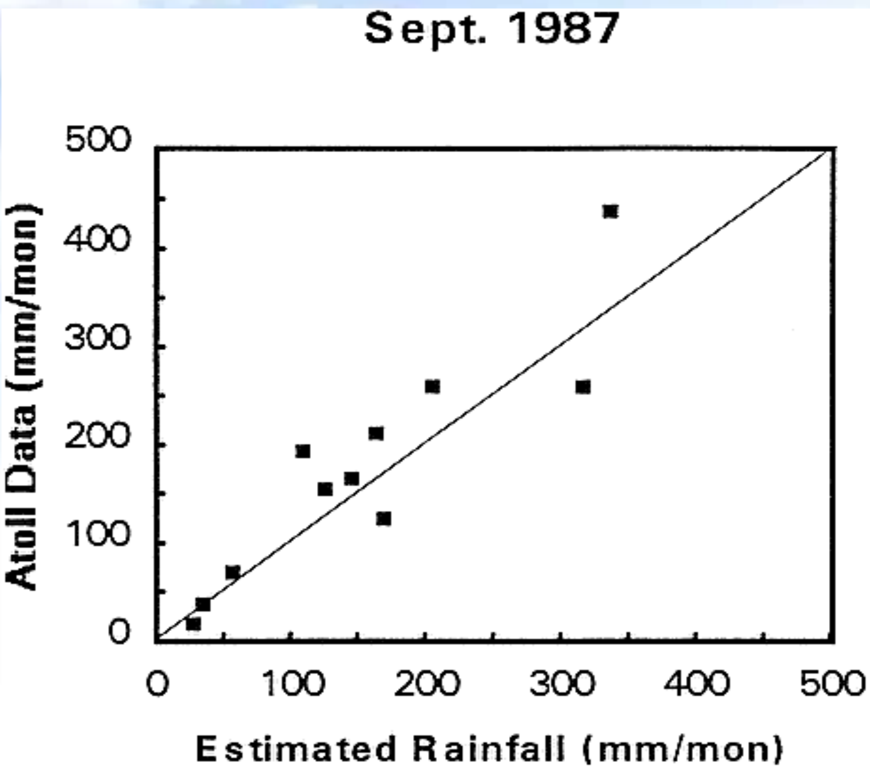
GPI

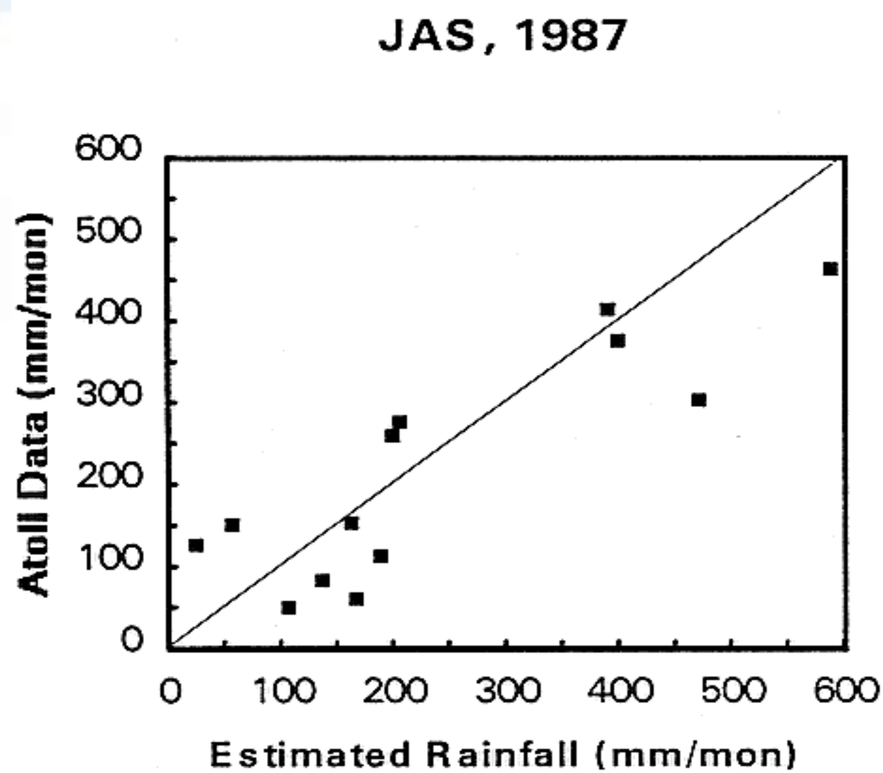

a) GPI (Arkin & Meisner)
30N
15N
EQ
15S
30S
14
12
10
8
6
4
2
0
mm/day


GPI Pacific Area
AART = 0.67GPI + 70.5
R = 0.85
AART (mm/month)
GPI (mm/month)
GPI CZ
AART=0.65*GPI + 75.2
R = 0.86
AART (mm/month)
GPI (mm/month)
GPI Equator
AART = 0.6397*GPI + 72.9
AART (mm/month)
GPI (mm/month)
GPI Tuvalu
AART = 0.74*GPI + 54.9
AART (mm/month)
GPI (mm/month)

SSM/I

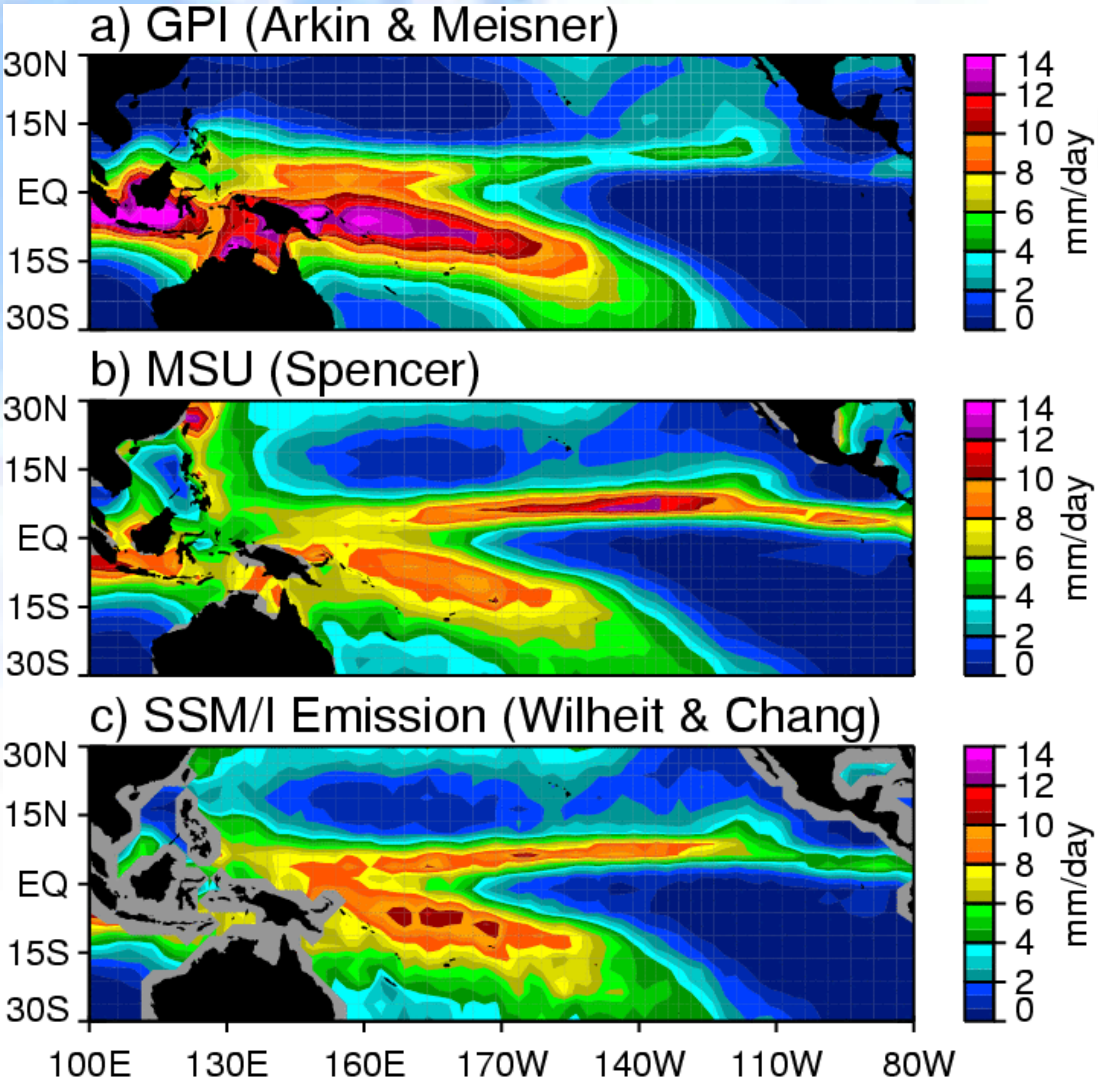

c) SSM/I Emission (Wilheit & Chang)
30N
15N
EQ
15S
30S
100E
130E
160E
170W
140W
110W
80W
14
12
10
8
6
4
2
0
mm/day


Sept. 1987
Atoll Data (mm/mon)
Estimated Rainfall (mm/mon)
0
100
200
300
400
500


JAS, 1987
Atoll Data (mm/mon)
Estimated Rainfall (mm/mon)
0
100
200
300
400
500
600

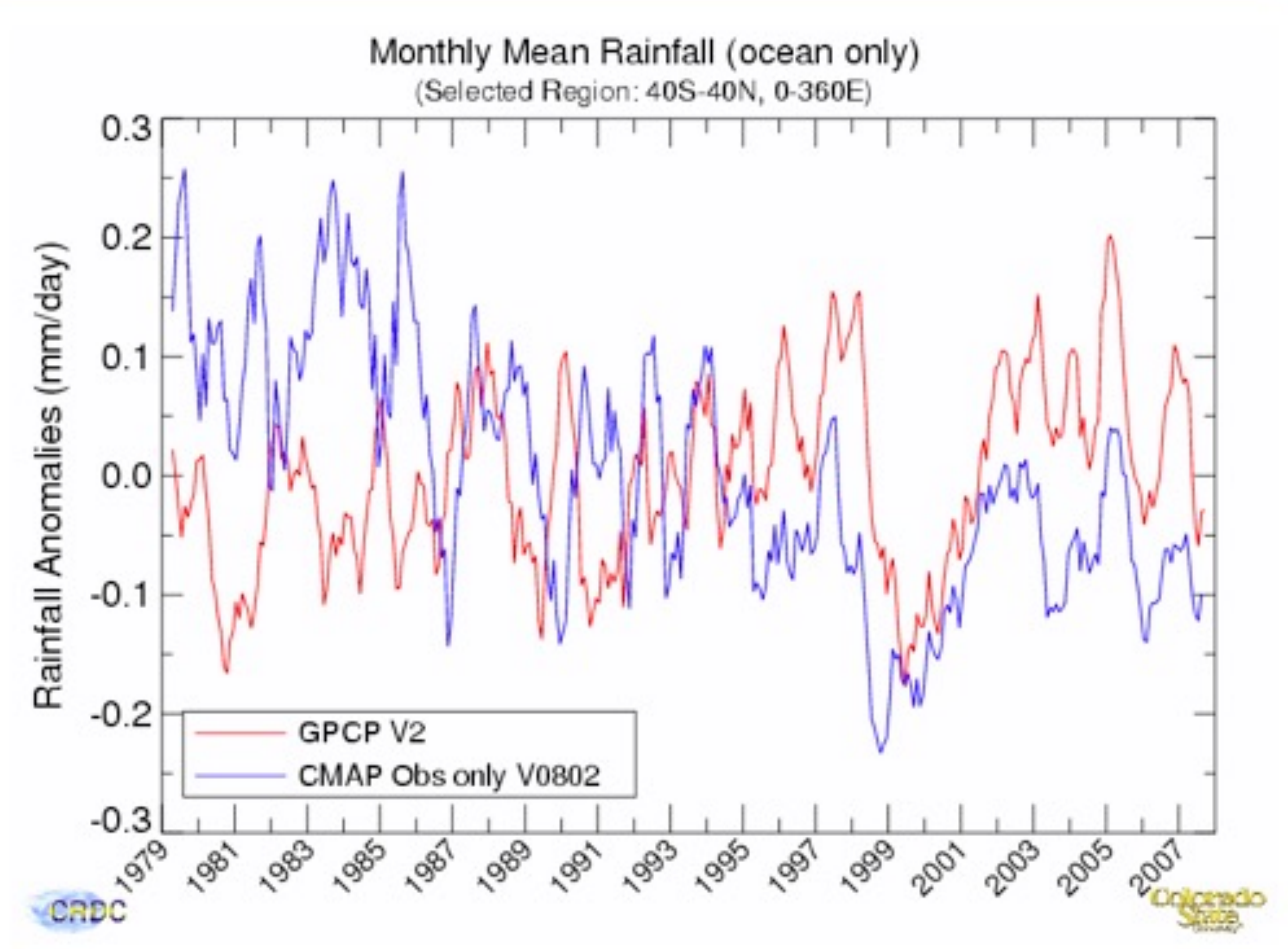
Satellite Rainfall Biases

Mean DJF Rainfall (1987 – 1996)



GPCP vs CMAP (Ocean only)

trend over land is nearly identical due to reliance on same gauge data



BUREAU OF METEOROLOGY
Department of the Environment, Sport and Territories

BMRC

Bureau of Meteorology Research Centre

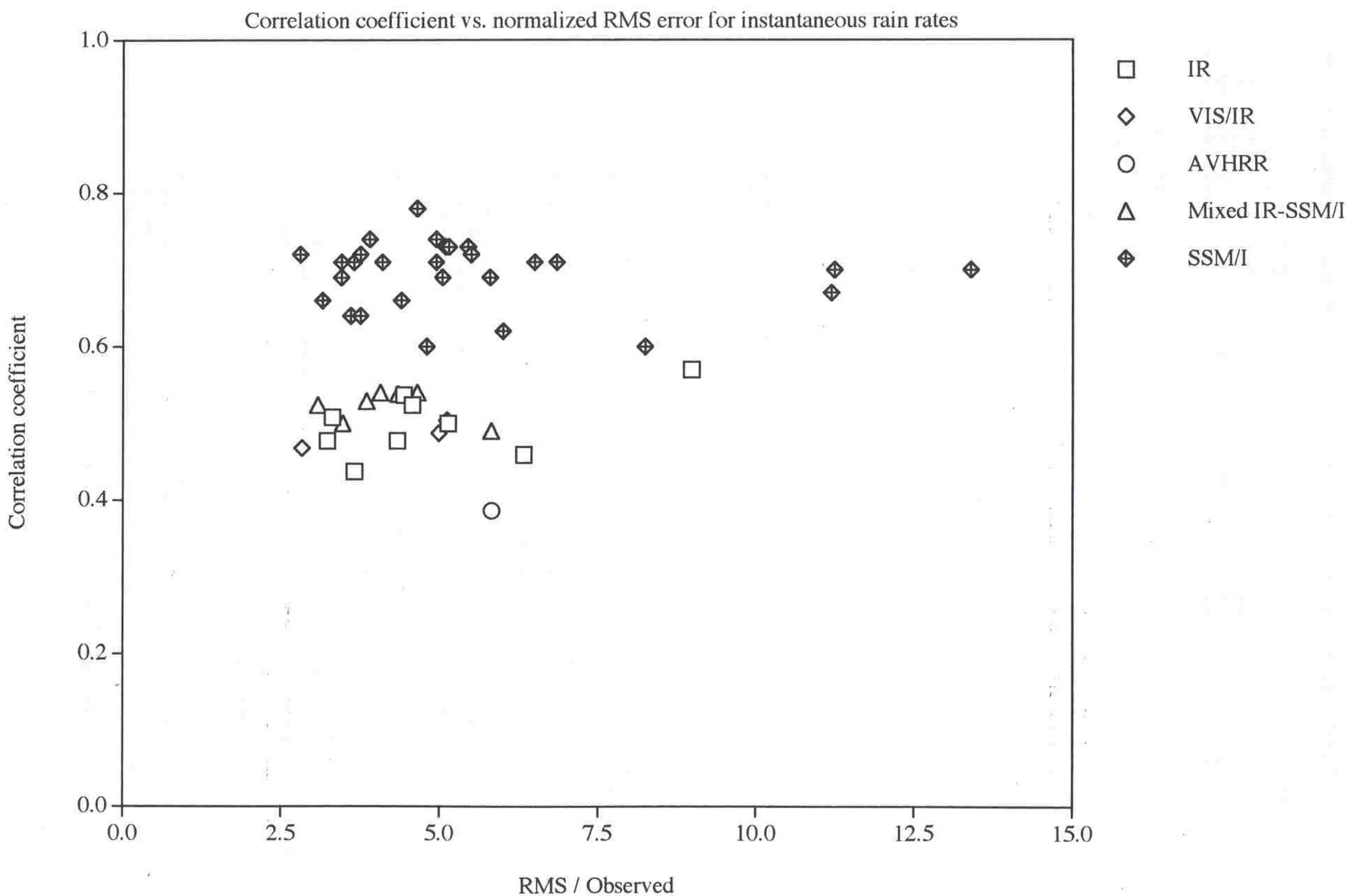
BMRC Research Report No. 55

RESULTS OF THE 3RD ALGORITHM INTERCOMPARISON PROJECT (AIP-3) OF THE GLOBAL PRECIPITATION CLIMATOLOGY PROJECT (GPCP)

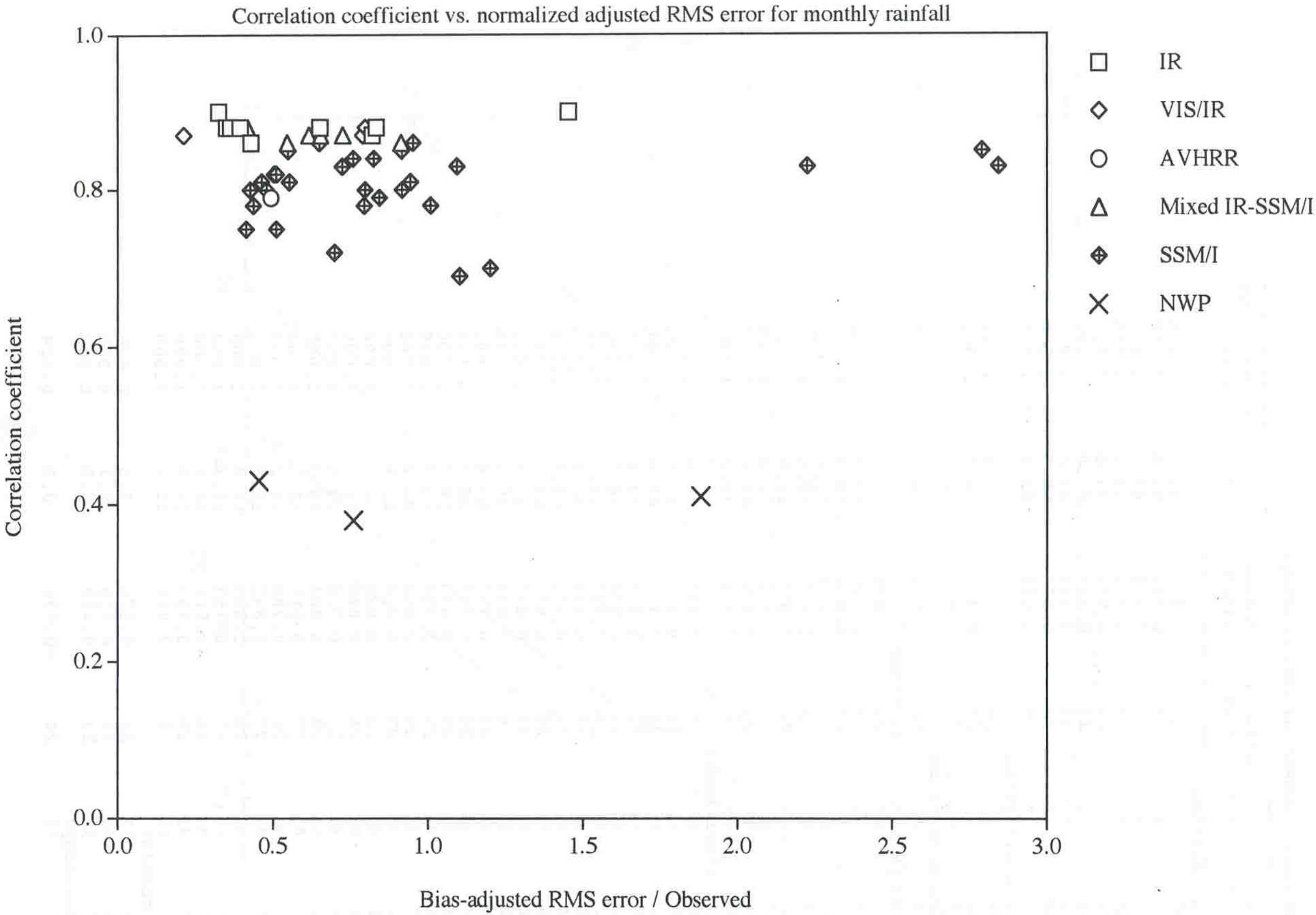
Elizabeth E. Ebert

MAY 1996

BMRC
GPO Box 1289K
Melbourne
Victoria
Australia 3001



Correlation coefficient vs. normalized RMS error for instantaneous rain rates
Correlation coefficient
RMS / Observed
1.0
0.8
0.6
0.4
0.2
0.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
IR
VIS/IR
AVHRR
Mixed IR-SSM/I
SSM/I

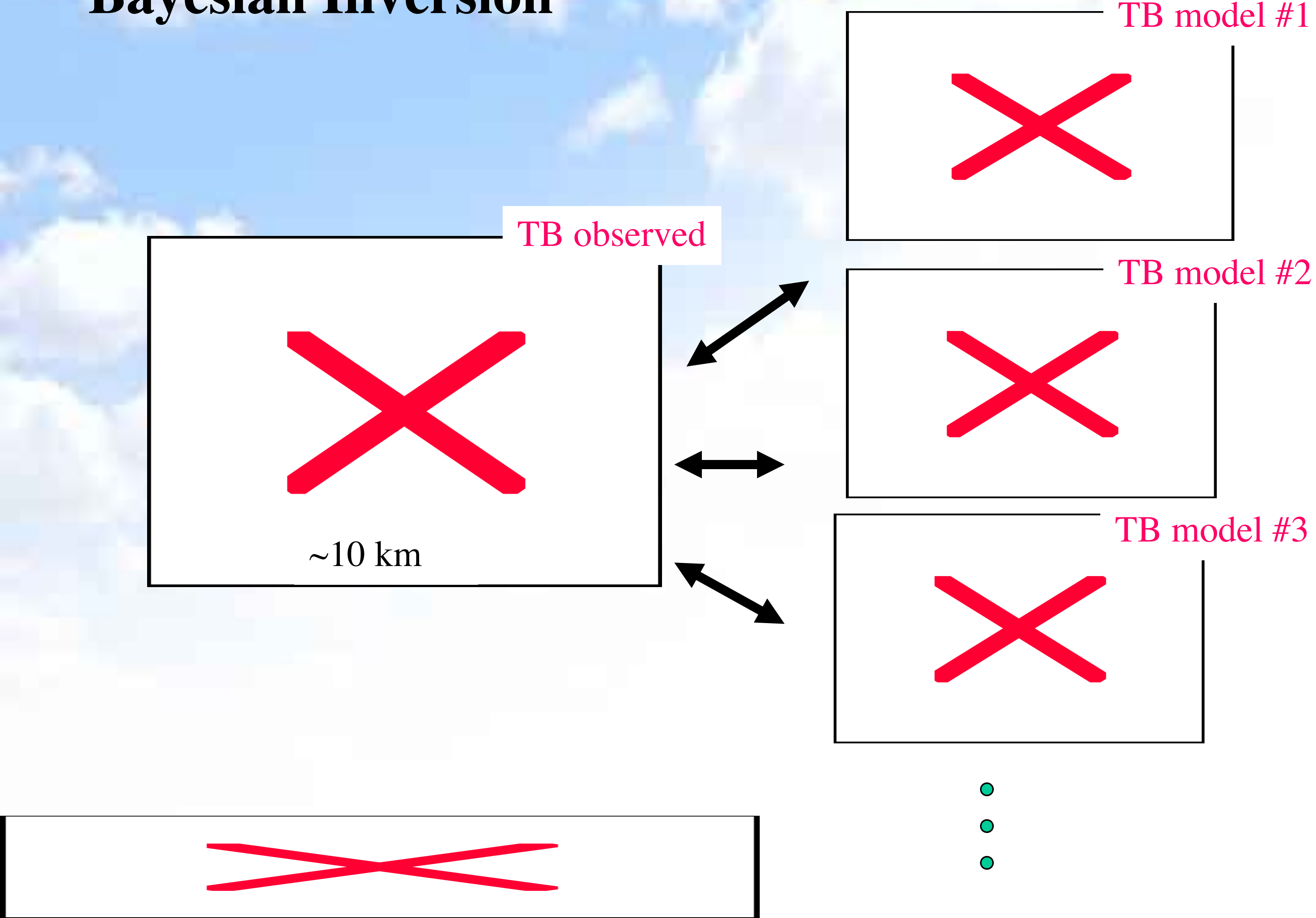

Correlation coefficient vs. normalized adjusted RMS error for monthly rainfall
Correlation coefficient
Bias-adjusted RMS error / Observed
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
IR
VIS/IR
AVHRR
Mixed IR-SSM/I
SSM/I
NWP

After AIP-3, all rainfall retrievals focused on passive microwave. TRMM active/passive once it was launched in 1997.

IR techniques were pursued primarily to improve sampling.

Bayesian Inversion

TRMM Radar & Model Database



Microwave Algorithm
(All sensors)

Create Data base

Start with observed PR rain profiles and non-raining background

Compute Tb at TMI channels and resolution and compare to observations

Adjust rain profiles to be consistent with PR and TMI

Use adjusted 4 km rain profiles to compute Tb for any sensor

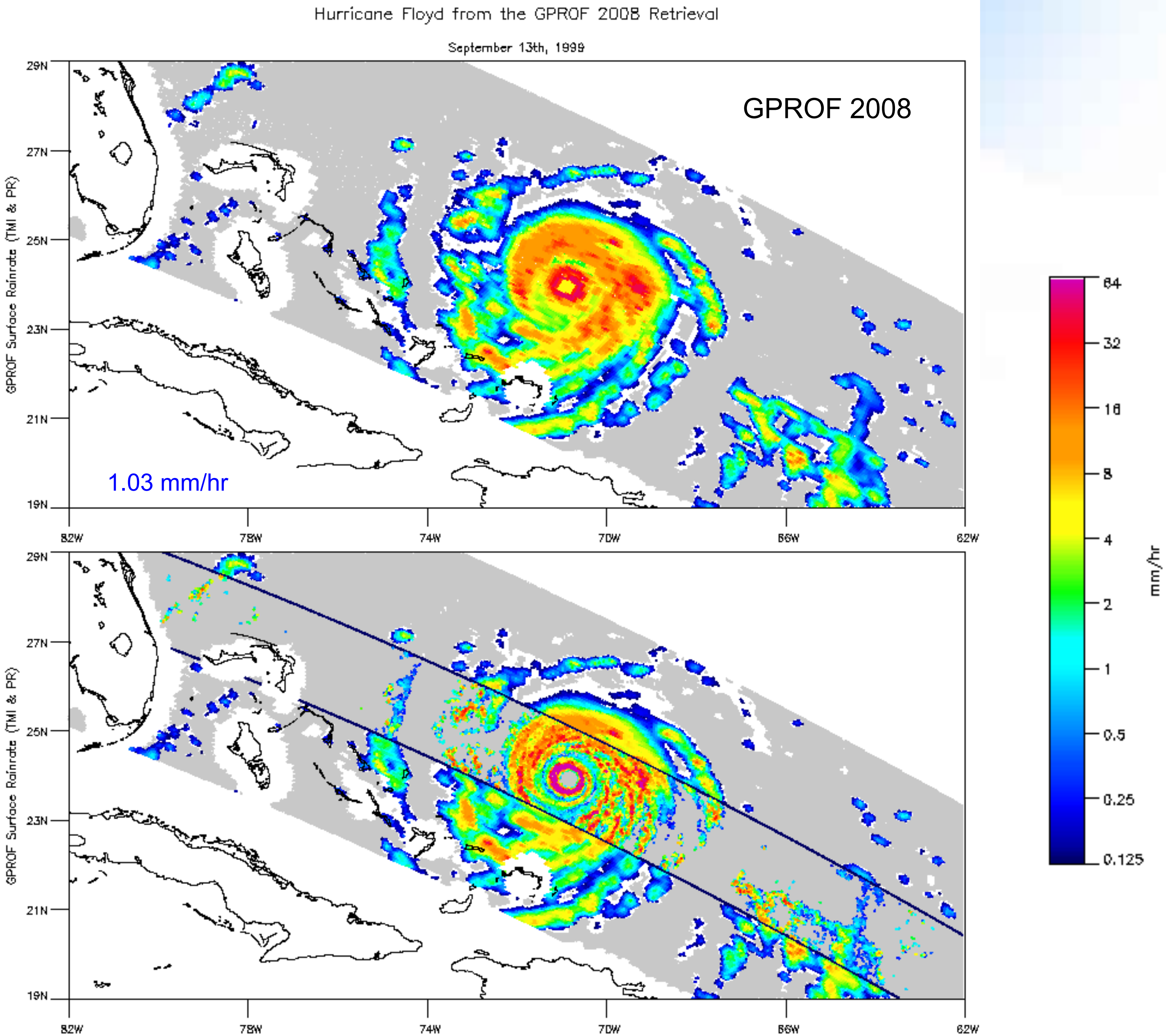
Create Database (raining and non-raining) pixels in 1K SST and 2 mm TPW bins.

Run Retrieval

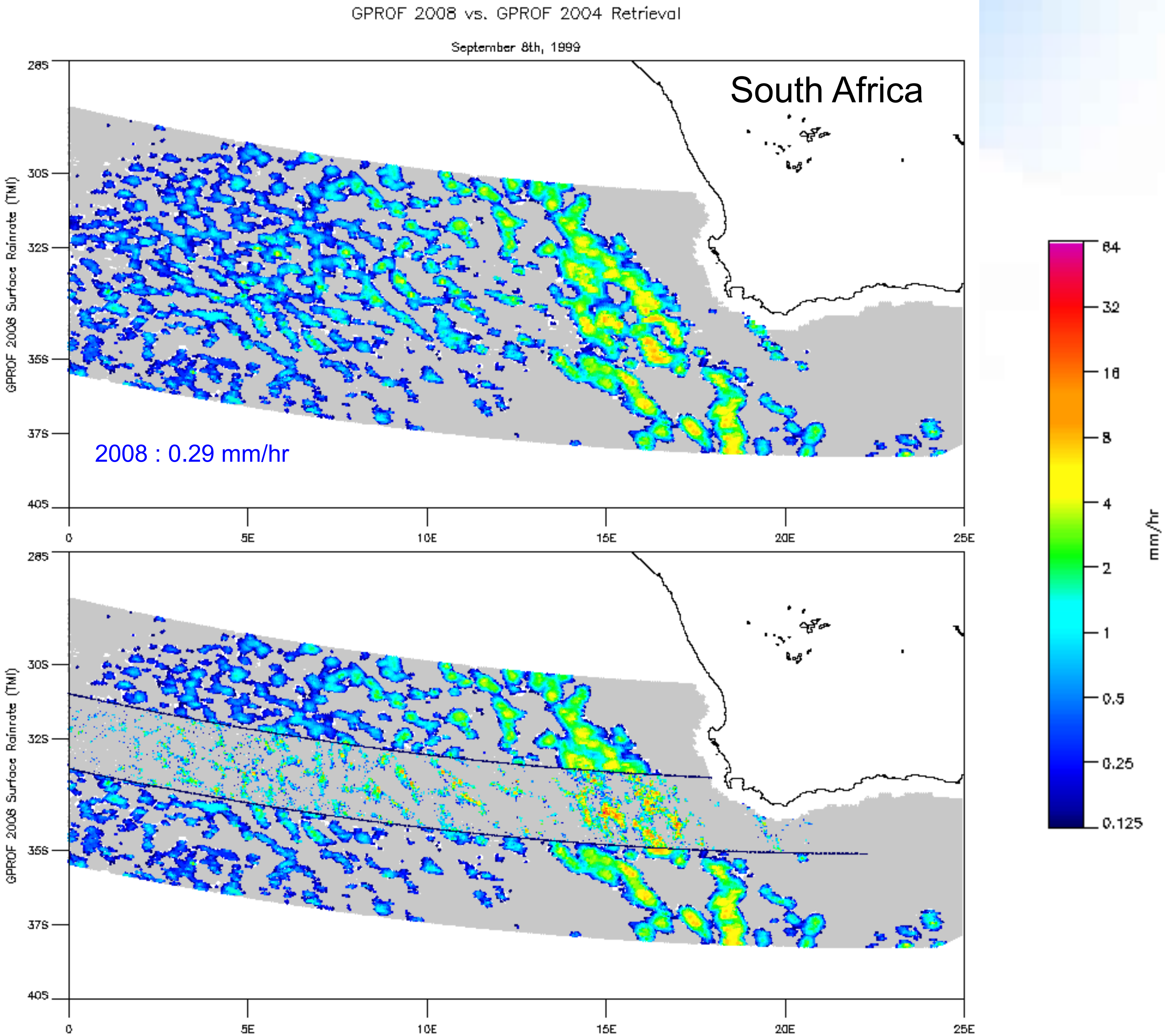
Determine SST & TPW

Compare observed Tb to dbase entries within ±1K (SST) and ±2 mm (TPW)

Weight of profile depending upon rms of channel difference.



Hurricane Floyd from the GPROF 2008 Retrieval
September 13th, 1999
GPROF 2008
1.03 mm/hr
GPROF Surface Rainrate (TMI & PR)
29N
27N
25N
23N
21N
19N
82W
78W
74W
70W
66W
62W
mm/hr
64
32
16
8
4
2
1
0.5
0.25
0.125



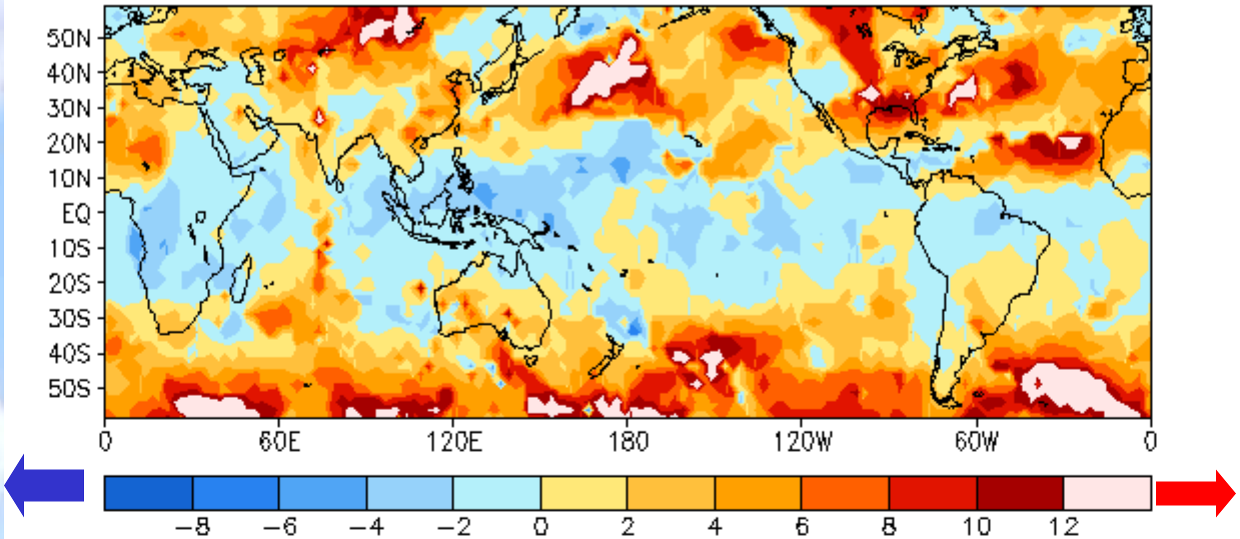
GPROF 2008 vs. GPROF 2004 Retrieval
September 8th, 1999
South Africa
2008 : 0.29 mm/hr
GPROF 2008 Surface Rainrate (TMI)
28S
30S
32S
35S
37S
40S
0
5E
10E
15E
20E
25E
64
32
16
8
4
2
1
0.5
0.25
0.125
mm/hr

CMORPH (CPC morphing technique)

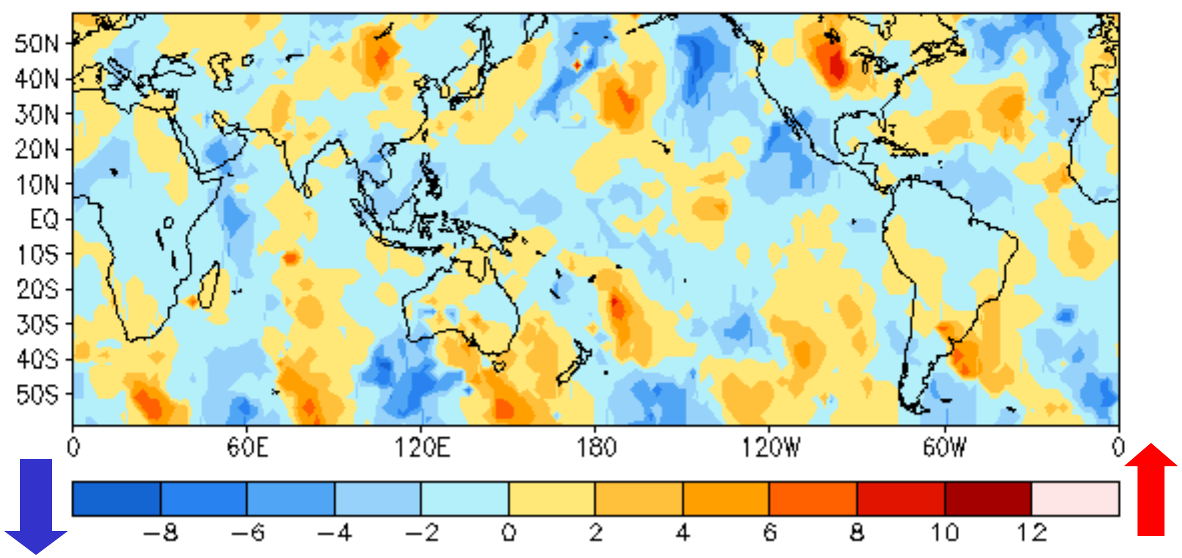
Bob Joyce, John Janowiak, Pingping Xie

Advection Vector Components

Zonal



Meridional



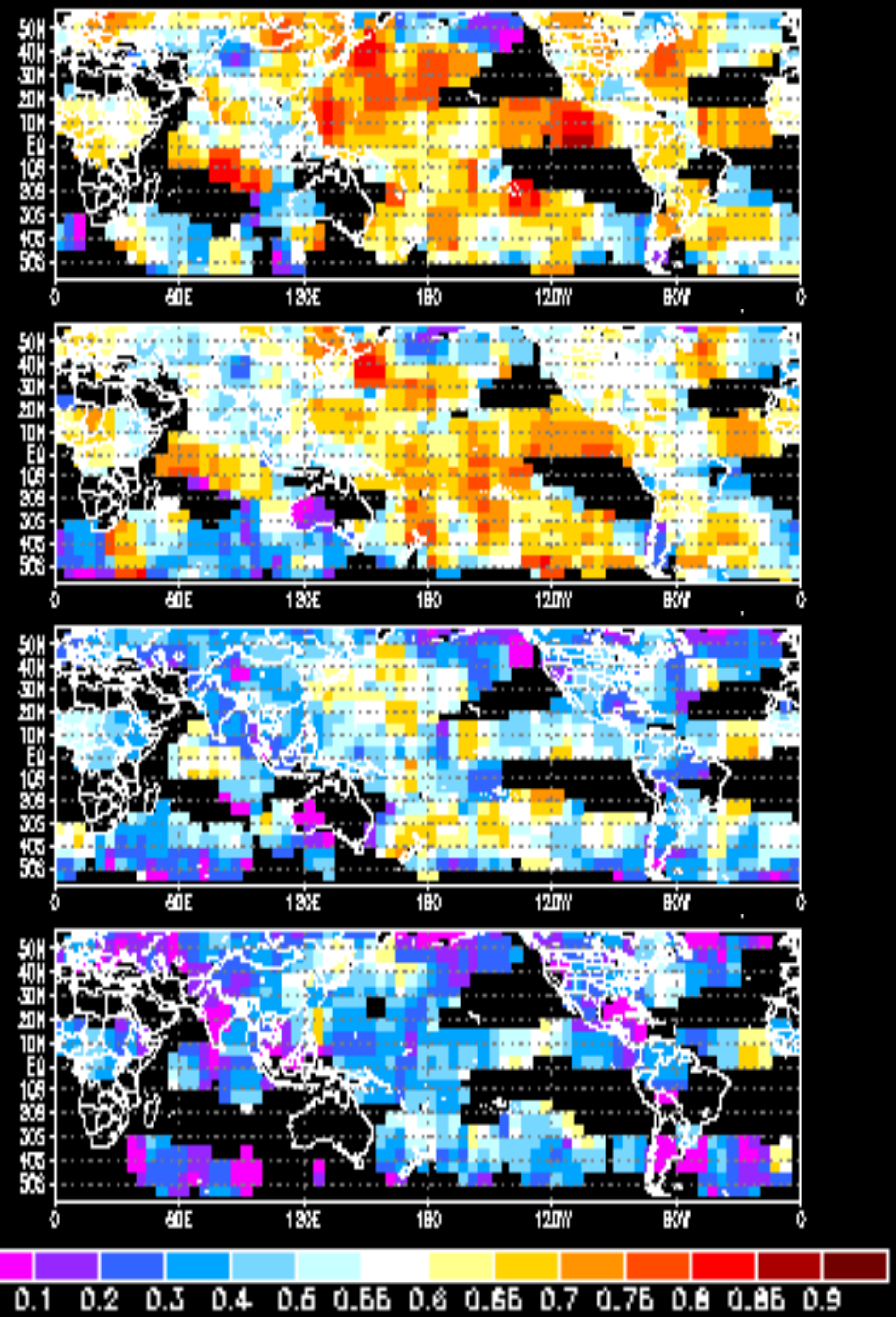
CMORPH correlation

30 minutes

60 minutes

90 minutes

120 minutes



3 issues

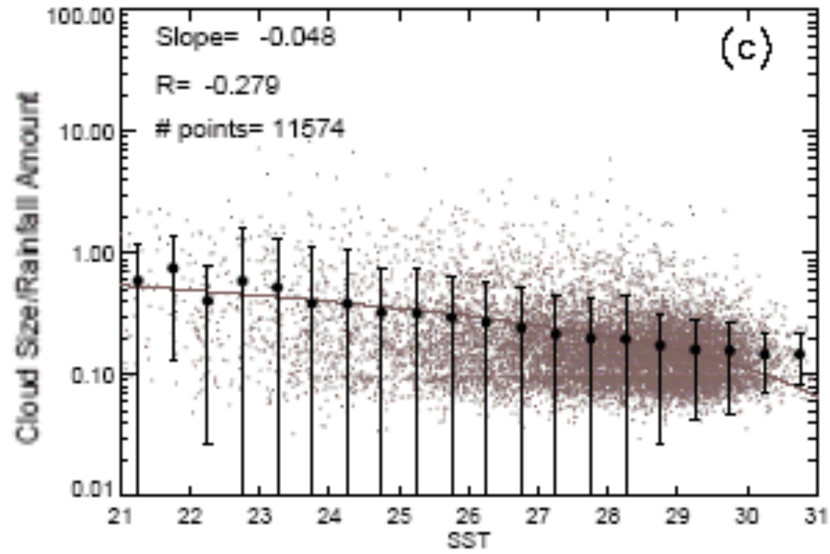
The iris hypothesis: As environment warms, precipitation efficiency increases. This reduces the amount of detrained cirrus clouds which in turn allow more radiation to escape. The increased OLR acts as a negative feedback

Rain suppression by aerosols - as aerosols increase, more CCN increase the number of cloud drops. This increases cloud albedo but suppresses the onset of precipitation.

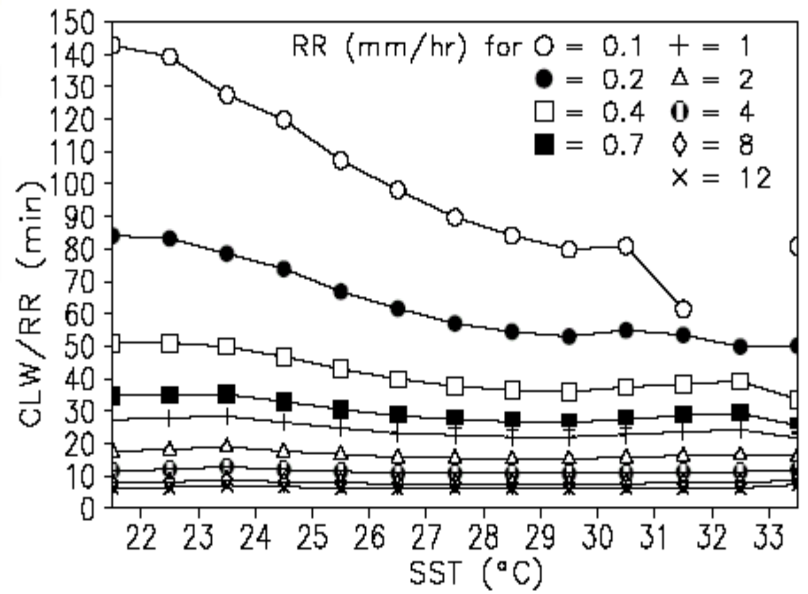
Precipitation increase in warmer climate: recent observational study suggests that oceanic precipitation is increasing at ~ 6%/°C (i.e. at the same rate as water vapor). Climate models predict a much smaller increase.

- While there is no general relationship between SST and the ratio of detrained cirrus to convection - the iris hypothesis appears to hold for warm rain systems.

- These clouds affect the hydrologic cycle through their moistening of the lower troposphere which in turn preconditions the atmosphere for deep convection
  - A reduction in the amount of evaporating warm rain clouds could alter the recycling timescales for deep convection



Rapp et al. (2004)

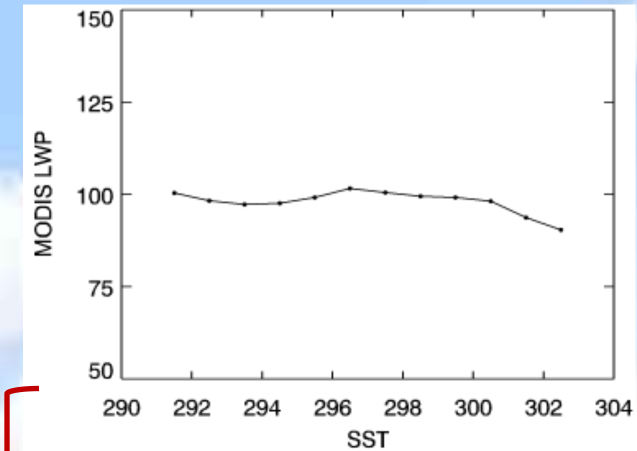


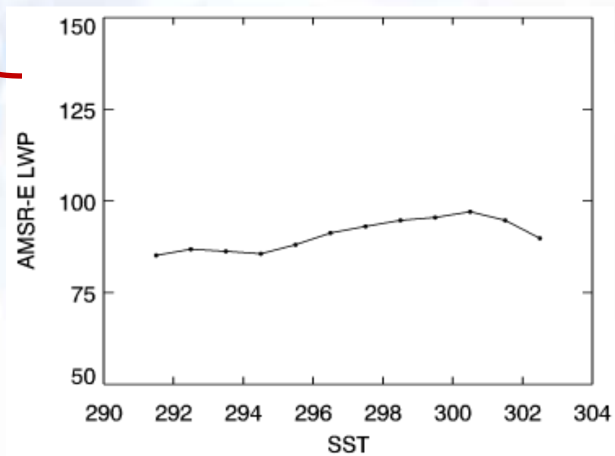
Lau and Wu (2003)

Are these systems responding to SST?

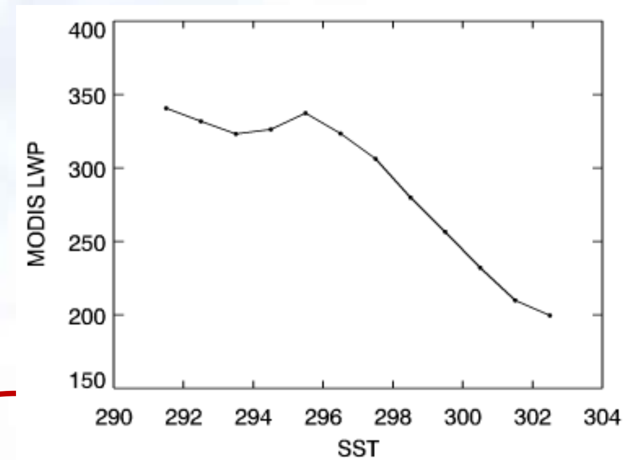
Look at retrievals from a variety of sensors and algorithms to see how warm rain systems respond to SST.

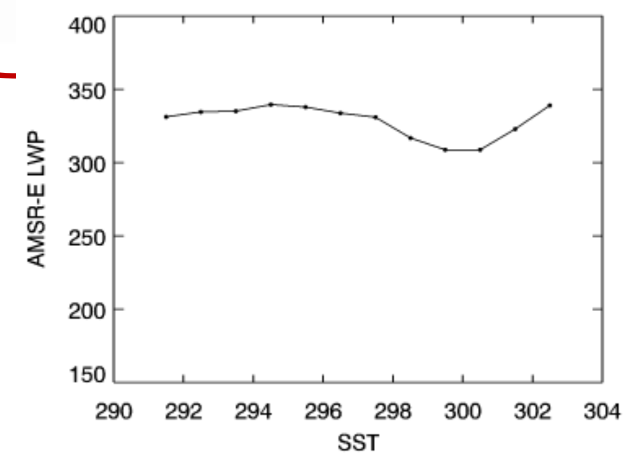
No rain





Rain





Basic OE Algorithm

Minimize Cost Function:

- **Ingest Observed Brightness Temperatures (TBs)**
- **Prior Knowledge of Atmospheric State (Water Vapor, Wind, Cloud Water)**

Simulate TBs

Iterate

Adjust Water Vapor, Wind, Cloud Water

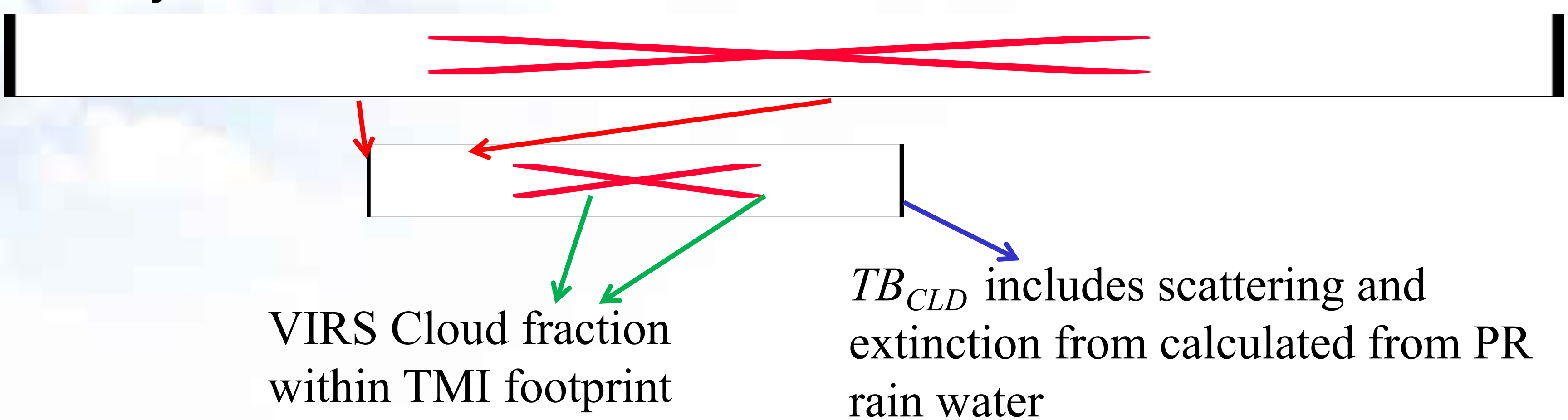
Establish Convergence Criteria Retrieval
(Determine Validity of Retrieval)

Modifications to OE Algorithm

New inputs -

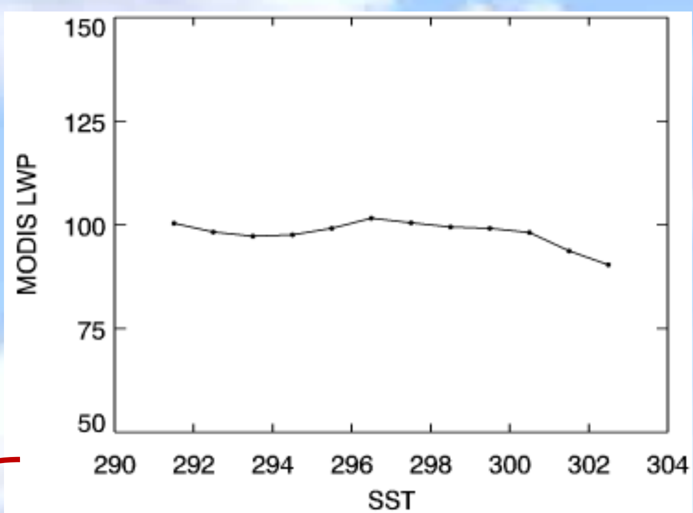
- Ingest deconvolved TMI Tbs
- VIRS cloud fraction calculated within TMI footprint
- Specify the rain column from PR-derived rain water and rain height

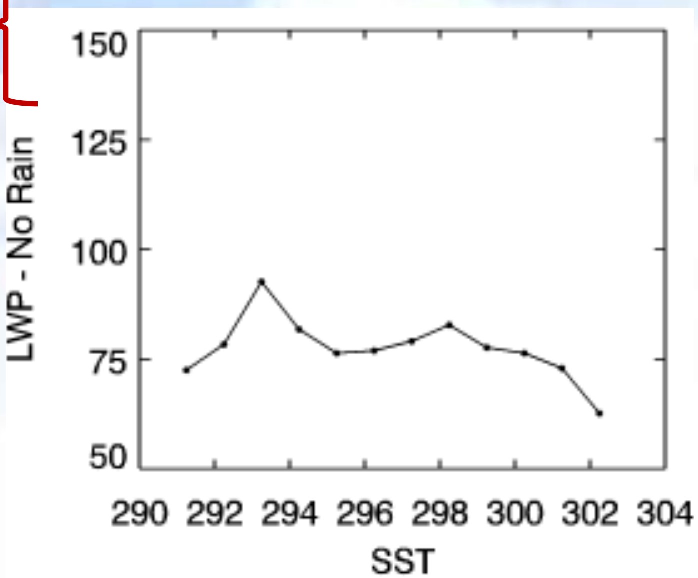
Modify cost function -



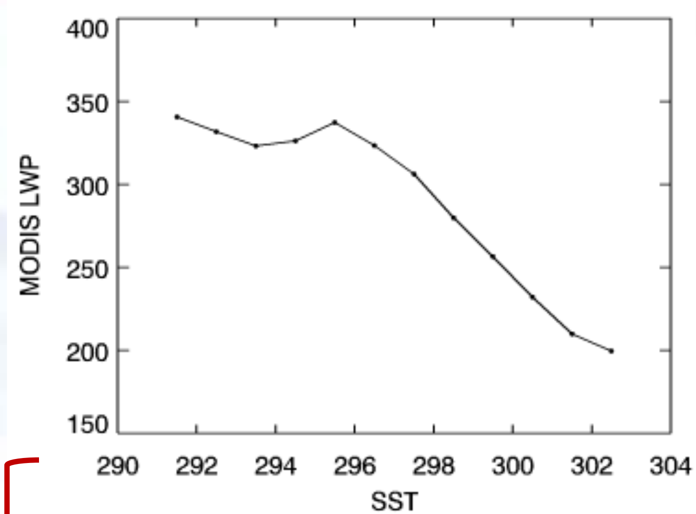
Results w/ SST

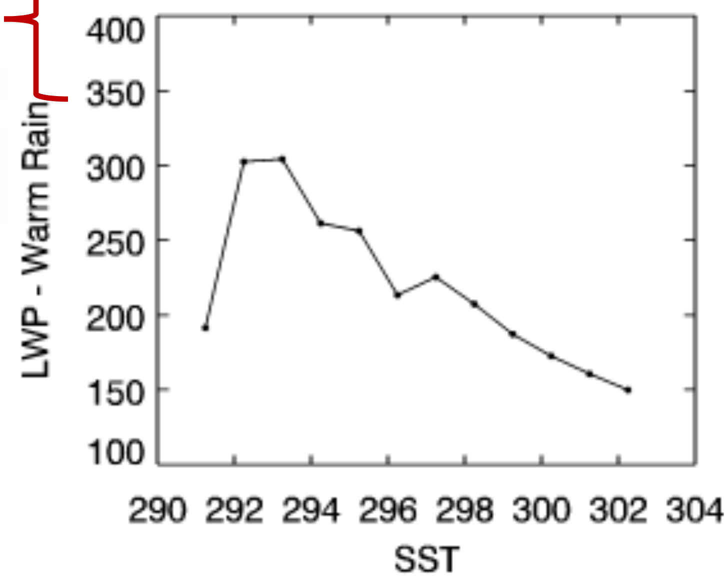
No rain





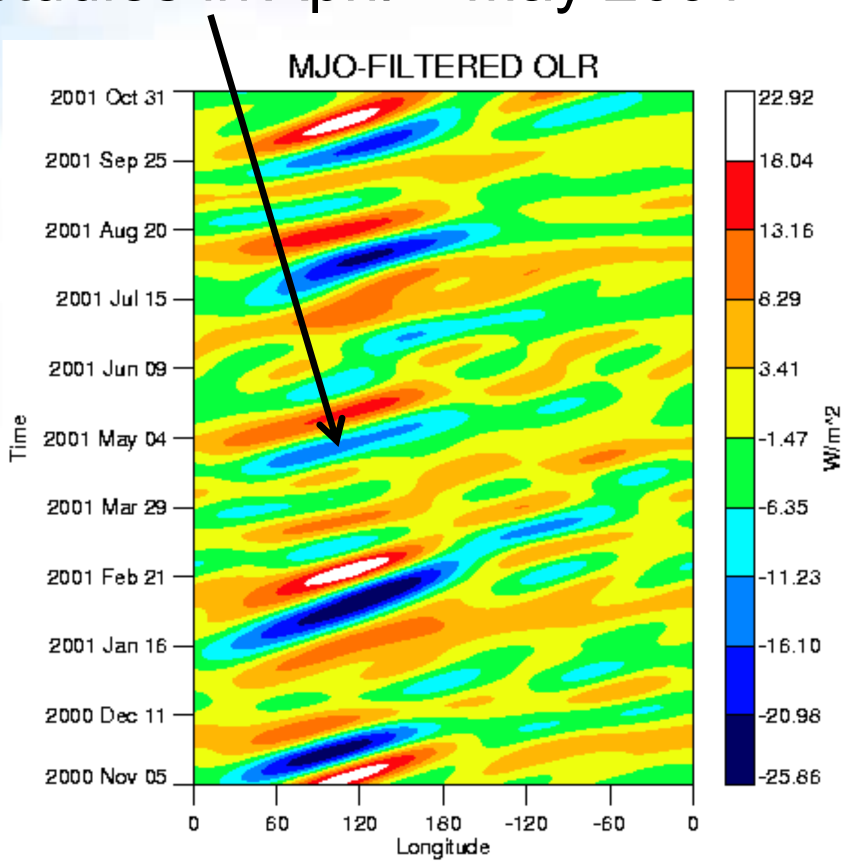
Rain



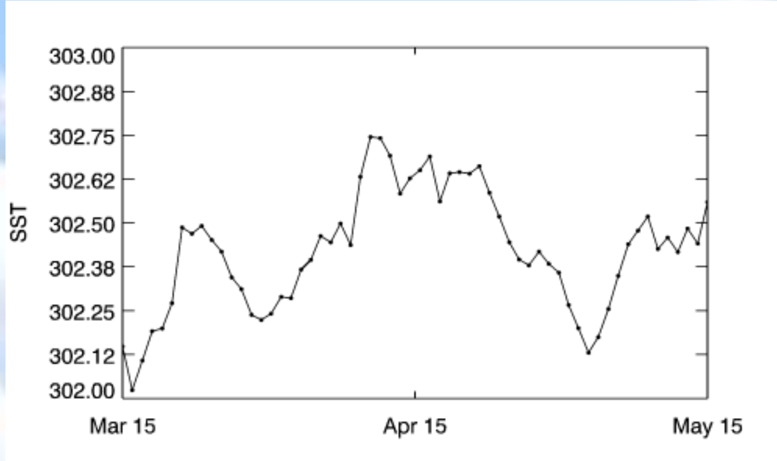


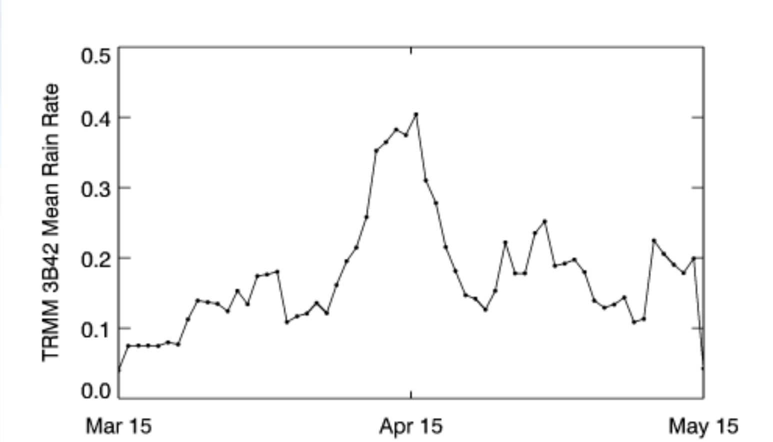
Testing Influence on Deep Convective Time Scales

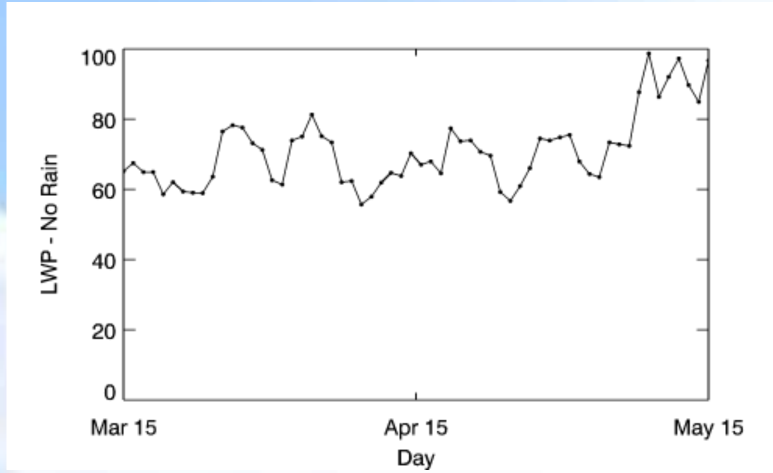
- One of the most obvious deep convective events in the Tropics is the Madden-Julian Oscillation
- MJO identified by numerous studies in April – May 2001
- Study time series of surface, atmospheric and cloud properties
- Examine the influence of properties of warm rain systems on lower tropospheric moistening

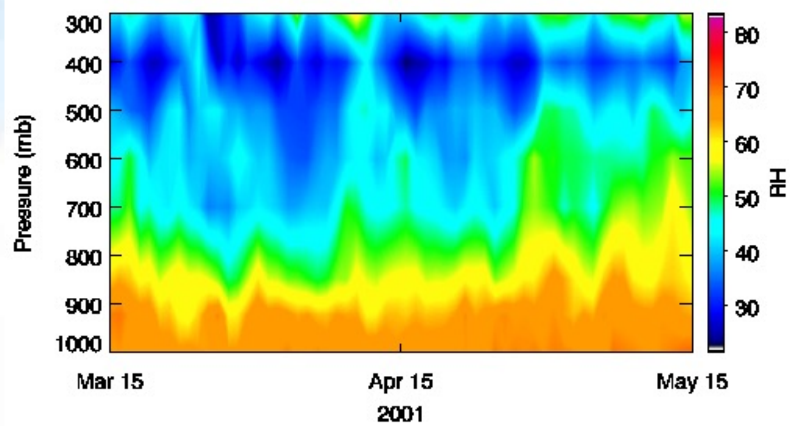


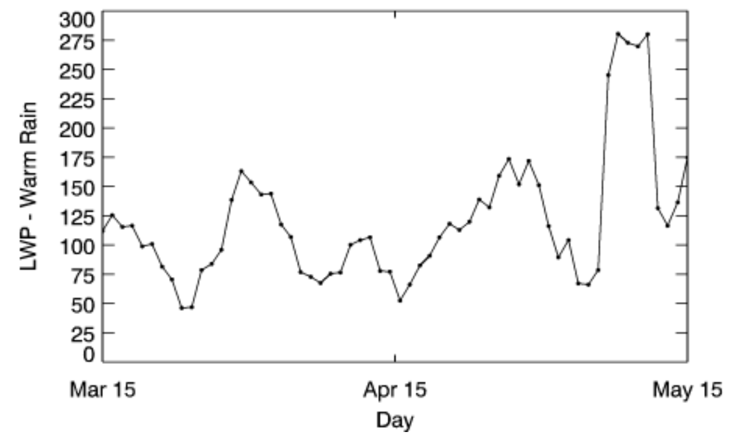
MJO Case Study Results





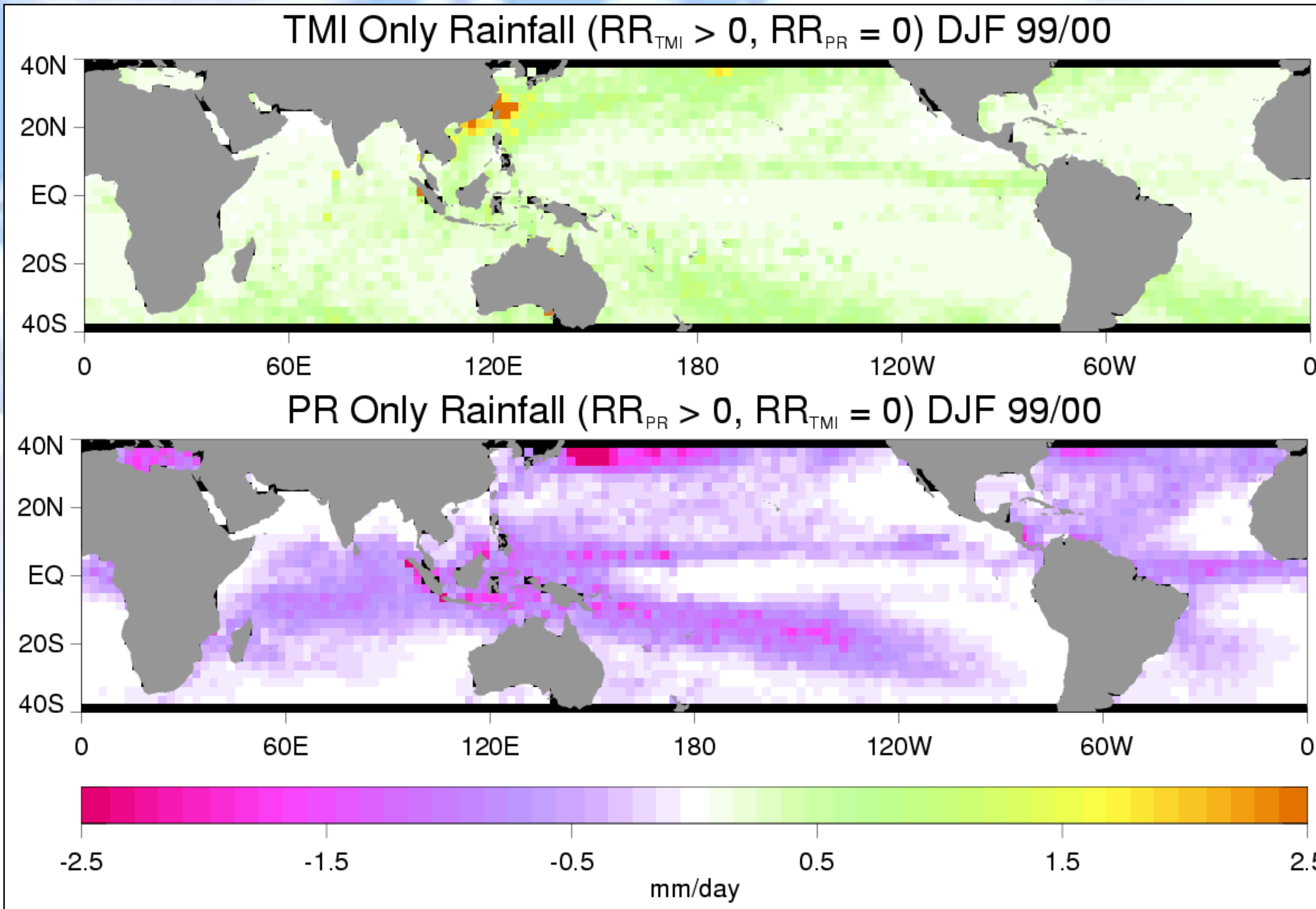






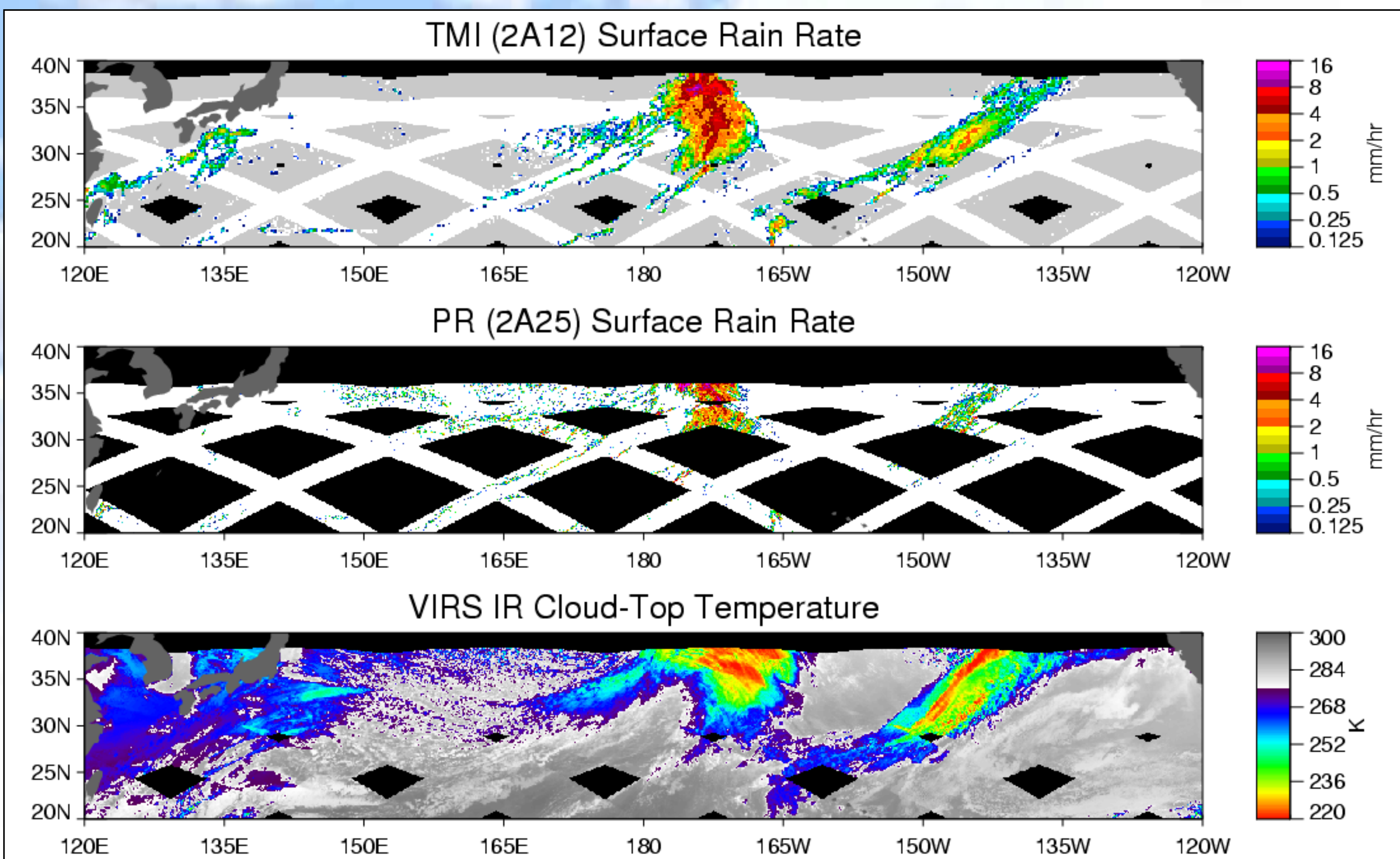
- Clouds/Aerosols and Precipitation

Rainfall Detection Errors



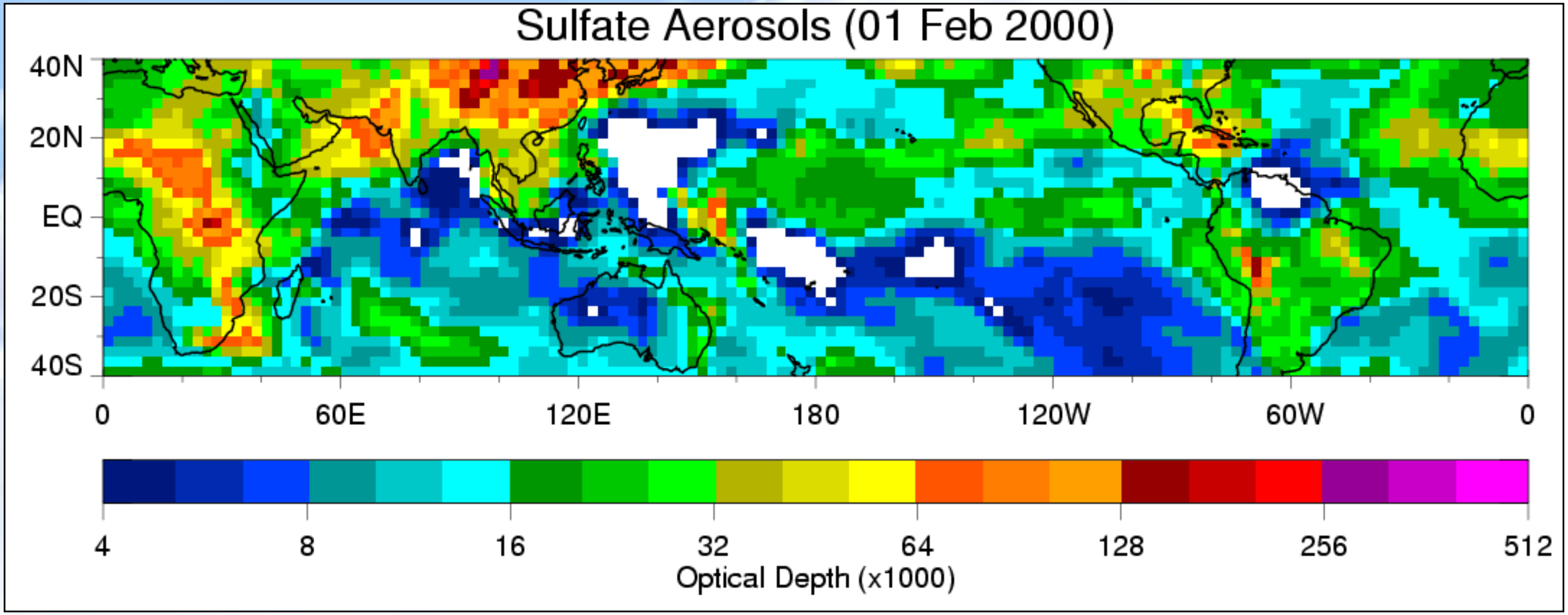
Rainfall Detection Errors

February 1, 2000



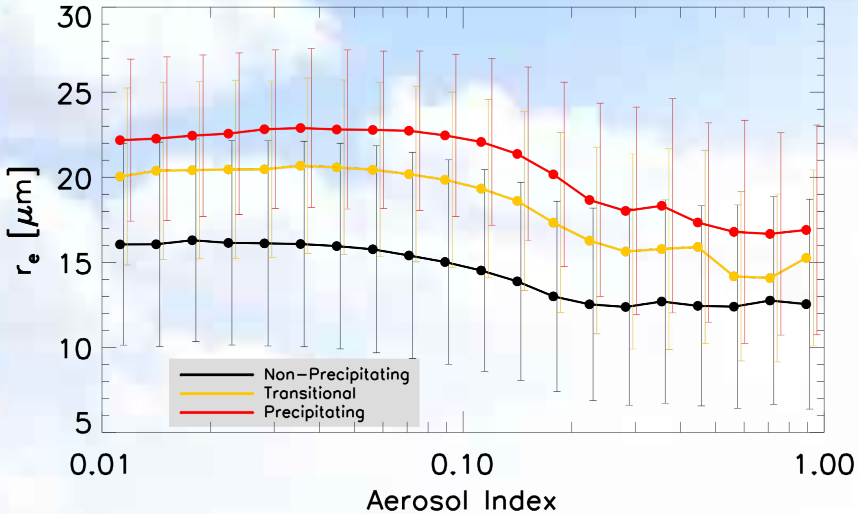
Role of Aerosols?

Impact on Drop Size

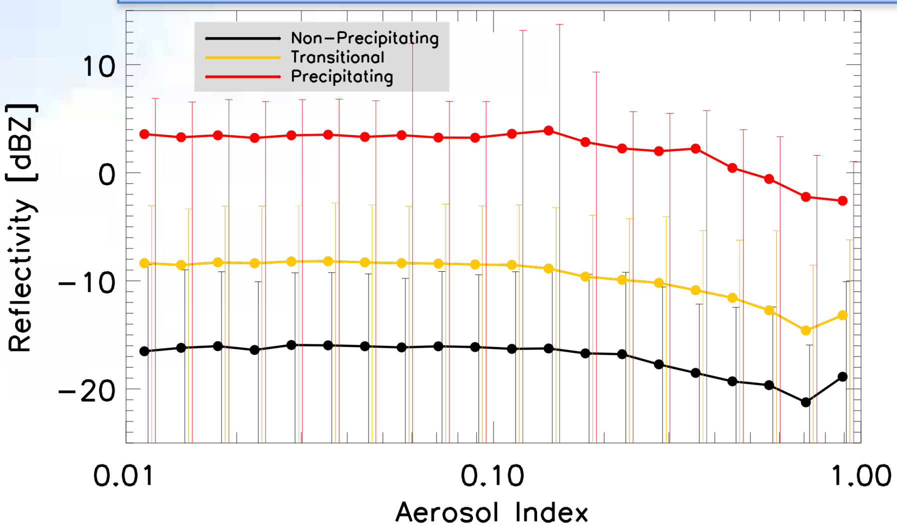


- Evidence for decreased droplet/drop sizes in high CCN air for raining and non-raining clouds

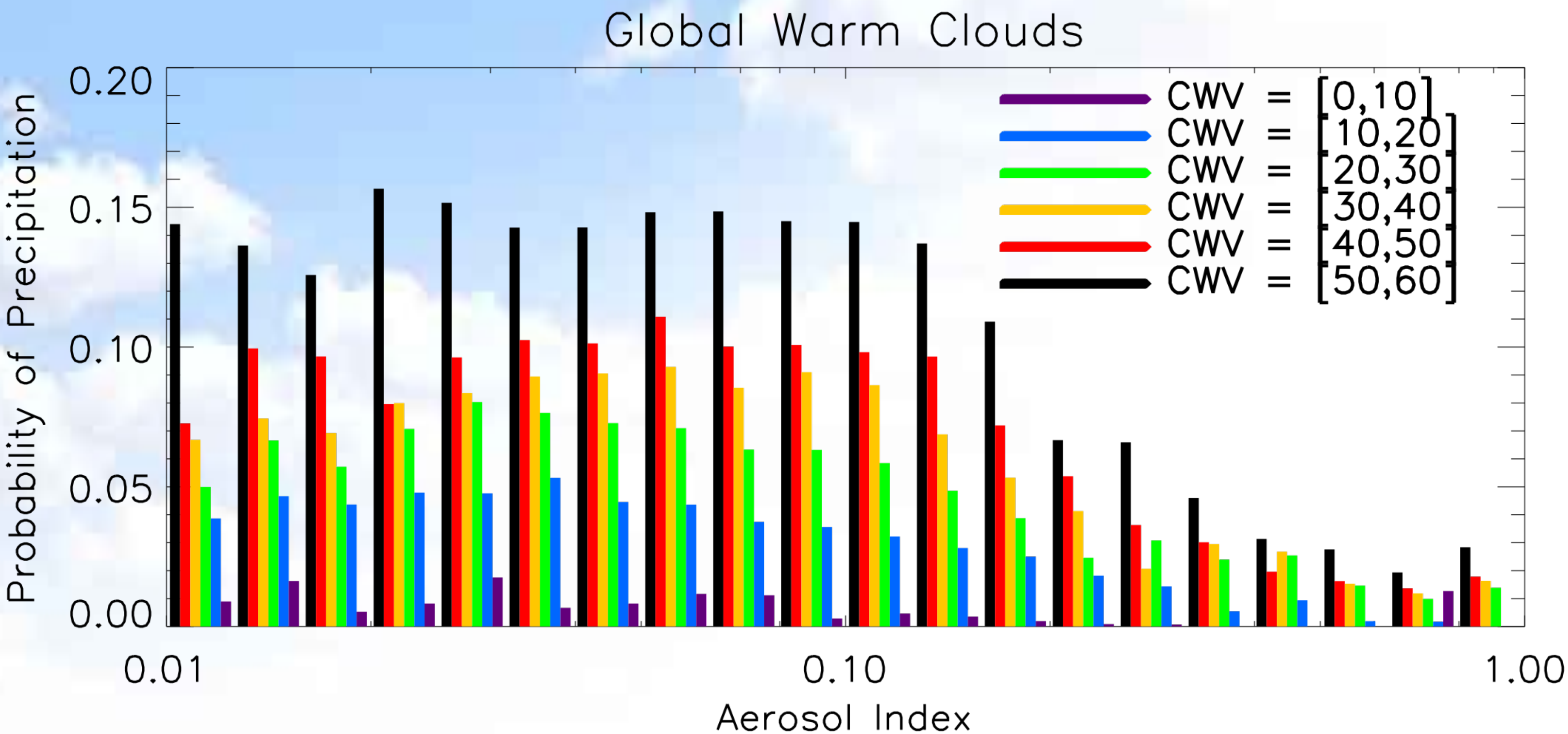
MODIS Effective Radius



CloudSat Mean Reflectivity

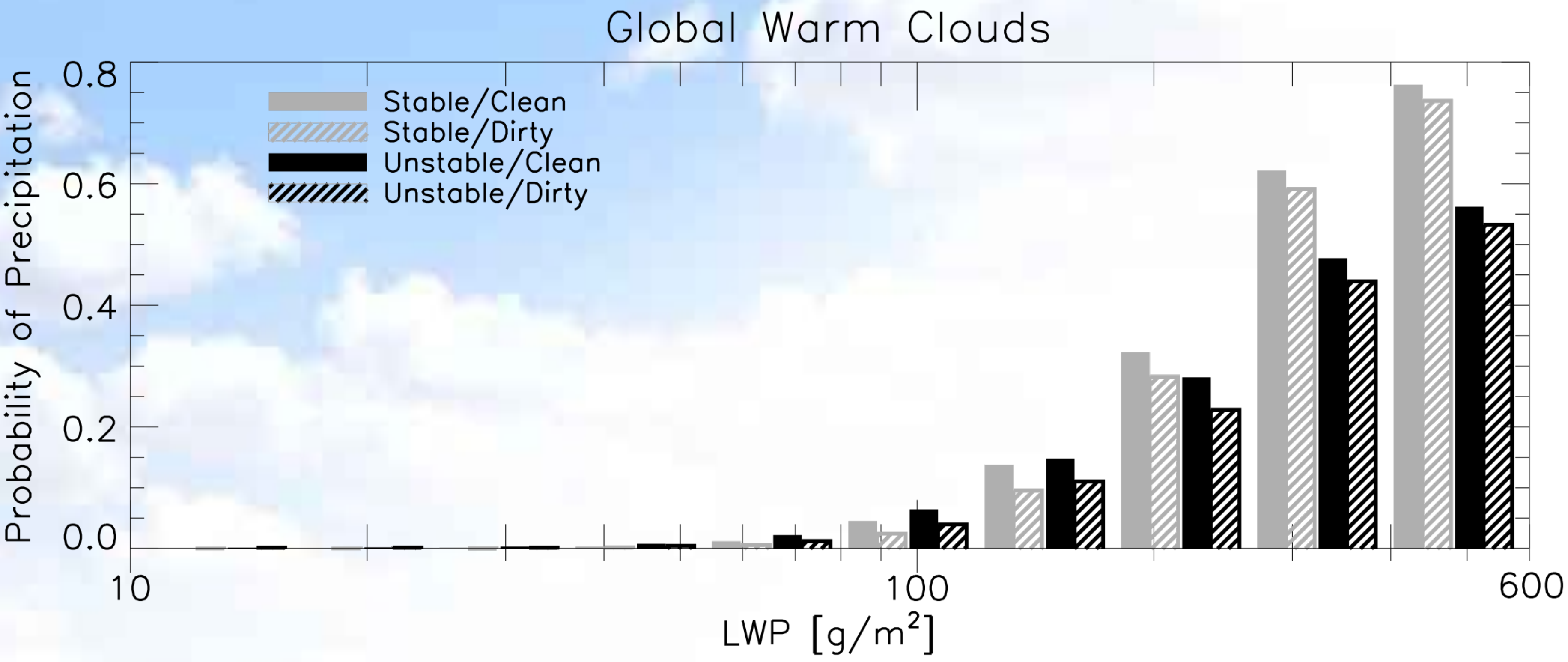


Probability of Precipitation and Aerosol



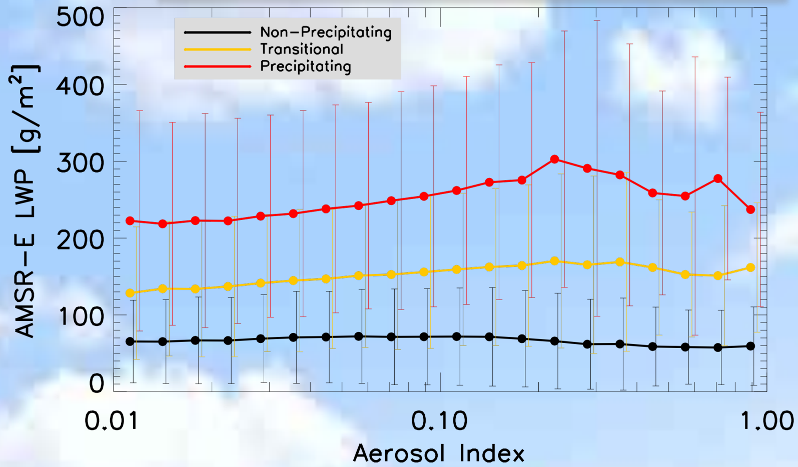
- POP decreases by as much as 10% with large aerosol burden

Probability of Precipitation and Water Path



- Dependence on thermodynamic stability greater than that of aerosol
- POP decreased by ~5% in dirty air regardless of LWP

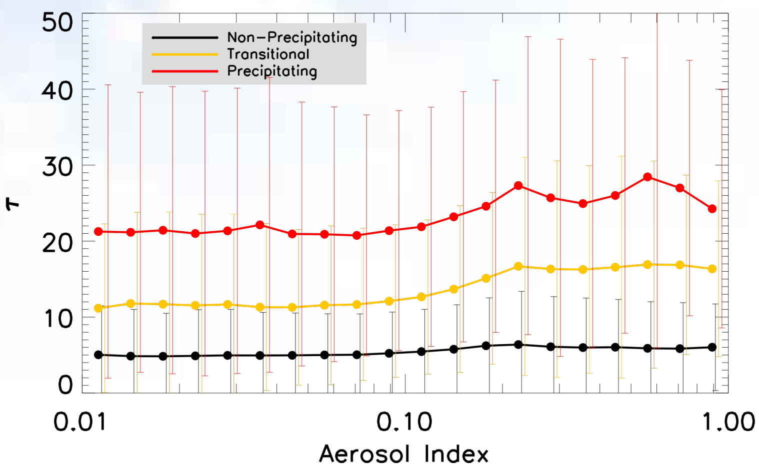
AMSR-E Water Path



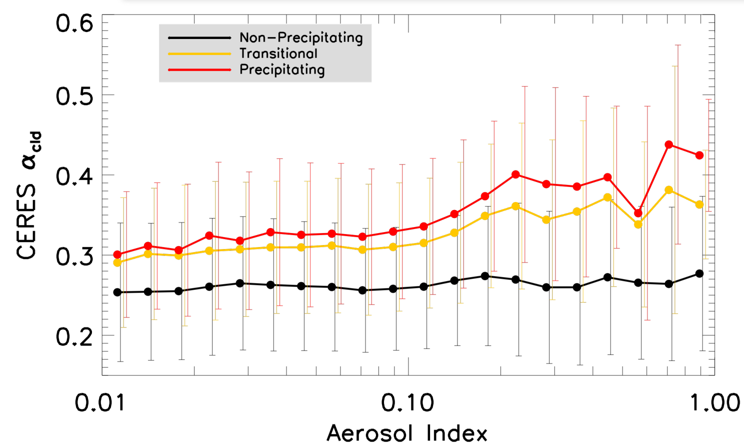
- The water path effect for Precipitating clouds dominates the radius effect in the albedo response of these clouds

$$\tau = \frac{3\text{LWP}}{2\rho_l r_e} \quad \alpha_{cld} \approx F(\tau) = F(r_e, \text{LWP})$$

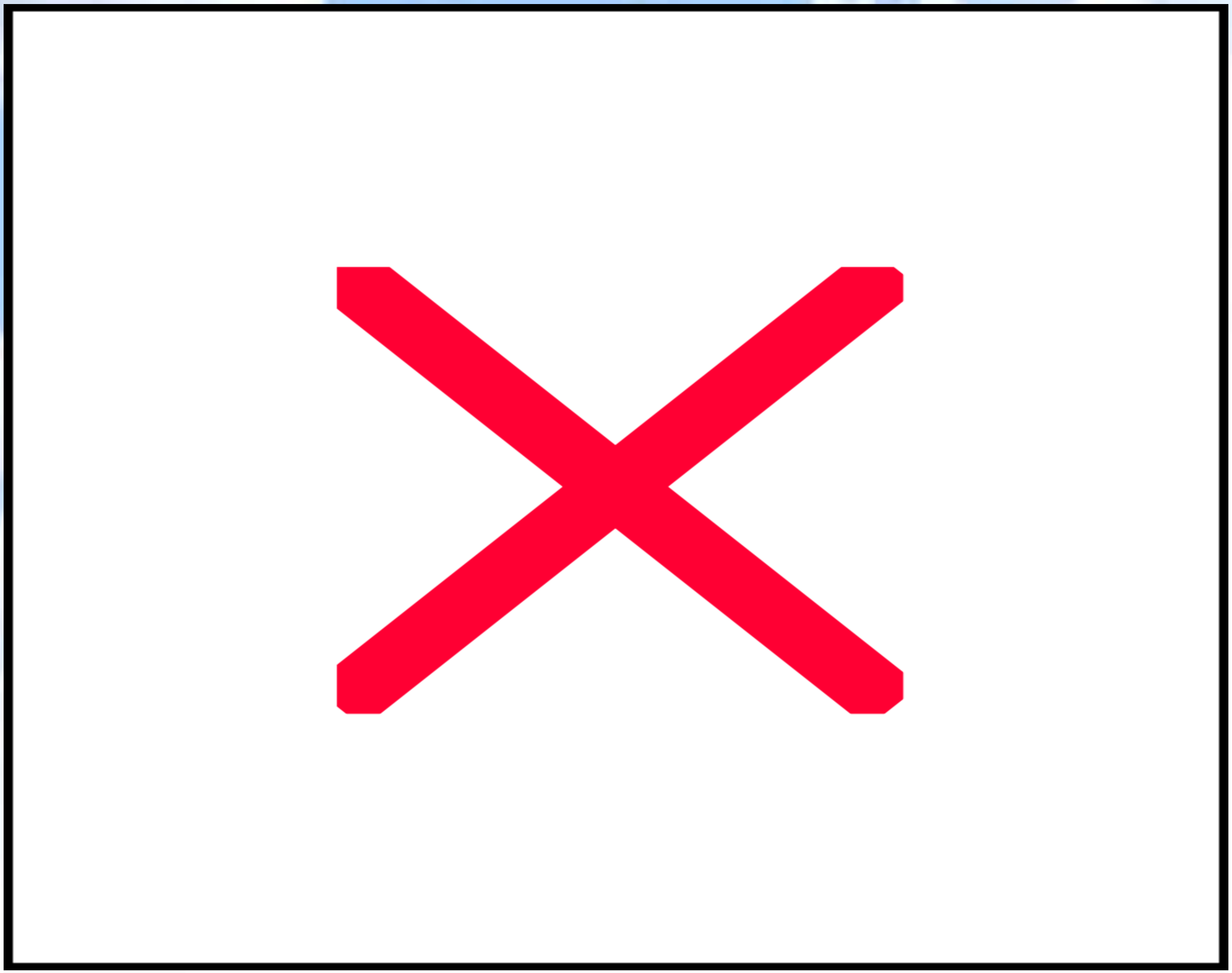
MODIS Optical Depth



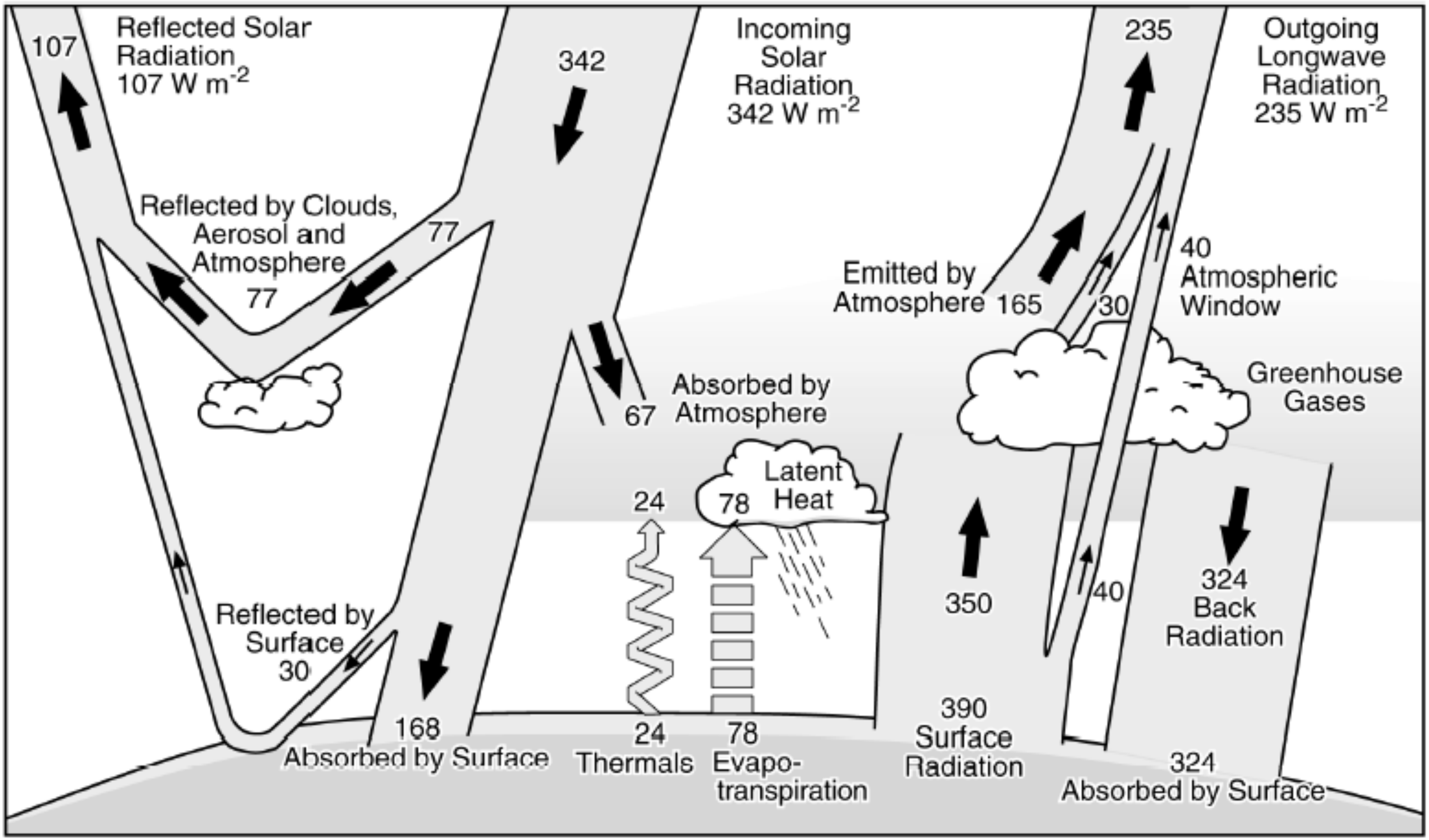
CERES Cloud Albedo



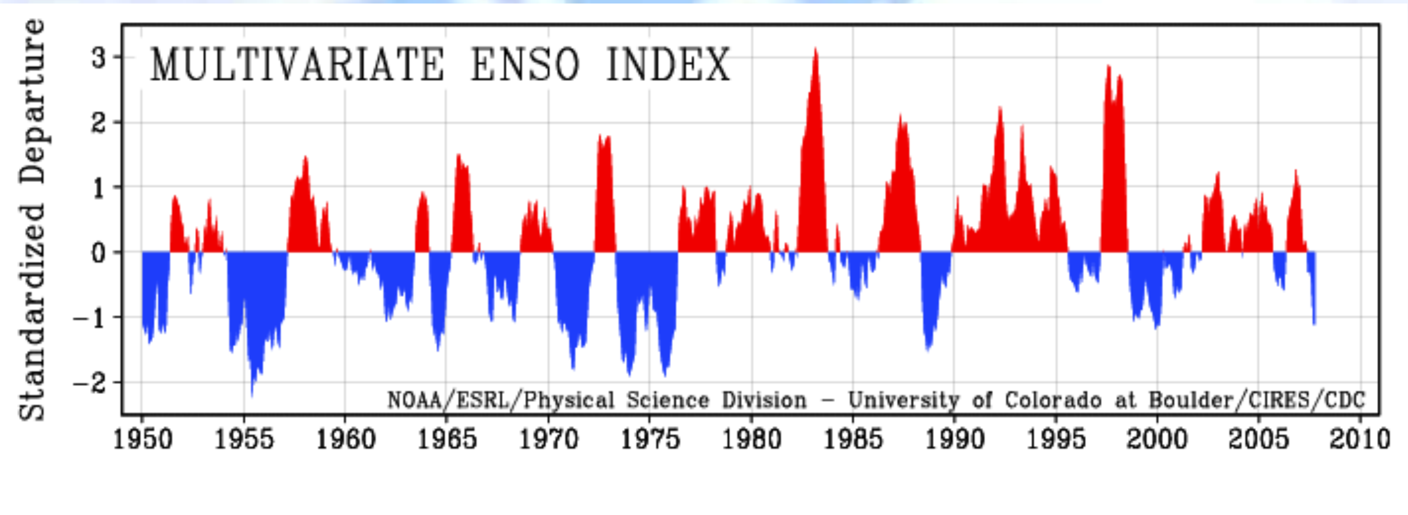
How much more rain will global warming bring?



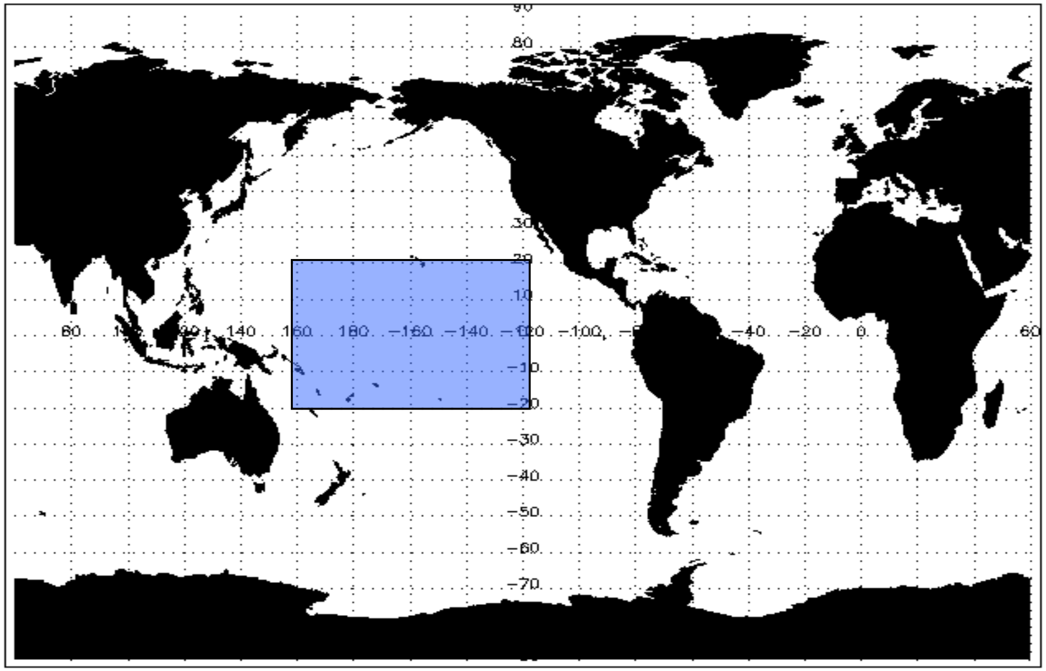
From: How much more rain will global warming bring?
Frank J. Wentz, L. Ricciardulli, K, Hilburn and C. Mears
Sciencexpress, 31 May 2007


107
Reflected Solar Radiation 107 W m-2
342
Incoming Solar Radiation 342 W m-2
235
Outgoing Longwave Radiation 235 W m-2
Reflected by Clouds, Aerosol and Atmosphere
77
77
Emitted by Atmosphere
165
30
40
Atmospheric Window
Greenhouse Gases
67
Absorbed by Atmosphere
Latent Heat
78
24
350
40
324
Back Radiation
Reflected by Surface
30
168
Absorbed by Surface
24
Thermals
78
Evapo-transpiration
390
Surface Radiation
324
Absorbed by Surface

What is the relationship between water and energy budgets over the Tropical Pacific?

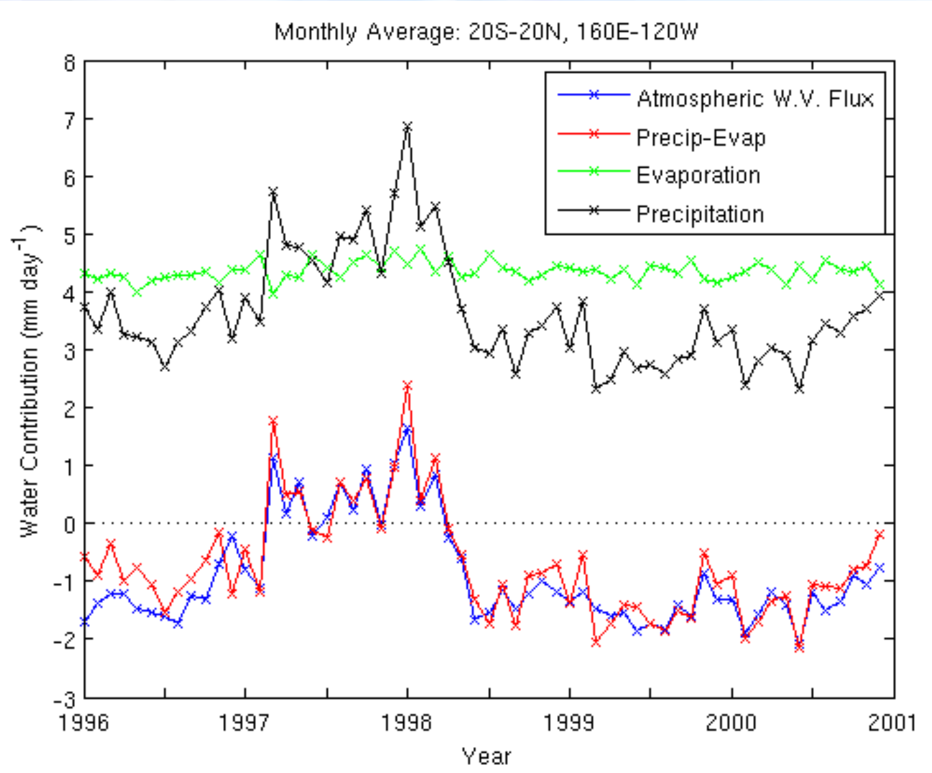


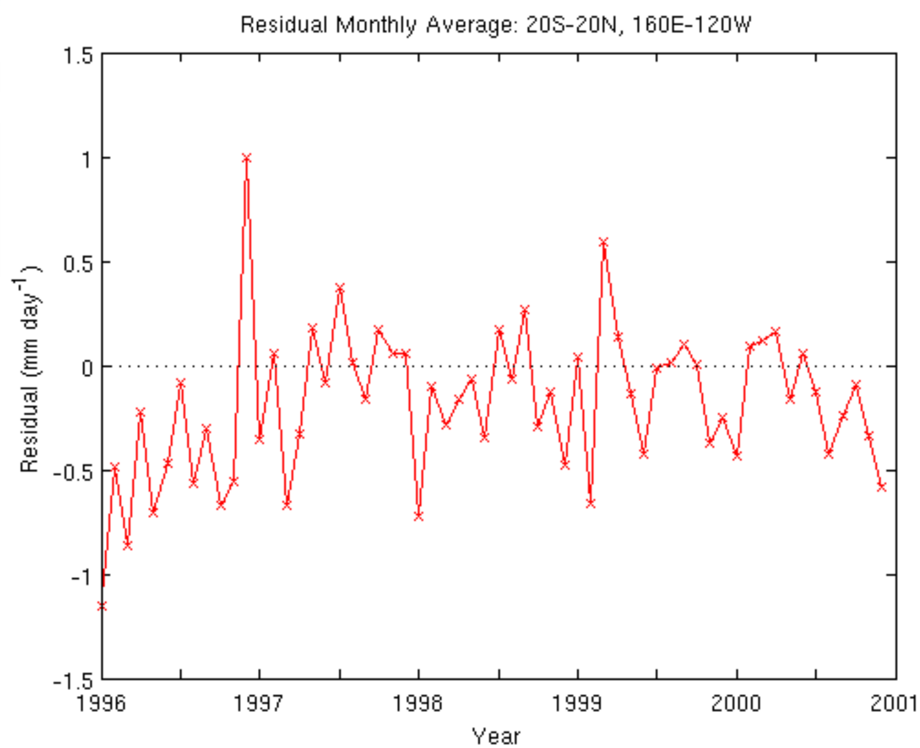
- Monthly means from 96 Jan through 00 Dec
- 20ºN-20ºS, 160ºE-120ºW



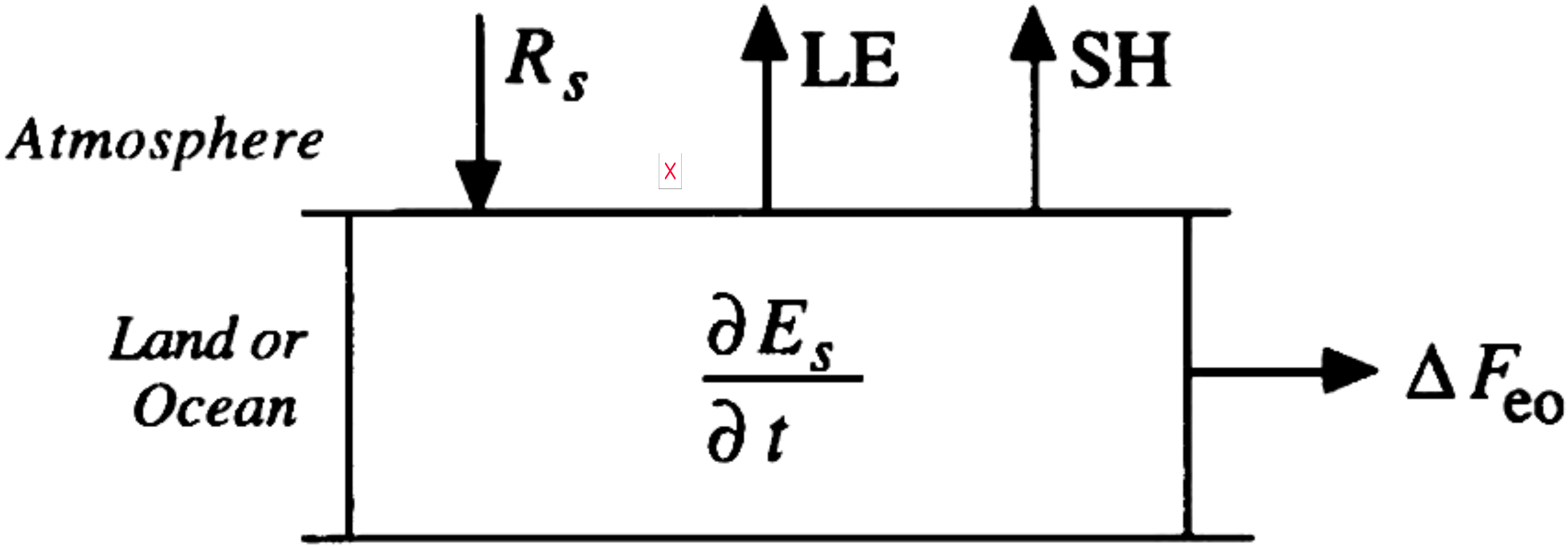
Water Budget

- Water Budget looks very close to being closed
  - Residual is always less than ~1.2 mm day^{-1}
  - Bias: -0.2 mm day^{-1} Std Dev: 0.4 mm day^{-1}





Surface Energy Budget



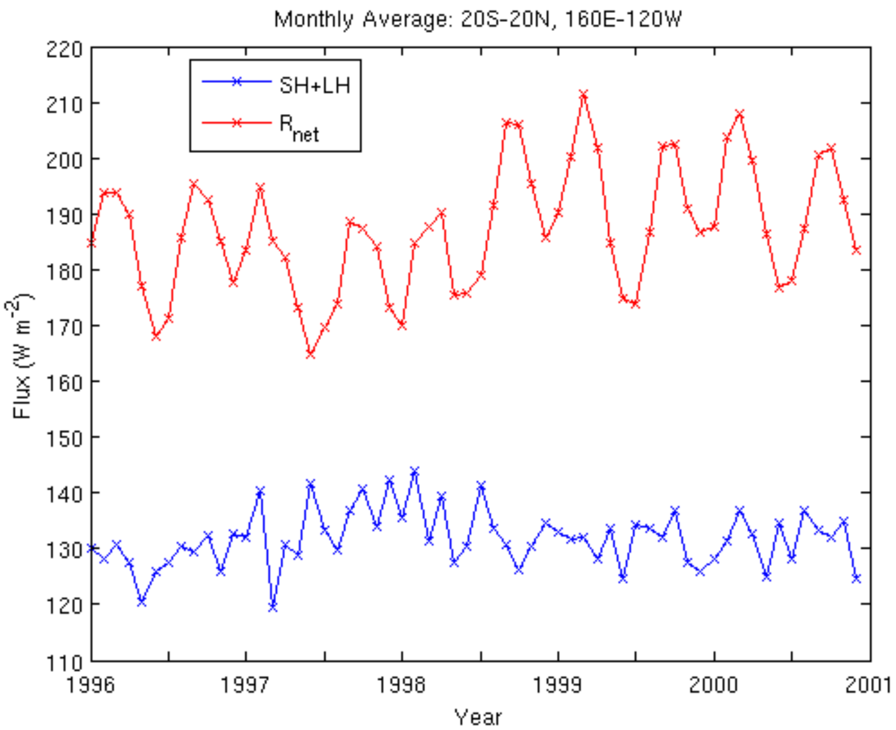
$$\frac{\partial E_s}{\partial t} = G = R_s - \mathrm{LE} - \mathrm{SH} - \Delta F_{\mathrm{eo}}$$

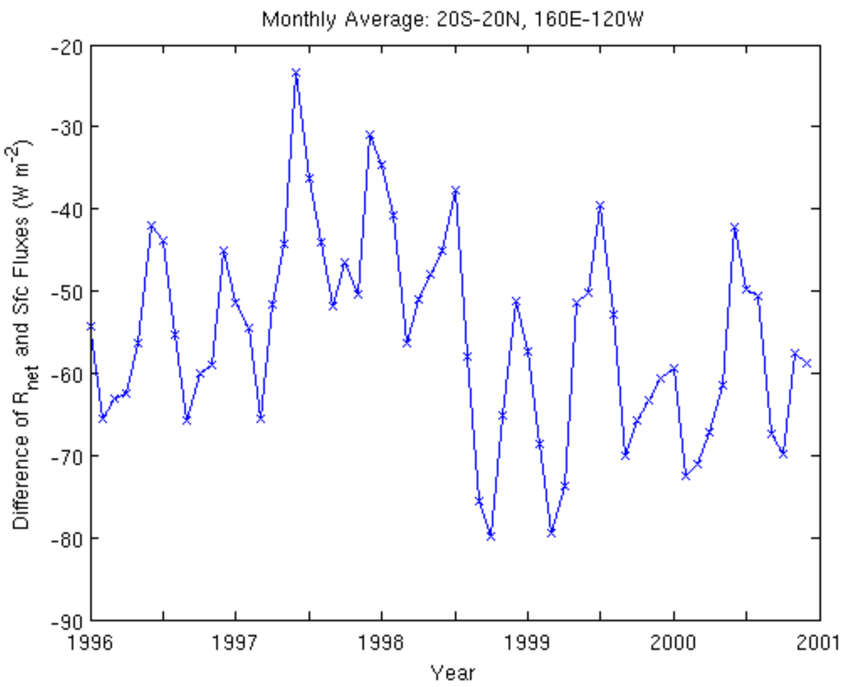
Surface Energy Balance

1°x1° gridded surface flux data

OAFlux project at Woods Hole Oceanographic Institute (Yu and Weller 2007

- Components: LH, SH, net surface radiation





Conclusions

- Microwave and IR techniques have settled into comfortable roles for precipitation estimation.
- All the interesting science questions require us to look at both the clouds and precipitation.
- Higher space time resolved aerosols/radiation/surface flux/clouds and precipitation will ultimately be needed to improve our understanding of feedbacks.