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Satellite Observations of Clouds and Precipitation

Overview 2: Precipitation (and Cloud) Observations

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International Workshop on the Assimilation of Satellite

Precipitation Observations in NWP Models. May 2, 20

Overview

- Next generation retrieval algorithms
- Validation geared at precipitation processes
  - Detailed microphysics in Sea of Japan
- Observations geared at precipitation processes
  - Cumulus Congestus in the tropics
  - Cloud/Aerosol interaction?
  - Climate scale relation between microphysics and TPW

The evolution of the Goddard Profiling (GPROF) algorithm

GPROF is a Bayesian algorithm developed primarily by C. Kummerow and Bill Olson over ocean and R. Ferraro over land but internal code has pieces written by much broader community [e.g. P. Bauer (melting particles), G. Petty (emission indices), Tom Wilheit (Freezing level), Ye Hong (C/S), etc.]

GPROF is evolving with new satellites but is kept backwards compatible.
Currently running GPROF-2004:

SSM/I - Version 7 (in house)
TMI - Version 6 (GSFC DAAC)
AMSR_E - Version B05 (NSIDC)

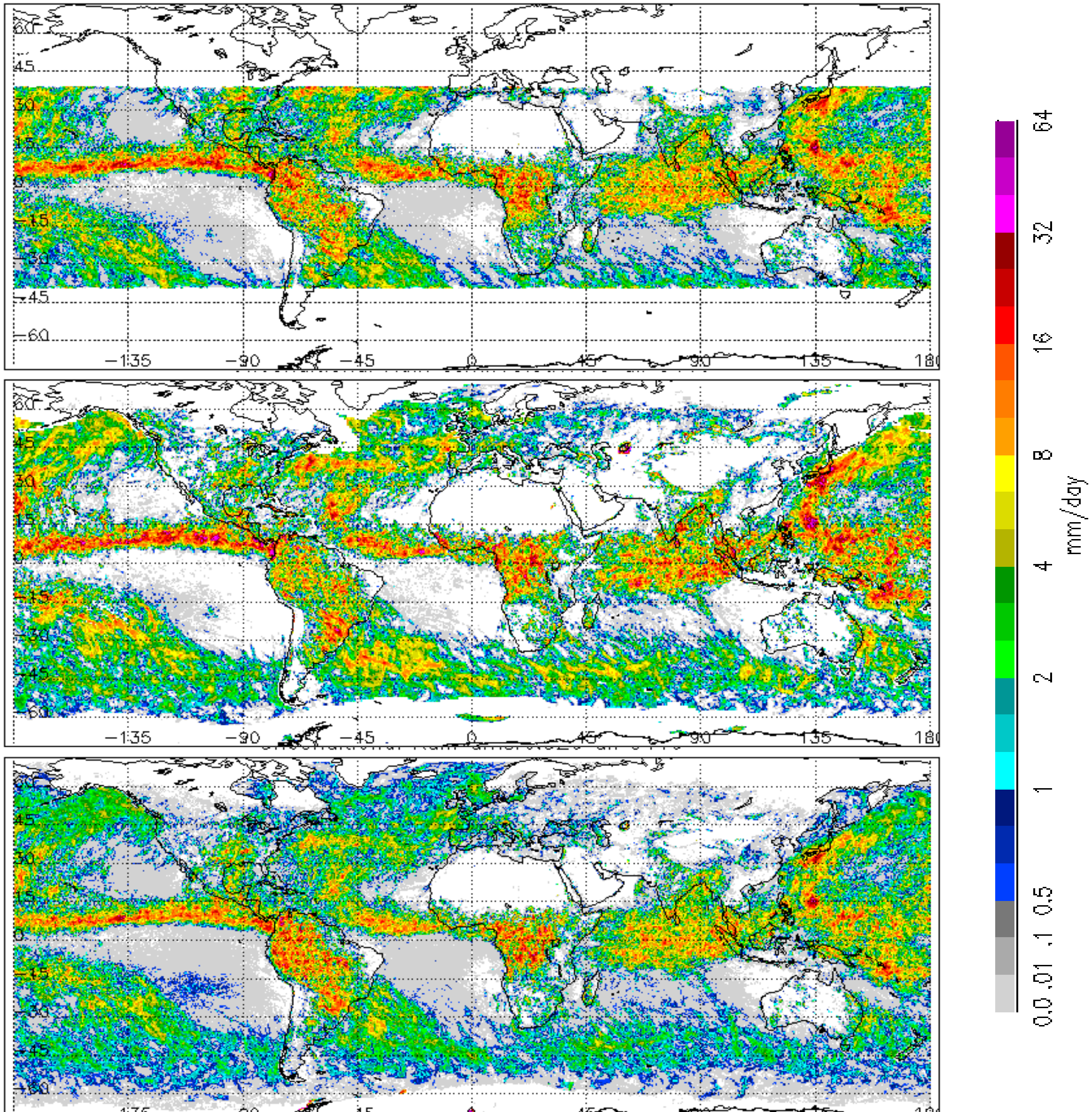
GPROF-2006 is currently under development to significantly improve *a-priori* data bases and make algorithm more parametric in preparation for GPM

Monthly rainfall maps from GPROF-2004

TMI

SSM/I
(F13)

AMSR-E



2.68 mm/d

2. 51mm/d
2.67 mm/d

2.41 mm/d
2.58 mm/d

The need for evolving GPROF

GPROF 2004 uses a relatively small set of pre-computed cloud model simulations for its a-priori database. Its representativeness or ability to capture regime dependent changes has always been questioned. GPROF error model cannot correctly capture uncertainty due to these database issues.

GPROF 2004 uses empirical screening routines developed for various sensors in its rain/no rain discrimination. A more statistical approach is preferable to better represent sensor strengths and weaknesses w/o tuning results to a reference product.

GPROF 2004 uses a semi-empirical method for assigning convective/ stratiform properties to precipitating pixels. A more statistical approach is preferable to better represent c/s and latent heating profiles.

Database refinement: Concept

Bayes's theorem

$$P(\mathbf{R}\,|\,\mathbf{T_b}) \propto P(\mathbf{R}) \times P(\mathbf{T_b}\,|\,\mathbf{R})$$

Prior PDF

Conditional PDF

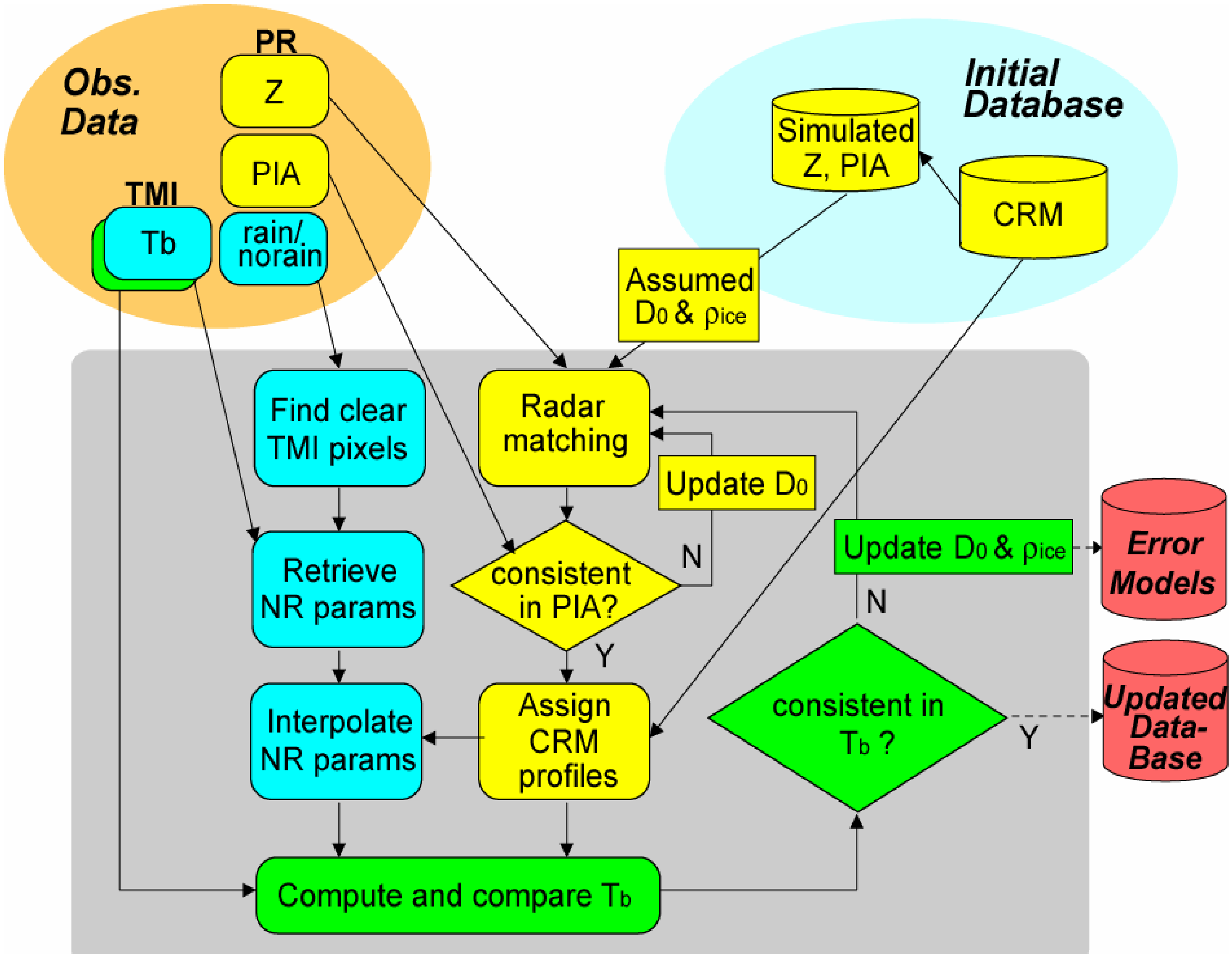
$$P(\mathbf{R}) = P_{\mathbf{R}\neq\mathbf{0}} \times \frac{P(\mathbf{R})}{P_{\mathbf{R}\neq\mathbf{0}}}$$

Rain probability

A priori database

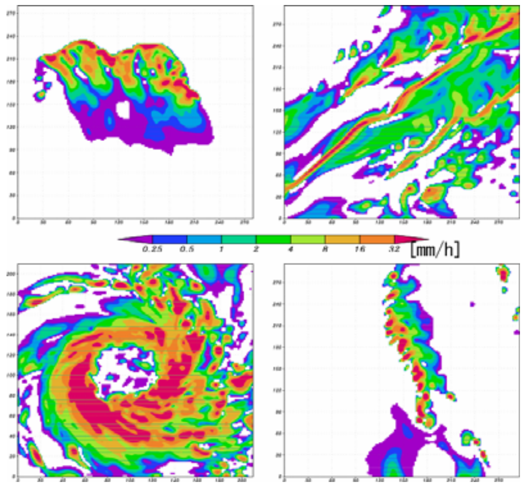
∴ Adequate modeling of the *a priori* database and rain probability is crucial for realistic estimation of $P(R)$.

Database refinement: Flowchart



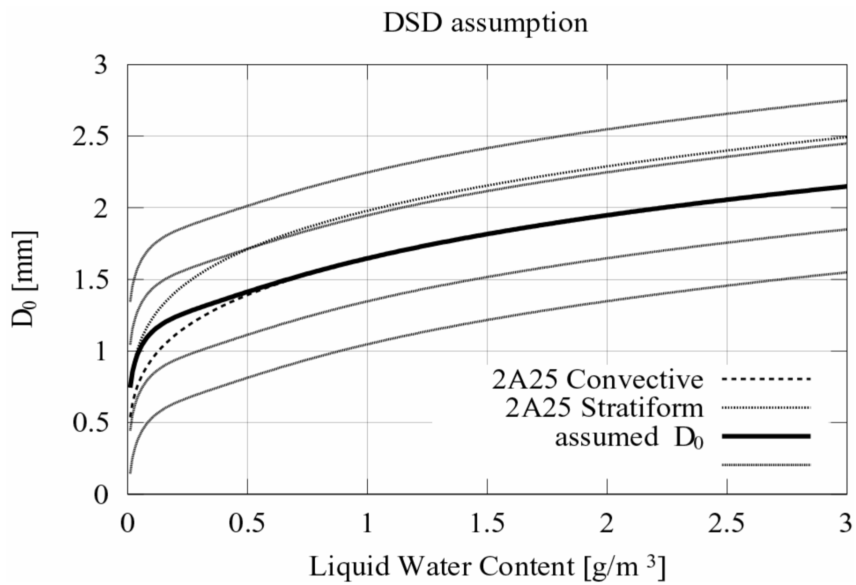
Initial CRM database

- Cloud-Resolving Model (CRM) database
  - *A priori* database for the current GPROF algorithm.
  - Using Goddard Cumulus Ensemble Model (GCE) and UW-Nonhydrostatic Modeling System.
  - About 30 snapshots from different simulations
    - Tropical convection & squall line
    - Hurricane
    - Mid Atlantic cold/warm frontal rain
    - Extra-tropical cyclone
    - …
  - 20,000+ pixels for each snapshot



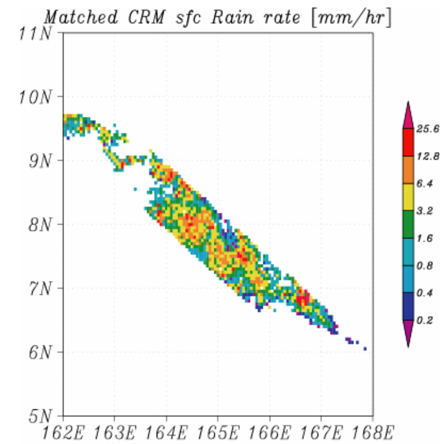
Raining parameters

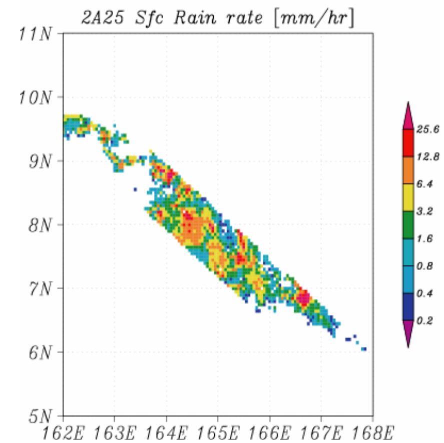
- DSD assumption
  - The initial assumption is same as adopted by the PR operational (2A25) algorithm.
  - Allow D_0 (median volume diameter) to change +/- 0.3 and +/- 0.6 mm from initial value when adjusting DSD.
  - Number of D_0 assumptions will be increased in the future and changed to ratio of original value.
- Ice density assumption
  - The initial assumption is same as adopted by the PR operational (2A25) algorithm.
  - Allow snow/grauple density to change +/- 20% and +/- 40% from initial value when adjusting DSD.



Raining parameters

- PR retrieval
  - Find the best-fit CRM profile in the radar reflectivity (Z) space.
- PIA adjustment
  - Parallel to the 2A25 algorithm.
  - Path-integrated attenuation (PIA) is used when reliable.
  - The best solution is sought under the constraint of PIA by varying the DSD model.

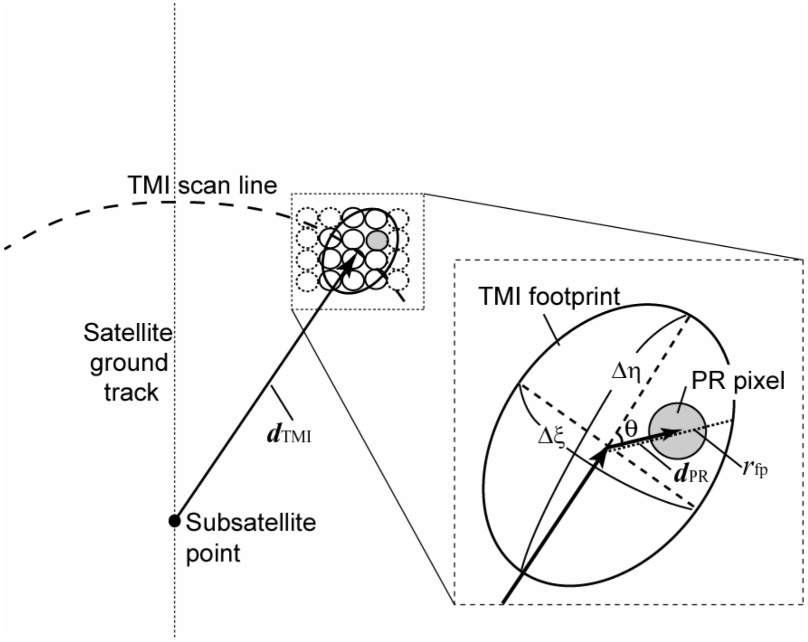




Identifying rain-free TMI FOVs

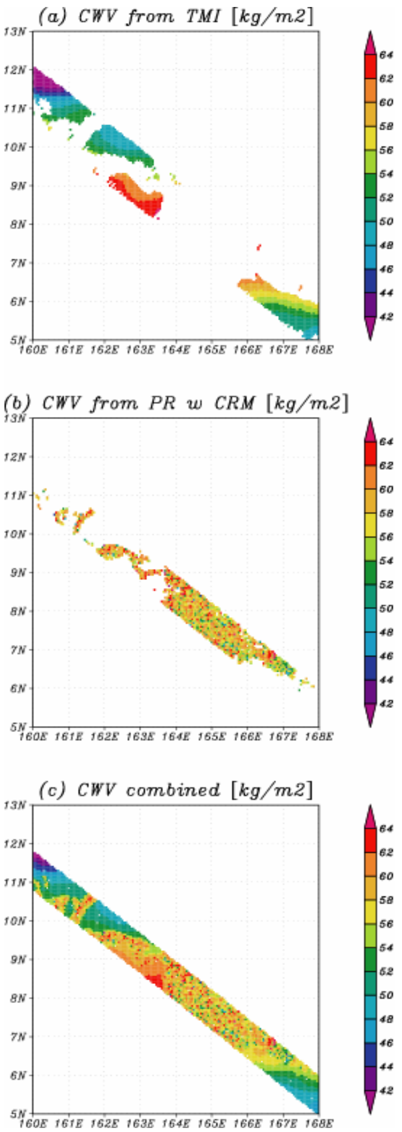
– Find PR pixels located within a given TMI 19-GHz FOV.

– If none of these PR pixels contains a rainfall signal, the TMI footprint is defined as "rain free".



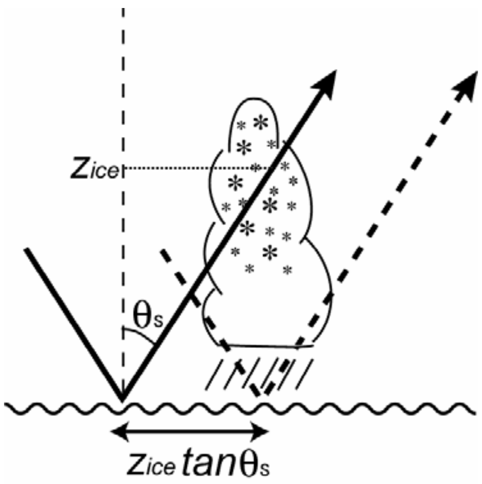
Non raining parameters

- Retrieve non raining parameters (water vapor, surface wind, cloud water, and SST) for rain-free TMI footprints.
- The Remote Sensing Systems datasets are currently used but will be replaced by an online algorithm in the future.
- WV and CLW are also derived for raining PR pixels from PR-matched CRM profiles.
- The complete fields of the non-raining parameters are obtained by spatial interpolation.



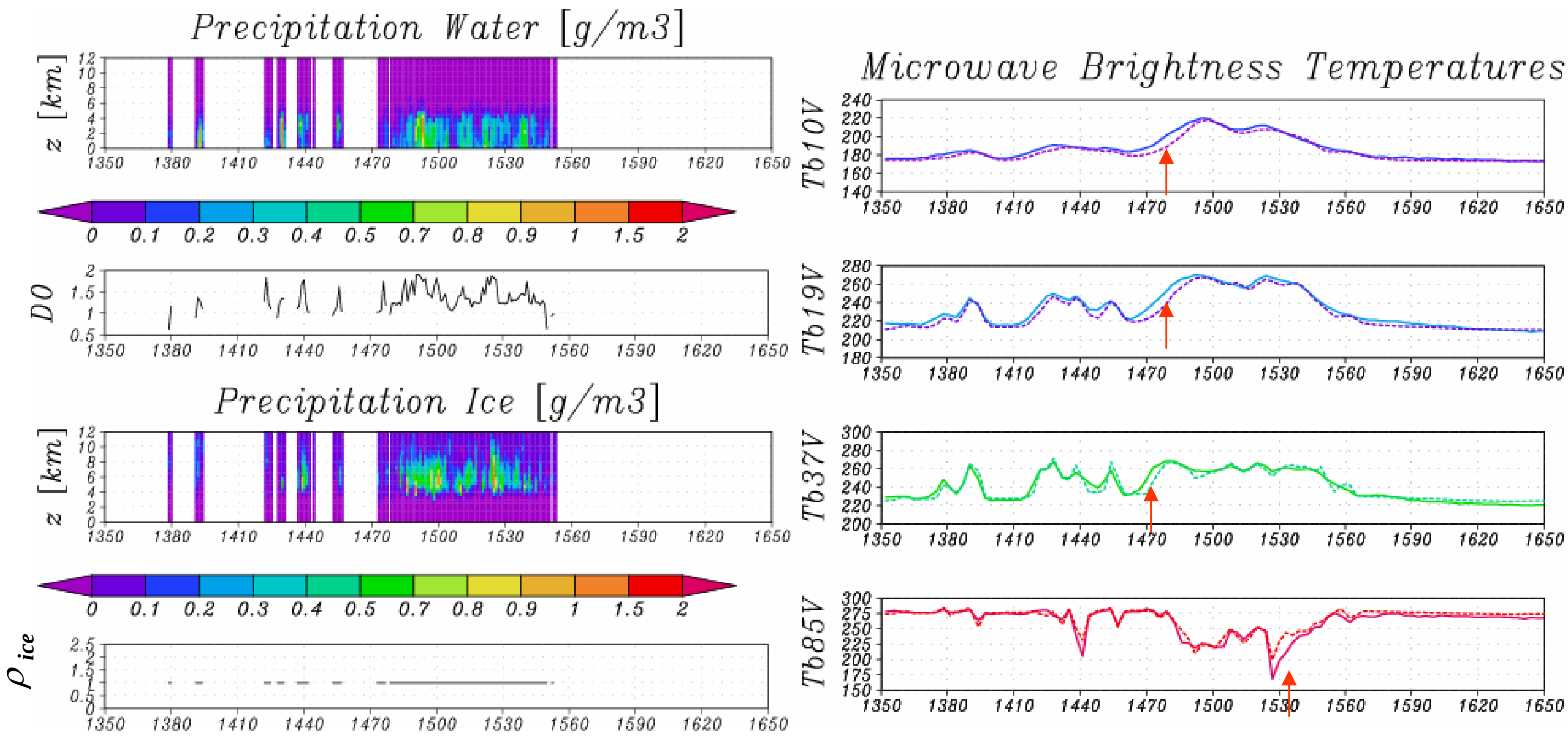
Tb computations

- Compute brightness temperatures
  - The 3-D structure of all the raining and nonraining parameters are now available.
  - Microwave brightness temperature is computed for comparison with TMI measurements.
  - A slant TMI sight line intersecting neighboring columns is taken into account.
  - Beam convolution is applied with a 2-D Gaussian beam pattern.



Tb computations

– PR-retrieved precipitation profiles exhibit bias in the computed Tb with the initial assumptions.

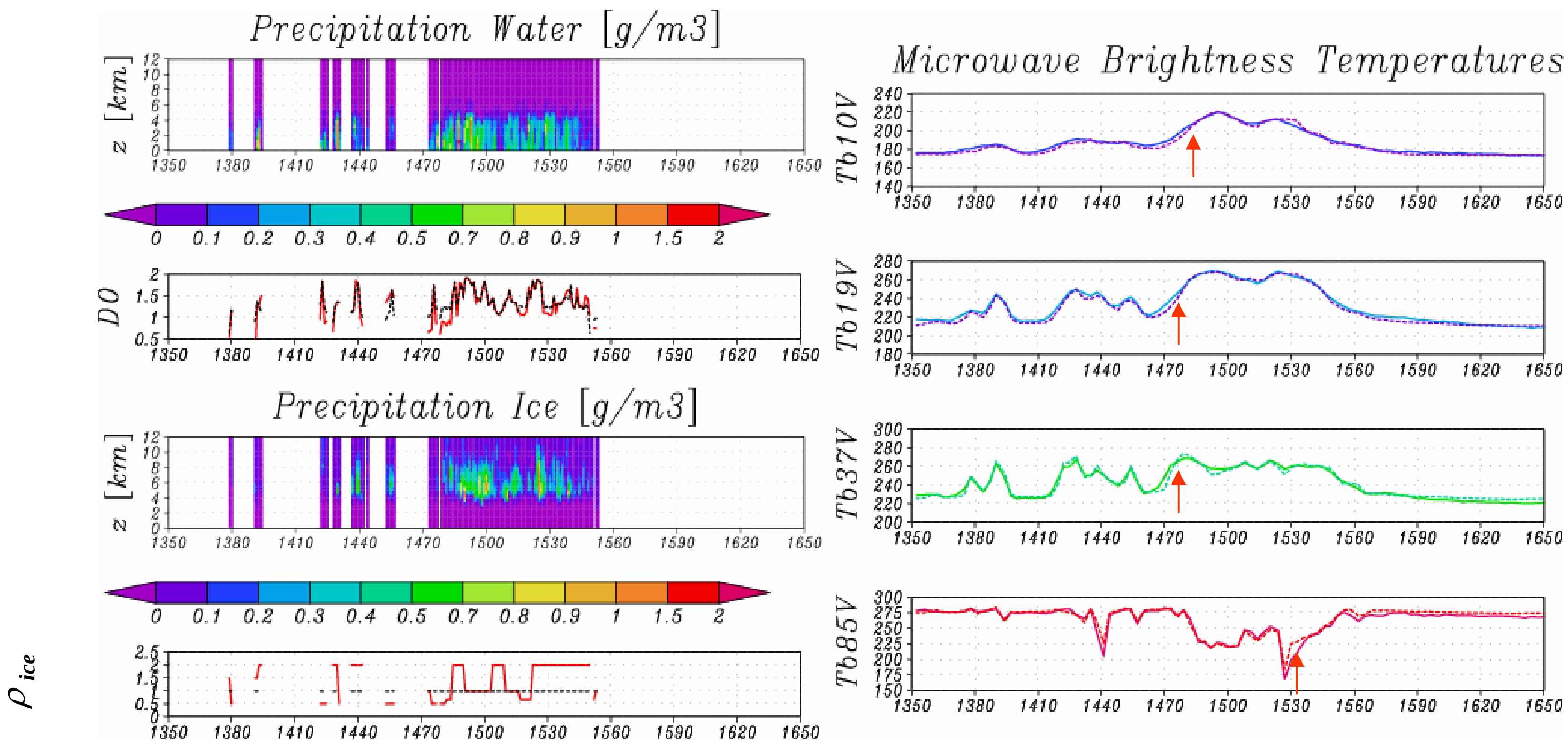


Updating assumptions

- Discrepancy in brightness temperatures
  - A larger (smaller) D_0 results in a colder (warmer) *Tb* in the emission channels through the underestimation (overestimation) of rain water.
  - A higher (lower) ice-particle density (or fluffiness) results in a colder (warmer) Tb in the scattering channels.
- Adjustment of DSD and ice-density models
  - Modify D_0 and ρ_{ice} (relative factor multiplied to the original ice-density model) and iterate the retrieval.
  - D_0 derived from the radar itself via PIA will be set back to the radar derived value. Flow diagram

Updating assumptions

– DSD and ice-density models are adjusted so that the bias in Tb is minimized.



Organizing the new database

- Rain probability

$$P(\mathbf{R}) = P_{\mathbf{R}\neq\mathbf{0}} \times \frac{P(\mathbf{R})}{P_{\mathbf{R}\neq\mathbf{0}}}$$

Rain probability

A priori database

– Rain/No rain discrimination must be replaced by statistical probability (determined from PR in a-priori database). Otherwise end up with physical inconsistency or different rain areas dcepending upon sensor.

– Convective/stratiform will be organized in similar manner. Texture and polarization difference will be used to assign probability of each.

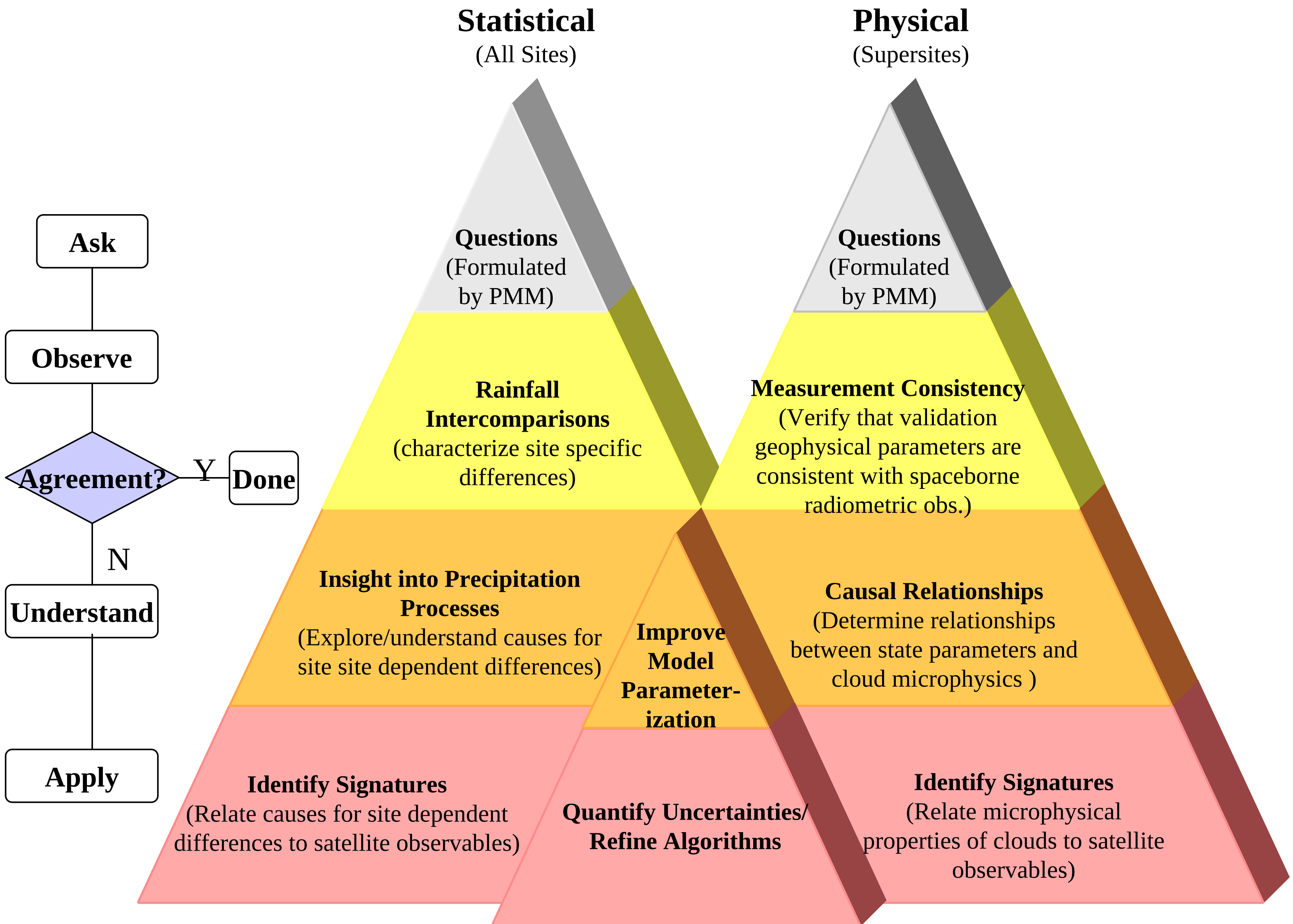
Physical Validation

- How do we know that D_0 and ρ_{ice} are the correct parameters to adjust?

-GPM Validation efforts

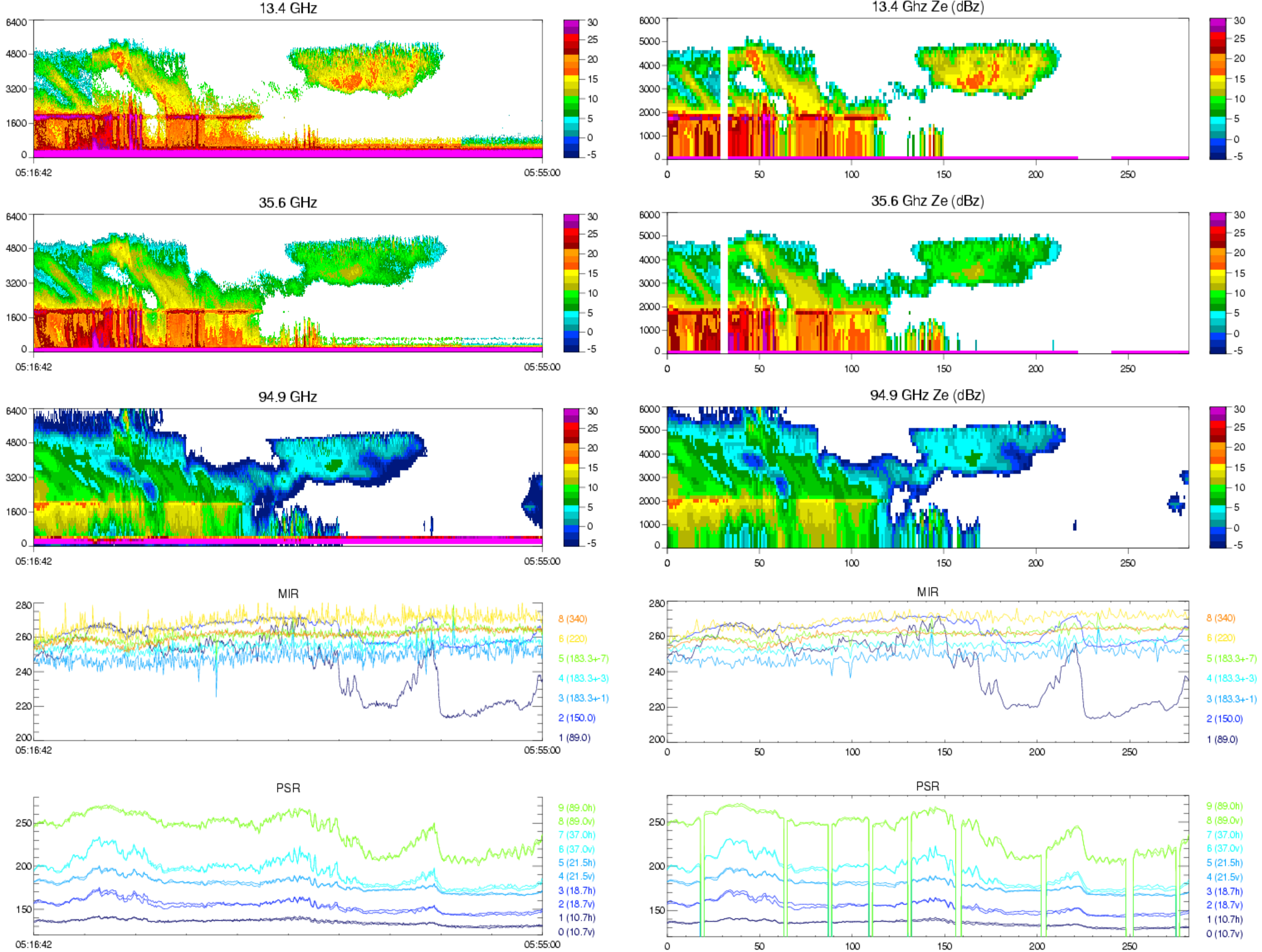
-Wakasa Bay experiment

A GPM Validation Concept

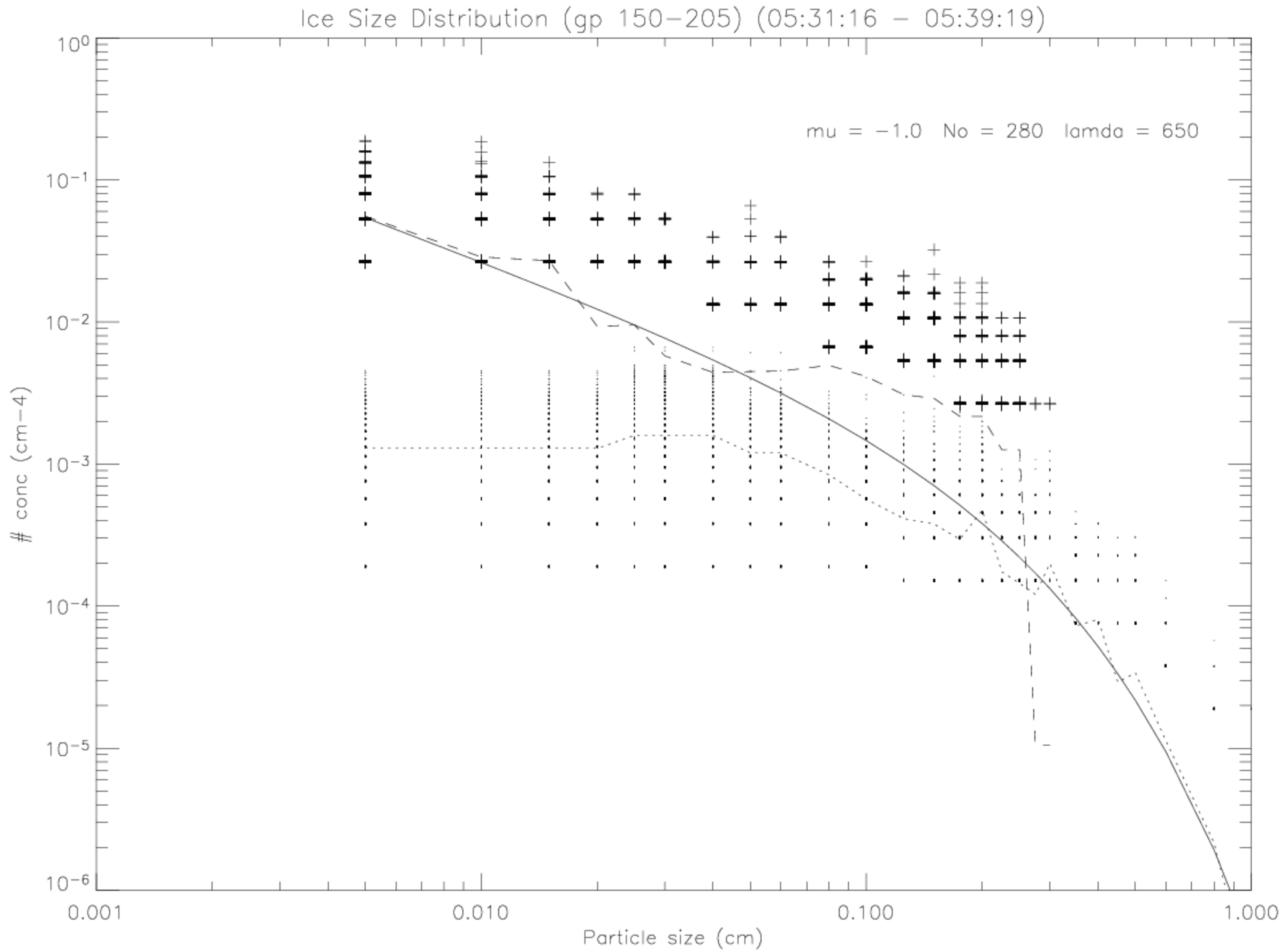


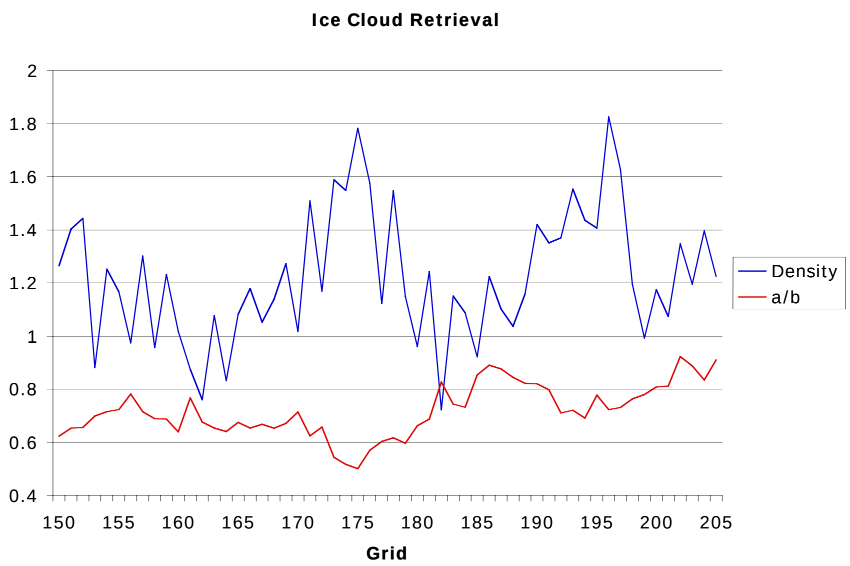
Wakasa Bay Experiments

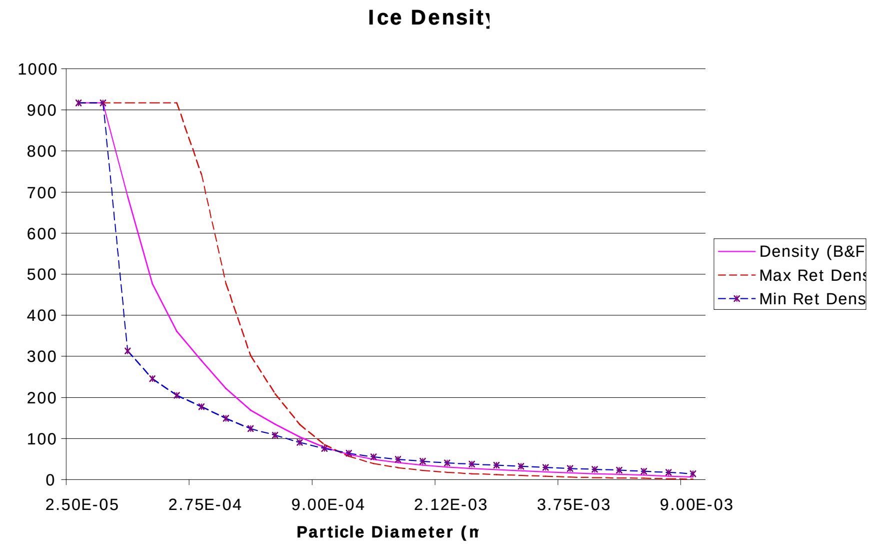
- Remote sensing retrievals often have more unknowns than observations
  - Requires assumptions to solve: ice - density, particle shape, PSD
- In Wakasa Bay - we simply measured everything we could.
  - Ku, Ka and W band radars (3 total)
  - MIR (89 - 340 GHz)
  - PSR (10.7 - 89 GHz)
- Optimal estimation retrieval - incorporates multiple observations
  - Can use radiometer, radar and in-situ
  - Reduces number of assumptions - reduces uncertainty in retrieval
  - Enforces physical consistency through radiative transfer model
- Retrieving ice cloud PSD
  - Uses 3 radars and in-situ cloud probe data to find ice particle characteristics - shape/density
  - Uses 3 radars and 11 radiometer frequencies to retrieve ice particle PSD (normalized gamma distribution)

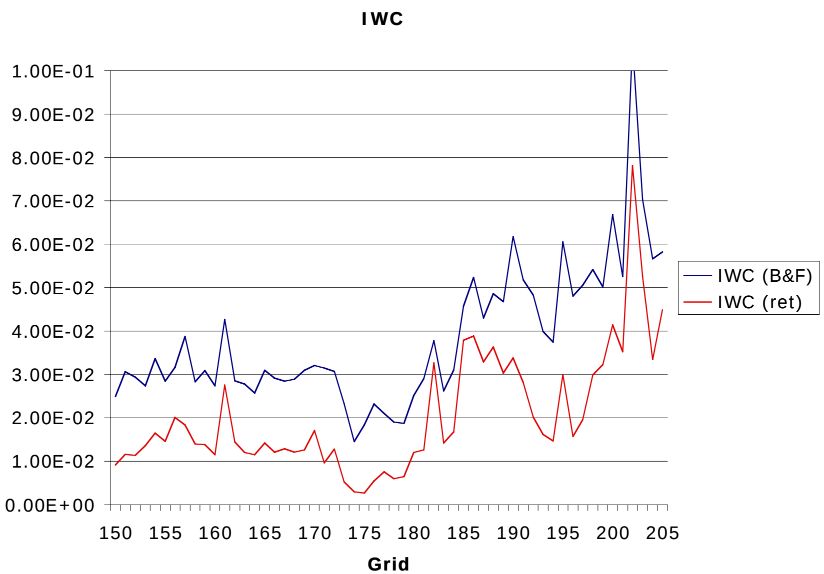

13.4 GHz
13.4 Ghz Ze (dBz)
35.6 GHz
35.6 Ghz Ze (dBz)
94.9 GHz
94.9 GHz Ze (dBz)
05:16:42
05:55:00
MIR
8 (340)
6 (220)
5 (183.3+-7)
4 (183.3+-3)
3 (183.3+-1)
2 (150.0)
1 (89.0)
PSR
9 (89.0h)
8 (89.0v)
7 (37.0h)
6 (37.0v)
5 (21.5h)
4 (21.5v)
3 (18.7h)
2 (18.7v)
1 (10.7h)
0 (10.7v)

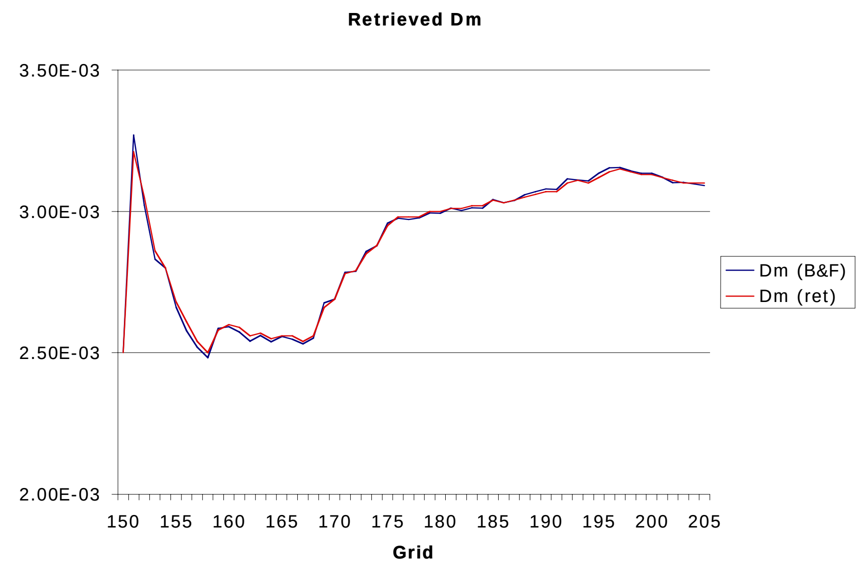
In-situ observations of ice DSD




Ice Cloud Retrieval
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
150 155 160 165 170 175 180 185 190 195 200 205
Grid
Density
a/b


Ice Density
1000
900
800
700
600
500
400
300
200
100
0
2.50E-05 2.75E-04 9.00E-04 2.12E-03 3.75E-03 9.00E-03
Particle Diameter (m
Density (B&F
Max Ret Dens
Min Ret Dens


IWC
1.00E-01
9.00E-02
8.00E-02
7.00E-02
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
150 155 160 165 170 175 180 185 190 195 200 205
Grid
IWC (B&F)
IWC (ret)


Retrieved Dm
3.50E-03
3.00E-03
2.50E-03
2.00E-03
150 155 160 165 170 175 180 185 190 195 200 205
Grid
Dm (B&F)
Dm (ret)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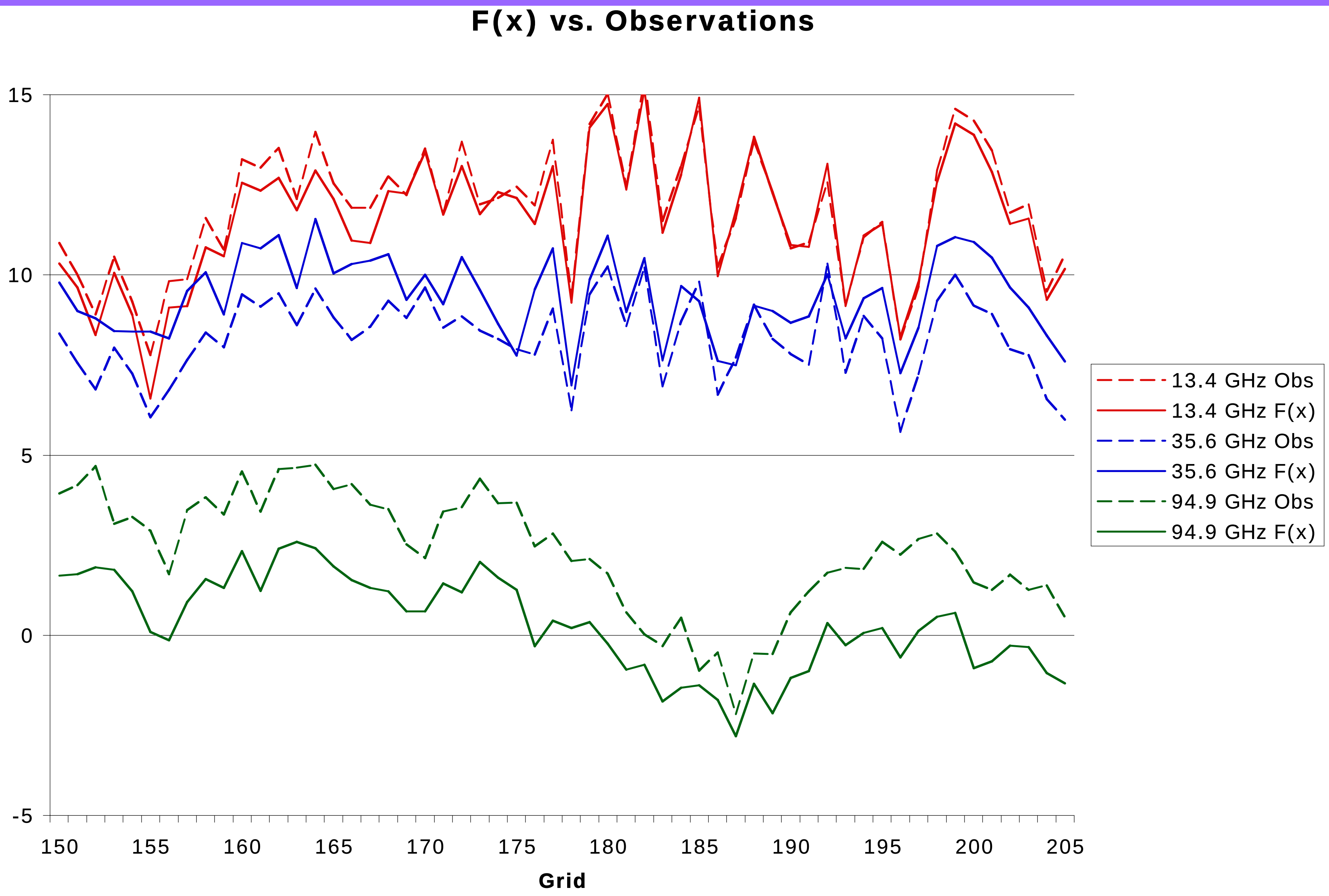

F(x) vs. Observations
15
10
5
0
-5
150
155
160
165
170
175
180
185
190
195
200
205
Grid
13.4 GHz Obs
13.4 GHz F(x)
35.6 GHz Obs
35.6 GHz F(x)
94.9 GHz Obs
94.9 GHz F(x)

Process Studies

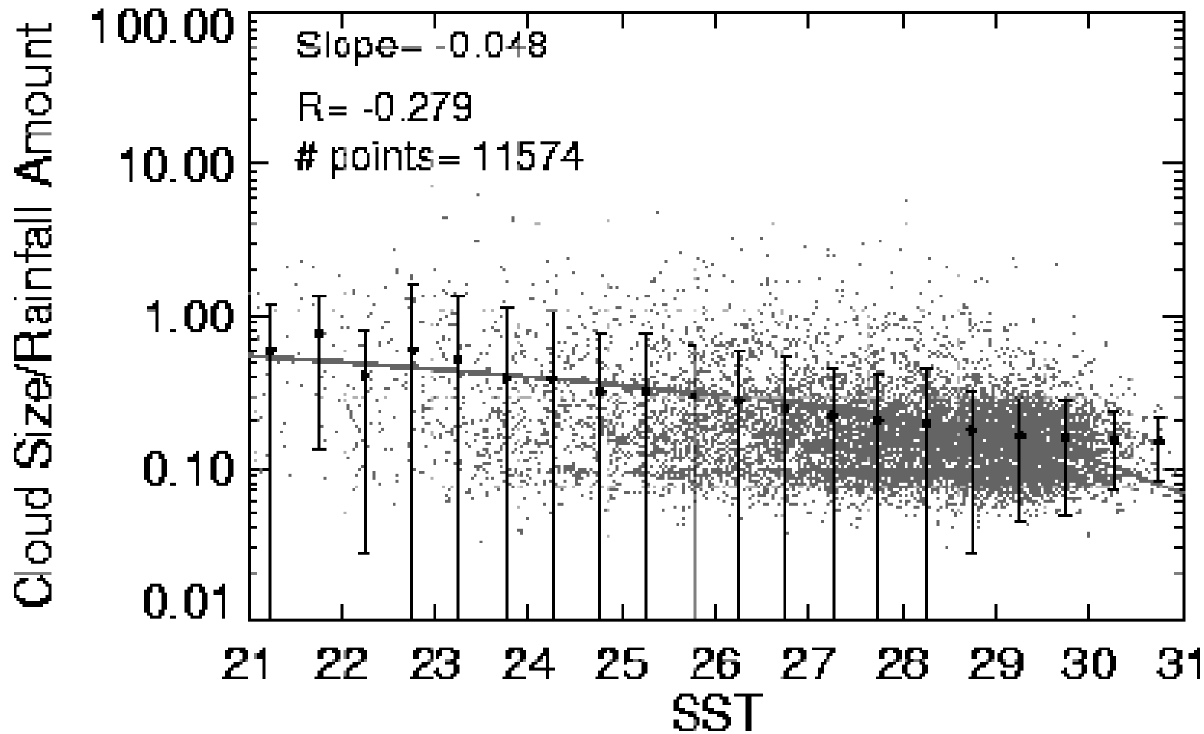
What are we learning from detailed comparisons between products?

- -The role of SST in determining Cloud/latent heat relations in the tropics
- -The correlation of TPW with relative errors between TRMM PR and TMI rain estimates
- - Aerosol impact on precipitation processes?

- Individual cloud areas identified with VIRS IR T_b < 280 K for Jan. 1998 - Feb. 2000
- Convective cores within each cloud are defined by a contiguous area of 10 mm/hr or greater PR rain rate
- Single-core cloud size is normalized by the rainfall amount and regressed against the underlying NCEP Reynolds SST (similar to Lindzen et al. 2001) as a proxy for the change in precipitation efficiency with SST
- Deep convection showed little sensitivity to the underlying SST
- Single-core warm clouds show a marked response to SST

Rainfall efficiency

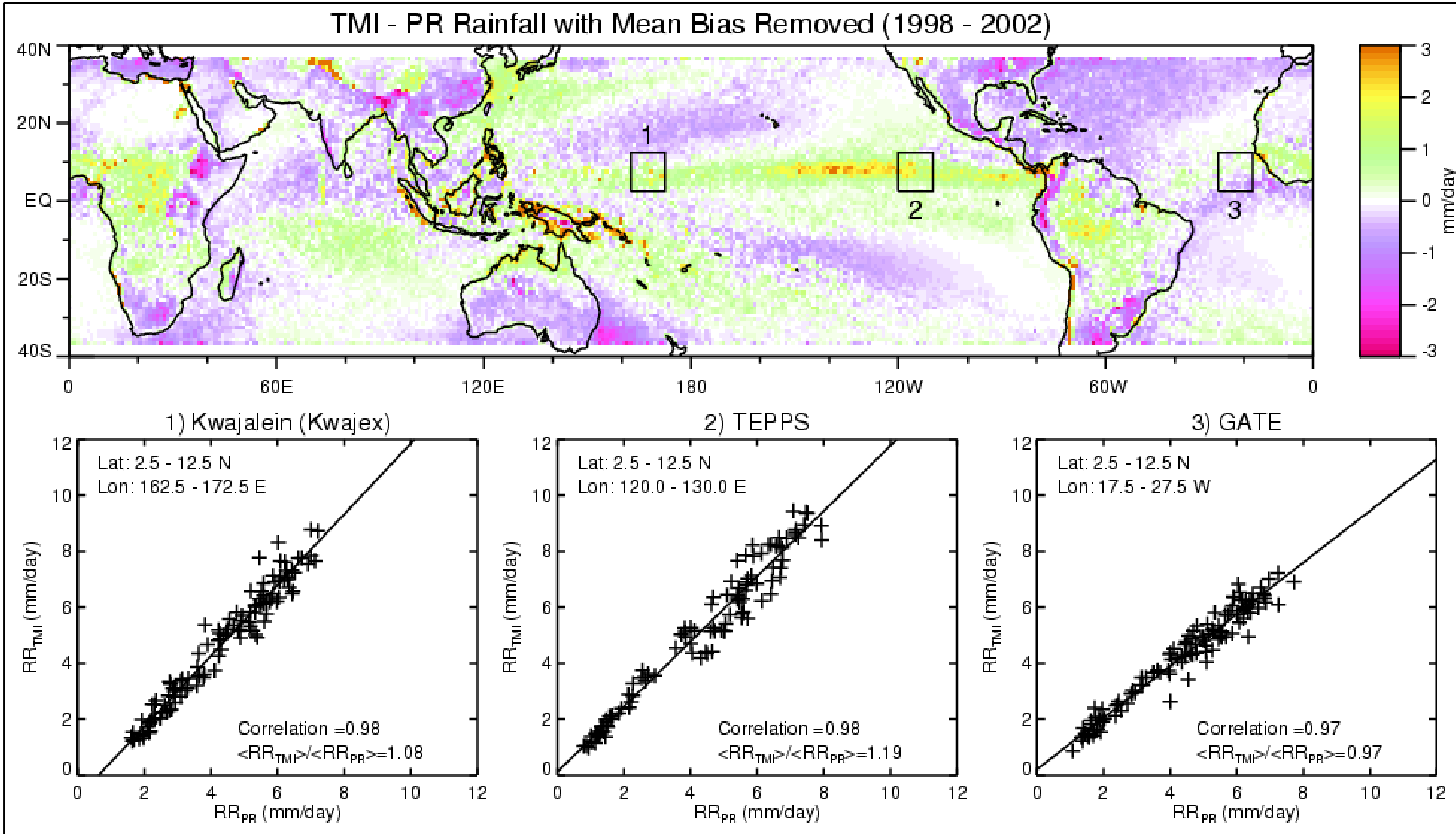
Implies that precipitation efficiency of warm rain systems is sensitive to the underlying SST and agrees with similar findings by Lau et. al (2003) of a 5-10% increase in rainfall efficiency per degree SST



Trend suggests that the increase in precipitation is at the expense of cloud area. This has implications for not only total tropical rainfall and the radiation budget, but also for the lower- and middle-tropospheric moistening and the pre-conditioning period for deep convection.

PR/TMI Rainfall Differences

(5-year mean PR-2A25 - TMI-2A12 from 3G68)



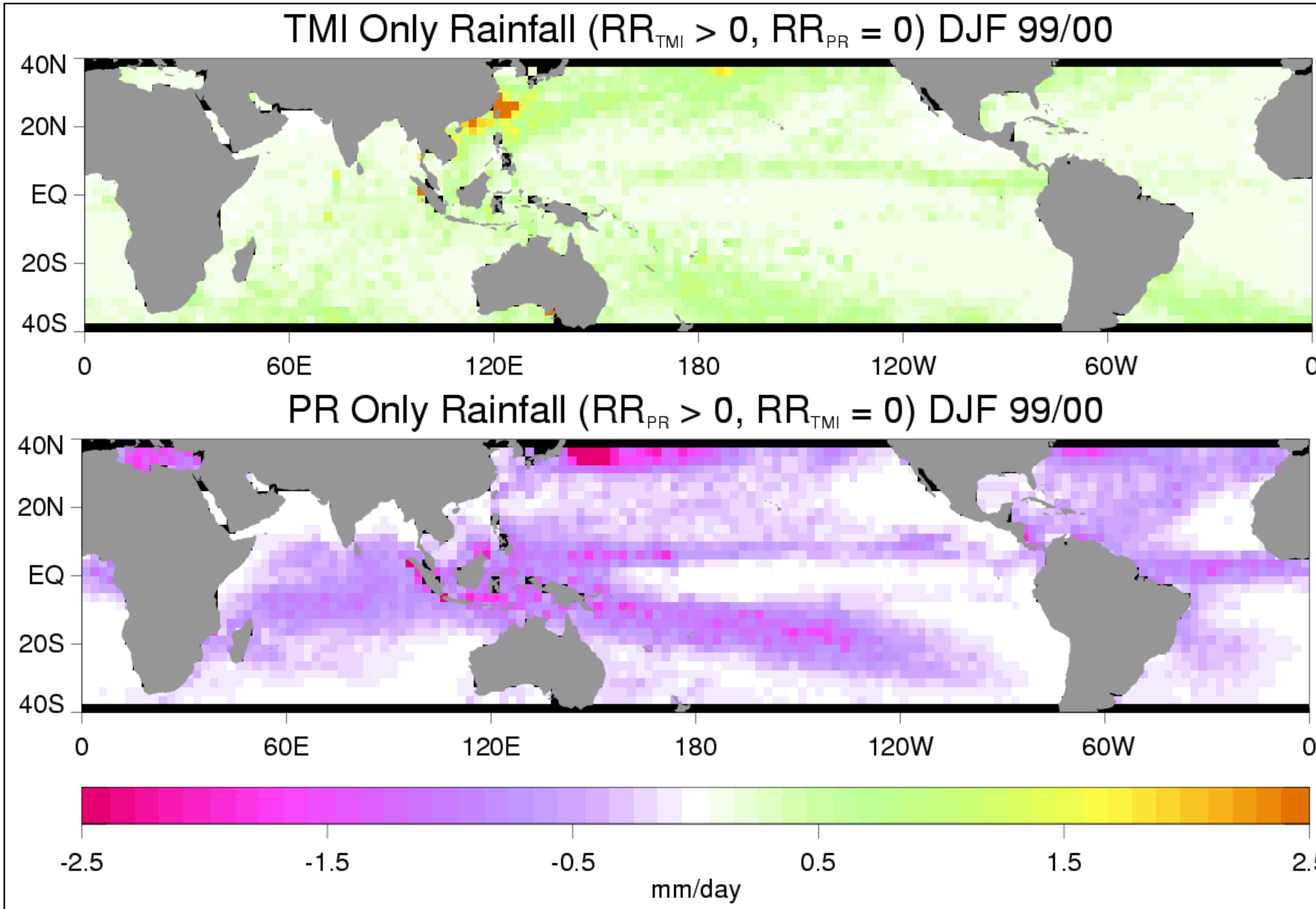
Rainfall Detection vs. Intensity

Breaking it into 3 Problems

- Rainfall Detection
  1. TMI Only ($RR_{TMI} > 0$, $RR_{PR} = 0$)
  2. PR Only ($RR_{PR} > 0$, $RR_{TMI} = 0$)

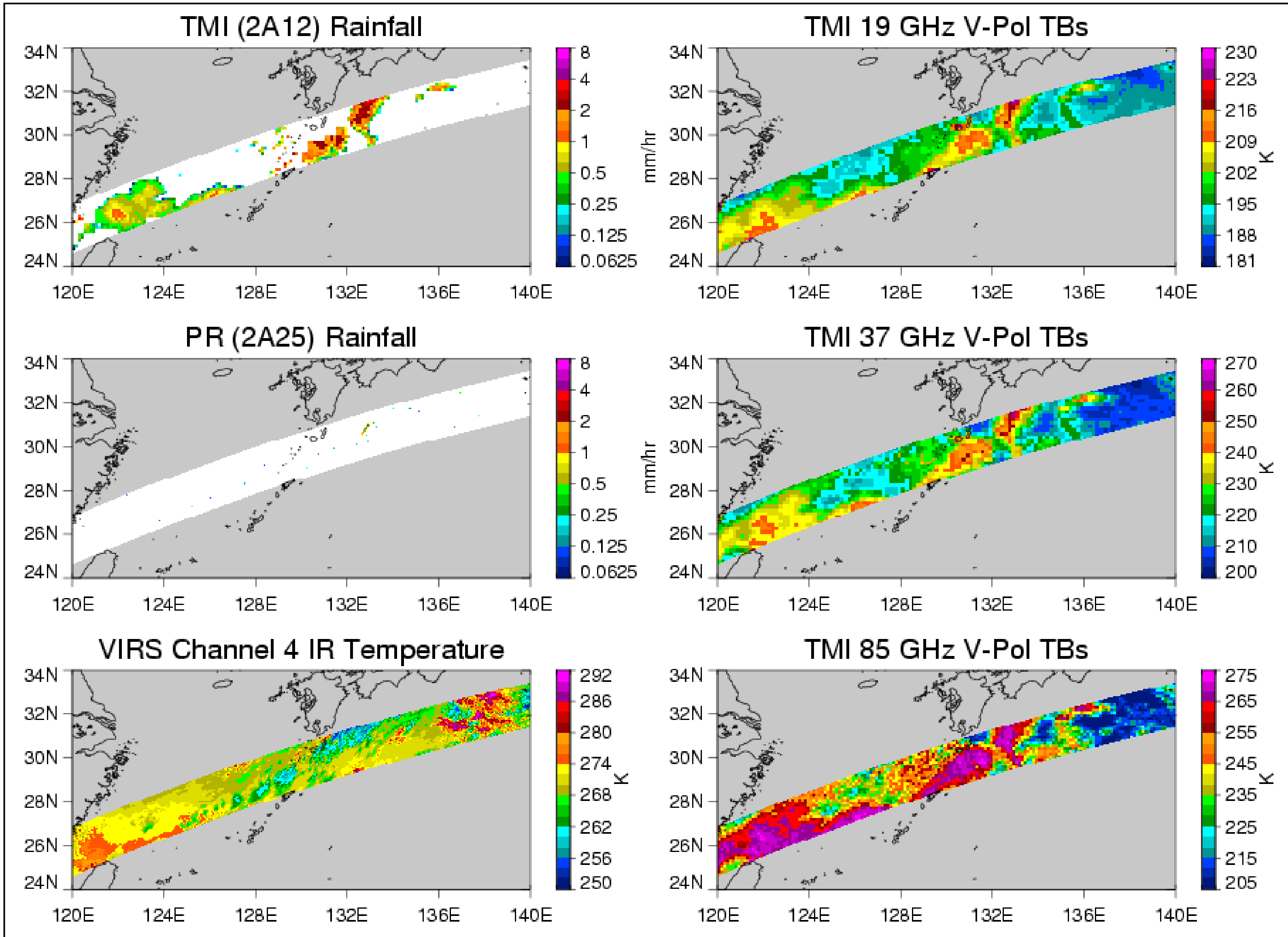
- Rainfall Intensity
  3. Differences in rain amount ($RR_{TMI} > 0$, $RR_{PR} > 0$)

Rainfall Detection Errors



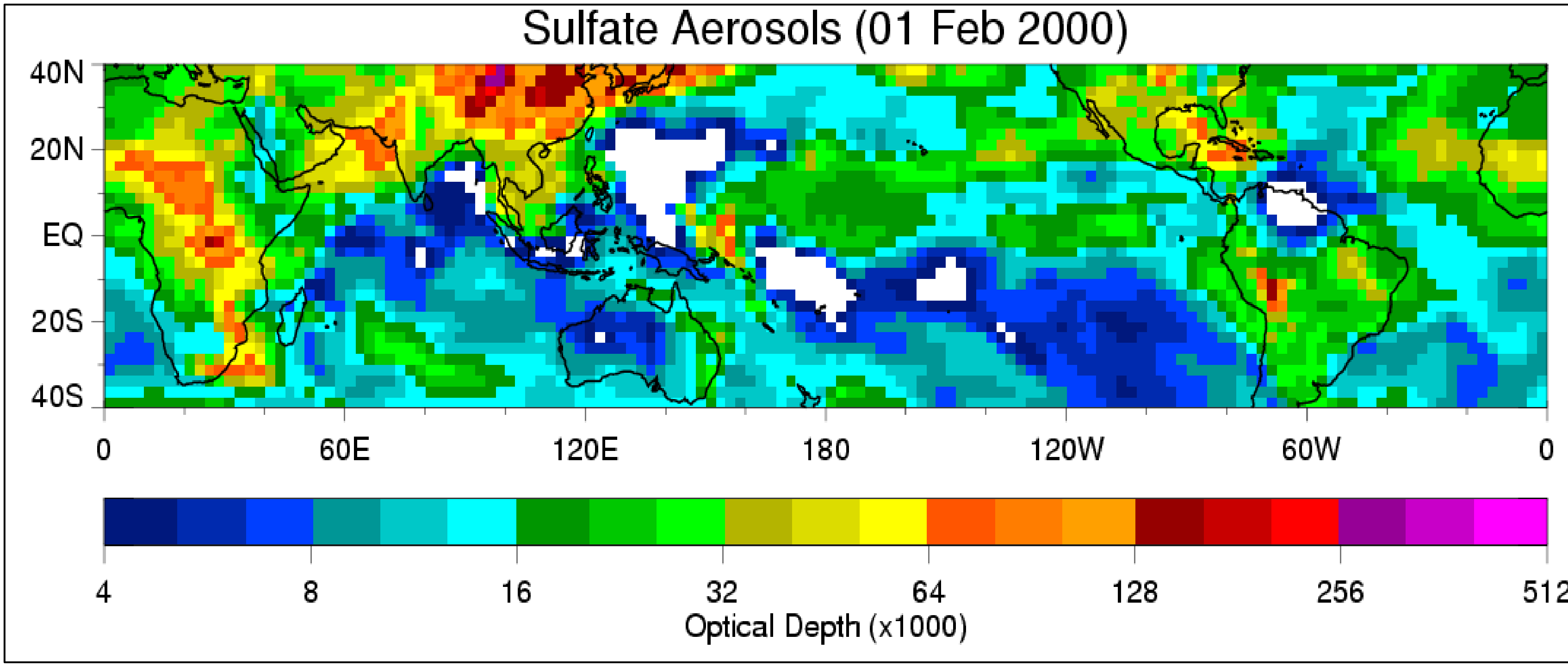
Rainfall Detection Error

February 1, 2000



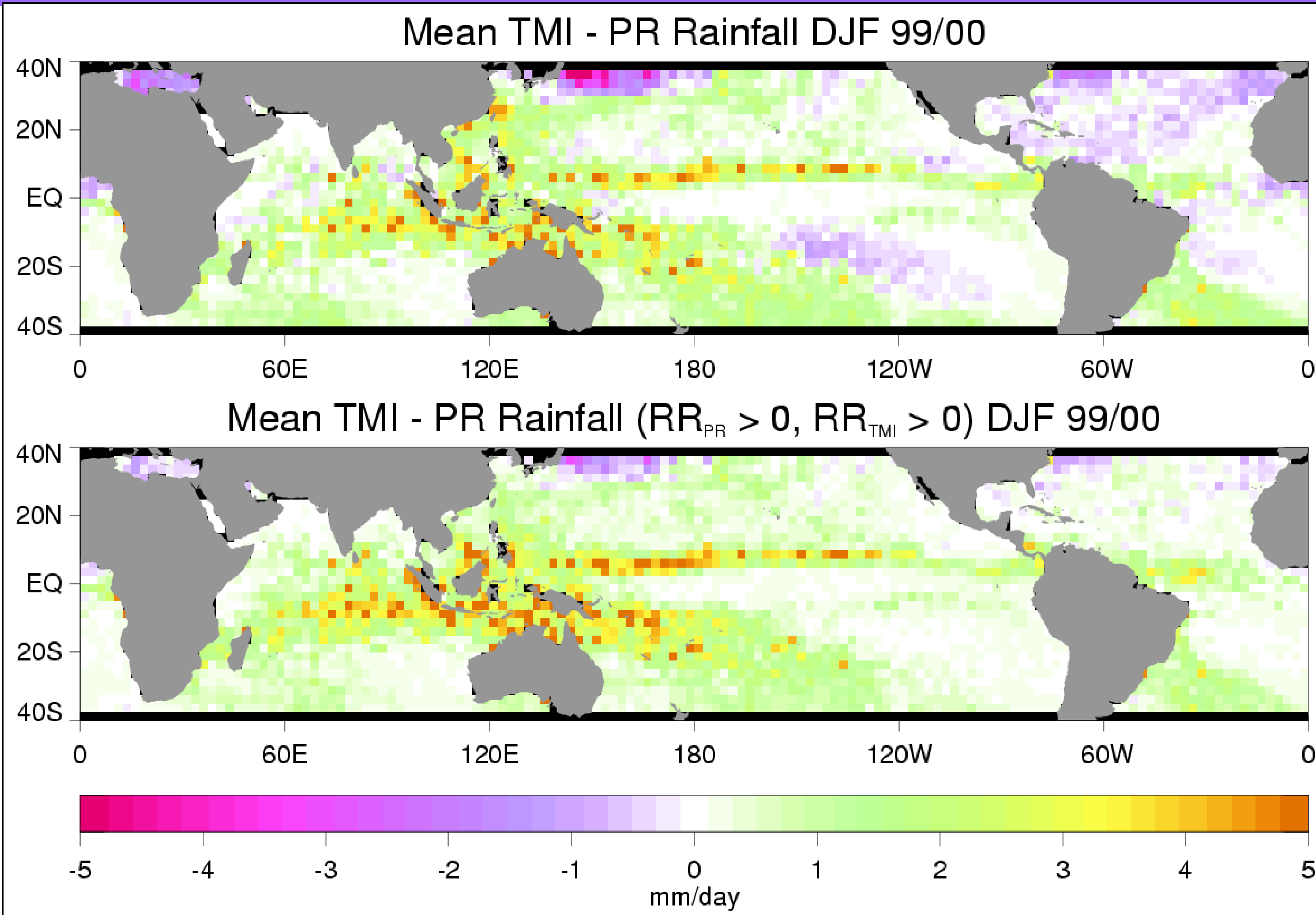
Role of Aerosols?

Impact on Drop Size



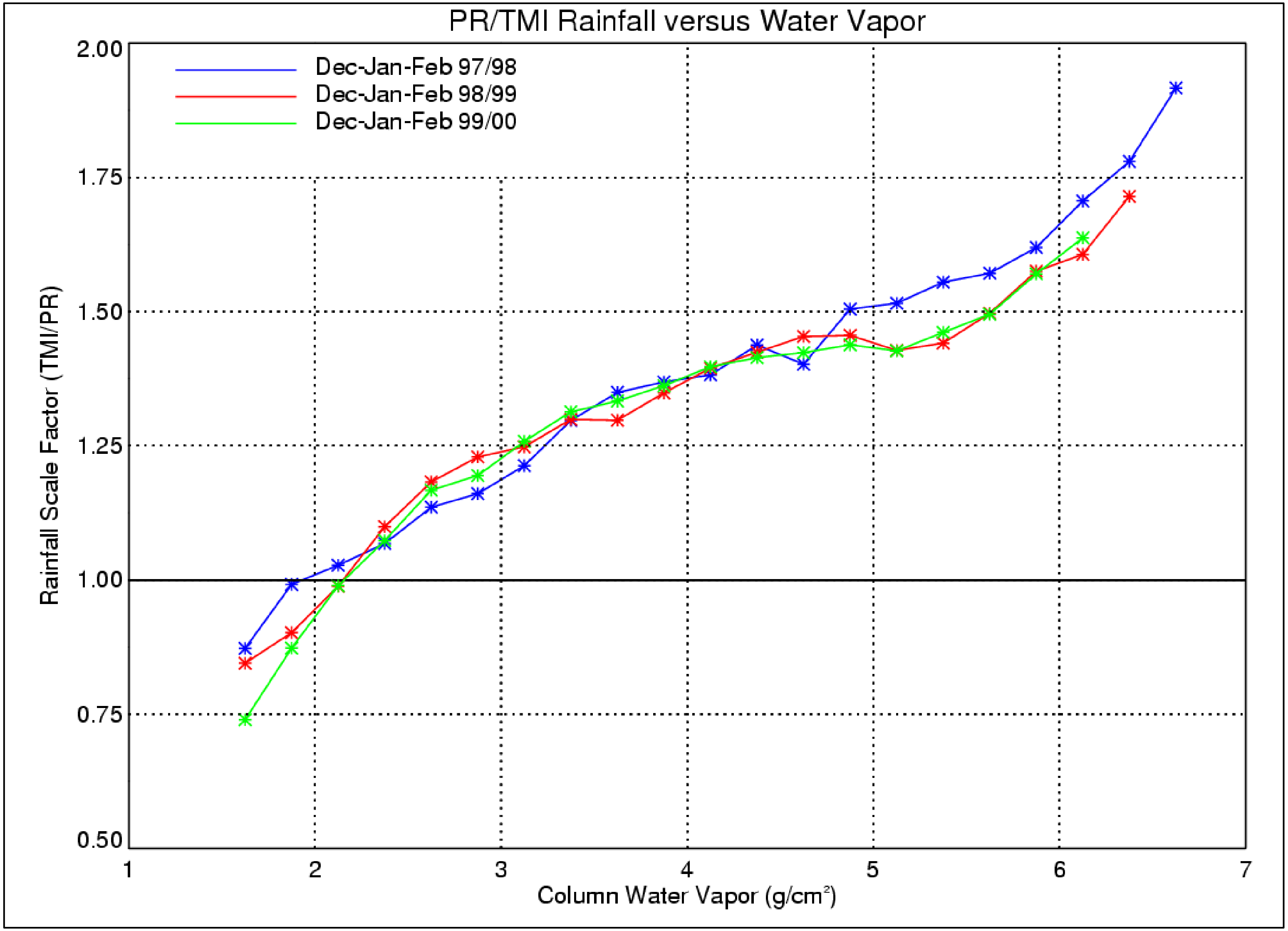
Rainfall Detection Errors

Impact on TMI/PR Differences



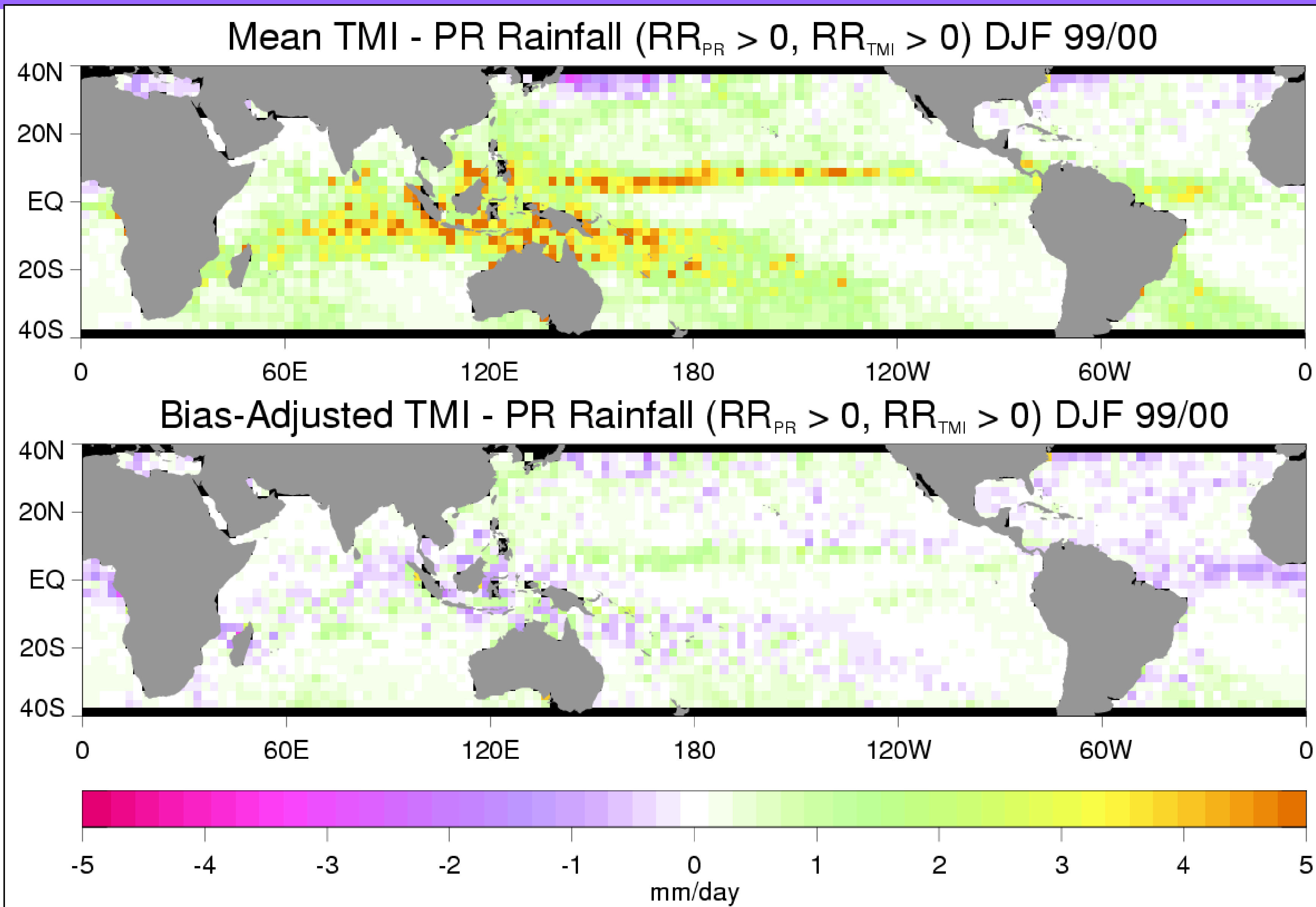
PR/TMI Rainfall Differences

as a Function of Column Water Vapor



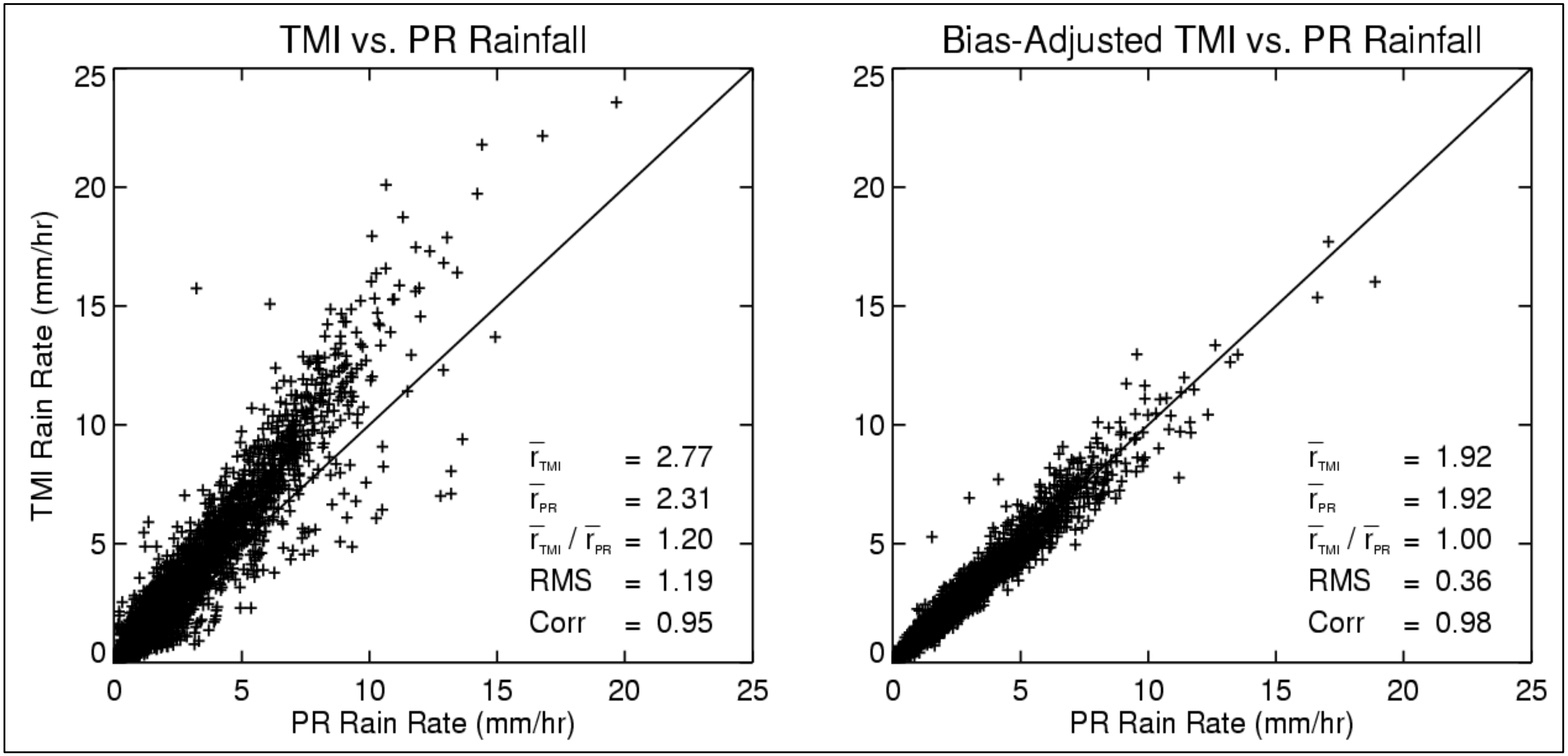
Rainfall Bias Removal

Based on Column Water Vapor



PR/TMI Rainfall Differences

Impact of Column Water Vapor Bias Adjustment



Summary

Better rainfall products are being developed for window channel radiometers in preparation for GPM

Microwave sounders not at same level of maturity

Validation efforts being designed for GPM can have impact on data assimilation if designed with assimilation in mind

Process studies are an emerging discipline. Will need closer ties with modeling community to bear fruit.

Applications for GPM is considering the merger of all rainfall products into a single framework. Something to think about …..