Cloud and Precipitation Retrievals from TRMM and GPM satellites – The Impact of A-priori Information

Christian Kummerow
Colorado State University

JCSDA
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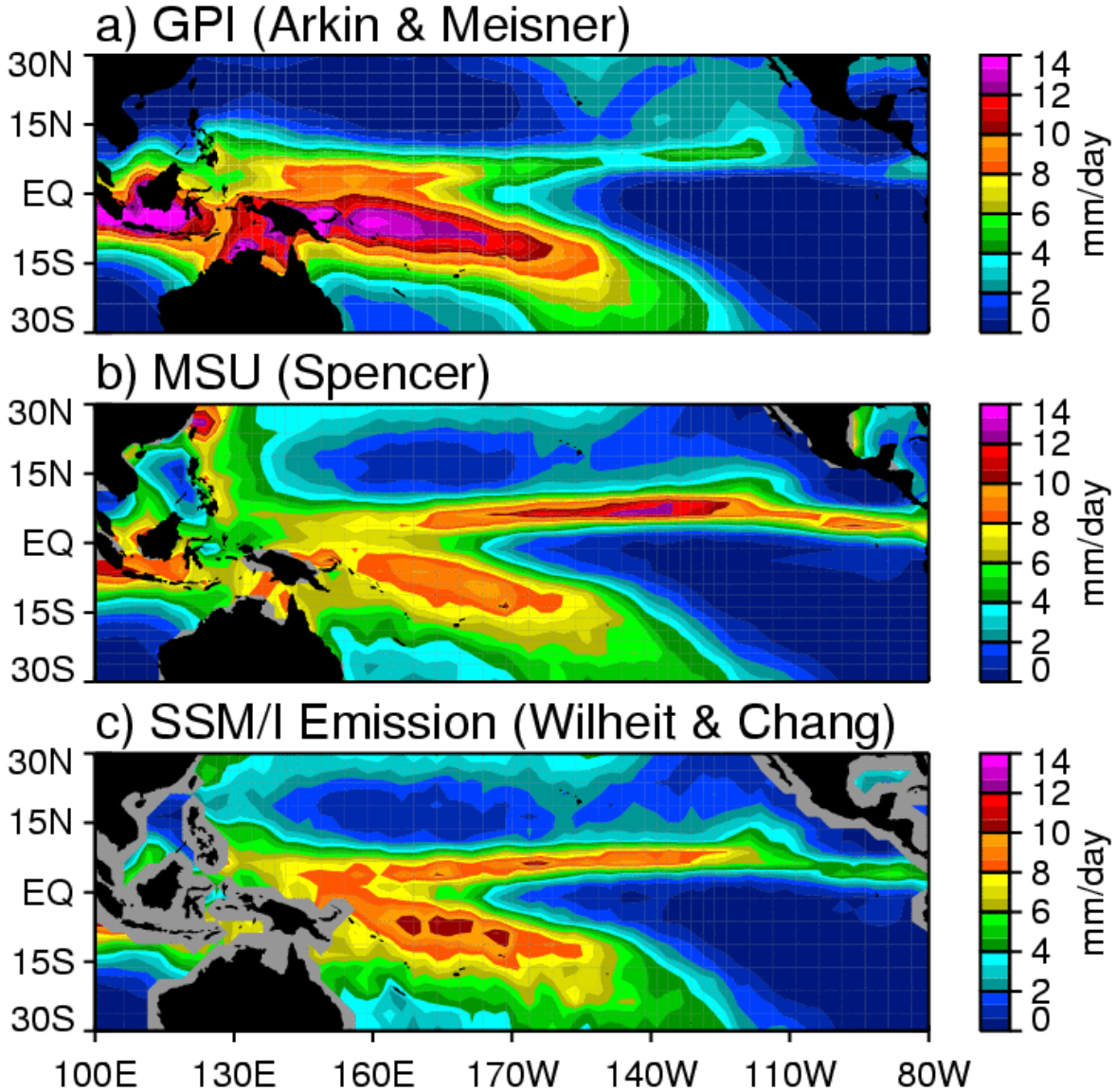
Outline

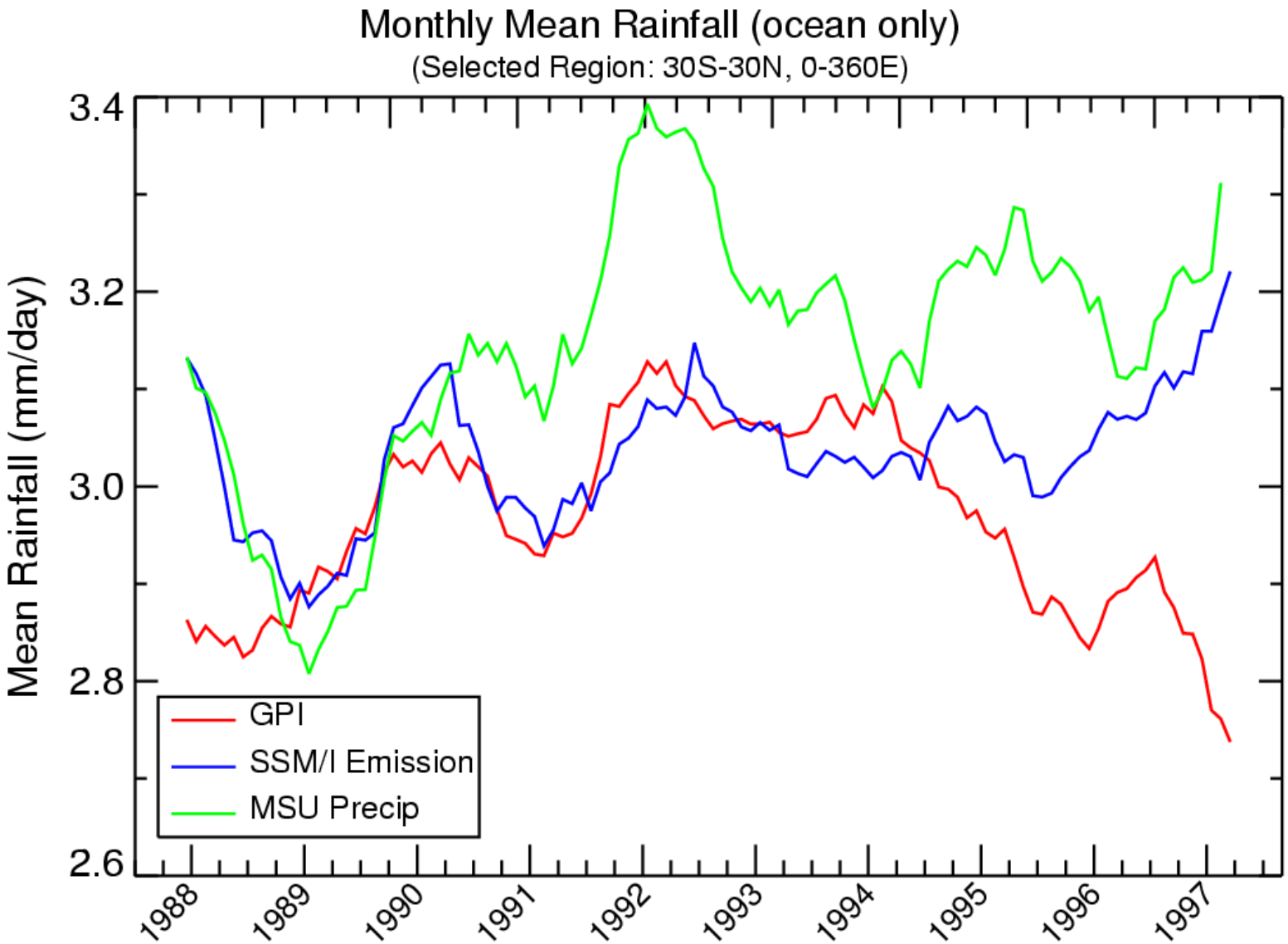
- *Briefly review the TRMM and GPM Missions*
- *Describe the parametric strategy being designed for GPM radiometers*
- *Describe the common database of cloud structures being developed for the parametric algorithms.*
- *Review rainfall retrieval capabilities and impact of a-priori cloud profile database information*
- *Compare ECMWF rainfall analysis to retrieved rainfall and relate differences to the a-priori information.*

Satellite Rainfall Biases

Mean DJF Rainfall (1987 – 1996)



Tropical Mean Rainfall Variability



Tropical Rainfall Measuring Mission (TRMM)

TRMM Sensors

Precipitation radar (PR):

- 13.8 GHz
- 4.3 km footprint
- 0.25 km vertical res.
- 215 km swath

Microwave radiometer (TMI):

- 10.7, 19.3, 21.3, 37.0
- 85.5 GHz (dual polarized
- except for 21.3 V-only)
- 10x7 km FOV at 37 GHz
- 760 km swath

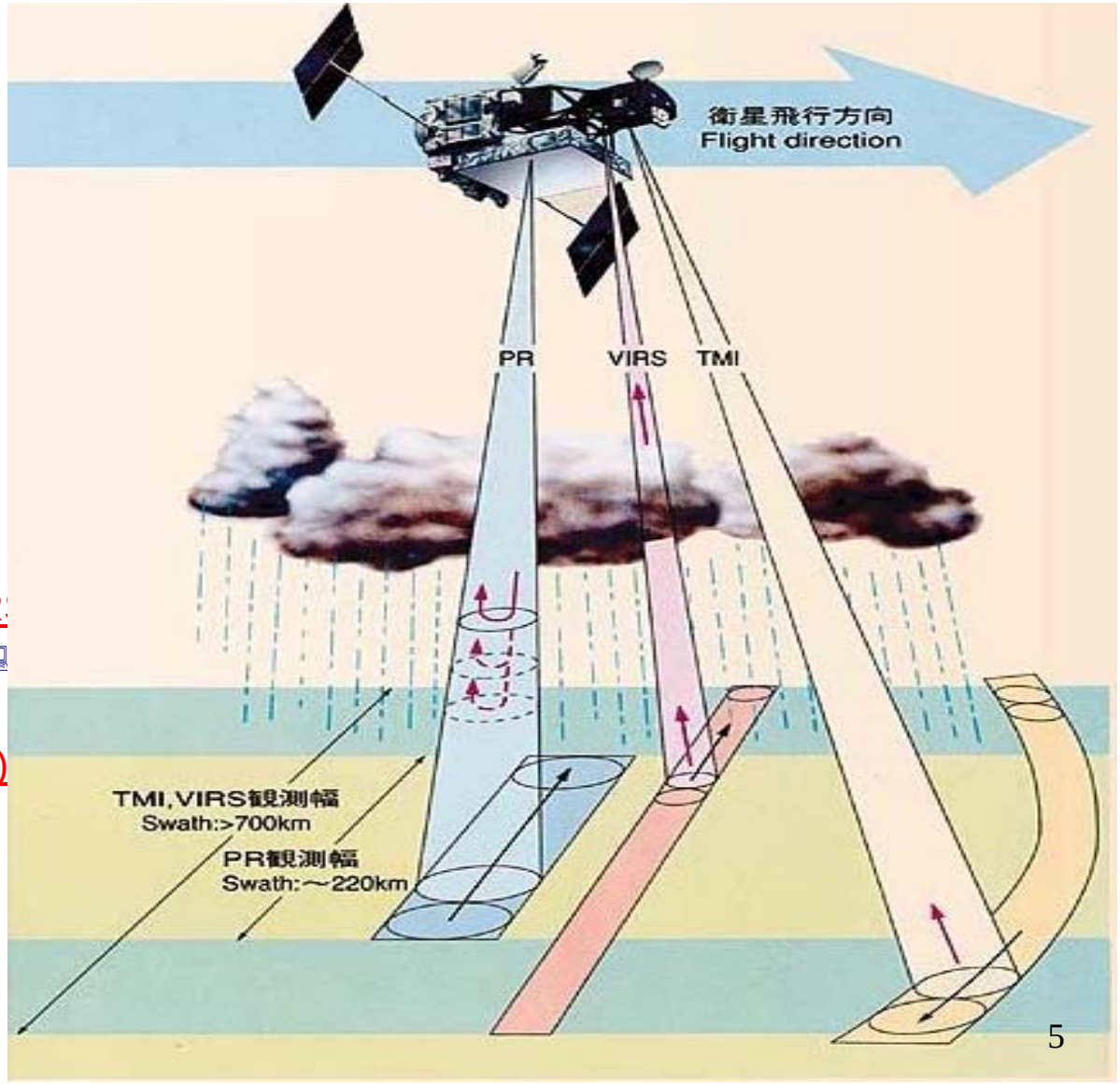
Visible/infrared radiometer (VIR

- 0.63, 1.61, 3.75, 10.8, and 12
- at 2.2 km resolution

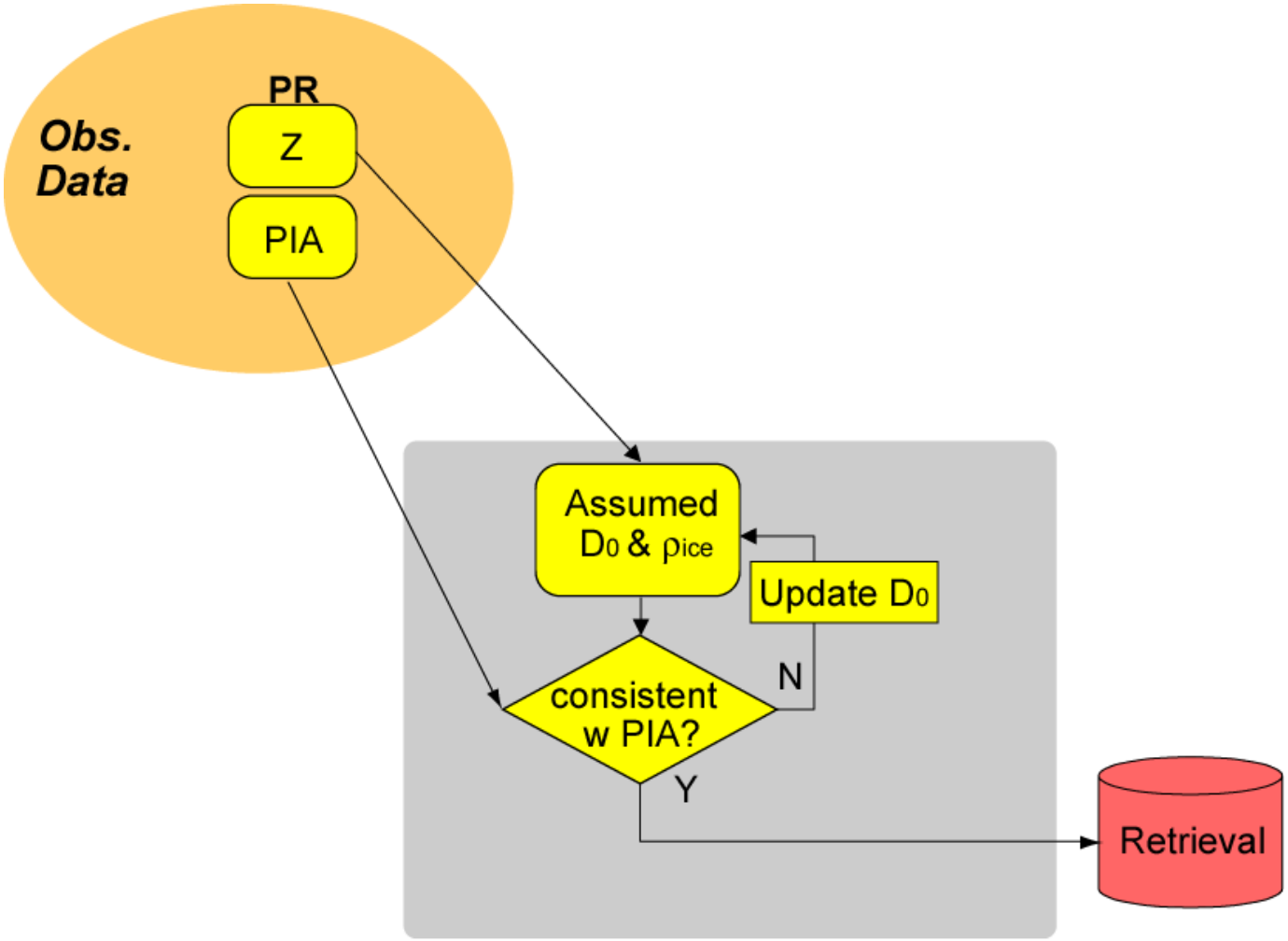
Lightning Imaging Sensor (LIS)

Cloud & Earth Radiant Energy System (CERES)

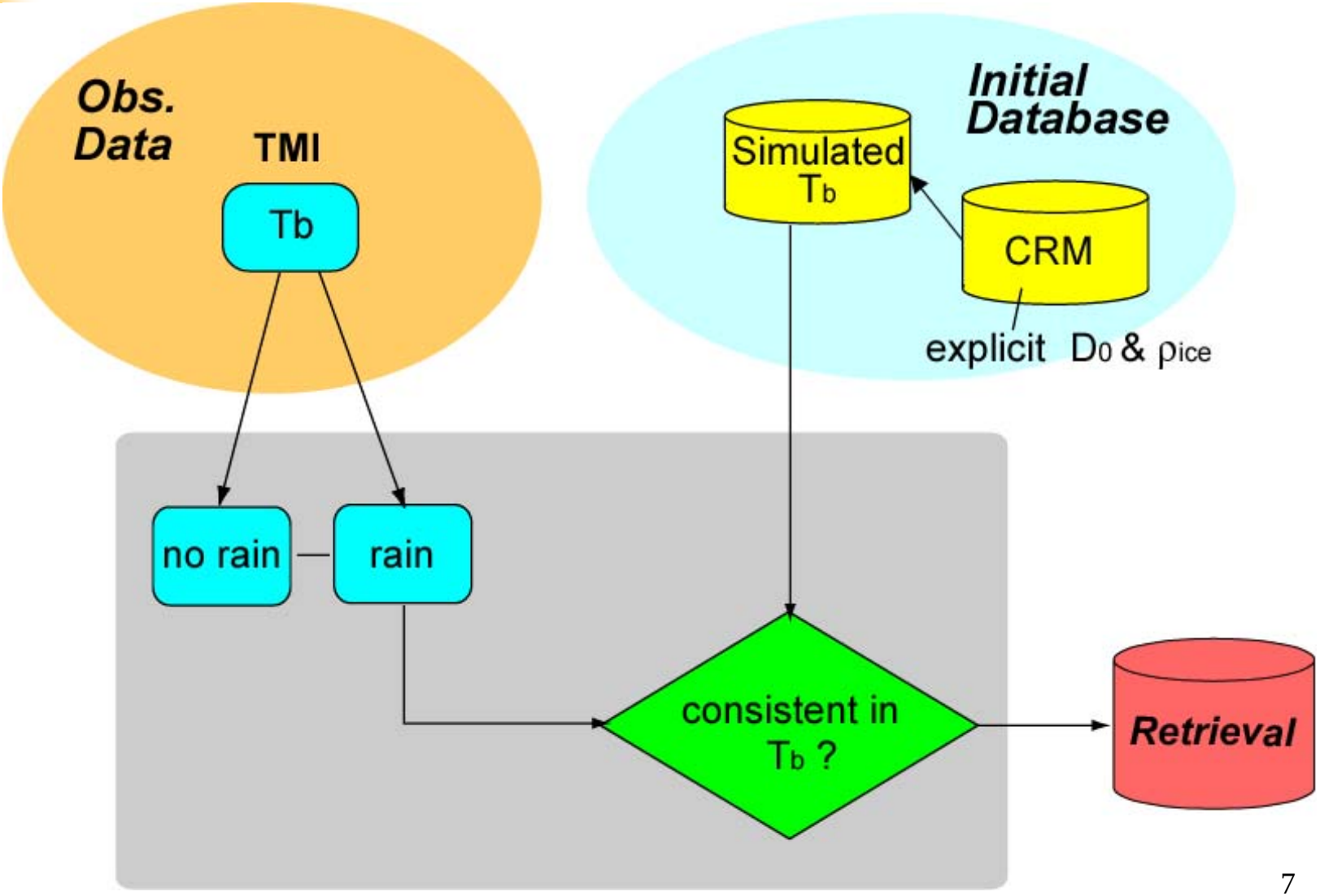
Nov. 1997 launch, 35° inclination; 402 km



TRMM radar retrieval

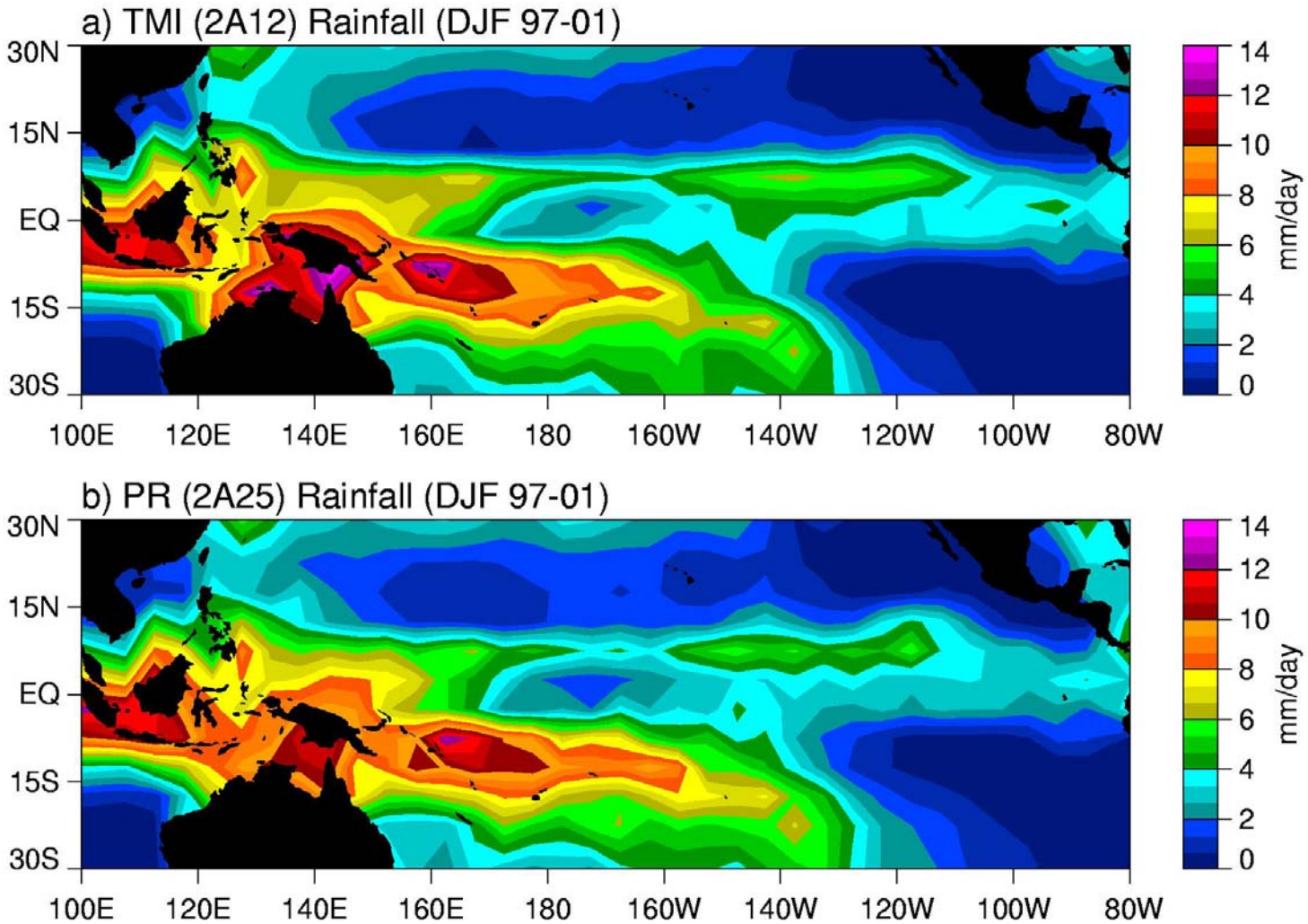


Radiometer retrieval - V6

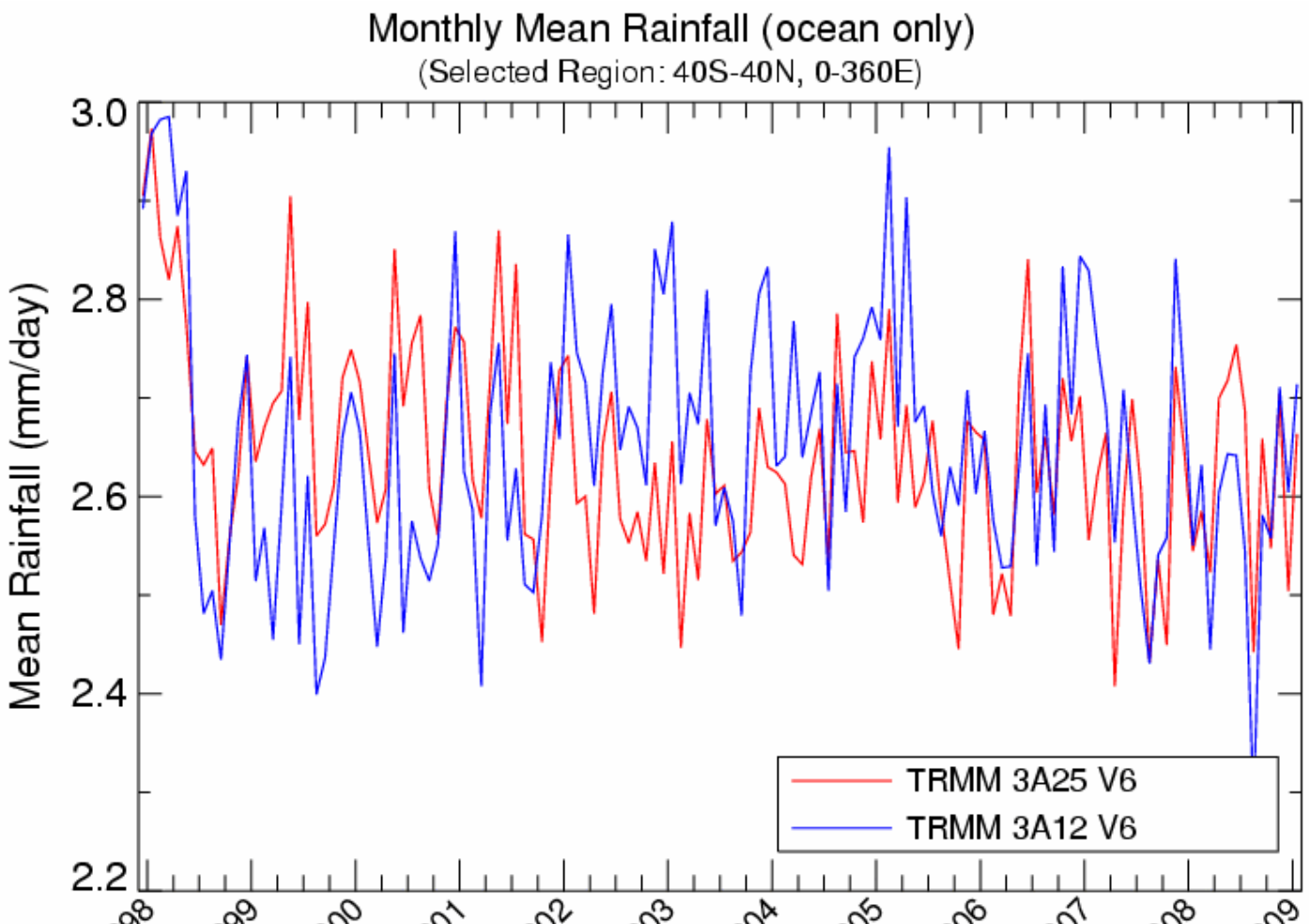


Mean DJF Rainfall

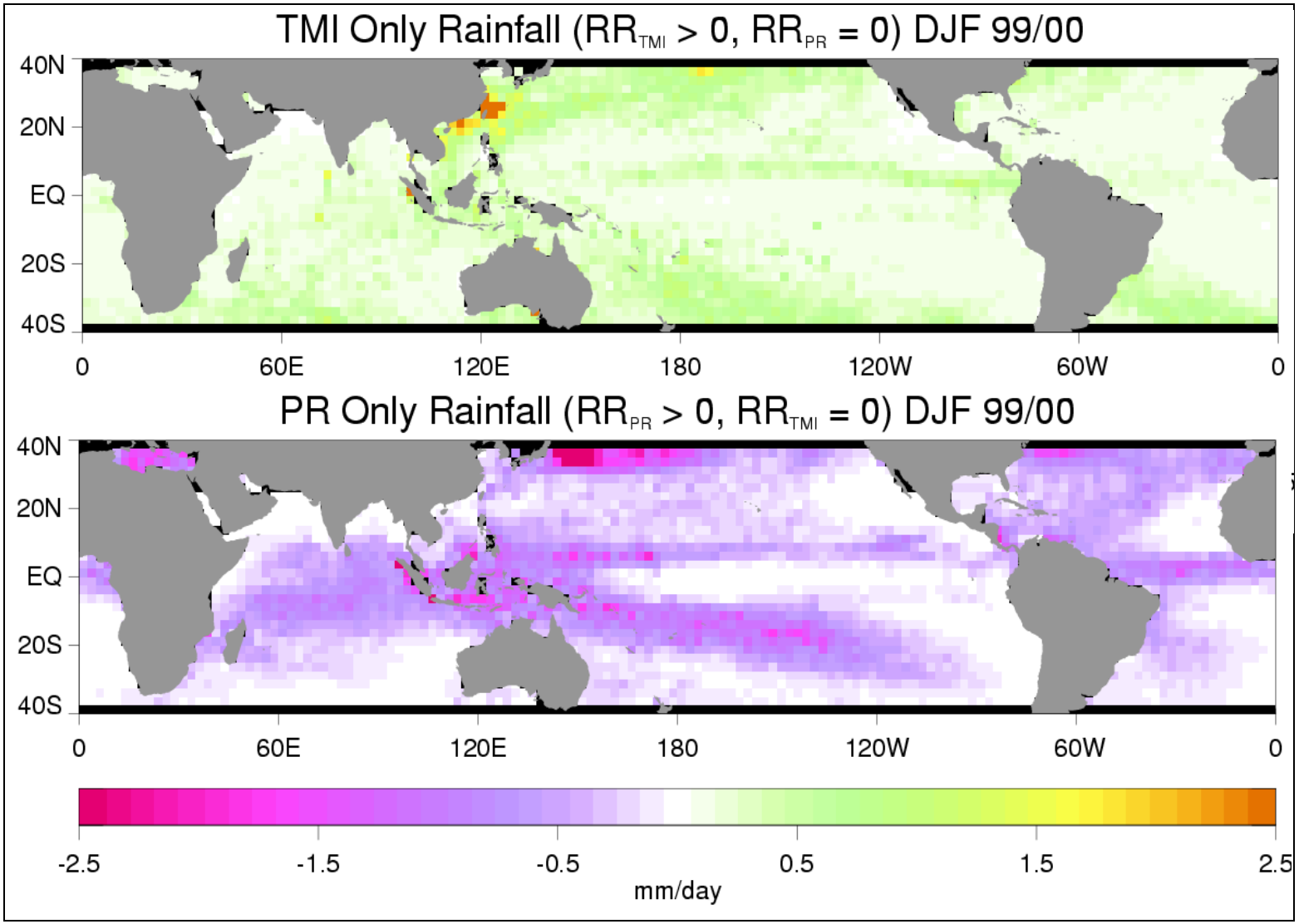
(TRMM Retrievals)



TRMM PR/TMI Rainfall Variability

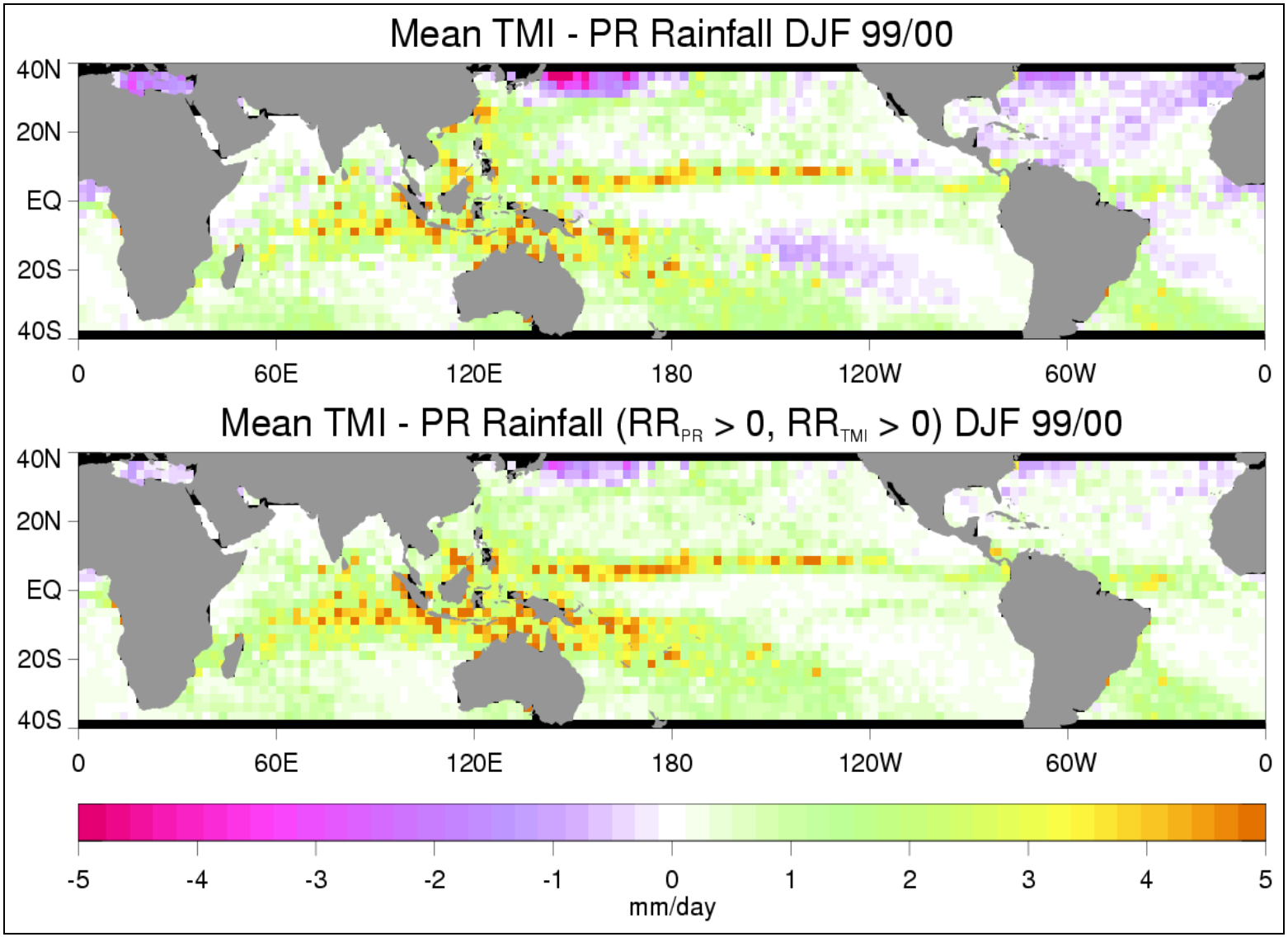


Rainfall Detection Errors

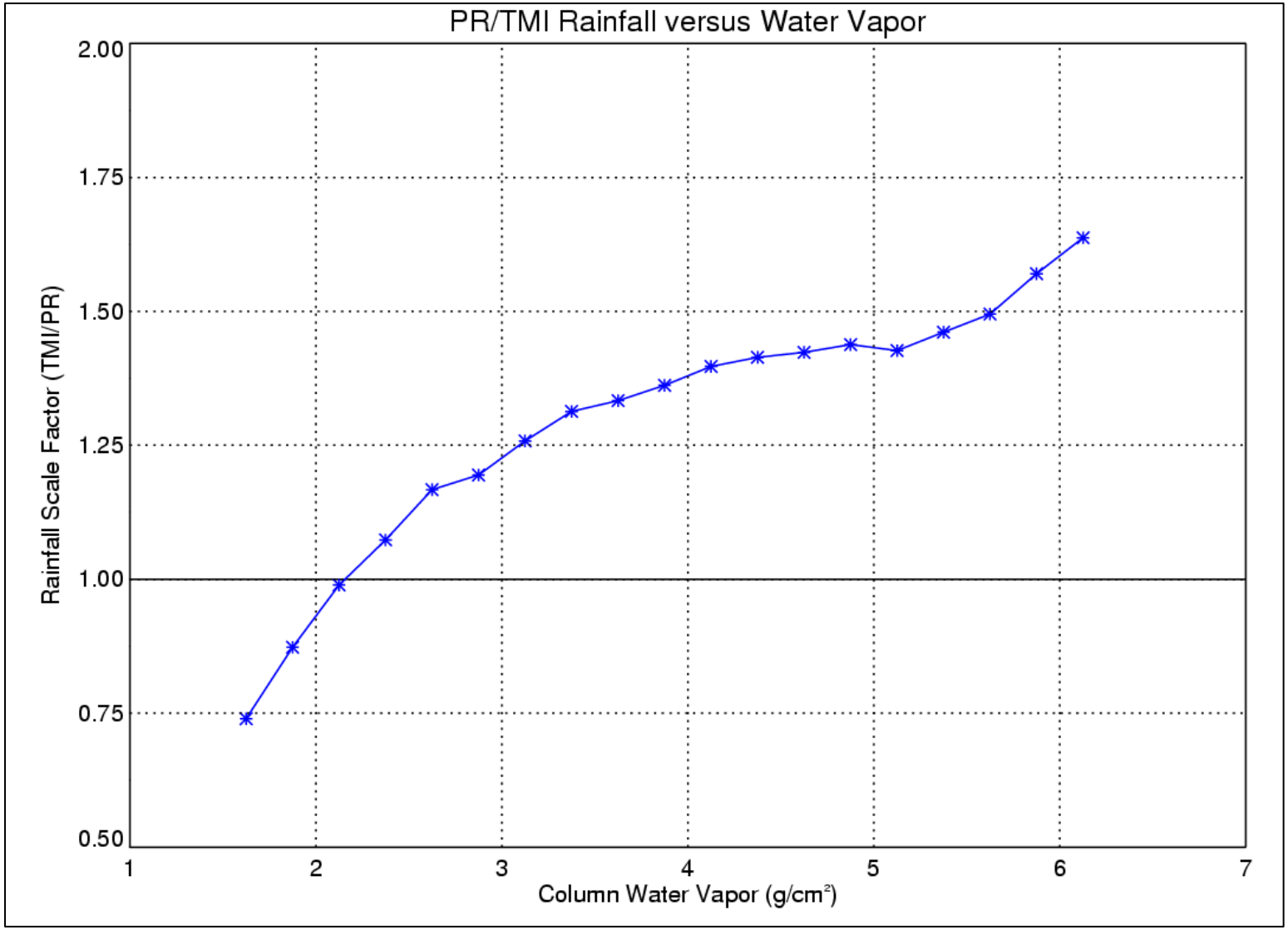


Rainfall Detection Errors

Impact on TMI/PR Differences

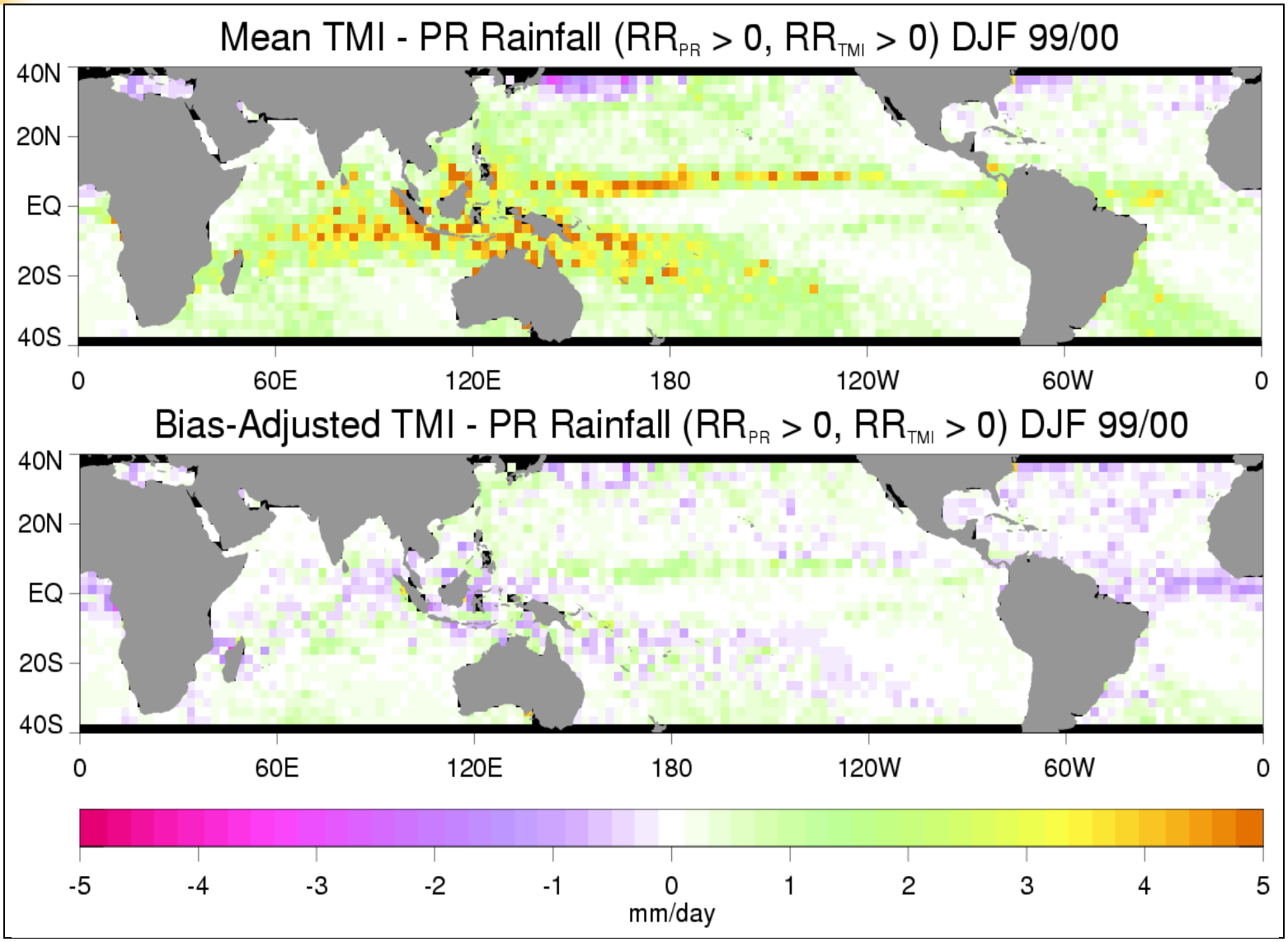


PR/TMI Bias vs. Column Water Vapor

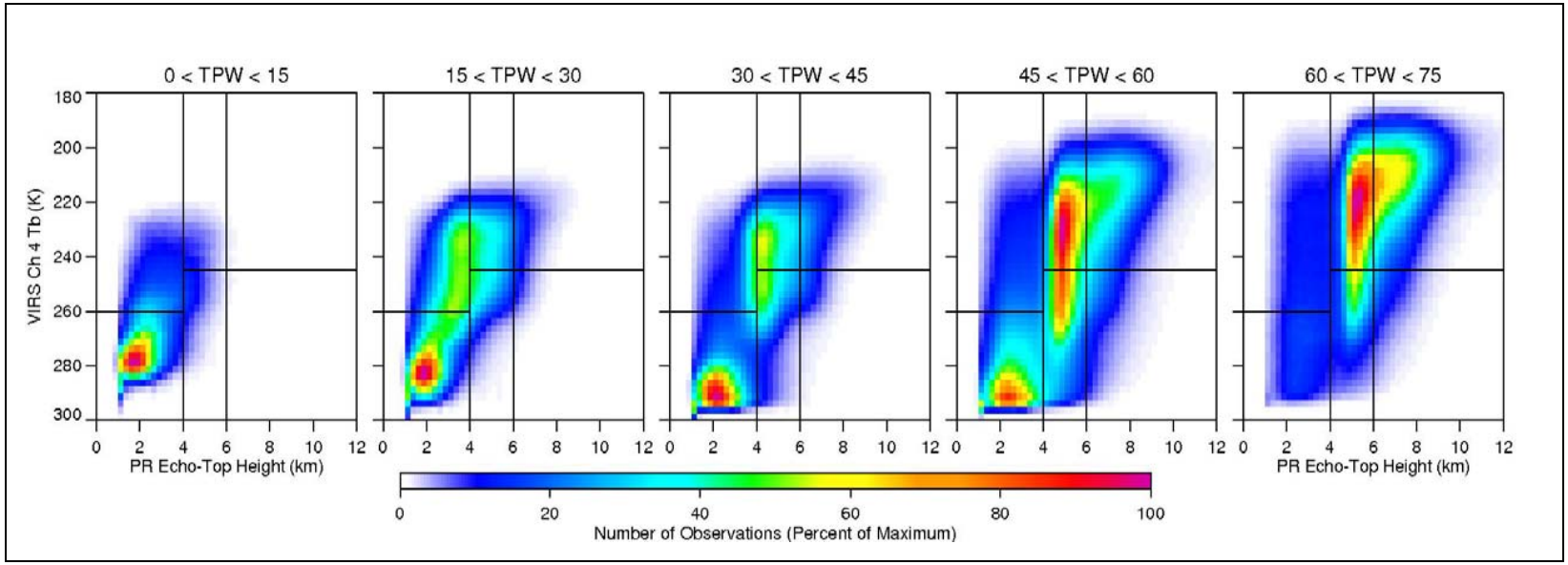


Rainfall Bias Removal

Based on Column Water Vapor



Cloud Profiles Partitioned by TPW



TMI Uncertainties due to Regional Rainfall Properties

Horizontal Structure	Vertical Structure	Freezing Level	Mean Error
---	---	---	12.0%
yes	---	---	6.8%
---	yes	---	10.7%
---	---	yes	4.0%
yes	yes	---	6.3%
yes	---	yes	2.4%
---	yes	yes	3.5%
yes	yes	yes	2.4%

The GPM Concept

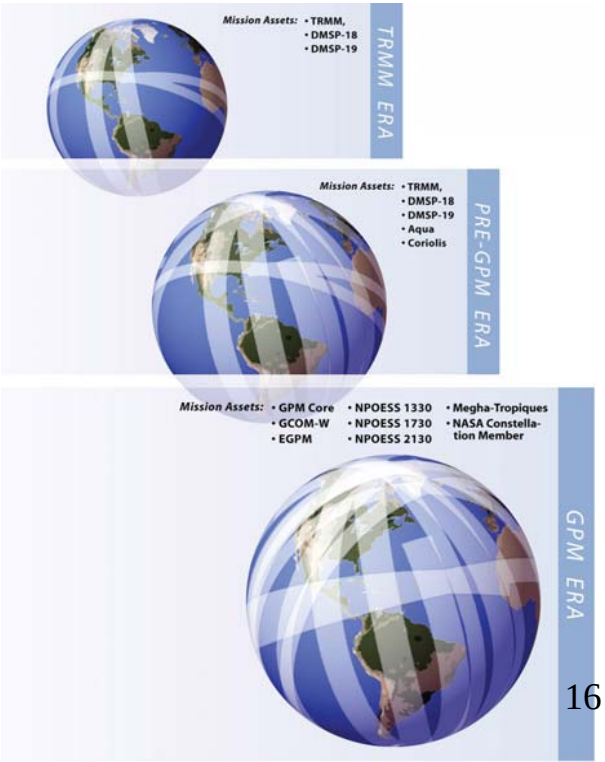
Everyone contributes constellation of dedicated and operational PMW radiometers for frequent sampling

- *NASA/JAXA contribute Core Satellite Precipitation Physics*

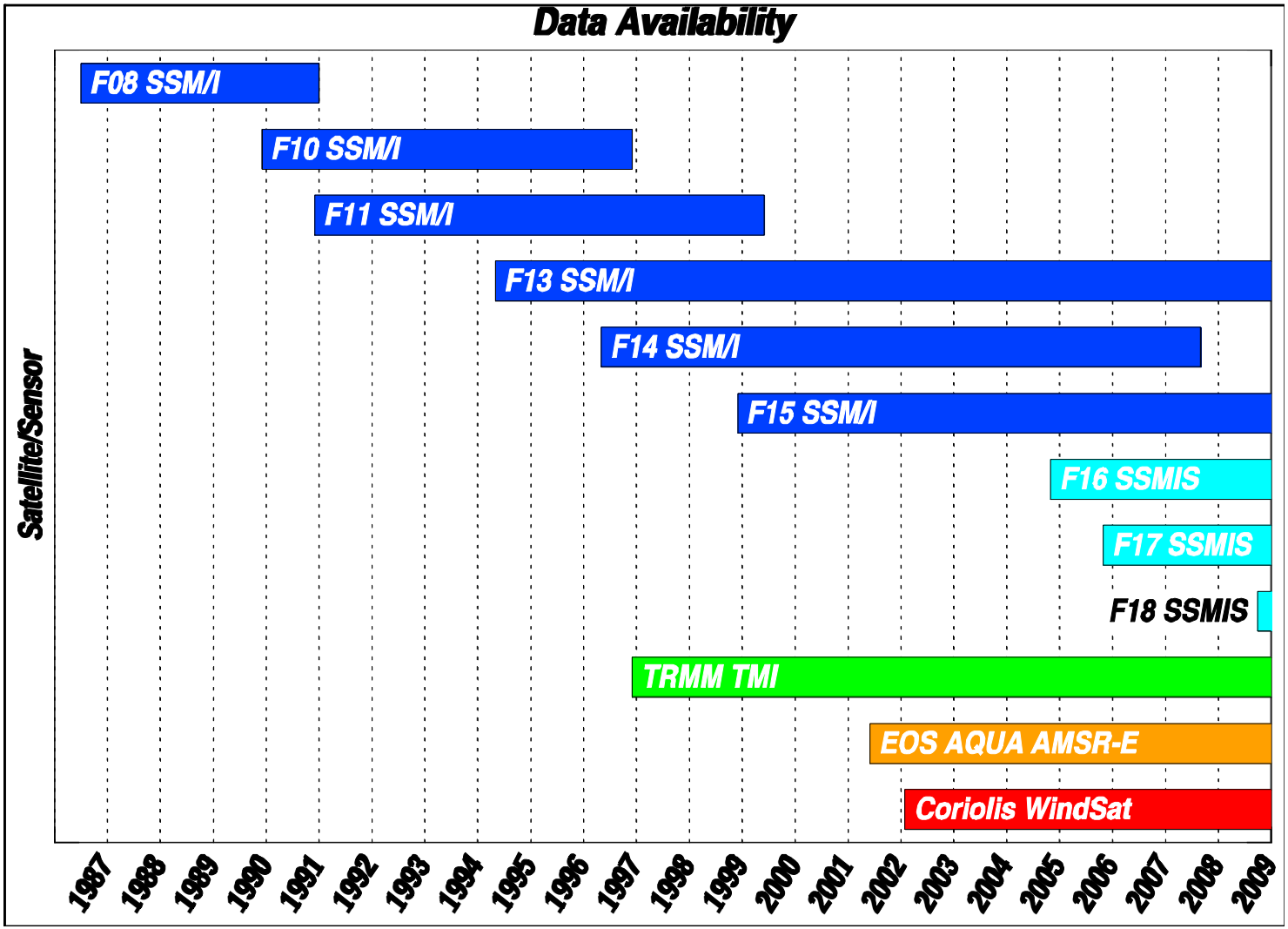
GPM Core Satellite carries:

- a dual-frequency radar &

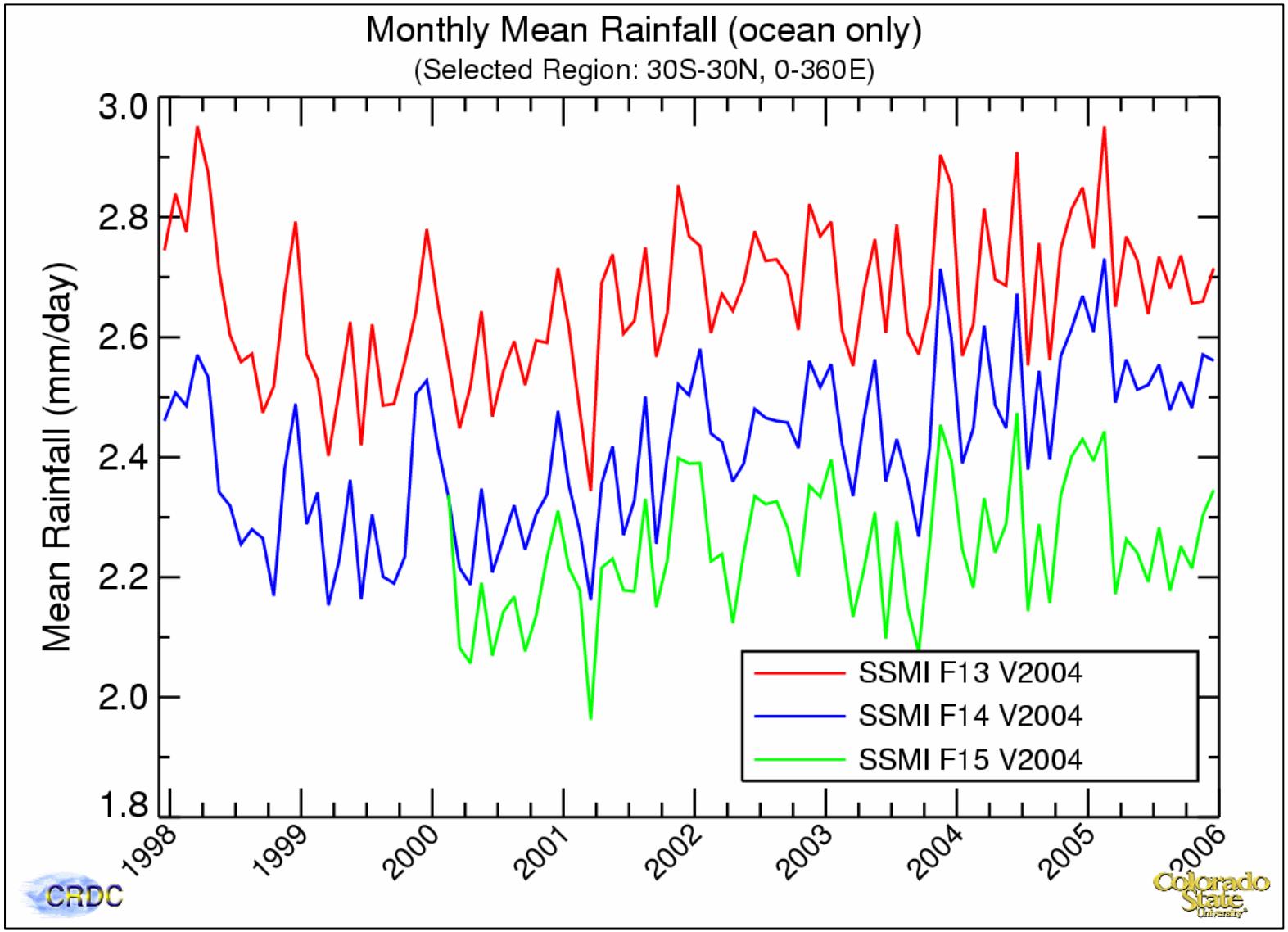
- a passive microwave imager with high-frequency capabilities



Available Microwave Imagers



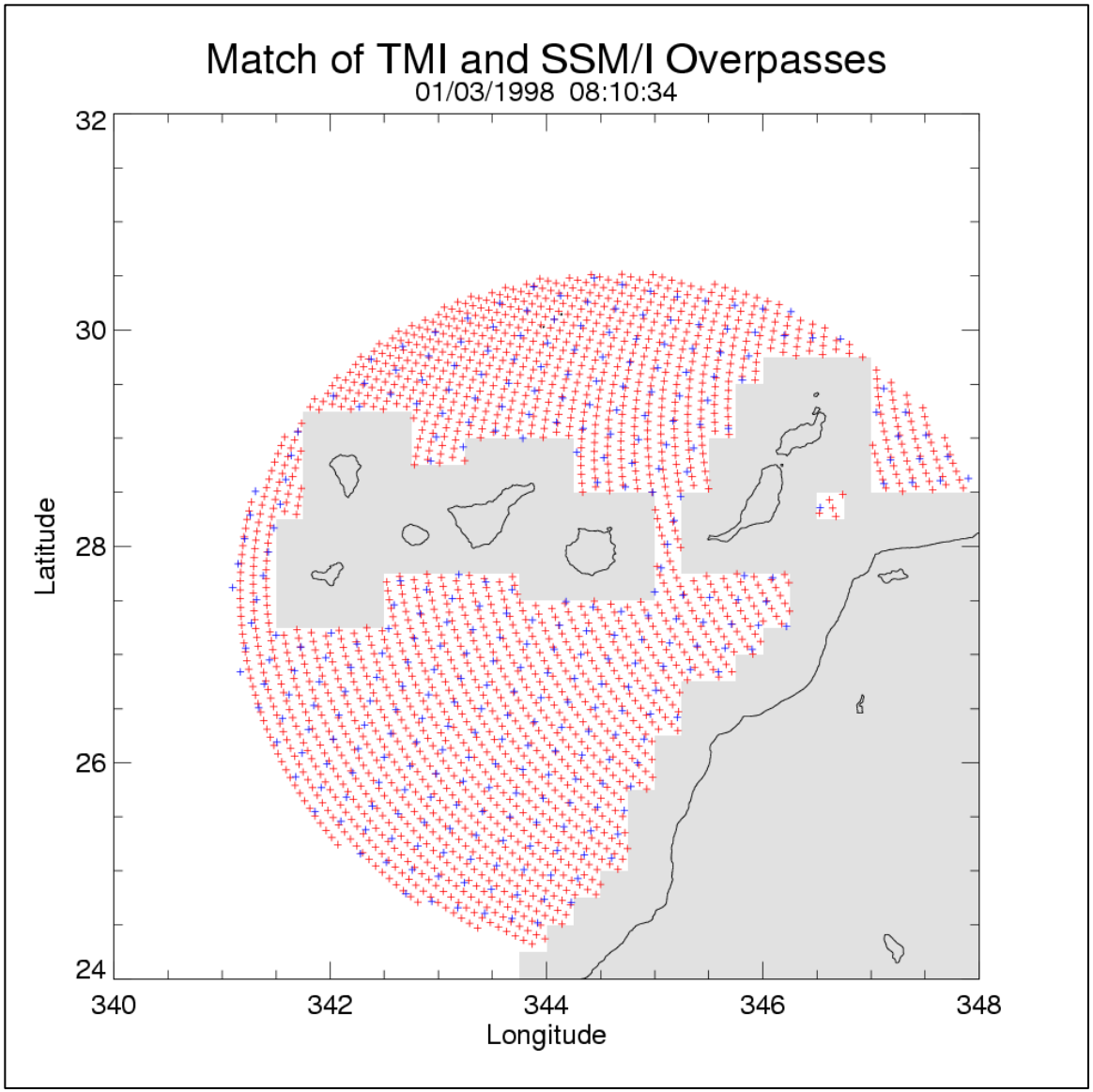
SSMI Rainfall w/o Tb calibration



The Intercalibration Plan

- *Find overpasses between radiometer X and TMI (GMI) within agreed upon time difference (5 min) and scene criteria (small σ_{Tb})*
- *Use TMI (GMI) Tbs to run OE of non-raining parameters (ocean and possibly selected land pixels)*
- *Use retrieved parameters to compute radiometer X Tbs and compare to actual observations.*
- *Keep track of instantaneous differences. Apply offsets to make consistent*

SSM/I – TMI Crossover



Optimal Estimation Framework

$$y = f(x, b) + \varepsilon_b + \varepsilon_y$$

y = Observed Brightness Temperatures (TBs)

ε_b, ε_y = Error term (model parameters; measurement errors)

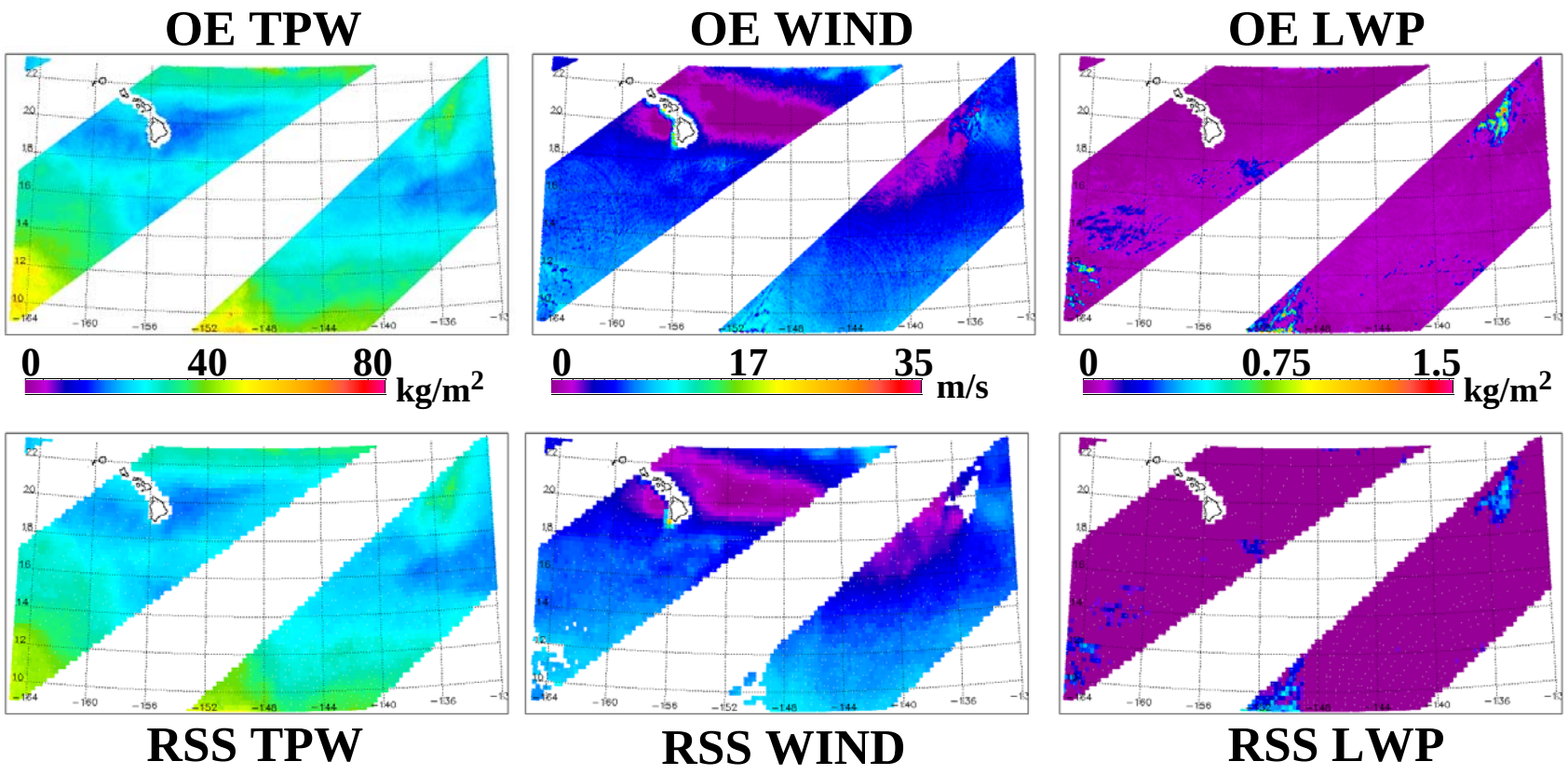
x = State Vector (water vapor, ocean surface wind, cloud water)

b = forward model assumption errors (vapor profile, emissivity model)

f = forward model (operates on x and b)

Goal: Find x that yields forward computed Tbs which agree with observed Tbs within allotted error range.

Optimal Estimation (OE) vs Remote Sensing Systems (RSS)



SSM/I Calibration Offsets

Sat	19V	19H	22V	37V	37H	85V	85H
F11	-0.8	-2.1	-1.5	-0.3	-1.5	-1.4	-2.8
F13	-1.3	-2.1	-1.9	-1.2	-2.2	-0.8	-1.3
F14	-1.2	-1.7	-1.8	-1.8	-2.0	-0.9	-1.3
F15	-0.1	-1.9	-1.2	-0.9	-1.8	-0.1	-0.8

Objective of Radiometer Rainfall Algorithm

- *Use the "physical" retrieval of clouds from GPM Core satellite to build comprehensive database of precipitation structures*
- *Use observed clouds coupled with radiative transfer and microwave sensor details to create a-priori database for any existing or planned radiometer.*
- *Use Bayesian schemes to retrieve rainfall for any existing radiometer.*
- *Report uncertainties such that different sensors can be merged intelligently into 3 hr accumulations.*

The Physical Retrieval from Core Satellite

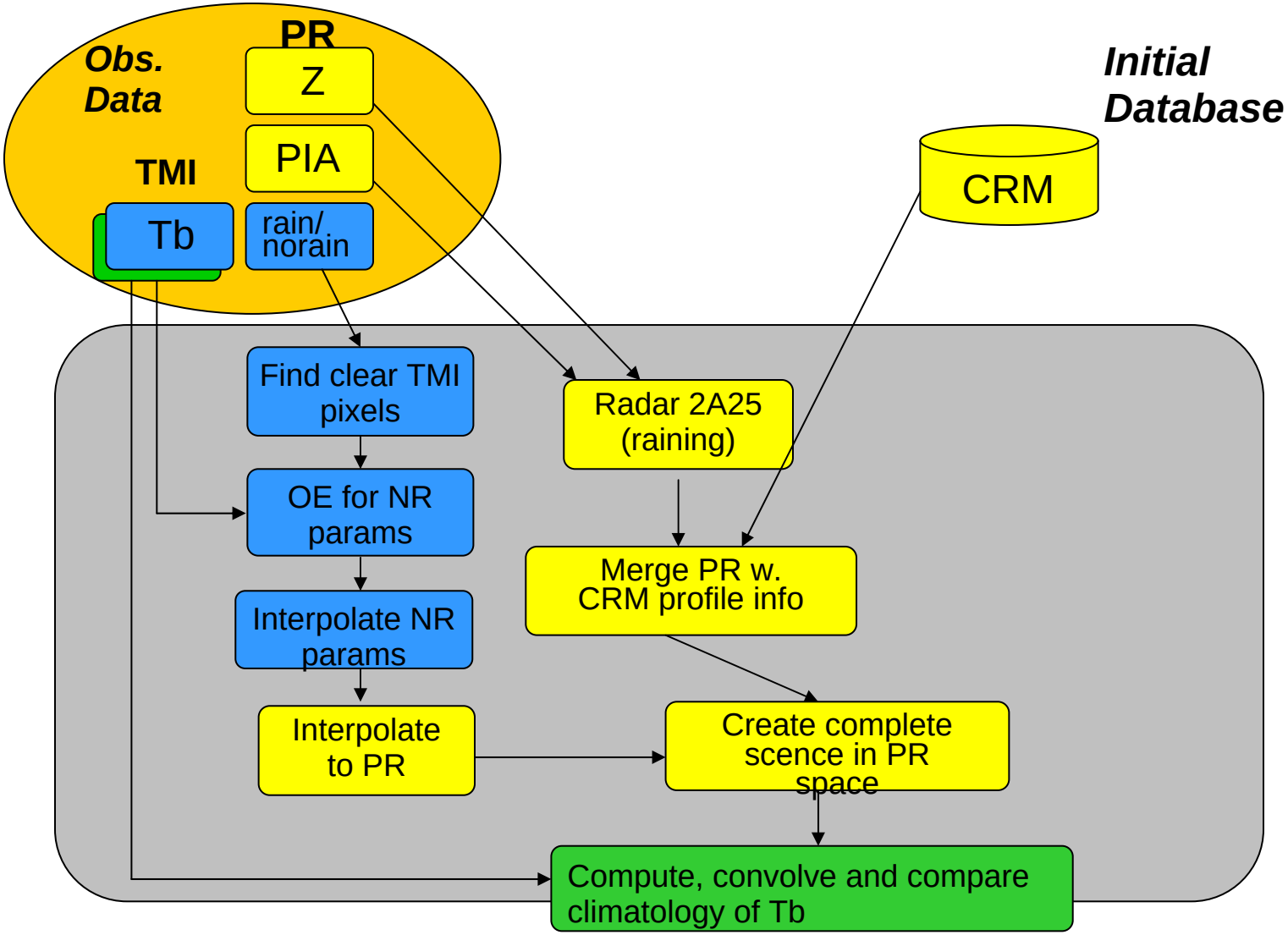
- *A number of methods already exist using TRMM PR and TMI*
  - *Haddad et al. (1997) TRMM combined algorithm*
  - *Grecu and Olson (2005)*
  - *Masunaga and Kummerow (2005)*
  - *GPROF2008*

- *GPROF2008 database uses TRMM PR operational product as baseline from which changes are made. Validation benefits.*

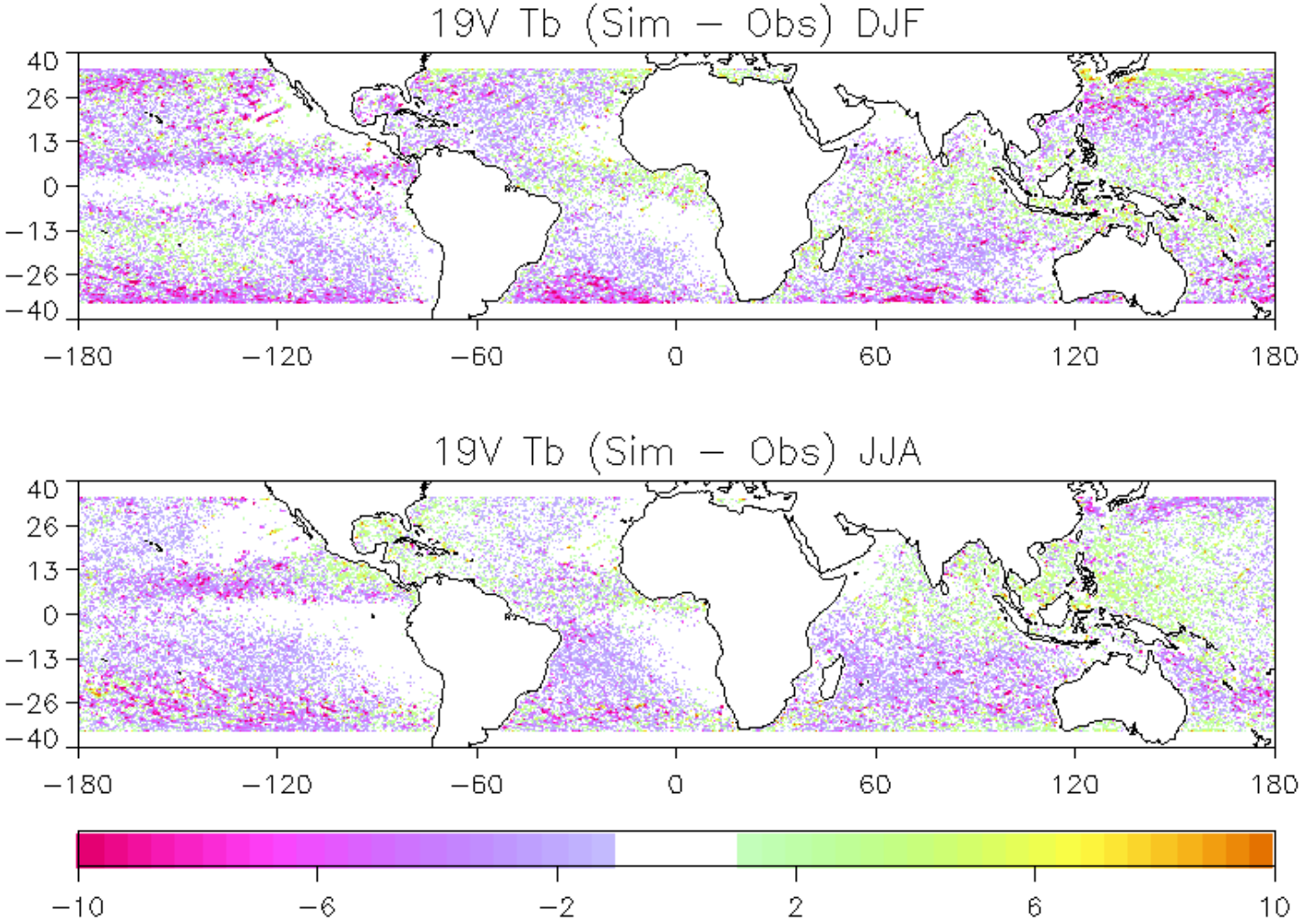
- *Because even radar and radiometer do not fully constrain possible clouds, GPROF2008 employs the most conservative strategy possible (i.e. make the smallest necessary changes to PR to force agreement with TMI).*

- *GPROF2008 partitions database into distinct SST and TPW bins. Radar solution is modified to minimize climatological differences. Rain is added below threshold of PR and DSD assumption in PR is modified when no reliable PIA is available.*

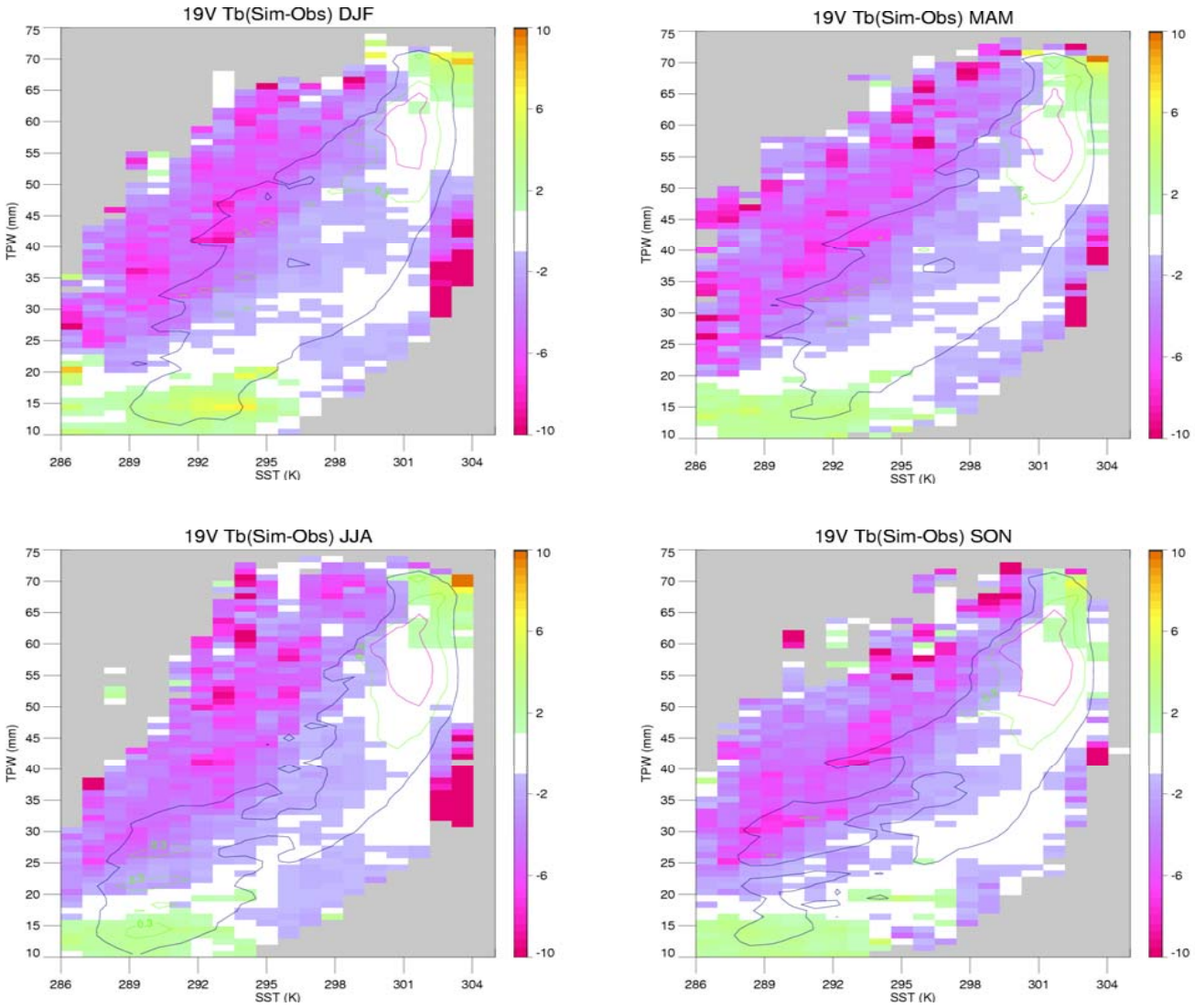
GPROF 2008 Default Database



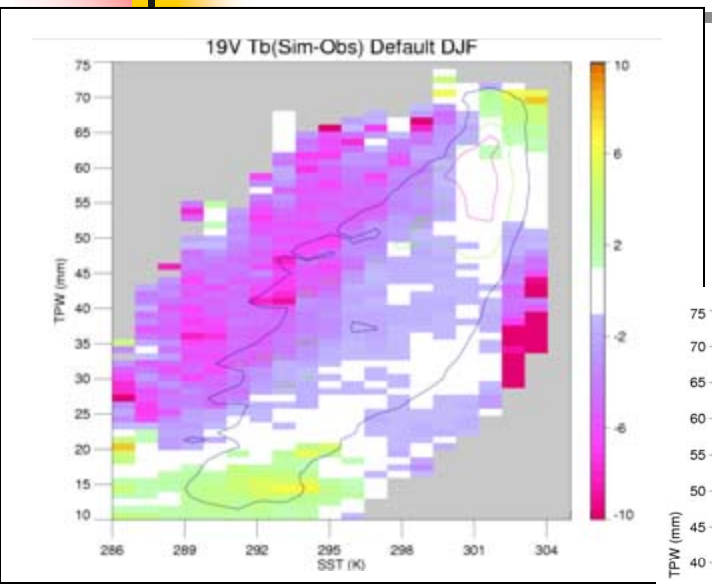
Regional 1st Guess Biases (Simulated - Observed Tb)



Database 1st Guess Biases Sorted by SST and TPW

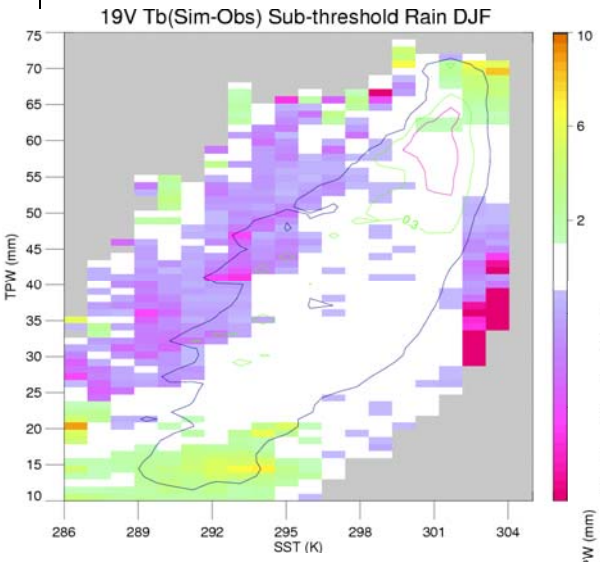


Database Adjustments

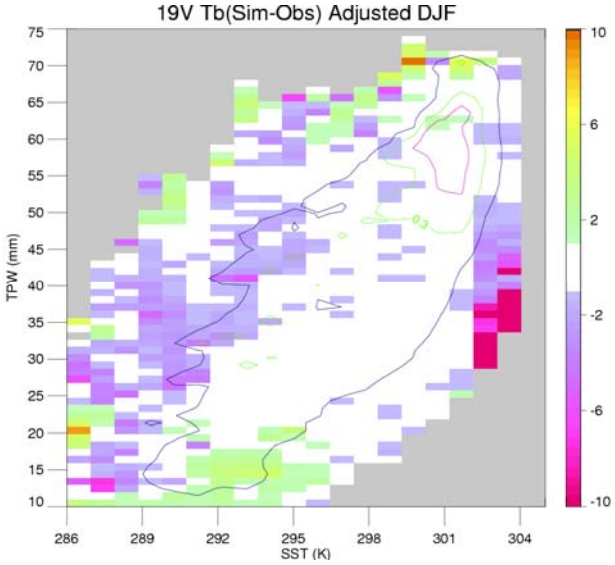


Original Tb differences

Tb differences after adding rain below PR threshold

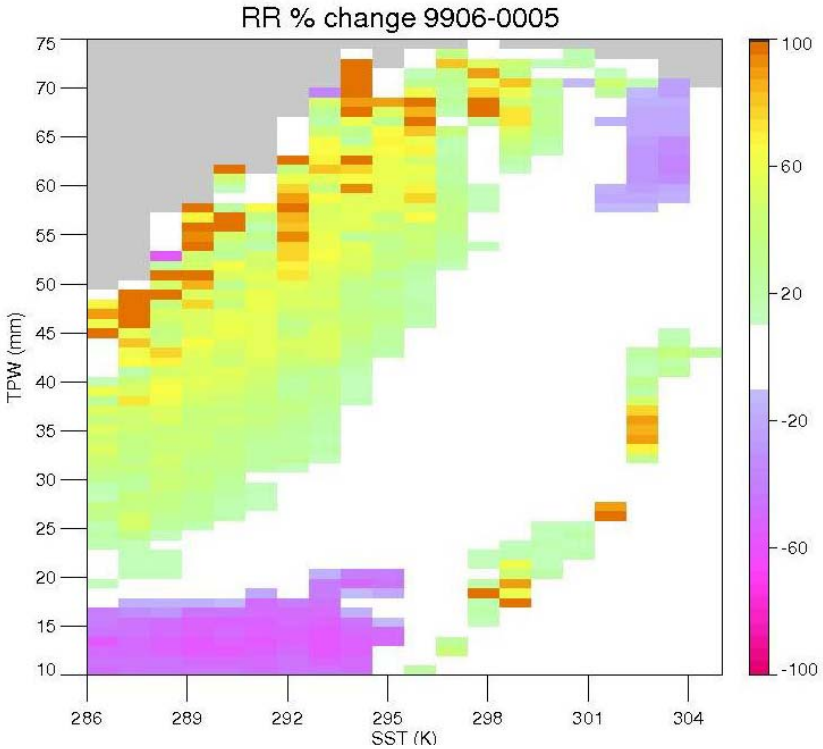


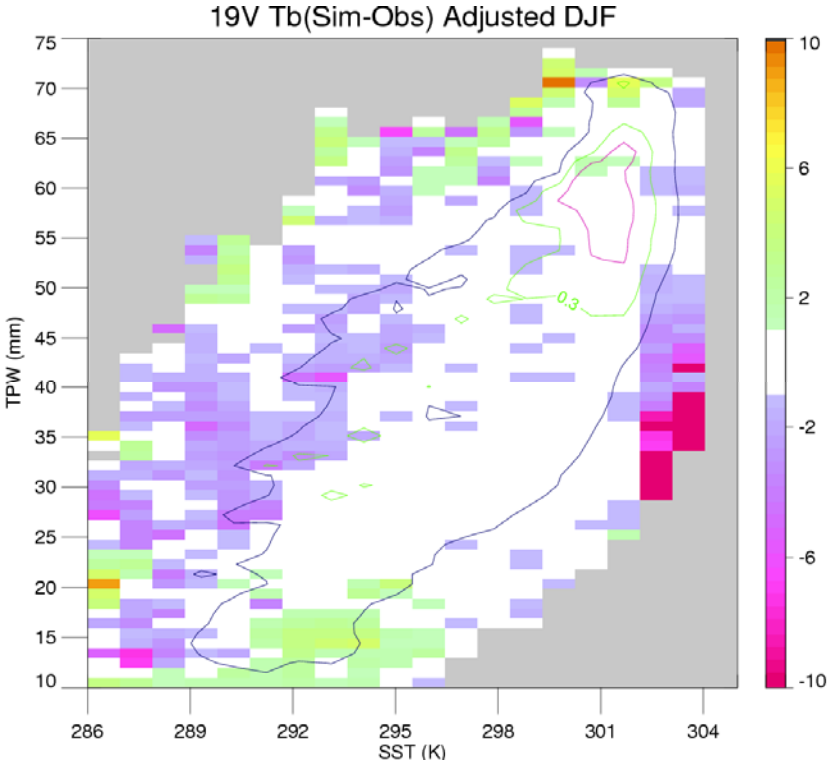
Tb differences after DSD modification



Net change is a 2% increase from 2A25. Biggest change in colder SST with high TPW

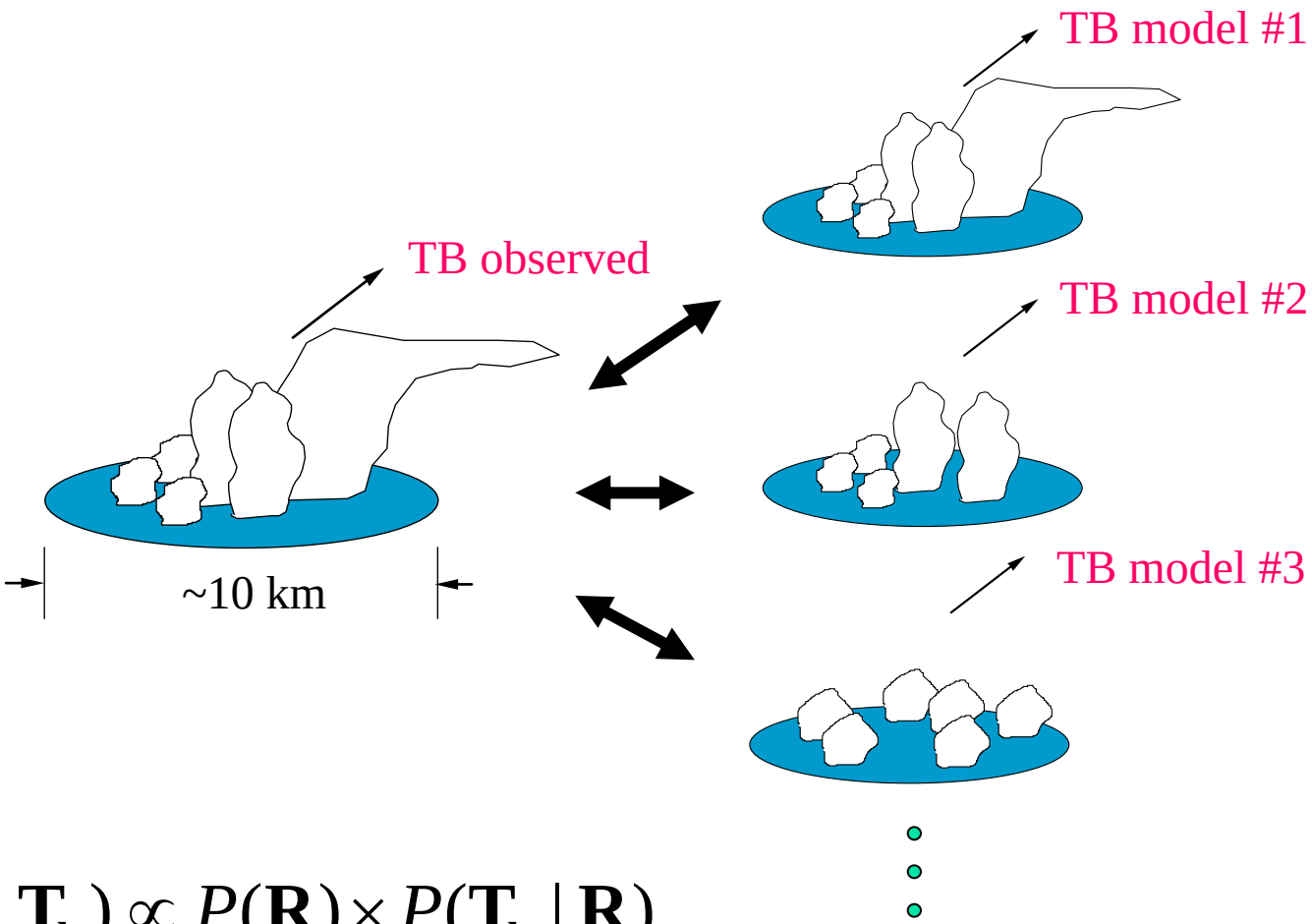
Final Adjustment of GPROF Database





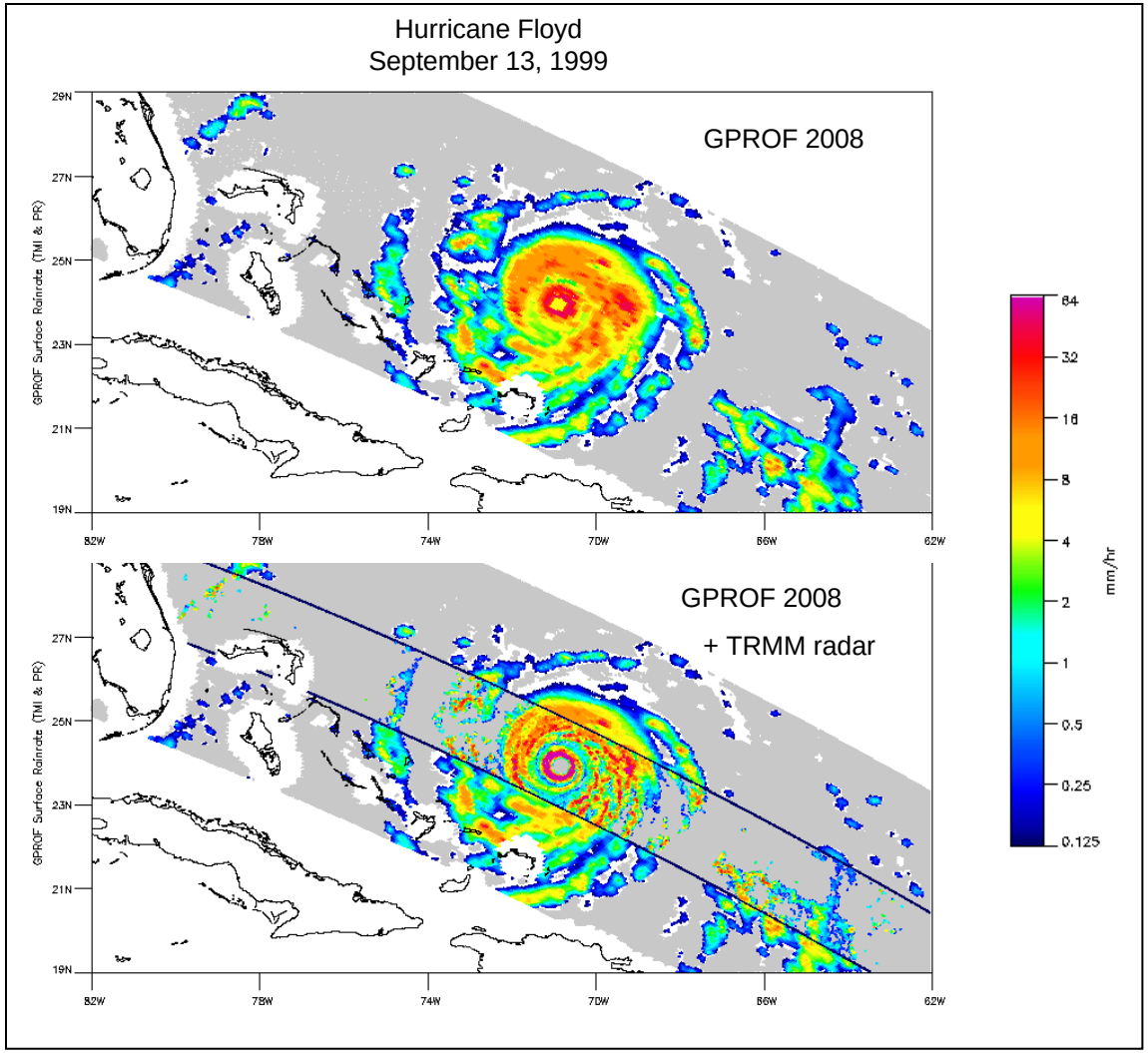
Bayesian Inversion

TRMM Radar & Model Database



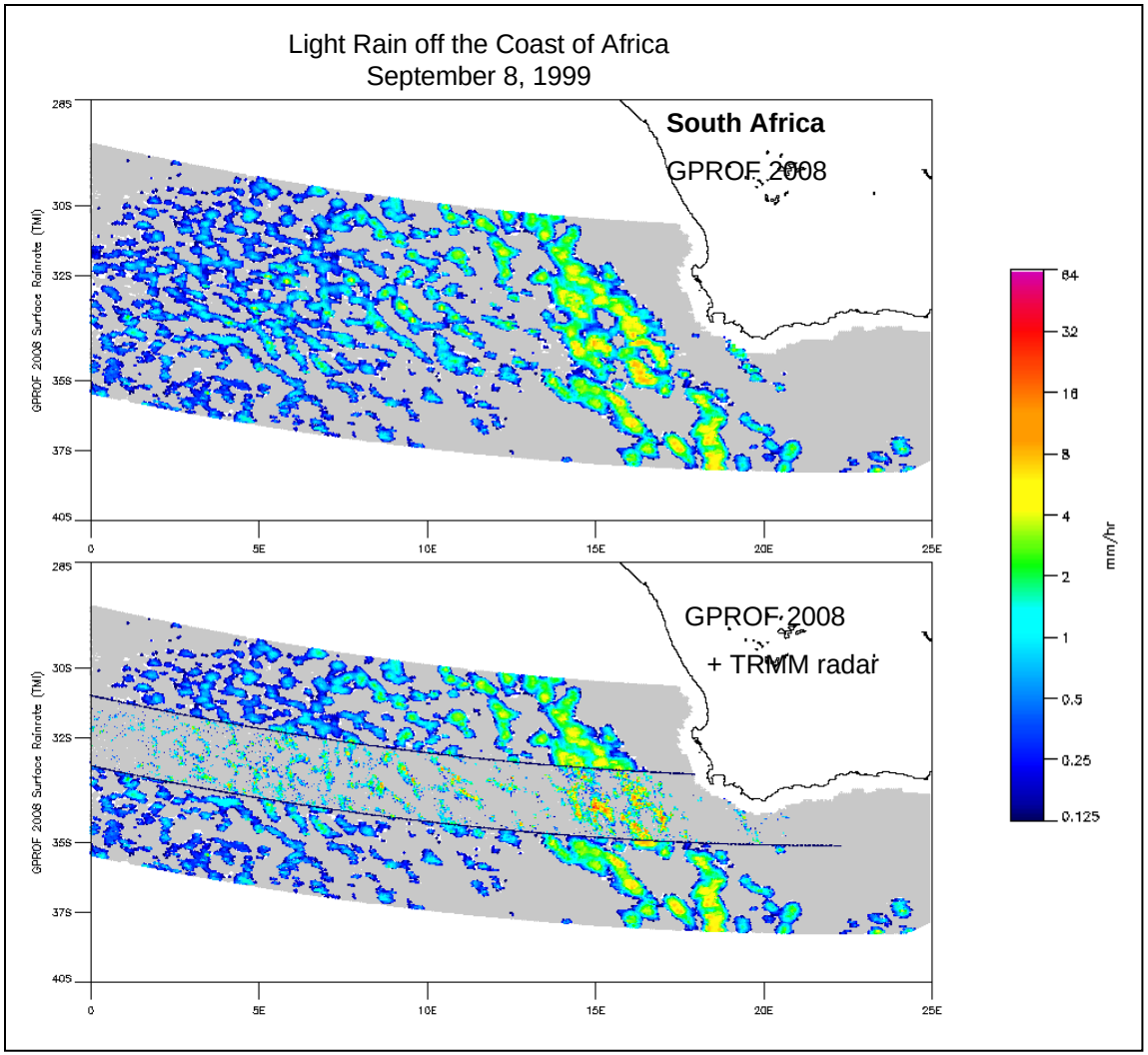
$$P(\mathbf{R} \mid \mathbf{T_b}) \propto P(\mathbf{R}) \times P(\mathbf{T_b} \mid \mathbf{R})$$

GPROF w. Empirical Database



- *Use TRMM PR as "truth"*
- *Database is built from PR rain and observed TMI Tb*
- *Bayesian scheme used to retrieve rainfall (TMI only). Database sorted by SST and TPW*

GPROF w. Empirical Database



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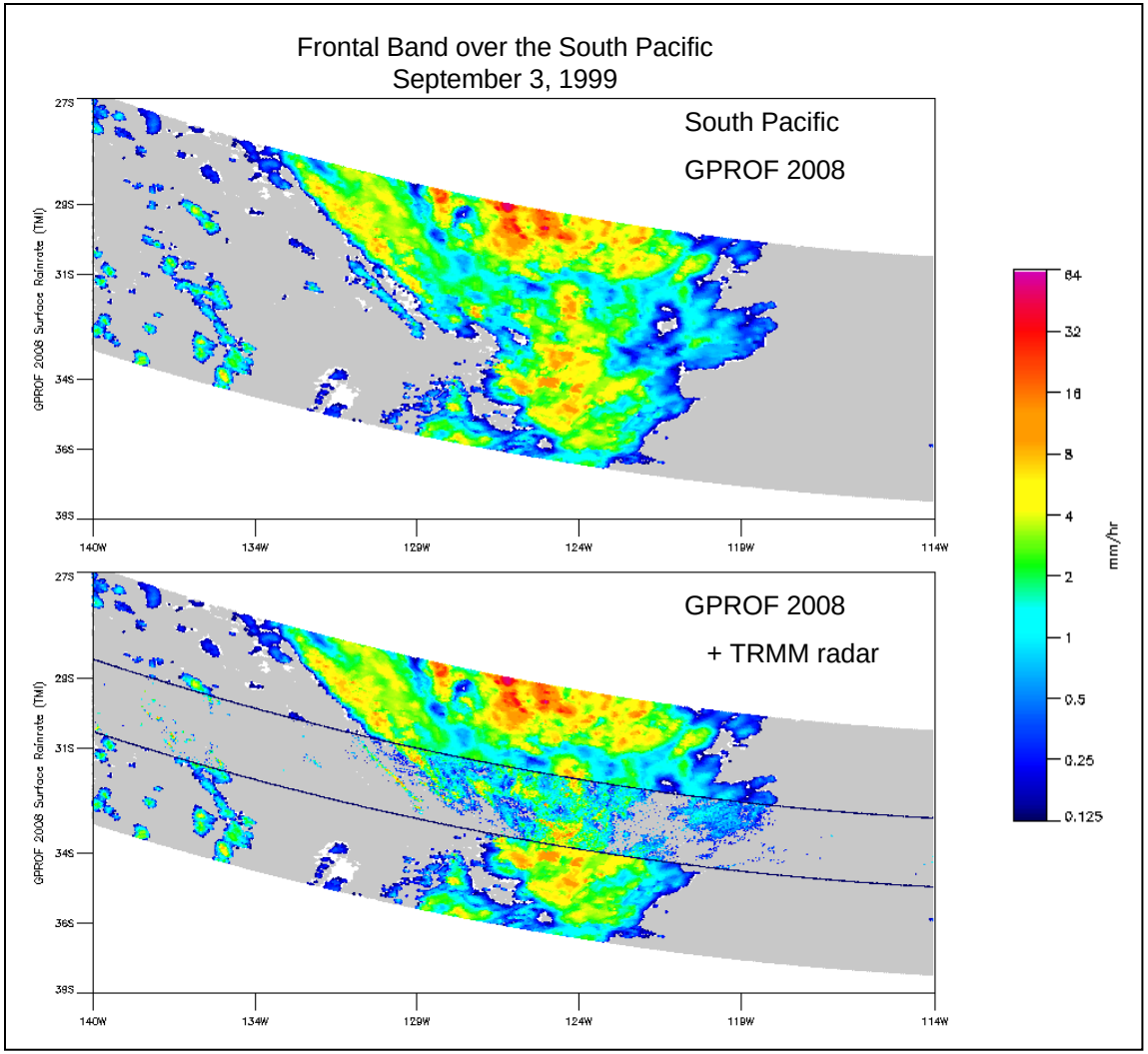
GPROF w. Empirical Database



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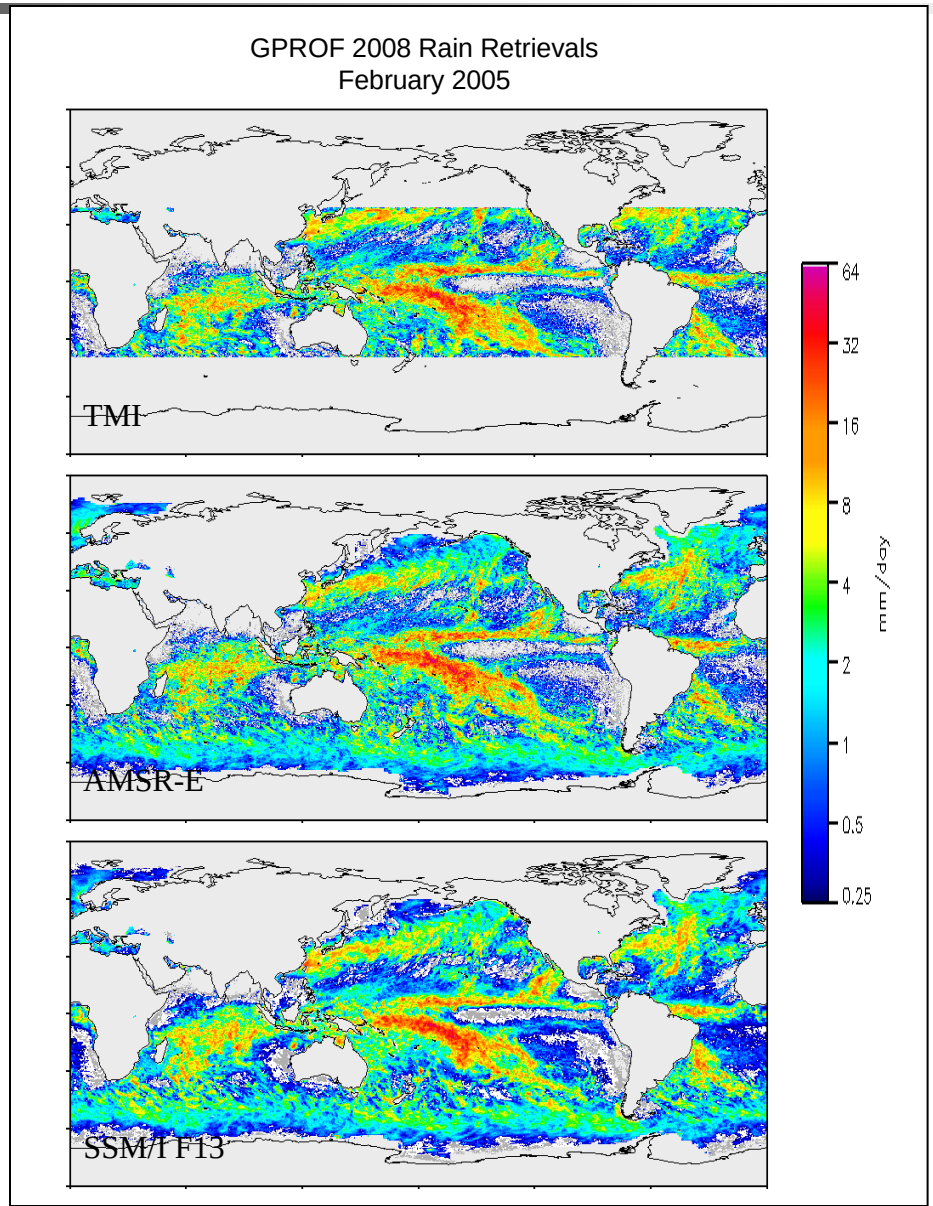
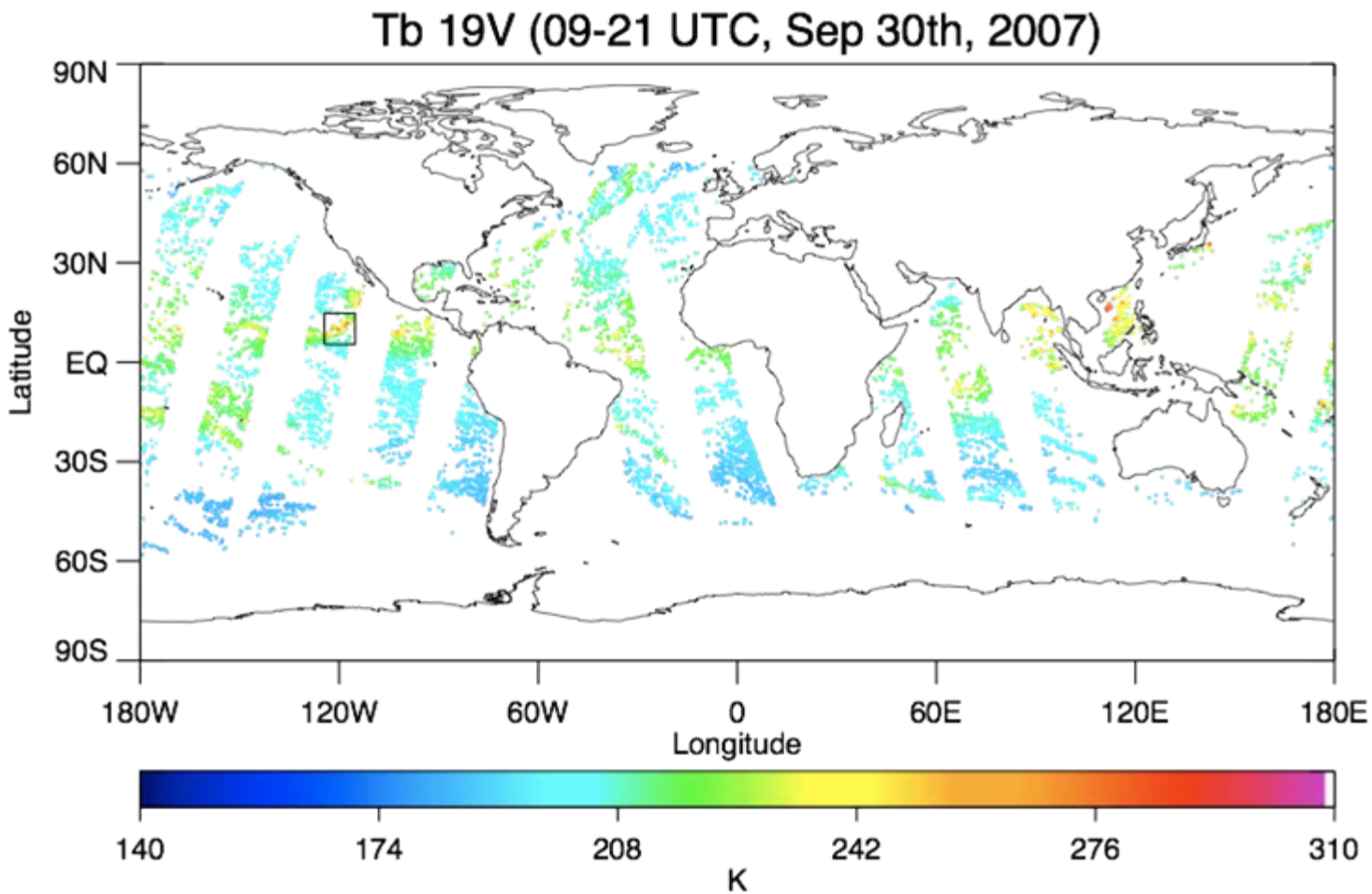
GPROF 2008 Retrieval (Physical Databases)



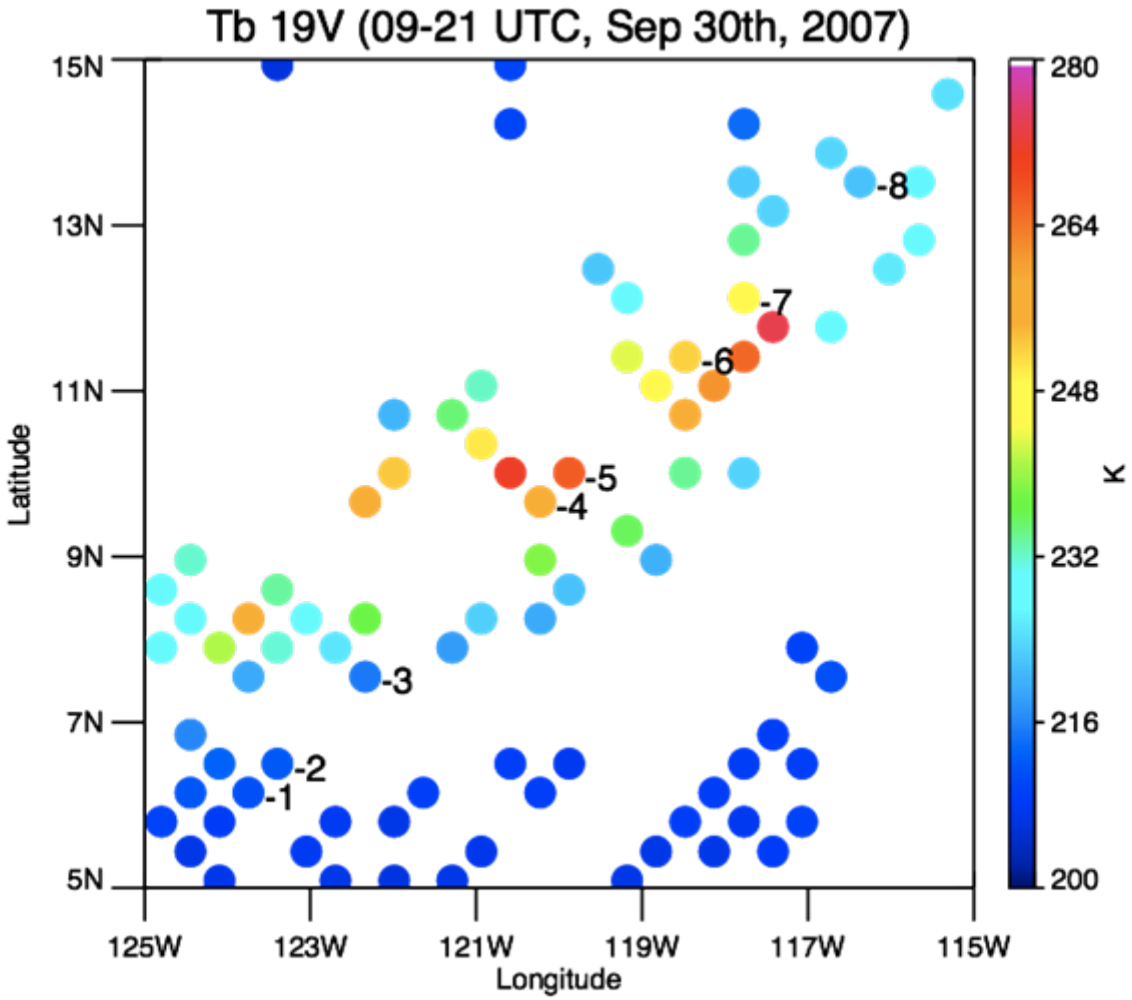
Retrieval Summary (Oceans)

- *Oceanic algorithm is more or less completed in tropics*
- *Bayesian retrieval seems very robust for its simplicity and ability to generate uncertainties.*
- *Future need to improved combined algorithm to serve as a-priori database.*
- *High latitude still a problem for SST/TPW not observed by TRMM. GPM will take next step forward.*
- *Database of observed profiles and corresponding Tb should also match radiance assimilation schemes*

ECMWF Assimilated Pixels (SSMI)

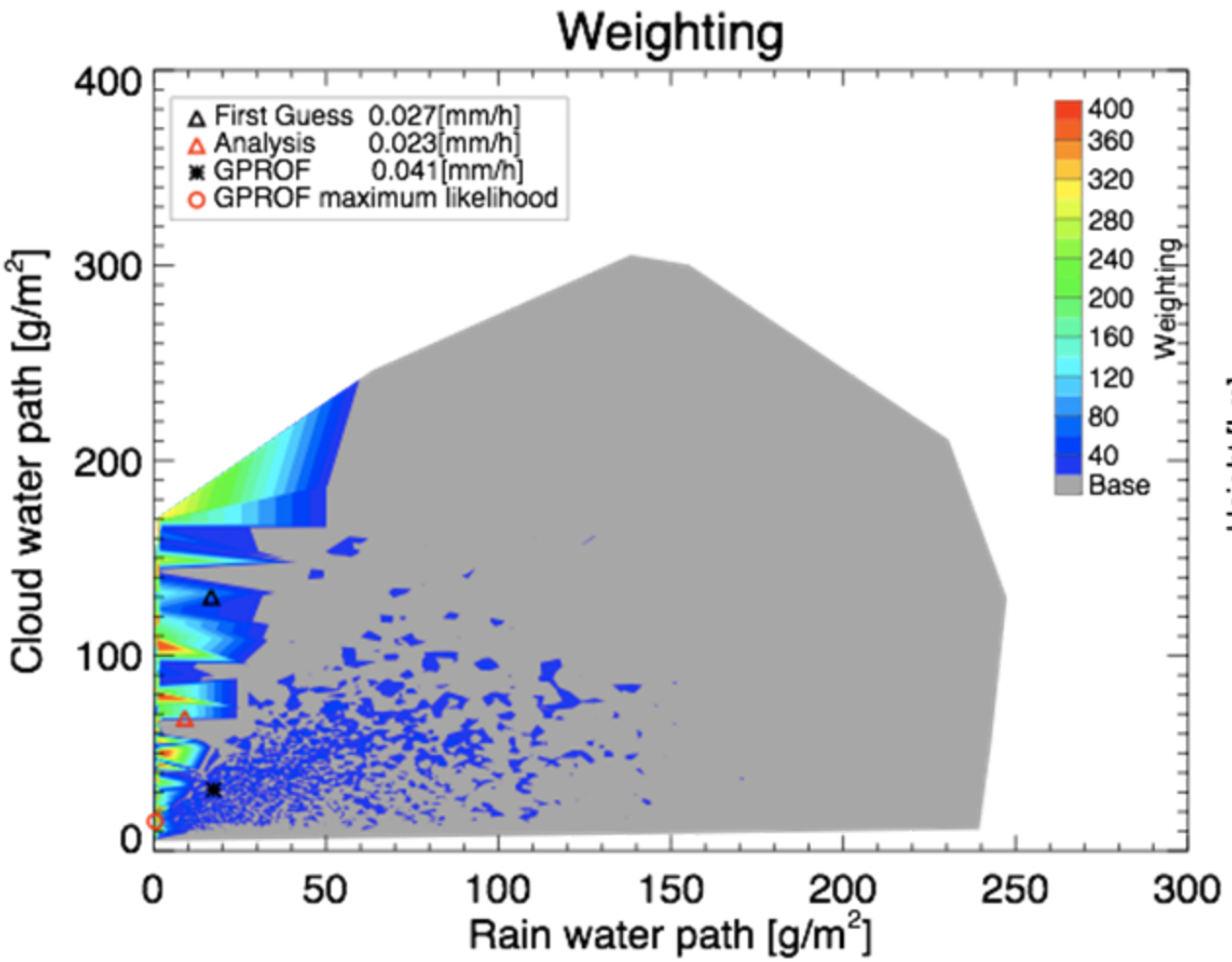


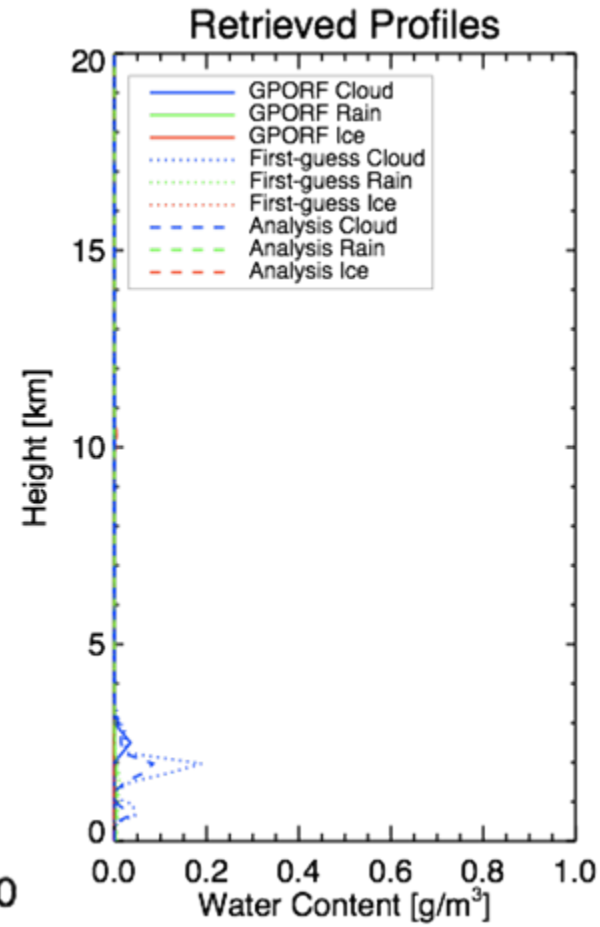
ECMWF Assimilated Pixels (SSMI)



Database, 1st guess, analysis and retrieved rainfall

Pixel #1





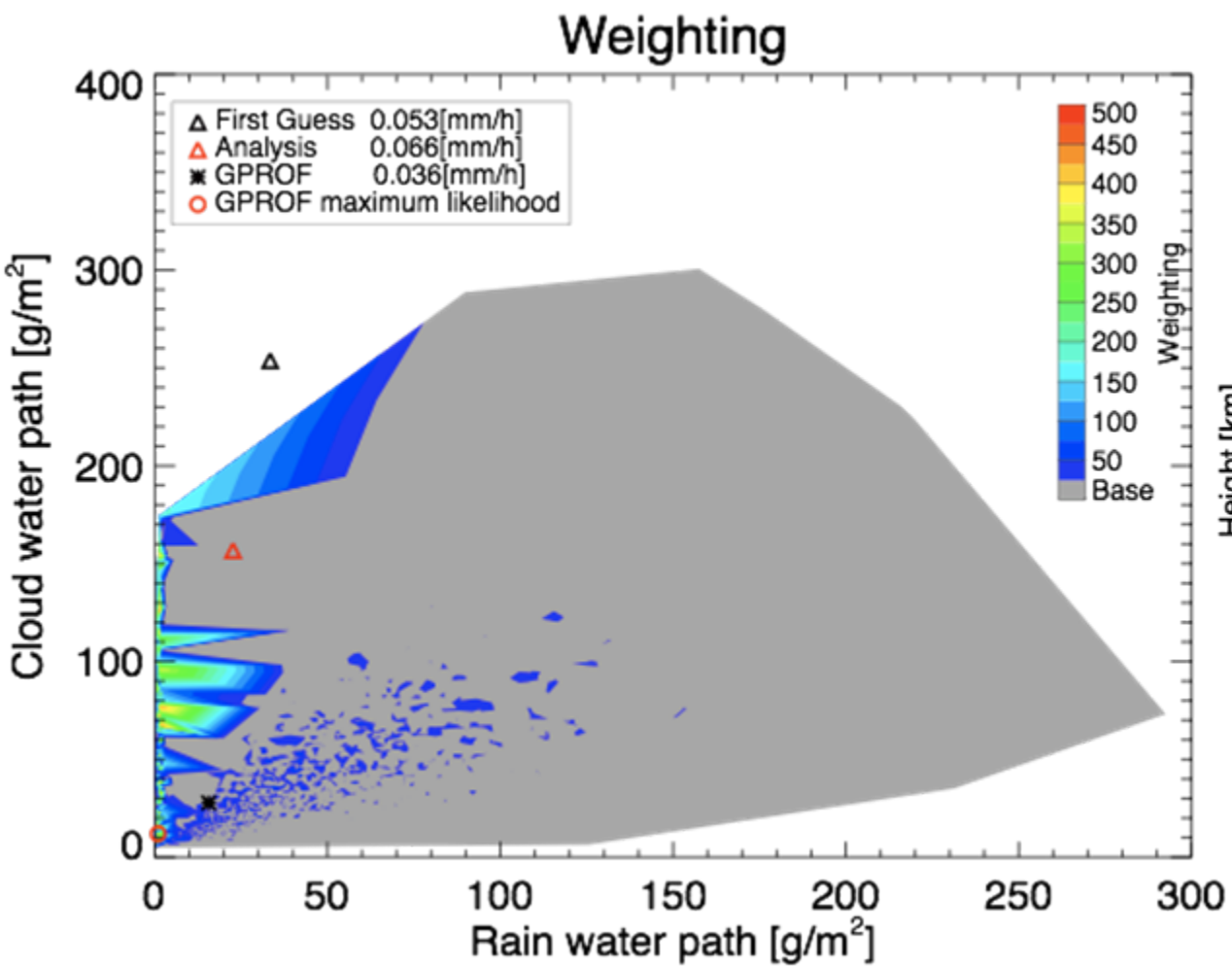
Retrieval and Model Biases

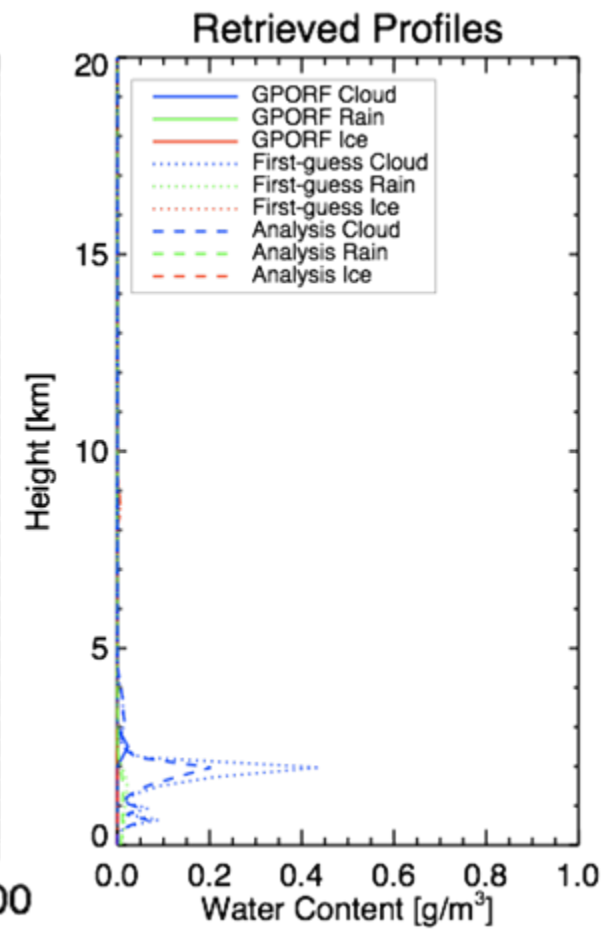
Pixel #1

Tb biases	**19V**	**19H**	**22V**	37V	37H	85V	85H
GPROF maximum likelihood	2.177	0.471	0.546	1.417	5.109	0.354	-4.56
ECMWF 1DVAR First Guess	1.662 (1.706)	5.583 (5.546)	1.739 (-0.246)	0.061 (4.704)	1.990 (6.446)	0.748 (3.064)	2.414 (5.362)
ECMWF 1DVAR Analysis	-0.236 (-0.192)	2.104 (2.067)	-0.204 -2.207)	-3.461 (1.182)	-4.904 (-0.447)	-1.628 (0.688)	-3.790 (-0.842)

Database, 1st guess, analysis and retrieved rainfall

Pixel #3





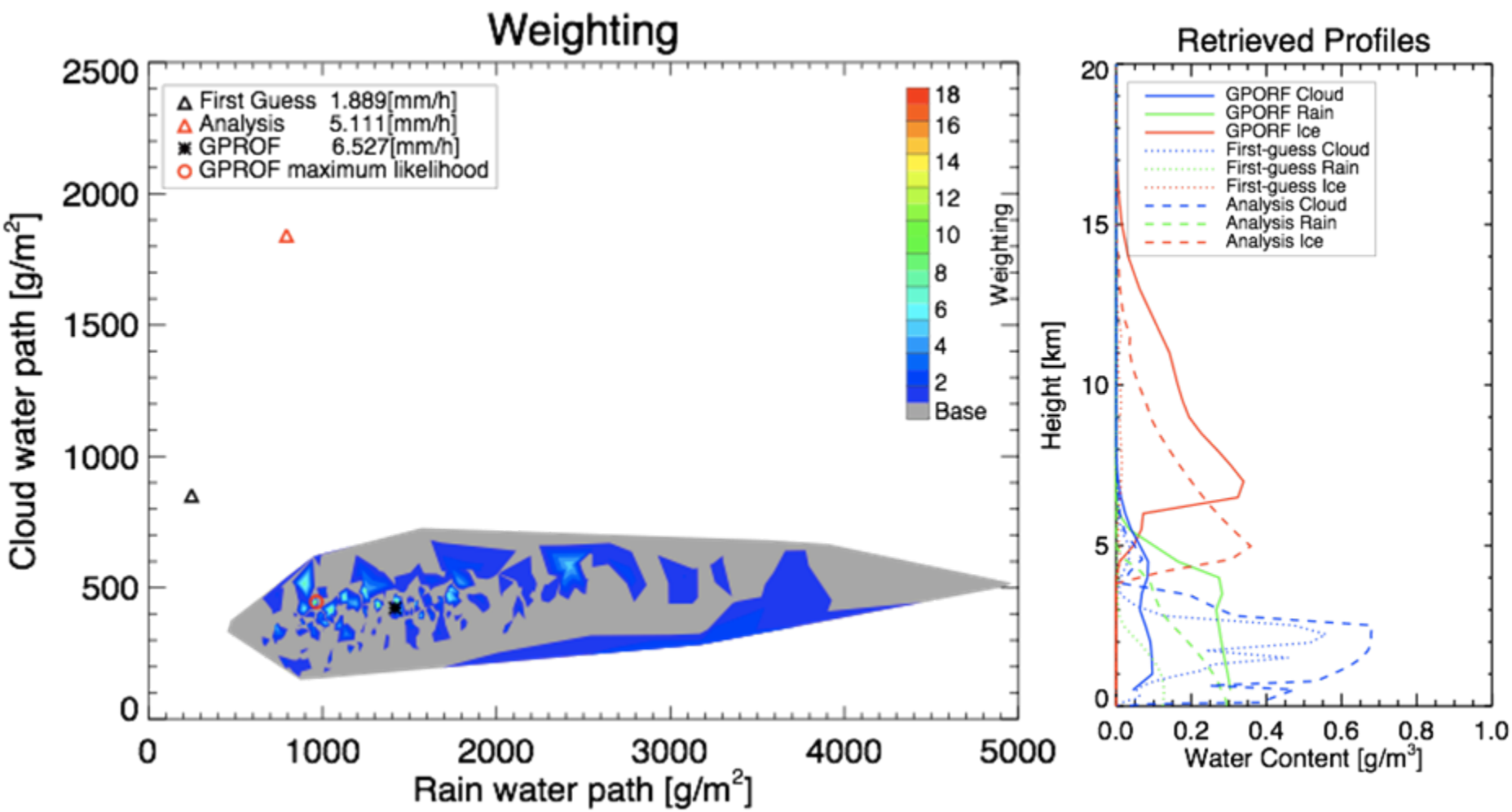
Retrieval and Model Biases

Pixel #3

Tb biases	**19V**	**19H**	**22V**	37V	37H	85V	85H
GPROF maximum likelihood	-1.773	0.124	-0.591	0.580	-1.220	0.394	-3.207
ECMWF 1DVAR First Guess	2.110 (2.299)	5.392 (5.764)	0.143 (-1.756)	4.578 (10.126)	9.865 16.257)	2.918 (5.864)	5.817 (10.654)
ECMWF 1DVAR Analysis	0.323 (0.511)	2.046 (2.418)	-1.057 (-2.956)	0.431 (5.979)	1.705 (8.097)	1.154 (4.082)	0.945 (5.782)

Database, 1st guess, analysis and retrieved rainfall

Pixel #5



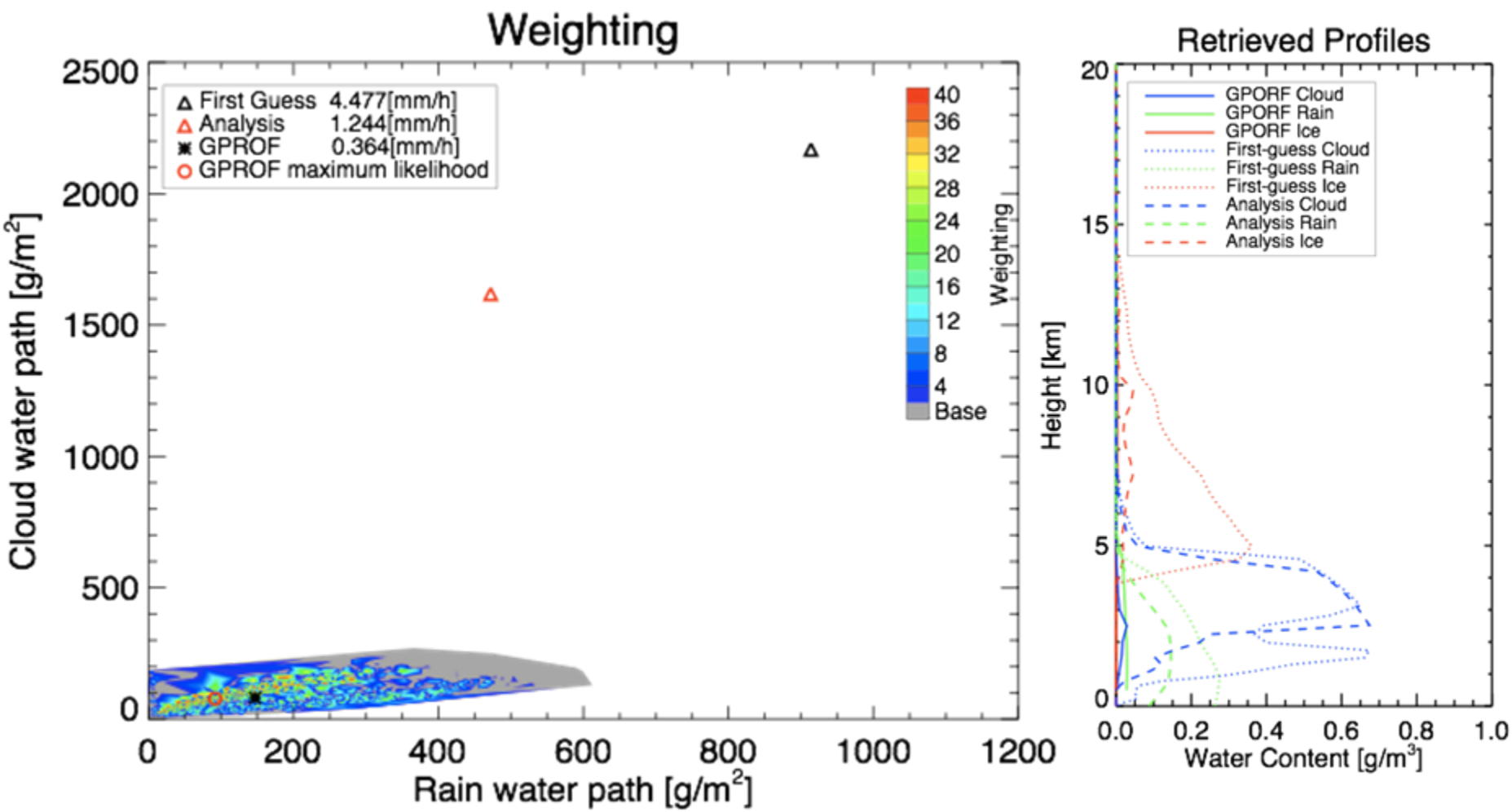
Retrieval and Model Biases

Pixel #5

Tb biases	**19V**	**19H**	**22V**	37V	37H	85V	85H
GPROF maximum likelihood	0.041	-0.912	-0.843	-1.224	0.001	-1.971	5.356
ECMWF 1DVAR First Guess	-30.448 (-21.418)	-57.784 (-40.638)	-9.600 (-7.899)	-13.397 (0.218)	-38.077 (-11.516)	41.604 (41.055)	40.655 (47.649)
ECMWF 1DVAR Analysis	-9.190 (-0.160)	-19.011 (-1.866)	-2.200 (-0.499)	-9.310 (4.305)	-19.629 (6.932)	13.160 (12.611)	12.515 (19.509)

Database, 1st guess, analysis and retrieved rainfall

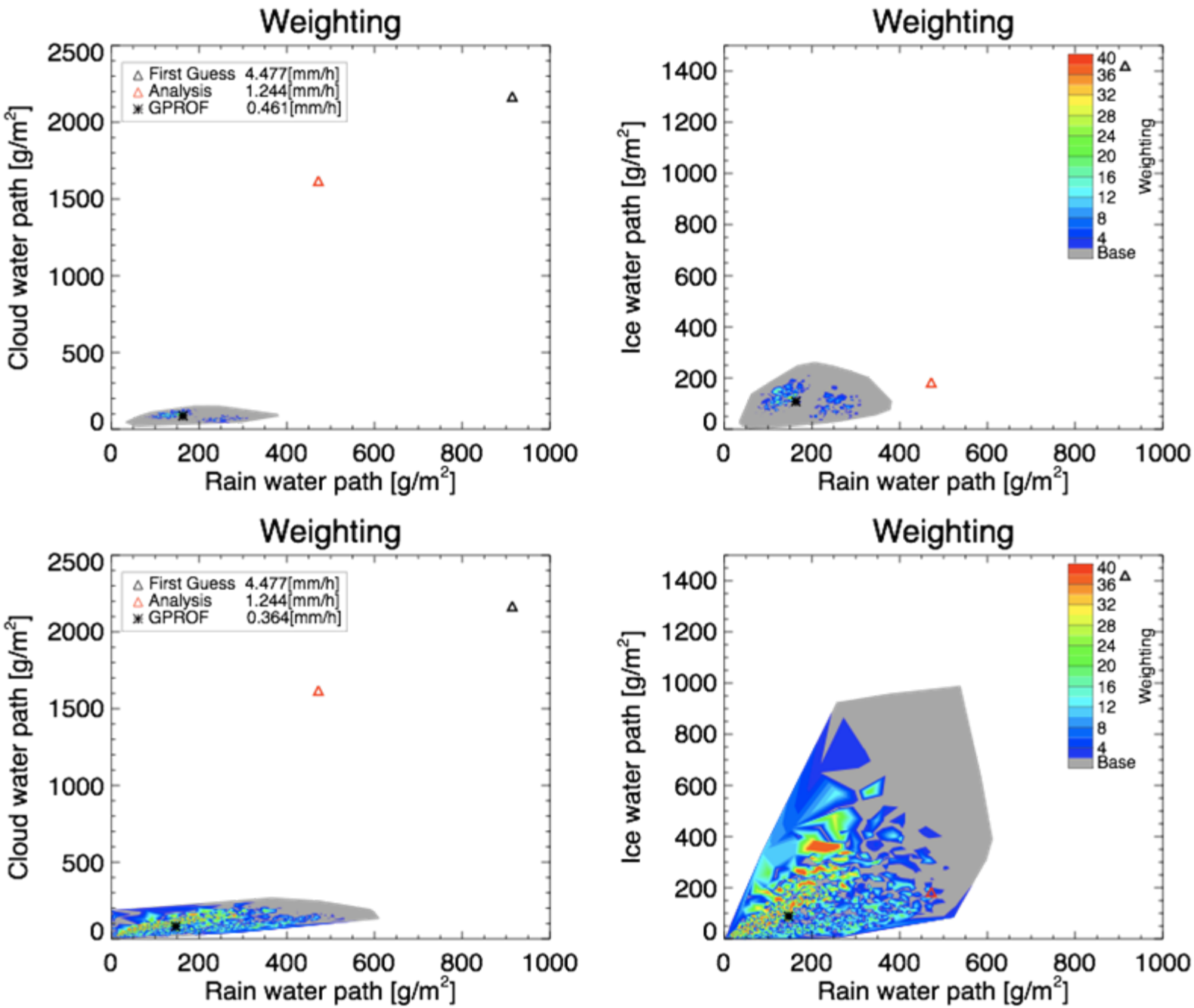
Pixel #7



Retrieval and Model Biases

Pixel #7

Tb biases	**19V**	**19H**	**22V**	37V	37H	85V	85H
GPROF maximum likelihood	0.191	1.105	0.222	-1.719	-6.165	4.629	4.288
ECMWF 1DVAR First Guess	13.212 (35.615)	23.246 (64.634)	4.788 (11.749)	6.430 (29.608)	13.467 (64.657)	-12.303 (-20.530)	-15.873 (-12.230)
ECMWF 1DVAR Analysis	0.684 (23.087)	-0.603 (40.785)	1.809 (8.770)	10.979 (34.158)	13.266 (64.456)	6.872 (-1.355)	3.283 (6.925)


Weighting
First Guess 4.477[mm/h]
Analysis 1.244[mm/h]
GPROF 0.461[mm/h]
Cloud water path [g/m2]
Rain water path [g/m2]
Weighting
Ice water path [g/m2]
Rain water path [g/m2]
Weighting
First Guess 4.477[mm/h]
Analysis 1.244[mm/h]
GPROF 0.364[mm/h]
Cloud water path [g/m2]
Rain water path [g/m2]
Weighting
Ice water path [g/m2]
Rain water path [g/m2]
Weighting
Base

Conclusions