



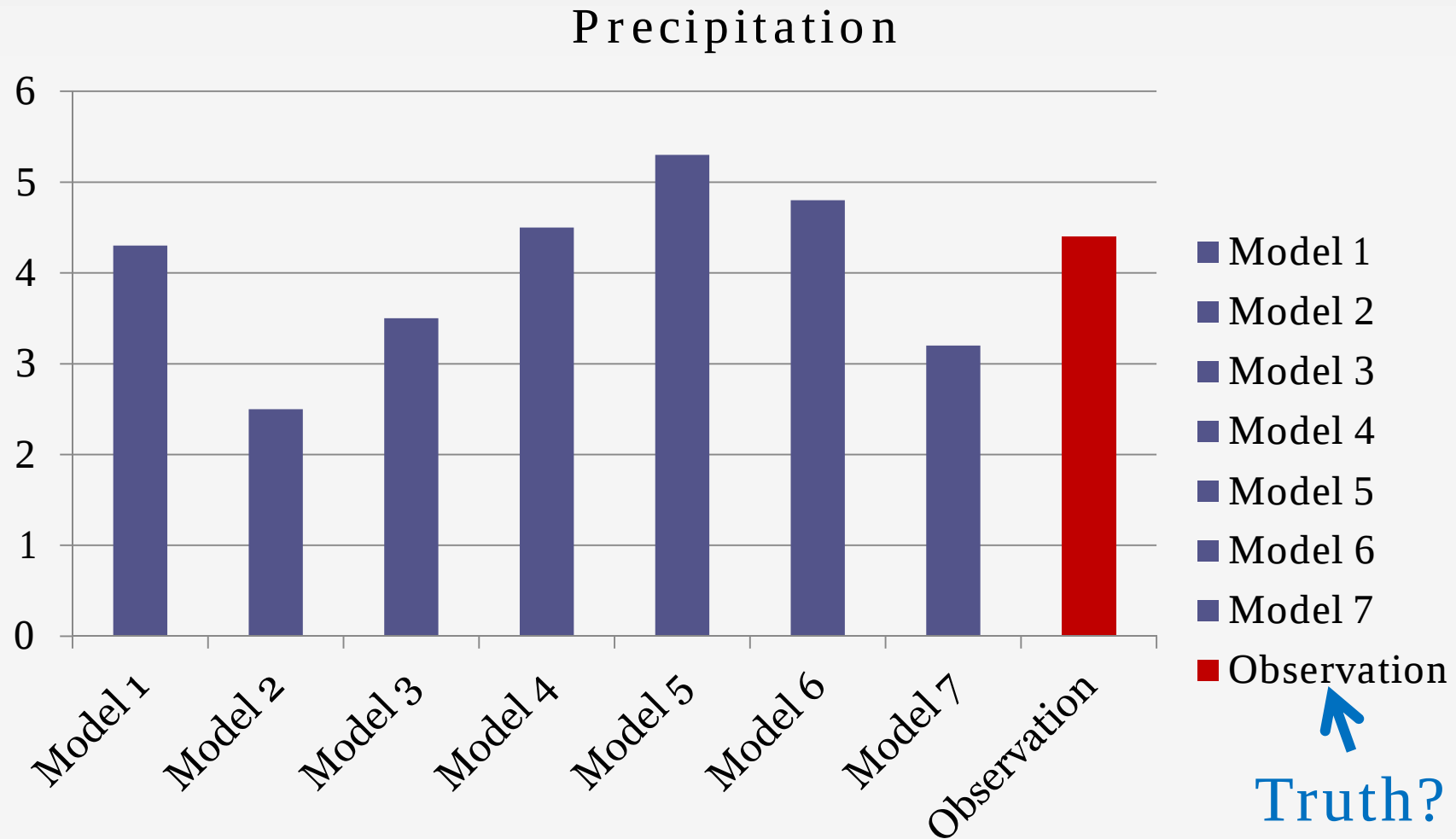
主として数値モデル検証ツールとしての

衛星データシミュレータが拓く可能性と課題

増永浩彦

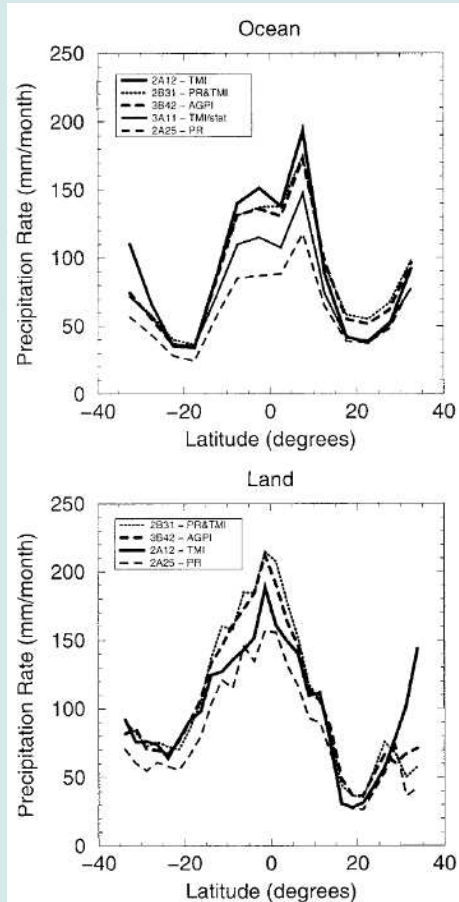
名古屋大学地球水循環研究センター

Model comparison with “the” observation

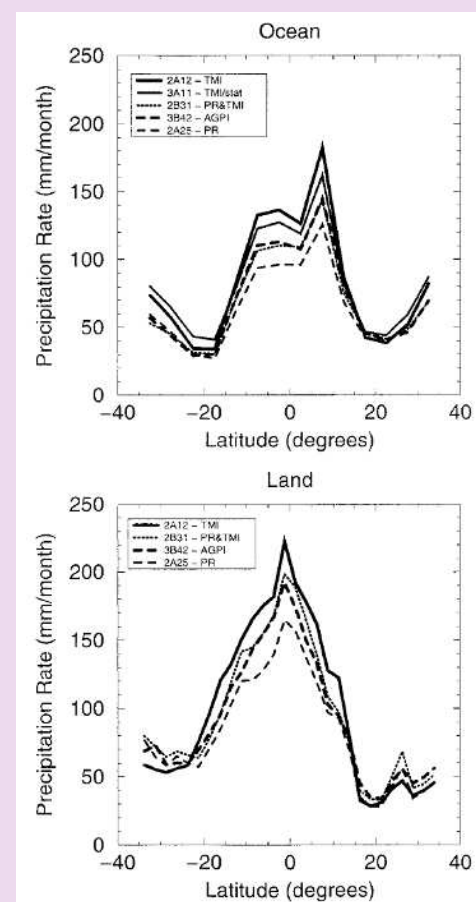


Is there any “truth” that you could rely on?

TRMM Rainfall Product Ver. 4

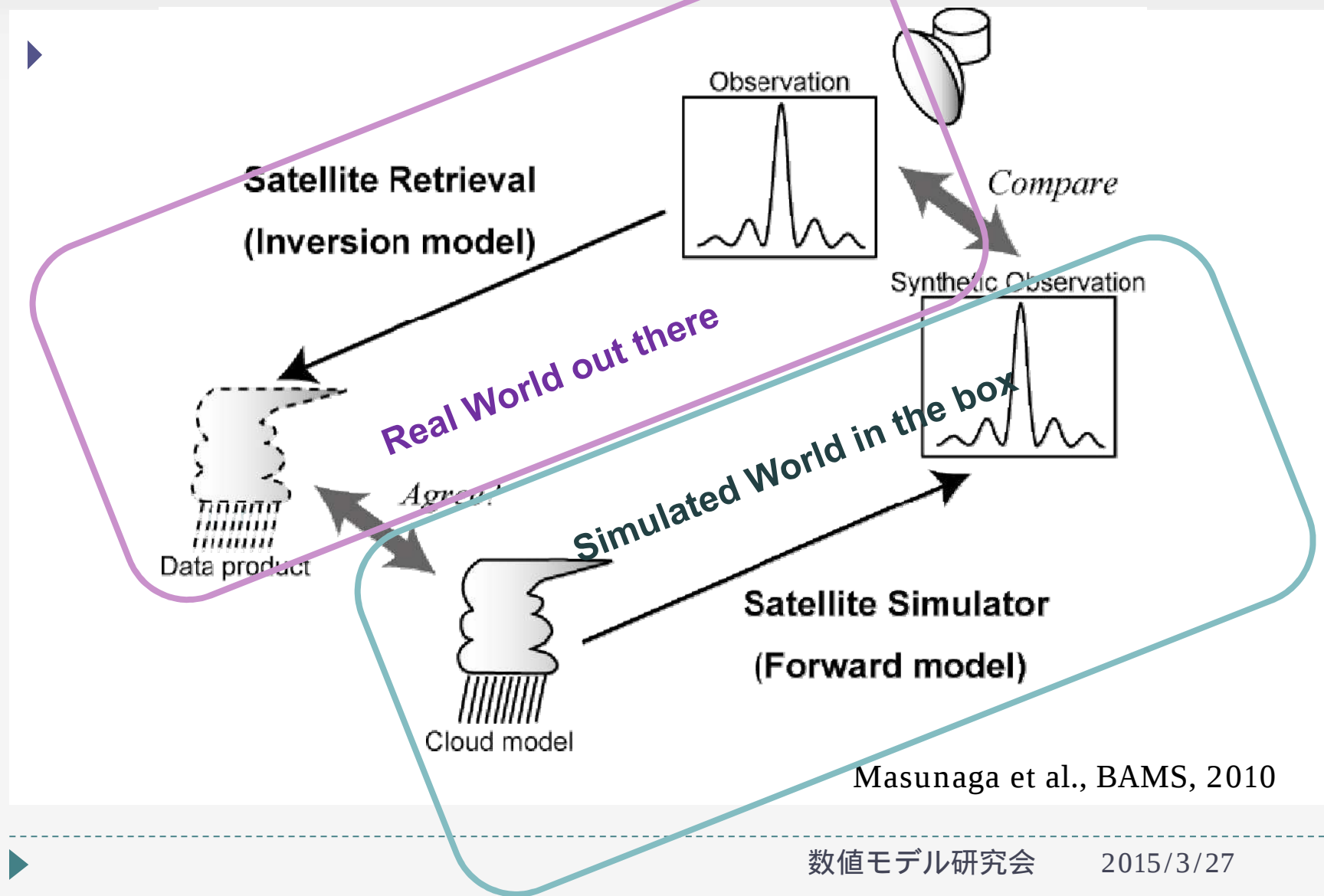


TRMM Rainfall Product Ver. 5

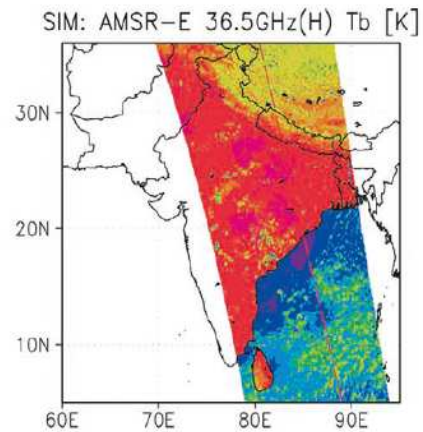
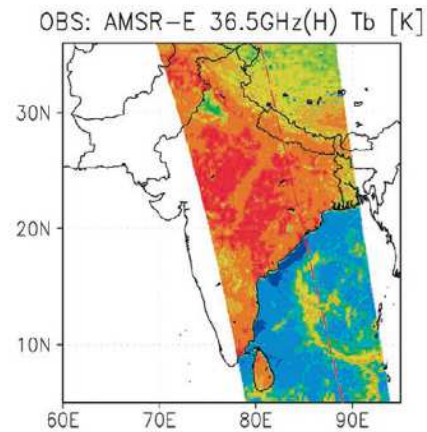


Kummerow et al., *J. App. Meteor.*, 2000

Why do satellite simulators do?

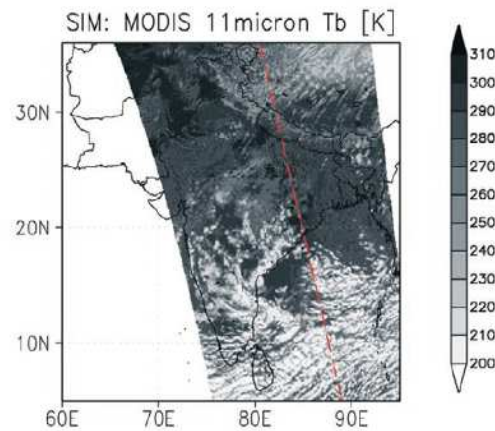
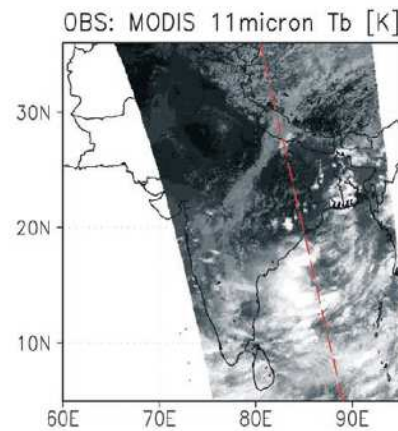


Observed
 μ -wave T_b
at 37 GHz



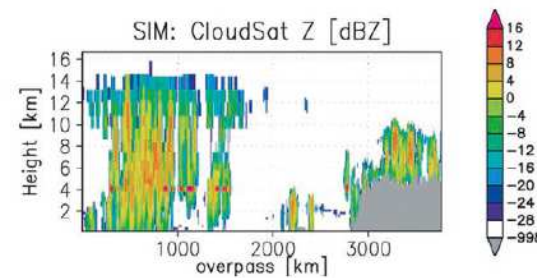
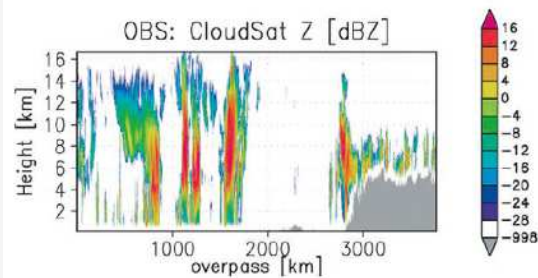
Simulated
 μ -wave T_b
at 37 GHz

Observed
infrared T_b
at 11 μ m



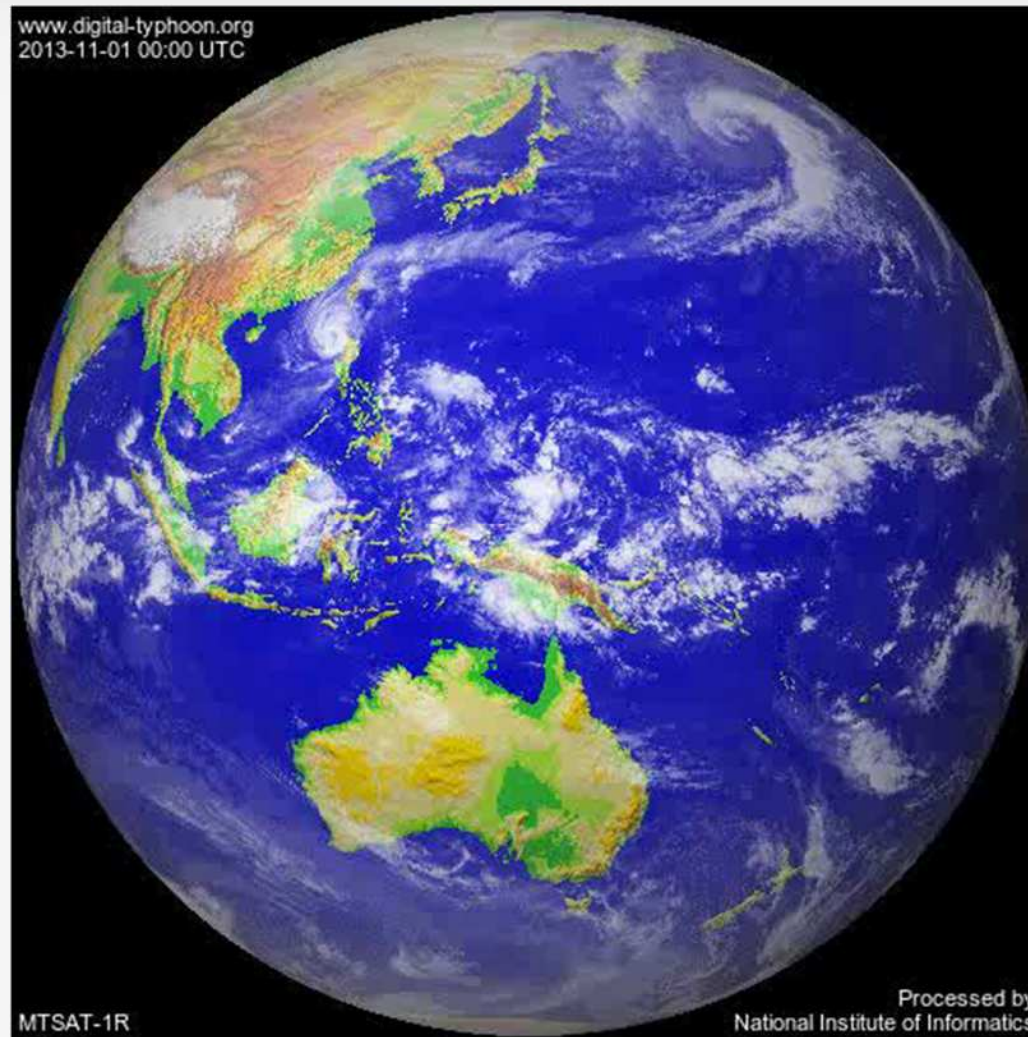
Simulated
infrared T_b
at 11 μ m

Observed
radar dBZ
at 95 GHz

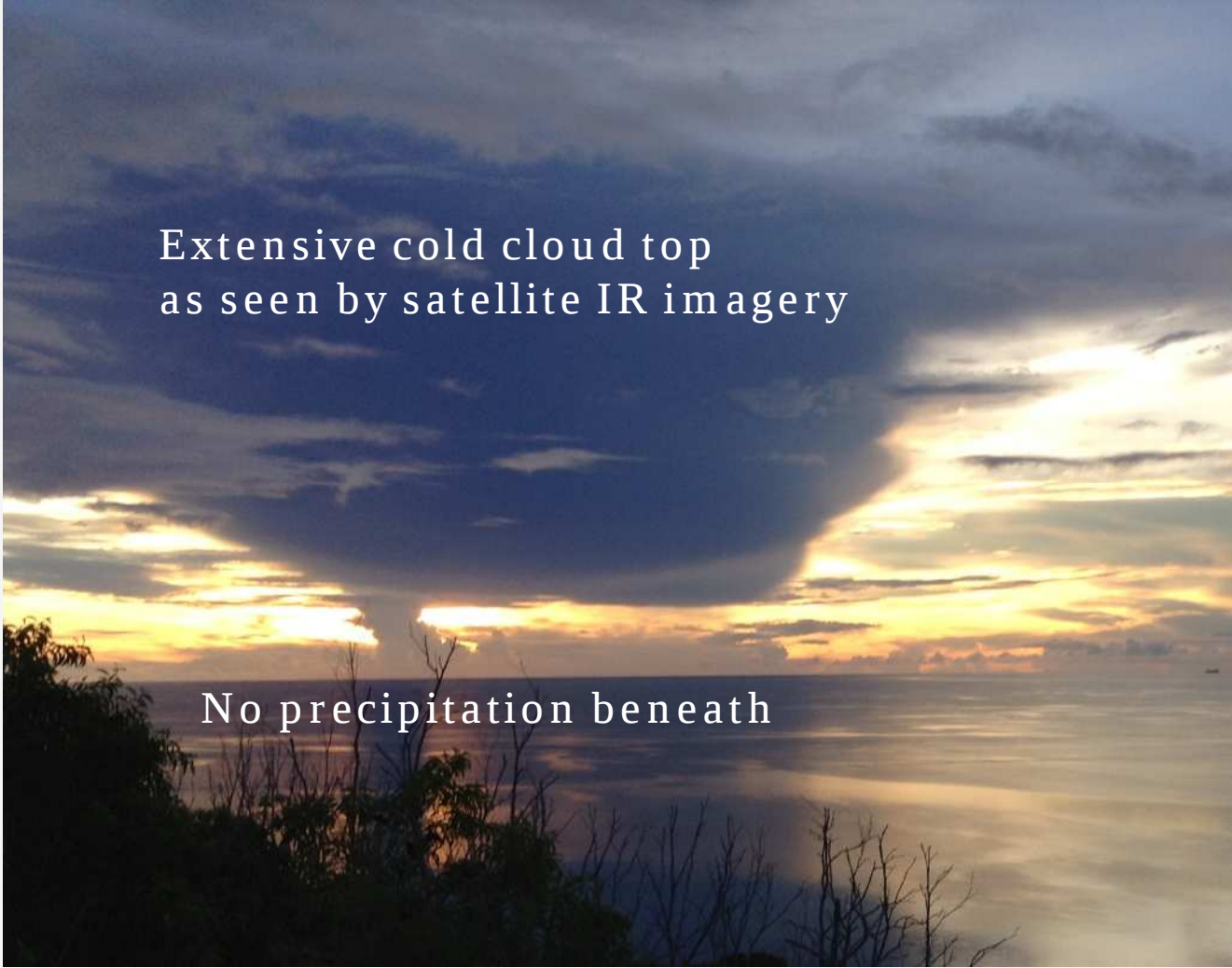


Simulated
radar dBZ
at 95 GHz

Geostationary infrared imagery (Nov. 2013)



What lies beneath a high cloud?



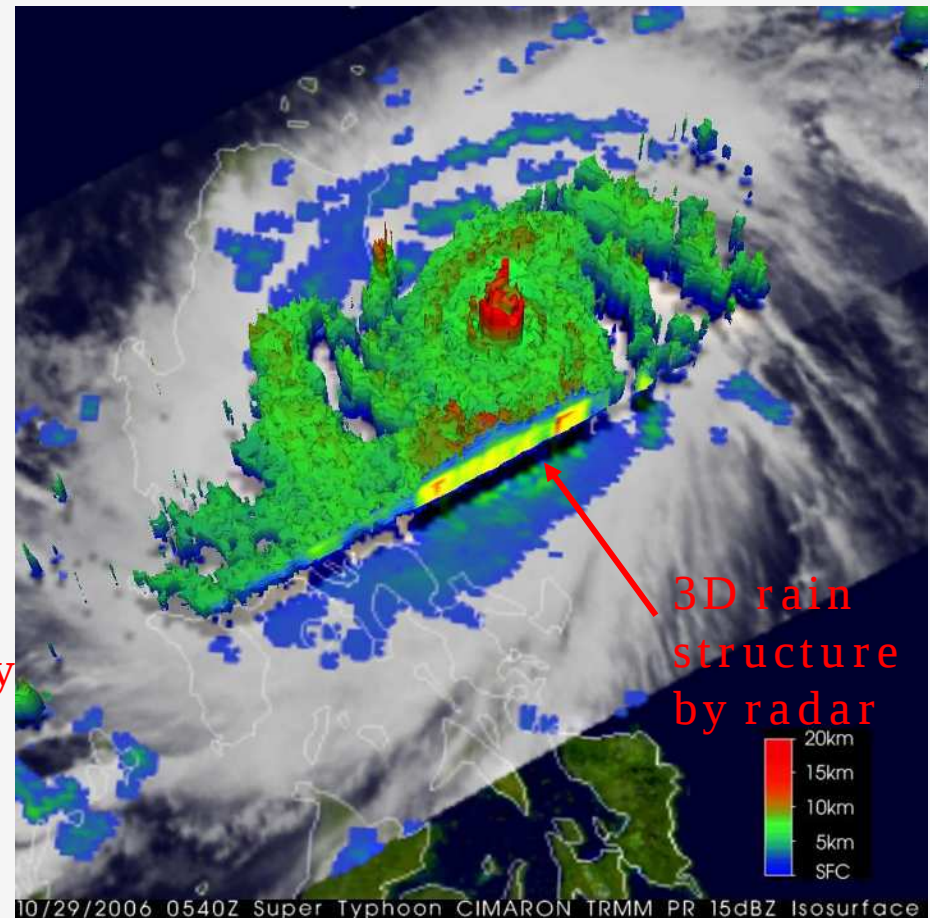
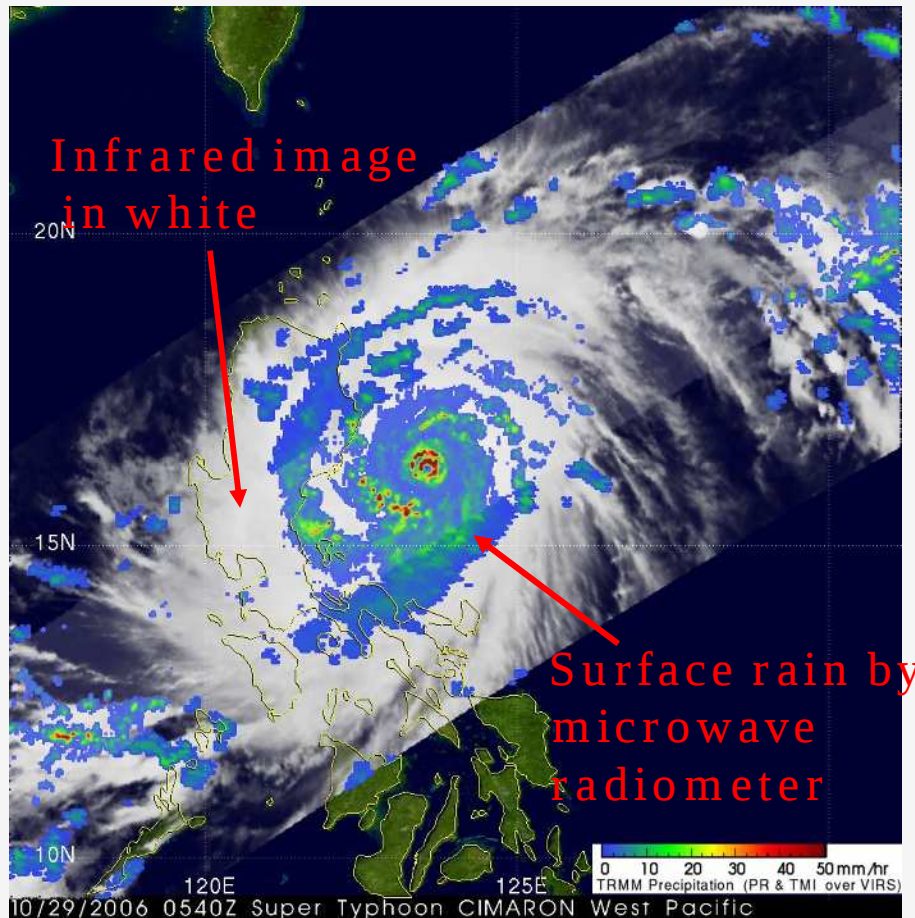
Extensive cold cloud top
as seen by satellite IR imagery

No precipitation beneath



Infrared versus microwave measurements

Typhoon Cimaron (2006) observed by the Tropical Rainfall Measuring Mission (TRMM) satellite
http://trmm.gsfc.nasa.gov/publications_dir/extreme_events.html



マイクロ波放射計と 衛星シミュレータ（概論）



Microwave effects on cloud and precip.

► Microwave radiative transfer equation

$$\frac{dT_b}{d\tau_\nu} = \underbrace{-T_b}_{\text{Extinction (Absorption + Shielding by scattering)}} + \underbrace{(1-\omega_\nu)T}_{\text{Thermal emission}} + \underbrace{\omega_\nu \int P_\nu(\Omega, \Omega') T_b' d\Omega'}_{\text{Confluence by scattering}}$$

* Low frequencies

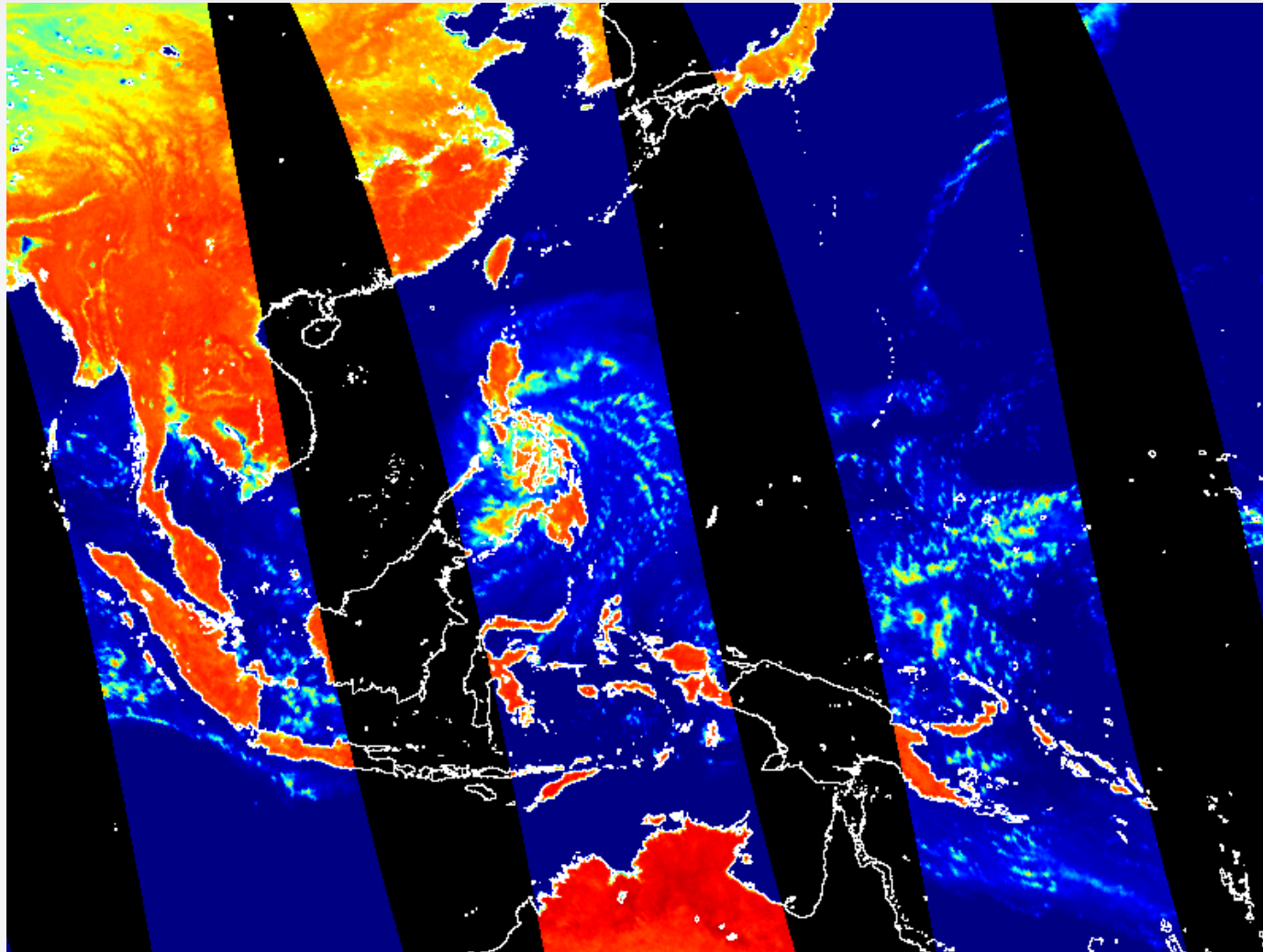
Absorption

Thermal
emission

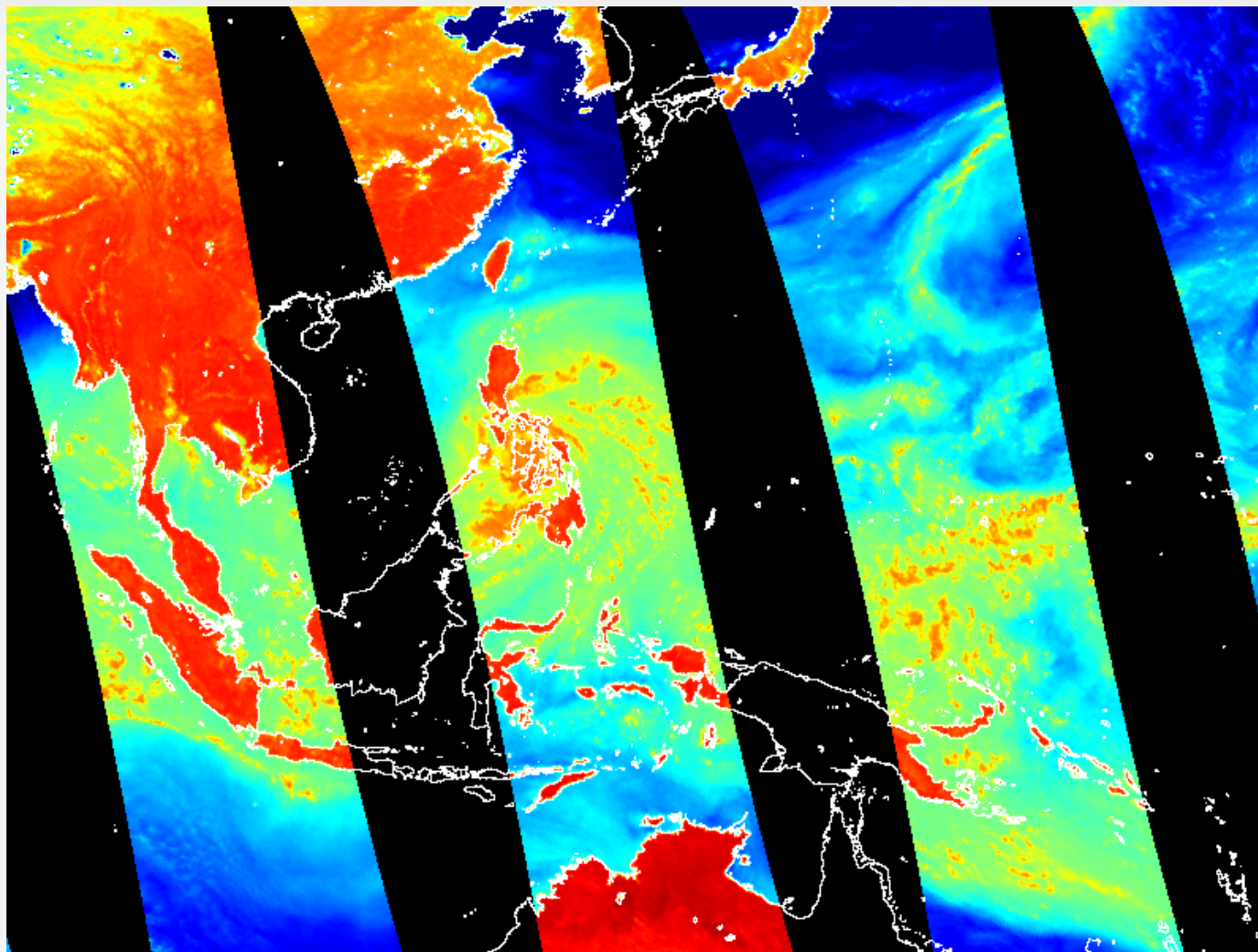
* High frequencies

Shielding by
scattering

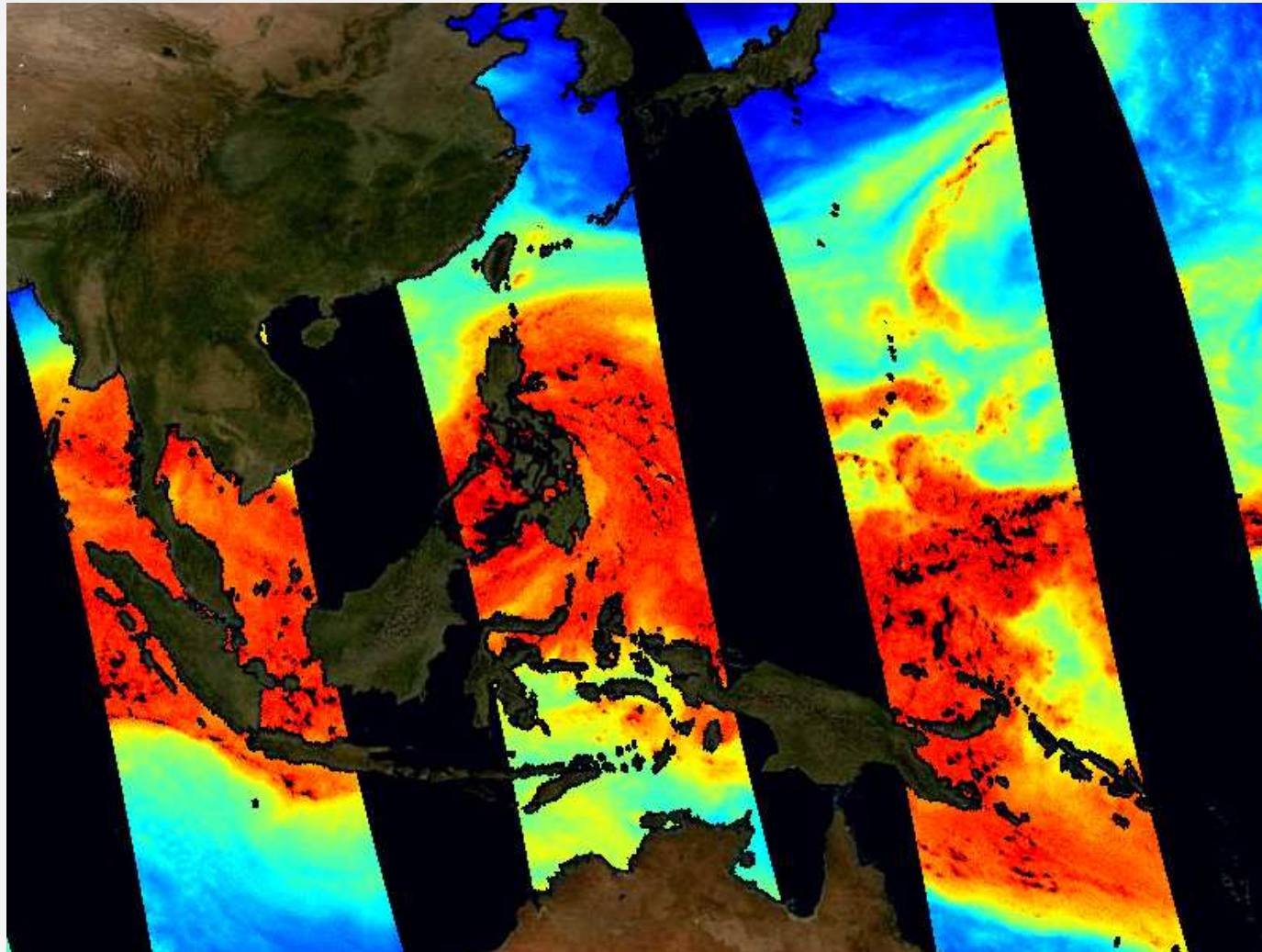
18GHz Brightness Temperature



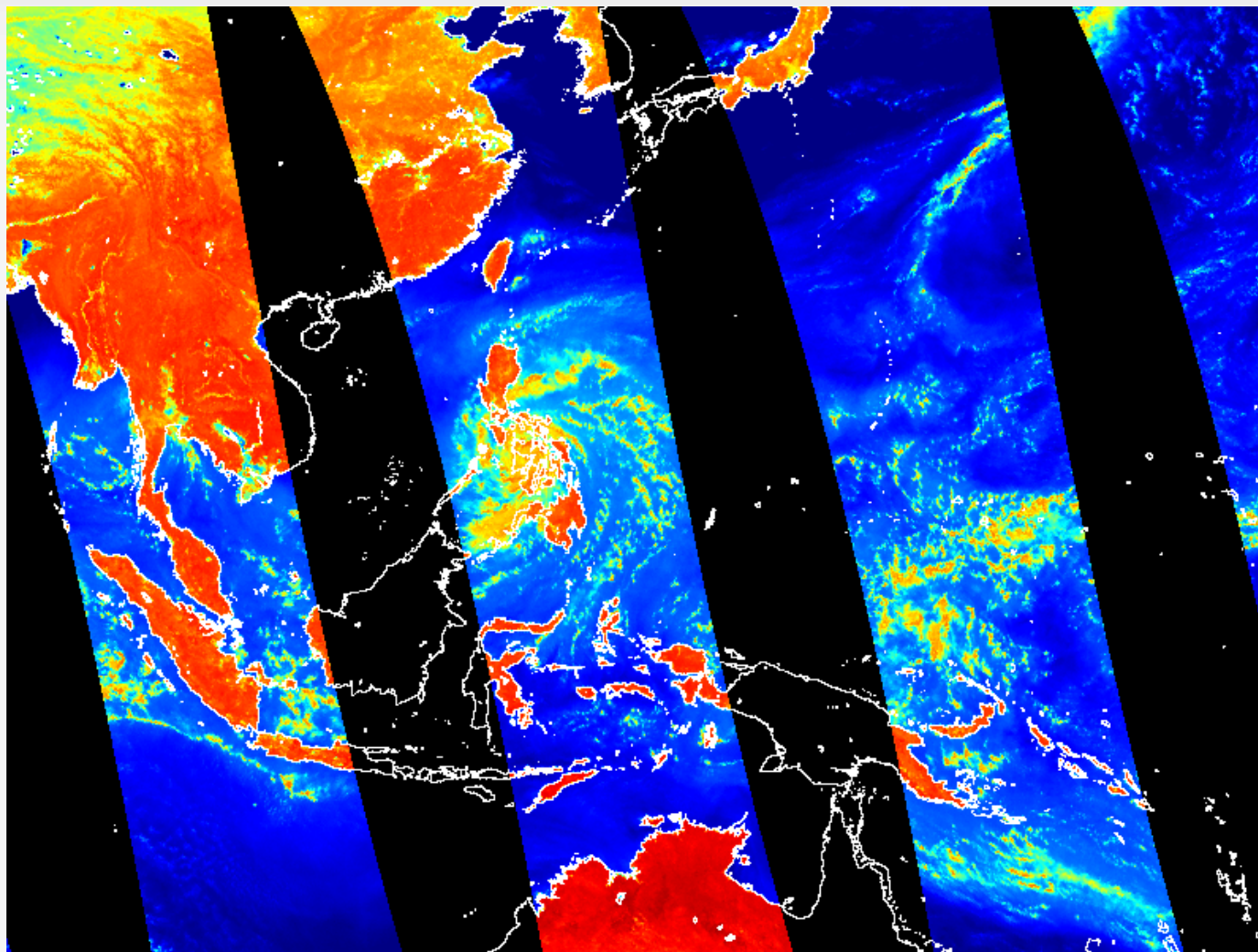
23GHz Brightness Temperature



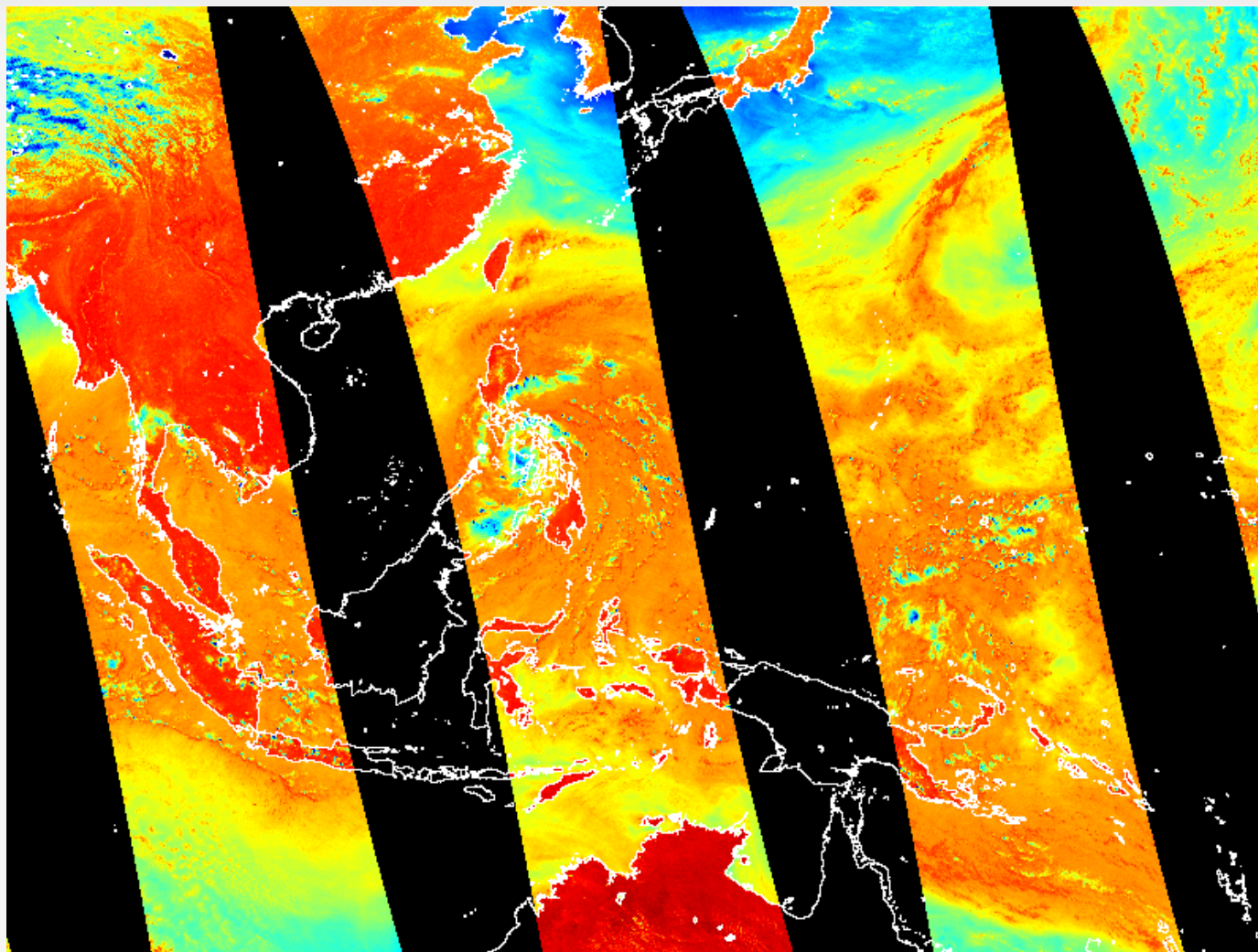
Precipitable Water (Column Water Vapor)



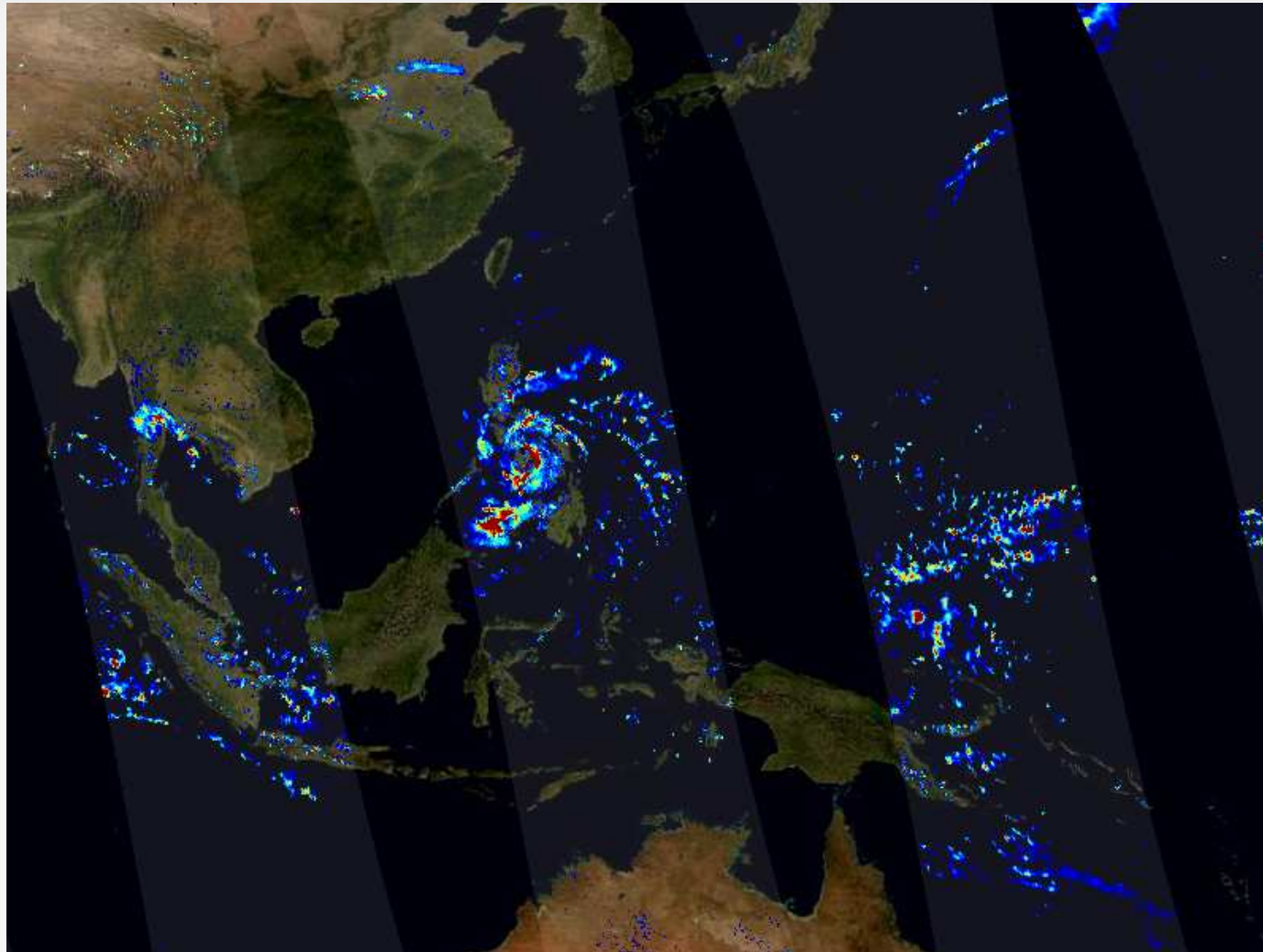
36GHz Brightness Temperature



89GHz Brightness Temperature



Surface Precipitation



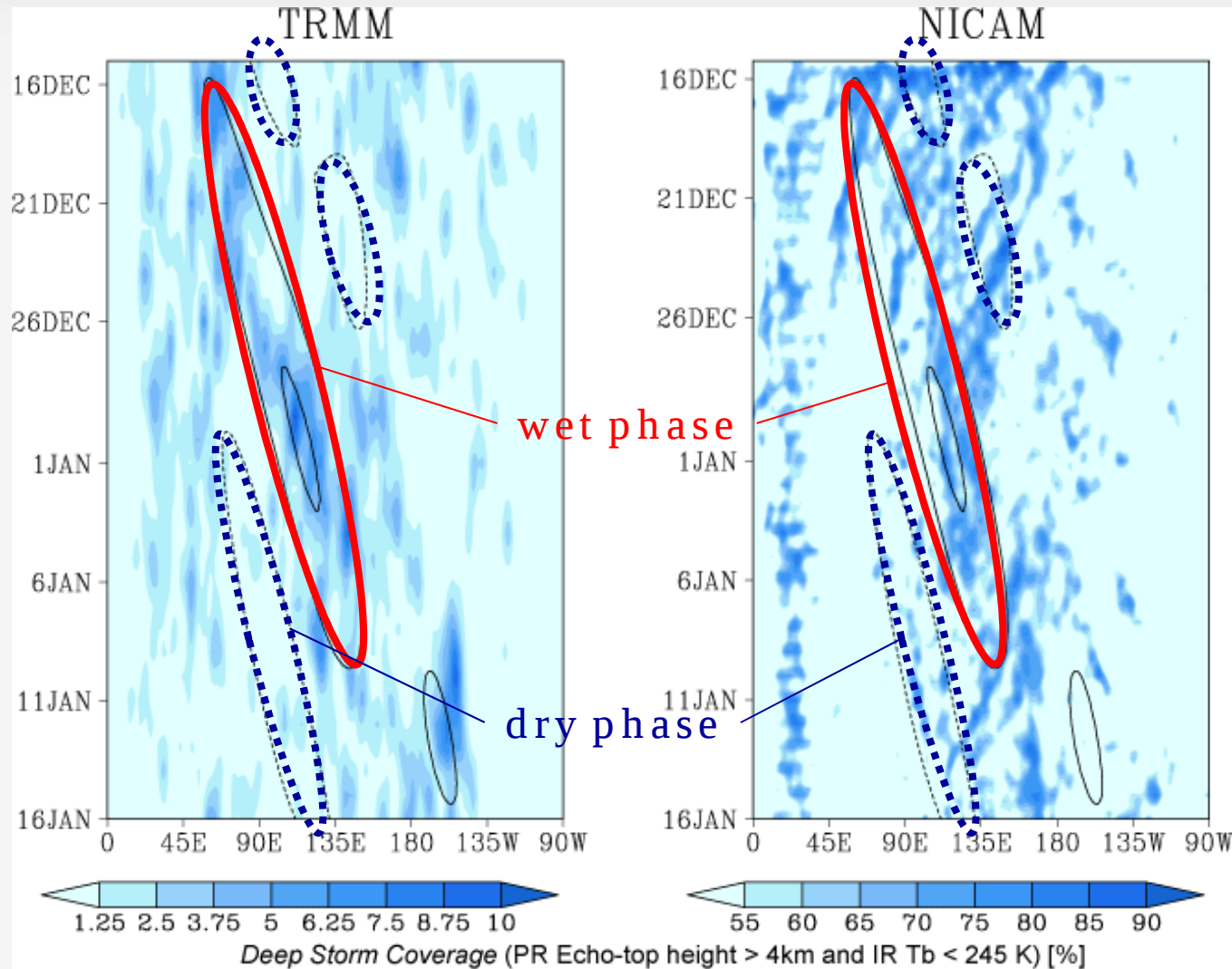
雲・降水レーダと 衛星シミュレータ（研究例）

Masunaga, Satoh, and Miura, *JGR* (2008)

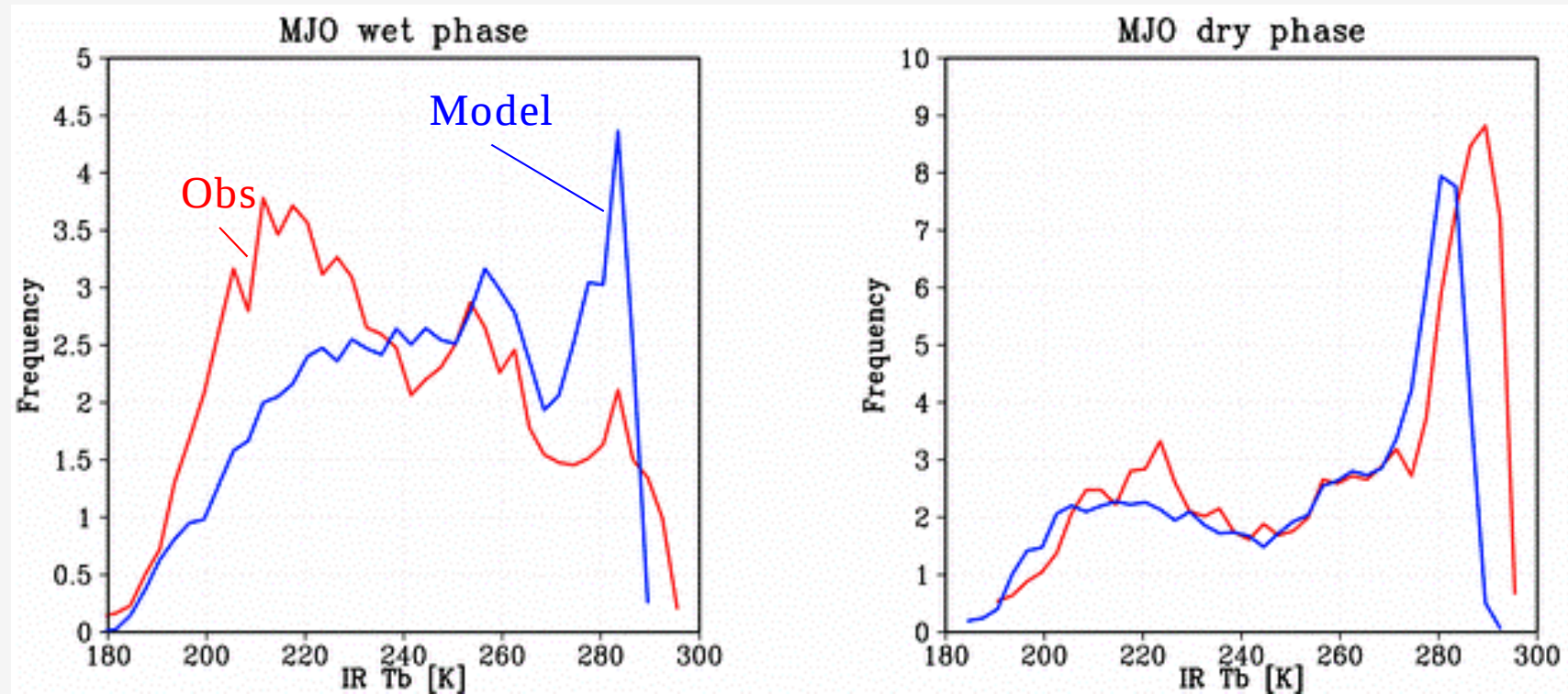


TRMM/NICAM MJO in the Hovmöller diagram

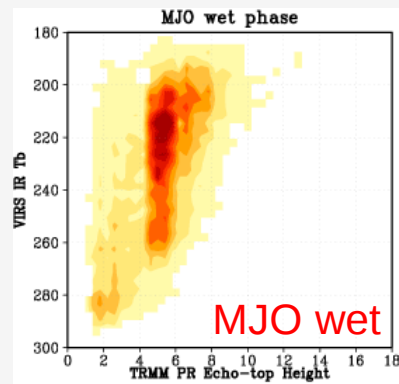
The MJO is filtered by 20-80 day and $k=1-7$



Infrared histogram: model vs. satellite

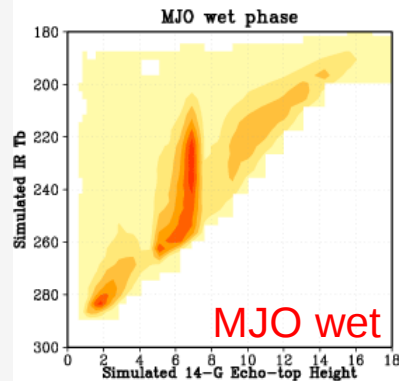


Cloud and Precip Top Heights (CTH and PTH)

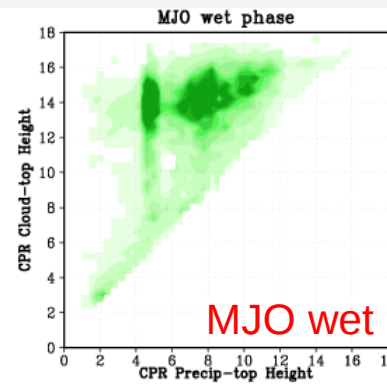


← TRMM
PR&VIRS

Infrared T_b
CTH
PTH
PR echo-top height

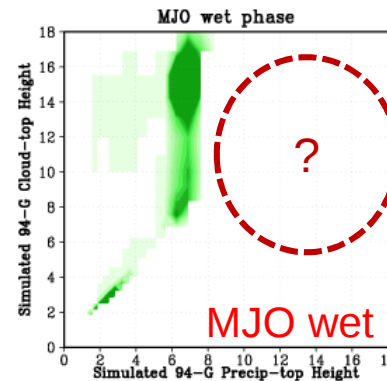


← NICAM+SDSU



← CloudSat CPR

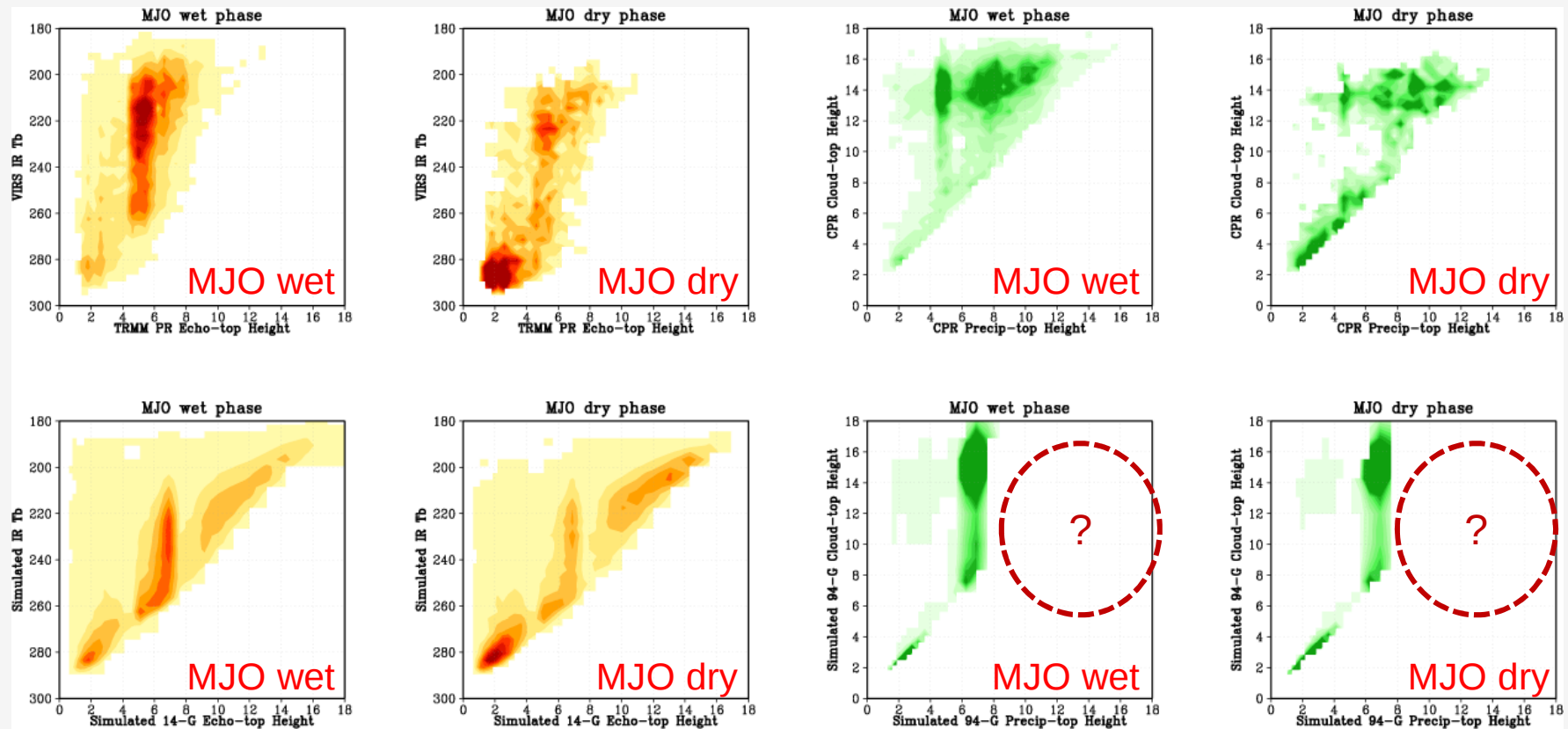
CPR echo-top height
CTH
PTH
CPR 10-dBZ height



← NICAM+SDSU

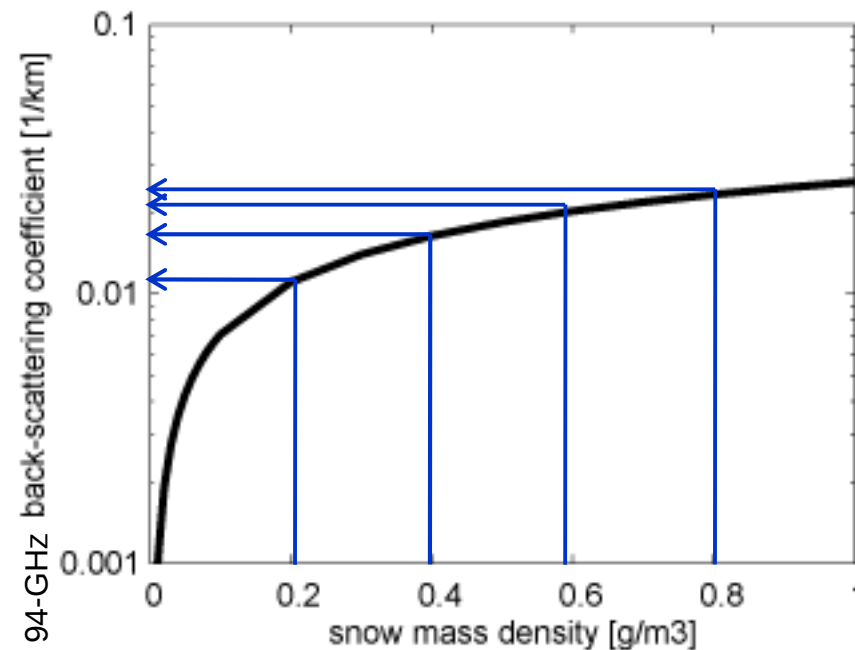


Cloud and Precip Top Heights (CTH and PTH)



Missing 94-GHz Echoes above 8 km

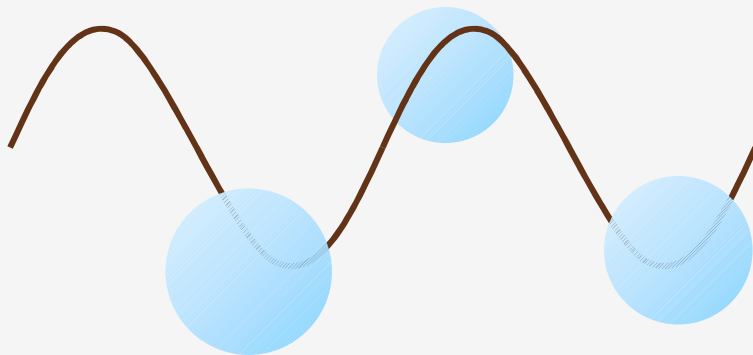
The 94-GHz back-scattering coefficient begins to be saturated due to non-Rayleigh scattering as snow content increases.



$$W = \frac{4}{3} \pi \rho N r^3 \quad \Rightarrow \quad r = \left(\frac{3W}{4\pi\rho N} \right)^{1/3}$$

Rayleigh regime

Wavelength $\gg 2\pi r$

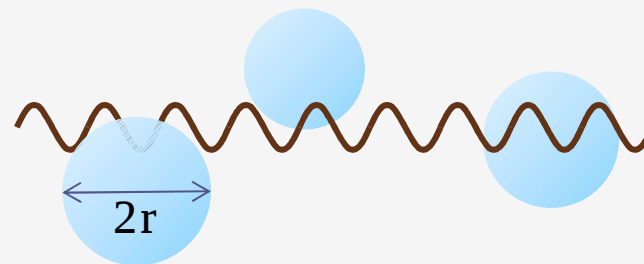


$$\sigma_s \propto N \frac{r^6}{\lambda^4} \propto \frac{W^2}{N \lambda^4}$$

$$\left. \frac{d\sigma_s}{dW} \right|_{N,\lambda} \propto W$$

Geometric optics regime

Wavelength $\ll 2\pi r$



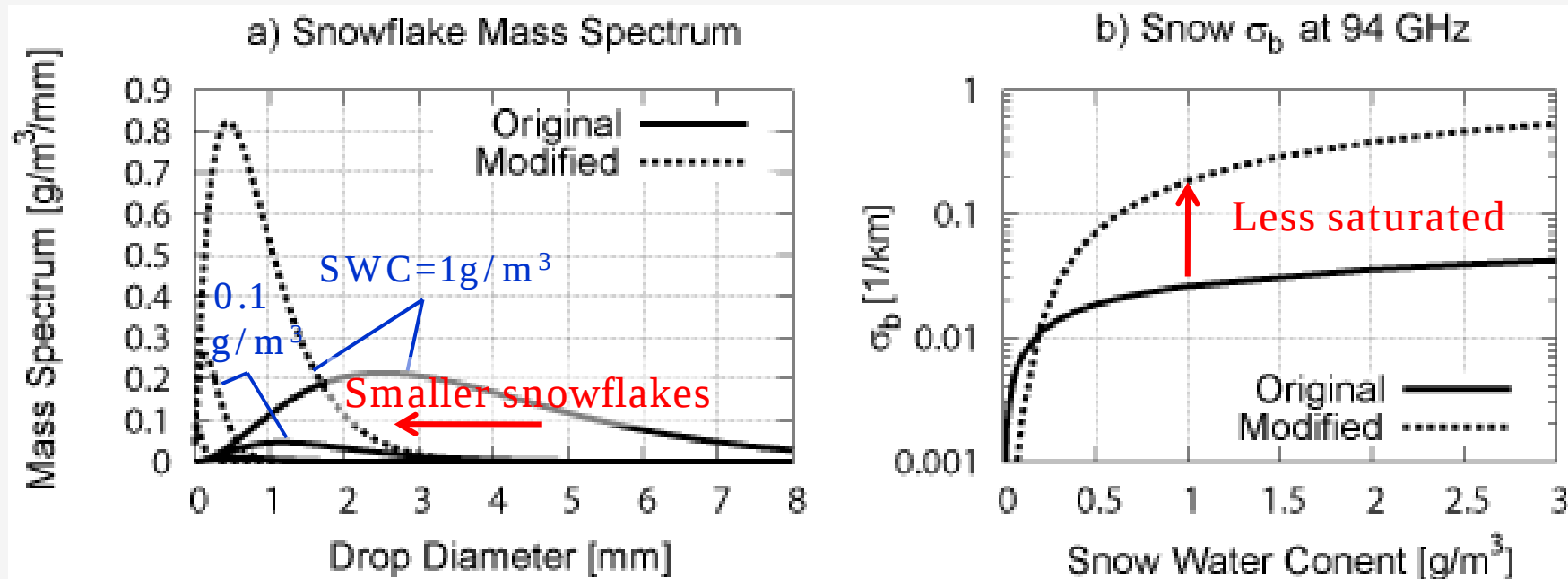
$$\sigma_s \propto N r^2 \propto (N W^2)^{1/3}$$

$$\left. \frac{d\sigma_s}{dW} \right|_{N,\lambda} \propto W^{-1/3}$$

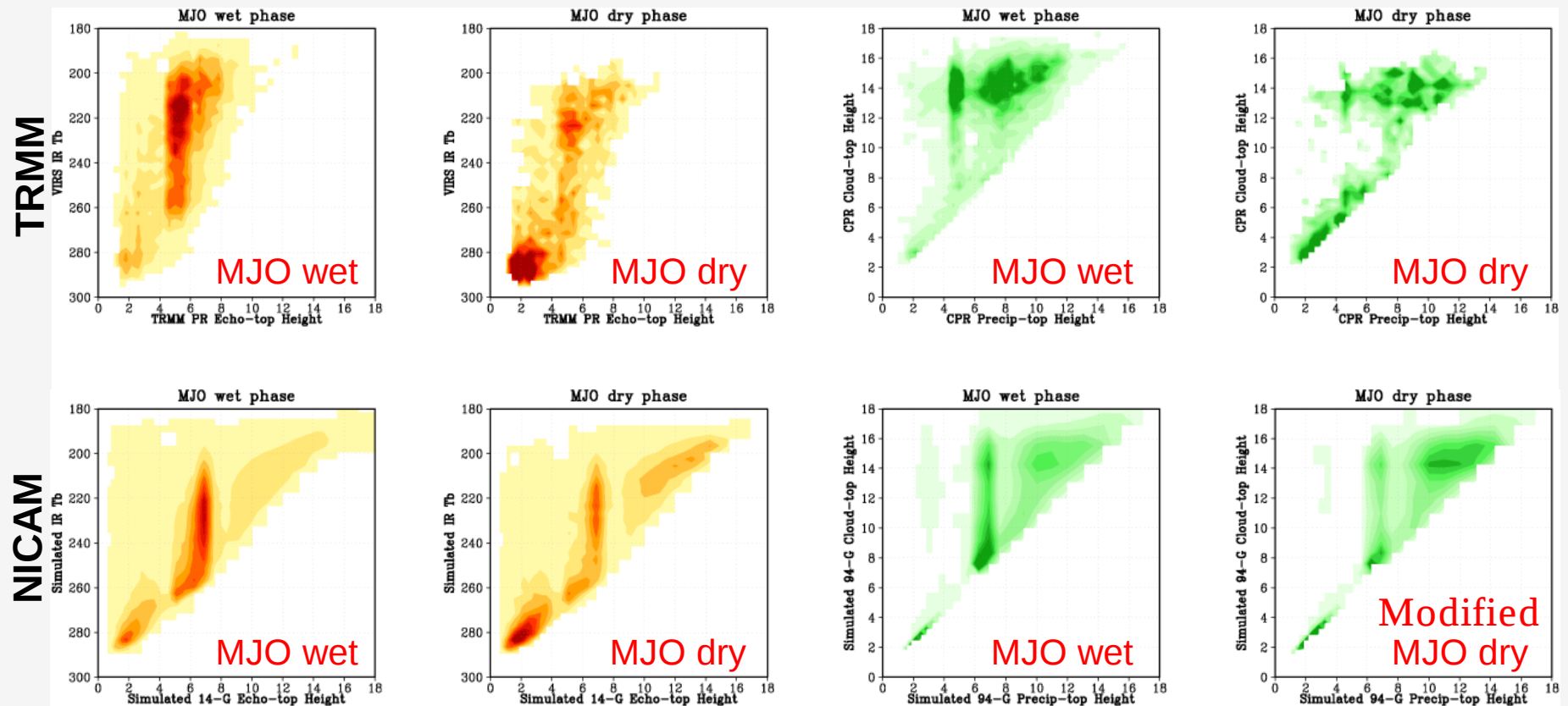


A Modification to snow microphysics

Snowflake mass spectrum = $\frac{m(D)n(D)}{aD^b N_0} \exp(-\lambda D)$
where $a=2.5 \times 10^{-2} \text{ kg m}^{-2}$ and $b=2$ (original=Grabowski, 1998)
 $a=5 \times 10^{-4} \text{ kg m}^{-1}$ and $b=1$ (modified)



PSD Impact on the CTH/PTH Histogram



Multi-sensor simulator packages

- ▶ **COSP: CFMIP Observation Simulator Package**
 - ▶ CFMIP (<http://cfmip.metoffice.com/COSP.html>)
- ▶ **ECSIM: EarthCARE Simulator**
 - ▶ ESA (Voors et al, 2007)
- ▶ **J-simulator: Joint Simulator for Satellite Sensors**
 - ▶ JAXA/U Tokyo (<http://www22.atwiki.jp/j-simulator/>)
- ▶ **RTTOV: Radiative Transfer Model for TOVS**
 - ▶ UK MetOffice/ECMWF (Matricardi et al. 2004; Bauer et al., 2006)
- ▶ **SDSU: Satellite Data Simulator Unit**
 - ▶ Nagoya U (<http://precip.hyarc.nagoya-u.ac.jp/sdsu/>)
- ▶ **Goddard SDSU**
 - ▶ NASA GSFC (<http://cloud.gsfc.nasa.gov/index.php?section=14>)
- ▶ Visit “Satellite Data Simulator Portal” for quick overview
 - ▶ <https://sites.google.com/site/satellitesimulators/>



The SDSU package

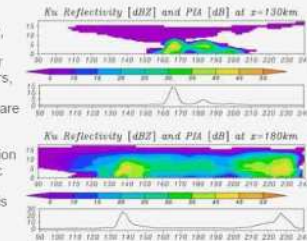
- ▶ SDSU WWW site
 - ▶ precip.hyarc.nagoya-u.ac.jp/sdsu/
- ▶ User registration
 - ▶ only requires your name and email address.
- ▶ Patches (Linux shell scripts)
 - ▶ available for existing SDSU-v2 users in case of future upgrades.
- ▶ SDSU v2.1.4 is the latest.

Satellite Data Simulator Unit (SDSU)

[SDSU ver. 2.1.0](#) is now available (released on Sep. 8, 2009).

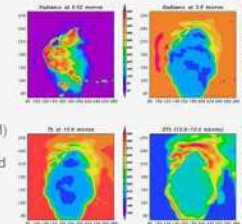
1. Overview

This package contains Fortran codes to simulate microwave brightness temperature, radar reflectivity, and visible/infrared radiance as measured by meteorological satellite sensors. The three simulator components aimed at microwave radiometers, radars, and visible/IR imagers can be executed either individually or all together. Radiative transfer codes are implemented with Mie-theory-based subroutines to compute the radiative properties of cloud and precipitating hydrometeors as well as a gas absorption database covering a broad range of electromagnetic spectrum. A beam-convolution program is also provided so that the non-uniform beam filling effect is taken into account for an arbitrary FOV size.



The existing and prospective satellite sensors applicable include (but are not limited to):

- i. Microwave radiometers and sounders^{*1}
 - Special Sensor Microwave/Imager (SSM/I)
 - Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI)
 - Advanced Microwave Scanning Radiometer (AMSR) and AMSR-E
 - Conolis WindSat
 - Global Precipitation Measurement Mission (GPM) Microwave Imager (GMI)
 - Advanced Microwave Sounding Unit (AMSU) and Microwave Humidity Sounder (MHS)
- ii. Radars
 - TRMM Precipitation Radar (PR)
 - CloudSat Cloud Profiling Radar (CPR)
 - GPM Dual-frequency Radar (DPR)
- iii. Visible and infrared imagers
 - Advanced Very High Resolution Radiometer (AVHRR)
 - TRMM Visible/Infrared Scanner (VIRS)
 - Moderate Resolution Imaging Spectroradiometer (MODIS)
 - Visible/IR sensors onboard operational geostationary satellites such as GMS (MTSAT), GOES, and Meteosat.



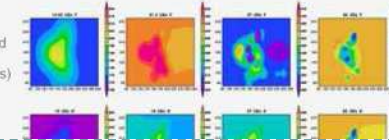
[SDSU gallery](#) shows some sample simulations.

[*1: A minor modification to the radiative transfer code will be needed to simulate mixed polarization channels, typical of cross-track scanning sounders.]

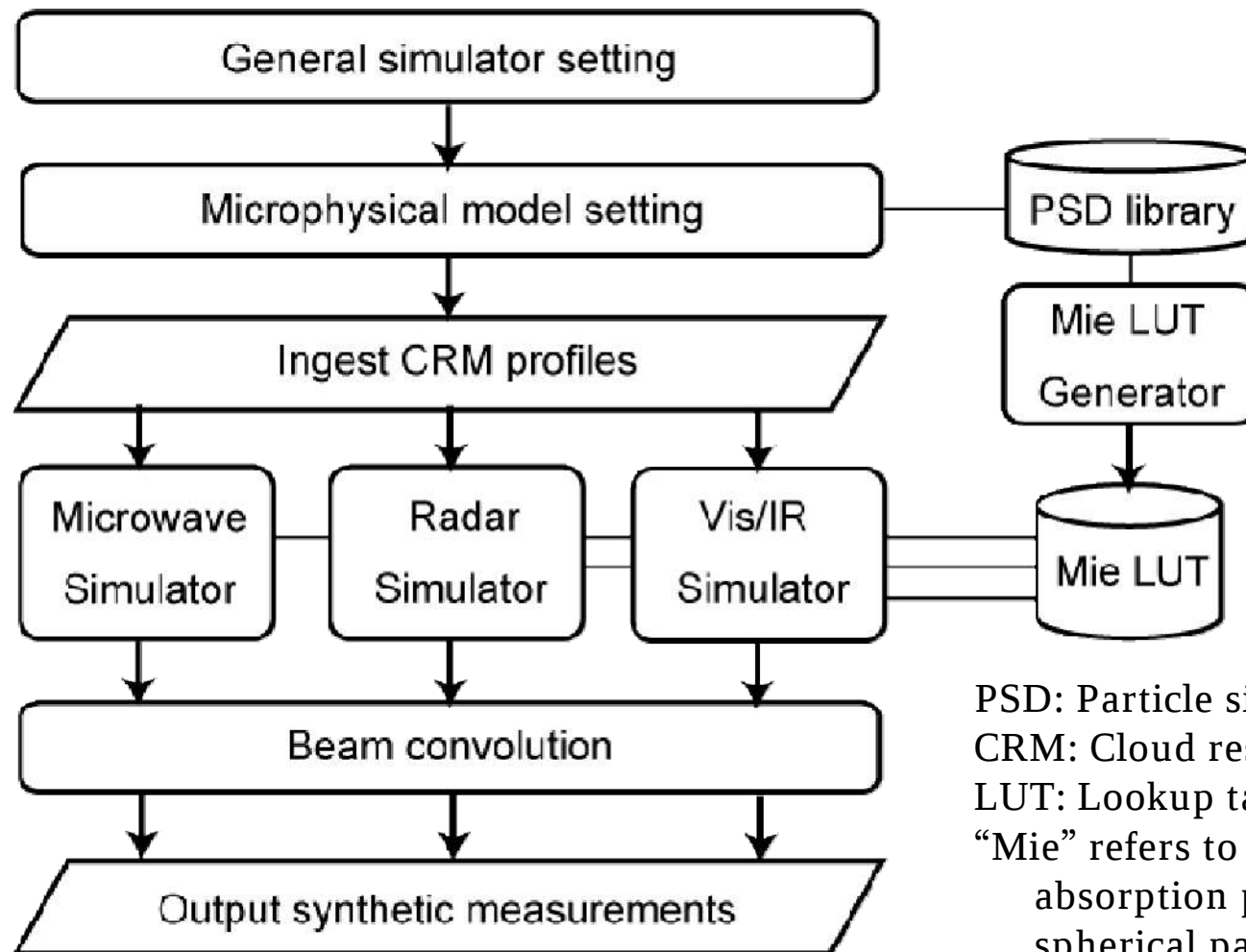
2. SDSU version 2

The SDSU is now upgraded to version 2. Major changes from the earlier version are

- The entire code has been rewritten in Fortran 90.
- New user interface is supported to customize the hydrometeor particle size distributions (PSDs) incorporated in the simulator.
- The PSD library currently consists of 9 PSD models



SDSU Structure



PSD: Particle size distribution
CRM: Cloud resolving model
LUT: Lookup table
“Mie” refers to the scattering & absorption properties of spherical particles

Summary: Advantages and challenges

▶ Advantages

- ▶ Independent of algorithm uncertainties, which are often very difficult to track down.
 - ▶ Sensitivity to assumptions can be tested with simulators.
- ▶ Simulators offer a tool to diagnose cloud microphysics.

▶ Challenges

- ▶ Interpretations of synthetic satellite measurements require a profound knowledge of physical principles in satellite remote sensing.
 - ▶ Radiative transfer theory, electromagnetic dynamics, etc.
- ▶ Close communication between scientists in different areas (modeling and satellite experts etc.) would be crucial.

