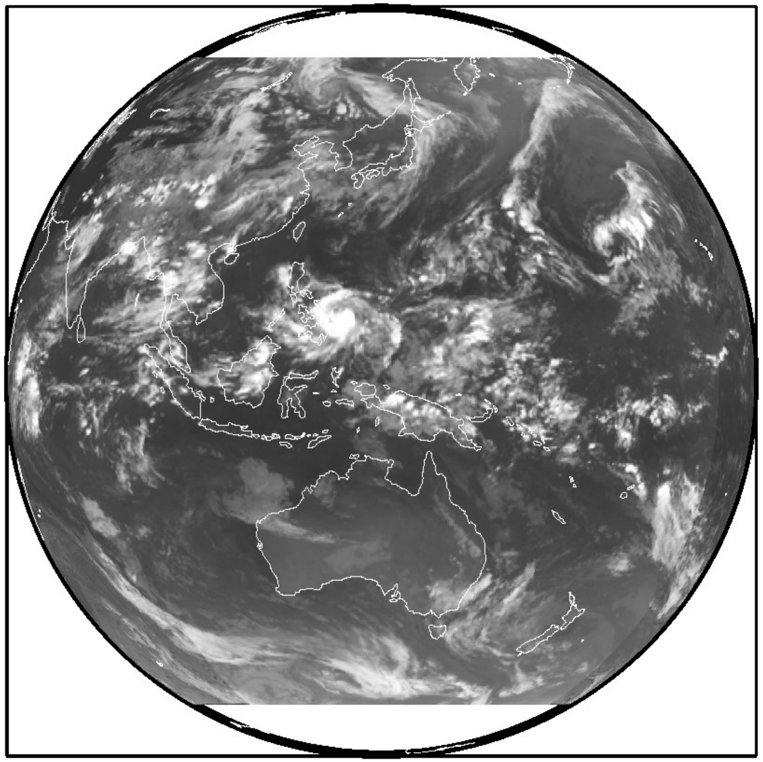
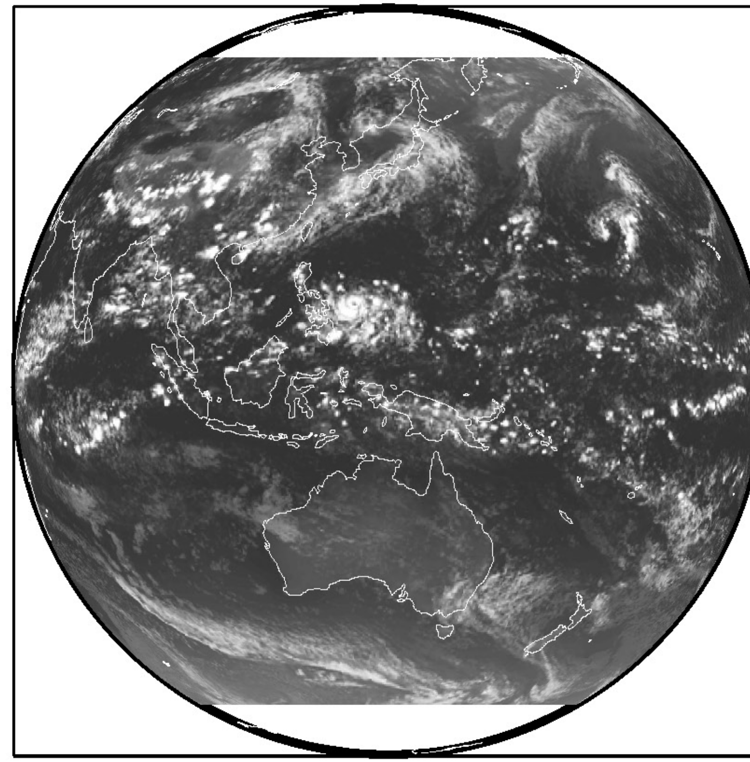
Joint-Simulator and A-train for evaluating clouds simulated by a global cloud resolving model





Tempei Hashino[1]
Email: hashino@aori.u-tokyo.ac.jp

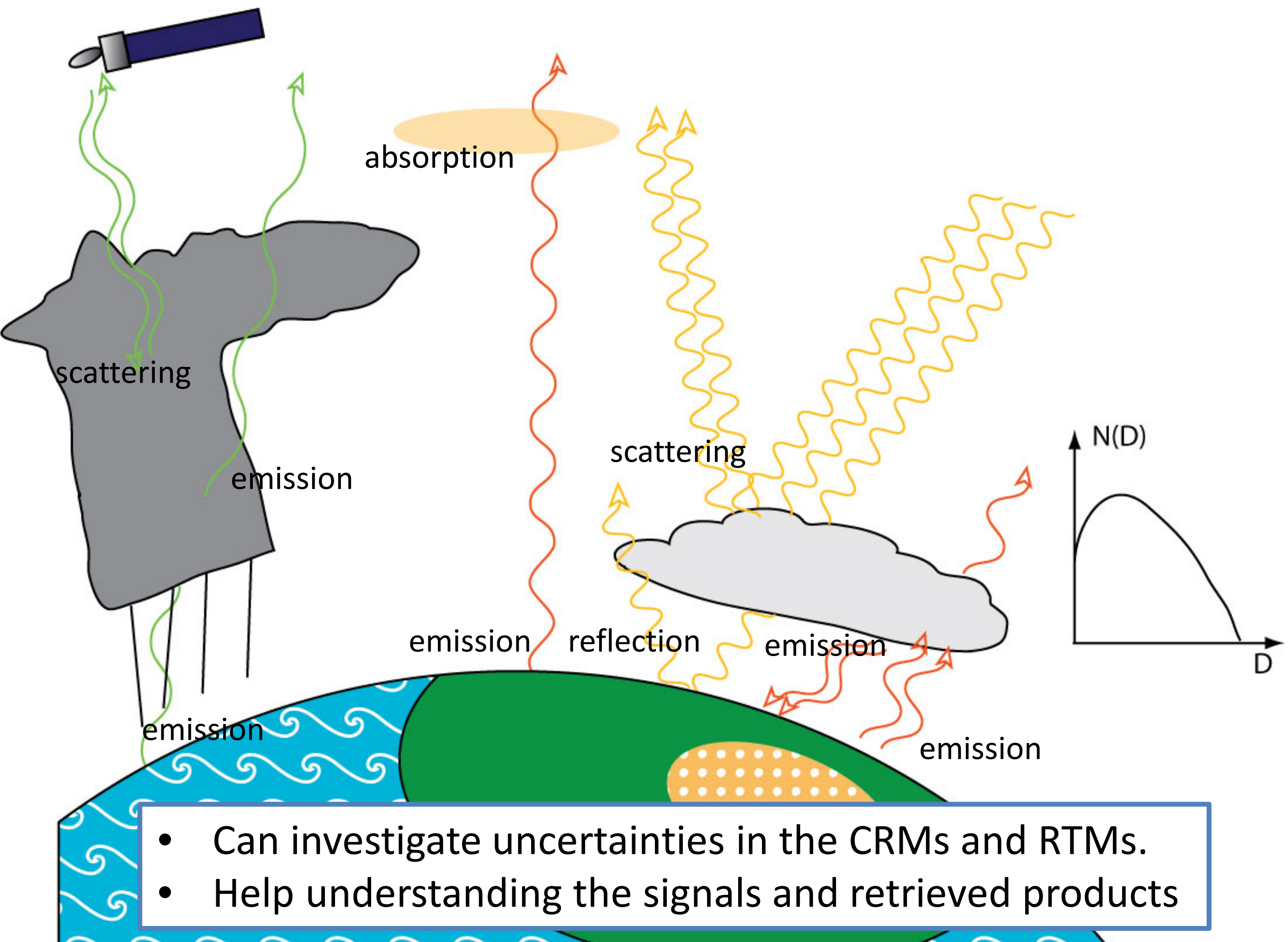
Mini-Workshop on A-train Science
March 8 2013

Masaki Satoh[1], Yuichiro Hagihara[2], Takuji Kubota[3], Toshihisa Matsui[4], Tomoe Nasuno[5], Hajime Okamoto[2], & Joint-Simulator team

1: Atmosphere and Ocean Research Institute, The University of Tokyo, 2: Research Institute for Applied Mechanics, Kyushu University, 3: JAXA/EORC, 4: NASA Goddard Space Flight Center, 5: Japan Agency for Marine-earth Science and Technology

What is Joint-Simulator?

- Joint-Simulator solves the 1D radiative transfer problems given by a cloud resolving model in *a consistent way among the sensor simulators and with the model*.



- Can investigate uncertainties in the CRMs and RTMs.
- Help understanding the signals and retrieved products

Cloud Resolving Model Outputs

↓

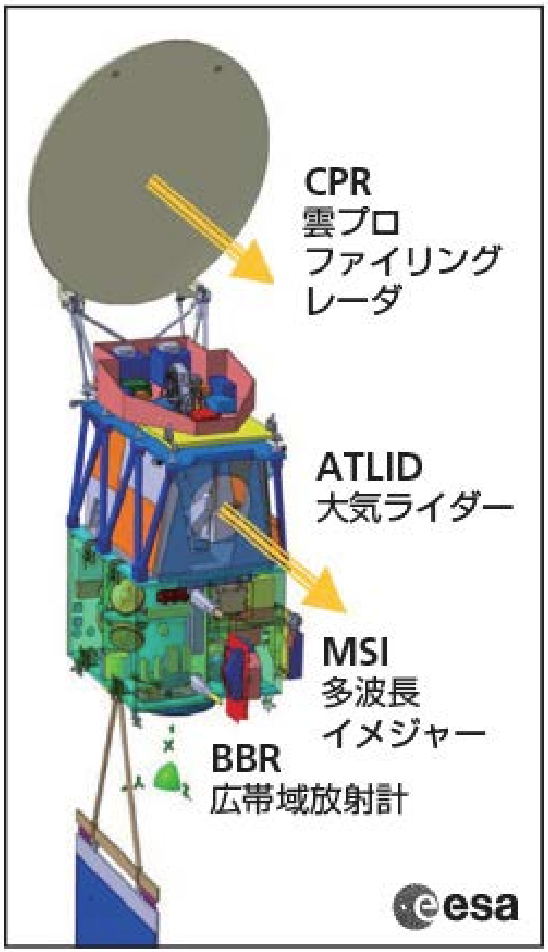
Satellite Data Simulator

↓

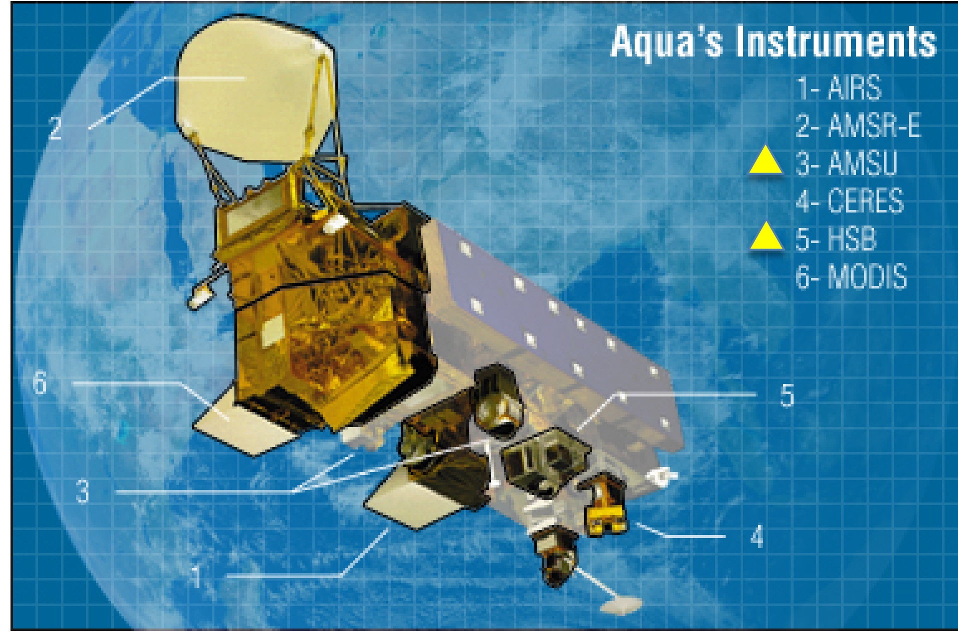
Synthetic Satellite Observation

Applicable sensors: examples

EarthCARE



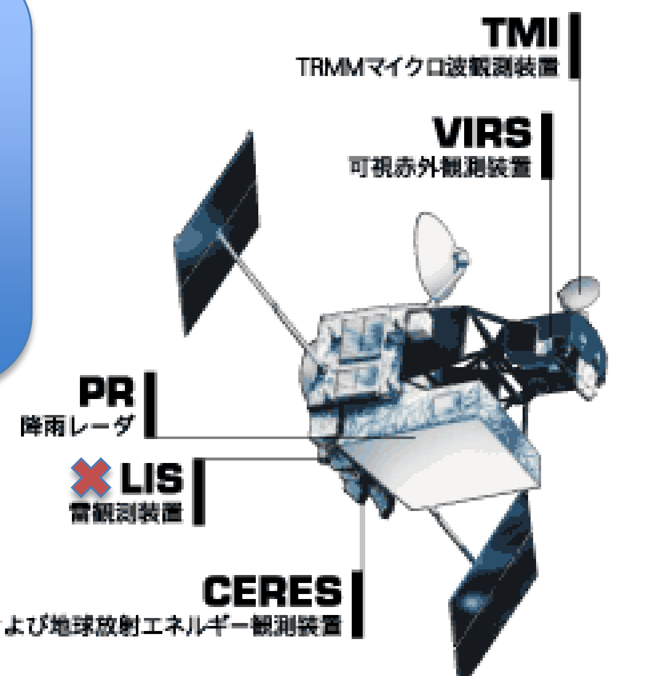
Pamphlet
http://www.jaxa.jp/projects/sat/earthcare/index_e.html



http://aqua.nasa.gov/about/instruments.php

- Microwave radiometers & sounders*
- Radars
- Lidars
- Visible & infrared imagers
- Broadband radiometers

Applicable to CloudSat CPR & CALIPSO CALIOP



http://www.eorc.jaxa.jp/TRMM/about/mechanism/main_j.htm

Sensor simulators

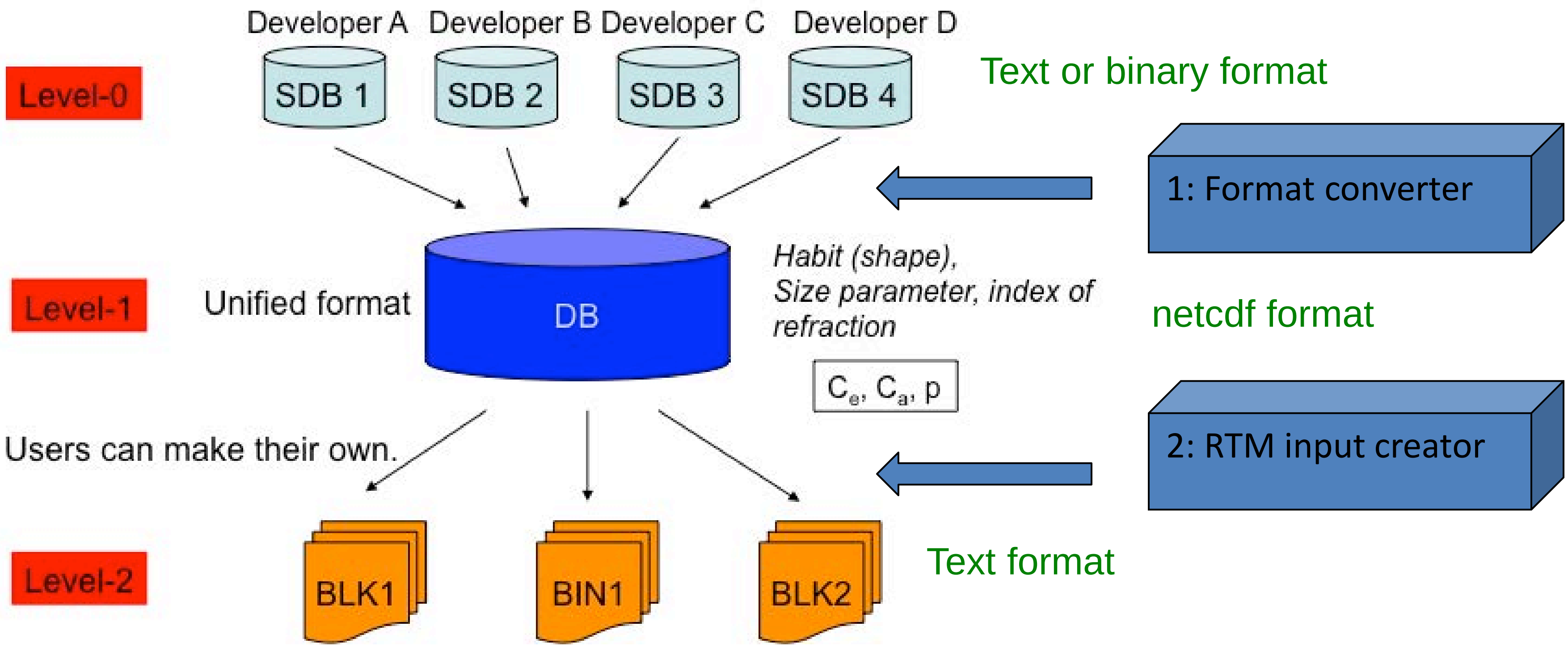
- Visible and infrared imager
  - RSTAR6b (Nakajima & Tanaka 1986, 1988)
    - Discrete-ordinate method/adding method
    - K-distribution table with HITRAN2004
- Microwave radiometer and sounder
  - Kummerow (1993)
    - Eddington approximation
- Radar
  - Masunaga & Kummerow (2005)
  - EASE (Okamoto et al. 2007, 2008; Nishizawa et al. 2008)
- Lidar
  - Matsui et al. (2009)
  - EASE
- Broadband radiometer
  - CLIRAD (Chou and Suarez 1994, 1999; Chou et al. 2001)
    - δελτα–Eddington approximation/adding method (two stream)
    - K-distribution method with HITRAN1996
    - 21 bands
  - MSTRN-X (Sekiguchi and Nakajima 2008)
    - Discrete-ordinate method/adding method (two stream)
    - Correlated-k distribution method with HITRAN2004
    - 18, 29, or 37 bands.

Blue: SDSU modules (http://precip.hyarc.nagoya-u.ac.jp/sdsu/index.html)

Green: NASA Goddard SDSU extension (http://opensource.gsfc.nasa.gov/projects/G-SDSU/index.php)

Orange: Joint-Simulator extension (https://sites.google.com/site/jointsimulator/home)

Non-spherical scattering database (web-based)



Main collaborators

Prof. Nakajima's group at Tokai University (planed next year)

Prof. Okamoto's group at Kyusyu University

Dr. Ishimoto at Meteorological Research Institute (included)

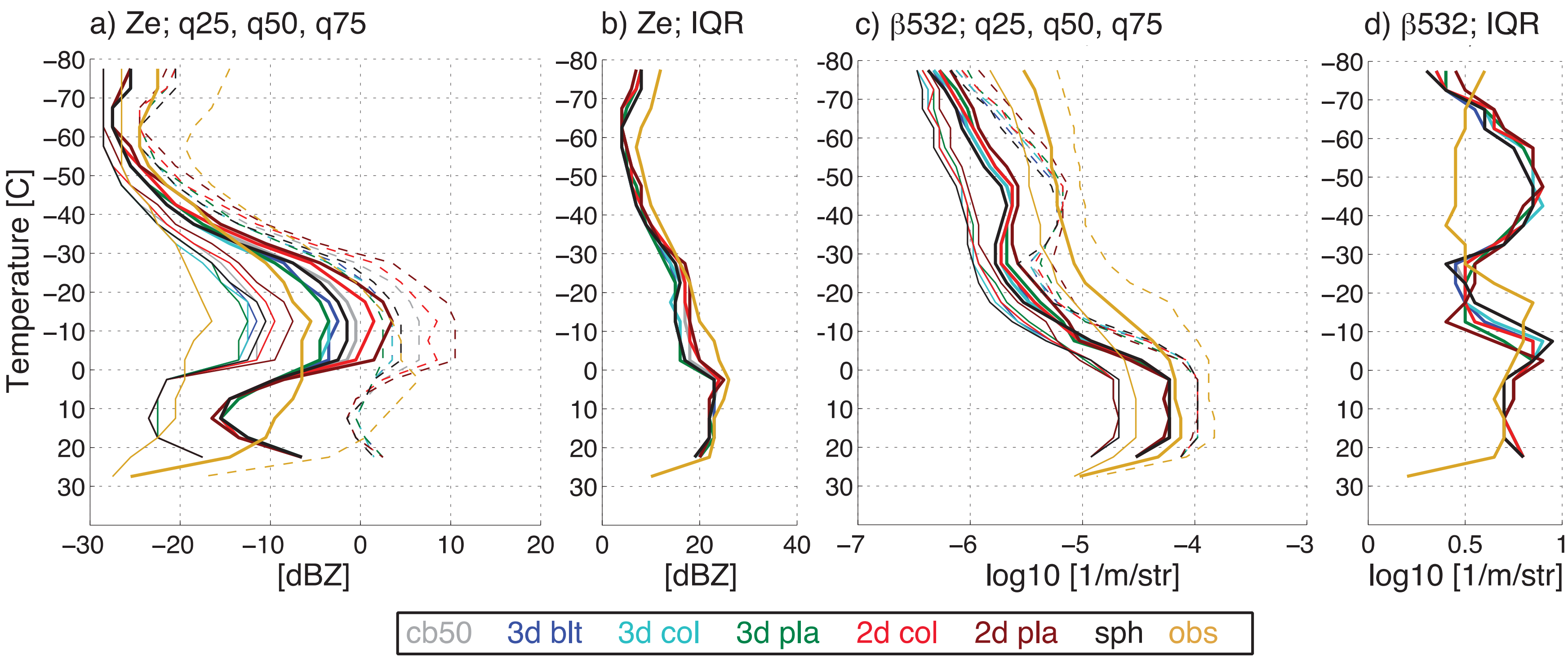
Potential international collaborators for microwave

Dr. Liu at Florida State University, USA (included)

Dr. Petty at University of Wisconsin-Madison, USA

1. Adjust and organize the original data into the unified format
2. Calculate lookup tables for the sensor simulator of interest based on user's cloud microphysical scheme.

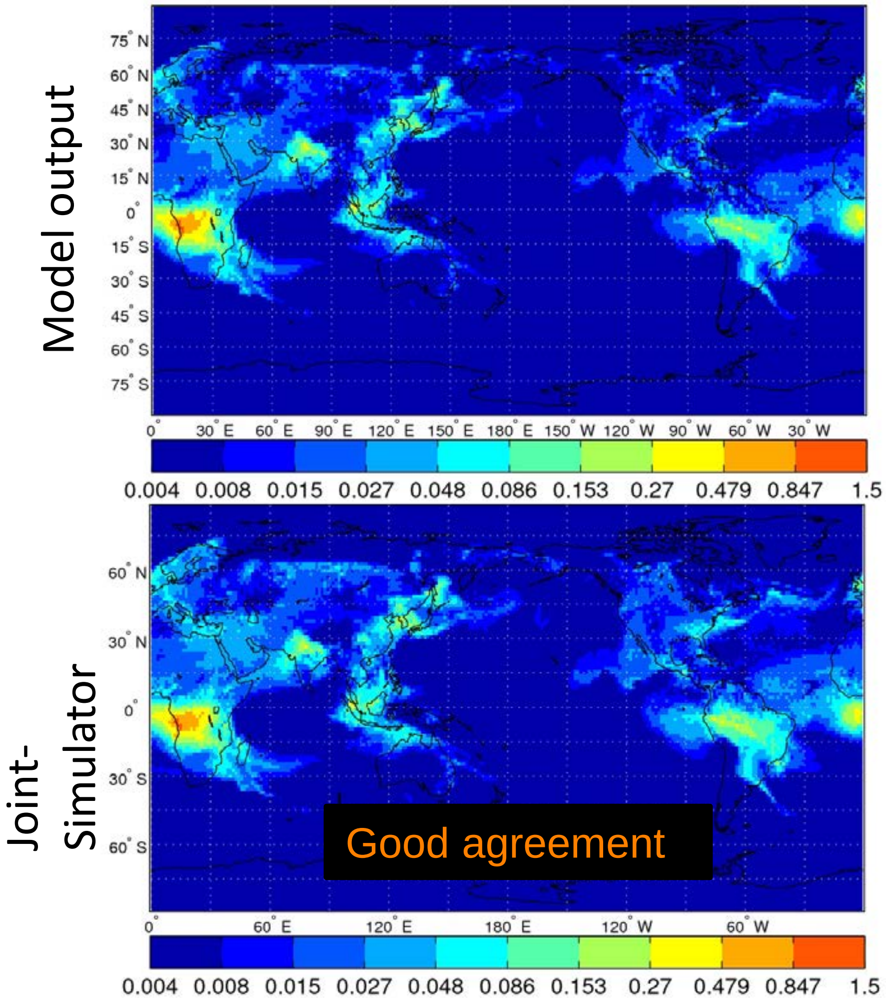
Uncertainty due to non-spherical ice scattering in CFEDs



Validation of simulated AOD (0.55 μm)

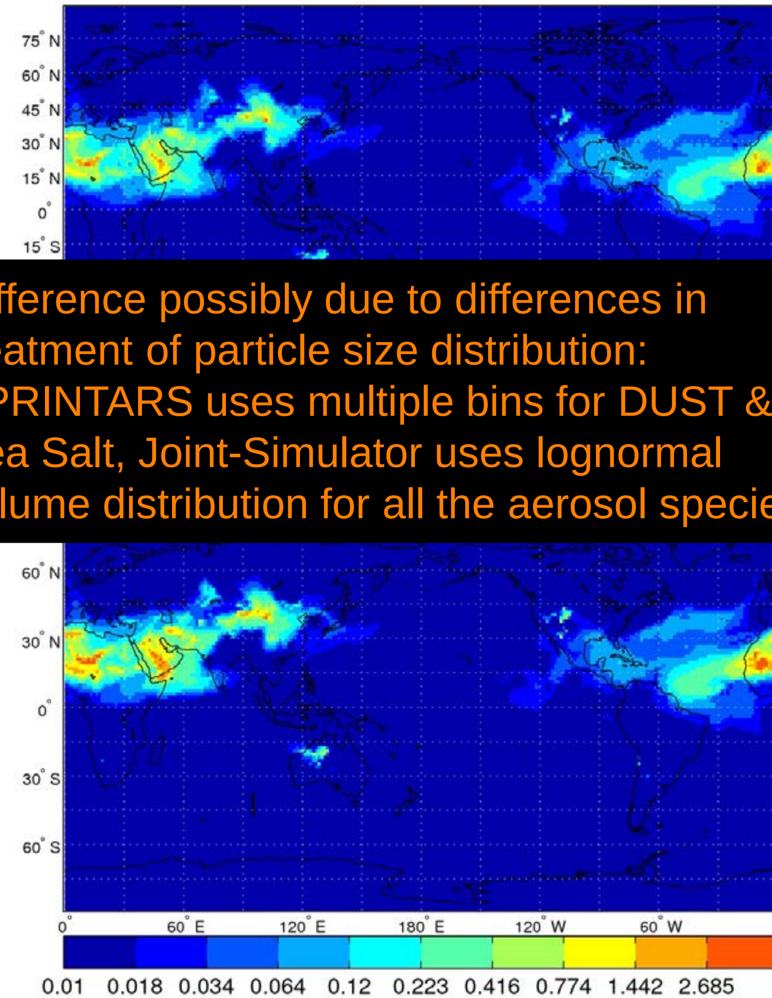
- NICAM-SPRINTARS global simulation provided by Dr. K. Suzuki@JPL with help of Dr. D. Goto.
- Aerosol Optical Depth (AOD) estimated with Joint-Simulator is compared against the outputs from SPRINTARS

Carbonaceous AP



Good agreement

Dust



Difference possibly due to differences in treatment of particle size distribution: SPRINTARS uses multiple bins for DUST & Sea Salt, Joint-Simulator uses lognormal volume distribution for all the aerosol species.

Approach for evaluating clouds simulated by CRMs with A-train

Variables evaluated	Satellite instrument			
Cloud fraction	CloudSat CPR	CALIPSO CALIOP	Aqua MODIS	
Cloud microphysics	CloudSat CPR	CALIPSO CALIOP	Aqua MODIS	Aqua AMSR-E
TOA & SFC broadband fluxes	Aqua CERES			
Surface precipitation	CloudSat CPR	Aqua AMSR-E		

Key word of this study

- Simple
- Synergetic uses of different sensors
- Forward approach

Data set for this study

Observation : CloudSAT-CALIPSO merged data set（Hagihara et al. 2010）+ α

Four cloud masks

- Radar mask (C1); cloud & precipitating particles.
- Lidar mask (C2); cloud particles.
- Radar and Lidar mask (C3); cloud particles
- Radar or Lidar mask (C4); all particles

Spatial resolutions and grids: 240m for vertical, 1.1km for horizontal.

AMSR-E L1B & CERES L2 SSF collocated.

NICAM global simulation : 2008 TC Fengshen (Nasuno et al. 2009)

- horizontal grid spacing: 3.5 km; # of vertical grids: 40 (0~3.8km)
- cloud microphysical parameterization: NSW6 (Tomita 2002)
  - ✓ 1 moment scheme, 6 categories (vapor, cloud, rain, cloud ice, snow, graupel)

↓ Forward calculation by Joint-Simulator

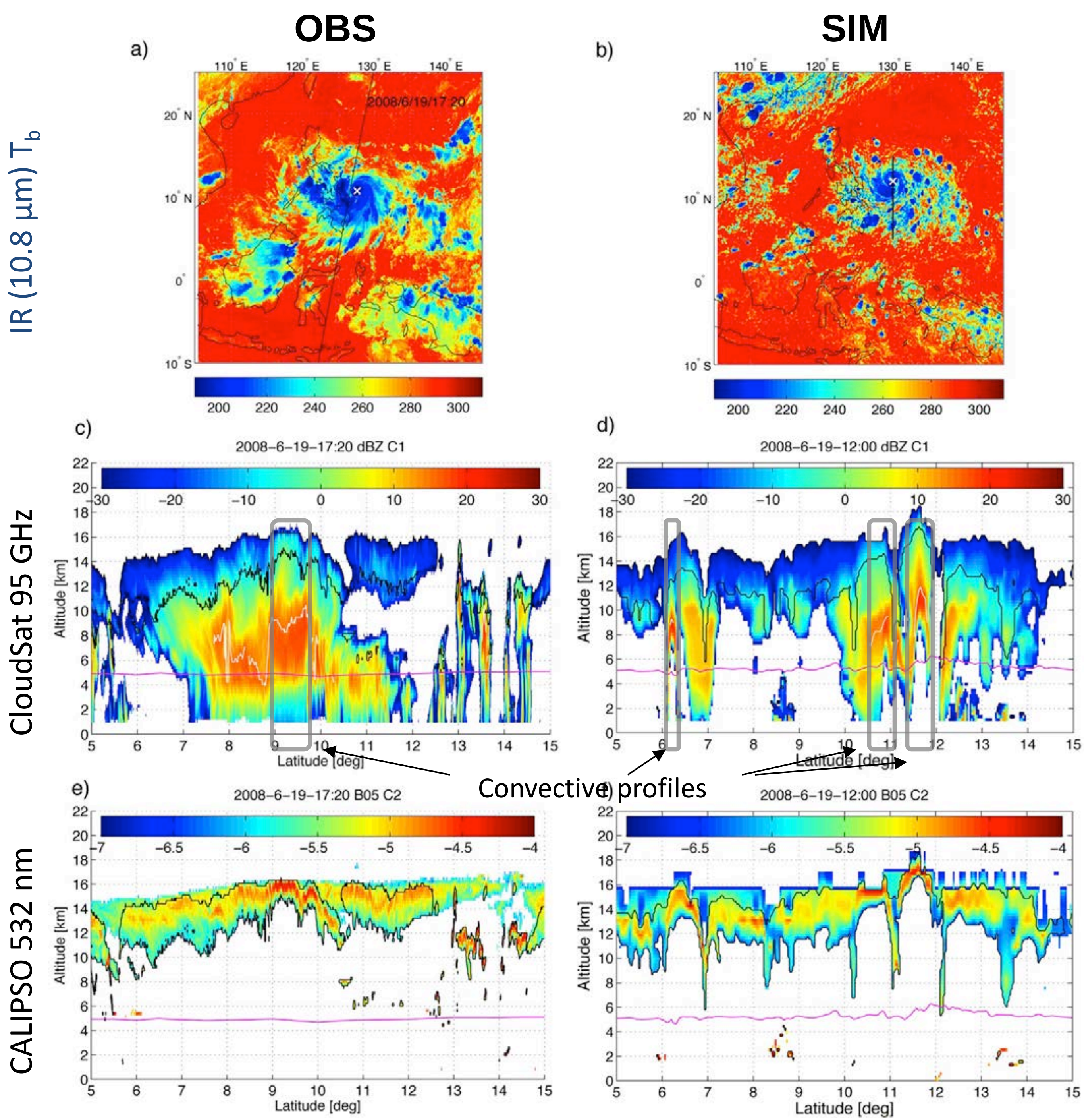
Simulation : CloudSAT & CALIPSO merged data set + α

Time period

Observation : 2008 June

Simulation : 2008 June 17th 00Z ~ 25th 00Z

Example 1: Tropical Cyclone



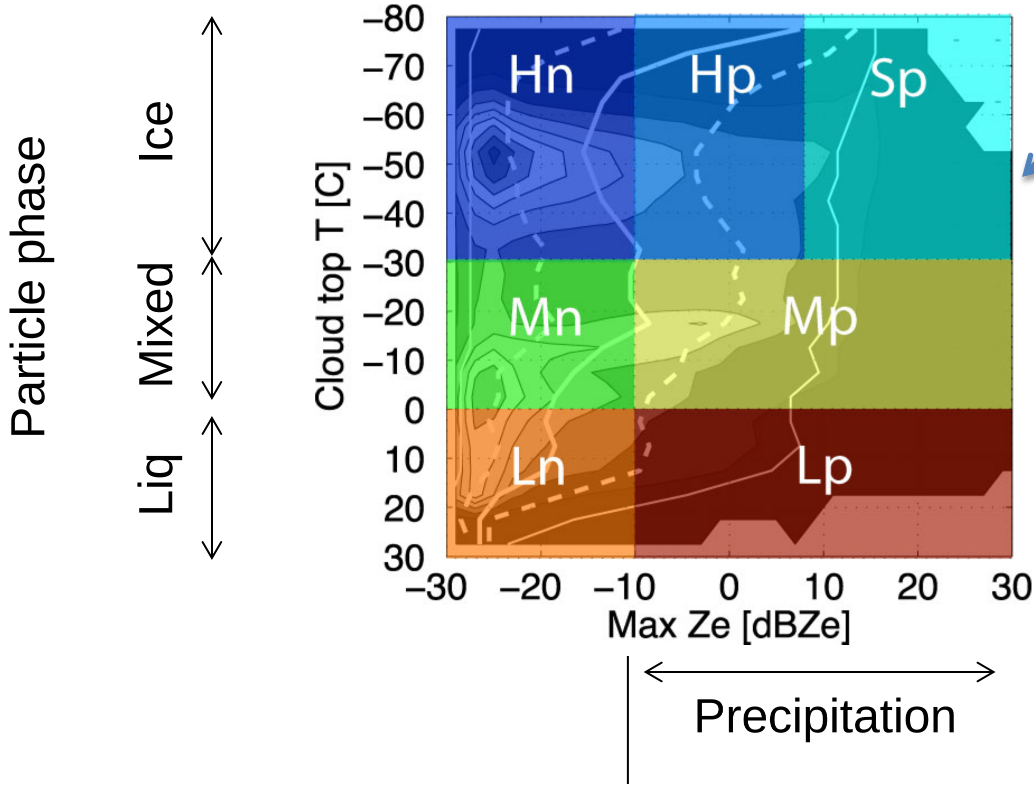
- North-south asymmetry of TC is simulated with NICAM.
- The simulated anvils and stratiform clouds are less spread.
- The altitude of multiple scattering onset (white lines, Battaglia et al. 2011) and high β532 suggest the convective profiles.

- Overlap regions of C1 and C2 mask (black lines) extends up to ~4 km both in OBS and SIM, but NICAM shows larger depth (optically thinner).
- SIM: a lack of radar reflectivity found in the convective cores where water contents are high (no MS parameterization for radar)

Proposed cloud type diagram

Define Cloud Type by separating the domain of Cloud top T and max Ze into seven sub-domains. H: High, S: Storm, M: Mixed-phase, L: liquid. p is for precipitating, n is for non-precipitating.

Cloud Type Diagram

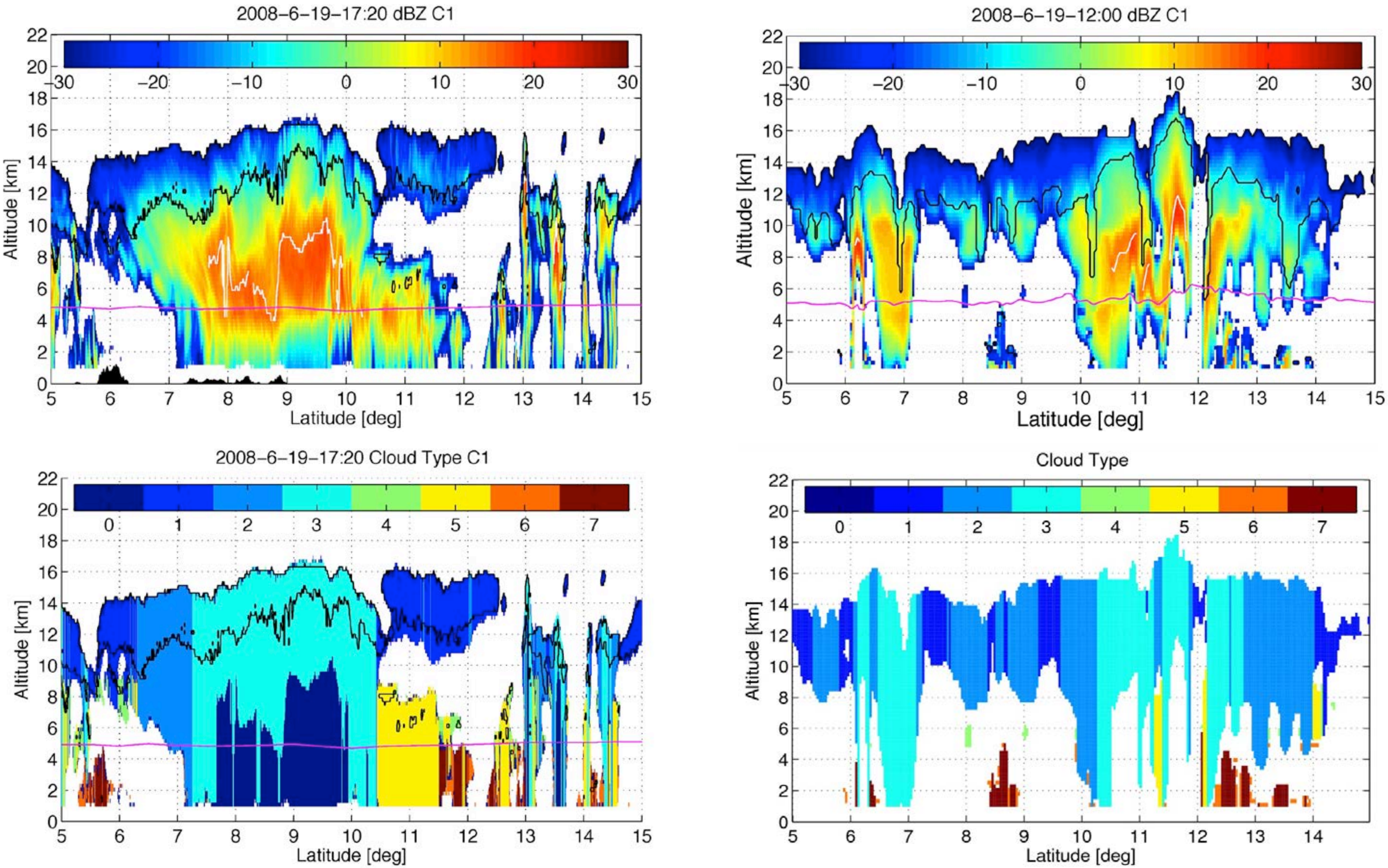


The background shows a global Joint PDF from CloudSat PR.

Cloud type condenses 3D information of radar reflectivity into 2D, facilitating spatial comparison and narrowing down samples.

Example of cloud type; TC Fengshen

OBS **SIM**

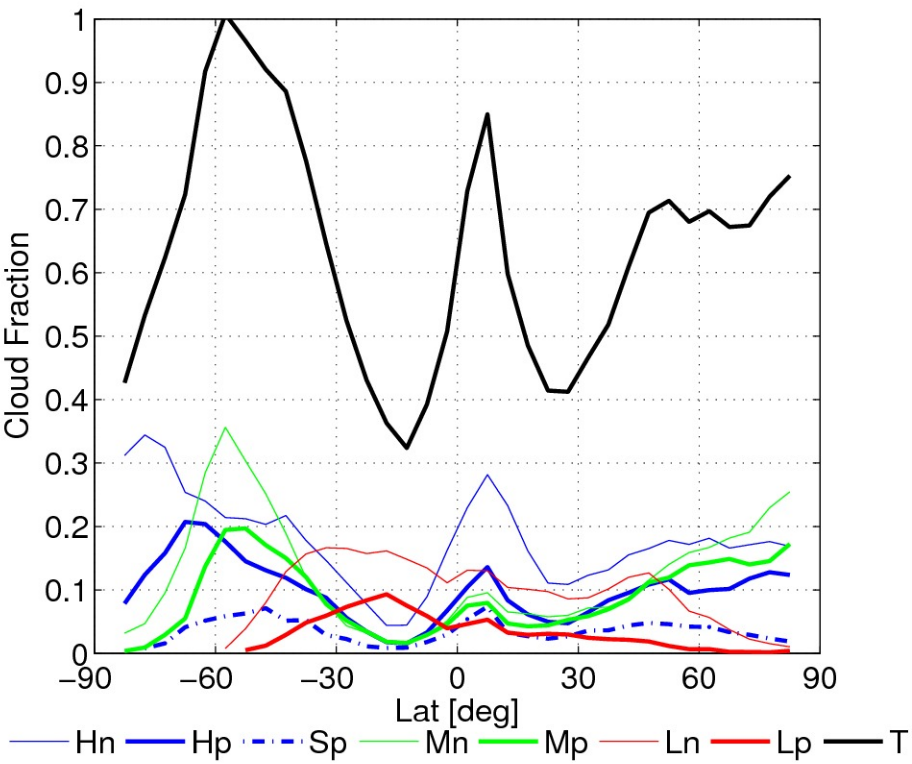


Cloud Type 0: No clouds, 1: Hn, 2: Hp, 3: Sp, 4: Mn, 5: Mp, 6: Ln, 7: LP

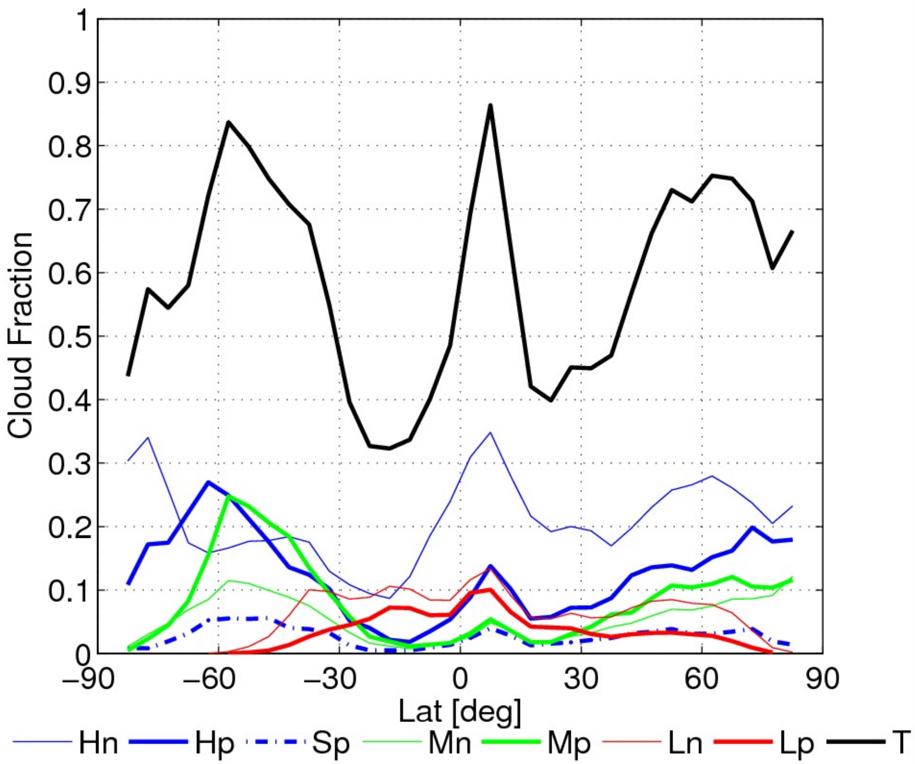
Zonal cloud fraction by cloud type

- Cloudy samples were divided into cloud layers, and then the number of cloud layers for a latitude range was divided by the total observation (multiple layers counted).

OBS



SIM



- Hn dominate at Antarctic, Northern latitudes.
- Mn & Mp peaks at 60S and Arctic.
- Ln & Lp peaks at 15S.

- Both of Hn and Hp are overestimated.
- Mp occurs more than Mn.
- Ln is underestimated.
- Lack of Mn contributes less CF at 70S-30S.

BETa-TEmperature Radar-conditioned diagram (BETTER)

Hashino et al. (2013, under revision)

Okamoto et al. (2003)

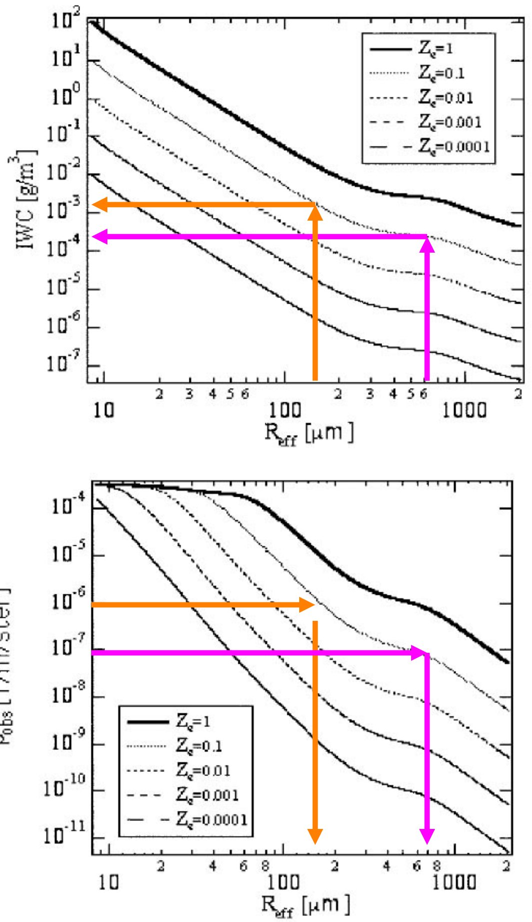


Figure 4. (a) Relationship between IWC and r_{eff} for a given $Z_{e,obs}$. A single cloud layer with geometrical thickness of 96 m is considered, and there is no cloud layer below this one. (b) Relationship between β_{obs} and r_{eff} for a given $Z_{e,obs}$. For a given $Z_{e,obs}$, IWC is estimated for each r_{eff}. Then β_{obs} is estimated for each set of r_{eff} and IWC.

Aim: obtain the relative information on size and IWC.

If Z_e are the same among two grid boxes, smaller ®$_{532}$ means larger $R_{eff,m}$ and smaller IWC

Effective radius in terms of Mass-equivalent radius

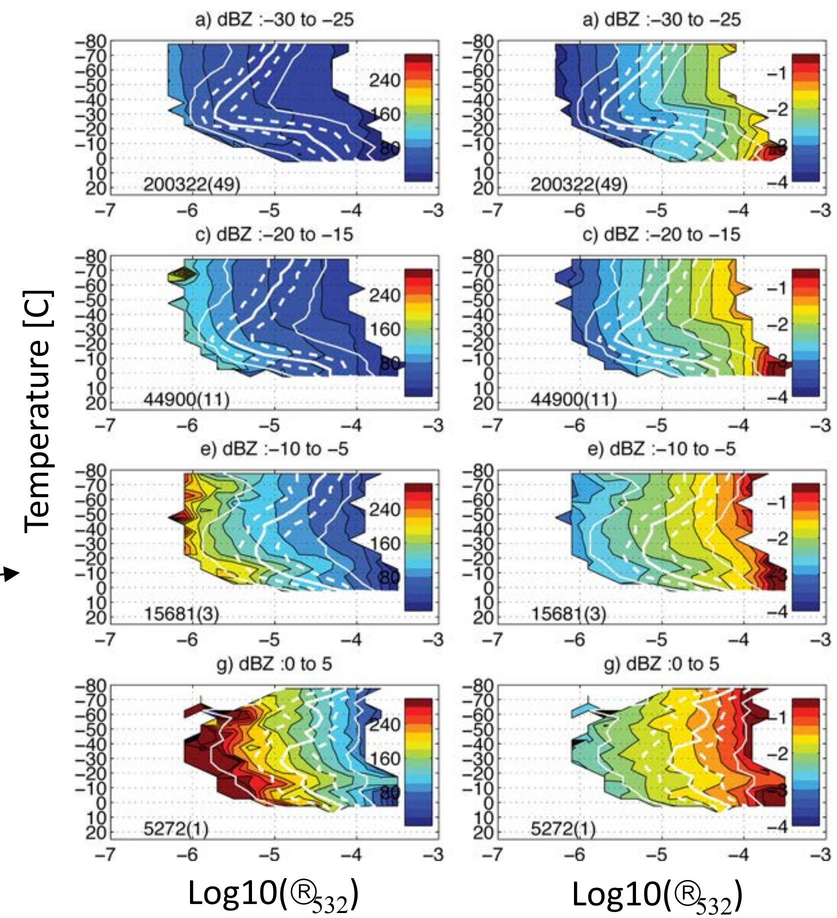
Mean $R_{eff,m}$ [μm]

Mean IWC [log10(g/cm^3)]

Assumption

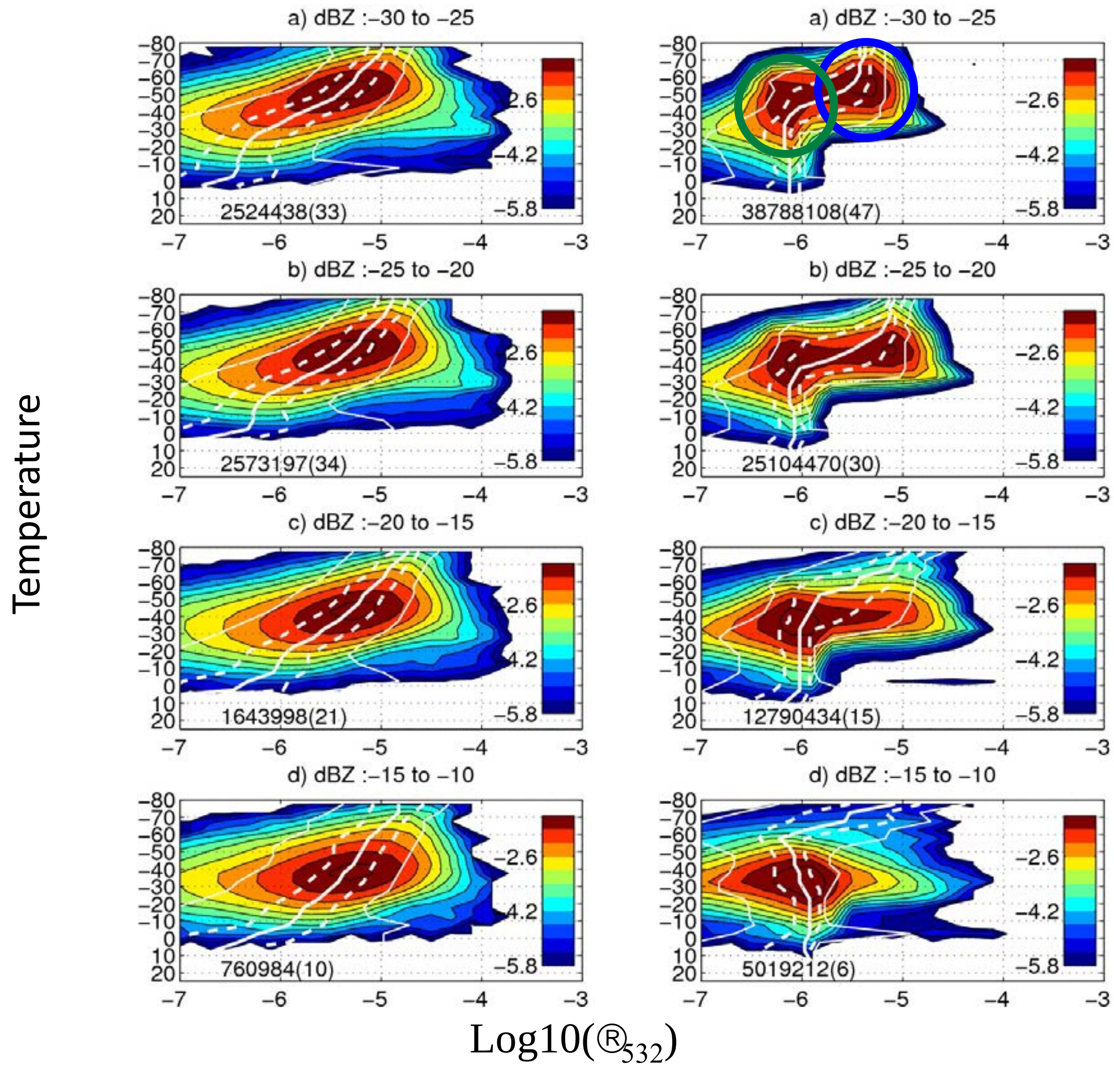
Both the observation and simulation follow a similar ®$_{532}$ - $R_{eff,m}$ and IWC - $R_{eff,m}$ relationship for a given Z_e.

- $R_{eff,m}$ and IWC are Okamoto et al. (2010)' s lidar-radar retrievals.
- The diagnosis usually valid for a range of T



Global BETTER Diagram
for High Non-Precipitating clouds (Hn)

OBS **SIM**



Cloud ice

$\circledR_{532}$ is similar to observation, which means ice water content (effective radius) is similar to observation.

Snow

$\circledR_{532}$ is smaller than observation, which means ice water content (effective radius) is larger (smaller) than observation.

It is necessary to understand this diagram in relation to the microphysical growth processes.

Normalized Polarization (P) and Scattering index (S)

Petty & Katsaros (1990, 1992)

$$P = \frac{T_V - T_H}{T_{V,O} - T_{H,O}}$$

Corresponding hypothetical Tb in the absence of all cloud

- Unlike Tb, P decreases monotonically with decreasing visibility of the sea surface.
- Sensitive to optical depth (or column transmittance *T*)

$$P = T^{1.69}$$

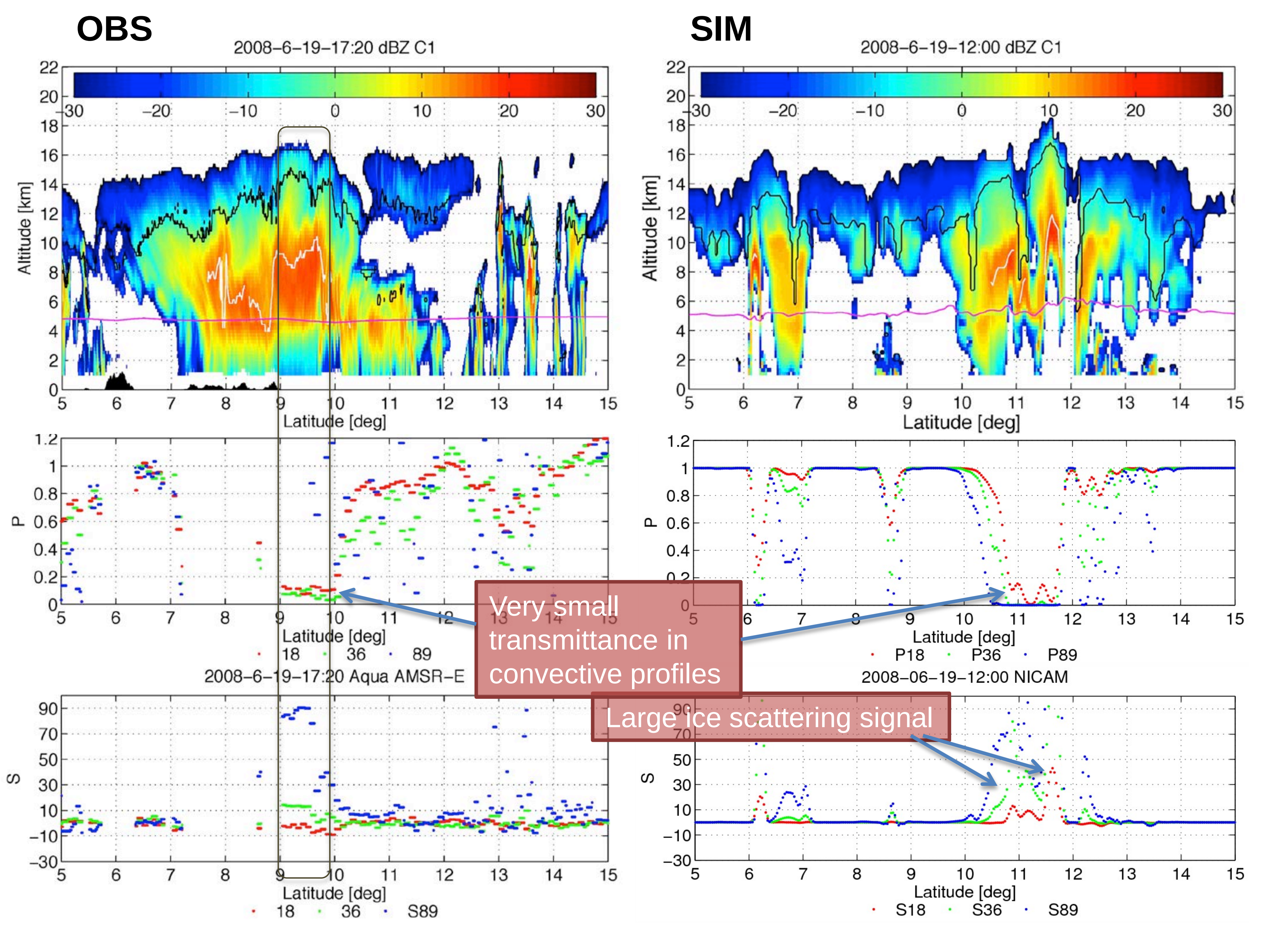
Petty (1994)

$$S = PT_{V,O} + (1 - P)T_c - T_V$$

$$T_c = 273$$

- Similar to polarization corrected temperature (PCT), but regarded as a PCT anomaly relative to the background value *Tc*.
- No empirical parameters required.

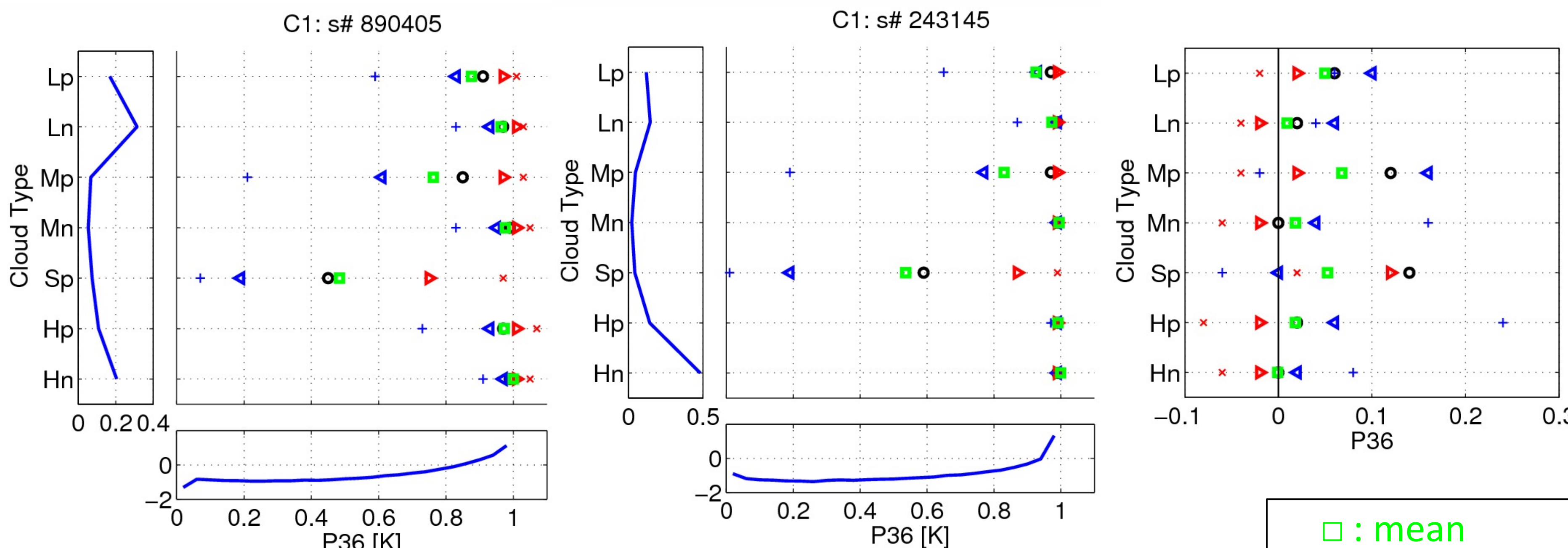
$T_{V,O}$ & $T_{H,O}$ can be estimated from nearby clear-sky observation identified with CloudSat CPR.


OBS
2008–6–19–17:20 dBZ C1
Altitude [km]
Latitude [deg]
P
Latitude [deg]
18 36 89
2008–6–19–17:20 Aqua AMSR–E
S
Latitude [deg]
18 36 S89
SIM
2008–6–19–12:00 dBZ C1
Altitude [km]
Latitude [deg]
P
Latitude [deg]
P18 P36 P89
2008–06–19–12:00 NICAM
S
Latitude [deg]
S18 S36 S89
Very small transmittance in convective profiles
Large ice scattering signal

P36 vs Cloud Type

- Samples taken in tropics (30S - 30N).
- Only profiles with a single cloud layer considered.

OBS **SIM** **SIM-OBS**



Small <- Transmittance -> large

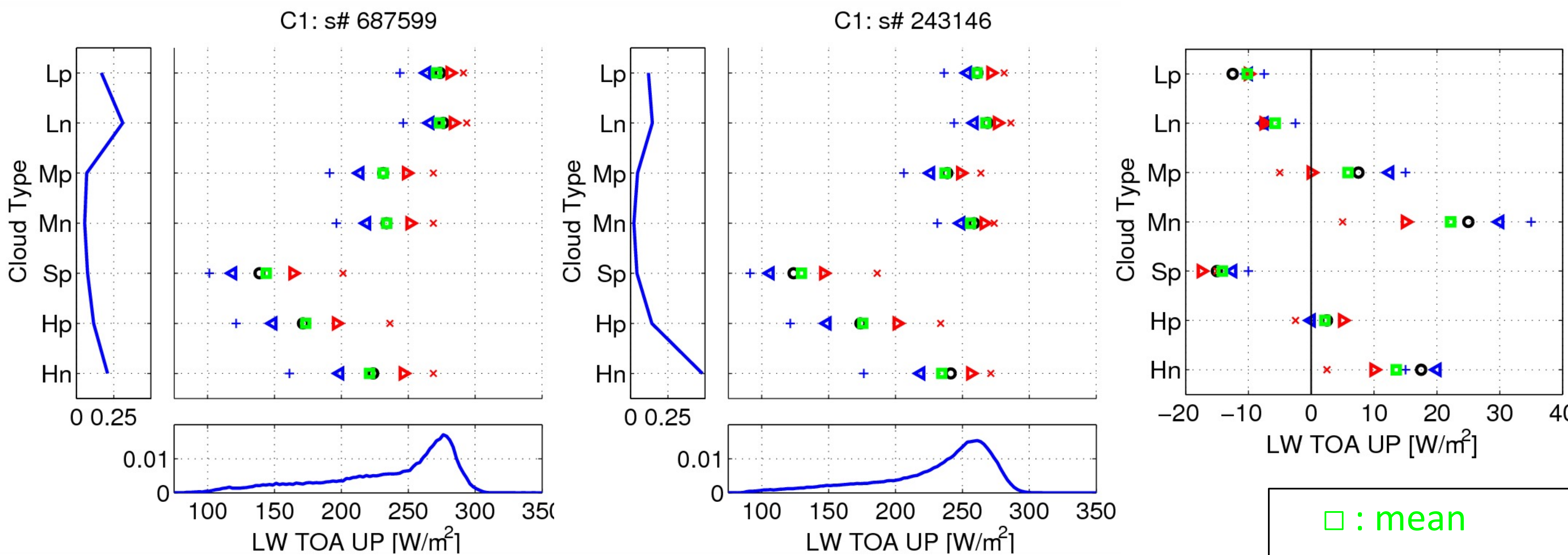
□ : mean
+: q_5 ◁: q_{25}
o: q_{50}
▷: q_{75} x: q_{95}

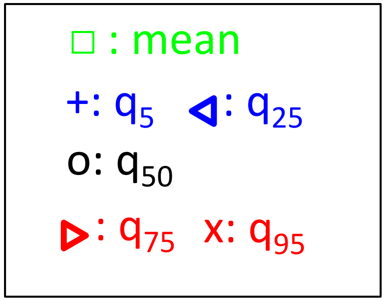
- OBS
  - decrease of the transmittance for precipitating clouds with liquid particles: Storm type (Sp) is the smallest transmittance.
  - Liquid may exists in Hn, Hp, Mn, but errors in identifying clear scene are possible, too.
- SIM
  - tends to overestimate the transmittance on average (less liquid water path).

OLR vs Cloud Type

- Samples taken in tropics (30S - 30N).
- Only profiles with a single cloud layer considered.

OBS **SIM** **SIM-OBS**





- OBS
  - Hn, Hp, and Sp (CTT<-40C) show a variety of OLR, although the others are not affected by existence of precipitating particles.
  - Symmetric distribution (normal distribution?)
- SIM
  - Sp, Ln, & Lp underestimate OLR, while Hn, Mp, & Mn overestimate.

Summary

Joint-simulator development

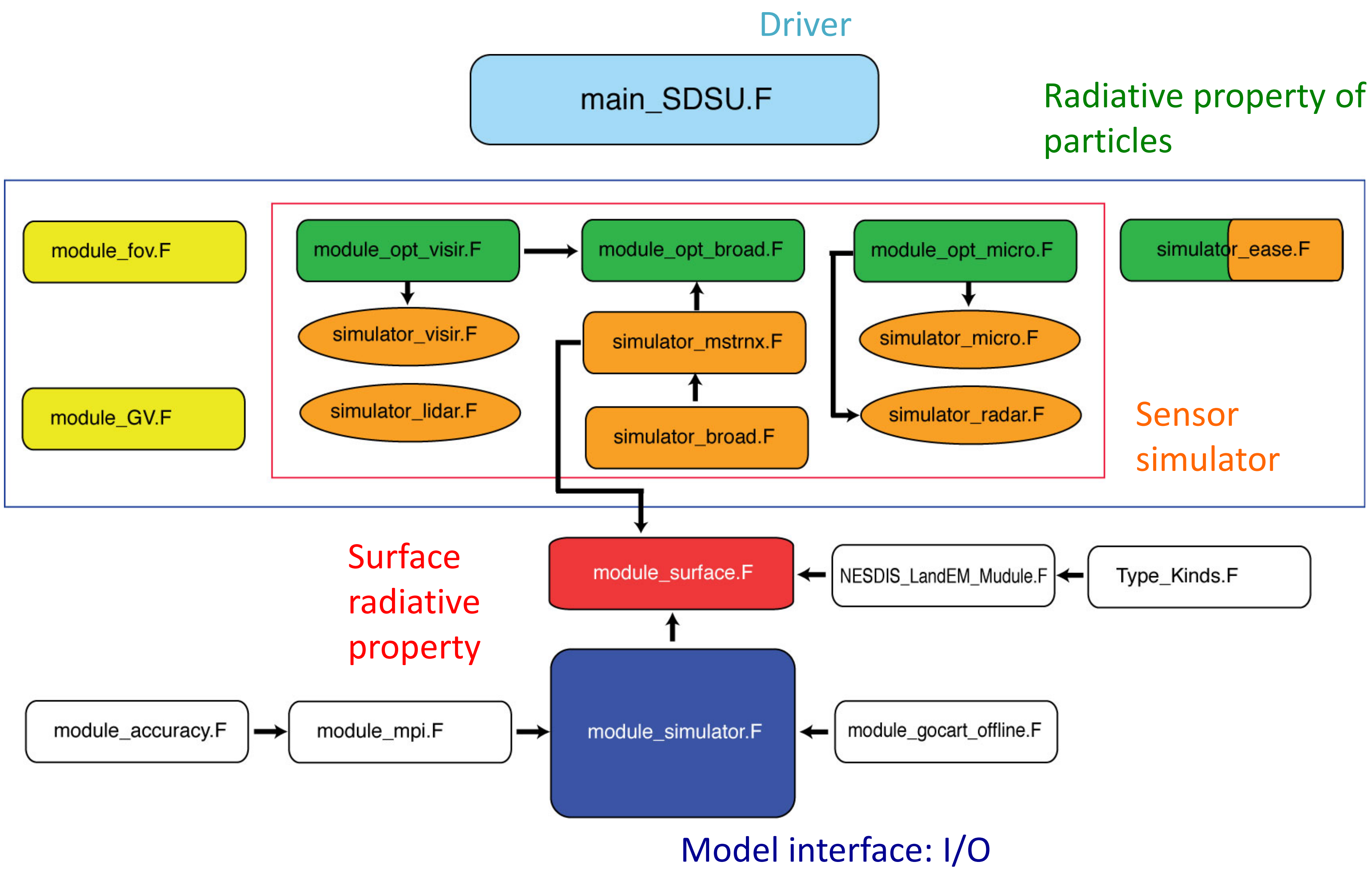
- Sensor simulators available for visible-IR, passive microwave, radar, lidar, and broadband.
- Universal interface for aerosol and cloud microphysical schemes has been developed. GCM interface is being added.
- Unified non-spherical scattering library was constructed for microwave frequency, and visible-IR range is planned next year.
- Open to the public (https://sites.google.com/site/jointsimulator/home).

Diagnosis & Validation dataset

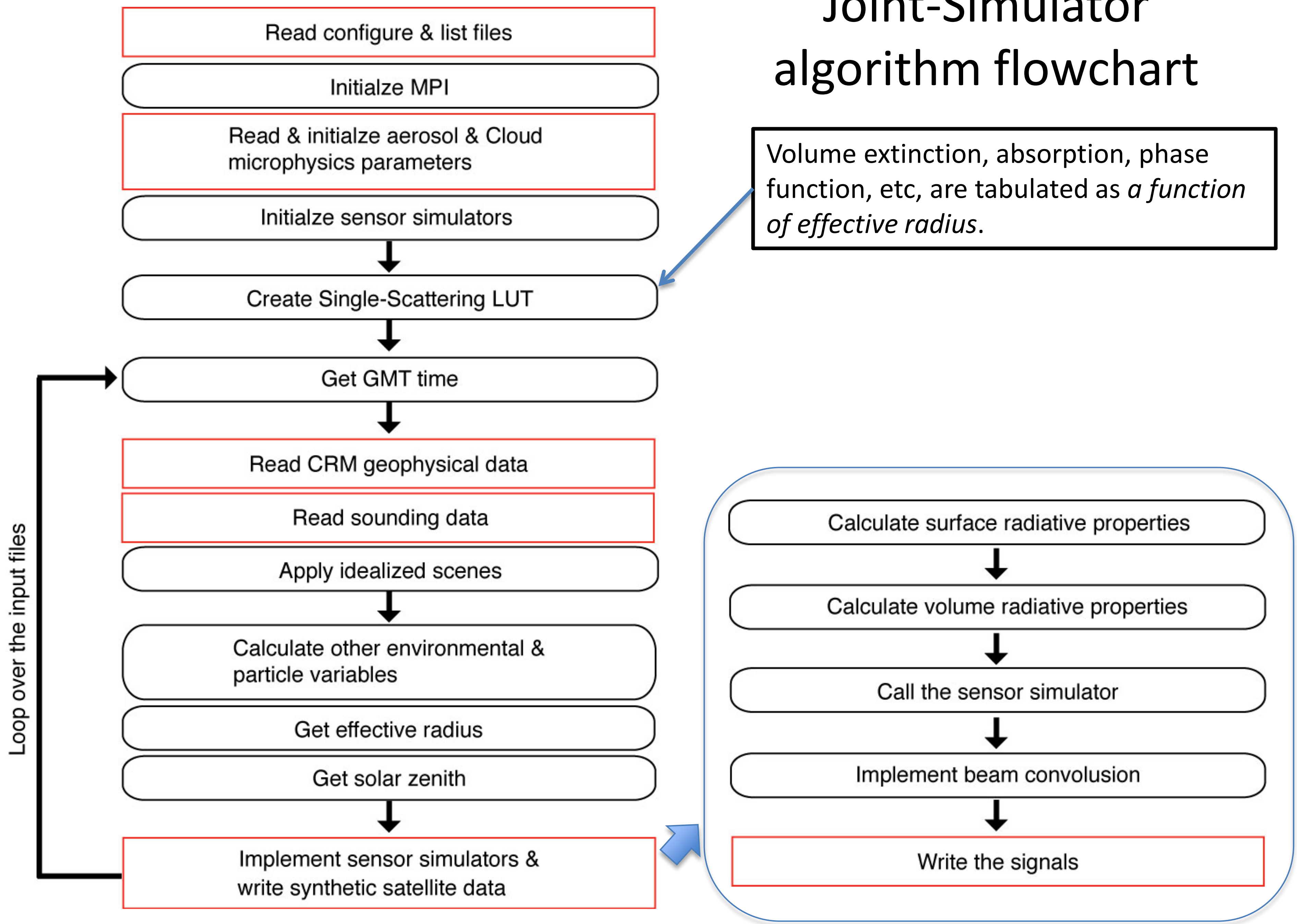
- AMSR-E and CERES collocated with CloudSat-CALIPSO Merged Dataset.
- The simple cloud type scheme proposed based on cloud top temperature and maximum radar reflectivity is useful to boil down the samples.
- Passive microwave provides information on columnar amounts of liquid and ice hydrometeors.
- Errors in OLR for each cloud type can be associated with the cloud microphysics.

Extra slides

Structure of Joint-Simulator



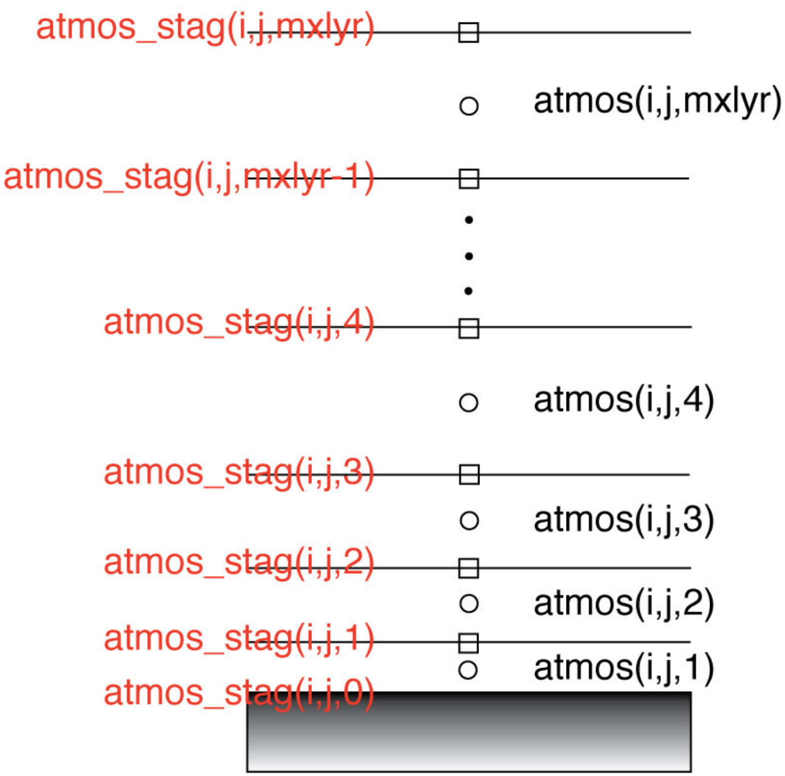
Joint-Simulator algorithm flowchart



How easy to implement Joint-simulator?

- Registration
  - Go to Joint-Simulator webpage (https://sites.google.com/site/jointsimulator/) and click "Contact & Registration"
  - Then, you can get a package from a ftp site.
- Requirement
  - A C-preprocessor, a Fortran compiler, and netcdf library
- Preparation of input
  - Put your model output (winds, thermodynamics, aerosol-cloud variables) in a single netcdf file.
    - Spherical (lat-lon) or rectangular grid system if the beam convolution is necessary.
  - Edit the configure file, Configure_SDSU.F, for your experiments and model assumptions.

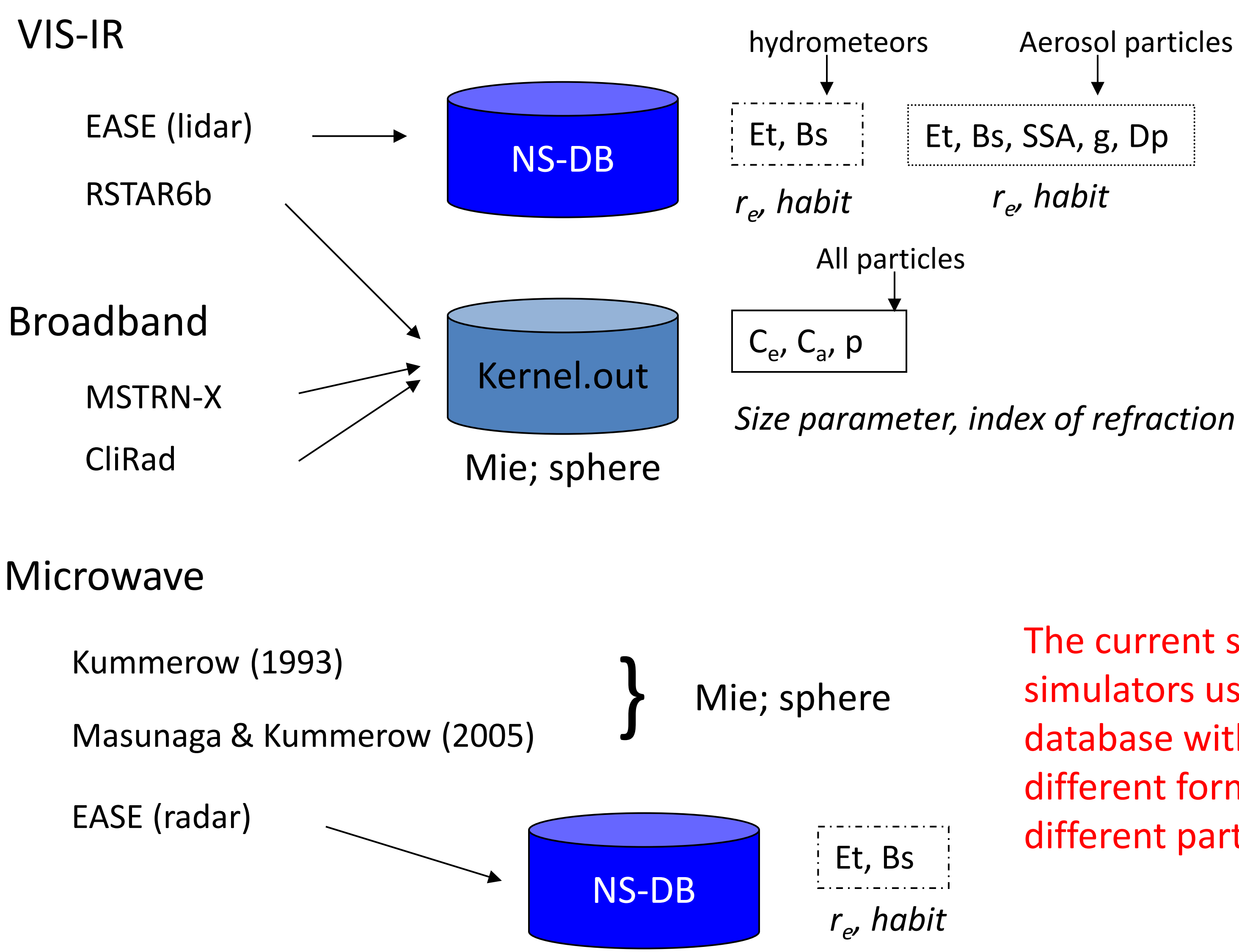
Preparing input data



- Grid information
  - ✓ Latitude, longitude
  - ✓ height
- Dynamical variables
  - ✓ Vertical wind (3D)
  - ✓ 10-m horizontal winds
- Thermodynamical variables
  - ✓ Air temperature
  - ✓ Total pressure or moist air density
  - ✓ Vapor mixing ratio or relative humidity
- Surface variables (example)
  - ✓ Land-cover type
  - ✓ Soil moisture content

- Cloud microphysical variables
  - ✓ Bulk: mass (and number) concentration for each category
  - ✓ Bin: mass concentration for each bin
- Aerosol microphysical variables
  - ✓ Bulk: same as the above
  - ✓ Internal mixture and hygroscopic growth of a particle

Current status of single scattering library in Joint-simulator

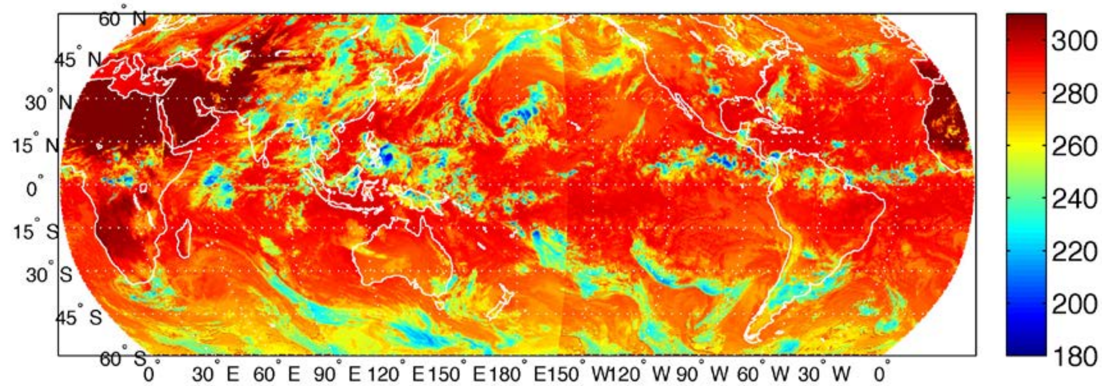


The current sensor simulators use the database with different formats and different particles.

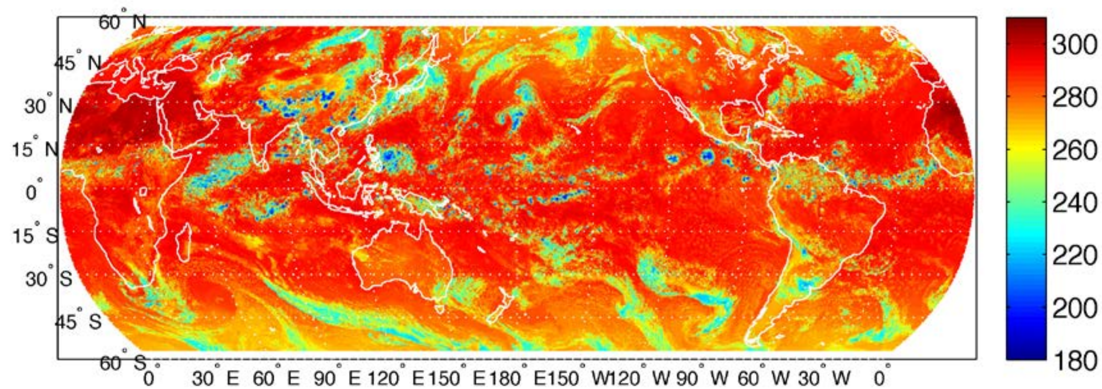
Adding an option for response function

- A better agreement between observation and NICAM can be seen over Saharan desert.
- In general, monochromatic simulation underestimates Tb. But, it overestimates Tb for high deep clouds.

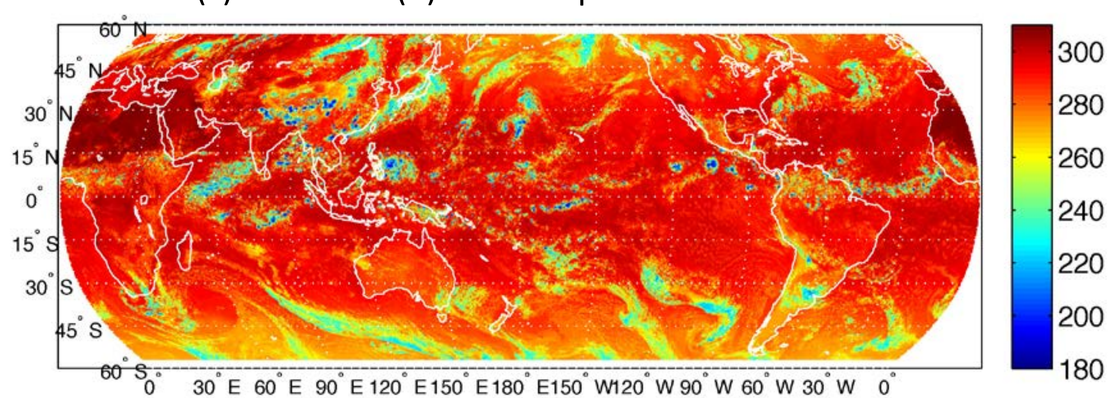
(a) Global IR (K) : 20080619.12



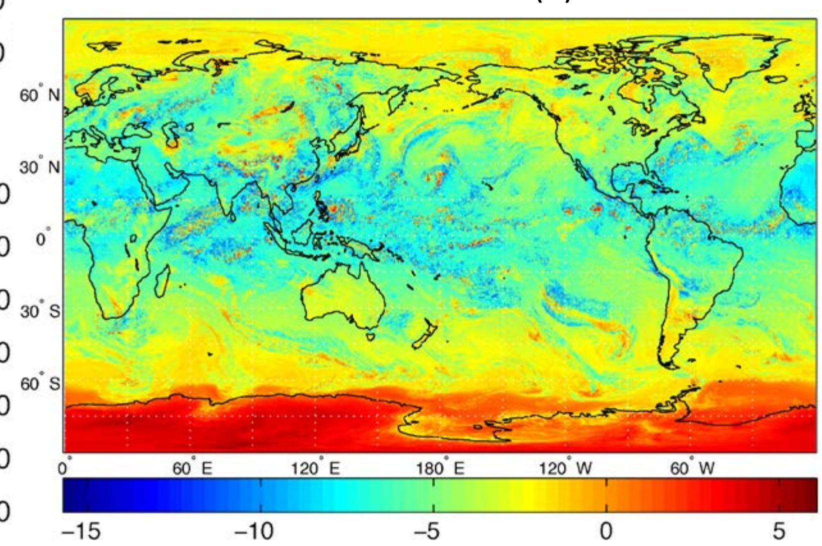
(b) NICAM IR (K): without response function



(c) NICAM IR (K): with response function

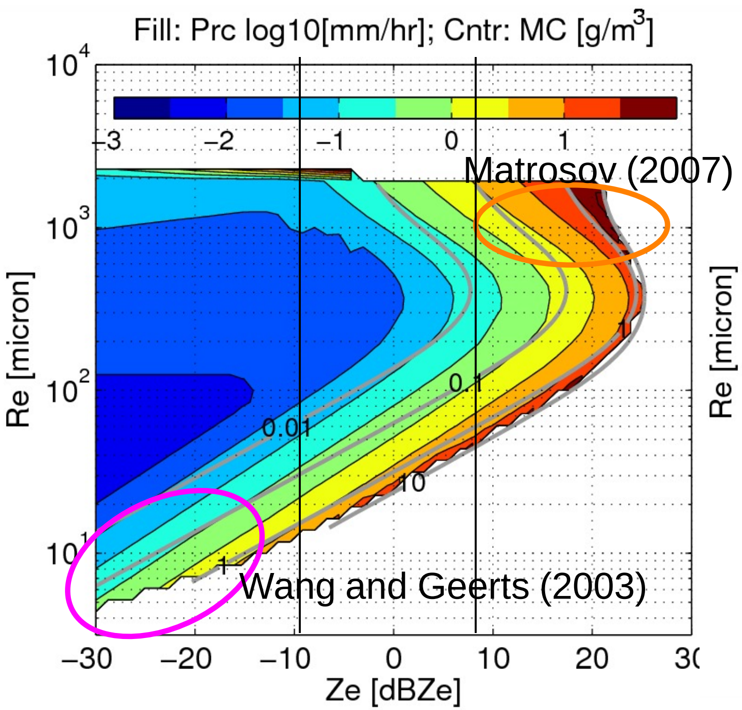


Difference: b-c (K)

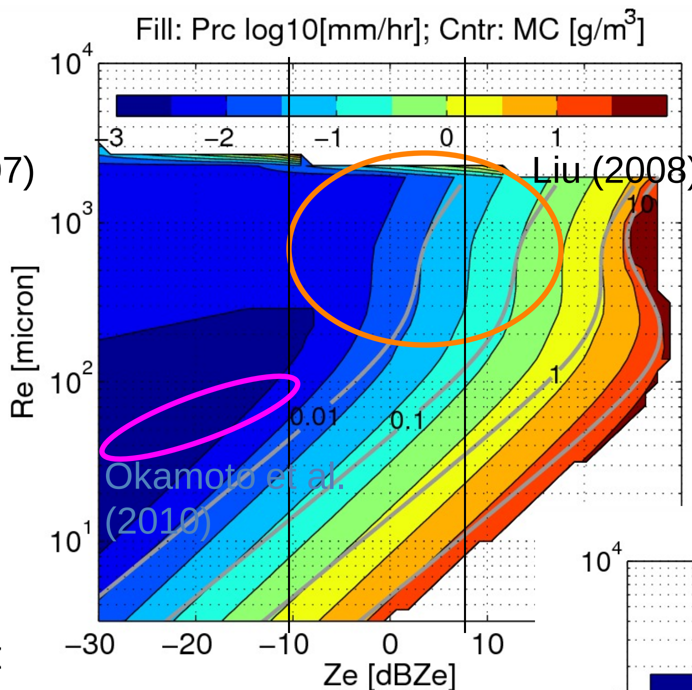


Precipitation rate and Ze

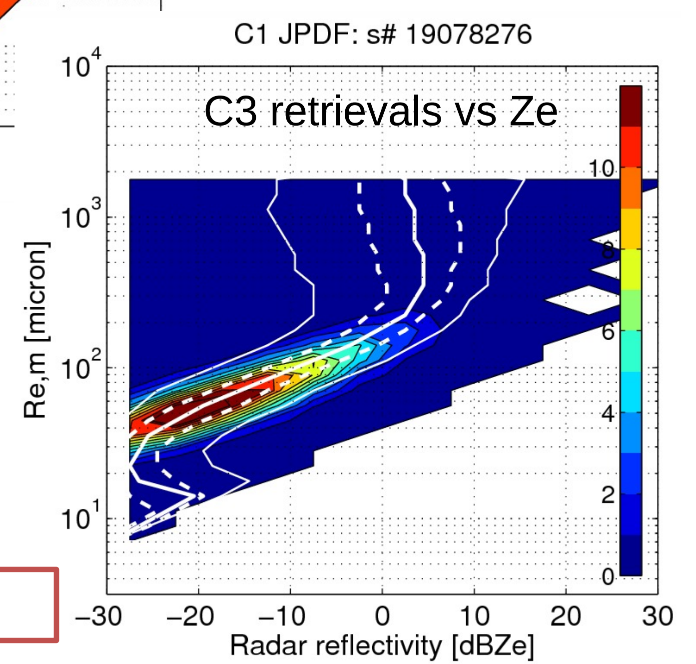
Rain



Snow



Assume inverse-exponential distribution, varied mass and # of a hydrometeor category, and calculated 94GHz radar reflectivity. Only one layer (240m) of a cloud is assumed above the surface.



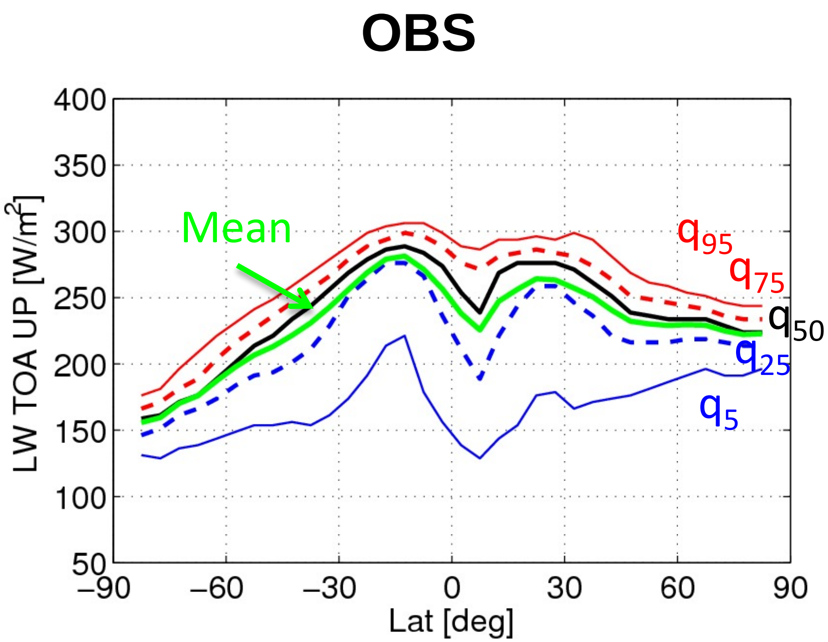
Rain: At -10 dBZe, Re>20 μm means precip rate<1 mm/hr
At 8 dBZe, precip rate>0.18 mm/hr

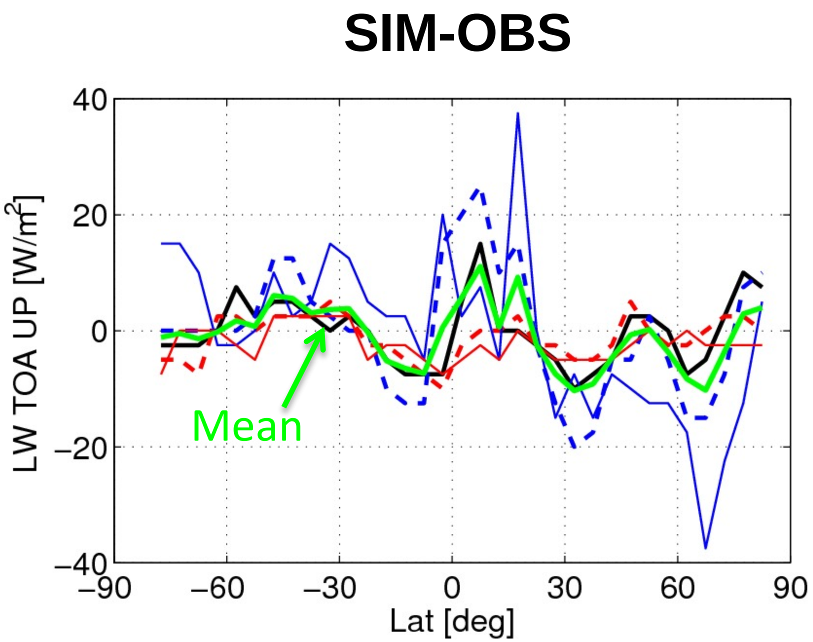
Snow: At -10 dBZe, Re>100 μm means precip rate<0.01 mm/hr
At 8 dBZe, precip rate>0.1 mm/hr

Attenuation is not included, leading to overestimation of Ze.

Zonal statistics of OLR

- Cloudy samples taken over ocean
- Radar-or-lidar cloud mask used





SIM

- Overestimate OLR in 0 – 20N and 60S – 30S
- Global mean (OBS: 226 W/m^2) is overestimated by 8 W/m^2, while the global mean (all scenes) shows a good agreement.

How fast does it run?

CPU: Intel Xeon(L5520) 2.26Ghz (4 cores)

Memory: 4x6 GB

- 32 CPUs
- 2560x1280x40 grid points
  - EASE: 26 min
  - RSTAR6b (one frequency): 40 min
  - MSTRNX: 13 min

Summary

- Sensor simulators include radar, lidar, and broadband simulators that are not in SDSU.
- Universal interface that can be applied for various aerosol & cloud microphysical outputs
  - ✓ Atmospheric models: NICAM, JMA-NHM, & WRF
  - ✓ Aerosol microphysical models: SPRINTARS & GOCART
  - ✓ Cloud microphysical models: NICAM single, double-moment bulk scheme, Hebrai University spectral bin model, and WRF microphysical schemes (Lin scheme)
  - ✓ Particle size distribution, mass-dimensional relationship, and fall velocity are easily specified with a namelist.
- Parallel-computation option (Message Passing Interface) is available.
- The response function can be applied in the visible-IR simulator.
- Write out data necessary for off-line implementation of 3D RTM.
- Can be useful for retrieval algorithm development as well.

Future works

- netcdf output & multiple snapshots
- Construction of non-spherical scattering database
- GCM interface
- Add interfaces for 3D RTMs

Comparison of 1D and 3D RTM (Preliminary results)

High resolution simulation of marine stratocumulus
- provided by Mr. Y. Sato (Prof. Nakajima group)
- horizontal resolution: 500x500m

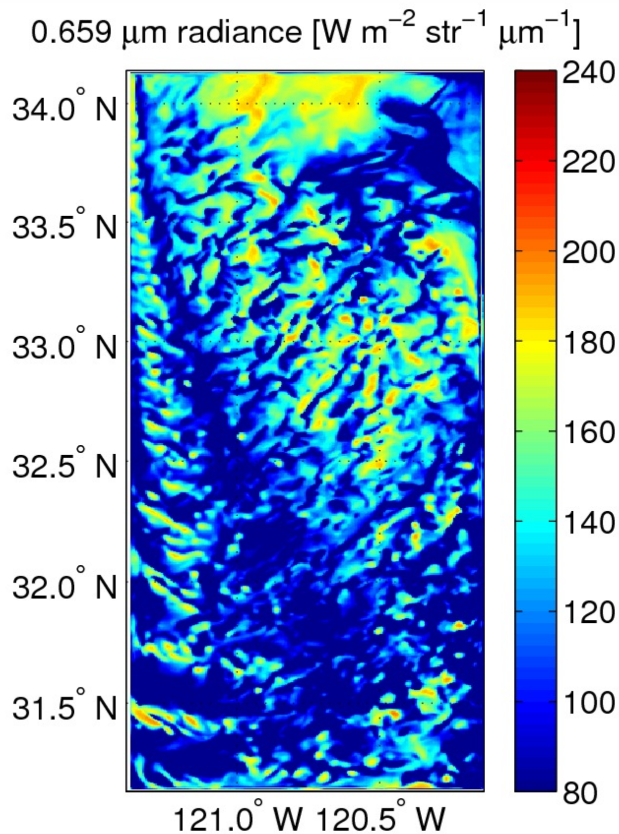
Can be useful for retrieval algorithm development

Experiment design

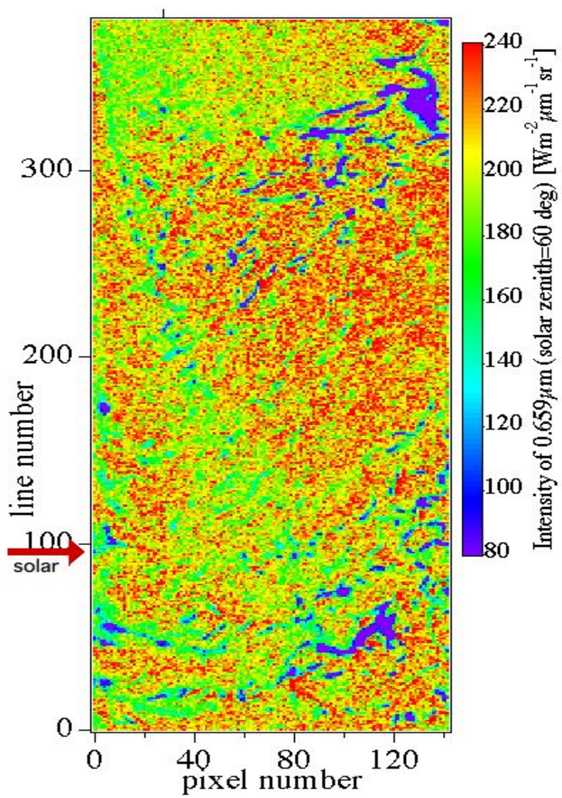
- solar zenith angle: 60°
- viewing zenith angle: 14.3°
- difference between solar azimuth angle and viewing azimuth angle:0°
- no surface reflection (RSTAR not changed yet)

RSTAR: lower radiance between clouds.

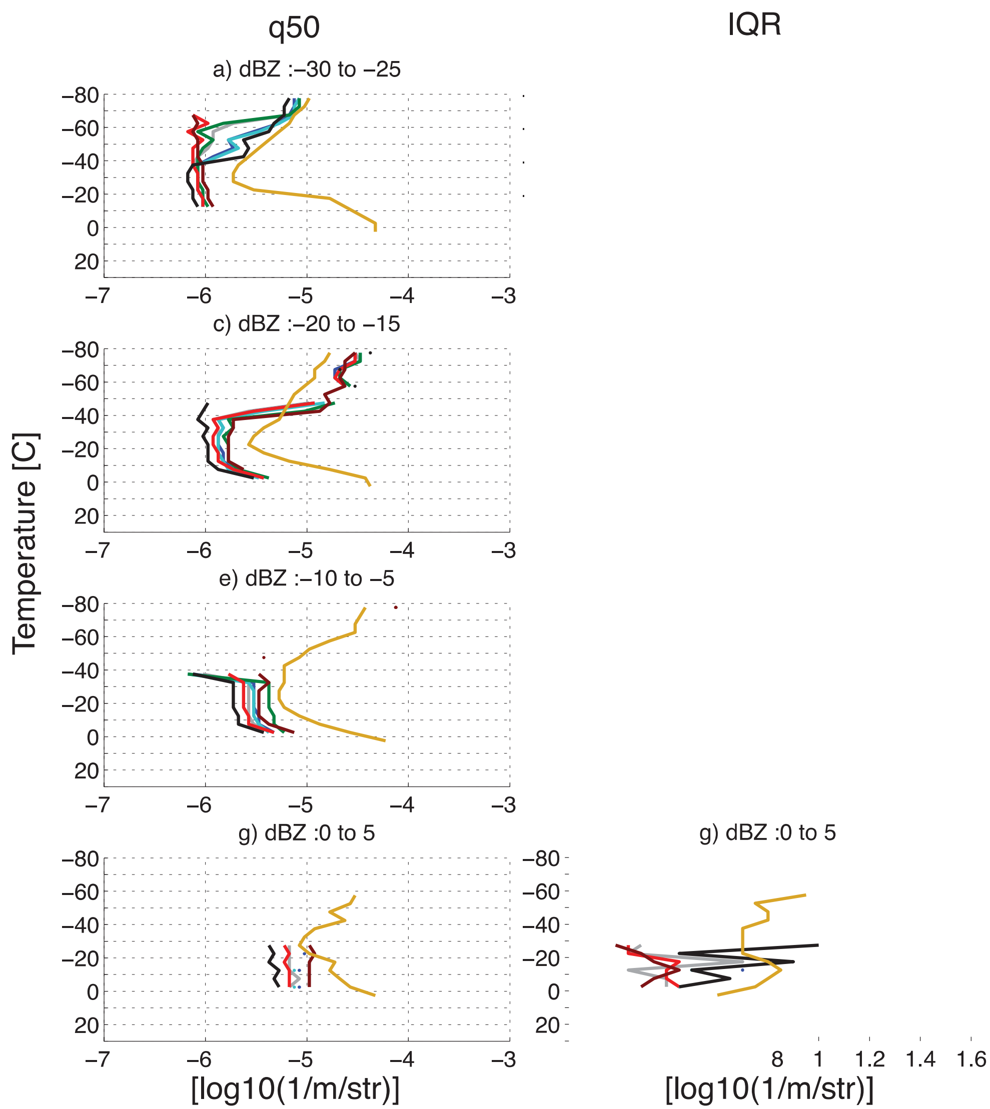
1D RTM: RSTAR6b



3D RTM: MCARaTS (Dr. Ishida)



Uncertainty due to non-spherical ice scattering in BETTER

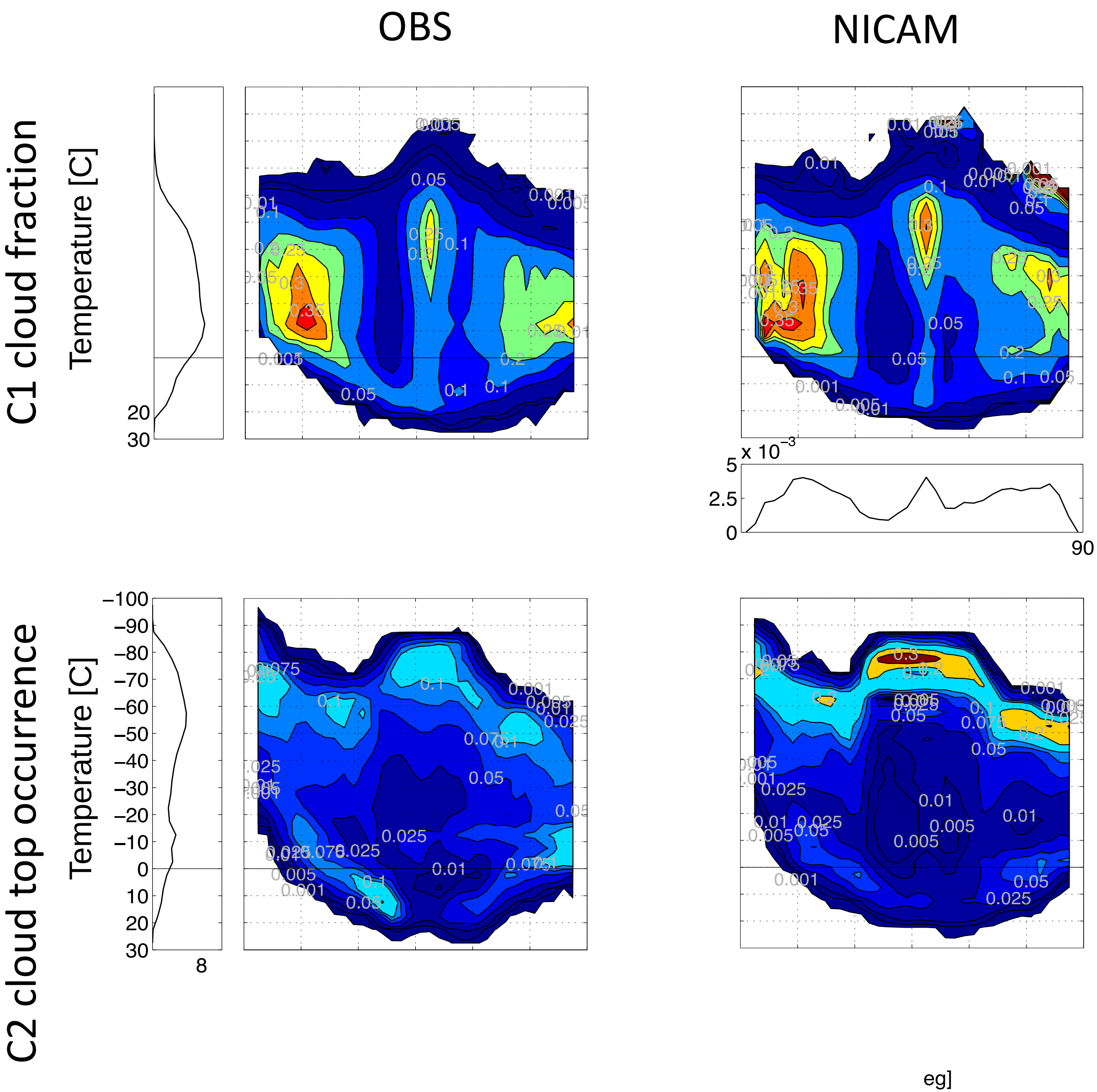


Approach for evaluating clouds simulated by CRMs

- Cloud microphysical evaluation (Hashino et al. 2013, JGR, under revision)
  - Synergetic use of CloudSat and CALIPSO for cloud fraction and in-cloud signals
  - BETa-TEmperature Radar-conditioned diagram (BETTER) for diagnosing water content and effective radius
- Simple cloud type scheme
  - Use cloud top temperature and maximum radar reflectivity to define “Cloud Type”
- Water path evaluation
  - Use co-located passive microwave data
  - To give a constrain on the column amount of hydrometeors in precipitating clouds
- TOA broadband fluxes evaluation
  - Use co-located broadband flux data

- Main data set
  - CloudSat-CALIPSO Merged Dataset (Hagihara et al. 2010)
    - C1 (radar), C2 (lidar), C3 (radar and lidar), C4 (radar or lidar) mask available
  - NICAM 3.5km global simulation (Nasuno et al. 2012)
    - One-moment bulk microphyscs scheme, NSW6
  - Aqua AMSR-E L1B (JAXA EORC)
  - Aqua CERES L2

Meridional-Temperature distribution



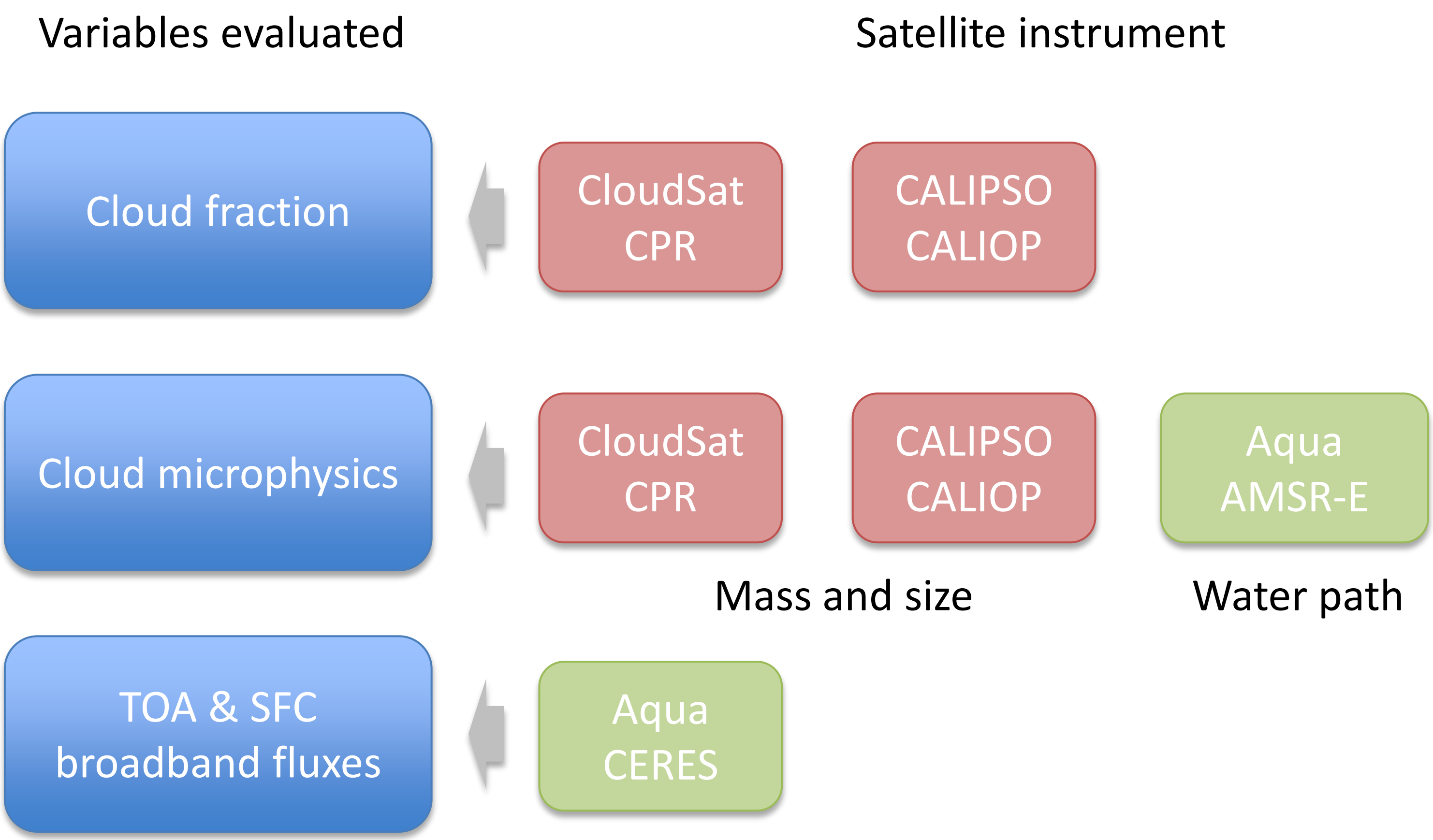
NICAM

- C1 CF: generally good agreement with OBS (R=0.88).
- Captures the max CF in the tropics.
- Overestimates
  - ✓ high clouds at T < -30° C over most of the latitudes.
  - ✓ low-level clouds in high latitudes.
- Underestimates
  - ✓ subtropical warm clouds

Further info on cloud types

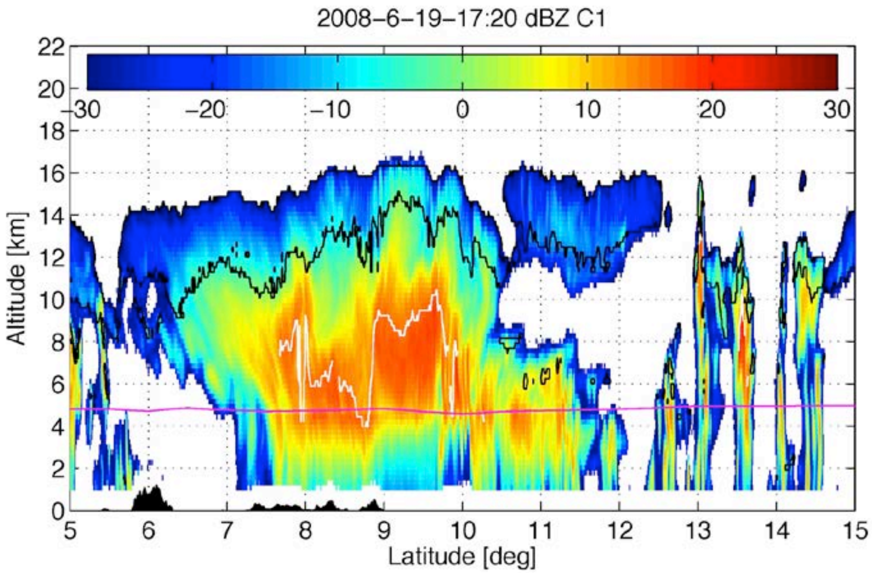
- C2 CTO: poor agreement with OBS.
- Captures the high and low clouds qualitatively.
- Misses middle clouds (-20 < cloud top T < -10C) in the tropics and northern mid latitudes.
- Polar stratospheric clouds are simulated.
- Higher relative occurrences of high clouds.

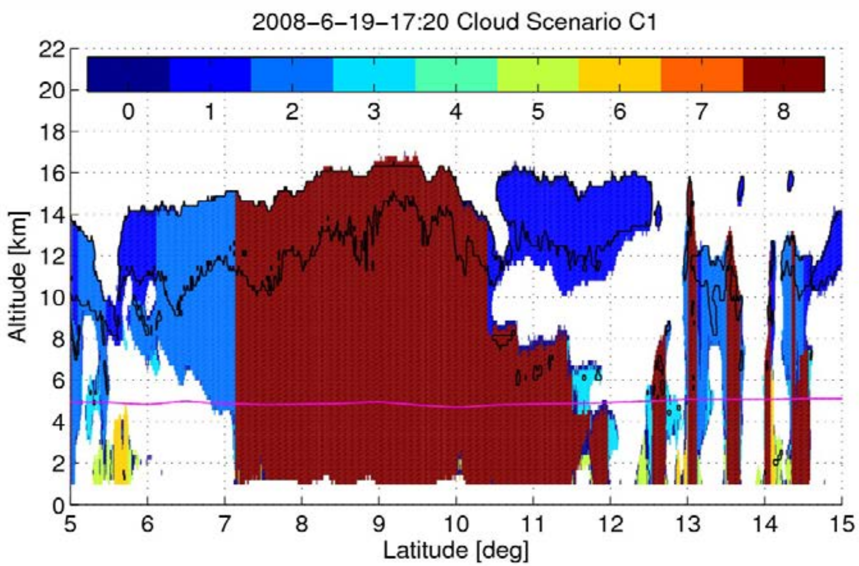
Approach for evaluating clouds simulated by CRMs with A-train



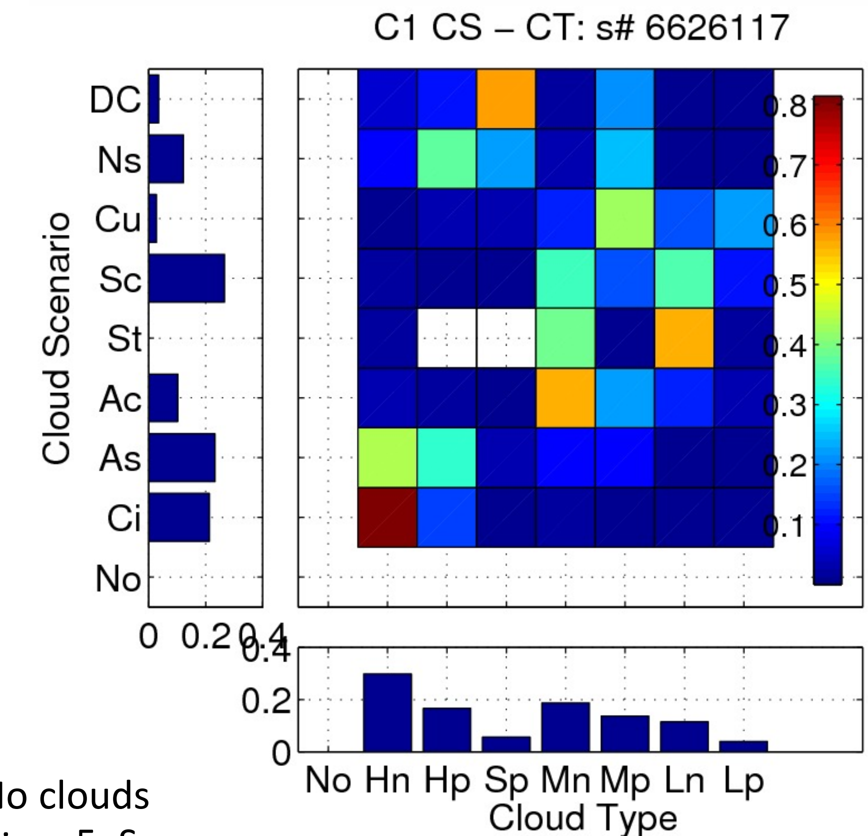
Comparison with cloud scenario

OBS





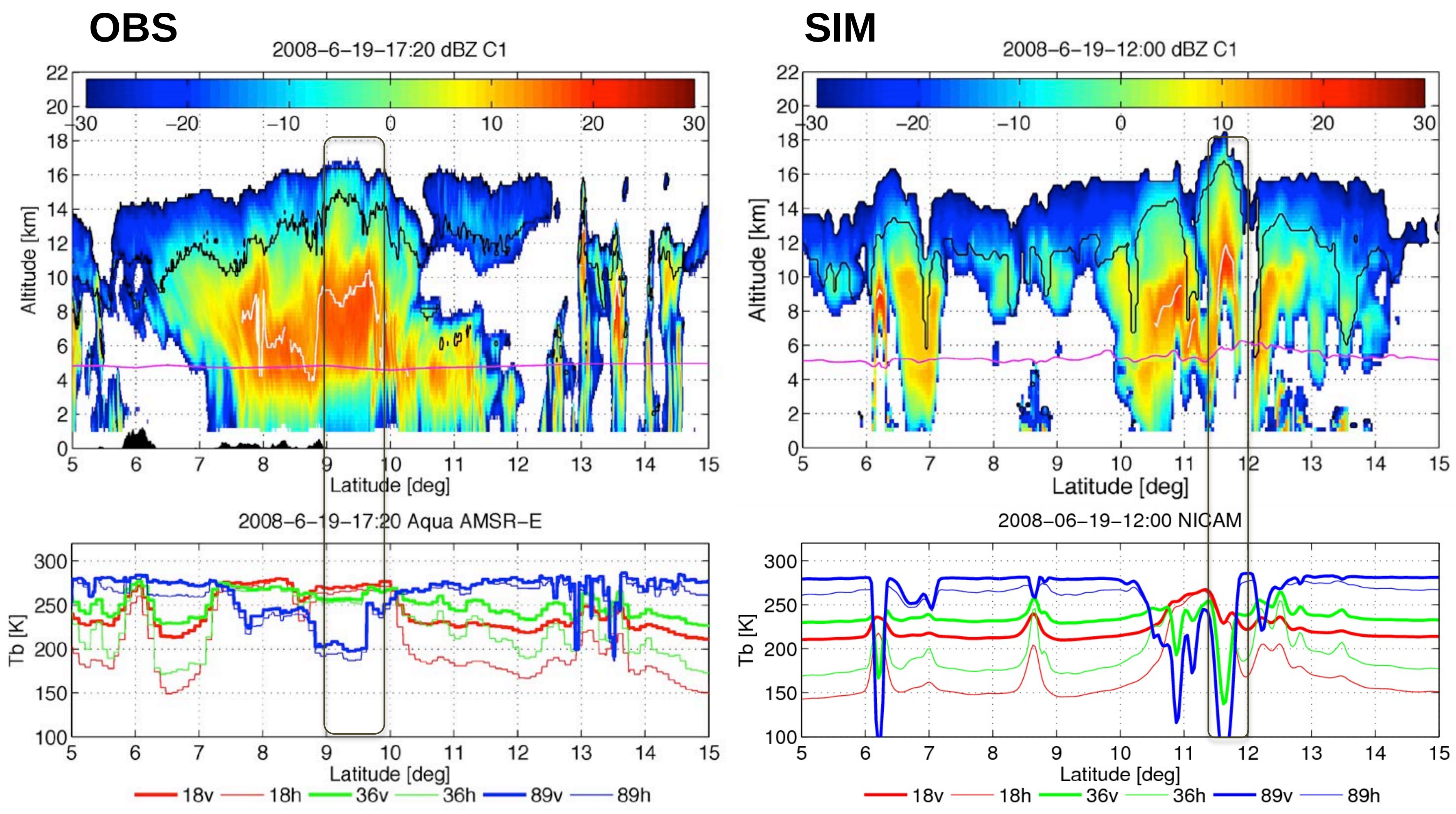
Frequency of clouds by Cloud Scenario and Cloud Type, and cloud type conditional frequency.



0: No clouds
1: Ci
2: As
3: Ac
4: St
5: Sc
6: Cu
7: Ns
8: DC

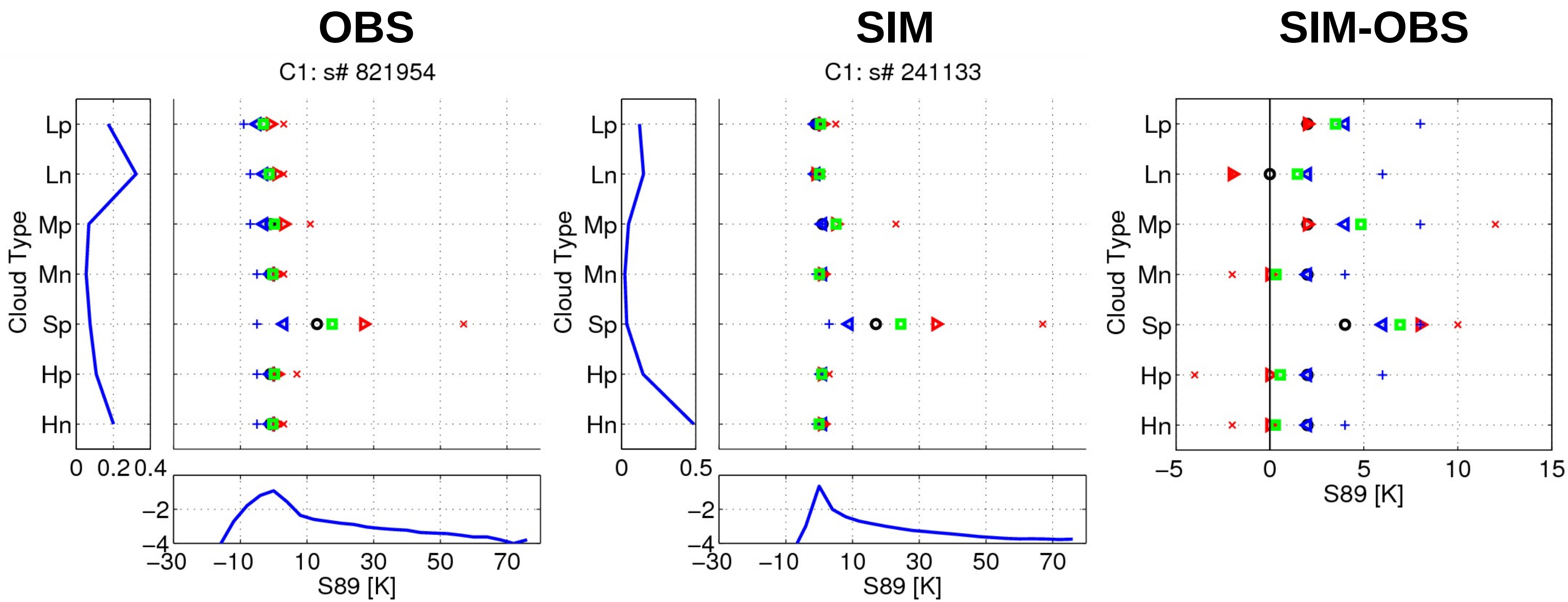
Good correspondence between Ci and Hn, DC and Sp, Ac and Mn, and St and Ln.

Example of collocated Tb

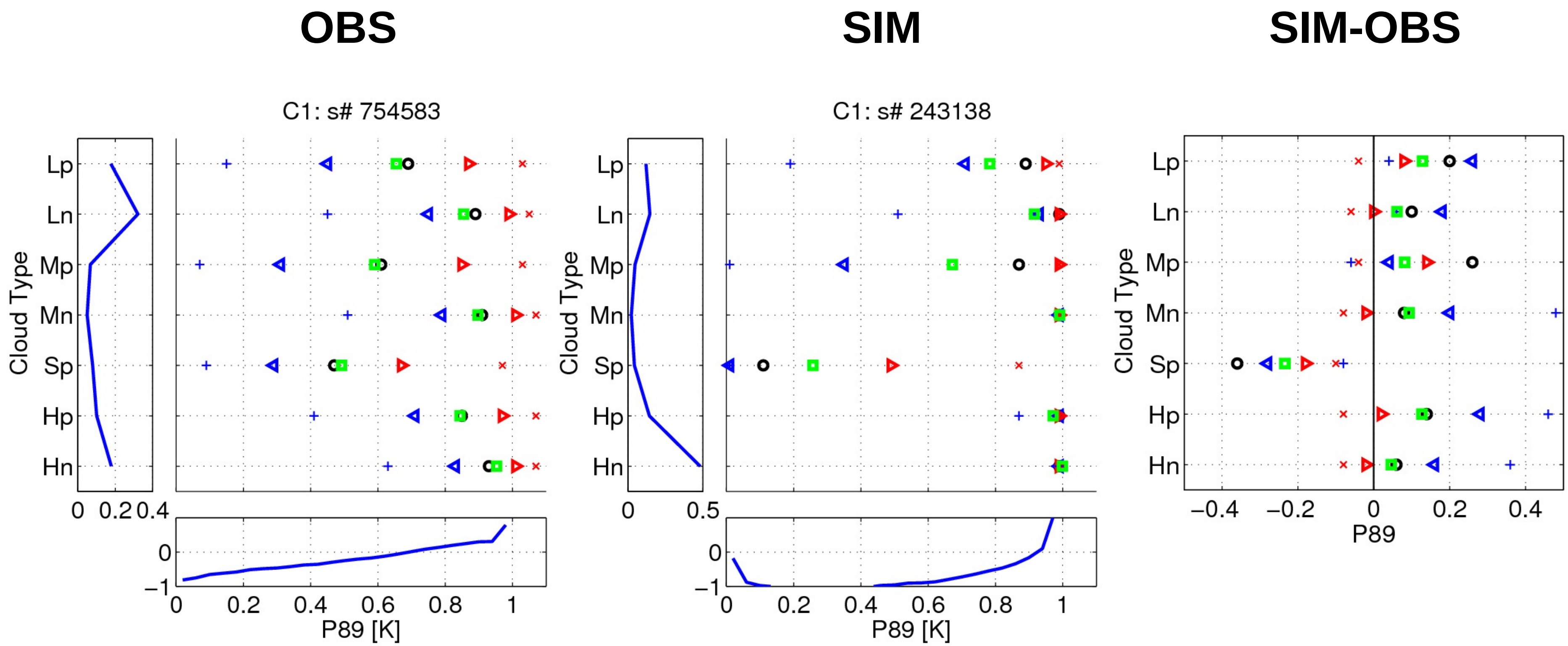


The simulated Tb are more depressed in the convective area, which implies overestimation of ice amount in the model.

S89 vs Cloud Type

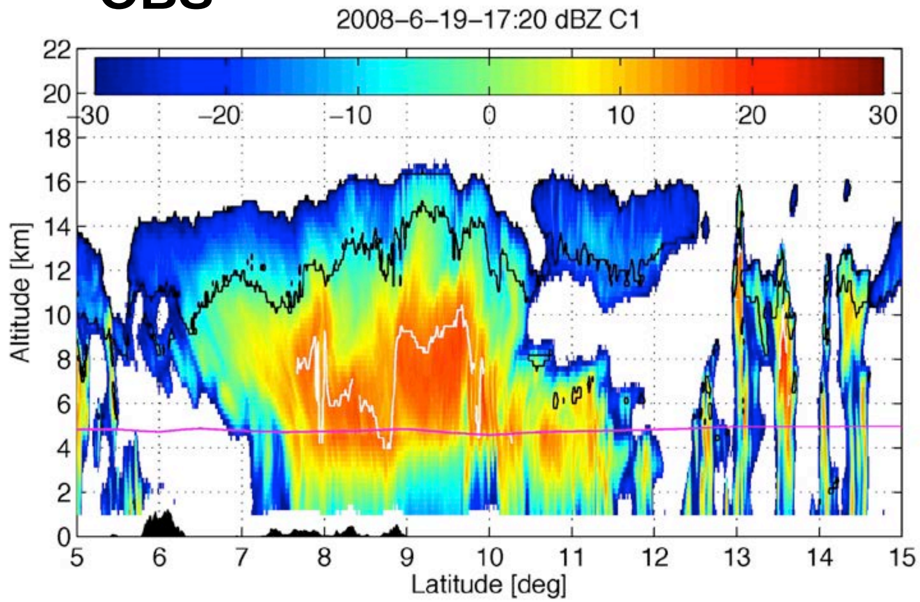


P89 vs Cloud Type

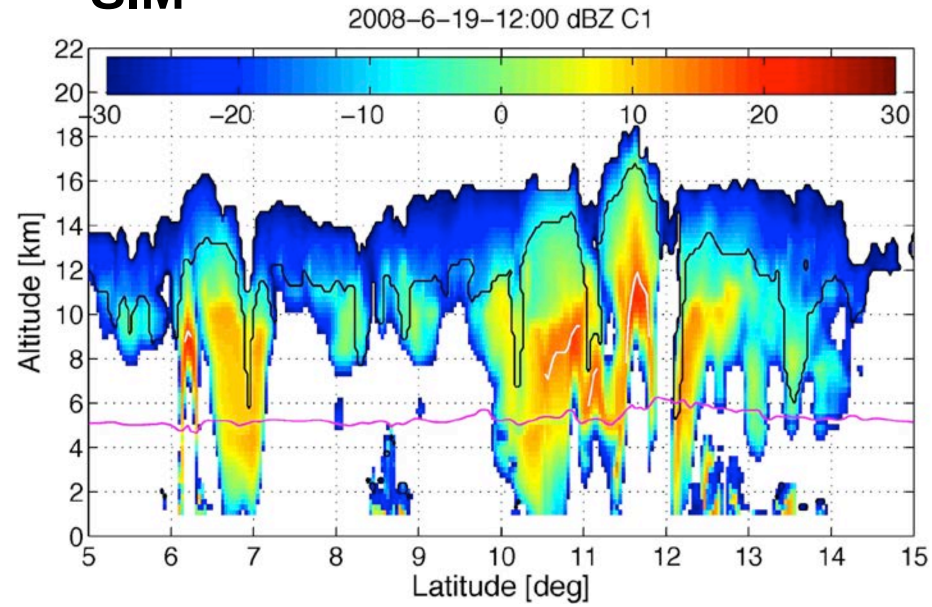


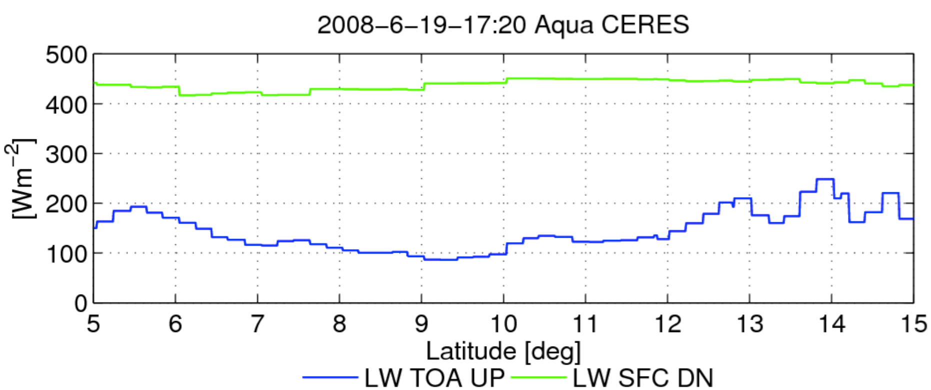
Example of collocated TOA fluxes

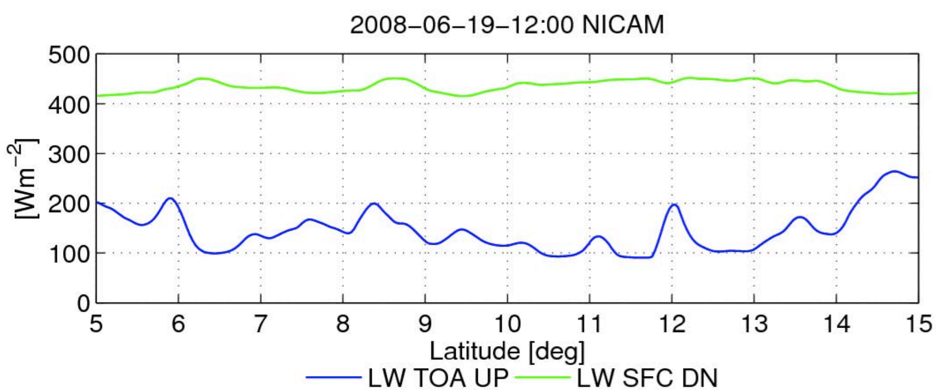
OBS



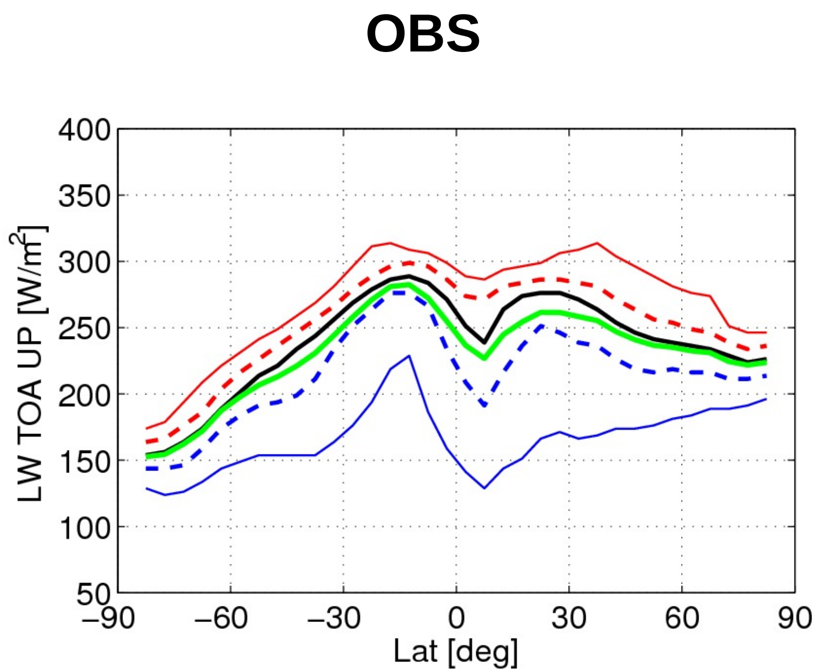
SIM

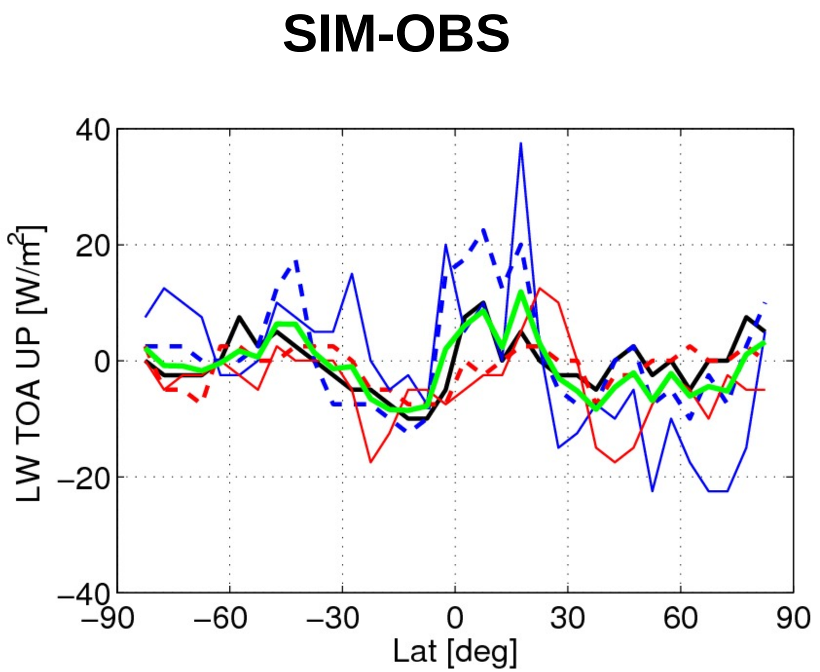






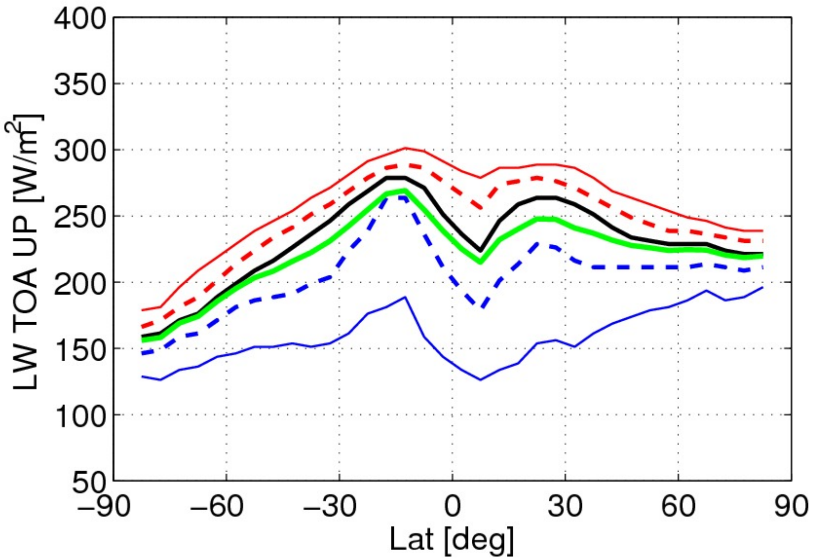
Zonal statistics of OLR



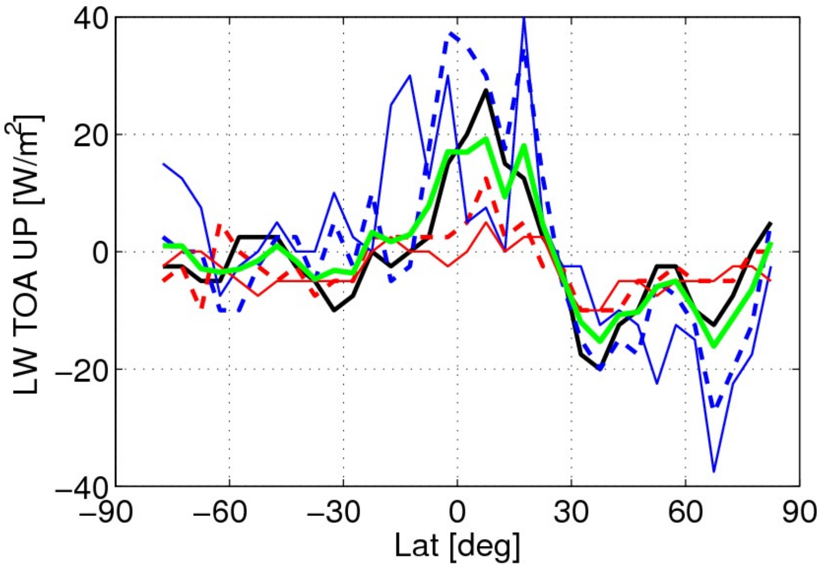


Zonal statistics of OLR over ocean

OBS



SIM-OBS

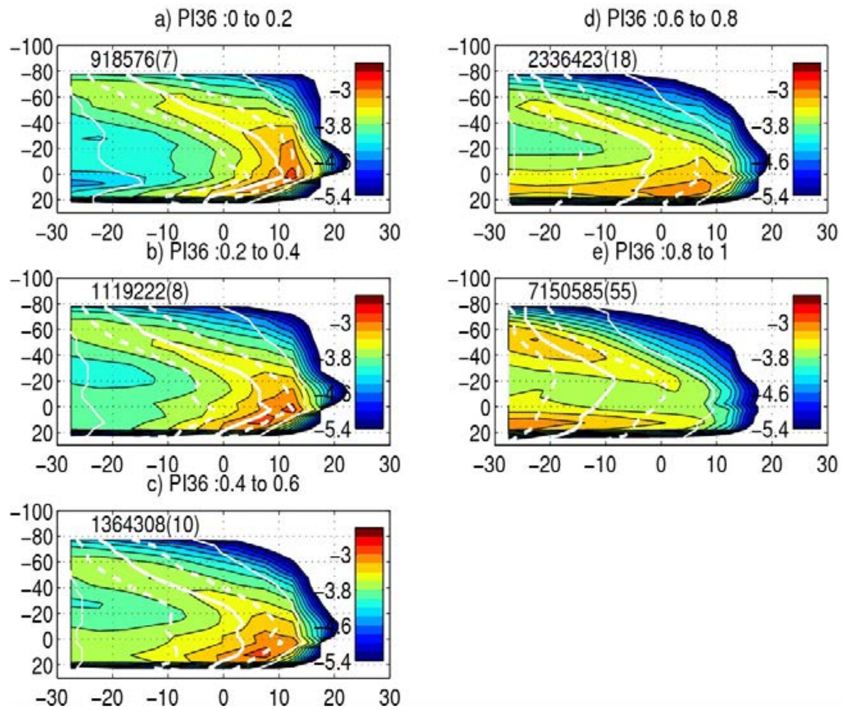


P36-sorted Joint-PDF of T & Ze in tropics

For each range of P and S, the joint PDF of Ze can be constructed.

OBS

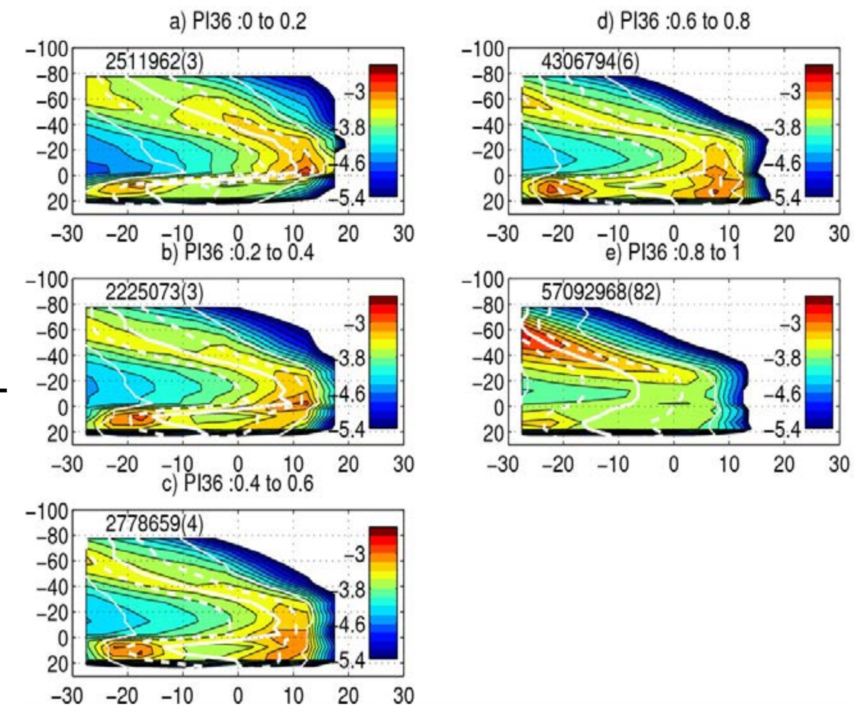
Temperature



Radar reflectivity [dBZ]

SIM

Temperature

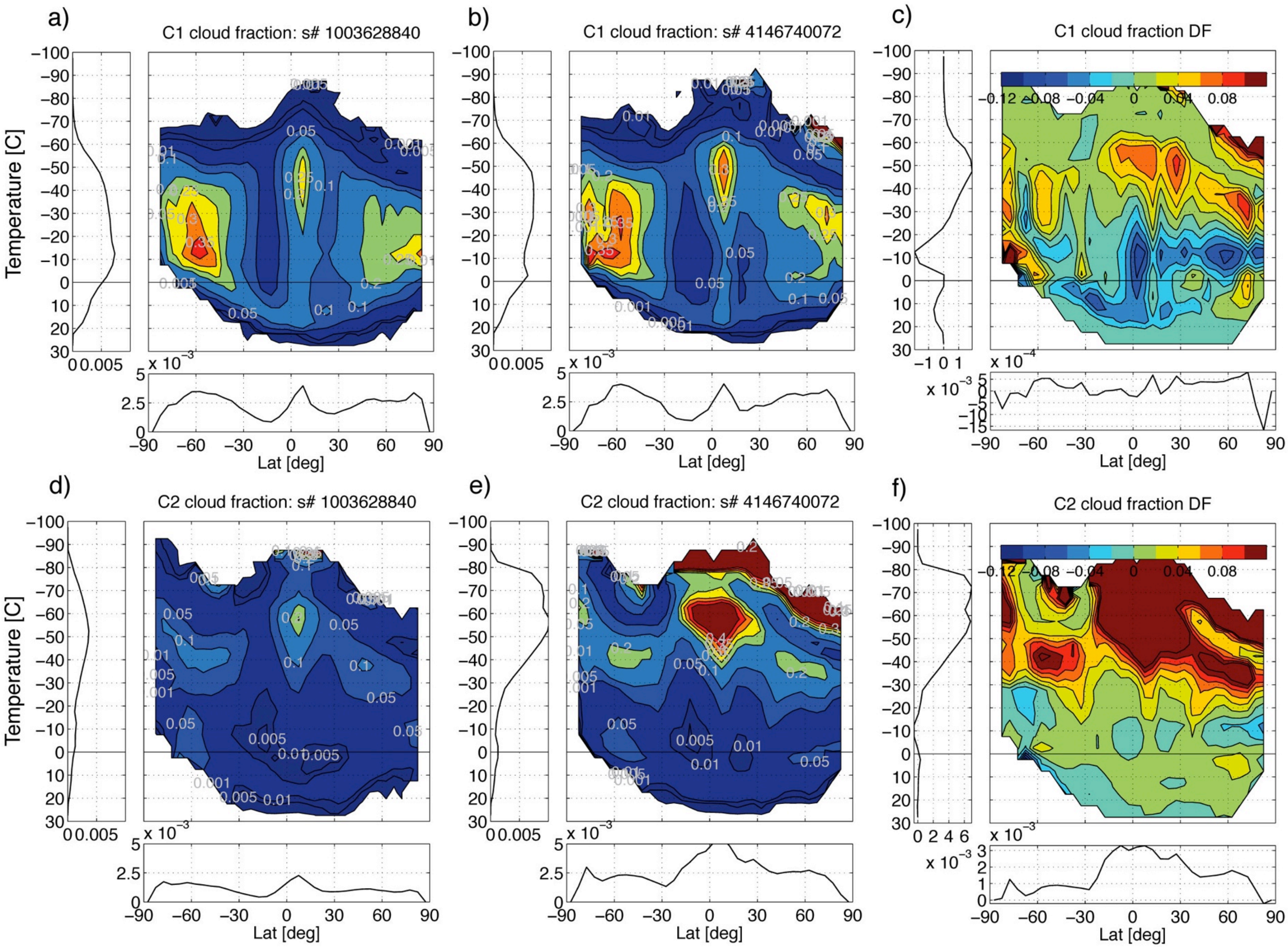


Radar reflectivity [dBZ]

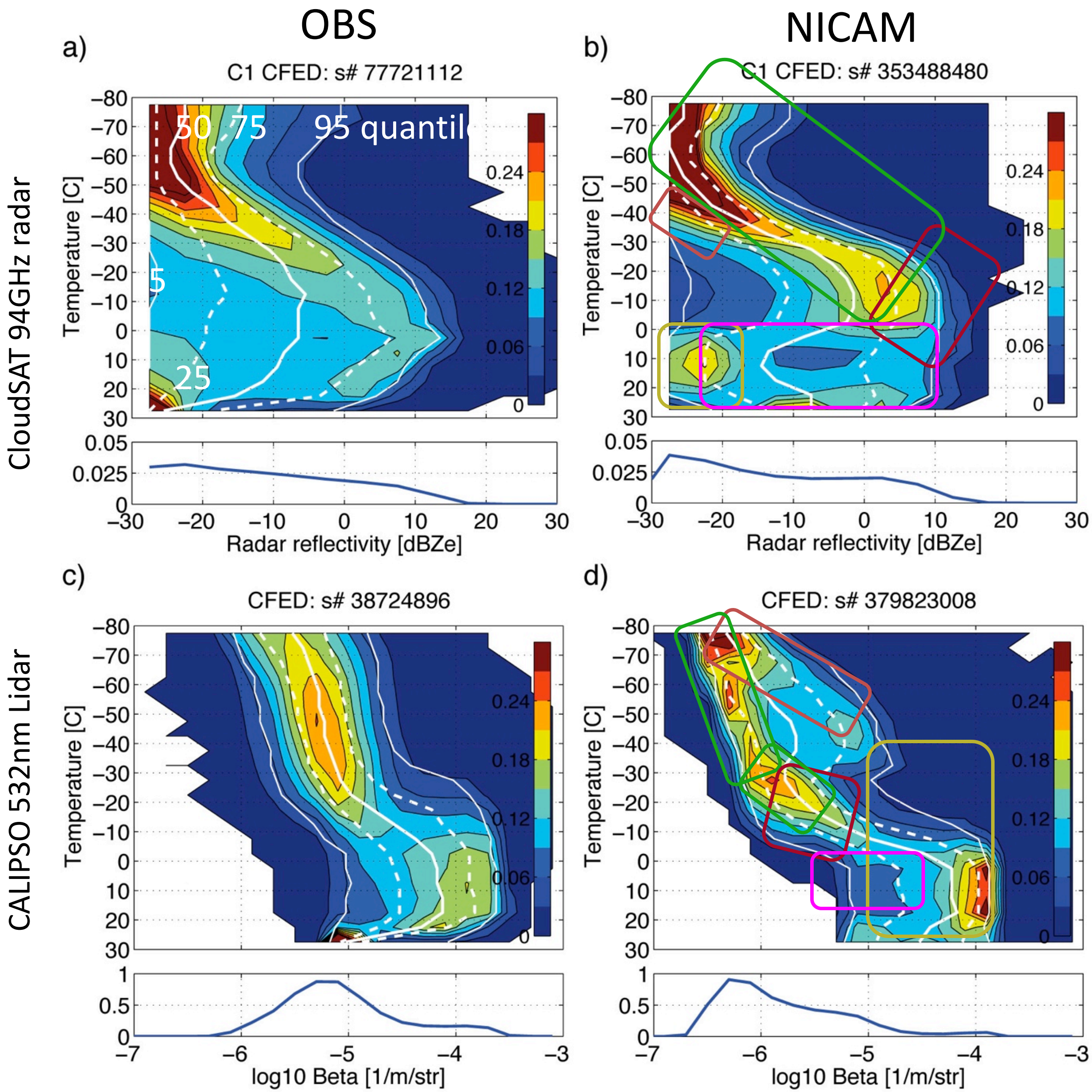
OBS
- The decrease in P36 is associated with high frequency of large Ze.
- Transition of clouds from cirrus+non-precipitating shallow cumulus, precipitating shallow cumulus, precipitating shallow cumulus, Nimbostratus, and then deep convection can be seen.

SIM
- Signals from cloud droplets are too often & stratiform precipitation is not apparent.

Meridional-Temperature distribution of Cloud Fractions



Global Contoured Frequency by tEmperature Diagram (CFED)



OBS

- one single dominant mode for a given T at T < -10C (z as vertical axis does not show it)

NICAM

- More pronounced non-precipitating regime & large ice .
- Overestimates the occurrence of 0 < dBZe < 10 dB.
- The 95th quantile smaller at T < -40 ° C and -20 < T < 10 ° C.
- The 50th quantile larger at -35 < T < 0 ° C.

- Two modes exist for log10(β_{532}) at T < -40° C level.
- 75th and 95th quantiles underestimated for liquid

Contribution of each hydrometeor category

Cloud ice

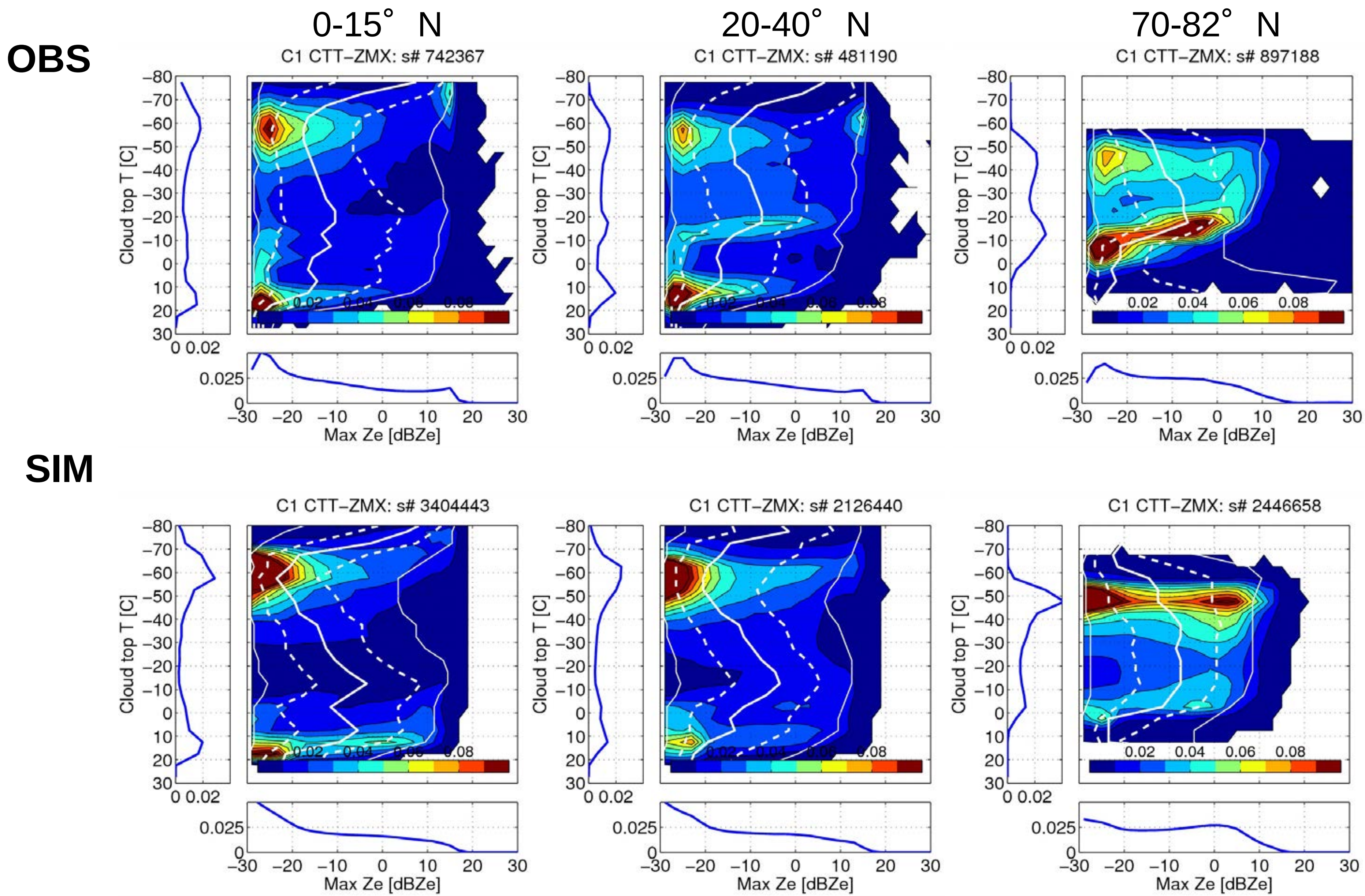
Snow

Graupel

Cloud droplets

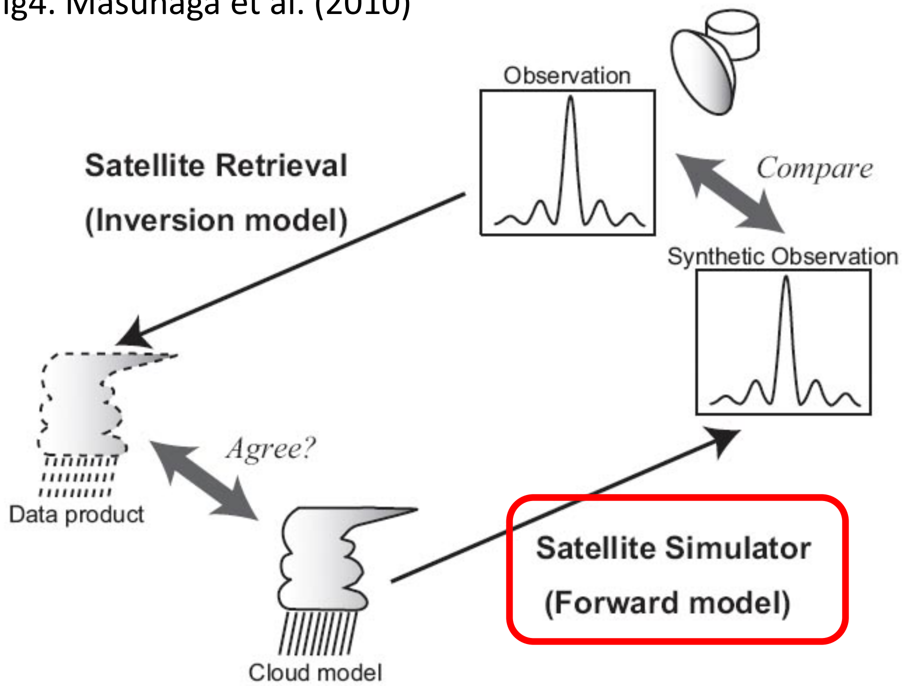
Rain

Joint PDF of Cloud top Temperature and max Ze



Intro: evaluation of aerosol & clouds

Fig4. Masunaga et al. (2010)



Two approaches for evaluation of aerosol-clouds simulated by GCMs and CRMs

- Retrieval approach: microphysical space
- Forward approach: radiatvie space

Uncertainty in

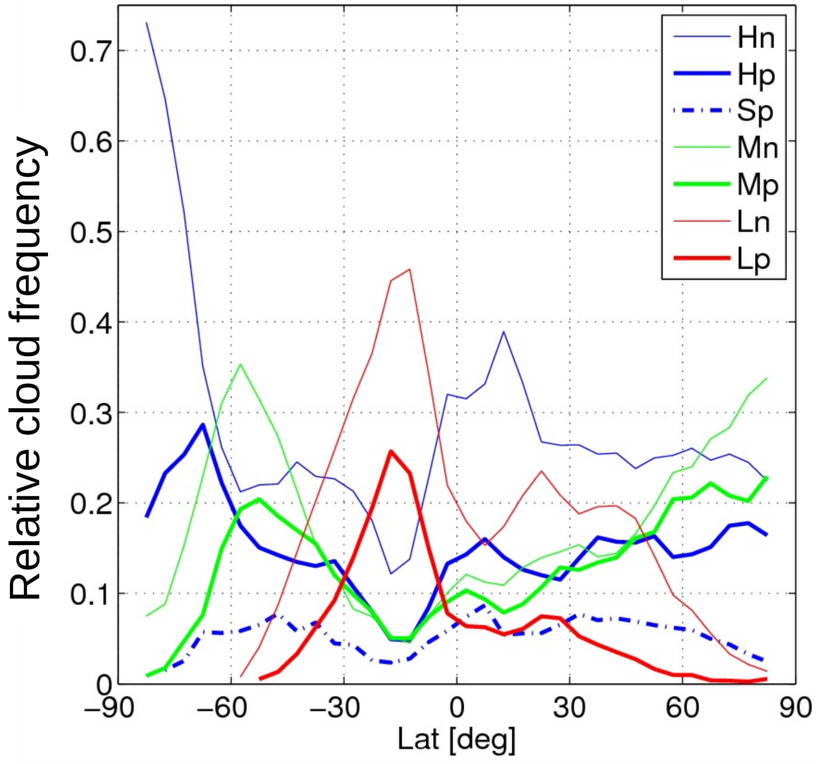
- Phase of hydrometeors
- Particle size distributions
- Habits
- Ice scattering model

Purpose of this study

- Develop a effective way to evaluate clouds simulated with a global cloud resolving model with combined use of A-train observation.

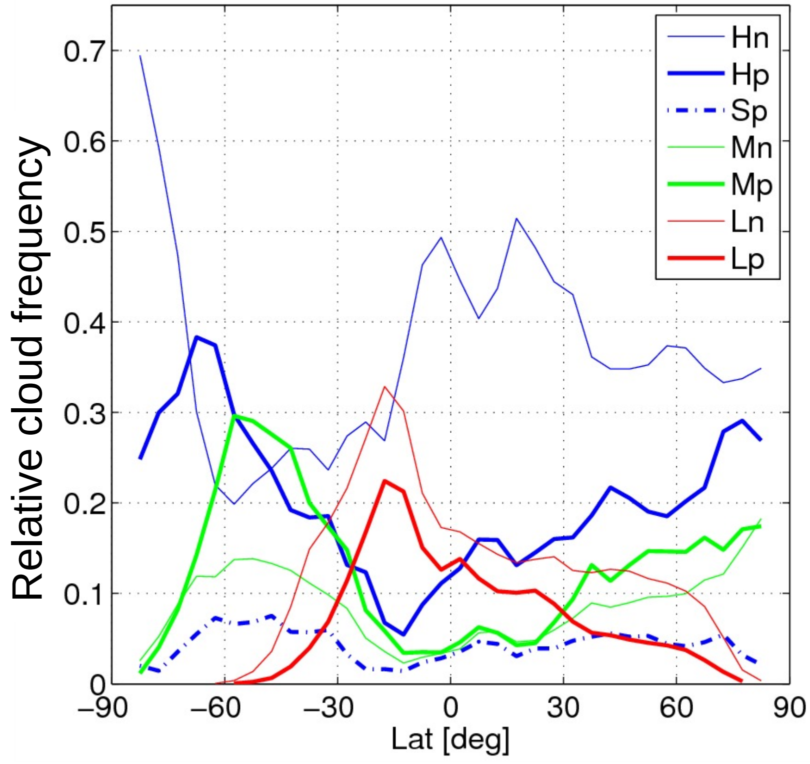
Zonal relative cloud occurrence by cloud type

OBS



- Hn dominate at Antarctic, Northern latitudes.
- Mn & Mp peaks at 60S and Arctic.
- Ln & Lp peaks at 15S.

SIM



- Both of Hn and Hp are overestimated.
- Mp occurs more than Mn.
- Ln is underestimated.

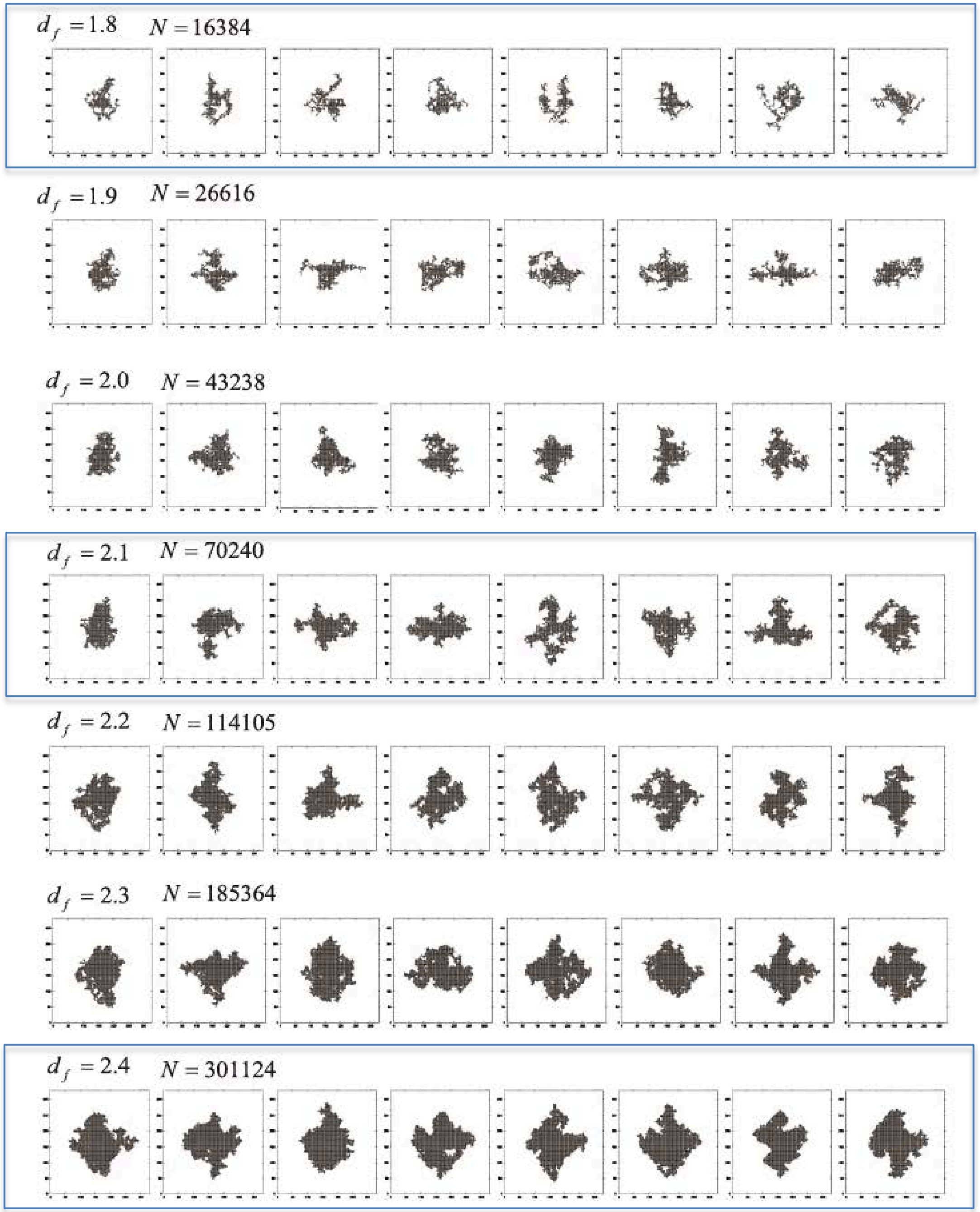


Fig. 1. Projected images of the modeled three-dimensional fractal particles with fractal dimension $d_f = 1.8$–2.4. The number of grids is 350×350 for all figures. See appendix for details of the Monte Carlo simulations.

ISMT-SF1

ISMT-SF2

ISMT-SF3

Snowflakes

Taken from Ishimoto (2008), Fig. 1.

$$m \propto D^{d_f}$$

- Method: Finite Difference Time Domain (FDTD)
- 1 habits
- 3 microwave frequency (GHz)
  - ✓ 36, 89, 95, 150
- 1 temperature points (K)
  - ✓ 250
- 9 size parameter points
- 181 scattering angles
- 6 phase function (F11, -F12/F11, F22/F11, F33/F11, -F34/F11, F44/F11)

Liu’s SCATDB

Liu (2008), BAMS

- Method: Discrete Dipole Approximation (DDA)
- 11 habits
- 22 microwave frequency (GHz)
  - ✓ 3, 5, 9, 10, 13.405, 15, 19, 24.1, 35.605, 50, 60, 70, 80, 85.5, 90, 94, 118, 150, 166, 183, 220, 340
- 5 temperature points
  - ✓ 233.15, 243.15, 253.15, 263.15, 273.15
- 20 size parameter points
- 37 scattering angles
- one phase function (F11)

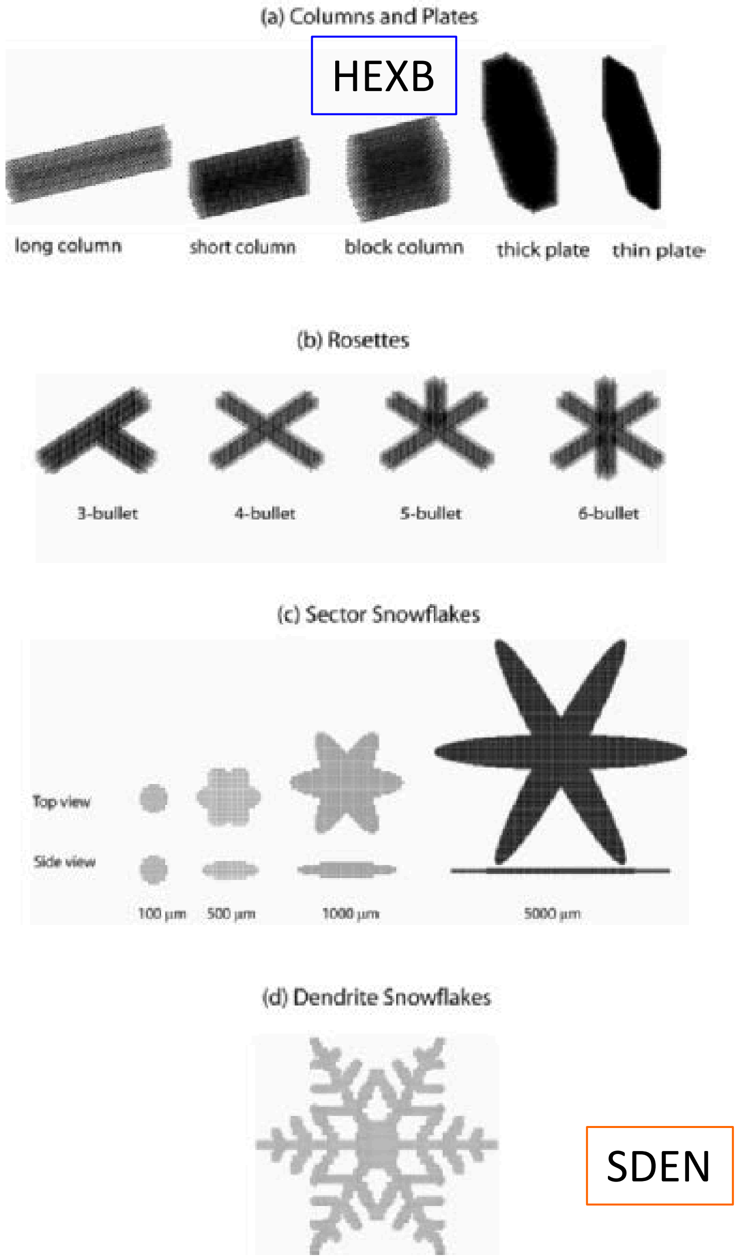
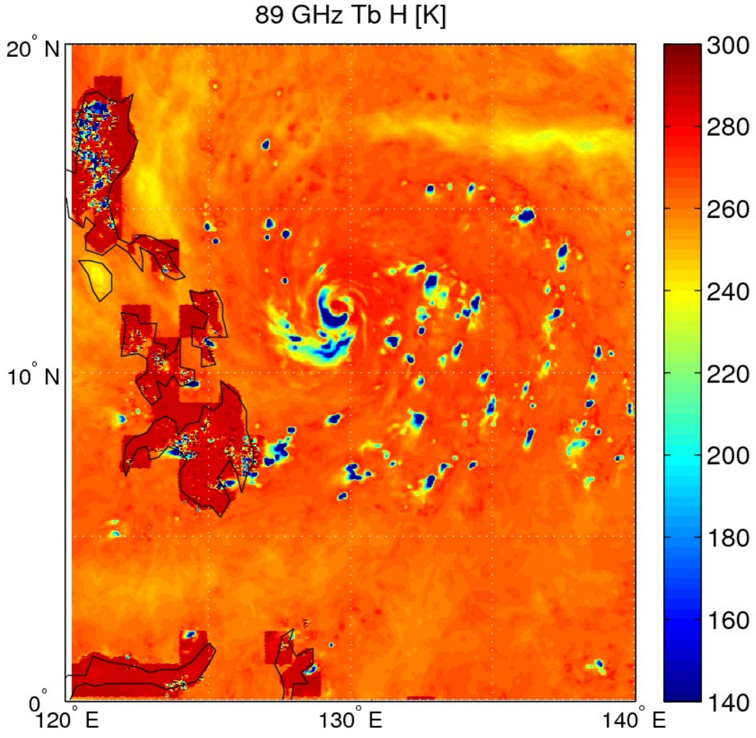


Fig. 1. Shapes of (a) columns and plates, (b) rosettes, (c) sector snowflakes, and (d) dendrite snowflakes. The drawings are made of small dots that are the dipoles used in DDA model simulations.

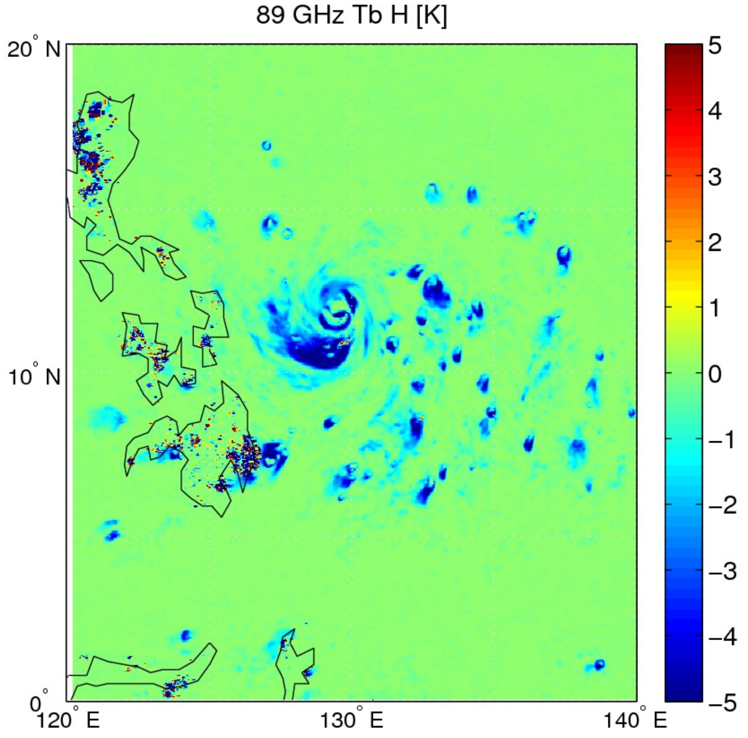
AMSR-E 89 GHz

- Comparison with Maxwell-Garnett dielectric mixing formula + Mie solution (MG-MIE1)
- Only snow category use the new table, ISMT-SF2

ISMT-SF2



Tb(ISMT-SF2) – Tb(MG-MIE1)

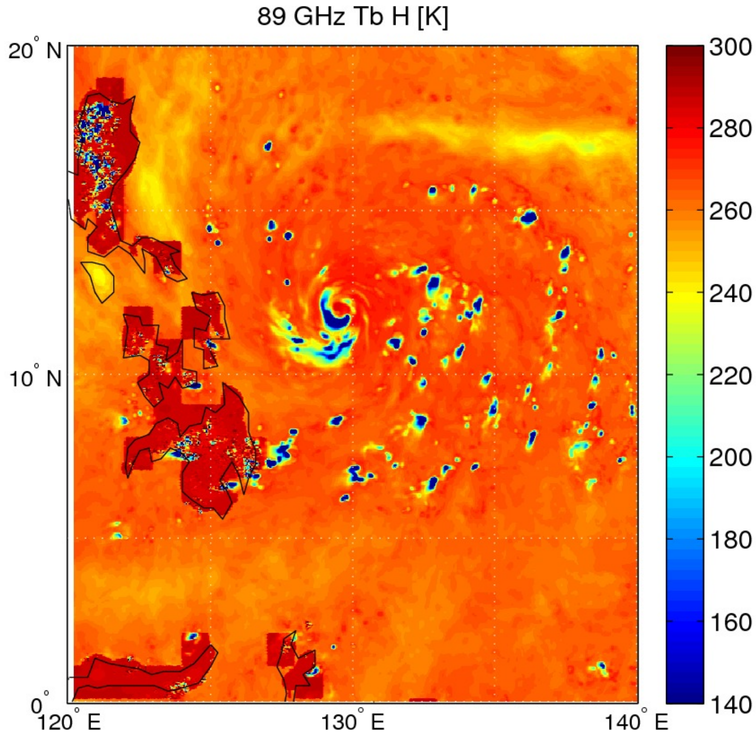


More Tb depression by ISMT-SF2 due to smaller asymmetry factor (smaller forward scattering)

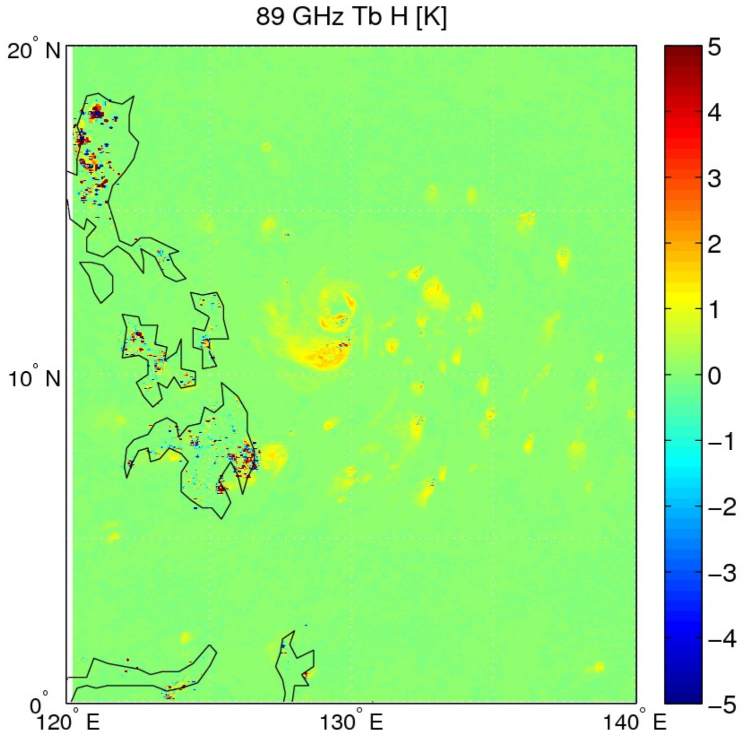
AMSR-E 89 GHz

Only snow category uses LIU-SDEN (dendrite snowflakes) data.

LIU-SDEN



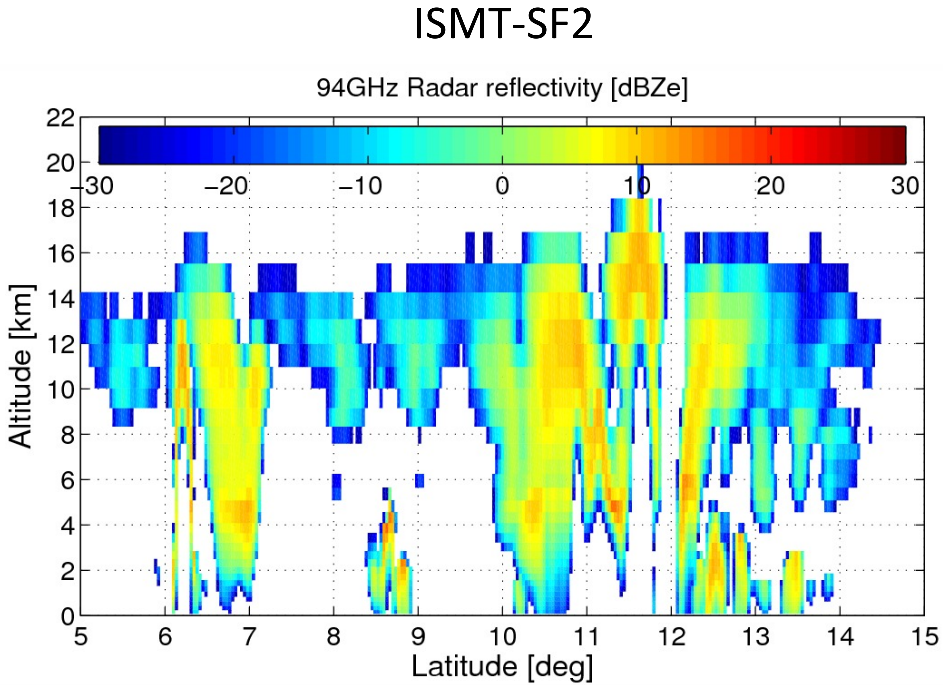
Tb(LIU-SDEN) – Tb(MG-MIE1)

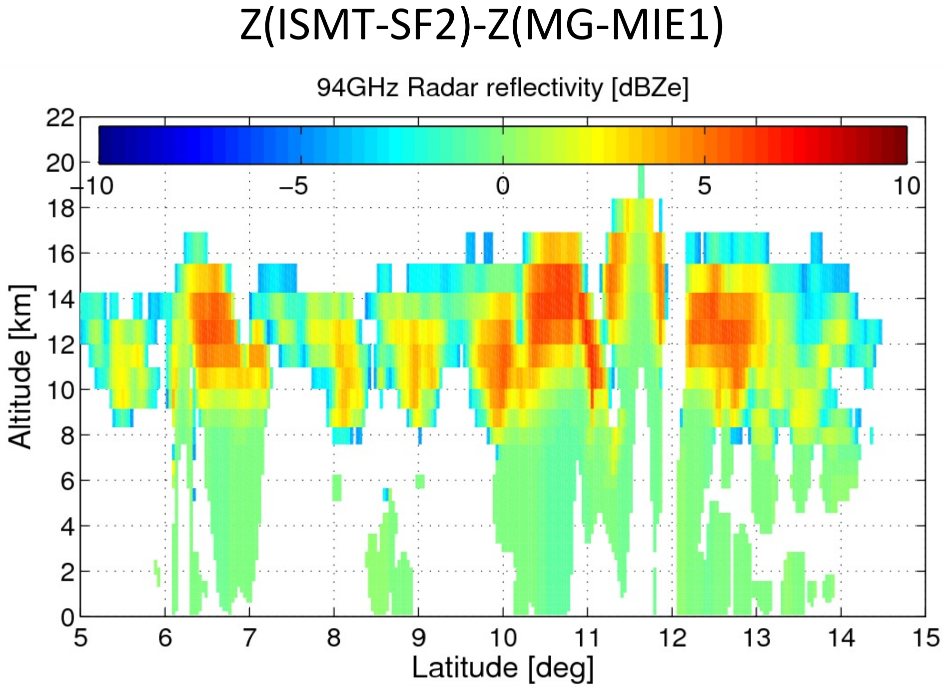


Less Tb depression by LIU-SDEN probably due to smaller extinction

CloudSat CPR 94GHz

- Only snow category use the new table, ISMT-SF2





More backscattering of large particles with ISMT-SF2