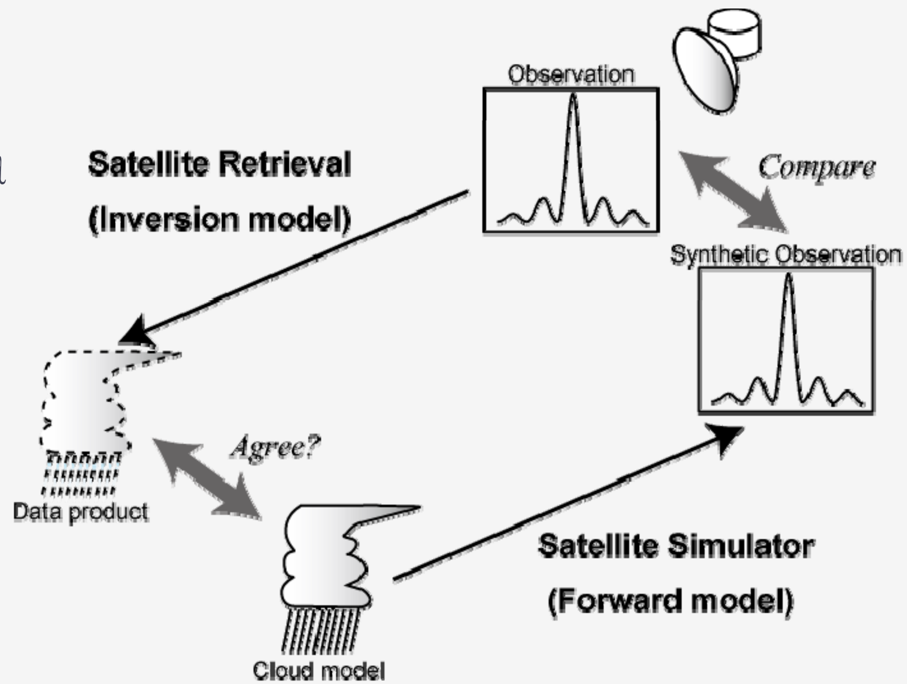
Satellite Data Simulator Unit (SDSU) version 2

HIRO MASUNAGA

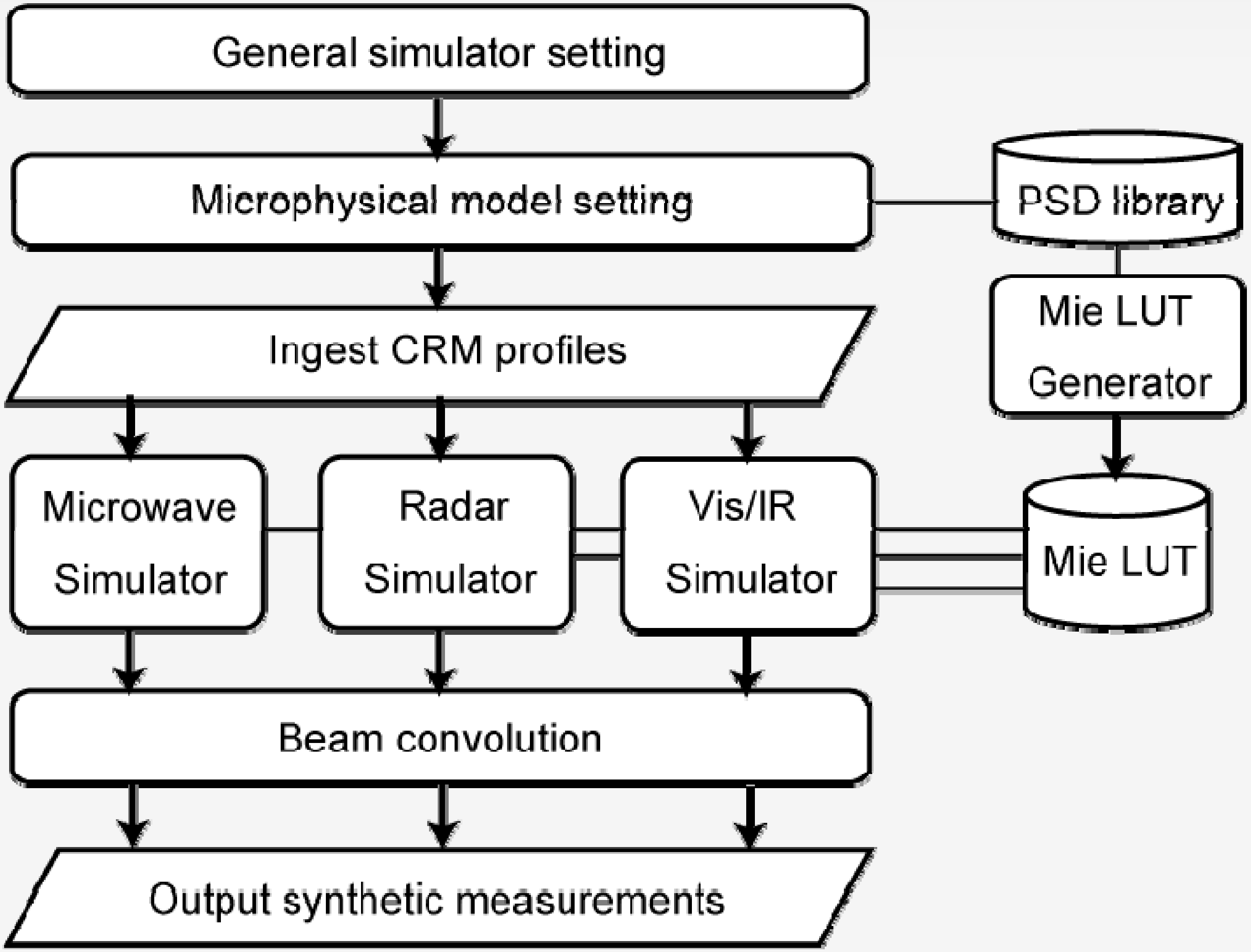
Hydrospheric Atmospheric Research Center, Nagoya University

Cloud model evaluation with observations

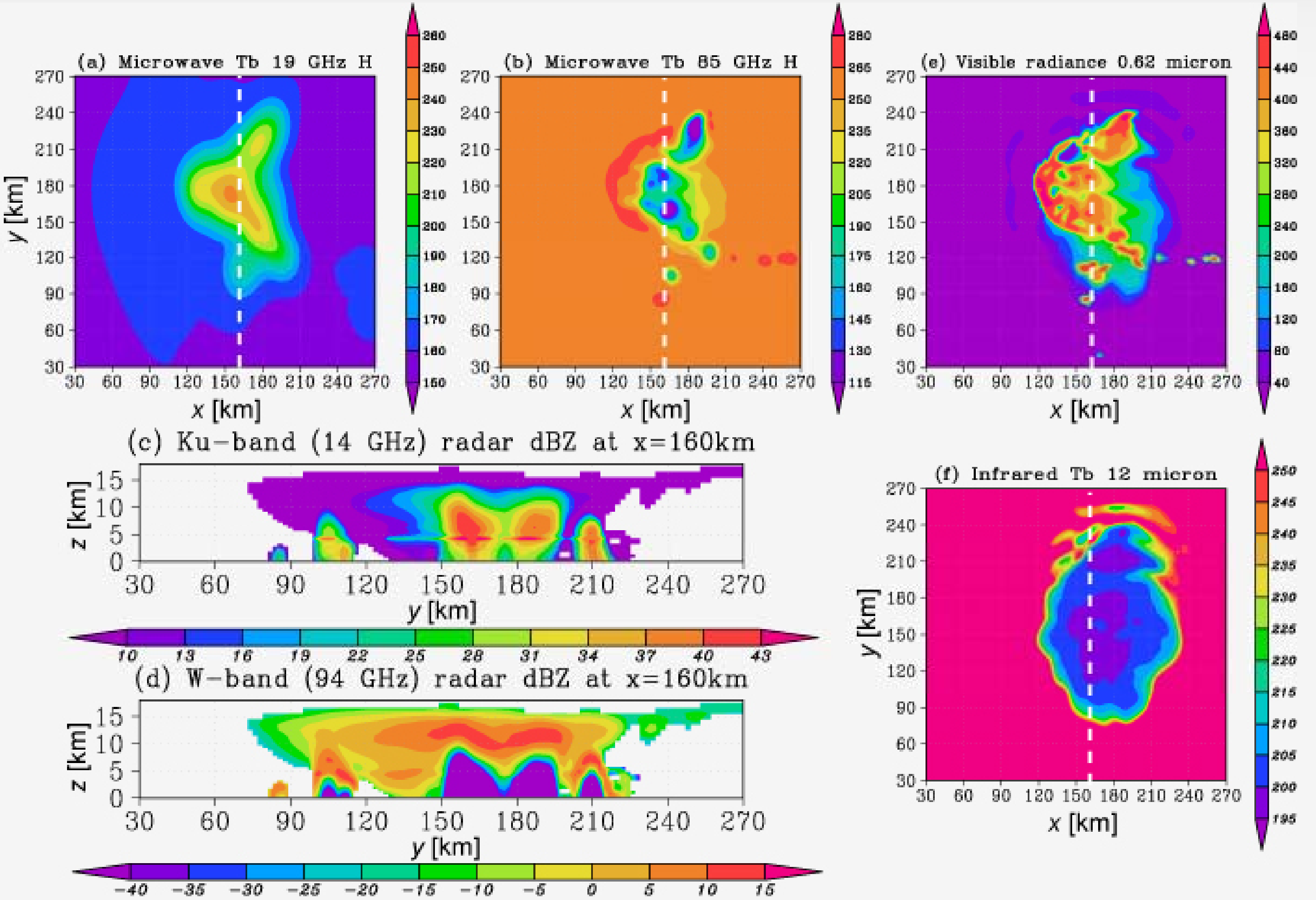
- Field experiment
  - Radars at different frequencies (X, C, Ka, …): dBZ
  - …
- Satellite measurements
  - Visible/infrared imagers: I_λ
  - Microwave radiometers: T_b
  - Spaceborne radars: dBZ
- Model outputs
  - q_r, q_c, q_v, T, …



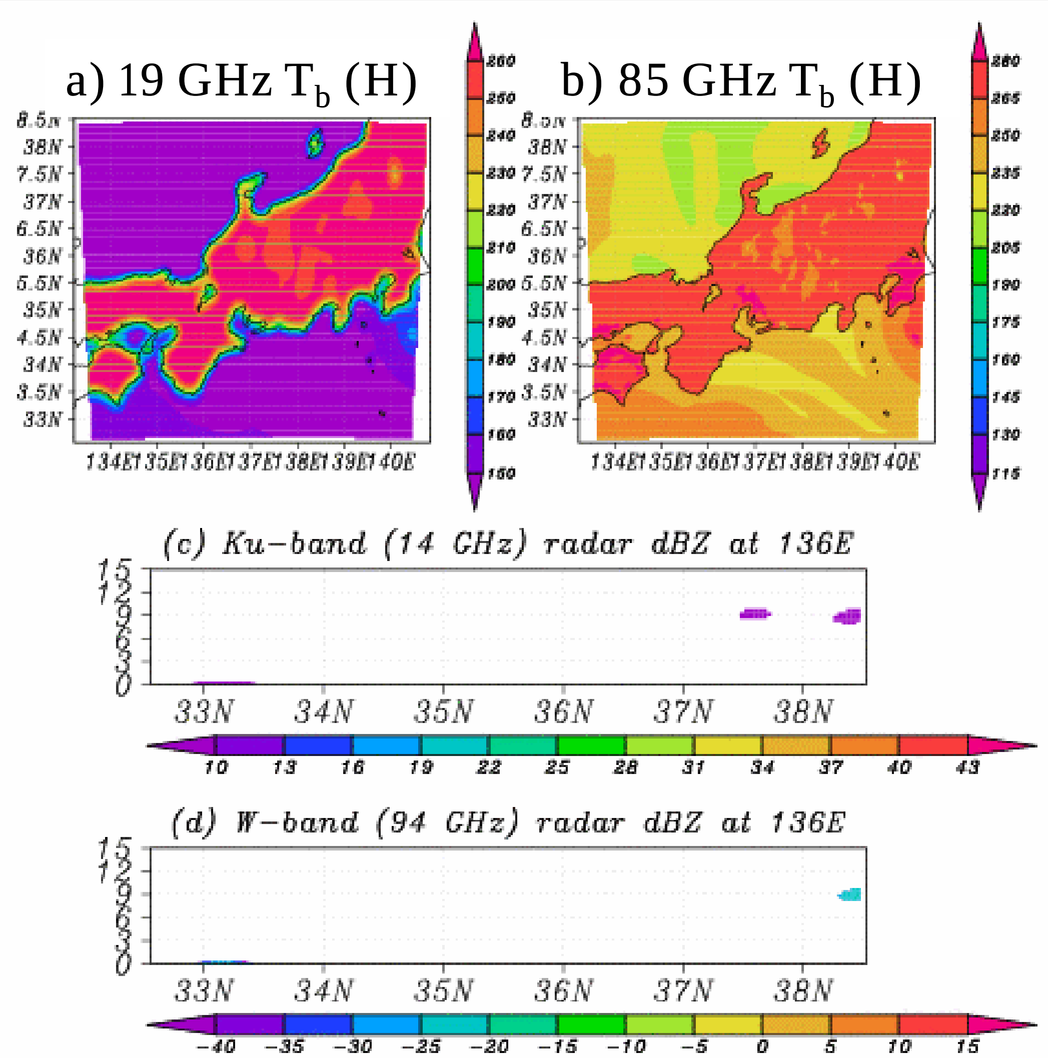
SDSU Structure



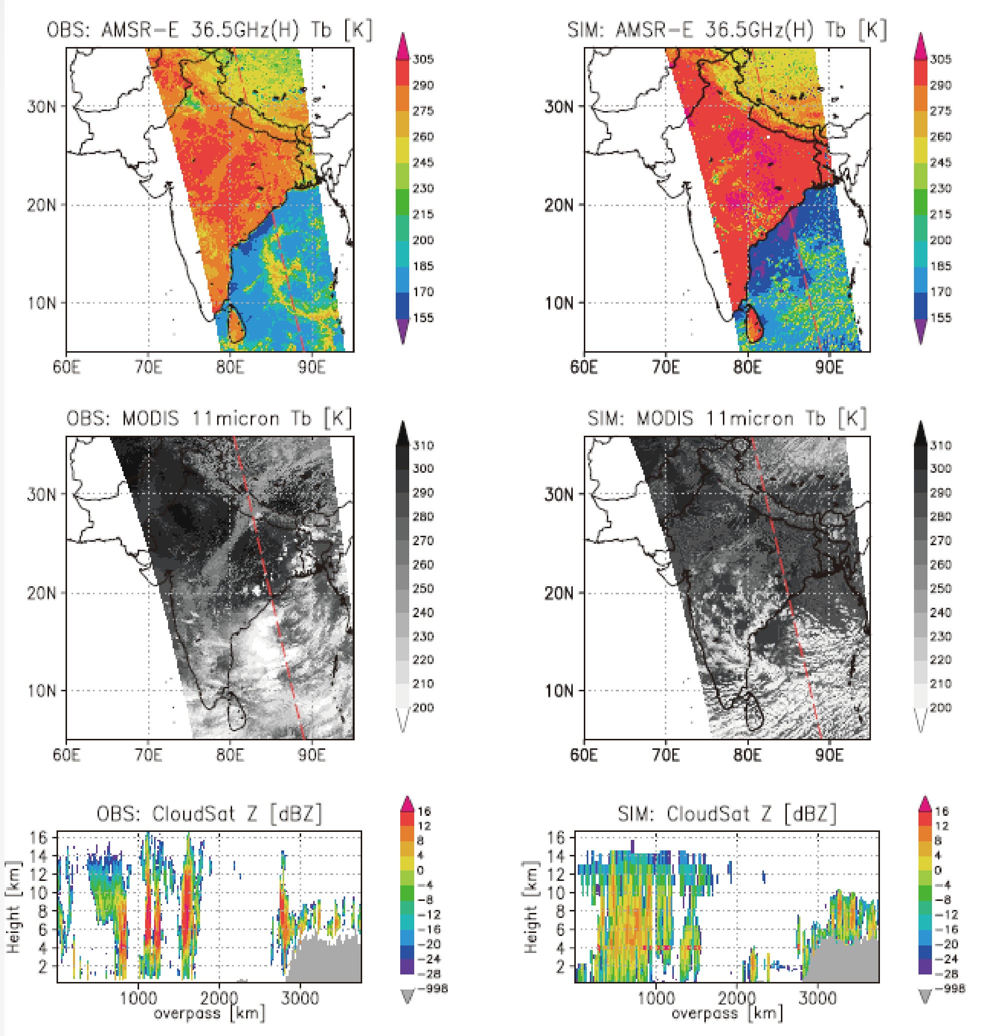
Tropical Squall Line (GCE)



Baiu-frontal Precipitation System (CReSS)

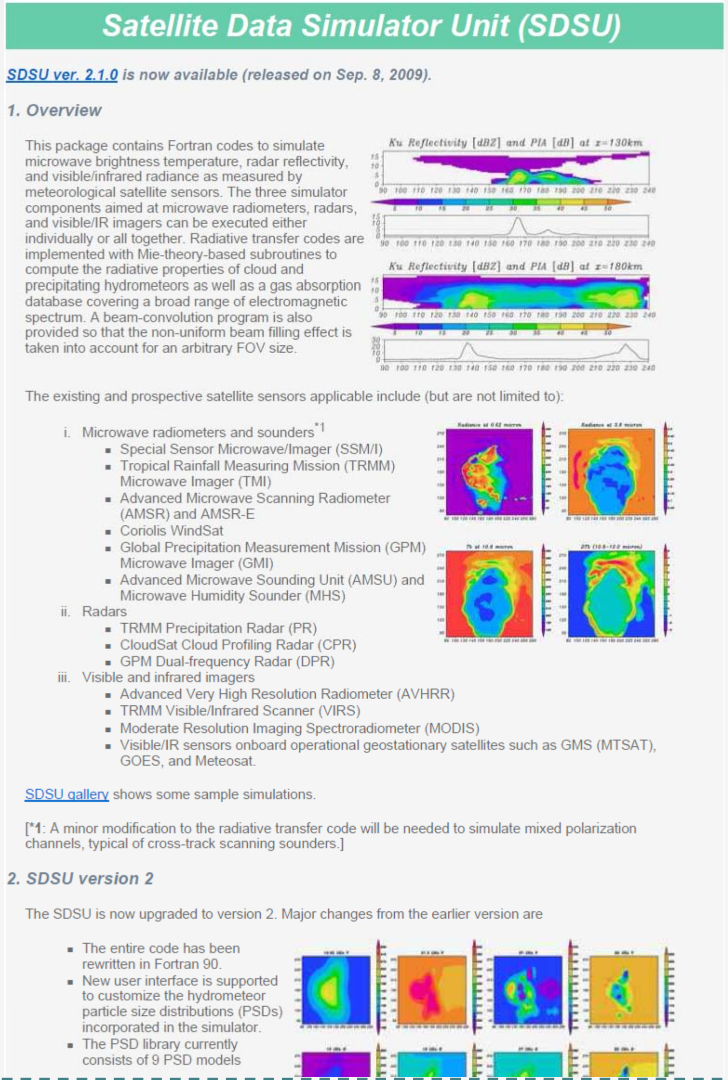


Indian Monsoon (WRF w Goddard SDSU)



Download 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.
  - BAMS SDSU article in press



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
   - Coriolis 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

Acknowledgment of Contributors

Simulator components	Contributors
Passive microwave	C. D. Kummerow (Colorado State U.)
Radar	H. Masunaga (Nagoya U.)
Visible/infrared	T. Nakajima (U. Tokyo) T. Y. Nakajima (Tokai U.)
Radiative properties	P. Bauer (ECMWF) W. S. Olson (NASA GSFC) M. Sekiguchi (Tokyo U. Marine Sci. Tech.)

Input CRM (for this talk)	Contributors
GCE	W.-K. Tao (NASA GSFC)
NICAM	M. Satoh (U. Tokyo/JAMSTEC) H. Miura (JAMSTEC)
CReSS	T. Ohigashi, T. Shinoda, K. Tsuboki (Nagoya U.)

A special thanks goes also to T. Matsui (NASA GSFC), Goddard SDSU developer.

A Multi-spectral, Multi-sensor Simulator

- Satellite Data Simulator Unit (SDSU)
  - A Fortran package to simulate synthetic observations for
    - *Passive microwave sensors* (radiometers and sounders)
    - *Radars*
    - *Visible and infrared imagers*
  - Applicable satellite missions and sensors include
    - Tropical Rainfall Measuring Mission(TRMM)
      - TMI, PR, and VIRS
    - A-Train constellation
      - Aqua AMSR-E, Aqua MODIS, and CloudSat CPR
    - Global Precipitation Measurement (GPM)
      - GMI and DPR
    - Earth Clouds, Aerosols, and Radiaion Explorer (EarthCARE)
      - CPR and MSI

SDSU Features

- Interface for input geophysical parameters
  - 6 hydrometeor species
    - *Rain*, *cloud water*, *cloud ice*, *snow*, *graupel*, and *hail*
  - Plug-in routines for variable conversion (v2.1.0+)
    - $q_v \rightarrow \mathrm{RH}$, $(\theta, p) \rightarrow T$, $q \rightarrow \rho q$, etc.
- Mie lookup table (LUT)
  - Dramatically accelerates RT computations.
  - The Mie LUT generator comes with the SDSU package.
- Beam convolution routine
  - Converts the input CRM resolution to the sensor FOV.
- Particle size distribution (PSD) library (v2.0+)

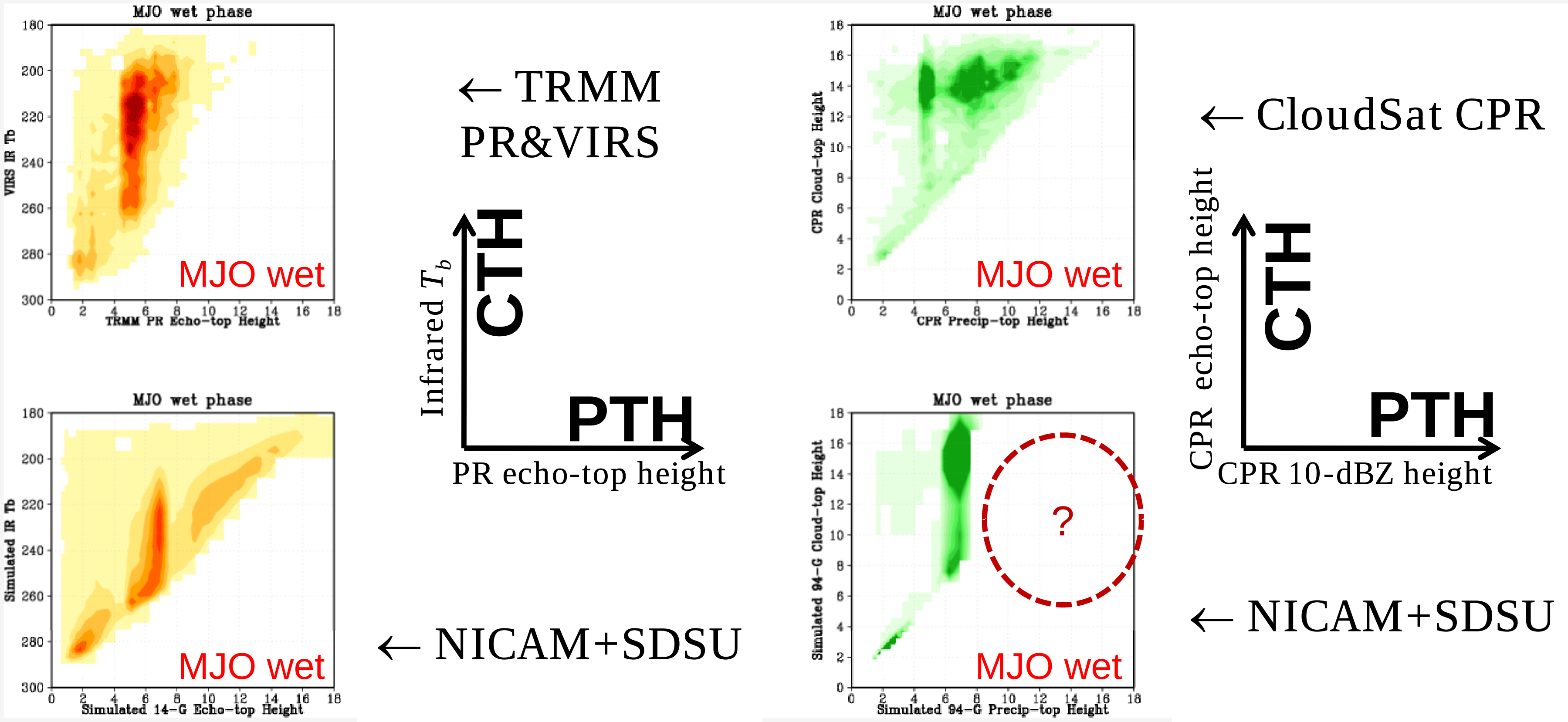
Particle Size Distribution (PSD) Library

- User interface to design hydrometeor PSD models
  - PSD is given in the form of a Fortran external function.
  - Affects the computations of k_{ext}, ω, g, and σ_b.
- Template PSD models pre-installed
  - 1-moment PSDs: *exponential*, *gamma*, *modified gamma*, *log-normal*, *exponential with* $m(D)=aD^b$, etc.
  - 2-moment PSDs: *exponential* and *log-normal*.
- "Build-your-own" PSD models
  - The SDSU user can add any 1- or 2-moment bulk microphysical models to the library inventory.

Examples

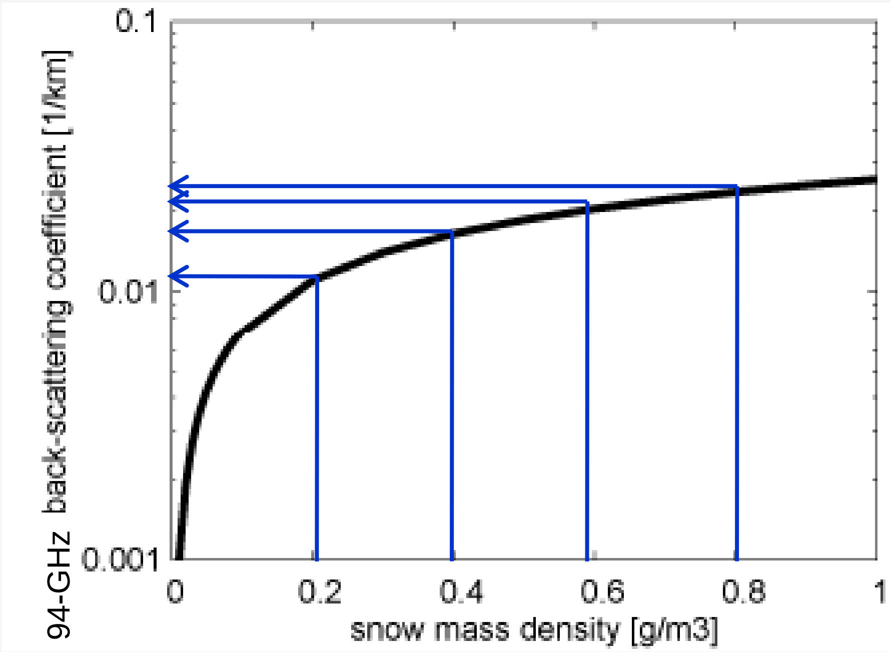
- Tropical squall line
  - Simulated with Goddard Cumulus Ensemble (GCE) model
  - Synthetic microwave T_b, radar dBZ, and visible/IR radiances
- Mid-latitude frontal precipitation
  - Simulated with Cloud Resolving Storm Simulator (CReSS)
  - Synthetic microwave T_b and radar dBZ
- Cloud- and precipitation-top height histogram
  - Based on the Non-hydrostatic ICosahedral Atmospheric Model (NICAM) 2006/07 MJO experiment (Miura et al., 2007) in comparison with TRMM and CloudSat observations (Masunaga et al., 2008)

Cloud and Precip Top Heights (CTH and PTH)



Missing 94-GHz Echoes above 8 km

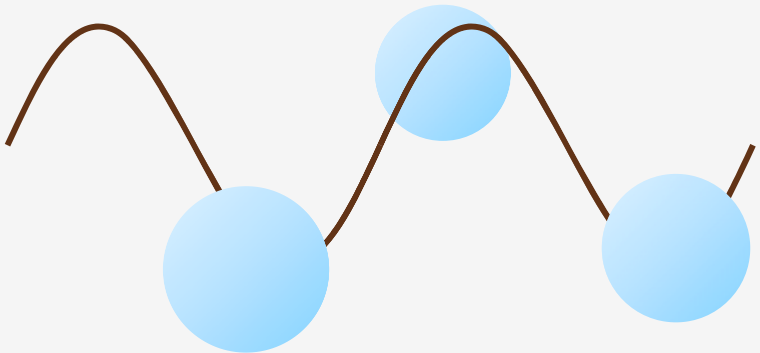
The 94-GHz back-scattering coefficient begins to be saturated due to non-Rayleigh scattering as snow content increases.



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

Rayleigh regime

Wavelength >> 2πr

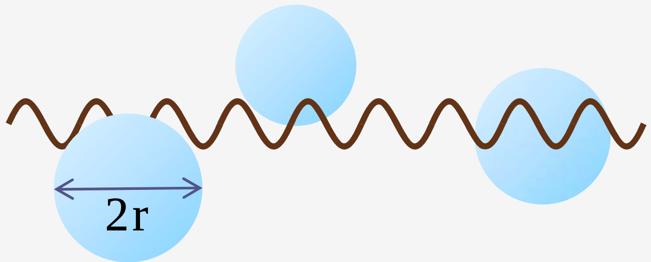


$$\sigma_s \propto N\frac{r^6}{\lambda^4} \propto \frac{W^2}{N\lambda^4}$$

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

Geometric optics regime

Wavelength << 2πr

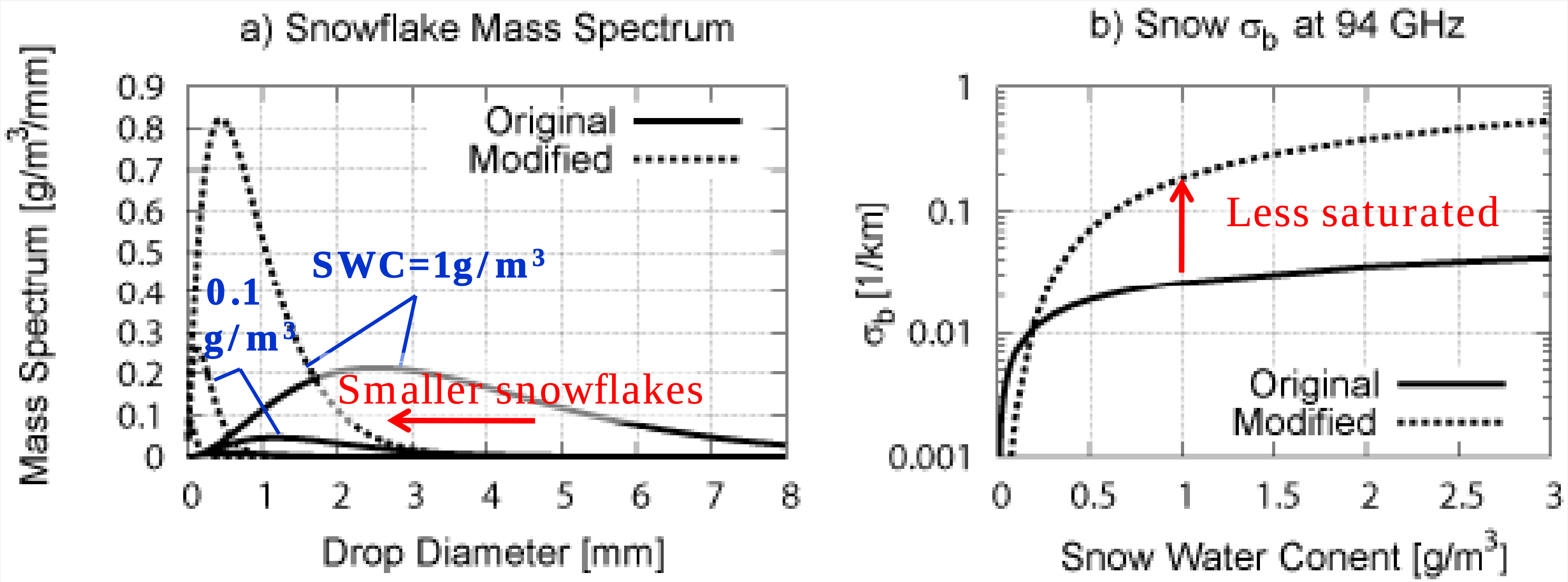


$$\sigma_s \propto Nr^2 \propto (NW^2)^{1/3}$$

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

A Modification to snow microphysics

Snowflake mass spectrum = $m(D)n(D)=aD^b N_0 \exp(-\lambda D)$
where $a=2.5\times10^{-2}$ kg m^{-2} and b=2 (original=Grabowski, 1998)
$a=5\times10^{-4}$ kg m^{-1} and b=1 (modified)



PSD Impact on the CTH/PTH Histogram