中国气象局地球系统数值预报中心
CMA EARTH SYSTEM MODELING AND PREDICTION CENTRE

All-sky Radiative Transfer Simulations based on the Advanced Radiative transfer Modeling System

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China Meteorological Administration (CMA)

Content

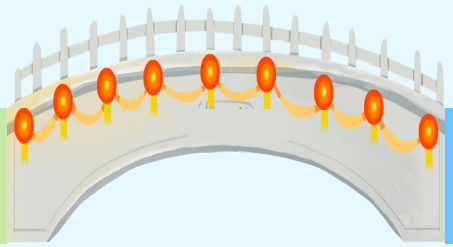
ARMS History

- Key Drivers for Developing ARMS:

a) Direct Radiance Assilimations Requirments

b) Support Sensors aborad Fengyun Satellites

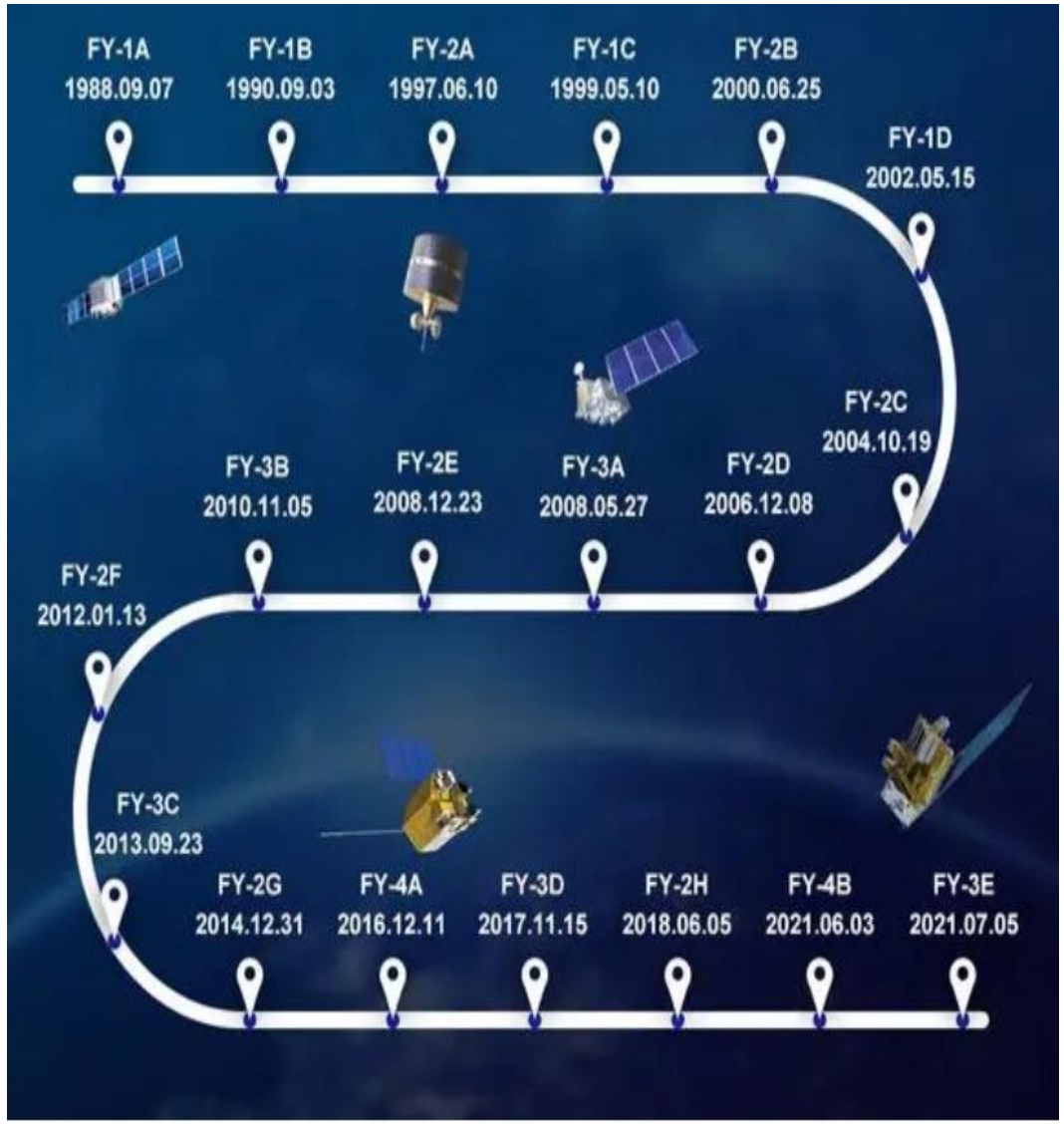
Fast RT Model



NWP Background | **Satellite Observations**

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + \frac{1}{2}(H(\mathbf{x})-\mathbf{y}^{obs})^T(\mathbf{O}+\mathbf{F})^{-1}(H(\mathbf{x})-\mathbf{y}^{obs})$$

$$J(\mathbf{x}_a) = \min_{\mathbf{x}} J(\mathbf{x}) \quad \forall \mathbf{x} \text{ near } \mathbf{x}_b$$

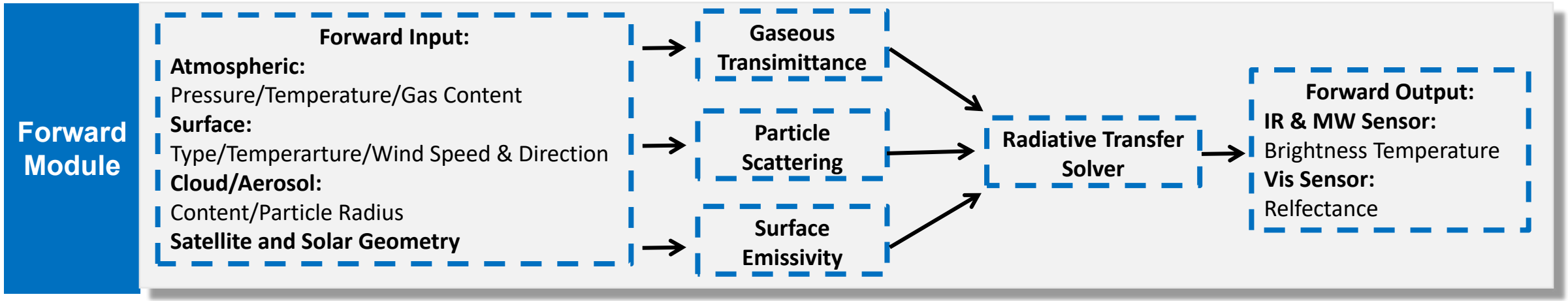


ARMS History

- Developing Process of ARMS:

ARMS History

ARMS Forward Structure:



ARMS Analytical Jacobian Calculation:

Tangent Linear Module

$$\text{FWD:}\quad Z = F(X,Y) \qquad \text{TL:}\quad \delta Z = \frac{\partial F}{\partial X}\delta X + \frac{\partial F}{\partial Y}\delta Y$$

Adjoint Module

$$\text{FWD:}\quad Z = F(X,Y) \qquad \text{AD:}\quad \delta X = \frac{\partial F}{\partial X}\delta Z \qquad \delta Y = \frac{\partial F}{\partial Y}\delta Z$$

Clear-Sky RT Simulation

- Gaseous Transimittance: Procedure:

For VIS/IR broadband Sensor:

5 variable gas components are considered

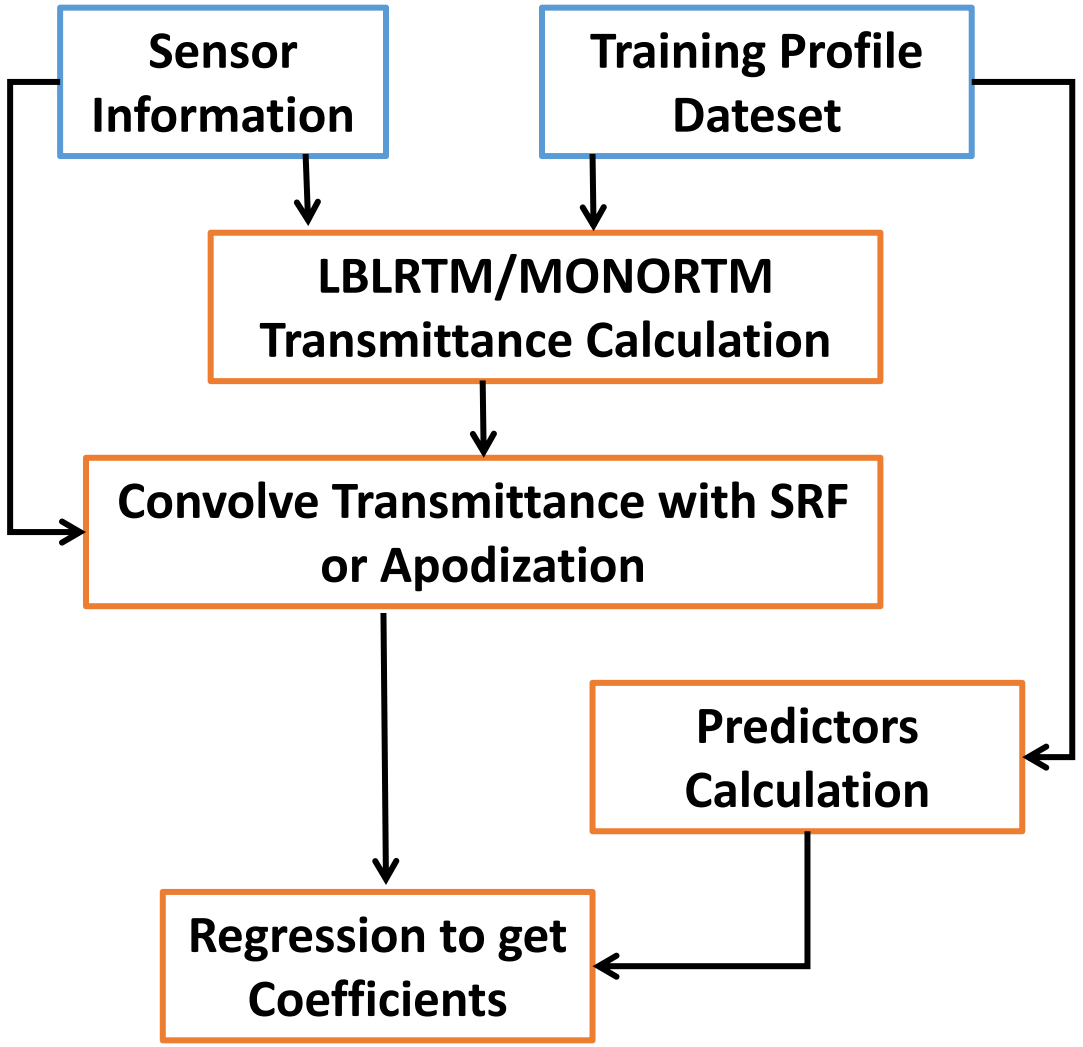
For IR Hyperspectral Sensor:

8 variable gas components are considered

For MW Sensor:

2 variable gas components are considered

An exhausting search is performed for each gas component and channel to select the best set of predictors



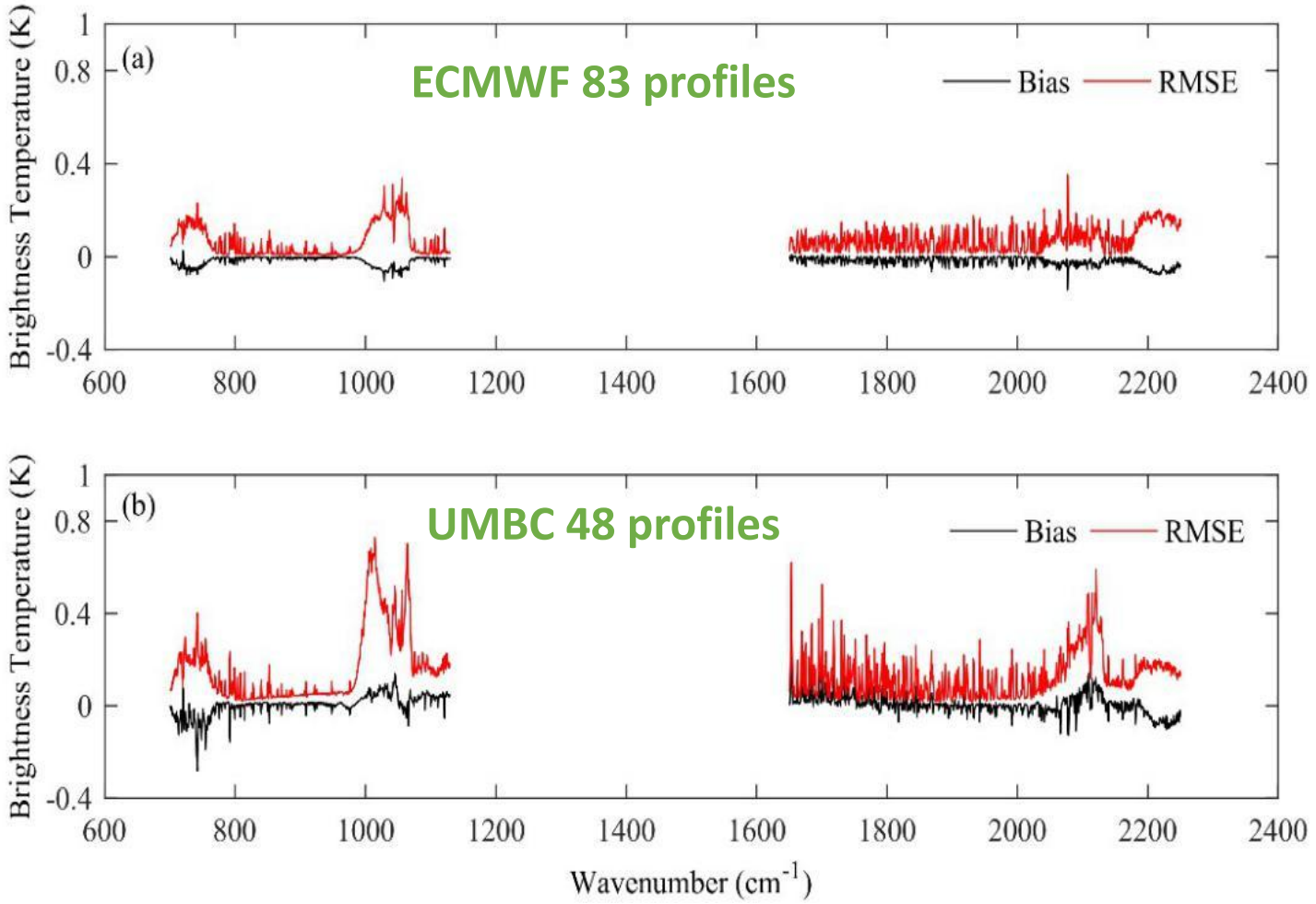
Clear-Sky RT Simulation

- Gaseous Transimittance: Accuracy Test (FY-4A GIIRS)

Benchmark BTs:
from LBL transimittance

ARMS BTs:
from Coefficients training in ECMWF 83 profiles

Surface Emissivity:
Lambertian Surface with Emissivity 0.98 is set in the comparsion



Clear-Sky RT Simulation

- Surface Emissivity:

Emissivity Module/Atlas which ARMS used now

	Surface	Ocean
MW Sensors	LandEM TELSEM2 atlas	FASTEM 6
IR Sensors	NPOESS IR atlas	WuSmith Emissivity model
VIS Sensors	NPOESS VIS atlas	NPOESS VIS atlas

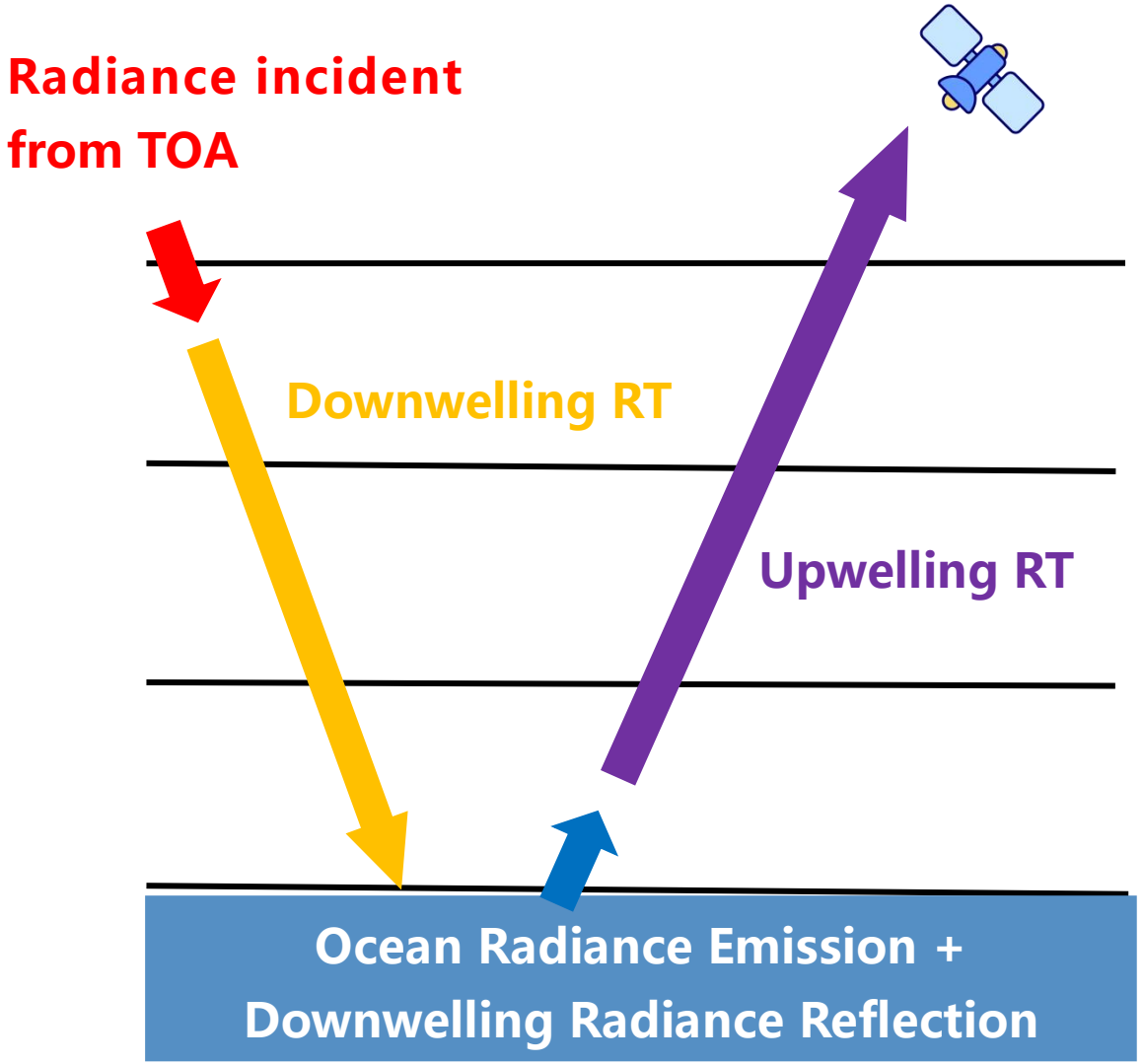
Clear-Sky RT Simulation

- Surface Emissivity:

FASTEM:
Reflection is not calculated directly and obtained by a correction of 1-Emissivity.

A MW Ocean Bidirectional Reflection Model is proposed following Two-scale theory. The Model is now ready for being coupled into ARMS.

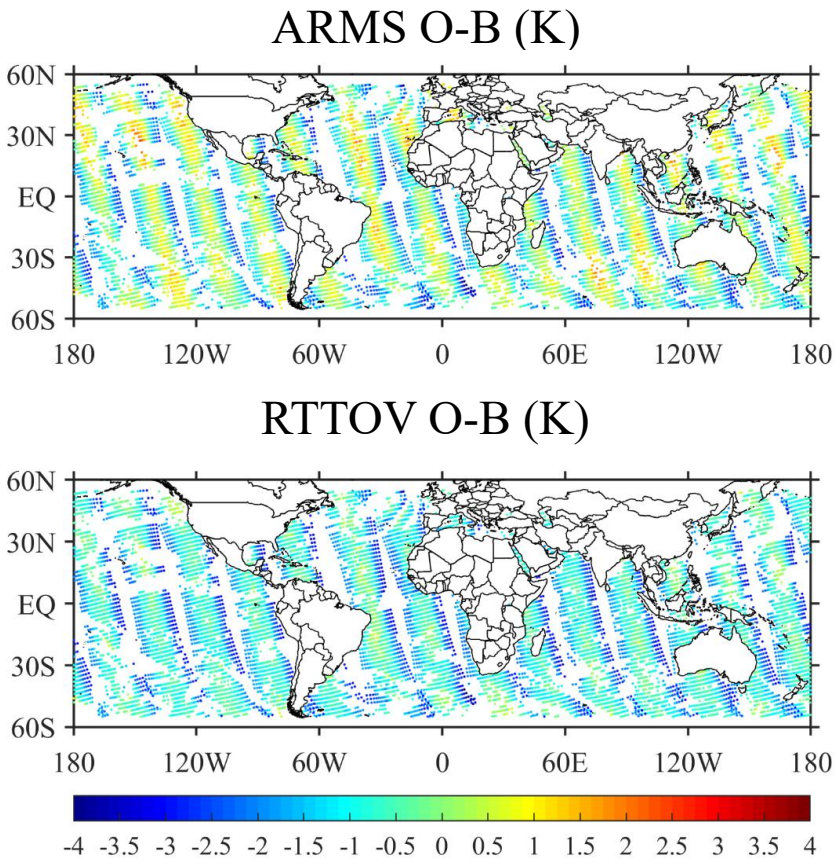
Detailed can be found at
10p.04 Improved Microwave Ocean Emissivity and Reflectivity Models Derived from the Two-scale Roughness Theory

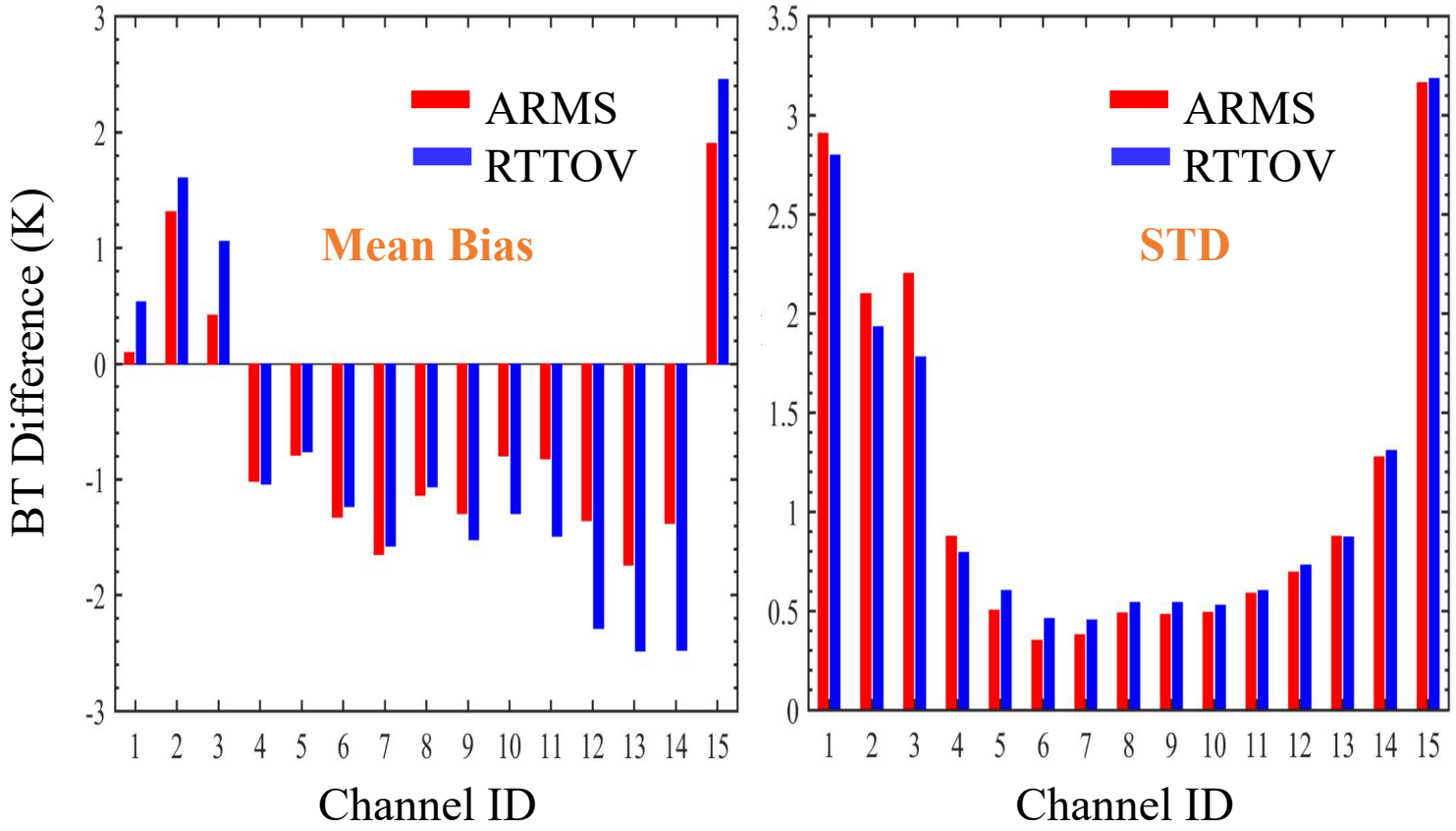


Clear-Sky RT Simulation

- ARMS Clear-Sky RT Simulation Result (MW):

➢MetOp-C AMSU-A Intercomparsion between ARMS and RTTOV

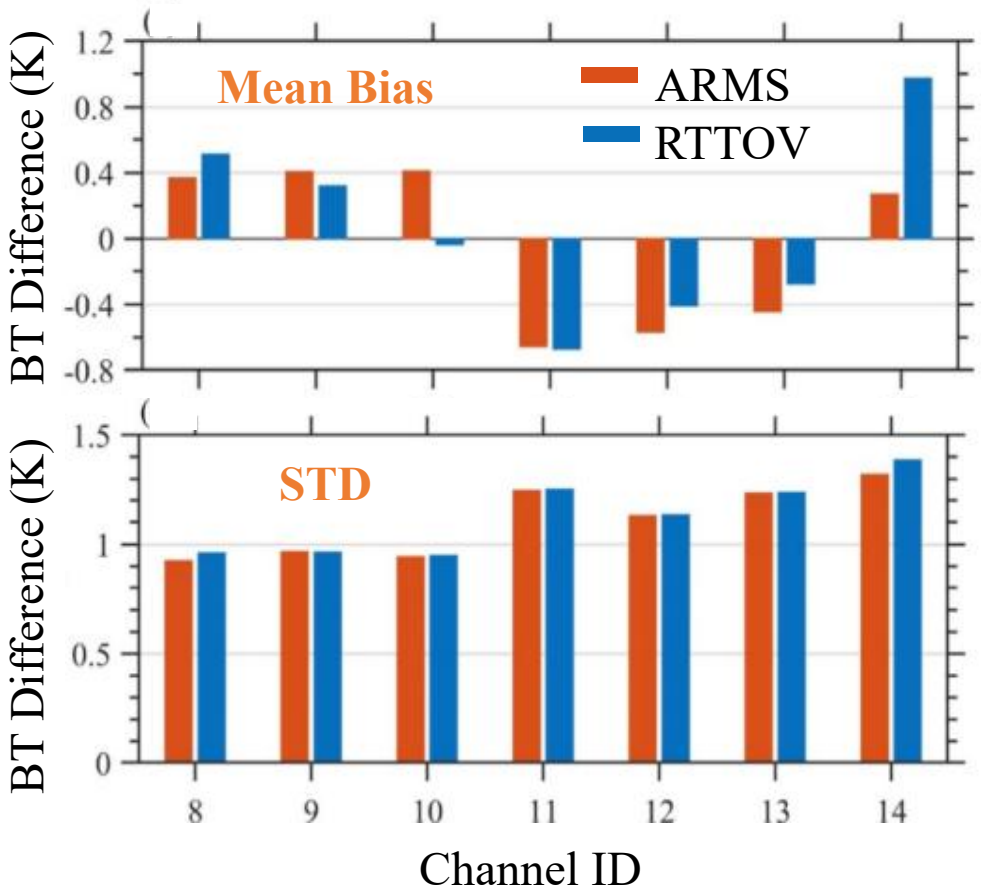


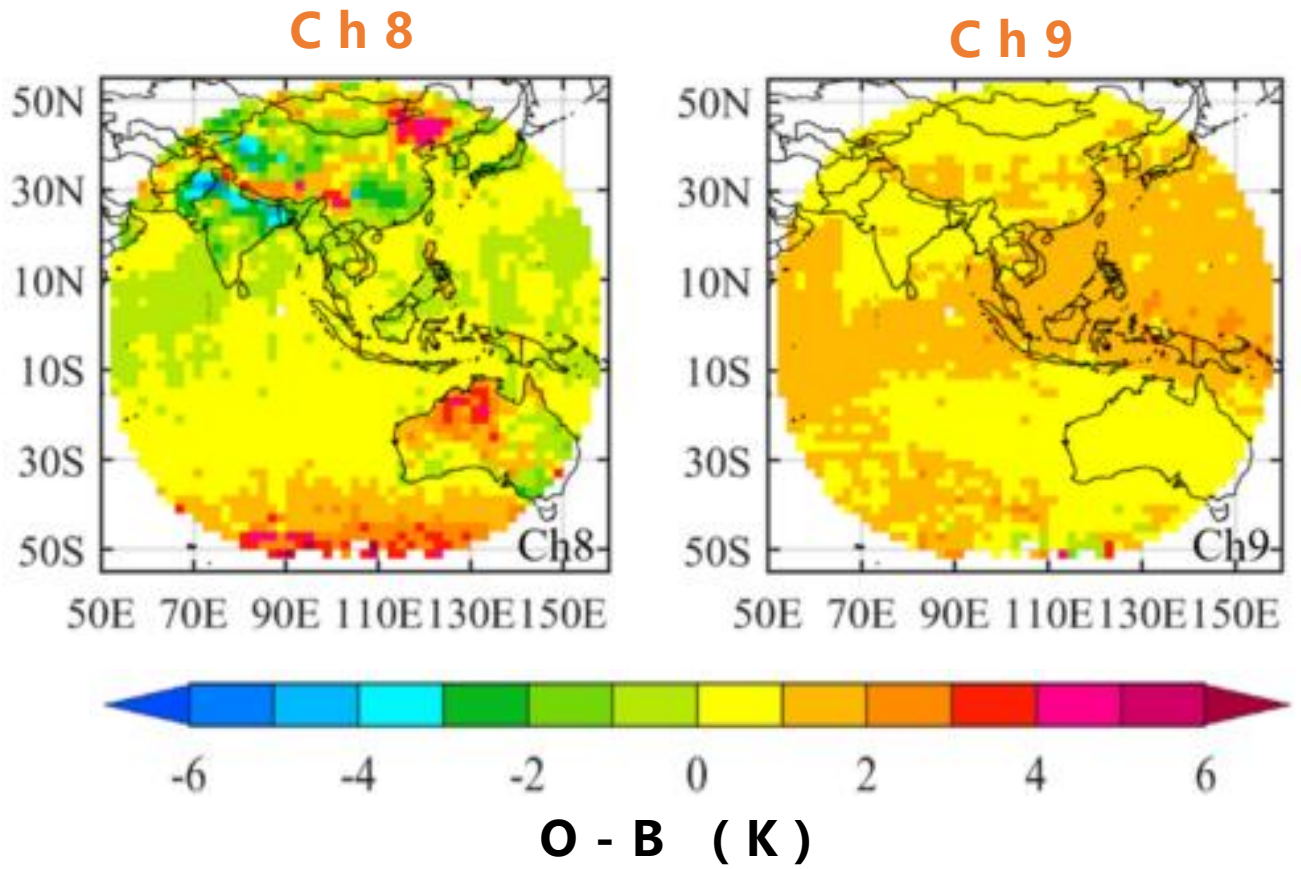


Clear-Sky RT Simulation

ARMS Clear-Sky RT Simulation Result (IR):

➢FY4A AGRI IR Channel Intercomparsion between ARMS and RTTOV. (Tang et al. 2021)

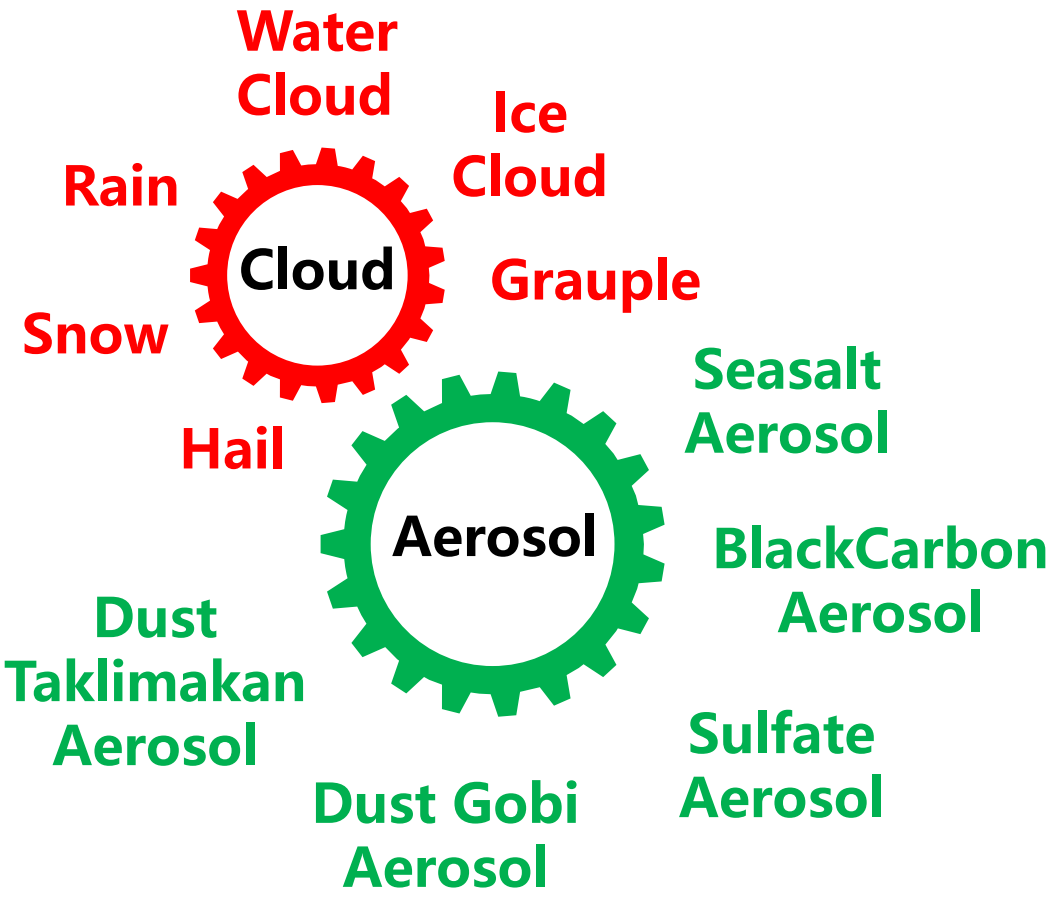




Cloudy-Sky RT Simulation

- ARMS Particle Scattering (VIS/IR):

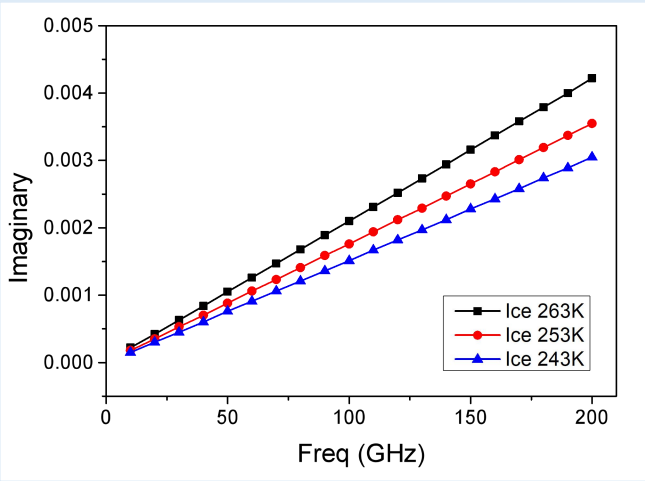
- ARMS Team cooperate with Zhejiang University (Prof. Lei Bi) and Sun Yat-sen University (Prof. Bingqi Yi) for building Aerosol/Cloud Scattering properties Dataset.
- Mie Scattering and T-Matrix is applied to handle spherical and non-spherical particle.



Cloudy-Sky RT Simulation

- ARMS Particle Scattering (MW): Procedure

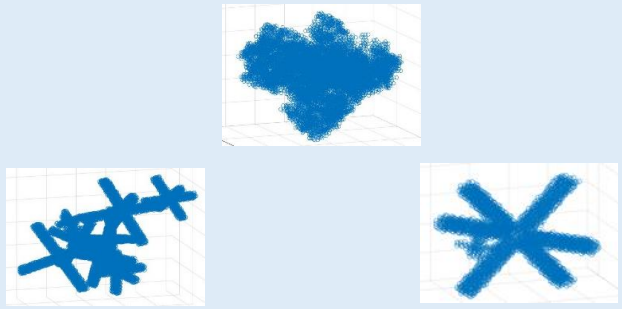
Refractive Index



Single Particle Scattering

Mie Scattering

Discrete Dipole Approximation



Particles Scattering

Gamma Disturbation:

$$n(r) = N_0 r^{(1-v)/v} e^{-\frac{r}{rv}}$$

Integral Scattering:

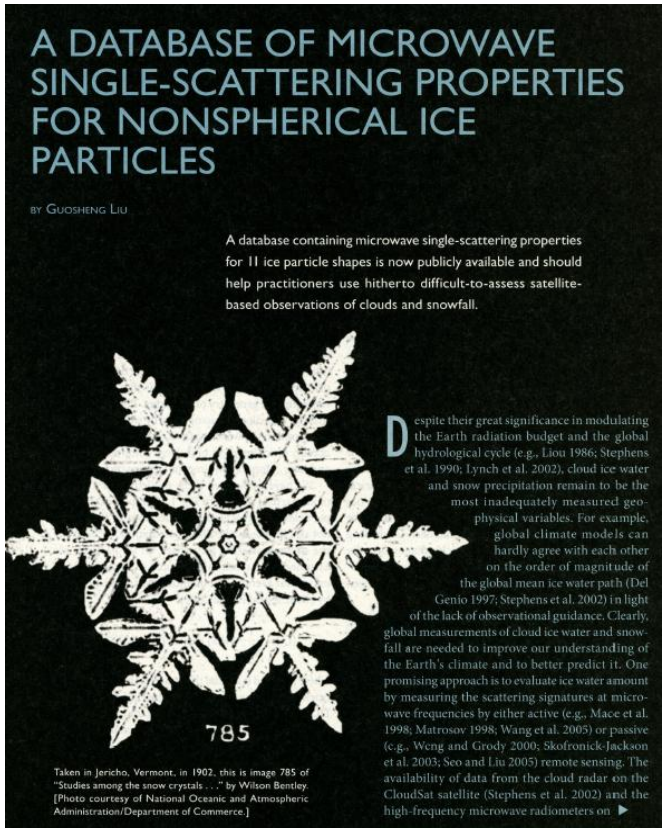
$$\overline{Q} = \frac{\int_{r_{\min}}^{r_{\max}} Q(r)A(r)n(r)dr}{\int_{r_{\min}}^{r_{\max}} A(r)n(r)}$$

Delta M Scaling

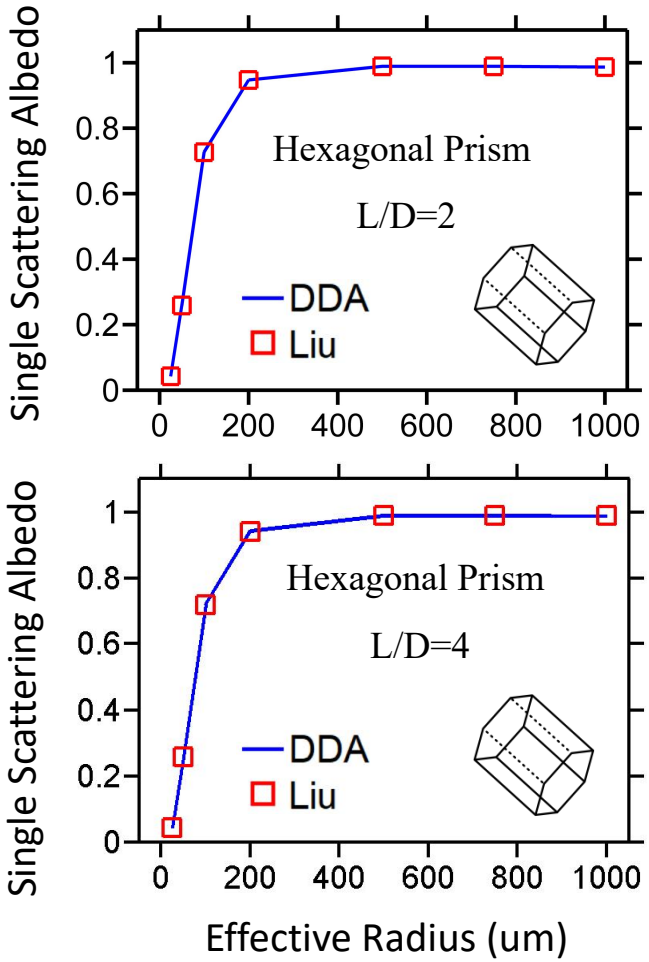
Cloudy-Sky RT Simulation

ARMS Particle Scattering (MW): Accuracy Test

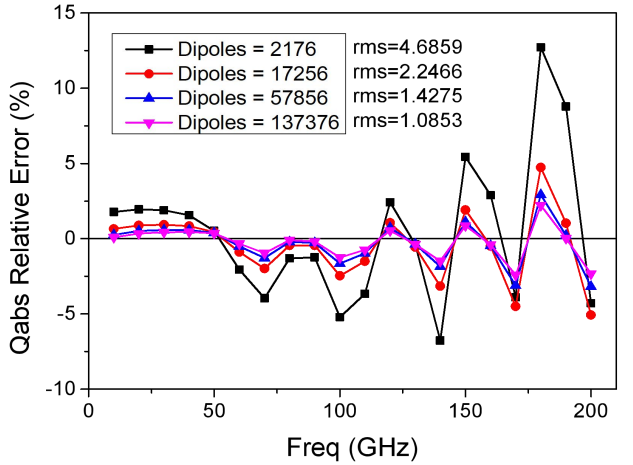
Benchmark Values:

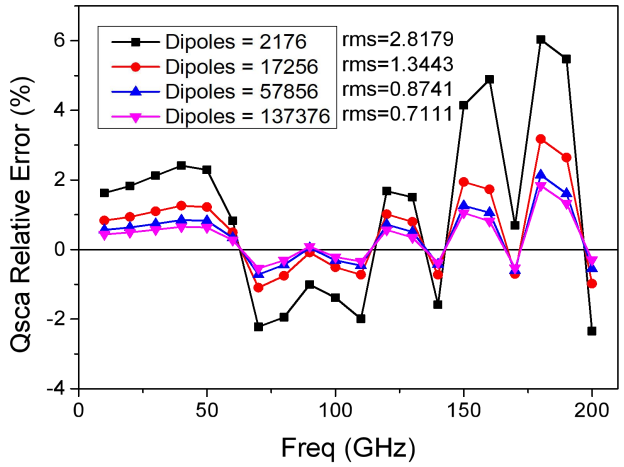


Liu Guosheng, et al., 2008)



Determine the number of dipoles





Cloudy-Sky RT Simulation

ARMS Radiative Transfer Solver

- In cloudy regions and Visible Spectrum, multiple scattering effect needs to be considered in RT equation.

$$\mu\frac{dI^m(\tau,\mu)}{d\tau}=I^m(\tau,\mu)-\frac{\omega}{2}\int_{-1}^{1}I^m(\tau,\mu')P^m(\mu,\mu')d\mu'-\delta_{m,0}(1-\omega)B-(2-\delta_{m,0})\frac{\omega}{4\pi}F_0P^m(\mu,-\mu_0)e^{-\tau/\mu_0}$$

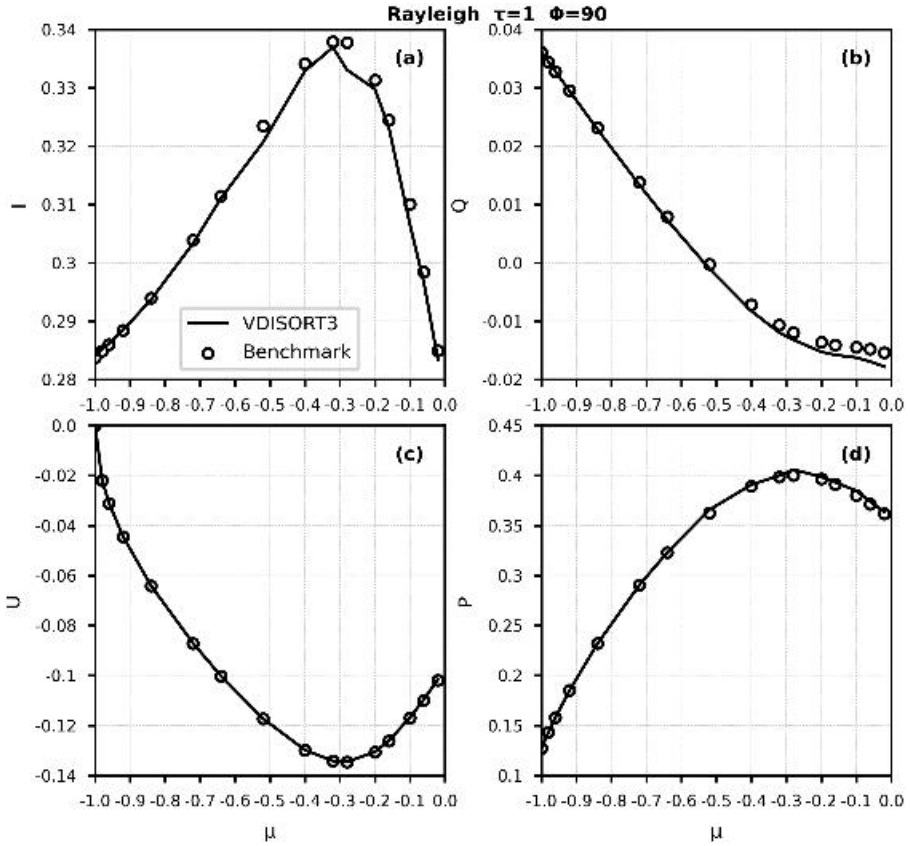
$$I(\tau,\mu,\phi)=\sum_{m=0}^{2M-1}I^m(\tau,\mu)\cos[m(\phi-\phi_0)]$$

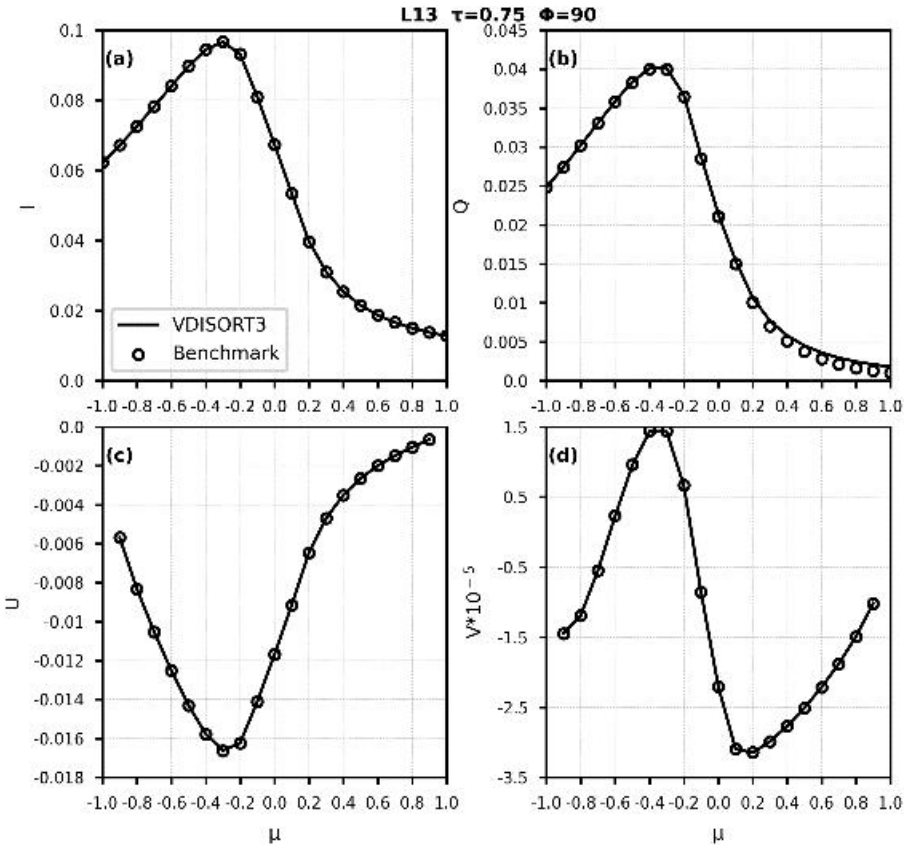
- ARMS use Discrete Ordinate Method to solve the equation.

Cloudy-Sky RT Simulation

ARMS Radiative Transfer Solver

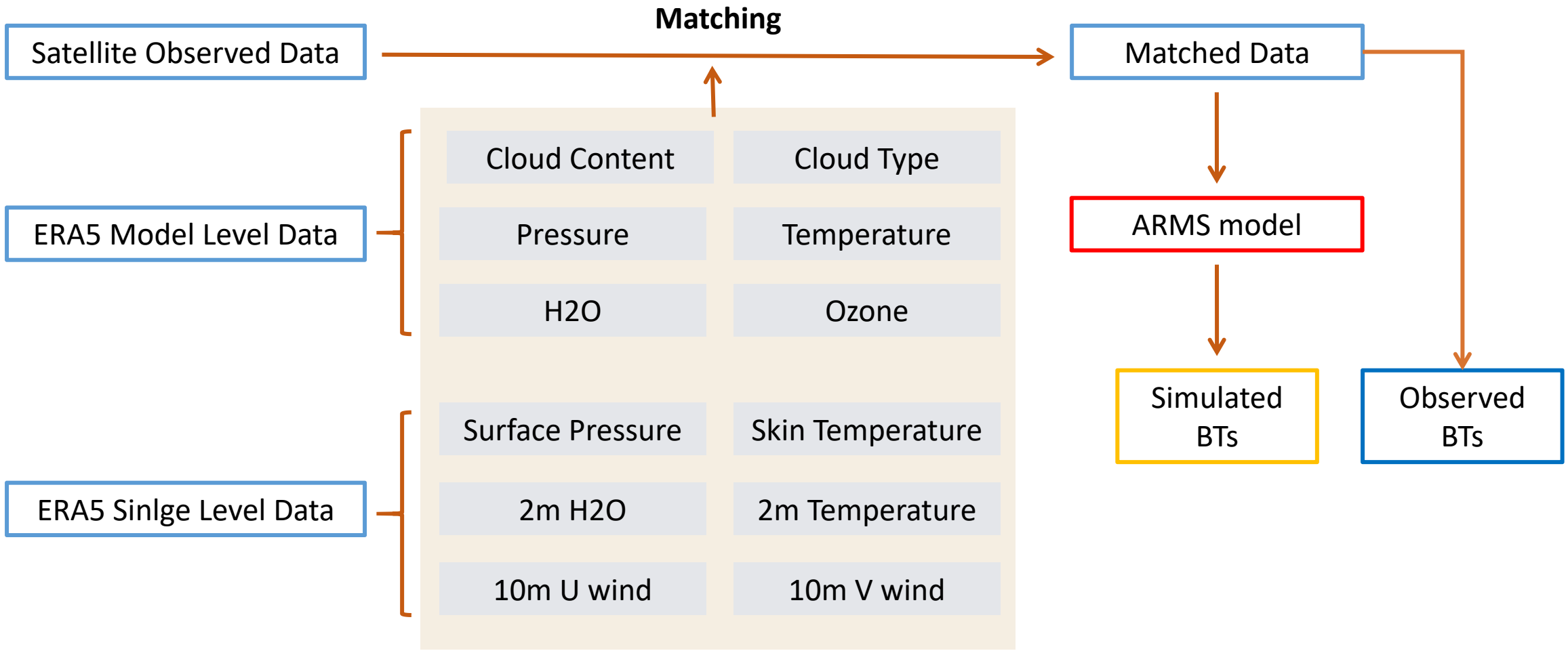
- In order to take both radiance and polarization states into account, Weng's VDISORT solver has been investugated in Rayleigh and L13 cases.





Cloudy-Sky RT Simulation

All-Sky RT Simulations: Procedure



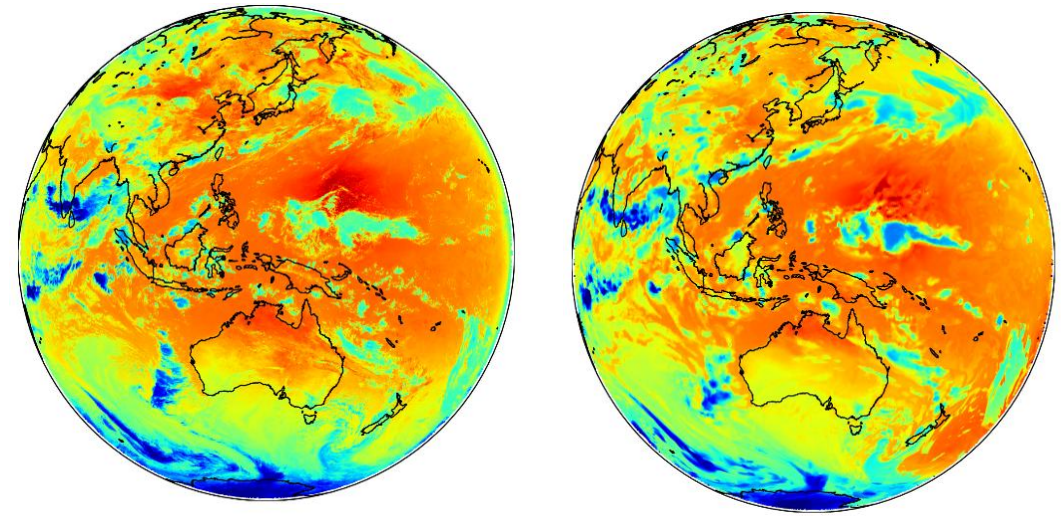
Cloudy-Sky RT Simulation

All-Sky RT Simulations: Results

- FY4B AGRI IR Channel

Channel 8 observed BTs

Channel 8 simulated BTs

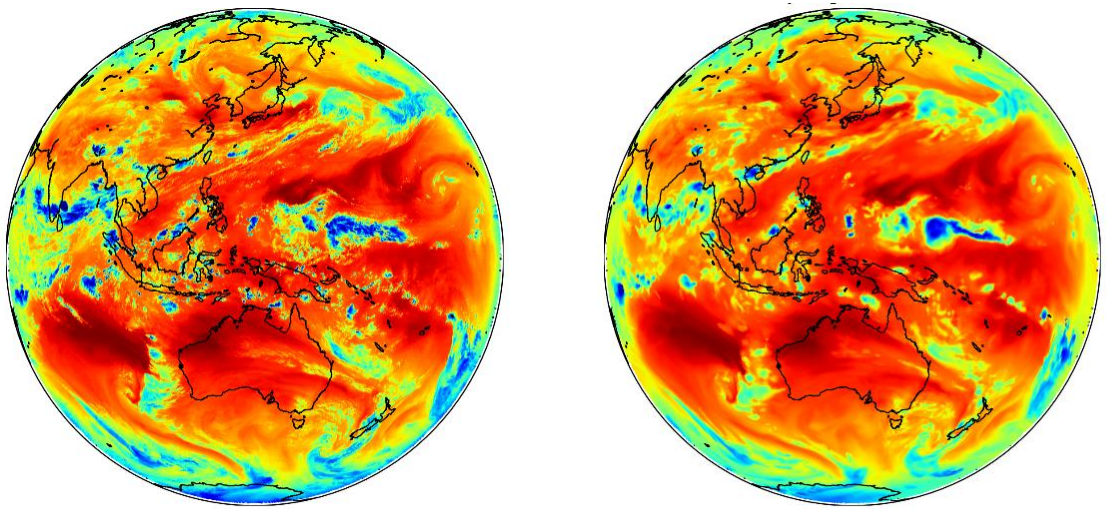


220 240 260 280 300 320

BT (K)

Channel 14 observed BTs

Channel 14 ARMS simulated BTs



200 210 220 230 240 250 260

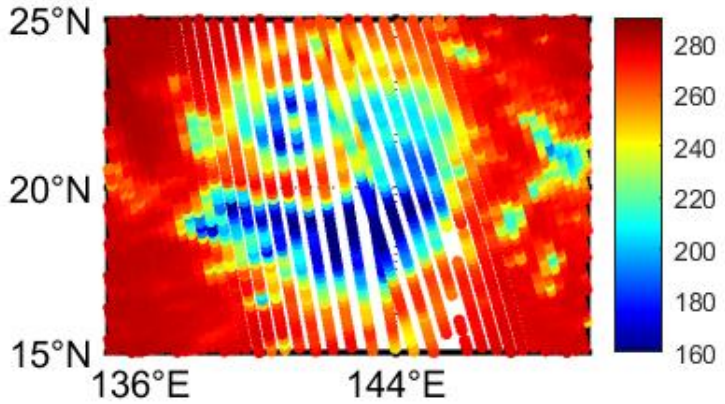
BT (K)

Cloudy-Sky RT Simulation

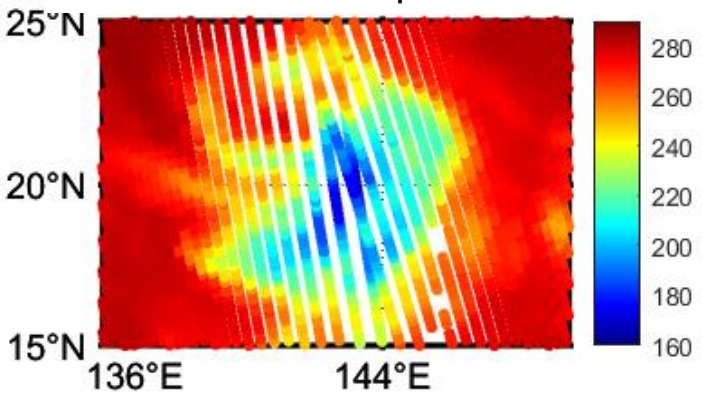
All-Sky RT Simulations: Results

FY3D MWTS

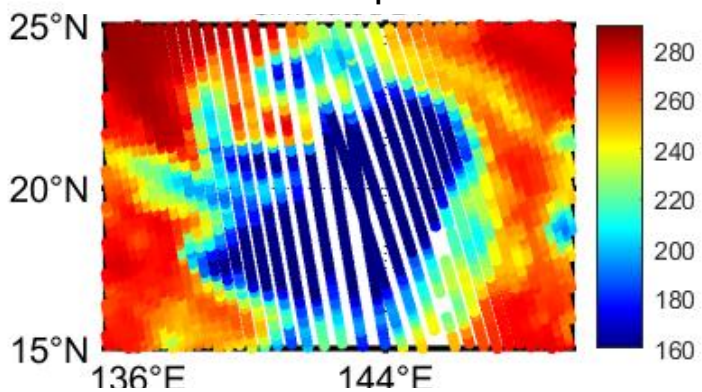
Channel 10 observed BTs



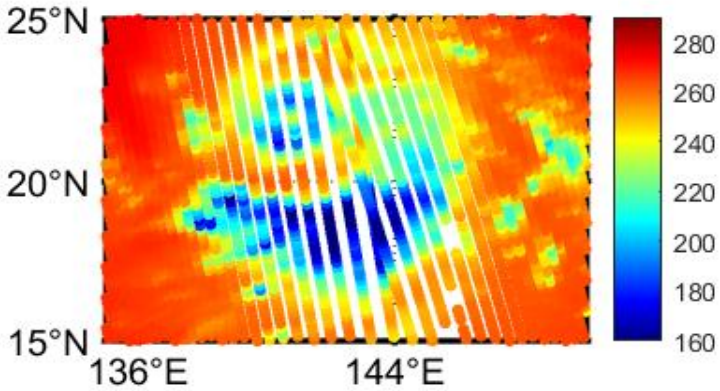
Channel 10 non-spherical BTs



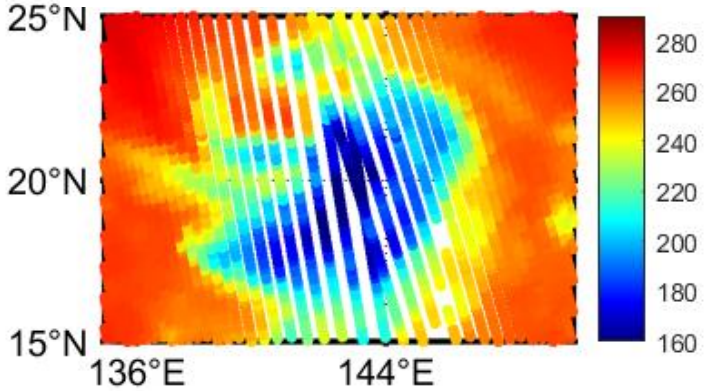
Channel 10 spherical BTs



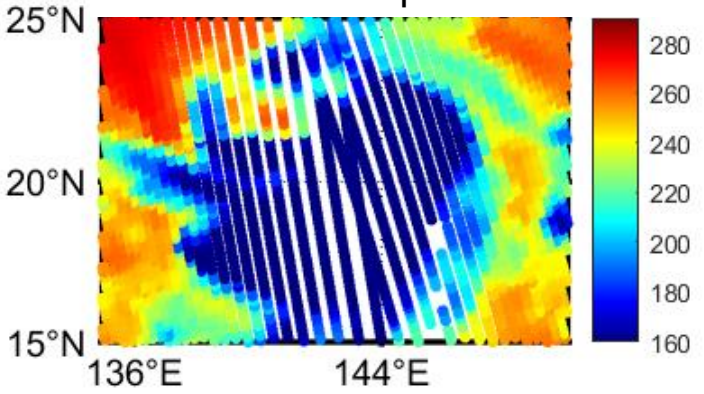
Channel 15 observed BTs



Channel 15 non-spherical BTs



Channel 10 spherical BTs



ARMS Application

- ARMS now has been used for forward simulations, 1DVAR retrivals, data assilimation.

- Application in 1DVAR retrival can be found at:
  6.09 The Cloud-dependent 1DVAR Algorithm for Retrieving Precipitation from FengYun-3D/E Microwave Sounders

- Application in CMA-GFS satellite data assilimation system:
  15.03 Assimilation of FengYun Satellite Data in CMA-GFS Using Advanced Radiative Transfer Modeling System (ARMS)

  12.02 Evaluation of Assimilation and Prediction Effects of Different Satellite Observation Operators in CMA-GFS

ARMS Next Step

- Gaseous Transimittance Module Updated:

  Develop Gaseous Transimittance to support UV hysperspectral sensors

- Surface Emissivity Module Updated:

  Coupling the MW Ocean Bidirectional Reflection Model and test its effect in forward simulation, ocean surface wind retrival and data assilimation.

- RT Solver Module Updated:

  Coupling Weng's VDISORT into ARMS, and accelerating VDISORT to meet the need to assilimating the satellite data with high temporal and spatial resolution.

THANKS!

CMA Earth Modeling and Prediction Centre
China Meteorological Administration (CMA)