



Reports from the Session of RT and Clouds and Precipitation

Co-Chairs: John Derber and Fuzhong Weng

Session Highlights

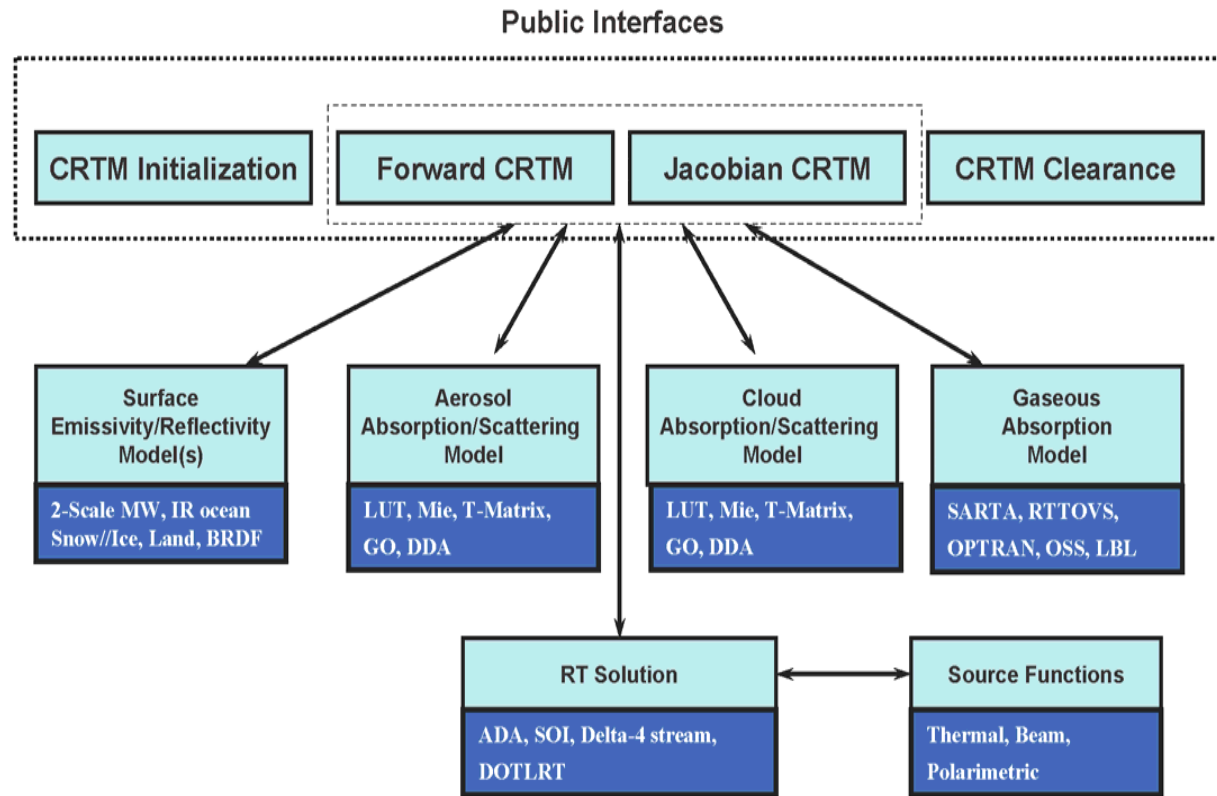
- ***Community Radiative Transfer Model (CRTM)***
 - CRTM status and development – P. Delst, EMC and Y. Han, STAR
 - Microwave emissivity model update – B. Yan et al., STAR
 - Optical properties of cloud particles and dust aerosols and the truncation of scattering phase function – P. Yang, Texas A&M
 - CRTM including aerosols and historical sensors – M. Liu et al., STAR
- ***New Radiative Transfer Schemes & Spectroscopy***
 - Assimilation of clouds & precipitation – R. Bennartz et al., U. Wisc.
 - Improved Spectroscopy for Microwave and Infrared Satellite Data Assimilation - Vivienne Payne, AER Inc.
- ***CRTM validation and error characterization***
 - Validation of CRTM by using CloudSat data – Y. Chan et al., STAR
 - Improved Clouds and Precipitation Products for NWP – N. Wang, CICS/UMD
- ***CRTM Impacts and Cloudy Radiances in NWP***
 - CRTM Implementation in Navy Assimilation Systems – N. Baker et al, NRL
 - Radiance Data Assimilation for WRF model: overview and results – Z. Liu et al., NCAR/AFWA
 - The inclusion of cloudy radiances in the NCEP GSI analysis system – M. Kim, STAR

Community Radiative Transfer Model

Supported Instruments

- GOES-R ABI
- Metop IASI
- TIROS-N to NOAA-18 AVHRR
- TIROS-N to NOAA-18 HIRS
- GOES-8 to 13 Imager channels
- GOES-8 to 13 sounder channel 08-1
- Terra/Aqua MODIS Channel 1-10
- METEOSAT-SG1 SEVIRI
- Aqua AIRS
- Aqua AMSR-E
- Aqua AMSU-A
- Aqua HSB
- NOAA-15 to 18 AMSU-A
- NOAA-15 to 17 AMSU-B
- NOAA-18 MHS
- TIROS-N to NOAA-14 MSU
- DMSP F13 to15 SSM/I
- DMSP F13,15 SSM/T1
- DMSP F14,15 SSM/T2
- DMSP F16 SSMIS
- NPP ATMS
- Coriolis Windsat
- SSU

Community Radiative Transfer Model (CRTM)

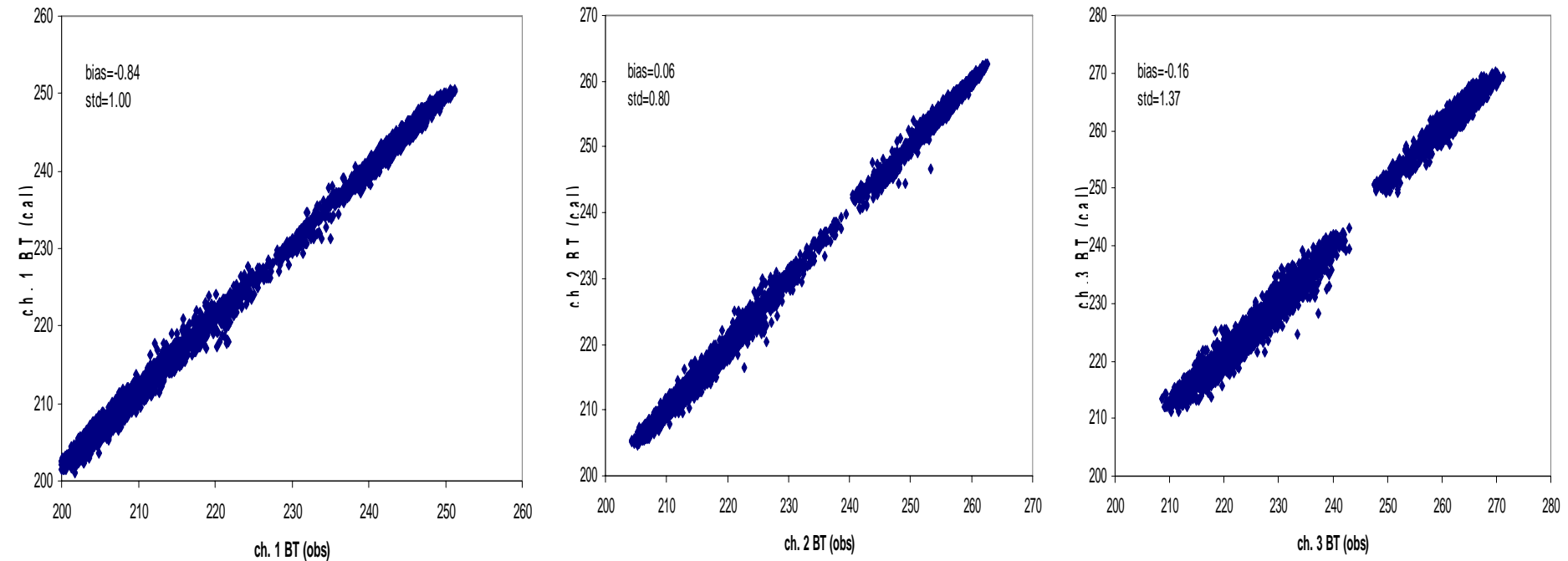


CRTM Status and Development (Paul van Delst and Yong Han)

- Derived analytical expressions for the scattering source function.
 - Azimuthal dependence of the solar source function taken into account.
 - Earth curvature effects at large solar zenith angles taken into account. (Also being applied to “regular” radiative transfer)
 - Cloud and aerosol optical property LUTs are being extended into the visible spectral region.
- Good progress made in CRTM development in the last year.
 - Feedback from users proved very helpful.
 - Public code repository should be online sometime in July.
- Modules completed and waiting:
 - SSU and Zeeman models ready to be included when multiple-algorithm transmittance module is completed.
 - SSMIS snow and ice emissivity models ready to be integrated.
- Modules still being developed:
 - Multiple algorithm transmittance model.
 - Trace gas transmittance model.
 - Improved IR and MW surface emissivity models.
 - Improved cloud and aerosol LUT data.
 - Visible models.

CRTM Simulated SSU vs. Measurements

(M. Liu et al)



**SSU and MLS data for 11/2004,
All match-up data points are plotted.**

Microwave Snow and Sea Ice Emissivity Modeling and Algorithm Developments

PI: Fuzhong Weng

Co-PI: Banghua Yan

NWP Center Collaborator: John Derber

Accomplishments

△ Microwave snow and sea ice emissivity empirical algorithms are updated to MHS and SSMIS

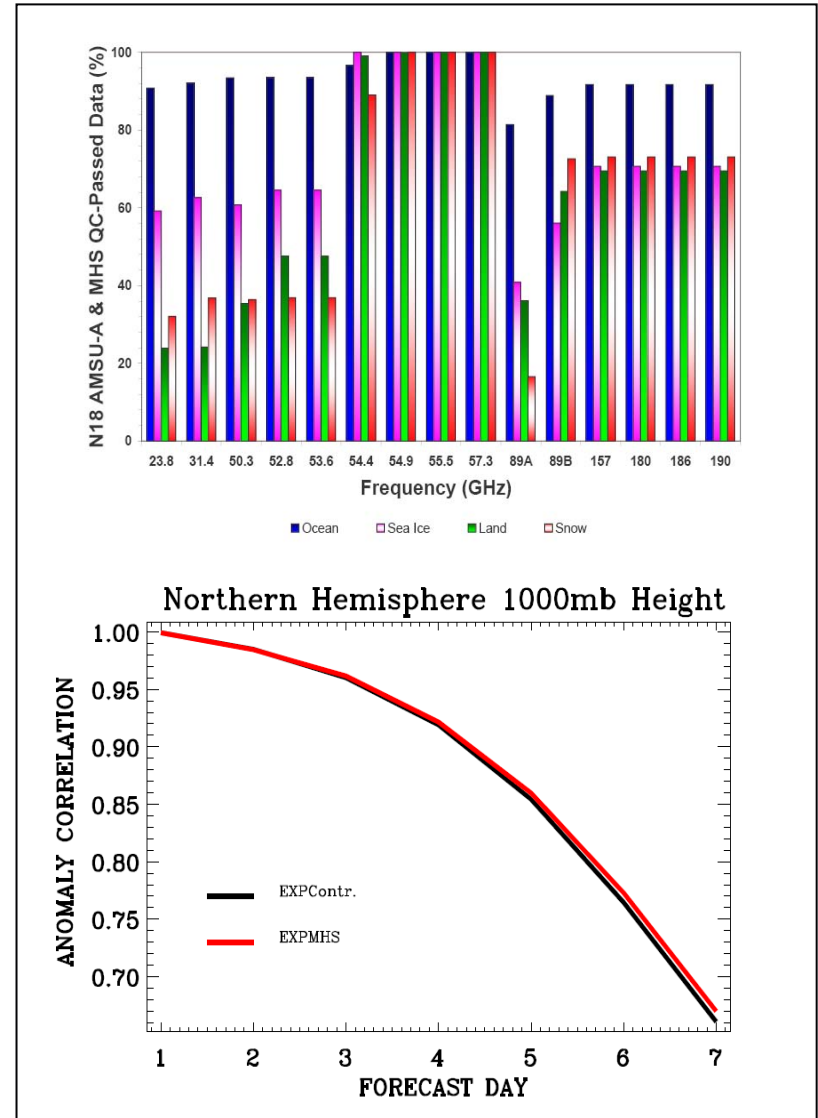
△ Improved MHS and SSMIS snow and sea ice emissivity simulations result around 50% sounding data passing QC

△ A positive assimilation impact on NCEP GFS is observed

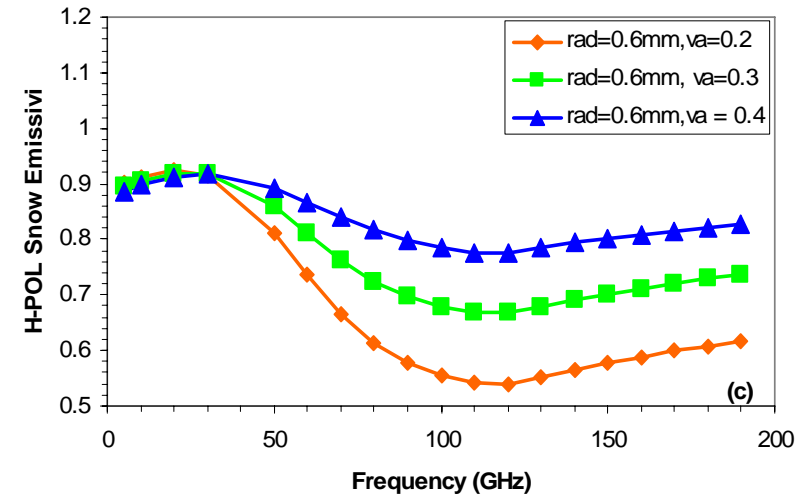
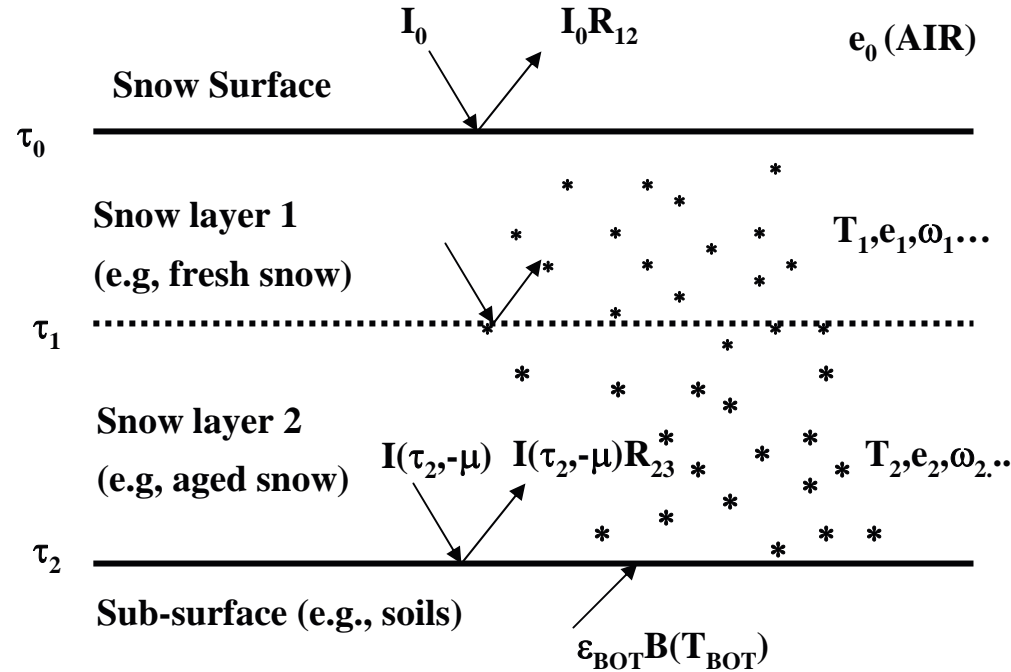
Future Plan

△ Improve microwave snow and sea ice emissivity physical model

△ Implement the updated snow and sea ice emissivity empirical model into JCSDA CRTM



Two-layer Microwave Snow Emissivity Model (Yan et al)

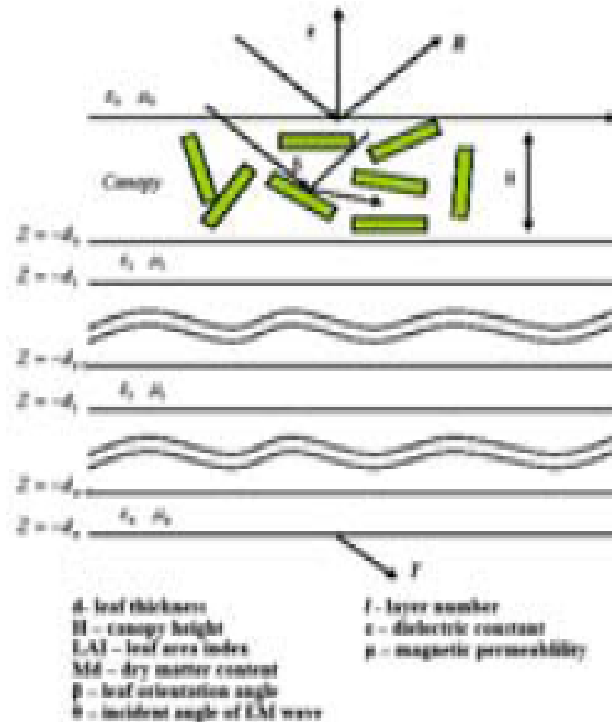


$$\varepsilon = \alpha_0 R_{12} + (1 - R_{21}) \alpha_1 \left[\frac{I_0'}{\gamma_1} - \frac{\gamma_2 (I_1' m_4 - I_2' m_2)}{\gamma_1 (m_1 m_4 - m_2 m_3)} + \frac{(I_1' m_4 - I_2' m_2)}{\alpha_1 (m_1 m_4 - m_2 m_3)} + B_1 \right]$$

Multilayer Soil/Vegetation Emissivity Model

F. Weng

1. Model Description



Soil dielectric model:

Dobson et al. (1985) developed a mixing rule for soil dielectric constant (Weng et al., 2003) which is

$$\epsilon_{\text{soil}}^2 = 1 + \frac{\rho_w}{\rho_s}(\epsilon_s^2 - 1) + m_s^2 \epsilon_s^2 - m_s, \quad (5.31)$$

where m_s is the soil volumetric moisture, ϵ_s is the dielectric constant of solids, and ρ_w is the density of soil, ρ_s is the density of solids, which are calculated from sand and clay fraction. The exponents, α , β are depending on soil type.

$$\alpha = 0.65 \quad (5.32)$$

$$\beta = 1.09 - 0.11S + 0.19C \quad (5.33)$$

$$\epsilon_s = (1.01 + 0.44 + \rho_s)^2 - 0.062 \quad (5.34)$$

Vegetation dielectric model:

$$\begin{aligned} \epsilon_{\text{veg}} = & 1.7 - (0.74 - 0.16m_g)m_g + m_g + (0.55m_g - 0.070) \\ & [4.9 + 75.0/(1 + \gamma_1) - \gamma_1] + \\ & 4.64m_g^2/(1 + 7.30m_g^2)[3.9 + 56.0/(1.0 + \sqrt{6})] \\ \gamma_1 = & \omega/18.0 \end{aligned} \quad (5.16)$$

where γ_1 is a complex value, m_g is the gravimetric water content (g/kg), ω is the frequency in GHz.

A mixing formula was also derived and validated for leaves (Mätzler, 1994a) having a higher gravimetric water content (e.g. > 0.5) which is

$$\epsilon_{\text{veg}} = (0.52 - 0.69m_d)\epsilon_w + 3.84m_d + 0.51, \quad (5.17)$$

where m_d is the dry matter content and ϵ_w is the dielectric of water.

Aerosol Models (M. Liu)

Global Model, Goddard Chemistry Aerosol Radiation and Transport (GOCART)

- Dust
- Sea Salt
- Organic carbon
- Black carbon
- Sulfate

Regional Model WRF-NMM, Community Multiscale Air Quality (CMAQ)

- Sulfate mass
- Ammonium mass
- Nitrate mass
- Organic mass
- Unspecified anthropogenic mass
- Elemental carbon mass
- Marine mass
- Soil derived mass

CRTM Model for GOES-R Applications (preliminary)

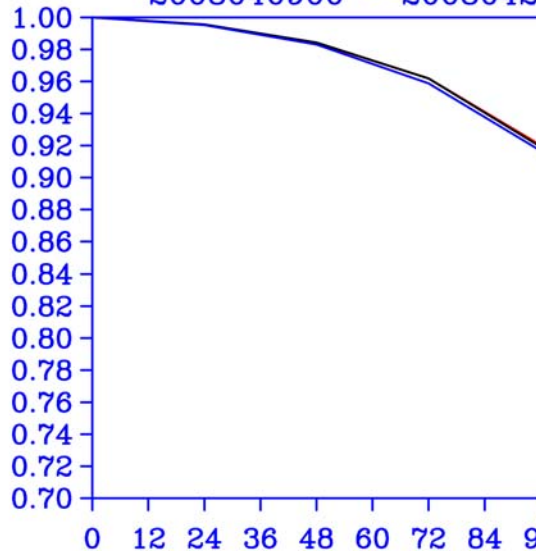
- Continental
- Urban
- Generic 1
- Heavy smoke 1
- Dust
- 5 Coarse mode aerosol
- 4 Fine mode aerosol

CRTM Implementation in Navy Assimilation Systems (Nancy Baker and Ben Ruston, NRL)

CRTM_rev1876, RTTOV-8.7, & RTTOV-6

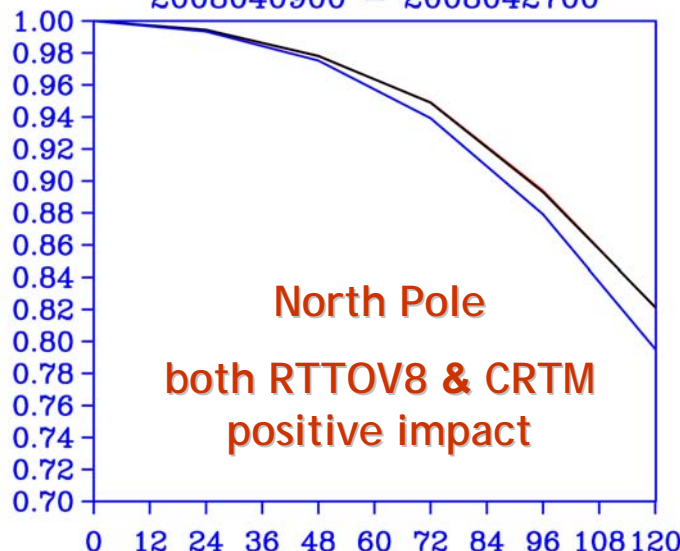
- The latest release of CRTM added climatology and extra layers above model top
- NAVDAS with CRTM is still being “spun-up”; however the verification statistics are quite similar to those from RTTOV-8.7
- Operational NAVDAS uses RTTOV-6

NOGAPS DATA ASSIMILATION
500 MB NORTH HEM HEIGHT AI
2008040900 – 2008042



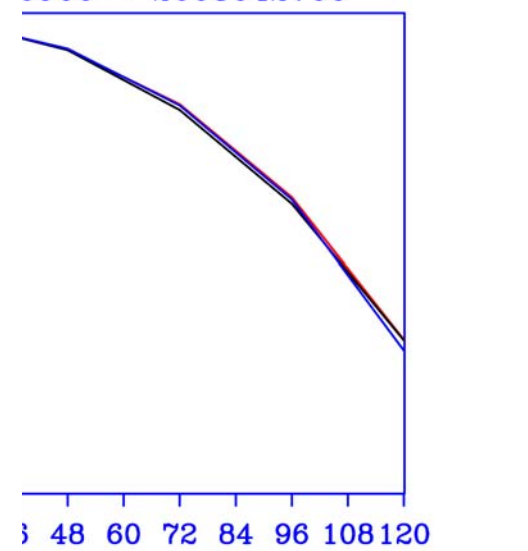
— CRTM — RTTOV8

NOGAPS DATA ASSIMILATION TEST
500 MB NP REGION HEIGHT ANOMALY COR
2008040900 – 2008042700



— CRTM — RTTOV8 — RTTOV6

ETA ASSIMILATION TEST
HEM HEIGHT ANOMALY COR
0900 – 2008042700

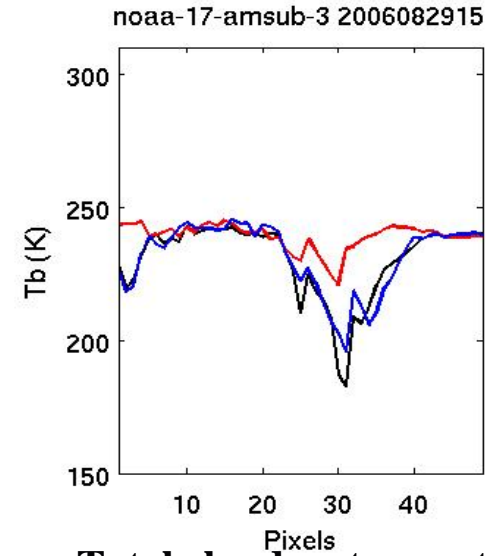
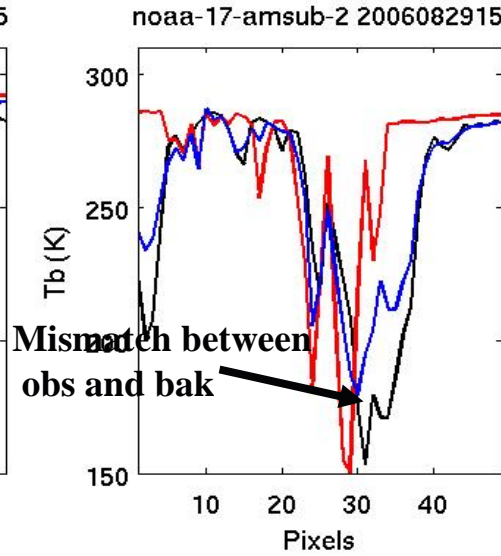
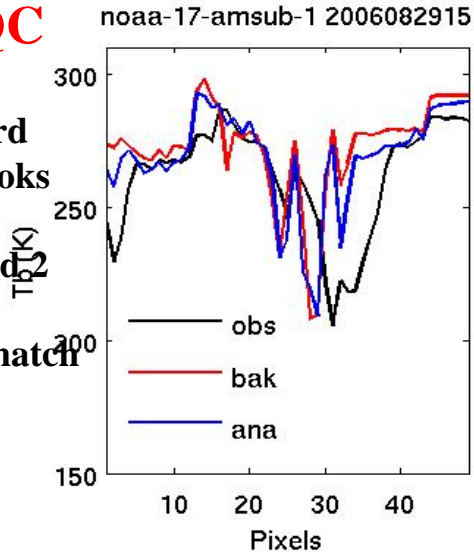


— CRTM — RTTOV8 — RTTOV6

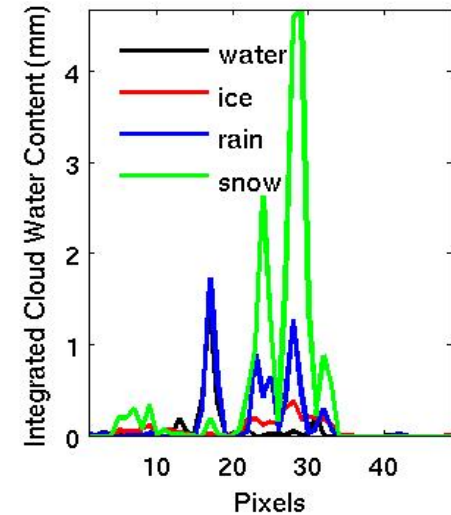
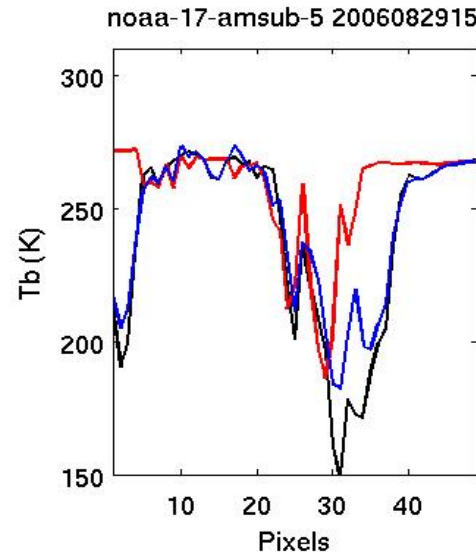
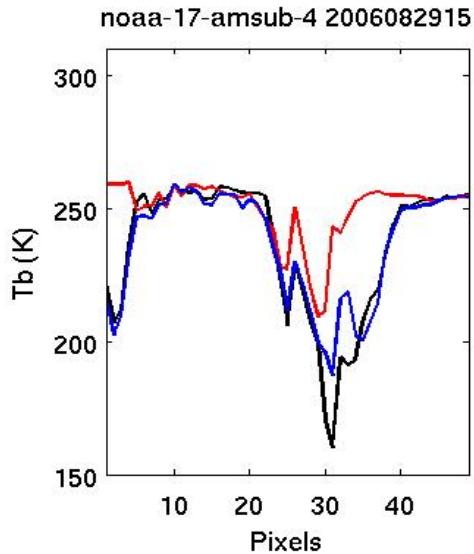
NOAA-17-AMSUB Tb along CloudSat path (Z. Liu et al., NCAR)

NO ANY QC

**CRTM forward
Calculation looks
quite good for
Channels 1 and 2
Regardless of
Location mismatch**

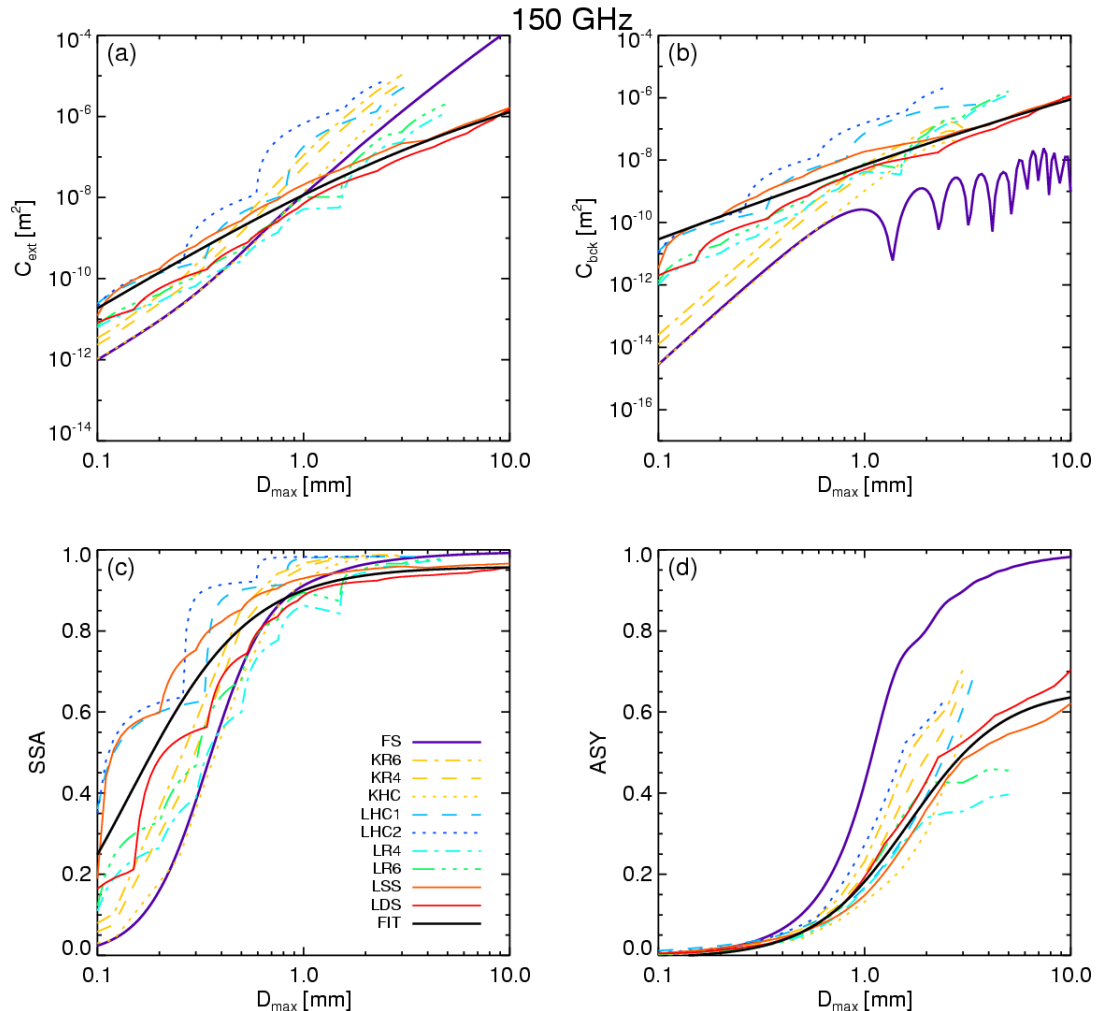


Total cloud water content



Sigmoid Snow/Rain Optical Properties Parameterization in MW (Bennartz et al.)

- Very accurate fits for all parameters
- Physically realistic behavior
- Sigmoid easy to differentiate ($dS/dx=S(1-S)$)
- Easy to implement TL and ADJ versions
- Uncertainties/errors can be specified via differences for different ice models



Improved Spectroscopy for Microwave and Infrared Satellite Data Assimilation

P.I.: J.-L. Moncet, AER, Inc.

Summary of Accomplishments

- **Microwave**
 - Publication on water vapor line widths
 - Validation of water vapor self & foreign H₂O continuum using ground-based measurements
- **Infrared**
 - Implementation of P&R branch line coupling for all CO₂ bands
 - Updated water vapor line widths
 - AIRS/LBLRTM/SARTA comparisons
 - IASI/LBLRTM comparisons

Future Work

- **Microwave**
 - Find optimal fit for self and foreign H₂O continuum
 - Zeeman splitting
- **Infrared**
 - Update CO₂ v3 line parameters
 - Update CO₂ line coupling, lineshape and continuum
 - Validation using up- & down-welling measurements
 - Assessment of H₂O continuum in 2500 cm⁻¹ region using upwelling, & downwelling measurements
 - Validation of LBLRTM in the stratosphere
 - Comparisons with “untuned SARTA”
 - Investigate alternative H₂O line parameters

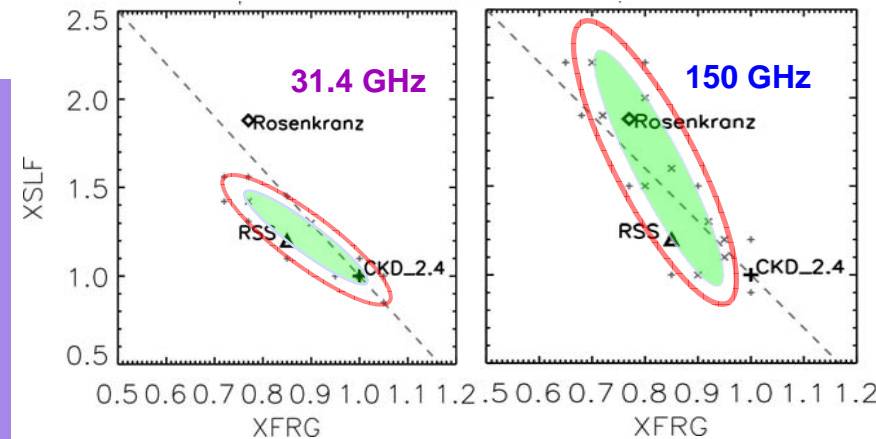


Figure 1: Current uncertainty on MW water vapor continuum

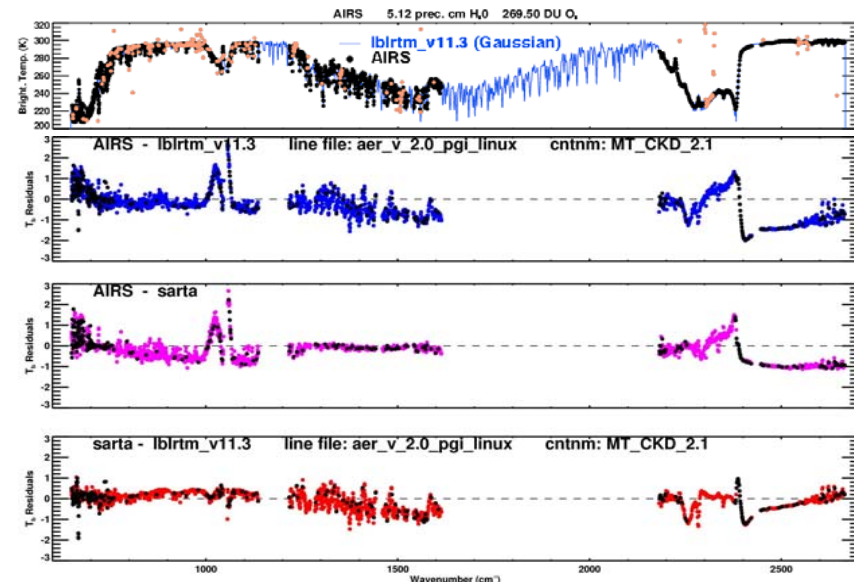


Figure 2: AIRS/LBLRTM/SARTA comparisons for ARM TWP

Enhancement of the capabilities of CRTM for simulating radiative transfer in ice-cloudy atmospheres

PIs and Co-PIs: Ping Yang

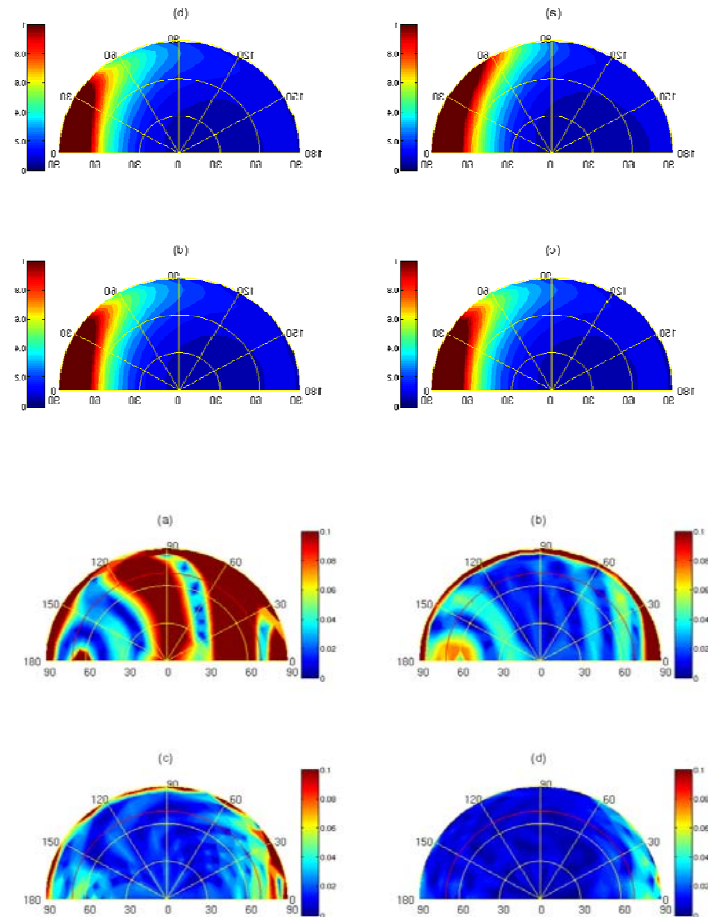
NWP Center Collaborators: Fuzhong Weng, Yong Han, and Paul van Delst

Accomplishments

- Delivered dust aerosol optical properties
 - The bulk scattering properties.
 - Interpolate the bulk scattering property database to 3001 wavelengths between 0.225 and 20.0 μm
 - Truncate the scattering phase function
- Delivered ice cloud optical properties
 - Same as dust aerosols
- Delivered water cloud optical properties
 - Same as dust aerosols

Future Plan

- Re-compute the single-scattering properties of ice crystals by using the latest ice refractive index data.
- Consider surface roughness of ice particles
- Add the shape distribution of spheroidal dust aerosols



Simulated dust aerosol bidirectional reflectances and relative errors for (a) 4, (b) 8, (c) 16, (d) 32 terms of the Legendre polynomials at $\lambda=0.55 \mu\text{m}$

Improved Clouds and Precipitation Products for NWP

PIs and Co-PIs: Nai-Yu Wang

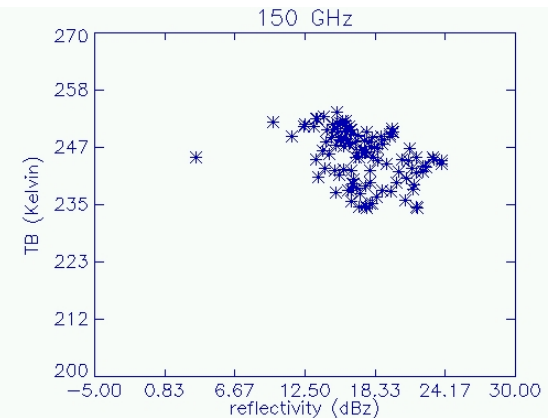
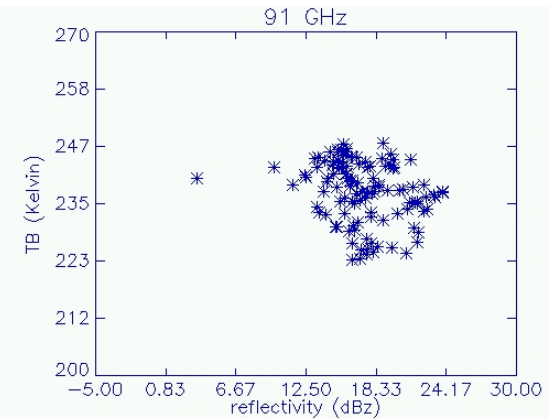
NWP Center Collaborators:

Accomplishments

- Improve understanding of microwave observation of snowfall over land, particularly for high frequency (> 85 GHz)
- Estimate microwave surface emissivity spectra for cold season land surface and derive snow microphysics using radar and aircraft data

Future Plan

- Continue field data analyses to develop realistic frozen hydrometeor profiles for RT model training
- Simulate microwave radiances using these profiles and CRTM RT solvers; develop modeling error characterizations



Validation of CRTM by using CloudSat data

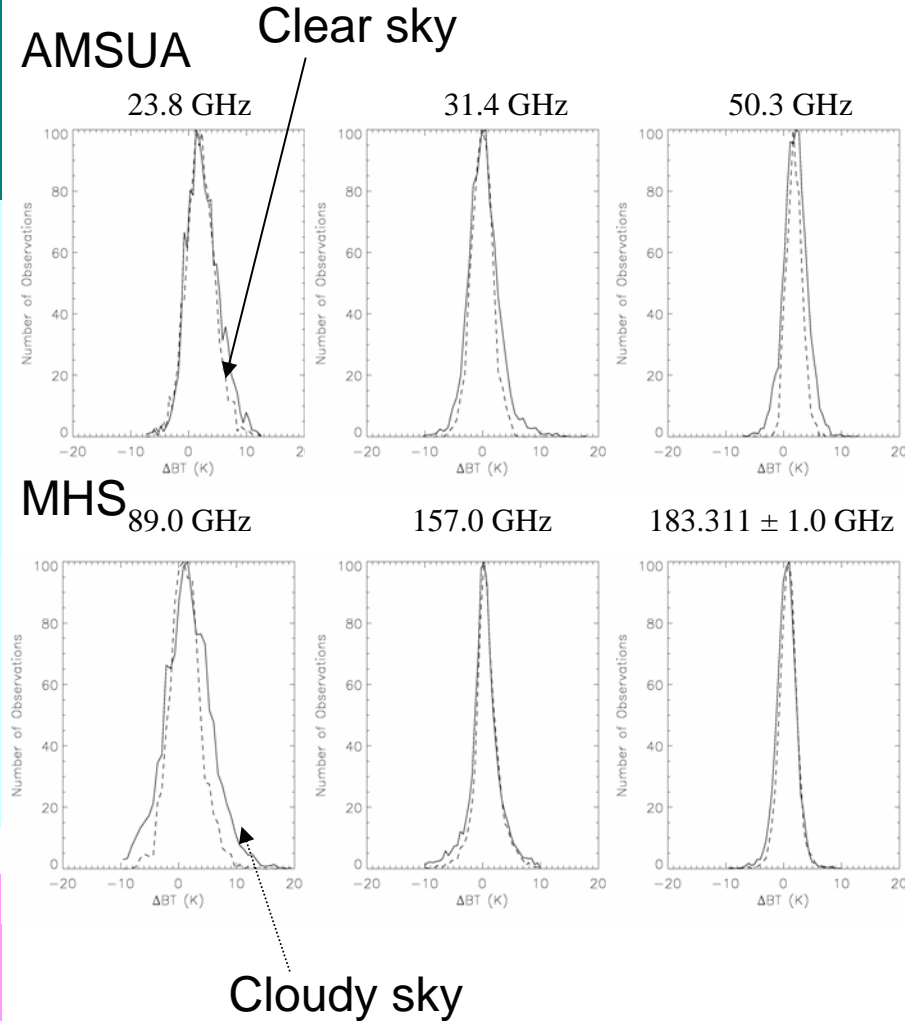
PIs and Co-PIs: Yong Chen, Fuzhong Weng
NWP Center Collaborators: John Derber and Nancy Baker

Accomplishments

We have validated the CRTM modules (gaseous absorption model, cloud absorption and scattering model, and surface emissivity models over ocean) that generate optical properties of the atmosphere and surface by using colocated CloudSat and NOAA-18 data under non-precipitation conditions, in the microwave and thermal infrared spectral region.

Future Plan

Continuation of the CRTM validations under cloudy environments, especially for precipitation weather conditions by using CloudSat and radar data, and validation for infrared sounders when cirrus clouds and aerosols are present in the atmosphere using a combination of CloudSat/CALIPSO data.



Observation – Guess

clear radiance vs. cloudy radiance

	Clear Sky, No BC Mean (STD) [K]		Cloudy Sky, No BC Mean (STD) [K]	
	Clear radiance DA	Cloudy radiance DA	Clear radiance DA	Cloudy radiance DA
Channel 1	-3.41(1.93)	-3.44 (2.00)	0.47(2.42)	-0.12(2.17)
Channel 2	-2.87 (1.34)	-3.03 (1.48)	4.49 (2.70)	3.18(2.67)
Channel 3	-0.167 (1.67)	-0.42 (1.78)	4.23 (3.17)	3.24(2.41)
Channel 15	0.69 (2.02)	0.39 (2.12)	7.84 (4.52)	6.53(3.94)

Inclusion of Cloudy Radiances in GSI

Tangent linear models (M. Kim et al)

$$\frac{\partial T_B}{\partial T_v} = \frac{1}{1 + \epsilon q} \frac{\partial T_B}{\partial T}$$

$$\frac{\partial T_B}{\partial q} = \frac{-\epsilon T}{1 + \epsilon q} \frac{\partial T_B}{\partial T} + \frac{1000}{(1 - q)^2} \frac{\partial T_B}{\partial w}$$

$$\frac{\partial T_B}{\partial cwmr} = \frac{P_{mb} \times 100 \times \Delta z_m}{R_d T_v} \cdot (1 - F) \frac{\partial T_B}{\partial CL} + \frac{P_{mb} \times 100 \times \Delta z_m}{R_d T_v} \cdot F \frac{\partial T_B}{\partial CI}$$

F: ice cloud fraction

Summary

- CRTM is a well modularized model, designed as a framework for the purpose of accelerating the transition from research to operation.
- Its current capabilities include Forward, Tangent-linear, Adjoint and Jacobian models for assimilations of clear and cloudy IR and MW radiance observations from satellite over ocean, land, snow and ice surfaces.
- Users feedbacks are very positive, NRL and NCAR/AFWA tested and compared with RTTOV and helped debug the codes,
- Accomplishments in the past year:
 - improvement of currently operational code;
 - Development of a fast RT model for SSMIS Zeeman affected channels;
 - extension to aerosol absorption/scattering component;
 - extension to VIS and UV regions for air quality applications;
 - validation for IASI, AMSUA and MHS;
 - New optical models and improved spectroscopy data base
 - validation and assessment of CRTM cloudy radiance simulation capability using CloudSat data;
 - development of multilayer land emissivity model
 - Development of a new IR land emissivity data base.

Discussions and Recommendations from the 6th Science Workshop (RT)

- How to improve the implementation process of CRTM at NWP centers?
- CRTM repository for accessing the code and email communications for testing results and feedbacks, lack of infrastructure for managing the codes from outsiders. CVS
- Difficult use CRTM for OSSE - better user guide/online instruction. Resource for documentation are lacking. CRTM core team is struggling for covering both science and documentation.
- Early engagement of JCSDA partners in new CRTM components such as radiance assimilation of aerosol-sensitive channels, which parts should be supported, assimilation part or RT part?
- CRTM developers should focus on simulated radiances with observations, and test jacobians. The tests of CRTM in NWP will be more relied on JCSDA NWP centers
- Any other line by line codes? Update the coefficients using latest LBLRTM, the major changes will be the MonoRTM.
- Surface emissivity coordination, particularly with land group.
- Cloud and aerosol scattering coordination: do forecast models provide the information for CRTM such as shape and size distribution. Tom Kleespies is collecting the information how to translate the model outputs to size parameters (16th ITOVS action)
- Air quality data assimilation requires strong CRTM supports for their developments. What is JCSDA position ?
- CRTM trace gas components should be ready even if users only have total concentration

Discussions and Recommendations from the 6th Science Workshop (Data Assimilation)

- Work with international community for getting new data sets for user in standard format (BUFR, UPP). JCSDA should do better in coordination fore early preparation for NPP, ..