Community Radiative Transfer Model (CRTM) Support to Satellite Cloud Radiance Assimilation

Quanhua (Mark) Liu[1,2], Paul van Delst[2,3], David Groff[2,3], Haixia Liu[3], Emily Liu[3], Ming Chen[1,2], Andrew Collard[3], Sid-Ahmed Boukabara[1], Fuzhong Weng[2], John Derber[3]
1 NOAA/NESDIS Center for Satellite Applications and Research, College Park, Maryland
2 Joint Center for Satellite Data Assimilation, College Park, College Park, Maryland
3 NOAA/NWS National Centers for Environmental Prediction, College Park, Maryland

1. Introduction

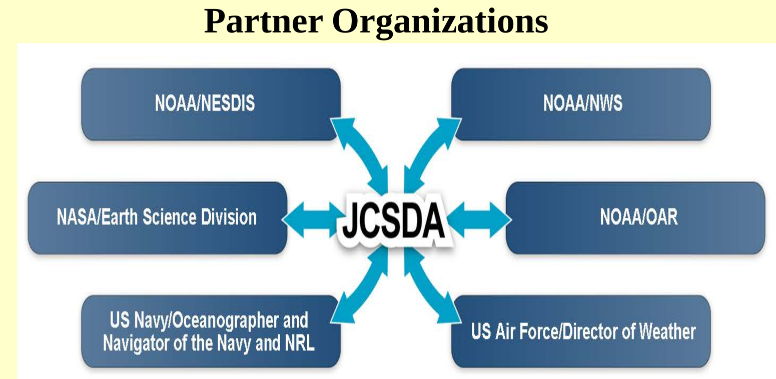
The Community Radiative Transfer Model (CRTM), developed at the Joint Center for Satellite Data Assimilation, has been applied to the NOAA/NWS operational radiance assimilation in supporting of daily weather forecasting, to the NOAA Microwave Integrated Retrieval System for operational satellite products, and to international remote sensing community for remote sensing sensor calibration, air quality application, and others including projects at CICS/ESSIC.

CRTM is applicable for passive microwave, infrared and visible sensors. It supports all NOAA satellite instruments, NASA MODIS, and many foreign meteorological satellites.

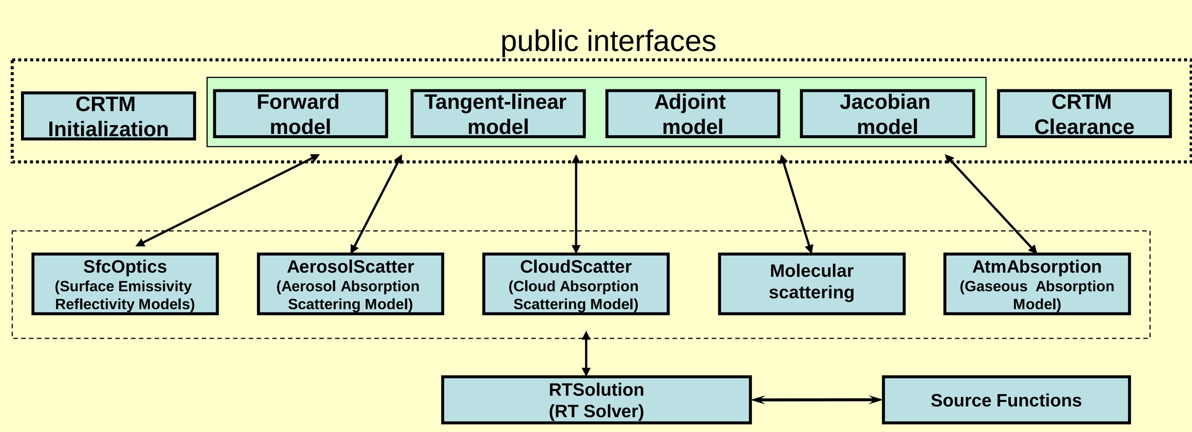
2. CRTM

- CRTM was initially proposed to support primarily the JCSDA partners to assimilate satellite radiance data into global/regional forecast systems
- It is now also supporting the US satellite program developments through generating a high quality proxy data for algorithm tests, developments and integrations
- It has been used in the NOAA/NESDIS microwave sounding product system
- It can be used to generate the synthetic satellite radiances from NWP nature runs for observation system simulation experiments (OSSE)
- It is linked to other key projects such as climate reanalysis and satellite cal/val

Joint Center for Satellite Data Assimilation (JCSDA) Partner Organizations



3. CRTM Modules and Supported Sensors



CRTM main modules

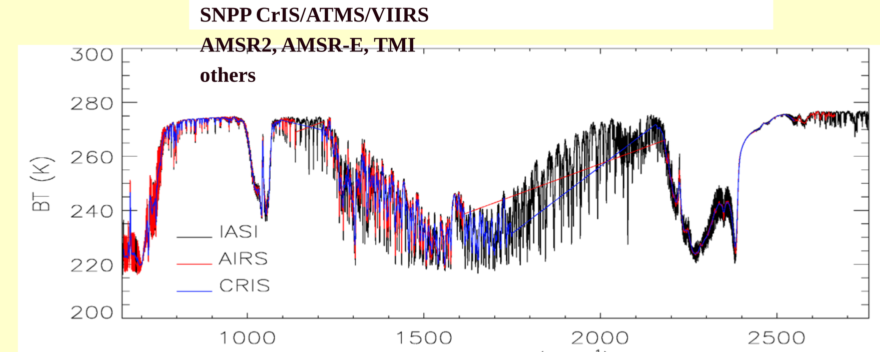
Support more than 100 Sensors

- GOES-R ABI
- TIROS-N to NOAA-19 AVHRR
- TIROS-N to NOAA-19 HIRS
- GOES-8 to 14 Imager
- GOES-8 to 14 sounder
- Terra/Aqua MODIS
- METEOSAT-SG1 SEVIRI
- Aqua AIRS, AMSR-E, AMSU-A, HSB
- NOAA-15 to 19 AMSU-A
- NOAA-15 to 17 AMSU-B
- NOAA-18, 19 MHS
- TIROS-N to NOAA-14 MSU,
- DMSP F13 to 15 SSM/I
- DMSP F13,15 SSM/T1
- DMSP F14,15 SSM/T2
- DMSP F16-20 SSMIS
- Coriolis Windsat
- TiROS to NOAA-14 SSU
- METOP-A IASI AMSUA, MHS, HIRS, AVHRR
- FY-3 IRAS, MWTS, MWHS, MWRI
- SNPP CrIS/ATMS/VIIRS
- AMSR2, AMSR-E, TMI
- others

4. CRTM Transmittance Model

4.1 Transmittance Model

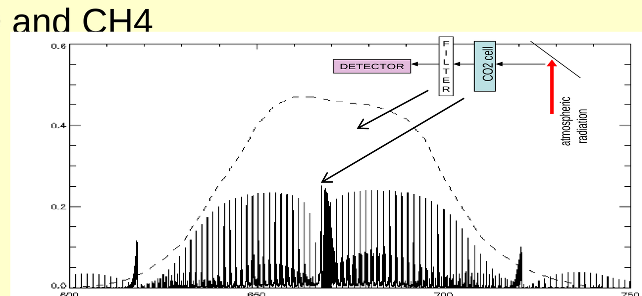
- The transmittance model is to compute atmospheric transmittance from absorbing gases
- In addition to ODAS model, a new transmittance model ODPS (Optical Depth in Pressure Space) has been implemented in version 2.
- Variable absorbing gases: H_2O, CO_2, O_3, CO, N_2O and CH_4



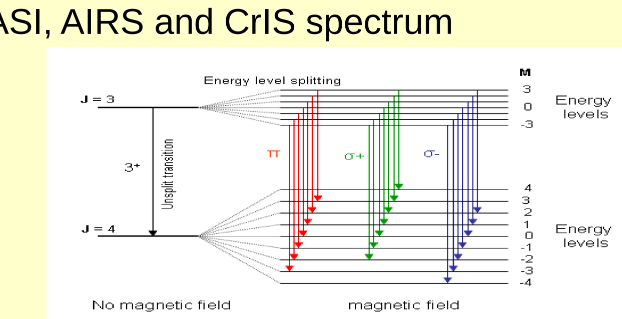
CRTM simulated IASI, AIRS and CrIS spectrum

4.2 Specific Transmittance Model

- Zeeman-splitting effect into account for affected microwave channels
- Stratospheric sounder unit transmittance for accounting for onboard CO2 cell pressure leaking.
- NLTE Model



SSU



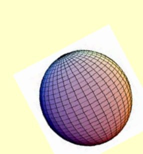
Zeeman effect:
The O_2 transition line is split into many sublines, which can change transmittance.

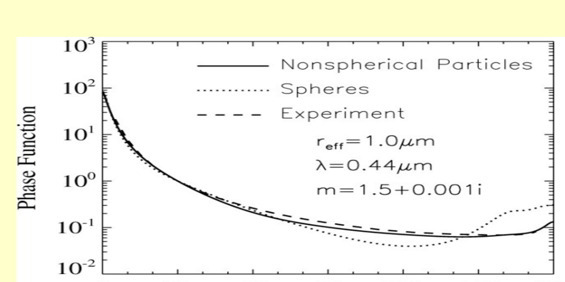
5. Aerosol and Cloud Models

Aerosols:
Global Model, GOCART
Dust, Sea Salt, Organic carbon, Black carbon, Sulfate
Regional Model
CMAQ is under implementation.
Aerosol are assumed to be spherical particles. Spheroid shape for dust is under consideration.

Clouds:
Liquid, Rain, Snow, Ice, Graupel, and Hail

Non-spherical particles for ice cloud are used for Visible and IR bands.



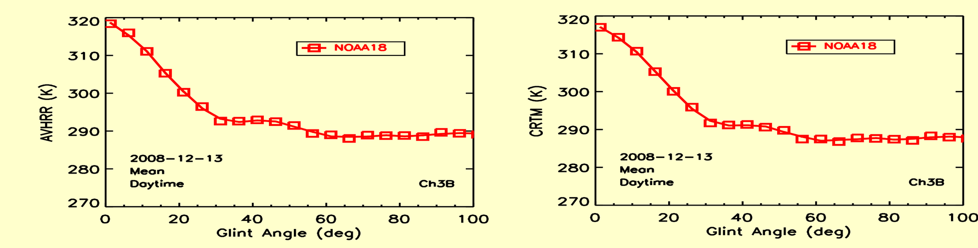


Effect of non-spherical particles. Ding, et al. TAMU

6. Surface Emissivity and Reflectance

The surface is divided as Water, Land, Ice, and Snow.

- CRTM computes emissivity and reflectance internally.
- CRTM accepts user defined emissivity data.
- CRTM uses Ocean BRDF IR model. Other BRDF is under development.

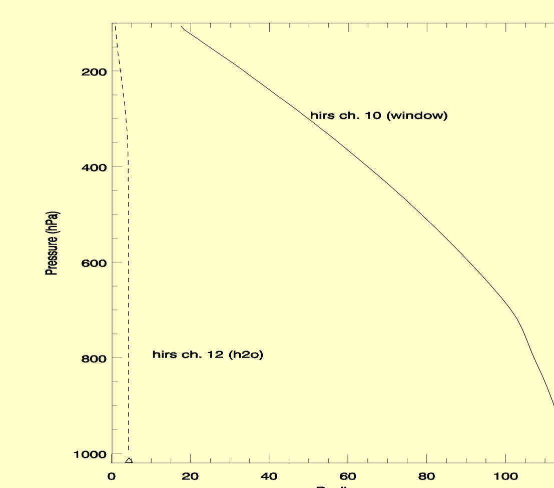


Using the CRTM IR BRDF model, simulations over oceans agree with measurements.

7. Satellite Cloud Radiance (v2.2.0)

7.1 Overcast radiance

NCEP data assimilation system utilizes clear-sky radiances and radiances not affected by clouds. Cloud height is a critical parameter for determining those radiances not affected clouds. CRTM can simulates black cloudy radiances (cloud emissivity=1) for multiple single cloud layer simultaneously without significant increase of computational time. Figure at the right shows the simulations for HIRS. For the window channel 10 (solid line) and , the TOA radiance decreases as the cloud height increases. For the water vapor channel 12 (dashed line), the TOA radiance remains unchanged for the cloud below 400 hPa because the weighting function is close to zero below 400 hPa. Diamond and triangle symbols represents clear-sky radiance.



7.2 Cloud fraction

Infrared and microwave sounders have a pixel size of 10 ~ 50 km at nadir. Most pixels are partially cloudy. However, the CRTM is one-dimensional radiative transfer that computes radiance under either clear-sky or cloudy condition in each calculation. For a pixel with a cloud fraction F, radiance can be expressed as the weighted sum of clear and cloud radiance:

$$R = (1-F)R_{clear} + F \times R_{cloud} \quad (1)$$

The derivative (or jacobian) of radiance to any geophysical parameter can be written as:

$$\frac{\partial R}{\partial x} = -R_{clear}\frac{\partial F}{\partial x} + (1-F)\frac{\partial R_{clear}}{\partial x} + \frac{\partial F}{\partial x} \times R_{cloud} + F \times \frac{\partial R_{cloud}}{\partial x} \quad (2)$$

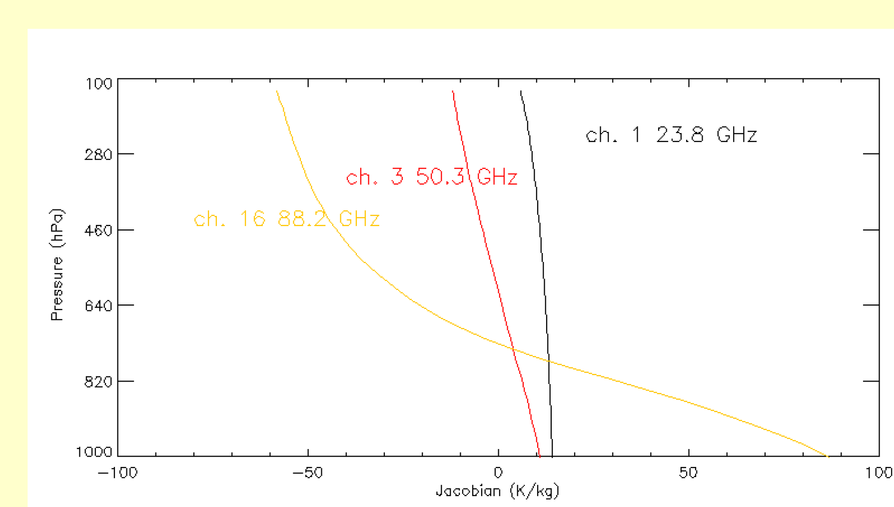
Eqs.(1) and (2) are handled inside the CRTM so that users can directly compute radiance and radiance jacobian for partially cloudy cases.

7.3 Cloud radiance jacobian at non cloud condition

CRTM doesn't compute cloud radiance radiance under clear-sky condition. However, cloud radiance assimilation and satellite product retrievals need the jacobian to infer cloud information even no clouds in inputs for cloudy cases. It is more important to utilize cloud radiance information to improve analysis when model background or the first guess fails to capture cloud feature. Mismatching cloud fields may significantly degrade forecasting score and satellite product retrievals.

Using revised a threshold for cloud water content, the CRTM can provide the jacobian to cloud water content and effective radius for a given cloud type and an effective radius.

The cloud radaiance jacobian computation at zero cloud can be trigged from users specified cloud type and effective particle size.



ATMS BT jacobian at non cloud condition over ocean.

a) The effect on clear-sky radiance calculation is negligible (<0.0001K)
b) The extra computation time for the cloud radiance jacobian is negligible.

CRTM 2.1.3 Release

CRTM 2.1.3 release is available from ftp.emc.ncep.noaa.gov
at jcsda/CRTM/REL-2.1.3