# Current Status of the JCSDA Community Radiative Transfer Model (CRTM)

Yong Han, Paul Van Delst, Fuzhong Weng, Quanhua Liu, Dave Groff, Banghua Yan, Yong Chen and Ron Vogel

Joint Center for Satellite Data Assimilation (JCSDA), Camp Springs, Maryland, USA

ITSC-17: Monterey, CA, 14-20 April 2010

# Community Contributions

| Personnel Name | Organization | AREA |
|---|---|---|
| Fuzhong Weng | STAR | CRTM technical oversight/emissivity |
| Yong Han | STAR | WG Co-Chair/CRTM interface with NESDIS |
| Paul van Delst | SAIC/NCEP | WG Co-Chair/CRTM interface with NCEP |
| Quanhua (Mark) Liu | Perot System/STAR | Transfer scheme |
| Banghua Yan | Univ of MD/STAR | Surface emissivity |
| Yong Chen | CIRA/STAR | CRTM Impacts in GFS |
| David Groff | SAIC/NCEP | Transmittance data base |
| Ron Vogel | IMSG/STAR | IR surface emissivity |
| Ping Yang | Texas A&M | Cloud/aerosol scattering LUT |
| Ralf Bennarts | Univ Wisconsin | Radiative transfer scheme |
| Jean-Luc Moncet/Vivienne Payne | AER | Line-by-line models |
| Tom Greenwalt | CIMSS | SOI |
| Eric Wood | Princeton Univ. | Snow emissivity |
| Al Gasiewski | Univ of Co | MW radiative transfer |
| K.N.Liou/S. Ou | UCLA | Radiative transfer scheme |
| Ben Ruston | NRL | IR land emissivity |

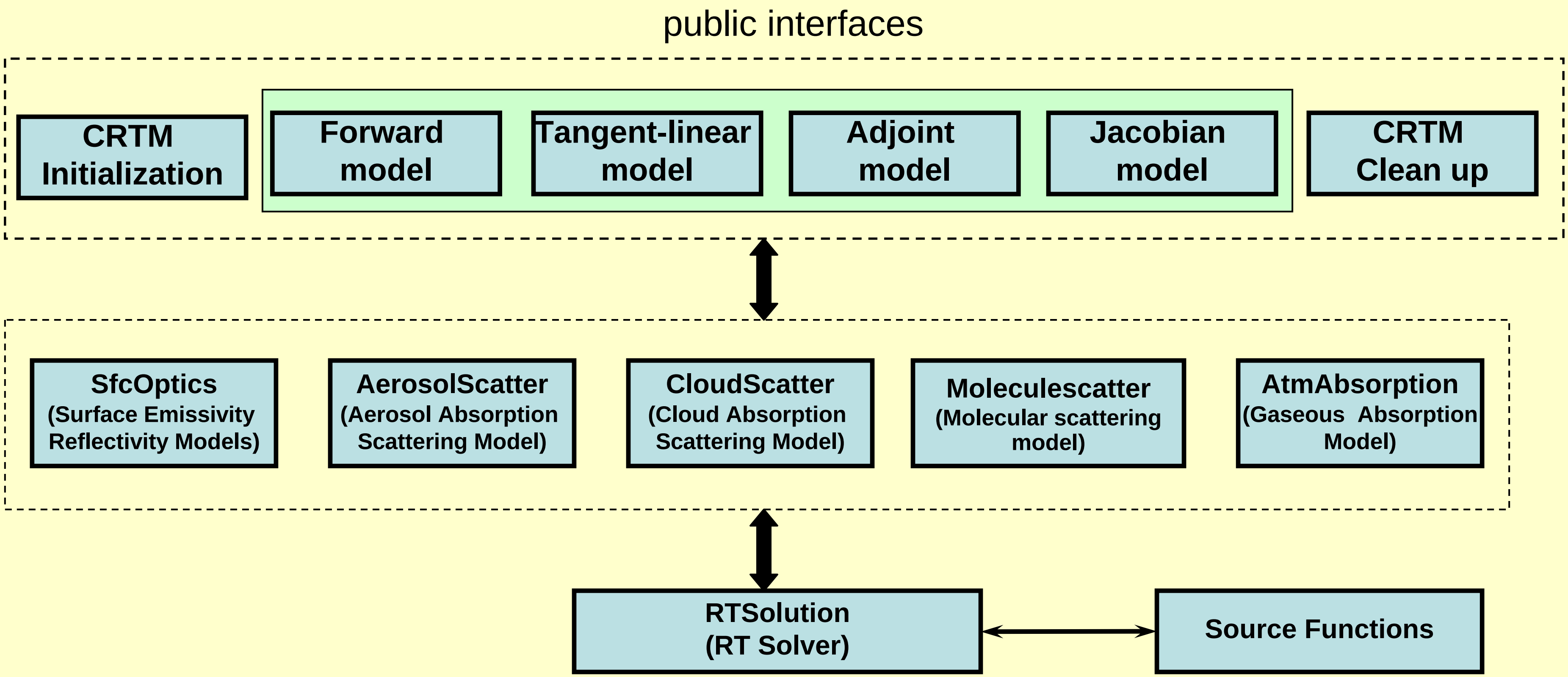
# Outline

- CRTM version 2.0 release
- CRTM modules
- Improvements and new components in CRTM-v2 (focus of this presentation)
- Ongoing and future work

# CRTM History

- pCRTM (before 2004)
  - Simple radiative transfer model for IR and MW radiance assimilations.
  - OPTRAN algorithm to compute absorption and emission with H2O and O3 as variable gases.
  - Surface emissivity is external provided by user; only Lambertian and specular surfaces are included.
  - Clear sky only.
- CRTM version 1 (2004 - 2010)
  - New software design and implementation.
  - Cloud/aerosol scattering and absorption.
  - A suite of surface emissivity/reflectivity models implemented internally for various surfaces (external input is included as an option).
  - Advanced Doubling-Adding radiative transfer solver.
- CRTM version 2 (released in February 2010)

# CRTM-v2 Major Modules



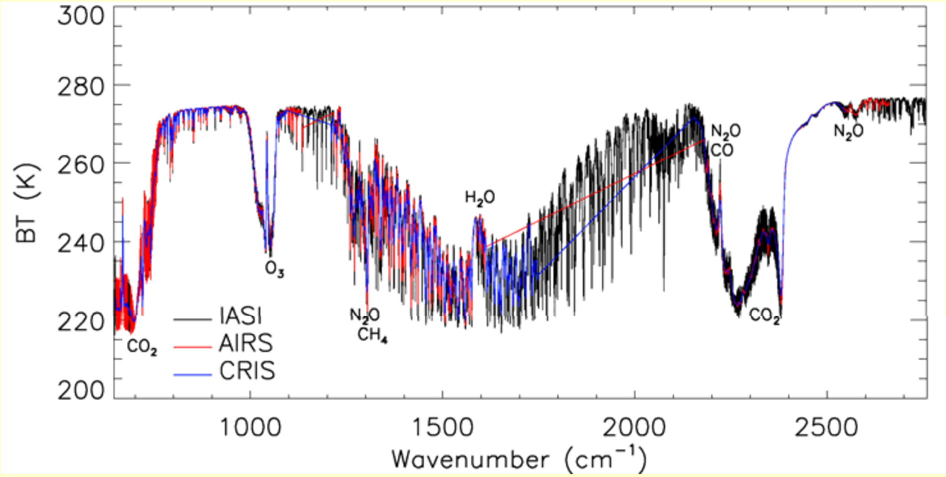
# What's new in CRTM v2

- Transmittance module
  - An additional general transmittance model ODPS
  - Fast SSU model
  - Fast Zeeman model for SSMIS UAS channels
- New modules and module extensions for Visible/UV sensors
- Surface emissivity/reflectivity module
  - Specular surface replacing Lambertian surface in calculations of the reflected IR downward atmospheric radiation over ocean.
  - BRDF for solar reflection over ocean
  - An additional IR ocean emissivity model
  - MW snow and ice empirical models for additional sensors
- Improved computational efficiency (under clear-sky conditions)
  - Forward model by a factor of 3
  - Jacobian model by a factor of 2

# General transmittance models (1)

Two general atmospheric transmittance models implemented:

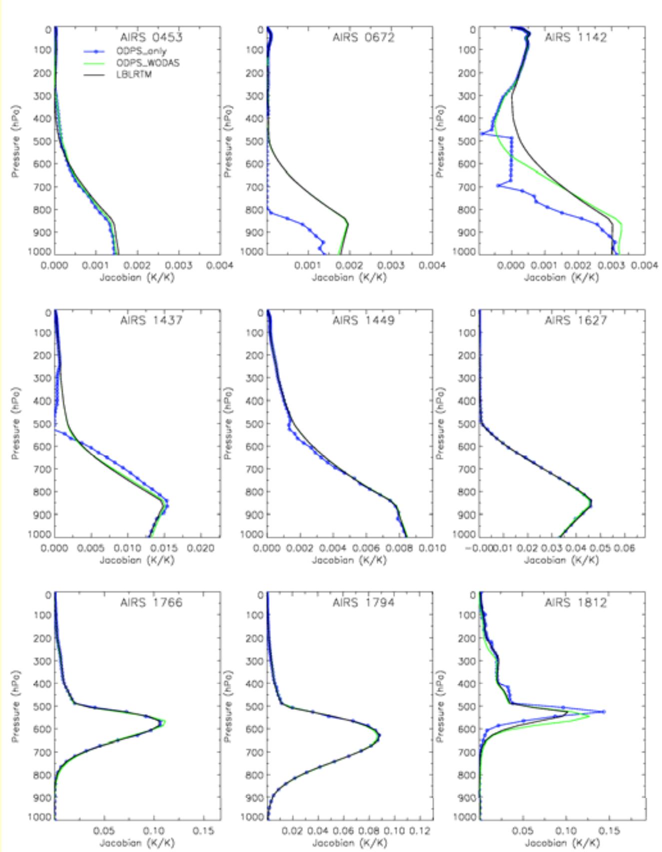
- ODAS (Optical depth in absorber space) – OPTRAN
  - Optical depth computed in the coordinates of integrated absorber amount
  - Variable gases: H2O and O3
- ODPS (Optical Depth in Pressure Space)
  - Optical depth computed in pressure coordinates
  - Variable absorbing gases: H2O, CO2, O3, CO, N2O and CH4
  - Water vapor line computed using ODAS (optional)



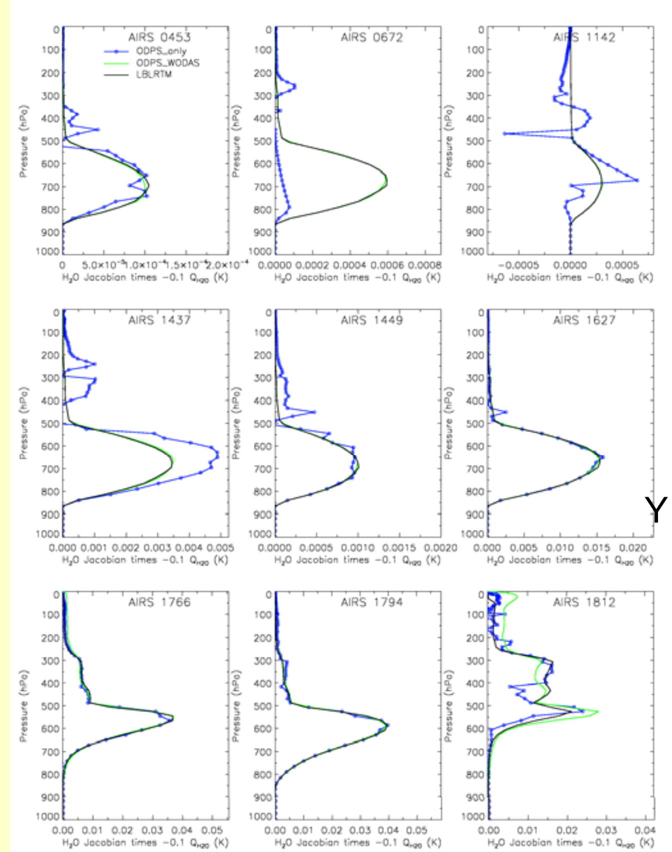

**CRTM simulated brightness temperature spectra for hyper-spectral infrared sensors IASI (black), AIRS (red) and CrIS (blue).**

# General transmittance models (2)

- In the ODPS model, the ODAS algorithm can be optionally used to compute water vapor line transmittances since it can provide better forward results and Jacobians for many IR channels.
- Preliminary results have indicated that this synergy of ODPS and ODAS has a positive NWP impact in comparison to using ODPS alone.




**Temperature Jacobians**




**Water vapor Jacobians**

ODPS only

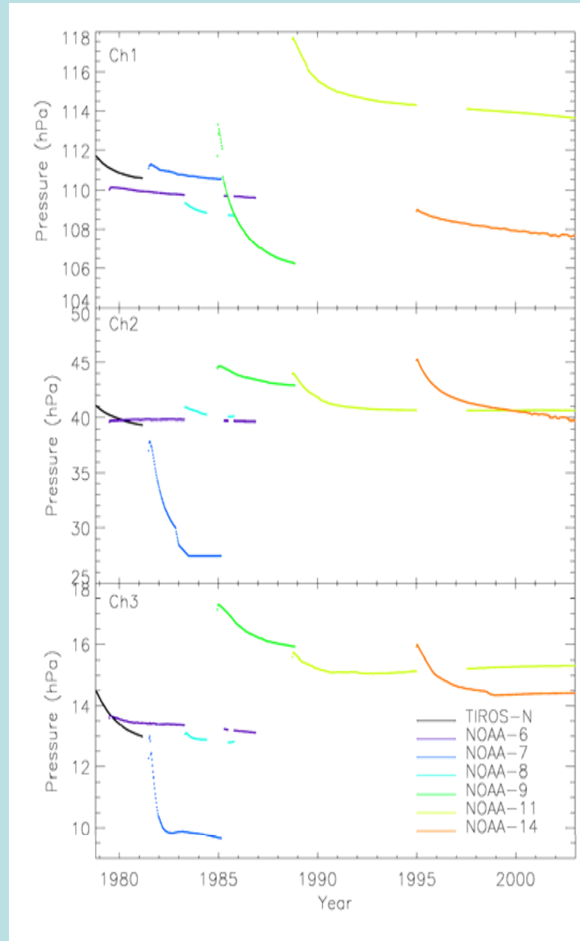
ODPS+ODAS

Line-by-line (LBLRTM)

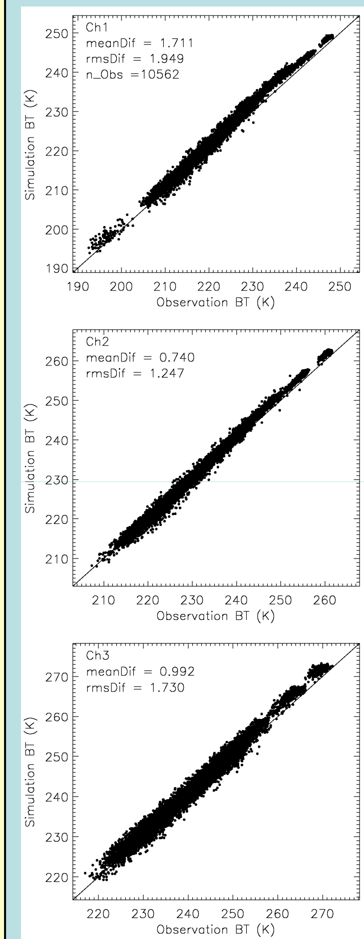
Y. Chen et. al. JGR, 2010

# Fast Transmittance Model for Stratospheric Sounding Unit (SSU)

- The SSU channel spectral response function (SRF) is a combination of the instrument filter function and the transmittance of a CO2 cell.
- The SRF varies due to the cell CO2 leaking problem.
- CRTM-v2 includes schemes to take the SRF variations into account (Liu and Weng, 2009; Y. Chen et al. 2010)
- $CO_2$ and $O_3$ are variables gases



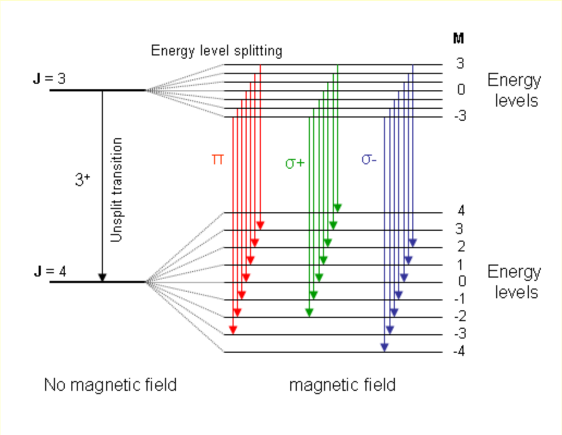

**CO2 cell pressure variations, which causes SSU SRF variations.**




**CRTM simulations compared with SSU observations for SSU noaa-14.**

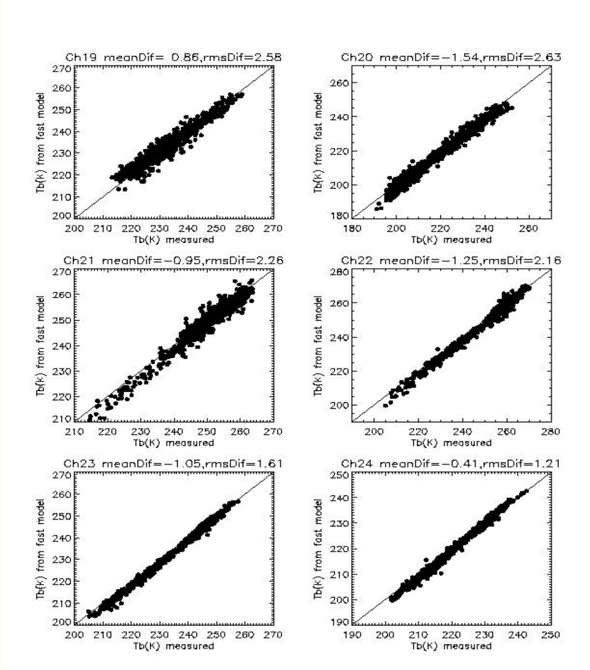
# Fast Transmittance Model for SSMIS Upper Atmospheric Sounding (UAS) Channels

- Zeeman-splitting can have an effect up to 10 K on SSMIS UAS channels.
- The Doppler shift from Earth-rotation can have an effect up to 2 K on SSMIS UAS channels.
- The fast transmittance model is implemented to take both effects into account (Han et al., JGR 2007; Han et al., JGR 2010).




**Zeeman effect:**

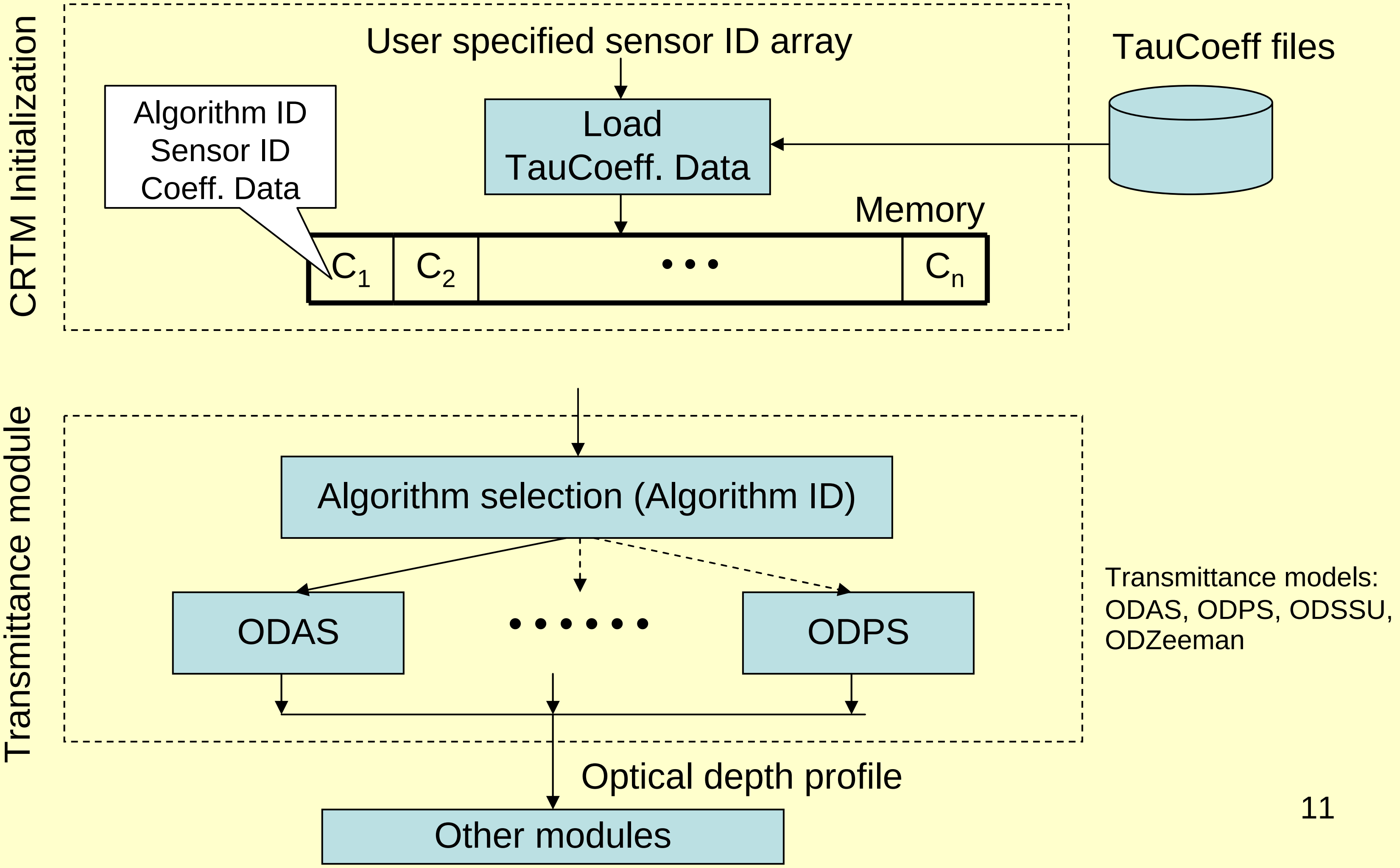
**The O2 transition lines are split into many sublines and the radiation is polarized.**




**CRTM simulations compared to observations (SSMIS f16).**

# Multiple Transmittance Algorithm Framework

The multiple transmittance algorithm framework is implemented in CRTM-v2 to allow multiple transmittance algorithms to coexist

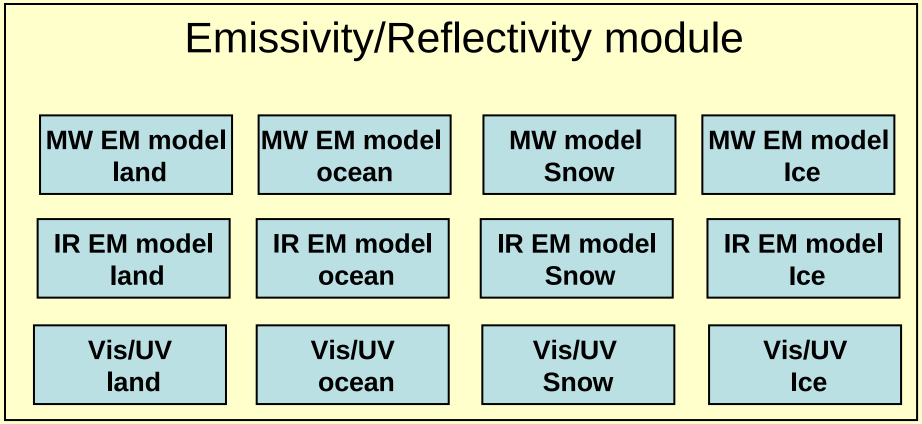


# CRTM Surface Emissivity/Reflectivity Module

- Ocean
  - **Infrared**
    - **Wu-Smith (1996, appl. Opt.) emissivity look-up table (LUT) for a rough surface.**
    - **N. Nalli Quasi-specular emissivity LUT for a rough surface (2008, appl. Opt.)**
    - **BRDF model for direct Sun reflection (Breon, 1993, Remote Sens. Environ)**
  - **Microwave**
    - **FASTEM – 1 (English and Hewison, 1998, Pro. SPIE) (> 20 GHz)**
    - **M. Kazumori ocean emissivity model (2008, Mon. Wea. Rev.) (< 20 GHZ)**
  - **Vis/UV**
    - **Emissivity LUT for various surface types (Carter et al. 2002)**

- Land
  - **Infrared & Vis/UV: LUT**
  - **Microwave: NESDIS Microwave Land Emission Model (LandEM) (Weng et al. 2001, Geophys Res.)**

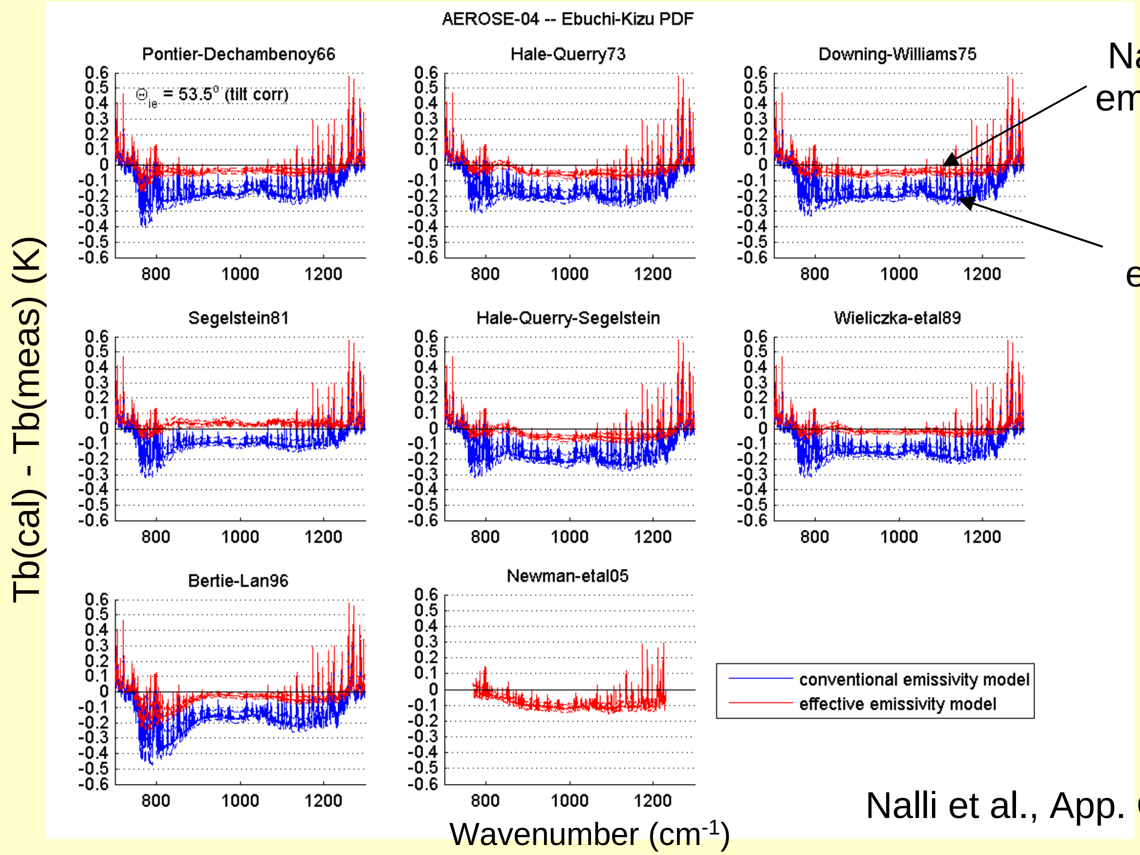
- Snow & Ice
  - **Infrared & Vis/UV: LUT**
  - **Microwave**
    - **LandEM**
    - **Empirical models (Yan et al. 2004, 8th MicroRad, JGR 2008)**




The CRTM surface emissivity module is split into sub-modules for different surface types and frequency regions.

# IR Sea Surface Emission Model (IRSSE)

- Two IRSSE models implemented based on the two physical models:
  - **Wu-Smith model** – derived from the facet geometric optics theory; Cox-Munk PDF; conventional approach treats only emitted component of surface-leaving radiance.
  - **Nalli model** - derived from the facet geometric optics theory; Cox-Munk/Ebuchi-Kizu PDF; use of effective wave facet emission angles to adjust emissivity for a quasi-specular sea surface; treats both emitted and reflected components of surface-leaving radiance.



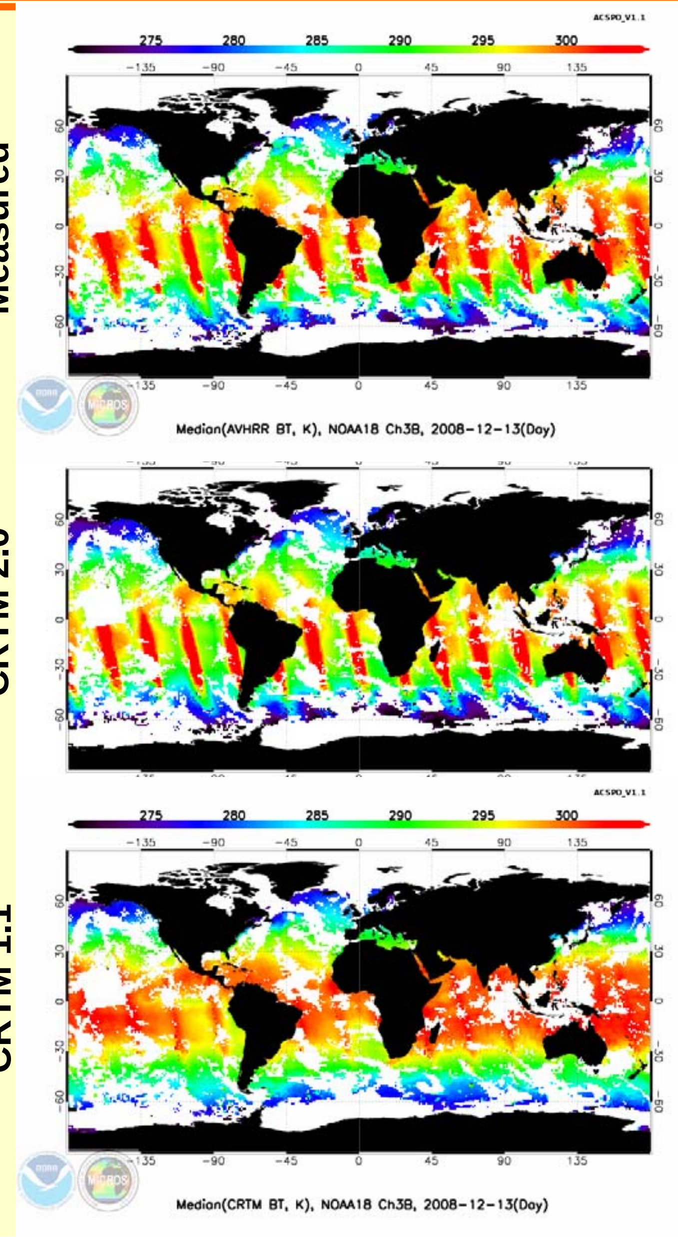

Nalli's "effective emissivity" model

"Conventional" emissivity model

Nalli et al., App. Opt., 2008

# BRDF for solar reflection over sea surface

- The bi-directional reflectance distribution function (BRDF) (Breon, 1993) is implemented in CRTM-v2 for solar refection over ocean surface.
- Up to 20 K improvement has been observed in the sun glint areas, compared to CRTM 1.1 which assumes a Lambertian reflection.




Measured

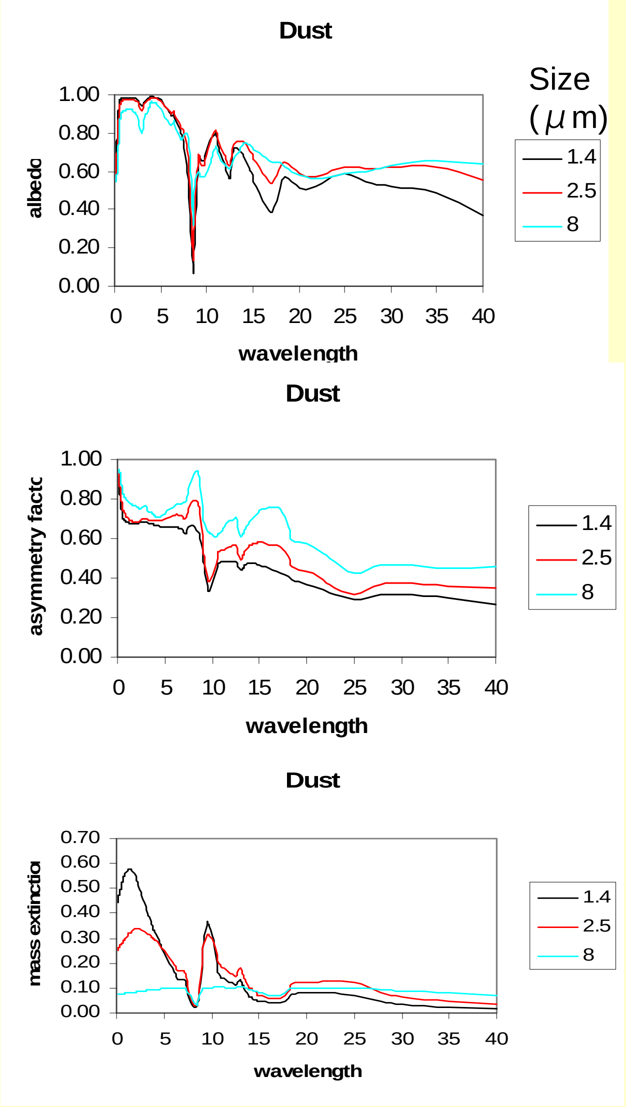
CRTM 2.0

CRTM 1.1

AVHRR ch3 BT

# Cloud/Aerosol Absorption/Scattering Modules

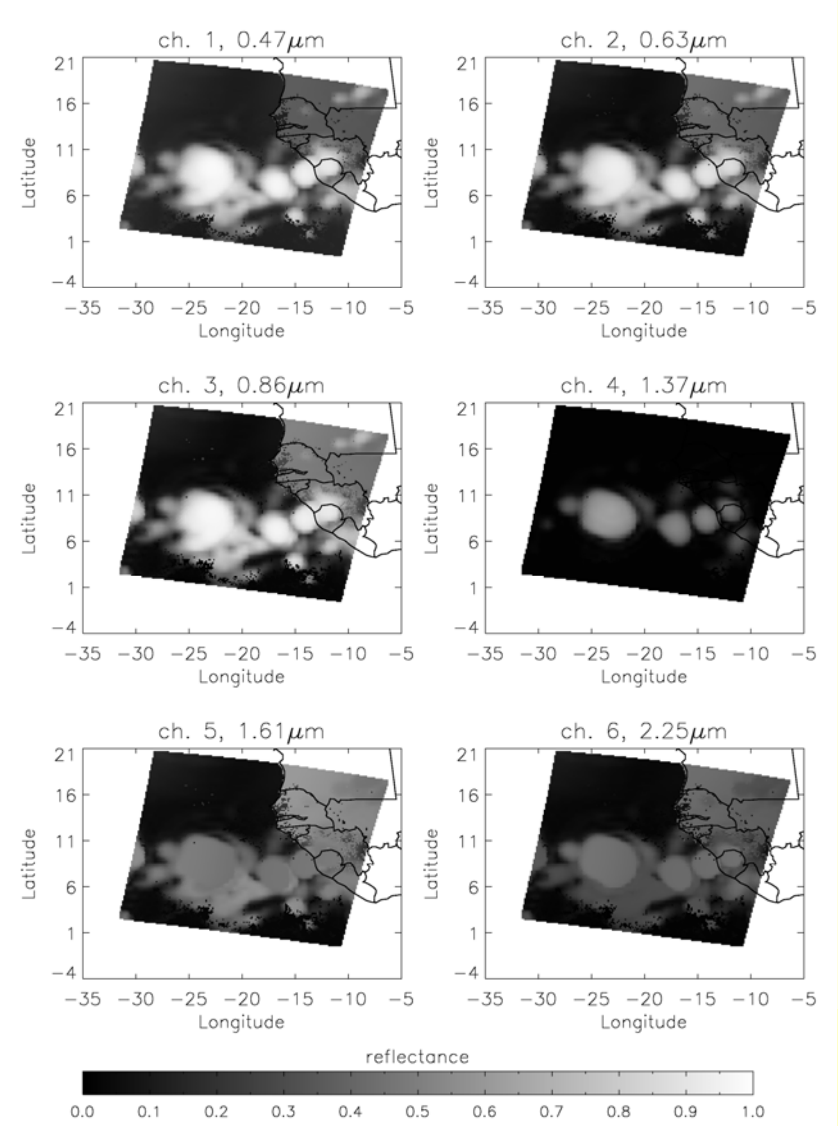
- Six cloud types: water, ice, rain, snow, graupel and hail
- Five aerosol types: Dust, Sea Salt, Organic carbon, Black carbon, Sulfate.
- Optical parameter Lookup table for spherical water, non-spherical ice cloud and aerosol particles: mass extinction coefficient, single scattering albedo, asymmetric factor and Legendre phase coefficients. (Liu and Weng, 2006, JAS)




Dust optical parameters

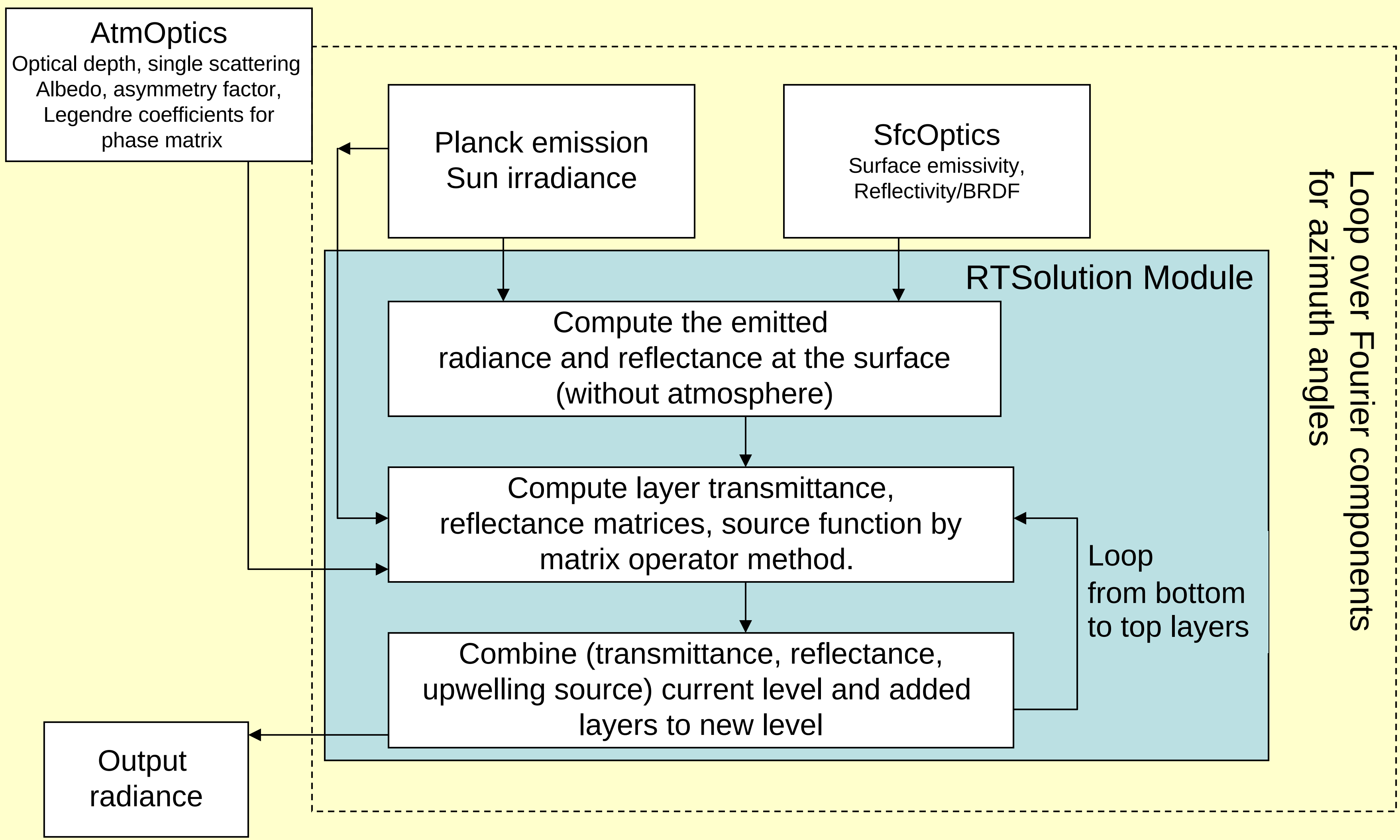
# Components for Visible/UV sensors

- MoleculeScatter module (new): compute molecule scattering optical properties
- Extension of AtmAbsorption module: compute molecule absorption for Vis/UV sensors
- Extension of CloudScatter and AerosolScatter modules: compute cloud and aerosol optical properties for Vis/UV sensors
- Extension of the Advanced Doubling-Adding (ADA) method: integrate the RT solution over Fourier components for azimuth angle




GOES-R ABI simulations with MODIS terra geometry parameters, GDAS data and GOCART aerosol data.

# RT solution for cloud/aerosol/molecule scattering environment: Advanced Doubling-Adding Method with a matrix operator method




Liu and Weng, 2006, JAS; Liu 2010

# CRTM-v2 software

ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM/

- Source code
- Coefficients files
- User guide
- Example programs

**Support more than 100 Sensors**

**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; Aqua AIRS, AMSR-E, AMSU-A, HSB**
**METEOSAT-SG1 SEVIRI**
**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**
**GOES-R ABI; NPP CrIS/ATMS**

# Ongoing and future work

- FASTEM-4 implementation in CRTM-v2.1 (due June, 2010)
- SOI implementation in CRTM-v2.1 (due June, 2010)
- Fast NLTE algorithm for hyper-spectral sensors (due September, 2010)
- UW emissivity database impact test (due June, 2010)
- GrELS (Greenness-adjusted Emissivity for Land Surface ) impact test (due June, 2010)
- Visible/UV surface BRDF models (due September, 2010)

# Summary

- CRTM has been upgraded to version 2.0 and is available from the CRTM website.
- CRTM v2.0 is a fast and accurate model to compute satellite radiance and radiance derivatives for IR, MW and Visible/UV sensors.
- CRTM v2.0 includes components for Visible/UV sensors, new and improved transmittance and surface emissivity/reflectivity models and improved computational efficiency.
- The JCSDA CRTM team will continue to collaborate with JCSDA partners to improve and extend the model for satellite radiance data applications.