National Environmental Satellite, Data, and Information Service

Advances in Radiative Transfer Modeling in Support of Satellite Data Assimilation

Fuzhong Weng

Sensor Physics Branch

Satellite Meteorology and Climatology Division

Office for Satellite Research and Applications

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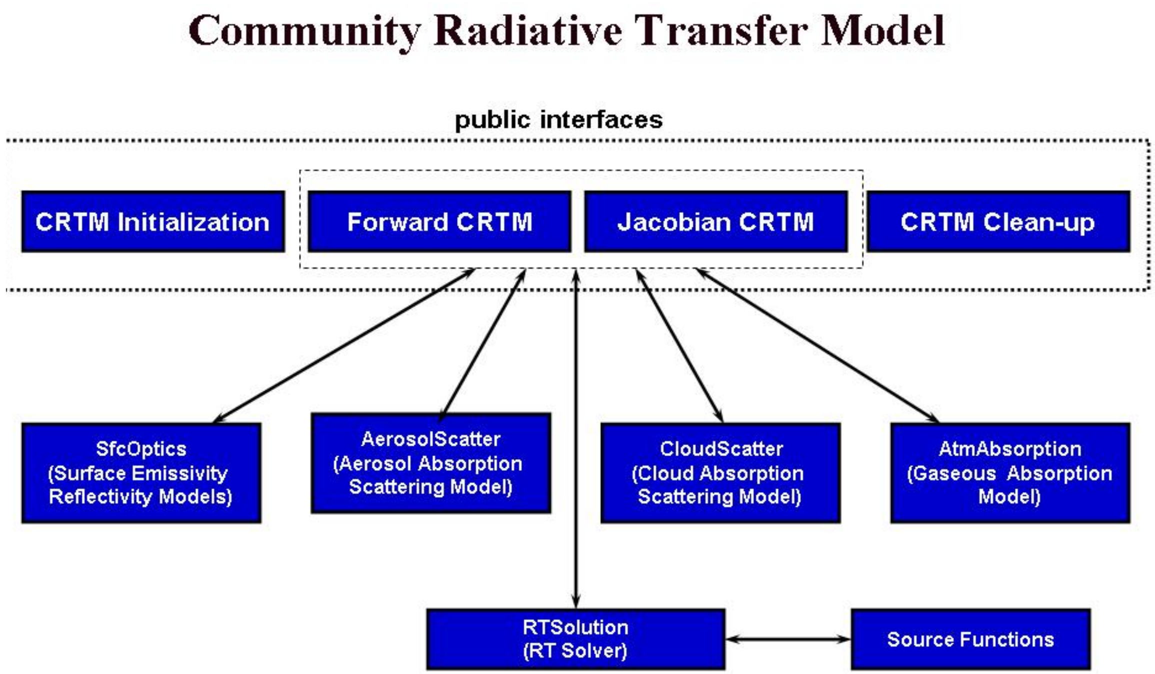
CRTM Capability

Supported Instruments

- TIROS-N to NOAA-18 AVHRR
- TIROS-N to NOAA-18 HIRS
- GOES-8 to 13 Imager channels
- GOES-8 to 13 sounder channel 08-13
- GOES-R ABI
- 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



Significance: CRTM framework is designed to accelerate transition of new radiative transfer science for assimilation of operational and research satellite data in NWP models and to improve the retrieval technology in satellite remote sensing system

Community Contributions

- Community Research: Radiative transfer science
  - UWisc – Successive Order of Iteration
  - University of Colorado –DOTLRT
  - UCLA – Delta 4 stream vector radiative transfer model
  - Princeton Univ – snow emissivity model improvement
  - NESDIS – Advanced doubling and adding scheme, surface emissivity models, LUT for aerosols, clouds, precip
  - AER – Optimal Spectral Sampling (OSS) Method
  - UMBC – SARTA
- Core team (ORA/EMC): Smooth transition from research to operation
  - Maintenance of CRTM
  - CRTM interface
  - Benchmark tests for model selection
  - Integration of new science into CRTM

Fast Radiative Transfer Schemes

- **Advanced doubling and adding (baseline scheme)**
- **Delta 4 streams vector radiative transfer model**
- **Discrete ordinate tangent linear riadiative transfer**
- **Successive order of iteration (*also see the presentation by Benartz: 11.10*)**

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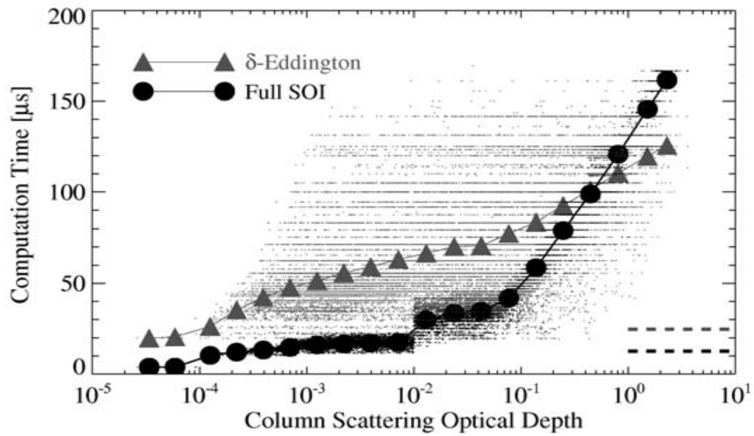
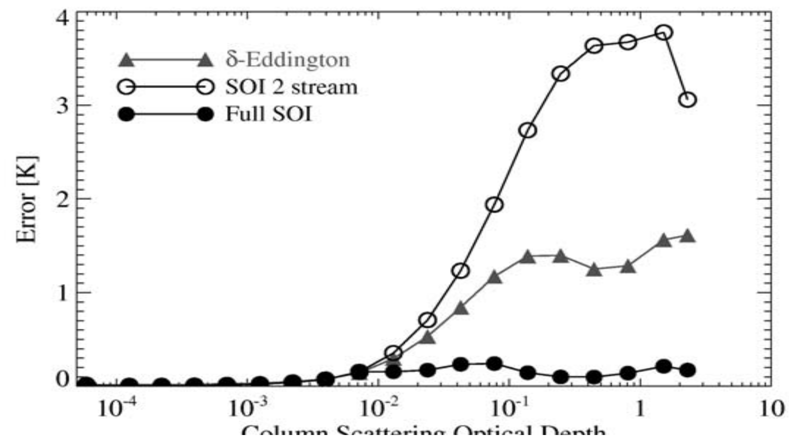
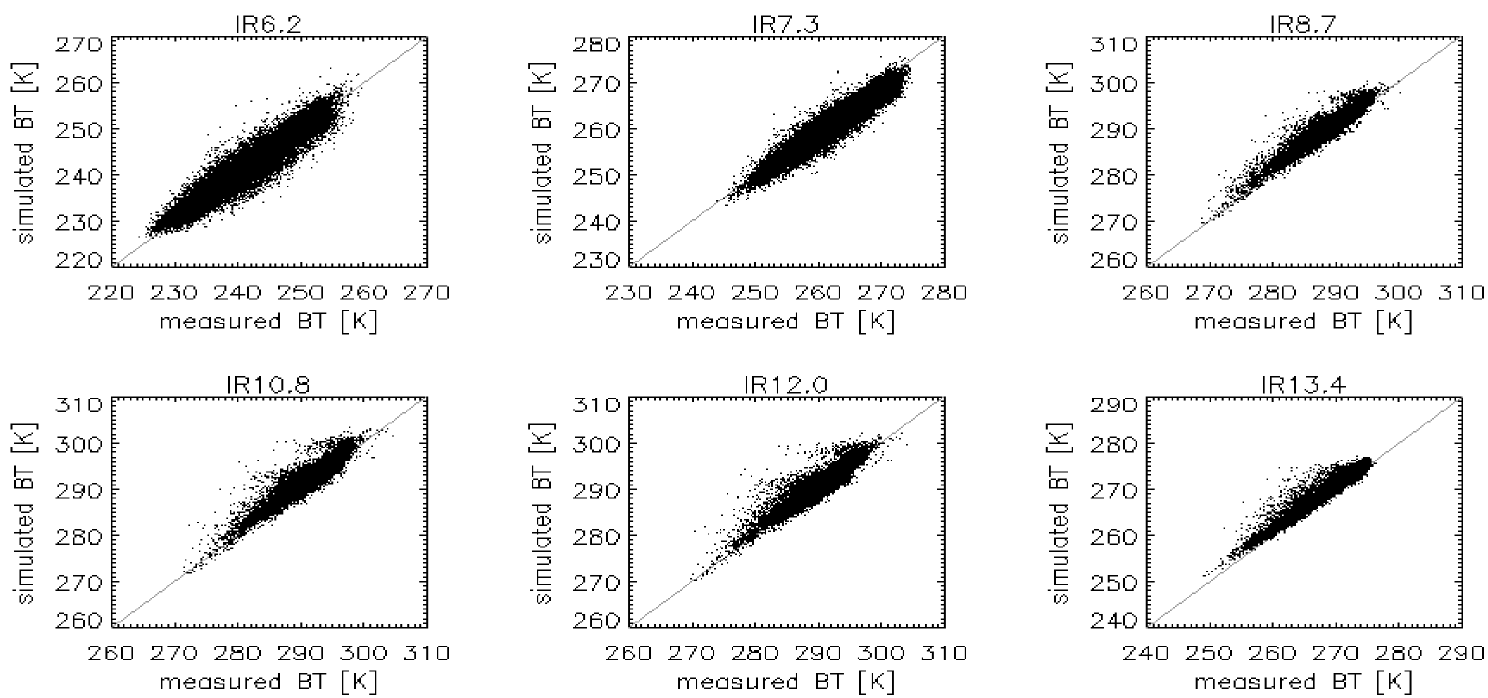
Radiative Transfer Scheme: Successive Order of Iteration





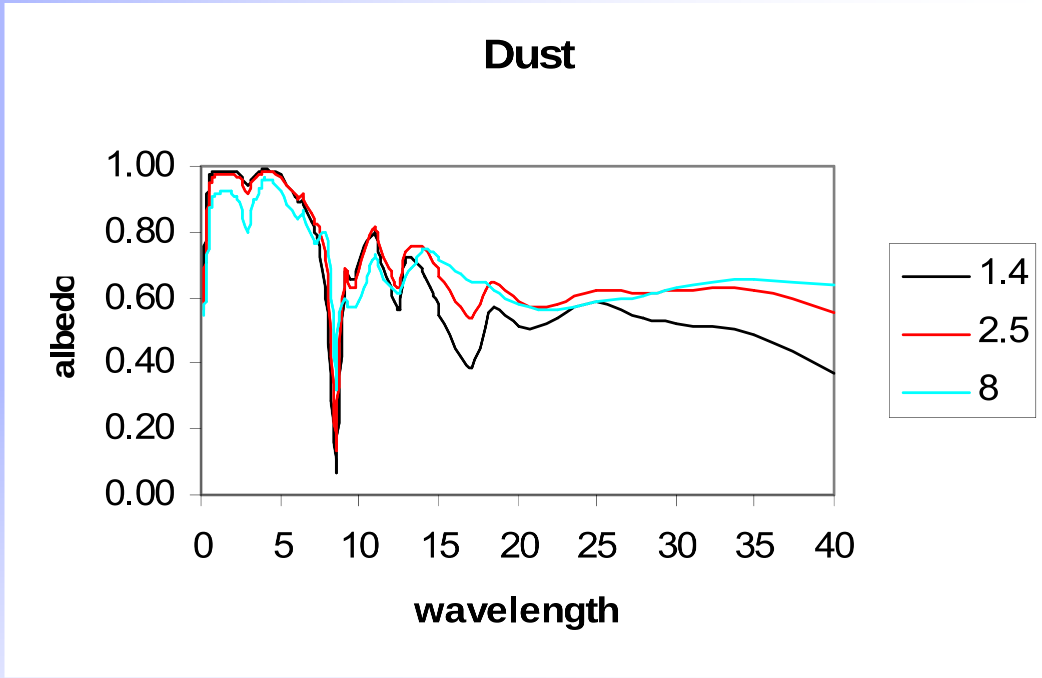


MSG SEVIRI

Bennartz et al., 2005

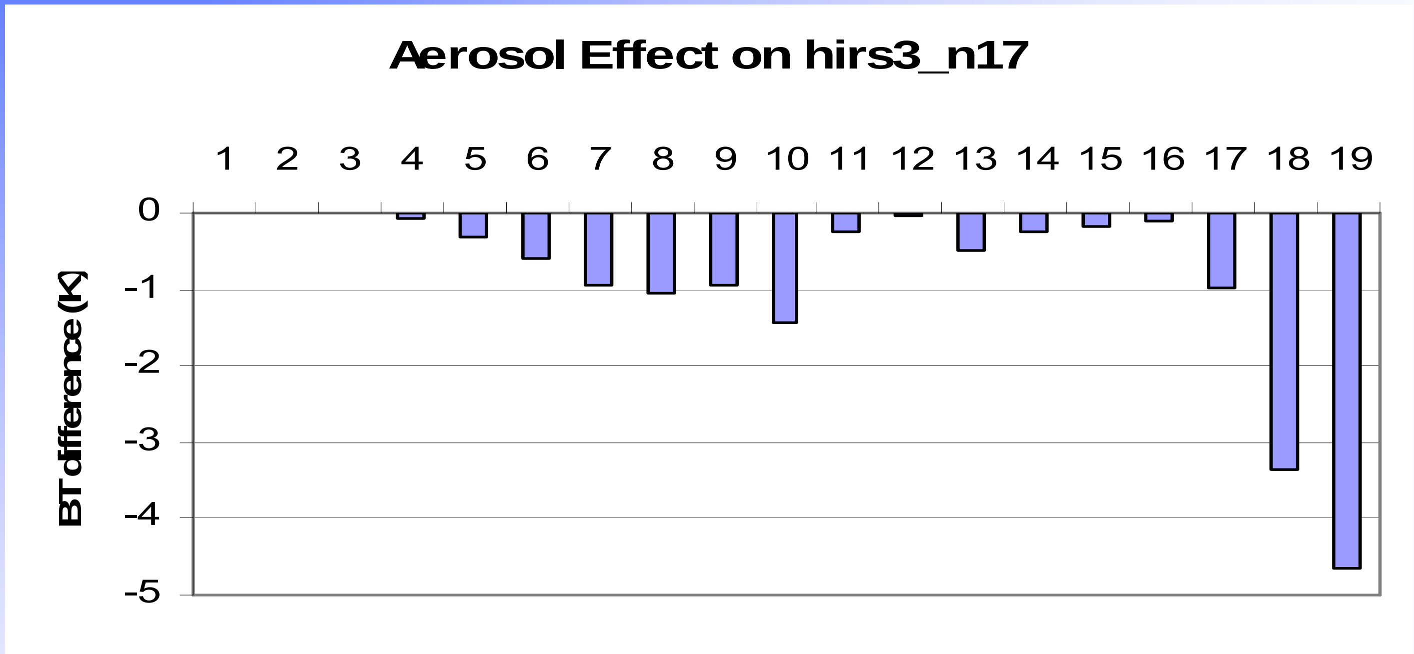
Aerosols Scattering Model

1. **Sulfur: DMS (Dimethyl sulfide), SO2, SO4, MSA (methanesulfonate)**
2. **Carbon: Hydrophobic BC/OC, hydrophilic BC/OC (water-like)**
3. **Dust: 8 bins: 0.1-0.18, 0.18-0.3, 0.3-0.6, 0.6-1, 1.0-1.8, 1.8-3.0, 3.0-6.0, 6.0-10.0 µm**
4. **Sea-salt: 4 bins: 0.1-0.5, 0.5-1.5, 1.5-5.0, 5.-10. µm**



Significance: The Goddard Chemistry Aerosol Radiation and Transport (GOCART) model simulates major tropospheric aerosol components, including sulfate, dust, black carbon (BC), organic carbon (OC), and sea-salt aerosols. It is also used by NOAA in its air quality forecast system. The same GOCART aerosol physics implemented into CRTM will attract more users for air quality data assimilation

Aerosol Effect on NOAA-17 HIRS/3 h

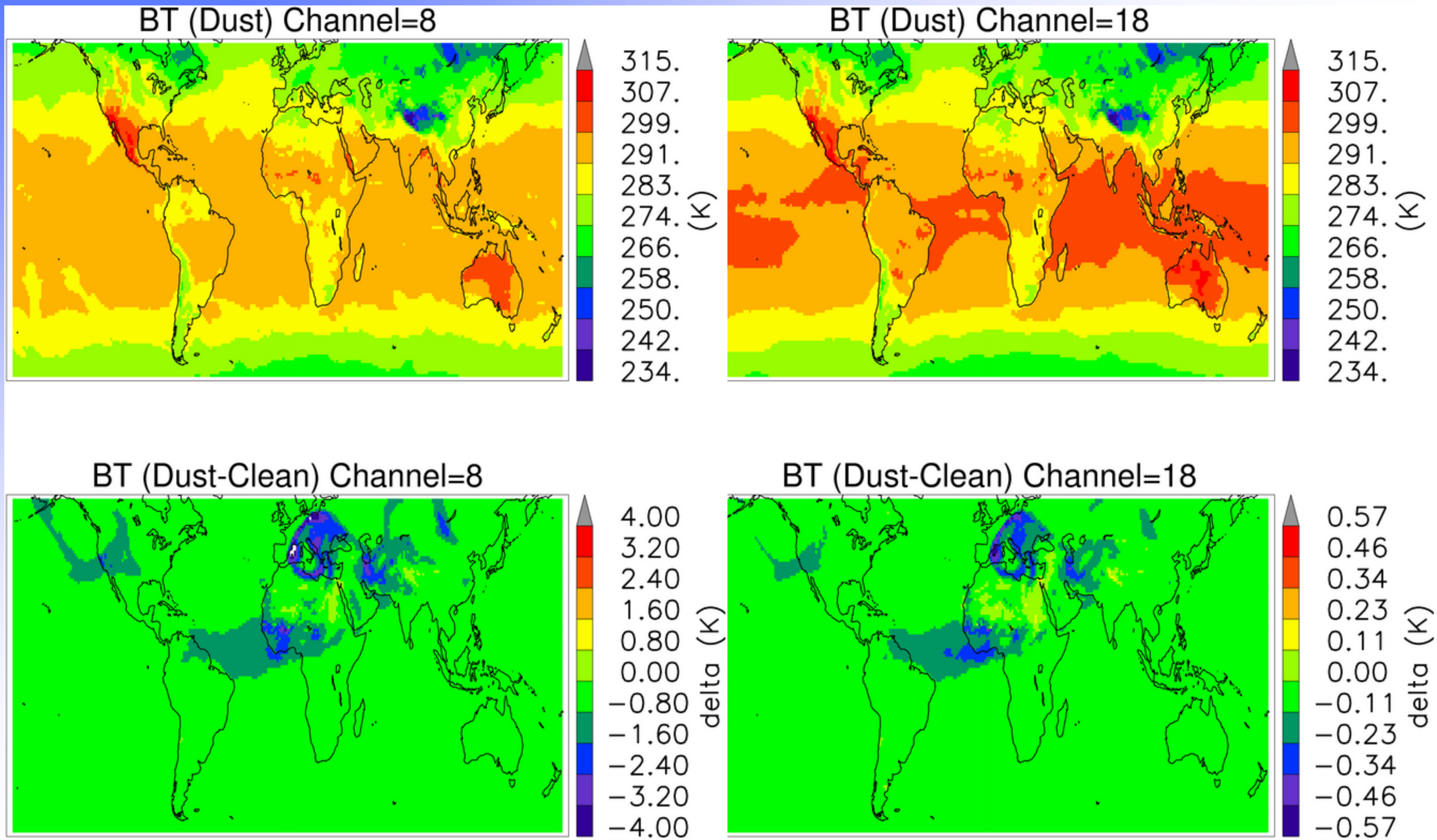


0.1 g/m^2 OC aerosol at layer 63 (300 hPa)

0.1 g/m^2 Dust aerosol at layer 80 (592 hPa)

0.1 g/m^2 Dust aerosol at layer 82 (639 hPa)

Aerosol Effects on HIRS Channels



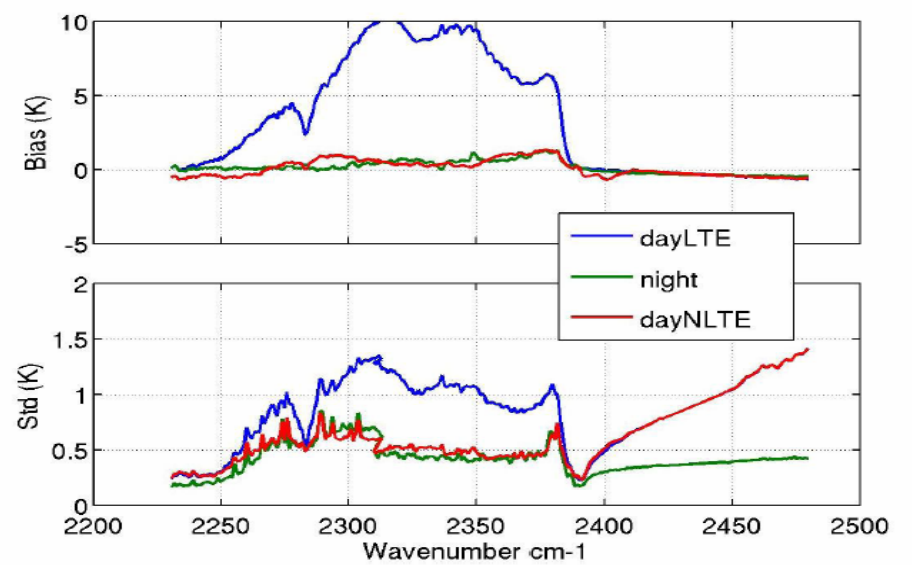
Weaver, 2005, UMBC

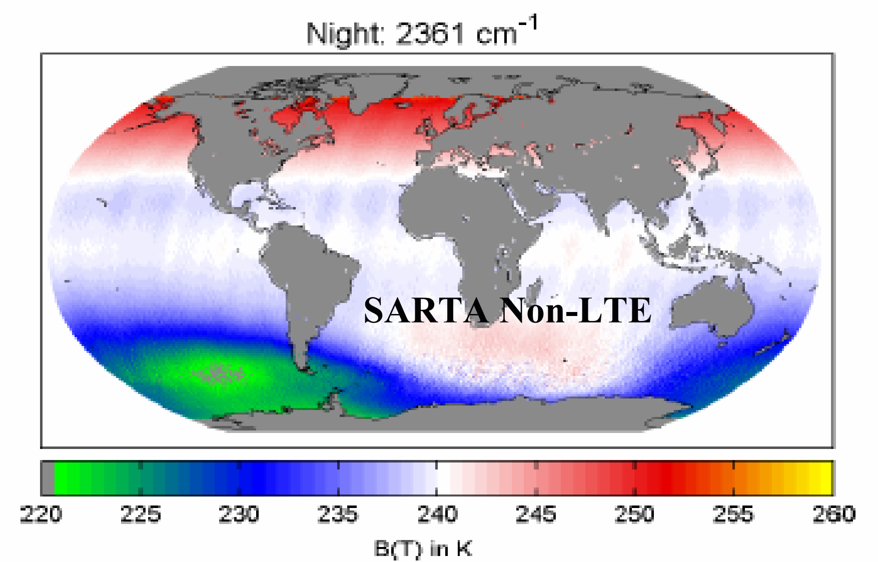
Gas Absorption Models

- **OPTRAN upgrades for new instruments (baseline version)**
- **Optimal spectrum sampling for more instruments (** ***also see the presentation by Han et al: B21)***
- **Stand-alone AIRS radiative transfer approximation**
- **Fast parameterization of Zeeman effect (*****also see the presentation by Han: 1.6)***

Stand-alone AIRS Radiative Transfer Approximation (SARTA) now in A CRTM

1. SARTA is a forward model developed by University Maryland at Baltimore County (UMBC).
2. A fast gas absorption model fitted with AIRS observations with the best accuracy comparing with all other fast models in the IR wavelengths, with about 0.2 K accuracy in mid- to lower-tropospheric temperature and water vapor sounding channels.
3. The model allows the user to vary mixing ratios of H20, O3, CH4, and CO. It also includes minor gas mixing ratios of CO2, SO2, HNO3 and N2O.
4. Non-LTE is incorporated .





Significance: In CRTM framework, the original SARTA program is re-coded to meet the CRTM standard. In addition, the SARTA tangent-linear and adjoint models have been also completed. This implementation for the forward and Jacobian computation is very useful for operational applications and for the consistency between forward and adjoint calculations in satellite data assimilation.

Zeeman Effects in CRTM

Energy level splitting:

In the presence of an external magnetic field, each energy level associated with the total angular momentum quantum number J is split into 2J+1 levels corresponding to the azimuthal quantum number M = -J, …, 0, …,J

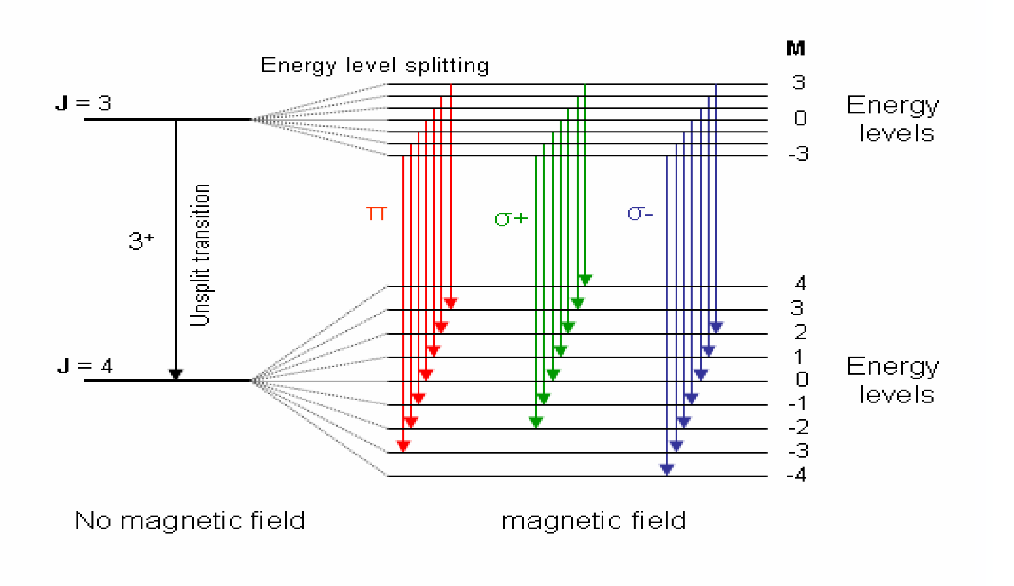
Transition lines (Zeeman components) :

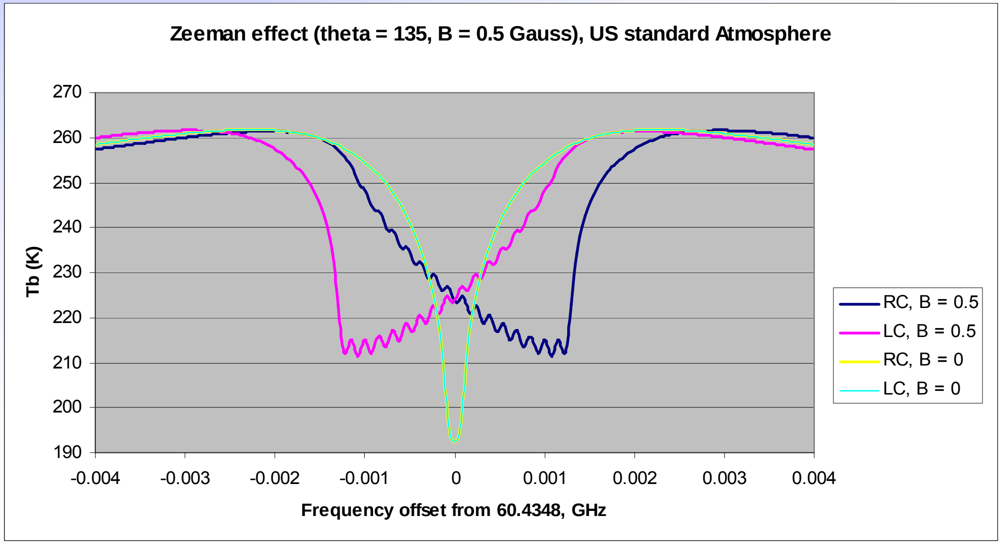
The selection rules permit transitions with $\Delta J = \pm 1$ and $\Delta M = 0, \pm 1$. For a change in J (i.e. J=3 to J=4, represented by 3^+), transitions with

- $\Delta M = 0$ are called π components,
- $\Delta M = 1$ are called σ+ components and
- $\Delta M = -1$ are called σ- components.

Polarization:

The three groups of Zeeman components also exhibit polarization effects with different characteristics. Radiation from these components received by a circularly polarized radiometer such as the SSMIS upper-air channels is a function of the magnetic field strength |**B**|, the angle θ_B between **B** and the wave propagation direction **k** as well as the state of atmosphere, not dependent on the azimuthal angle of **k** relative to **B**.





Fast Zeeman Absorption Model

(1) Atmosphere is vertically divided into N fixed pressure layers from 0.000076 mb (about 110km) to 200 mb. (currently N=100, each layer about 1km thick).

(2) The Earth's magnetic field is assumed constant vertically

(3) For each layer, the following regression is applied to derive channel optical depth with a left-circular polarization:

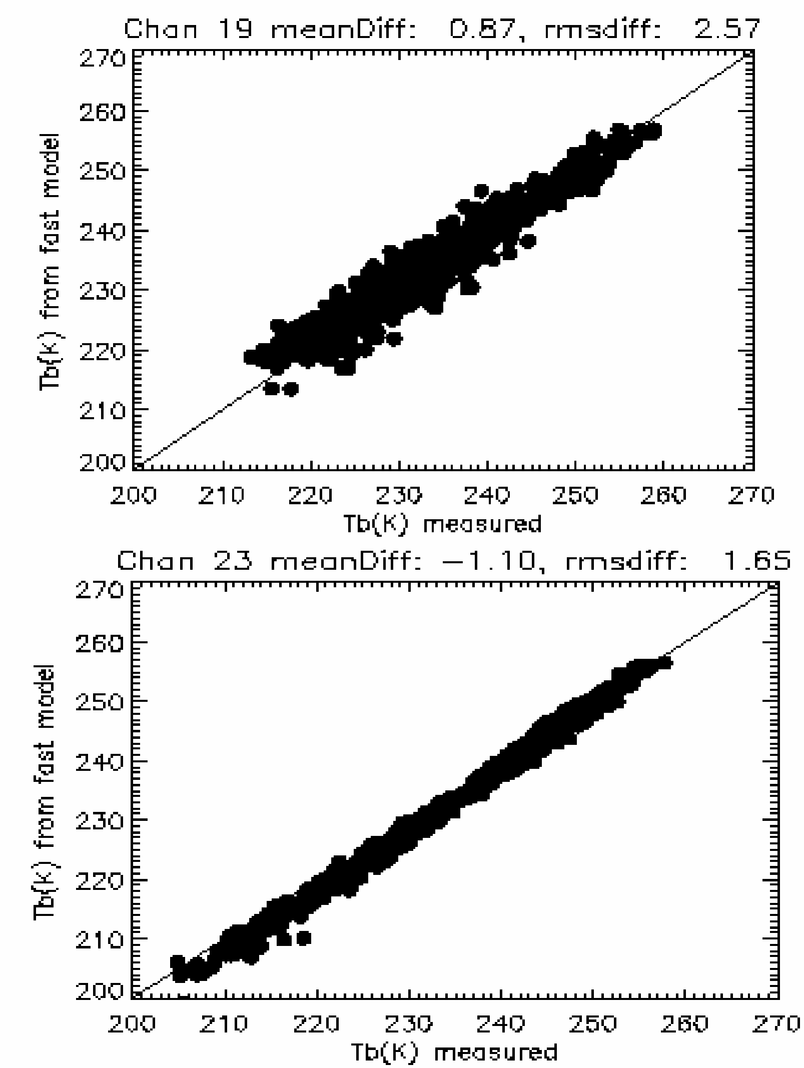
$$T_{b,lc} = \sum_{i=1}^{n} (\tau_{i-1} - \tau_i) T_{air,i}$$

$$\tau_i = \tau_{i-1} \exp(-OD_{lc,i} / COS(\theta)), \quad \tau_0 = 1$$

$$OD_{lc,i} = c_{i,0} + \sum_{j=1}^{m} c_{i,j} x_{i,j}$$

ψ – 300/T; T – temperature
B – Earth magnetic field strength
θ_B – angle between magnetic field and propagation direction

SSMIS UAS Simulated vs. Observed

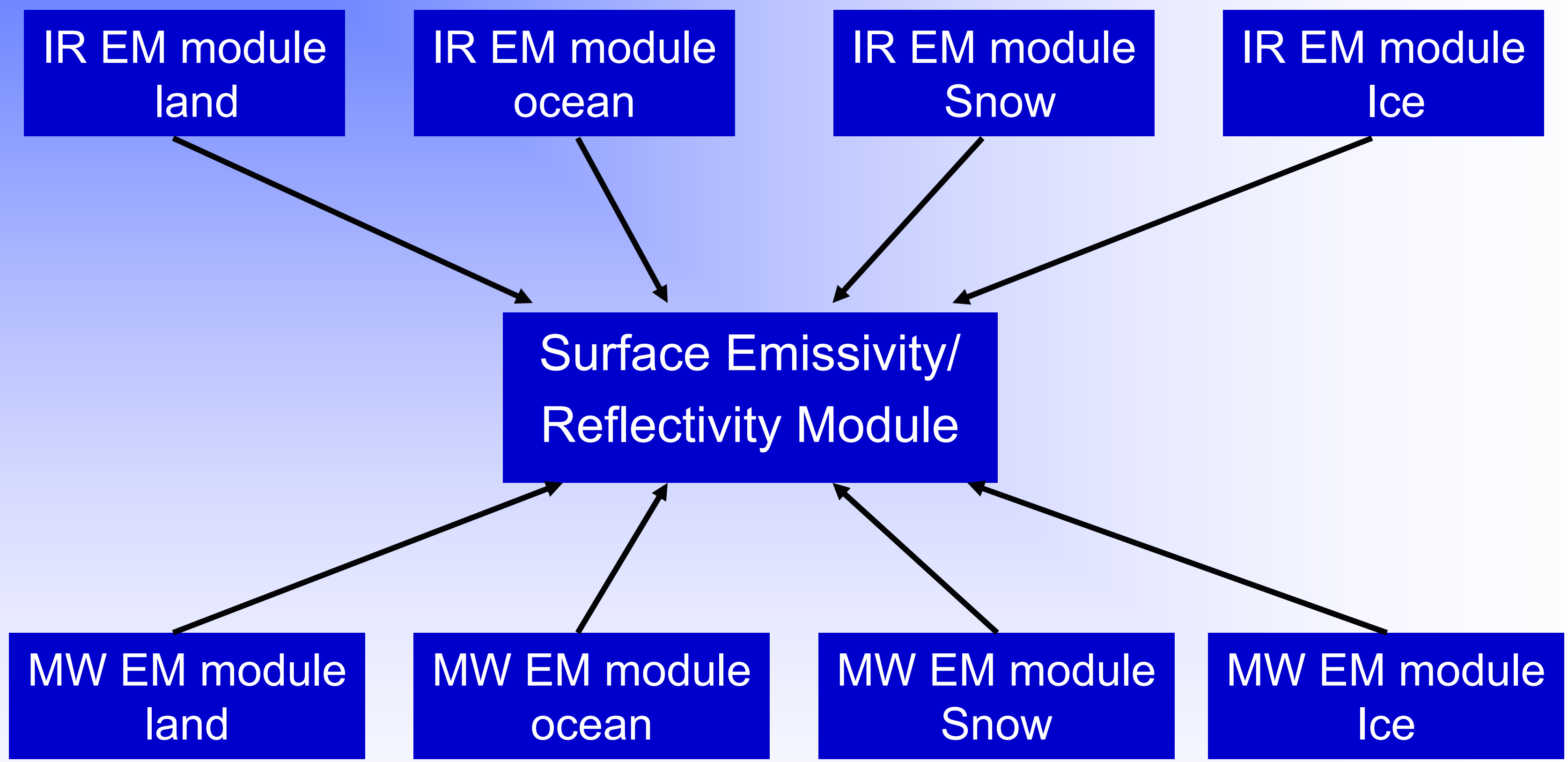


From Han, 2006, 15th ITSC

Surface Emissivity Models

- Upgrade snow and sea ice emissivity for new microwave instruments
- Improve the performance of microwave ocean emissivity model
- Evaluate several advanced snow emissivity models
- Study MW and IR emissivity relationship

Community Surface Emissivity Model



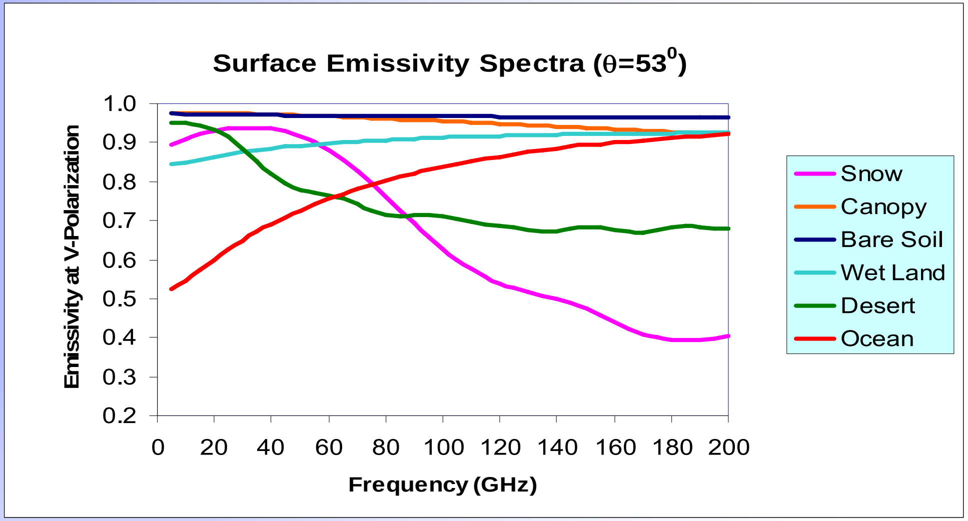
FASTEM-1/3 (English and Hewison, 1998)

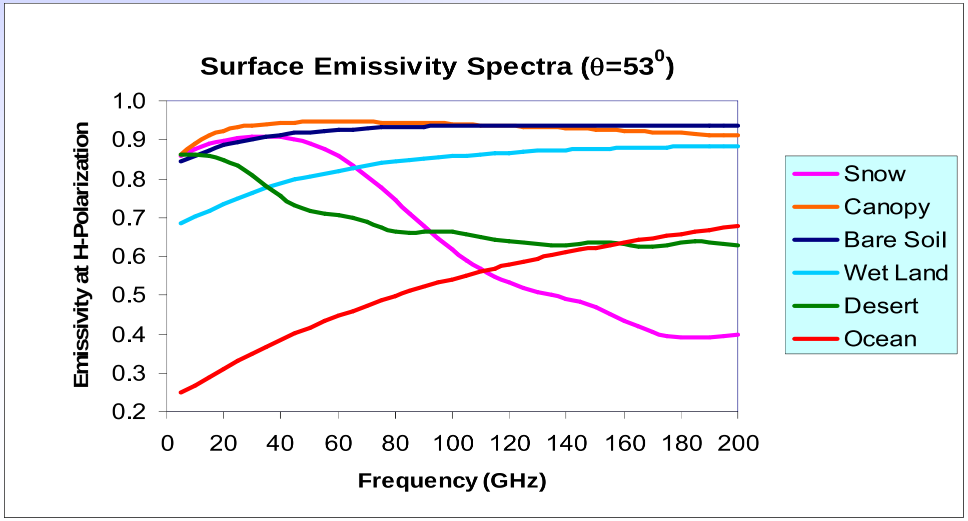
OceanEM (full polarimetric, Weng and Liu, 2003)

Surface Emissivity Modeling

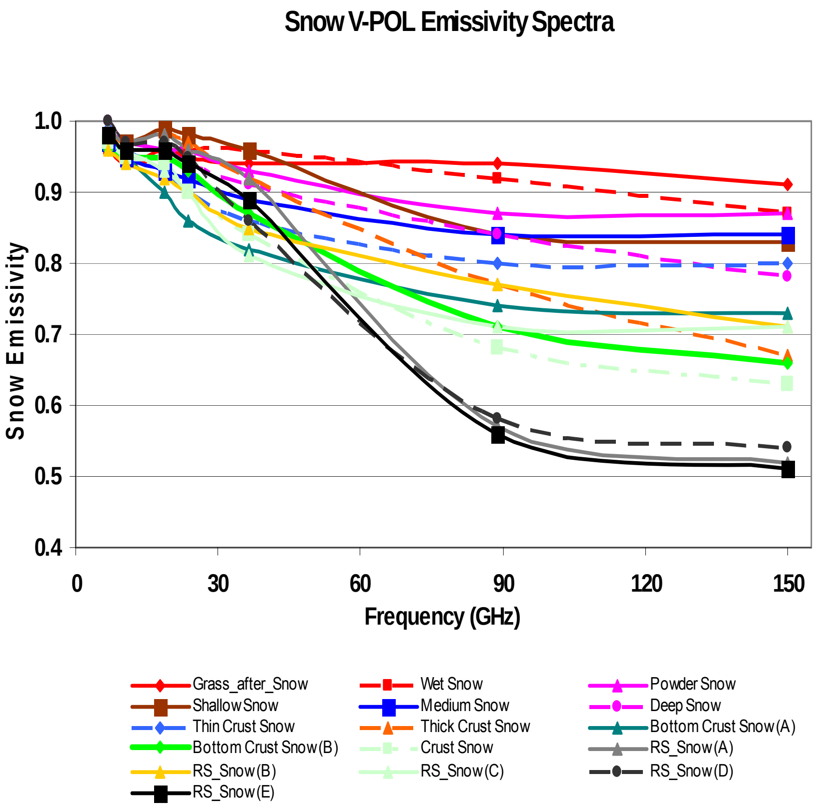
- **Open water** – two-scale roughness theory
- **Sea ice** – Coherent reflection
- **Canopy** – Four layer clustering scattering
- **Bare soil** – Coherent reflection and surface roughness
- **Snow/desert** – Random media

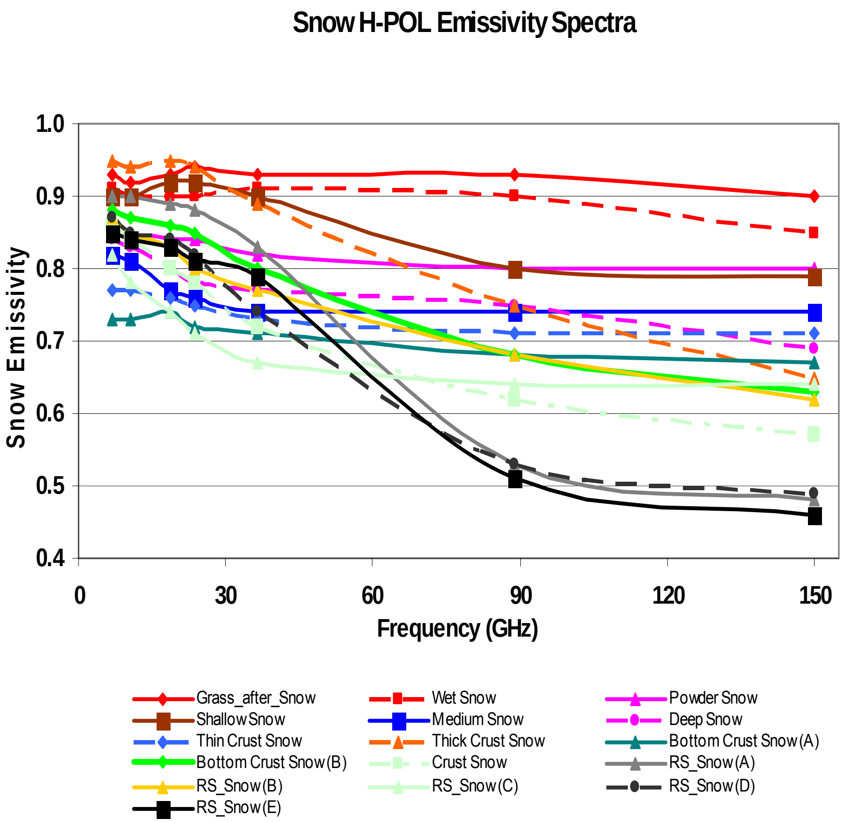
Weng et al (2001, JGR)





Snow Microwave Emissivity Spectra





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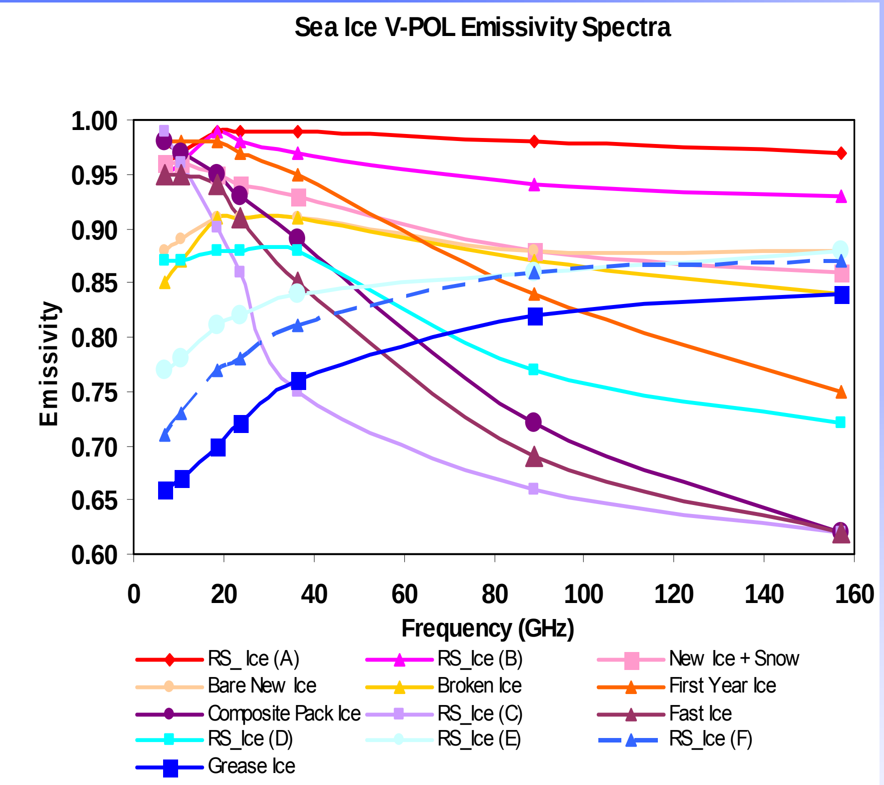
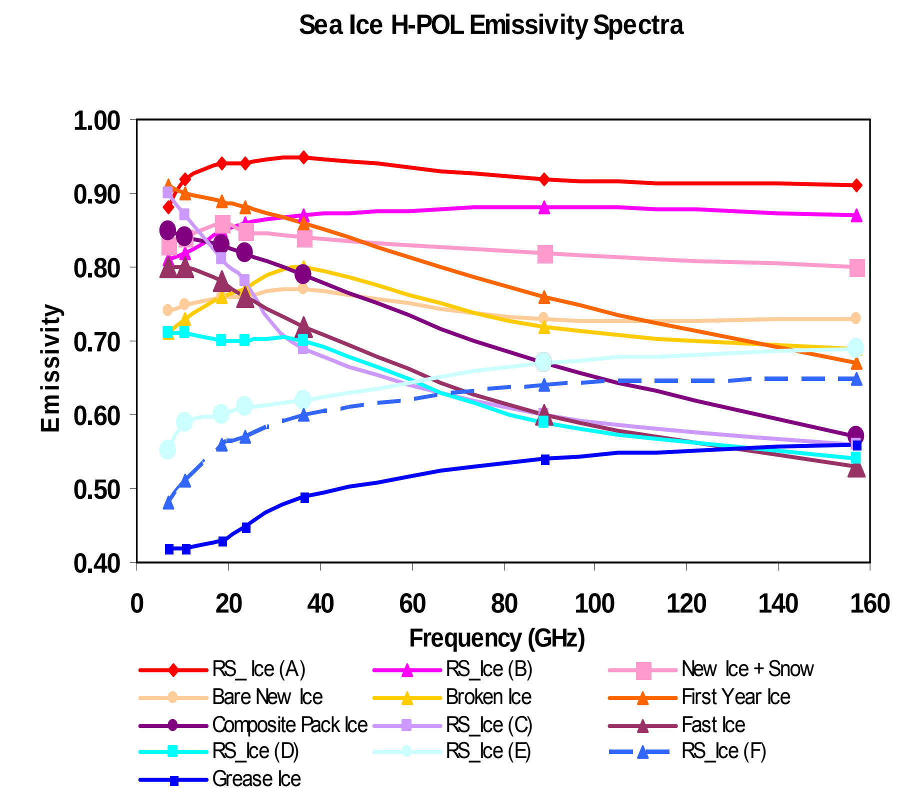
Sea Ice Microwave Emissivity Spectra





Advanced Snow Emissivity Models

All Seasons LSMEM (Drusch et al., 2001, 2004; Gao et al., 2004)

- Calculates microwave emission from a surface partially covered with vegetation and/or snow
- Snow component based on the semi-empirical HUT emission model
- Treats snowpack as a single homogeneous layer
- Dielectric constants of ice and snow calculated from different optional models
- Inputs include snow depth, density, temperature, grain size and ground temperature

DMRT (Tsang et al, 2000)

- Calculates Tb from a densely packed medium
- A quasi-crystalline approximation is used to calculate absorption characteristics with particles allowed to form clusters
- The distorted Born approximation is used to calculate the scattering coefficients
- Inputs include snow depth, snow temperature, fractional volume and grain size

MEMLS (Matzler, 1998)

- Calculates Tb from a multi-layer snow medium
- The absorption coefficient is derived from snow density, frequency and temperature
- The scattering depens on snow density, frequency and correlation length
- Inputs include snow depth, temperature,density, ground temperature and correlation length
- So far successfully validated only for dry snow conditions

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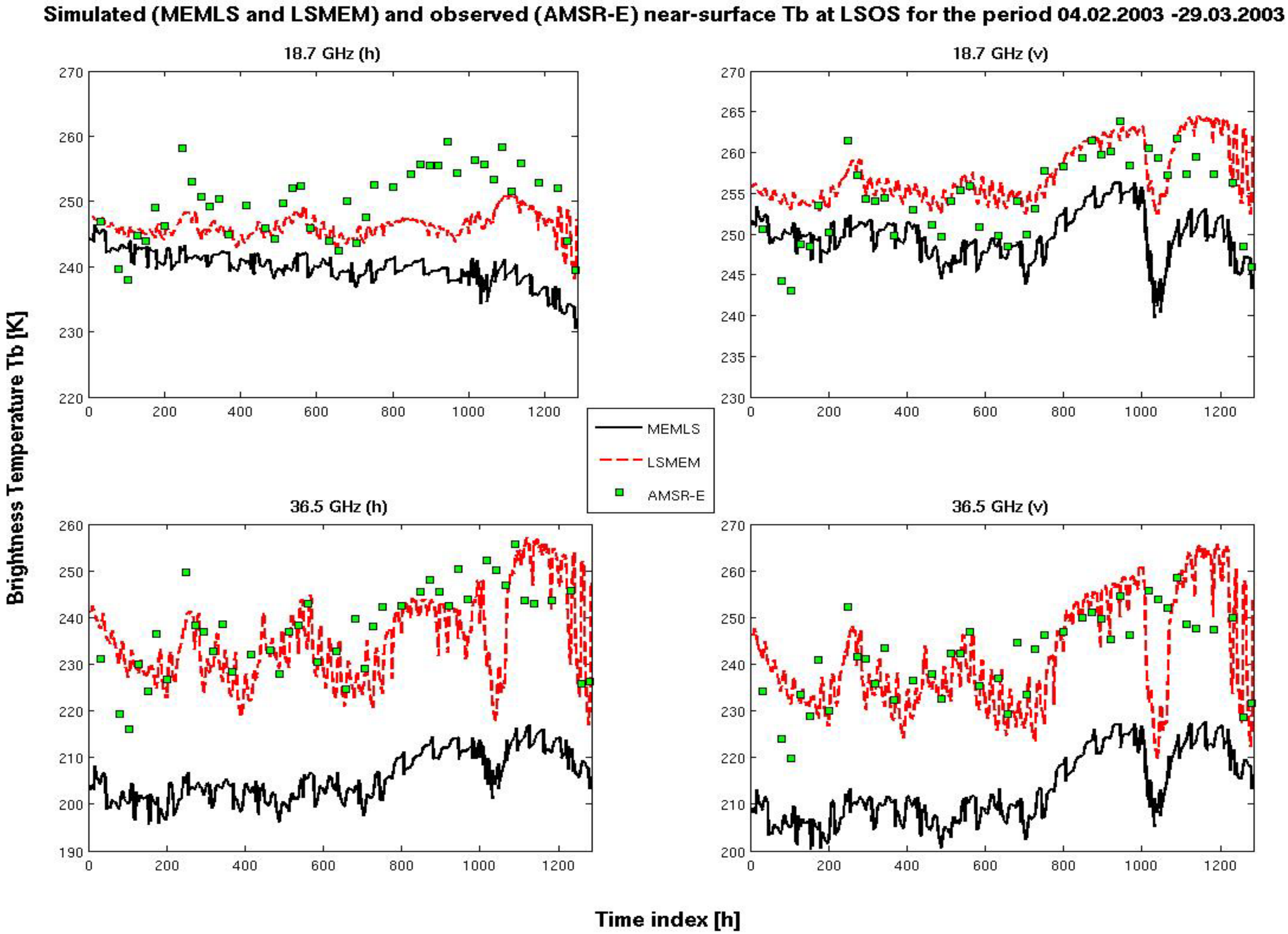
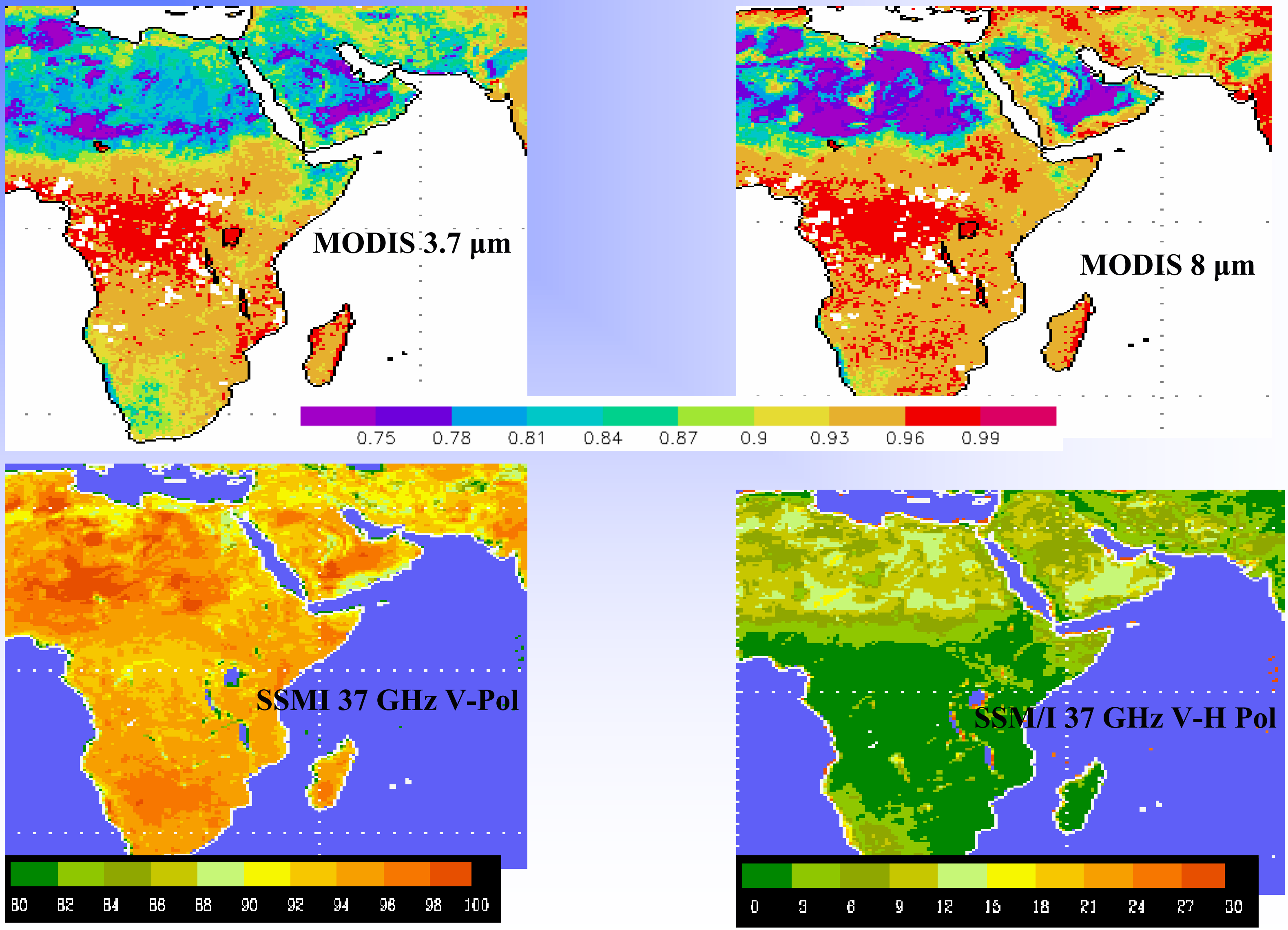
Snow Emissivity Model Evaluation



IR and MW Emissivity Relationship



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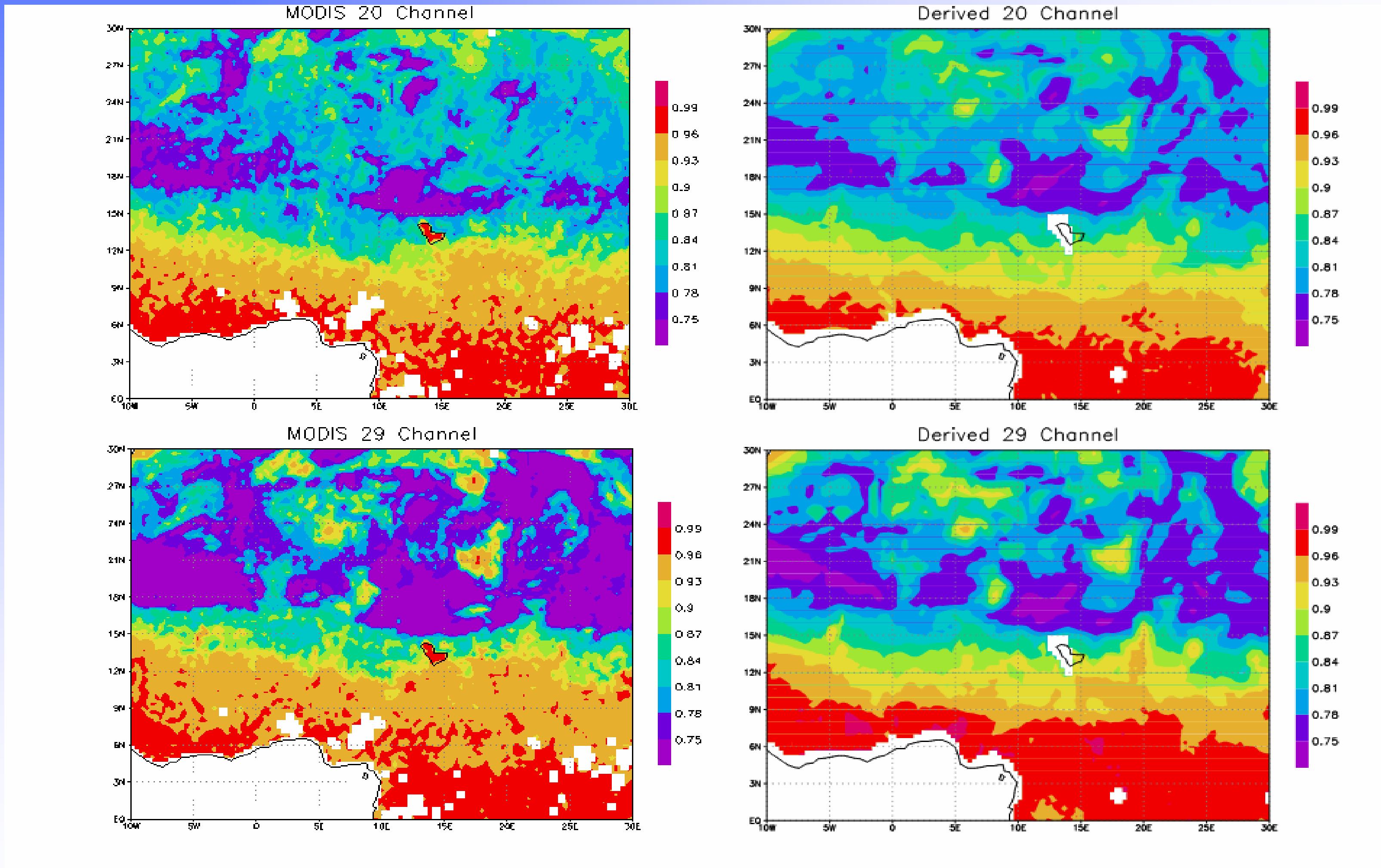
Predicted IR Emissivity from MW

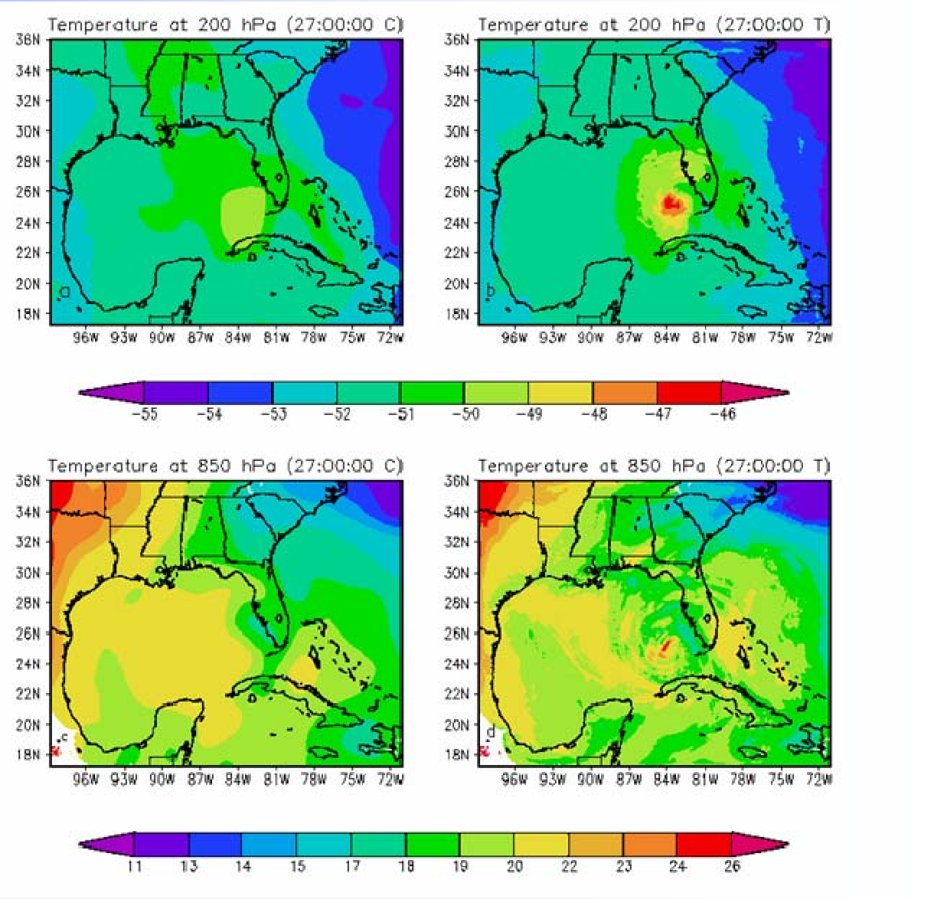


Dr. Peiming Dong (CMA Visiting Scientist)

Direct SSMIS Cloudy Radiance Assimilation

DMSP F-16 SSMIS radiances is at the first time assimilated using NCEP 3Dvar data analysis. The new data assimilation improves the analysis of surface minimum pressure and temperature fields for Hurricane Katrina. Also, Hurricane 48-hour forecast of hurricane minimum pressure and maximum wind speed was significantly improved from WRF model

Significance: Direct assimilation of satellite radiances under all weather conditions is a central task for Joint Center for Satellite Data Assimilation (JCSDA) and other NWP centers. With the newly released JCSDA Community Radiative Transfer Model (CRTM), the JCSDA and their partners will be benefited for assimilating more satellite radiances in global and mesoscale forecasting systems and can improve the severe storm forecasts in the next decade



The initial temperature field from control run (left panels) w/o uses of SSMIS rain-affected radiances and test run (right panels) using SSMIS rain-affected radiances

Summary

- A community radiative transfer model (CRTM) framework allows for effectively transition to operations fast radiative transfer schemes and components
- CRTM-Version 1 was implemented in NCEP GSI, including OPTRAN, IR/MW emissivity models, and ADA. It is also being tested for WRF-Var data assimilation
- IR and MW emissivity spectra displays a strong correlation in deserts. This correlation may be used to estimate IR emissivity under cloudy conditions from MW emissivity data base
- The Version 2 will include the zeeman absorption, aerosol scattering, SARTA, OSS, and possible interface with RTTOV