National Environmental Satellite, Data, and Information Service

Land Surface Emissivity Characterizations for CRTM Applications

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NOAA/NESDIS/Center for Satellite Applications and Research

and

Joint Center for Satellite Data Assimilation

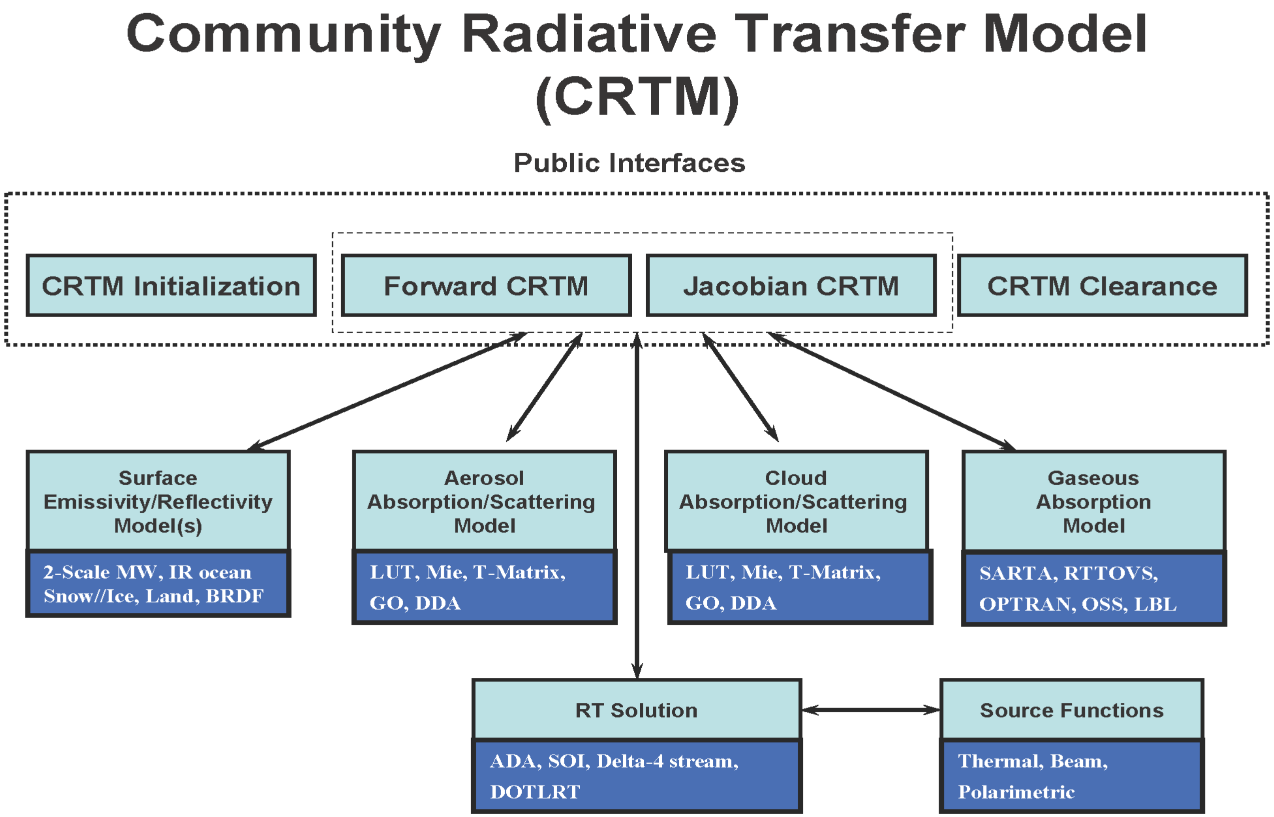
The 2nd Workshop on Remote Sensing and Modeling of Surface Properties,

Toulouse, France, June 8-11, 2009

Community Radiative Transfer Model

Support over 100 Sensors

- GOES-R ABI
- Metop IASI/HIRS/AVHRR/AMSU/M
- 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
- Terra/Aqua MODIS Channel 1-10
- MSG SEVIRI
- Aqua AIRS, AMSR-E, AMSU-A,HSB
- NOAA-15 to 18 AMSU-A
- NOAA-15 to 17 AMSU-B
- NOAA-18/19 MHS
- TIROS-N to NOAA-14 MSU
- DMSP F13 to15 SSM/I
- DMSP F13,15 SSM/T1
- DMSP F14,15 SSM/T2
- DMSP F16-20 SSMIS
- Coriolis Windsat
- TiROS-NOAA-14 SSU
- FY-3 IRAS, MWTS,MWHS,MWRI
- NPP/NPOESS CrIS/ATMS



"Technology transfer made possible by CRTM is a shining example for collaboration among the JCSDA Partners and other organizations, and has been instrumental in the JCSDA success in accelerating uses of new satellite data in operations" – Dr. Louis Uccellini, Director of National Centers for Environmental Prediction

Acknowledgements

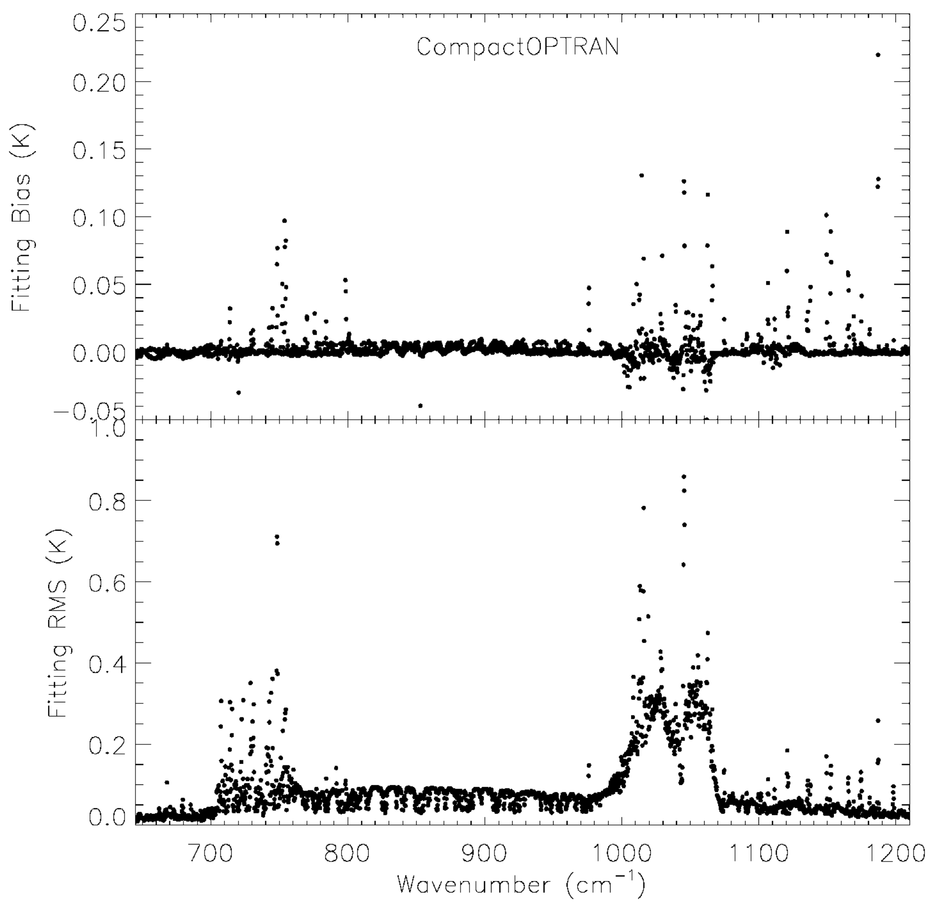
CRTM Members:	Organization	Areas of Expertise
Fuzhong Weng	STAR	CRTM technical oversight/emissivity
Yong Han	STAR	CRTM interface with NESDIS -CoChchair
Paul van Delst	NCEP	CRTM interface with NCEP -CoChair
Ben Ruston	NRL	CRTM interface with NRL
Ping Yang	Texas A&M	Cloud/aerosol scattering LUT
Ralf Bennarts	Univ Wisconsin	Transfer scheme
Jean-Luc Moncet	AER	Absorption model
Quanhua (Mark) Liu	Perot System	Transfer scheme
Banghua Yan	Perot System	Surface emissivity
Yong Chen	CIRA	validation/absorption model
David Groff	NCEP	transmittance data base
Ron Vogel	IMSG	IR surface emissivity
Jun Li	CIMSS	ABI retrieval algorithm
Tim Schmit	STAR	CRTM assessment
Tom Greenwalt	CIMSS	SOI
Alan Huang	CIMSS	GOES-R proxy data

CRTM Recent Accomplishments

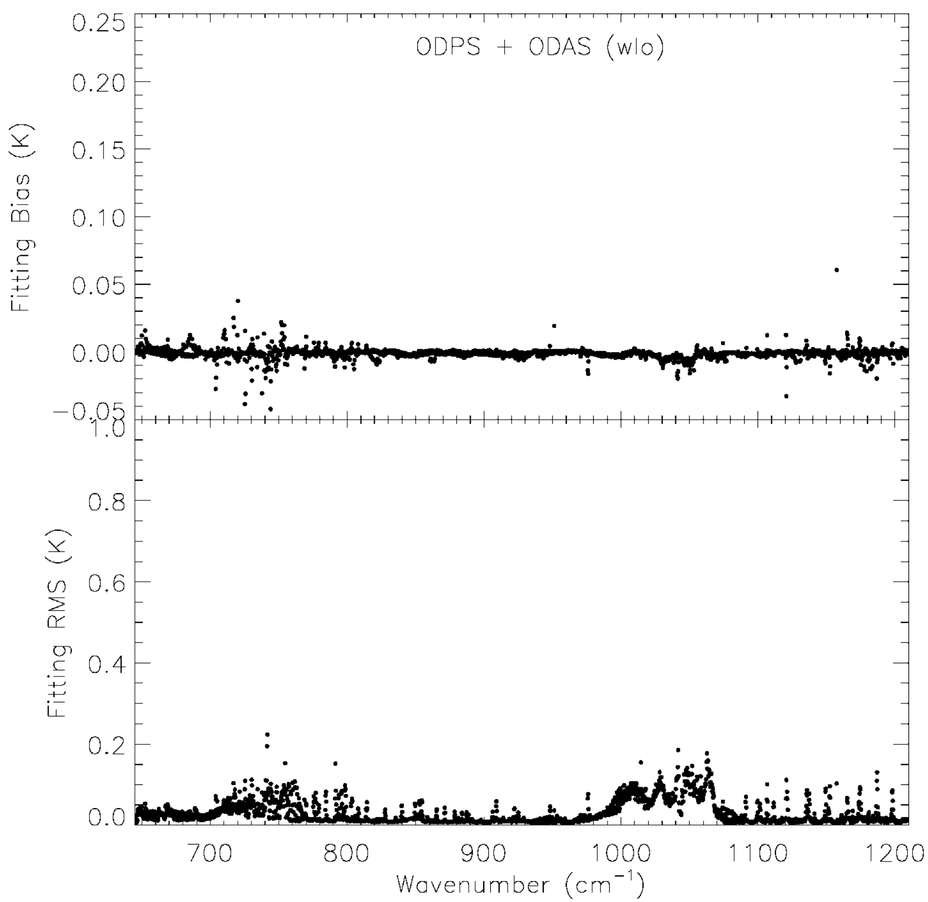
- Upgrade the LUT for scattering from clouds and Aerosols
- Including gas absorption due to Zeeman splitting effects
- Correction of ocean microwave emissivity through tuning large scale roughness parameters
- Gas absorption model for historical sensors in OPTRAN
- Validation of CRTM using Cloudsat data matched satellite
- Upgrade MHS snow and sea ice emissivity
- Upgrade microwave desert emissivity
- New considerations in LBL data base
- Multiple transmittance interface including variable trace gases
- New considerations on infrared land infrared emissivity properties

CRTM Fast Gaseous Absorption Models

Version 1 performance:
Variable gases: H2O, O3
Fixed gas: CO2, CO, CH4, N2O, O2



Version 2 performance
Variable gases: CO2, H2O, O3
Fixed gas: CO, CH4, N2O, O2, CFCs and others



Efficiency comparison between CRTM ODPS (version 2) and Compact-OPTRAN (Version 1)

Satellite Sensor	Forward Model		K-Matrix Model	
	ODPS	Compact-OPTRAN	ODPS	Compact-OPTRAN
avhrr3_n18*	0m10.12s	0m22.02s	0m49.43s	0m57.58s
hirs4_n18*	0m37.40s	2m13.32s	2m41.37s	4m11.99s
amsua_n18*	0m23.69s	1m29.70s	1m37.38s	2m59.44s
iasiB1_metop-a#	0m38.70s	2m31.69s	2m44.84s	4m30.27s
iasiB2_metop-a#	1m0.41s	3m33.24s	4m4.27s	6m25.05s
iasiB3_metop-a#	0m53.00s	3m12.81s	3m42.78s	5m51.30s

Satellite Sensor	Tangent Linear Model		Adjoint Model	
	ODPS	Compact-OPTRAN	ODPS	Compact-OPTRAN
avhrr3_n18	0m39.67s	0m53.79s	0m42.15s	0m55.14s
hirs4_n18	1m28.29s	3m39.11s	1m34.40s	3m42.18s
amsua_n18	1m3.11s	2m34.89s	1m8.77s	2m35.65s
iasiB1_metop-a	1m7.50s	3m43.84s	1m14.44s	3m45.89s
iasiB2_metop-a	1m45.91s	5m16.16s	1m54.56s	5m18.10s
iasiB3_metop-a	1m28.31s	4m45.37s	1m38.17s	4m48.63s

All sensors were run with UMBC 48 profiles at nadir, and full channels.

* **repeat 1000 times; # repeat 10 times**. Notice the new version is about 2-5 times faster

Microwave LBL (MonoRTM) Data Base

- Update to MT_CKD water vapor continuum in microwave
  - Based on ARM ground-based radiometer data
  - Preliminary numbers for changes:
    - ~10 % decrease in foreign
    - ~20 % increase in self
- Additional features:
  - Extension beyond microwave region
  - Improved consistency with LBLRTM in terms of coding and databases

Improvement of Infrared LBL Data Base

Atmospheric and Environmental Research, Inc.

LBLRTM

CO_2 line parameters
Tashkun et al. (1999)

CO_2 line coupling
Application of Niro et al. (2005) code to Tashkun line parameters

CO_2 continuum
Using ARM ground-based interferometer meas.

H_2O line parameters
Coudert et al. (2008)

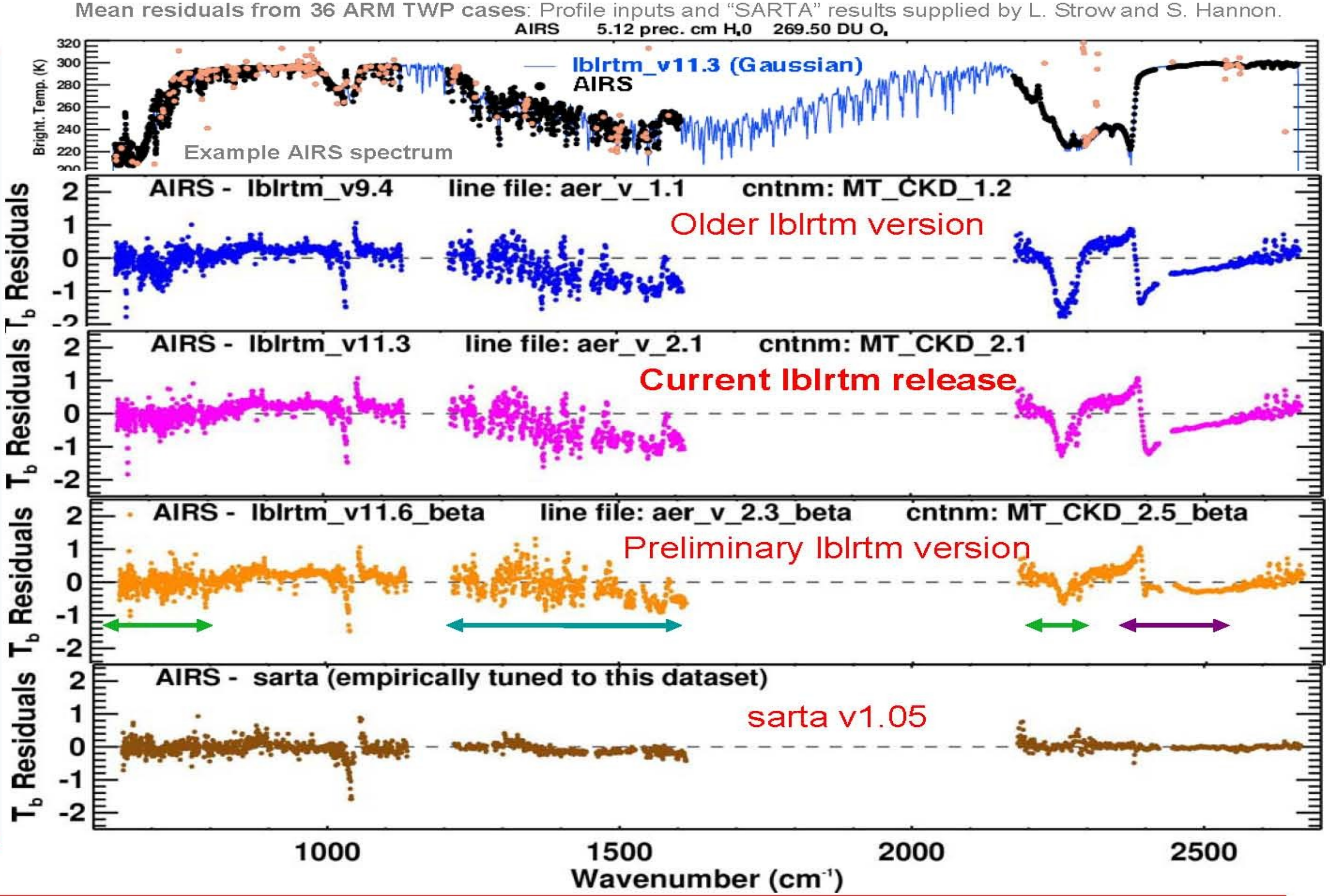
Updates to LBLRTM are all independent of the AIRS dataset used here to demonstrate them.

MonoRTM

H_2O continuum
Using ARM ground-based radiometer meas. (Payne et al., 2009, in preparation)

Updates to spectroscopy in AER's line-by-line RT models

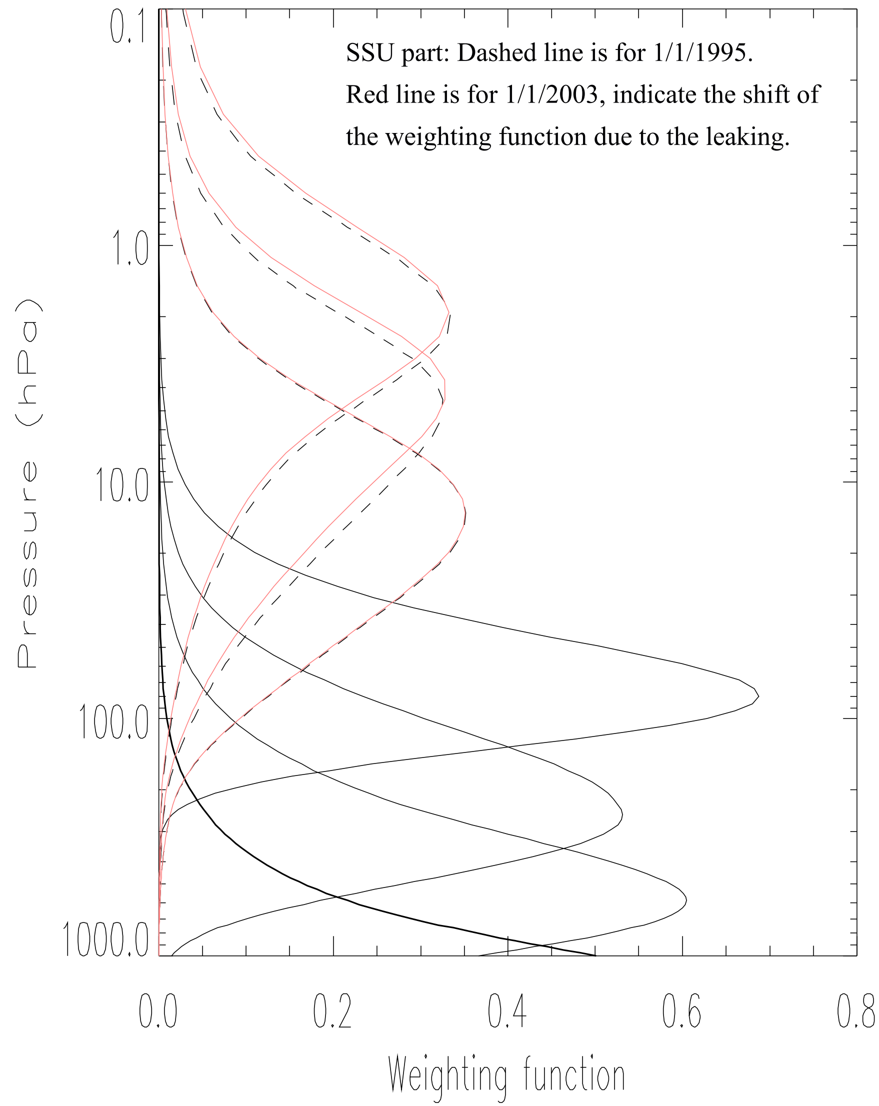
Mean residuals from 36 ARM TWP cases: Profile inputs and "SARTA" results supplied by L. Strow and S. Hannon.



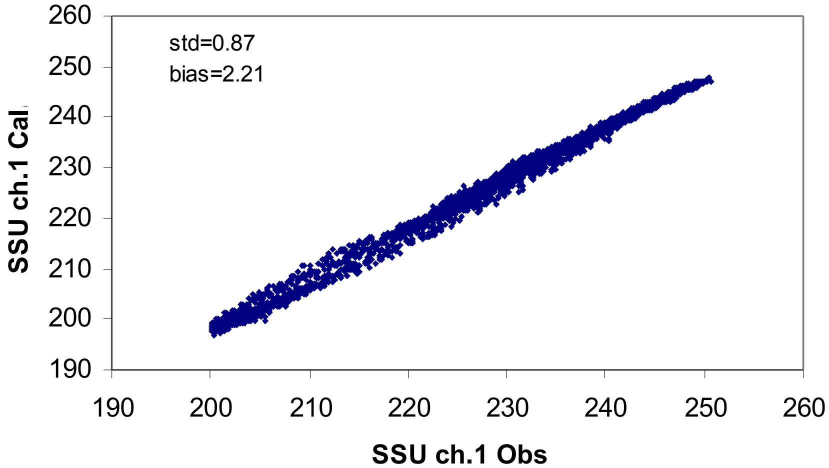
Significant improvements to consistency between spectral regions!

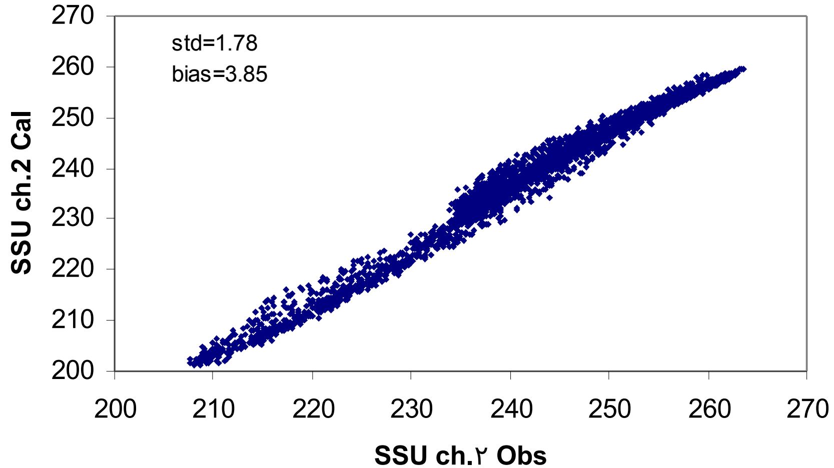
Modeling Stratospheric Sounding Unit (SSU)

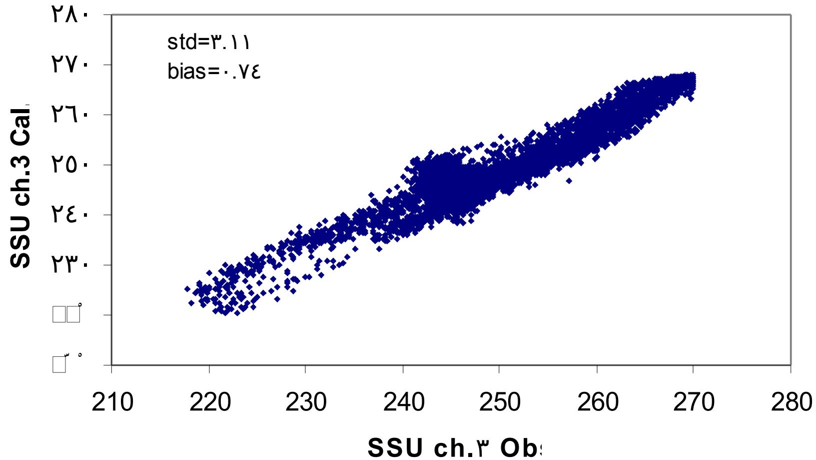
- Stratospheric Sounding Unit data is a three-channel sensor onboard
- NOAA series satellites (started from TIROS-N in 1978 and ended at NOAA-14 in 2006)
- The data in past 29 years is unique for middle and upper tratospheric temperatures
- Using CO2 cell pressure modulation onboard satellite, the single CO2 15 µm is split into 3 channels and shifted up to middle an upper stratosphere.
- In absent of a fast and accurate transmittance model, the SSU data has not used in NCEP analysis and reanalysis.



Comparisons between observation and modeling







The peaks of the SSU weighting function approximately locate at 15, 5, and 1.5 hPa.

The simulated BT bias at channels 1 and 2 could be caused by a cold bias in stratosphere in the NCEP analysis.

The large scatters for channel 3 is partly due to the limited top height (~ 0.2 hPa) in analysis.

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

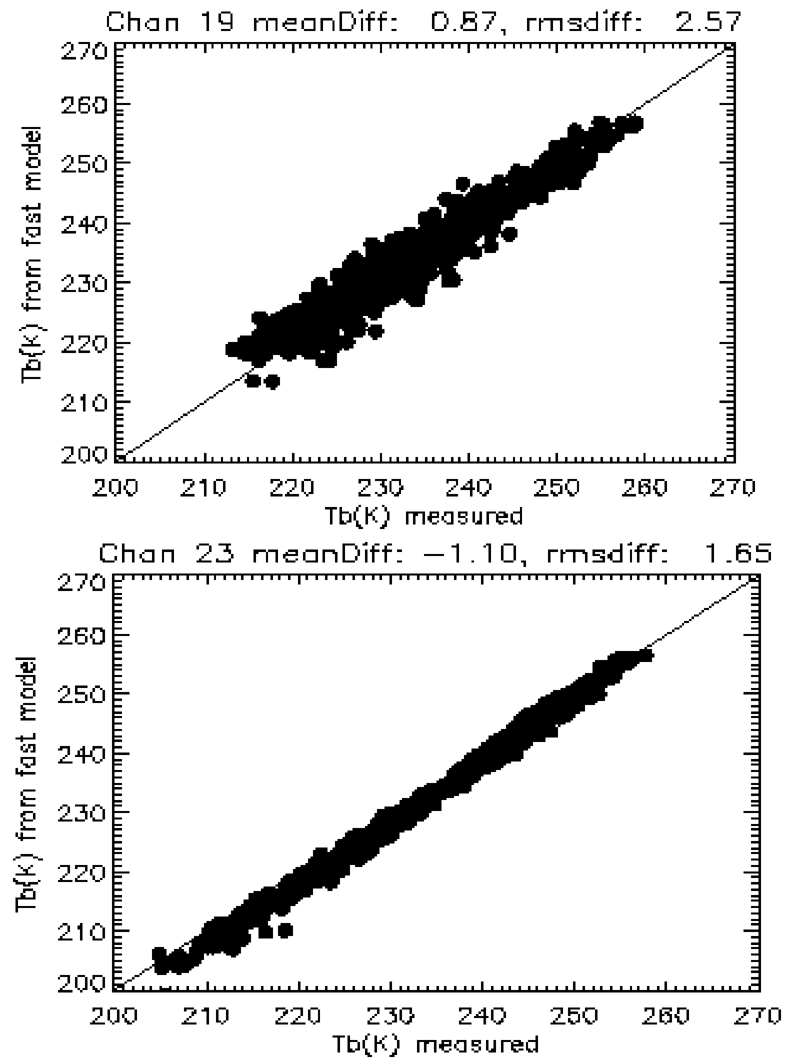
(3) For each layer, the following regression is applied to derive channel optical depth with a left-circular polarization:

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

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

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

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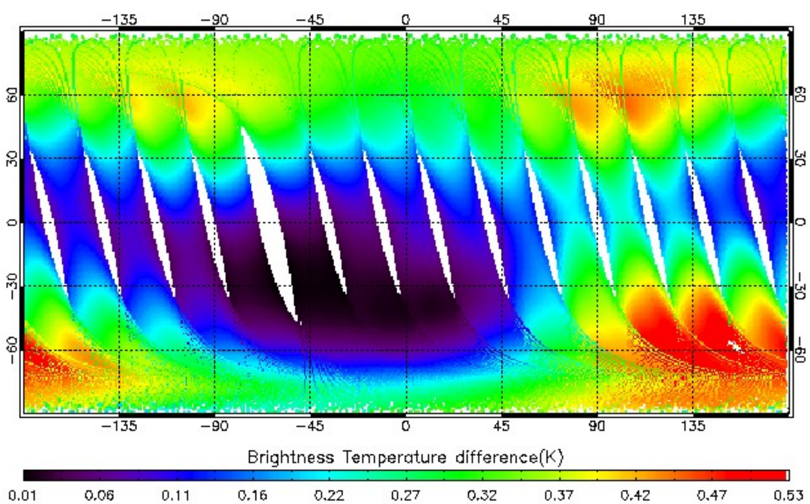
AMSU-A channel-14 brightness temperature differences between RT models w/o Zeeman-splitting effect

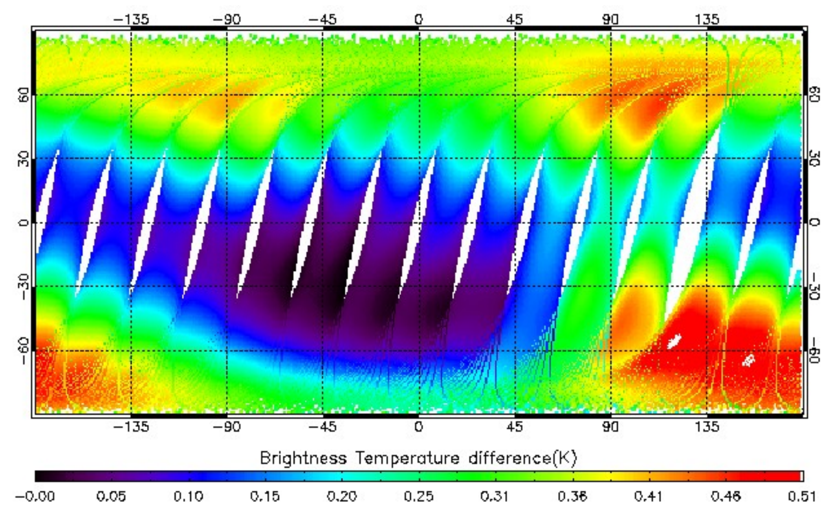
Model inputs:

B_e, θ_e, Φ_e – calculated using IGRF10 and data from AMSU-A MetOp-a 1B data files on September 8, 2007.

Atmospheric profile – US standard atmosphere applied over all regions.



Ascending



Descending

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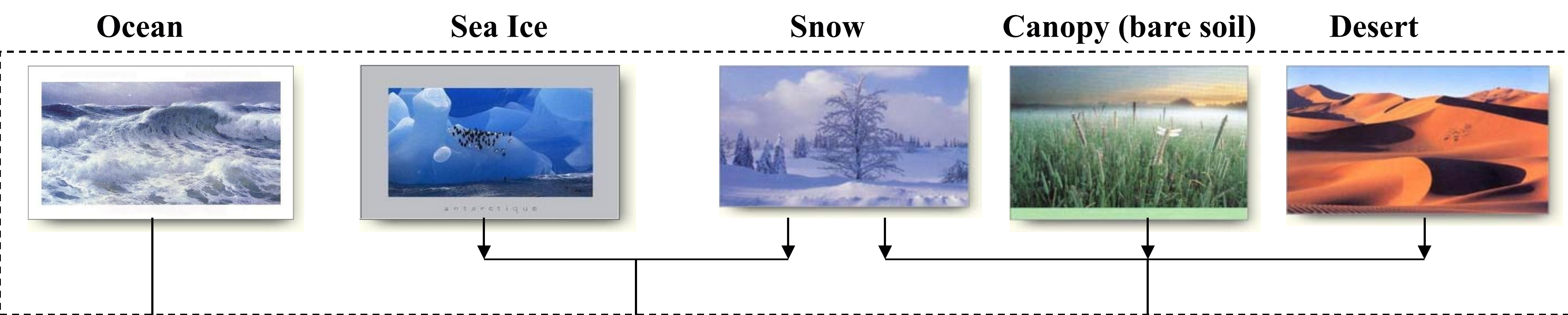
CRTM Surface Emissivity Module



Microwave land emissivity model (Weng et al., 2001) and desert emissivity data base

NPOESS Infrared emissivity data base

Empirical snow and sea ice microwave emissivity data base (Yan and Weng, 2003; 2008)

New two layer snow emissivity model (Yan, 2008)

FASTEM microwave emissivity model from (English and Hewison, 1998)

IR emissivity model (Wu and Smith, 1991; van Delst et al., 2001)

New Snow Emissivity Model

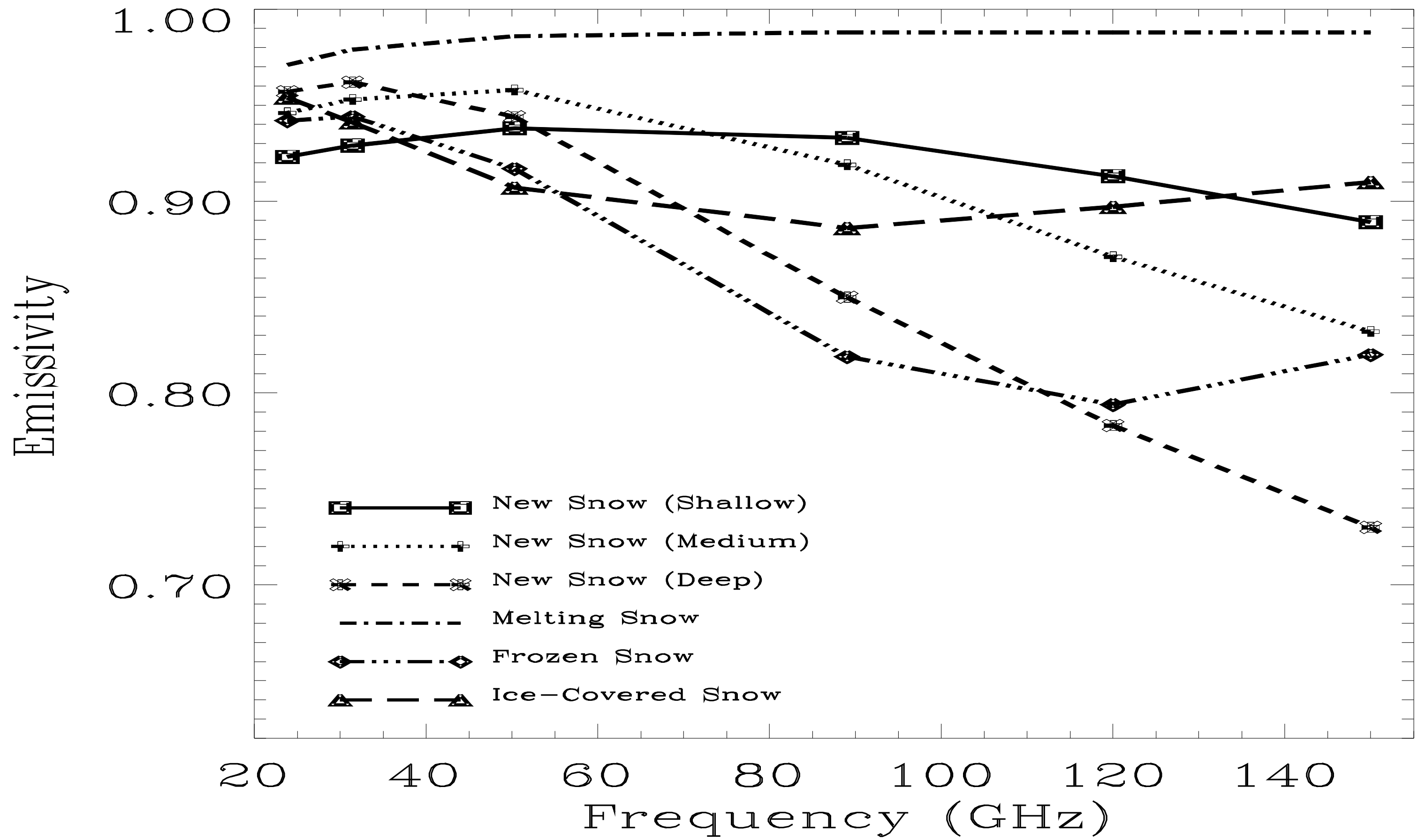
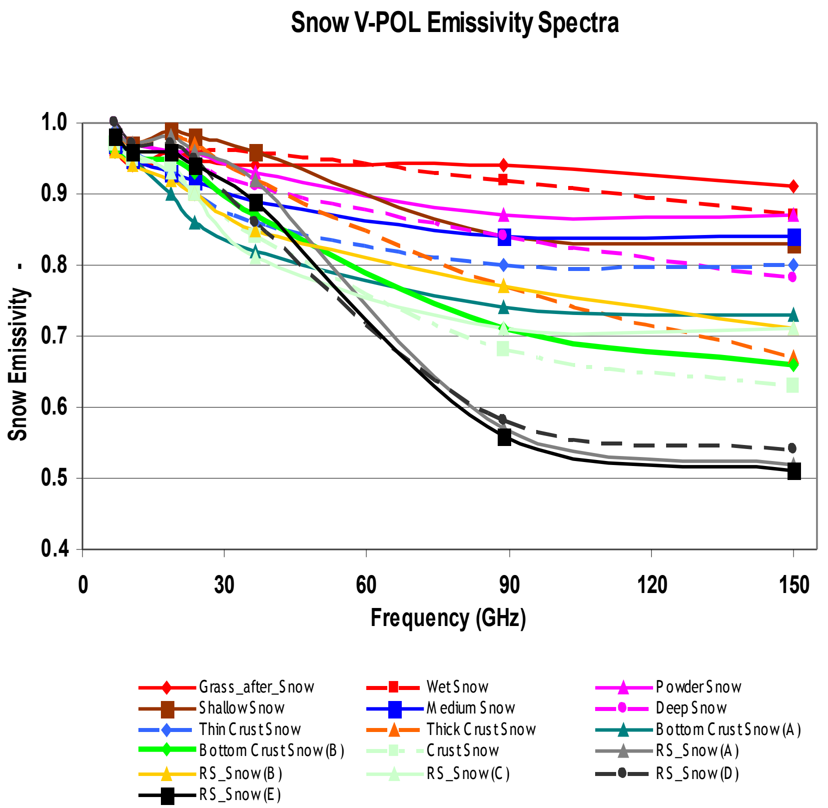
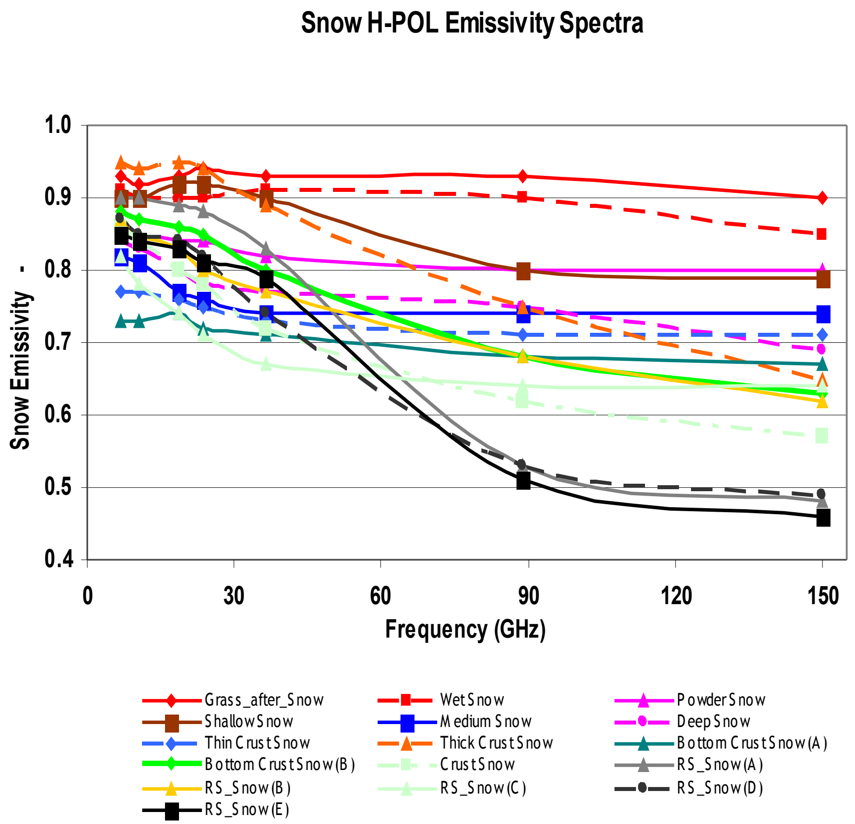


Figure courtesy of Banghua Yan

Snow Microwave Emissivity Spectra





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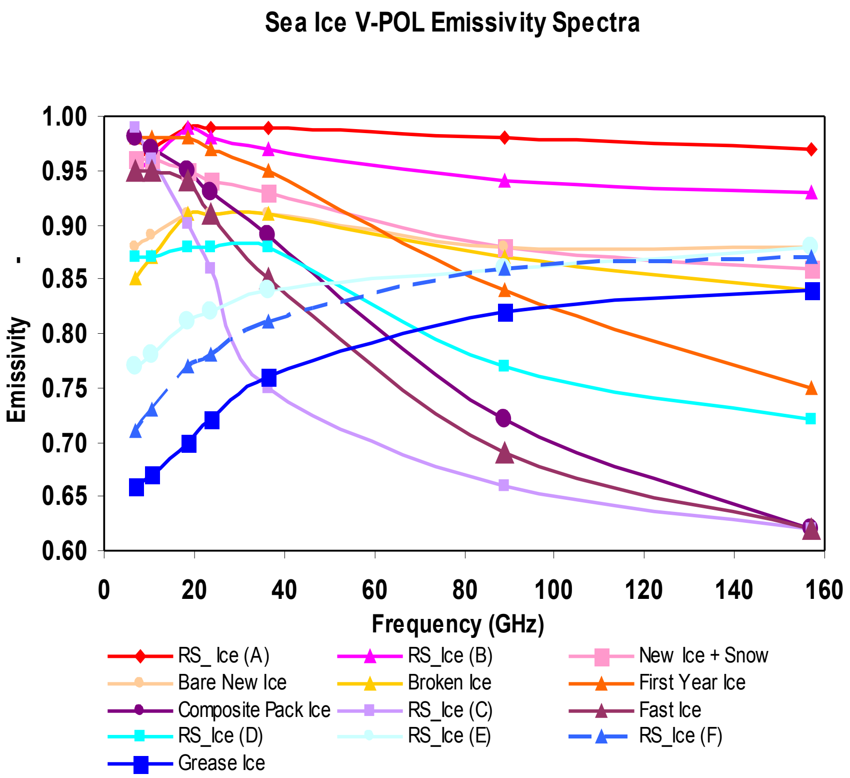
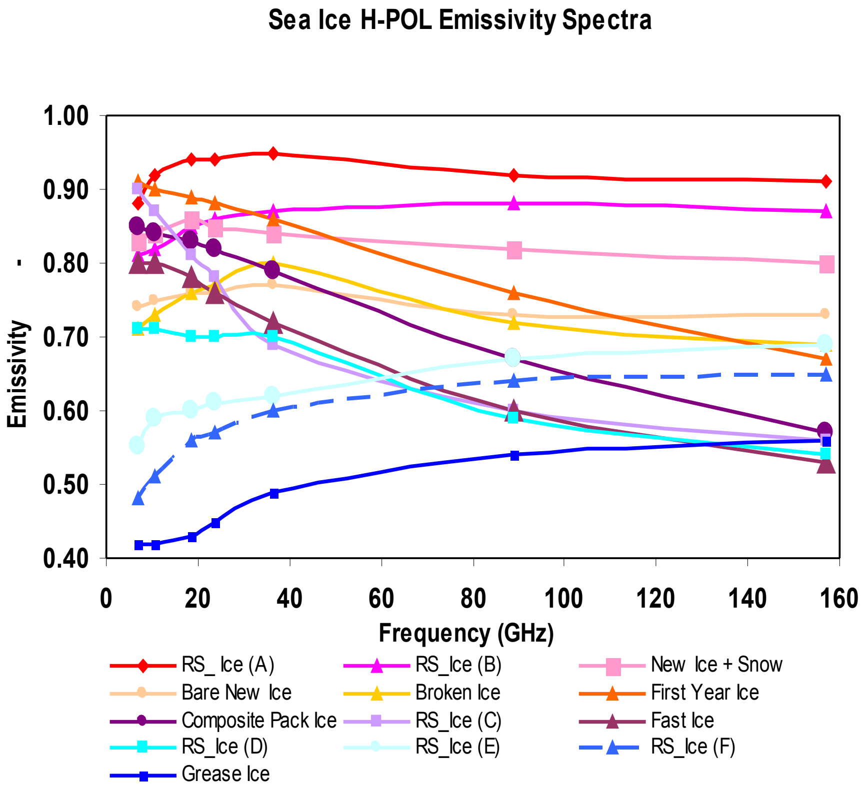
Sea Ice Microwave Emissivity Spectra





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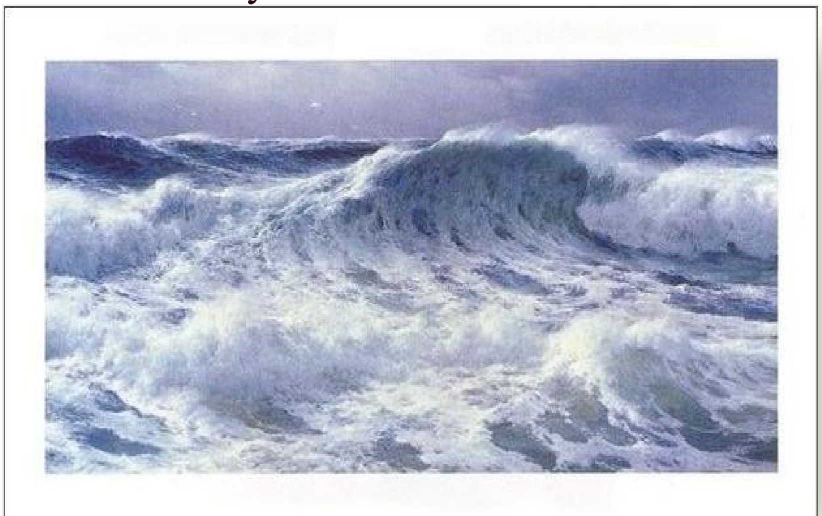
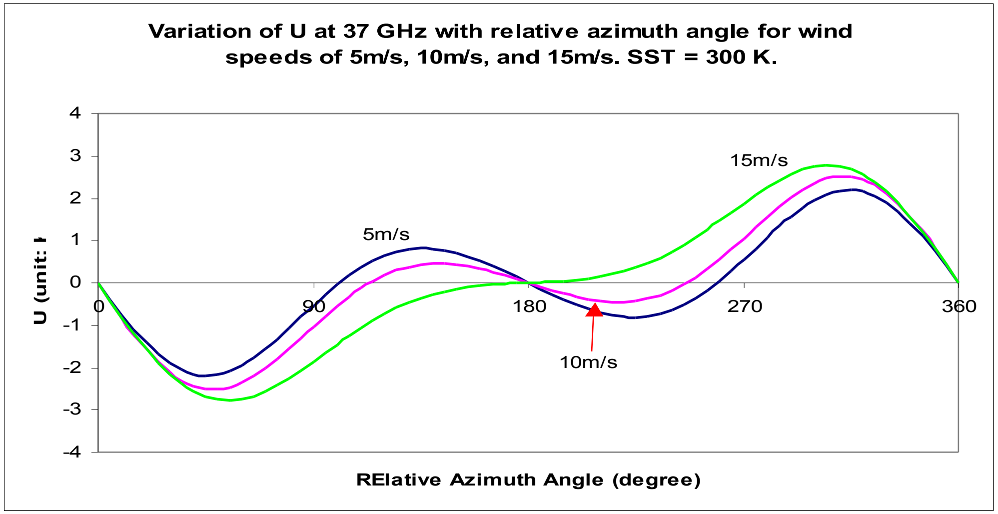
Oceanic Emission Model

Phenomenology.

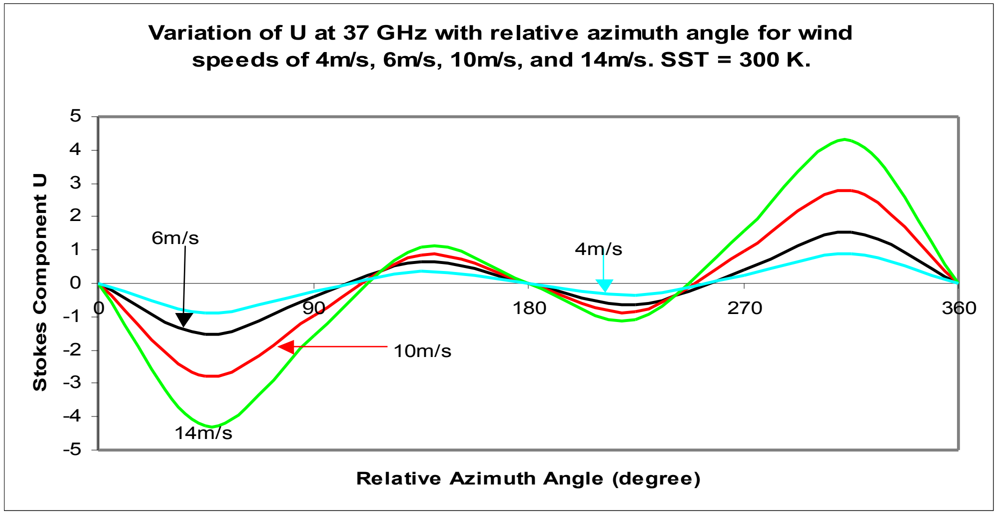
- Large gravity waves, whose wavelengths are long compared with the radiation wavelength.
- Small capillary waves, which are riding on top of the large-scale waves, and whose RMS height is small compared with radiation wavelength.
- Sea foam, which arises as a mixture of air and water at the wind roughened ocean surface, and which leads to a general increase in the surface emissivity.



Two-scale Simulations



Aircraft Measurements

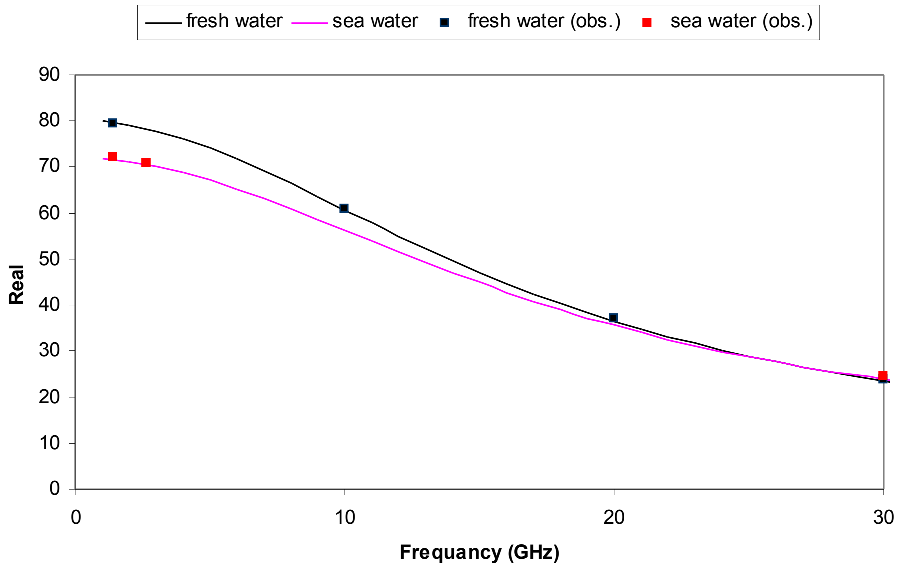


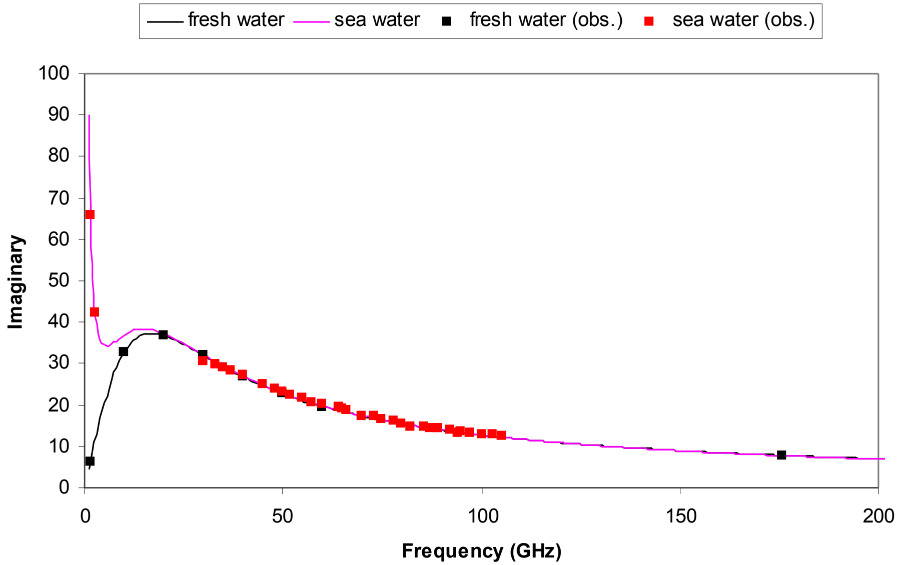
New Permittivity Models

- **Why**: for a low frequency (< 20 GHz), permittivity depends on salinity but CRTM and RTTOV both use FASTEM-3 whose coefficients are derived from Ellison et al. (2003) with a fixed salinity of 35‰.
- **How**: Double Debye Model (Meissner & Wentz, 2004) with a removal of salinity dependence of permittivity at infinite frequency in MW model (a clear conflict with physics) and with a revised fitting coefficients

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_1}{1 + j2\pi f \tau_1} + \frac{\varepsilon_1 - \varepsilon_\infty}{1 + j2\pi f \tau_2} + j\frac{\sigma}{2\pi f \varepsilon_0}$$

- Revised Meissner and Wentz permittivity model are valid up to 500 GHz and fits well measurements well





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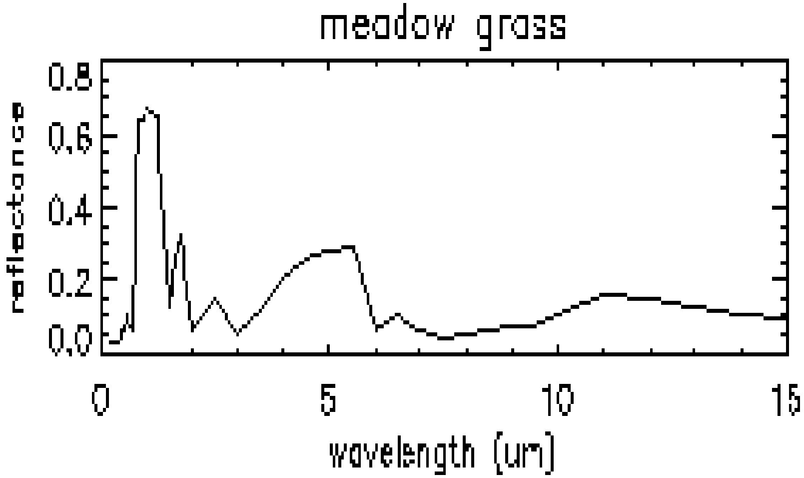
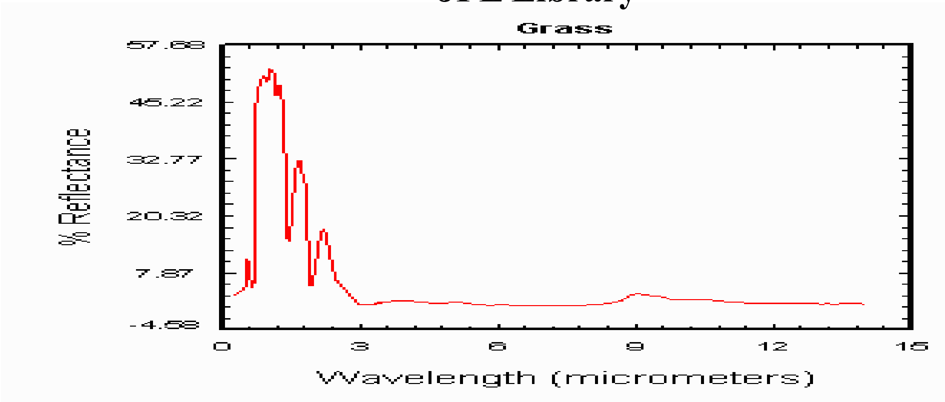
CRTM Infrared Emissivity Data Base over Land

- In general, CRTM baseline version reflectivity (emissivity) is higher (lower) than JPL library
- Lack of seasonal information
- Course surface types
- No angular dependent information
- Some discontinuity

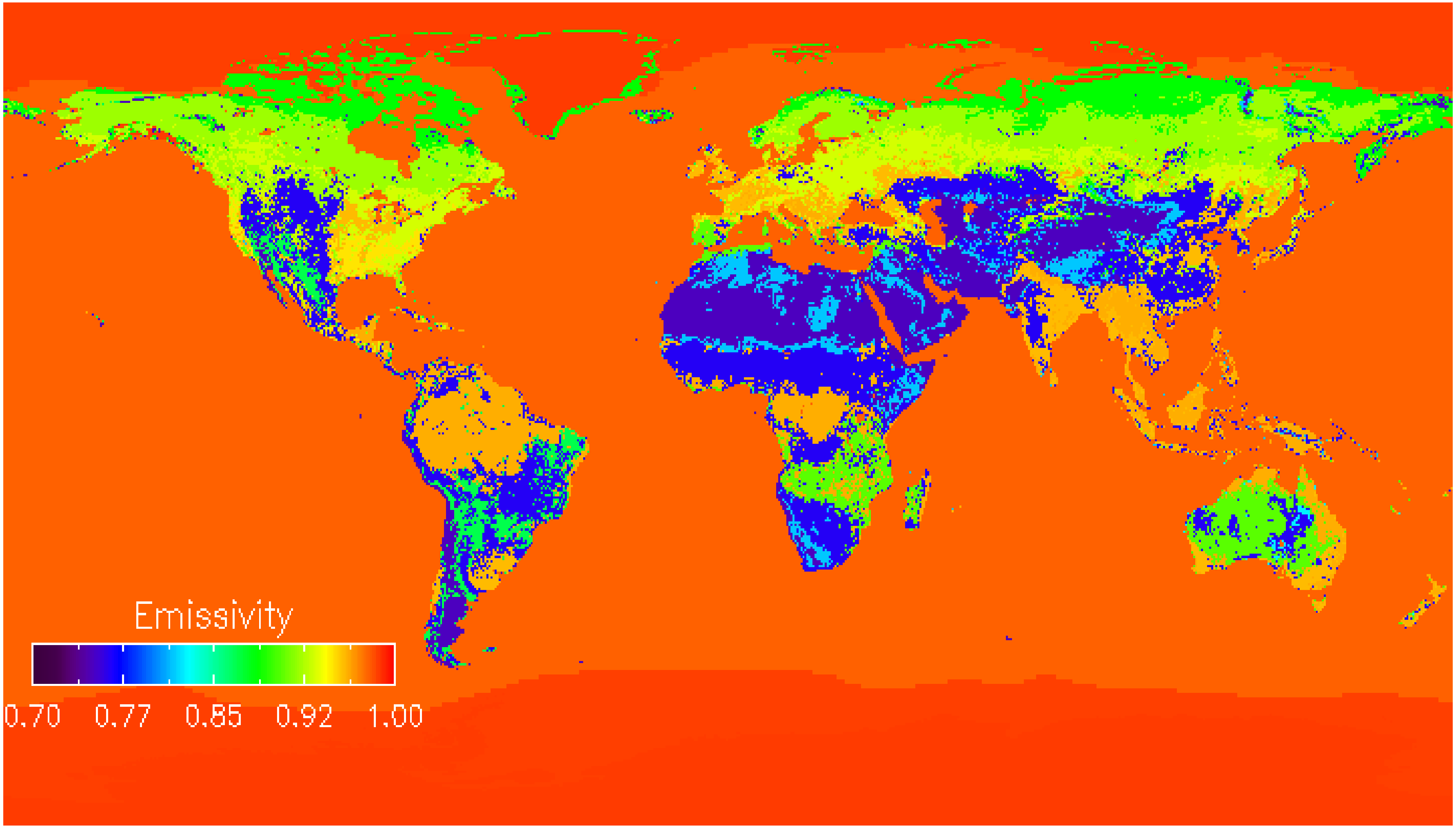
CRTM Baseline Model



JPL Library



CRTM Simulated Emissivity at 4.3 micron



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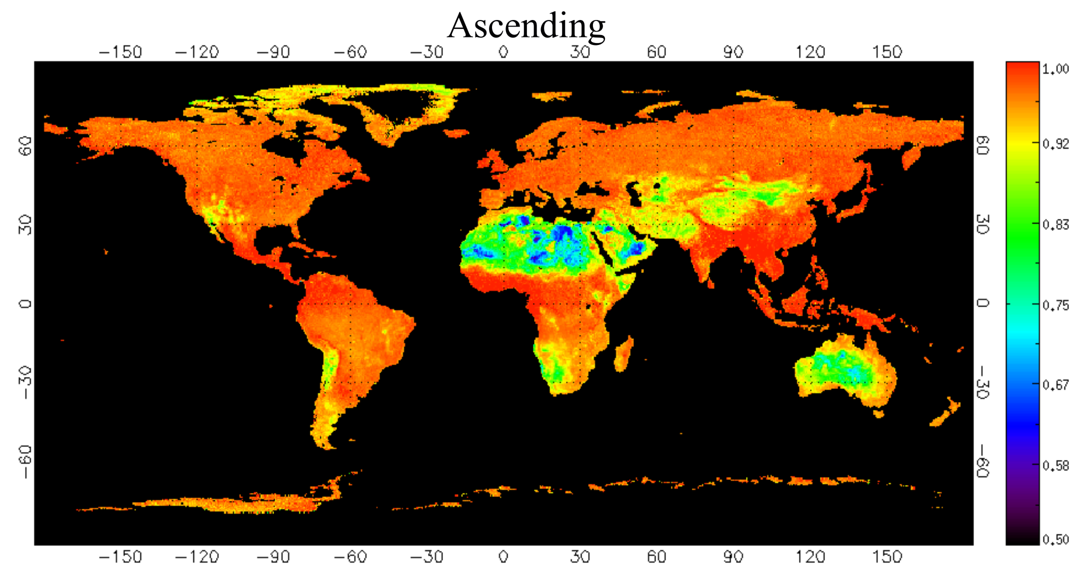
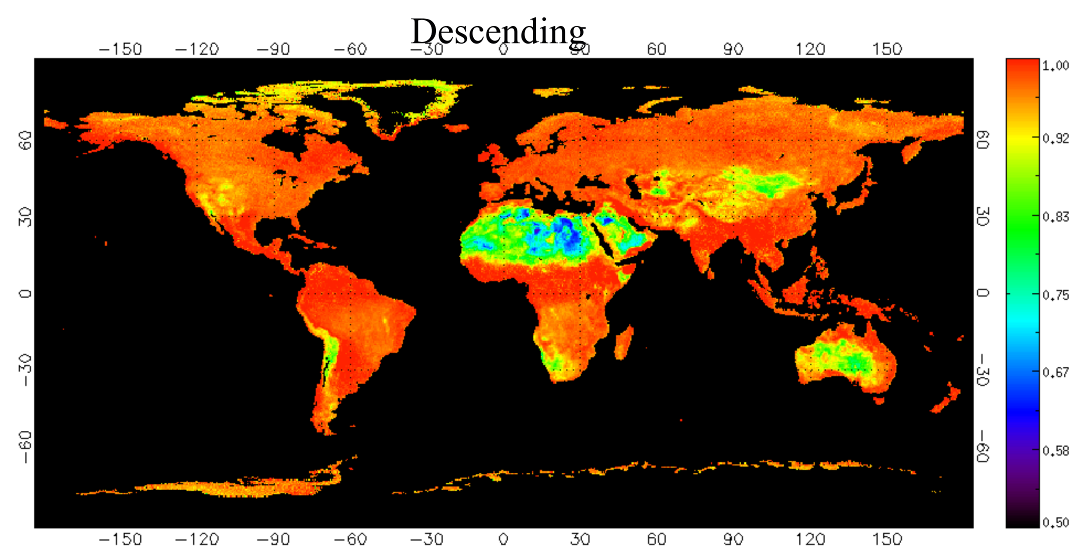
AIRS Version 5 Land Emissivity at 8.3 micron

- Day-night difference is significantly large over desert

- Some angular dependent features

- Large spatial variability over desert



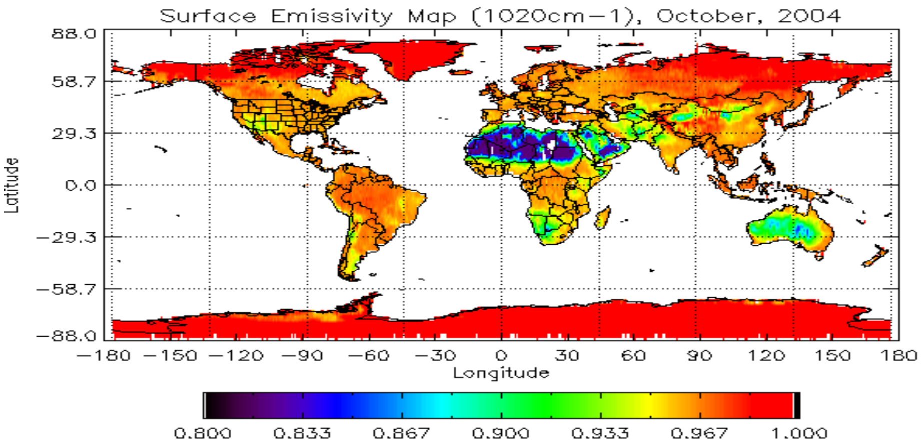


Hyperspectral Emissivity Data Base

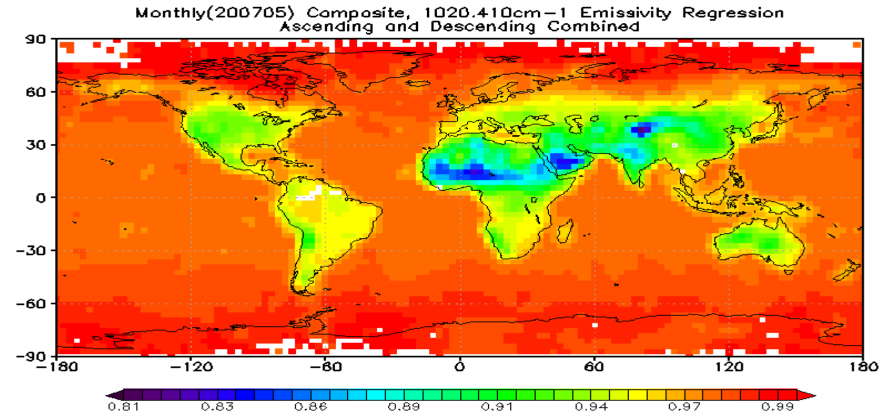
- **AIRS and IASI 39 hinge point emissivity data are retrieved in AIRS/IASI systems**
- **Two LSE data sets agree well within 1-3 % for most areas**
- **Differences exist over coastal areas and desert region where the large variations of emissivity occur**

Infrared emissivity data sets will result in improved uses of surface sensitive sounding channels from hyperspectral instruments

AIRS

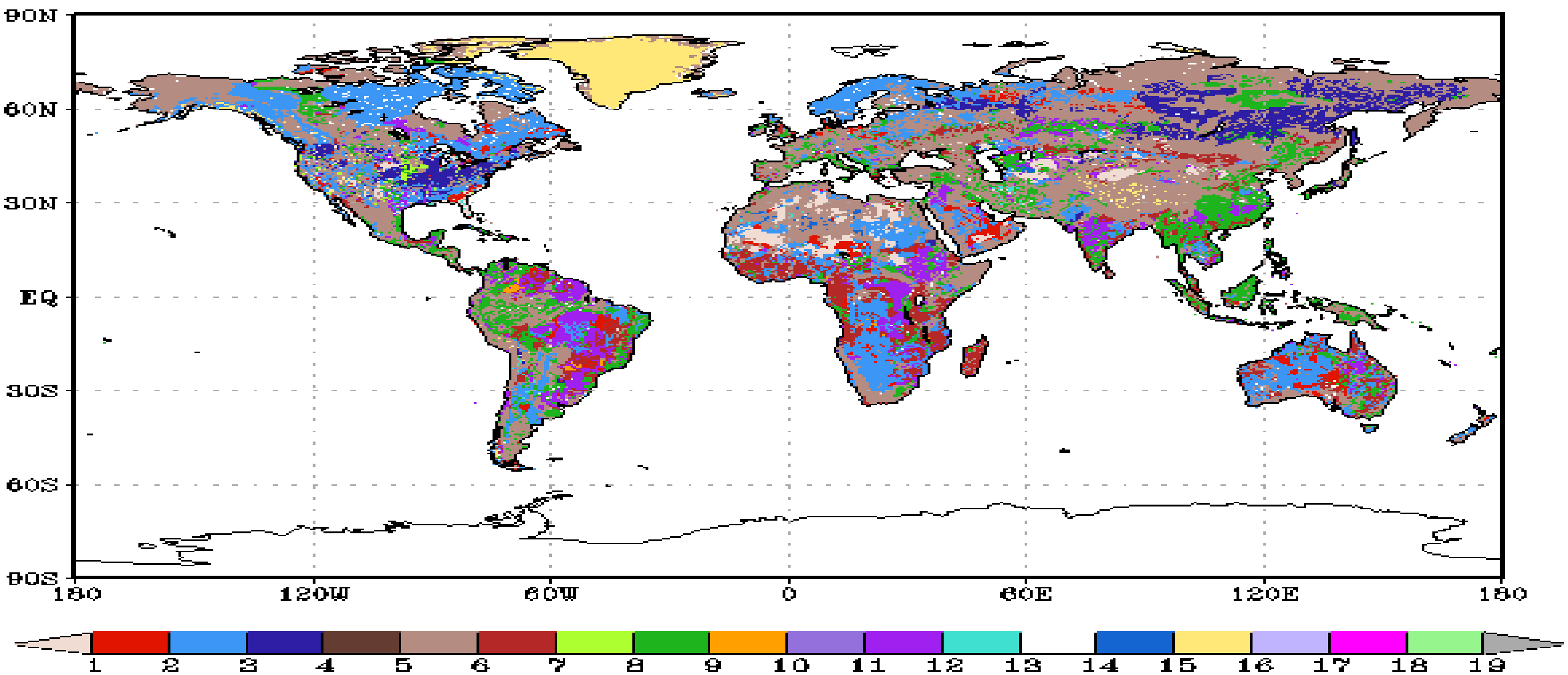


IASI



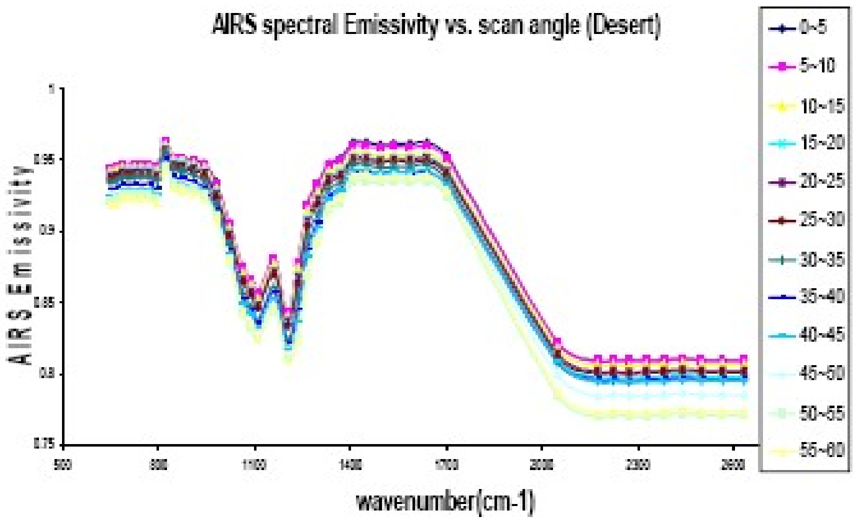
Uses of NOAH LSM Surface Types for Surface Emissivity Characterization

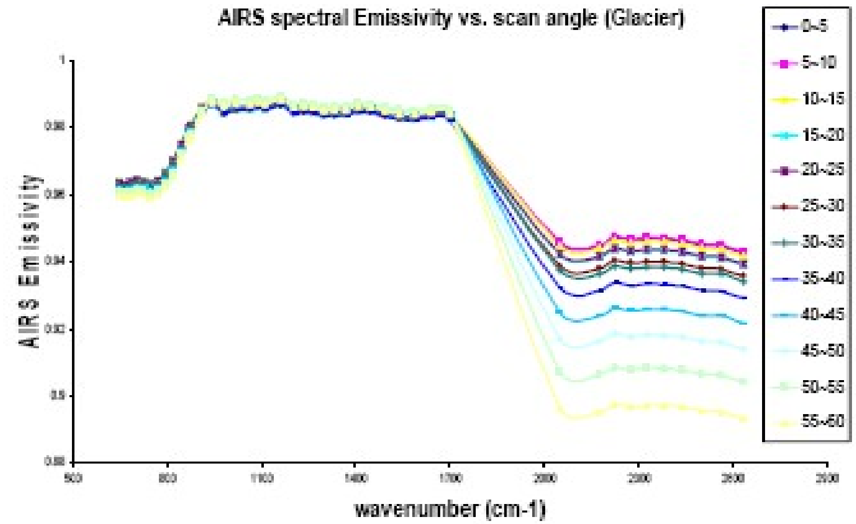
FAO/STATSGO Soil Type

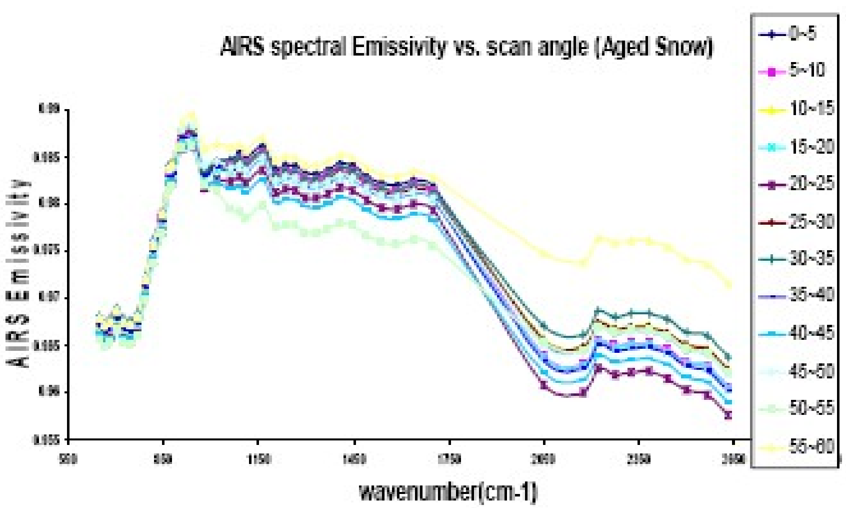


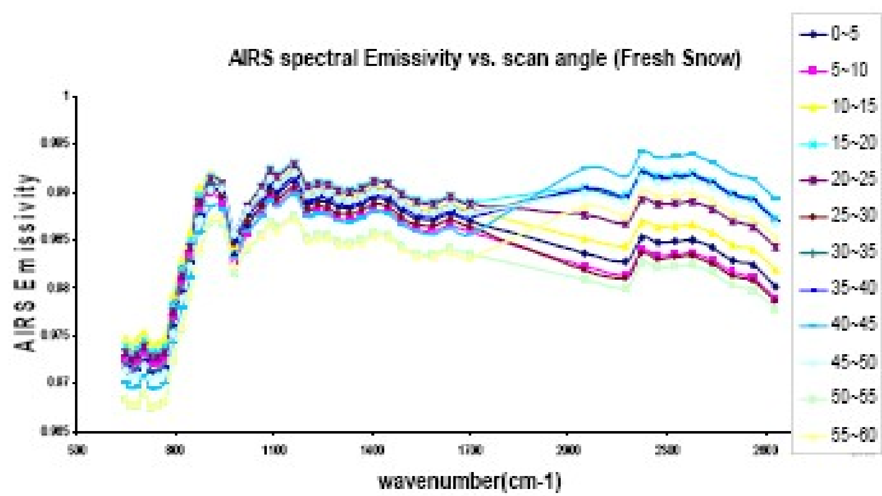
1 Sand	6 Loam	11 Silty Clay	16 Land-Ice
2 Loamy Sand	7 Sandy Clay Loam	12 Clay	17 Playa
3 Sandy Loam	8 Silty Clay Loam	13 Organic Materials	18 Lava
4 Silt Loam	9 Clay Loam	14 Water	19 White Sand
5 Silt	10 Sandy Clay	15 Bedrock	

Infrared Emissivity vs. Scan Angle

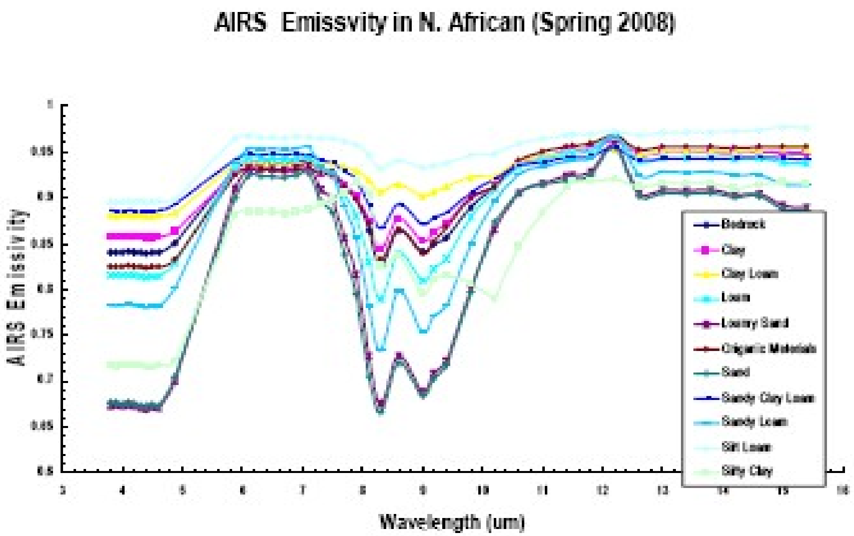


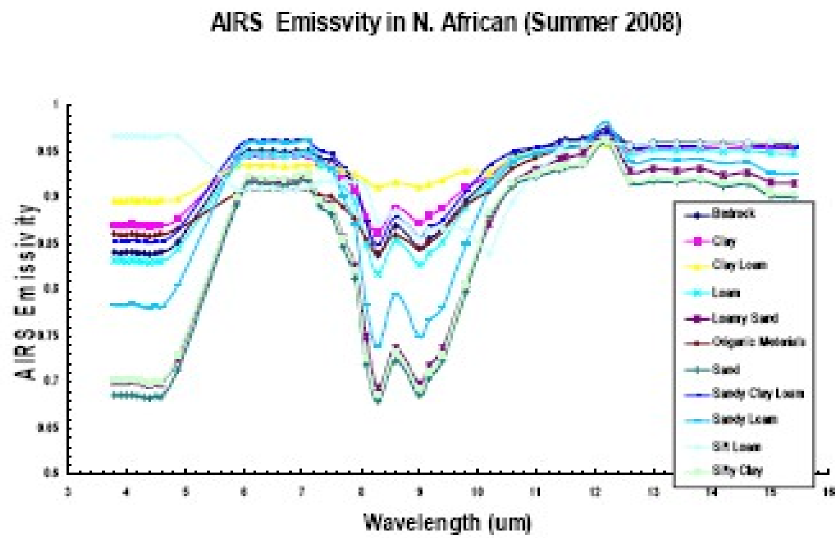


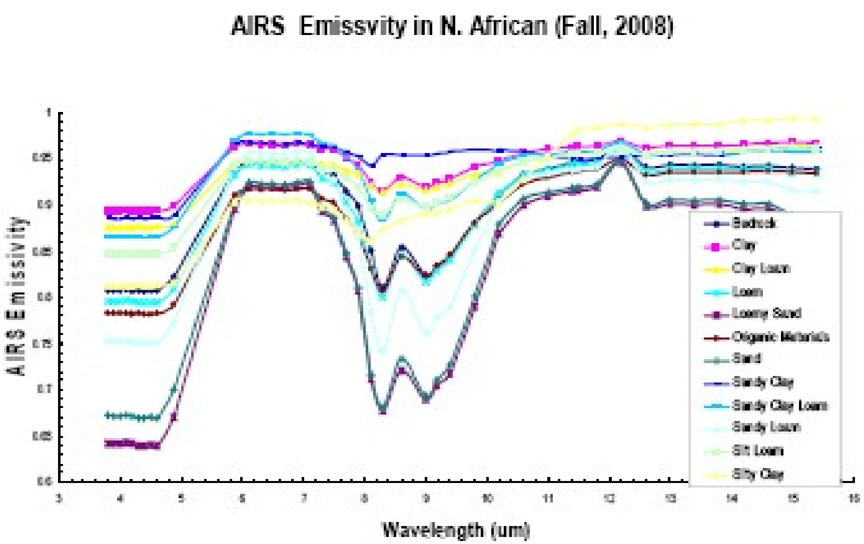


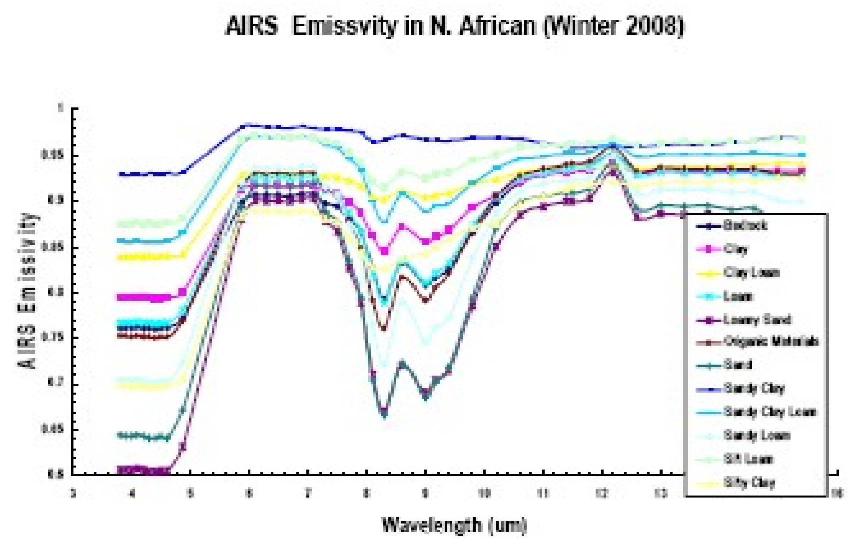


Seasonal Variation of Infrared Emissivity over N. Africa

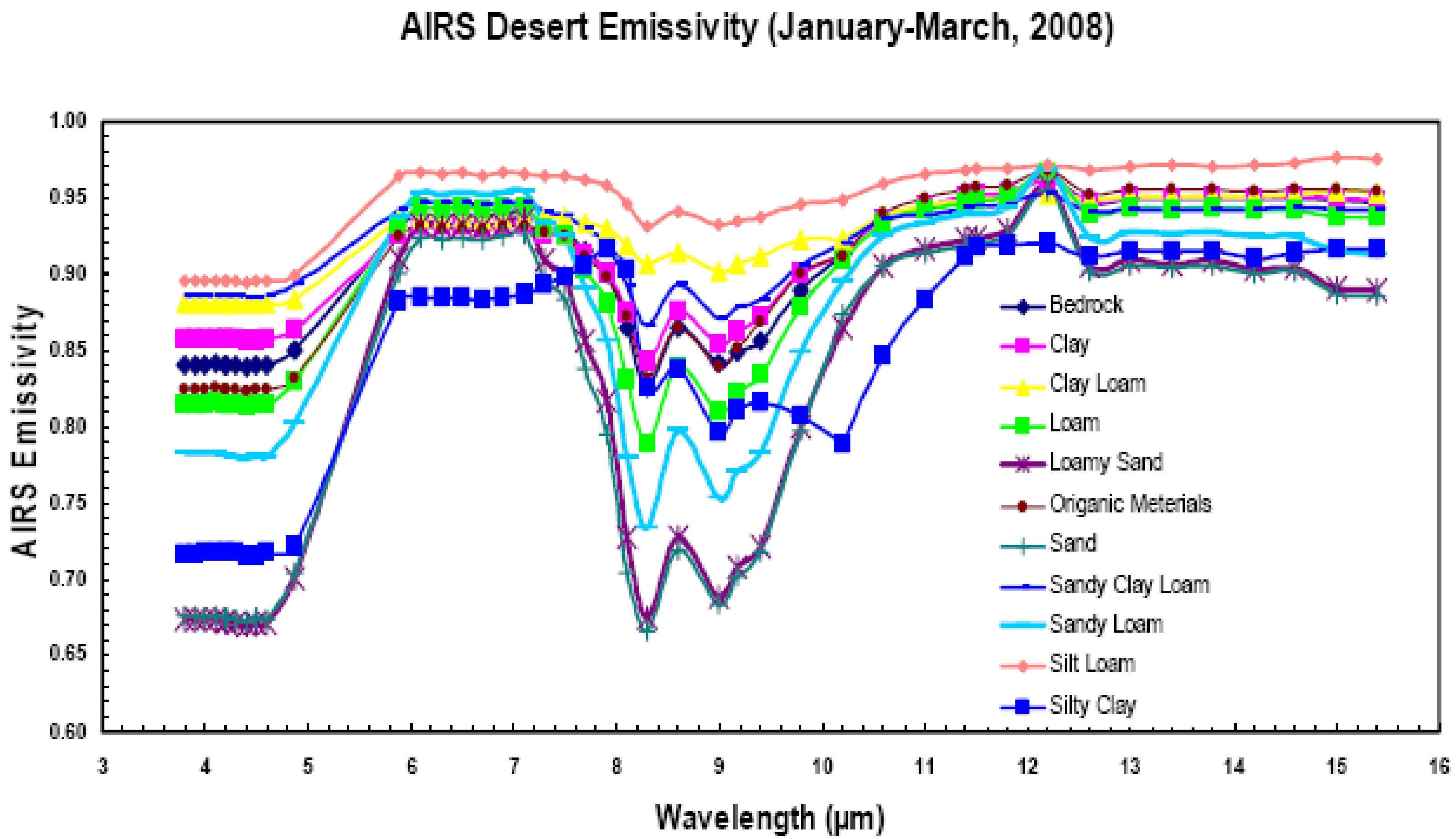








Infrared Emissivity vs. Soil Structure (N. Africa, Jan – Mar 0-12, 2008)



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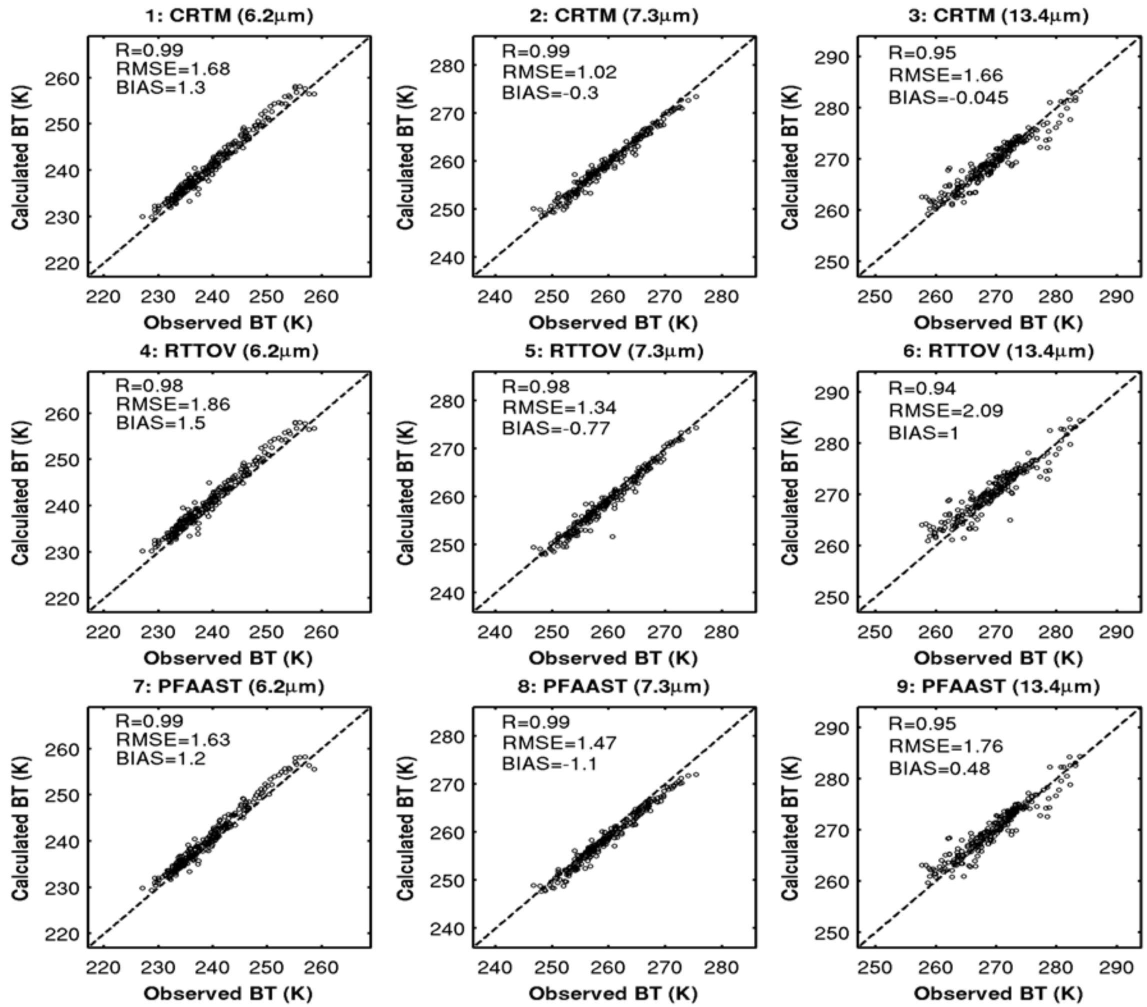
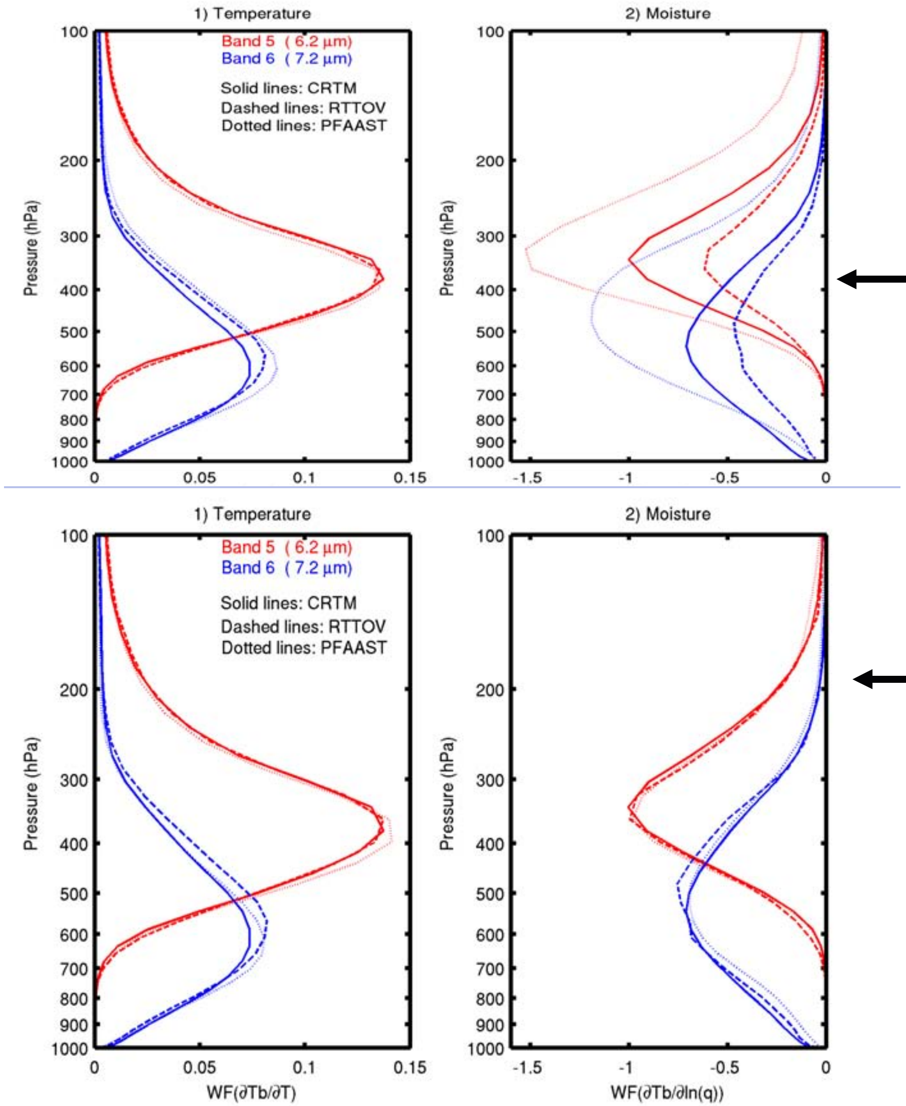
Inter-comparison of CRTM with RTTOV/PFAAST

Jun Li/Tim Schmit



Simulated vs observed brightness temperatures using 457 radiosonde profiles

Weighting Functions at GOES-R ABI water vapor-absorbing bands

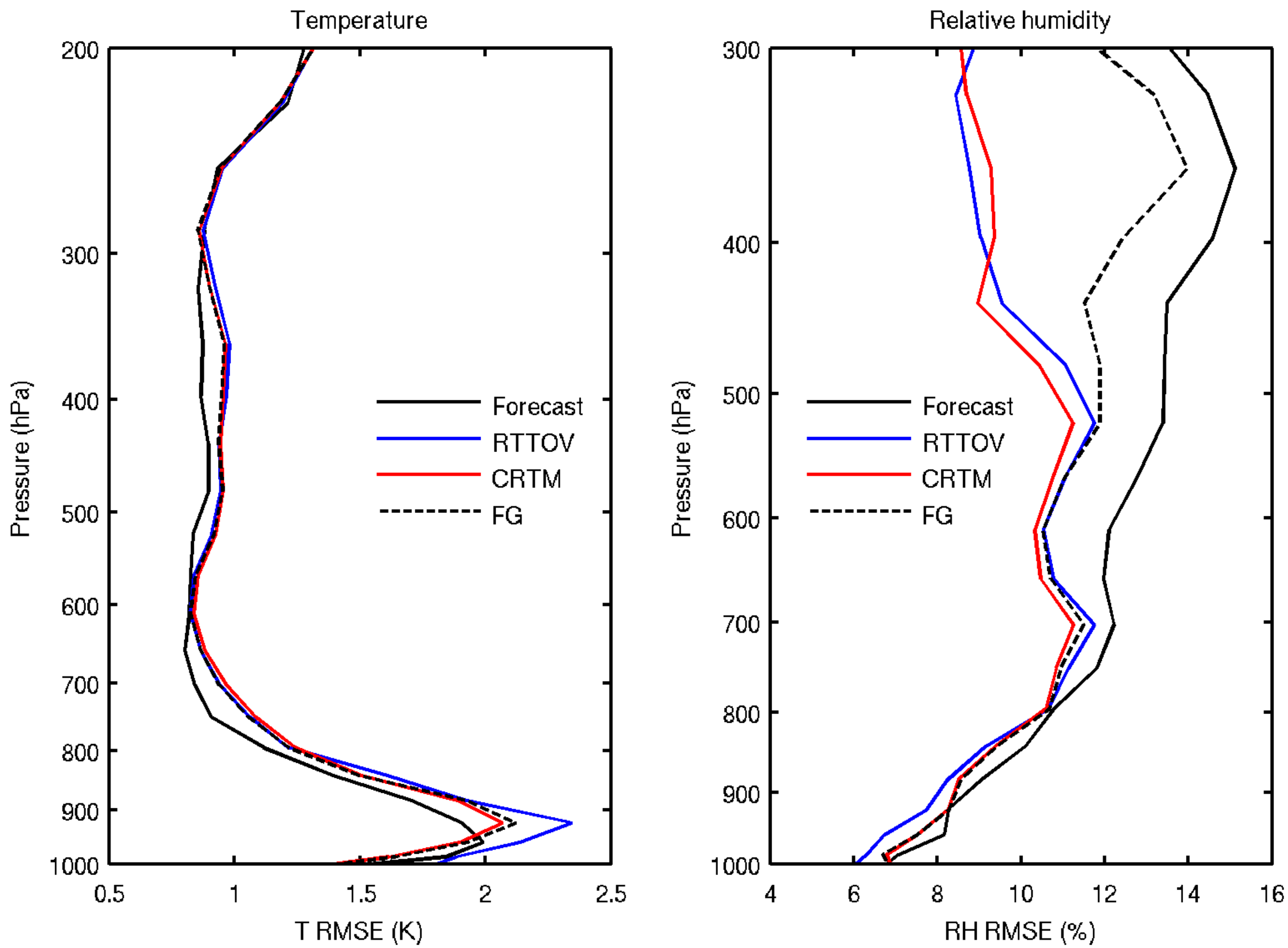


Internal Jacobian schemes

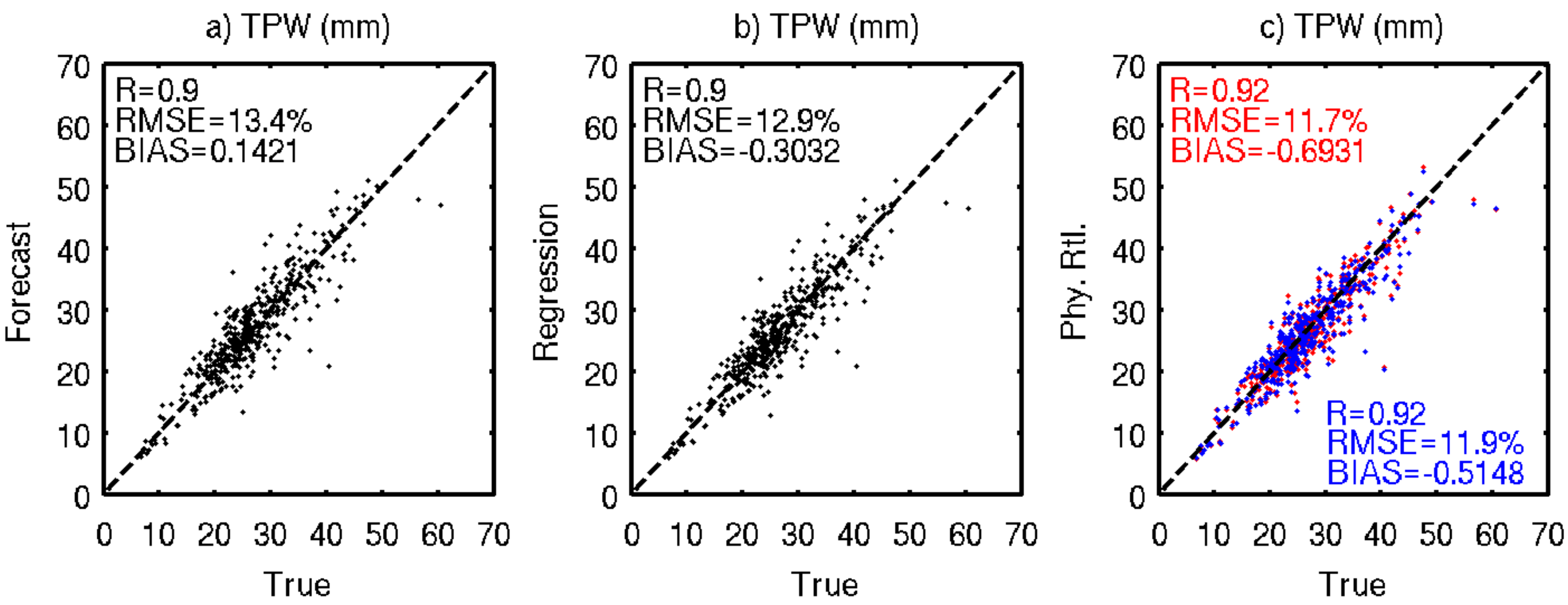
Perturbation method

Assumption: surface emissivity = 0.98, local zenith angle = 0 deg., and skin temperature = 300 K

Profile RMSE Retrieved from ABI by CRTM and RTTOV



TPW Retrieved by CRTM and RTTOV



Blue: RTTOV, Red: CRTM

Summary

- US Joint center for satellite data assimilation (JCSDA) program has developed a new generation of radiative transfer model (community radiative transfer model, CRTM) for uses in NWP data assimilation system
- Currently, CRTM has been used by JCSDA partners NCEP, NRL, GMAO, NCAR/AFWA, GOES-R Program.
- Version 2 CRTM upgrades include ODPS, MW land emissivity, aerosols, and other advanced algorithms
- Independent assessments of CRTM by CIMSS team show excellent performance for several applications, i.e., ABI and SEVERI retrievals, and NWP applications
- Impacts of CRTM on GFS analysis and other data assimilation systems are positive. Impacts of the emissivity models alone on global 6-7 forecasts are also assessed and significant.
- Infrared emissivity analysis from AIRS retrievals demonstrates large variability depending on surface type, and scan angle, etc. LSE diurnal variability over deserts seem to be too large and unreal.