Cloud Scattering and Surface Emission in (CRTM)

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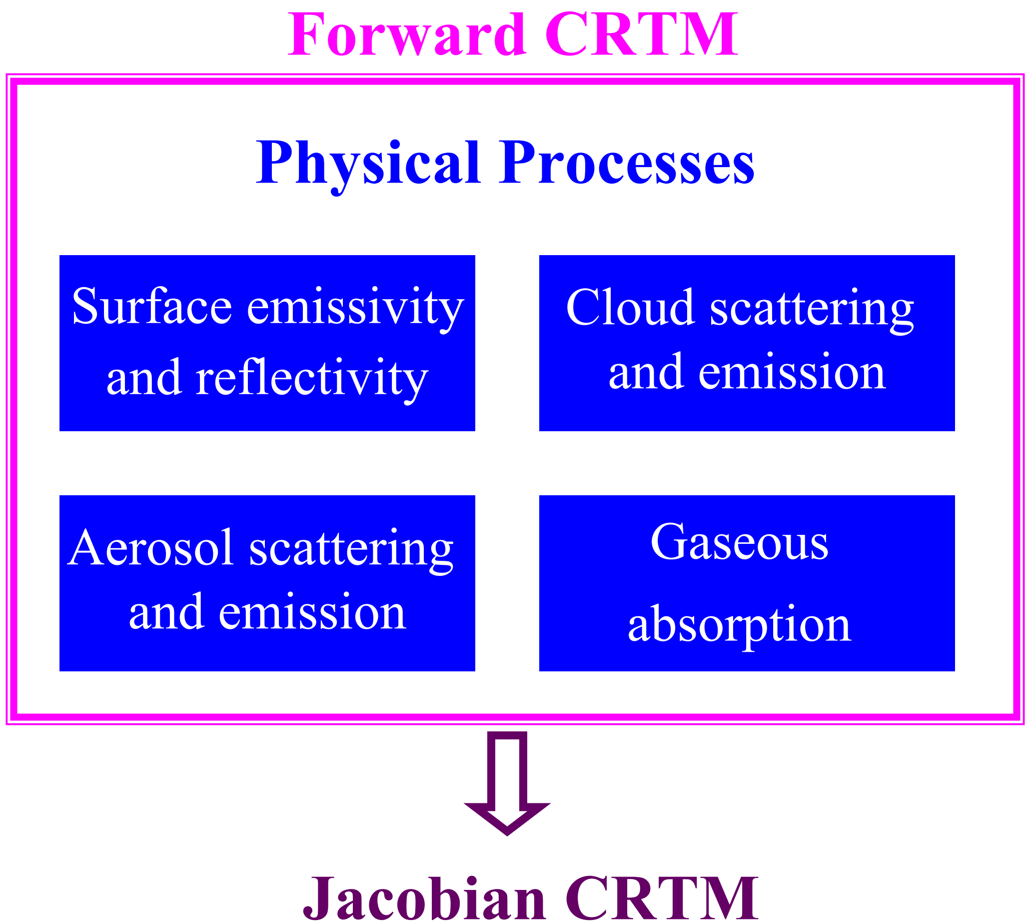
Outline

- Latest Updates on CRTM
- Microwave and Infrared Emissivity Models
- New Global Emissivity Data Base and Modeling Theory
- Impact of Emissivity Data and Models on NWP
- Summary and Conclusions

CRTM: Community Radiative Transfer Model



Latest Updates on CRTM

- Computational efficiency Improved
  - Forward model speedup by a factor 3
  - Jacobian model speedup by a factor 2
- Multiple transmittance algorithm framework

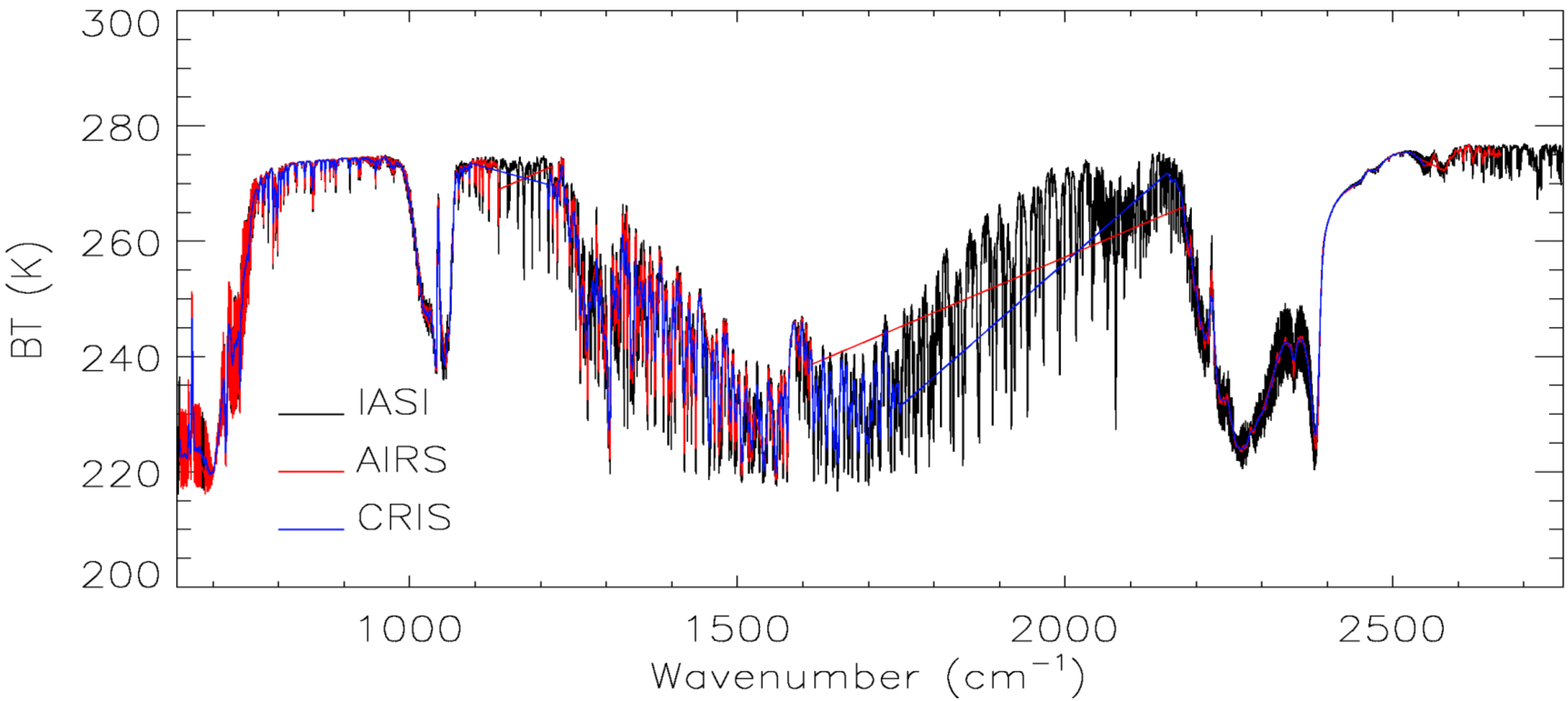
  OPTRAN ODPS model

  SSU model SSMIS and AMSUA Zeeman models
- Visible and UV sensors and molecular scattering added
- Surface emissivity/reflectivity module
  - BRDF for solar reflection over ocean
  - Improved IR ocean emissivity model
  - MW snow and ice empirical models for additional sensors
- Additional Instruments

  FY3-MWTS FY-3 MWHS FY-3 MWRI MSG-SEVIRI

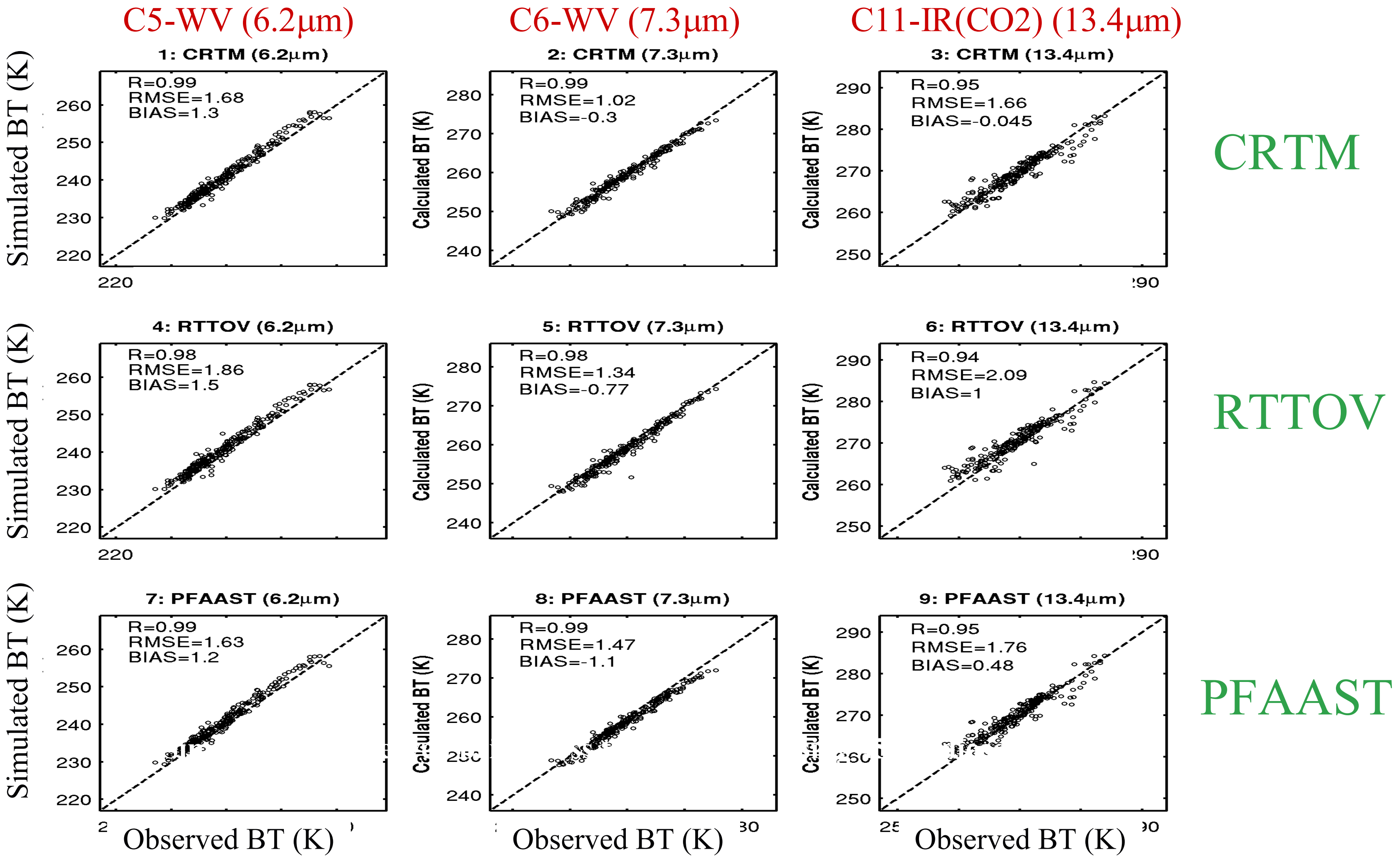
  FY3-IRS DMSP-SSMIS GOES-R ABI

CRTM Simulated BT Spectrum for Hyperspectral Infrared Sensors

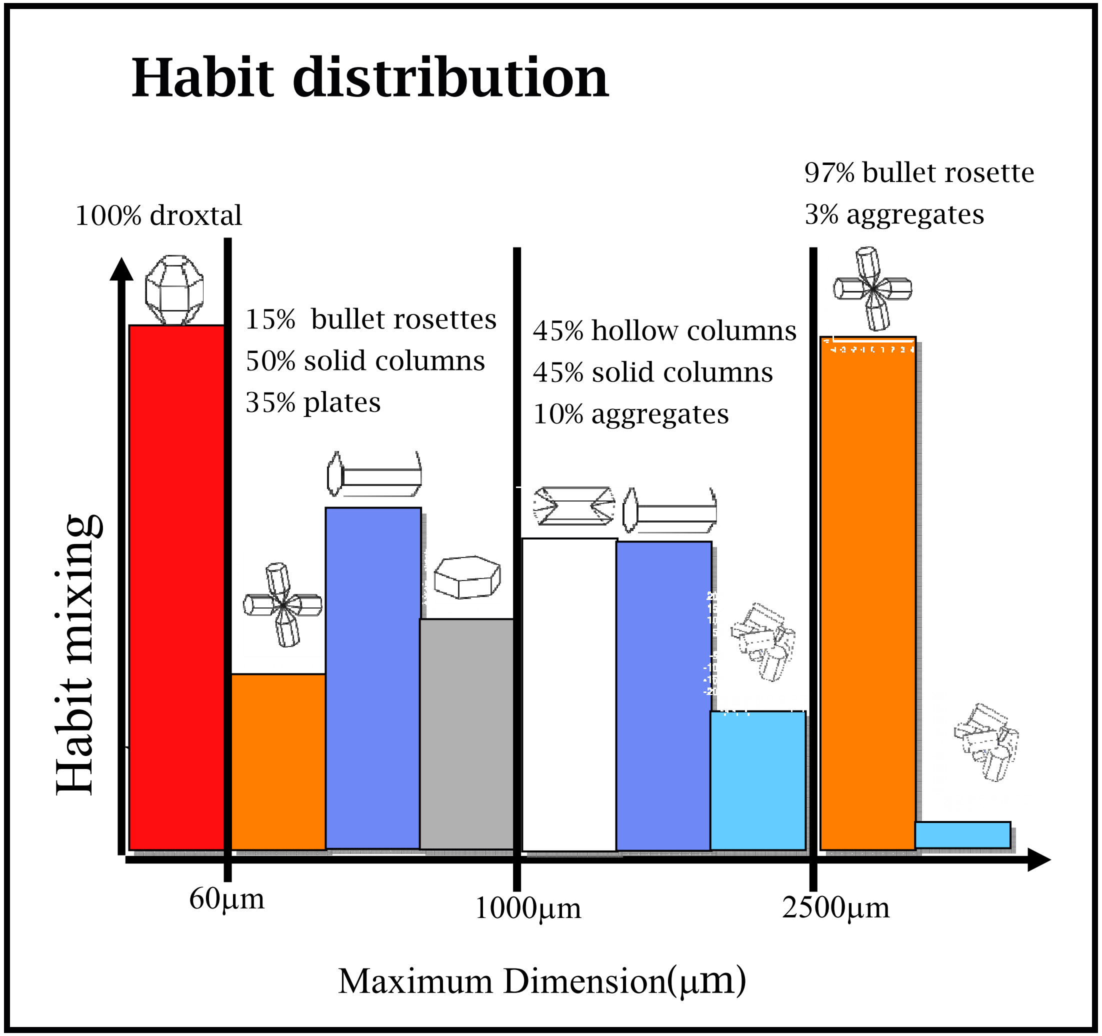


IASI (black line) AIRS (red line) CrIS (blue line)

Inter-Comparison between Different RTM for Simulating MSG SEVIRI Data



Cloud Absorption/Scattering Module



Cloud Types:

water	ice
rain	snow
graupel	hail

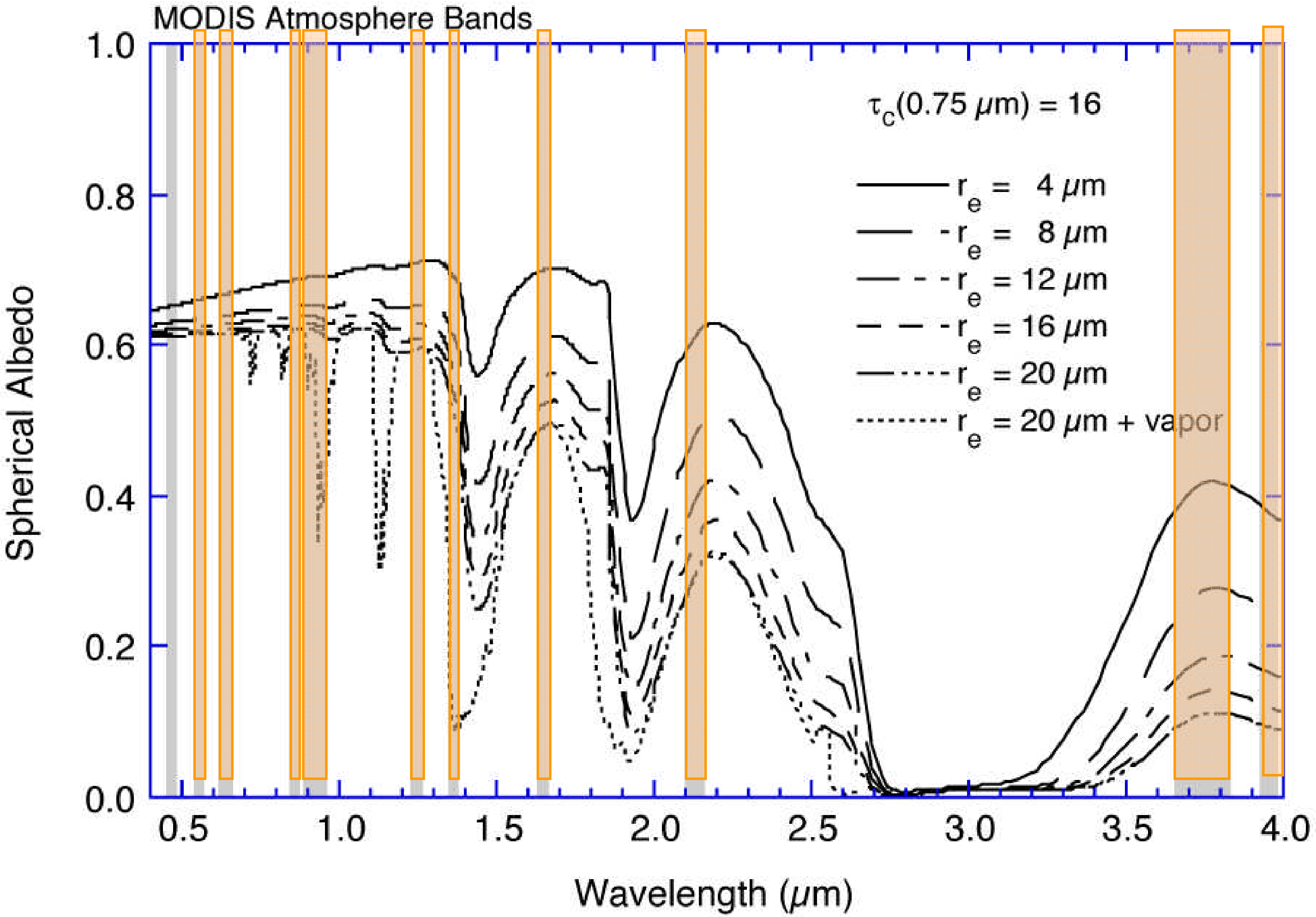
Look-up Table:

- mass extinction coefficient
- single scattering albedo
- Asymmetric factor
- Legendre phase coefficients

✓ spherical cloud droplets (Simmer, 1994)

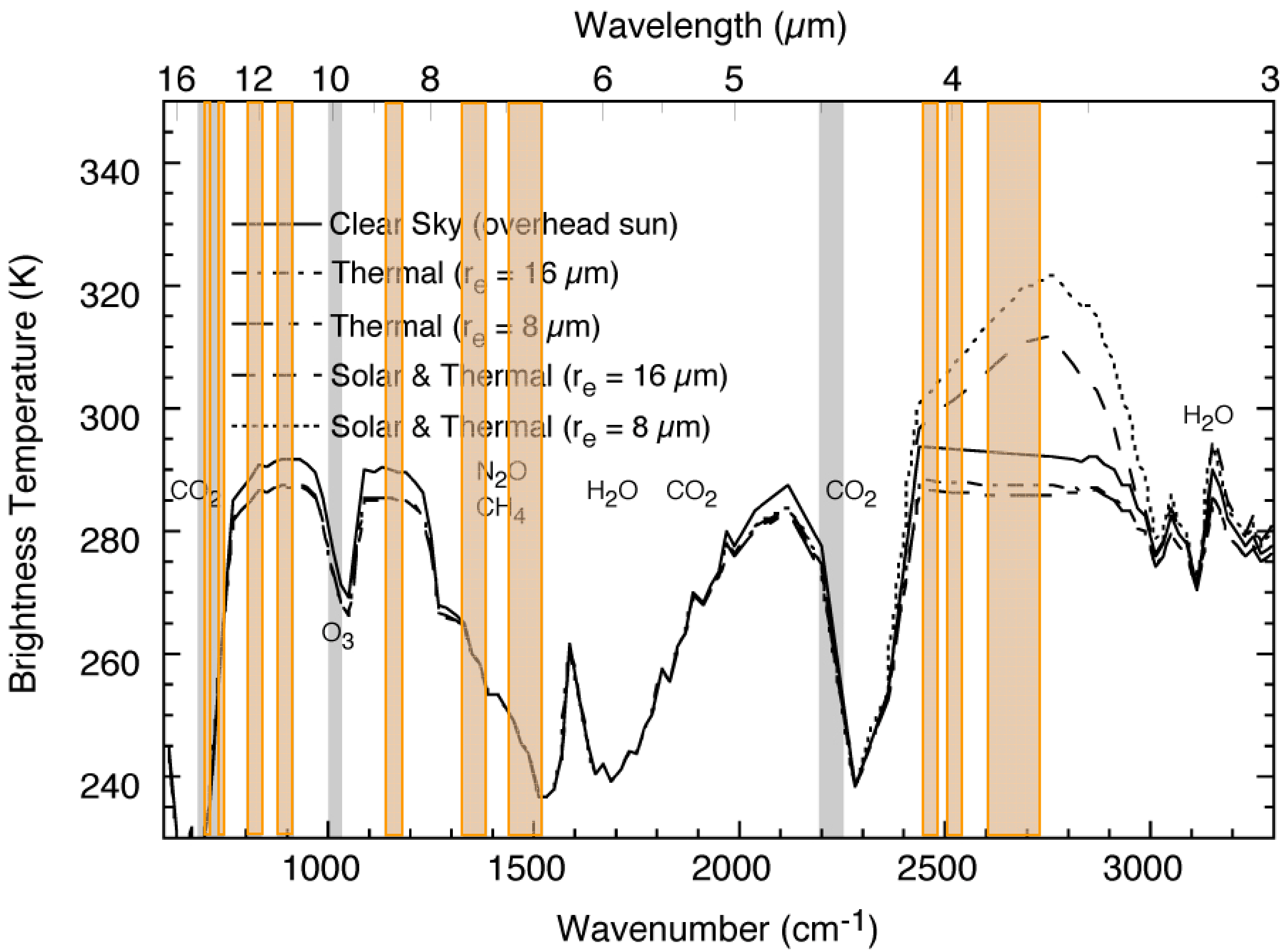
✓ non-spherical ice cloud particles (Yang et al., 1997; Macke, Mishenko et al.; Baum et al., 2001)

Shortwave Properties of Clouds
Cloud Mask Bands

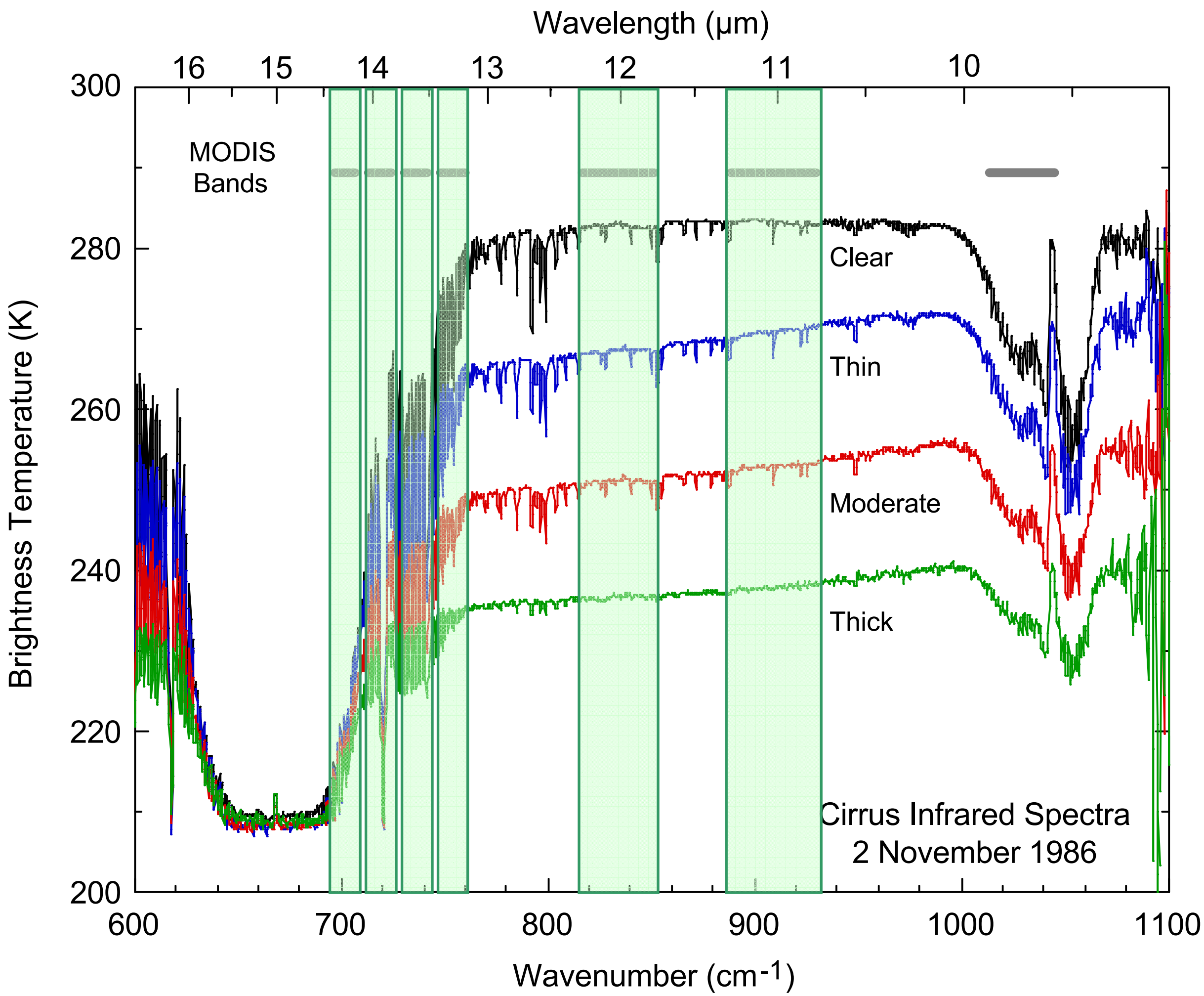


Infrared Properties of Clouds

Cloud Mask Bands



Infrared Properties of Clear Skies & Cirrus CO_2 Slicing Bands

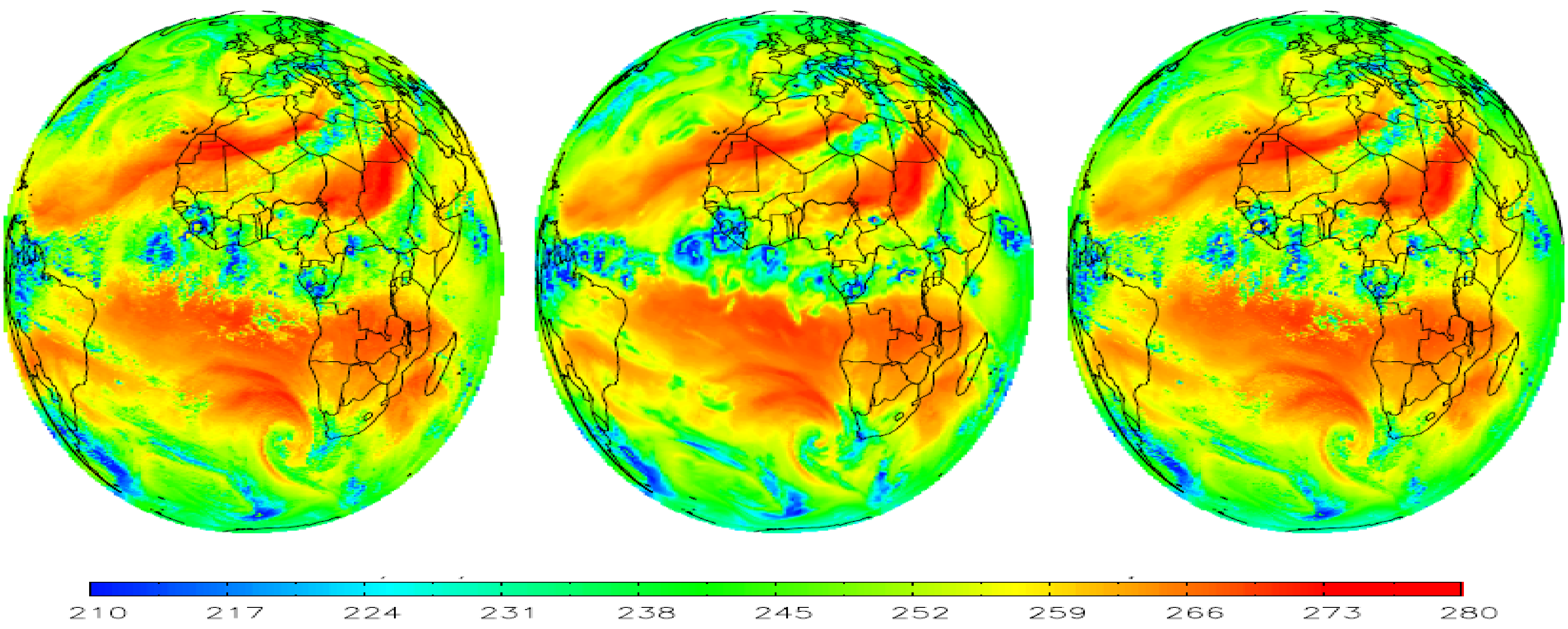


Observed and CRTM Simulated SEVIRI Channel 3

SEVIRI Observation

Simulated with ECMWF Cloud

Simulated with IR Cloud



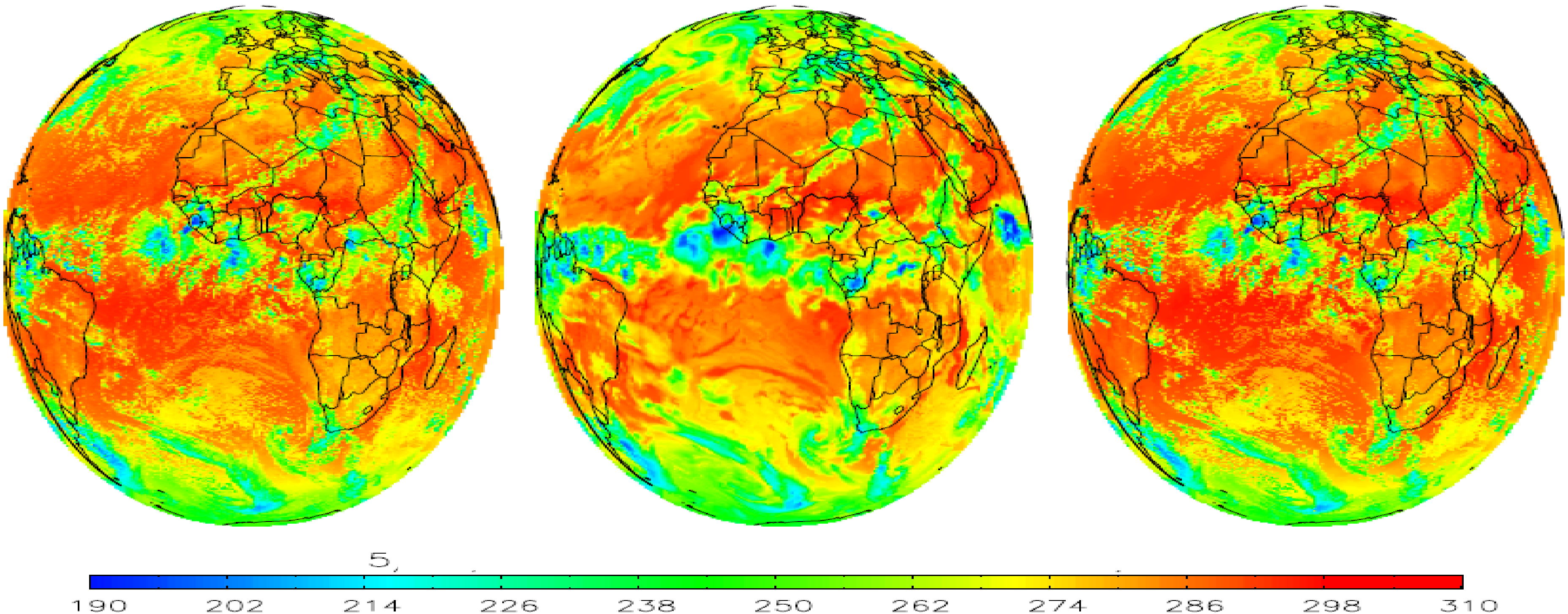
0030 Z May 20, 2008, 7.35μm

Observed and CRTM Simulated SEVIRI Channel 4

SEVIRI Observation

Simulated with ECMWF Cloud

Simulated with IR Cloud



0030 Z May 20, 2008, 8.7μm

SEVIRI Observations vs Simulations

Channel	Clear-Sky		ECMWF		ECMWF+IR Cloud	
	Bias	Sigma	Bias	Sigma	Bias	Sigma
1	-30.14	36.39	-4.06	15.90	-1.29	2.02
2	-4.39	8.71	-0.02	6.33	-0.79	2.20
3	-12.46	18.35	-0.72	10.80	-0.83	1.86
4	-34.12	40.41	-2.46	17.05	-0.11	1.38
5	-19.10	23.73	-2.19	9.73	-0.44	1.46
6	-36.02	42.64	-1.82	17.97	0.48	1.48
7	-35.18	41.73	-1.80	17.82	0.36	1.47
8	-20.97	26.85	-0.93	12.54	-0.40	1.56

Datasets Used for CRTM Validation

- **CloudSat data**

  Afternoon satellite, Local time ascending node 1:31pm

  – Cloud Geometrical Profile: 2B-GEOPROF

  – Cloud Classification: 2B-CLDCLASS

  – Cloud Liquid/ICE Water Content & particle size: 2B-CWC-RO

- **Analyses**

  Temperature, water vapor and O_3 profiles and surface state

  – ECMWF analysis data set: ECMWF-AUX

  –NCEP surface analysis data set

- **NOAA 18 data**

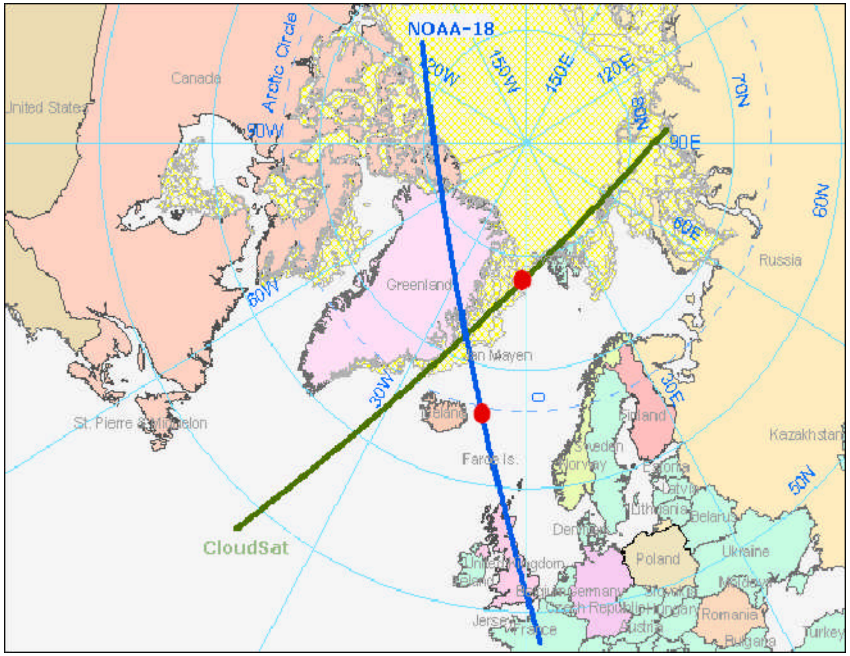
  Afternoon satellite, Local time ascending node 1:38pm

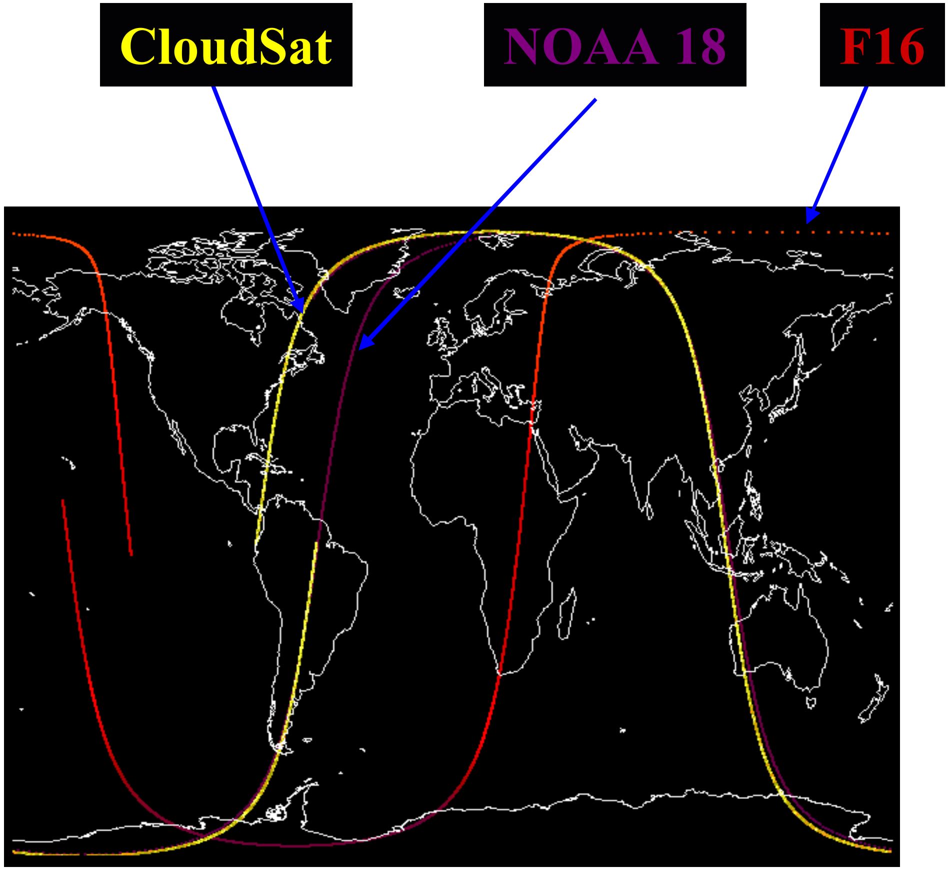
  –AMSUA Level 1B and Level 2 data set

  – MHS Level 1B and Level 2 data set

  – AVHRR/3 Level 1B (GAC) data set

CRTM Validation Using CloudSat Data
NOAA 18 Orbit Data Matching





Using SNO method to match the polar-orbiting satellite radiometers.

Matching Criteria for CloudSat and NOAA 18 Data

Spatial distance <
- 50 km AMSUA
- 16 km MHS
- 4 km AVHRR/3

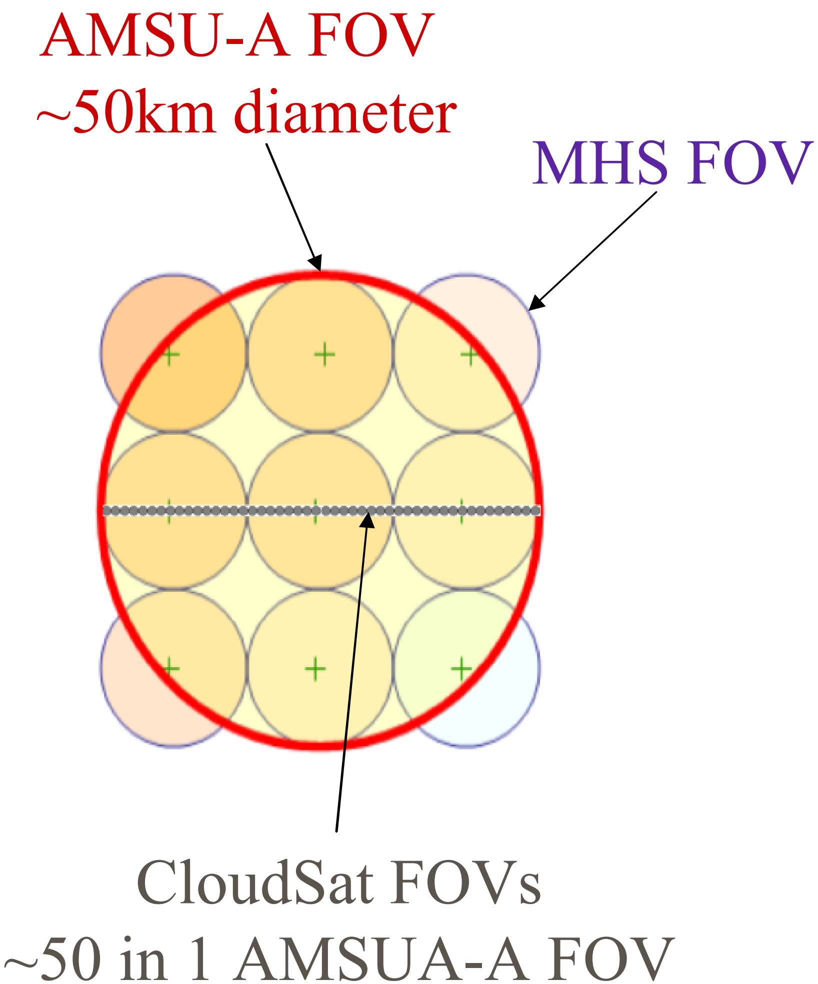
Time difference < 2 minutes

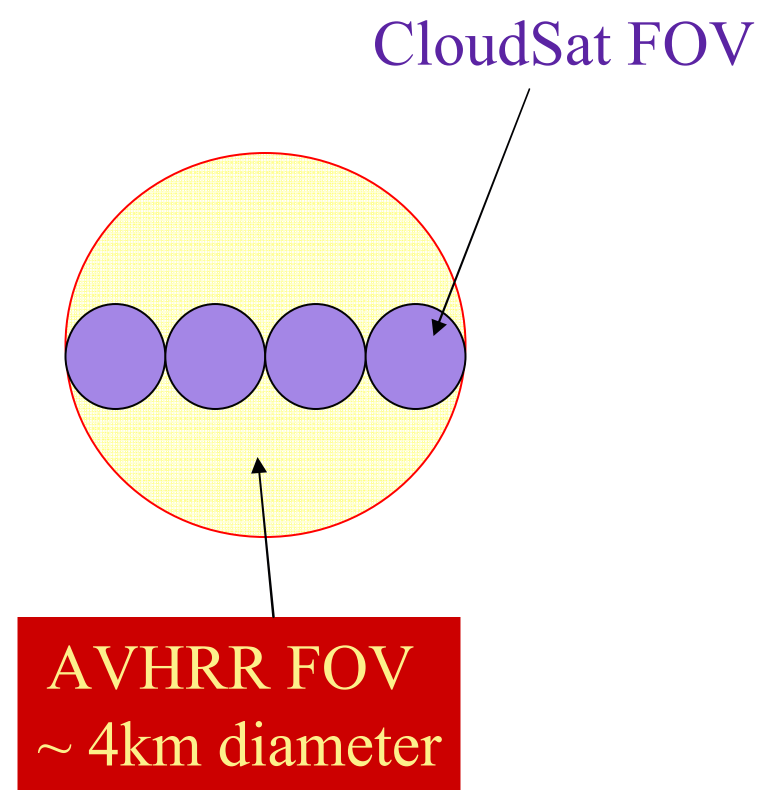
Time periods:
- 07/07/06-08/16/06
- 10/01/06-11/04/06
- 01/01/07-02/01/07

Other constraint: $-50^{o}N < \varphi < 50^{o}N$ and over ocean

A total of 31 orbit data meet the requirements.

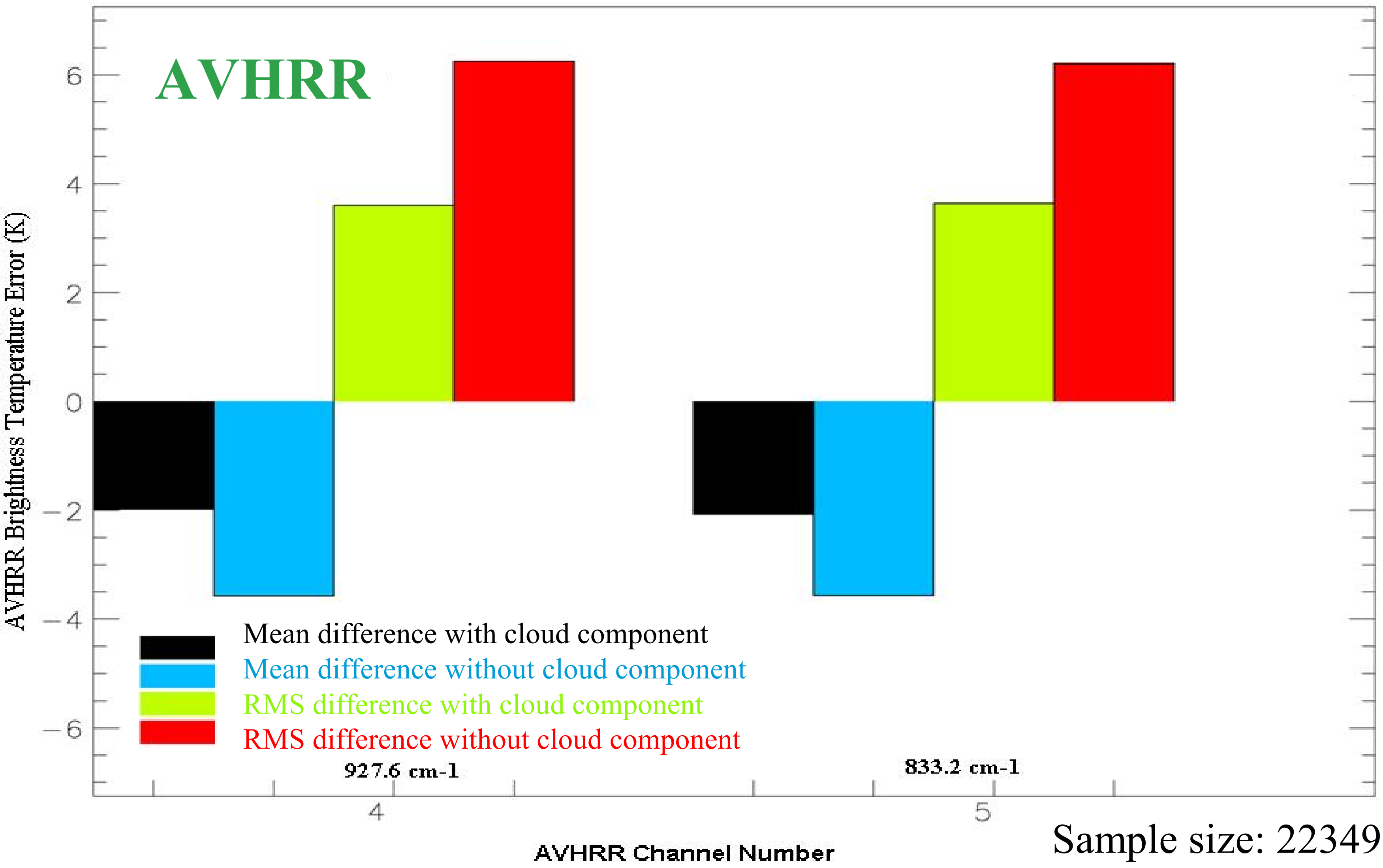
Handling of Cloud Inhomogeneity Effects on CRTM Validation





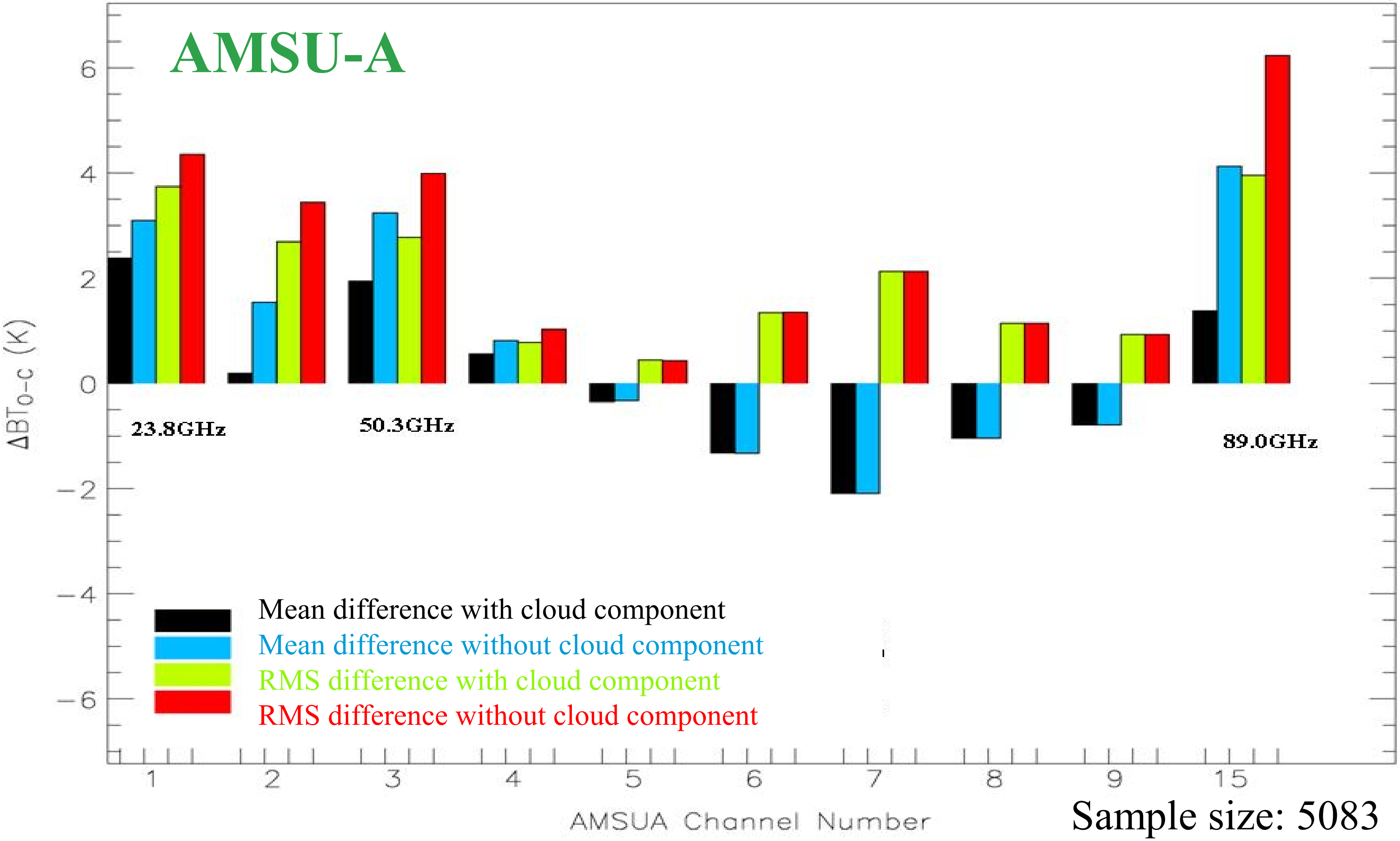
(Chen et al., 2008, JGR)

Effects of Cloudy Components in CRTM



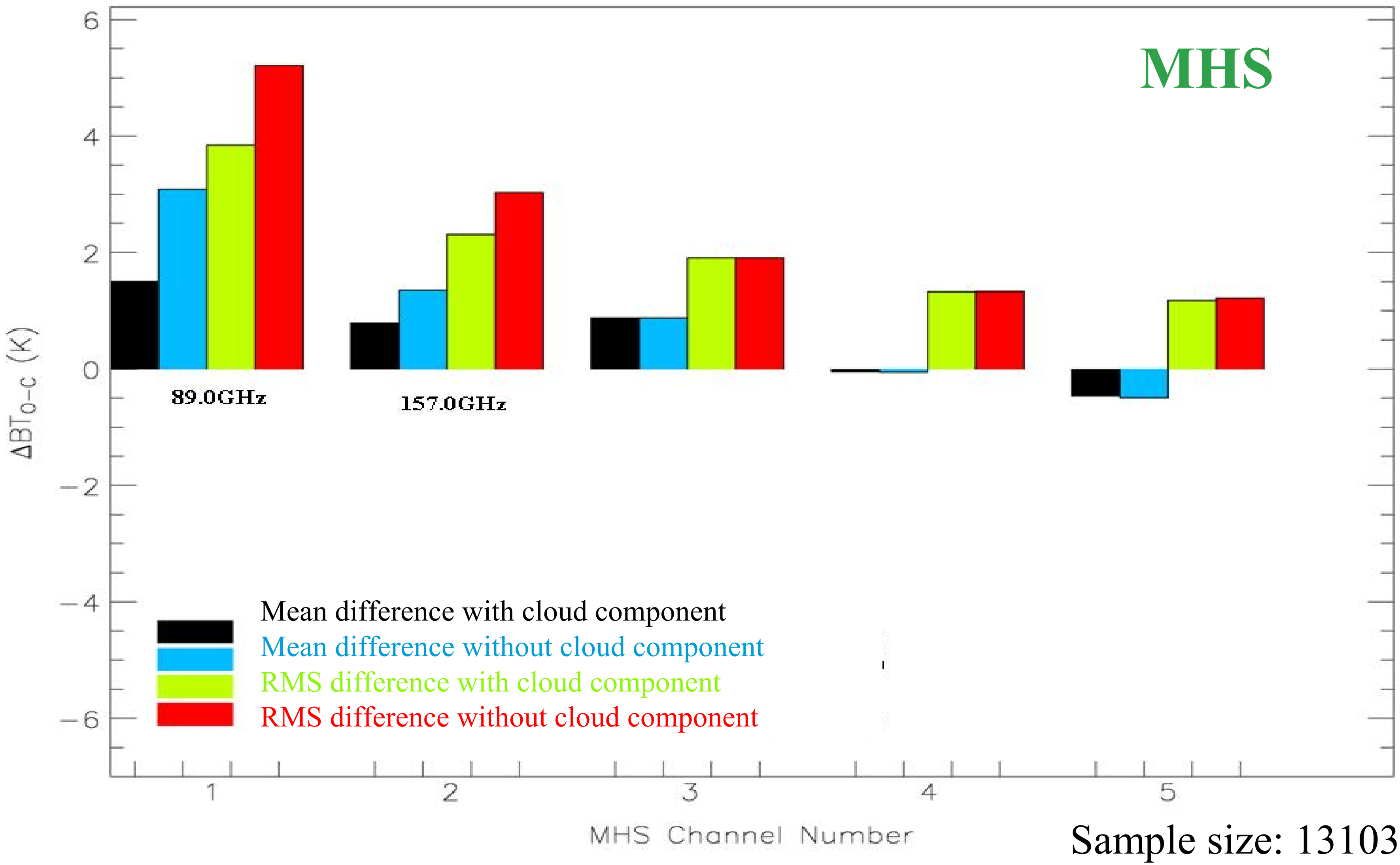
Sample size: 22349

Effects of Cloudy Components in CRTM



Sample size: 5083

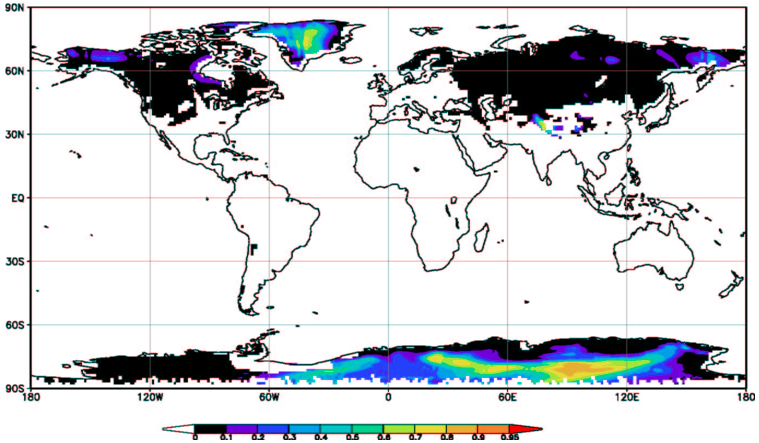
Effects of Cloudy Components in CRTM



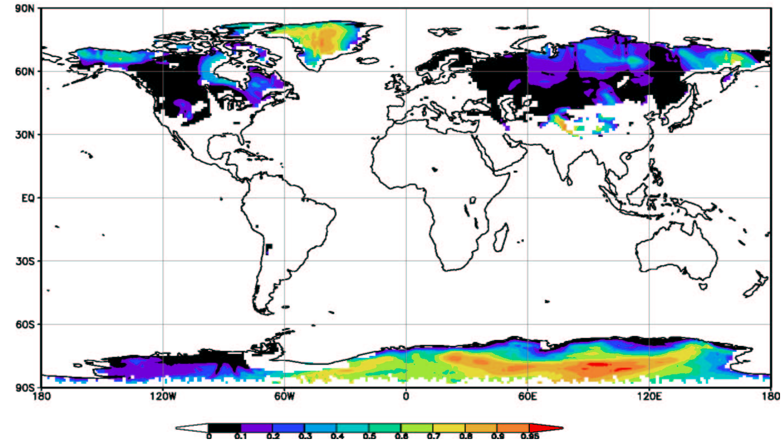
Sample size: 13103

Atmospheric Transmittance

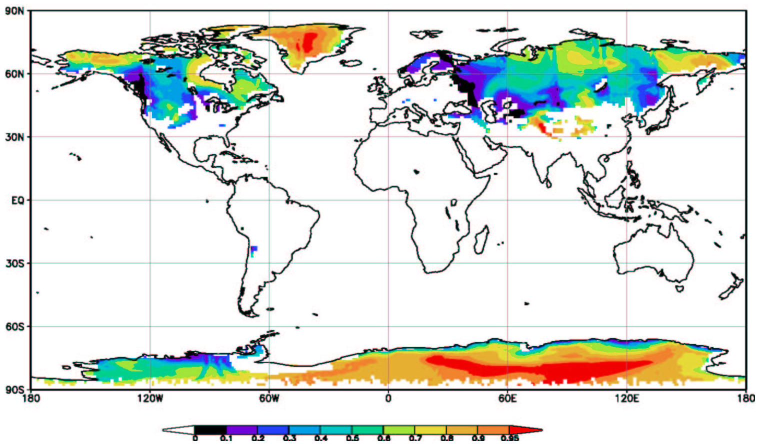
Atmospheric Transmittance at 183.3 ± 1 GHz



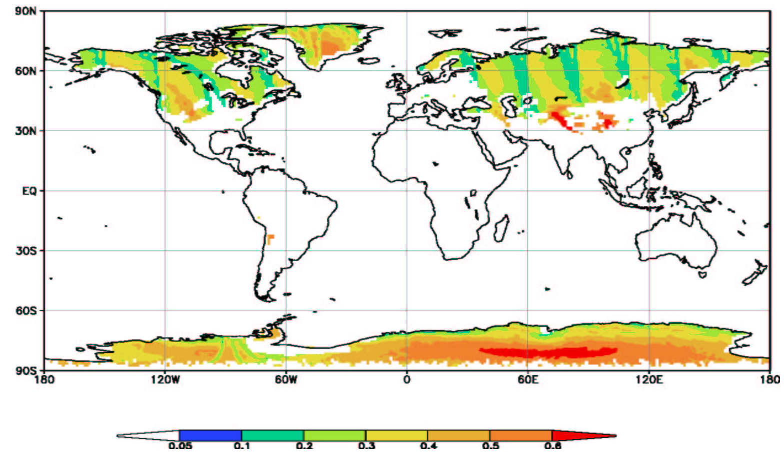
Atmospheric Transmittance at 183.3 ± 3 GHz



Atmospheric Transmittance at 183.3 ± 7 GHz



Atmospheric Transmittance at 52.8 GHz



A typical channel for atmospheric profiling can become surface sensitive in certain conditions (e.g. dry moisture, high elevation)

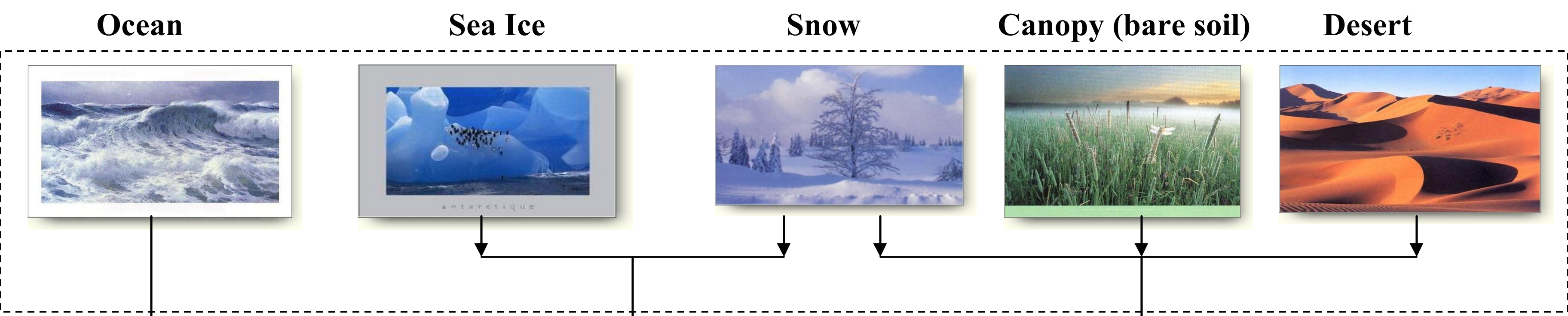
Sensitivity of BT to Surface Emissivity

Freq (GHz)	Ts = 230 K and TPW = 0.5 mm					
	Ps = 600 (mb)			Ps = 1000 (mb)		
	Td(K)	τ	ΔTa(K)	Td(K)	τ	ΔTa(K)
6.925	1.50	0.99	9.08	4.00	0.98	8.87
10.65	1.60	0.99	9.07	4.40	0.98	8.84
18.7	2.30	0.99	9.02	6.20	0.97	8.70
23.8	3.30	0.98	8.93	8.50	0.96	8.51
36.5	7.10	0.97	8.63	19.10	0.91	7.69
50.3	49.30	0.77	5.59	112.50	0.49	2.29
52.8	111.20	0.49	2.34	188.60	0.15	0.25
89	8.20	0.96	8.54	22.30	0.90	7.46
150	4.40	0.98	8.84	12.50	0.94	8.21
183.3±7	16.60	0.93	7.89	43.50	0.81	6.02
183.3±3	55.30	0.75	5.24	104.10	0.54	2.71
183.3±1	134.60	0.39	1.50	160.10	0.29	0.81

$$\Delta T_a = \tau (T_s - T_d) \Delta \varepsilon \qquad \Delta\varepsilon = 0.04$$

Uncertainty in Surface emissivity of 5-10% will produce brightness temperature uncertainty up to several degrees!

CRTM Baseline Surface Emissivity Modules



Microwave land emissivity model (Weng et al., 2001) and desert microwave emissivity library (Yan and Weng, 2010)

NPOESS Infrared emissivity data base

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

Two-layer snow emissivity model (Yan, Weng, Liang, 2010)

Fast multi-layer snow emissivity model (Liang, Weng, Yan., 2010)

FASTEM3 microwave emissivity model (English and Hewison, 1998)

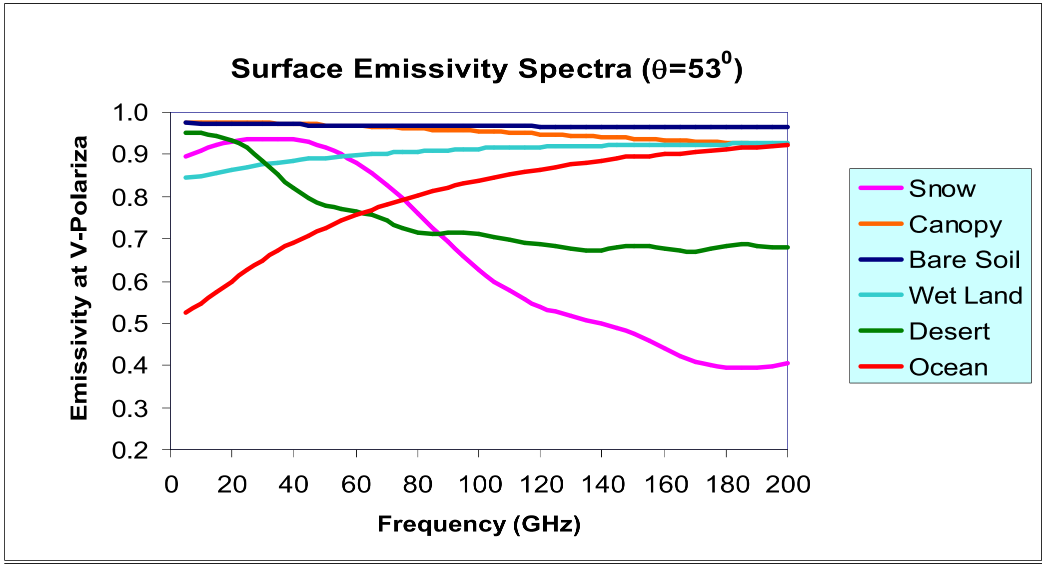
IR emissivity model (Wu and Smith, 1991; van Delst et al., 2001)

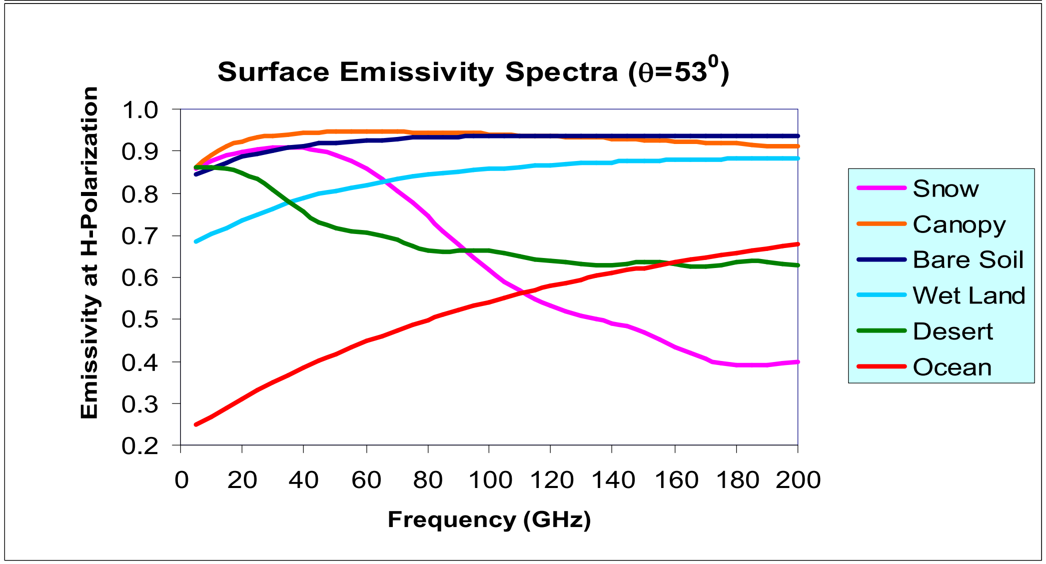
FASTEM4 microwave emissivity model (Liu, Weng, English, 2010)

Surface Emissivity Modeling

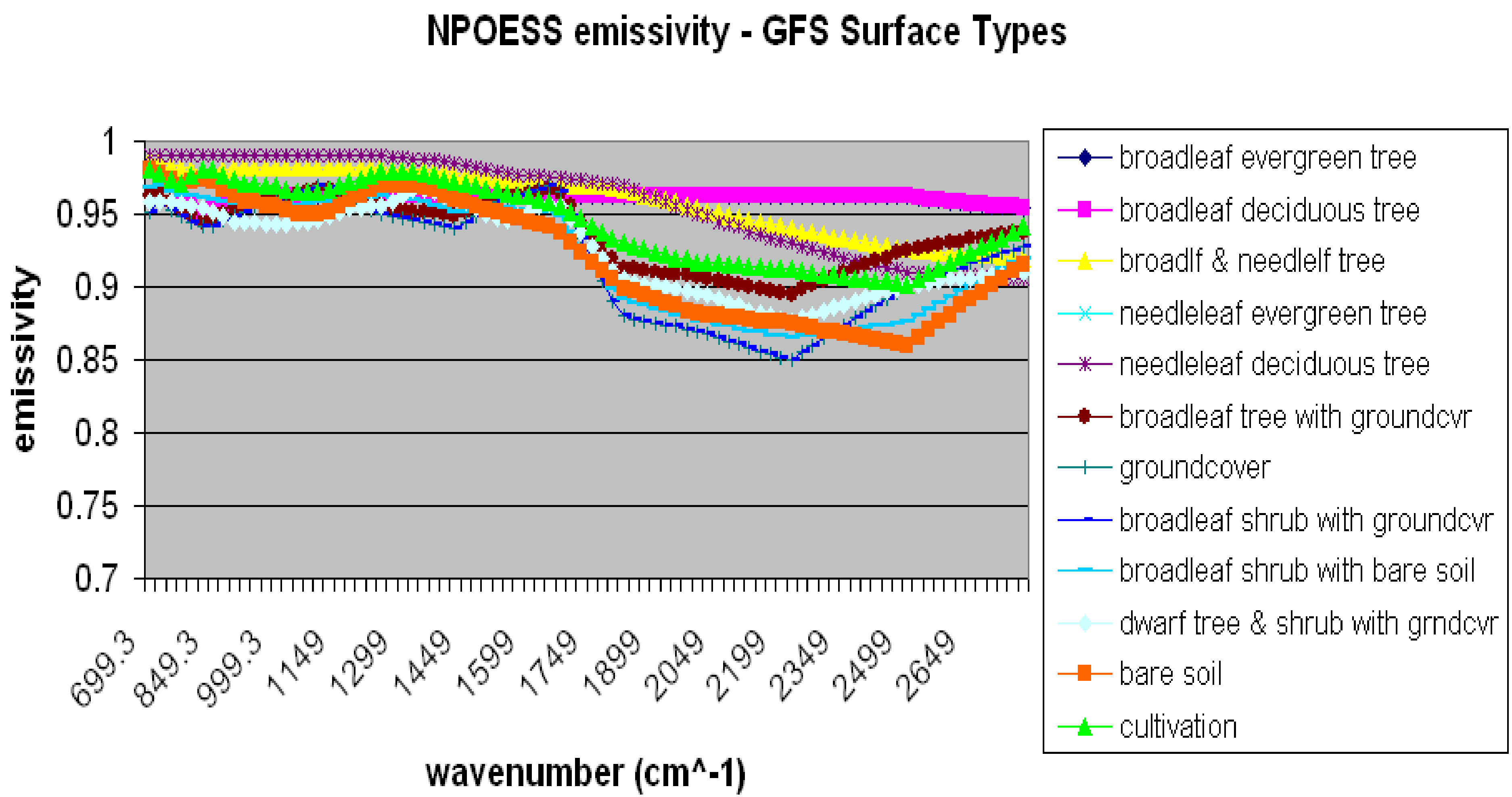
- **Open water** – two-scale roughness theory
- **Sea ice** – Coherent reflection
- **Canopy** – Four layer clustering scattering
- **Bare soil** – Coherent reflection and surface roughness
- **Snow/desert** – Random media

Weng et al (2001, JGR)

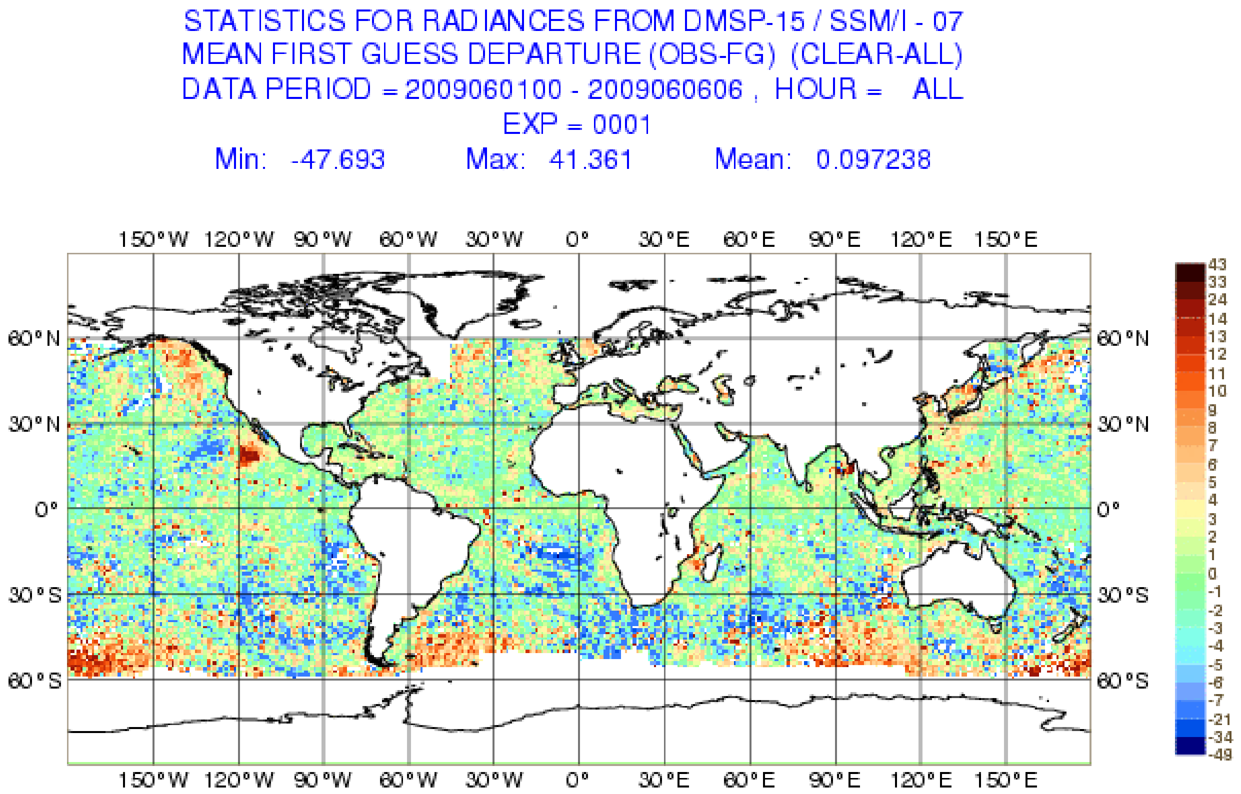




Land Infrared Emissivity Database



Major Problems in Baseline Surface Emissivity Models



- FASTEM3 displays a large bias at low (< 20 GHz) and high (> 60 GHz) frequencies
- Microwave land emissivity model (MLEM) displays certain bias over snow and desert surfaces

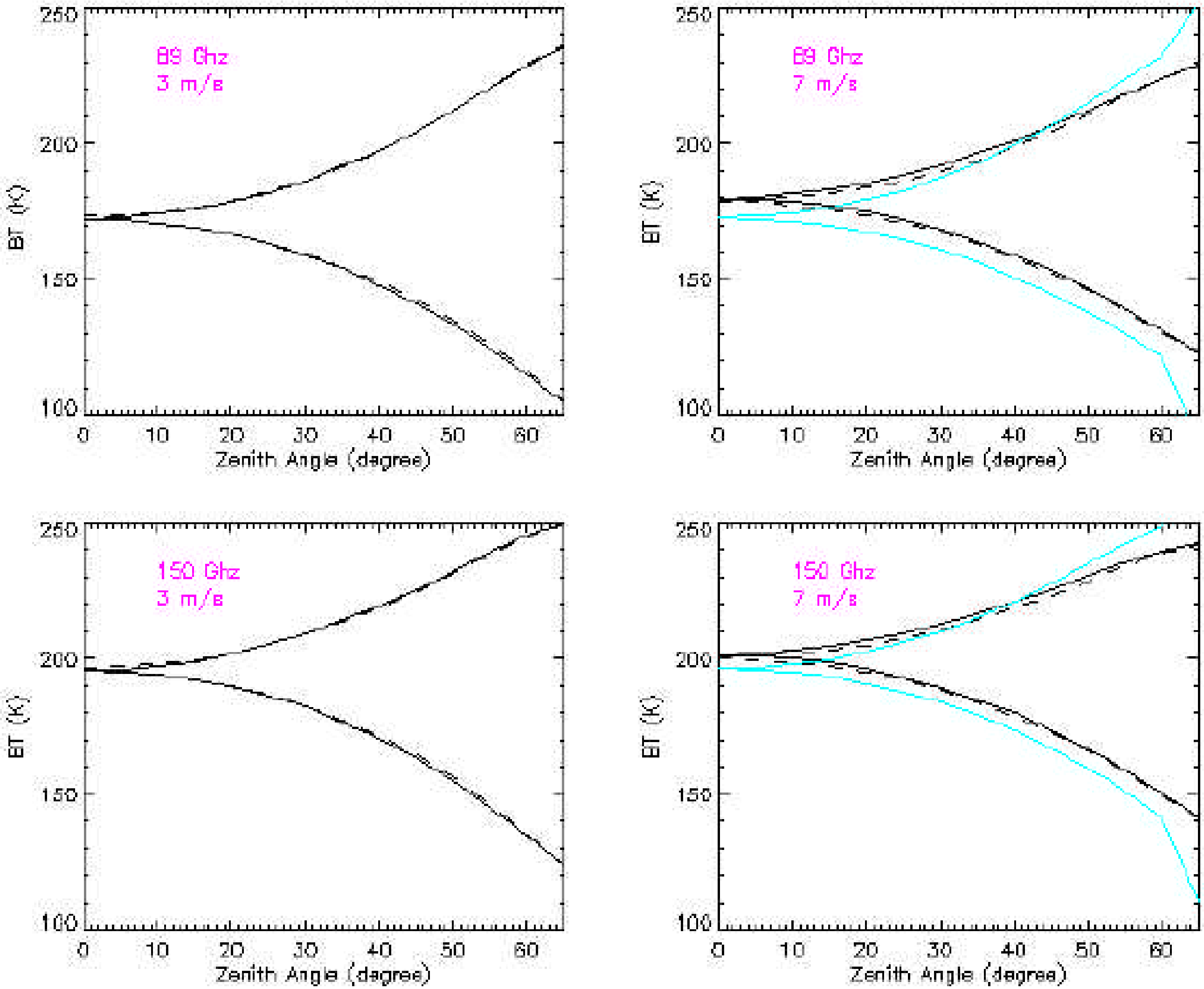
Planned Upgrade to CRTM Emissivity Models

- Ocean microwave emissivity, FASTEM4
  - ✓ Liu, Weng, and English, TGRS, 2010
- Two-layer snow microwave emissivity model
  - ✓ Yan, Weng, and Liang (2010)
- A fast multi-layer snow microwave emissivity model based on QCA/DMRT model
  - ✓ Liang, Weng, and Yan (2010)
- Desert microwave emissivity library
  - ✓ Yan and Weng, submitted to TGRS (2010)
- UWISC IR land emissivity data base from JPL/MODIS
  - ✓ Borbas ana Seaman (200X)

FASTEM-4

- Revised Double-Debye permitivity model with variable salinity & intermolecular interaction
- A factor 2 of slope variance from Durden and Vesecky spectrum model – upwind and cross-wind slopes
- Variable foam emissivity depending on angle and polarization (non-unity)
- Two-scale approximation with an automatic cutoff wavenumber calculation

FASTEM-4



Diamond symbol:

Measurement

Black solid:

two-scale simulation

Black dash:

FASTEM4

Blue line :

FASTEM3

Double Debye's Model with Intermolecular Interaction

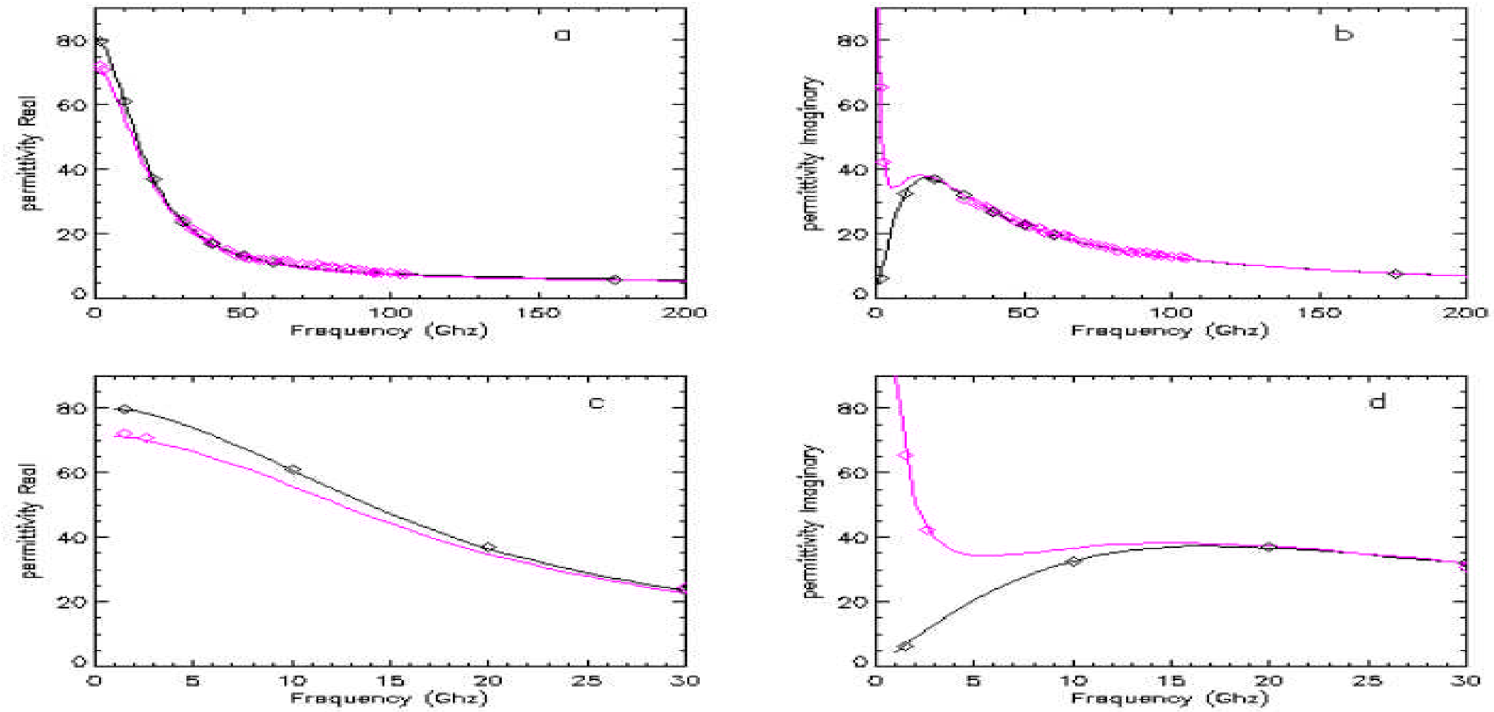


Figure 1. Panels (a) and (b) represent the real and imaginary parts of the permittivity. Panels (c) and (d) are a zoom-in part for low frequencies. The back line is for fresh water and the red line is for salted water. The water temperature is 25°C. The salinity of sea water is 35‰. The solid lines represent model results. The diamond symbols are for measurements.

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

Intermolecular interaction

Durden and Vesecky (DV), DV2 and Cox-Munk Models

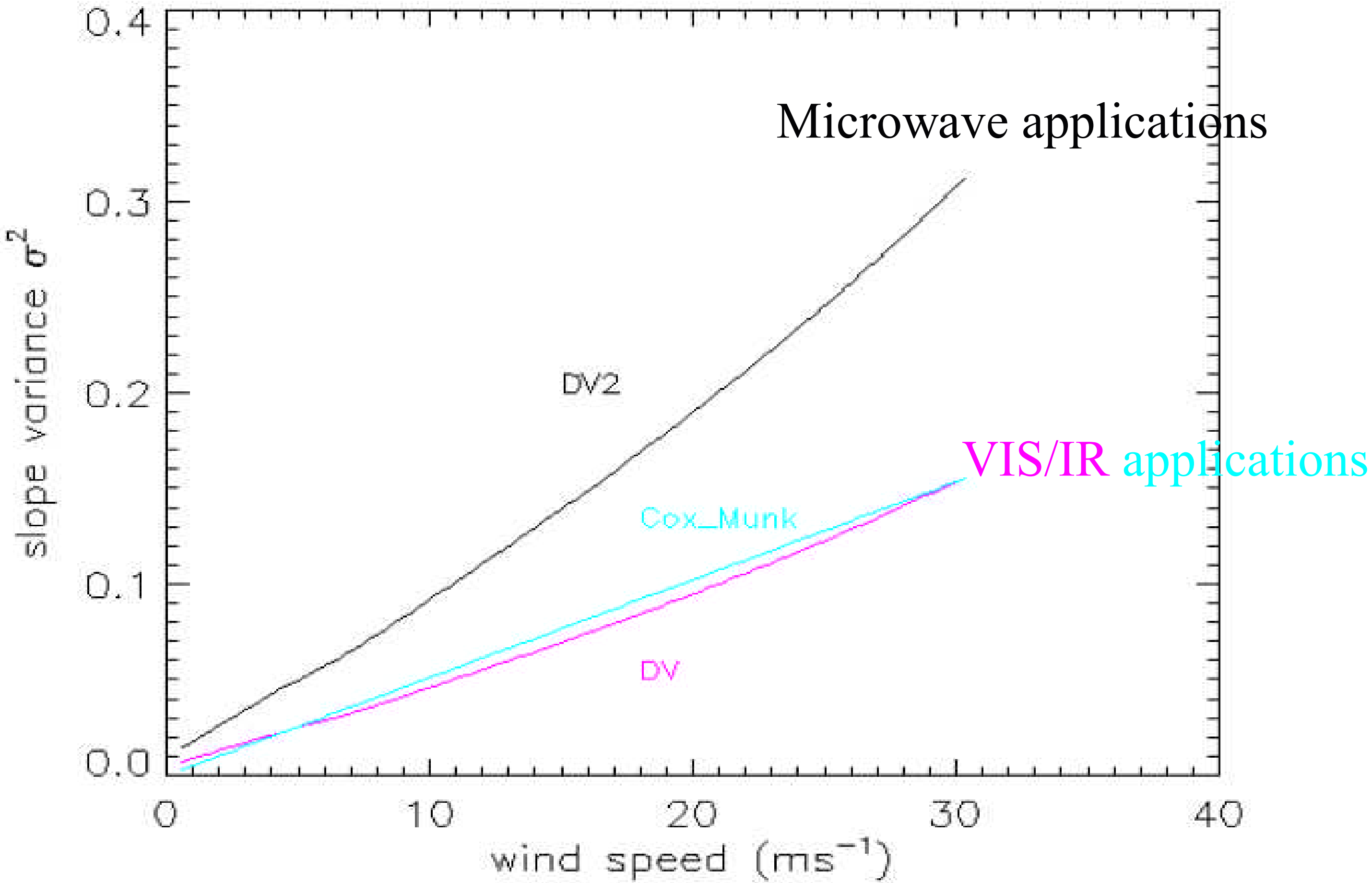
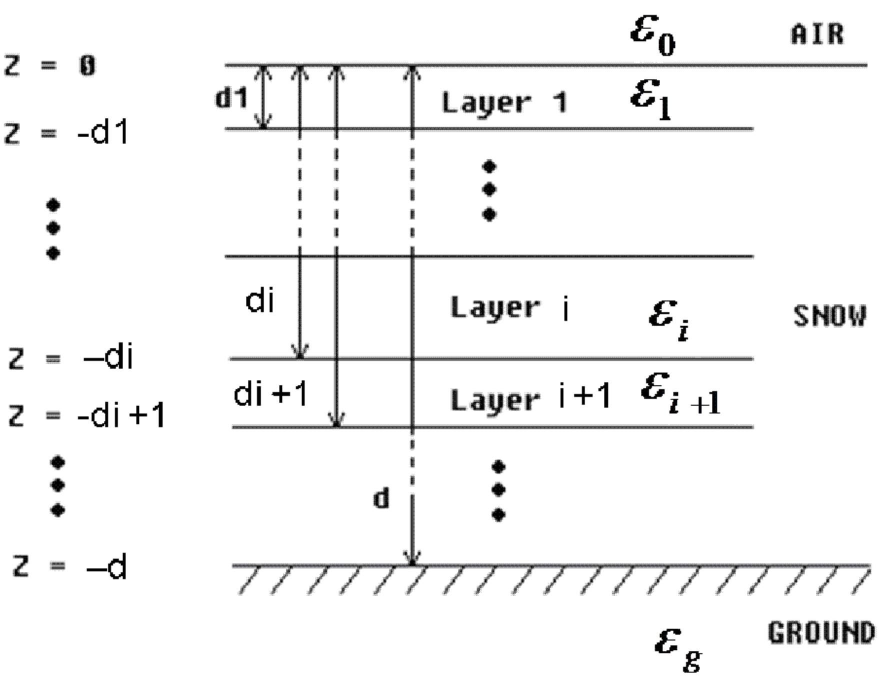


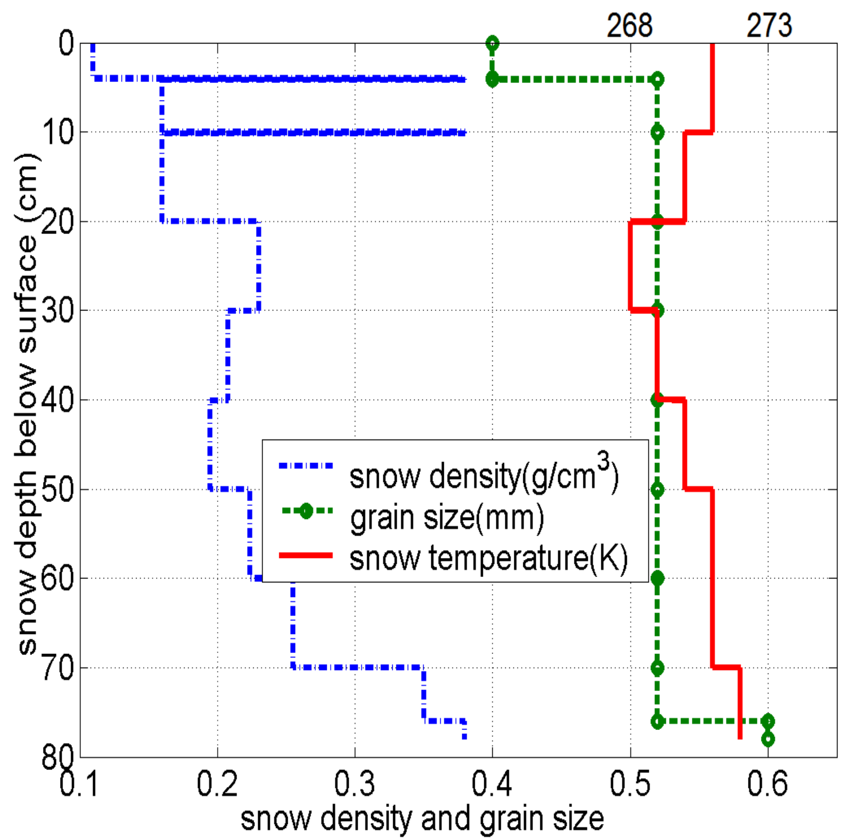
Figure 2. Slope variances for the DV, DV2 spectrums and Cox-Munk as a function of the wind speed at 10 meter above the surface.

Layered Snow Emissivity Modeling from QCA/DMRT

Dense media radiative transfer equations in layer i:

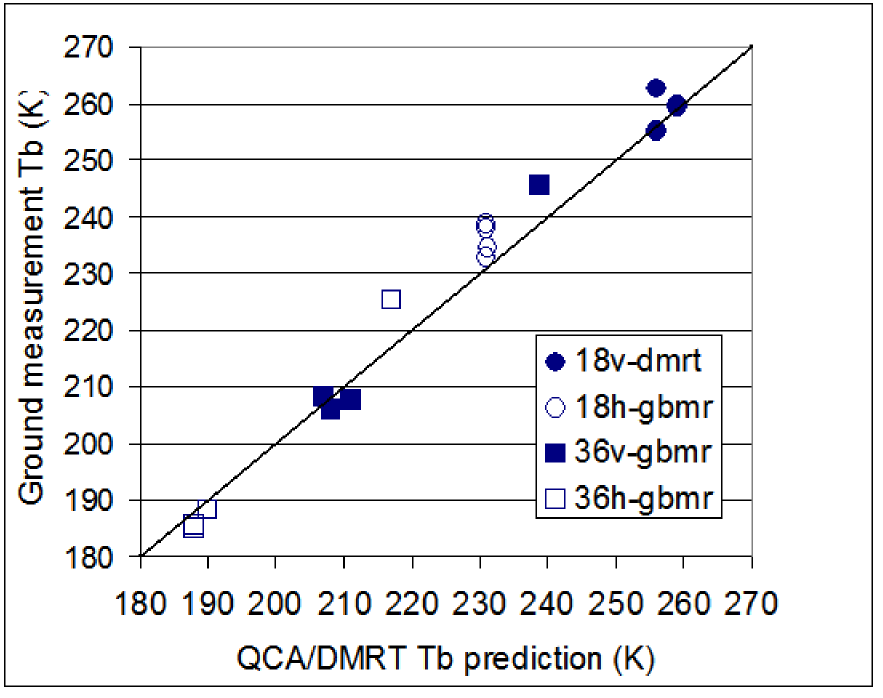
$$\cos\theta \frac{d\bar{I}_i(\theta,z)}{dz} = -\kappa_{ei} \cdot \bar{I}_i(\theta,z) + \kappa_{ai} T^i + \int_0^{\pi} d\theta' \sin\theta' \bar{\bar{P}}_i(\theta;\theta') \bar{I}_i(\theta',z)$$



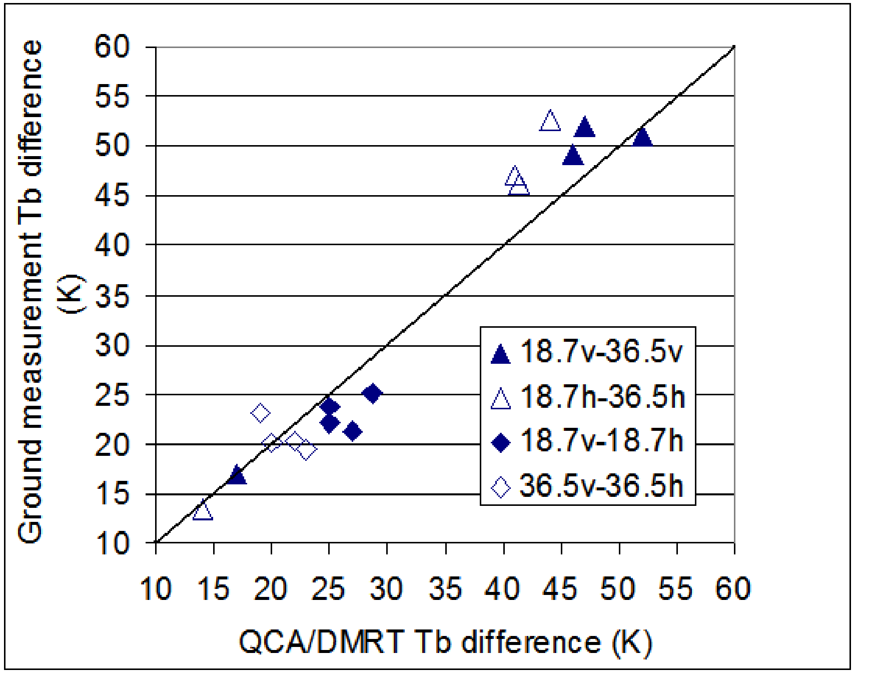


Validation of DMRT Brightness Temperatures

TB comparisons

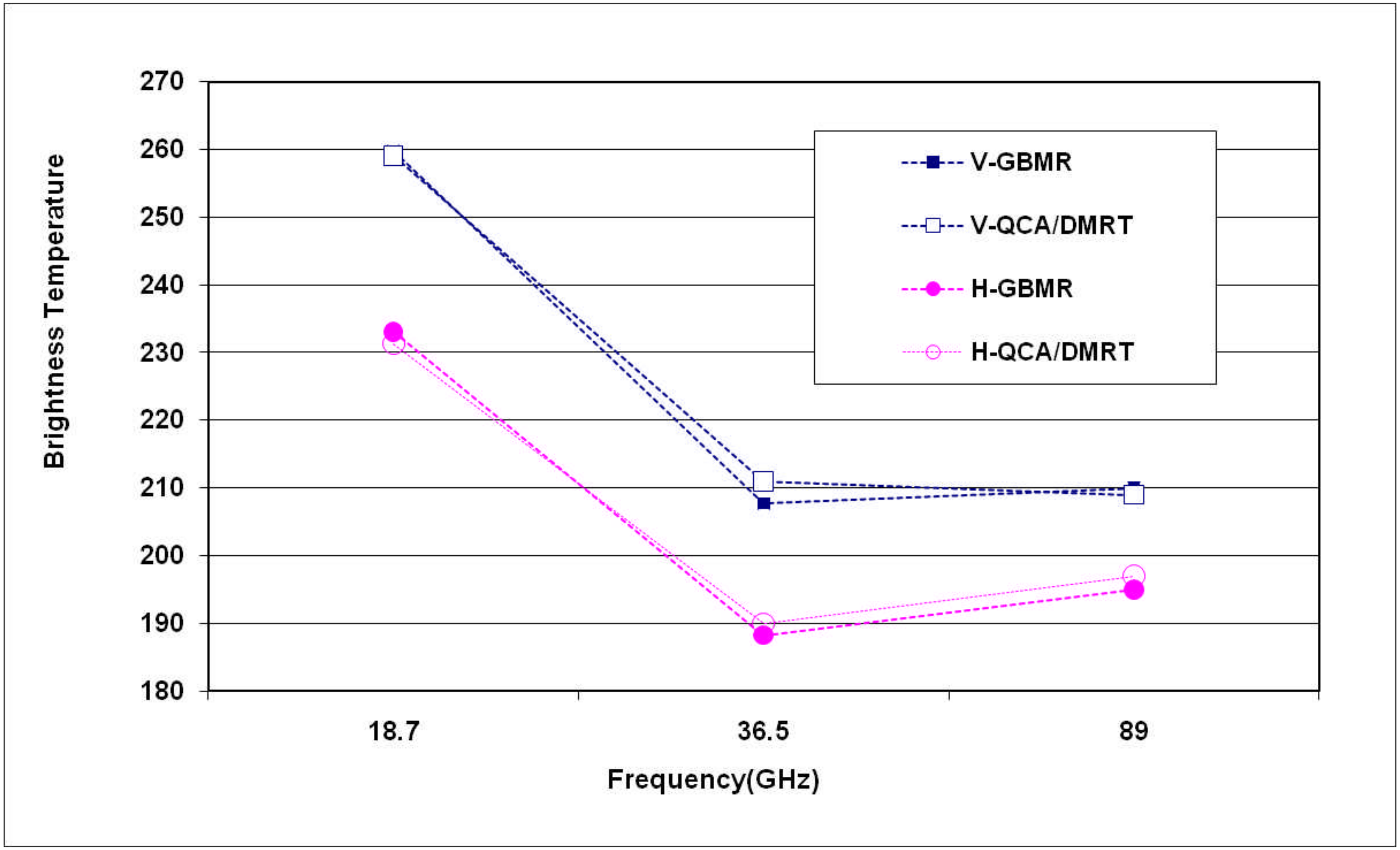


TB polarization difference comparisons

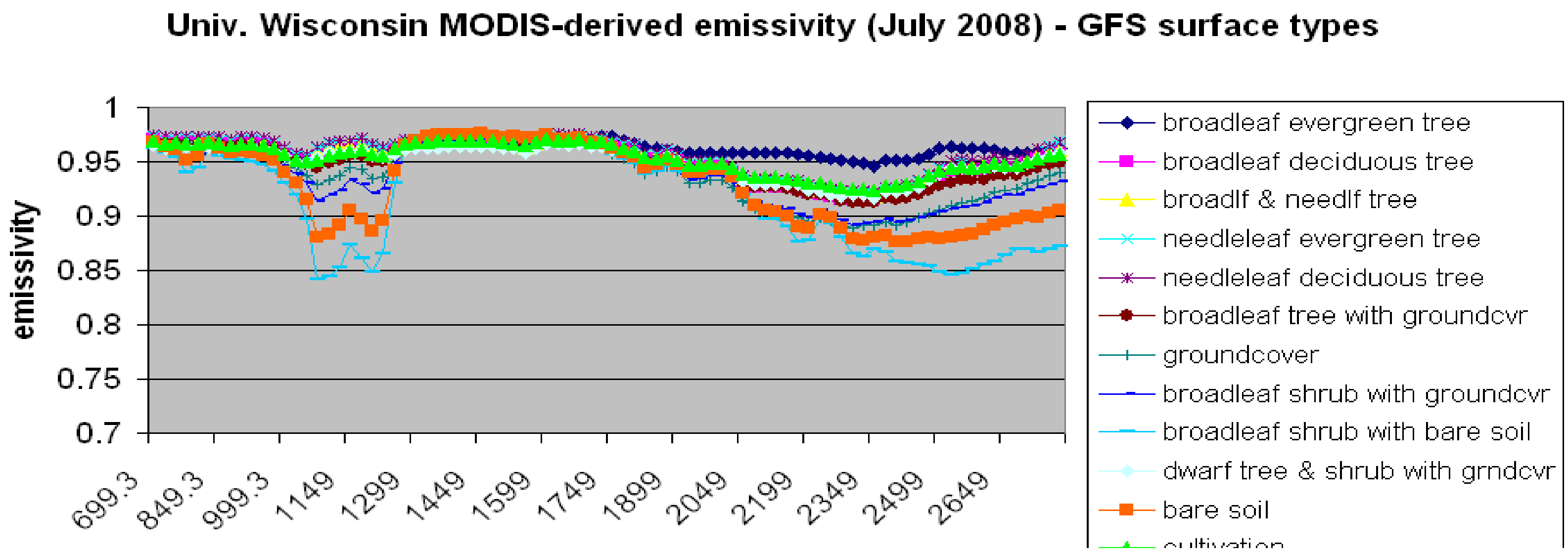


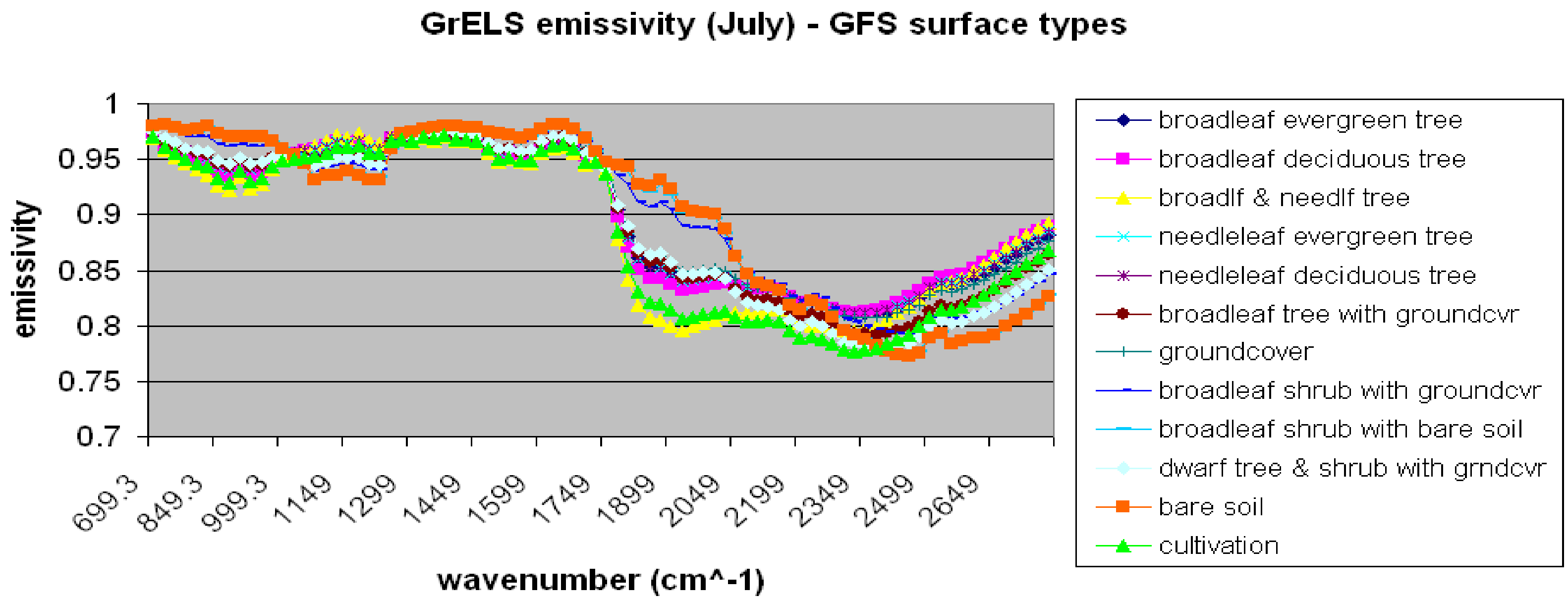
1) Modeled T_b show close agreement with the ground Tb observation.
2) Polarization difference (18.7v-18.7h and 36.5v-36.5h) predicted by DMRT show close agreement with observations.
3) Frequency dependence(18.7v-36.5v and 18.7h-36.5h, right figure) predicted by DMRT agrres well with observations.

GBMR Point Tb Observations Compared with QCA/DMRT Prediction



Uses of New Infrared Emissivity in CRTM





Impacts of Emissivity Data Base in GFS

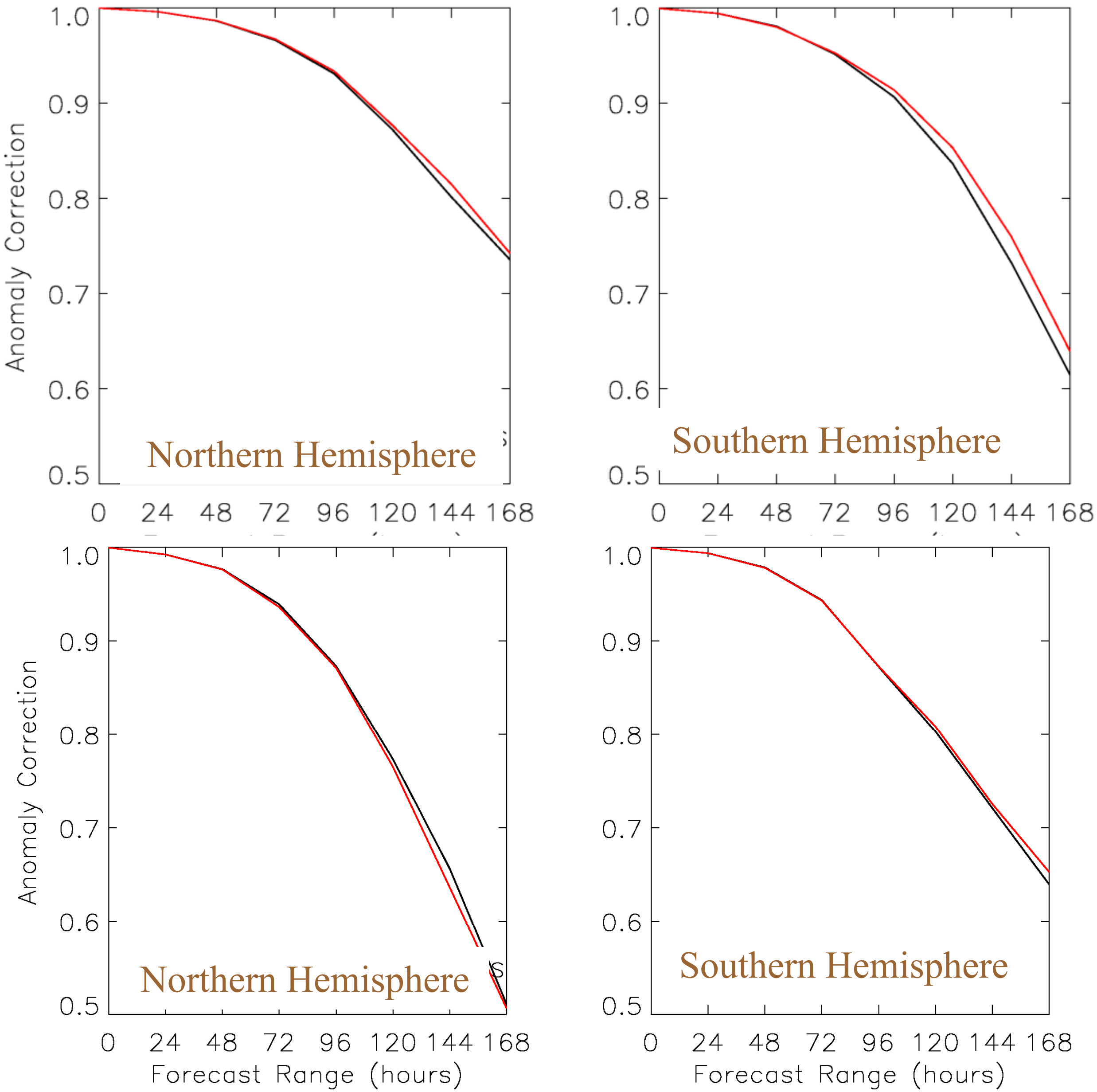
Experiment setup:

- Experiments are set up in GSI with two months data on 2008 (January, and July), CRTM v2.0 with NPOESS database, and UWIREMIS database

Conclusions to be drawn:

- UWIREMIS database has some positive impact in winter season, especially for Southern Hemisphere. However, it is inferior to the CRTM baseline IR land emissivity in Northern Hemisphere during summer time

Impacts of Emissivity Data Base in GFS



NPOESS data base

MODIS data base

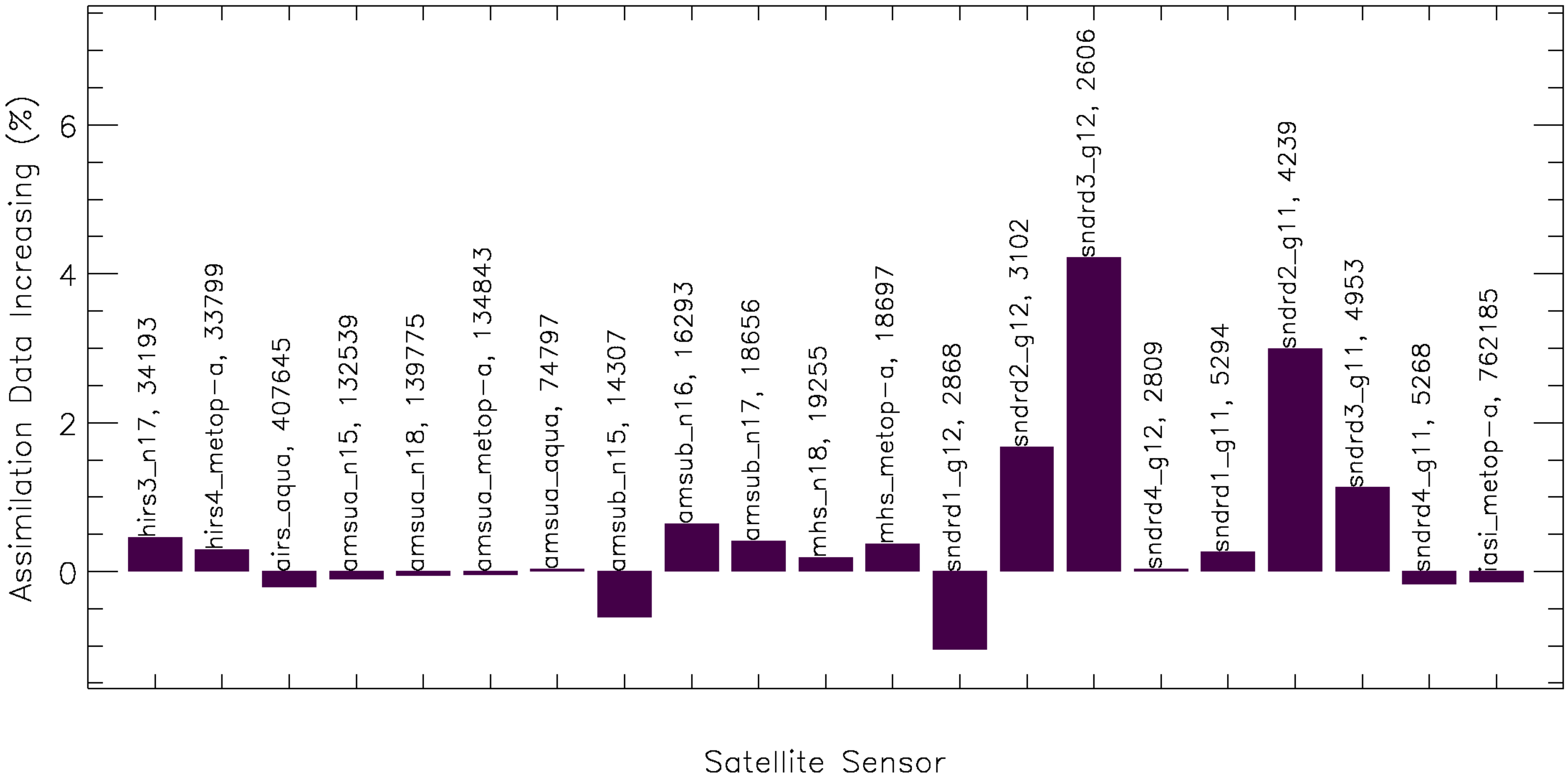
Winter

01/09/2008-01/22/2008

Summer

07/09/2008-07/19/2008

Changes of assimilated data volumes for different sensors (MODIS V.S. NPOESS) on January 22 UTC 00, 2008



Summary

- CRTM version 2 releases resulted in some significant positive impacts
- New surface emissivity data bases including IR and MW are being assessed in GFS
- Land MW emissivity library has been developed and shows some positive impact on forecast skill
- Several land IR emissivity data bases are tested. MODIS data set has some positive impacts on forecasts during the cold seasons
- MW ocean emissivity calculation has been updated through FASTEM4 which has significantly improved the emissivity simulations at low and high frequencies
- A two-layer microwave snow emissivity model has been developed to characterize emissivity at a wide frequency range for stratified but shallow snow
- A fast multi-layer microwave snow emissivity model, applicable for highly stratified snow is being developed based on QCA/DMRT model

Acknowledgements

Personnel Name	Organization	Areas of Expertise
Fuzhong Weng	STAR	CRTM technical oversight/emissivity
Yong Han	STAR	CRTM interface with NESDIS
Paul van Delst	NCEP	CRTM interface with NCEP
Quanhua (Mark) Liu	Perot System	Transfer scheme
Banghua Yan	Univ of MD	Surface emissivity
Yong Chen	CIRA	CRTM Impacts in GFS
David Groff	NCEP	transmittance data base
Ron Vogel	IMSG	IR surface emissivity
Ping Yang	Texas A&M	Cloud/aerosol scattering LUT
Ralf Bennarts	Univ Wisconsin	Radiative transfer scheme
Jean-Luc Moncet	AER	Absorption model
Jun Li	CIMSS	ABI retrieval algorithm
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
Steve English	Metoffice	MW Ocean Emissivity