Improving Surface Emissivity Models for Community Radiative Transfer Model (CRTM) Applications

Fuzhong Weng[1,2], Banghua Yan[2,3], Quanhua Liu[2], Ellen Liang[2], Steve English[4], Yong Chen[2], and Ron Vogel[2],

1.NOAA/NESDIS/Center for Satellite Applications and Research

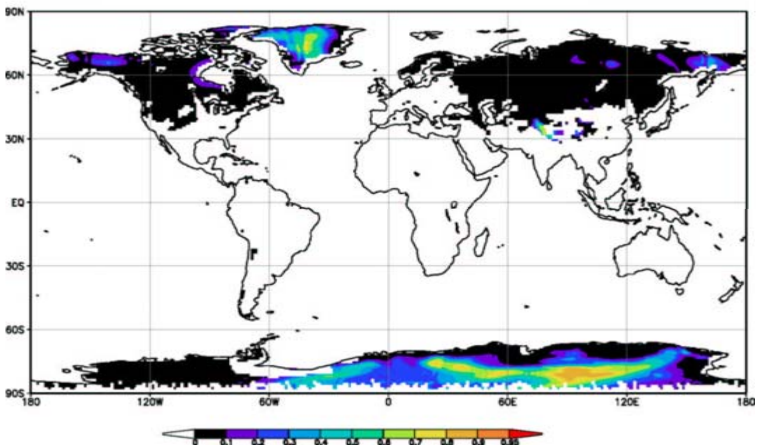
2. Joint Center for Satellite Data Assimilation

3. University of Maryland

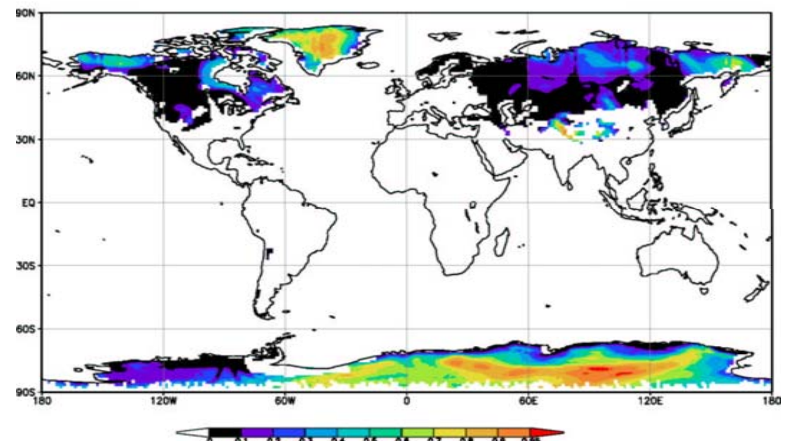
4. The MetOffice, UK

Atmospheric Transmittance

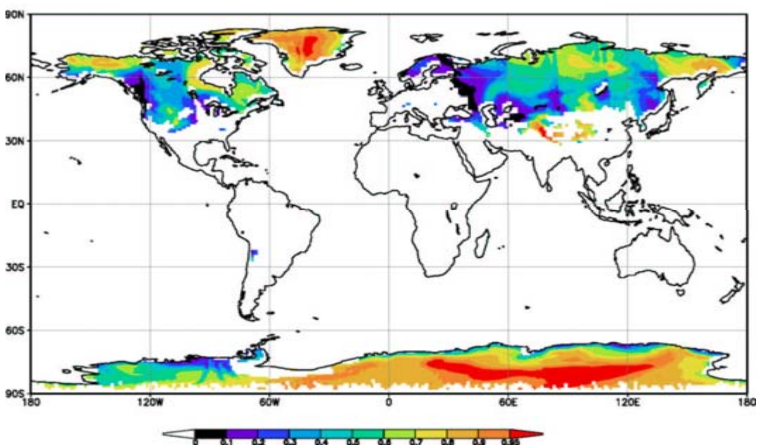
(a) 183.3±1 GHz



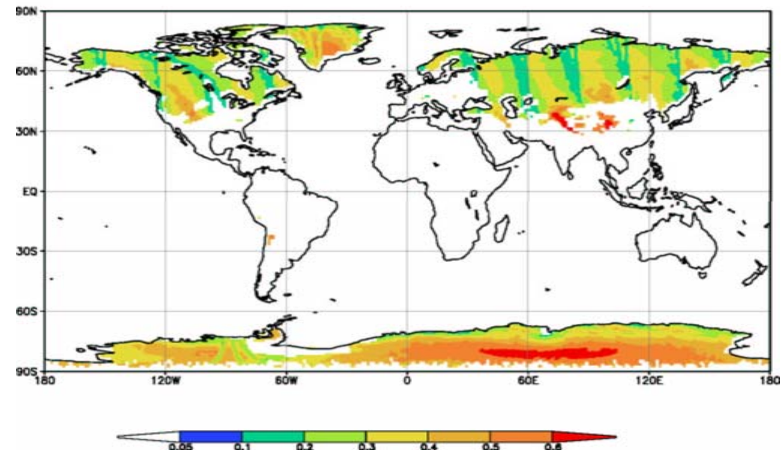
(b) 183.3±3 GHz



(c) 183.3±7 GHz



(d) 52.8 GHz



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

Brightness Temperature Sensitivity to Surface Emissivity

Freq (GHz)	Ts = 230 K and TPW = 0.5 mm					
	Ps = 600 (mb)			Ps = 1000 (mb)		
	Td(K)	τ	ΔTB(K)	Td(K)	τ	ΔTB(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

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

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

CRTM Baseline Surface Emissivity Modules

Ocean

Sea Ice

Snow

Canopy (bare soil)

Desert

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

NPOESS infrared emissivity data base

AIR land infrared emissivity data base

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

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

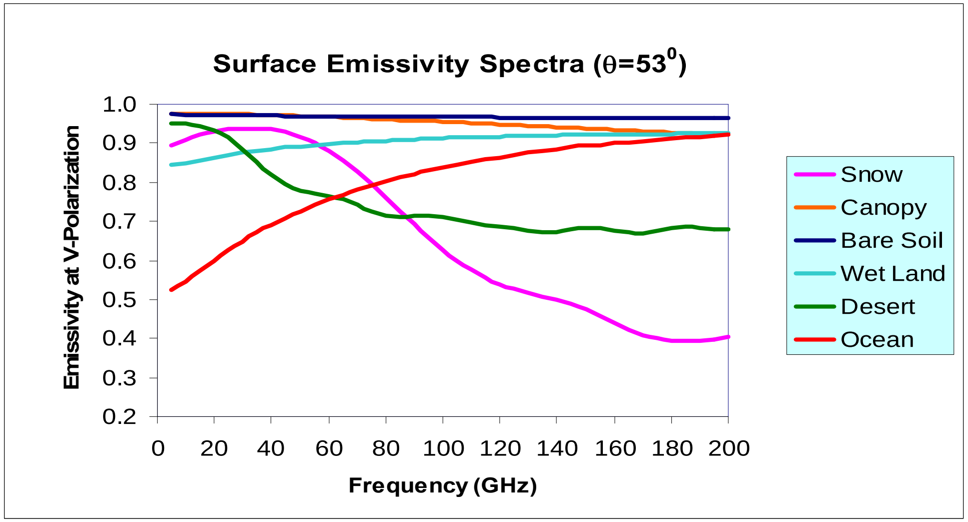
Fast multi-layer snow emissivity model (Liang, Weng, Yan, 2010)

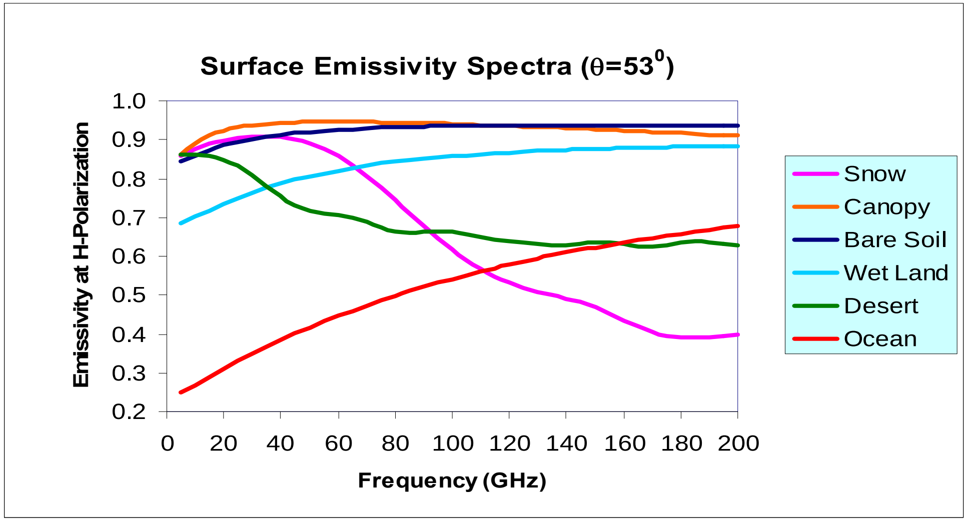
FASTEM3 microwave emissivity model (English and Hewison, 1998)
IR emissivity model (Wu and Smith, 1991; van Delst et al., 2001)
FASTEM4 microwave emissivity model (Liu, Weng, English, 2010)

Surface Emissivity Spectrum vs. Surface Type

- **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)

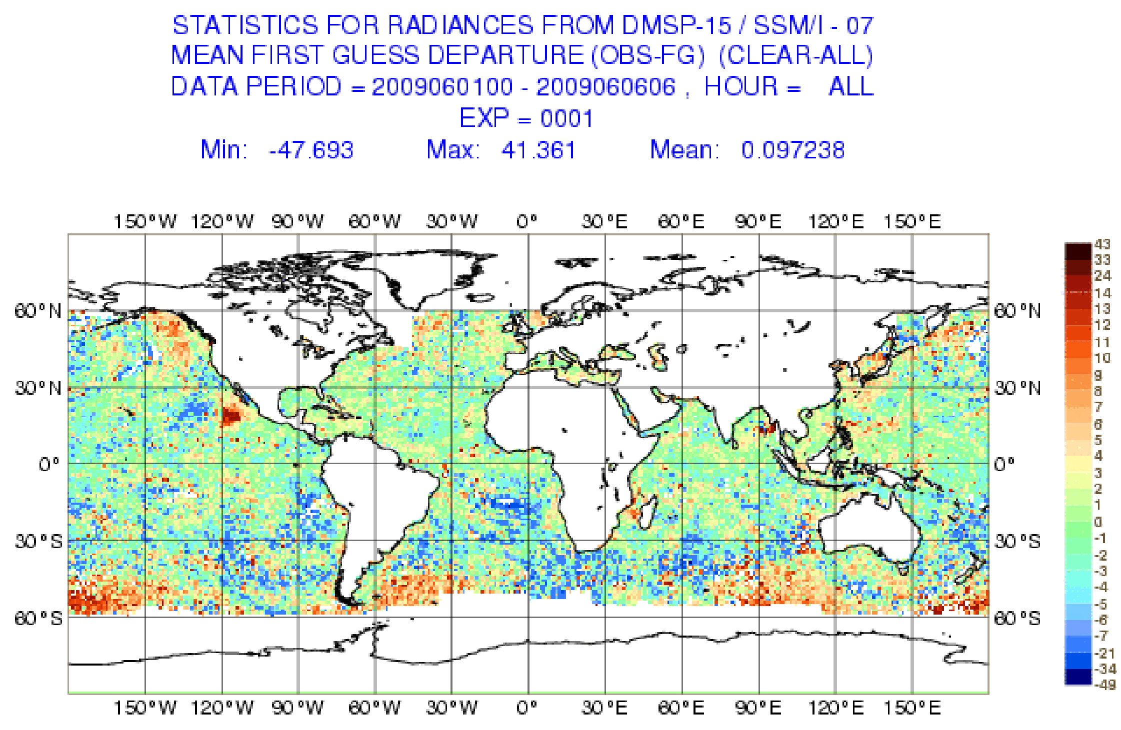




National Environmental Satellite, Da

Major Problems in Baseline Surface Emissivity Models

- FASTEM3 displays a big bias at low (e.g., below 20 GHz) and high (e.g., above 60 GHz) frequencies
- Microwave land emissivity model (MLEM) displays certain bias over snow and desert
- NPOESS infrared emissivity data base ignores variation of emissivity with soil structure



O – B (SSM/I CH. 7)

Planned Upgrade to CRTM Baseline 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)
- **IR land emissivity data base derived from AIRS emissivity V5.0 L2** (ref. Zhou et al. 2008)

FASTEM-4

- Revised Double-Debye permittivity 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

Double Debye's Model with Intermolecular Interaction

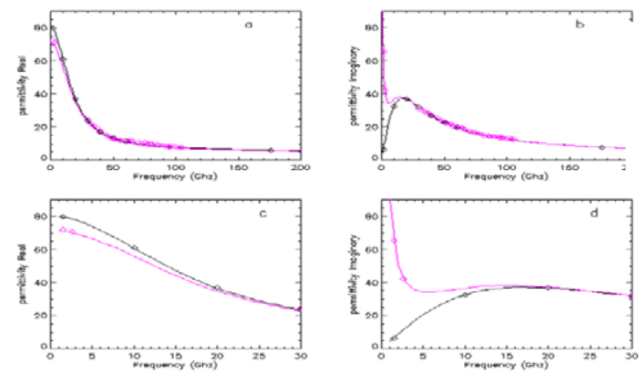


Figure 1. Panels (a) and (b) represent the real and imaginary parts of the permittivity. Panels (c) and (d) are a zoom-in part for low frequencies. The back line is for fresh water and the red line is for salted water. The water temperature is 25°C. The salinity of sea water is 35‰. The solid lines represent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

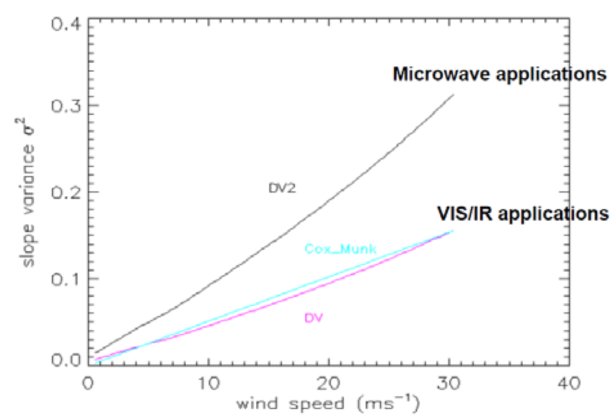
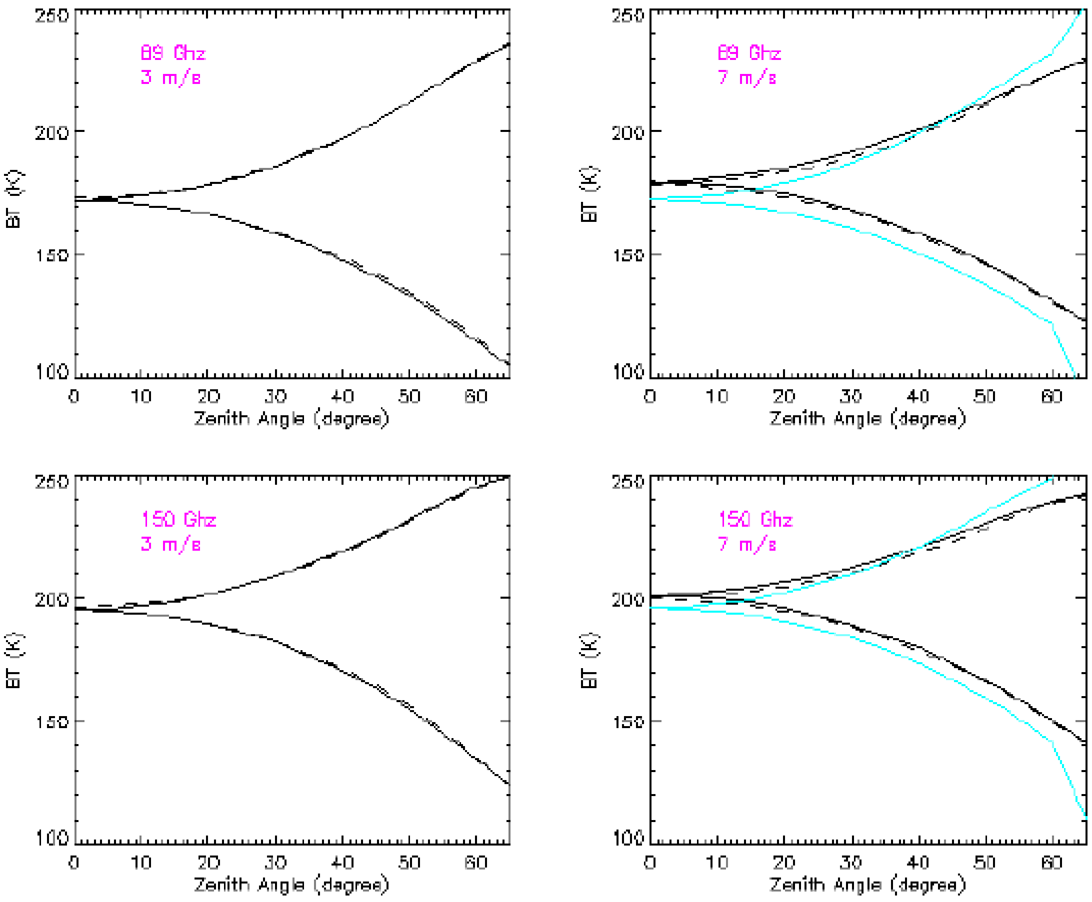


Figure 2. Slope variances for the DV, DV2 spectrums and Cox-Munk as a function of the wind speed at 10 meter above the surface.

Comparison of Ocean Surface Brightness Temperature between Simulations and Observations



Diamond symbol: Measurement

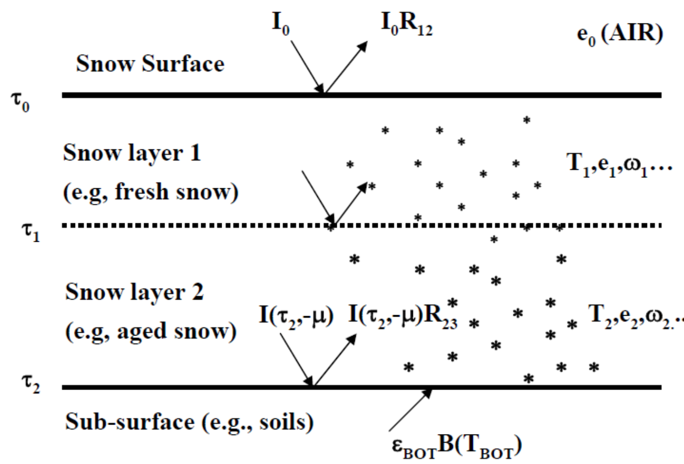
Black solid: two-scale simulation

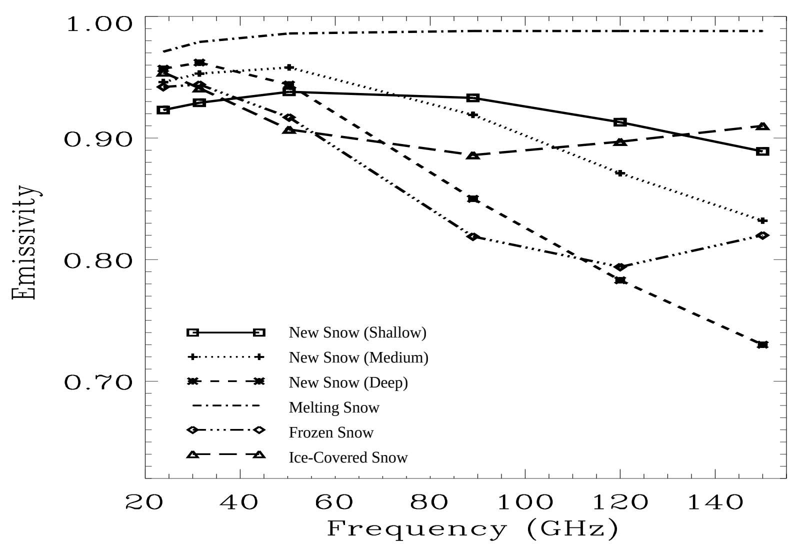
Black dash: FASTEM4

Blue line : FASTEM3

Two-layer Microwave Snow Emissivity Model

- A two-layer snow emissivity model which is derived based on one-layer model in Weng et al. (2001)
- Snow optical parameters are currently computed using an approximate approach from Grody and Weng (2008)
- Snow optical parameter calculations will be updated using a lookup-table from Quasi-Crystalline Approximation (QCA)-DMART

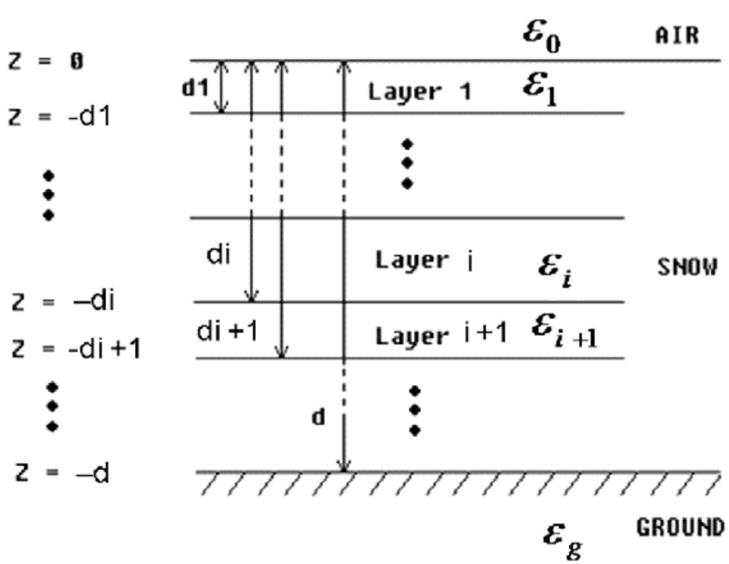


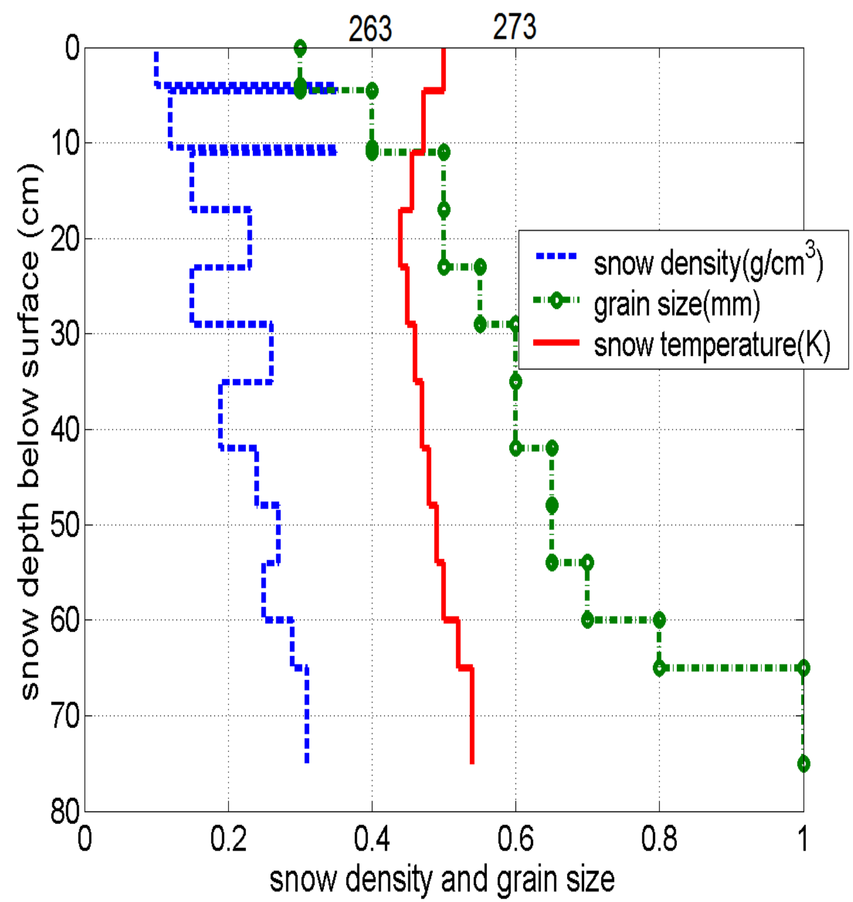


QCA/DMRT equations for Microwave Remote Sensing of Layered Snow

Dense media radiative transfer (DMRT) equations in layer i (Liang and Tsang, 2009) :

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

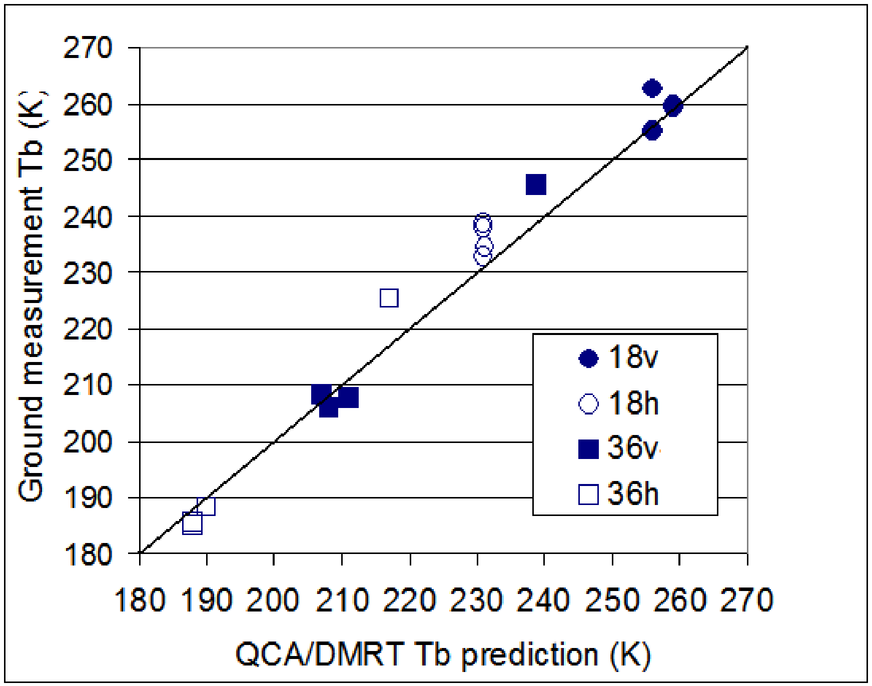




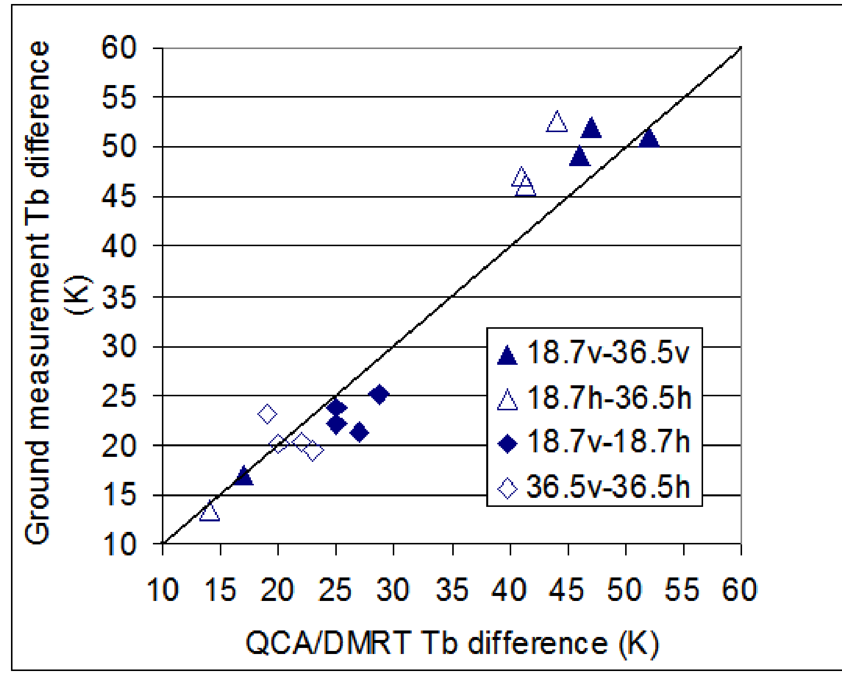
where phase matrix and extinction coefficients are computed using Quasi-Crystalline Approximation (QCA).

Validation of QCA/DMRT Brightness Temperatures

TB comparisons



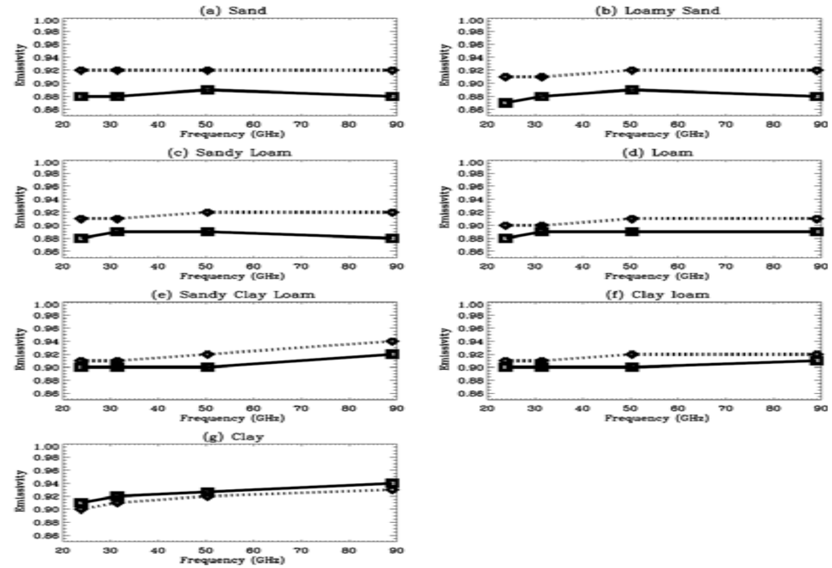
TB polarization difference comparisons

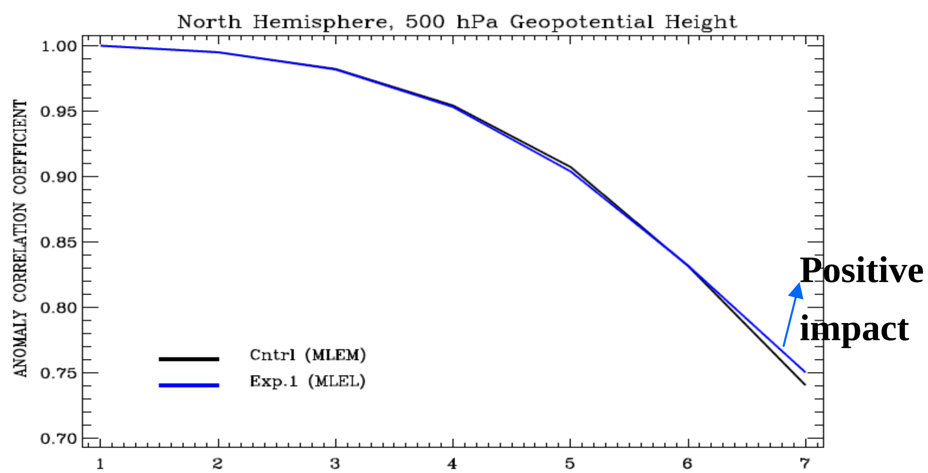


1)The model Tb prediction (left figure) show close agreement with the ground Tb observation.
2)Polarization difference (18.7v-18.7h and 36.5v-36.5h,right figure) predicted by DMRT show close agreement with observations.
3) Frequency dependence(18.7v-36.5v and 18.7h-36.5h, right figure) predicted by DMRT show close agreement with observations.

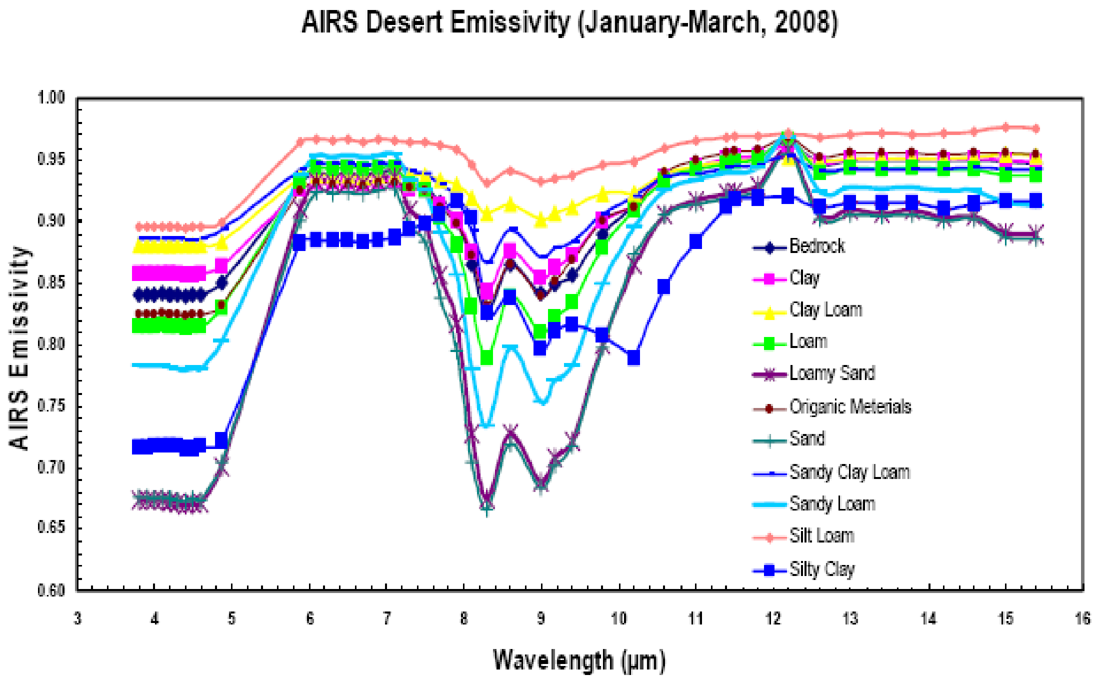
New Microwave Desert Emissivity Library

- Microwave land emissivity library (MLEL) is developed according to soil type from AMSU-A data for improving satellite data assimilation.
- MLEL data results in more data usage in AMSU-A data over desert areas compared to current Microwave land emissivity model (MLEM)
- MLEL data results in a positive impact on global medium-range forecasts in GFS





Infrared Land Emissivity vs. Soil Structure



- Emissivity of bare ground surfaces is much more variable than vegetated surfaces
- Infrared land emissivity spectra from 3.7 to 15.4 microns are derived according soil structure from AIRS V5.0 L2 (Zhou et al., 2008)
- Soil structure is classified according to FAO (Food and Agriculture Organization of the United Nations) data base

IR Emissivity for Soil Surfaces

MODIS Channel (μm)	NPOESS (no soil) emissivity	AIRS FAO soil type-based emissvity	UWisc-HSR FAO soil type-based emissivity	UWisc-HSR LatLon database	UWisc-BF LatLon database	Constant = 0.9
3.75 (Ch 20)	2.226	1.865	2.953	1.280	1.304	2.087
3.96 (Ch 22)	1.295	1.293	2.347	0.042	0.593	1.548
4.05 (Ch 23)	1.014	1.099	1.826	0.282	0.518	1.284
11.03 (Ch 31)	0.931	1.532	1.521	0.691	0.597	-1.668
12.01 (Ch 32)	0.243	0.700	0.753	0.315	0.583	-2.307

Tb Bias (K), CRTM minus MODIS Obs: North Africa, 2008-May-20, nighttime, N = 5,850,426, smallest bias in RED

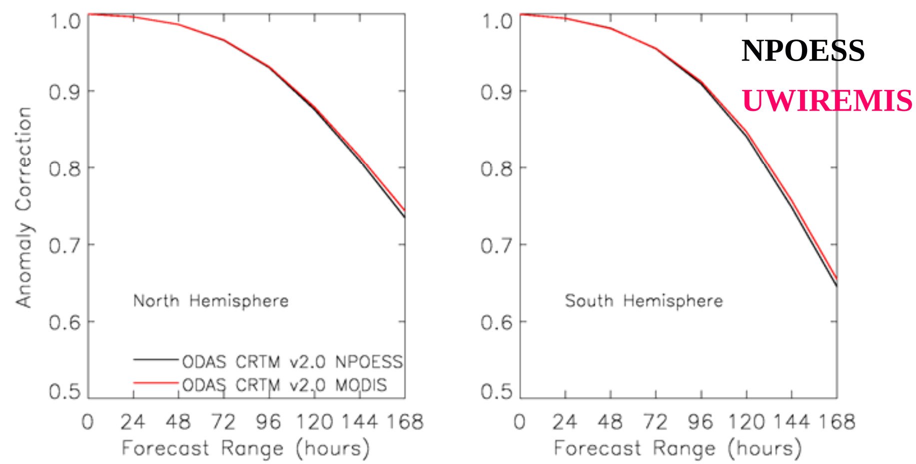
Impact of UWisc HSR Emissivity Data Base in GFS

(500 hPa geopotential height anomaly correlation coefficients)

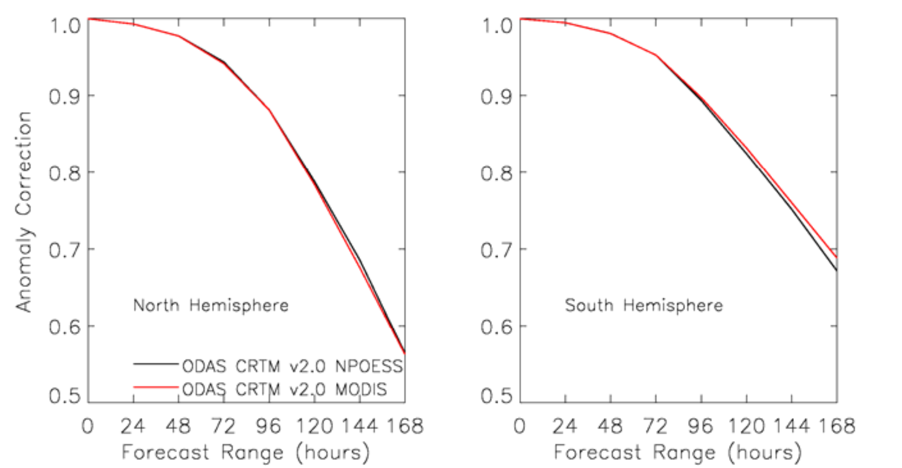
- Experiments are set up in GSI with two months data on 2008 (January, and July), CRTM v2.0 with NPOESS database, and UWIREMIS database

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

(a) 01/09/2008-01/31/2008 (Winter)



(b) 07/09/2008-07/27/2008 (Summer)



(Preliminary results)

Summary

- MW ocean emissivity has been updated through FASTEM4 which will significantly improve 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 is being developed based on QCA/DMRT model which will be applicable for highly stratified snow
- Land MW emissivity library has been developed and displays a positive impact on forecast skill
- Several land IR emissivity data bases are tested and impacts on forecasts in GFS are being assessed.