Development and Improvement of Community Surface Emissivity Model (CSEM) System

Ming Chen[1,2] and Fuzhong Weng[1]

1.NOAA Center for Satellite Applications and Research
2. Joint Center for Satellite Data Assimilation

Outline

1. Overview of current CSEM status
2. Model design, implementation and documentation
3. Model physics improvements and the impacts on CRTM forward simulation, GFS forecasting
4. Summary

CSEM Design and Implementation Status

- Completed the bottom-up design to account for the diversity of low-level algorithms, and implemented most of the infrastructure surface emissivity models that are currently used in CRTM.
- Completed the interfacing design (top-down) and drafted the design document.
- Implemented the interfacing modules for (IR/VIS/MW)(Land/Snow/Ice) models.
- Completed software unit testing for CSEM LandMW (snow-free land, snow covered land, sea ice, desert), and implemented CSEM MW modules in CRTM.

Highlights of CSEM Physics Improvements

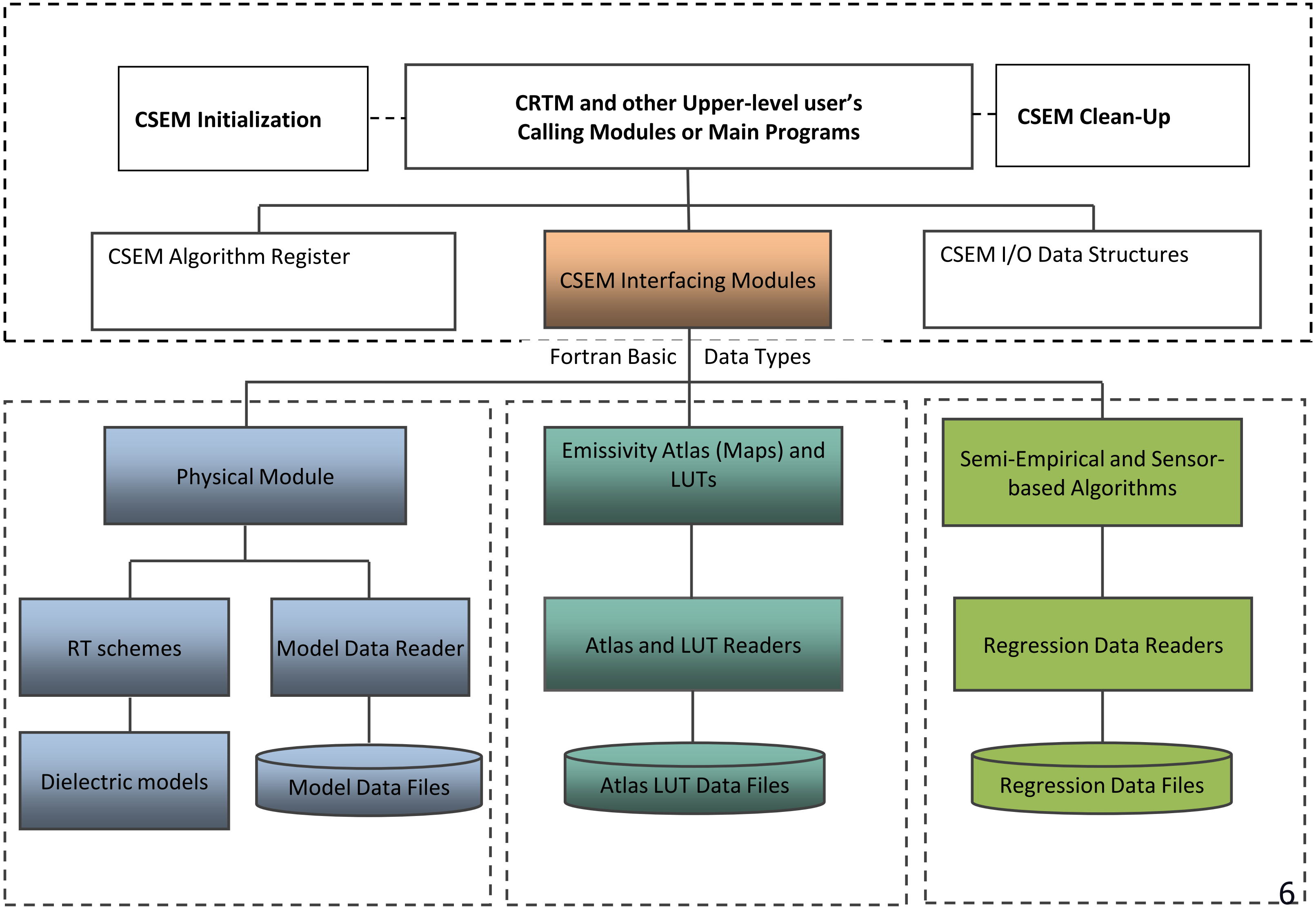
- Improved soil roughness correction modeling by a) adding optional models and b) optimizing our tanh-based model;
- Introduced new dielectric model for frozen soil and modified the soil moisture profiling algorithm to improve the top soil moisture impact on soil reflectivity;
- Modified canopy scattering asymmetry parameterization and retuned canopy model parameters to take in the impact of new soil model reflectivity;
- Refined the two-stream canopy RT model to account for the thermal deference between canopy and underlying soil;
- Improved canopy volume scattering with a more general leaf inclination distribution model;
- Performed parallel GFS runs on Zeus to evaluate the potential impact of the land MW emissivity models on weather forecasting.

General CSEM Design Concepts

Objective: To built up an independent model system to facilitate the development, improvement and optimization of surface emissivity modeling, and the easy coupling with upper-level user systems, e.g. CRTM.

- CSEM will have its own independent I/O data structures to provide efficient two-way data communication methods between CSEM and the host system, and to enable the establishment of generalized CRTM-CSEM interfaces. The interfaces between CSEM , CRTM and other the upper-level host model systems should be adaptable enough to allow easy model expansion and code maintenance on both sides.
- CSEM will have its own infrastructure module design and software abstract layers to facilitate the off-line model improvements and the R2O processes for the implementation in CRTM. It will completely hide the high-level CRTM complexity from the low-level CSEM developers and users, and vice versa.
- It will require the minimum CRTM modification efforts, but keep the full functionalities and accuracies of the earlier CRTM surface modules.
- It will cover the full functions of the current surface subsystem of CRTM, which provided forward, tangent-linear, and adjoint computations in the microwave, infrared, and visible spectral regions for the supported sensors, and over different Earth's surfaces.

Diagram of Unit CSEM Infrastructure and CRTM-CSEM Interfacing Design



Current Status of CSEM Implementation

First-Round		Algorithm Modules			Interface Modules			Code Review			CSEM Testing			CRTM-CSEM Testing		
Land	MW	√	√	√	√	√	√	√	√	√	√	√	√			
	IR	√	√	√	√	√	√	√	√	√	√	√	√			
	VIS	√	√	√	√	√	√	√	√	√	√	√	√			
Water	MW															
	IR															
	VIS	√	√	√	√	√	√									
Snow	MW	√	√	√	√	√	√									
	IR	√	√	√	√	√	√									
	VIS	√	√	√	√	√	√									
Ice	MW	√	√	√	√	√	√									
	IR	√	√	√	√	√	√									
	VIS	√	√	√	√	√	√									

Comments: This is the first-round design-implementation status. More cycles may be needed.

tanh-based Roughness Correction and Polarization Mixing

❑Hyperbolic tangent function is a well-behaved function with bounded asymptotic values,

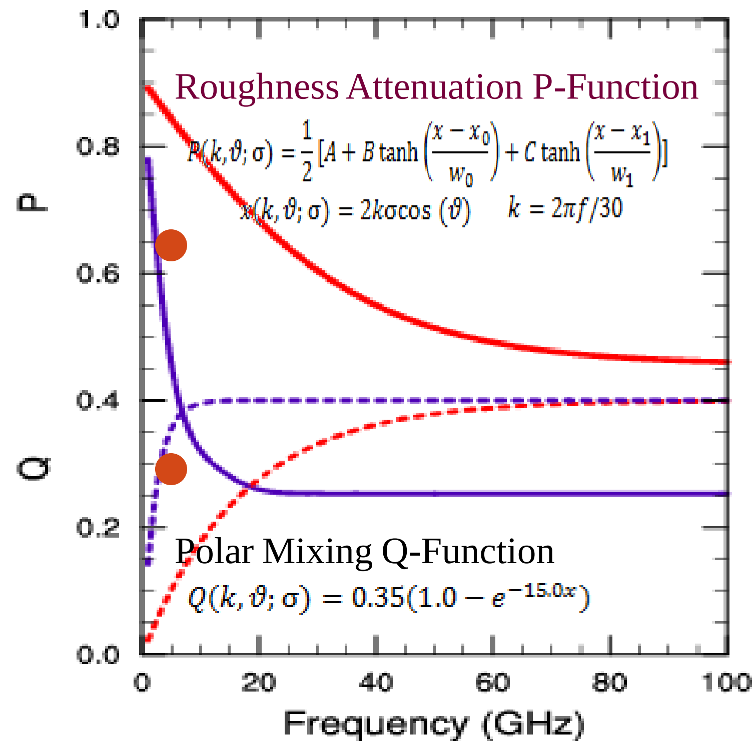
$$\tanh(X) = \frac{e^x - e^{-x}}{e^x + e^{-x}} = \frac{e^{2x}-1}{e^{2x}+1} \quad with \begin{cases} \lim_{x\to\infty} \tanh(x) = 1 \\ \lim_{x\to-\infty} \tanh(x) = -1 \end{cases}$$

which was used characterize the distinct roughness effects at very low-frequency bands and high-frequency bands (Chen & Weng, TGARS, 2015)

❑The closed-form solutions to nonlinear ODEs and PDEs may be expressed in terms of polynomial or power series of tanh, which implies the enhanced generality of a semi-empirical model formed with tanh.

❑The model has been validated and its robustness was demonstrated with comprehensive ground-based measurements.

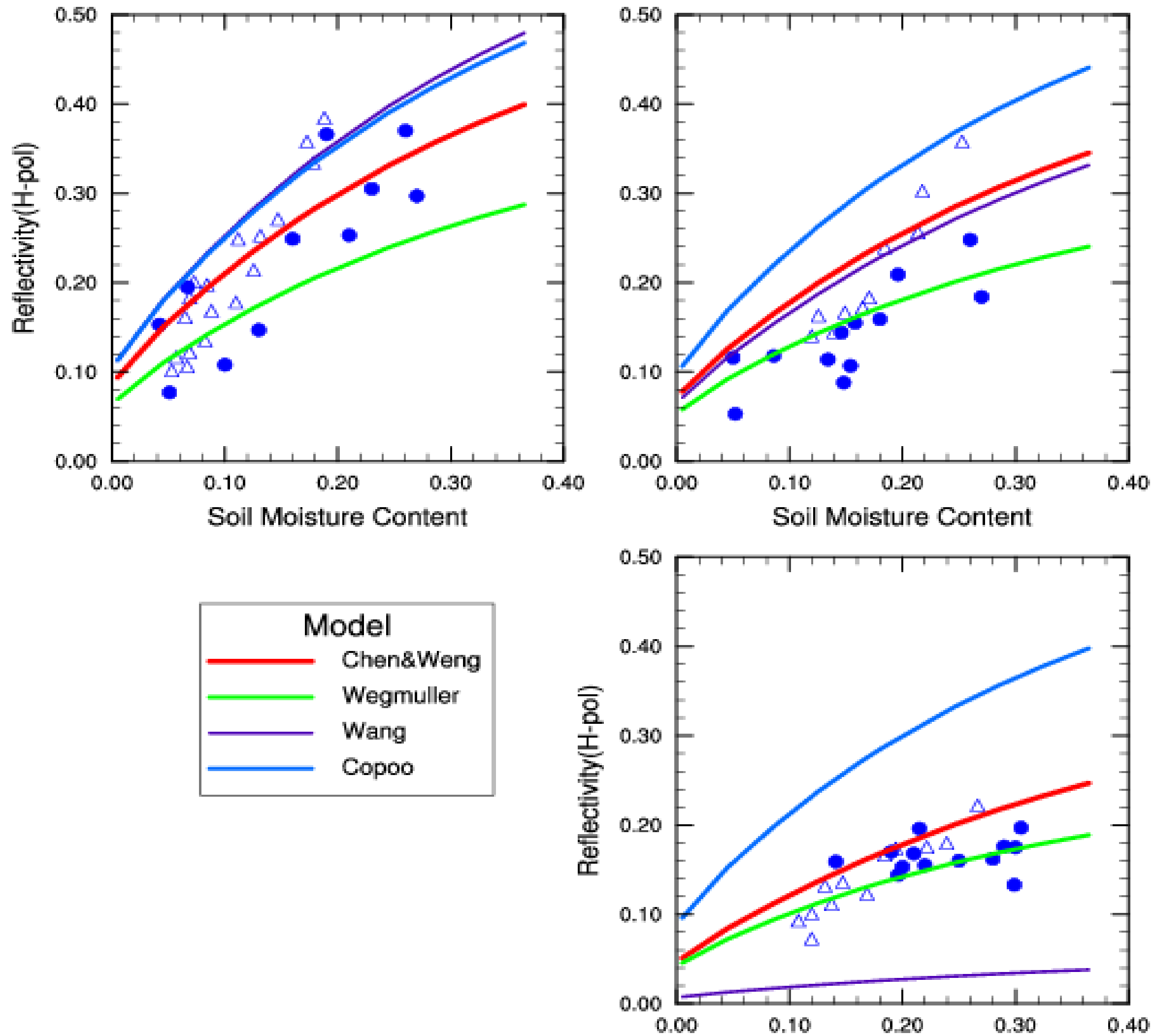
Chen & Weng 2014



$$\frac{\varepsilon_{CSEM}}{\varepsilon_{CRTM2.1.3}} \approx 0.5 - 1.0$$

Validity With Different Soil Moisture

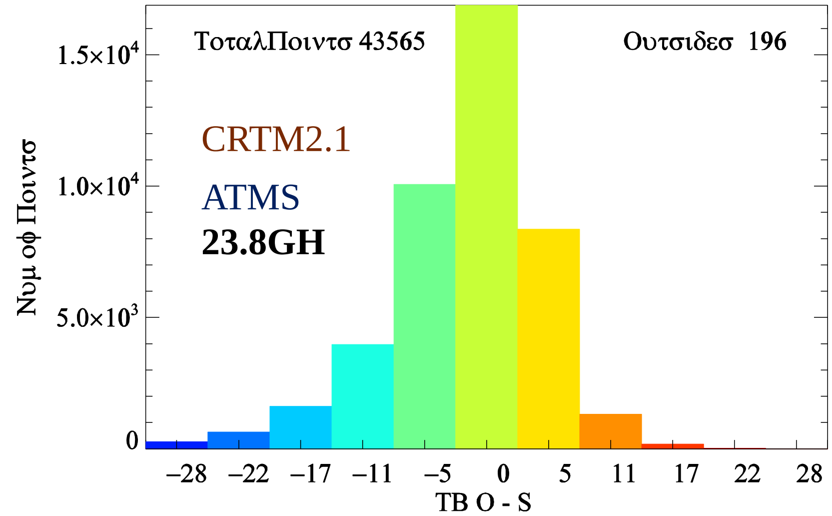
1.4GHz

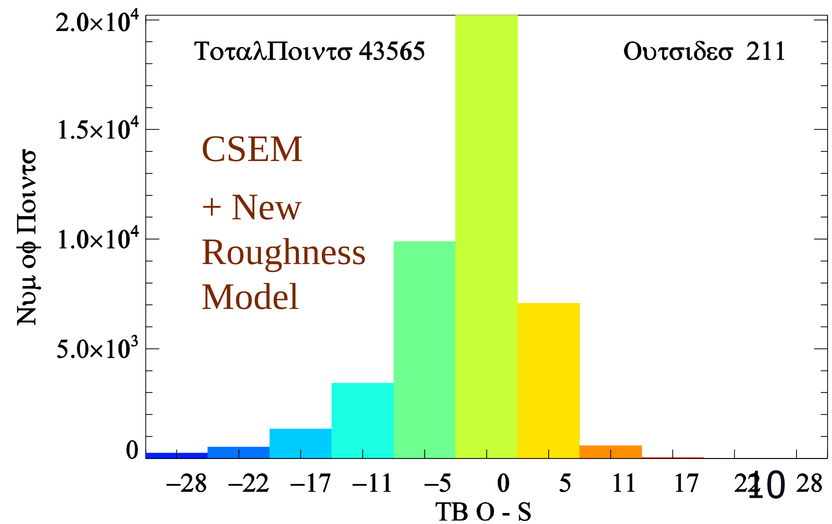


Impacts of Soil Roughness Correction on Vegetation-Covered Surface (23.8GH)

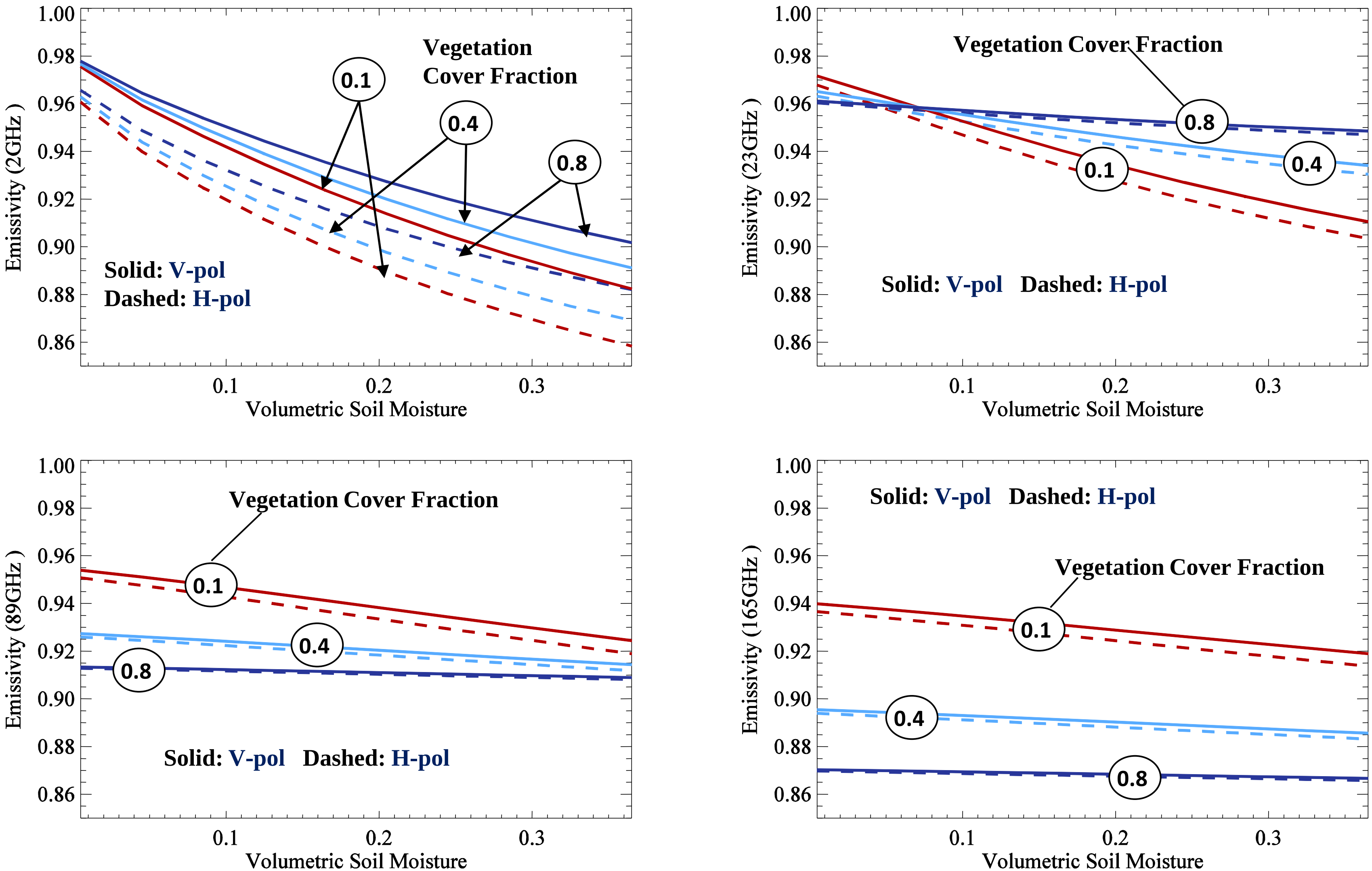
The new roughness model has no obvious impact on high-frequency channels, especially v-pol channels due to lower surface reflectivity (higher emissivity).

However, it brings about significant impacts on low-frequency h-pol channels due to the enhanced surface reflectivity, where soil moisture is a key variable determining the surface dielectric property.

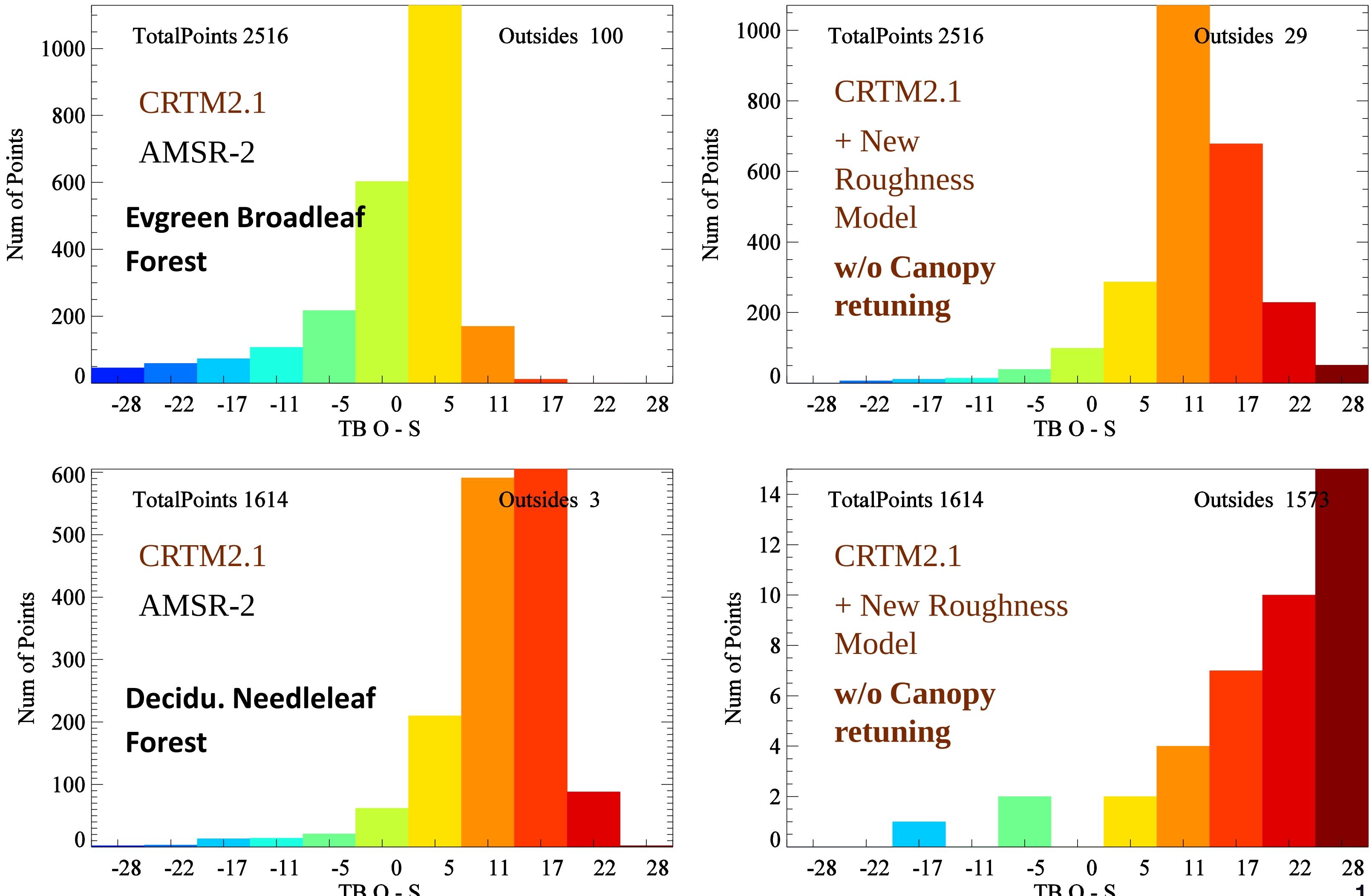




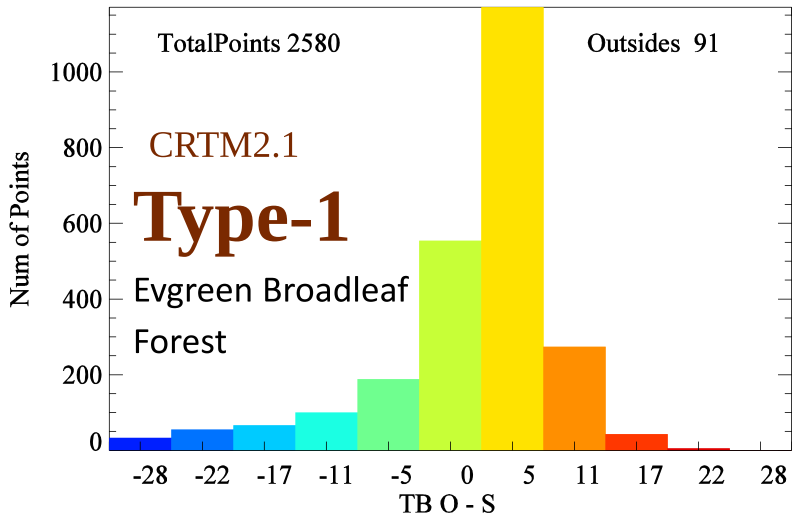
Dependence of Land MW Model Emissivity on Soil Moisture

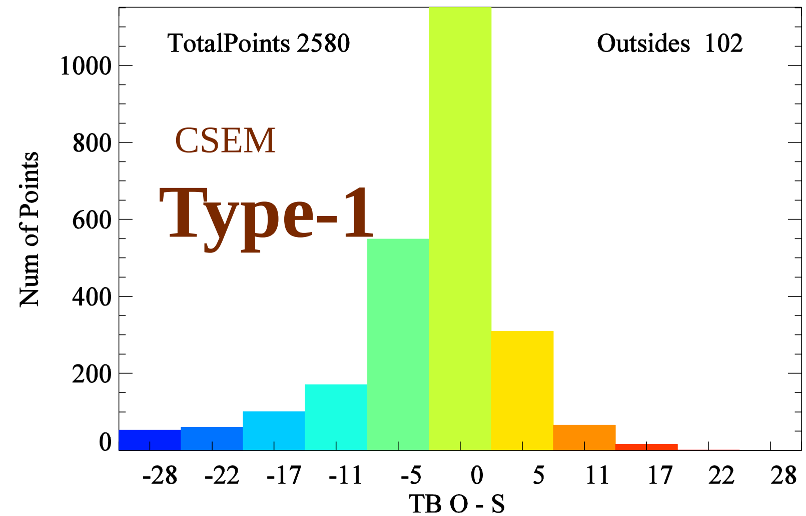


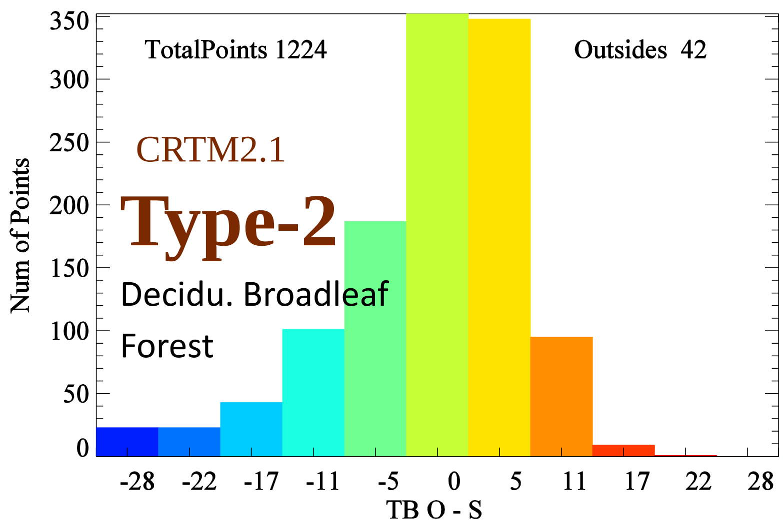
Impacts of Soil Roughness Correction on Vegetation-Covered Surface (6.5GHz-H)

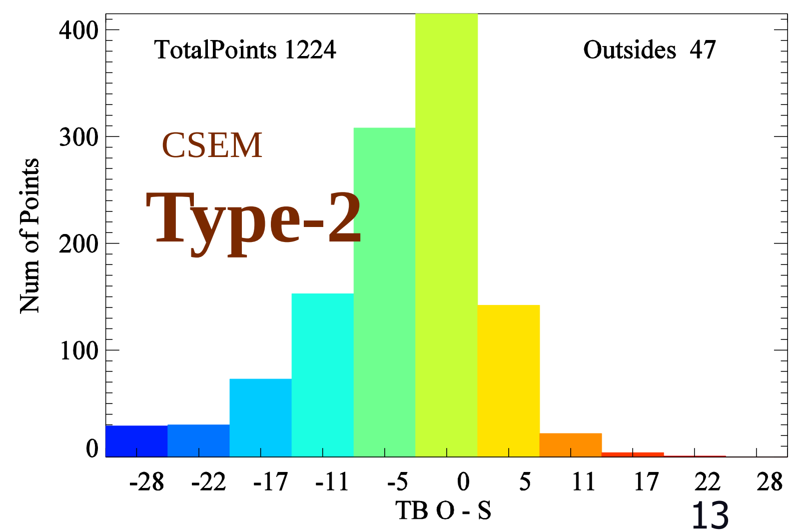


O-B Histogram Of Different Surface Types With Model Retuned: AMSR-2 6.9GHz-H (1)

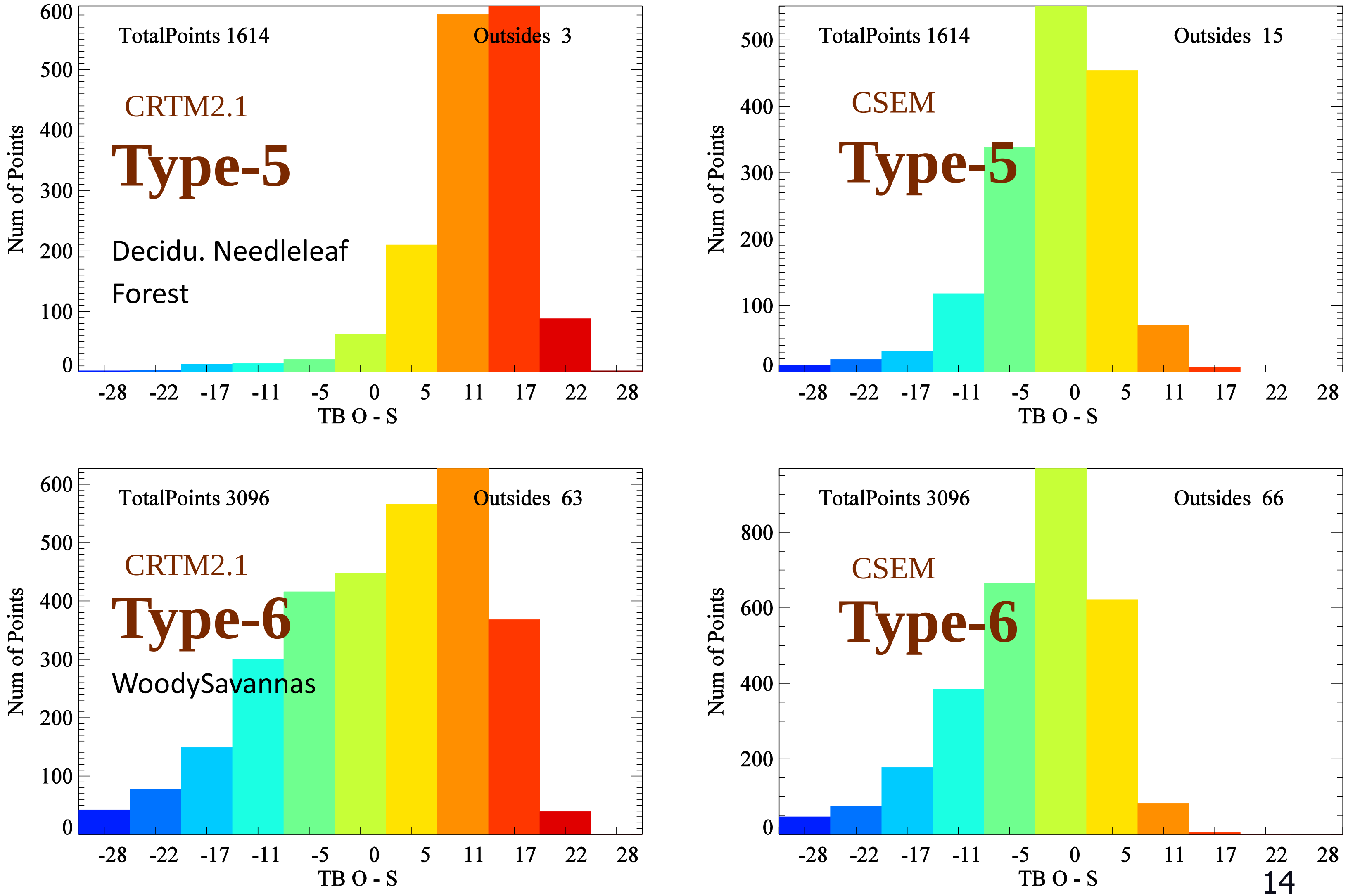








O-B Histogram Of Different Surface Types With Model Retuned: AMSR-2 6.9GHz-H (2)

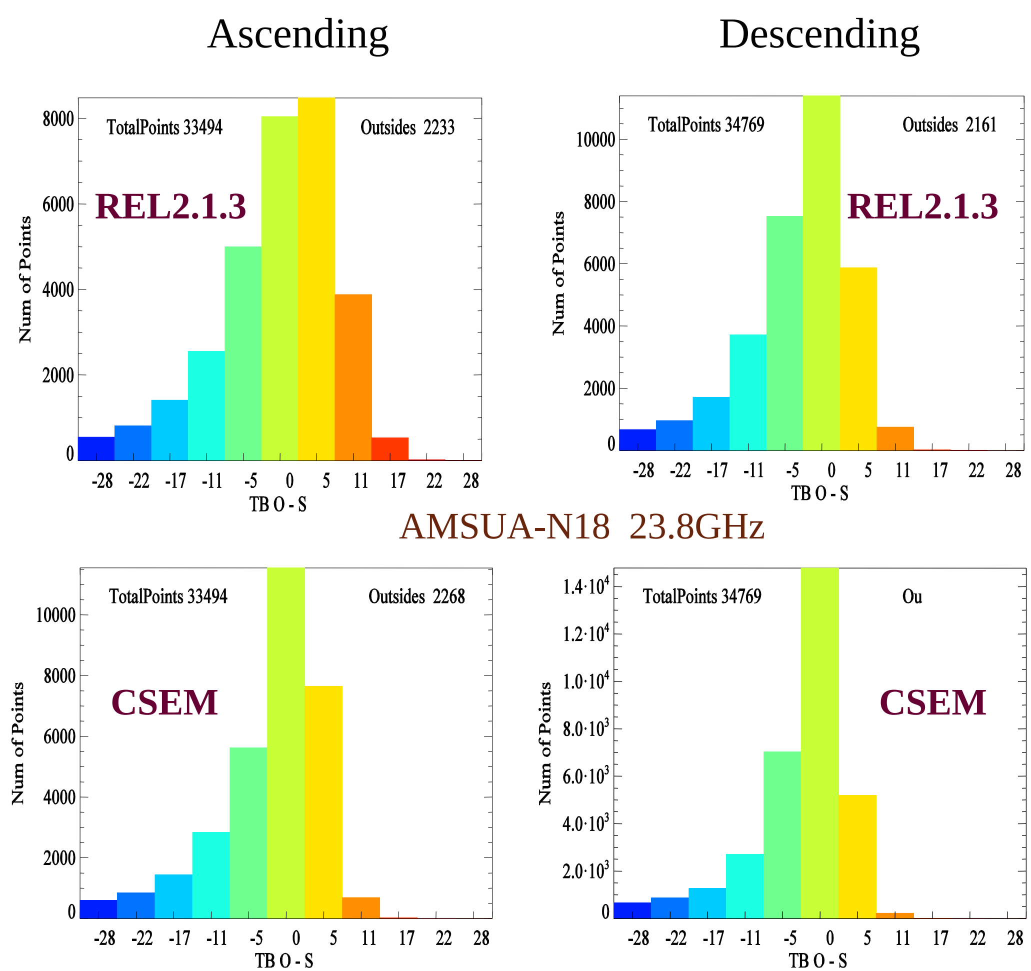


Improvement of Model Performance Consistency Over Different Orbits

Extensive analyses indicated that LandEM in REL2.1 has fairly different model performance for ascending and descending orbits, and for different NWP inputs.

The original surface emissivity model in CRTM REL 2.1.3 tends to have positive bias in ascending orbit, which is not so normal.

To account more physical details, meanwhile keeping the model integrity and consistency on every aspects, the microwave LandEM has been under systematical refinement.



About 20% more data points may be assimilated with CSEM.

Physical Soil MW Emissivity Model with Volume Scattering, Multi-layer Profiling

❑Desert Model Equations

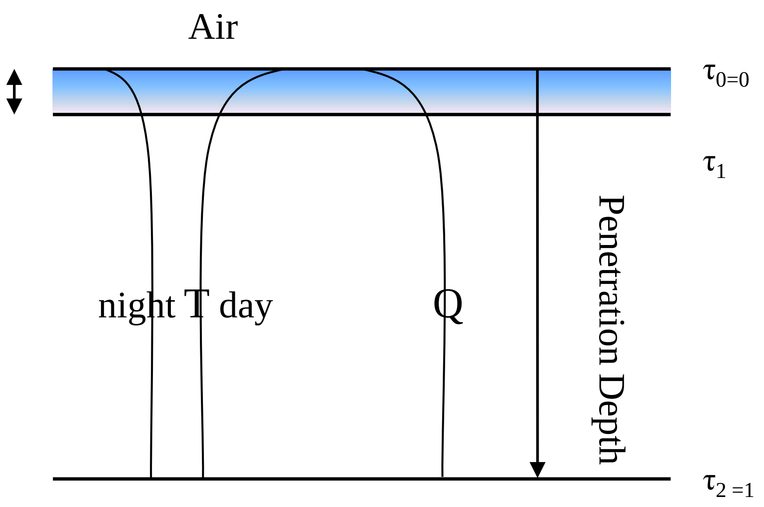
$$\frac{d\mathbf{I}}{d\tau} = \mathbf{AI} + \mathbf{B}$$

Where,

$$\mathbf{I} = \begin{pmatrix} I(\tau,\mu) \\ I(\tau,-\mu) \end{pmatrix} \quad \mathbf{A} = \begin{pmatrix} \omega_1 & -\omega_2 \\ \omega_2 & -\omega_1 \end{pmatrix} \quad \mathbf{B} = \frac{1}{\mu}\begin{pmatrix} -(1-\omega)B_{Soil} \\ (1-\omega)B_{Soil} \end{pmatrix}$$

Top Soil

Sensitive to air-soil molecular and turbulent processes



T: Soil Temperature Q: Soil Moisture

❑Single scattering albedo, and asymmetric parameter

L. Tsang, J. A. Kong, and R. T. Shin, 1985

Grody and Weng (2008)

❑Soil Dielectric

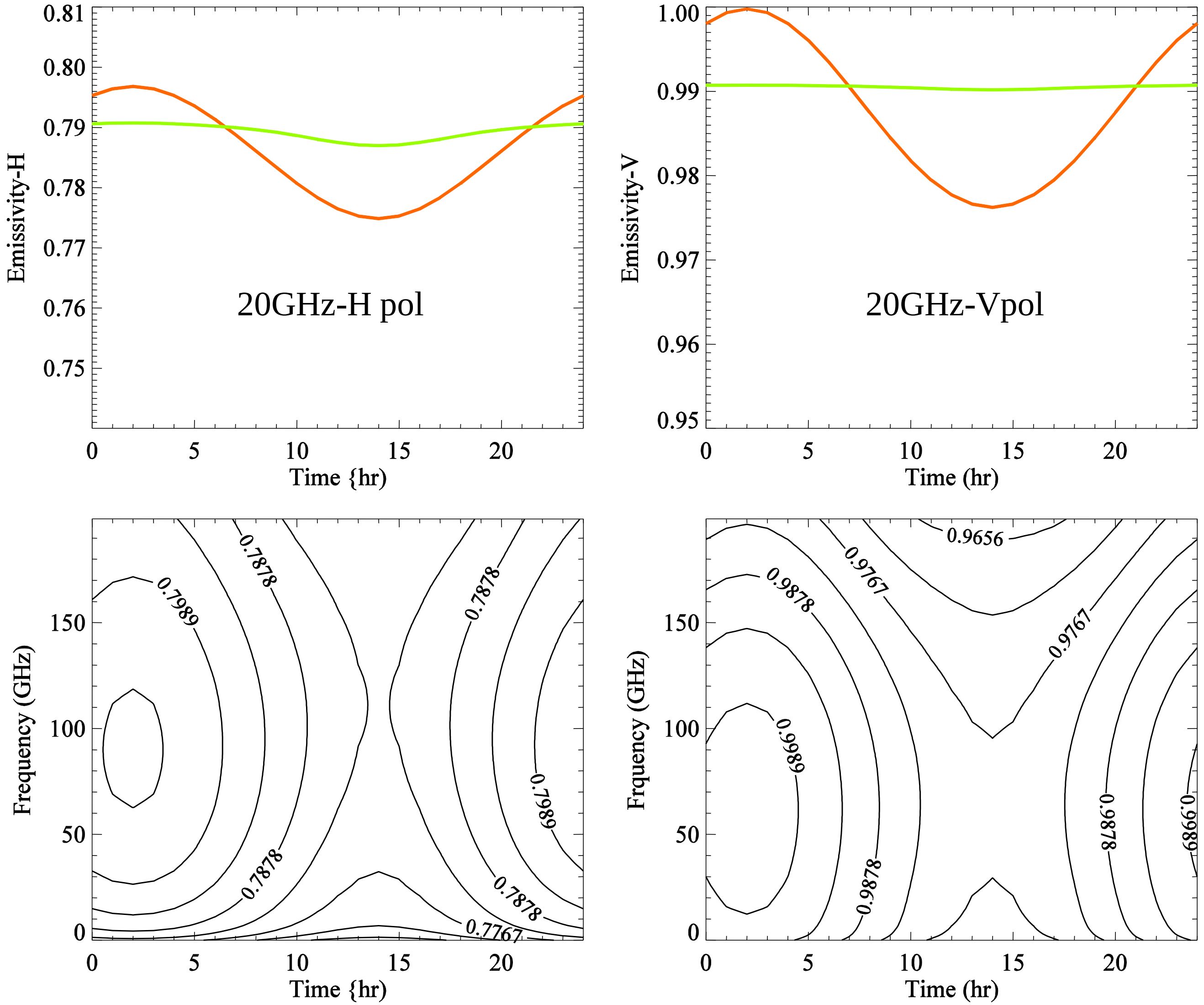
Dielectric soil-water mixing model (Dobson ,1985) is the function of soil temperature profiles

❑Boundary Conditions

Efforts in Accounting for Diurnal Variation (Orbit Changes)

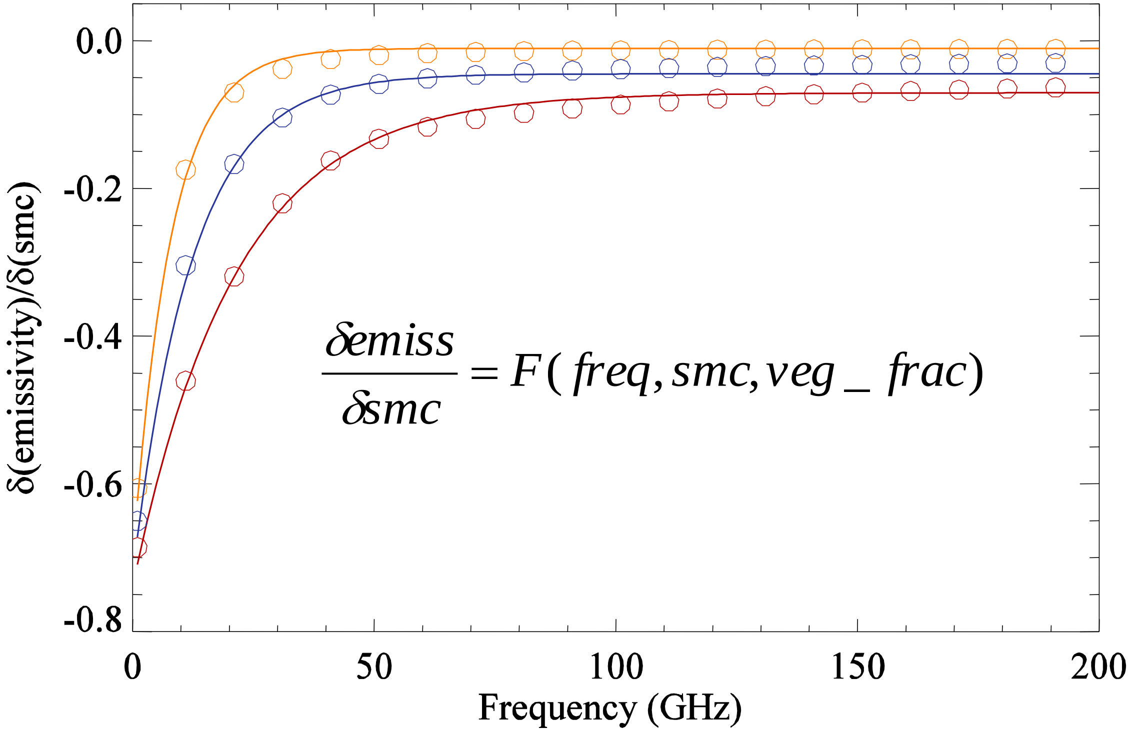
There are relative small diurnal variation in original model solution, which just accounts for top layer diurnal change

The ongoing improvements account for both the layer diurnal variation and the diurnal gradient change.



Development of LandMW_TL and LandMW_AD

- Analytic TL/AD model may be built up over reduced model state space, where only a few sensitive parameters or model variables are used in model property analysis, and high-order differential regression models are derived.
- Such analytic TL/AD model may be used in GSI, meanwhile it provides the relationship between the sensitivities of different channels, which may be used to quantify the uncertainty of sensitive model inputs from few channels.
- "Real-time" model I/O correction analysis may be performed with the observations of one or two channels.

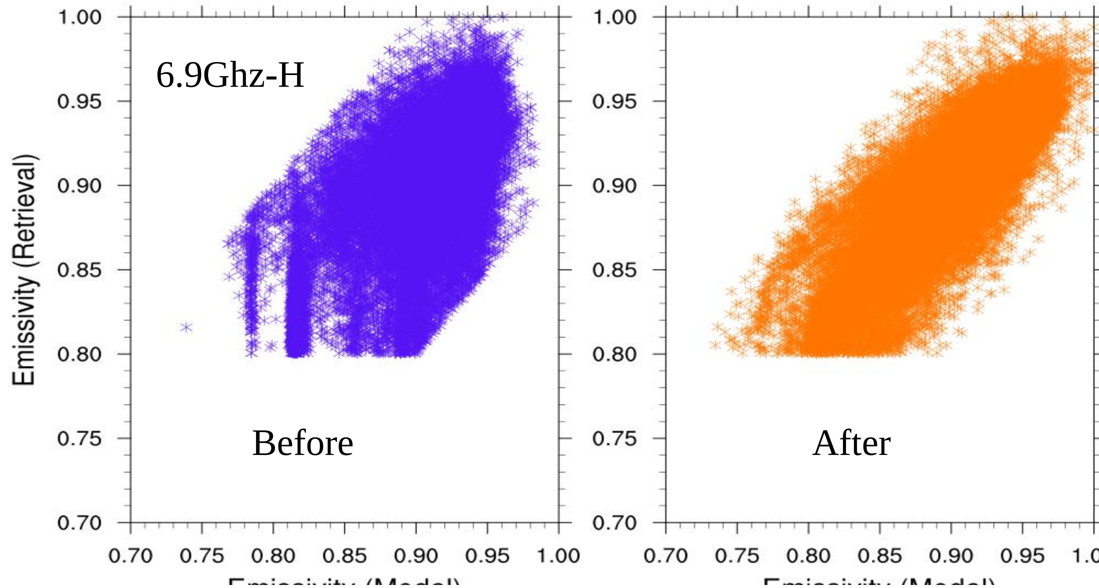


$$\frac{\delta emiss}{\delta smc} = F(freq, smc, veg\_frac)$$

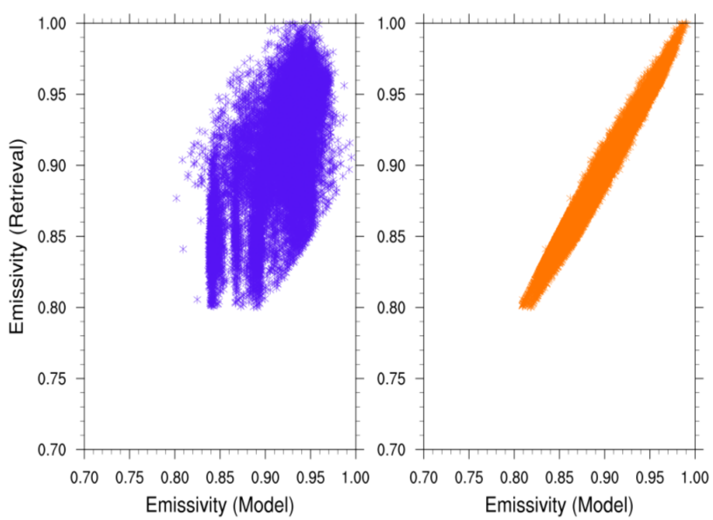
Emissivity Scatter Plots of AMSR-2

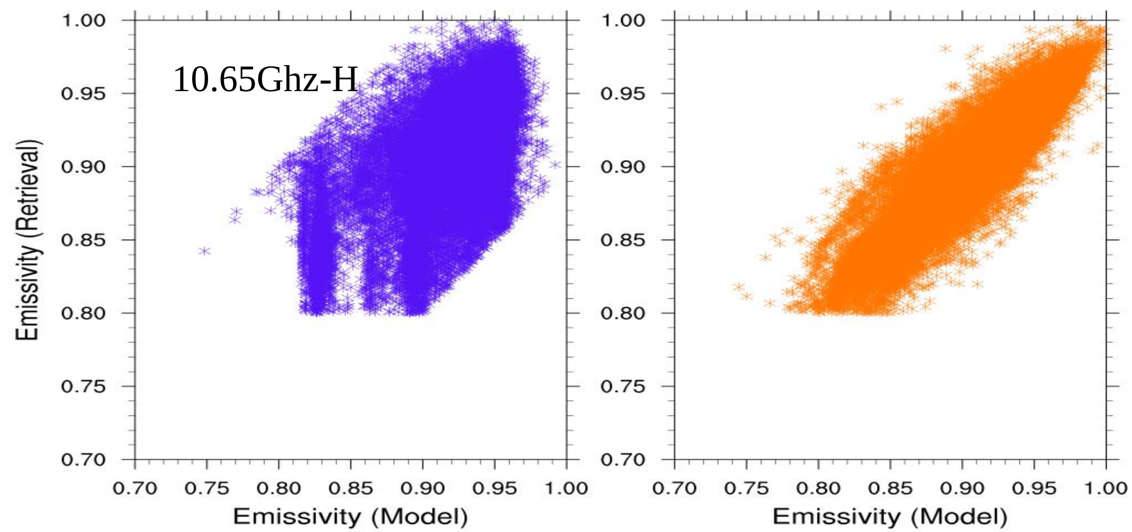
(Model Vs. Retrl)

Correction analysis with observation of only one channel (23.8GHz)



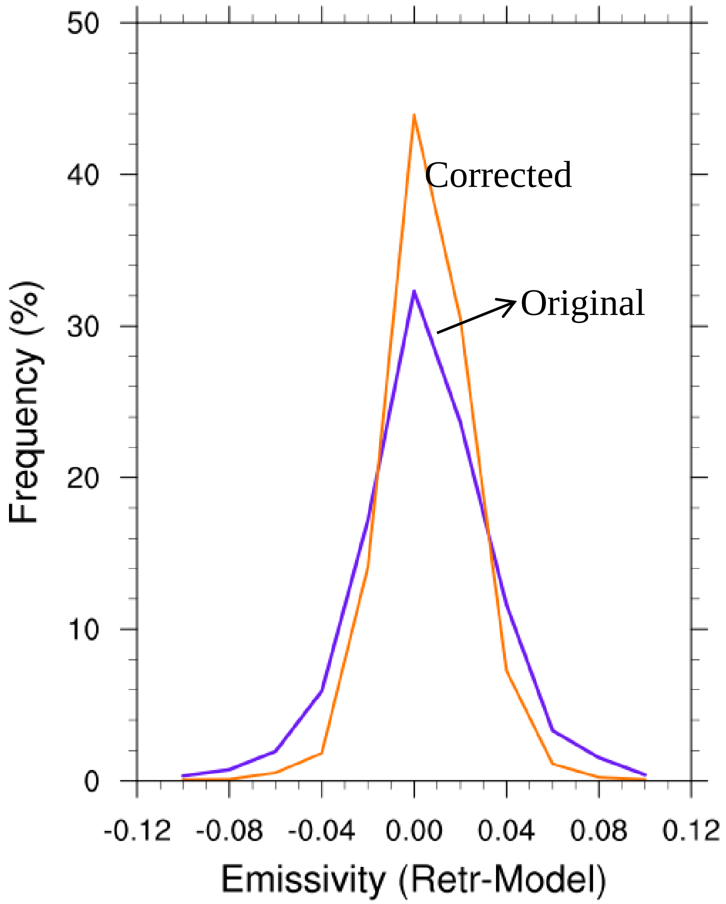
23.8GHz-H



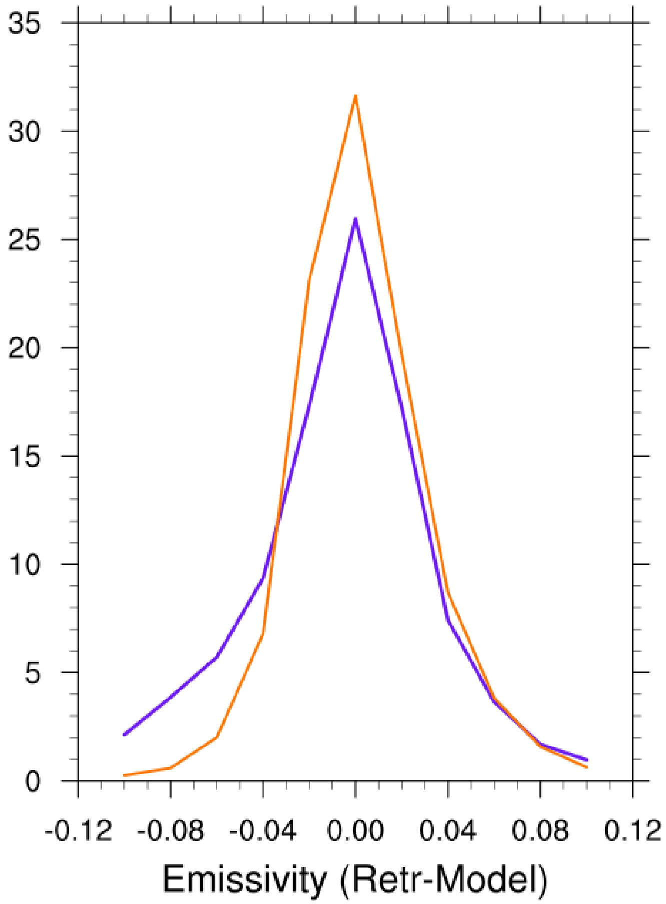


Frequency Histogram of Emissivity (Retrl-Model)

AMSR-2 6.9GHz-H

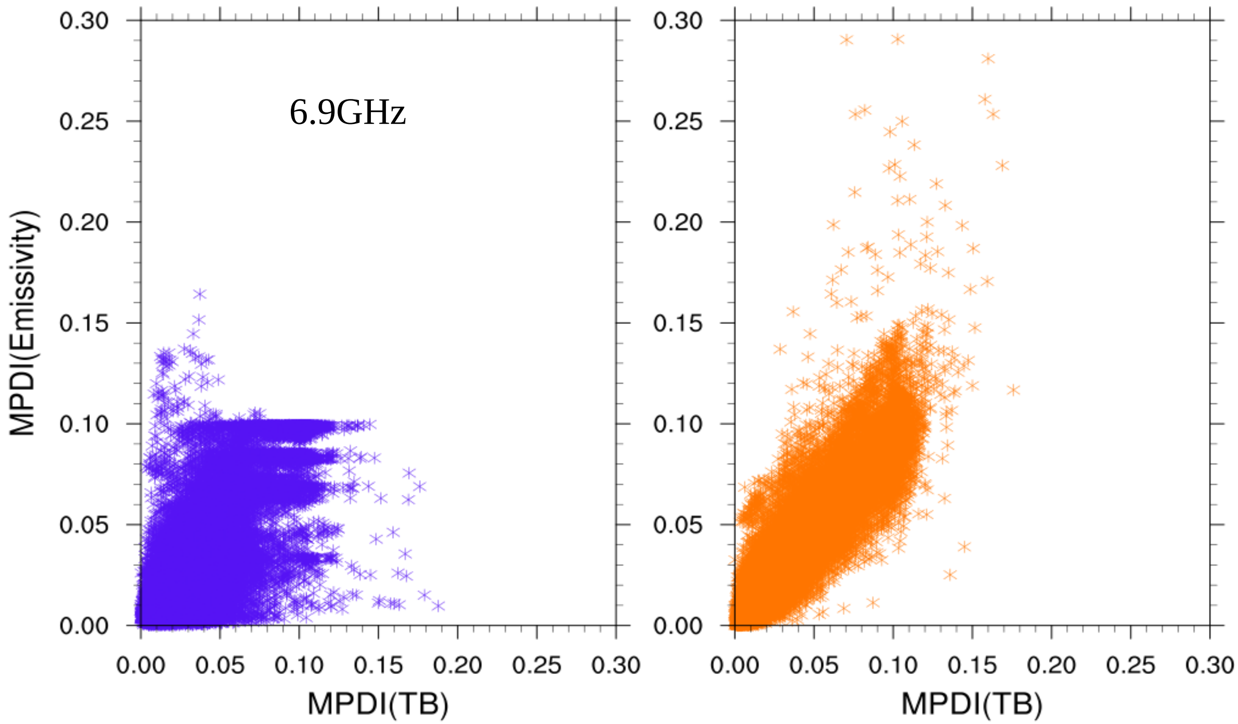


AMSR-2 6.9GHz-V



MPDI Scatter Plots of AMSR-2

Microwave Polarization Difference Index (MPDI)

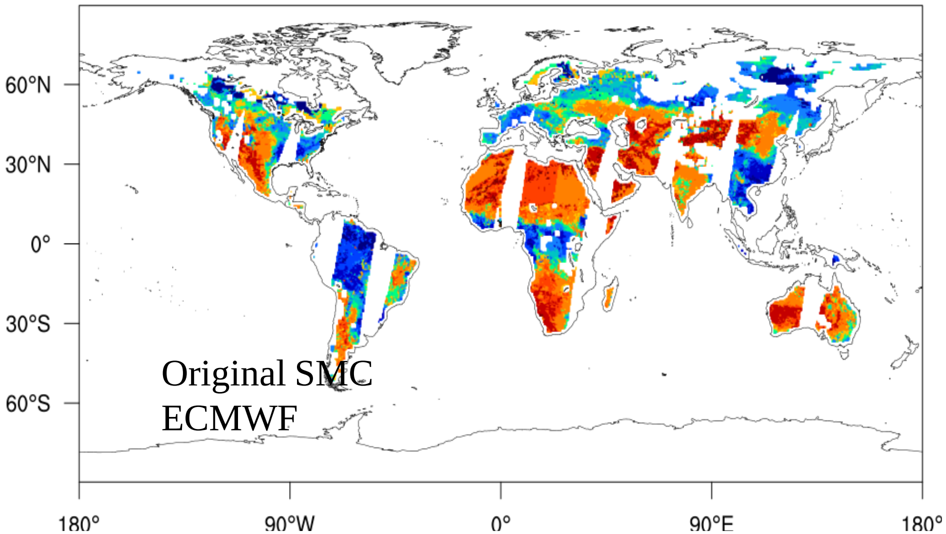


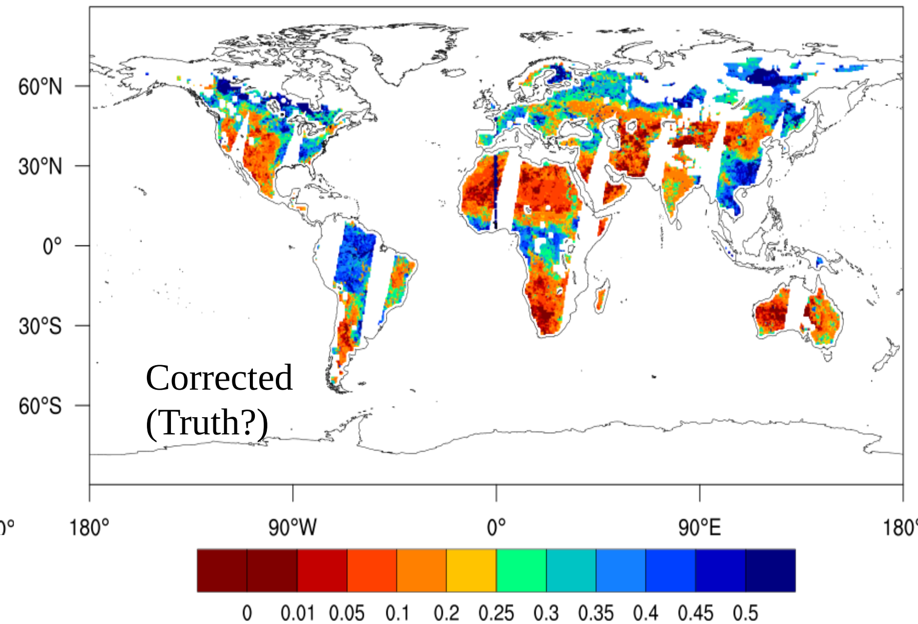
$$\begin{cases} MPDI_{Tb} = \dfrac{\mathrm{Tb_v} - \mathrm{Tb_h}}{\mathrm{Tb_v} + \mathrm{Tb_h}} \\ MPDI_{\varepsilon} = \dfrac{\varepsilon_v - \varepsilon_h}{\varepsilon_v + \varepsilon_h} \end{cases}$$

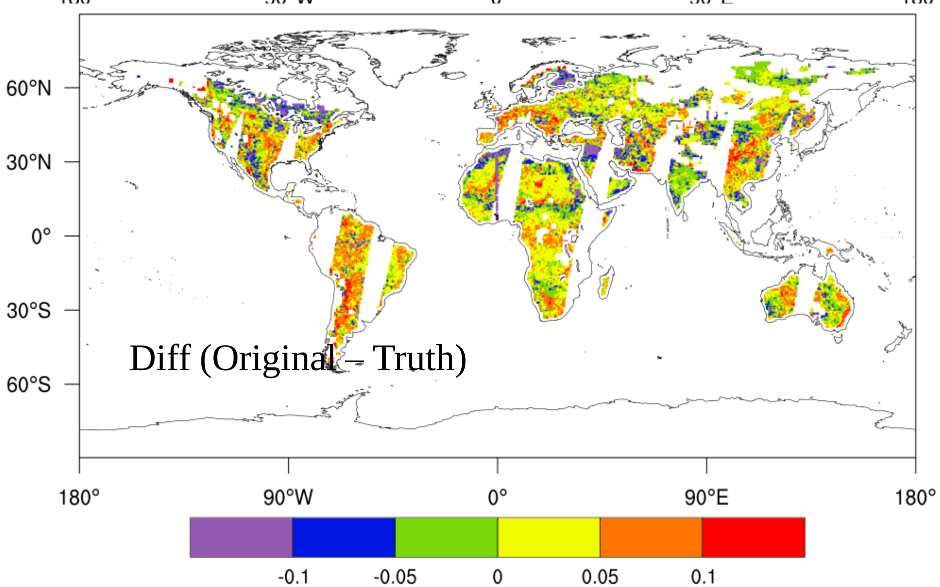
$$if: Tb \approx \varepsilon T$$

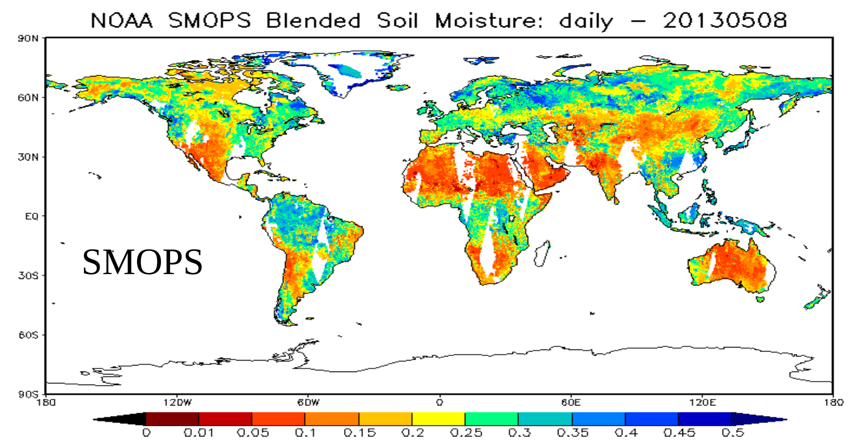
$$then \ MPDI_{Tb} \approx MPDI_{\varepsilon}$$

Uncertainty of Model SMC Inputs



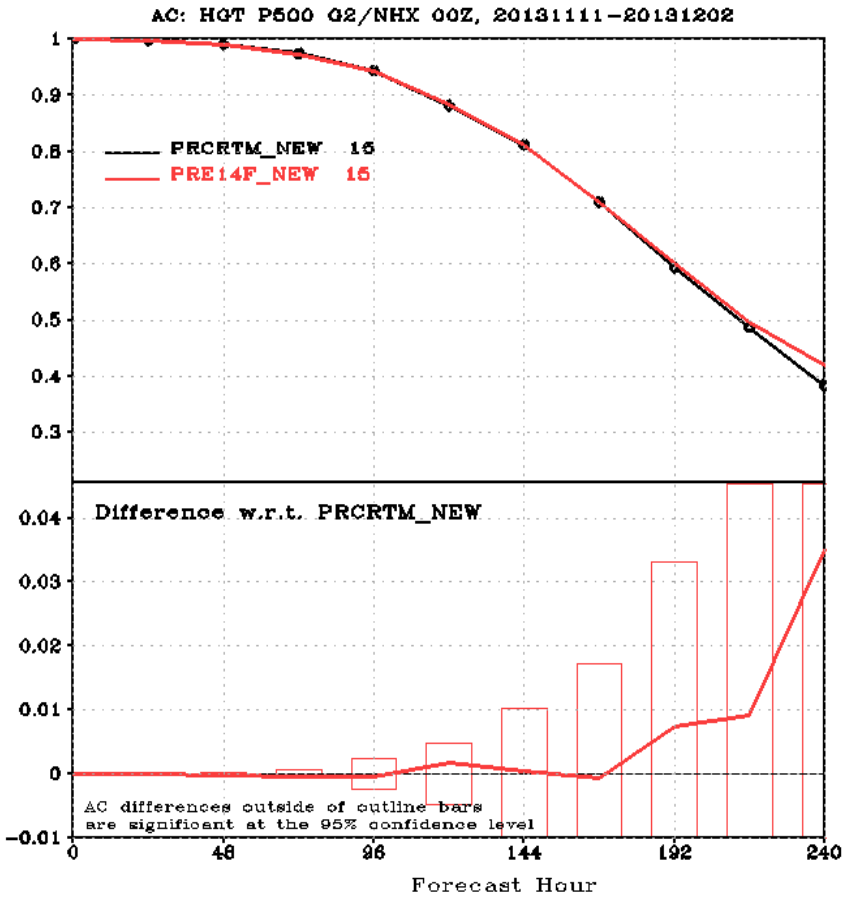






Results from GFS Parallel Runs

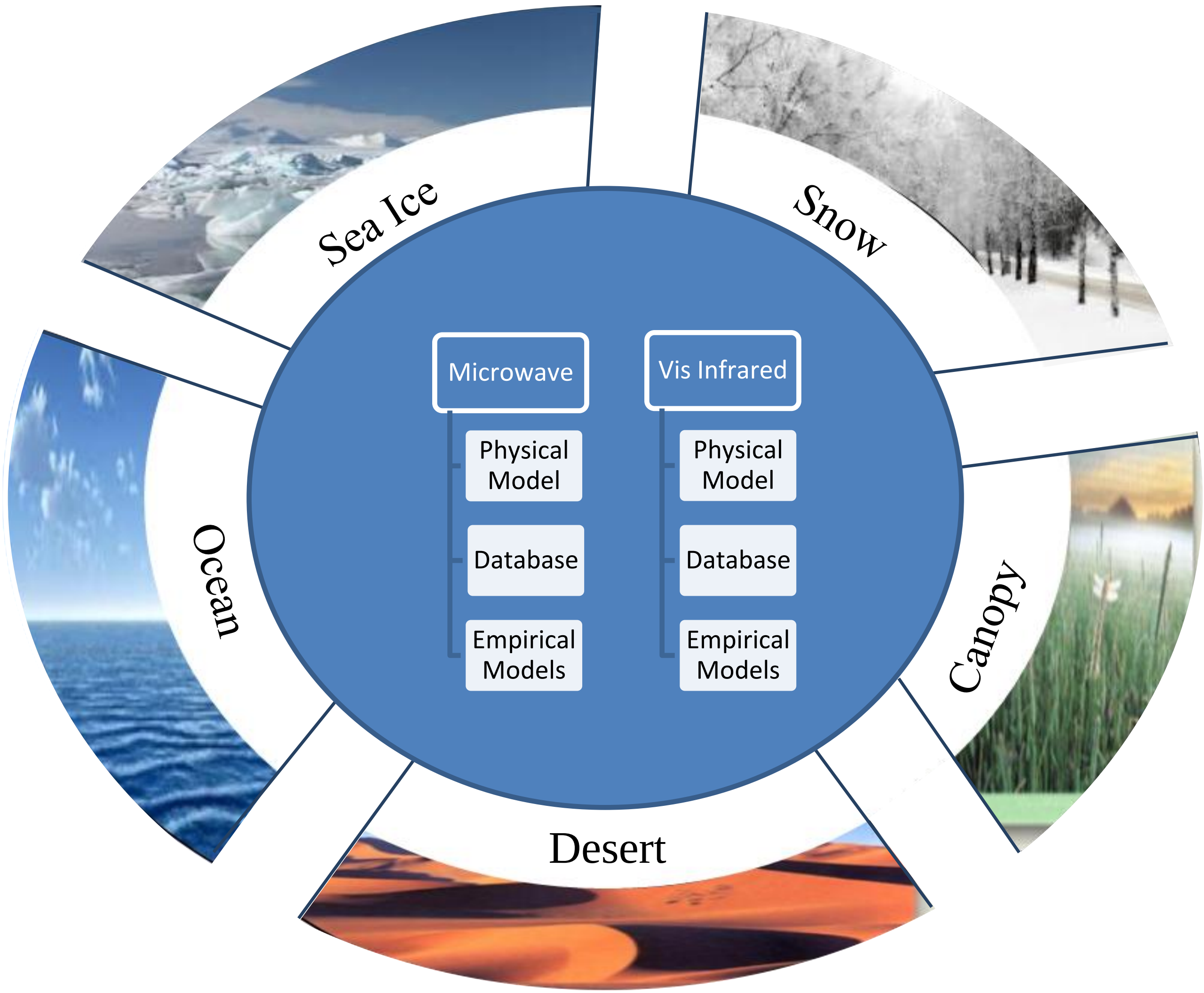
Performed parallel GFS runs on Zeus to evaluate the potential impact of the land MW emissivity models on weather forecasting. Two GFS-GSI runs were successfully completed and analyzed. The configurations of the two GFS-GSI runs were the same except using different versions of the CRTM land MW emissivity models. It was found that the current improvement of the land MW emissivity model generally brings about positive impact on the GFS forecasting scores. More experiments will be performed.



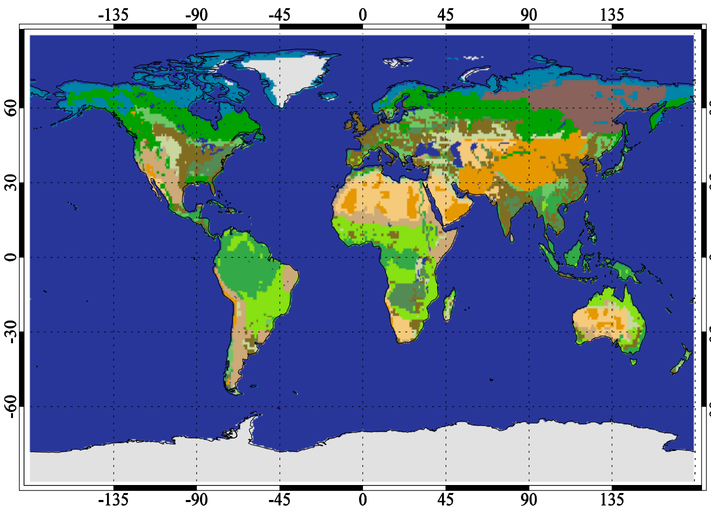
Summary

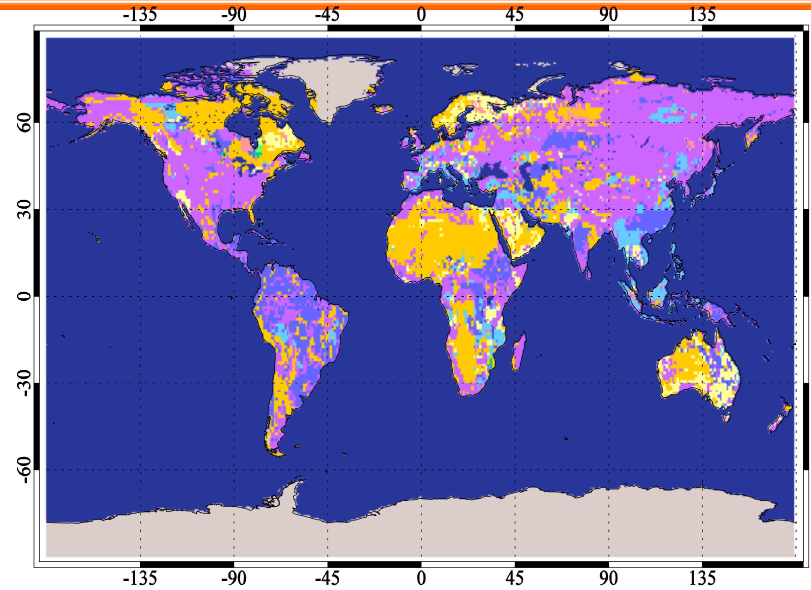
1. Completed the general CSEM system design, which includes model infrastructure design and the design for interfacing with upper-level host system (e.g., CRTM).
2. Implemented VIS/IR/MW Land/Snow/Ice forward emissivity models in CSEM.
3. Implemented CRTM-CSEM interfacing modules.
4. The improvements of model physics showed significant impacts on CRTM forward simulations, and neutral/slightly positive impacts on GFS forecasting.

Community Surface Emissivity Modules (CSEM)

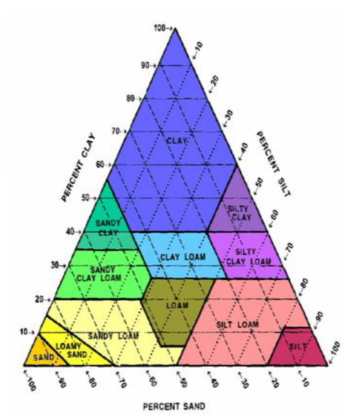


Unified Surface-Tying Based on Vegetation and Soil Unit-Types





Index	IGBP Name	Percentage
1	E BroadForest	9.1
2	D BroadForest	3.9
3	MixedForest	4.4
4	E NeedleForest	13.6
5	D NeedleForest	6.9
6	WoodySavannas	9.6
7	Grasslands	4.2
8	ClosedShrubs	6.9
9	OpenShrubs	8.1
10	MixedShrubs	12.3
11	Bare Soil	8.6
12	Croplands	12.3



Index	USGS Name	Percentage
1	Sand	25.6
2	Silty Clay Loam	45.2
3	Clay	13.5
4	Sandy Loam	7.1
5	Sandy Clay	0.2
6	Clay Loam	6.8
7	Sandy Clay Loam	0.1
8	Silty Loam	1.5