Visible-Infrared Emissivity & BRDF Models of Land Surfaces

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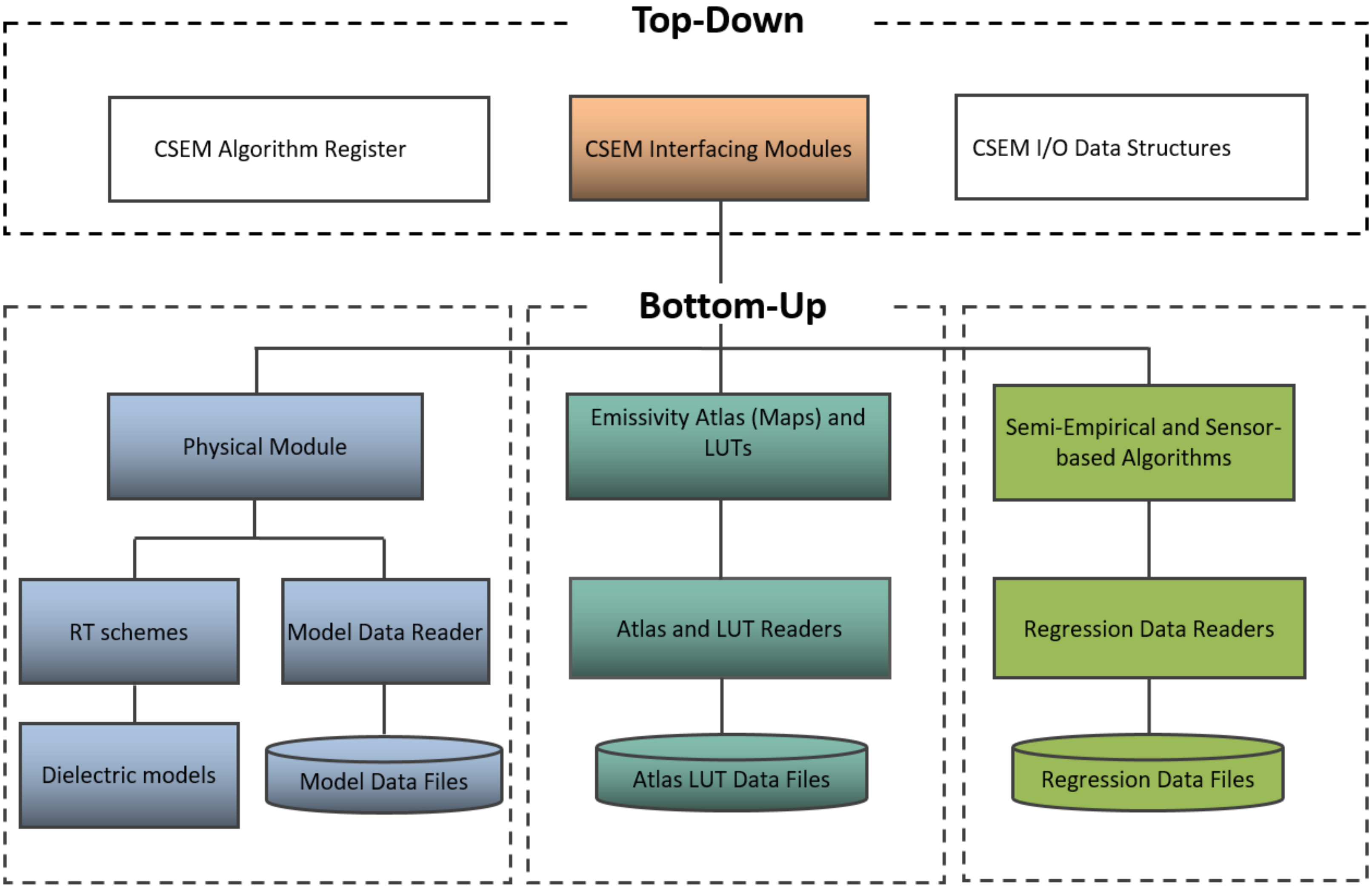
Outline

1. A short introduction to CSEM
2. Land surface visible & infrared emissivity/BRDF models implemented in the CSEM system
3. Physical visible bidirectional canopy reflectance model
4. The variational Kramers-Kronig analysis of leaf refractive index spectra and the physical infrared emissivity model
5. Summary

Diagram of Unit CSEM Infrastructure & Interfacing Design



Top-Down

CSEM Algorithm Register

CSEM Interfacing Modules

CSEM I/O Data Structures

Bottom-Up

Physical Module

RT schemes

Model Data Reader

Dielectric models

Model Data Files

Emissivity Atlas (Maps) and LUTs

Atlas and LUT Readers

Atlas LUT Data Files

Semi-Empirical and Sensor-based Algorithms

Regression Data Readers

Regression Data Files

CSEM Model Repository

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# This text file serves as an Algorithm Register for developers to add their new models to the model pool, and
# meanwhile serves as a Configuration file for users to specify a model for experimental or operational purpose.
# Special Chars   "[ ]" Model Class     "," - Delimiter    "#" - Comment lines
# Text Format  Col1 – Model Options   Col2 – Model Option On/Off    Col3 – Coefficient file path
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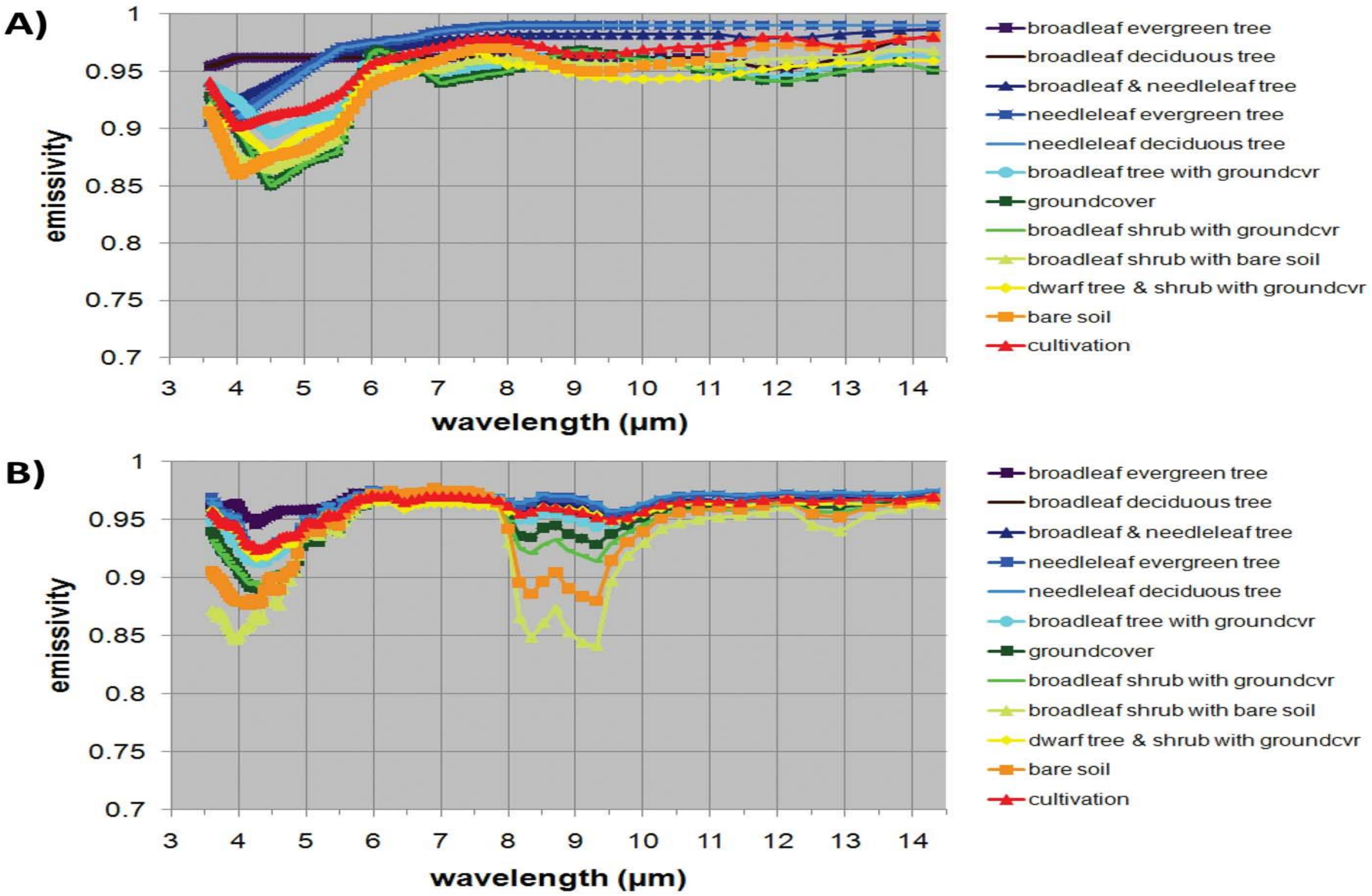
SensorBased	,	1									

Land Surface Visible & Infrared Models Implemented in the CSEM System

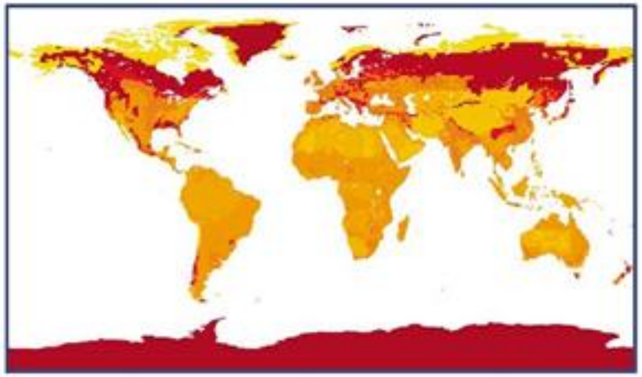
	Models	Model Features	Spectral Range
1	NPOESS-LUT	• Reflectivity/emissivity spectra of 24 different surface-cover types • Global mapping of the 24 surface cover types	0.2um ~ 15um **54 + 20** spectral points
2	RTTOV-BRDF *Seemann & Borbas, 2008* *Lucht et al.(2000)* Roujean et al, 1992 Wanner eta al, 1995	• Monthly BRDF/Bi-hemispheric Albedo(0.1°x0.1°) • Accuracy depends on MODIS MOD43 data, 3 Kernel-driven parametrization, the set of laboratory spectra used in principle component analysis.	0.4um ~ 2.5um **2101** spectral points
3	RTTOV-UWIREmis *Seemann & Borbas, 2008*	• Monthly gridded emissivity ataas (0.05°x0.05°) • Accuracy depends on UW/CIMSS baseline-fitted emissivity DB, MODIS MYD11 data and the set of laboratory spectra used in principle component analysis.	3.6um ~ 14.3um **416** spectral points
4	IASI Emissivity Database *Zhou et al., 2011*	• Monthly Gridded emissivity atlas (0.5°x0.5°) • Based on multistage linear EOF regression at 8461 IASI channels 645 – 2760 (cm^{-1}) measurements • Multiple training datasets	3.6um ~ 15.5um

NPOESS LUT Vs. RTTOV-UWIR Emissivity Atlas

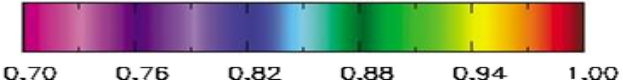


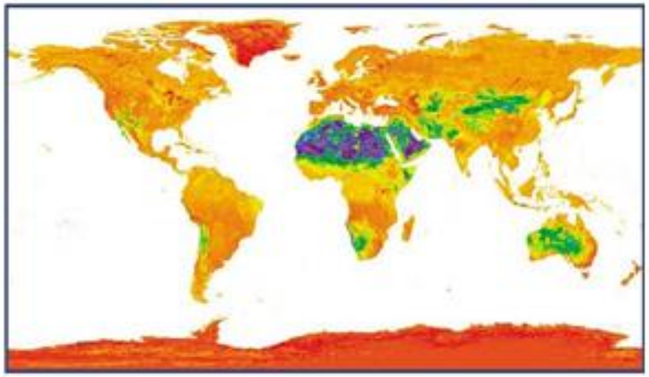
A) NPOESS **B)** UWIR spectra constructed by averaging globally the original UWIR emissivity atlas (July) in terms of each of the NPOESS surface classes

Comparison of Tb Observations - CRTM Simulations

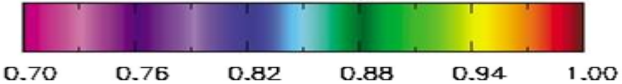


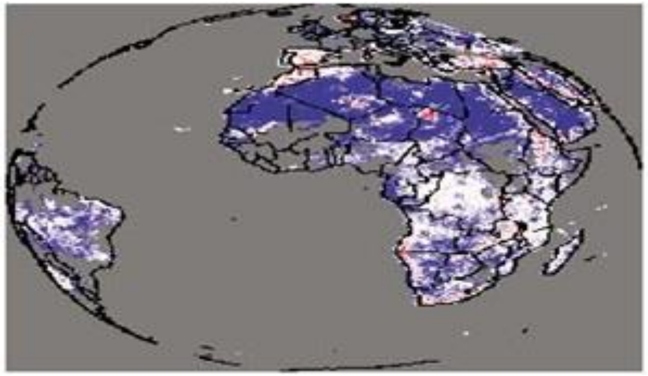
NPOESS Emissivity (8.7µm)



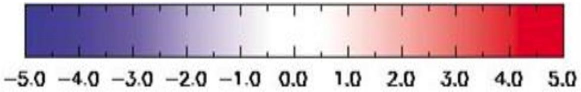


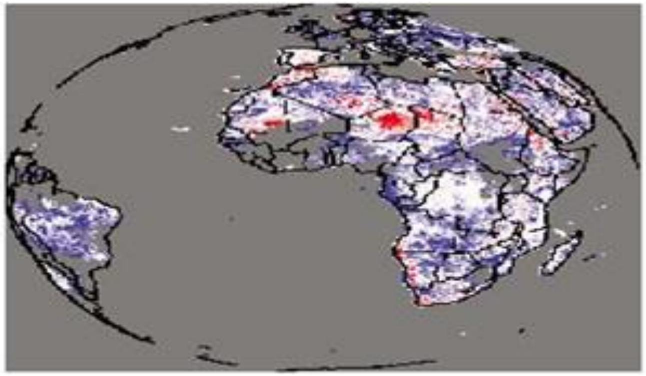
UWIR Emissivity (8.7µm)



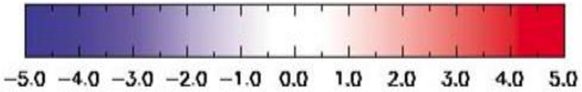


Tb Obs - Sim w/ NPOESS





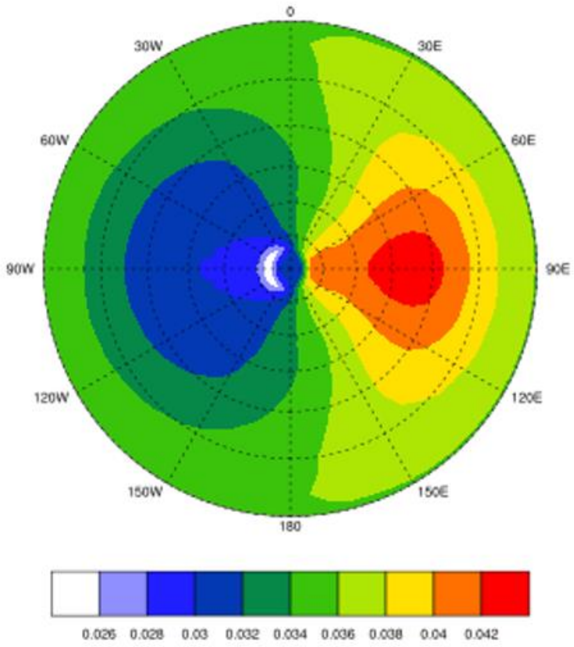
Tb Obs - Sim w/ UWIR



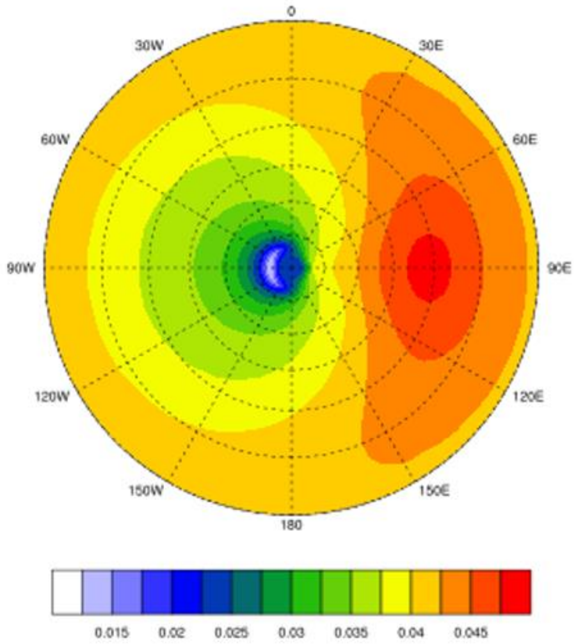
(Ronald L. Vogel, JGR,2011)

Seasonal & Angular Variation of RTTOV-UW BRDF

March



September



Emissivity/BRDF LUTs Vs Physical Models

- LUTs is Fast and has necessary quality as “first-guess”
- The spectra are discrete, static
- Generally limited for the instrument the database was developed from, because different instruments have different bandwidths and IFOV and scanning FOV
- Earth surface Infrared emissivity is very sensitive to the surface properties such as land cover types, roughness and canopy structures, view angles, polarization, soil texture and soil moisture, *etc* . The emissivity from a database is not directly linked with the parameters from land surface model, so it is difficult to find a unique database to ensure the RTM performance in every case. And it is hard to track the causes leading to the variations of model performance.

PROSAIL (PROSPECT+SAIL) Physical Model

LEAF OPTICAL MODEL

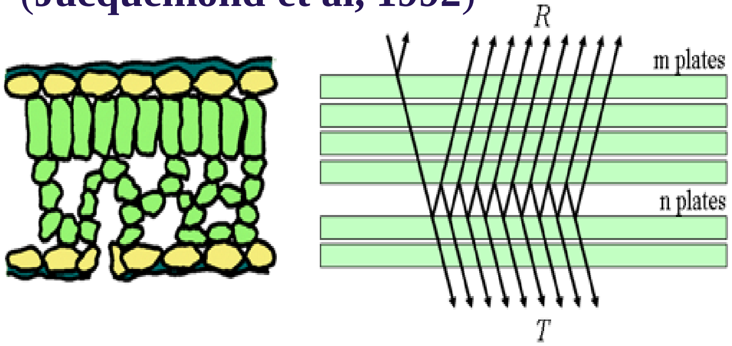
N	Leaf structural layers
C_{ab}	Chlorophyll a+b content
C_{bp}	Brown pigment content
C_w	Water content
C_{dm}	Dry matter content

$n(\lambda)$	Refractive index
$k_i(\lambda)$	Absorption coefficient of leaf constituants

PROSPECT

Dicotyledon leaf model w/ multiple reflections produced by a set of plates

(Jacquemond et al, 1992)



CANOPY REFLECTANCE MODEL

LAI	Leaf Area Index
θ_l	Mean leaf angle
ρ_l	Leaf reflectance
τ_l	Leaf transmittance

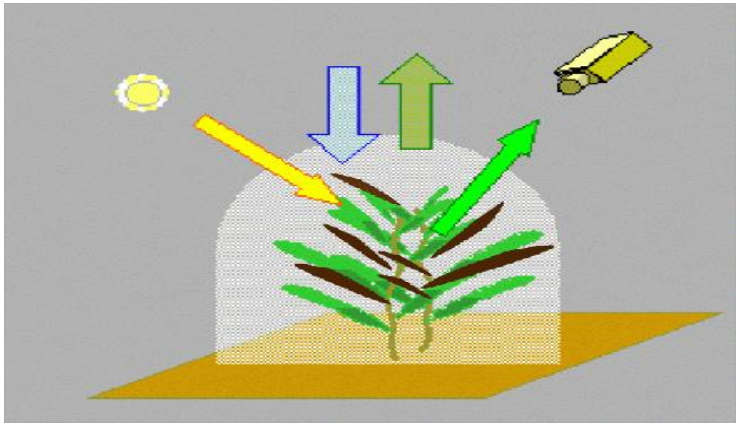
ρ_s - Soil reflectance

Θ - Solar zenith angle

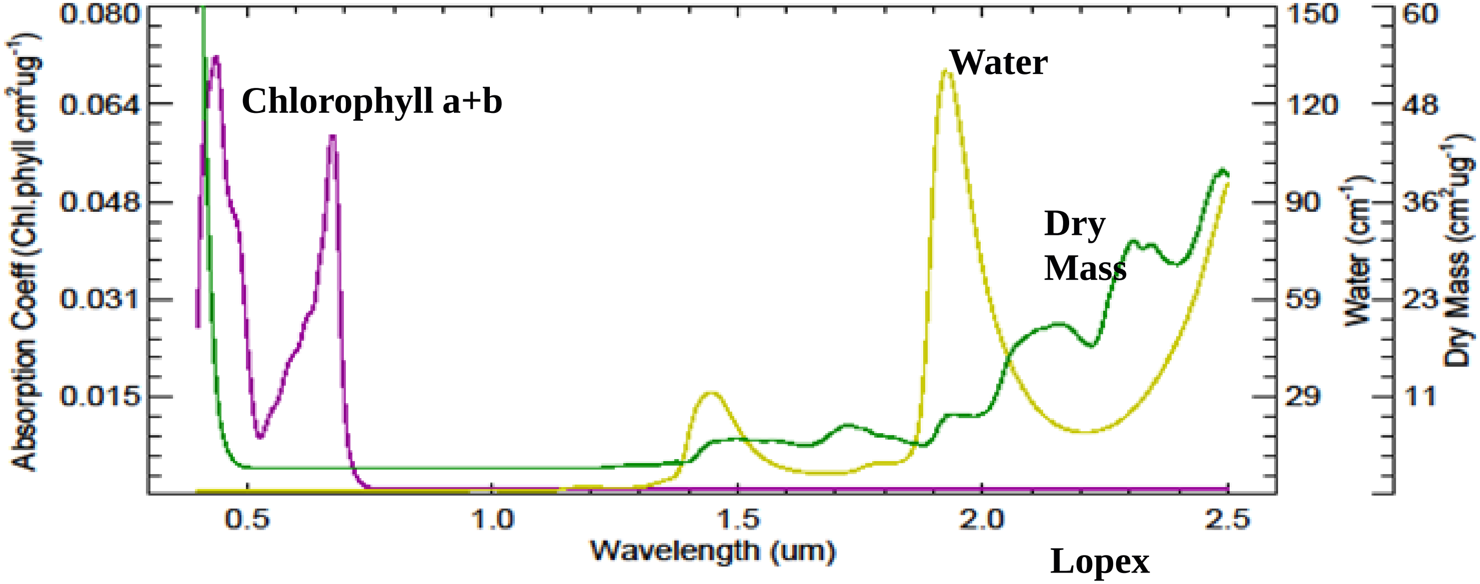
φ - View zenith angle

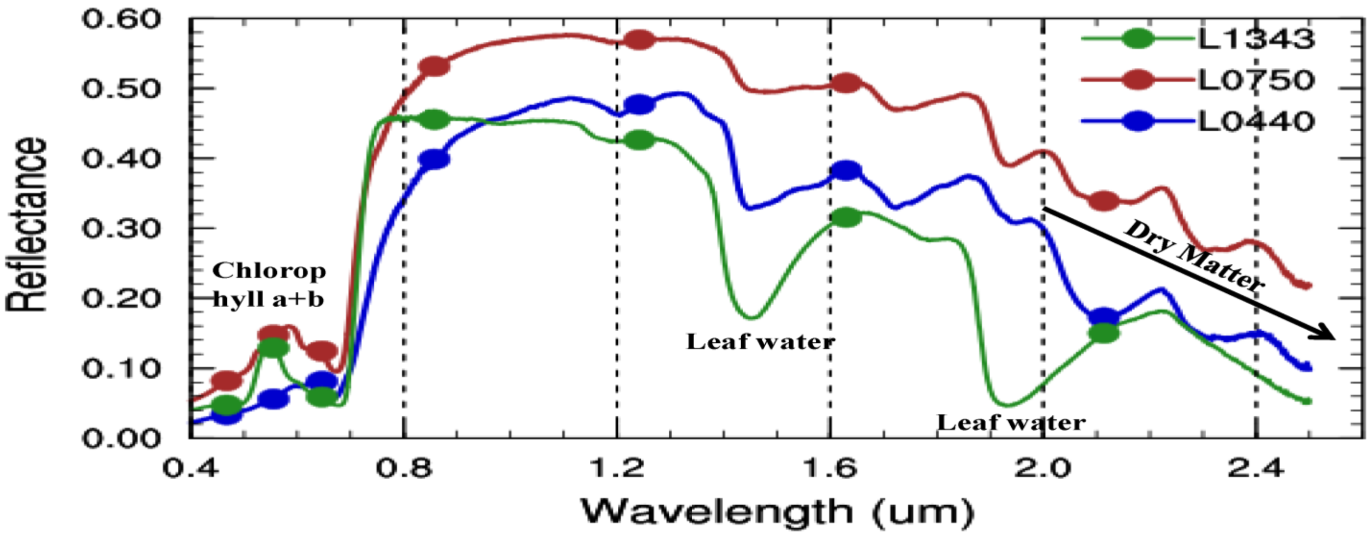
SAIL

Four-fluxes model with multiple **S**cattering **A**rbitrary **I**nclined **L**eaves (Verhoef, 1984)



Visible &Near Infrared Leaf Optical Spectrum Characterized by Absorptions



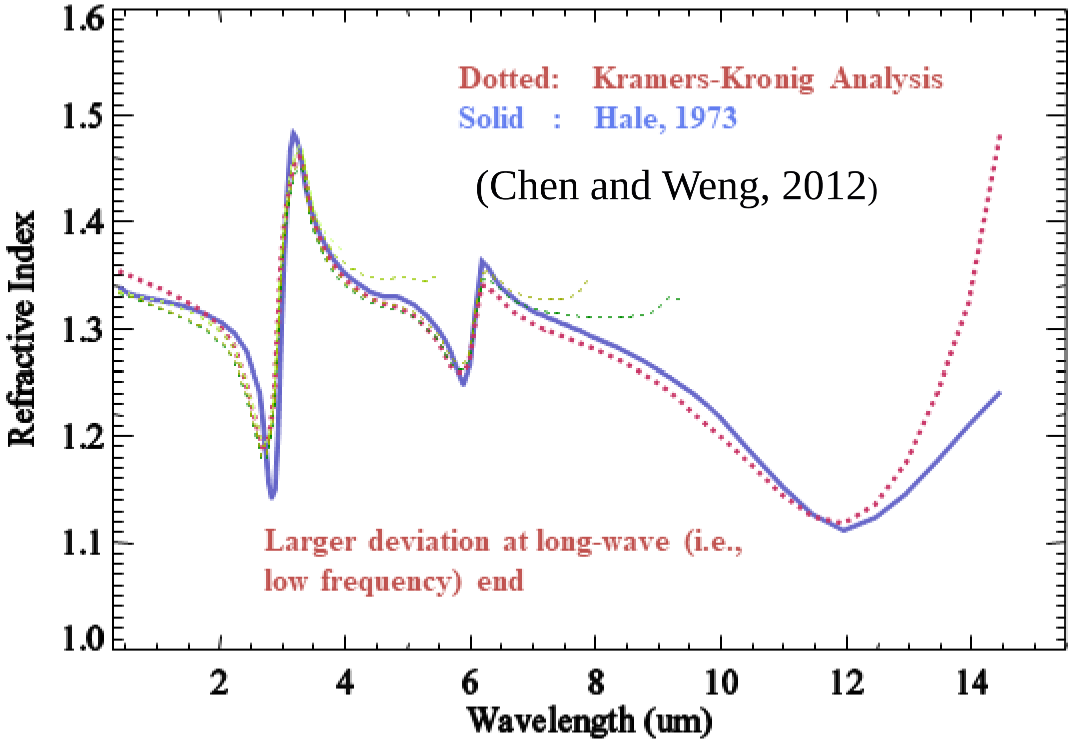


Variational Analysis of Refractive Index with Kramers-Kronig (KK) Dispersion Relation

Kramers-Kronig Dispersion Relations

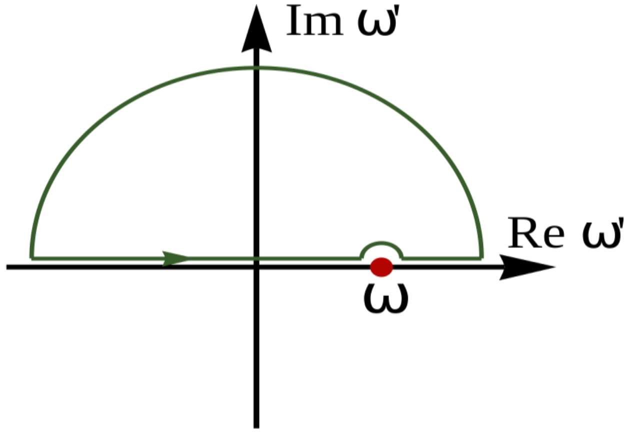
$$n(w) - 1 = \frac{2}{\pi} p \int_0^{\infty} \frac{x k(x)}{x^2 - w^2} dx$$

$$k(w) = \frac{2w}{\pi} p \int_0^{\infty} \frac{n(x) - 1}{x^2 - w^2} dx$$



(Chen and Weng, 2012)

Larger deviation at long-wave (i.e., low frequency) end

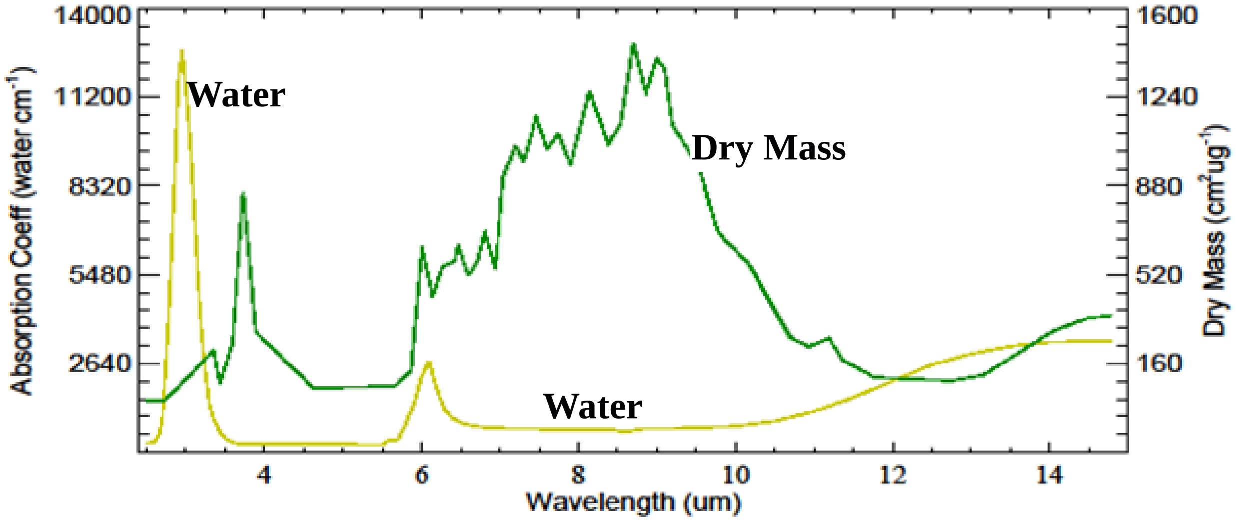


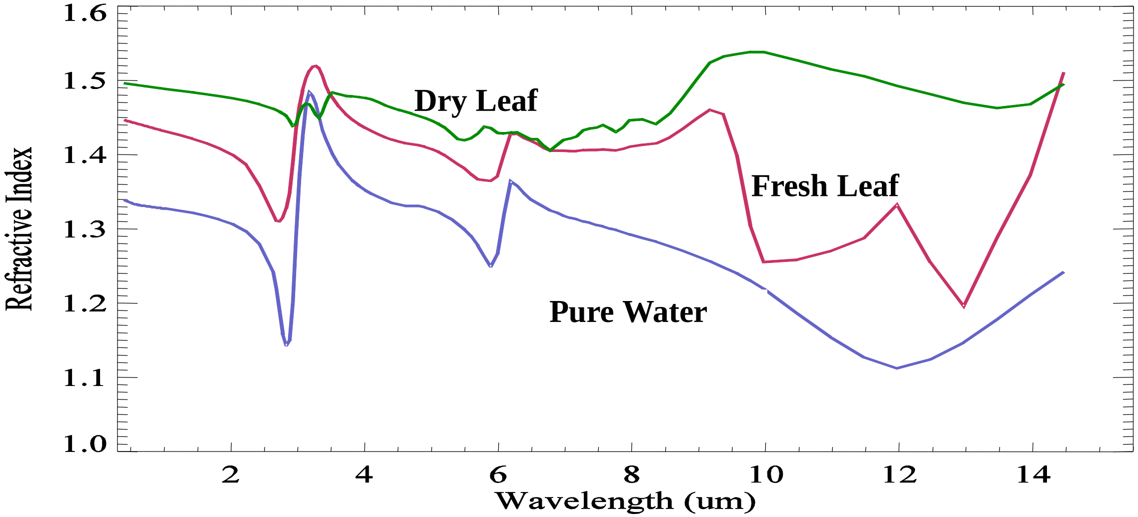
Solid line is the refractive index by Hale, which servers as the true values. Dotted lines are the refractive index calculated from water absorption coefficient K(x). Different cutting ranges are tested as shown by different dotted lines. Larger deviation may be seen at the cutting edges. Yet it may be avoided by proper extrapolation assumption, or simply by using extended K(x) data.

Leaf Refractive Index of 2.5µm-15µm Derived From KK Analysis

We tried to extend the PROSPECT model to the thermal infrared range of 2.5µm — 15µm with the establishment of leaf absorption spectra from different sources, and applied the KK-analysis to derive the corresponding refractive index spectra.

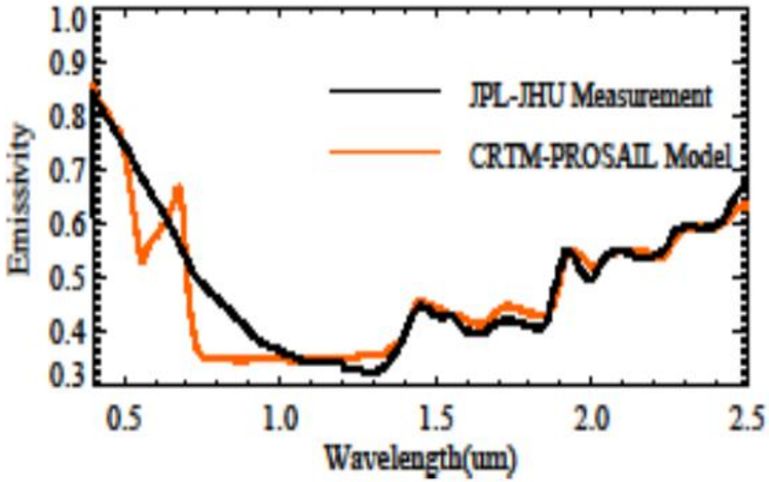
Shown in Figure are the leaf water and dry mass absorption spectra (upper), and the KK-based refractive index (lower)



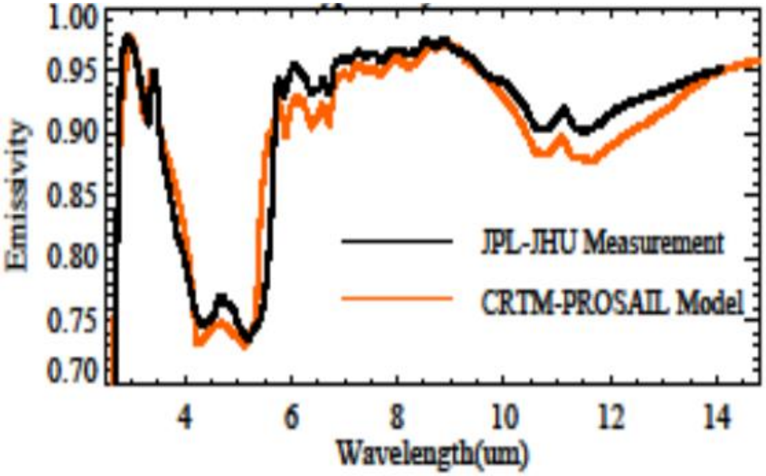


Simulation of JPL-JHU Measurements

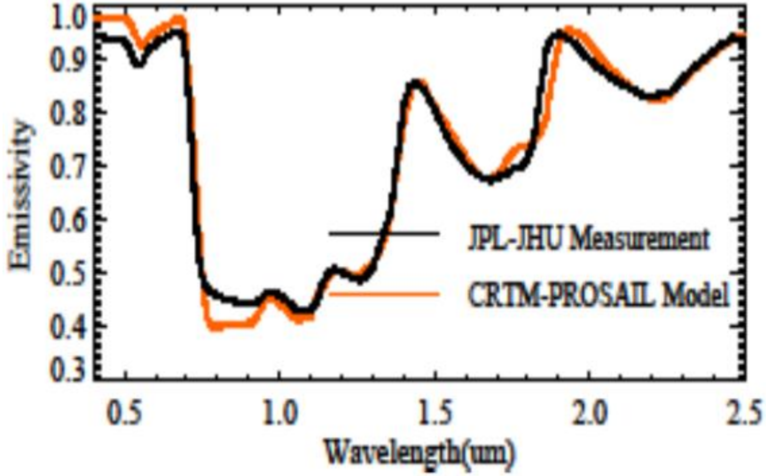
Dry Grass (0.4 - 2.5 μm)



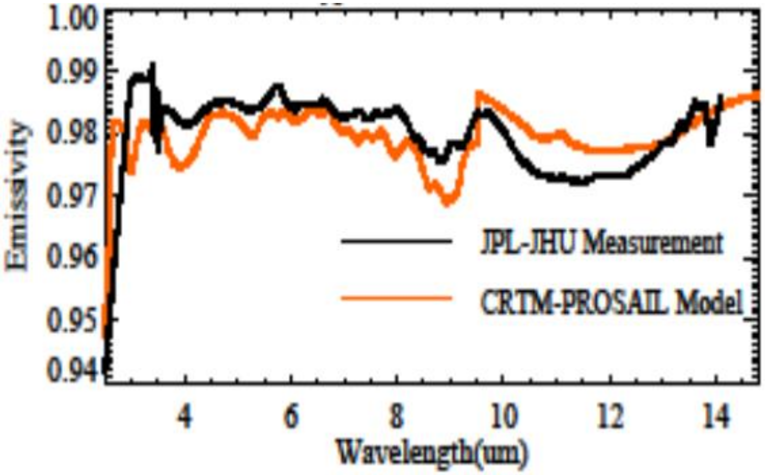
Dry Grass (2.5 - 15 μm)



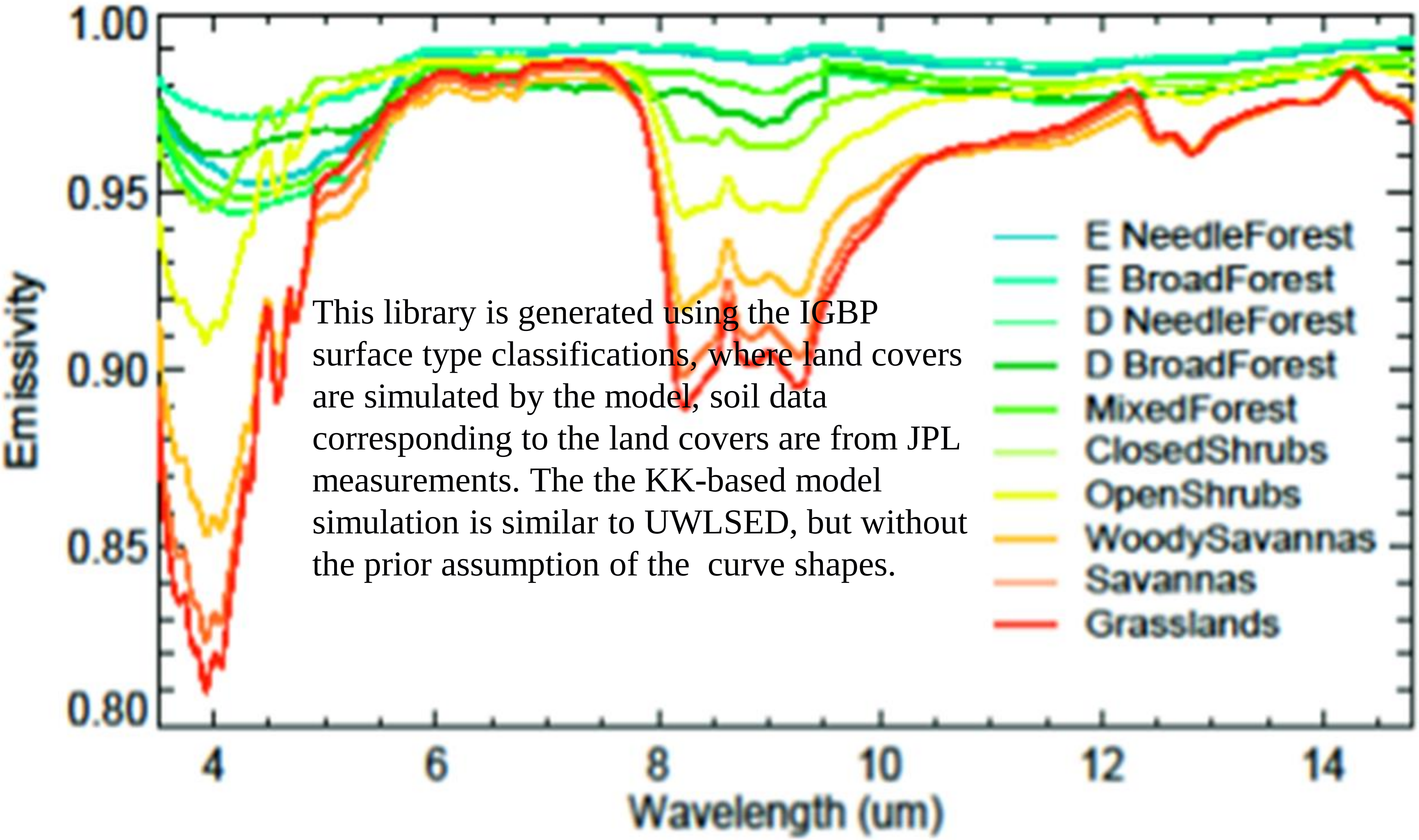
Deciduous Tree (0.4 - 2.5 μm)



Deciduous Tree (2.5 - 15 μm)

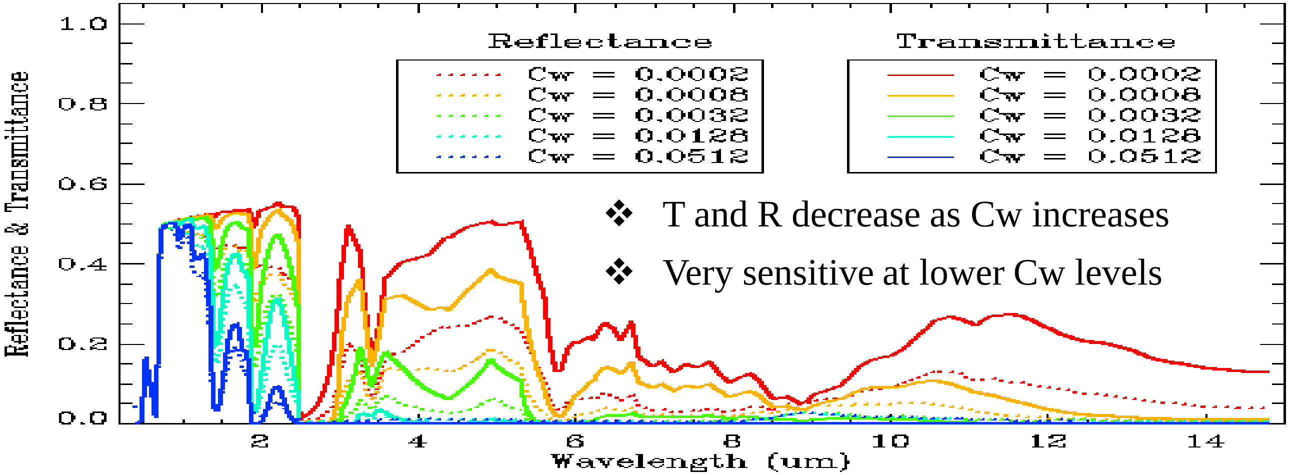


KK-PROSAIL IR Emissivity Simulations By IGBP Surface Cover Types

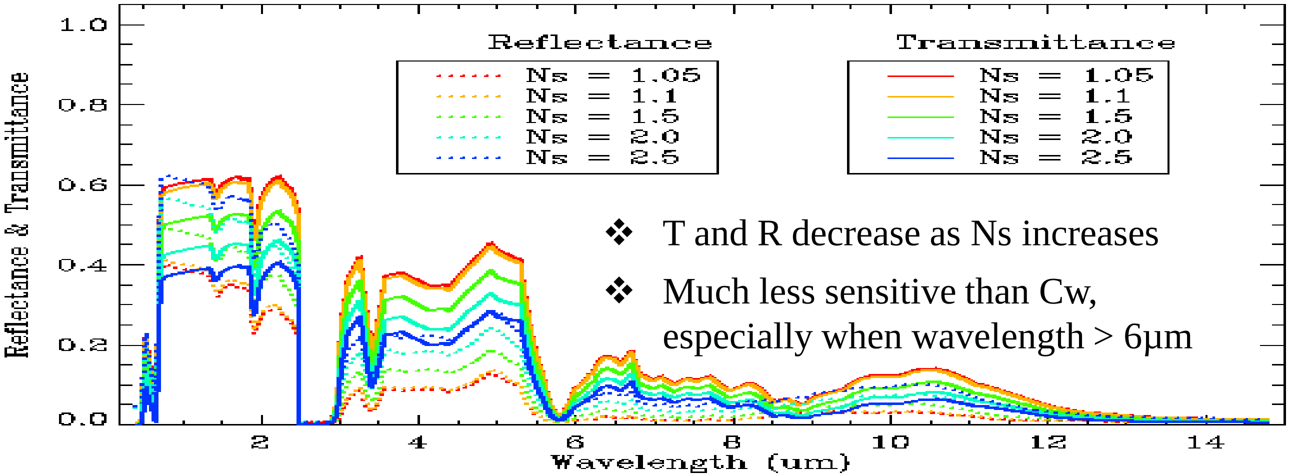


This library is generated using the IGBP surface type classifications, where land covers are simulated by the model, soil data corresponding to the land covers are from JPL measurements. The the KK-based model simulation is similar to UWLSED, but without the prior assumption of the curve shapes.

Implications of Diurnal & Seasonal Variations by Sensitivity Analysis



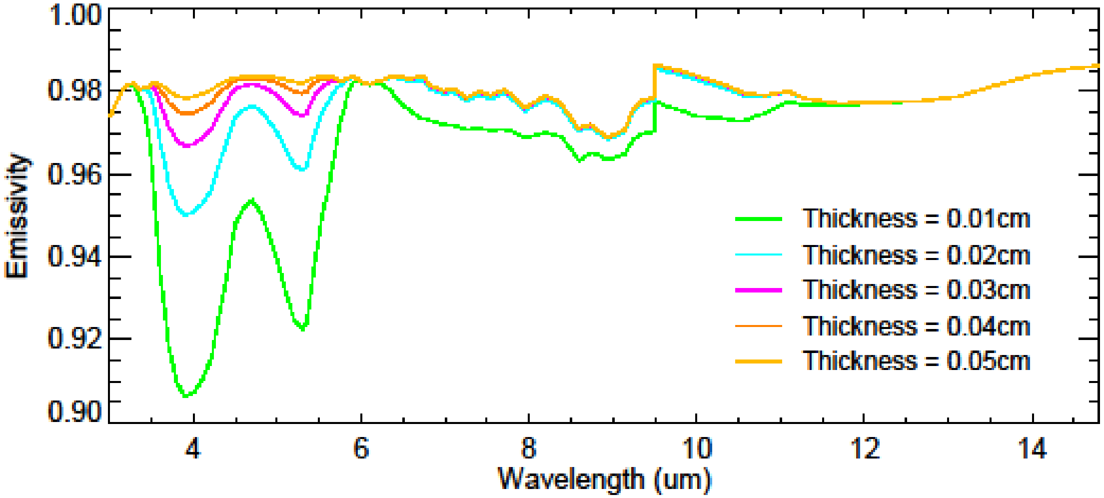
- ❖ T and R decrease as Cw increases
- ❖ Very sensitive at lower Cw levels

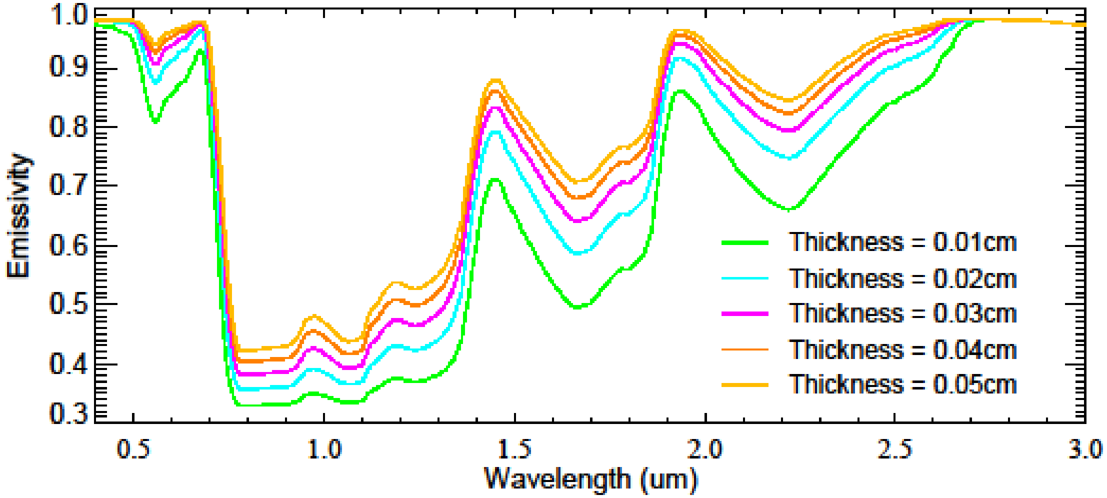


- ❖ T and R decrease as Ns increases
- ❖ Much less sensitive than Cw, especially when wavelength > 6µm

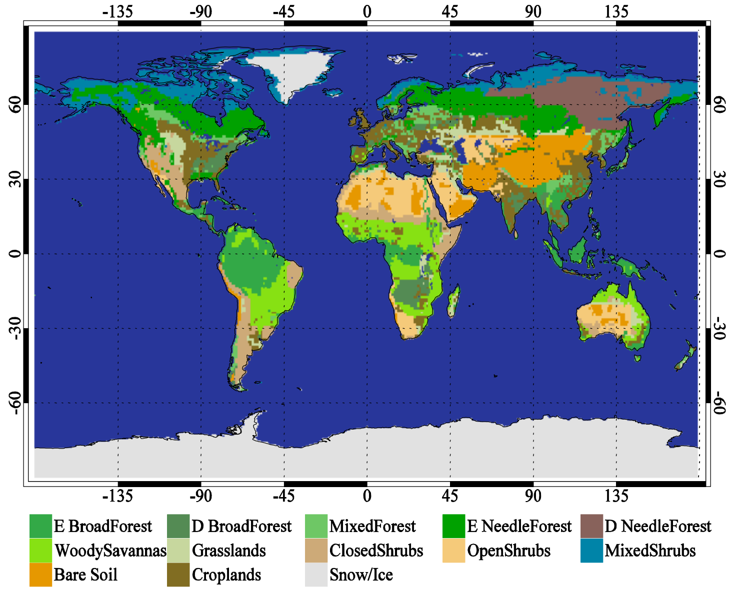
Advantages of Using a Physically-Based Model

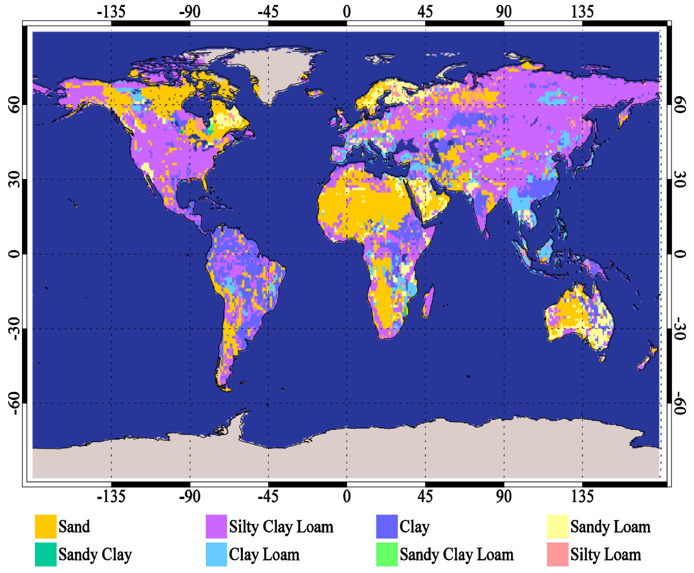
The model may be used to dynamically simulate the diurnal & seasonal variations through the simulation of **leaf biomass life cycle and the daily leaf water content variations**.





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





Unit-Type Definition

Type Parameters

Vegetation: Leaf thickness, Volumetric air fraction, Leaf gravimetric moisture, Mass density of cell materials

Soil: Soil textures, Wilting point, Soil Climatology Temperature, Maximum Soil Water content

Transformation

Unified functions mapping the fundamental unit-type geophysical parameters to composite geophysical, geochemistry & radiometric parameters

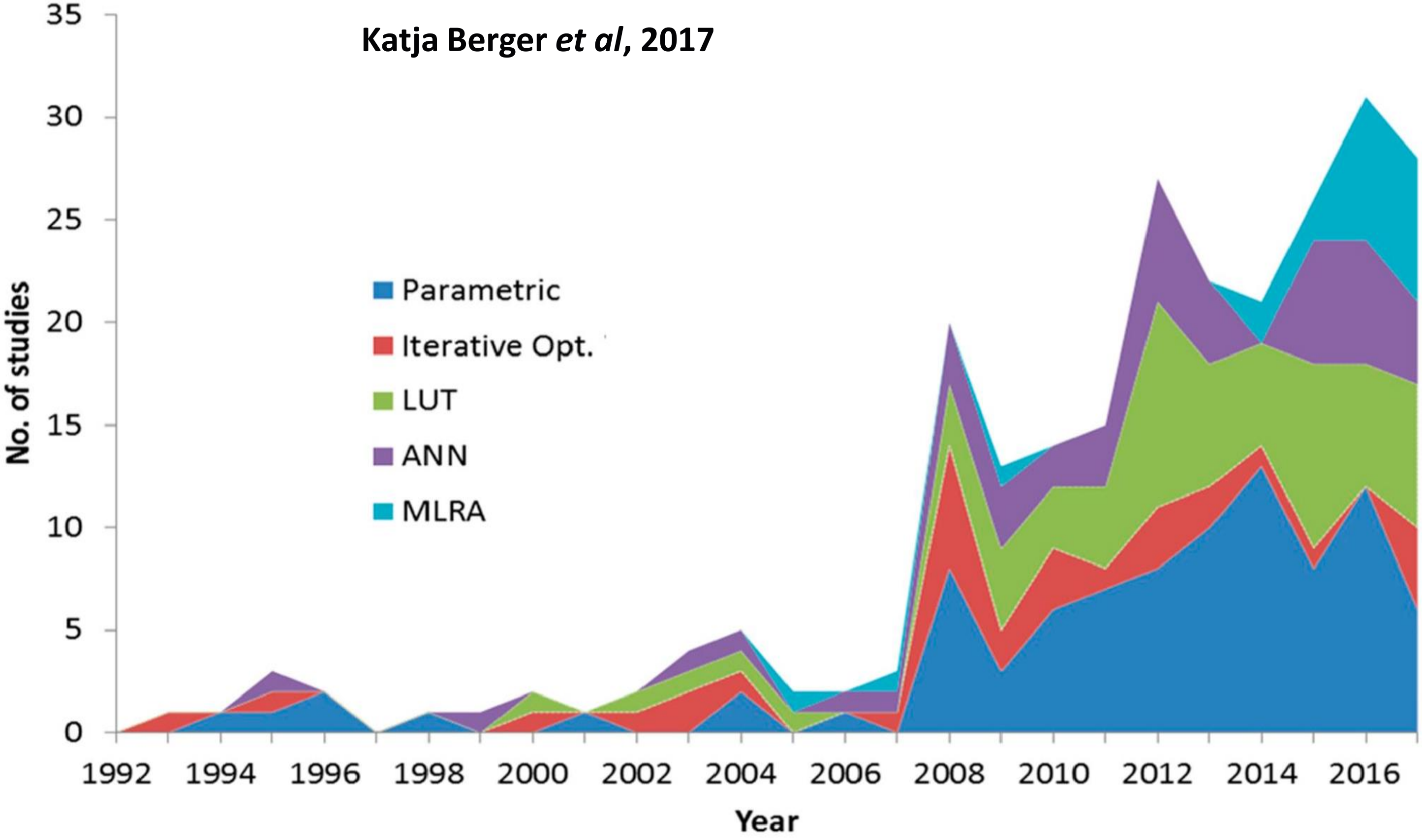
e.g., $N=f(v_{air},d,\cdots)$

RT Model Inputs

Visible, Infrared & Microwave

Vegetation, Soil model input parameters

Methods to Develop Equivalent FAST Models

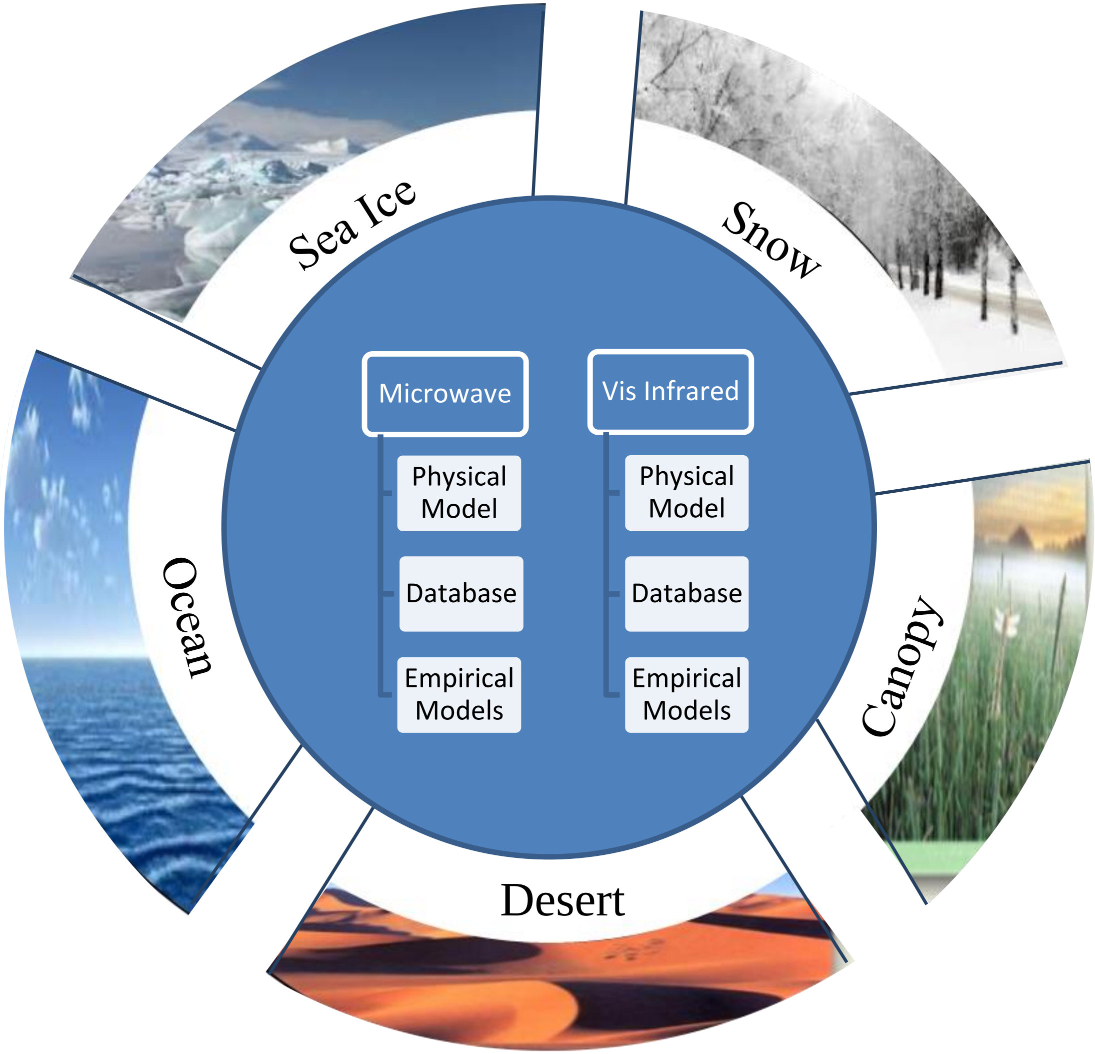


Temporal development of different methods for variable retrieval with the PROSAIL model from 1992 to 2017

Summary

1. CSEM is a plug-play surface RT modeling platform for both surface RT research and operational applications. It may be used as an offline package or coupled with different atmospheric RT models for operational purpose.
2. Several efforts were made to improve the physical MW land emissivity model, which includes the non-isothermal model formulation, enhanced canopy scattering scheme, the tanh-based roughness correction model, multi-layer soil RT schemes, TL and AD operators. The improvements showed significant impacts on CRTM forward simulations, and neutral/slightly positive impacts on GFS forecasting.
3. Some ongoing efforts include 1) the development of ocean surface MW BRDF/Emissivity model to be coupled with the multi-stream Scattering RT of Cloudy Cases 2) the development of KK-based physical IR land emissivity model 3) the improvement of desert and frozen bare soil emissivity 3) the empirical snow/sea ice models for newly launched sensors.

Community Surface Emissivity Model (CSEM)



CSEM— An Open-System for Research and Operational Applications

Open systems are computer systems that provide some combination of interoperability, portability, and open software standards so that third party development of hardware and software is encouraged.

No single model is good enough to handle all the RT complexities of the Earth's surface. An open model system turns out to be essential for exchanging and integrating the modeling efforts from different research groups. The following are some typical challenges we are encountered:

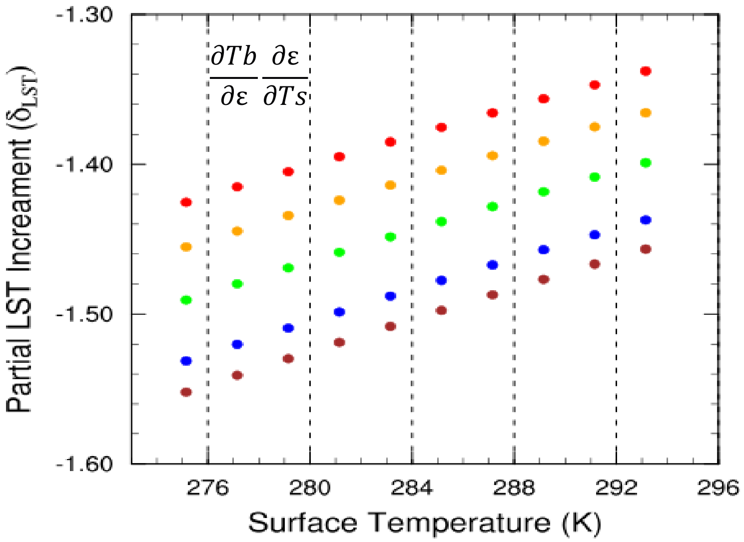
1) The complexity of surface dielectric media compositions, especially the land surfaces, has brought about a variety of surface typing and morphological models, as well as different dielectric models.
2) The complexity of the interactions of electromagnetic waves with different surface media has given birth to various surface emissive (absorptive), reflective and scattering models in research communities for different surface media, each of which has their own strength on some aspects and weakness on other sides.
3) The complexity of the radiative properties of different wave bands has resulted into numerous RT models applicable over specific wave bands.
4) The complexity of time and space scales requires much extra efforts in model optimization and applicability expansion.

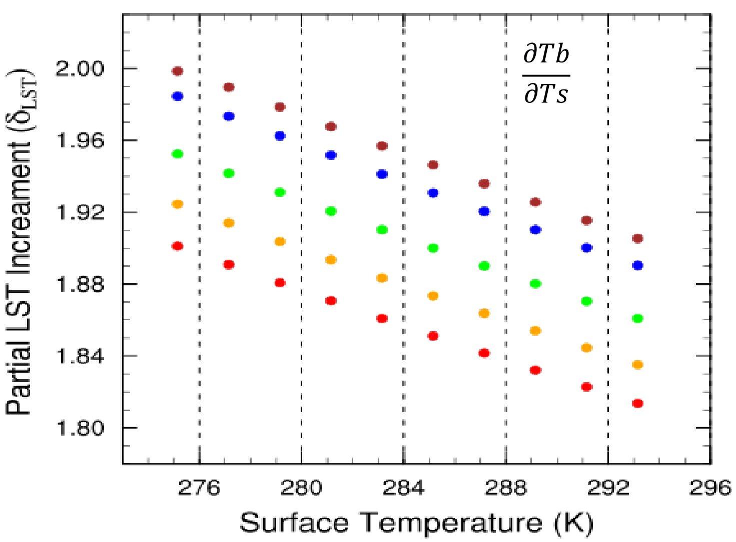
CSEM Technical Features as an Open System

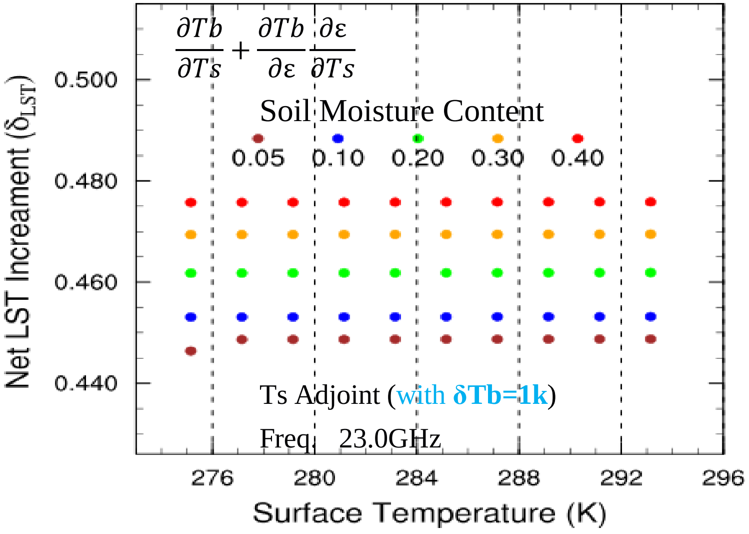
CSEM is a feature-rich OOP-based surface emissivity model system:

- It may be used as an independent model system or as a subsystem of upper-level systems, e.g. CRTM.
- CSEM is designed to offer such a platform where optional research algorithms (models) may be easily developed, added, tested and used besides those that have been chosen for operational (default) use.
- CSEM has its own infrastructure module design and software abstract layers to facilitate the off-line model optimizations and the R2O processes for the implementation in CRTM. It completely hides the high-level CRTM complexity from the low-level CSEM developers and users, and vice versa.
- The OOP-based I/O data structures and software architecture provide efficient two-way data communication methods between CSEM and the host systems, and enable very flexible interfacing with different host systems. The flexible interfaces between CSEM , CRTM and other the upper-level host model systems allow easy model expansion and code maintenance on both sides.
- It requires the minimum CRTM modification efforts, but covers 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.

What if Emissivity is a control-variable over Land







Ts Adjoint (with δTb=1k)

Freq: 23.0GHz

Tb = ε●Ts

ε = ε(**Ts, SMC, VFR**…)

$$\frac{\delta Tb}{\delta Ts}=\frac{\partial Tb}{\partial Ts}+\frac{\partial Tb}{\partial \varepsilon}\frac{\partial \varepsilon}{\partial Ts}$$

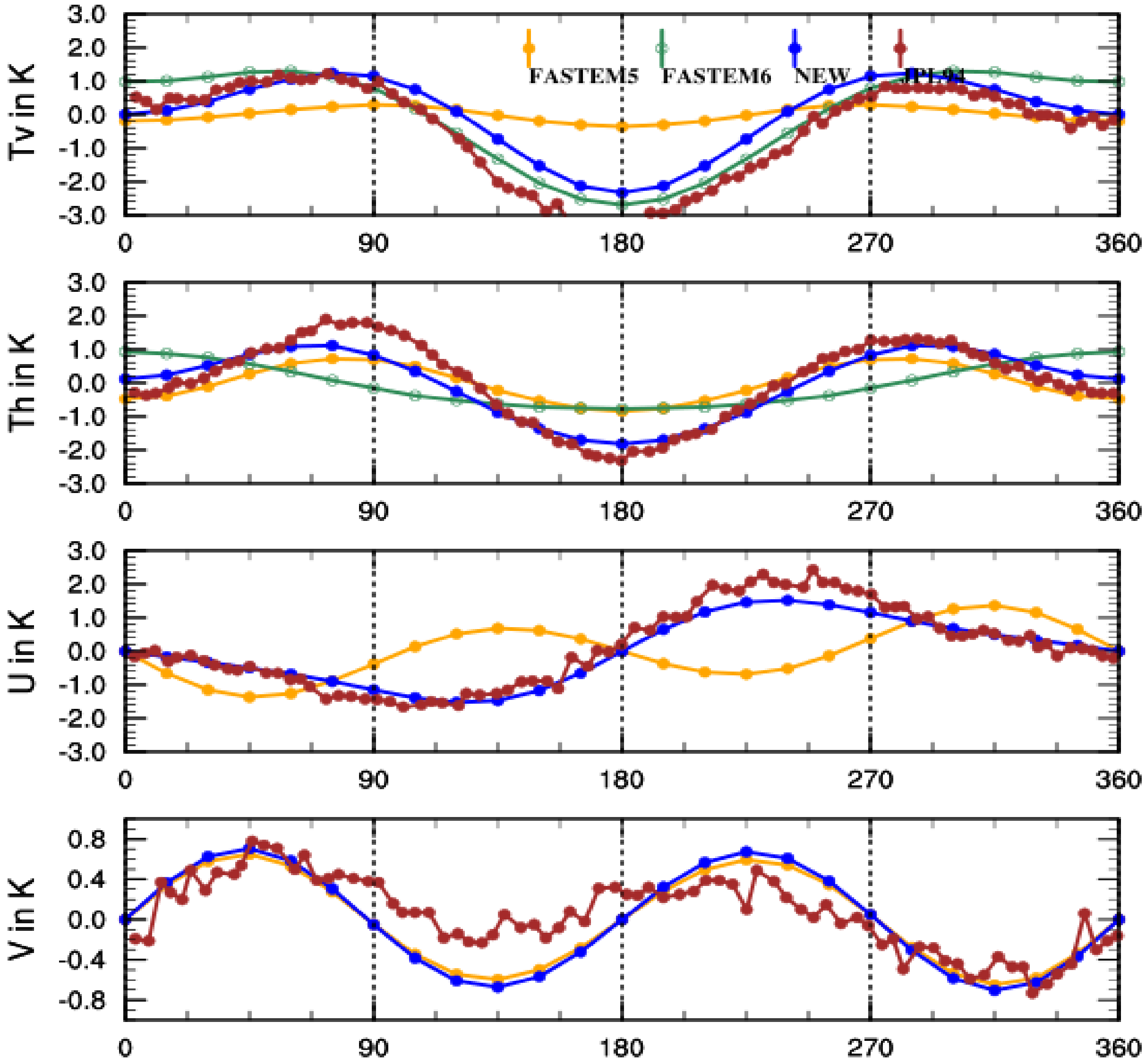
If Emissivity is used as an independent control variable, the property of the adjoint (K-matrix) will be different from the truth, which will direct the optimization algorithm of the cost function in a somewhat wrong way, resulting in a misleading Ts analysis increment.

Comparison of Azimuthal Dependency FASTEMs Vs JPL WINDRAD Observations

FASTEM-5 had the 3rd and 4th Stokes components; but the azimuthal variation of the 3rd component is out of phase.

FASTEM-6 doesn’t have the 3rd (U) and 4th (V) Stokes components.

A new FASTEM version (**NFASTEM**) has been developed, which is based on physical two-scale ocean surface emissivity model and the latest machine learning technique. All the Stokes components of NFASTEM are in good agreement with the **OBSERVATION** in terms of both magnitude and phase.



Comparison of MW Ocean Model Limits

FASTEM-6 limits:

- 19GHz to 200GHz
- View angle < 60°
- Only V-pol and H-pol

RTTOV-TESSEM limits:

- 19GHz to 700GHz
- Only V-pol and H-pol

NFASTEM limits:

- 1GHz to 700GHz
- View angle < 85°
- Full Stokes