Microwave Emissivity Model Update

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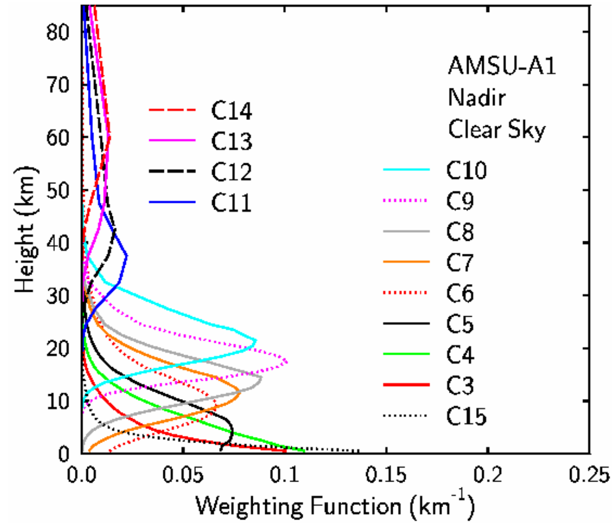
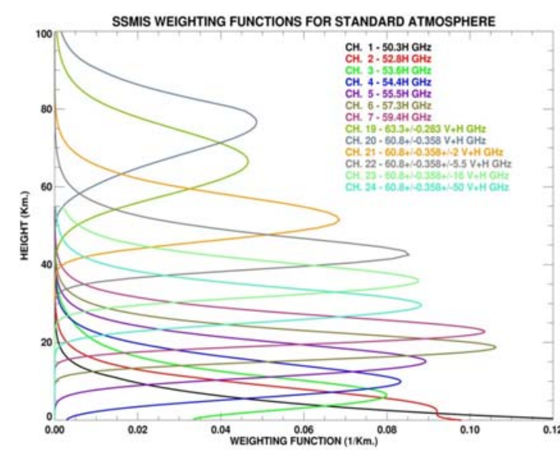
Outline

- Background
- Snow and sea ice emissivity empirical algorithm update for MHS and SSMIS
- Improved microwave snow emissivity physical model
- Improved microwave soil and vegetation emissivity physical model
- Summary and future plan

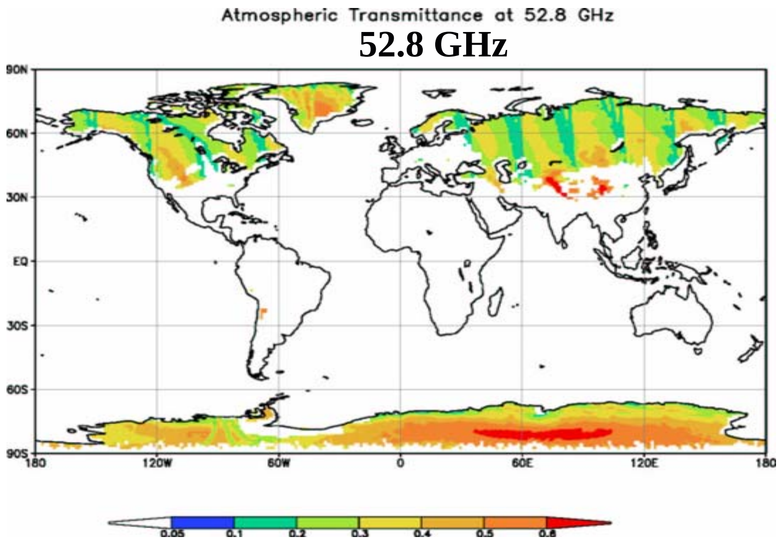
AMSU and SSMIS Sounding Principle

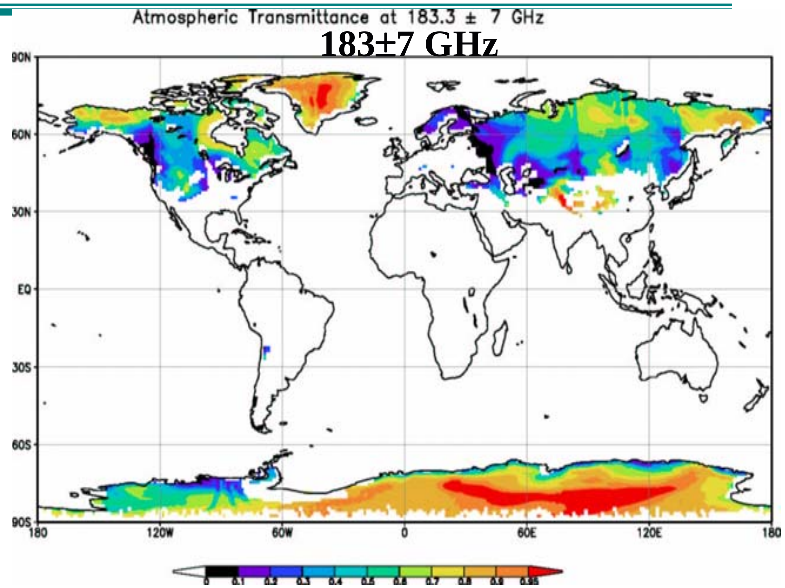
- AMSU/SSMIS measurement at each sounding channel responds primarily to emitted radiation within a layer, indicated by its weighting function
- The vertical resolution of sounding is dependent on the number of independent channel measurements
- Lower tropospheric channels are also affected by the surface radiation which is highly variable over land

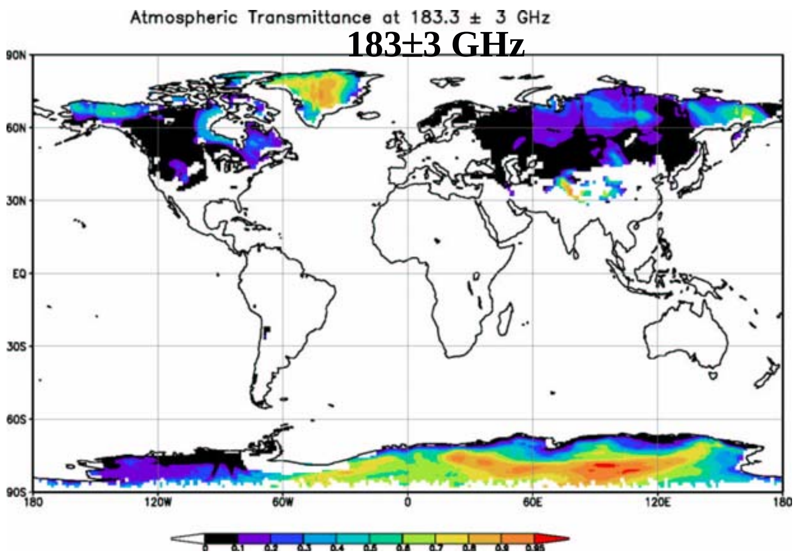




Atmospheric transmittance at sounding channels







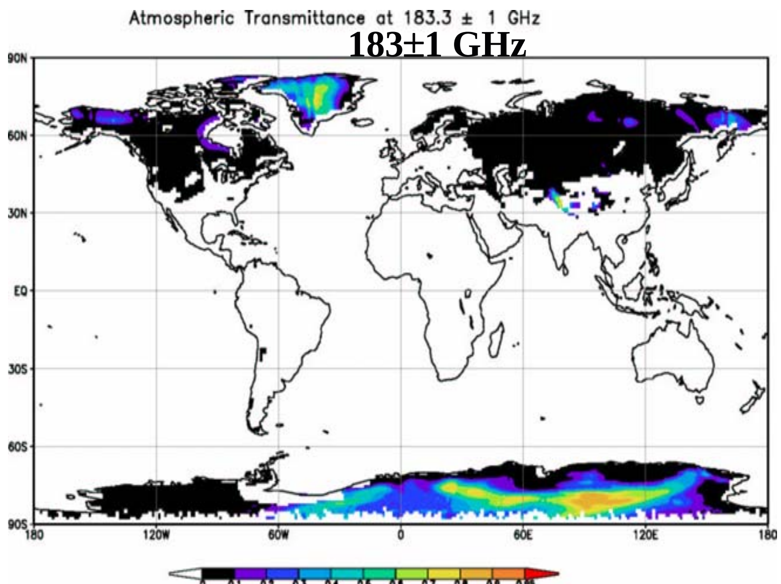


Fig. 2

Data Assimilation Scheme

Significance? In satellite data assimilation scheme, the cost function is defined as

$$J = \frac{1}{2}\left(\mathbf{x}-\mathbf{x}^b\right)^T \mathbf{B}^{-1}\left(\mathbf{x}-\mathbf{x}^b\right)+\frac{1}{2}\left[\mathbf{I}(\mathbf{x})-\mathbf{I}^o\right]^T(\mathbf{E}+\mathbf{F})^{-1}\left[\mathbf{I}(\mathbf{x})-\mathbf{I}^o\right]$$

Satellite Observations

RTM Simulations

where

x is a vector related to atmospheric and surface parameters.

$\mathbf{I}_0$ is the observed radiance vector

I is the radiance vector

B is the error covariance matrix of background

E is the observation error covariance matrix

F is the radiative transfer model error matrix

With a surface emissivity model, the difference dT_B (=I(X)-I^O) is calculated and further is used to adjust the surface and atmospheric parameters

JCSDA Microwave Surface Emissivity Models

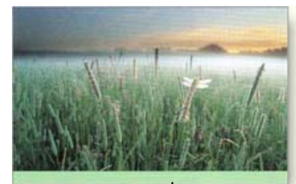
Five Surface Types

Ocean

Sea Ice

Snow

Canopy (bare soil)



Desert

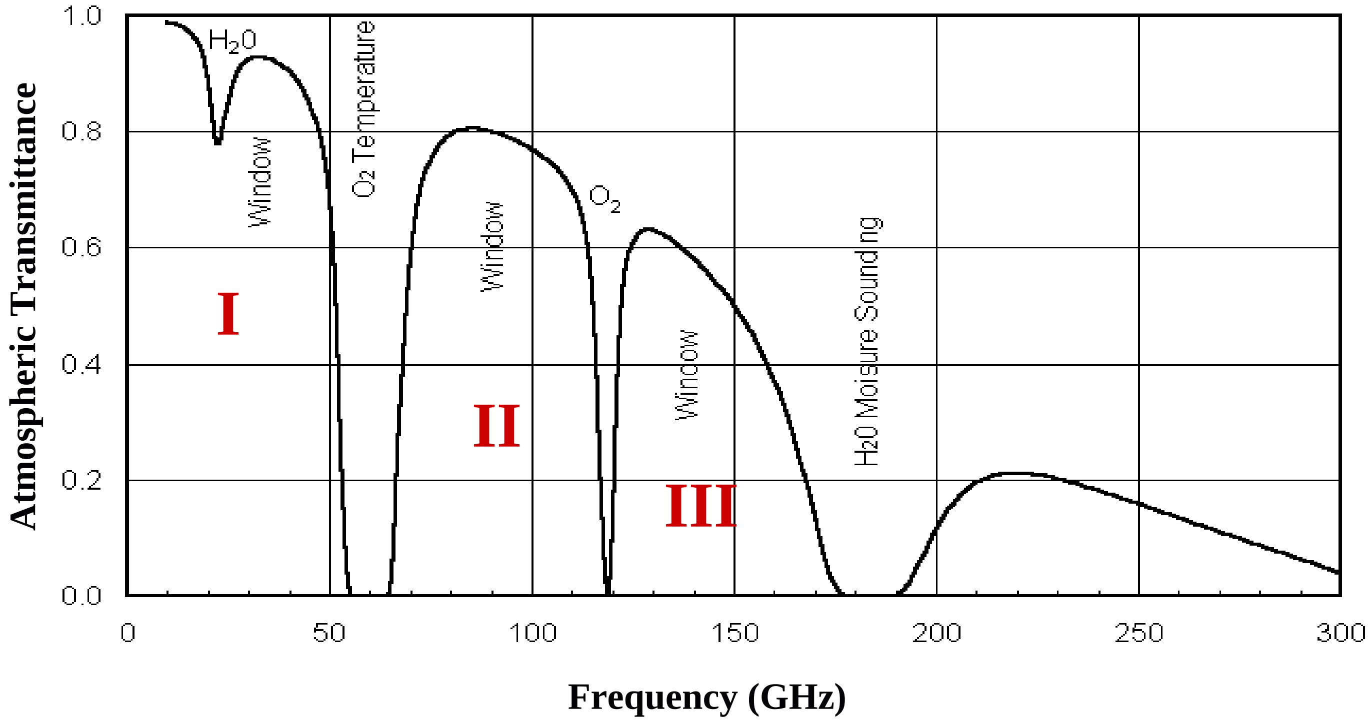
A microwave land emissivity physical model (LandEM) was developed by F. Weng, B. Yan, N. Grody (JGR, 2001)

Empirical snow and sea ice emissivity algorithm using microwave satellite window channels of measurements (B. Yan and F. Weng, 2003; 2008)

(1) A fast microwave ocean emissivity physical model (English and Hewison, 1998)
(2) Microwave ocean emissivity physical model (Weng and Yan)

No. 1: Empirical Algorithm Update of Microwave Snow and Sea Ice Emissivity for MHS and SSMIS

Microwave Atmospheric Transmittance



$$TB_P = \varepsilon_P \zeta T_s + T_u + (1 - \varepsilon_P)\zeta T_d$$

At these window channels, ζ: 0.5 ~ 1.0, T_u and T_d << TB_P, so, satellite-observed brightness temperatures contain rich information of surface emissivity.

Snow and Sea Ice Emissivity Simulations: Empirical Algorithm

- ***Generate snow/sea ice emissivity training data bases at a wider frequency range using an emission-based radiative transfer equation***

$$\varepsilon = \frac{T_b - T_u - T_d\,\tau}{\tau\,(T_s - T_d)}$$

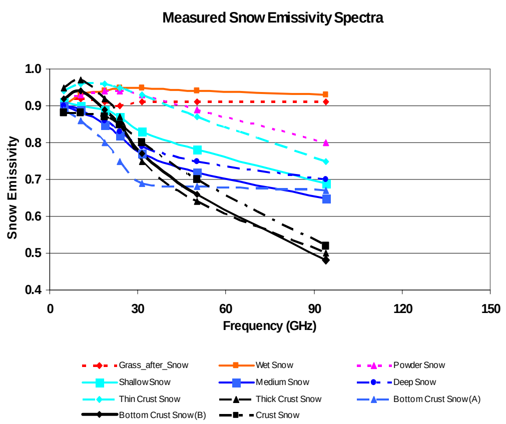
e.g., Eight SSMIS window channels:

V-POL: 19, 22, 37, 92 GHz

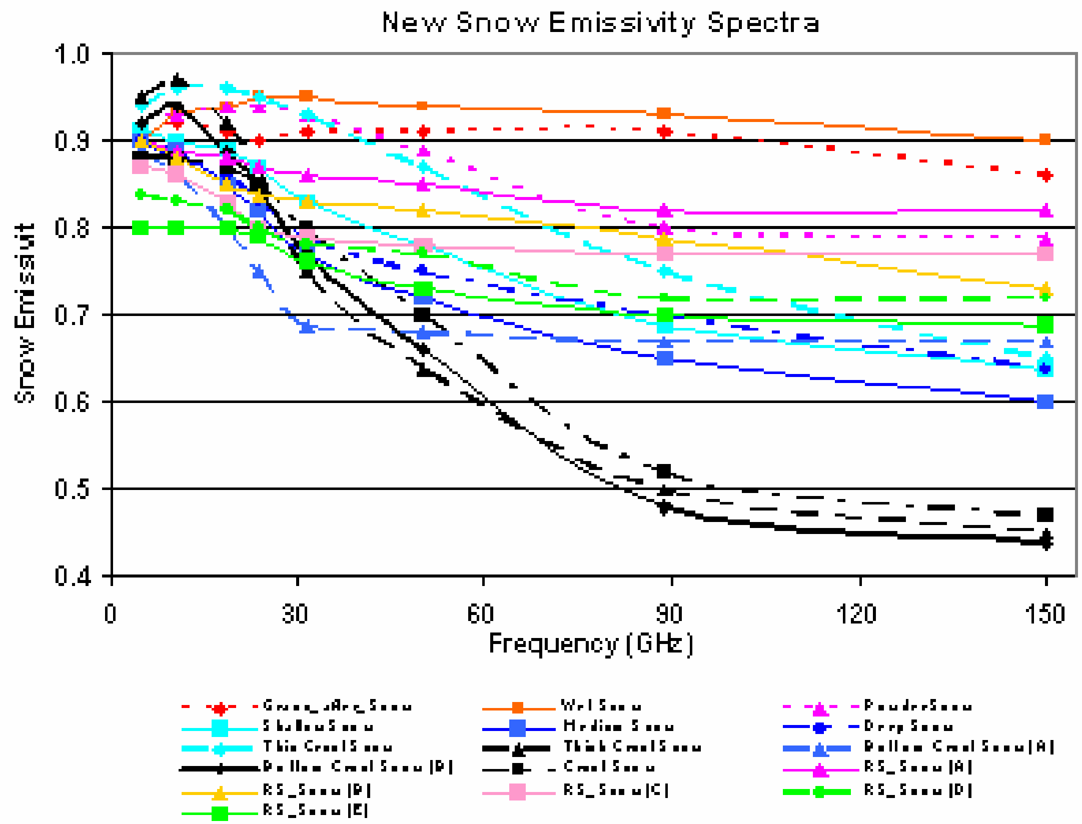
H-POL: 19, 37, 92, 150 GHz

where T_b is brightness temperature at window channel, T_s the surface temperature, τ atmospheric transmittance, T_u and T_d the brightness temperatures associated with upwelling and downing radiance, respectively.

Microwave Spectra of Snow Emissivity

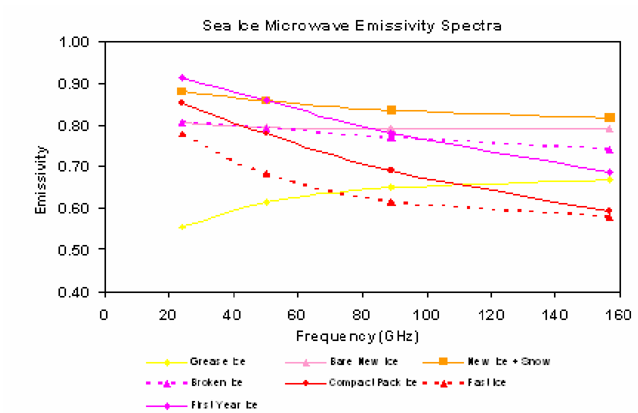


11 Ground-measured emissivity
Of snow emissivity (4.9~94 GHz)
(Mätzler, C., 1994)



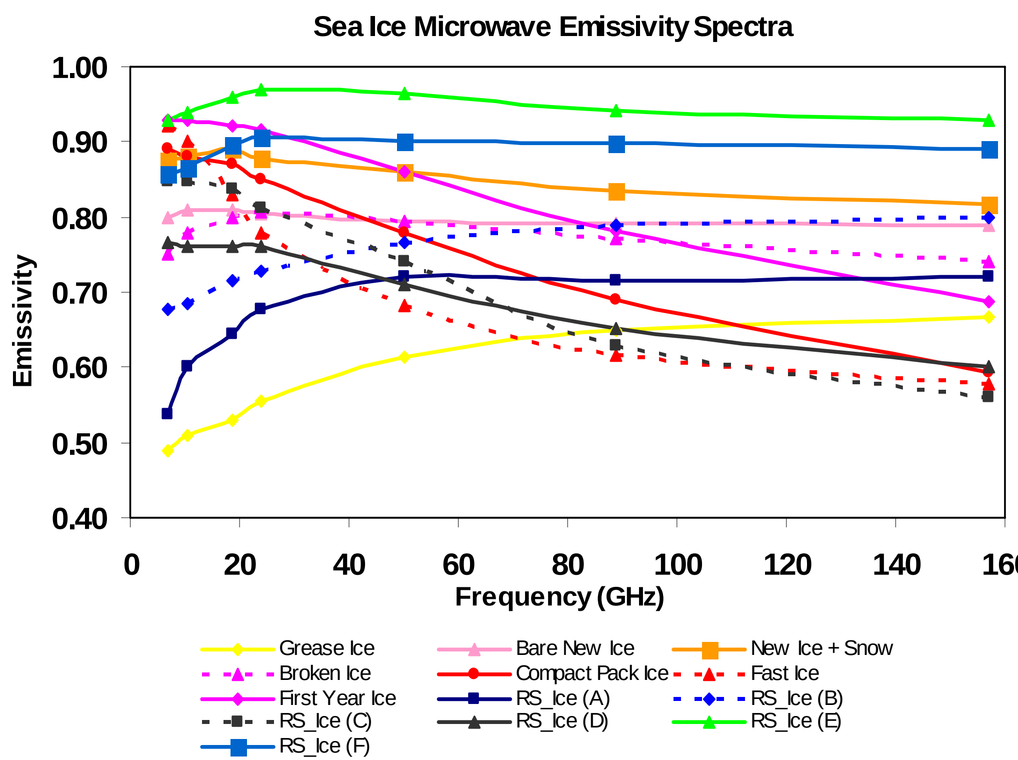
New various snow emissivity spectra based upon satellite-retrieved and ground-measured data of snow emissivity (4.9 ~ 150 GHz)
(Yan et al., 2004)

Microwave Emissivity Spectra of Sea Ice



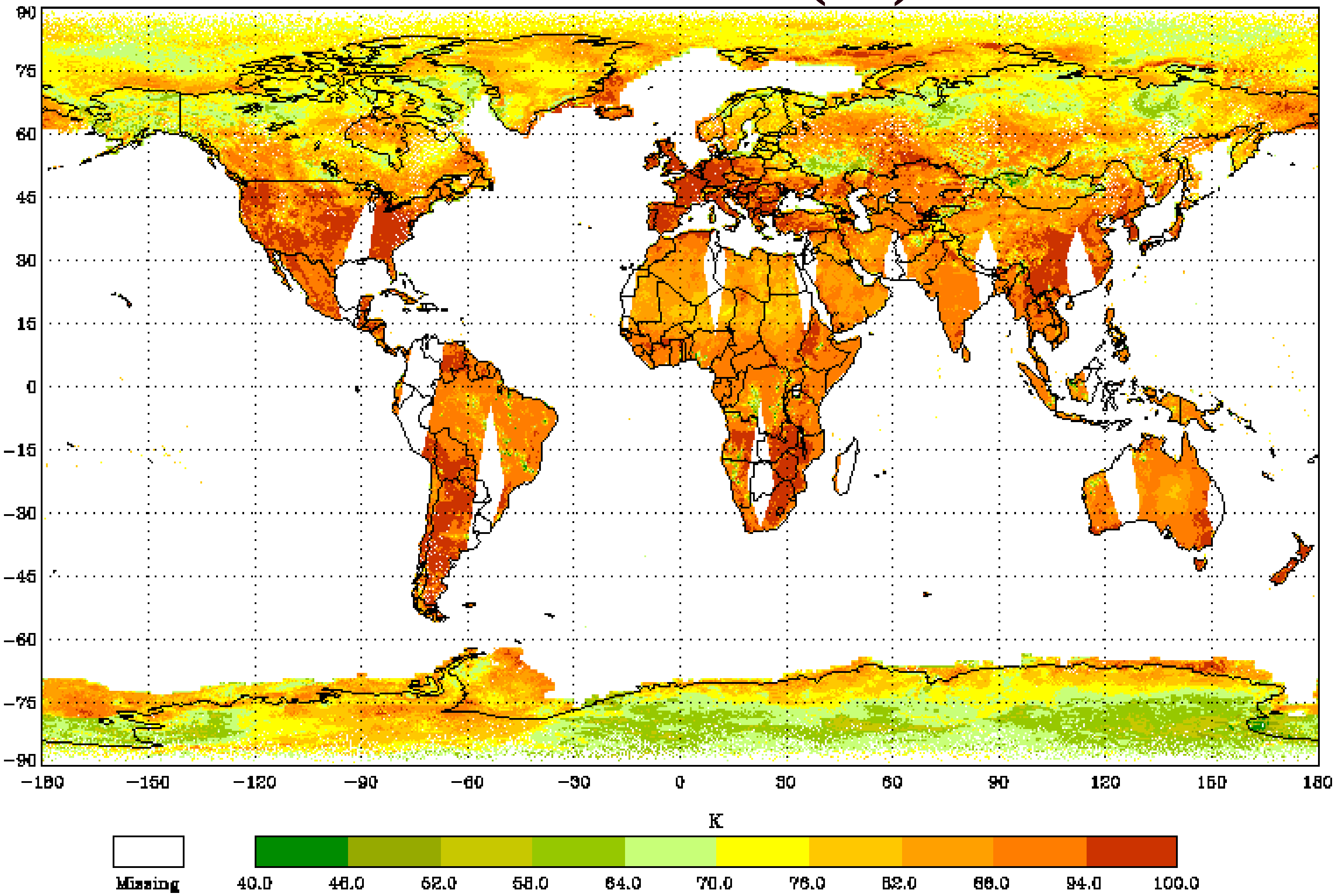
7 sea ice emissivity spectra (24 ~ 157 GHz)

(Hewison and Englisg, 1999).



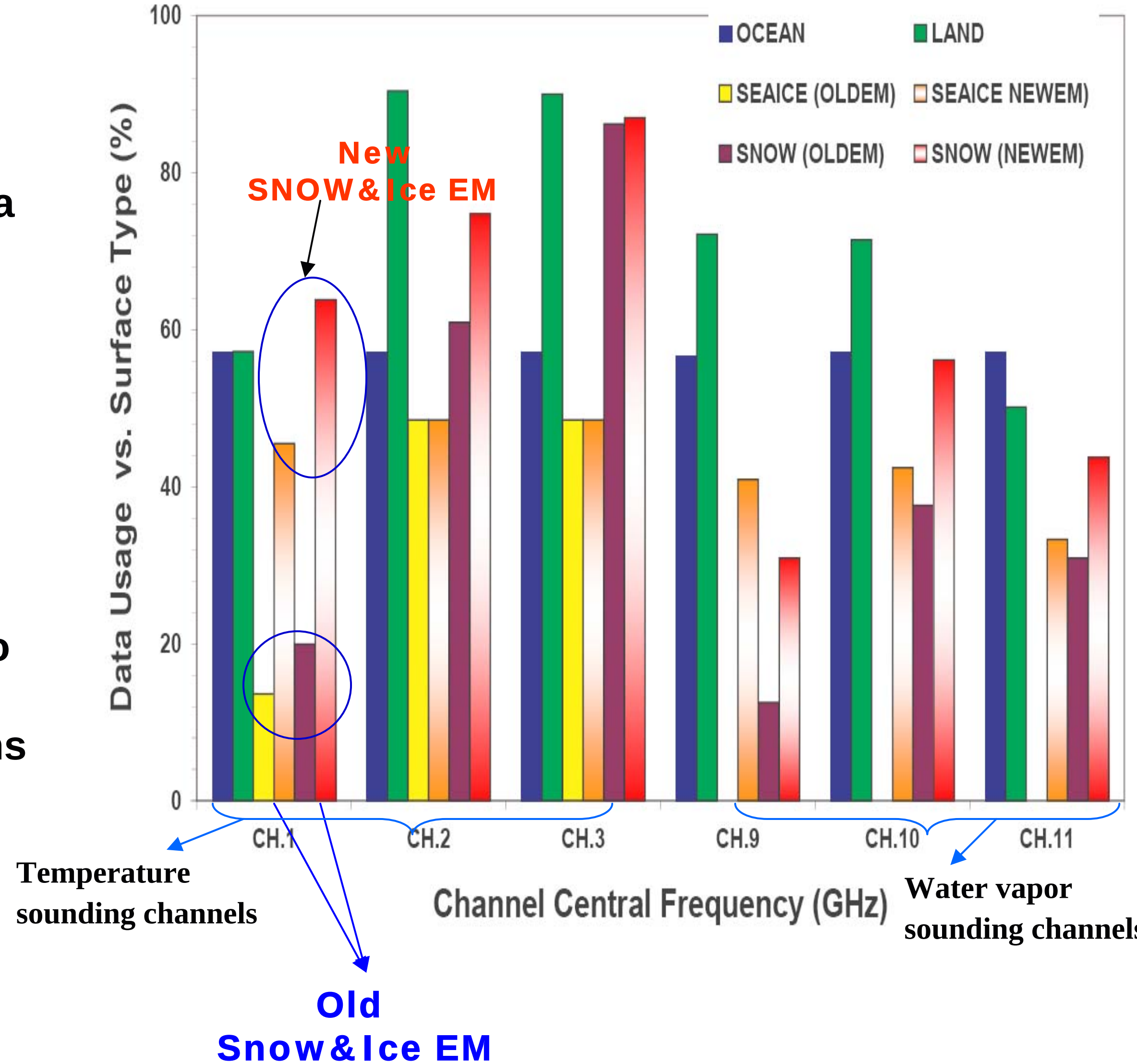
New various sea ice emissivity spectra based upon satellite-retrieved and ground-measured data of sea ice emissivity (6 ~ 157 GHz) (Yan et al., 2004)

Simulated Land, Snow, and Sea Ice Emissivity at 183 GHz (%)



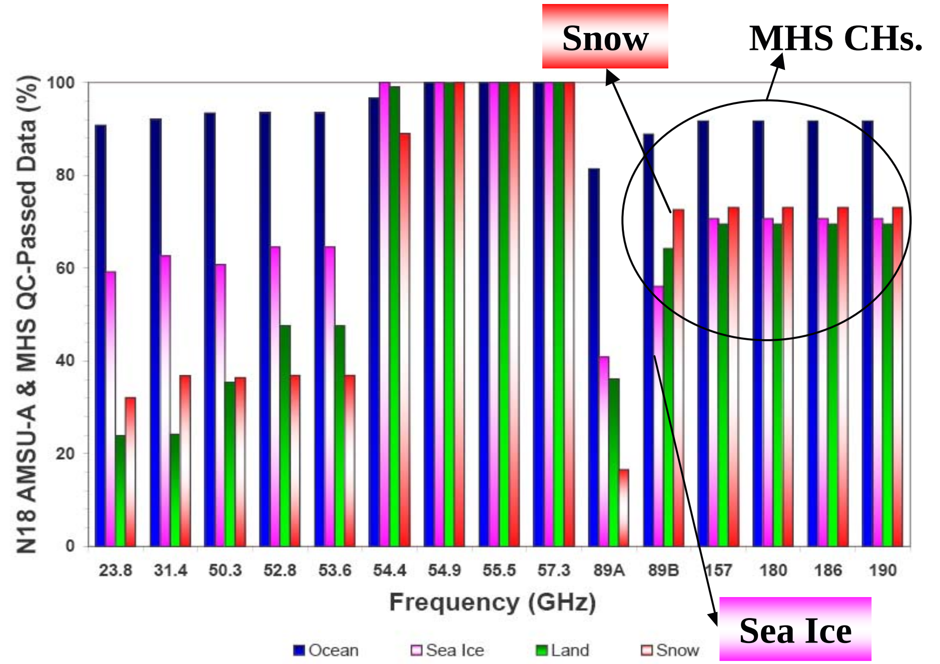
Impact of Improved Snow and Sea Ice Emissivity at SSMIS Channels on F16 SSMIS Data Usage

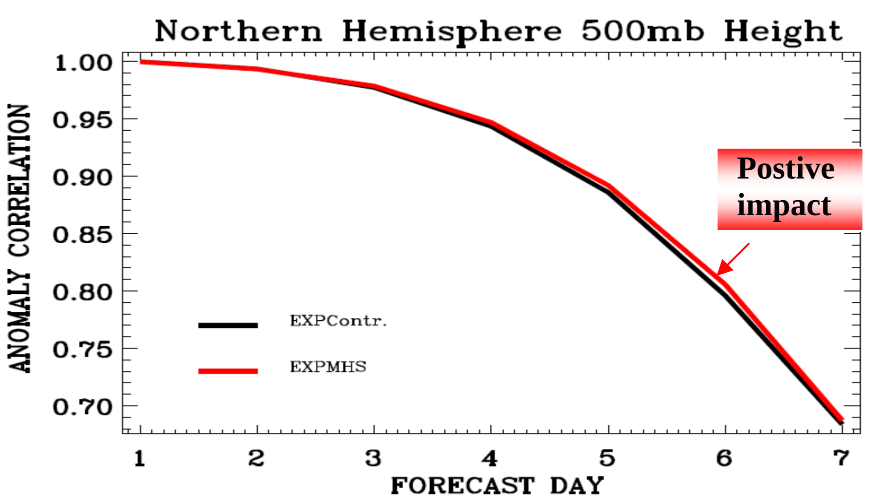
- Several SSMIS sounding channels are sensitive to highly variable emissivity especially over snow and sea ice conditions
- Only about 20% SSMIS data passed quality control in NCEP/GSI using the old models
- Around 50% SSMIS data passed quality control due to improved SSMIS snow and sea ice emissivity simulations



Improved Snow and Sea Ice Emissivity Simulations Increases use of MHS Data in NCEP GFS

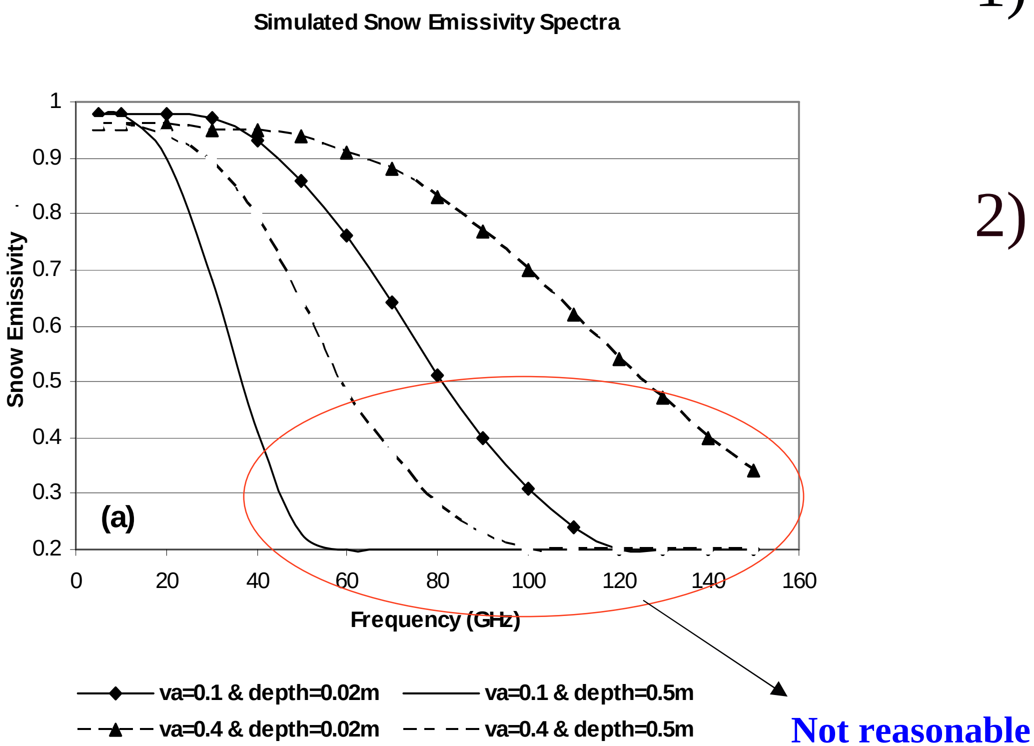
- MHS, especially over snow and sea ice conditions, is highly affected by variable emissivity
- Currently, only 20-30% MHS data passed quality control in NCEP/GSI
- Improved MHS snow and sea ice emissivity models results in more than 60% data passing QC
- The impact of the MHS data using the new emissivity model is positive





CRTM Microwave Snow Emissivity Model Deficiencies

- Snow emissivity simulation (Weng, et al, 2001):



Possible reasons:

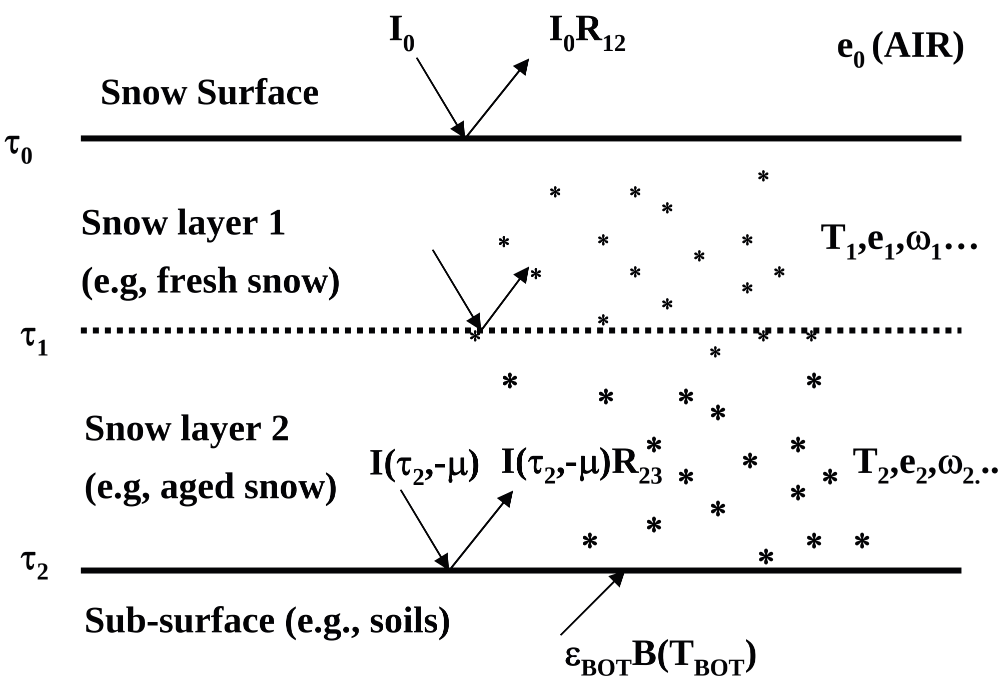
1) One-layer emissivity model is insufficient for a highly stratified snow medium
2) Snow optical parameter calculations are limited to lower frequencies/small particles due to invalidity of the dense media theory, etc.

Not applicable to a wide variety of frequency and snow type

No. 2: Microwave Snow Emissivity Model Update

- ***One-layer is extended to two-layer model***
- ***Snow optical parameter calculations are improved***

Two-layer Microwave Snow Emissivity Model



Based on Weng et al. (2001) one-layer snow emissivity model, we derived following expression of two-layer snow emissivity:

$$\varepsilon = \alpha_0 R_{12} + (1 - R_{21})\alpha_1 [\frac{I_0'}{\gamma_1} - \frac{\gamma_2 (I_1' m_4 - I_2' m_2)}{\gamma_1 (m_1 m_4 - m_2 m_3)}$$

$$+ \frac{(I_1' m_4 - I_2' m_2)}{\alpha_1 (m_1 m_4 - m_2 m_3)} + B_1]$$

Snow optical parameter calculation update

- Accurate solution from the dense media theory ($k_0 r \leq 1.5$, $k_0 = 2\pi/\lambda$)
- Approximate expression ($k_0 r > 1.5$) (Grody and Weng, TGRS, 2008)

$$K_a = \frac{3v_a}{4r} Q_{ac}, K_s = \frac{3v_a}{4r} Q_{sc}$$

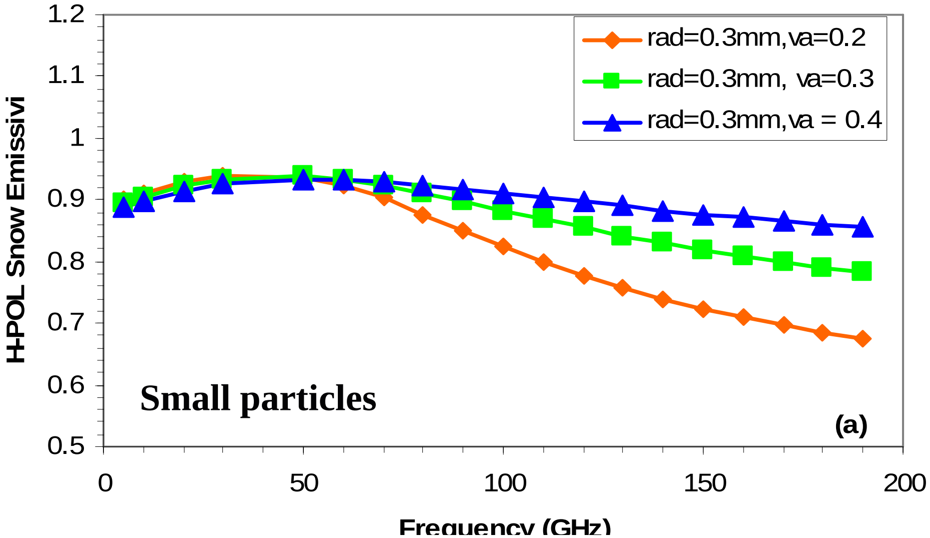
where Q_{ac} and Q_{sc} are absorption and scattering efficiencies respectively, as $k_0 r = 1.5$

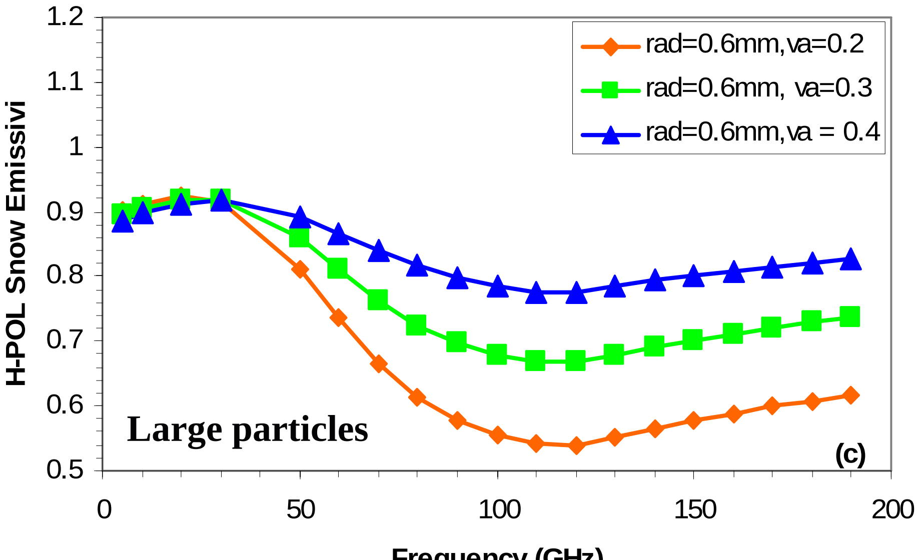
$$Q_{sc} = \frac{8}{3v_a}\left[\frac{k_0 v_a y_r^2 (k_0 r_c)^3 (1-v_a)^4}{(1+2v_a)^2 (1-v_a y_r)^2}\left(\frac{1-v_a y_r}{1+2v_a y_r}\right)^{0.5}\right]$$

$$Q_{sc} = \frac{8}{3v_a}\left\{\frac{k_0^2}{2K_r}\left[\frac{3v_a y_i}{(1-v_a y_r)^2} + \frac{2v_a y_r^2 (k_0 r_c)^3 (1-v_a)^4}{(1+2v_a)^2 (1-v_a y_r)^2}\right] - Q_{sc}\right\}$$

$$K_r = k_0\left[\frac{1+2v_a y_r}{1-v_a y_r} - \frac{4v_a y_i y_r (k_0 r_c)^3 (1-v_a)^4}{(1+2v_a)^2 (1-v_a y_r)^3}\right]^{0.25}$$

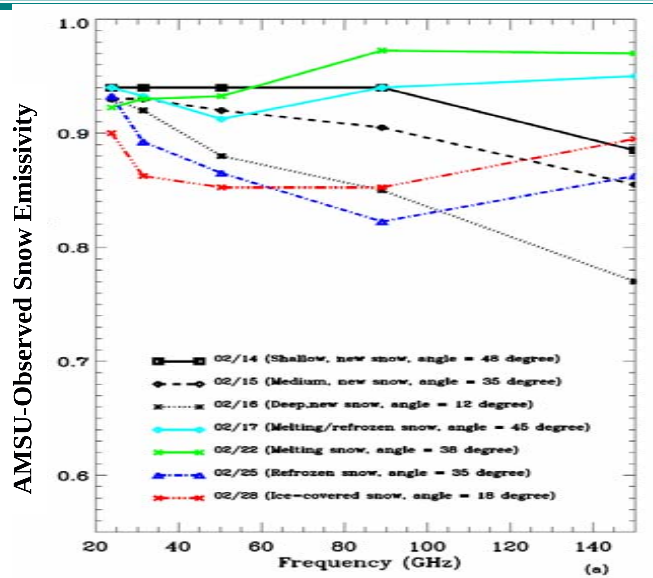
Simulated Snow Emissivity Spectra Using Two-layer Microwave Snow Emissivity Model

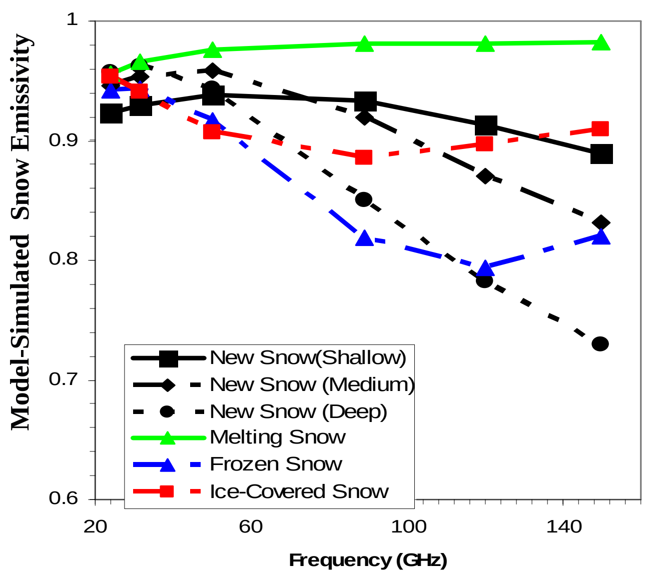




- Emissivity is simulated using the improved SnowEM (snow depth = 10 cm)
- Emissivity decreases monotonously with frequency for small snow particles
- Emissivity varies exponentially with frequency for large snow particles

Comparison of Simulated and Observed Snow Emissivity Spectra





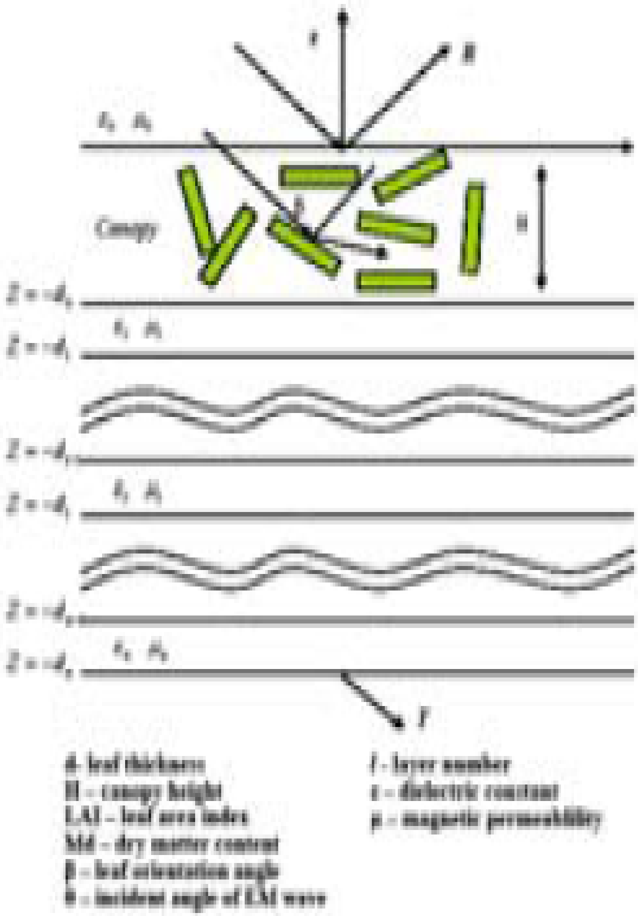
- Seven types of snow events are observed at Hagerstown, Maryland in February 2003
- Observed emissivity is retrieved using AMSU brightness temperatures (Yan et al., 2008)
- Spectral feature of simulated snow emissivity is qualitatively consistent to the satellite-observed emissivity

No. 3: Multilayer Soil/Vegetation Emissivity Model Development (Weng et al., ITOVS-16, 2008)

- one layer vegetation scattering medium overlying a multi-layer soil medium
- attenuation (or absorption) coefficients of each soil layer are derived from the conservation of the energy flux (Wilheit, 1978)

Multilayer Soil/Vegetation Emissivity Model

1. Model Description



Soil dielectric model:

Dobson et al. (1985) developed a mixing rule for soil dielectric constant (Weng et al., 2001) which is

$$\epsilon_m^\alpha = 1 + \frac{\rho_b}{\rho_s}(\epsilon_s^\alpha - 1) + m_v^\beta \epsilon_{fw}^\alpha - m_v, \tag{5.21}$$

where m_v is the soil volumetric moisture, ϵ_s is the dielectric constant of solids, and ρ_b is the density of soil, ρ_s is the density of solids, which are calculated from sand and clay fraction. The exponents, α, β are depending on soil type.

$$\alpha = 0.65 \tag{5.22}$$

$$\beta = 1.09 - 0.11S + 0.18C \tag{5.23}$$

$$\epsilon_s = (1.01 + 0.44\rho_s)^2 - 0.062 \tag{5.24}$$

Vegetation dielectric model:

$$\begin{aligned} \epsilon_{veg} &= 1.7 - (0.74 - 6.16 m_g) m_g + m_g (0.55 m_g - 0.076) \\ &\quad [4.9 + 75.0/(1 + y_i) - y_i] + \\ &\quad 4.64 m_g^2/(1 + 7.36 m_g^2)[2.9 + 55.0/(1.0 + \sqrt{y_i})] \qquad (5.16) \\ y_i &= i\nu/18.0 \end{aligned}$$

where y_i is a complex value, m_g is the gravimetric water content (g/kg), ν is the frequency in GHz.

A mixing formula was also derived and validated for leaves (Mätzler, 1994a) having a higher gravimetric water content (e.g. > 0.5) which is

$$\epsilon_{veg} = (0.52 - 0.69 m_d)\epsilon_w + 3.84 m_d + 0.51, \tag{5.17}$$

where m_d is the dry matter content and ϵ_w is the dielectric of water.

Weng et al. (ITOVS, 2008)

Multilayer Soil/Vegetation Emissivity Model

2. Simulated Brightness Temperature from Soil **(Weng et al., ITOVS, 2008)**

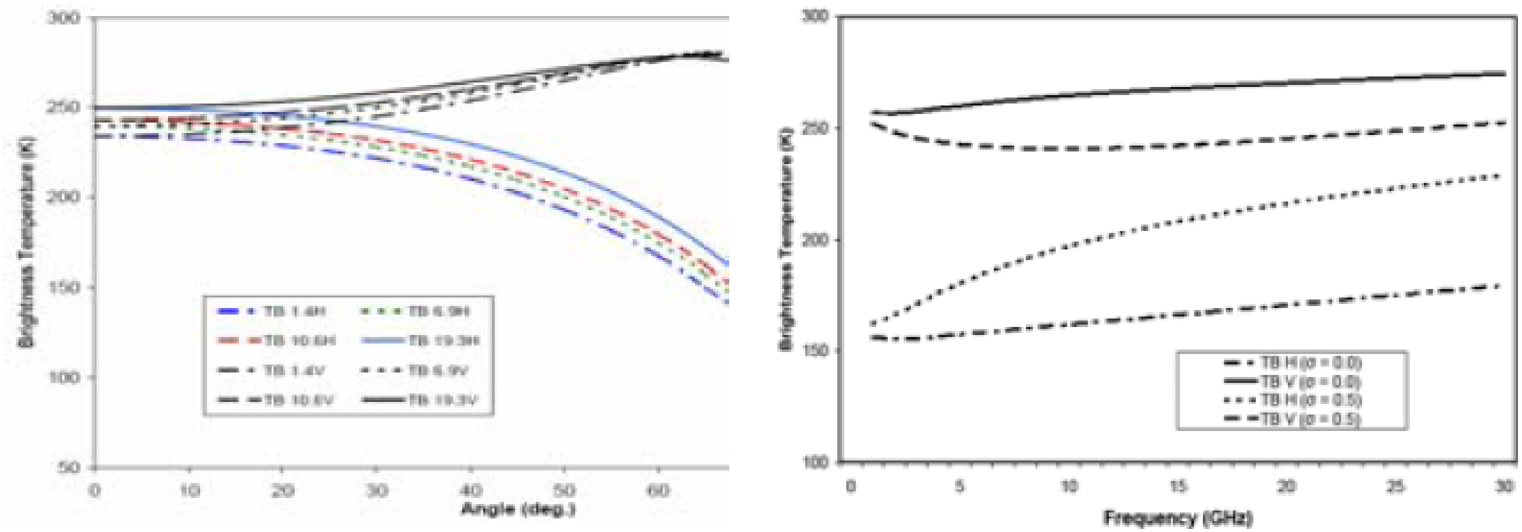
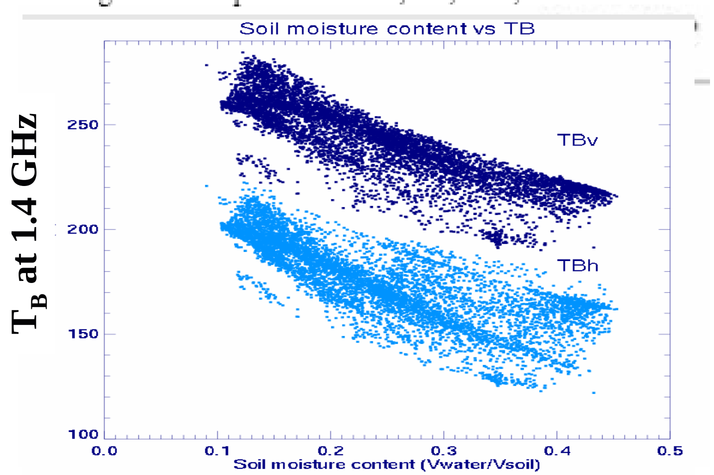
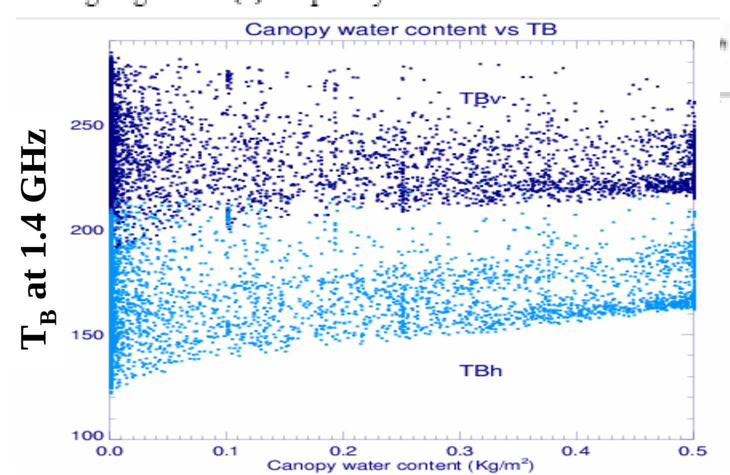


Figure 1. Brightness temperature at 1.4, 6.9, 10.7, and 19.3 GHz vs. (a) viewing angle and (b) frequency





Summary and Conclusions

- Updated microwave snow and sea ice emissivity empirical algorithms result in around 60% MHS and SSMIS data passing QC in NCEP GDAS, which produces a positive impact on GFS due to improved radiance assimilation
- Two-layer microwave snow emissivity physical model provides more reasonable snow emissivity spectra which are qualitatively consistent to several AMSU-observed emissivity spectra
- A multilayer soil/vegetation emissivity model provides more reasonable simulations of vegetation overlying soils at lower frequencies

Therefore, our microwave land emissivity model capability is significantly enhanced.

Future Plans

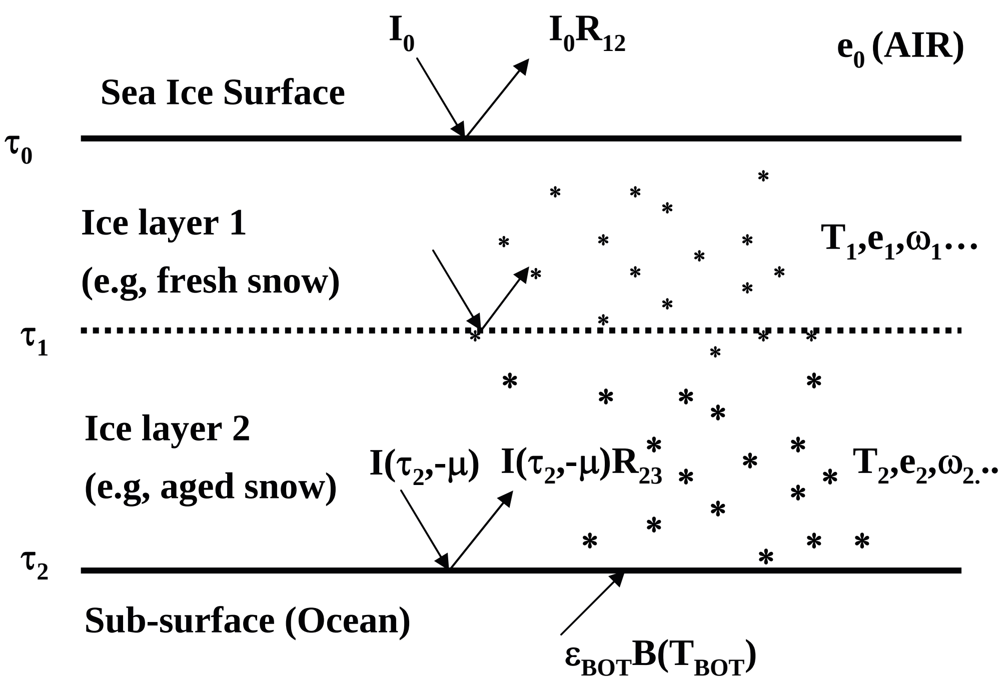
- Validate both microwave multilayer snow and soil/vegetation emissivity physical models
- Assess assimilation impacts of the updated microwave snow, and soil/vegetation emissivity physical models on GDAS and GFS
- A composite of multilayer microwave land emissivity physical model based on the above work will be implemented into JCSDA CRTM

- backup

Five Basic Approaches for Surface Emissivity

- **Approach 1:** Calculate emissivity using emission-based RTM with a proper atmospheric correction, for given atmospheric profiles such as GDAS Products (clear sky) (Training data set)
- **Approach 2:** Regression algorithm based upon the training data set of emissivity and TBs from microwave brightness temperatures at window channels (Empirical Approach)
- **Approach 3:** Surface emissivity physical models (e.g., English and Hewison, 1998; Wiesmann and Mätzler, 1999; Weng et al., 2001) (Physical model)
- **Approach 4:** Iterative algorithm to simultaneous retrievals of emissivity and other atmospheric and surface parameters from microwave brightness temperatures at window channels
- **Approach 5:** 1dvar algorithm to simultaneous retrievals of T_s, T_u, T_d, ζ (atmospheric profiles) and emissivity from microwave window and sounding channels

Two-layer Microwave Sea Ice Emissivity Model



Based on Weng et al. (2001) one-layer snow emissivity model, we derived following expression of two-layer sea ice emissivity:

$$\varepsilon = \alpha_0 R_{12} + (1-R_{21})\alpha_1\left[\frac{I_0'}{\gamma_1} - \frac{\gamma_2(I_1' m_4 - I_2' m_2)}{\gamma_1(m_1 m_4 - m_2 m_3)} + \frac{(I_1' m_4 - I_2' m_2)}{\alpha_1(m_1 m_4 - m_2 m_3)} + B_1\right]$$

where

$$m_1 = \frac{1}{\alpha_1}e^{-k_1\tau_1} - \frac{\alpha_1\gamma_2}{\gamma_1}e^{k_1\tau_1}, m_2 = \frac{\alpha_2\beta_2}{\beta_1}e^{k_2(\tau_1-2\tau_2)} - \frac{1}{\alpha_2}e^{-k_2\tau_1}, m_3 = e^{-k_1\tau_1} - \frac{\gamma_2}{\gamma_1}e^{k_1\tau_1}$$

$$m_4 = \frac{\beta_2}{\beta_1}e^{k_2(\tau_1-2\tau_2)} - e^{-k_2\tau_1}, I_0' = I_0 - (1-R_{21})B_1, I_s' = I_s - (1-R_{23})B_2$$

$$I_1' = B_2 - B_1 - \frac{\alpha_1 I_0'}{\gamma_1}e^{k_1\tau_1} + \frac{I_s'}{\alpha_2\beta_1}e^{k_2(\tau_1-\tau_2)}, I_2' = B_2 - B_1 - \frac{I_0'}{\gamma_1}e^{k_1\tau_1} + \frac{I_s'}{\beta_1}e^{k_2(\tau_1-\tau_2)}, \alpha_1 = \frac{1+\omega_1}{1-\omega_1}, \alpha_2 = \frac{1+\omega_2}{1-\omega_2}$$