A New Microwave Snow Emissivity Model

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By 2010, a numerical weather prediction community will be empowered to effectively assimilate increasing amounts of advanced satellite observations. The radiances can be assimilated under all conditions with the state-of-the-science NWP models.

**Resources:**

- **OK**
- **Deficiency**

**Advanced JCSDA community-based radiative transfer model, Advanced data thinning techniques**

- NPOESS sensors (CMIS, ATMS...)
- GOES-R
- The CRTM includes scattering & polarization from cloud, precip and surface

**Improved JCSDA data assimilation science**

- AIRS, ATMS, CrIS, VIIRS, IASI, SSM/IS, AMSR, more products assimilated
- The radiances from advanced sounders will be used. Cloudy radiances will be tested under rain-free atmospheres, and more products (ozone, water vapor winds) are assimilated

**Pre-JCSDA data assimilation science**

- AMSU, HIRS, SSM/I, Quikscat, AVHRR, TMI, GOES assimilated
- The radiances of satellite sounding channels were assimilated into EMC global model under only clear atmospheric conditions. Some satellite surface products (SST, GVI and snow cover, wind) were used in EMC models

**Radiative transfer model, OPTRAN, ocean microwave emissivity, microwave land emissivity model, and GFS data assimilation system were developed**

2002 2003 2004 2005 2007 2008 2009 2010
JCSDA Community-based Radiative Transfer Model

- Atmospheric State Vectors
- Atmospheric Spectroscopy Model
- Forward Radiative Transfer Schemes
- Receiver and Antenna Transfer Functions
- Jacobian (Adjoint) Model
- Surface State Vectors
- Surface Emissivity, Reflectivity Models
- Aerosol and Cloud Optical Model
Surface Emissivity Model

Natural Scenes

Theory Base

Two-Scale Approx.

Scattering/observations

Geometric Optics

Scattering/observations
Surface Emissivity

- **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)
Deficiencies of Snow Modeling

• Not applicable for aged snow
• Limited at frequencies less than 50 GHz
• Not applicable for vertically stratified snow
• Two stream radiative transfer approach
Brightness Temperature Sensitivity to Surface Emissivity

\[ \Delta T_B = \tau (T_s - T_d) \Delta \varepsilon \]

\[ \Delta \varepsilon = 0.04 \]

<table>
<thead>
<tr>
<th>Freq (GHz)</th>
<th>( T_d ) (K)</th>
<th>( \tau )</th>
<th>( \Delta T_B ) (K)</th>
<th>( T_d ) (K)</th>
<th>( \tau )</th>
<th>( \Delta T_B ) (K)</th>
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<tbody>
<tr>
<td>50.3</td>
<td>49.30</td>
<td>0.774</td>
<td>5.593</td>
<td>112.5</td>
<td>0.487</td>
<td>2.289</td>
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<tr>
<td>52.8</td>
<td>111.2</td>
<td>0.492</td>
<td>2.337</td>
<td>188.6</td>
<td>0.153</td>
<td>0.253</td>
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<tr>
<td>150</td>
<td>4.4</td>
<td>0.980</td>
<td>8.844</td>
<td>12.5</td>
<td>0.944</td>
<td>8.209</td>
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<tr>
<td>183.3±7</td>
<td>16.6</td>
<td>0.925</td>
<td>7.893</td>
<td>43.5</td>
<td>0.807</td>
<td>6.018</td>
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<tr>
<td>183.3±3</td>
<td>55.3</td>
<td>0.750</td>
<td>5.242</td>
<td>104.1</td>
<td>0.538</td>
<td>2.709</td>
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<tr>
<td>183.3±1</td>
<td>134.6</td>
<td>0.392</td>
<td>1.496</td>
<td>160.1</td>
<td>0.288</td>
<td>0.806</td>
</tr>
</tbody>
</table>
Advanced Microwave Sounding Unit
Sounding Channels

52.8 GHz

53.7 GHz

183+-1 GHz

183+-3 GHz
Snow Emissivity Data Base

Emissivity Retrieval:

\[ \mathcal{E} = \frac{T_b - T_u - T_d}{\tau} \frac{\tau}{(T_s - T_d)} \]

AMSU-A: 23.8, 31.4, 50.3, 89 GHz
AMSU-B: 89, 150 GHz
AVHRR: Ts
RAOBS temperature/q profiles

Winter season of 2003: Eastern part of US: persistent snow cover during February
Snow Storms (February 2003)
AMSU Measurements at Hagerstown, MD (39.7N, 77.7W)

Date in February 2003

Tb (K)

Dry snow >12 in  Heavy rain  Refrozen  New snow

23.8 GHz  31.4 GHz  50.3 GHz

89.0 GHz  150.0 GHz  Ts
Brightness Temperatures in Relation to Snow Properties

• For newly formed and deep snow, brightness temperature decrease as frequency increases (2/15-2/16)

• While snow experiences metamorphosing, brightness temperature at lower frequencies can be strongly depressed due to an increasing scattering of large particles (2/18)

• After snow refrozen, brightness temperature decreases with frequency and then increases (2/24-2/25)

• For new snow falling on the top of a layer of crust ice, brightness temperatures increases with frequency (2/27)
Detection of Snow Types

• A set of discriminators was developed using AMSU window channels and other auxiliary data
• A neural network approach was used to define the coefficients in discriminators
Microwave Snow Emissivity Model (SnowEM)

Option 1:
(AMSU-AB) $T_B, T_s$

Discriminator Generator I

5 Discriminators
(23.8, 31.4, 50.3, 89, 150 GHz)

Default:
Snow Depth, $T_s$

LandEM

5 Discriminators
(23.8, 31.4, 50.3, 89, 150 GHz)

Option 2:
(AMSU-AB) $T_B$

Discriminator Generator II

5 Discriminators
(23.8, 31.4, 50.3, 89, 150 GHz)

Option 3:
(AMSU-A) $T_B, T_s$

Discriminator Generator III

5 Discriminators
(23.8, 31.4, 50.3, 89, 150 GHz)

3 Discriminators
(31.4, 89, 150 GHz)

Option 4:
(AMSU-A) $T_B$

Discriminator Generator IV

5 Discriminators
(23.8, 31.4, 50.3, 89, 150 GHz)

3 Discriminators
(31.4, 89, 150 GHz)

Option 5:
(AMSU-B) $T_B, T_s$

Discriminator Generator V

3 Discriminators
(31.4, 89, 150 GHz)

Option 6:
(AMSU-B) $T_B$

Discriminator Generator VI

3 Discriminators
(31.4, 89, 150 GHz)

Snow Type & Snow Emissivity

16 Microwave Snow Emissivity Spectra
# Performance of SnowEM

<table>
<thead>
<tr>
<th>Option</th>
<th>Mean RMS Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23.8 (GHz)</td>
</tr>
<tr>
<td>AMSU-AB &amp; Ts</td>
<td>0.02</td>
</tr>
<tr>
<td>AMSU-AB</td>
<td>0.03</td>
</tr>
<tr>
<td>AMSU-A &amp; Ts</td>
<td>0.02</td>
</tr>
<tr>
<td>AMSU-A</td>
<td>0.03</td>
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<tr>
<td>AMSU-B &amp; Ts</td>
<td>0.05</td>
</tr>
<tr>
<td>AMSU-B</td>
<td>0.05</td>
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<tr>
<td>LandEM</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Next Step

• Extensive tests are needed in GDAS (EMC operational implementation) to understand the impacts
• Extend the current approach to polarization sounding measurements (e.g. SSMI/S, CMIS)
• Apply the current approach to derive sea ice emissivity at AMSU-A/B, ATMS, SSMIS
Backup Slides
Random Media Scattering Model

Air $\varepsilon_1$

Snow $\varepsilon_2$

Subsurface $\varepsilon_3$

- It is a dense media with a high volume fraction of scatters
- Its permittivity varies during snow metamorphosing
- Reflection occurs at interfaces as snow melt and refrozen
Snow Scattering Properties

Parameters
- Snow depth
- Volume fraction
- Grain size/bulk density
- Vertical stratification

Methodology: Mie theory using an effective permittivity derived from strong fluctuation theory
Emissivity vs. Snow Depth

![Graph showing the relationship between emissivity and snow depth]

- 23.0 GHz
- 31.4 GHz
- 50.3 GHz
- 89.0 GHz
- 150.0 GHz
Independent Tests
Independent Tests

31.4 GHz

(1) ABTs

(2) AB

(3) ATs

(4) A

(5) BTs

(6) B

(7) ALandEM
NOAA-15 AMSU retrieved & simulated emissivity at 50.3 GHz, 02/10, 2003.
NOAA-15 AMSU retrieved & simulated emissivity at 150 GHz, 02/10, 2003.