Simulations of the sea ice thermal microwave emissivity

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A short introduction to sea ice for microwave radiometry
First-year ice
Ridges/ deformed ice
Multiyear ice
Melt-ponds
Refrozen meltponds
Emission modelling why and where?

• Estimation of uncertainties in sea ice concentration, sea ice thickness, snow surface temperature...

• For simplification of forward models to reduce the computational cost or to reduce the number of free parameters.

• Understanding limitations and ambiguities for example between salinity, thickness and ice concentration in thin ice thickness estimation using SMOS.

• For planning of field campaigns which parameters to sample.

• For use in parameter retrieval or data assimilation for example in snow cover retrieval.
Forward emission and scattering models

- **Empirical models**: the gradient ratio snow thickness algorithm, ice concentration algorithms.
- **Semi-empirical models**: the OSISAF near 50GHz emissivity model
- **Sophisticated physical models**: for example MEMLS with multiple layers, multiple reflections, volume and surface scattering interaction.

These models are valid in the range roughly 1-100 GHz and some of these principles can also be used at higher frequencies (>100GHz). However, for ICI frequencies (183-664GHz) the emission processes are from a shallow layer at the snow surface and the models for permittivity and scattering have not been tested in this range.
The snow thickness algorithm - an empirical regression model

The line slope and offset are based on a particular dataset.
Snow and sea ice

Sea ice concentration
Spatial distribution of e.g. roughness

Layer thickness
Temperature
Snow/ice type
Density/porosity
Scatter size
Salinity/water content
roughness

Simplification is a necessity
-Yet we need to capture the most important processes
Assumptions, dielectric and scattering models

- Mixing and empirical models...
- DMRT (stickiness) and IBA (correlation length)...

Fig. E.16 Dielectric permittivity of sea ice as a function of brine volume fraction at 9.8 GHz. The theoretical results were obtained by using salinities from 4% to 8% and 3°C to 16°C (from Hallikainen, 1977).

Fig. E.17 Theoretical dielectric constant of sea ice compared to experimental results for frazil ice (density 0.836) and columnar ice (density 0.896) by Vannt et al. (1974). Frequency is 10 GHz, and salinity for theoretical calculations is 4.4% (from Hallikainen, 1977).

Fig. 8. Scattering coefficient at 37 GHz as a function of the density for different stickiness parameters $r$ and grain radius $a$. The temperature is 260 K.
## Permittivity models for sea ice

<table>
<thead>
<tr>
<th>Ice type</th>
<th>Model type</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-year frazil ice</td>
<td>Randomly oriented brine needles in pure ice</td>
</tr>
<tr>
<td>First-year columnar ice</td>
<td>Vertically oriented brine needles in pure ice</td>
</tr>
<tr>
<td>Multiyear hummock</td>
<td>Any shape of air inclusions in pure ice</td>
</tr>
<tr>
<td>Pond ice</td>
<td>Vertically oriented brine needles and spherical air bubbles</td>
</tr>
</tbody>
</table>

After Shokr, 1998
Second-order radiative transfer multi-layer model, MEMLS

- Physical properties include: temperature, layer thickness, density, roughness, scatter size, snow/ice type, salinity (snow wetness), viewing angle, electromagnetic frequency.
- Compute for each layer, reflectivity, loss, volume scattering, second order scattering and reflection.
- Brightness temperature, emissivity and effective temperature...
- The detailed input is a major challenge we use a thermodynamical model.
The simulated data

ECMWF NWP data

Thermodynamic model

MEMSL for sea ice

Wentz atmospheric model(s)

Ice concentration algorithms

ERA-40 / 6 hourly, radiation balance, wind, temperature, pressure, precipitation

Profiles with density, grain size, temperature, salinity

Tb, e, Teff, etc.

RR database

IC

The system is described in:
Energy and mass balance

- Air temperature
- Wind speed
- Radiation balance
- Snow accumulation
- Ice growth
The microwave emissivity (6-150GHz)
The effective temperature (6-150GHz)
Multiyear ice air temperature surface temperature

Snow surface temperature [K]

2m air temperature [K]
Penetration depth is a function of (ice) temperature and *vice versa*.

Measurements collocated with satellite observations (from Phil Hwang)

6 simulated multiyear ice profiles

Physical temperature vs. effective temperature?
The physical and microwave emission temperature

If it is cold, penetration is deep into something which is relatively warmer.

**Tb 6 GHz vs. snow ice interface temperature**

**The 50 GHz effective temperature vs. The snow ice interface temperature**
Applications

- ESA CCI Sea ice concentration algorithm evaluation
- The EUMETSAT sea ice near 50GHz emissivity product
Evaluation of sea ice concentration algorithms and methodology for building sea ice climate data: 1) low sensitivity to noise, 2) explicit reduction of noise, 3) minimization of artificial trends, 4) quantification of (residual) uncertainties.
Air, meteorological input

Snow, multiple layers, metamorphosis...

Multiyear sea ice

Water, saline
The polarisation ratio sensitivity to the atmosphere over ice in the Ross Sea
The EUMETSAT sea ice near 50GHz emissivity product

| Remarks | Note that during Arctic summer season (May-September) the ice type product is dubious because melting of the ice surface obscures the ice type signals. |

**PRE-OPERATIONAL**

<table>
<thead>
<tr>
<th>Title</th>
<th>OSI-404: The near 50GHz global sea ice emissivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>The sea ice surface emissivity is representative for the near 50 GHz channels used for temperature sounding of the atmosphere using satellite radiometers such as SSMIS and AMSU. <a href="#">&gt;&gt; access more details</a></td>
</tr>
<tr>
<td>Data used</td>
<td>SSMIS brightness temperatures at 19v, 37v and 37h</td>
</tr>
<tr>
<td>Formats</td>
<td>NetCDF</td>
</tr>
<tr>
<td>NRT access</td>
<td>FTP (last 31 days in NetCDF)</td>
</tr>
<tr>
<td>Archive</td>
<td>FTP</td>
</tr>
<tr>
<td>Documentation</td>
<td>Product User’s Manual, Validation Report, ATBD</td>
</tr>
<tr>
<td>Links</td>
<td>Quicklooks NH, Quicklooks SH</td>
</tr>
<tr>
<td>Remarks</td>
<td>The emissivity is combined with the surface effective temperature, sometimes called the skin temperature, in the radiative transfer equation. Model simulations indicate that the snow-ice interface temperature or alternatively the 6 GHz brightness temperature is a closer proxy for the 50 GHz effective temperature than the snow surface or air temperature</td>
</tr>
</tbody>
</table>

**OPERATIONAL**

<table>
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<tr>
<th>Title</th>
<th>OSI-405-b: Sea Ice Motion Maps with 48 hours span, on 62.5 km Polar Stereographic Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>The low resolution sea ice drift product from the EUMETSAT OSI SAF. Ice motion vectors with a time span of 48 hours are estimated by an advanced cross-correlation method (the Continuous MCC, CMCC) on pairs of satellite images. Several single-sensor products are available, along with a merged (multi-sensor) dataset. <a href="#">&gt;&gt; access more details</a></td>
</tr>
</tbody>
</table>
The development of an operational 50 GHz emissivity model for EUMETSAT
The model parameter $R$ and $S$ simulated relationships

$$e(\theta) = S(1 - Rr(\theta))$$

The 50 GHz emissivity as a function of the 18/36 GHz spectral gradient

The 50 GHz polarisation as a function of the 18, 36 and 89GHz polarisation.
The model parameters, $S, R$

The $S$-factor, magnitude

The $R$-factor, the polarisation, $R=0$ diffuse, $R=1$ specular
Arctic 50 GHz sea ice nadir emissivity

Antarctic 50 GHz sea ice nadir emissivity

Depth hoar above ice surface
*Lincoln Sea 2006*
Simulated and observed Tb using RTTOV and HIRLAM atmospheric profiles

The simulated, using the OSI SAF model, and observed Tb's at NOAA 15- AMSU A channel 4 (52.8GHz). STD: 1.54K

The simulated, using the tie-point model, and the NOAA 15 AMSU A channel 4 (52.8GHz). STD 1.76K
Scatter Plot of Emissivity in the Northern Hemisphere on 2015-01-02
Comparison – ongoing...

Emissivity (2015-01-02)

Difference between emissivity & reference data
Forward models for ice and snow

On the one hand, there are ways forward: detailed input multilayer microwave emission models can simulate realistic signatures and variability. Semi-empirical models can simulate signatures at selected frequencies without prior knowledge of the snow and ice.

On the other hand, 1) one or two layer models suitable for OE and assimilation with bulk snow and ice parameters does not capture the measured signatures with realistic physical input, and 2) the valid range (spectral) of emissivity models is limited.