The Microwave Emissivity of Sea Ice: – an overview

Christian Melsheimer

Institute of Environmental Physics, University of Bremen, Germany

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Overview

1. Motivation

2. Sea ice emissivity

3. Sea ice emissivity modeling

4. Sea ice emissivity measurement/retrieval

5. Summary and Outlook
Sea Ice

- covers about **5%** of global oceans
- affects **heat** flow (thermal insulation of ocean)
- affects **radiative** balance (emissivity and albedo)
- can **vary quickly** (hours to days) on large scales (> 100 km) (advection, thermodynamics)
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Emissivity of Sea Ice

- much *higher* than emissivity of open ocean!
- varies with *frequency* and *polarization* (and temperature...)
- needs to be known for remote sensing in polar regions
  - sea ice concentration
  - sea ice type
  - sea ice thickness
  - water vapour, clouds (background: ocean and sea ice)
- Interesting frequency range (current satellites):
  - 1 GHz – 200 GHz
- Satellites/sensors: SMOS, AMSR2/AMSR-E, SSMIS, AMSU-A, AMSU-B/MHS
Sea ice: Complex structure

- Ice with brine inclusions
- Snow layer(s) on top
- Brine slowly percolates down
- Summer: Melt water flushes brine $\Rightarrow$ air inclusions

from Ulaby et al. [1986]
Sea ice: Processes

- **emission** by water, sea ice and snow
- **absorption** by sea ice and snow
- **scattering** by brine and air inclusion, snow grains
- **reflection** at interfaces between layers

- **emitting layer depth/penetration depth:** strong dependence on frequency
  - below 10 GHz: whole ice and water underneath contribute
  - at 100 GHz: top few cm only

- melting conditions drastically change everything
Sea ice emissivity modeling

- No closed model for 1–200 GHz
- Approach by Tonboe [2010]
- *dielectric* model of sea ice with *brine* or *air* inclusions, one or few layers
- in addition: layers of *snow* on top
  ⇒ using extension of land snow *model for layered snow* [MEMLS, Wiesmann and Mätzler, 1999]
    - refraction and reflection at layer interfaces
    - absorption by layers
    - scattering by snow grains, brine and air inclusions
      - using improved *Born approximation*
      - *correlation function* approach for scatterer size and distribution
  ⇒ non-trivial relation between *grain size* and *correlation length*
Sea ice emissivity modeling (ctd.)

- problem: where to get realistic sea ice and snow profiles?
  including crusts from surface melt and refreeze
  – few comprehensive observations
  ⇒ 1-dim. thermodynamic model of evolving sea ice and snow,
  driven by meteorological reanalysis data incl. precipitation
- Note: emissivity modeling breaks down when the surface is wet!
Measuring Sea Ice Emissivity: Principle

- emissivity = \frac{\text{brightness temperature}}{\text{physical temperature}}

\[ T_B(\nu, \theta) = E_T + (1 - E) T_d(\nu, \theta) \]

\[ E = \frac{T_B - T_d}{T_s - T_d} \]
Measuring Sea Ice Emissivity: Principle

- emissivity = \( \frac{\text{brightness temperature}}{\text{physical temperature}} \)

- Well...
  Brightness temperature of the ground measured directly above the ground (viewing angle \( \theta \), frequency \( \nu \)):

\[
T_B(\nu, \theta) = ET_s + (1 - E)T_d(\nu, \theta)
\]

where
- \( E \): emissivity of the surface
- \( T_s \): physical temperature of the surface
- \( T_d \): downwelling radiation, i.e. emission from atmosphere
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Measuring Sea Ice Emissivity: Principle (Ctd.)

⇒ must also measure surface temperature and downwelling radiation
  • measure skin temperature with IR, but true temperature profile in emitting layer usually not known
  • Note: in winter strong temperature gradient in snow layer ($\gg 10 \text{ K/m}$!)

⇒ when using skin temperature: “effective emissivity”
  • when not in-situ, atmospheric absorption and upwelling emission has to be allowed for
Measuring Sea Ice Emissivity: Configurations

- **in-situ** radiometer measurements and temperature measurement
  - **but:** single point measurements
- **Airborne** campaigns
  - Measuring brightness temperature along same track from high and low altitude ⇒ derive contribution from atmosphere
  - measure surface temperature: brightness temperature → emissivity
  - **but:** short time period only, spatially limited
- **Satellite** “measurement” (retrieval)
  - in principle large areas and time periods
  - **but:** need to model atmospheric contribution (and surface temperature)
Emissivity Measurements: Example

Sea ice and open water emissivity at microwave frequencies [Sreen et al. 2008]
Emissivity Retrieval from Satellite Data

- Total brightness temperature measured by satellite sensor like AMSR-E or AMSR2 (viewing angle $\theta \approx 55^\circ$, frequency $\nu$):

$$T_B(\nu) = T_u(\nu, \theta) + e^{-\tau \sec \theta} E T_s + (1 - E) T_d(\nu, \theta) e^{-\tau \sec \theta}$$

where
- $T_u$: upwelling radiation from atmosphere
- $\tau$: opacity of atmosphere (integrated absorption coefficient)
- $T_d$: downwelling radiation from atmosphere
- $T_s$: physical temperature of the surface
- $E$: emissivity of the surface

$$\Rightarrow E = \frac{[T_B - T_B(E = 0)]}{[T_B(E = 1) - T_B(E = 0)]}$$
Emissivity from Sat. (Ctd.)

\[ E = \frac{T_B - T_B(E = 0)}{T_B(E = 1) - T_B(E = 0)} \]

- This means: Emissivity at given \( \nu \) can be determined from measured (AMSR-E) \( T_B \) if we simulate \( T_B(E = 0) \) and \( T_B(E = 1) \) for \( \nu \)

- Here: MWMOD (MicroWave radiative transfer MODel). Input: Atmospheric profile from ECMWF analysis [Mathew et al., 2008, 2009]
Emissivity from Sat. (Ctd.)

- Emissivity retrieval from AMSR-E or AMSR2 – in principle daily coverage of Arctic/Antarctic
- However: Rather noisy, temporal/spatial averages more sensible
  - Monthly emissivities of typical first-year and multiyear ice areas, and their variabilities
    ⇒ e.g., for improved a priori surface emissivity data in other retrieval
  - Correlation of FYI and MYI emissivities at different AMSR-E frequencies and polarizations
Correlation between FYI emissivities for January 2005 (top left) to December 2005 (bottom right)
Summary

- Sea ice is a complex layered medium (more or less saline ice plus layered snow)
- Sea ice emissivity higher than open water emissivity
- Depends on ice type, snow layer, temperature
Summary (Ctd.)

- **Modeling:** No closed model
  - **dielectric** mixing models for ice with brine or air inclusions
  - **snow** models for layered snow on top
  - models usually do not cover 1 GHz to 200 GHz range
  - recently: extended model for layered snow to include ice underneath
  - emissivity in summer (wet snow) not well modeled/investigated!

- **Measuring:**
  - point measurements with hand-held/airborne radiometers
  - measurement over larger area and time only from satellite (retrieval)
  → needs RT modeling of the atmosphere
Ideas, Outlook

- ARTS atmospheric RT modeling for emissivity retrieval from satellite?
- measurement campaigns?
- include/connect sea ice emissivity module to ARTS?
End
References I


References II


AMSР-E

- AMSR-E (Advanced Microwave Scanning Radiometer) on “Aqua”
- polar orbit, about 100 min
- conical scan (47.4° off-nadir) ⇒ Viewing angle on Earth: 55°
- 5 frequency [en], 2 polarization [en]

<table>
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<th>Freq. [GHz]</th>
<th>6.93</th>
<th>10.65</th>
<th>18.7</th>
<th>23.8</th>
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<td>Resol. [km]</td>
<td>56</td>
<td>38</td>
<td>21</td>
<td>24</td>
<td>12</td>
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- Daily coverage of Arctic/Antarctic
SSMIS

- SSMIS (Special Sensor Microwave Imager/Sensor)
- conical scan (45° off-nadir) ⇒ viewing angle on Earth: 53.1°
- 21 frequencies (19–188 GHz), z.T. 2 polarization [en]

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<th>Freq. [GHz]</th>
<th>19.35</th>
<th>22.24</th>
<th>37.0</th>
<th>..</th>
<th>91.0</th>
<th>..</th>
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<td>V</td>
<td>H,V</td>
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<td>H,V</td>
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<td>Resol. [km]</td>
<td>45×74</td>
<td>45×74</td>
<td>28×45</td>
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- Daily coverage of Arctic/Antarctic
- operational satellite series (Defense Meteorological Satellite Program), since 2005
- currently 3 satellites operational
Data source: AMSR-E/AMSR2 and SSMIS

- **AMSR-E** on sat. “Aqua”
- **AMSR2** on sat. “GCOM-W1 (Shizuku)”
  - Since Aug. 2012
  - Resolution about 20 km

- **SSMIS** on DMSP satellites
  - Operational satellite series, since 2005
  - Resolution about 50 km

- **Daily** coverage of Arctic/Antarctic