The Microwave Emissivity of Sea Ice: – an overview

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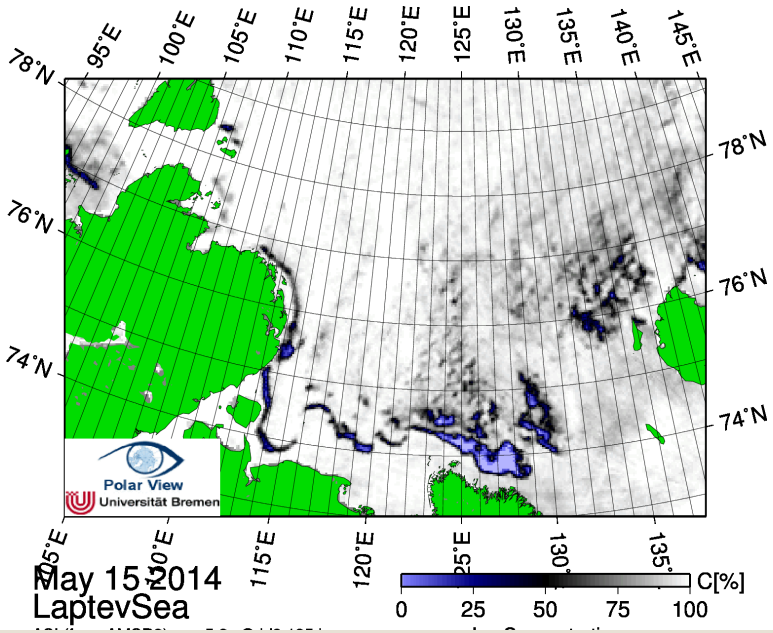
ARTS Workshop, Kristineberg, Sweden
9-11 June, 2014

Overview

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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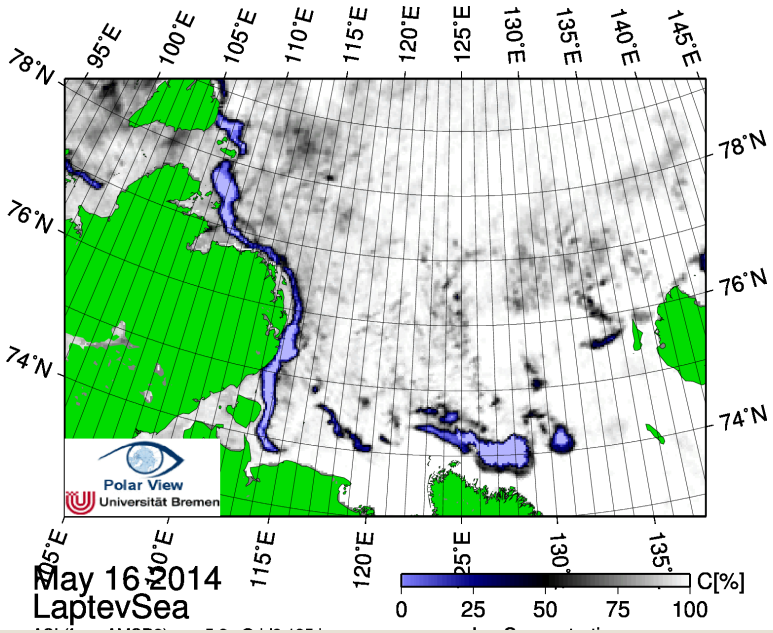

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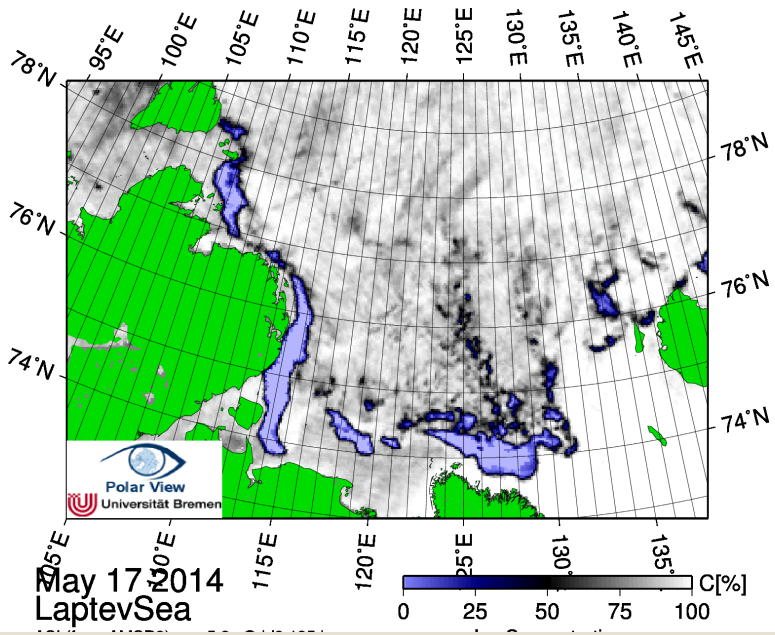
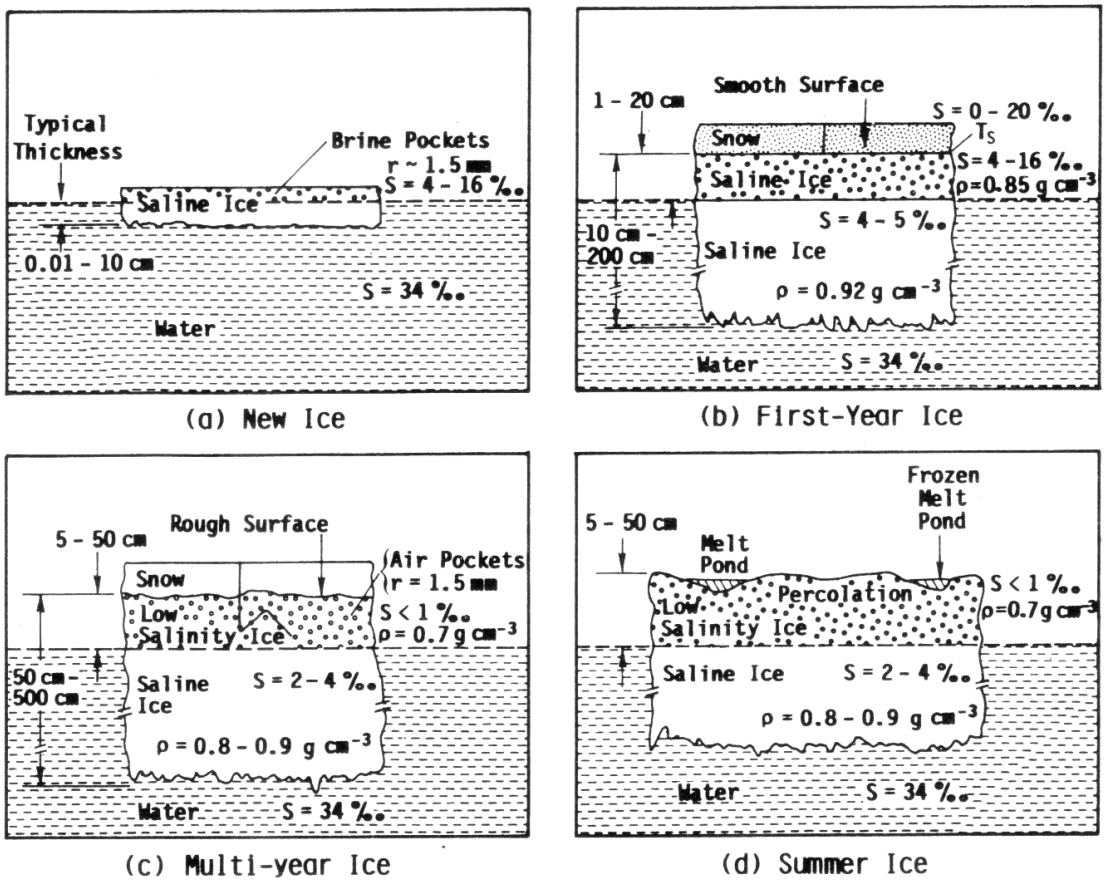


Emissivity of Sea Ice

- 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

$\Rightarrow$ 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

  $\Rightarrow$ 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!

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- Well...
  Brightness temperature of the ground measured directly above the ground (viewing angle θ, frequency ν):

$$T_B(\nu, \theta) = E T_s + (1 - E) T_d(\nu, \theta)$$

where

E: emissivity of the surface
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$\Rightarrow$ $E = [T_B - T_d] / [T_s - T_d]$

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 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

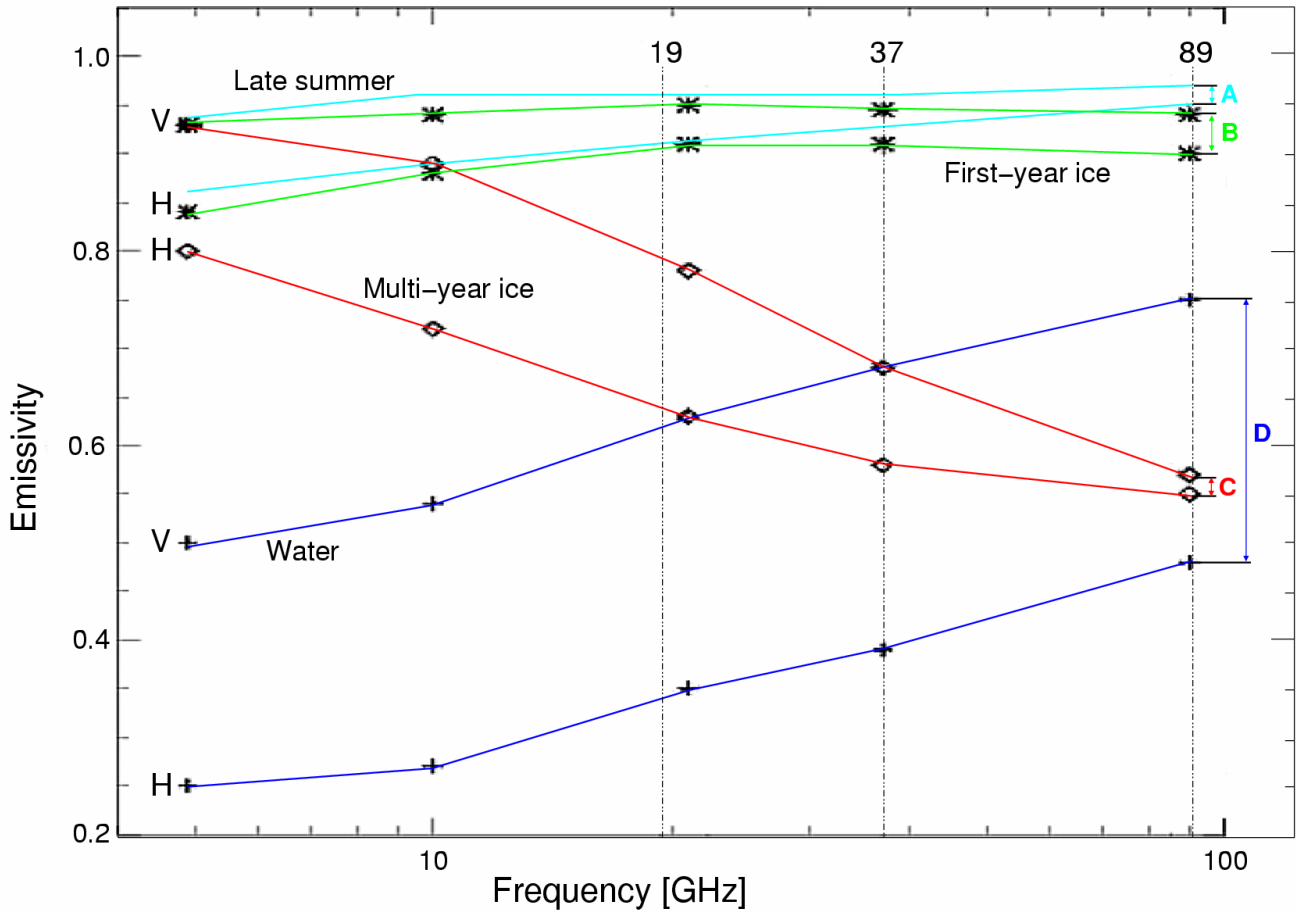
- in-situ radiometer measurements and temperature measurement

  but: single point measurements
- Airborne campaigns
  - Measuring brightness temperature along same track from high and low altitude $\Rightarrow$derive contribution from atmosphere
  - measure surface temperature: brightness temperature $\rightarrow$ 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 [Spreen et al. 2008]

Emissivity Retrieval from Satellite Data

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

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

where

T_u: upwelling radiation from atmosphere
τ: opacity of atmosphere (integrated absorption coefficient)
T_d: downwelling radiation from atmosphere
T_s: physical temperature of the surface
E: emissivity of the surface

$$\Rightarrow E = [T_B - T_B(E=0)] \,/\, [T_B(E=1) - T_B(E=0)]$$

Emissivity from Sat. (Ctd.)

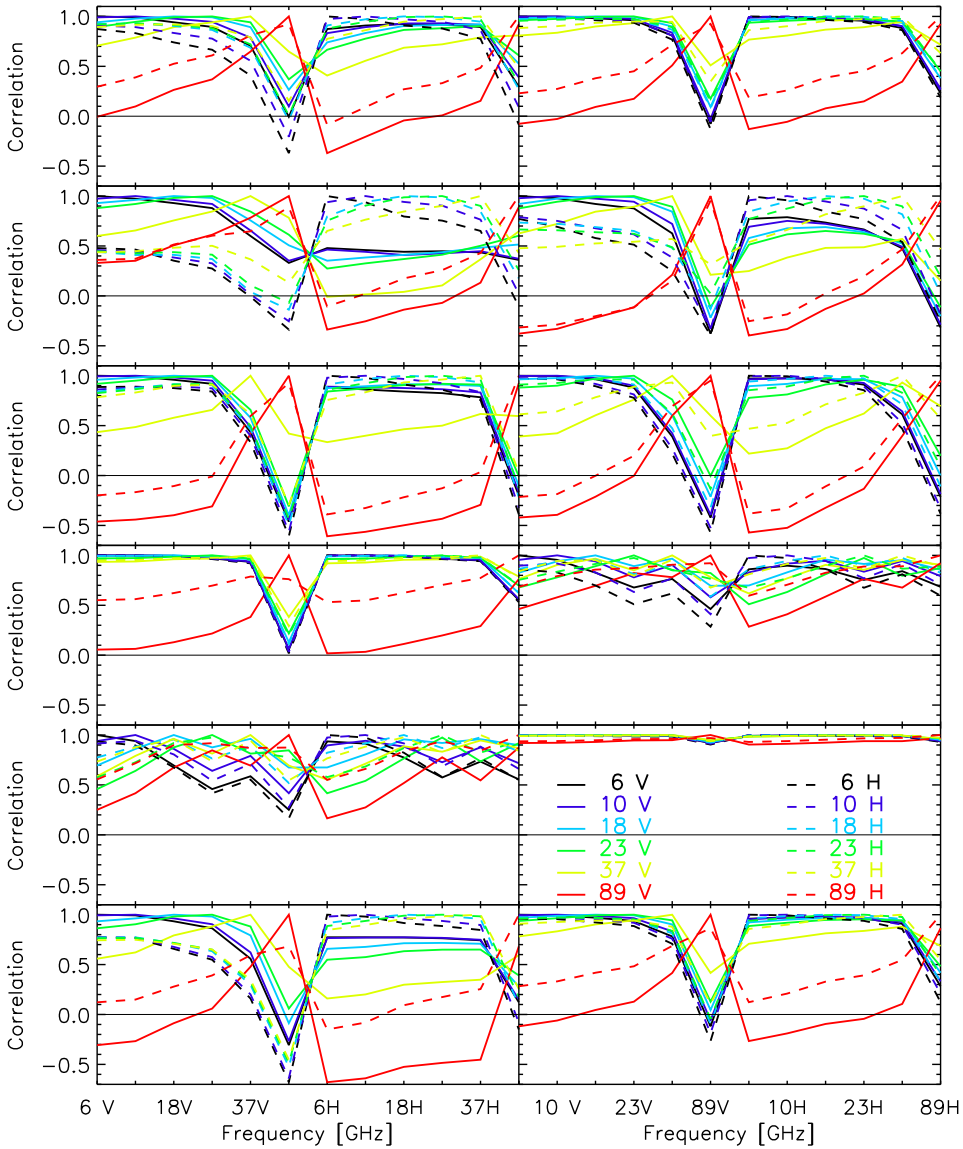
$$E = [T_B - T_B(E = 0)] / [T_B(E = 1) - T_B(E = 0)]$$

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

  $\Rightarrow$ 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)
    $\rightarrow$ 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

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AMSR-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]

Freq. [GHz]	6.93	10.65	18.7	23.8	36.5	89.0
pol.	H,V	H,V	H,V	H,V	H,V	H,V
Resol. [km]	56	38	21	24	12	5.4

- Daily coverage of Arctic/Antarctic
- 2002 – Oct. 2011

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]

Freq. [GHz]	19.35	22.24	37.0	..	91.0	..
pol.	H,V	V	H,V		H,V	
Resol. [km]	45×74	45×74	28×45		14	

- 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”
- 2002 – Oct. 2011
- 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