Remote Sensing of Polar Ocean and Atmosphere

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Overview

1. ASI (*) with atm correction
2. Thickness of thin sea ice from SMOS (*) : synergy with SMAP
3. Retrieval of multiyear ice from passive microwave sensors (*) with corrections
4. Snow on sea ice
5. Retrieval of albedo and melt pond fraction of sea ice in summer from optical sensors
6. Total water vapor over sea ice and open ocean

(*) = currently NRT production
High resolution sea ice information in NRT needed at

- Low ice concentrations $C$ for navigation
- High ice concentrations $C$ for NWP: heat transfer $\sim (1-C)$

Produced

- based on AMSR-E 89 GHz data and ASI algorithm
- resolution $\sim$5km
- since 2002 by IUP for worldwide user community, new address: https://www.seaice.uni-bremen.de

Research

- Atmospheric correction
1: ASI Algorithm with individual weather correction

- Dynamic range of signal increased from 46 to 61 K
- Summer correction ongoing; more complicated ice conditions require specific treatment (melting snow, melt ponds)
2: Thickness of thin sea ice

Relevance

Heat transfer: \( \sim 1 / \text{thickness} \rightarrow \text{heat balance} \)
Rheology: Less resistance to drift and deformation by wind and ships
Operational: Ship routing
Motivation: Need of thin ice data (cont’d)

Arctic Ice Extent 1972 – 2012

Differences:
⇒ Firstyear Ice, Area increasing with reducing sea ice minima

Minima:
⇒ _Area of Multiyear Ice

Maxima

10 Year Trends

Sea Ice Extent $[10^6 \text{ km}^2]$
**L band sensors SMOS and SMAP**

**Soil Moisture** – penetration depth required → low frequency

**Ocean Salinity** – sensitivity

L-band – 1.4 GHz; \( \lambda = 21 \text{ cm} \)

Launch 2009

Resolution ~ Aperture / \( \lambda \)

\( \lambda = 21 \text{ cm}, \ \text{Res} = 50 \text{ km} \rightarrow A = 10 \text{ m} !?? \)

**SMAP Soil Moisture Active and Passive**

- Conically scanning
- Active part broken
- Launch 2015
Preparing synergy SMOS - SMAP

- **SMOS**: Problem: influence of irregular data distribution within selected incidence angle range.
- **SMAP**: Conically scanning $\theta=40^\circ$
- Solution: fit analytical function to all data of one day
- Use fit also filter out RF iteratively:
  - Exclude points with highest std
  - After 5 iterations: 30% data remaining

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![Graphs showing data distribution and fitting results for SMOS and SMAP](image-url)
Ice thickness: SMOS vs SMAP
Difference in ice thickness SMAP - SMOS

- Small differences in areas of homogeneous thin ice
- Larger differences at ice edges and thicker ice areas
- Differences are within the uncertainty of the SMOS product (<30%)

Different overflight times and footprint geometries are suspected as main reason for the difference
• Good agreement of SMOS and SMAP retrieved ice thicknesses, RMSD ~ 3.3 cm
• Potential for combined ice thickness product from SMOS and SMAP
3. Multiyear sea ice concentration

- Multiyear ice (MYI): survives at least one summer
  - thicker, lower salinity, more snow
  - Conducts less heat from the ocean to the atmosphere
  - More resistance against deforming forces
  - Populated by microorganisms

- First year ice (FYI): forms after the last summer
  - thinner, higher salinity, less snow

Universität Bremen
Progress for Multiyear sea ice concentration

Misclassification in autumn
- Misclassification of MYI as FYI
- Correction based on surface air temperature
- Results

Misclassification in spring
- FYI as MYI
- Correction work ongoing

Both corrections published

Operational processing:
- NASA Team multiyear ice concentrations available at https://seaice.uni-bremen.de
- Corrections being implemented
Synopsis: The operational services

- Contour of C_MA in Nov similar to SIC contour at preceding sea ice minimum
- SIT map gives information about ice formed since last minimum
4. Snow Depth on Sea Ice

Why?

- snow depth and properties highly variable in time and space

- Influences Earth’s radiative balance:
  - high albedo
  - high heat turnover during formation and melt
  - acts as insulator for the ocean-atmosphere heat flux through sea ice
  - the thicker the snow layer the higher the insulation

→ observation of snow depth important for calculation of ocean-atmosphere heat fluxes in the Polar Regions

→ derivation of sea ice thickness from freeboard requires snow mass [Kwok et al., 2004, 2007, Kwok and Cunningham, 2008, Kurtz et al., 2009]

Here reporting: snow depth on **Antarctic** sea ice. Arctic ongoing.
First procedure to retrieve snow depth on sea ice from passive microwave (SSM/I) satellite observations (Marcus and Cavalieri 1998):

\[ GR_{V,ice} = \frac{T_B(37V) - T_B(19V) - k_1(1-C_{ice})}{T_B(37V) + T_B(19V) - k_2(1-C_{ice})} \]
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Snow depth

\[ SD = a + b \, GR_{V,\text{ice}} \]

Procedure transferred to AMSR-E (2002-2011) by linear regression of TBs (Brucker and Marcus 2013)

Data sets provided by NSIDC for NASA Team 2 ice concentrations and snow depth:

AMSR-E: 2002 – 2011
Antarctic: In situ data

**ASPeCt** Antarctic Sea Ice Processes and Climate Protocol [Worby and Allison, 1999, Worby et al., 2008]:
- snow depths from nine more cruise 2006 – 2011, all recorded using the ASPeCt protocol, collected by S. Kern and A. Beitsch [2013]

**ASPeCt-Bio** [Meiners et al. 2012]:
Ice core data from 32 cruises 1983 – 2008
Results

Day
15 Sep 2009

Month
Sep 2009
Snow Depth – monthly averages 2002 - 2016
### Example month September

<table>
<thead>
<tr>
<th>Average</th>
<th>Trend</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow Depth [cm/y]</td>
<td>cm/y</td>
<td>cm/y</td>
</tr>
</tbody>
</table>

Pale red and blue means < ± 1 cm/y: insignificant. Large area of decreasing trend in inner ice pack of Bellingsh-Amundsen and Ross, increasing towards MIZ.
Trends all months 2002-2016
Uncertainty of trends 2002-2016
Antarctic Snow Depth Conclusions

New algorithm derived for AMSR-E and AMSR2 2002-2016 based on the same field observations
- daily SD, error, monthly trends
- SD highest in West Antarctic, low in East Antarctic
- Large region of decreasing trend in inner ice pack of Bellingshausen-A and Ross sectors from Jun to Dec
- Smaller region of increasing SD same sectors, outer parts, Jul to Nov

Outlook
More detail/case studies required for better understanding of relation of SD and satellite observations, potentially including meteorological history

Work supported by ESA SICCI project
5: Retrieval albedo and melt pond fraction

Relevance

Albedo of sea ice
- High and little variable in winter
- Low and variable during melting season
- Strong influence of melt ponds

Melt ponds
- Up to 50% of sea ice area in summer
- Absorb much solar energy
- Depth and fraction not available in GCMs

Pedersen et al. (2005)
Data used: MERIS, 1km x 1km L1b resolution, spectral albedo delivered at 6 wavelengths, 9/15 ch. used.

Forward model: ice as random mixture of grains with inclusions (air bubbles, brine, sediments, etc), melt pond on top as fresh water, in VIS/NIR, scattering by Rayleigh-Gans approx.

Constraints on the model parameters to remove the unphysical solutions are developed analyzing a set of ~200 field spectra of ponds and ice. Algorithm does not use a priori values for sea ice or pond optical properties!

Refs:
1. Istomina et al., TC 2015, 9, 1551-1566.
2. Dito1567–1578
Arctic MPF

Meris cloud mask

Additional AATSR cloud screening:

- Amount of data reduced
- MPF range extended from 8%..25% to 5%..34%
6. Atmospheric total water vapor (TWV) Retrieval
Challenge: combine both data sets (Arctic Amplification (AC3); INTAROS)
Conclusions:

Remote sensing of polar surface and atmosphere at UB

1. ASI with atm correction: high res., improved sea ice concentration by weather correction. Summer version ongoing (SICCI-2, AC3)
2. Thickness of thin sea ice: developing synergy SMOS (aperture synthesis) and conically scanning SMAP (UB)
3. Multiyear ice: basic algorithm output available in NRT; implementing corrections for warm air intrusion and drift (UB-X)
4. Snow on sea ice: Arctic ongoing (SICCI-2, UB-X)
6. Total water vapor over sea ice and open ocean from microwave sounders and imagers (UB, AC3, INTAROS)

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Cooperations

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