Innovative sea ice data products for AMSR3:
I. High *resolution* sea ice concentration,
II. Snow depth on sea ice

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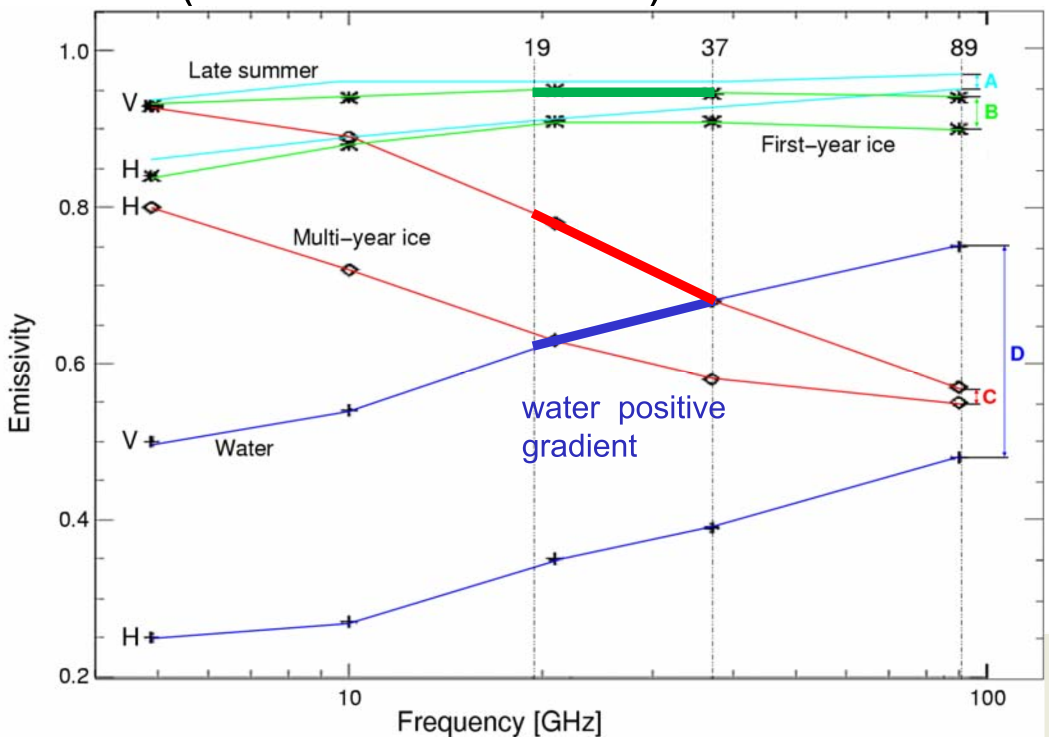
GCOM
Global Change Observation Mission

I. High *resolution* sea ice concentration: ASI (ARTIST Sea Ice) algorithm

- High resolution ice concentrations needed for
  - Navigation
  - NWP + climate research
  - 0.5% of open water transmit equal heat to atm as 99.5% sea ice.
- Horizontal resolution ~ λ/aperture,
  AMSR2: 89 GHz: **3 x 5 km**
  19 GHz: 14 x 22 km
- Use *polarization differences* near 90 GHz (Svendsen et al. 1987):
- Large for OW: tie Point P_0 = D
- Small for all ice types:
  tie points P_1 = A ~ B ~ C
- Challenge: weather influence, mainly over open water



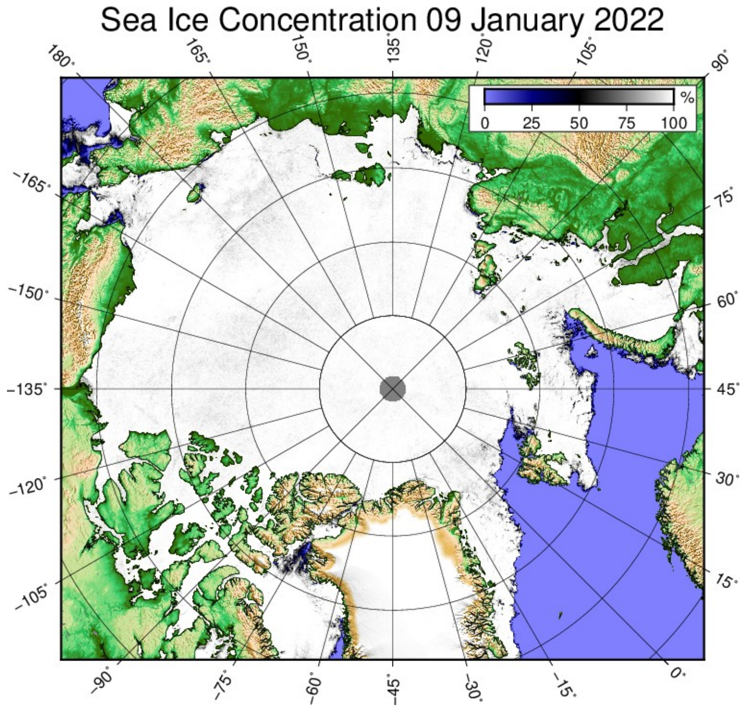
Three types of weather correction for ASI sea ice concentrations

1. **ASI**: screen weather influenced OW pixels with 3 weather filters (Spreen et al., 2009)
   - GR 18-23: Water Vapor
   - GR 18-37: CLW
   - C(Bootstrap) < 5%.

   Current processing.

2. **ASI2**: correct TBs based on ECMWF model fields of TWV, T_surf, WS. Being validated for AMSR3 high resolution SIC standard product. [Lu et al., J-STARS 2018]

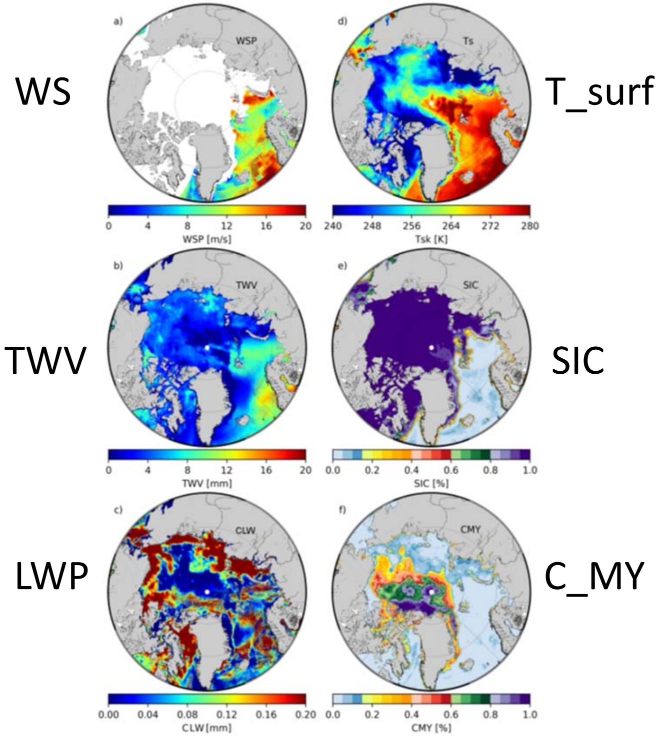
3. **ASI3**: correct TBs based on **OEM retrieval** (Scarlat et al. J-STARS 2017) of TWV, T_surf, WS **and LWP** derived form AMSR2 [Lu et al., 2022, JGR in press] .

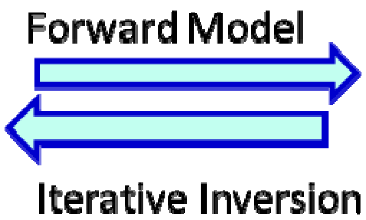


https://seaice.uni-bremen.de

Multi-parameter Optimal Estimation retrieval

Simultaneously determines all parameters affecting the observed TBs (wind speed, surface temperature, total water vapor, SIC, liquid water path, multiyear ice concentration) all channels, so that, when fed into a common forward model, they best reproduce the observations
(Scarlat et al. 2018).





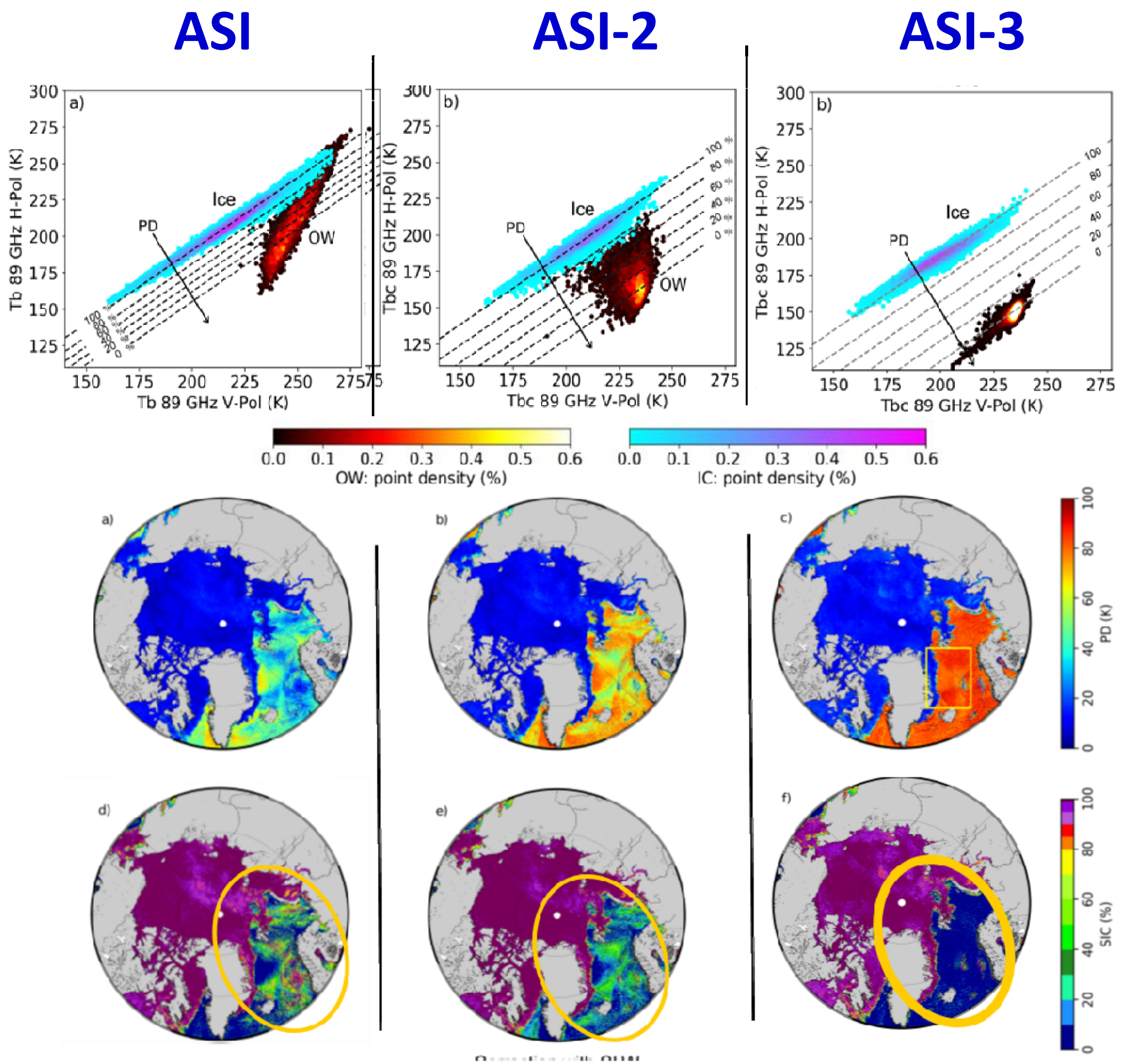
10 AMSR-E TBs
6.9 GHz
10.9 GHz
18 GHz
23 GHz
37 GHz
Each h+v pol

Comparing three ASI versions

Capability to separate 0% and 100% SIC cases in the 89V – 89 H space

89 GHz Pol Difference

SIC no Weather Filter



All maps: 11 Jan 2006

Cal/Val Efforts

Tie points and performance

- Derived for ASI-2 and ASI-3 from Round Robin Data Package (RRDP) with confirmed 0% and 100% SIC, ASI tie points taken from Spreen et al. (2008)

	ASI noWF	ASI-2 noWF	ASI-3 noWF
	Tie Points		
P_0 [K]	47	72	80
P_1 [K]	11.7	12.3	14
Dynamic range [K]	35.3	59.7	66
	RRDP results: bias ± stdev		
Open water [% SIC]	27.7 ± 31.3	15.8 ±20.7	0 ± 0.6
100% SIC [% SIC]	-0.3 ±1.0	-0.5 ± 1.3	-0.8 ± 1.5

Further activities

- Validation wit Validation with Landsat scenes
- ASI-2 and ASI-3 ported to Python 3, provided to JAXA for op. implementation and more validation
- ASI-2 planned as AMSR3 “at launch” high resolution sea ice concentration standard data product ASI-3 planned as AMSR3 high resolution sea ice concentration research data product, might become standard product after implementation and validation
- More validation scenes suggested to JAXA

II. Retrieval of Snow Depth on Arctic Sea Ice

Why we need it

Snow depth on sea ice key influences on Arctic climate system:

- Reduces **heat transfer**
- High **albedo**
- Reduces sea ice **freeboard**
- Influences **radar backscatter**
- Attenuates **light transmission**

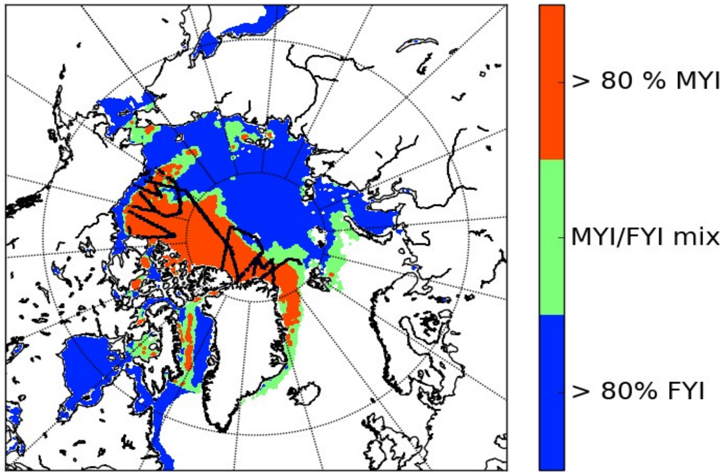
Earlier shown

- Snow depth (SD) *linearly estimated* from gradient ratio GR at different frequencies, classically

$$GR\,(37,19) = \frac{Tb_{37} - Tb_{19}}{Tb_{37} + Tb_{19}}$$

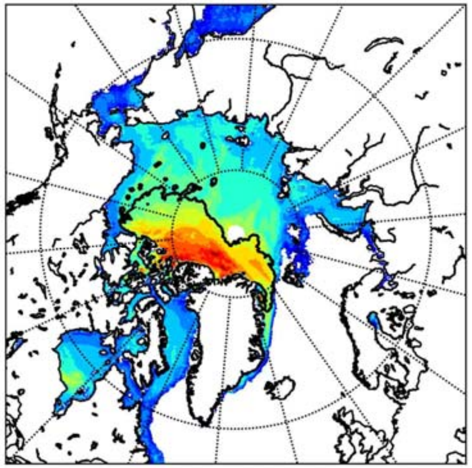
- Lower frequencies: better sensitivity to higher snow depths, best results with combination GR (37,19) and GR(19,7)
  → reduces uncertainty
- Calibration with airborne observations of **Operation Ice Bridge** (2009-2015, March and April) in Beaufort and Greenland Seas.
- Retrieval over FYI: $Sd_{FYI} = 19.26 - 553 \cdot GR(19/7)$ RMSD = 4 cm
  over MYI $Sd_{MYI} = 19.34 - 365 \cdot GR(19/7)$ RMSD = 5.5 cm

OIB flights for calibration

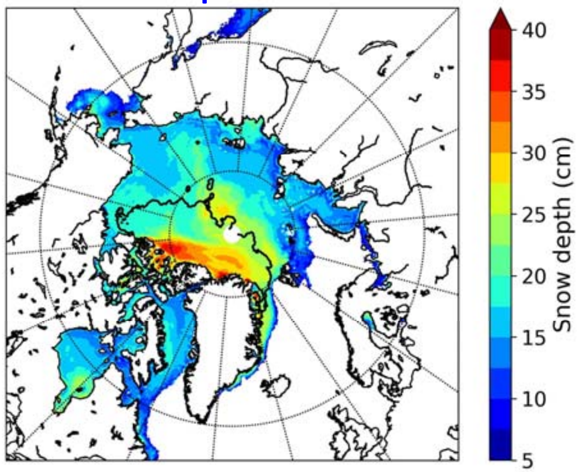


Data set: Arctic-wide March Snow Depth

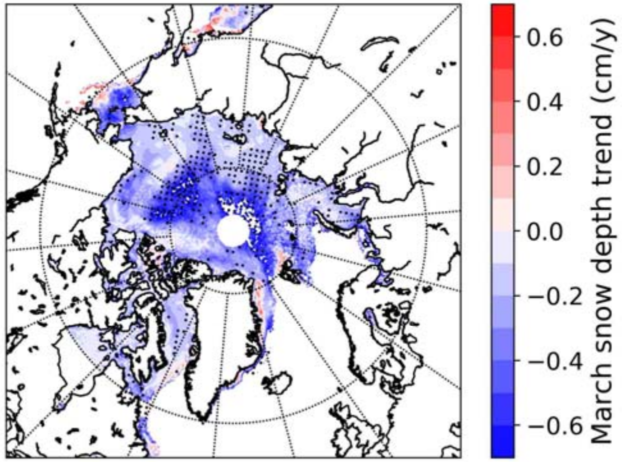
Map 2004



Map 2017

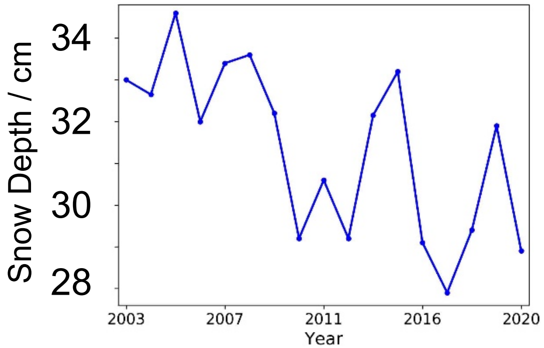


Trend 2003-2020

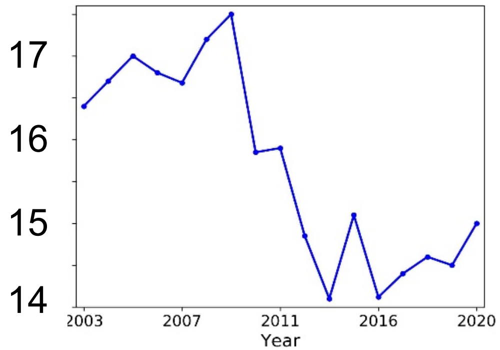


Dots: significant trends ($p < 0.05$)

Time series: FYI



MYI

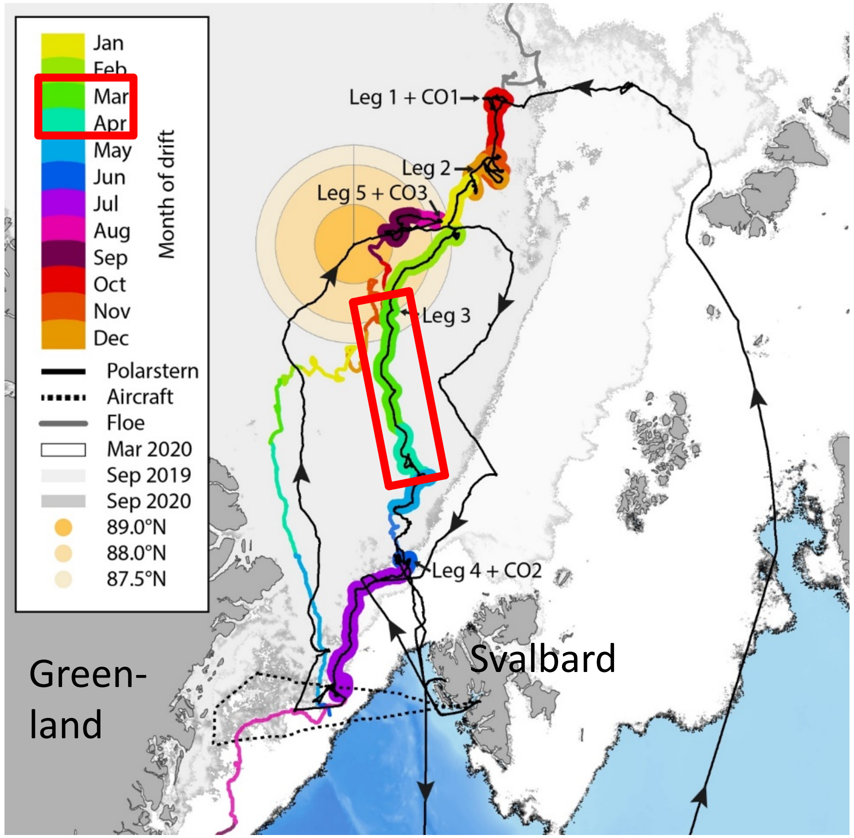


Data set Snow Depth on Arctic Sea Ice:

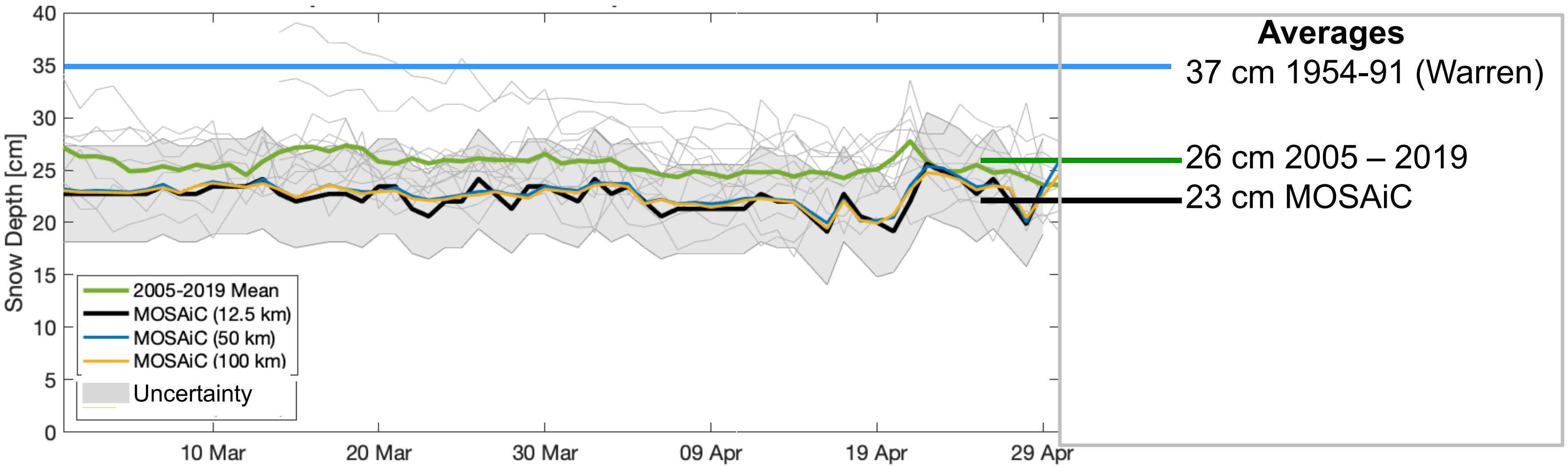
- https://seaice.uni-bremen.de
- doi.pangaea.de/10.1594/PANGAEA.902748

Application during MOSAiC campaign

- MOSAiC ice floe predominantly second-year ice, SD for MOSAiC is only available March and April: red rectangle.
- Retrieved:
- **Snow depth** retrieved
  – at Polarstern positions and
  – 50 km and
  – 100 surroundings
- **Uncertainties** based on Monte Carlo simulations varying input parameters for a snow and sea ice emission model MEMLS (Tonboe et al., 2006) and atmosphere (PAMTRA; Mech et al., 2020). Most sea ice, snow and atmosphere .properties not known to SD retrieval.
- Result: uncertainty on MYI 5 … 10 cm.



Snow depth MOSAiC 2020 and years 2005-2019



Snow depth

- almost constant during Mar-Apr 2020 along Polarstern path
- increased ~ 3 cm during snowfall event April
- During MOSAiC along Polarstern path:
  - 3 cm smaller than 2005-2019 average
  - 13 cm smaller than in 1954 – 1991 climatology (Warren et al. 1999)
- Relevant for estimation of ice thickness from altimeter freeboard observations.

Conclusions: Three Innovative sea ice data products for AMSR3

PI G Heygster, U Bremen, Germany

1. **High *resolution* sea ice concentration (SIC) : ASI with atmospheric correction**:
   - *ASI -2* (correction from ECMWF model):
     Developed to maturity of operational application as AMSR3 "at launch" high resolution sea ice concentration standard product
   - New development*: ASI-3* (weather correction from Optimal Estimation retrieval and AMSR-2/3 TBs, *new: also cloud liquid water correction*): planned as AMSR3 high resolution sea ice concentration research product, procedure in press (Lu et al. JGR 2022), being validated in RA-3 project.
2. **High *accuracy* sea ice concentration (Cl C Prigent, Paris Observatory)**

   Combines *low atm influence at low frequencies* with high accuracy at higher frequencies:
   - Optimal Estimation retrieval of SIC with simple mixing forward model,
     also retrieves SST, SSS, snow depth
   - Scheme to combine retrievals of different resolutions suggested (Kilic et al. 2019, 2020)
3. **Snow depth on sea ice**:
   - Retrieval using gradient ratio GR(19, 7) instead of GR(37,18) to reduce uncertainty
   - Uncertainty estimated with thermodynamic and RT models, and field measurements:
     - Lower frequencies less influenced by ice type and clouds
     - But: snowpack properties strongly influence satellite observations (Rostosky 2018)
   - Arctic snow depth data set 2005-2019 established (Rostosky et al., 2020)
   - Pilot application: Snow depth during MOSAiC campaign (2020) and climatology (Krumpen et al. 2021)

Publications

- **Kilic L**., R. T. Tonboe, **C. Prigent, and G.Heygster**: Estimating the snow depth, the snow–ice interface temperature, and the effective temperature of Arctic sea ice using Advanced Microwave Scanning Radiometer and ice mass balance buoy data. JGR 2019.
- **Kilic, L., C. Prigent**, F. Aires, **G. Heygster**, V.Pellet, C. Jimenez::Estimation of sea ice concentration from multi-channel passive microwave satellite observations. Part 1: a new methodology designed for the Copernicus Imaging Microwave Radiometer. JGR subm. 2019.
- **Lu, J**., R. Scarlat, **G. Heygster, G Spreen**, Reducing Weather Influences on Sea Ice Concentration Retrieval at 89 GHz using Passive Microwave Observations. JGR in press 2022.
- Krumpen, T., L. von Albedyll, H. F. Goessling, S. Hendricks, B. Juhls, **G. Spreen**, S. Willmes, H. J. Belter, K. Dethloff, C. Haas, L. Kaleschke, C. Katlein, X. Tian-Kunze, R. Ricker, **P. Rostosky**, J. Rückert, S. Singha, & J. Sokolova (2021). MOSAiC drift expedition from October 2019 to July 2020: sea ice conditions from space and comparison with previous years. *The Cryosphere*, 15, 3897–3920. doi:10.5194/tc-15-3897-2021.
- **Rostosky, P., G. Spreen**, S. Gerland, M. Huntemann, & M. Mech (2020). Modeling the Microwave Emission of Snow on Arctic Sea Ice for Estimating the Uncertainty of Satellite Retrieval. J. Geophys. Res. Oceans, 125(3), e2019JC015465. doi:10.1029/2019JC015465
- Fritzner, S., R. Graversen, K. H. Christensen, **P. Rostosky**, & K. Wang (2019). Impact of assimilating sea ice concentration, sea ice thickness and snow depth in a coupled ocean–sea ice modelling system. *The Cryosphere*, 13, 491–509. doi:10.5194/tc-13-491-2019.
- **Rostosky, P., G. Spreen**, S. L. Farrell, T. Frost**, G. Heygster**, & C. Melsheimer (2018). Snow depth retrieval on Arctic sea ice from passive microwave radiometers—Improvements and extensions to multiyear ice using lower frequencies. J. Geophys. Res. Oceans, 123(10), 7120–7138. doi:10.1029/2018JC014028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