Sea ice thickness observations for ocean-atmosphere interaction studies

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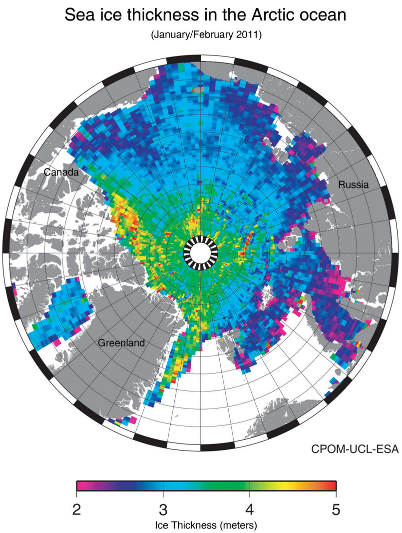
Vorstellung im Rahmen des Berufungsverfahrens für die
W2-Professur "Satellitengestützte Beobachtung des Meereises"

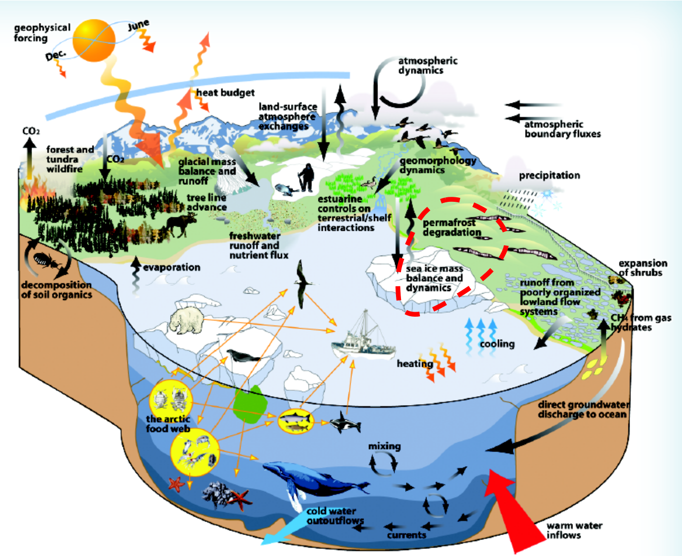
Structure

- Introduction: science plan and motivation
  - link between sea ice and permafrost
- How to measure sea ice thickness?
- Sea ice thickness retrieval from SMOS brightness temperature
- Arctic freeze-up case study and validation
- Outlook and conclusion



CryoSat preliminary result of Centre for Polar Observation and Modelling at University College London (2011)

CliSAP-2 Research Topic B-1: Arctic and Permafrost



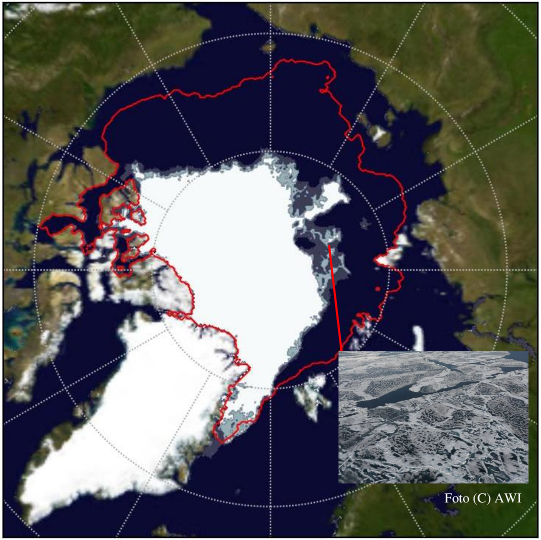
Roberts et al. (2010), *A Science Plan for Regional Arctic System Modelling*

- **link between sea ice loss and permafrost thawing**
- **ocean-atmosphere heat transfer moderated by sea ice**

CliSAP *Renewal Proposal*

Arctic ice "rotten" to the North Pole

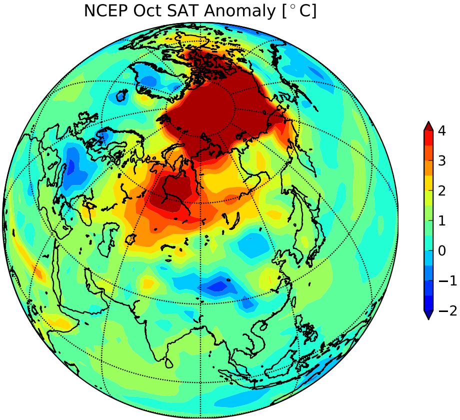
(Dave Barber, The Vancouver Sun, 1st Oct 2012)



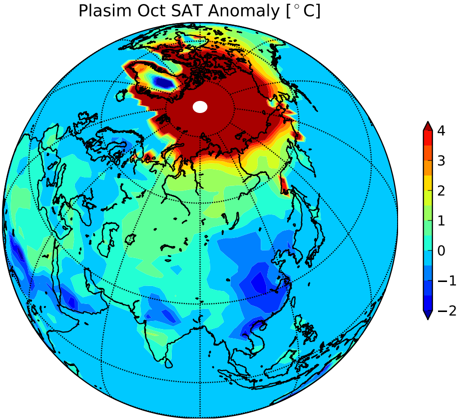
Kaleschke (2012), *KlimaCampus press conference on sea ice minimum*

- Sea ice area dropped to $\mathbf{2.2} \times 10^6$ km^2
- Amount of thin first year ice expected to increase up to $\mathbf{12} \times 10^6$ km^2 during freeze-up
- Impact on weather and climate
- Future development of Arctic sea ice is highly uncertain

Influence of sea ice loss on surface air temperature (SAT)



Reanalysis 2007-2011 – 1950-1980

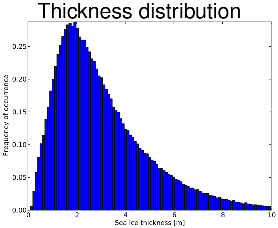


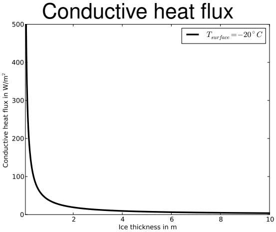
Sea ice loss experiment – reference

Kaleschke (2012, unpublished); *University of Hamburg Earth-System-Model Planet-Simulator at T42 resolution, 10 yrs*

Energy exchange over sea ice during the cold months

Convection over sea ice and leads in Fram Strait



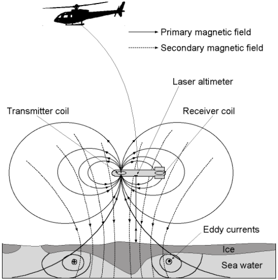


Ice less thick than half a meter dominates the overall heat exchange in the Arctic.

Maykut (1978)

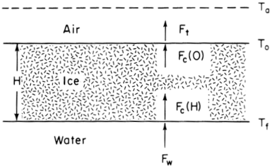
Remote sensing methods for sea ice thickness d

El.mag. induction: d from conductivity



Haas (2000)

Heat flux: d from surface temperature T_0

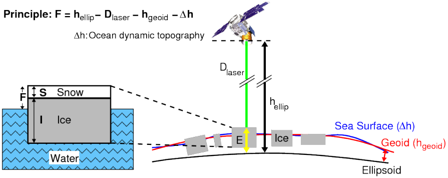


$$\frac{k}{d}(T_0 - T_f) = C(T_a - T_0)$$

Thermal conductivity k, heat transfer coefficient C, air temperature T_a, freezing temperature T_f

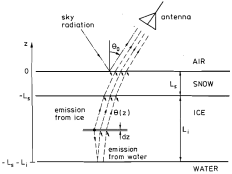
Maykut (1987)

Altimeter: d from surface elevation (freeboard)



Spreen (2008)

Microwave Radiometry: d from emissivity



Hallikainen (1983)

ESA's Soil Moisture and Ocean Salinity Mission (SMOS)

- **M**icrowave **I**maging **R**adiometer using **A**perture **S**ynthesis MIRAS
- 3 arms with 69 antennas: Ø 8 m synthetic aperture
- Nadir resolution ≈ 35 km
- Swath width 1000 km
- Wavelength λ=21 cm (L-band)
- Multi-angle polarimetric measurements

SMOS is approaching its nominal 3-years life time in November 2012. Thanks to the excellent technical and scientific status of the mission, operations will continue (SMOS Quarterly Status Report, Oct. 2012).

Model for brightness temperature observed at 1.4 GHz

- Brightness observed by the satellite:

$$T_{\mathrm{obs}}(p,\theta) = [(1-C)e_{\mathrm{sea}}T_{\mathrm{sea}} + Ce_{\mathrm{ice}}T_{\mathrm{ice}}]e^{\tau} + T_{\mathrm{other}} \quad (1)$$

  - Ice concentration C
  - Temperature of ice/water T
  - Atmospheric opacity τ and other “noise” contributions

- Sea ice emissivity: $e_{\mathrm{ice}}(\epsilon_{\mathrm{ice}}, d, p, \theta)$

  Menashi et al. (1993)

  - Ice thickness d
  - Polarization p
  - Incidence angle θ

- Sea ice permittivity: $\epsilon_{\mathrm{ice}}(V_b)$
  Vant et al. (1978)

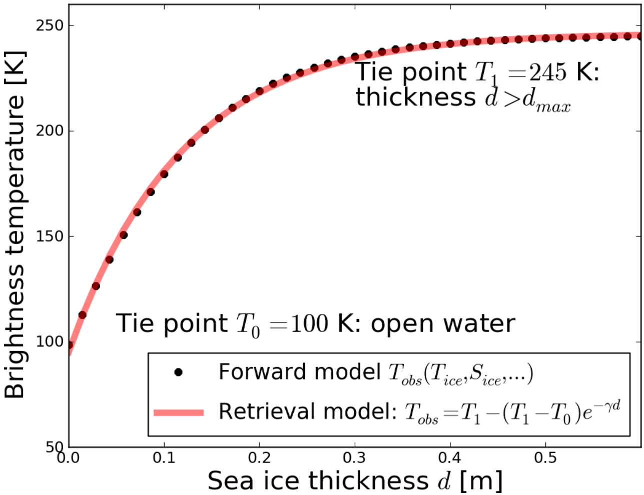
- Relative brine volume: $V_b(T_{\mathrm{ice}}, S_{\mathrm{ice}}, \rho_{\mathrm{ice}})$

  Baltic: Leppäranta and Manninen (1988); Arctic: Cox and Weeks (1983)

  - Sea ice temperature T_{ice}
  - Sea ice salinity S_{ice}
  - Sea ice density ρ_{ice}

Kaleschke, et al. (2010): *A sea-ice thickness retrieval model for 1.4 GHz radiometry and application to airborne measurements over low salinity sea-ice*, The Cryosphere

Forward and retrieval model



Retrieval parameters T_0, T_1, and γ can be obtained from forward model (1):

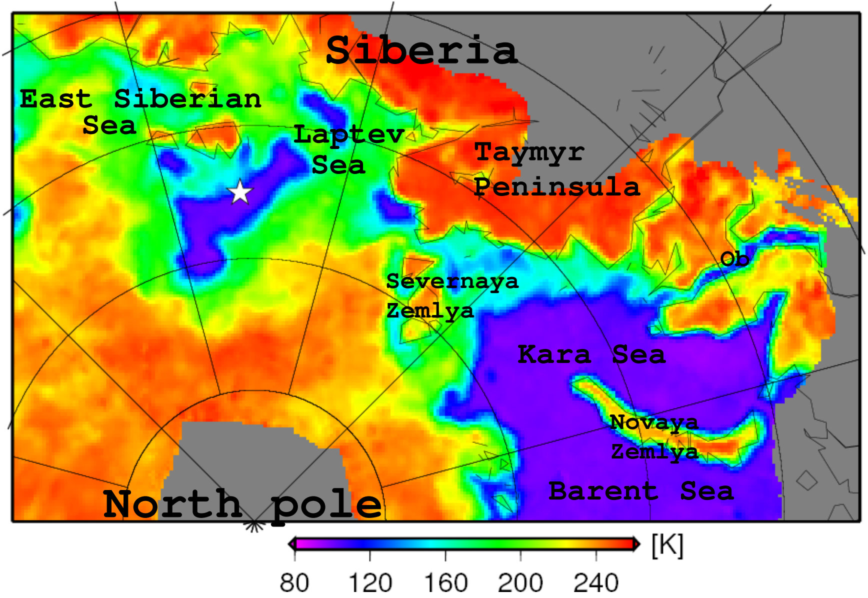
$$T_{\mathrm{obs}}(T_{\mathrm{ice}}, S_{\mathrm{ice}}) \rightarrow T_0, T_1, \gamma$$

Inversion for retrieval:

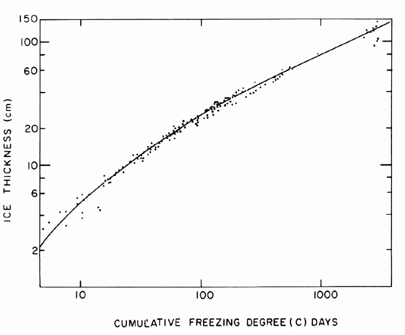
$$d = -\frac{1}{\gamma}\ln\left(\frac{T_1 - T_{\mathrm{obs}}}{T_1 - T_0}\right).$$

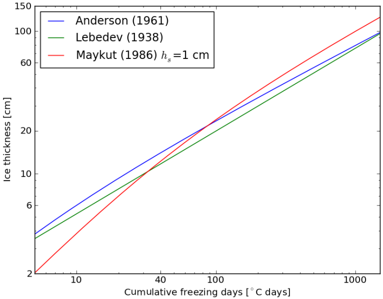
Assumptions: $C \approx 1$, T_0, T_1 and γ=const

SMOS brightness temperature, 20 October 2010



Sea ice growth estimate from surface air temperature





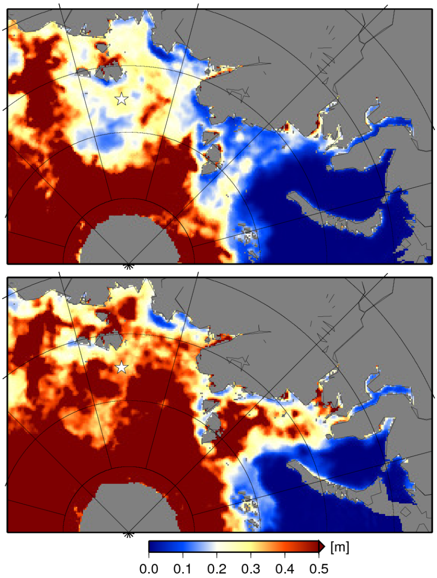
Anderson (1961)

Cumulative freezing days: $\Theta = \int_0^t (T_f - T_a) dt$

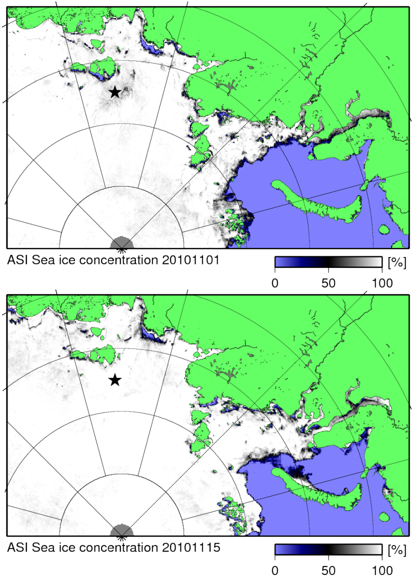
Sea ice thickness, e.g. Lebedev (1938): $d = 1.33\Theta^{0.58}$ [cm]

Freezing point of sea water $T_f \approx -1.9°$C, air temperature T_a from reanalysis (NCEP)

Arctic freeze-up October to December 2010

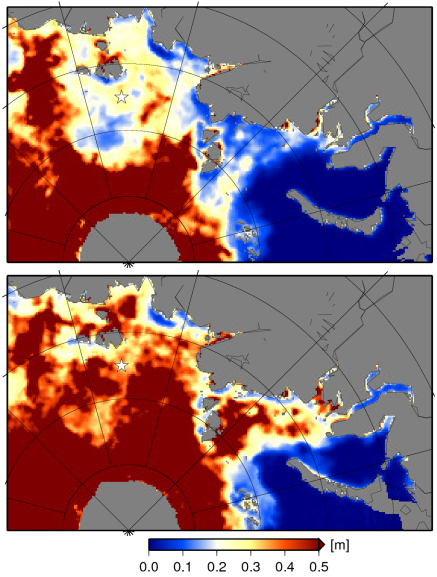


SMOS ice thickness November 1, 15 2010

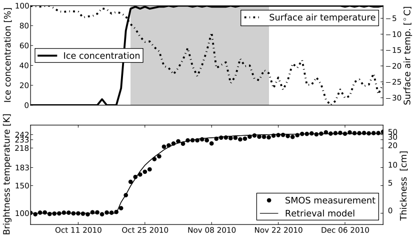


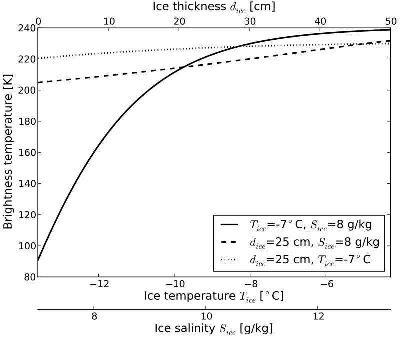
AMSR-E ice concentration November 1, 15 2010

Arctic freeze-up October to December 2010

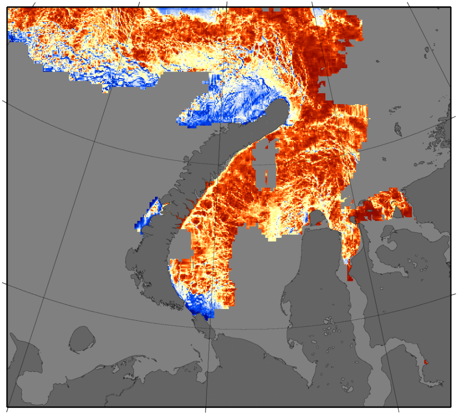


SMOS ice thickness November 1, 15, 2010

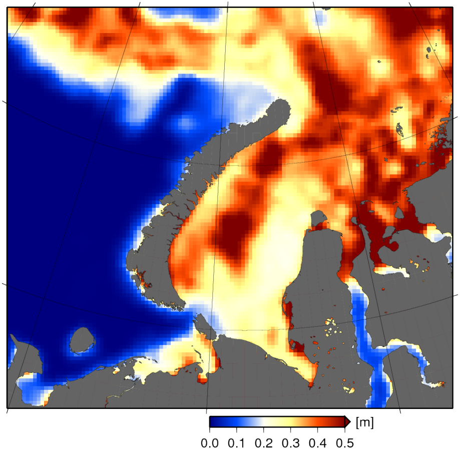




Validation with MODIS IR thickness - Kara Sea



MODIS ice thickness derived from ice surface temperature and heat flux estimates

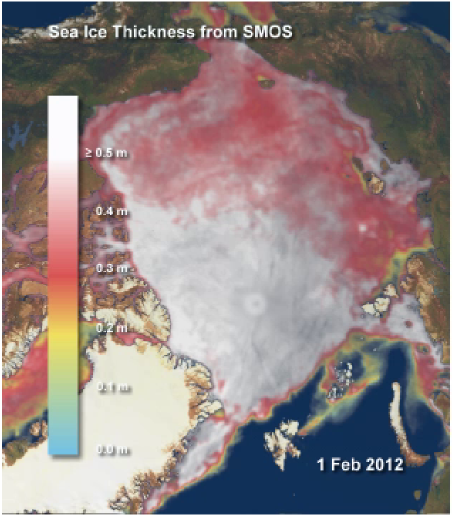


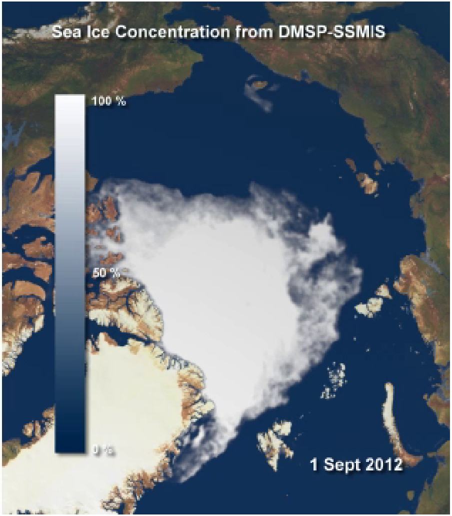
SMOS ice thickness, 26 Dec 2010

- RMSE: 10 cm; bias: -2 cm
  pixel-by-pixel correlation: $R^2 = 0.5$

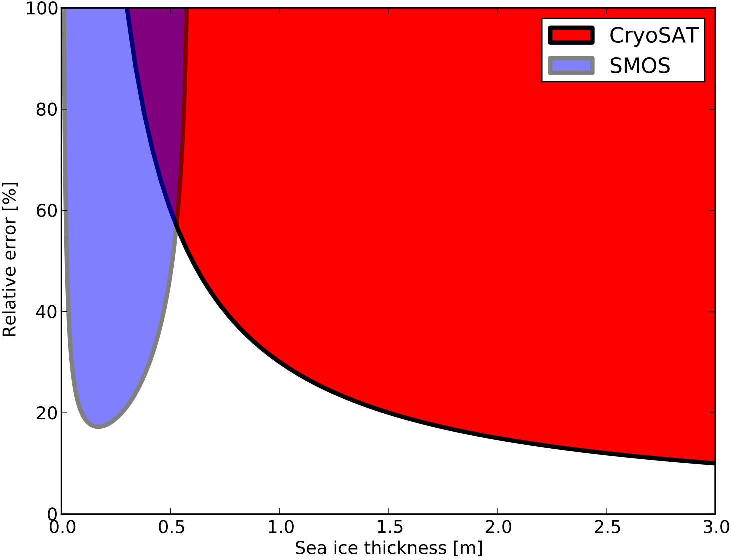
MODIS ice thickness provided by M. Mäkynen (FMI)

Sea Ice Thickness from SMOS





Complementarity of SMOS and CryoSat sea ice thickness retrieval



Modified after Kaleschke et al.(2010)

Summary and conclusions

- Sea ice thickness observations are urgently required
- Clear correlation between SMOS brightness temperature and sea ice thickness
- Causality is demonstrated through sensitivity analysis based on a physical emissivity model
- SMOS can be used to retrieve sea ice thickness up to half a meter with 20% uncertainty under ideal cold conditions
- Uncertainties due to changes in temperature, salinity, snow depth and ice concentration
- Preliminary results show interannual ice thickness variability
- SMOS complements altimetric thickness measurements in the thin ice range

Kaleschke, L., X. Tian-Kunze, N. Maaß, M. Mäkynen, and M. Drusch (2012), *Sea ice thickness retrieval from SMOS brightness temperatures during the Arctic freeze-up period*, Geophys. Res. Lett.
Kaleschke, L., Maaß, N., Haas, C., Hendricks, S., Heygster, G., and Tonboe, R. T. (2010): *A sea-ice thickness retrieval model for 1.4 GHz radiometry and application to airborne measurements over low salinity sea-ice*, The Cryosphere

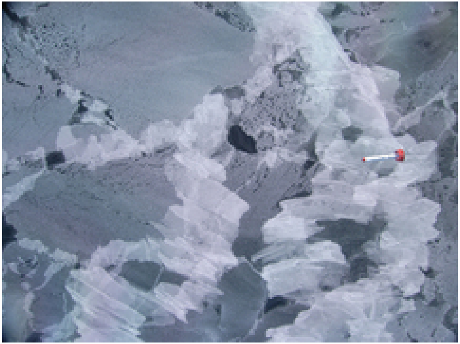
Thank you for your attention!

smosice
support to science element

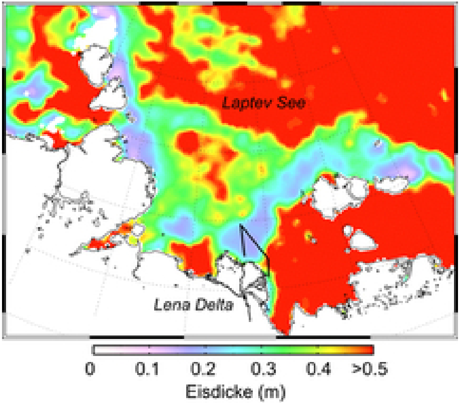
Acknowledgements

- University of Hamburg: **Xiangshan Tian-Kunze, Nina Maaß**, Stefan Kern, Anja Rösel, Johannes Lohse, Sebastian Bathiany, Pavan Siligam, David Bröhan, Alexander Beitsch, Amelie Tetzlaff, Meike Demgen, Lisa Schneider, ...
- University of Bremen: Georg Heygster, Marcus Huntemann, Huanhuan Wang, Peter Mills, ...
- FMI: Marko Mäkynen, ...
- DMI: Rasmus Tonboe, ...
- AWI: Stefan Hendricks, Thomas Krumpen, ...
- University of Alberta: Christian Haas, ...
- University of Trier: Günther Heinemann, Sascha Wilmes, Susanne Adams, ...
- NERSC: Laurent Bertino, ...
- ESA: Matthias Drusch, Tania Casal, Susanne Mecklenburg, ...
- Planetary Visions: Philip Eales, Tim Wilkinson, ...

More validation: Transdrift 2012

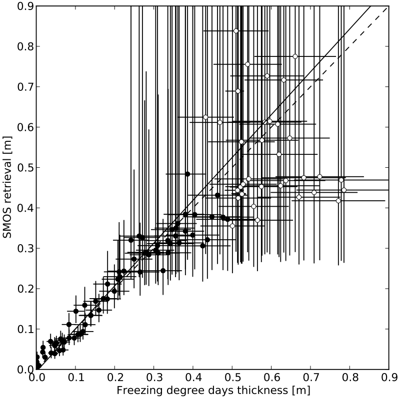


EM-Bird over thin ice (Nilas)



- Extensive thin ice area have been encountered during the Transdrift campaign in April 2012
- Data still not available due to Russian toll regulations

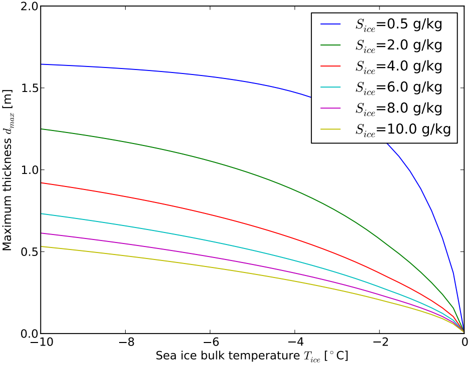
Retrieval uncertainty under ideal conditions



- $R^2 = 0.95$ for $d < 0.5$m
- Uncertainty strongly increases for $d > 0.4$m

Thickness range [cm]	RMSE [cm]
0-10	2
10-30	4
30-40	5
40-50	12

Maximum retrievable ice thickness d_{max}



$$d_{\mathrm{max}} = -\frac{1}{\gamma} \ln\left(\frac{\delta}{T_1 - T_0}\right)$$

$T_0 \approx 100$ K, $T_1 \approx 245$K, $\delta \approx 2$K

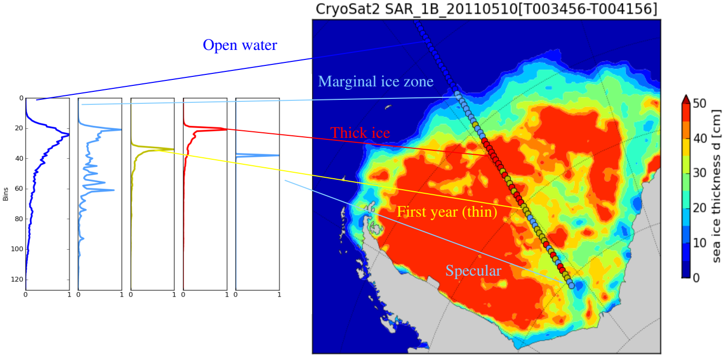
- 0.5 m for Arctic and Antarctic freeze-up conditions
- 1.5 m for Baltic
- Less than 0.1 m for melting conditions

Model for observed brightness temperature at 1.4 GHz

Main assumptions

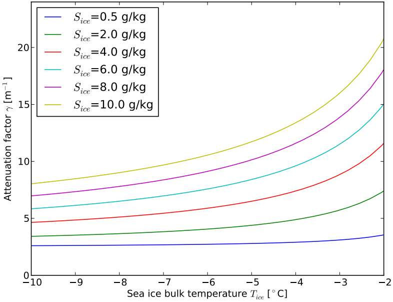
- Specular reflecting surface (Fresnel coefficients)
- Thermodynamic equilibrium (emissivity=1-reflectivity)
- Sufficient variability of sea ice thickness within the footprint (incoherent approach)
- Effective permittivity accounts for vertical temperature gradient
- Volume scattering (air bubbles, brine pockets) can be neglected
- Atmospheric attenuation can be neglected ($\tau < 0.01$)

SMOS and CryoSat2



- CryoSat2 classification based on max-min elevation and waveform
- Large potential for synergistic application of SMOS and CryoSat2

Estimation of retrieval parameters



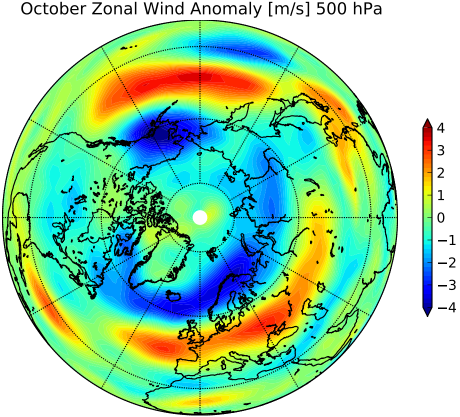
Different methods to obtain retrieval parameters:

1. Forward simulation $T_{\mathrm{obs}}(T_{\mathrm{ice}}, S_{\mathrm{ice}}) \rightarrow T_0, T_1, \gamma$
2. Calibration with ice thickness data (model or observation)

$$T_{\mathrm{obs}}(T_{\mathrm{ice}} = -7^\circ\mathrm{C}, S_{\mathrm{ice}} = 8 \text{ g/kg}) \rightarrow \gamma = 8.5 \text{ m}^{-1}$$

Assumption for retrieval: T_0, T_1, γ = constant

Atmospheric response to Summer sea ice loss



Atmospheric GCM forced by present day ocean and sea ice conditions (reference); September and October sea ice removed (experiment).

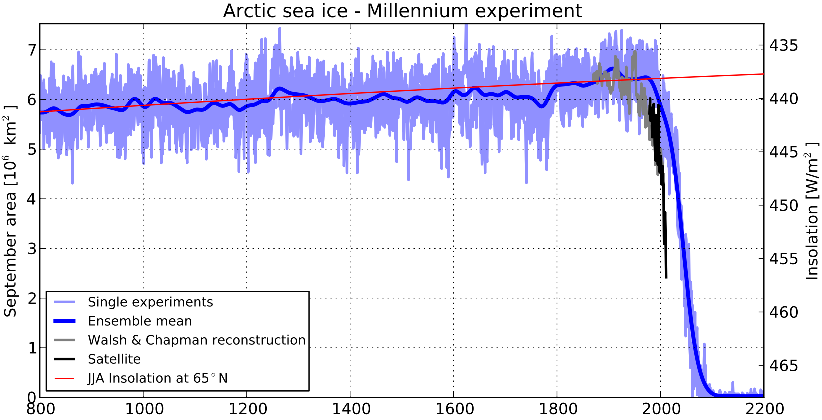
- Lower tropospheric temperature increase largely limited to the high latitudes
- Substantial change of mid-latitude zonal wind

Confirmation of earlier results (e.g. Newson, 1973).

Results of University of Hamburg Earth-System-Model Planet-Simulator at T42 resolution; 10 year simulation.

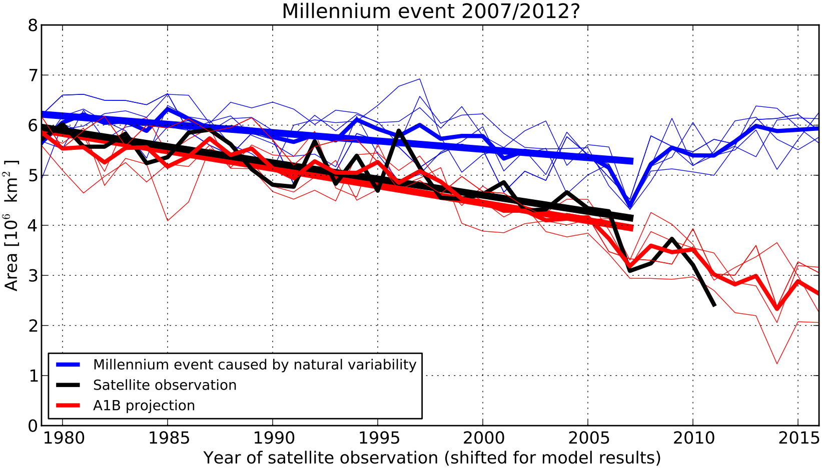
Kaleschke (2012, unpublished)

Motivation



Based on data of Jungclaus et al (2010).

Motivation



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