How much sea ice is produced in the Laptev Sea of the Siberian Arctic?

G. Heinemann[1], S. Willmes[1], L. Ebner[1], S. Adams[1], M. Bauer[1], D. Schröder[2], R. Timmermann[3]

[1]University of Trier, Fac. of Geography / Geosciences, Dept. of Environmental Meteorology, Trier, Germany
[2]University College London, Centre for Polar Observation and Modelling - Pearson Building, London, United Kingdom
[3] Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany
Contact: heinemann@uni-trier.de

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1. Motivation

Arctic flaw polynyas are considered to be highly productive areas for the formation of sea ice throughout the winter season. Particularly the polynya system in the Laptev Sea area of the Siberian Arctic (Fig.1) is known to contribute to considerably to the total Arctic ice budget. However, estimates of sea ice production in the Laptev Sea polynyas are arguable since high resolution and high quality atmospheric data is not available for that area. Previous estimations of ice production rely on global reanalyses as atmospheric forcing, such as NCEP with about 200km horizontal resolution, which is too coarse to take polynyas into account.

2. Data sets

We study ice formation in the Laptev polynya using different data sets:

A) Simulations using the limited area atmospheric model COSMO (Schröder et al. 2011) with 5km resolution

B) MODIS thermal infrared data (1km)

C) Passive microwave satellite data (SMMR, SSM/I, 25km and AMSR-E, 6km) (Willmes et al. 2011)

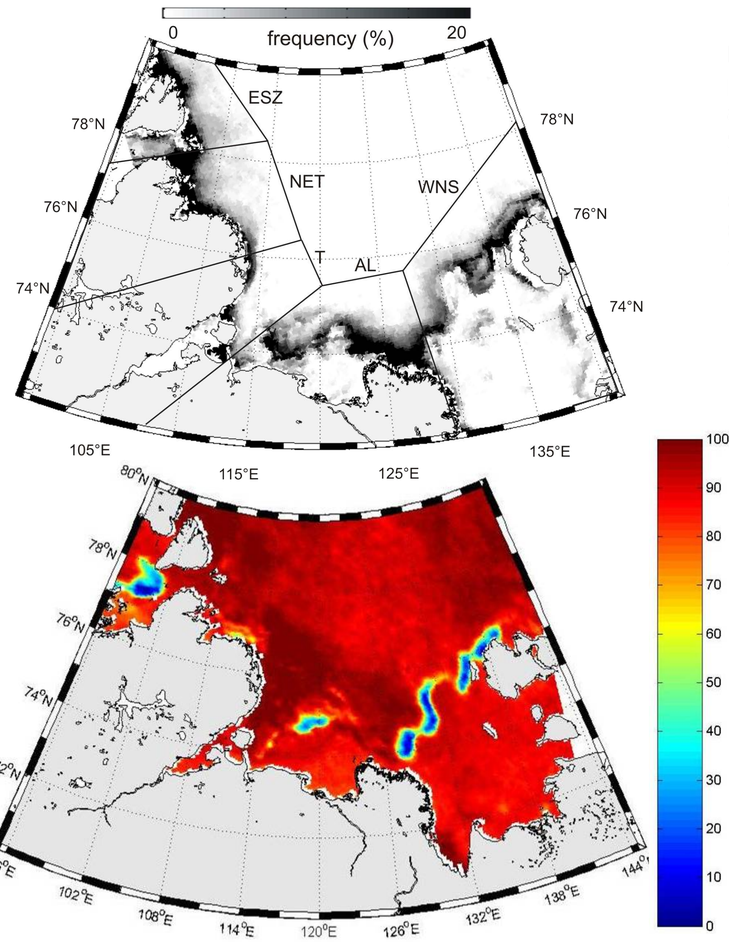

Fig.1: Map of the Laptev Sea showing polynya frequency (Nov-Apr, 2002-2008) and the polynya sub-areas of the East Severnaya Zemlya (ESZ), Northeastern Taimyr (NET), Taimyr (T), Anabar-Lena (AL) and the Western New Siberian (WNS) polynyas (from Willmes et al. 2011).

Fig.2: Sea ice coverage for 30 April 2008 (AMSR-E data) showing a large polynya in the eastern Laptev Sea.

3. Methods

The surface energy balance equation is the basis of the estimation of sea ice production in polynyas (Fig.3):

$$Q_0 - H_0 - E_0 = B_0$$

Q_0: net radiation
H_0: sensible heat flux
E_0: latent heat flux
B_0: soil heat flux

In the case of the water being at the freezing point, B_0 corresponds to ice production. The different data sets require different methods for computing the terms of the left side.

A) COSMO simulations yield net radiation and turbulent heat fluxes directly. For sea ice coverage, AMSR-E data is used. Polynya areas are defined by a 70% threshold (see Fig.2), open water and 10cm thin ice is assumed.

B) MODIS data yield the surface temperature as the signal. Atmospheric data are needed to compute the energy balance terms and thin ice thickness via parameterizations of turbulent fluxes and incoming longwave radiation. We use a modified approach of Yu and Lindsay (2003), and NCEP, GME (global model of the German Meteorological Service) and COSMO data (only for thin ice thickness <20cm, Fig.4).

C) Microwave satellite data yield only sea ice concentration. We use a prescribed thin ice thickness distribution (climatology from MODIS, Fig.5) together with NCEP reanalyses.

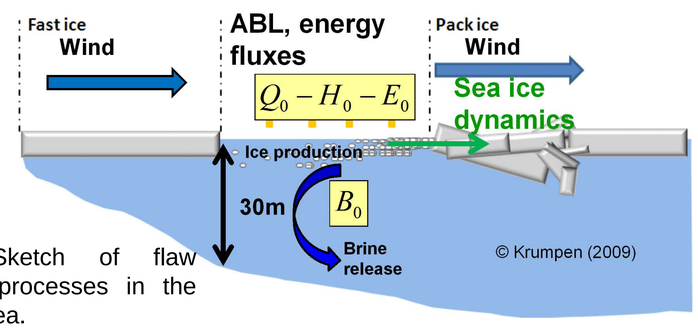

Fig.3: Sketch of flaw polynya processes in the Laptev Sea.

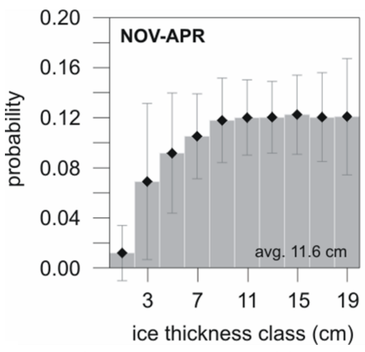

Fig.5: MODIS thin ice statistics for 59 Laptev polynya cases using NCEP data (from Willmes et al. 2011).

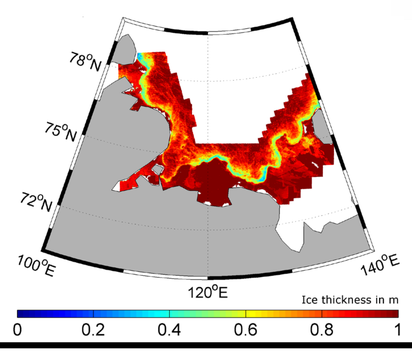

Fig.4: MODIS thin ice thickness for April 2008 using NCEP data.

4. Results

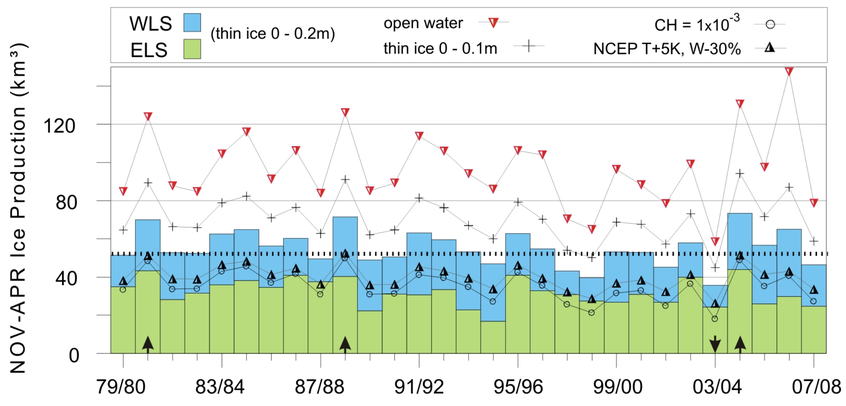

Fig.6: Microwave satellite data-based ice production (1979-2008) in the Laptev Sea polynya areas (eastern Laptev Sea (ELS, green bars, western Laptev Sea (WLS, blue bars)). Lines with symbols indicate sensitivity studies (open-water, a limit of 0.1m for thin ice thickness, reduced heat transfer coefficient, and with modified NCEP data. Black arrows mark years with significant deviation from the long-term average (from Willmes et al. 2011).

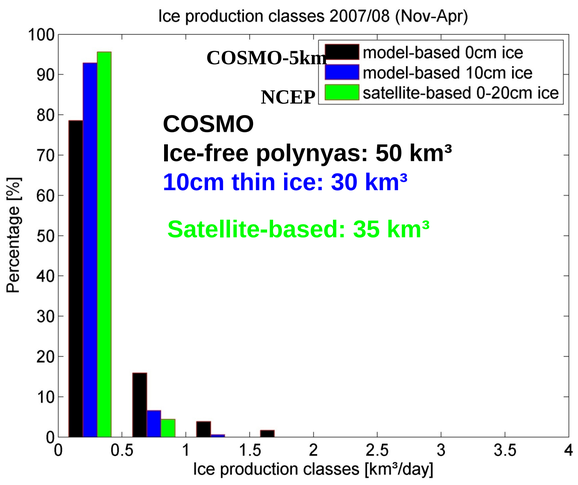

Fig.7: COSMO model-based ice production (2007/08) in the Laptev Sea polynya areas for different ice production classes. Black bars: open water polynya, blue bars: polynya with 10cm thin ice, green bars: microwave satellite data-based ice production .

Net annual ice volume production

Laptev Sea:

NAOSIM, Kohnemann (2010): 780 km³ ±180 km³ (1990–2008)
Dmitrenko et al. (2009): 1000 ±500 km³ (1960–1990)
→ 25-30% of annual ice export trough Fram Strait (3000 km³)

Laptev polynyas:

Observation-based studies Dethleff et al. (1998): 258 km³ (only 1990/91)
satellite-based studies Willmes et al. (2011): 55 ±15 km³ (1979–2008), Tamura and Ohshima (2011): 152 ±43 km³ (1992–2007)
COSMO-based study: Ice-free 50 (123) km³, 10cm thin ice 30 (73) km³ for 2008 (2009)

- The model-based estimation of ice production is sensitive to the assumption of thin ice distribution in the polynya.
- Satellite-based estimations are sensitive to the thin ice retrieval, but also to the parameterization of surface energy terms and the driving atmospheric data
- our results (satellite and model) show much smaller ice production for the Laptev polynyas compared to other studies

References

Dethleff D., Loewe P. and Kleine E. (1998) The Laptev Sea flaw lead - detailed investigations on ice formation and export during 1991/1992 winter season. Cold Regions Science and Technology 27, 225-243.

Dmitrenko I.A., Kirillov, S.A., Tremblay, B., Bauch, D. and Willmes, S. (2009) Sea-ice production over the Laptev Sea shelf inferred from historical summer-to winter hydrographic observations of 1960s-1990s. Geophysical Research Letters, 36: pp. L13605.

Kohnemann, S. (2010) Investigation of the Arctic sea ice budget using the regional sea ice/ocean model NAOSIM. BSc thesis, Environmental Meteorology, University of Trier, 55 pp.

Schröder, D., G. Heinemann, and S. Willmes (2011) Implementation of a thermodynamic sea ice module in the NWP model COSMO and its impact on simulations for the Laptev Sea area in the Siberian Arctic. Polar Research 30, 6334.

Tamura, T., and K. I. Ohshima (2011) Mapping of sea ice production in the Arctic coastal polynyas, J. Geophys. Res. 116, C07030.

Willmes, S., S. Adams, D. Schroeder and G. Heinemann (2011) Spatiotemporal variability of sea-ice coverage, polynya dynamics and ice production in the Laptev Sea between 1979 and 2008. Polar Research 30, 5971.

Yu, Y. and Lindsay, R.W. (2003) Comparison of thin ice thickness distributions derived from RADARSAT Geophysical Processor System and advanced very high resolution radiometer data sets, Journal of Geophysical Research, 108(C12).

Acknowledgements

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