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The observation of the thin-ice thickness distribution within the Laptev Sea polynya using MODIS data

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1. Motivation

- Laptev Sea = Ice factory
- Variables essential for the ice-production calculation:
  - Polynya area
  - Thin-ice thickness distribution
  - Atmospheric Variables
- Thin-ice layer = Insulation layer that effectively reduces the heat loss to the atmosphere
- Remote sensing data is suitable to derive the thin-ice thickness distribution, however, the spatial resolution issue has to be taken into account
- We use high-resolution MODIS data to derive the thin-ice thickness distribution within a polynya

2. Thermal thin ice thickness retrieval

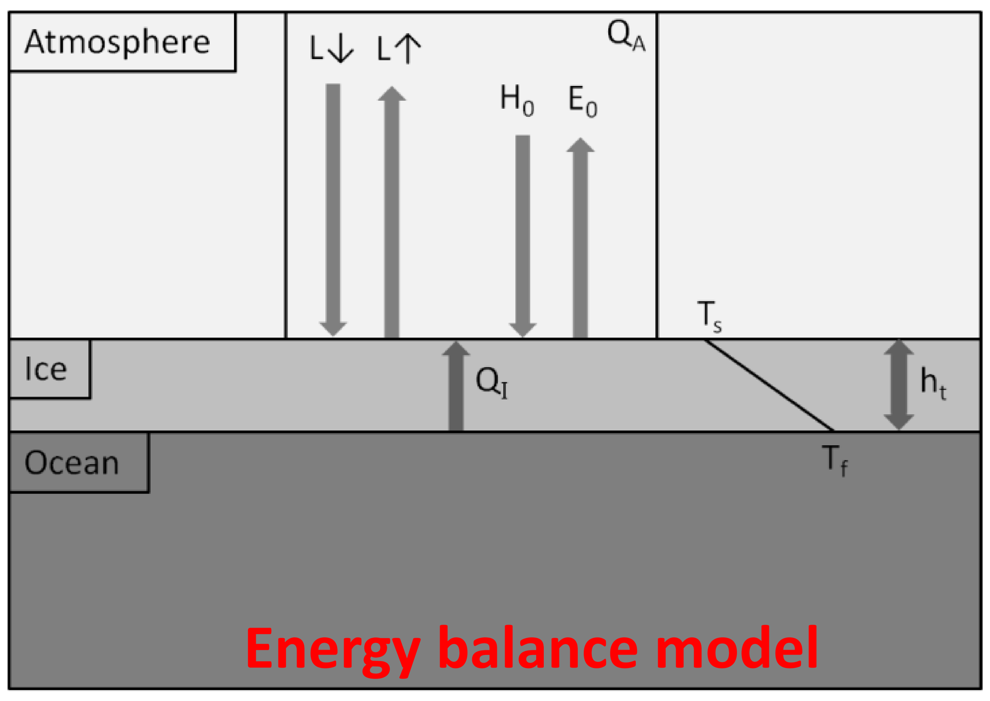


Figure 1: Thin-ice thickness retrieval scheme. L↓ and L↑ are the incoming and outgoing long-wave radiation components, H_0 and E_0 are the turbulent fluxes, Q_A is the net energy flux to the atmosphere, Q_I is the conductive heat flux through the ice, T_s is the ice-surface temperature, T_f is the freezing temperature of sea water and h_t is the ice thickness.

- Thin-ice thickness retrieval is based on the relation between ice-surface temperature and thin-ice thickness
- Calculation of TIT following Yu and Lindsay, 2003)
- Atmospheric heat flux to the atmosphere Q_A equals the conductive heat flux through the ice Q_I (Fig. 1)
- Modification of the algorithm at two calculation steps:

(1) Calculation of the turbulent heat fluxes (iterative bulk approach based on Launiainen & Vihma, 1990 instead of simple bulk equations)
(2) Calculation of the atmospheric emission coefficient required for the determination of the incoming long-wave radiation (newer improved parameterization following Jin et al., 2006)

3. Example of the MODIS thin-ice thickness

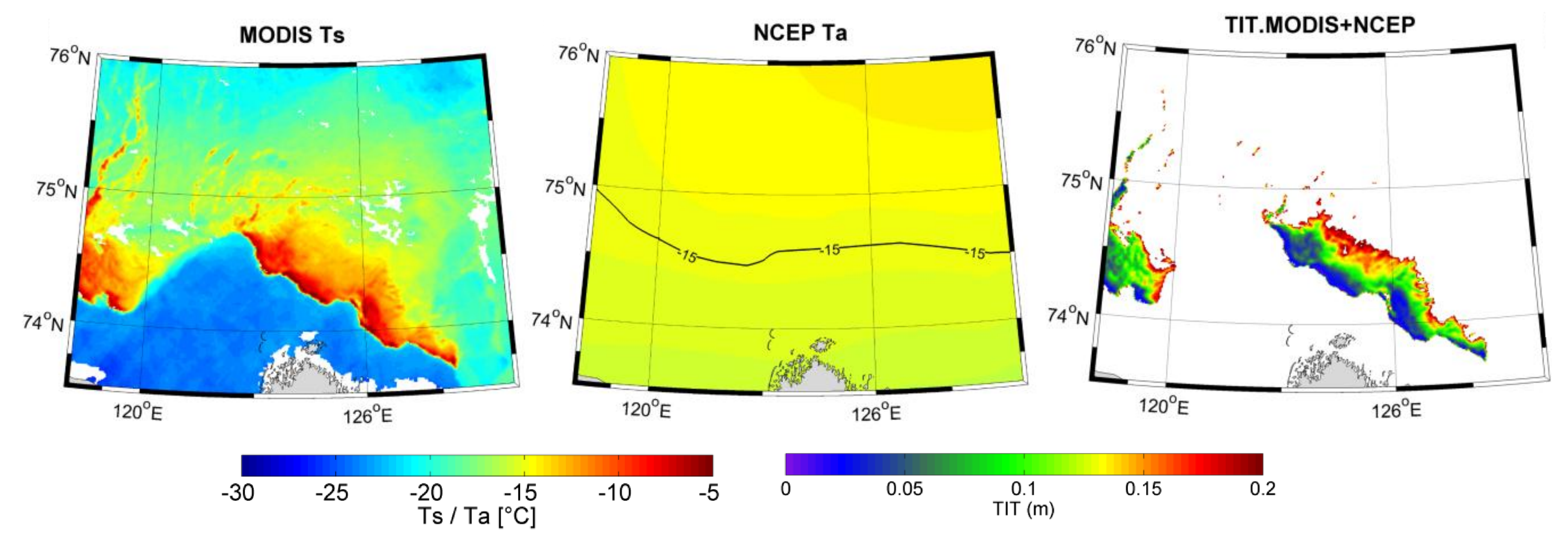
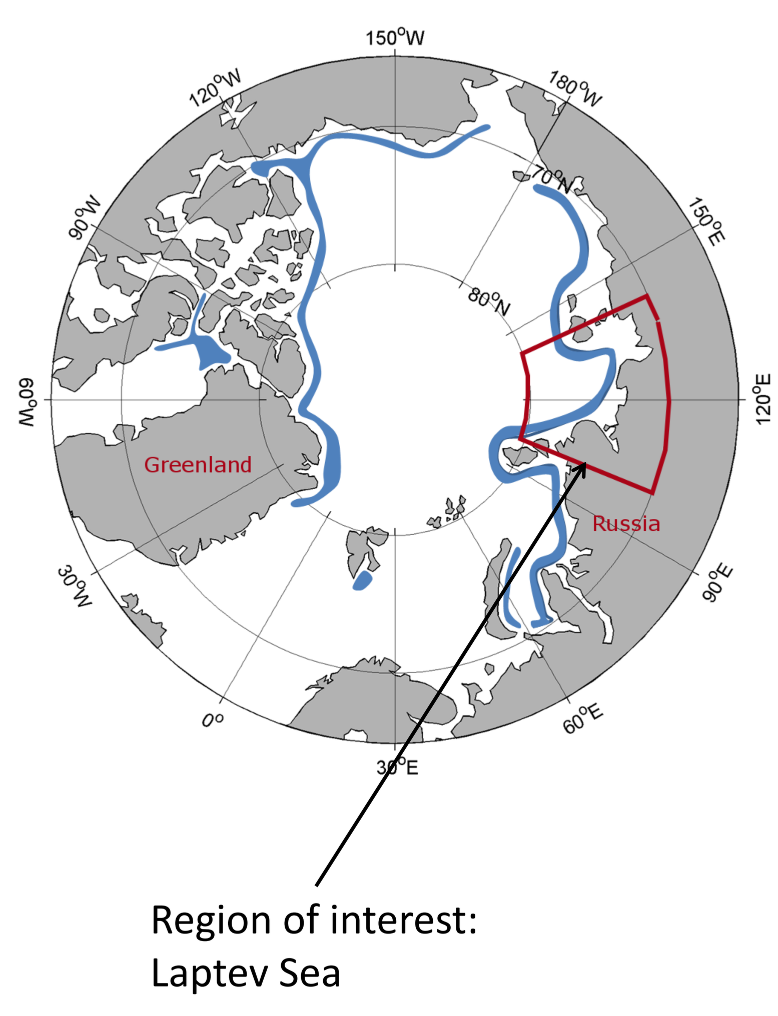


Figure 2: MODIS Ts from 6 January 2009 0205 UTC; corresponding NCEP Ta from 6 January 2009 0000 UTC; ice-thickness distribution as calculated with MODIS Ts and NCEP atmospheric variables (TIT.MODIS+NCEP).



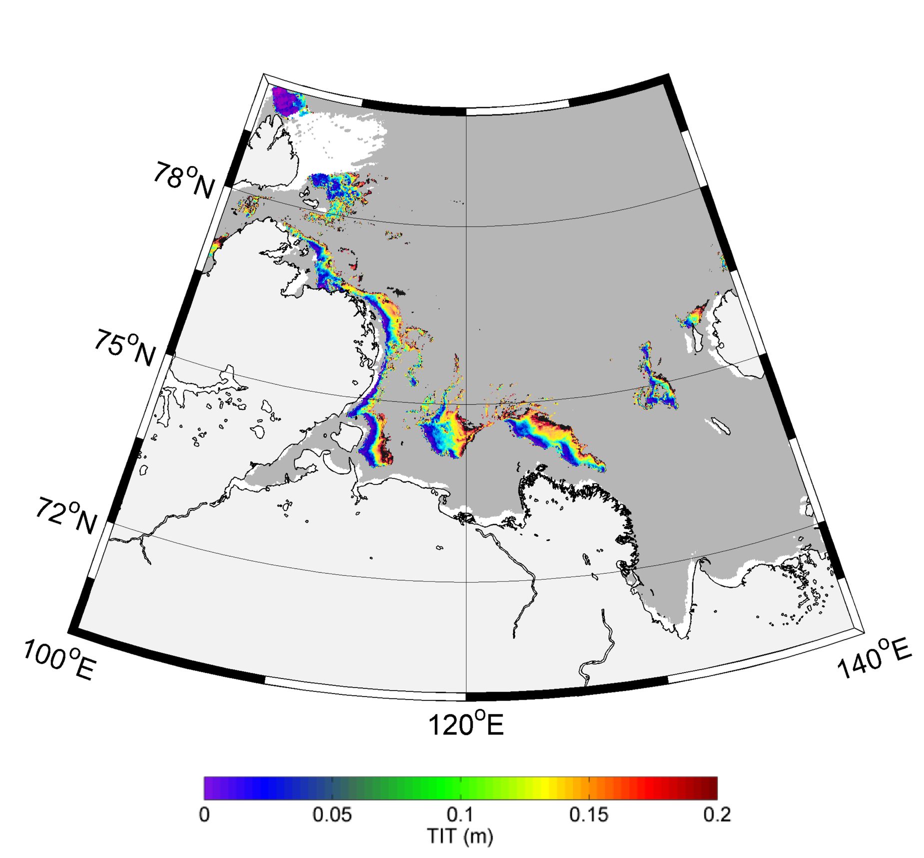


Figure 3: Daily MODIS TIT map from 6 January 2009 (gray = thick ice).

- Daily maps are assimilated into the sea ice model (see Section 5)

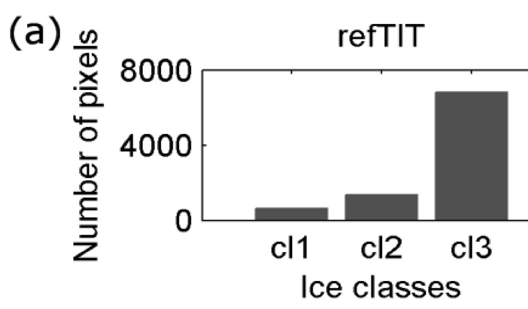
4. Sensitivity analysis of the MODIS thin-ice thicknesses

(a)	MODIS	NCEP
Ice-surface temp.	±1.6 °C	
2-m air temp.		±4.5 °C
10-m wind speed		±1.3 m s^{-1}
Relative humidity		±20 %

Tables: (a) Uncertainties of the input variables for the calculation of thin-ice thicknesses. Values from Hall et al. (2004), Ernsdorf et al. (2011), Renfrew et al. (2002). (b) Results of the Monte Carlo error estimation for winter 2007/08 and 2008/09.

(b)	Winter 2007/08	Winter 2008/09	Mean of both winters
Ice class (m)	$TIT_{MODIS+NCEP}$ (cm)	$TIT_{MODIS+NCEP}$ (cm)	$TIT_{MODIS+NCEP}$ (cm)
0.00 - 0.05	±1.0	±1.0	±1.0
0.05 - 0.10	±2.0	±2.2	±2.1
0.10 - 0.20	±5.2	±5.3	±5.3
0.20 - 0.30	±16.8	±12.0	±14.4
0.30 - 0.40	±34.2	±28.4	±31.3
0.40 - 0.50	±36.7	±60.2	±48.5
mean up to 0.20	**±4.7**	**±4.6**	**±4.7**
mean up to 0.50	**±26.1**	**±36.0**	**±31.1**

- T_s and 2-m air temperature (T_a) strongly influence the calculation of the ice thickness (not shown)
- Underestimation of T_a = strong underestimation of TIT; overestimation of T_a = moderate overestimation of TIT
- Uncertainties in the atmospheric variables have a smaller impact on very thin ice than on thicker ice
- The atmospheric data (T_a) have a strong impact on the quality of the retrieved ice thickness (Fig. 4)



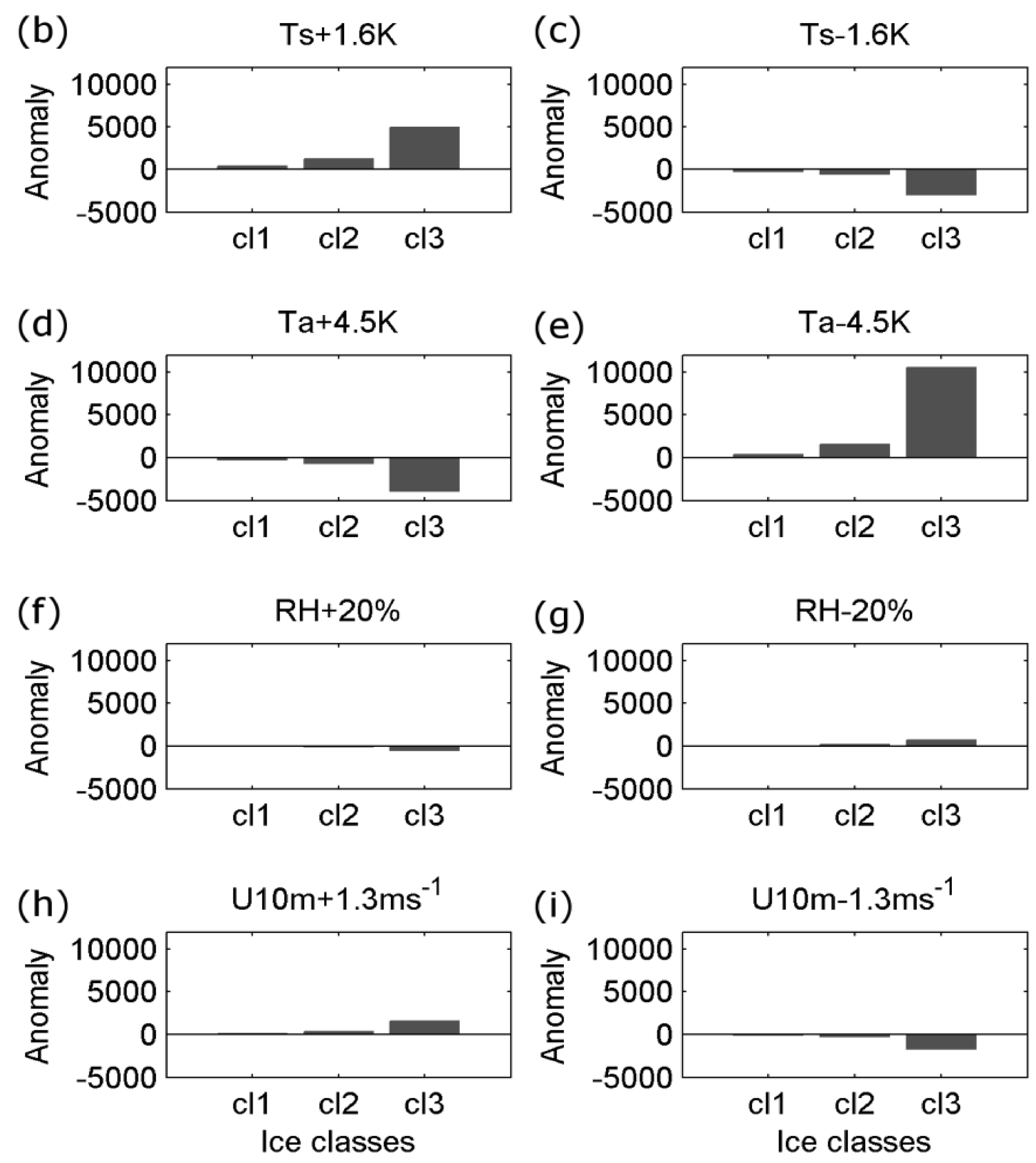
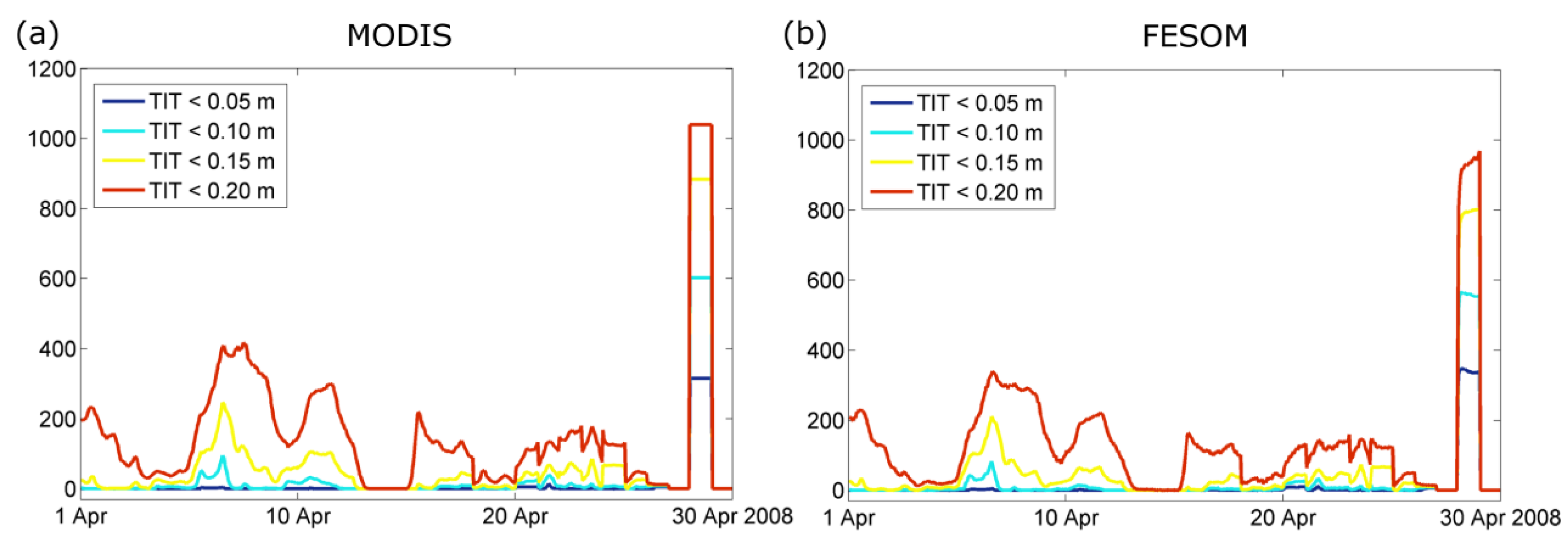


Figure 4: (a) Averaged sum of reference thin-ice pixels for ice classes cl1 0 – 0.05 m, cl2 0.05 – 0.1 m and cl3 0.1 – 0.2 m. (b)-(i) Anomaly to reference ice thickness for the input variables with their minimum and maximum uncertainty.

5. Combined remote sensing – sea ice model approach



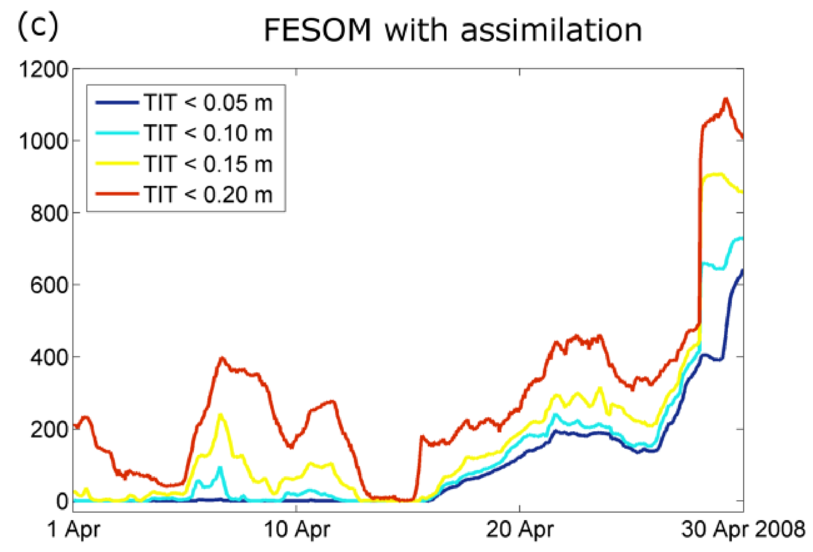


Figure 5: Number of grid points for different ice-thickness classes for April 2008. (a) MODIS thin-ice thickness data. The data is interpolated to FESOM's 5-km grid. (b) Simulations of FESOM's independent model run. Grid cells with available MODIS data are used only. (c) Simulations of FESOM's assimilated model run. All grid cells are shown.

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