Implementation of sea-ice topography dependent drag coefficients in a coupled sea-ice–ocean model.

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Introduction

Ice pack motion in the Arctic Ocean is subject to a delicate force balance. The main driver is the wind. In the momentum balance equation for sea ice, the intensity of the air-ice interaction is determined by the drag coefficients. These drag coefficients should take into account the sea ice surface characteristics. Because of the spatial and temporal inhomogeneities of the sea ice surface, observed drag coefficients have spatial and temporal variations. Still many state-of-the-art coupled atmosphere-ice-ocean numerical models use constant drag coefficients and neglect the dependence of the atmospheric drag coefficients on the surface topography of the ice.

In this study, we implement a parameterization for the atmospheric drag coefficients that accounts for the distribution of ridges in the MITgcm [Marshall et al., 1997] and compare the effects on sea-ice concentration, sea-ice thickness, sea-ice drift and mixed layer depth to a case with a constant drag.

Model setup

The region of the simulation comprehends the Arctic Ocean, the Nordic Seas and the North Atlantic. The resolution is ¼ of degree, the model has a ocean–sea-ice coupling and it is forced with atmospheric reanalysis data. After a spin up run from 1948 to 1978 using CORE2 forcing, we run the simulations for the period 1979-2010 using NCEP data. The runs presented in this work are:

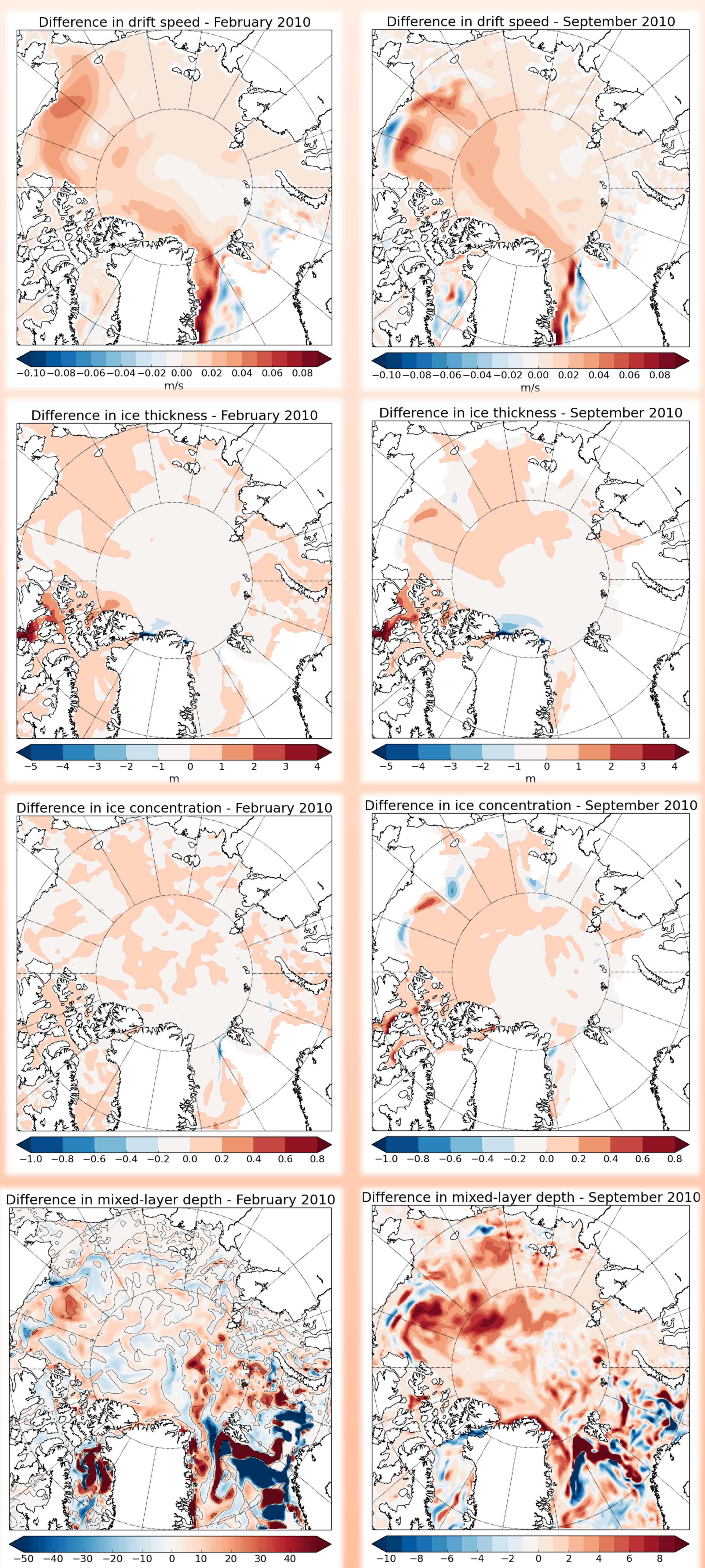
- Run1 (or Standard run): constant atmospheric drag coefficients $c_a = 1.2 \times 10^{-3}$
- Run2: topography-dependent atmospheric drag coefficients

In Run2 we introduce a deformation energy R following the approach by [Steiner et al., 1999], whose temporal evolution is described by the following equation:

$$\frac{\partial R}{\partial t} = -\nabla \cdot (\mathbf{u}R) + E_{\mathrm{int}} + m_{\mathrm{R}} R \tilde{M}_{\mathrm{h}}$$

$\tilde{M}_{\mathrm{h}}$ = melt rate
m_{R} = proportionality factor
E_{int} = internal work

Effects of topography-dependent drag



Drag coefficients and ridge density

The atmospheric drag coefficients and the density of the ridge sails are directly calculated from the deformation energy R. In particular, given R, the atmospheric drags c_a are:

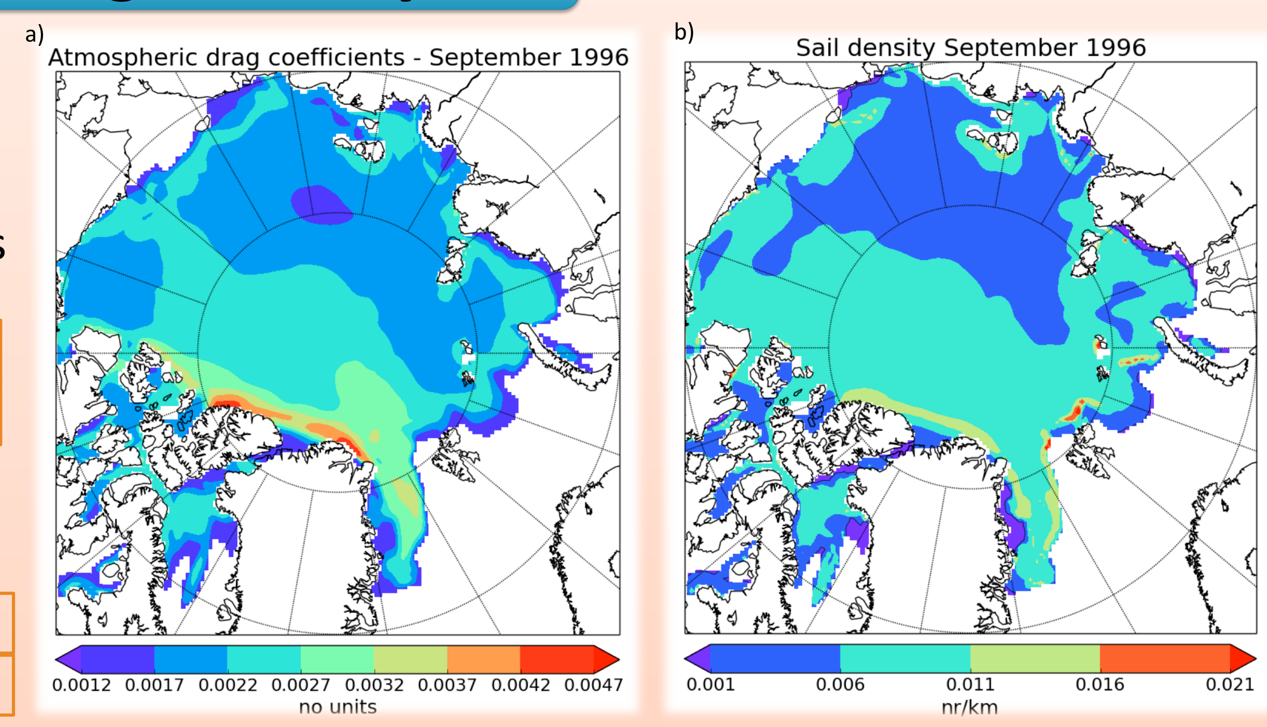
$$c_a = m_a R + b_a$$

$m_a = 1.94 \cdot 10^{-8}\ \mathrm{m^2/J}$
$b_a = 1.2 \cdot 10^{-3}$

And the sail density S_d:

$$S_d = \frac{1}{c_D}\sqrt{\frac{R}{h}}$$

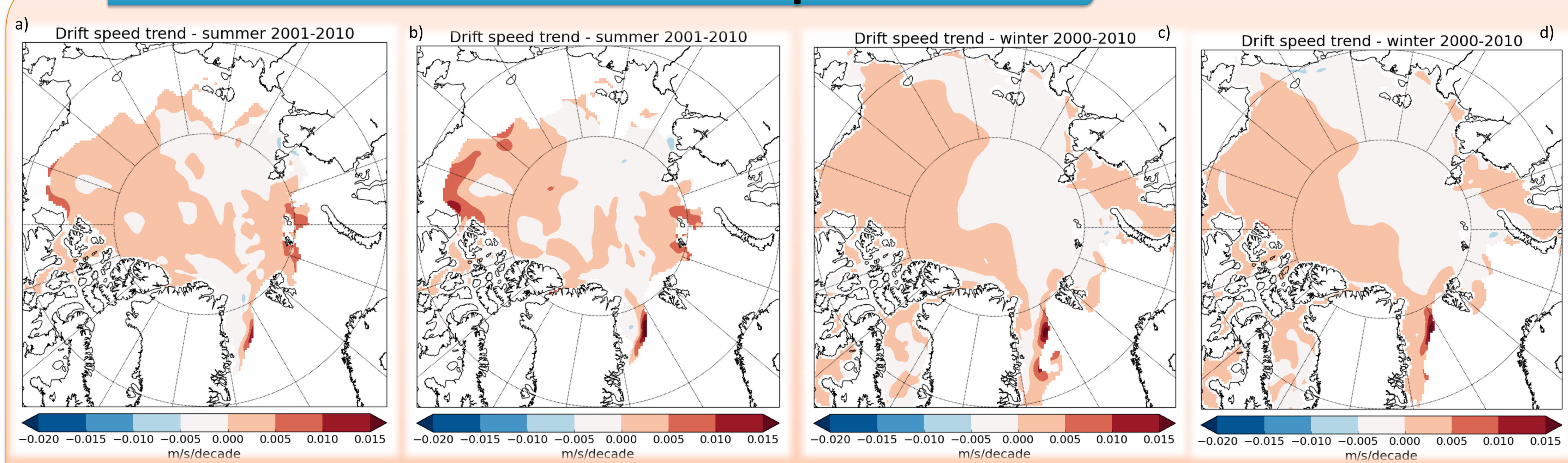
$c_D = 14 \cdot 10^3\ \mathrm{J^{1/2} m^{-1/2}}$
h = ice thickness



The atmospheric drag coefficients obtained with the model simulation have been compared with drag coefficients calculated from surface topography data using a parameterization well validated with turbulence measurements ([Garbrecht et al., 1999], [Garbrecht et al., 2002]). The maximum and minimum values of the atmospheric drag coefficients calculated on the basis of observed topography over different regions of the Arctic Ocean are listed in the table. Figure a) demonstrates the large variability of the modelled drag coefficients and a comparison with the values listed in the table shows that the range of variation is realistic with no unphysical values.

Region	c_a Max (10^{-3})	c_a Min (10^{-3})
Laptev sea	3.15	0.9
Central Arctic	2.66	0.86
North Greenland	5.59	1.02
Beaufort sea	2.08	0.99
Fram Strait	4.62	0.87

Trend in sea-ice drift speed



Following the approach by [Kwok et al., 2013] we calculated the trend in the sea-ice drift over the last decade (2001-2010). We present in the above figures the results for summer (June-September) and for winter (December-March) for the two runs: constant drag coefficients (a - c) and topography dependent drag coefficients (b - d).

CONCLUSION

- The atmospheric drag coefficients calculated with the model show a good agreement with drag coefficients calculated on the basis of observed topography;
- The run with topography-dependent drag coefficients shows an increase in drift speed in both winter and summer, mostly in the Fram Strait region and in the Beaufort Sea;
- Differences up to 5 m in ice thickness can be seen North of Greenland and a difference of up to 80% in ice concentration can be seen in the marginal ice zone in the Beaufort Sea in summer;
- The effect on the mixed layer depth is pronounced mostly in summer with differences of ±10 m: the possible reasons are the increase in sea-ice drift speed and the increase in the surface stress. The contribution of the two must be better investigated with further simulations;
- The trend in drift speed registered during the last decade is represented by both simulations but in the case of topography-dependent drags the trend is more pronounced in the marginal sea-ice zone and in the Fram Strait;

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