Role of variable form drag coefficients over sea ice for the ocean surface layer in polar regions

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Introduction

Image courtesy of Torge Martin.

Sea ice features a variety of obstacles to the flow of air and ocean near its surface:

- Sea surface roughness, or skin
- Edges from floes and melt ponds
- Ridges and keels in deformed ice

Broken ice and floeberg. Deformed ice. Level ice and deformed ice.

From Fig. 5, Kim et al, 2019 - https://doi.org/10.1016/j.rineng.2019.100036

=> Sea ice surface and bottom state impact the surface fluxes between the ocean and the atmosphere

Introduction : air-ice and ocean-ice fluxes

Bulk formulas

- Fluxes of momentum (tau), sensible heat (H), and latent heat (LE) in general circulation models are expressed through bulk-formulas:

$$\boldsymbol{\tau} = \rho C_d(z)U(z)[\cos\theta\mathbf{U}(z) + \sin\theta\mathbf{k}\times\mathbf{U}(z)],$$

$$H = \rho c_p C_H(z)(\theta_s - \theta_z)U(z),$$

$$\mathrm{LE} = \rho\gamma C_E(z)(q_s - q_z)U(z),$$

- The drag coefficients Cd are usually set constant over sea ice models
- Tsamados et al. (2014) introduced a method to estimate the drag coefficients over sea ice as a function of sea ice features
- The scheme decompose the drag coefficients in the sum of individual drag coefficients associated to the surface skin, floe edges, ice ridges, and melt ponds edges

Conceptual framework for variable drag coefficients over sea ice

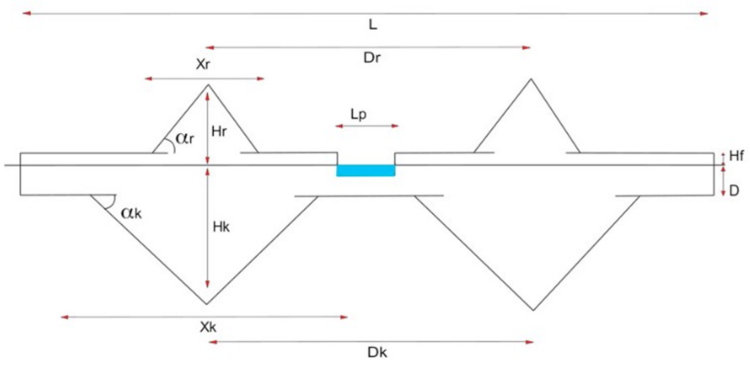
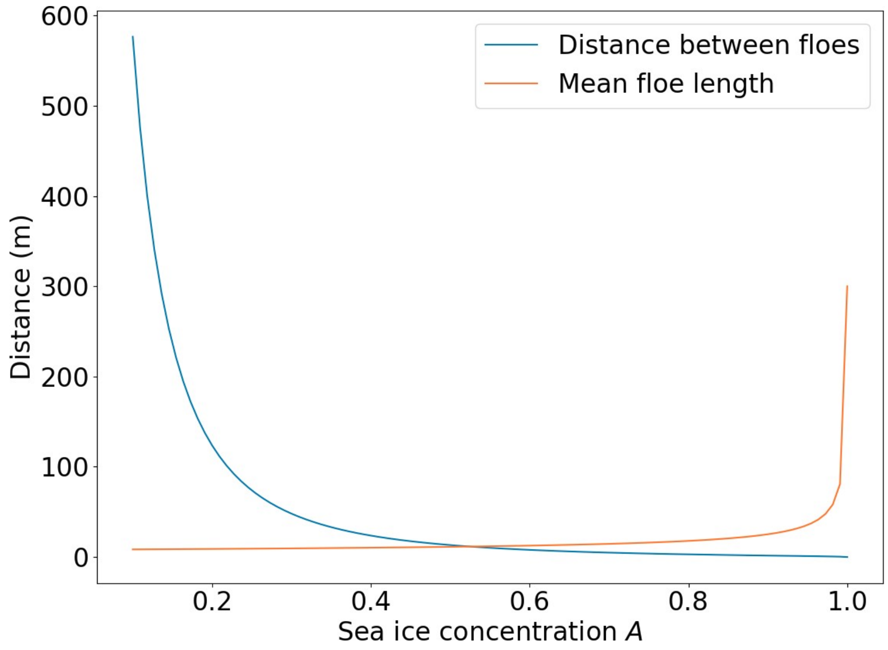


FIG. 1. Schematic representation of an idealized sea ice floe comprising a system of two triangular sails and keels and a single melt pond. The quantities that are needed to derive the ANDC and ONDC are shown: the floes size L, the freeboard H_f [Eq. (26)], the draft D, the pond size L_p, the distance between sails D_s, the distance between keels D_k, the sail and keel heights H_s and H_k, the slopes of the sail and keel α_r and α_k, and the bases of the sail and keel X_s and X_k.

From Tsamados et al (2014)

Introduction : contribution from ice floes

Floe size distribution is prescribed by Lupkes et al. (2012), as a function of the ice concentration



when A tends to 0:

- the distance between the floes tends toward infinity
- the mean floe length tends to a minimum value (here set to 8 m)
- Cd_ia and Cd_io tends toward 0

When A is not equal to zero:

- Cd_ia and Cd_io are made dependent to the distance between the floes, the freeboard height or the draft of the ice floes

Introduction : contribution from ridges and keels

The frequency of ridges and keels as well as their height are estimated from the concentration and volume of deformed ice, using an idealized sea ice floe

Deformed ice is calculated within the model from a tracer of level ice

Level ice is defined as the part of sea ice that has not undergone deformation (ridging or rafting)

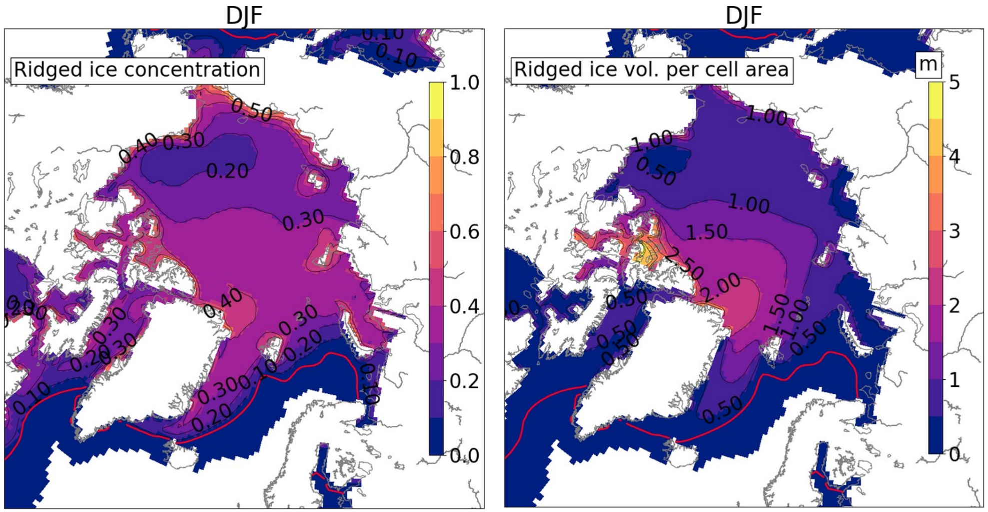


Fig: Mean concentration of deformed/ridged ice (left) and volume (right) in winter (December-January-February), from 1980-2019

$$a = a_{rdg} + a_{lvl}$$
$$v = v_{rdg} + v_{lvl}$$

The sum of deformed ice and level ice concentration (volume) is equal to the sea ice concentration (volume)

Introduction : melt ponds

We estimate the area covered by melt ponds using the so-called topographic scheme of Flocco and Feltham (2007)

Melt ponds are calculated using the Ice Thickness Distribution (ITD)

Melt water accumulates on thin ice first, and gradually expands over thicker ice

Mean melt pond length is given by Lupkes et al. (2012):

$$L_p = L_{p_{\min}} A_p + L_{p_{\max}} (1 - A_p)$$

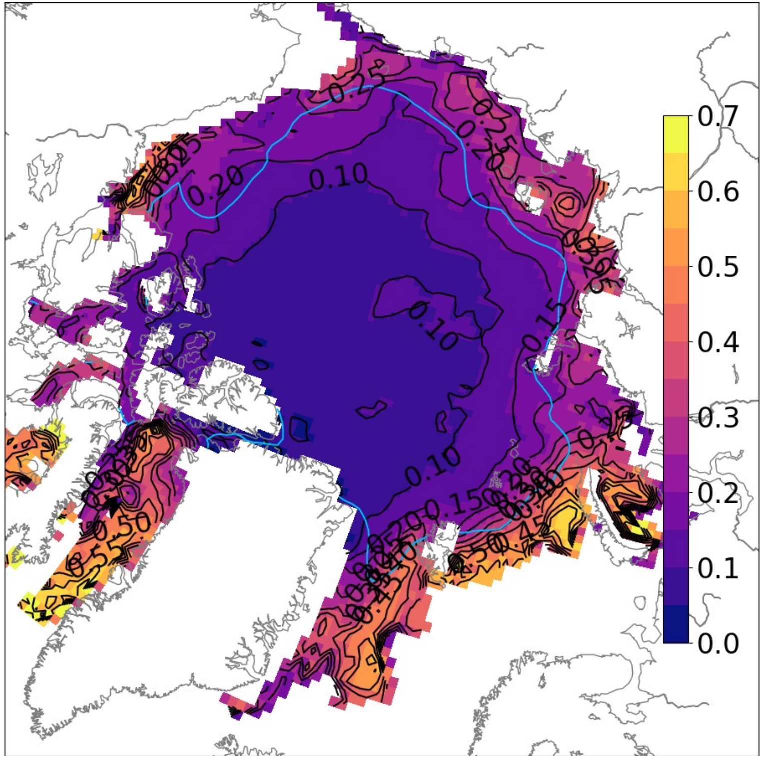


Fig: Mean melt pond area fraction of sea ice, in August 1980-2019, using variable drag coefficients

Methods : objectives and experimental setup

Objectives

In this presentation, we will look at:

- the representation of variable drag coefficients over sea ice
- the impact on the sea ice state
- the changes in heat fluxes and surface stress applied to the ocean surface
- the subsequent impact on the ocean surface

Methods

- configuration:
  - NEMO3.6 + LIM3 with ORCA1 family grid
  - prescribed atmosphere from JRA-55 (1958 to 2019)

- Simulations:
  - CST: constant default drag coefficients of LIM3 (1.4e-3 for air and 5.0e-3 for ocean)
  - DRG : variable drag coefficients given by Tsamados formalism

Variable neutral drag coefficients

- The total drag coefficients at the ocean-ice and atmosphere-ice interfaces are maximum in summer
- Floes edges contribute to a large part to the seasonal maximum in total drag coefficients
- Ice ridges and surface skin contribute to the total drag all-year round
- Melt ponds are effective in summer only, and are minor compared to the other form drag components

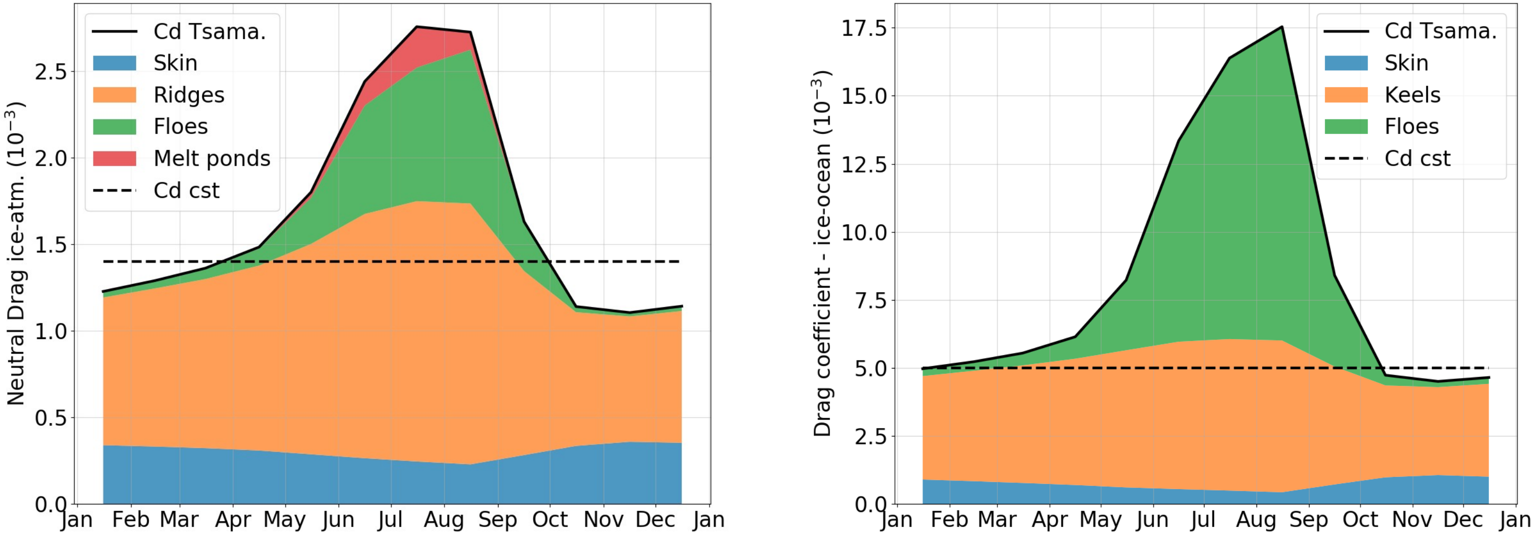


Figure: mean seasonal cycles of the form drag components in NH from 1980 to 2019, at the air-ice (left) and ocean-ice (right) interfaces

Variable neutral drag coefficients

- Surface skin contribution equalize the contribution from floe edges in central Arctic
- Melt pond contribution is small compared to the other form drag components
- Floe edges and ridges are important contributors, especially in Fram Strait and the Arctic Archipelago

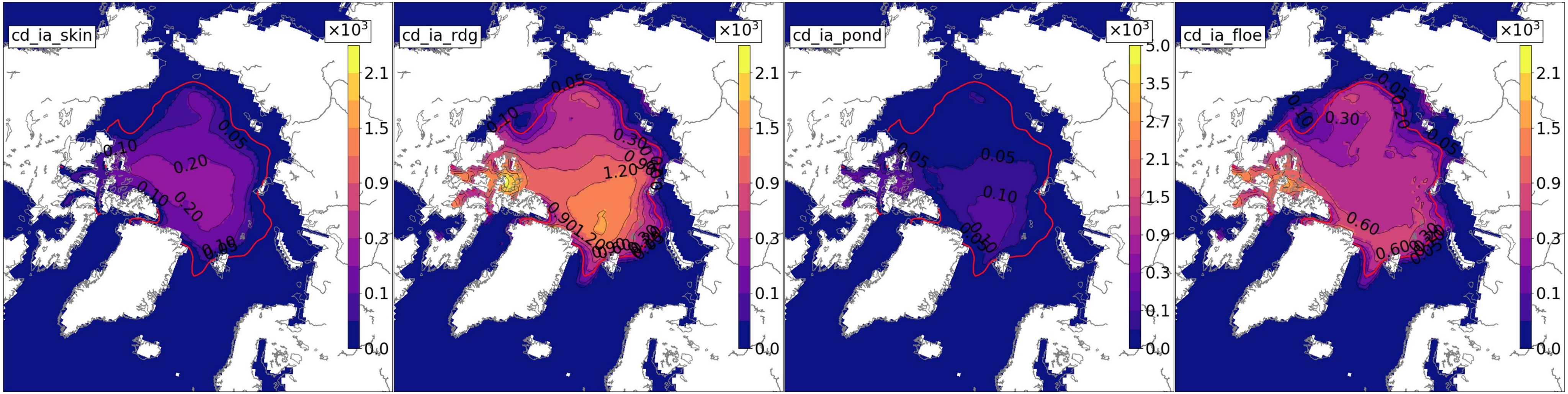
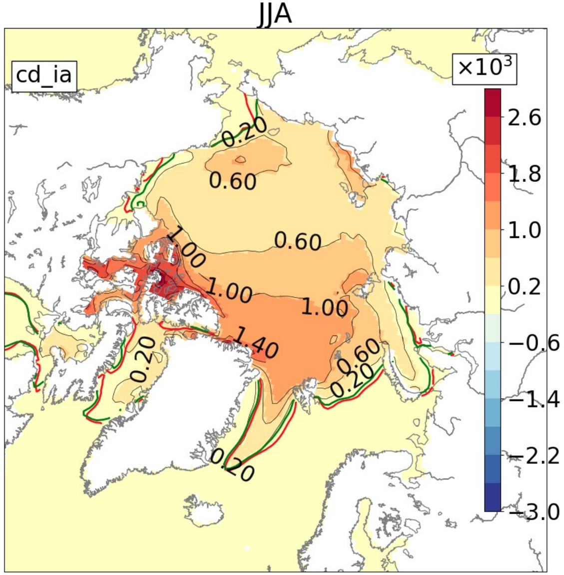


Figure: climatology of the form drag components at the air-ice interface from 1980 to 2019, from left to right: surface skin, ridges, melt ponds, and floe edges. Drag components are multiplied by the ice concentration.

Variable neutral drag coefficients

- In summer, the difference constant and variable drag coefficients double to triple near Fram Strait and in the Arctic Archipelago, at both the air-ice and ocean-ice interfaces
- The increases in total drag coefficients are less important in the pacific sector of the Arctic (Beaufort, Chukchi, East Siberian Seas)
- In winter, the differences between constant and variable drag coefficients are weaker, within [-0.2; 0.2]



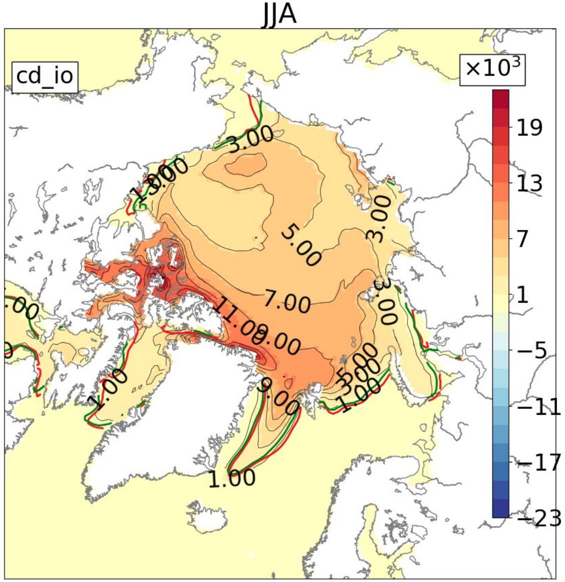


Figure: Difference between the total form drag and constant drag coefficients, at the air-ice (left) and ocean-ice (right) interfaces, averaged in summer from 1980 to 2019

Effect of the variable drag on the sea ice

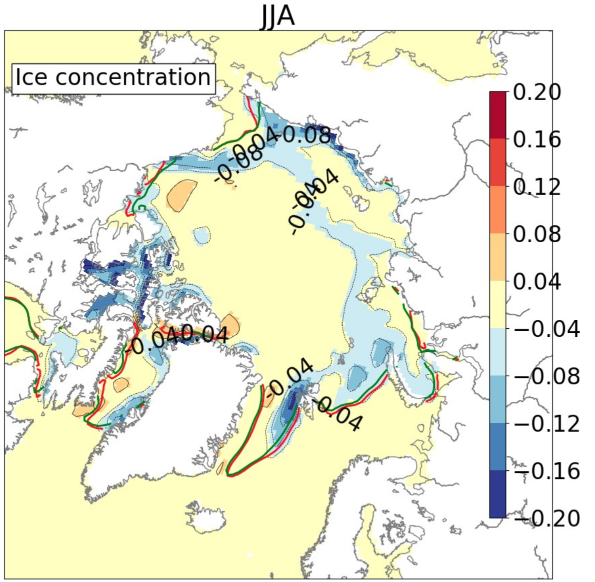


Fig: Difference of mean sea ice concentration between DRG and CST in summer

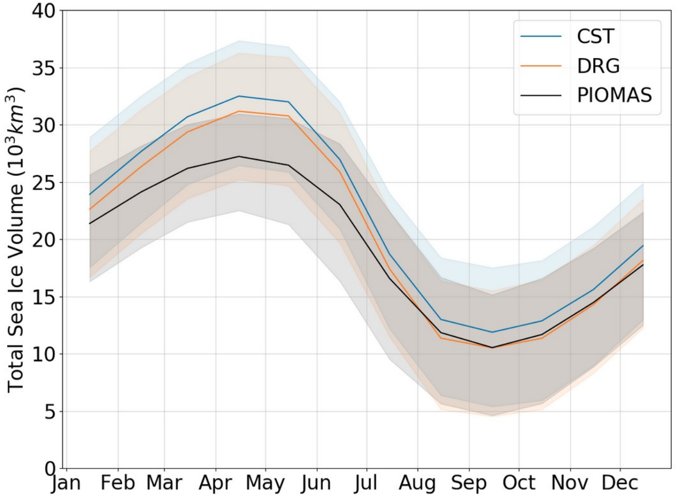


Fig: mean seasonal cycle of the total sea ice volume, in the Arctic

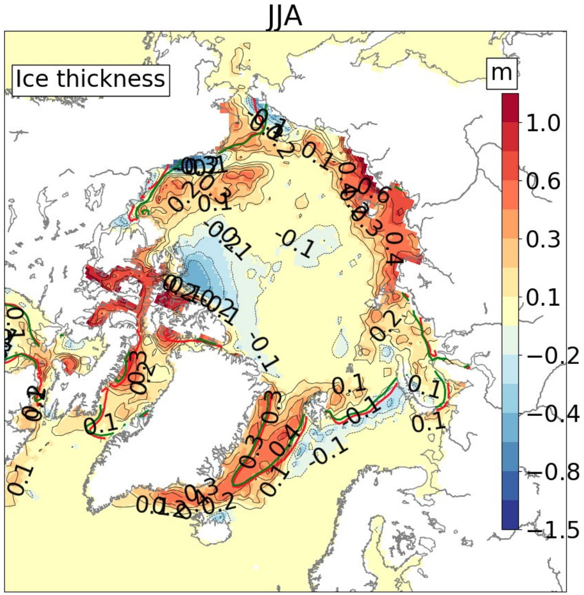
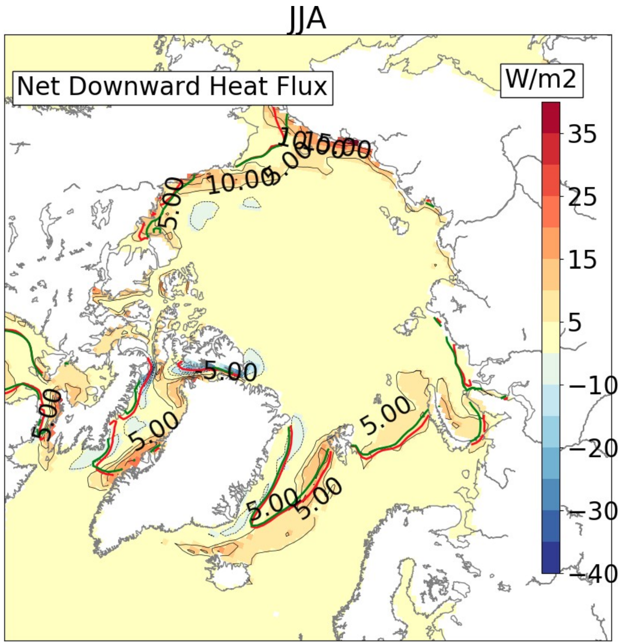


Fig: Difference of mean sea ice thickness between DRG and CST in summer

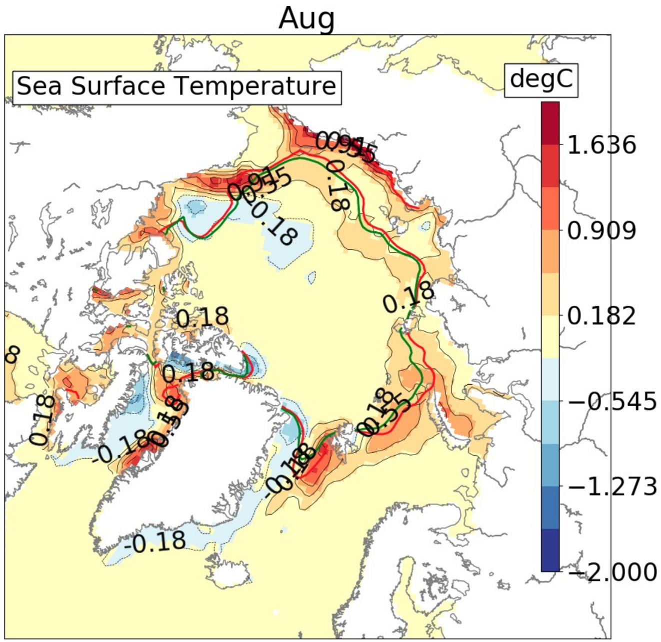
- Sea ice concentration is reduced by 0.04 to 0.12 points in the MIZ when using the form drag scheme
- The monthly means in total sea ice volume are reduced by a constant amount
- The effective ice thickness increases where sea ice concentration is reduced, in the MIZ and in the Arctic Archipelago

Ocean surface fluxes: net downward flux

- The net downward heat flux to the ocean is not impacted within sea ice
- Increased heat in MIZ leading to subsequent rise in temperature along the ice edge
- Associated to the negative change in sea ice concentration



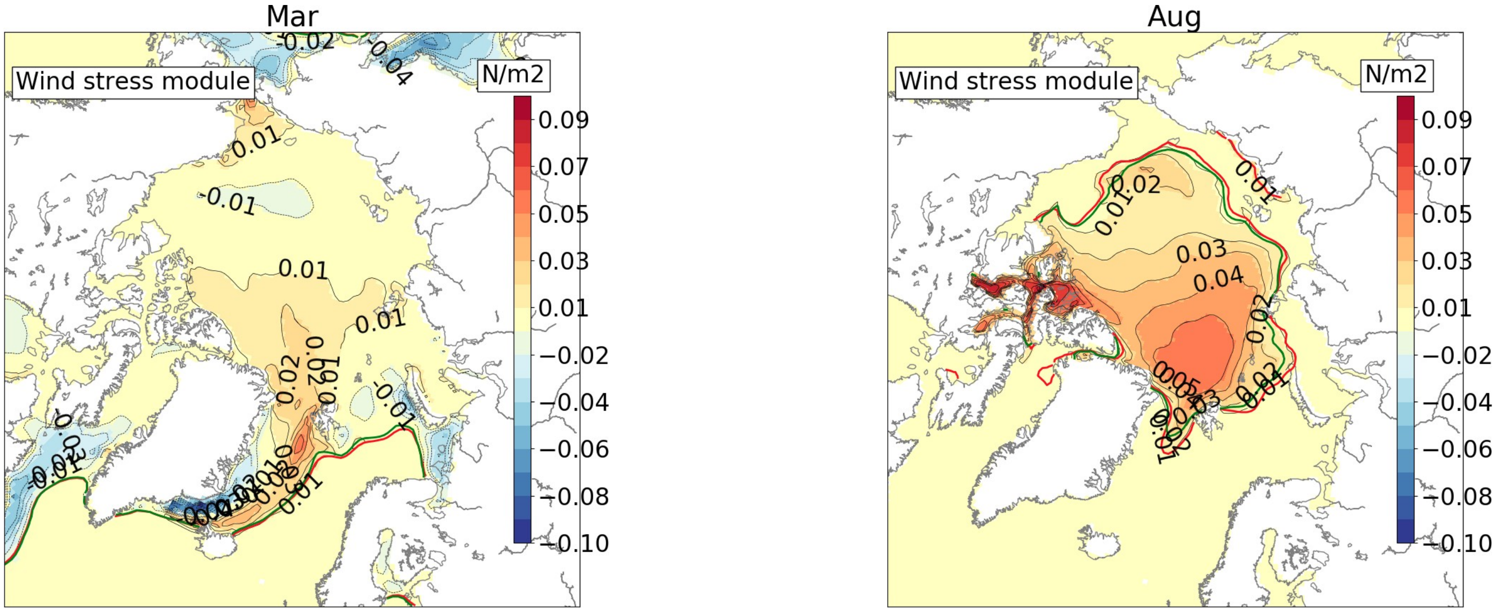
Difference of mean net downward heat flux between DRG and CST in summer (June-July-August)



Difference of mean SST between DRG and CST in August

Ocean surface fluxes: surface stress

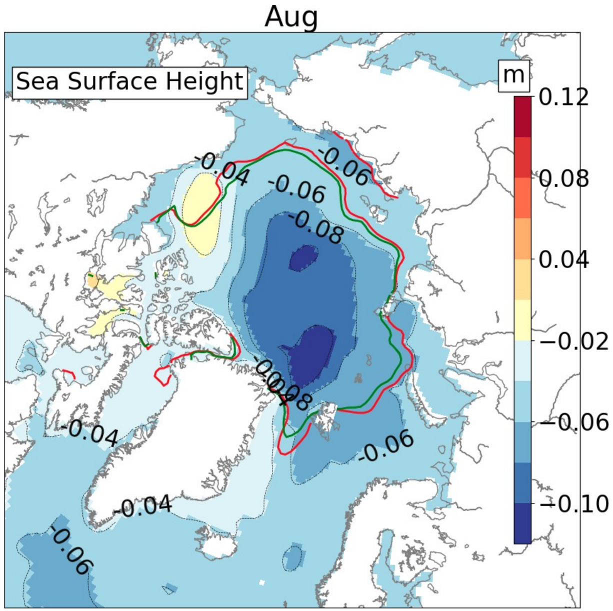
- In summer, the surface stress applied to the ocean is increased between DRG and CST all over the Arctic sea ice covered regions
- The ocean surface in the Arctic Archipelago and Fram Strait experiences gains in surface stress between 0.05 and 0.09 N/m2
- In winter, changes in surface stress have different signs depending of the region



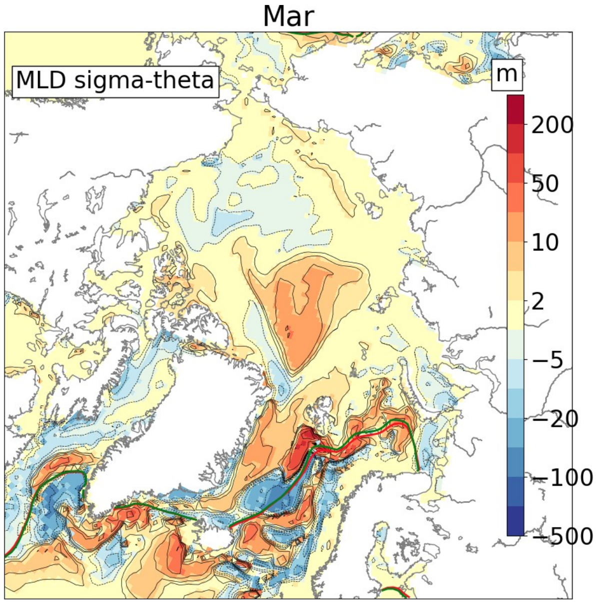
Difference of mean surface stress between DRG and CST in March (left) and August (right)

Ocean surface fluxes: surface stress

- The deepening of the Mixed Layer Depth in winter whereas the maximum in mean drag coefficients happens in summer, thus the effect of the drag on the MLD is reduced. Within the ice pack, the difference in MLD varies between +/- 10m
- The SSH in the central Arctic is lower in DRG compared to CST. The difference persists in winter as well, and goes with an increase in the ocean surface velocities of +0.5 to 1 cm/s (to be investigated)



Difference of mean SSH between DRG and CST in August



Difference of mean MLD between DRG and CST in March

Conclusion

In summer, variable drag coefficients double (atm.) and triple (ocean) the constant values specified in LIM3, whereas in winter the difference between the coefficients is less marked

During summer months in the Arctic marginal ice zone, the form drag leads to a reduction of the ice concentration and an increase in the mean ice thickness. The total sea volume is reduced all-year round by the form drag.

The reduction in sea ice concentration in the marginal ice zone in DRG results in greater absorption of heat by the ocean through open water, and higher sea surface temperature

The ocean surface experiences greater surface stress under sea ice in summer when using the form drag formalism. The SSH is lower in DRG and the ocean surface velocities are slightly increased under sea ice.

The mixed layer depth (MLD) varies under sea ice between the DRG and CST simulations. However, the deepening of the MLD occurs in winter, whereas the seasonal maximum in variable drag coefficients happens in summer. Thus, impact of the form drag scheme on the MLD is limited