Modelling MIZ dynamics in a global model

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1. Introduction

The Marginal Ice Zone (MIZ) is a transitional area between the open ocean and pack ice measuring up to several hundred kilometers across.[1] It is characterised by high surface ocean waves and consists of severely fragmented sea ice with ice floes less than 100m in diameter. Retreat of the Arctic summer sea ice and exposure of large, previously ice-covered areas of the Arctic Ocean to the wind and to surface ocean waves results in the Arctic pack ice cover becoming more fragmented and mobile, with large regions of the ice cover evolving into a MIZ (Fig. 1).

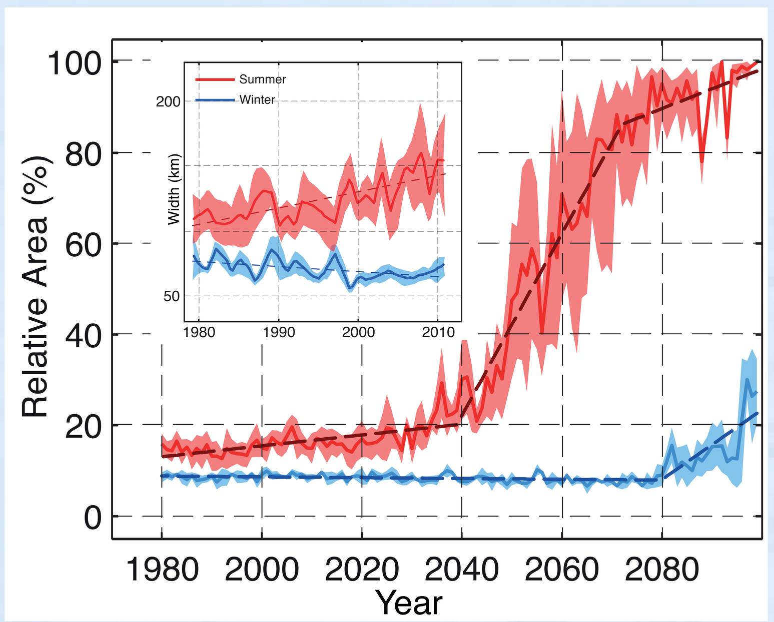

Figure 1: Observed and predicted increase of the Arctic MIZ.[1,2]

2. Motivation

The need for better climate predictions, along with growing economic activity in the Polar Oceans, necessitates climate and forecasting models that can simulate fragmented sea ice with a greater fidelity. Current models are not fully fit for the purpose, since they neither model surface ocean waves in the MIZ, nor account for the effect of floe fragmentation, nor include sea ice rheology that represents both the currently thinner pack ice and MIZ ice dynamics. All these processes affect the momentum transfer from the atmosphere through the sea ice to the ocean.

3. Methods

- Sea ice dynamics are governed by the momentum equation, including a contribution of internal stress (σ), which is calculated from the strain rates using sea ice rheology as follows (here u and m are the ice velocity and mass; τ_a and τ_o are the air-ice and ice-ocean stresses; f and k are the Coriolis parameter and the unity vector):

$$m\frac{D\vec{u}}{Dt} = -mf\vec{k}\times\vec{u} + \tau_a + \tau_o + \nabla\cdot\sigma. \qquad (1)$$

- Feltham et al.[3] combined Elastic-Viscous-Plastic (EVP) rheology and an extended collisional rheology, creating a unified sea ice rheology (Table 1) suitable for both the central pack ice and the MIZ as follows (here ε is the strain rate tensor and δ the Kronecker delta):

$$\sigma_{ij} = 2(\eta^{EVP}+\eta^{COL})\dot{\varepsilon}_{ij} + ((\zeta^{EVP}+\zeta^{COL}) - (\eta^{EVP}+\eta^{COL}))\dot{\varepsilon}_{kk}\delta_{ij} - \frac{1}{2}(P^{EVP}+P^{COL})\delta_{ij}. \qquad (2)$$

- The turbulent kinetic energy of the ice floe motion ("granular temperature") sets the contribution of collisional rheology. Evolution of the granular temperature (G_T) can be derived from different sources and sinks as:

$$\frac{DG_T}{Dt} = Diffusion + Wind\ and\ Ocean\ Stress\ Fluctuations + Internal\ stress - Floe\ rubbing - Floe\ collisions. \qquad (3)$$

- The combined ice rheology is implemented in the Los Alamos CICE model and tested in the 1-degree resolution global NEMO (Nucleus for European Modelling of the Ocean) Ocean General Circulation model, and integrated for 2000-2012 with DRAKKAR atmospheric re-analysis.[4,5,6]

Table 1: Elastic-Viscous-Plastic (EVP) and Collisional rheologies formulation

	Collisional	EVP
Shear viscosity	$\eta = \frac{\gamma(1+e')}{3\pi}\frac{\sqrt{2}G_T^{1/2}}{L_f}$	$\eta = \frac{P}{2\Delta e^2}$
Bulk viscosity	$\zeta = \frac{\gamma(1+e')}{\pi}\frac{\sqrt{2}G_T^{1/2}}{L_f}$	$\zeta = \frac{P}{2\Delta}$
Replacement pressure	$P = \gamma\frac{\sqrt{2}}{\pi^2}(1+e')\frac{2G_T}{L_f^2}$	$P = g(A)P^*h$

G_T: granular temperature
L_f: floe size
e': restitution coefficient
P*: ice strength
ρ_s: ice density
h: ice thickness
A: ice concentration
e: eccentricity of the yield curve
$0 < g(A) < 1$

4. Results

4.1 Effect of rheology

- Simulations with EVP and Combined rheology are compared.
- In the MIZ, significant changes in volume tendency occur and are associated with the granular temperature maximum (Fig. 2).

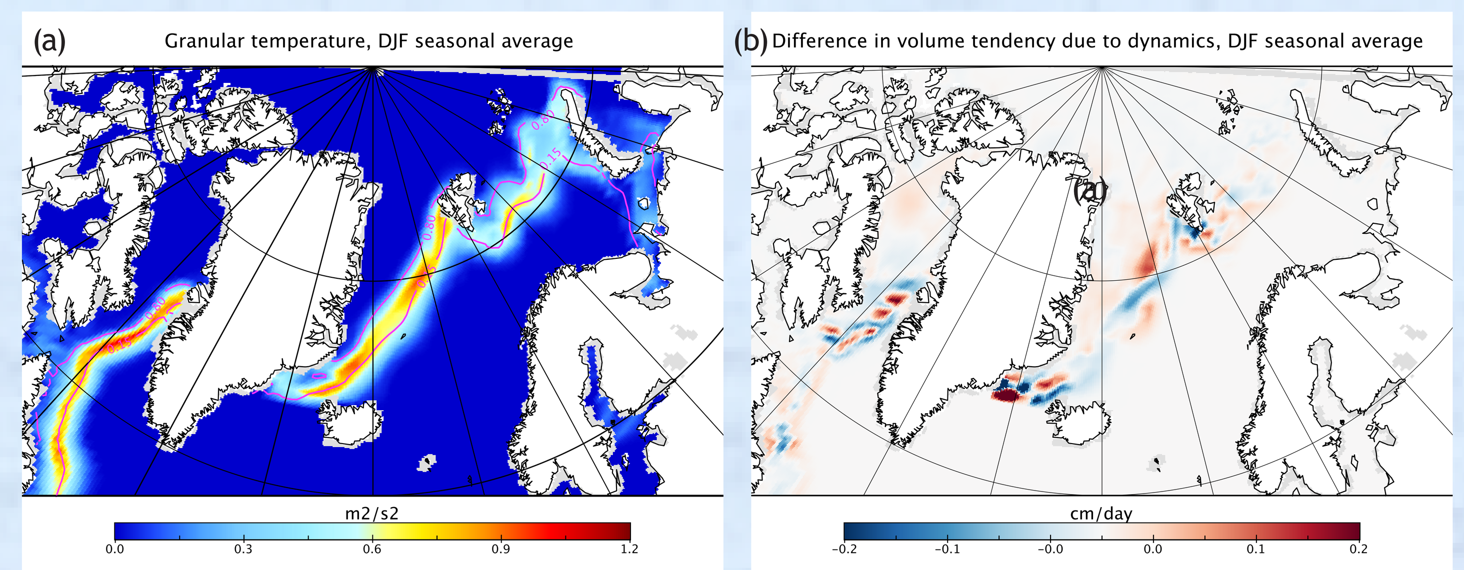

Figure 2: Comparison between granular temperature and dynamical volume tendency, DJF seasonal average: (a) granular temperature with ice concentration contours defining the MIZ (b) dynamical volume tendency.

4.2 Effect of ice fragmentation

- Simulations with floe sizes from wave break-up and with constant 300m floe size are compared.
- After one year the ice thickness in the pack ice is larger, in the MIZ it is reduced.
- The winter ice concentration is reduced in the MIZ due to the smaller floe sizes, whereas in the pack ice the concentration does not change as it is maximum in both the integrations (Fig. 3).

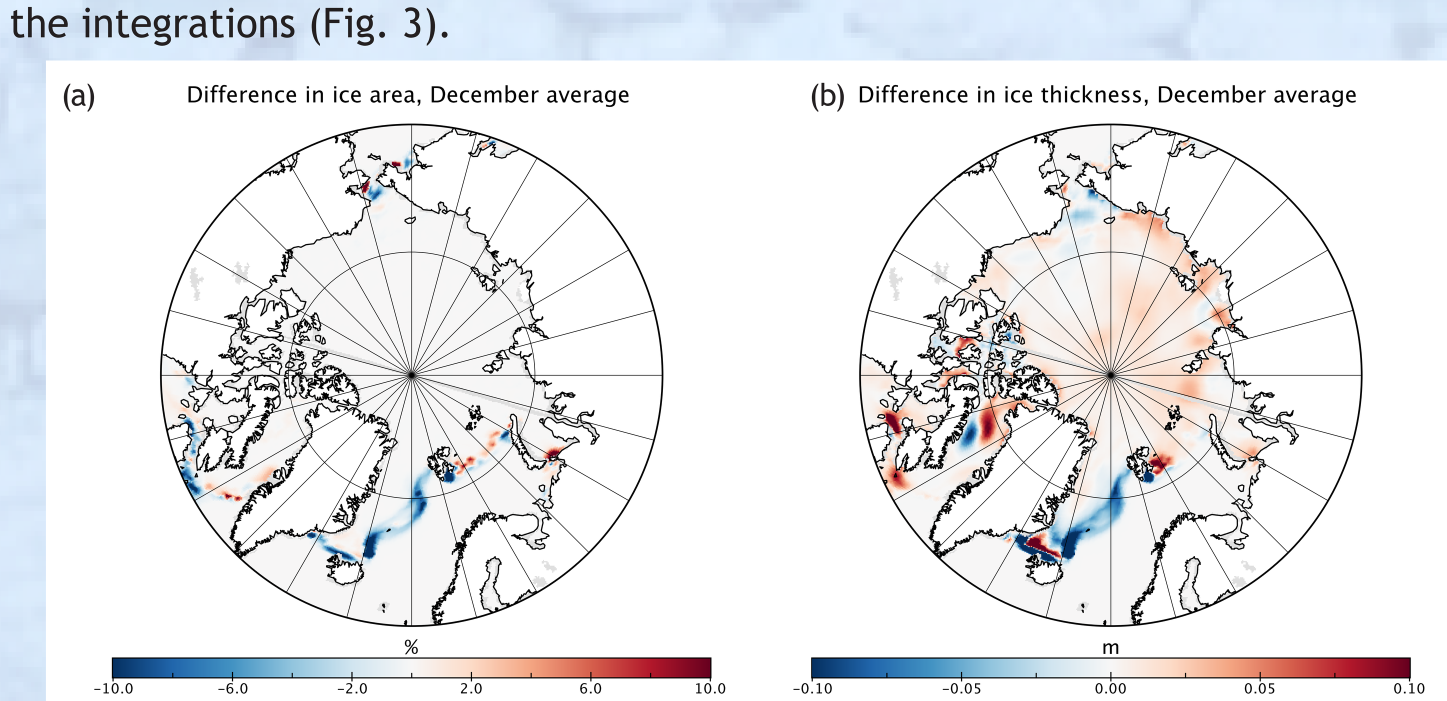

Figure 3: Comparison between simulations with constant 300m floes and floe sizes simulated from wave break-up, December averages after one year are shown: (a) ice area (b) ice thickness.

4.3 Comparison with the theory

- In the MIZ the granular temperature values lie within the theoretical limit, allowing for the full solution to be replaced by a parameterisation (Fig. 4).
- There are regional and seasonal variations in how close the model granular temperature gets to the theoretical maximum.
- The floe size has the largest influence on the maximum granular temperature.
- The wind and ocean stress fluctuation (F) and restitution coefficient (e') have an approximately linear and inverse linear effect on the maximum granular temperature (Table 2).

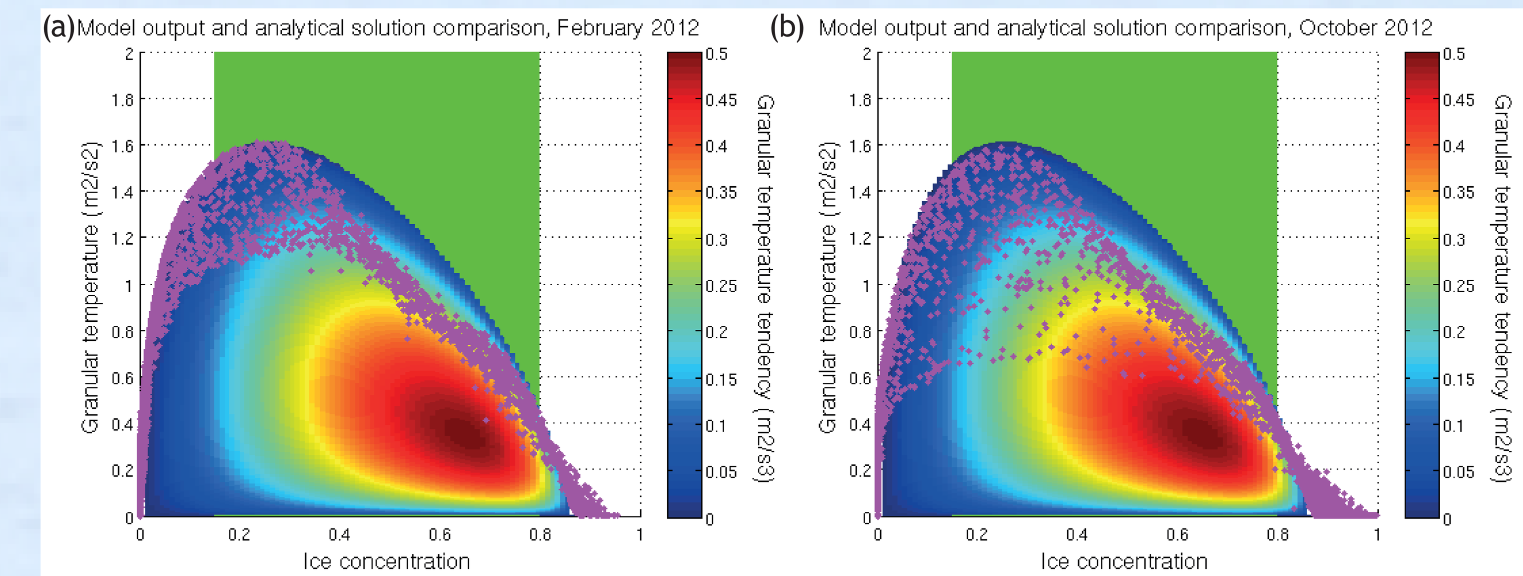

Figure 4: Comparison between the analytical granular temperature tendency and simulated granular temperature values from a band around Antarctica in (a) February and (b) October. The MIZ is highlighted in green.

Table 2: Maximum granular temperature for different parameters

Experiment 1: Floe size		Experiment 2: Wind and ocean stress fluctuation		Experiment 3: Restitution coefficient	
Lf (r = 0.1, F = 2)	max G_T	F (Lf = 300, r = 0.1)	max G_T	e' (Lf = 300, F = 2)	max G_T
300	1.620	1	0.810	0.1	1.620
1000	5.400	2	1.620	0.375	0.440
Lüpkes[7]	0.059	4	3.240		

5. Conclusion

- Using the combined rheology mostly affects the ice cover in the MIZ.
- The effect of ice fragmentation is basinwide, increasing (decreasing) the ice thickness as floe size increases (decreases).
- The maximum turbulent kinetic energy of ice floes can be parameterised if the dependency of the floe size on the ice concentration is known, e.g. as in [7].

6. Outlook

- As the Arctic ice cover retreats and the wave action is expected to increase, the effect of the floe fragmentation can accelerate ice decline, introducing a new positive feedback into the system.
- Hence, It is necessary to include MIZ processes in climate models to improve accuracy of climate modelling and forecasting.

References

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