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Rapid changes in sea ice: processes and implications

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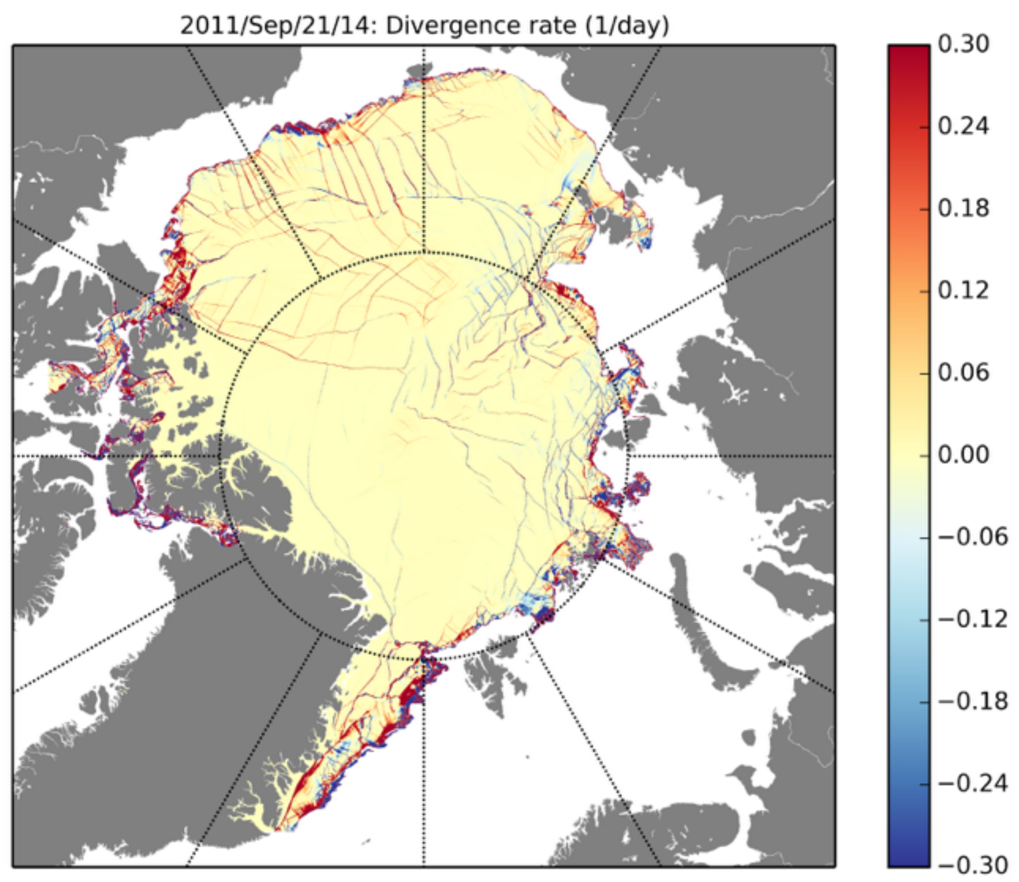
Characteristics of sea ice deformation in high-resolution viscous-plastic sea ice models

Leads in viscous-plastic (VP) models

VP sea ice models at coarse resolution are known to reproduce statistical and scaling properties of sea ice deformation inappropriately [*Girard et al., 2009*], but …

Figure: Divergence rate in MITgcm model run with an average horizontal grid spacing of 1km in the Arctic (D. Menemenlis, personal communication). Sea ice deformation localises in linear failure lines.



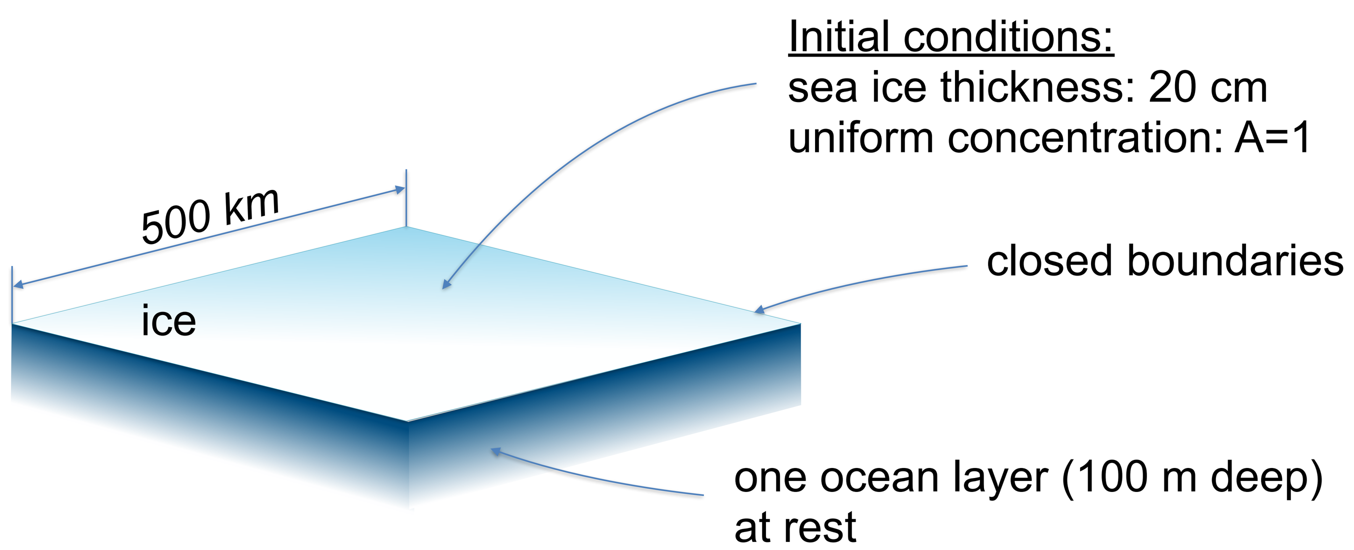
➡ At very high resolution leads emerge in viscous-plastic sea ice models.

Research Objectives: Do the emerging leads in VP sea ice models at very high resolution result in statistical and scaling properties of sea ice deformation comparable to satellite observations?

Model Set-Up

Model: MITgcm (VP rheology)

Idealised Environment: 500 km x 500 km ocean box covered with sea ice



Wind forcing:

- Idealised: Sequence of passing high and low pressure system, 16 day cycle
- Reanalysis wind fields: 0.14º ECMWF analysis with 15-km grid spacing

Deformation rate distributions

Method: Determine the basin of attraction of the Probability Distribution Functions (PDF) of sea ice deformation rates

Compute PDF of deformation rates ➡ Fit power-law tails: $P(\dot{\epsilon}) \sim \dot{\epsilon}^{-\eta}$ ➡ $\eta \geq 3$: converge to Gaussian shape / $\eta < 3$: converge to stable Lévy law

➡ Different grid spacing of sea ice model (1, 2, 5, and 10 km) are tested

Results: Power-law tails flatten with increasing resolution and PDFs enter the basin of attraction to a stable Lévy law.

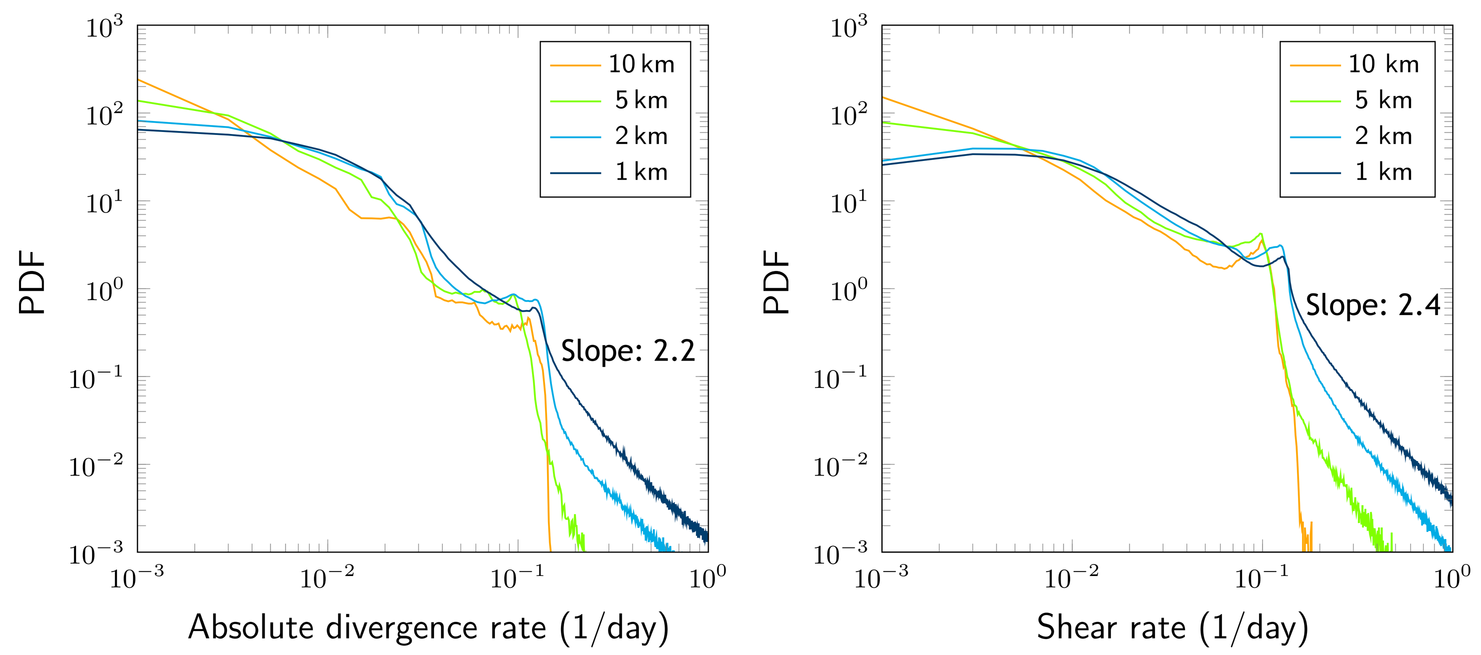


Figure: PDFs of both strain rate invariants for different horizontal grid spacing. The peaks in the PDFs are artefacts of the idealised wind forcing.

➡ At high resolution emerging leads localise deformation rates
➡ Deformation rates are dominated by extreme deformation events and characterised by wild randomness

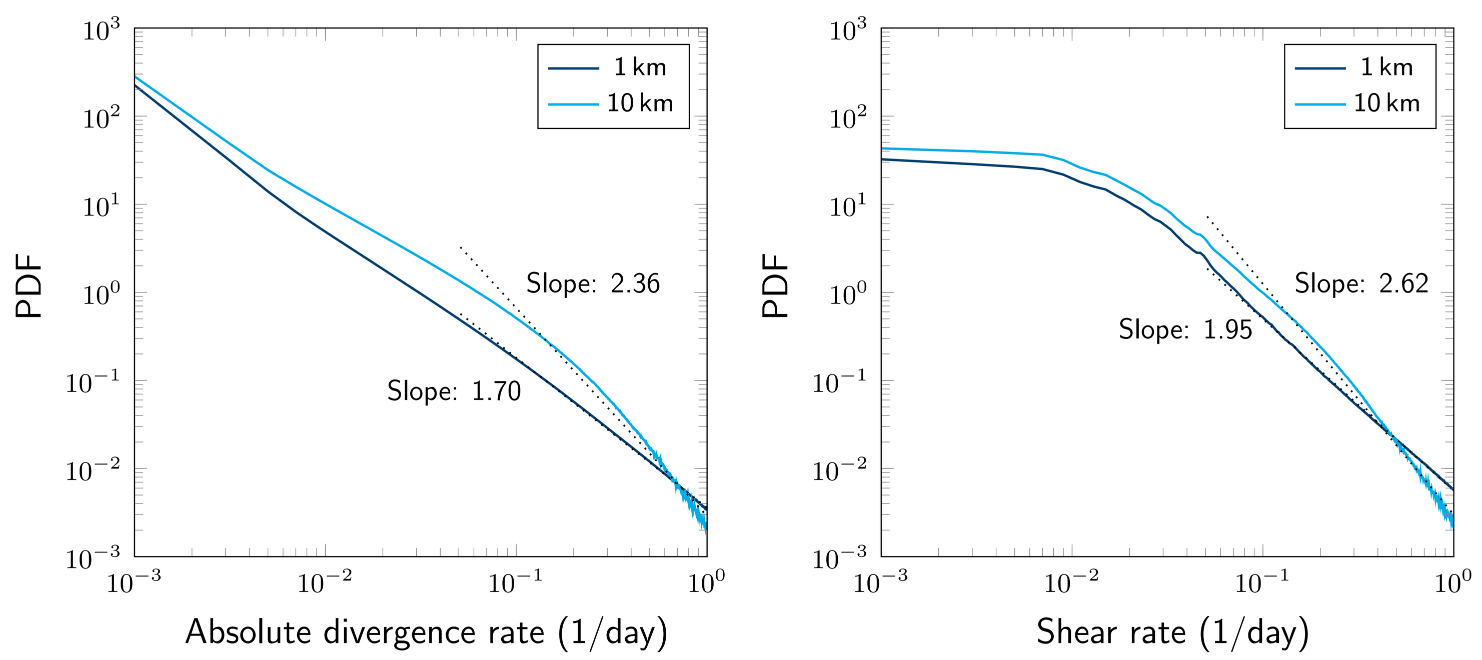


Figure: PDF of both strain rate invariants in the Pan-Arctic set-up (1-km grid spacing, wind forcing: 0.14º ECMWF analysis). PDFs are given for the original grid scale of 1 km and coarse grained to 10 km scale.

Discussion: Good agreement of the slopes of the power-law tails obtained from the Pan-Arctic simulation with *Girard's et al.* [2009] satellite observations (divergence: 2.4 and shear: 2.6).

Conclusions

- With increased resolution the VP rheology has the potential to reproduce features of localised strain rates
- The resolved leads influence strongly the PDFs and scaling properties of deformation rates
- Increasing the resolution of the wind forcing driving the sea ice motion improves spatial scaling properties
- VP rheology appears to be an appropriate framework for modelling sea ice deformation at high resolution

Spatial scaling of deformation rates

Method: *Herman and Glowacki's* [*2012*] scaling analysis adapted from a Lagrangian approach [*Marsan et al., 2004*] to data on an Eulerian grid.

Compute sea ice velocity gradients ➡ Coarse grain to spatial scales ➡ Compute deformation rates & average

➡ Different grid spacing of sea ice model (1, 2, 5, and 10 km) are tested
➡ Effects of different wind forcing resolutions (15 and 125 km) are studied

Results: Spatial scaling improves with increasing model grid spacing as well as with increasing resolution of the wind forcing.

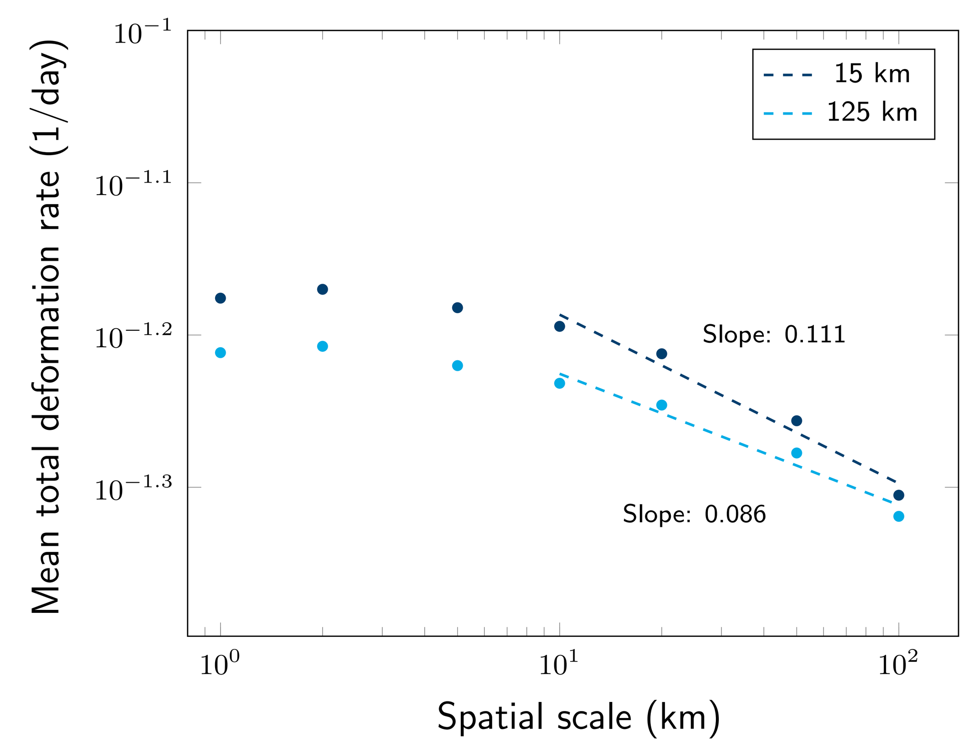


Figure: Spatial scaling of the total deformation of 1-km model. The model is forced with 0.14º ECMWF analysis on its original 15-km grid and coarse grained to 125 km.

Discussion: Good agreement with scaling coefficient of elasto-brittle rheology 0.11 [*Rampal et al., 2015*]. Scaling coefficients of satellite observations vary around 0.2 [*Marsan et al., 2004*, *Stern et al., 2009*], but are are thought to be overestimated by 60% [Bouillon *et al., 2015*].

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