Advancing Arctic sea ice model dynamics

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SPARWASSER ARCTIC CLIMATE CHANGE RESEARCH FORUM, May 1-2, 2024

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Advancing Arctic sea ice model dynamics

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ArcTrain

NSERC CRSNG

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Martin Losch
with contributions from
Damien Ringeisen, Mischa Ungermann, Yuqing Liu,
Nils Hutter, Mahdi Mohammadi-Aragh, Xinyue Li and more

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Which satellite?

Which satellite?

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MITgcm (Menemenlis, Hill, 2014)

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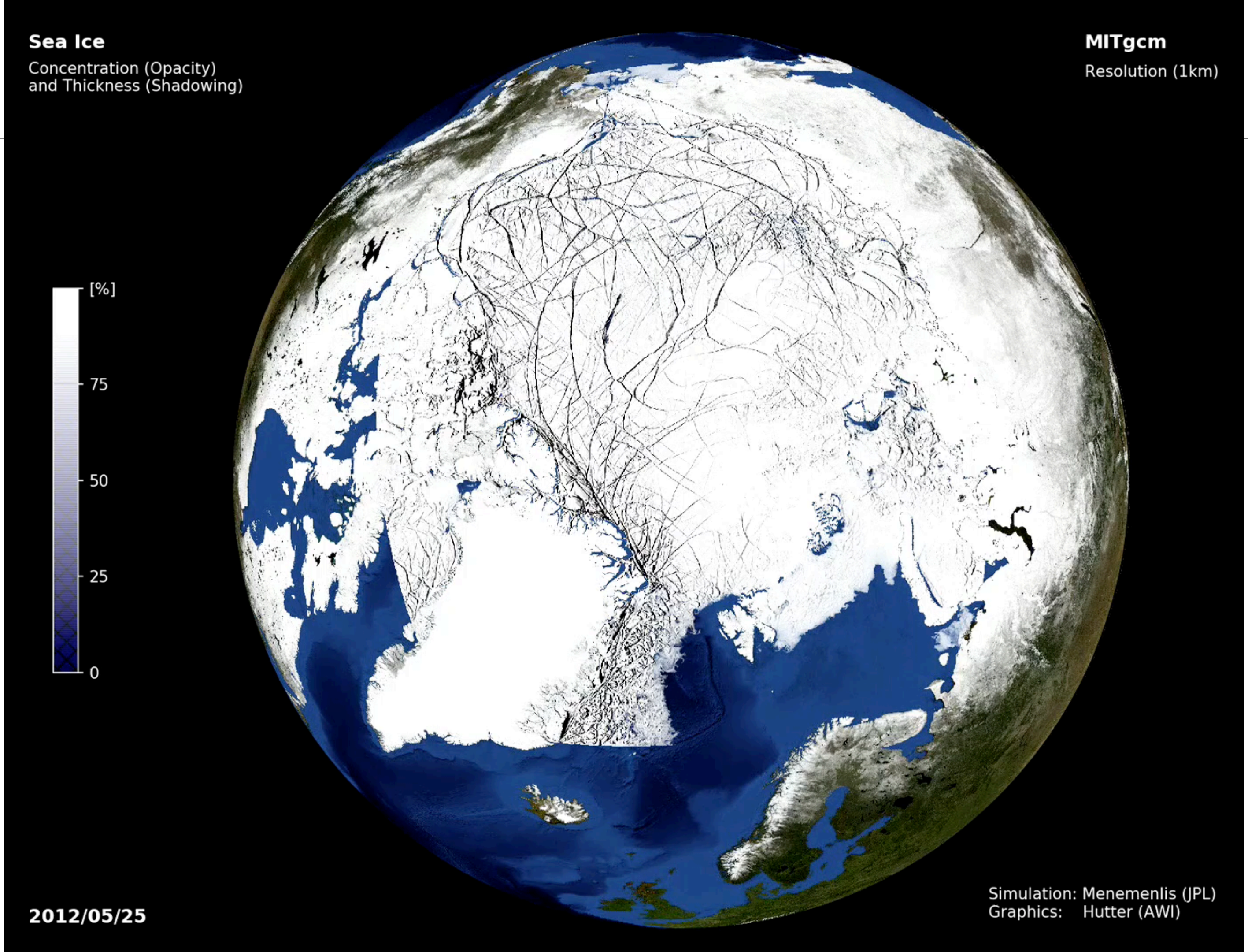
Sea Ice
Concentration (Opacity)
and Thickness (Shadowing)
MITgcm
Resolution (1km)
[%]
75
50
25
0
2012/05/25
Simulation: Menemenlis (JPL)
Graphics: Hutter (AWI)

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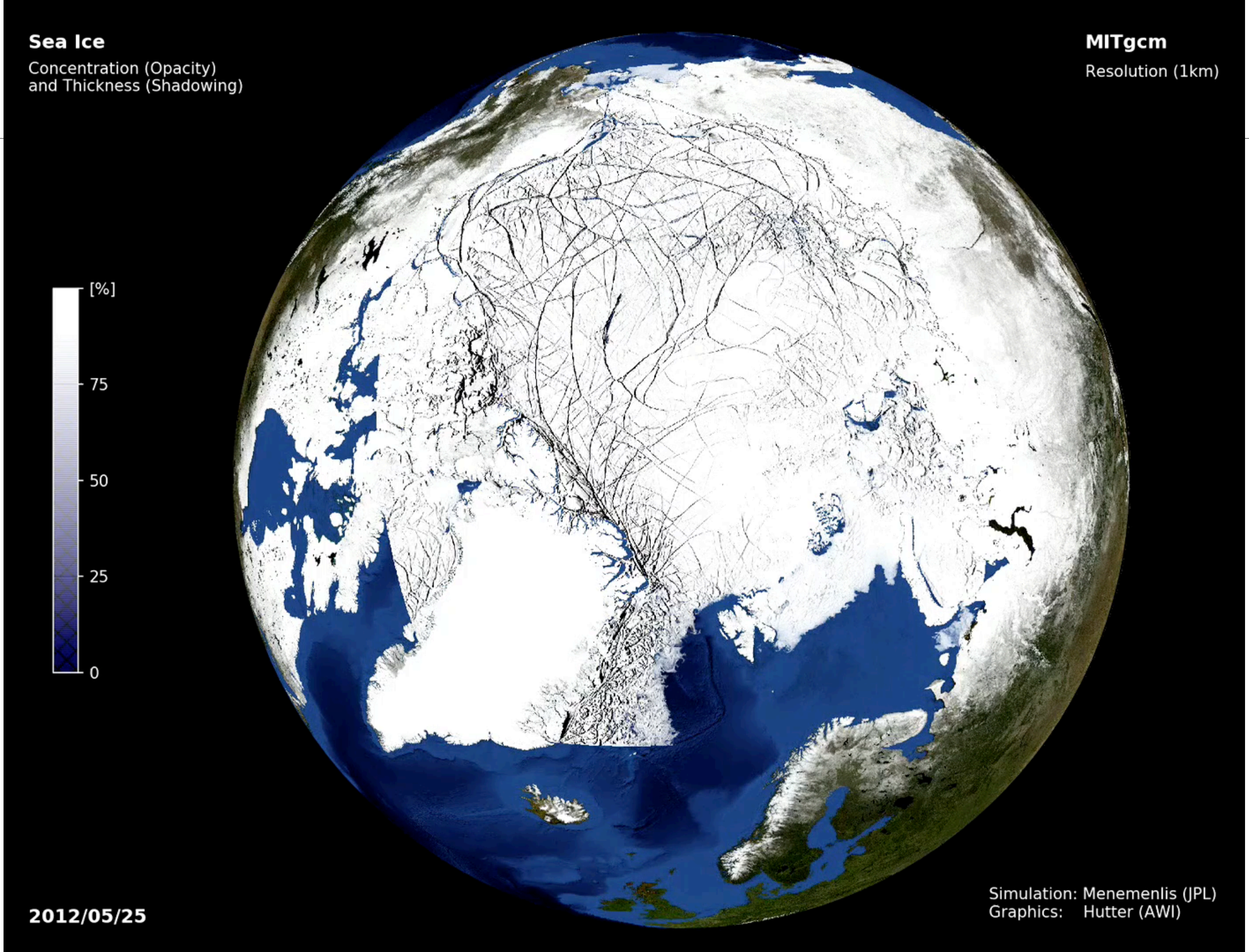
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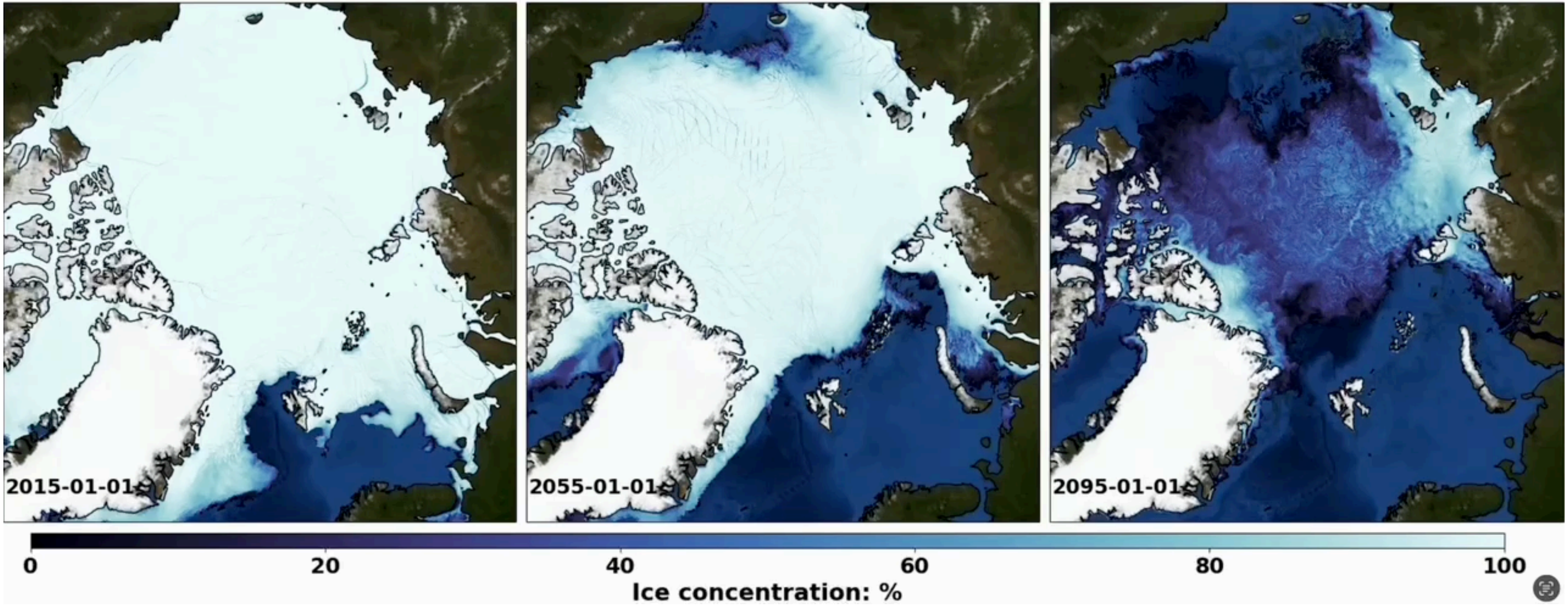
Numerical sea ice model of a future Arctic



Li et al. (2024), Nature Climate Change; model: FESOM

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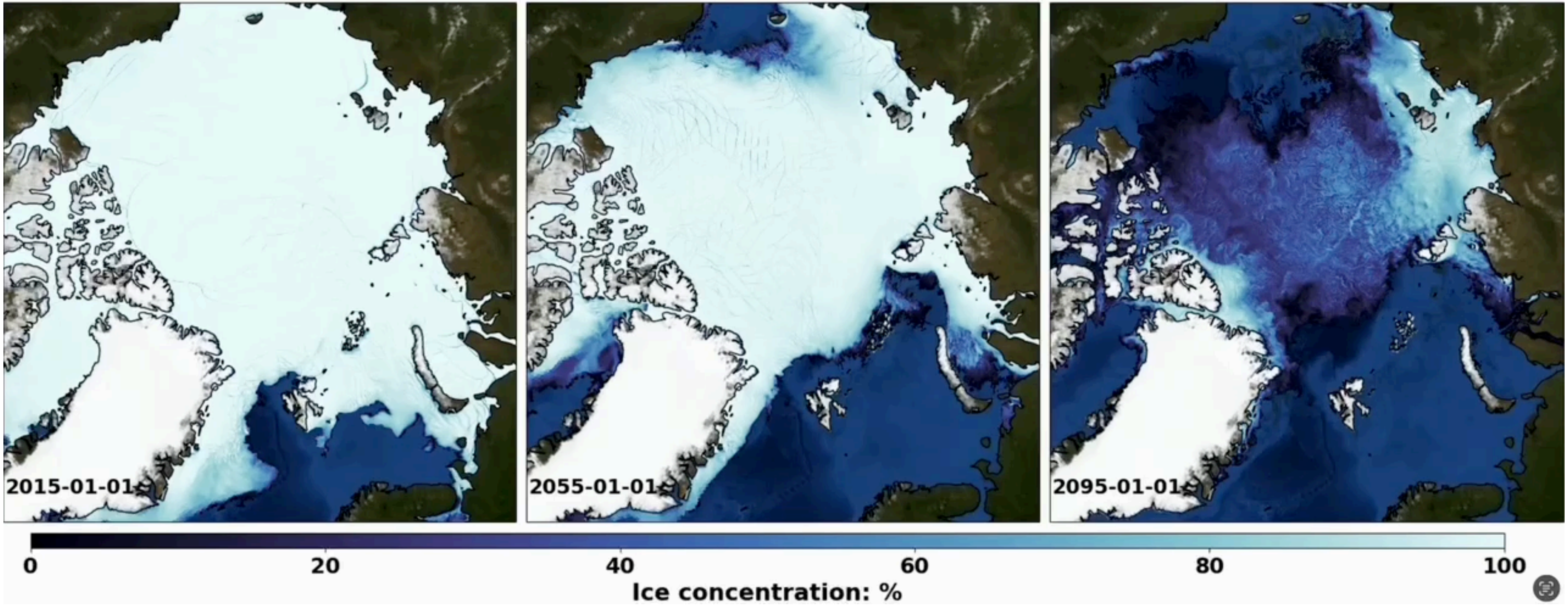

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Simulated details matter to people

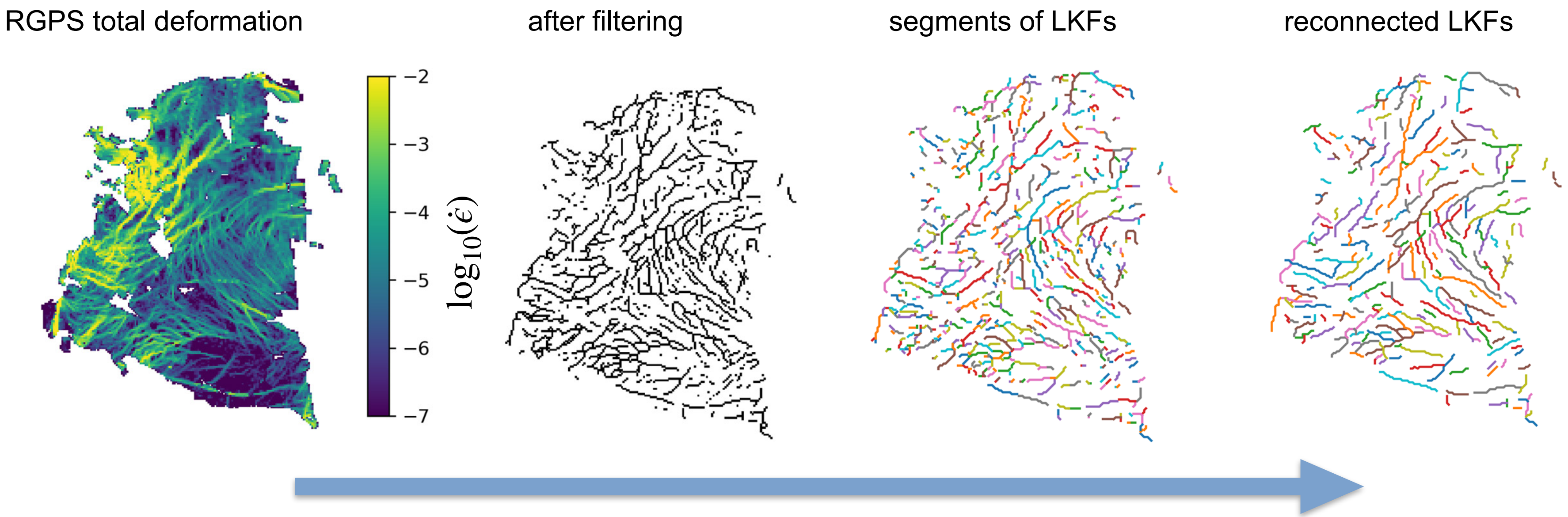
Evaluate high-resolution simulations to improve

- Sea ice rheology
- Land fast ice
- Ice thickness distribution

➡Combine models and observations: Data Assimilation for better prediction

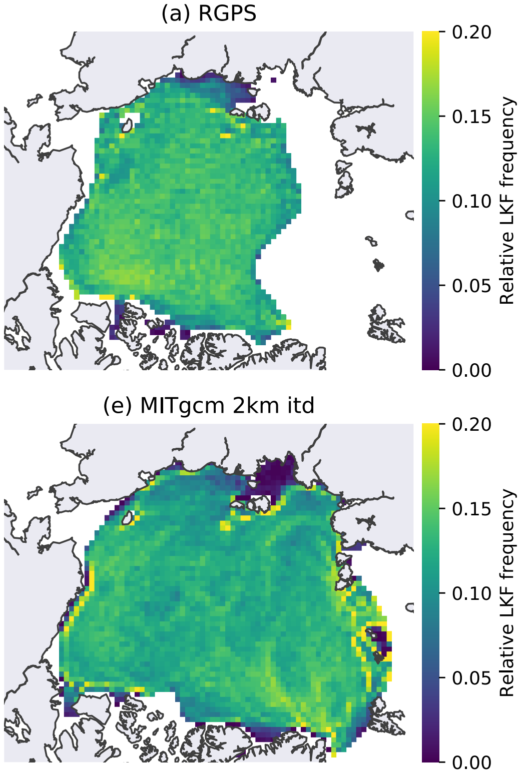
towards feature based analysis

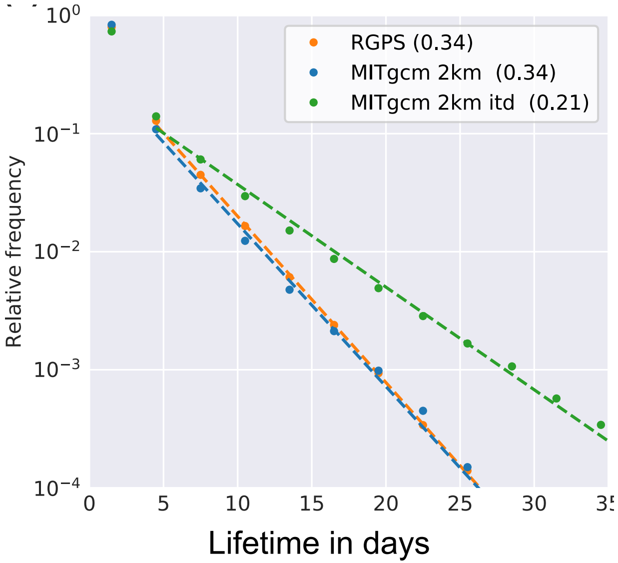
- detection and tracking algorithm (Linow and Dierking, 2017, Hutter et al. 2019):

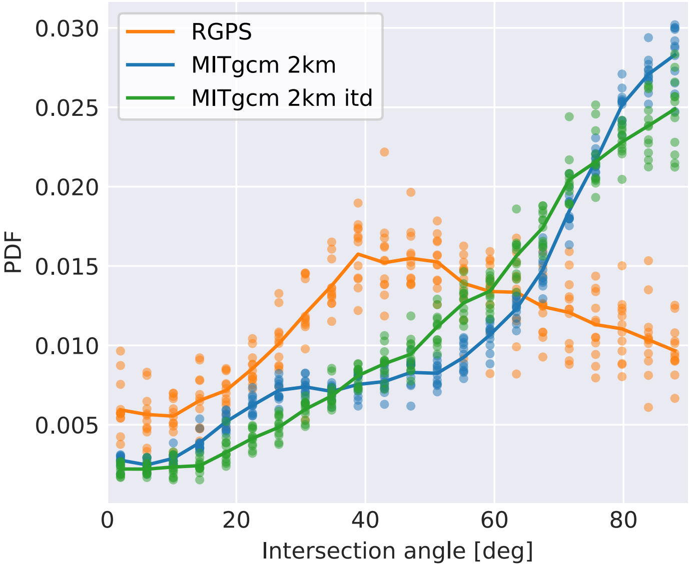


- result: list of linear kinematic feature (LKF) objects with temporal evolution

feature based analysis, examples







- many more: number of LKFs, orientation, length, growth rates (Hutter and Losch, 2020)
- SIREx (Bouchat et al 2022, Hutter et al 2022)

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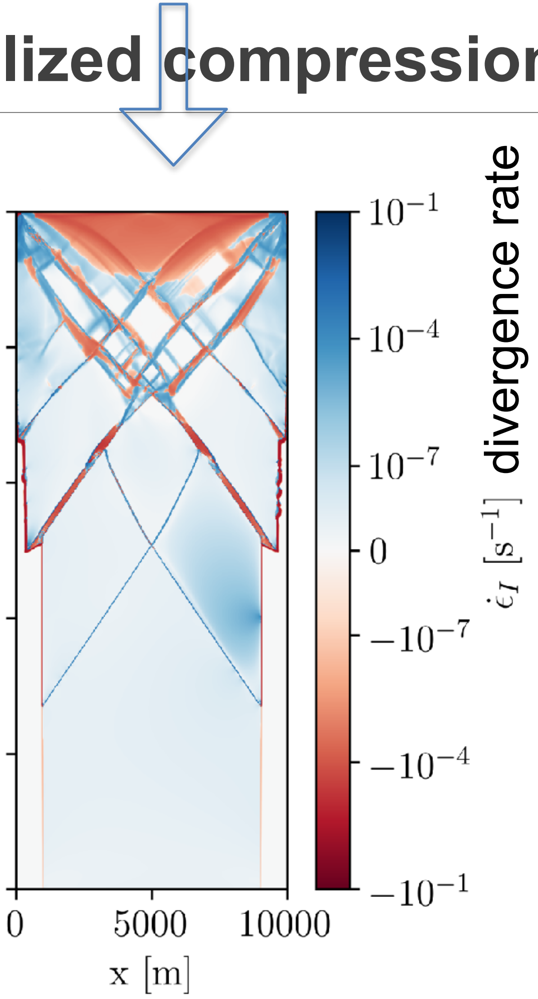
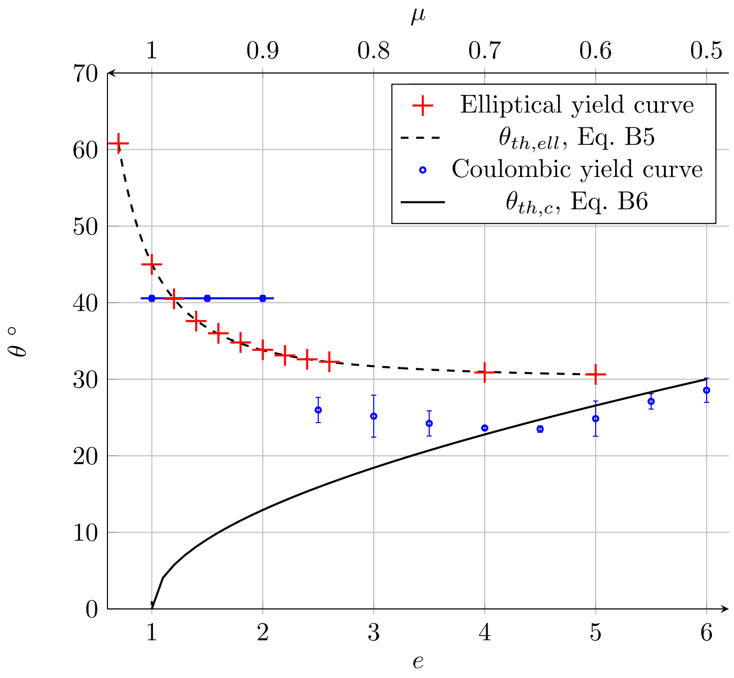
idealized compression experiments show limits





Ringeisen et al. (2019)

$$\theta_{ell} = \frac{1}{2} \arccos \left[\frac{1}{2} \left(1 - \frac{1}{e^2} \right) \right] \geq 30^\circ$$

Sea ice rheology outlook

- Continuum mechanics
  - Viscous-plastic (VP) with different (and new) yield curves
  - Brittle models, e.g. Maxwell-Elasto-brittle (MEB), BBM (Olason et al 2022)
- Discrete element models, e.g. SubZero (Manucharyan and Montemuro, 2022, JAMES)

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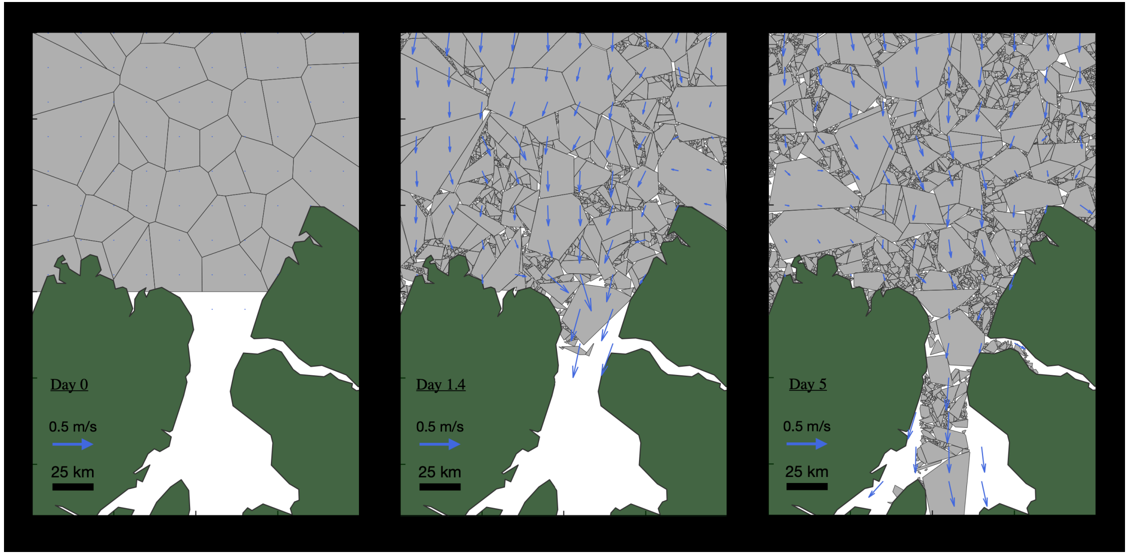
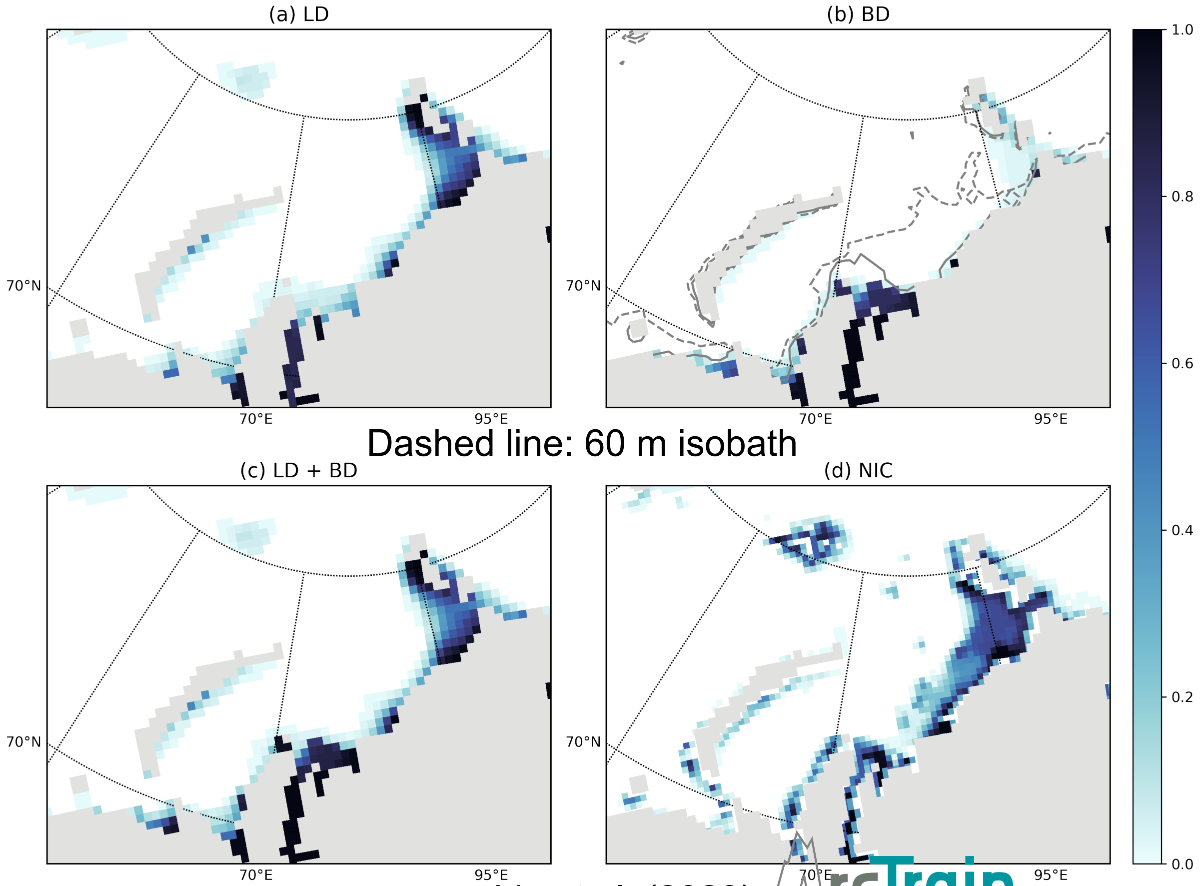


https://deep.ocean.washington.edu/subzero.html

Landfast ice

- vanilla ice dynamics don’t cut it
- additional paramterizations are necessary (e.g. Lemieux et al. 2015/2016)
- basal drag, lateral drag, shear strength
- resolution appears to be a player, too



Dashed line: 60 m isobath

Liu et al. (2023)

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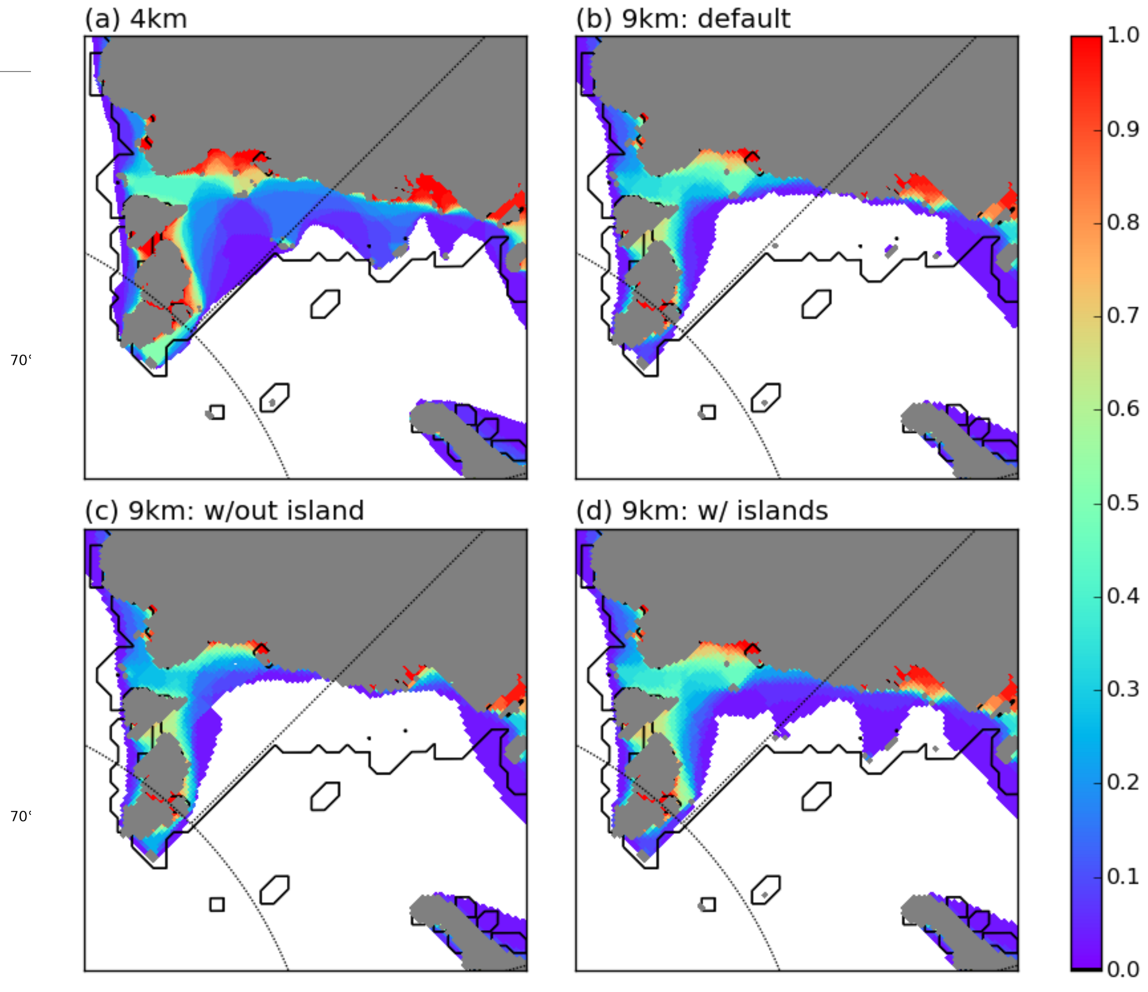

dynamic ice thickness distribution: redistribution + ridging

- ice concentration equation is replaced by an equation for thickness distribution function $g(h)$

$$\frac{\partial c}{\partial t} = -\nabla \cdot (c\,\mathbf{u}) + S_c \longrightarrow \frac{\partial g}{\partial t} = -\nabla \cdot (\mathbf{u} g) - \frac{\partial}{\partial h}(fg) + \Psi$$

ridging function

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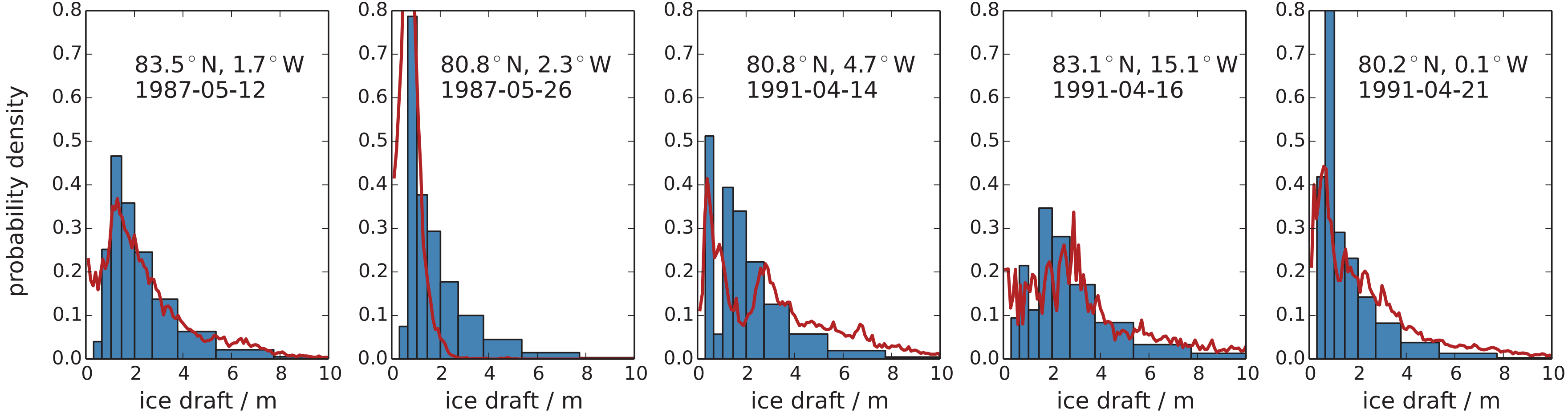


red: observations, blue: model

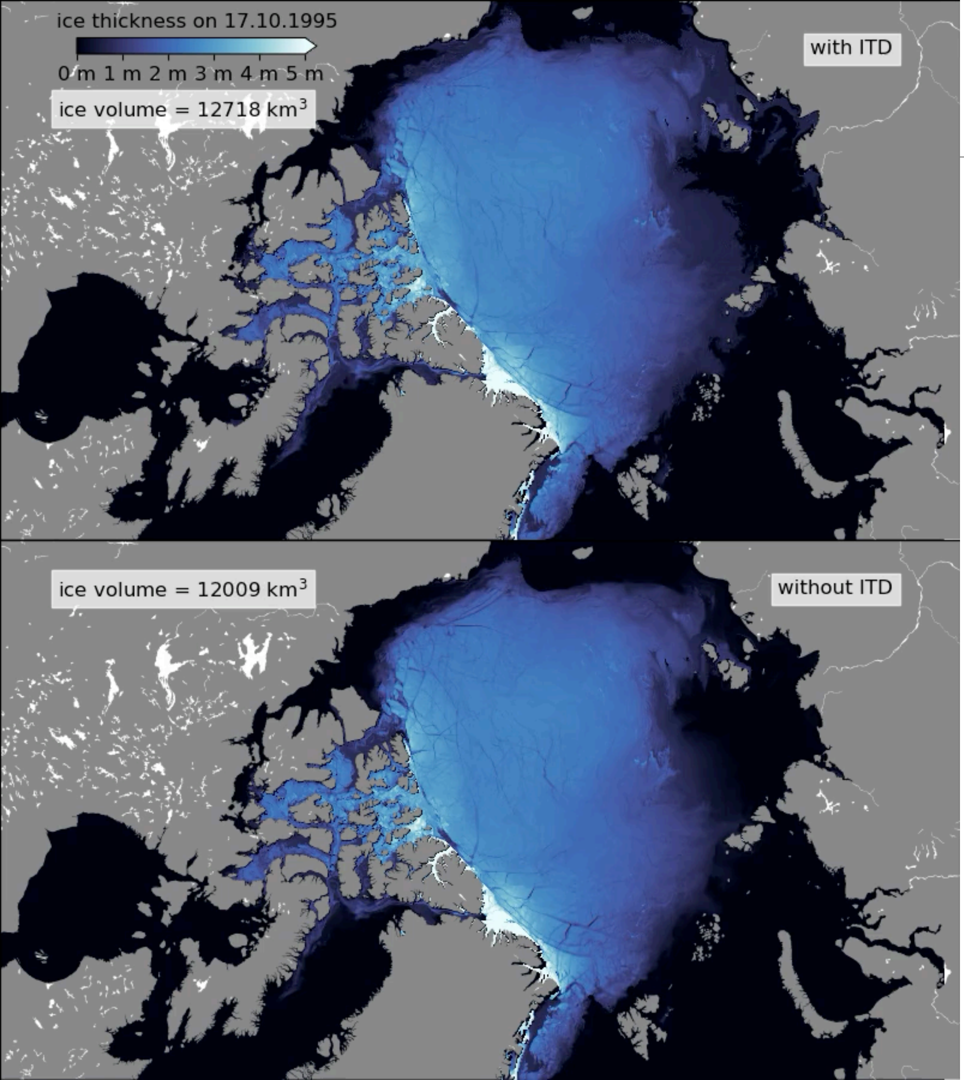
from Ungermann and Losch (2018)

Ice strength parameterizations

Hibler (1979): $P = P^*(hc)\,e^{-C^*(1-c)}$

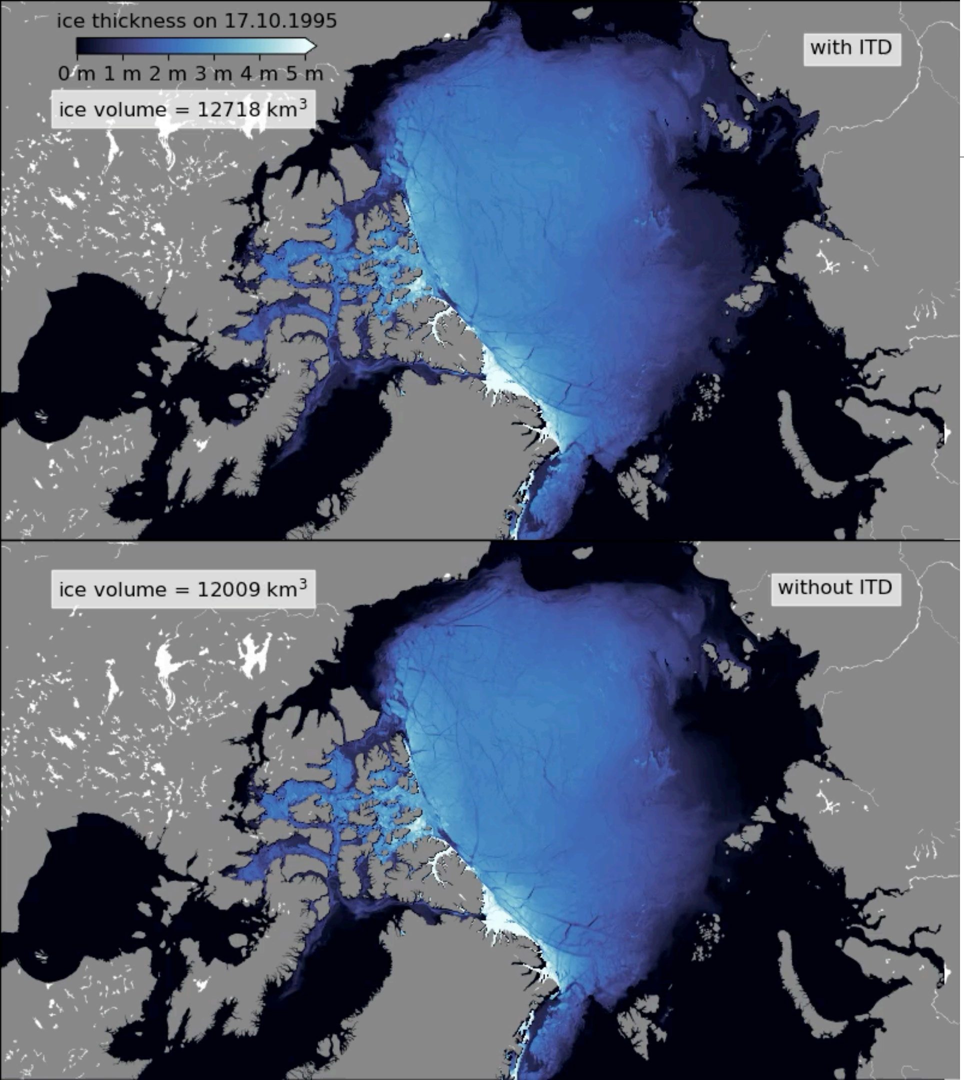
Rothrock (1975): $P = C_f\,C_p \int_0^\infty h^2 \omega_r(h)\,dh$

- Hibler (1979) is simple and plausible, but "ad-hoc" with little physical basis.
- Rothrock (1975) invokes potential energy arguments ("potential energy produced per unit area per unit strain in pure convergence"), but requires Ice Thickness Distribution sub-model, in practice leads to heterogeneous strength fields ⇒ effectively weaker pack ice (Ungermann et al. 2017)



Parameterisation

- Dynamic ice thickness distribution (ITD) and different formulation of ice strength (Rothrock, 1975, Thorndike et al 1975)
- Nils Hutter, unpublished



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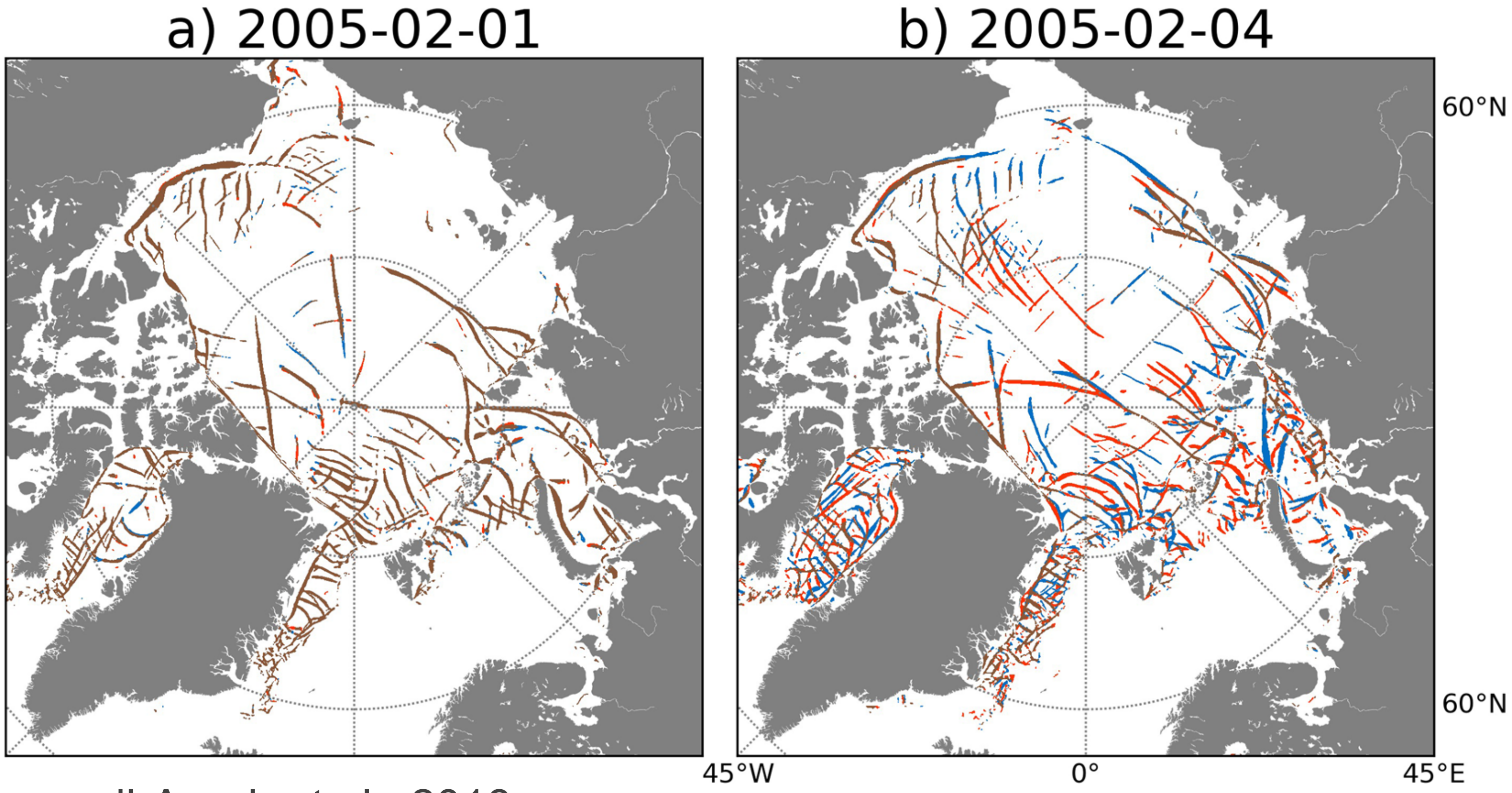
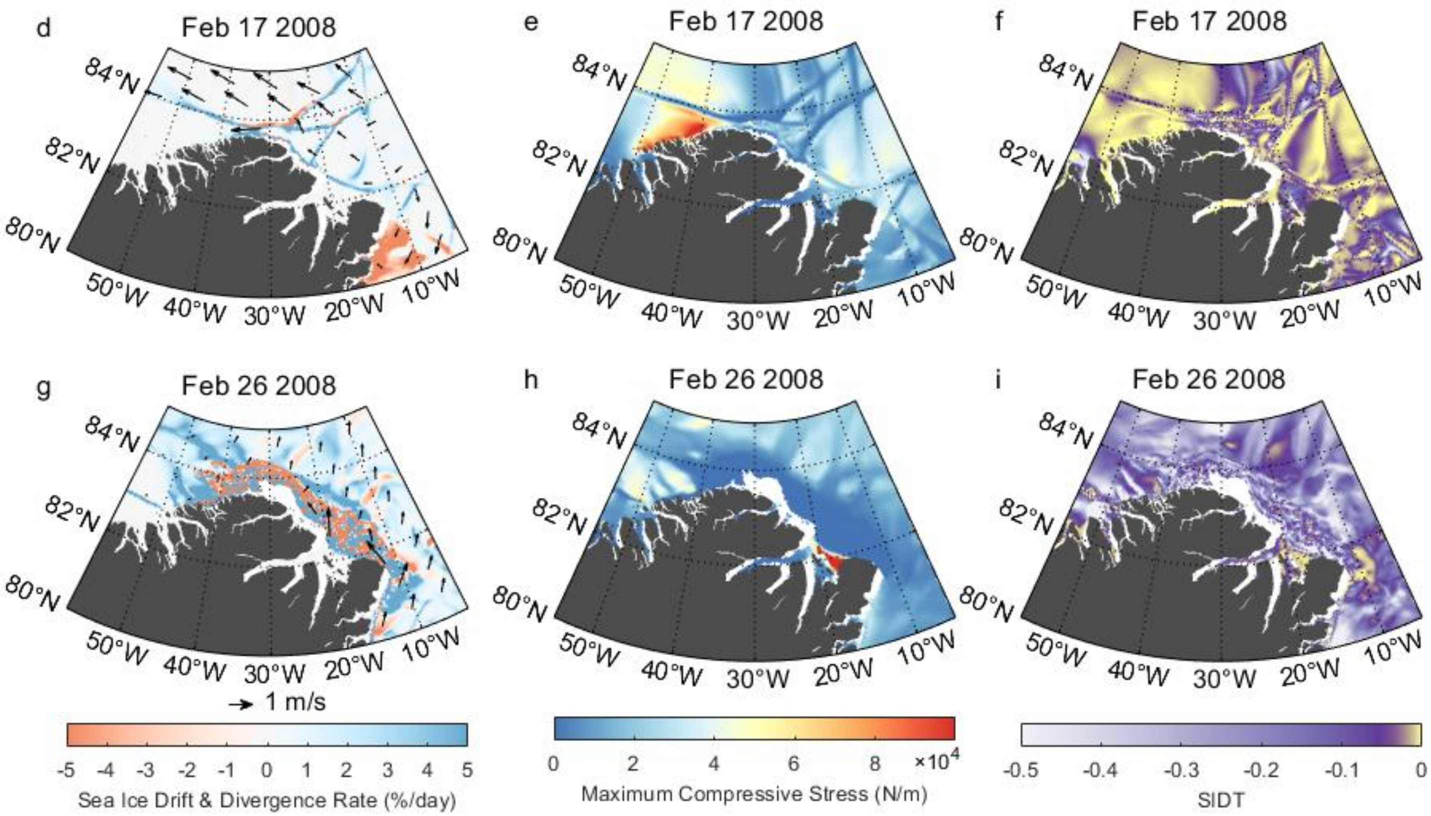
Can we predict the heterogeneity?



Mohammadi-Aragh et al., 2018

2018 Wandel Sea polynya north of Greenland



Liu et al, submitted

Summary

- High-resolution sea models allow more realistic simulations and potentially predictions with useful information about the ice state for those who depend on sea ice
- How will current methods fare in future Arctic sea ice?
  - Rheology, brittle rheologies, DEM
  - Sub-grid-scale parameterisation (landfast ice, ITD)
  - Predictability of details (LKFs)