A comparison of two alternative approaches to modelling the sea ice floe size distribution

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Processes in the marginal ice zone (MIZ) are key to understanding summer ice retreat

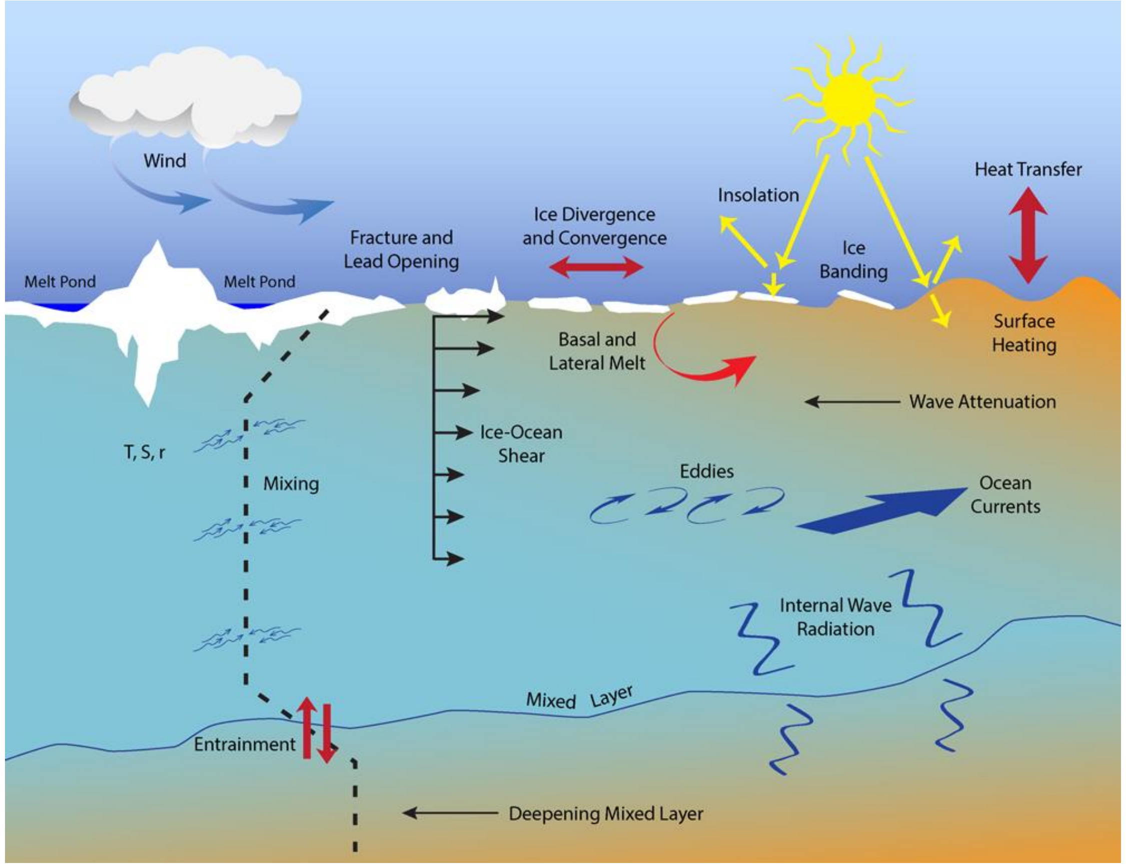


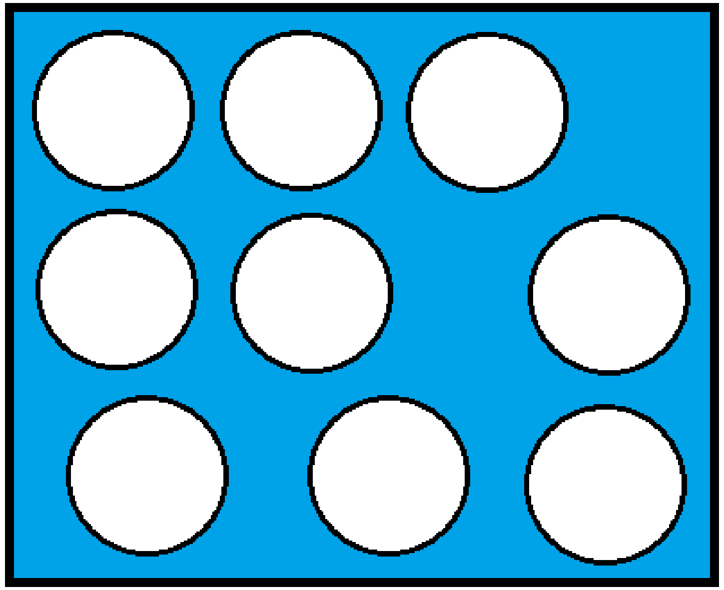
Figure obtained from Lee, C.M., S. Cole, M. Doble, L. Freitag, P. Hwang, S. Jayne, M. Jeffries, R. Krishfield, T. Maksym, W. Maslowski, B. Owens, P. Posey, L. Rainville, B. Shaw, T. Stanton, J. Thomson, M.-L. Timmermans, J. Toole, P. Wadhams, J. Wilkinson, and Z. Zhang, 2012. Marginal Ice Zone (MIZ) Program: Science and Experiment Plan, Technical Report APL-UW 1201. Applied Physics Laboratory, University of Washington, Seattle, September 2012, 48 pp.

To model the MIZ, interactions between the sea ice, atmosphere and ocean must all be considered e.g.

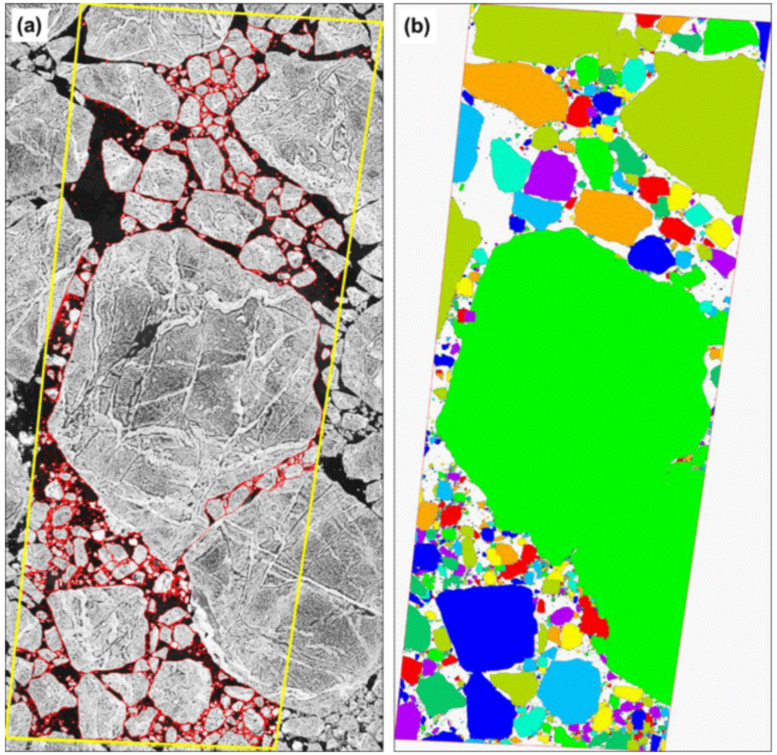
- Interactions between ocean surface waves and sea ice cover.
- Solar radiation on a mixed albedo surface.
- Sea ice-ocean-atmosphere surface fluxes.
- Wind stress on sea ice.

Floe size is important in the marginal ice zone

sea ice floes in models



observations of sea ice floes



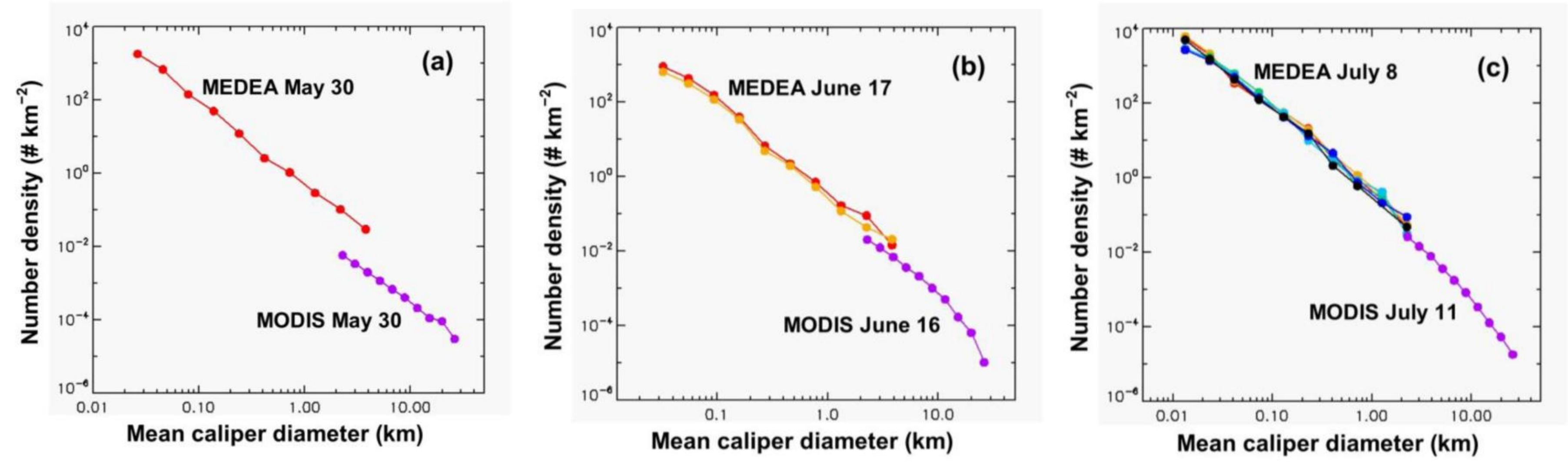
Plot on right obtained from: Stern, Harry L., Axel J. Schweiger, Margaret Stark, Jinlun Zhang, Michael Steele, and Byongjun Hwang. "Seasonal evolution of the sea-ice floe size distribution in the Beaufort and Chukchi seas." Elem Sci Anth 6, no. 1 (2018).

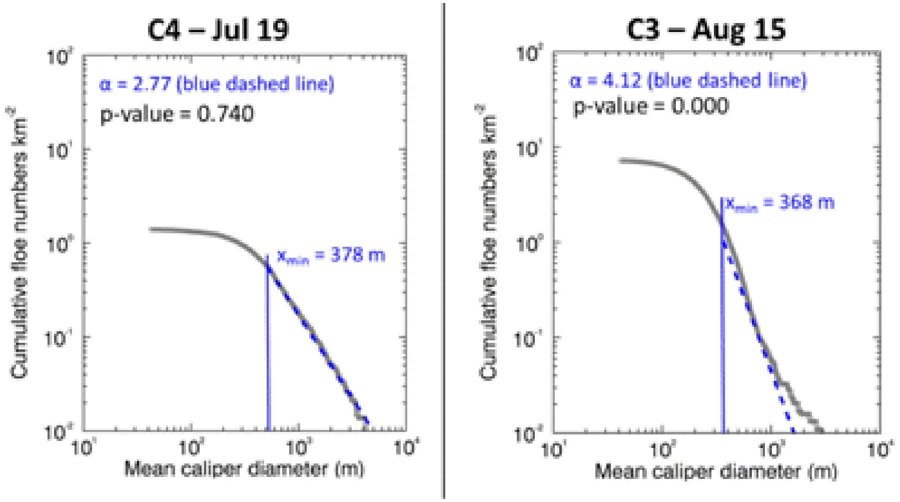
Currently sea ice models mostly assume a constant floe size.

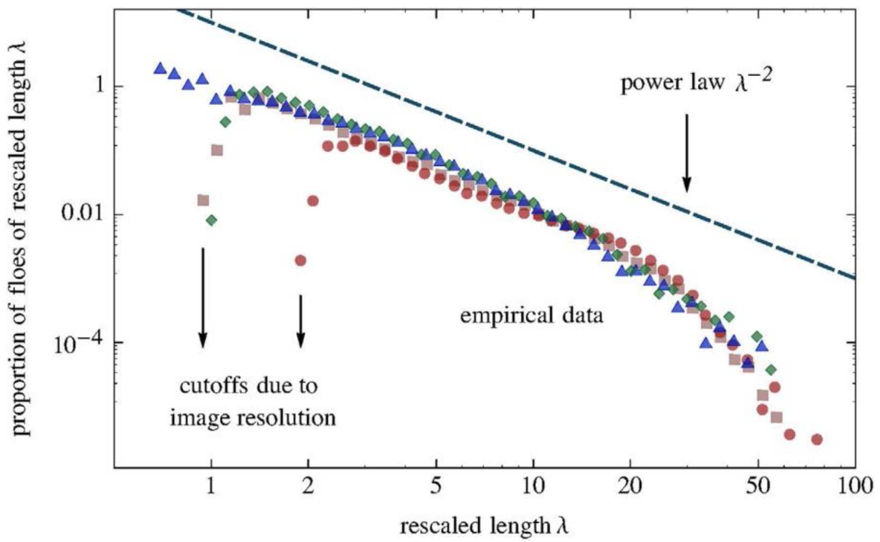
Floe size is important for several processes:

- Lateral melt volume
- Ice rheology
- Momentum transfer between the sea ice, atmosphere and ocean

Observations constrain the likely shape of the floe size distribution (FSD)







Plots obtained or adapted from (clockwise from top left):

Stern, Harry L., Axel J. Schweiger, Margaret Stark, Jinlun Zhang, Michael Steele, and Byongjun Hwang. "Seasonal evolution of the sea-ice floe size distribution in the Beaufort and Chukchi seas." Elem Sci Anth 6, no. 1 (2018).

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Hwang, Byongjun, Jeremy Wilkinson, Edward Maksym, Hans C. Graber, Axel Schweiger, Christopher Horvat, Donald K. Perovich et al. "Winter-to-summer transition of Arctic sea ice breakup and floe size distribution in the Beaufort Sea." Elementa Science of the Anthropocene 5 (2017).

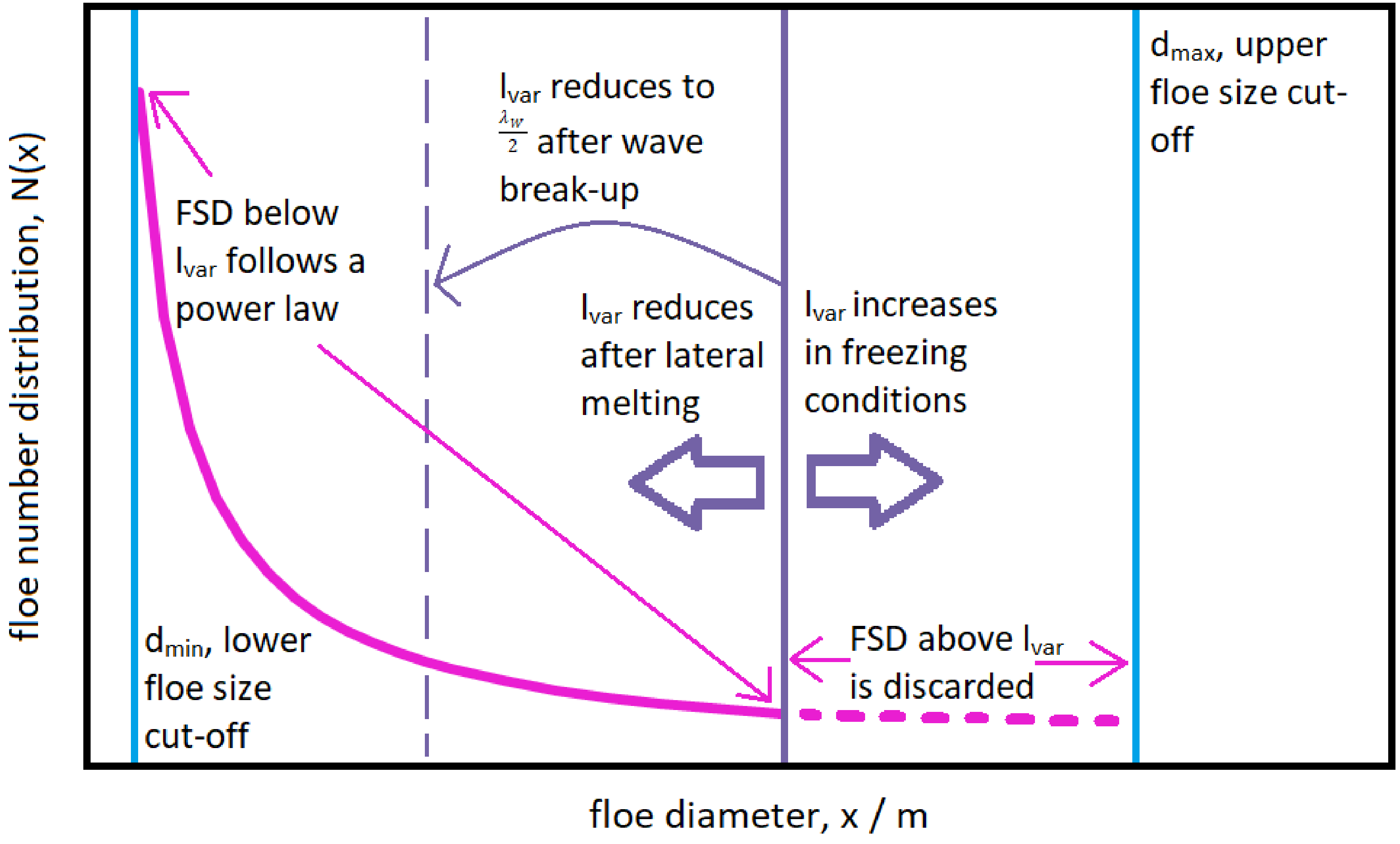
Overview of this talk

- Introduce two alternatives approaches to modelling the floe size distribution (FSD): a fitted power law model and a prognostic model.

- Compare the impact of each modelling approach on key sea ice metrics within the CICE (Los Alamos) sea ice model.

- Discuss the advantages and disadvantages of the different modelling approaches.

The fitted power law model imposes a power law onto the FSD with a fixed exponent (Bateson et al. 2020)



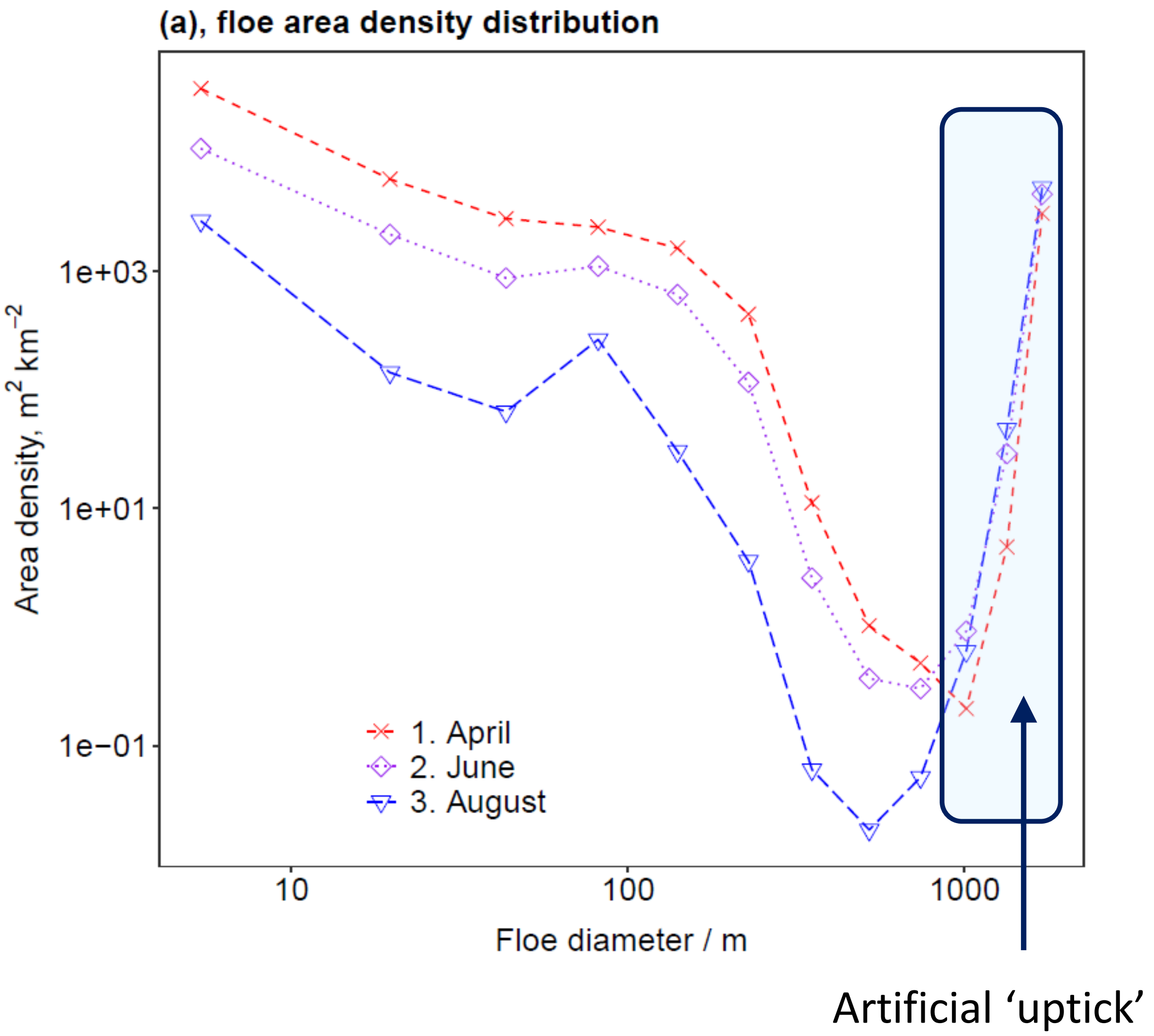
$$N(\,x \mid d_{min} \leq x \;\leq\; l_{var}\,) = Cx^{-\alpha}$$

The FSD model is adapted from an implementation developed at the National Oceanography Centre of the UK (NOC). The model includes a wave attenuation and floe breakup model adapted from waves-ice model of the Nansen Environmental and Remote Sensing Centre (NERSC) Norway, details are given by Williams et al. (2013a, 2013b).

The prognostic model (Roach et al., 2018, 2019) uses an FSD that does not make assumptions about the shape of the distribution

- Model assigns sea ice area to specific floe size-thickness categories.

- Several processes are parameterised:
  - Lateral melt and growth.
  - Advection.
  - Welding together of floes.
  - Wave break-up of floes.
  - Wave dependent floe formation.
  - Brittle fracture (new).



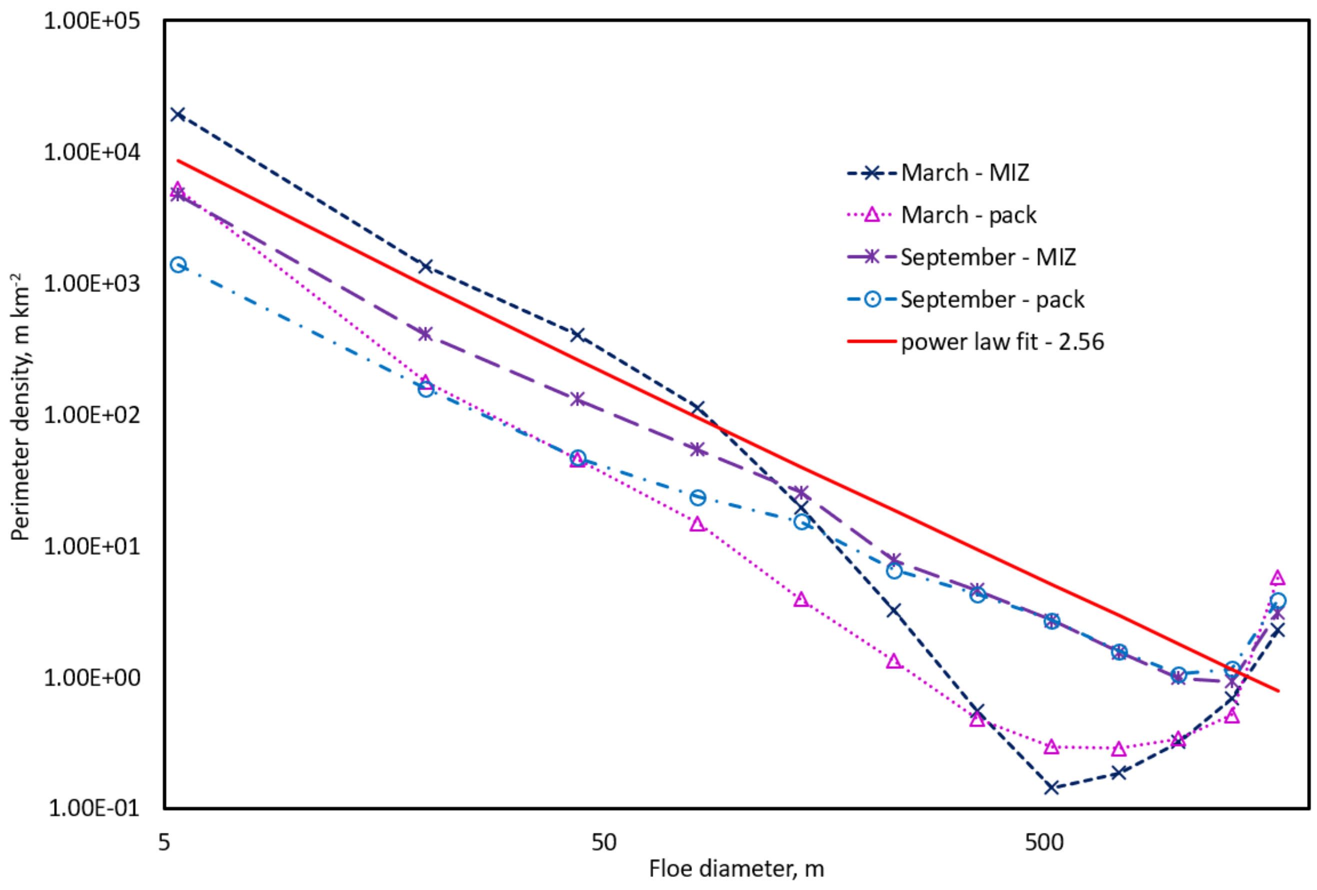
Model setup for comparison

- CPOM CICE sea ice model based on CICE v 5.1.2 with extra physics
- CPOM CICE-ML-FSD is a version of CPOM CICE with:
  - prognostic Mixed Layer (ML) [Petty et al., 2013]
  - *either* **power law FSD model** [Bateson et al., 2020]
    $d_{min} = 5.38$ m, $d_{max} = 1701$ m, $\alpha = -2.56$ (α value determined from observations)
  - *or* **prognostic FSD model** [Roach et al., 2018, 2019]
  - **reference** run uses a fixed floe size of 300 m
- Stand-alone, atmosphere-forced runs over Arctic Ocean, NCEP-2 atmosphere
- ORCA1 grid
- Ocean spectra (significant wave period and height) from ERA-interim
- Ocean properties restored to MYO-WP4-PUMGLOBAL-REANALYSIS-PHYS-001-004 (MYO) reanalysis

- Spin up from 1980-1999, **analysis from 2000-2016**

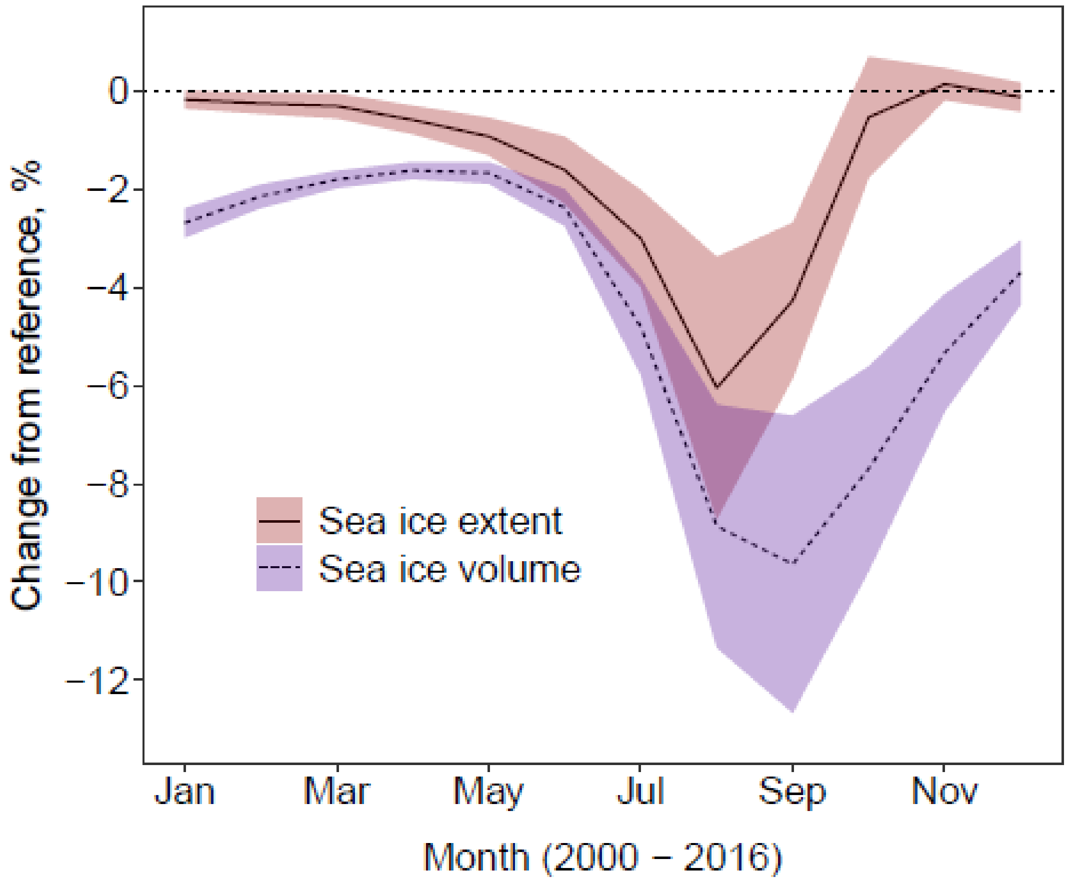
Emergent distribution from prognostic model broadly follows a power law but shows significant spatial and temporal variability

- Plot of emergent perimeter density distribution per unit sea ice area (2000 – 2016 mean) from prognostic model.
- A power law (exponent determined from observations) gives a reasonable fit to the emergent distributions.
- The perimeter density in the smaller floe size categories decreases over the melting season from March to September.

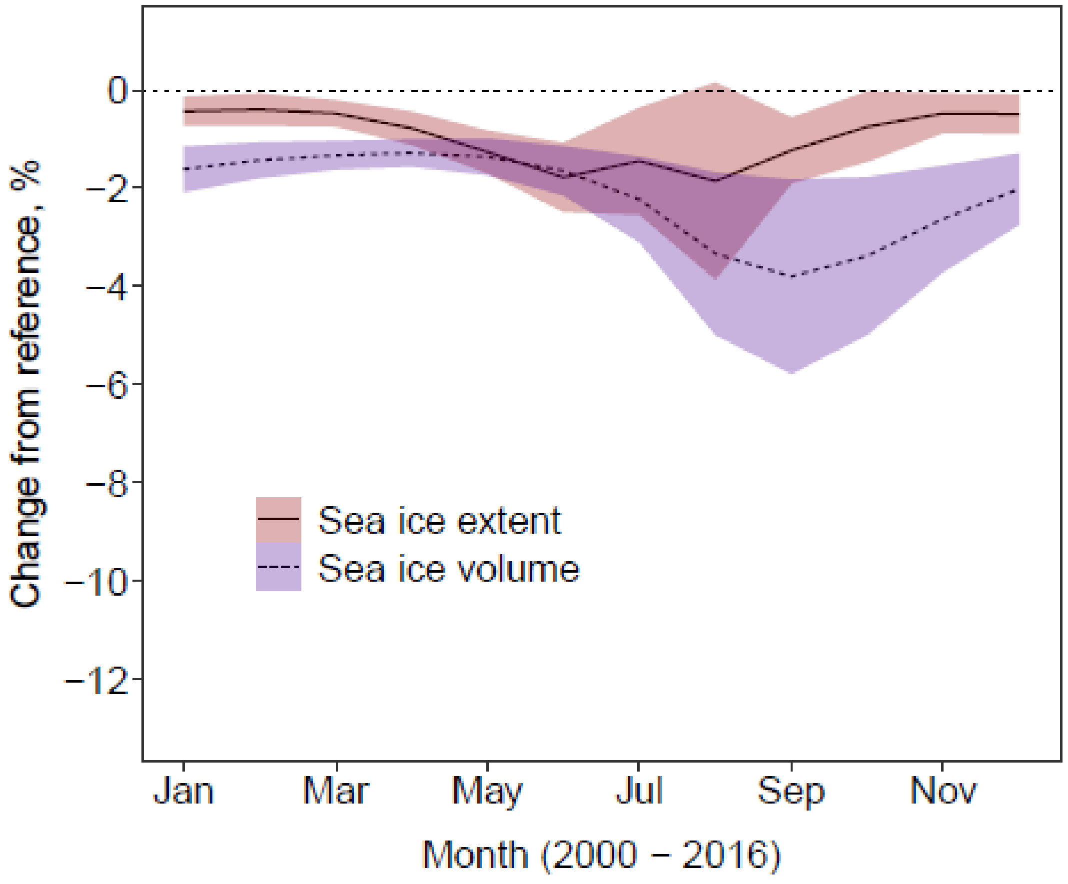


The WIPoFSD model has a larger impact on the sea ice mass-balance than the prognostic model

power law FSD – reference



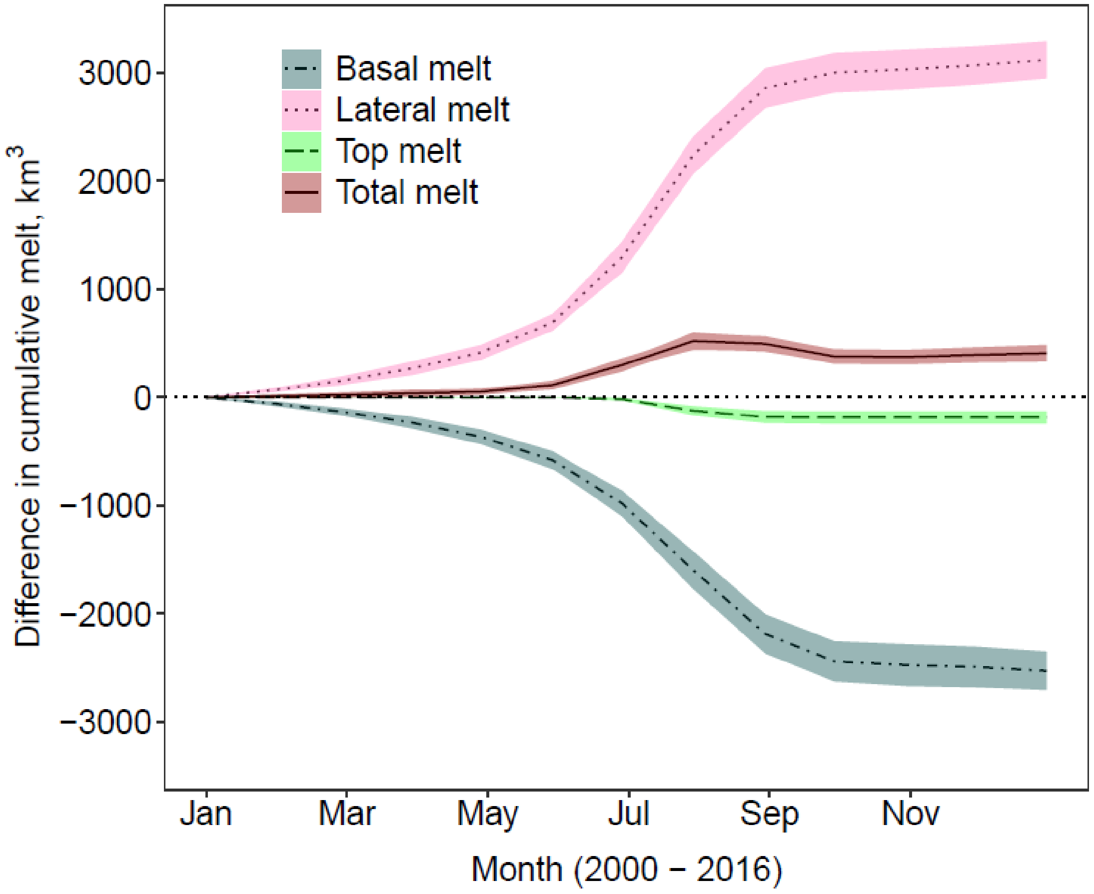
prognostic FSD – reference



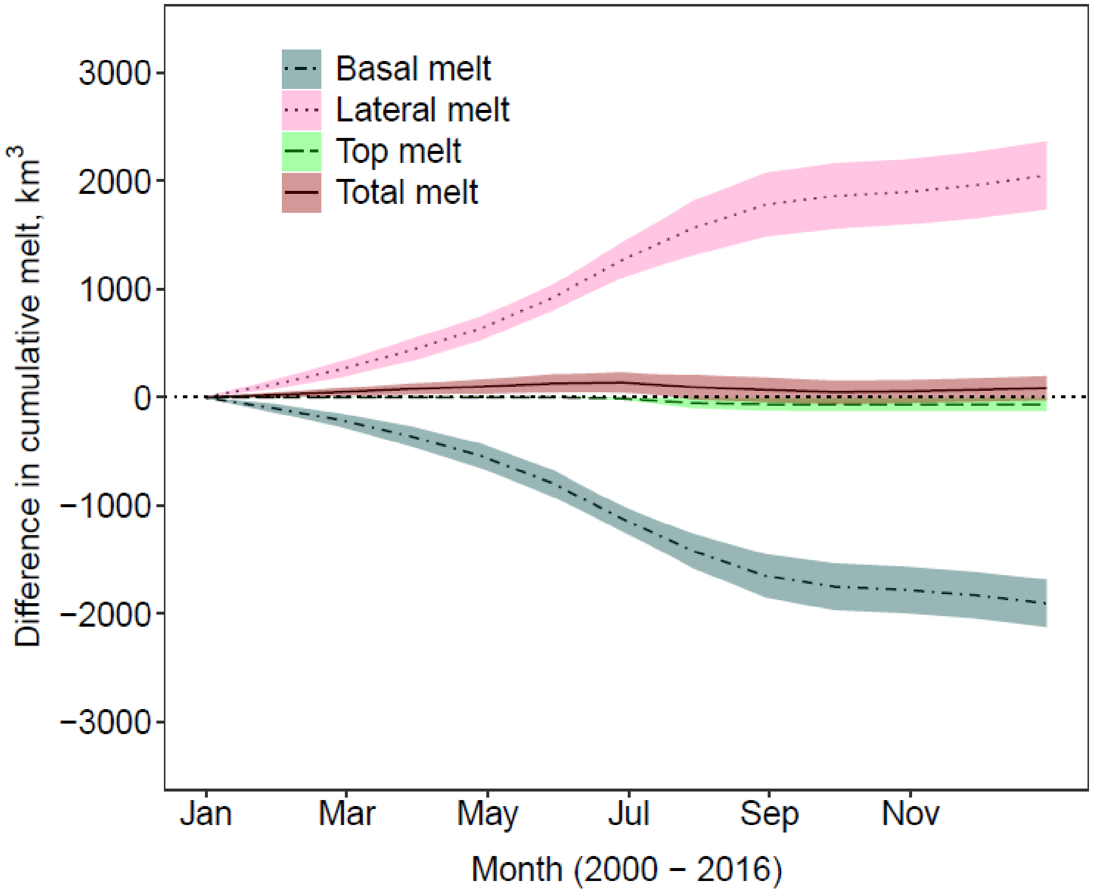
Plots show the difference in the sea ice extent and volume for simulations with an FSD model compared to simulations without.

The power law FSD produces a higher increase in the cumulative lateral melt than the prognostic FSD, particularly in the later melt season

power law FSD – reference



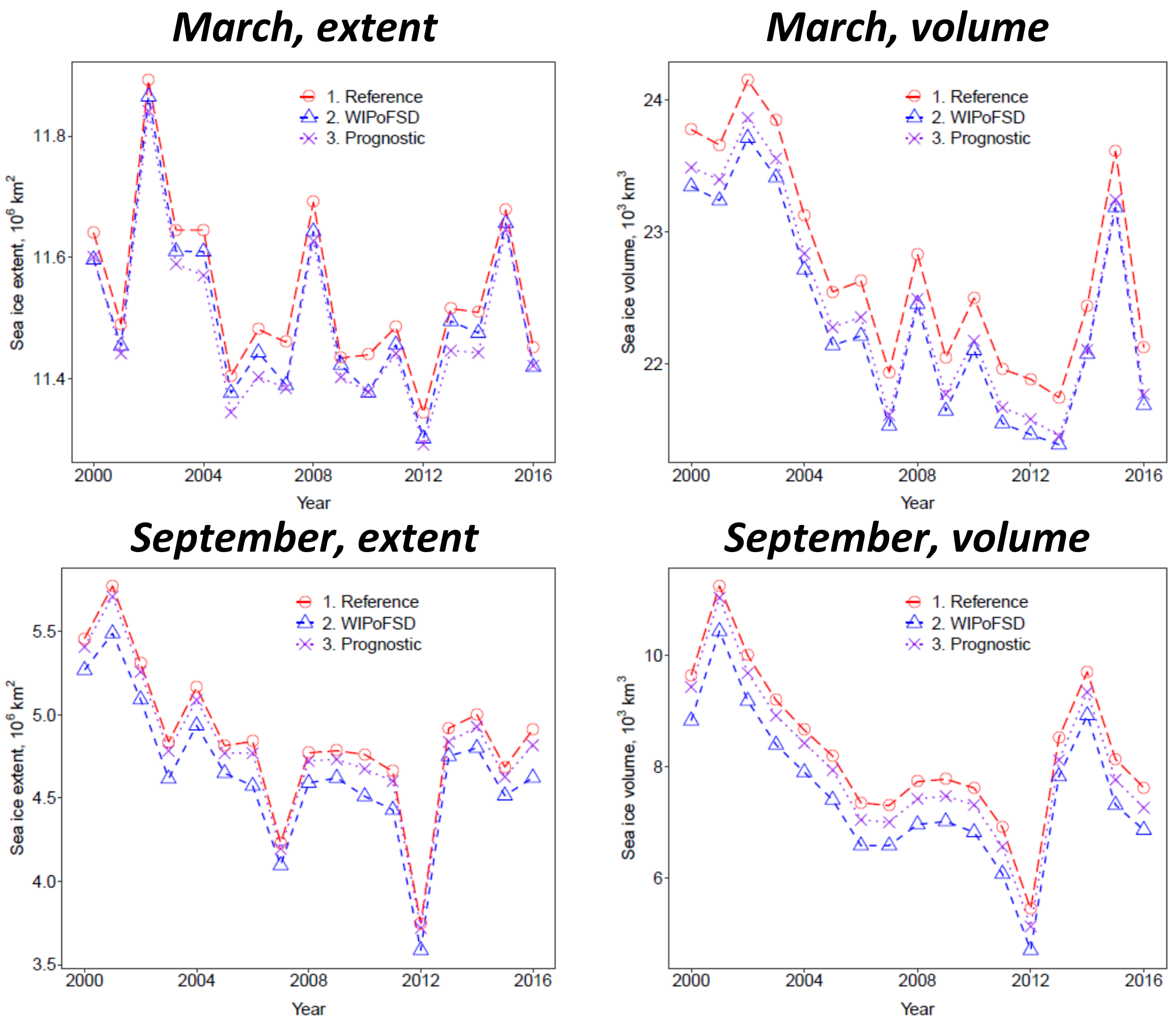
prognostic* FSD *– reference



Plots show the difference in the cumulative melt for simulations with and without an FSD model

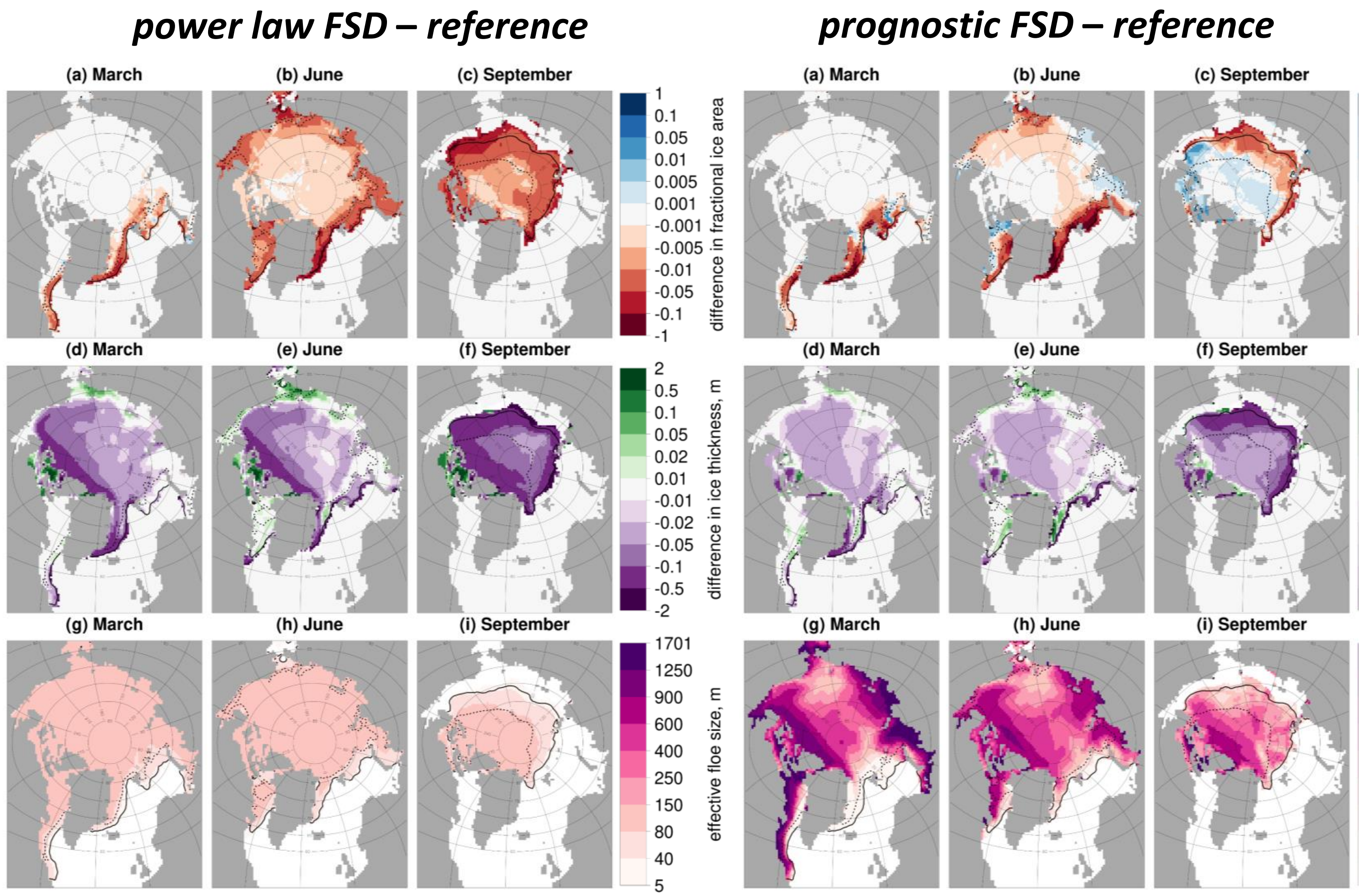
The inclusion of either FSD model does not have a large impact on the interannual variability of the sea ice extent or volume

- Comparison of total sea ice extent and volume in March and September (to represent minimum and maximum sea ice extent).
- Both FSD models produce a reduction in extent and volume but no clear change in interannual variability.
- The prognostic model produces a lower sea ice extent in March but higher in September compared to the power law model.



The prognostic model has a less homogeneous impact on the sea ice extent and thickness compared to the WIPoFSD model

- Effective floe size = perimeter-weighted average floe size.
- Both FSD models produce significant reductions in the sea ice thickness, particularly in September.
- The prognostic FSD model shows a higher discrimination between the MIZ and pack ice.
- The different spatial impacts of the FSD models can be linked to the larger spatial variability in the effective floe size for the prognostic model.



Advantages and disadvantages of the power law and prognostic FSD models

Power law FSD model

Simple model – easier to constrain mechanisms that cause the impacts.

Better fit to observations.

Assumption of a fixed power law not necessarily valid across all floe sizes (see Horvat et al., 2019).

Evidence exists that the fitted exponent to the power law varies through the year (Stern et al., 2018).

Prognostic FSD model

The impact of processes on the FSD can be represented in a physically realistic manner.

Able to capture more variability in FSD processes across the sea ice cover.

Can only produce a physically realistic distribution if all relevant processes are included in the model.

Model is data intensive – standard setup requires 60 new floe size-thickness outputs.

References

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