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Feedbacks emerging from variable floe size in the Arctic sea ice cover

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British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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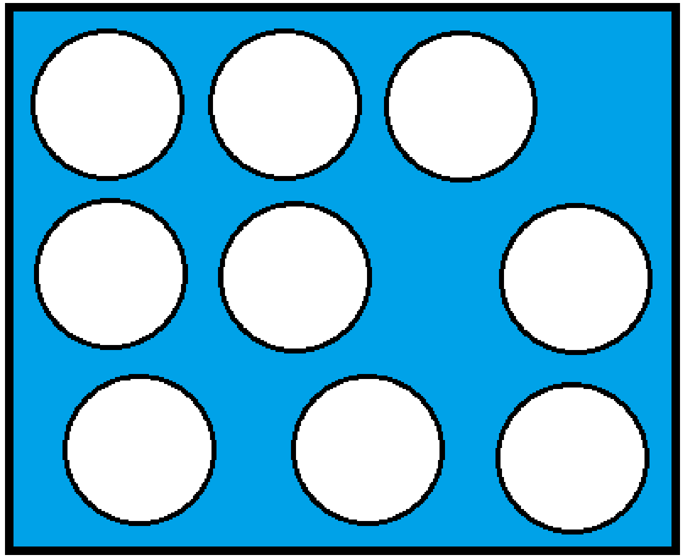
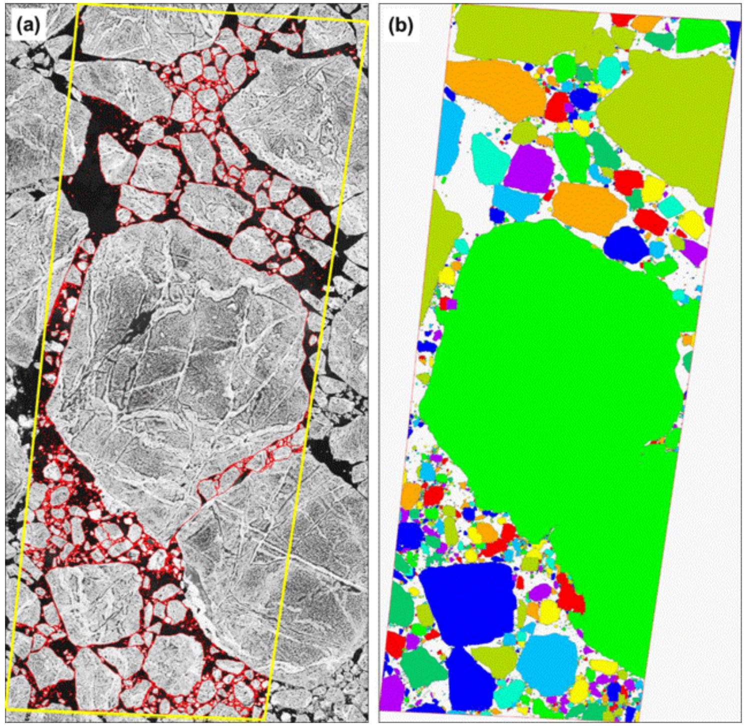
Sea ice is composed of discrete units called floes

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). Plot reproduced under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

There have been several recent efforts to introduce a model of floe size distribution (FSD) into sea ice models.

Floe size can impact several processes e.g.

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

Floe size therefore also has a potential to impact feedbacks within the Arctic system. Of particular interest here is the ice-ocean albedo feedback mechanism.

Overview of presentation

- There have been several recent efforts to model the floe size distribution (FSD) in sea ice models such as the Los Alamos sea ice model, or CICE.

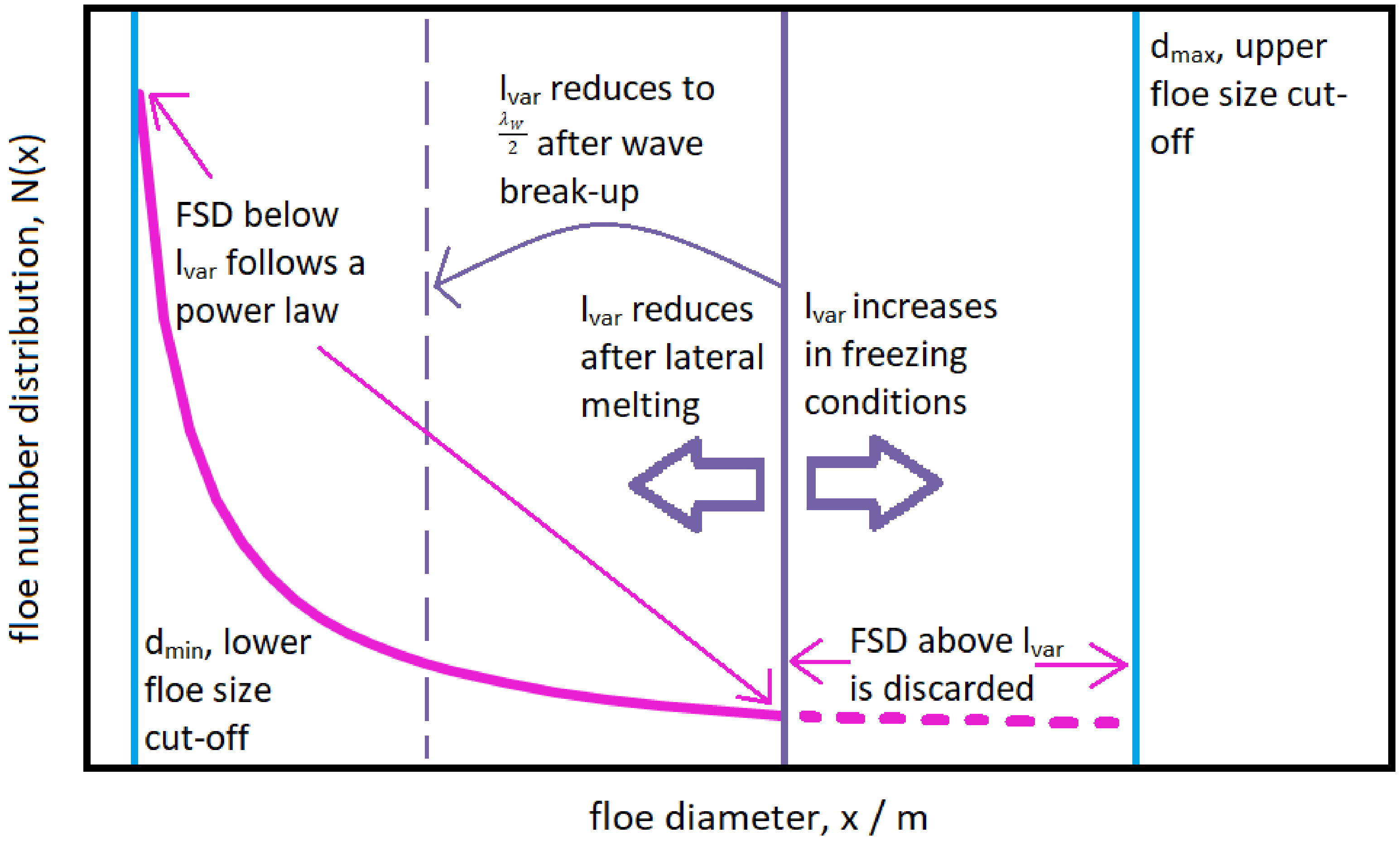
- Here we implement two different FSD models in CICE: the WIPoFSD model of Bateson et al. (2020), which assumes a power law, and the prognostic FSD model of Roach et al. (2018, 2019), which allows the shape of the FSD to emerge at process level.

- We consider how the two FSD models impact sea ice over a pan-Arctic scale, and find limited evidence for a substantial ice-ocean albedo feedback effect despite large increases in lateral melt.

- We explore changes at local scales and identify case studies where local floe conditions may enable a more substantial change in albedo feedback to emerge.

- We finally present results from sensitivity studies using the prognostic model to consider FSD states that are likely to be associated with larger increases in the albedo feedback effect.

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



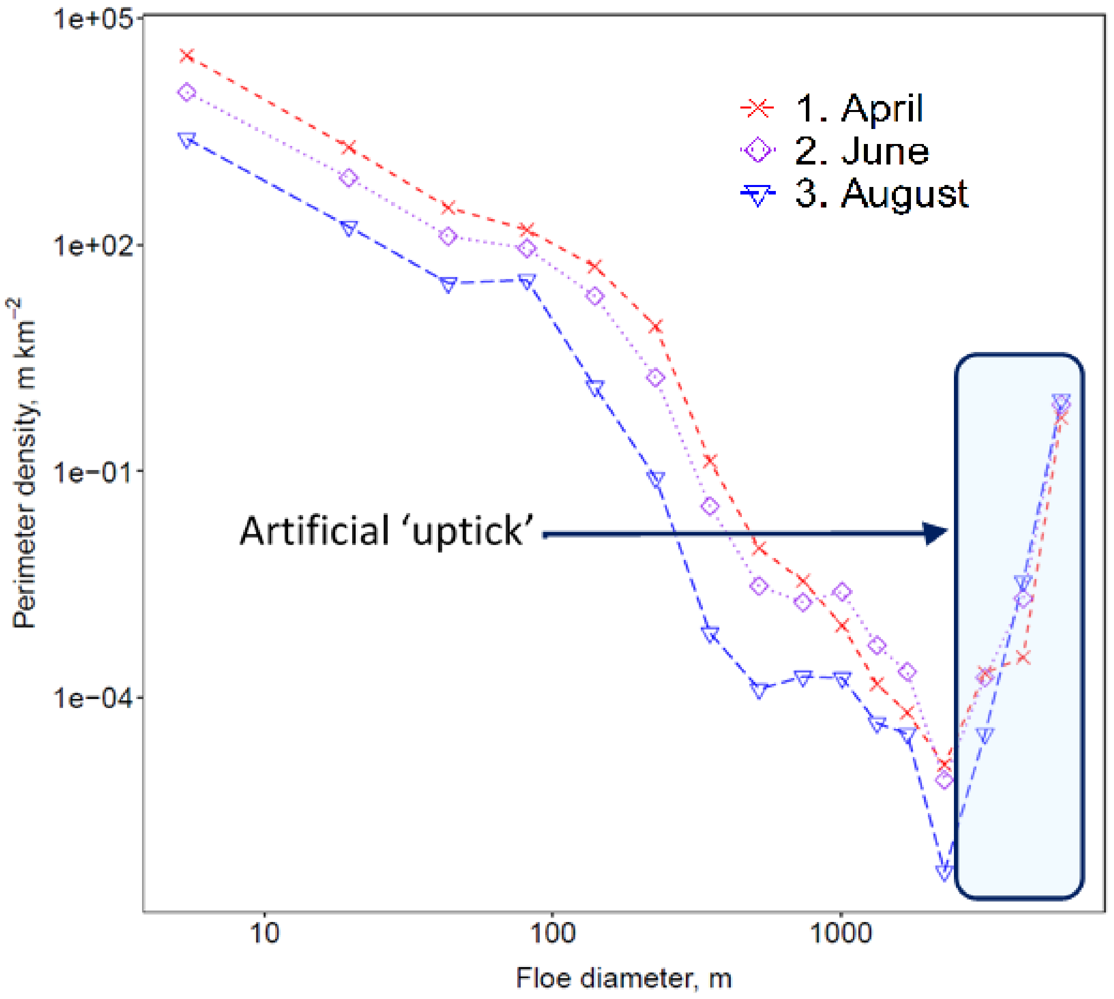
$$N(\, x \mid d_{min} \leq x \leq l_{var}\,) = Cx^{\alpha}$$

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).



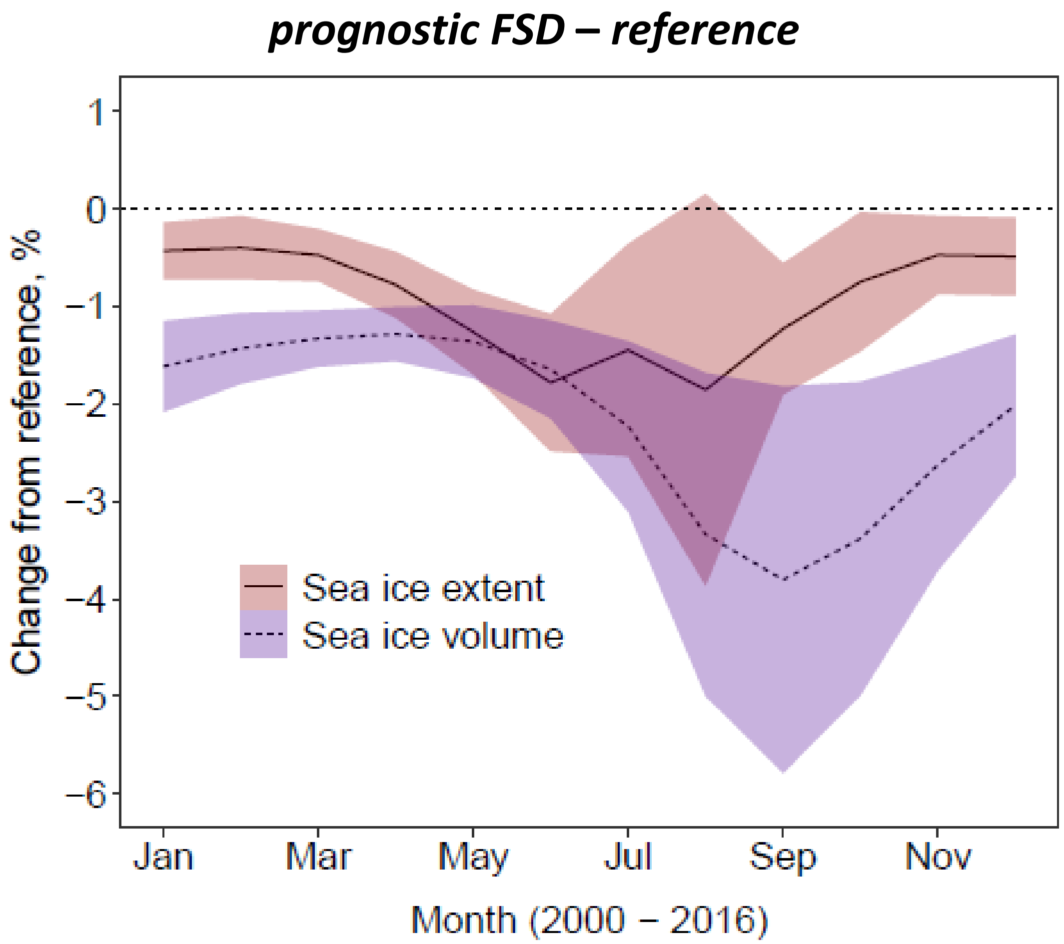
Description of simulations

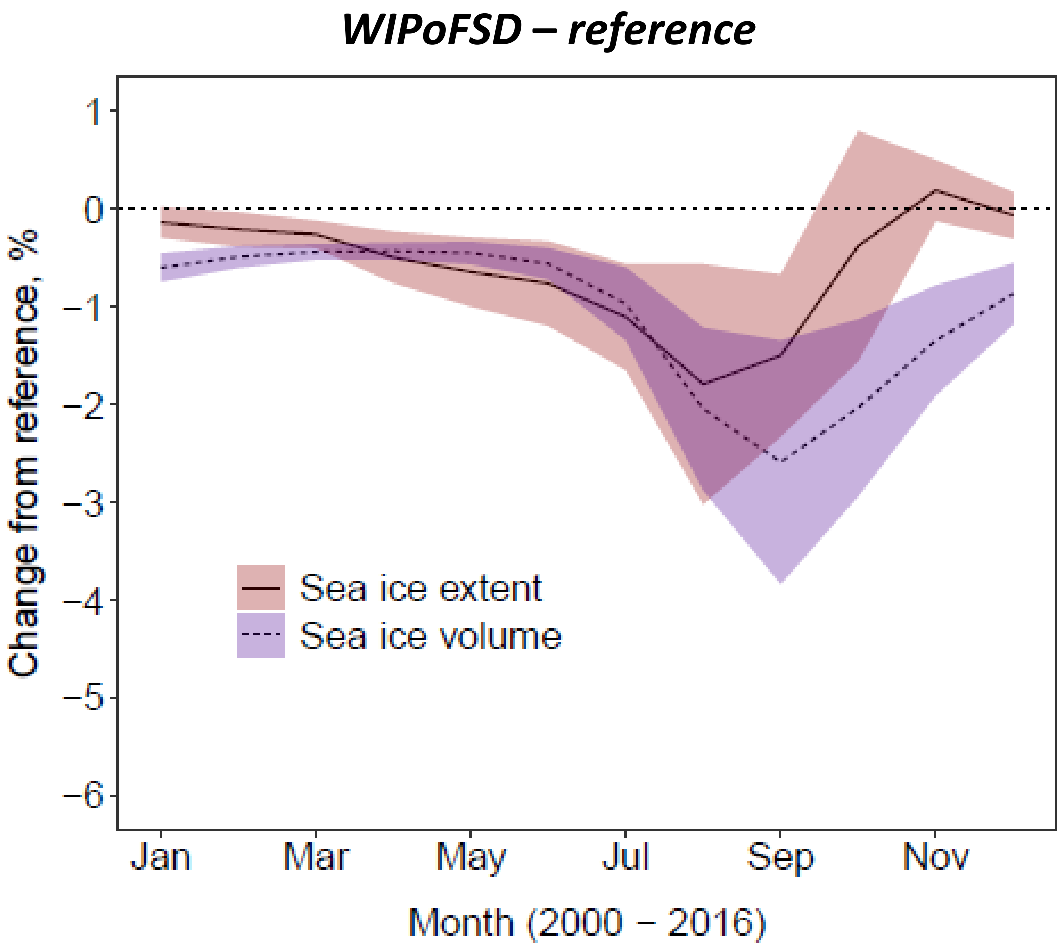
- CPOM CICE-ML-FSD is a version of CPOM CICE with:
  - prognostic Mixed Layer (ML) [Petty et al., 2014]
  - form drag [Tsamados et al., 2014]
  - *either* **WIPoFSD (power law) model** [Bateson et al., 2020]
    $d_{min} = 5.38$ m, $d_{max} = 30000$ m, $\alpha = -2.56$ (α value determined from observations)
  - *or* **prognostic FSD model** [Roach et al., 2018, 2019] **+ brittle fracture**
  - **reference** run uses a fixed floe size of 300 m

- Stand-alone, atmosphere-forced runs over Arctic Ocean.

- Spin up from 1980-1999, **analysis from 2000-2016** (averaged over this period unless otherwise stated).

Simulations including FSD models show changes in sea ice extent and volume of up to 4% in summer

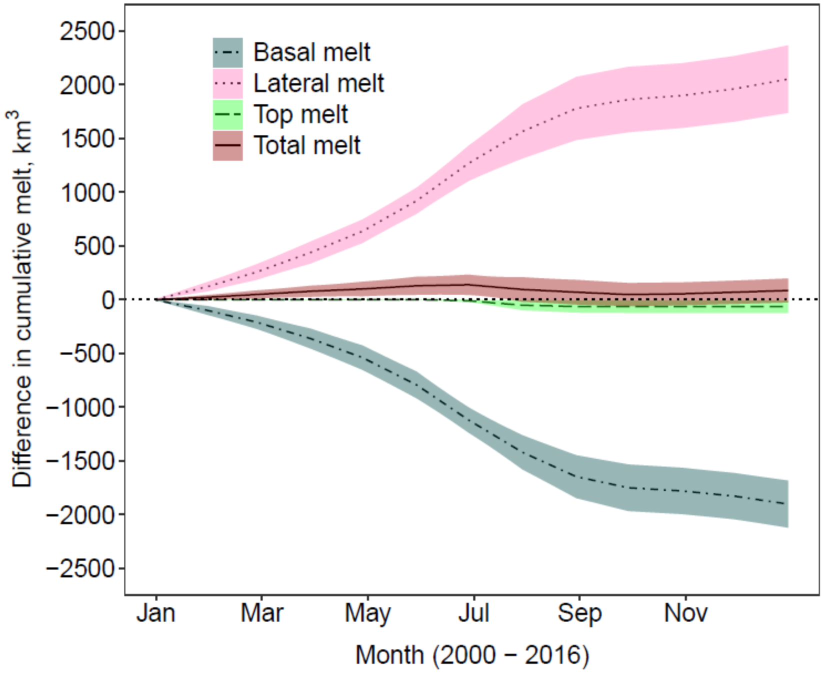




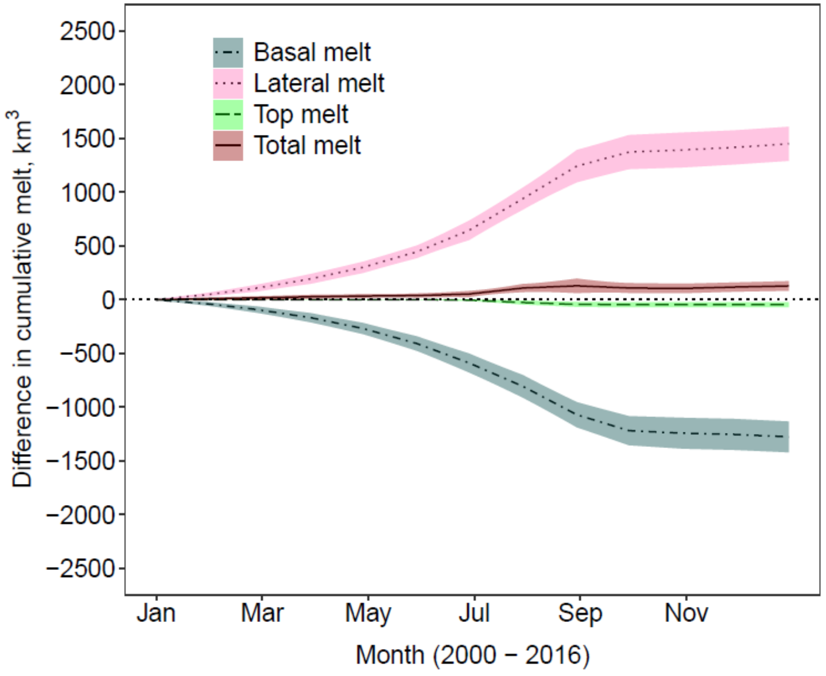
Plots show the difference in the sea ice extent and volume for simulations with an FSD model compared to simulations without.

Both FSD models produce only a small increase in total melt, suggesting limited impact on pan-Arctic albedo feedback

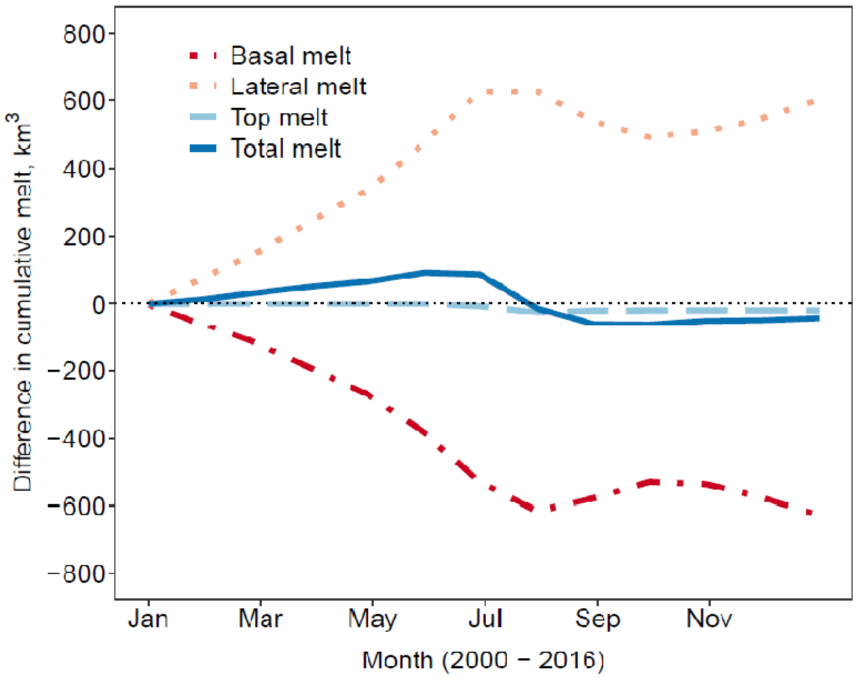
prognostic* FSD – *reference



power law FSD* – *reference



prognostic* FSD – *power law FSD



Plots show the difference in the cumulative melt between the different simulations

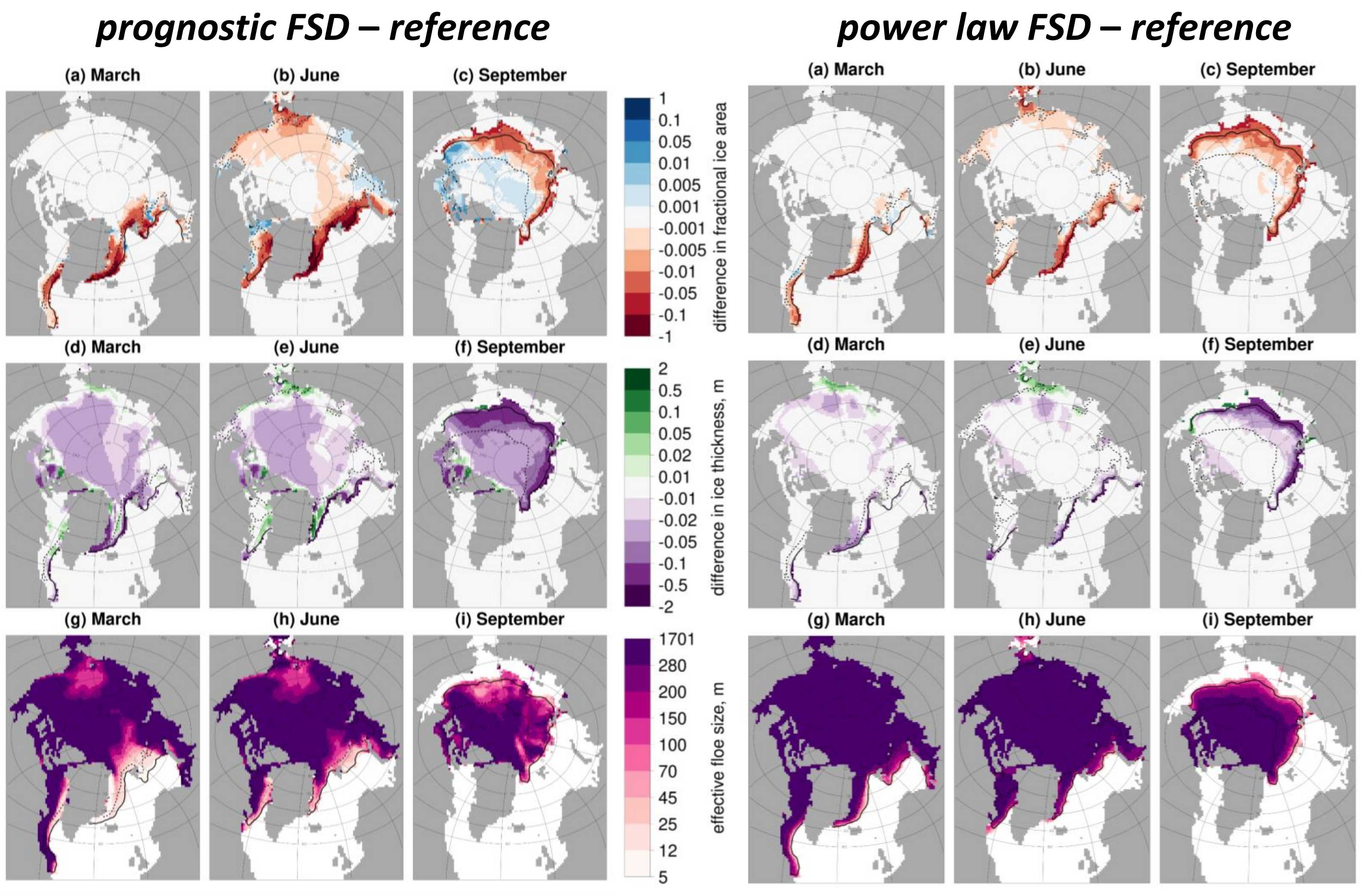
Impact of FSD models over the Arctic sea ice cover varies significantly; the largest changes can be found in the MIZ

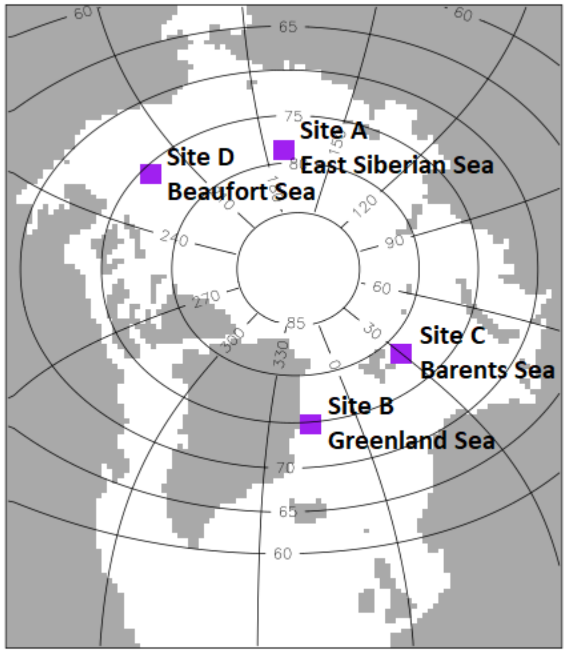
- Effective floe size (l_{eff}) = single floe size with same perimeter density as FSD.

- Both FSD models produce significant reductions in the MIZ sea ice thickness and ice area fraction, though with different seasonality.

- Generally changes in pack ice are small to negligible.

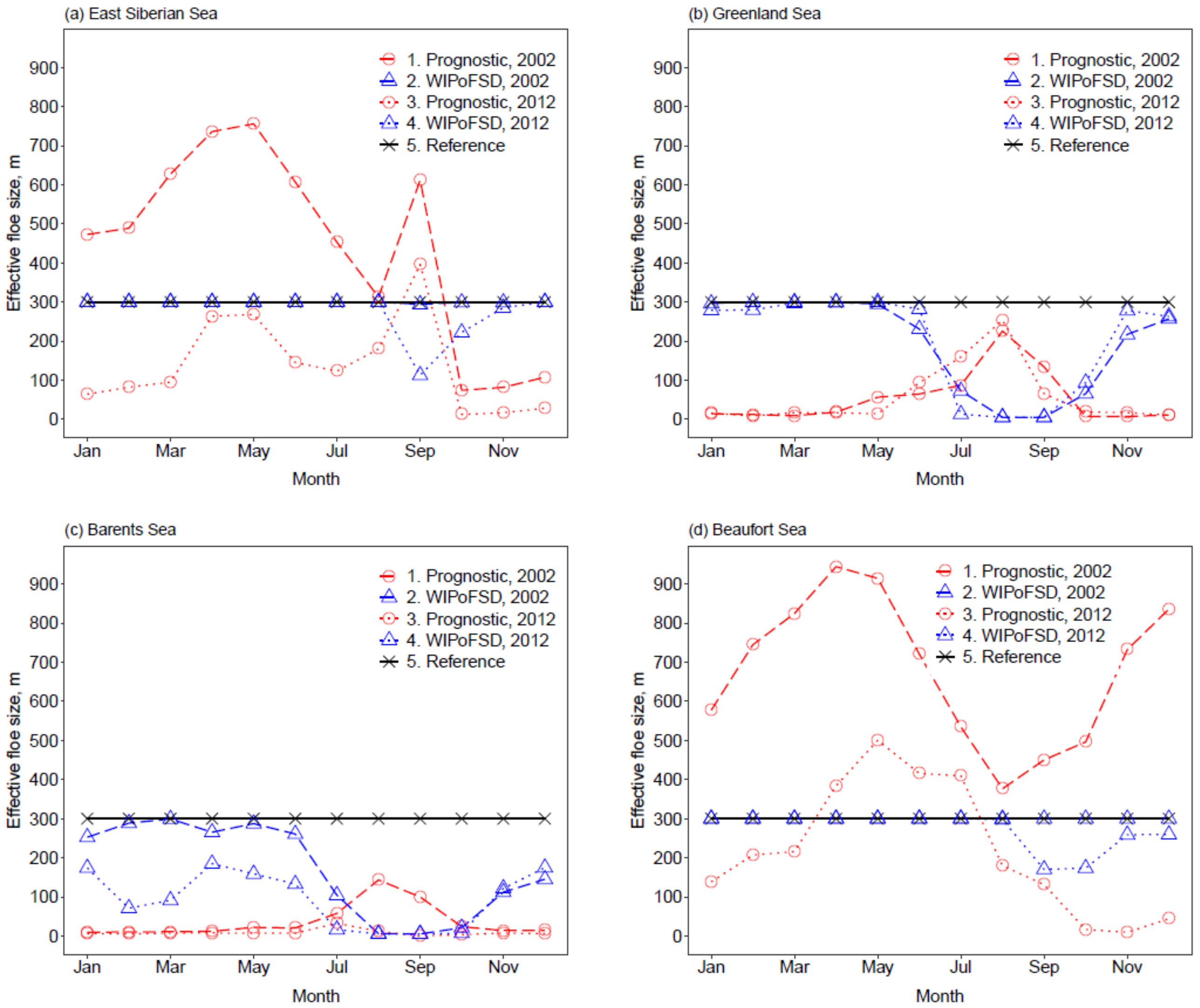
- Spatial distribution in l_{eff} corresponds well to regions of larger sea ice change, though more for ice area fraction than thickness.





We can identify regions of potentially large FSD impacts using timeseries in effective floe size

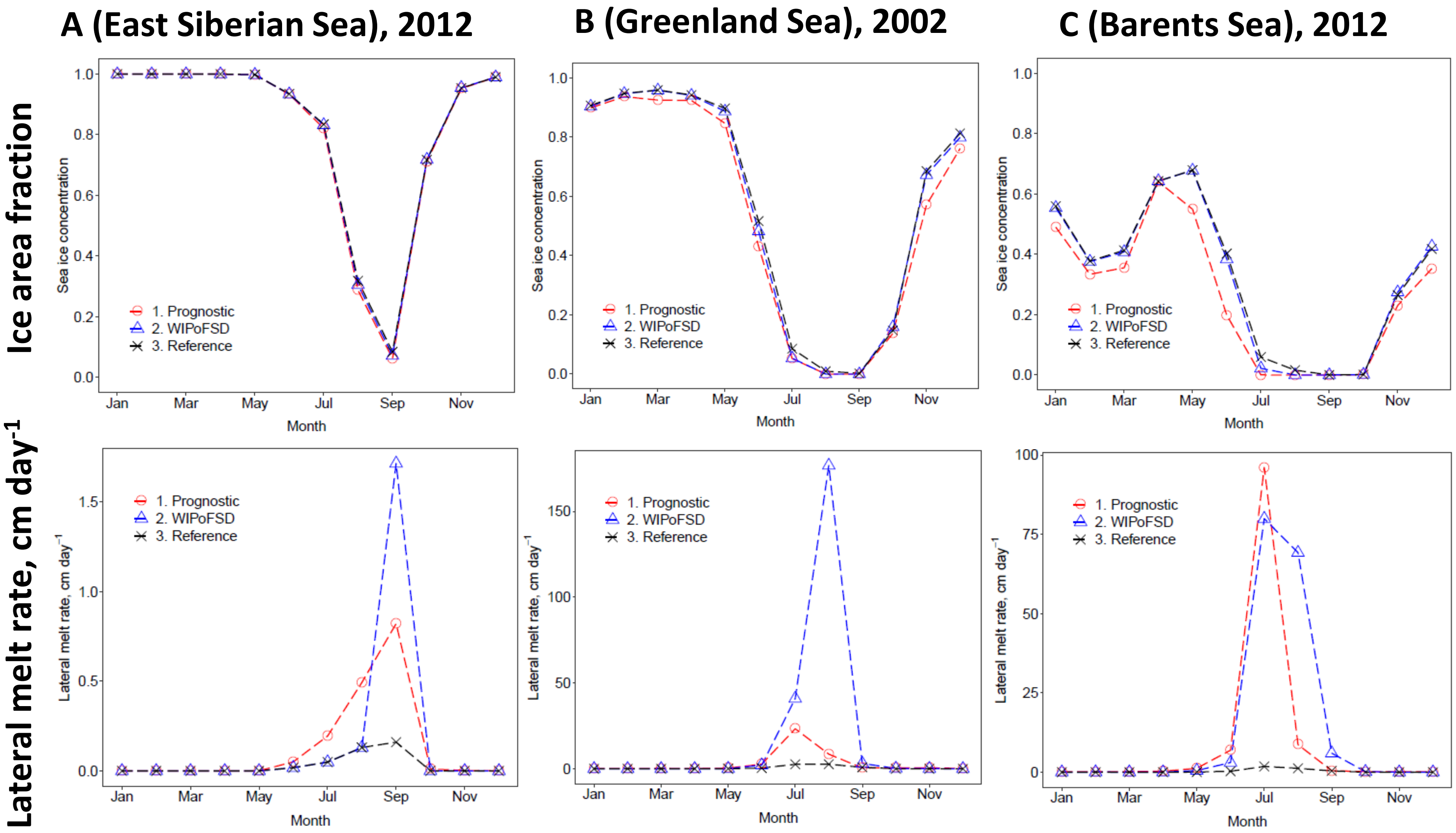
Plots show annual evolution of l_{eff} in 2002 and 2012, averaged over 4 different 5 x 5 grid cells.



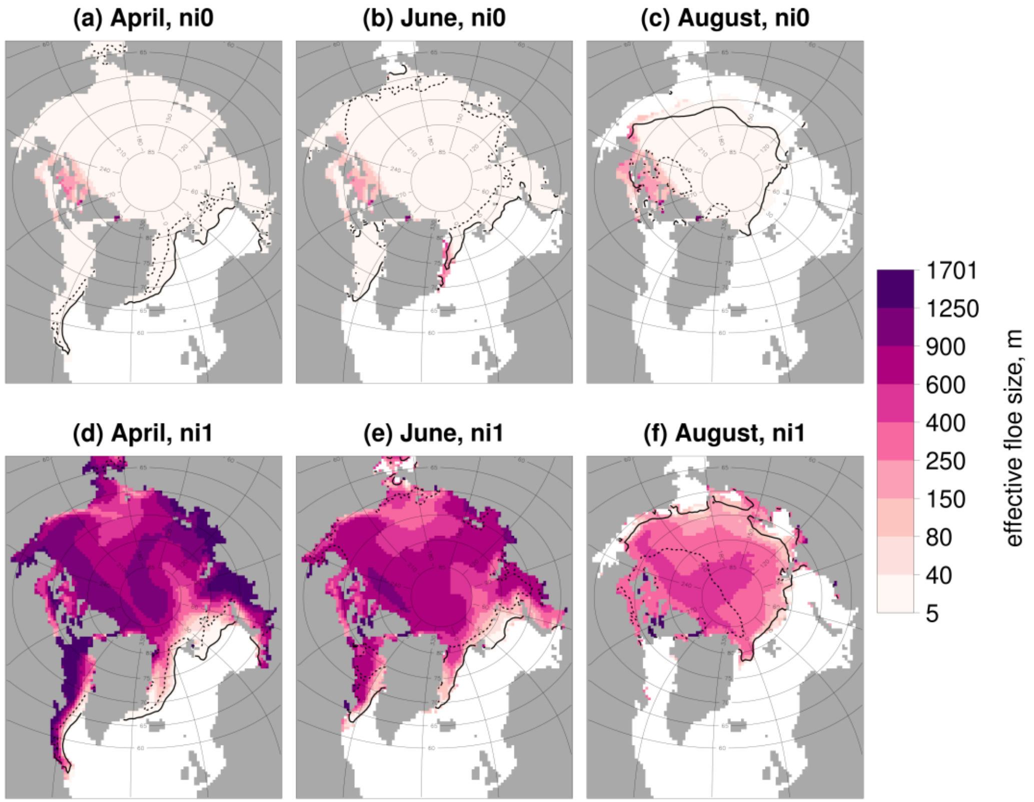
- Differences emerge between the two models due to different treatments of floe formation and growth processes (restoring vs explicit treatment).
- Increase in l_{eff} in August for prognostic model driven by melt out of smallest floes in distribution – physically realistic but no observational evidence.
- Highest FSD impacts expected for sustained low values of l_{eff} e.g. Greenland Sea in 2002 (prognostic), and Barents Sea in 2012 (both).

Potential for significant albedo feedback only in cases where there is a substantial increase in lateral melt rate i.e. where l_{eff} is small

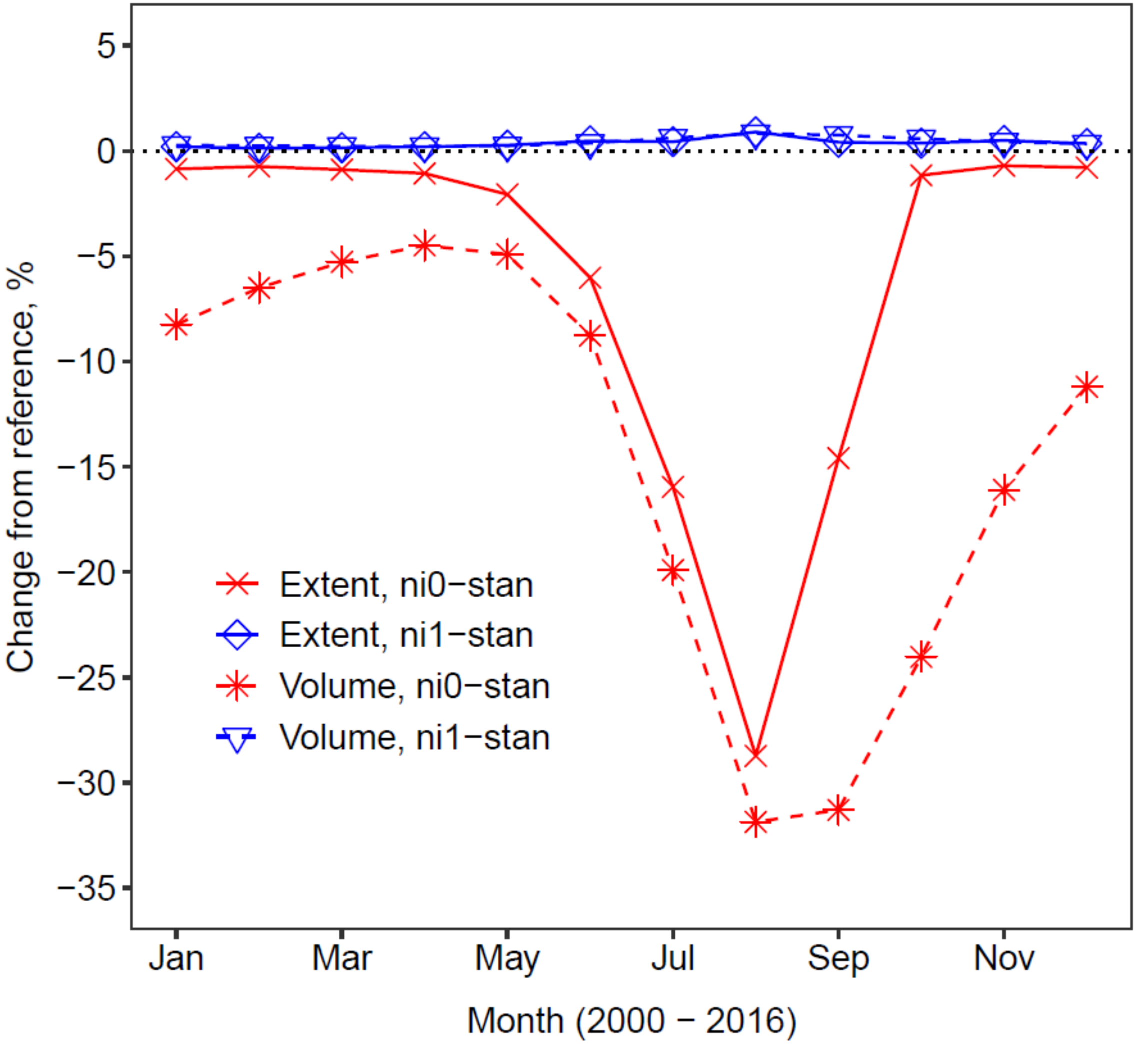
- Potential for albedo feedback where reduction in ice area fraction compared to reference is substantial.
- Large increases in lateral melt rate (e.g. WIPoFSD in case B) insufficient to drive changes in ice area fraction – increase must occur in early melt season (e.g. prognostic in case C).
- Sustained low values of l_{eff} through early melt season prerequisite for albedo feedback potential.
- Co-temporal increase in lateral melt not only factor driving differences in concentration during melt season.
- Evidence of additional feedback via slower sea ice freeze-up (e.g. B).



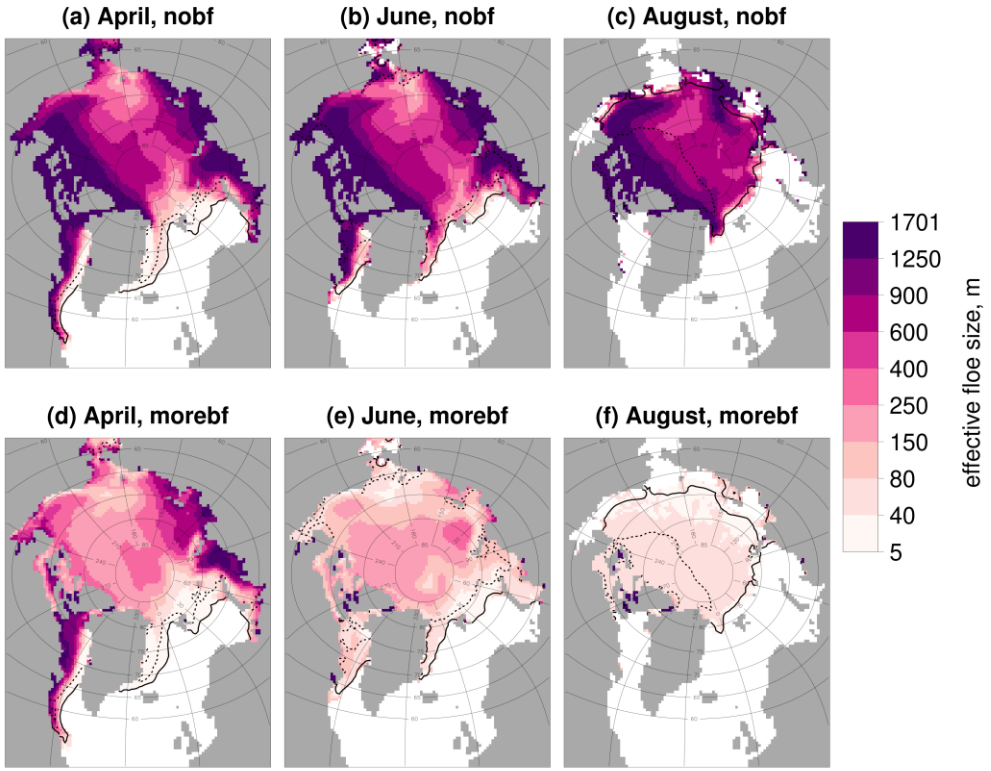
Simulations where all floes form as pancakes show small l_{eff} and large impacts on mass balance i.e. potential for albedo feedback

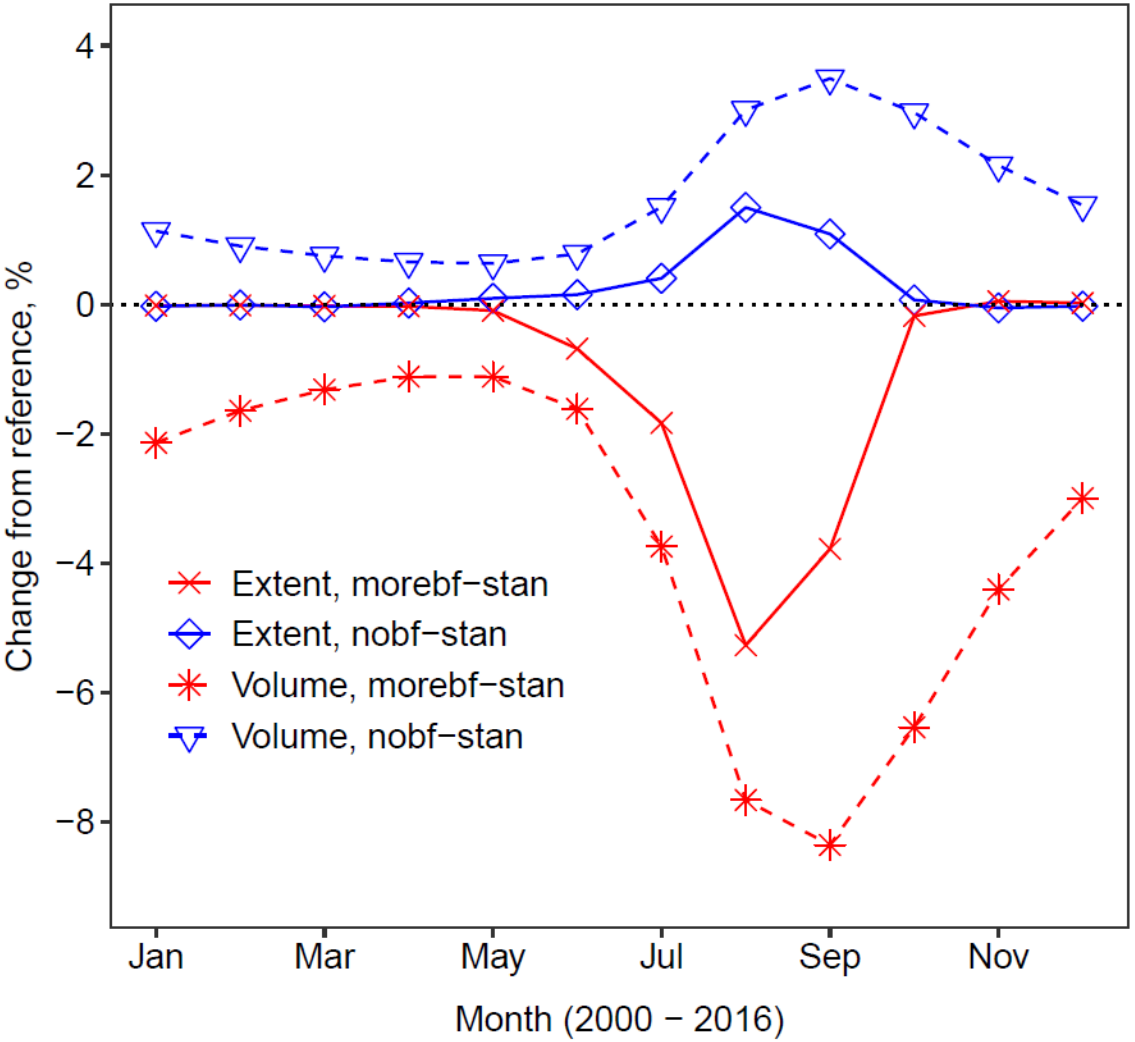


Plots show results from sensitivity studies.
ni0 = New floes form as pancakes.
ni1 = New floes form in the largest size category.



Similarly, enhanced floe fragmentation may also produce the conditions necessary for significant albedo feedback





Plots show results from sensitivity studies.
nobf = Simulation has no brittle fracture scheme.
morebf = Brittle fracture impact on FSD shape is increased.

Conclusions

- Introduction of floe size distribution (FSD) models in sea ice models has produced direct impacts on key sea ice metrics such as extent and volume, but may also influence sea ice feedback processes.
- In particular, increased lateral melt may enhance the ice-ocean albedo feedback mechanism.
- Both FSD models considered produced large increases in lateral melt, but small increases in total melt i.e. no evidence of substantial albedo feedback resulting from FSD inclusion at pan-Arctic scales.
- Case studies over smaller regions of sea ice cover show potential for increased albedo feedback if lateral melt increase is during early melt season i.e. sustained small floes during this period.
- Regions of pancake ice formation or enhanced floe fracture (to a lesser extent) could produce necessary conditions for substantial influence on ice-ocean albedo feedback.
- Coupled simulations needed to fully explore how the FSD impacts sea ice-ocean and atmospheric feedbacks.

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