Constraining CMIP6/CESM2 sea ice simulations with ICESat-2

Alek Petty[1], Chris Cardinale[1], Maddie Smith[2]

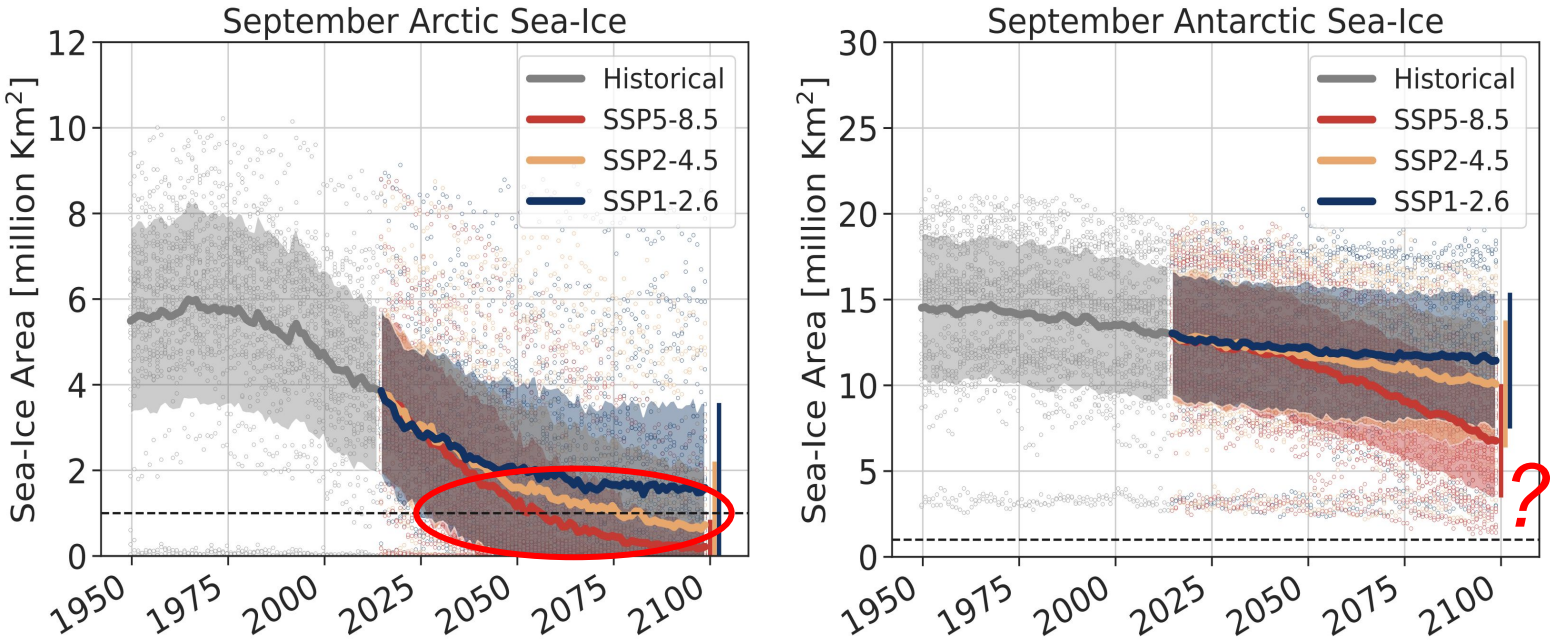


Petty, A. A., C. Cardinale, M. Smith, Constraining CMIP6 sea ice simulations with ICESat-2, submitted to Geoscientific Model Development.

NASA ROSES 2022 solicitation: *A.32 Studies with ICESat-2*
80NSSC23K1253

[1]ESSIC, University of Maryland, College Park, MD, USA
[2]WHOI, Falmouth, MA, USA

Future sea ice projections show wide inter-model spread



Figures by C. Cardinale; based on figures from SIMIP, 2020 and Roach et al., 2020

Various sea ice assessment/calibration methods out there!

Model exclusion: SIMIP Community (2020)/IPCC AR6/Roach et al., (2020).

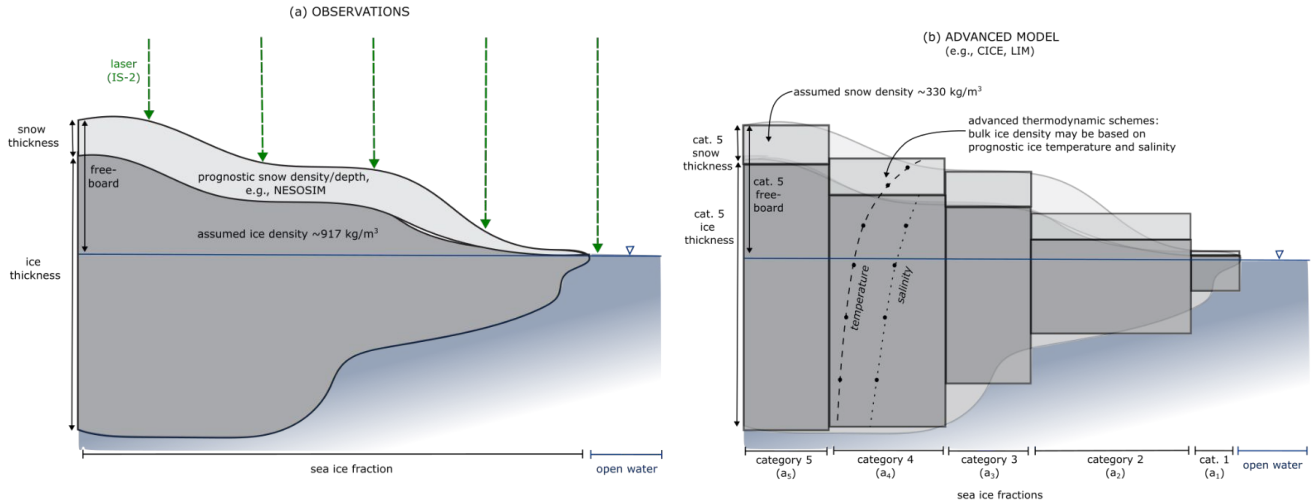
Model recalibration: Bonan et al., (2021), Kim et al., (2023), Topal and Ding (2023).

Model re-tuning!?: Kay et al., (2022)

Model weighting by plausibility? See less of that for some reason..?

Depends heavily on the ultimate goal (e.g. Notz et al., 2015).

Integrate new observations from ICESat-2



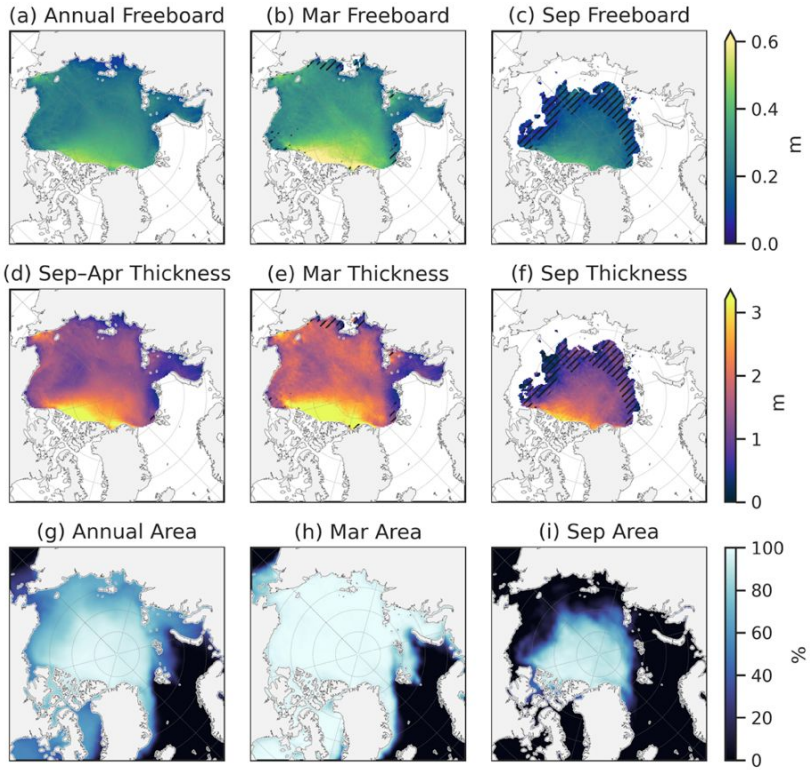
Pros:

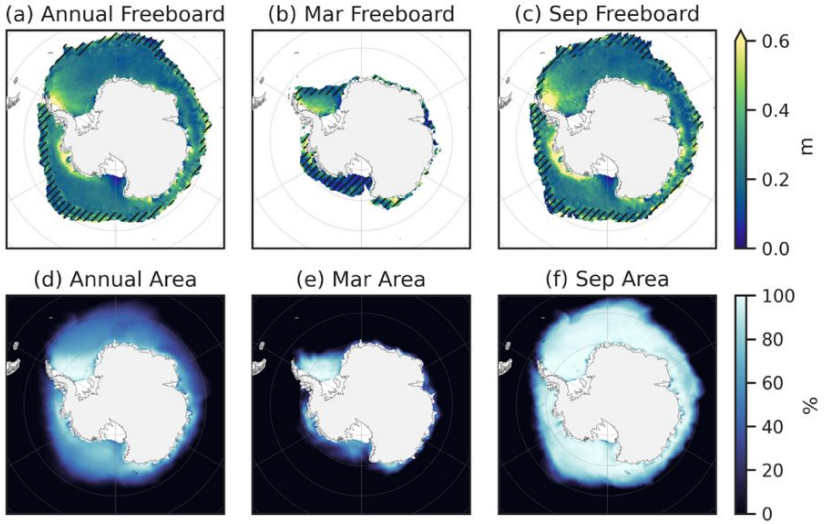
- Total freeboard observations are very precise, and across both hemispheres.
- Captures a lot of the thickness variability signal across basins.

Cons:

- Very short time period → high internal variability?
- Need to consider coverage issues.
- Uncertain uncertainties, especially for thickness.

Our goal: Integrate new observations from ICESat-2





**Hatched areas indicate regions of non-perennial coverage (that we discard)*

The freeboard/bulk ice density rabbit hole

- Direct ice freeboard output: ~15 models provide!
  - Add snow thickness to compare with total freeboard from ICESat-2.
  - Can derive bulk ice density by rearranging hydrostatic equilibrium Eq.

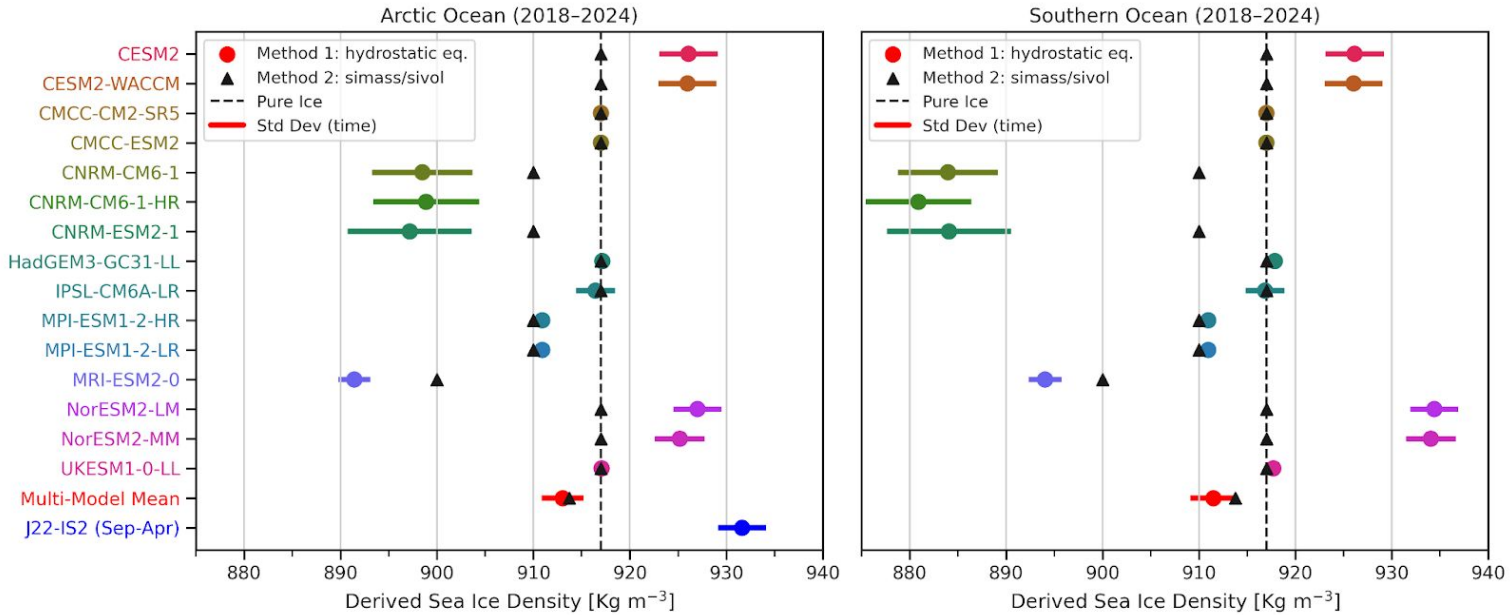
$$F_i = \frac{\rho_w - \rho_i}{\rho_w} H_i - \frac{\rho_{sn}}{\rho_w} H_{sn}$$

$$F_{total} = F_i + H_{sn}$$

- Can also derive bulk ice density from mass and volume variables!

Before we look at freeboard, we want to assess bulk ice density as a key variable in the freeboard conversion.

The freeboard/bulk ice density rabbit hole



Model plausibility: obs uncertainty and internal variability

Plausible range

$$P = +/- 2\sqrt{(\sigma_{int}^2 + \sigma_{obs}^2)}$$

Plausibility index

$$\phi = \left|\overline{mod} + \overline{obs}\right| / \sqrt{(\sigma_{int}^2 + \sigma_{obs}^2)}$$

Uncertainty estimates (σ_{obs})

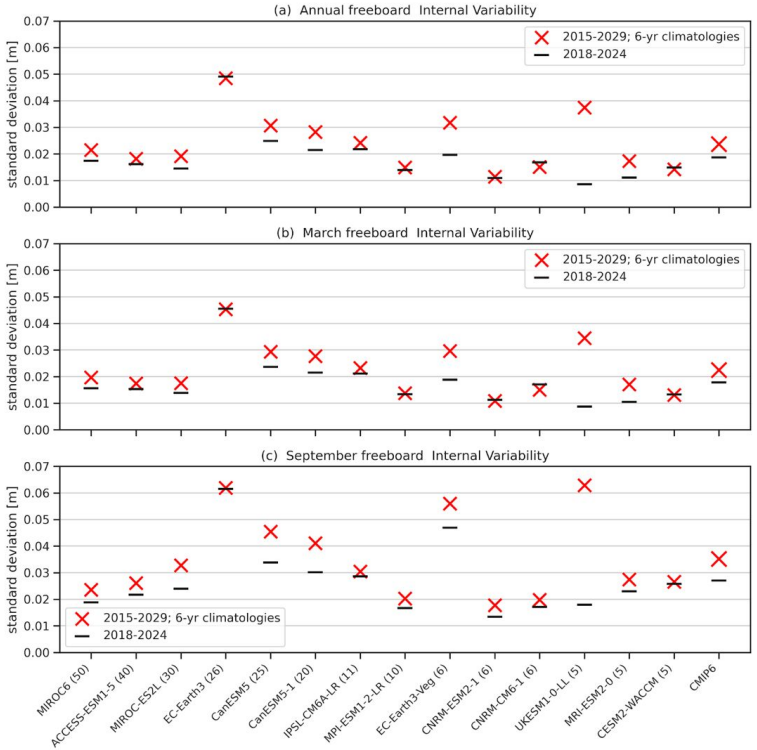
Variable	Low uncertainty estimate	High uncertainty estimate
Sea ice area (million km^2)	0.5	1.0
Total freeboard (cm)	1.5	3.0
Winter Arctic sea ice thickness (cm)	15	30

*Heuristic (very educated guesses!) from synthesized lit review.

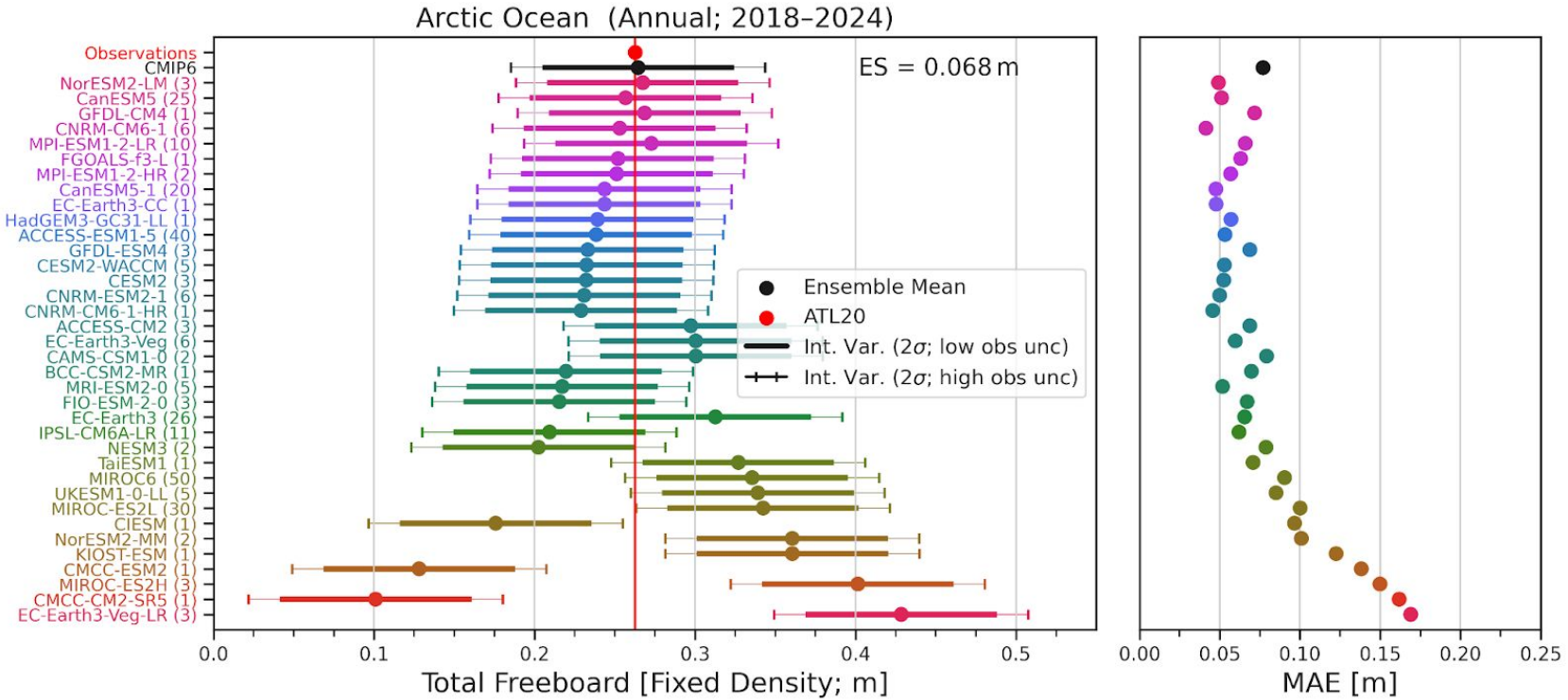
**Apply the same values at the grid-scale too for regional assessments…

Internal variability estimates (σ_{int})

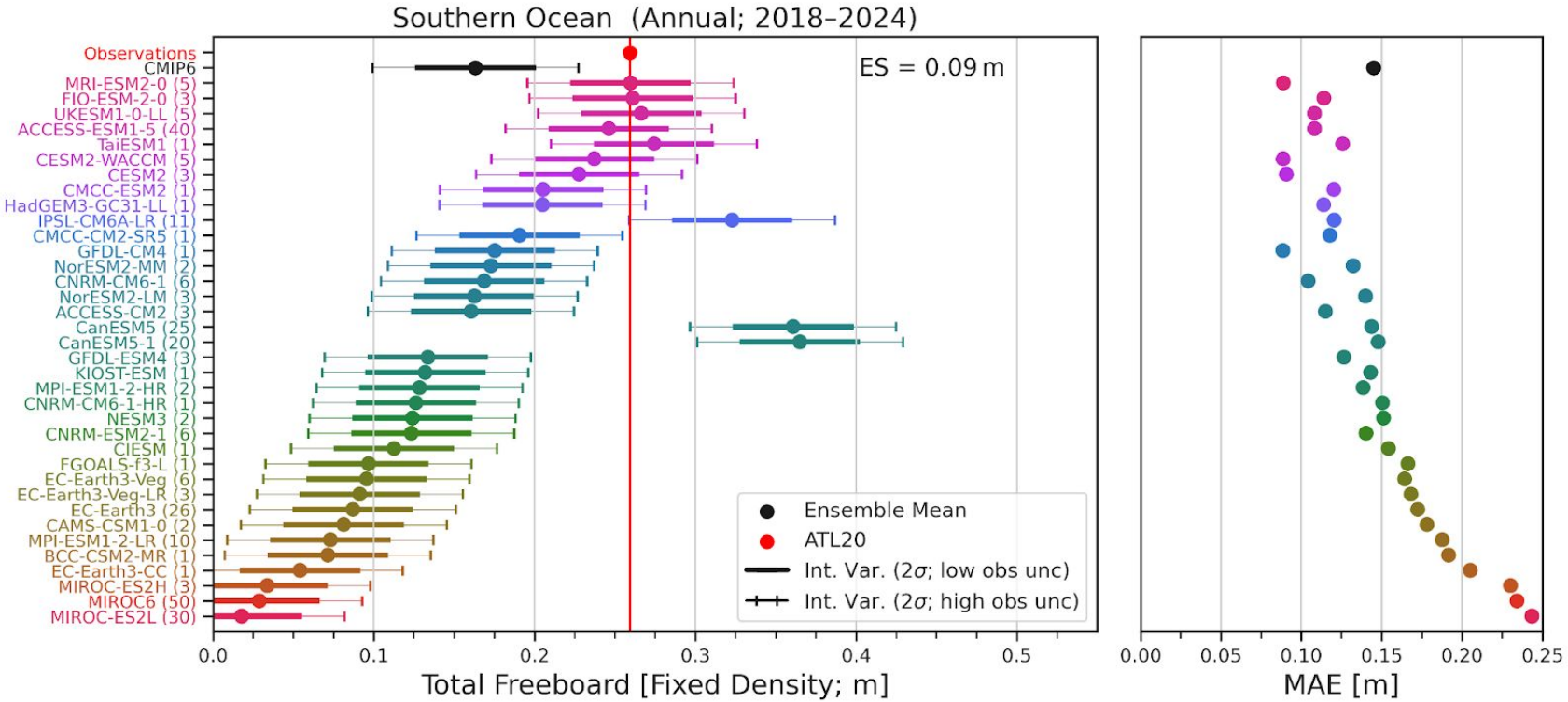
- Calculate for all models with at least 5 ensemble members.
  - Calculate for the 2018-2024 means but also multiple 7 year means across a wider 2015 to 2035 time-period.
  - Repeat for all metrics and time-periods.
- Can do similar calculations regionally too, but is even more questionable..



Plausibility assessments (lots of them)

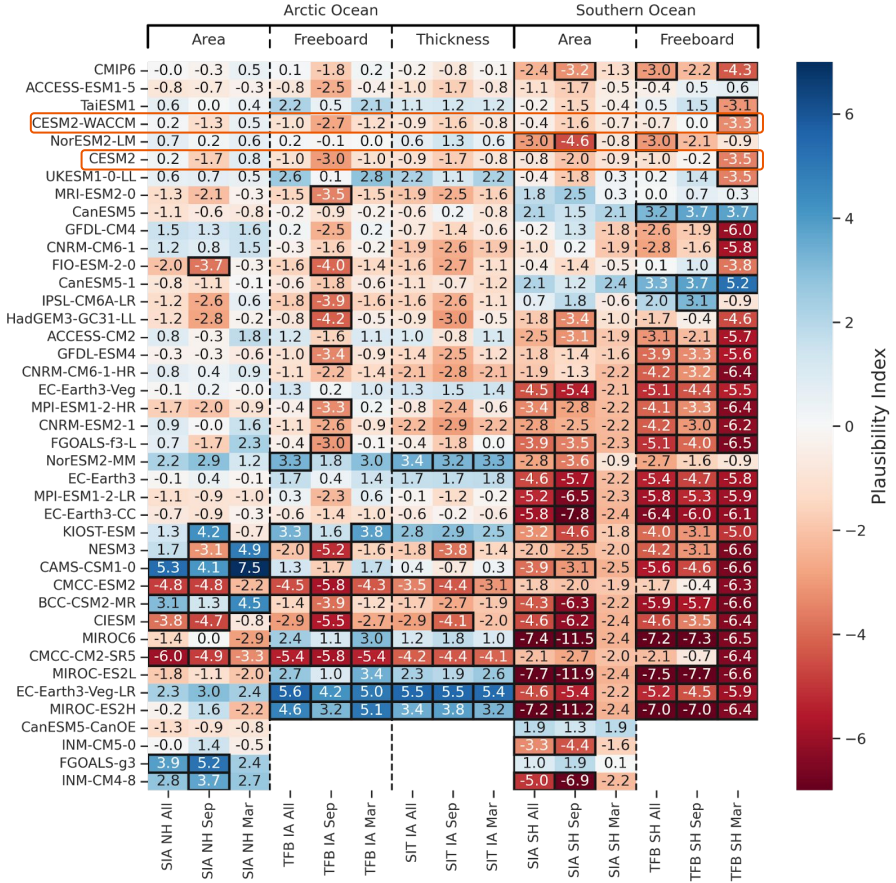


Plausibility assessments (lots of them)



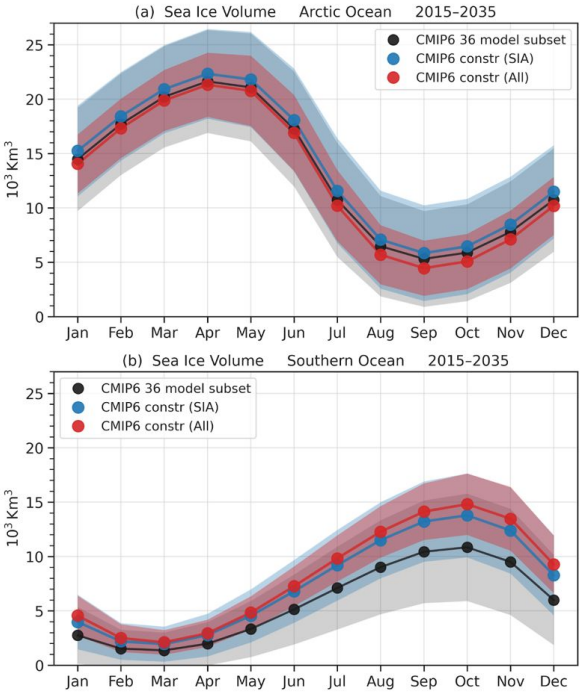
Plausibility across metrics

- Models ranked by mean plausibility across all 15 metrics with CMIP6 mean listed at the top.
- More implausible SO results as expected but some quite plausible models!
- CESM2/CESM2-WACCM one of the better performing over both hemispheres.
  - Late summer low sea ice bias kinda evident in our metrics…

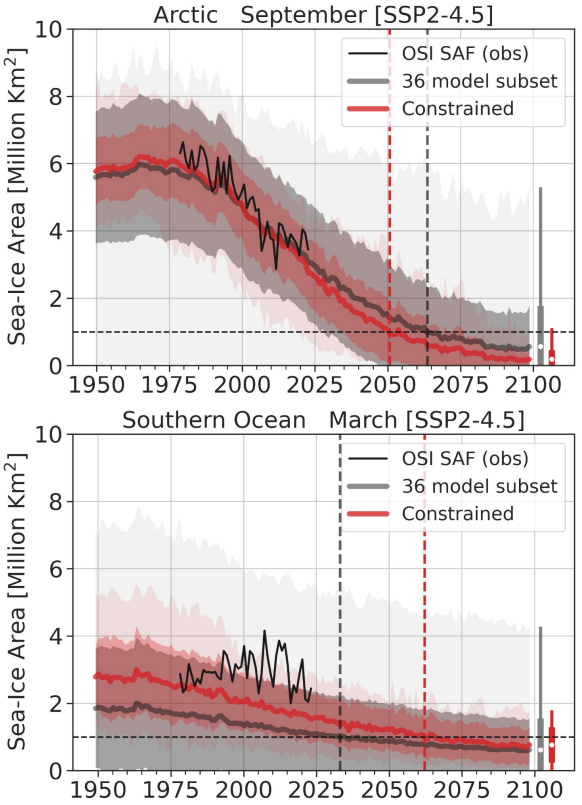


Impacts of our constraints

Modern-era seasonal sea ice volume

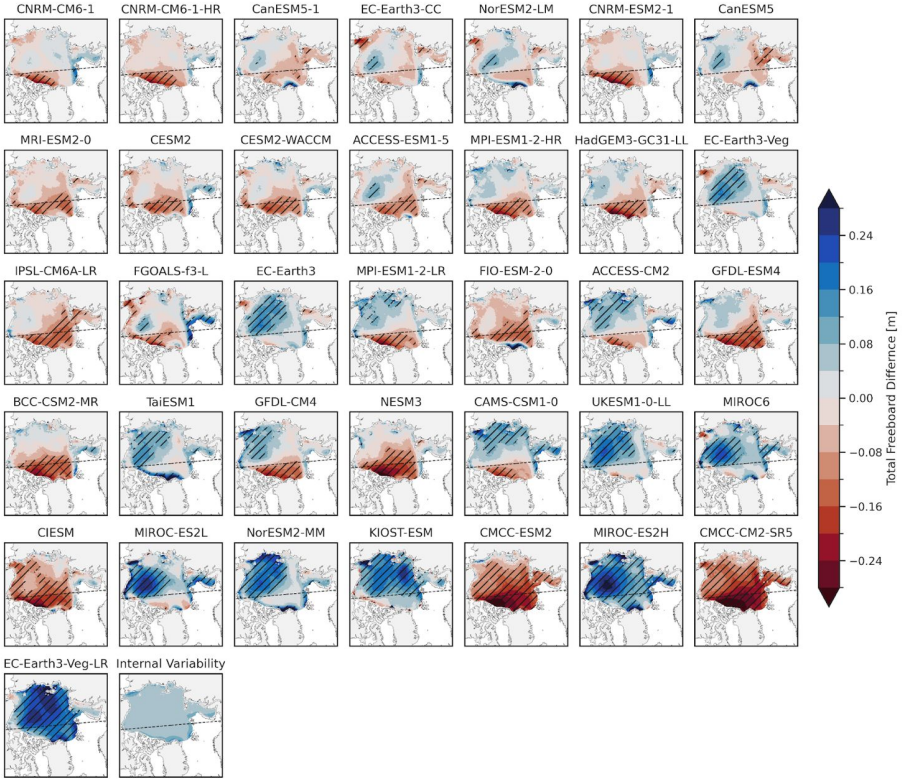


Future sea ice area projections



Regional sea ice assessments

- Implausible regions highlighted by hatchings.
- Lots of good performing models still struggle with the thicker ice north of CAA.
- How much should we trust the regional internal variability estimate though?
- More regional assessments including composite analysis included in the paper!



Discussion points

- Bulk ice density estimates in models and obs a little confusing and need more focused examination
- Better uncertainty quantification, ideally observational ensembles, would really help with this kind of assessment.
- Internal variability estimates, especially for this short time-period, are more questionable, but at least less trend contaminated!
  - Even more so for regional analyses.
- How best to combine with existing recalibration methods for improving predictions!?

Some next steps

- Interested in decadal-scale predictions with our plausibility subsets and different exclusion/weighting/recalibration schemes, ideally with community/SIMIP involvement!
- Bring in ICESat-OG data (working on a reprocessing, hoping to tackle representation issues, get in touch if interested).
- Looking into more melt-focussed metrics through our new NASA Cryo project (melt pond fraction/albedo etc).