Constraining CMIP6, CESM2 AND CESM3 sea ice simulations with ICESat-2

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



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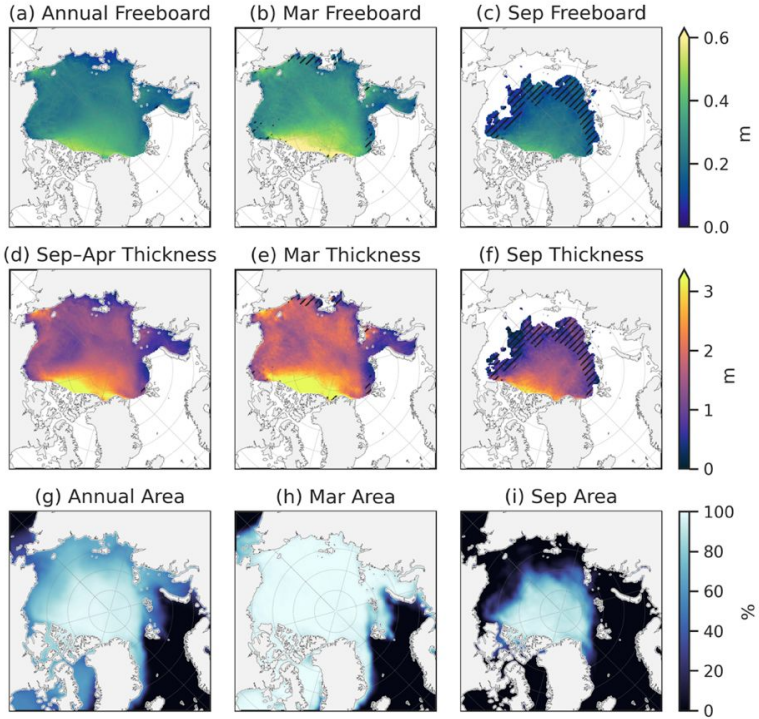
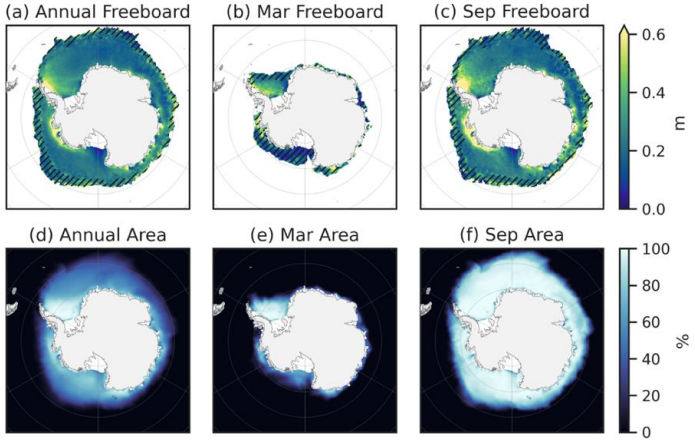
[1]ESSIC, University of Maryland, College Park, MD, USA
[2]WHOI, Falmouth, MA, USA

Use new observations from ICESat-2 to constrain CMIP6





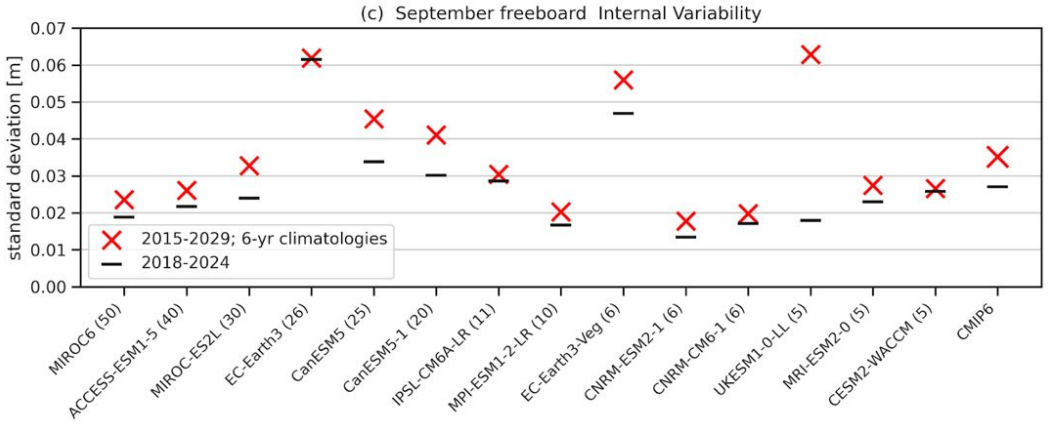
**Hatched areas indicate regions of non-perennial coverage (that we discard)*

Model plausibility: obs uncertainty and internal variability

Plausible range:

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

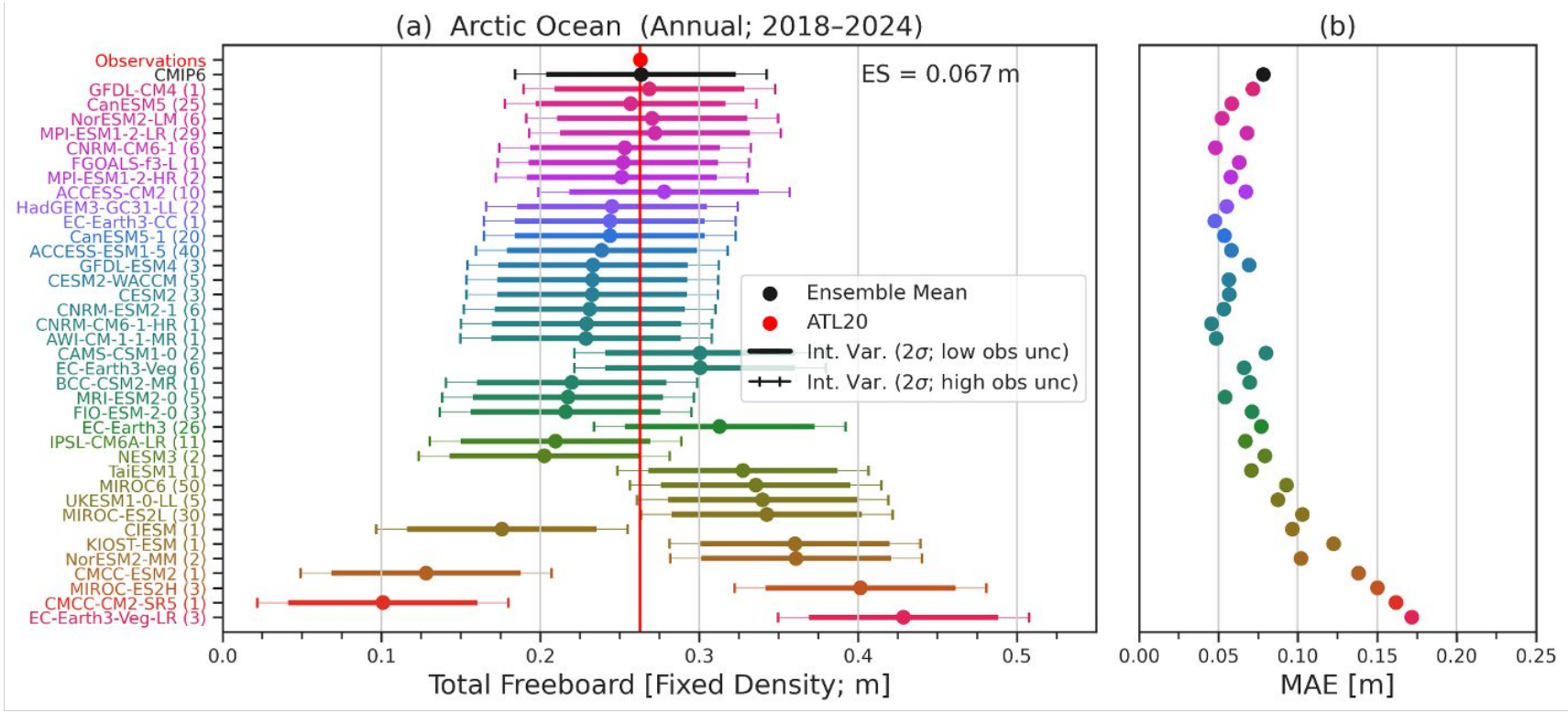
$$\phi = \left|\overline{mod} + \overline{obs}\right| / \sqrt{(\sigma_{int}^2 + \sigma_{obs}^2)}$$



Variable	Low/high unc
Sea ice area (million km^2)	0.5 / 1.0
Total freeboard (cm)	1.5 /3.0
Winter Arctic thickness (cm)	15 / 30

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

Plausibility assessments (lots of them)



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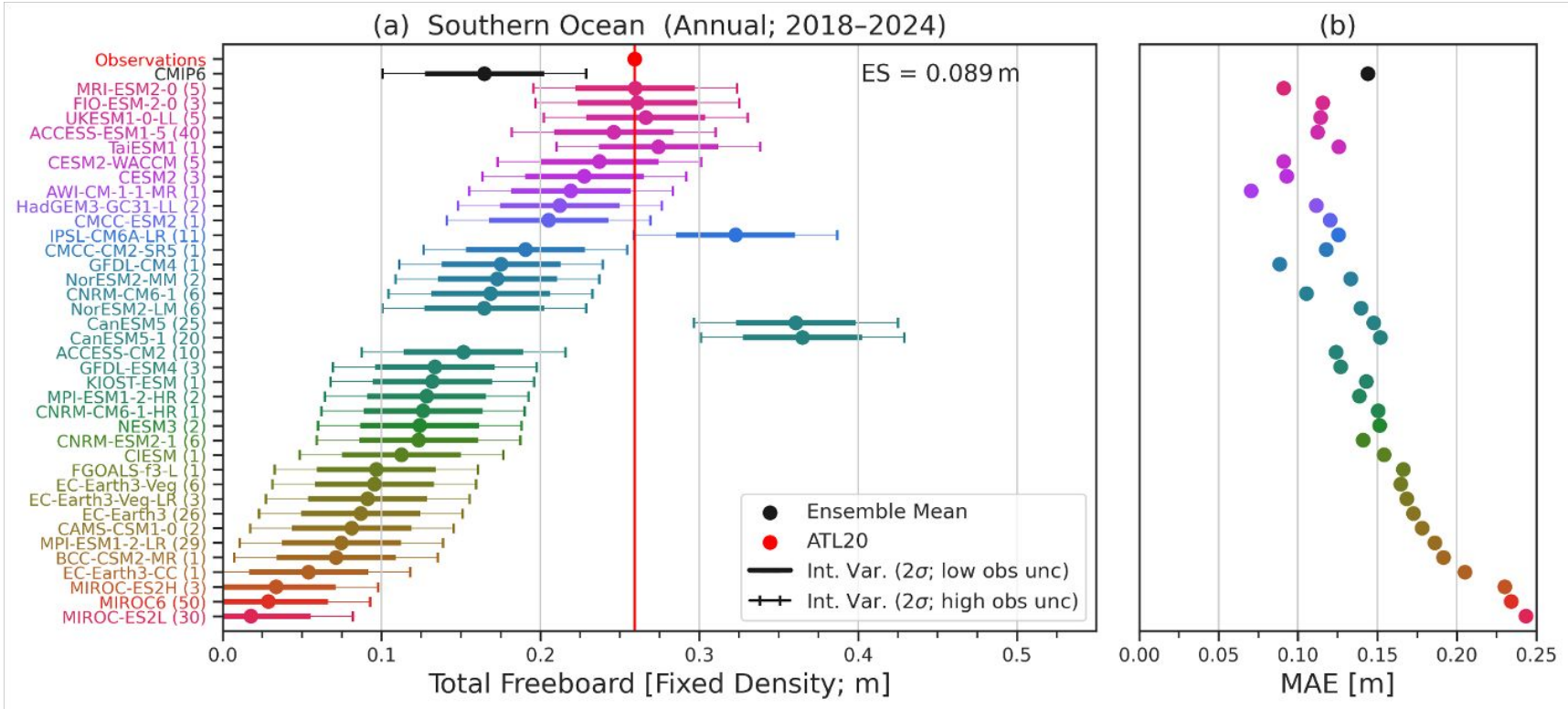
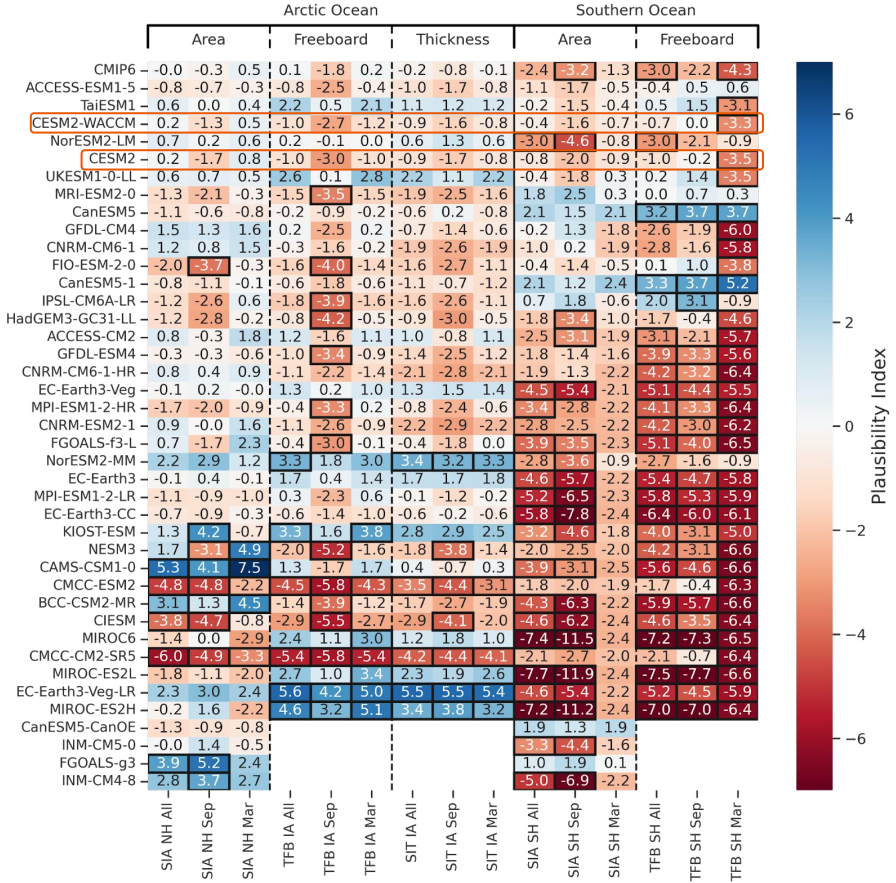


Plausibility across metrics

- 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…



Plausibility across metrics

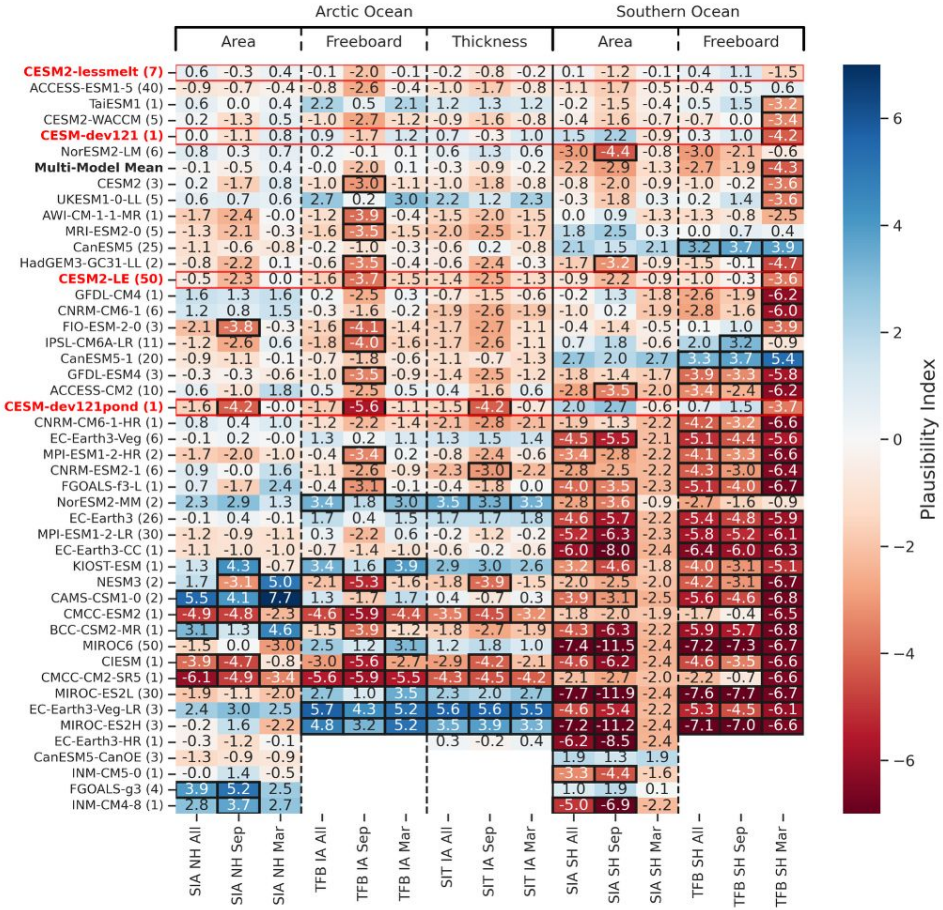
Impacts of constraints on CMIP6 mean seasonal cycle and regional plausibility analysis described in our preprint :

Petty, A. A., C. Cardinale, M. Smith, Constraining CMIP6 sea ice simulations with ICESat-2, EGUsphere (preprint), 2025-766, doi: 10.5194/egusphere-2025-766, in review at Geoscientific Model Development (GMD).

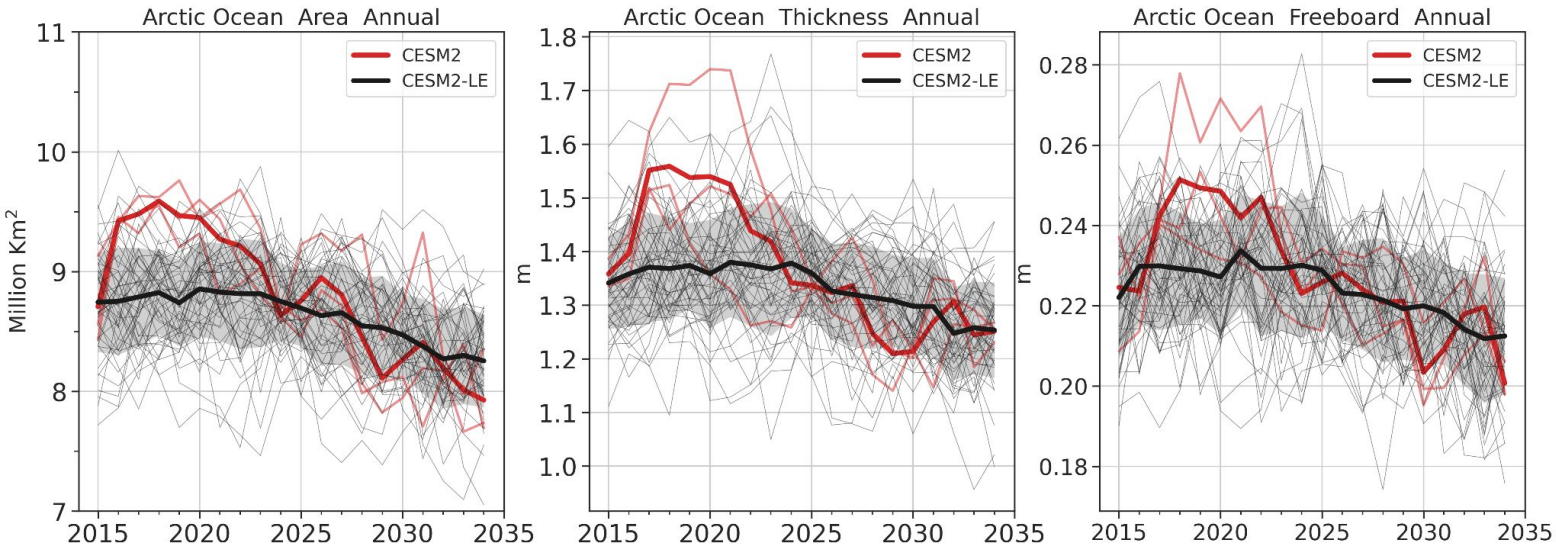
Now working to add in more CESM models..!

Adding more CESM

- Access to CESM2-lessmelt and CESM3 development runs on Deracho (thanks Dave & Alice!).
- CESM2-lessmelt performs the best now, but it was calibrated to do so..! (Kay et al., 2022)
- The dev runs show a mixed response, we see some evidence of the positive bias in SO area but decent performance overall? Short time-period…



CESM2-CMIP6 vs CESM2-LE (time series)

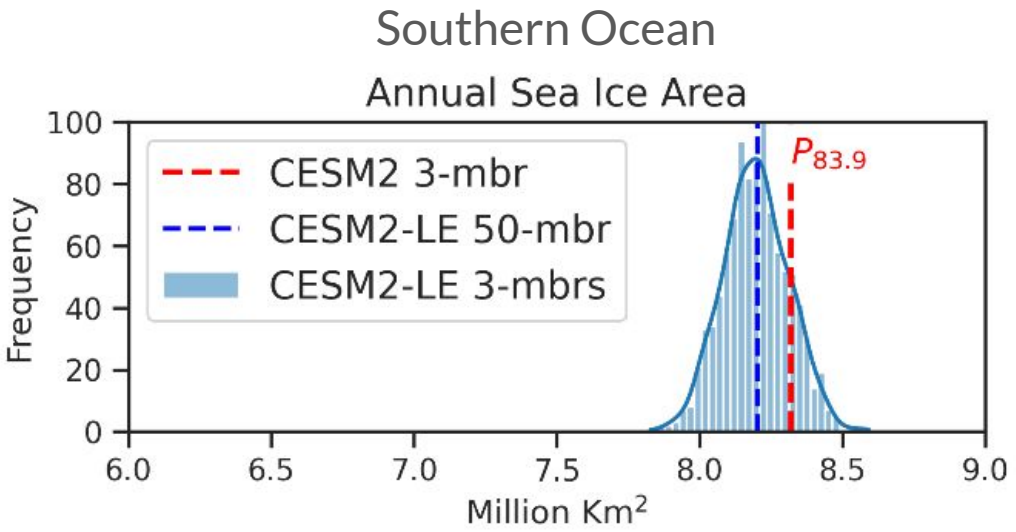


ICESat-2 era shows an interesting positive bias in CESM2-CMIP6 (red)

Exploring impact of small ensemble size

Inspired by emails with Marika/Alice/Dave!

- Compare CESM2-LE (50+ members) and CESM2-CMIP6 (3 members)
  - same forcing, but initialized a little differently…
- Use Bootstrapping applied to CESM2-LE (50 mems)
  - Randomly sample 3-member means for CESM2-LE and compare with CESM2-CMIP6
  - Repeat for metrics & plausibility scores.



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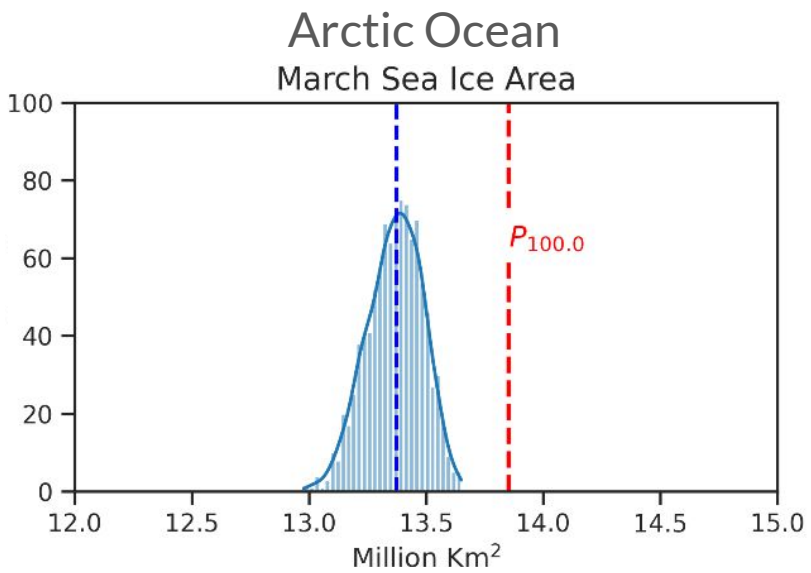


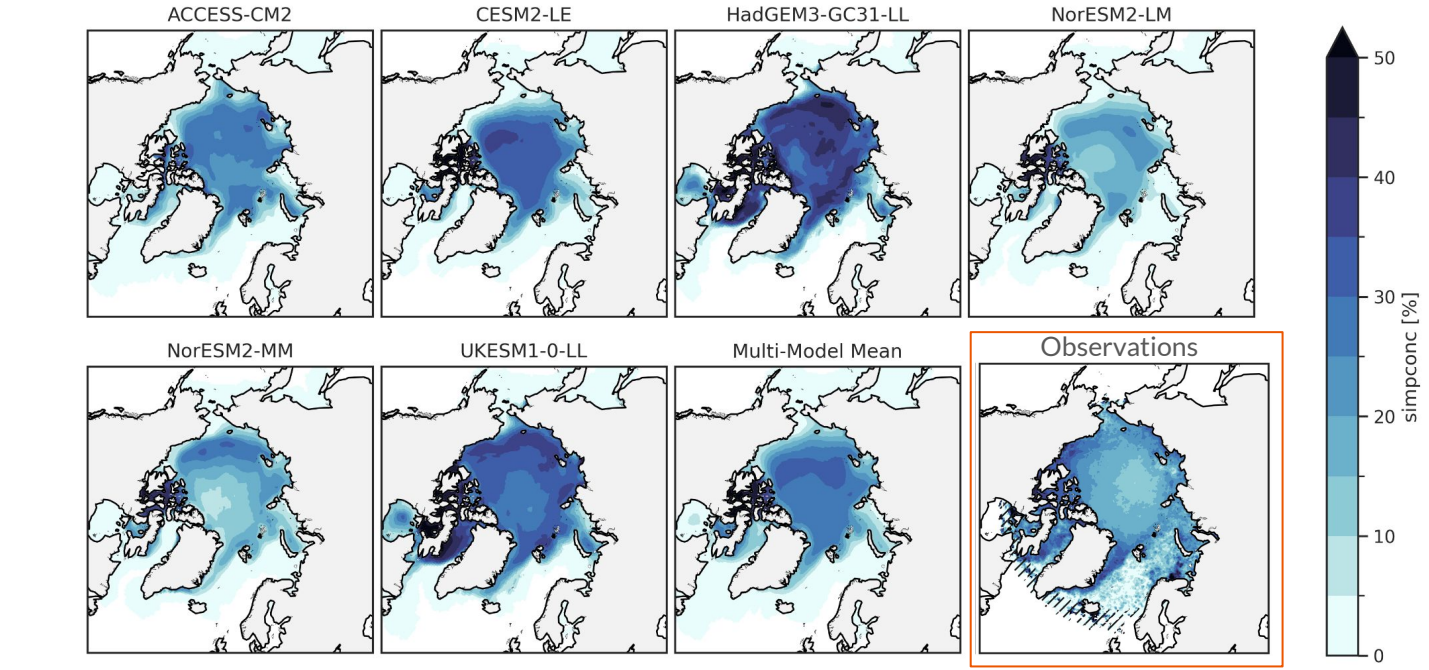
New work: Sea ice melt in CMIP6/CESM

Model		*Pond scheme*	*Albedo scheme*
ACCESS-CM2	*CICE5.1.2*	*Topographic (Flocco et al., 2012)*	*Dual band (CCSM3)*
CESM2-LE	*CICE5.1.2*	*Level ice (Hunke et al., 2013)*	*delta-Eddington*
HadGEM3-GC31	*CICE5.1.2*	*Topographic (Flocco et al., 2012)*	*Dual band (CCSM3)*
NorESM2-LM	*CICE5.1.2*	*Level ice (Hunke et al., 2013)*	*delta-Eddington*
NorESM2-MM	*CICE5.1.2*	*Level ice (Hunke et al., 2013)*	*delta-Eddington*
UKESM1-0-LL	*CICE5.1.2*	*Topographic (Flocco et al., 2012)*	*Dual band (CCSM3)*

5 CMIP6 models + CESM2-LE provide outputs of sea ice melt pond coverage (all CICE)

New work: Sea ice melt in CMIP6/CESM

July melt pond coverage



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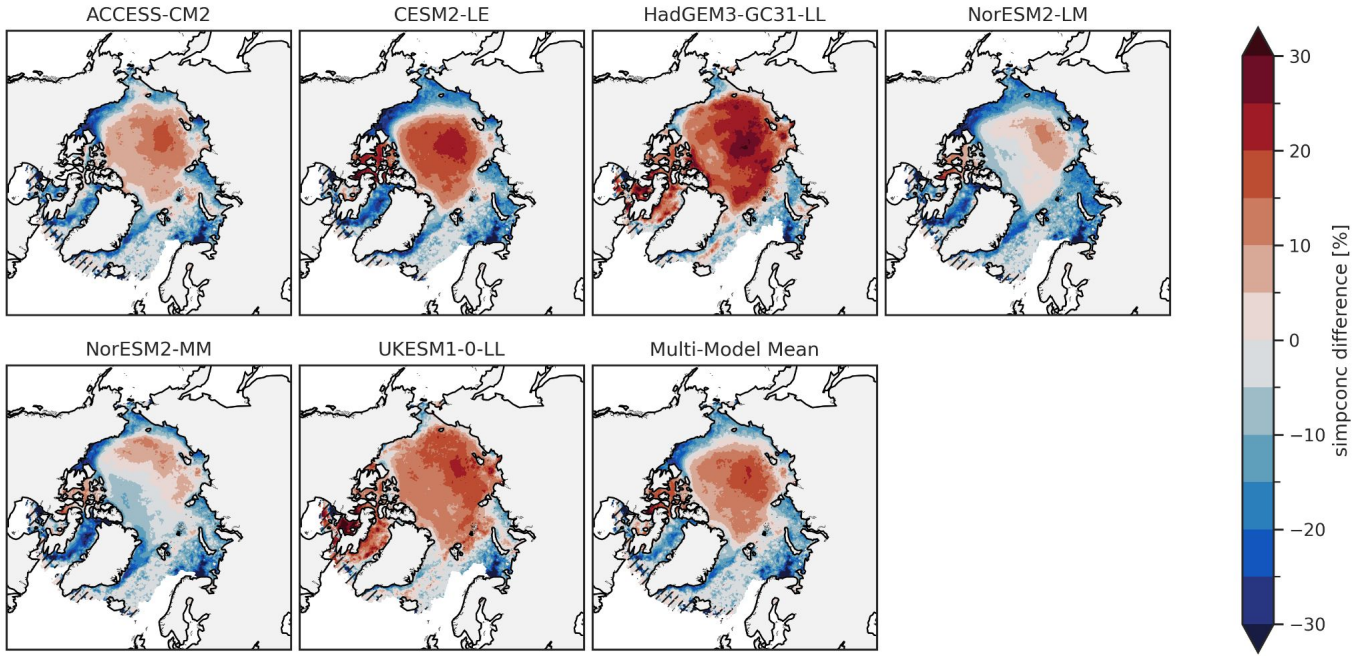


CESM2-LE similar to multi-model mean but much higher than the obs (Sentinel-3 based MPD2).

Quick shout-outs..

- We have all-season/dual-hemisphere ICESat-2 freeboard down to 50% SIC but just winter (September to April) Arctic sea ice thickness estimates.
  - Trying to increase ICESat-2 coverage down to 0% SIC using fancy interpolation schemes (Gregory et al., 2024)
  - Also working on all-season thickness estimates from ICESat-2, showing good agreement with CryoSat-2/validation data.

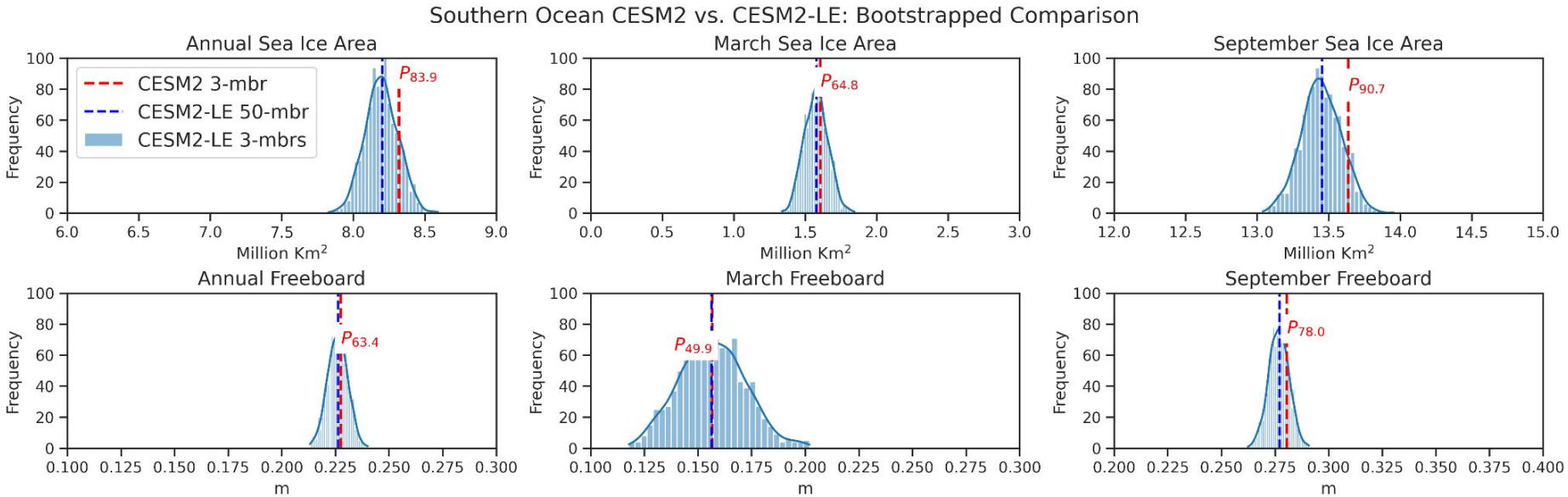
Petty, A. A., A. Cabaj, J. Landy, Initial assessment of all-season Arctic sea ice thickness from ICESat-2, submitted to Journal of Glaciology (preprint hosted on EarthArXiv). Thickness data available on Zenodo.

- Working towards all-season ICESat-2 sea ice volume! Getting there…

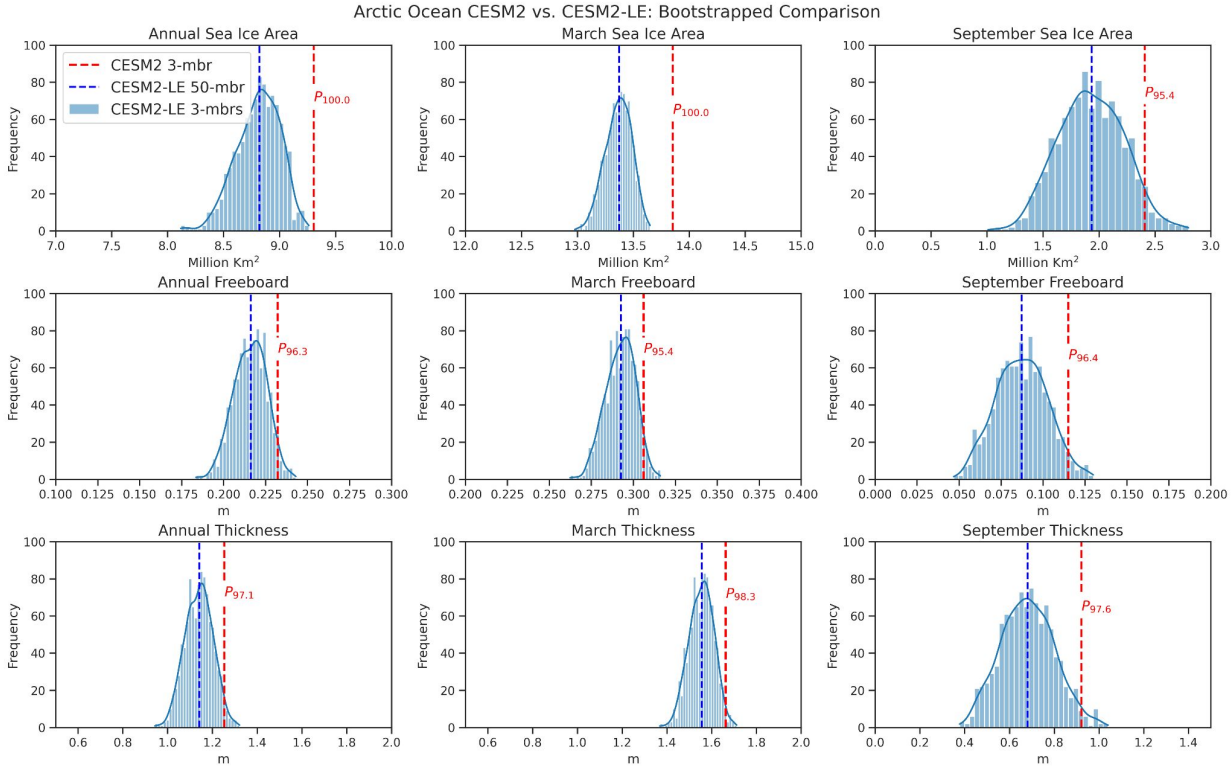
Summary

- We have a sea ice plausibility framework in place to assess CMIP-like sea ice output with estimates of sea ice area, freeboard and thickness.
  - Can combine with existing longer-term analyses.
- Freeboard is proving to be a useful extra diagnostic
  - v. reliable and available across all months and hemispheres.
- Looking into ensemble size/internal variability concepts in preparation for CMIP7 analysis.
  - Impacts of extra years of IS-2 vs CS-2 data.
- Related projects on sea ice melt and improved all-season IS-2 data showing promise!

Extra


Southern Ocean CESM2 vs. CESM2-LE: Bootstrapped Comparison
Annual Sea Ice Area
March Sea Ice Area
September Sea Ice Area
CESM2 3-mbr
CESM2-LE 50-mbr
CESM2-LE 3-mbrs
$P_{83.9}$
$P_{64.8}$
$P_{90.7}$
Frequency
Million Km^2
Annual Freeboard
March Freeboard
September Freeboard
$P_{63.4}$
$P_{49.9}$
$P_{78.0}$
m

CESM2-CMIP6 vs CESM2-LE (Arctic, 2018-2024)



CESM2-CMIP6 vs CESM2-LE (Arctic, 2025-2030)