Regional Discrepancies in Arctic Melt Pond Distribution of CMIP6 Models and CESM2-LE with Satellite Observations

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NASA ROSES 2024 solicitation: *A.15 Cryospheric Science*
80NSSC24K1446 (2025-2027)

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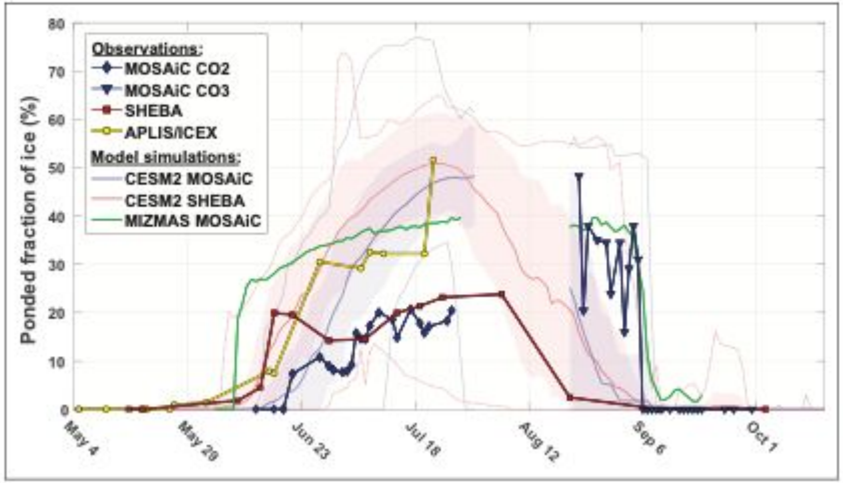
Prior work evaluating/comparing GCM melt ponds

Regional observational assessments (e.g., Webster at al., 2022; right) suggests models can overestimate melt pond area.

New basin-scale melt pond products more recently available (S3/MODIS), enabling broader comparisons!

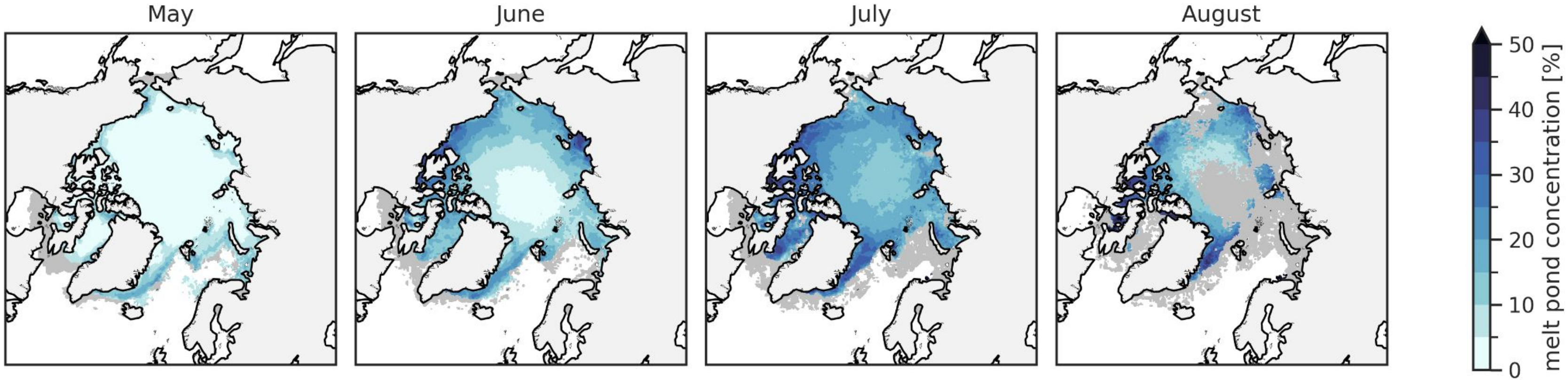


Webster et al., (2022)

Observations of Arctic monthly melt pond concentration

Grid cells with melt pond data on fewer than 20% of days are masked out (grey)!

Sentinel-3 OCLI/MPD2 data, 2017-2025 (*Niehaus et al., 2024*)



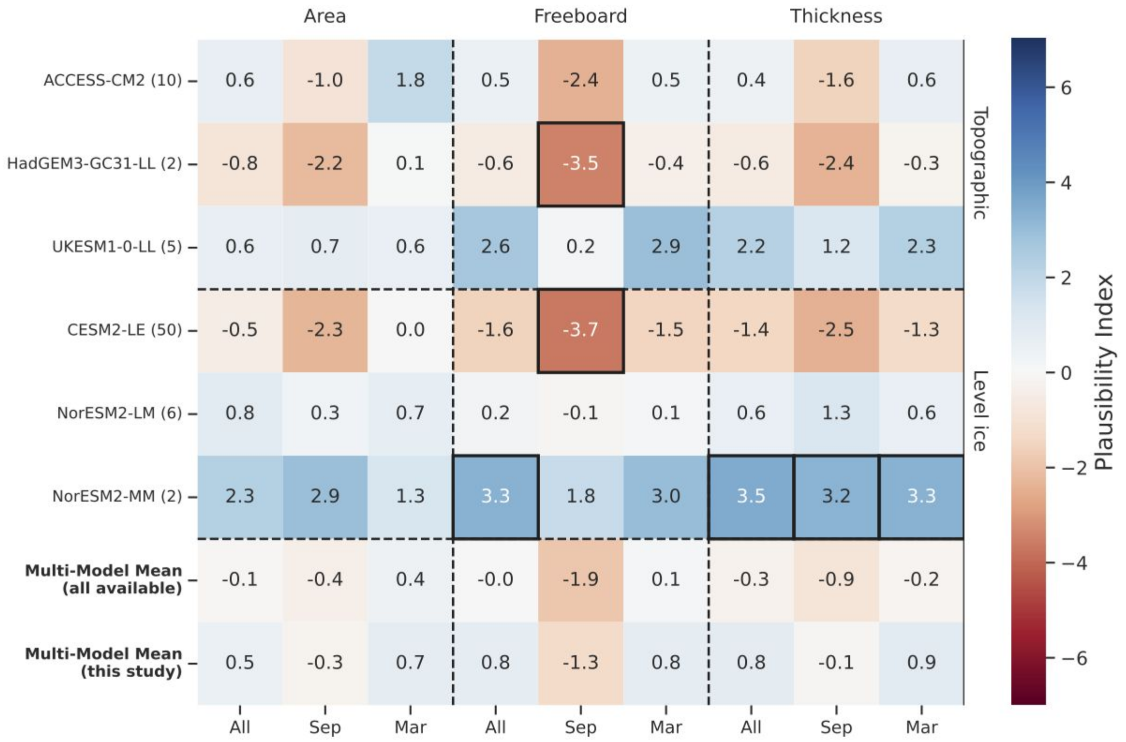
Not shown: Broad regional agreement between MPD2 (S3/OCLI), SWJTU (MODIS) and CPOM (MODIS), with caveats. CPOM product has reduced spatial coverage, SWJTU/CPOM has more limited temporal range.

Five CMIP6 model outputs and CESM2-LE

Model	*Sea ice 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)*

Of the 6 models with melt pond outputs available, half each use **topographic** and **level-ice** schemes

Model performance on sea ice state variables

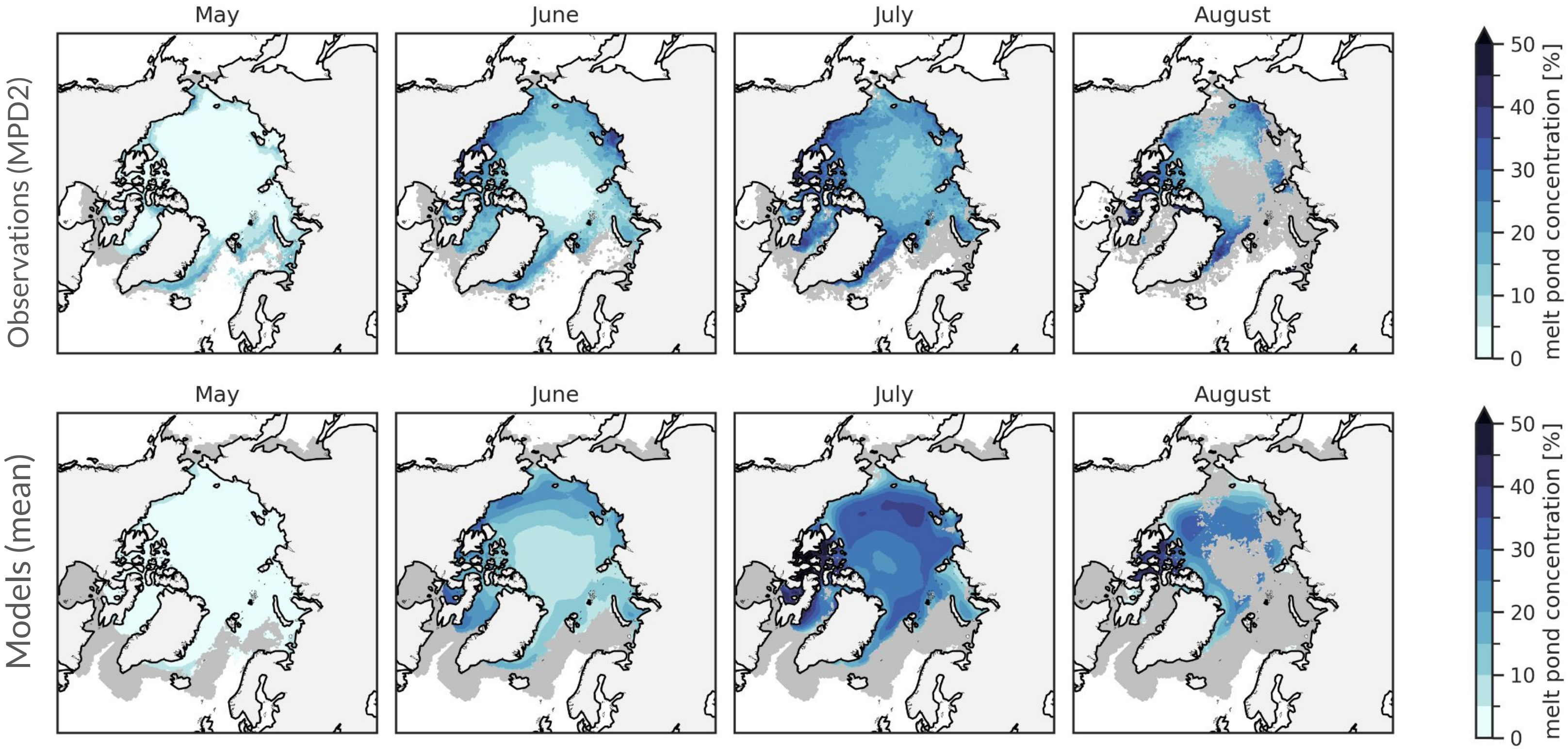


The 6 available models perform reasonably well in terms of Arctic sea ice state variables (exception maybe NorESM2-MM)

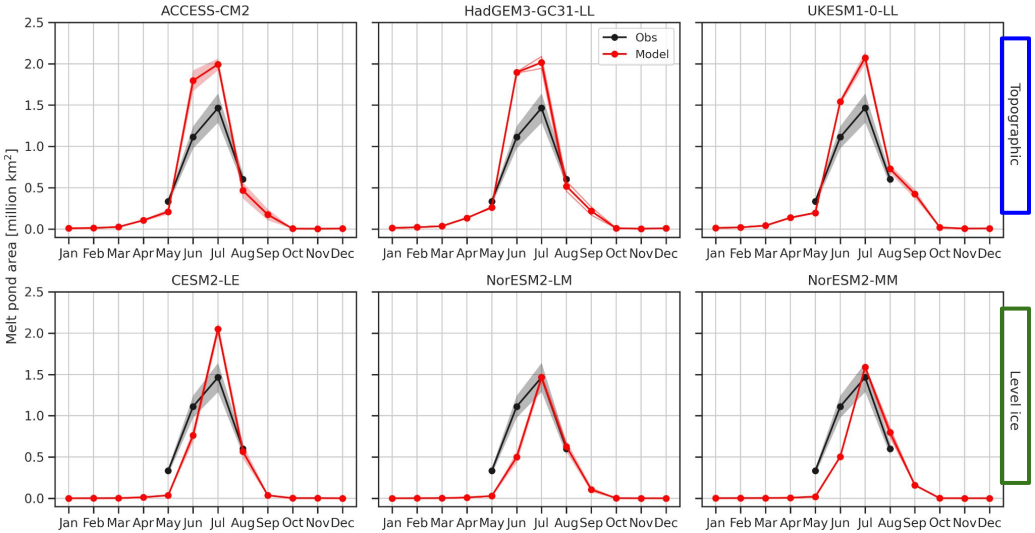
Comparable multi-model mean to full ensemble.

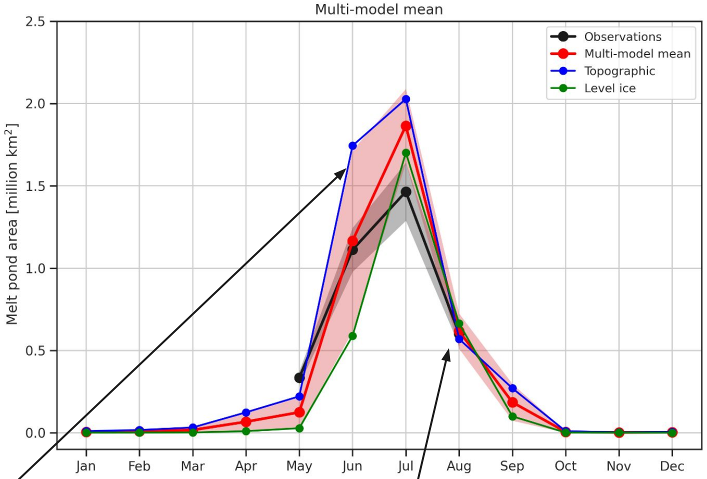
Method from Petty et al., (2025, GMD).

Sea ice melt ponds in CMIP6/CESM vs obs



Hemispheric melt pond area in models vs obs





Strong June positive bias in topo models vs negative bias in the level ice models.

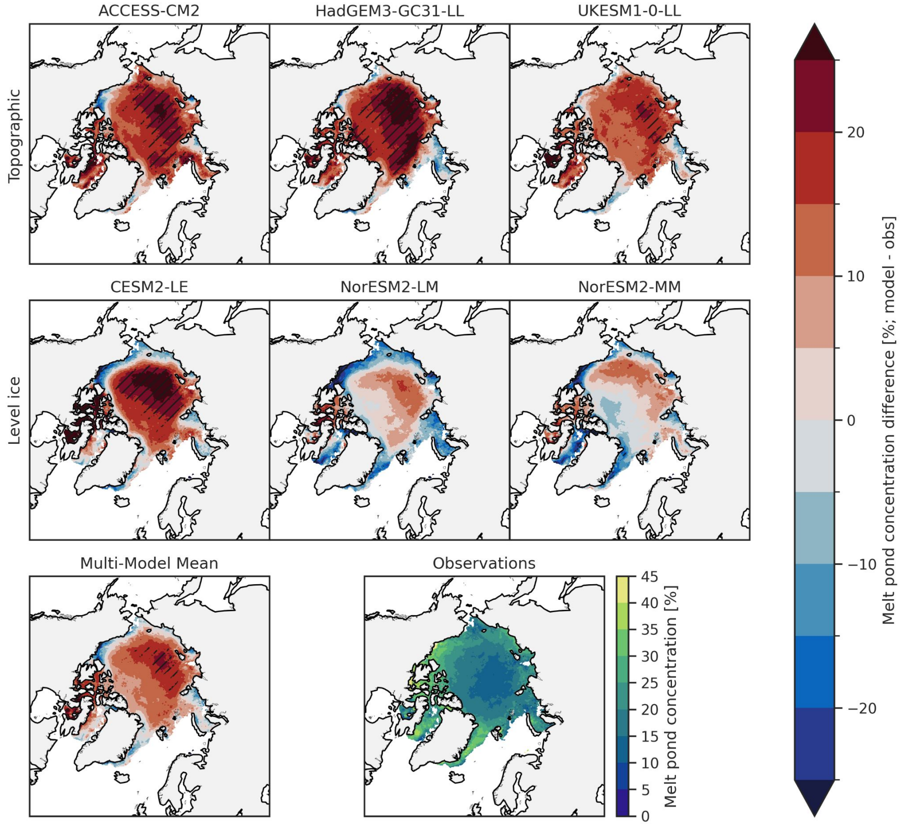
Closer agreement between the models & obs in July/August.

Regional differences (July)

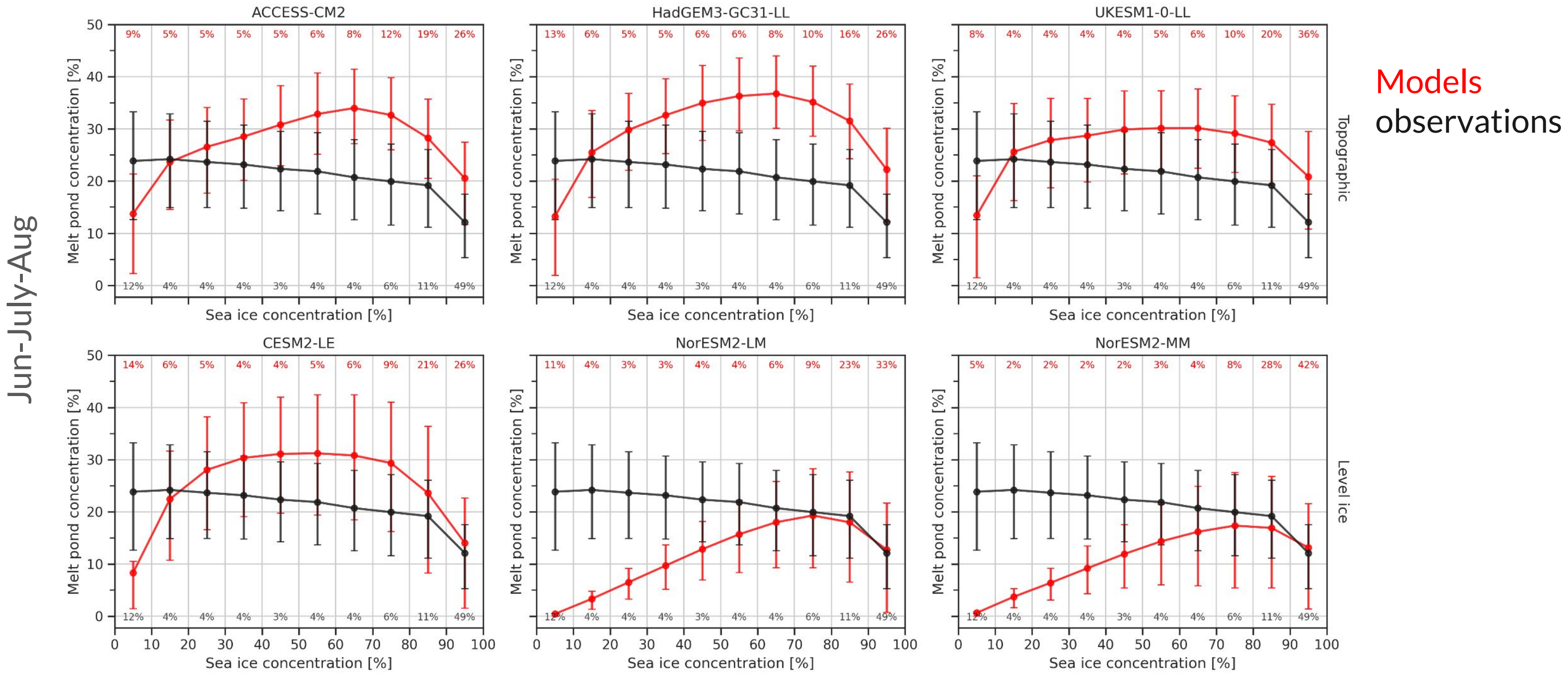
Despite reasonable hemispheric totals, regional maps show competing biases spatially

Generally... models have too many melt ponds in the Central Arctic and too few melt ponds around the margins.

What drives these differences? We are still exploring this...

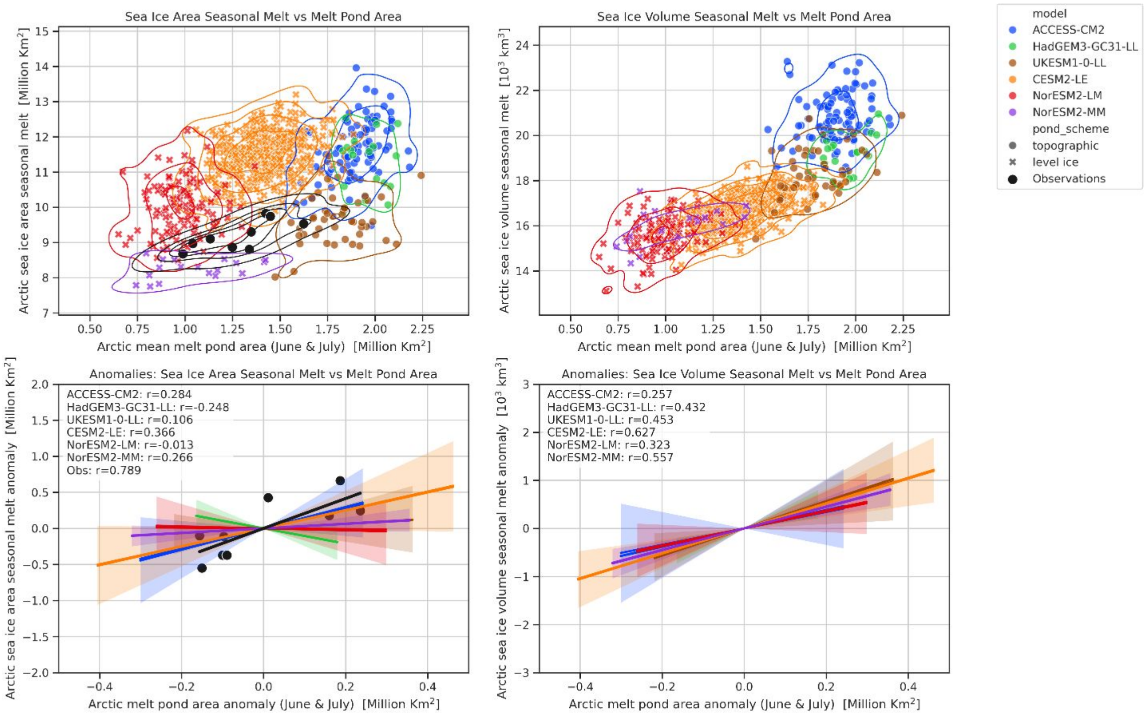


Melt pond conc. as a function of sea ice conc.



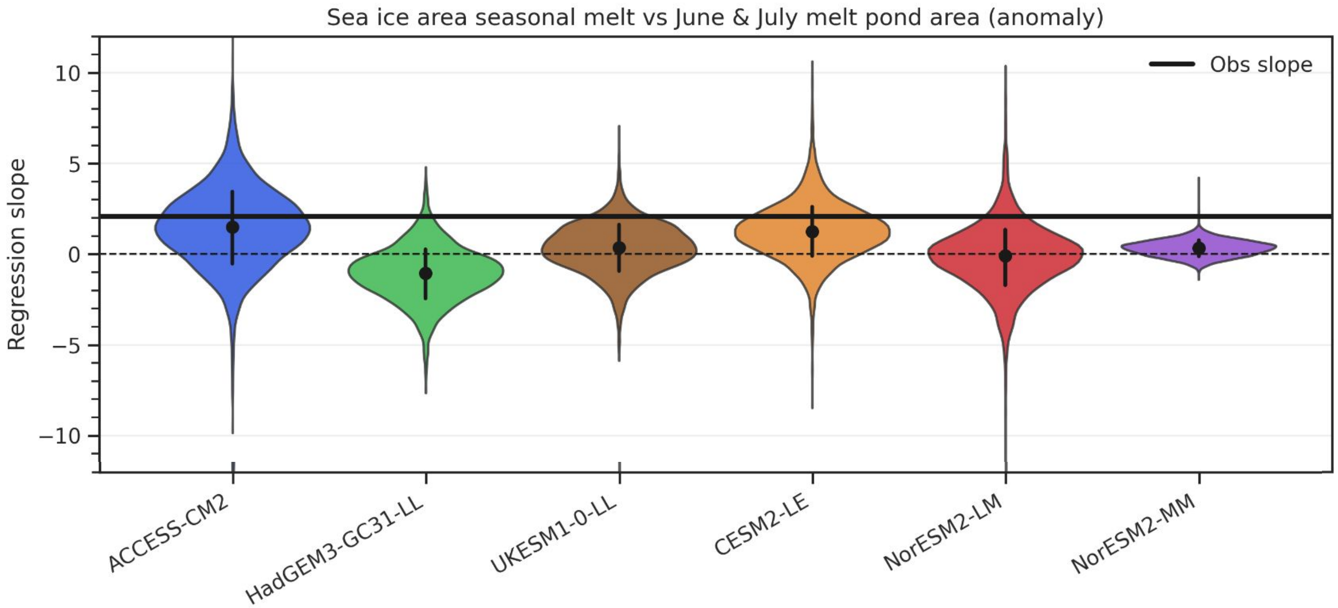
Most models show melt pond conc. dependence on SIC that is **not** supported by observations

Melt ponds and seasonal ice melt



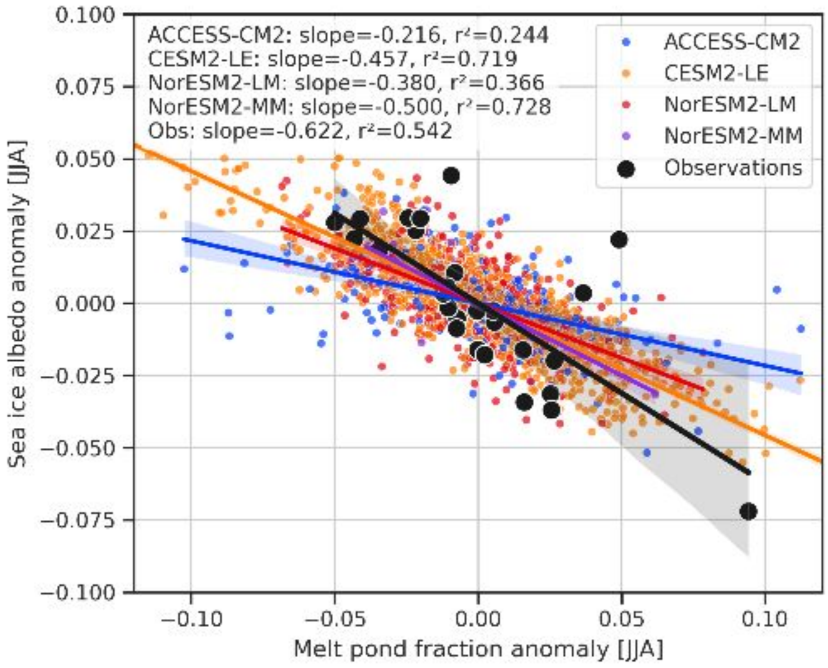
Models *under-represent* the strength of relationship between melt pond area and sea ice minimum

Melt ponds and seasonal ice melt (bootstrapping)



Only CESM2 and ACCESS are plausible with the observed slope to 1 SD?

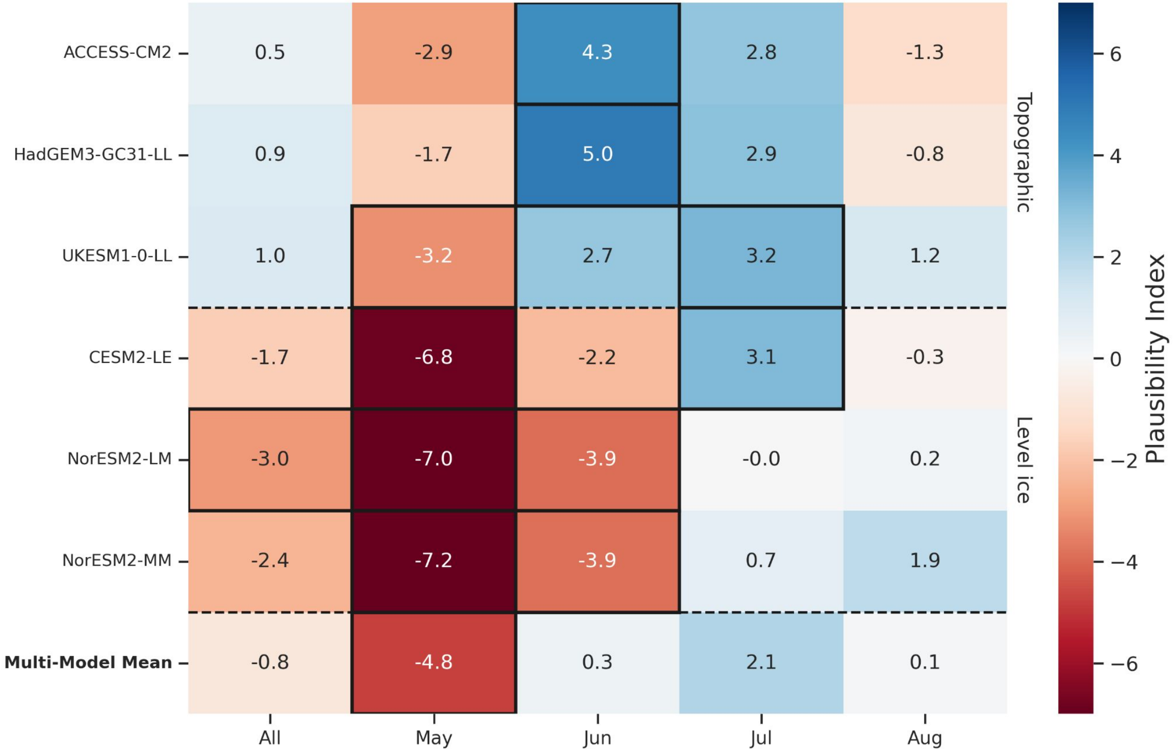
Sea ice albedo relationship with melt pond anomalies



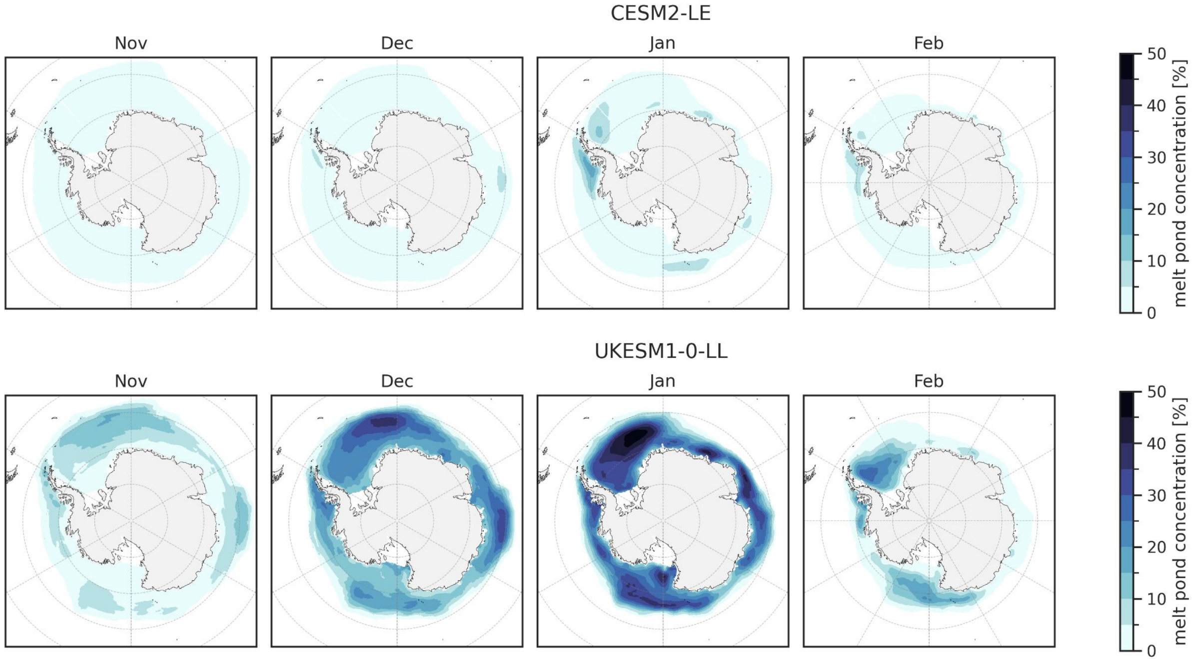
Models also *under-represent* the strength of relationship between melt pond anomaly and sea ice albedo

Improving melt pond fractions and optical properties are likely to change the representation of key feedbacks

Plausibility of melt ponds in CMIP6 models



Antarctic melt ponds?

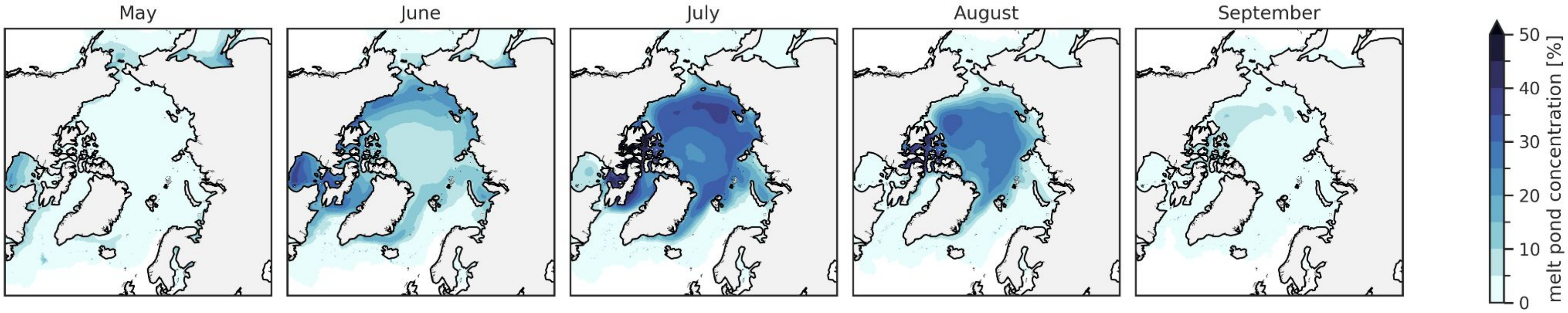


A PCWG 2026 summer talk?!

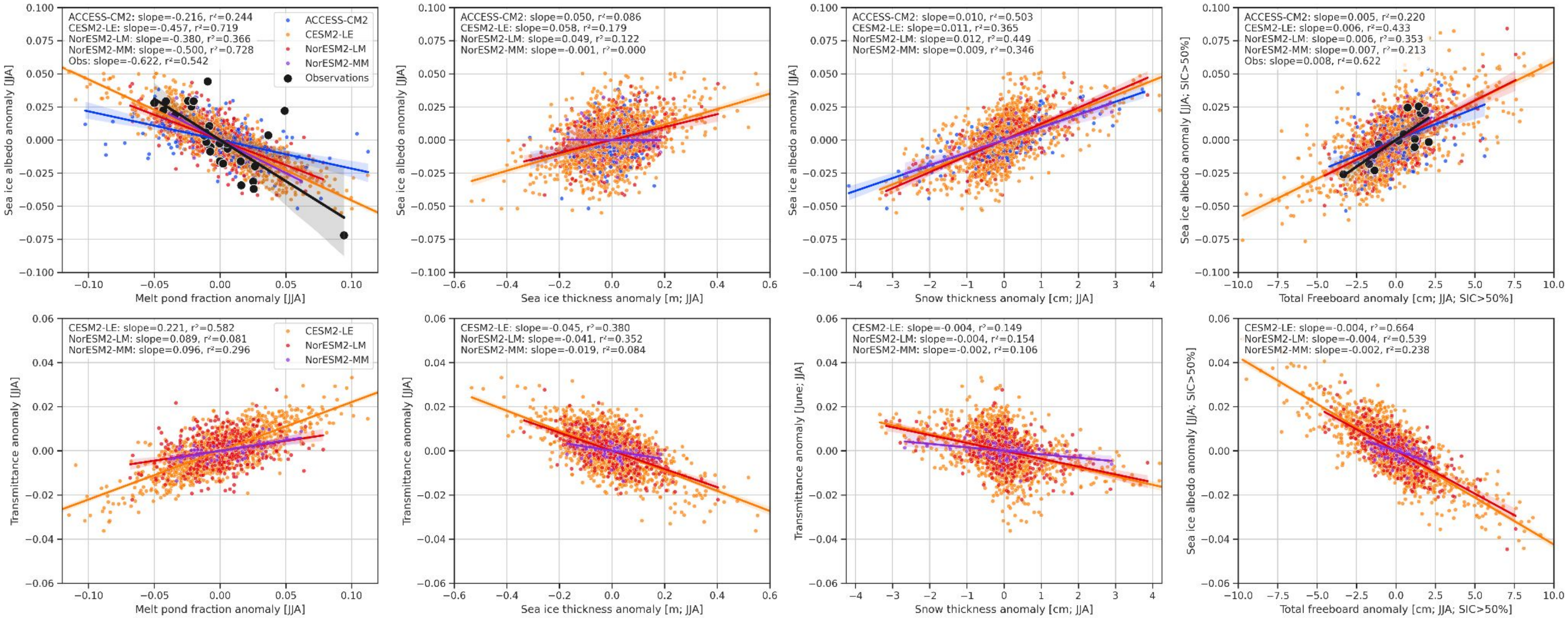
Photo from Ellen Buckley via Instagram

BACKUP SLIDES

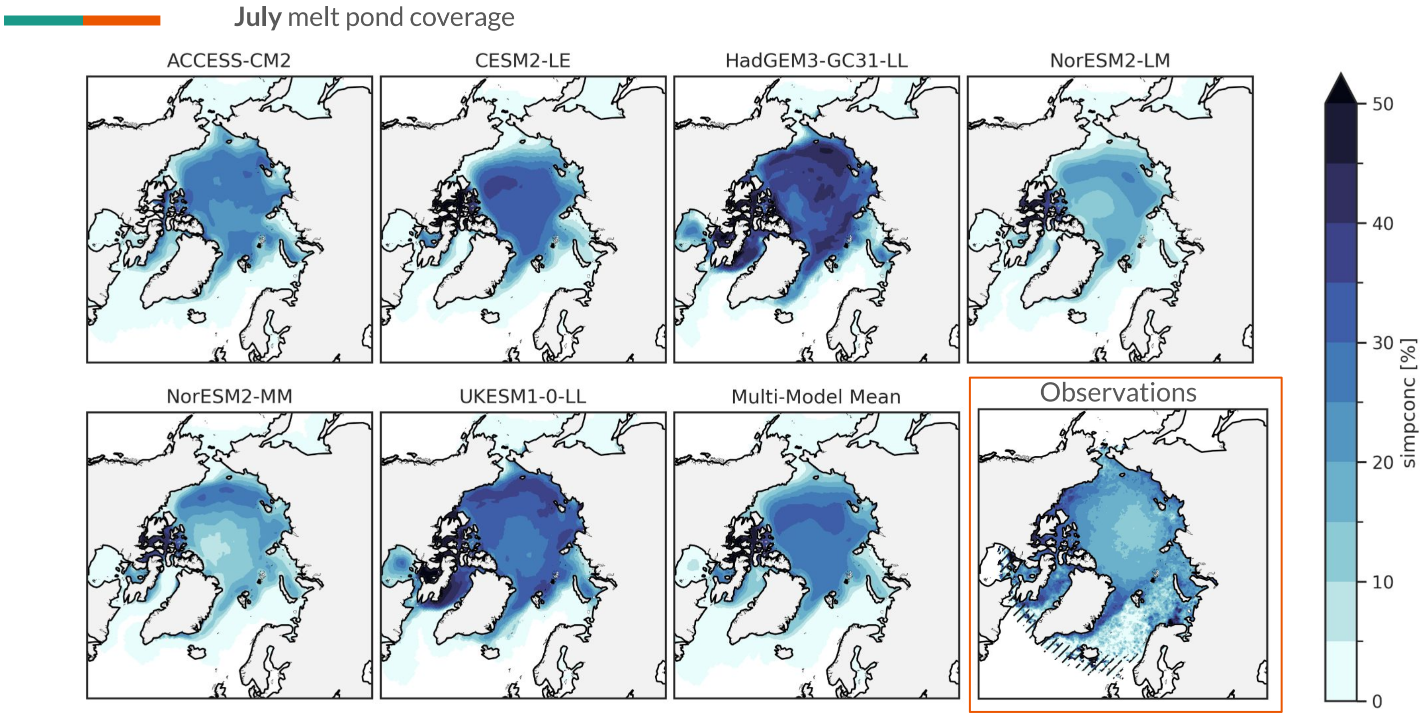
Unmasked CMIP6 multi-model mean



Melt ponds, thickness vs. albedo & transmittance

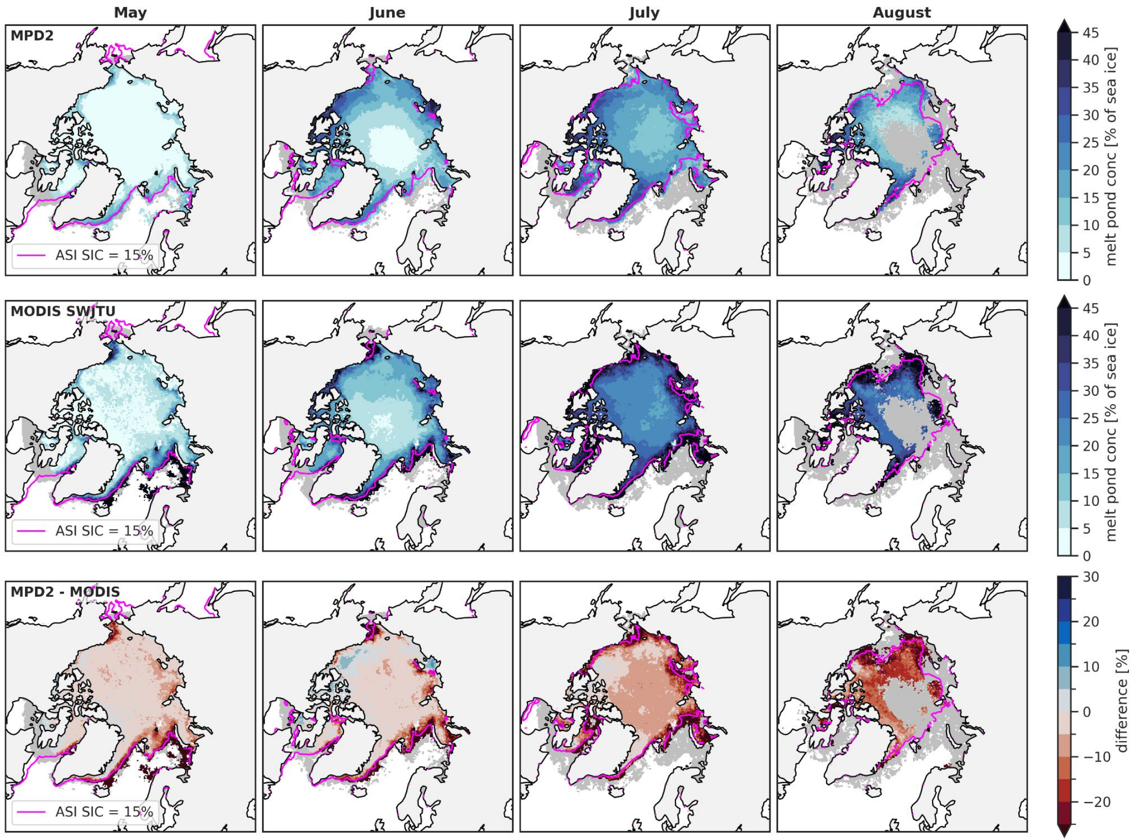


From last summer New work: Sea ice melt in CMIP6/CESM

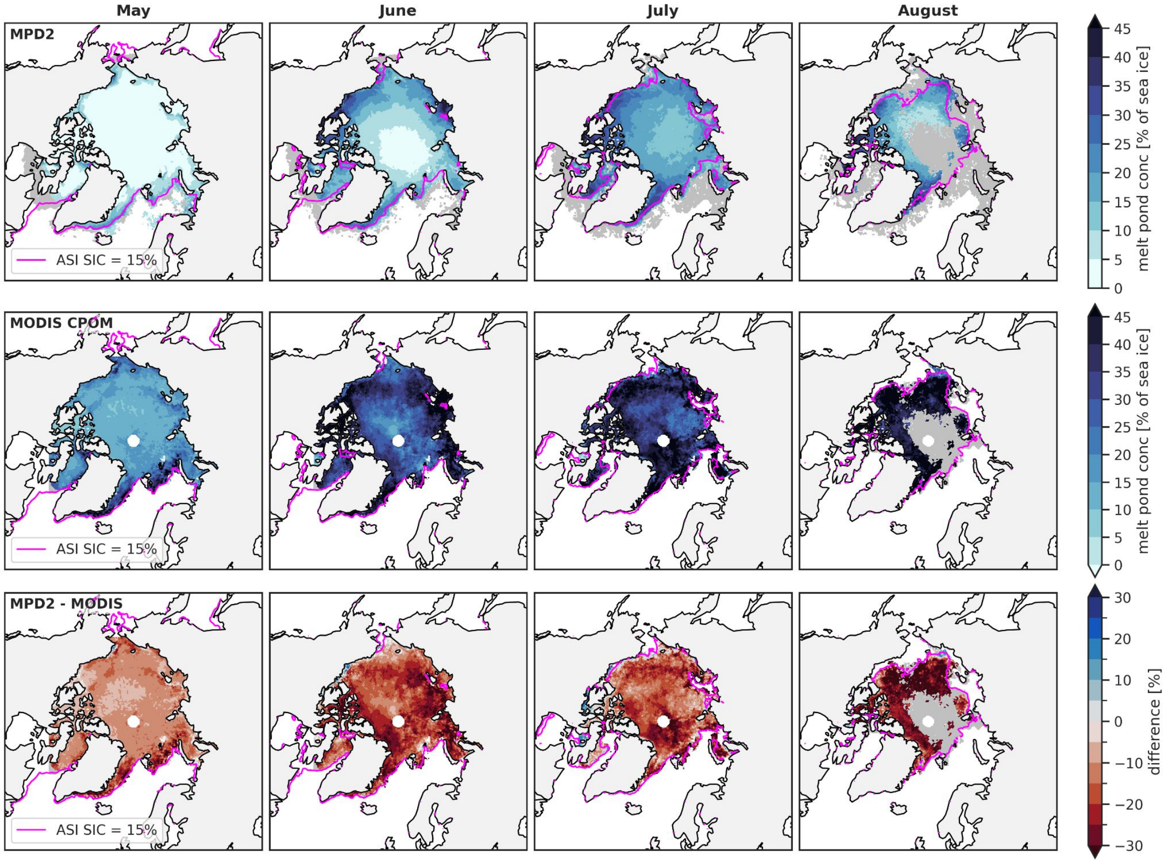


5 CMIP6 models + CESM2-LE provide outputs of sea ice melt pond coverage (all CICE)

Observational comparison: MPD2 vs. MODIS SWJTU



Observational comparison: MPD2 vs. MODIS CPOM



CESM PCWG meeting abstract

Melt ponds strongly influence Arctic sea ice melt through their impact on surface albedo, yet their large-scale representation in climate models remains uncertain. We evaluate melt pond coverage in six CMIP6 models which all use the CICE sea ice model, including CESM2-LE, with satellite observations from the Melt Pond Detection Algorithm version 2 (MPD2) based on Sentinel-3 data for 2017–2025. The CMIP6 multi-model mean captures general patterns in the observed seasonal cycle and basin-mean melt pond area, as does the average from CESM-LE. However, regional comparisons reveal systematic spatial biases. In summer, CESM2 simulates excessive ponding over high sea ice concentration regions in the central Arctic and insufficient ponding in lower-concentration and marginal ice zones.

These compensating errors obscure biases in hemispheric totals but distort the spatial pattern of pond-driven albedo feedbacks. All CMIP6 models examined, including CESM2, exhibit a strong positive dependence of melt pond fraction on sea ice concentration that is not supported by observations. While CESM2 reproduces the sign of the observed relationship between melt pond anomalies and surface albedo, the magnitude of the albedo response is weaker, indicating an underestimated melt–albedo feedback. This likely contributes to the relatively weak link between early-summer melt pond anomalies and the September sea ice minimum in CESM2. Together, these results suggest that melt pond biases primarily reflect structural limitations of the pond parameterization used, where CESM2 uses the level-ice scheme, rather than the shortwave radiation scheme, highlighting the need to improve links between melt ponds, subgrid-scale topography, freeboard, and drainage processes in future CESM development.