Forced increase in Antarctic snow accumulation partly mitigates sea level rise during 1901- 2050

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The Problem

A warmer atmosphere holds more moisture, leading to the expectation that Antarctic snowfall will increase in a warming climate. A large increase in Antarctic snowfall could temporarily slow the contribution of the Antarctic Ice Sheet (AIS) to sea level rise.

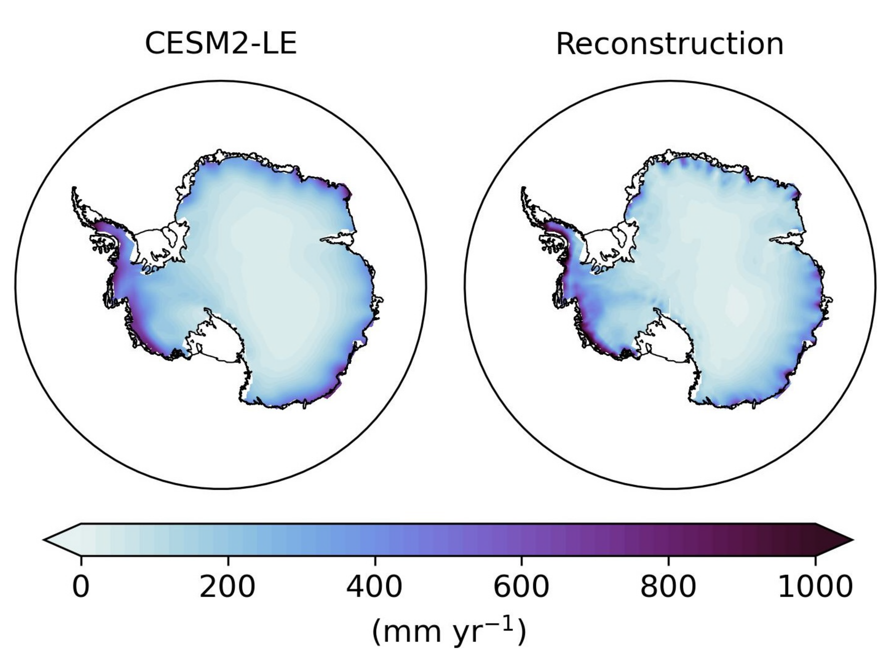
Has the expected snowfall increase been observed?

It is difficult to measure Antarctic precipitation, and there are few precip. datasets with trustworthy trends. Models generally suggest that we should be seeing the snowfall increase by now.
Are the models correct?

Two observational studies stand out, providing a test for models:

1) Analyzing GRACE and GRACE-FO gravitational satellite data, Velicogna et al. (2020) observe that **a sharp increase in snowfall in Queen Maud Land (Atlantic sector) since 2009 paused the acceleration of AIS mass loss after 2016.** (In 2022, the AIS had record-high snowfall.*^)

2) Combining temporal information from ice cores with spatial information from reanalyses, Medley and Thomas (2019) 'MT19' produce a gridded reconstruction of annual snow accumulation for 1801-2000. Integrating accumulated snow across the AIS year-by-year, MT19 find **a cumulative mass gain due to increased snow accumulation equivalent to ~10 mm of sea level mitigation during 1901-2000.**



20th-Century average annual snow accumulation (aka 'surface mass balance') on the grounded AIS according to MT19 data (right panel), is well simulated by CESM2 (left panel). For a full evaluation of the surface climatology in CESM2, see Dunmire et al. (2022).

Our Goals

Attribute the MT19 trend and project it forward to 2050, using a suite of all-forcing, single-forcing and nudged CESM2 experiments. Assess the roles of as many influences on Antarctic snow accumulation as we can. Place snow accumulation in the context of the broader climate system, especially atmospheric circulation, SST and surface air temperature trends.

The Runs

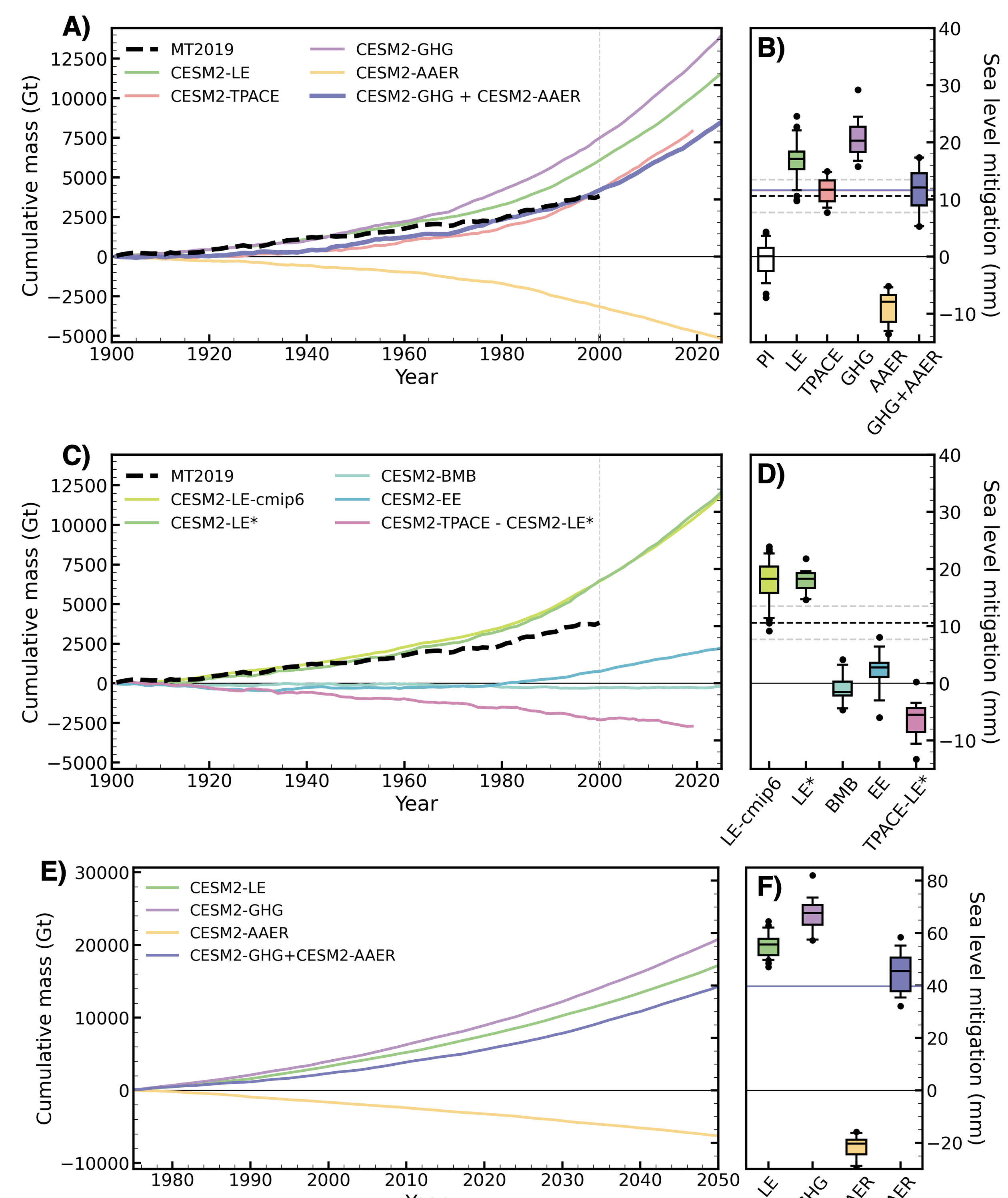
CESM2-LE**: 100-member CESM2 Large Ensemble, split into two halves (one with smoothed biomass burning; one with CMIP6 standard forcing)

CESM2-SFLE*: Consists of 4 sub-ensembles of 15-20 members, including single-forcing greenhouse gas (GHG), anthropogenic aerosol (AAER), and biomass burning (BMB) ensembles. Plus an "everything else" (EE) ens. forced by natural factors (volcanic and solar) and time-varying ozone.

CESM2-TPACE: 10-member ensemble with same forcing as CESM2-LEcmip6; SST anomalies in tropical Pacific nudged to observed anomalies.

CESM2-WNUDGE: 1 member (so far); model winds nudged to ERA5*** winds across 55°S-80°S and above 850 hPa; Forcing as in CESM2-LEcmip6.

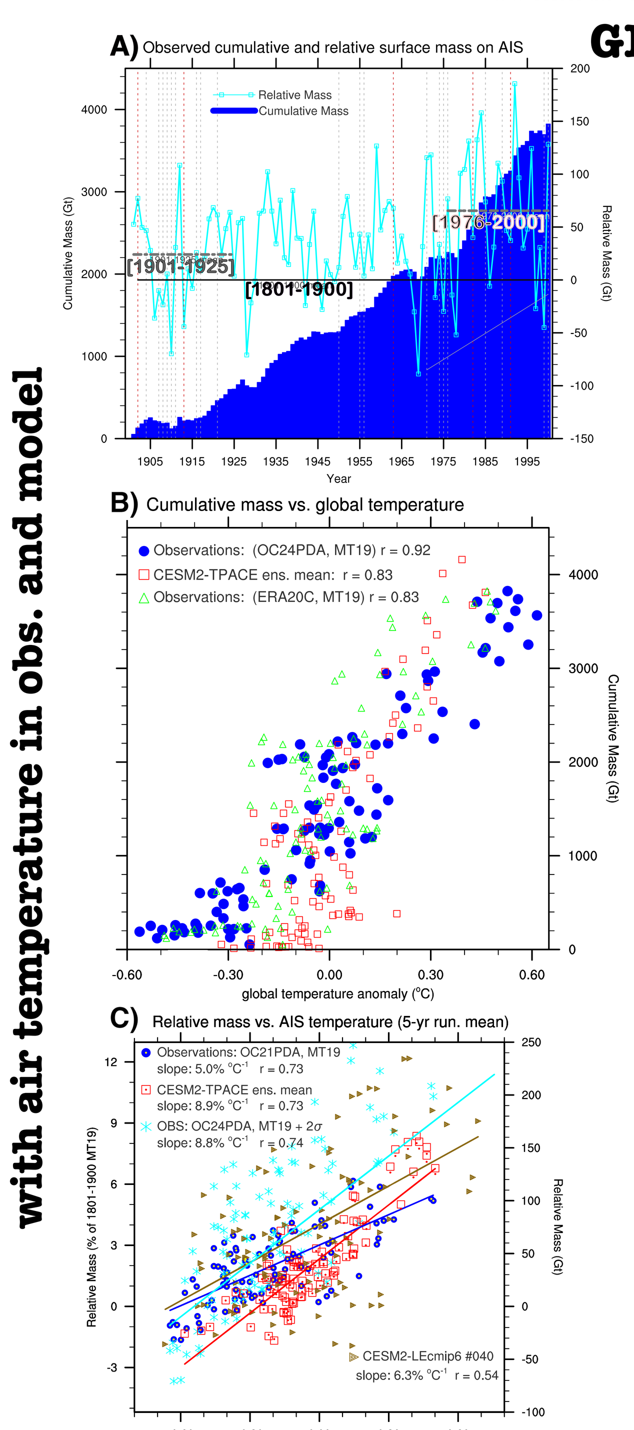
Cumulative mass gain (or loss) due to snow accumulation on grounded AIS

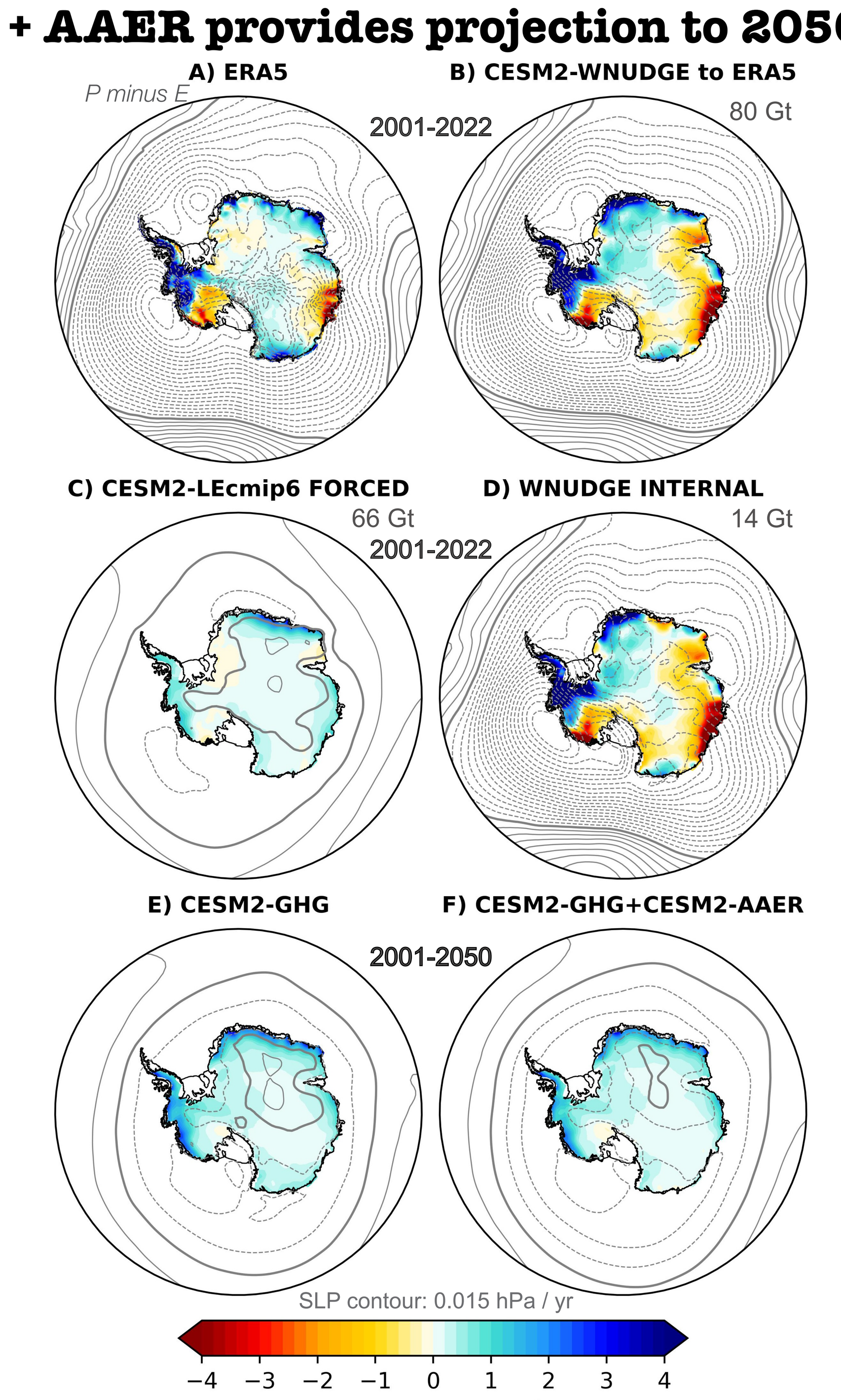


Ensemble-mean cumulative mass timeseries (a, c, e); ensemble spread at year 2000 (b, d) or year 2050 (f) as box-whisker plots; horiz. lines show MT19 mean and ±1σ error (b, d).

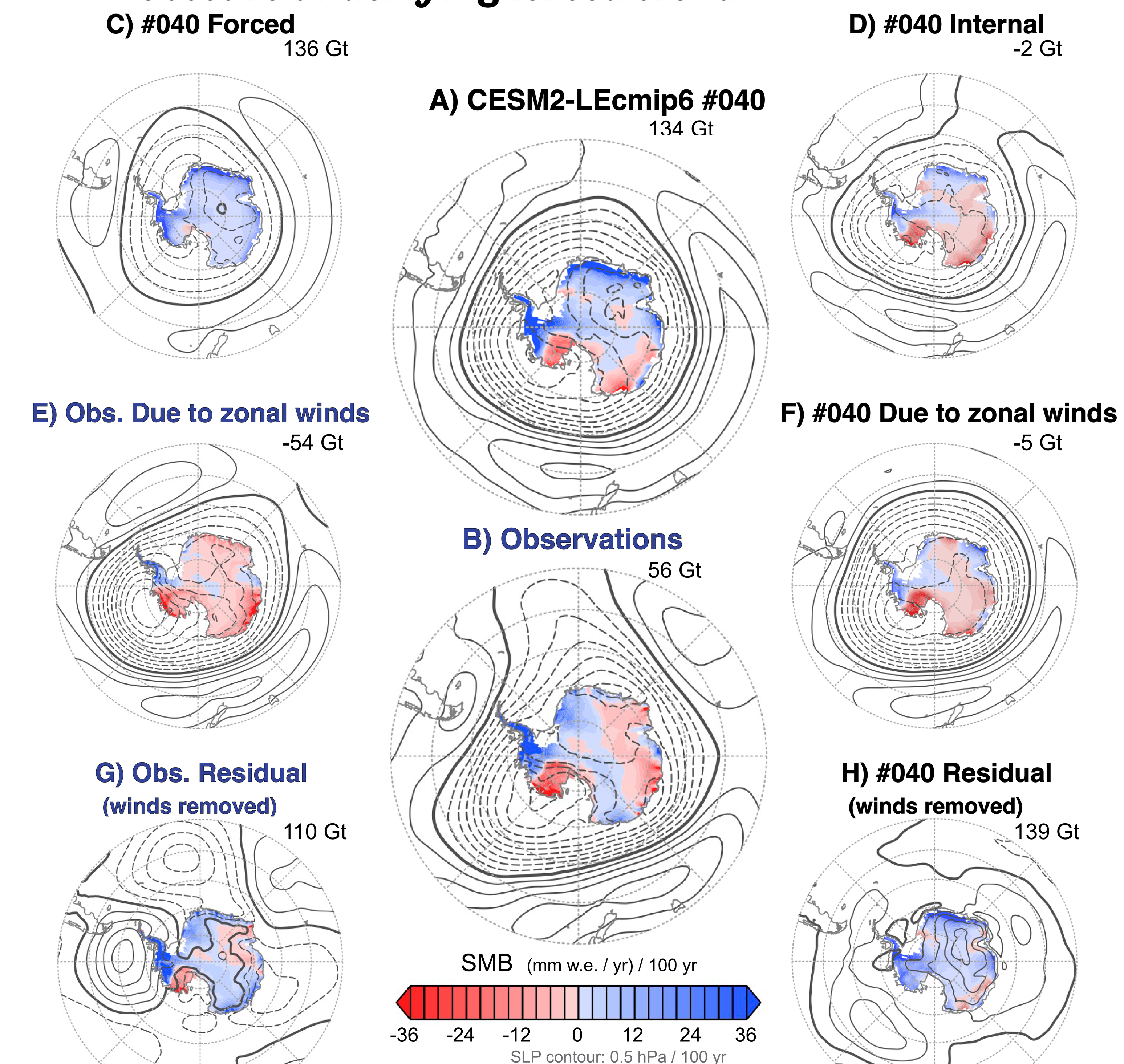
Wind-nudged run captures early 21stC trend; GHG + AAER provides projection to 2050

Snow accumulation significantly correlated with air temperature in obs. and model





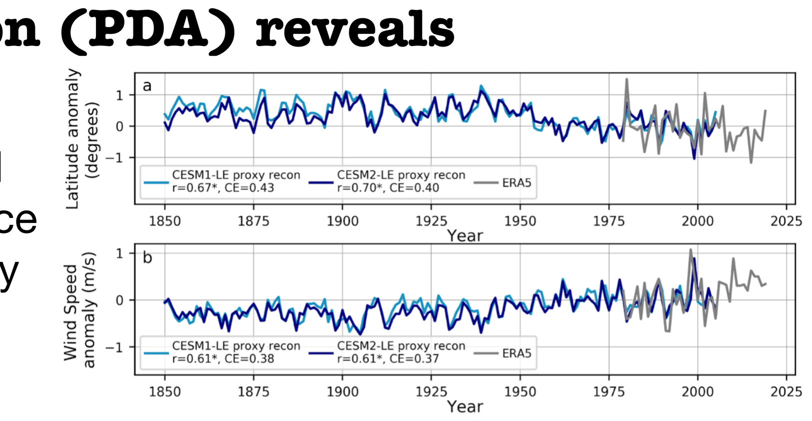
Wind-driven patterns in snow accumulation obscure underlying forced trend



20th-Century linear trends (1901-2000) in snow accumulation and SLP, according to CESM2-LE-cmip6 and the MT19 & PDA reconstructions. The ensemble member of the LE (a) with the highest pattern correlations to the reconstructions (b) is selected for further analyses. Member #040 is broken down into forced (c) and internal (d) components. We construct indices of the zonal winds averaged over 50°S-70°S from #040 and the PDA, to find the snow accumulation patterns that are congruent with the wind trends in reconstructions (e) and model (f). We infer that most of the modeled snow accumulation increase is forced, while the wind trend has both forced and internal components. The wind-driven pattern masks an underlying forced accumulation trend (c, g, h) that features strong upward trends in coastal West Antarctica and Queen Maud Land.

Paleo. Data Assimilation (PDA) reveals wind history

We reconstruct global fields of zonal winds, sea level pressure, and surface air temperatures using a global proxy network with CESM2-LE as the model prior, following O'Connor et al. (2021) methods.



Anomalies in Southern Hemisphere westerly wind position (a) and strength (b) in two proxy-based reconstructions and ERA5. Reconstructions generated by PDA using two different priors: CESM1-LE (O'Connor et al., 2021) and CESM2-LE (this study).

Key Points

>The cumulative mass gain observed in MT19 is forced.
>Upward trend primarily caused by GHGs; substantially counteracted by AAER.
>Consistent with thermodynamic expectations from increased air temperatures.
>Internal variability cannot explain the mass gain.
>Internal variability is large, and together with the forced response, brings the CESM2-LE in agreement with observations.
>Real-world internal variability, captured in TPACE, dampens the mass gain.
>Stronger westerlies shape the spatial pattern of snow accumulation change, masking the underlying mass gain. Similar patterns in 20th & early 21st Centuries.
>GHG + AAER projects a possible sea level mitigation of ~30 mm over 2001-2050 due to increased Antarctic snow accumulation.

References: *^Datta et al. (2023) | Dunmire et al. (2022) | ***Hersbach et al. (2020) | Medley and Thomas (2019) | O'Connor et al. (2021) | **Rodgers et al. (2021) | *Simpson et al. (2023) | Velicogna et al. (2020).
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