Comparison of Low-Frequency Variability of Summer Arctic Sea Ice Extent in Three Coupled Climate Models

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Introduction

- Observed decline of summer Arctic sea ice extent (ASIE) is faster than that in most CMIP5 models forced by anthropogenic changes.
- Internal variability may account for a considerable part of ASIE decline.
- Key predictors for internal low-frequency variability of summer ASIE: ocean heat transport from Atlantic (HT_{ATL}), Pacific (HT_{PAC}), and Arctic Dipole (AD) [Zhang 2015, PNAS].
- Long control runs from coupled climate models: GFDL CM2.1 (3600 yrs), GFDL CM3 (3600 yrs), NCAR CESM (1800 yrs); 30-yr low-pass filtered

Model Mean States

- Simulated Sep ASIE by GFDL CM3 is closest to observed (NSIDC, 1979-2015).
- CM2.1 has a too small summer Arctic sea ice cover.
- CESM shows excessive summer sea ice, especially on the Atlantic side.

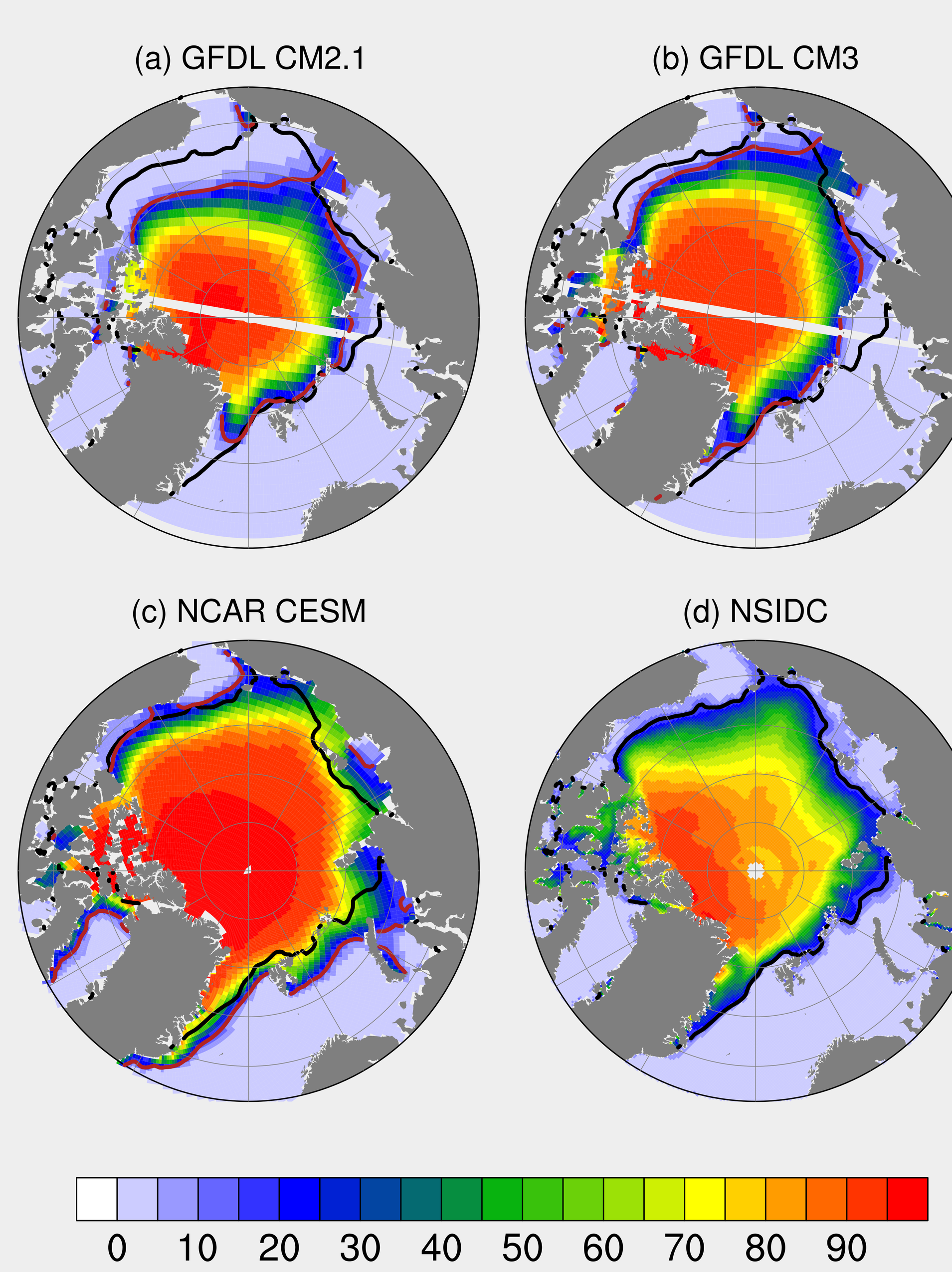

Fig. 1: Comparison of September ASIE climatology simulated in three coupled GCMs. Color: sea ice concentration; Black contour: observed (NSIDC) Sep sea ice edge (15%); Red contour: simulated Sep sea ice edge.

- The positive phase of Arctic Dipole enhances transpolar wind and ice drift, resulting in stronger ice export into the Atlantic.

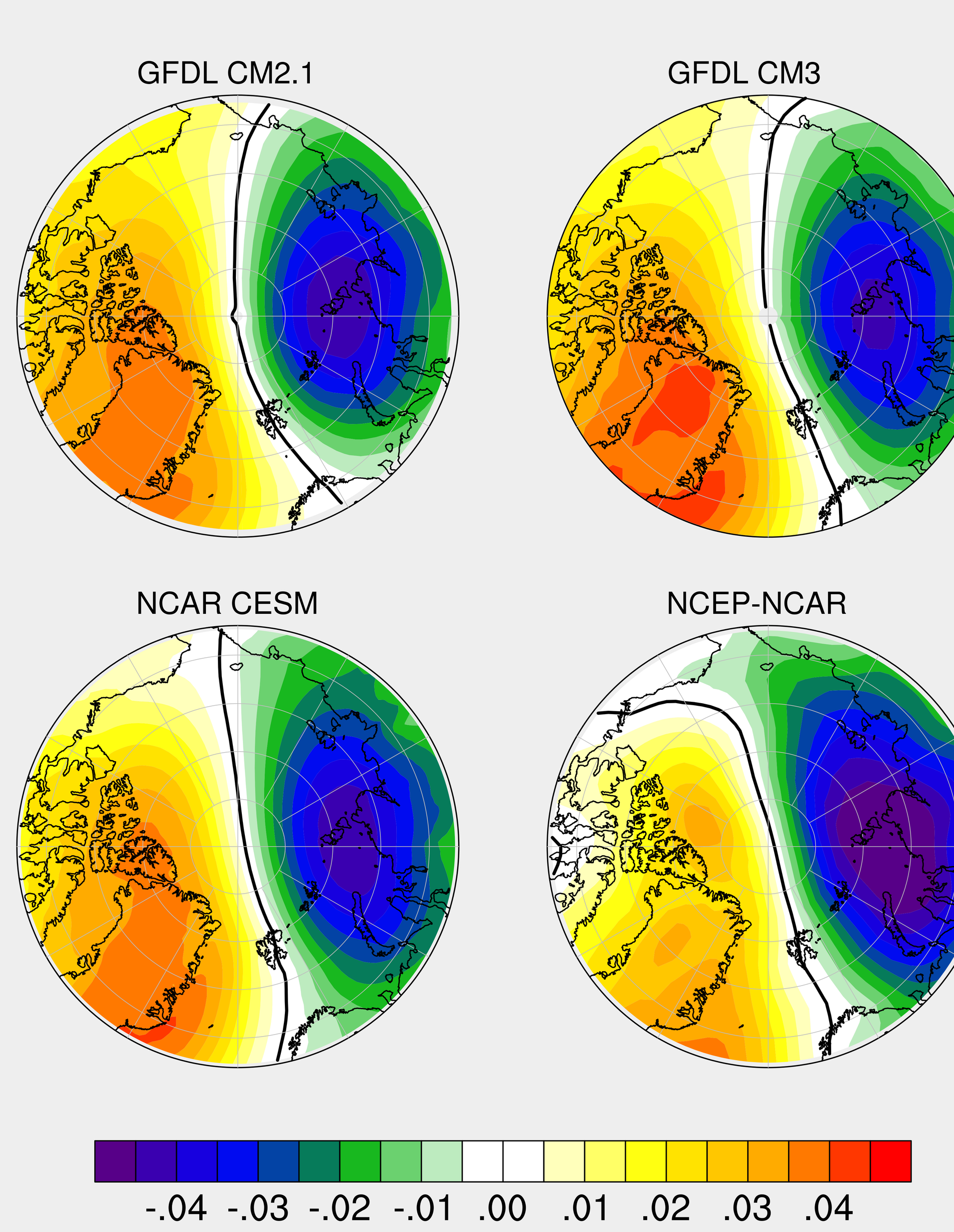

Fig. 2: Spatial patterns of AMJJ Arctic Dipole (EOF2 of AMJJ SLP) simulated in three coupled GCMs, and that calculated with NCEP-NCAR reanalysis data (1948-2015).

Multiple Regressions

- Multiple regression model:

$$SIE(t) = m_{ATL}HT_{ATL}(t-\tau_{ATL}) + m_{PAC}HT_{PAC}(t-\tau_{PAC}) + m_{AD}HT_{AD}(t-\tau_{AD}) + \epsilon = SIE_R(t) + \epsilon \quad (1)$$

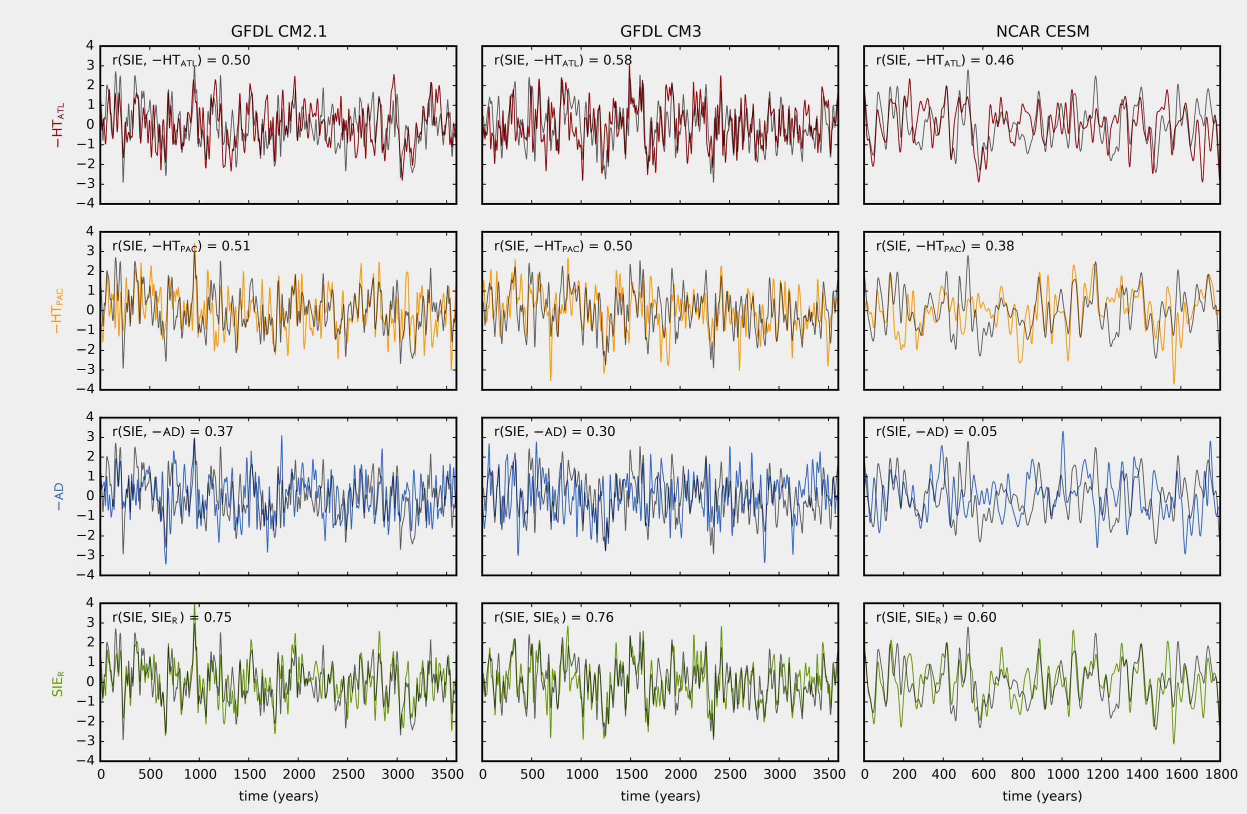

Fig. 3: Anomalies of annual-mean inverted HT_{ATL}, inverted HT_{PAC}, inverted AMJJ AD, and reconstructed Sep ASIE shown together with Sep ASIE. All time series are 30-yr LPF and normalized.

Spatial Patterns

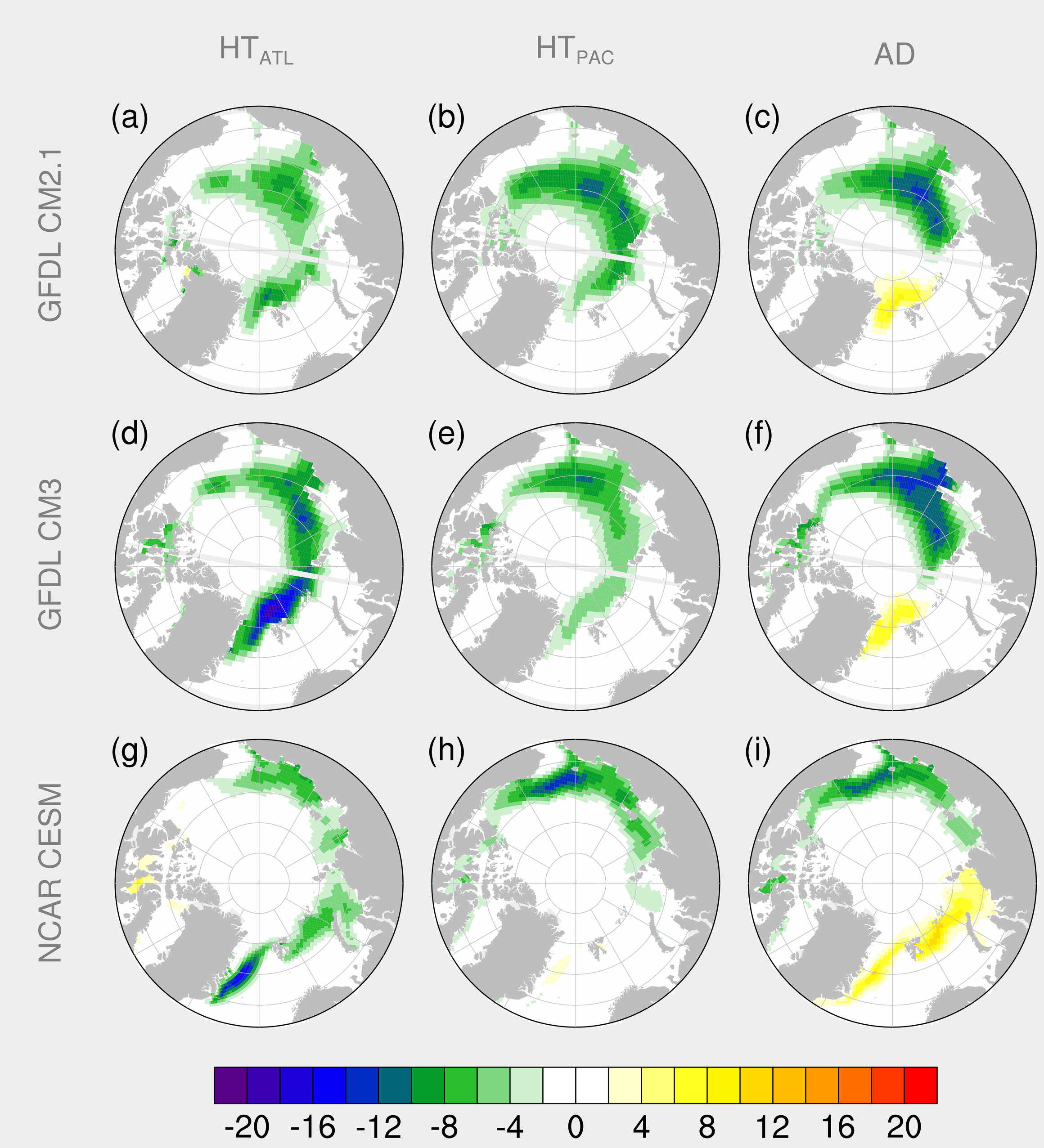

Fig. 4: Regressions of Sep SIC anomalies on 20 TW HT_{ATL}, 1 TW HT_{PAC}, and 20 hPa AD.

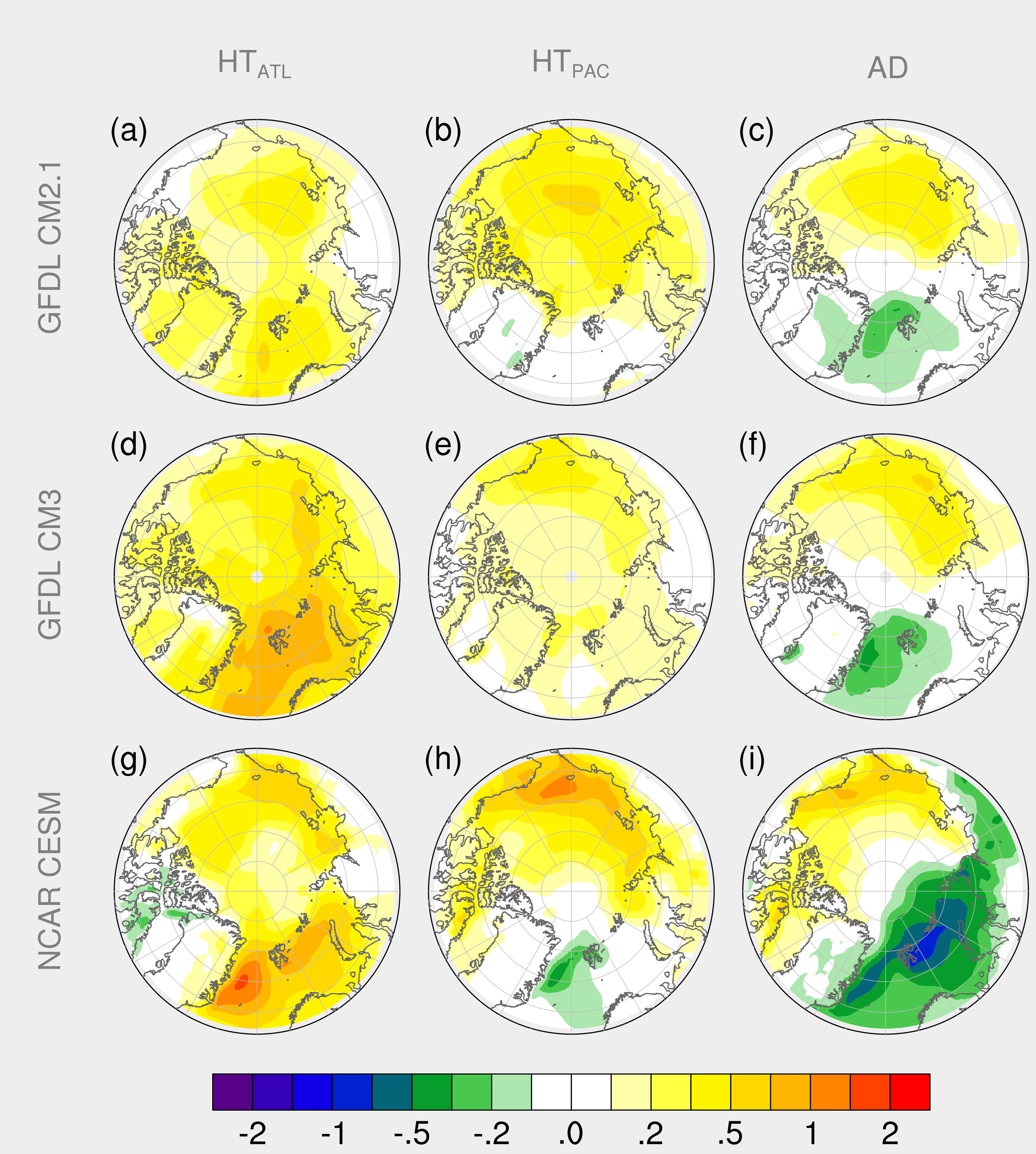

Fig. 5: Regressions of Sep 2-meter temperature anomalies on 20 TW HT_{ATL}, 1 TW HT_{PAC}, and 20 hPa AD.

Arctic Dipole and SIE

- Positive AD decreases SIE on the Pacific side, but increases SIE on the Atlantic side. In CESM control run, these two effects almost cancel out for SIE of the whole Arctic region.

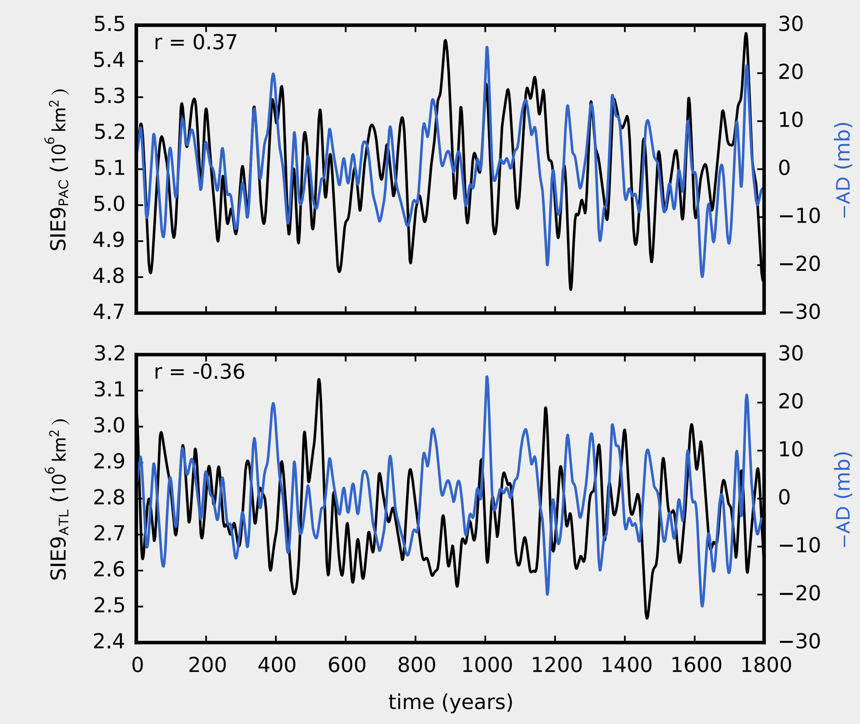

Fig. 6: Anomalies of AMJJ AD index and

March Barents Sea Ice

- The coherent variability of Mar Barents Sea SIE and Sep ASIE reveals the importance of Atlantic inflow.

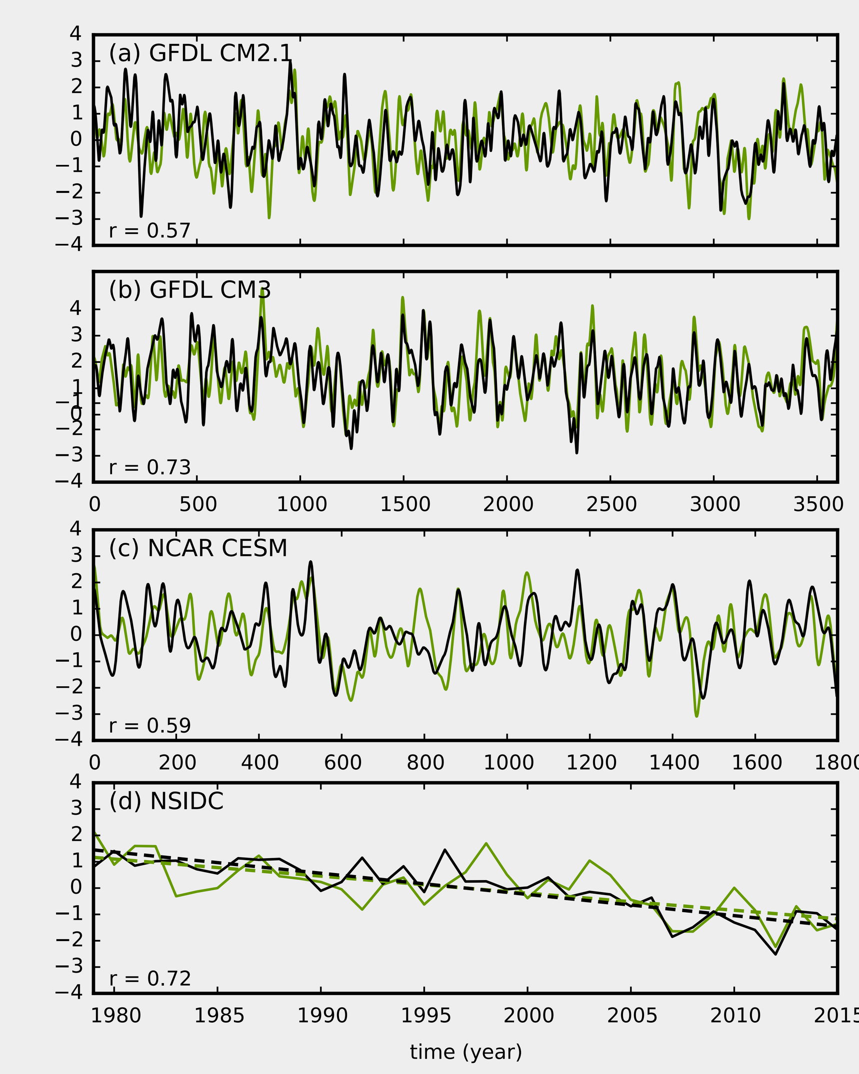

Fig. 7: Sep ASIE and Mar Barents Sea SIE in model control runs and observation (NSIDC).

Bjerknes Compensation

- At multi-decadal time scale, the anticorrelation between ocean and atmospheric heat transport across the Arctic circle provides a negative feedback to ASIE variations.

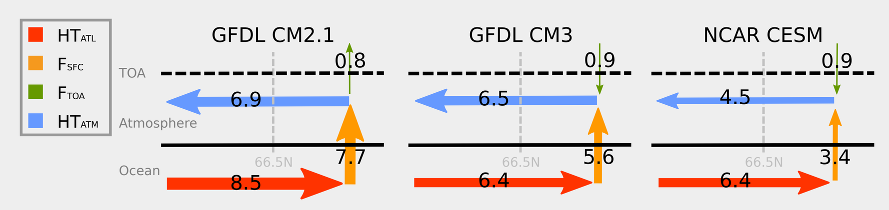

Fig. 8: Bjerknes compensation between HT_{ATL} and atmospheric heat transport across the Arctic Circle. Also shown are net ocean-atmosphere heat fluxes and net top of the atmosphere fluxes.

Summary

- All three models show strong influence of Atlantic/Pacific inflow on the variability of summer ASIE. HT_{ATL} appears to be less efficient than HT_{PAC} due to a much greater portion is lost before reaching the ice cover.
- AD modulates SIC via transpolar ice drift; Its net effect on ASIE depends on the sea ice mean state.
- Responses of surface air temperature and albedo to SIC provide positive feedbacks.
- Bjerkness compensation provides a negative feedback.

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