On the Discrepancy between Observed and CMIP5 Multi-Model Simulated Barents Sea Winter Sea Ice Decline

Dawei Li[1], Rong Zhang[2], Thomas R. Knutson[2]

1. Princeton University AOS, USA; 2. NOAA GFDL, USA

Questions to address

- What are the relative roles of changes in external radiative forcing versus internal variability in causing the observed winter Barents Sea SIE decline (1979-2015)?
- Are there any substantial discrepancies between the observed and CMIP5-simulated externally forced response in winter NH sea ice decline?

Discrepancies between observations and CMIP5 ensemble

- Observations: SIE (NSIDC), SAT (NCEP/NCAR, ERA-Interim, MERRA) from 1979 to 2015 (37 years)
- 79 ensemble members from 32 CMIP5 models
- Multimodel-ensemble mean: response to changes in external radiative forcings in the models (internal variability in individual members tends to cancel out)

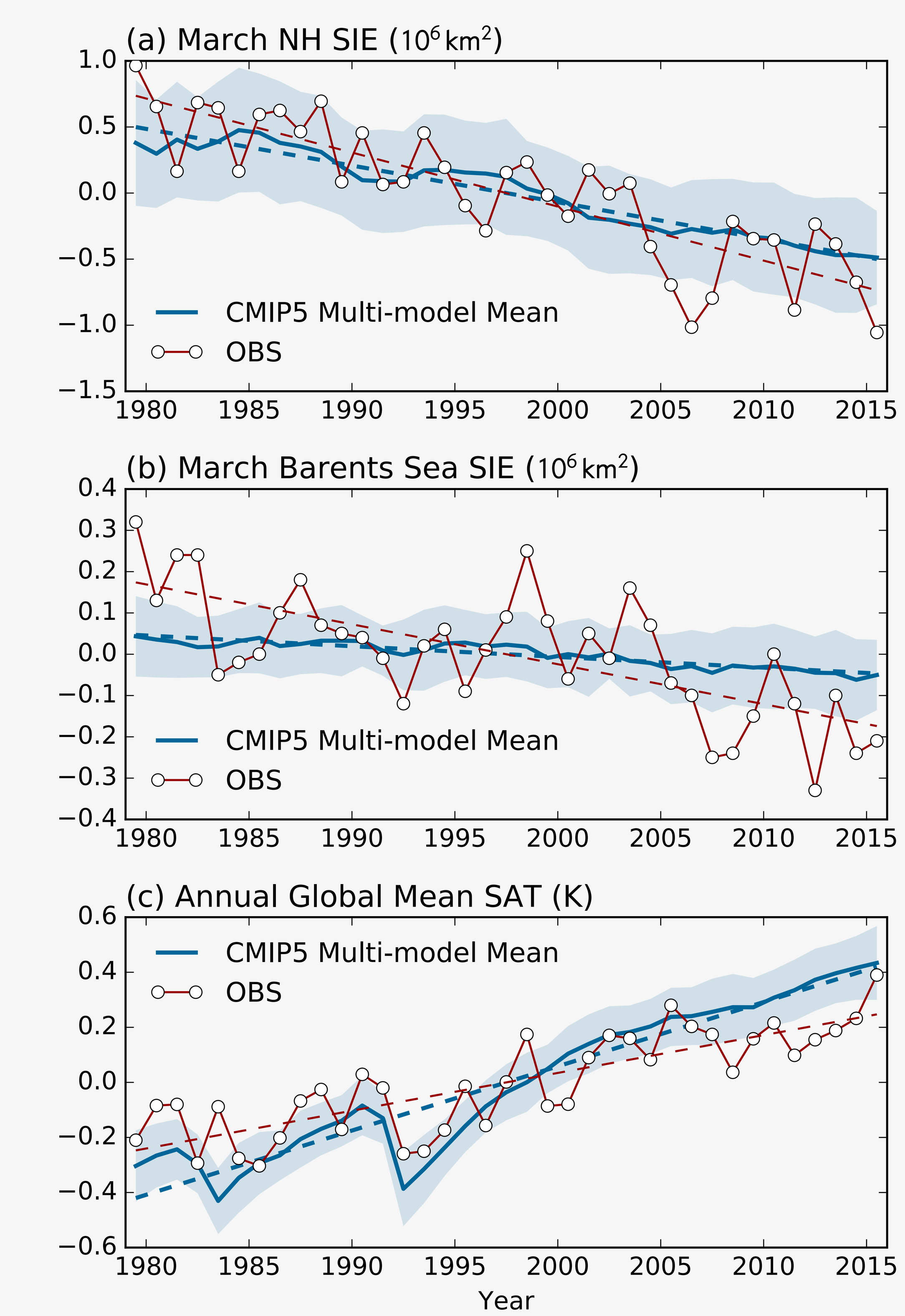

Fig. 1: (a) March NH SIE anomaly (b) March Barents Sea SIE anomaly (c) Annual global mean SAT anomaly. Blue solid lines: CMIP5 ensemble mean; blue shadings: spread (± 1 s.d.) across ensemble members; blue dashed line: linear trends. Red solid lines: observations; red dashed lines: linear trends.

- The CMIP5 multi-model ensemble mean March NH SIE declining trend (-1.03 million km^2/37yr) is weaker than that observed (-1.51 million km^2/37yr), but still accounts for a substantial part (68%) of the observed declining trend (Fig 1a).
- The observed March Barents Sea SIE declining trend is not well captured by the CMIP5 multi-model ensemble mean. Both the observed March Barents Sea SIE declining trend and anomalies often stay outside of the ± 1 s.d. of the CMIP5 multi-model ensemble mean (Fig 1b).
- Despite the weaker than observed declining trends in March NH and Barents Sea SIEs in the CMIP5 multi-model ensemble mean, the annual global mean surface air temperature (SAT) simulated by the CMIP5 multi-model ensemble mean displays a warming trend (0.86K/37yr) stronger than that observed (0.51K/37yr) (Fig 1c).

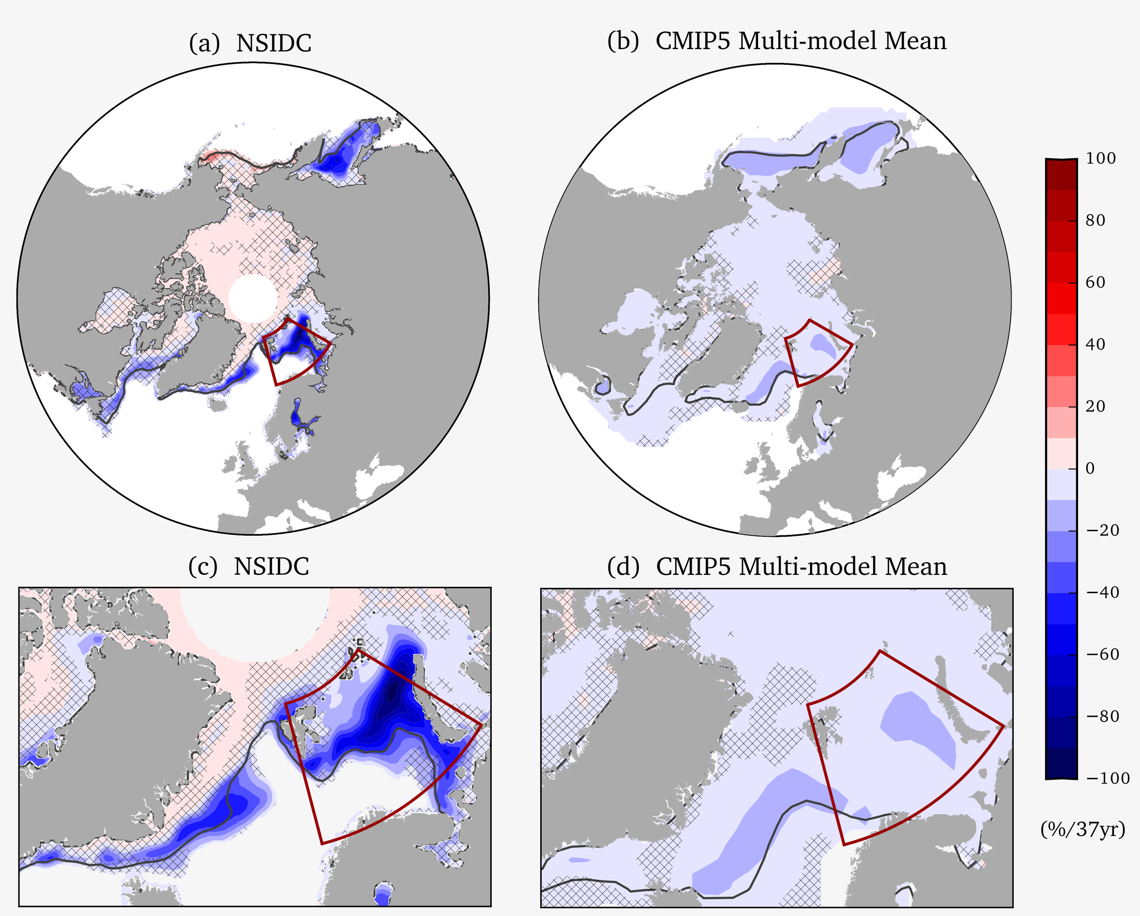

Fig. 2: Spatial pattern of observed and CMIP5 multi-model simulated Marc SIC trend over 1979-2015. (a,c) Observations (NSIDC), (b,d) CMIP5 multi-model ensemble mean. Black lines: climatological March sea ice edge; red box: Barents Sea; unhatched regions: statistically significant trends at 95% confidence level.

- Observed declining trend in March NH SIC: most pronounced in the northeast section of the Barents Sea (Fig 2a,c); also significant in the Sea of Okhotsk and Greenland Sea; a slight increase in the Bering Sea and central Arctic (Fig 2a).
- CMIP5 externally forced response in March NH SIC: much weaker declining trend in regions where the observed decline is most pronounced (Fig 2b,d); a weak declining trend over a broader region in the NH; an opposite trend to that observed in central Arctic (Fig 2a,b).
- CMIP5 externally forced declining trend in March NH SIE is not much weaker than that observed (Fig 1a) because the discrepancy in the spatial pattern is masked by summing over the entire NH.

Impact of Atlantic heat transport

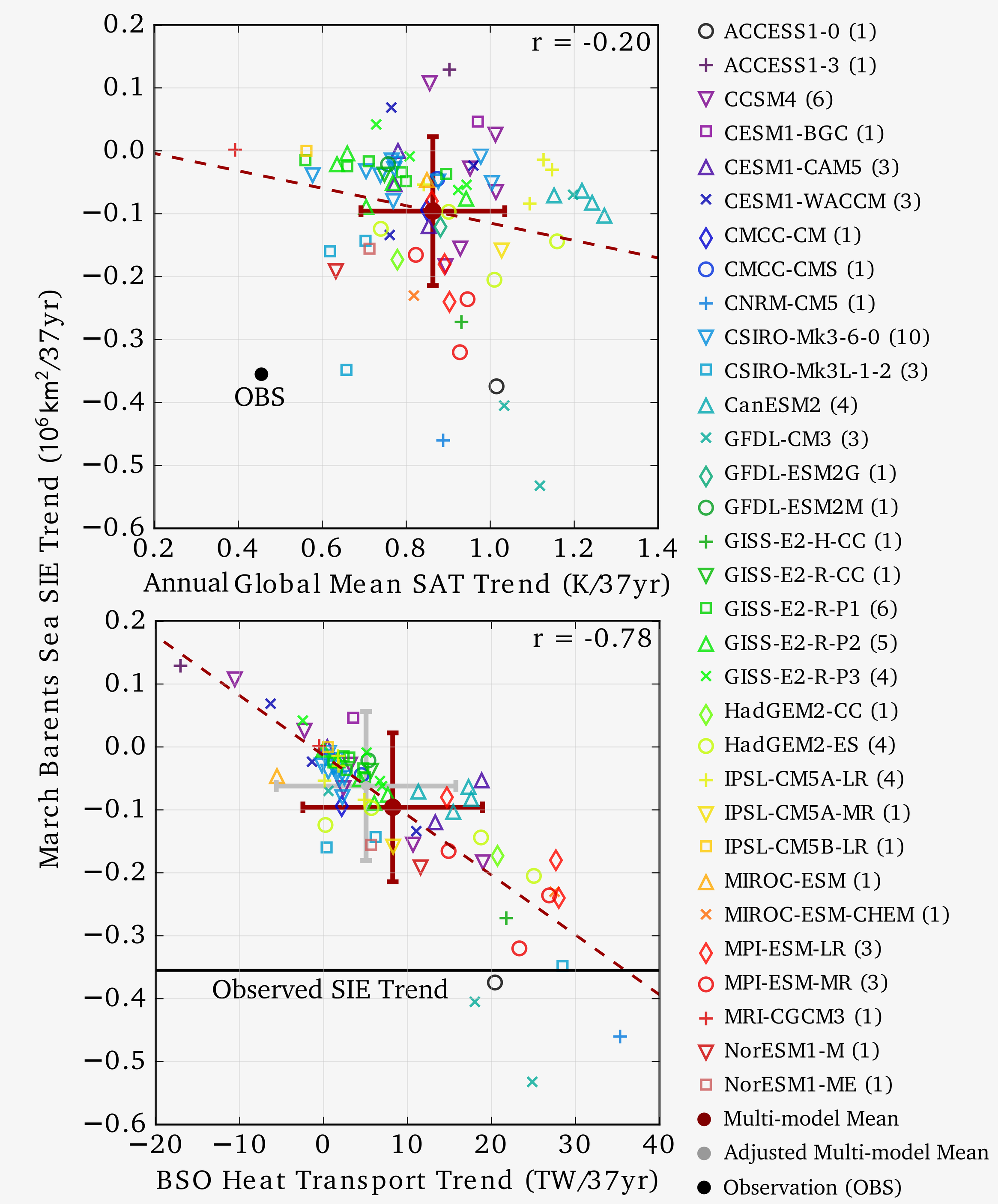

Fig. 3: Scatter plots of trends over 1979-2015 from CMIP5 multi-model ensemble members. (a) March Barents Sea SIE trend versus annual global mean SAT trend (b) March Barents Sea SIE trend versus trend of annual mean Atlantic heat transport across the BSO (HT_{BSO}). In parentheses (model list): number of ensemble members for each model. Solid red circles: CMIP5 multi-model ensemble mean trends. Thick red crosses: spread (± 1 s.d.) across ensemble members. Grey solid circle and thick grey cross in b: adjusted multi-model mean trends and spread. Red dashed lines: least-square linear fits.

- No significant correlation (r = -0.2) between annual global mean SAT trends and March Barents Sea SIE trends over the 37-year period across the CMIP5 ensemble members (Fig 3a).
- March Barents Sea SIE trends are strongly anti-correlated with the trends in the annual mean Atlantic heat transport across the BSO (HT_{BSO}) (r = -0.78, Fig 3b) over the 37-yr period across the CMIP5 ensemble members.
- An increase in HT_{BSO} on the order of 30TW/37yr is necessary to explain the decrease of winter Barents Sea SIE seen in recent decades (Fig 3b).
- Simulated March Barents Sea SIC declines in response to a positive trend of HT_{BSO} (scaled to 30TW/37yr) in control simulations from three models (Fig 4) are on the same order as that observed (Fig 2c,d).

- Response in March Barents Sea SIE to a positive trend of HT_{BSO} (scaled to 30TW/37yr) in three models are -0.31, -0.55, -0.25 million km^2, respectively.

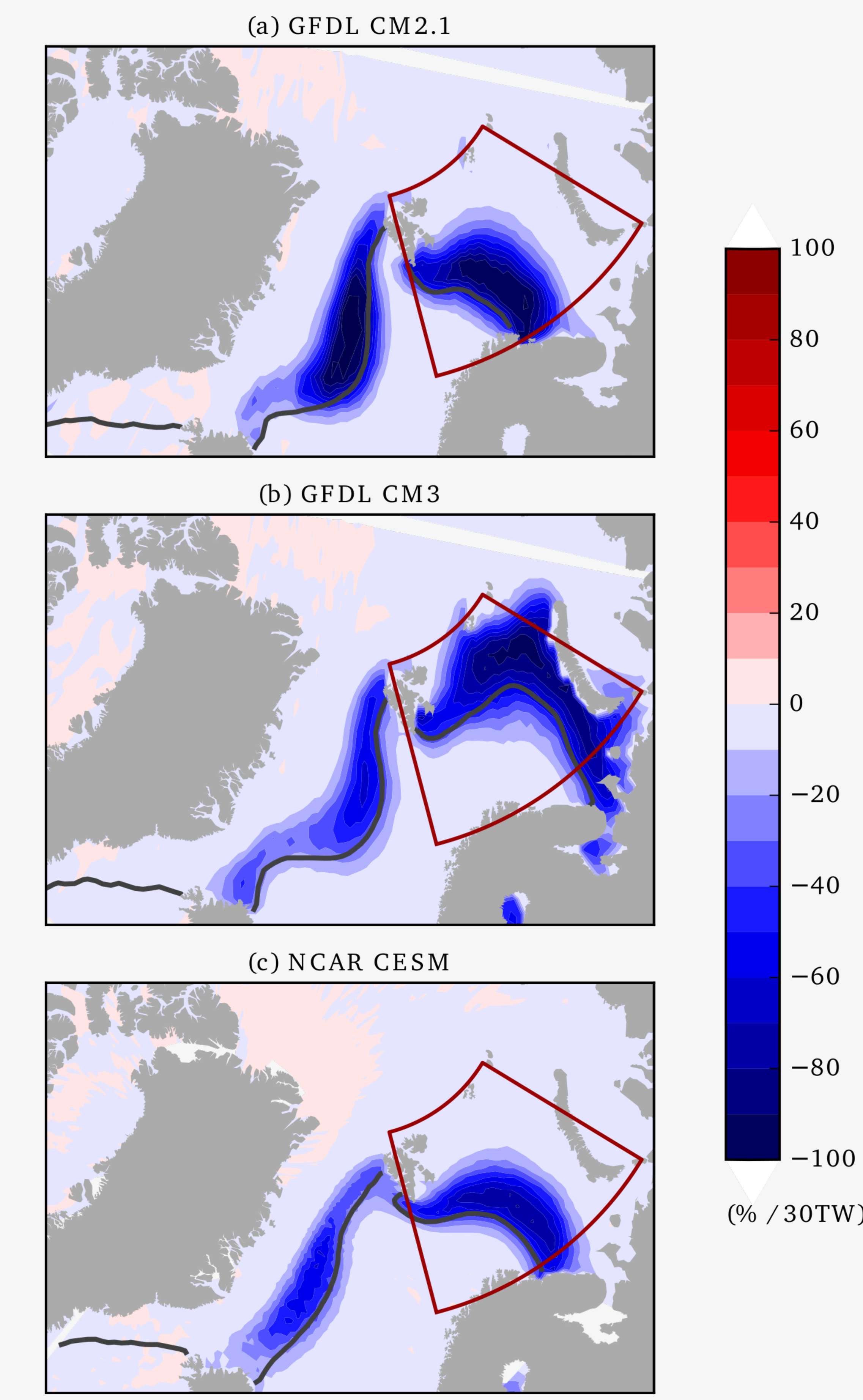

Fig. 4: Regression of 37-year March SIC trends on 37-year HT_{BSO} trends in three control simulations. (a) GFDL CM2.1 (b) GFDL CM3 (c) NCAR CESM (scaled to correspond to a positive trend of 30TW/37yr in HT_{BSO}).

Summary Conclusions

- Spatial patterns reveals that the CMIP5 externally forced March NH SIC trend in individual regions differs substantially from that observed, showing a much weaker decline in regions where the observed decline is most pronounced (Barents Sea).
- Enhanced HT_{BSO} associated with regional internal variability may have played a leading role in the observed decline in winter Barents Sea SIE over the satellite period.

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