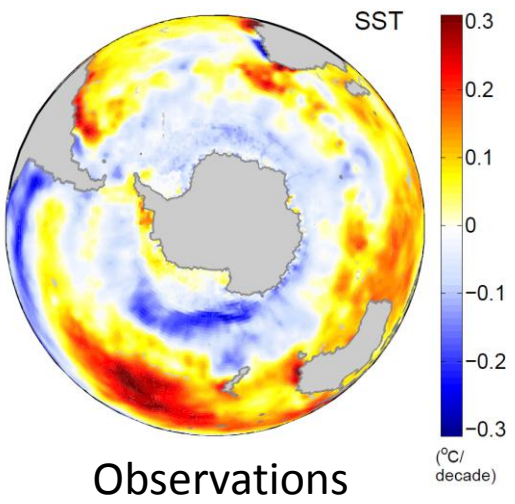
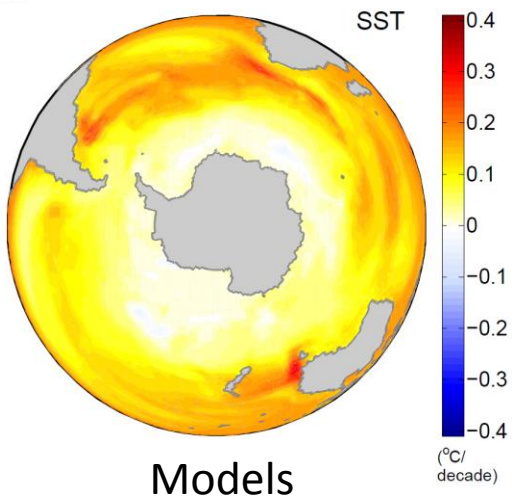
Understanding historical Southern Ocean trends in observations and simulations

1979-2014



Observations

1979-2014



Models

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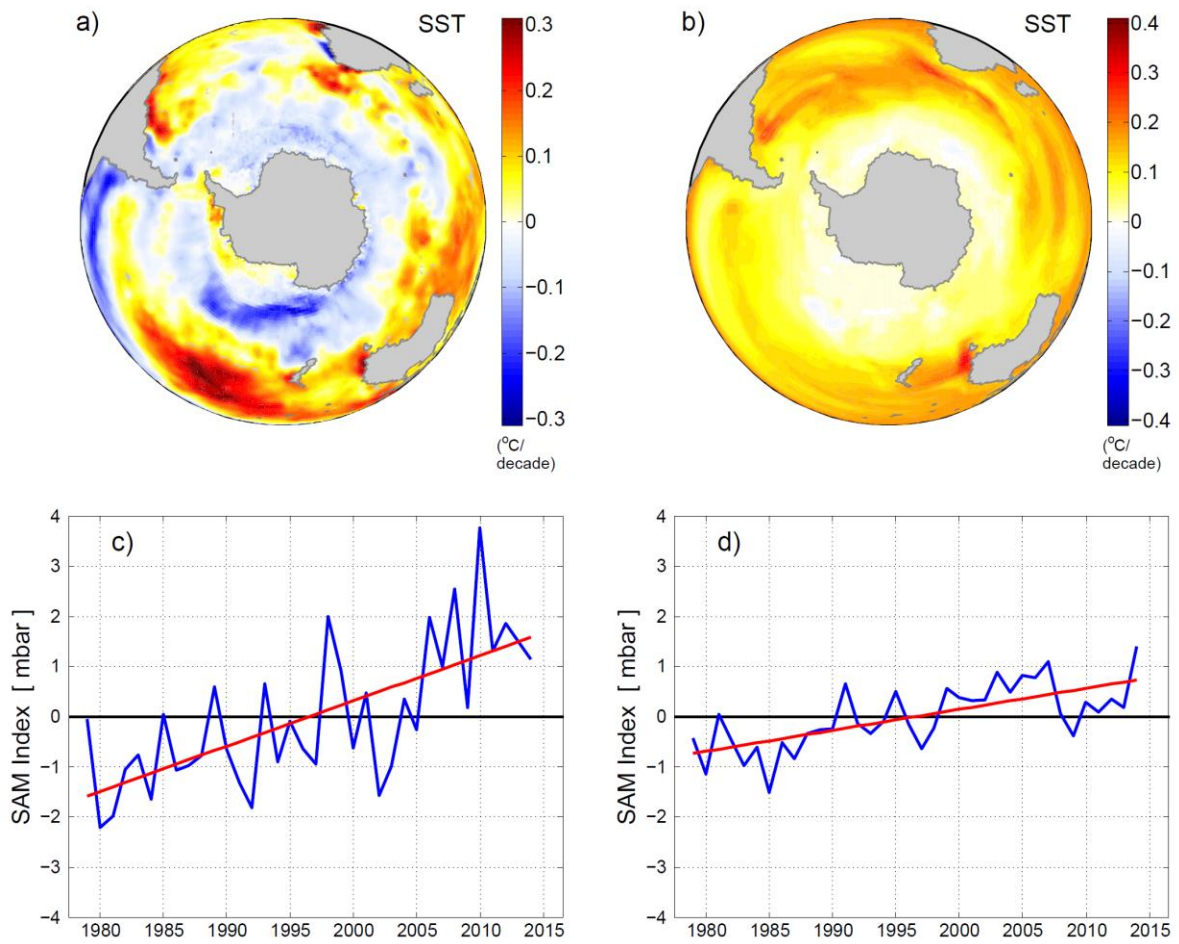
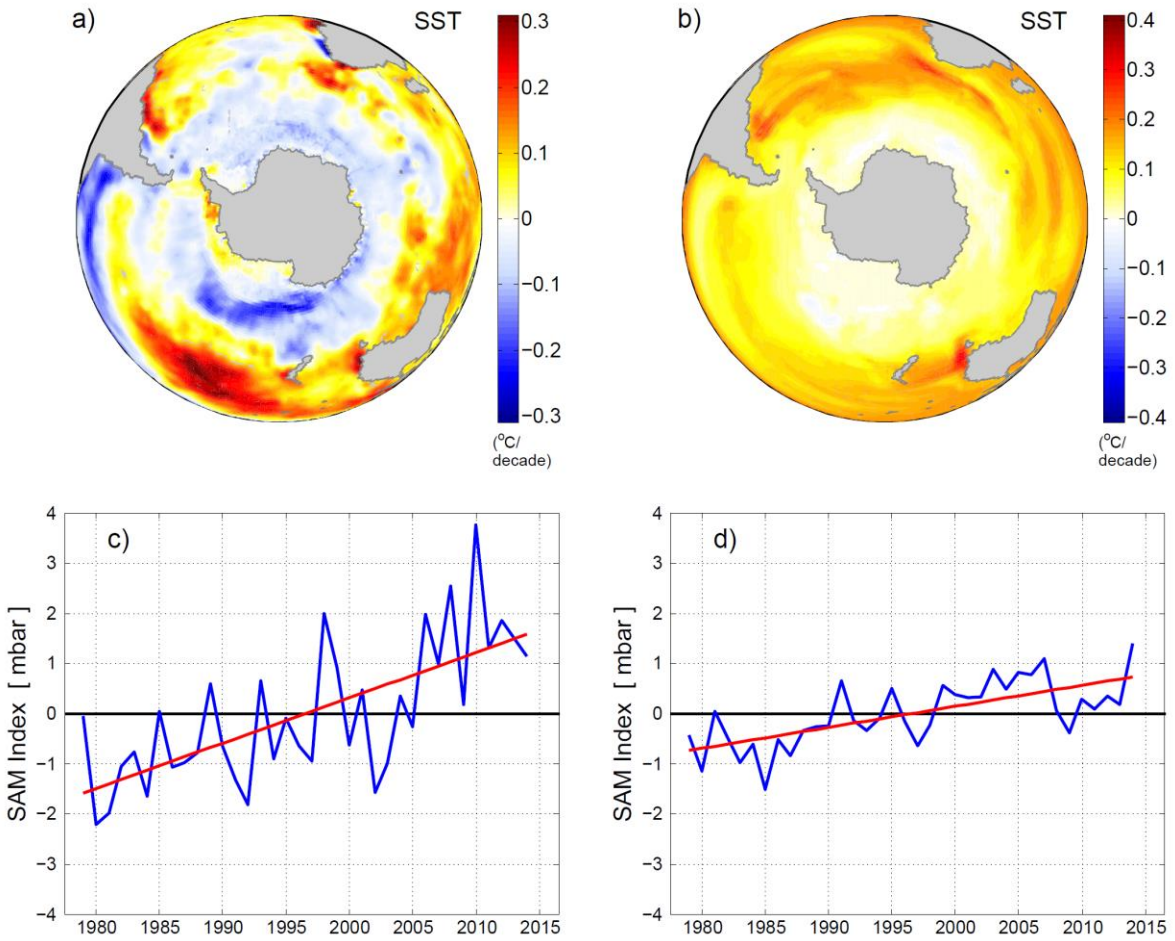


Emphasis on the seasonality

1979-2014 Observations:
HadISST and HadSLP2r

1979-2014
CMIP5 Historical Simulations



We reconstruct the SO SST trends from CMIP5 historical simulations.

We use linear convolutions of SO step response functions with:

1) Seasonal SAM forcing;

2) Greenhouse gas (GHG) forcing;

3) SAM trend due to greenhouse gas forcing (overlap).

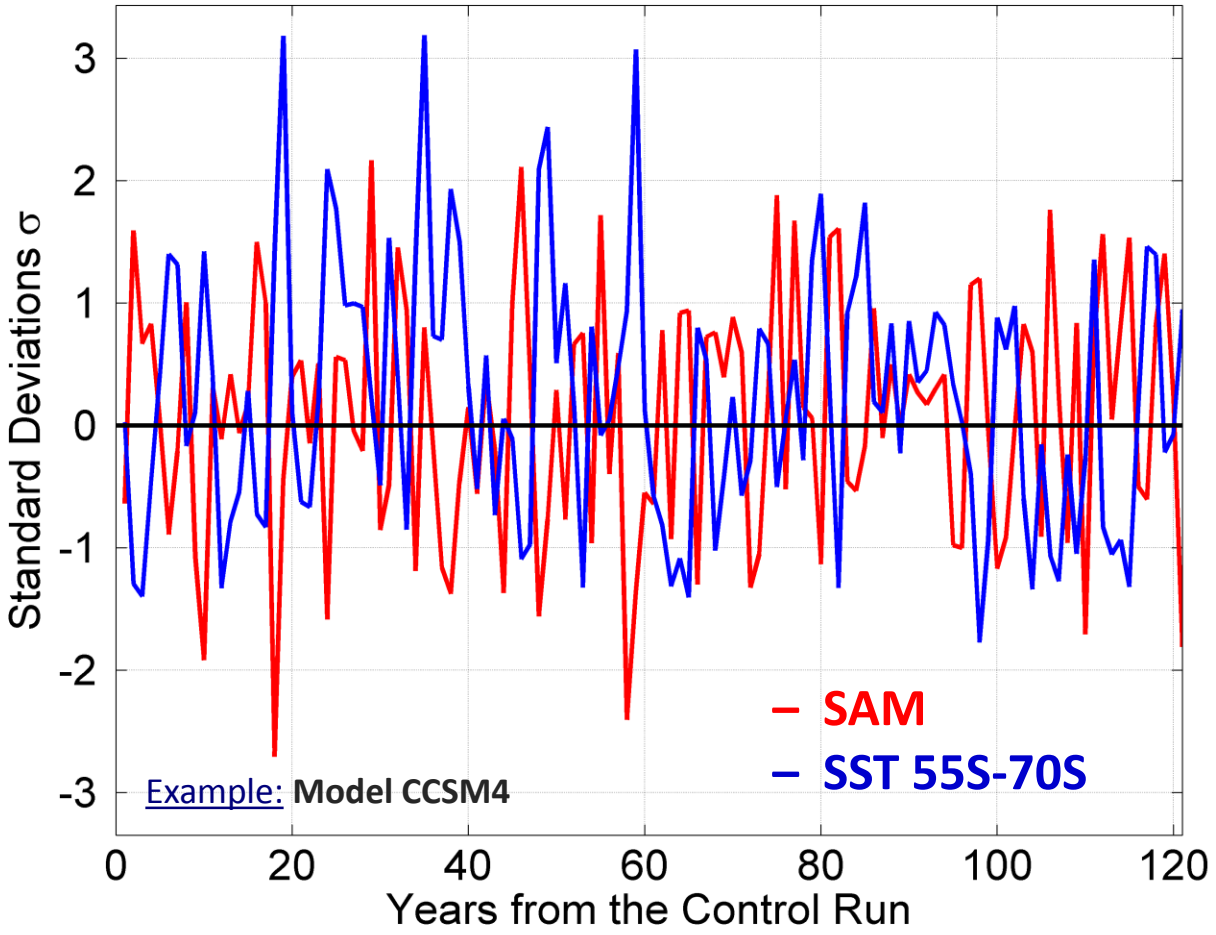
Convolving the Step Response S with the Evolution of Historical Forcing SAM_{hist}

Given a history of observed forcing, we can estimate the SAM contribution to SST anomalies via the convolution

$$SST_{hist}\,(t) = \int_0^t S(\tau)\left(\frac{dSAM_{hist}}{dt}\Big]_{(t-\tau)}\right)d\tau$$

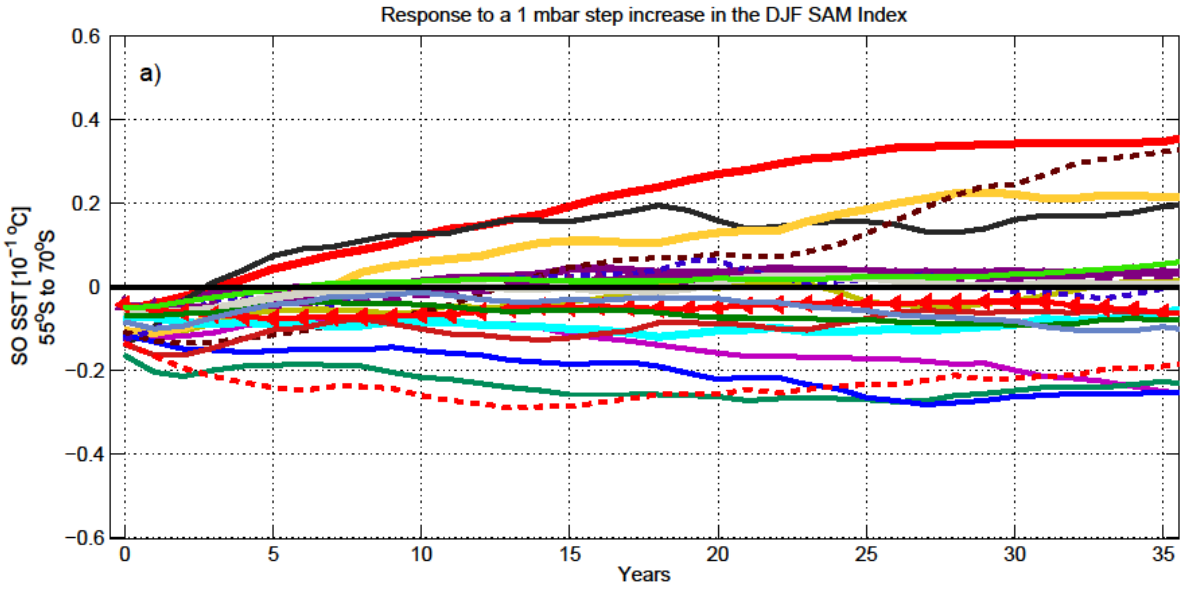
where $S(\tau)$ is the SO SST step response to SAM

We obtain the SO SST step-responses to SAM from control runs as in Kostov et al. (2017, published)



We first estimate the **impulse** response function $G(\tau)$ from the control runs

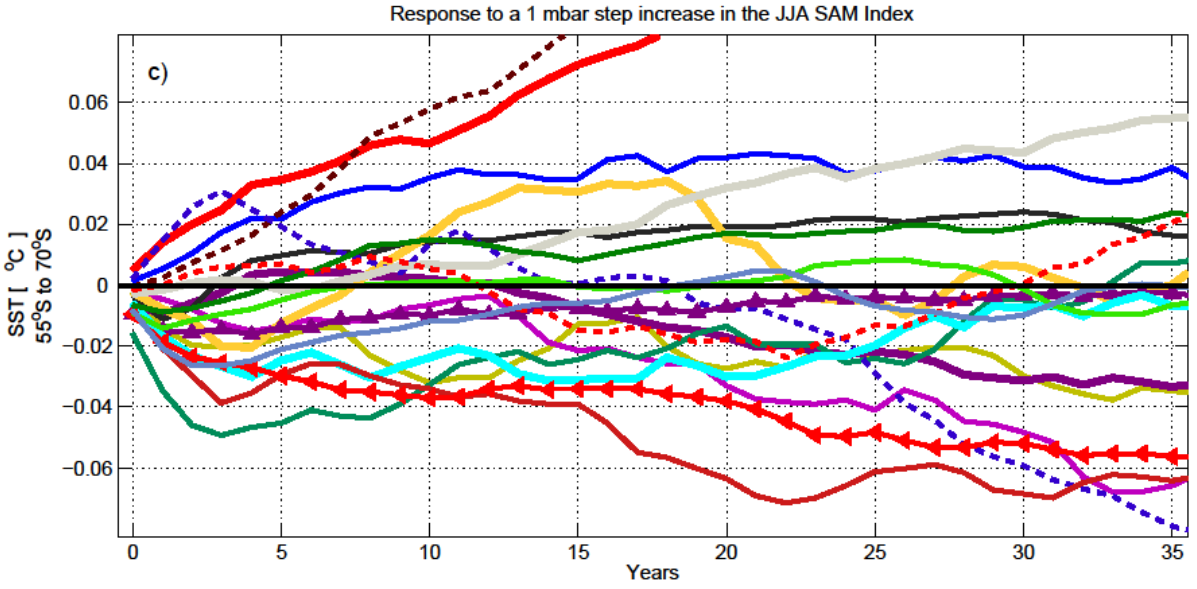
$$SST(t) = \int_0^{+\infty} G(\tau)\, SAM(t-\tau)d\tau + \varepsilon \approx \int_0^{\tau_{max}} G(\tau)\, SAM(t-\tau)d\tau + \varepsilon$$



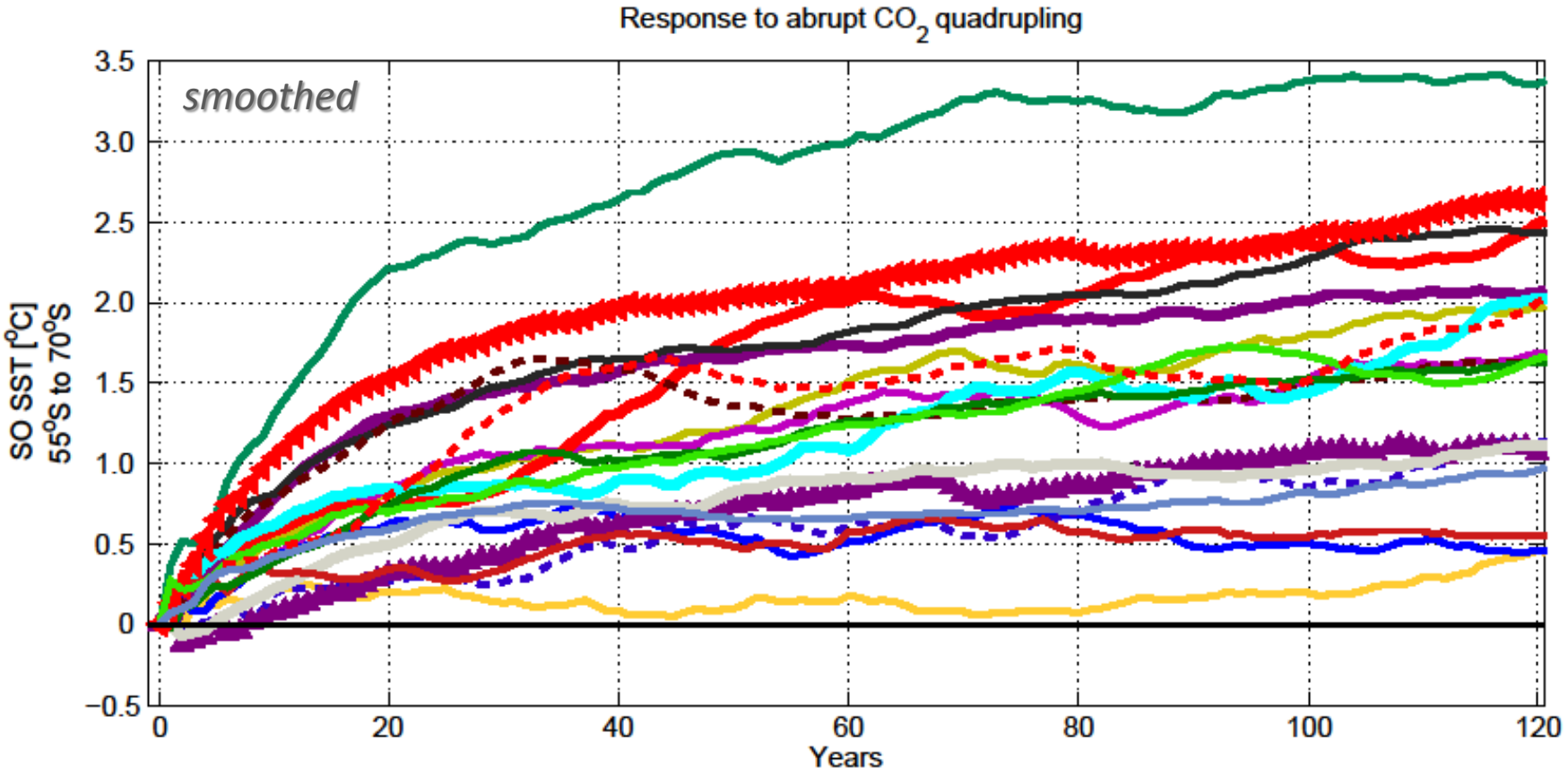
Stronger fast response to DJF SAM (summer)

Weaker fast cooling JJA SAM (winter)

Consistent with Purich et al. (2016)

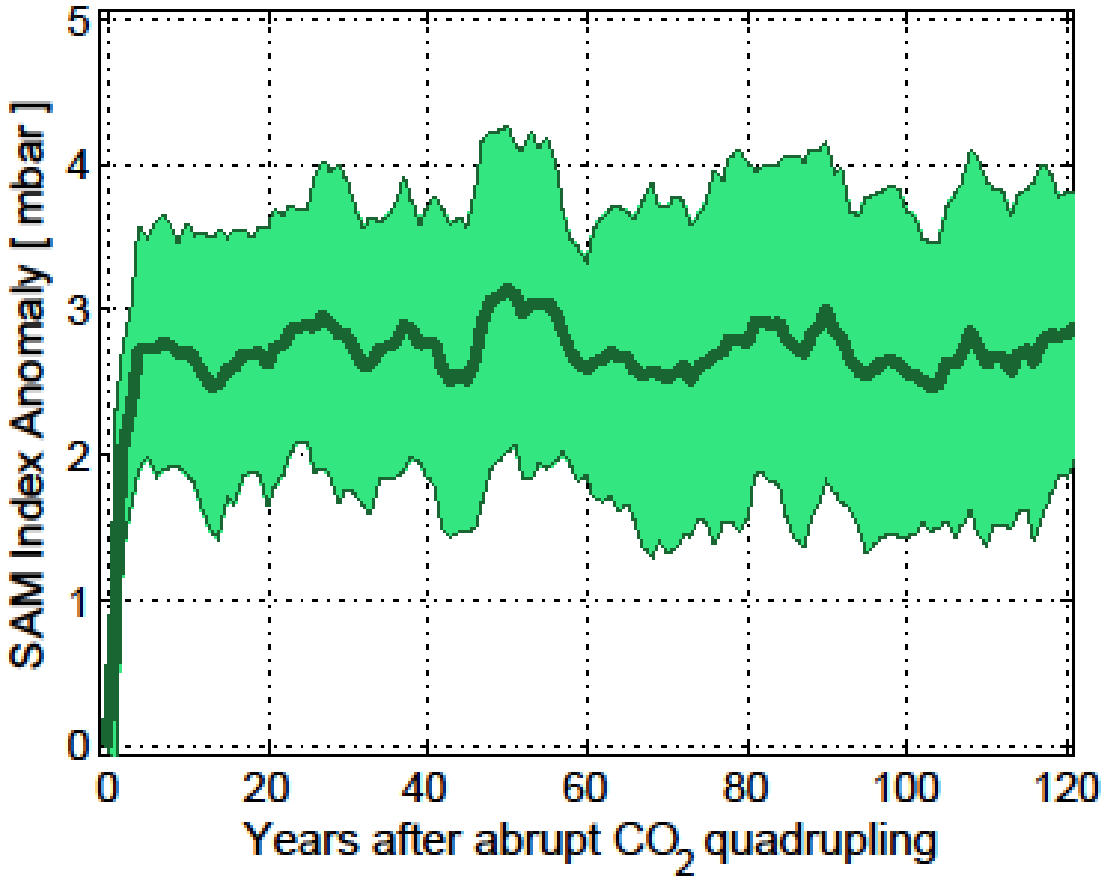


CMIP5 Step Responses to Greenhouse Gas Forcing



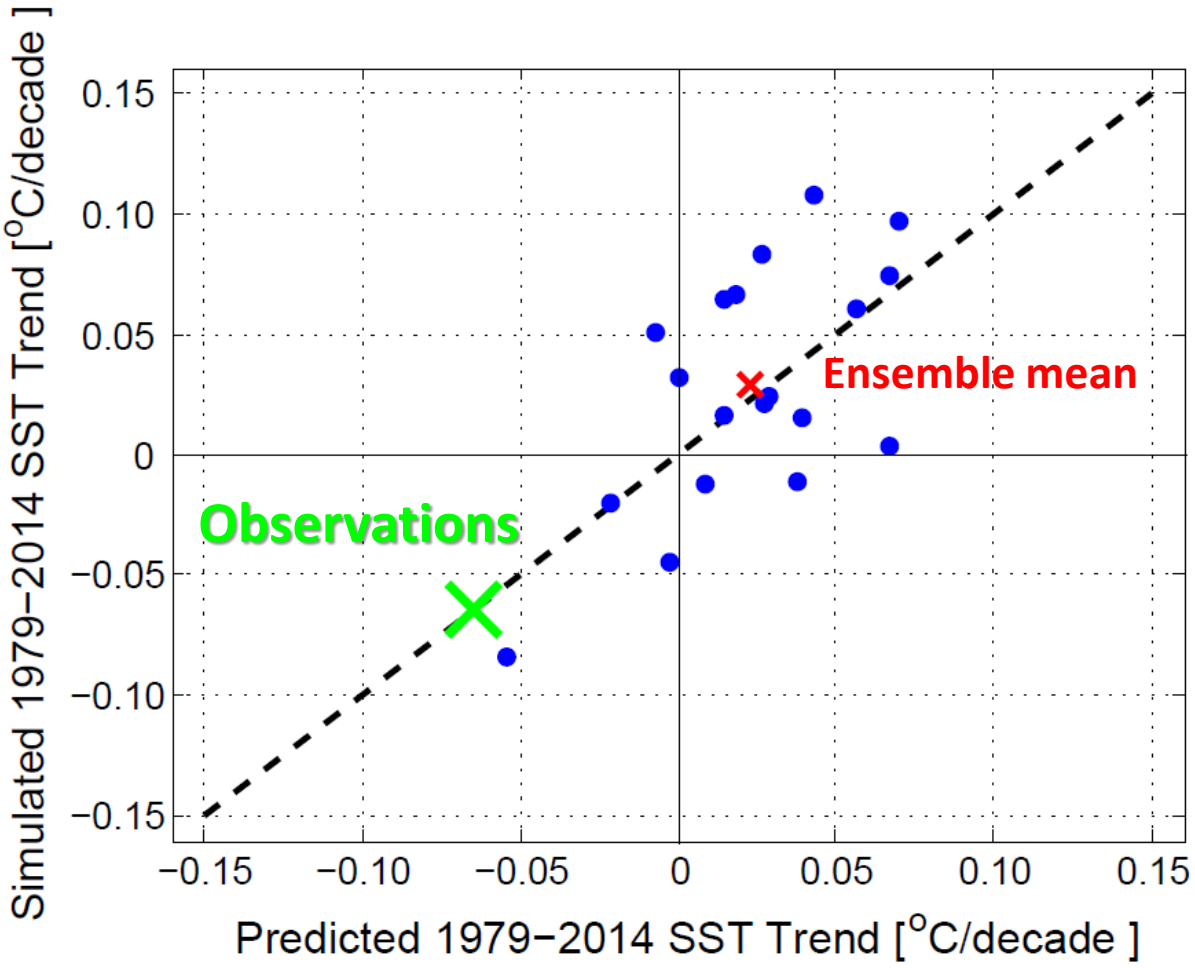
- Based on CMIP5 abrupt CO_2 quadrupling experiments
- Monotonic Southern Ocean warming but slower than the global signal (delayed Southern Ocean warming as in Armour et al., 2016)
- Constitute step responses functions of SO SST to TOA radiative forcing.

Impact of GHG forcing on the SAM



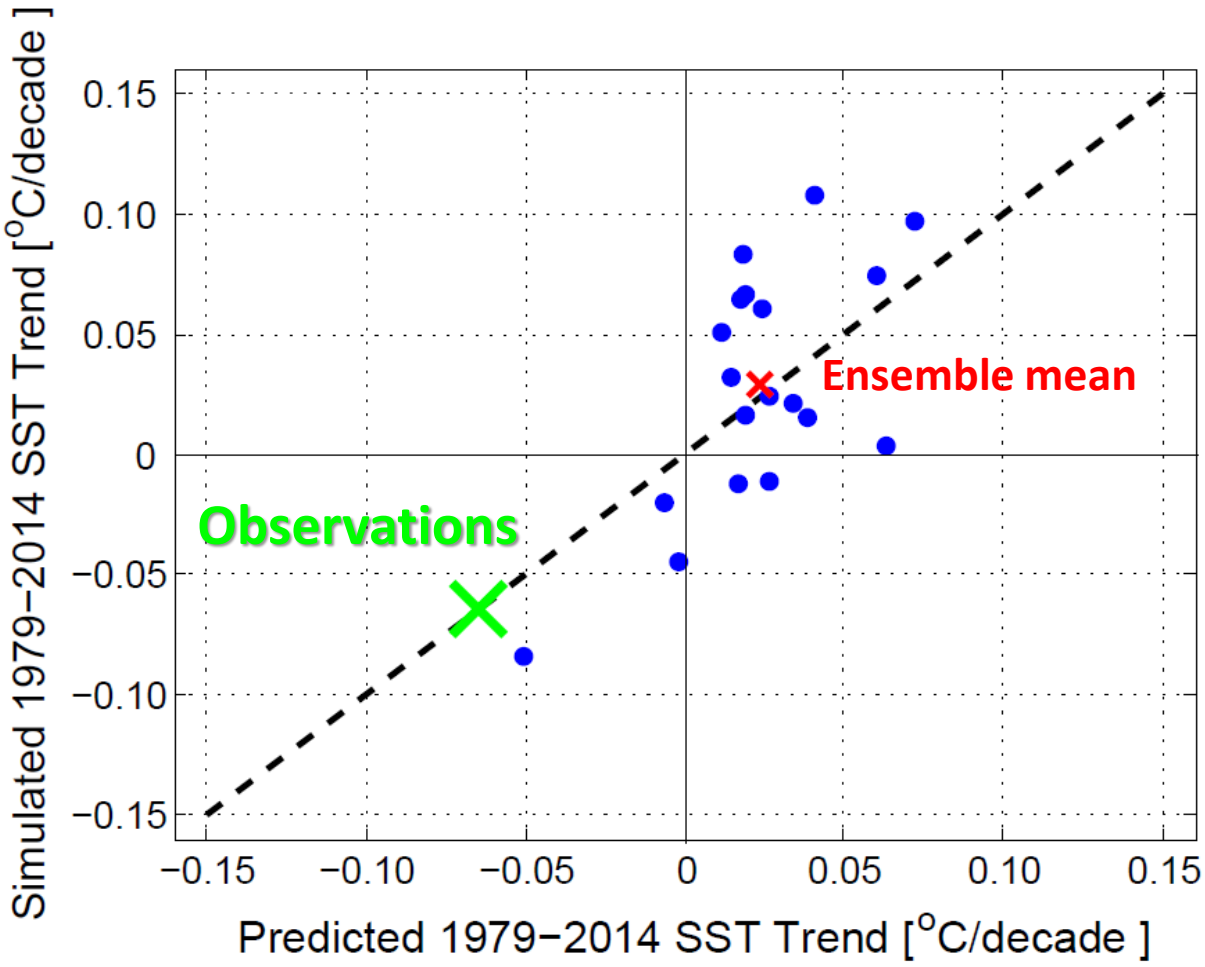
- Based on CMIP5 abrupt CO_2 quadrupling experiments;
- Constitute step responses functions of SAM to TOA radiative forcing.

Combined GHG and SAM Convolutions
(using seasonal SAM forcing & responses)



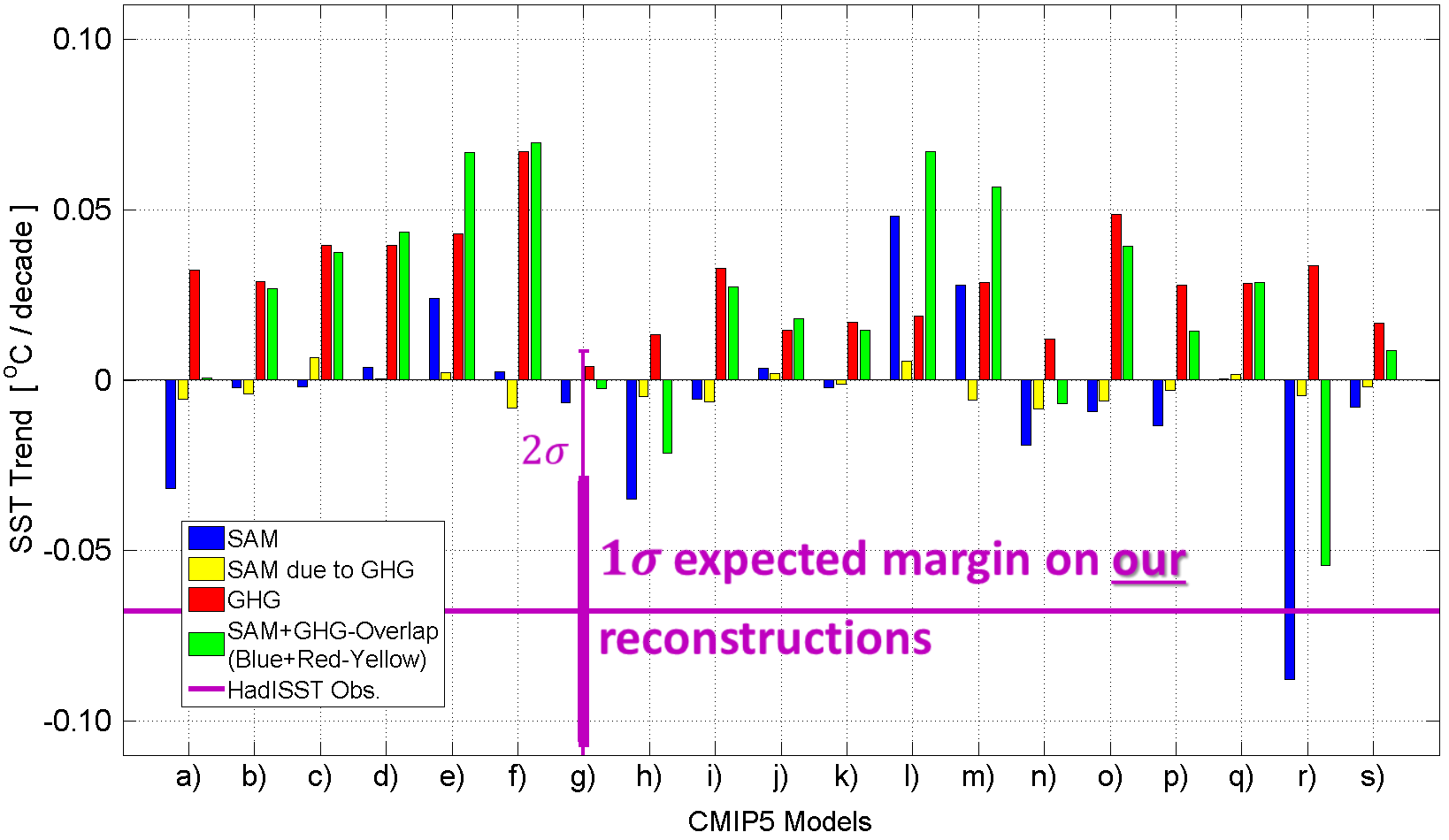
- Reproduces the ensemble mean response;
- Captures the intermodel spread.

Combined GHG and SAM Convolutions
(using only DJF and MAM SAM forcing & responses)

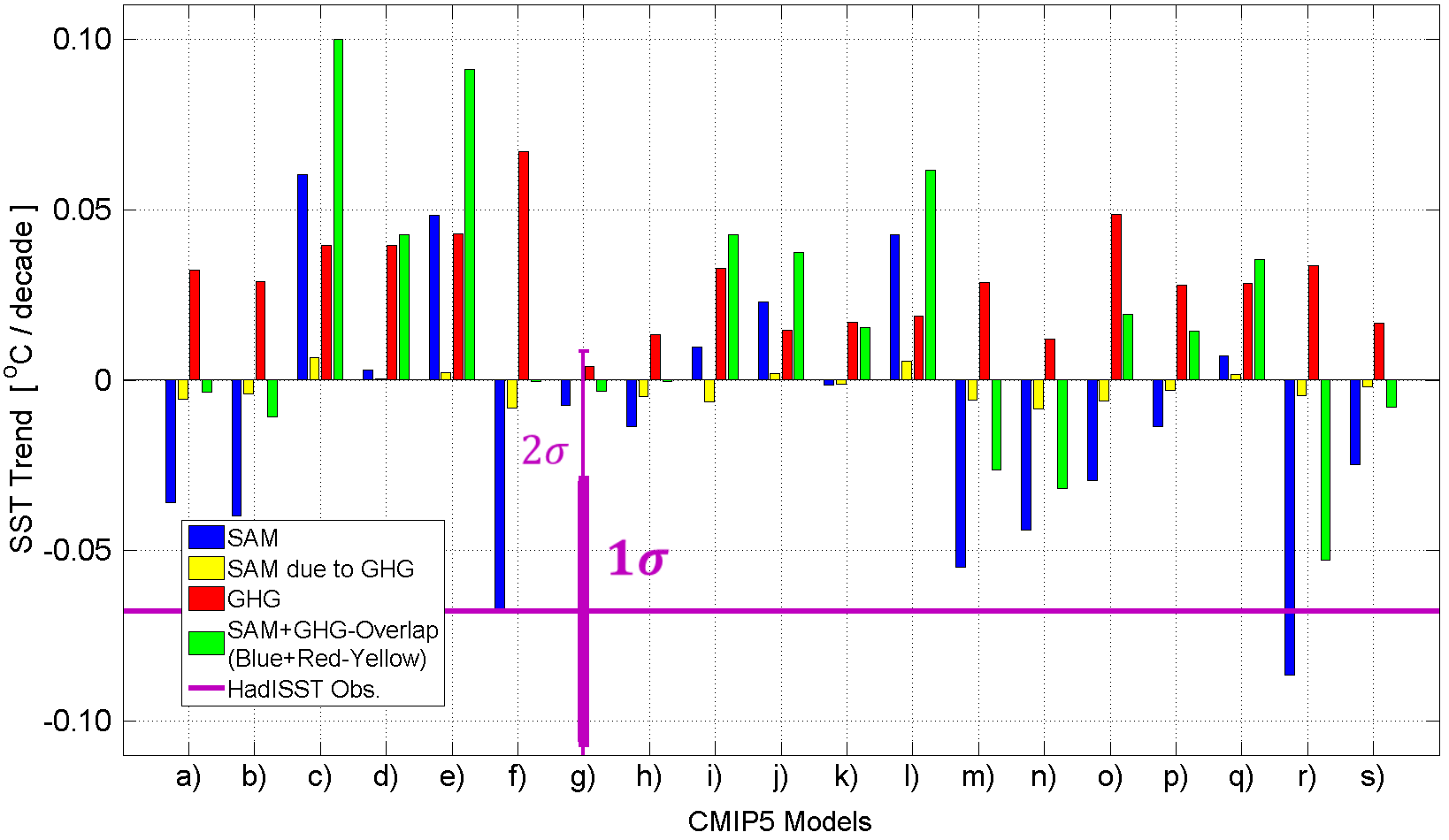


- The summer and fall SAM have a major contribution.
- Consistent with the seasonal signature of the ozone hole.

Reconstructing the observed SST Trends using CMIP5 step responses convolved with SAM from historical simulations and GHG trends

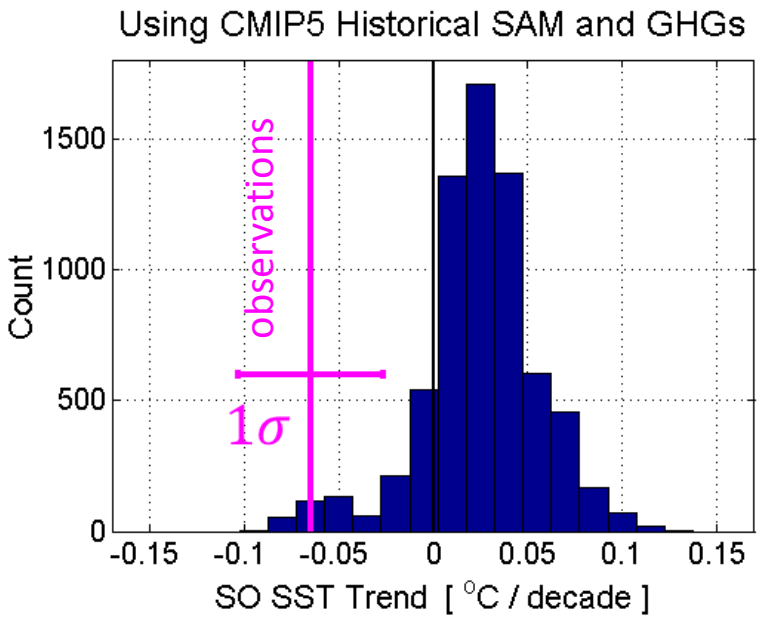


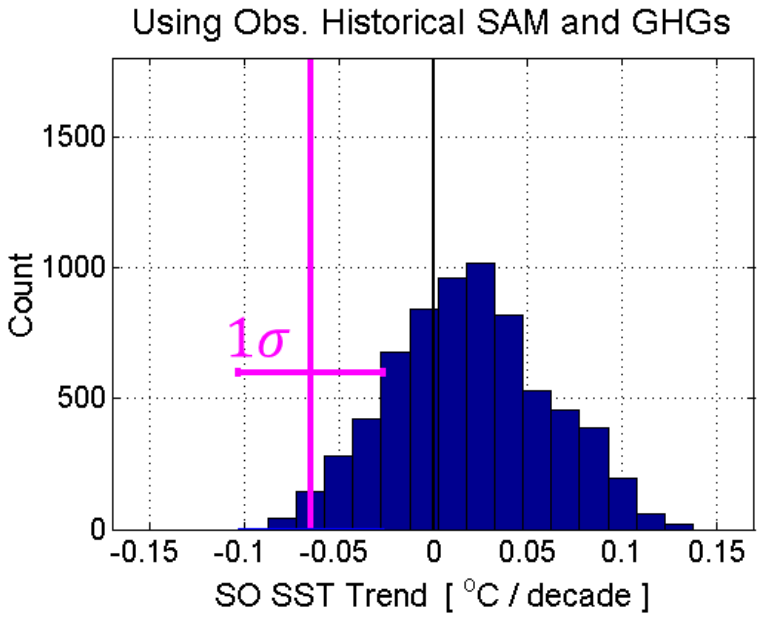
Reconstructing the observed SST Trends using CMIP5 step responses convolved with **observed** SAM and GHG trends



Possible combinations of GHG and SAM responses

- The GHG and SAM convolutions across the ensemble are uncorrelated.
- We consider all possible re-combinations of plausible GHG and SAM convolutions with simulated or with observed SAM.
- 19 models → 19^3 possible combinations.
- Using observed SAM in the convolutions removes some of the bias.





Conclusions

- Historical Southern Ocean SST trends: both **seasonal** SAM and greenhouse gas (GHG) forcing play important roles.
- In CMIP5 the response to GHG forcing is monotonic warming.
- Many coupled GCMs exhibit a two-timescale response of the Southern Ocean to SAM. The fast cooling regime can transition to a slow warming response.
- Seasonal SAM – consistent with the impact of the ozone hole.
- Poor representation of historical SAM trends → biased response.
- To reproduce the observed Southern Ocean cooling trends, models need **both** realistic SAM anomalies **and** a realistic ocean climatology.