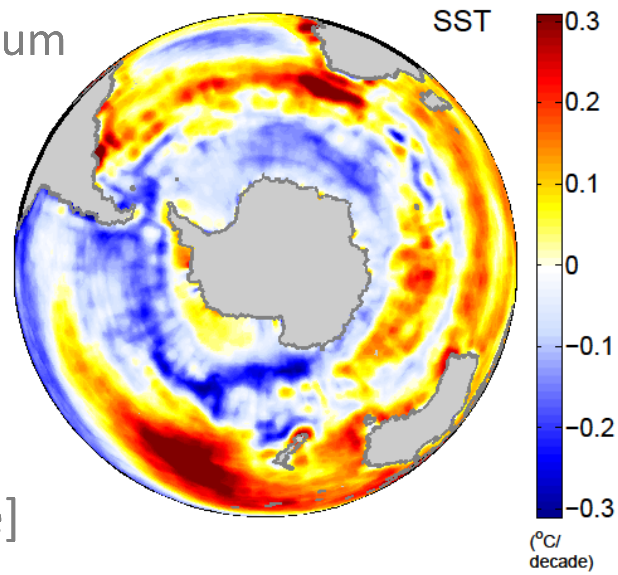
The Response of Southern Ocean SSTs to SAM

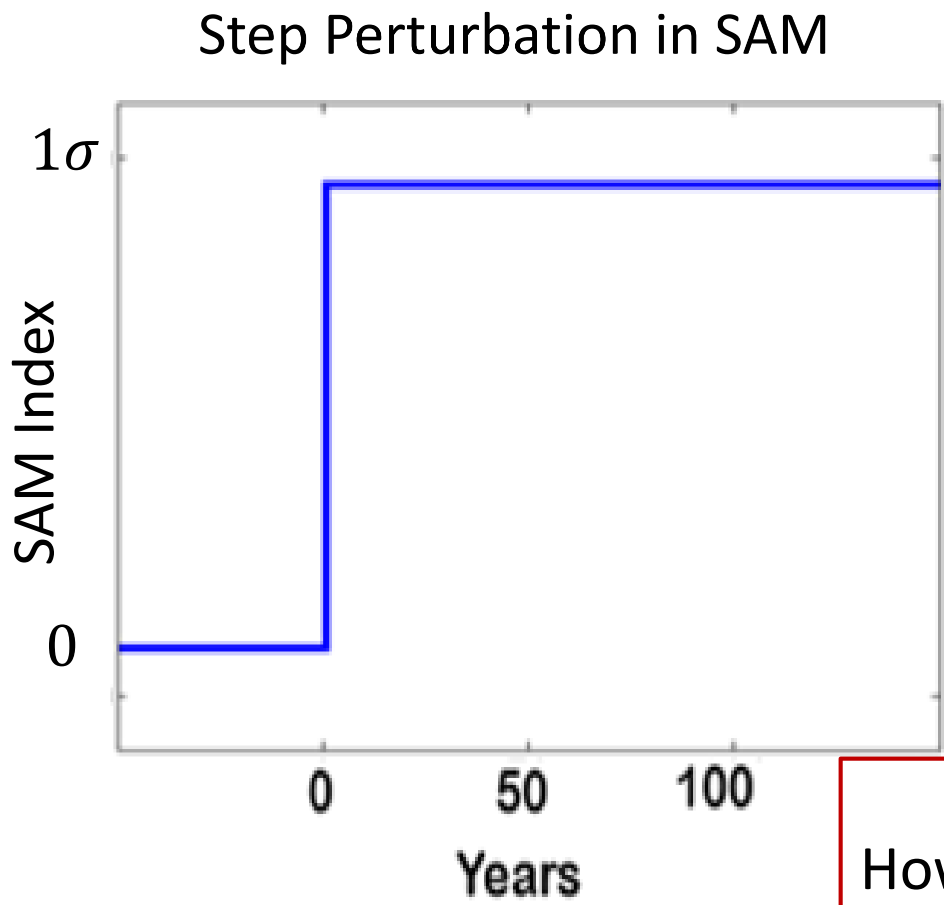
NOAA Reynolds Optimum Interpolation Dataset 1982-2012



SST Trends [K/decade]

Yavor Kostov
Massachusetts Institute of Technology

John Marshall, Kyle Armour, Ute Hausmann



How would CMIP5 models respond to a SAM-like wind perturbation?

Using only
data from control runs.

How would the SST response in the Southern Ocean evolve on multiple timescales?

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

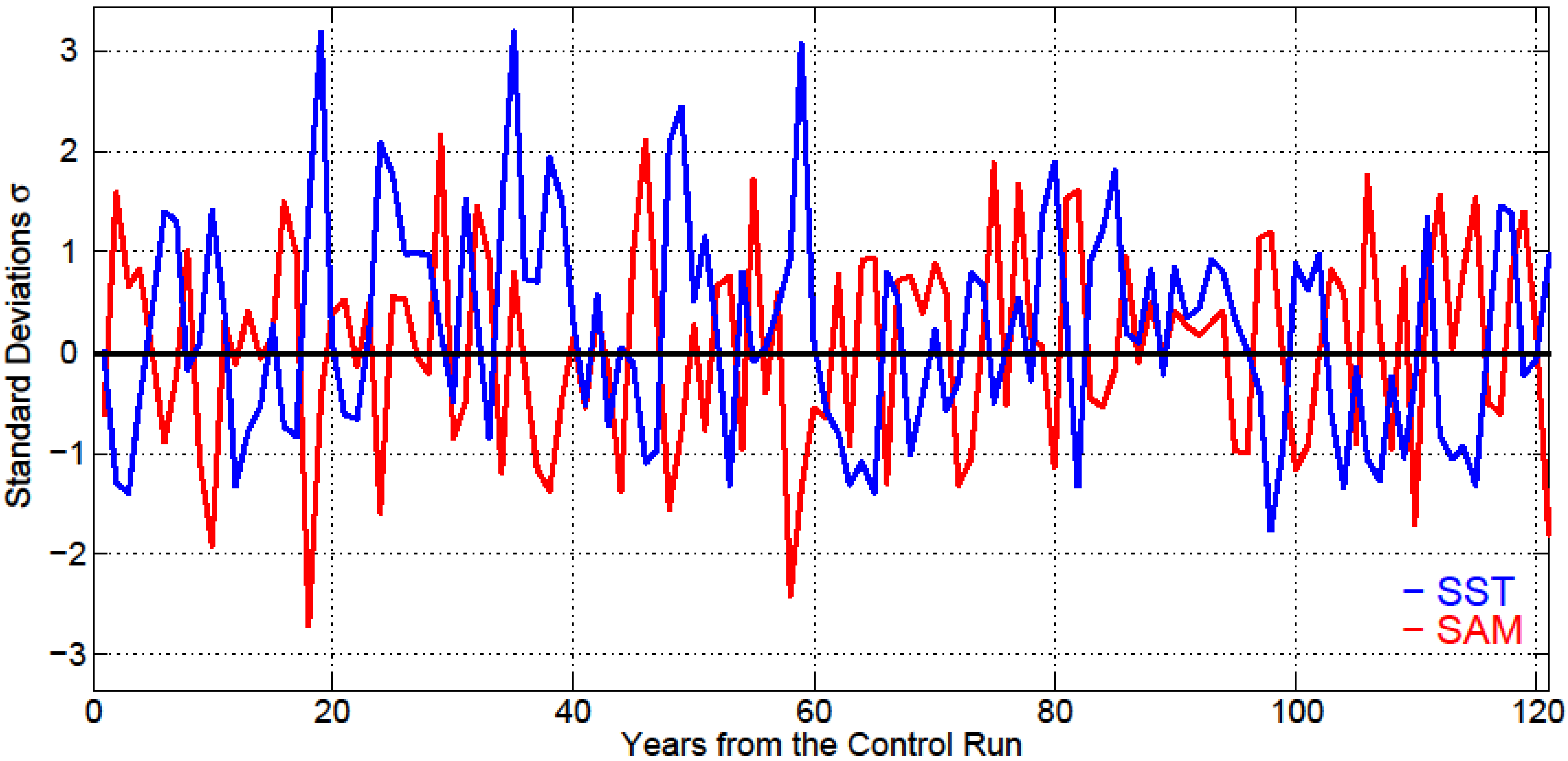
The convolution

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

gives us an estimate of the historical SST response at time t.

See Marshall et al., 2014.

The SAM index compared to a Southern Ocean SST index



Example: **Model CCSM4**

Extracting the Response to Impulse Forcing from Unforced Control Experiments

Least-squares regression of the lagged SST and wind (SAM) timeseries gives the coefficients g_i, where

$$SST(t) \approx \sum_{i=0}^{\tau_{max}} g_i \, u(t-i) + \varepsilon$$

can be written in matrix notation as

$$\boldsymbol{Y} = \boldsymbol{X}\boldsymbol{g} + \boldsymbol{\varepsilon}$$

$\Rightarrow$ We estimate $\hat{\boldsymbol{g}} = (\boldsymbol{X}^T\boldsymbol{X})^{-1}\boldsymbol{X}^T\boldsymbol{Y}$

We also calculate uncertainties for each estimated $\widehat{g}_i$.

Extracting the Response to Impulse Forcing from Unforced Control Experiments

$$\boldsymbol{Y} = \boldsymbol{X}\boldsymbol{g} + \boldsymbol{\varepsilon}$$

$\Rightarrow$ We estimate $\hat{\boldsymbol{g}} = (\boldsymbol{X}^T\boldsymbol{X})^{-1}\boldsymbol{X}^T\boldsymbol{Y}$ and residuals $\boldsymbol{\varepsilon}$

We calculate uncertainties for each estimated $\widehat{g}_i$.

- The covariance matrix

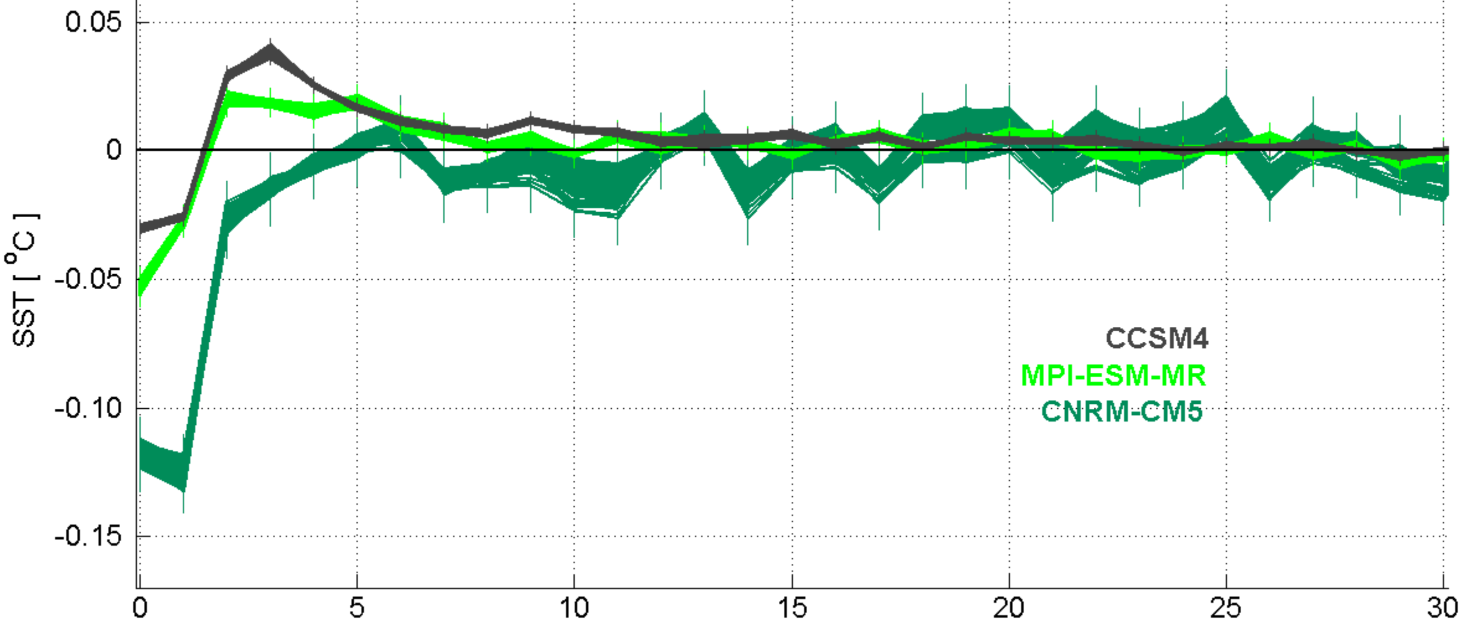
$$\left(\frac{\hat{\boldsymbol{\varepsilon}}^T\hat{\boldsymbol{\varepsilon}}}{Length(\boldsymbol{Y}) - n}\right)(\boldsymbol{X}^T\boldsymbol{X})^{-1}$$

gives us the uncertainties for each estimate $\widehat{g}_i$.

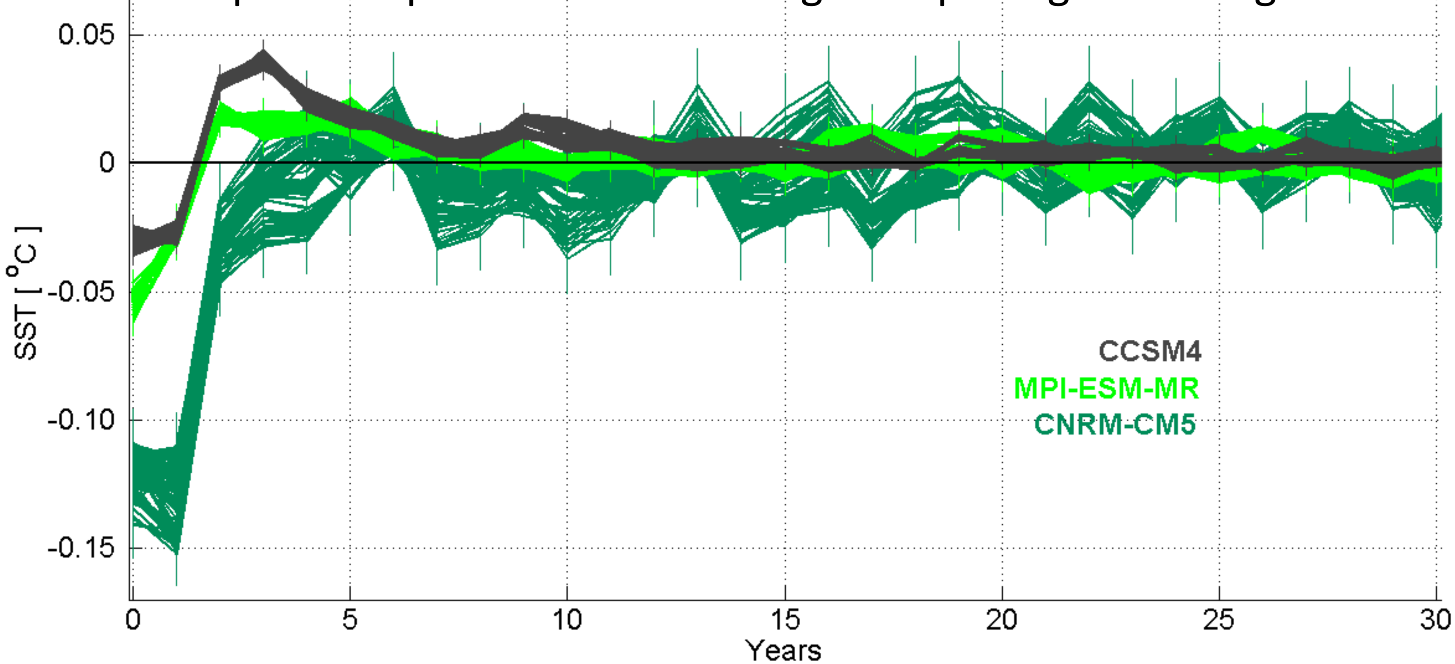
Extracting the Response to Impulse Forcing from Unforced Control Experiments

- We obtain an uncertainty envelope by varying the number n of impulse response coefficients g_i (how far our memory of previous forcing states goes).
- We also use different shorter chunks of the available SST and wind time series to see how this affects our estimates.

Impulse response obtained using the ARX function built in Matlab



Impulse response obtained using a simple regression algorithm



Extracting the Response to Step Wind Forcing from Unforced Control Experiments

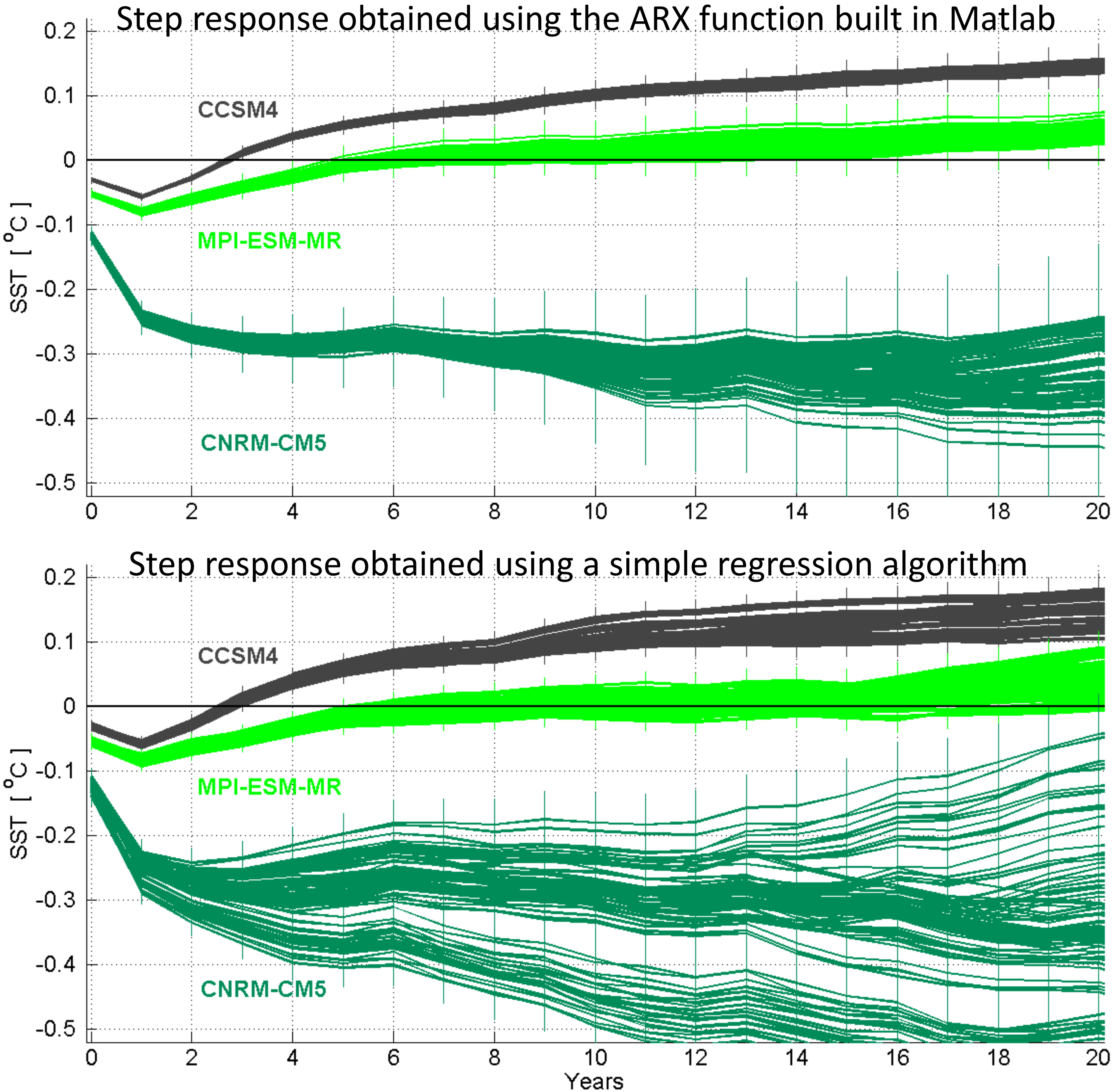
We integrate the estimated impulse response to obtain the step response.

The response to step forcing applied at time 0 is

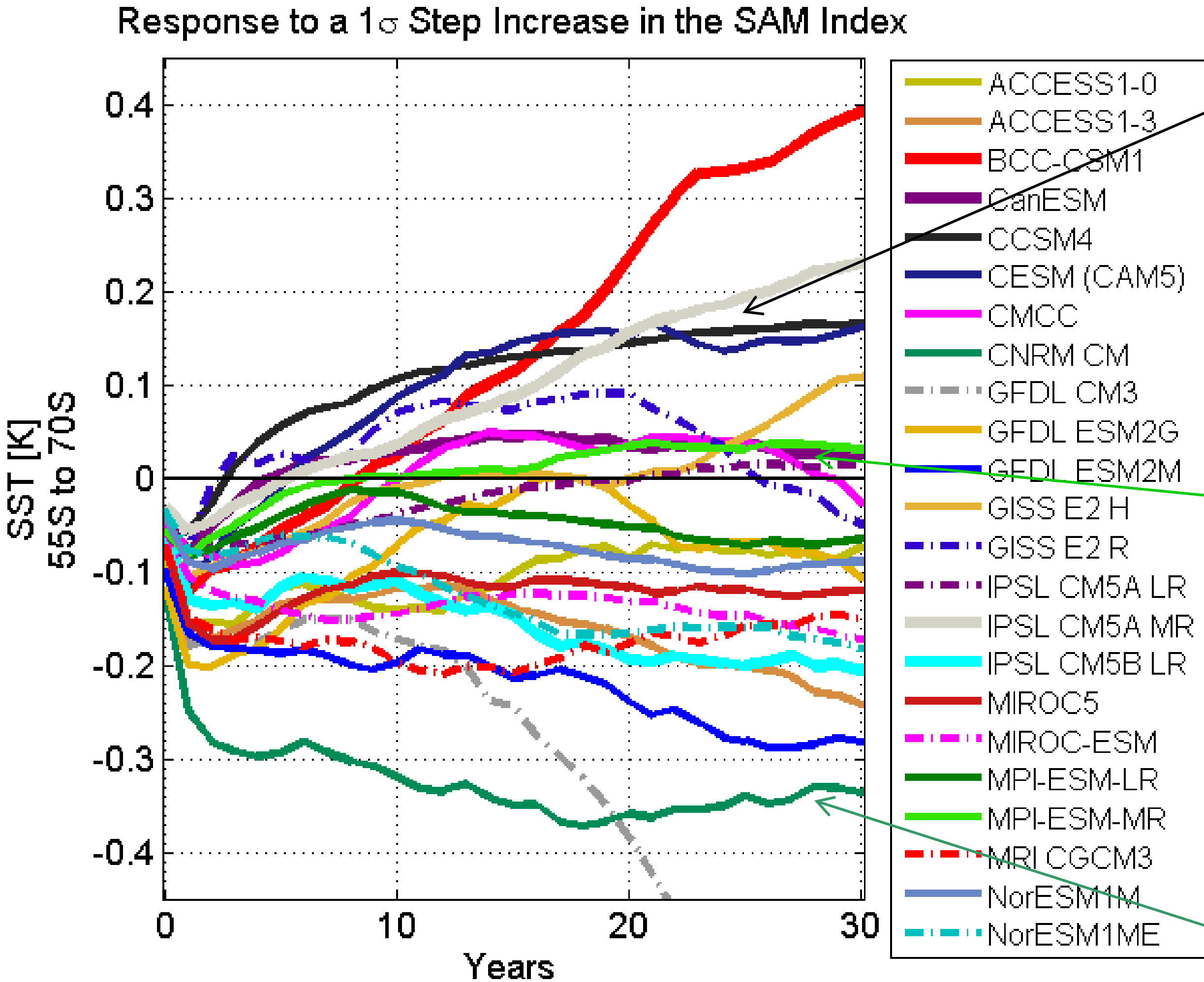
$$SST\ Step\ Response\ S(t) = \int_0^t G(\tau)d\tau \approx \sum_{i=0}^{\tau_{max}} g_i$$

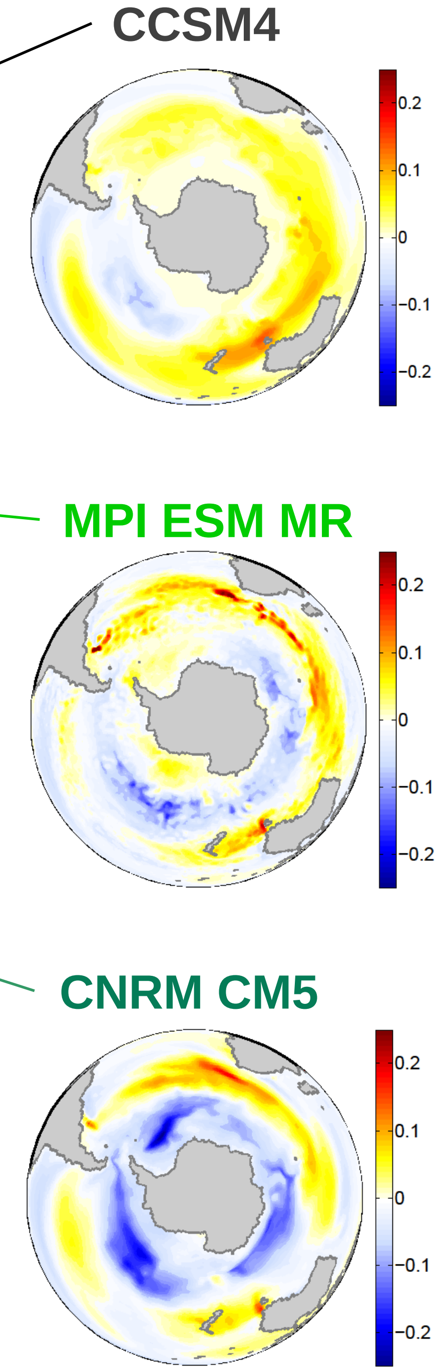
Smoother but more uncertain than the Green's function.

As we go further in time, larger uncertainties on our Step Response Function estimate **accumulate**.

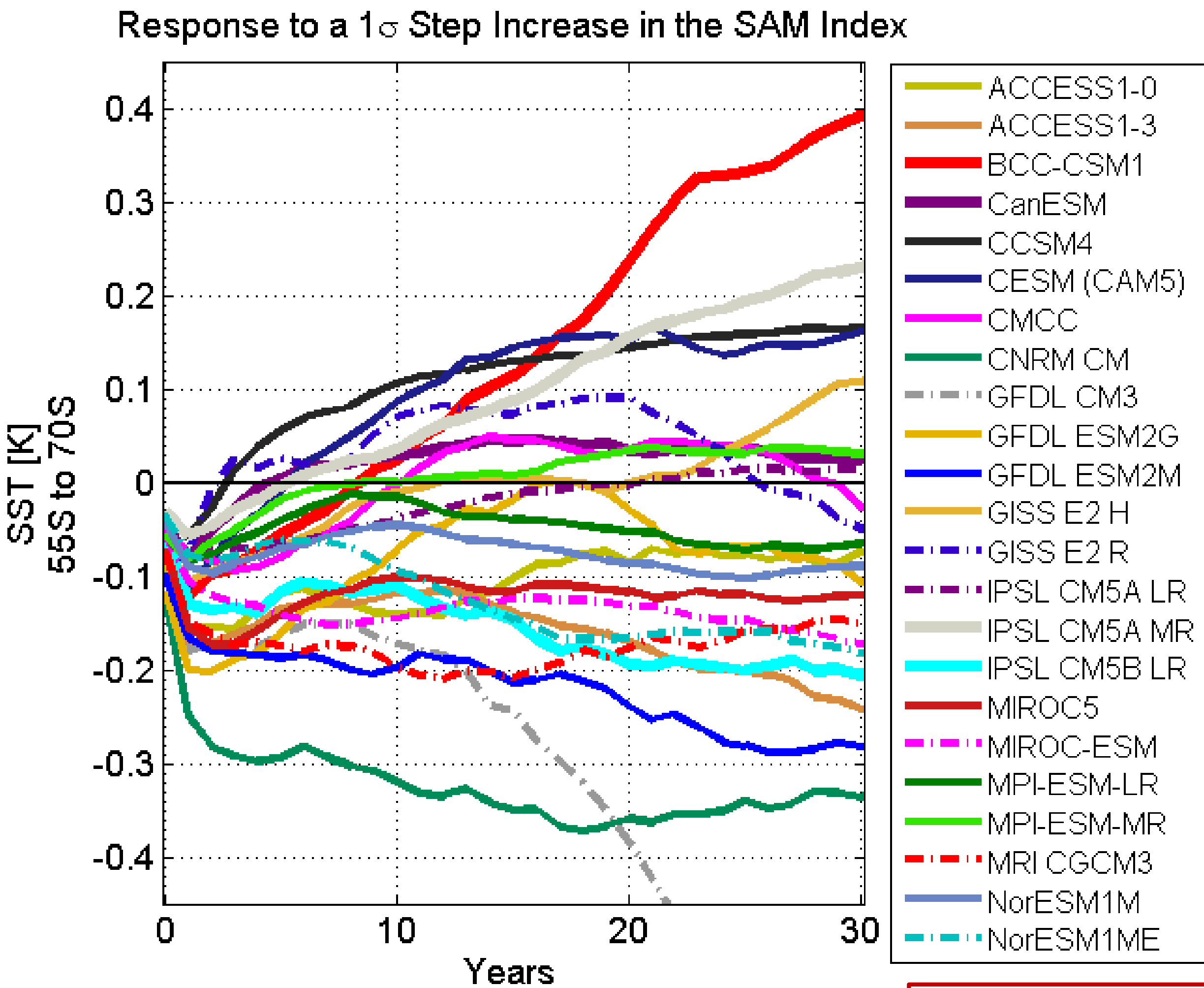


Step response obtained using the ARX function built in Matlab
CCSM4
MPI-ESM-MR
CNRM-CM5
SST [°C]
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
2
4
6
8
10
12
14
16
18
20
Step response obtained using a simple regression algorithm
CCSM4
MPI-ESM-MR
CNRM-CM5
SST [°C]
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
2
4
6
8
10
12
14
16
18
20
Years





Comparing the step response functions (above) with composited SST trends [K/decade] from 30-year periods of extreme SAM trends (right) in the control runs.



How would CMIP5 models respond to a SAM-like wind perturbation?

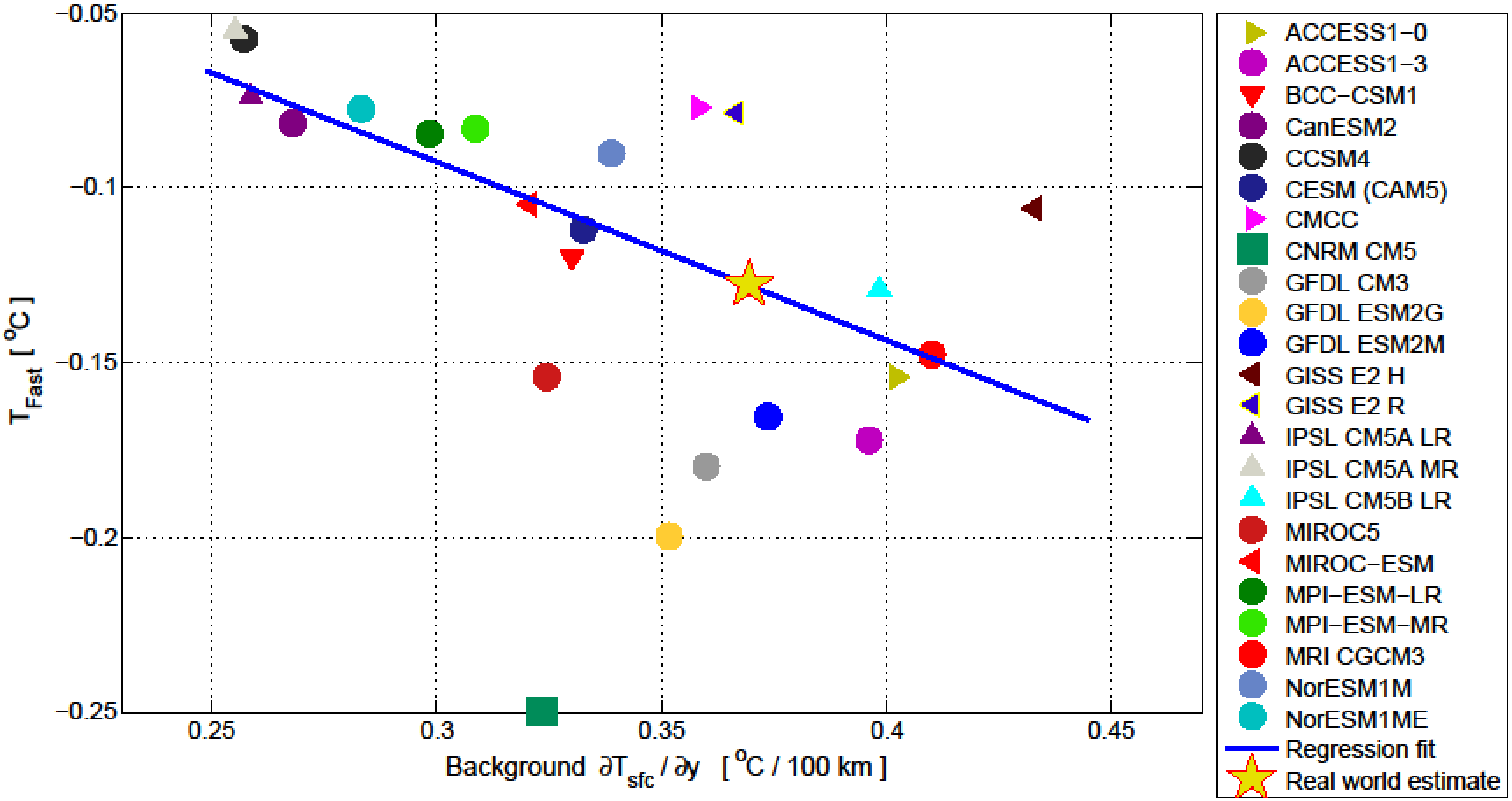
Using lagged regressions on output from control runs.

-- Fast Response: Equatorward transport of colder water → **Cooling**;
-- Slow Response: Upwelling of warmer water → **Warming**;

(Mechanisms discussed in Ferreira et al 2015, Marshall et al 2014).

Fast Response:

> The year 1 cooling response to a $+1\sigma$ SAM is correlated with the meridional gradient of climatological SST.



(As if real data was model output)

Conclusions

- Many CMIP5 models exhibit a two-timescale response as in Ferreira et al., 2015;
- We attempt to explain the processes which govern how the Southern Ocean SSTs respond to a SAM perturbation;
- We relate the intermodel diversity in the step response functions to differences in the climatological stratification of Southern Ocean across the CMIP5 ensemble.