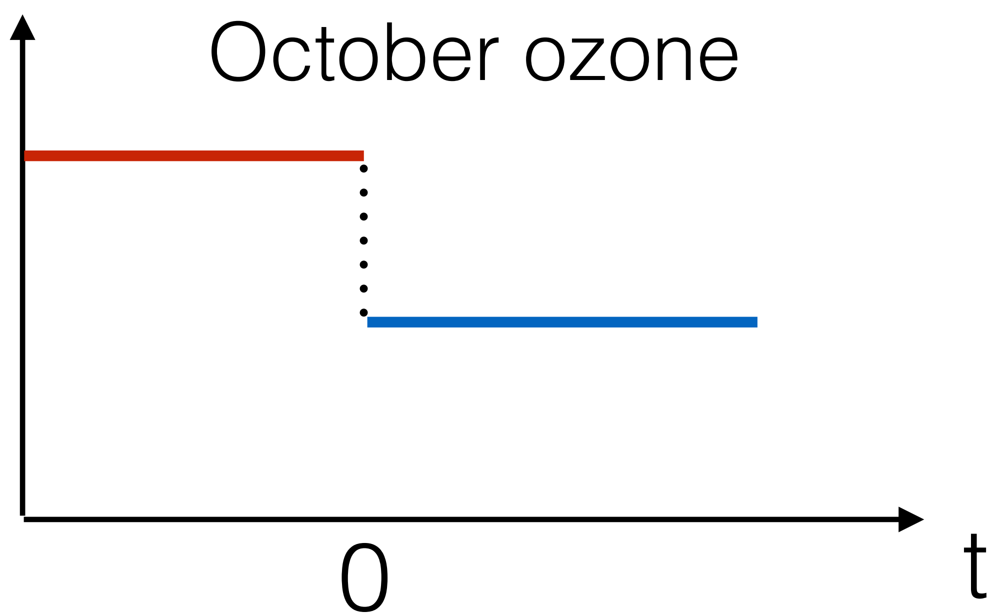
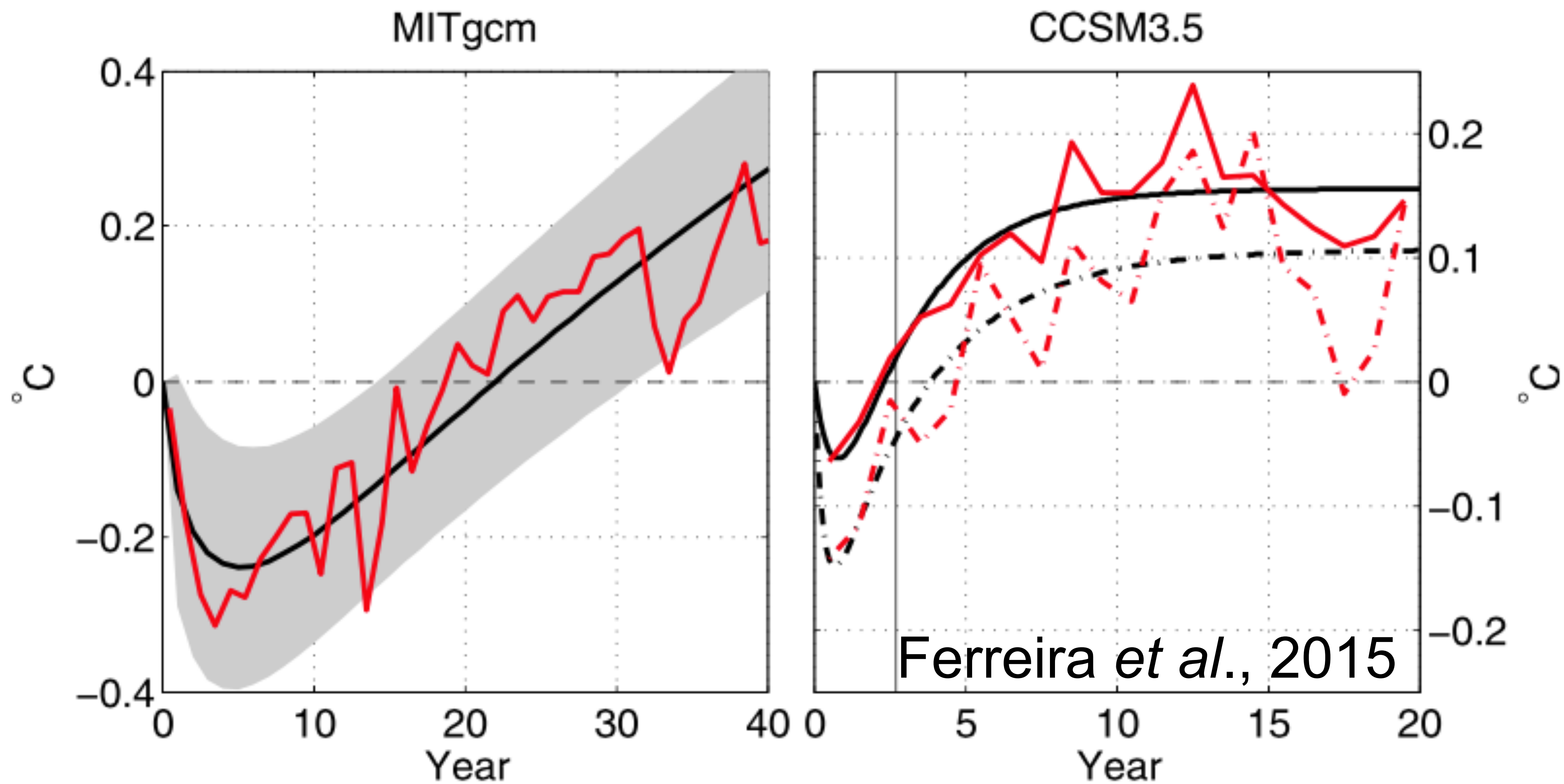
The transient response of the Southern Ocean to ozone depletion in GFDL ESM2Mc

William Seviour wseviou1@jhu.edu
Anand Gnanadesikan
Darryn Waugh



FESD Meeting, June 7th 2016

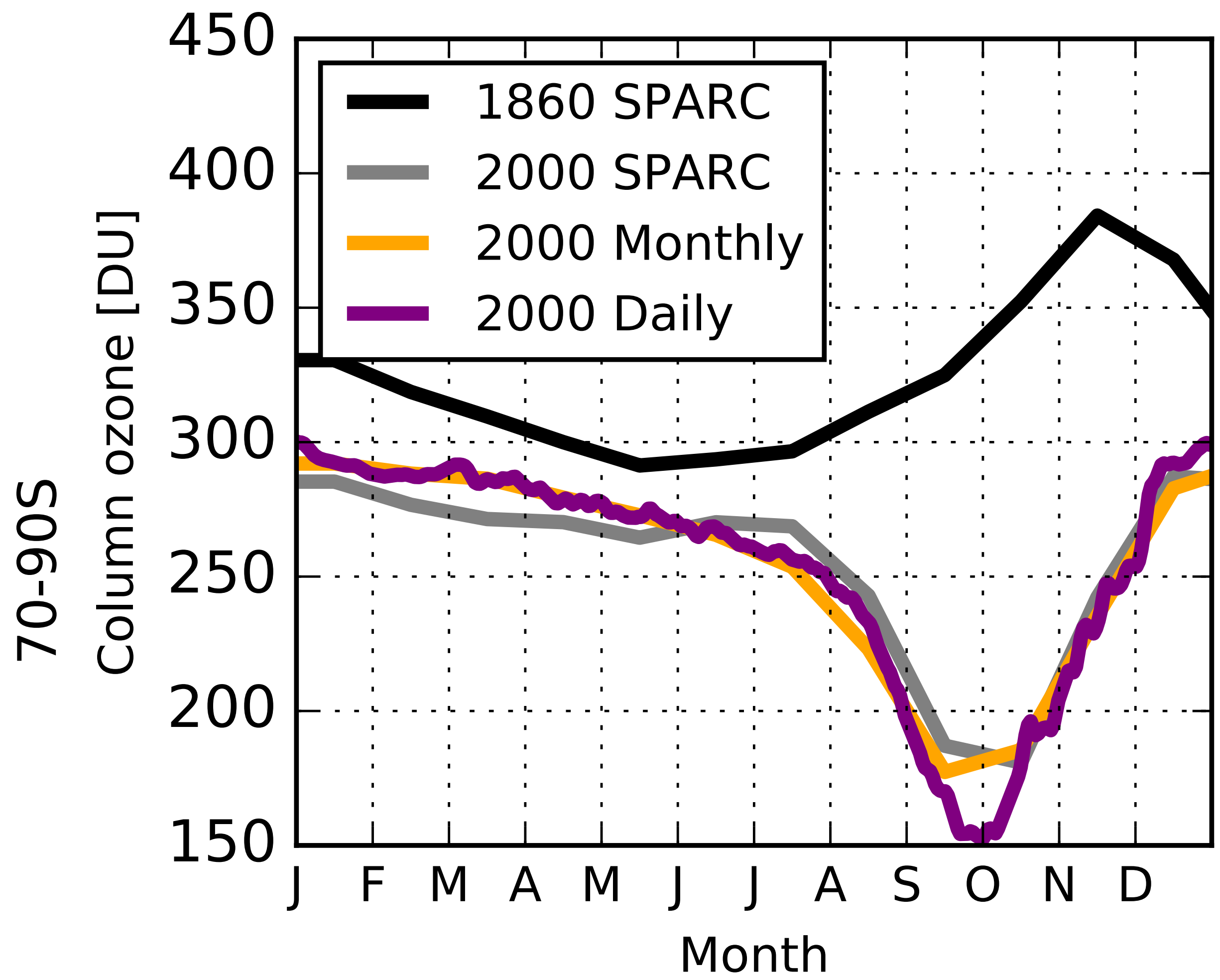
50-70S SST response to ozone hole



Time scales different in MITgcm (Double-Drake, simplified atmosphere) and CCSM3.5 (full coupled model).

Can similar behavior be found in the GFDL ESM2Mc model?
How sensitive is the response to (a) ozone forcing?
(b) initial conditions?

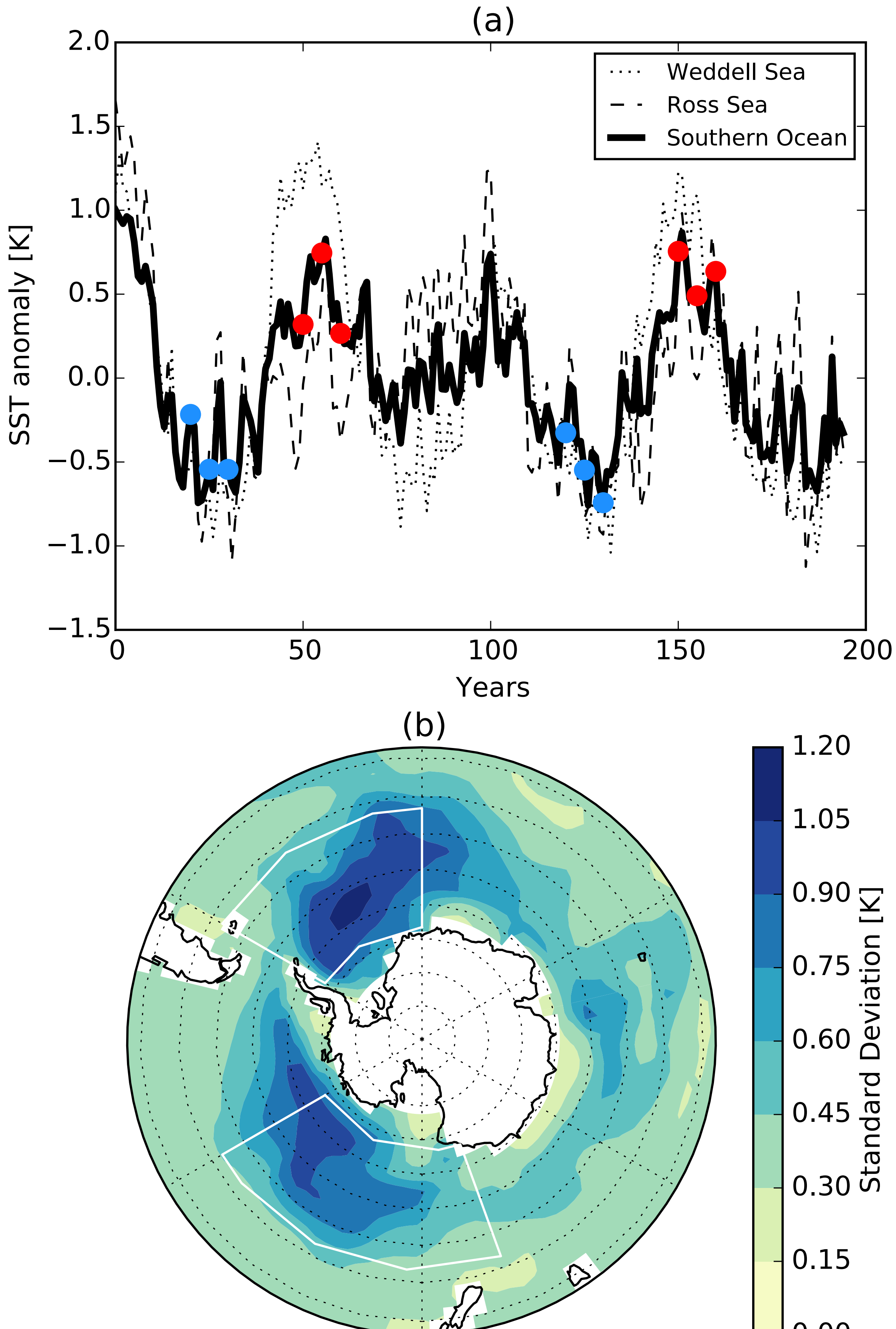
Ozone response simulations: ozone forcing



- Coarse resolution (~3x1.5 degrees) version of GFDL ESM2M. 24 vertical levels in the atmosphere, uppermost at ~3 hPa. 28 levels in ocean.

- '2000' ozone is taken from the WACCM-SD (Specified Dynamics) simulation, average over 1996-2001. **Monthly means** and **daily values** are used. (Motivation: Neely et al. 2014)

Ozone response simulations: initial conditions



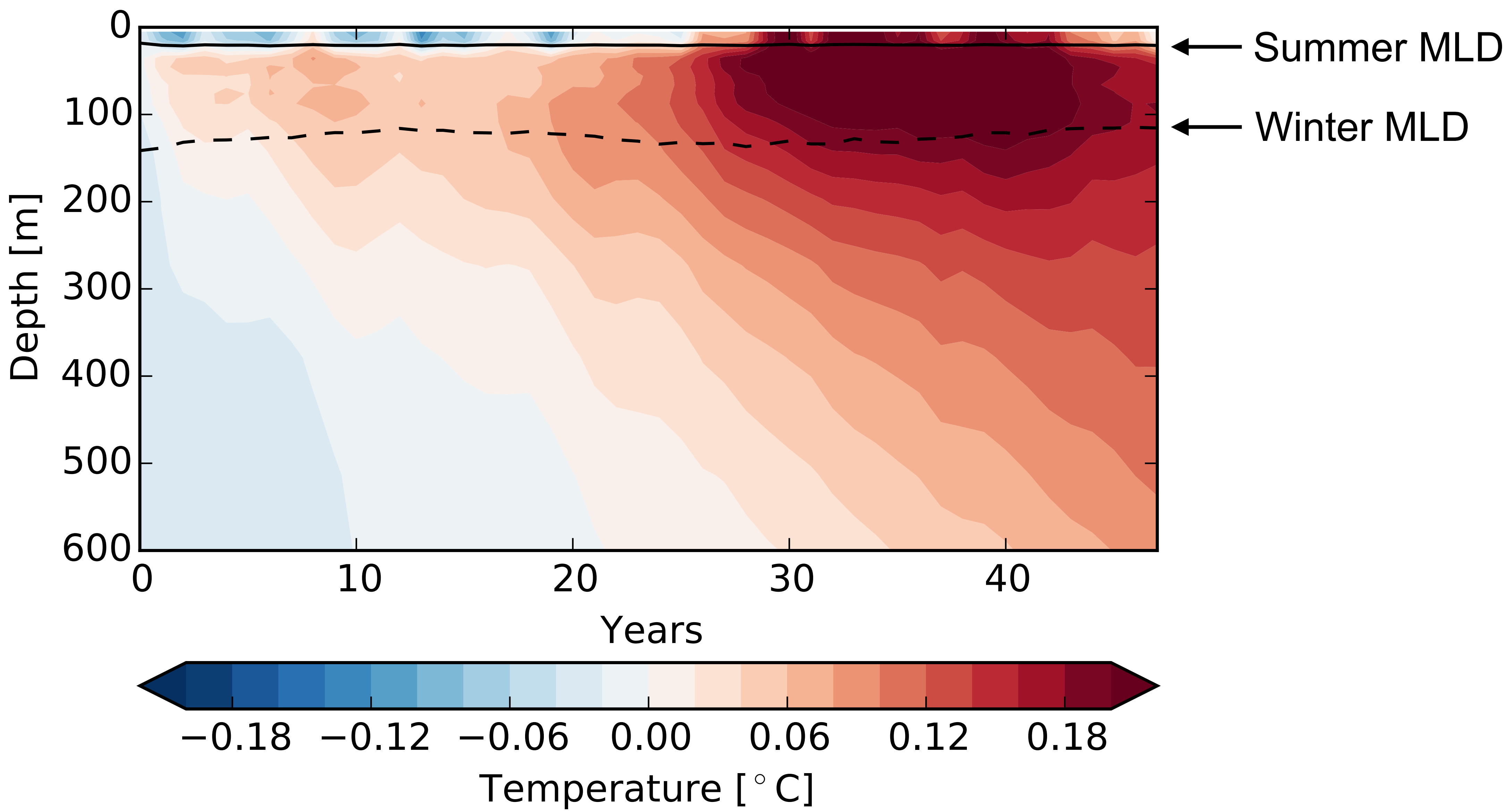
Control simulation shows quasi-periodic variability in the SO, driven by convective events in the Ross and Weddell Seas.

In order to test sensitivity to the initial conditions we start half the simulations in a **cold period**, and half in a **warm period**.

In total there are **24 ensemble members**:

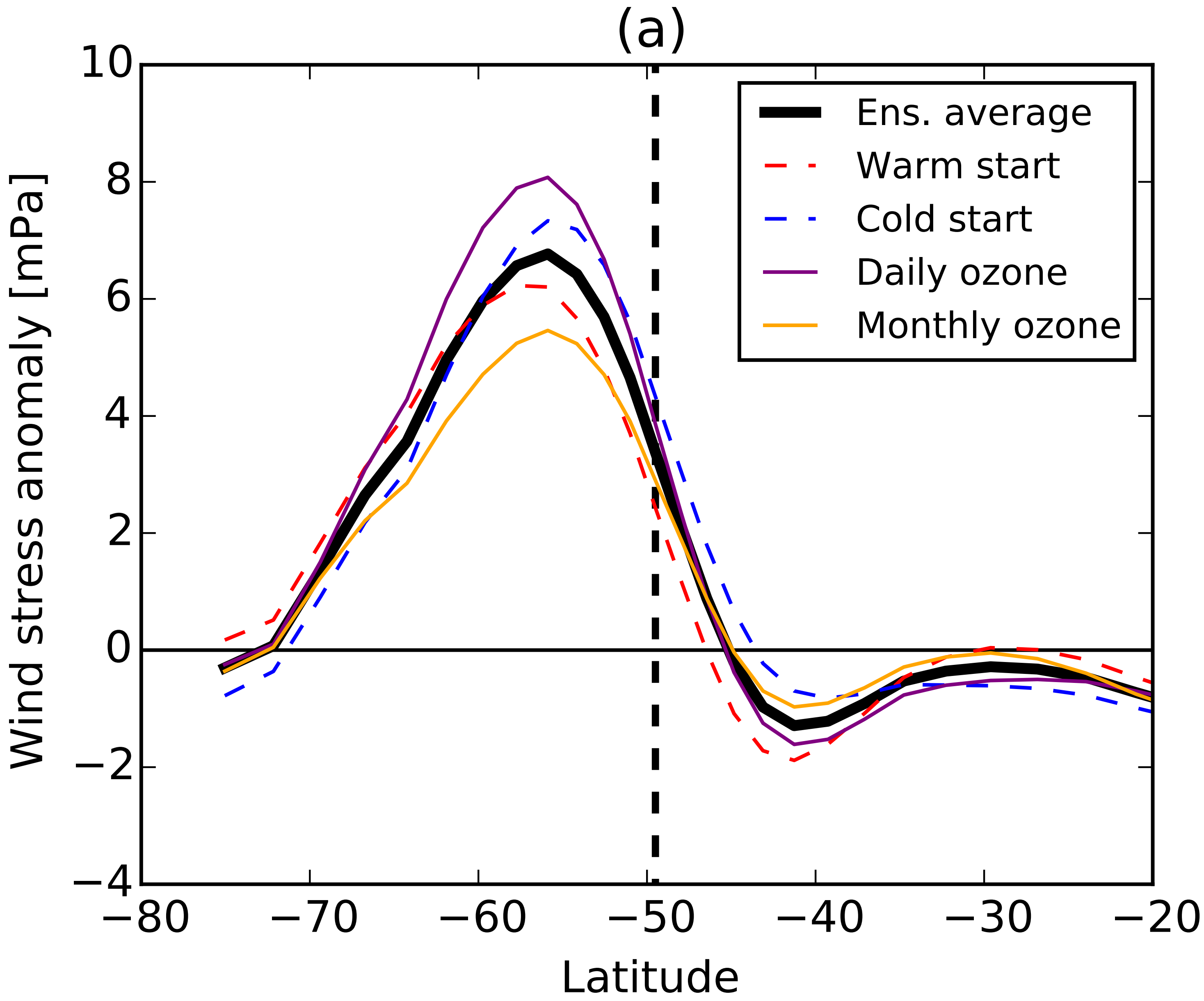
- **6 warm start** + **6 cold start**
- **Monthly** and **daily** ozone for each

Ensemble mean response



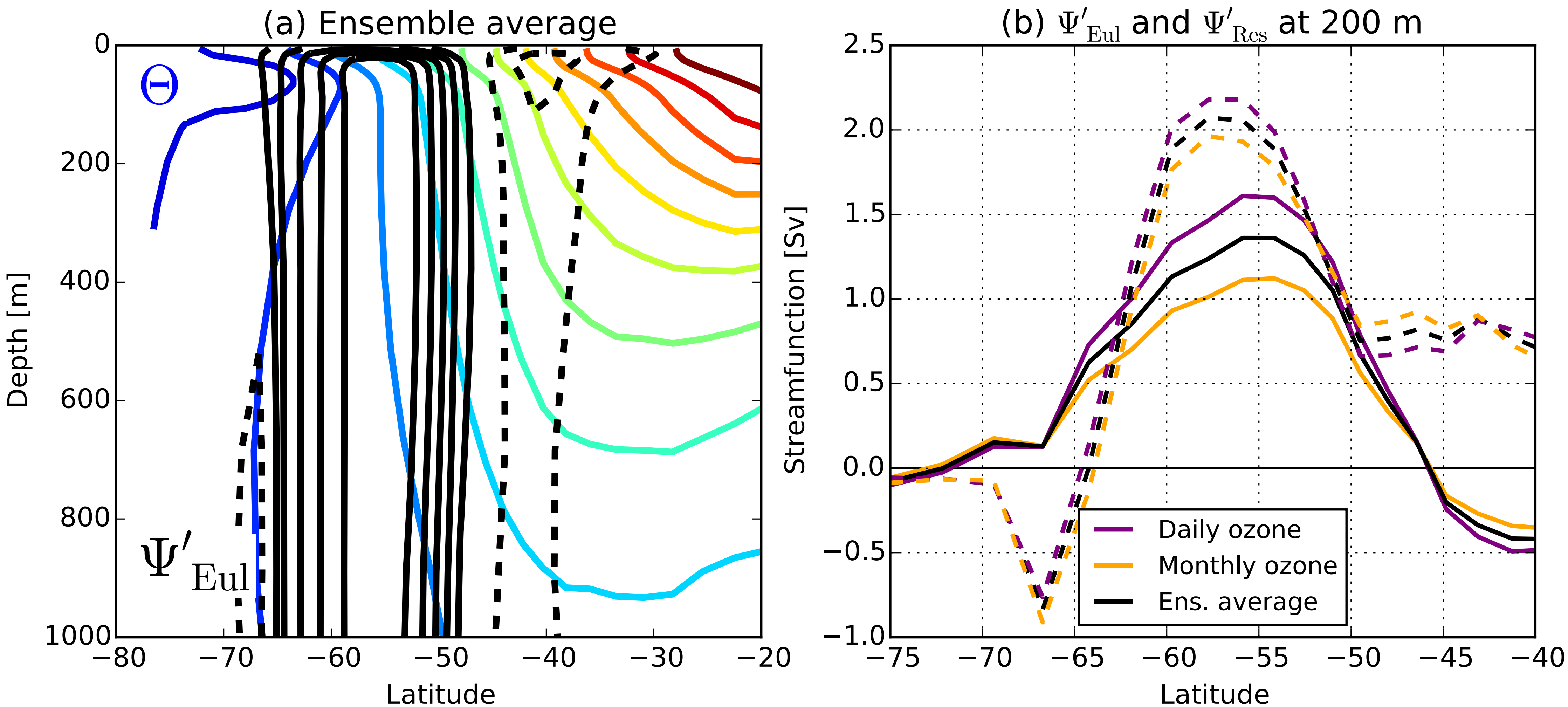
Initial cooling for ~25 years above summer mixed-layer, similar magnitude as Ferreira et al. (2015).

Daily vs Monthly Ozone



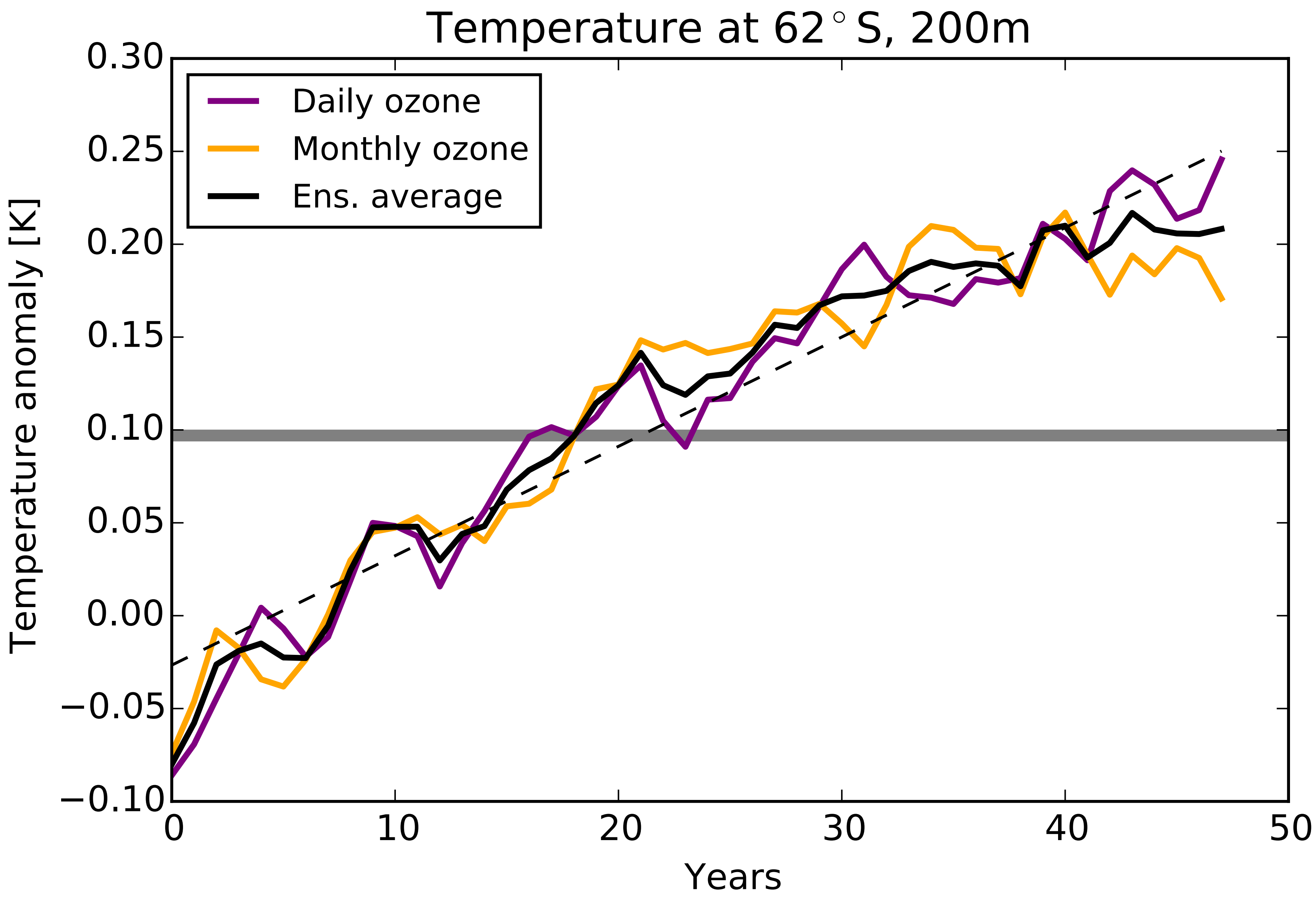
- Wind stress anomaly increases by ~50% on changing from monthly to daily ozone.
- Differences between warm and cold start not statistically significant

Daily vs Monthly Ozone



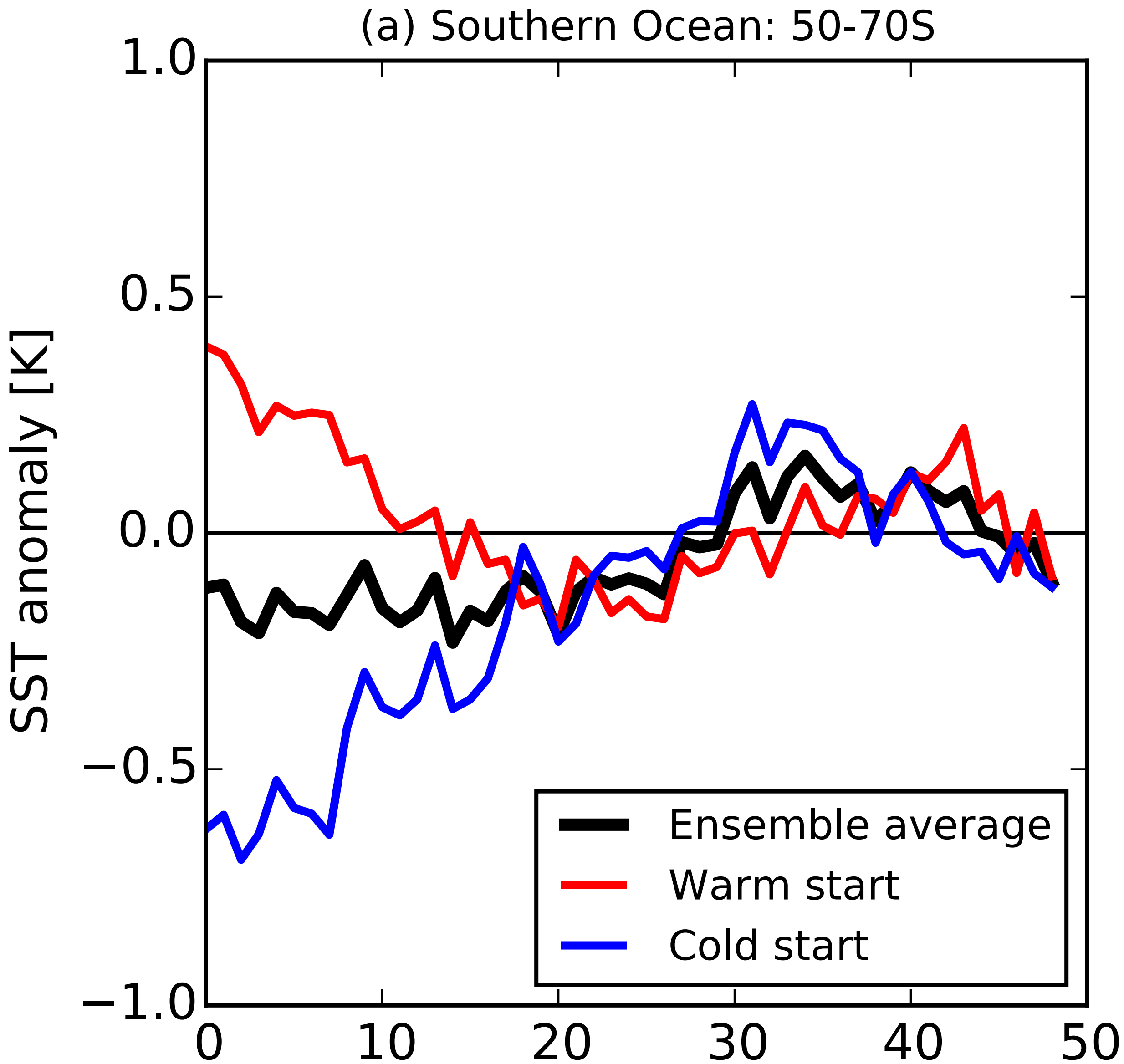
- Anomalous wind stress induces anomalous Eulerian circulation. Again, about 50% increase from monthly to daily ozone.
- Residual circulation is stronger than Eulerian at shallow depths due to increase in stratification, reduction in submesoscale overturning.
- Residual circulation is similar strength for daily and monthly.

Daily vs Monthly Ozone



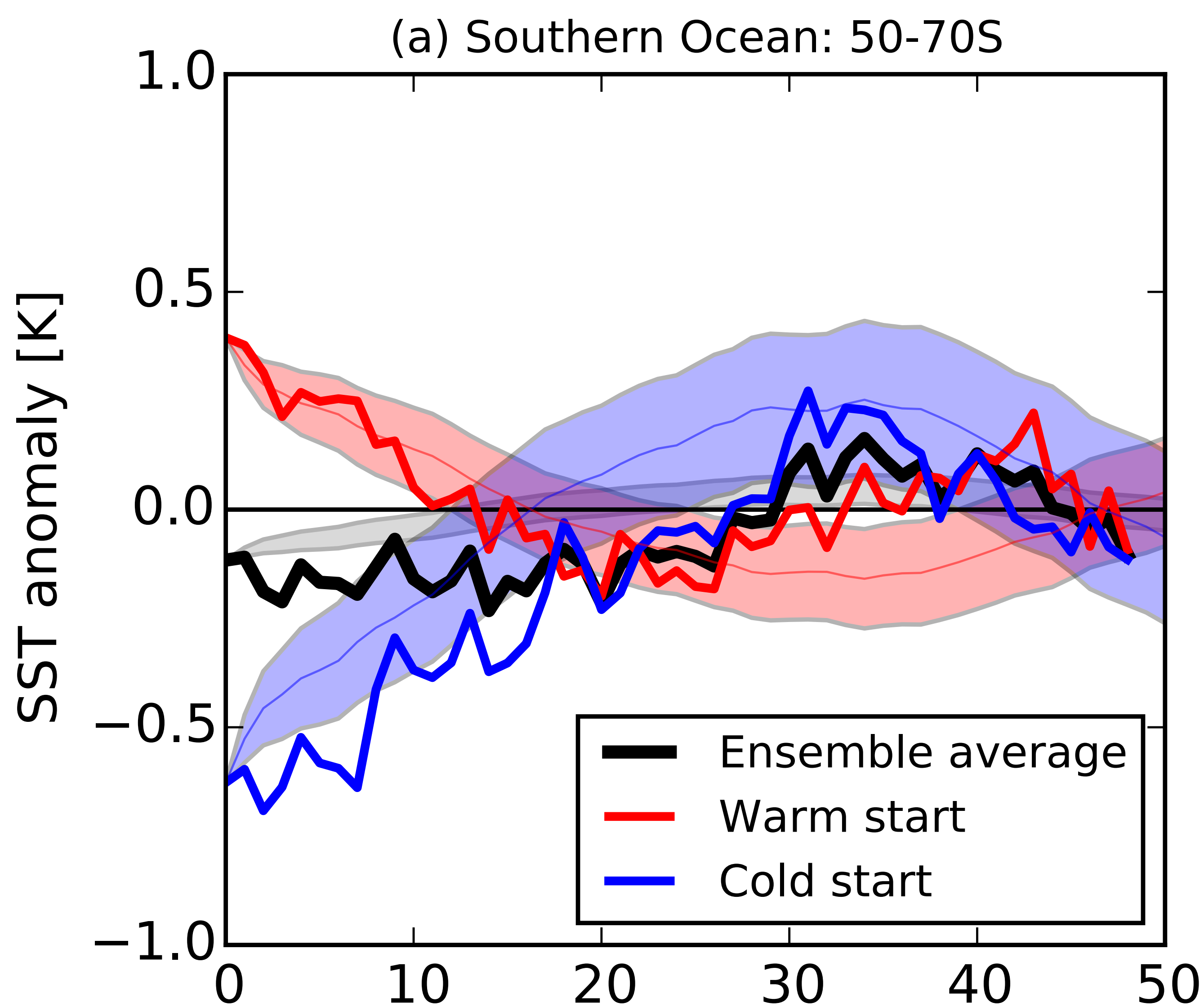
Similar residual circulation leads to similar temperature trends in daily and monthly ozone simulations.

Warm Start vs Cold Start



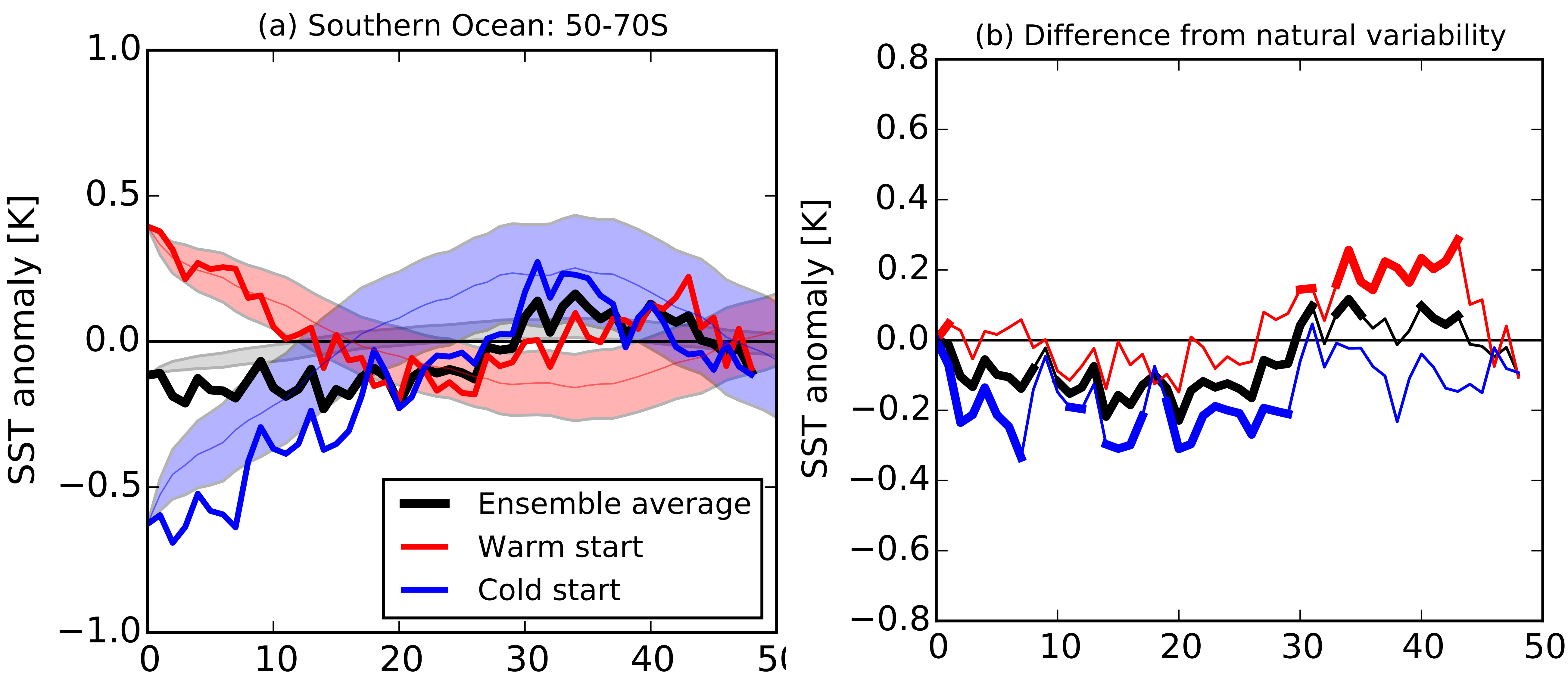
- Warm start initially cools, while cold start warms. Natural variability > forced response.
- We are interested in the response *relative* to natural variability.

Warm Start vs Cold Start



Shaded region shows 95% probability range of natural (unforced) variability, using the autocorrelation of a 500-year-long control run.

Warm Start vs Cold Start

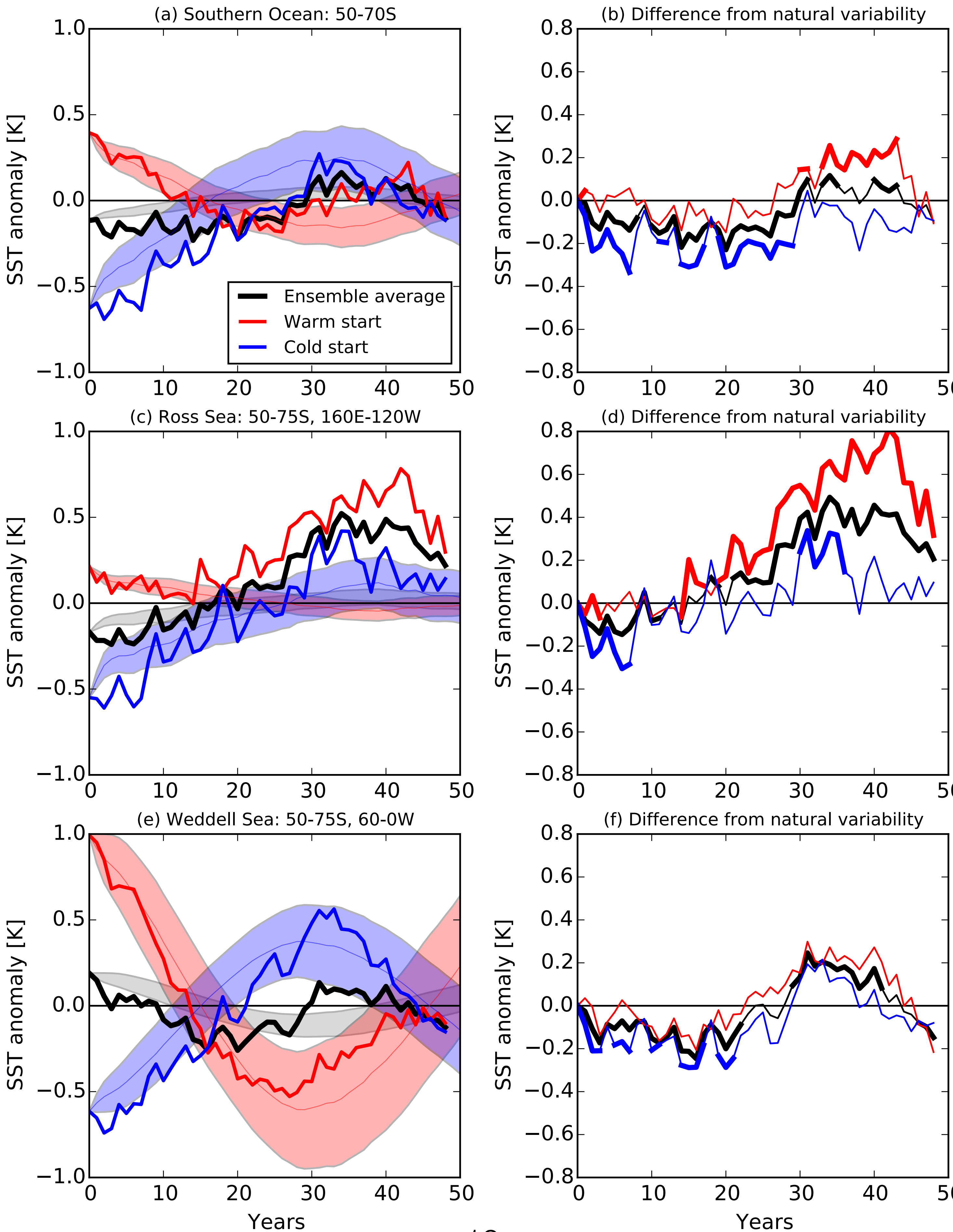


Bold lines are where forced response lies outside natural variability interval.

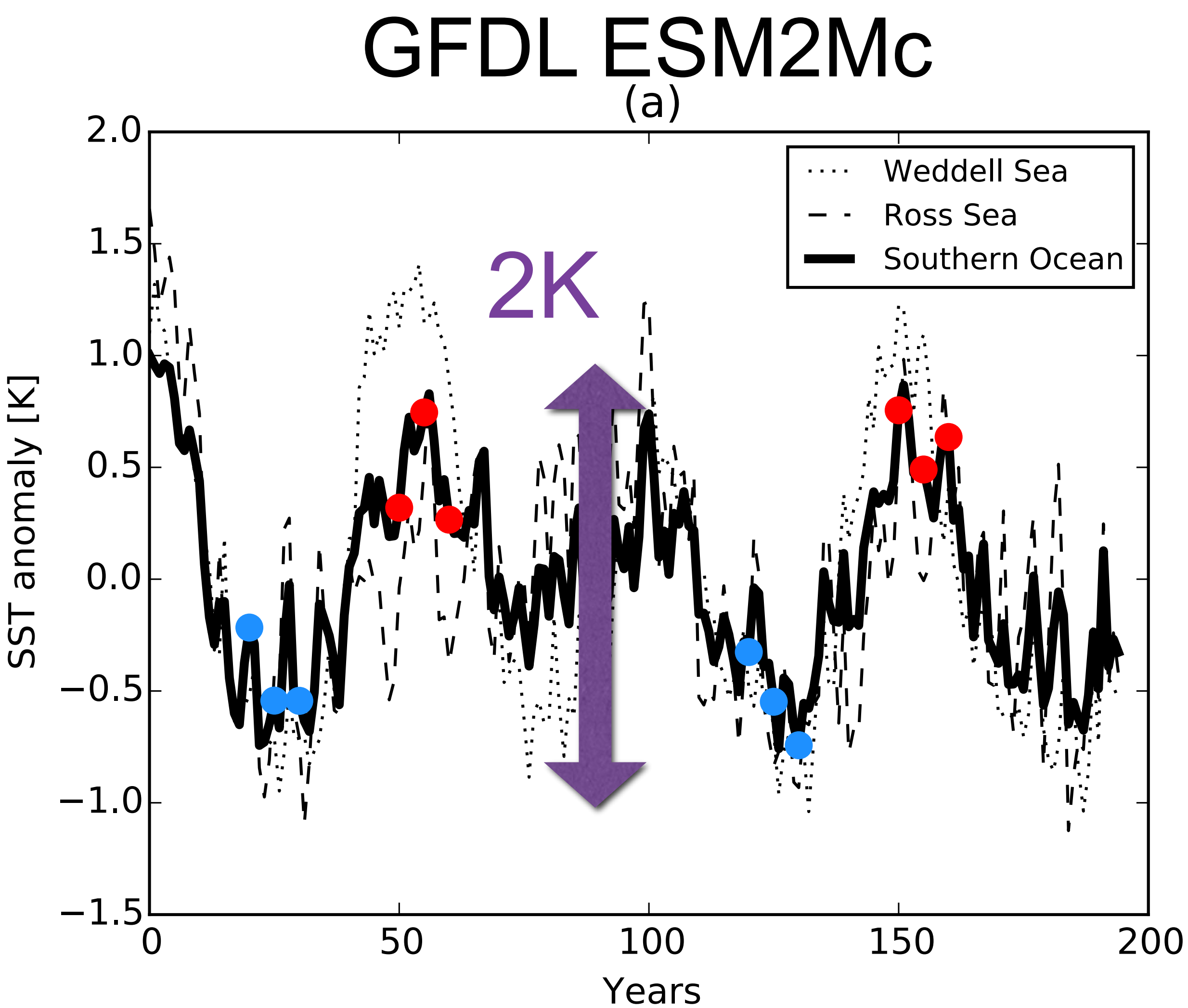
Southern Ocean

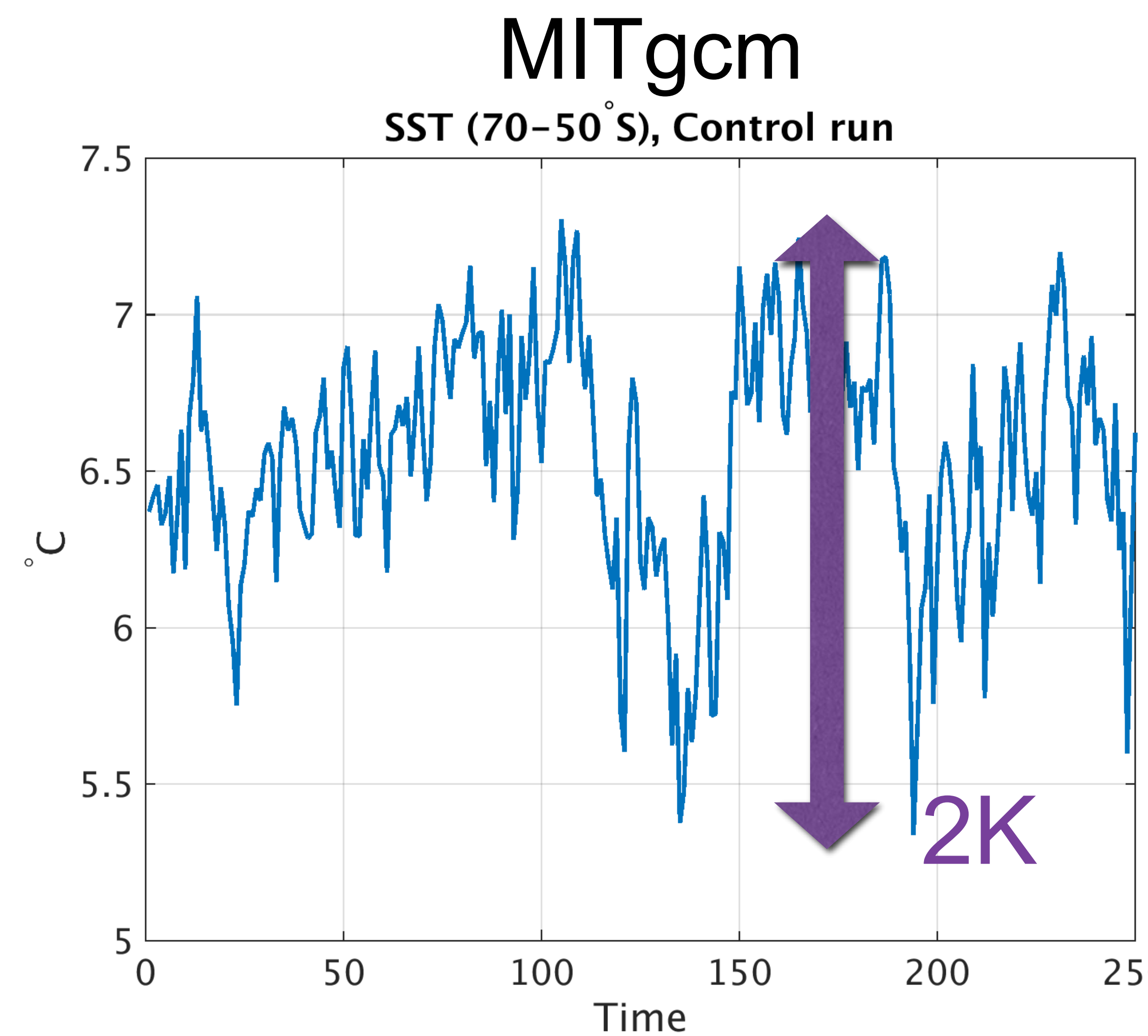
Ross Sea

Weddell Sea



Forced response vs natural variability





In both GFDL ESM2Mc and the MITgcm, initial cooling response is about 1/4 the interannual standard deviation of the model.

Would take at least ~20 years to detect this cooling with statistical significance. About as long as the cooling itself lasts.

Conclusions

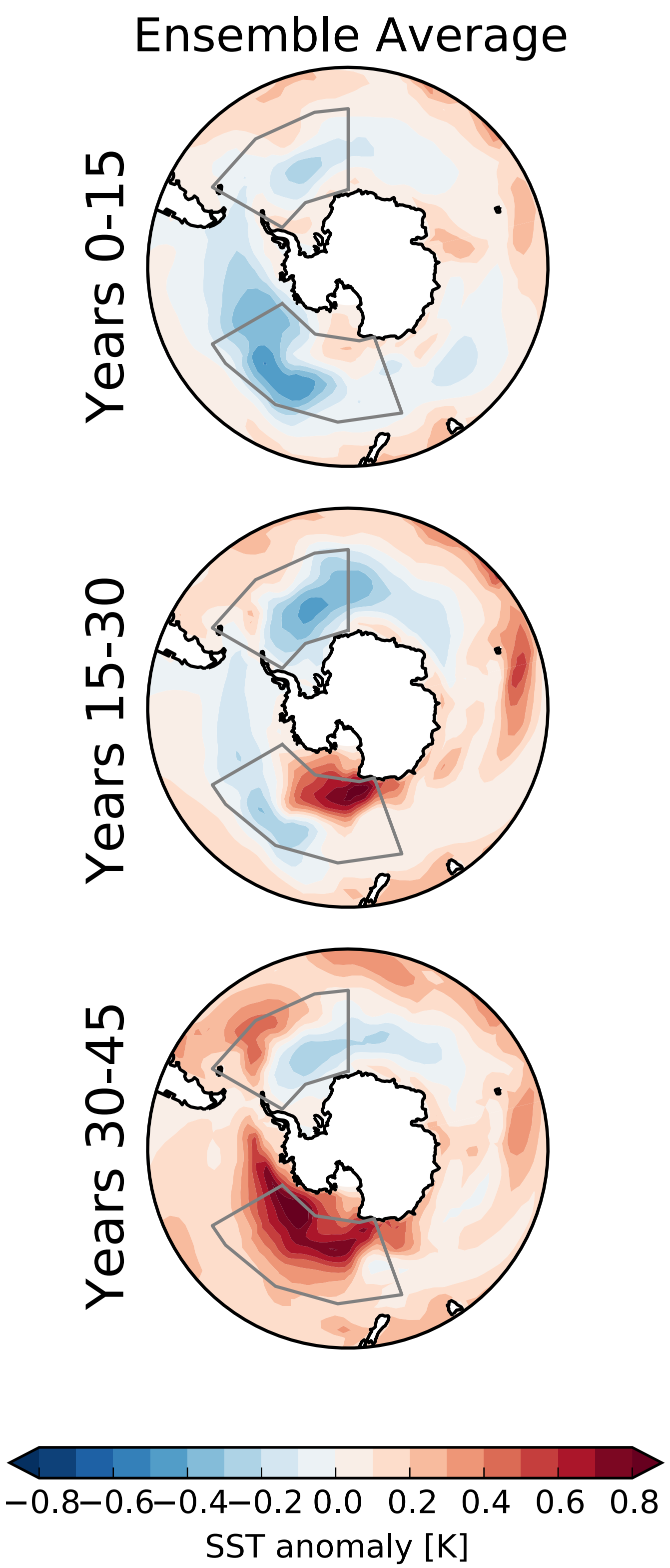
1. Initial cooling response with similar magnitude and duration as the MITgcm is found in GFDL ESM2Mc, a comprehensive coupled model with an explicit representation of ozone.

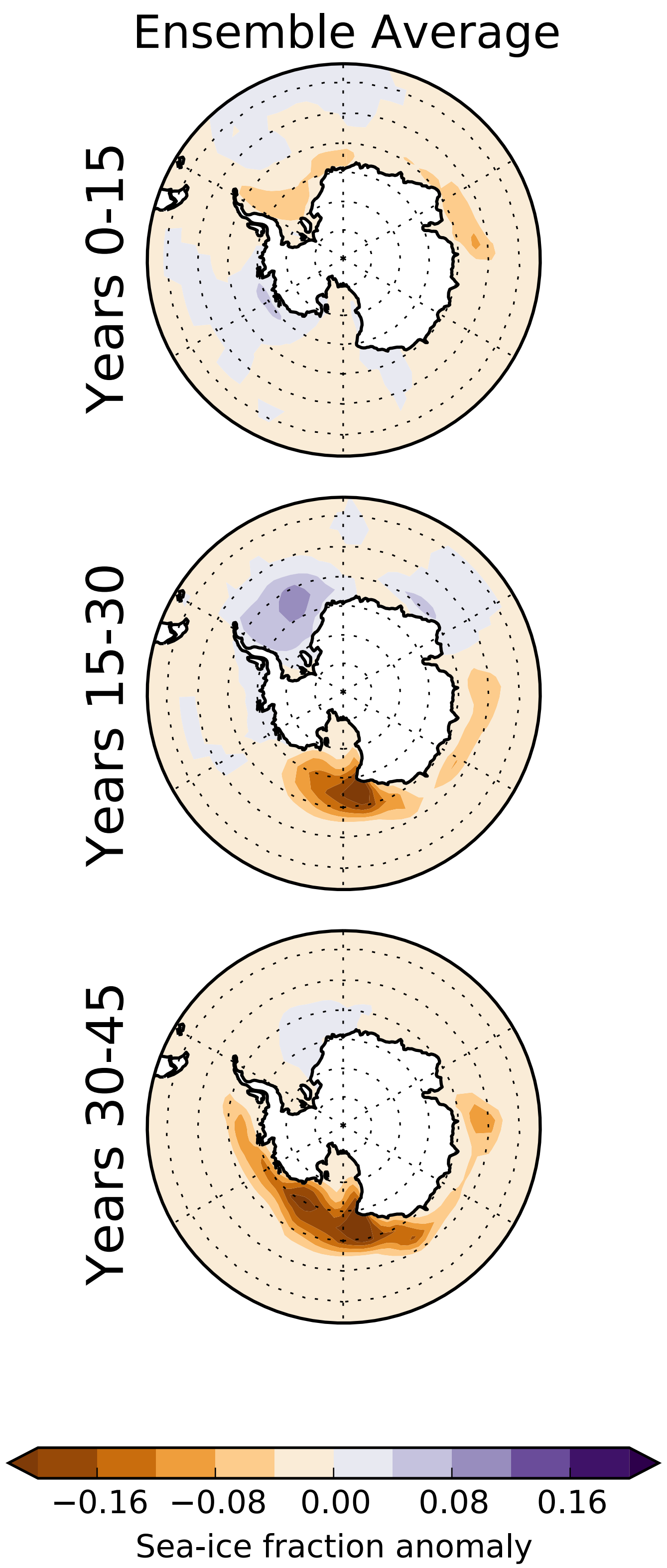
2. Daily ozone produces an ~50% greater wind stress response than monthly. This also leads to a greater Eulerian-mean overturning. However the residual circulation, and temperature response is similar.

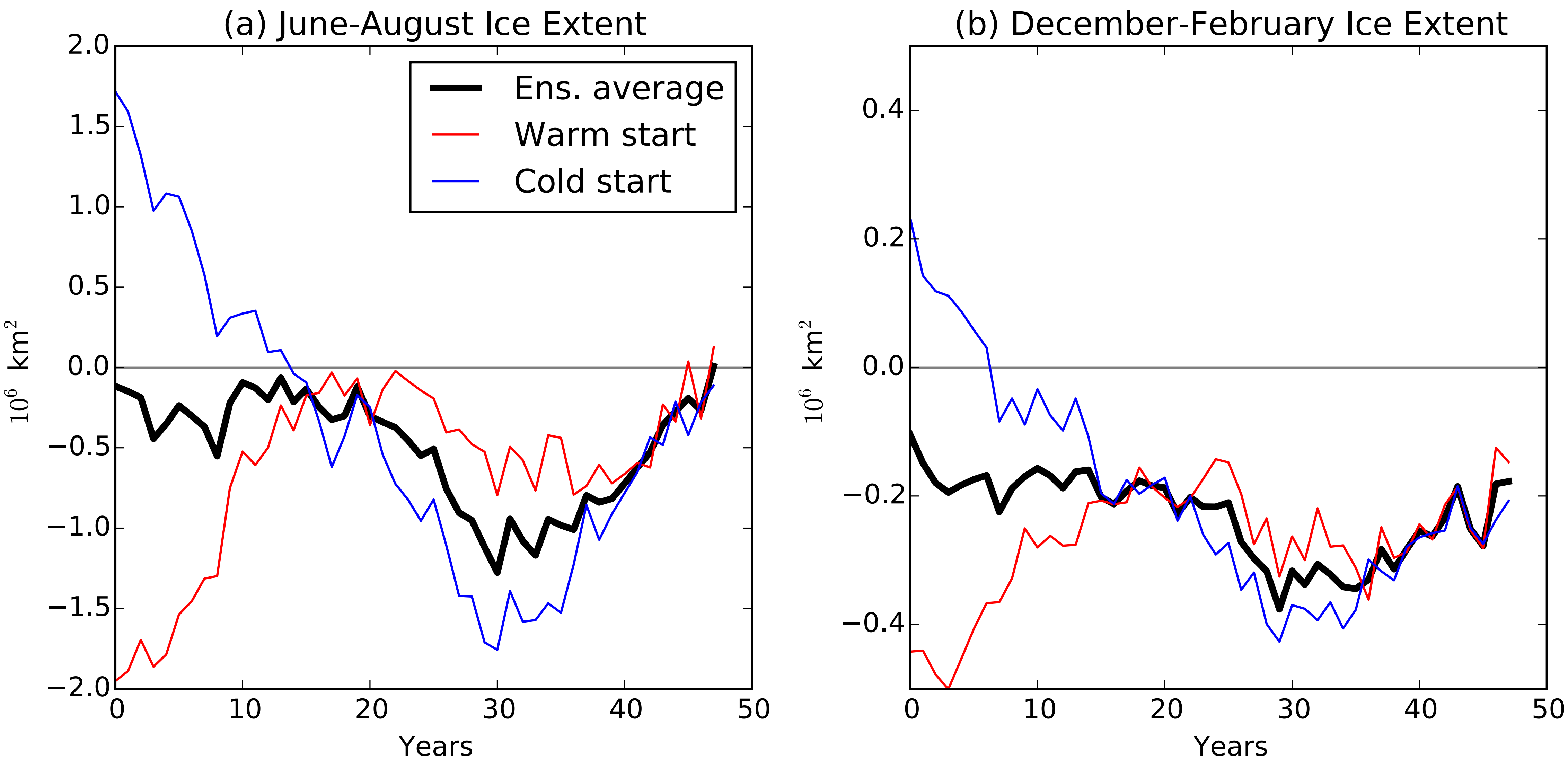
3. Natural variability is large compared to to the forced response.

SST

Sea-ice concentration






(a) June-August Ice Extent
(b) December-February Ice Extent
Ens. average
Warm start
Cold start
10^6 km^2
Years
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0.4
0.2
−0.2
−0.4
0
10
20
30
40
50