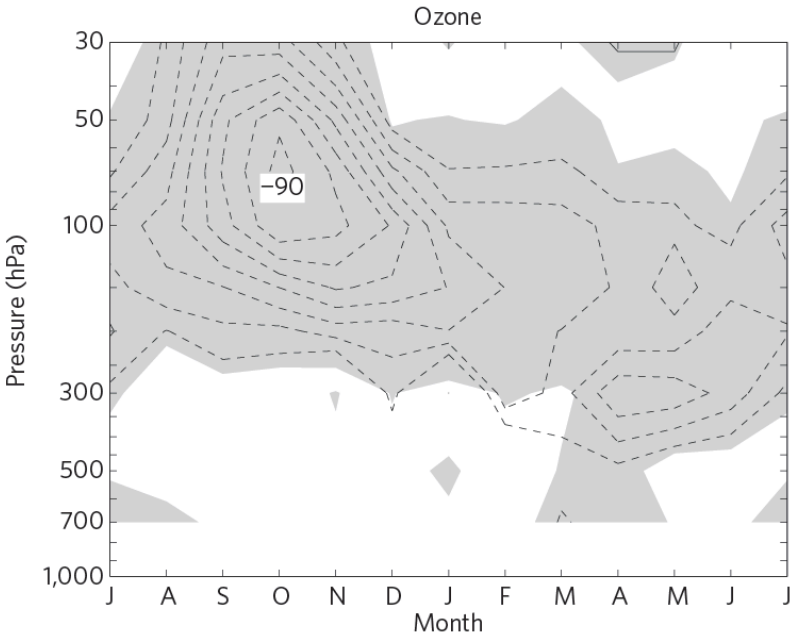
Mitigation of Projected 21st Century Antarctic Sea Ice Loss by Ozone Recovery

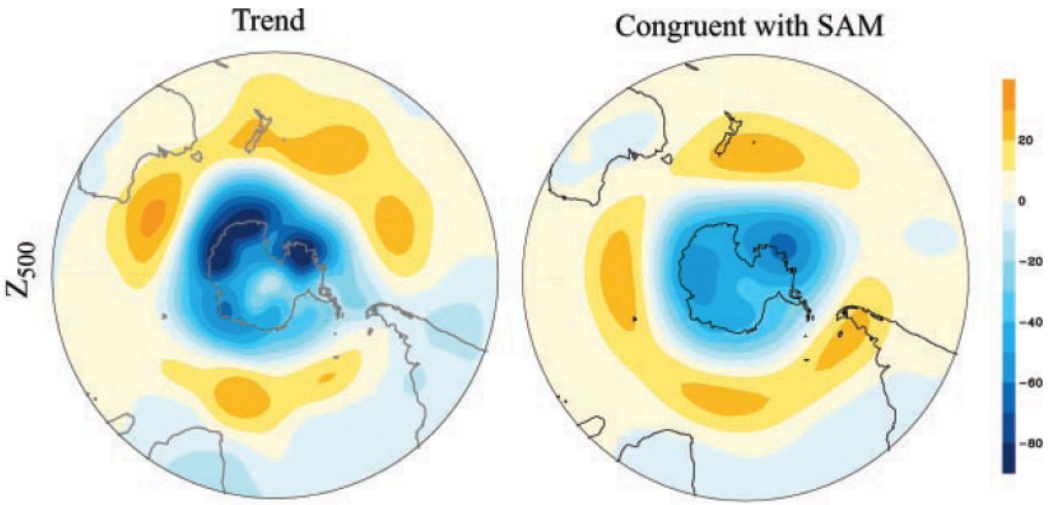
Karen L. Smith[1], Lorenzo M. Polvani[1,2]
Daniel R. Marsh[3]

[1]Lamont-Doherty Earth Observatory, Palisades, NY, USA
[2]Applied Physics and Applied Mathematics Department, Columbia University, New York, NY, USA
[3]Atmospheric Chemistry Division, NCAR, Boulder, CO, USA

Antarctic Climate Change

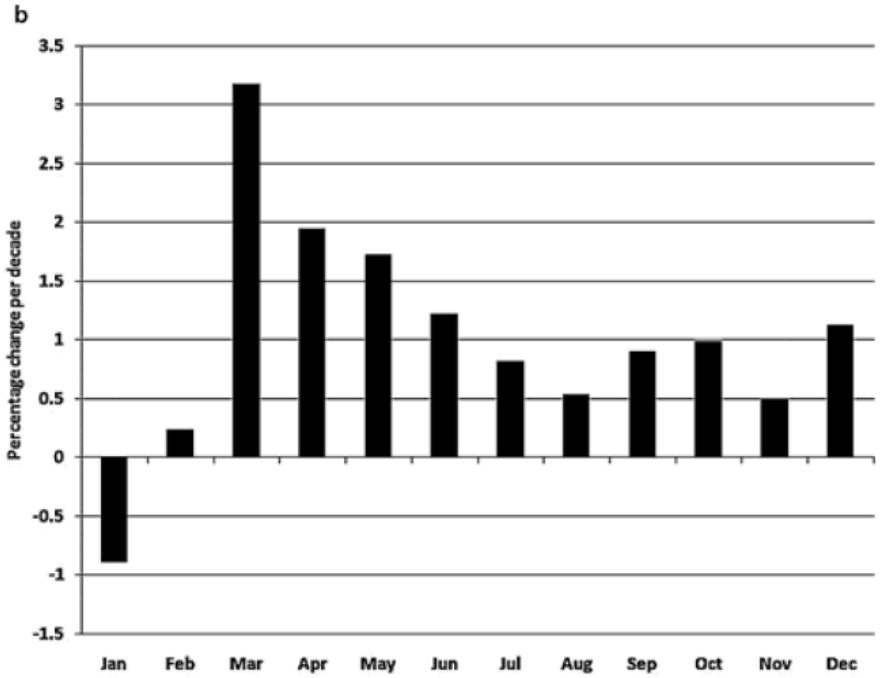
- Antarctic climate change over the past several decades has been dominated by the effects of stratospheric ozone depletion

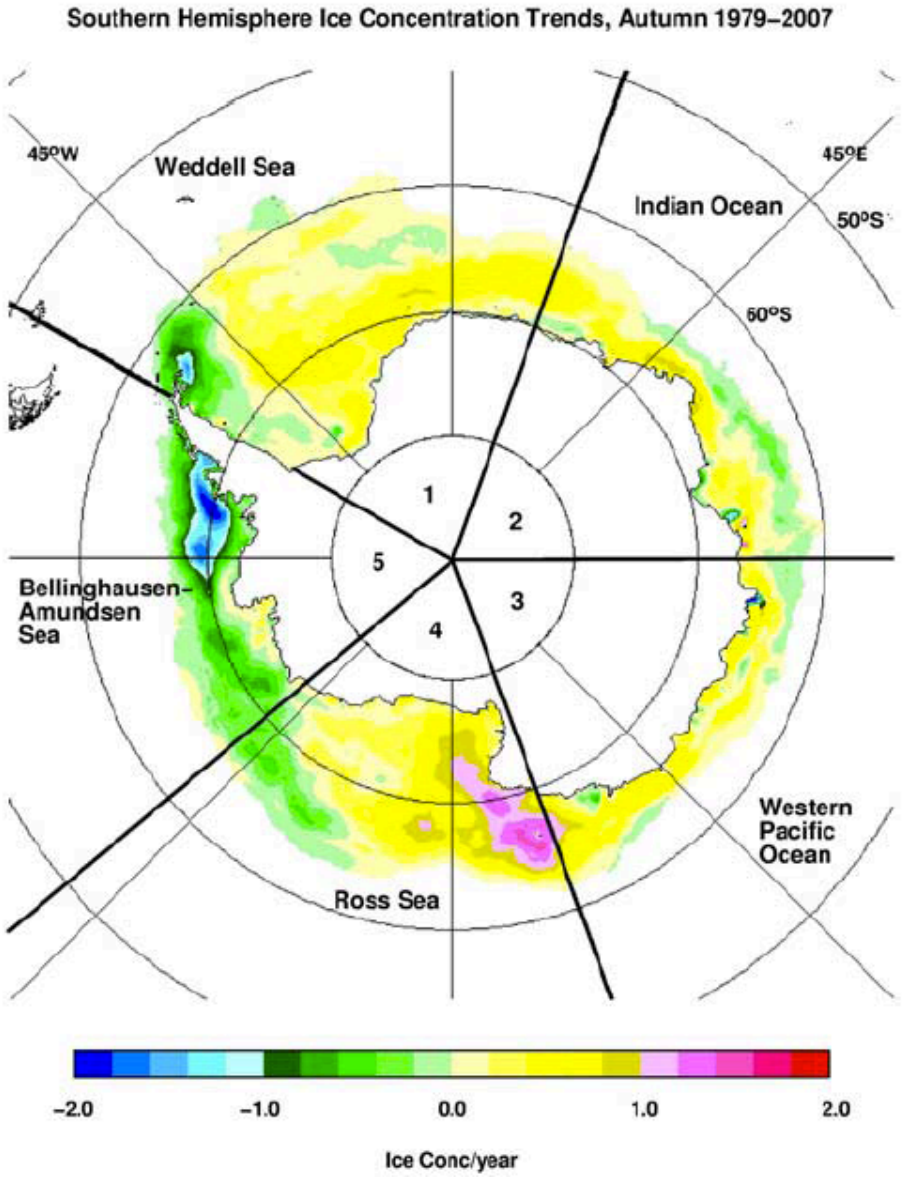




Thompson et al. 2011; Thompson and Solomon 2002

Antarctic Sea Ice Trends





Observed trend in 1979-2007 Antarctic sea ice is positive and statistically significant at 0.97% / dec.

- Arctic trend: -2.4% / dec

Turner et al. 2009

Is there a connection between trends in stratospheric ozone, the SAM and Antarctic sea ice?

Lack of Consensus

- Lefebvre and Goosse (2004, 2005)
  - ocean-sea ice model forced with NCEP winds and temperatures from 1948-1999.
  - +SAM is associated with more sea ice in Ross Sea region due to deepening of Amundsen Low.

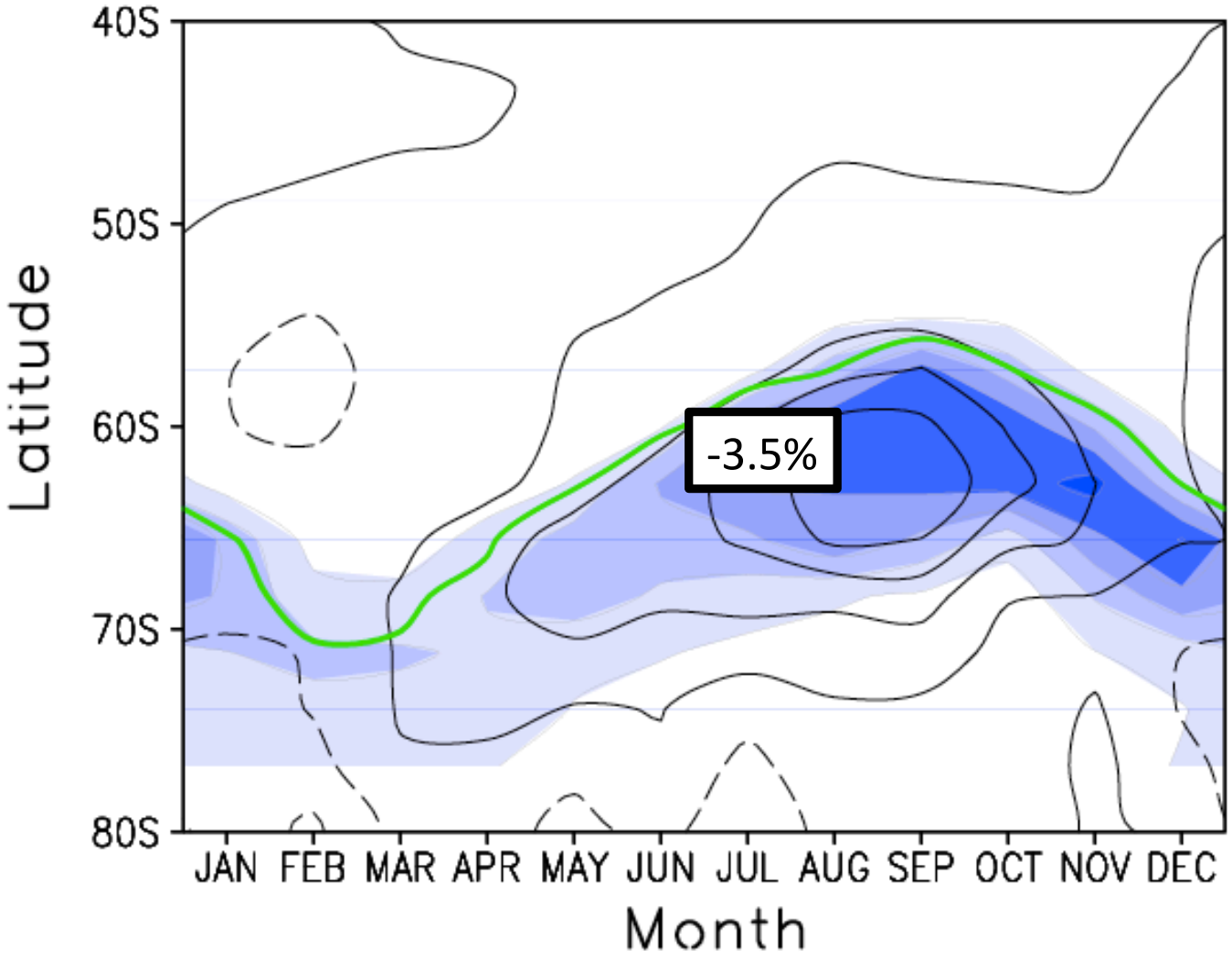
Lack of Consensus

- Lefebvre and Goosse (2004, 2005)
  - ocean-sea ice model forced with NCEP winds and temperatures from 1948-1999.
  - +SAM is associated with more sea ice in Ross Sea region due to deepening of Amundsen Low.
- Turner et al. (2009)
  - reanalysis and AR4 data to show that trend in Amundsen Low and is consistent with LG04 argument.
  - +SAM trend due to ozone depletion is responsible for +Antarctic sea ice trend.

Lack of Consensus

- Lefebvre and Goosse (2004, 2005)
  - ocean-sea ice model forced with NCEP winds and temperatures from 1948-1999.
  - +SAM is associated with more sea ice in Ross Sea region due to deepening of Amundsen Low.
- Turner et al. (2009)
  - reanalysis and AR4 data to show that trend in Amundsen Low and is consistent with LG04 argument.
  - +SAM trend due to ozone depletion is responsible for +Antarctic sea-ice trend.
- Sigmond and Fyfe (2010)
  - Two 3-member, 100-year CMAM ensembles with and without an ozone hole.
  - ensemble with ozone hole had ***less*** Antarctic sea ice.
  - stratospheric ozone depletion cannot explain observed trends in sea ice

Antarctic Sea Ice and Ozone



Sigmond and Fyfe 2010

Methodology

- GCM simulations using Whole Atmosphere Community Climate Model Version 4 (WACCM4; Marsh et al. 2012)
  - 1.9 x 2.5° horizontal resolution
  - 66 vertical levels up to 140 km
  - coupled middle atmosphere chemistry
  - coupled ocean and sea ice components

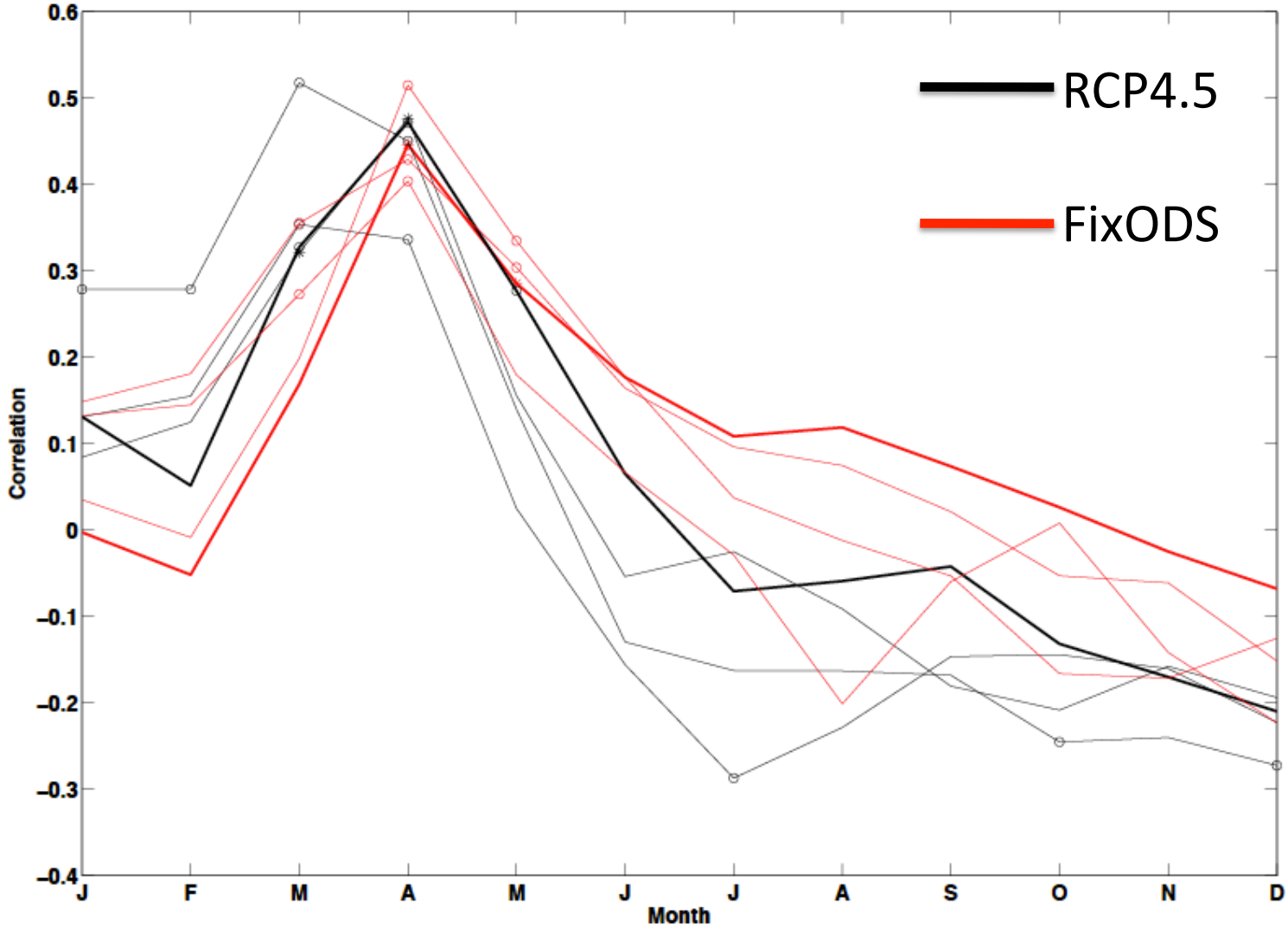
Methodology

- GCM simulations using Whole Atmosphere Community Climate Model Version 4 (WACCM4; Marsh et al. 2012).
  - 1.9 x 2.5° horizontal resolution
  - 66 vertical levels up to 140 km
  - coupled middle atmosphere chemistry
  - coupled ocean and sea ice components

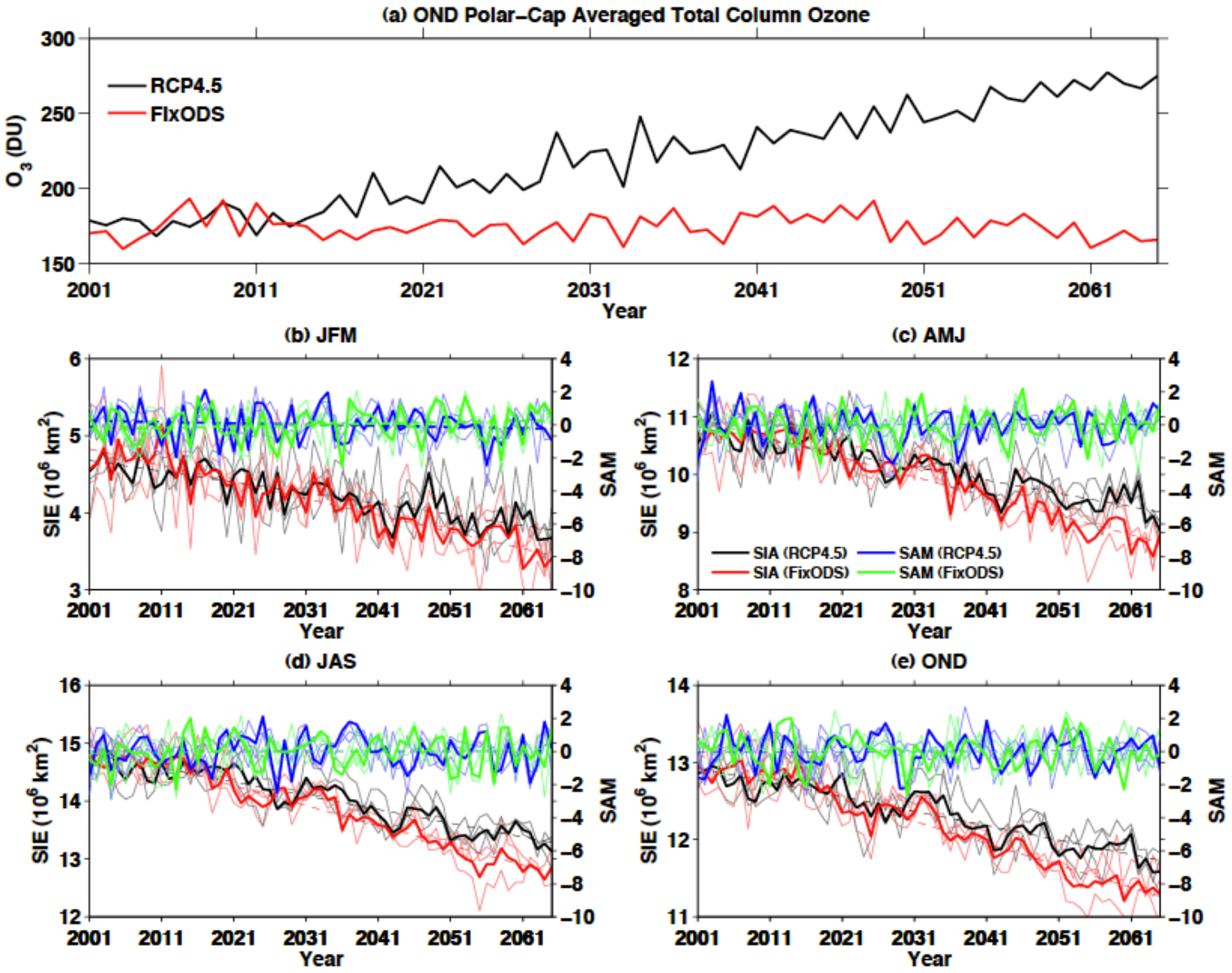
- Two 3-member ensembles of 21st century (2001-2065) integrations with and without ozone recovery.
  - 1st Ensemble, **RCP4.5**: Standard RCP 4.5 including ozone recovery.
  - 2nd Ensemble, **FixODS**: RCP 4.5 with surface ozone-depleting substances fixed at year 2000 levels.
  - Response is ensemble mean FixODS – RCP4.5 averaged over last 10 years of integration.

Antarctic Sea Ice Extent (SIE) and the SAM

Correlation between ***detrended*** Summer SAM and Monthly SIE

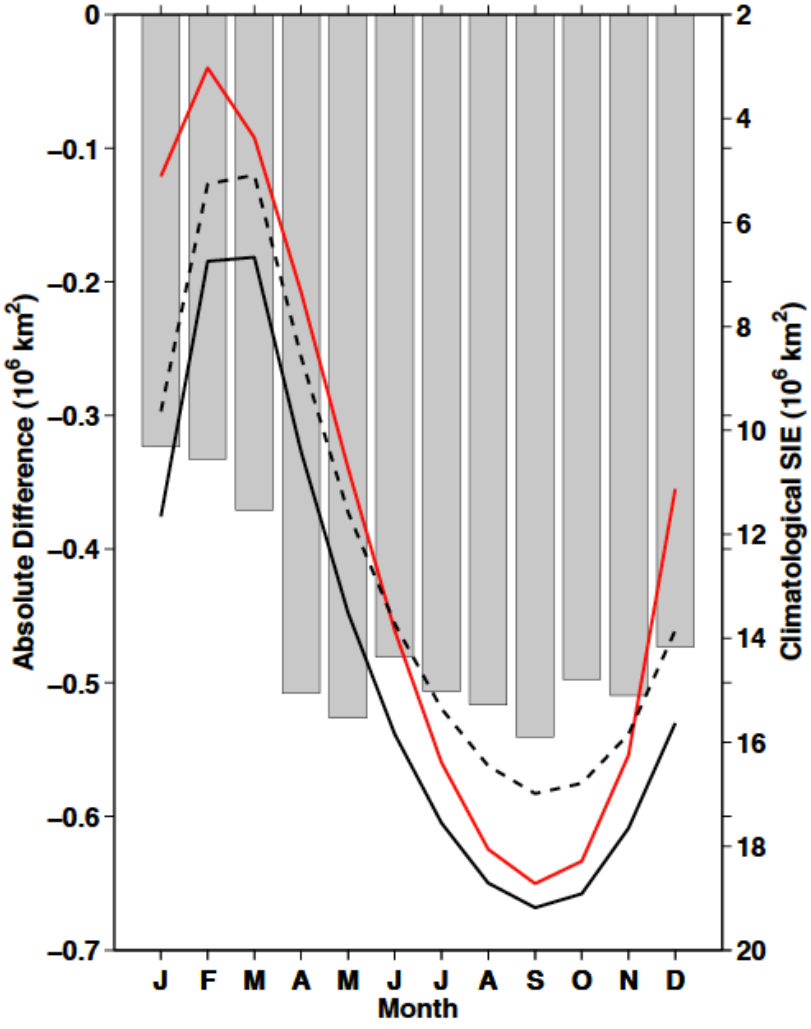


Antarctic Sea Ice and SAM Trends

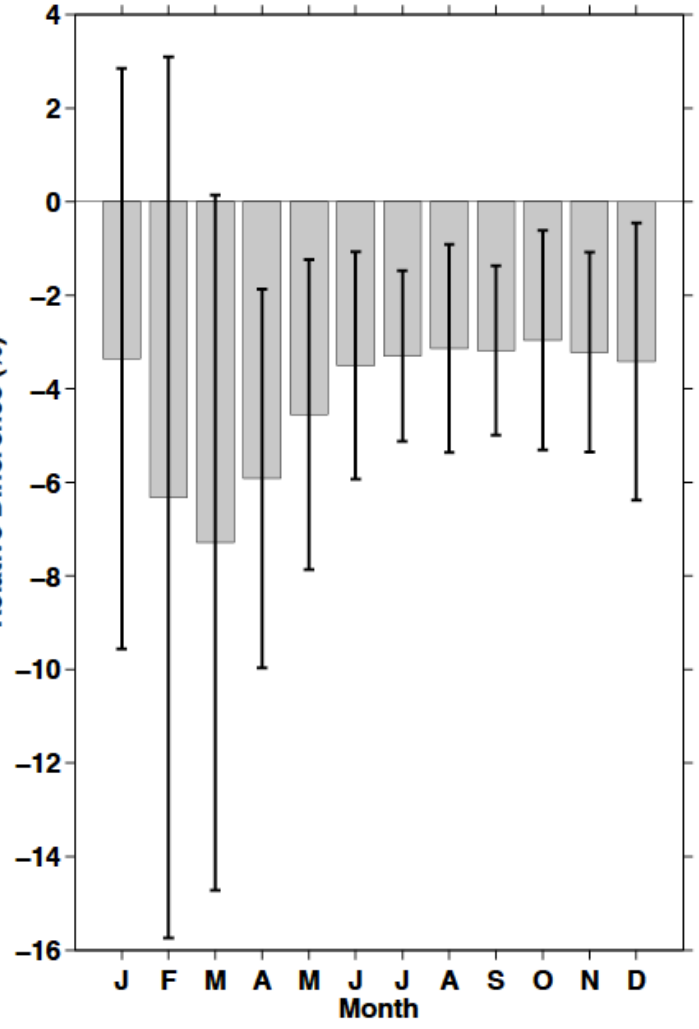


Monthly Sea Ice Response

Absolute Difference



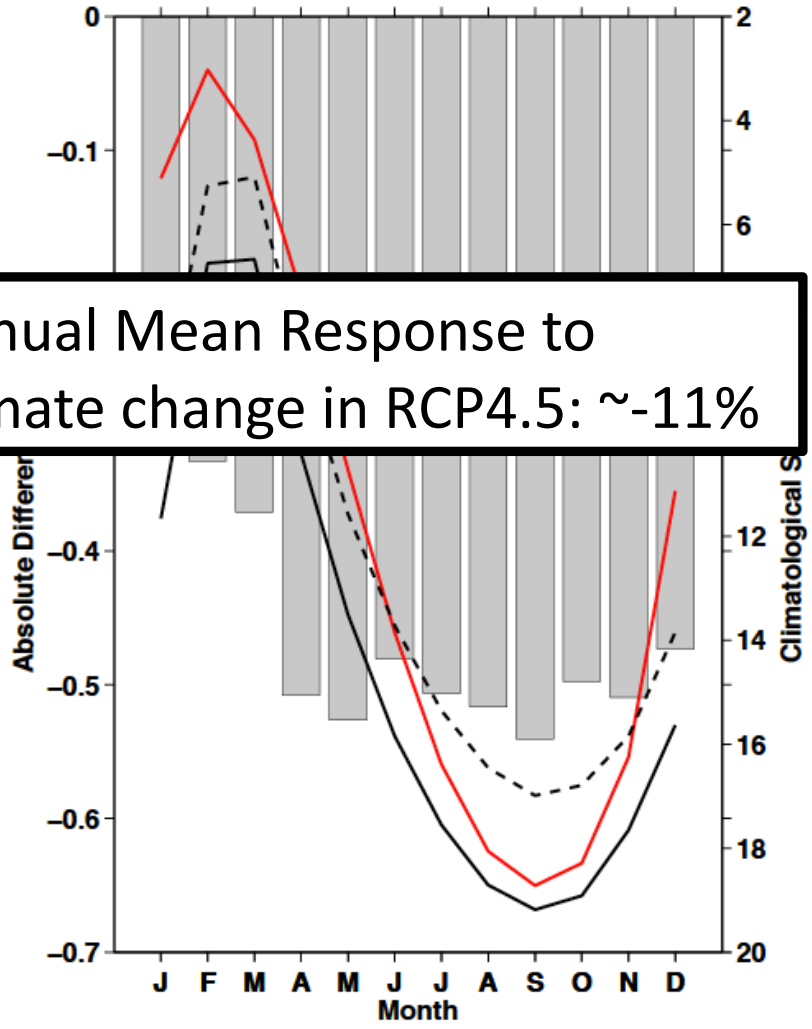
Relative Difference

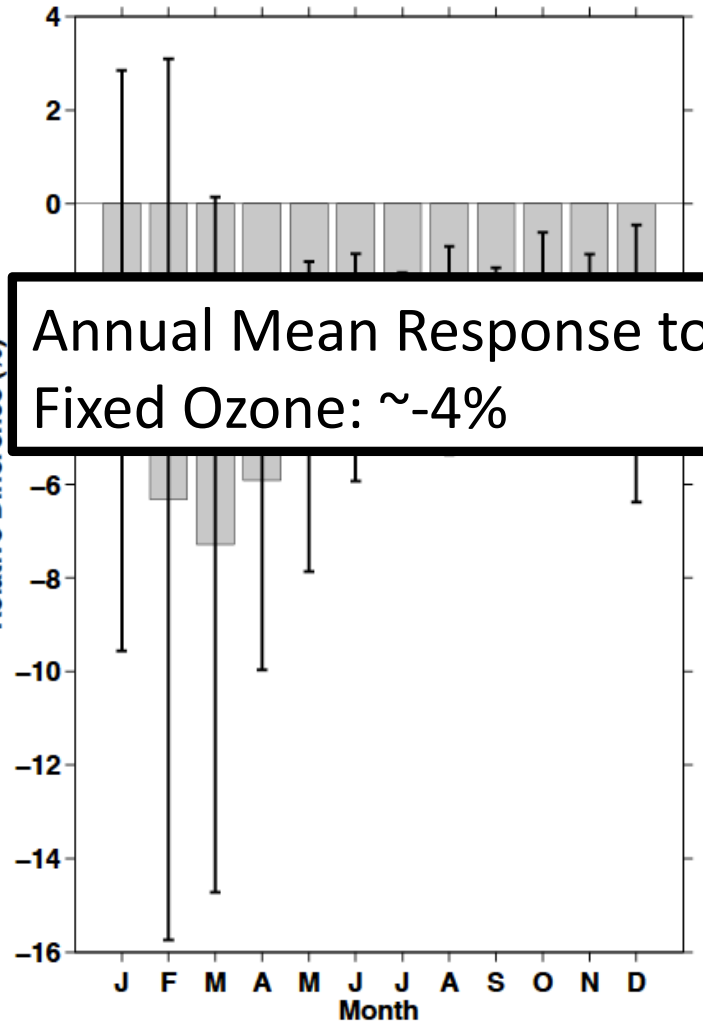


Monthly Sea Ice Response

Absolute Difference

Relative Difference

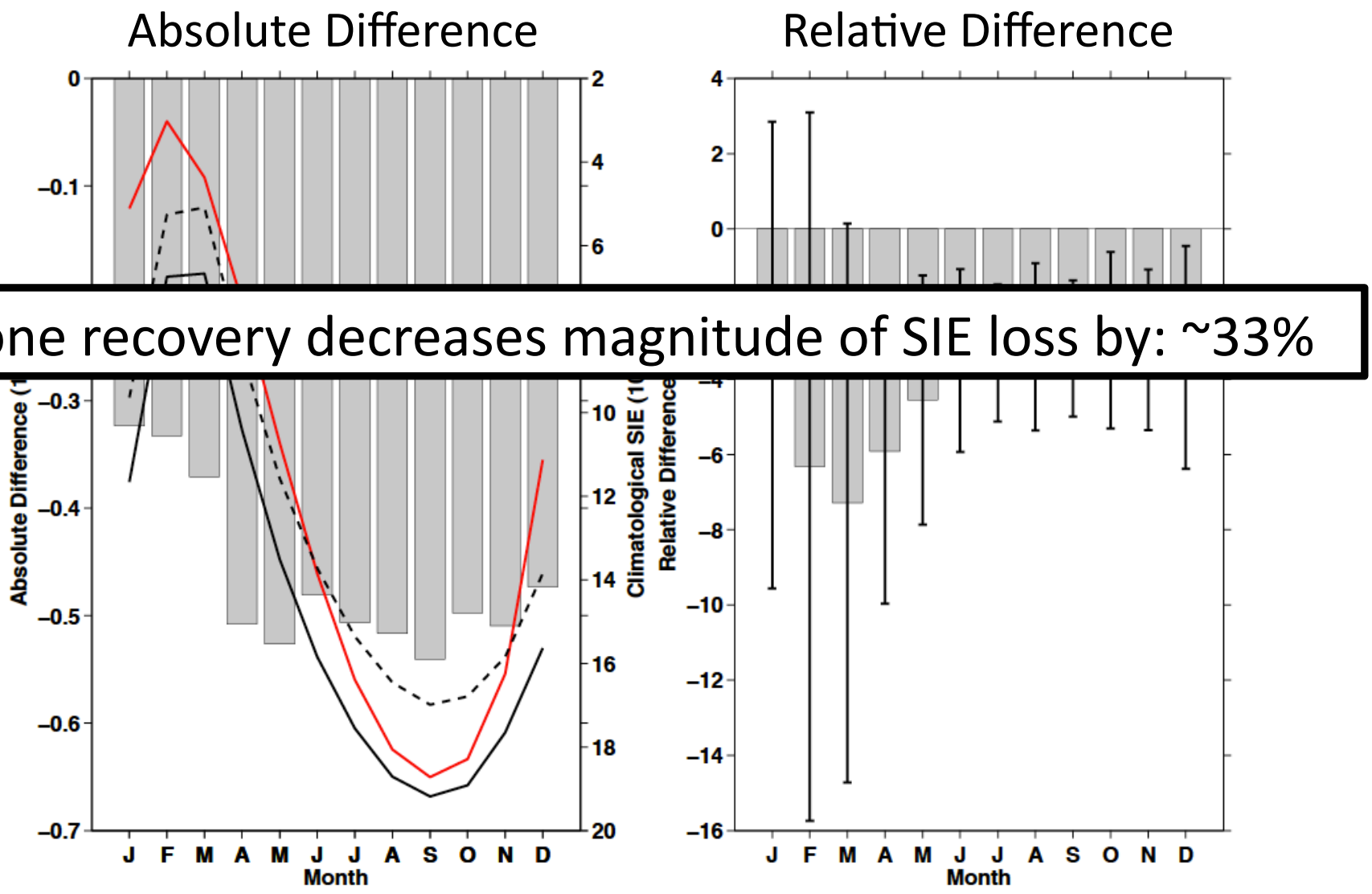




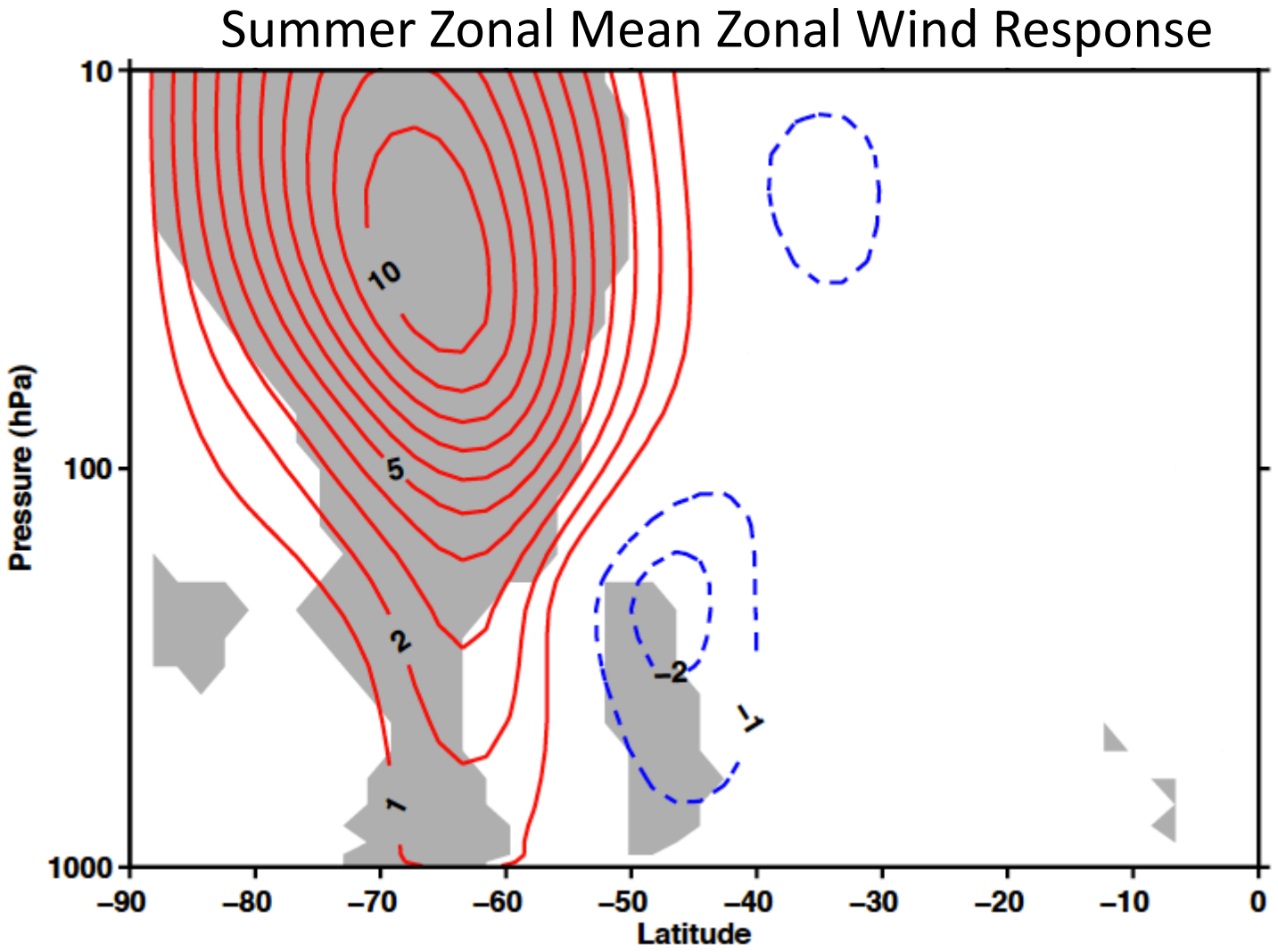
Annual Mean Response to climate change in RCP4.5: ~-11%

Annual Mean Response to Fixed Ozone: ~-4%

Monthly Sea Ice Response



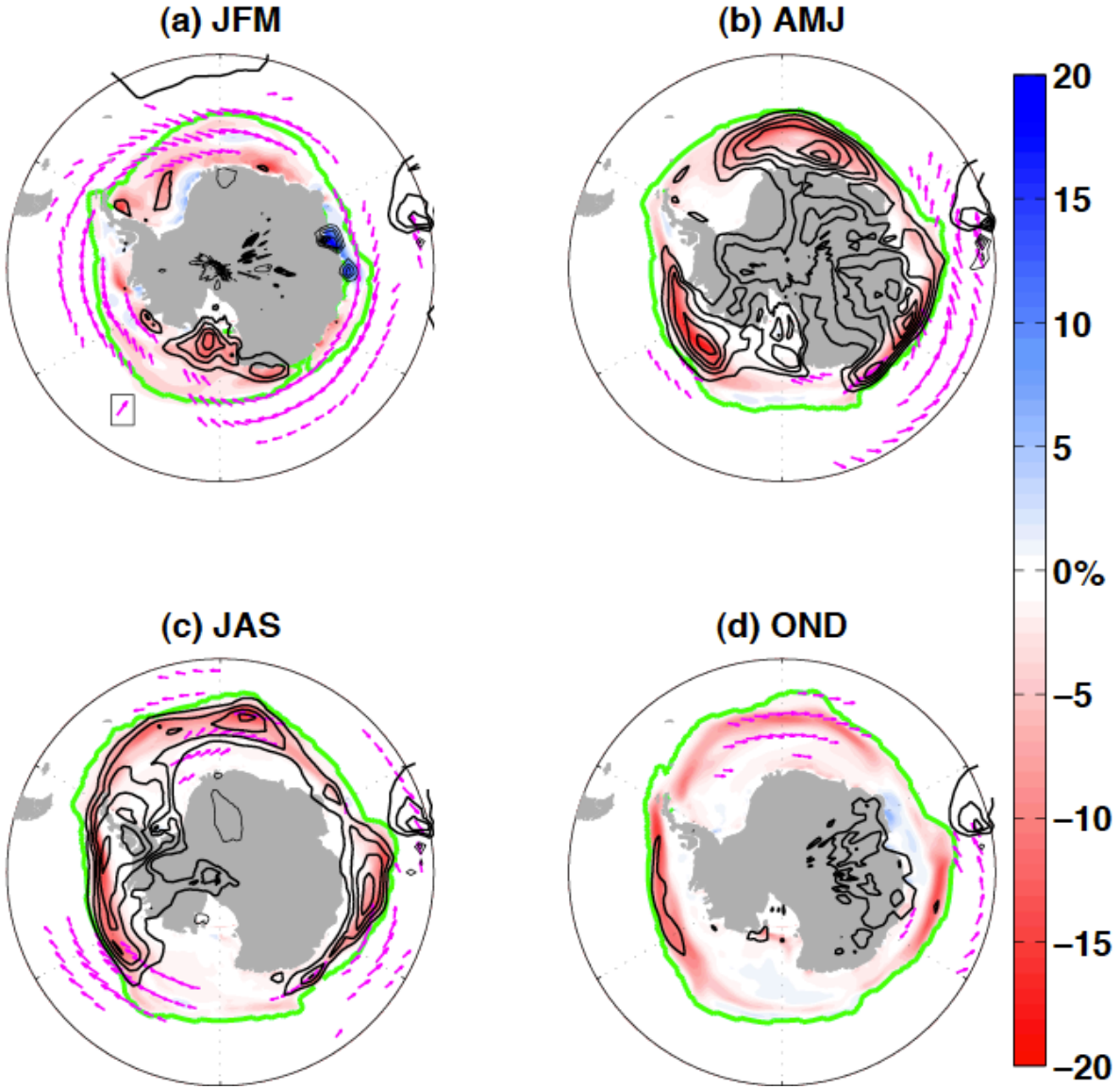
Zonal Mean Zonal Wind Response



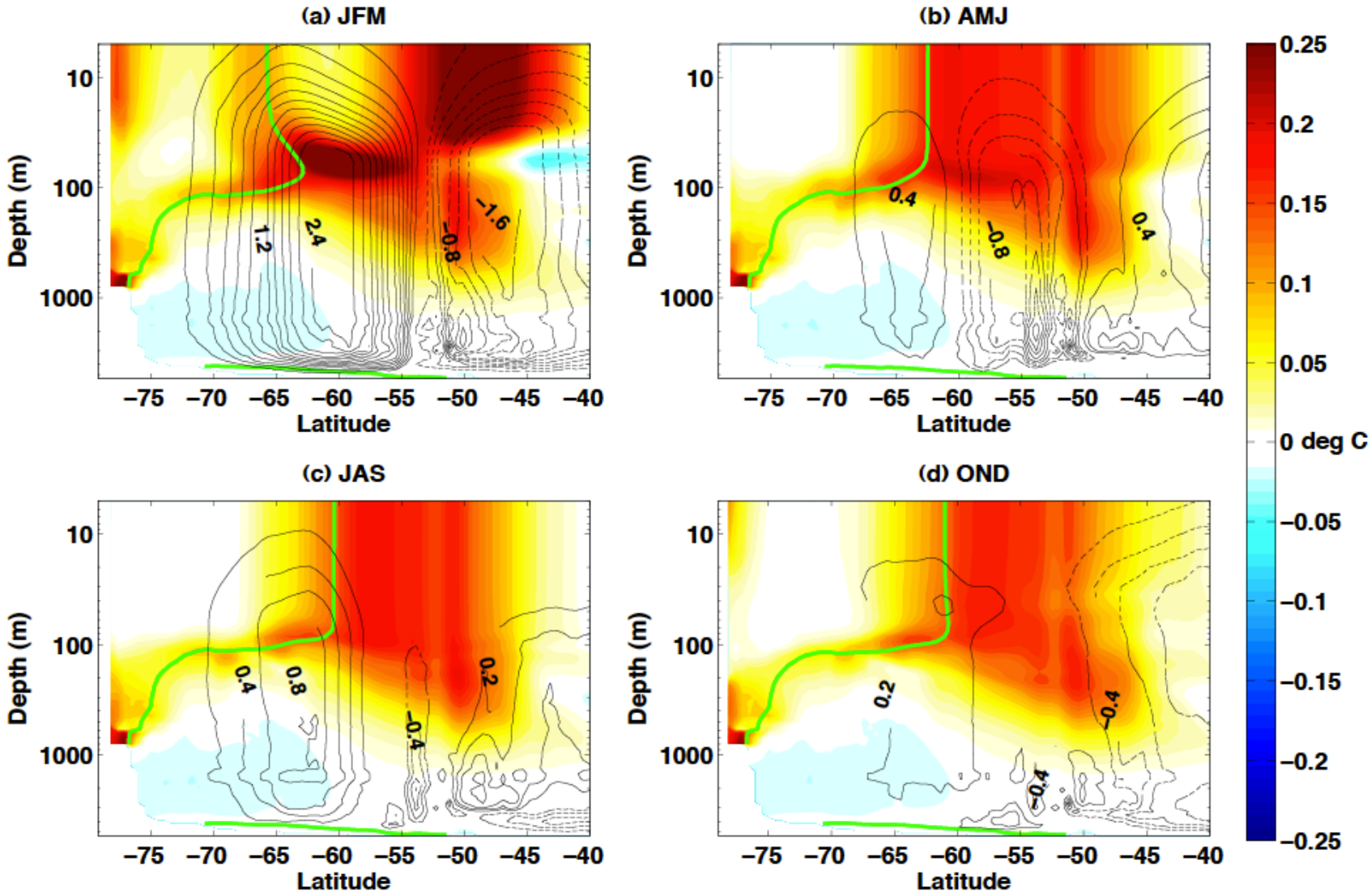
Contour interval is 1 m/s. Gray shading indicates 95% statistical significance.

Surface Wind Stress, Temperature and Sea Ice Concentration Response

- Sea ice concentration response (%; shading),
- Surface wind stress (magenta vectors; only vectors greater than 0.01 N m2 are displayed),
- Surface temperature (black curves; contour interval in K is [-0.75, -0.5, 0, 0.5, 0.75, 1, 1.25,…])



Zonal Mean Temperature and MOC Response



Conclusions

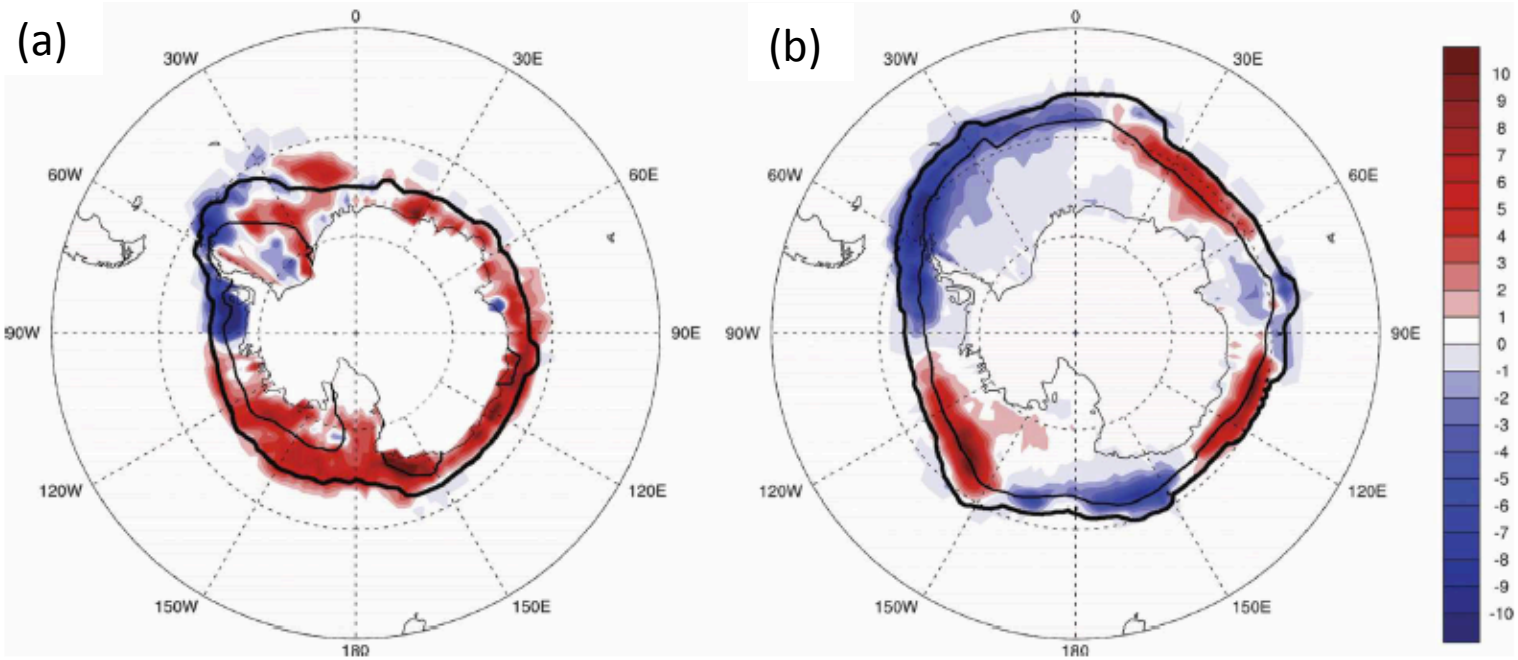
- Transient GCM simulations show greater 21st century Antarctic sea ice loss when ozone recovery is excluded.
  - This is primarily due to warming of the upper ocean and a retreat of the ice edge.

- Findings are qualitatively similar to Sigmond and Fyfe 2010 despite using a different GCM and including transient GHG forcing.
  - Also similar to a new study by Bitz and Polvani using CCSM3 with a 0.1° ocean model.

- The regulation of CFC's has implications well beyond the reduction of harmful UV.

Thank you!

Interannual Antarctic Sea Ice Variability



Regressions on the SAM of sea ice extent (SIE) lagged by 1-month for (a) Jan-Feb-Mar-Apr and (b) Jun-Jul-Aug-Sep.

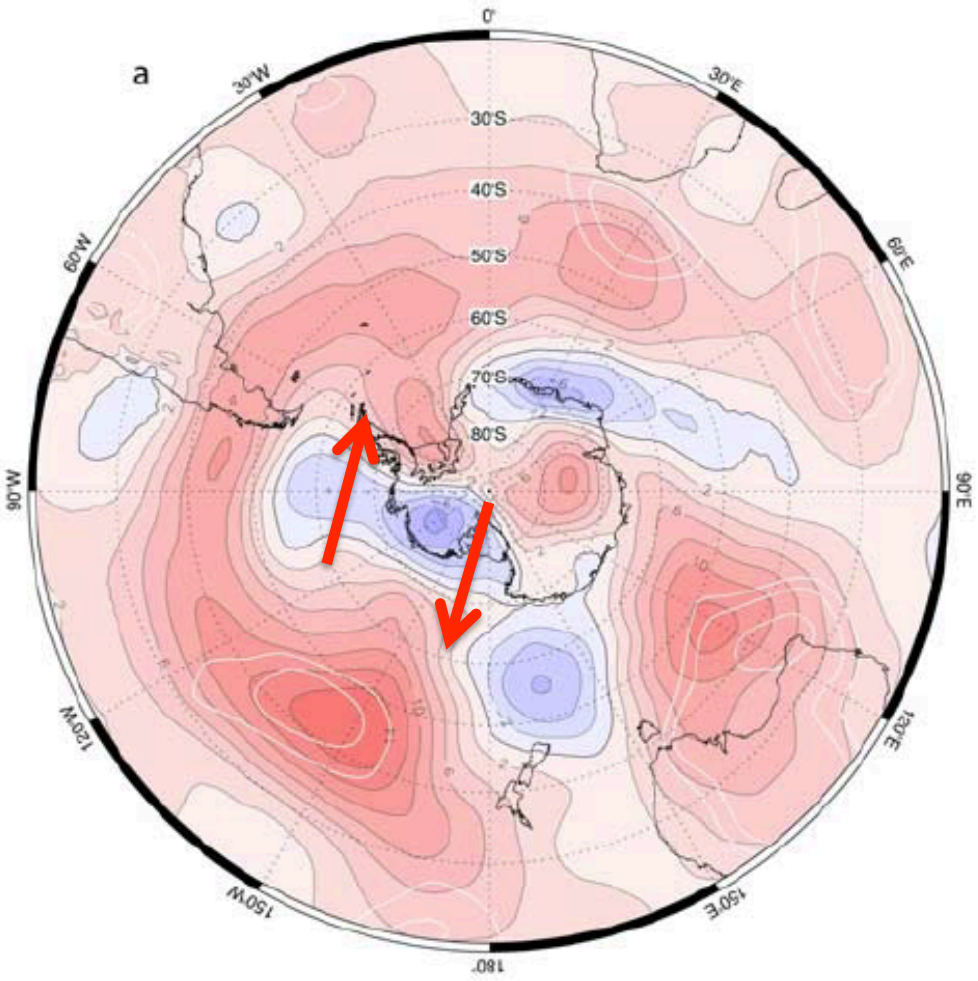
***Regression is positive in most regions in summer/early fall.

***Highly regional pattern in late fall/winter.

Sen Gupta and England 2006

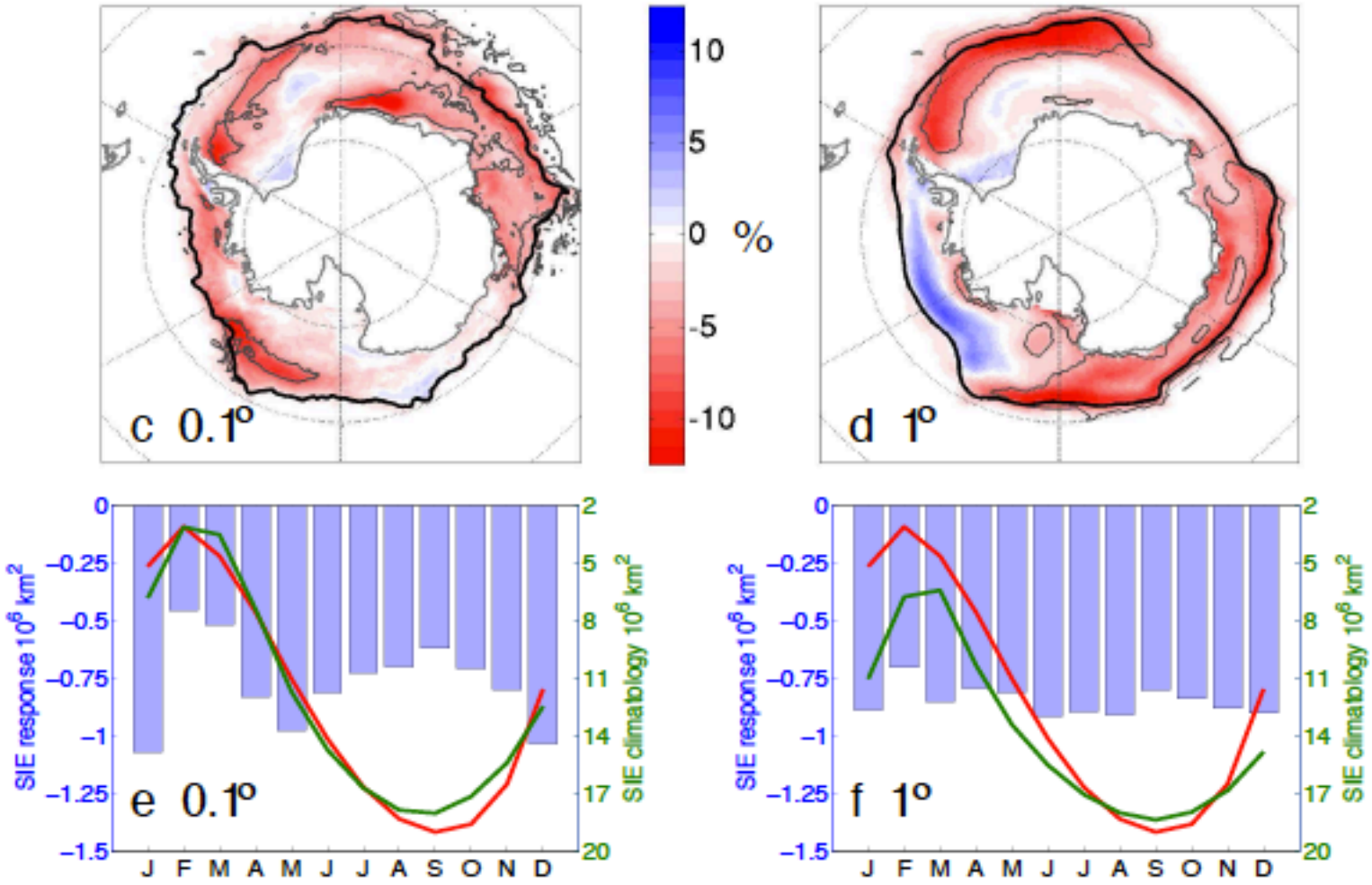
Trend in Amundsen Low

- Trend in ECMWF 500 hPa height for 1979-2006 (m/dec)
- Deepening of the Amundsen Low

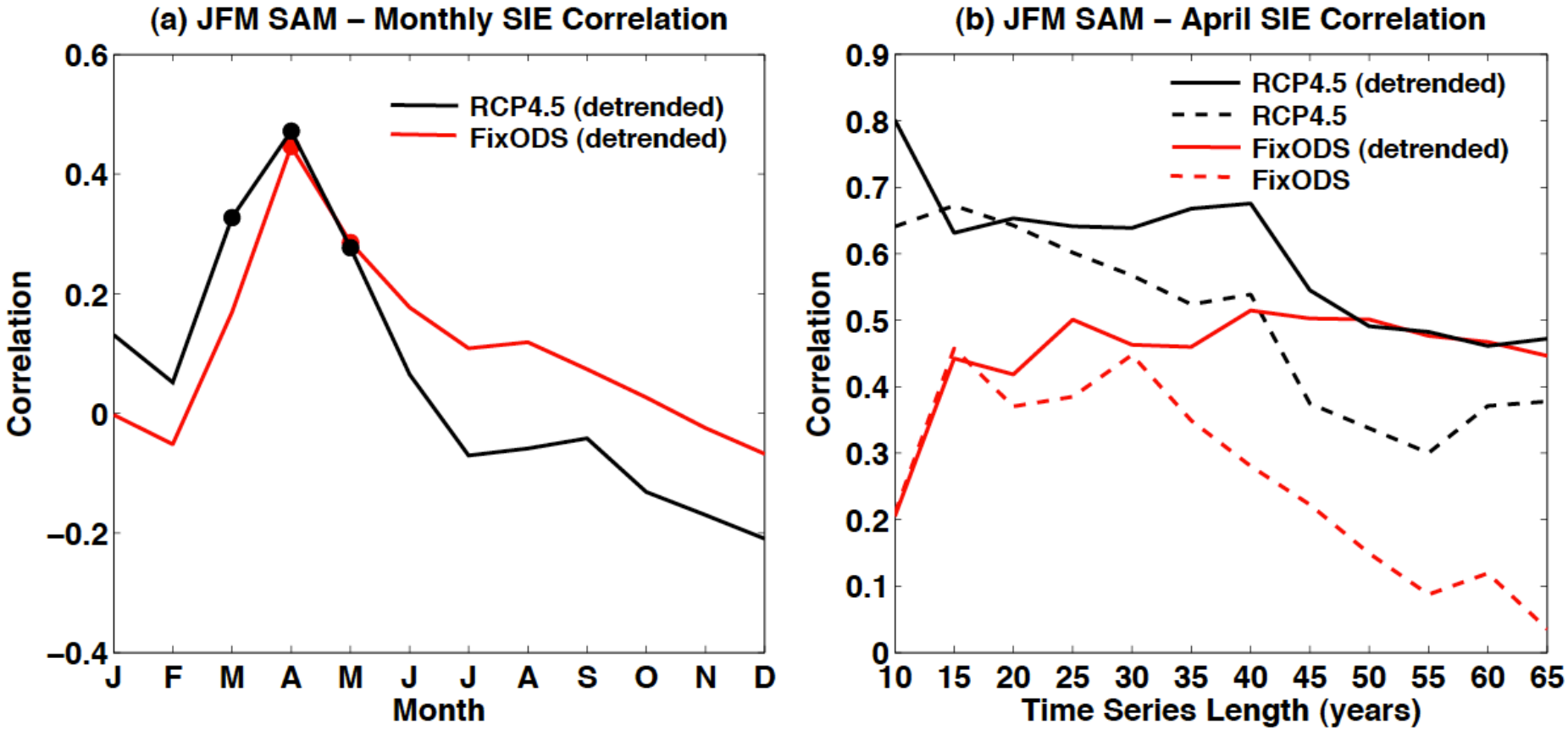


Turner et al. 2009

Bitz and Polvani (2012)



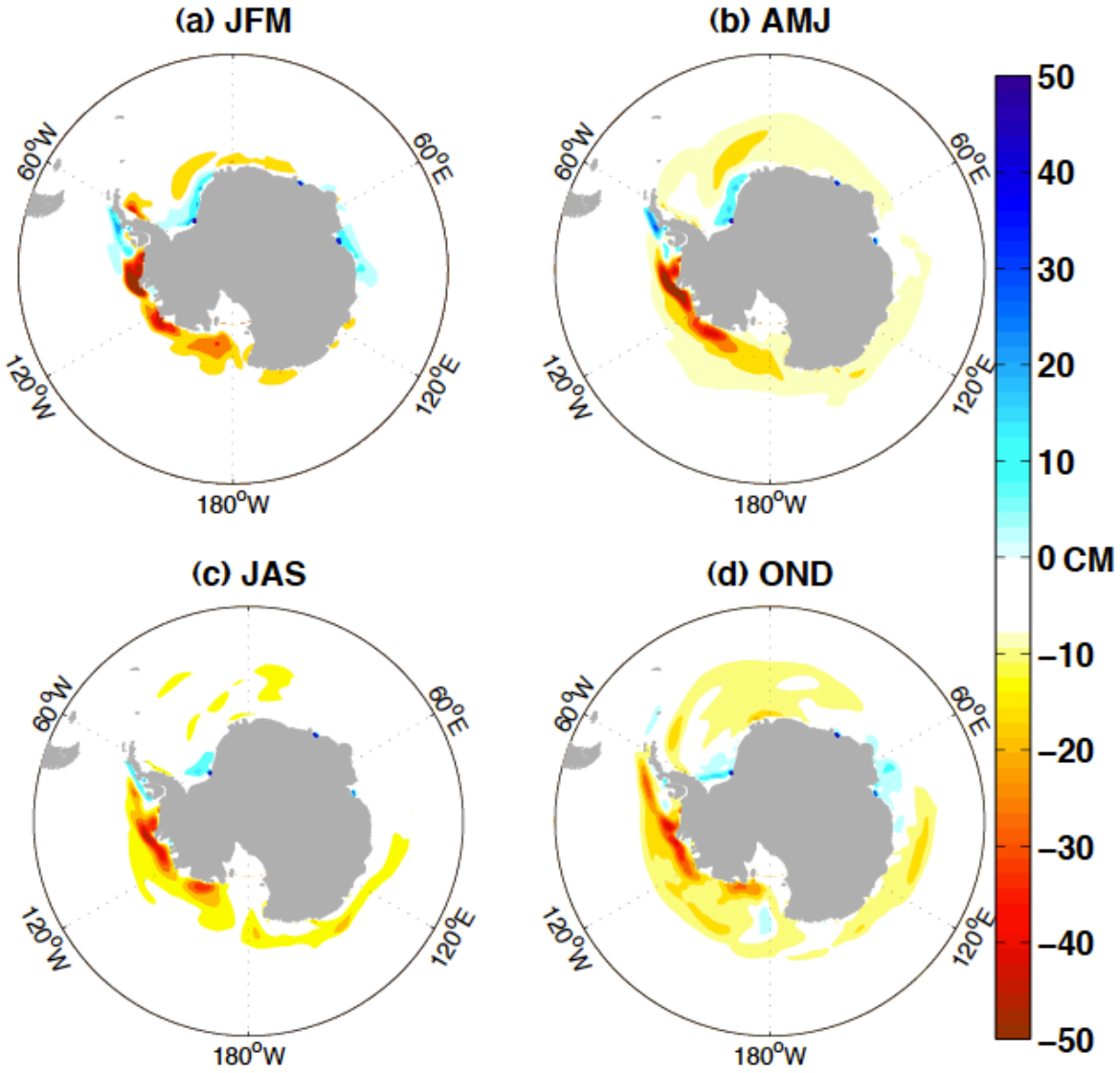
Antarctic Sea Ice Extent (SIE) and the SAM



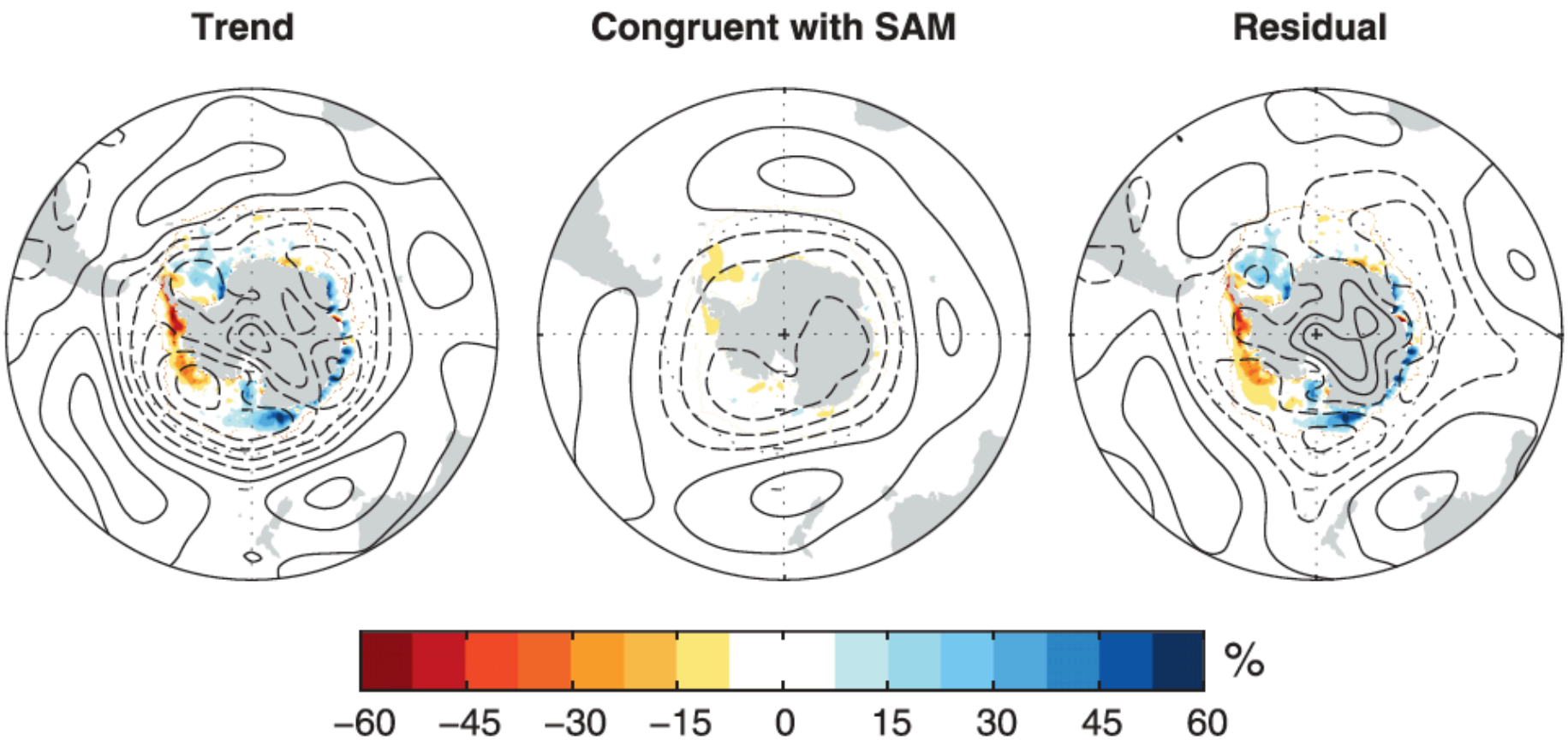
SAM-April SIE correlation as function of time series length.

Correlation between Summer SAM and April SIE breaks down as length of time series increases.

Sea Ice Thickness Response



Simpkins et al. 2012



Holland and Kwok 2012