



Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

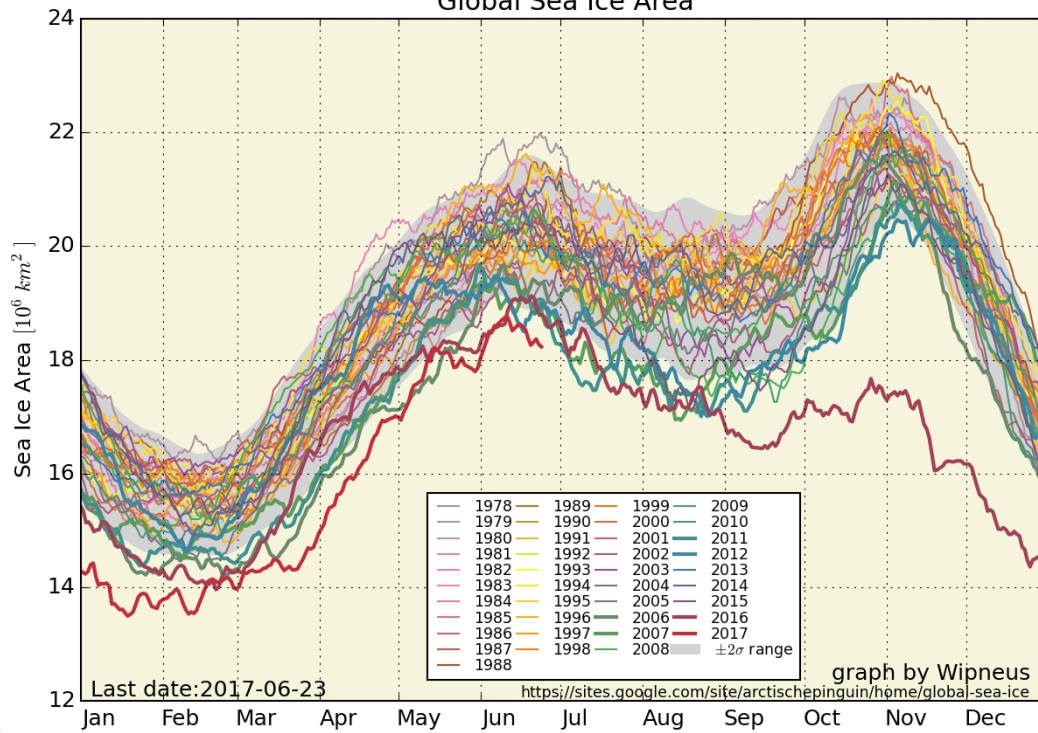
Canada

Recent trends in Antarctic sea ice

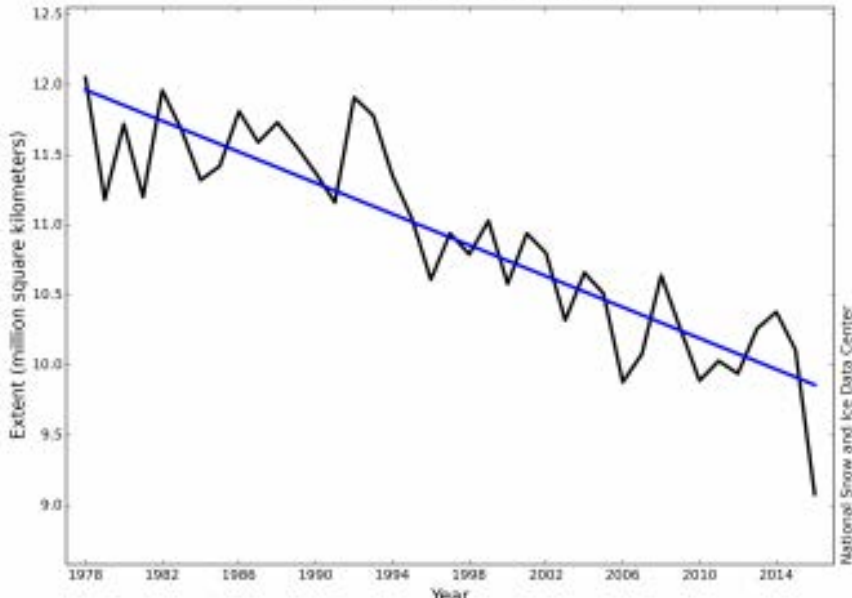


michael.sigmond@canada.ca

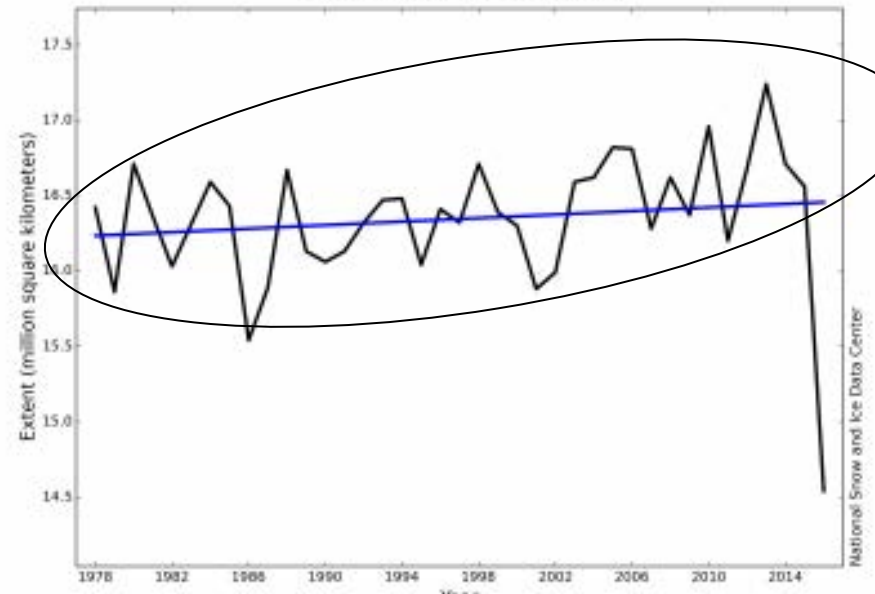
from NSIDC sea ice concentration data
Global Sea Ice Area



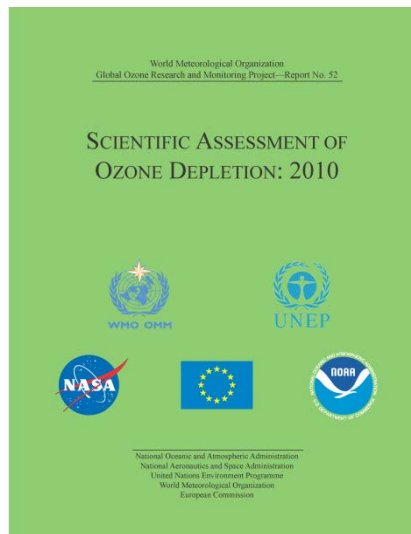
Average Monthly Arctic Sea Ice Extent
November 1978 - 2016



Average Monthly Antarctic Sea Ice Extent
November 1978 - 2016

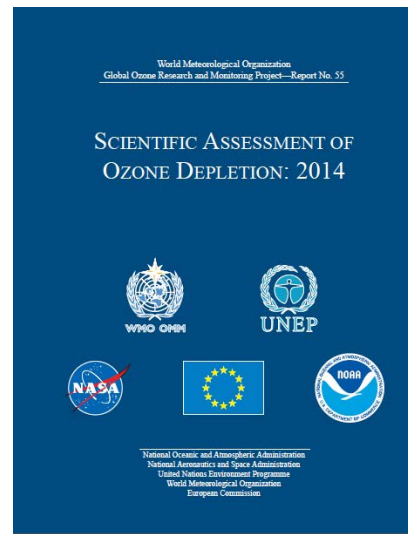


Is the ozone hole the driver of increased Antarctic sea ice?



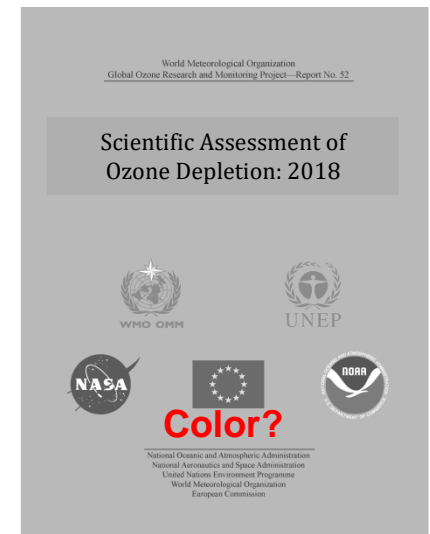
2010 Assessment

Yes



2014 Assessment

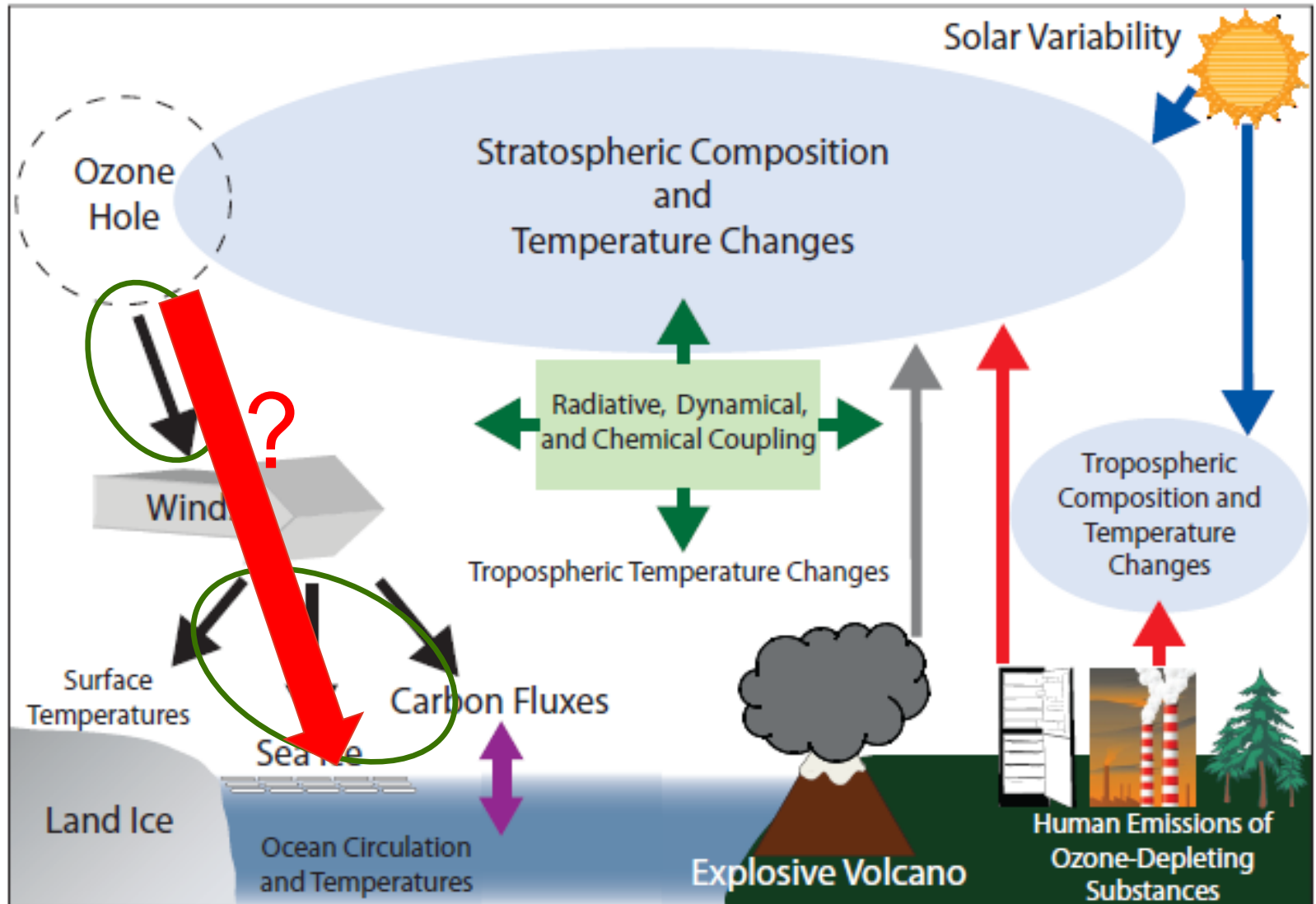
Probably not



2018 Assessment

It's complicated

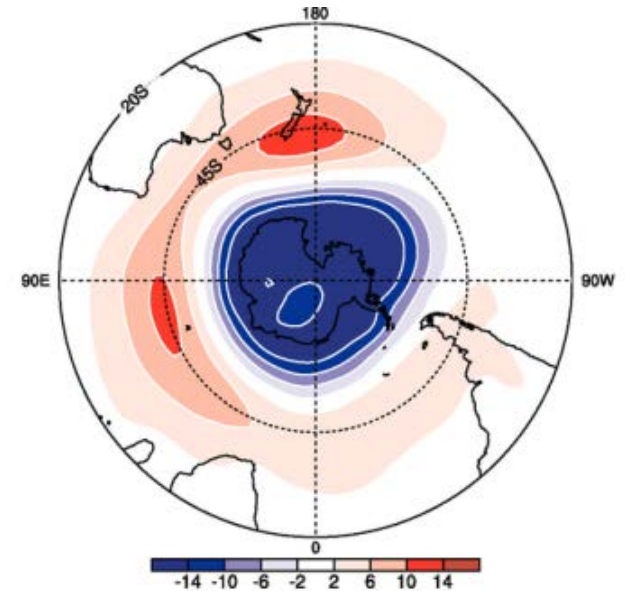
WMO 2010



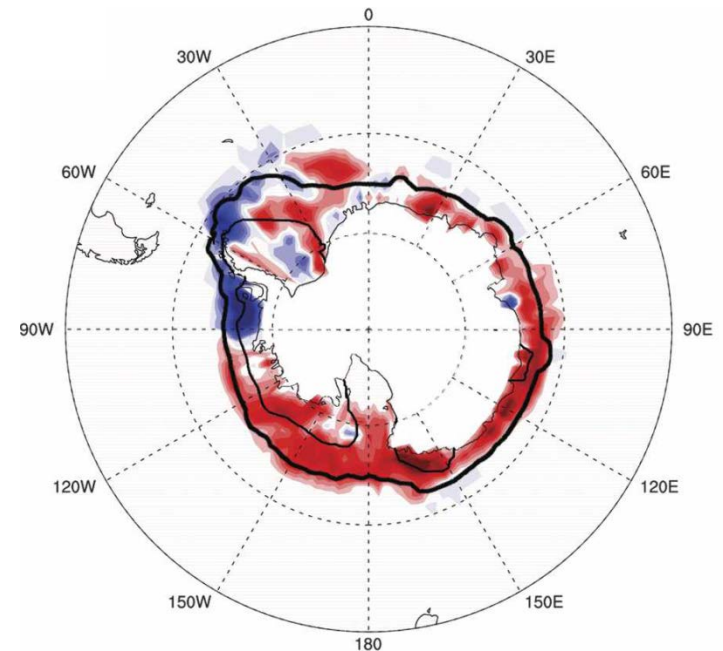
Southern Annular Mode

- Dominant mode of climate variability in the SH extratropics (first EOF of surface pressure south of 20S)
- Positive phase: poleward shift and strengthening of westerlies
- On month to month timescales, positive SAM associated with increased sea ice

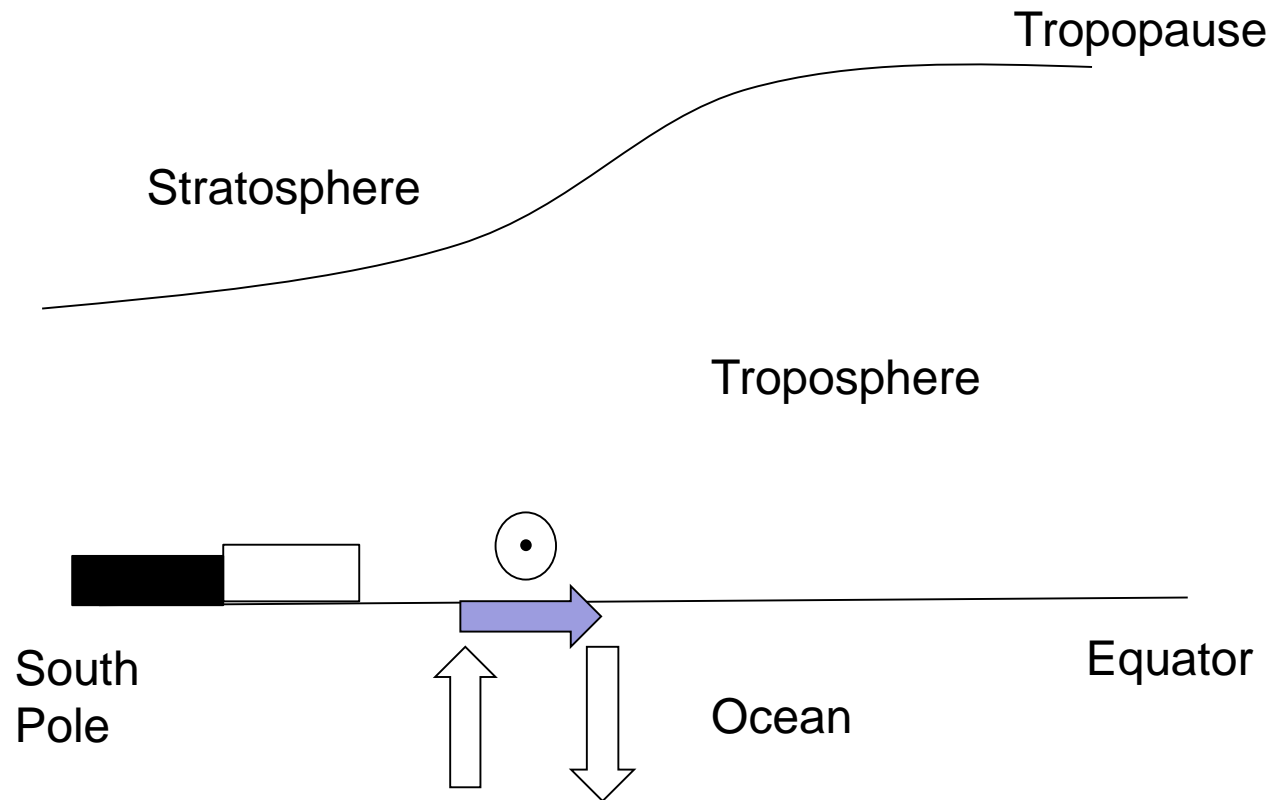
SAM pattern



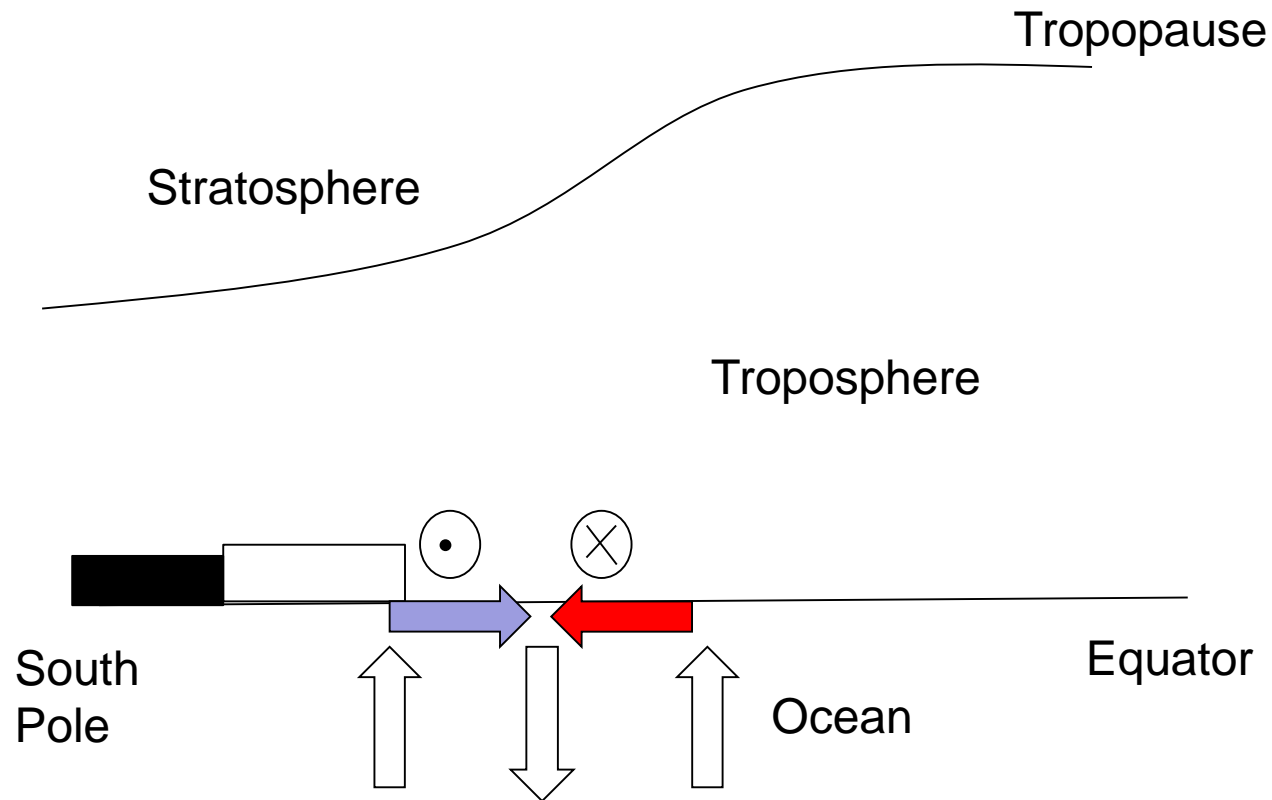
Co-variability sea ice with SAM



Average circulation

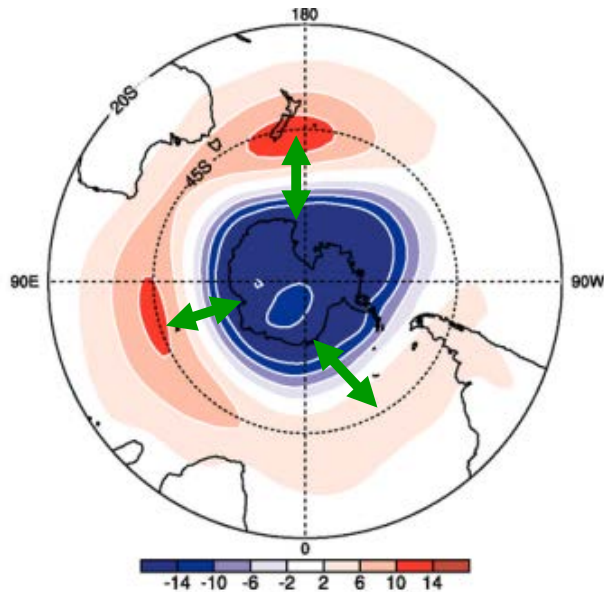


Positive SAM (anomalies)

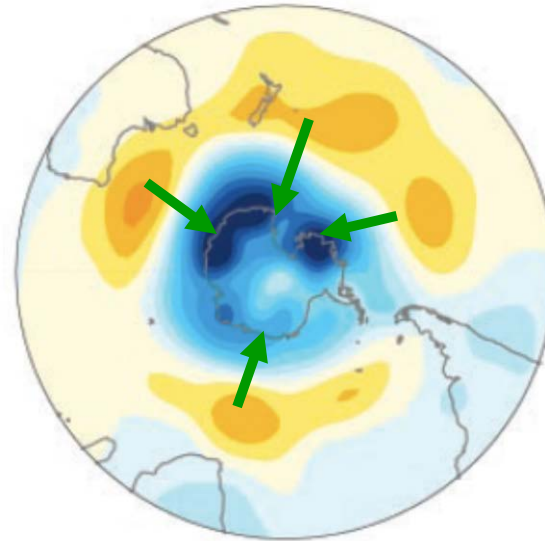


Long term trend (since 1979) towards positive SAM

SAM variability



Z500 trend since 1979



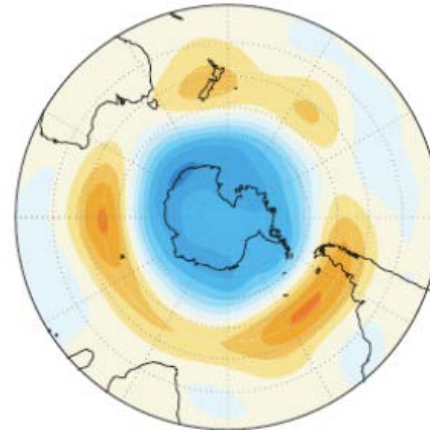
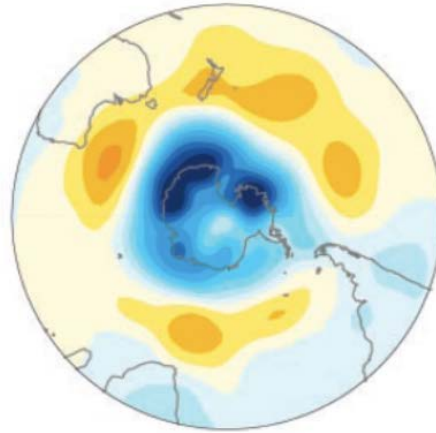
- Circulation trends bears strong similarity with positive SAM
- Long-term trend towards a positive SAM

SAM trend attributed to ozone hole

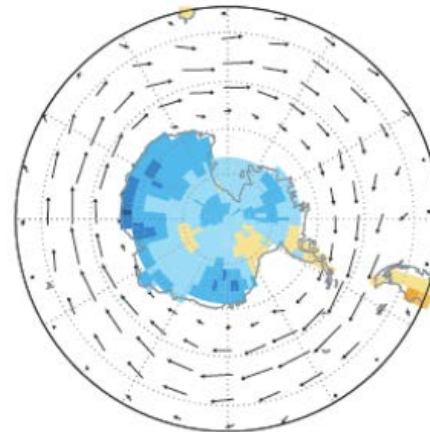
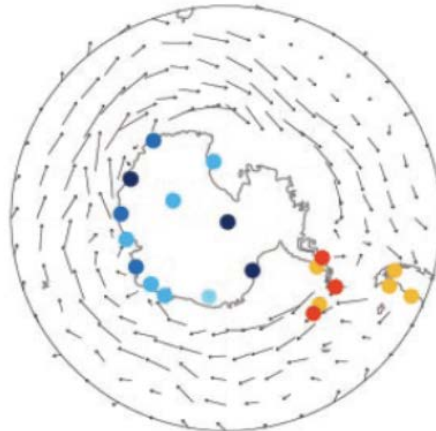
OBSERVED TREND

CLIMATE MODEL
(only O₃ forcing)

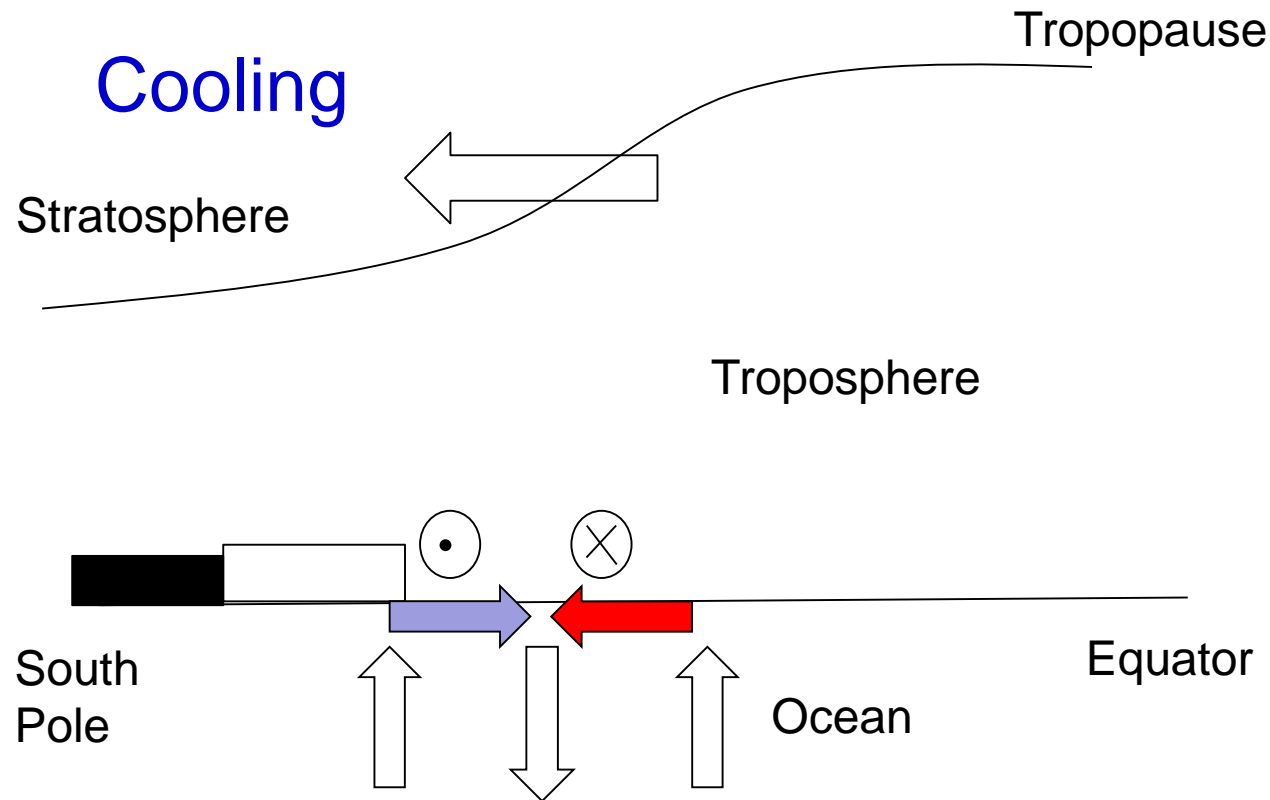
Circulation
(Z500)



Surface wind
and
temperatures



Positive ozone hole-induced SAM (trend)



Indirect evidence for ozone hole inducing Antarctic sea ice increase

- O₃ depletion → positive SAM
 - Positive correlation between SAM and sea ice (month-to-month)
- } → ozone hole increases sea ice

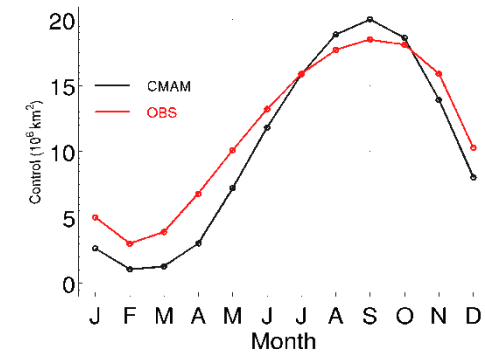
Other pieces of evidence (WMO 2010)

- Positive sea ice trend reproduced in ocean/sea ice model prescribed with observed wind&temperature (Goose et al 2009)
- Atmospheric circulation pattern trend that was thought to be responsible for regional sea ice trends, reproduced in atmosphere-only model simulation forced with observed ozone hole (Turner et al. 2009)
- WMO 2010 conclusion: Observed sea ice increase is related to ozone-induced atmospheric circulation trends (level of scientific understanding: 'Medium')
- However: no coupled atmosphere-ocean-sea ice simulations with ozone hole available to confirm this hypothesis

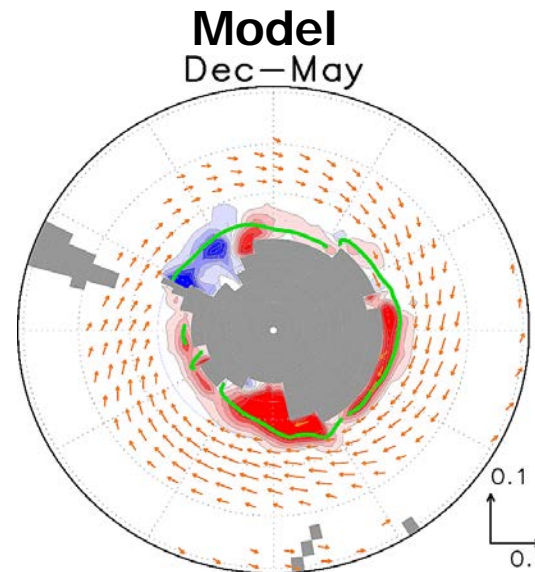
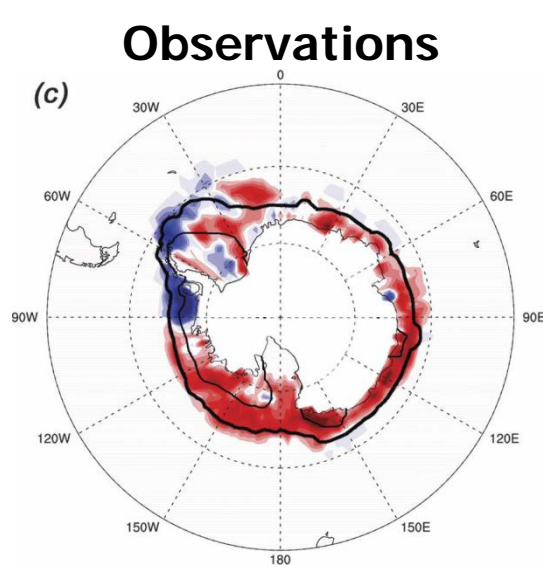
Coupled model simulations

- First model simulation employing a coupled atmosphere-ocean-sea ice model that directly simulates the sea-ice response to ozone depletion

climatology

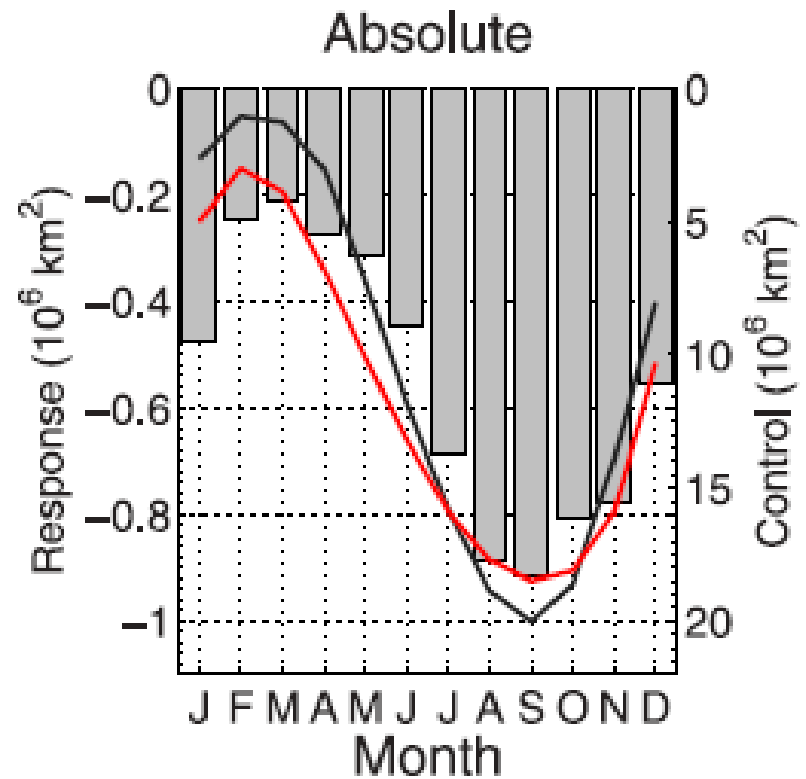
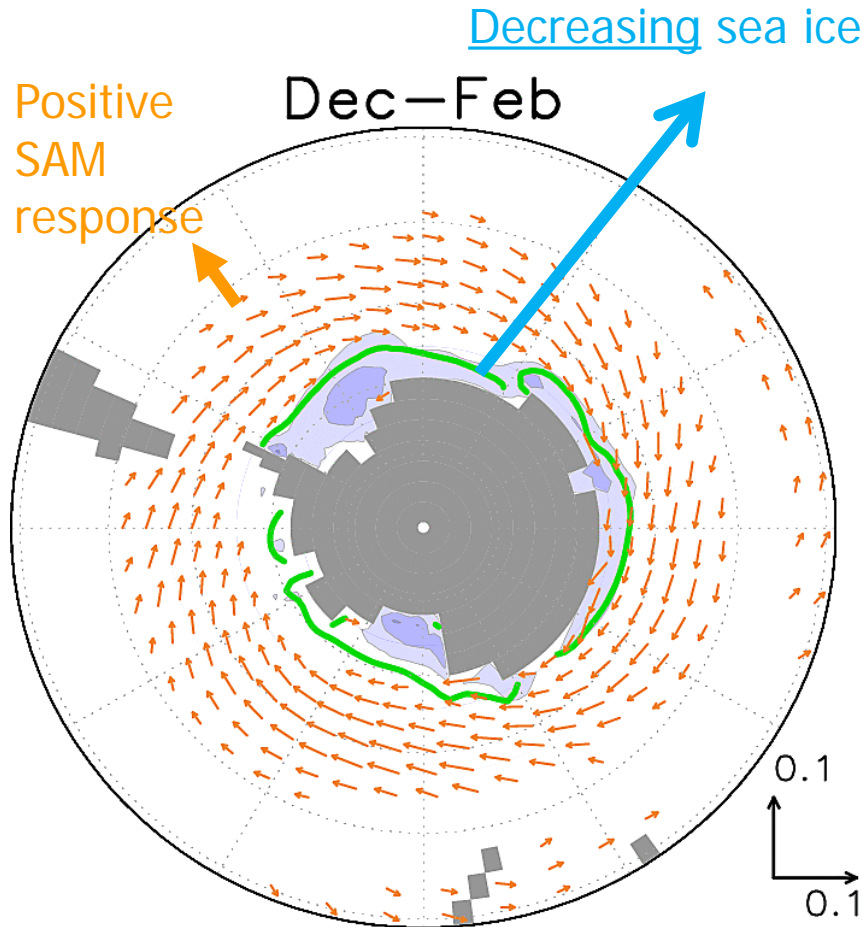


Co-variability SAM and sea ice



- positive correlation
- positive SAM response to ozone hole
- **increased sea-ice ?**

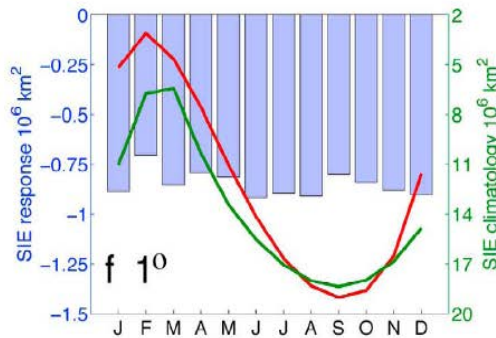
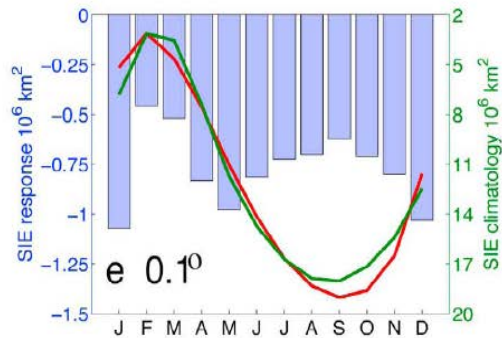
Sea ice decreases in response to ozone hole!



→ stratospheric ozone depletion has NOT contributed to the recent increase of Antarctic sea ice

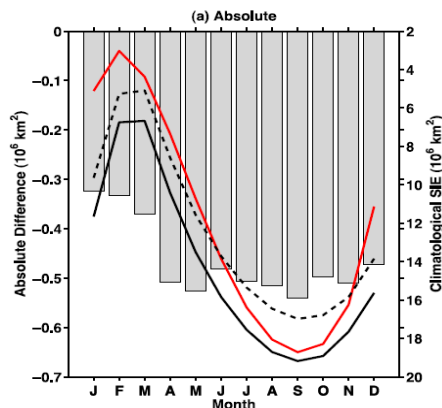
How robust is this response to ozone depletion?

Bitz and Polvani (2012)



[CCSM3.5, robust to ocean model resolution: eddy compensation occurs too far north to influence the results]

Smith et al (2012)

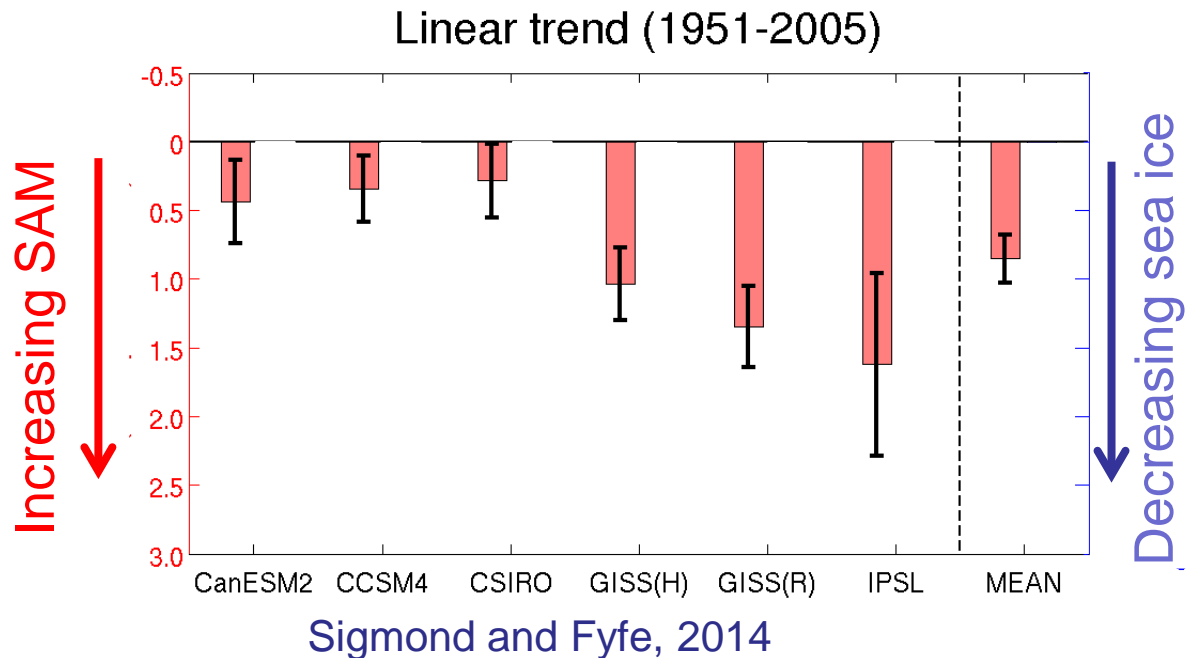


[WACCM4, transient simulations]

Robust in CMAM and 2 NCAR models. What can we learn from CMIP5 models?

CMIP5 'ozone only runs'

SAM and sea ice response in all CMIP5 models with 'ozone-only' runs



- All models show **positive SAM** response
- All models show **negative sea ice** response!

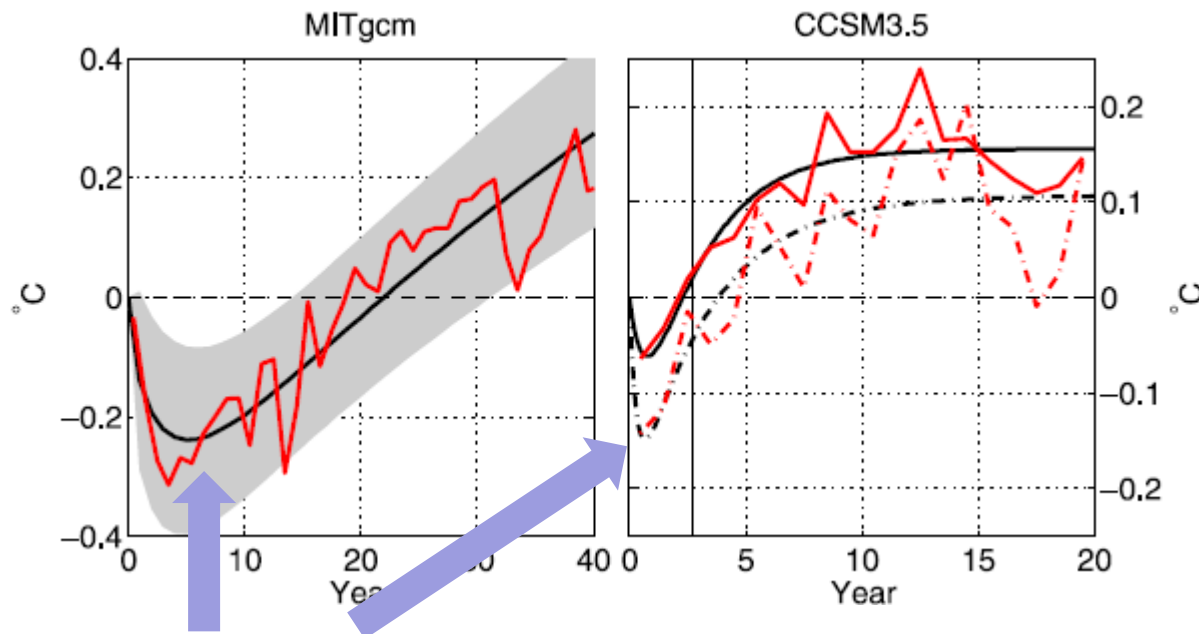
→ Confirm that stratospheric ozone depletion has NOT contributed to the recent increase of Antarctic sea ice

WMO 2014 conclusions

- In all modelling studies that have isolated the impact of stratospheric O₃ depletion, Antarctic sea ice declines in all seasons
- This suggest that ozone depletion has not contributed to the Antarctic sea ice increase
- However, confidence in the simulated response to ozone depletion is limited

Progress since WMO 2014

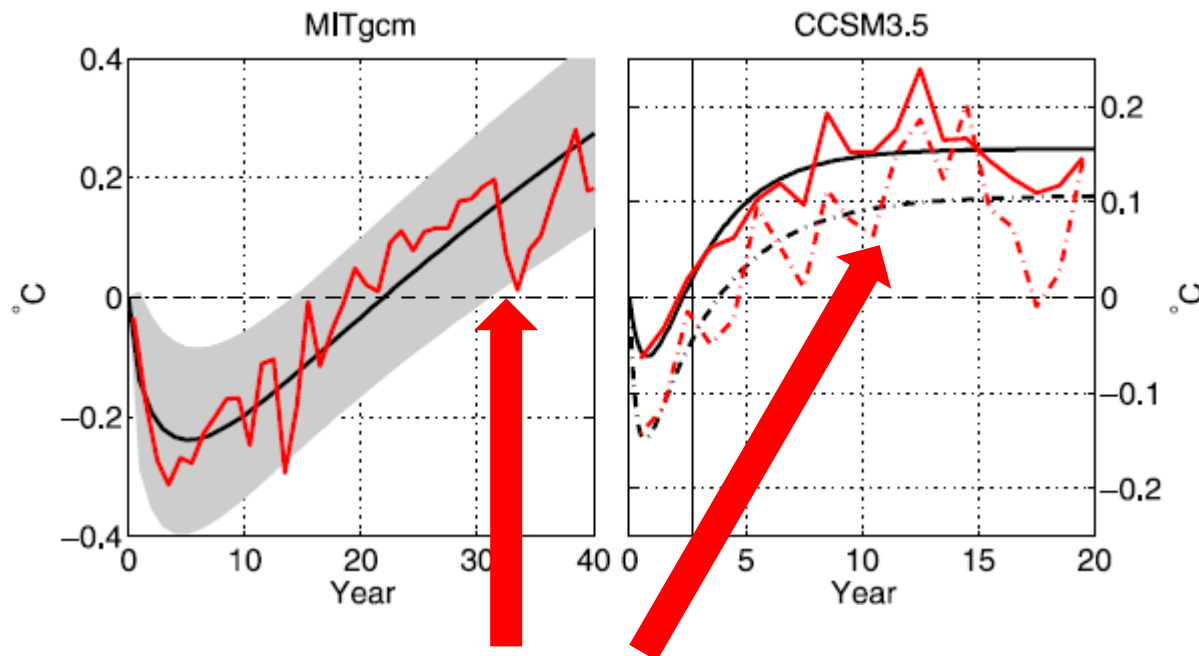
- A few studies reported on the time-varying ocean/sea ice response to an instantaneous ozone hole forcing
- Identified a two-time scale behaviour



Initial cooling, consistent with positive sea ice response to SAM (month-to-month)

Progress since WMO 2014

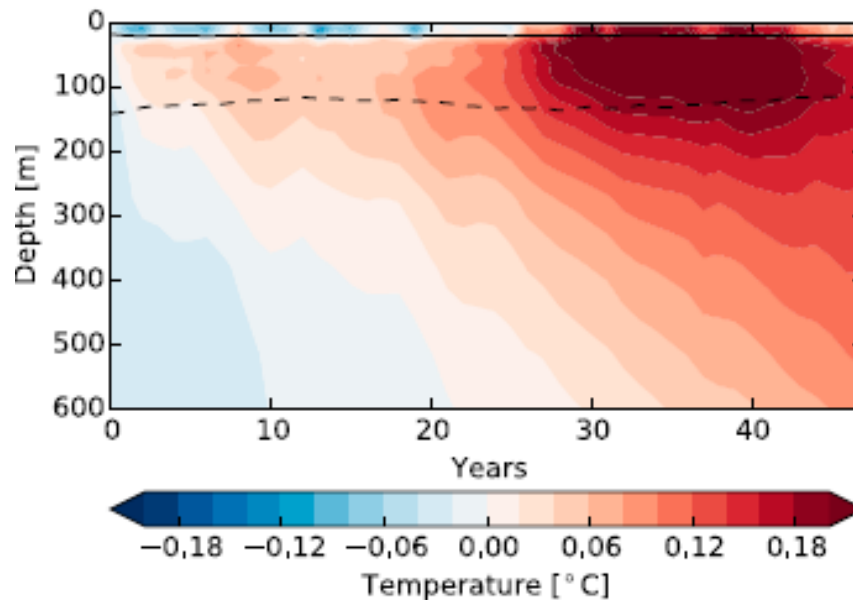
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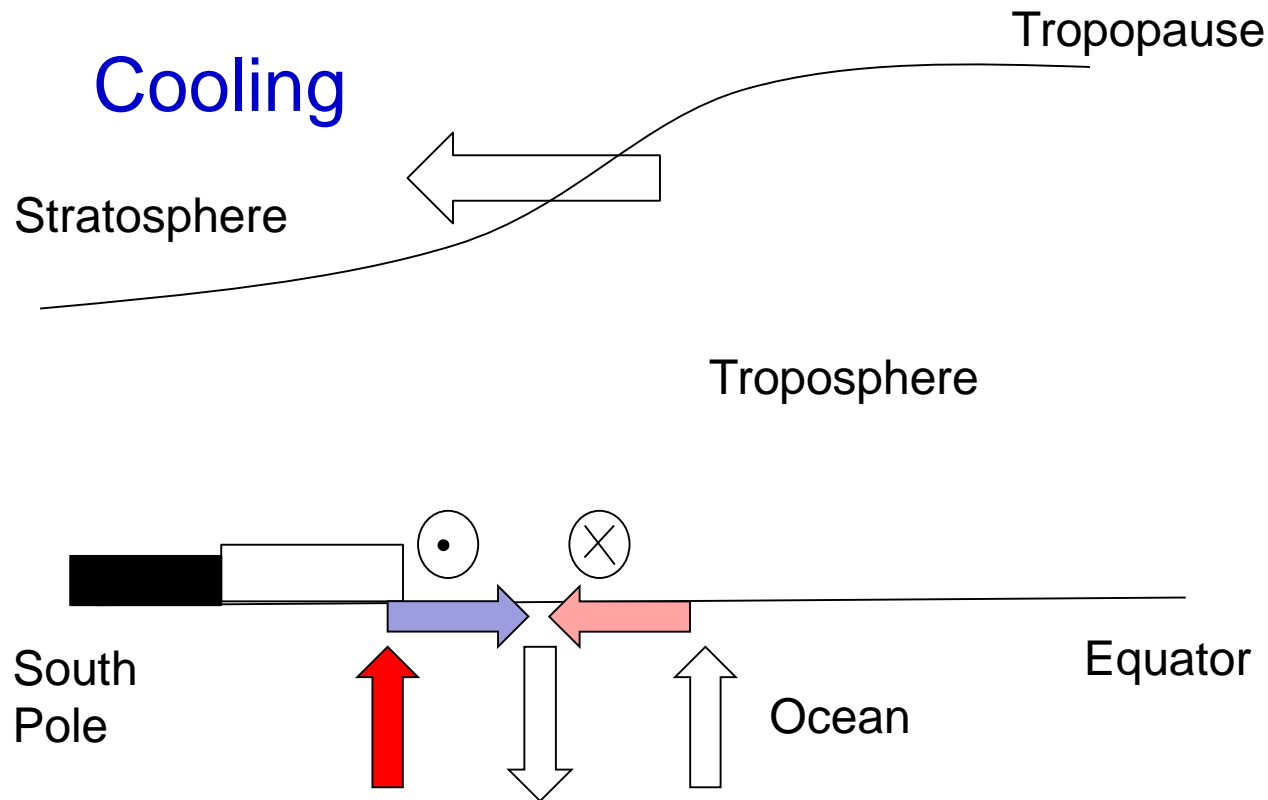
Transitions to warming,
consistent with sea ice
decrease on longer
timescales

Progress since WMO 2014

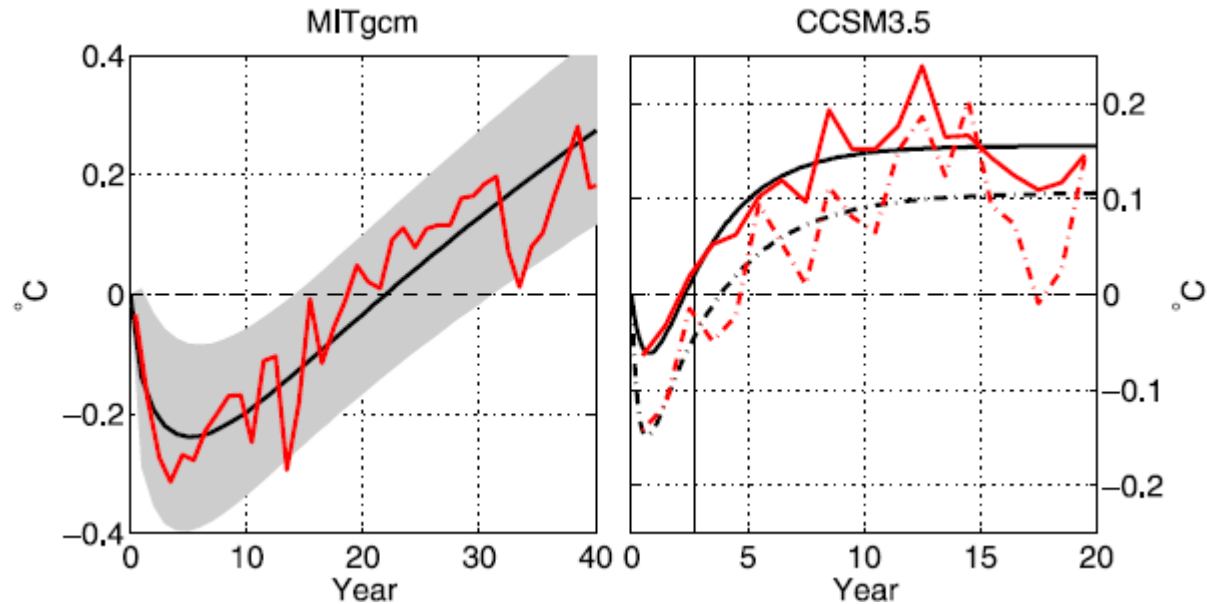
- On short time-scales, ocean cooling consistent with wind-induced northward Ekman transport
- On longer timescales warming due to transport from intermediate depths



Positive ozone hole-induced SAM (trend)



Progress since WMO 2014



- Two-timescale behaviour reconciles 'WMO 2010' and 'WMO 2014' conclusions
- 'ozone depletion could drive a transient expansion of sea ice'
- However, influence of the real (time varying) ozone depletion on the sea ice extent will critically depend on the time scale of the transition from cooling to warming, which is very uncertain

WMO 2018 key bullets (first draft)

- Significant progress regarding the understanding of processes involved in the response of Antarctic sea ice to (abrupt) ozone depletion, which is now believed to entail a fast and slow timescale
- However, uncertainty remains regarding the impact of the more realistic time-evolving ozone hole on Antarctic sea ice
- An important aspect is the ocean mean state, which appears to be biased in many models

Other potential sources of Antarctic sea ice increase:

1. Multi-decadal internal variability (more sea ice in mid 1960s than today)
2. Freshening upper ocean due to ice sheet melt (conflicting evidence)
3. Teleconnections (atmospheric Rossby waves) excited in the tropical Pacific

1: Gagne et al, 2014, Geophys. Res. Lett.

2: Bintanja et al. 2013 Nat. Geosc, Swart and Fyfe, 2013, Geophys. Res. Lett.

3: Purch et al 2016, J. Clim., Meehl et al. 2016, Nat. Geosc.

Conclusions

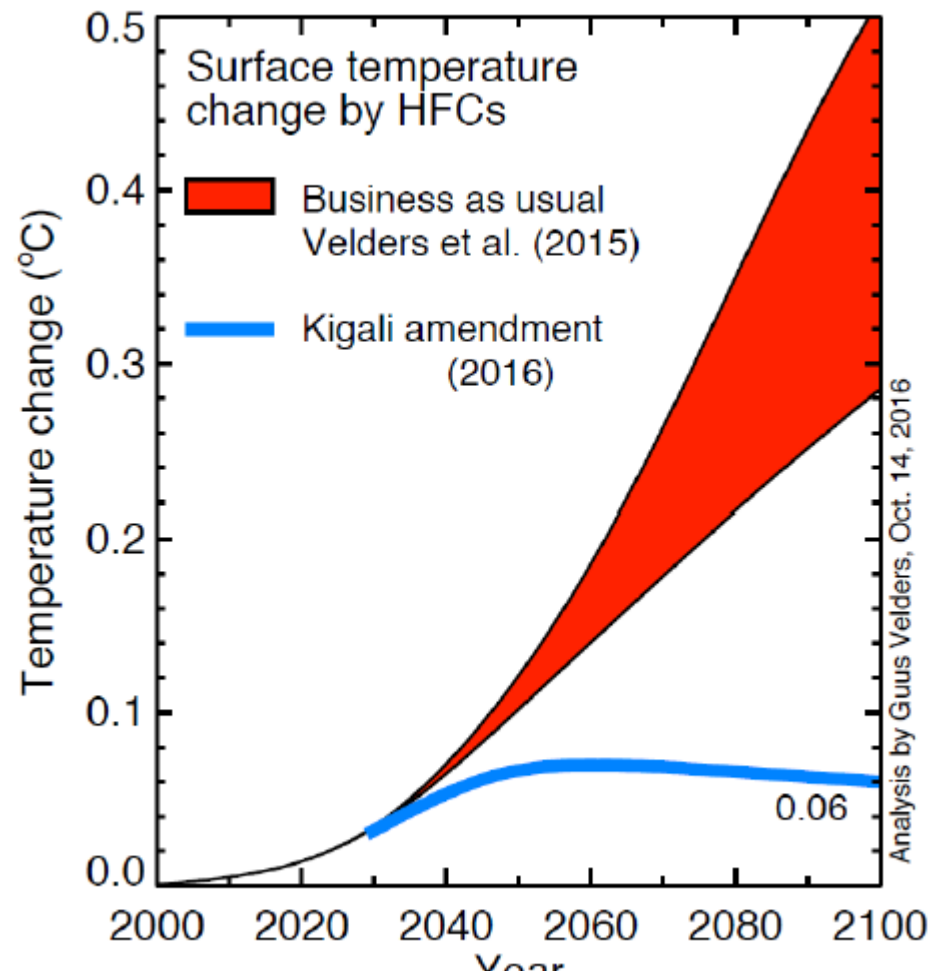
- WMO 2010 was too quick to conclude that Antarctic sea ice increase is due to ozone-induced circulation trends
- Most state-of-the-art coupled climate models indicate that ozone depletion is not responsible for the trends
- But caution is needed as we know models have biases
- Many open questions → potential to make substantial contributions to a high-profile research question!



Ozone hole and global temperature targets

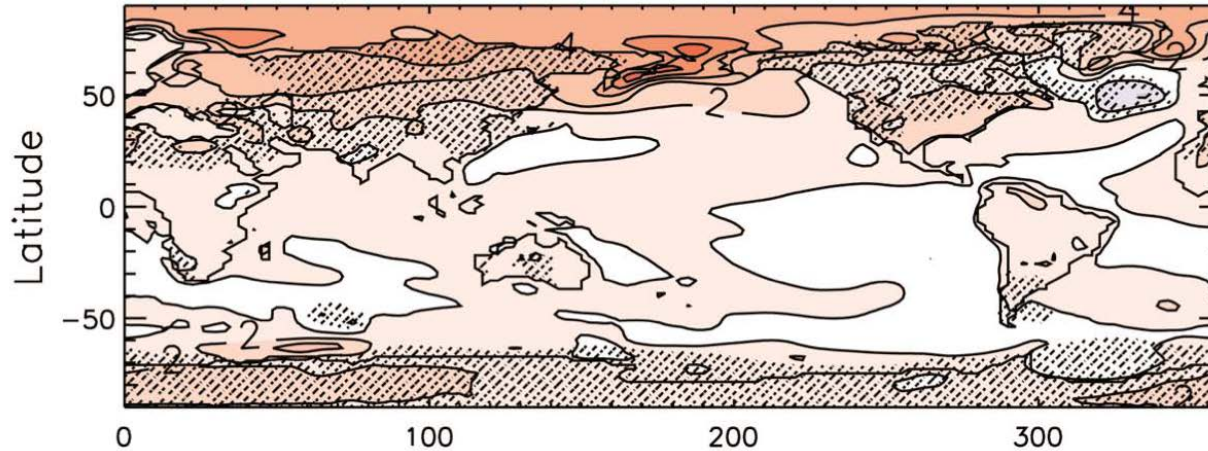
Kigali Amendment

- Amendment to phase-down HFCs under the Montreal Protocol
- Expected to help avoid up to 0.5 C of global mean temperature rise
- Adopted on October 15, 2016

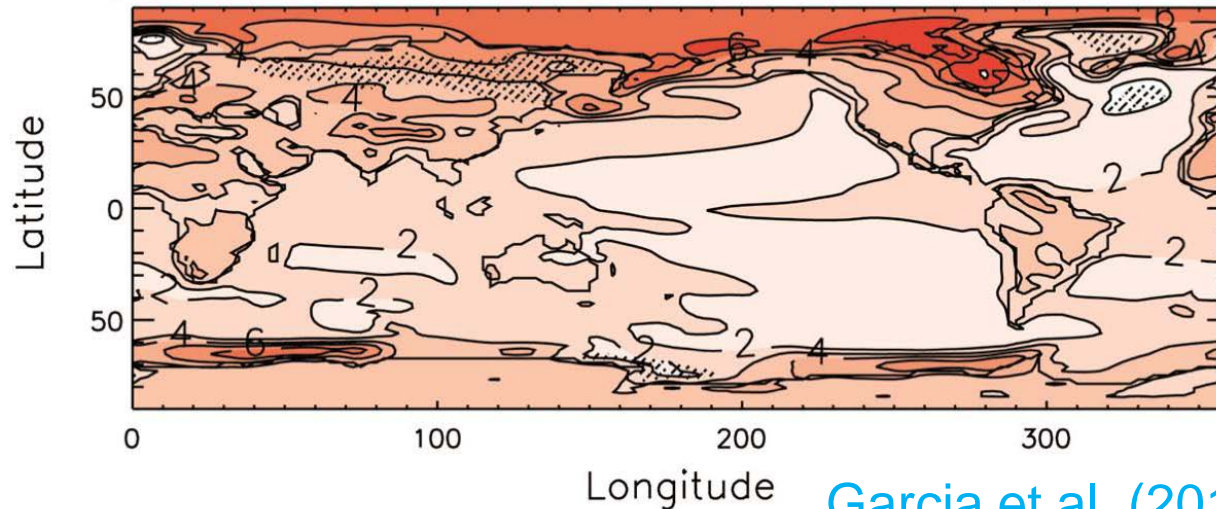


World avoided (WMO 2014)

(a) CONTROL: ΔTS (2060-2070) – (1990-2000)



(b) WORLD AVOIDED: ΔTS (2060-2070) – (1990-2000)



Garcia et al. (2012)