

# The ozone hole, the Southern Ocean and Antarctic sea ice trends



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Thanks: Greg Flato, Bill Merryfield, Marc D'Orgeville

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# Introduction

## Previous talks:

- Stratospheric ozone trends induce trends in SH tropospheric wind patterns (in particular in austral summer)

## This talk:

- What is the effect of an interactive ocean on these ozone-induced wind trends?

Sigmond, Fyfe and Scinocca, May 2010, GRL

- What is the influence of ozone-induced wind trends on Antarctic sea ice?

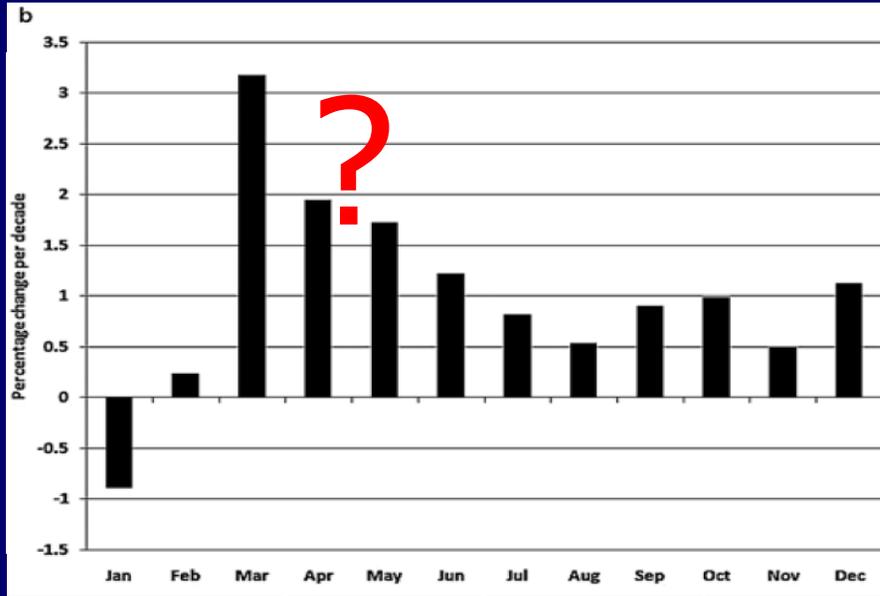
Sigmond and Fyfe, Sept. 2010, GRL



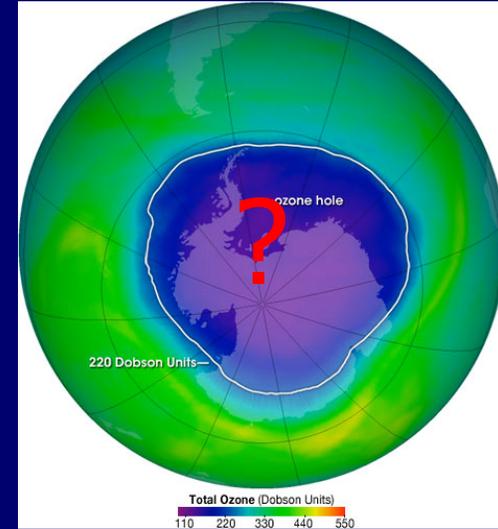
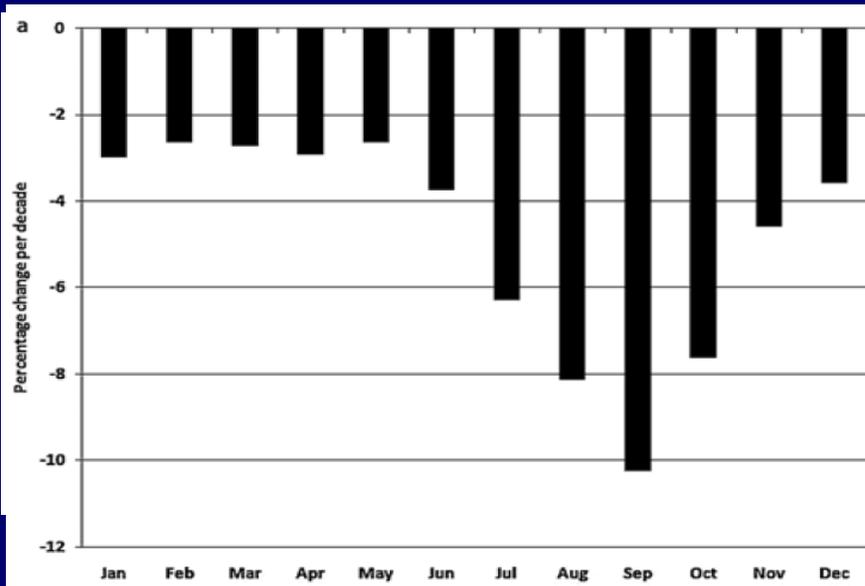
Nordenskjöld Coast in the Weddell Sea, Courtesy of Konrad Steffen (CIRES/U of Boulder)

# Sea Ice trends

SH



NH



Turner et al. (2009)

## Previous studies:

- Conclusions generally obtained *indirectly* by:
  - simulation of atmospheric circulation response to ozone depletion  
(poleward shift and strengthened tropospheric westerlies, or positive SAM)
  
  - correlating month-to-month variations of atmospheric circulation and sea ice extent  
(positive correlation between SAM and SIE)
  
  - Inferring the influence of ozone hole on sea ice trends  
(Ozone hole induces positive SIE)

## Has the ozone hole contributed to increased Antarctic sea ice?

- In contrast to previous studies we employ *coupled atmosphere-ocean-sea ice model* that *directly* simulates the sea-ice response to ozone depletion

# Model and Experiments:

## Model:

CMAM with an interactive ocean and sea ice model

## Atmosphere:

2.8° (lon) x 2.8° (lat), 71 vertical levels up to ~100 km

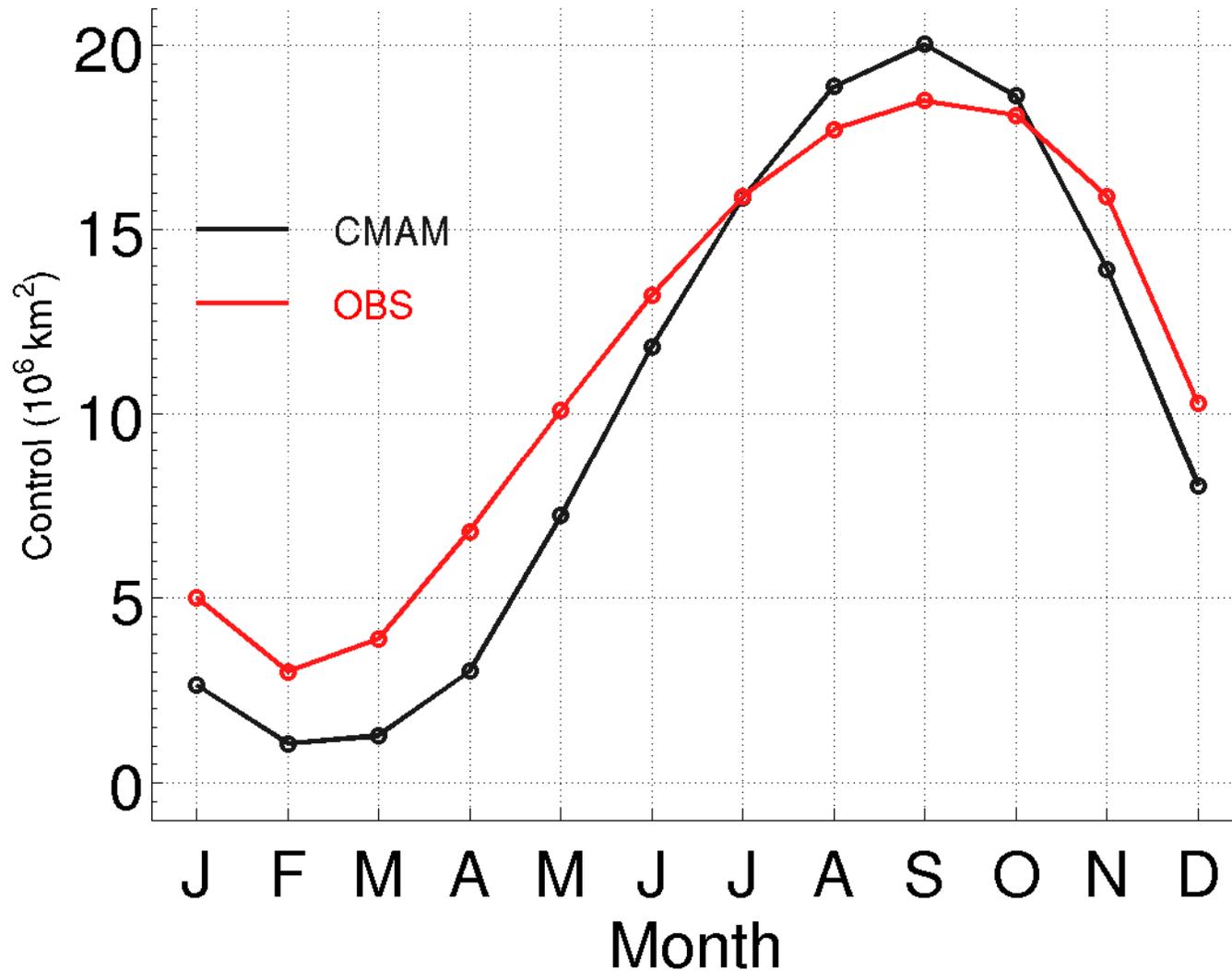
## Ocean & sea ice:

- modified version of NCOM1.3, 40 levels, 1.41° (lon) x 0.94° (lat)
- dynamical + thermodynamical sea ice components

## Experiments:

- Force with 'observed' zonal-mean ozone hole ([Randel and Wu, 2007](#))
- 80 year 'Time-slice' experiments (control + (3) ozone hole runs)

# Model validation: climatology

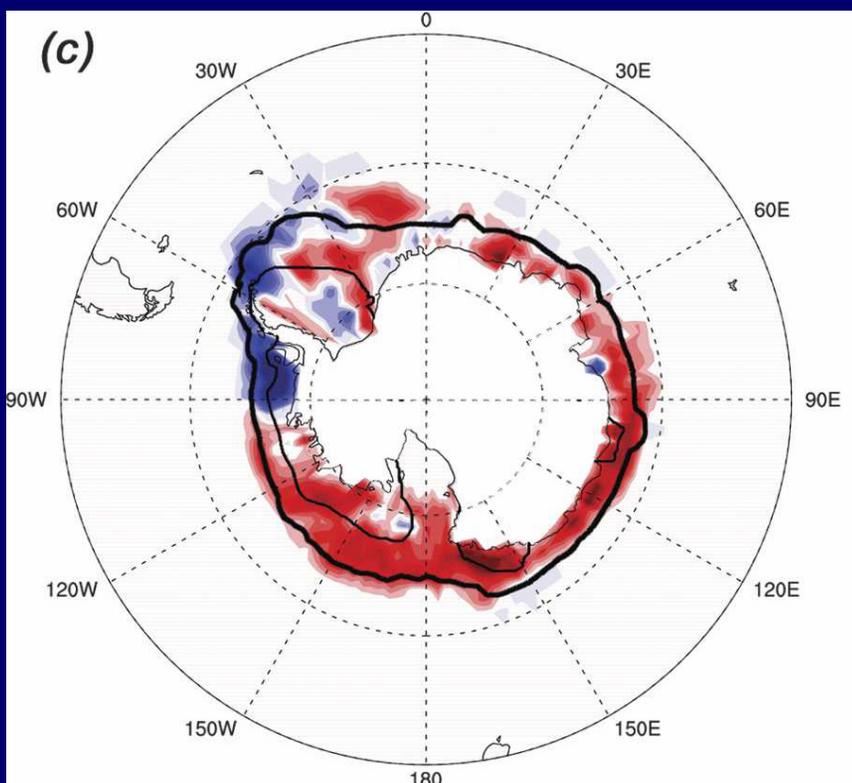


OBS: Cavalieri and Parkinson (2008)

# Model validation: SAM-sea ice covariability

## Influence SAM on Sea-ice

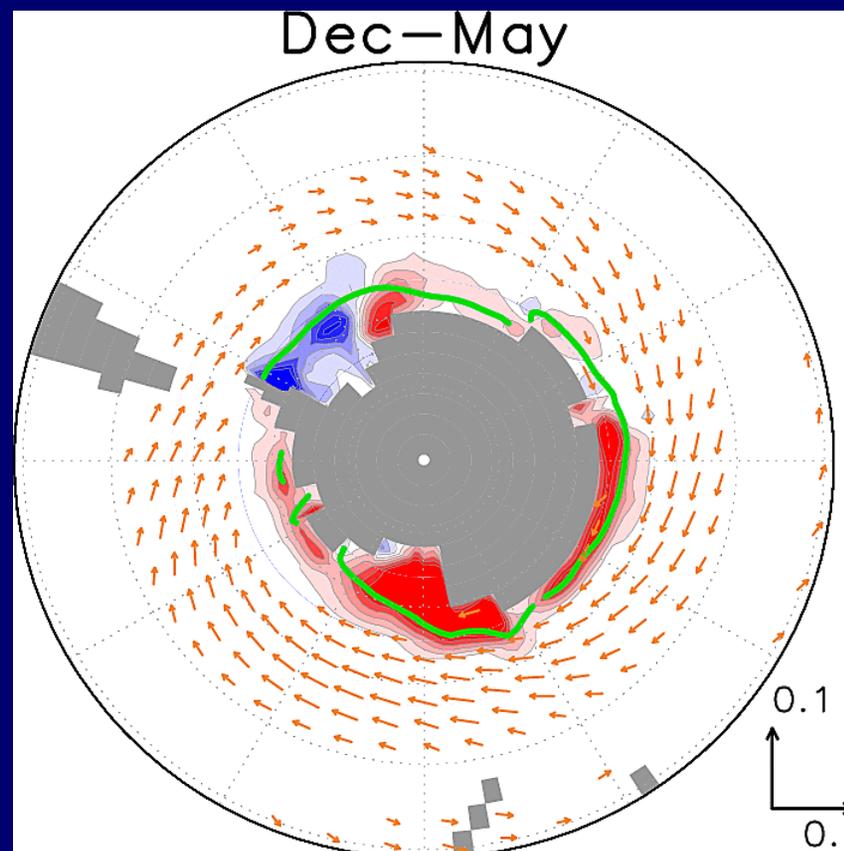
Observations (Jan-Apr)



Sen Gupta and England (2006)

Model

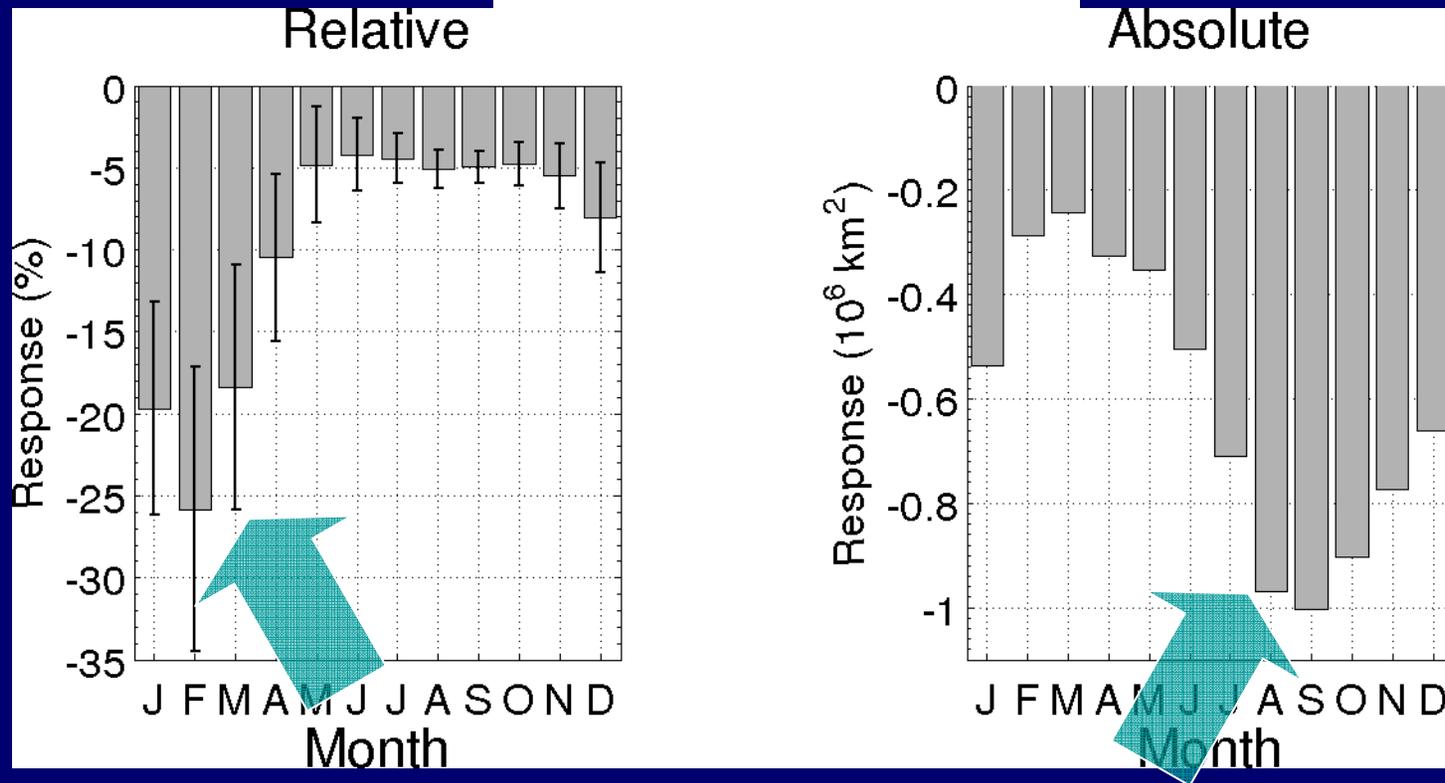
Dec-May



- Positive correlation between SAM and total SIE (Jan-Apr)  
(ozone induced positive SAM → increased SIE ??)

# Response to ozone hole:

## Antarctic SIE response



Sigmond and Fyfe,  
2010, GRL

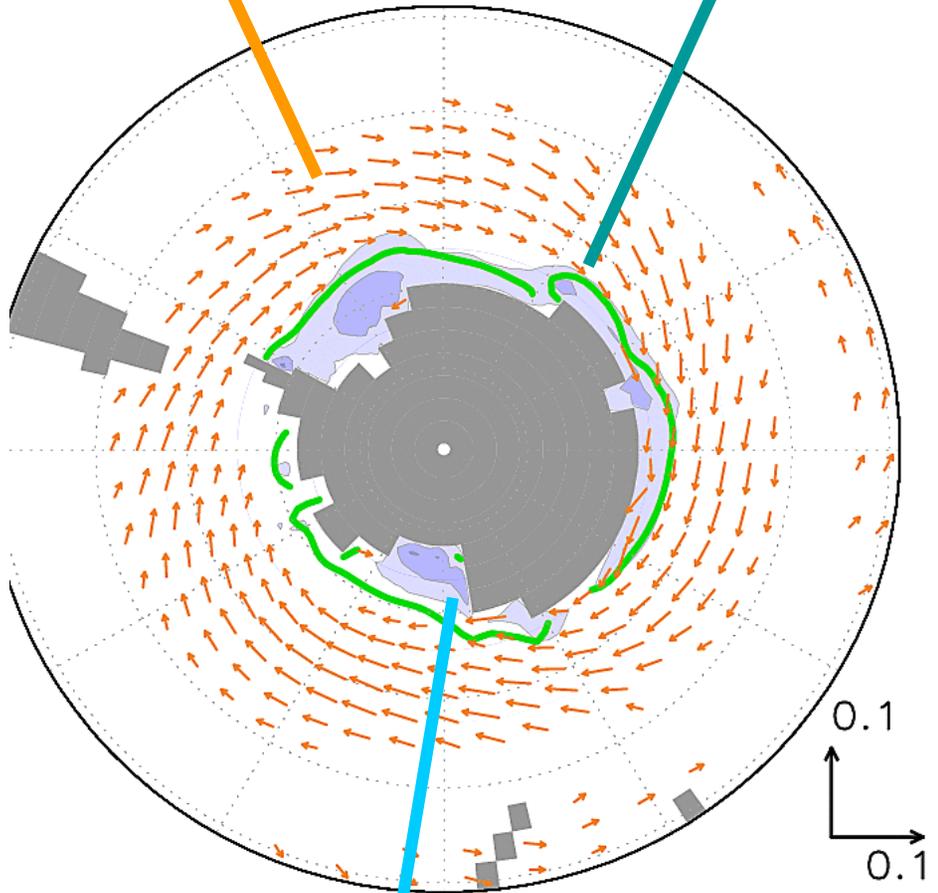
- Annual mean:  $\sim -2.3\%$  per decade

→ Ozone hole has not contributed to observed positive trend!

Maximum  
wind  
response

Minimum  
climatological  
sea ice

Dec-Feb



Maximum sea ice response  
near continent

Maximum wind response

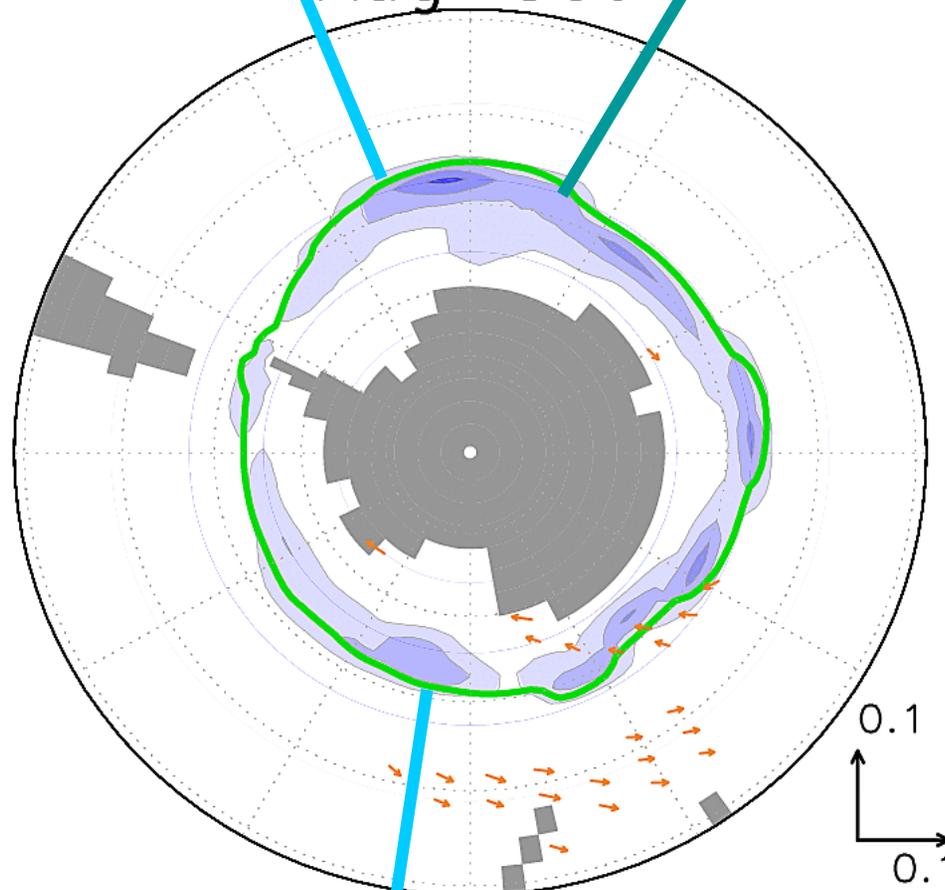
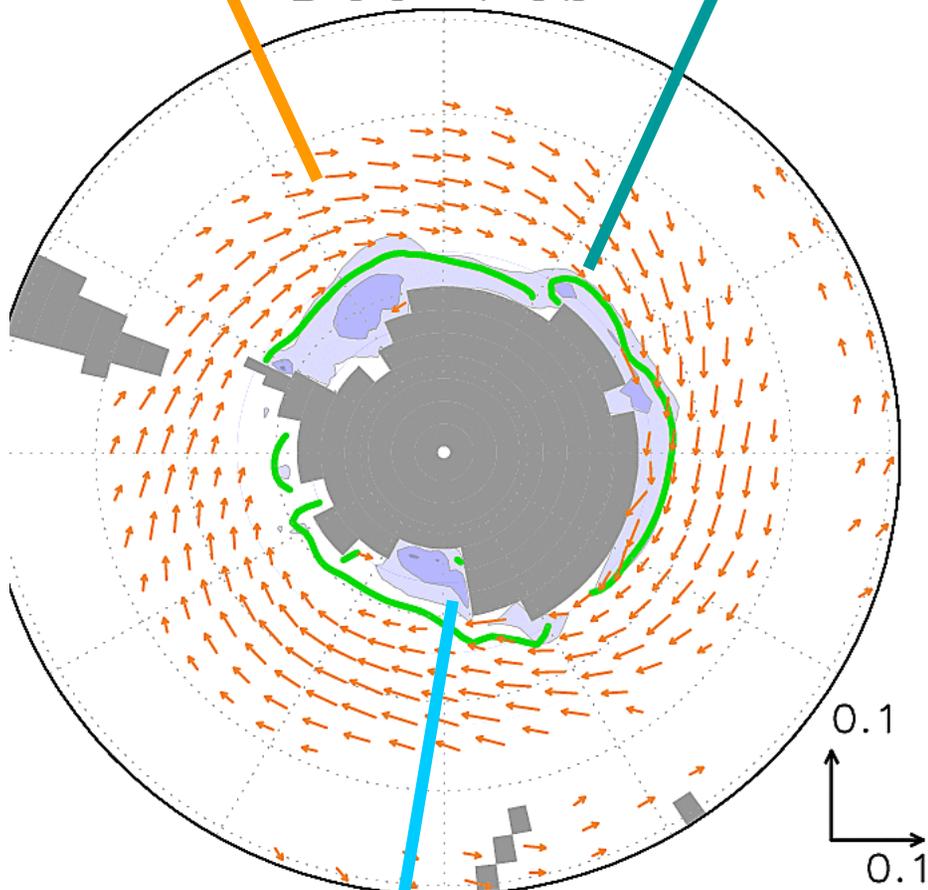
Minimum climatological sea ice

Maximum absolute sea ice response

Maximum climatological sea ice

Dec–Feb

Aug–Oct

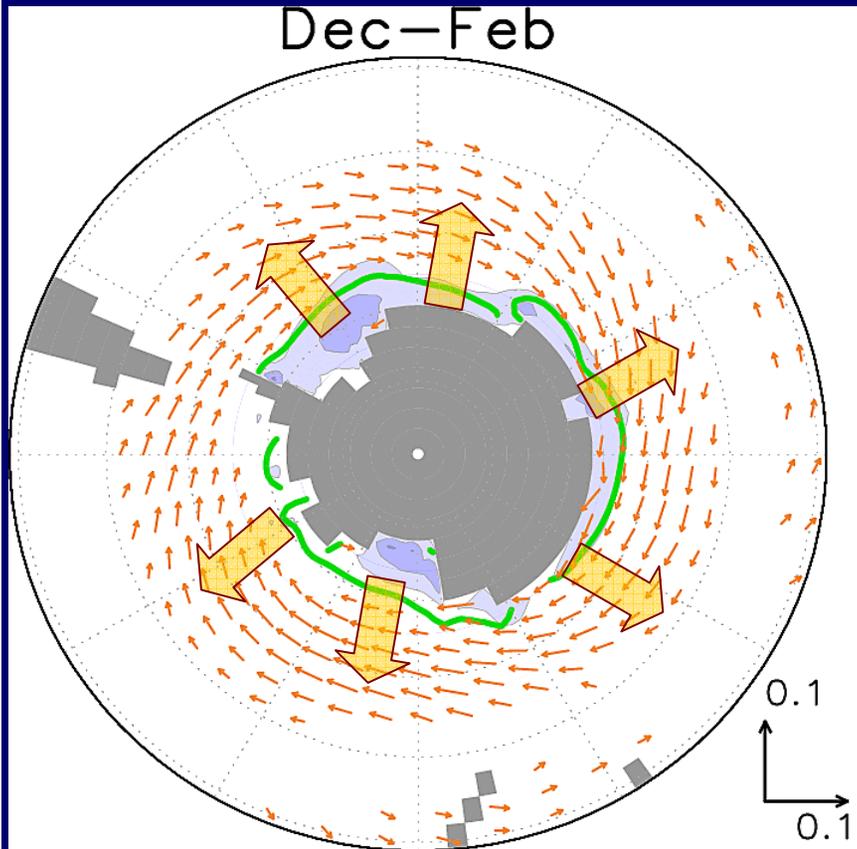


Maximum sea ice response near continent

Maximum sea ice response near sea ice edge

# Mechanism DEC-FEB response?

(Saenko et al. 2002, Fyfe et al. 2007, Spence et al. 2010)



Poleward shift of wind

equatorward Ekman ice transport

Enhanced regrowth of new sea ice, which is thinner

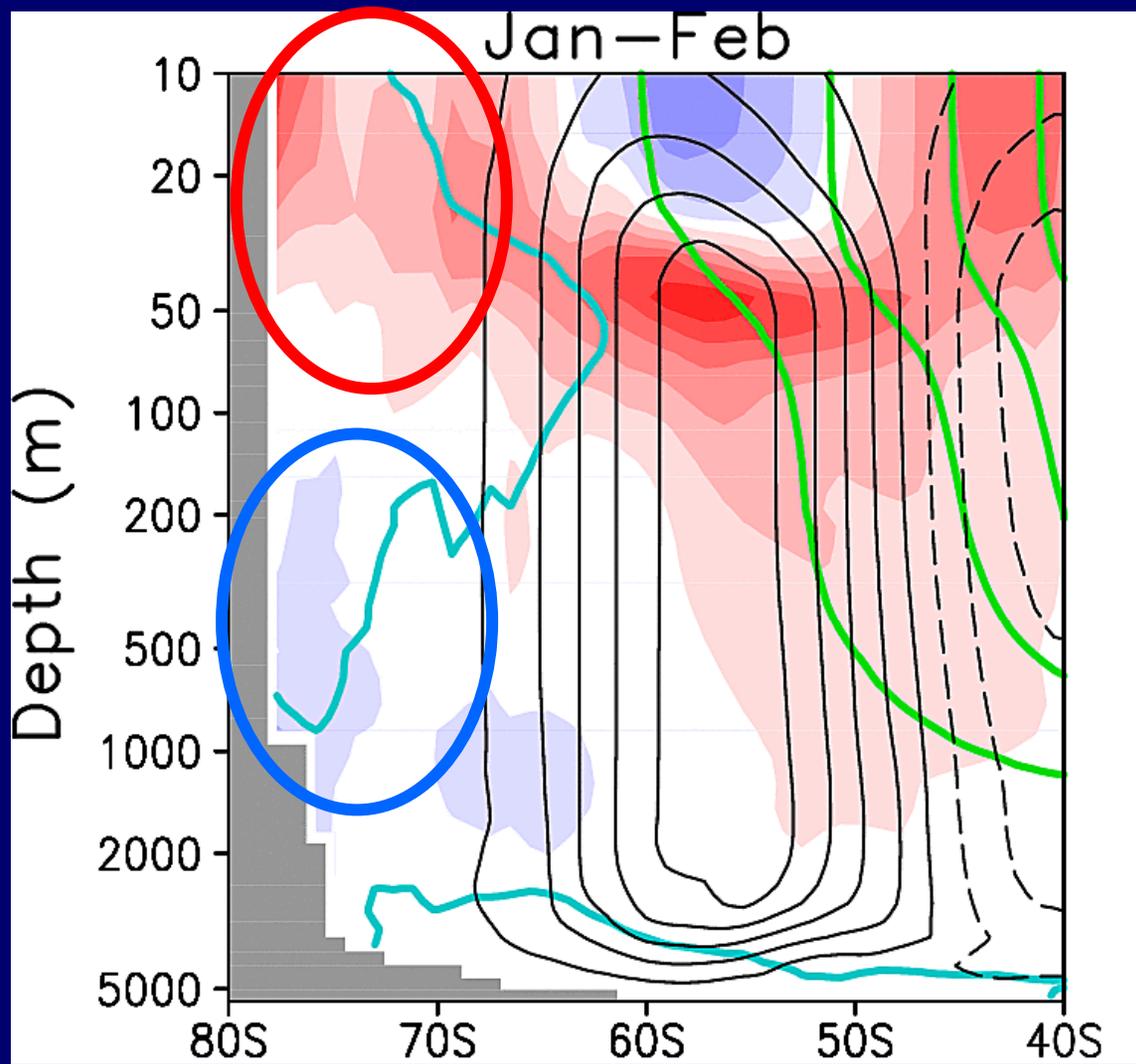
~ less ice near continent, decreased SIE

Brine rejection and heat loss

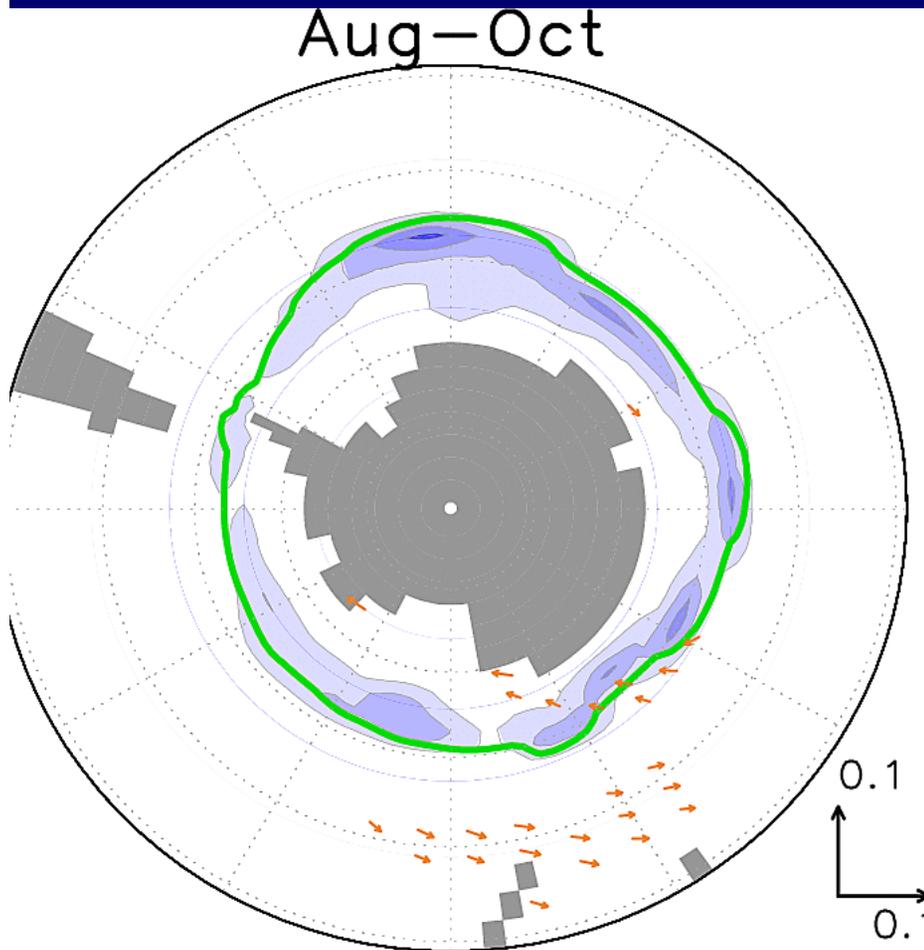
Enhanced convection

~ Cooling deep ocean  
Warming surface ocean

# Ocean Response: [T] (color) and overturning $\phi$ (contours)



# Mechanism AUG-OCT response?



Poleward shift of wind  
(summer)



Poleward shift of  
the ocean  
isotherms  
(year round)

~

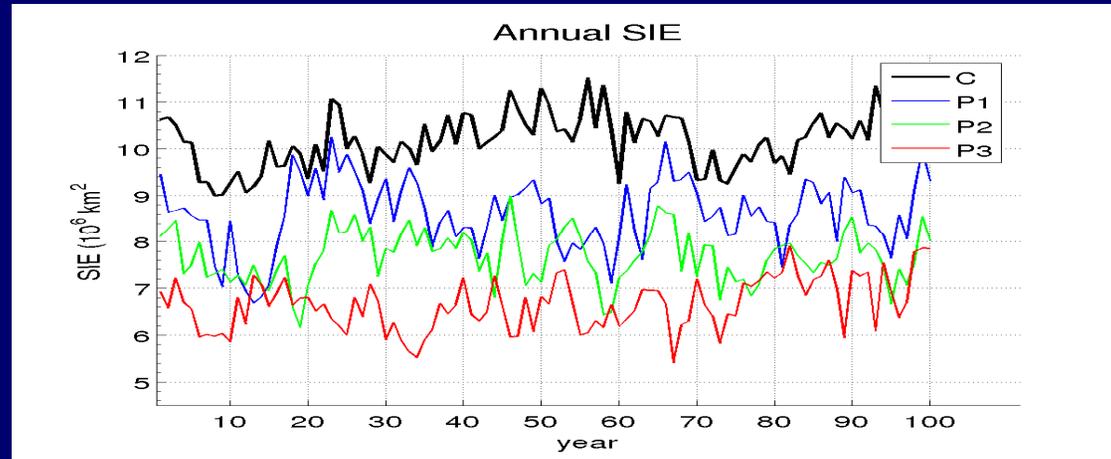
Ocean warming



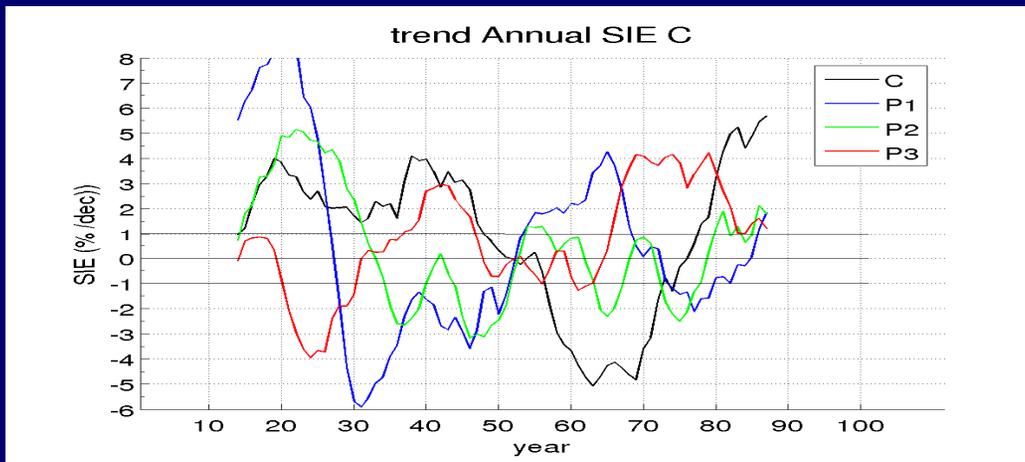
Inhibits sea ice  
growth  
(March-Aug)

- Ozone hole has NOT contributed to increased Antarctic SIE
- Then what *can* explain the increased SIE?

Timeseries SIE in time-slice runs (constant Ozone forcing)



'running' 26 year trends



7 out of 10 trends are larger than  $\pm 1\%$  per decade!

→ most likely (multi-decadal) variability

# Does the ocean impact the atmospheric response to ozone depletion?

Sigmond, Fyfe and Scinocca, May 2010, GRL

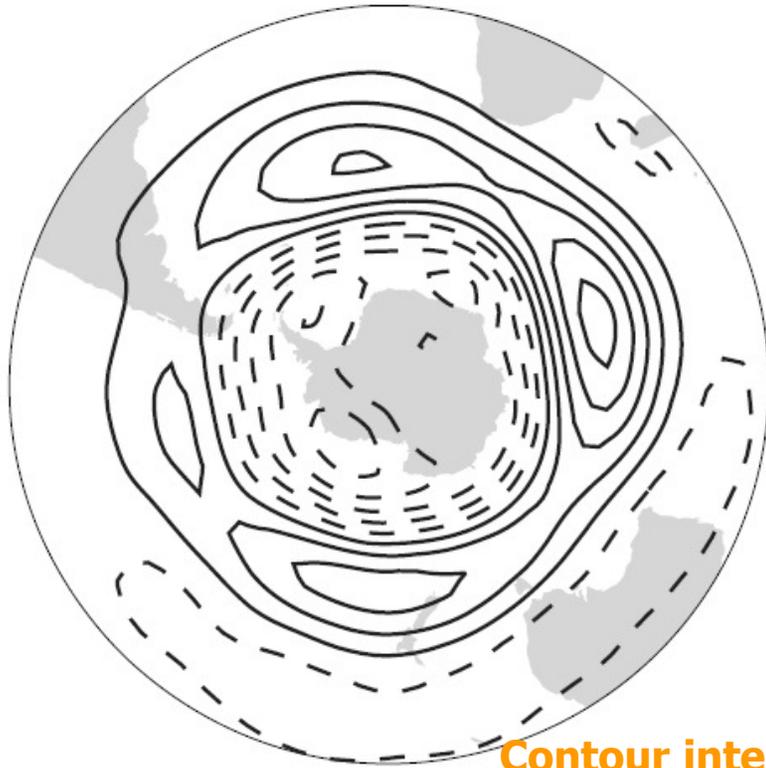
- Almost all climate models with well-resolved stratosphere (CCMVal models) do not include an interactive ocean model
  - may be missing important feedback leading to wrong predictions
- We compare the surface wind response to stratospheric ozone depletion in a model with and without an interactive ocean

## Results:

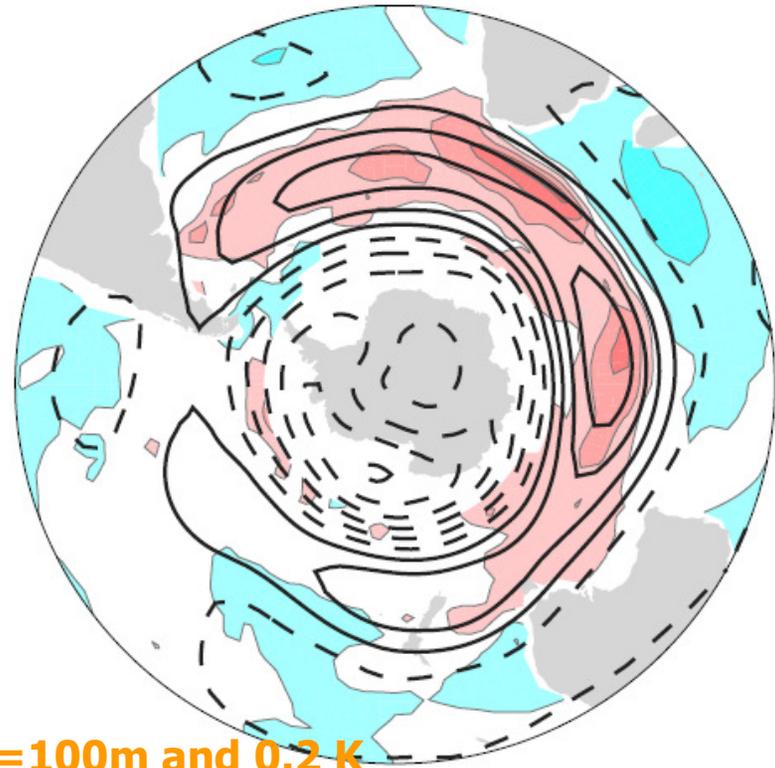
- Ocean acts to extend the time scale of internal atmospheric wind variability ( $\sim 2.4$  months vs  $\sim 3.2$  months) (Watterson 2001, Sen Gupta and England 2007)
- However, this does not translate into an effect of the ocean on the forced response to ozone depletion

**z500**(contours) and **SST** (colors) response [January]

Uncoupled

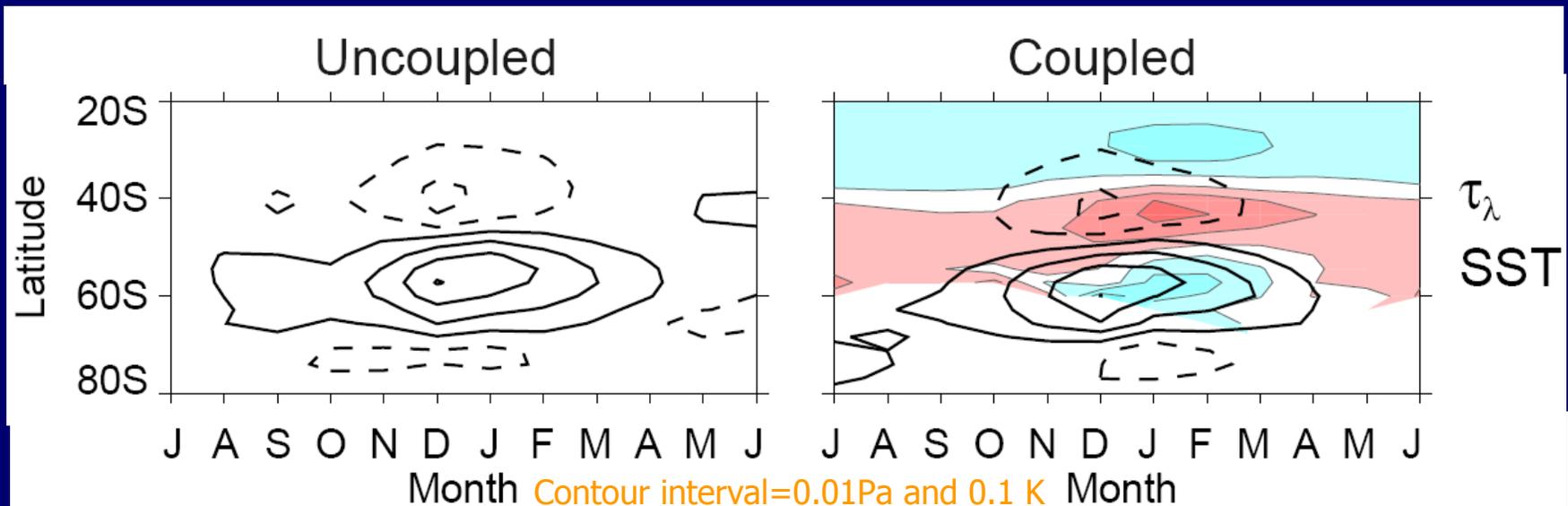


Coupled



Contour interval=100m and 0.2 K

## Zonal mean response of zonal wind stress (contours) and SST (colors)



- No difference in response of zonal surface wind stress
- Tripole pattern of SSTs:
  - maximum 1 month after wind response
  - year-round response

Ocean does not significantly modify SH wind response to ozone depletion

- Ozone hole induced circulation changes do modify SST pattern
- But no significant feed back onto the atmospheric circulation

# Conclusions

- Employing a coupled atmosphere-ocean-sea ice model we find a year-round decrease of Antarctic sea ice in response to stratospheric ozone depletion
  - This suggests that processes other than ozone depletion must be causing the observed positive trend in Antarctic SIE
- An interactive ocean does not affect the atmospheric response to ozone depletion
  - An interactive ocean component is not key for prediction of ozone-induced atmospheric changes