

# The impact of the Ozone Hole on surface climate

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# Introduction

The Montreal Protocol not only had an impact of UV radiation reaching the surface, but also had an impact on surface climate. These climate effects occurred because

- ODSs, replacement gases, and ozone are greenhouse gases.
- The Ozone Hole modified the southern hemisphere tropospheric circulation

Focus here on the latter.

# Outline

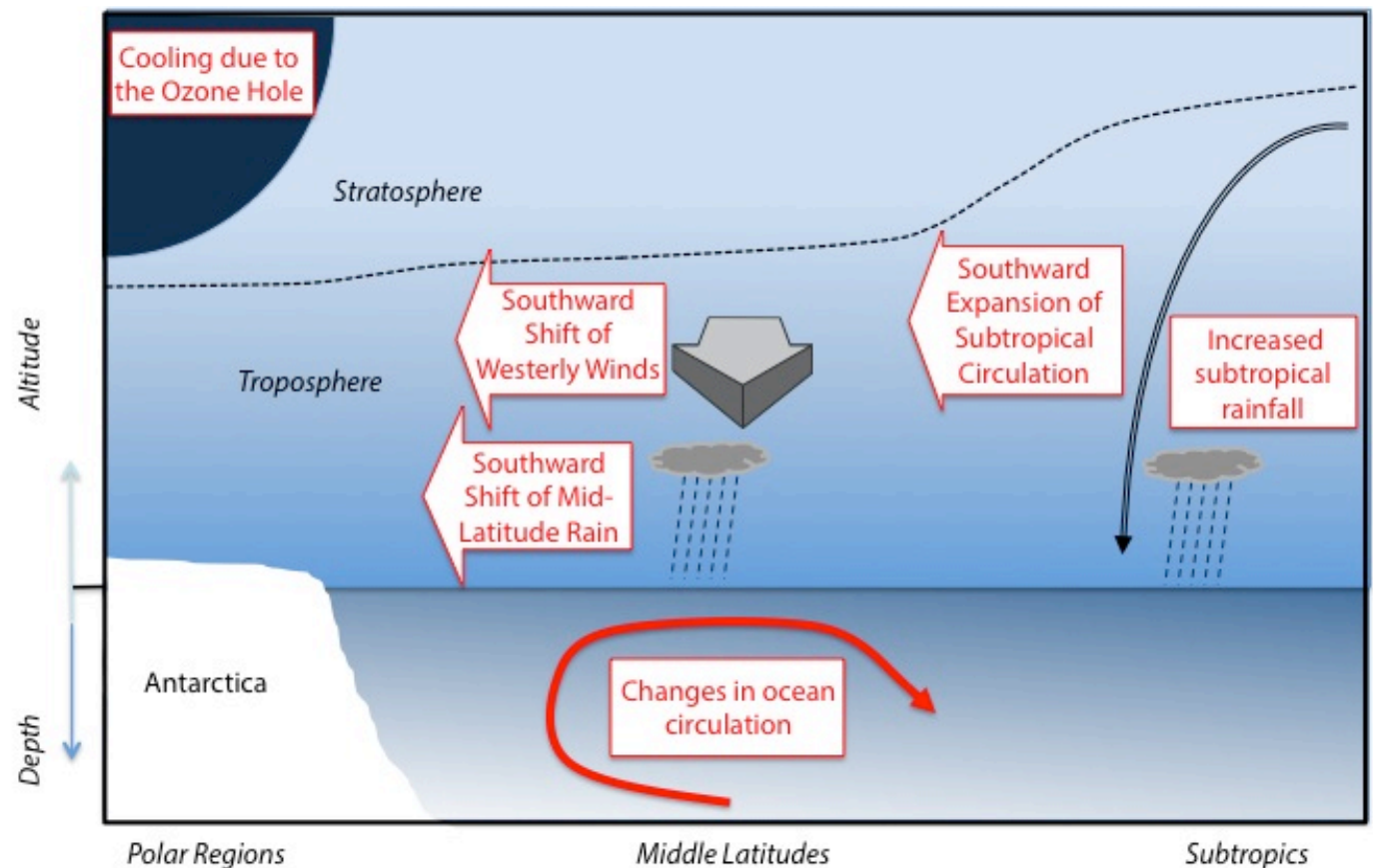
1. Observed changes in Southern Hemisphere.
2. Attribution – Role of the Ozone Hole
3. Future – Impact of ozone recovery

# OBSERVED CHANGES

Widespread changes in SH climate system have been observed in last few decades, especially during summer.

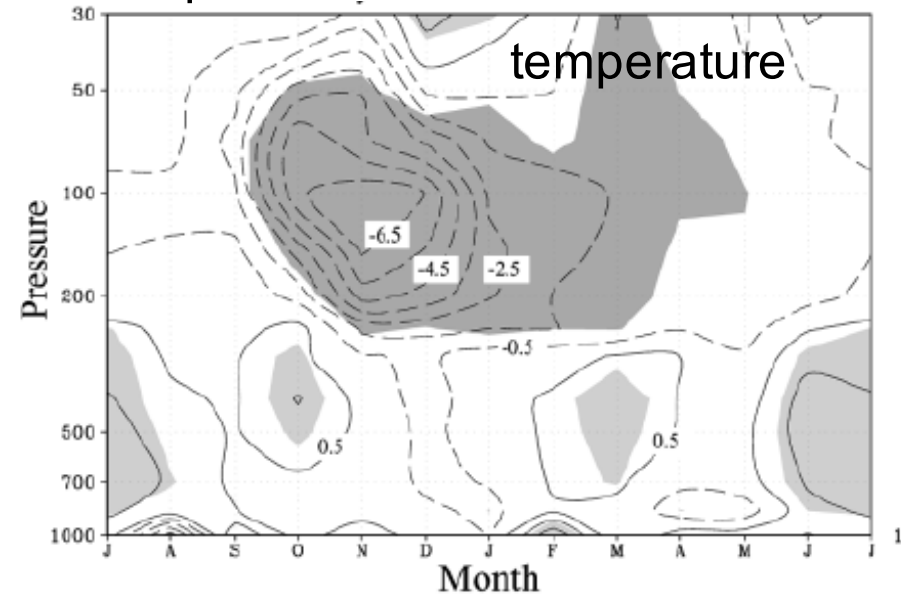
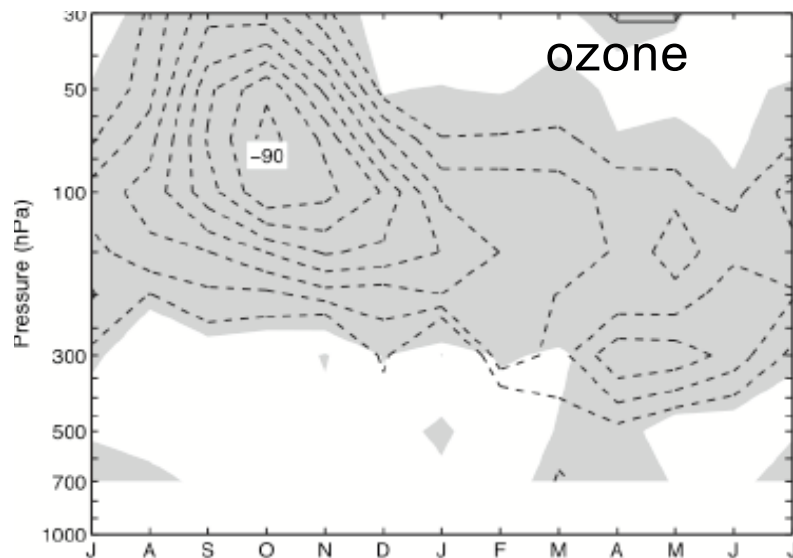
Changes observed from

- Stratosphere down to surface and into oceans.
- Polar regions to subtropics.

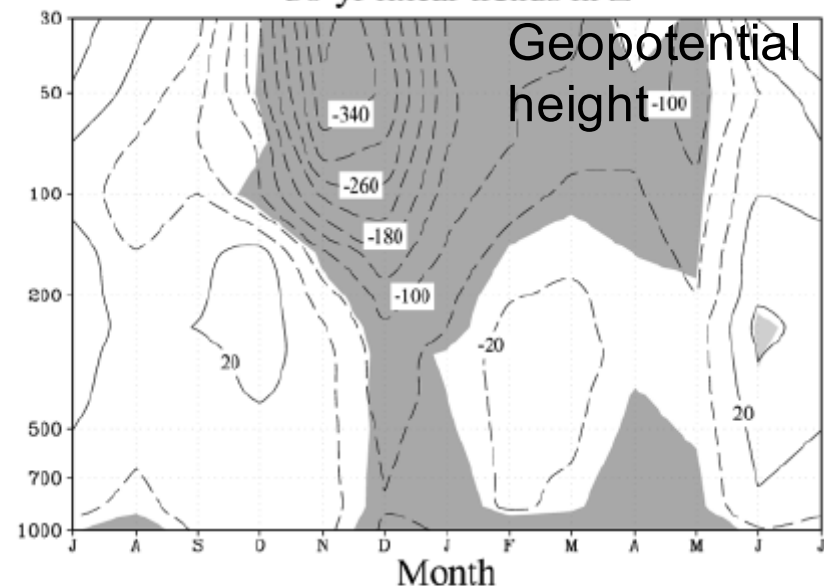


# Ozone – Temperature – Geopotential Height

30-yr trends of polar

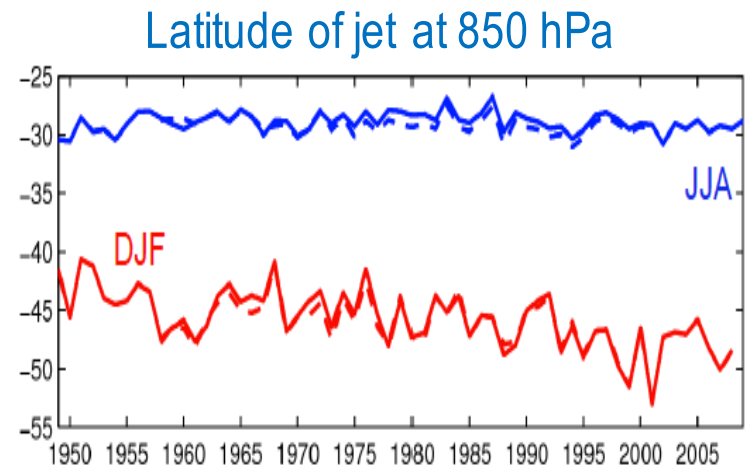
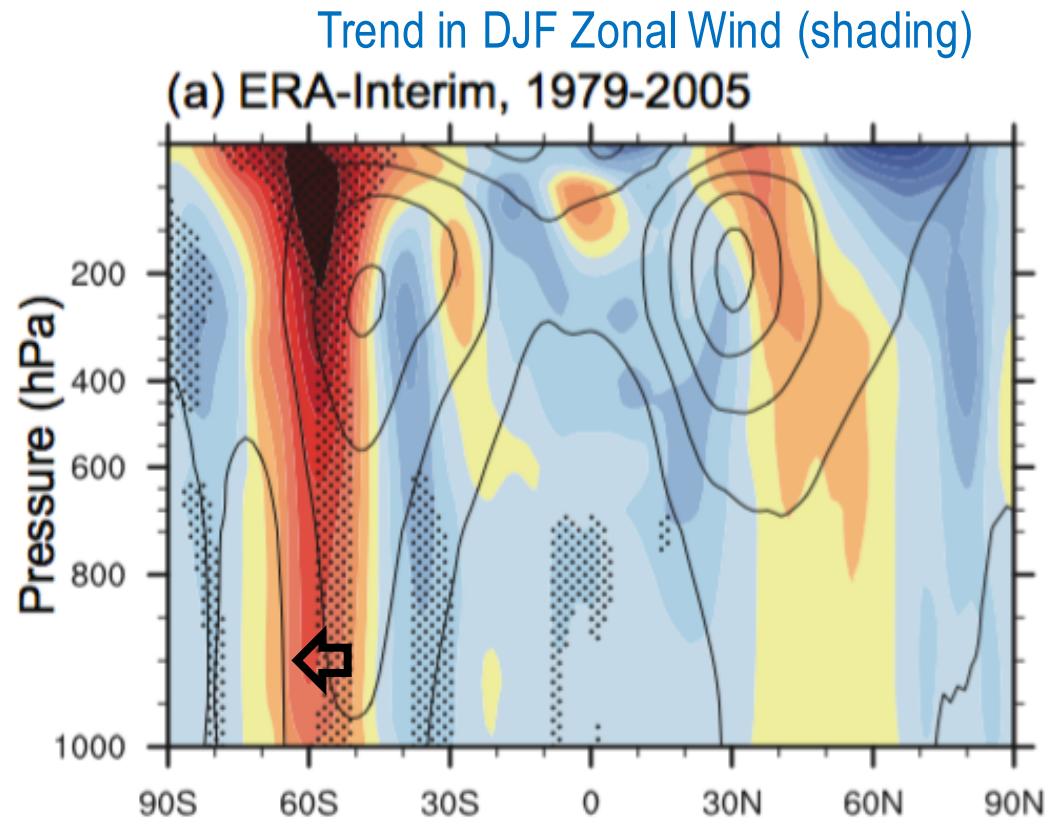


1. Large  $O_3$  depletion observed in Antarctic lower stratosphere from (Aug-Jan).
2. Cooling in polar lower stratosphere (Oct-Feb)
3. Decrease in geopotential height, down to surface (DJF).



# Mid-latitude Westerlies

This lead to a strengthening of winds on poleward side of the jet, and weakening on equatorward side\*.

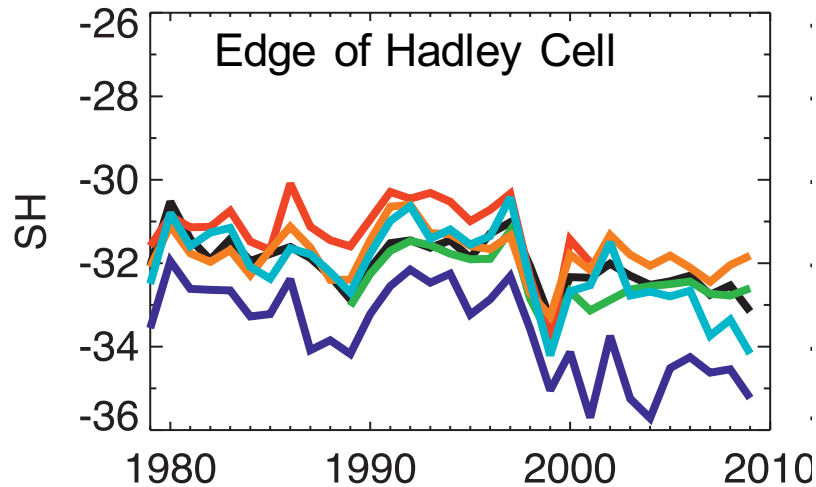


\*During summer but not winter

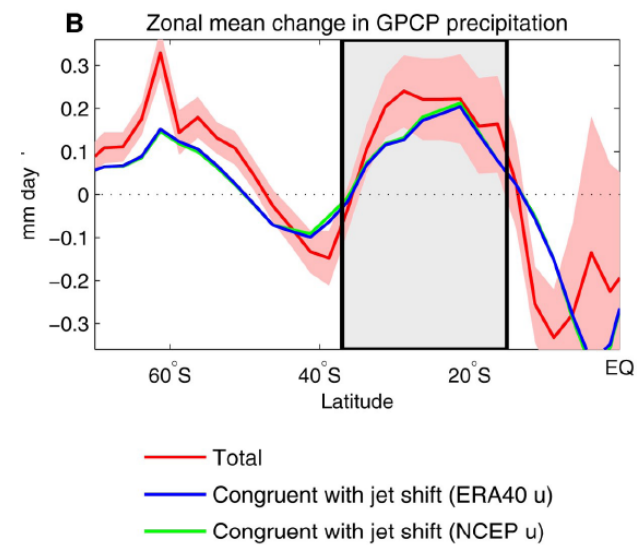
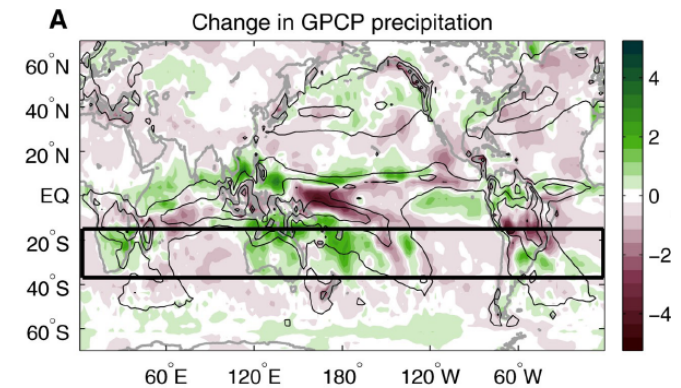
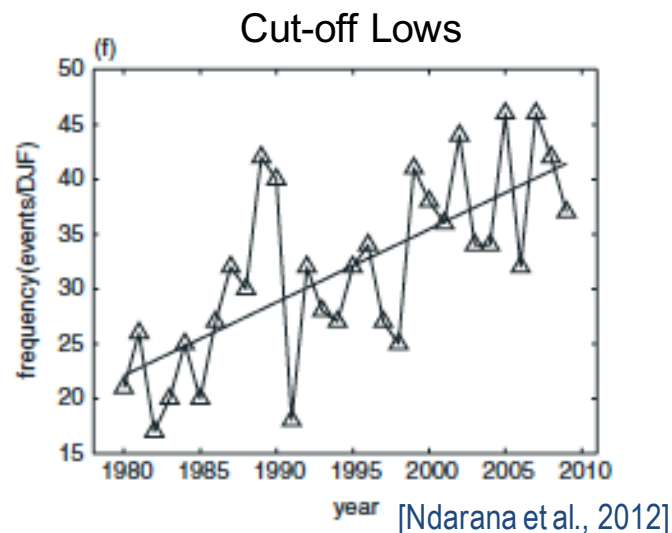
This change in westerly winds is associated with a wide range of changes ...

# Tropical Widening, Precipitation, and Weather

Also observed summer-time trends in edge of Hadley Cell, storm tracks, clouds, precipitation, weather systems, ....



[Davis & Rosenlof, 2012]



[Kang et al., 2011]

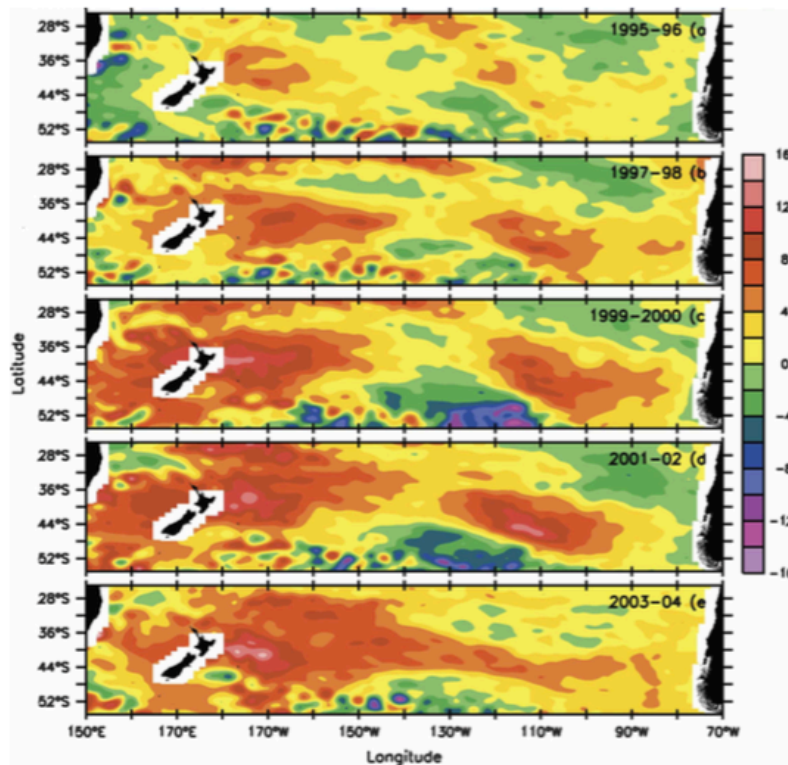


# Ocean Circulation

Also observations of changes in ocean circulation consistent with a strengthening and shift of westerly winds.

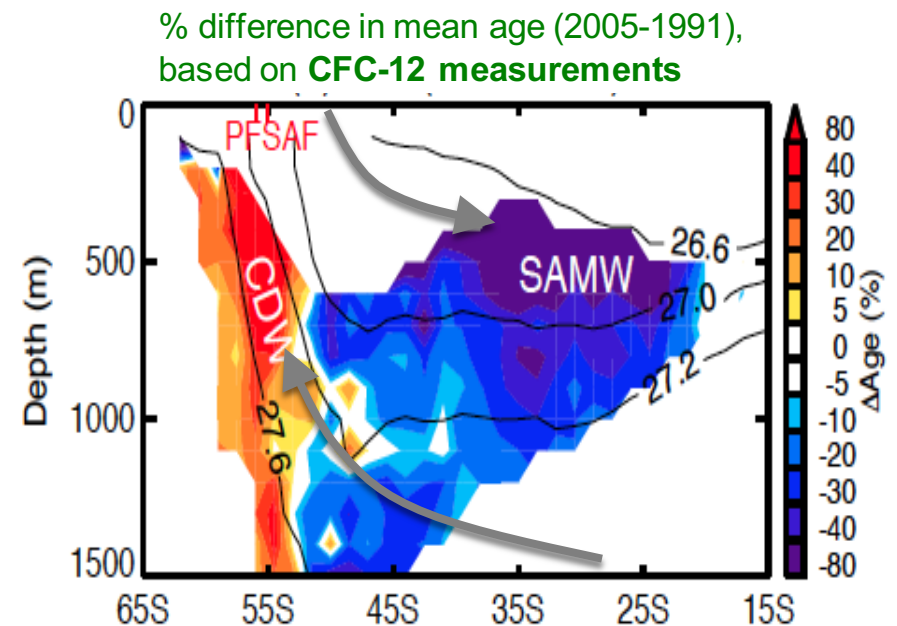
E.g.,

Spin-up (strengthen) of subtropical gyres



[Roemmich et al., 2007]

Ocean “ventilation” time\*



[Vaugh et al., 2013]

\* Increased upwelling of circumpolar deep water linked to a decrease in ocean uptake of carbon dioxide.



# ATTRIBUTION

Observed changes in SH climate are consistent with ozone hole, but could also be due to increases in greenhouse gases (GHGs) and/or natural atmosphere-ocean variability.

Seasonality suggest ozone depletion plays a much larger role than increased GHGs.

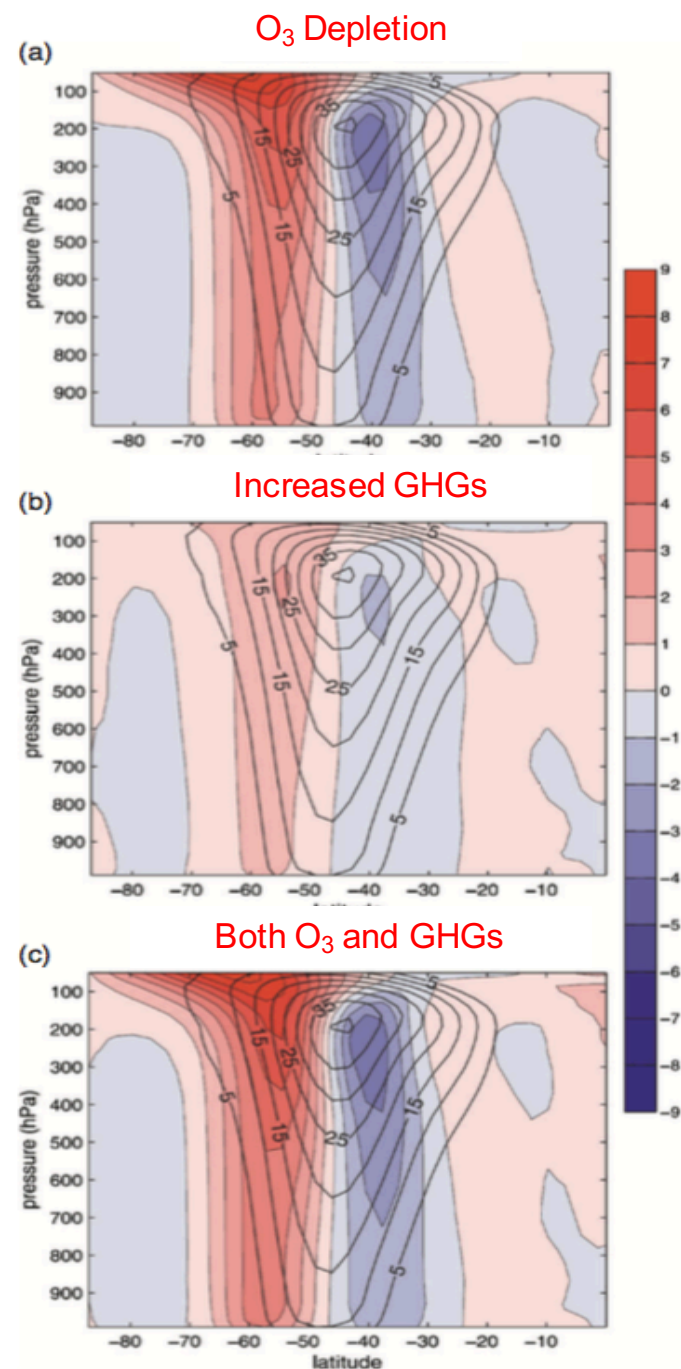
Modeling studies ...

# Attribution: O<sub>3</sub> vrs GHGs.

Multiple modeling studies show much larger shift in jet, and associated changes in other aspects, for ozone depletion than for increased GHGs.

Seasonality of response also only consistent with observations for ozone depletion.

Difference in DJF zonal winds between integrations



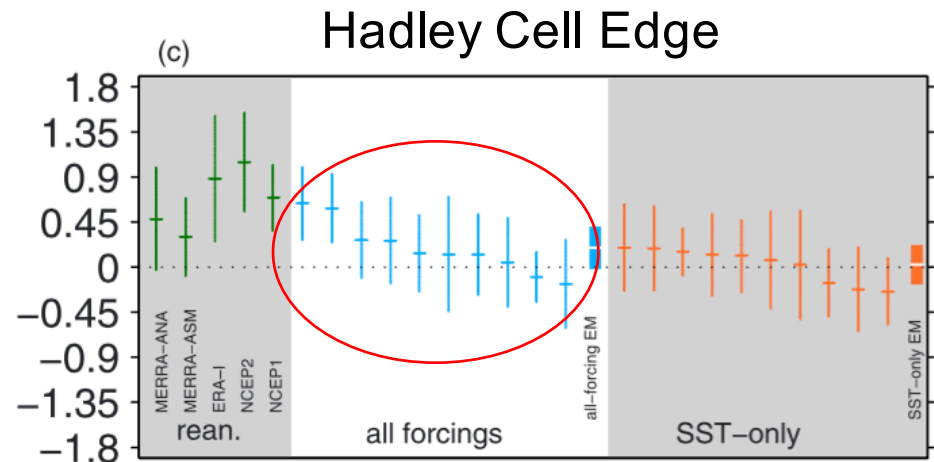
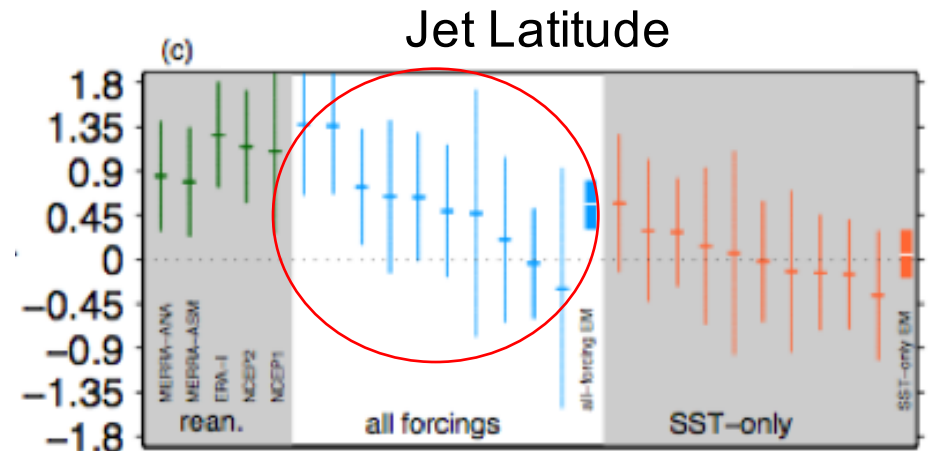
Polvani et al., 2011

# Attribution: Natural Variability

30-yr trends in circulation can occur due to natural variability, and this may have also contributed to observed trends.

Illustrated by differences among simulated trends from single model (with prescribed SSTs).

Trends in DJF mean (degree/dec)



(Garfinkel et al. 2015)

# FUTURE: OZONE RECOVERY

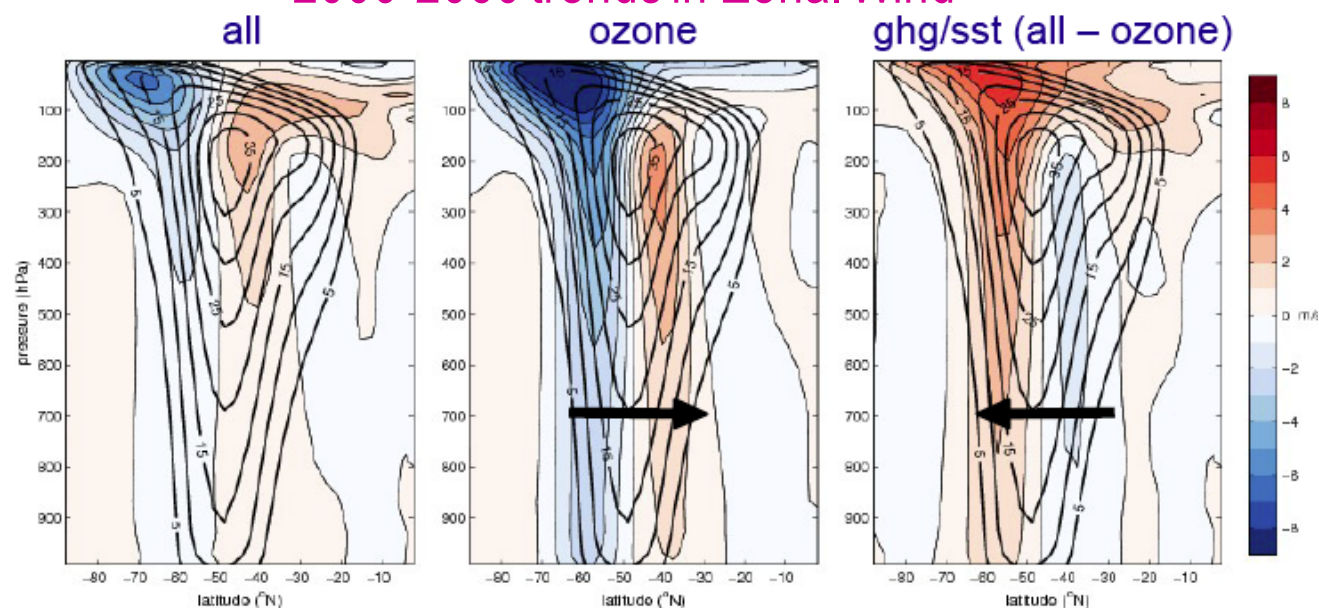
What is expected to happen as Antarctic ozone recovers?

# FUTURE: OZONE RECOVERY

What is expected to happen as Antarctic ozone recovers?

- The reverse changes in summer time circulation, and associated impacts, are expected as the ozone hole disappears.
- These changes will oppose the circulation changes due to continued increases in GHGs.

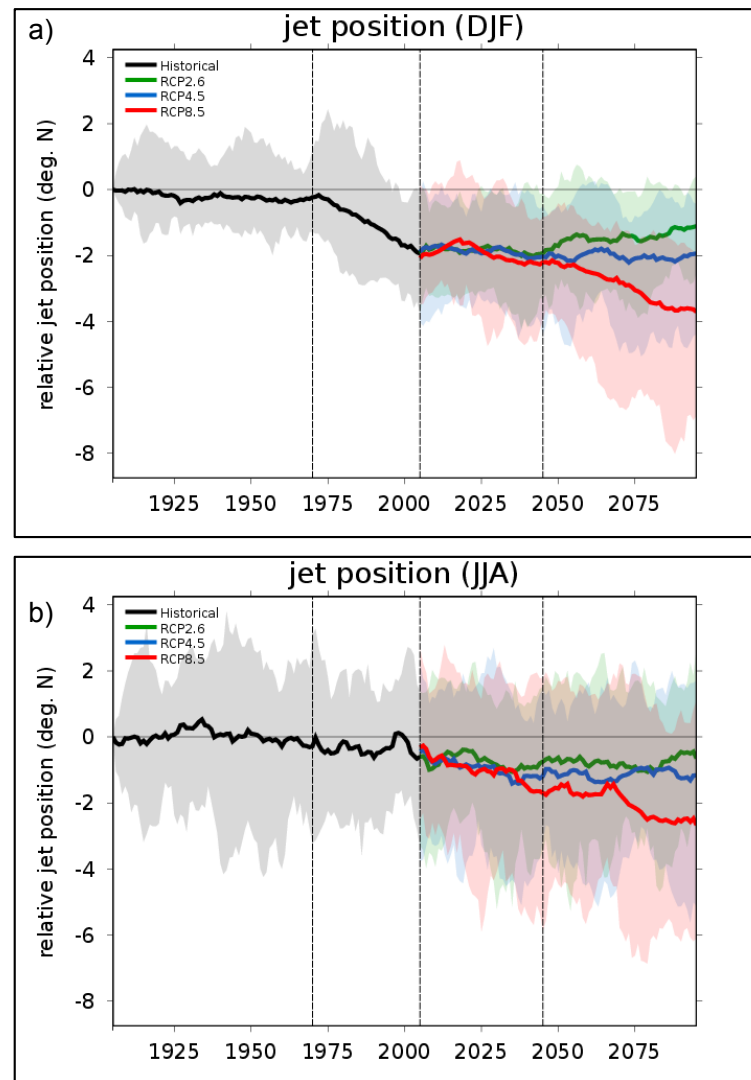
## 2000-2060 trends in Zonal Wind



Weak changes due to cancelation of ozone recovery and increased GHGs

# Ozone Recovery

The net change in SH circulation will depend on magnitude of future GHG emissions.



Low emissions scenario

High emissions scenario

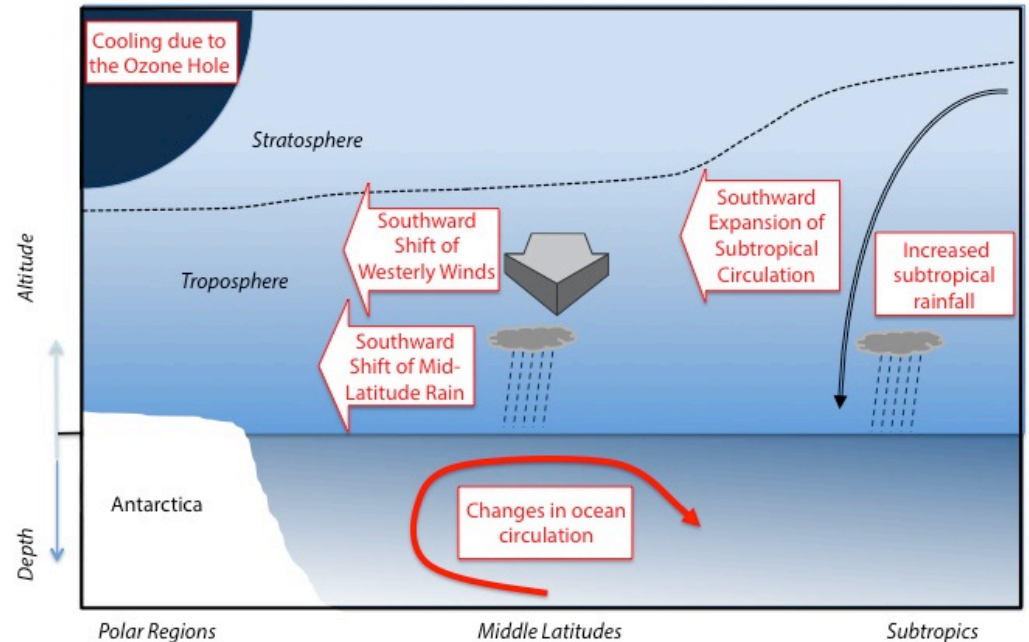


# CONCLUSIONS

Widespread changes in SH summer climate have been observed over last few decades.

The ozone hole has been a major contributor to these changes.

Ozone recovery will cause the reverse changes, and partially offset circulation changes due to increased GHGs.



# QUESTIONS?

# Antarctica

- Antarctic surface temperatures: Ozone hole has likely contributed to warming over Peninsula and cooling over rest of the Continent.
- Antarctic sea-ice: Influence of ozone hole on (pre-2016) increase in sea-ice extent is unclear (sign is under debate), and cause of increase is unknown.

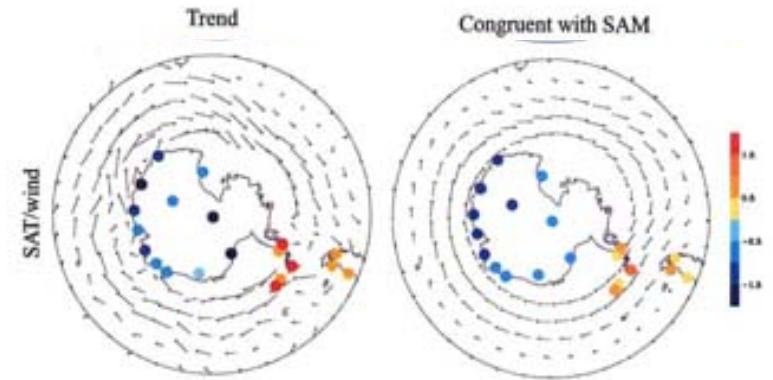


Fig. 3. December-May trends (left) and the contribution of the SAM to the trends (right). Top.

