# Ozone Change and Its Influence on Climate

A summary primarily from

*Chapter 5: Stratospheric Ozone Changes and Climate*

From the *Scientific Assessment of Ozone Depletion: 2018*

Lead authors: Amanda Maycock and Alexey Karpechko

Coauthors: Marta Abalos, Julie Arblaster, Hideharu Akiyoshi, Chaim Garfinkel, **Karen Rosenlof**, Michael Sigmond

Assessment steering committee: David Fahey, Paul Newman, John Pyle, Bonfils Safari, Martyn Chipperfield, David Karoly, Doug Kinnison, Malcolm Ko, Michelle Santee

**EARTH SYSTEM RESEARCH LABORATORY**

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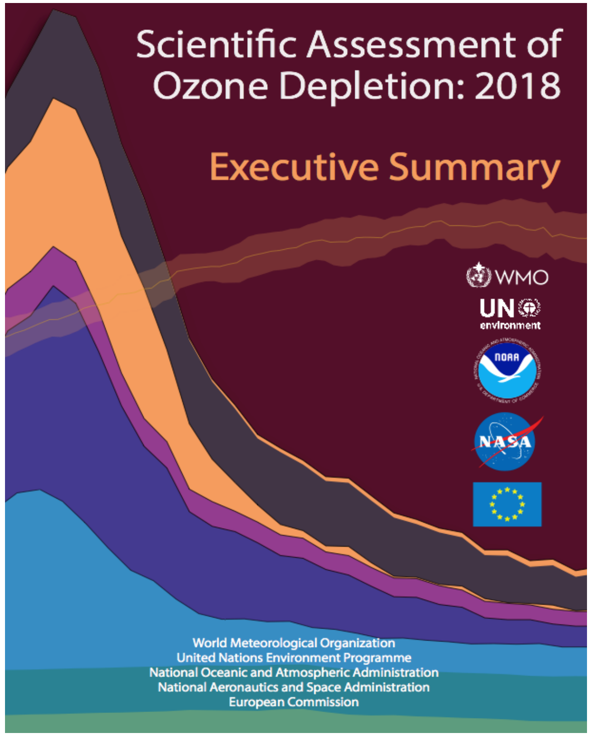
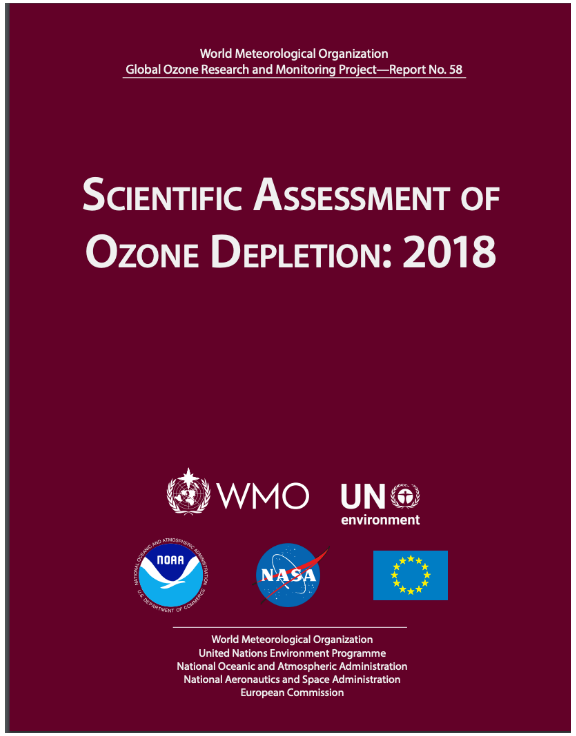
# The 2018 UNEP/WMO Assessment of Ozone Depletion

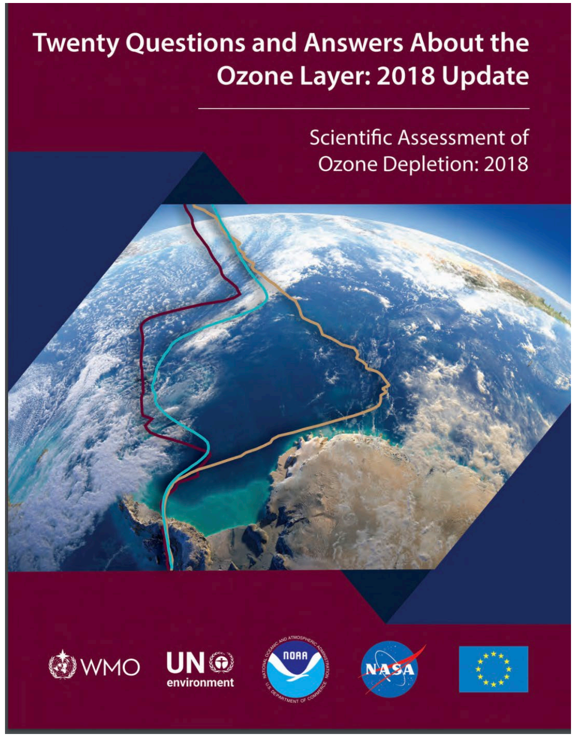
Executive Summary




Assessment Chapters




20 Questions & Answers




This report (and previous) available at

https://www.esrl.noaa.gov/csd/assessments/ozone/

SAP chairs:
David W. Fahey, NOAA
Paul A. Newman, NASA
John A. Pyle, U of Cambridge and NCAS
Bonfils Safari, U of Rwanda

- 9th Quadrennial Assessment produced under the auspices of the World Meteorological Organization and UN Environment to inform the Parties of the Montreal Protocol (signed in 1987)

The Parties have been requesting these reports from the Scientific Assessment Panel approximately every 4 years; the first was in 1989; the next will have a publication year of 2022. (other MOP panels include the Environmental Effects Assessment and Technology and Economic Assessment Panels.)

# Assessment Highlights: Ozone-depleting substances (ODSs)

• Actions taken under the Montreal Protocol have led to decreases in the atmospheric abundance of controlled ODSs and the start of the recovery of stratospheric ozone.

CFC-11-eq emissions (ODP-weighted)

• Total emissions of ODSs continue to decline

Equivalent effective stratospheric chlorine (EESC)

• Atmospheric chlorine and bromine levels remain high and continue to decline

*CFC-11 lifetime: 52 yrs*
*CFC-12 lifetime: 102 yrs*

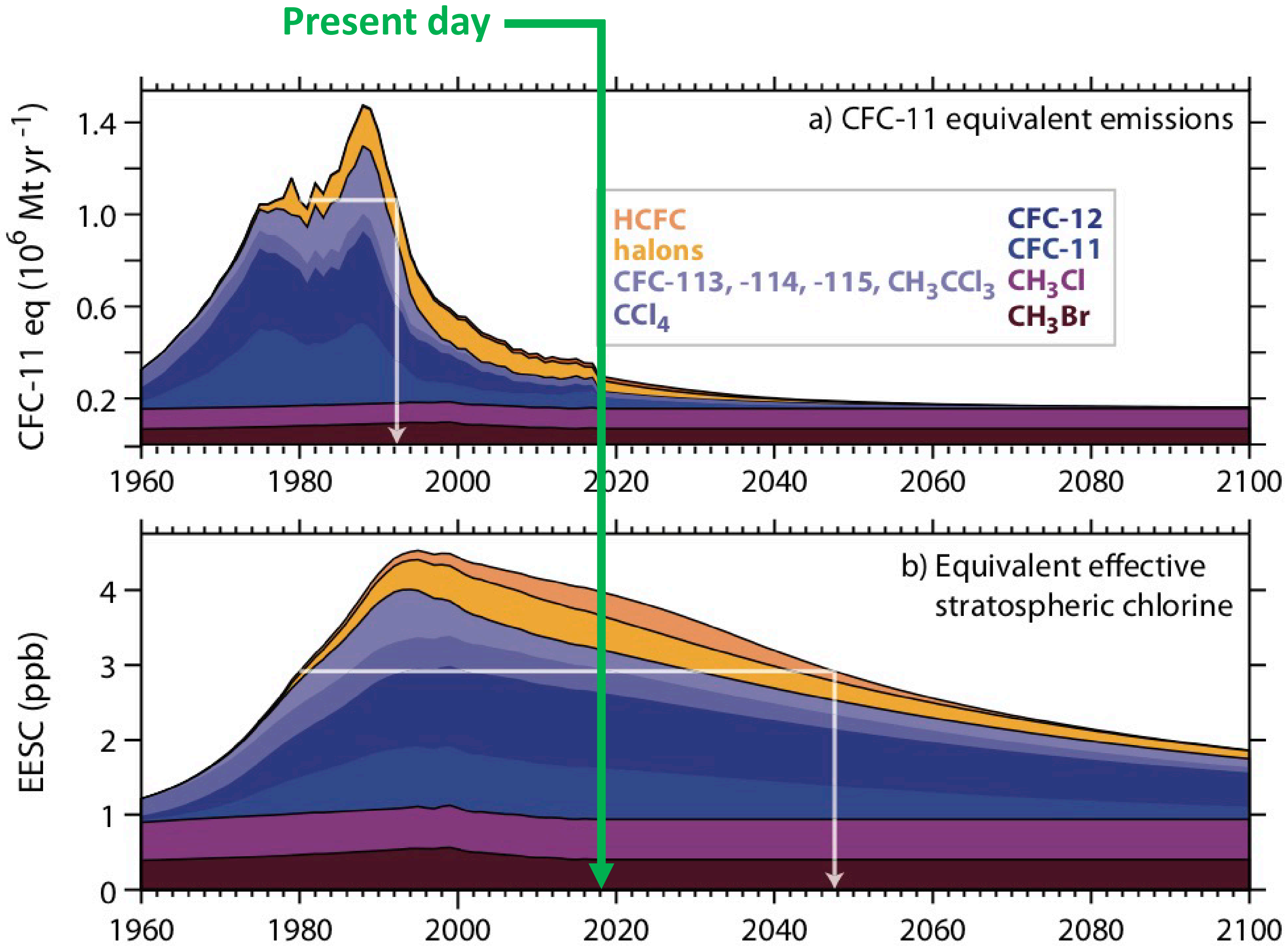



Figure ES-1

From executive summary - 2018

# Assessment Highlights: Ozone-depleting substances (ODSs)

• Actions taken under the Montreal

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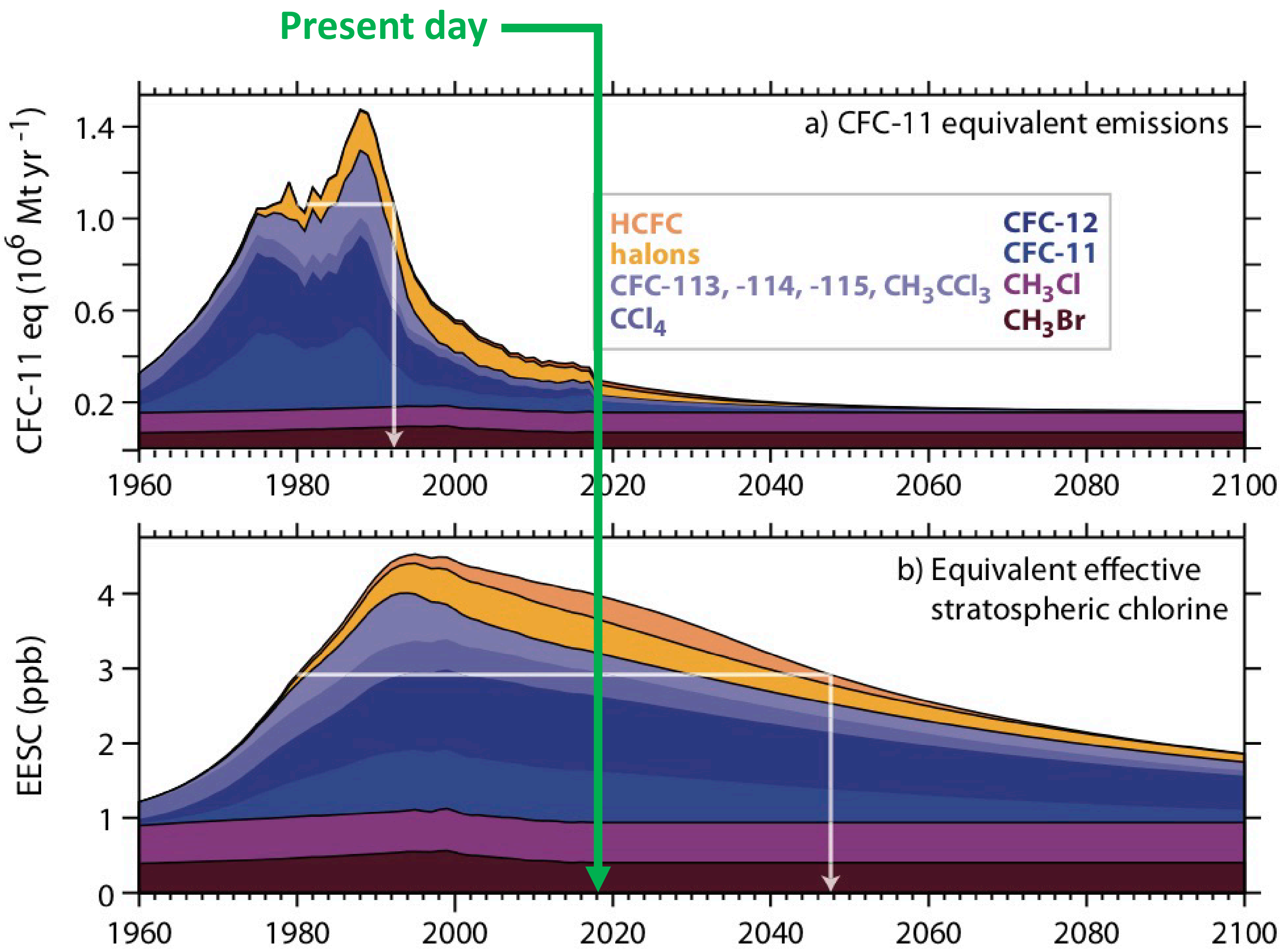
• Continued success of the Montreal Protocol in protecting stratospheric ozone depends on continued compliance with Protocol regulations.




*CFC-11 lifetime: 52 yrs*
*CFC-12 lifetime: 102 yrs*

Figure ES-1

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# Assessment Highlights: CFC-11 emissions

• There has been an unexpected and unreported increase in global total emissions of CFC-11 starting ~2012..

• Estimated increase in global emissions of approximately 10 Gg $yr^{-1}$ (~15%) is required for 2014–2016, compared to 2002–2012

10 Gg = ~60 rail tank cars

• Unlikely to be explained by increasing emissions from banks (reservoirs)

• Findings indicated new production not reported to the UN Environment. Source region has been described as 'eastern Asia'.

• Emissions are currently not a threat to the ozone layer. Responding to evidence of unreported emissions is a challenge to the Montreal Protocol process.

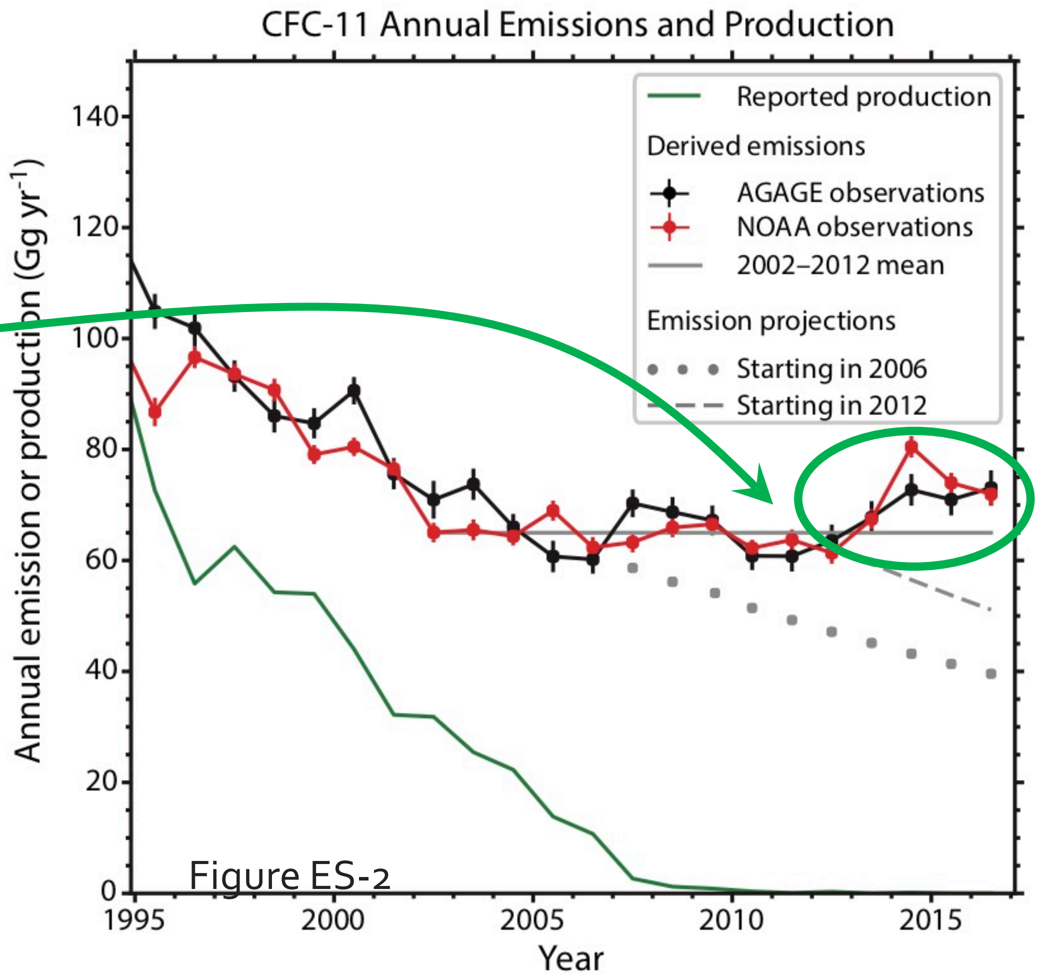

Figure ES-2

Work by Steve Montzka et al., Nature 2018
Matt Rigby et al., Nature 2019
Special CFC-11 report currently in preparation (following spring 2019 Vienna meeting)
Harris et al., 2019, SPARC report on unexpected CFC-11 emissions (reported on at MOP-31)

From executive summary - 2018

# Assessment Highlights: Global and Antarctic total ozone trends

- Global total column ozone:
  - no detectable recovery trend
  - recovery expected around mid-century.

- The Antarctic ozone hole continues to occur every year with some indication of recovery starting. As a result of the Montreal Protocol, much more severe ozone depletion in the polar regions has been avoided.

- The Antarctic ozone hole is expected to gradually close in the 2060s.

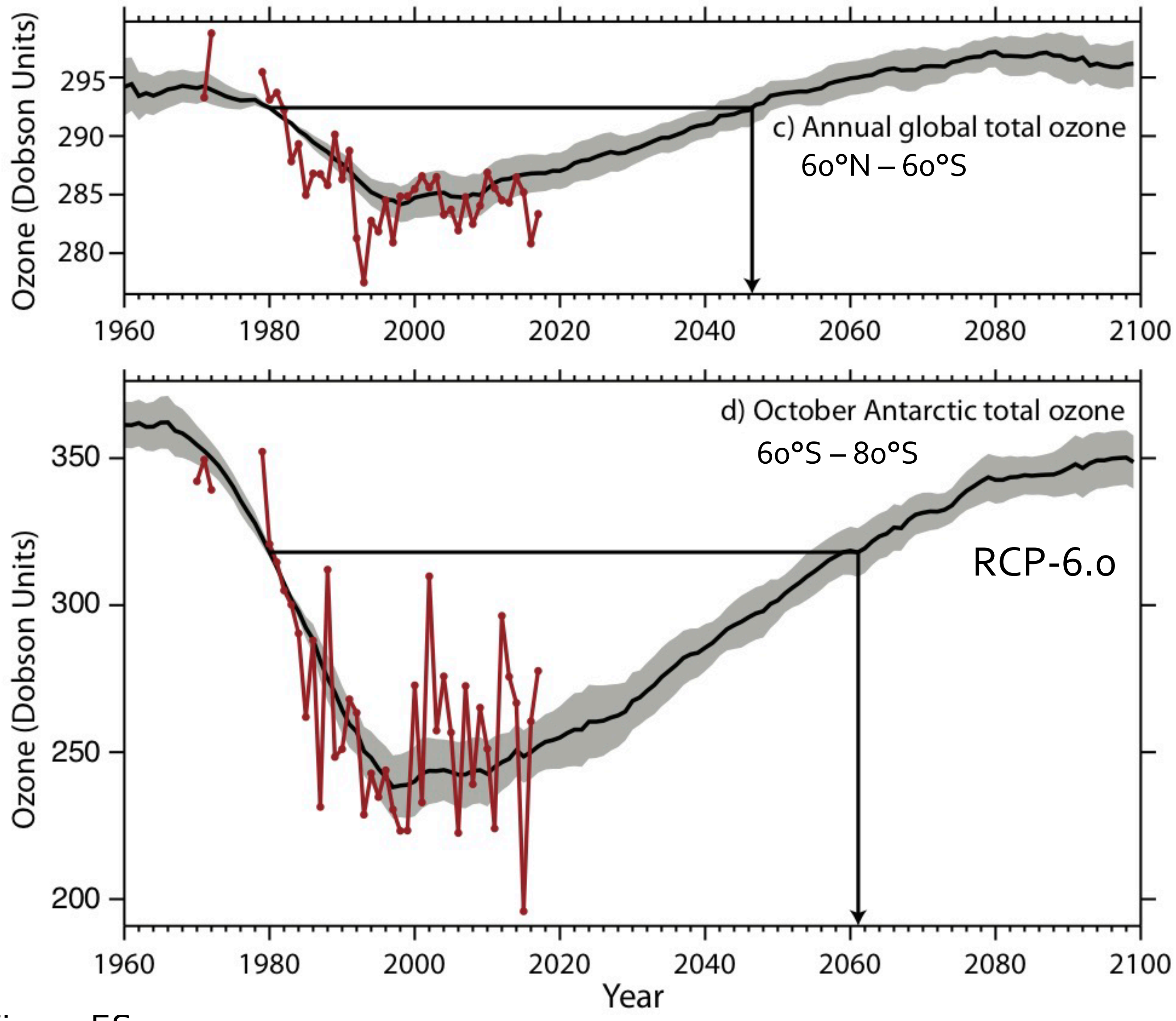


Figure ES-1

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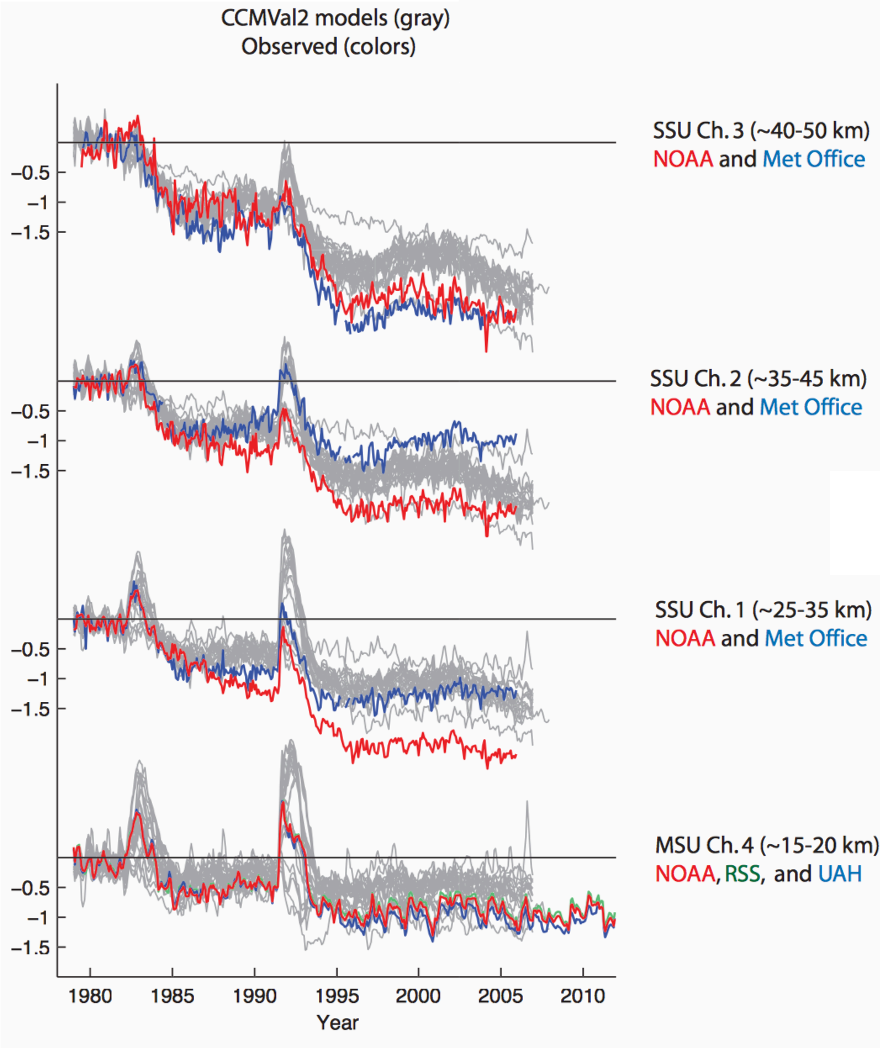
# Chapter 5: Ozone and Climate

**Purpose of Chapter 5:** Assess the recent work (since the previous assessment in 2014) on how changes in stratospheric ozone affect climate.

- impacts on stratospheric temperature and circulation
- impacts on the troposphere, including composition, circulation and surface climate
- impacts on the ocean (& sea ice)

# Chapter 5: Ozone and Climate: Temperature (1)

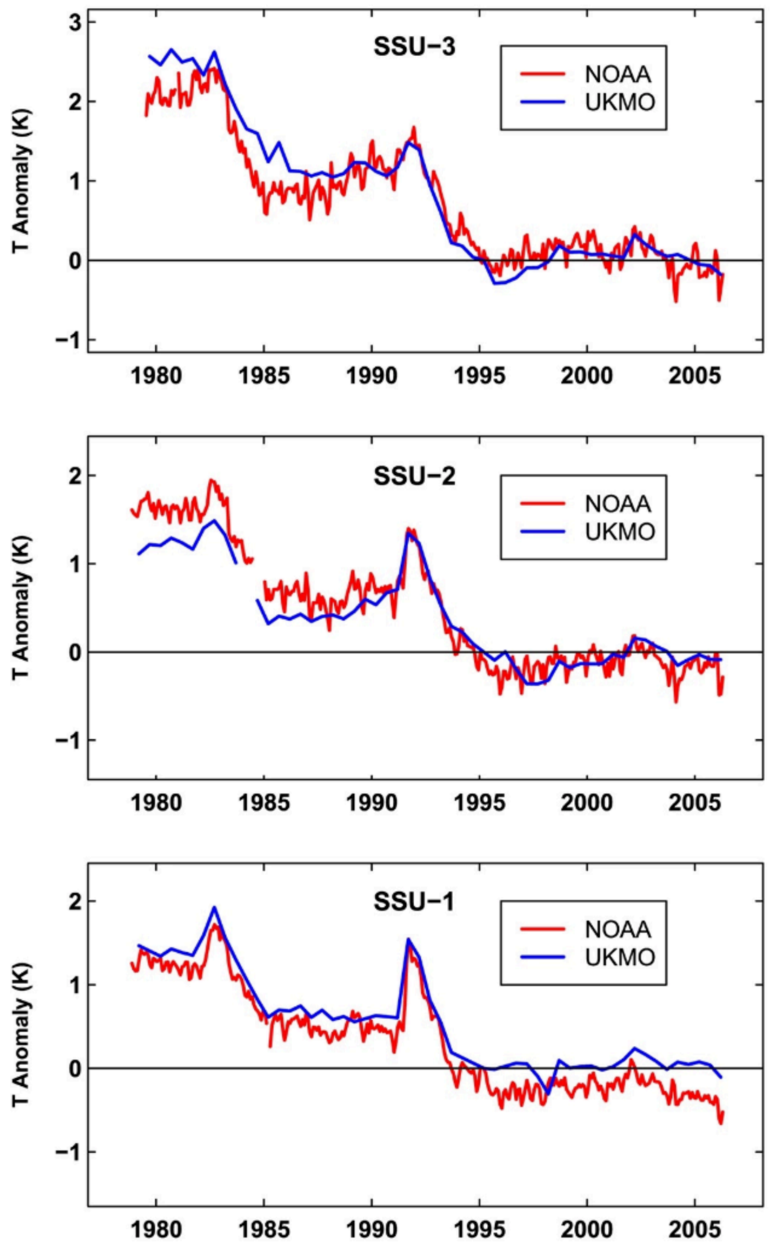
In the 2014 assessment, it was noted that global middle stratosphere temperature trends computed from 2 analyses of the same underlying satellite radiances (SSU) gave different trends, and didn't agree well with CCMVAL2 model results.




From Chapter 4, 2014 WMO Ozone Assessment

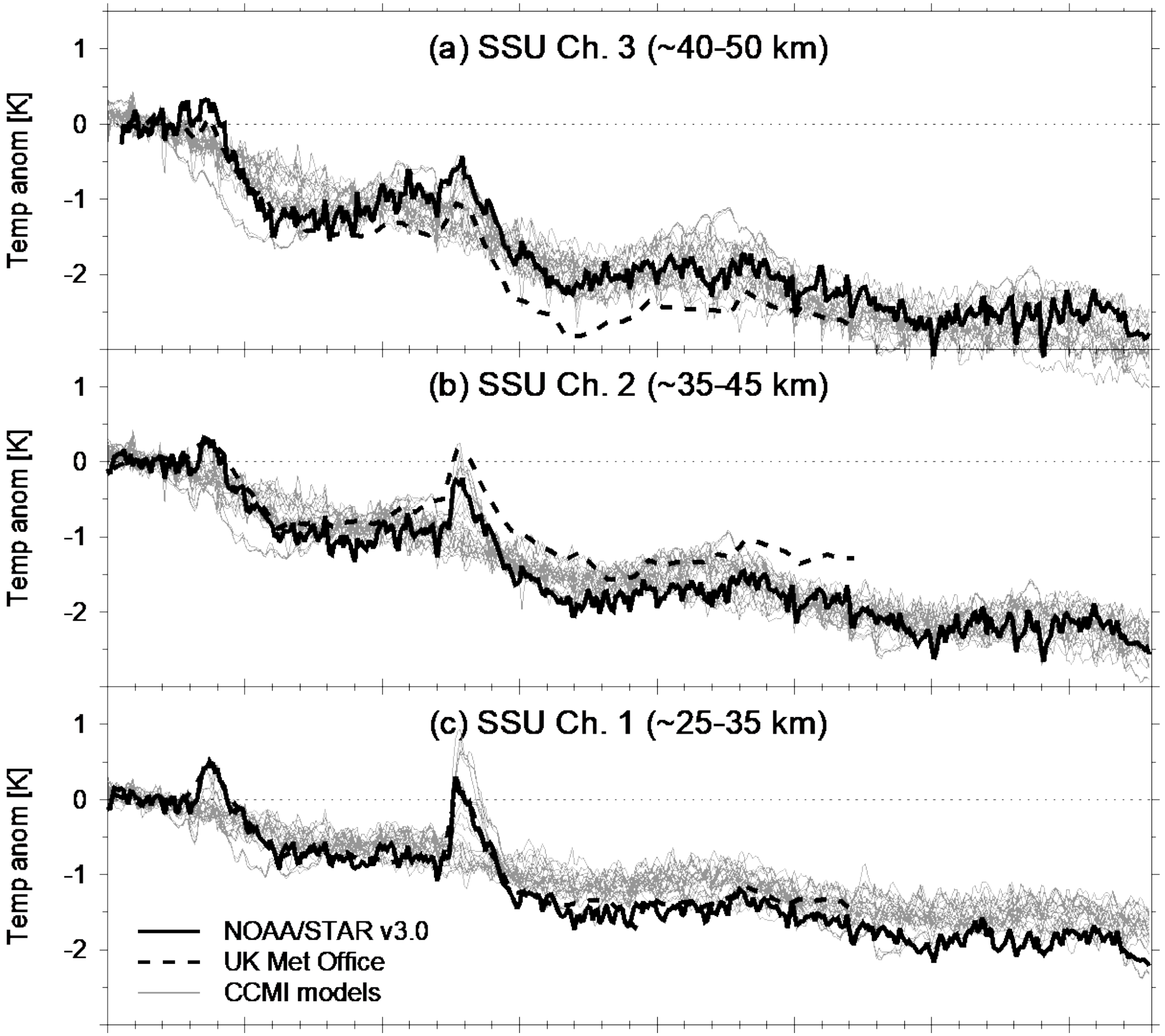
# Chapter 5: Ozone and Climate: Temperature (2)

After the 2014 Assessment was published, SSU temperatures were reprocessed by NOAA and the Met Office, and now show greater consistency in long-term temperature trends in the middle and upper stratosphere.



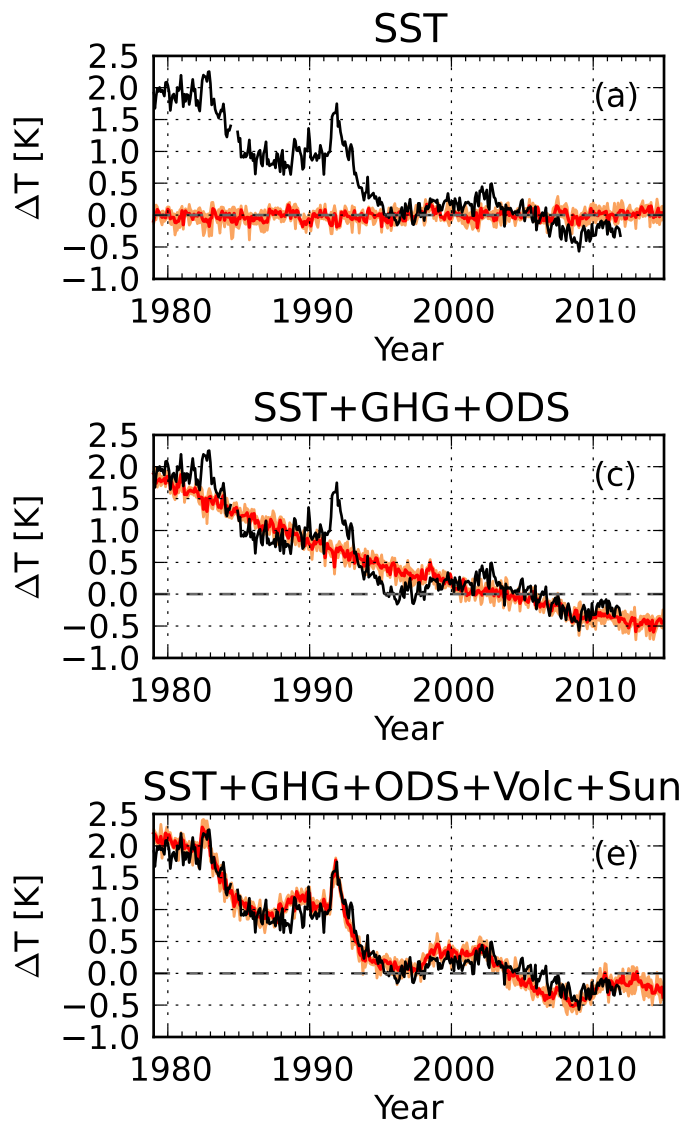
# Chapter 5: Ozone and Climate: Temperature (3)

There is now better agreement between the two satellite products based on the SSU data, but there is better agreement with models (grey lines are CCMI models).



# Chapter 5: Ozone and Climate: Temperature (4)

There is improved understanding of the causes of temperature trends and variability since the 2014 assessment.




Mid-upper stratosphere

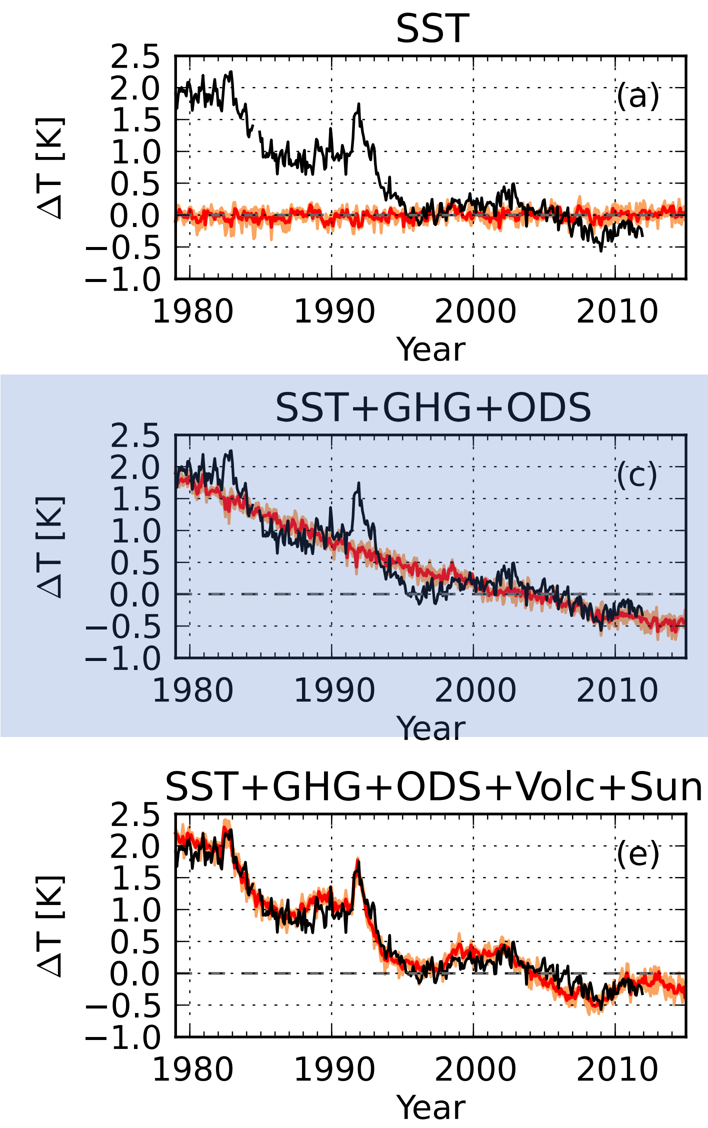
Data: black, global anomalies,
SSU-2, 35 -45km

Model: red

Adapted from Aquila et al. (2016) JGR

# Chapter 5: Ozone and Climate: Temperature (5)

There is improved understanding of the causes of temperature trends and variability since the 2014 assessment.



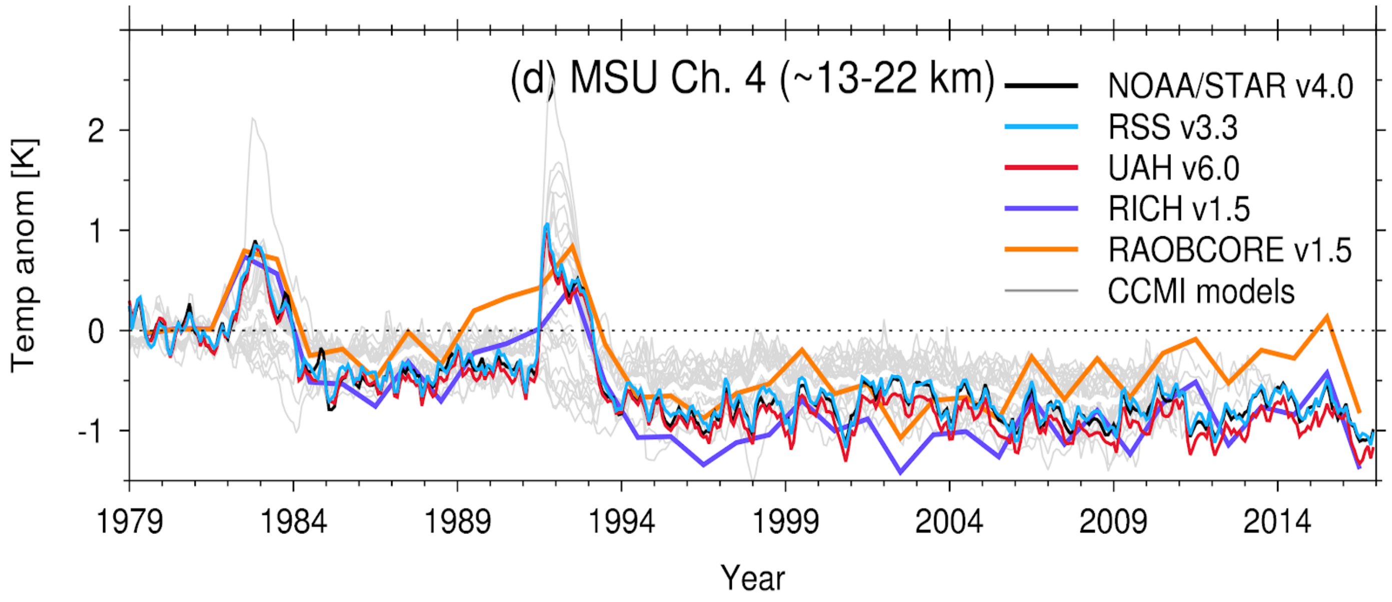

**Adding ozone depletion in a modeling study improves the agreement between the trends in the modeled and measured temperature time series.**

1/3 of the pre 2005 cooling is attributed to $O_3$ changes, with, 2/3 to GHG changes.

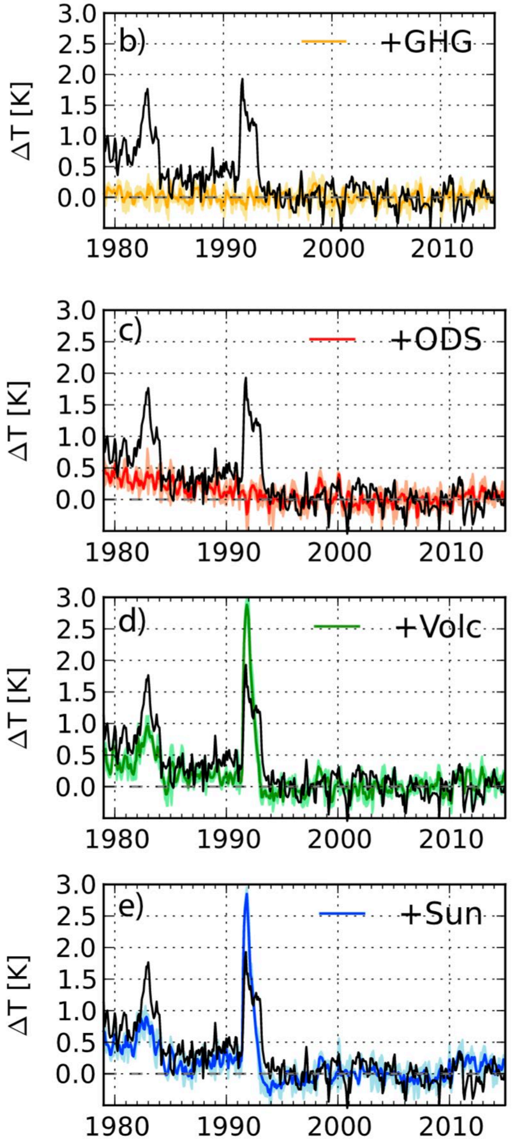
Data: black, global anomalies,
SSU-2, 35 -45km
Model: red
Adapted from Aquila et al. (2016) JGR

# Chapter 5: Ozone and Climate: Temperature (6)

Lower stratospheric temperatures cooled in the global mean between 1979 and 2016 by ~1 K. The majority of the observed global lower stratospheric cooling in the MSU4 record occurred before the mid-1990s. Since then there has been little overall global temperature change in the MSU4 record. Ozone trends are asserted to be the major cause of the observed cooling in the lower stratosphere (13–22 km) between the late 1970s and the mid-1990s.

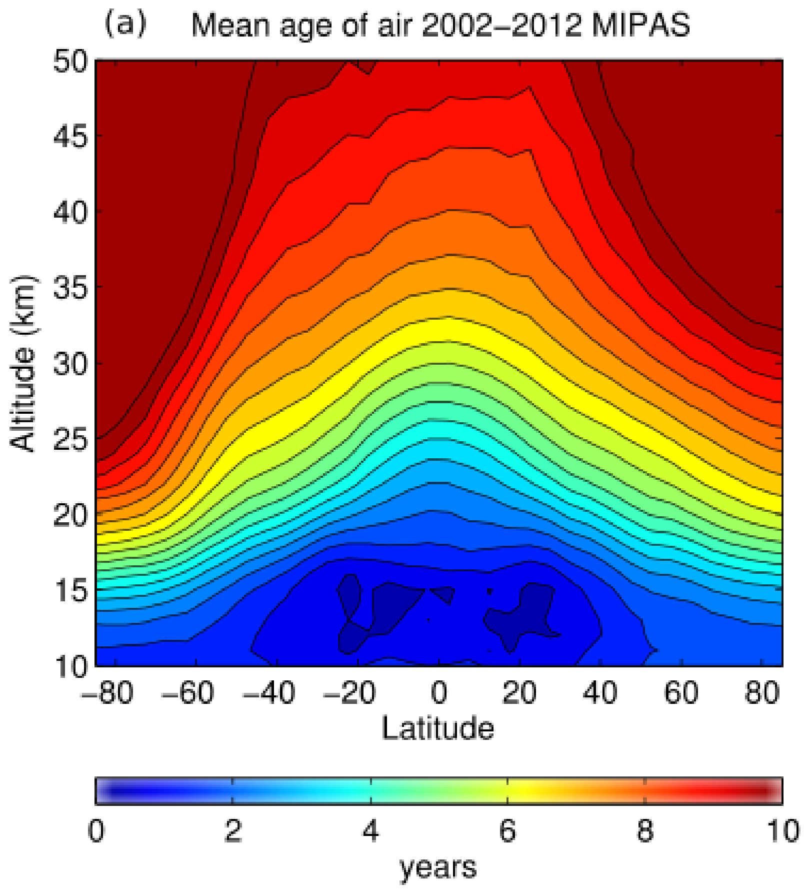


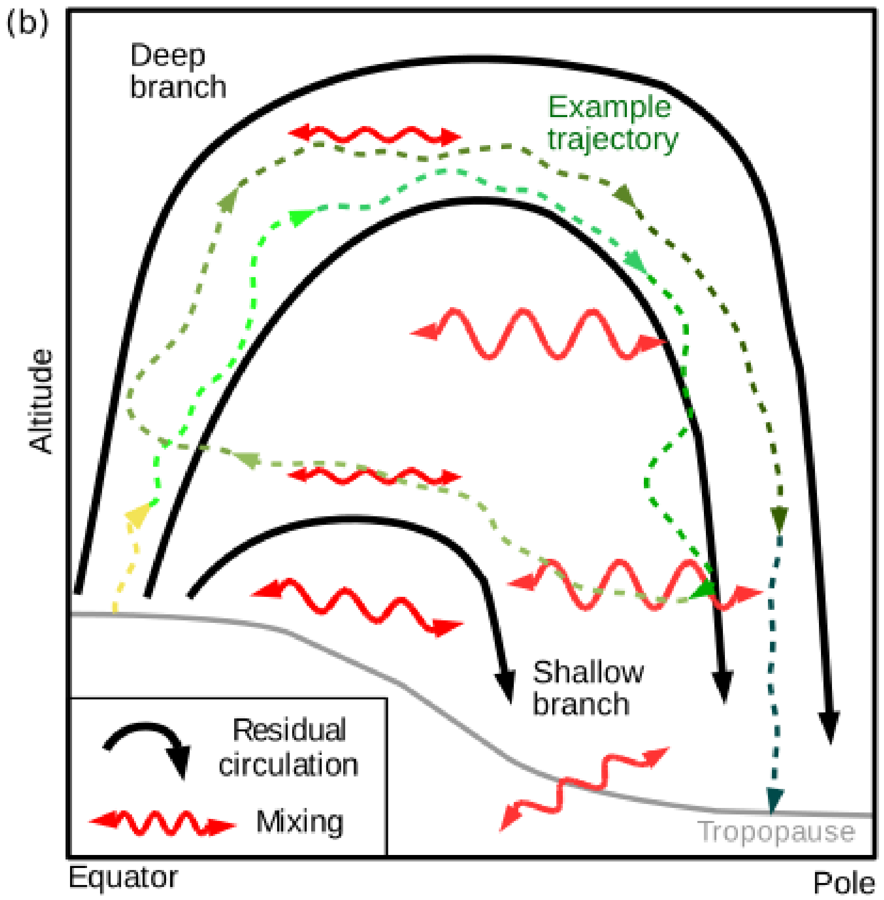

Adapted from Maycock et al. (2018) JGR




MSU-Channel 4, 13-22 km

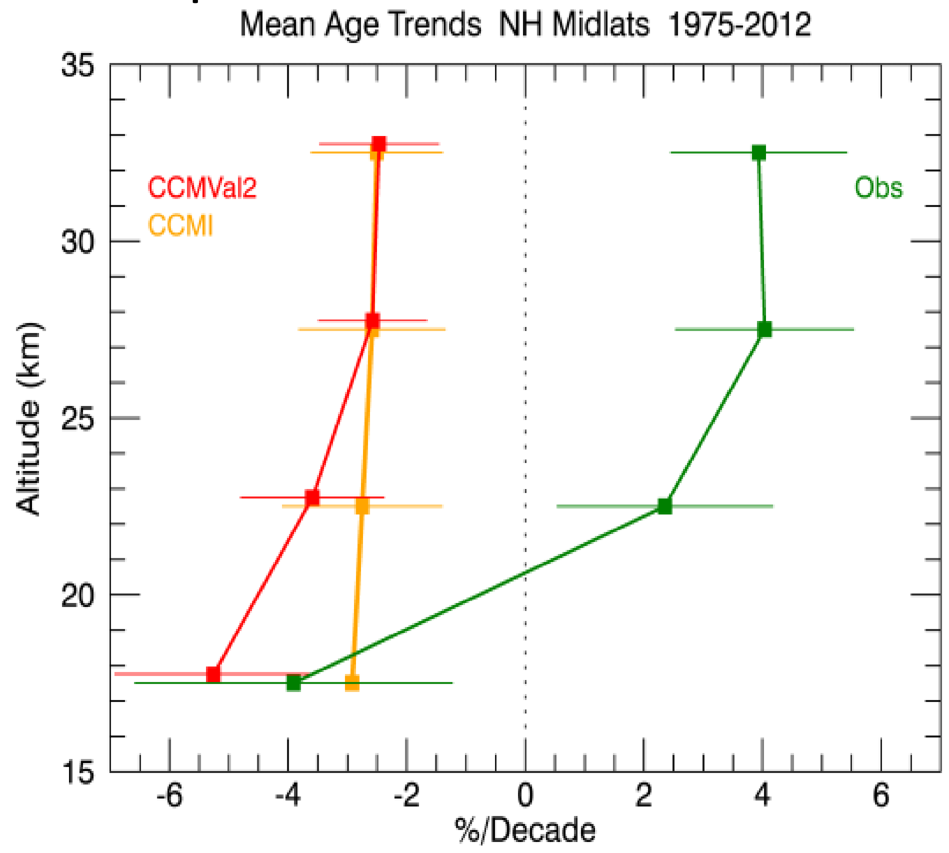
Ozone changes can lead to circulation changes, and circulation changes can lead to ozone changes. One parameter we can use to examine those changes is mean age of air, which gives the average amount of time a parcel has spent in the stratosphere.



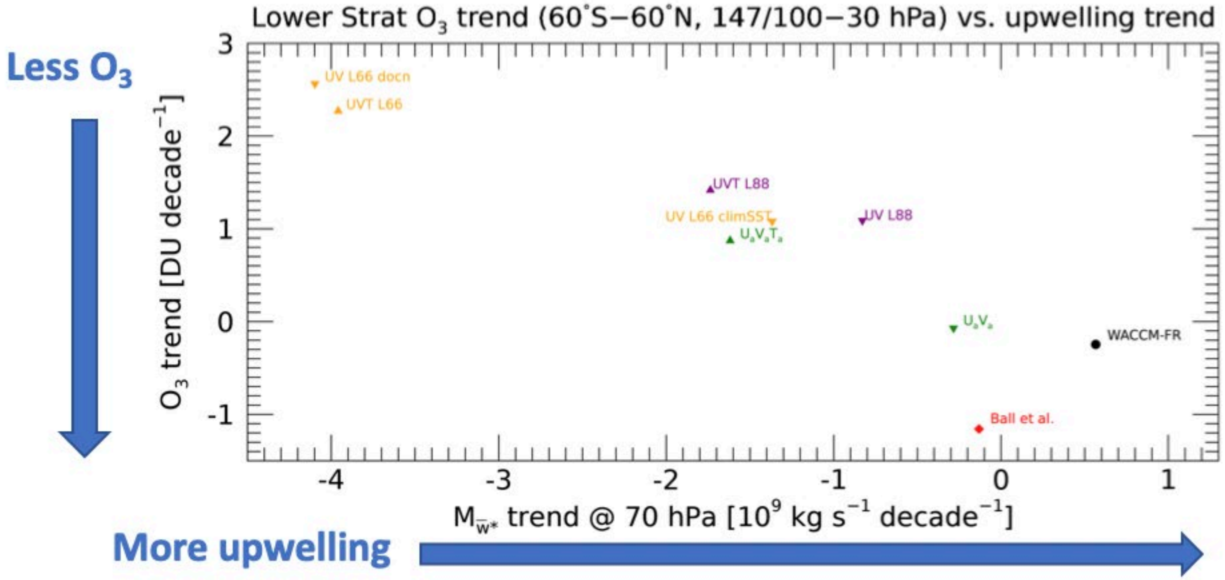



# Chapter 5: Ozone and Climate: Circulation (2)

There are indications that the stratospheric overturning circulation in the lower stratosphere has accelerated over the past few decades.



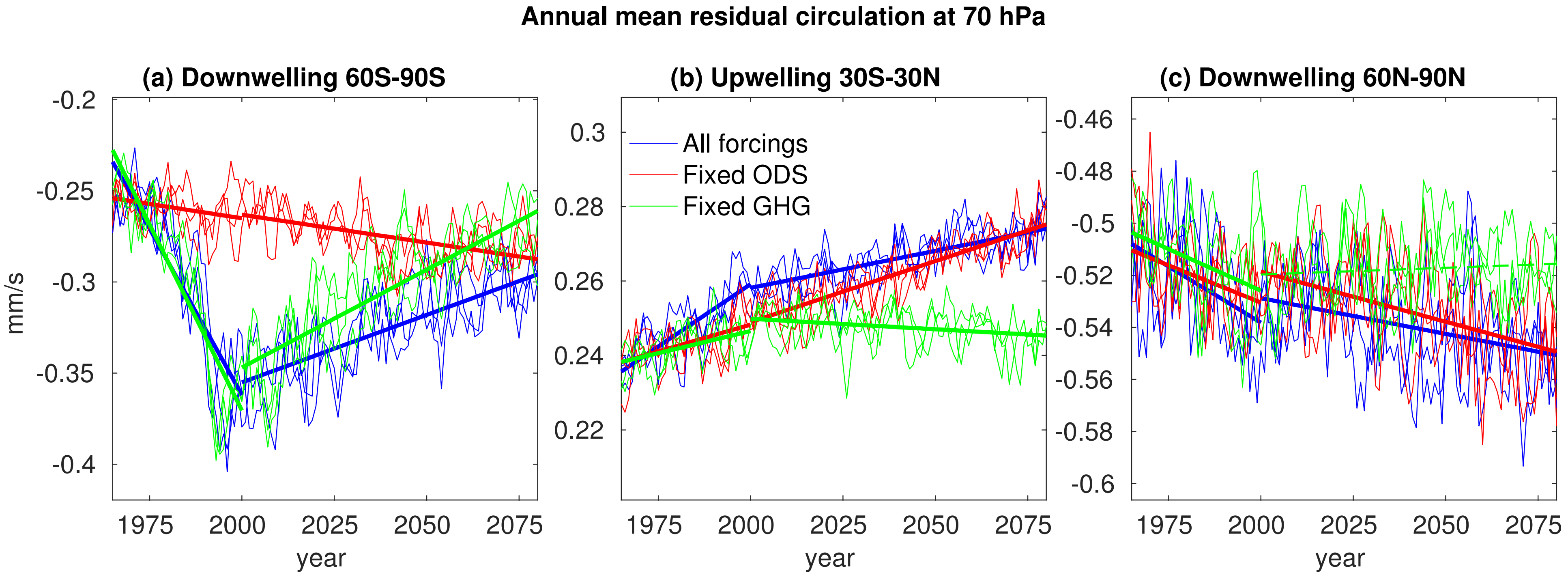

Observations and models both indicate acceleration (or a decrease in age of air) in the lower stratosphere (Ray et al, 2014, JGR)




Ozone trends (LS column) plotted against upwelling strength in a variety of nudged models. (figure by Nick Davis)

# Chapter 5: Ozone and Climate: Circulation (3)

Model studies attribute the acceleration over the end of the 20th century to changes in $O_3$ that are a consequence of ODS increases. Changes in $O_3$ due to decreases in ODSs drive future changes in circulation strength in models, with changes in downwelling the Antarctic a major contributor at the end of the 20th century.

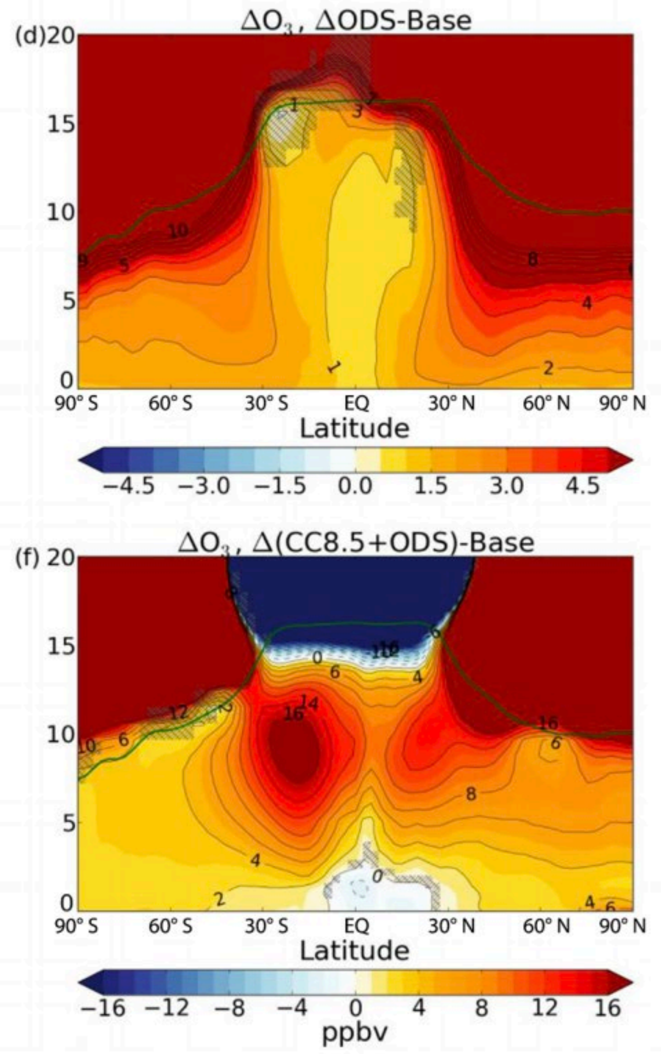



Adapted from Polvani et al. (2018) GRL.

# Chapter 5: Ozone and Climate: Tropospheric Impacts (1)

Increases in the strength of the stratospheric overturning circulation coupled with decreases in ODSs are expected to increase the flux of ozone into the troposphere.

The bottom panel shows circulation induced increases in ozone (RCP 8.5) between 2100 and 2000, while the top panel shows the contribution just due to declining ODSs. Both show increases in tropospheric ozone. (from Banerjee et al., 2016, ACP)

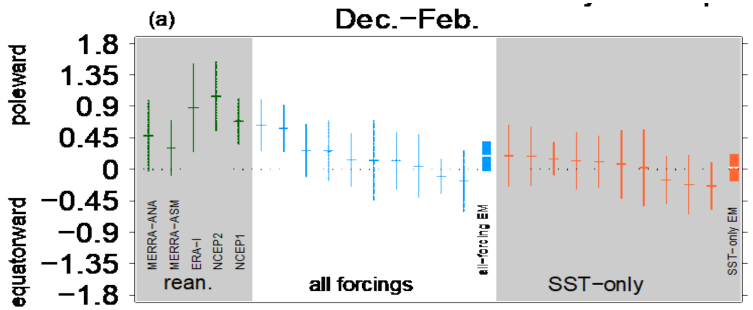


# Chapter 5: Ozone and Climate: Tropospheric Impacts (2)

Antarctic ozone depletion was the dominant driver of the changes in Southern Hemisphere tropospheric circulation in DJF during the late 20th century, with associated weather impacts.

1) Poleward shift of the midlatitude jet
2) Poleward shift of the Hadley Cell edge

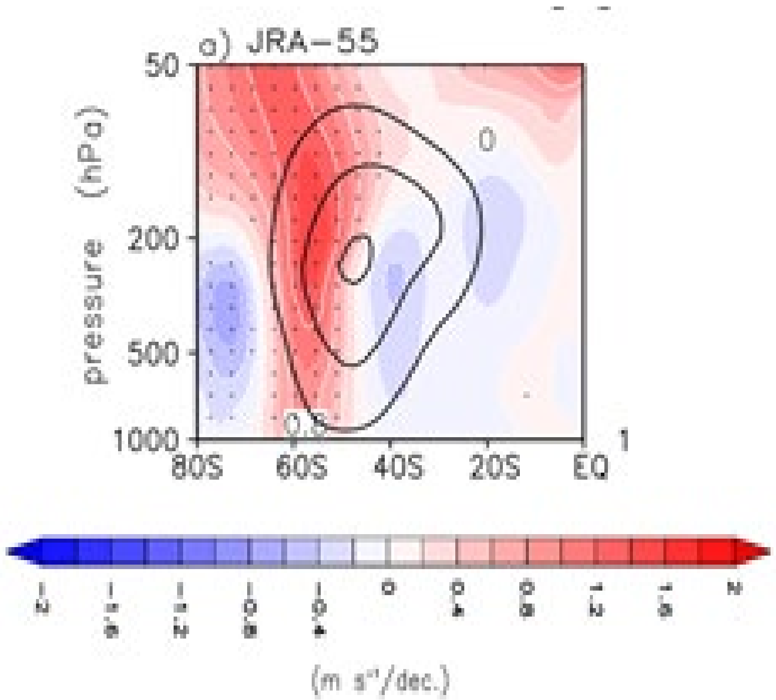
**SH Hadley Cell edge trend @ 500 mb**




1980-1999 deg/dec

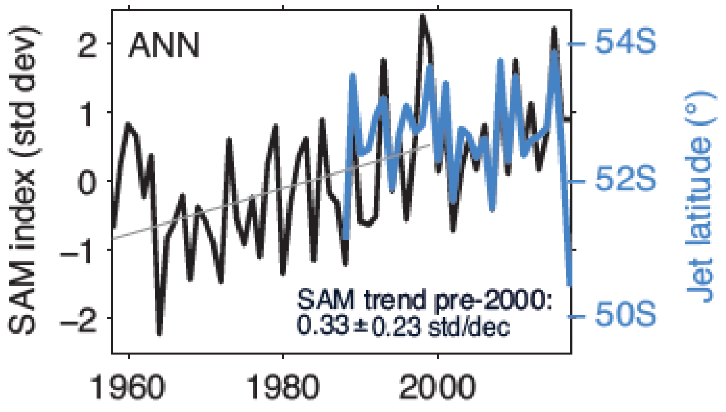
Adapted from Garfinkel et al. (2015), GRL

**Trend in DJF U**



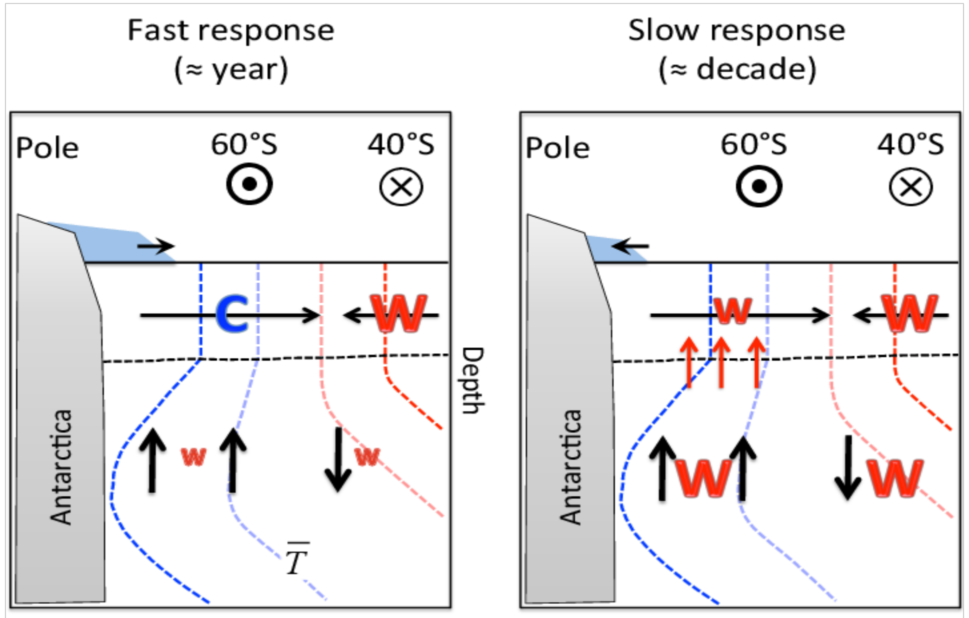

Adapted from Son et al. (2018) ERL

Observed Changes in the Southern Hemisphere Circulation

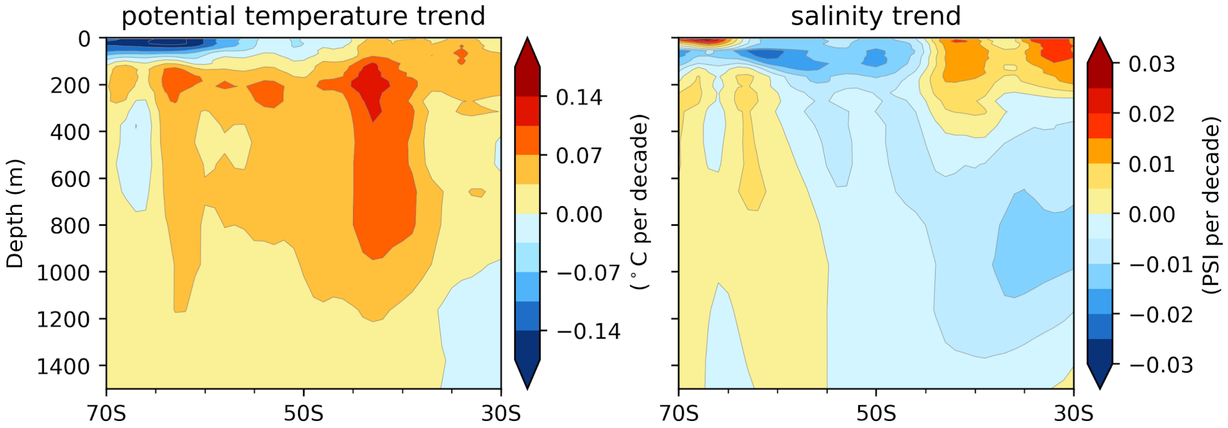


Changes in tropospheric weather patterns driven by ozone depletion have played a role in recent temperature, salinity, and circulation trends in the Southern Ocean.

Change in $O_3$ leads to a change in tropospheric winds, which then leads to a change in wind stress at the surface, which further leads to ocean circulation changes.



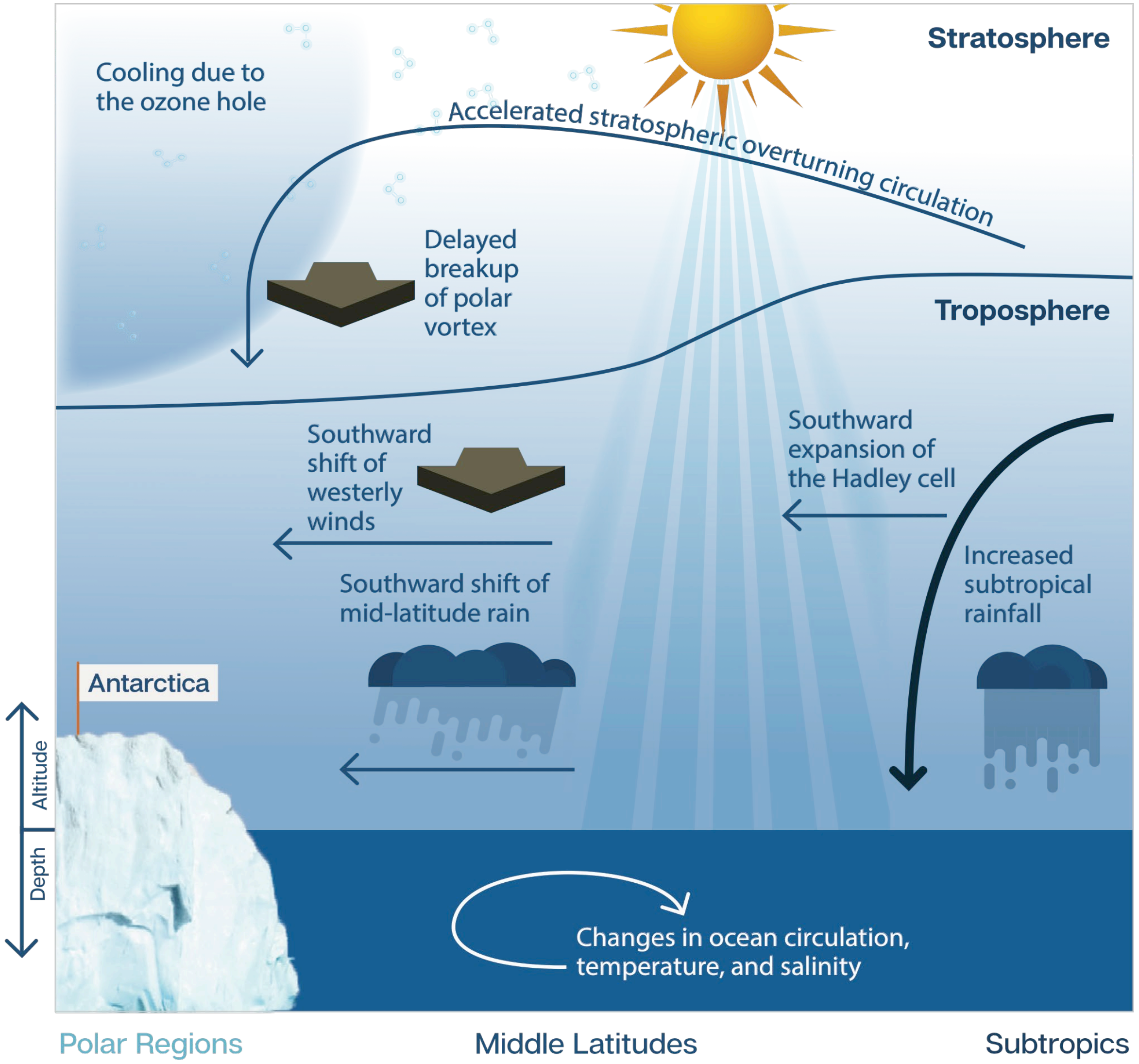

Adapted from Ferreira et al. (2015), J. Climate




From Good et al. (2013) JGR

# Chapter 5: Ozone and Climate: Summary schematic

## Antarctic Ozone Depletion Impacts on Summer Southern Hemisphere Climate




Ozone depletion has cooled the Antarctic stratosphere, leading to a delayed breakup of the stratospheric polar vortex and an accelerated stratospheric overturning circulation. Impacts extended into the troposphere: A region of strong westerly winds and associated rainfall shifted southward, affecting the ocean circulation. The subtropical edge of the tropical circulation also expanded poleward, leading to reduced precipitation in mid-latitudes and enhanced precipitation in the subtropics.

# 2022 Assessment: Ozone and Climate: Potential topics

1) Reconciling model results relating ozone depletion and Antarctic sea ice extent with the measurements.
2) Assessing connections (if they exist) between ozone trends and northern hemisphere climate
3) Quantifying the climate effects of the Kigali amendment to the Montreal Protocol. (2016 amendment that phases down global HFC use, HFCs are ODS substitutes that do not impact ozone but are greenhouse gases)
4) Assessing impacts on the ozone layer if climate intervention in the form of stratosphere aerosol injection were to occur. (This will likely be a new chapter requested by the Parties. (terms of reference are being negotiated now.)