OZONE AND CLIMATE

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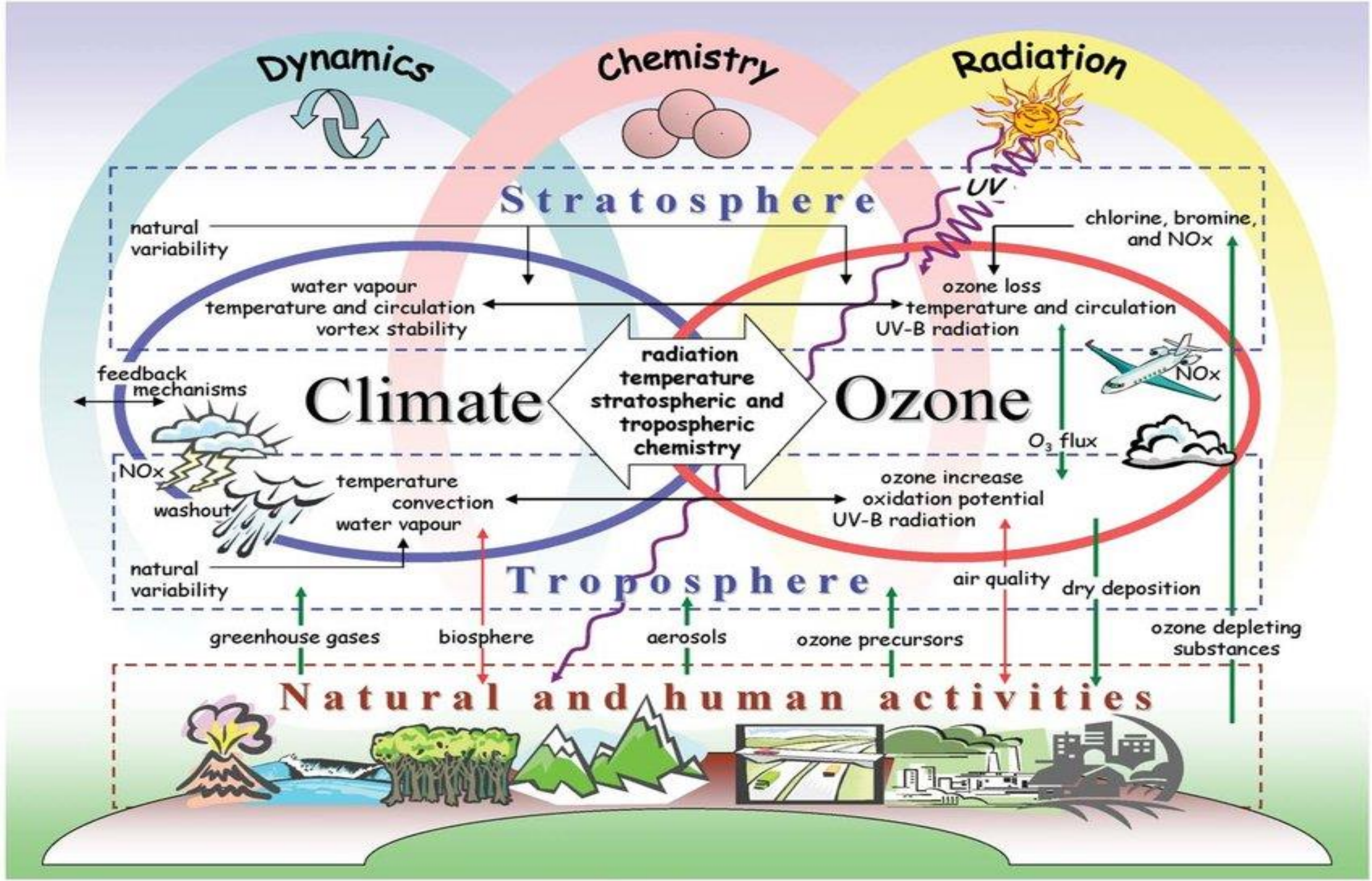
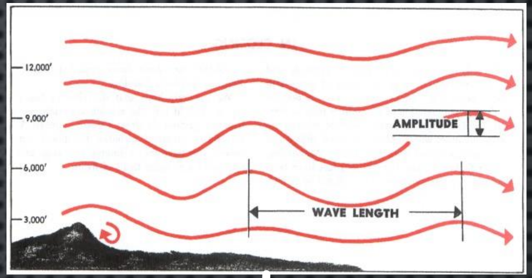
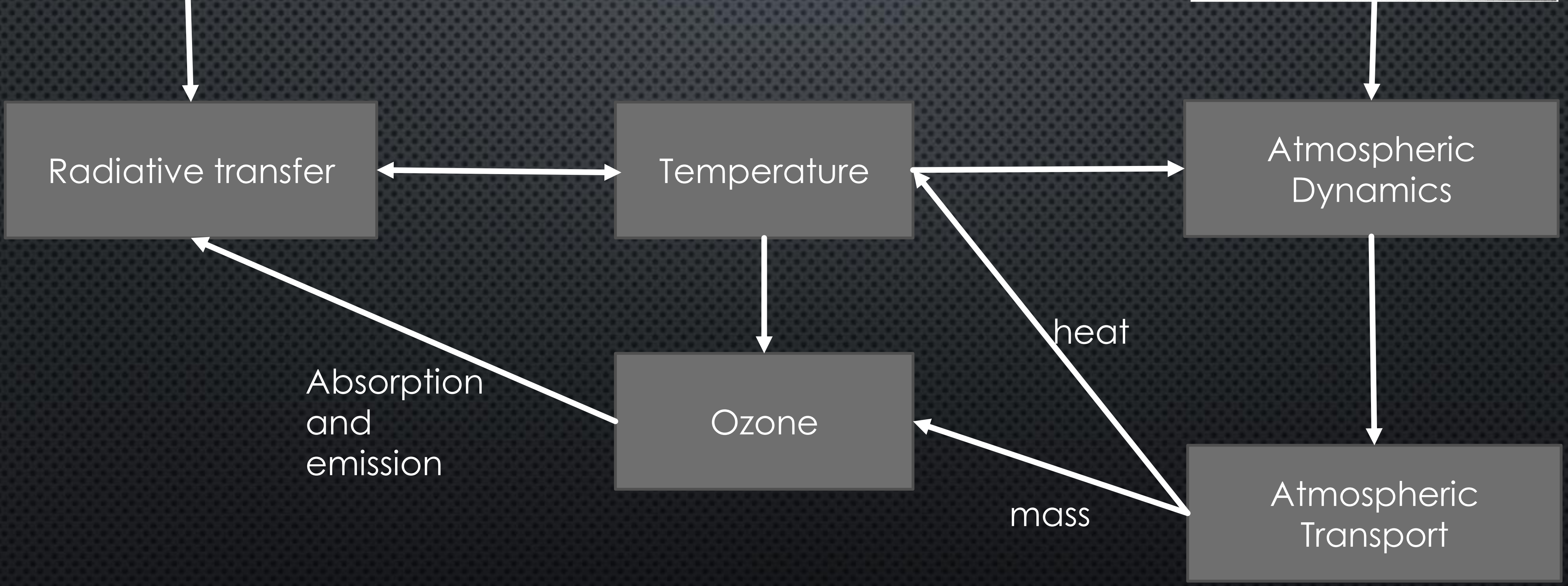

Dynamics
Chemistry
Radiation
UV
Stratosphere
natural variability
chlorine, bromine, and NOx
water vapour
temperature and circulation
vortex stability
ozone loss
temperature and circulation
UV-B radiation
feedback mechanisms
Climate
radiation
temperature
stratospheric and tropospheric chemistry
Ozone
NOx
O_3 flux
NOx
washout
temperature
convection
water vapour
ozone increase
oxidation potential
UV-B radiation
natural variability
Troposphere
air quality
dry deposition
greenhouse gases
biosphere
aerosols
ozone precursors
ozone depleting substances
Natural and human activities

THE PROCESSES

Forcing and Coupling in the stratosphere

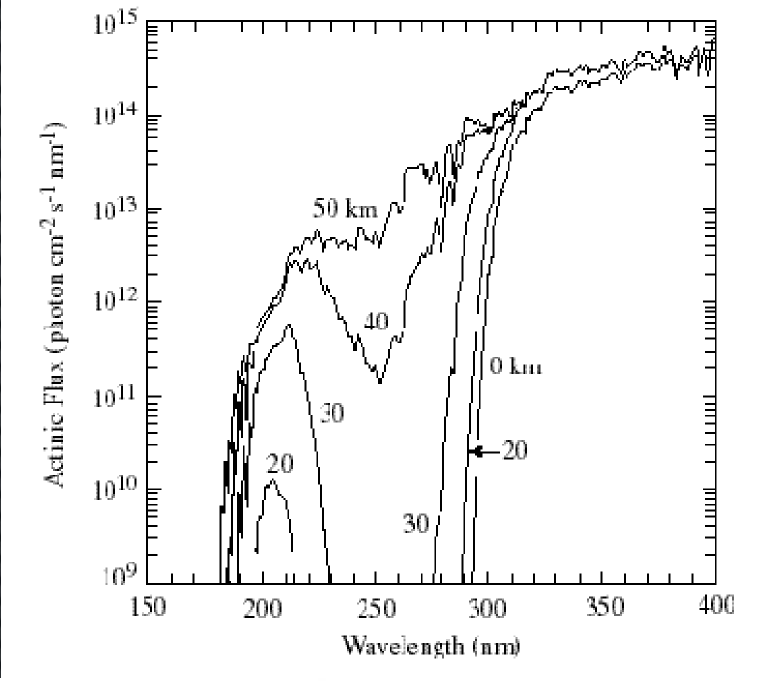


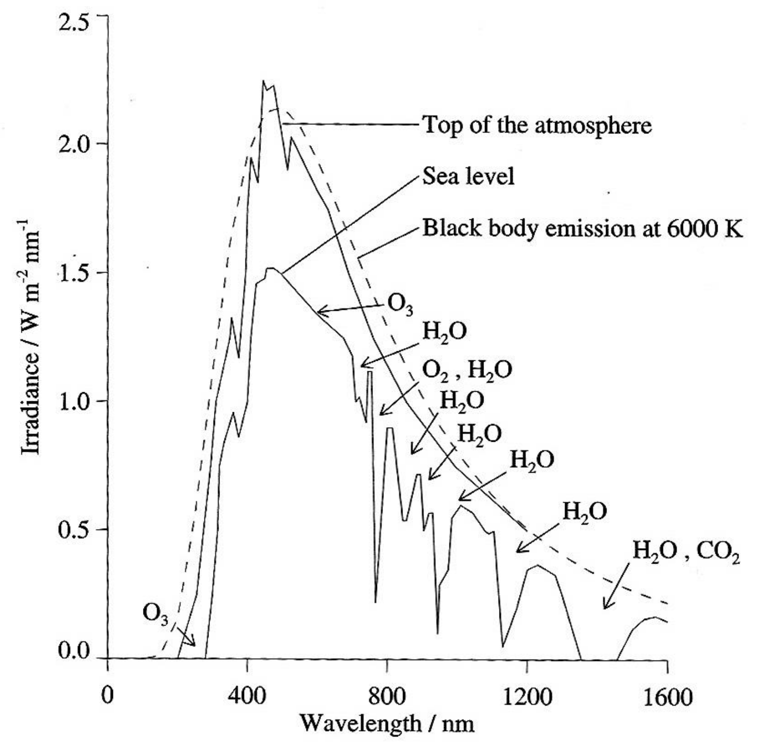


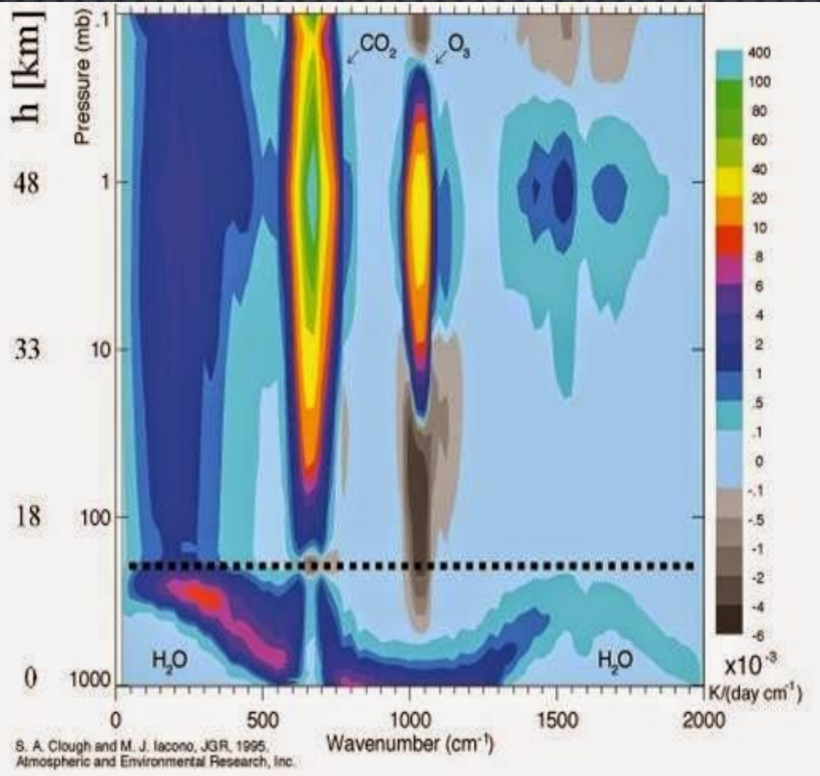
CLIMATE CHANGE ALTER THE STRATOSPHERIC OZONE DISTRIBUTION

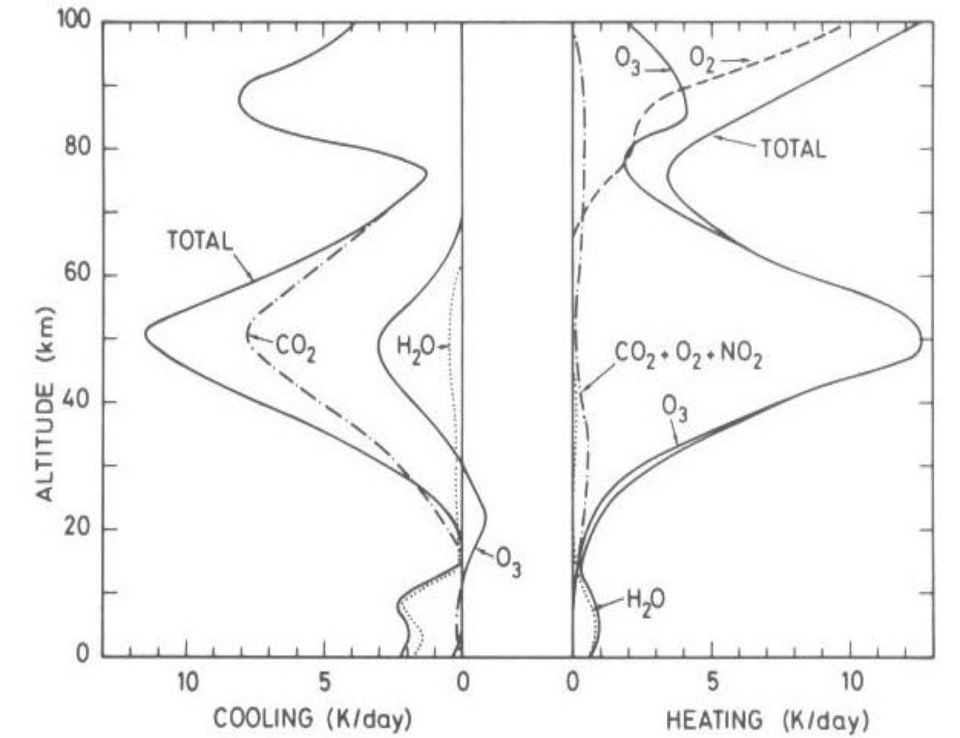
- CHEMICAL REACTIONS ARE TEMPERATURE DEPENDENT: COOLING OF THE STRATOSPHERE SLOWS DOWN OZONE DESTRUCTION
- COOLING OF THE WINTERTIME POLAR LOWER STRATOSPHERE INCREASES THE OCCURRENCE OF POLAR STRATOSPHERIC CLOUDS WITH ENHANCED POLAR OZONE DESTRUCTION
- CHANGES IN STRATOSPHERIC CIRCULATION AFFECT TRANSPORT OF OZONE DEPLETING SUBSTANCES AND THEIR LIFETIMES.
- CHANGES IN TRANSPORT AND TEMPERATURES AFFECTS WATER VAPOR INPUT TO THE STRATOSPHERE AS WELL AS TRANSPORT OF OZONE IN THE STRATOSPHERE AND THROUGH THE TROPOPAUSE

OZONE ABSORBS SOLAR ULTRAVIOLET RADIATION AND INTERACT WITH INFRARED TERRESTRIAL RADIATION









The Chapman Mechanism (1929)

(J_{O2}); O_2 + UV light (< 242 nm) → O + O

(K_2); O + O_2 + M → O_3 + M

(J_{O3}); O_3 + UV light → O + O_2

(K_3); O + O_3 → 2 O_2

The loss reaction O + O_3 is strongly sensitive to temperature

THE RELATION BETWEEN TEMPERATURE AND OZONE IN THE UPPER STRATOSPHERE (CHAPMAN MECHANISM)

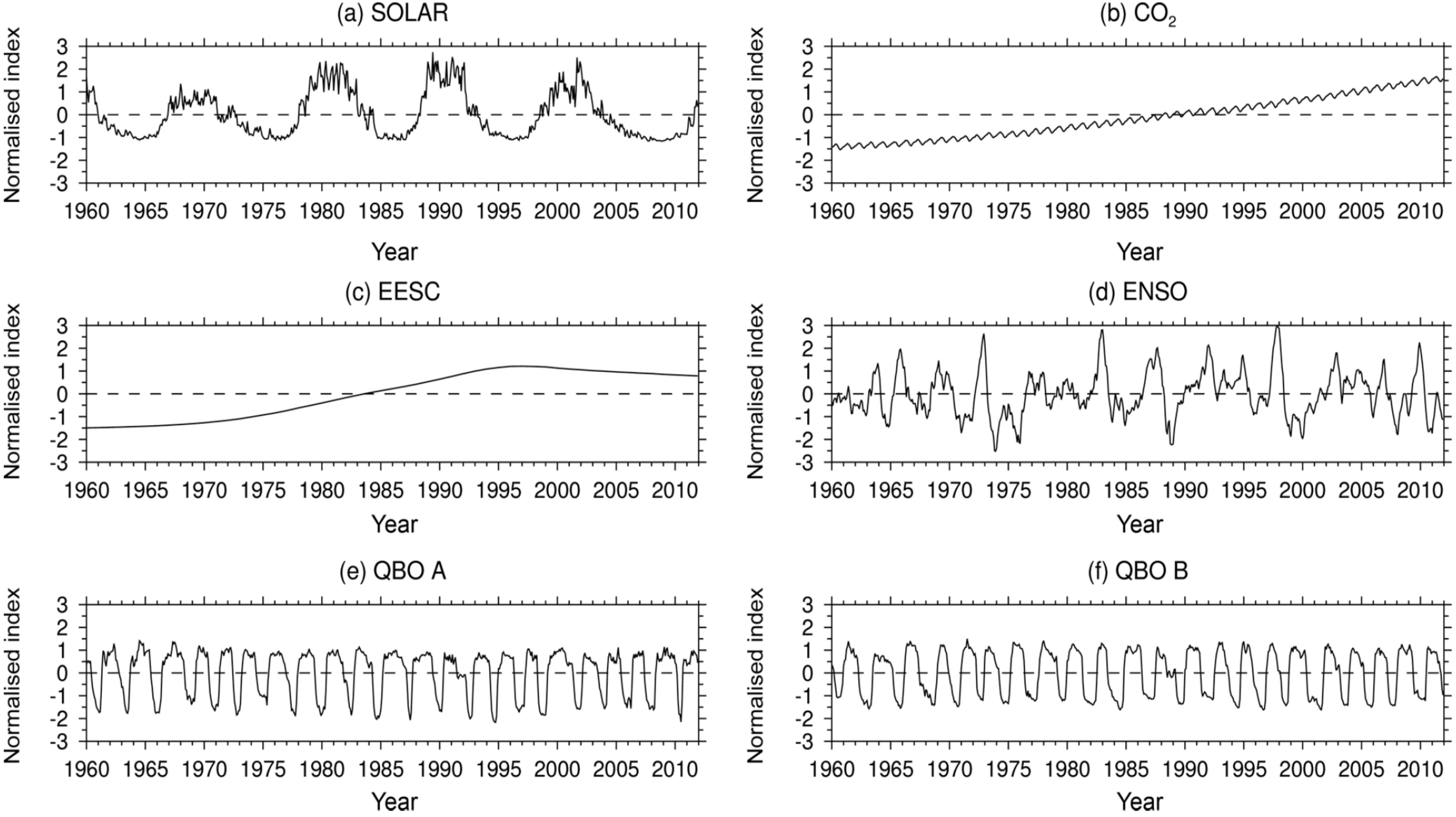
$$\Delta T = \frac{Heating}{\alpha} \frac{\Delta O_3}{O_3}$$

where Heating (solar) = 10 K/day and
radiative relaxation rate (infrared) α = 0.2/day

An ozone reduction of 20% leads to a temperature decrease of 10 K

$$\frac{\Delta O_3}{O_3} = \frac{1}{2} \frac{\Delta (k_2/k_3)}{k_2/k_3} = -\frac{1400}{T^2} \Delta T$$

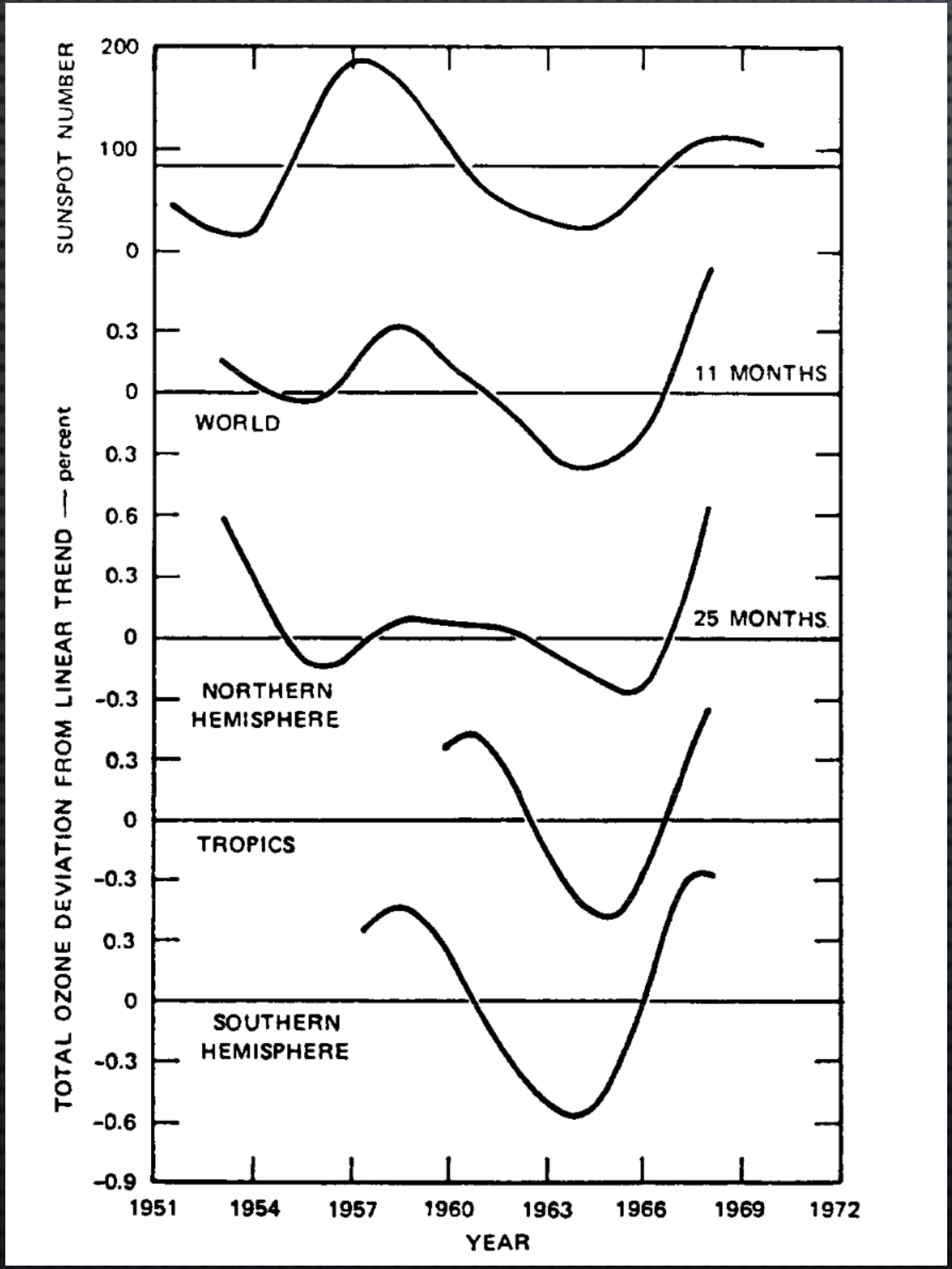
A temperature increase of 10 K produces a decrease of 20% in ozone



(a) SOLAR
(b) CO_2
(c) EESC
(d) ENSO
(e) QBO A
(f) QBO B
Normalised index
Year
3
2
1
0
-1
-2
-3
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

RESPONSE OF OZONE TO SOLAR VARIABILITY

EARLY STUDIES OF THE EFFECT OF SOLAR VARIABILITY ON STRATOSPHERIC OZONE



Angell

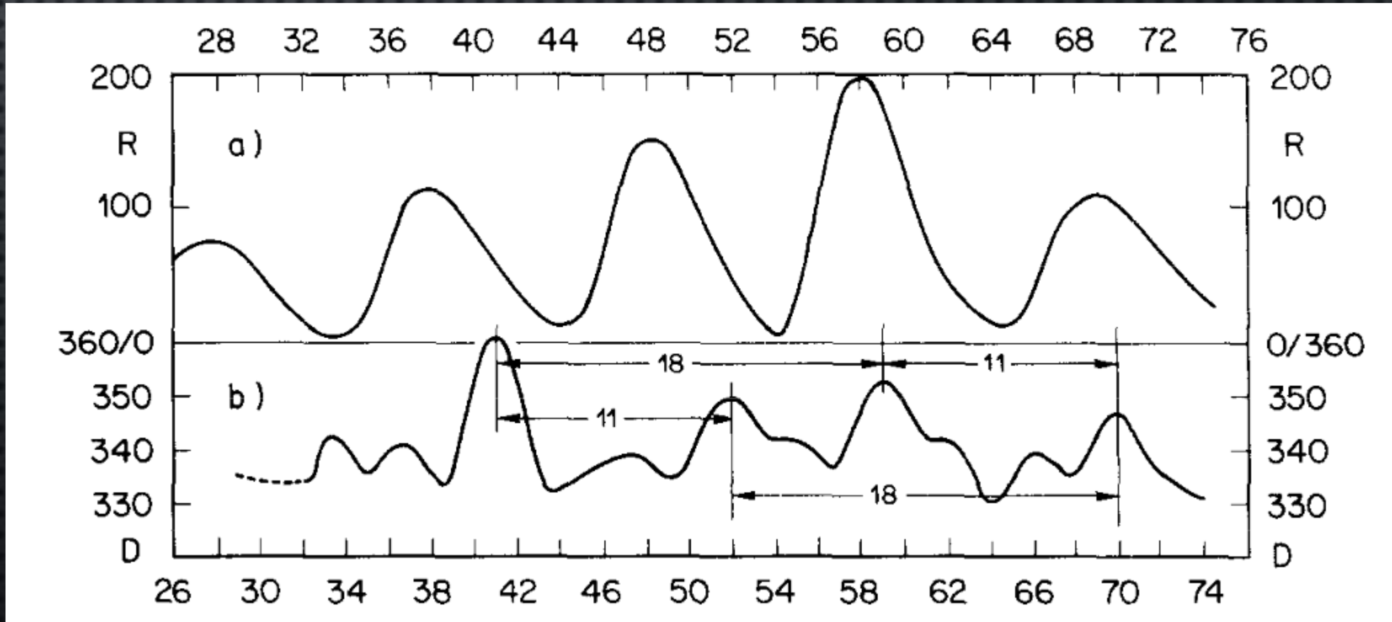
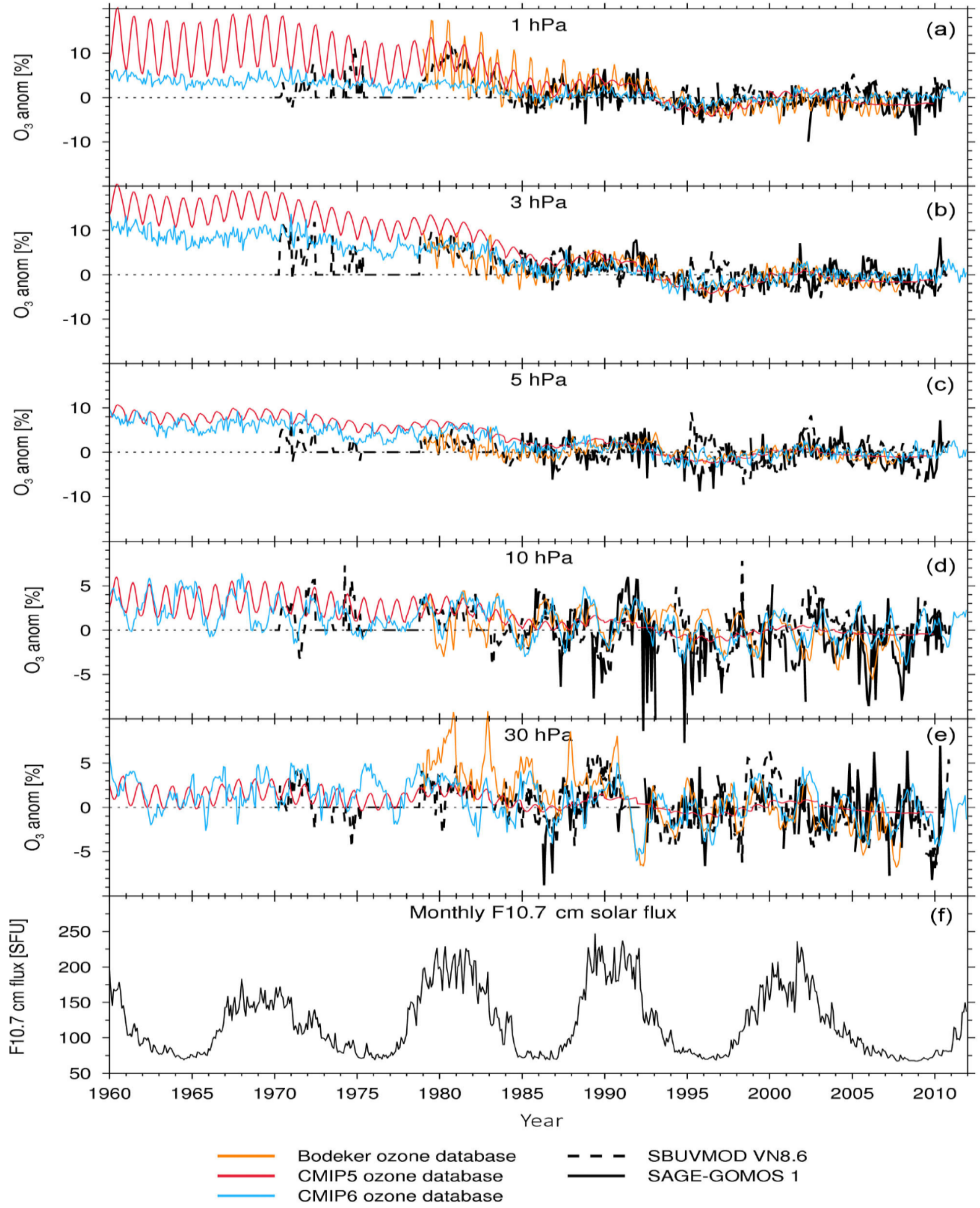


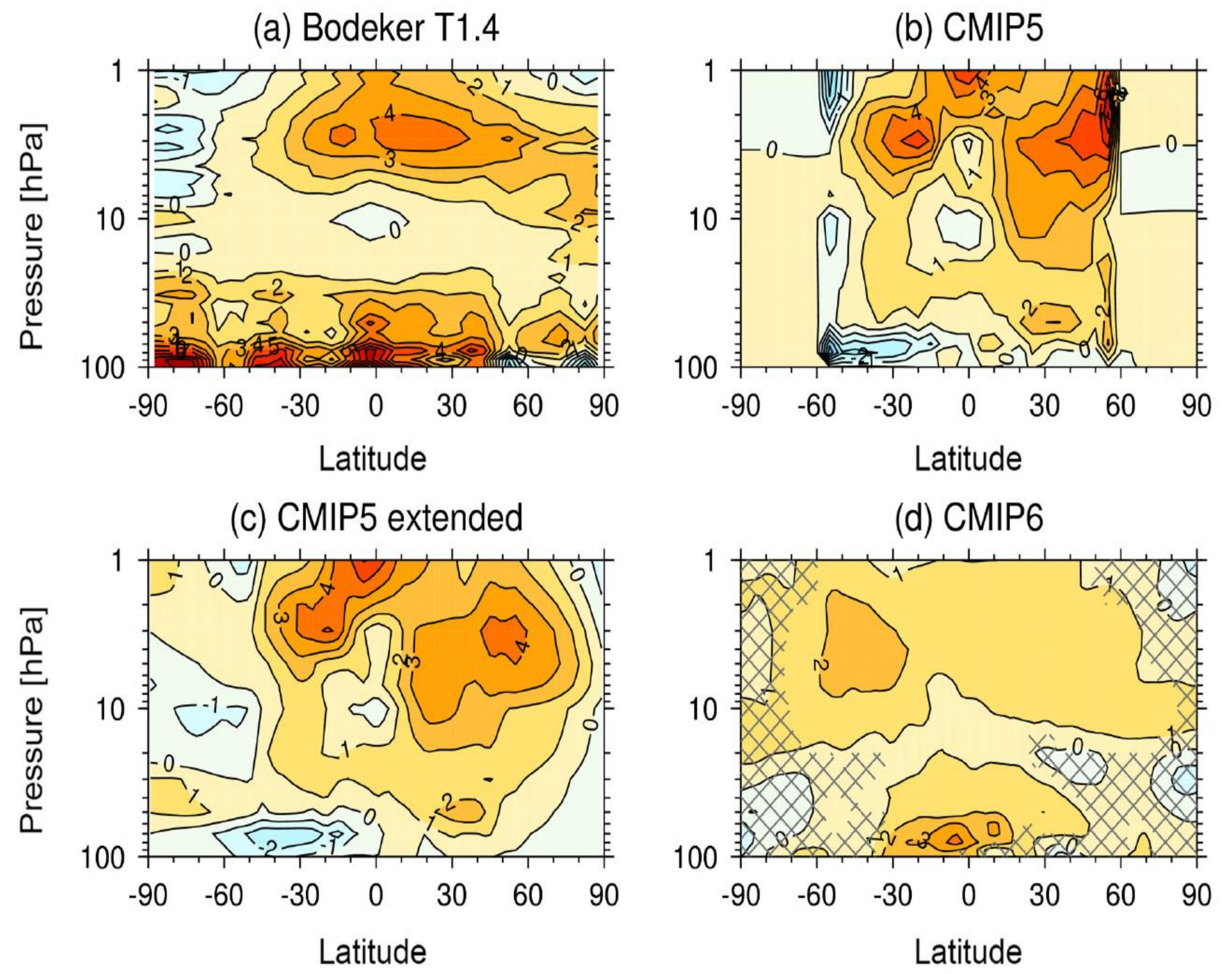
Fig. 4. Filtered series of sunspot number (a) and total ozone at Arosa (b).

Dutsch

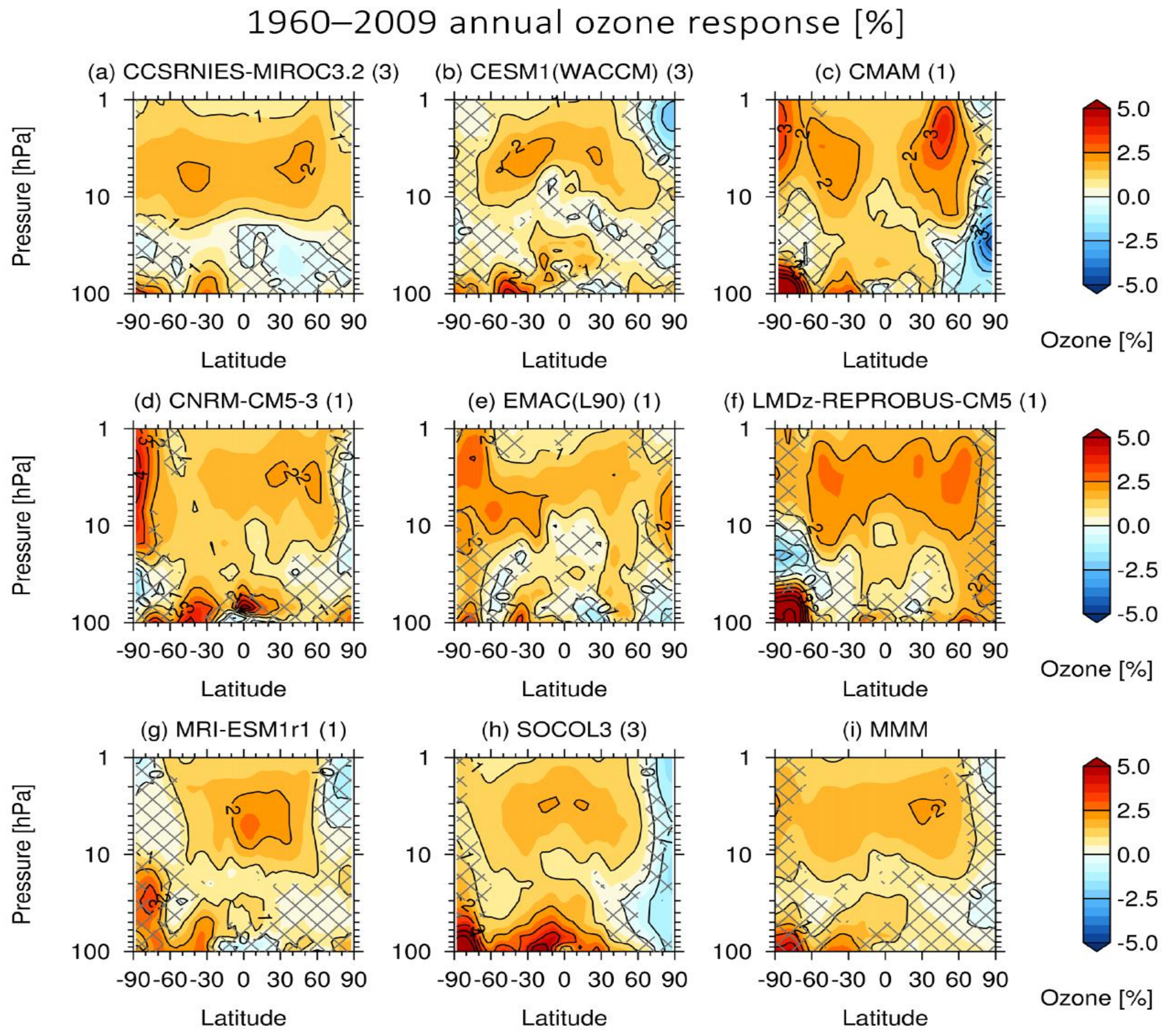
EVOLUTION OF OZONE AT DIFFERENT ALTITUDES BASED ON SPACE OBSERVATIONS AND ON MODEL SIMULATIONS



RESULTING RESPONSE OF OZONE TO11-YEAR SOLAR CYCLE

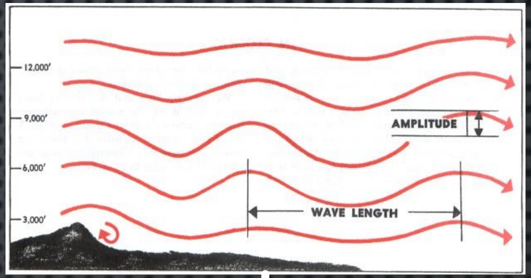


SIMULATED RESPONSE OF OZONE TO THE SOLAR CYCLE
[PERCENT]



THE RESPONSE OF OZONE TO HUMAN ACTIVITIES

Forcing and Coupling in the stratosphere



Radiative transfer

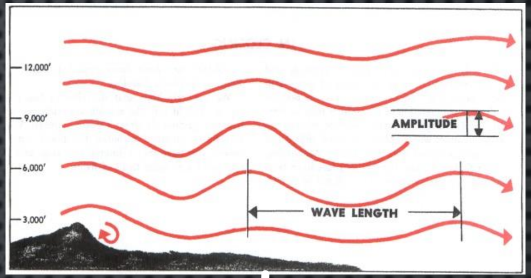
Temperature

Atmospheric Dynamics

Ozone

Atmospheric Transport

Forcing and Coupling in the stratosphere



Radiative transfer

Temperature

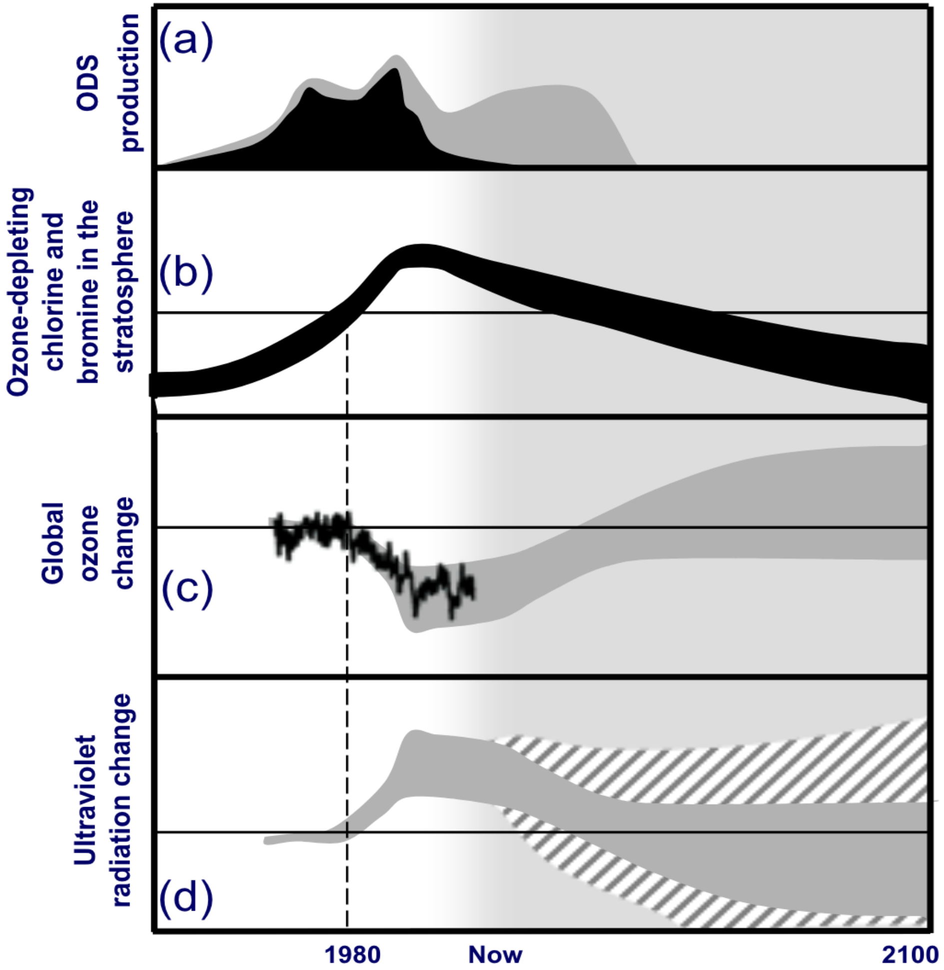
Atmospheric Dynamics

Ozone

Ozone depleting substances (CFCs)

Atmospheric Transport

Scientific Findings



ODS production

ODS in the atmosphere

Ozone levels- measured and predicted

UV levels- measured and predicted

"There is even stronger evidence since the 2002 Assessment that the Montreal Protocol is working"

Radiative Forcing

- Positive direct forcing due to all halocarbons:

  0.34 ± 0.03 W/m^2

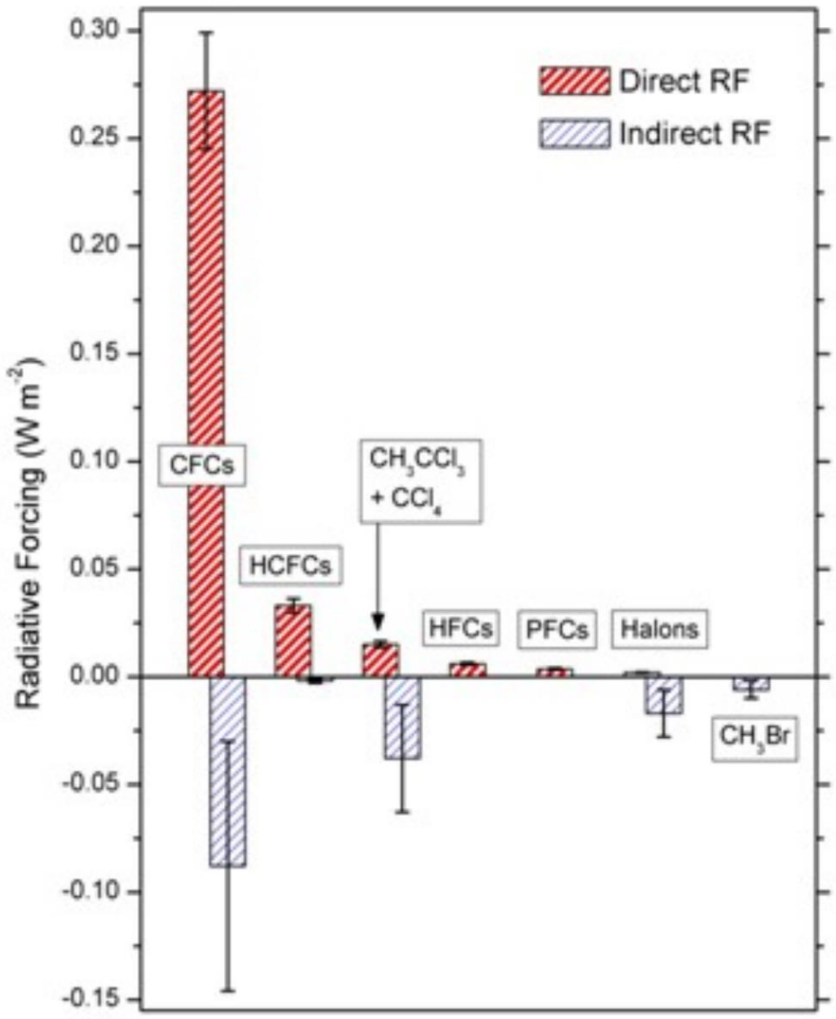
- Positive direct forcing due to ODSs only:

  0.33 ± 0.03 W/m^2

- Negative indirect forcing due to ozone depletion:

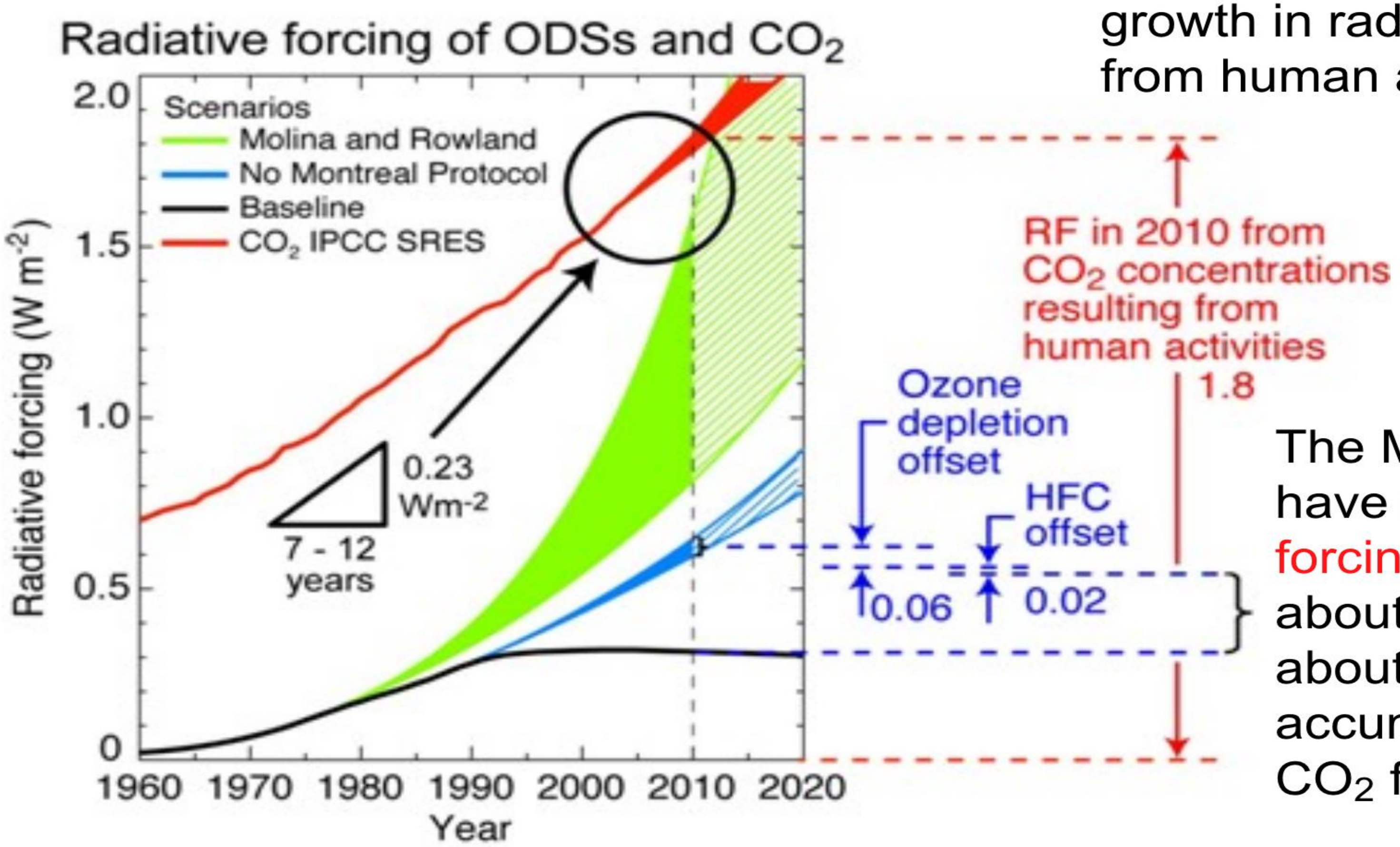
  -0.15 ± 0.10 W/m^2

- Different types of gases make different contributions to positive and negative forcing

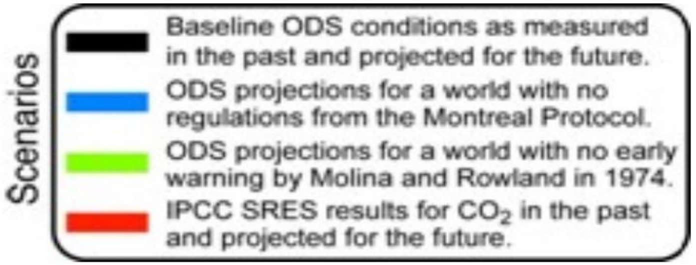


IPCC/TEAP 2005

The Montreal Protocol net reduction in ODS radiative forcing in 2010 will be equivalent to about **7-12** years of growth in radiative forcing of CO_2 from human activities.



The Montreal Protocol will have **reduced** net radiative forcing from ODSs in 2010 by about **0.23 Wm^{-2}**, which is about **13%** of that due to the accumulated emissions of CO_2 from human activities.



G. Velders *et al.*, PNAS, 2007

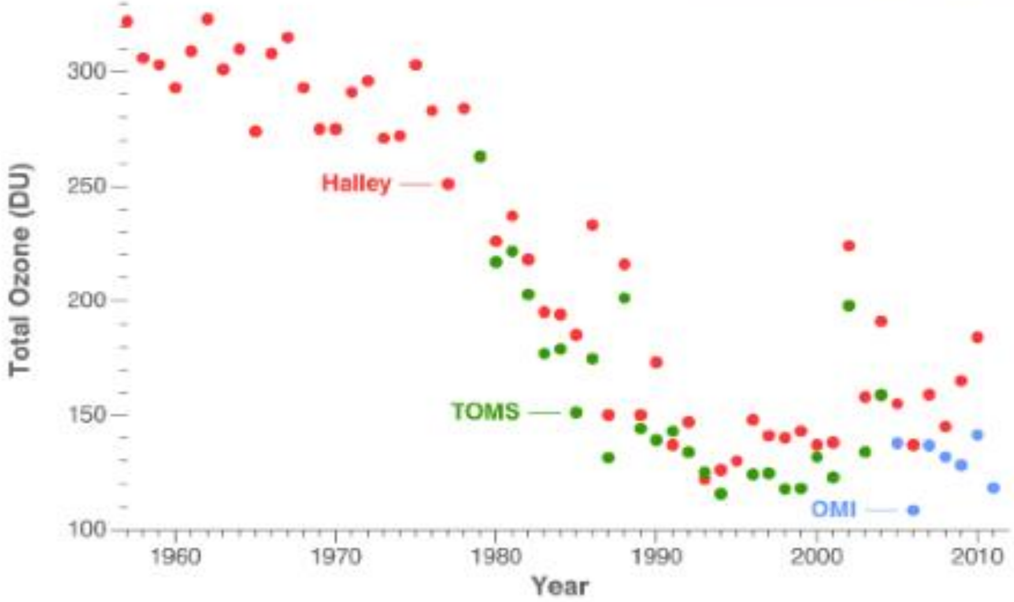
THE OZONE HOLE

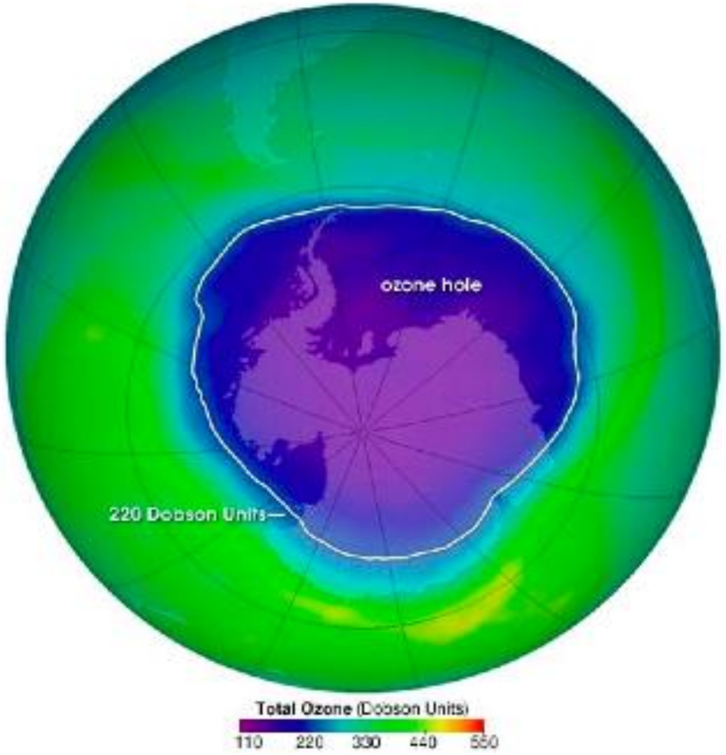
⇒ Ozone depletion over Antarctica of more than 50% compared to 1980 levels

⇒ Predominantly in spring months, impact on surface climate in summer

⇒ Recovery of the ozone hole projected by mid-late 21st Century

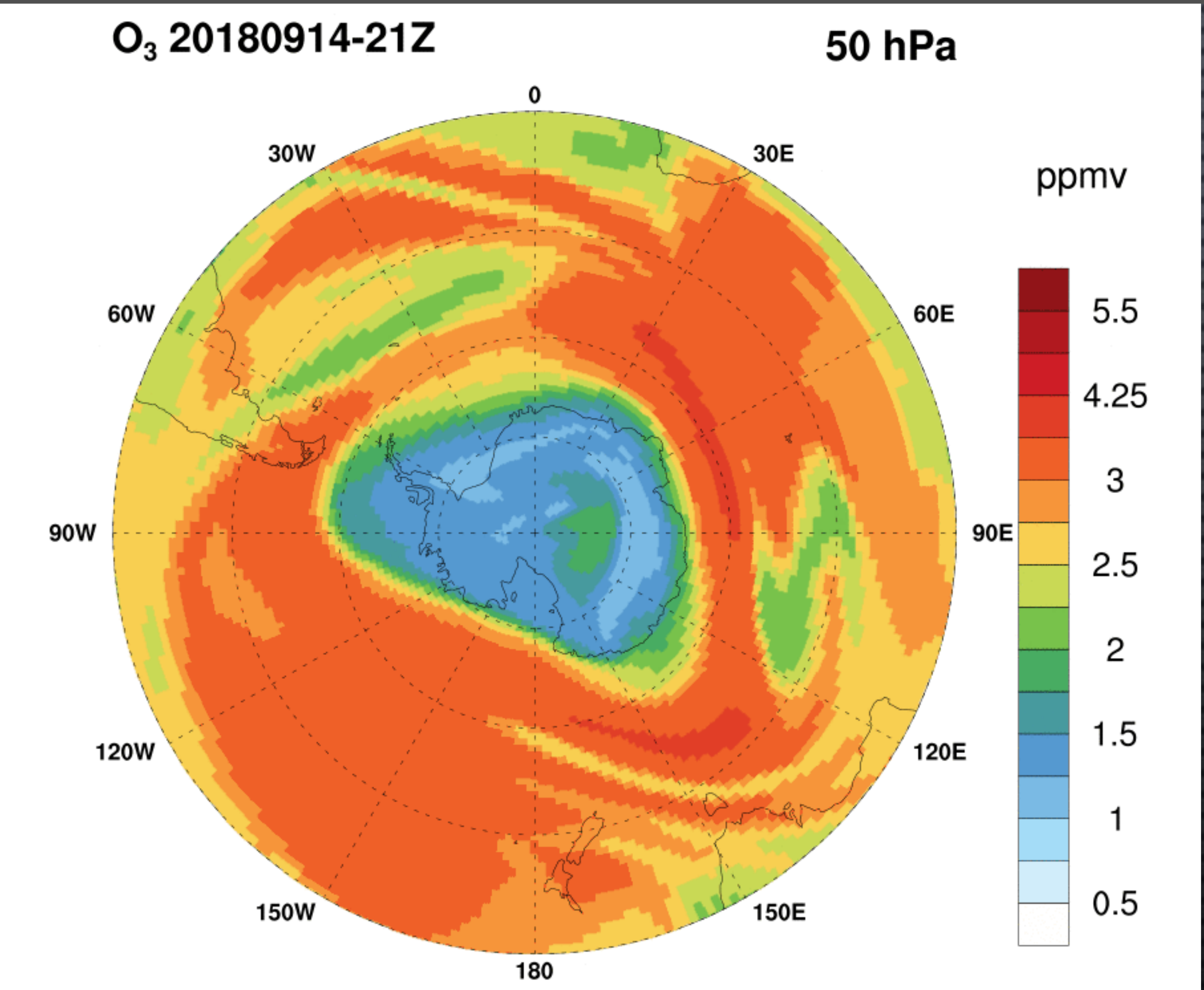
⇒ Stratospheric ozone has only a minor impact on global surface temperatures



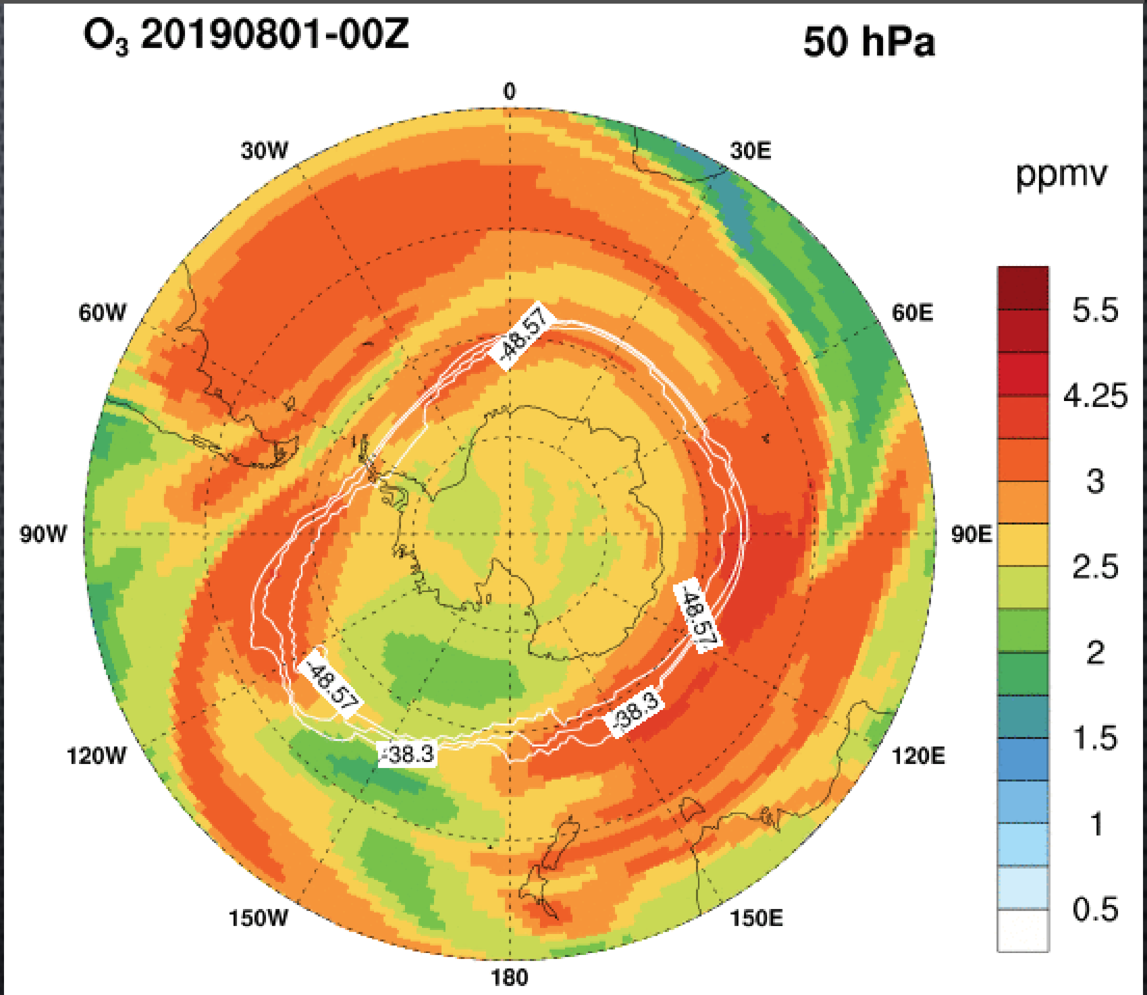


NASA

2018



2019



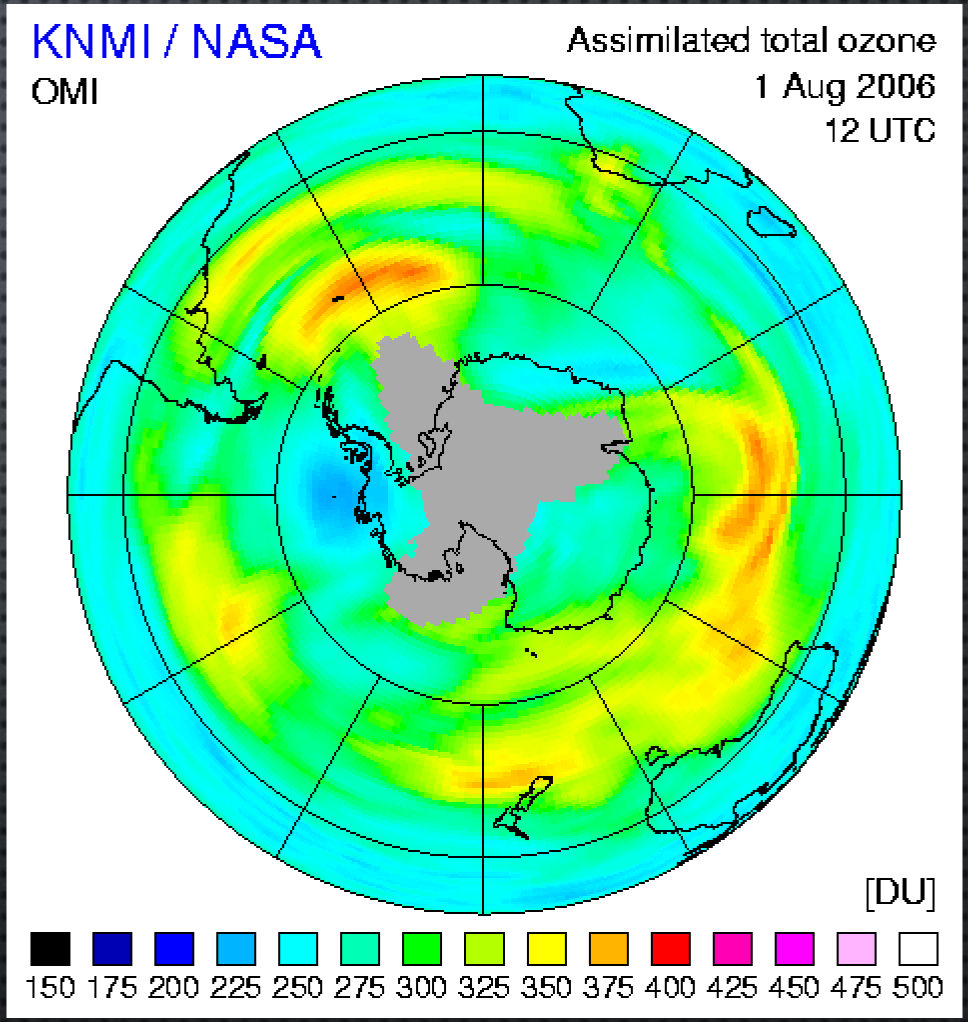
Simulation of the ozone hole by WACCM

THE SH DYNAMICAL RESPONSE TO THE OZONE HOLE

OZONE HOLE AND CLIMATE

- What is the impact of the stratospheric ozone hole in the Antarctic on the dynamics (vortex) and temperature of the southern hemisphere?

- How will the expected ozone recovery affect climate change?



Ozone hole 2006, measured by OMI on EOS-Aura
Veefkind et al., 2006

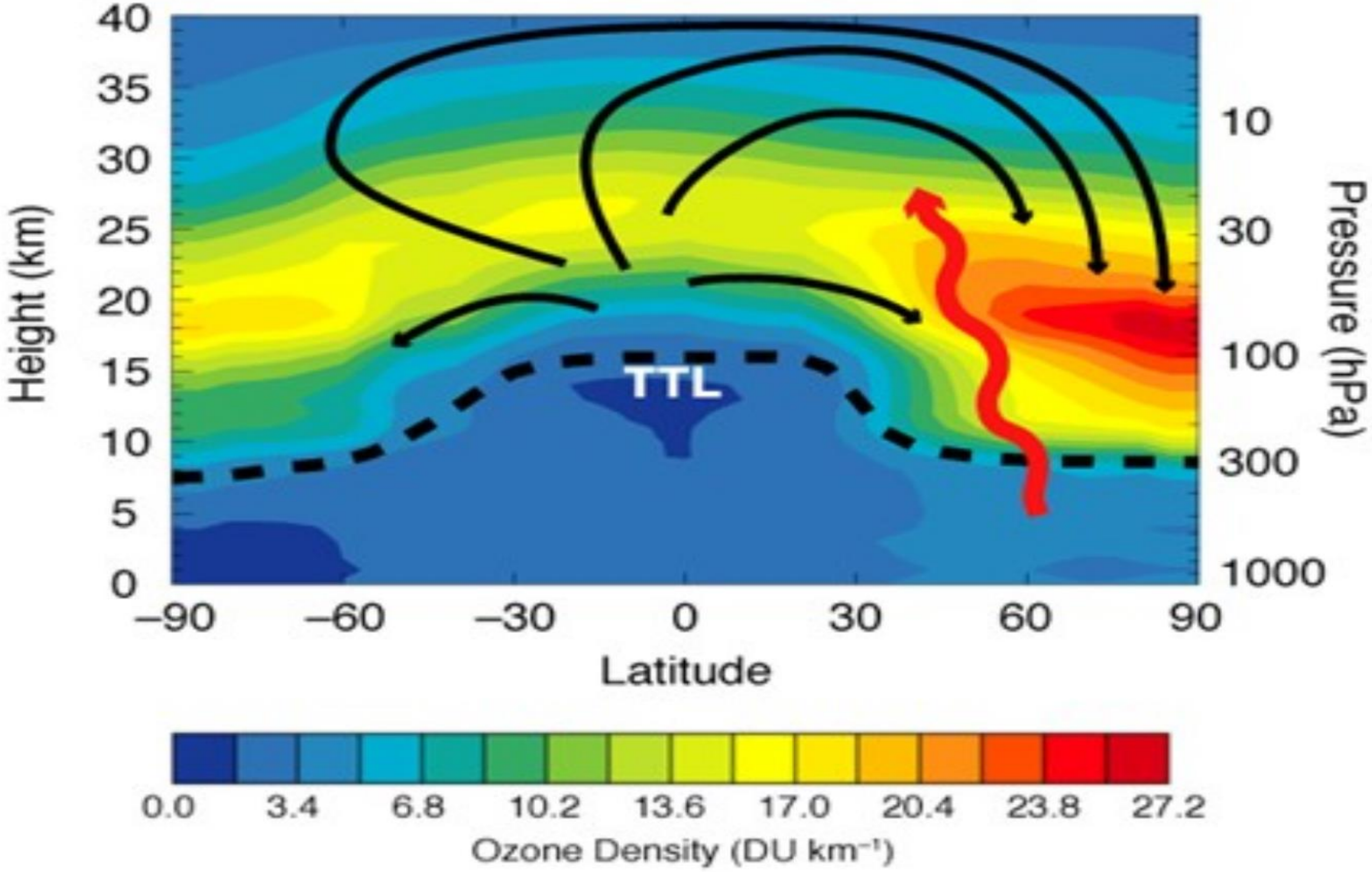
Impacts of anthropogenic changes on stratospheric dynamics in the Southern Hemisphere

The most prominent features of climate change in the southern hemisphere over the second half the the 20th century have been:

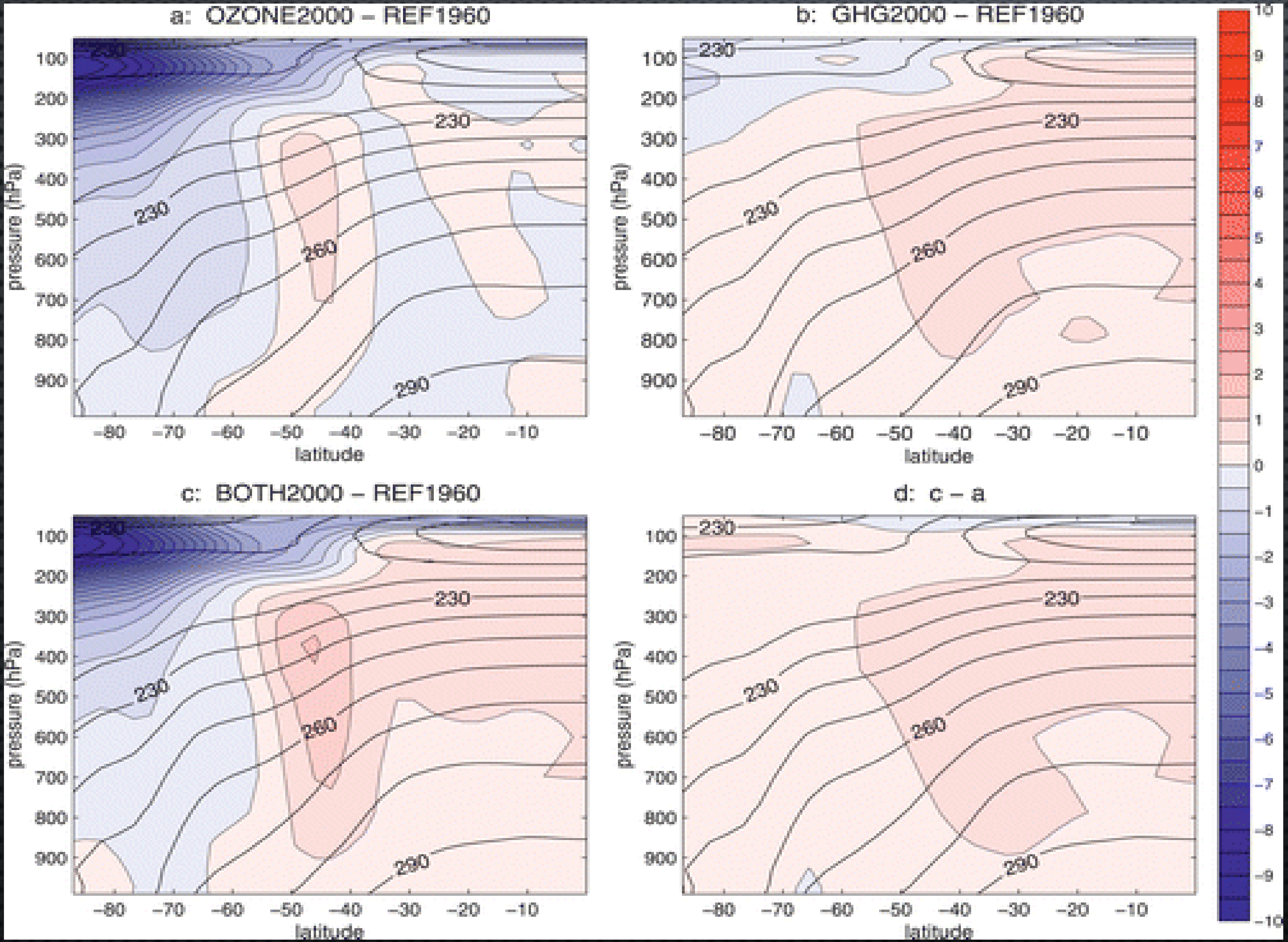
- A poleward shift of the mid-latitude SH jet and the related storm tracks
- A poleward shift of the edge of the Hadley circulation
- A poleward expansion of the subtropical dry zones

These changes are attributed to stratospheric ozone depletion and to greenhouse gas increases. The relative contribution of these two effects is debated.

Stratospheric Dynamics: Circulation and Waves



Ozone Depletion Increase in GHGs



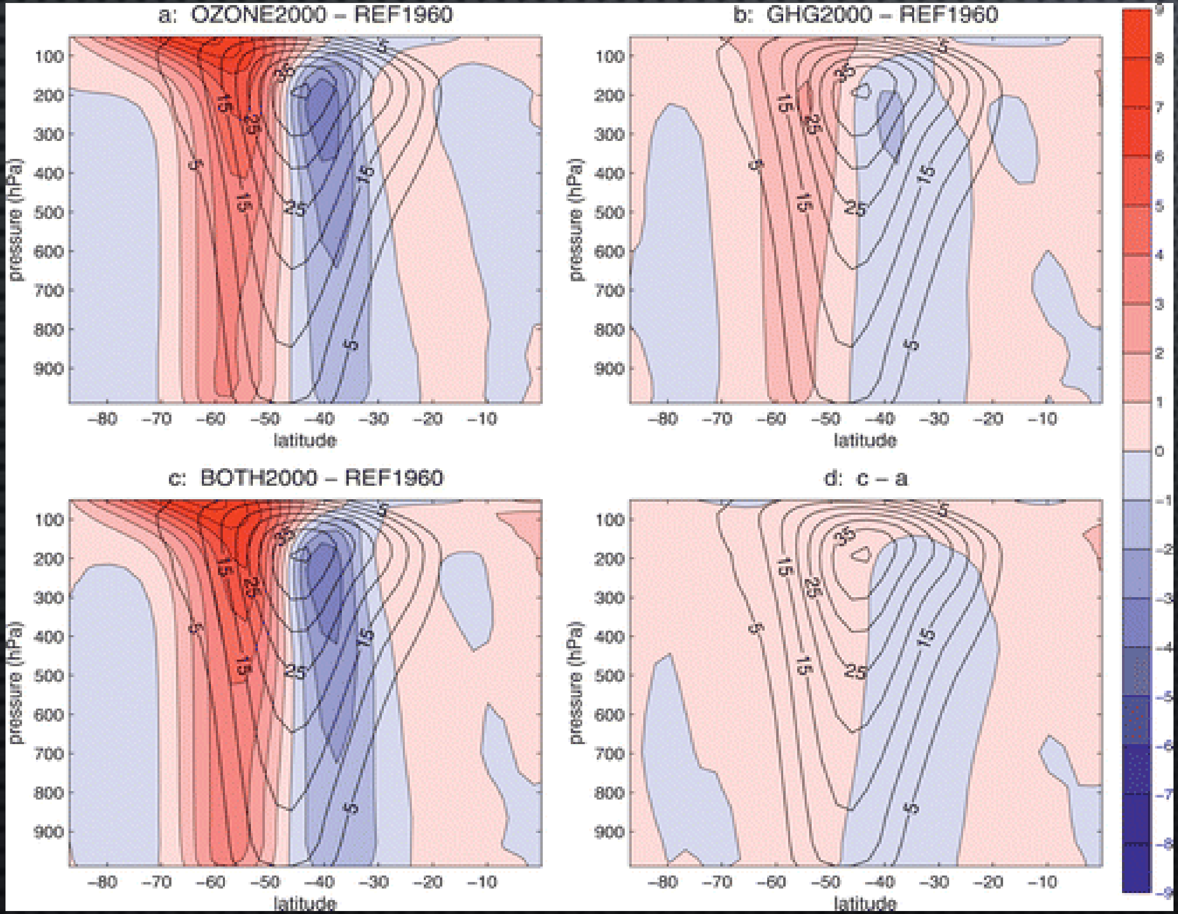
CHANGES (1960 -2000) IN TEMPERATURES DUE TO OZONE DEPLETION AND INCREASE IN GREENHOUSE GASES

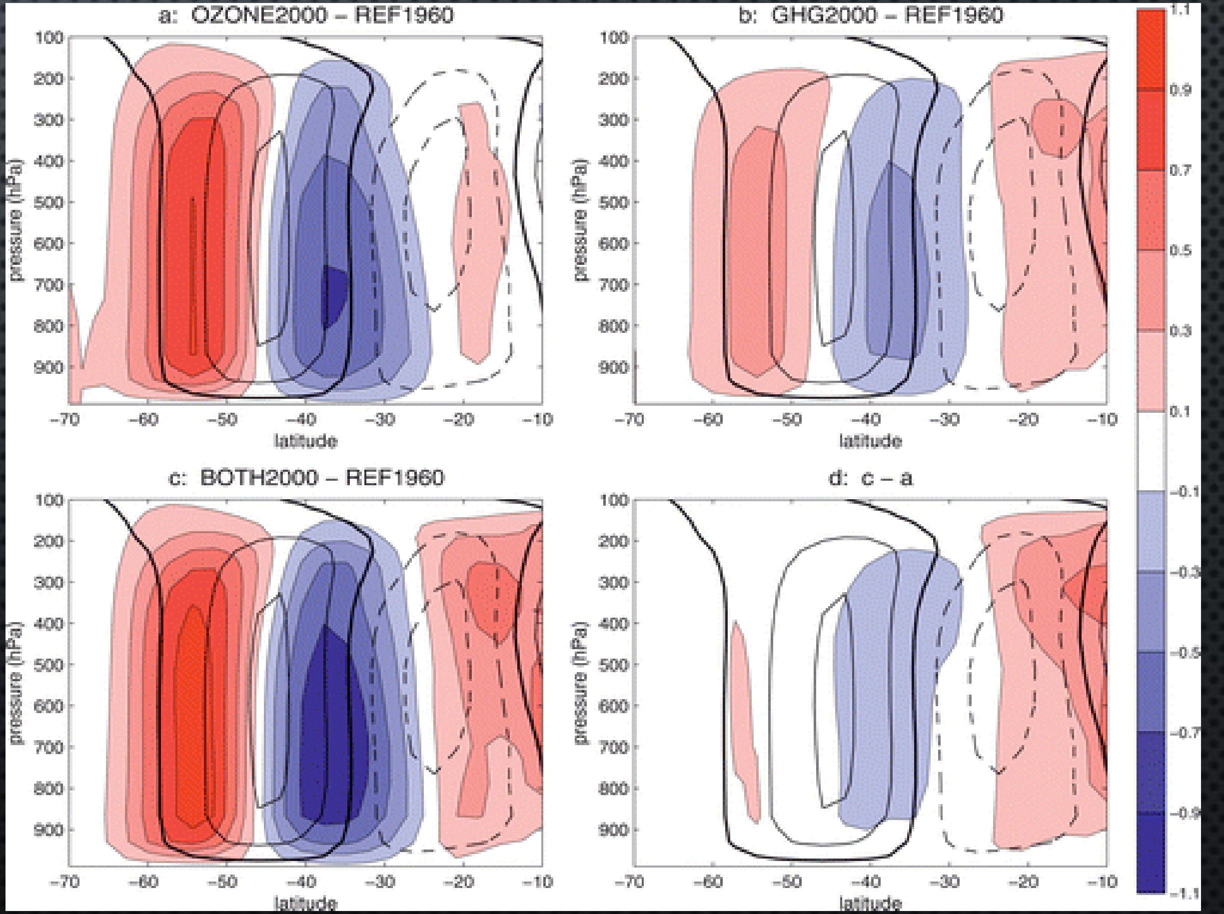
POLVANI ET AL. J. CLIMATE 2011

CHANGES (2000-1960) IN THE MEAN ZONAL WIND AND IN THE MERIDIONAL CIRCULATION (STREAM FUNCTION)

POLVANI ET AL. J. CLIMATE 2011.

Ozone Depletion **Increase in GH** **Ozone Depletion** **Increase in GH**



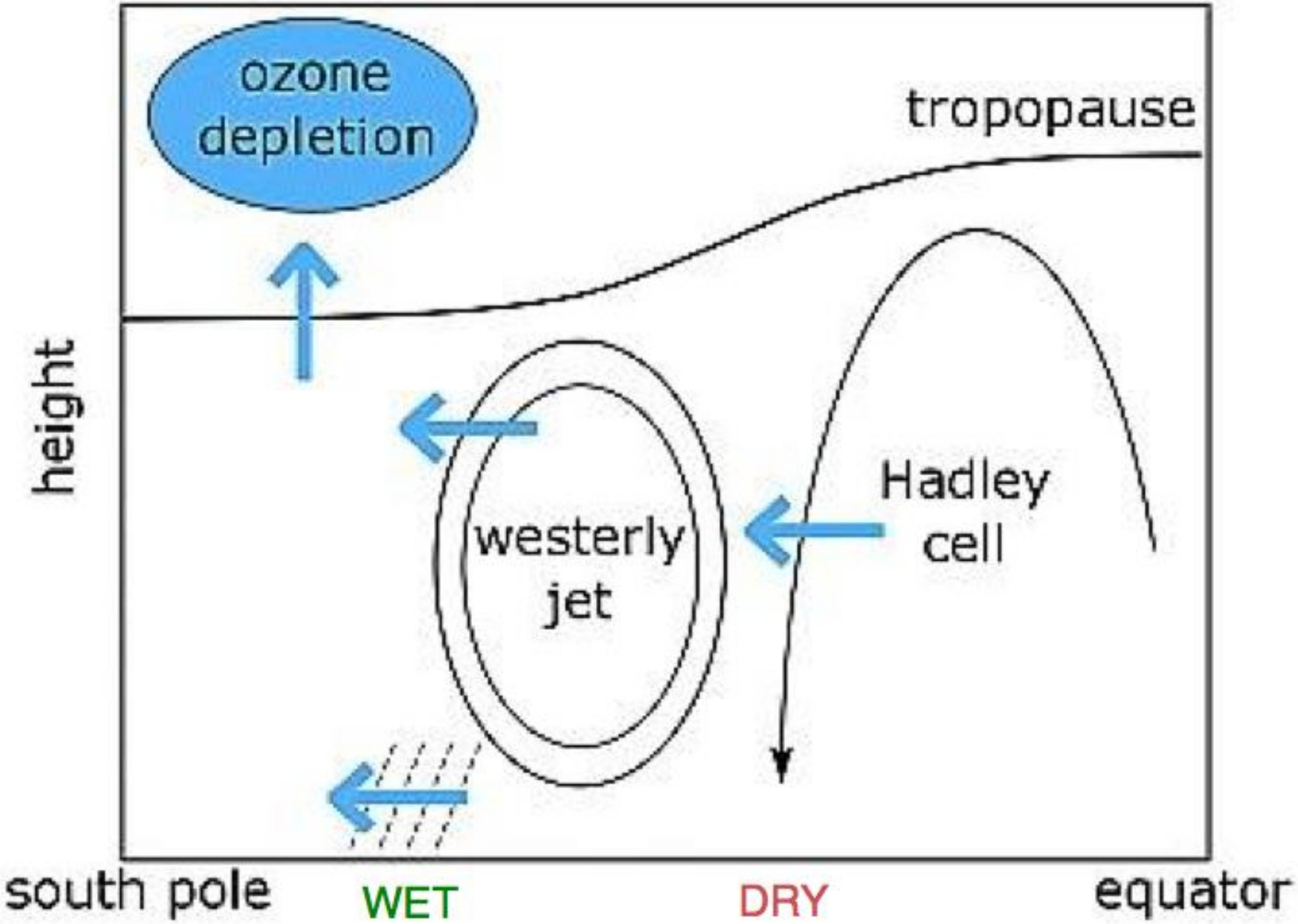


Ozone depletion and Southern Hemisphere atmospheric circulation

Depletion =>

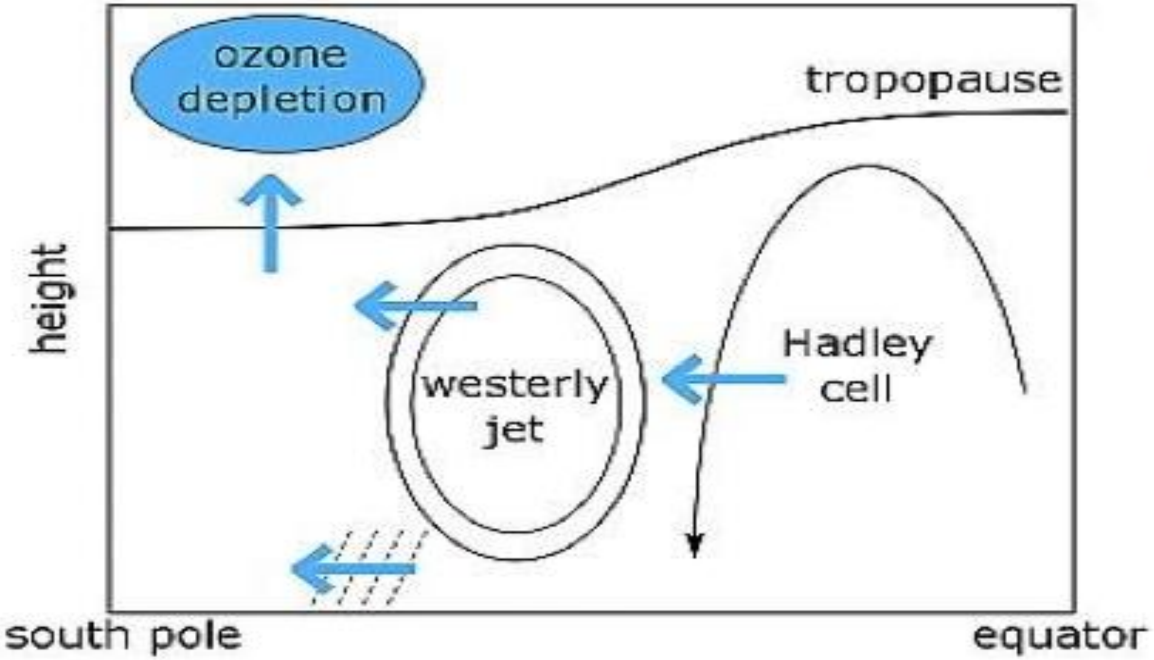
cooling in Antarctic stratosphere =>

changes in atmospheric circulation and rainfall



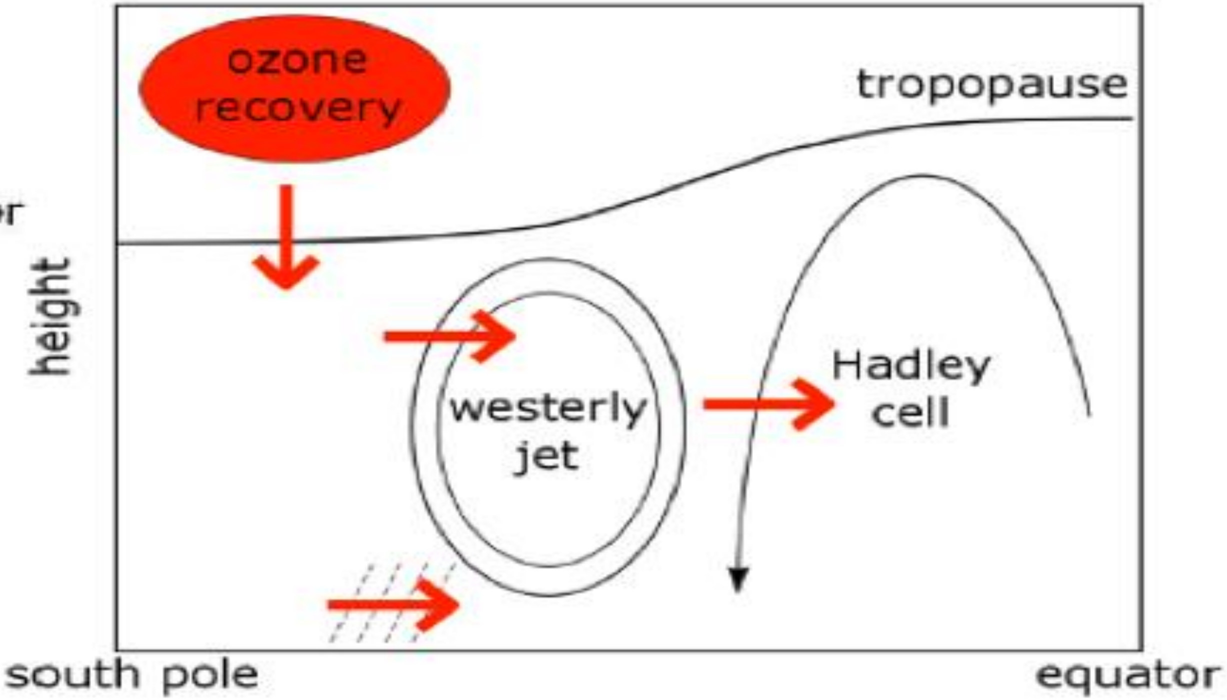
THE FUTURE

What of the future?



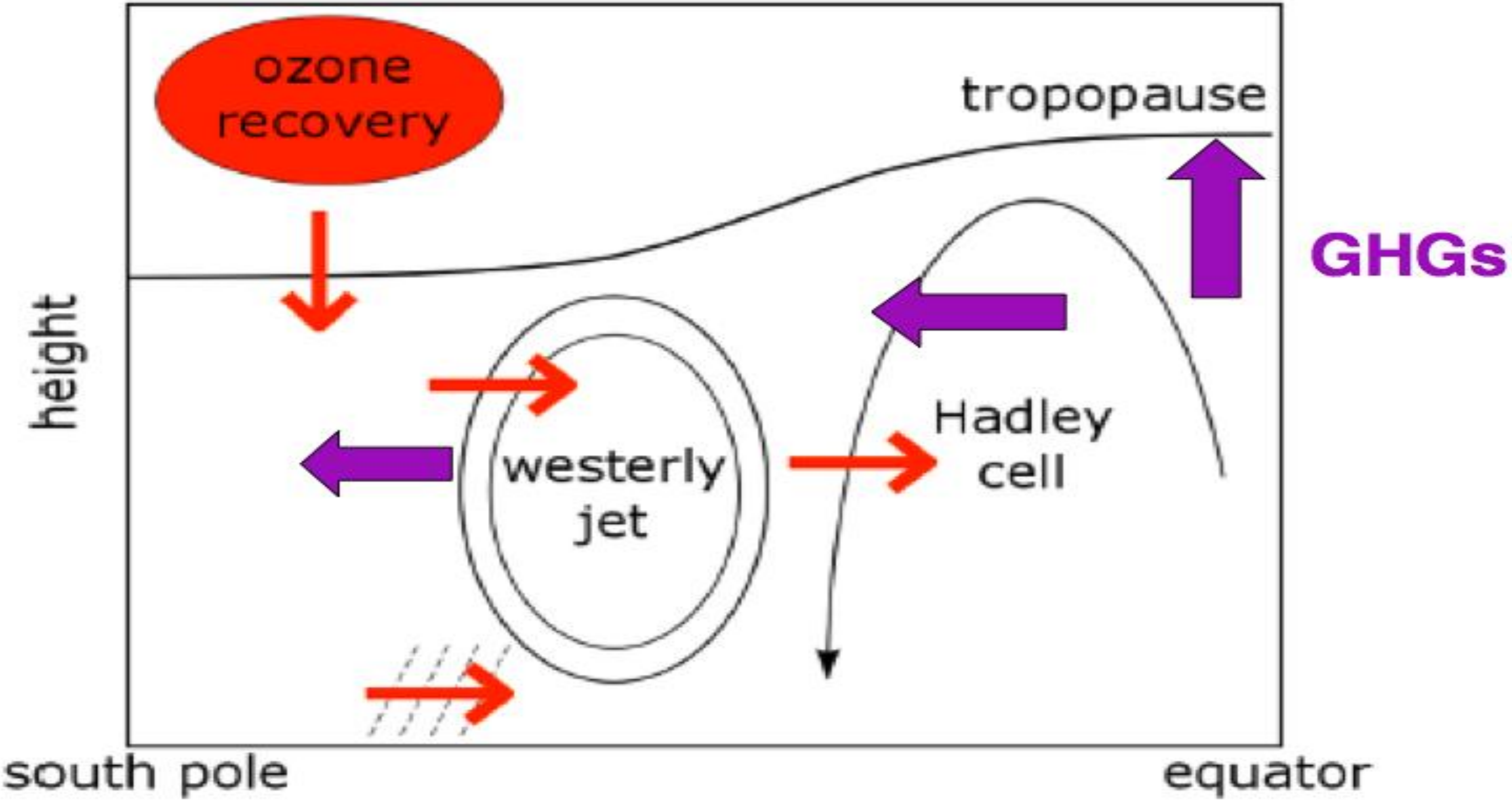
<= past

future =>



Son et al 2010

Future changes in the Southern Hemisphere

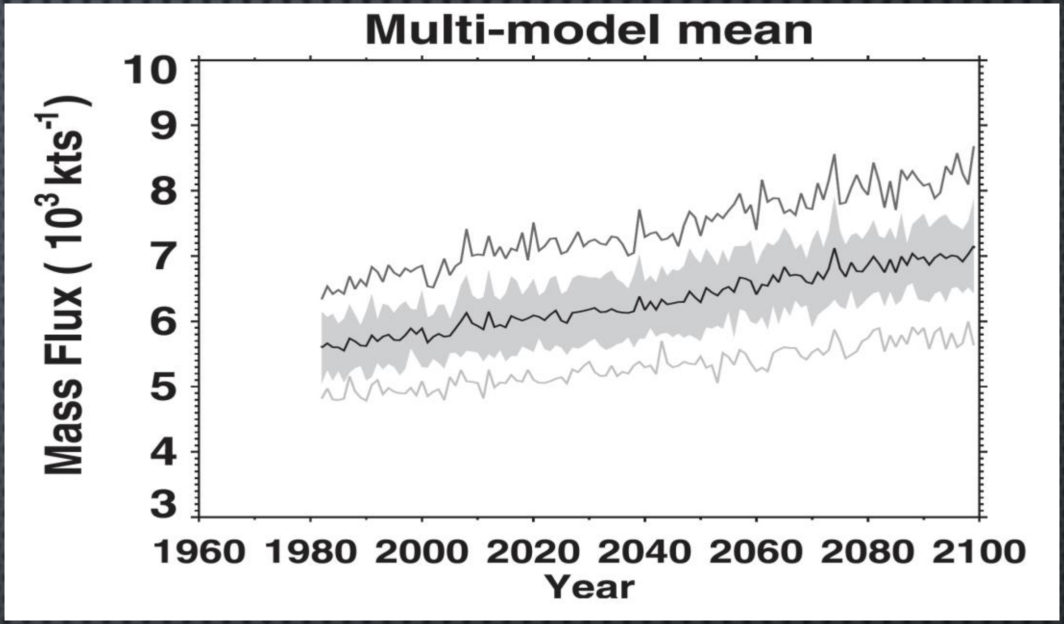


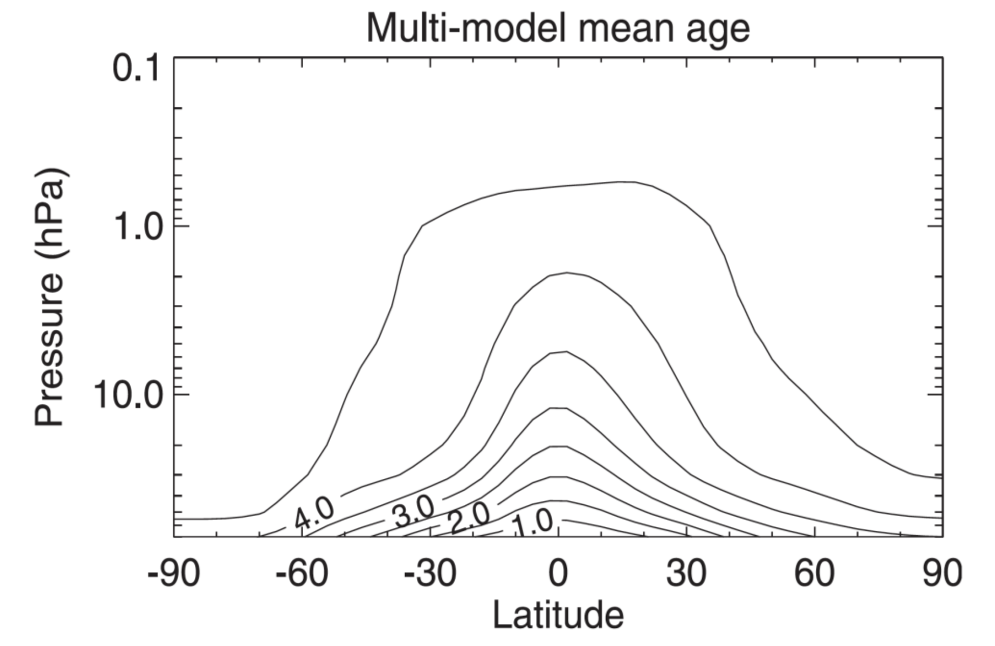
Son et al 2010

FUTURE REDUCTION IN THE MEAN AGE OF AIR (STRONGER BREWER DOBSON CIRCULATION)

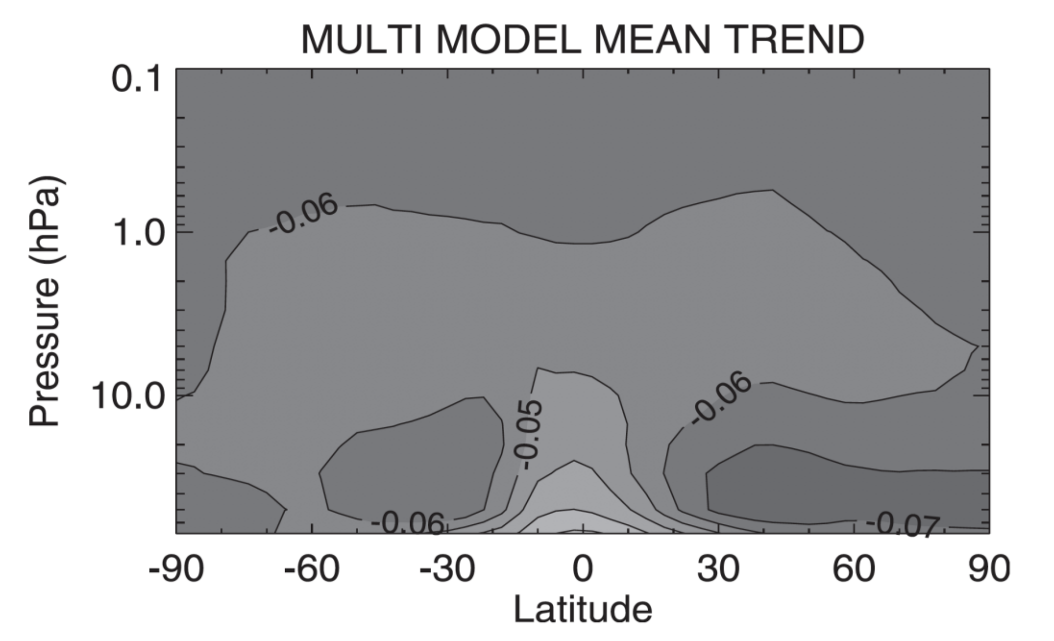
BUTCHART ET AL. J. CLIMATE 2010

Model
AMTRAC
CCSR/NIES
CMAM
E39C
GEOS CCM
MAECHAM4CHEM
MRI
SOCOL
ULAQ
UMSLIMCAT
WACCM (version 3)





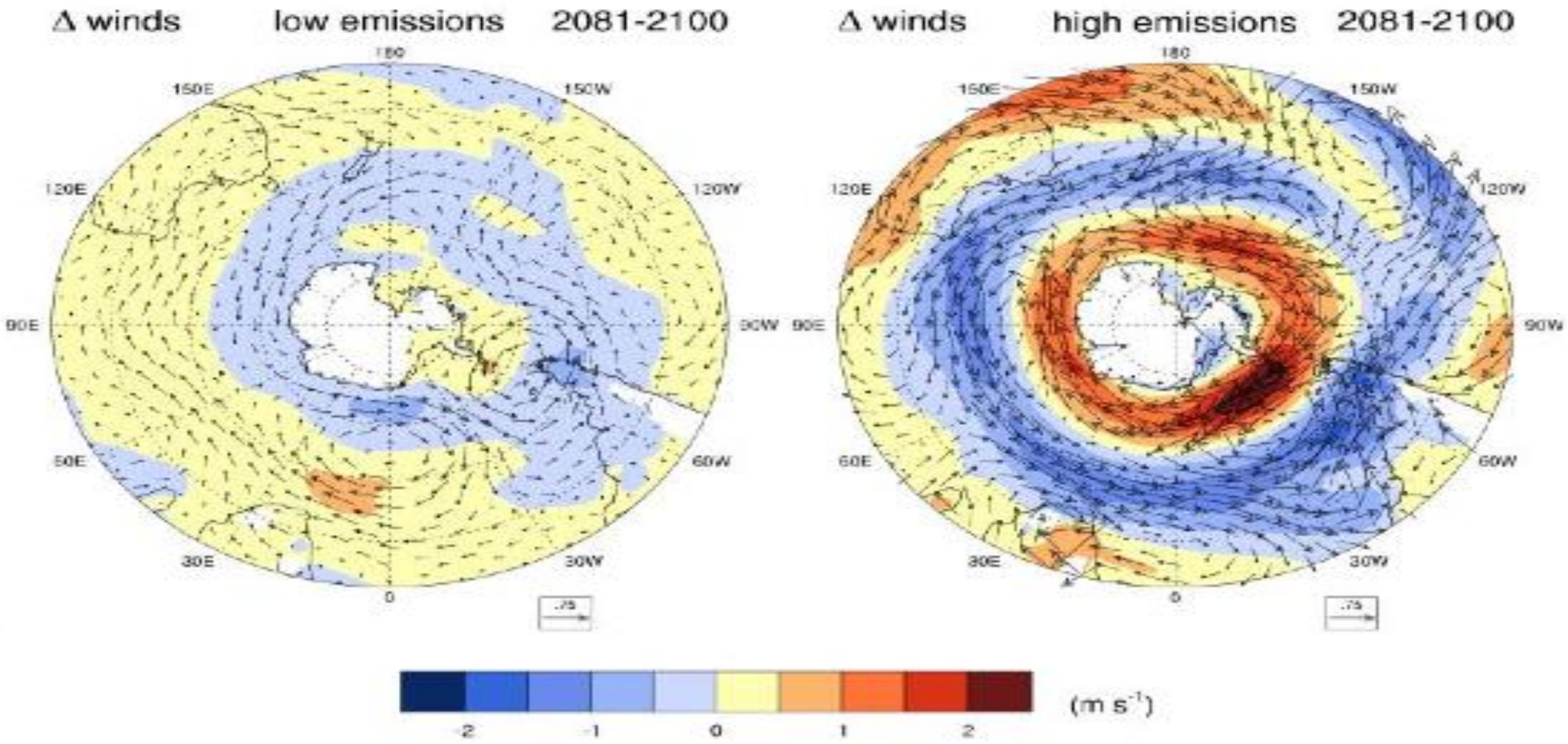
Years



Years per decade

Future climate change scenarios

- a poleward shift in the SH extratropical circulation (*westerly jet, SAM*) is one of the most robust responses to global warming
- ozone recovery will offset this shift in austral summer to some extent
- which forcing dominates in future climate change scenarios?



=> low-emissions scenario RCP2.6: ozone recovery wins and SH winds shift equatorward

=> high-emissions scenario RCP8.5: GHGs wins and SH winds poleward

Meehl et al. J Climate 2012

CONCLUSIONS

- THE STRATOSPHERE PLAYS A SIGNIFICANT ROLE IN THE NATURAL VARIABILITY AND THE FORCED RESPONSE OF THE EARTH SYSTEM.
- INCLUDING STRATOSPHERIC PROCESSES IN ATMOSPHERIC MODELS PROVIDES ADDITIONAL SKILLS ON SEASONAL FORECASTS.
- STRATOSPHERIC OZONE LOSS HAS CONSIDERABLY INFLUENCED CLIMATE TRENDS IN THE LAST DECADES, IN ADDITION TO ITS IMPACTS ON UV RADIATION.
- STRATOSPHERIC OZONE CHANGE WILL CONTINUE TO AFFECT CLIMATE CHANGE INTO THE TWENTY-FIRST CENTURY.
- RECENT RESEARCH HAS IDENTIFIED A CHAIN OF PROCESSES: HALOGEN COMPOUNDS ON OZONE CHEMISTRY, OZONE CHANGES ON STRATOSPHERIC TEMPERATURE CHANGE AND STRATOSPHERIC PERTURBATIONS ON TROPOSPHERIC CIRCULATION ANOMALIES

THANK YOU