Future ozone in a changing climate

Ulrike Langematz

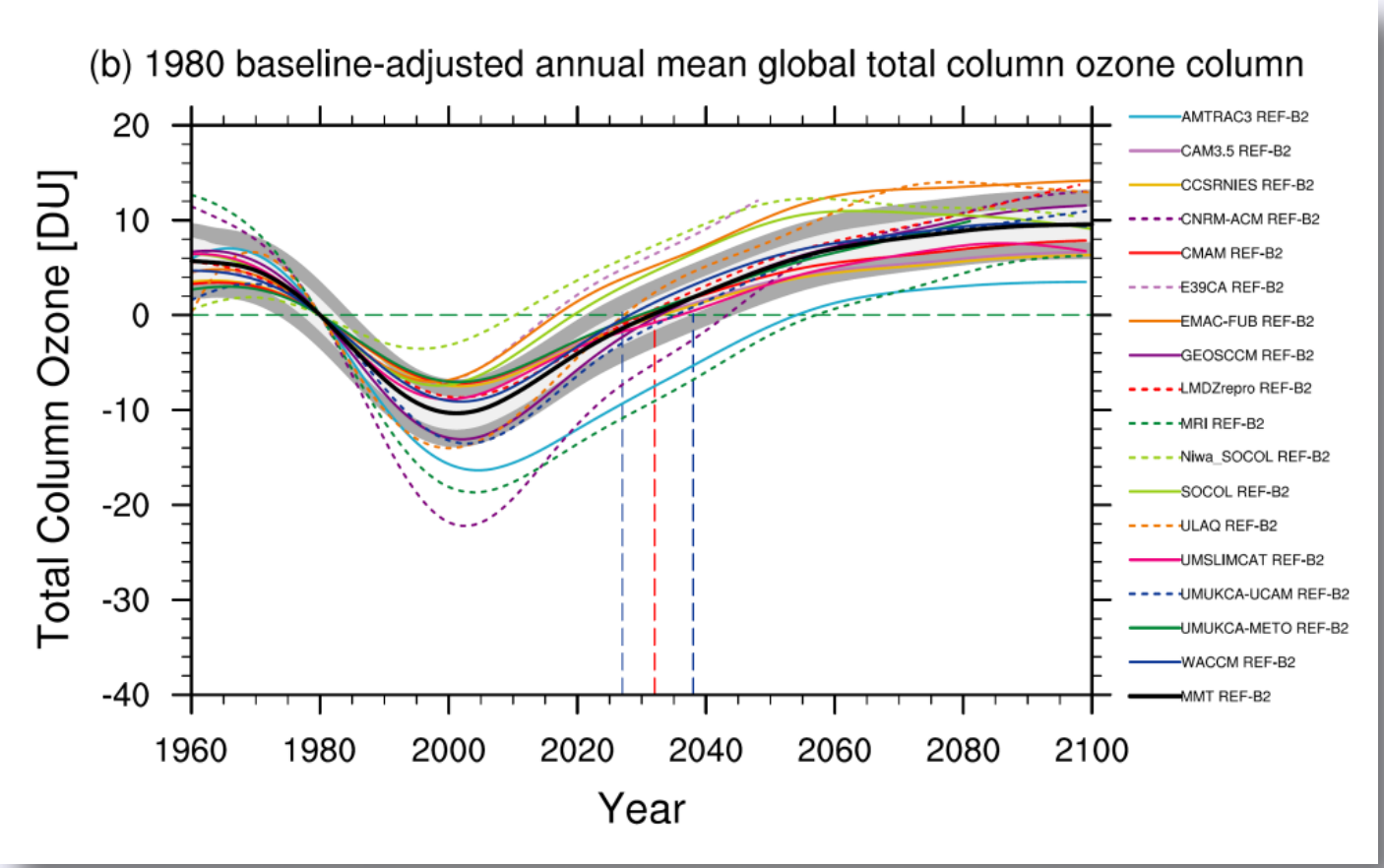
with contributions from

Stefanie Meul, Sandip Dhomse, Irene Cionni and the CCMI community

Freie Universität Berlin

Annual global mean total ozone 1960-2100

from Chemistry-Climate Model projections



Eyring et al, 2010; WMO 2011

CCMVal projections

polar spring

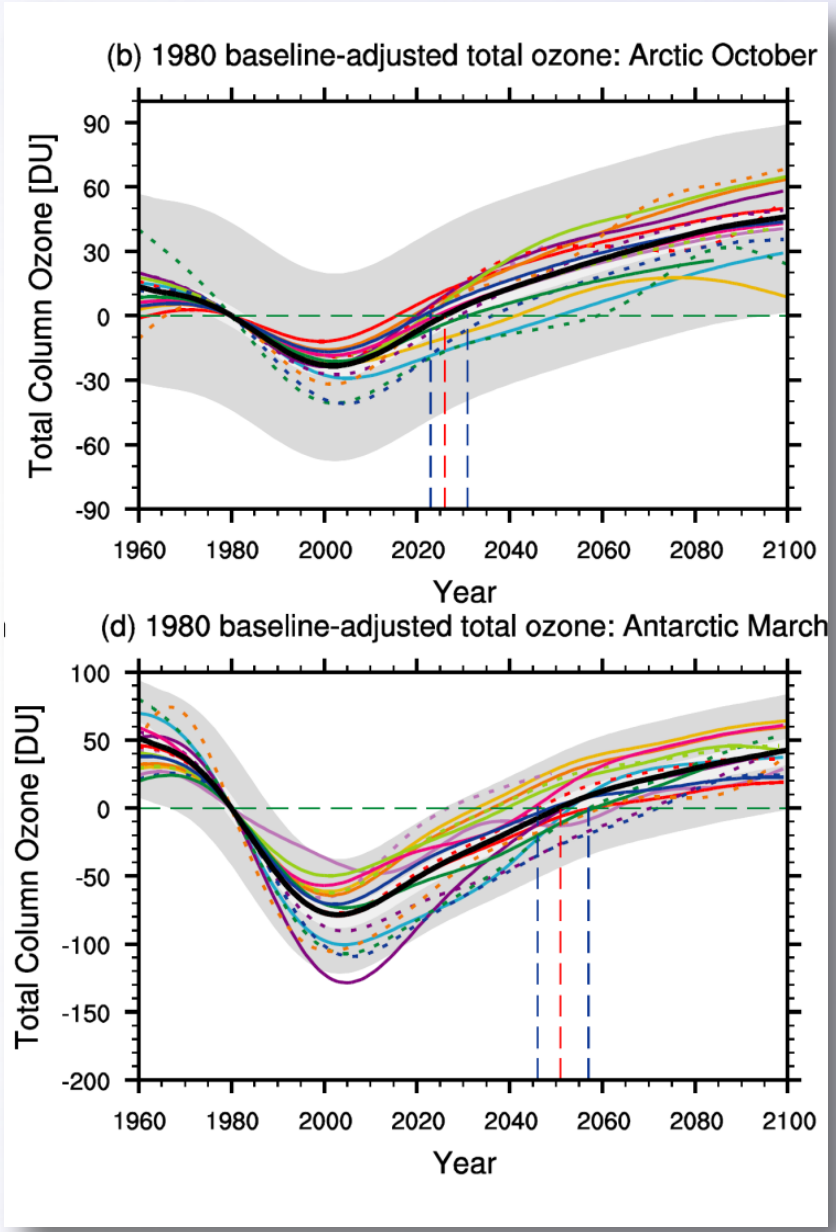
Expected return of total ozone to 1980 levels

Arctic (March)	2026 (2023-2031)
Antarctica (October)	2051 (2046-2057)
NH mid-latitudes	2021 (2017-2026)

Eyring et al, 2010; WMO 2011

Arctic, March

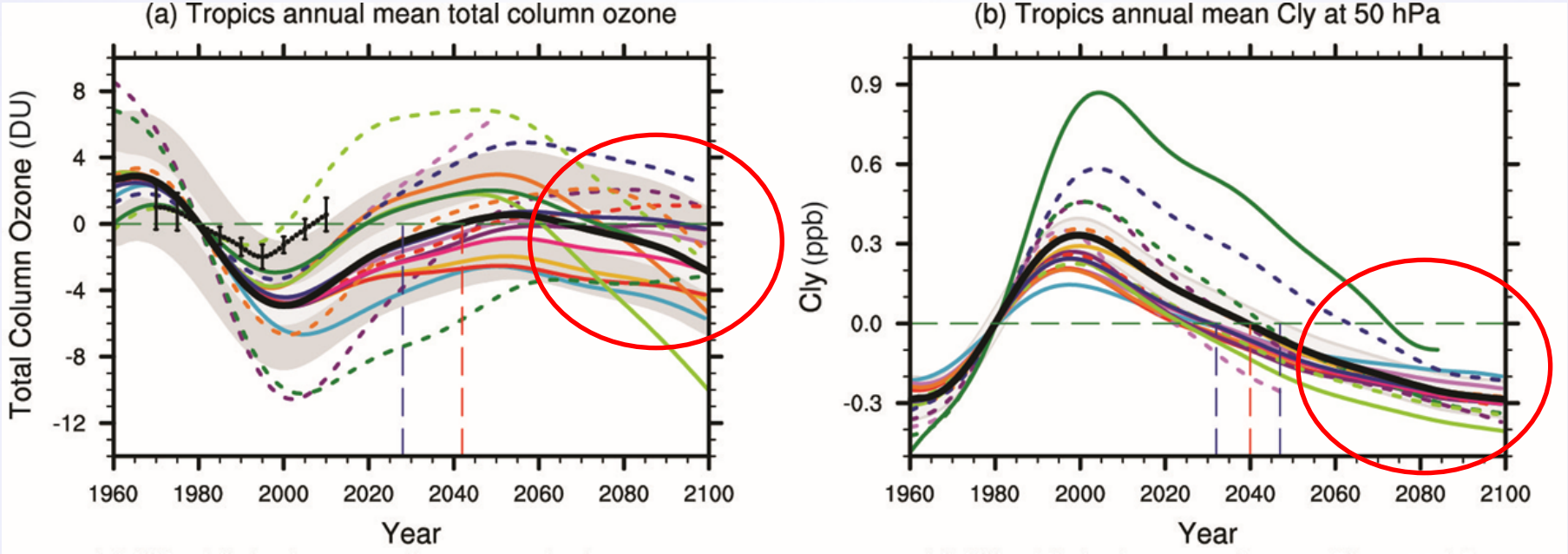
Antarctic, October



Tropical ozone

Ozone

Cl_y at 50 hPa



From Chapter 3 of *Scientific Assessment of Ozone Depletion: 2010* (WMO, 2011).

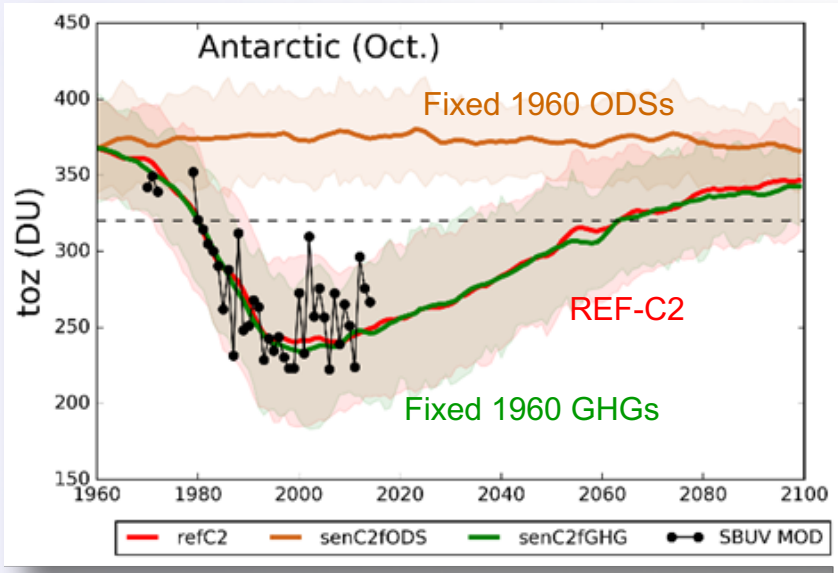
Chemistry-climate interactions affect the future evolution of ozone.

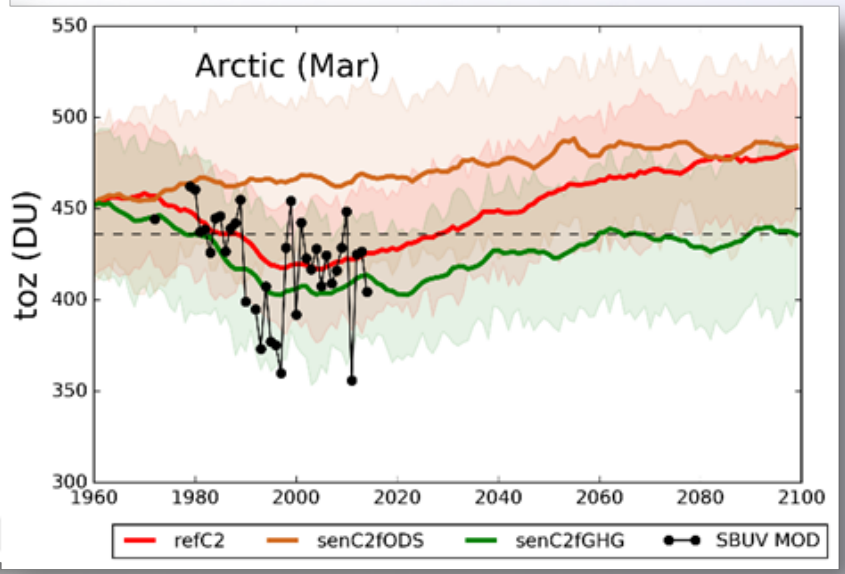
Outline

- How do – increasing - GHGs affect ozone recovery?
- Future ozone in the tropics and Arctic spring
- Impact of climate change scenario
- Relevance of N_2O and CH_4

Projected total ozone column [DU] in1960-2100

from new CCMI simulations

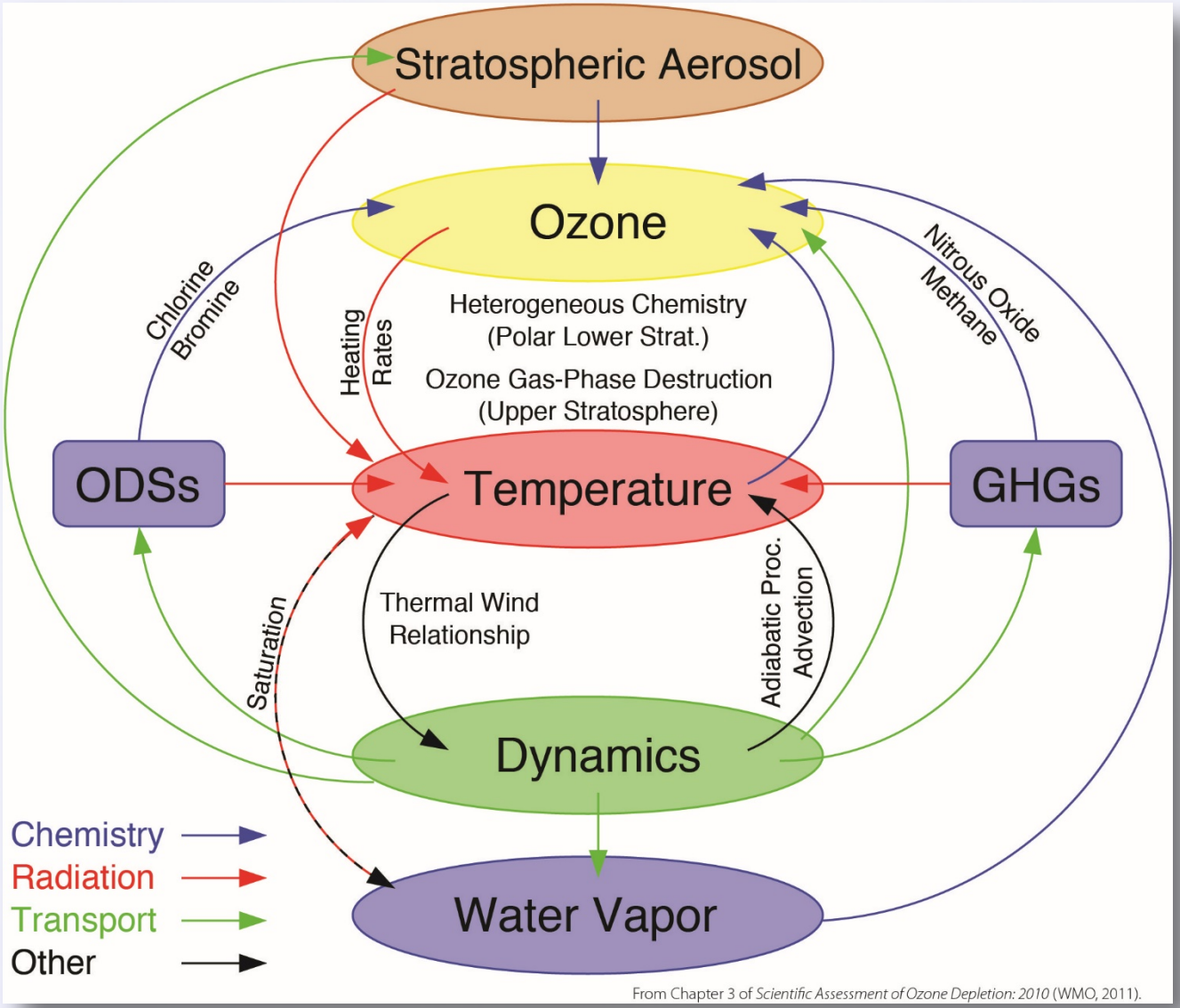




Dhomse et al., 2017, in preparation

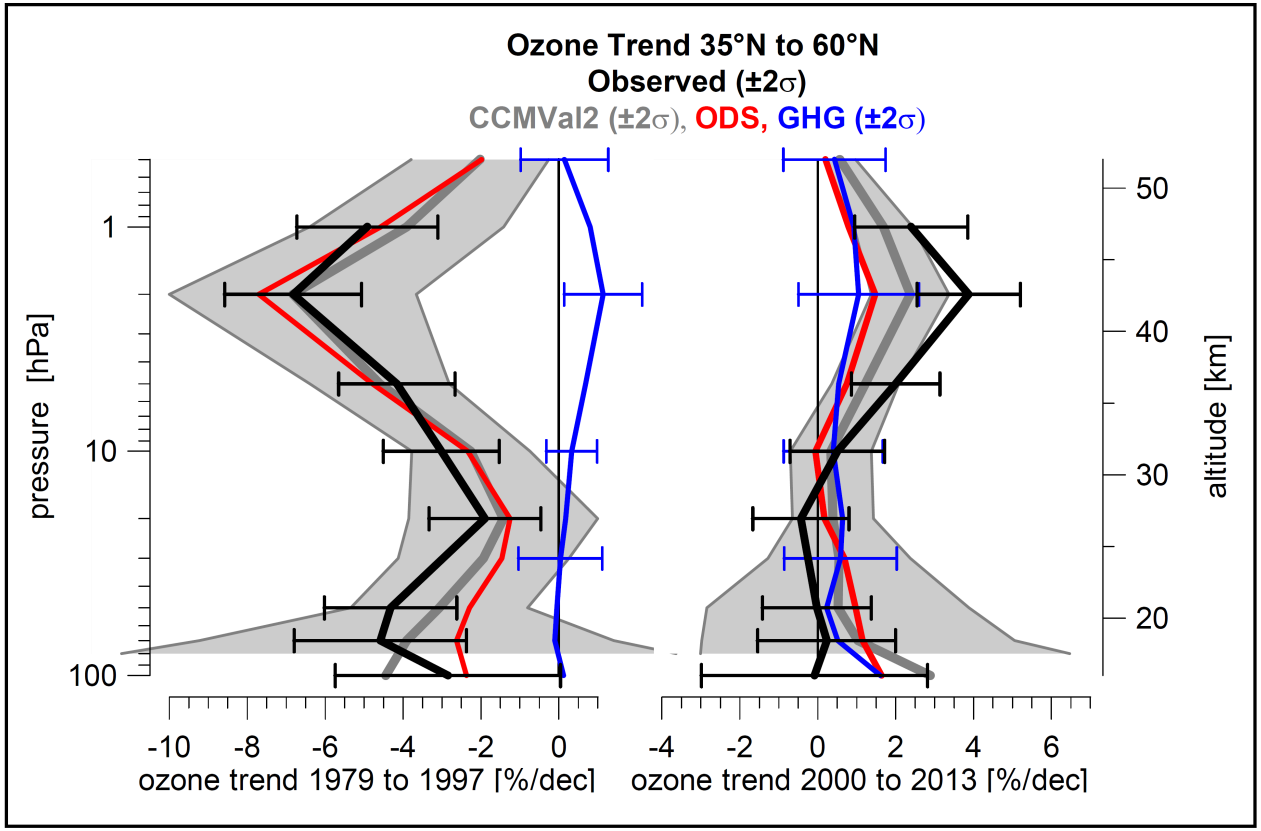
- Climate change affects stratospheric ozone.
- Regionally varying ozone response to climate change.
- GHGs may accelerate ozone return to historical values.

Which processes are involved?



WMO, 2011

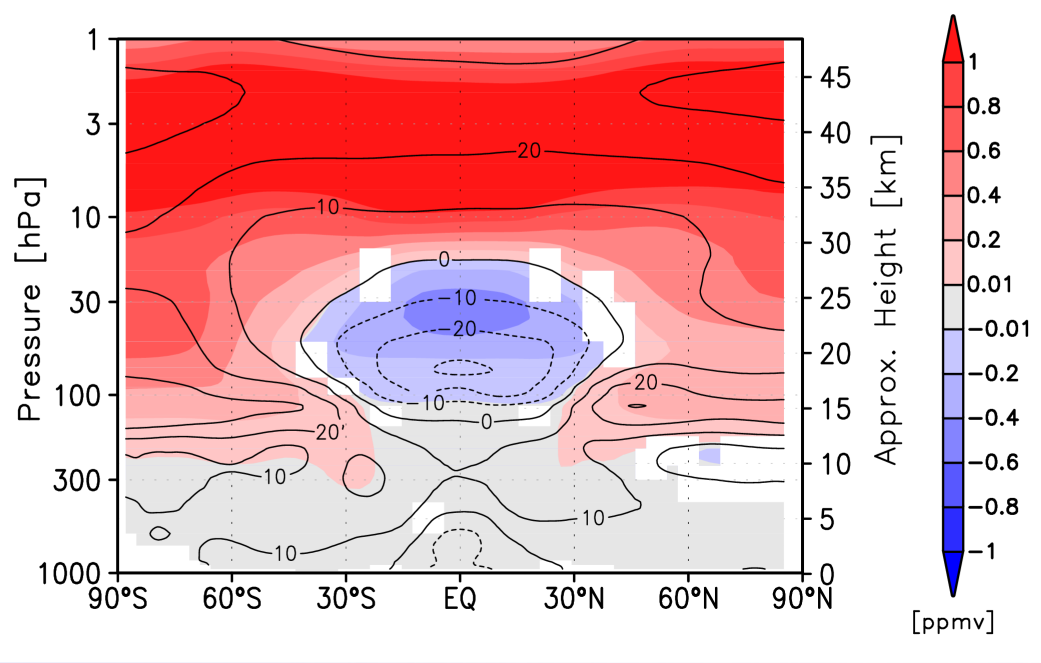
Did GHGs affect ozone in the past?



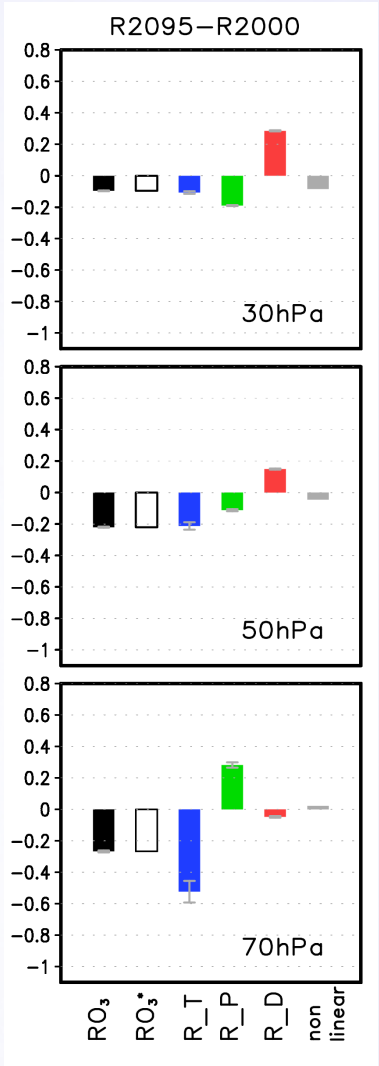
WMO, 2014

Tropical ozone: Future Recovery?

Change in annual mean ozone from 2000 to 2095



EMAC CCM

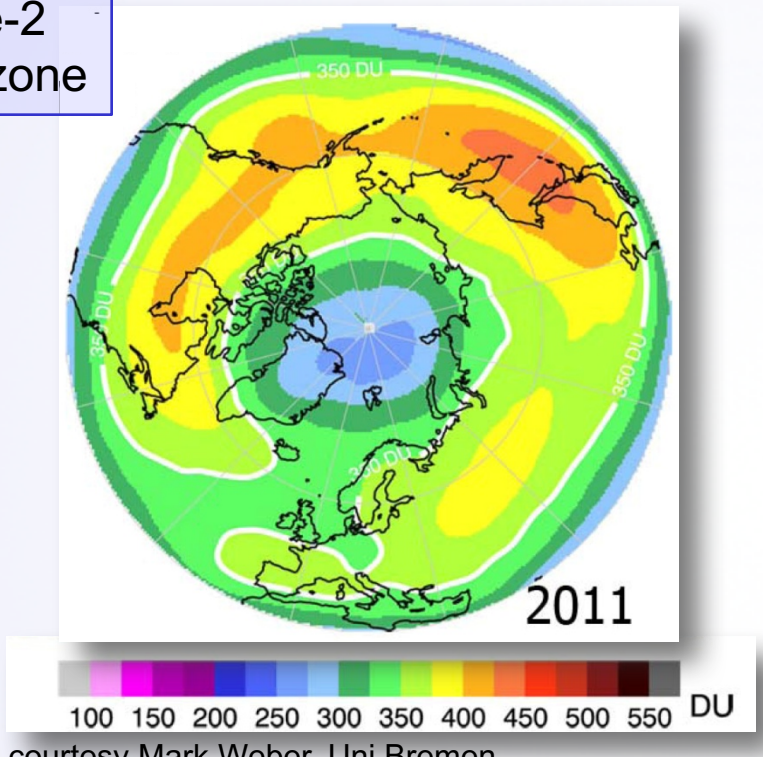


Ozone loss in lower/middle stratosphere due to enhanced tropical upwelling in strengthened Brewer-Dobson Circulation

Meul, Langematz et al., ACP, 2014

Arctic Ozone: Future ozone holes?

Gome-2
Total Ozone



courtesy Mark Weber, Uni Bremen

- Unprecedented Arctic ozone loss in March 2011
- Comparable to Antarctic ozone hole
- Due to
  - persistent cold lower stratosphere from early winter into spring
    - early onset of denitrification
    - long-lasting enhanced chlorine activation
  - large V_{PSC}

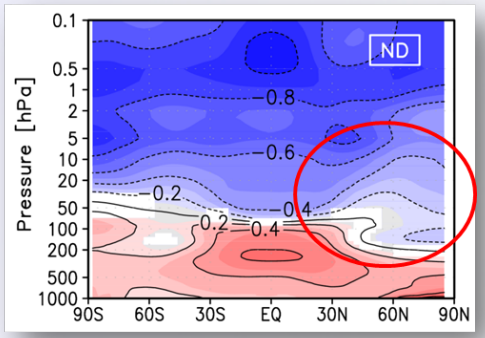
Manney et al., 2011

Will Arctic ozone-hole-like events become more frequent with climate change?

Arctic total ozone in March

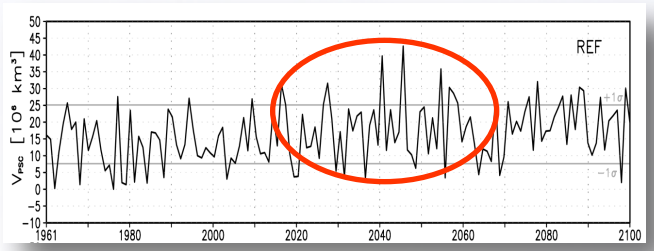
1st half of 21st century

November/December

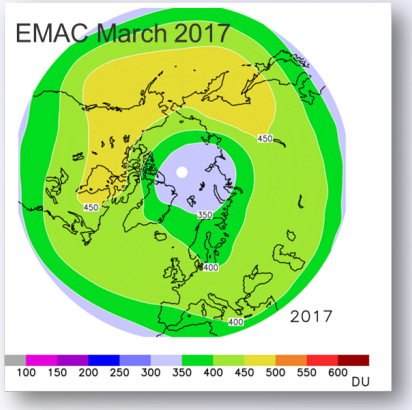


GHG induced early winter cooling

EMAC CCM model study



Maximum V_{PSC} with climate change during 1st half of 21st century

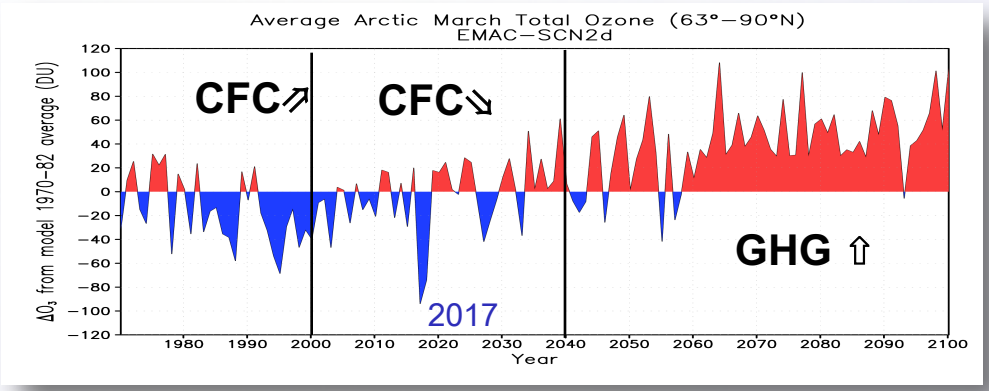


Individual low-ozone years may occur

2nd half of 21st century

Increased dynamical variability in Arctic winter; ozone increase due to cooling and enhanced ozone transport

REF

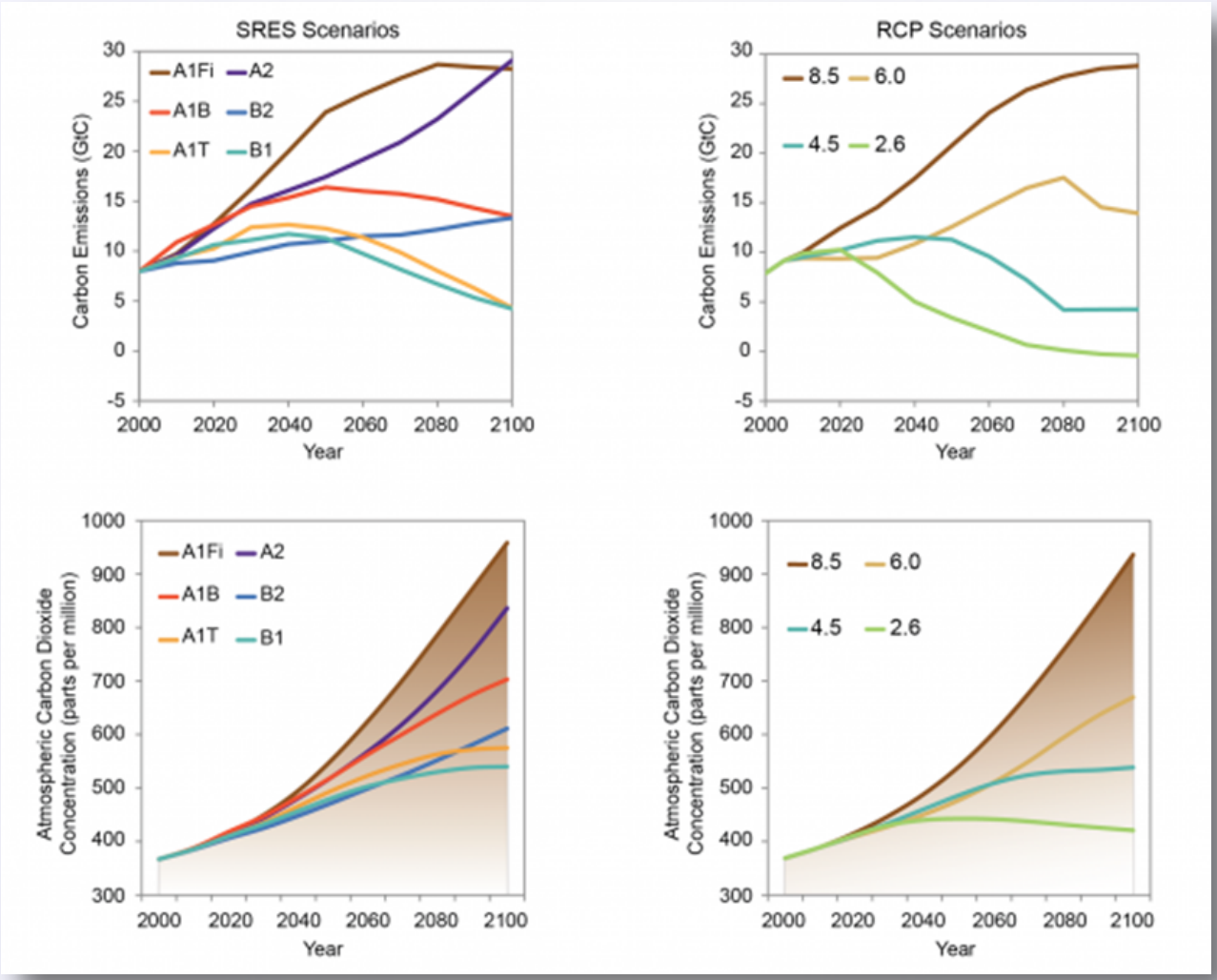


Langematz et al. (2014) (see also Bednarz et al., 2016)

➢ Impact of climate change scenario

Emission / concentration scenarios for model projections

SRES used in CCMVal-2



RCPs used in CCMI

http://www.globalchange.gov

Meinshausen et al., 2011

Stratospheric ozone column

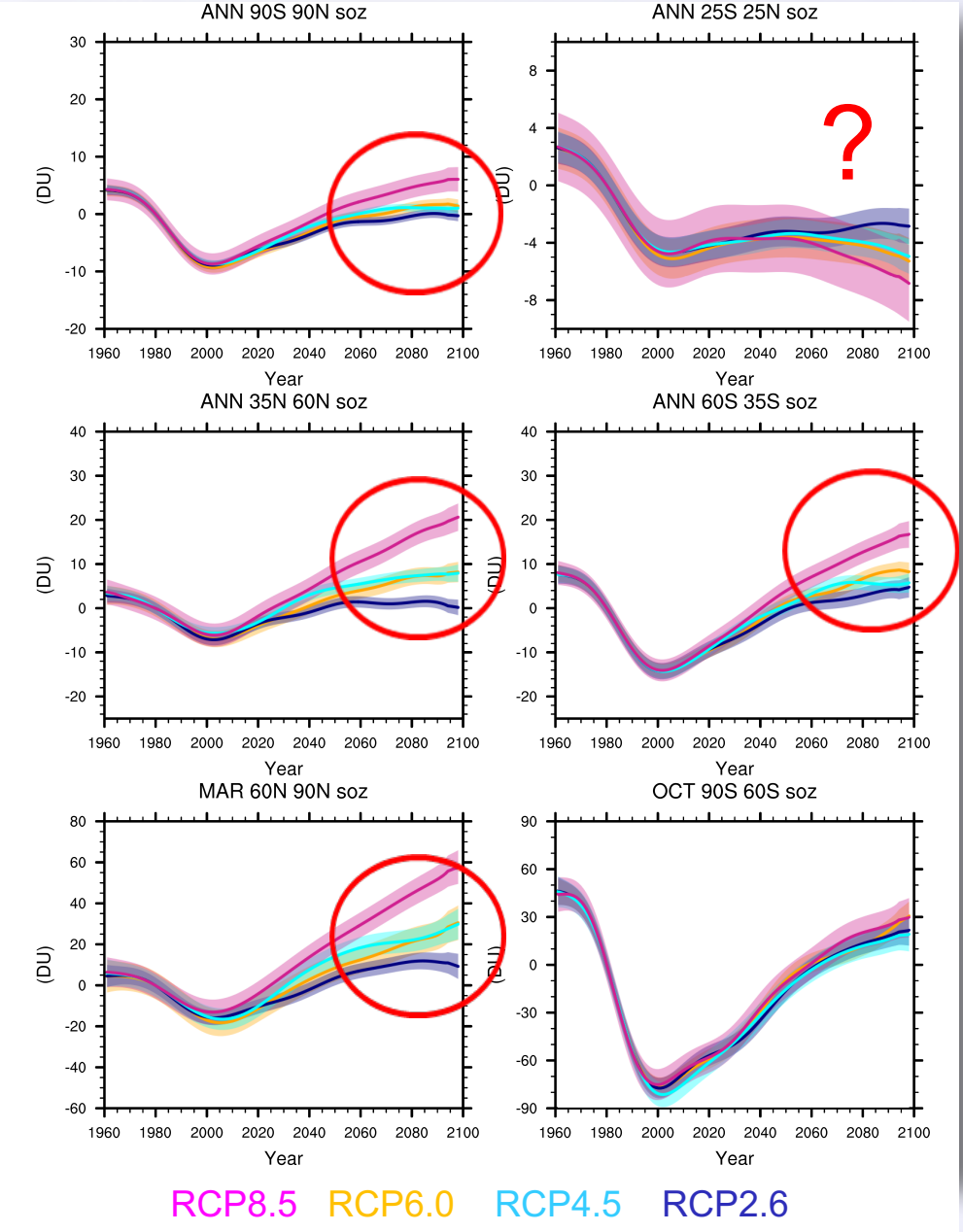
1960 – 2100

CCMI simulations

Stratospheric ozone recovery increases with RCP

except for
- Tropics
- Antarctic spring

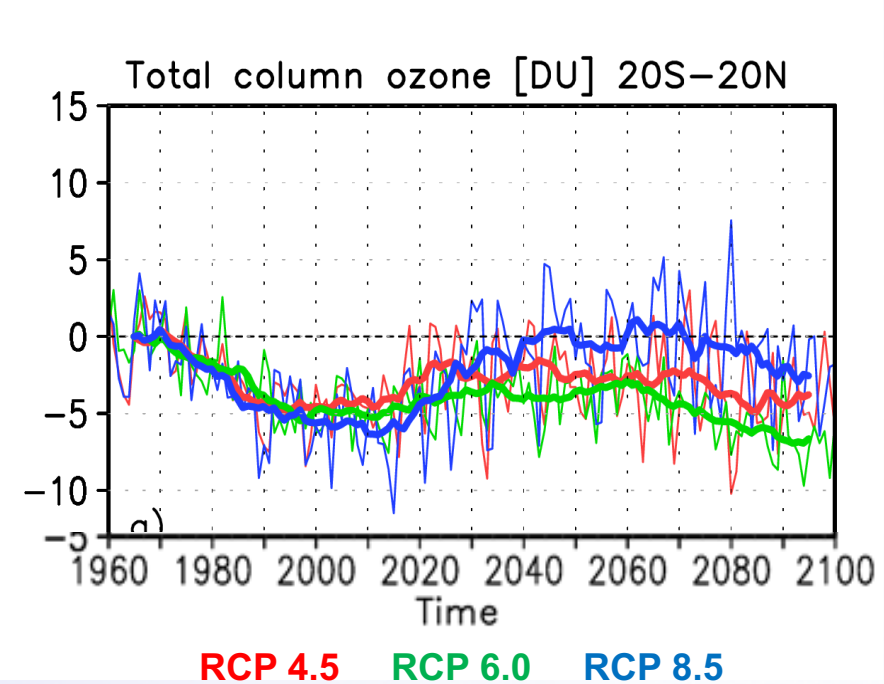
Cionni et al., to be submitted



Total tropical column ozone

20°S-20°N

EMAC CCM

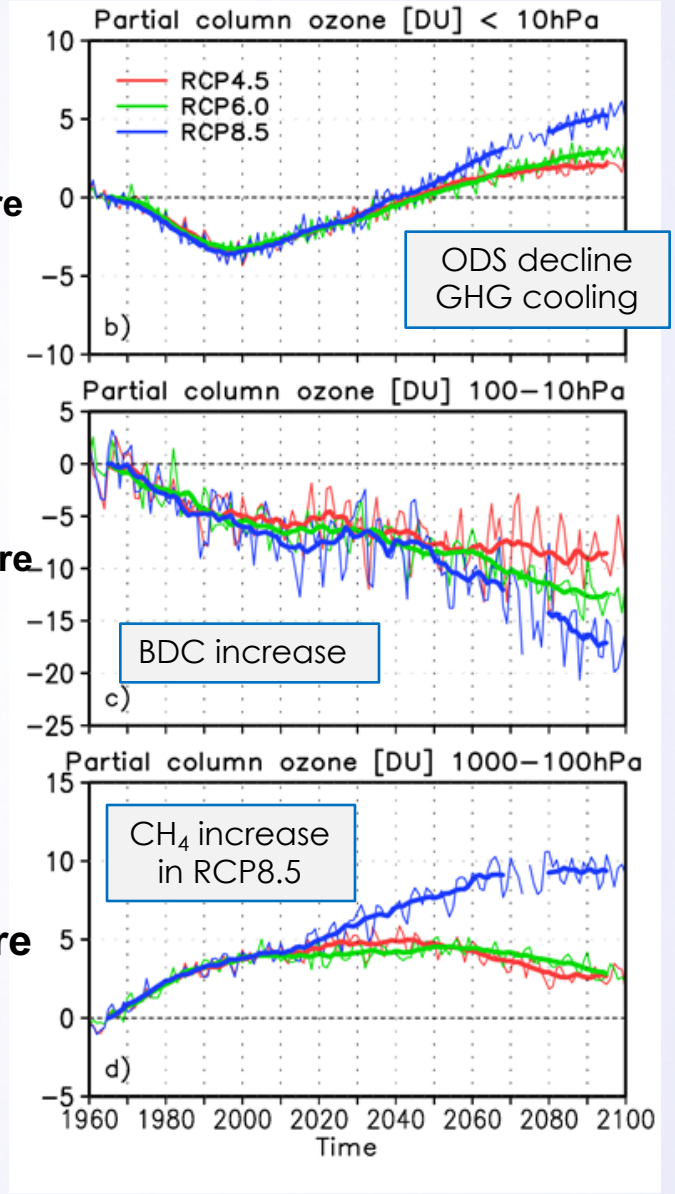


RCP 4.5 **RCP 6.0** **RCP 8.5**

upper stratosphere

lower stratosphere

troposphere



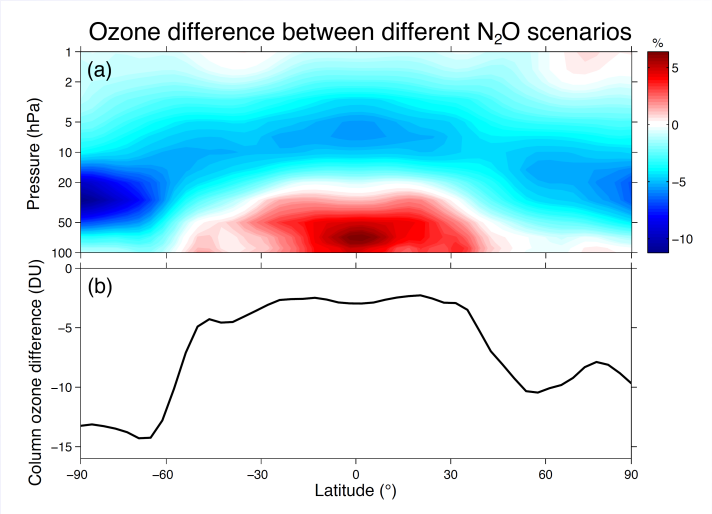
Meul, Dameris, Langematz et al., GRL, 2016

- Future increases in CH_4 and N_2O

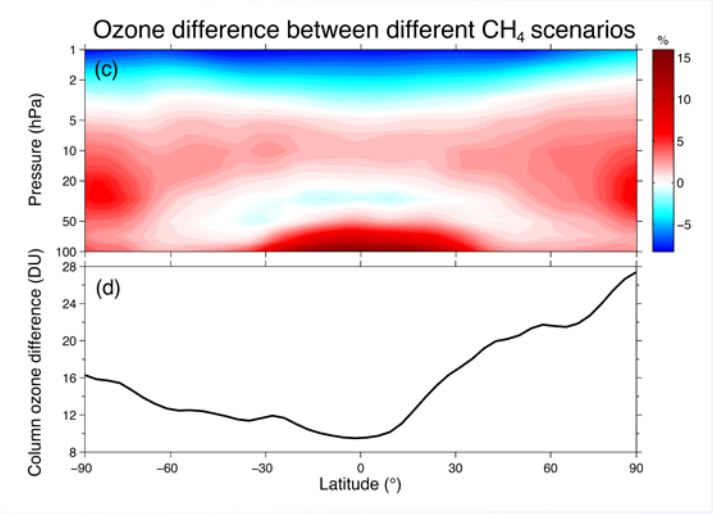
Ozone changes in the 2090s due to different N_2O and CH_4 scenarios

NIWA-SOCOL CCM simulations

N_2O



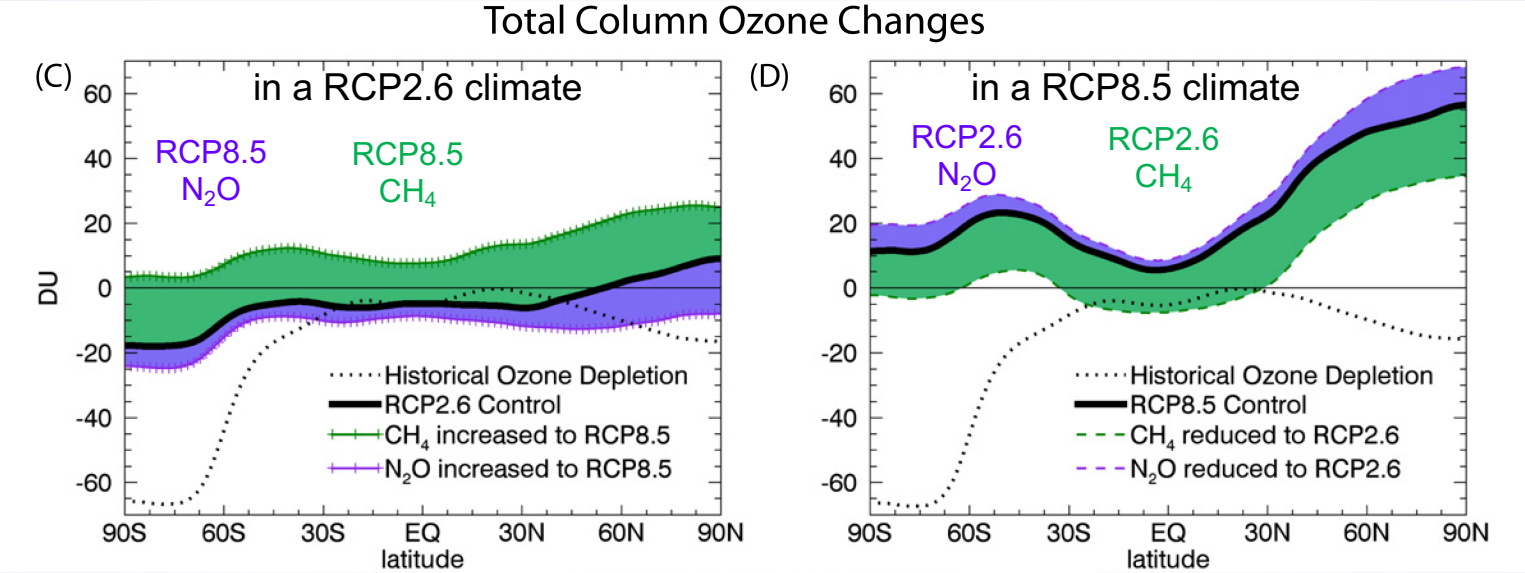
CH_4



Revell et al., 2012

- Enhanced N2O emissions in the extreme RCP8.5 reduce ozone.
- Enhanced CH4 emissions in the extreme RCP8.5 enhance ozone.

Future - historical



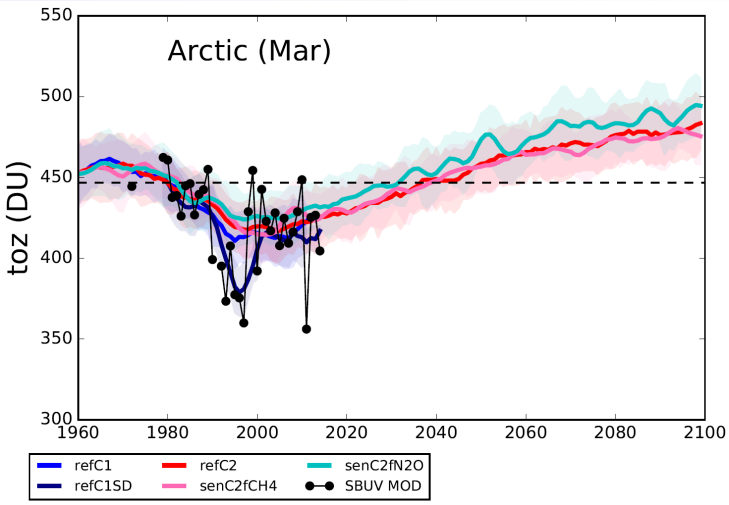
Butler et., al 2016

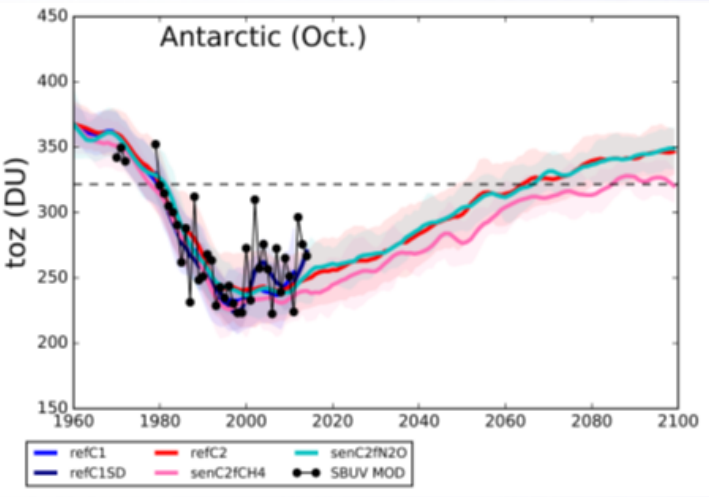
Implications of N_2O and CH_4 changes depend on background atmospheric state.

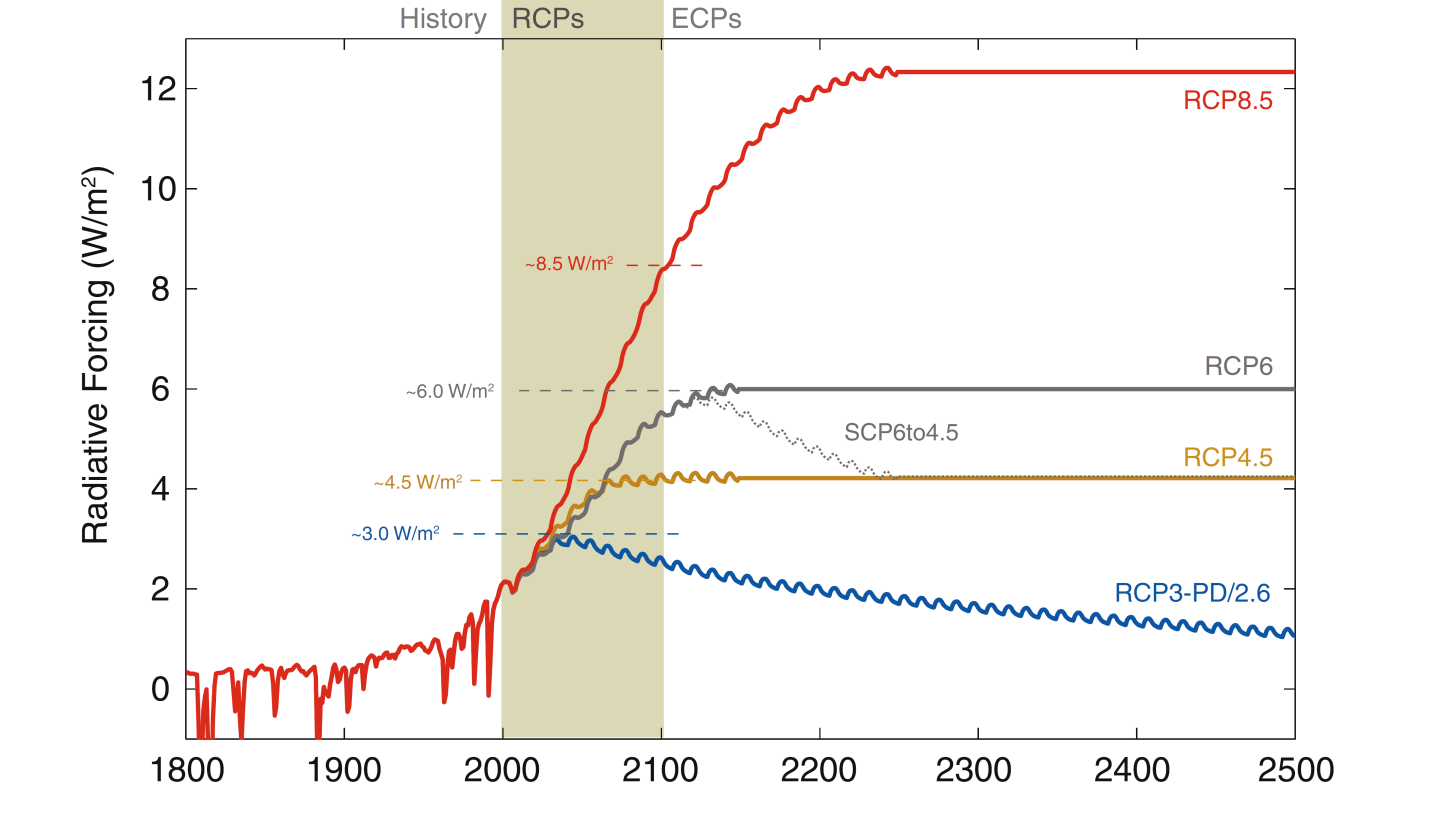
Conclusions

- Increasing GHGs affect ozone through changes of stratospheric temperature and circulation, and by direct chemical interactions.
- Increasing GHGs enhance ozone in the upper stratosphere and accelerate the return of total column ozone to historical baseline values (except for the Tropics and Antarctica).
- Tropical ozone will not recover to 1960 baseline values due to an overcompensation of ozone increases in the upper stratosphere (due to cooling) and troposphere (due to CH_4) by lower stratospheric ozone decrease (due to enhanced BDC upwelling).
- Arctic ‚ozonehole like' spring ozone depletion may occur in individual years until about 2050s due to GHG induced early winter cooling.
- Stratospheric ozone recovery is strongly influenced by the RCP scenario.
- Growing N_2O abundances in the extreme GHG scenario will enhance ozone depletion; growing CH_4 abundances will enhance ozone.

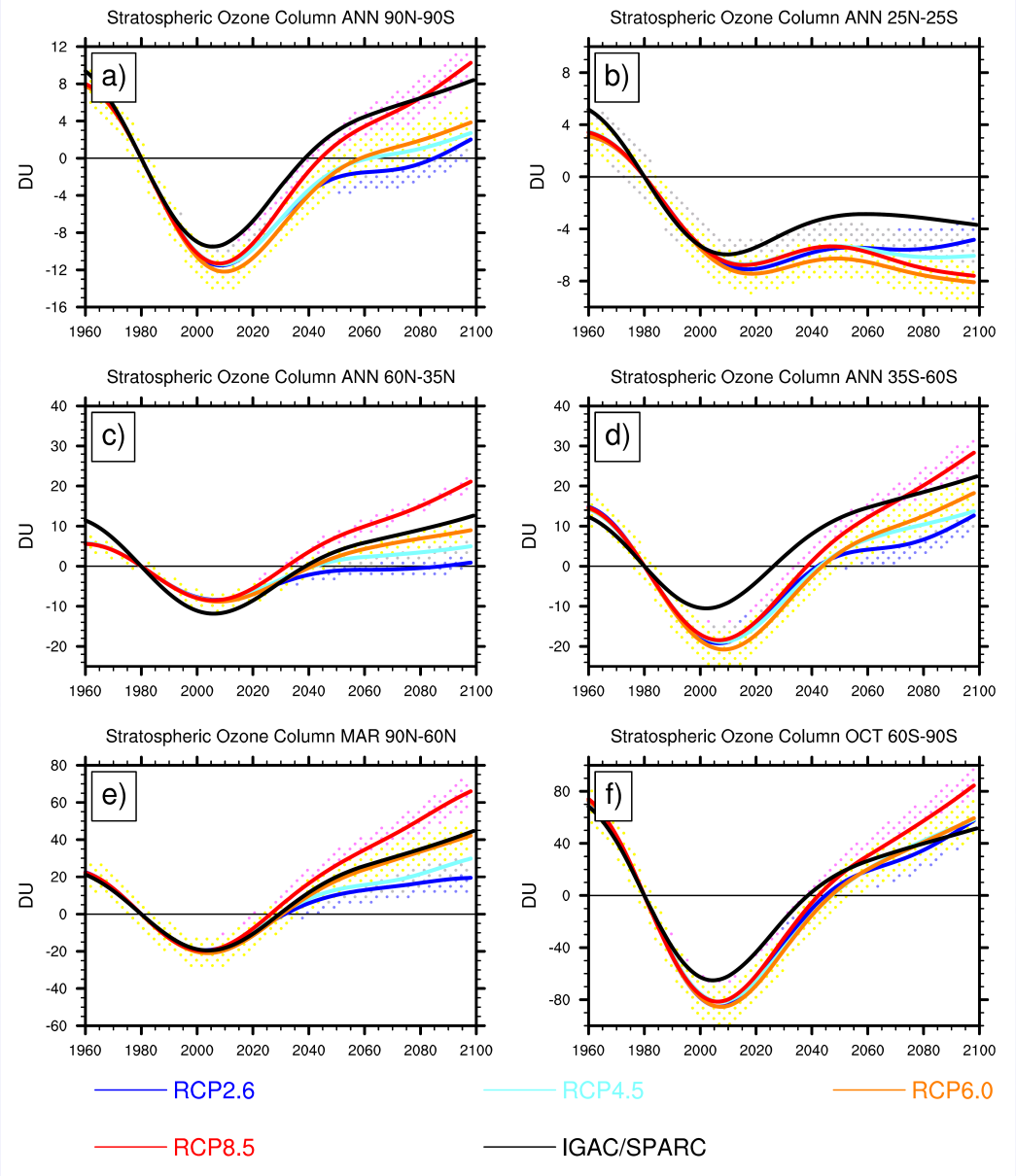
Thank you!


Arctic (Mar)
toz (DU)
550
500
450
400
350
300
1960
1980
2000
2020
2040
2060
2080
2100
refC1
refC1SD
refC2
senC2fCH4
senC2fN2O
SBUV MOD


Antarctic (Oct.)
toz (DU)
450
400
350
300
250
200
150
1960
1980
2000
2020
2040
2060
2080
2100
refC1
refC1SD
refC2
senC2fCH4
senC2fN2O
SBUV MOD

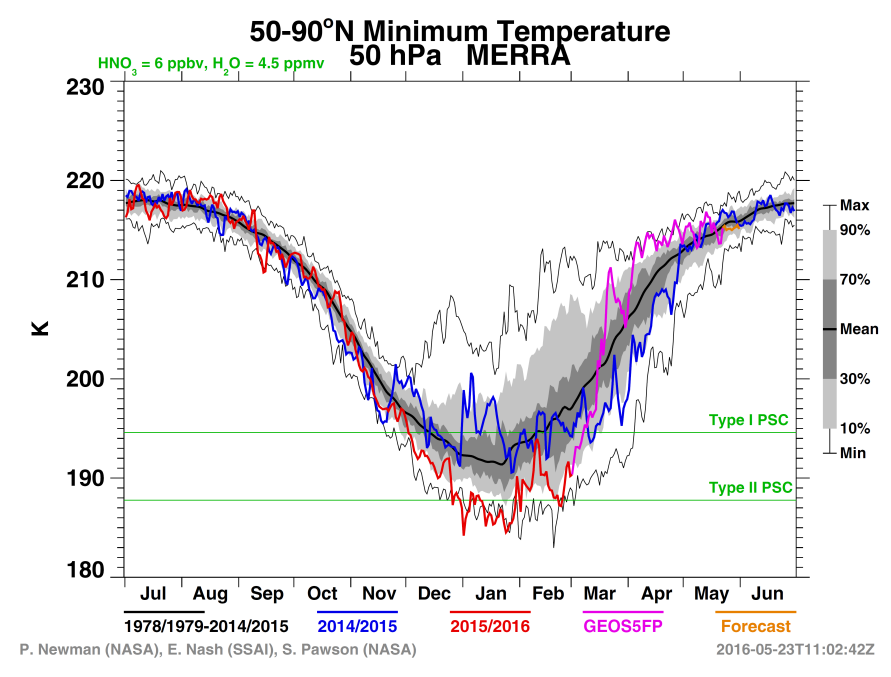

History
RCPs
ECPs
Radiative Forcing (W/m²)
12
10
8
6
4
2
0
1800
1900
2000
2100
2200
2300
2400
2500
RCP8.5
~8.5 W/m²
RCP6
~6.0 W/m²
SCP6to4.5
RCP4.5
~4.5 W/m²
~3.0 W/m²
RCP3-PD/2.6

Impact of climate change scenario

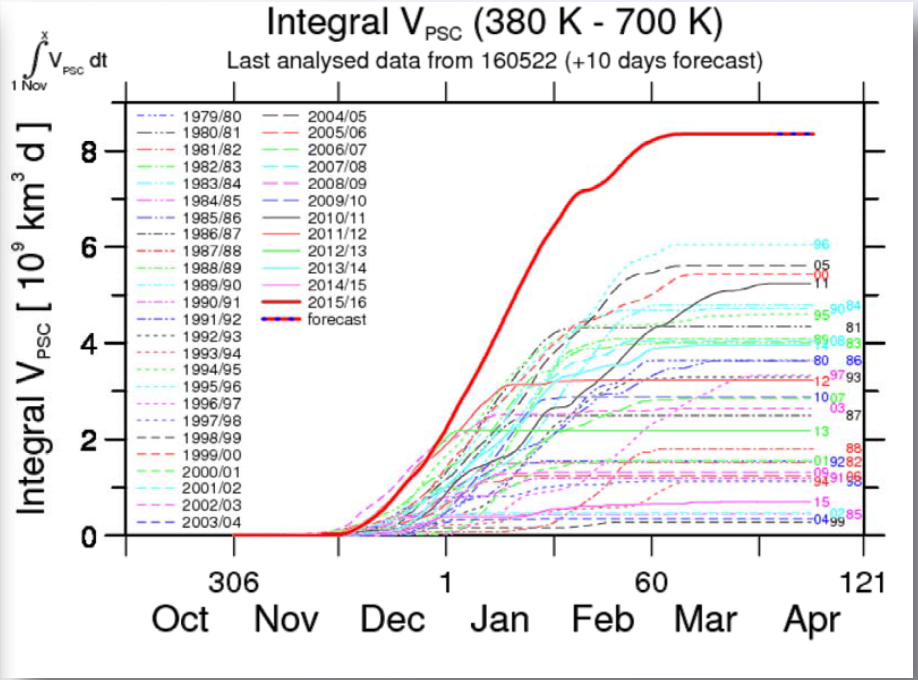


Eyring et al., JGR, 2013

Arctic Winter 2015/16



http://ozonewatch.gsfc.nasa.gov

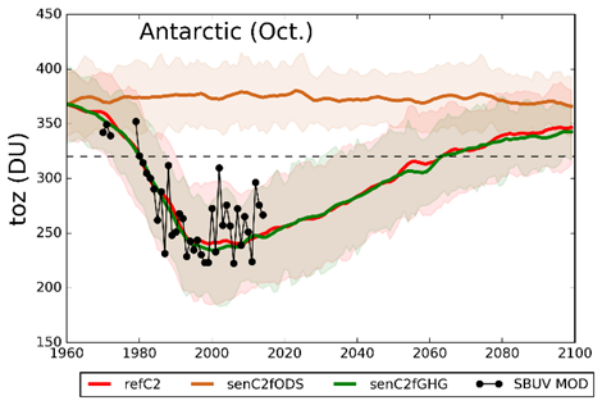


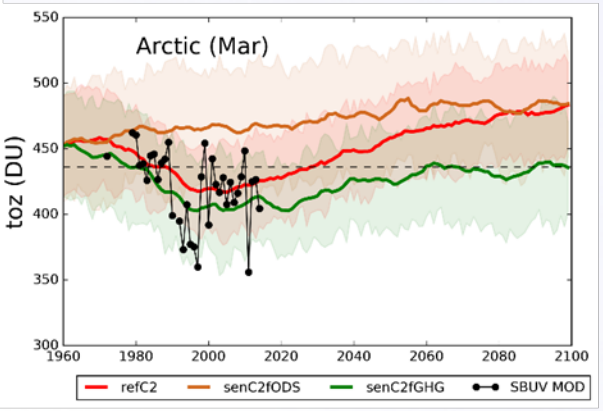
http://www.atmo-projects.net/match/

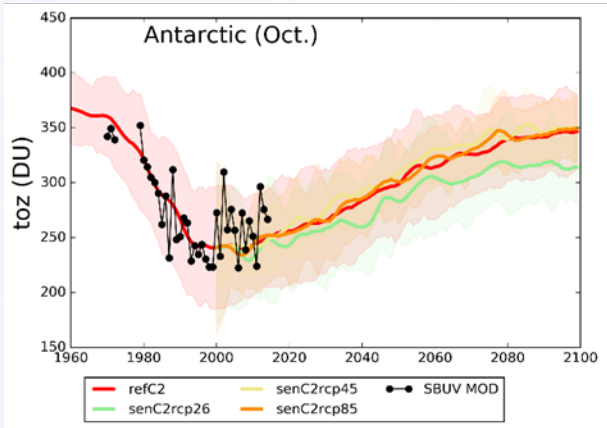
Record low strato. temperatures in early winter

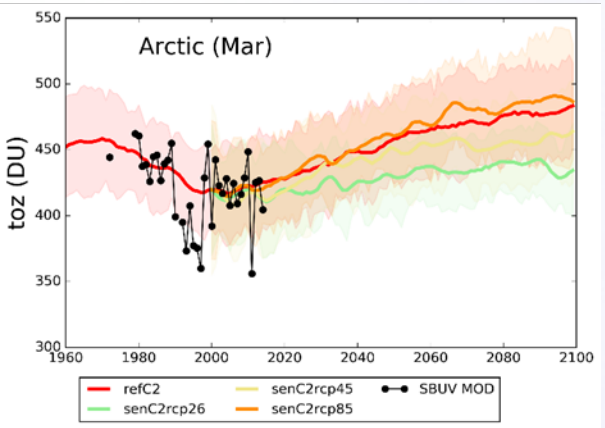
Record high accumulated PSC volume

Record low Arctic spring ozone ?









Dhomse et al., 2017, in preparation