Preliminary investigation of ozone recovery and climate change in the 21st century using the UM-UKCA climate-compostion model

S. C. Hardiman, N. Butchart and W. Collins (UK Met Office)

O. Morgenstern (University of Cambridge and NIWA, Lauder, New Zealand)

P. Braesicke, and J. Pyle (University of Cambridge)

Introduction

In support of the 2010 WMO/UNEP Scientific Assessment of Ozone Depletion the Chemistry-Climate Model Validation Activity for SPARC (CCMVal) organised a multimodel ensemble of simulations using near identical forcings:

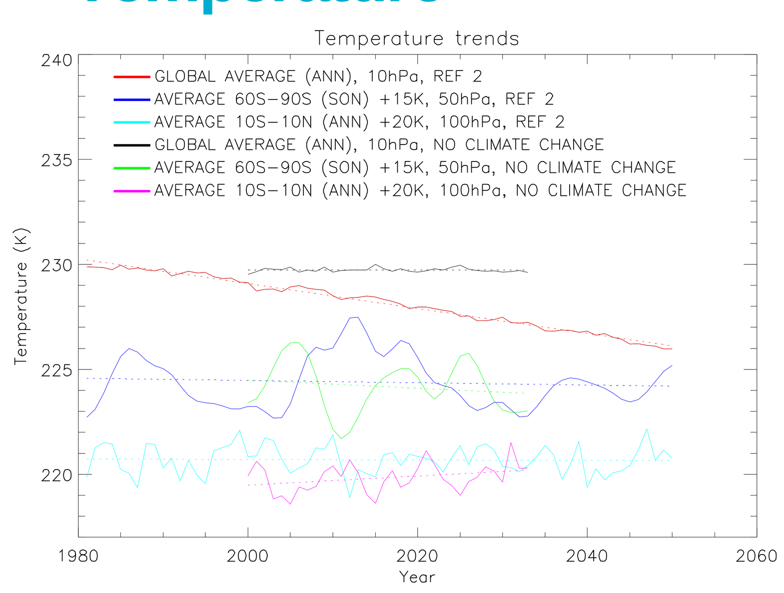
- Surface concentrations of GHGs follow the IPCC A1b scenario.
- Sea surface temperatures and sea ice amounts are taken from ocean-atmosphere simulations using the same GHG scenario.
- Surface halogens are prescribed according the A1b scenario of WMO(2003).

The CCMVal Reference 2 simulation (REF2), run from 1960-2100, and a No Climate Change simulation (NCC) are used to study ozone recovery and stratospheric climate change, focussing on the period 1980-2050. NCC differs from REF2 in the following ways:

- CO_2 held fixed
- 1995-2005 SSTs and sea ice are repeated every 10 years from 2005

The simulations are performed with the Met UM coupled to the UKCA composition model[1,2]

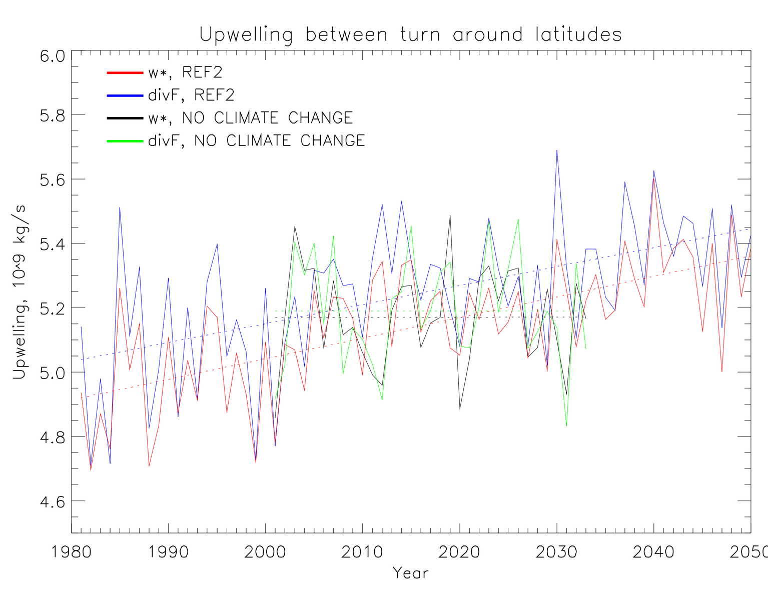
Temperature

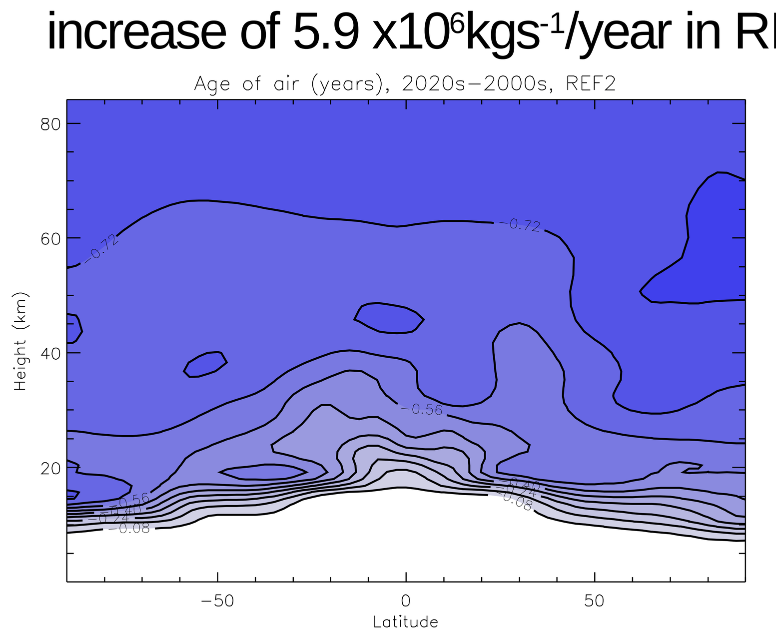


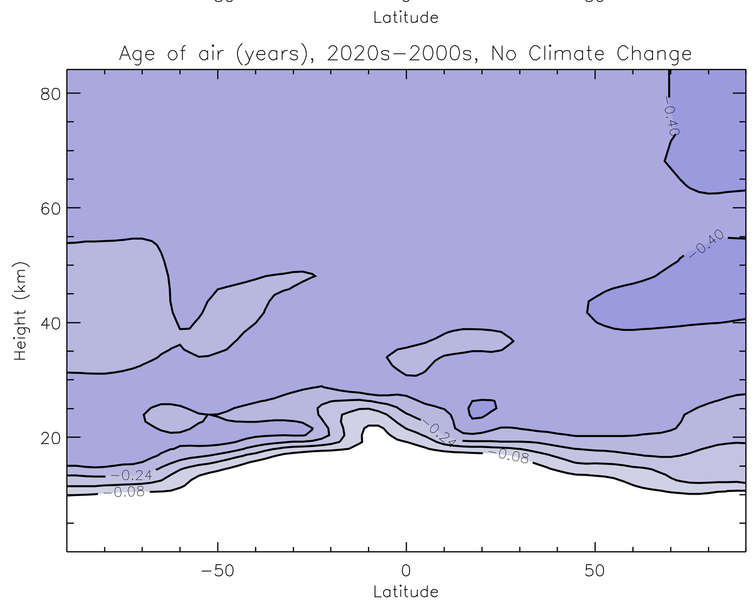
- At 10hPa there is a global mean cooling of around 0.6K per decade in REF2 (significant at 95% level) but no cooling in NCC.
- At 50hPa there is no change in south pole temperature (SON) for either run
- The tropical tropopause warms by 0.2K per decade in NCC (significant at 90% level) consistent with other studies[3,4]. This warming is probably due to increasing ozone.

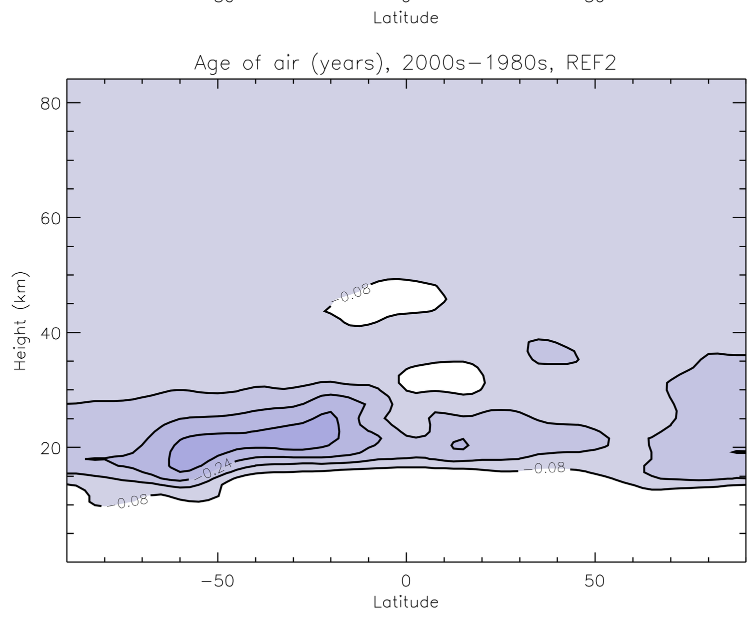
Upwelling

- Tropical upwelling calculated from residual vertical velocity, w*, shows increase of 6.4 x10^{6}kgs^{-1}/year in REF2, and less than 0.1 x10^{6}kgs^{-1}/year in NCC.
- Planetary wave contribution to upwelling, calculated using downward control, shows increase of 5.9 x10^{6}kgs^{-1}/year in REF2







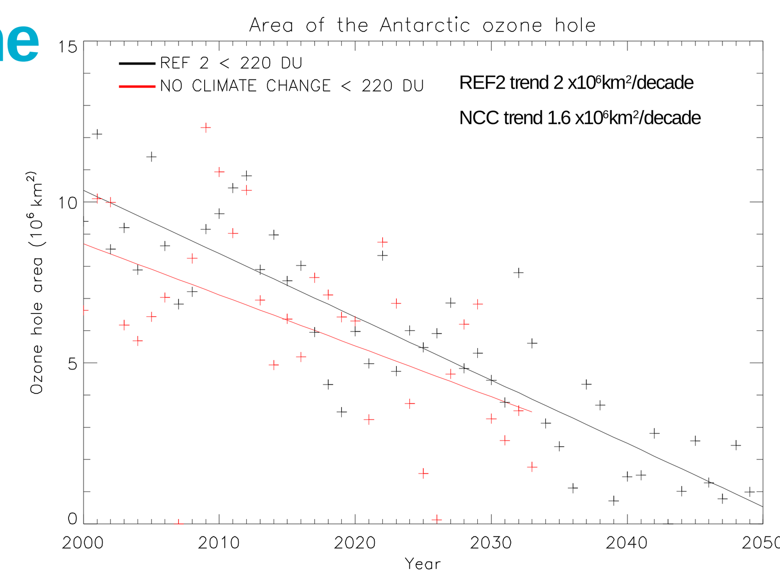


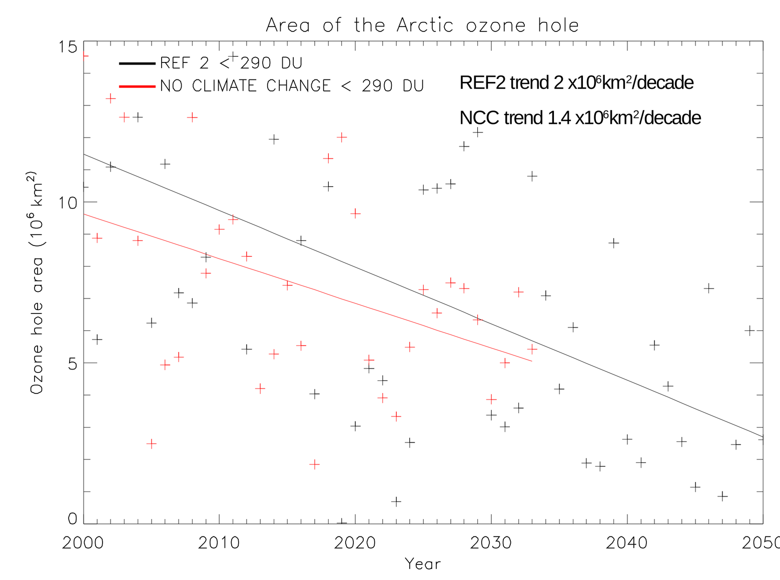
Age of air

Figures show differences in decadal average Age of air (years): 2000s-1980s for REF2 and 2020s-2000s for REF2 and NCC.

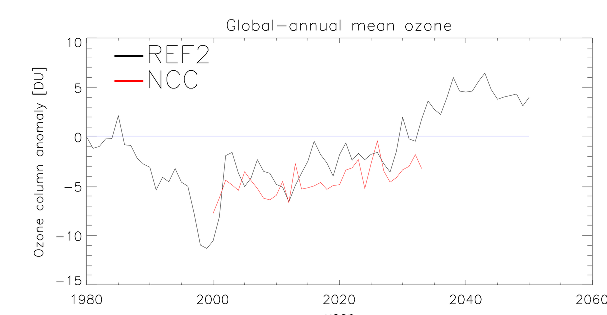
- Age of air decrease of about 0.5 years in REF2 from 2000s to 2020s is consistent with a stronger Brewer Dobson Circulation (i.e. increase in upwelling)
- Age of air also decreases by about 0.25 years in NCC. This is most likely due to ozone recovery[5]. Cly is identical in the two simulations, peaking at 3.8ppbv around 2000 and then decreasing
- Consistent with this possibility, age of air decrease in REF2 is only around 0.1 years from 1980s to 2000s, when ozone has been depleted, despite similar increases in wave driven upwelling seen during this time.

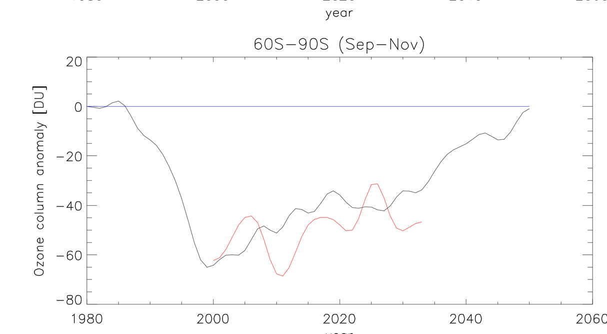
Ozone

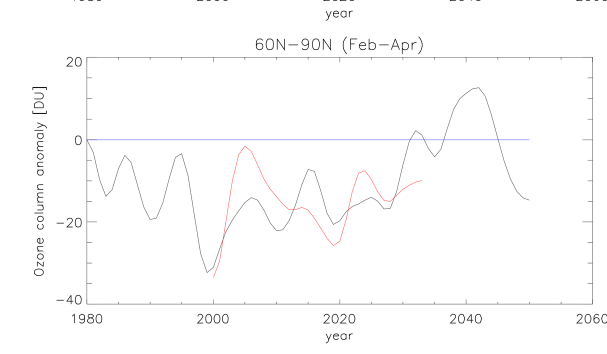




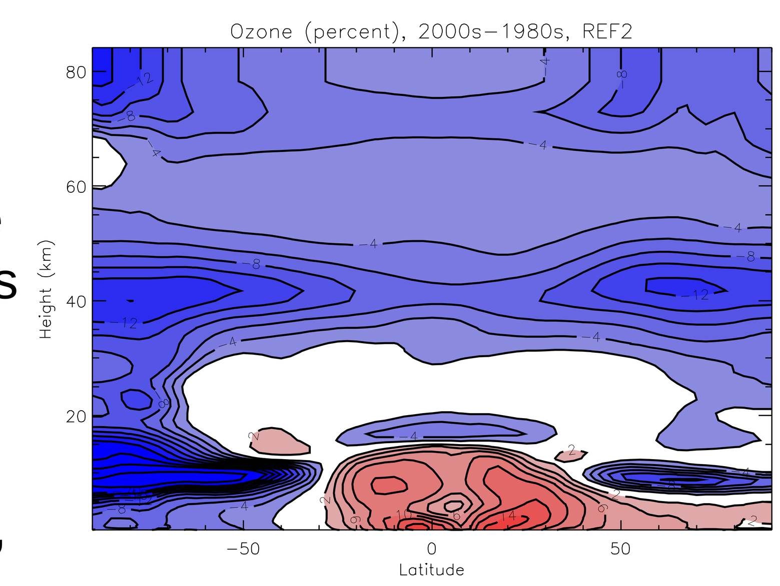
- Climate change increases the rate at which the size of the Antarctic ozone hole is shrinking by 25%. The same is true in the Arctic.
- Climate change likely speeds up ozone recovery by increased transport of ozone to the poles in the stratosphere.





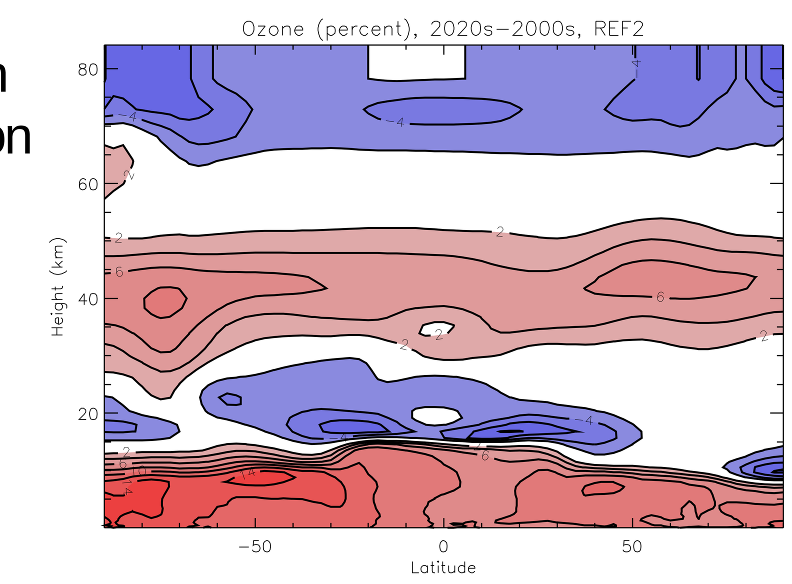


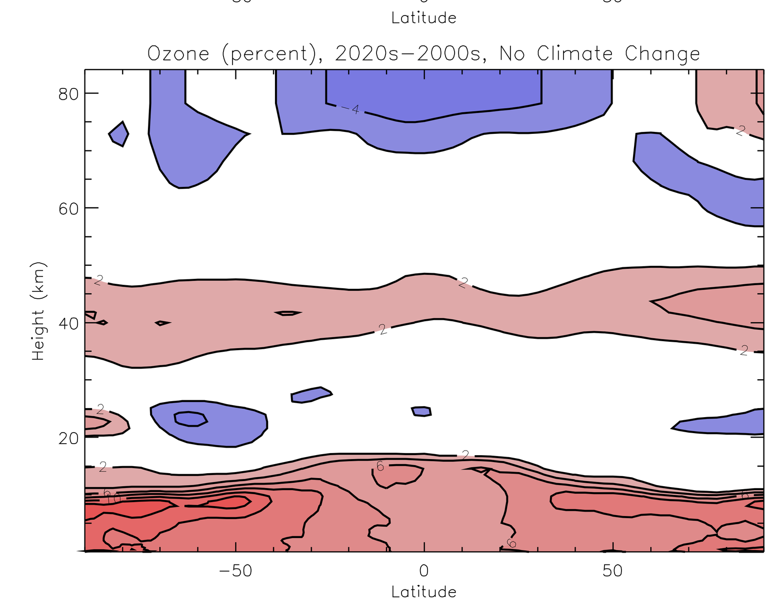
- Similarly, column ozone is seen to recover in both runs, but recovery is faster with climate change (REF2) than without (NCC) at the south pole.
- In REF2, ozone recovers to 1980 values by around 2035 in the global mean, but not until around 2050 at the south pole in SON, and around 2045 at the north pole in FMA.
- The NCC integration is ongoing. Ozone recovery dates are not yet known for this run.



Figures show % differences in decadal average ozone: 2000s-1980s for REF2 and 2020s-2000s for REF2 and NCC.

- REF2 shows ozone loss from 1980s to 2000s throughout the lower stratosphere at both poles, and throughout the upper stratosphere.
- Ozone recovery from 2000s to 2020s is seen in the upper stratosphere, with continuing depletion in the lower stratosphere.
- This structure is similar in both runs but magnitudes of ozone recovery/depletion are greater in REF2 than NCC. Ozone recovery in the mid stratosphere is greater under climate change, around 6-8% rather than 2-4%, likely due to stratospheric cooling by GHGs





Conclusions

- Due to climate change, 21st century temperatures show significant cooling at 10hPa
- Climate change causes increase in wave driven upwelling
- Even without climate change Age of air decreases, likely due to ozone recovery, but decrease is greater with climate change, likely due to increased Brewer Dobson Circulation
- Ozone holes at both poles recover at significant rates. Recovery is about 25% faster with climate change, likely due to increased transport of ozone to the poles and increased ozone present in the mid-stratosphere due to stratospheric cooling.
- The net effect of decreasing chlorine and an increased Brewer Dobson circulation is that ozone recovery to 1980 values occurs by around 2040. Recovery occurs slightly later at the south pole than other regions.

Steven Hardiman
Afill: **Met Office** FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom
Email: steven.hardiman@metoffice.gov.uk

References:

[1] Morgenstern, O., et al., 2008: The world avoided by the Montreal Protocol. *Geophys. Res. Lett.*, **35**, L16811, doi:10.1029/2008GL034590
[2] Morgenstern, O., et al., 2008: Evaluation of the new UKCA climate-composition model. Part 1: The Stratosphere. To be submitted to *Geoscientific Model Development*
[3] Gettelman, A., T. Birner, V. Eyring, et al., 2008: The tropical tropopause layer 1960-2100. *Atmos. Chem. Phys. Discuss.*, **8**, 1367-1413.
[4] Eyring V., et al., 2007: Multi model projections of stratospheric ozone in the 21st century. *J. Geophys. Res.*, **112**, D16303, doi:10.1029/2006JD008332
[5] Li, F., J. Austin and J. Wilson, 2008: The Strength of the Brewer–Dobson Circulation in a Changing Climate:Coupled Chemistry–Climate Model Simulations. *J. Climate*, **21**, 40-57, doi:10.1175/2007JCLI1663.1