20 years on: The impact of the Montreal Protocol

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Motivation

- Montreal Protocol was ratified 20 years ago.
- Generally credited with "saving the ozone layer".
- Was based on imperfect science
- What would be the state of the atmosphere without the Montreal Protocol?
- We are only interested here in ozone-climate feedbacks; radiative impact of CFCs is ignored.

Chlorine scenarios

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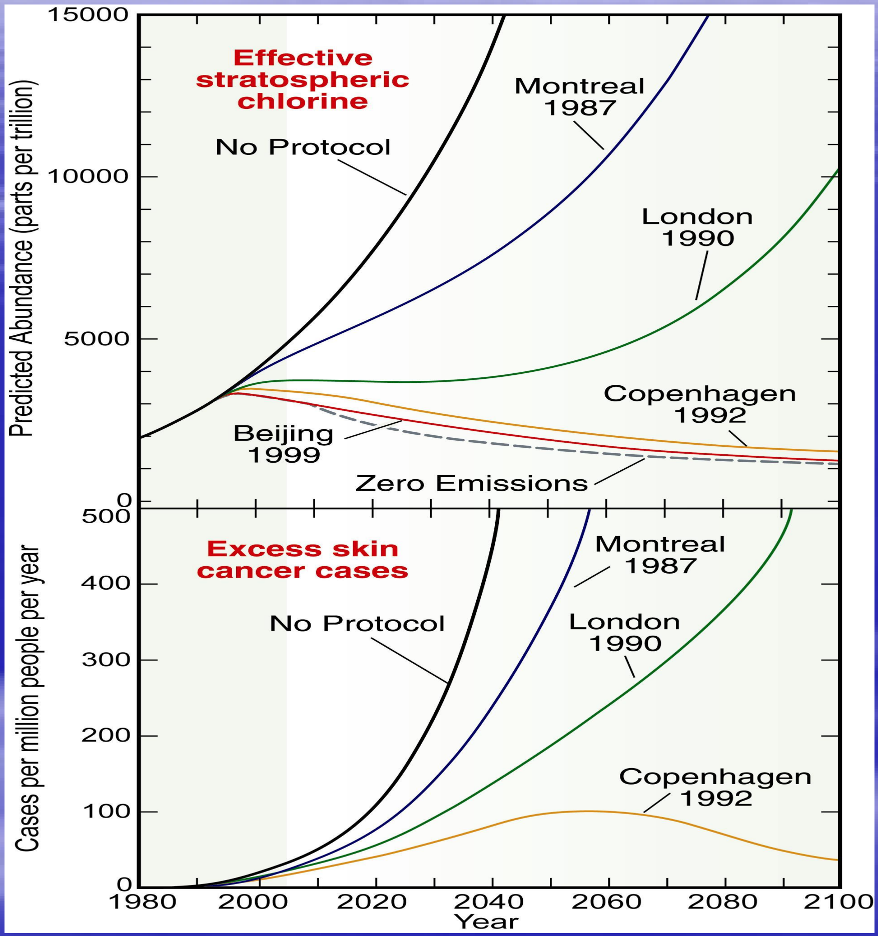

Chlorine abundance under different scenarios

(from WMO ozone assessment, 2006)

Effective Cl would reach 9 ppbv at ~2030.

UKCA model

- Couples aerosols – gas phase chemistry – climate
- Based on New Dynamics UM
- Has got representations of major processes affecting composition
- Particularly, halogen chemistry and polar stratospheric clouds are foreseen.

Simulations with UKCA

- **Simulation A**
  - *Present-day*
  - AMIP2 SSTs + ice
  - 3.5 ppbv total Cl
  - 20 pptv total Br
  - SPARC aerosol incl Pinatubo signature
  - Present-day GHGs
  - 1989-1999

- **Simulation B**
  - Same as A
  - 9 ppbv of total Cl

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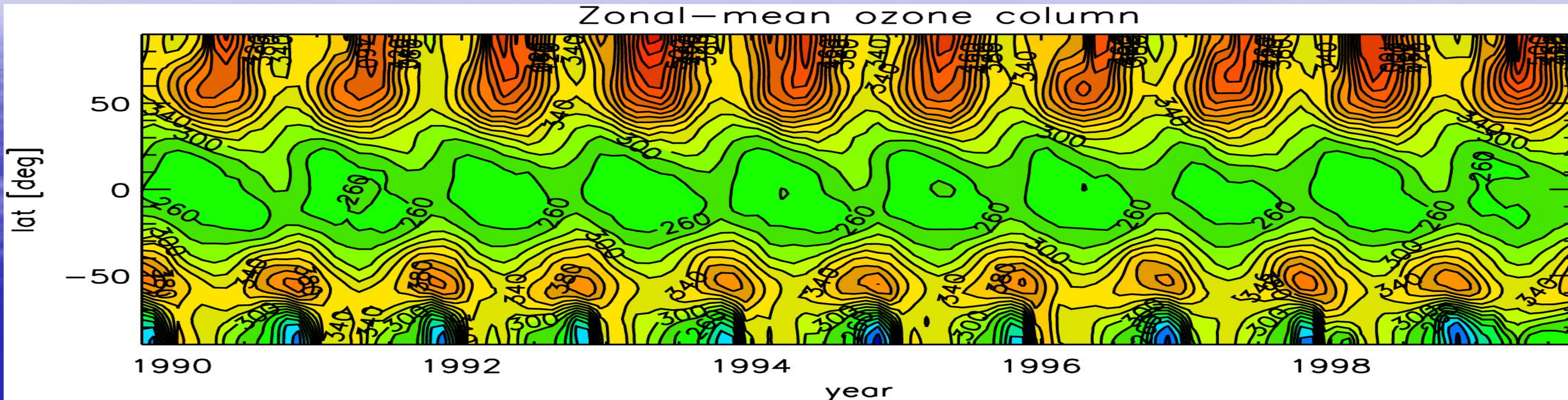
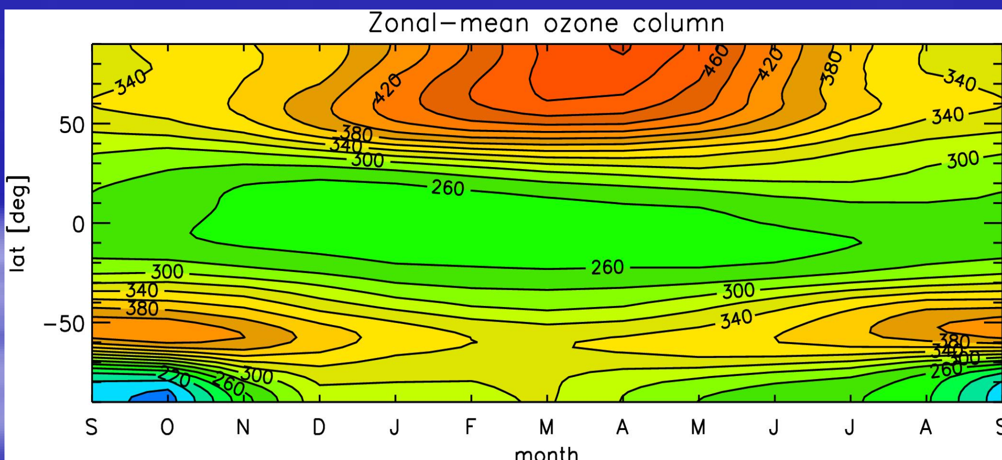
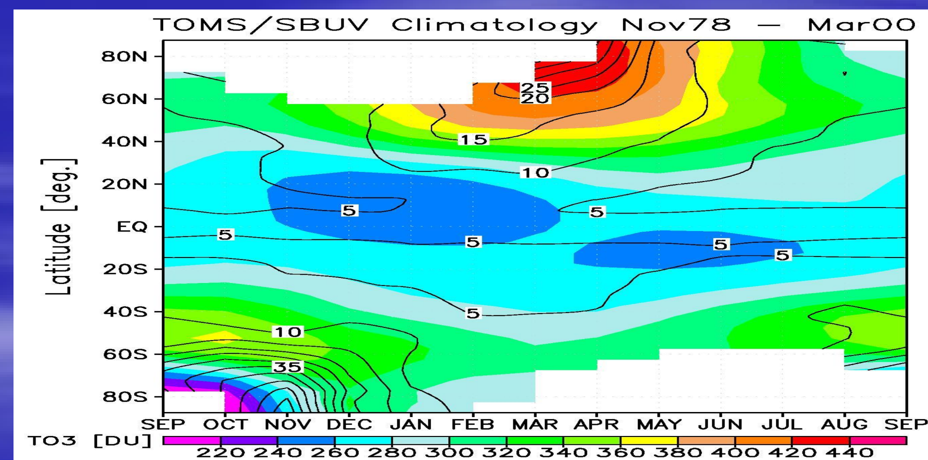
Ozone column







Top: ozone column in present-day situation (Sim A).
Bottom: Mean annual cycle versus TOMS/SBUV climatology

Ozone

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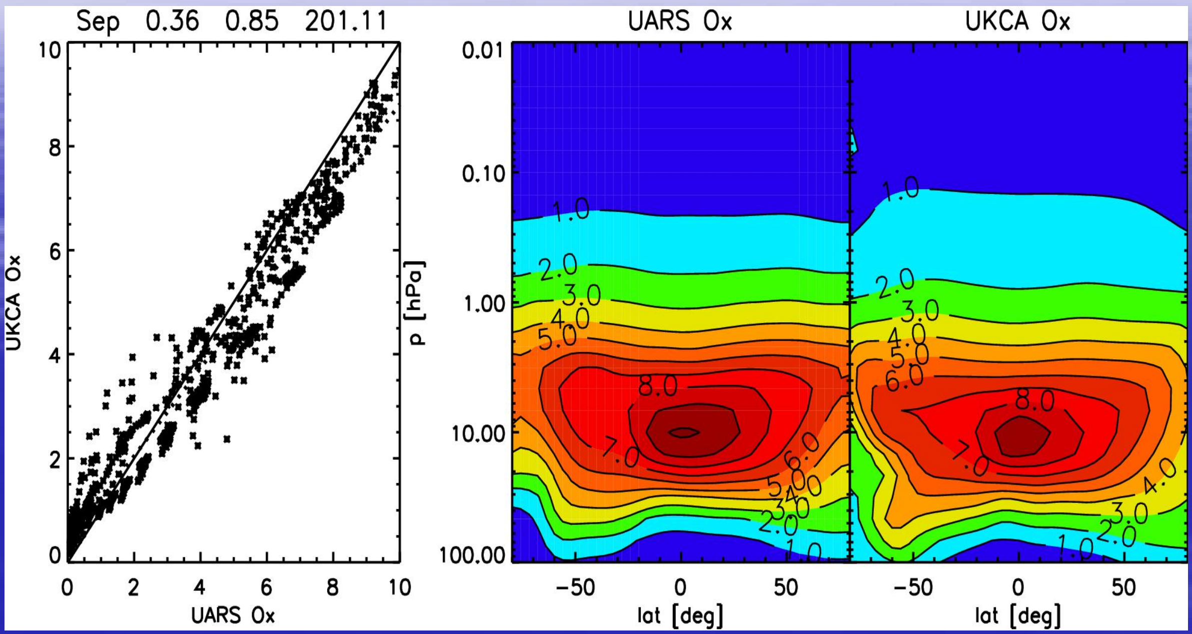
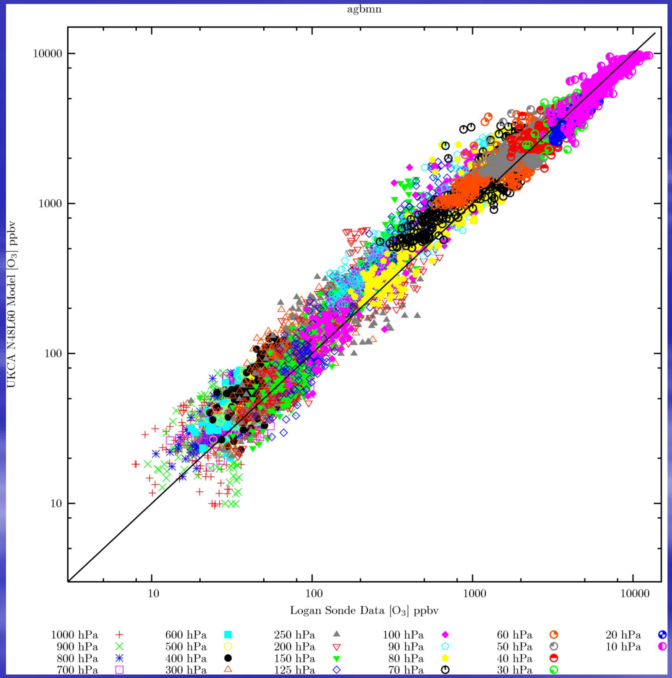


Mean ozone VMR versus HALOE climatology for September

Mean ozone versus sonde climatology (Logan, 1999)



(courtesy of Luke Abraham)

Age of air

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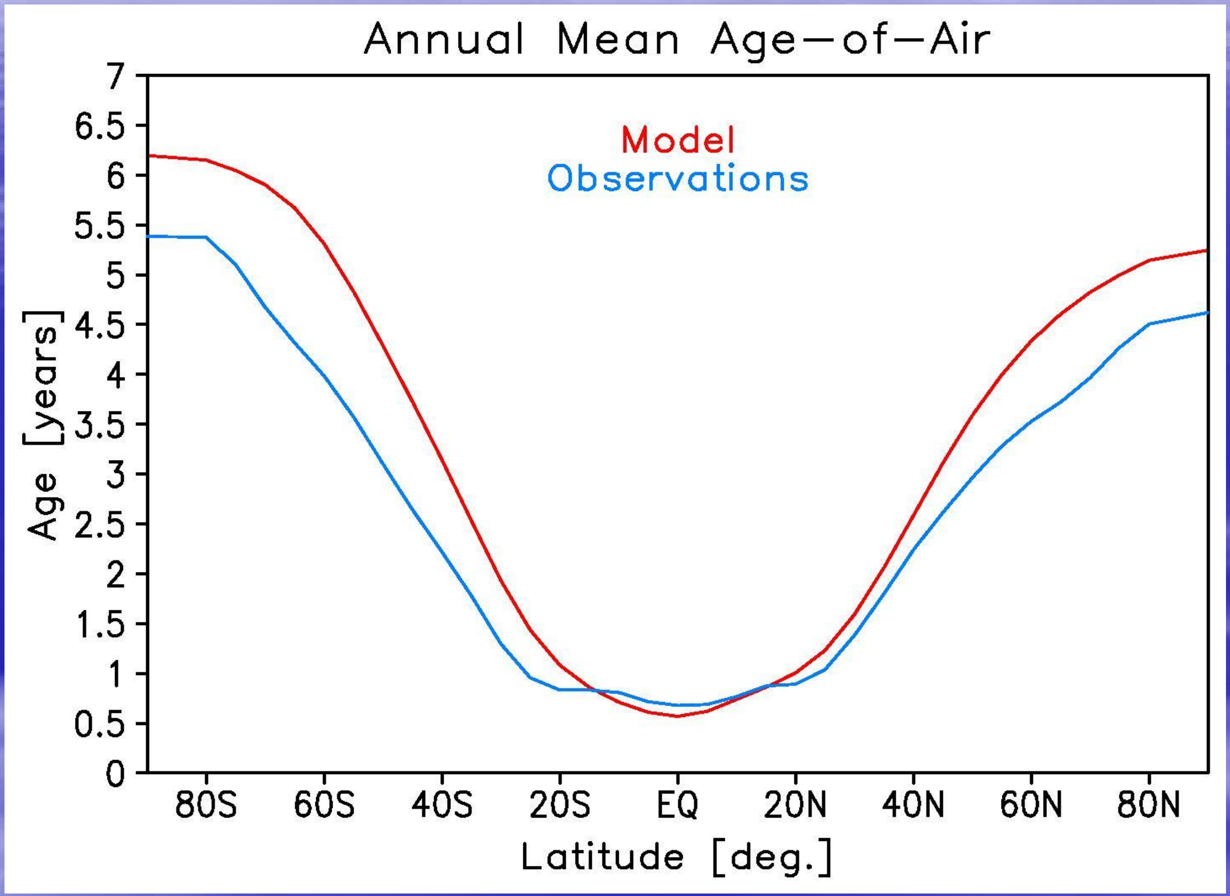
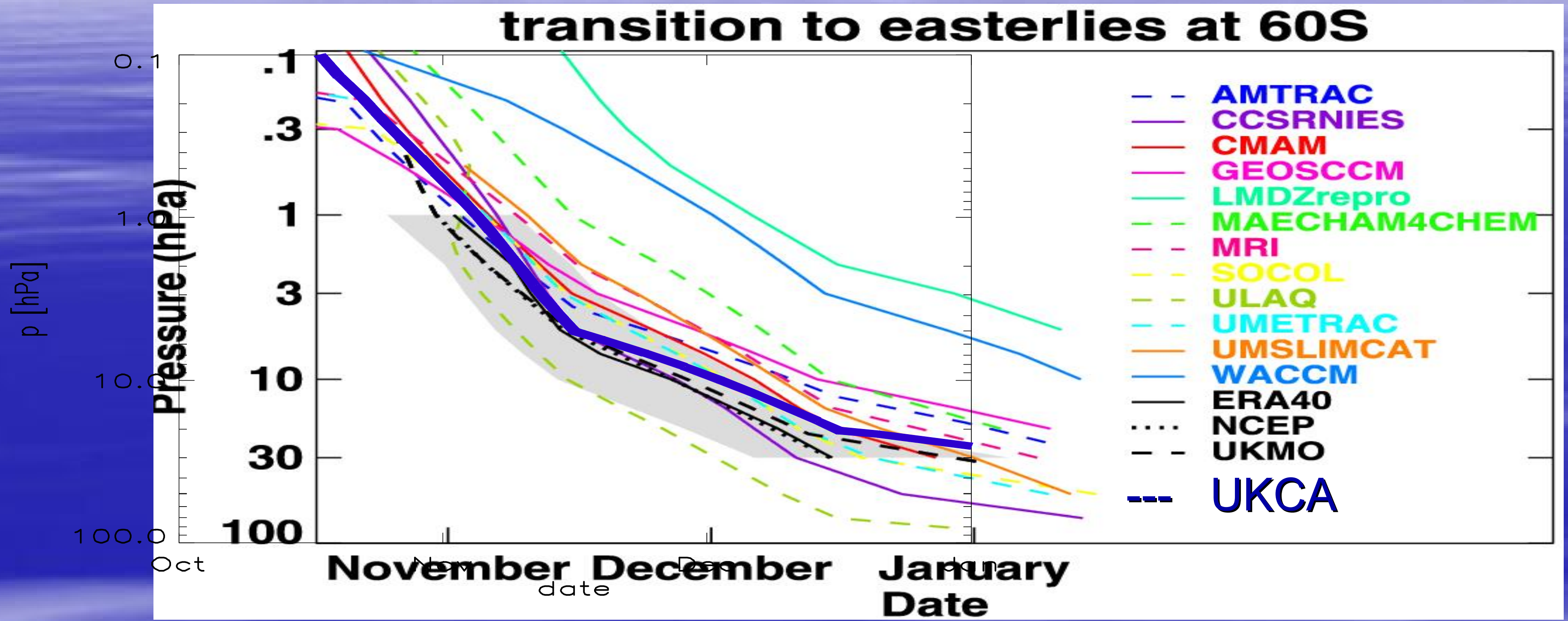


UKCA mean age of air vs MIPAS SF_6 observations (courtesy of G. Stiller, FZ Karlsruhe)

(see poster by Peter Braesicke et al.)

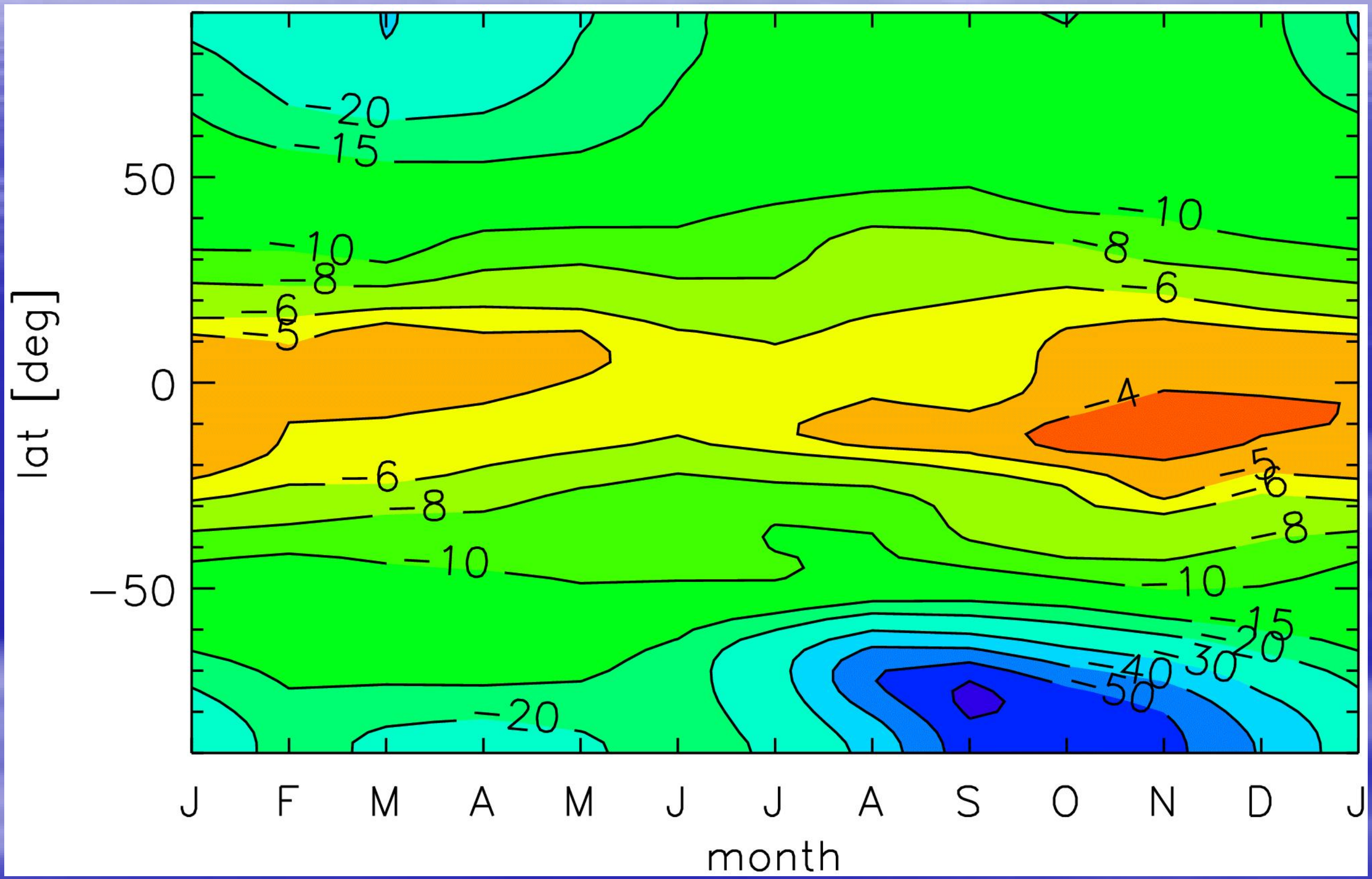
Longevity of polar vortex



Timing of zonal-wind reversal at 60°S from zonal-mean zonal winds. (Figure from Eyring et al., 2006)

Lifetime of southern polar vortex well captured.

Ozone column



Percentage change in mean annual cycle of ozone column

Ozone cross section

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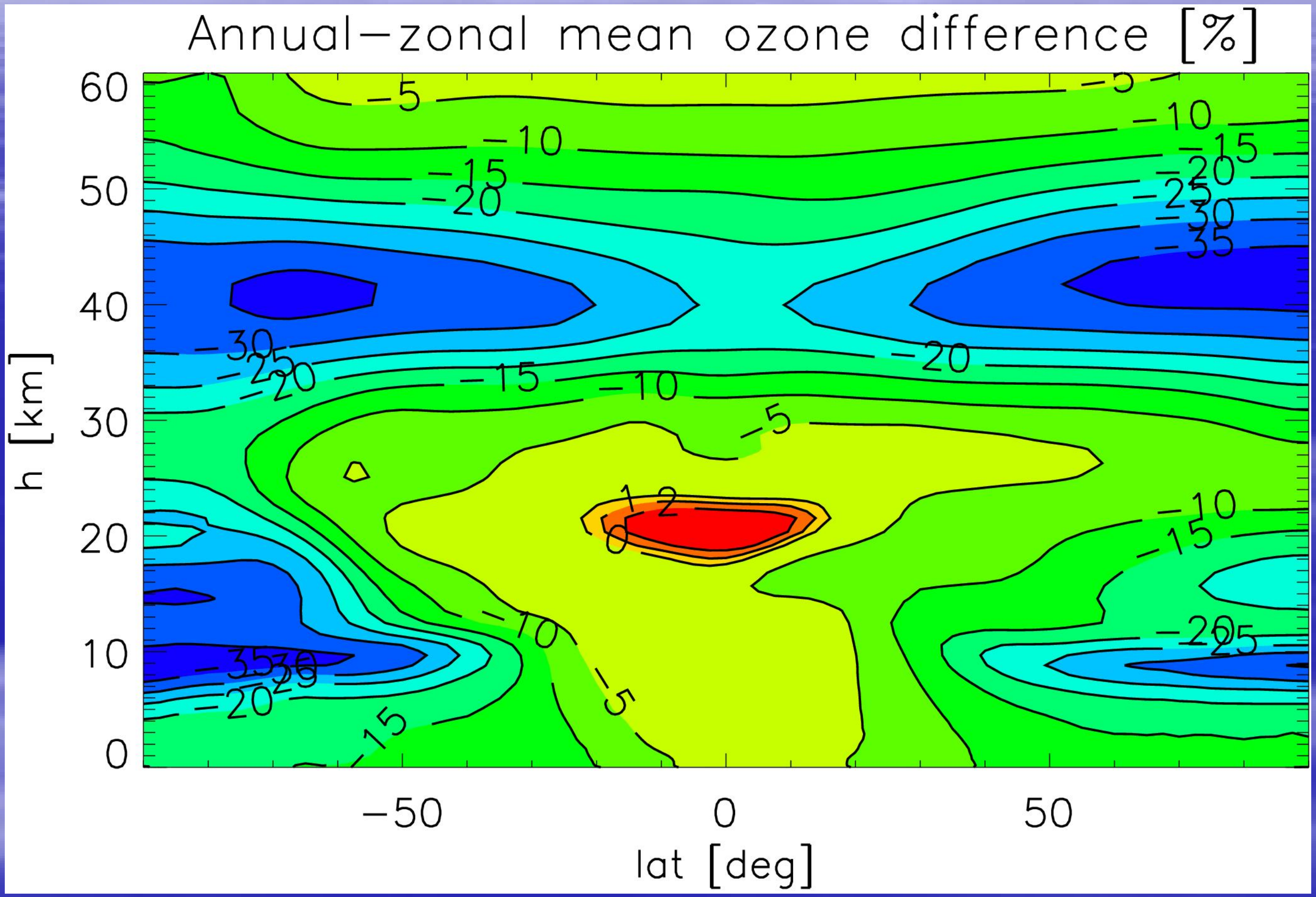
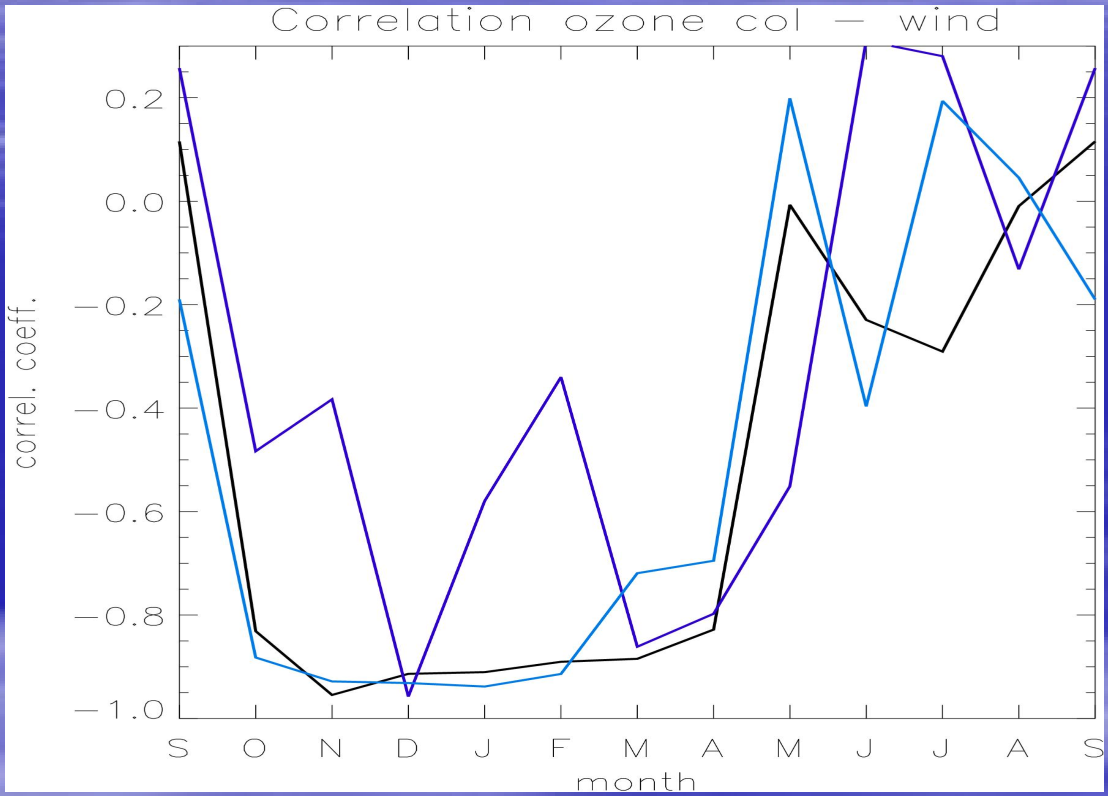


Annual-mean ozone change (%)

Correlation polar jet-ozone column



Correlation coefficient between ozone column at and zonal winds at 50 hPa

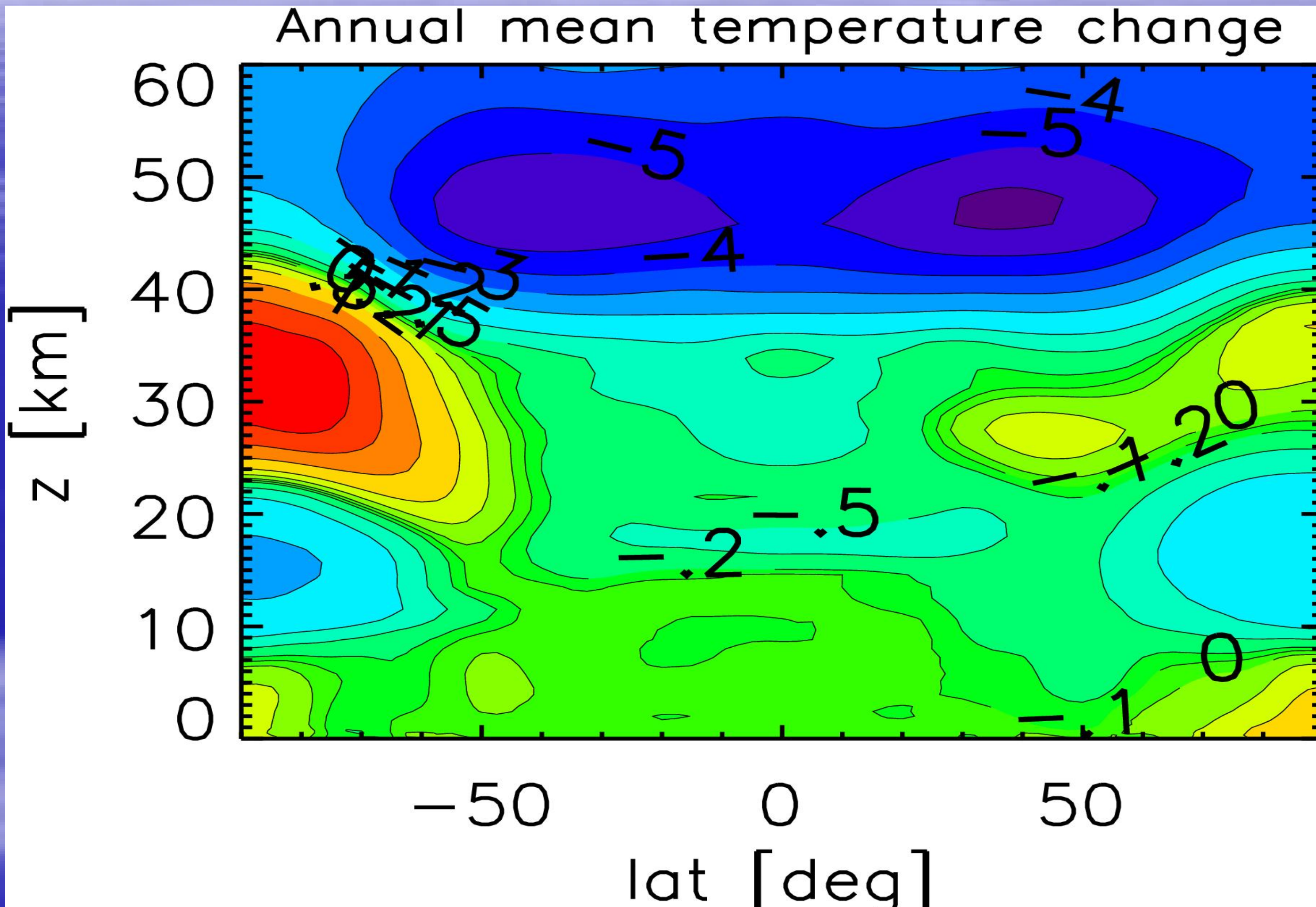
Black: reference

Blue: 2050

Violet: 9 ppbv

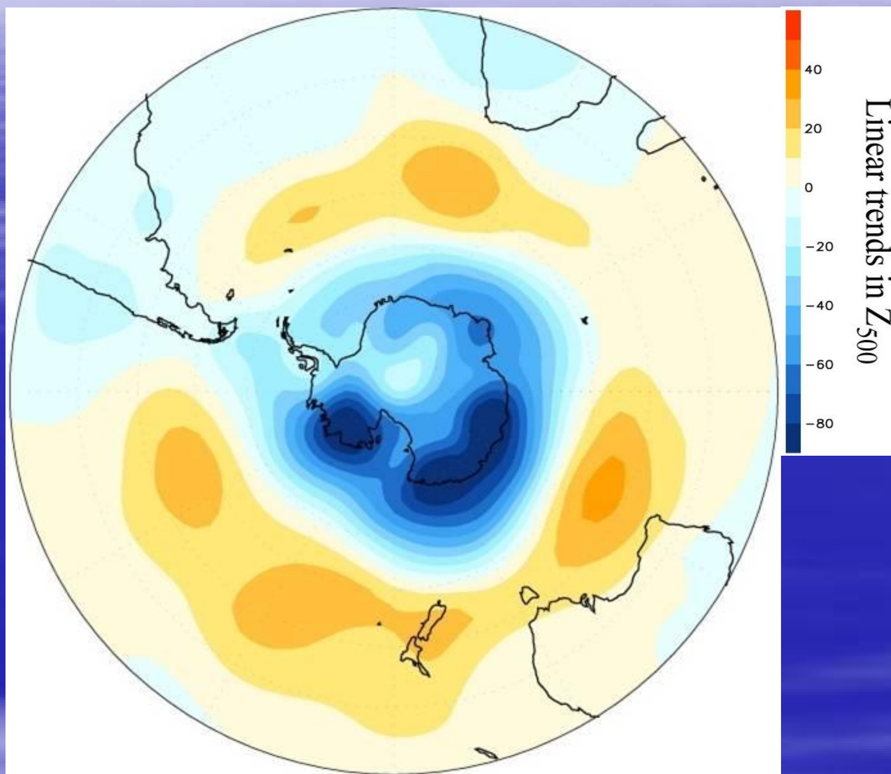
Anticorrelation between polar jet and polar ozone column breaks down.

Effects on temperature

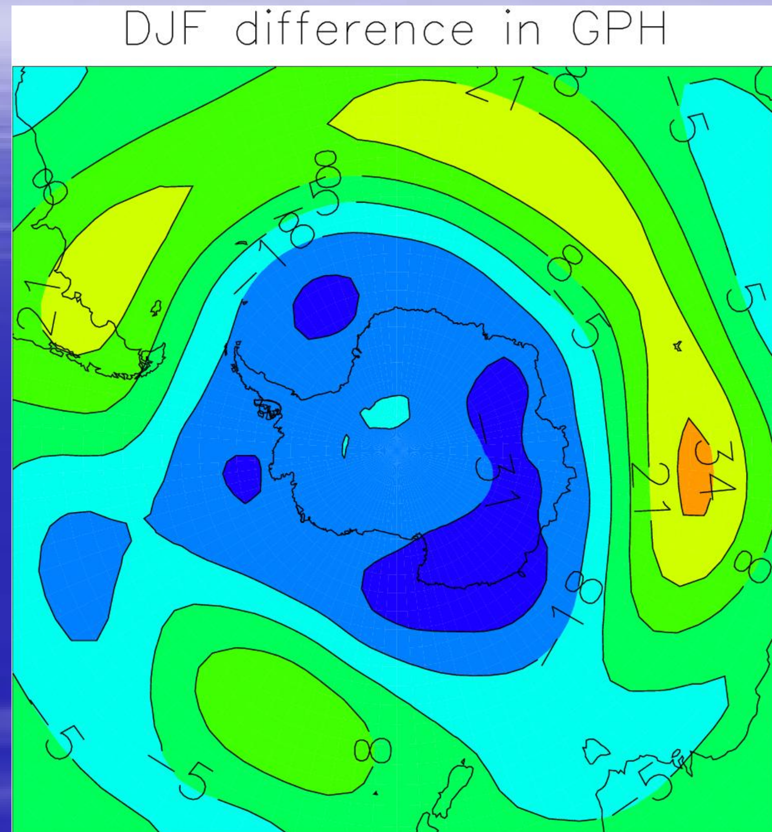


ZM temperature difference for 9 ppbv of chlorine

Tropospheric climate



Geopotential height trend at 500 hPa (m) in DJFMAM from 1979 to 2000 (Thompson and Solomon, 2002)



Geopotential height difference vs reference at 500 hPa in DJF.

Southern Annular Mode is strengthened by additional chlorine.

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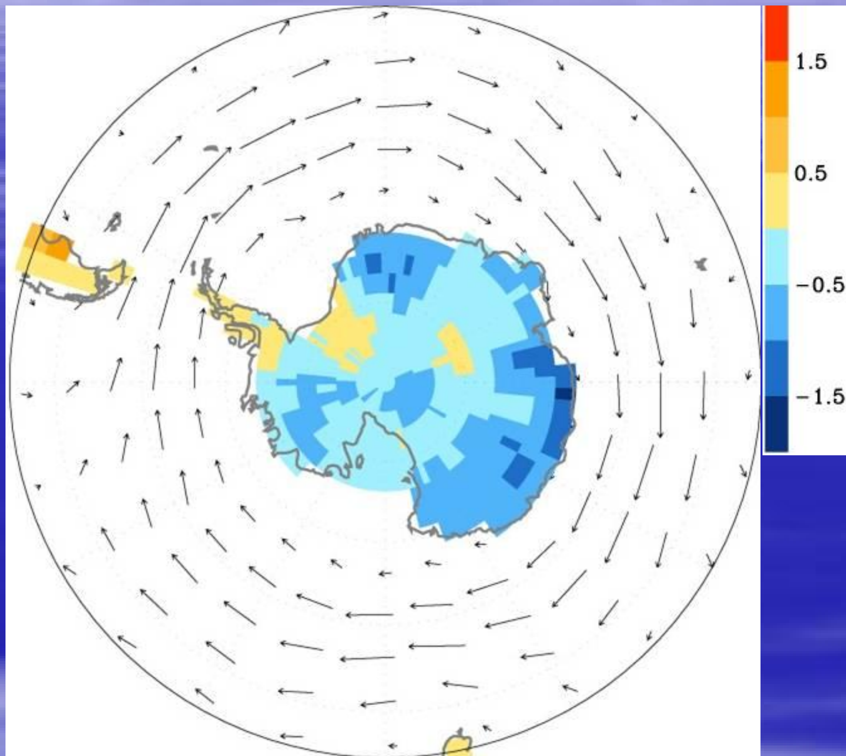
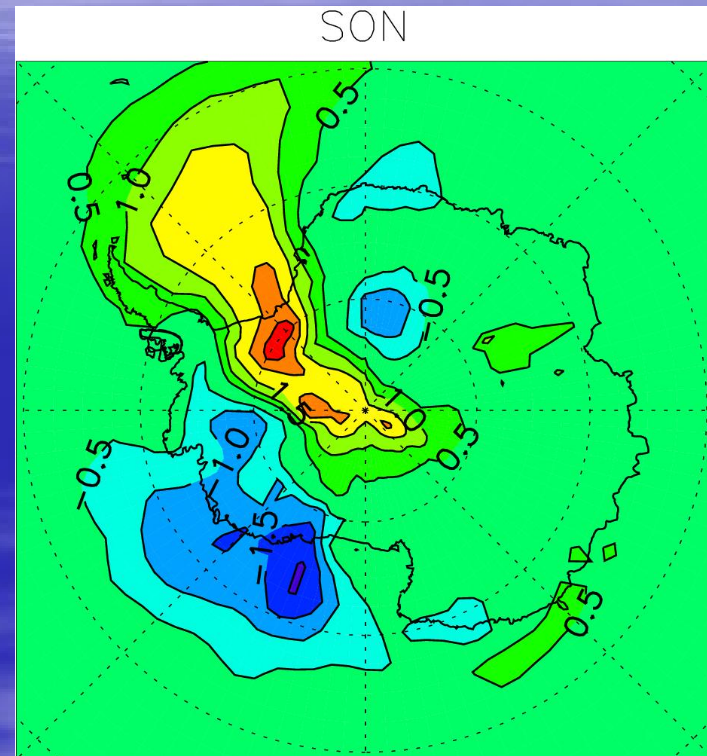
Antarctic surface temperature change



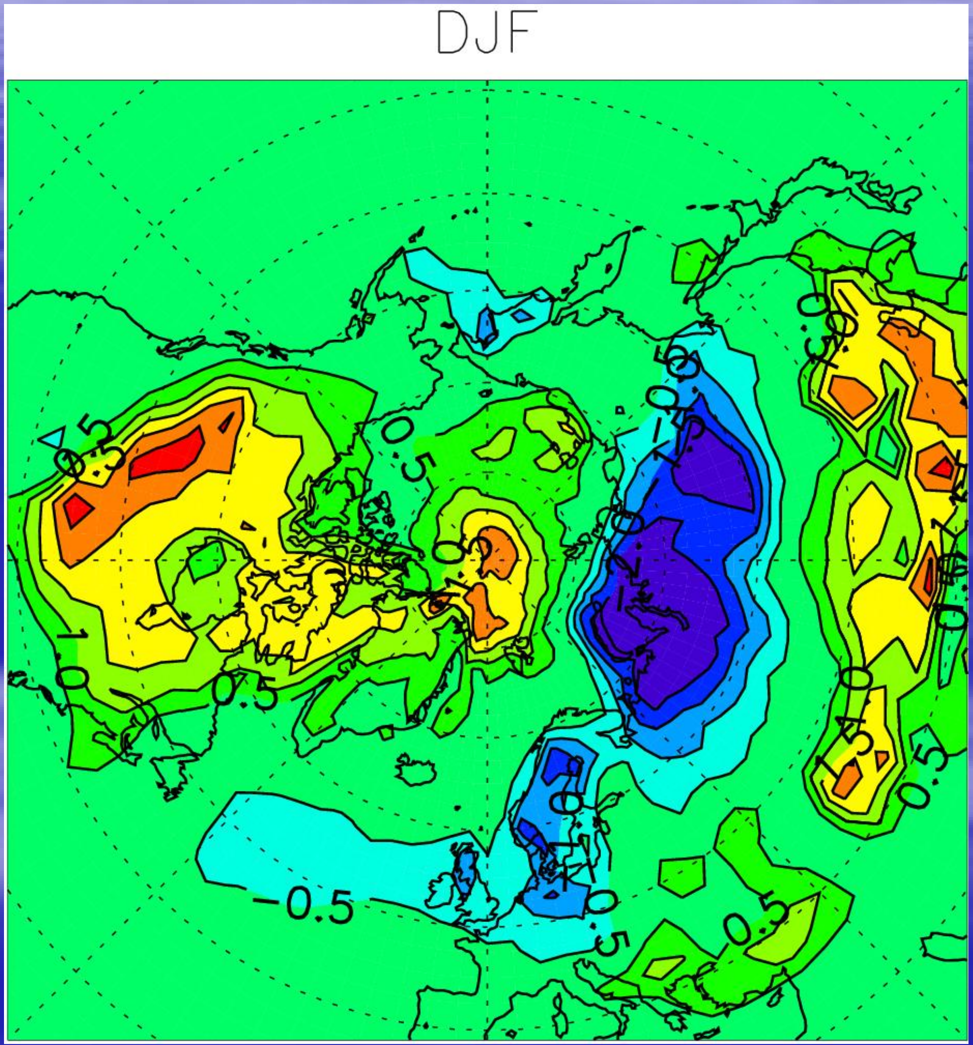
Simulated climate change signal (Gillett and Thompson, 2003)



20m temperature difference in UKCA due to ozone change

Stronger westerlies favour increased lee cyclogenesis around Antarctic Peninsula → warming.

NH surface temperature change in winter



North America, Arctic Ocean and parts of Asia warm, Northern Siberia, North-west Europe cool.

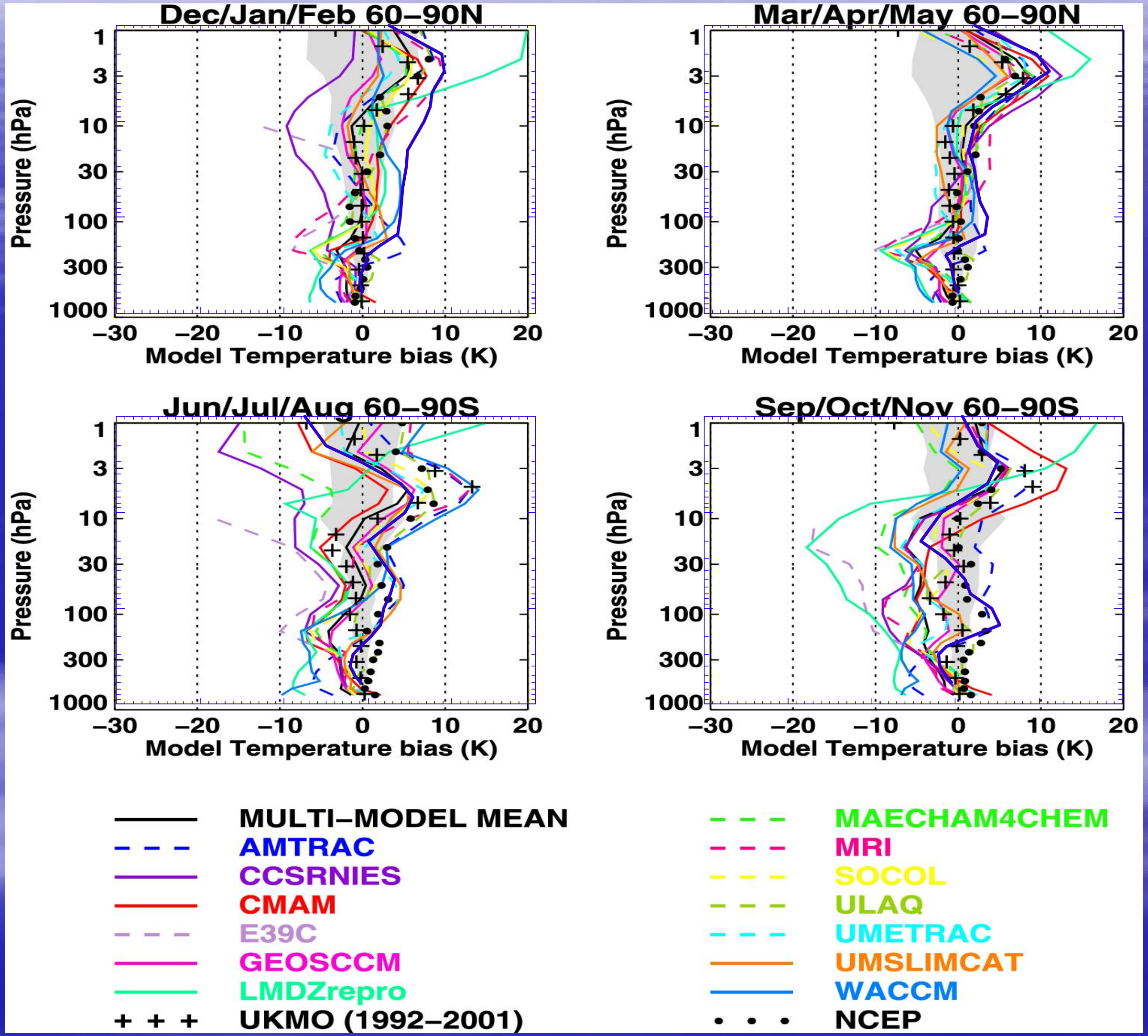
Summary

- Simulations of present-day and high-chlorine atmospheres have been carried out.
- Present-day simulation compares generally well with observations.
- 9 ppbv of chlorine substantially affect climate, esp. in polar regions.
- Similarities of simulated high-chlorine climate with observations.
- Publication in progress

Outlook

- Move to HadGAM2; address temperature bias
- Integrate with nudging
- Whole-atmosphere chemistry
- Mesoscale modelling with UKCA
- NERC-funded model validation / climate engineering project
- Participate in CCMVal, WMO and IPCC activities

Temperature



High-latitude temperature biases of various models versus ERA-40 (from Eyring et al, 2006).

Dark blue: UKCA versus UARS climatology.

Temperature differences

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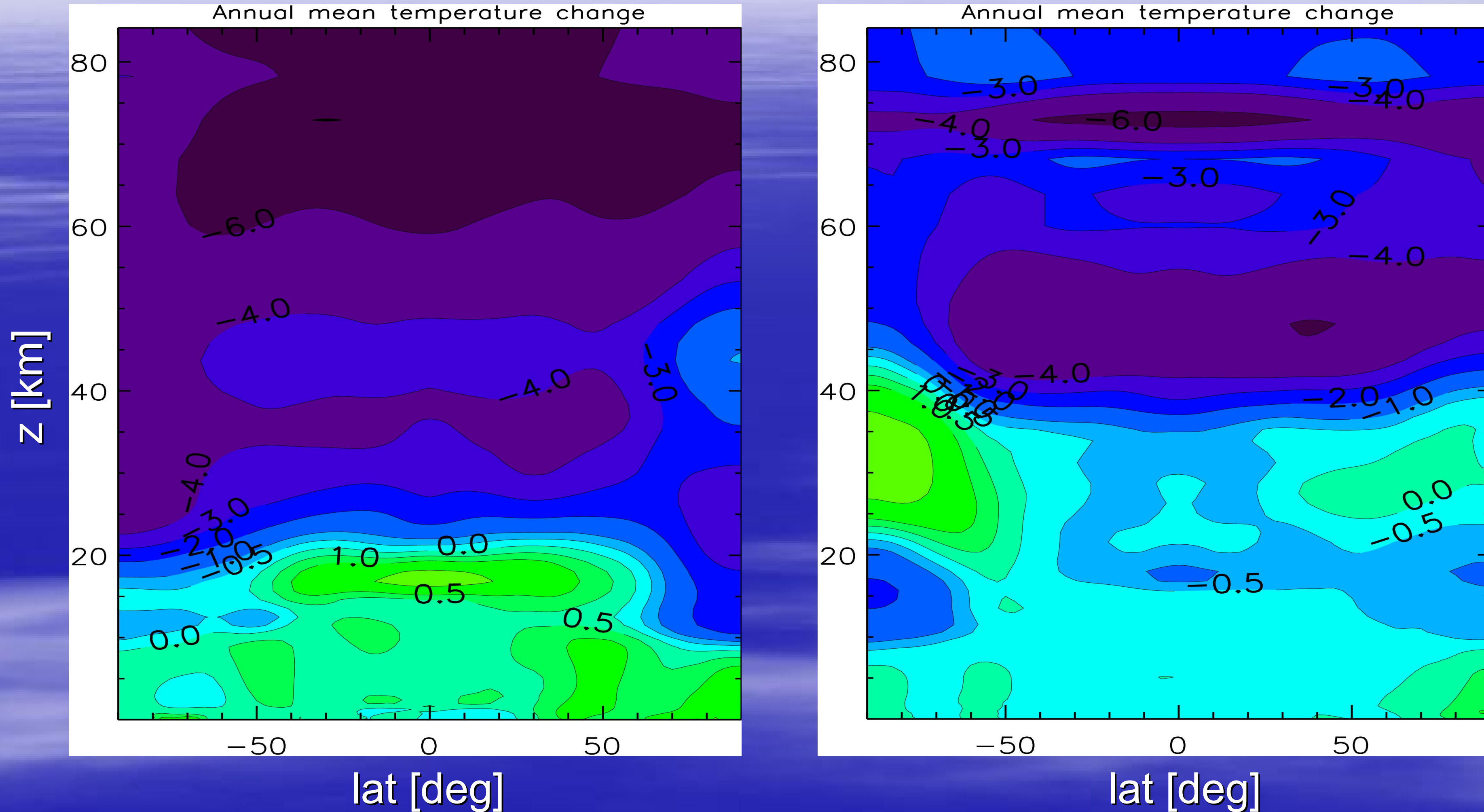
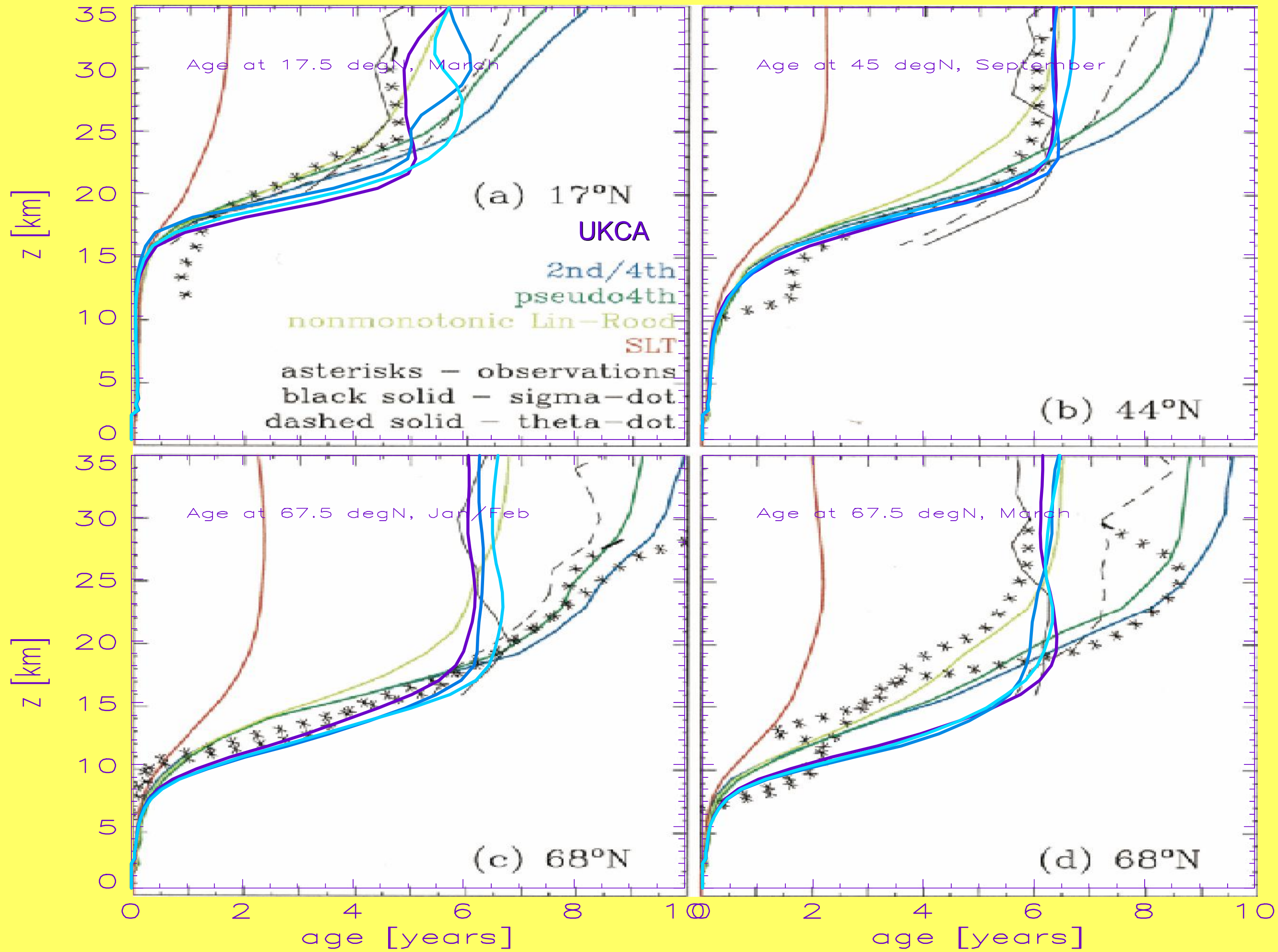


Annual-mean temperature changes: (left) B-A (right) C-A

Age of air profiles



(from Eluszkiewicz et al., 2000)