UKCA

Stratosphere and whole atmosphere modelling

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Structure

- The base model: the new dynamics Unified Model
- The stratospheric UKCA (with background troposphere)
- Science examples:
  - Climatological validation (Morgenstern et al., GMD(D), 2008)
  - Process-oriented validation (e.g. N_2O PDFs)
  - UKCA constrained by the "real world" (Telford et al., ACP, 2008)
  - The "world avoided" simulation (Morgenstern et al., GRL, 2008)
- Summary
- Outlook: comprehensive whole atmosphere chemistry

The base model

- The new dynamics Unified Model:
  - Solves the 3d equations of (air) motion and does not use the hydrostatic approximation → the vertical velocity is a prognostic variable
    - Horizontal Arakawa-C grid, hybrid geometric height coordinate
  - The model uses a corrective (mass) conservative, off-centred, semi-implicit, semi-Lagrangian transport scheme (Priestly, 1993) → total mass conservation is guaranteed, but “elemental” conservation not necessarily
  - Here: UM6.1, N48L60
    - N48: 3.75º in longitude x 2.5º in latitude (N96 possible)
    - L60: surface to slightly above 80km
  - For any problems not entirely constrained by surface emissions a stratospheric model should be used. STE!

The stratospheric UKCA

- The stratospheric UKCA :
  - Solves the chemical equations using a Newton-Raphson solver for individual species (no family approach, hourly time step possible)
  - Controls “elemental” conservation (idea: e.g. total chlorine is transported, and checked against the individual species)
  - Results shown here follow largely CCMVal Ref1 and Ref2 recommendations
  - Sea-ice coverage and sea-surface temperatures are prescribed from HadISST (present day) or from coupled AO integrations with the UM (thanks to the Hadley Centre and BADC)

The stratospheric UKCA

- Comprehensive stratospheric chemistry (incl. Cl/Br) …
  - Lumped source gases ($CFCl_3$, CF_2Cl_2, CH_3Br)
  - Prescribed sulphate aerosol layer
  - Heterogeneous / PSC processes, denitrification
- … background tropospheric chemistry (CH_4, CO, NO_x).
  - Dry & wet deposition of tropospheric species
  - Surface, lightning & aircraft emissions (NO, CO, CH_2O)
- Individual species (40+, no families!)
- Halogen compounds, N_2O and CH_4 prescribed at the surface
- Water vapour can be prescribed in tropical UTLS region
- Off-line photolysis or Fast-J2 implementation
- Ozone, etc. are used in the radiative transfer calculation

Science example 1

Climatological validation

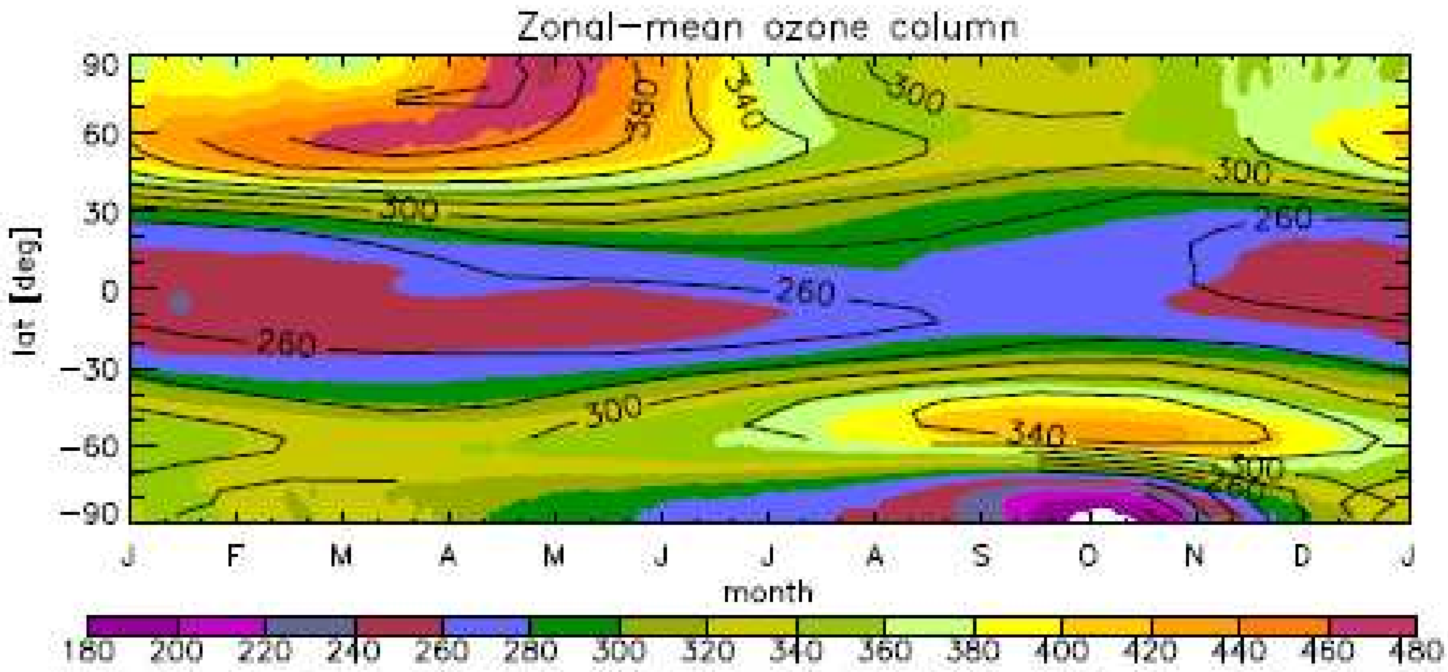


Fig. 9. Multiannual- and zonal-mean ozone column (Dobson Units). Colours: Strat-UKCA, with daily resolution. Contours: TOMS/SBUV climatology, with monthly resolution.

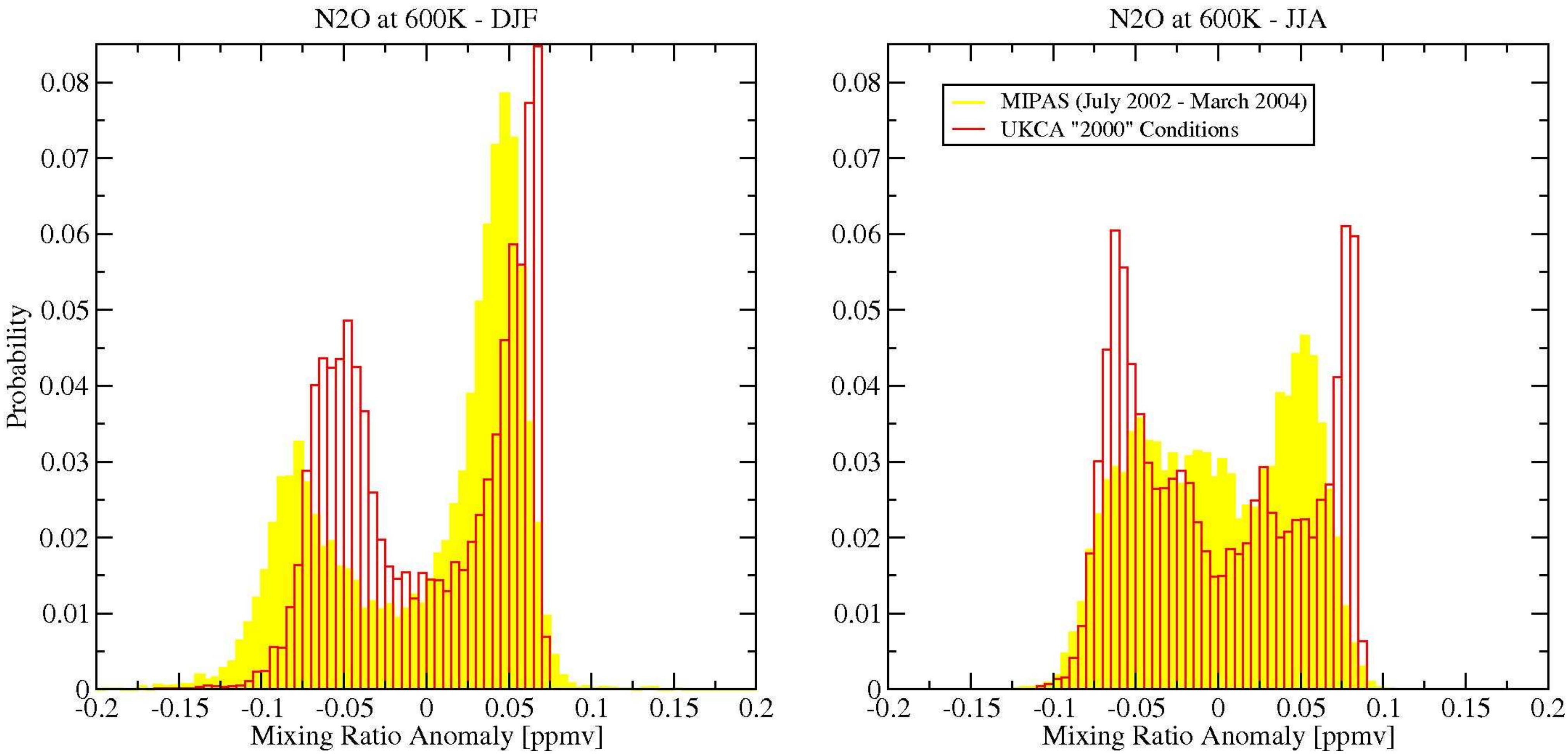
www.geosci-model-dev-discuss.net/1/381/2008/gmdd-1-381-2008.html

Science example 2

Process-oriented validation using N_2O PDFs

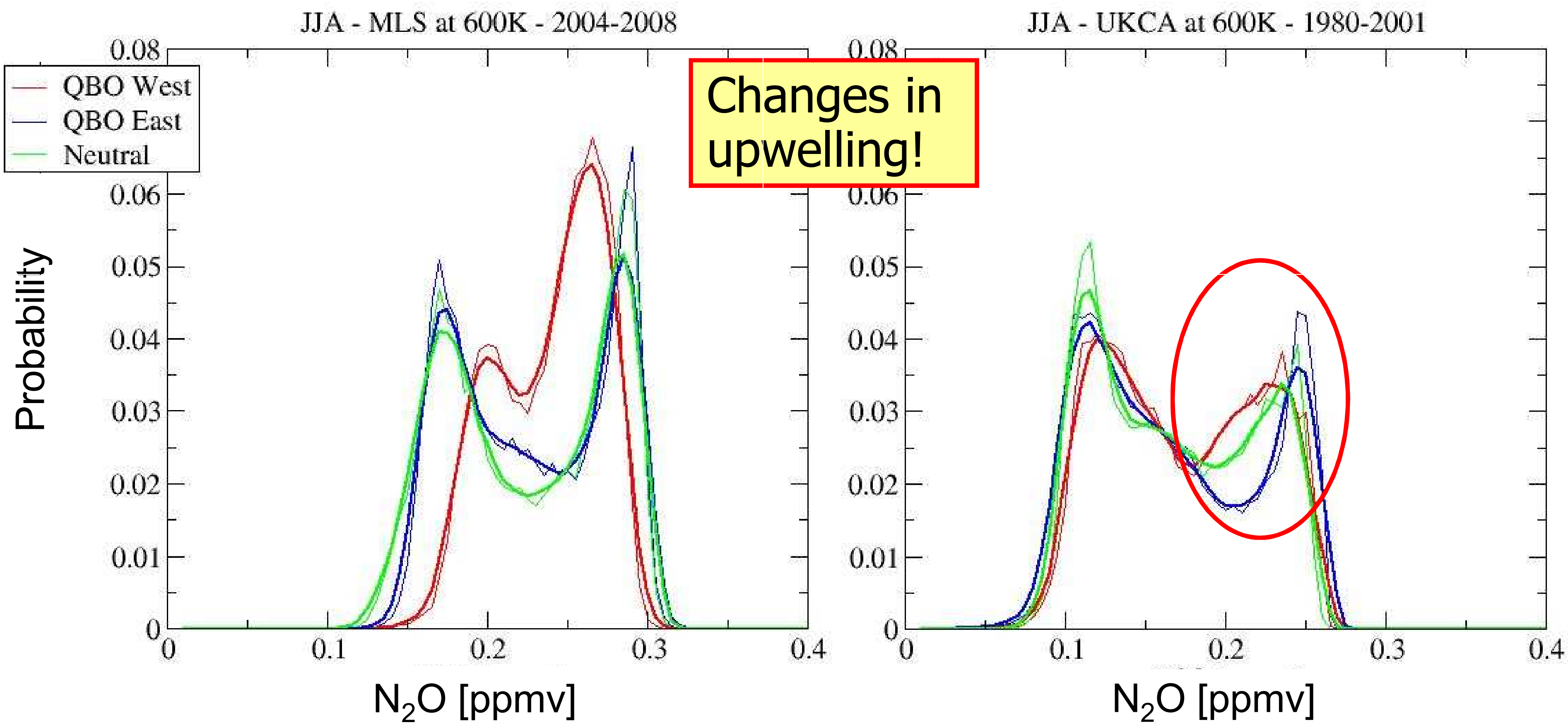
- Why are they useful?
  - A simple means of assessing the upwelling branch of the BDc and the existence of a surf zone (in models and data)
- What lessons can be learned?
  - Isolation of different latitude regimes; do we find two distinct peaks in the distribution?
  - How does the QBO affect inter-annual variability of the upwelling BDc branch (up and down of “high value peak” during summer)?

Recent N2O PDFs



Snapshot NH PDFs between 10S and 40N

N2O JJA QBO Modulation



Science example 3

UKCA constrained by the “real world”

(Telford et al., ACP, 2008)

Experimental setup to estimate ozone loss due to Pinatubo aerosol in the 1990s:

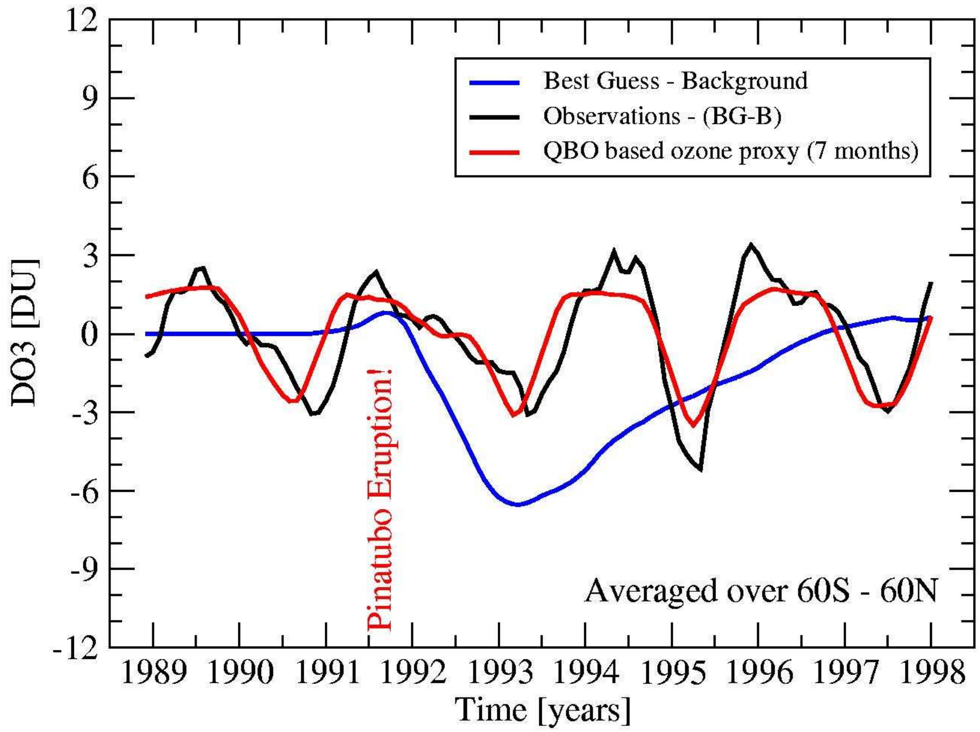
- Two nudged UKCA runs:
  - Best guess: nudged with ERA-40, observed surface aerosol density (SAD) monthly means
  - Background: nudged with ERA-40, background SAD only
- Observational data:
  - Assimilated total ozone data (originator: NIWA, Greg Bodeker)

Pinatubo
June 12, 1991
Three days before major eruption of June 15, 1991

(hijacked from Alan Robock's volcano lecture)

Quantifying Pinatubo

"Global Ozone" (60S-60N)

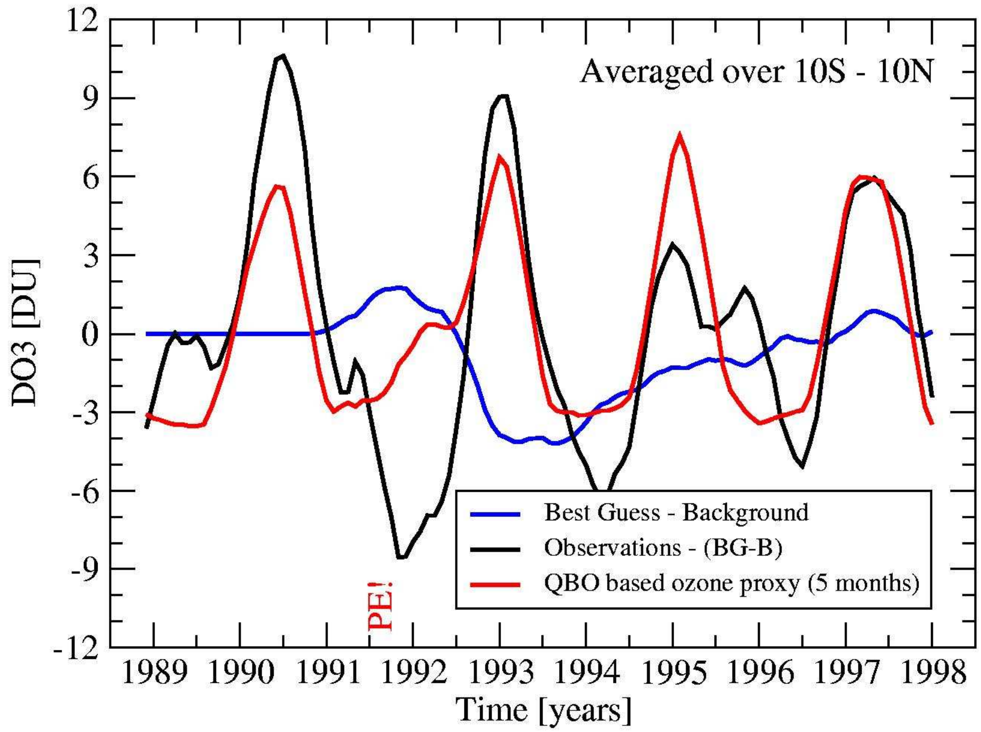


~70% of residual variability is explained the QBO

Ozone lost due to chemistry on aerosols (model only).
Residual (dynamical) ozone variation (observation and model).
QBO proxy (can account for most of the residual).

Quantifying Pinatubo

"Tropical Ozone" (10S-10N)



Significant amount of residual variability is explained by QBO; amplitude modulation of the residual is caused by ENSO

Ozone lost due to chemistry on aerosols (model only).
Residual (dynamical) ozone variation (observation and model).
QBO proxy (can account for most of the residual).

Science example 4

The "world avoided" simulation

(Morgenstern et al., GRL, 2008)

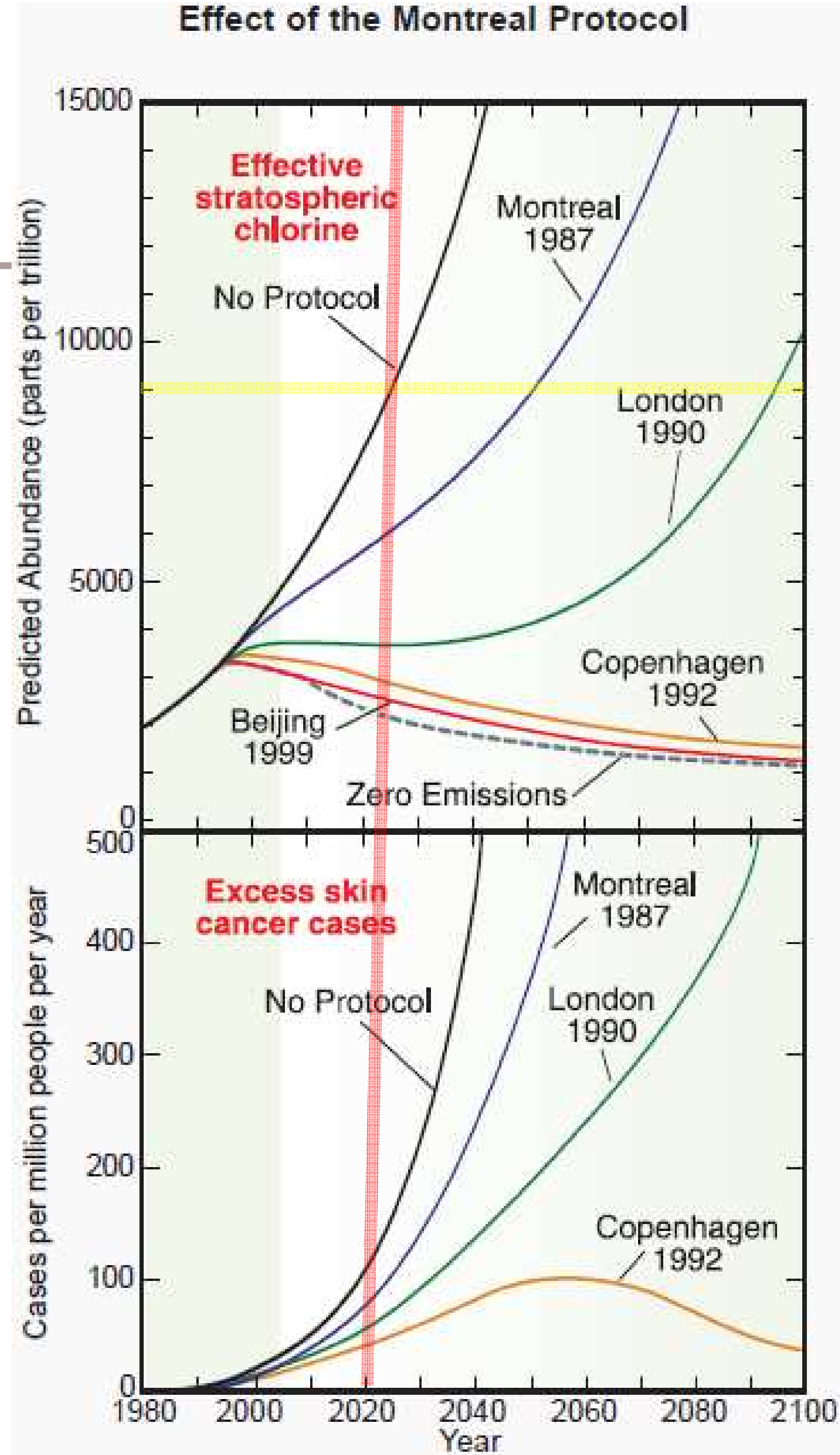
- UKCA has been used to study a world without the Montreal Protocol and its amendments.
- A business as usual scenario would have meant 9ppbv of total chlorine before 2030.
- Two time slice runs with 3.5ppbv and 9ppbv under "present day" boundary conditions are compared.

Motivation

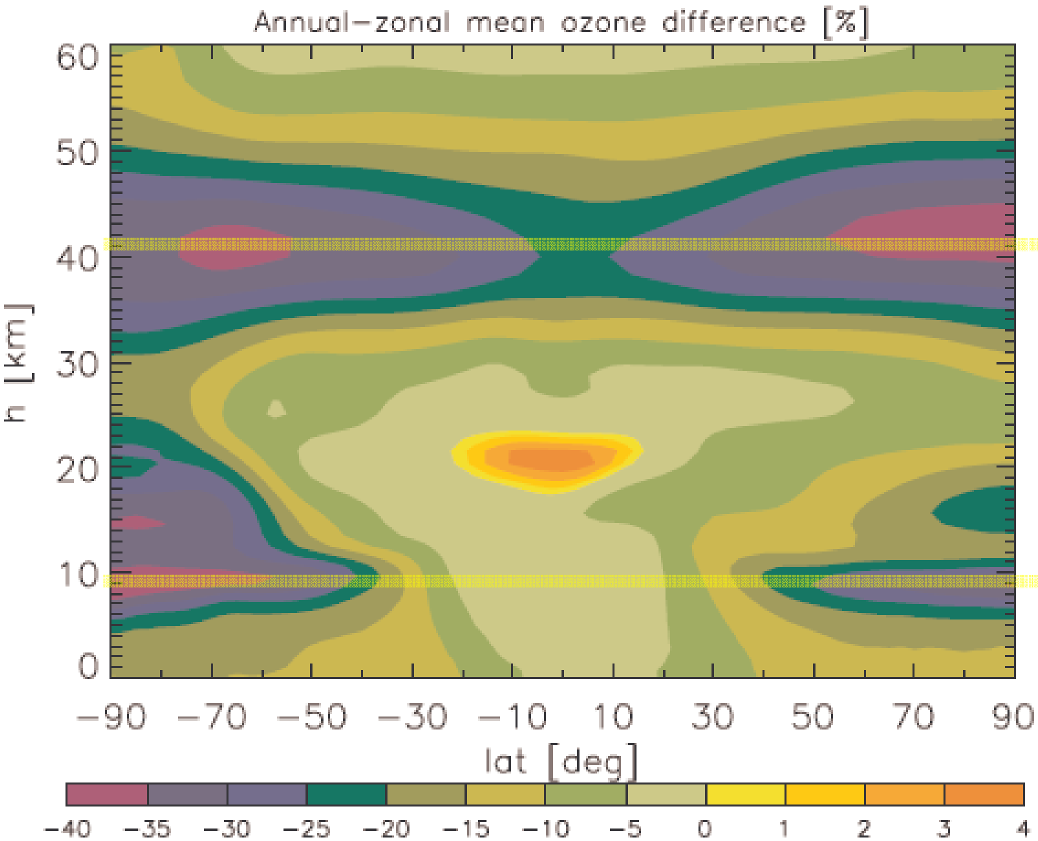
What would have happened without the Montreal Protocol and its amendments?

Here:
We study the impact of the avoided ozone changes only!

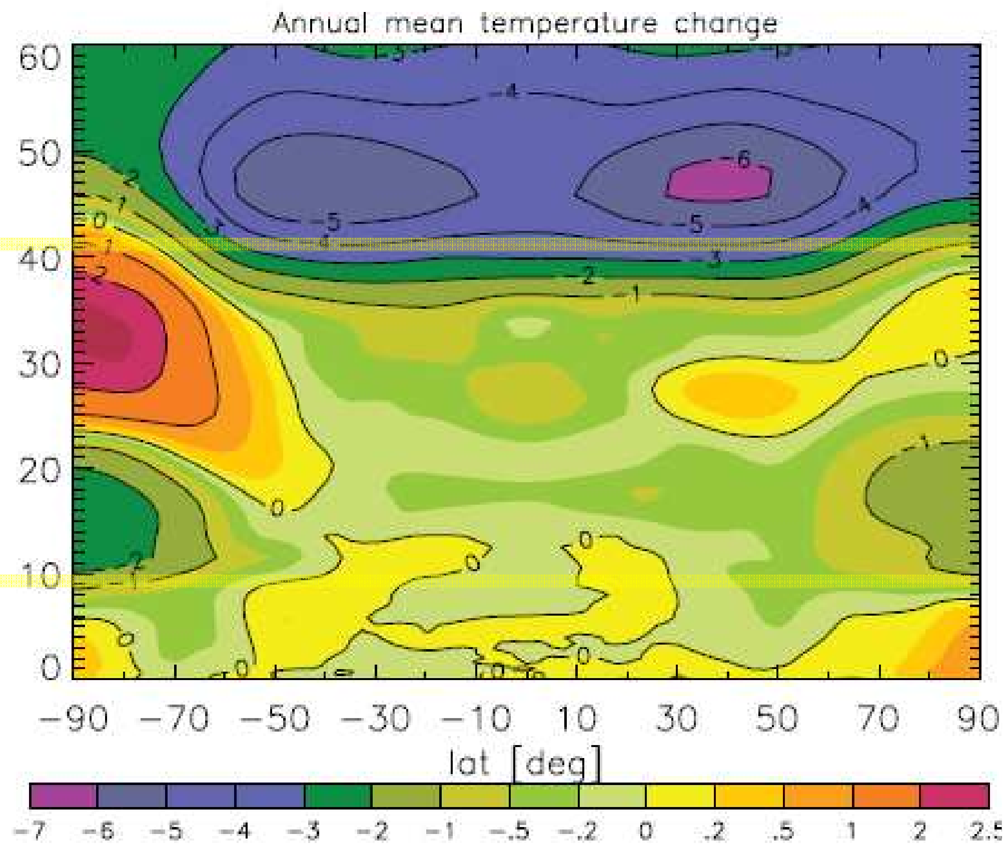
(Additional GHG impacts are not considered!)



WA global mean



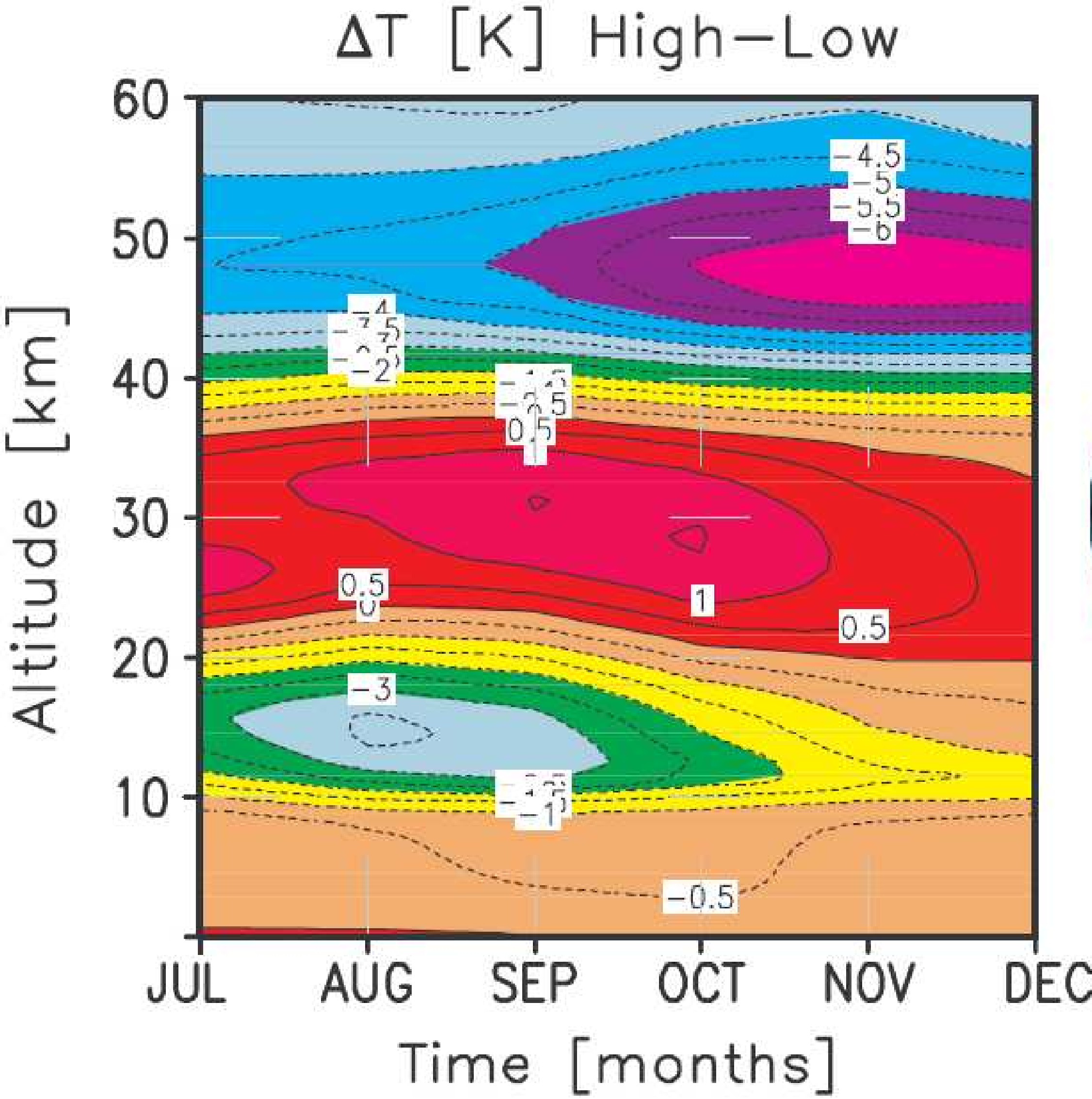
[%], relative to 3.5ppbv Cly

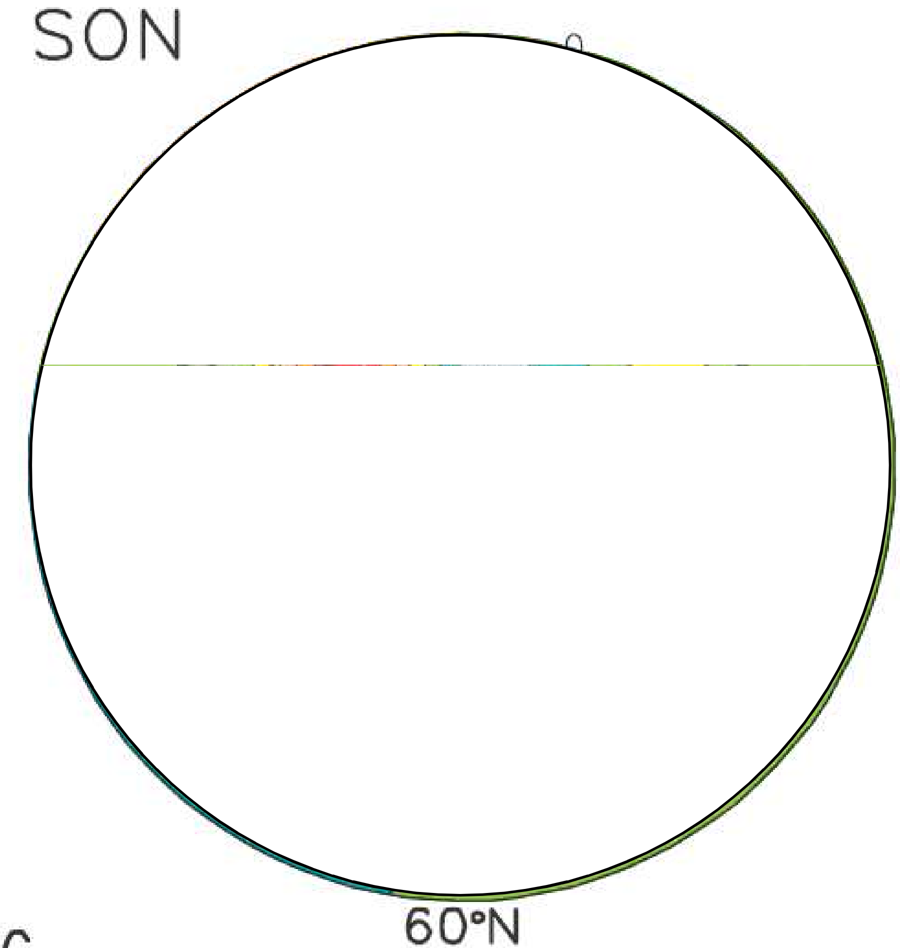


[K], T(9ppbv Cly)-T(3.5ppbv Cly)

Morgenstern et al., GRL, 2008

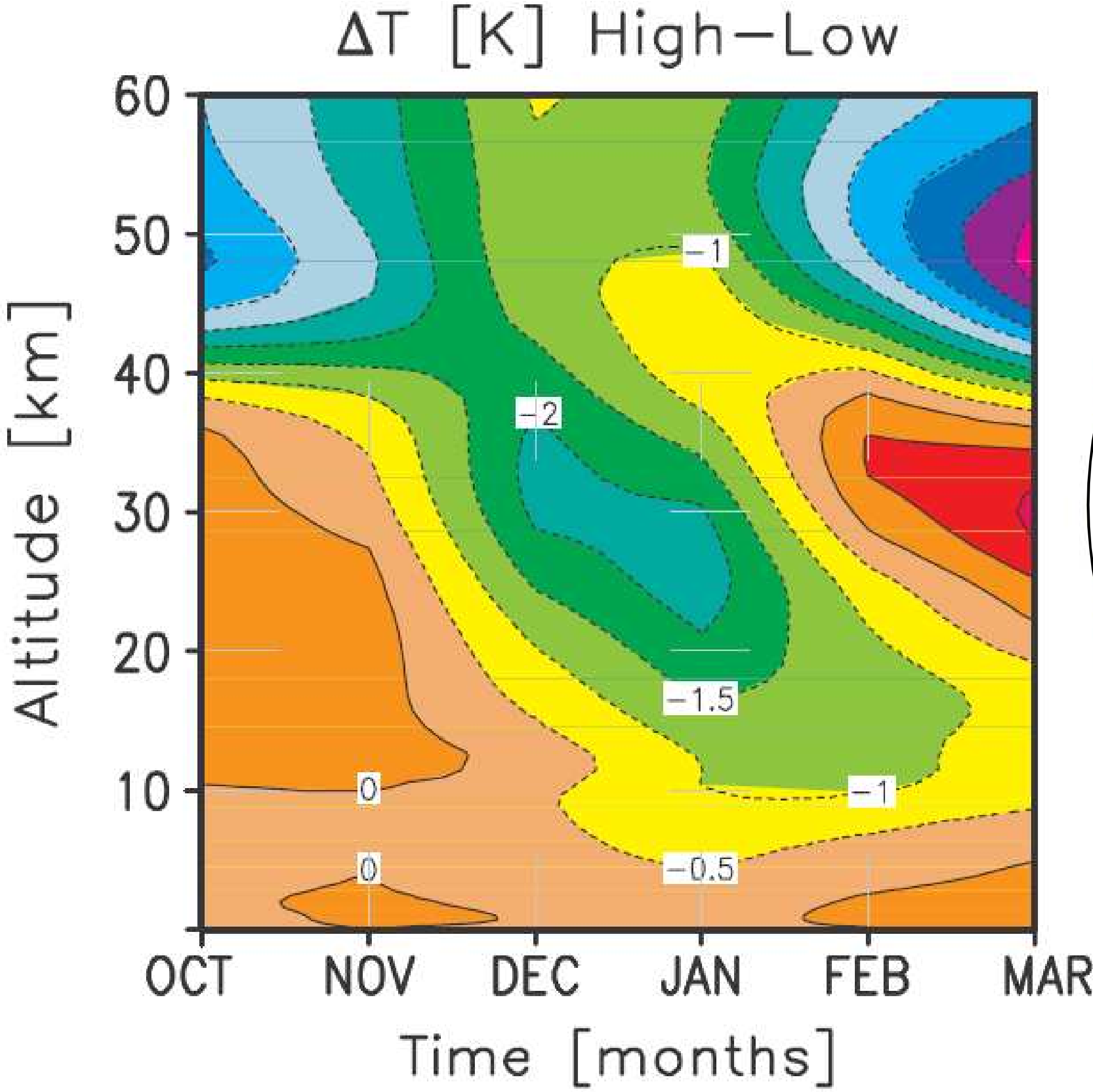
“World Avoided” on the SH

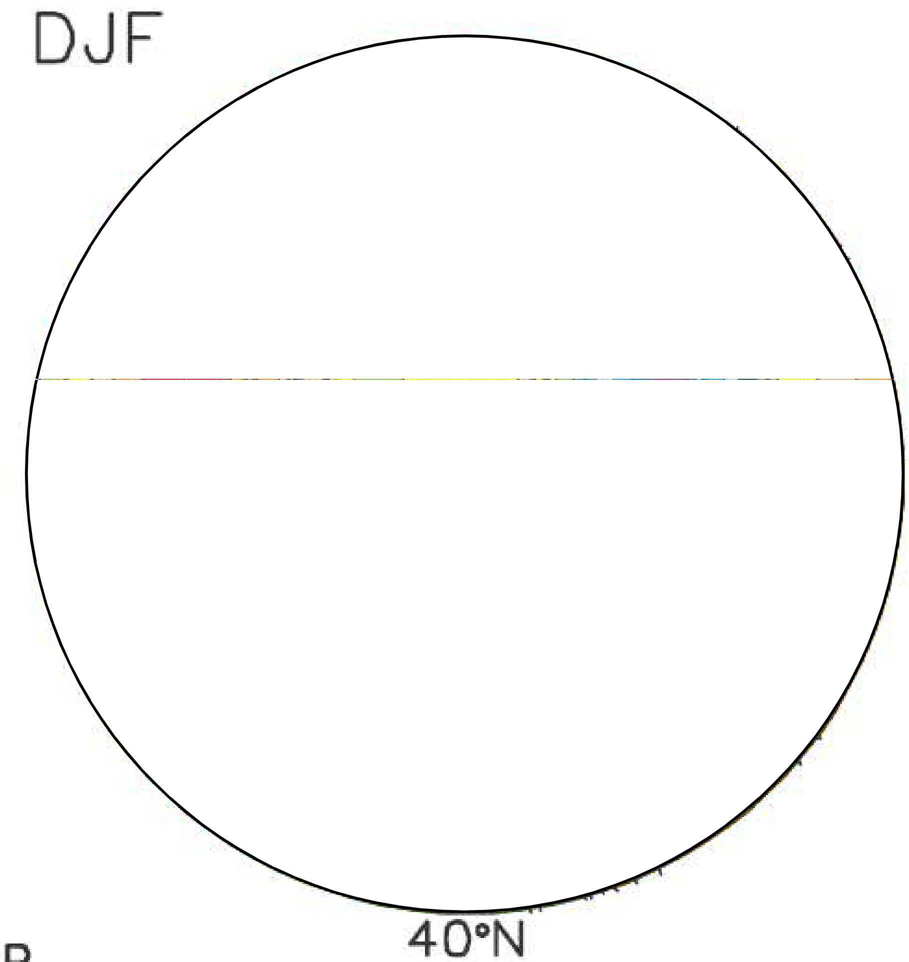




Morgenstern et al., GRL, 2008

"World Avoided" on the NH





Morgenstern et al., GRL, 2008

WA Summary

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L16811, doi:10.1029/2008GL034590, 2008

Click Here for Full Article

The World Avoided by the Montreal Protocol

Olaf Morgenstern,[1] Peter Braesicke,[1] Margaret M. Hurwitz,[2,3] Fiona M. O'Connor,[4]
Andrew C. Bushell,[5] Colin E. Johnson,[4] and John A. Pyle[1]

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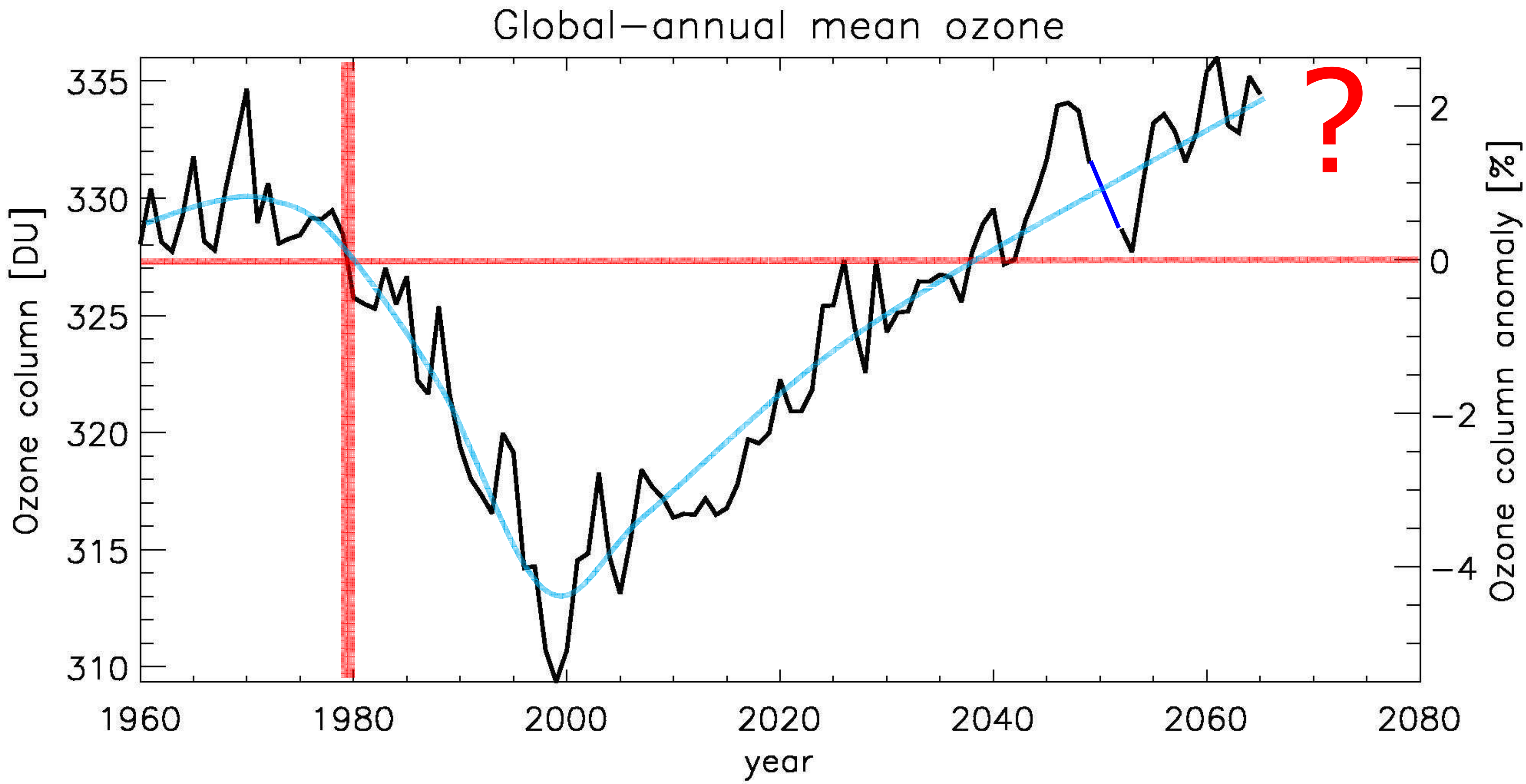
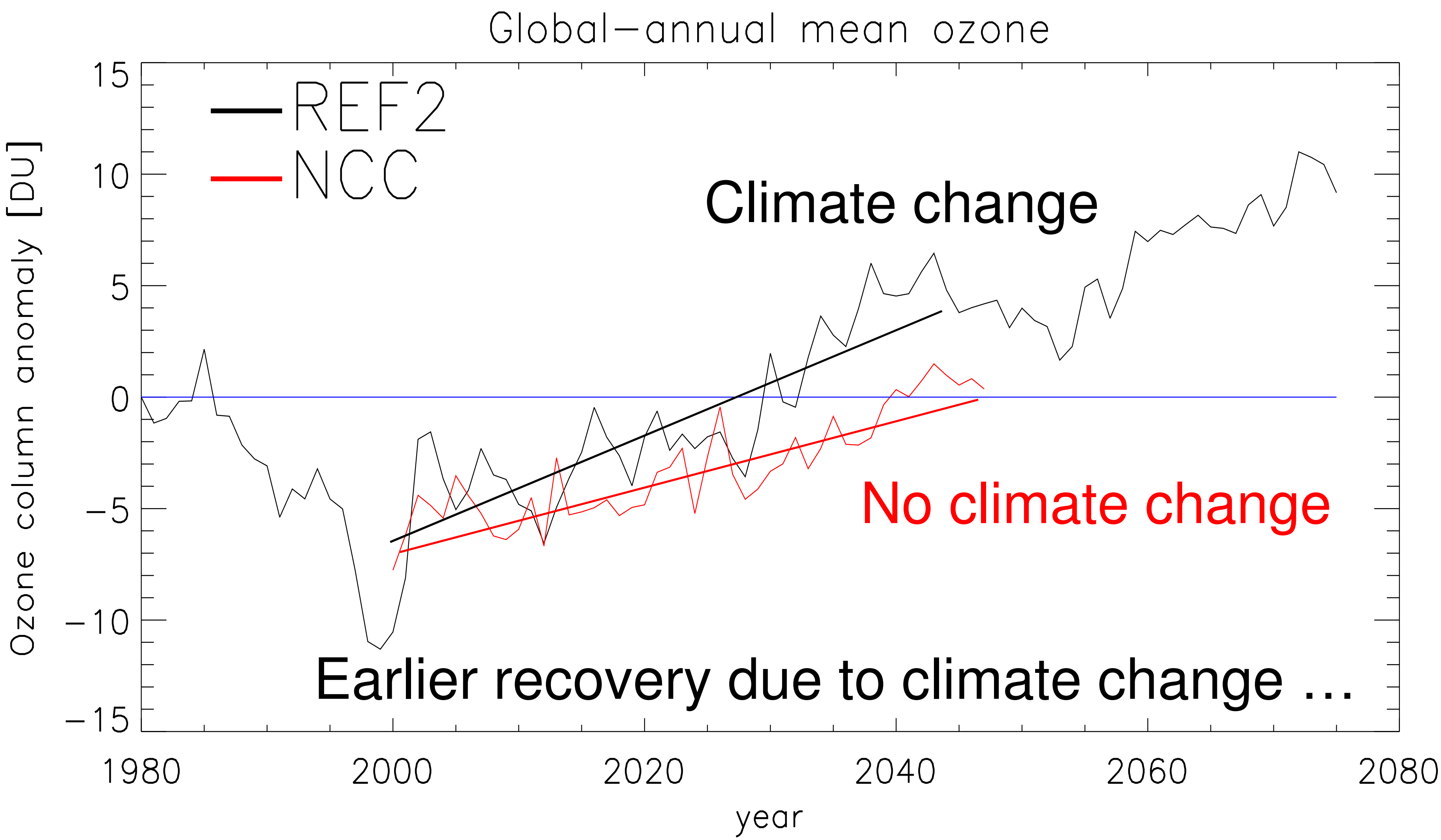
Nonetheless, we conclude that the Montreal Protocol has provided an enormous benefit not only to the stability of the stratospheric ozone layer but also to surface climate.

UKCA Ref2 Ozone Evolution



NCAS integration

O3 recovery + climate change



Met Office integration

Summary and outlook

- The stratospheric UKCA has a competitive performance (model validation)
- The nudging ability is useful for relating model results to real data (Pinatubo example)
- Assessment of coupled chemistry-climate change problems is possible (“world avoided”)
- Forthcoming results will be contributed to CCMVal
- Whole atmosphere chemistry
  - merging of UKCA troposphere and stratosphere
  - straightforward, but some informed choices required
- Move to UM7.1 (straightforward, but work)
- Challenges: Resolution, Ocean

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Thank you for your attention!

University of Leeds

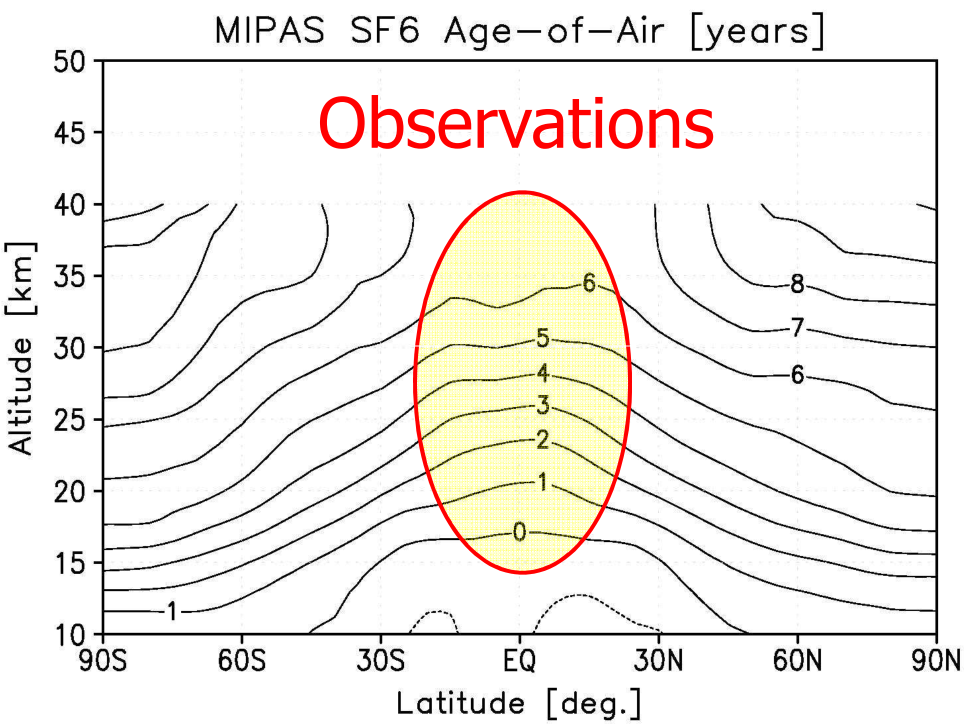
Met Office

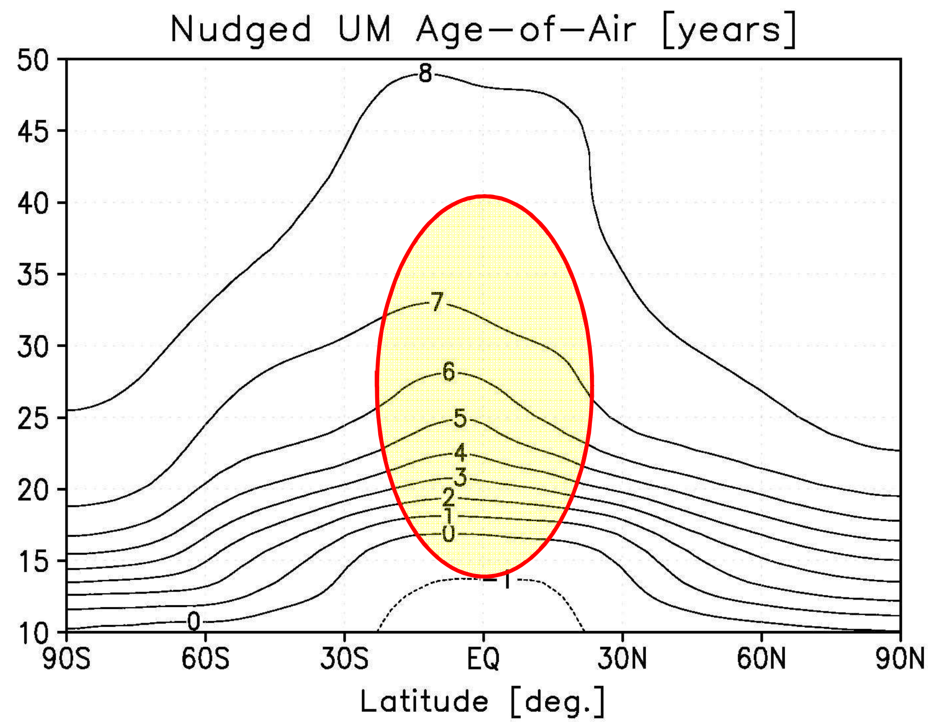
University of Oxford

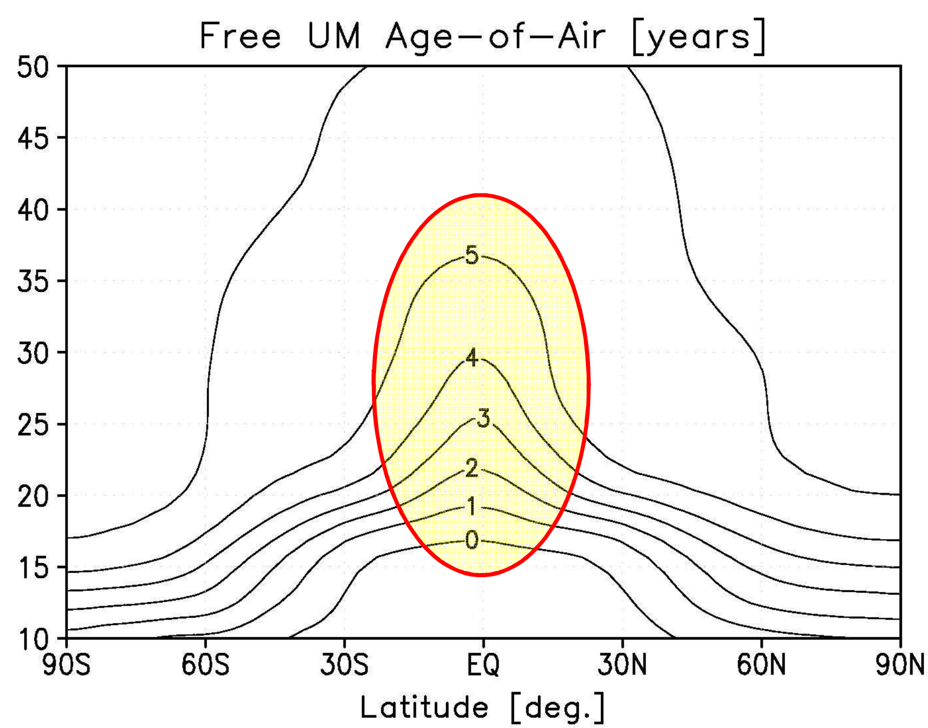
University of Reading

National Centre for Atmospheric Science
Natural Environment Research Council

Age-of-Air Summary



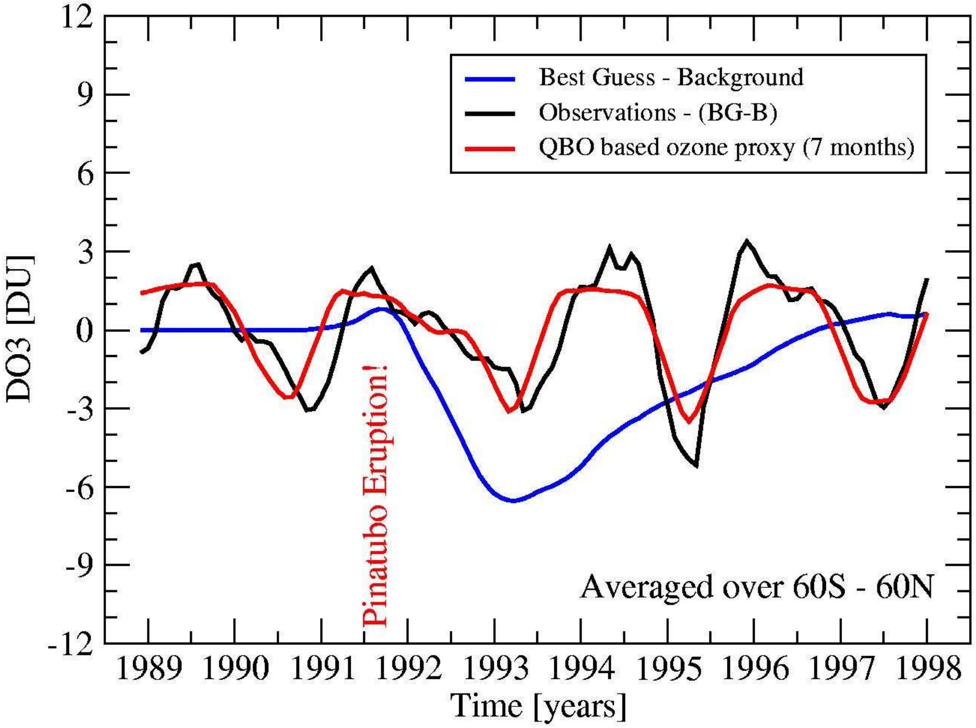




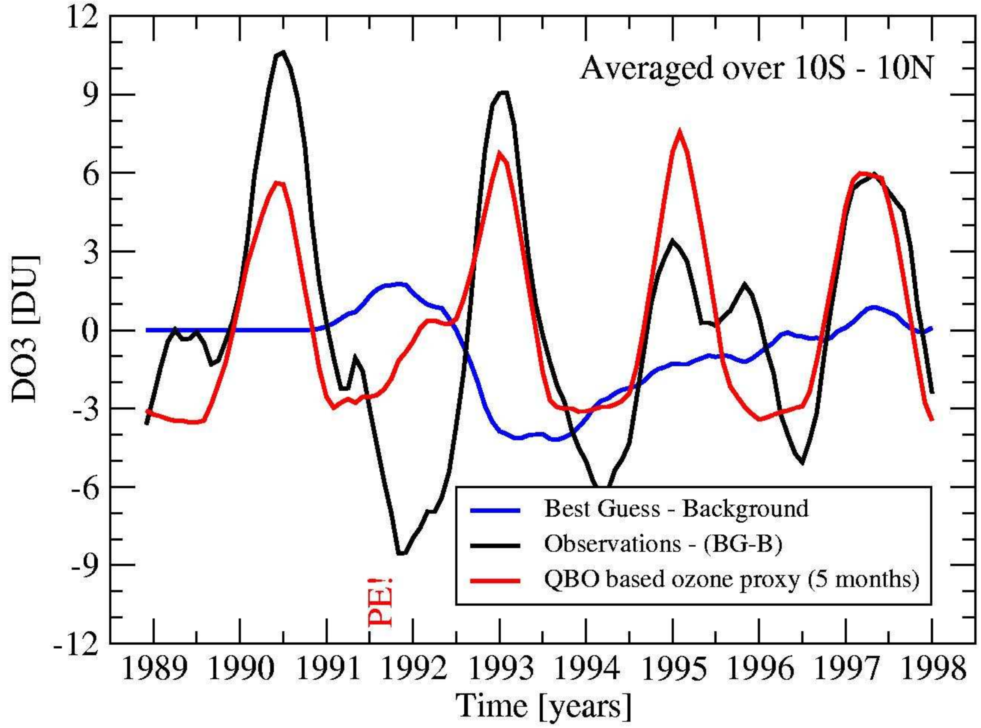
Caveat: Observations of SF6 still sparse! Model results are from equilibrated 10 year integrations.

Quantifying Pinatubo

"Global Ozone" (60S-60N)

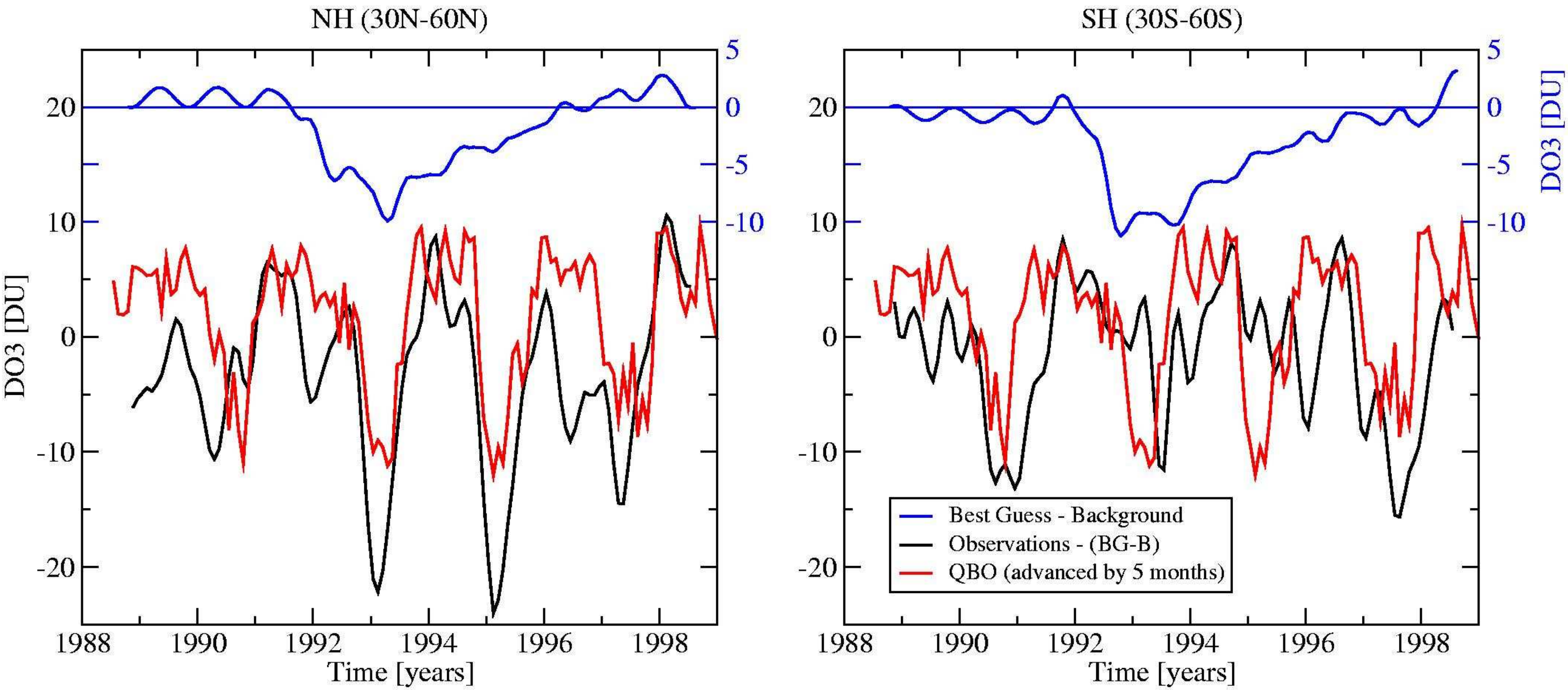


"Tropical Ozone" (10S-10N)



Ozone lost due to chemistry on aerosols (model only).
Residual (dynamical) ozone variation (observation and model).
QBO proxy (can account for most of the residual).

Quantifying Pinatubo



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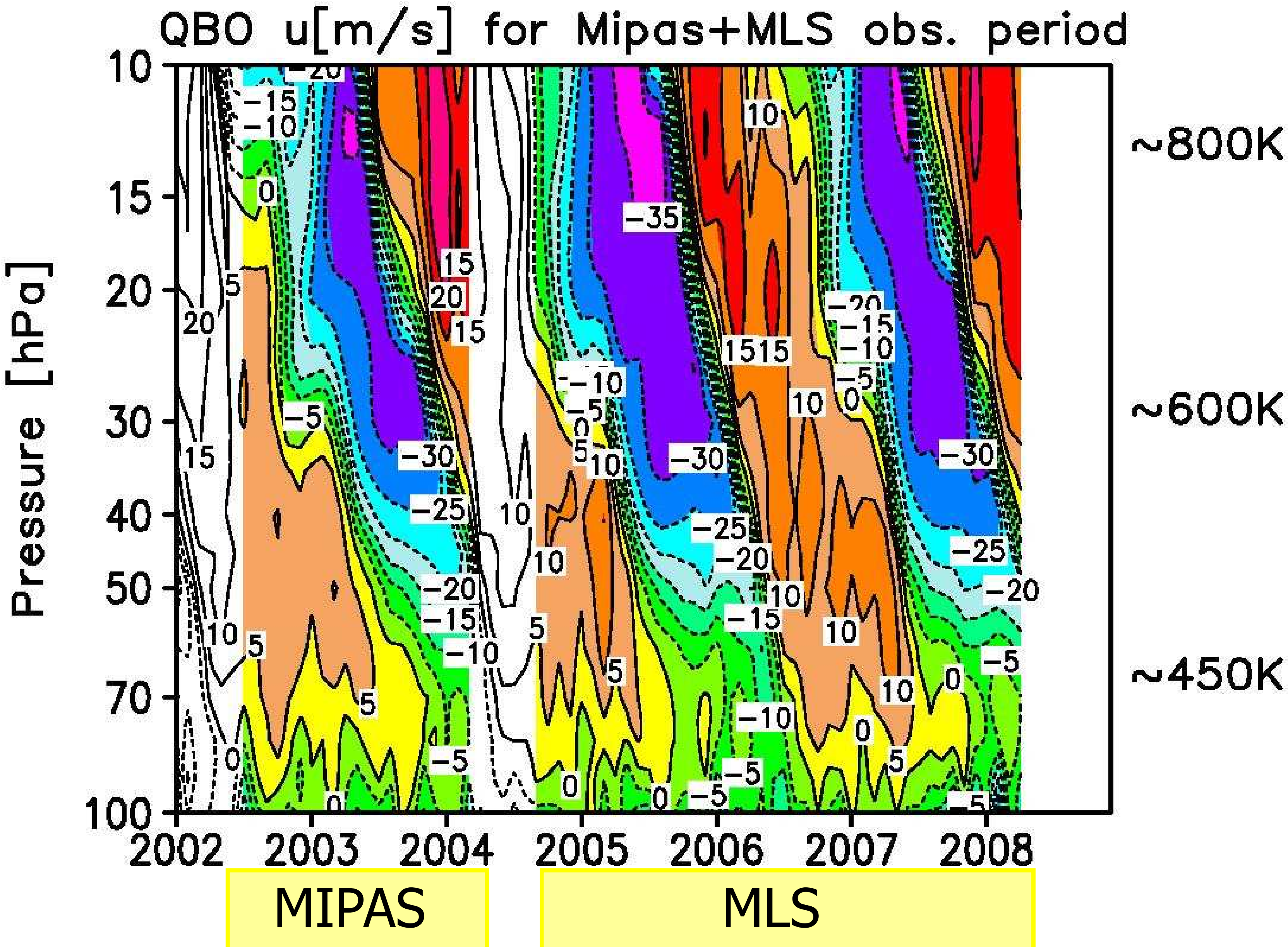
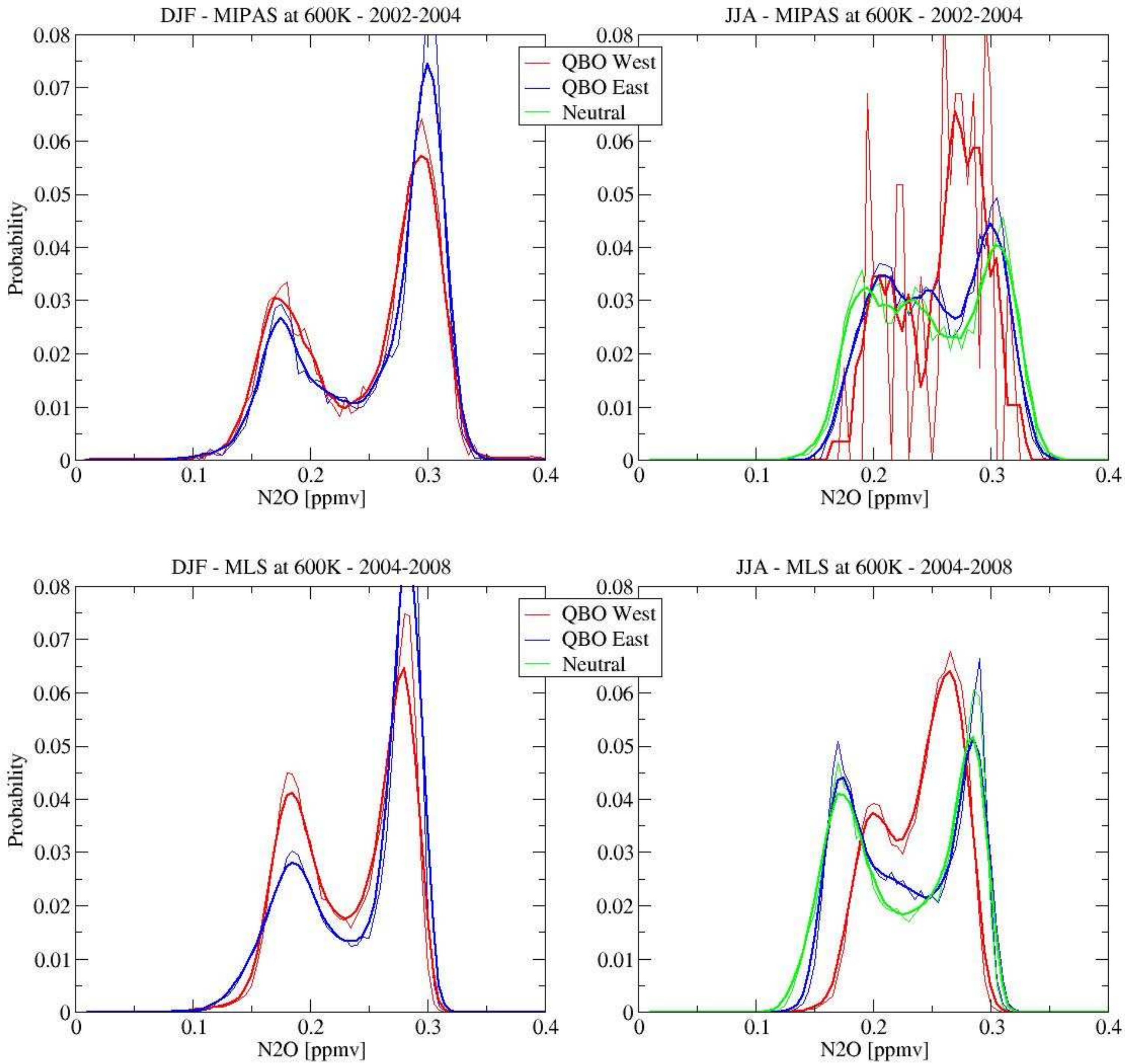
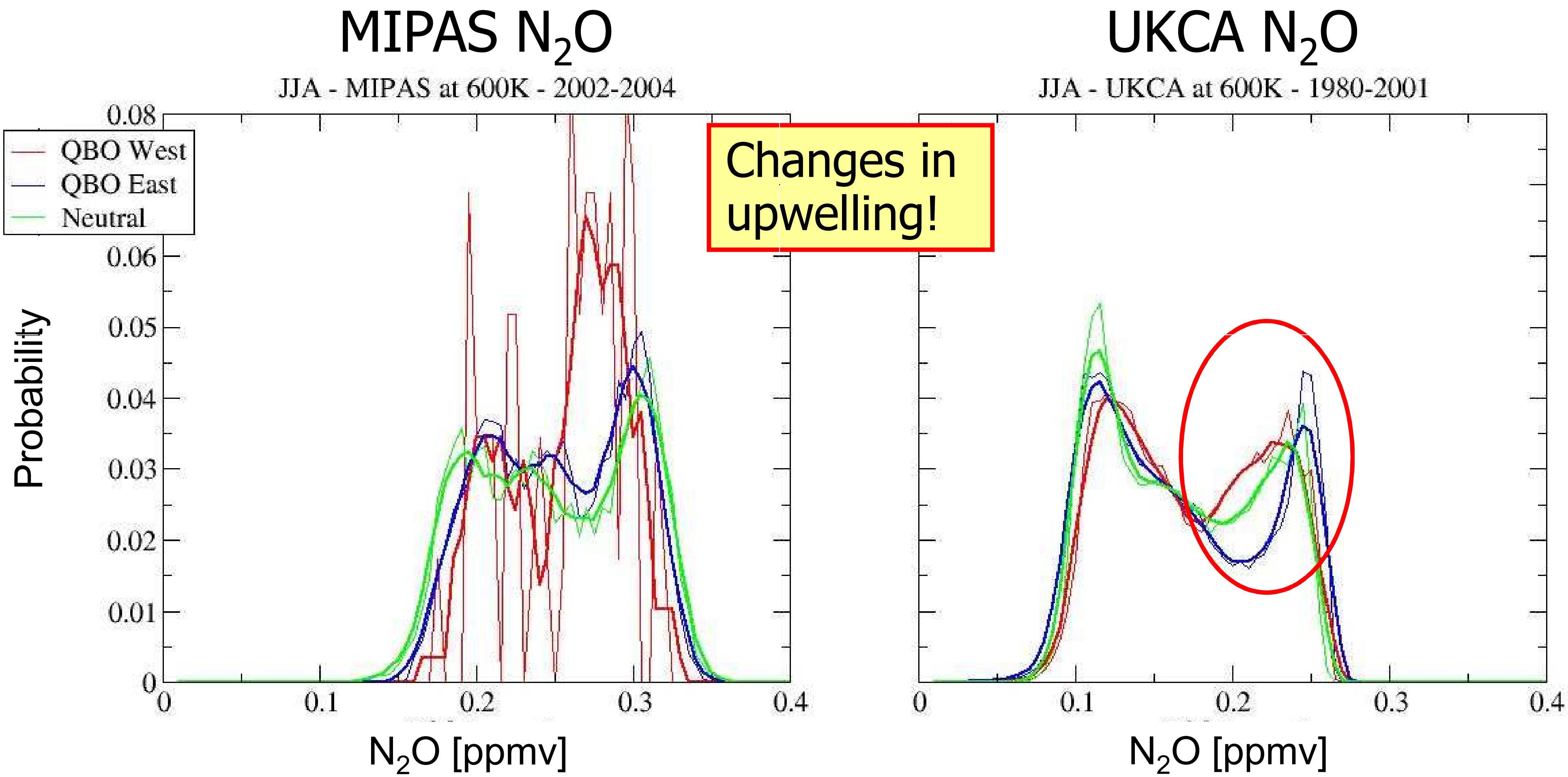
QBO during N2O observations




DJF - MIPAS at 600K - 2002-2004
JJA - MIPAS at 600K - 2002-2004
DJF - MLS at 600K - 2004-2008
JJA - MLS at 600K - 2004-2008
QBO West
QBO East
Neutral
Probability
N2O [ppmv]
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.1
0.2
0.3
0.4

N2O JJA QBO Modulation



Snapshot versus 22 year climatology!