A combined Eulerian-Lagrangian model study of QBO effects on stratospheric transport

Introduction

While there has been progress on modelling the quasi-biennial oscillation (QBO) in general circulation models (GCMs) in recent years, it is still hard to gain a quantitative understanding of how the QBO affects stratospheric transport from such Eulerian models alone. A Lagrangian approach is more suitable in this respect.

Both horizontal and vertical motion are known to be modulated by the secondary meridional circulation (SMC) of the QBO (see box). The QBOs effect on transport can be thought of as the integral of the circulation anomalies over a time scale of several months.

We choose a novel combined modelling approach, using the output of a Eulerian GCM with representation of the stratosphere and chemistry to drive a Lagrangian transport model.

Approach

The representation of the quasi-biennial oscillation (QBO) [Baldwin et al, 2001] in a global circulation model can be achieved by nudging zonal wind in the tropical stratosphere towards observations.

In a simulation with the chemistry-climate model (CCM) MAECHAM4-CHEM [Steil et al, 2003] performed for the CCMVal project [REF1, Eyring et al, 2006], the QBO anomalies in the circulation and the QBO effects on trace gas concentrations are reproduced [Punge & Giorgetta, 2008].

Air parcel backward trajectory calculations can reveal the effects of the circulation anomalies caused by the QBO on transport explicitly, as will be presented here.

Winds and heating rates from the CCM are fed into the trajectory module of the CLaMS model [McKenna et al, 2002; Konopka et al, 2005] to follow groups of parcels with a common starting level backward to their location up to 3 months earlier.

Conclusions

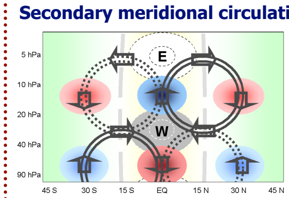
The course of backward trajectories in the tropical stratosphere depends on the phase of both QBO and annual cycle.

The upwelling of equatorial air parcels is modulated by the QBO's secondary meridional circulation, the ascent over 90 days differs by a factor of two between the easterly and westerly shear phases.

In solstitial seasons, a significant fraction of equatorial air stems from the summer subtropics due to the greater strength of the circulation in the winter hemisphere.

The QBO impact on horizontal transport is most pronounced in the maximum easterly and westerly wind phases. In particular, a transport barrier is diagnosed in the summer time subtropics during the easterly QBO phase both from trajectory analyses and the vorticity field.

Secondary meridional circulation of the QBO



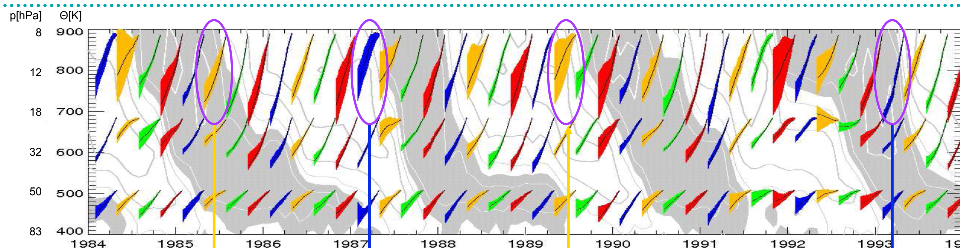
Anomaly of the stratospheric circulation due to β -effect on QBO jets:

- Weaker ascent at the Equator in westerly shear region
- Pole ward divergence during the easterly phase
- Stronger ascent at the Equator in easterly shear region
- Convergence towards the Equator during the westerly phase

1. Impact of QBO wind shear phases at the Equator

A) QBO variations of equatorial (5°S - 5°N) upwelling.

Ascent and vertical spread of air parcels equally depend on QBO phase and time in the year. The Figure shows the mean altitude and altitude range for parcels up to 90 days before their arrival at 875, 675 or 500 K. (release dates 28 January, 28 April, 28 July, 28 October).



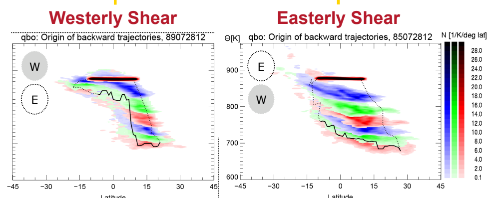
Grey shading & Contours: zonal wind, esterlies (white) and westerlies (grey) of the QBO. Contours drawn at –25, -15, -5, 5, 15, 25m/s.

Solid lines: Mean vertical motion of parcels

Colored by season: Range, 10th to 90th percentile

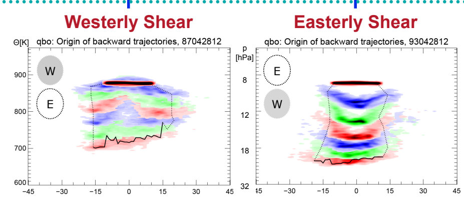
B) Ascent in solstitial seasons.

Both the influence of the QBO at the Equator and of advection towards the southern, winter hemisphere are reflected in the distribution of parcels released on **July** 28 of years with pronounced QBO shear phase.



Zonal mean distribution of 8640 parcels released at 875K (10hPa, 12°S to 12°N) on July 28 1989 and 1985, depicted in 15 day intervals.

At each step, 3% of the parcels are pole ward of the dashed lines, respectively. Solid line: Mean altitude at day 90.



Zonal mean distribution of 8640 parcels released at 875K (10hPa, 12°S to 12°N) on April 28 1987 and 1993, depicted in 15 day intervals.

At each step, 3% of the parcels are pole ward of the dashed lines, respectively. Solid line: Mean altitude at day 90.

C) Ascent in equinoctial seasons.

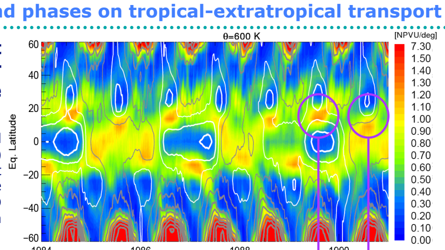
The weaker (stronger) equatorial ascent in westerly (easterly) shear phases is seen clearly in the distribution of parcels released on **April** 28 of years with pronounced QBO shear phase.

2. Impact of QBO wind phases on tropical-extratropical transport

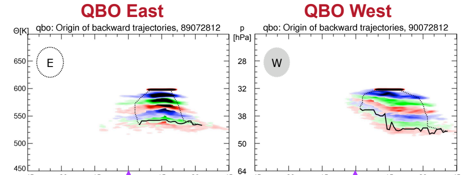
A) Apparent transport barrier in summer subtropics during the easterly QBO phase

Strong gradients of potential vorticity (PV) at 600K (32hPa) indicate a transport barrier at about 15º latitude during the easterly phase of the QBO during summer in both hemispheres.

During easterly phase, low PV air diverges from the Equator, which leads to a low PV gradient there.



Shading: PV gradient with respect to equivalent latitude
Contours: Easterly (white, -25, -15, -5 m/s) and westerly (5, 15, 25, 35... m/s) zonal wind



Zonal mean distribution of 2880 parcels released at 600K (32hPa, 12°N to 20°N) on July 28 1989(left) and 1990 (right), depicted in 15 day intervals.

At each step, 3% of the parcels are pole ward of the dashed lines, respectively. Solid line: Mean altitude at day 90.

B) Balance of SMC and solstice advection

In easterly years, the pole ward SMC balances the southward advection during northern summer, which causes the weaker horizontal motion and more compact distribution of parcels in the summer hemisphere subtropics compared to westerly years.

References

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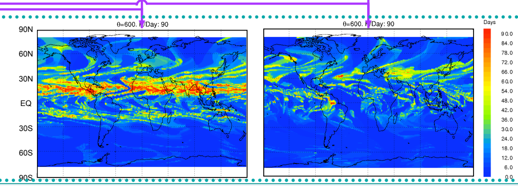
C) Residence time of parcels increased at barrier

The time parcels released at 600K spent within ± 5º latitude of their initial location reaches up to 90 days between 12-20ºN during northern summer when the QBO phase is easterly, but is much lower when the QBO is in westerly phase.



Shading: Time period after release (on July 28 1989 (left) and 1990 (right)) for which parcels stay within +/- 5° around their original latitude

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