Stratospheric circulation in the WACCM chemistry-climate model: mean age of air against observations and CTM

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Abstract

The mean age of air is a classical diagnostic of the transit time from the troposphere to the various region of the stratosphere, providing insights on the strength and structure of the Brewer-Dobson Circulation (BDC), the polar vortex and irreversible mixing in the mid-latitudes. We apply this diagnostic to the WACCM chemistry-cliamate model for the 1985-2014 period. A comparison is presented between unconstrained simulations (FR-WACCM) with and without the representation of the Quasi-Biennial Oscillation (QBO), simulations nudged to the MERRA-2 reanalysis (SD-WACCM), in-situ measurements and a chemistry-transport model (CTM). The results are different depending on the simulations, with SD-WACCM resulting closer to the observation w.r.t. FR-WACCM.
In the FR-WACCM the QBO plays a role leading to older age of air. The time evolution over the considered period is slightly decreasing, while observations show a positive (not significant) trend. Given those results, further studies have to be carried out investigating the multi-decadal trends of mean age of air and involving actual tracers.
This study is part of the ACCROSS project, in collaboration with the University of Liege.

Introduction

The mean age of air (aoa) is defined as the interval between the time when the mixing ratio of a monotonically increasing tracer reaches a certain value *X* at some location in the stratosphere and the (earlier) time when the same mixing ratio was reached at the reference location:
$T=t(X,Y)-t(X,Y_0)$,
where Y and Y_0 are the spatial coordinates of the tracer (Waugh and Hall, 2002).
It is widely used as a proxy for the Brewer-dobson Circulation (BDC): the aoa absolute value gives the strength of the BDC, i.e. small values are related to strong BDC, while its trends are used to evaluate its changes (speed up ro slow down). Chemistry-Climate models (CCMs) predict negative trends for simulations of the 20th century (increasing GHGs); observational studies, on the other hand, find positive (not significant) trends.

Methods

- The Whole Atmosphere Community Climate Model (WACCM) is a fully-coupled chemistry-climate model (Garcia et al, 2011).
- Top at approximately 150 km with 66 vertical levels (88 for SD-WACCM) and *1.9x2.5* degrees horizontal resolution.
- QBO imposed relaxing winds to observations at the tropics.
- Free Running (FR-WACCM): configuration with online computation of meteorological fields. 1)QBO-FR-WACCM: imposed QBO, 2)noQBO-FR-WACCM: no imposed QBO.
- Specified Dynamics (SD-WACCM): configuration with meteorological fields relaxed towards the MERRA-2 reanalysis.
- BASCOE-CTM (m250): chemistry-transport model driven by MERRA-2 reanalysis
- Balloon and satellite observations from Engel et al, 2017 and Kovacs et al, 2017 .

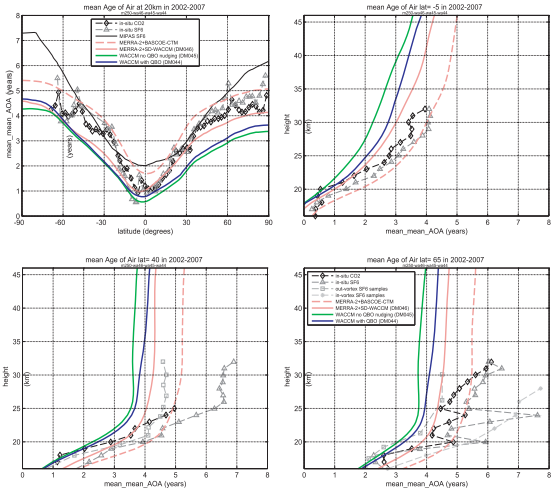

Figure 1. Mean age of air (aoa) in 2002-2007 period for QBO-FR-WACCM (blue), noQBO- FR-WACCM (green), SD-WACCM (pink solid) and m250(pink dashed). Upper left: values at 20 km; upper right: vertical profiles at 5*S*; lower left: vertical profiles at 40*N*; lower right: vertical profiles at 65*N*. The black solid line represents aoa from MIPAS SF_6 observations in 2002-2007 (Kovacs et al., 2017). The symbols represent in-situ observations collected during 1990's (Waugh and Hall, 2002).

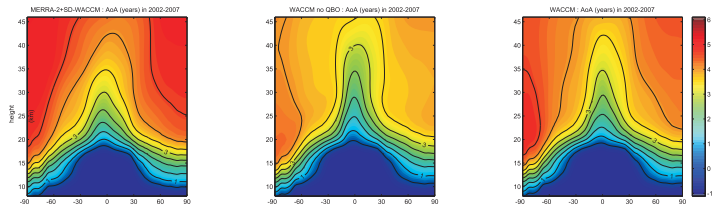

Figure 2. Latitude-height distribution of mean aoa in the 2002-2007 period. Left: SD-WACCM. Middle: noQBO-FR-WACCM. Right: QBO-FR-WACCM.

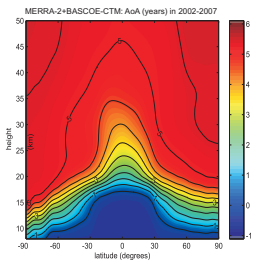

Figure 3. Latitude-height mean aoa distribution for the 2002-2007 period for m250.

Results:

- SD-WACCM provides realistic aoa for the considered period , following the observations in the tropics and to a less extent at the Poles (Fig. 1).
- FR-WACCM simulations provide younger aoa w.r.t. observations: 1 year in the NH, and less than 0.5 years in the tropics (Fig. 1).
- noQBO-FR-WACCM provides slightly younger aoa w.r.t. QBO-FR-WACCM, but both provide younger aoa w.r.t. to the CTM and SD-WACCM (Fig. 1, 2, 3).
- Latitudinal gradient stronger in the SH w.r.t. NH (Fig. 2, 3). noQBO-FR-WACCM has the youngest aoa (4.5 years) and SD-WACCM has the oldest (5.5 years) (Fig. 2).
- FR-WACCM simulations show younger aoa in the middle stratosphere (30-40 km) in the tropics w.r.t. SD-WACCM and m250 (Fig. 2, 3).
- Long term time series (Fig. 4, 5) are decreasing for the 3 simulations, with a slight increase in the last years of the QBO-FR-WACCM simulation, and at the beginning of SD-WACCM simulation (1985-1992).
- The seasonal cycle dominates with very similar phases among the simulations (Fig. 4), oldest in winter/fall and youngest in summer/spring. Weak QBO signal in SD-WACCM (2005-2010) and QBO-FR-WACCM (1990-1995, 2005-2010) (Fig. 4).
- Positive (not significant) trends found by the observations not matched by the model simulations (Fig. 5), which show slightly decreasing time series. Model simulations lie all in the error bars of the observations.

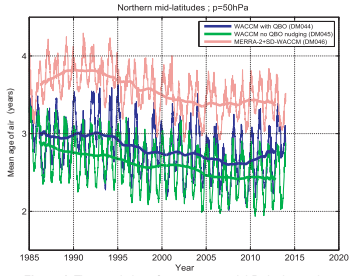

Figure 4. Time evolution of mean aoa at 50 *hPa* in the northern mid-latitudes (40-50*N*). Thin lines shows model output every 5 days, thick lines show one-year running mean. Color code as **Figure 1**.

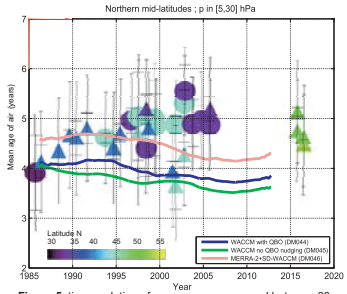

Figure 5. time evolution of mean aoa as averaged between 30 *hPa* and 5 *hPa* for the 2002-2007 period in the Northern mid-latitudes (40-50*N*). Symbols represent values from balloon observations of SF_6 (circles) and CO_2 (triangles) with color code showing the latitude of the measurement and outer error indicating sampling uncertainties (Engel et al., 2017).

Conclusions:

- SD-WACCM provides more realistic representation of mean aoa w.r.t. FR-WACCM simulations.
- QBO plays a role leading to younger mean aoa, i.e. weak BDC.
- All model simulations show decreasing mean aoa, related to an acceleration of the BDC. Observations show an increase which is not significant.

References

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- Engel et al., 2017: Mean age of stratospheric air derived from AirCore observations, *Atmos. Chem. Phys.*, **17**, 6825-6838.
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