Investigation of Stratospheric Circulation using Long-Lived Tracers with the WACCM Chemistry-Climate Model, the BASCOE Chemistry-Transport Model and a Reanalysis of MLS Observations.

D. Minganti[1], S. Chabrillat[1], Y. Christophe[1], Q. Errera[1], M. Prignon[2], E. Mahieu[2], M. Abalos[3]

[1] Royal Belgian Institute for Space Aeronomy, BIRA-IASB, Brussels, 1180 Belgium. [2] Institute of Astrophysics and Geophysics, University of Liege, 4000 Liege, Belgium. [3] Universidad Complutense de Madrid, Spain.

Abstract

The stratospheric circulation is investigated using WACCM (Whole Atmosphere Community Climate Model version 4), together with the BASCOE CTM (Belgian Assimilation System for Chemical Observations Chemistry-Transport Model) and a reanalyses of stratospheric composition as observed by AURA MLS (BASCOE Reanalyses of AURA MLS release 2, BRAM2) over the period 2005-2015.

We use a long-lived tracer (N2O), and the Transformed Eulerian Mean (TEM) framework to analyze the tracer budget. We focus on the terms due to advection and eddy mixing for the 3 datasets and on mean analysis increments in the case of BRAM2. We consider annual and seasonal (June-July-August, JJA) means.

While the annual mean pattern is in general agreement among the 3 datasets, substantial differences are found in the JJA patterns. Eddy mixing in WACCM (free dynamics and chemistry) is smaller and has less variability than in the CTM (constrained dynamics and free chemistry) and in BRAM2 (constrained dynamics and chemistry). Particularly striking is the near absence of the SH polar transport barrier in WACCM, while it is depicted both in the CTM and the reanalysis.

The next step of our research is to perform this analysis with the newer version of WACCM (version 6) as well as new BASCOE CTM and BRAM runs using different reanalysis products. Multi-decadal changes in terms of the budget, and their dependence on the location will be investigated as well.

Introduction

The stratospheric circulation is mainly characterized by the Brewer-Dobson Circulation (BDC), composed by:

- a mostly vertical advection term (the **residual circulation**) (**Fig.1**): mainly in the tropics (upwelling) and in the polar regions (downwelling).
- a mostly horizontal term due to irreversible **eddy mixing** (**Fig.1**): mainly in the extra-tropics and characterized by poleward transport.

Both processes are originated by the tropospheric wave-breaking in the stratosphere (stronger in the winter season): transfer of momentum and heat.

Changes in stratospheric circulation have been detected through observations of chemical tracers (*Mahieu et al., 2014*). It is now important to disentangle the contribution of advection and mixing in these changes. To this end we use the Transformed Eulerian Mean (TEM) framework (*Andrews et al., 1987*) to analyze the tracer budget.

We selected N2O as long-lived tracer to assess the ability of the BASCOE CTM and WACCM to reproduce the annual and seasonal patterns of such quantities, comparing them to BRAM2.

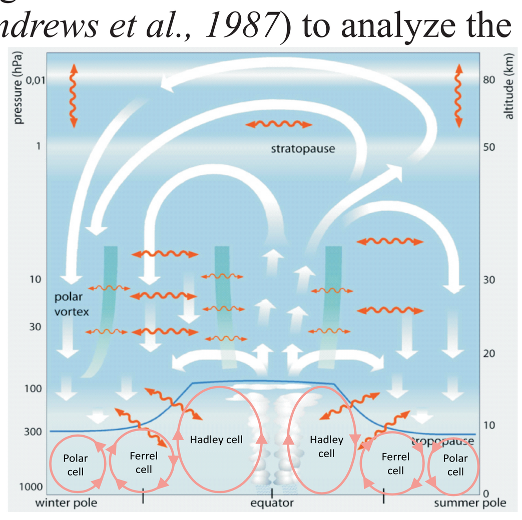

Figure 1. latitude-height cross section of the schematic of the BDC. The thick white arrows depict the meridional circulation, while the wavy orange arrows indicate the mixing. The thick green lines represent the stratospheric transport barriers. After *Bonisch et al., 2011*.

Data and Methodology

- **WACCM** (Whole Atmosphere Community Climate Model version 4): chemistry-climate model (*Marsh et al., 2013*). Run length: 1985-2015. Considered Period: 2005-2015. Free-Running configuration and MOZART3 chemistry scheme (*Kinnison et al., 2007*). Resolution: 1.9x2.5° with 66 levels up to ~150 km. Lower boundary conditions (Lbc): CMIP6 recommendations (*Meinshausen et al., 2017*).
- **BASCOE CTM** (Belgian Assimilation System for Chemical Observations Chemistry-Transport Model) (*Errera et al. 2008*): CTM driven by ERA-interim. Resolution: 2x2.5° with 60 levels up to ~0.1 hPa. Run length: 1985-2015. Considered Period: 2005-2015. Chemistry scheme similar to WACCM for the stratosphere. Lbc: CMIP6 recommendations (*Meinshausen et al., 2017*).
- **BRAM2** (BASCOE Reanalysis of AURA MLS release 2): chemical reanalysis produced by BASCOE. Data Assimilation: EnKF (*Skachko et al., 2016*). Chemical observations: AURA MLS v4.2 profiles of O3 H2O HNO3, N2O, HCl, ClO , CO and CH3Cl. Validity Period: Aug 2004-Dec 2017. Considered Period: 2005-2015. MLS N2O assimilated between 0.5 and 70 hPa.

TEM analysis (*Abalos et al., 2013, 2017*). It allows to evaluate the N2O budget (**Fig.2**):

- the time derivative (local time variation)
- the residual advection
- the chemical productions and losses (***P-L***)
- the eddy mixing term (***divM***)
- the remaining term: what is needed to close the budget.
- the AI (mean Analysis Increment) for BRAM2 only: roughly represents the correction enabled by the assimilation of N2O observations (**Fig. 3,4g**).

time derivative, residual advection, P-L, eddy mixing

$$\bar{\chi}_t + \bar{v}^*\bar{\chi}_y + \bar{w}^*\bar{\chi}_z = \bar{S} + \rho_0^{-1}\nabla\cdot\mathbf{M} + remaining + AI$$

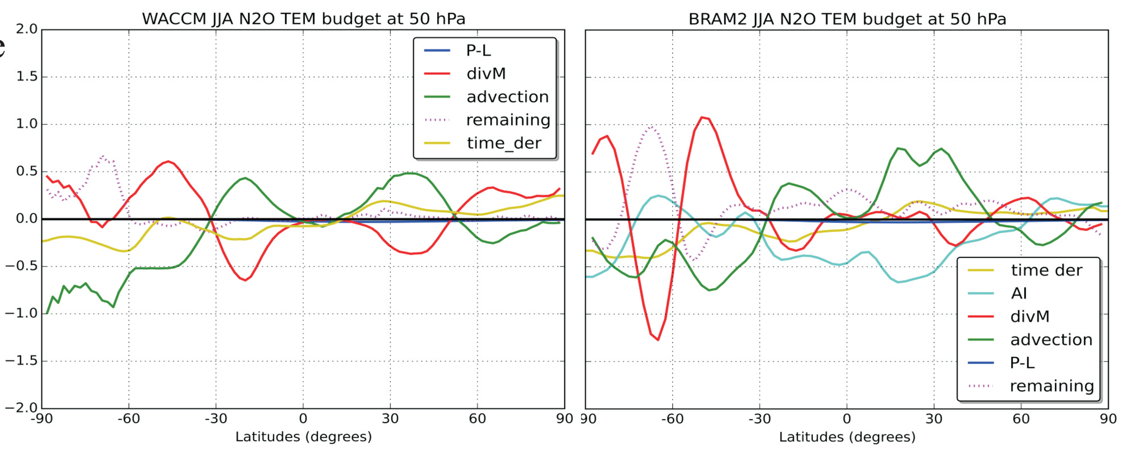

Figure 2. Latitudinal profile of the terms of the TEM budget at 50 hPa for the JJA mean (2005-2015) for WACCM **(a)**, and for BRAM2 **(b)**. Color code is shown in the legend. Units are ppb/days.

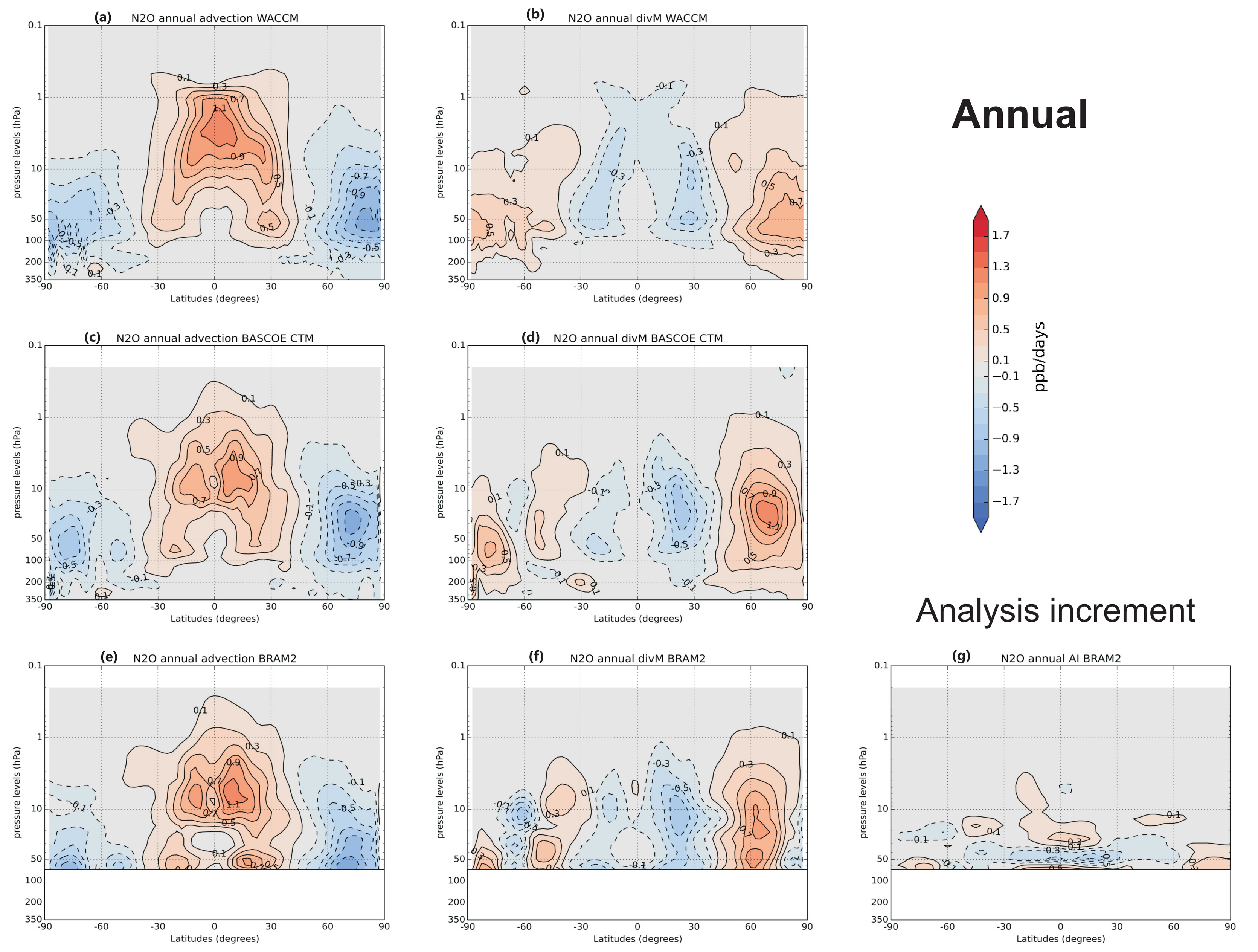

Figure 3. Latitude-pressure cross sections for the annual mean (2005-2015) advection term (left column), the mixing term (right column) and AI for BRAM2 (third column) of the N2O TEM budget. The first row **(a)** and **(b)** is for WACCM; the second row **(c)** and **(d)** BASCOE CTM; the third row BRAM2 **(e)**, **(f)** and **(g)**. The colorbar is the same for all the plots. Units are ppb/days. The white area below 70 hPa in the BRAM2 plots depict the region where MLS is not assimilated.

WACCM

BASCOE CTM

BRAM2

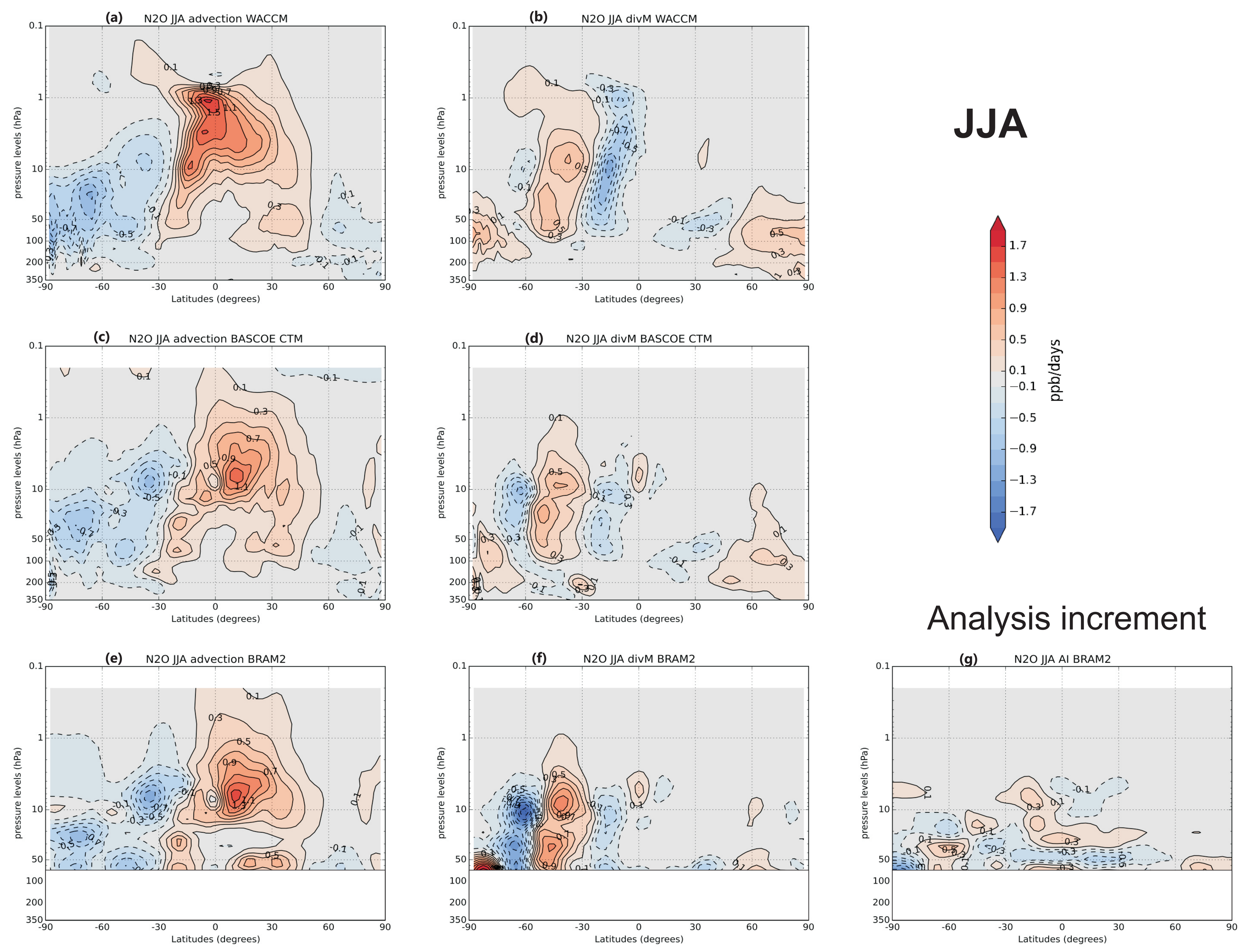

Figure 4. Latitude-pressure cross sections for the JJA mean (2005-2015) advection term (left column), the mixing term (right column) and AI for BRAM2 (third column) of the N2O TEM budget. The first row **(a)** and **(b)** is for WACCM; the second row **(c)** and **(d)** BASCOE CTM; the third row BRAM2 **(e)**, **(f)** and **(g)**. The colorbar is the same for all the plots. Units are ppb/days. The white area below 70 hPa in the BRAM2 plots depict the region where MLS is not assimilated.

Discussion

- **Annual mean:** similar patterns for the 3 datasets (**Figs. 3a,b,c**), showing the vertical advection in the tropical middle stratosphere (between 10 and 1 hPa), and downwelling at the Poles, with larger amplitudes in the NH. Some differences: more wavy contours in the BASCOE CTM and BRAM2 (**Figs 3c,e**), a strong vertical gradient in the advection in WACCM in the tropics at around 1 hPa (**Fig.3a**), not present in the CTM runs.

The mixing term presents the largest differences among the datasets: nearly symmetric with respect to the equator in WACCM (**Fig. 3b**), while there are larger values in the NH in BASCOE CTM and BRAM2 (**Figs. 3d,f**). In the SH WACCM is not able to reproduce the polar transport barrier at ~60S, while it appears in the datasets with assimilated dynamics (**Figs. 3b,d,f**).

The AI term (**Fig. 3g**) presents a strong vertical gradient in the tropics in the lower stratosphere (under 30 hPa).

- **JJA mean:** most of the differences are found in this season, especially regarding the mixing term. The advection is in general agreement between the 3 runs (**Figs. 4a,c,e**), although the BASCOE runs present larger spatial variability ("patches") in the SH polar and mid latitudes which are not present in WACCM (**Figs. 4a,c**). WACCM (**Fig. 3b**) delivers less mixing in the SH, and its latitudinal gradient are smaller than in the CTM and much smaller than in the N2O reanalysis (**Fig. 4d,f**). This indicates that the polar tranport barrier is week in WACCM. The AI term (**Fig. 4g**) shows large negative values in the lower stratosphere at the South Pole, together with several positive and negative patches, mostly in the SH. Those features lower the remaining term and make it more similar to the BASCOE CTM remaining (not shown).

Conclusions

- A comparison of the representation of the stratospheric circulation among a free running model (WACCM), and CTM (BASCOE CTM) and a chemical reanalysis (BRAM2) has been carried out.
- The TEM budget of N2O is analyzed, concentrating on the evaluation of the advection and mixing terms over annual and seasonal (JJA) mean for the 2005-2015 period.
- The annual mean advection is the most similar amongst the considered datasets, both in magnitude and location. Some differences can be found in the annual eddy mixing term, which presents different patterns in WACCM wrt both BASCOE CTM and BRAM2. Those differences are more prominent in the seasonal means.
- For the JJA season the advection term is fairly in agreement amongst the models. The mixing term presents some remarkable differences, both in magnitude and location.
- It seems that WACCM underestimates the seasonal contribution of the mixing term, missing some key features in the SH, like the weak reproduction of the polar transport barrier. Such a feature is present also when taking into account the remaining term (not shown).
- Further investigation is needed to understand the remaining term and its impact on the budget.
- We will also investigate time variations of the TEM budget and extend this analysis to different CTM runs using different reanalyses (S-RIP) and to the newer version of WACCM (version 6).

References

- Mahieu, E., Chipperfield, M. P., Notholt, J., Reddmann, T., Anderson, J., Bernath, P. F., Blumenstock, T., Coffey, M. T., Dhomse, S. S., Feng, W., Franco, B., Froidevaux, L., Griffith, D. W. T., Hannigan, J. W., Hase, F., Hossaini, R., Jones, N. B., Morino, I., Murata, I., Nakajima, H., Palm, M., Paton-Walsh, C., III, J. M. R., Schneider, M., Servais, C., Smale, D., and Walker, K. A.: Recent Northern Hemisphere stratospheric HCl increase due to atmospheric circulation changes, Nature, 515, 104–107, doi:10.1038/nature13857, http://dx.doi.org/10.1038/nature13857, 2014.
- Bönisch, H., Engel, A., Birner, Th., Hoor, P., Tarasick, D. W., and Ray, E. A.: On the structural changes in the Brewer-Dobson circulation after 2000, Atmos. Chem. Phys., 11, 3937-3948, https://doi.org/10.5194/acp-11-3937-2011, 2011.
- Andrews, D. G., J. R. Holton, and C. B. Leovy (1987), Middle Atmosphere Dynamics, Academic Press, San Diego, Calif.
- Marsh, D.R., M.J. Mills, D.E. Kinnison, J. Lamarque, N. Calvo, and L.M. Polvani, 2013: Climate Change from 1850 to 2005 Simulated in CESM1(WACCM). J. Climate, 26, 7372–7391, https://doi.org/10.1175/JCLI-D-12-00558.1
- Kinnison, D. E., et al. (2007), Sensitivity of chemical tracers to meteorological parameters in the MOZART-3 chemical transport model, J. Geophys. Res., 112, D20302, doi: 10.1029/2006JD007879.
- Meinshausen, M., Vogel, E., Nauels, A., Lorbacher, K., Meinshausen, N., Etheridge, D. M., Fraser, P. J., Montzka, S. A., Rayner, P. J., Trudinger, C. M., Krummel, P. B., Beyerle, U., Canadell, J. G., Daniel, J. S., Enting, I. G., Law, R. M., Lunder, C. R., O'Doherty, S., Prinn, R. G., Reimann, S., Rubino, M., Velders, G. J. M., Vollmer, M. K., Wang, R. H. J., and Weiss, R.: Historical greenhouse gas concentrations for climate modelling (CMIP6), Geosci. Model Dev., 10, 2057-2116, https://doi.org/10.5194/gmd-10-2057-2017, 2017.
- Errera, Q., Daerden, F., Chabrillat, S., Lambert, J. C., Lahoz, W. A., Viscardy, S., Bonjean, S., and Fonteyn, D., 4D-Var Assimilation of MIPAS chemical observations: ozone and nitrogen dioxide analyses, Atmos. Chem. Phys., 8, 6169-6187 (2008).
- Skachko, S., Ménard, R., Errera, Q., Christophe, Y., and Chabrillat, S.: EnKF and 4D-Var data assimilation with chemical transport model BASCOE (version 05.06), Geosci. Model Dev., 9, 2893-2908, https://doi.org/10.5194/gmd-9-2893-2016, 2016.
- Abalos, M., Randel, W. J., Kinnison, D. E., and Serrano, E.: Quantifying tracer transport in the tropical lower stratosphere using WACCM, Atmos. Chem. Phys., 13, 10591-10607, https://doi.org/10.5194/acp-13-10591-2013, 2013.

Acknowledgments:
This work has been primarily supported by the F.R.S.-FNRS, Brussels, through the research project ACCROSS (convention T.0040.16).

contact: daniele.minganti@aeronomie.be

AGU 100 FALL MEETING Washington, D.C. | 10–14 Dec 2018