Preliminary characterization of the stratospheric circulation using long-lived tracers with the WACCM chemistry-climate model and observations

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Abstract

The changes in stratospheric circulation are one of the major sources of uncertainty in climate projection, therefore they are a major area of research.

The current work is part of the ACCROSS (Atmospheric Composition and Circulation investigated with meteorological Reanalyses, Observational datasets and models for the Study of the Stratosphere and its changes) project, which intends to improve our understanding of the circulation changes in the past years through an extensive use of observations and model simulations of selected long-lived tracers.

Here we compare simulations of a state-of-the-art Chemistry Climate Model with satellite observations of HF and N_2O from February 2004 to February 2013. To accomplish this task major modifications to the model chemistry scheme have been made.

This early comparison shows poor agreement in the HF distribution in the middle stratosphere for all latitudes, while in the low stratosphere the agreement is better, especially in the tropics. Since good agreement is found in the N_2O distribution, the residual circulation is well represented, e.g. the model reproduces well the position of the transport barriers in the SH, this suggests that the disagreement in the HF distributions is due to an incomplete chemical scheme. A comparison with chemistry-transport models using the same chemistry scheme and boundary conditions is needed to evaluate this point.

Introduction

Changes in atmospheric circulation are one of the major climate change issues. Atmospheric circulation and composition are closely related with many feedback processes, e.g. ozone and greenhouse gases (GHG) distribution. In the stratosphere, the Brewer Dobson Circulation (BDC), generated by the breaking of tropospheric waves into the stratosphere, transports chemical tracers from the troposphere to the stratosphere. Those features are projected to change, hence it is important to see if the current chemistry-climate models are able to reproduce those changes and their impact on stratospheric dynamics.

Climate model simulations indicate that increasing temperatures, driven by the accumulation of GHG in the troposphere, will result in an amplified wave activity and in a speedup of the BDC (SPARC CCMVal, 2010). However, there is no clear supporting evidences, with observations studies that show no significant BDC change using SF_6, CO_2 (Engel et al., 2017), or hemispherical asymmetries using HCl (Mahieu et al., 2014).

This multi-year change of stratospheric dynamics will also affect other stratospheric tracers (e.g. HF, N_2O and CH_4) with possible significant impact on their abundances. Since those tracers are well observed, they are a good diagnostics for changes in the BDC.

We aim to perform a careful investigation comparing the distributions and the time evolution of these tracers in a state-of-the-art climate model with observational datasets.

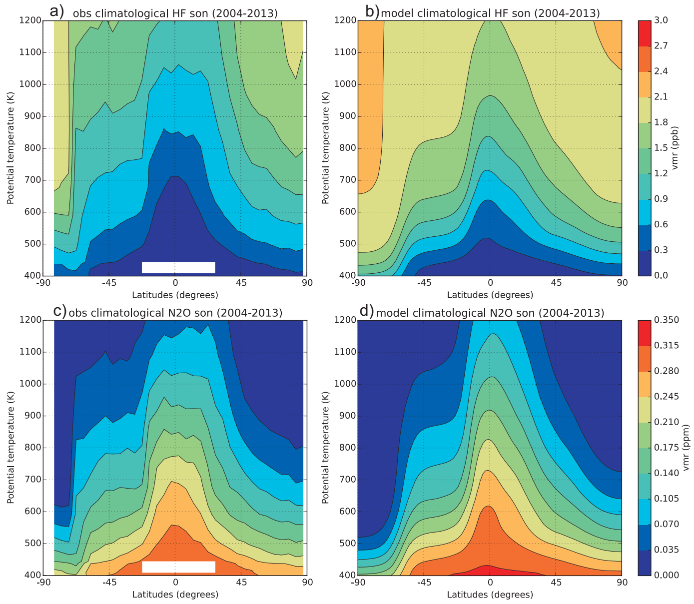

Figure 1. **a)** Latitude vs potential temperature contour plots of climatological September-October-November (SON) HF (ppb) in the lower-middle stratosphere for ACE-FTS data. **b)** same as **a)** but for WACCM simulation. **c)** Latitude vs potential temperature contour plots of climatological September-October-November (SON) N_2O (ppm) in the lower-middle stratosphere for ACE-FTS data. **d)** same as **c)** but for WACCM simulation.

Conclusions

- A comparison between model simulation and observations has been carried out. The WACCM results of HF show poor agreement with respect to the observations, in most of the stratosphere: the model overestimates the HF abundances at almost all latitudes.
- Latitudinal profiles, on the other hand, point out the good representation of the transport barriers in the springtime SH.
- Comparison between modeled and observed N_2O abundances shows good agreement, suggesting that the residual circulation is not the culprit and that the major modification of the WACCM chemistry scheme (i.e. inclusion of HF) should be revised and adjusted in order to match the observations.
- Further studies are needed in this direction: first of all comparing WACCM results with CTM data driven by the same initial and boundary conditions and chemistry scheme, and with observational tracers timeseries.

Methods

- The Whole Atmosphere Community Climate Model (WACCM): fully coupled chemistry-climate model (Marsh et al., 2013). Specific configuration of the atmospheric model (CAM, Community Atmosphere Model) of the Community Earth System Model 1.2.2 (CESM).
- Top of the model at approximately 150 km with 66 vertical levels and *1.9x2.5* degrees horizontal resolution.
- Free-running configuration with major modification of the chemistry scheme: inclusion of HF and its sources, new reactions for N_2O and CH_4.
- Initial conditions from in-house data assimilation product (Errera et al., EGU 2017). Boundary conditions from the latest Coupled Model Intercomparison Project 6 (CMIP6) recommendation (Meinshausen et al., 2017).
- Observations: from Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) climatological dataset (Koo et al., 2016) from February 2004 to February 2013.

48 vertical pressure levels from 1000 hPa to 10^{-4} hPa (~105 km), with 5-degrees latitude spacing from 90*S* to 90*N*. Data use: zonally averaged seasonal climatology (DJF, MAM, JJA, SON).

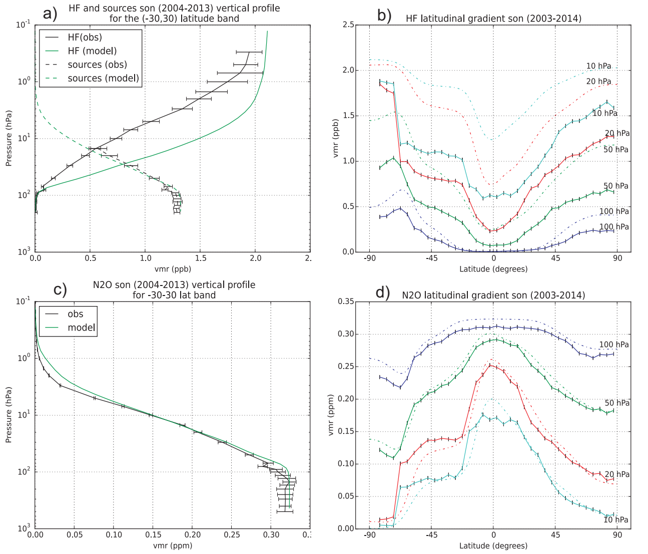

Figure 2. **a)** Stratospheric vertical profiles in the Tropics (-30,30) for HF (solid) and its sources (CFC-11+2*CFC-12) (dashed). Observations are in black, model in green. Units are ppb. **b)** HF (ppb) latitudinal profiles for different pressure levels: *100, 50, 20, 10 hPa*. Observations are the continue lines, model data are the dashed lines. **c)** Stratospheric vertical profiles in the Tropics (-30,30) for N_2O in ppm (solid). Observations are in black, model in green. **d)** N_2O (ppm) latitudinal profiles for different pressure levels: *100, 50, 20, 10 hPa*. Observations are the solid lines, model data are the dashed lines

Results

- WACCM provides larger HF values w.r.t. ACE-FTS for the considered period (Fig. 1a,b). The abundances are almost twice in the model w.r.t. the observations in the whole stratosphere, except for the tropical lower stratosphere (<500 K).
- The WACCM representation of the position of the tropical transport barrier at around 20*S* matches the observations as well as the vortex edge position at around 80*S* (Fig. 1a-d, 2b, d).
- The WACCM simulation shows realistic values of N_2O (Fig. 1c, d) w.r.t. the observations, with a small overestimation in the tropical middle stratosphere (<900 K).
- The WACCM vertical profiles of HF for the tropics (Fig. 2a) show poor agreement w.r.t. the observations (with almost 1 ppb of difference at 10 hPa), except the lower stratosphere (100 hPa). The modeled HF sources on the other hand show good agreement w.r.t. the observations throughout the stratosphere.
- The modeled HF latitudinal gradients (Fig. 2b) do not agree with the observations, with differences of almost 1 ppb, except in the tropical lower stratosphere (100 hPa).
- WACCM vertical profiles of N_2O for the tropics show good agreement w.r.t. the observations, especially in the middle stratosphere.
- WACCM shows good agreement w.r.t. the observations in the latitudinal N_2O distribution (Fig. 2d), except in the mid-stratosphere southward of 45*S*, where the model underestimates the observed values.

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