Implications of the enhanced Brewer-Dobson circulation in ERA-40 for the downward transport of ozone to the troposphere

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Abstract. As part of the EU project RETRO, whose aim is to reanalyse the tropospheric chemical composition since the late 1950s on the basis of ERA-40, the 45-year meteorological reanalysis that has recently been completed by the ECMWF, this study addresses the question how to simulate the downward transport of stratospheric ozone given that the Brewer-Dobson circulation in ERA-40 has a strong bias.

Introduction

The Brewer-Dobson circulation, characterized by rising motion across the tropical tropopause, poleward drift in the stratosphere and descent in the extratropics, plays a key role in determining the large-scale distribution of ozone. Of particular importance for tropospheric chemistry is the downward branch of the circulation, which transports air from the stratospheric 'overworld' into the lowermost stratosphere and the troposphere and carries along ozone and other stratospheric constituents. A major source of inaccuracy in the description of stratosphere-troposphere exchange (STE) in off-line chemistry-transport models (CTMs) is due to the difficulty of producing a realistic Brewer-Dobson circulation in general circulation models (GCMs) and numerical weather prediction systems (NWPs), in many cases resulting in an enhanced circulation strength.

This deficiency is particularly pronounced in ERA-40, as we demonstrate in this study by analysing the net air mass fluxes across the 100-hPa surface and the tropopause, following the method of *Appenzeller et al.* [1996]. This finding has major consequences for the use of ERA-40 in stratospheric as well as tropospheric chemistry-transport modeling and challenges the feasibility of chemical reanalyses of the atmosphere on the basis of ERA-40 meteorology.

Linearized ozone

To estimate the impact of the enhanced Brewer-Dobson circulation in ERA-40 on the net downward transport of ozone, we apply a simple, single-tracer model of stratospheric ozone chemistry. It is based on the principle that the ozone chemical tendency in the stratosphere approximately varies as a linear function of the ozone concentration, overhead column density and temperature [*Cariolle and Déqué*, 1986]. In our calculations the values of the Cariolle coefficients are taken from the linearized ozone (Linoz) model of *McLinden et al.* [2000]. In order to describe the stratospheric chemistry and transport as accurately as possible, we have retained all model levels above 300 hPa of the 60-layer ECMWF model. Tropospheric ozone chemistry and surface deposition are simulated by relaxing ozone below 900 hPa to 25 ppbv with a time constant of 2 days. Figure 1 shows the zonal and monthly mean ozone distribution for December 1997 obtained with the Linoz model driven by ERA-40. The corresponding ozone flux at 100 hPa (shown in Figure 2) exceeds the observational range of 450-590 Tg/yr [*Gettelman et al.*, 1997] by a factor 2–3.

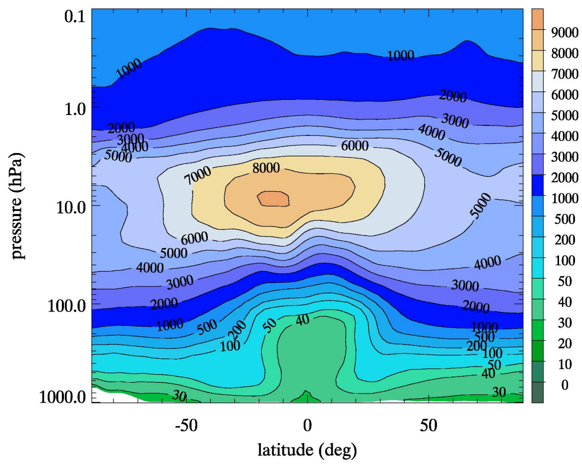

Figure 1. Zonal and monthly mean ozone concentration (ppbv) for December 1997 obtained using the Linoz model driven by ERA-40 meteorology at a horizontal resolution of 3^o x 2^o.

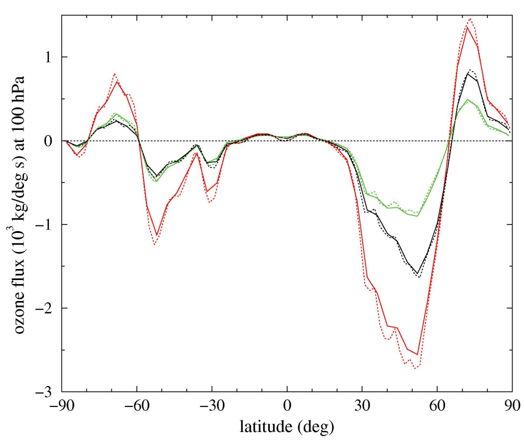

Figure 2. Zonally integrated, monthly mean ozone flux at 100 hPa for December 1997, comparing the results for Linoz (red), Synoz (green) and the model with relaxation (black) at a horizontal resolution of 6^o x 4^o (solid lines) and 3^o x 2^o (dotted lines).

Synthetic ozone versus relaxation

As a first possible alternative to overcome the problem of excessive downward transport of stratospheric ozone in tropospheric CTMs driven by ERA-40 winds, we consider the synthetic ozone (Synoz) model [*McLinden et al.*, 2000]. It basically is a method to constrain the total net downward transport of ozone by imposing its chemical production rate in the stratosphere. Ozone is injected in the tropical middle stratosphere (10–70 hPa, 30^oS–30^oN) at a fixed rate per unit mass. Thus, the rate of injection directly controls the total net downward transport of ozone from the stratospheric overworld (550 Tg/yr in our case). The resulting ozone flux at 100 hPa for December 1997 is shown in Figure 2. Although solving the problem of excessive downward transport, the Synoz scheme results in a dramatic underprediction of the ozone concentrations in the stratosphere and the upper troposphere (see Figure 3).

A second alternative is to impose stratospheric ozone concentrations by relaxation to a zonal and monthly mean climatology. In many of the present tropospheric CTMs some kind of relaxation scheme is used to provide the stratospheric boundary condition for ozone. However, in CTMs driven by ERA-40 it is necessary to extend the relaxation to levels approaching the lowermost stratosphere. Application of the relaxation scheme down to 100 hPa in the extratropics and down to 50 hPa in the tropics in our model results in a reduction of the ozone flux by more than a factor 2 (see Figure 2). Nevertheless, with 715 and 760 Tg/yr at a resolution of 6° x 4° and 3° x 2°, respectively, the ozone flux is still significantly above the range of observational estimates.

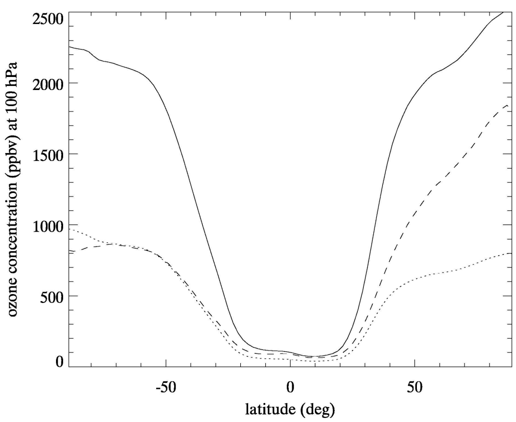

Figure 3. Zonal and monthly mean ozone concentration (ppbv) at 100 hPa for December 1997, comparing the results for Linoz (solid), Synoz (dotted) and the model with relaxation (dashed) at a horizontal resolution of 3° x 2°.

Forecast winds

As a third alternative we assess the benefits of using wind fields from the 1-day forecast of the reanalysis instead of the standard 'first guess' (6-hour forecast). Analysis of the net air mass fluxes across the 100-hPa surface and the tropopause in both hemispheres shows that in all seasons the 1-day (18/24-hour) forecast winds exhibit significantly reduced vertical transport at these levels.

The impact on the downward transport of ozone has been evaluated using the Linoz model as well as the model with relaxation (see Figure 4). The improvement is most pronounced in the Northern Hemisphere, where the overestimation of the ozone concentrations in the lowermost stratosphere has become much less severe (see Figure 5). In combination with the relaxation scheme, the use of forecast winds at a resolution of 6° x 4° results in a reduction of the ozone flux at 100 hPa from 715 to 640 Tg/yr, approaching the observational window. We therefore conclude that it is advantageous to use short-term forecasts beyond the 6-hour first guess in combination with a relaxation scheme that constrains the ozone field in the lower stratosphere.

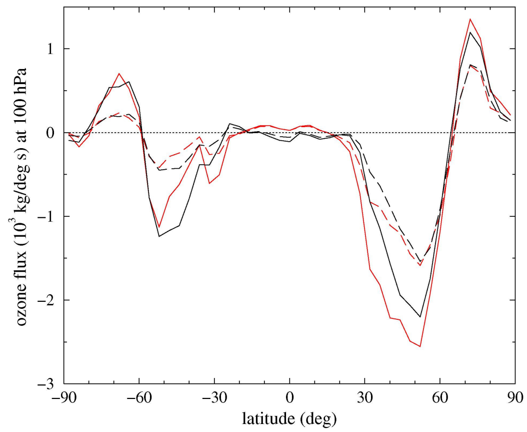

Figure 4. Zonally integrated, monthly mean ozone flux at 100 hPa for December 1997, comparing the results obtained using forecast winds (black) to those obtained using the first guess (red) for the Linoz model (solid lines) and the model with relaxation (dashed lines) at a horizontal resolution of 6° x 4°.

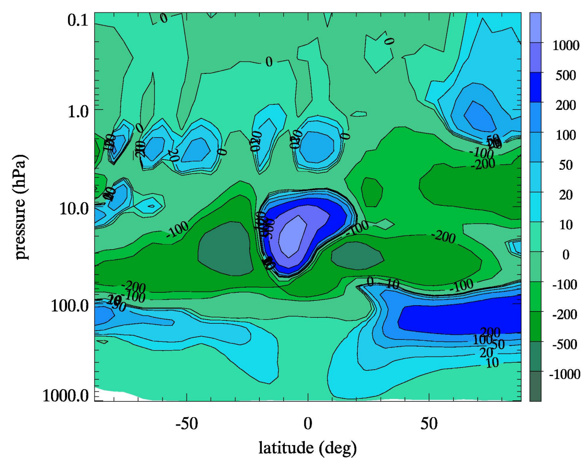

Figure 5. Zonal and monthly mean ozone concentration difference (ppbv) for December 1997 between the Linoz model driven by first-guess winds and the Linoz model driven by forecast winds at a horizontal resolution of 6° x 4°.

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