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Interactive Comment

Interactive comment on “Stratospheric dryness” *by* J. Lelieveld et al.

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We thank Dr. Fueglistaler for his comments and his request for a more detailed description of some of our results, which we will be happy to provide.

(1) Fueglistaler et al. (2005) and Fueglistaler and Haynes (2005) performed trajectory calculations based on meteorological analyses, whereas we developed a coupled stratosphere-troposphere chemistry-GCM. Therefore, we dispute the remark "it is not obvious what is new/different compared to the above mentioned studies". Our modelling approach is very different, and one can hardly claim that all issues regarding stratospheric dryness have been resolved since the above mentioned studies.

- Fueglistaler et al. performed Lagrangian transport studies using 6-hourly mean meteorological data, pre-calculated with the ECMWF model (ERA-40). The trajectory calculations were performed at 2° horizontal resolution. The results of this work deserve scrutiny, and justify additional and independent studies, because ERA-40 has serious deficiencies in representing the Brewer-Dobson circulation and stratosphere-troposphere exchange (van Noije et al., 2004, 2006). Fueglistaler and Haynes (2005) report a modest tropical tropopause cold bias of 1-2K. Oikonomou and O'Neill (2006) conclude that in the tropical lower stratosphere ERA-40 has a wet bias up to 70 hPa and a dry bias aloft.

- Our global model interactively describes the ozone and water cycles in both the troposphere and stratosphere, and computes dynamical, cloud and radiation processes with a 15 min time step (Jöckel et al., 2006). This time resolution does justice to diurnal dependencies of diabatic processes. The horizontal resolution of our model (about 2.8°) is less than of Fueglistaler, however, our vertical resolution is higher (near the tropical tropopause by a factor of 2), being critical for the representation of vertical wave propagation (Giorgetta et al., 2006). Our model extends deeper into the mesosphere than ERA-40, leading to an improved simulation of the momentum forcing by gravity waves. As a result, our model realistically reproduces the QBO, SAO, sudden stratospheric warmings and transport barriers without observational constraints in the TTL and stratosphere (contrary to ERA-40).

These differences in model approaches can have important consequences for the accurate calculation of vertical velocities and transport in the TTL and stratosphere. Furthermore, Fueglistaler et al. (2005) mention the difficulty of following individual trajectories, and infer the statistical properties of atmospheric transport by calculating ensembles of back-trajectories. Our trajectory scheme tracks individual air parcels throughout the GCM domain (a new method), and we use it to compute vertical air mass fluxes. With our nudging technique (see below) we approximate actual synoptic conditions and variability of e.g. temperature and tracers, which can be directly compared with satellite data. Fueglistaler et al. (2005) mention that in ERA-40 "horizontal wind fields in the tropics are probably poorly constrained, with implications both for individual trajectories and for the ensemble".

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The Newtonian relaxation toward ECMWF analyses has been applied to nudge the model toward realistic synoptic conditions. This facilitates the direct comparison of model results with measurement data. As explained in section 4, the nudging is very weak and restricted to the model domain below 200 hPa (free troposphere). The strongest constraint to simulate realistic meteorology is that SSTs are prescribed, a main reason why the weak nudging suffices. As a consequence, the TTL and stratospheric dynamics, physics and chemistry are computed freely and interactively.

We agree temperature is important and that ECMWF analyses have a temperature bias, as stated by Fueglistaler and colleagues (2005), contributing to uncertainties in their studies. If we extend the nudging up to 100 hPa or higher altitudes in our model, the results deteriorate (by adopting errors from ECMWF). The weak temperature nudging below the TTL has negligible influence on calculations of temperature within the TTL and aloft.

We believe that the stratospheric part of our model is more comprehensive and accurate than in ERA-40, even though the ECMWF model has been constrained by observations. Our model prognostically calculates the relevant stratospheric processes and more realistically represents transport processes in the tropopause region. The weak nudging optimizes boundary conditions ($<$ 200 hPa) for the stratospheric simulations. This may be conceived as an innovation since the studies referred to by Dr. Fueglistaler.

Nevertheless, to meet Dr. Fueglistaler's reservations we aim to include a comparison of model calculated temperature distributions with AIRS data at 100 hPa in the revised version of our manuscript.

(2) Our hypothesis that overshooting convection contributes to moisten the TTL is based on deductive reasoning. Nevertheless, we agree that a more elaborate presentation of our argument would improve the manuscript, hence this will be included in the revision (see also the reply to referee #3). Our hypothesis could be tested with higher

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resolution (cloud-resolving) models and observations. First comparisons of our model results with aircraft measurements, performed in the TTL north of Darwin (N-Australia) in November 2005, indicate that our model reproduces the influence of convection on water vapour rather well.

True, the ozone high-bias may also have other causes, which we will discuss in the revised manuscript. Presently, we are investigating the role of chemical ozone destruction caused by short-lived halogen compounds.

(3) Fueglistaler and Fu (2006) play down the contribution of thin cirrus to radiative cooling within the TTL by comparing "clear sky" and "all sky" radiation transfer calculations. The cloud information was derived from measurements by a millimetre cloud radar, not sensitive to thin cirrus and small ice particles. Sensitivity studies were performed by assuming subvisible cirrus clouds above the radar-detected clouds, indicating a relatively minor contribution to radiative cooling. I see no disagreement with our study. Then again, we emphasize the radiative contribution by thin cirrus (and ozone) after the cumulonimbus anvils have decayed. The infrared radiative contribution by thin cirrus then changes from cooling to warming, which contributes to the ascent of air parcels. It is the difference that counts. To my knowledge, this emphasis is new.

The strongest tropical tropopause "drain" in our model, i.e. over the Indian Ocean during NH summer, represents rather slow descent, with a downward mass flux at 100 hPa of about 0.1x10-3 kg/m2/s. In the revised manuscript we will present a diagram with heating rates, as requested by Dr. Fueglistaler (relating to the year 2003 for which we have applied for AIRS data; see above).

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