An intercomparison of different approaches to calculating trajectories in the tropical tropopause layer

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Introduction

The tropical tropopause layer (TTL) is the transition region observed within the tropics between troposphere and the stratosphere. It plays an important role in regulating fluxes of chemical tracers such as water vapour or Very Short Lived Species (VSLS) into the stratosphere.

Stratospheric water vapour depend on a number of TTL processes, including deep overshooting convection, synoptic-scale circulation and troposphere-to-stratosphere exchange. Some recent studies have employed trajectory calculations using assimilated winds and temperature fields to study transport and dehydration in the TTL. Characteristics such as annual mean and seasonal variation of entry mixing ratios, have be reproduced to observational uncertainty by large-scale dynamics and temperature resolved by these global-scale models (*Fueglistaler et. al*, 2004, 2005).

However, some concerns regarding accuracy remain. These include

- Noisy vertical velocity fields due to low temporal resolution of input data and small errors in horizontal winds being exaggerated through solving the mass continuity equation.
- Neglection of microphysics and other small-scale processes when modelling water vapour in lower stratosphere.

Approach: We investigate the impact of noise in vertical velocity fields on estimating lower stratospheric water vapour. Trajectory calculations are performed for one year using ECMWF 40-year Reanalysis (ERA-40). Experiments are run at different temporal resolutions and employing both 'kinematic' (vertical velocity by mass continuity) and 'diabatic' (integration on isentropic levels, driven by heating rates) trajectory codes. We examine two features of stratospheric water vapour, the 'tape recorder signal' and the meridional propagation in the lower stratosphere.

Method

Data:
ECMWF ERA-40 Reanalysis winds, temperature and diabatic heating rate fields, at T159 ($\sim 1.125^\circ \times 1.125^\circ$) resolution on 60 model levels. Analysis fields supplied at 00, 06, 12, 18 hours, and forecast at 03, 09, 15 and 21 hours.

Trajectories: Trajectories were initialised globally between (90N, 90S) with horizontal resolution of $2^\circ \times 2^\circ$ on every 10K potential temperature levels between 340K and 440K. They were initialised every 10 days in 2001 and integrated backwards in time for 4 months, using a modified version of OFFLINE3 (*Methven*,1997) trajectory code.
Three experiments were performed:

- Input data at 6 hourly resolution, vertical velocity from mass continuity equation, integration on model levels. (ERA-40 6h)
- Input data at 3 hourly resolution, vertical velocity from mass continuity equation, integration on model levels. (ERA-40 3h)
- Input data at 6 hourly resolution, integration on potential temperature levels, vertical motion driven by diabatic heating rates (ERA-40 diabatic)

Water vapour: To estimate water vapour, a simple dehydration model similar to *Fueglistaler et al.* 2004 was employed. For trajectories on an isentropic level, troposphere-to-stratosphere (TST) trajectories are defined as those that cross the 340K isentropic surface with PV less than 2PVU in the 4 months of integration. TST trajectories are assumed to have crossed the cold-point tropopause and assigned the minimum saturation mixing ratio encountered along its path. Non-TST trajectories are assigned the minimum value of saturation mixing ratio minimum along its path and the annual mean water vapour of tropical TST trajectories.

We compare our results with HALOE climatological water vapour distributions.

Results

Trajectory dispersion

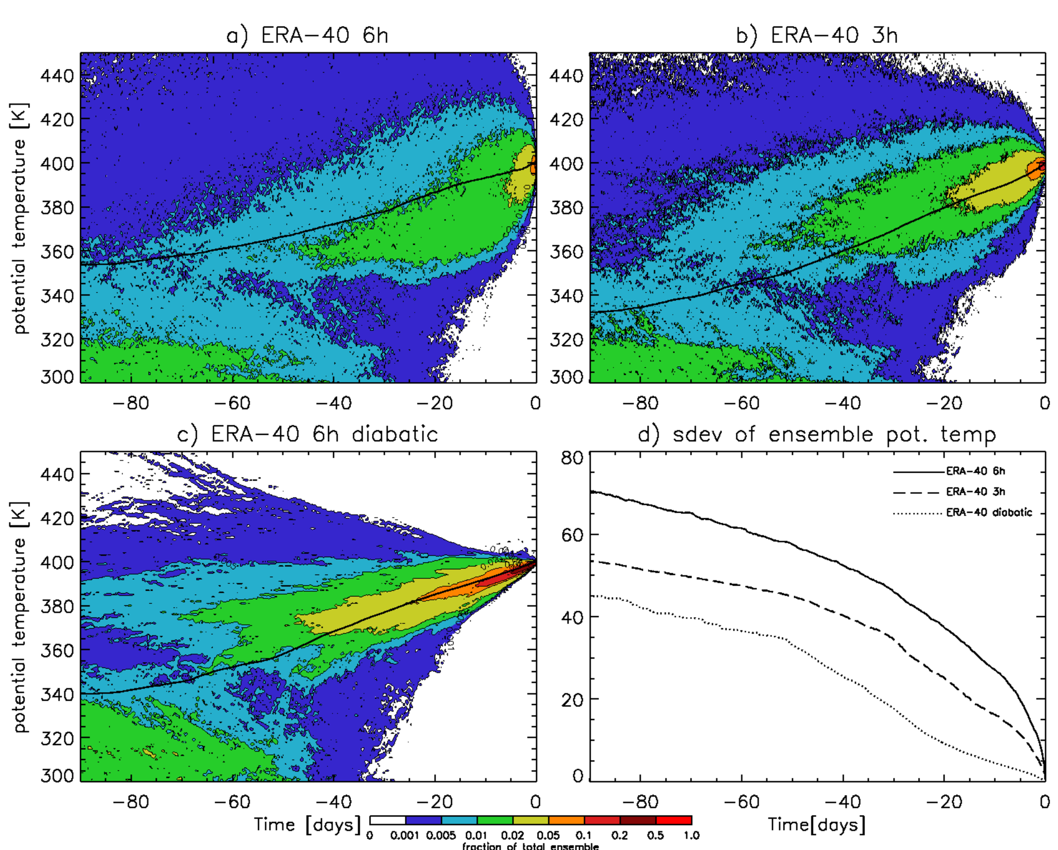

Figure 1: *a)-c) PDF of the first three months for trajectories initialised on 400K, with black solid line indicating ensemble mean potential temperature. d) Shows the evolution of ensemble standard deviation of potential temperature with time.*

The 'tape recorder' signal

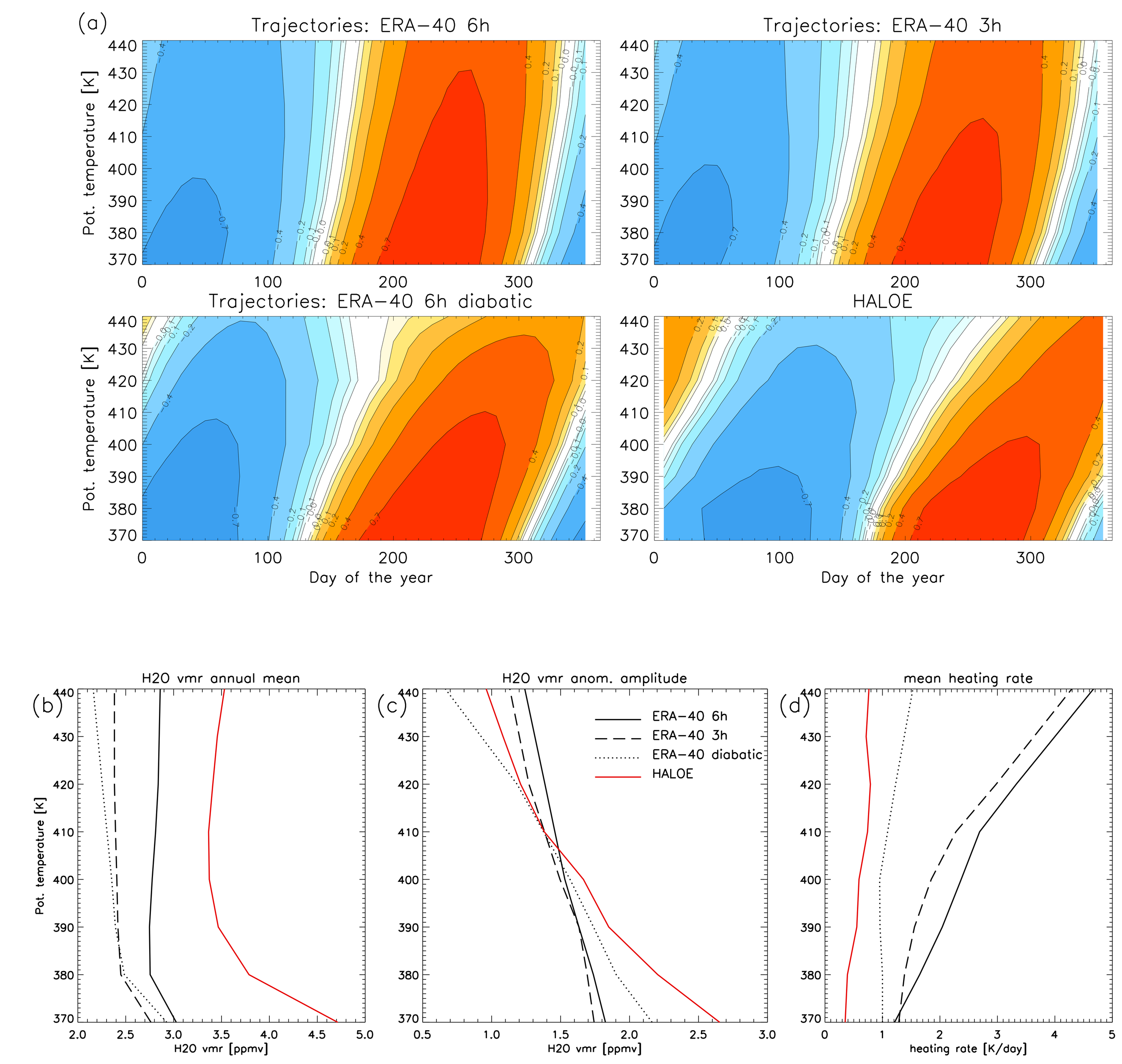

Figure 2: *a)Seasonal cycle of tropical water vapour concentration anomalies (the 'tape recorder' signal, in ppmv) derived from trajectories and HALOE climatological mean. Tropical refers to averaging over (20N, 20S). Trajectories can reproduce the 'tape recorder' signal, but the rate of propagation is too fast for the 'kinematic' trajectories. b)Tropical annual mean profiles of water vapour concentrations. Reducing vertical dispersion reduces the annual mean value. c) Amplitudes of seasonal cycles of tropical water vapour concentration anomalies. d) Derived annual mean total radiative heating rate profiles from propagation rate of the 'tape recorder' signal. Trajectory estimated heating rates are greater than observed. Performance of kinematic trajectory predictions decrease with height.*

Latitudinal variations of water vapour on an isentropic surface

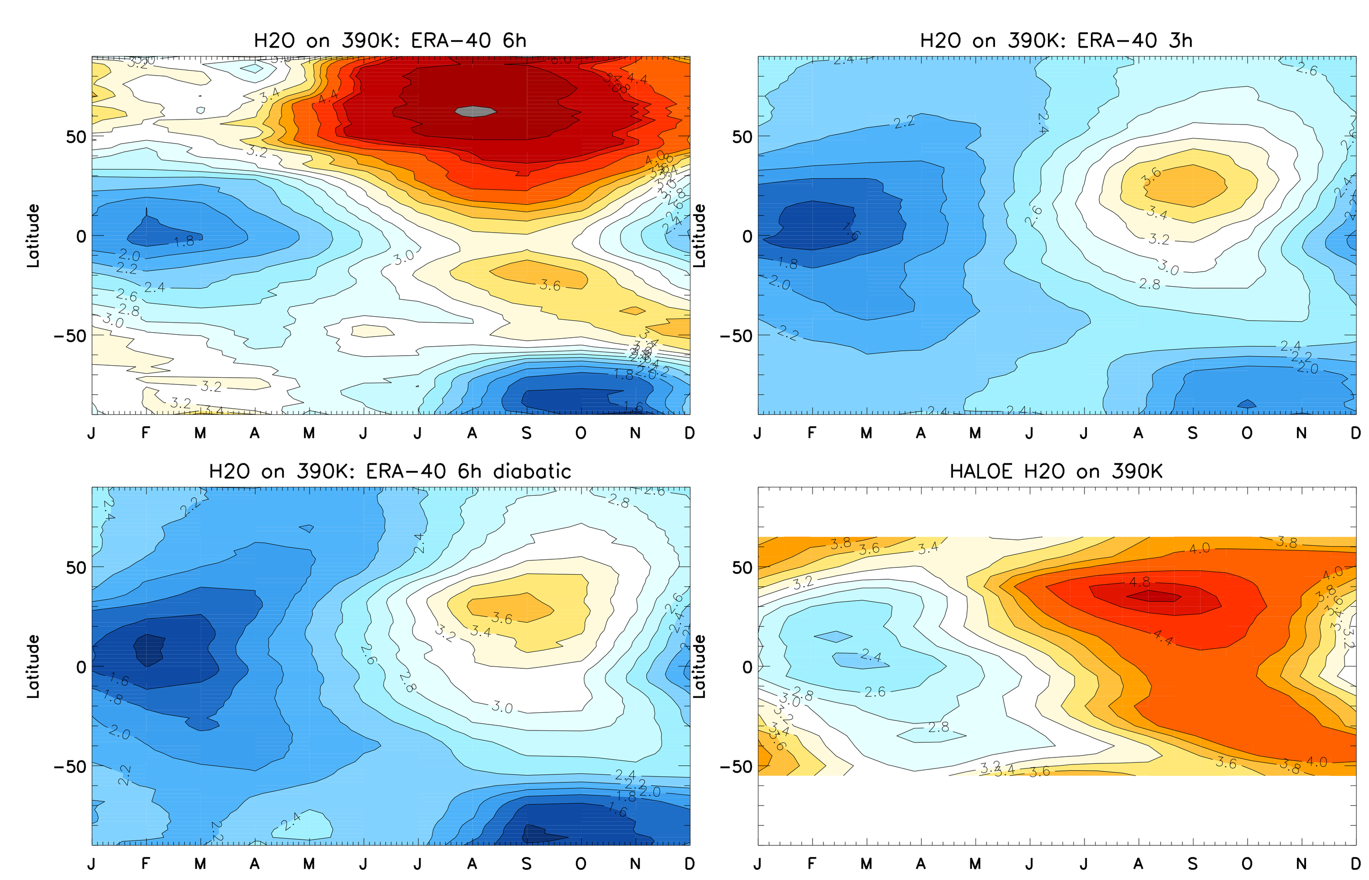

Figure 3: *Seasonal cycle of zonal mean water vapour mixing ratio on 390K estimated from trajectories, compared with HALOE climatology. 6h hourly kinematic trajectories fail to capture the summertime maximum in the northern hemisphere, due to the large number of spurious TST trajectories in the extra-tropics. Trajectory estimates are less than HALOE since they neglect stratospheric processes such as methane oxidation.*

Conclusion

- Increasing temporal resolution/use of diabatic trajectories reduces vertical dispersion in the trajectories, quantified by the standard deviation of ensemble potential temperature.
- Reduced vertical dispersion leads to estimates of propagation rate of the tape recorder signal closer to observations. It also allows transport features such as the meridional propagation of water vapour in the lower stratosphere to be resolved.
- Reduced vertical dispersion produces annual mean water vapour estimates lower than 6 hourly kinematic trajectories and HALOE. This may provide an estimate for the effect of microphysical processes involved in dehydration.
- Caveats: There are some accuracy issues with ERA-40 diabatic heating rates in the tropical stratosphere (*Fueglistaler et al.*2008) which may affect our results here.

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Acknowledgements

NERC, ECMWF and the ACTIVE/SCOUT-O_3 Research consortia.
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