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Interactive comment on "Constraining tropospheric mixing timescales using airborne observations and numerical models" *by* P. Good et al.

P. Good et al.

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The authors would first like to thank the referee for taking the time to study our manuscript, and offering useful comments which will lead to a much improved paper.

The referee comments may be addressed by text clarifications; presentation of results of some tests where the resolution of the gridded initial data (from TOMCAT) was degraded; and by more extensive use of the KS statistic.

Responses to specific referee comments are given below.

Responses to General remarks: ——————————

1- Text added to introduction: 'Convection is of course in general a significant problem in the interpretation of trajectory calculations. However it is important for the current study only if convection affects a significant part of the air sampled. To mitigate this and other model errors, extended flight segments and a large number of trajectories - 100-200 - are used to extract each mixdown time-scale. Turbulent mixing through convection tends to homogenise tracer mixing ratios, reducing the amount of small-scale structure. So, in regions where convection is important, the data will show less structure than otherwise. Hence, shorter trajectories are required for model advection to reproduce the observed amount of structure. If the convection is extensive enough to be significant for a large part of the flight, then this will mostly appear evident as a reduced mixdown timescale.' This is seen for the flight of August 3, backed up by lightning observations; and possible for August 8, although in this case independent supporting data is lacking.

2- The mixdown timescale is of course affected by the resolution of the initial data, and the effect was actually estimated in the final paragraph of the text - namely an increase of about 3 days per e-folding increase in grid dimension. In response to referee comments, a section on 'Sensitivity to the mixing spatial scale' has been added to the revised manuscript, including tests with initial data of degraded resolution.

3- Statistical tests were not used in the main body of the text, because it was felt that a) within the sensitivity allowed by model errors and variability between flights, the results could easily be derived by inspection and b) inspection of the plots is important, since this is a new technique, even if a statistical test is applied later. In the revised manuscript, plots of KS test P-values are presented and discussed for the five similar flights of Aug 16,17,22a,22c,24. For Aug 3 and 8, the extra precision offered by the KS test is not appropriate, since both results are treated with some caution.

Responses to Specific remarks ——————————

'Abstract': This sentence removed.

'p2, col1, line 13': see response to general comments above 'p2, col1, "The approach suggested here..."': this paragraph, the main explanation of the method, has been extended. To clarify the method description, the middle of the paragraph now reads: 'That is, t_m may be chosen such that for trajectories longer than t_m the model overestimates the small-scale structure, while for trajectories shorter than t_m, the model underestimates the amount of small-scale structure. If the observations show a lot of small-scale structure, then it might in general be expected that longer trajectories would be required for advection to reproduce this, so t_m will tend to be long. On the other hand, if the observations are very homogeneous, then it is likely that only relatively short trajectories will reproduce the observed small-scale structure, so t_m will be correspondingly short. A numerical model is required to quantify this for each set of observations. The Lagrangian model has no explicit treatment of mixing, so the timescale t_m is the time-scale at which structure in the real atmosphere starts to lose its identity through mixing.'

'p2, col2': See response to general comments above.

'p3, col 2, top section 4'; and 'p5, col 1'. Clarification of the basic method of the paper is necessary, and is done in paragraph 4 of the introduction. Briefly, the result is the length of lagrangian advection required for the model to exceed the amount of small-scale structure in the data. Lagrangian advection results in continuous generation of smaller scales. Hence, if the data is relatively homogeneous, shorter trajectories are likely to be required - a shorter mixing timescale; whereas if there is a lot of observed small-scale structure, in general longer trajectories will be needed. A model is required to quantify these general comments. The referee suggests a contradiction between the discussion for Aug 3 and Aug 8. This is not the case: for Aug 3, a 'large amplitude' and 'small scale' refers to the model results, whereas for Aug 8, 'homogeneity' refers to the data. Hence, the 'homogeneity', that the referee mentions as reported by two other ACPD papers - and was indeed referred to in our paper - does not contradict but support our result. The two papers mentioned by the referee use models to derive a Southeast Asian origin. Our suggestion of relatively recent mixing (homogenisation)

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does not necessarily conflict with this, since it is unclear to what extent homogenisation would affect the bulk origin of the air. This will be highly case dependent and would require much greater understanding of the processes involved. This said, the result for Aug 8 would need independent support for a strong statement to be made - as for Aug 3 - and this is emphasised in the revised text.

Paragraph added: 'Scheeren et al, 2003 and Roelofs et al.,2003 use numerical models to infer a Southeast Asian origin for the air observed in this flight. The above suggestion of relatively recent mixing (homogenisation) does not necessarily conflict with this, since it is unclear to what extent homogenisation would affect the bulk origin of the air. This will be highly case dependent and would require much greater understanding of the processes involved. This said, the short mixing timescale derived in this work for August 8 requires independent support, since model errors are another explanation for the result.

'p4, col2': Text changed to: '7 August, 6 August and 4 August'

'p5, col1': See response to 'p3, col 2, top section 4' above.

'p6, col 2, l5-6': (presumably 'col 1' was intended) Text changed to: 'The feature produced by the TOMCAT model is due to the flight track cutting through the very edge of a modelled stratospheric intrusion. Its classification as a stratospheric intrusion is clear from examination of time-series of TOMCAT results.'

'p6, col 2, l21': (presumably 'col 1' was intended) Text added: ', an instrument which detects cloud-to-ground lightning discharges'

'p8, fig 10': Text added: 'For flight c of 22 August, CiTTyCAT shows a large peak at 13.6hr; this is due to trajectories originating from the PBL, and is not apparent in the TOMCAT Eulerian model because this feature is too small to be maintained on the model grid.'

'p8' see response to general comments above

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’p9, col 2, bottom half’: Text added: ’That is, trajectory models initialised from Eulerian tracer fields implicitly have mixing at the spatial scale of the Eulerian initialisation, imposed over the timescale of the trajectory length.’ (In addition, the method description in the introduction has been clarified, as described earlier).

Responses to Technical remarks ——————————

All changed as required

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