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Interactive comment on "Variability of the Lagrangian turbulent diffusivity in the lower stratosphere" *by* B. Legras et al.

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1.a-b) We have also observed that tracer fluctuations sometimes correlate strongly with potential temperature fluctuations. This cannot, however, be taken simply as a manifestation of gravity waves since the aircraft does not fly on a constant metric or pressure level and such fluctuations are also strongly correlated with fluctuations in pressure and altitude. Having said that, potential temperature fluctuations are taken into account by launching each particle exactly at the altitude of the aircraft with the accuracy of the on-board instruments;

1.c) We believe that comparing well identified structures in the observations and the reconstructions is the best way to estimate local (in a Lagrangian sense) turbulent diffusion. This approach is extended that of previous studies by Waugh et al. (1997)

and Haynes and Balluch (1997)

2.a-b) Dr Sparling correctly notices that diffusion dominates dispersion only over the first few days of the backward integartion and it does not make much difference to switch it off after, say, 5 days. This is, however, very different from launching a curtain of particles above and below the flight-track since during these 5 days the cloud elongates and deforms over typically 500 km under the action of strain and shear. It is only by chance that the vertical variance of the deterministic trajectory matches the width of the yellow band in Fig. 2.

2.c) The origin of the deterministic tracer variability that increases in time without limit is chaotic advection by both vertical and horizontal velocity. As established in many previous studies, isentropic motion alone is able to generate a large amount of small-scale structures (see Fig.1 in Legras et al., 2003, for a comparison between isentropic and 3D advection). The spurious vertical transport is acting on synoptic scales and hence does not average locally as a smoothing factor. It is only when averaged over large spatial and temporal extend that is can be seen as a diffusion. Furthermore, it is incorrect to assume that the smooth dependence on the tracer field at $t-\tau$ limits provides a smooth reconstruction, as shown below.

2.d) The non diffusive or inviscid limit for three-dimensional turbulent flows is indeed known as singular (in the sense that dissipation stays finite). We have added a panel with $D = 10^{-4}$to Fig.6.

3.a) It is correct that the Green function at time t is a smooth function of x for a given source in y when $t-s$ is large enough. This does not mean, however, that the reconstructed curve is smooth as it can be seen from the following example where we consider the advection-diffusion equation for a pure strain with $\alpha > 0$:

$$\partial_t \chi + \alpha x \partial_x \chi - \alpha y \partial_y \chi = D\Delta\chi$$

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The Green function is then

$$G(x,y,x_0,y_0,\tau) = \frac{1}{4\pi f g} \exp\left(-\frac{(x - x_0 e^{\alpha\tau})^2}{4f^2} - \frac{(y - y_0 e^{-\alpha\tau})^2}{4g^2}\right),$$

with $f^2 = \frac{D}{2\alpha}(e^{\alpha t} - 1)$ and $g^2 = \frac{D}{2\alpha}(1 - e^{-\alpha t})$, and one particular solution is

$$\chi(x,y,t) = A(t)\cos(ke^{-\alpha t}x)\cos(ke^{\alpha t}y)$$

with $A(t) = \exp(-\frac{D}{\alpha}k^2 \sinh 2\alpha t)$. It can be checked with some work that the above expressions for G and χ satisfy Eq.(3) in the manuscript. However, when t is large, $\chi(x,y,t)$ exhibits fast variations in y while the $\tau \rightarrow \infty$ limit of G is

$$G \approx \frac{\alpha}{2\pi D} e^{-\alpha t} \exp\left(-\frac{\alpha}{2D}x_0^2\right) \exp\left(-\frac{\alpha}{2D}y^2\right)$$

which is smooth for both arguments x_0 and y. Tracer gradient is here bounded by diffusion but can reach large value if $\frac{D}{\alpha}k^2$ is small enough. In this example, the maximum gradient is followed by a super-exponential decay while in our reconstructions, decay occurs on the time-scale of the Brewer-Dobson circulation over which a tracer get mixed in the absence of sources and sinks.

3.b) At first sight, it looks as if 1000 particles is not big enough but the temporal stability of the reconstruction in Fig. 3 demonstrate that there is no need to go much beyond.

3.c) The scatterplot has been added.

4) We do find that there is so much sensitivity to the shift, taking into account that it doubles from one case to the other. Wavelet analysis is, of course, another possibility to characterize roughness. Work is in progress in that direction. It is not a priori expected that the roughness curve of the reconstruction matches that of the observations. The fact that it does quite often is a sign that the scaling properties of the fluctuations also match.

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5) Inertial volume is defined from the inertia matrix. Details have been added in the text. In a pure linear strain, tracer concentration decays exponentially. Such effects are automatically taken into account in (4) and (5).

Reference:

Young, W.R., Rhines, P.B. and C. Garrett, Shear flow dispersion, internal waves and horizontal mixing in the ocean, J. Phys. Ocean, 12, 515–527, 1982.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 8285, 2004.

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