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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Lagrangian mixing in an axisymmetric hurricane model" *by* B. Rutherford et al.

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The author's would like to thank referee 2 for the detailed and helpful comments, and the literature review. We would like to first address each of the major comments, and then address the specific comments and technical comments.

1 General Comments

1. Literature Review. We will extend our literature review including the suggested references, specifically the references on hyperbolic trajectories, FSLEs, and open domains, along with the other suggested references provided in the specific comments.

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2. Methodology.

(a) The suggested plots will be added. The FMR and MMR are dependent on initial time, and the proper figures will be added.

(b) We will add the log-log plots, along with explanation of the methods.

(c) We will add the error estimates.

(d) The statistical significance of the correlations will be presented as highlighted points on the figures that will replace tables 7 and 8.

3. Bifurcations

The bifurcations that we had in mind are with respect to initial time. We will eliminate all language referring to bifurcations. The additional sources will also be added and the second paragraph of section 5 will be changed significantly.

4. Tables and figures

The tables and figures will be changed to make comparisons easier. The text will also be changed to match with the figures, specifically in the places referred to in the specific comments.

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(a) Colorbars will be added to figures 1 and 4-13.

(b) Figure 1 a and b will be switched.

5. Notation and definitions.

These will be addressed in the response to specific and technical comments.

2 Structure

Figures 4-7 and 11-13 along with Tables 3 and 4 will be removed or shortened. The organization of the tables will be altered to better relate the physical locations of the regions. Tables 1 and 2 will each be split into 2 new tables. The same change will be done to Tables 3 and 4. Tables 5 and 6 will be remade to show the dependence of mixing rates to time lags. Sections 5 and 6 will be shortened, while section 7 will be shortened due to the removal of Table 3. Figures 18 and 19 will be removed.

3 Specific Comments

p18548, l5: We will change the wording to indicate that the unbounded domain presents challenges in implementation, and the incompressibility is assumed in the derivation of the techniques.

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p18548, l11: The wording will be changed to indicate the Eulerian frame of reference, and coherence of structures will be emphasized.

p18548, l18: The wording will be changed to “local in the Lagrangian frame.”

p18548, l23: We will combine this sentence and the next to add clarity.

p18550, l15-17: We will add the references for finite-size Lyapunov exponents.

p18550, l15-17: We will add the references for distinguished hyperbolic trajectories.

p18550, l25-26: A proper reference will be added.

p18551, equation (1): We will adjust the formulation. Also, a comment will be added noting the use of the absolute value of (t-t0) for backward time integration.

p18552, l1-2: The degree of homogenization will be changed to A1/(A0+A1).

p18552, l7: We will remove the notion of orthogonal divergence.

p18553, equation (7): Epsilon should be defined as $||x0||$. We will correct the equation.

p18554, l1: P should also depend on t0, which will be added to the equation.

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p18554, l8-13: These lines were intended to motivate an optimal choice of integration time. The wording will be adjusted to make this more clear. The paragraph will be shortened considerably; in particular the sentences addressing "excessive filamentation" amd "dominant diffusion" will be omitted.

p18556, l6-7: The use of the L2-norm is only to aid in visual comparison, as normalization of a time-series does not affect correlation. The sentence will be omitted and the normalization will be introduced in Section 8 when referring to the figures.

p18556, l23: The velocity fields appear fairly similar at all times, aside from a secondary updraft that is sometimes noticable in the vertical velocity field. We will make this point and add the time for this snapshot.

p18557, l9: The wording "hyperbolic processes" will be changed to "tangle of hyperbolic manifolds".

p18557, l10-14: This paragraph will be moved to the results section.

p18557, l18: We will change “initial conditions” to “locations of seeded particles”.

p18558, l3-4: This was a mistake. The correct seeding is 64 times in the radial by 8 times in the vertical direction, giving 350 by 50 total trajectories in the box $0 \leq z \leq 2km$ and $0 \leq r \leq 20km$. The text and figures will be changed to make this consistent.

p18558, l18: “$\Sigma_\rho(t)$-A1” should have been used, and the wording will be changed. Note that we will change the notation and replace σ_C by Σ_ρ and C by ρ.

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p18559, l5-7: We agree, and will change the wording accordingly. We will only point out that there is a transition region.

p18559, l7-9: We agree, the wording of this sentence will be changed.

p18559, l14: The figures are correct. Figure 8 is a zoom of a particular ridge. We will add colorbars and scales to figure 8.

p18559, l14-15: The intention of these statements was to point out that for increasing integration time, the LCS's approximate invariant manifolds, but the strong time dependence causes the wrapping of the manifolds into a tangle, making identification of LCS's difficult. The wording will be changed to make this more clear.

p18560, l17-18: This sentence will be moved to the next paragraph, where the specific LCS considered is defined. In figure 9, the backward time integrations are initiated at 420 min and 460 min to show the structures associated with those times. Additional seeded trajectories were integrated from 400 min to show the behavior of trajectories in relation to this LCS over varying initial time, demonstrating persistence. We will adjust the caption and text to give a more clear description of this LCS.

p18561, l15: By separating from the sea-surface, we mean the point at which the LCS becomes vertically oriented, at about r=15 km. The LCS is never actually on the sea-surface. We will make this more clear. The section will be rephrased and reorganized.

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p18561, l17: This sentence was considered as motivation for the steady-state approximation. We agree that instantaneous stagnation points do not mark hyperbolic trajectories in strongly time-dependent flows and will change the wording to avoid this implication. In meteorological studies, a steady state velocity field is often used to infer properties of the time-dependent flow. We relate the Eulerian flow only to short-time effects, and will adjust the wording to make this more clear.

p18562, l14-17: We will add a comment referring to the LCS's in the FTLE fields of the composite velocity fields.

p18562, l22-23: We will change the wording to indicate that there is no real preference of the FMR to the MMR, but that they are within a factor of 2.

p18562, l8-11: We will move these sentences to become the first sentences in the last paragraph of Section 8.

p18563, l23-25: The "not" was missing and will be inserted.

p18564, l2-10: We have tried to compare the variation in the rates in our study with the study of Voth et al., who applied the rates of Antonsen Jr. et al. and noted a factor of 10 variation in the rates, but noted the difference in treatment of the boundary. We are simply noting the variation that we have seen in our study and that our boundary was open. We will add a remark pointing out the variation of a factor of 2 within the boxes (in contrast to the factor of 10 between different boxes), and hypothesize that the difference in the results seen by Voth et al. and us are likely due to the non-closedness of our domain, but restrain from discussing this point further.

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p18564, l11-22: A figure separating super- and sub- will not be included, however thresholds for sub- and super-diffusion will be given in the text, and mixing rates above and below the critical values will be shown in the tables and mentioned in the text.

p18565, l8-9: We will make this consistent with p18566, l13-15 by switching forward and backward at this point.

p18565, l20: Autocorrelations are computed on the time-dependent wind fields, over the quasi-steady state. We will add this information in the text.

p18565, l26-27: The time-series (red curve in Figure 19a) shows oscillations (times between consecutive maxima and minima) between 20 and 40 minutes. 40 minutes is above one oscillation and below two oscillations. We will describe this more accurately in the text.

p18566, l19-24, l26-29: We will adapt the conventions of lag and lead. The table will be replaced by figures, so we will plot the correlations against lag/lead.

p18566, l25: The correlations for the FRD will be added to the plots, which will replace the table.

p18568, l13-14: We will make the suggested change.

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4 Technical Comments

We agree with all of the technical comments and will make the necessary changes. In particular, the suggested format change in the tables will be adopted, and the lead/lag correlation table will be changed to graphs.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 18545, 2009.