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Interactive Comment

Interactive comment on "A Lagrangian analysis of a developing and non-developing disturbance observed during the PREDICT experiment" *by* B. Rutherford and M. T. Montgomery

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The authors would like to thank referee 4 for the helpful and constructive comments, which have helped to improve the quality of the resubmitted manuscript. In light of the reviewer's comments, we have made significant changes to Section 2 and have added also the suggested references. We will address each comment individually.

P33276, l16-22: The second sentence does not quite follow from the first: if the tendency is for the middle and upper troposphere to become progressively drier in the systems that do not develop, why does the most prominent difference between non-developing and developing system lie in the lower troposphere "between the surface and a height of 3 km"?

As discussed in the pouch model of tropical cyclogenesis, a finite-amplitude Easterly wave provides a recirculation region below approximately 4 km altitude (the lower troposphere). Without this wave-pouch region, which serves to protect the air mass from dry-air intrusions and contain moisture lofted by deep convection, storm development is highly unfavored. The vertical profile of moisture in the 3 – 5 km layer (low- to mid-troposphere) is very important for reasons discussed by Smith and Montgomery (2012, QJRMS). The amount of moisture in the upper troposphere (above 8 km) is considerably less than in the lower and middle troposphere and thus is not as important. We have revised our wording to clarify this point.

P33277, l20-22: There are two senses of "Lagrangian" in this sentence and on the whole, in the manuscript. The first "Lagrangian" refers to following the trajectory of a fluid element; the second "Lagrangian" refers to following the propagation of the Easterly wave. The two meanings must be clearly distinguished. In fact, it is recommended that the latter use of "Lagrangian" should be dropped throughout the manuscript since it is not truly "Lagrangian" as is usually understood in both dynamical systems and meteorological communities. "Wave-relative" might be a better word for the second sense, with an initial definition of this term as referring to the frame following the propagation of the Easterly wave.

We have changed this paragraph significantly to carefully distinguish between the two uses of 'Lagrangian', and we now use the terminology 'co-moving frame' for the frame of reference that moves with the parent easterly wave.

P33279, l3-4: Wrong concept of "Galilean invariant" here. A Galilean transformation only involves two frames moving at constant velocity with respect to each other. Thus, rotations and general time dependent frame transformations are not Galilean and invariance to such transformations is not Galilean invariance.

We have corrected the use of Galilean invariance.

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P33279, l25-27: Two objections: (1) any method that identifies Lagrangian structures in a flow must be sensitive to the time-dependence of the flow by definition; if a time-dependent and a constant flow field yields the same Lagrangian structure, something must be wrong with the algorithm. (2) Besides the algorithms of Duan and Wiggins (1996) and Ide et al. (2002) mentioned, other algorithms exist and they are not *sensitive* to the persistence of stagnation points, e.g. Koh and Plumb (2000) and Joseph and Legras (2002).

The Lagrangian frame and streamlines of the steady flow yield similar but not exactly the same structures. This is now clarified. Regarding the computatiuon of a DHT, we have included references for the algorithms of Koh and Plumb (2000) and Joseph and Legras (2002

p33281, l17: Did the present authors not published a paper on finite-time Lagrangian diagnostics on a model hurricane development? So "not yet appeared in the tropical meteorology literature" is carrying the claim of novelty a little too far.

Much of the Introduction and Section 2 have been rewritten to avoid giving the impression that the methods used herein are new.

P33281, l24: Hyperbolicity is strictly not just a property of the linearized velocity field. In mathematics, a nonlinear flow field can be classified as hyperbolic, elliptic or parabolic as well. Linear analysis in a steady flow field is convenient and helpful but is not necessary in the definition of the concept.

We have removed the suggestion that hyperbolicity is only related to a linearized flow approximation.

P33282, l17: The notion of convergence is not well-defined, or strictly speaking, does not exist in finite time. The verb "approach" would be more suitable than "converge"

We have changed the wording from 'converge' to 'approach.'

* p33282, l18-21: Any set of trajectories forming a 2D surface in a 3D flow (or a 1D

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surface in a 2D flow) is not crossed by trajectories. There is nothing unique or distinguished about this feature. Anysuch set can form a flow boundary in time-dependent flow. The only catch is whether such a set provides a conceptually and/or practically useful boundary

We agree and have removed the word 'distinguished.'

P33282, l24: Delete this sentence since complex geometry of stable and unstable manifolds, in particular the formation of lobes, occurs even in time-independent flows

We have changed this sentence so that the requirement of time-dependence is not required for the formation of lobes.

* p33283, l8-9: The intersection of stable and unstable manifolds do not identify DHT uniquely because as stated clearly on p33282, l25, they also intersect at points other than DHT. So, how is DHT uniquely identified beyond merely labelling the intersections of stable and unstable manifolds? Likewise, p33282, l12-13 should be re-written

The uniqueness of the DHT is that the intersections of the manifolds of the DHT occur near a stagnation point of the co-moving frame, whereas the secondary intersections occur in regions where velocities are not nearly zero. Lines 12-13 will also be rewritten to reflect this idea.

P33284, l8: "larger" or "largest"? Is the flow field considered 2D or 3D in this section? The context suggests 2D and so it must be said explicitly and the extension of the ideas to 3D flow must be discussed if relevant to subsequent diagnostics, e.g. the complication of compressibility in the 2D section of a 3D flow (even if incompressible) must be addressed.

The flow here is layerwise 2D and we have changed the wording to 'larger'. The implications of incompressible and 3D flow are also now discussed.

P33285, l5: The authors should elaborate what is meant by "parameter dependent". Are FTLEs also "parameter dependent" or are they not

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We have discussed the parameter dependence of both FSLEs and FTLEs.

* P33285, l5: The authors should elaborate what is meant by “purely a diagnostic”. Are FTLEs also “purely diagnostic” or are they not? This reviewer has not seen any rigorous proof that shows the ridges of FTLEs or FSLEs in forward and backward time as respectively mathematically equivalent to the stable and unstable manifolds (which are rigorously defined with respect to the mathematically well-defined DHTs). Such rigorous proof would be unavoidable to be convincing that FTLEs or FSLEs are not diagnostic

We have discussed the diagnostic nature of the FTLE and FSLE fields. We have also removed any suggestion that in a general setting, the ridges of FTLEs are equivalent to the stable and unstable manifolds of the flow.

* P33286, l9-10: High auto-correlation does not indicated *conservation* of a quantity; high autocorrelation values *for a long time tau* indicates persistence in the sign of a perturbation in that quantity and by implication, a slow decay of the anomalies in that quantity

We have removed autocorrelation values for OW and RH. We now use autocorrelation times only for velocities as a simple way of quantifying the time-dependence of the flow.

p33291, l21 : see the earlier comment on the use of the word “Lagrangian”

The use of ‘Lagrangian’ has been clarified here and elsewhere in the manuscript.

P33293, l2: Streamlines are well-defined at every time-slice of a time-dependent flow and can be computed by keeping the flow from that time-slice fixed. The problem is not that they cannot be computed, but whether it is worthwhile computing them

We have changed the wording in this sentence to eliminate any implication that streamlines cannot be computed at fixed times.

P33296–p33302: This comment pertains the underlying philosophical interpretation of

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the results: do the existence of LCSs really explain the transport pattern; or does the transport pattern itself reveal the existence of LCS? (See p33277, l8-10.) To constitute an explanation for the transport pattern, it seems that the existence of LCSs must be related to the meteorology and not simply be "diagnosed" from the kinematic flow pattern. Think about an analogous example: the diagnosis of a hyperbolic stagnation point in a steady flow field does not *explain* the hyperbolicity of the flow and the consequent transport pathways; it is rather more like a succinct and insightful *description* of the flow field. Having said this, LCSs not being an explanation for the flow pattern does not detract from the usefulness of LCSs in understanding the conceptual organization of the flow pattern in an Easterly wave. The results here can be important for the direction of further work on how hurricane development or non-development depends on Lagrangian transport of moist or dry air. Some discussion of this aspect at the end of Section 5 seems pertinent if continued use of Lagrangian kinematic methods is to be encouraged

We agree with this comment and have carefully reworded the manuscript to reflect that LCSs are a useful marker of the flow field, but do not cause mixing or transport. We have added a further discussion of the use of 'Lagrangian methods' in further studies as suggested.

p33302, l23: see the earlier comment on the claim on the novelty of this piece of work

As noted above, we have changed the text to avoid giving the impression that the methods used here are new.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 33273, 2011.

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