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Interactive comment on "Intensification of tropical cyclones in the GFS model" *by* J. C. Marín et al.

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This study uses vorticity (circulation) and entropy diagnostics to assess tropical cyclone intensification in the GFS numerical weather prediction model. Changes in the circulation strength are marked by a predominate imbalance between vorticity convergence and frictional damping. From a thermodynamic point of view, changes in intensity are related to surface fluxes, the gross moist stability, and environmental ventilation.

Vorticity Diagnostics

The authors state that "it is valuable to determine the factors which control genesis and intensity in the GFS model." The first part of the paper examines this statement from a vorticity budget standpoint. Intensifying storms in the model are characterized by a net flux of vorticity in to a control volume encompassing the tropical cyclone, most of which occurs in the lowest 2km (figure 7a). However, it is important to note that this

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convergence is not the driving force that is behind the strengthening of the storms, but rather the increased feedback between the surface fluxes and the wind as shown by the second half of the paper. The vorticity budget only serves as a diagnostic between the increased circulation or vorticity of the storm and the convergence of vorticity slightly outpacing frictional effects. It would be misleading to say that convergence of vorticity "controls" the intensity without citing the role of surface fluxes.

The magnitude of the residual circulation tendency is also somewhat alarming as it indicates the signal is as large as the error despite the results agreeing with qualitative expectations. The authors attribute this to uncertainties in the Reynolds stress divergence, but the residual could also be due to using a relatively coarse dataset over a small region.

Genesis

Vorticity budget calculations may be more valuable to study genesis when there is not yet a strong wind-evaporation feedback. The authors' case studies only involve storms which have reached tropical depression classification and are therefore successful cases of genesis. It is also important to also look at failed genesis cases.

Though numerical weather prediction models, including the GFS, have begun to show some skill in tropical cyclogenesis, it is unclear why this is so and whether the route to genesis is correctly represented in the global models. There are two often cited routes to genesis: a bottom-up theory involving concentration of vorticity by intense vortical hot towers (e.g. Montgomery et al. 2006) and a top-down theory where a stratiform induced mid-level vortex penetrates down to the surface (e.g. Ritchie and Holland, 1997).

In examining cases of genesis in the GFS, are the relevant process(es) represented? From the point of view of the bottom-up theory, one would not expect the GFS to represent the scale or strength of vortical hot towers or the complex interaction of vorticity at the surface in the incipient stages of genesis. Even at the mesoscale, a mid-

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level mesoscale convective vortex will likely not be accurately represented in the GFS analyses. Why should models have any skill then in forecasting tropical cyclogenesis? This strongly suggests that resolve scales have a role in priming an area for genesis, and hence, the vorticity diagnostics would be useful in assessing the degree of priming. There will again likely be large cancellation of the individual terms in the circulation tendency equation for the volume budget, but vertical profiles of the individual terms as shown in figure 7 and 9 may be insightful. For instance, if a mid-level vortex is being maintained by stratiform processes, there should be a broad mid-level region in which there is convergence of absolute vorticity. There is some evidence of this in figure 9a in the tropical depression stage, but ideally, one needs to see more cases.

Ventilation

The authors show that ventilation represents an important sink in the entropy budget. However, it is unclear whether the radial flow of the environment is in fact the mechanism which drives in low entropy air or asymmetries, such as vortex Rossby waves, that are responsible for the ventilation. If the latter is indeed important, the GFS is obviously incapable of resolving the small scale eddies and the value of the model calculated budget is questionable.

In other words, there could be a net flux of low entropy air in to the vicinity of the tropical cyclone, but this potential source of low entropy air may in fact run in to a stagnation radius whereby it becomes impossible for it to be carried further in by the mean environmental flow, particularly for strong circulations. This air may slowly be moistened by shallow convection or detrainment from outer rainbands and exit the control volume with a higher value of entropy making it appear as if there is an entropy sink acting on the tropical cyclone's entropy budget. In reality, there is no realizable effect on the entropy budget if one takes the control volume to be inside the stagnation radius.

One cannot expect the GFS to capture subgrid scale eddies or mixing events. There

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are times when the ventilation appears appreciable, yet the tropical cyclone strengthens, as it does in the case of Emily (figure 15). It is plausible that the tropical cyclone is strong enough to buffer itself from any palpable ventilation by the environmental relative flow. Despite the data resolution, it would be nice to repeat the calculation for different control volumes to investigate if the ventilation term is sensitive to the size of the control volume. Likewise, vertical profiles of the ventilation term would be quite helpful in seeing where the ventilation is actually occurring. One expects that the greatest effect would be at low to mid-levels where the climatological entropy minimum lies.

Nevertheless, it is important that budgets like the one undertaken by the authors be calculated despite their uncertainties as it will yield insights as to the environmental control of intensity and be a potential useful operational tool. Recent field experiment data collected from the West Pacific may prove very useful in estimating a more detailed budget of entropy from a variety of (non)-developing and developed tropical cyclones.

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