Comments on: "Marathon versus sprint: Two modes of tropical cyclone rapid intensification in a global convection-permitting simulation" by F. Judt and coauthors

MICHAEL T. MONTGOMERY,

Department of Meteorology, Naval Postgraduate School, Monterey, CA USA

AND ROGER K. SMITH

* *Meteorological Institute, Ludwig-Maximilians University of Munich, Munich, Germany*

* *Corresponding author address:* Prof. Michael T. Montgomery, Department of Meteorology, Naval Postgraduate School, Monterey, CA, USA

E-mail: mtmontgo@nps.edu

In their thought-provoking paper, Judt et al. (2023) used a 40-day-long global convection-permitting simulation to explore the rapid intensification (RI) of tropical cyclones and found that out of the 23 tropical cyclones produced by the simulation, seven experienced RI. In their analysis of the RI cases, they identified what they believed to be two distinct modes of intensification, which they called the marathon RI mode and the sprint RI mode. The marathon mode was characterized by a gradual and sustained intensification period in which deep convection was approximately axisymmetric, while the sprint mode exhibited sudden and short-lived bursts of intensification associated with isolated deep-convective features away from the centre of the broadscale circulation.

In their Introduction, Judt et al. make a few statements which invite comment. The fact that "RI is notoriously difficult to predict" is likely to be a lack of predictability of deep convection, itself, than from "a lack of scientific understanding". While there may be "no consensus on what processes cause RI", we are unaware of evidence that the dynamics of RI are any different from those of "I"! At a very basic level, *there is no lack of scientific understanding on how intensification works*. The primary[1] way a tropical cyclone intensifies is by deep convection inducing an overturning circulation with convergence in the lower troposphere above the surface friction layer, usually in a region of enhanced vertical rotation. By Stokes' theorem, the accompanying convectively-induced convergence of absolute vorticity leads to an amplification of the circulation in the lower troposphere. The ensuing intensification rate depends in detail on the structure of convective elements within the circulation, which has a significant stochastic element. The central issue is how the convection becomes organised and how it is maintained by enhanced surface enthalpy fluxes in the presence of processes that act against such organization and maintenence. Whether or not RI occurs must depend to a large extent on these details, which, as noted above, have some lack of

[1] In general, the change of horizontal circulation occurs via a line integral of a horizontal vorticity flux vector. The flux vector is the sum of an advective and non-advective component (see e.g., Sections 2.15 and 11.1 of our book Smith and Montgomery 2023).

predictability. At this level, the individual processes are arguably *quite well understood*.

The issues concerning the precise rate of intensification may be likened to those determining the speed of a motor car: if the car is moving in rush hour traffic, its speed will be limited, but if it is travelling on the autobahn, its speed may be considerable. Nevertheless, in either case, the car engine is working just the same to propel the car forwards. To determine "what conditions must be met for RI to happen" is likely to have at least some stochastic component on account of the limited predictability of deep convective systems that develop within the incipient "pouch" circulation. On the road, the car speed will be limited at any time by the density of traffic.

In summary, we would argue that the dynamics of RI is no different to that of "I" and it is unlikely to be fruitful to hunt for special mechanisms as, for example, in a recent ONR[2] program! After all, the definition of RI by forecasters is quite arbitrary from a dynamical perspective, even though it may be useful in communicating forecasts.

Judt et al. write: "Scholars that study RI usually examine canonical RI events, that is, events where a weak, incipient TC enters a sustained period of RI and strengthens into a major hurricane (a "marathon" in the parlance of this paper). The present study documents that RI can also take on a "sprint" mode. We show that marathon and sprint modes *have distinct underlying mechanisms* (our highlighting), and we argue that the existence of multiple RI modes should be acknowledged for better understanding and predicting RI." Based on the foreging remarks, we would argue that the marathon and sprint modes *do not have distinct underlying mechanisms*: both involve the amplification of a vortex by deep convection as described above. The only difference is the way in which the convective organization proceeds and in the structure and timing of the convective systems that develop.

In calculations for the prototype problem for tropical cyclone formation and intensification that we have studied (e.g., Montgomery et al. 2006; Kilroy et al. 2017, 2018; Smith et al. 2021) as well as in the study by Nolan (2007), RI always takes the form of the "sprint

[2]US Office of Naval Research.

mode" and happens after one or more days of gestation in which deep convection becomes progressively organized. Eventually, a deep vortical convective system forms near the centre of the initially-weak, broadscale circulation and this convective system becomes the ultimate focus for rapid vortex growth. At first, the vortex is small in radial scale (on the order of 10 km), but grows in radial scale as absolute vorticity is progressively drawn inwards above the surface friction layer. This whole process is intrinsically three-dimensional on account of the localized nature of convective updraughts and it is not until RI is nearing its end that the inner-core of the vortex has undergone an appreciable degree of axisymmetrization.

This is not to say that the so-called "marathon mode" could not be interpreted in the same framework described above[3]. It is entirely plausible that in circumstances different from those in the prototype problem, the organization of deep convection might acquire an appreciable degree of axisymmetry first as the vortex intensifies more slowly than the RI threshold (recall that RI is an arbitrary threshold). We do know that deep convection organized in rings is geometrically more effective in producing a coherent overturning circulation (Persing et al. 2013) so there is nothing mysterious to us about the marathon mode, and nothing really different dynamically within the broad picture.

Judt et al. liken the marathon mode to the "classic spin up of a weak vortex", citing the paper by Miyamoto and Takemi (2013) as an example, but these latter authors invoke the enignmatic[4] WISHE-mechanism to explain vortex intensification in their model. It is a pity that Judt et al. did not describe the lead up to this near axisymmetric state, which they would have likely found to be interpretable in the broad picture described above also, but without the development of the strong mesoscale convective system found in the sprint mode.

In their Conclusions, Judt et al. write: "Examining the vortex structure of the marathon

[3] We have expounded this framework in more detail in Chapter 11 of our book (Smith and Montgomery 2023) where we refer to it as *the rotating-convection paradigm*.

[4] See e.g., Chapter 12 and Section 16.1 of our book (Smith and Montgomery 2023) as well as Smith et al. (2024).

and sprint RI cases in the simulation, we observed clear differences. The marathon mode cases displayed well-defined and symmetric vortices at the onset of RI, whereas the sprint mode cases exhibited asymmetric vortices with poorly defined centers. These structural variations underscored the distinct nature of the two RI modes. By comparing the archetypes of each mode, *we identified unique intensification mechanisms* (our highlighting). The marathon archetype involved a symmetric, continuous amplification of the primary vortex, similar to *the classic spinup process observed in idealized TCs* (our highlighting). On the other hand, the sprint archetype featured an asymmetric intensification process characterized by a chain of discrete events. This chain started with a convective burst that formed in the downshear-left quadrant of a weak and poorly defined parent circulation. The burst spawned a mesovortex, which grew in scale and strengthened while absorbing the parent circulation." We would argue that it is misleading to refer to the identification of "unique intensification mechanisms" when describing the marathon and sprint RI cases: the mechanisms are exactly the same within the broad picture of how intensification works. Simply, the details of deep convective organization are different in the two cases and presumably in all the cases that undergo RI.

In closing, we look forward to learning more about the early evolution of the "marathon" cases and further diagnostic studies examining whether these events can be interpreted in the genesis and intensification framework that we describe.

Acknowledgments.

MTM acknowledges the support of the National Science Foundation, the Office of Naval Research and the U.S. Naval Postgraduate School.

REFERENCES

Judt, F., R. Rios-Berrios, and G. H. Bryan, 2023: Marathon versus sprint: Two modes of tropical cyclone rapid intensification in a global convection-permitting simulation. *Mon. Wea. Rev.*, **151**, 2683–2699.

Kilroy, G., R. K. Smith, and M. T. Montgomery, 2017: A unified view of tropical cyclogenesis and intensification. *Quart. Journ. Roy. Meteor. Soc.*, **143**, 450–462.

— 2018: The role of heating and cooling associated with ice processes on tropical cyclogenesis and intensification. *Quart. Journ. Roy. Meteor. Soc.*, **144**, 99–114.

Miyamoto, Y. and T. Takemi, 2013: A transition mechanism for the spontaneous axisymmetric intensification of tropical cyclones. *J. Atmos. Sci.*, **70**, 112–129.

Montgomery, M. T., M. E. Nichols, T. A. Cram, and A. B. Saunders, 2006: A vortical hot tower route to tropical cyclogenesis. *J. Atmos. Sci.*, **63**, 355–386.

Nolan, D. S., 2007: What is the trigger for tropical cyclogenesis? *Aust. Meteorol. Mag.*, **56**, 241–266.

Persing, J., M. T. Montgomery, J. McWilliams, and R. K. Smith, 2013: Asymmetric and axisymmetric dynamics of tropical cyclones. *Atmos. Chem. Phys.*, **13**, 12299–12341.

Smith, R. K., G. Kilroy, and M. T. Montgomery, 2021: Tropical cyclone life cycle in a three-dimensional numerical simulation. *Quart. Journ. Roy. Meteor. Soc.*, **147**, 3373–3393.

Smith, R. K. and M. T. Montgomery, 2023: *Tropical cyclones: Observations and basic processes*. Elsevier, London, 411pp.

Smith, R. K., M. T. Montgomery, and S. Wang, 2024: Can one reconcile the classical theories and the WISHE-theories of tropical cyclone intensification? *Quart. Journ. Roy. Meteor. Soc.*, **150**, 1–12.