Final author comments: responses to Reviewers

Title: Meteorological Landscape of Tropical Cyclone
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MS No.: egusphere-2025-1458
MS type: Methods for assessment of models

We thank both reviewers for their careful and constructive assessments. We agree that the original manuscript did not yet establish (i) how MeteoScape relates to the established physics of TC motion, particularly steering-flow control, (ii) what additional value it provides relative to existing clustering and EOF/sensitivity-based diagnostics, and (iii) how the method should be interpreted by the TC community. In the revised manuscript, we will therefore narrow the scope of our claims, add direct methodological comparisons, strengthen the physics-oriented discussion, and move part of the mathematical development to the Supplement.

Responses to RC1

> In the abstract, the authors make the case that advancing knowledge on a topic like TCs would benefit from knowledge from other areas. I fully agree with this statement and as an atmospheric scientist who has worked on TC predictability for years, I welcome input and techniques from other disciplines on this topic.

We appreciate this positive perspective. At the same time, we agree that interdisciplinary novelty alone is not sufficient to justify the method in a TC context. In the revised manuscript, we will clarify much earlier what specific TC-related question MeteoScape addresses and how it complements, rather than replaces, established TC-track analysis methods.

> With that being said, I have difficulty identifying how these concepts would advance knowledge on TCs, especially since TC motion is not something like a cell division with lots of degrees of motion and a random-appearing evolution. Instead, TC motion is primarily driven by the concept of steering flow, which evolves based on the dynamics of large-scale atmospheric features. I would encourage the authors to review the current state of the science on this, particularly for irregular tracks (see: Magnusson et al. 2019).

Thank you for this important comment. We agree that the original manuscript did not sufficiently position our framework within the existing tropical-cyclone literature, especially studies that interpret track uncertainty through the steering environment and large-scale

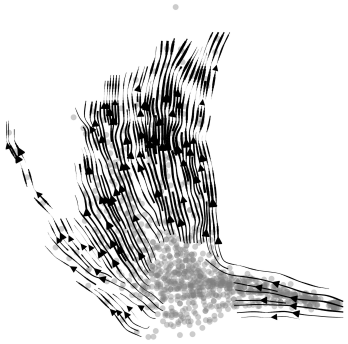
flow features. In the revised manuscript, we will revise the Abstract and Introduction to make the scope of the study more precise: our goal is not to replace physically based analyses of TC motion, but to provide a data-driven geometric diagnostic of branching structures in ensemble forecast tracks.

We will also add a dedicated paragraph in the Introduction reviewing existing approaches for irregular-track analysis and predictability, including sensitivity-analysis and steering-flow-based interpretations, and we will explicitly discuss how MeteoScape should be interpreted relative to those approaches. In addition, the Discussion will be expanded to clarify that the potential/rotational decomposition in MeteoScape is a decomposition of forecast displacement fields and should not be interpreted as a direct reconstruction of the atmospheric steering flow itself. This revision will help us avoid overstating the physical interpretation of the method while better connecting it to the meteorological context.

> Track bifurcation is an important problem, but the atmospheric science community has developed methods for addressing this using methods that are much less complex, yet give similar information, such as clustering (e.g., Kowaleski and Evans, 2020), empirical orthogonal function decomposition (e.g., Torn et al. 2025) among others. The paper would be far more compelling if the authors demonstrated how these compare to what is already present in the atmospheric science literature, along with what new information could be gained from adopting these approaches. I don't see a compelling case for these methods when I can get similar information from simpler techniques.

We agree that, in its current form, the manuscript does not yet make a compelling case for the TC community, particularly because we did not directly compare MeteoScape with simpler existing approaches. In the revised manuscript, we will add direct comparisons with objective track clustering and EOF/sensitivity-based summaries, and we will explicitly discuss what additional information MeteoScape provides, for example the rotational component or the landscape-based view, and where it remains only complementary. We will also moderate our claims throughout the manuscript so that the work is presented as a complementary diagnostic framework for ensemble-track geometry rather than as a demonstrated advance in TC predictability.

We have applied MeteoScape to the TC "Dorian" case using the same ECMWF-Ens. data from TIGGE, with forecasts up to +120-h.

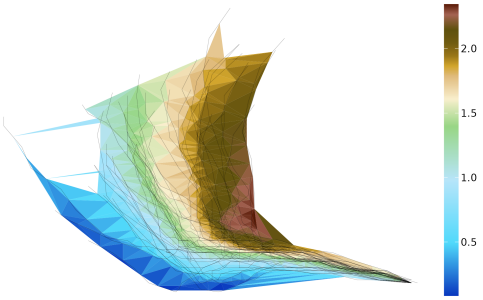


Point velocities

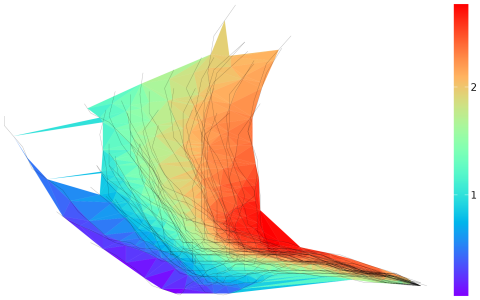
Potential flow

Rotational flow

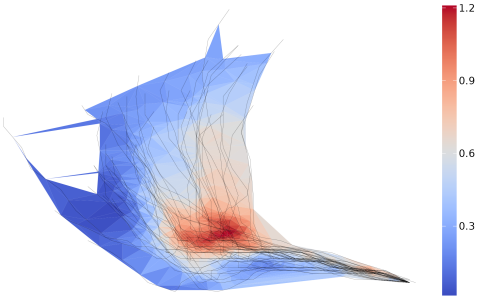
Because the different positions of the TC are dictated by the steering environment of each ensemble member, we will investigate how these flows relate to the steering flows and see if they can act as a simplified representation of the local steering flows, in the case of a single initialization time, or mean regional steering flows when several, successive, initialization times are considered at once.



Velocity orbit and TC "Dorian" tracks



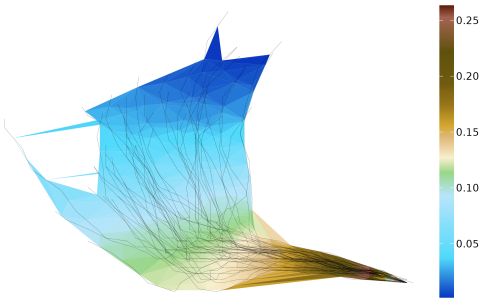
Development orbit and TC "Dorian" tracks



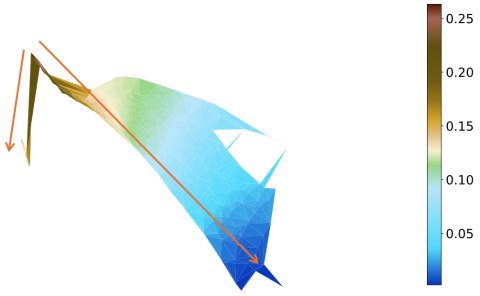
Periodic orbit and TC "Dorian" tracks

According to MeteoScape, the contribution ratio is 54.65% for the potential and 45.35% for the rotation. We clearly see the tracks following the velocity and development orbit isolines, with higher values where the curvature of the tracks is the most pronounced. There is also this patch of high periodic orbit values where the tracks both curve and diverge. Torn et al. (2025) notice that tracks start to diverge after 48 hrs, and with the clear separation between

72- and 96-hr. This corresponds to the highest values of the periodic orbit (> 1), showing the temporal curving of the TC tracks.



Potential and TC "Dorian" tracks



Landscape (red arrows indicate slope direction)

There is a clear descending slope going from earlier forecasts to latest forecasts. But there is also a noticeable artifact at the beginning, with the ascending slope between the analysis time and the subsequent forecasts, which is not desirable, because of opposite velocity directions at the beginning of the forecast.

> Finally, I assume the audience for this paper is atmospheric sciences working on TCs. If so, I think this paper is going to be very dense and difficult to follow for them because it provides an extensive description of the mathematics behind the method and relatively little about how this method could be useful. Most of the analysis is superficial and does not make a compelling case for adopting or trying out this method.

We agree that the manuscript in its original form was too mathematically dense for the intended atmospheric-science audience. In the revised version, we will shorten the mathematical development in the main text, move the detailed derivations to the Supplement, and expand the physical interpretation and practical use of each diagnostic quantity in the Results and Discussion sections. We appreciate this comment and agree that the balance between mathematical description and meteorological interpretation was not appropriate for the intended readership. In the revision, we will streamline the main text so that the conceptual workflow and meteorological interpretation are presented first, while technical derivations and implementation details will be moved to the Supplementary Material as much as possible.

> I would encourage the authors to work with TC expertise to help with these concerns.

Thank you for this suggestion. We agree that the atmospheric-science framing needs to be strengthened. In the revised manuscript, we will incorporate a more explicit meteorological

interpretation of the case studies and revise the discussion so that the proposed framework is presented in a way that is more consistent with the concerns and terminology of the TC community.

> With these concerns, I cannot recommend publication of this journal at this time. Addressing the concerns I have listed above will take time and allow the authors to craft a potentially more impactful paper for the TC community.

We appreciate the candid assessment. In response, we will substantially revise the manuscript by narrowing the claims, adding comparisons with established TC methods, strengthening the physical interpretation, and restructuring the presentation for an atmospheric-science audience.