Response to Reviewer #1

We would like to express our gratitude to the reviewer for their insightful and constructive feedback. In response to the observations of the reviewer, we have initiated simulations for two other Ionian cyclones, Zorbas and Daniel, using the same methodological framework as employed in the current study. Because the identification of moisture sources relies on backward-time Lagrangian analysis, these new simulations cover extended periods, resulting in significantly increased computational demands. Furthermore, we are conducting a sensitivity test using higher temporal resolution, which we believe could offer added value to the analysis, should the reviewer deem it relevant to the scope of the present manuscript. We respectfully request that the editor consider allowing time for the completion of these additional simulations and the incorporation of their results.

We have made every effort to address the reviewer's comments thoroughly. Reviewer comments are presented in bold, followed by our responses.

MAJOR POINTS:

1. **...The moisture uptake was discussed for medicane Qendresa in a previous paper by some of the authors (Coll-Hidalgo et al., 2023), sharing some points with the present paper; also, the paper has some analogies with the work done in Scherrman et al. (2023) and Miglietta et al. (2021), although they consider a different perspective for a similar purpose. A comparison with these works would probably highlight some peculiarities of this case and some analogies with the results in these studies.**

   We agree that a more explicit comparison with the studies by Coll-Hidalgo et al. (2023), Scherrman et al. (2023), and Miglietta et al. (2021) would enrich the discussion and better highlight both the peculiarities and the analogies of the present case study. In the revised manuscript, we will incorporate a more detailed comparative discussion with these studies.

2. **...Ianos has already been extensively studied in the scientific literature... I think some generalizations of your results to other cyclones is required, for example applying the same methodology (shortly) to other Ionian cyclones (e.g., Zorbas or Daniel) and drawing some general conclusions.**

   We agree that the case of Ianos has received considerable attention in the literature. Our objective, however, was to offer a novel Lagrangian-based quantification of moisture sources and uptake timing, employing high-resolution WRF simulations coupled with FLEXPART, which allow us to resolve near-core moisture uptake processes during the final intensification phase of Ianos.

   We fully acknowledge the reviewer's suggestion to strengthen the study by comparing Ianos with other similar medicanes. Following this recommendation, we have initiated the simulation and analysis process for two additional Ionian medicanes: Zorbas (2018) and Daniel (2023), which share geographical and seasonal similarities but exhibit different structural and dynamical evolutions.

   As of the date of this response, the simulations and Lagrangian tracking for these cases are in progress, but not yet complete. With the reviewer's agreement and the editor's approval for additional time, we will finalize this comparative component and integrate it into the revised manuscript.

3. **Are 6 hours enough to represent correctly the moisture uptake? A comparison with the results obtained using a finer temporal resolution (1 h?), at least for part of the trajectory, would convince me that the procedure is appropriate.**

   We agree that temporal resolution can influence the identification of moisture source regions and uptake timing, particularly in fast-evolving systems such as medicanes. At present, our priority is to complete the simulations for the additional cases of Zorbas (2018) and Daniel (2023), which form part of the expanded comparative analysis. However, contingent on the editor's approval of an extension to the revision timeline, we plan to conduct a dedicated sensitivity experiment using 1-hour output to directly assess the robustness of our results against the current 6-hour baseline.

   We would like to emphasize that our use of a 6-hour time step is informed by established precedent in the literature. Previous studies employing similar Lagrangian diagnostic methods (e.g., Läderach & Sodemann, 2016; Fremme & Sodemann, 2019) have shown that a 6-hour resolution provides a reasonable compromise: it captures the main physical processes while avoiding excessive numerical noise that may arise with shorter intervals. As discussed in Appendix B of Fremme & Sodemann (2023), reducing the time step can lead to more precise source attribution but may also amplify the impact of interpolation errors, particularly when the specific humidity threshold used to distinguish between evaporation and precipitation events approaches the magnitude of numerical fluctuations. Conversely, time steps longer than 6 hours tend to degrade trajectory fidelity and may obscure diurnal variability, ultimately reducing the diagnostic accuracy of source attribution. The estimated uncertainty in moisture source distance associated with time-step selection is on the order of 10–20%, or several hundred kilometers.

   Nevertheless, we fully acknowledge the importance of verifying the sensitivity of our results to this choice. We intend to include the outcome of the planned 1-hour resolution test in the revised manuscript.

   Fremme, A. and Sodemann, H.: The role of land and ocean evaporation on the variability of precipitation in the Yangtze River valley, Hydrol. Earth Syst. Sci., pp. 2525–2540, https://doi.org/10.5194/hess-23-2525-2019, 2019.

   Fremme, A., Hezel, P. J., Seland, Ø., and Sodemann, H.: Model-simulated hydroclimate in the East Asian summer monsoon region during past and future climate: a pilot study with a moisture source perspective, Weather and Climate Dynamics, 4, 449–470, https://doi.org/10.5194/wcd-4-449-2023, 2023.

   Laederach, A. and Sodemann, H.: A revised picture of the atmospheric residence time of water vapour, Geophys. Res. Letters, 43, 924–933, https://doi.org/10.1002/2015GL067449, 2016.

4. **Please clarify the need of the additional parameterizations in FLEXPART: is not the vertical wind field already contained in the WRF model outputs? what is the need of activating the convection and turbulence schemes?**

We appreciate the reviewer's insightful question regarding the need for additional parameterizations in FLEXPART-WRF. While the vertical wind component and the full three-dimensional wind field are indeed provided by the WRF outputs and used by FLEXPART for advective transport, the inclusion of turbulence and convection schemes in FLEXPART serves a critical complementary role.

Following recommendations from the FLEXPART-WRF framework (Brioude et al., 2013), without turbulence parameterization, FLEXPART operates as a non-dispersive Lagrangian trajectory model. Using the Hanna turbulence scheme (Hanna, 1982), FLEXPART internally computes planetary boundary layer (PBL) turbulent mixing based on WRF-derived parameters such as PBL height, Monin–Obukhov length, convective velocity scale, roughness length, and friction velocity.

Regarding convection, the choice to activate convective parameterizations depends primarily on the WRF model's horizontal grid spacing. Convective schemes are generally recommended for grid spacings larger than ~30 km, where convection is unresolved, while grid spacings finer than ~10 km typically allow convection to be resolved explicitly, especially below ~2 km. For intermediate resolutions, such as our ~6 km domain, no strict consensus exists; however, we adopted the Kain-Fritsch scheme in agreement with established literature (e.g., Miglietta et al., 2015; Fita and Flaounas, 2018; Miglietta et al., 2021). Consequently, consistent with Brioude et al. (2013), when a convective scheme is employed in WRF, the corresponding convective parameterization should also be activated in FLEXPART, to parameterize subscale convection.

Brioude, J., Arnold, D., Stohl, A., Cassiani, M., Morton, D., Seibert, P., Angevine, W., Evan, S., Dingwell, A., Fast, J. D., Easter, R. C., Pisso, I., Burkhart, J., and Wotawa, G.: The Lagrangian particle dispersion model FLEXPART-WRF version 3.1, Geosci. Model Dev., 6, 1889–1904, https://doi.org/10.5194/gmd-6-1889-2013, 2013.

Fita L, Flaounas E. Medicanes as subtropical cyclones: the December 2005 case from the perspective of surface pressure tendency diagnostics and atmospheric water budget. Q J R Meteorol Soc. 2018;144:1028–1044. https://doi.org/10.1002/qj.3273

Miglietta, M.M., Mastrangelo, D. and Conte, D. (2015) Influence of physics parameterization schemes on the simulation of a tropical-like cyclone in the Mediterranean sea. Atmospheric Research, 153, 360–375.

Miglietta MM, Carnevale D, Levizzani V, Rotunno R. Role of moist and dry air advection in the development of Mediterranean tropical-like cyclones (medicanes). Q J R Meteorol Soc. 2021; 147: 876–899. https://doi.org/10.1002/qj.3951

MINOR POINTS

1. **L47-48: Consider that the results in Zhang et al. (2020) are based on the relatively coarse ERA5 reanalysis, while the structure may change significantly for high-resolution runs. L48-50: Note that convection mainly occurs in the extra-tropical phase.**

   The paragraph has been updated, also incorporating suggestions from Reviewer #2:

"While a medicane may follow an offshore trajectory and be relatively small in size, the geographically constrained nature of the Mediterranean basin still allows it to produce significant impacts (Scicchitano et al., 2021; Borzi et al., 2024). The spatial distribution of winds and precipitation, particularly in relation to complex terrain and landfall, has been the focus of extensive research due to its potential to intensify local hazards. Zhang et al. (2020) reported that rainfall totals increase from the centre to approximately 0.8° before decreasing; however, this pattern may be affected by the limited horizontal resolution (~30 km) of the ERA5 dataset used in their analysis. Recent findings by Dafis et al. (2020), which focus on convective activity within a 200 km radius of the cyclone centre, reveal that only a subset of Medicanes exhibit intense inner-core convection. Among these, persistent deep convection in the upshear quadrants emerges as a key driver of intensification."

2. **L51: Lagouvardos not Lavaguardos.**

   Thank you.The reference to Lagouvardos has been corrected accordingly.

3. **L71: a short summary of the paper is missing here.**

   We fully agree that a concise summary of the manuscript structure is necessary for reader guidance.

4. **L113: what do you mean with "The selection of particle numbers ensured a balanced distribution across both grid points and vertical levels"?**

   FLEXPART conserves atmospheric mass by design, requiring sufficient particle representation across all vertical levels. To achieve this, 10 million air parcels were initially distributed homogeneously throughout the atmosphere, ensuring adequate sampling of both horizontal grid points and vertical layers (Fernández-Alvarez et al., 2023). The number of particles needed depends on the scientific objective: while a few million may suffice for global-scale transport statistics, higher resolution is essential for case studies of specific synoptic events (Pisso et al., 2019).

   We have revised the sentence accordingly to clarify this point:

   "Ensuring atmospheric mass conservation and full three-dimensional coverage of the model domain required selecting a number of air parcels that provided a physically consistent and representative distribution across all horizontal grid cells and vertical levels (Pisso et al., 2019; Fernández-Alvarez et al., 2023)."

Fernández-Alvarez, J. C., M. Vázquez, A. Pérez-Alarcón, R. Nieto, and L. Gimeno, 2023: Comparison of Moisture Sources and Sinks Estimated with Different Versions of FLEXPART and FLEXPART-WRF Models Forced with ECMWF Reanalysis Data. J. Hydrometeor., 24, 221–239, https://doi.org/10.1175/JHM-D-22-0018.1.

Pisso, I., Sollum, E., Grythe, H., Kristiansen, N. I., Cassiani, M., Eckhardt, S., Arnold, D., Morton, D., Thompson, R. L., Groot Zwaaftink, C. D., Evangeliou, N., Sodemann, H., Haimberger, L., Henne, S., Brunner, D., Burkhart, J. F., Fouilloux, A., Brioude, J., Philipp, A., Seibert, P., and Stohl, A.: The Lagrangian particle dispersion model FLEXPART version 10.4, Geosci. Model Dev., 12, 4955–4997, https://doi.org/10.5194/gmd-12-4955-2019, 2019.

5. **L130-131: what do you mean with *filter the centers* in "The cyclone phase space method (Evans and Hart, 2003) was employed to filter the tracked low-pressure centres"?**

   We have revised the sentence:

   "The cyclone phase space method (Evans and Hart, 2003) was employed to characterize and classify the structure of the tracked low-pressure centres."

6. **L210-211: the values do not correspond with those shown in Fig. 3b.**

   Thank you for pointing this out. We will update Figure 3b to ensure that the values correspond accurately with the text.

7. **L217: 1008 hPa? Or 998 hPa?**

   The in-text values are correct, and we will update the figure accordingly to reflect these accurate pressure values.

8. **L217: what does it mean "which further corroborates the observed profiles"?**

   We have revised the sentence:

   "On 19 September, at 0300 UTC, the pressure data from the Pylos buoy, although located farther from the cyclone center (76.7 km from the ERA5 track), still captured a decrease in MSLP, peaking at 1008 hPa. The MSLP profiles from the simulations show lower central pressures than those recorded by the Pylos buoy. Simulation-derived MSLP profiles exhibit lower central pressures than those measured by the buoy, reflecting the expected radial pressure gradient characteristic of intense cyclones."

9. **L251: the reasons for the development of the "low-PV values bubble" are not provided.**

   Regarding the development of the "low-PV values bubble", we acknowledge that the underlying mechanisms were not explicitly detailed in the original text. Our simulations successfully reproduce this key feature of Ianos's evolution. A comprehensive analysis of this phenomenon is presented in Sanchez et al. (2024).

10. **L288: how are the pathways of precipitating particles selected in Fig. 6?**

    We initially selected a subset of particles characterized by extended trajectory lengths. From this subset, we subsequently extracted a variable number of particles based solely on their visibility within the map, aiming to capture sufficient representation from different pathways while maintaining clarity for distinction.

11. **Figure 7 top panels: x and y are not shown in the Figure. If the x-axis is horizontal, I would expect it represents longitude not latitude, as in the paper.**

    In Figure 7 (top panels), the x- and y-axes were inadvertently not labeled. The x-axis corresponds to longitude, while the y-axis corresponds to latitude, consistent with the rest of the paper. We will correct the figure labels and caption to accurately reflect this.

12. **Figure 8: it is not immediate to identify the time each panel refers to. Please specify it. Also, please add "H" and "L" to identify high and low pressure you are referring to in the manuscript.**

We will update Figure 8. The figure will also be simplified to accommodate the inclusion of new cases for improved clarity.

13. **L353: what do you mean with "daily MSLP"?**

    The paragraph has been revised to clarify that moisture uptake is measured every 12 hours, not daily as originally proposed. Therefore, the MSLP corresponds to the instantaneous value at the start of each 12-hour moisture uptake period.

14. **L371, 372: southerly should be northerly.**

    Revised.

15. **Figure 9: only the top panel is commented on.**

    Thank you for your comment. The revised text now reads:

    "Figure 9 presents the 6-hourly instantaneous moisture uptake along backward trajectories for Ianos on 17 September at 0600 UTC, corresponding to the timeframe shown in Figure 8d. In the initial 6-hour segment (Fig. 9a), moisture acquisition occurs predominantly over the Mediterranean Sea. Extending the analysis to 12-hour backward trajectories (Fig. 9b) reveals a pronounced moisture uptake over inland Libya, where the intensity of moisture gain increases. This inland region experienced a marked rise in low-level water vapor mixing ratio throughout the 18-hour period, closely aligned with prevailing surface wind patterns (Figs. 9d–f). The peak moisture uptake at 12 hours likely reflects a local accumulation of air parcel density (Fig. S12). Interestingly, moisture uptake diminishes at 18 hours (Fig. 9c), coinciding with a reduction in particle density within this moist environment (Fig. S12)."

    Regarding the bottom panel of Figure 9, we acknowledge that its labeling was incorrect. This panel was actually intended to be removed and should not have been included, as our analysis relies exclusively on the low-level water vapor mixing ratio (middle panel) rather than the total Integrated Vapor Transport (bottom panel) to better represent the moisture conditions relevant to the backward trajectories.