

The manuscript, “Air–Sea Interactions and Biogeochemical Responses to Medicane Daniel” by B. Jangir and E. Strobach, investigates air-sea interactions during Medicane Daniel and examines the role of warm- and cold-core eddies, marine heat waves, and ocean heat content in influencing the storm’s intensity. The study also analyzes how the ocean responds to the storm, focusing on both physical and biogeochemical changes.

Using multiple satellite and reanalysis datasets, the authors examine atmospheric and oceanic parameters relevant for cyclone dynamics, as well as pre-storm, during-storm, and post-storm changes in chlorophyll. They show that the presence of a warm-core eddy and the marine heatwave in the path of the storm contributed to the intensification, primarily through enhanced moisture convergence. The study also uses high-resolution SWOT data to detect mesoscale ocean structures that may influence cyclone intensity, providing a better understanding of the relationship between Mediterranean cyclones and underlying ocean features. Finally, the manuscript investigates the response of ocean biogeochemical parameters to the passage of the storm, including enhanced chlorophyll concentrations associated with cyclone-induced mixing and upwelling.

The manuscript contains interesting scientific analyses which are relevant to the community, especially as it uses SWOT data for highlighting finer eddy structure and better heterogeneity on biogeochemical parameters. However, in my opinion, the manuscript requires substantial revisions in terms of structure and overall presentation to improve readability and clarity. In addition, it requires further discussion to put the findings in a better context; for example, the methodology and rationale behind each section should be described more clearly. The study should also discuss the potential limitations of the data used and interpretation, such as causation vs association. My comments are following:

Response: We sincerely thank the reviewer for their time, careful evaluation, and constructive feedback on our manuscript. Below, we address each concern in detail. All reviewer comments have been carefully addressed. The reviewer’s comments are in black, and our response is in blue.

**General Comment:**

In its present form, the manuscript attributes cyclone intensification primarily to the presence of warm-core eddies and marine heat waves along the storm track. However, the analysis is, right now, showing an association, rather than causation. Though showing such an association is important and scientifically justified, as this study is mainly observation-based, probable limitations or other factors that may support or contradict these findings must be discussed.

The manuscript requires clear separation between two components: how existing oceanic conditions influence the storm, and then how the storm influences the ocean, which could be done with a better presentation and restructuring of the write-up. In its current form, many important findings are lost or require multiple readings of the manuscript. Also, how authors’ own previously published articles as cited show similar findings, it would benefit how this case study contributes to existing literature over would significantly improve the impact of the work.

Response: We acknowledge that the distinction between oceanic influence on the storm and storm-induced ocean response was not sufficiently clear in the original version. In the revised manuscript, we have restructured the study into two clearly defined components:

1. The role of oceanic features, such as mesoscale eddies and marine heatwaves, in supporting cyclone intensification.
2. The impact of the cyclone on ocean biogeochemistry, including changes in chlorophyll and productivity.

This restructuring improves readability and ensures that key findings are presented more clearly.

Furthermore, we have strengthened the discussion on how this study contributes to existing literature. Previous studies have largely focused on documenting the impact of cyclones on ocean biogeochemistry; however, the underlying physical mechanisms are often not clearly explained. In this study, we make two key contributions:

- We demonstrate the utility of SWOT satellite data in resolving mesoscale features during such events.
- We provide a clearer mechanistic explanation for the observed increase in chlorophyll and productivity, particularly over regions influenced by eddies and marine heatwaves, through analyses of Ekman pumping and related physical processes.

The reported increase in chlorophyll and nutrient concentrations following the cyclone is interesting; however, the mechanisms responsible for these changes remain unclear. In some sections, the manuscript attributes the increase in chlorophyll to enhanced Ekman pumping and cyclone-induced upwelling, while later the discussion indicates that Ekman pumping is negative (i.e., downwelling) at the same location and instead suggests subsurface mixing as the dominant mechanism. These differing explanations create ambiguity regarding the physical processes responsible for the observed biological response. Clarifying the dominant mechanism and ensuring consistent terminology throughout the manuscript would strengthen the interpretation.

Response: We appreciate this important point. In the revised manuscript, we have clarified this issue as follows: We now present daily Ekman pumping fields (shown in Figure R1 below and also included as SI Figure 7), which clearly show that during the passage of the cyclone, positive Ekman pumping (i.e., upwelling) dominates, leading to enhanced nutrient supply and subsequent increases in chlorophyll concentration at the surface. It is important to note that downwelling starts from 10 September, as seen in the new SI Figure 7 (also shown below). Because of this, when we calculate the total Ekman pumping from 5 to 10 September, the inclusion of 10 September introduces a negative (downwelling) signal at the intensification location. In the new Figure 3f (now we replaced it as Figure 6c), we decided to exclude September 10 from the average. This does not change our conclusions, as on the 10th, the cyclone was already above land. This point is now further clarified in the revised manuscript.

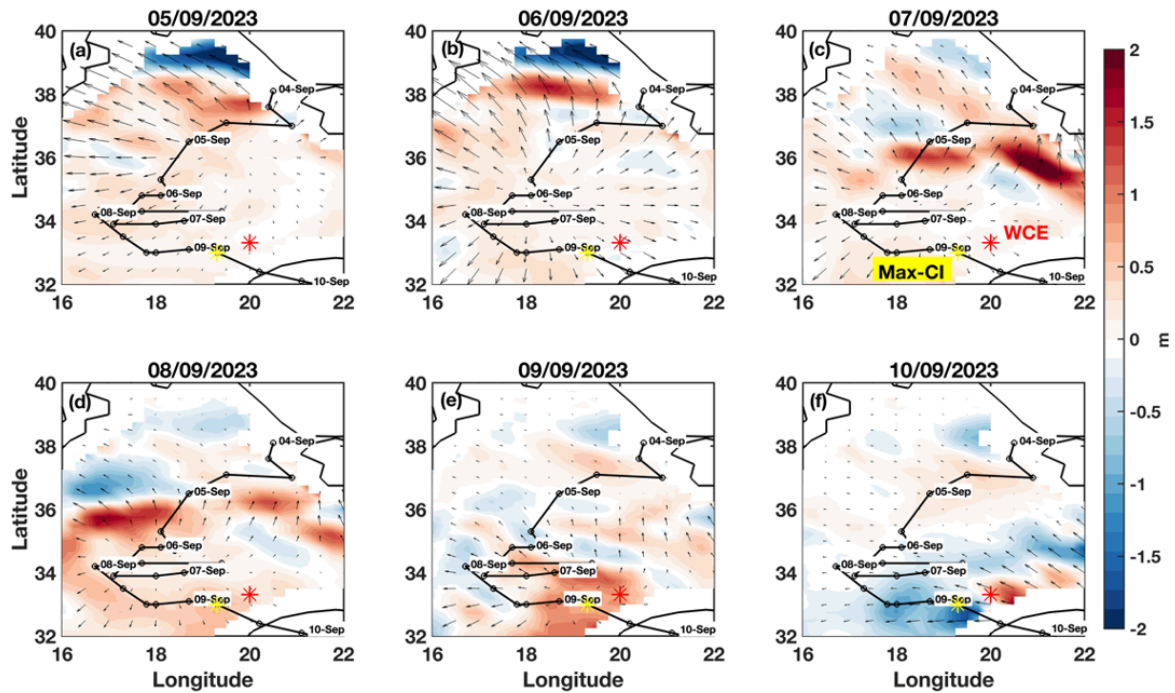


Figure R1: Daily Stern Ekman pumping ( $m\ day^{-1}$ ) and Ekman transport vectors over the Mediterranean Sea during 5-10 September 2023. Ekman pumping is shown as shaded contours, red (positive) indicating upwelling and blue (negative) indicating downwelling, and white representing near-zero values. Black arrows denote Ekman transport vectors. The track of Storm Daniel is overlaid in black, with red markers highlighting the cyclone's position on each corresponding day. The yellow star indicates the location of maximum cyclone intensity, while the red star marks the warm core eddy location. Coastlines are shown in black.

The abstract contains too much information, which is relevant and important, but not structured properly, and which could be structured better. Currently, it sounds a bit incoherent.

Response: We have revised the abstract to improve its clarity, conciseness, and logical flow. We hope that the revised abstract addresses your concerns and is now clearer, better structured, and easier for readers to understand.

### Minor Comments

L47: “positioned”?

Response: We modified it to ‘Situated’.

L51: “Phenomenon” to “Events” in this context

Response: We replaced it with ‘Events’.

L63-64: phrasing feels a bit odd “*under-researched and often inadequately communicated,*”

Response: Thank you for pointing this out. We have modified it as ‘under-researched and often poorly communicated.’

L168: “originated” to “developed.”

Response: We replaced it as you suggested.

L198: recheck (‘Total Column Water’)

Response: We agree that the terminology needs clarification. In ERA5, the correct variable name is Total Column Water (TCW), which includes all phases of water (water vapor, cloud liquid water, cloud ice, rain, and snow).

L217: I think this warrants a section of its own, which includes a high-level summary of retrievals, gridding and averaging procedure, any potential limitations and uncertainty bound

Response: Thank you for this valuable suggestion. We agree that the satellite chlorophyll dataset and its processing deserve a more detailed description. Accordingly, we have added a dedicated subsection in the revised manuscript, which provides a brief overview of the retrieval methodology, gridding and averaging procedures, as well as potential limitations and associated uncertainties. This addition improves the clarity and reproducibility of the study.

We added the section as ‘Daily satellite-derived chlorophyll products (OCEANCOLOUR\_MED\_BGC\_L4\_NRT) with a spatial resolution of 1 km were used in this study (Volpe et al., 2019; Volpe et al., 2018; Berthon and Zibordi, 2004). These datasets are archived by the Copernicus Marine Service (<https://doi.org/10.48670/moi-00298>) and are provided by the Italian National Research Council (CNR, Rome, Italy), with data availability from January 2023 to the present. The multi-sensor product integrates observations from SeaWiFS, MODIS, MERIS, VIIRS, and OLCI, and includes key biogeochemical variables such as chlorophyll a (Chl-a), diffuse attenuation coefficient at 490 nm (KD490), and primary production (PP).

Despite their advantages, these datasets are subject to uncertainties arising from atmospheric correction errors, cloud contamination, aerosol effects, and reduced accuracy in optically complex coastal waters. In addition, the gap-filling procedure used to generate continuous fields may introduce smoothing in regions with persistent data gaps. Nevertheless, these products provide robust, high-resolution information on surface biogeochemical variability associated with cyclone-induced ocean processes.’

L221: Better phrasing of what aspects of Medicane, and also this should be a place where you summarize what each subsection will describe, and what relevance they have in your interpretation of results.

Response: Thank you for this helpful suggestion. We modified the section as ‘In this study, we investigate the intensification, structure, and impacts of Medicane Daniel. This section outlines

the datasets and methodologies used to analyze the oceanic and atmospheric conditions associated with the event. The analysis focuses on key processes influencing cyclone formation and intensification, including the role of oceanic features such as WCE and MHWs, the contribution of ocean heat content as a source of subsurface thermal energy, and atmospheric variables such as moisture and wind fields. In addition, the impact of the cyclone on ocean physical (temperature and salinity) and biogeochemical (chlorophyll, phytoplankton, nutrients, and oxygen concentration) properties is examined, along with the processes governing these changes. The methods used for the identification of the sea eddies and MHWs, as well as the computation of ocean heat content, are described below. ’

L291: It should have one paragraph, what are the major results that you further divided into subheadings

Response: Thank you for the suggestion. Accordingly, we have added a concise opening paragraph that highlights the key findings, which are then elaborated under the subsequent subheadings for clarity and better organization.

In this introductory paragraph, we clearly highlight the two main aspects of the study:

(i) the role of pre-existing oceanic conditions, including warm-core eddies and marine heatwave conditions, in supporting the intensification of Medicane Daniel, and  
(ii) the subsequent impact of the cyclone on ocean biogeochemistry, particularly the observed enhancement in surface productivity. We also clarify the underlying mechanisms responsible for this increase, linking it to cyclone-induced physical processes. We added a paragraph as ‘In this section, we present the results of our study on Cyclone Daniel, focusing on two primary aspects. First, we analyze the influence of pre-existing oceanic conditions, specifically warm-core eddies and marine heatwave phenomena, on the cyclone's intensification. Second, we investigate the cyclone's impact on ocean biogeochemistry, particularly the observed increase in surface productivity as indicated by enhanced biogeochemical parameters. Our findings also explore the physical mechanisms behind these changes, highlighting the interactions between the ocean and atmosphere throughout the lifecycle of Medicane Daniel.’

L292-293: “The presence of ocean features, i.e., Eddies, Marine Heat Wave, and Ocean Heat Content along the cyclone track and their Impact on cyclone intensity.” This subheading should be shortened

Response: Thank you for the suggestion. We replaced it with “Role of oceanic features in intensification of medicane Daniel.”

L312-314: rephrase the sentence for better clarity

Response: Thank you for the suggestion. We rephrased the sentence as ‘Cyclones extract heat from the ocean, resulting in surface cooling due to enhanced mixing and evaporation, which acts to reduce cyclone intensity.’

L338-340: Calculation of MSLP is not clear, mentioning the Cressman technique without describing details, for example, search radius, etc.

Response: Thank you, we have not included the details in the method section. We added a subsection in the method section as ‘3.2.4 Computation of Mean Sea Level Pressure (MSLP) and Wind Speed (WS) along the track of Medicane Daniel.’

To estimate MSLP and wind speed (WS) along the cyclone track, we applied Cressman averaging (Cressman, 1959). Once the cyclone center was identified, a spatial average within a 2° radius around the center, weighted by inverse square distance, was computed for MSLP and wind speed. This method captures changes within a 2-degree radius of the cyclone centre, while regions outside this radius are not included. The approach was used to assess variations in cyclone intensity along its path and has been widely employed in previous studies (Jangir et al., 2023). ’

L339: warm-core eddy, which region in the plot 2a (I think it would be better to mention the green line), also associated with figure 2, seems distorted.

Response: Thank you for this valuable comment. We have clarified this in the revised manuscript by explicitly referring to the region along the green line in Figure 2a. We mentioned in the figure caption, *and the green box represents the location of the warm core eddy and the marine heatwave.* Additionally, we have improved the figure quality to address the distortion and ensure better clarity and interpretation.

L337-344: This paragraph mentions at least three eddies; however, in Fig. 2a not shown where they are on the timeline. I think it will be needed for a coherent interpretation. Also, my suggestion would explain systematically and follow the chronological evolution of the storm.

Response: Thank you for this insightful comment. We agree that the identification of multiple eddies in relation to the timeline was not clearly represented in Figure 2a. To improve clarity and coherence, we have revised the figure and corresponding text to explicitly indicate the locations of the eddies along the storm timeline. Additionally, we have reorganized the paragraph to follow the chronological evolution of the storm more systematically, ensuring a clearer interpretation of the results. We have revised Figure 2 accordingly, and the updated version is presented as Figure R3.

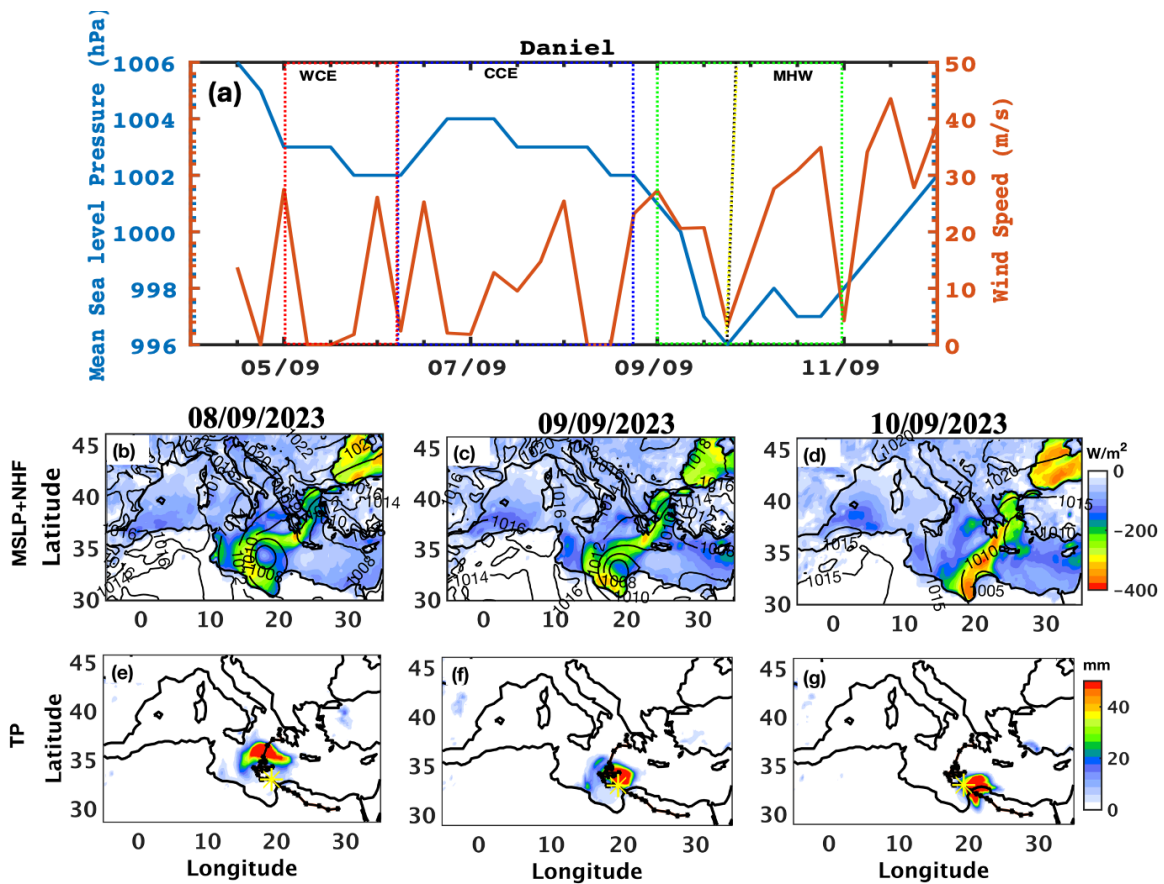


Figure R3: (a) Mean sea level pressure and wind speed computed using the Cressman average along the track of the Medican Daniel, and the red, blue, and green boxes represent the location of warm core eddy, cold core eddy, and marine heatwave. Max-CI is indicated by a vertical yellow line. (b-d) Medican track overlaid on Contours of the daily mean of MSLP and daily mean of latent heat fluxes (positive downward). (e-g) total precipitation during the cyclone, on the 8th, 9th, and 10th September 2023. The yellow star represents the max-CI location.

Fig 2b-g: From the caption, these plots are not anomalies; thus, it would be better to show them with some sequential colormap. Also, line contours are not legible

Response: Thank you for the valuable suggestion. We agree that these plots represent absolute values rather than anomalies. Accordingly, we have updated Figures 2b-g using an appropriate sequential colormap to improve clarity. We have also enhanced the visibility of the contour lines by adjusting their thickness and contrast to ensure better readability. We have revised Figure 2 accordingly, and the updated version is presented as Figure R3.

L362: Only Eddy supplied moisture? Or is it a positive association, while other factors may also be influencing moisture convergence?

Response: Thank you for the comment. We referred to eddy-supplied moisture because, in our previous analysis, we identified enhanced moisture convergence over the WCE location, which contributed to cyclone intensification. This is also supported by the results shown in Supplementary Information Figure 4. However, we acknowledge that other factors also

influence moisture convergence and cyclone development. We have clarified this point in the revised manuscript to avoid overemphasis on a single factor.

L383: This section, as claimed, is the major focus of the study; however, the discussion does not justify it. It should clearly convey and highlight the contrast of what was not adequately represented in the low-resolution data. Also, it will improve the clarity if you separate the physical and biogeochemical parameters.

Response: Thank you for this important comment. We agree that the role of SWOT data needs clearer justification. In the revised manuscript, we have explicitly highlighted the advantage of SWOT in resolving fine-scale ocean structures that are not captured by lower-resolution altimetry. We have also clarified the distinction between physical and biogeochemical parameters to improve the interpretation of cyclone-ocean interactions.

We added a new paragraph as ‘Unlike traditional altimeters, SWOT's wide-swath coverage enables improved detection of mesoscale and sub-mesoscale eddies, frontal gradients, and filaments that regulate ocean heat distribution and air-sea exchanges. These features are often underrepresented in low-resolution datasets, limiting their ability to capture localized processes such as eddy-cyclone interactions and cyclone-induced mixing. By resolving these fine-scale physical structures, SWOT also provides a framework for interpreting biogeochemical responses. While coarse datasets show bulk chlorophyll changes, SWOT helps identify localized regions of enhanced mixing and upwelling that drive nutrient supply and biological variability. This allows for a clearer linkage between physical forcing and biogeochemical response. Overall, SWOT overcomes key limitations of conventional altimetry by preserving high-frequency spatial gradients, enabling a more accurate representation of the ocean state during extreme events such as Medicane Daniel.’

L409: One sentence is required to show what those parameters are, as a follow-up to the previous sentence ending “*profiles of key variables along the cyclone’s.*”

Response: We modified this sentence as ‘To investigate the impact of the medicane on oceanic physical (temperature and salinity) and biogeochemical properties (i.e., chlorophyll, phytoplankton, nitrate and phosphate, and oxygen concentration), we analyzed vertical profiles of key variables along the cyclone’s track.’

L413: mention the exact box with colors shown in the plot, for example, WCE (red lines) in Fig 4a

Response: Thank you for your suggestion. We modified the sentence as ‘The results reveal a notable decrease in temperature along the cyclone path, with a general strong cooling along its path except for a short pause in the cold SST anomaly region in the morning of the 8<sup>th</sup> (Figure 1n). This region was also relatively outside the MHW domain (Figure 1l)’.

L414: No discussion on salinity, while it is included in plots Fig. 4b?

Response: We have also included a sentence addressing salinity, noting that precipitation associated with the cyclone leads to a decrease in surface salinity. We added in text ‘The salinity also decreases on the surface presumably due to a massive influx of freshwater from heavy rainfall, again, except for the morning of the 8<sup>th</sup>, in which the cyclone was outside the influence of WCEs and MHW (Figure 4b).’

L421: what is “DCM”? It is not defined in the throughout the manuscript, including any of the figure? My suggestion would be to reduce the number of such abbreviations.

Response: DCM stands for Deep Chlorophyll Maximum. We apologize for the inconvenience. We have now added this definition to the text and reduced the use of abbreviations where necessary, in accordance with your suggestion. We reviewed all acronyms again, MR acronym was removed in the new version. All other acronyms are widely used in other studies.

L436: (panels b-d and h-i). of which figure ?

Response: Thank you for pointing this out. We have corrected the reference to Figure 5 and revised the text accordingly for clarity.

L438: “circulation motion starting.” The word “motion” is redundant.

Response: Thank you for the helpful suggestion. We agree that the term “motion” is redundant in this context. Accordingly, we have revised the sentence to improve clarity by removing the word “motion.”

L446: WCE should be panel (a) of Fig 6 if you are discussing this first

Response: Thank you for pointing this out. It should be Figure 5a. We have revised it as follows: “To explore the dynamical mechanisms, Figure 6 shows vertical profiles from 1 to 15 September 2023 of Chl-a at two locations along the same line as in Figure 5a, one inside the Cold Core Eddy (panel a) and the other inside the Warm Core Eddy (panel b).” for better clarity. We hope this revision improves understanding.

L448-455: Needs careful revision, as it is not clear in its current form.

Response: Thank you for the comment. The red line in Figure 5a extends from the cold-core eddy (CCE) to the warm-core eddy (WCE), and the vertical profiles in Figure 6 are extracted along this section, representing both regions. Now we have modified Figure 6, where we have plotted the chlorophyll profile over the location of the cold and warm core eddy locations, which makes our results clearer. For clarity and simplicity, we have revised the corresponding sentence in the manuscript.

L478: Sentence seems incomplete.

Response: Thank you. We have modified the sentence to: ‘This case study provides comprehensive insights into the intensification and impacts of Medicane Daniel, which developed over the MS in September 2023.’