Sensitivity of a Mediterranean tropical-like cyclone to diabatic processes

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1 Introduction

The Mediterranean sea is known for its intense cyclonic activity due to its complex topography and its geographical location. Certain Mediterranean cyclones called "medicanes" are particularly dangerous for the population and represent a major meteorological risk of the region. It is therefore very important to be able to predict them accurately. However, the importance of diabatic processes in their development and the low number of occurrences make it particularly difficult to simulate them correctly.

This scientific mission focused on the sensitivity of Medicane Ianos (2020) to diabatic processes to better understand the influence of those processes on the dynamic of medicanes. It is the most violent Mediterranean cyclone ever recorded, which caused many damages in South Italy and in Greece because of abundant precipitations, floods and wind gusts up to 54 m/s at the mature stage.

2 The analysis of Medicane Ianos

Ianos was a medicane that occurred in September 2020. The cyclogenesis took place the 15^{th} in the Gulf of Sidra off the coast of Libya, the mature stage was reached in the Ionian Sea on the 17^{th} and the dissipation occurred the 21^{st} south of Crete (Fig. 1).

To study Ianos, I used a control simulation, which corresponded to the real case in terms of trajectory and intensity. The simulation came from the WRF model, with a time step of one hour and a spatial resolution of 10 km, with a domain covering the whole Mediterranean basin.

The first objective of this mission was to analyse Ianos, to study its characteristics and the role of diabatic processes for this cyclone. Ianos formed because of an intrusion of stratospheric air in the upper troposphere, then it intensified rapidly as a consequence of the trough and diabatic processes. Therefore, I analysed the dynamic and morphological structure of Ianos during the cyclogenesis and the mature stage to identify its tropical and extratropical characteristics.

The thermal structure of Ianos during the cyclogenesis (Fig. 2) is not symmetric, with unaligned hot poles in the upper and lower troposphere, which is a characteristic of mid-latitude cyclones. The non symmetric vertical structure of PV is also characteristic of the cyclogenesis of

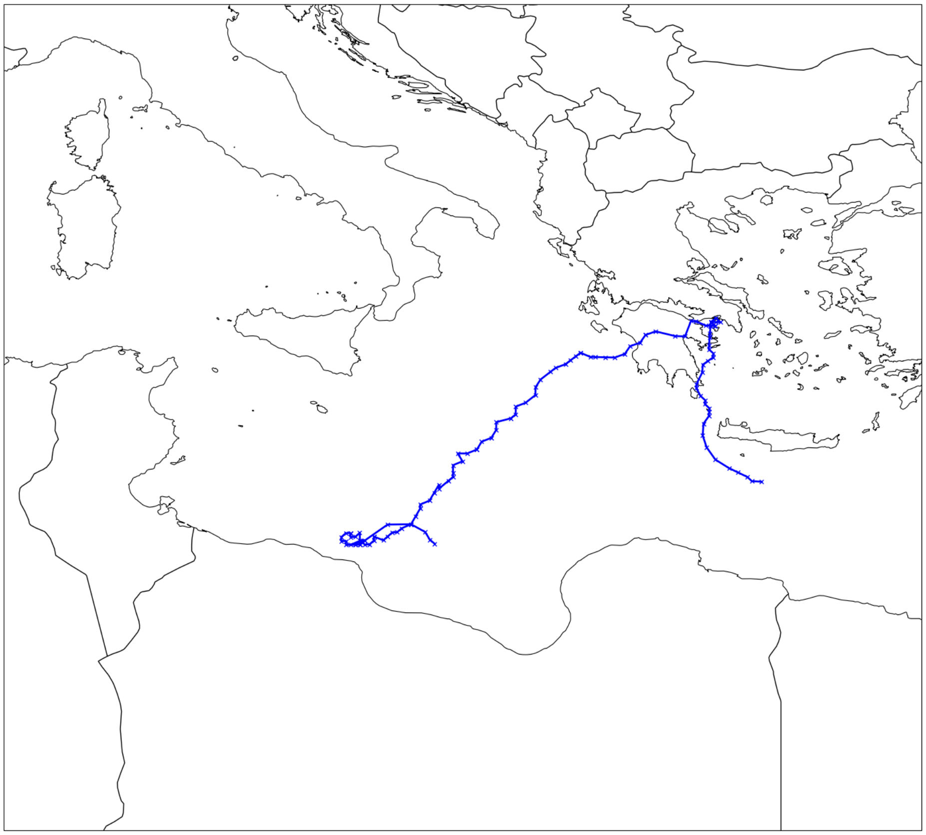

FIGURE 1 – Trajectory of the control simulation of Ianos

a mid-latitude cyclone. However, at the mature stage (Fig. 3), the thermal and the PV structures of Ianos form a column, which is characteristic of tropical cyclones. Furthermore, Ianos possesses a hot core at its mature stage as the equivalent potential temperature inside the cyclone is higher than around it, which is also a tropical characteristic.

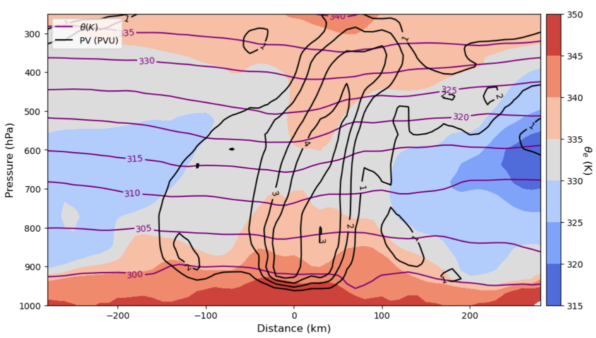

FIGURE 2 – Cyclogenesis, the 15/09 at 12h UTC

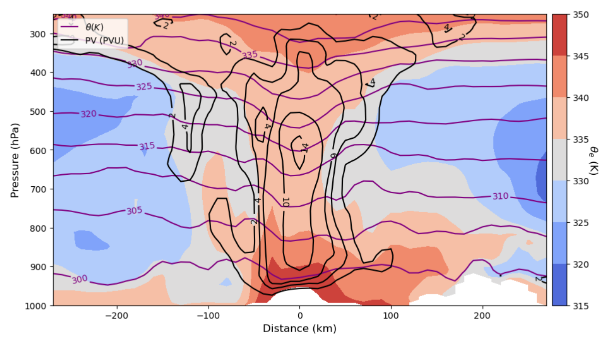

FIGURE 3 – Mature stage, the 17/09 at 18h UTC

FIGURE 4 – Vertical cross section of Ianos during the cyclogenesis and the mature stage. PV values are in black contours, the potential temperature θ is in purple contours and the colours represent the equivalent potential temperature θ_e.

The convective structure of Ianos also presents an interesting evolution between the cyclogenesis and the mature stage. I analysed it by observing the evolution of θ_{LH}, which is the instantaneous contribution of latent heat to θ. During the cyclogenesis (Fig.5), the convective structure is not symmetric with a moderate convection, but the gradient of θ_{LH} is important and vertically homogeneous which represents an important source of PV inside the cyclone. On the other hand, at the mature stage the convection is strong and the convective structure is axisymmetric, with a clear eye in the middle and an eye-wall around. However, the gradient of θ_{LH} generates sources and sinks of PV, which means that convection is not a source of intensification like during the cyclogenesis.

These first results show that Ianos intensified mostly due to diabatic processes during the cyclogenesis and until its mature stage, the PV streamer which caused the cyclogenesis being strong in PV values but comparable to other strong Mediterranean cyclones. Also, strong diabatic processes during the cyclogenesis and the following hours induced a tropical transition for Ianos, with dynamic and morphological characteristics of tropical cyclones.

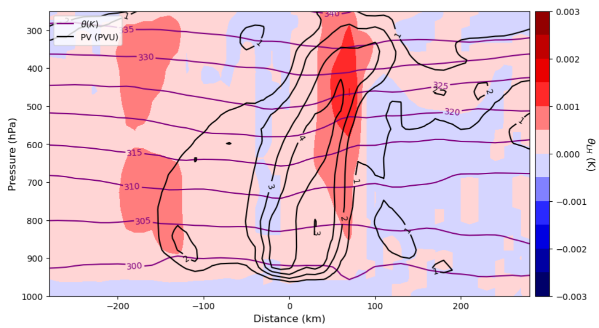

FIGURE 5 – Cyclogenesis, the 15/09 at 12h UTC

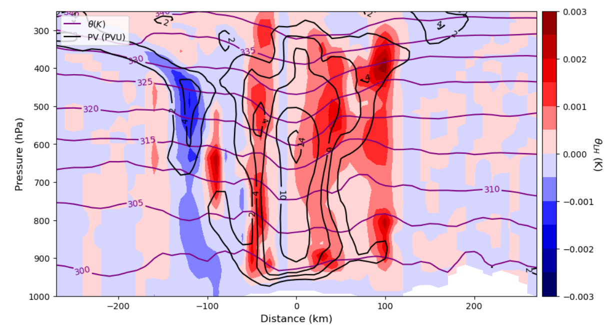

FIGURE 6 – Mature stage, the 17/09 at 18h UTC

FIGURE 7 – Vertical cross section of Ianos during the cyclogenesis and the mature stage. PV values are in black contours, the potential temperature θ is in purple contours and the colours represent the instantaneous contribution of latent heat to θ, noted θ_{LH}.

3 Sensitivity of Ianos to diabatic processes

The second objective of the mission was to conduct sensitivity tests on diabatic processes for Ianos. To do that, I used a set of ten simulations with the same initial conditions as the control simulation, but including stochastic perturbations on diabatic processes with the SPPT method (Fig. 8).

First, the obtained trajectories and intensities are very spread (Fig. 8 - 9), which shows that diabatic processes had a huge influence on the trajectory and the intensity of this cyclone. In addition, the strong cyclones tend to have northern trajectories, and weak cyclones moved more to the south, which implies a correlation between the trajectory and the intensity of the obtained cyclones.

In order to better understand the sensitivity of Ianos to diabatic processes, I constructed a table to compare the strongest and most northerly cyclone (SPPT 10) and the weakest and most

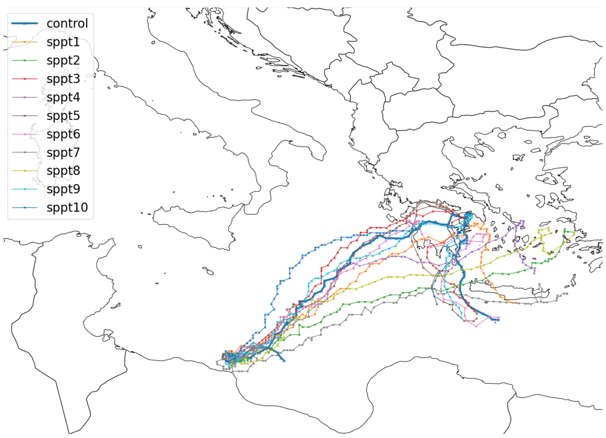

FIGURE 8 – Trajectories of the set of simulations.

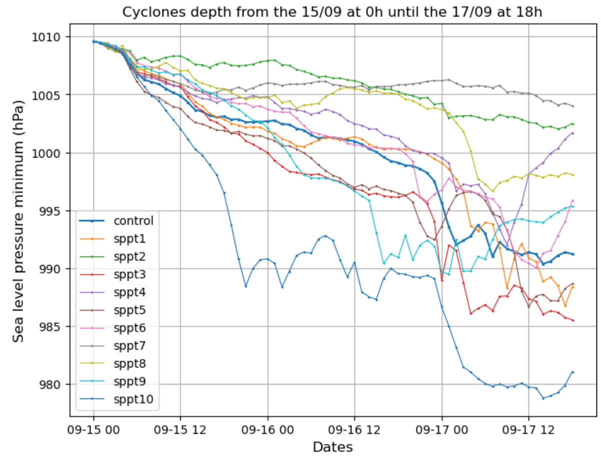

FIGURE 9 – Time-series of the minimum sea level pressure (slp) for the 11 simulations of Ianos.

southerly cyclone (SPPT 7) to the control simulation at 850 hPa (Fig.10).

The weakest cyclone (SPPT 7) is characterised by lower PV values during the cyclogenesis when the stochastic coefficient is slightly negative (Fig.10), and the PV values become even weaker during the cyclone's intensification (16/09) when the stochastic coefficient reduces by half the contribution of diabatic processes for the intensification of the cyclone. The obtained cyclone at the mature stage of Ianos is weaker than Ianos with a minimum of SLP of 1004 hPa instead of 991 hPa on the 17/09 at 18h UTC (Fig.9) and with a wind speed lower by 10 m/s.

On the other hand, the strongest cyclone is characterised by PV values higher than the control simulation by 7 PVU since the cyclogenesis and until the mature stage (Fig.10). However, it is only during the cyclogenesis that the stochastic coefficient increases the contribution of diabatic processes to the intensification of the cyclone, multiplying this contribution by two. The following days, the stochastic perturbations reduce the contribution of diabatic processes but the cyclone SPPT 10 remains the strongest and its minimum of SLP continues to drop (Fig.9). The obtained cyclone at the mature stage is much stronger than Ianos with a minimum of SLP of 981 hPa instead of 991 hPa on the 17/09 at 18h UTC (Fig.9) and with a wind speed higer by 15 m/s.

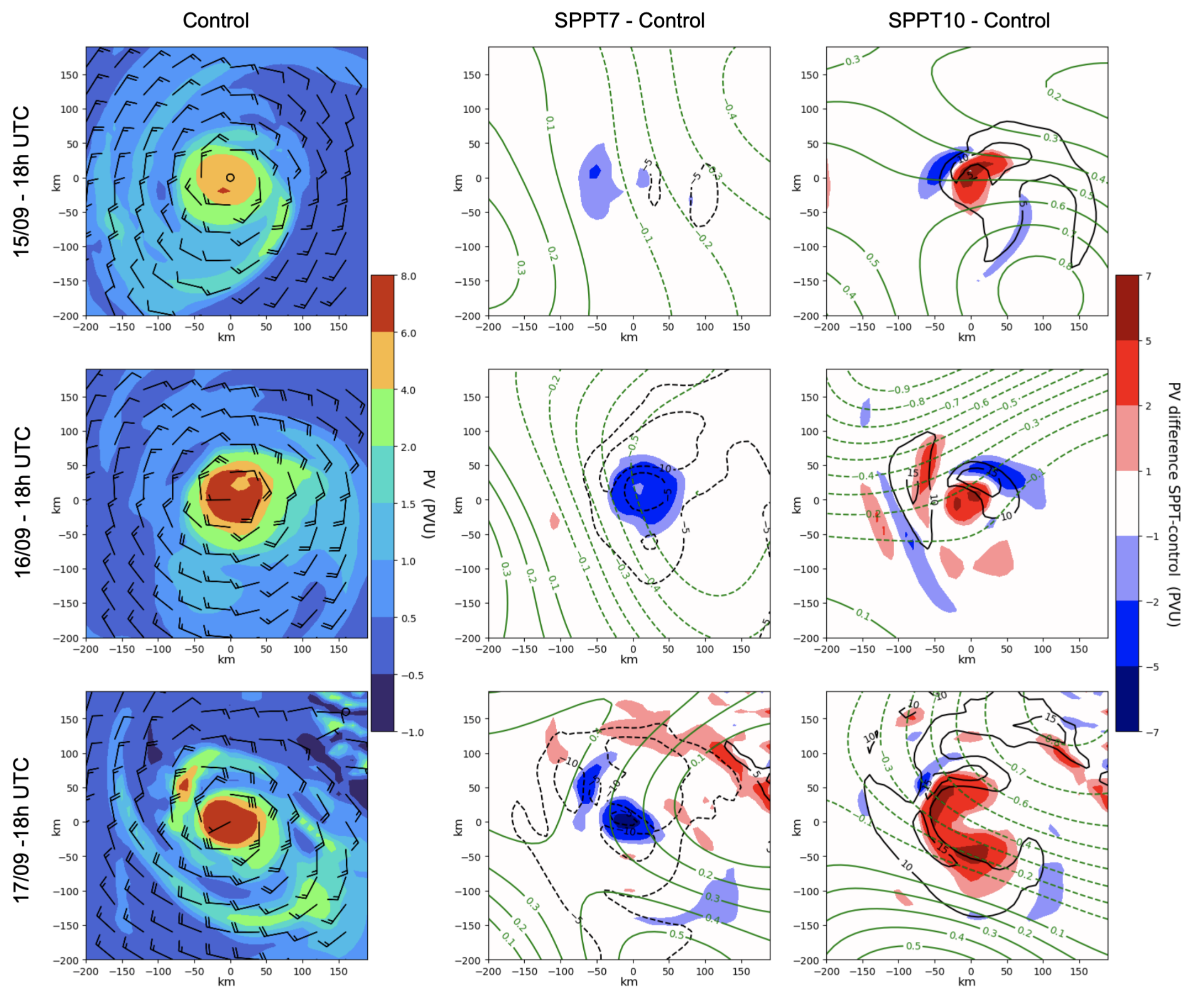

FIGURE 10 – Comparative table of the control simulation, the strongest cyclone (SPPT 10) and the weakest cyclone (SPPT 7) throughout time at 850 hPa. For the control simulation, the colours are the PV values and the wind barbs represent the wind speed. For the SPPT simulations, the green contours show the stochastic coefficient, the black contours show the difference of wind between the SPPT and the control simulations, and the colours represent the difference of PV between the SPPT and the control simulations.

4 Conclusion

The results of this study show that diabatic processes have a very significant influence on the trajectory and the intensity of Medicane Ianos, particularly during the cyclogenesis and the early intensification of the cyclone. The influence of diabatic processes on the trajectory may be due to the divergence of the wind in the upper-troposphere due to intense convection, but additional studies would be necessary to prove it.

The particularly strong intensification of Ianos, as well as its tropical characteristics are due to a strong diabatic forcing which induced a tropical transition during the intensification of the medicane. Moreover, Ianos was influenced by diabatic processes in terms of trajectory and intensity, particularly during the cyclogenesis and the early stages of intensification.