Assessing the Sensitivity of COSMO/GR Atmospheric Model to Effectively Simulate the Influence of Diabatic Heating on Eastern Mediterranean Explosive Cyclogenesis Under Different Parameterizations of the Model Physics

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Abstract Mediterranean explosive cyclogenesis is the result of the interaction between upper level baroclinic and low level diabatic processes. This interaction presents significant differences in specific Mediterranean sub-areas and in different cases of rapid deepening, especially regarding the evolution of the diabatic processes. In this study, the regional atmospheric model COSMO-GR is used for the evaluation of the spatial and temporal variations of low level diabatic heating in a case of explosive cyclogenesis in the north Aegean Sea. Model runs were performed for a series of different values of the model parameter sea roughness, which has proved to significantly affect the simulation of the diabatic processes. It was found that smaller values of the above parameter compared to the default parameterization, lead to significant enhancement of the model calculated surface turbulent fluxes and the respective surface deepening rates during the explosive deepening period and thus to lower minimum pressures, which are closer to ERA-Interim reanalysis values. Moreover, the intrusion of the diabatic heating in the middle troposphere due to latent heat release was also examined, demonstrating

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the necessity for the determination of the most suitable parameterization of the model physics.

1 Introduction

Mediterranean explosive cyclones are characterized by heavy rain and consequent flooding, hail, significant wave heights and gale force winds that can severely affect coastal, touristic and agricultural areas, ports and shipping with serious social and economic impacts (Nissen et al. 2010). Low-level diabatic processes play an important role in Mediterranean explosive cyclogenesis, especially in the Eastern basin (Kouroutzoglou et al. 2015). Moreover, Shay-El and Alpert (1991) and Lolis et al. (2004) have shown that low level diabatic heating in the eastern Mediterranean is enhanced compared to the western and central Mediterranean.

Operational numerical models are not always capable of simulating effectively the real surface deepening rates due to the respective effect of the diabatic processes (Reed et al. 1988). Moreover, according to Khain et al. (2015), the physically expected sensitivity of the COSMO model to specific tested parameters is examined, based on the calibration method described in Bellprat et al. (2012).

The objective of this study is to assess the ability of the regional high resolution model COSMO/GR to effectively simulate the influence of diabatic heating and the produced surface deepening rates, under different parameterizations of the model physics.

2 Data and Methodology

The examined case study exhibits a 30-h total duration of explosive deepening (absolute value of the normalized deepening rate ≥1 Bergeron) between 05/01/2012 12UTC (05/12UTC) and 06/01/2012 18UTC (06/18UTC). Both the explosive cyclogenesis and the maximum explosive deepening occurred in the coastal areas between the SW Balkans and the southern Adriatic Sea at 06/12UTC (1.53 Bergerons). The complete cyclonic track, derived from the University of Melbourne cyclone finding and tracking algorithm (MS algorithm) based on ERA-Interim MSLPs on a $0.5° \times 0.5°$ latitude-longitude grid, is displayed in Fig. 1.

The COSMO/GR model runs were performed using the 6 hourly analysis of the ECMWF operational model and the outputs are at a 7 km grid on an hourly time step. The model sensitivity is examined on the basis of different model runs with different values of the parameter sea roughness (hereafter rat_sea). Sea roughness represents the heat resistance length of laminar layer, but over the sea. The higher is rat_sea the higher is the resistance of laminar layer for heat transfer and consequently, the lower is the heat transfer between the surface and the lower atmosphere (Buzzi 2008). One should expect that the effect of rat_sea will be pronounced only

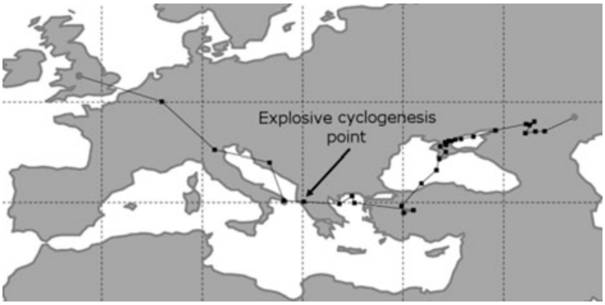

Fig. 1 Explosive cyclone track (propagating eastwards) as derived from the MS algorithm

over the sea or near coastal areas at wintertime, when the sea is relatively warm. The increase of rat_sea should decrease the temperature and humidity fluxes from the sea to the air, leading to decrease of precipitation. The dates and times referred to in the following sections will be noted using the abbreviation dd/hh, where dd is the day of the month and hh is the hour in UTC.

3 Results

In the default run, at the time of the explosive cyclogenesis, an extended 500 hPa cyclonic circulation covered Eastern Europe and the Balkans, centered over the southern Adriatic Sea, while at surface a respective extended cyclonic circulation covered the area between central-north Greece, the NW Aegean and the SW Balkans with pressures about 986 hPa. During the next 6 h, the surface cyclone propagated towards the northern Aegean Sea and presented further deepening.

According to the cyclone track (see Fig. 1), after 05/18UTC, the cyclonic center at its S-SE movement was found over the maritime region of the Adriatic Sea, favoring the air-sea interaction and, consequently, this phase of the cyclone's evolution is likely to be mostly crucial. Diabatic heating contributes to cyclogenesis indirectly, by increasing the low level instability. Sensible heat flux steepens the lapse rate and latent heat flux creates convective instability (Metaxas 1978). Indeed, all model runs depict an enhancement of the surface turbulent fluxes and especially the latent heat fluxes, during the second half of the 24 h explosive deepening period. Sensible heat fluxes were mostly strengthened after the passage of the cyclone's frontal activities, where low level flow shifted in northern directions favoring the low level cold advection and consequently the air-sea interaction. Nevertheless, there is a distinct strengthening of the fluxes in the cyclone's center area with smaller values of the rat_sea parameter. A characteristic example is illustrated 12 h before the explosive cyclogenesis (not shown) until the explosive cyclogenesis and maximum explosive deepening at 06/12UTC, in the coastal areas of SW Balkans, regarding the latent heat fluxes (Fig. 2) and the sensible heat fluxes (not shown).

Except for the thermal fluxes enhancement in the 30 h explosive deepening, the differentiation of the roughness parameter also affects the calculated cyclone deepening rates. From Fig. 2, it can be easily seen that when rat_sea = 1 a cyclonic center of 982 hPa is located over the NW Aegean Sea and 984 hPa over the coastal areas of the SW Balkans. On the contrary, with the default value of the parameter, an extended center with the last closed isobar of 986 hPa covers the greatest part of the Central-North continental Greece and the NW Aegean Sea (Fig. 2b).

The temperature variations due to the latent heat release were calculated for the isobaric levels of 700, 600, 500 and 400 hPa (not shown), to take a first insight into the intrusion of the surface and low-level diabatic heating in the mid-troposphere. It was found that for rat_sea = 1, the highest 600 hPa temperature increase was observed in the area of the upper-level closed cyclonic center between the SW Balkans and the southern Adriatic Sea, while the upper-level cyclone was deeper, supporting the interaction between upper level baroclinic and diabatic processes.

The effect of the different simulations is also highlighted in the spatial distribution of the calculated hourly total precipitation at the time of the explosive cyclogenesis (not shown). Differences in the simulations arise at the area of the explosive cyclone center, i.e. the NW Aegean Sea and central North Greece and at the area of the cold front of the depression, i.e. the region between the central and the northeastern Aegean Sea.

The effect of the parameterization of rat_sea is more precisely illustrated through the temporal variations of minimum mean sea level pressure, following the cyclone's center, covering the wider geographical area from the southern Adriatic to the northern Aegean Sea (see rectangle in Fig. 2), being denoted as explosive cyclone zone (Fig. 3a). Also, the respective variations are shown for the 96-h period of the study, at two specific points during the explosive deepening phase, namely at 06/06UTC (Fig. 3b) and 06/18UTC (not shown). The sensitivity was gauged through six different simulations, employing values of rat_sea between 1 and 100, which constitute, respectively, the lower and upper parameter limits in the COSMO model. It is evident that pressure differences between the six runs seem to

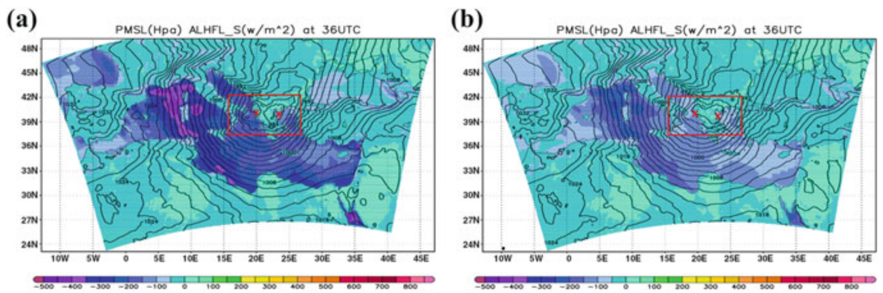

Fig. 2 MSLP and latent heat flux distribution for model run with: **a** rat_sea = 1, **b** rat_sea = 20 (default value), during explosive cyclogenesis. Contour intervals are 2 hPa-50 W/m^2, respectively. The *rectangle* denotes the explosive zone and the crosses the positions of the explosive deepening

arise 24 h after the beginning of the runs, being maximized during the period 36–42 h, namely during the explosive deepening, where surface fluxes and especially latent heat fluxes presented an enhancement in the cyclone area, as was previously referred, almost for all model runs, but primarily for model runs with smaller rat_sea, equal to 1 and 10 and, secondly, for the default run (rat_sea = 20). In every distribution of Fig. 3, the pressure difference in the model simulation for rat_sea = 1 and rat_sea = 100 is almost 5–6 hPa during the period of explosive deepening and begin to flatten 42 h after the model initiation.

Furthermore, the MSLP simulations of the model at 06/12UTC (Fig. 4) and 06/18UTC (not shown) were compared to the respective ERA-Interim MSLP on the finest available grid 0.125° × 0.125° grid. From the comparison, it becomes evident that the simulation for rat_sea = 1 is very similar to the respective reanalysis pattern for both the 06/12UTC (36 h run) and 06/18UTC (42 h run) with pressure values closely to 980 hPa. Even 6 h before the explosive cyclogenesis (06/06UTC), where the cyclone center was in the Brindisi area (see Fig. 1), the ERA-Interim

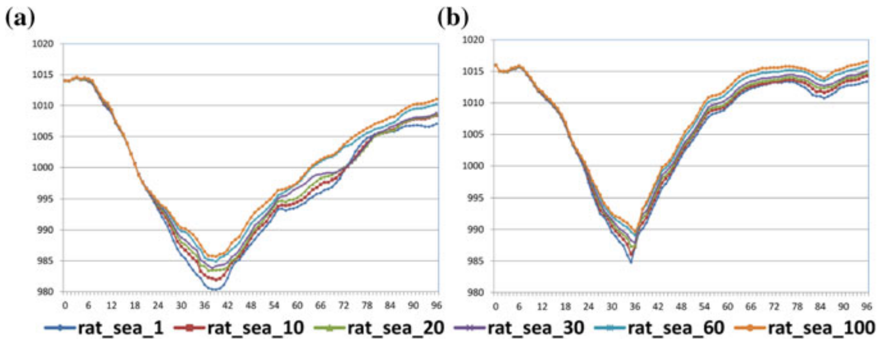

Fig. 3 Temporal variations of **a** minimum pressure in the explosive cyclone zone, **b** pressure in longitude 18.12° and latitude 40.18° at 06/06 UTC, for the 96 h time period of all models runs

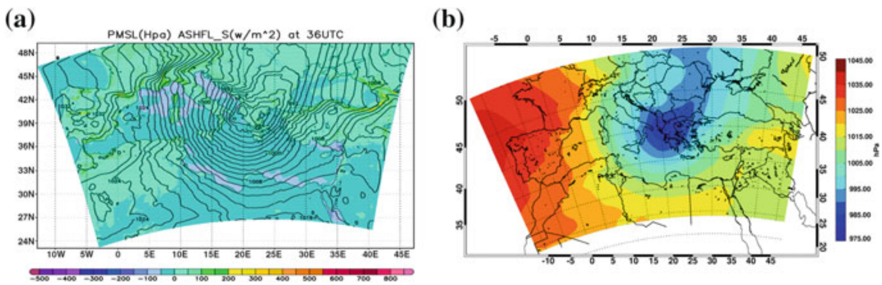

Fig. 4 **a** MSLP and sensible heat fluxes at 06/12UTC from COSMO/GR with rat_sea = 1 and **b** ERA-Interim MSLP at 06/12UTC. Contour intervals: 2 hPa-50 W/m^2 and 5 hPa, respectively

simulation was very closely to the respective COSMO simulation with rat_sea = 1 (not shown), which can be also verified by the distribution of Fig. 3b. When the cyclone passed from that area (30 h run), the pressure was approximately 987 hPa (Fig. 3b), while the respective analysis value is 986 hPa.

4 Conclusions

In this study a first attempt was made to assess the sensitivity of COSMO/GR atmospheric model to effectively simulate the influence of diabatic heating on a characteristic case of explosive cyclogenesis in the eastern Mediterranean, under different parameterizations of the sea roughness parameter, which is highly affected by the air-sea interaction in both the maritime and coastal areas. It was found that smaller values provide stronger surface turbulent heat fluxes and mid-level diabatic heating, which in turn produce higher deepening rates. The respective temporal variations of pressure in the explosive cyclone's zone and pressure in specific time steps within the explosive deepening period, revealed that lower values compared to the default parameterization, simulate the cyclone's evolution in a more effective way. The above results provide a good basis to examine the possible effect of changes in other parameters of the model physics related to the simulation of the non-baroclinic processes, to expand the above assessment on the climatology of Mediterranean explosive cyclogenesis and, thus, to improve the model parameterization for the needs of the operational forecasting in the Hellenic National Meteorological Service.

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