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Cyclonic Activity and Severe Jugo in the Adriatic

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Abstract. A case study on 2-3 April 1996 is presented, as an example of the typical chain of mesoscale events over the Adriatic region. The case is characterised by the extreme amounts of daily precipitation along the Croatian coast of the Adriatic. Besides heavy precipitation, strong jugo, with gusts up to 30 m/s, occurred in the southern Adriatic. Analysis of the Meteosat infrared images shows that a shallow cyclonic vortex develops in the Adriatic parallel to the development of the cyclone in the Mediterranean. The ability of the mesoscale ALADIN model to simulate the process is presented. Results of simulation show that the model successfully reproduced the distribution and the intensity of recorded precipitation as well as the jugo strength along the coast.

1 Introduction

The eastern Adriatic coast belongs to the areas with strongest precipitation in the Alpine region (Frei and Schär, 1998). Absolute maximum of precipitation in all seasons is found in the northern part of Adriatic area, where the Dinaric Alps are narrow and steepest. Another maximum is located at the southern Adriatic coast.

Climatology of heavy precipitation events relates them to the occurrence of strong to severe southeasterly wind, locally called jugo, which carries warm, humid Mediterranean air to the Adriatic. Jugo belongs to the family of southeasterly winds in the Mediterranean, generally known under a common name *scirocco*. Forecasting strong and severe jugo is of special importance since it induces high tides in the Adriatic, the process that occasionally leads to a flood of the northern Adriatic lowlands (e.g. Venice).

The strongest jugo blows prior to intense cyclogenesis south of the Alps, particularly when cyclogenesis occurrs in the northern Adriatic and the Po valley. Further on, a cold air outbreak over the Alps takes place, followed by strong bora along the coast and behind the cyclone moving fast along the Adriatic sea channel to the southeast. In the process of the Adriatic cyclone development important role is played by the Dinaric Alps which, through their upstream blocking, induce strong pressure and temperature gradients behind the cyclone along the coast. The Apennines orography acts to separate cyclonic circulation in the lower troposphere, with two centers in pressure and wind fields located offshore on either side of the Italian peninsula (Brzović, 1998).

Today there is a growing need and importance of forecasting this chain of mesoscale events, particularly the intensity of precipitation, one of the main questions addressed within the Mesoscale Alpine Program (Binder and Schär, 1998).

This work presents an event which follows the above described scenario. The aim of the paper is to describe some aspects of the process of Alpine cyclogenesis using the Meteosat images and to verify the capability of a mesoscale operational model to reproduce observed wind and pressure patterns at low levels as well as the precipitation pattern.

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2 Synoptic overview and local characteristics

The development of a deep cyclone started in the Atlantic and proceeded across the western Europe towards the Golf of Genoa. On 1 April at 18 UTC (Fig. 1) a warm front associated to the cyclone can be observed over the Apennine peninsula and the western Mediterranean. At this time the main cyclonic center is located over the southeastern France. Surface analysis indicates that in the next hours a secondary shallow low develops over the northern Italy (Fig. 5).

However, the attached cloud system spreads more to the north, covering the whole Adriatic and a large part of Central Europe (Fig. 2), suggesting that a center of this secondary low is situated somewhere in the northern Adriatic. The subsequent surface analysis (Fig. 6) clearly shows a small low in the northern Adriatic, while the main center has moved towards the northeast and both cloud systems have merged together into one (Fig. 3). The whole cloud system has then moved towards the northeast. On 3 April the center of the cy-

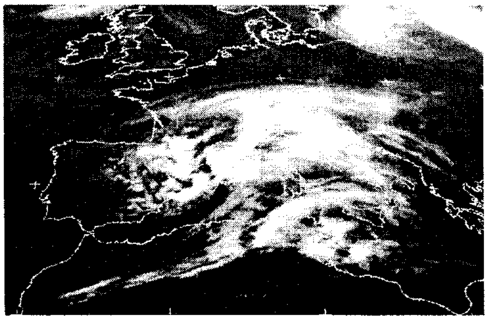

Fig. 1. Meteosat infrared image for 1 April 1996, 18 UTC.

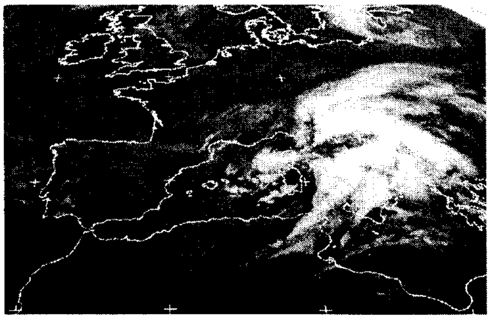

Fig. 2. Meteosat infrared image for 2 April 1996, 06 UTC.

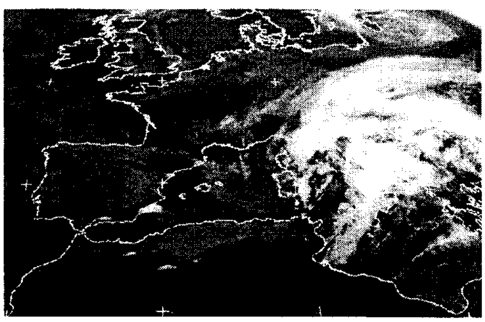

Fig. 3. Meteosat infrared image for 2 April 1996, 12 UTC.

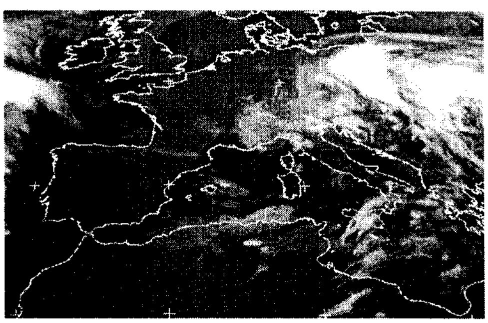

Fig. 4. Meteosat infrared image for 3 April 1996, 06 UTC.

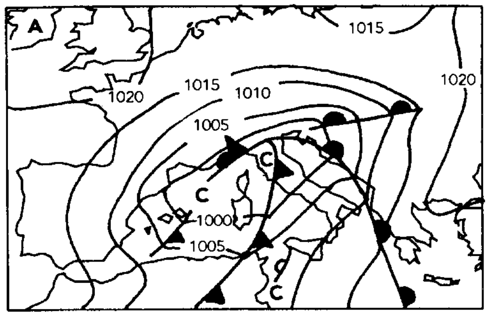

Fig. 5. Sea level pressure (hPa, interval 5) analysis based on the surface chart of the German Weather Service for 2 April 1996, 06 UTC.

clone was moving along the Adriatic and dissipating slowly (analysis not presented).

The strongest processes took place during the 2nd of April when heavy rainfall occured along and near to the Adriatic coast. The 24-hours precipitation measured at 06 UTC on 3 April in some regions exceeded 150 mm (Fig. 7). The largest amount of precipitation in the northern Adriatic region was 173 mm, measured at the station Baške Oštarije (north of Zadar). In the afternoon and evening on 2 April, while the cyclone was moving towards the southern Adriatic, rainfall was the heaviest at the southern Adriatic coast, again with amounts near to or exceeding 100 mm in 24 hours. The two pronounced maxima can be found northeast of Split (108 mm) and in the region near Dubrovnik (180 mm), while the absolute maximum of precipitation, 212 mm in 24 hours, was measured at the station Kozica, nortwest of Ploče. At many stations the total amount of precipitation measured during that case was nearly the average monthly amount. It is noteworthy to mention that the precipitation analysis given in Fig. 7 is based on 394 rainfall measurements, including all measurements of the Meteorological Service as well as several additional rainfall networks.

Besides heavy precipitation, strong jugo blew over the southern Adriatic. Maximal jugo gusts reached 30 m/s and were recorded during the noon hours on 2 April when the sec-

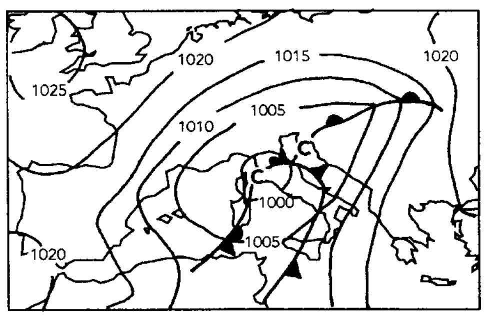

Fig. 6. Sea level pressure (hPa, interval 5) analysis based on the surface chart of the German Weather Service for 2 April 1996, 12 UTC.

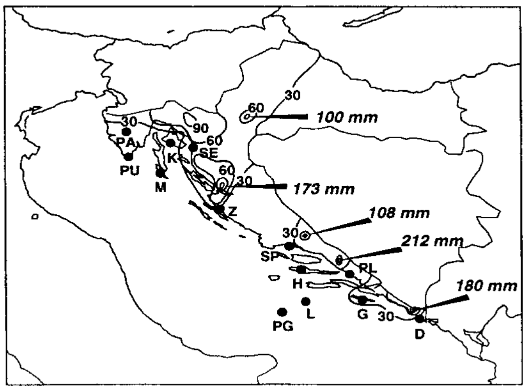

Fig. 7. 24-hours precipitation (mm) measured on 3 April 1996, 06 UTC. 30, 60 and 90 mm isolines and location of maximal precipitation are presented. One/two-letter codes designate stations mentioned in the text: D-Dubrovnik, G-Mljet, L-Lastovo, PG-Palagruža, PL-Ploče, H-Hvar, SP-Split, Z-Zadar, M-Mali Lošinj, K-Krk, S-Senj, PU-Pula, PA-Pazin.

ondary cyclonic center was situated in the northern Adriatic.

3 Numerical simulation

Numerical simulation is a result of a mesoscale model ALADIN. It is a primitive equations, spectral model that evolves from the collaboration between the Météo-France and National Meteorological Services of several European countries (members of the ALADIN international team, 1997). More details about the model can be found in Bubnova et al. (1995) and Cordoneanu and Geleyn (1998). Since recently the model is running operationally on a daily basis on different domains over participating countries. In all cases the initial state and time-dependent lateral boundary fields are obtained from the operational outputs of the global ARPEGE model.

The Meteorological and Hydrological Service of Croatia has joined the project in 1995 and the present experience with the model shows that it provides valuable forecast information for predicting cyclonic activity in the Adriatic region, as already presented by Brzović et al. (1997).

The present simulation starts on 2 April, 00 UTC and the model is run for 48 hours. Simulation domain covers the Adriatic region together with the surrounding orography of the Alps, Balkan and Apennine peninsula. A Lambert grid contains 135×111 points and 27 vertical unequally spaced levels. The horizontal resolution is 10.8 km. Initial and boundary conditions come from the objective analyses of the global model ARPEGE.

During the morning hours on 2 April, the strength of jugo over the Adriatic was increasing. At 06 UTC forecast jugo speed along the coast was 10-15 m/s, in agreement with synoptic observations. Over the open Adriatic wind blew stronger, in the northern Adriatic cyclonically turning to the west (Fig. 8). Another cyclonic vortex in the wind field is found near Corsica, at the location of the main cyclonic center at this time

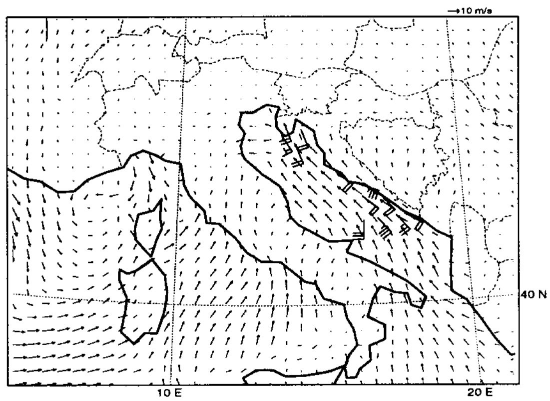

Fig. 8. 6-hours forecast of 10 m wind (m/s), valid at 06 UTC, 2 April 1996. Synoptic reports (m/s, conventional notation) are overlayed. Positions of the stations can be seen in Fig. 7.

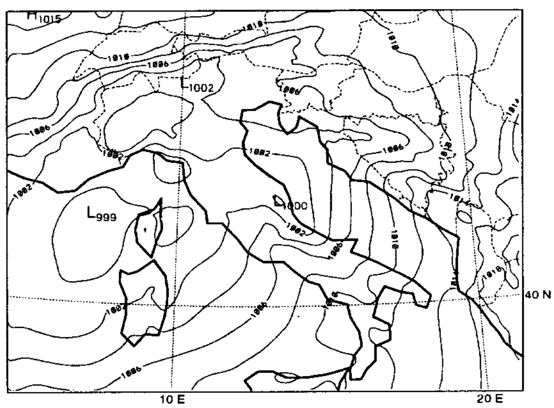

Fig. 9. 6-hours forecast of mean sea level pressure (hPa, interval 2), valid at 06 UTC, 2 April 1996.

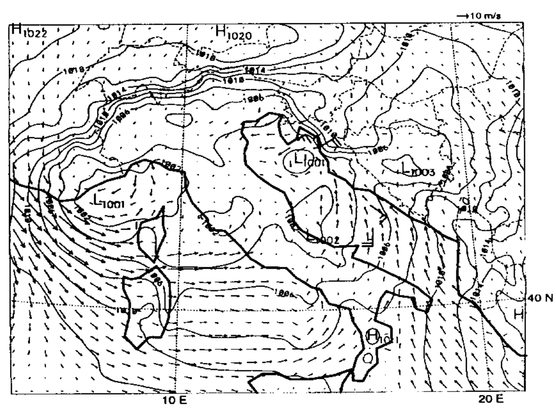

Fig. 10. 27-hours forecast of mean sea level pressure (hPa) and 10 m wind (m/s), valid at 03 UTC, 3 April 1996. Wind observations at Pula, Senj, Hvar and Palagruža are overlayed.

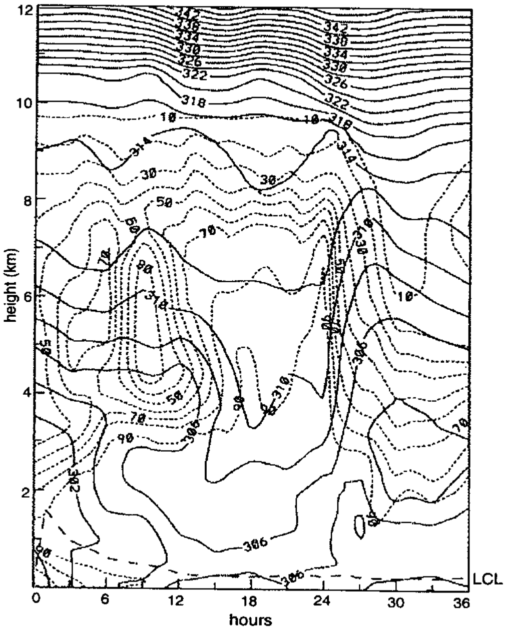

Fig. 11. Time-height cross-section of relative humidity (dashed lines) and equipotential temperature (solid lines), extracted from the model at grid point closest to Dubrovnik, during the period from 2 April 1996, 00 UTC to 3 April 1996, 12 UTC. LCL marks lifting condensation level.

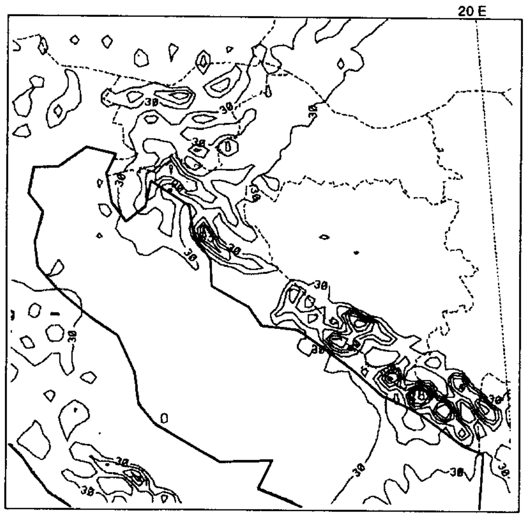

Fig. 12. 24-hours accumulated precipitation from the model during the period 2-3 April 1996, 06 UTC (zoom over the region of interest). Isolines each 30 mm, starting from 30 mm.

(Figs. 2, 5). Forecast wind strength continues to increase until the end of the day, when the recorded speeds also reached their maximal values.

Mean sea level pressure features are under the dominant influence of the local orography. Besides the main center situated in the Ligurian sea, a shallow, secondary low starts developing close to the Adriatic coast of northern Italy (Fig. 9). The model has captured the whole process of time and space variations very well. After 27 hours of integration (Fig. 10), the northwestern flow around the eastern Alps has strengthened. Significant pressure gradients have established across the Alps and the northern part of the Dinaric Alps. Bora started in both model and reality while jugo in the southern Adriatic has weakened (wind observations at Pula, Senj, Hvar and Palagruža are overlayed in the Figure). By the end of the day on 3 April (e.g. the end of the model integration) bora speed down of the steep Velebit mountain was between 10 and 15 m/s.

Fig. 11 shows a time-height cross-section of relative humidity and equipotential temperature extracted from the model at the grid point closest to Dubrovnik, where during the noon hours on 3 April a tragic accident occurred to the American State Department plane. Data are extracted at every 3 hours and interpolated using a method presented by Glasnović et al. (1994), which is currently operationally used by the Weather Service in Zagreb and some other member countries of the ALADIN project. The model forecast largest content of humidity during the afternoon on 2 April, with 70% up to the 8 km height. This was indeed the period of the most intense precipitation in the southern Adriatic area. Consequently, lifting condensation level (LCL) is located at about 500 m above the ground. After the midnight (24 hour of integration) humidity content has rapidly decreased following the passage of a cold front. The front is well indicated by the isopleths of equipotential temperature that steeply lift up.

The precipitation produced by the model, shown in Fig. 12 for the same time range as the recorded precipitation (seen in Fig. 5), gives the last and the most important evidence of the model good performance. Two main regions of maximal precipitation are well reproduced: Dubrovnik area and the northern Adriatic region. The forecast maxima also agree very well with the observation, particularly in the northern parts (163 mm in comparison with the recorded 173 mm).

4 Conclusions

In this work a typical chain of mesoscale events over the Adriatic region was analyzed using the satellite images and the results of numerical simulation. Consecutive events are jugo, a humid, warm wind blowing inside the warm sector of a cyclone in the Mediterranean, generation of a cyclonic vortex in the Adriatic, and bora onset behind it following the passage of the cold front over the Alps. The most intense cases bring large amounts of precipitation to the eastern Adriatic coastlands.

Special attention in the presented case is given to the precipitation forecast. The ability of the mesoscale ALADIN model to reproduce the recorded maxima and intensity of precipitation along the eastern Adriatic coast has been investigated. The results show that the ALADIN model, even without any special tunning, is able to describe the sensitive mesoscale chain of processes over the Adriatic sea and surrounding orography. The model successfully reproduced distribution and the amounts of recorded precipitation, as well as the jugo strength and cyclonic circulation in the Adriatic. Specially the timing and the intensity of the particular event are here important: jugo strength, due to the high tides it induces in the shallow northern Adriatic sea, bora onset, usually very abrupt and sometimes dangerous for the ferryboat traffic and the maximum of precipitation.

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