WEATHER DEVELOPMENTS LEADING TO HEAVY SNOW IN THE SOUTH-EASTERN ALPINE REGION

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Abstract: Heavy precipitation events occuring in the Western and Central Alps have been the focus of a number of studies. However, extreme Alpine precipitation (EAP) events observed in the South-Eastern Alps appear to have received little attention. Here we concentrate on the winter EAP events that led to heavy snowfall in the South-Eastern Alpine region in the last 25 years. Four types of synoptic pattern are identified as being responsible for the extreme precipitation, and for each type a case study is presented. Their analysis has been performed by looking at the large-scale dynamics of the Atlantic-European region, with particular emphasis on the potential vorticity (PV) view of synoptic development. These synoptic patterns differ mainly in shape and position of the upper level positive PV anomaly. In one case, the latter appears as a narrow streamer elongated in the north-south direction, approaching the Alps from the West and associated with a broad trough extended over Western and Central Europe. In a second case, the same initial PV structure occurs but, in presence of a cold advection and north-westerly flow impinging upon the Alps at the lower levels, Alpine lee cyclogenesis is triggered. In the other two cases, isolated tropopause level positive PV anomalies lead to the heavy snow events over the South-Eastern Alps. The PV anomaly may penetrate into the Mediterranean Sea from the North and then it approaches the Southern slopes of the Alps from the South-West, or it may move from the North-East towards the northern side of the Alpine ridge. The identification of these features may constitute an aid for weather forecasting in this region and also for the evaluation of models for it.

Keywords: Extreme Alpine Precipitation, Heavy Snowfall Events, Potential Vorticity.

1. INTRODUCTION

The first slopes of South-Eastern Alps receive a large amount of winter precipitation (Fig. 1a), but the frequency of days with precipitation is low compared to many other sectors of the Alps with similar values of total mean winter amount (Fig. 1b). This points to the high precipitation intensity that is often measured along the southern rim of the Alpine ridge (Frei and Schär, 1998). Here the large-scale synoptic patterns that lead to winter-time EAP in the form of heavy snow events in the South-Eastern Italian Alps are analysed.

2. DATA AND METHODS

Snow-related data measured from December 1981 to March 2006 in the Trentino district have been analysed. The events that led to a daily new snow amount larger than 50 cm in at least 4 stations in Trentino have been taken to be major EAP events. Fifteen such events were found, and four different types of synoptic developments have been identified as being responsible for them. The basic snow-related data for Trentino province were collected from the public meterological centre *Meteotrentino*. To complement this, the snow amounts registered by the local weather centres in the nearby Veneto (*Arpav*), Friuli Venezia Giulia (*Osmer*) and Alto Adige (*Ufficio Idrografico*) districts were also considered.

The diagnosis of the synoptic developments has been performed using the ERA-40 reanalysis upto 2001 and the operational at ECMWF after that. The spectral resolution of these analyses is T159 and T511, respectively; both use 60 levels. Particular emphasis has been given to the PV view of synoptic development as described in Hoskins *et al.* (1985) and Hoskins (1997). This quantity has been considered because it is conserved in 3-D motion in the absence of frictional and diabatic effects and because it gives a complete representation of synoptic-scale atmospheric dynamics and thermodynamics: it is possible to deduce the wind, pressure and temperature fields given the PV distribution.

3. EXTREME PRECIPITATION EVENTS

The synoptic situation of the storms that have been considered here to be good examples of the four different categories of those that produce large snow falls in the SE Alps is shown in Fig.2. The upper tropospheric state is described by the distribution of PV on the 315K potential temperature surface, whereas the streamfunction at 850 hPa, indicating the direction and strength of the rotational flow, represents the lower tropospheric circulation.

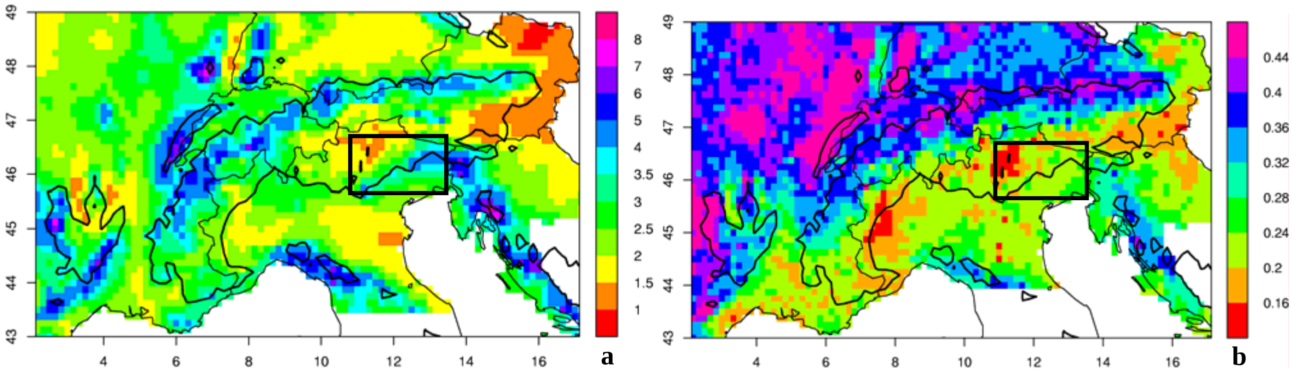

Figure 1 Mean winter precipitation as mm/day (a) and winter frequency (%) of days with precipitation ≥1mm (b) for the period 1971 – 1990. The thick line represents the 800 m asl topographic contour, whereas the black box indicates the location of the South-Eastern Italian Alps. Courtesy of C. Frei.

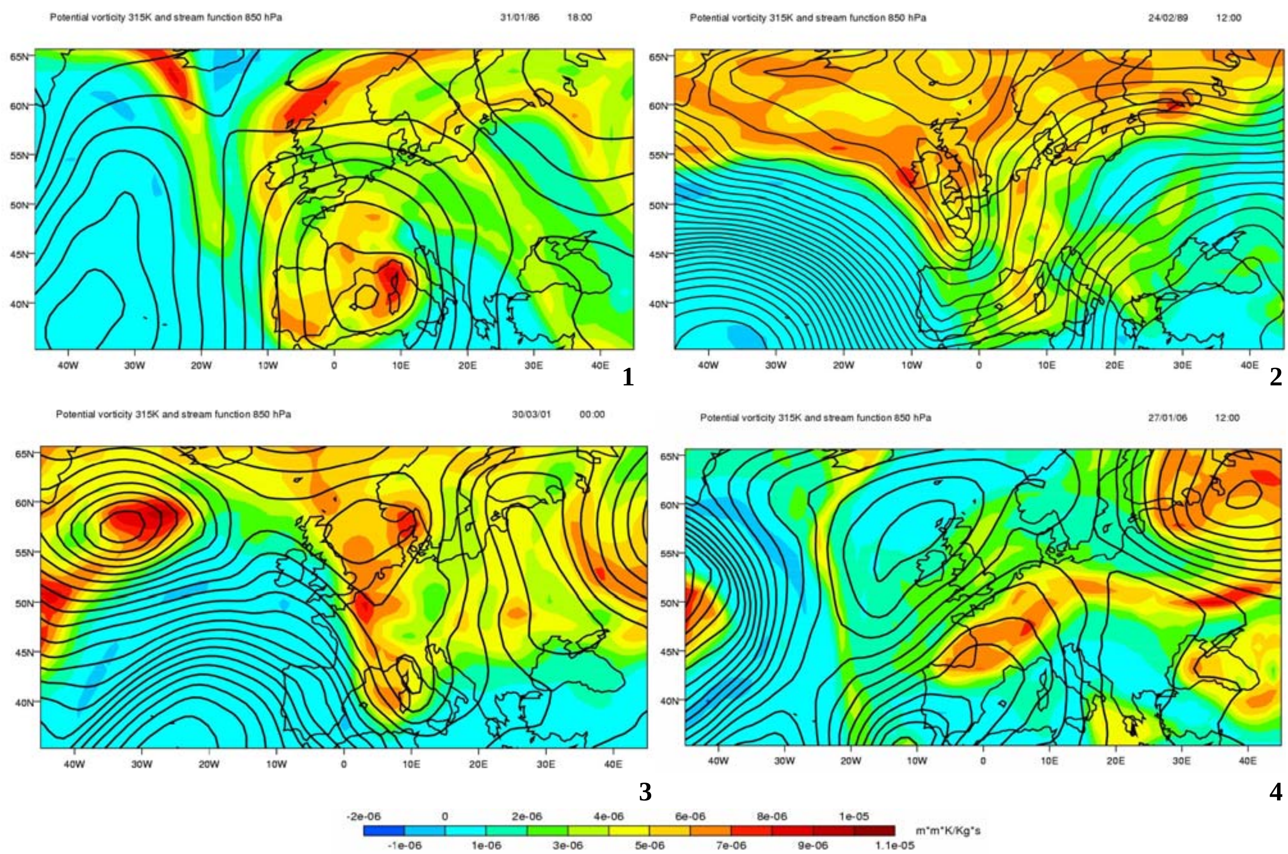

Figure 2: Potential vorticity on the 315K isentropic surface (colours) and 850 hPa stream function (lines) relative to the most significant phase of the presented snowstorms, whose date is indicated at the top of each panel.

Case 1: The heavy snow of 31 January and 1 February 1986

The snowstorm at the end of January 1986 gave the highest values of daily snow recorded in many places in the region. Snow was observed from 29 January until 4 February, but the most intense phase of precipitation lasted from 12 UTC on 31 January to 12 UTC on 1 February. Trentino, Veneto and South Alto Adige received the largest quantity of snow, more than 2 meters on the first alpine slopes and almost 3 meters in a few places. The surface temperature during the snowstorm was characterized by a moderate warming followed by a cooling from the early hours of 1 February. Fig. 2.1 refers to 18 UTC on 31 January, at the beginning of the period in which the largest precipitation rate was recorded in the South-Eastern Alps. The high PV region seen between the Ligurian Sea and Corsica was advected southwards in the previous days by the northerly flow present on the eastern flank of a strong, extended anticyclone in the North-Atlantic. The high PV air supply ended by the further building of this high to form a blocking anticyclone. In the lower troposphere a cyclonic circulation was centred between Corsica and the Balearic Islands, causing an intense warm advection over Southern Italy, extending almost up to South-Eastern Alps. This air flow is very moist and it was force to ascend above the Alpine slopes.

Case 2: The heavy snow of 24 and 25 February 1989

In the last week of February 1989 snow falls were observed every day in the South-Eastern Alps, with the most intense phase of the precipitation being recorded from the afternoon of 24 until the night 25/26 February. The Central Alps were most affected by the snowstorm but rapid snow accumulations were also measured in the South-Eastern Alps, up to 80 cm in 24 hours. During the snow fall there was a general cooling in the region.

Fig. 2.2 refers to 12 UTC on 24 February, when the most intense precipitation was approaching the South-Eastern Alps. It shows the presence of a broad trough over Central Europe, between an intense Atlantic anticyclone and another anticyclone over Eastern Europe. The trough appeared in the previous days as a streamer of large PV air moving eastwards and broadening. The winds were south-westerly in the upper and lower troposphere leading to a large flux of moisture into Alpine region.

Case 3: The heavy snow of 29 and 30 March 2001

This snowstorm lasted about a day from 12 UTC on 29 to 12 UTC on 30 March 2001, and snow accumulations up to 75 cm in 24 hours were measured. The snow rate was quite constant during the most intense phase of the snowstorm, whereas the near-surface temperature showed more variation with a general warming until the middle of 29 March, followed by a moderate cooling and the by a second warming.

Fig. 2.3 summarises the upper and lower tropospheric situation at 00 UTC on 30 March. A broad, intense anticyclonic wave is seen over the Atlantic Ocean, with advection of high PV air south-eastwards towards the Alps. During the previous days north-westerly winds in the lower levels advected cold air towards the Alpine ridge. Thus both the basic features recognized by Tafferner (1990) as being responsible for Alpine lee cyclogenesis were present; in particular, the south-east movement of the upper level trough is typical of the *vorderseitentype* Alpine lee cyclogenesis, following Pichler and Steinacker (1987). At 00 UTC on 30 March (Fig. 2.3) the cyclonic circulation was centred over the Gulf of Genoa, and it caused a strong advection of warm air from the south-east into the South-Eastern Alps, whereas cold air penetrated into the Western Mediterranean through the Rhone gap.

Case 4: The heavy snow of 26 and 27 January 2006

The snowstorm of the end of January 2006 lasted about 40 hours from the afternoon of 26 to the early morning of 28 January. The largest snow amounts were measured in the Forealps of Veneto and Trentino, up to 160 cm. The whole snowstorm was characterized by a continuous warming whose intensity three times larger at the high altitude stations compared with the valley. The precipitation rate was quite constant for the duration of the snowstorm.

The upper and lower tropospheric state for 12 UTC on 27 January 2006 is represented in Fig. 2.4. The main feature of note in the upper troposphere is the blocking anticyclone centred northwest of Scotland. Its anticyclonic circulation advected high PV air from the north-east towards the Alps, which in the following period cut-off and moved south-westwards to the Atlantic where it weakened. During the whole duration of this snowstorm the Alps were located in a region of large upper level PV gradient, with the positive PV anomaly remaining north of the Alpine ridge. The 850 hPa streamfunction shows the presence of the cyclonic portion of the block, which led to an intense southerly warm and moist flow over Italy creating the conditions for the large snow fall on the first slopes of the Alpine ridge.

4. DISCUSSION

The storms here briefly described share a number of common characteristics. They were all preceded by a strong upper tropospheric anticyclonic circulation in the North-Atlantic region that extended into relatively high latitudes. On the eastern side of this anticyclone high potential vorticity air was advected from northern latitudes into the neighbourhood of the Alps. In the lower troposphere relatively warm moist air was advected from lower latitudes around a cyclonic system into the Alpine region. There was dynamical forcing of ascent in this air stream and the intense snow fall occurred when there was also lifting over the Alpine slopes.

However the four cases differed in the details and development of these four related features: the meridional structure of the Atlantic anticyclone, the nature of the PV trough and the location of the high PV tip, the nature and the position of the lower tropospheric cyclone and the direction of the flow towards the Alps.

The North-Atlantic anticyclone was particularly extended into northern latitudes in Case 1, whereas it appeared as a cut-off blocking high in Case 4. The positive upper tropospheric PV anomaly showed different shapes: it formed a meridionally oriented streamer approaching the Alps from the west in Cases 2 and 3, it was advected southwards and formed a low cut-off south of the Alps in Case 1, it appeared as a tongue with a NE-SW orientation which led to a low cut-off north of the Alps in Case 4. A meridionally oriented high PV streamer was previously recognized by Massacand *et al.* (1998) to be a precursor of heavy precipitation over Central and Western Alps.

The surface cyclone caused strong south-easterly winds impinging upon the Alps and it was associated with the large upper tropospheric PV cut-off in Case 1, whereas in Case 4 it was part of the large-scale blocking structure. During case 3 the winds veered from south-west to south-east due to the Gulf of Genoa low pressure formation; in Case 2 there was a deep south-westerly flow ahead of the advancing trough. The latter synoptic pattern was previously identified by Ferretti *et al.* (2000) and Grazzini (2007) as being responsible for heavy precipitation over the Western Alps.

It is hoped that the identification of the features associated with intense snowfall events in recent years in the South-Eastern Alps will aid forecasting in this region and also in the evaluation of models for it. It would be of interest to investigate whether extreme precipitation events in this region in other seasons have similar synoptic characteristics.

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