1.3
Orographic forcing and Doppler winds, the key for nowcasting heavy precipitation in the mountains

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Summary

A superposed epoch analysis of radar data of 92 days with orographic precipitation in the Lago Maggiore region in the southern European Alps reveals a strong relation between the upstream flow, air mass stability and heavy precipitation amounts and distribution in the mountains. This result is the scientific basis of a novel heuristic nowcasting tool currently being developed at MeteoSwiss, which will benefit from the presence of the orographic forcing and will make use of high-quality precipitation and Doppler wind radar estimates and other observational data.

1 Introduction

In the Lago Maggiore region, which is located in southern central European Alps between Piedmont, Italy, and Ticino, Switzerland (Fig.1), some of the highest amounts of rain in the Alps are registered during the autumn season (Frei and Schär, 1998). Moreover, heavy rain and floods are frequent in this region (Lionetti, 1996; Doswell et al., 1998; Ferretti et al., 2000; Rotunno and Ferretti, 2001). The area has been chosen as one of the target zones of the Mesoscale Alpine Programme (MAP). During the MAP Special Observing Period (September-November 1999) a big number of observational instruments collected a considerable amount of meteorological data in the region (Bougeault et al., 2001). Thus this area has been the object of several studies concerning the synoptic and mesoscale processes leading to orographic precipitation; they are organically resumed in Rotunno and Houze (2007).

A necessary condition for heavy precipitation in the Lago Maggiore area is a moist large-scale flow, which is provided by an upper level trough approaching the Alpine chain from the West (Grazzini, 2007; Ferretti et al., 2000), accompanied by a narrow, deep and elongated streamer of intruded stratospheric air extending from the British Isles to the western Mediterranean (Massacand et al., 1998; Martius et al., 2006). During heavy precipitation events the flow in the upper levels is usually from South to South-West over the Alpine south-side, whereas in the low levels it is typically from South to South-East (Kappenberger and Kerkmann, 1997). Thus the southerly moisture-laden flow advects warm humid air from the Mediterranean Sea towards the Alps, determining the lifting of the air masses over the orographic barrier.
The role of the mesoscale flow and air mass stability during precipitation events observed in the region has been investigated by Houze et al. (2001) and Medina and Houze (2003). They found that the location of the maximum of orographic precipitation is closely linked to the strength and direction of the flow which is observed at the low levels over the Po Valley. Moreover, they proved that flow with an high Froude number (i.e. large velocity and small stability, unblocked situations) leads to a great enhancement of precipitation over the lower windward slopes and over the portions of the Po Valley just upstream of the mountains. On the other hand, when the Froude number is low (small velocity and large stability, blocked conditions), the flow at low levels turns cyclonically as it approaches the Alpine barrier, instead of rising over the terrain, and the enhancement

of precipitation over the mountains is not observed. Similar findings are also illustrated by James et al. (2004), who studied orographic precipitation enhancement mechanisms over coastal northern California.

In this study, which is based on the work done by Houze et al. (2001), heavy orographic precipitation events occurred from January 2004 through May 2008 in the Lago Maggiore area are examined. The objective of the superposed epoch analysis here presented is to establish the relative importance of wind speed, wind direction and air mass stability in determining orographic rain amounts and distribution in the Lago Maggiore region. The analysis focuses here on heavy rain events, and it makes use of radar maps of precipitation at the ground level and Doppler radar wind estimates. The final aim of this work is to provide the scientific framework upon which to build an heuristic system for nowcasting long-lasting and widespread heavy rain in the mountains (Panziera and Germann, 2007). The basic hypothesis to be proved is that if mesoscale wind and thermodynamic conditions explain space-time patterns of rainfall, radar wind and radiosounding information can be used for operational nowcasting.

2 Data

2.1 Radar Data

The primary source of data of this analysis is the MeteoSwiss Doppler weather radar located on Monte Lema (Fig.1), one of the southernmost mountains of the Alpine ridge in the Lago Maggiore region (Fig.2). Information on precipitation is obtained by the operational radar product for quantitative precipitation estimation, which is the result of sophisticated data processing based on 40 years of experience in radar operation in the Alpine environment at MeteoSwiss (Germann et al., 2006; Joss and Lee, 1995). The spatial resolution is 1km x 1km, the temporal resolution is 5 minutes. Radar data processing includes automatic hardware calibration, ground clutter elimination,visibility correction, correction for vertical profile of reflectivity, removal of residual non-weather echoes and bias correction. The latter compensates for systematic errors due to non-uniform beam filling, low-level growth not seen by the vertical profile correction and attenuation. The mesoscale flow is estimated by the Doppler velocity measurements, which are taken over 20 elevation angles and are updated every 5 minutes with a spatial resolution of 1 degree in azimuth and 1 km in range (Joss et al., 1998).

2.2 Automatic stations and sounding data

To characterize the atmospheric conditions upstream and in the Lago Maggiore region, this study makes use of radiosoundings and ground stations data. Radiosoundings data are relative to the Milano operational site, which is located just south-east of the Lago Maggiore area (see Fig.2). The observational frequency was four per day up to February 2006 (0000,0600,1200 and 1800 UTC), two per day afterthat (00,1200 UTC); radiosoundings are managed by the Italian Meteorological Service (Aeronautica Militare).

Ground stations data are derived from the MeteoSwiss automatic stations network, consisting of 115 automated meteorological stations all over Switzerland which measure the main meteorological parameters every 10 minutes. These data were used to estimate the stability of the lower atmosphere within the Lago Maggiore area. To this end, two couples of adjacent stations located at different heights were taken into account: Locarno Monti and Cimetta, Stabio and Monte Generoso (see Fig.2).

3 Methods

3.1 The choice of the heavy orographic precipitation events

Heavy precipitation in the Lago Maggiore region is typically accompanied by large-scale supply of moisture towards the Alps, as briefly described in Sect.1. This leads to long lasting precipitation spread over large areas. Cases with isolated convection and air-mass thunderstorms, which are mainly driven by mechanisms other than orographic forcing and are more localized both in

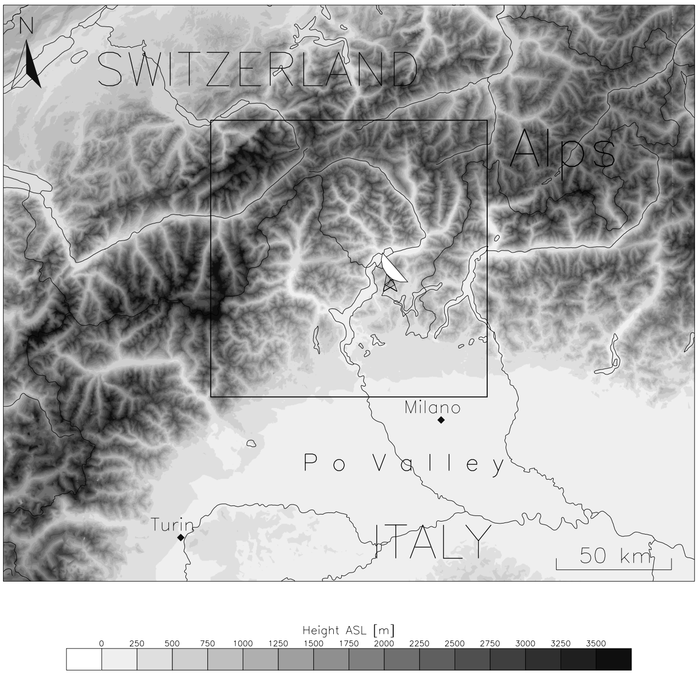


Figure 1: Orographic map of the Central Alps between Italy and Switzerland. The black box indicates the Lago Maggiore region, with the location of Monte Lema radar.

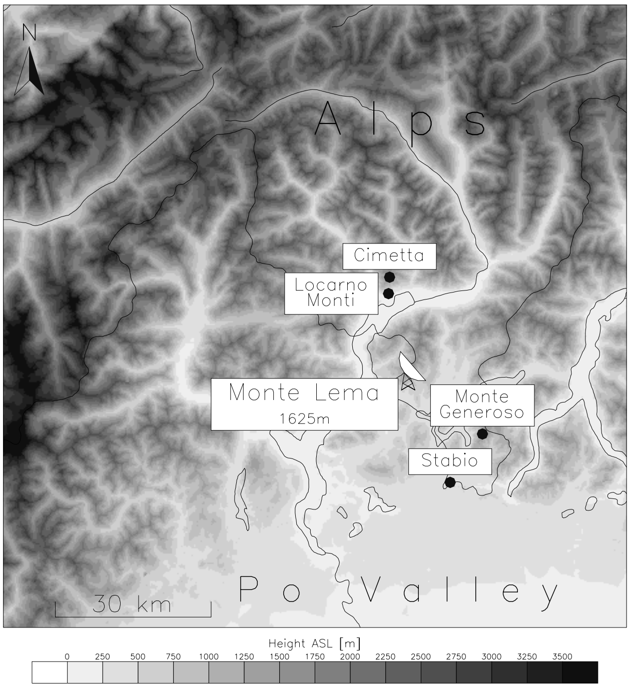


Figure 2: Zoom on the Lago Maggiore region. The location of MeteoSwiss Monte Lema radar is indicated, as well as the position of the ground stations considered in this study: Locarno Monti (*LOM*, 383 m), Cimetta (*CIM*, 1672 m), Stabio (*SBO*, 353 m), Monte Generoso (*GEN*, 1608 m). The spatial domain of this image is used also in the following figures, which show the results of the superposed epoch analysis.

space and time, are excluded from this study. The criterion adopted for the choice of the events is based on a careful analysis of the data relative to the operational radar product for quantitative precipitation estimation. In particular, the 2006 radar data-set was taken into account: in that year there were 103 days in which at least 0.63 mm/h of rain has been detected by the radar in at least 1000 km^2 within the Lago Maggiore region (which is ~ 8000 km^2 large); the time slots with missing data in the whole 2006 correspond to 9.4 days.
Since the number of heavy rain events varied depending on the thresholds used to define the intense rainfall, a simple statistical analysis was performed in order to find the reflectivity threshold values which exclude isolated convection cases. The resulting adopted criteria are: the reflectivity within the Lago Maggiore region has to exceed 34 dBZ (corresponding to a rain rate of 4 mm/h) in at least 1000 km^2 for at least 2 hours consecutively, and in at least 2000 km^2 for at least 1 hour consecutively. 49 events were found from January 2004 to May 2008, corresponding to 92 days of precipitation (2207 hours). 15 events were observed in the summer months (June to August), corresponding to 19 days of rainfall, whereas 2 events occurred in winter (December to February), causing 5.5 days of precipitation. Once an event was identified, its whole duration was calculated setting the reflectivity threshold to 22 dBz (corresponding to a rain rate of 0.63 mm/h) and the minimum area affected by precipitation within the Lago Maggiore region to 100 km^2.

3.2 Estimation of mesoscale flows

In order to detect the characteristic components of the mesoscale wind field producing heavy precipitation in the Lago Maggiore region, Doppler measurements are used to estimate the wind intensity and direction at different vertical levels and in specific areas. The location of the regions in which the flows are estimated was chosen by considering typical mesoscale conditions leading to heavy rain and analyzing the main geographical features of the Lago Maggiore territory in relation to the location of Monte Lema radar and radar visibility. A number of regions were found as possible areas in which to estimate the significant features of the mesoscale flow. The regions in which the wind estimate (described in detail in Sect.3.2.1) was possible and of high quality for the longest time periods during the whole data-set have been chosen. Four different regions have been identified, corresponding to four distinct flows (Fig.3):

1. The Low Level Flow (*LLF*), aimed to detect the wind at low levels over that part of the Po Valley closest to Lago Maggiore, between 1.5 and 2 km asl (the lowest height visible by the radar).
2. The Mid Level Flow (*MLF*), whose objective is to detect the wind ascending over the terrain in the Lago Maggiore region, between 2 and 3 km asl, estimated in a circle around the radar.
3. The Upper Level Flow (*ULF*), estimated in a wide ring around the radar between 4 and 5 km asl, in order to detect the synoptic upper level flow.
4. The Cross Barrier Flow (*CBF*), which represents the wind just south of the Alpine crest between 2.5 and 3.5 km asl northwest of Lago Maggiore. This region was chosen to retrieve the north-westerly wind associated with the passage of cold fronts which usually indicates the let-up of heavy precipitation in the region.

3.2.1 Wind estimation technique

To obtain the radial velocity of a target, Doppler weather radars determine the Doppler frequency of the backscattered signal. If the pulse repetition frequency of the radar is too low to resolve the phase shift that occurs between successive pulses reflected by moving precipitation particles, aliasing occurs. In this case the apparent phase shift detected by the radar differs from the true one by plus or minus some integer multiple of 2π. Therefore Doppler radar measurements need to be dealiased before the estimation of the wind can be performed. We make use of the four-dimensional Doppler dealiasing scheme developed by James and Houze Jr. (2001). This algorithm

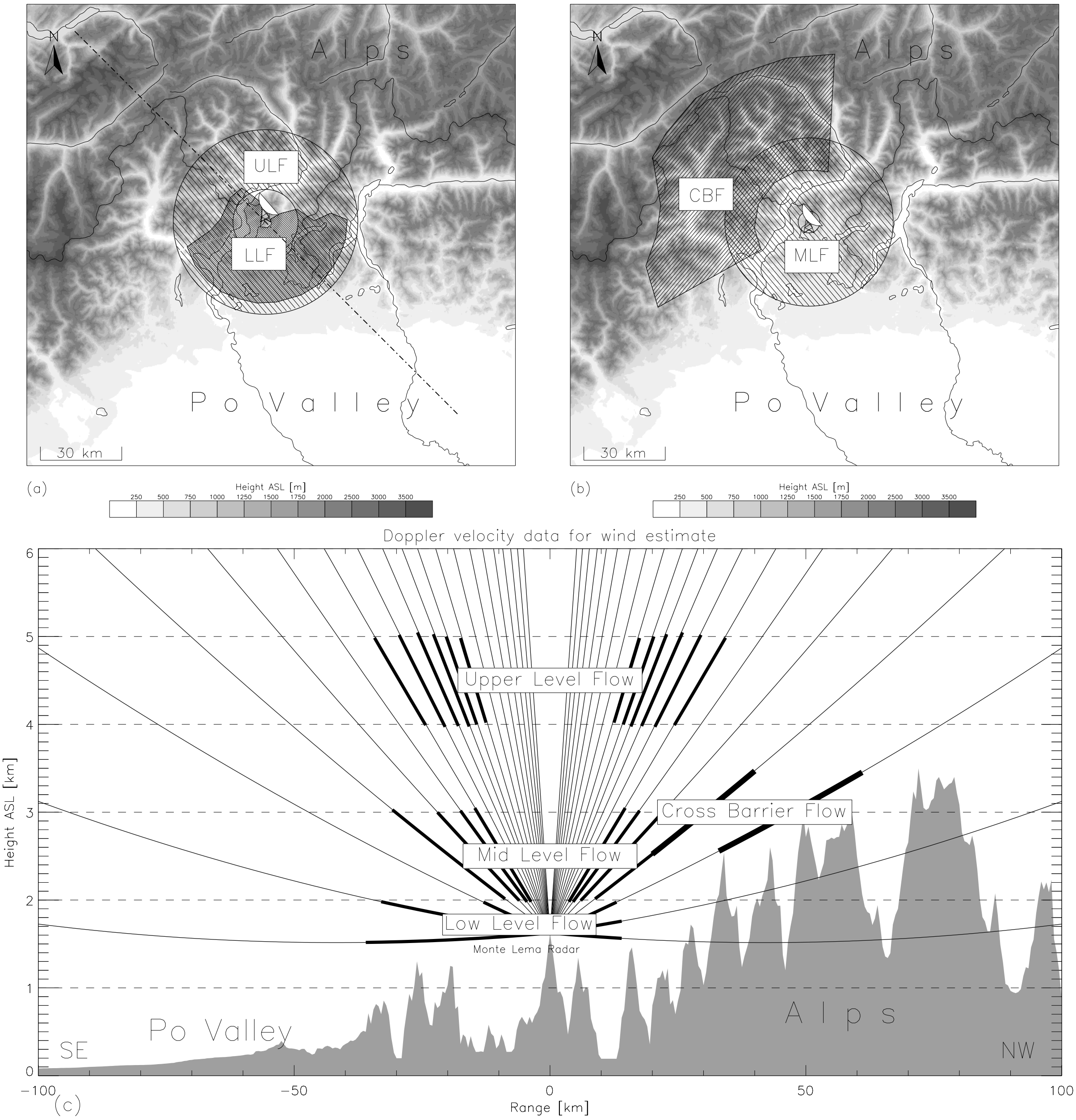


Figure 3: Location of the four regions in which the flows are estimated from Doppler measurements. (a) Horizontal extension of LLF and ULF; (b) Horizontal extension of CBF and MLF; (c) Vertical cross section performed along the dotted line in (a) showing the 20 elevation angles of Monte Lema radar scan strategy (thin lines) and the regions selected for the estimate of the flows (thick lines).

exploits not only the continuity of the radar measurements in space (three dimensions), but also in time (fourth dimension). After the dealiasing process, the intensity and direction of the flows are estimated by fitting a linear wind to all valid Doppler measurements within the pre-defined regions shown in Fig.3. Fitting is done by multiple regression using normal equations and Singular Value Decomposition. A number of automated quality controls is performed before and after the fitting, in order to reject the data which lead to wrong flow estimates and to detect the low quality flow estimates.

4 Superposed epoch analysis

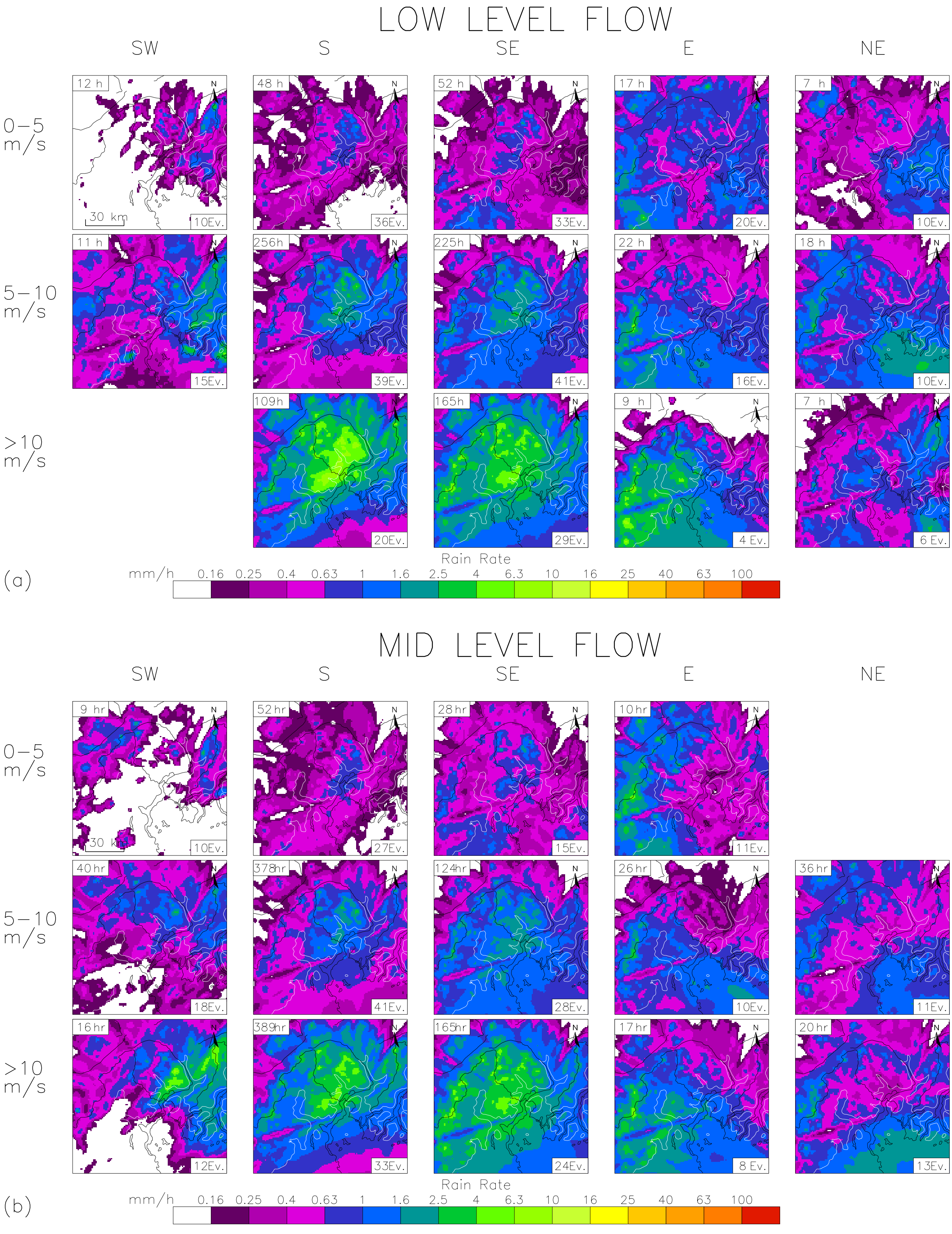
The general relation between different flow regimes and heavy orographic precipitation in the Lago Maggiore region is investigated by means of superposed epoch analyses. These investigations select from the 92-days heavy precipitation data-set the rainfall rates corresponding to particular *epochs*, which are defined by some specific requirements on atmospheric dynamic and thermodynamic parameters. Here, the specific requirements are given by the mesoscale flows and air mass stability. Then, mean precipitation rates are calculated at each grid point for each epoch. The objective of this investigation is not only to understand how mesoscale flows and air mass stability affect the character of orographic precipitation, but also to demonstrate whether or not any nowcasting tool based on their behaviour would improve operational nowcasting of heavy rain. A large amount of rain rate maps are averaged in this analysis, thus reducing the stochastic part of the uncertainties in radar rainfall estimates. The remaining uncertainty is not critical, as the focus here is not on the absolute values of the rain estimates, but rather on their variability in space and time.

4.1 Flows

In Fig.4 the mean rain rates corresponding to different classes of intensity and direction of LLF, MLF and ULF are presented. The number of total hours of precipitation, as well as the number of heavy precipitation events involved in each subset, are indicated in the corners of each panel. The results of this investigation for CBF are not shown, since they are very similar to the maps of MLF. Fig.4 clearly shows that the intensity of the rain over the orography and the spatial extension of the area affected by heavy precipitation increase with increasing intensity of the flows. The direction of the flows, on the other hand, seems to regulate the spatial distribution of the rain. The classes corresponding to southerly winds result the most populated and cause the heaviest precipitation in the Lago Maggiore area.
This stage of the superposed epoch analysis highlights the basic role of the orographic forcing in determining precipitation amounts and distribution in this region. Since only cases of precipitation detected by the radar are considered, the air is assumed to be saturated or nearly saturated by the time it produces rainfall over the Alps. Thus higher velocities of impinging flows cause a larger flux of moisture towards the Alps, which is orographically forced to ascent, resulting in more precipitation than in the case with low velocities.
This investigation was also performed by limiting the data-set to the most intense phases of the precipitation, and the results are qualitatively very similar to that shown in Fig.4, although the rain amounts are larger.

4.2 Stability

In order to investigate the sensitivity of orographic precipitation mechanisms to variations in the thermodynamic properties of the flow at lower levels, superposed epoch analysis of mean rain rate based on the moist Brunt-Väisälä frequency (Durran and Klemp, 1982) has been performed. Negative values of squared moist Brunt-Väisälä frequency denote potential instability, positive values indicate stable stratification. The main findings of this stage of the study are here reported, but the images reulting from this analysis are not shown.
In the first stage of this analysis, the stability of the atmosphere has been estimated by considering radiosoundings data of Milano, which is located about 50 km upstream of the Alpine barrier (see Fig.2). The subsets of data were simply given by the rain measured in correspondance



LOW LEVEL FLOW
SW
S
SE
E
NE
0−5 m/s
5−10 m/s
>10 m/s
12 h
48 h
52 h
17 h
7 h
10Ev.
36Ev.
33Ev.
20Ev.
10Ev.
30 km
11 h
256h
225h
22 h
18 h
15Ev.
39Ev.
41Ev.
16Ev.
10Ev.
109h
165h
9 h
7 h
20Ev.
29Ev.
4 Ev.
6 Ev.
(a)
Rain Rate
mm/h
0.16 0.25 0.4 0.63 1 1.6 2.5 4 6.3 10 16 25 40 63 100
MID LEVEL FLOW
SW
S
SE
E
NE
0−5 m/s
5−10 m/s
>10 m/s
9 hr
52 hr
28 hr
10 hr
10Ev.
27Ev.
15Ev.
11Ev.
30 km
40 hr
378hr
124hr
26 hr
36 hr
18Ev.
41Ev.
28Ev.
10Ev.
11Ev.
16 hr
389hr
165hr
17 hr
20 hr
12Ev.
33Ev.
24Ev.
8 Ev.
13Ev.
(b)
Rain Rate
mm/h
0.16 0.25 0.4 0.63 1 1.6 2.5 4 6.3 10 16 25 40 63 100

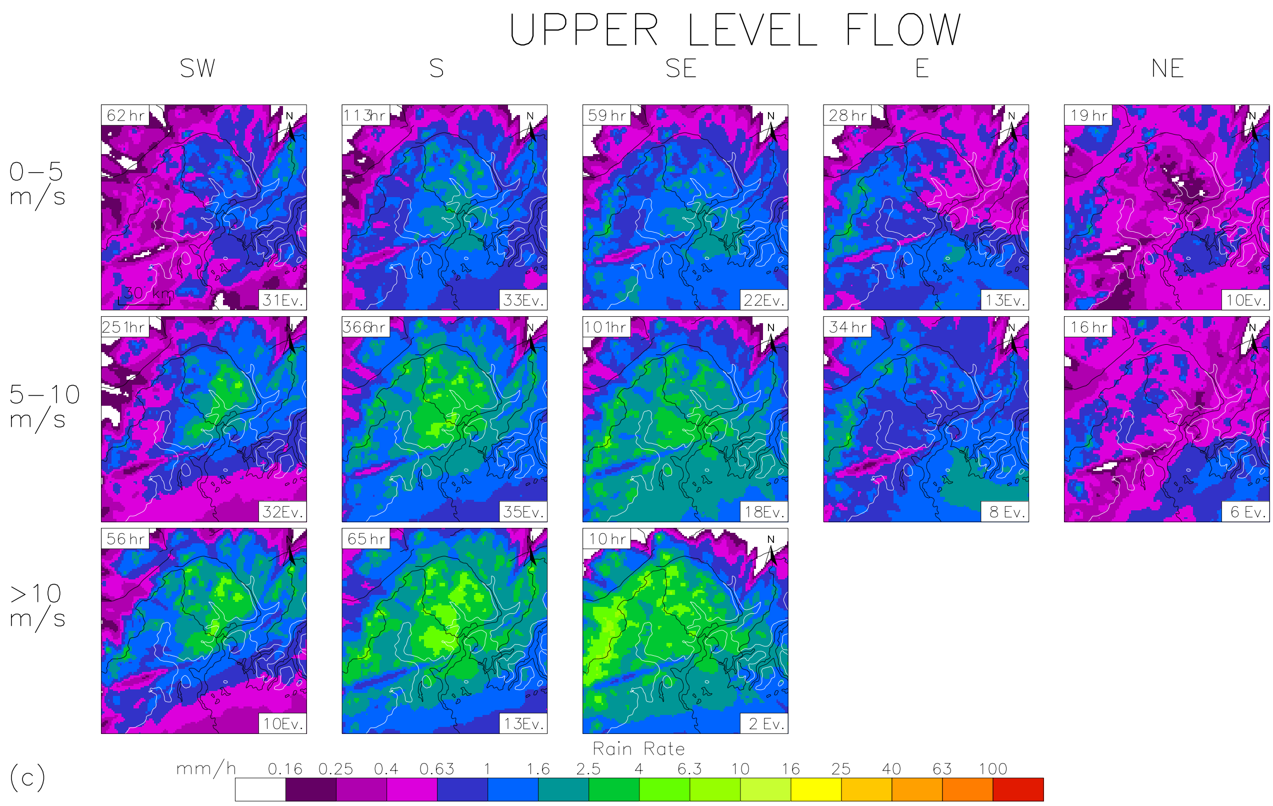


Figure 4: Superposed epoch analysis of mean rain rate in the Lago Maggiore region for different classes of intensities and directions of (a) Low Level Flow (b) Mid Level Flow and (c) Upper Level Flow . The total hours of precipitation and the number of heavy precipitation events populating each class are indicated at the top left and at the bottom right corner of each panel respectively. If the total hours of precipitation of one class are less than 5, mean rain rates corresponding to that class are not presented. The white line denotes the 800 m asl terrain contour, while the black line represent lakes, rivers and the political borders.

with negative and positive values of squared moist Brunt-Väisälä frequency, averaged over different vertical layers. Each stability value derived from radiosounding, in particular, was considered valid from two hours before to two hours after the time of launch; a single sounding is thus associated to no more than four hours of precipitation. In a first step, all the soundings launched in Milano during an heavy precipitation event occurring in the Lago Maggiore region were considered. However, the results of this superposed epoch analysis do not show any significant difference in the mean rain rate between stable and unstable conditions. This is probably due to the fact that the thermodynamic conditions of the lower troposphere observed near Milano during heavy rain in the Lago Maggiore may significantly differ from the ones occurring in the Alpine area, where precipitation actually takes place. Therefore, in a second step only radiosoundings launched during rainfall being measured by the radar in proximity of Milano (mean rain rate larger than 0.16 mm/h in a 400km^2 square box centered around the city) were taken into account. The results of this superposed epoch analysis indicate that the area with the largest values of rain rates (2.5 to 4 mm/h) is slightly more extended with unstable conditions than with stable ones.
In the second stage of this analysis, two couples of adjacent automatic ground stations located in

the Lago Maggiore area were used to estimate the stability: Locarno Monti and Cimetta, which are located at the northern edge of Maggiore Lake, Stabio and Monte Generoso, positioned on the first slopes of the Alps (see Fig.2). These couples of stations are located at different altitudes, thus permitting to estimate an average value of moist static stability in the low levels. Whereas the difference in rain rate between negative and positive stability derived from Locarno Monti and Cimetta is not significant, the analysis performed using Stabio and Monte Generoso data shows that unstable atmospheric conditions lead to a larger area affected by heavy rain respect to the stable case. One may speculate that by considering Stabio and Monte Generoso the differences between unstable and stable cases are larger since these stations are located on the first Alpine slopes, where the mechanical mixing of the low atmosphere due to the mesoscale winds is larger than in the inner valleys of the Alps, as in the area of Locarno Monti and Cimetta. The thermal gradient between these two latter stations, in fact, could be reduced by the persistence of a cold pool at the lower levels, especially during the cold season. Unstable conditions dominated during precipitation events, occurring for more than 70% of the total time of precipitation. A seasonal superposed epoch analysis did not give any additional information, except that the hours of stable cases during summer dropped to less than 10% of the total time.

4.3 Stability and flows

In this stage of the superposed epoch analysis the sensitivity of orographic precipitation mechanisms to both dynamic and thermodynamic conditions of the impinging flow are investigated.

Fig.5 represents the mean rain rates corresponding to positive and negative squared moist Brunt Väisälä frequencies for three classes of intensity of south-easterly LLF. The Brunt Väisälä frequency was obtained averaging radiosoundings data between 350 and 1000 m, taking into account only soundings launched during rain affecting not only Lago Maggiore region but also the area of Milano. The most pronounced differences in rain amounts are given by the velocity of the flow; however, also the moist static stability plays an important role in determining the general pattern of precipitation. In fact, the rain amounts are significantly larger with unstable than with stable lower atmospheric conditions. It should be noted that the hours of precipitation are reduced in this analysis, since it requires a lot of conditions to be satisfied. This superposed epoch analysis was performed also for southerly LLF, but in this case the differences between stable and unstable conditions are less significant than for south-easterly LLF.

The behaviour of a flow impinging an obstacle can be described by the Froude number $Fr = U/(NH)$, where U is the upstream flow speed perpendicular to the terrain, N the Brunt-Väisälä frequency and H is the height of the mountain barrier (Houze, 1993). Fr indicates whether or not the upstream flow has enough kinetic energy to rise over the barrier (Durran, 1990; Houze, 1993). Flow with an high Fr rises easily over a mountain, originating robust upslope flow which can enhance precipitation over the windward side of the obstacle; flow with low Fr is blocked by the mountain, and lifting and enhancement of rainfall can occurr upstream of the barrier. As mentioned in Sect.1, Houze et al. (2001) and Medina and Houze (2003) found significant differences in precipitation amounts and distribution in the Lago Maggiore region between high and low Fr flows. Stimulated by their results, in the last stage of our study superposed epoch analyses based on Fr were performed (Fig.6). As the Alps present a concavity in the Lago Maggiore region (see Fig.1), the direction of the flow perpendicular to the terrain is not univocally definable. In this investigation southerly and south-easterly LLF was considered as an estimate of the flow impinging perpendicularly to the mountain barrier. The average height of the Alps in the region, representative of the mountain height in the calculation of Fr, was assumed to be 3000 m. The moist Brunt-Väisälä frequency was obtained both by stations and radiosoundings data. Fig.6 presents the results of this investigation; the first two lines are relative to Fr calculated with stability from stations data. In these cases, about 62% of the hours of precipitation presents negative values of squared moist static stability, thus not permitting to calculate the Froude number. Precipitation appears to be enhanced on the first Alpine slopes with these conditions, originating a band of large rain rates in that area. In the remaining time slots, a large difference in rain rate between cases with Froude number smaller and larger than 1 is seen in Fig.6: the precipitation is largely enhanced over the mountains and penetrates in the inner part of the Alps with Froude numbers larger than 1 (6% of total time of precipitation). With Froude numbers between 0 and 1 (about 32% of total time), mean rain rates are significantly smaller than in other cases. These differences in rainfall accumulation are particularly clear taking into account Froude numbers calculated using the moist static stability derived from Locarno Monti and Cimetta. The results obtained with stability derived from radiosoundings data are slightly different. Firstly, the total hours of precipitation is largely reduced, since only radiosoundings launched during rain also over Milano are considered (see Sect.4.2). Secondly, mean rain rates in not-defined and less-than-1 *Fr* cases are not very similar. Thirdly, with *Fr* larger than 1 the precipitation is more intense and widespread than with stations data derived stability (and it involves 13% of total time).

5 Single cases analysis

The temporal behavior of the flows intensity and direction relative to each heavy rain event was compared to the precipitation accumulated in different alpine valleys of the Lago Maggiore region. Fig.7 represents this analysis for three events, and it gives an immediate insight into the potentialities of this system as a precious aid for the forecasters in nowcasting situations. In fact, the graphs of Fig.7 generally show that the largest rain rates were measured in correspondence or after the most significant increases of the flows intensity. Moreover, the flow direction variations seem to accompany the most significant changes in the precipitation intensity. However, the variability of the estimated flows intensity is large, and more sophisticated data processing tools need to be developed before this information can be used in an operational context.

6 Conclusions

A radar climatology of 92 days of heavy precipitation occurred from January 2004 to May 2008 in the Lago Maggiore region in central European Alps was presented. Four mesoscale flows were estimated by means of Doppler radar measurements, whereas thermodynamic quantities were derived from both radiosoundings and ground stations data. A number of superposed epoch analyses based on the flows intensity, direction and air mass stability characteristics have been performed. They indicate that both the intensity and the extension of heavy precipitation are strongly related to the upstream wind intensity. The direction of the wind, on the other hand, determines over which geographical areas the largest accumulations are measured. It was also found that rain rates are larger over the first slopes of the Alps with potentially unstable lower atmospheric conditions than with a stable stratification. Superposed epoch analysis based on Froude number combined the effects of wind, air mass stability and terrain height on orographic precipitation. The most intense and widespread rain was observed with Froude larger than 1 (high wind speed, low static stability); with lower Froude numbers, mean rain rates are significantly smaller. The results of the superposed epoch analyses clearly state the fundamental role of the orographic forcing in determining the precipitation characteristics in the region of Lago Maggiore.

Analyzing individual events the relation between the mesoscale flows and the rain rate is not as clear as it is by the superposed epoch analysis perspective. In fact, the variability of the flows intensity is large during each event and it also depends on the overall performance of the wind estimation algorithms, which in the end depends on the wind field itself.

The findings of this study will be exploited to build an heuristic system for nowcasting heavy orographic precipitation in the Alpine region. Specific predictions about the duration and the intensity of the rain in particular geographical areas will be based on significant changes in the mesoscale flow field, and on other observational evidences. The output of this system will be probabilistic, in order to account for the uncertainty associated

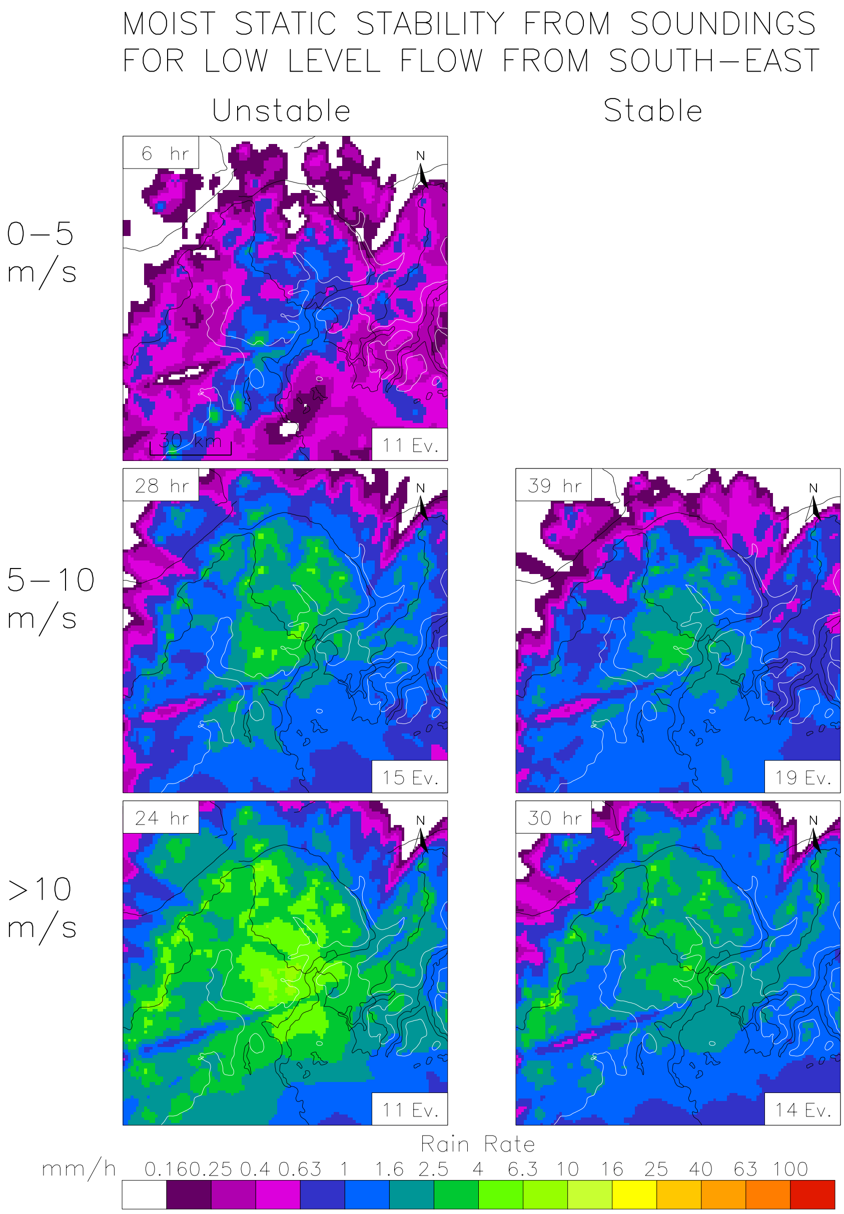


Figure 5: Superposed epoch analysis of mean rain rate in the Lago Maggiore region for imaginary (unstable) and positive (stable) values of the moist Brunt-Väisälä frequency derived from Milano soundings (averaged between 350 and 1000 m) for different classes of intensity of South-Easterly LLF. The total hours of precipitation and the number of heavy precipitation events populating each class are indicated at the top left and at the bottom right corner of each panel respectively. If the total hours of precipitation of one class are less than 5, mean rain rates corresponding to that class are not presented. The white line denotes the 800 m asl terrain contour, while the black line represent lakes, rivers and the political borders.

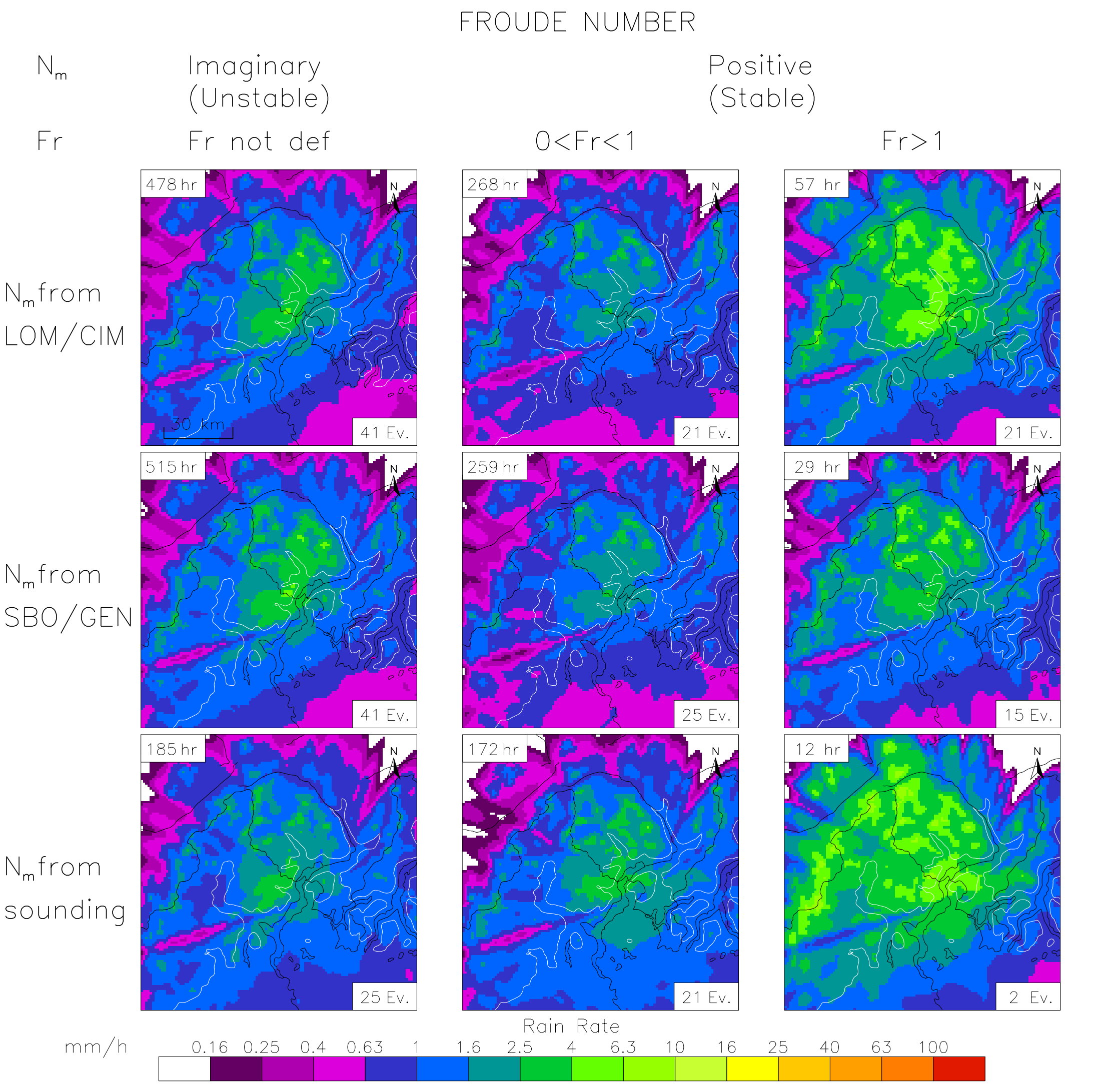


Figure 6: Superposed epoch analysis of mean rain rate in the Lago Maggiore region based on Froude number. In the first two lines moist static stability is derived from two couples of stations: Locarno Monti and Cimetta, Stabio and Monte Generoso (see Fig.2). In the third line, stability is obtained from radiosoundings data launched during rain being measured by Monte Lema radar also in the area of Milano (see Sect.4.2). Flow intensity is derived from the LLF estimated by radar, taking into account only Southerly and South-Easterly directions. The height of the orographic barrier is assumed to be 3000 m. Froude number is not defined if the Brunt-Väisälä frequency is imaginary. The total hours of precipitation and the number of heavy precipitation events populating each class are indicated at the top left and at the bottom right corner of each panel respectively. The white line denotes the 800 m asl terrain contour, while the black line represent lakes, rivers and the political borders.

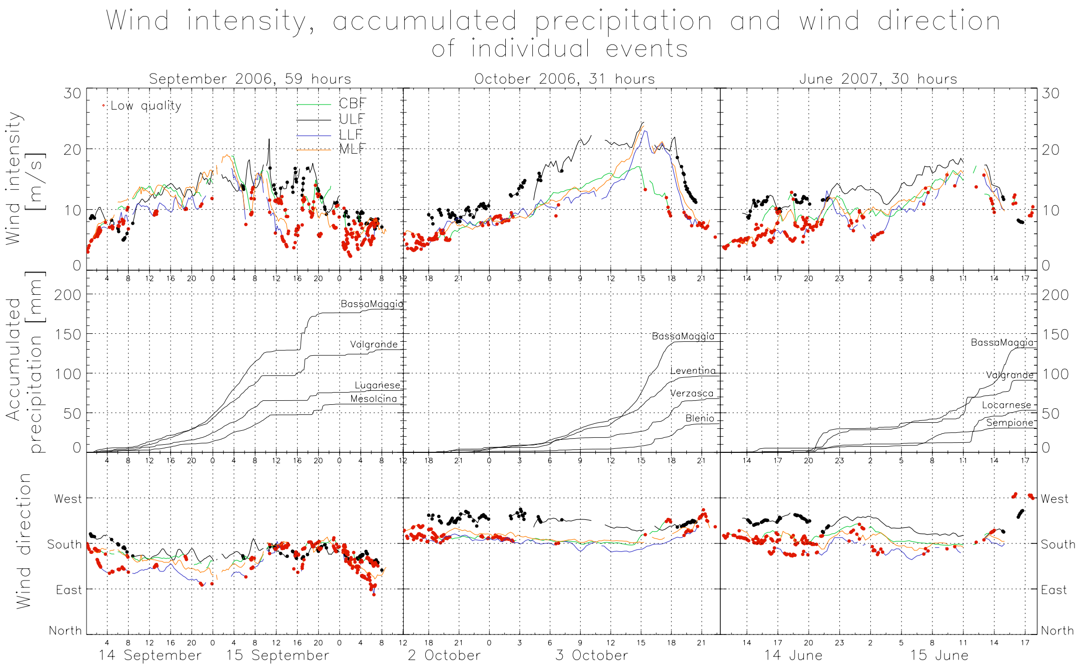


Figure 7: Wind intensity, accumulated precipitation and wind direction for three events of heavy rain in the Lago Maggiore region. The red stars indicate a low quality wind estimate. The accumulated precipitation is averaged over four different alpine catchments of the Lago Maggiore region.

with these forecasts.

Acknowledgements

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