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The Contribution of Orographically Driven Banded Precipitation to the Rainfall Climatology of a Mediterranean Region

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ABSTRACT

Studies carried out worldwide show that topography influences rainfall climatology. As in most western Mediterranean regions, the mountainous Cévennes–Vivarais area in France regularly experiences extreme precipitation that may lead to devastating flash floods. Global warming could further aggravate this situation, but this possibility cannot be confirmed without first improving the understanding of the role of topography in the regional climate and, in particular, for extreme rainfall events. This paper focuses on organized banded rainfall and evaluates its contribution to the rainfall climatology of this region. Stationary rainfall systems made up of such bands are triggered and enhanced by small-scale interactions between the atmospheric flow and the relief. Rainbands are associated with shallow convection and are also present in deep-convection events for specific flux directions. Such precipitation patterns are difficult to observe both with operational weather radar networks, which are not designed to observe low-level convection within complex terrain, and with rain gauge networks, for which gauge spacing is typically larger than the bandwidth. A weather class of banded orographic shallow-convection events is identified, and the contribution of such events to annual or seasonal precipitation over the region is assessed. Moreover, a method is also proposed to quantify the contribution of banded convection during specific deep-convection events. It is shown that even though these orographically driven banded precipitation events produce moderate precipitation intensities they have long durations and therefore represent a significant amount of the rainfall climatology of the region, producing up to 40% of long-term total precipitation at certain locations.

1. Introduction

Global warming is expected to be responsible for heavier daily rainfall because of the increased atmospheric content of water vapor and warmer air temperatures (Ramasmamy

et al. 1995). Although rising temperatures have now been confirmed at both global and regional scales, the intensification of moisture-related phenomena is highly uncertain, in particular at regional scales (Christensen et al. 2007). Christensen et al. (2007) reported that intense precipitation events will likely increase over central Europe in winter, but trends over the Mediterranean regions remain uncertain because of complex interactions at different scales (presence of topography; interactions

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and feedback among atmosphere–ocean–land processes) that play a predominant role in climate and the related ecosystems. Because the Mediterranean region has been identified as one of the two main “hot spots” of climatic change, it is important to determine how climatic change will affect rainfall there. This goal will require a better understanding of regional climate and, in particular, the role of topography in modulating rainfall patterns.

According to the American Meteorological Society Glossary, orographic rainfall refers to rainfall both triggered and reinforced by topography (see, e.g., Smith 2006). The observed strong dependence of rainfall on meteorological factors such as frontal or cyclonic convergence, mesoscale convergence associated with winds in valleys, instability, and humidity suggests that it is difficult to observe “pure” orographic rainfall and therefore to quantify rainfall enhancement by topography (Barros and Lettenmaier 1994). This orographic effect obviously affects rainfall amounts (e.g., in the Alps; Frei and Schär 1998) as well as rainfall patterns at the event time scale (e.g., Ducrocq et al. 2008). Note that it is not always possible to distinguish stratiform orographic rainfall from convective orographic rainfall. Indeed, convective cells sometimes develop in stratiform clouds formed by orographic lifting, intensifying the rainfall locally (Kirshbaum and Durran 2004; Fuhrer and Schär 2005). Minder et al. (2008) more recently pointed out that most studies devoted to orographic rainfall involve single events and that little is known about the variations of rainfall patterns that can occur for different orographic events and their combined influence on long-term amounts of precipitation falling on a given region.

This article attempts to quantify the relative contribution of orographic rainfall to the long-term annual and seasonal precipitation falling on the Cévennes–Vivarais region in France. The Cévennes–Vivarais area, located along the southeast edge of the Massif Central region (Fig. 1a), is exposed to the Mediterranean climate. Its midelevation mountains play an important role in the triggering (Cosma et al. 2002; Anquetin et al. 2003; Ducrocq et al. 2008), enhancement (Angot 1919; Bois et al. 1997; Frei and Schär 1998; Molinié et al. 2011, manuscript submitted to *J. Appl. Meteor. Climatol.*) and spatial distribution (Mitard 1927; Miniscloux et al. 2001; Nuissier et al. 2008) of rainfall. Since 2000, the Observatoire Hydrométéorologique Méditerranéen Cévennes–Vivarais (OHMCV; see online at <http://www.ohmcv.fr/>) has been gathering hydrometeorological observations to analyze the climatological behavior of rainfall in this region, including its trend in the general context of climatic change and its impacts on the hydrological cycle in this region. As in most western Mediterranean regions, this area experiences “heavy precipitation events” that lead to devastating

flash-flood events. Nuissier et al. (2011) established the climatological characteristics of these events to identify the synoptic- and mesoscale features favoring such intense precipitation.

For this region, previous studies have shown that the maps of extreme rainfall statistics depend on the considered accumulation duration (Bois et al. 1997; Molinié et al. 2011, manuscript submitted to *J. Appl. Meteor. Climatol.*). For a daily time step, the signature of the relief is clearly visible on the maps, whereas at smaller time intervals (e.g., hourly) no specific orographic signature is observed. Molinié et al. (2011, manuscript submitted to *J. Appl. Meteor. Climatol.*) showed this result for the whole OHMCV dataset of hourly records (1993–2008). The authors linked this result to atmospheric conditions. Extreme hourly rainfall should be linked to deeper convection than extremes over longer time intervals. Moreover, extreme daily rainfall should result from less intermittent precipitation. It is useful to take into account such considerations to understand better the regional climate and, in particular, to identify the relative importance of extreme precipitation events in the “climatology.” On the basis of previous observations (Pointin et al. 1988; Miniscloux et al. 2001; Ducrocq et al. 2002; Delrieu et al. 2005), we consider that rainfall in this region may be associated with three types of convective systems: 1) deep convection with quasi-stationary mesoscale systems (Ducrocq et al. 2002, 2008; Delrieu et al. 2005; Nuissier et al. 2008) that generally produce highly intermittent intense rainfall, 2) shallow convection that produces banded rainfall patterns with much weaker intensities and stable patterns with a strong dependence on the thermodynamic properties of the incoming flux and relief features (Miniscloux et al. 2001; Cosma et al. 2002; Anquetin et al. 2003), and 3) other meteorological situations mainly associated with frontal systems. Deep and shallow banded orographic convections are not always mutually exclusive. On the basis of numerical simulations, Ricard (2002) showed, for one specific event, that these two types of convective systems may overlap. This result is important for our work here.

In the Cévennes–Vivarais region, shallow banded orographic convection (BOC) was first observed by an experimental S-band radar installed in the mountains (Pointin et al. 1988; Miniscloux et al. 2001). The relative contribution of such events to total rainfall over longer periods is unknown because the density of the rain gauge network is insufficient and the operational weather radar network is not designed to observe low-level convection close to the complex topography.

Such rainfall patterns have been observed elsewhere in comparable settings [e.g., in the United States (Kirshbaum and Durran 2005b) and Japan (Yoshizaki et al. 2000)],

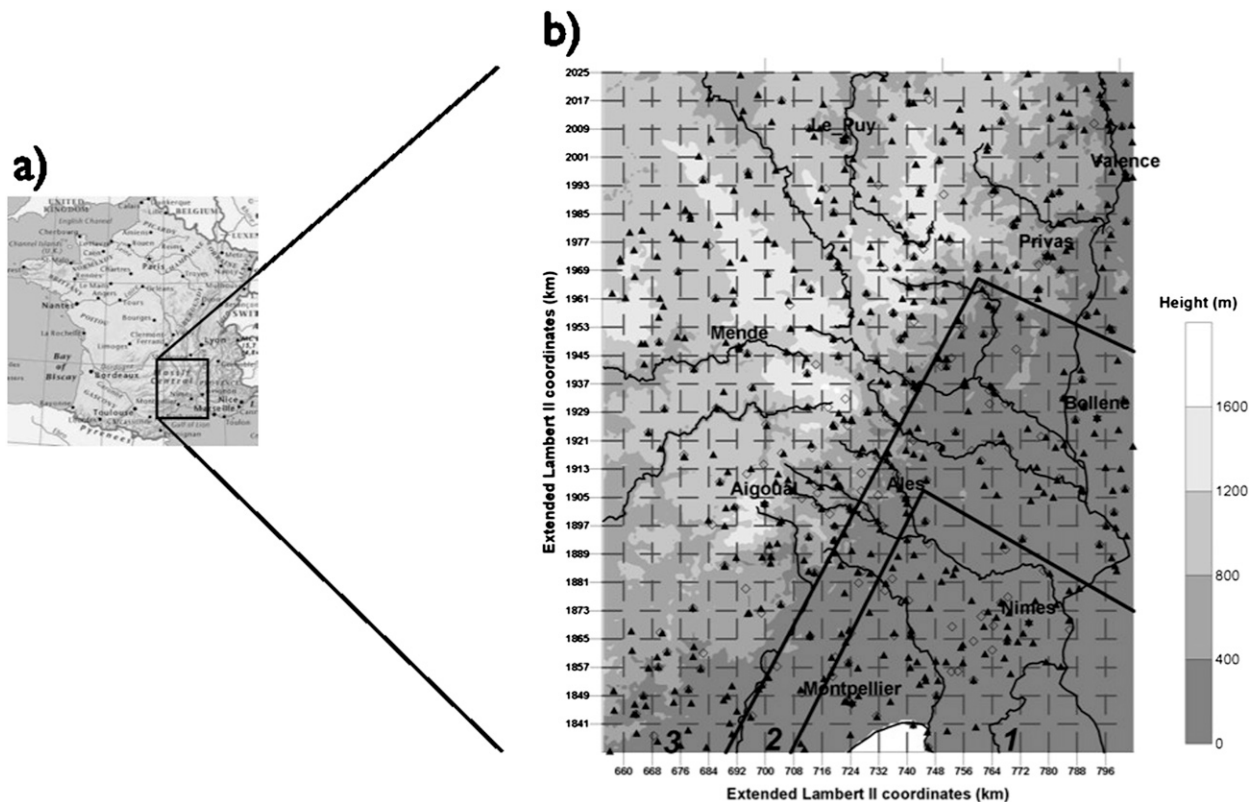


FIG. 1. (a) Cévennes–Vivarais area in France. (b) Topography of the area (grayscale) showing the main rivers (black lines), main towns and sites (stars), hourly (white diamonds) and daily (black triangles) rain gauge stations, and SAFRAN grid ($8 \text{ km} \times 8 \text{ km}$). The three topographic sectors are delimited by the black lines (1: plain; 2: piedmont; 3: mountains).

and their impact on precipitation amounts measured over a given region may not be negligible (Frei and Schär 1998; Yoshizaki et al. 2000; Fuhrer and Schär 2007). Minder et al. (2008) mapped rainfalls over the Olympic Mountains from fifth-generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model (MM5) simulations with a resolution of 4 km. At this resolution, the bands observed by Kirshbaum and Durran (2005b) were not visible. Because the correlation between simulated and observed rainfall was good, Minder et al. (2008) suggested that the banded organization of convection was not a prominent mechanism in the rainfall climatology of this area.

This paper aims to quantify the relative contribution of orographically driven banded precipitation to the rainfall of the Cévennes–Vivarais region. This contribution is the sum of two terms: 1) the contribution of pure BOC events and 2) the contribution of BOC enhancement present in deep-convection events as shown by Ricard (2002).

To compute this contribution, the paper is organized as follows. After a presentation of the region of interest and the dataset used, section 2 introduces our meteorological object, the BOC, that is, banded orographic rainfalls

associated with shallow convection. The method used to define a weather class producing such rainfall is detailed, and its main characteristics are discussed (seasonality and duration of the events). In section 3, we evaluate the contribution of this weather class to the annual and seasonal rainfall over the region. Banded orographic enhancement during deep-convection events is discussed. We analyze the role of the topography and the importance of this organized rainfall regime for the regional water resources in section 4. The results provide new insight to the need for both a specific observation strategy and a clearer understanding of extreme precipitation events.

2. Definition of a weather class producing banded orographic rainfall

a. Region of interest and datasets used

The Cévennes–Vivarais area is a southeasterly-facing slope limited by the Mediterranean Sea shore to the south and the Rhône valley to the east (Fig. 1a). The elevation varies from sea level up to 1500 m (Mount Lozère), over roughly 30 km (Fig. 1b). This hilly terrain is dissected by relatively deep and narrow valleys (500 m

deep, 10 km wide) that are mainly oriented along a northwest–southeast axis. The topography is divided into three sectors (Fig. 1b): 1) the plain where the elevation does not exceed 200 m; 2) the mountains where the elevation is above 500 m; and 3) the piedmont, a hilly sector between these two elevations.

The meteorological dataset employed is based on 1) soundings at Nîmes (Fig. 1b) at 0000 and 1200 UTC extracted from the University of Wyoming (online at <http://weather.uwyo.edu/>) dataset for the 1976–2005 period and 2) ground-station records at a 3-h time step (Nîmes and Mount Aigoual) provided by Météo-France and covering the periods 1972–80, 1986–88, and 2000–03. This region benefits from long rainfall records coming from weakly connected operational services (water management services, Météo-France, and Electricité de France), each with their own policy of network management. In 2000, the OHMCV began compiling a research database by gathering, analyzing, and archiving these operational data. Figure 1b presents the networks used in this study. It is composed of 308 hourly gauges and 756 daily gauges that ran discontinuously over the periods 1972–80, 1986–88, and 2000–05 (Godart et al. 2009).

In addition to these hydrometeorological archives used to build the weather class (Godart et al. 2009, 2010), we used Système d'Analyse Fournissant des Renseignements Atmosphériques à la Neige (SAFRAN) reanalyses (Durand et al. 1993; Quintana Segui et al. 2008) to compute the contribution of the weather class to the rainfall climatology in the region. The SAFRAN reanalyses system was developed in the 1990s at Météo-France for operational avalanche forecasting in the main French mountainous areas (Durand et al. 1993, 1999). This concept was subsequently extended to the whole country (Quintana Segui et al. 2008). Hourly SAFRAN reanalyses are available for 1970–2006 at a spatial resolution of $8 \text{ km} \times 8 \text{ km}$ (Fig. 1b). In this study, we will consider only 24-h totals (Godart 2009) to obtain more reliable values.

b. Definition of the weather class

Various studies have taken a close look at the synoptic environment of BOC events (Miniscloux et al. 2001; Kirshbaum and Durran 2004, 2005a). The main ingredients are conditional instability, high relative humidity in lower layers, moderate wind speed, weak directional wind shear, and a high vertical wind gradient at the lowest levels. Long-lasting rainband events are associated with stationary flow, and the bands are parallel to the flow.

In the Cévennes–Vivarais region, very few observations of such events are available (Miniscloux et al. 2001). In a previous study, Godart et al. (2009) used meteorological and rainfall criteria to extract BOC events from the above-

described hydrometeorological archive. The meteorological criteria are 1) southerly wind at the sounding station of Nîmes, 2) mean wind speed between the ground and 800 hPa of more than 7 m s^{-1} , and 3) low directional shear below 800 hPa, corresponding to a rotation of the wind vector with elevation of less than 15° km^{-1} . The rainfall criteria defined for hourly rainfall data are 1) mean rainfall intensity in the mountains that is larger than that on the plains and 2) decreasing intermittency (percentage of zeros) with elevation.

Among the 21 944 available soundings, only 880 satisfy the three meteorological criteria and constitute the class of southerly wind events (SWE). Because of the incomplete hourly rainfall database, the rainfall criteria could be applied to only 350 events of this class, and only 121 were identified as BOC events. To overcome the lack of rainfall data, Godart et al. (2010) implemented an extraction strategy based on the joint use of two statistical methods to class the 530 (880 – 350) remaining SWE. At the end, among the 880 SWE, they obtained a set of 224 BOC events (i.e., 25% of the class of southerly wind events). They used the nonhydrostatic mesoscale “MésO-NH” model (Lafore et al. 1998) to validate this approach (Godart 2009; Godart et al. 2010).

The annual distribution of BOC events is illustrated in Fig. 2 for the 1976–2005 period. We observe a slight increase in the number of BOC events in the 1990s that is difficult to explain. In Fig. 3, the seasonal distribution shows that autumn (September–November) is the most favorable season for BOC events. Note that the frequency of occurrence of such events remains very low (Fig. 3b), however, and does not exceed 5% of the rainy events of the autumn season.

3. Contribution of BOC events to the rainfall climatology of the Cévennes–Vivarais area

The amount of rain falling around the time of a selected sounding is computed with SAFRAN reanalyses. For this calculation, hourly rainfall values are accumulated $\pm 12 \text{ h}$ around the time of the sounding. For any other day, the 24-h accumulated rainfall is computed from 0000 to 0000 h of the following day. To show the relative importance of BOC events in the study region, the mean daily rainfall over the 1976–2005 period is given for 1) all events (Fig. 4a), 2) the class of southerly wind events (Fig. 4b), and 3) the class of BOC events (Fig. 4c).

A comparison between Fig. 4a and Fig. 4b suggests that the SWE are, on the average, the most productive. Over the period 1976–2005, it has been shown that accumulated rainfall for the SWE events accounts for more than 55% of the annual total rainfall of the area although such events involve only 8% of the rainy days (Godart 2009). This

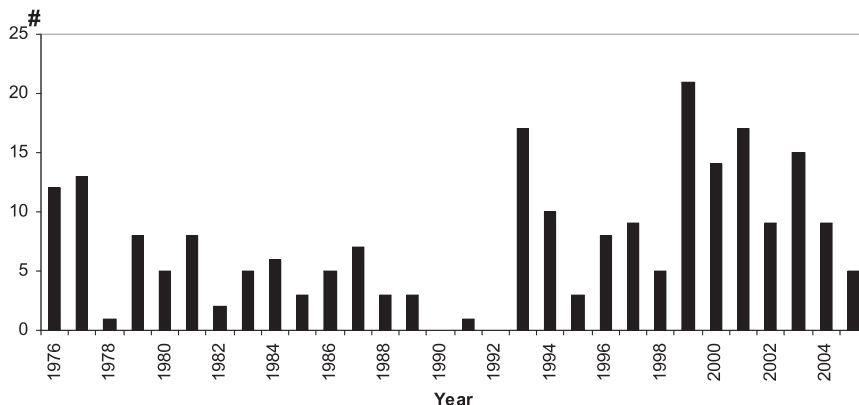


FIG. 2. Annual frequency distribution of BOC events between 1976 and 2005.

result is in good agreement with the main conclusions of Nuissier et al. (2011). The map of the mean daily rainfall associated with BOC events (Fig. 4c) confirms what we expected in terms of location. Most of the rainfall is located on the lee side of the crests, and the mean daily rainfall is greater than that of SWE. In terms of structure, the banded aspect is not visible for two reasons:

1) The resolution of the SAFRAN reanalyses is too coarse. In the Cévennes–Vivarais region, the typical

width of the bands is from 4 to 5 km (i.e., one-half of the size of a SAFRAN grid cell). Godart (2009) showed that the rainband structure is clearly visible at a 1-km resolution and disappears when the rain field is plotted at an 8-km resolution.

2) The orientation of the bands is directly linked to the direction of the atmospheric flow (Yates 2006), which varies slightly for the different BOC events. The banded patterns overlap, and the mean pattern presents a more homogeneous structure.

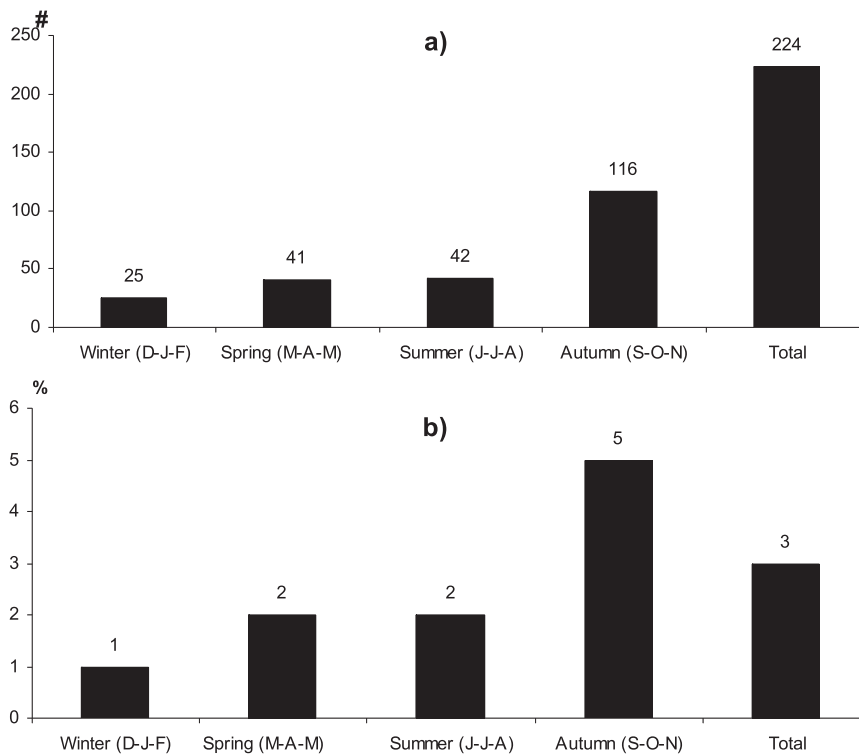


FIG. 3. (a) Seasonal frequency distribution of BOC events. (b) Percentage of soundings associated with BOC events among all rainy days of the season.

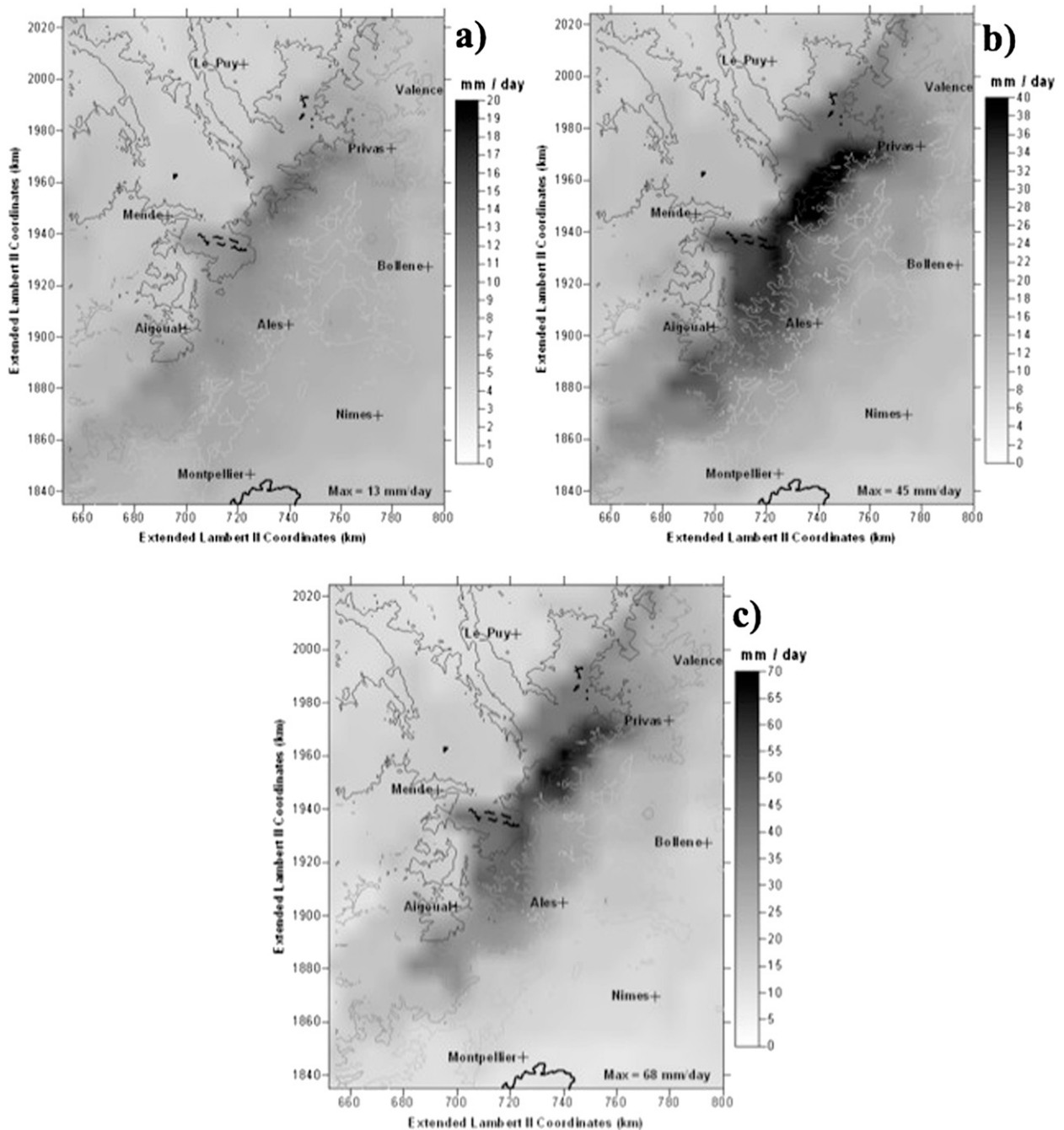


FIG. 4. Mean daily rainfall (mm day^{-1}) in the Cévennes–Vivaraïs area over the 1976–2005 period for (a) all events, (b) SWE (Godart et al. 2009), and (c) BOC events. The plus signs indicate the main towns and sites, the black thick line delineates the coast, and the solid dark and gray lines are the topographic contours (200, 500, 1000, and 1500 m). The grayscales vary by panel.

The percent contribution of BOC events to the rainfall climatology in the Cévennes–Vivaraïs over the 1976–2005 period is presented in Fig. 5. This weather class may locally contribute up to 26% of the total precipitation although the rainband events only correspond to 3% of rainy days over the 1976–2005 period (Fig. 3b). In Table 1,

the mean contributions are given for the different topographic sectors. Over the whole area, the mean contribution reaches 15%. The relative amount of rainfall associated with BOC events appears to be higher in the Cévennes–Vivaraïs area than in the Olympic Mountains (Minder et al. 2008).

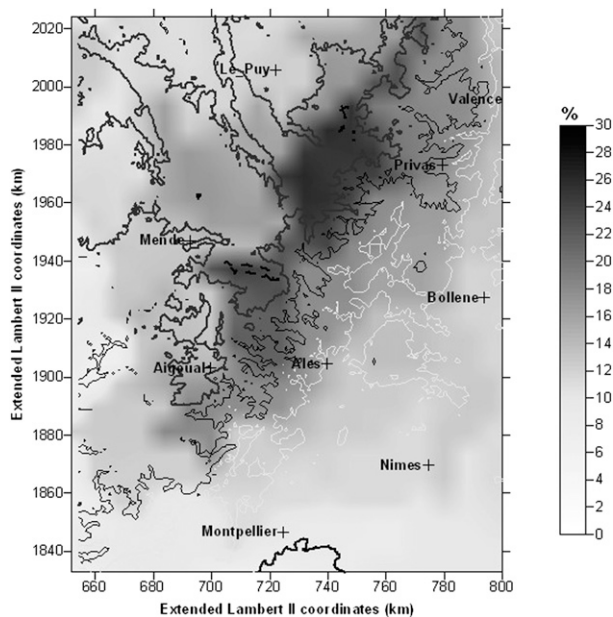


FIG. 5. Contribution (%) of BOC events to the rainfall climatology of the Cévennes–Vivarais area over the 1976–2005 period. The plus signs indicate the main towns and sites, the black thick line delineates the coast, and the solid dark and gray lines are the topographic contours (200, 500, 1000, and 1500 m).

The long-term contribution of the BOC weather class for different seasons is given in Fig. 6. For each season, we compute the ratio between the rainfall associated with the BOC events and the accumulated rainfall of all rainy days. The resulting patterns of the BOC weather class contribution vary with season. In spring (Fig. 6a), rainfall associated with the BOC events largely affects the region adjacent to the mountain as well as the piedmont sector. In summer (Fig. 6b), the contribution shifts slightly along the crest, between Mont Aigoual and Privas, but the plain sector is also affected by such events. The autumn contribution (Fig. 6c) is clearly the highest and reaches more than 38% at some locations in the mountains. This result enhances our understanding of the climatology of the study region (Molinié et al. 2011, manuscript submitted to *J. Appl. Meteor. Climatol.*). Extreme rainfall-accumulation events may result from either deep-convective events (Nuissier et al. 2011) or shallow-convective events associated with lower but longer lasting instantaneous rainfall intensities. In winter (Fig. 6d), orographic banded rainfall contributes significantly to the seasonal totals in the mountain sector, but less than in autumn (Fig. 6c).

The contribution of the weather class is shown in Fig. 7 for different periods. The contributions are computed in the same way as above, but this time for three 10-yr periods: 1976–85, 1986–95, and 1996–2005. Table 1 summarizes the mean contributions for the different sectors and

TABLE 1. Mean contribution (%) of BOC events to the rainfall of the whole Cévennes–Vivarais area and to the three topographic sectors (plain, piedmont, and mountains) for different periods.

	1976–2005	1976–85	1986–95	1996–2005
Cévennes–Vivarais	15	14	10	19
Plain sector	11	10	8	14
Piedmont sector	14	13	9	19
Mountain sector	15	15	11	20

periods. The rainfall patterns and the associated amplitudes do not vary significantly over the 30-yr periods.

4. Banded orographic enhancement during deep-convective events

Previous numerical studies (Cosma et al. 2002; Anquetin et al. 2003; Colle 2004; Kirshbaum and Durran 2005b) showed that rainfall associated with BOC events is essentially linked to small-scale features of the topography. With high-resolution numerical simulations, Ricard (2002) also showed that the signature of the BOC triggered by the topography is present in the rainfall field structure during a quasi-stationary mesoscale system with fully developed convection. This author simulated the same event with two representations of the topography: the “real” topography at $2.5 \times 2.5 \text{ km}^2$ resolution, displaying the details of the valleys, and the “smoothed” topography, at the same resolution but with a filtered relief representing only the general shape of the mountain ridge. He computed the difference between the rainfall-accumulation fields obtained from the two simulations. When the relief is fully described, the positive bias appeared to be organized in narrow stationary bands behind the relief shoulders exposed to the predominant wind. In this section, we propose a method to evaluate the contribution of orographic enhancement assumed to be 1) present during deep-convective events and 2) organized in bands as shown by Ricard (2002).

Nuissier et al. (2011) classified the synoptic-scale circulation patterns related to the occurrence of significant rainfall events (SRE) in the Cévennes–Vivarais area, combining the European Centre for Medium-Range Weather Forecasts 40-yr large-scale reanalysis (ERA-40) with selected daily rain gauge records provided by Météo-France. For the 1960–2001 period, they divided these SREs into four weather classes according to the geopotential heights at 500 hPa.

The periods that were chosen by Nuissier et al. (2011) (1960–2001) and that were chosen in this work (1976–2005) overlap for the 1976–2001 period. In the BOC weather class defined by Godart et al. (2010), 88 events belong to the 1976–2001 period. Among them, 77 are

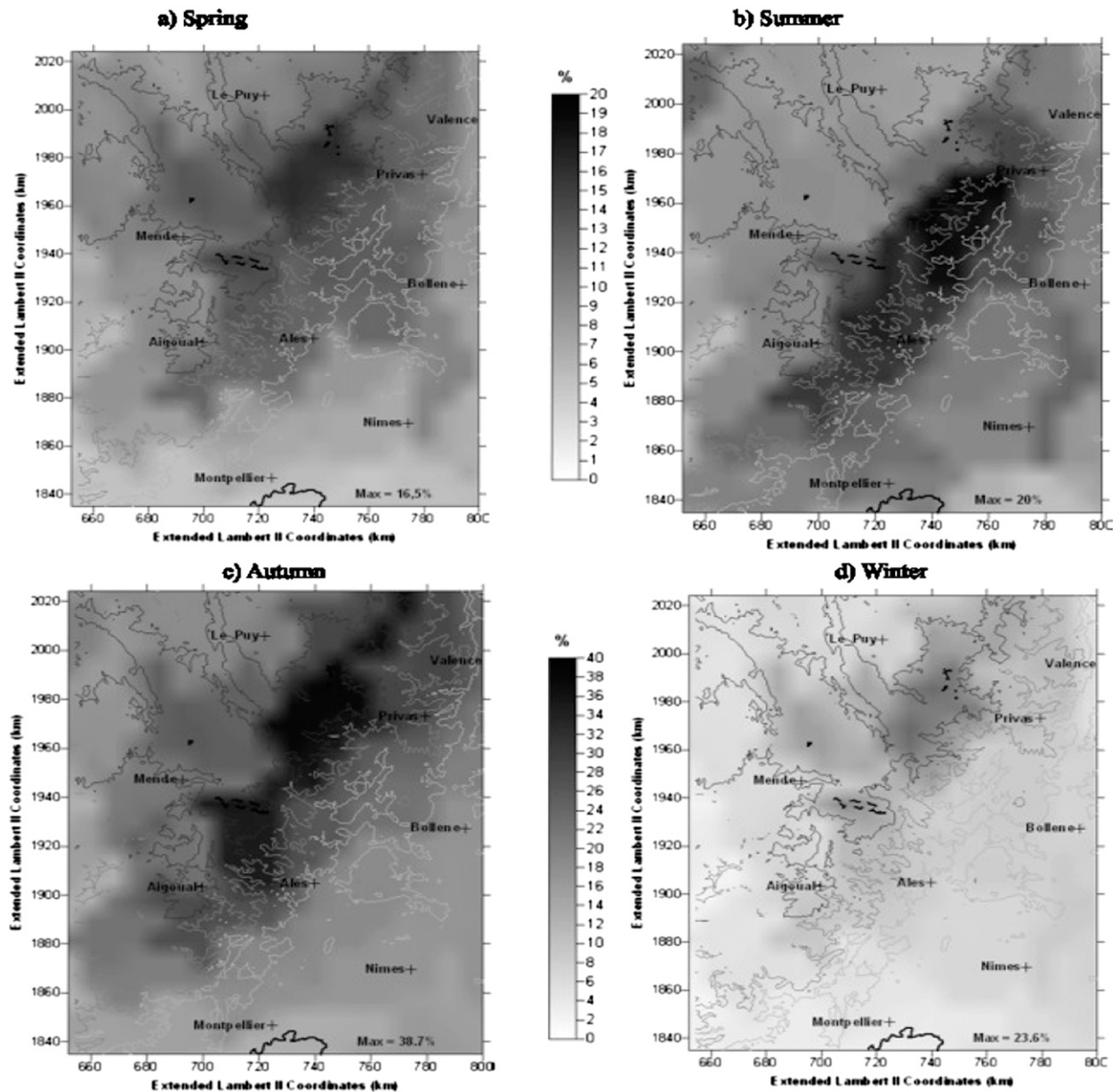


FIG. 6. Contribution (%) of BOC events to the rainfall of each season over the 1976–2005 period. The top and bottom grayscales are not the same.

defined as SREs. According to the classification of Nuissier et al. (2011), 54 of these 77 BOC events belong to the strong cyclonic southwesterly flow (CSW) class and 15 of the BOC events belong to the cyclonic southerly flow (CS) class. Thus, almost 90% of BOC events belong to these two classes that present upper-level synoptic features favorable to triggering and maintaining convective activity over southern France (Nuissier et al. 2011). This result suggests that the orographic enhancement organized in bands may be found in SREs that 1) belong to either of these two classes and 2) have

properties given by the Nîmes soundings that satisfy our meteorological criteria.

Orographic enhancement organized in bands during SREs that are not in our BOC weather class can then be identified using the following procedure:

- 1) Determine the number of SREs in the classes CSW (N_{CSW}) and CS (N_{CS}) that satisfy our meteorological criteria (i.e., belong to the SWE class), but do not belong to our BOC weather class; these events will be subsequently referred to as nonshallow SREs.

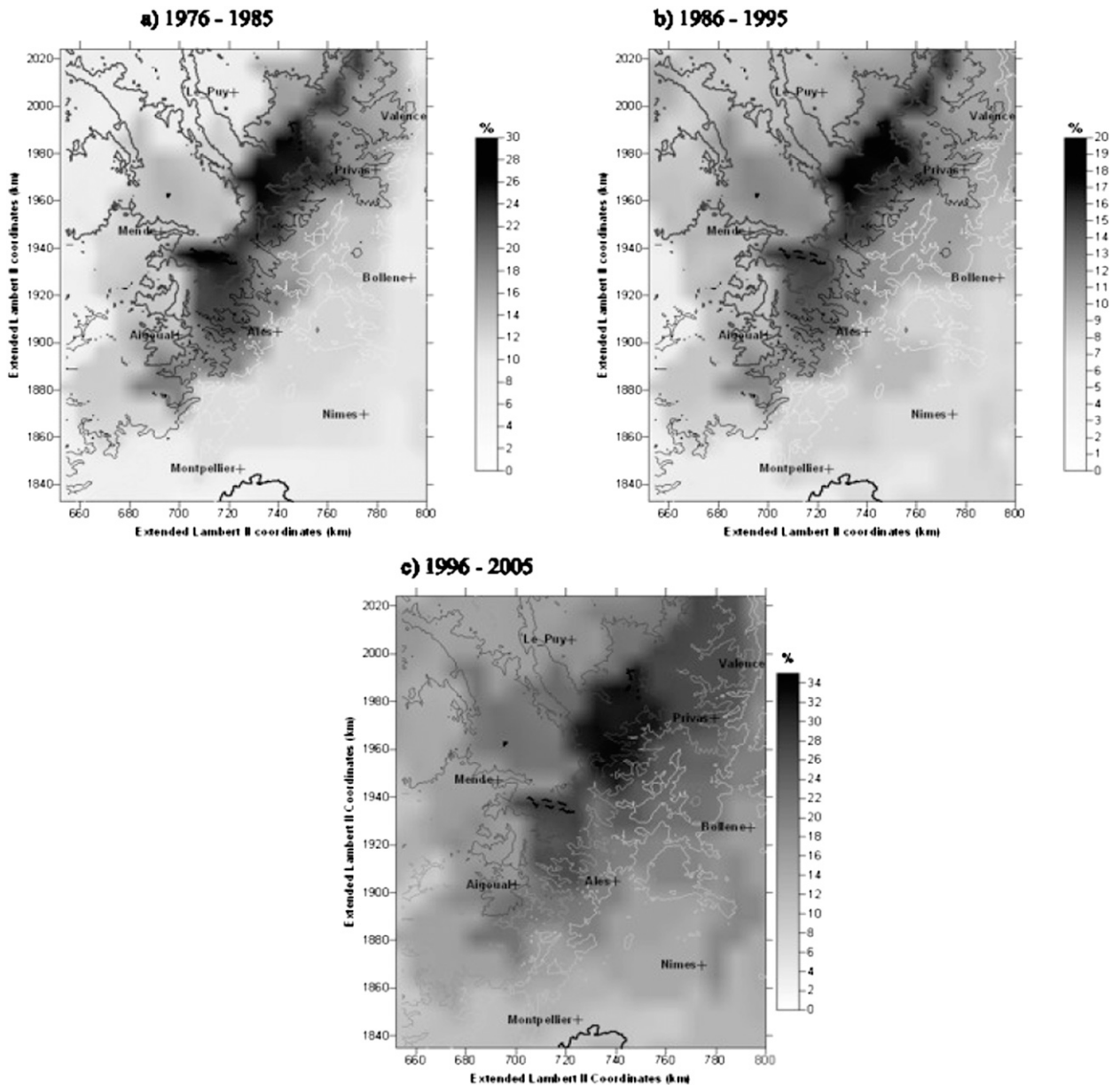


FIG. 7. Contribution (%) of BOC events to the rainfall of the Cévennes–Vivarais area for different periods (a) 1976–85, (b) 1986–95, and (c) 1996–2005. The grayscales are different for each period.

- 2) Compute the mean daily rainfall intensity for shallow BOC events that belong to the CSW (M_{CSW}) and CS (M_{CS}) classes.
- 3) Compute the contribution of orographic enhancement organized in bands for nonshallow SREs simply as $N_{CSW}M_{CSW} + N_{CS}M_{CS}$.

During the 1976–2001 period, 57 (N_{CSW}) nonshallow-convective SREs satisfy the meteorological criteria, as defined by Godart et al. (2010), in the CSW class and 25 (N_{CS}) in the CS class satisfy the criteria.

Figure 8 presents the mean daily intensities associated with BOC events that belong to the CSW (M_{CSW}) and CS (M_{CS}) classes. The structures are consistent with the rainfall composites given by Nussier et al. (2011). The maximum of the composite rainfall in the CSW class is located in the upper north of the mountain area, whereas for the CS class the pattern shifts to the south.

Therefore, the contribution of orographic enhancement associated with nonshallow SREs is computed as described above and added to the contribution of orographic

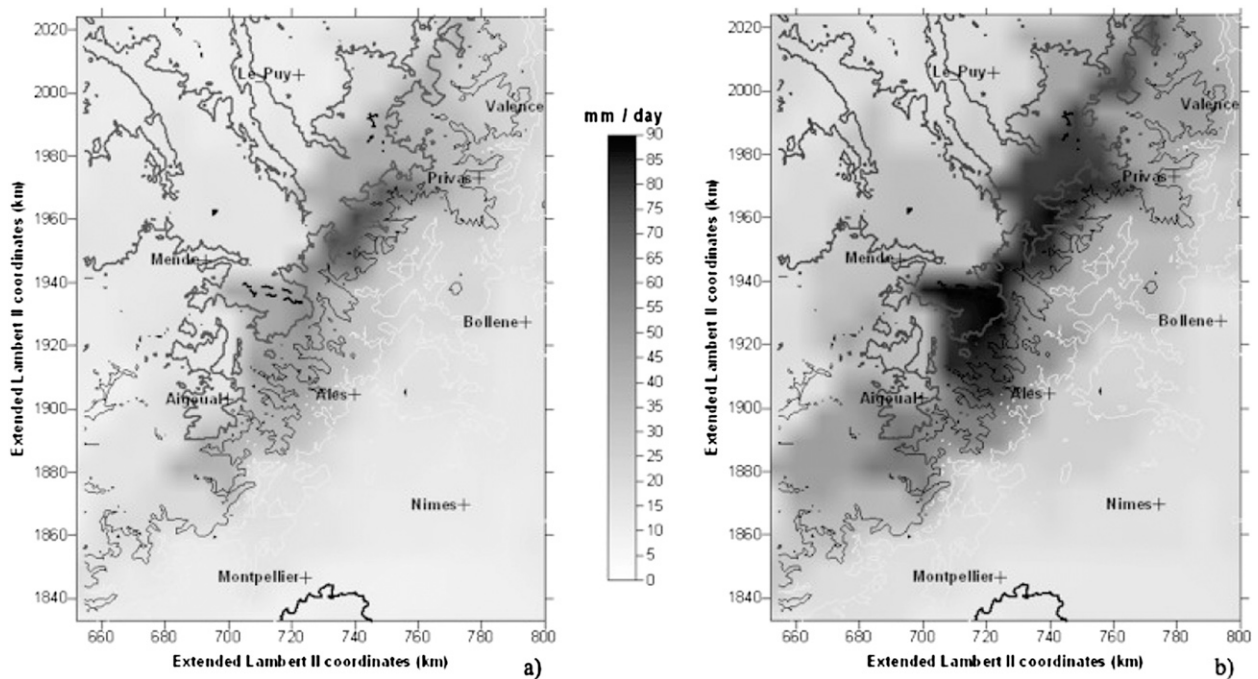


FIG. 8. Mean daily rainfall intensities associated with BOC events that belong to (a) class CSW and (b) class CS of the Météo-France weather-type classification (Nuissier et al. 2011).

banded rainfall associated with BOC events (Fig. 5). The resulting patterns are shown in Fig. 9, and the percent contributions for the entire area and per sector are presented in Table 2. The portion of the rainfall associated with the nonshallow SREs is nonnegligible since the

maximum contribution of the orographic “banded” rainfall now reaches 40% over a significant area. This result is important for understanding of the role of topography in the rainfall-regime climatology. Although the banded structure of the BOC events has been confirmed by both

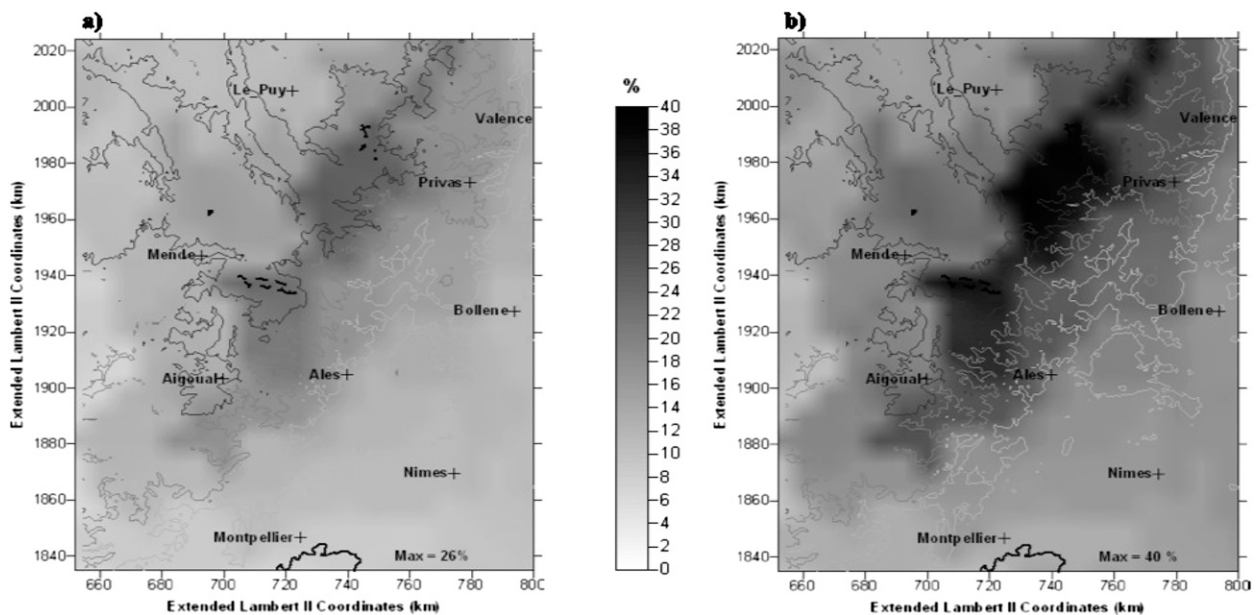


FIG. 9. Contribution (%) of (a) BOC events (same as Fig. 5) and (b) the sum of nonshallow SREs and BOC events to the rainfall of the Cévennes–Vivaraix area over the 1976–2001 period.

observations (Miniscloux et al. 2001) and numerical simulations (Cosma et al. 2002; Anquetin et al. 2003; Godart 2009; Godart et al. 2010), this is not the case for the orographic enhancement associated with nonshallow SREs. The contribution of these events is impossible to confirm with the available observation networks, and significant numerical and human resources would be required to apply the strategy proposed by Ricard (2002) for a single event to all of the nonshallow SREs. Nevertheless, these results demonstrate the need for an appropriate observation system to understand better the physical processes associated with the rainbands. Such a field experiment is under construction within the Hydrological Cycle in Mediterranean Experiment (HyMeX; see online at www.hymex.org) project that aims to improve our understanding and prediction of the water balance in the Mediterranean region, which is highly impacted by extreme events (floods, droughts, and strong winds).

5. Conclusions

From a meteorological point of view, stationary banded orographic rainfall events are important for at least two reasons: 1) they are a good example of a topographically related rain pattern and 2) they likely produce a large portion of the rainfall in mountainous areas despite their moderate rainfall intensity. This paper estimates the contribution of orographic banded rainfalls to the rainfall climatology of the Cévennes–Vivarais area.

The first step was the creation of a database gathering these events. The available hydrometeorological archive imposed the analysis timeframe (1976–2005). On the basis of a previous study (Godart et al. 2010), 224 soundings were selected to represent banded orographic convection events leading to rainfall fields organized in bands. Banded rainfall events were subsequently looked for in nonshallow events by assuming that, because these rainfall structures are only triggered and enhanced by the topography, they persist whatever the vertical development of the convective system might be. Within deep convection, the banded structure of this moderate-intensity rainfall disappears among the rainfall patterns associated with deeper convective systems that are no longer influenced by topographic details. Using the weather-type classification provided by Météo-France, 82 nonshallow events were extracted. They are assumed to present a banded rainfall pattern combined with more intense convective rainfall. The contribution of these events to the rainfall of the area was computed using the SAFRAN rainfall reanalyses provided by Météo-France.

The results show that rainfall associated with shallow BOC events (the first 224 events) contributes up to 26% of the long-term rainfall at certain locations. If we add

TABLE 2. Mean contribution (%) of shallow BOC events and shallow and nonshallow orographic convective events to the rainfall of the whole Cévennes–Vivarais area and to the three topographic sectors (plain, piedmont, and mountains) for the 1976–2001 period.

	Shallow-convective events	Shallow and nonshallow orographic convective events
Cévennes–Vivarais	13	20
Plain sector	10	16
Piedmont sector	13	20
Mountain sector	16	22

the contribution of the nonshallow events (82 more events), which may represent banded rainfall blended within the convective rainfall pattern, the contribution increases to up to 40% of the rainfall climatology.

This result is important for understanding the role of topography in the rainfall climatology. It also provides new insight into the regional climate and demonstrates the need for an appropriate observation system. Although the banded structure of the shallow BOC events has been observed in the field and has been validated by numerical simulations, this is not the case for the orographic enhancement associated with nonshallow events. An observation system dedicated to such rainfall patterns is under construction and will be composed of a network of X-band radars, mainly located in the mountainous area. Such observations should improve our understanding of the physical processes involved in the banded rainfall. The next step will be to identify the weather types associated with BOC events and to study how they may be affected by climate change.

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