RESEARCH THESIS

Transition between Shallow Band-Organized Convection and Deep Convection over the Cévennes area using the WRF Model

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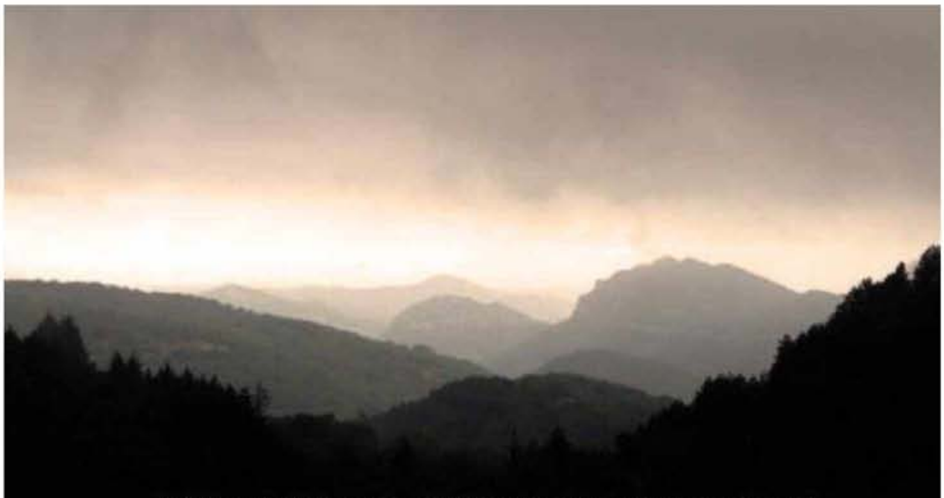

Rainfall over the Cévènes region - Picture from http://episodecevenols.e-monsite.com/

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Aknowledgement

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Abstract

Southeastern France is prone to flash-floods events due to heavy precipitating events. Deep convective systems remain stationary over the same area for several hours. Recently, shallow convective systems organized in bands were observed over complex terrain around the globe and especially in the Cévennes region. These bands remain for several hours and their contribution to the hydrological cycle can be important and lead to floods events. In this context, modelisation is a very useful tool for the understanding of the mechanisms of these systems. A key point of this investigation is the transition from the shallow to the deep convection.

In this paper, the advanced research WRF model is used for the first time as a tool for this problematic of the transition between both kinds of convection. A validation of the data used has been firstly done before using it with the WRF model. The model provides good results for the simulation of a deep convective cell over the region of interest as well as for a band-organized convective event.

Based on the synoptic ingredients leading to heavy precipitation over this region, the question of the transition is dealed through the anomaly of potential vorticity but the comparison of our simulations with simulations using the Meso-NH model shows that the wind shear may have a much more important role in the understanding of this question far from being obvious.

Résumé

Le sud-est de la France est une région affectée par des crues éclaires dues à des évènements précipitants intenses. Des systèmes convectifs profonds deviennent stationnaires pendant plusieurs heures au-dessus de la même zone entrainant ces crues. Plus récemment, des systèmes convectifs peu profonds organisés en bandes ont été observées dans différentes régions montagneuses dans le monde et notamment sur les Cévennes. Ces bandes peu intenses sont stationnaires pendant plusieurs heures et leur contribution à la pluviométrie de la région peut devenir importante et entrainer des phénomènes de crues. Dans ce contexte, la modélisation est un outil très utile pour étudier et comprendre les mécanismes de ces systèmes. Un point clef de cette recherche est la transition entre la convection peu profonde et la convection profonde.

Dans cet article, le modèle de recherche WRF est utilisé pour la première fois concernant cette problématique de transition. Une validation des données utilisées a été réalisé avant de les utilisées dans le modèle WRF. Le modèle donne de bon résultats dans la simulation d'évènements de convection profonde aux dessus des Cévennes tout comme pour la simulation de convection peu profonde organisée en bandes.

En se basant sur les ingrédients à l'échelle synoptique des évènements de précipitations intenses dans la région, la question de la transition est traitée à partir de l'étude des anomalies de tourbillon potentiel mais la comparaison de nos résultats avec les simulations effectuées à l'aide du modèle Méso-NH montre que le cisaillement du vent pourrait avoir un rôle d'autant plus important dans la compréhension de cette question qui est loin d'être triviale.

Περίληψη

Η Νοτιοανατολική Γαλλία είναι ιδιαίτερα επιρρεπής στις ξαφνικές πλημμύρες εξαιτίας των ισχυρών επεισοδίων βροχόπτωσης. Έντονα συστήματα κατακόρυφης ανάπτυξης παραμένουν στάσιμα πάνω από την ίδια περιοχή για αρκετές ώρες. Πρόσφατα, ρηχά συστήματα κατακόρυφης ανάπτυξης οργανωμένα σε ζώνες, παρατηρήθηκαν πάνω από ποικιλόμορφο ανάγλυφο παγκοσμίως και ιδιαίτερα πάνω από την περιοχή Cévennes, στη Γαλλία. Αυτά τα συστήματα νεφών παραμένουν για αρκετές ώρες και η συνεισφορά τους στον υδρολογικό κύκλο πιθανόν να είναι σημαντική έτσι ώστε να προκαλέσει πλημμυρικά φαινόμενα. Σε αυτό το πλαίσιο, η χρήση μοντέλων είναι ένα πολύ χρήσιμο εργαλείο για την κατανόηση των μηχανισμών αυτών των συστημάτων. Το σημείο-κλειδί αυτής της έρευνας είναι η μετάβαση από τη ρηχή στην έντονη κατακόρυφη μεταφορά.

Στην παρούσα εργασία χρησιμοποιείται για πρώτη φορά το προηγμένης έρευνας μοντέλο WRF ως εργαλείο για τη διερεύνηση της μετάβασης μεταξύ των δύο τύπων κατακόρυφης μεταφοράς. Τα δεδομένα που χρησιμοποιήθηκαν τεκμηριώθηκαν προτού χρησιμοποιηθούν στο μοντέλο WRF. Τα αποτελέσματα του μοντέλου προσομοιώνουν καλά ένα κύτταρο έντονης κατακόρυφης ανάπτυξης πάνω από την περιοχή ενδιαφέροντος, καθώς επίσης και ένα σύστημα κατακόρυφης ανάπτυξης οργανωμένο σε ζώνες .

Λαμβάνοντας υπόψη τις συνοπτικές συνθήκες που προκαλούν έντονες βροχοπτώσεις, το θέμα της μετάβασης αντιμετωπίζεται μέσω των ανωμαλιών του δυναμικού στροβιλισμού. Ωστόσο συγκρίνοντας τα αποτελέσματα των προσομοιώσεών μας με τις προσομοιώσεις από το Meso-NH μοντέλο, προκύπτει ότι ο άνεμος παίζει πιο καθοριστικό ρόλο στην κατανόηση αυτού του θέματος.

Keywords : Deep convection, shallow convection, bands, transition, WRF.

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1. Introduction

The Cévennes-Vivarais area is a geographical region of southeastern France, more precisely situated on the southeastern part of the Massif Central. This region can be characterized by gradients going from the crest of the mountain to the Mediterranean Sea coast. A gradient of topography with medium mountains on the west side and the plain of the Rhône valley on the east side. A gradient of population between the mountainous area poorly populated and the Valley and coast line more urbanized and populated. A climatic gradient going from a dry Mediterranean Climate on the southeastern part of this region to a more humid and alpine like climate the more we get in height. The region is also characterized by a gradient of mean annual precipitation between more than 1500mm to less than 1000mm per year between the north-west and the south-east of the area (*Angot,* 1919, *Mitard,* 1927, *Frei and Schär,* 1998).

This region is also prone to Heavy Precipitating Events (HPEs) leading to dramatic flash-floods. These events occur generally during the fall season when warm and moist air coming from the Mediterranean sea hits the foothill of the Massif central. The orography of the region triggers convective systems which can be locally stationary. The understanding and the quantification of these events and their hydrological impacts is the goal of the OHMCV (Observatoire Hydro-météorologique Méditerranéen Cévennes Vivarais) observatory.

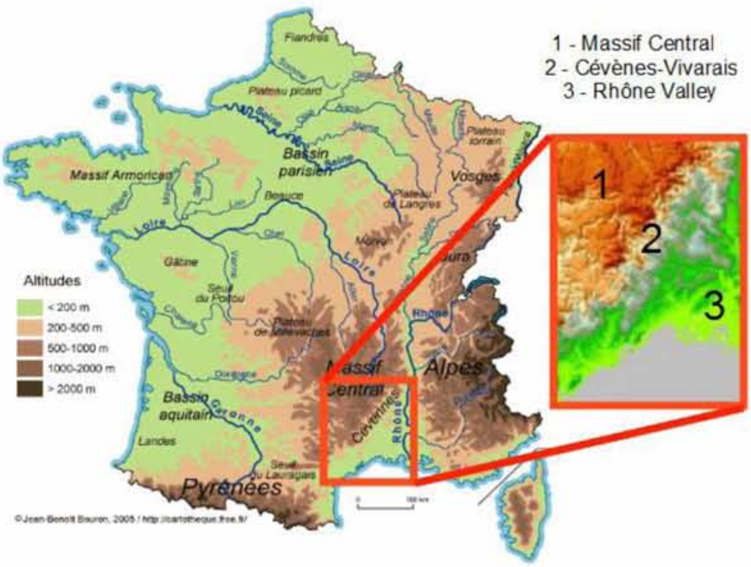


Figure 1 : Geographic situation of the Cévennes-Vivarais area and the topography of the region

These extremes rainfall are generally associated with deep Mesoscale Convective Systems (MCS) for which the vertical development can reach the top of the troposphere and the local convergence of winds can made them becoming stationary, it means that new intensive cells are generating at the same location while old and dying cells are gradually transported downstream. But we recently observed some Shallow Convective (SC) precipitating clouds where the height of the cloud does not exceed a few kilometers (3-4 km) (*Kirshbaum and Durran,* 2005b, *Yoshizaki and al.* 2000, *Miniscloux and al.*, 2001). There are a very few observations of these systems because their signature is difficult to get with the today's tools. In fact, these bands are characterized by small rainfall intensity and so the bands are often masked by the heaviest precipitation of a MCS then we are not able to see them with radar. It is also very difficult to observe them thanks to a raingauge network because of their spatial structure.

Because it is difficult to observe that kind of systems, we must use the modelization in order to improve our understanding in the processes leading to the formation of these bands. Numerous studies and simulations have been done previously in order to identify the sensitivity of rainfall bands over the orography structure, their triggering and their localization (*Cosma and al.*, 2002, *Kirshbaum and Durran*, 2004, 2005a, 2005b, *Fuhrer and Schär*, 2005, 2007, *Godart*, 2009). The aim of this study is to use the Advanced Research WRF (ARW) model in order to explore the atmospheric factors that can be relevant in the formation of these bands and test their sensitivity to some perturbation so we can investigate the physic ingredients relative to the transition between the shallow and banded organized convection with the deep convective systems.

In this work, the data and the method used will be evaluated using the event of shallow convection according to *Godart (2009)* of the 10th of August 2004. Then the synoptic ingredients of the different type of convection will be examine and the case of the 13th and 14th of October 1995 will be studied. This event has been chosen according to the Météo France classification (*Nuissier and al., 2011)* in which this event has the two types of convection whereas according to the classification of Godart the event is not classified in a specific type of convection. The simulation of this event will be performed using the WRF model and the results will be presented. The results and the different classifications will be discussed.

2. Data and Methods

2.1. ECMWF ERA-Interim Reanalysis

The European Centre for Medium-Range Weather Forecasts provides through internet daily reanalysis maps all over the world. Some of these reanalysis are freely available. These reanalysis offers us a lot of meteorological fields at different level which are needed by the WRF model.

Fields were chosen on 37 pressure levels, on the surface level and according to 4 layers for the ground.

In order to perform the synoptic analysis of the event and also at the local scale, the different fields were extracted over all western and central Europe, and also over a window corresponding to western France with a part of western Europe and of the Mediterranean sea.

We get these fields with a grid resolution at 0.75° per 0.75°.

The validation of these dataset was done plotting some sounding, over the location of Nimes, of temperature and relative humidity versus real observed sounding at the same time. We will take a look especially on the plot of the relative humidity since it is a key variable for the development of convective systems in a typical Cévennes case.

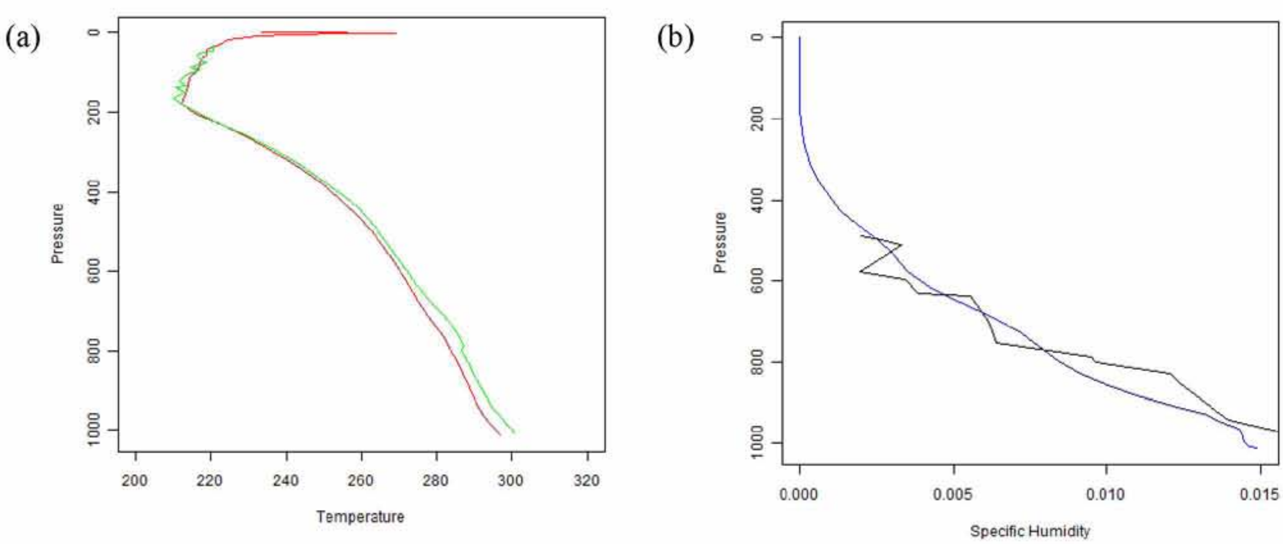


Figure 2 : ECMWF and real observed sounding for the 10th of August 2004 (a) for Temperature (°C) and (b) for the relative humidity (g/kg). Pressure in (hPa)

2.2. Advanced Research WRF Model

The Advanced Research WRF Model is a no-hydrostatic, anelastic model developed at the National Center for Atmospheric Research (NCAR). The main equations governing the state of the atmosphere are described in the scientific documentation available there: http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf. It is the first time that this model is implemented at LTHE. It was indeed a major part of the work to perform the implementation of this model, at first on a local computer to get used to the basics of the model, and then on a supercomputer with the help of the administrator of this special workspace.

This model is following a specific flow chart that has to be fully done in order to initialize and run the model. The flow chart of the model is presented in the figure 3.

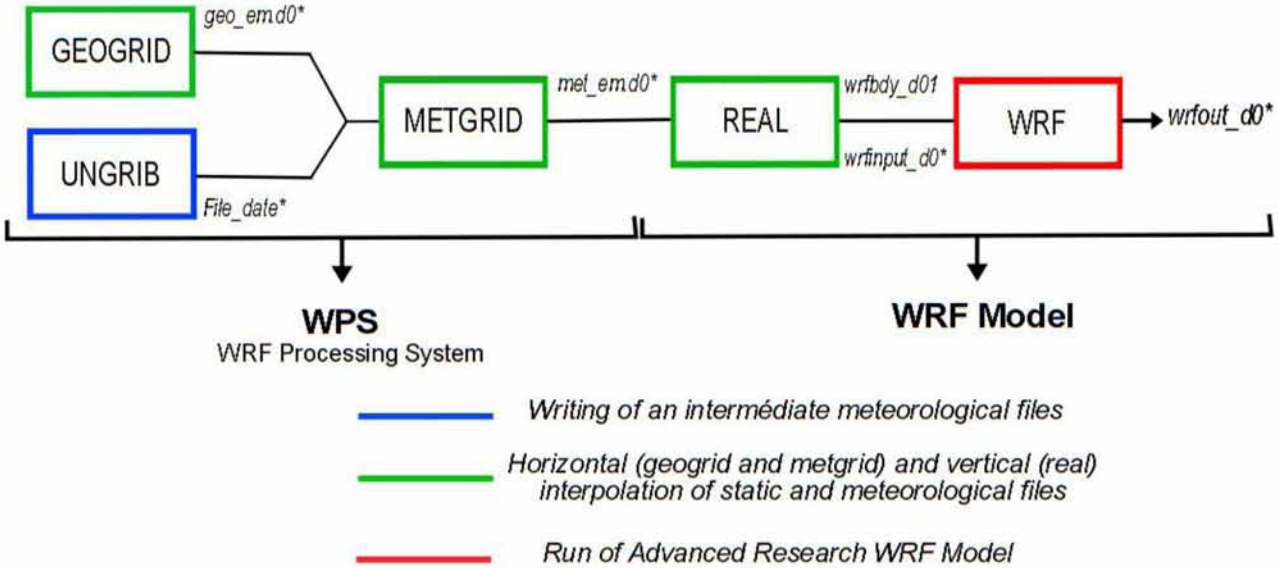
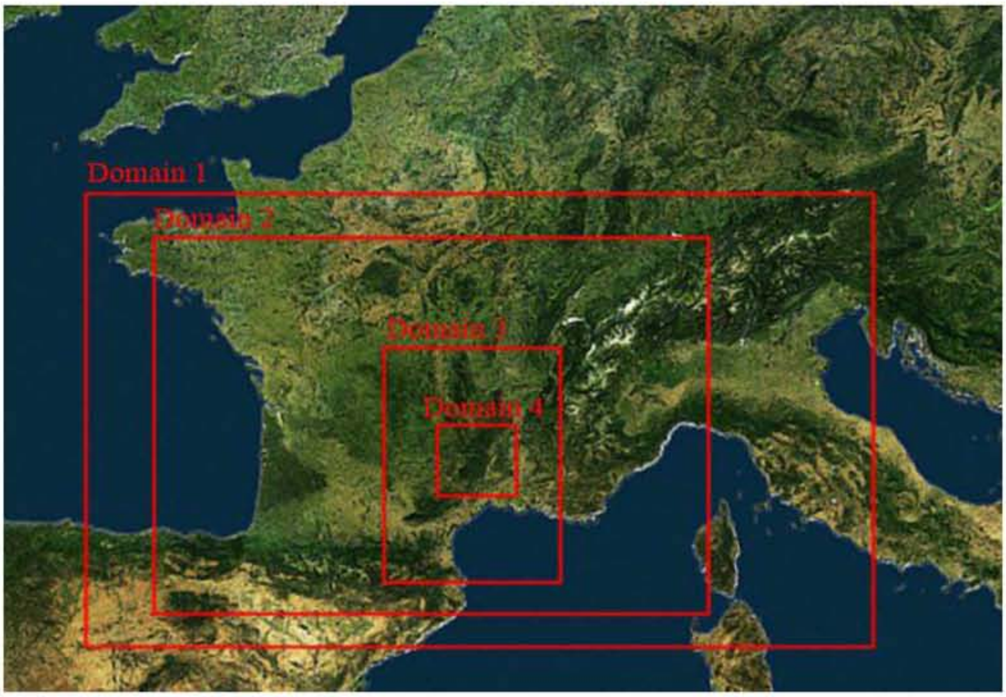


Figure 3 : WRF modeling system flow chart for real cases

The model is constructed with two main programs : the WRF Processing System (WRF) and the model (WRF Model). In the WPS program, there are three subroutines that are used for the extraction and the interpolation of meteorological fields. First of all, the subroutine GEOGRID is used for the interpolation of the static fields (land use, land-sea mask, topography). This step is also very important for the definition of the different domains. Then the program UNGRIB is used to extrapolate the grib coded meteorological fields into an intermediate format that is readable by the others steps of the model. When domains are defined and the meteorological fields are extrapolated, the METGRID program interpolate the meteorological fields horizontally on the domains. After all the steps of the processing systems are done, we have to initialize the initial and boundary conditions of the model with the REAL program of the WRF model part. If all these steps are done successfully, the model can be run.

In this work, we will use the WRF model over 4 domains in one way nesting (Figure 4). The parameterization has been chosen according to previous work over the same region made by the LAMP (Laboratoire de Météorologie Physique) and is presented in the table 1 for the two last domain (the three first are similarly parameterized). The different simulations presented in this study will be discussed in another part.

(a)



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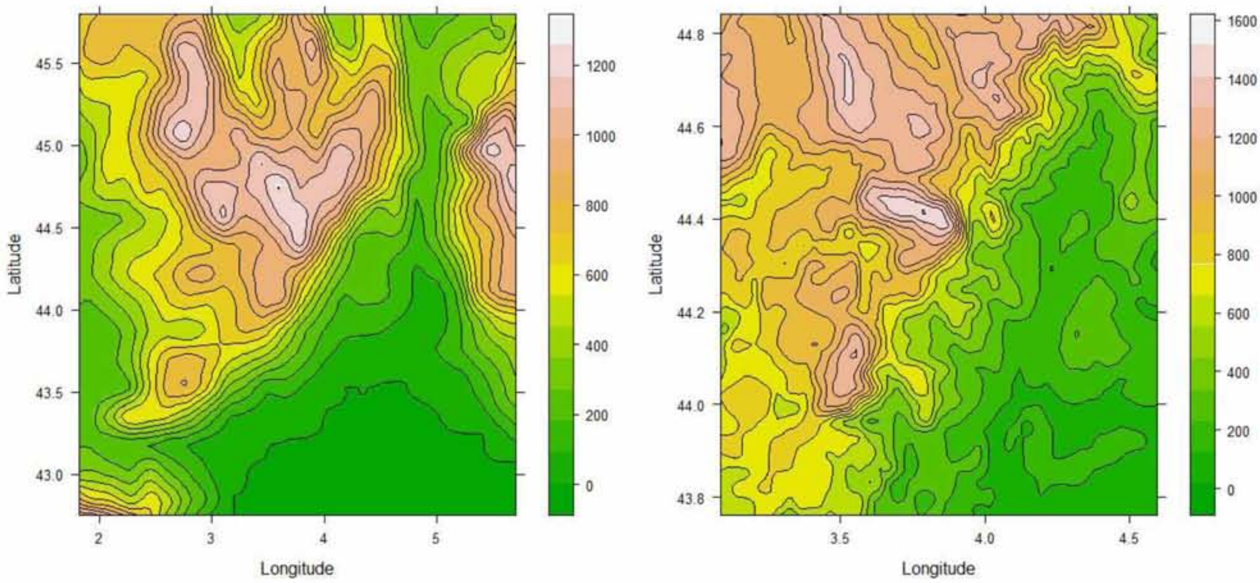


Figure 4 : (a) The four domains used with the WRF model and (b) the topography of the 3rd and 4th model

	3rd Domain	4th Domain
Resolution	4km	1km
Land Use	Noah Land surface Model	
Turbulence scheme	1,5 order TKE closure (3D)	
Convection scheme	Kain-Fritsch scheme	none
Microphysics scheme	Thompson and al. scheme	
Resolution (grid points)	80x88x37	124x124x37
Time step	24s	6s

Table I : parameterization of the 3rd and 4th domains

Since this is the first time that the WRF model is implemented at LTHE, a part of validation of the model has been done. The validation has not been done on the parameterization of the model because the evaluation of those was already done in the past for this model so we assume that the parameterization is good. We want to use the model for the study of shallow convection over the Cévennes region in France, so we want to evaluate the accuracy of the model to reproduce an event of shallow convection. The MESO-NH model has already been used and validated for the modelization of shallow precipitating convective systems (*PhD of Godart., A.*). The evaluation of our model will be done on the basis of this work using the event of shallow convection of the 10th of August 2004. The simulation of these event will follow the protocol of Godart so the model will be forced with the same fields during each 6 hours during 24h in one way nesting. The first step of this evaluation is qualitative, the mean hourly rain produced by the model is compared for each model and also the spatial pattern of the rain field. The figure 5 shows that there is a southeasterly shift of the rain field pattern even if the main direction is correctly represented. Furthermore, there is a little underestimation of the maximum of the precipitation with the WRF model.

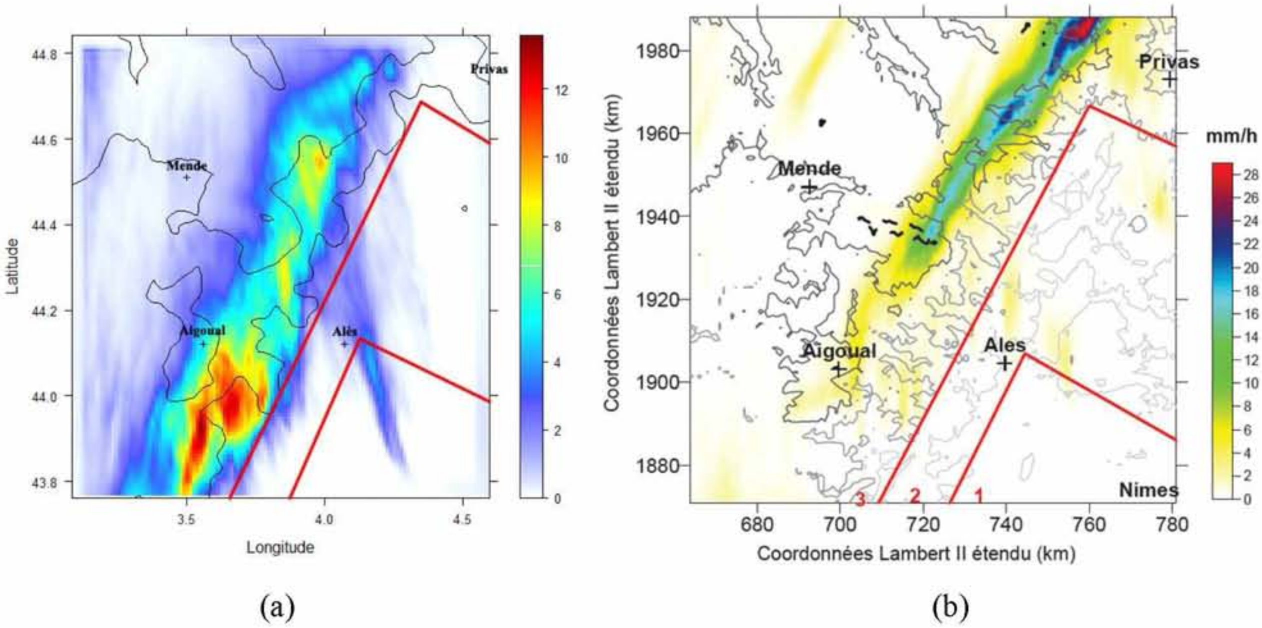


Figure 5 : (a) mean hourly precipitation with the WRF model for the 10 August 2004 (b) the same for the MESO-NH model

To evaluate quantitatively the model, some rainfall criterions are used to define the banded organized shallow convection. This classification was already done in Godart phd (2009). The main characteristics are presented here in order to analyze the following graphs. We are working on a 24 hours basis of hourly precipitation. For each hour, the mean of positive precipitation and the intermittence per sector is calculated. The time slot of which the mean of rainfall increased and the intermittence decreased with altitude will be considered as a shallow convection event. The time slot has to be at least of 3 hours.

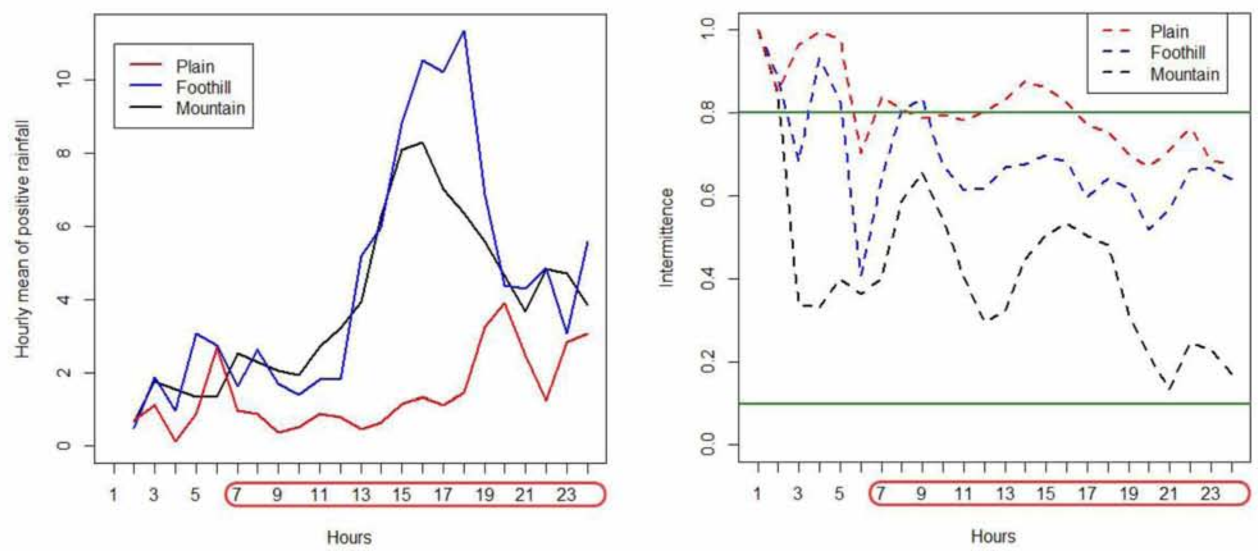
Therefore, these criterions do not allowed us to distinguish banded organized shallow convection with stratiform precipitations, deep convection events concentrated in the mountain or either isolated cells. An arbitrary threshold is chosen in order to distinguish these different types of storms. All the criterions are resumed as :

- A mean intensity in the mountain greater than 1mm/h and higher than in plain.
- Intermittence in the mountain lower than the intermittence in plain and foothills.
- Intermittence in mountain in the range of 10% to 80%.
- Intermittence in foothills lower than in plain and less than 90% or intermittence in foothills and plain greater than 90%.
- Intermittence in plain greater than 70% and greater than 50% in foothills.
- At least 3 consecutively hours has to present the previous criterions.

The different sector (plain, foothill and mountain) are defined according to elevation of each pixel.

The plain is defined as the pixels with an elevation under 200m (asl), the foothill sector is defined between 200m and 500m (asl) and the mountain is all the pixels above 500m (asl). To represent schematically these sectors, red lines are drawn as on Figure 5. The sector 1 (Figure 5b) is the sector of plain, the sector 2 represents the foothill and the 3rd sector is the mountain. The analysis of the event of the 10th of August 2004 according to these criterions shows that the WRF model validate all the criterions from 7h to the end of the simulation.

Intermittence is lower in the mountains, Intermittence in foothills is lower than in plain and less than 90% and greater than 50% while in plain intermittence is greater than 70%. In the same time, the mean rainfall is greater than 1mm/h in the mountain and higher than in plain as it is shown in the figure 6.



(a) (b)

Figure 6 : (a) Hourly mean of positive rainfall and (b) Intermittence (divided by 100) for the simulation of the 10th of August 2004.

The ECMWF ERA-Interim data used with the ARW (WRF) Model shows that the model seems to succeed in the simulation of Shallow convection events organized in bands. The first results obtained for a specific case are in agreement with the work of Godard 2009 on the characterization of the orographic banded organized precipitation over the Cévennes.

3. Transition between shallow and deep convection

3.1. Synoptic ingredients

In the literature, there are a lot of papers about convection in mountainous region because of the interaction between the orography and the initiation of the convection. Numerous of these studies focused on the initiation of deep convection over a mountainous region (*Lin and al.*, 2001, *ducrocq and al.,* 2008, *Kottmeier and al.,* 2008, *Barthlott and al.,* 2011) because of the important hydrological impact in small watersheds in mountainous area (flashfloods, landslide …). Even if there is still a lot of questions in this domains, field campaigns like COPS or observatory like OHMCV help a lot in the understandings of the mechanisms that leads to initiation of deep convection and on its hydrological impacts. From that kind of observations in deferent regions of the world, scientists start to take an interest into banded convection over complex terrain (*Miniscloux and al.,* 2001, *kirshbaum and durran,* 2005, *Kirshbaum and al.,* 2006, *Godart and al.,* 2009) because their mechanisms are still unclear and their hydrological signature is also important. In the Cévennes area, precipitations from banded organized convection can contribute to 40% of the precipitation of some sectors (*godart and al.,* 2009). In all these papers, just a few deals with the transition from shallow convective cloud to deep convective cells (*Khairoutdinov and Randall*, 2006, *Zehnder and al*., 2006, *Wu and al.,* 2009, *Kirshbaum* 2011) and moistly they deal with the transition from shallow cumulus to deep convection but not with the transition from shallow precipitating convection to deep convection and this question is really important for the forecasting of precipitating events over mountainous area.
In fact, the synoptic ingredients for triggering shallow or deep convection over orography are very close. Since that in the case of deep convective systems that can be stationary the hydrological response is very fast in small catchments whereas in the case of banded organized convection that are less intense the hydrological response is very different, it is very important to know what kind of mechanisms lead to one or the other kind of convection and when. In order to focus our study on this question of the transition from shallow precipitating to deep convection, a state of the art of synoptic ingredients leading to both kind of convection was done. Then, the synoptic analysis of the event of the 13th and 14th of October 1995 and the protocol for the simulations of this event will be presented.
More complete synoptic analysis of deep convective systems over the Cévennes area can be found in *Nuissier and al*., 2008 or more generally over the alps in *Lin and al*., 2001. The synoptic ingredients of shallow banded organized convection are presented in *Kirshbaum and Durran*., 2004

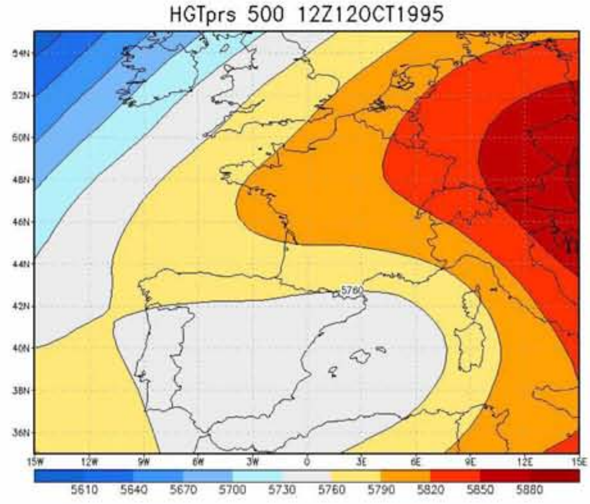
and more precisely for the Cévennes area in *Godart and al.*, 2009. The main ingredients are presented in the following table in order to point out the similitudes between these ingredients.

	Deep convection synoptic ingredients	**Band-organized convection synoptic ingredients**
1	Conditional or potential unstable airstream impinging on the mountains	Potential instability
2	Orographic effect to release conditional instability	Strong stability of unsaturated atmosphere
3	Very moist and moderate low level jet (northward wind greater than 10 $m.s^{-2}$ and water vapor flux greater than 100 $kg.s^{-1}.m^{-2}$)	Strong unidirectional and weak directional wind shear
4	Upper tropospheric deep south west trough of high potential vorticity anomaly approaching the area	Moderate northward wind velocity (greater than 10 $m.s^{-2}$)
5	Upper tropospheric quasi-stationary high pressure ridge	Thalweg from Ireland to Gascogne Golfe and an upper tropospheric high pressure ridge

Table II : Synoptic ingredients for deep convection and band-organized convection over southeastern France

3.2. Analysis of the 13th and 14th of October 1995 event

The case of the 13th and 14th of october 1995 will be examined in this study since according to a Météofrance classification the 13th of October 1995 was considered as a deep convective event whereas the 14th of October 1995 was considered as a shallow convection event. The interest of this case is to evaluate the synoptic ingredients of these days to see if they fit with the synoptic ingredients presented above and then to investigate physical processes between those two days that can explain the transition from one kind of weather to another. First of all, the synoptic ingredient will be examine through the field of geopotential at 500hPa (Figure 7).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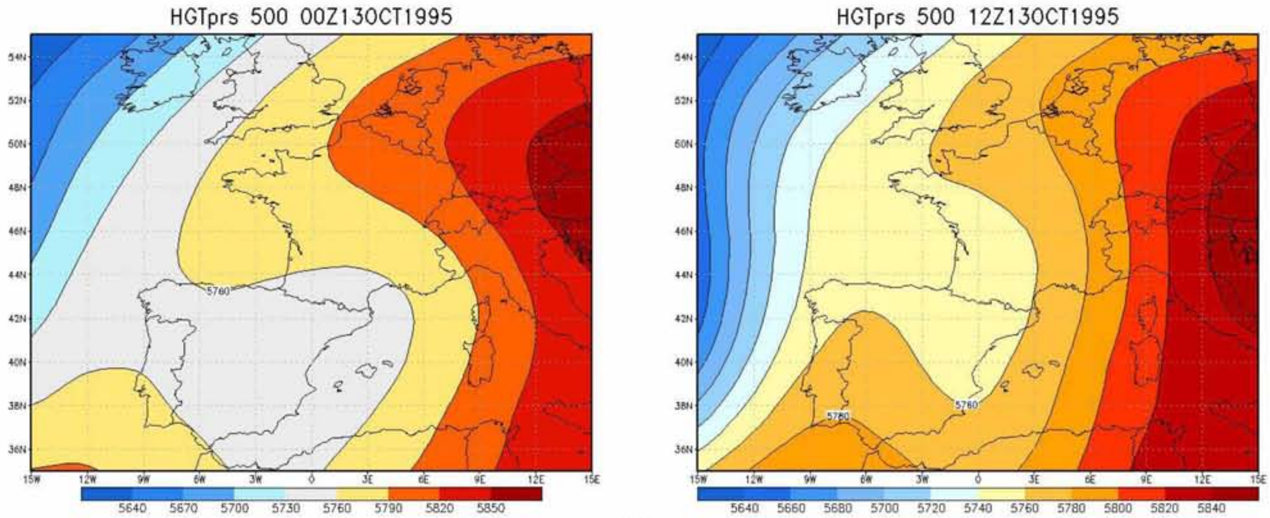
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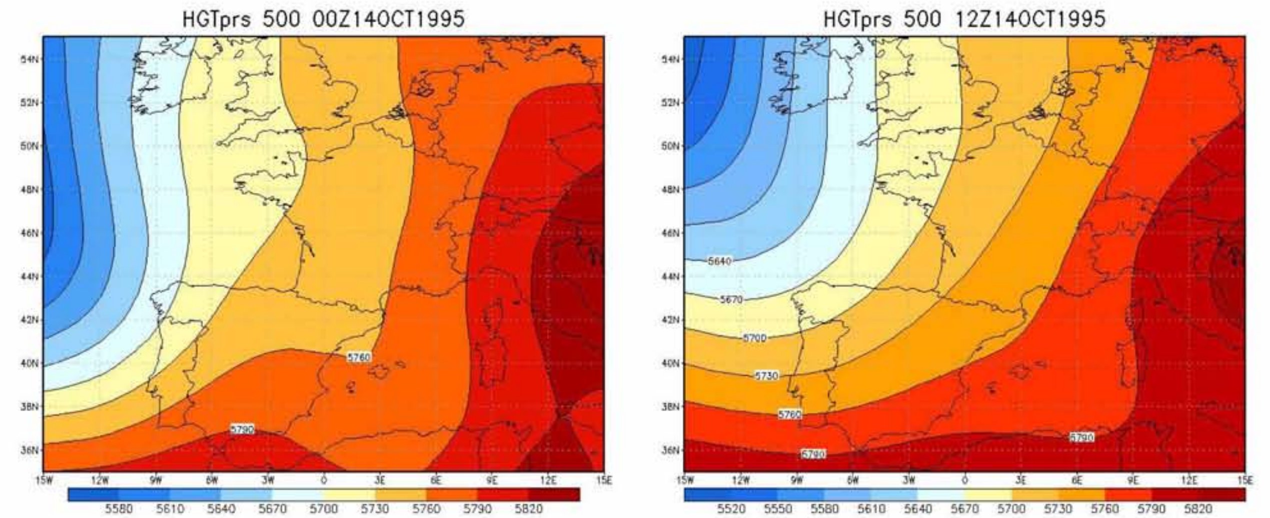
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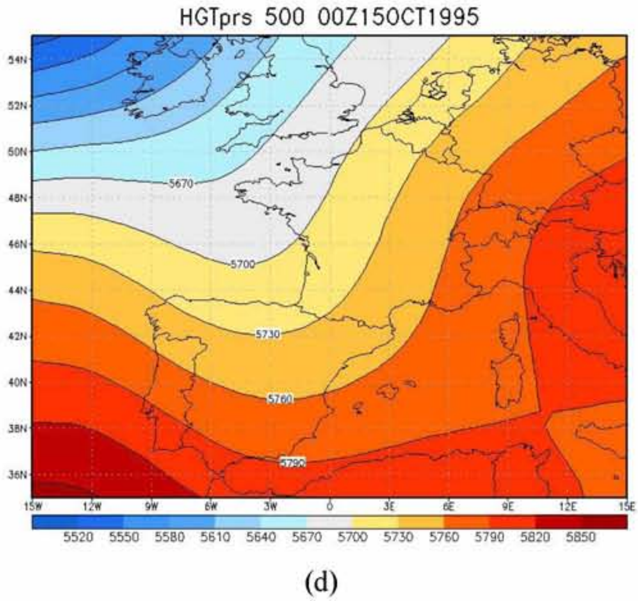
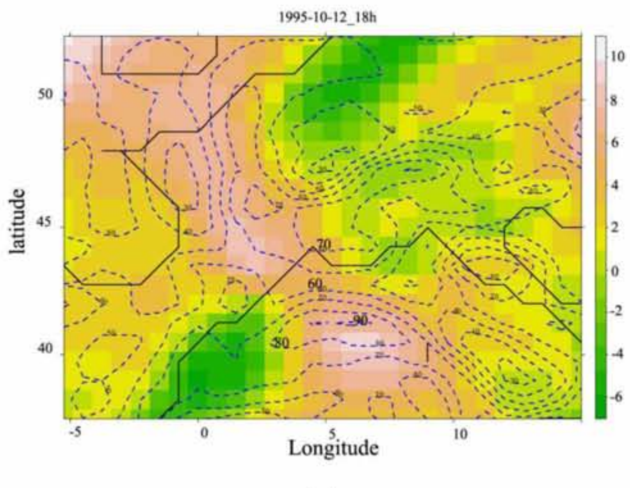


(d)

Figure 7 : Synoptic evolution of Geopotential at 500hPa for (a) 12th of October 1995 at 12h (b) 13th of October 1995 at 00h and 12h (c) 14th of October 1995 at 00h and 12h and (d) 15th of October 1995 at 12h

These maps show a stationary high pressure ridge on the eastern part of Europe for both days associated with a trough more on the north west (the center of the trough is out of the frame) leading to southerly wind on the Cévennes region. That kind of situation with a depression on the North West of the region associated with a high pressure ridge is typical of a Cévenol event and this is in agreement with the synoptic ingredients leading to heavy precipitating events in southeastern France.

The low level jet will be examine in the following figure which shows the low level (850 hPa) northward wind and the relative humidity (figure 8).



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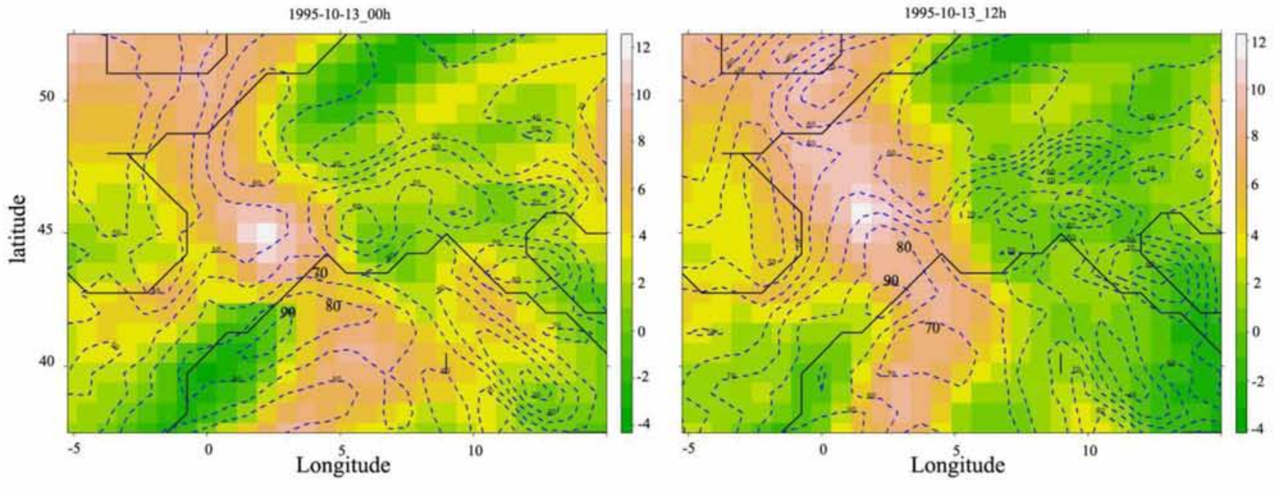

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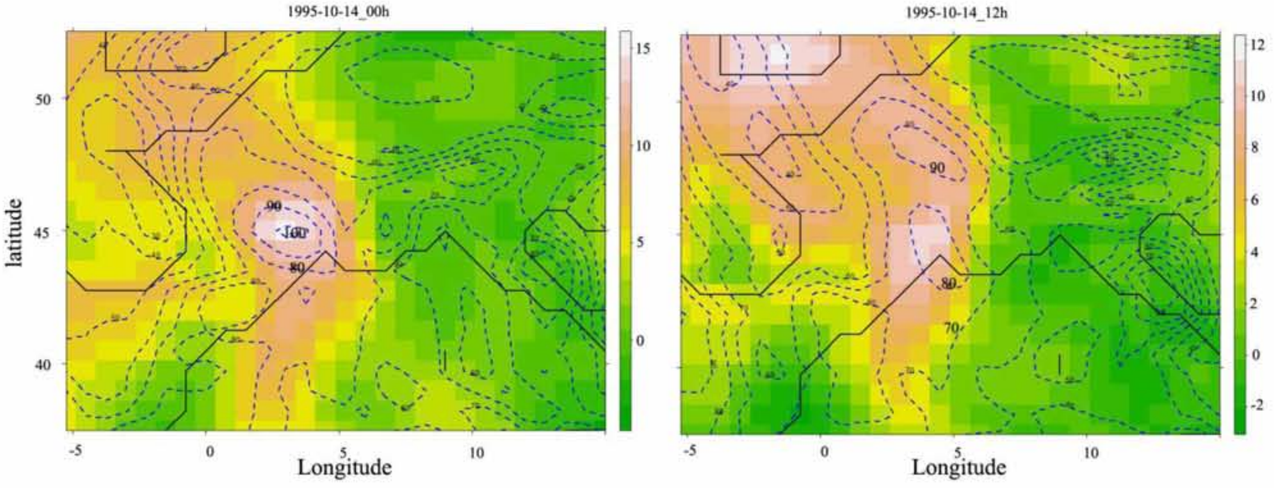

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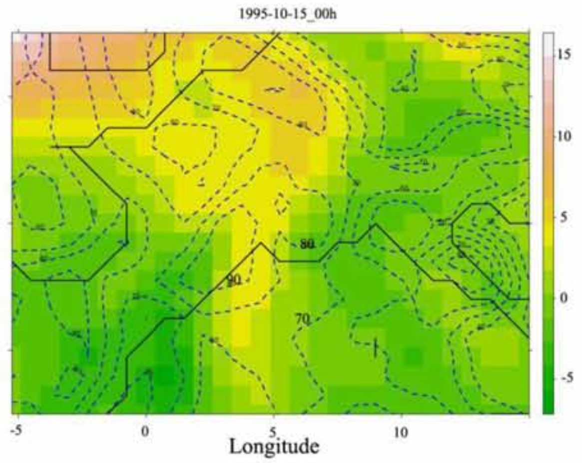


(d)

Figure 8 : Low level (850hPa) northward jet component (shaded) and low level relative humidity (%) in dashed blue line for (a) the 12th of October 1995 at 18h (b) the 13th of October 1995 at 00h and 12h (c) the 14th of October 1995 at 00h and 12h and (d) the 15th of October 1995 at 00h. Black line represents the land/sea limit.

For both days of 13th and 14th of October, the low level wind is moderate around 10m/s and the relative humidity of the layer is quite high. This ingredient is also present for this event.
The stability is studied from observed sounding over the Nîmes station (Directly in at the south of the Cévennes area). From these soundings some indices are calculated and we will use the Convective Available Potential Energy (CAPE) which is the positive buoyancy of an air parcel, the Convection Inhibition (CIN) which is the amount of energy to prevent an air parcel from rising to its level of free convection and the Lifted Index (LI) which is the difference of temperature between a lifted air parcel and its environment. These indices are sum up in the following table (Table III).

Day and time	CAPE (J/kg)	CIN (J/kg)	LI (K)
1995-10-12 12h	0	0	1.46
1995-10-13 00h	0	0	2.77
1995-10-13 12h	39.61	-45.90	1.46
1995-10-14 00h	0	0	2.59
1995-10-14 12h	919.26	-1.05	-3.73
1995-10-15 00h	152.64	-35.94	-0.47

Table III : Stability indices for the event of 13th and 14th of October 1995

The values of CAPE and CIN for the 13th of October do not show a real instability of the atmosphere (CIN greater than CAPE and a LI not really favorable) but some studies shows that the local ingredients like local convergence because of the topography can be sufficient to trigger convection in a marginal unstable environment (*Barthlott and al.*, 2011). The environment for triggering convection on the 14th of October is good with moderate value of CAPE and very low CIN.

3.3. WRF Simulations of the 13th and 14th of October 1995

The aim of this study is to investigate what factors trigger deep convection or inhibit it from a shallow convective cloud. We showed in the second part of this study that the WRF model succeeds in reproducing the band-organized shallow convection. From the simulations of this special event, we want to show our parameterization of the WRF model allow the good simulations of both kind of convection. Thus the first simulation that will be performed has to show that the model succeeds in the simulation of real deep convective event. For the 13th October the model will be forced by the ECMWF files every 6 hours during 24 hours from 00h to 24h. for the 14th of October, we will applied the same protocol as for the 10th of August 2004 since it is classified as a shallow convective event to see this event is organized or not in bands. The same file will forced the model each 6 hours during 24h from 00h to 24h.

We will investigate rain fields produced by the model and vertical cross sections of the water content in the atmosphere in order to see the development of clouds in each case. The intermittence and the mean rainfall will also be investigate by sector.

3.4. Transition between band-organized shallow convection and deep convection

Our study of the question of the transition between both kind of convection will be based on the analysis of the potential vorticity. In fact, it has been shown in several papers (*Hoskins and al.*, 1985, *Hoinka and al.*, 2003, *hoinska and davies*, 2007, *Ruissel and al.*, 2009) that there is a link between the triggering of deep convection and anomalies of potential vorticity. In fact, an approaching anomaly of potential vorticity will destabilized the layer upstream. The deeper is the anomaly, upstream of the anomaly is more destabilized. Moreover, it has been identified that in general an anomaly of potential vorticity is associated with a descending layer of dry air from the stratosphere in the troposphere. Again, the deeper is the anomaly, the lower is the dry descending layer from the stratosphere. Our hypothesis is that an approaching anomaly of potential vorticity to our area of study for the event of the 13th and 14th October 1995 triggered the deep convection on the 13th of October and then the descending dry layer inhibited the convection on the 14th of October. The analysis will be done on the ECMWF data in a first time to see at a synoptic scale if our hypothesis is validated.

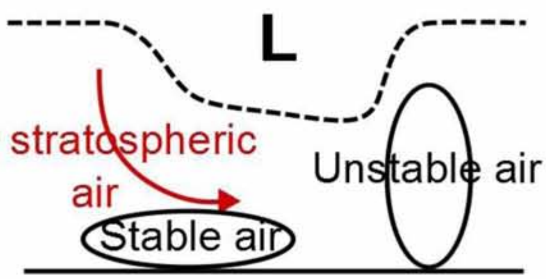


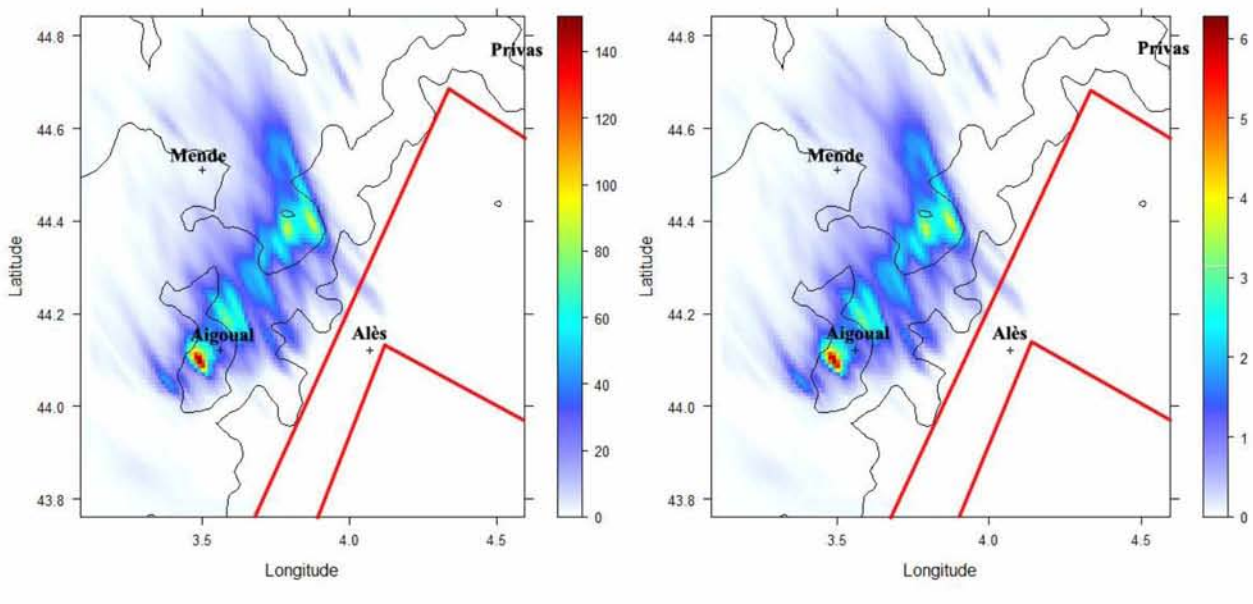
Figure 9 : sketch of an anomaly of potential vorticity. Solid line represents the surface. Dashed line is the Traupopause.

4. Results

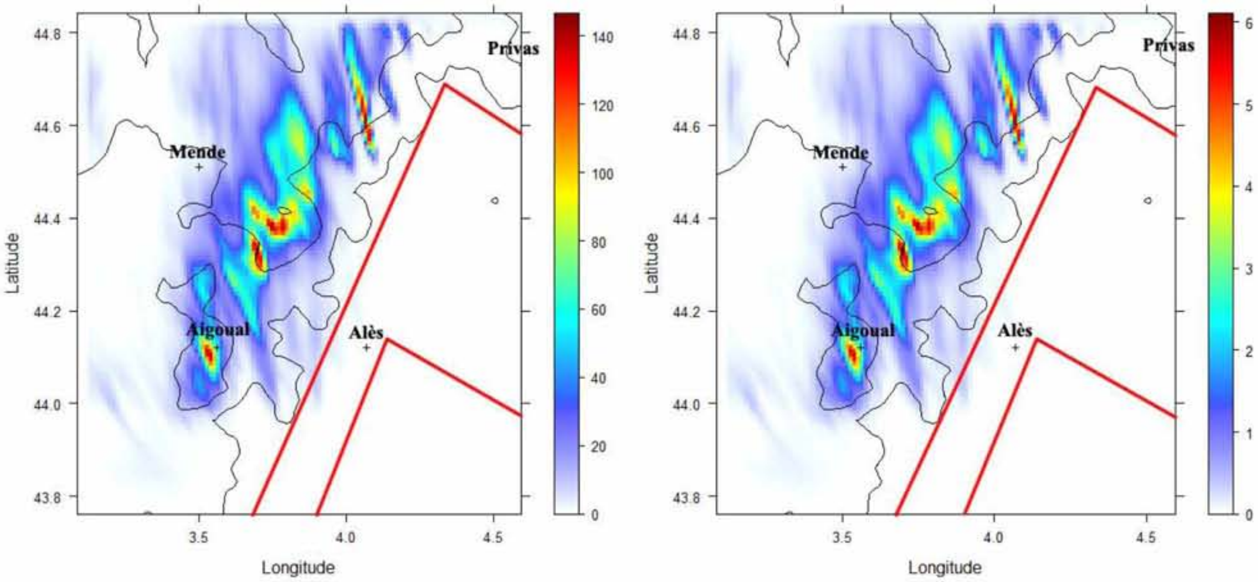
A first analysis of the hourly rain fields step by step shows the difference between the two days of the 13^{th} and 14^{th} of October 1995 event. On the one hand, we get a not well organized pattern advected from the south for the 13^{th} of October while on the other hand persistent bands took place for the 14^{th} of October. A qualitative analysis of this observation will be presented in a first part thanks to the rain fields. Then we will investigate visually the height of water content so see whereas we are in presence of deep or shallow convection. The quantitative analysis of this observations will be done thanks to the graphs of Intermittence and mean positive rainfall. To finish this part, the results of the study on the potential vorticity will be presented

4.1. Rain fields

A first analysis of the pattern of the rain fields permit to see according to the accumulation of rainfall over the 24h and the mean hourly precipitation rate if the model seems correct in the simulation. Moreover, in the case of band-organized shallow convection the signature of bands should be visible on the pattern as we can see in the figure 9b.



(a)



(b)

Figure 10 : Accumulated rainfall (left) and mean hourly precipitation (right) for (a) 13th of October 1995 simulation and (b) 14th of October 1995 simulation.

The intensity and the total accumulated rainfall for both events are quite similar. Nevertheless, the pattern for each simulation is quite different. In fact, for the 13th of October, the peak of intensity fits exactly with the peaks of the topography (Mount Aigoual 1 565m asl) and the highest intensities fit with the relief. Since we saw that the conditions were not very favorable to trigger convection the 13th of October and also that even at marginal instability deep convective cells can develop. Looking step by step the mean hourly precipitation, it seems that this is the kind of situation that occurs on the 13th of October.

For the 14th of October, the pattern is very different, highest intensities take place in different places and show some organization especially at the north of pattern with a very clear band. Some convective cells cannot be excluded because of the environment favorable to deep convection but the analysis step by step of the mean hourly precipitation shows bands organization on several points which persist for several hours.

4.2. Cross section

The investigation of deep convection or not within the system can be done thanks to North-south vertical cross section. The global water content in the atmosphere is examined with qh which is defined as :

$$qh = qcloud + qrain + qice + qsnow + qgraup \quad (1)$$

Where qcloud, qrain, qice, qsnow, qgraup is respectively the cloud, rain, ice, snow and graupel water content in the atmosphere (in kg/kg).

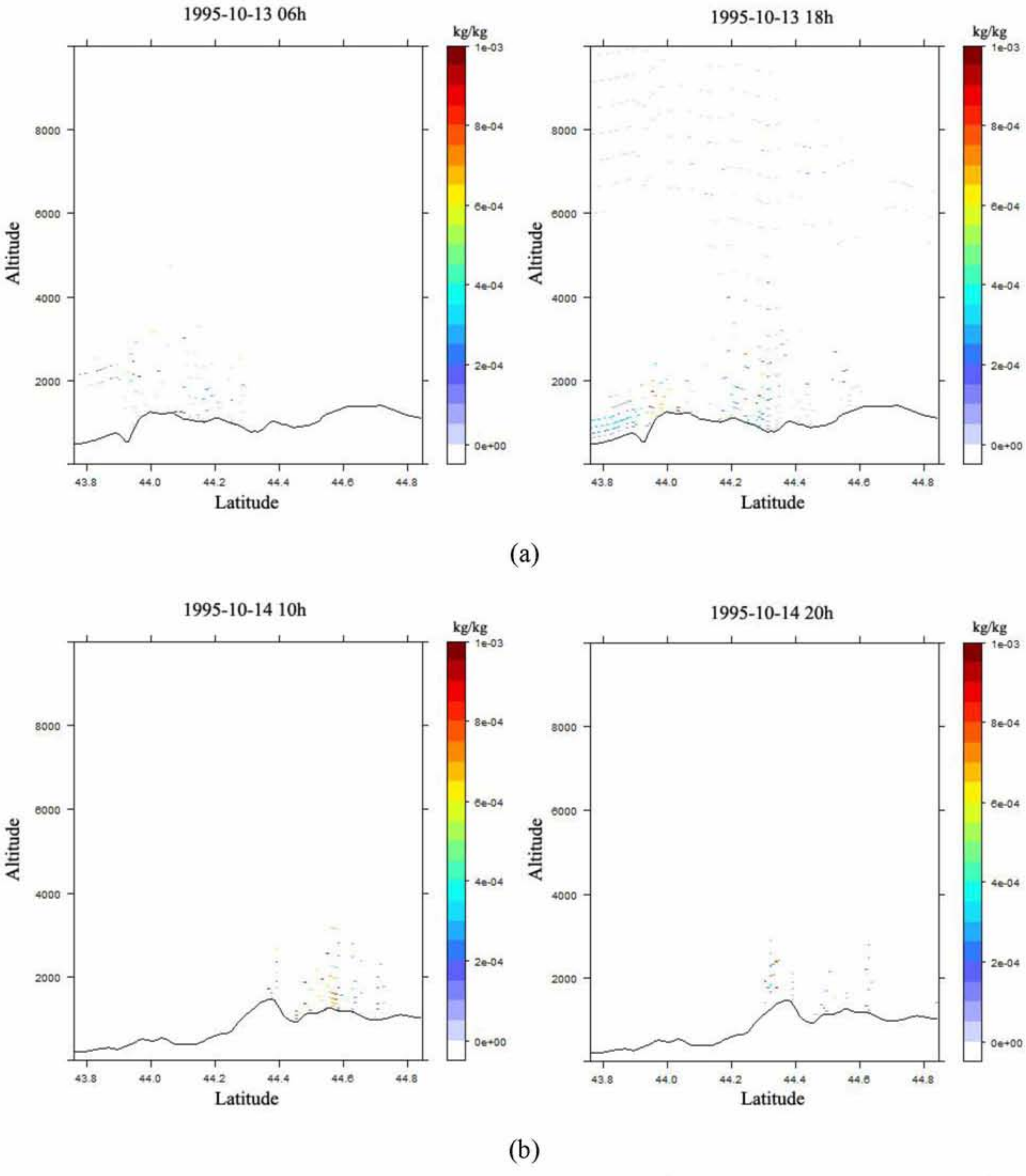
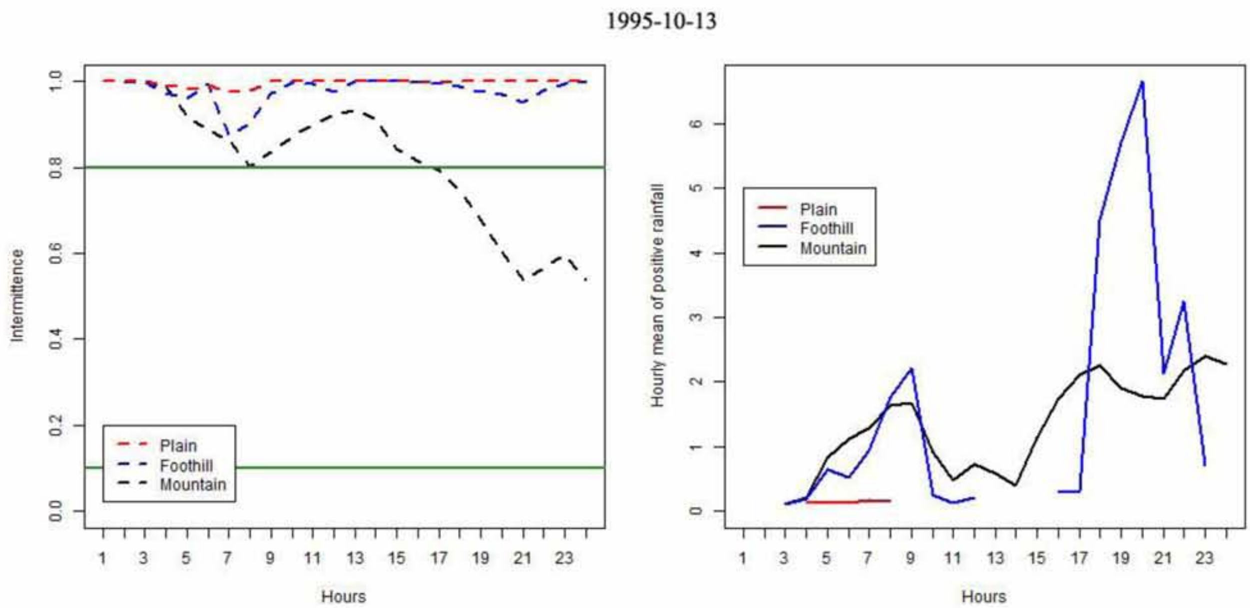


Figure 11 : Vertical cross section at different times for (a) the 13th of October 1995 and (b) the 14th of October 1995. The cross section for (a) is at 3.50° in longitude and for (b) at 3.83° in longitude.

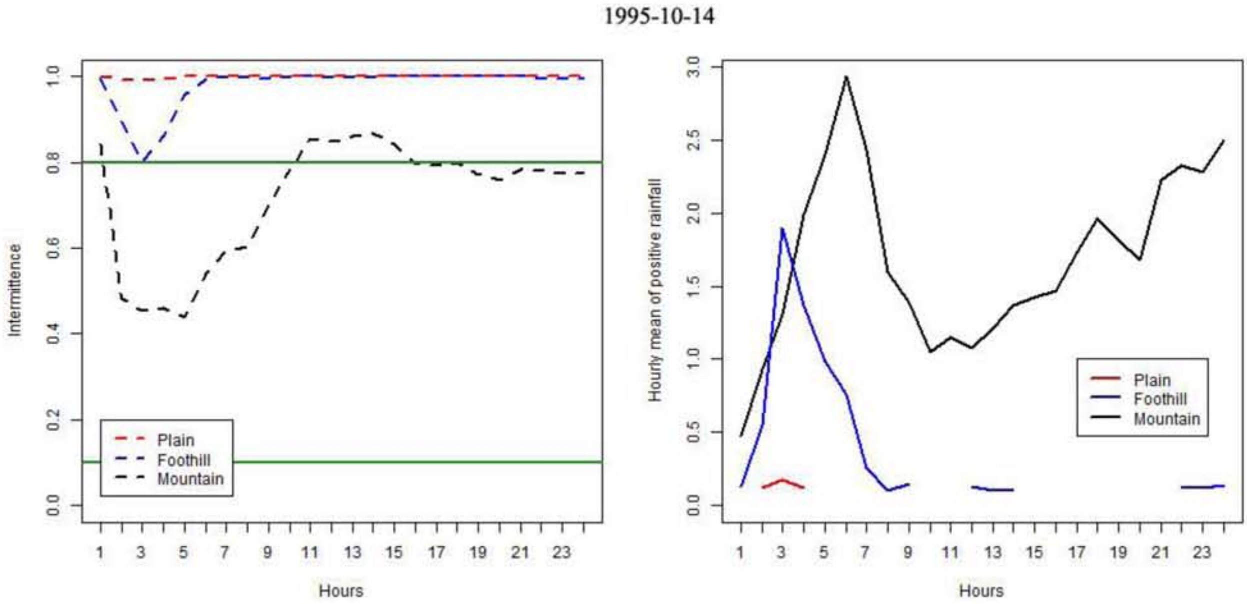
For the 13th of October, the vertical cross section is placed over the mount Aigoual in order to check our results from the analysis of the rain fields. We can see on the two cross section of the figure 9(a) that there is deep convective cloud over the location of the mountain. The presence of water content continuously within the atmosphere from the ground to the top of the troposphere is in agreement with this result. Moreover, the analysis step by step of the cross sections for this day shows that there is statiform clouds during most of the event and after 17 hours of simulations a cell exploded over the location of the Mount Aigoual and is advected downstream which is in agreement with the analysis step by step of the rain fields for the same day. The case of the 14th of October is also confirmed as a shallow band-organized convective system thanks to the analysis of these cross sections. In fact, as we can see on the figure 9(b) the convection take place mainly over the mountain and is quite elongated as bands. During the all simulation time, the convection is inhibited around 4 kilometers even if there is punctually some development more important but not reaching an altitude greater than 6 kilometers.

4.3. Intermittence and mean rainfall analysis

Previous results show qualitatively signature of deep or shallow convection our region of interest. The quantitative analysis will be here investigate with the same tools used for the validation of the WRF model for the case of the 10th of August 2004. The intermittence of the rainfall per sector will be examined as well as the mean positive rainfall for both cases.



(a)



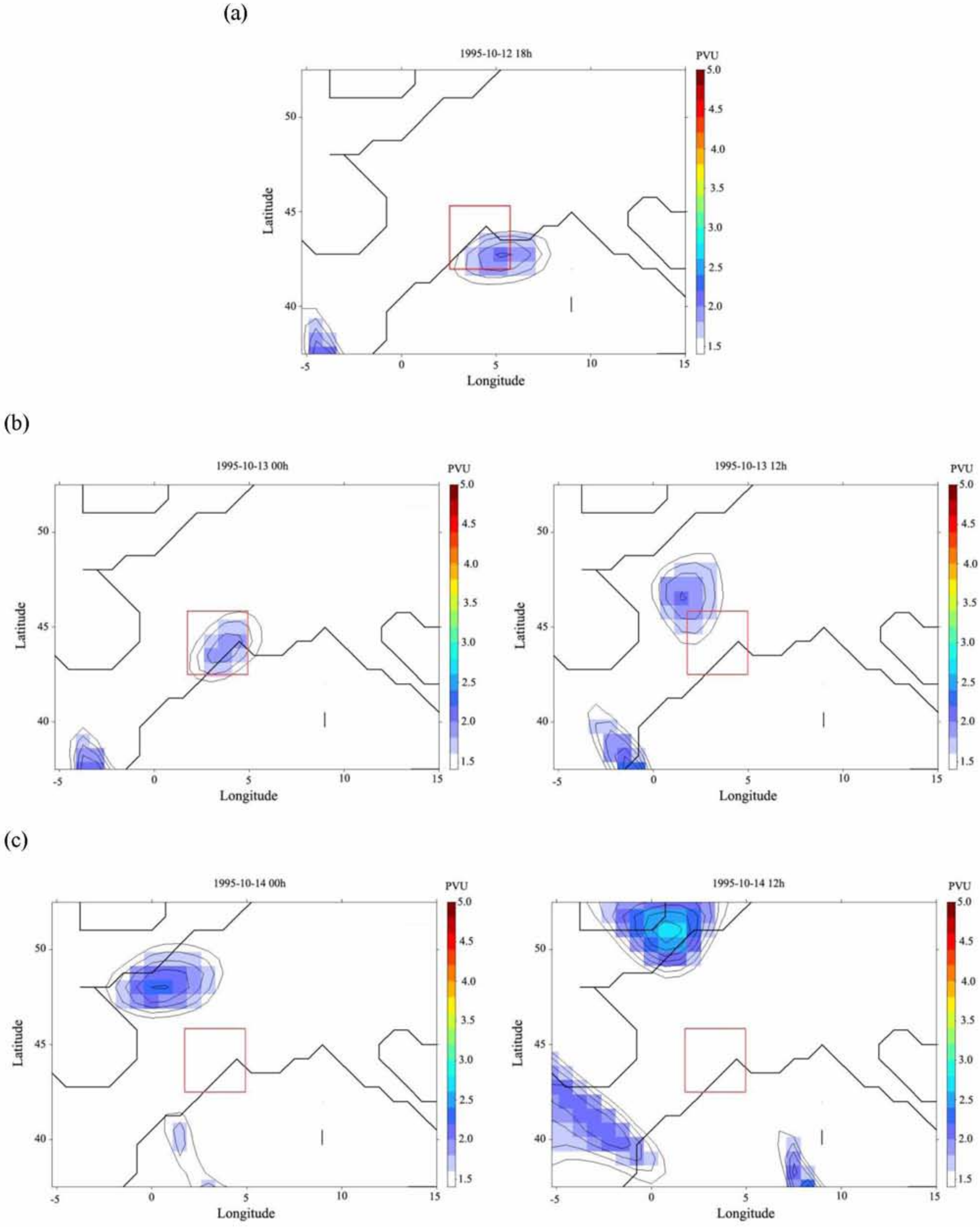
(b)

Figure 12 : Intermittence (on the left) and hourly mean of positive rainfall (on the right) for (a) the 13th of October 1995 and (b) the 14th of October 1995

The threshold on the intermittence on the mountain sector shows that the case of the 13th of October is not a shallow convection event since that most of the time the intermittence is greater than 80%. We can notice that after 17 hours of simulations, the intermittence decreases under 80% and for more than 3 hours. Intermittence for the foothill and plain regions are always greater than 90%. In the same time, the hourly mean of positive rainfall is greater in mountain than in plain and superior than 1mm. for the 14th of October, intermittence for the piedmont and plain sector is greater than 90% except for the piedmont that as a whole at 80% at the beginning of the simulation. Intermittence for the mountain region is mostly between 10 and 80% even if there is a few consecutive hours between 11 and 16 hours of simulations that are a little bit above this threshold of 80%. We will come back on this variation in the discussion.

4.4. Transition between deep and shallow convection : Analysis of the Potential vorticity

The potential vorticity at the tropopause is conventionally taken at 1.5PVU (1 PVU = 10^{-6}) at 300 hPa. An anomaly of potential vorticity due do a depression of the tropopause is visible when the value of potential vorticity at 300 hPa increase. The highest values are, the deepest is the tropopause trough.



(a)
1995-10-12 18h
(b)
1995-10-13 00h
1995-10-13 12h
(c)
1995-10-14 00h
1995-10-14 12h
Latitude
Longitude
PVU

(d)

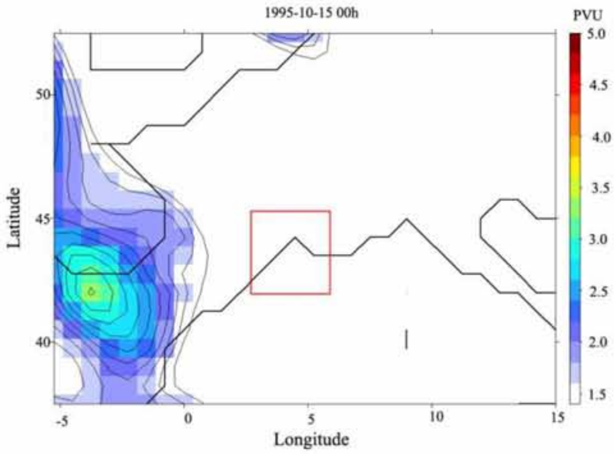


Figure 13 : Analysis of the potential vorticity at 300hPa for (a) the 12th of October 1995 at 18h (b) the 13th of October 1995 at 00h and 12h (c) the 14th of October 1995 at 00h and 12h and (d) the 15th of October 1995 at 00h. The red square represents the 3rd domain of simulation. The value greater than 1.5PVU are shaded

On the 13th of October, there is a small potential vorticity anomaly moving quickly from the south to the North through our region of study. According to previous results for this day, the timing does not fit between this moving anomaly and the initiation of convection over the mountain.

5. Discussion

The analysis of these results gives us some interesting news but we must take care of some points. First of all, the quantitative analysis of the 13th and 14th of October 1995 event shows one part not in agreement with the main result for each days. For the 13th of October, after 17 hours of simulation, we can see that the signature of the system turned into the signature of the shallow convection. In fact, this change appears with the initiation of deep convection over the mountain. This is a questionable point of the methodology adopted. Even if we apply some threshold in order to catch the signature of band-organized shallow convection, some systems like the development of single cells moving downstream can validate the parameter. Since we know here the evolution step by step of the system, we can confirm our results this day is not classified as band-organized shallow convection. For the case of the 14th of October, a period of 5 hours as an intermittence greater than 80%. Again, this is not in agreement with the main result. Looking at the evolution step by step of the system, there are clearly bands at these times (figure in annex) but are not really elongated. The way we adapted the methodology can explain this result. This quantitative study is based on the work of *Godart* 2009 who used observation from a rain gauge network and applied the methodology from this network. Here, we are doing the calculation for each pixel of each sector. Since the sector of the mountain is quite large, the bands not fully elongated are not covering a large surface over the sector while in the case of rain gauges, the number of rain gauge measuring the rainfall in regard to the number of rain gauges in the sector depending on their location can be more important.

Another important point of our results is the failure of our hypothesis about the role of an anomaly of potential vorticity. We must keep in mind that this analysis is done only on one case and should be taken as strong as a study over several cases. In any case, this result shows us that this could have been a simple explanation of the transition between shallow and deep convection but, for this case and for sure in general, more complex physic mechanisms have to be taken into consideration.

The main important of discussion for this work, is the difference of protocol between this work and the work of *Godart* 2009. Indeed our validation of the WRF model and the analysis is mainly based on this work. A very interesting point in the work of *Godart* 2009 is that in her classification, our event studied is not classified as a band-organized shallow convection system. Despite this difference of classification, we found that, qualitatively and quantitatively the 13th of October can be classified as a day of deep convection whereas the 14th of October as a band-organized shallow convection day. This difference of results can be explained by the protocol adopted. In *Godart* 2009, the Meso-NH model is used and force by a sounding. The same sounding is used during the all-time of the simulation with a constant wind within the atmosphere. Moreover, the model uses 2 domains in two-way nesting. It means that the first domain give the boundary conditions of the second and the modification of the second domain leads to modifications in the first domain. In our work with the WRF model, the forcing is done thanks to meteorological fields. The boundary conditions of the first are determined by these fields which are constant during the simulation to fit as much as we can with the other work. Since we used 4 domains, it was not possible to put the two last domains in two-way nesting so all our domains are in one-way nesting. It means that the first domain give the boundary conditions for the second and the second for the third etc., without feedbacks to the previous domain. For the simulation of band-organized convection the only common thing between the two ways of simulation is the constant forcing for the first domain. This can be a key point for the study of band-organized shallow convection and also for the question of the transition. We presents in the synoptic ingredient that the wind shear is important in the case of shallow convection. In our simulation, the wind does not vary during the time.

6. Conclusion

This work provides some interesting results. First of all the implementation and the validation of the Advanced Research WRF model for the simulation of deep and shallow convection over the Cévennes area in southeastern France. Especially for the case of the 13th and 14th of October with the characteristics of having a the 13th of October classified as a day with deep convection and the 14th of October as a day with shallow convection according to the classification of *Nuissier and al*., 2001.

The second main result of this work is obtain from the comparison of protocol between our work with the use of WRF and the one of *Godart*, 2009 using the Meso-NH model. The key point of this comparison is that the wind shear can have an important role in the initiation of band-organized shallow convection. Some previous results were saying that this ingredient is important for the localization and the shape of bands. Here, our results suggest that in the case of a uniform wind during the simulation (same direction and same strength), WRF and Meso-NH model succeed in reproducing band-organized shallow convection.

As we saw that our hypothesis that anomalies of potential vorticity does not seems to be a key ingredients for the transition from shallow to deep convection, the question of the role of the wind for the formation of band-organized shallow convection should be motive of further investigation.

Taking more events to analyze with the WRF model and the analysis of the wind could be a great following to this work. Moreover, one can imagine adding some random fluctuation in the wind at the boundary layer in order to check whereas it leads to inhibition or triggering of convection.

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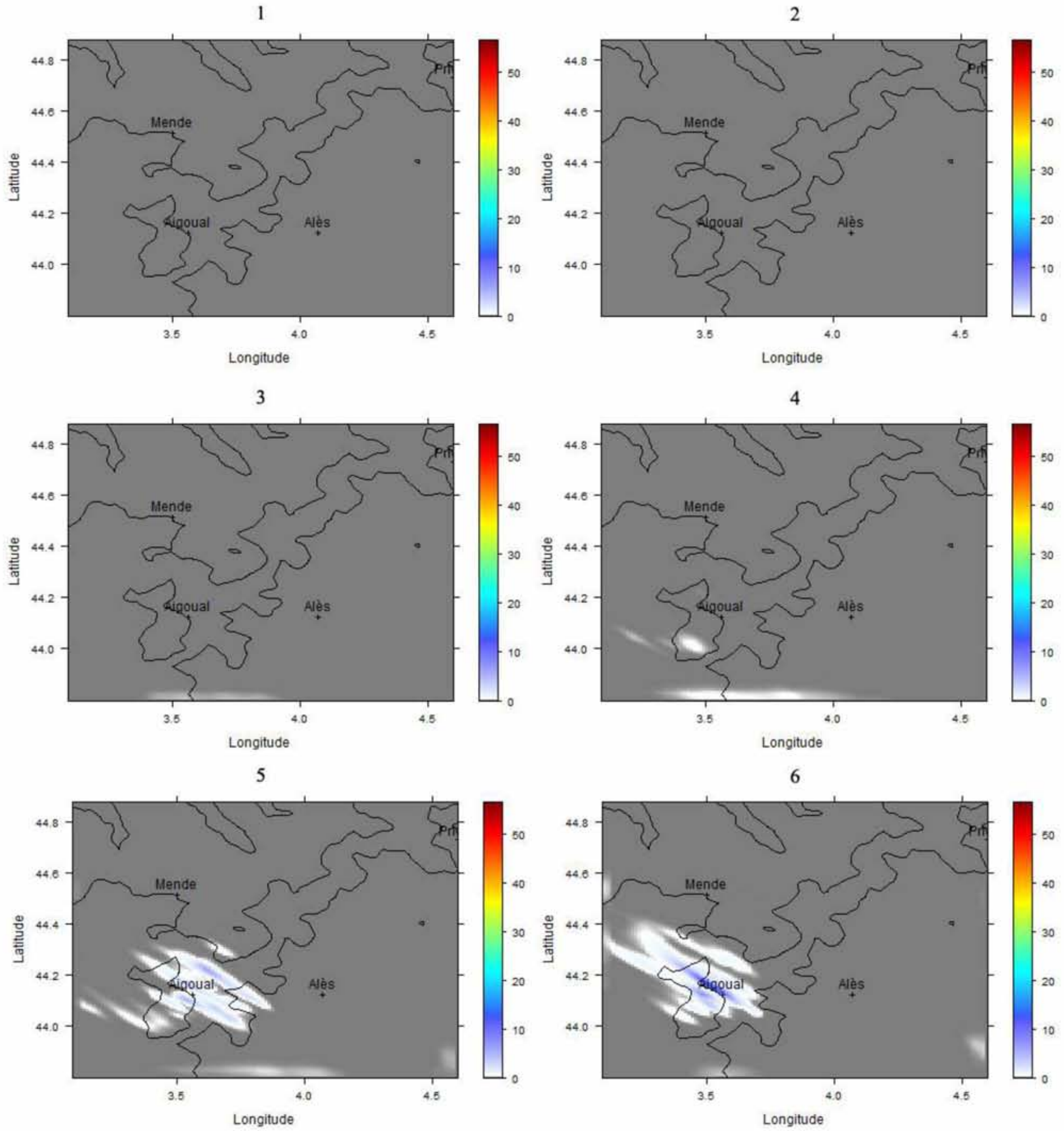
Annexes



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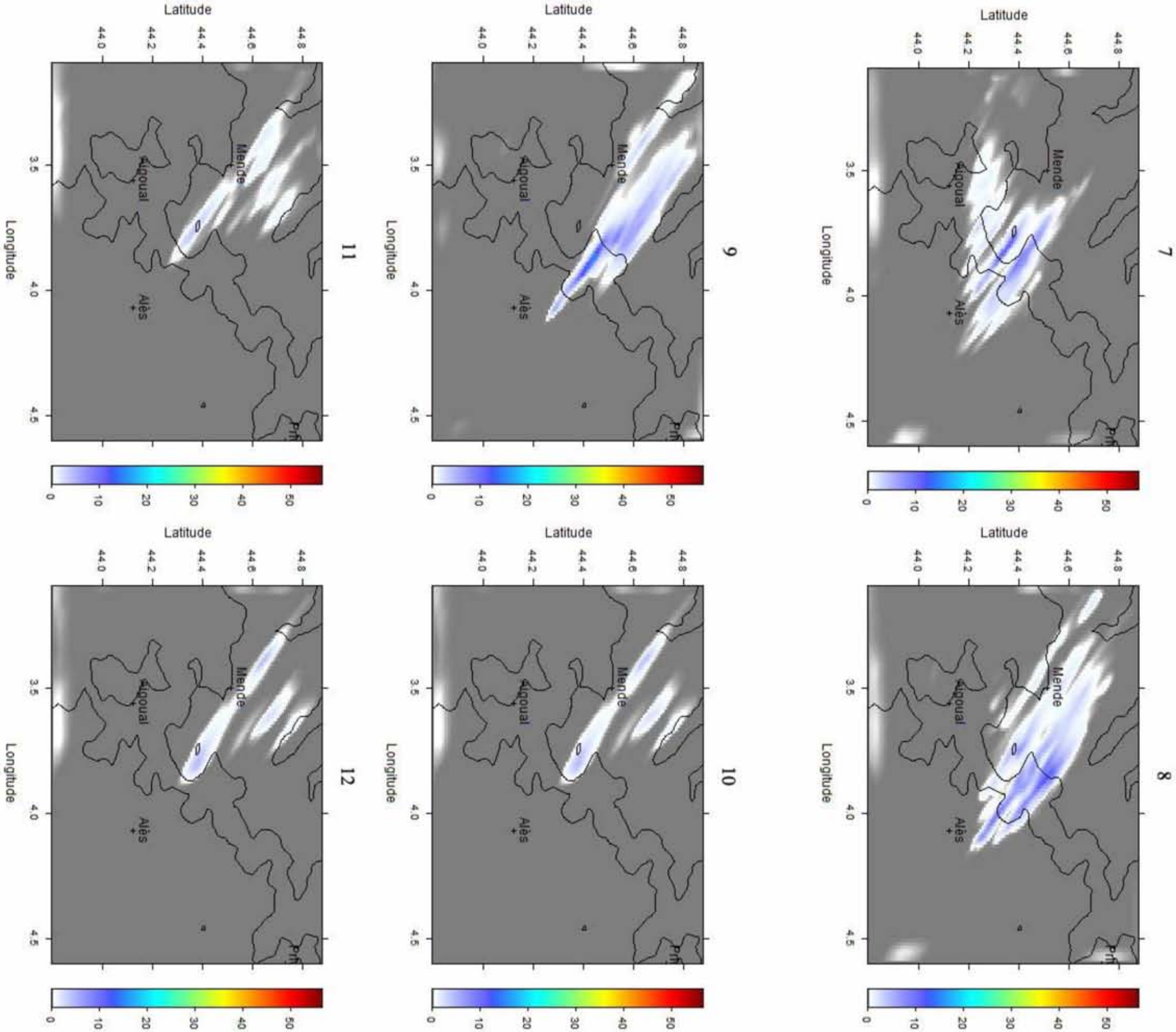
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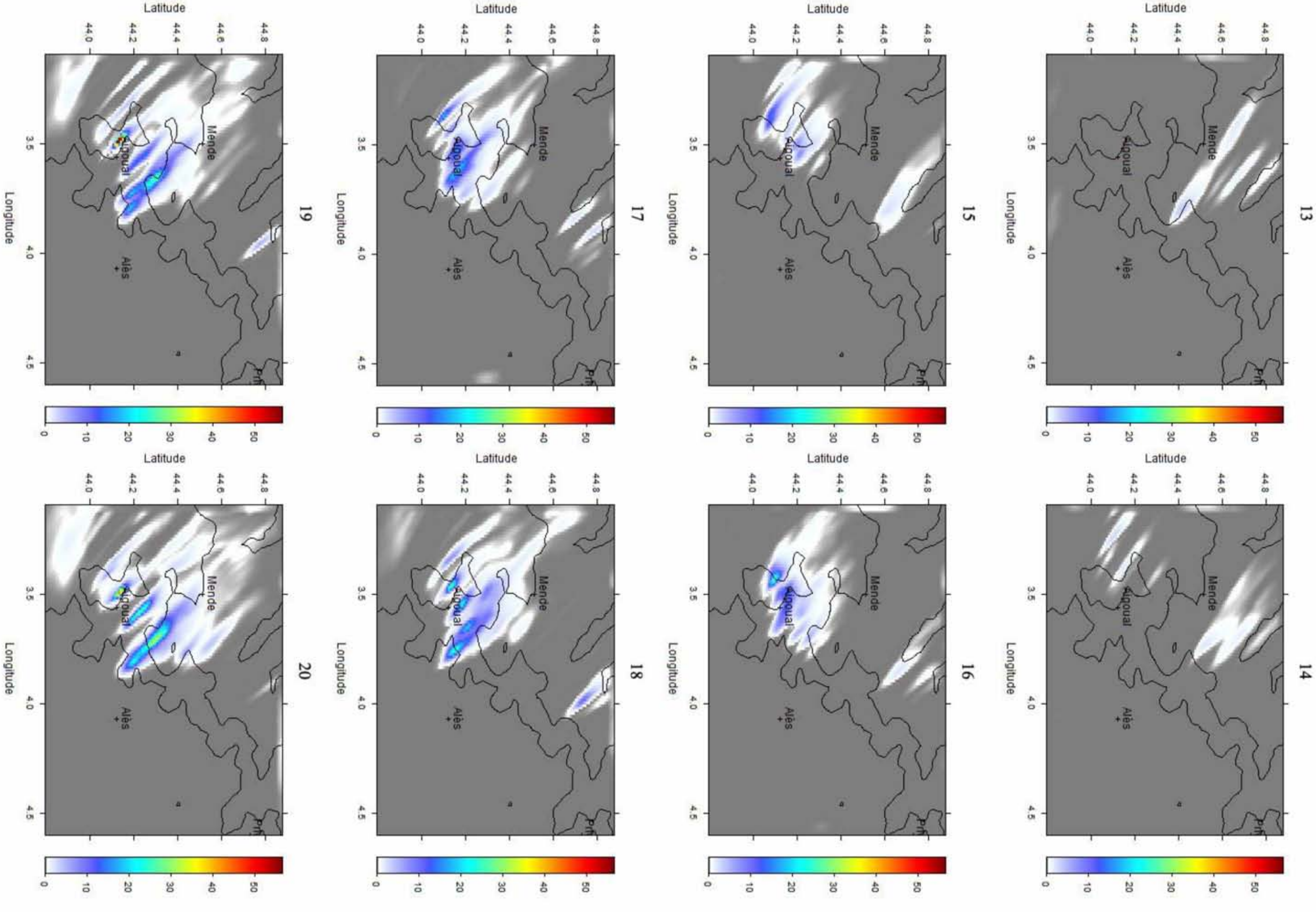
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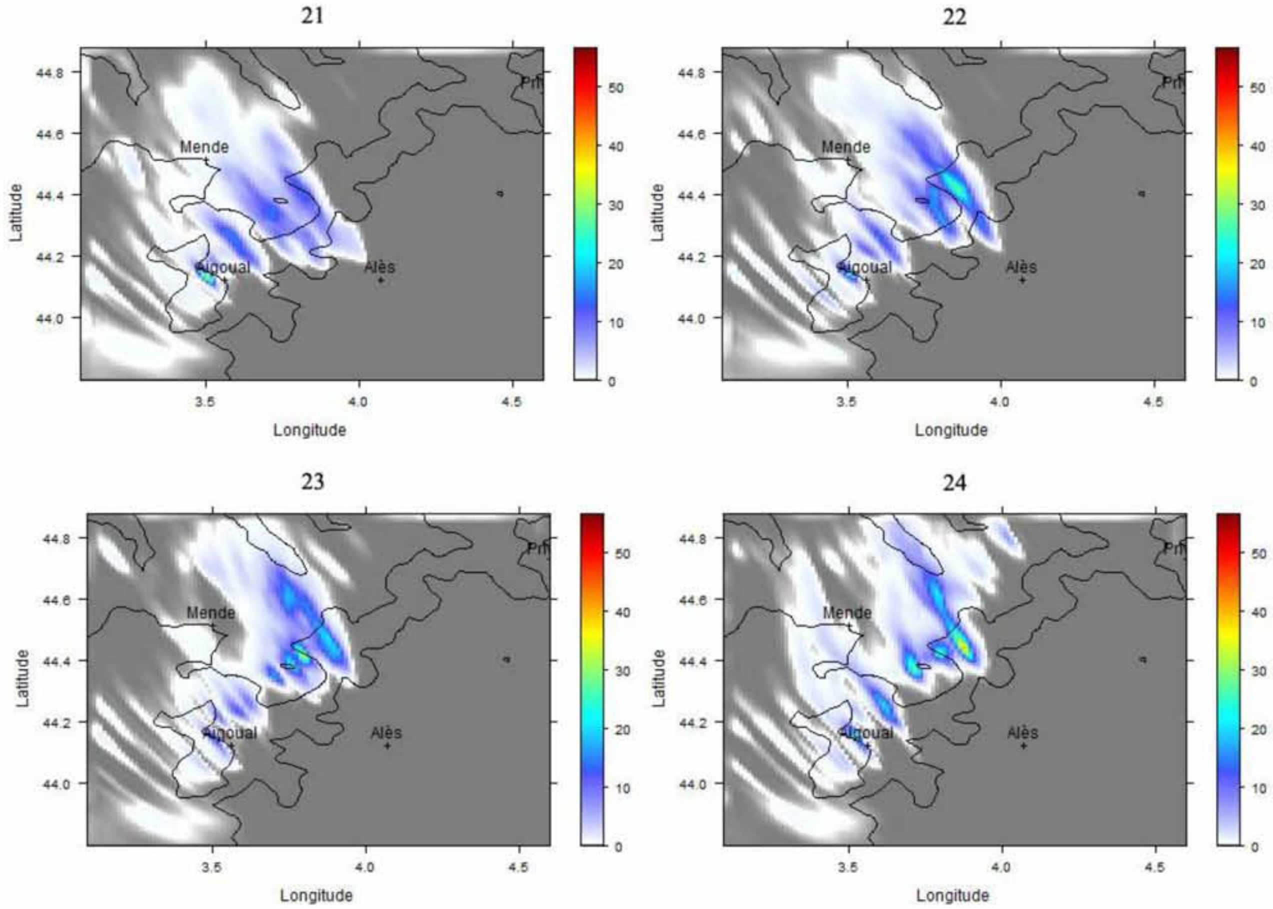
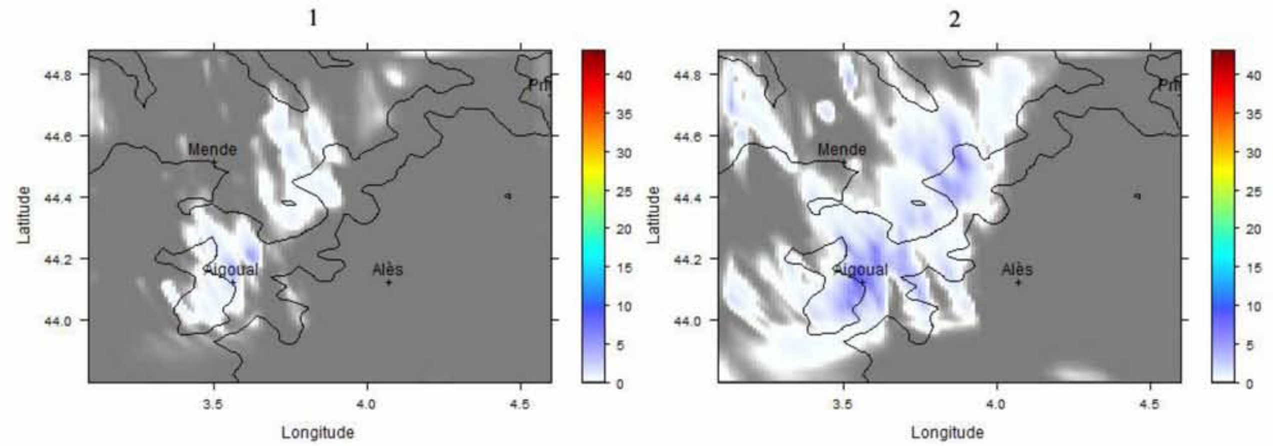
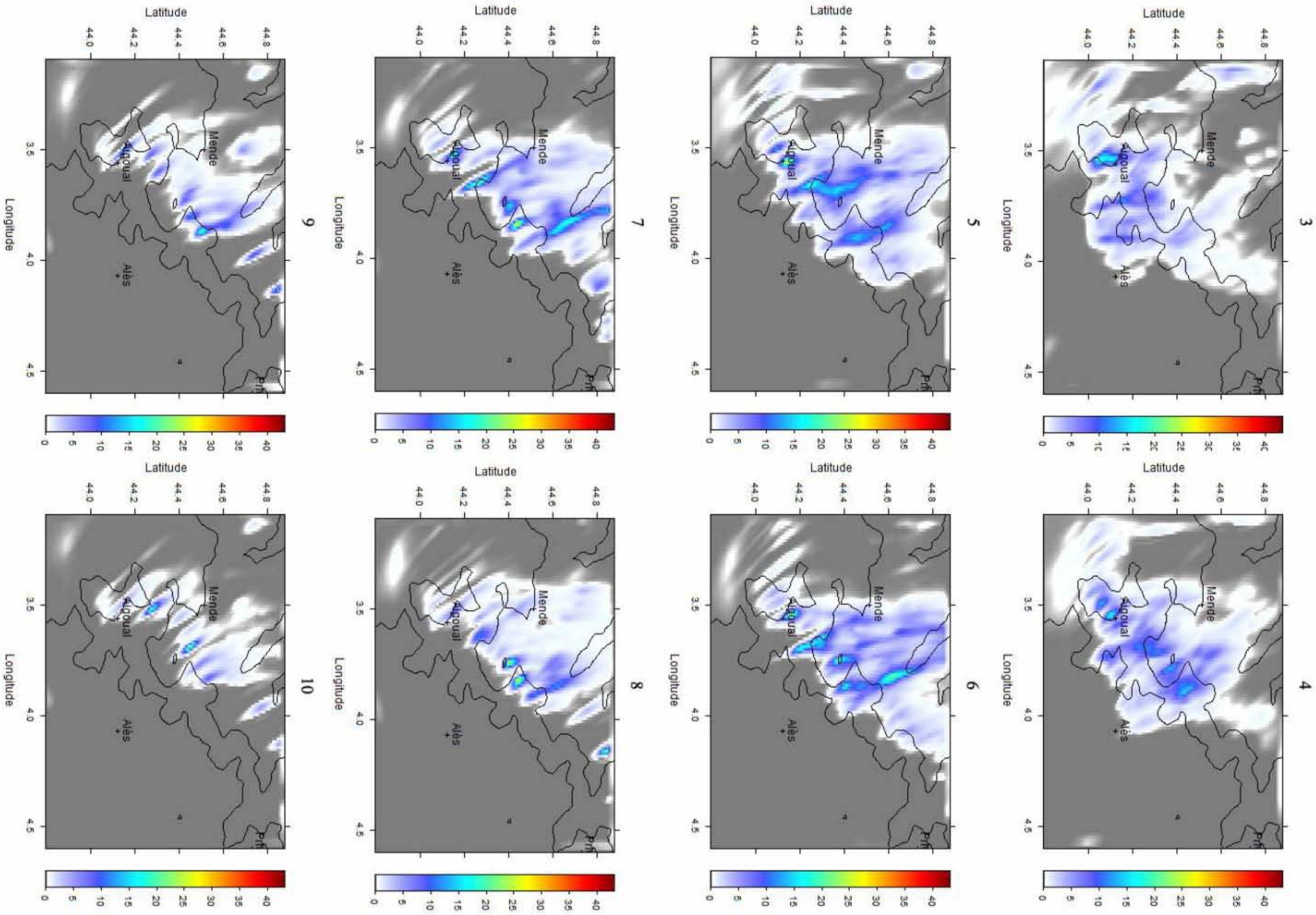


Annex A : Hourly rainfall for the 13^{th} of October 1995

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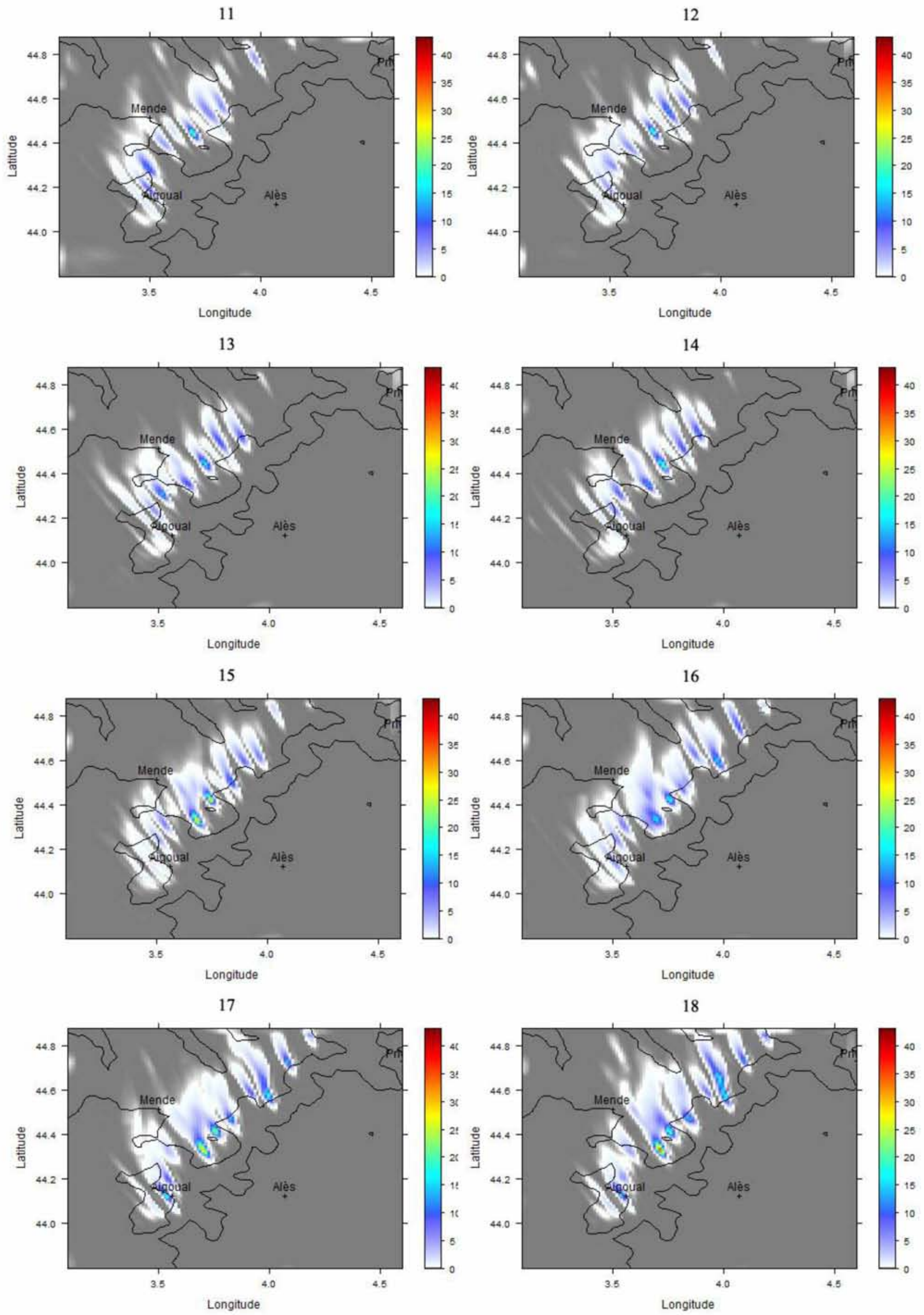
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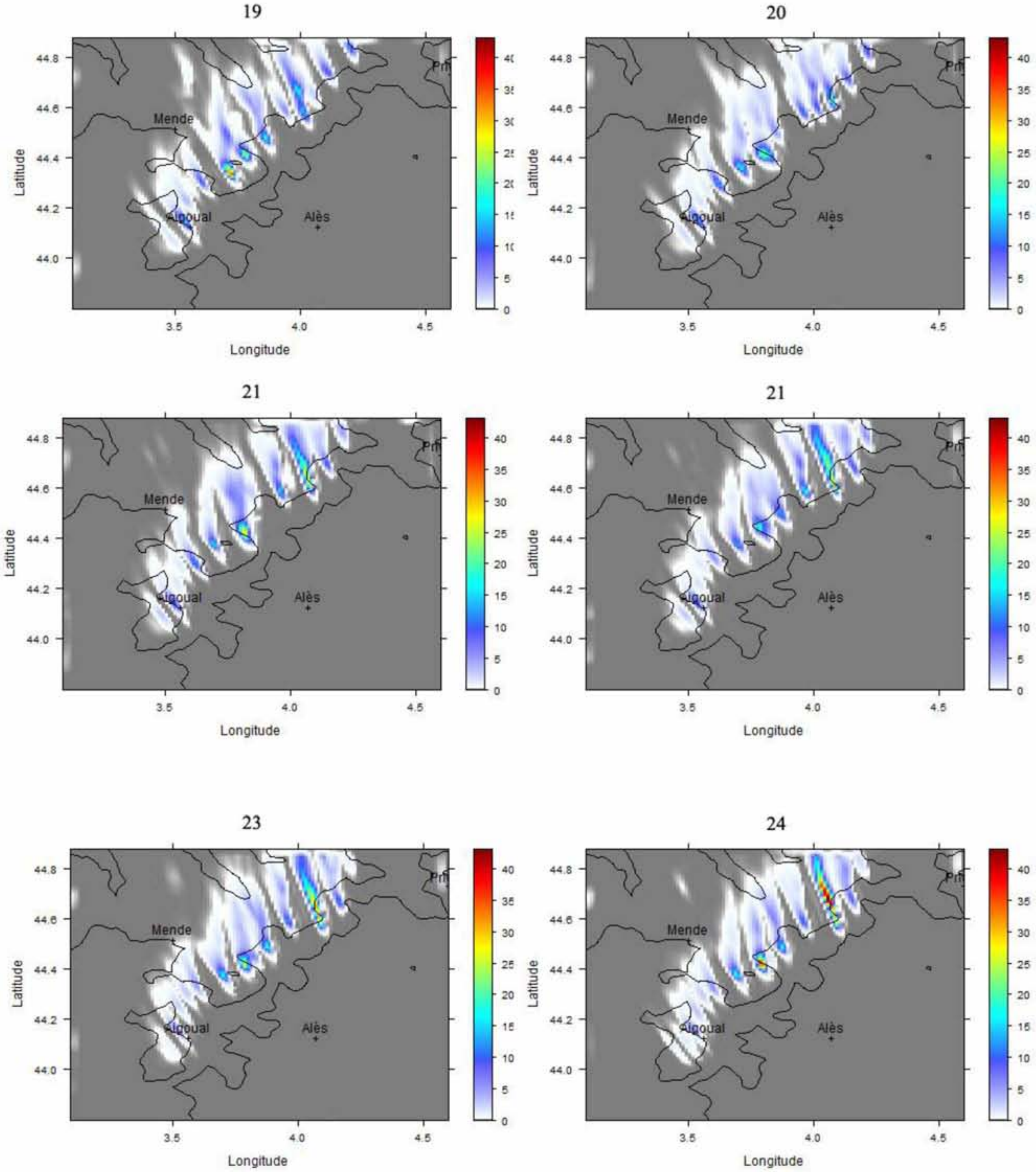

Annex B : Hourly rainfall for the 14th of October 1995