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Analysis of convective situations over the Alps during the MAP SOP.

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1. INTRODUCTION

During the fall 1999, took place the Mesoscale Alpine Program(MAP) Special Observational Period (SOP) from the 10 September until the 15 November. A lot of experimental means were deployed for this campaign and part of the supplementary measurements were taken into account by the operational analysis schemes. These data were used to document 8 scientific projects. Among them, we concentrate on the project P1, devoted to the study of the orographic convection. The aim of the work (Arnal 2003) is to test on the whole SOP, different ingredients for heavy rain on the Alps proposed by Lin et al (2001) or Tripoli et al (2002) mostly based on selected case studies.

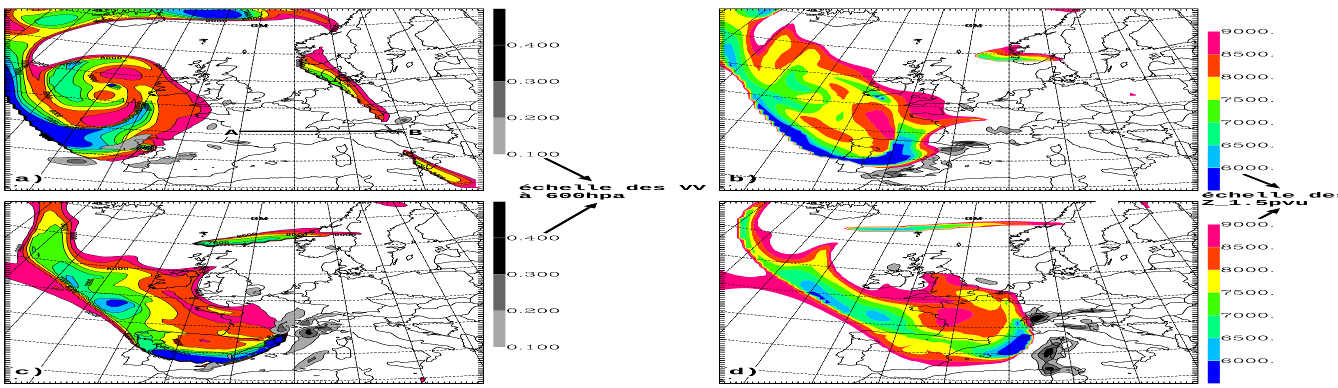

Figure 1: *Altitude of the 1.5 PVU surface in color and positive vertical velocity (m/s) in grey tones. The fields are computed from the ARPEGE analysis: a) 19 September at 00 UTC,b) 19 September at 12 UTC, c) 20 September at 00 UTC, d) 20 September at 12 UTC.*

We use the 3D-VAR Arpege analysis system (Thépaut *et al.*1998), which was operational during the SOP in Météo-France to provide a view continous in time and space of the meteorological fields. In Part 2, we define on the case of the MAP IOP 2, which can be considered as the golden case of the SOP, different integral quantities which quantify the convective airflow upstreams or over the Alps. We will test the sensitivity of these integral parameters by comparison with another analysis system (reanalysis MAP performed by the European Center (Keil *et al.*2003) and with forecasts performed by a meso-scale model (the Meso-NH model (Lafore *et al.*1998)) Part 3 shows the temporal series of the selected parameters along the whole SOP and correlates them with the measured rain over selected areas of the Alps. The importance of the ingredients is thus determined and critized for the different IOP of the MAP experiment. The main conclusions are collected in last part.

2. REGIONAL DIAGNOSTICS: APPLICATION TO THE IOP 2

The IOP 2 is the strongest event of the whole SOP, it leads to maxima of accumulated rain around 400 mm in two days in the Lago Maggiore area. It corresponds in many aspects to a classical heavy rain event with a very warm and humid maritime boundary layer formed over the Mediterranean Sea and advected by strong southerly winds toward the Alps. This generates convective cells before, during and after the frontal passage responsible of the strong winds. This case has been documented largely by numerical and experimental studies (Rotunno and Ferreti (2003), Asencio *et al.*(2003), etc).

A very deep PV anomaly is responsible of the circulation over the Mediterranean Sea and the Europe. This anomaly moves eastwards during the IOP (Figure 1) and its active part located on the eastern flank generates strong mesoscale

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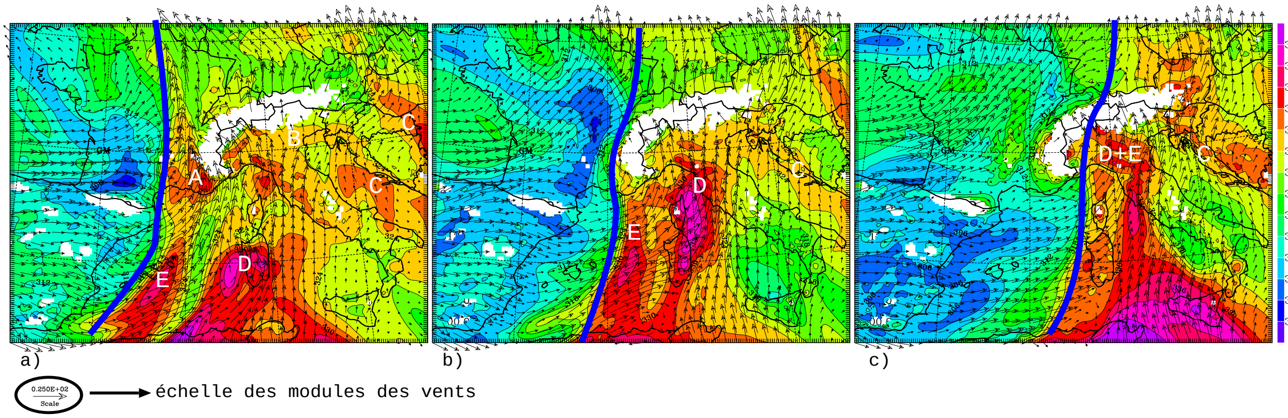

Figure 2: Θ_e *(K) and horizontal wind at 850 hPa. The cold front is represented by a blue line. The fields are computed from the ARPEGE analysis: a) 20 September at 00 UTC, d) 20 September at 06 UTC, d) 20 September at 12 UTC.*

vertical motions. The low levels were characterized by the advection of warm and humid air over the Mediterranean Sea in a very intense southerly flow ahead of the cold front which moves easwards during the whole IOP(Figure 2).We first want to concentrate the informations provided by the preceeding plots by some integral numbers.

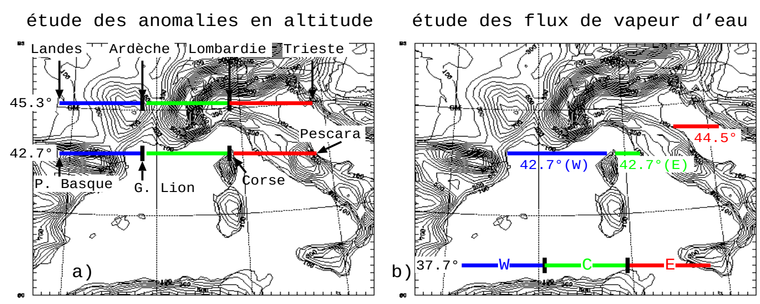

Figure 3: *Localisation of the vertical planes for the study of the PV anomalies (a), and for the moisture flux computation (b).*

We perform the vertical average in the layer between 500 and 300 hPa (Massacand *et al.*, 1998) and take the maximum value in the selected plane (Figure 3)and plot the temporal serie of this quantity. The temporal serie plotted on Figure 4 shows that the tropopause anomaly exceeds the typical threshold of 2 PVU during one day for the vertical planes over the Alps. Even for the latitude 42.7 (not shown), we recover the same duration. The heavy rain period anticipates of more than one day the maximum of this integral parameter.

The jets linked to the anomaly have been analyzed in the same way by looking at its intensity and direction. The temporal serie corresponds very well to the rain activity variation with a maximum corresponding to the strong south winds. The spatial localisation of the rain also moves easstwards together with the wind maximum.

The upper level flow seems to be a necessary ingredient for the convection enhancement but another credible ingredient is the moisture flux:

$$Flux = \frac{1}{S}\int\int_S \rho_v \mathbf{u}.\mathbf{dS}$$

This quantity has been evaluated across the whole troposphere or the lower troposphere. In both cases, it should be noted that a strong correlation exists between the fluxes evaluated in the South of the Mediterranean Sea and their counterparts just upstream the French or Italian coasts (Figure 5). The time necessary to flow accross the whole Sea is around one day and is accompagnied by a moistening of the air mass by evaporation as can be checked from the comparison of the curves of the same colour.

The next integral parameter is the mean value of the CAPE, evaluated in different regions upstream of the Alps. The selected boxes are represented on Figure 6. The evolution of the CAPE (Figure 7) on the Po valley reveals strong value for the first day of the IOP (i.e. IOP 2A) compared to the IOP 2B. The reduced values can be interpreted as

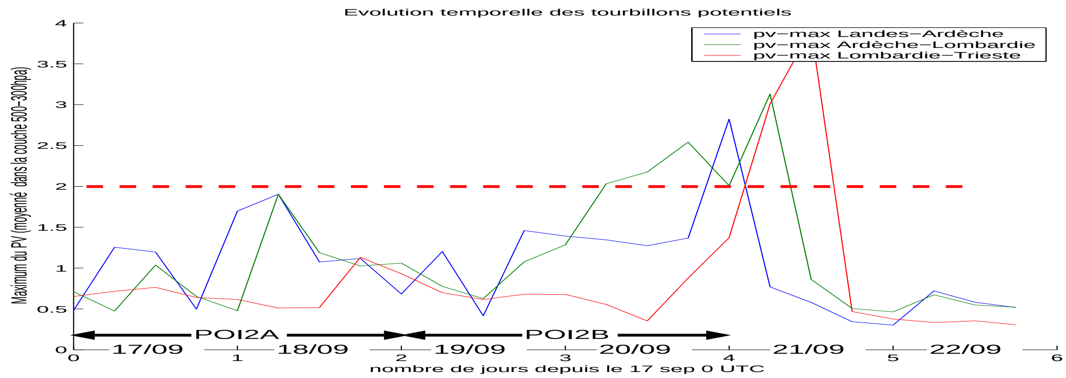

Figure 4: ***maximum of PV (averaged in the layer 500-300hPa) in 3 boxes along the latitude 45.3N :*** *17-22 september 1999.*

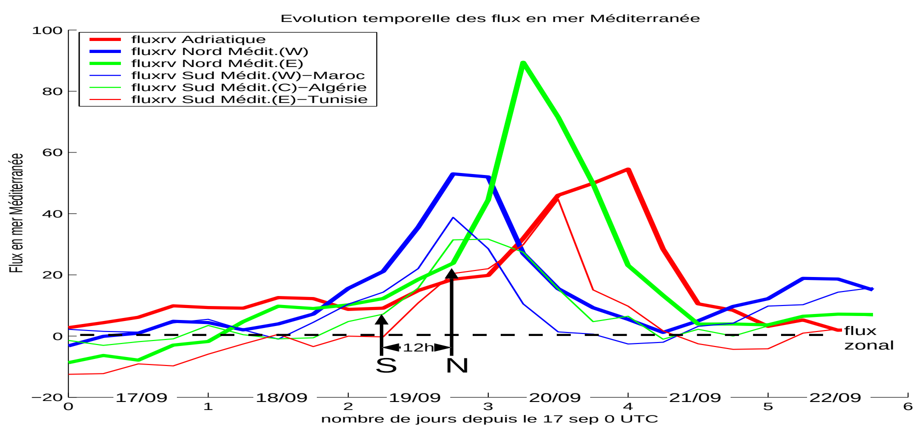

Figure 5: ***Water vapor flux*** *($kg.s^{-1}.km^{-2}$)* ***in the North and in the South of the Mediterranean Sea :*** *17-22 September 1999.*

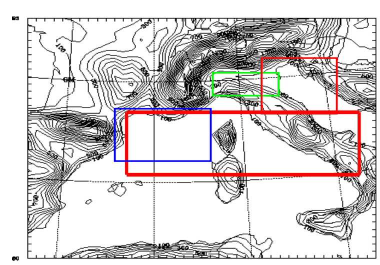

Figure 6: ***localisation of the boxes used to average the CAPE (3 smallest boxes) and $\hat{h}$ (large red box).***

the result of the mixing of the very moist boundary layer present over the Mediterranean Sea with dryer air above the Apennines before its entrance in the Po valley.

The last integral parameter is the non-dimensional height $\hat{h} = Nh/V$ of the Alps, to compute this parameter, we take a fixed mean height of the Alps $h = 2000m$ and the stability is averaged in the 2000-7000m together with V. This parameter is computed only when the meridian component V of the wind is greater than a tenth of the zonal component. The temporal serie is plotted in Figure 8 and shows that the variation of $\hat{h}$ is dominated by the wind variation. The IOP 2B corresponds to a reduced value of $\hat{h}$, which signs the flow-over configuration which promotes the convection triggering over the alpine slopes.

Sensitivity tests against the analysis have been performed by comparing the temporal evolution of the integral parameters from ARPEGE with the IFS reanalysis of the European Center(not shown). The shape of the temporal series is not sensitive to the system of analysis.

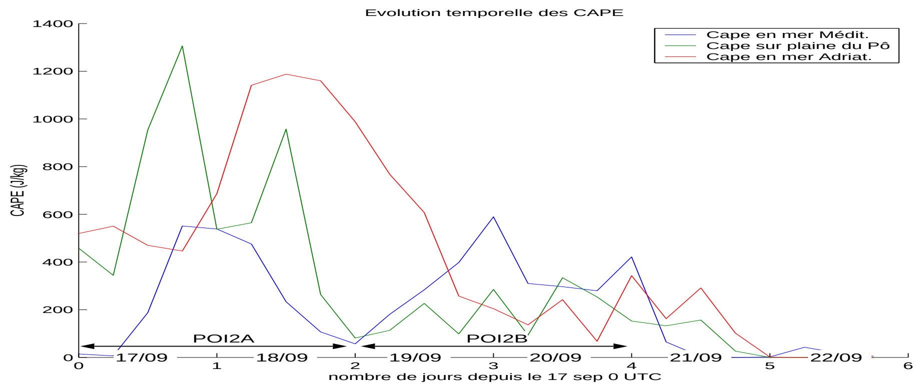

Figure 7: ***Temporal evolution of the CAPE ($J.kg^{-1}$) in the selected boxes represented in Figure 6 :*** *17-22 september 1999.*

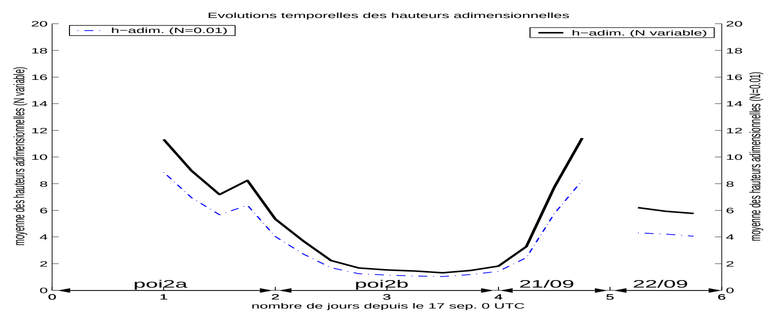

Figure 8: ***Non-dimensional height*** *: 17-22 september 1999. The dotted curve corresponds to the case where N is variable and the full line to N=0.01*

The same type of comparison has been done again against simulated results generated by the meso-scale model Meso-Nh (Lafore *et al.*, 1998). The moisture fluxes, the tropopause anomalies and even the CAPE show the same general shapes for the temporal series (not shown) and this confirms that the ARPEGE analysis contains this regional information and in the following, we will concentrate on the exploration of the whole SOP only with the ARPEGE analysis.

3. TEMPORAL SERIES DURING THE SOP

The temporal series of the different integral parameters have been compared with the temporal serie of the rain accumulated during one day and averaged over different domains. The rain gridded data have been computed by Frei and Haeler (2001) and have been extracted from the MAP data center. Some supplementary boxes have been added in France (see Figure 9) in order to follow the rainy systems which generally propagates eastwards together with the fronts. It allows also to present the Aude case, which happens during the MAP IOP 16 and was characterized by a maximum of accumulated rain of 625 mm in 48 hours in the Aude-Roussillon blue box.

The comparison of the temporal series of the averaged rain with the Massacand *et al.*(1998) diagnostic confirms the necessary presence of a significant upper level feature for a strong convection but further insight reaveals that one of the deepest anomaly (28 Sept.) does not correspond to a rainy situation over the Alps even if this PV streamer has the same morphology as the Vaison la Romaine or Brig ones (Massacand *et al.*1998). The absolute value of the averaged PV doest not discriminate between strong and weak convection. An example is given by the strongest values found during the first month for the IOP 2B and the IOP4-5 cases, where only the first IOP was a significant case in term of convection.

During the second month (not shown), the IOP 15 also illustrates this point with a deep anomaly giving only weak convection one day before the Aude case. The upper-level jets intensity and direction have also been analyzed (not shown) in the same way and a South-Southwesterly jet is also a necessary ingredient for the convection initiation but some counter-examples can be found. The two main events (IOP 2B and 16) present both tropopause folds above the region where the convection occured. Nevertheless they are neither the deepest nor the most widespread anomalies and the associated jets are not the most intense (IOP 3 and 10 are more intense) but have a South orientation during part of the event.

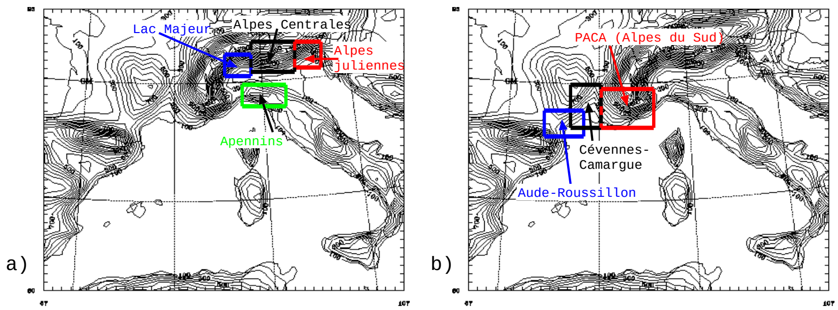

Figure 9: ***localisations of the boxes where the precipitation is averaged including mountains in the :*** *a) South of France, b) North Italy.*

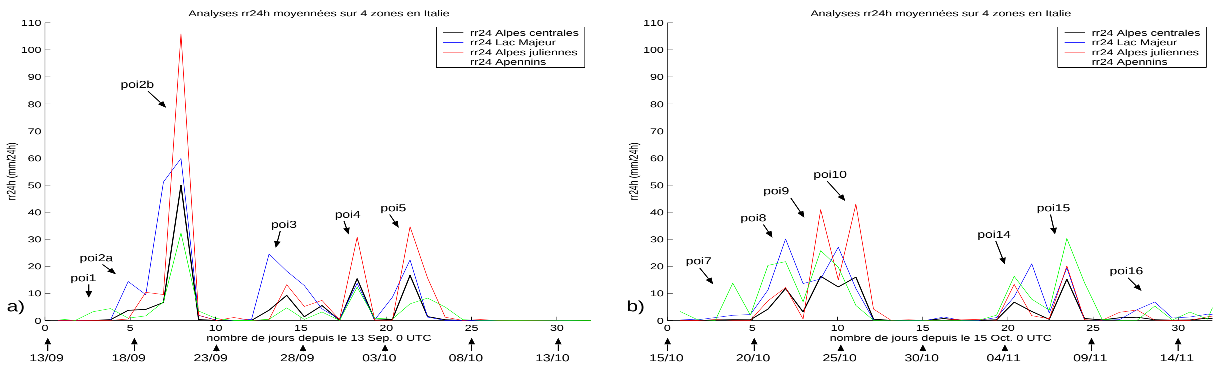

Figure 10: ***temporal serie of accmulated rain in*** $mm.j^{-1}.m^{-2}$ ***, averaged on the boxes plotted in Figure 9 b in North Italy:*** *a) from 13 Sep. until 14 oct. 1999, b) from 15 oct. until 15 nov. 1999.*

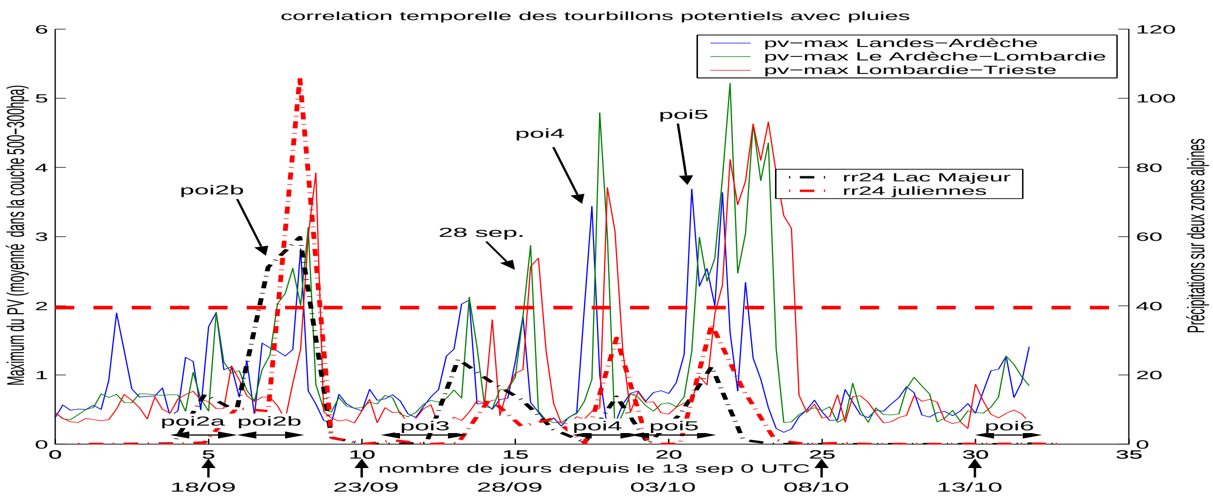

Figure 11: ***maximum of the mean PV (500-300 hPa) for 3 boxes along the latitude 45.3N and precipitation*** ***(***$mm.j^{-1}.m^{-2}$***) over two MAP target areas (LMTA and Friuli) :*** *13sep.- 14oct. 1999.*

The second ingredient to be considered is the moisture flux (Fig 12 and Fig 13). A strong correlation with the rain activity exists. The IOP2 shows the strongest flux and also the most coherent flux. This last characteristic (coherence between the flux in the South and the North Mediterranean Sea) is not recovered for the other IOPs. The IOP 8 also presents at the same time a strong PV anomaly and a strong moisture flux but the rain is lower than for the IOP 2. This is due to a very cold airmass present in the low troposphere above the Po valley which protects the Alps from the arrival of the moist south flux. The second strong case (IOP 16) olny presents a modest moisture flux in opposition to the IOP 9-10 and 11 which are characterized by a lack of PV anomaly which limits the convective rains of these IOPs.

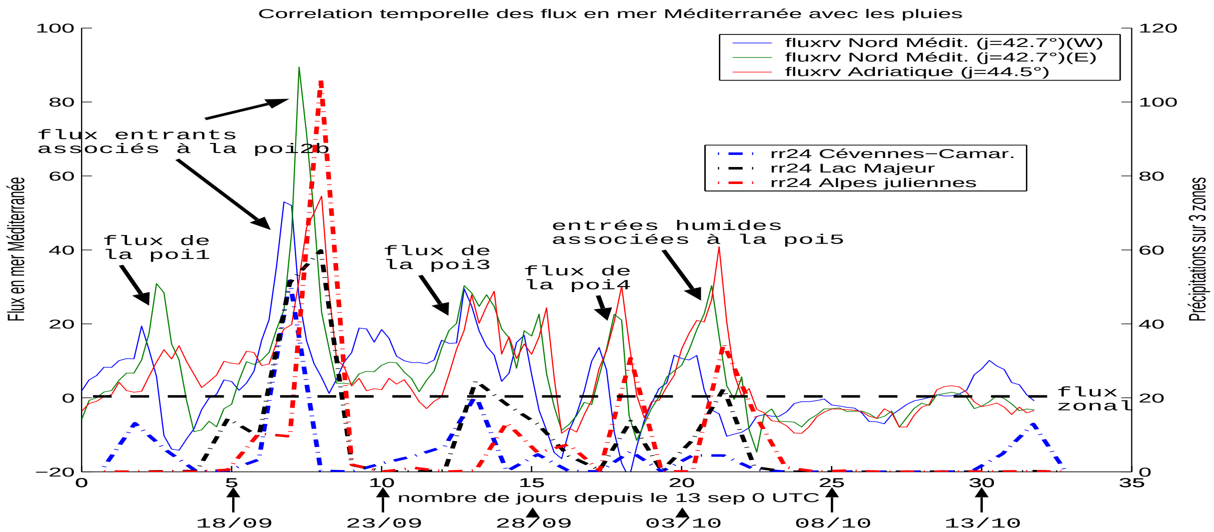

Figure 12: ***Moisture flux in the North of the Mediterranean and Adriatic Seas** (J.kg^{-1}.km^{-2}) **and precipitation on 3 selected boxes: 13 sep.-14oct. 1999.***

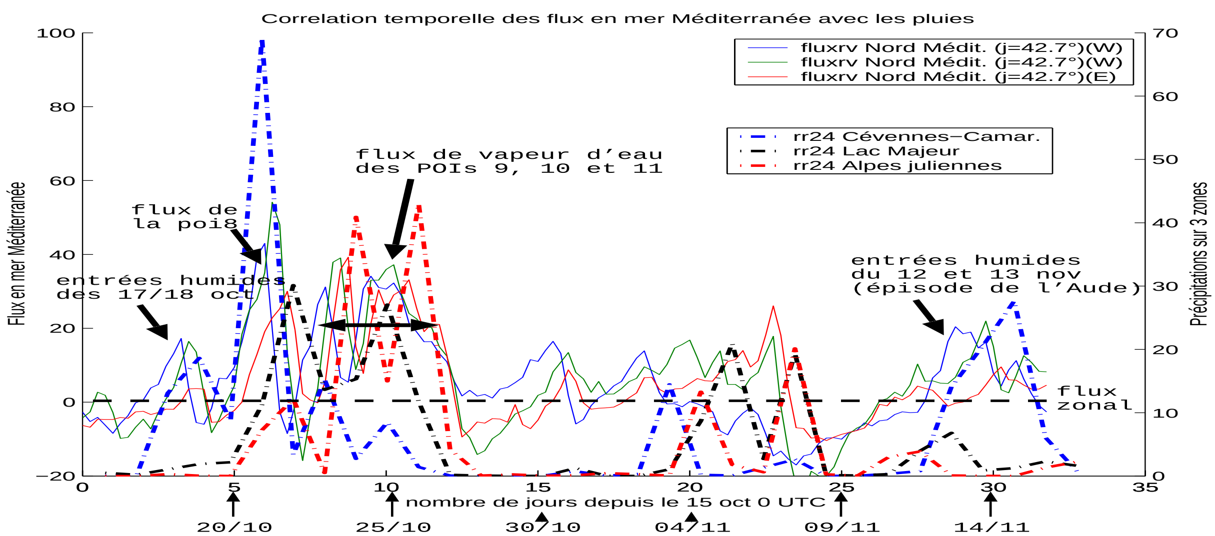

Figure 13: ***Moisture flux in the North of the Mediterranean and Adriatic Seas** (J.kg^{-1}.km^{-2}) **and precipitation on 3 selected boxes: 15 oct.-15nov. 1999.***

The CAPE temporal serie (not shown) helps us to conclude that the convective nature of the airmass is a necessary ingredient but no clear quantitative estimation can be gained from it when we analyze all the IOPs of the SOP. IOP 2 and 16 are not at all unusal and only the beginning (IOP 2A) presents strong values. The non-dimensional height reduction is well correlated to the IOPs (Fig 14), they correspond to flow-over configuration i.e. low values of $\hat{h}$ which is a favourable condition for the convection triggering over the Alps. Like the CAPE, $\hat{h}$ is not directly linked to the amplitude of the convection as can be checked by comparing IOP 2B, IOP 15 and 16 for instance.

4. CONCLUSION

Regional mean quantities have been computed from the ARPEGE analysis for the whole SOP. These estimations are only weakly dependent on the assimilation system or the simulation system. Among them, the following ingredients must be present at the same time to allow strong convection above the Alps: a deep PV anomaly in the vicinity of the Alps, a strong moisture south flux, moderate or strong CAPE and a reduced non-dimensional height. Only IOP

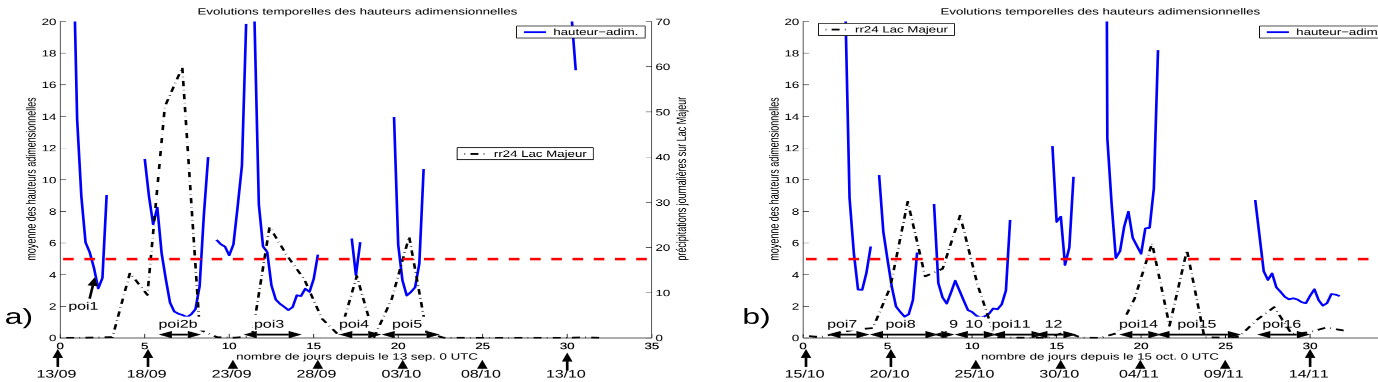

Figure 14: ***Nondimensional height averaged on a part of the Mediterranean Sea and precipitation:*** *a) 15 sep.-14 oct. 1999 et b) 15 oct.-15 nov. 1999. $\hat{h}$ is computed only when ($\overline{V} \geq 0$ et $\overline{V} \geq \frac{\overline{U}}{10}$).*

2 and 16 (the strongest cases) fulfill all these conditions even if the other IOPs can be intense with only part of these ingredients.

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