MEDITERRANEAN CYCLONES: SUBJECT OF A WMO PROJECT

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1. INTRODUCTION

It is known that the Mediterranean area presents the highest concentration of cyclogenesis in the world, at least during winter, even if only the macroscale cyclones are considered -Petterssen (1956)-, fig. 1.

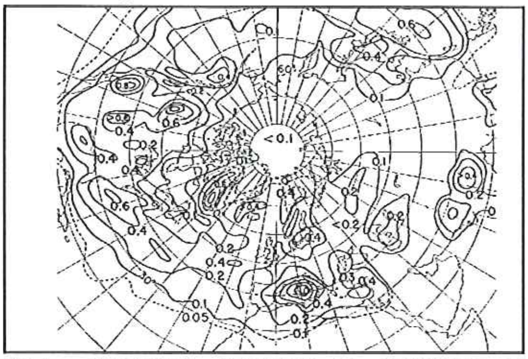

Fig.1.- Percentage frequency of occurrence of cyclogenesis in squares of 100,000 km^2 in winter (Petterssen 1956)

Several papers -Radinovic (1987), for a review, as well as Alpert et al. (1990)- deal with the question of the statistics of the Mediterranean cyclones. Several tens of macroscale cyclones appear every year in the Mediterranean, highly concentrated in the Genoa zone, south of the Alps, and in the Cyprus region. This number has to be multiplied at least per ten if the meso-scale cyclones are also considered -Radinovic (1978), Genoves and Jansa (1989), Genoves and Jansa (1993), INM (1993), Picornell et al. (1993)-. See Figs. 2 and 3.

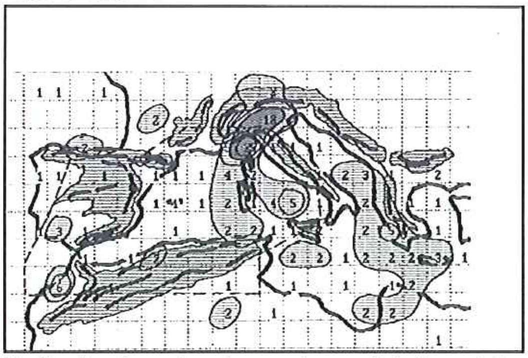

Fig.2.- Number of cyclones observed during winter 1991-92 (Dec-91/Feb-92), in 2°X2° squares. Objective analyses (LAM-INM, resolution, 0.91°), i.e., 'large-scale' cyclones

On the other hand, although the weather in the Mediterranean area is usually fine and sunny, sporadic events of severe phenomena (heavy rain and wind storms) also constitute a climatic feature in the region of critical practical importance. Amounts of precipitation over 200 mm (up to 800 mm in the strongest cases we know) in less than 24 hours have been registered in a wide variety of places in the region (see "La Météorologie", num

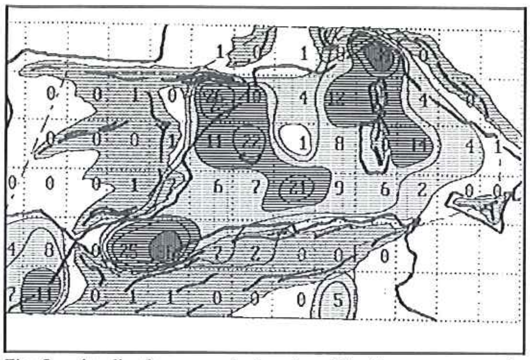

Fig.3.- As fig.2, except, hand subjective meso-scale analyses, i.e., meso-scale perturbations included

37, 1983, among others). Catastrophic floods are a usual consequence of such violent rain events. Violent winds are not rare in the regions affected by the Mistral, the Tramontane, the Bora or the Etesians -Reiter (1975), among others-. During the Pyrenean Experiment (PYREX) -Bougeault et al. (1990)-, sustained wind speeds of 60 kts have been mesaured in the gulf of Lion, only a few hundreds of meters over the sea -Koffi et al. (1991)-.

Related to the Mediterranean cyclogeneses, two questions of crucial importance arise from the previous assesments, a) due to the very high frequency and concentration of the Mediterranean cyclogeneses, is it licit to consider them as usual extratropical cyclogeneses or do we need an specific conceptual model?, b) is there a direct relantionship between severe weather and cyclogenesis in the Mediterranean or are there independent phenomena?

A complete answer to the open questions is not the objetive of the present contribution. Our objective is to present the line of work we have initiated to do it in the frame of WMO Mediterranean Cyclone Study Project and the Spanish Meteorological Western Mediterranean Studies Programme (PEMMOC, in Spanish). Nevertheless we will summarise first our present ideas about these points.

2. SEVERE WEATHER AND CYCLOGENESIS

We have to distinguish between deep and/or intense cyclones from the shallow and/or weak cases. Many of the most large Genoa cyclones are intense and deep. The most of the Cyprus lows are weak and shallow -Alpert et al. (1990)-, as well as the most of the meso-scale perturbations.

It is easy to relate the first to strong wind, but the relationship is not so direct. Few observed Mediterranean cyclones have been intense enough to produce wind storms by themselves, as in December 1979 or December 1980 -Jansa (1987)-, but it is more usual the contribution of additional effects. The most important Mediterranean wind system, the Mistral-Tramontane, is usually related to the action of the Genoa cyclones, but we have recently demostrated -Campins et al. (1993)- the crucial contribution of the orographic effect of the Pyrenees to intensify the pressure gradient and the wind speed.

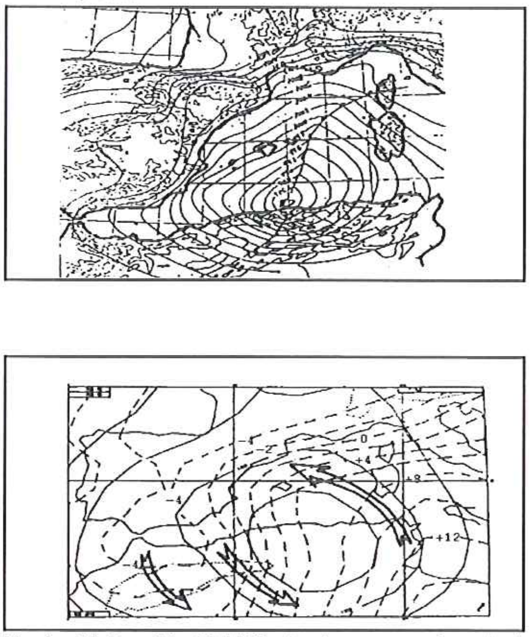

Fig.4.- 21-Dec-79, 12 UTC. Analyses at surface (up) and 850 hPa (down).

The secondary circulations associated to any intense and deep cyclone warrant the production of quite intense rain, namely, 20-40 mm/day. But this is not the specific heavy rain we are talking about in the Mediterranean. The cyclonic dynamics is not able to explain rainfall amounts of tens of mm in one hour or hundreds of mm in one day. The orographic ascent can provide an additional contribution, but, in general, intense and/or focused convection is needed. Anycase, in a Mediterranean environment, close to the instability, the cyclonic dynamics -ascending motion- can provide the mechanism to instabilise the air column and trigger the convection. Embeded convection is frequently observed within intense Mediterranean cyclones.

Furthermore, although the most of the Mediterranean cyclones are shallow and weak (and small) and are usually enable to produce severe weather by themselves, in an appropiated environment, they can contribute as the most efficient mechanism to trigger, focus and anchor a

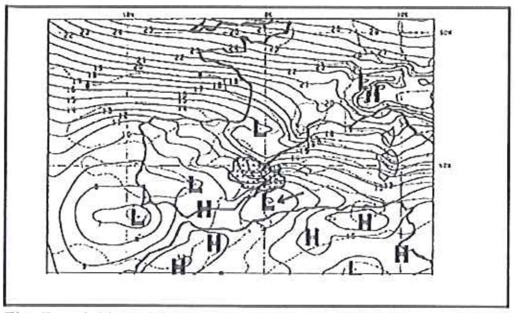

Fig.5.- 4-Nov-1987, 00 UTC. A shallow moderate low (arrow) provides the organised warm inflow that anchors a convective system (shading)

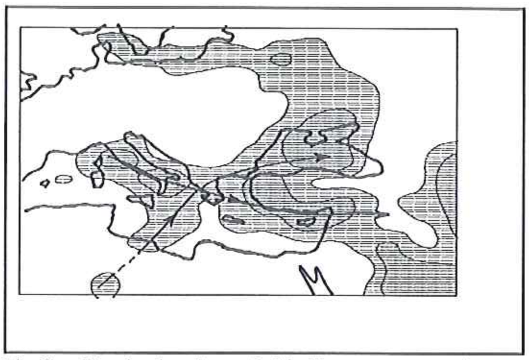

Fig.6.- Track density of Mediterranean cyclones, January, 1982-87, objectively obtained from ECMWF analyses -Alpert et al. (1990b)-

convective system to localy produce enormous amounts of precipitation, as it occurred in Gandia (Spain), in 1987, Jansa et al. (1991), fig. 5.

3. MEDITERRANEAN CYCLONES

75 years after the papers by Bjerkness (1919) and Bjerkness and Solberg (1922), the conceptual model of the most typical extratropical cyclones (the frontal cyclones) has evolved and improved very much, but its essence is still alive: the cyclones self-develop along a frontal band, from a more or less casual initial disturbance. Although the main orographic systems provide many initial disturbances, what means a tendence to the concentration of cyclogenesis on the lee of the mountains -Petterssen (1956)-, the seasonal and day-to-day variations in position and orientation of the main polar frontal band and the possibility of initiation and evolution of the cyclone from anywhere, along the band, give a quite important geographical-statistical dispersion of cyclogenesis and cyclonic presence in the extratropical zone. It would even be true from the Hoskins et al. (1985) conceptual model: an upper level PV anomaly locates the initial cyclone over the frontal band, but the position of the first may be independent on the surface geography and some dispersion in location of cyclogenesis remains warranted.

What characterises the Mediterranean cyclogenesis is its high concentration. The Mediterranean area is a reduced region itself where many cyclones appear and evolve. On the other hand, the Mediterranean cyclones tend to appear close to the same particular locations, mainly Genoa and Cyprus for the large-scale cyclones, some other additional places when the meso-scale cyclones are also considered. Part of the Mediterranean cyclones remain almost stationary. The tracks for the other -see Alpert et al. (1990)- have also a geographical constriction, fig. 6.

When putting togheter the charts of location of cyclones and cyclogenesis and the main orographic features, it looks evident a connection between orography and cyclogenesis. Godev (1970) has stressed a relationship between orographic shape and frequency of cyclonic presence. Even the cyclonic tracks seem to be conducted within the mountain barriers that surround the Mediterranean sea.

Abundant literature has been devoted to Mediterranean cyclogenesis, mainly to the Genoa cyclones, usually considered as lee-Alpine cyclones. Pyoner work on this matter, nearly simultaneous to the Bergen model of extratropical cyclones -Ficker (1920)-, related the Genoa cyclogenesis to the orographic influences, as an effect of the blocking of cold air by the Alps and the consequent retardation of a cold front. In the frame of Sutcliffe's (1947) theory of development, Radinovic (1965) formulated his explanation of the Genoa cyclogenesis trough the deformation of a cold front by the mountain blocking of cold air. Tafferner (1990) has re-taken the idea, now referred to the Hoskins et al (1985) model. Alternative formulations -Buzzi and Speranza (1982), Pierrehumbert (1985), Smith (1984)- are based on the orographic modification of baroclinic instability. In all these views, the Mediterranean (Genoa, Alpine) cyclogenesis is seen as a 'secondary' process, a 'parent' main perturbation is needed, the Mediterranean orography provides a mechanism of location, focusing the low.

Since the work by Egger (1972), the use of numerical models, trough numerical experimentation, the role of the mountains in determining the location, shape and intensity of the Mediterranean cyclones has became more and more evident, not only for Genoa cyclones, but for other Mediterranean lows, like the Algerian sea perturbations -Jansa et al. (1991)-.

The orography is partially responsible for most of the Mediterranean lows, even meso-scale perturbations. But, do exist cyclones produced by pure orographic effects? Is the presence of a 'parent' disturbance necessary to develop a cyclone? Is certain degree of baroclinicity needed? Are there additional factors to be considered?

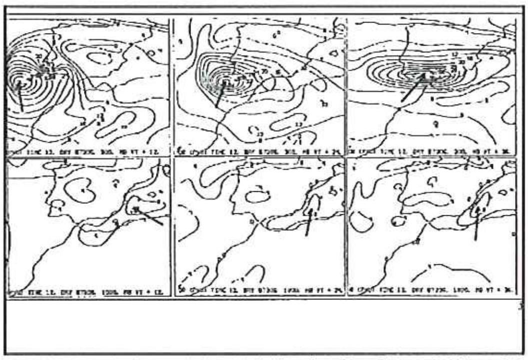

Fig.7.- Evolution of the PV distribution from 3-Nov-87 at 00 UTC to 4-Nov-87 at 00 UTC, at 300 hPa (up) and 1000 hPa (down) -Jansa et al. (1992)-

As a partial answer to the first and second questions above, fig. 7 shows the evolution of the PV distribution at 300 hPa and 1000 hPa corresponding to the perturbation of fig. 5: An important 'parent' perturbation does exist at 300 hPa but the surface perturbation evolves independent of the first. The 1000 hPa PV maximum is present before the arrival of the 300 hPa one and remains stationary.

Related to the last question, the Mediterranean sea, apart from a 'flat terrain' surrounded by mountains, is also a pool of warm water and therefore, a source of sensible and latent heat. In this sense, Shay-El and Alpert (1991) have stressed the different thermodynamical features of the Mediterranean region, in front of the tropics and the northern-extratropical environments, as a factor of characterisation of the specific Mediterranean cyclogenesis. Due to the geographical coincidence between the orographic influences and the heat source, a synergetic coupling of factors could also be important.

Extratropical-tropical interaction can also be important in some cases of Mediterranean cyclonesis: as a result of the interaction, very warm African air can irrupt into the Mediterranean, favouring or intensifying the cyclogenesis -see fig. 4, Jansa (1987)-.

4. THE WMO STUDY PROJECT

The WMO-ICSU Alpine Experiment, ALPEX, the last big field experiment of GARP, was designed to document the orographic influences on the air flow, with important emphasis on the lee cyclogenesis -Kuettner (1980)-. Due to the selection of the region to implement the experiment, the Alps and surrounding area, the lee cyclones that ALPEX documented were Mediterranean-Genoa cyclones. ALPEX has generated much work on Mediterranean cyclogenesis, even from the very begining -WMO-ICSU (1982)-.

Nevertheless, just past ALPEX, WMO recognised the intrinsec importance of the theoretical and practical problem of the Mediterranean cyclones and its Executive Council aproved in 1984 an specific "Mediterranean Cyclone Studies Project (MCP)", with the general objective of better understanding and better forecasting the Mediterranean cyclones and their consequences. Nowdays MCP is the part a) of the Study Project III of the Weather Prediction Research Programme (sub-programme on short-range prediction). A steering group was formed to implement MCP and four countries accepted to be activity centers for the Project, Bulgaria, Egipt, Italy and Spain. Israel and Greece have also been invited to become new activity centers very recently.

The MCP steering group has organised several meetings and a workshop during the past years, to promote and exchange experiences and knowledge about the Mediterranean cyclones, and the proceedings have been publised by WMO (1985, 1986, 1987, 1989, 1991, 1992, 1994). A general report on Mediterranean cyclones was prepared by Radinovic (1987), by request of the MCP steering group.

5. THE SPANISH ACTIVITIES

The Spanish Mediterranean region suffers the consequences of the specific Mediterranean disturbances with such an intensity and frequency that it constitutes a problem of the biggest practical importance. During the last 15 years, tens of extreme heavy rain events have produced catastrophic floods, with hundreds of deaths and enormous material losses. For this reason, the Spanish National Institute of Meteorology has devoted the past decade to drastically update its technical equipment, i.e., power of computation, satellite data traitement, radar, lighting and authomatic station networks and so on. The present equipment and the paralel development of methodology have improved the watching and forecasting of the severe Mediterranean events, but more research is necessary to better understand the processes themseleves and more improve the results.

In 1991 the Spanish National Institute of Meteorology (INM) implemented a domestic research programme on Western Mediterranean meteorological studies (PEMMOC, in Spanish) in many aspects convergent to the WMO MCP. PEMMOC is coordinated from the Meteorological Center at Palma de Mallorca (Balearic islands) of the Spanish National Institute of Meteorology. Through PEMMOC and in the frame of MCP, a systematic collection and archieve of data about Western Mediterranean cyclones and hazardous weather in the zone has been initiated, as well as a writen periodic bulletin -'Boletin PEMMOC', INM (1993)-, including an enunciated calendar of all the observed cyclones -even shallow mesoscale perturbations- and a documented catalogue of a set of selected events. By this way a base for systematic studies would be ready and continously updated.

6. SOME PRELIMINARY RESULTS

The 'Boletín PEMMOC' constitutes itself a quick look to the factors influencing the Western Mediterranean cyclogenesis, as well as to the possible relationship between cyclonic presence and severe weather in the zone. Apart from the exhaustive calendar of cyclones, that constitutes the first part of the bulletin (and a separate data bank), and the statistical analysis from it, that forms the second part, the third part of the 'Boletín PEMMOC' is a graphical documentation (hand mesoscale analyses, satellite pictures and a selection of fields obtained objectively, geopotential, temperature, wind or streamlines or vorticity at several levels, as well as potential vorticity and PV advection at 300 hPa and 850 hPa and vertical stability) for selected cases. The cases are selected by a high value of vorticity (presence of an intense cyclone) or by the presence of severe weather (strong wind, heavy rain or presence of mesoscale convective systems). To select a cyclone by vorticity, this magnitude is computed by finite differences with gridlenghts of 200 and 400 km: when both values are higher than $1.3x10^{-4}$ s^{-1} the cyclone is selected as intense.

Very preliminary results can be exposed from the first year of monitoring Mediterranean cyclones and severe weather.

From two analyses every day, 740 cyclonic perturbations have been detected in the area shown in fig.3 during a period of six months (730 charts), being the most of them small and weak or moderate. 156 of these cyclonic perturbations appear in the south of the Pyrenees. We know from PYREX that this high frequency can be related to the effectivity of the Pyrenees as a sink of momemtum, mainly during cold advections, when average drag values of 5 or more Pa are not rare, what means dipolar pressure perturbations (positive anomaly in the windward, negative anomaly in the lee) of around 7 hPa, that is, a local cyclonic perturbation, with a pressure several hPa lower than the surrounding area -Bessemoulin et al. (1993)-. The importance of the cold advection in this cases has to be stressed. Another concentration of small-weak/moderate cyclonic perturbations is the Albaoran Channel, north of the Atlas. In this case, the warm African advection looks important, in addition to pure orographic forcing -see fig.5-.

Therefore, what we have in the Mediterranean is a lot of shallow-small-weak/moderate local cyclonic perturbations, due to orographic and thermal effects. From the Hoskins et al. (1985) model, the Merditerranean can be seen as an almost permanent source of low level perturbations to be catched by a previous upper air PV maximum: if the interaction occurs, a deep-intense cyclogenesis would develope.

We have investigate the presence of significant upper level PV advection near all the low level intense cyclones. The results are in the table I: although in 12/32 cases there is a significant presence of upper level PVA near the vertical of the surface cyclone, there is no evidence of such a coupling in more than half of the cases of observed surface intense cyclone!

Table I. Cases of intense cyclones versus presence of 300 hPa PVA in the vicinity (less than 666 km of horizontal distance) (PVA in PVU/6 h)

Cases (total)...............	32
300 PVA > 1.................	12
300 PVA > 3.................	11
300 PVA > 5.................	7

About the possible retaionship between severe weather and cyclogenesis, we have only investigated the cases of simultaneity between presence of any intense cyclone and severe weather in the Spanish Mediterranean (there were no data from other parts). The results are summarised in table II.

The presence or not of severe weather in other countries in connection with the presence of cyclones has to be investigated. Also the connection between severe weather and weak or moderate cyclones. The theresholds now choosen have also to be rewied. Of course, the factors influencing the cyclogenesis itself have also to be studied with more detail. Anycase, the 'Boletín PEMMOC' and the work associated to it will provided a good base for doing all this work.

Table II. Cases of intense cyclone (ICY), heavy rain (HR, more than 60 mm/day) and strong wind (SW, more than 44 km/h of sustained speed or than 80 km/h of gust)

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total cases....................43
total ICY......................32
total HR.......................14
total SW.......................17
ICY+HR..........................5
ICY+SW.........................10
ICY+HR+SW.......................4
HR+SW only (no ICY).............5
HR only (no SW, no ICY).........4
SW only (no HR, no ICY).........2
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