SPECIFIC ASPECTS
OF
MEDITERRANEAN CYCLONES

Mediterranean School on Mesoscale Meteorology – 1st Edition
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SOME ILLUSTRATIVE WORDS

"The inhabitants of the countries of the Mediterranean basin are quite aware of the frequent occurrence of severe weather in the Mediterranean region, such as heavy rainfall and strong winds associated with extreme weather events. Rainfalls of over 200 mm, and in some extreme cases, in excess of 800 mm, in 24 hours have been known to occur from time to time, while sustained wind speeds in excess of 100 km/h have been recorded in connection with events such as the Mistral, Tramontane, Ethesian and the Bora. As a result of these phenomena, significant losses in life and property are frequently reported in many countries. We recall some of the events which made headline news in the last few years. These include the exceptional and extensive heavy rains which affected wide parts of Egypt, including the Sinai Peninsula, in November 1994. In that event, more than 500 people lost their lives and large areas were inundated; even the famous ancient tombs of Luxor were menaced by flood surges. Fifty people died when a bridge collapsed after heavy rains in northern Algeria in October 1995. Torrential cloudbursts, reported to be the worst in 80 years at some locations, caused severe, widespread flooding and landslides in Southeast France, Corsica and north-western Italy during a four-day period in early November 1994. Over 50 lives were lost and thousands were left homeless in France, while the floods in Italy were even worse than the notorious event of November 1951 when the River Po overflowed its banks. Economic losses in northern Italy were reported at US $9 billion. During 1996 as a whole, several periods of above normal precipitation affected the Mediterranean basin. The drought-prone regions of southern Spain and northern Morocco received annual precipitation between 700 to 900 mm above normal, while 250 to 750 mm above normal were received in other areas on both sides of the western half of Mediterranean. Despite the benefits of the rainfall, excessive amounts resulted in some deaths, dislocation of people and significant crop damage. Notable example is the disastrous flash flood which caused significant loss of life at a camp site in Spain in August last year."

MEDITERRANEAN CYCLONES ⟷ **HIGH IMPACT WEATHER**

(Prof. Obasi, Secretary-General WMO, *Opening address at the INM/WMO International Symposium on Cyclones and Hazardous Weather in the Mediterranean*, Palma de Mallorca, Spain, 14 April 1997)

Specific ideas (heavy rain) - 1

- Most frequent in late summer and autumn: Role of the ***Mediterranean air-mass*** (warm and wet at low levels – convective instability).
- Also needed a ***mechanism*** to force air ***ascent*** and a ***feeding current*** of warm and wet air towards the area of sustained heavy rain.
- Role of a ***Mediterranean low, not necessarily deep and strong***, by organizing differentiated air currents and low-level frontal boundaries (optimum area to reach and/or release the convective instability at the tip of the warm-wet current, where intersecting a thermal-humidity boundary). Upper-level forcing is not a critical ingredient.
- Or a ***mountain barrier*** (notice the Mediterranean basin) instead of the boundary to force the ascent of the warm-wet current. Commonly, both factors in combination.

Specific ideas (heavy rain) - 2

- A near ***cyclonic centre*** in found in more than ***70%*** of the cases of heavy rain in the western Mediterranean region, usually located in a position compatible with the previous conceptual model.
- Even in cases of deep and self-organized convection (***MCS***), the close presence of a cyclone centre is detected in about ***65%*** of the cases.
- But ***some Mediterranean heavy rain*** events depart from the previous conceptual model: Strong and deep upward forcing, that is, dynamically driven cases usually related to ***intense cyclogenesis*** (continuous stratiform rain, although convective instability is easily reached and released – embedded convection). Symmetric instability and slantwise convection could also play a role.

Specific ideas (strong winds)

- Not necessarily linked to intense cyclones: ***Local strong winds*** (Mistral, Tramontane, Cierzo, Ponent, Levante, Scirocco, Etesians, Bora, Shamsin, Sharav, etc …) owing to geographical factors.
- ***Orographically induced pressure perturbation***: lee depression and/or the associated windward high-pressure. By its very nature, these local winds tend to be shallow (1.5-2 km), and in the case of cold air outbreaks, act as gravity currents.
- ***Indirect effect*** of the local winds: Formation of cyclonic and anticyclonic potential vorticity -*PV*- ***banners***.
- But neither the orographically induced primary lee (warm) depressions and the positive PV banners, very frequent, can be considered as ***true cyclogenesis***.

Specific ideas (cyclones) - 1

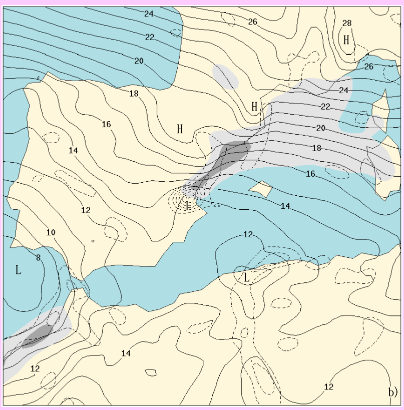
- Mediterranean area: ***highest concentration*** of true cyclogenesis in the world, at least in winter. Some events reaching the category of “meteorological bombs”.
- ***Preferential areas***: Genoa region, Cyprus and Aegean region, Adriatic, Palos-Algerian sea, Catalonian-Balearic sea and gulf of Lyon. Also, shallow thermal lows over the Iberian-African plateau.
- ***High concentration of cyclones*** as a result of the particular geography of the Mediterranean region: Very frequent lee warm primary depressions and low-level positive PV banners ready to interact with upper-level PV positive anomalies when moving over the region (explanation ***based on PV thinking***)

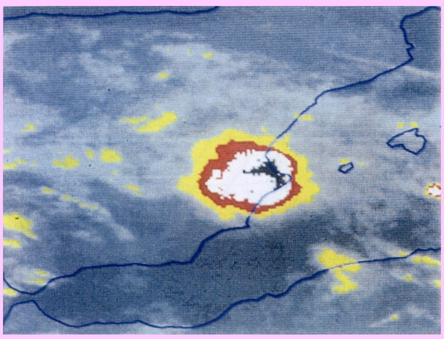
Specific ideas (cyclones) - 2

- Role of ***latent heat release*** for the spin-up and/or sustenance of the cyclone (considered as a ***secondary*** effect for orographic cyclogenesis events).
- ***However***, some cyclones owe their source of energy to the great amount of latent heat released in big convective cloud clusters (CISK, air-sea interaction): ***Quasi-tropical cyclones***.
- ***And other influences*** of latent heat release, not necessarily linked to convection (e.g., enhanced baroclinic instability in saturated air, etc.).
- The most likely scenario for any given ***cyclone is a mixture*** of physical processes such as those described ***!!!***

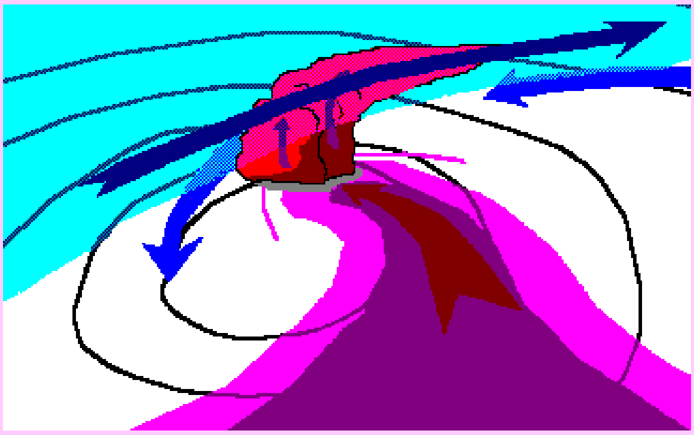
Example (A): Gandía flood:

MCS (33 h, 200 km diameter)
1000 mm / 36 h



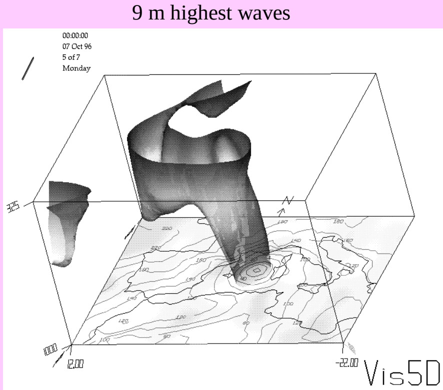


Type (A): The cyclone (that can be shallow; e.g. orographic origin) organises the inflow of moist and warm Mediterranean air



Example (B): Sardinian cyclone:

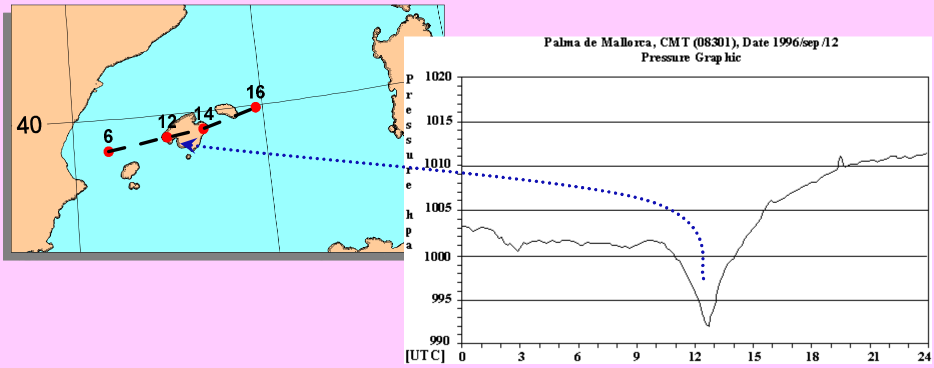
>100 mm in 3 hrs
118 km/h wind gust
9 m highest waves



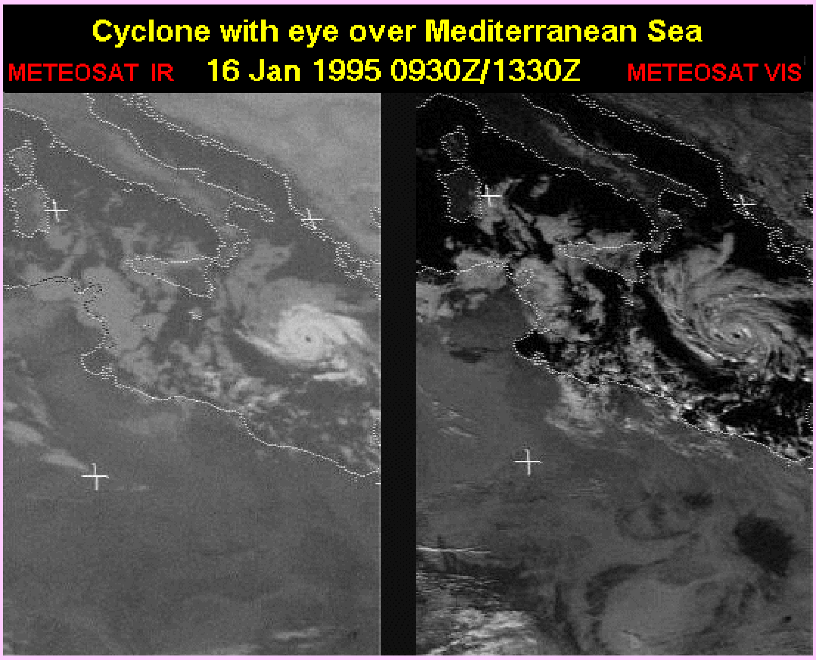
Type (B): deep cyclone and hazardous weather are two aspects of the same evolution (baroclinic origin)

Example (C): Quasi-tropical cyclone:

115 km/h wind gust
27 mm/ 1 h

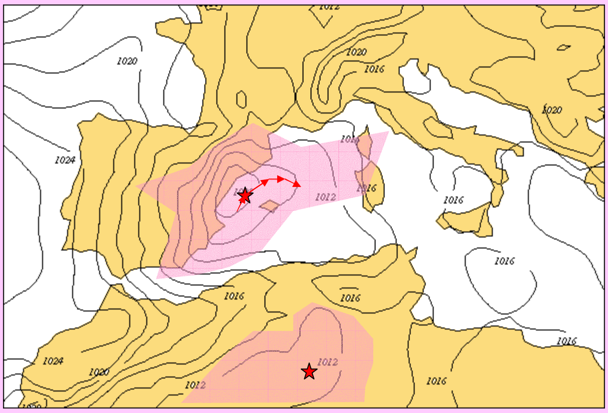


Type (C): cyclone driven by latent heat release
(as a result of previous heavy rain)



DATA BASE OF MEDITERRANEAN CYCLONES

Thanks to my colleagues from the INM center in the Balearics !!!



Data base of cyclones

The methodology already implemented permits:

Objective and automatic detection of cyclones
+
Dynamical description

For example:

Detection

- Smoothed SLP: Cressman filter with a radius of influence of 200 km
- Relative minimum of SLP
- Pressure gradient ≥ 0.5 hPa/100 km in at least 6 of the 8 main directions

Tracking

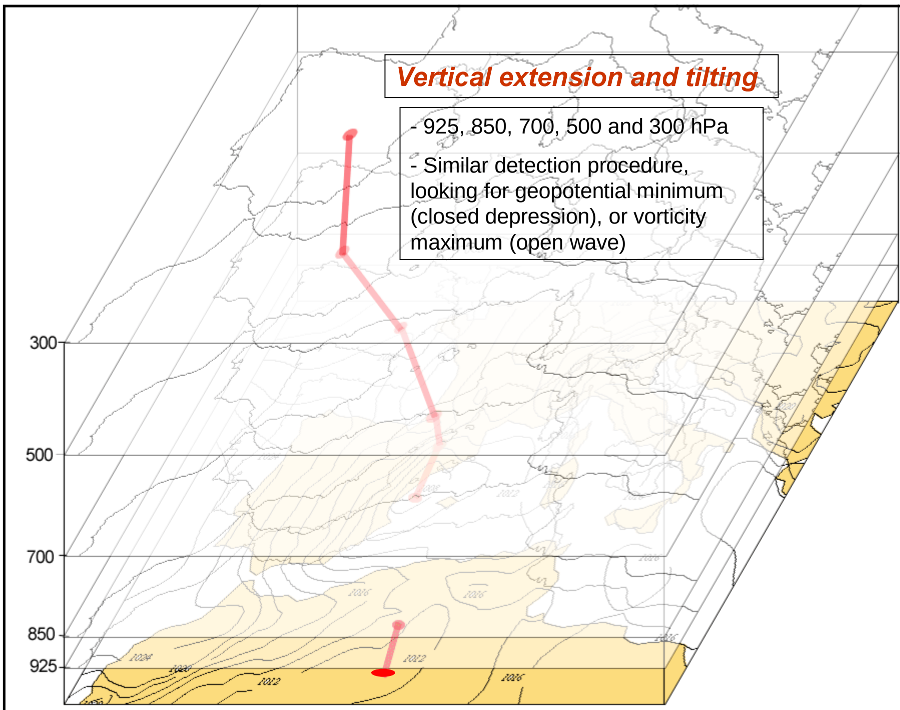
- Cyclone detected on successive analysis times within elliptical area defined by the average wind at 700 hPa (steering level)

Domain

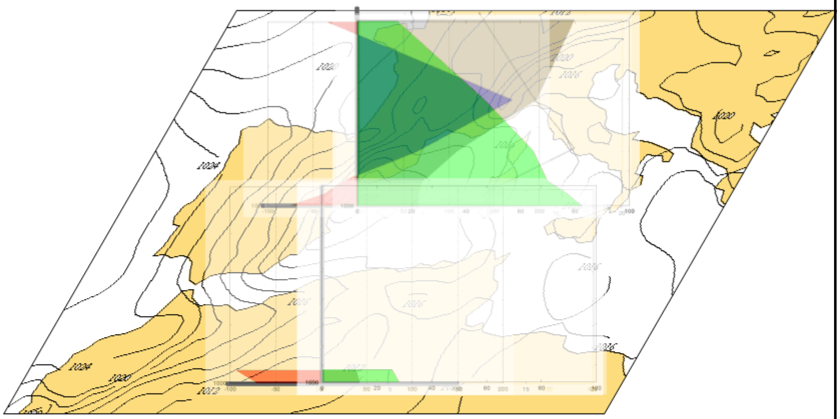
- Region of positive geostrophic vorticity around the cyclone center. This defines its mean radius (has to be ≥ 100 km)

Vertical extension and tilting

- 925, 850, 700, 500 and 300 hPa
- Similar detection procedure, looking for geopotential minimum (closed depression), or vorticity maximum (open wave)



Vertical profiles of cyclone attributes



Profile of radius

Profile of circulation: **A** x **ς**

Other profiles

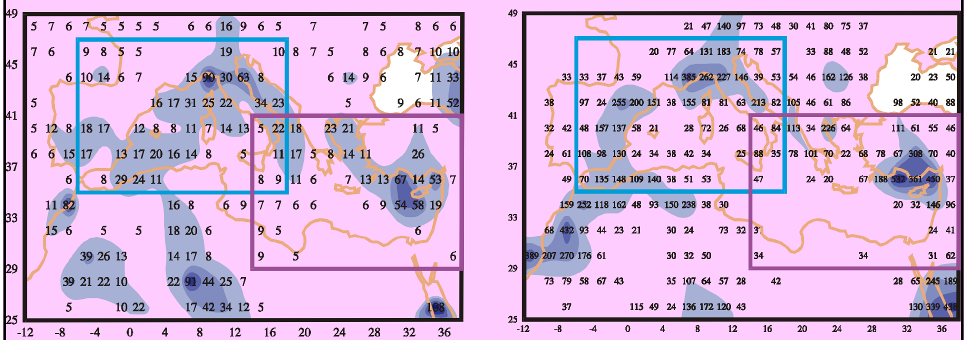
Thermal profile: Δ**T**

Profile of relative humidity

COMPARISON BETWEEN WEST AND EAST MEDITERRANEAN BASINS

Using ECMWF-0.5⁰ analyses (00, 06, 12 and 18 UTC)

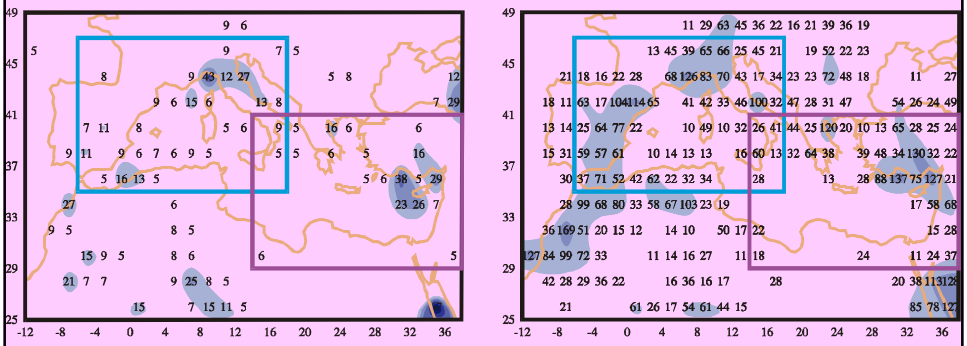
June 1998-May 2001 (only surface cyclones and annual analysis)



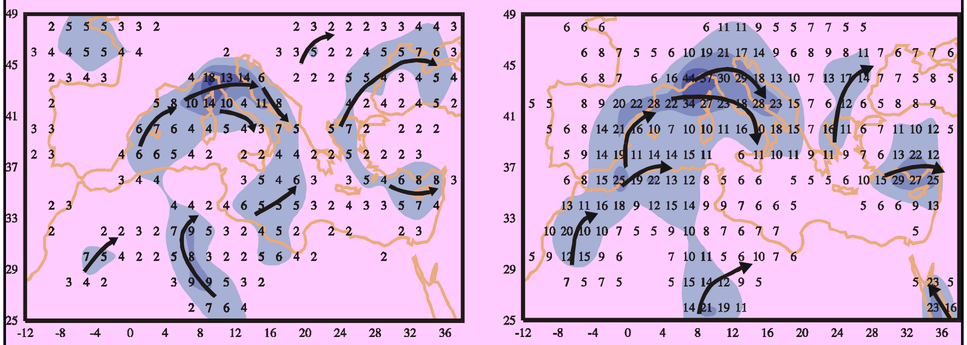
Annual mean frequency of detected cyclonic centres

(2^0x2^0 boxes, from smoothed -left- and non smoothed -right- SLP field)

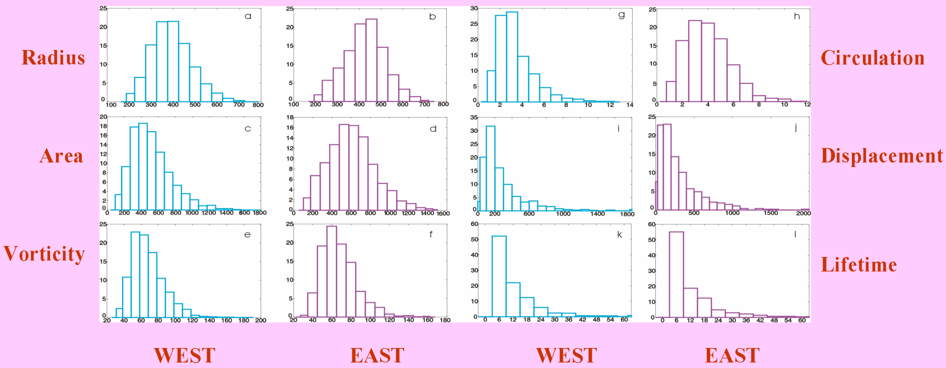
Mean number of cyclones	*Smoothed*	*Non smoothed*
East Zone	353	2248
West Zone	437	2910



First detection mean frequency for cyclones with lifetime > 6 h
(2^0x2^0 boxes, from smoothed -left- and non smoothed -right- SLP field)



Mean track density for cyclones moving a total distance > 250 km
(2^0x2^0 boxes, from smoothed -left- and non smoothed -right- SLP field)



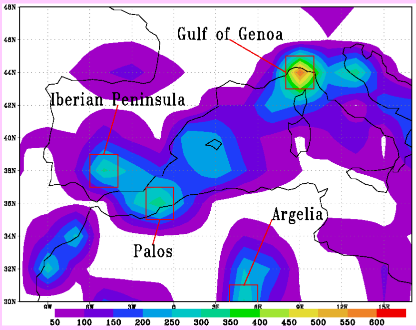
	Radius (km)	*Area* (km^2)	*Vorticity* ($x10^{-6}s^{-1}$)	*Circulation* ($x10^7m^2s^{-1}$)	*Displacement* (km)	*Lifetime* (h)
East Zone	426.6	603558.9	67.7	4.0	269.4	12.5
West Zone	394.2	512588.0	67.4	3.4	264.1	12.5

WESTERN MEDITERRANEAN CYCLONES

Using HIRLAM-INM-0.5^0 analyses (00, 06, 12 and 18 UTC)

June 1995-May 2002 (3D structure and seasonal analysis)

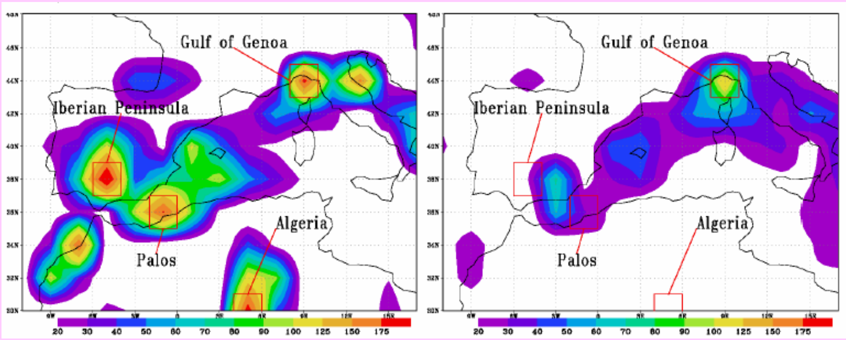
NUMBER OF CYCLONES



Total

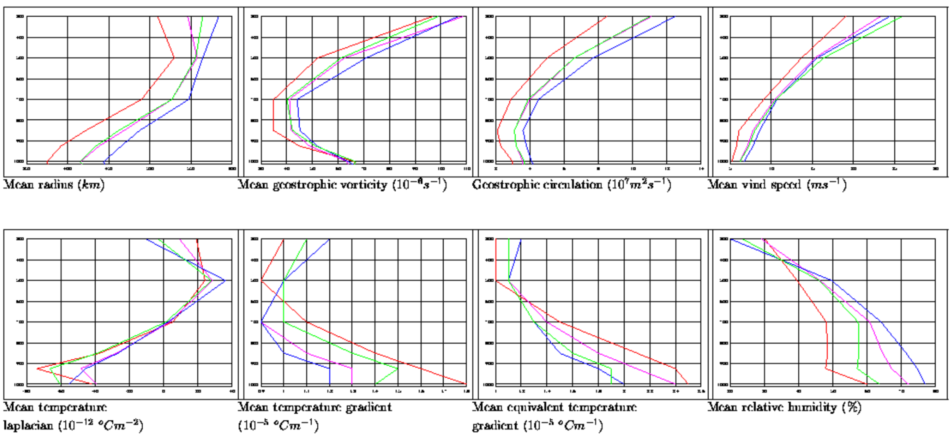
Summer

Winter

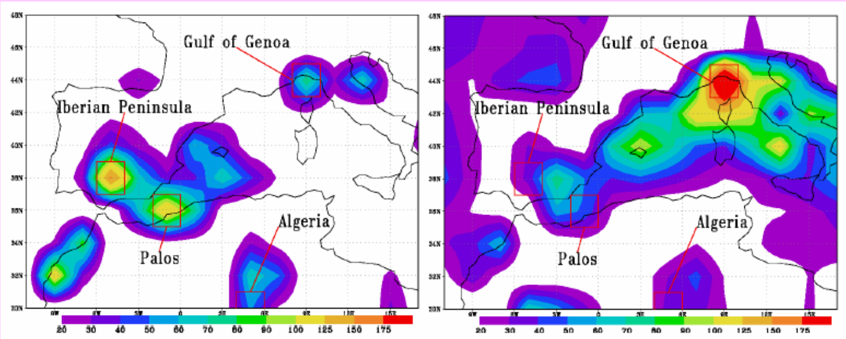


Mean seasonal vertical profiles of cyclone attributes:

Summer (red), Autumn (purple), Winter (blue) and Spring (green)

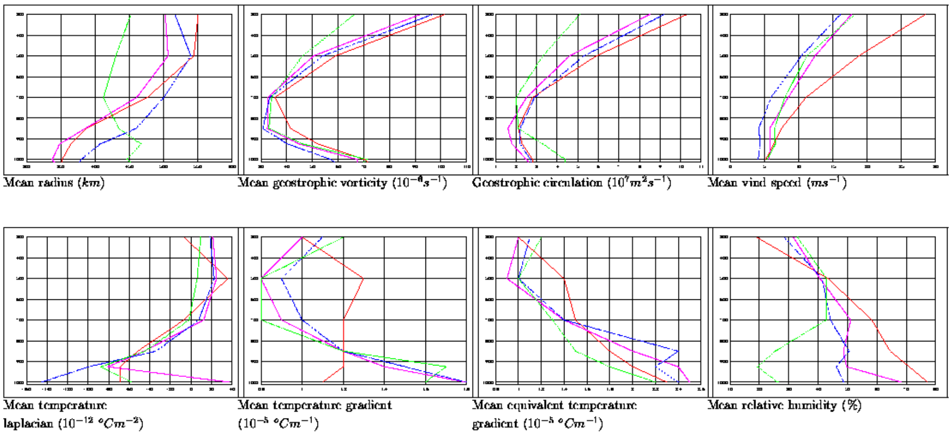


Shalow (1000-925 hPa) **Deep (1000-300 hPa)**



	Summer	*Autumn*	*Winter*	*Spring*	*G Genoa*	*Palos*	*Iberian*	*Algeria*
Shallow	70.5	43.6	31.8	46.3	41.9	79.6	80.7	79.0
Medium	9.5	12.1	11.7	12.1	14.6	6.0	8.4	9.5
Deep	20.0	44.3	56.5	41.6	43.5	14.4	10.9	11.5

Mean vertical profiles of cyclone attributes for different regions:
Gulf of Genoa (red), Palos (purple), Iberian Peninsula (blue) and Algeria (green)



HEAVY RAIN AND CYCLONES IN THE WESTERN MEDITERRANEAN

Using HIRLAM-INM-0.5^0 analyses (00, 06, 12 and 18 UTC)

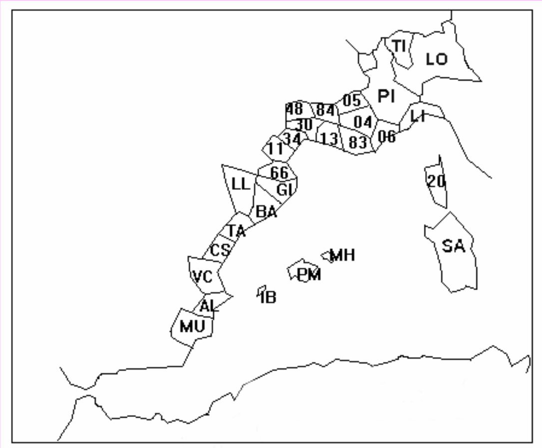
June 1995-November 1996 (simultaneity with heavy rain)

Heavy Rain Database

- 28 “territorial units” (departments, provinces or islands).
- Heavy Rain threshold >= 60 mm/24h.
- GTS and non-GTS data.
- Period: from June 95 to November 96.

Heavy rain event: if the threshold was surpassed in at least one station of any “territorial unit”:

(160 days / 300 events)

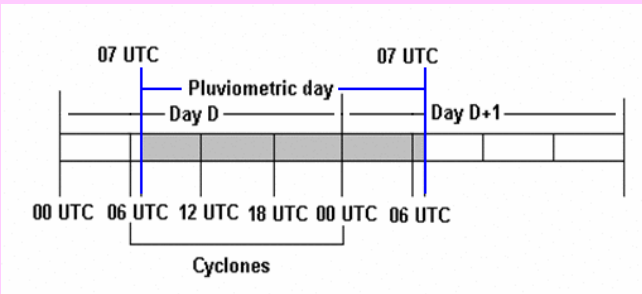


66: Perpignan
11: Carcasone
34: Montpellier
30: Nimes
48: Mende
13: Marseille
84: Avignon
83: Toulon
05: Embrum
04: Digne
06: Nice
20: Corsica

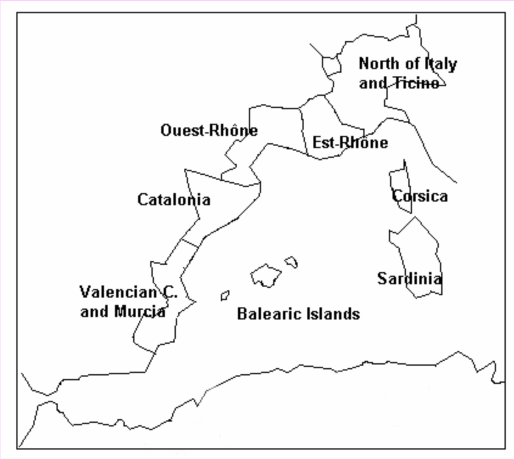
TI: Ticino
PI: Piamonte
LI: Liguria
LO: Lombardia
SA: Sardinia
LL: Lleida
GI: Girona
BA: Barcelona
CS: Castellón
VC: Valencia
AL: Alicante
MU: Murcia
MH: Minorca
PM: Mallorca
IB: Ibiza

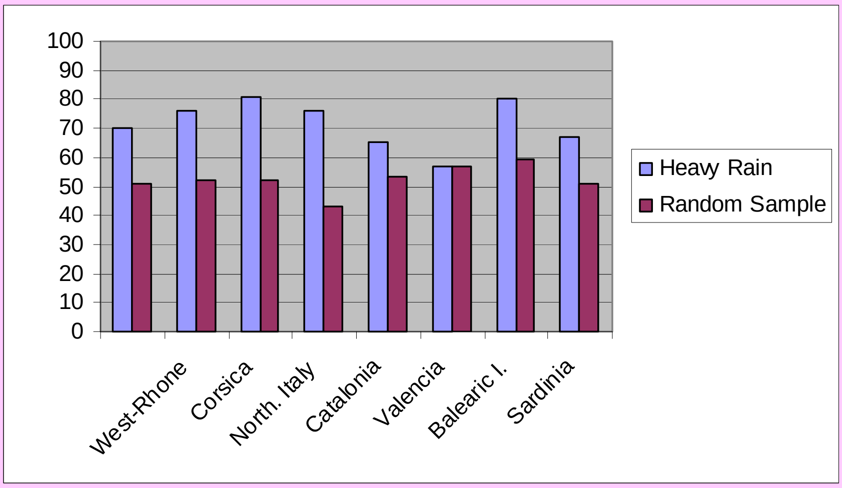
Simultaneity Heavy Rain Event-Cyclone

For each Heavy Rain Event (60 mm/24 h) in “regional unit” T for day D we look for the closest cyclone for day D at 06, 12 and 18 UTC and at 00 UTC for day D+1.



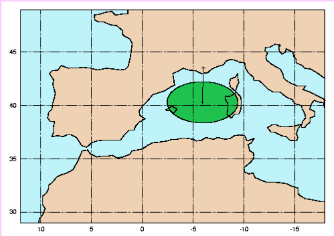
Due to the small number of events per “territorial unit” the results were grouped into **8 regions**:



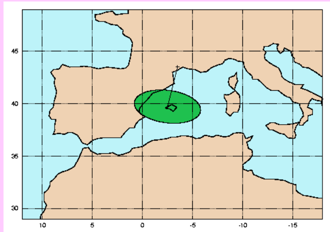


Frequency (%) of cyclonic centres within a 600 km radius
for the 8 regions: heavy rain events and random sample of events

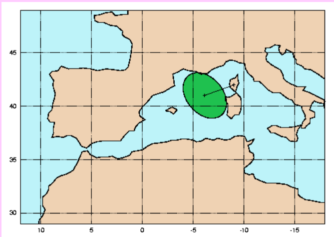
Simultaneity Cyclone-Heavy Rain



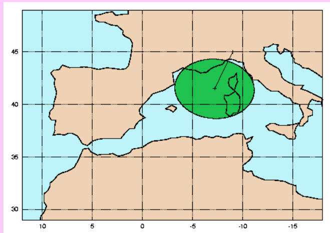
East-Rhône



West-Rhône

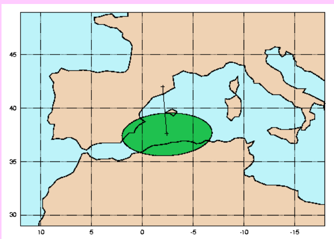


Corsica

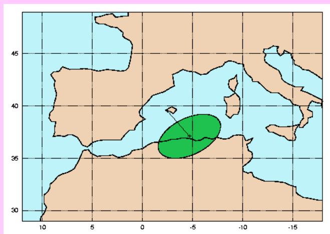


North Italy and Ticino

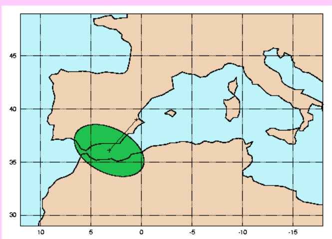
Simultaneity Cyclone-Heavy Rain



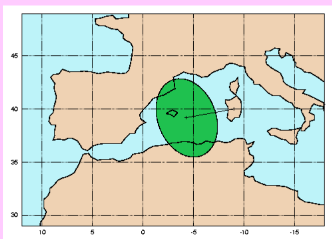
Catalonia



Balearic Islands

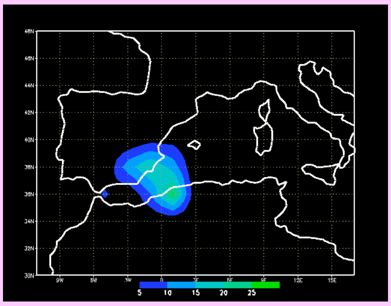


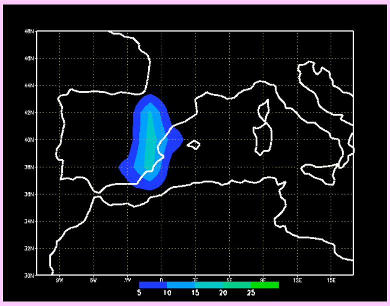
Valencia



Sardinia

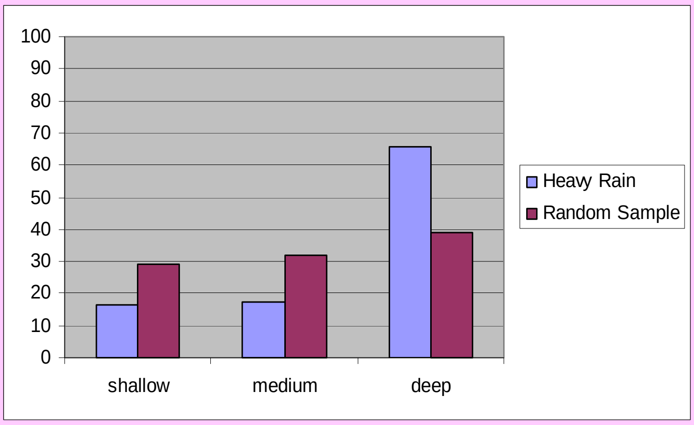
With a non-smoothed cyclone database, for the Valencian C. and Murcia region, in more than 90% of heavy rain events a cyclone is closer than 600 km. The same with a random sample of events, but in a different location:





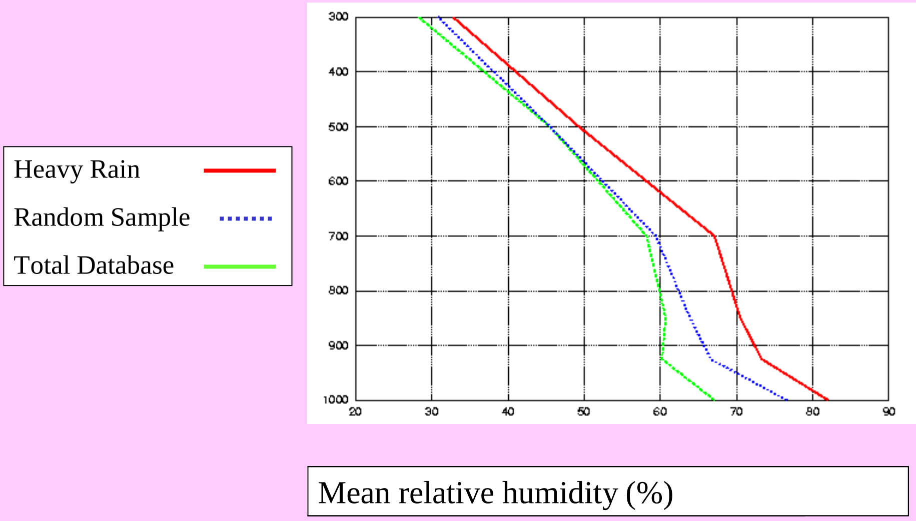
Frequency (%) of closest cyclonic centres
for heavy rain events (left) and a random sample events (right)

Tridimensional structure of cyclones



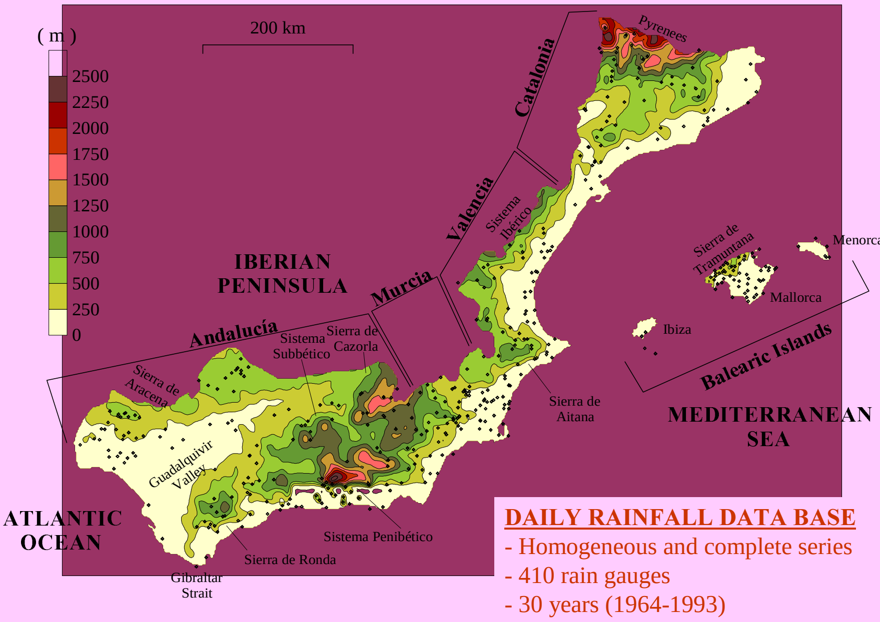
Frequency (%) of cyclone depth for all the closest cyclones:
heavy rain events and a random sample of events

Tridimensional structure of cyclones



CYCLONES AND PRECIPITATION IN MEDITERRANEAN SPAIN

Trying to classify the complex reality …



DAILY RAINFALL DATA BASE

- Homogeneous and complete series
- 410 rain gauges
- 30 years (1964-1993)

CLASSIFICATION RAINFALL PATTERNS (RPs)

			Win	*Spr*	*Sum*	*Aut*
Significant rainfalls 1964-93 ⟹	*5 % - 5 mm* ⟹	*3941 days*	*(30.0%*	*29.6%*	*13.6%*	*26.8%)*

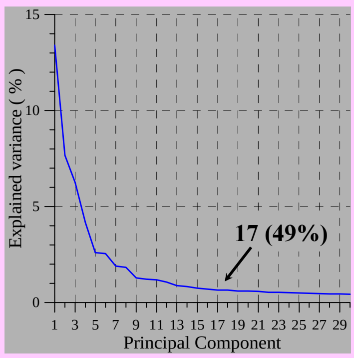
T-mode
(day-by-day)
correlation matrix

↓

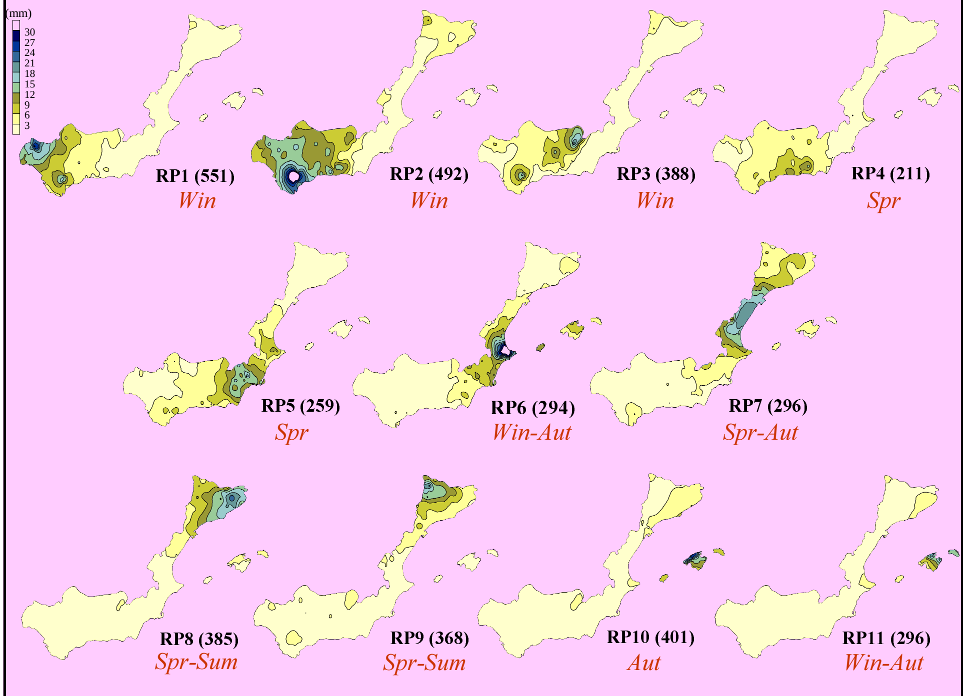
Principal Components Analysis
PCA

↓

Cluster Analysis (k-means)
CA



11 RPs

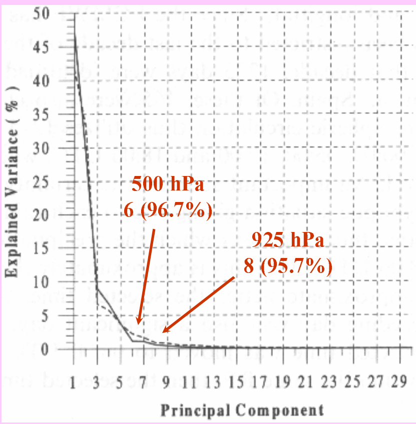


CLASSIFICATION ATMOSPHERIC PATTERNS (APs)

ECMWF analyses on significant days (1984-93) ⟶ *1275 days*

Geographical window 33.75N-45.75N 11.25W-6.00E ⟶ *408 grid points*

Classification based on geopotential height at 500 and 925 hPa



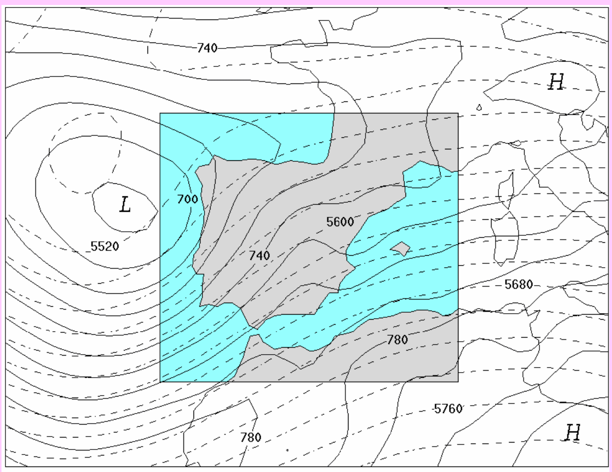
T-mode
(day-by-day) correlation matrix
↓
Principal Components Analysis
PCA
↓
Cluster Analysis (k-means)
CA

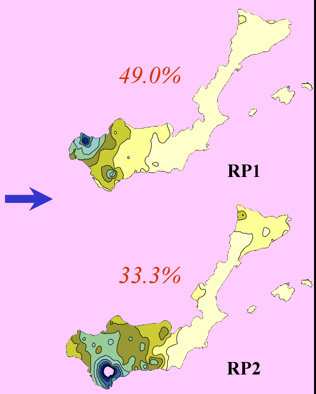
19 APs

Table II. Percentage frequency of the 11 daily RPs within the 19 APs (in bold, percentages greater than 15%) and seasonal distribution of the APs (in bold, percentages greater than 30%)

Atmospheric pattern	Number of days	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RPO	RP9	RP10	RP11	Winter	Spring	Summer	Autumn
AP1	51	**49.0**	**33.3**	0.0	2.0	0.0	0.0	5.9	5.9	2.0	0.0	1.9	**43.1**	17.6	5.9	**33.4**
AP2	71	**46.5**	**23.9**	**15.5**	0.0	1.4	0.0	0.0	2.8	1.4	4.2	4.3	**54.9**	18.3	1.4	25.4
AP3	84	**35.7**	**36.9**	0.0	1.2	4.8	1.2	8.3	8.3	2.4	0.0	1.2	20.2	19.0	6.0	**54.8**
AP4	105	**30.5**	**36.2**	4.8	0.0	0.0	1.0	8.6	2.9	12.4	1.9	1.7	25.7	29.5	3.8	**41.0**
AP5	58	**22.4**	**25.9**	0.0	12.1	**15.5**	5.2	8.6	0.0	6.9	1.7	1.7	25.9	**36.2**	0.0	**37.9**
AP6	78	**17.9**	**15.4**	5.1	7.7	**21.8**	9.0	**17.9**	3.8	0.0	0.0	1.4	29.5	**33.3**	9.0	28.2
AP7	100	13.0	9.0	**25.0**	4.0	3.0	2.0	2.0	14.0	**25.0**	2.0	1.0	22.0	**35.0**	8.0	**35.0**
AP8	76	2.6	13.2	**15.8**	1.3	3.9	0.0	10.5	**23.7**	**21.1**	6.6	1.3	7.9	**42.1**	23.7	26.3
AP9	86	2.3	8.1	**41.9**	3.5	0.0	1.2	2.3	**16.3**	4.7	10.5	9.2	**45.3**	29.1	9.3	16.3
AP10	28	3.6	10.7	0.0	0.0	10.7	14.3	14.3	**28.6**	3.6	7.1	7.1	**46.4**	10.7	0.0	**42.9**
AP11	70	1.4	1.4	4.3	2.9	4.3	11.4	11.4	**30.0**	**20.0**	7.1	5.8	5.7	**30.0**	**41.4**	22.9
AP12	23	0.0	0.0	0.0	8.7	4.3	**69.6**	0.0	4.3	0.0	8.7	4.4	**47.8**	17.4	0.0	**34.8**
AP13	66	1.5	3.0	0.0	3.0	**28.8**	**40.9**	12.1	4.5	1.5	4.5	0.2	**53.0**	19.7	3.0	24.3
AP14	56	3.6	3.6	8.9	3.6	**17.9**	**16.1**	**21.4**	3.6	14.3	5.4	1.6	8.9	**35.7**	**33.9**	21.5
AP15	25	4.0	8.0	0.0	**16.0**	**20.0**	4.0	**24.0**	0.0	8.0	8.0	8.0	16.0	**32.0**	12.0	**40.0**
AP16	73	4.1	4.1	0.0	9.6	**16.4**	8.2	6.8	**20.5**	0.0	**17.8**	12.5	12.3	28.8	**38.4**	20.5
AP17	52	0.0	3.8	0.0	5.8	9.6	**36.5**	0.0	1.9	0.0	**19.2**	**23.2**	**30.8**	23.1	15.4	**30.7**
AP18	86	2.3	2.3	8.1	0.0	4.7	7.0	2.3	**17.4**	2.3	**24.4**	**29.2**	26.7	**41.9**	8.1	23.3
AP19	87	0.0	1.1	1.1	4.6	1.1	5.7	1.1	10.3	1.1	**37.9**	**36.0**	**34.5**	**40.2**	4.6	20.7
Total	1275	13.7	13.6	8.5	3.8	7.8	9.1	7.5	10.9	7.5	9.1	8.3	28.2	29.9	12.1	29.8

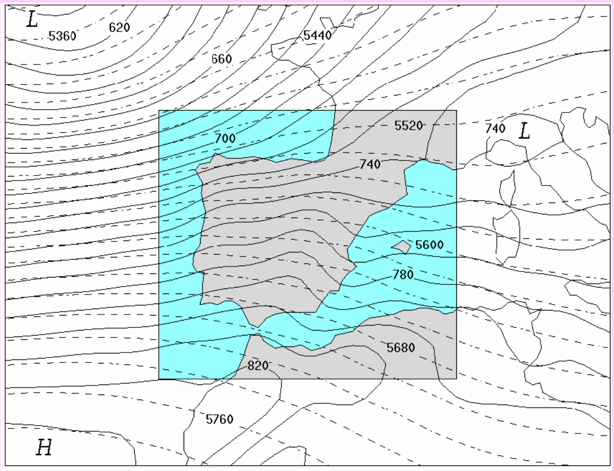
CLEAR ASSOCIATION

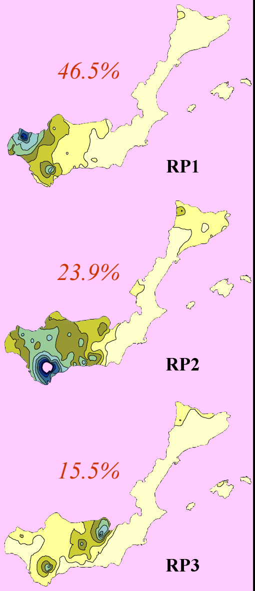




AP1

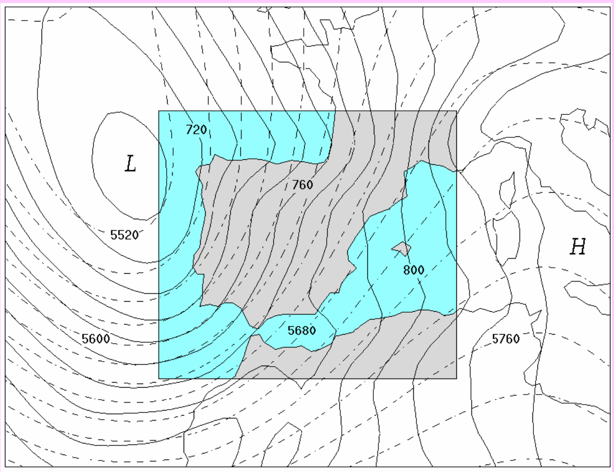
Win *43.1%* - ***Aut*** *33.4%*
Heavy *15.7%*

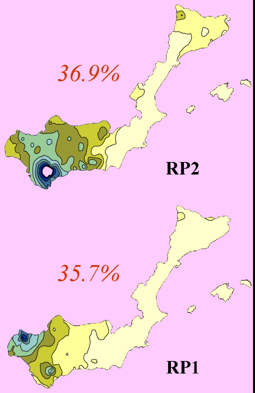




AP2

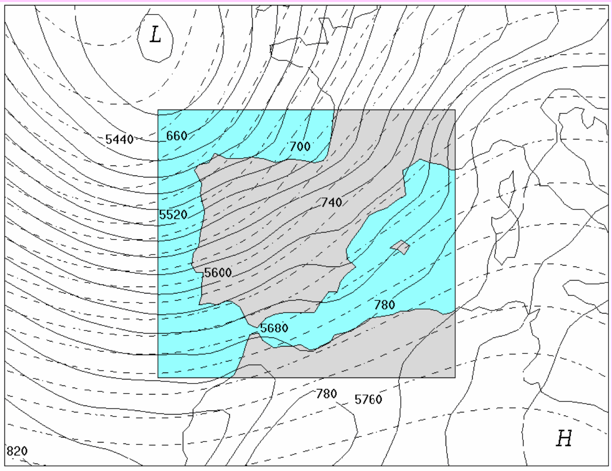
Win *54.9%*
Heavy *11.3%*

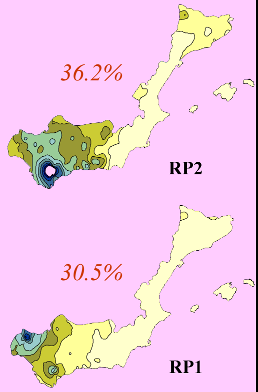




AP3

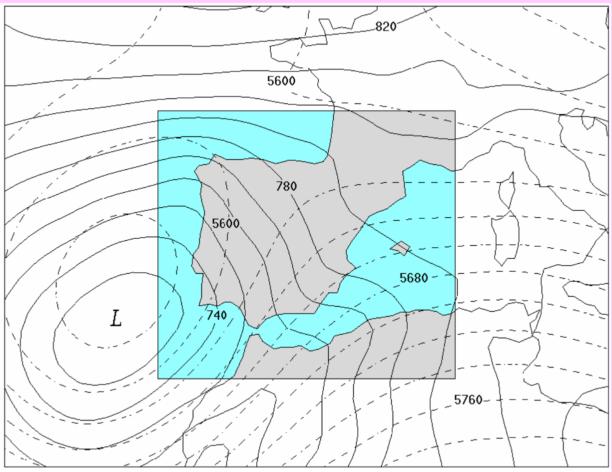
Aut *54.8%*
Heavy *25.0%*

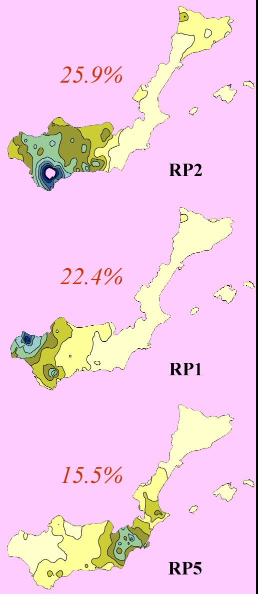




AP4

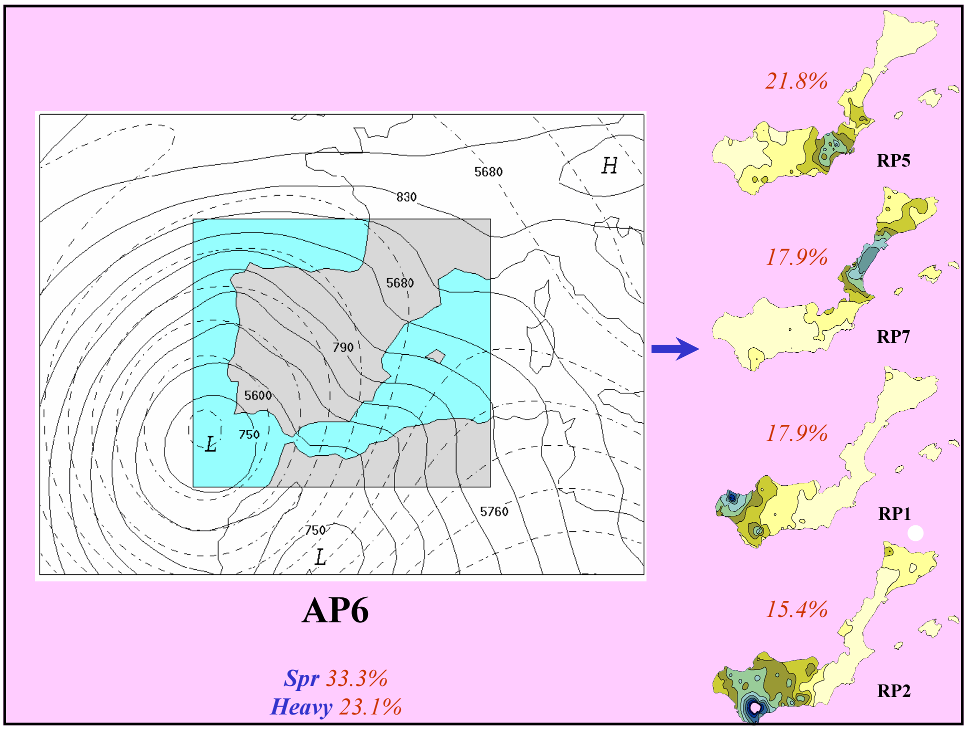
Aut *41.0%*
Heavy *15.2%*



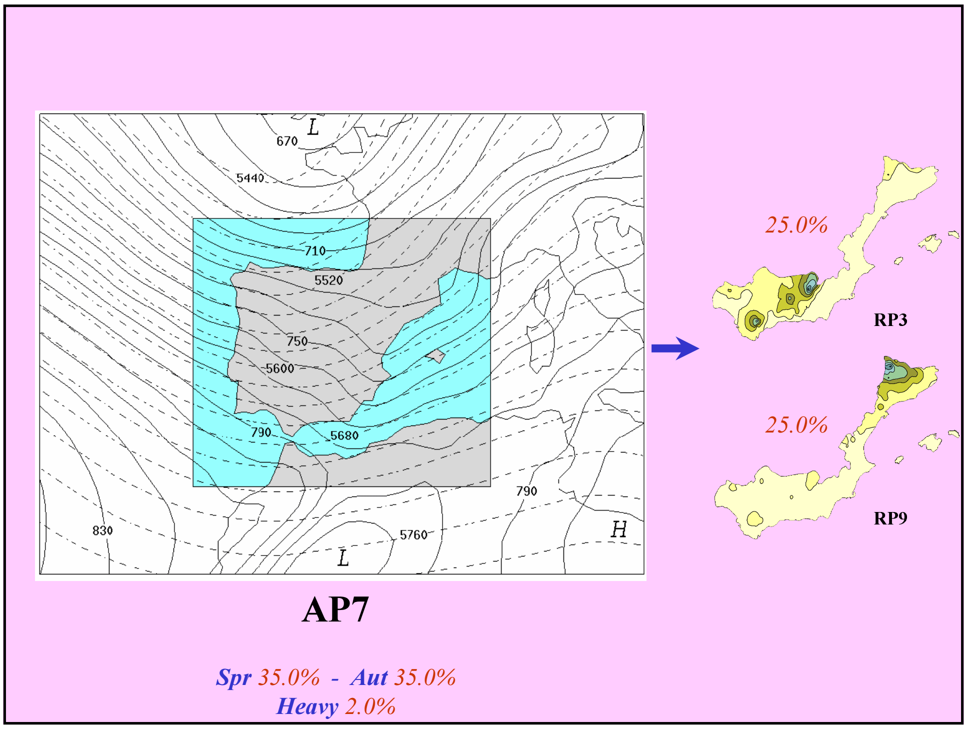


AP5

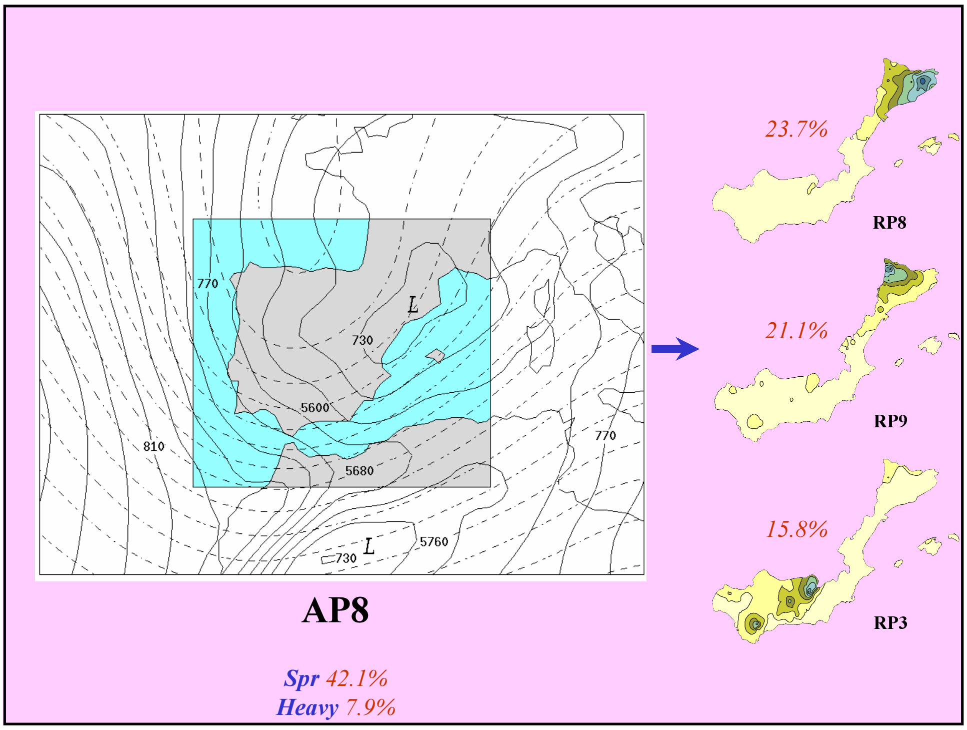
Aut *37.9%* - ***Spr*** *36.2%*
Heavy *17.2%*

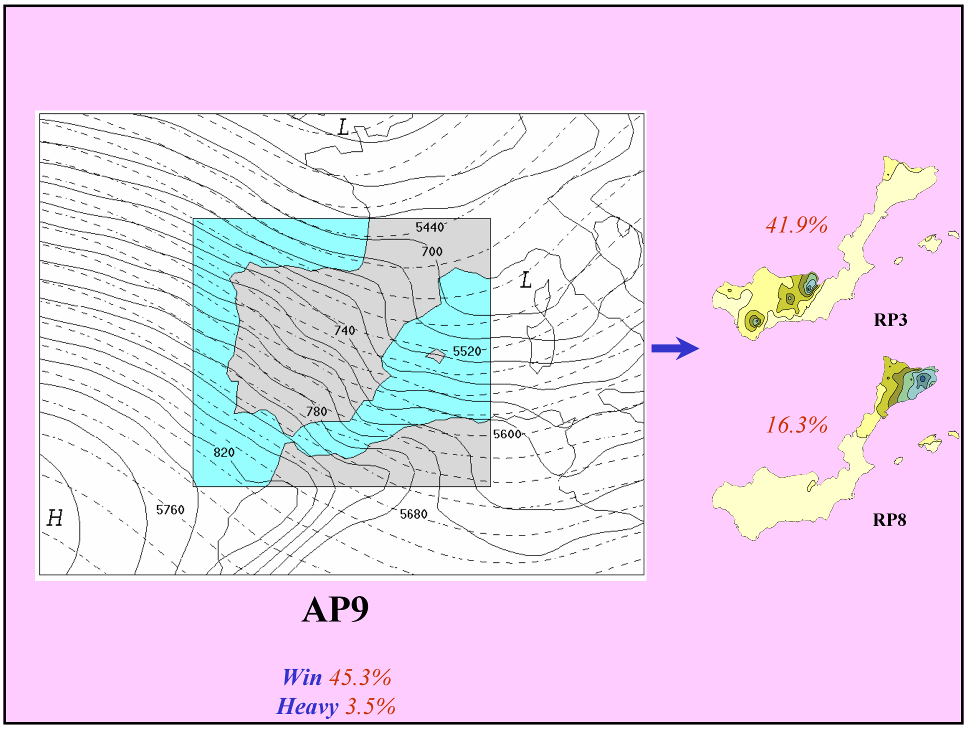


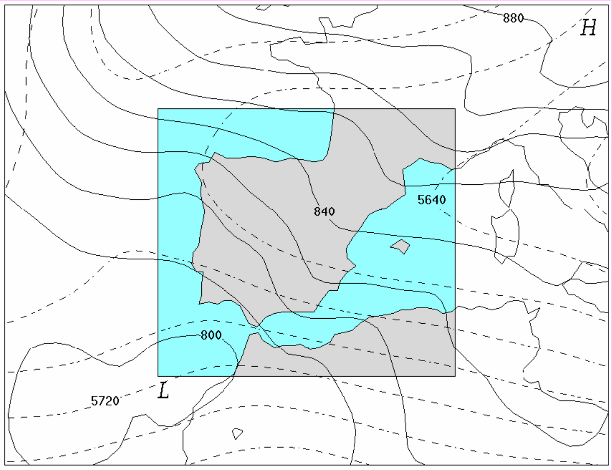
AP6
Spr 33.3%
Heavy 23.1%
21.8%
RP5
17.9%
RP7
17.9%
RP1
15.4%
RP2

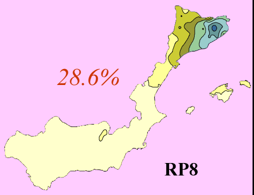


AP7
Spr 35.0% - Aut 35.0%
Heavy 2.0%
25.0%
RP3
25.0%
RP9


770
L
730
5600
810
5680
770
L
730
5760
23.7%
RP8
21.1%
RP9
15.8%
RP3
AP8
Spr 42.1%
Heavy 7.9%

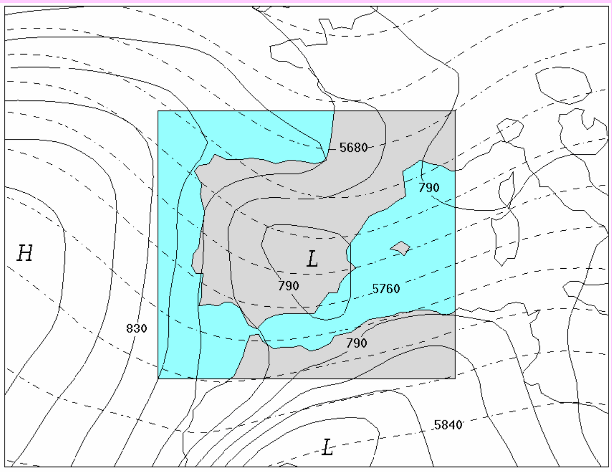

L
5440
700
L
740
5520
780
5600
820
H
5760
5680
41.9%
RP3
16.3%
RP8
AP9
Win 45.3%
Heavy 3.5%

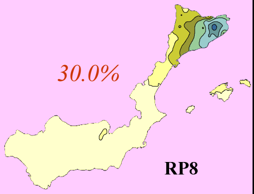


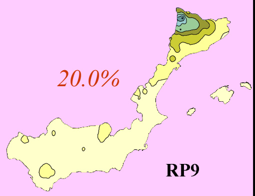


AP10

Win 46.4% - Aut 42.9%
Heavy 10.7%

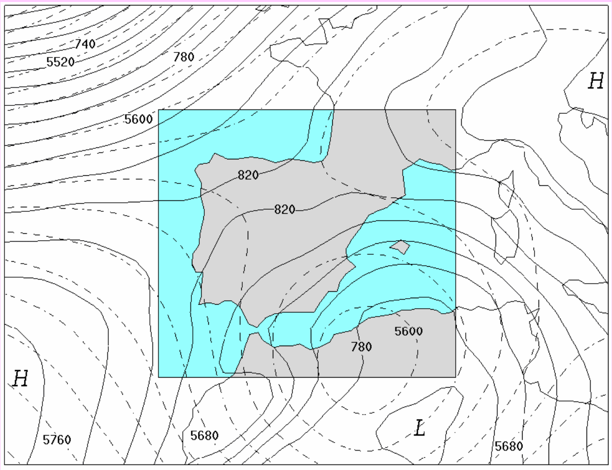




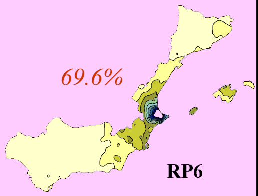


AP11

Sum 41.4% - Spr 30.0%
Heavy 0.0%



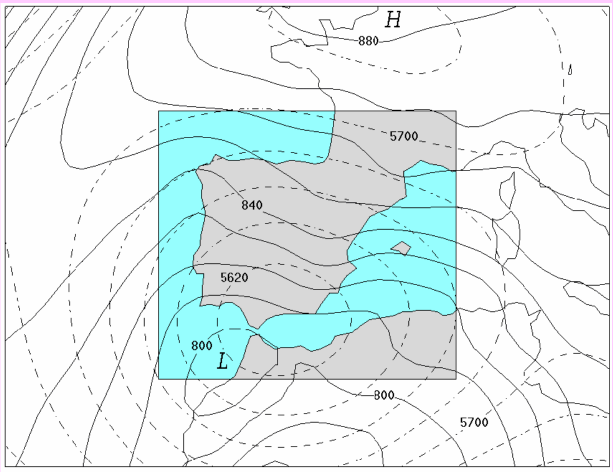
69.6%



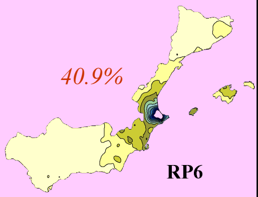
RP6

AP12

Win 47.8% - Aut 34.8%
Heavy 21.7%

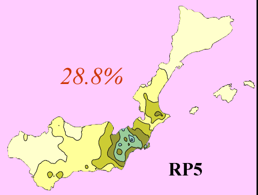


40.9%



RP6

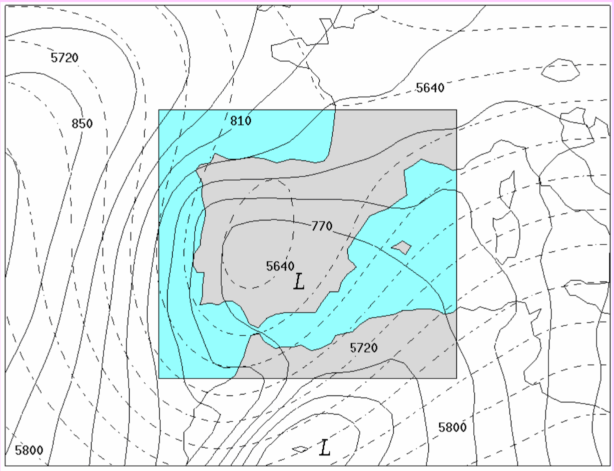
28.8%

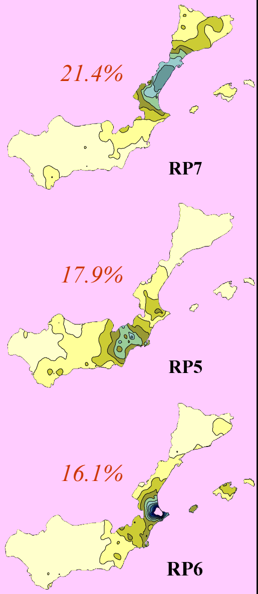


RP5

AP13

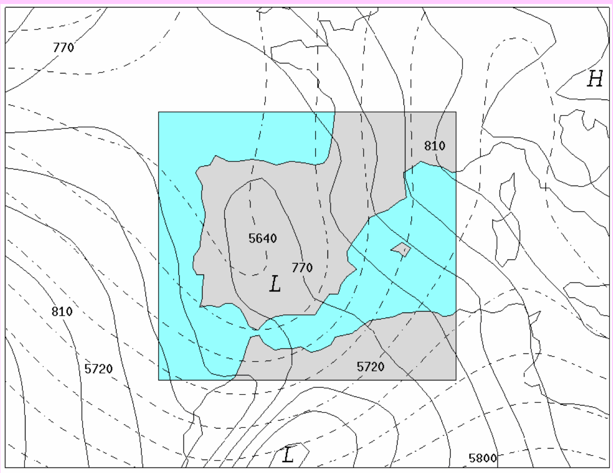
Win 53.0%
Heavy 37.9%

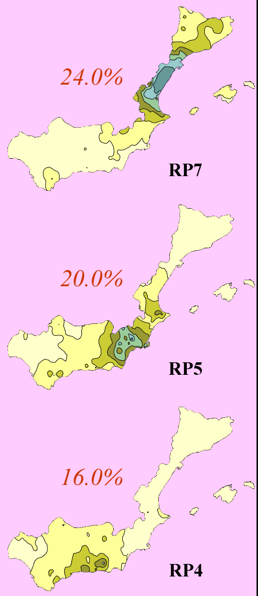




AP14

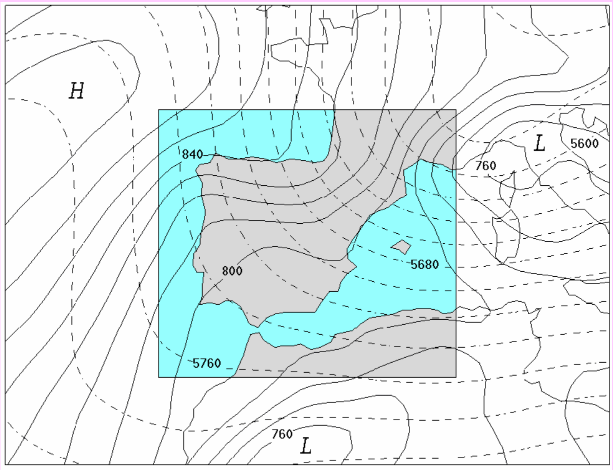
Spr *35.7%* - ***Sum*** *33.9%*
Heavy *19.6%*

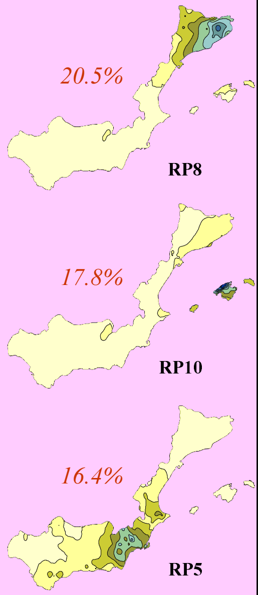




AP15

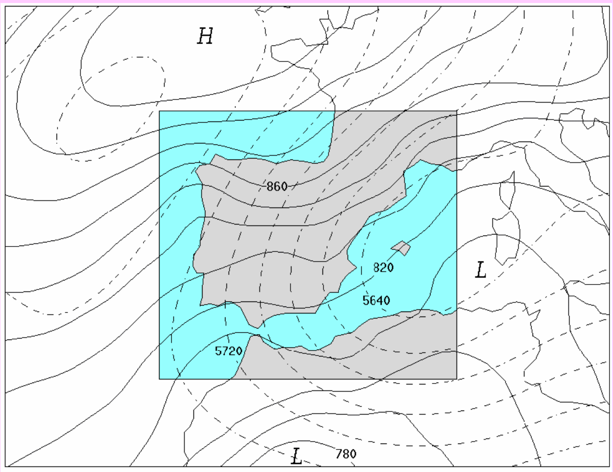
Aut *40.0%* - ***Spr*** *32.0%*
Heavy *32.0%*

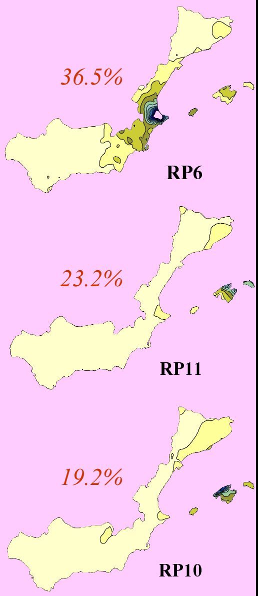




AP16

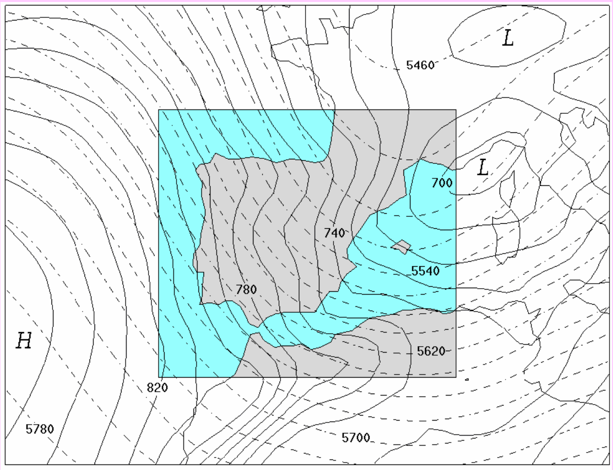
Sum *38.4%*
Heavy *0.0%*





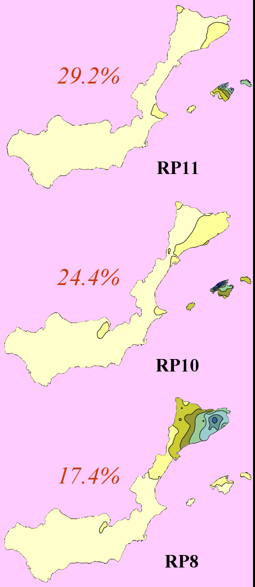
AP17

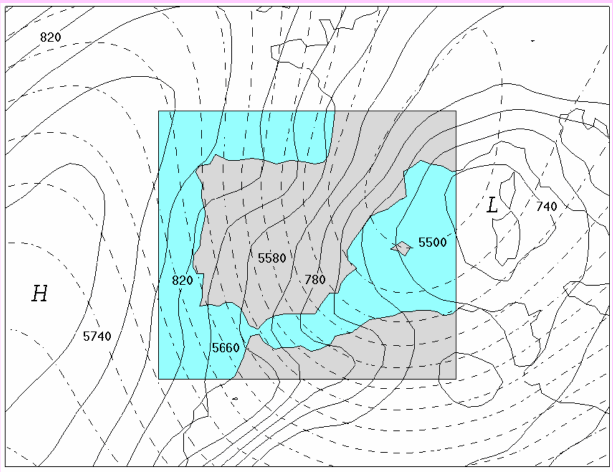
Win *30.8%* - ***Aut*** *30.7%*
Heavy *13.5%*



AP18

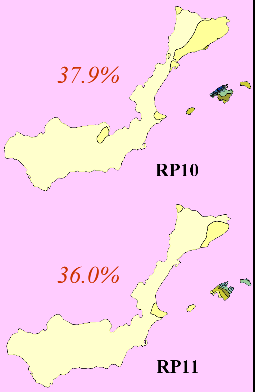
Spr *41.9%*
Heavy *4.7%*





AP19

Spr *40.2%* - ***Win*** *34.5%*
Heavy *11.5%*



RELATED WITH THIS PRESENTATION: Lecture 5

THE MEDEX:
A PROJECT ON MEDITERRANEAN CYCLONES
(SPECIAL PRESENTATION)