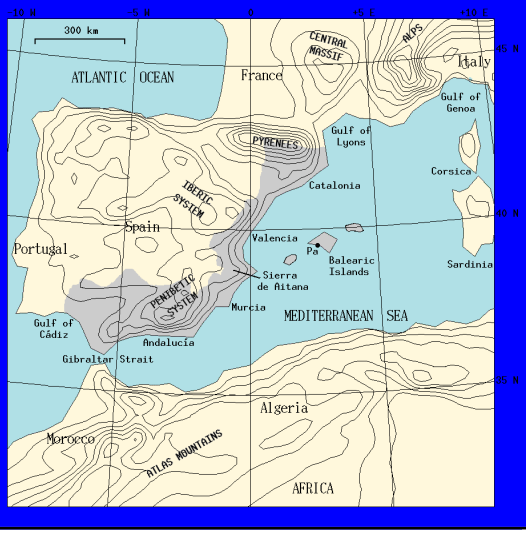
HEAVY PRECIPITATIONS IN MEDITERRANEAN SPAIN: CLIMATOLOGY AND MESOSCALE NUMERICAL SIMULATIONS

Romualdo Romero
Visiting Post-Doctoral, NSSL/CIMMS

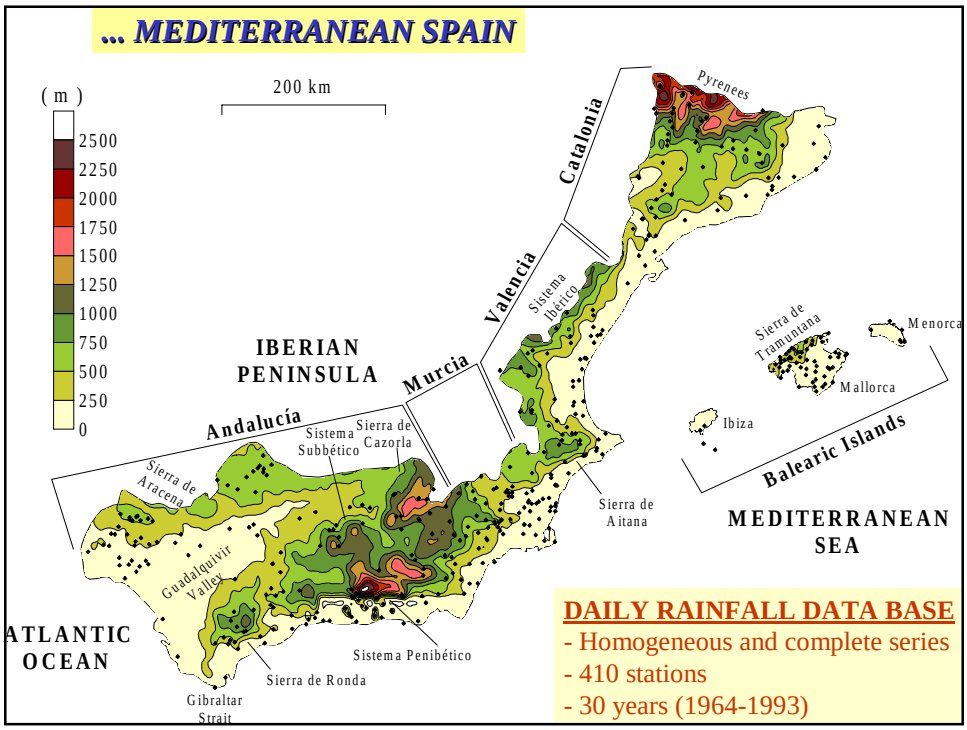


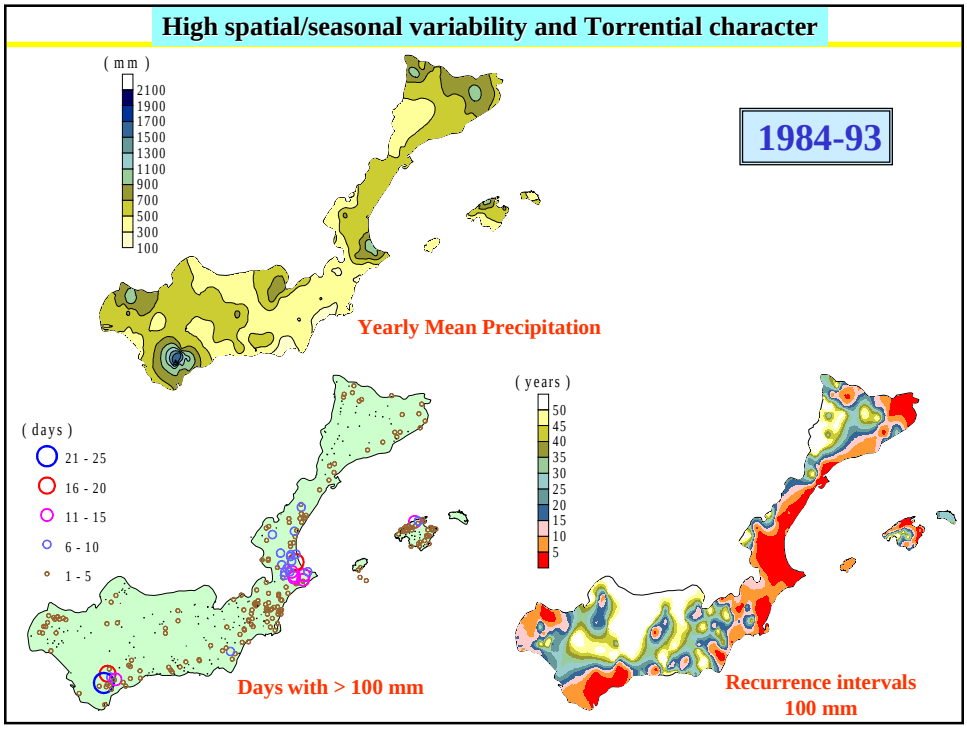
STRUCTURE

Climatology (emphasis h.p) → Daily rainfall patterns ?

Climatology (emphasis h.p) → Responsible atmospheric patterns ?

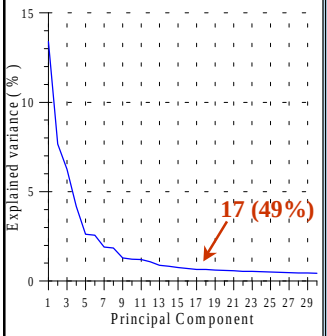
Mesoscale numerical study of two flash flood events produced by long-lived quasistationary MCSs


... MEDITERRANEAN SPAIN
(m)
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
200 km
Pyrenees
Catalonia
Valencia
Murcia
Sistema Ibérico
IBERIAN PENINSULA
Andalucía
Sistema Subbético
Sierra de Cazorla
Sierra de Aracena
Guadalquivir Valley
Sierra de Aitana
Sierra de Tramuntana
Menorca
Mallorca
Ibiza
Balearic Islands
MEDITERRANEAN SEA
ATLANTIC OCEAN
Sistema Penibético
Sierra de Ronda
Gibraltar Strait
DAILY RAINFALL DATA BASE
- Homogeneous and complete series
- 410 stations
- 30 years (1964-1993)


High spatial/seasonal variability and Torrential character
(mm)
2100
1900
1700
1500
1300
1100
900
700
500
300
100
1984-93
Yearly Mean Precipitation
(days)
21 - 25
16 - 20
11 - 15
6 - 10
1 - 5
Days with > 100 mm
(years)
50
45
40
35
30
25
20
15
10
5
Recurrence intervals 100 mm

Methodology Rainfall Patterns

		Win	Spr	Sum	Aut
Significant *rainfalls*	*5 % - 5 mm* → *3941 days*	*(30.0%*	*29.6%*	*13.6%*	*26.8%)*
Torrential *rainfalls*	*2 % - 50 mm* → *449 days*	*(35.2%*	*14.9%*	*5.1%*	*44.8%)*



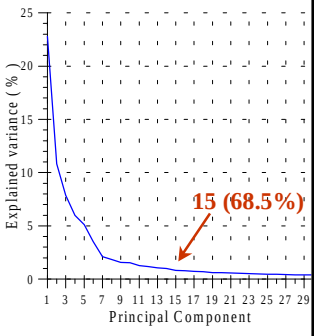
T-mode
(day-by-day)
correlation matrix

↓

Principal Components Analysis
PCA

↓

Cluster Analysis (k-means)
CA



Significant (11 RPs)

Torrential (8 RPs)

11 PGs for SIGNIFICANT rainfalls

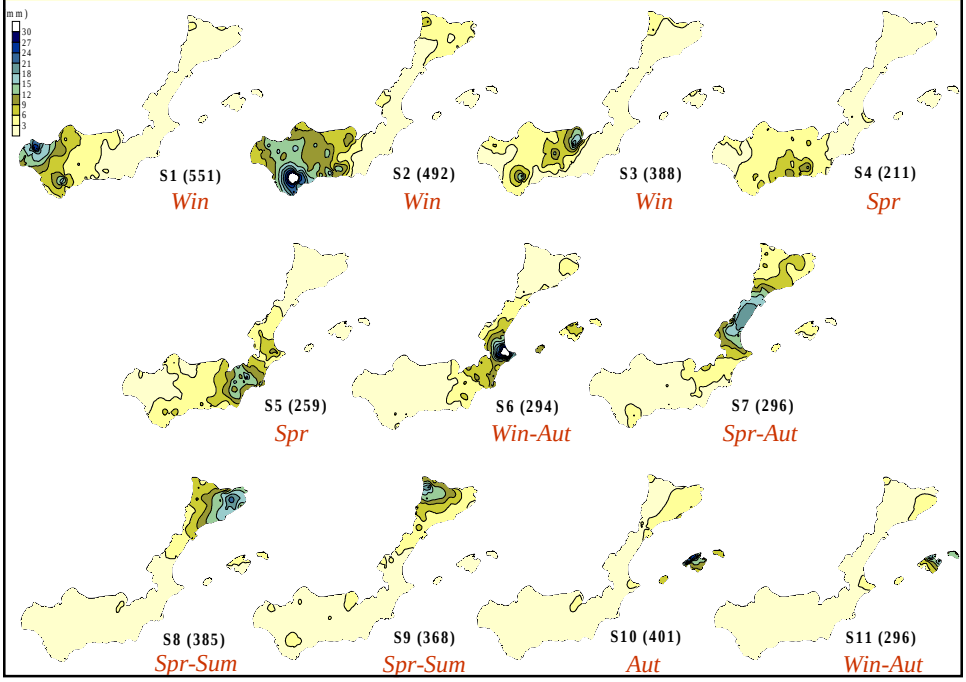
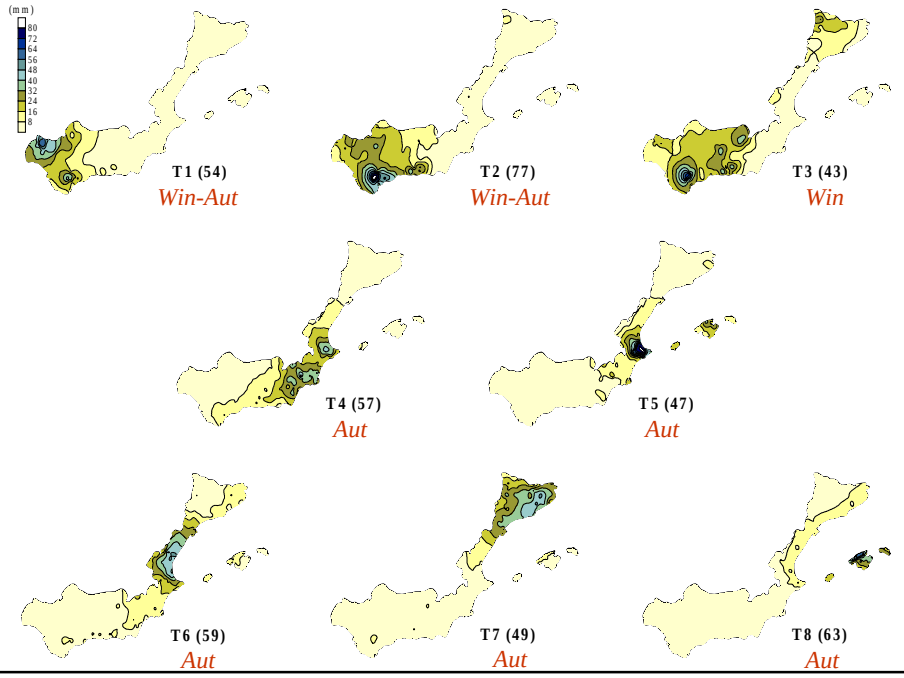
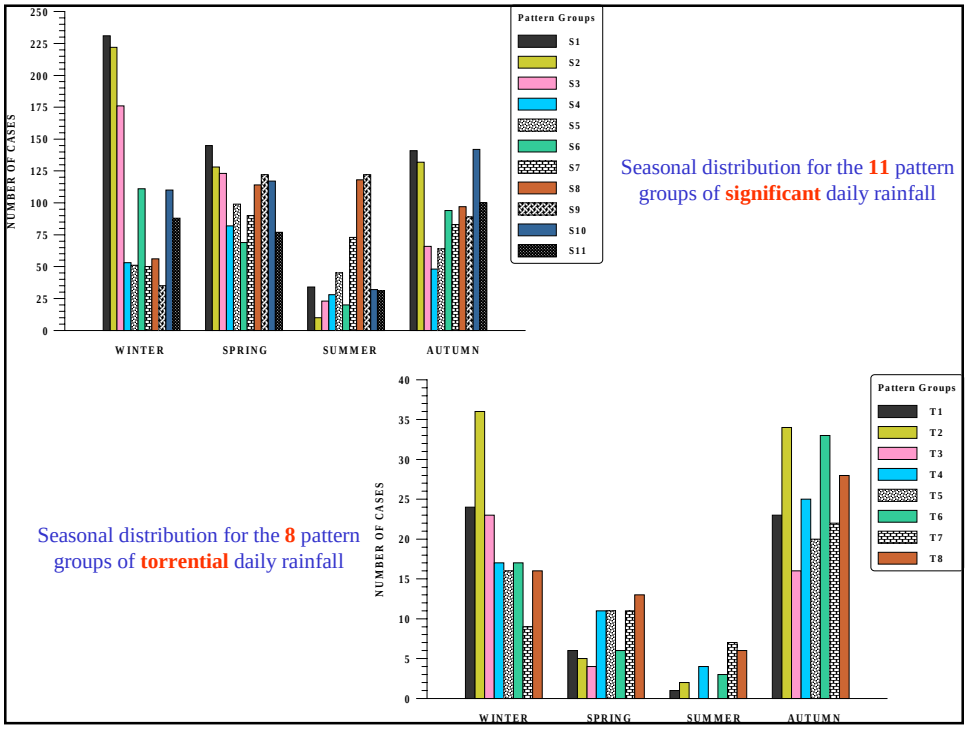


Table II. Probabilities (%) of getting the 11 significant rainfall PGs or an insignificant day (columns), conditioned to having the 11 PGs or an insignificant day (rows) on the previous day

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	INSIG
S1	21.6	26.5	8.0	3.6	3.8	1.8	3.6	3.1	9.3	2.4	1.3	15.1
S2	10.6	26.2	12.6	10.0	4.7	3.7	3.3	5.7	6.5	3.7	3.7	9.6
S3	7.0	6.2	24.7	3.4	2.8	1.0	2.3	3.6	4.1	5.9	5.2	33.8
S4	8.1	8.1	6.2	10.9	12.8	4.7	1.9	2.8	2.4	4.3	2.8	35.1
S5	3.9	4.6	1.9	11.6	18.5	11.6	9.7	3.1	2.7	3.5	2.7	26.3
S6	2.0	2.4	1.7	3.4	8.2	28.2	7.8	3.7	0.7	6.1	5.1	30.6
S7	3.7	4.1	4.4	2.7	4.4	8.8	19.9	13.9	5.4	6.4	4.1	22.3
S8	5.7	3.9	2.3	1.8	3.1	3.9	4.9	16.6	3.6	10.4	6.5	37.1
S9	5.7	3.8	6.3	2.7	0.8	1.6	7.3	11.4	15.2	4.9	1.9	38.3
S10	3.2	2.5	5.2	1.5	0.2	3.0	3.0	4.5	1.7	19.2	10.2	45.6
S11	3.0	4.1	3.4	1.4	2.4	4.4	3.4	3.4	0.3	12.8	14.5	47.0
INSIG	3.5	1.3	1.2	0.4	1.0	1.0	1.0	1.8	2.3	1.7	1.4	83.4

8 PGs for TORRENTIAL rainfalls





Seasonal distribution for the **11** pattern groups of **significant** daily rainfall

Seasonal distribution for the **8** pattern groups of **torrential** daily rainfall

CONCLUSIONS Rainfall Patterns

Extent of the region and the exposure-sheltering systems induced by the complex topography ⟶ clear regionalization of rainfalls

Significant and Torrential patterns basically equivalent

Significant
- west: winter
- east: different behaviours

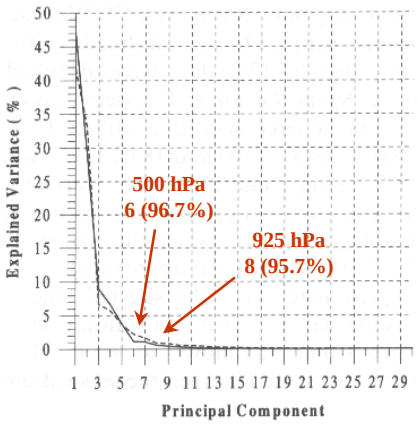
Torrential
- west: winter and autumn
- east: autumn

Methodology Atmospheric Patterns

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

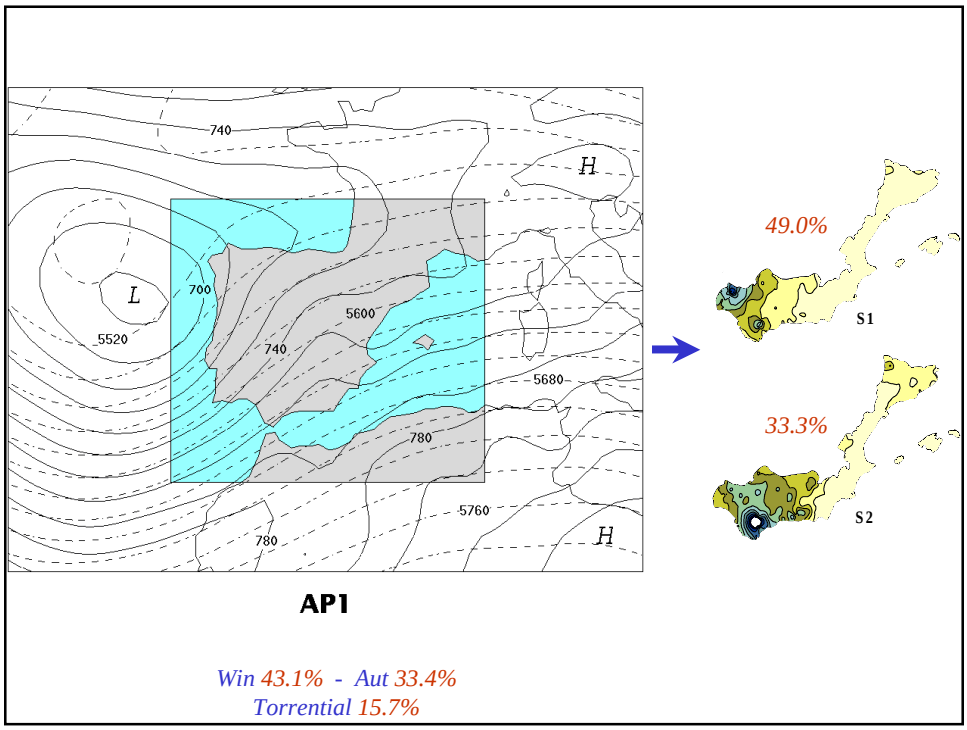
↓

Cluster Analysis (k-means)
CA

19 APs

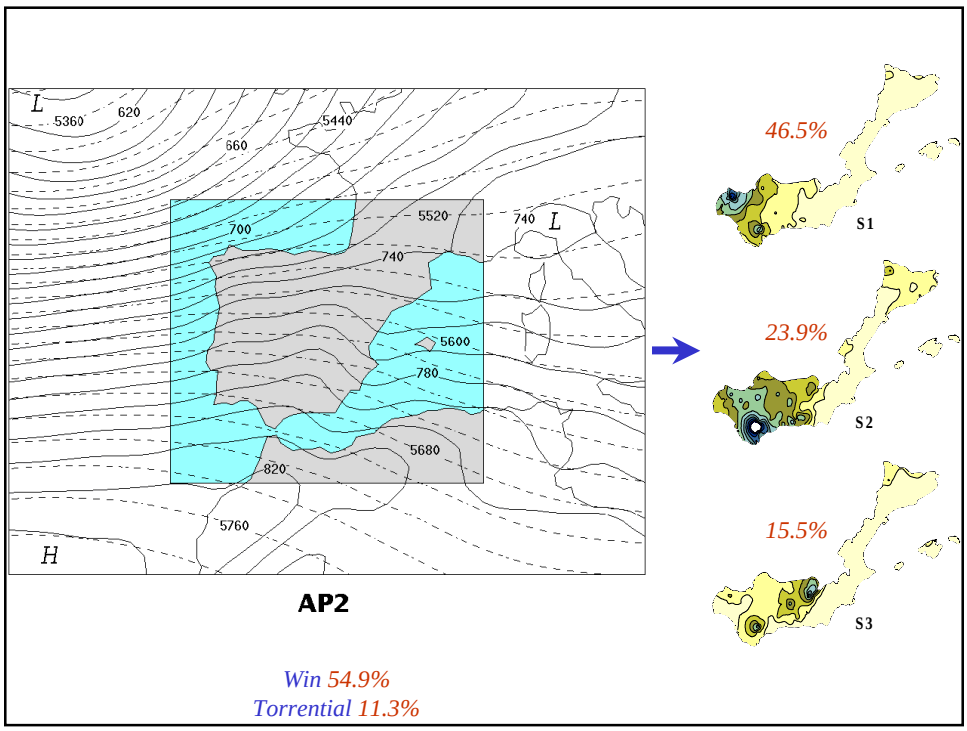
Table II. Percentage frequency of the 11 daily RPs within the 19 APs (in bold, percentages greater than 15%) and seasonal distribution of the APs (in bold, percentages greater than 30%)

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



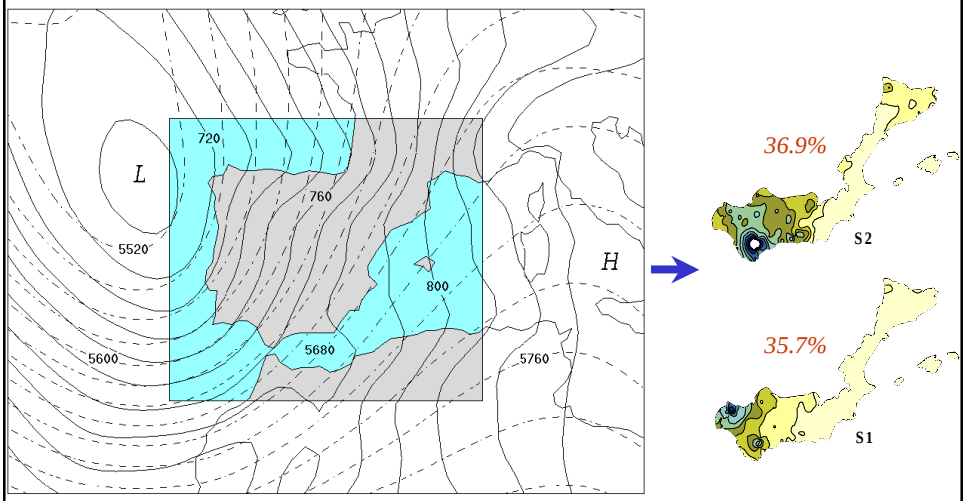
AP1

Win 43.1% - Aut 33.4%
Torrential 15.7%



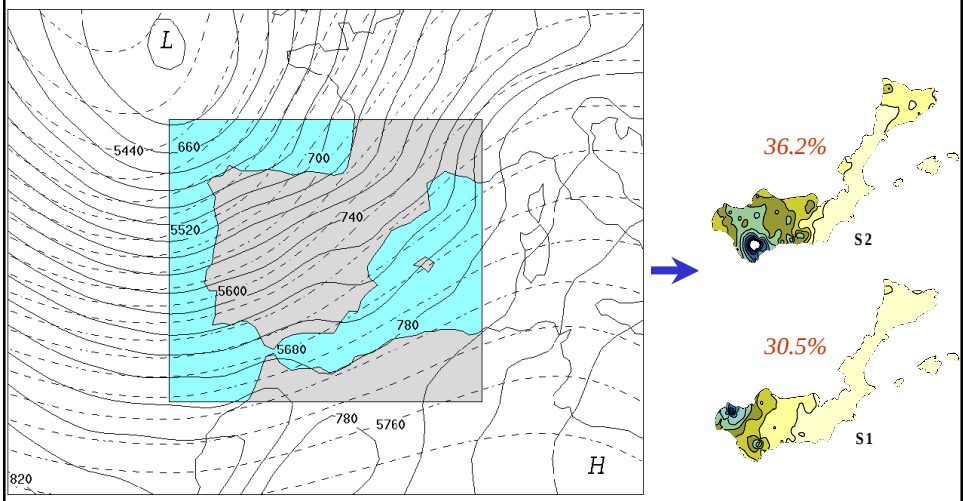
AP2

Win 54.9%
Torrential 11.3%



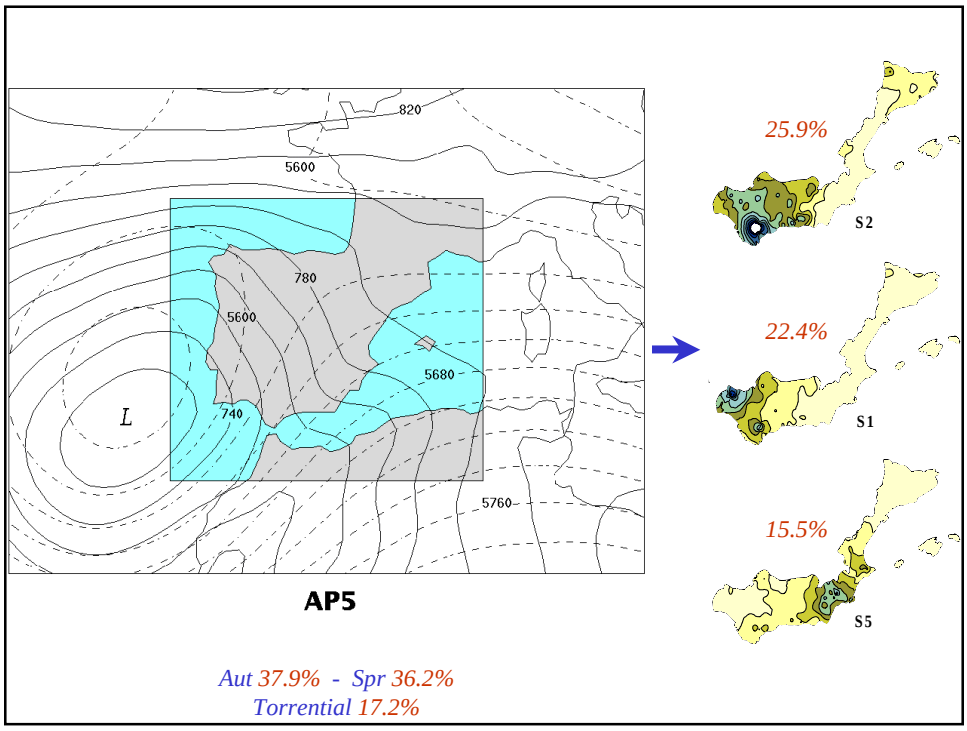
AP3

Aut 54.8%
*Torrential **25.0%***



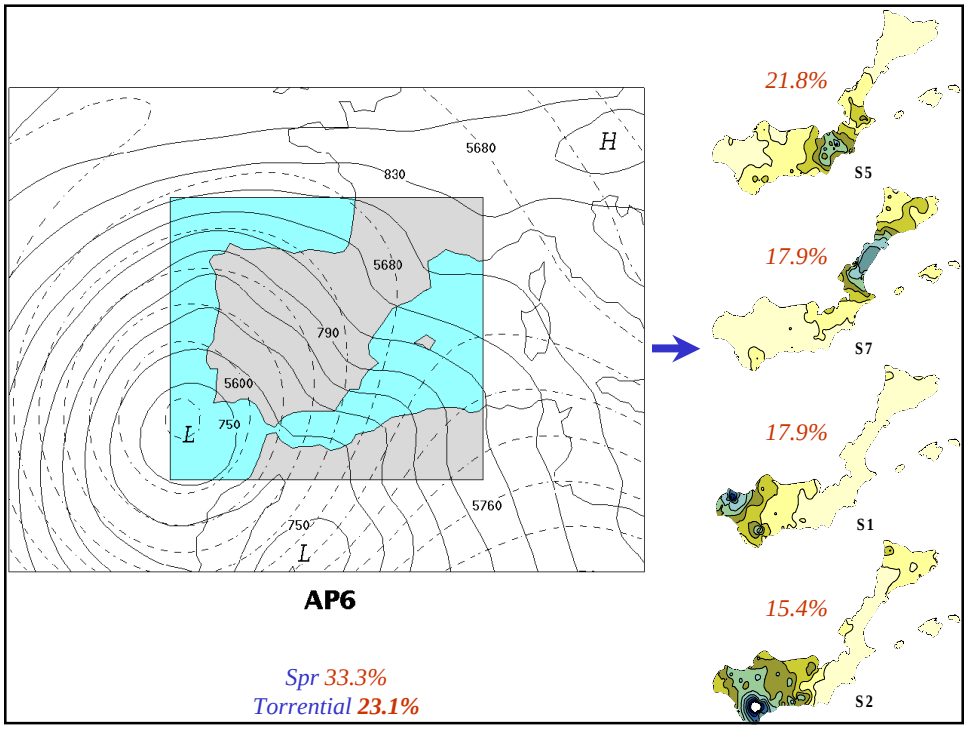
AP4

Aut 41.0%
Torrential 15.2%



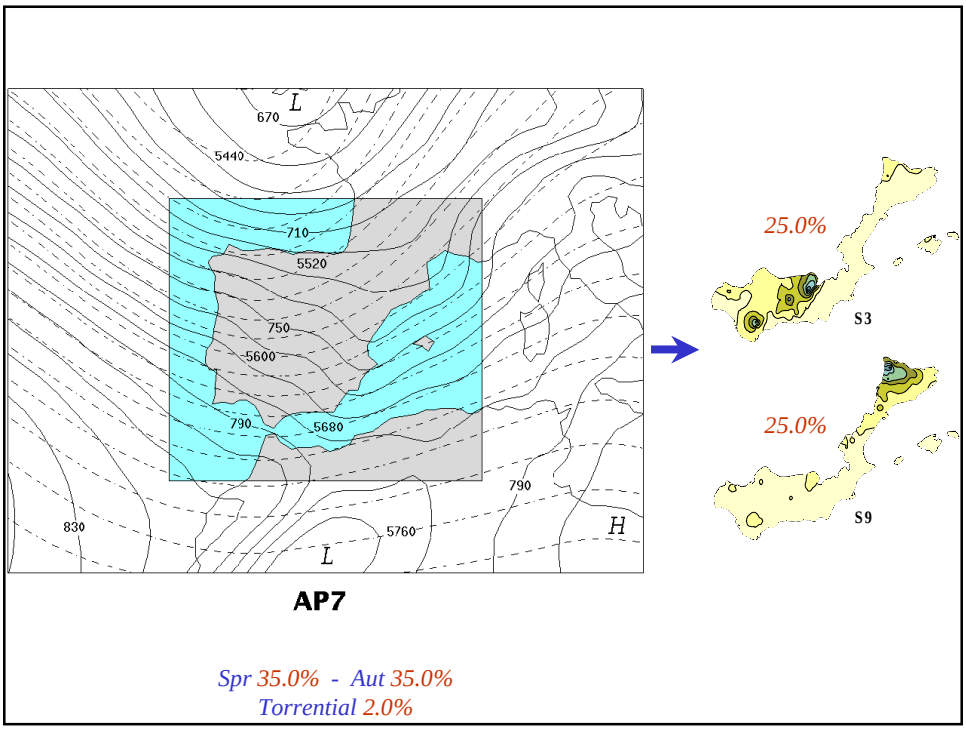
AP5

Aut 37.9% - Spr 36.2%
Torrential 17.2%



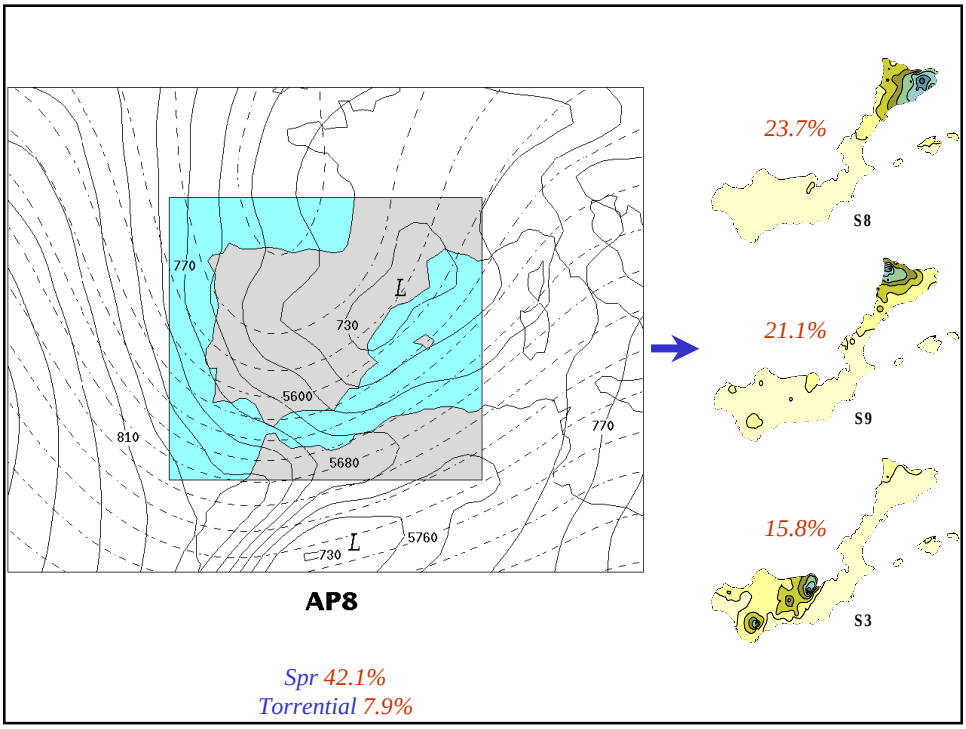
AP6

Spr 33.3%
*Torrential **23.1%***



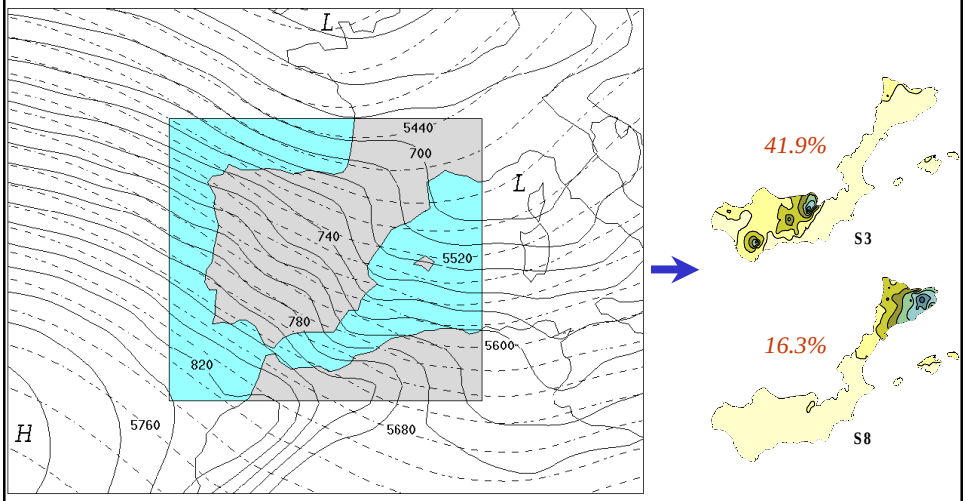
AP7

Spr 35.0% - Aut 35.0%
Torrential 2.0%



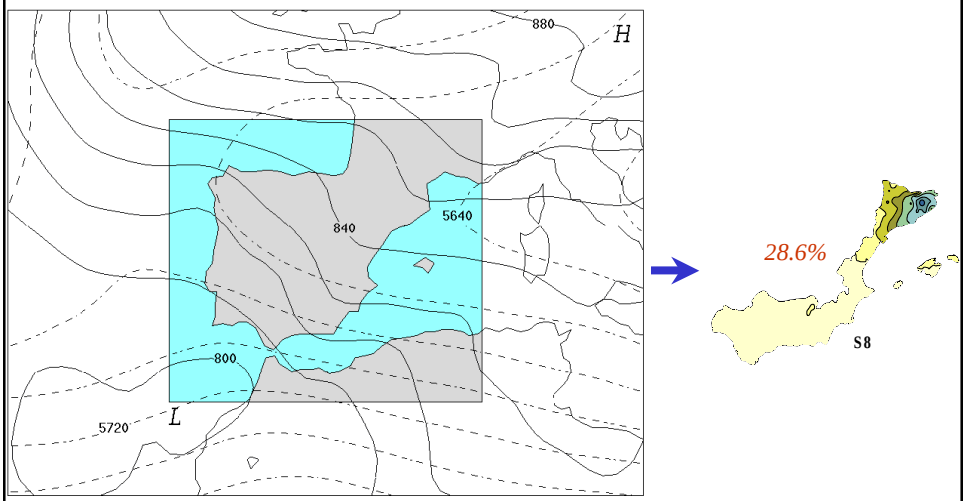
AP8

Spr 42.1%
Torrential 7.9%



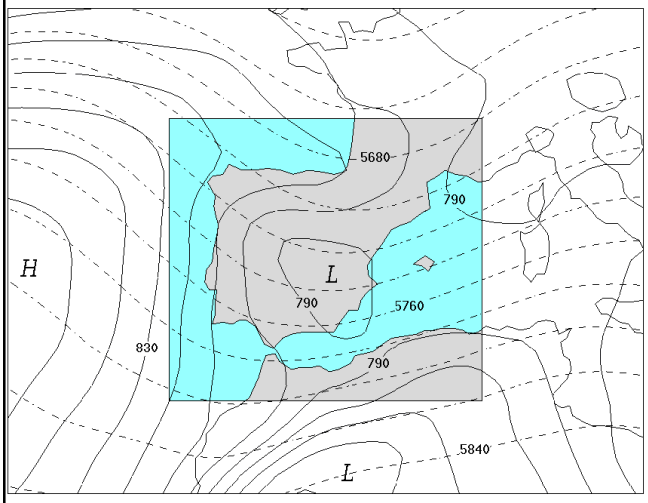
AP9

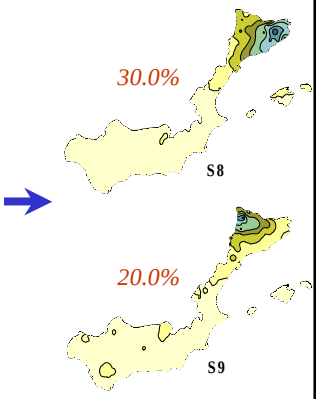
Win 45.3%
Torrential 3.5%



AP10

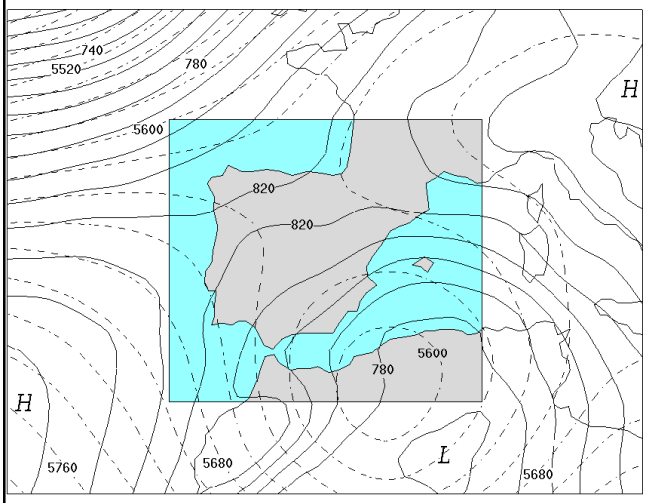
Win 46.4% - Aut 42.9%
Torrential 10.7%

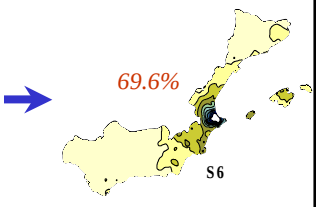




AP11

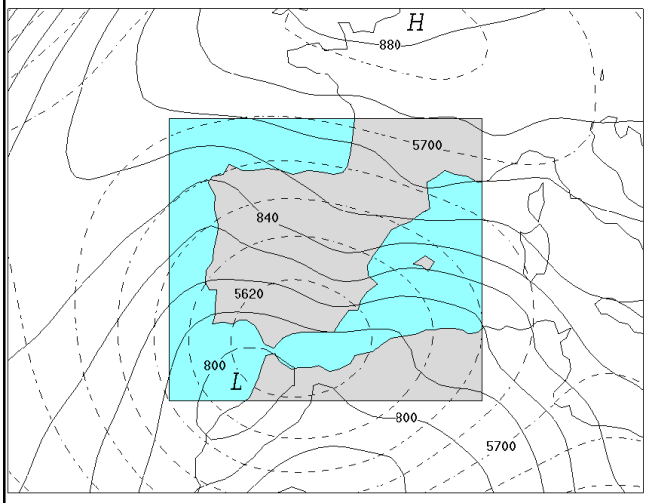
Sum 41.4% - Spr 30.0%
Torrential 0.0%

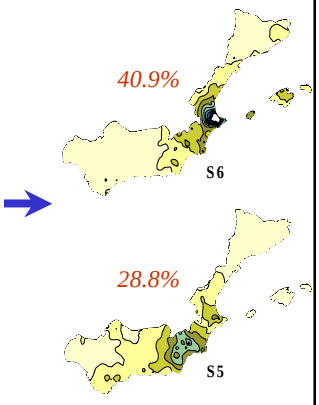




AP12

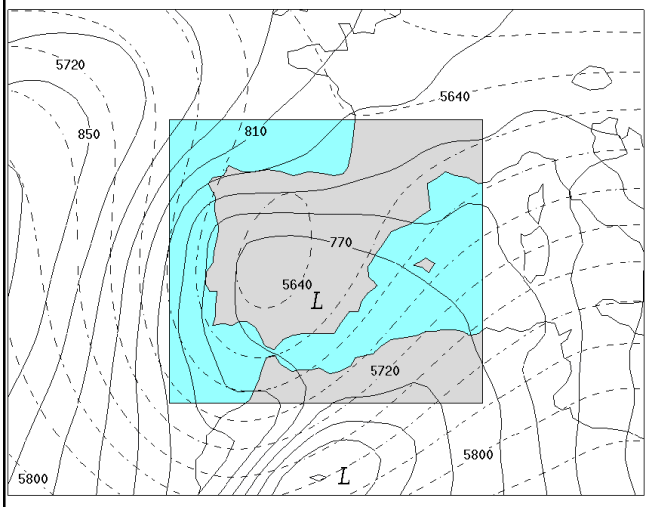
Win 47.8% - Aut 34.8%
*Torrential **21.7%***

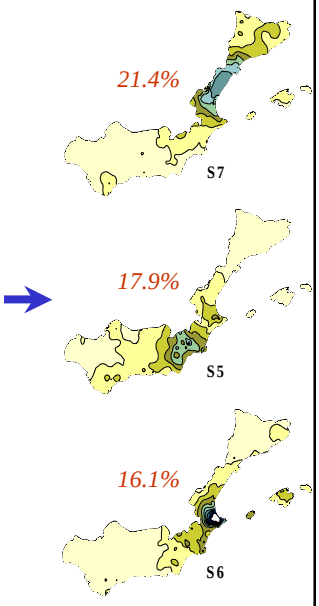




AP13

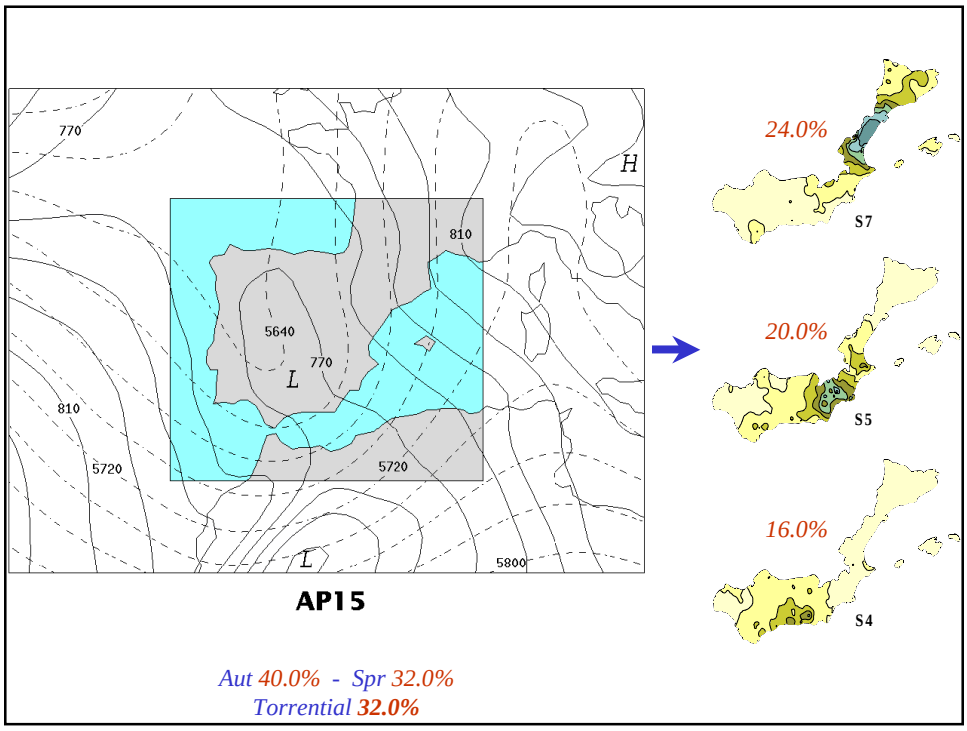
Win 53.0%
*Torrential **37.9%***





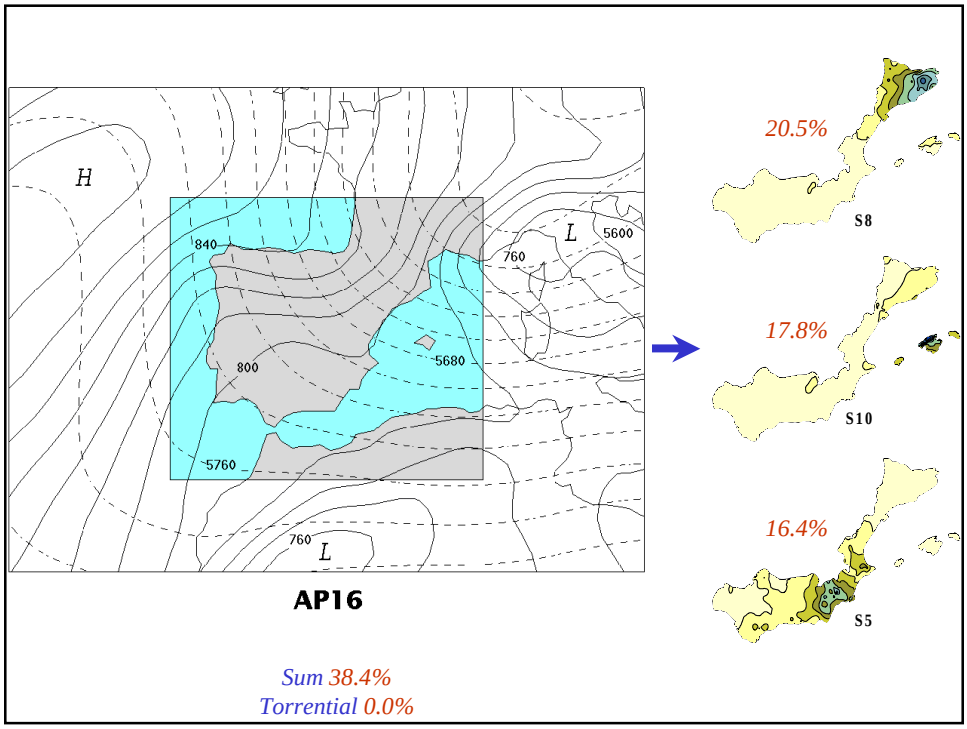
AP14

Spr 35.7% - Sum 33.9%
Torrential 19.6%



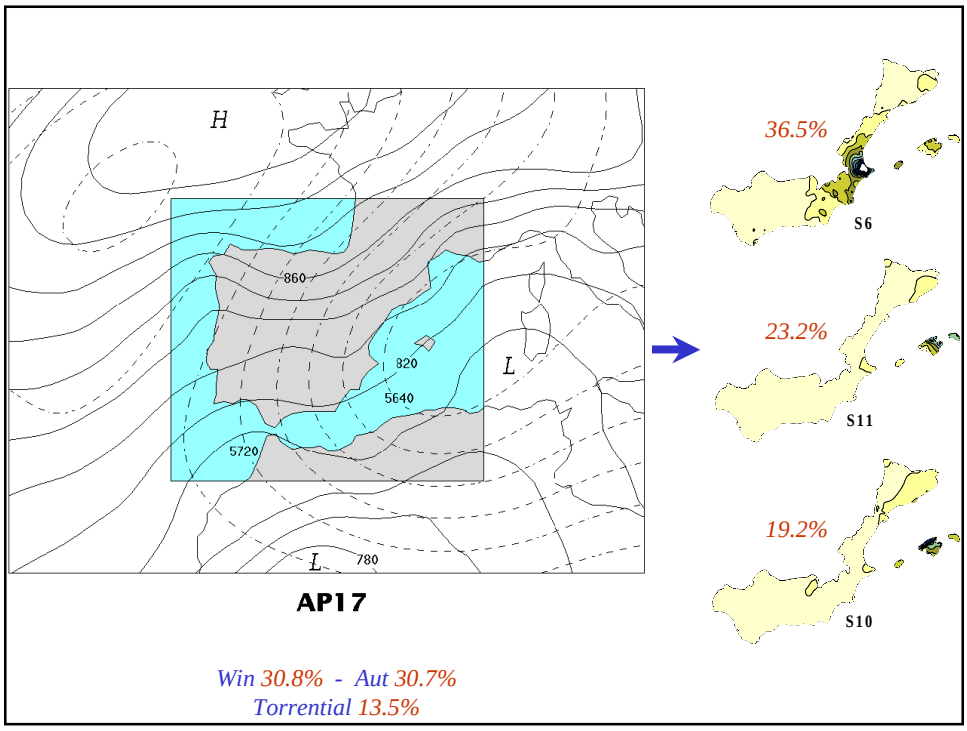
AP15

Aut 40.0% - Spr 32.0%
*Torrential **32.0%***



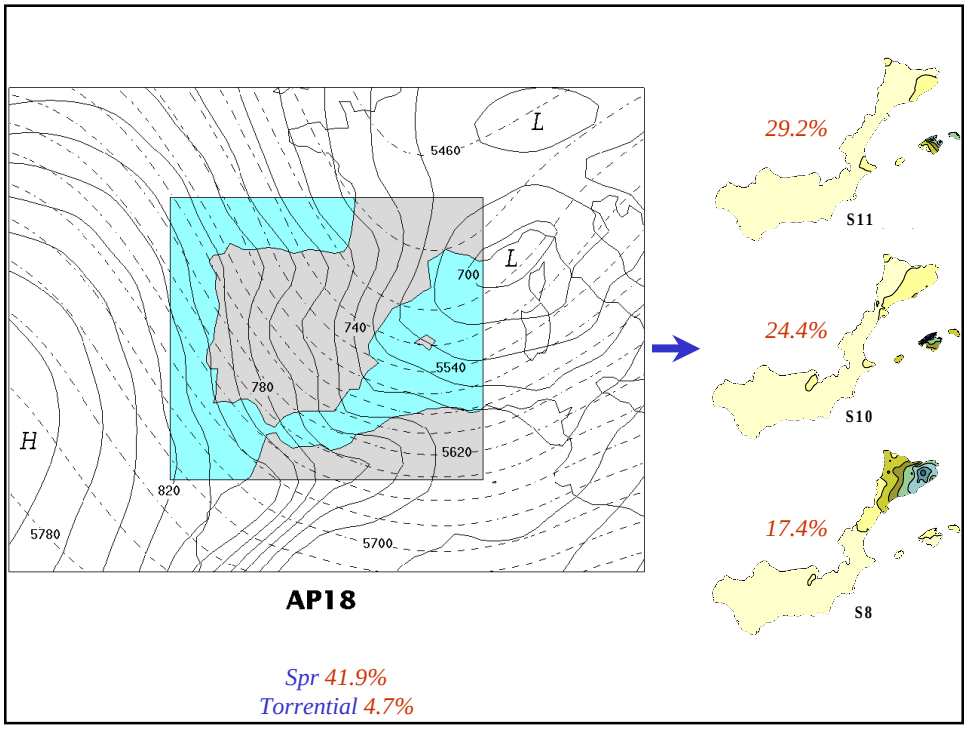
AP16

Sum 38.4%
Torrential 0.0%



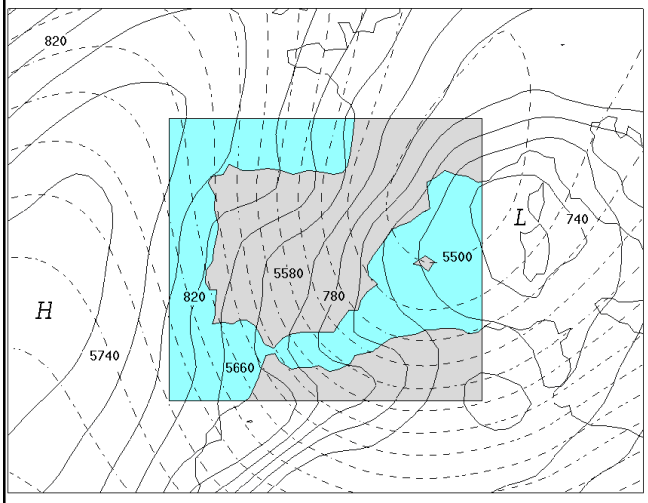
AP17

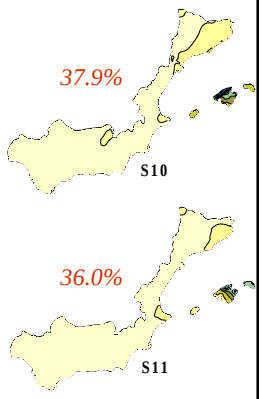
Win 30.8% - Aut 30.7%
Torrential 13.5%



AP18

Spr 41.9%
Torrential 4.7%





AP19

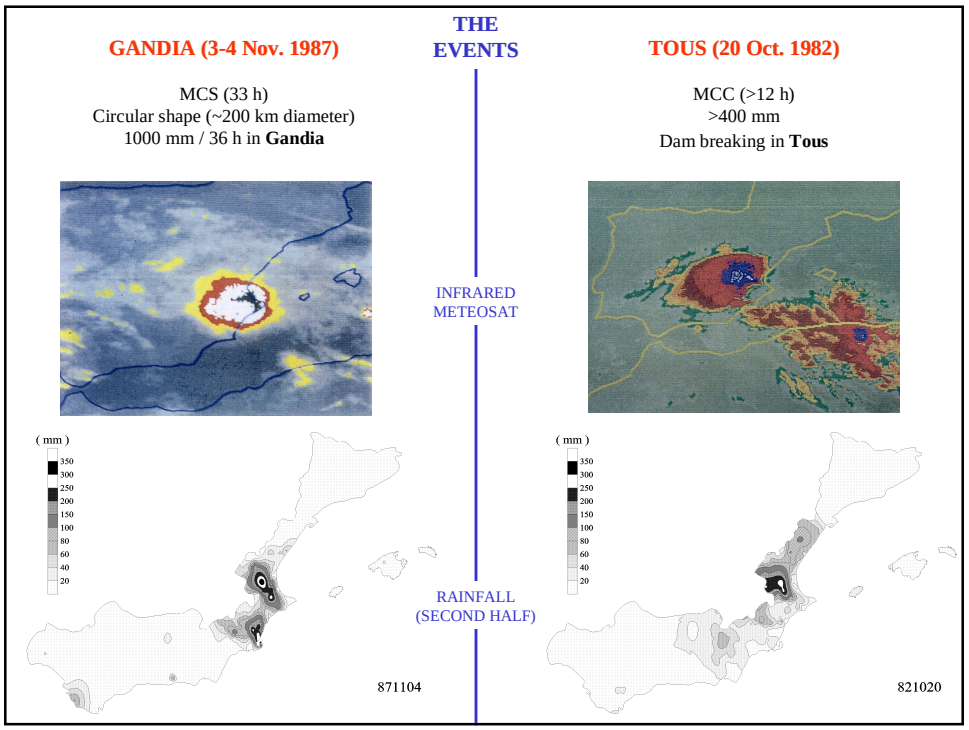
Spr 40.2% - Win 34.5%
Torrential 11.5%

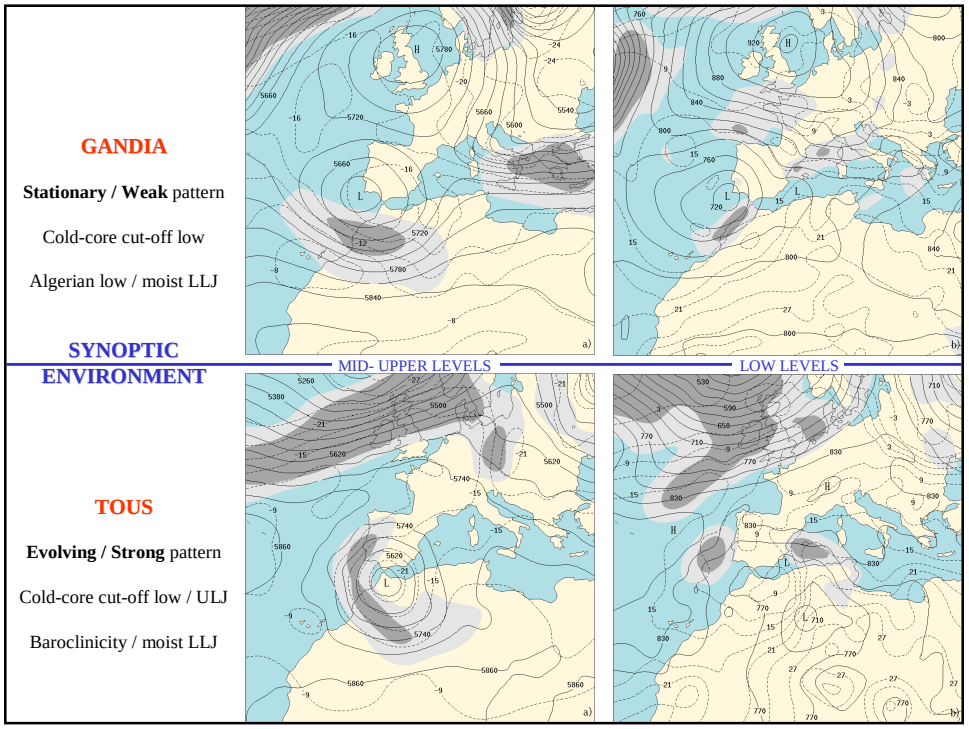
CONCLUSIONS Atmospheric Patterns

Clear, and useful, association between the 19 APs and the 11 typical RPs of the region

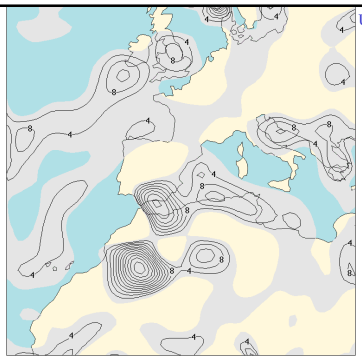
Physical interpretation straightforward in terms of the topographic enhancements under Atlantic/Mediterranean airflows and dynamic factors associated with the upper level disturbance

Torrentiality
- some APs irrelevant
- high propensity of APs characterized by disturbances located about the south of the Iberian Peninsula


THE EVENTS
GANDIA (3-4 Nov. 1987)
MCS (33 h)
Circular shape (~200 km diameter)
1000 mm / 36 h in Gandia
TOUS (20 Oct. 1982)
MCC (>12 h)
>400 mm
Dam breaking in Tous
INFRARED METEOSAT
(mm)
350
300
250
200
150
100
80
60
40
20
RAINFALL (SECOND HALF)
871104
821020

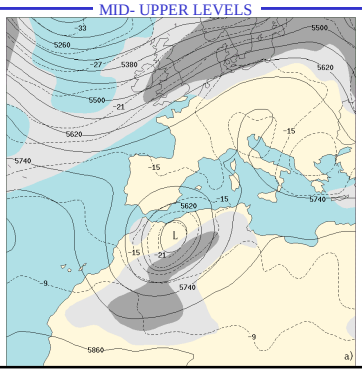

GANDIA
Stationary / Weak pattern
Cold-core cut-off low
Algerian low / moist LLJ
SYNOPTIC ENVIRONMENT
MID- UPPER LEVELS
LOW LEVELS
TOUS
Evolving / Strong pattern
Cold-core cut-off low / ULJ
Baroclinicity / moist LLJ

SYNOPTIC ENVIRONMENT

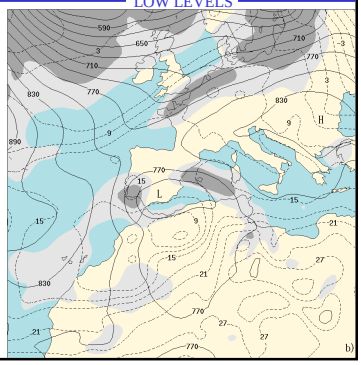


UPWARD QUASIGEOSTROPHIC FORCING 500 hPa

MID- UPPER LEVELS



LOW LEVELS



TOUS

Evolving / Strong pattern

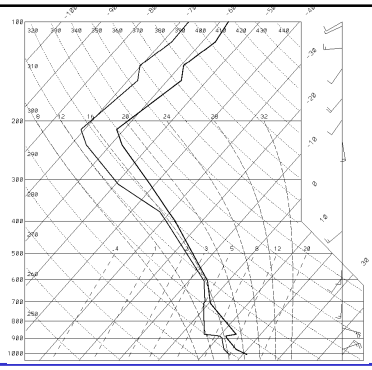
Cold-core cut-off low / ULJ

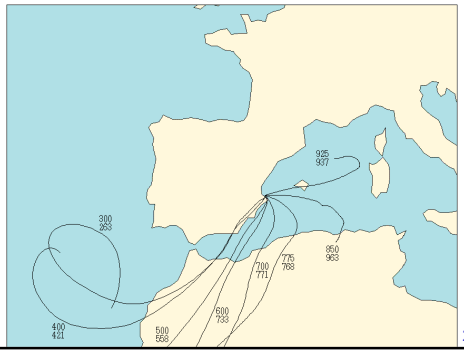
Baroclinicity / moist LLJ

PRECONVECTIVE SOUNDING

GANDIA

CAPE	909 J / kg
CIN	12 J / kg
TT	47
K	31
LI	0
PW	35 mm

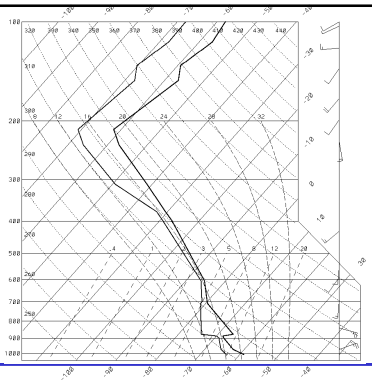




2-DAYS BACK TRAJECTORIES

GANDIA

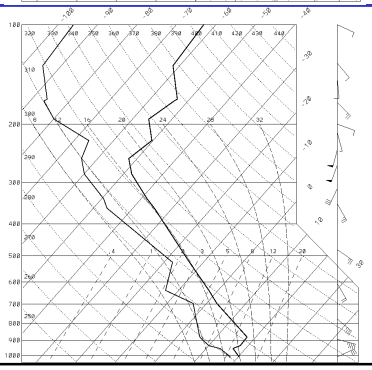
CAPE	909 J / kg
CIN	12 J / kg
TT	47
K	31
LI	0
PW	35 mm



PRECONVECTIVE SOUNDING

TOUS

CAPE	1243 J / kg
CIN	192 J / kg
TT	52
K	30
LI	-1
PW	32 mm



MESOSCALE NUMERICAL SIMULATIONS

*** PSU-NCAR mesoscale model (non-hydrostatic version MM5)**

*** Simulations:**

- 2 domains: 82x82x31 (60 and 20 km)
- Interaction: two-way
- I.C and B.C: NCEP global analysis + Surface and Upper air obs.
- GANDIA: 36 h, from 00 UTC 3 Nov. 1987
- TOUS: 24 h, from 00 UTC 20 Oct. 1982

*** Physical parameterizations:**

- PBL: Based on Blackadar (1979) scheme (Zhang and Anthes 1982)
- Ground temperature: Force-restore slab model (Blackadar 1979)
- Radiation fluxes: Considering cloud cover (Benjamin 1983)
- Explicit convection: Cloud water, rainwater, cloud ice and snow (Zhang 1989)
- Parameterized convection: Coarse: Betts-Miller (1986) / Fine: Kain-Fritsch (1990)

GANDIA

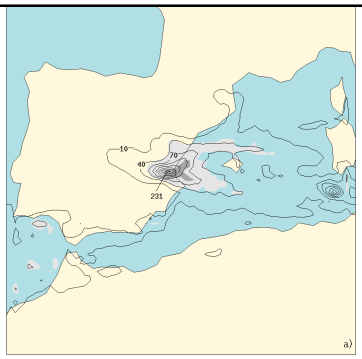
Location / Stationarity: well
QPF: underestimated

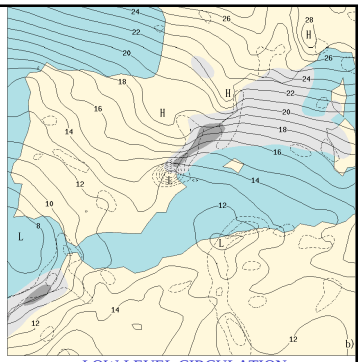
Algerian low / Mesolow
Convergence ahead of LLJ

FULL SIMULATION

PRECIPITATION

LOW-LEVEL CIRCULATION

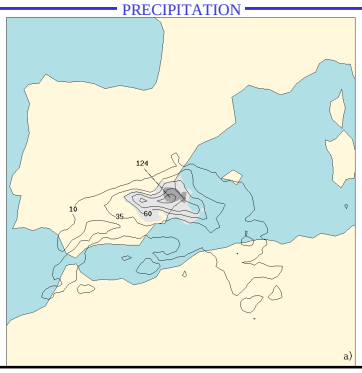


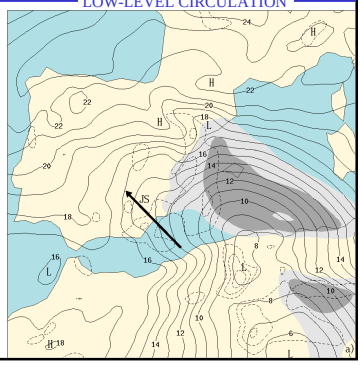


TOUS

Location / Stationarity: well
QPF: underestimated

Westward-moving low / ULJ
Embedded mesolow
Convergence over SE Spain





GANDIA

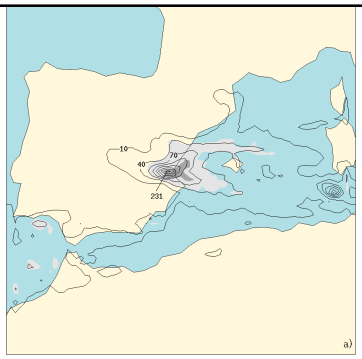
Location / Stationarity: well
QPF: underestimated

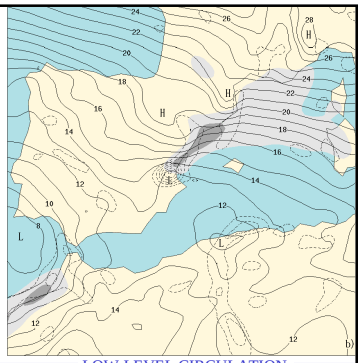
Algerian low / Mesolow
Convergence ahead of LLJ

FULL SIMULATION

PRECIPITATION

LOW-LEVEL CIRCULATION





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Westward-moving low / ULJ
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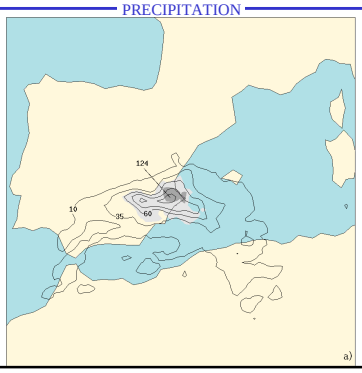
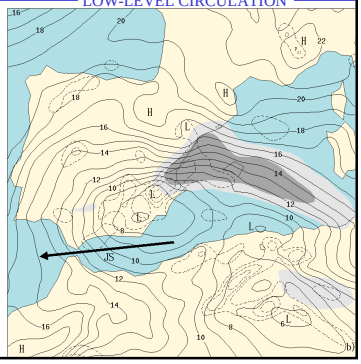




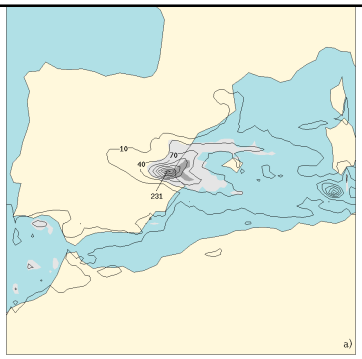
GANDIA

Location / Stationarity: well
QPF: underestimated

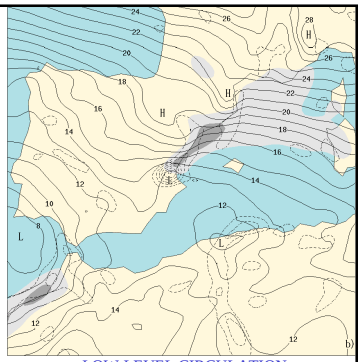
Algerian low / Mesolow
Convergence ahead of LLJ

FULL SIMULATION

PRECIPITATION



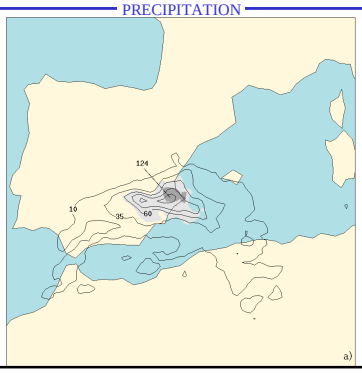
LOW-LEVEL CIRCULATION

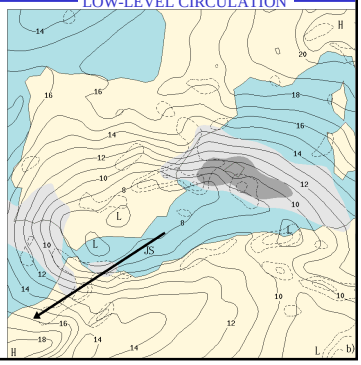


TOUS

Location / Stationarity: well
QPF: underestimated

Westward-moving low / ULJ
Embedded mesolow
Convergence over SE Spain



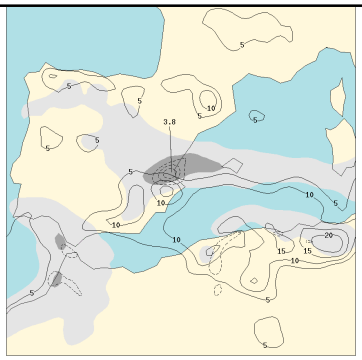


GANDIA

Strong WV flux convergence
Boundary of instability
E-W elongated moist tongue

FULL SIMULATION

WV FLUX CONV. / CONVECT. INST. / PW

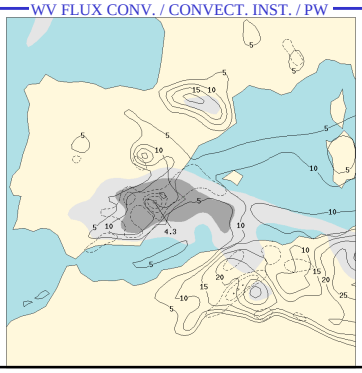


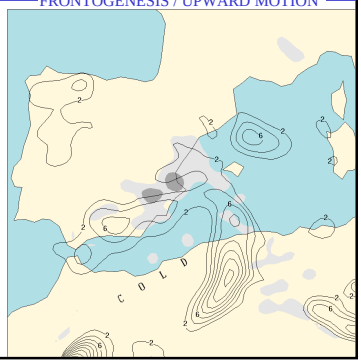
FRONTOGENESIS / UPWARD MOTION

TOUS

Strong WV flux convergence
Convective instability
High values of PW

Frontogenetic action
Upward motion in response





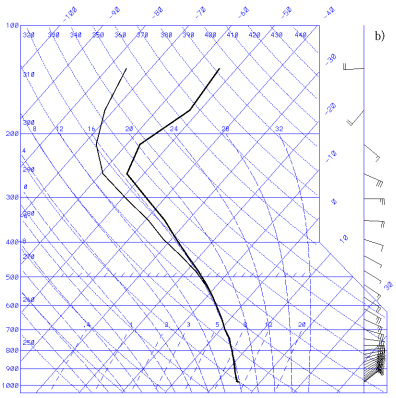
FULL SIMULATION

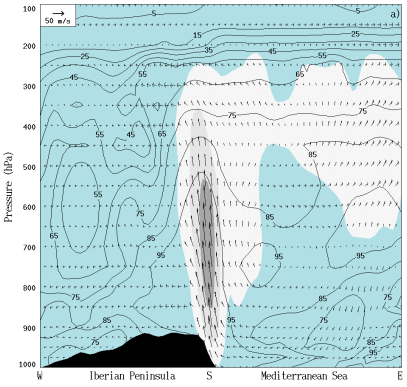
GANDIA

Coastal plume of moist, ascending air
Precipitation efficiency / Mesolow
Explicit convection

Local orography ⟶ 60% precipitation

MODEL SOUNDING AT S





W-E CROSS SECTION
(CIRCULATION / RELATIVE HUMIDITY)

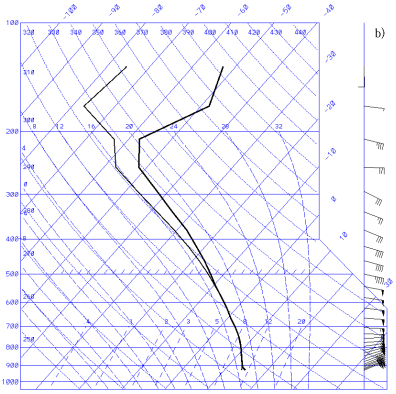
FULL SIMULATION

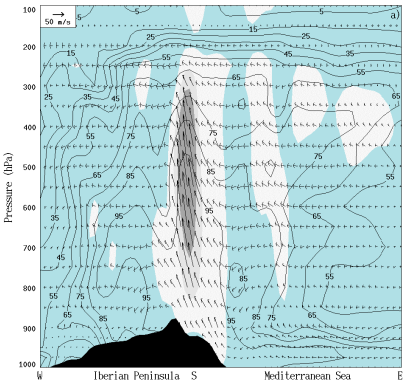
TOUS

Deep plume of moist, ascending air / Dynamic forcing
Precipitation efficiency / Mesolow
Explicit convection

Local orography ⟶ 30% precipitation

MODEL SOUNDING AT S





W-E CROSS SECTION
(CIRCULATION / RELATIVE HUMIDITY)

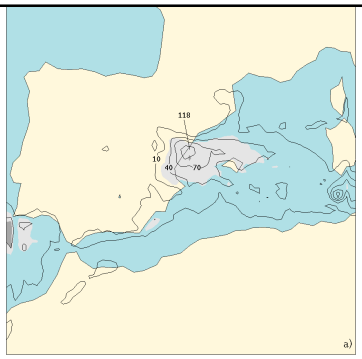
GANDIA

Rainfall suppression
No inland peak

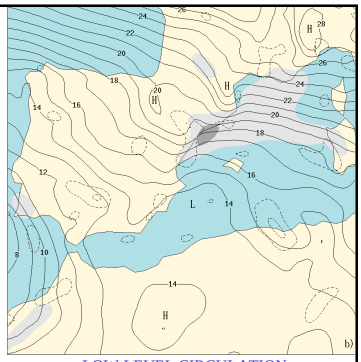
SLP appreciably modified
Less convergence / Shift LLJ

NO ATLAS
NO LATENT HEAT

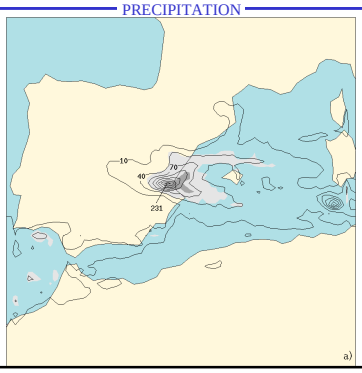
FULL SIMULATION

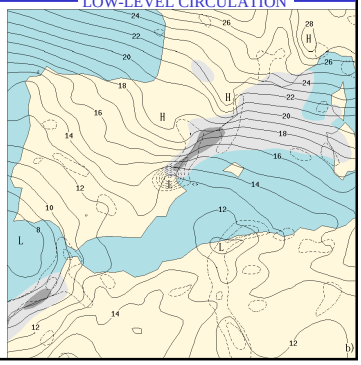


PRECIPITATION

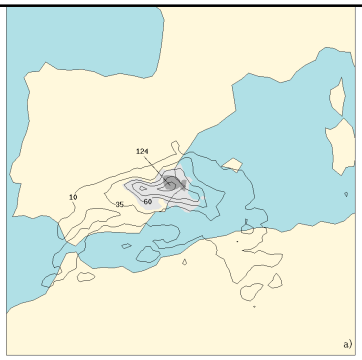


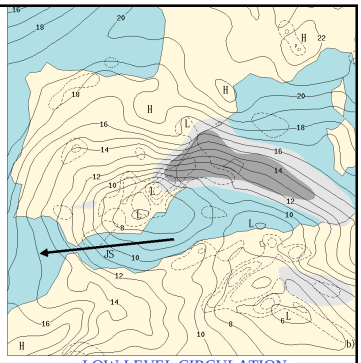
LOW-LEVEL CIRCULATION





FULL SIMULATION





NO ATLAS
NO LATENT HEAT

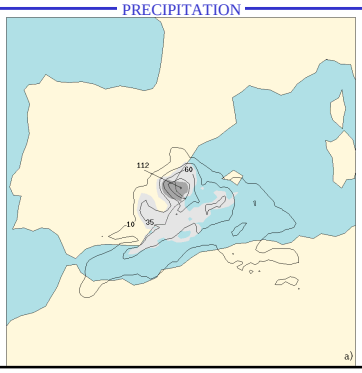
PRECIPITATION

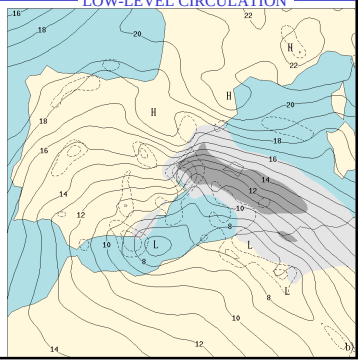
LOW-LEVEL CIRCULATION

TOUS

Rainfall suppression
No inland structure

SLP appreciably modified
Shift Low / LLJ
Weak convergence SE Spain





FACTOR SEPARATION STUDY

Method of Stein and Alpert (1993)

n factors → **2^n simulations**

Experiment	Atlas orography	Latent heat exchange
F_0	no	no
F_1	yes	no
F_2	no	yes
F_{12}	yes	yes

a. Effect of the Atlas Mountains = $F_1 - F_0$

b. Effect of the Latent heat = $F_2 - F_0$

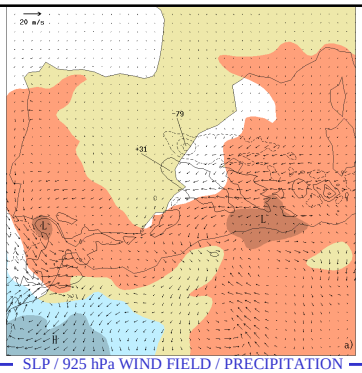
c. Effect of the interaction Atlas/Latent heat = $F_{12} - (F_1+F_2) + F_0$

GANDIA

Extensive pressure decrease over the Mediterranean

Cyclogenesis / Enhancement of easterlies and convergence

Southward shift of the rainfall activity



SLP / 925 hPa WIND FIELD / PRECIPITATION

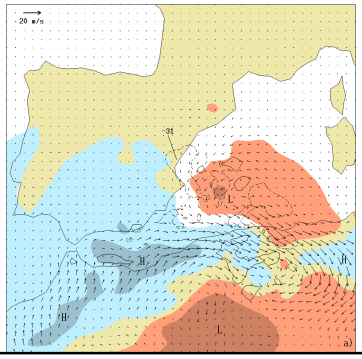
EFFECT
ATLAS MOUNTAINS

TOUS

Pressure decrease limited to the east of the Balearics

Northerly winds and offshore outflows over eastern Spain

General rainfall suppression



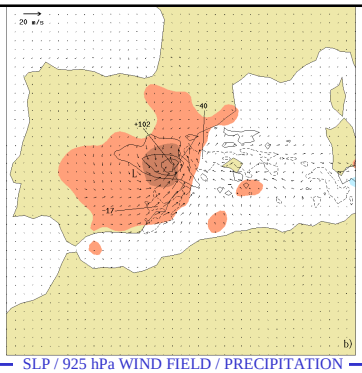
GANDIA

Mesolow over eastern Spain

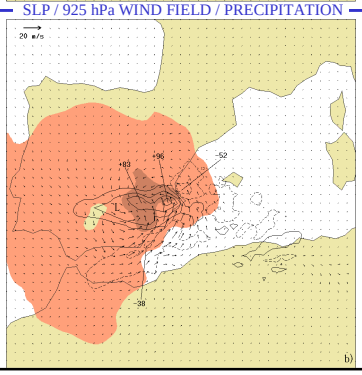
Intense mesoscale cyclonic circulation / strong convergence

Focusing of rainfall over central Valencia

EFFECT
LATENT HEAT



SLP / 925 hPa WIND FIELD / PRECIPITATION



TOUS

Mesolow over southeastern Spain

Intense vortex / strong convergence line

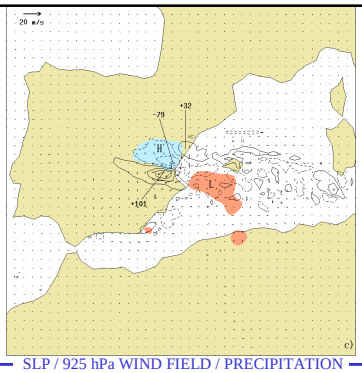
Substantial rainfall enhancement (elongated structure)

GANDIA

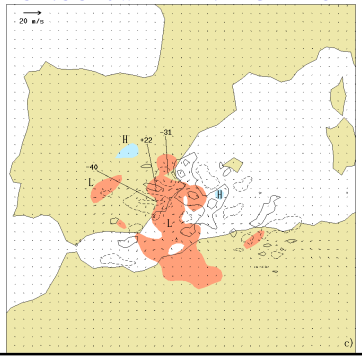
Complex pattern in space and time

Southward shift of the rainfall activity

EFFECT
ATLAS MOUNTAINS / LATENT HEAT



SLP / 925 hPa WIND FIELD / PRECIPITATION



TOUS

Complex pattern in space and time

General rainfall suppression over land

CONCLUSIONS Mesoscale Study

*** Synoptic-scale similarities, but also unique characteristics:**
- Gandia: Long-lasting and dynamically weak context
- Tous: Relatively strong dynamic forcing and baroclinicity

*** Stationary character of the MCSs linked to:**
- Gandia: Stagnancy of the large-scale pattern
- Tous: Westward-moving disturbance

*** Mesoscale models represent a valuable forecasting tool:**
- Location and Stationarity: Good guidance (Topography !!!)
- QPF: Underestimates (Deep convection !!!)

*** Atlas mountains:**
- Gandia: Modulation by lee cyclogenesis (fits conceptual model)
- Tous: Irrelevant or even negative (exception '' '')

*** Latent heat:**
- Gandia: Strongly positive interaction
- Tous: '' '' ''