POSIBLE MODIFICACIÓN DEL RÉGIMEN PLUVIOMÉTRICO EN LA ZONA MEDITERRÁNEA A CAUSA DEL CAMBIO CLIMÁTICO

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An estimate of the effects of climate change on the rainfall of Mediterranean Spain by the late twenty first century

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Abstract The study uses a GCM (ECHAM-OPYC3) and the association between the atmospheric circulation at 925 and 500 hPa and the distribution of daily precipitation for Mediterranean Spain (from earlier analyses) to give estimates of the probable annual precipitation for the late twenty first century. A downscaling technique is used which involves the matching of daily circulation output from the model for a sequence of years in the late twentieth century (1971–90) and for a corresponding period in the late twenty first century (2080–99) to derive probable regional atmospheric pattern (AP) frequencies for this latter period, and thence to estimate likely changes in annual precipitation. Model days are classified by searching for the closest analogue westerly type situations. The study utilises a 'moving window' technique in an attempt to derive measures of inter-decadal variability within the two 20 year periods. This avoids use of data from outside the periods, which would incorporate changing AP frequencies during a period of sustained climate change. Quite pronounced changes in frequency are indicated for certain APs. Marked decreases in frequency are indicated for many near-surface circulations with a westerly or northerly component. For APs with an easterly component, some are shown to increase, others to decrease. Increases in inter-decadal variability are strongly indicated for most APs, though for some easterly situations there is no clear signal. A significant annual precipitation reduction of

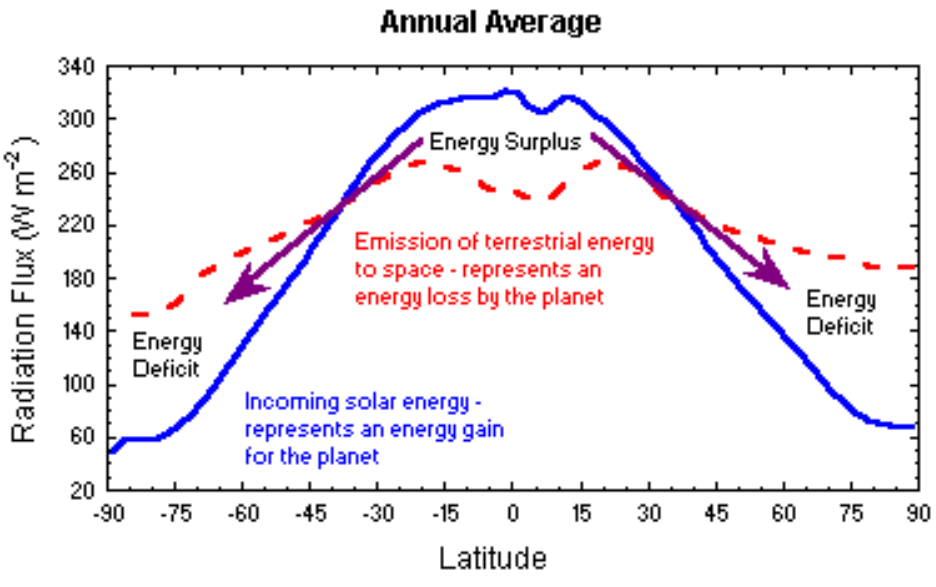
ESQUEMA DE LA PRESENTACIÓN

- La problemática del cambio climático y su regionalización
- Trabajos previos en los que se basa el estudio
- Metodología
- Resultados: Precipitación a final de siglo y su variabilidad

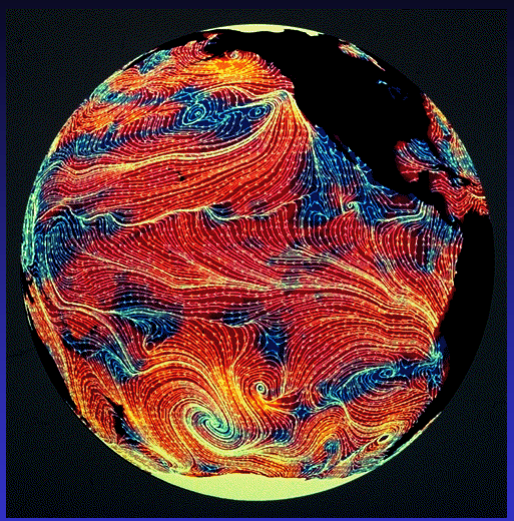
Clima:

Rasgos característicos de las condiciones ambientales
(temperatura y precipitación)
en intervalos de tiempo 'largos'

- No sólo valores medios: variabilidad espacial y temporal
- Percepción a través de la atmósfera
- Tratamiento estadístico adecuado de series largas instrumentales de las variables meteorológicas

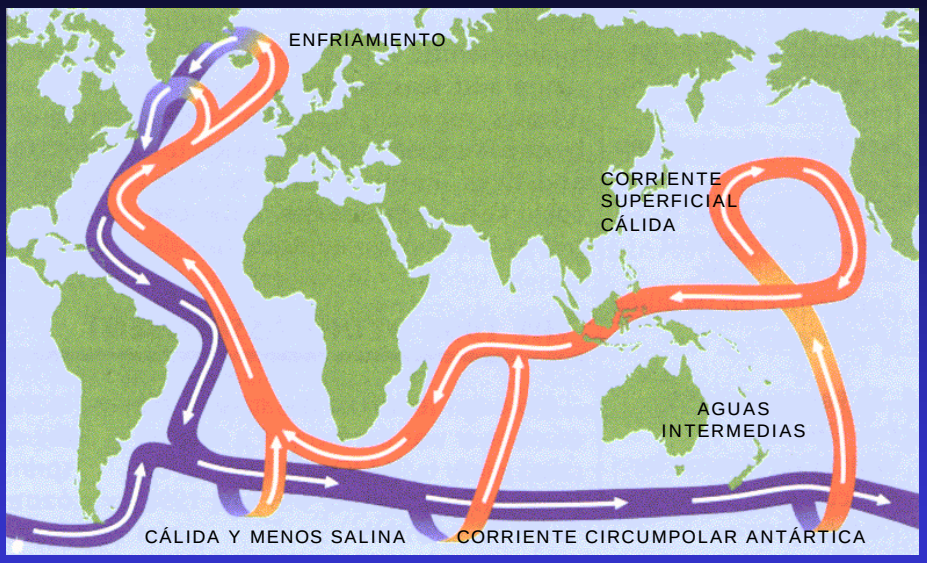


En latitudes bajas hay un exceso de energía y un déficit en las altas, que debe tender a reducirse



Vientos sobre el Océano Pacífico

CIRCULACIÓN OCEÁNICA GLOBAL



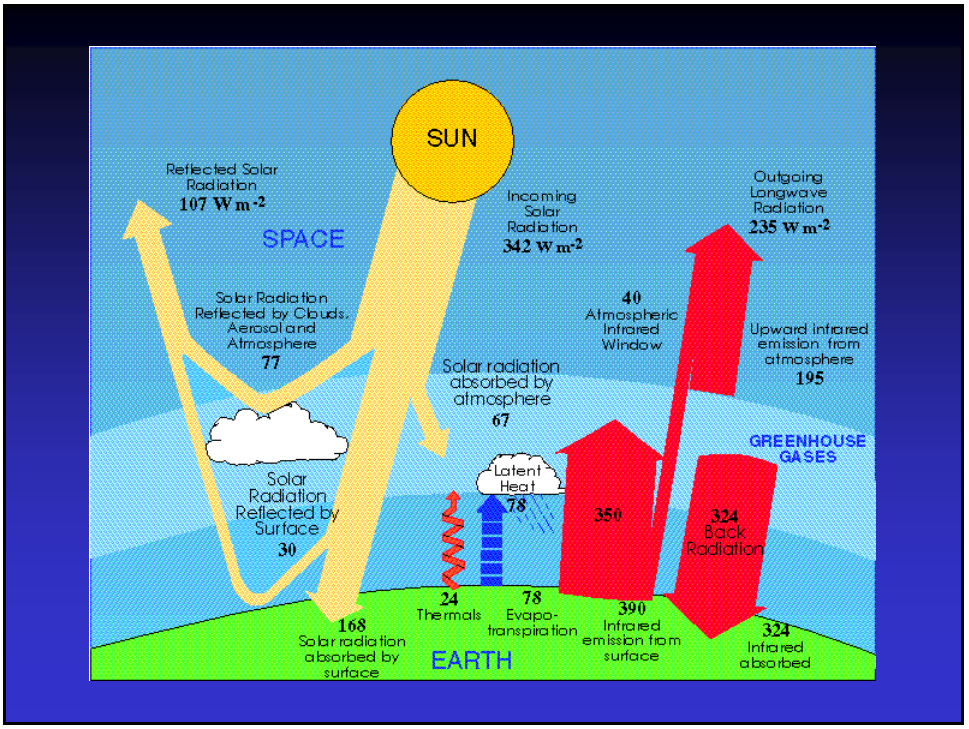
Hadley Centre

Met Office

Son muchas las

Causas que determinan el clima

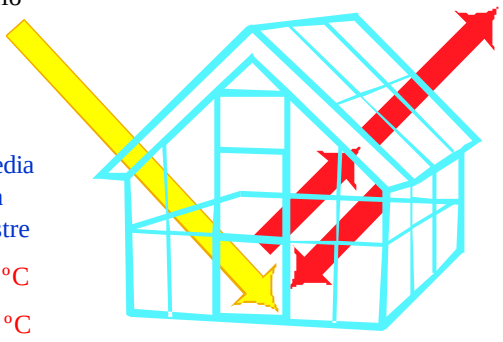
Cualquier cambio en ellas puede acabar modificando el clima



EFECTO INVERNADERO

La energía visible procedente del sol pasa a través del cristal y calienta el suelo

La energía calorífia procedente del suelo es parcialmente reflejada por el cristal y parte queda atrapada dentro del invernadero



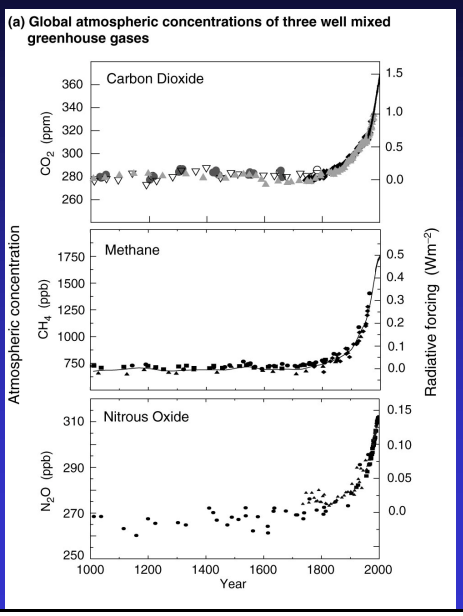
Temperatura media del aire en la superficie terrestre

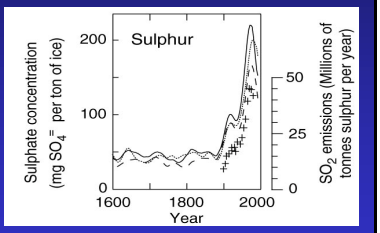
SIN E. I. = -18 ºC

CON E. I. = 15 ºC

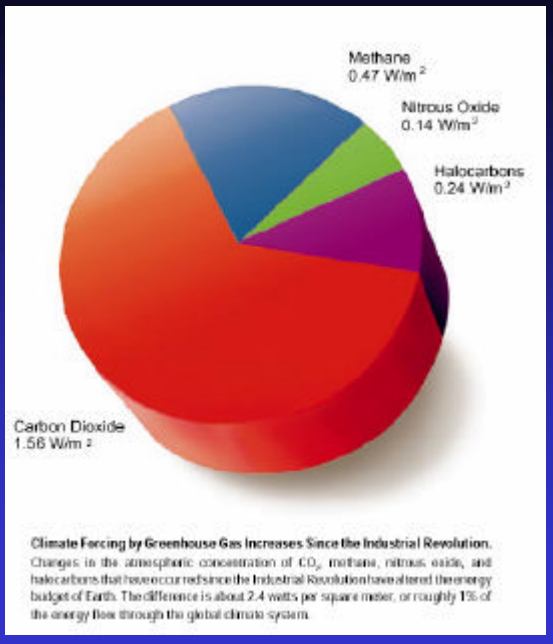
Hadley Centre

La composición de nuestra atmósfera ha cambiado afectando al balance planetario de energía

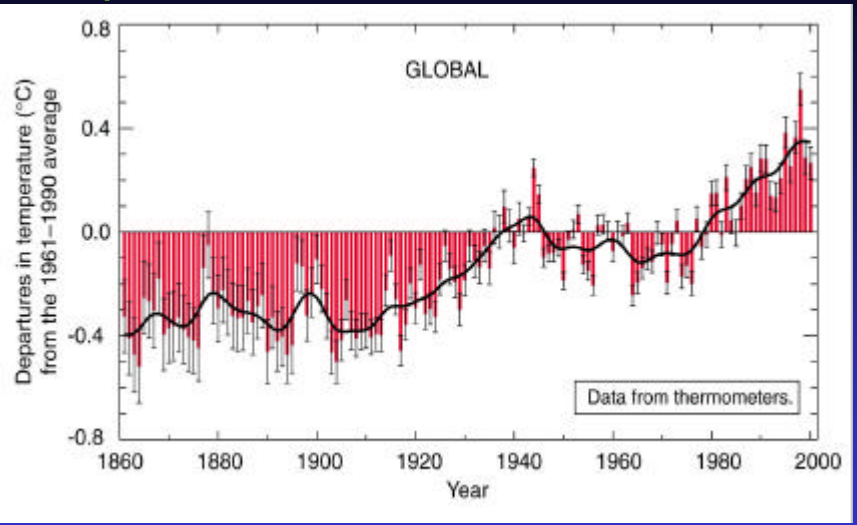




Contribución al calentamiento global



Variaciones de la temperatura media del aire en la superficie de la Tierra en los últimos 140 años



En el siglo XX entre 0.4 y 0.8 ºC.
Probablemente el calentamiento mas intenso de los últimos 1000 años en el HN

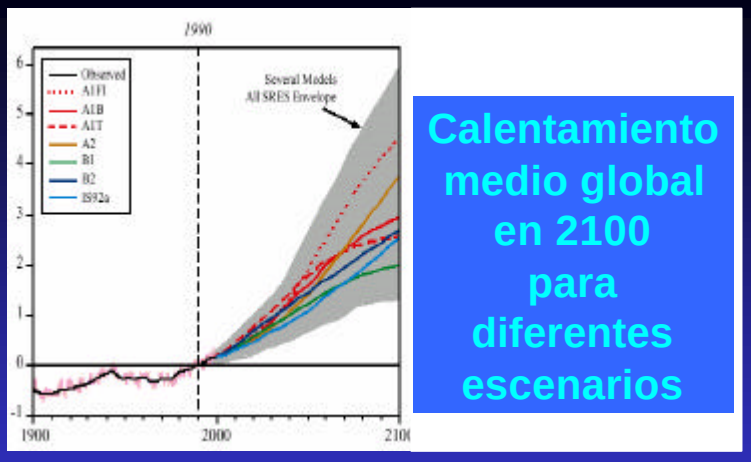
Hadley Centre

Met Office

Escenarios de cambio climático global

Escenarios de Emisiones (IPCC)

Escenario	2020 CO_2 ppm	2050 CO_2 ppm	2080 CO_2 ppm
B1-bajo	421	479	532
B2-medio	429	492	561
A1-medio	448	555	646
A2-alto	440	559	721



°C

Año

Calentamiento medio global en 2100 para diferentes escenarios

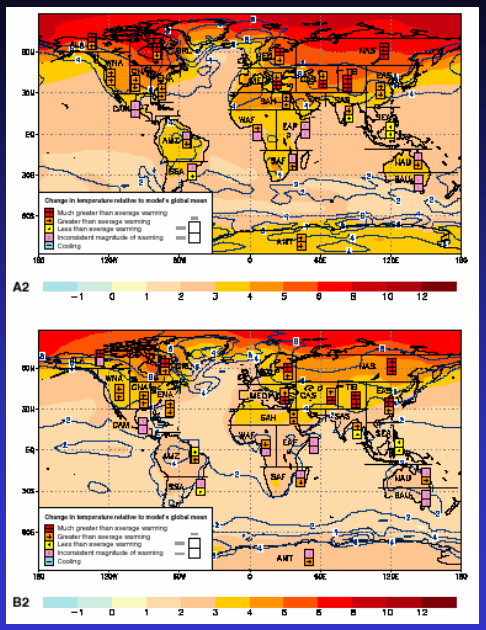
Calentamiento entre 2 y 15 veces lo observado en los 100 últimos años y posiblemente en más de 10000 años

Temperatura

2071-2100 desde 1961-1990

Muy desigual distribución geográfica

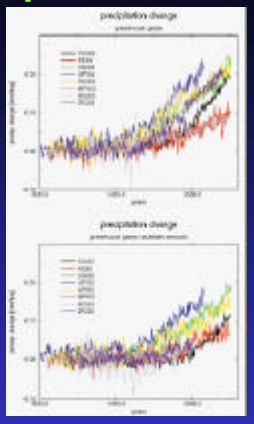
Pueden llegar a superarse los valores medios

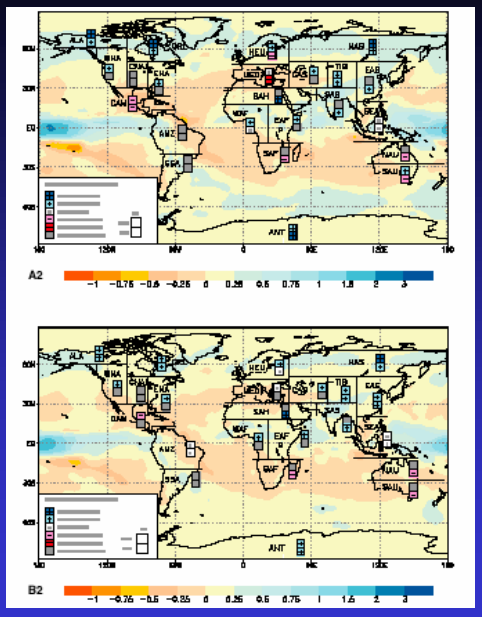


ºC

Precipitación

2071-2100 desde 1961-1990





Pueden cambiar las escorrentías

Aumento del riesgo de sequía

Mayores y más frecuentes crecidas

mm/día

Se hace necesaria una REGIONALIZACIÓN de los resultados de los modelos de simulación del clima ("Downscaling")

-Downscaling dinámico

-Downscaling estadístico

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TRABAJOS PREVIOS

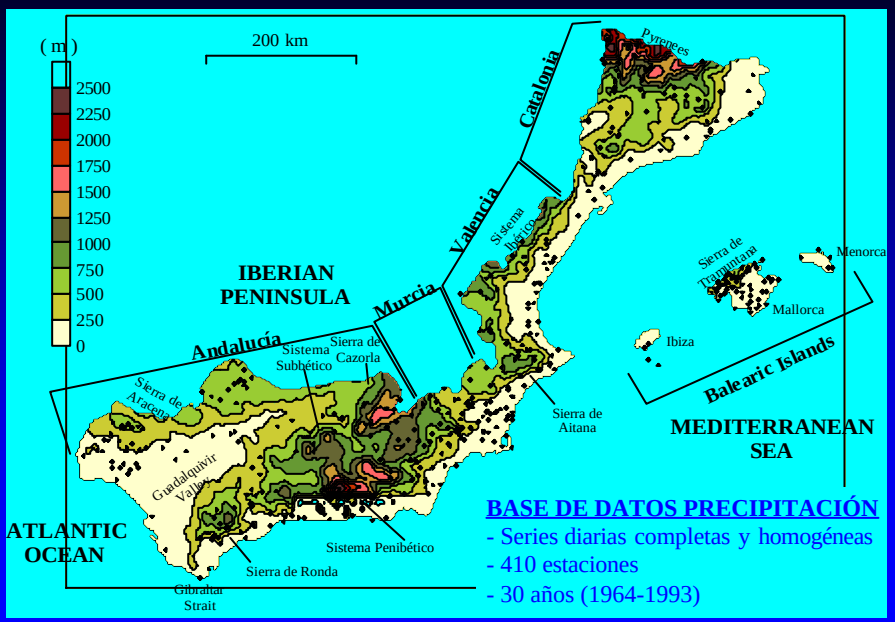
11 estructuras de la lluvia diaria (RPs) en la zona mediterránea española

? *Daily rainfall patterns in the Spanish Mediterranean area: An objective classification (1999)*	*Romero, R.* *Ramis, C.* *Guijarro, J. A.*	*Int. J. Climatol.* *Vol. **19**, 95-112*

RELACIÓN CUANTITATIVA

19 estructuras de la circulación atmósferica (APs) para los días de lluvia

? *A classification of the atmospheric circulation patterns producing significant daily rainfall in the Spanish Mediterranean área (1999)*	*Romero, R.* *Sumner, G. N.* *Ramis, C.* *Genovés, A.*	*Int. J. Climatol.* *Vol. **19**, 765-785*



BASE DE DATOS PRECIPITACIÓN
- Series diarias completas y homogéneas
- 410 estaciones
- 30 años (1964-1993)

CLASIFICACIÓN ESTRUCTURAS DE LLUVIA (RPs)

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

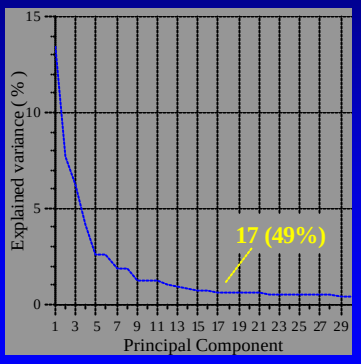
T-mode
(day-by-day)
correlation matrix

↓

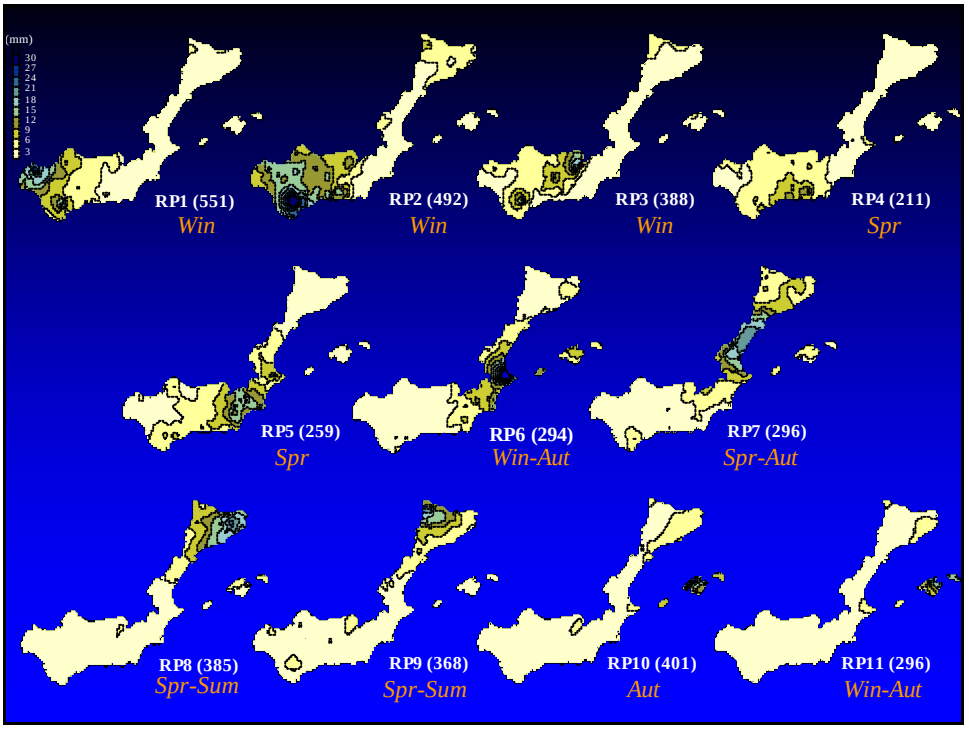
Principal Components Analysis
PCA

↓

Cluster Analysis (k-means)
CA



11 RPs

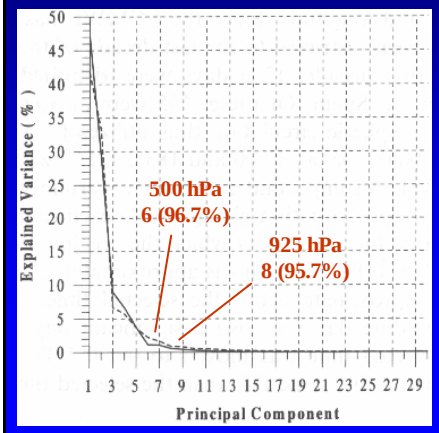


CLASIFICACIÓN ESTRUCTURAS ATMOSFÉRICAS

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

↓

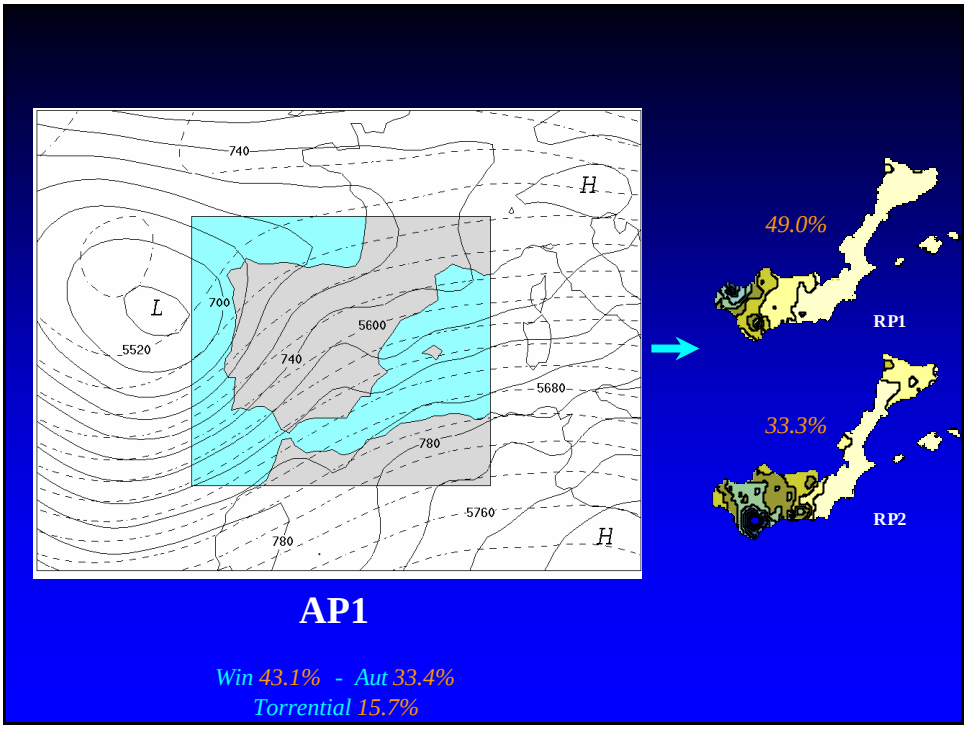
Cluster Analysis (k-means)
CA

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%)

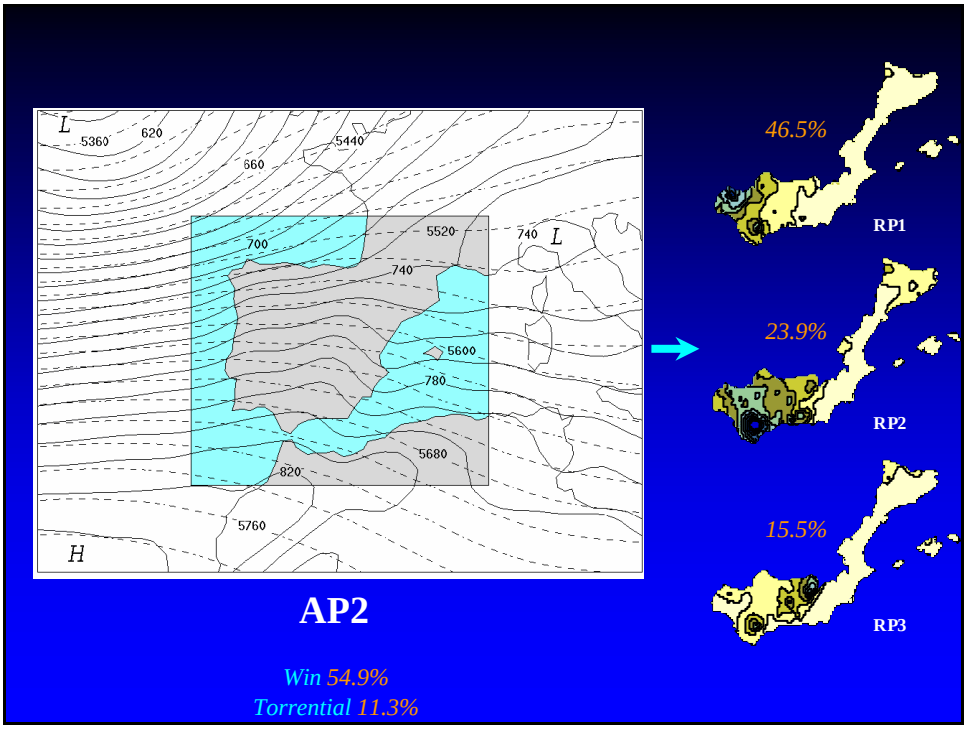
Atmospheric pattern	Number of days	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RPO	RP9	RP10	RP11	Winter	Spring	Summer	Autumn
AP1	51	**49.0**	**33.3**	0.0	2.0	0.0	0.0	5.9	5.9	2.0	0.0	1.9	**43.1**	17.6	5.9	**33.4**
AP2	71	**46.5**	**23.9**	**15.5**	0.0	1.4	0.0	0.0	2.8	1.4	4.2	4.3	**54.9**	18.3	1.4	25.4
AP3	84	**35.7**	**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

ASOCIACIÓN MUY CLARA



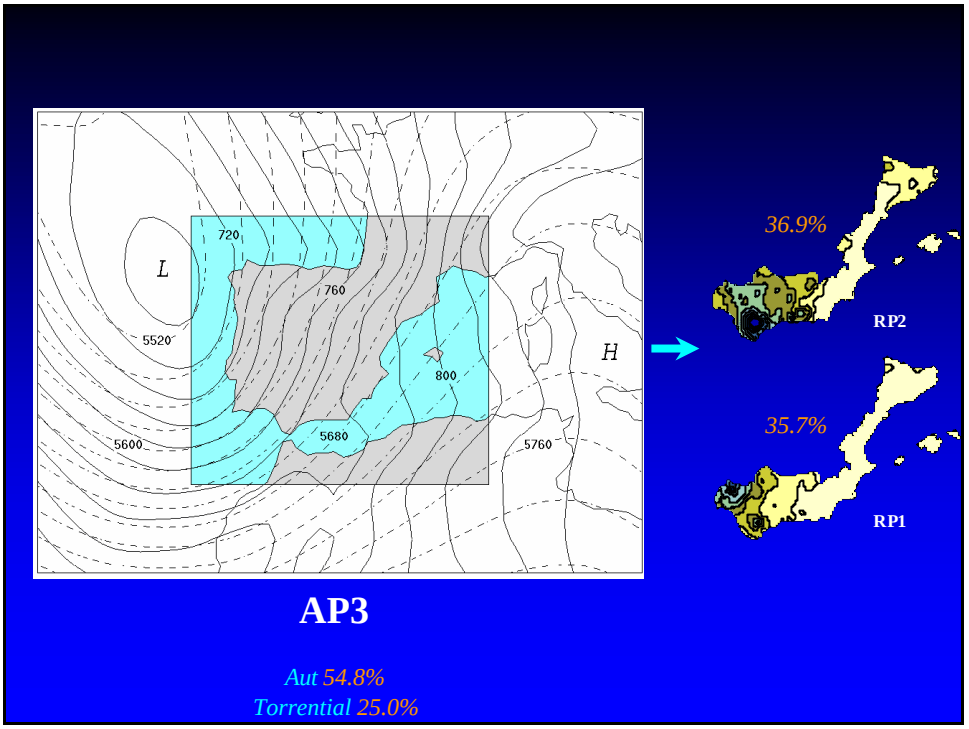
AP1

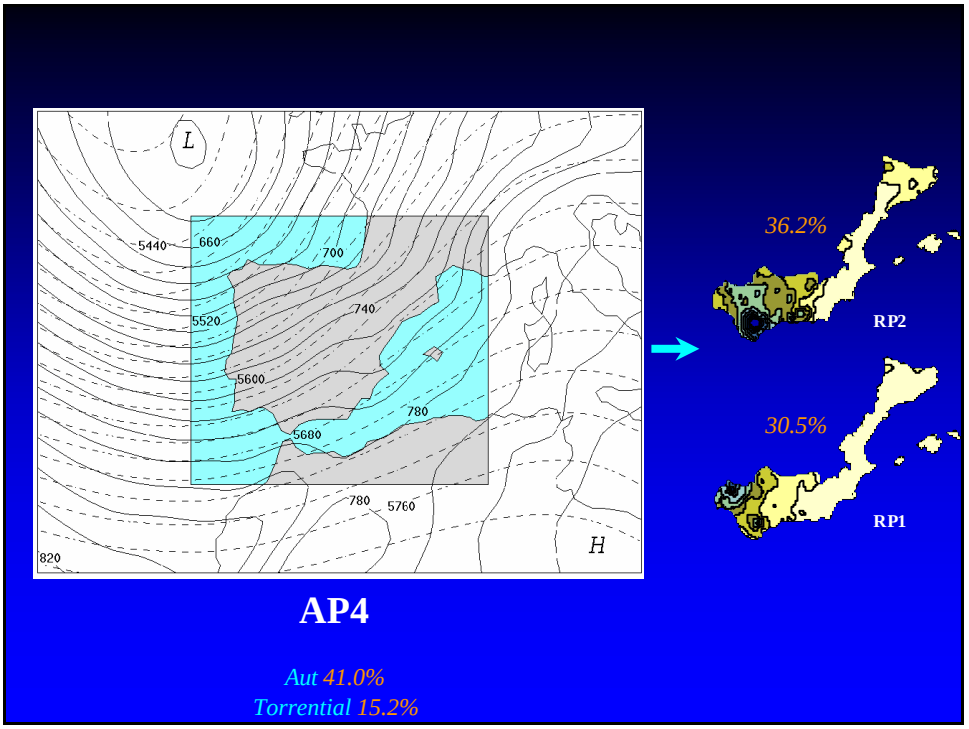
Win 43.1% - Aut 33.4%
Torrential 15.7%

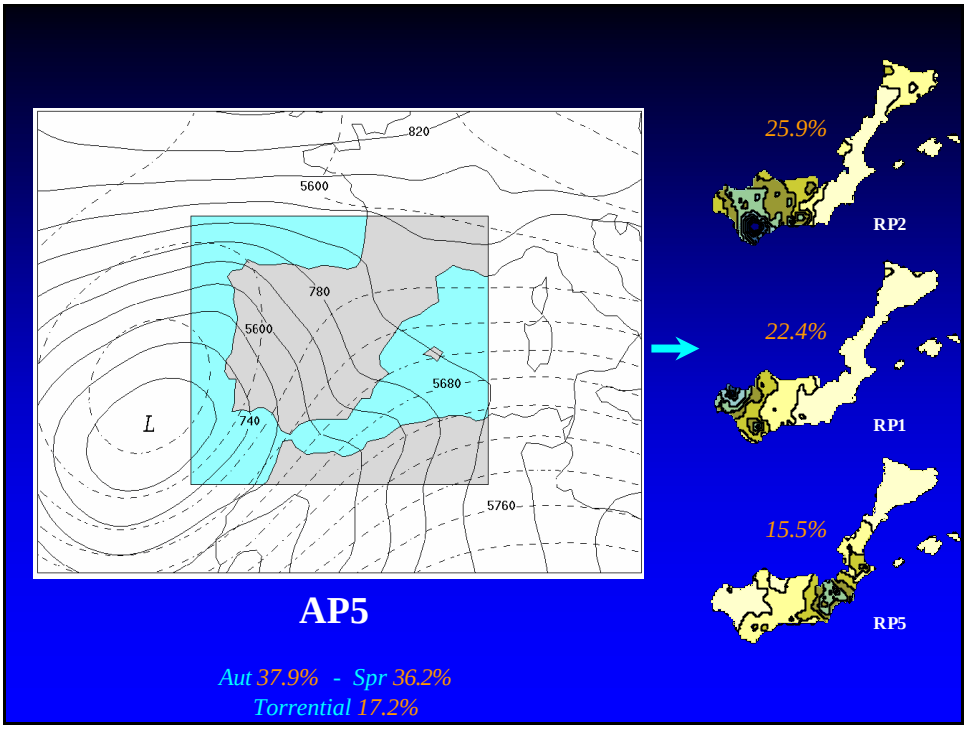


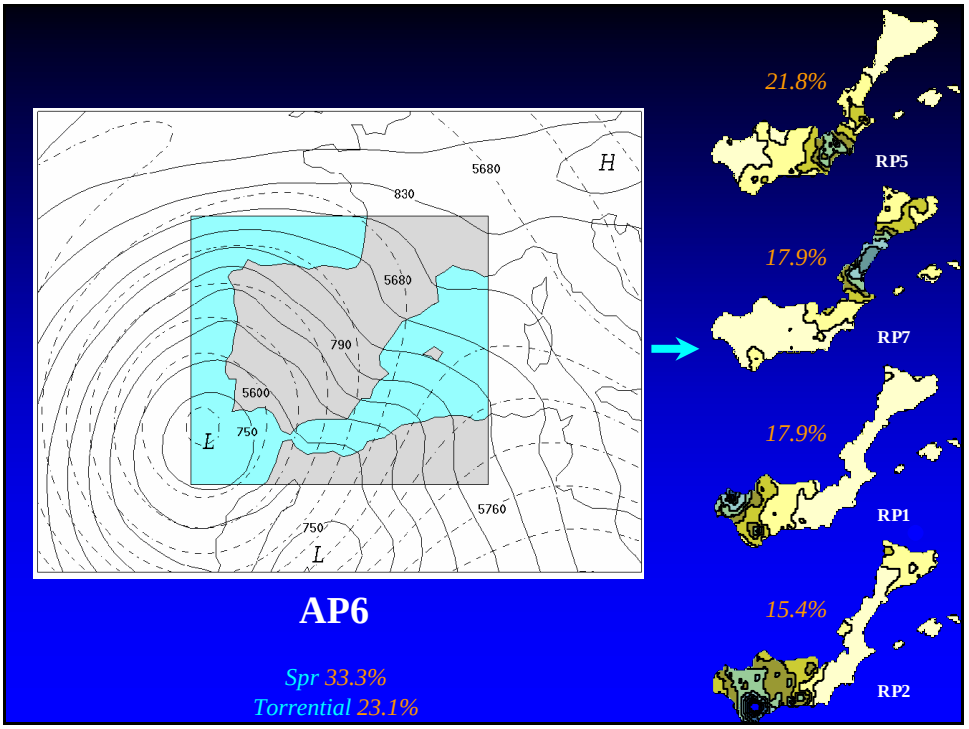
AP2

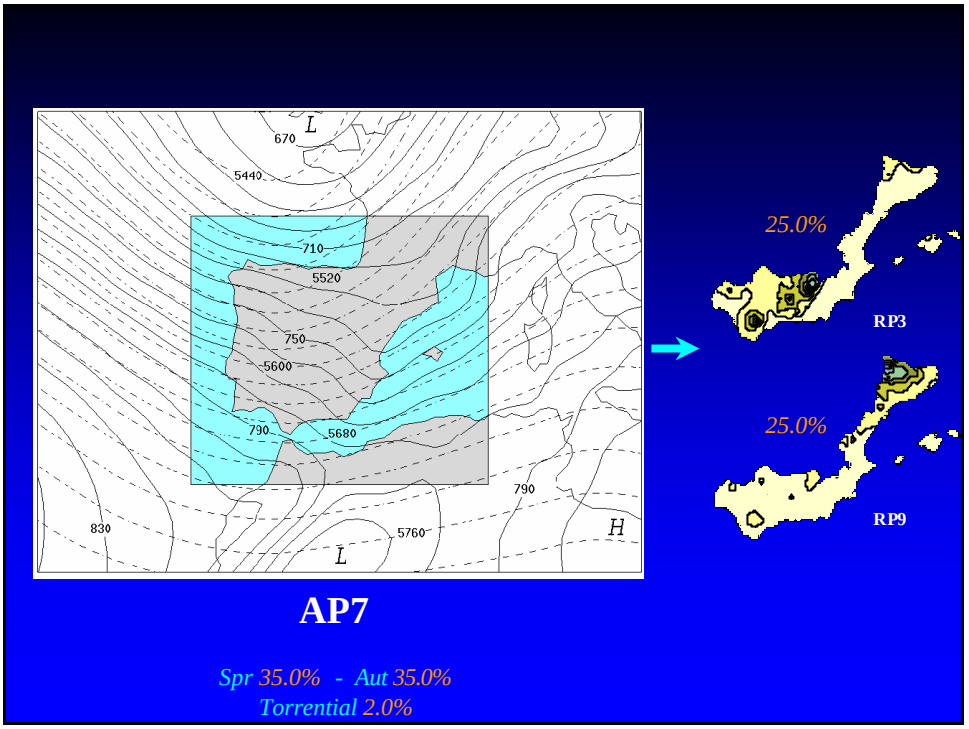
Win 54.9%
Torrential 11.3%


L
720
760
5520
800
H
5600
5680
5760
36.9%
RP2
35.7%
RP1
AP3
Aut 54.8%
Torrential 25.0%


L
5440
660
700
740
5520
5600
780
5680
780
5760
820
H
36.2%
RP2
30.5%
RP1
AP4
Aut 41.0%
Torrential 15.2%

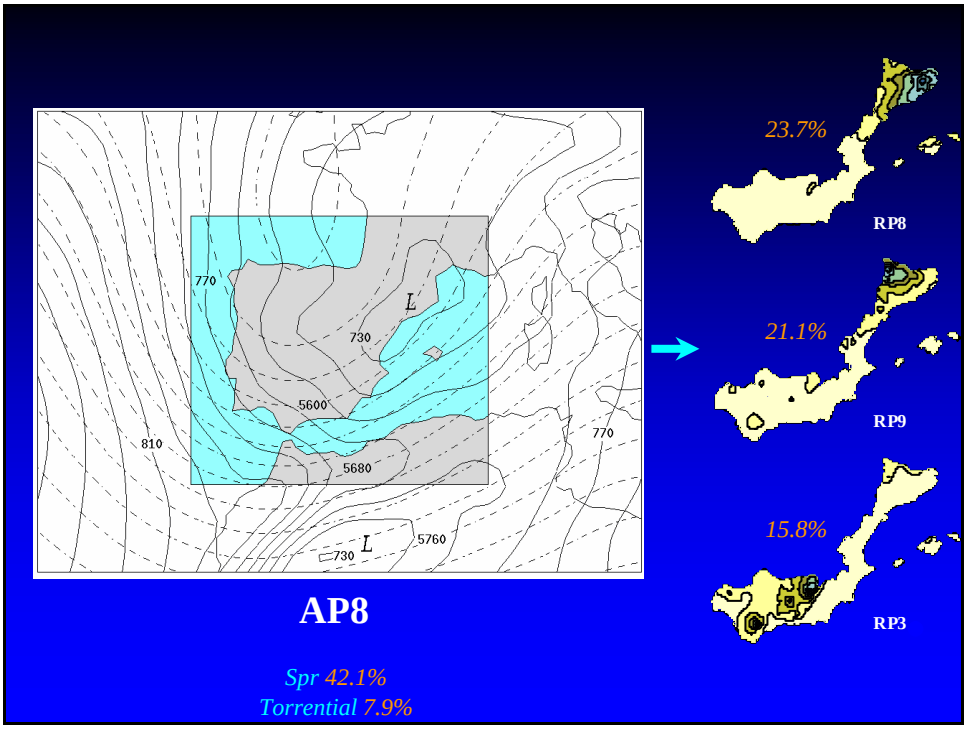

820
5600
780
5600
5680
740
L
5760
25.9%
RP2
22.4%
RP1
15.5%
RP5
AP5
Aut 37.9% - Spr 36.2%
Torrential 17.2%


5680
H
830
5680
790
5600
L
750
5760
750
L
21.8%
RP5
17.9%
RP7
17.9%
RP1
15.4%
RP2
AP6
Spr 33.3%
Torrential 23.1%



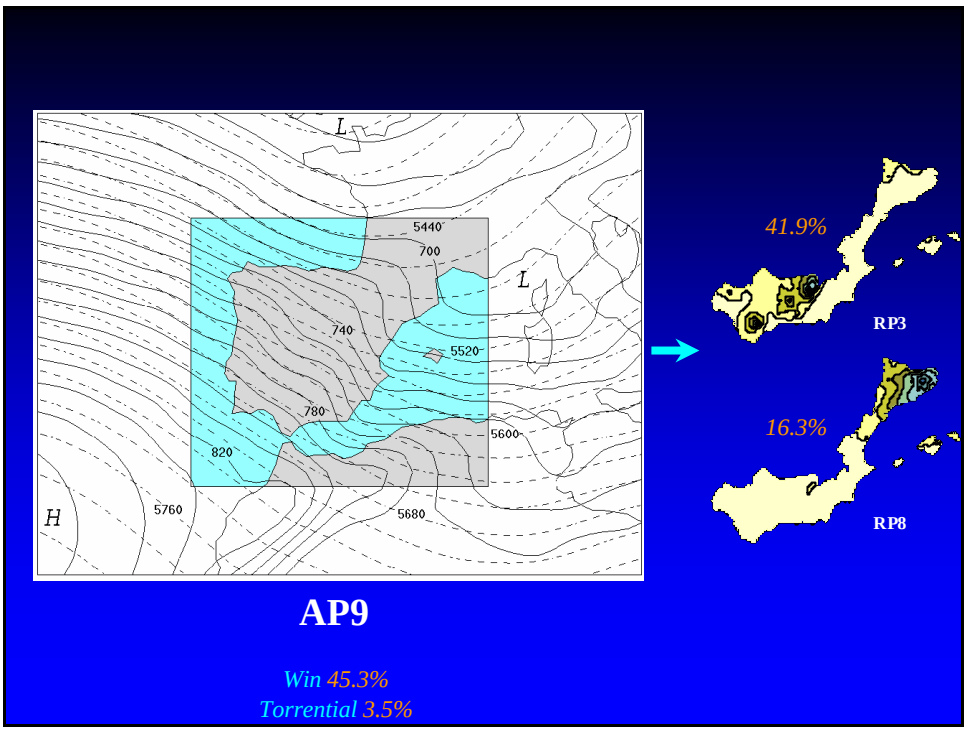
AP7

Spr 35.0% - Aut 35.0%
Torrential 2.0%



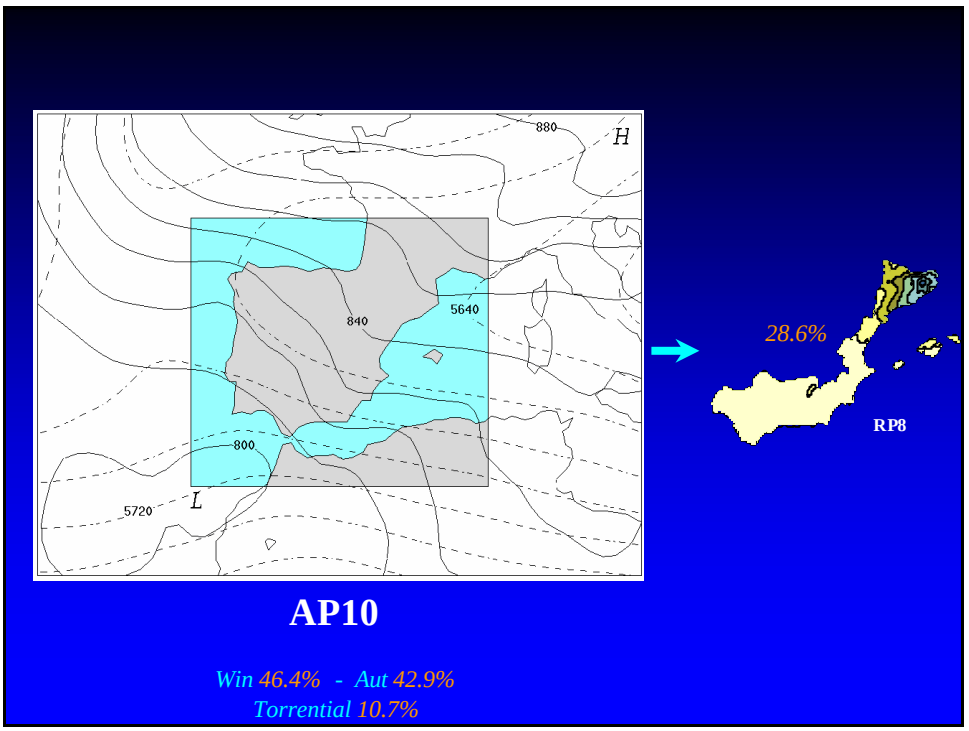
AP8

Spr 42.1%
Torrential 7.9%



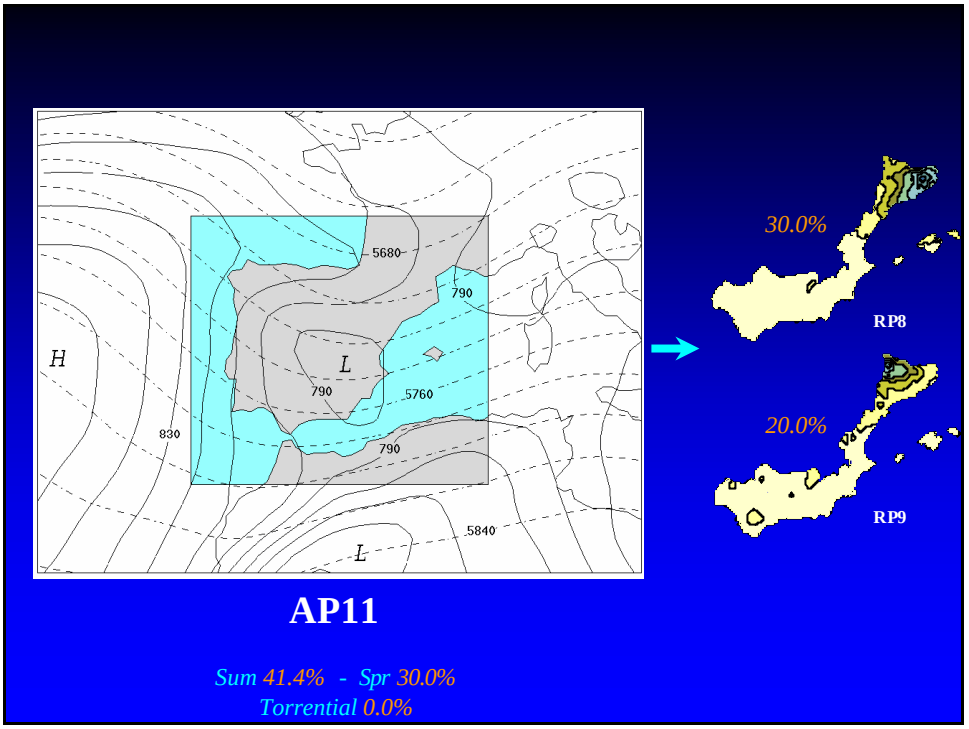
AP9

Win 45.3%
Torrential 3.5%



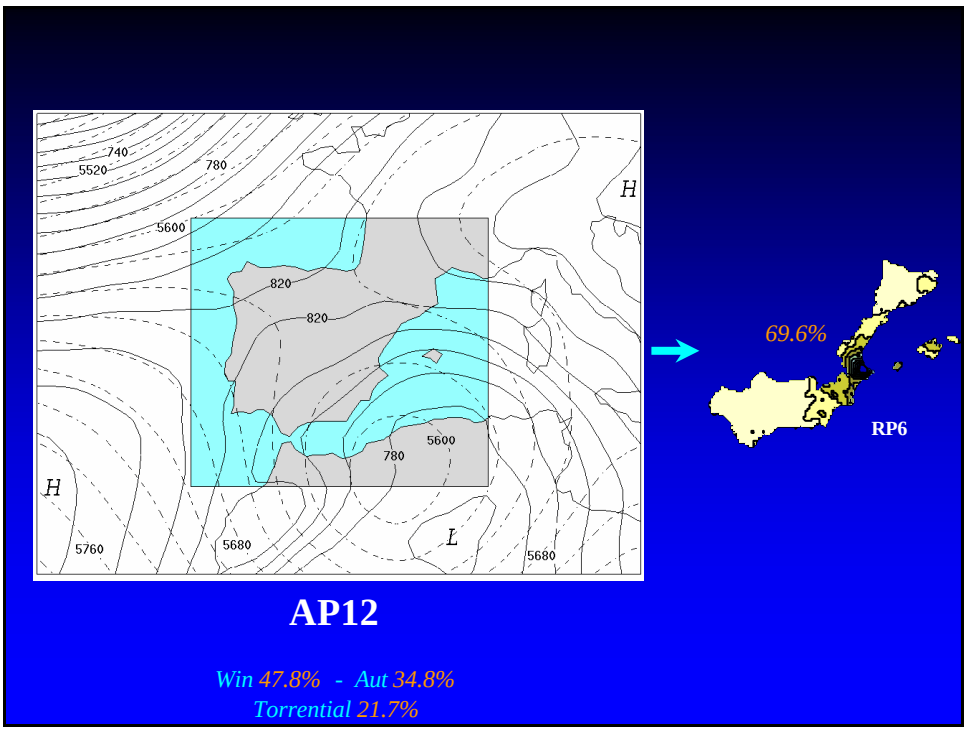
AP10

Win 46.4% - Aut 42.9%
Torrential 10.7%



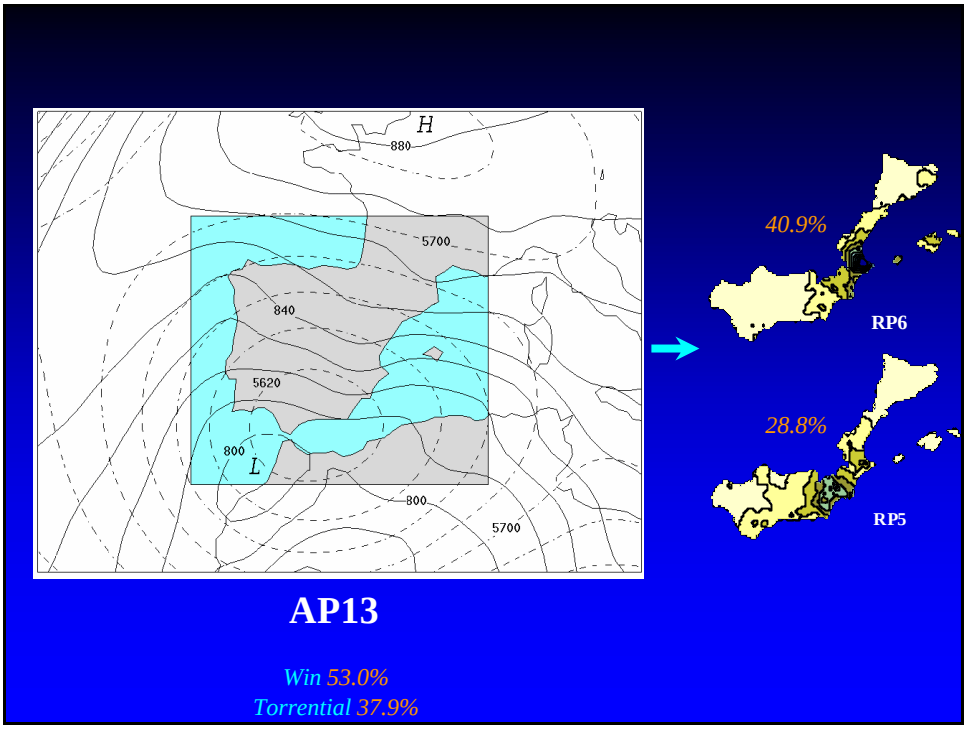
AP11

Sum 41.4% - Spr 30.0%
Torrential 0.0%



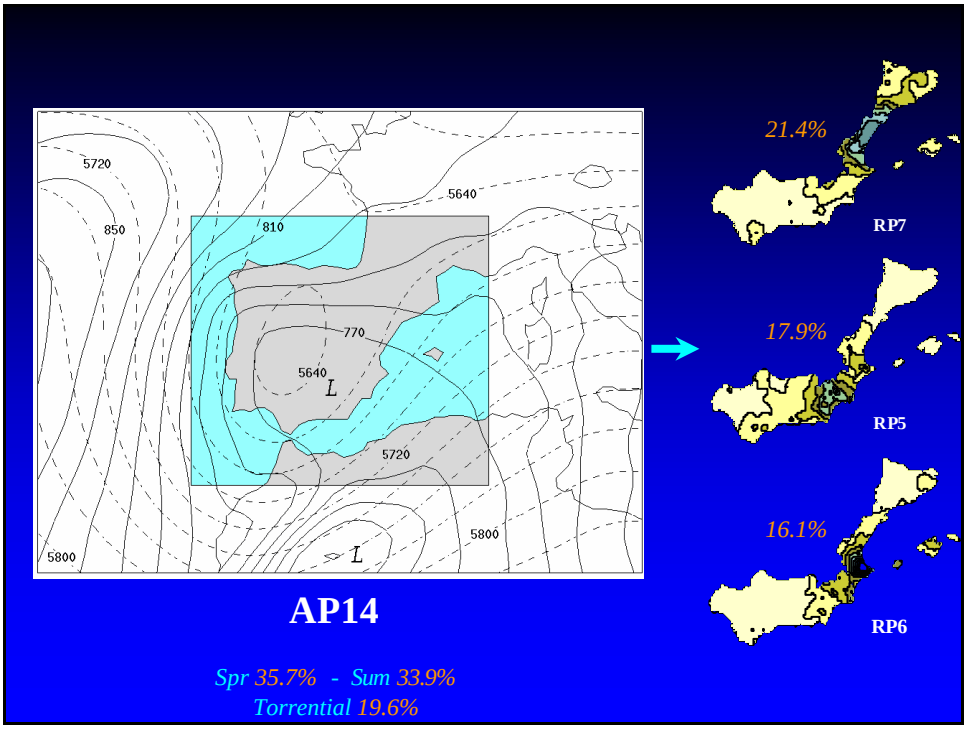
AP12

Win 47.8% - Aut 34.8%
Torrential 21.7%



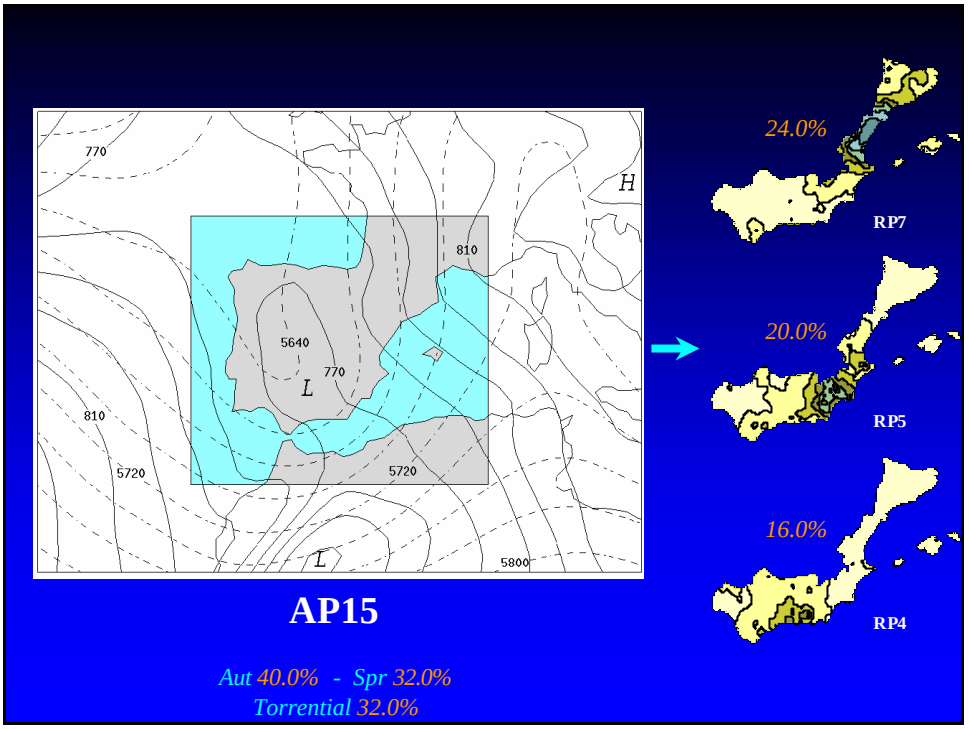
AP13

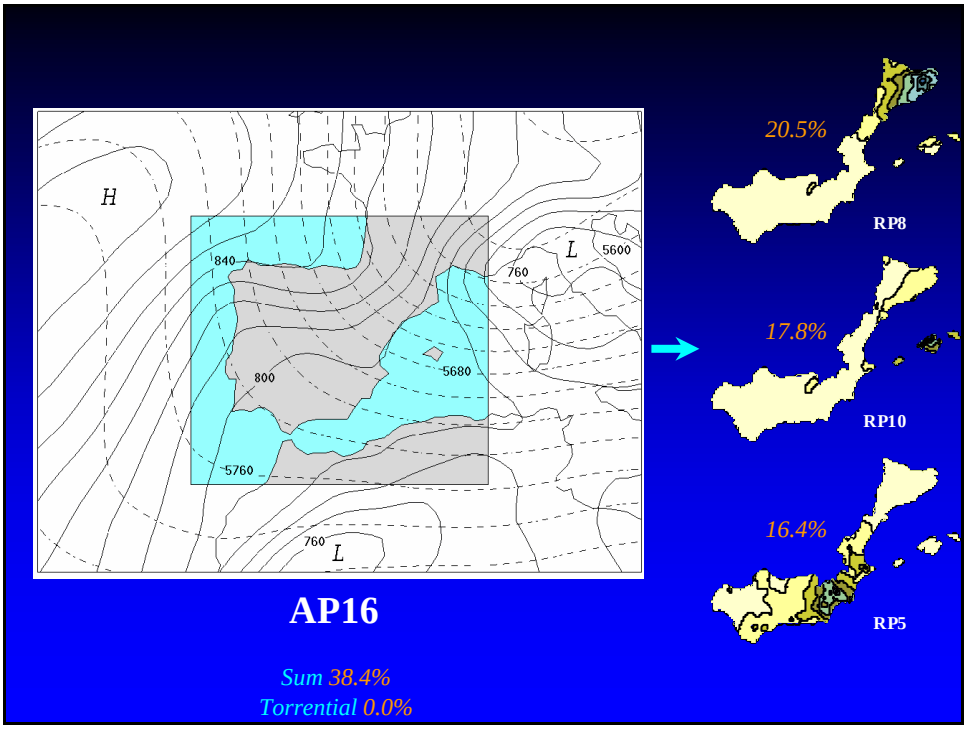
Win 53.0%
Torrential 37.9%

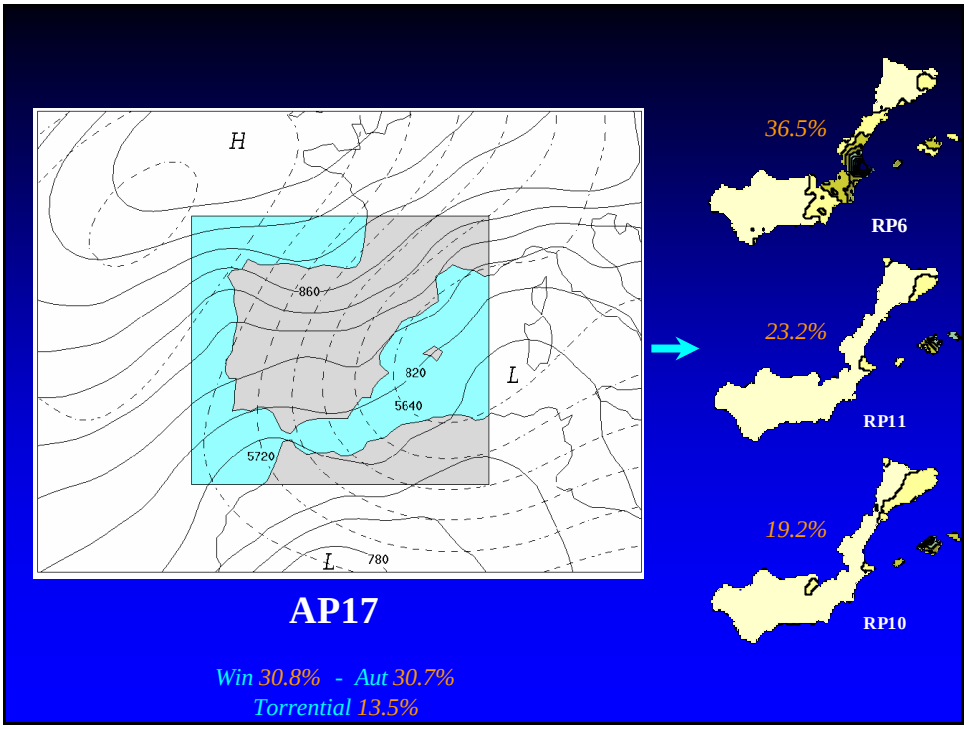


AP14

Spr 35.7% - Sum 33.9%
Torrential 19.6%

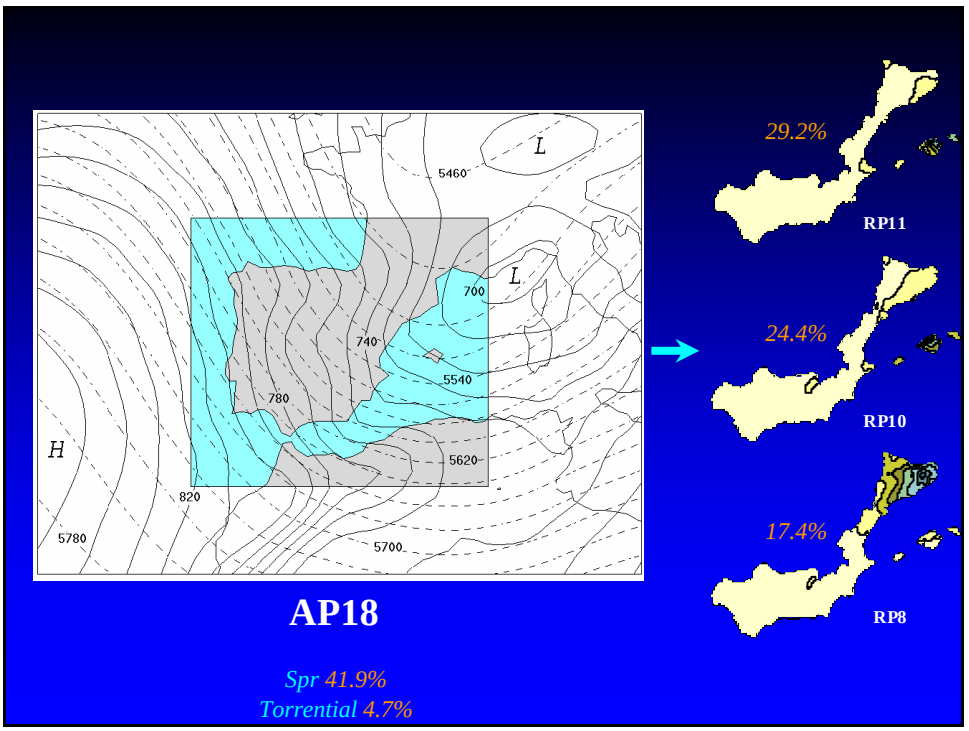

770
H
810
5640
770
L
810
5720
5720
L
5800
24.0%
RP7
20.0%
RP5
16.0%
RP4
AP15
Aut 40.0% - Spr 32.0%
Torrential 32.0%


H
840
800
5760
760
L
L
5600
760
5680
20.5%
RP8
17.8%
RP10
16.4%
RP5
AP16
Sum 38.4%
Torrential 0.0%



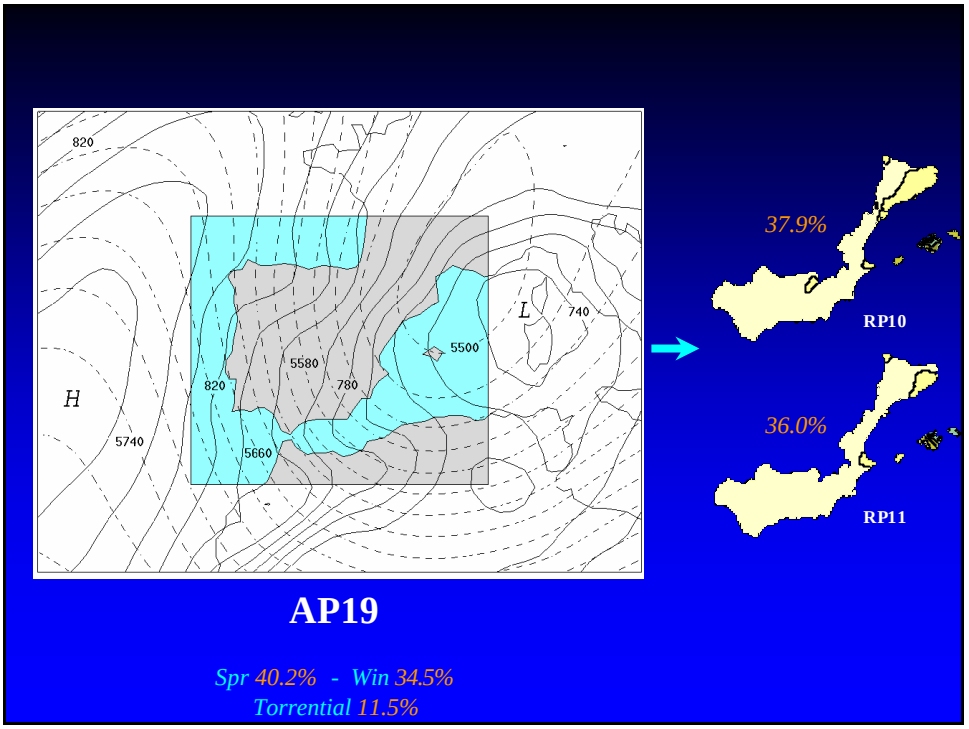
AP17

Win 30.8% - Aut 30.7%
Torrential 13.5%



AP18

Spr 41.9%
Torrential 4.7%



ESQUEMA DE LA PRESENTACIÓN

- La problemática del cambio climático y su regionalización
- Trabajos previos en los que se basa el estudio
- Metodología
- Resultados: Precipitación a final de siglo y su variabilidad

"DOWNSCALING" EN BASE A LOS RESULTADOS PREVIOS

Simulación del clima futuro con un GCM

Modelo ECHAM-OPYC3 aplicado a 1860-2099

- Modelo *T42 ECHAM4*: 19 niveles verticales / 2.8º de resolución horizontal
- Modelo *OPYC3*: 11 niveles verticales / mayor resolución en los trópicos
- *1860-1990*: Concentraciones históricas de los gases de E.I.
- *Tras 1990*: Escenario A (IPCC)

↓

MÉTODO DE DOWNSCALING

↓

Cambios en la precipitación de la zona mediterránea a finales del presente siglo ?

ESTRATEGIA

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	ECHAM FUTURO	**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		**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		**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		**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		**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		**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		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		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		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		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		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		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		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		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		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		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		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		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		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		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

2080 – 2099

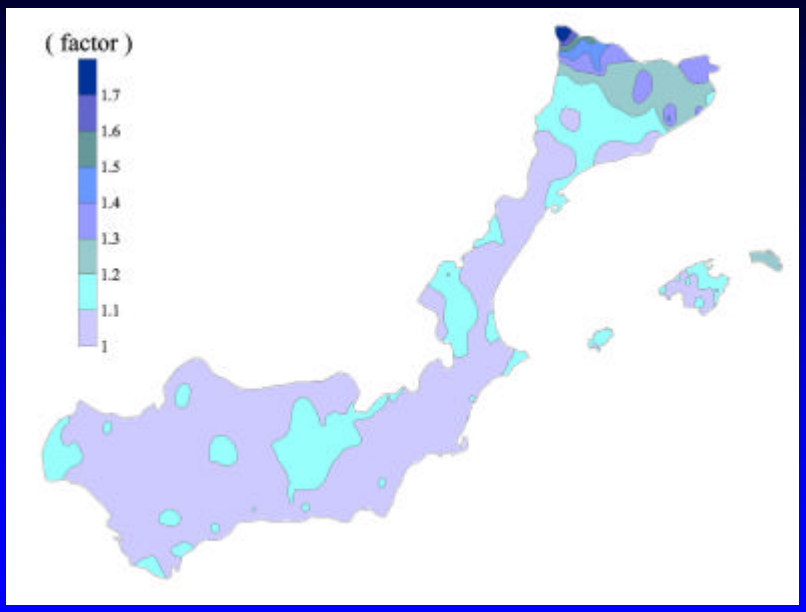
11 décadas móviles

↓

1) Mismas relaciones entre APs y RPs
2) Similar magnitud de la precipitation para cada RP
3) Mismo factor $?_i? R_i/S_i$ para la obtención de totales

↓

PRECIPITACIÓN FUTURA



ESTRATEGIA (continuación)

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%)

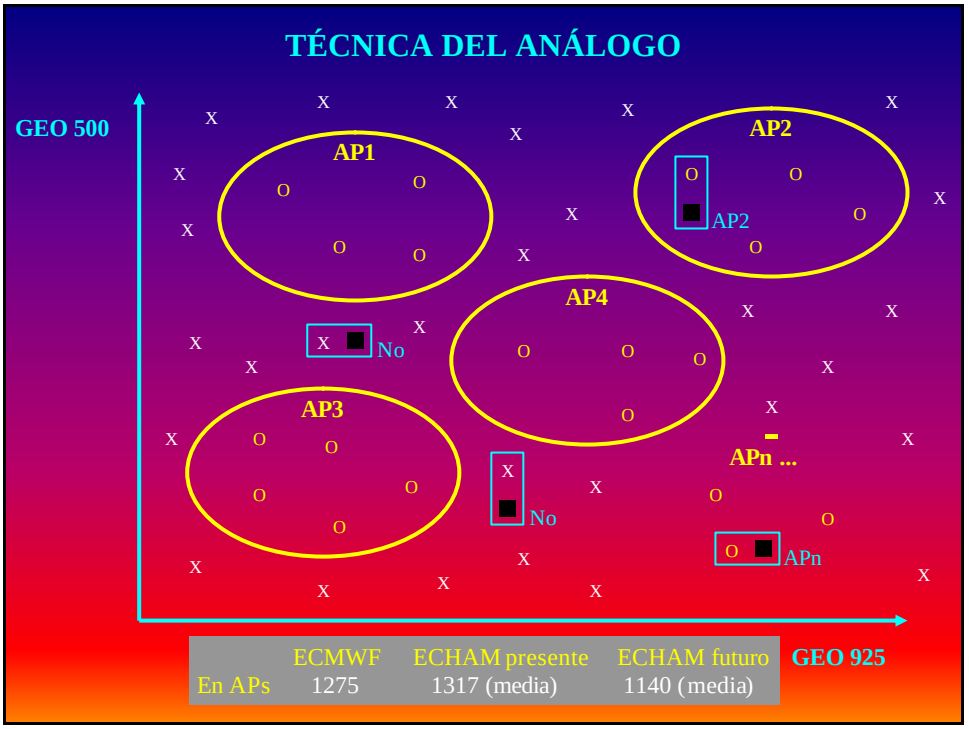
Atmospheric pattern	Number of days	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RPO	RP9	RP10	RP11	Winter	Spring	Summer	Autumn
AP1	E	**49.0**	**33.3**	0.0	2.0	0.0	0.0	5.9	5.9	2.0	0.0	1.9	**43.1**	17.6	5.9	**33.4**
AP2	C	**46.5**	**23.9**	**15.5**	0.0	1.4	0.0	0.0	2.8	1.4	4.2	4.3	**54.9**	18.3	1.4	25.4
AP3	H	**35.7**	**36.9**	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	A	**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	M	**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	P	**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	R	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	E	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	S	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	N	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	T	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		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		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		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		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		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		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		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		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		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

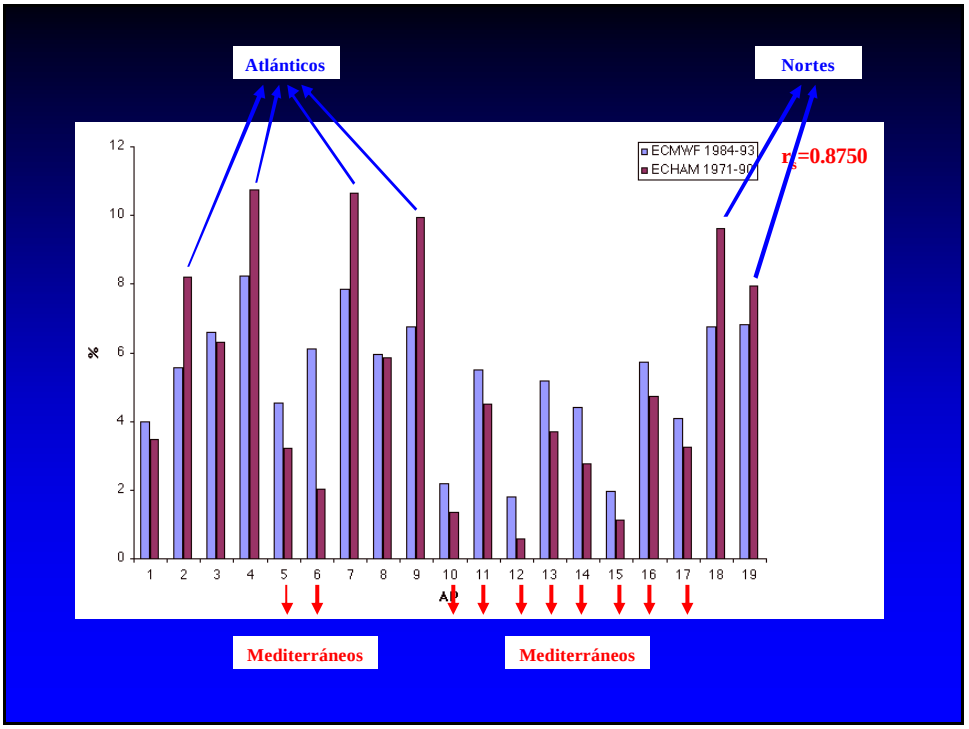
1971 – 1990

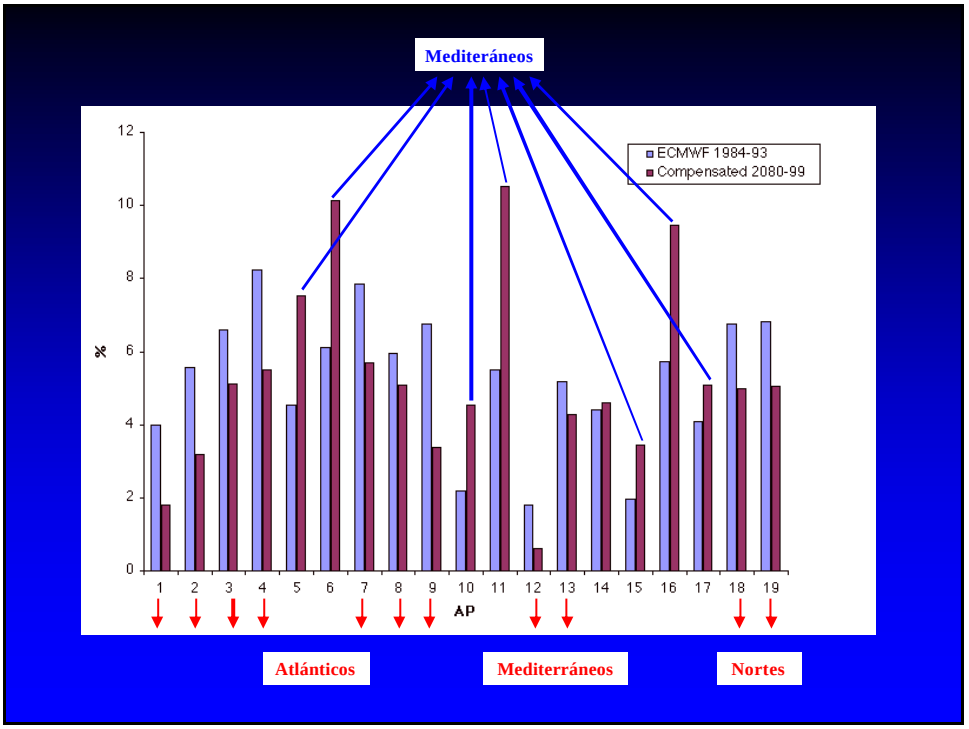
11 décadas móviles

VALIDACIÓN / CALIBRACIÓN DEL MODELO

FUTURO COMPENSADO
121 décadas (MEDIA + VARIABILIDAD)


TÉCNICA DEL ANÁLOGO
GEO 500
AP1
AP2
AP2
AP4
No
AP3
APn ...
No
APn
ECMWF
ECHAM presente
ECHAM futuro
GEO 925
En APs
1275
1317 (media)
1140 (media)


Atlánticos
Nortes
ECMWF 1984-93
ECHAM 1971-90
r=0.8750
%
AP
Mediterráneos
Mediterráneos



ESQUEMA DE LA PRESENTACIÓN

- La problemática del cambio climático y su regionalización
- Trabajos previos en los que se basa el estudio
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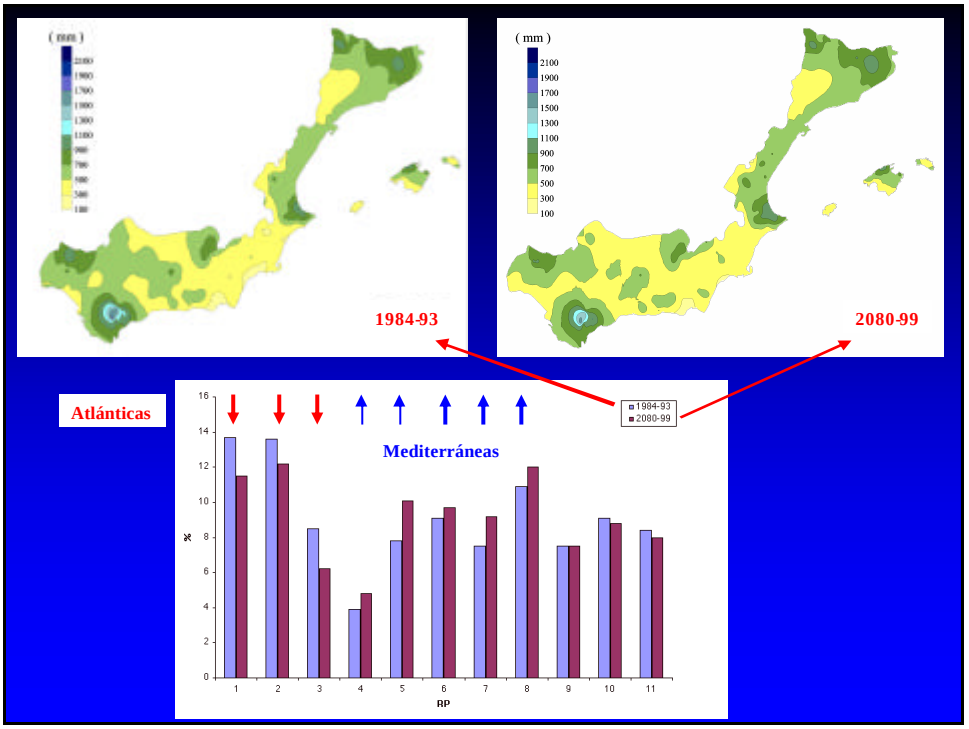
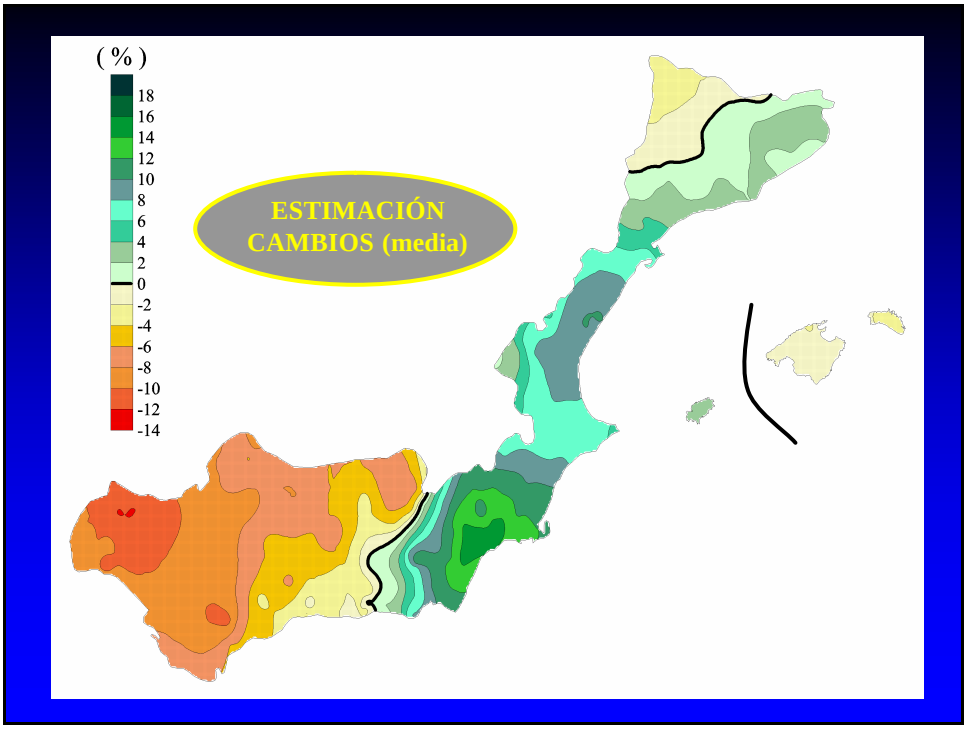
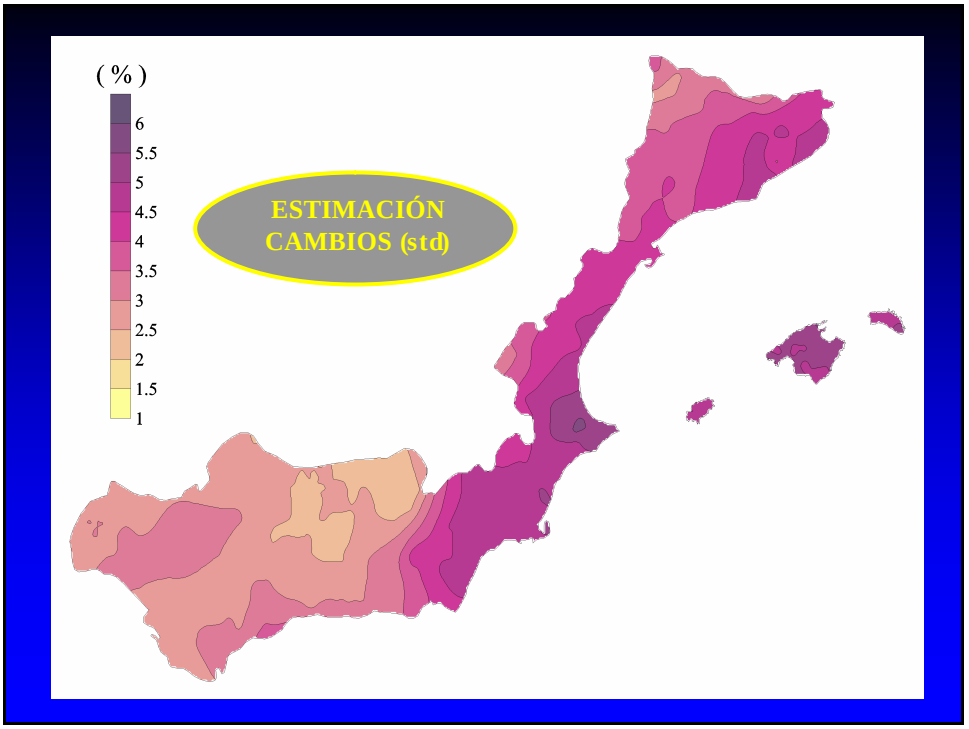

(mm)
2100
1900
1700
1500
1300
1100
900
700
500
300
100
1984-93
2080-99
Atlánticas
Mediterráneas
1984-93
2080-99
%
RP


(%)
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
ESTIMACIÓN
CAMBIOS (media)



ALGUNAS OBSERVACIONES DEL PASADO RECIENTE (Guijarro J. A. 2002)

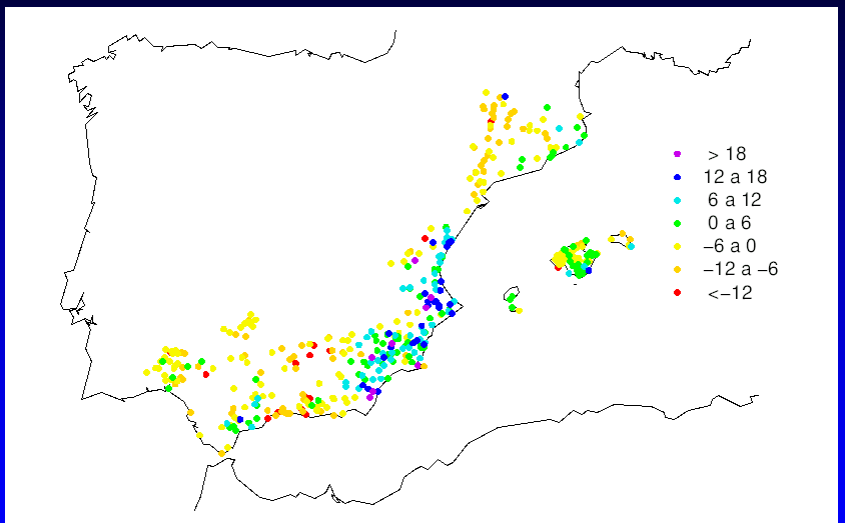


Figura 4: Distribución espacial de las tendencias (% por década) de la precipitación en el área mediterránea española (1964-1993).