T8.- MEJORA DE RESOLUCIÓN EN LAS PROYECCIONES CLIMÁTICAS: DOWNSCALING

Módulo 1.01.- Motores del clima, escenarios futuros y fenómenos extremos

Máster UIMP/CSIC en Cambio Global – Octubre 2013

Universitat de les Illes Balears

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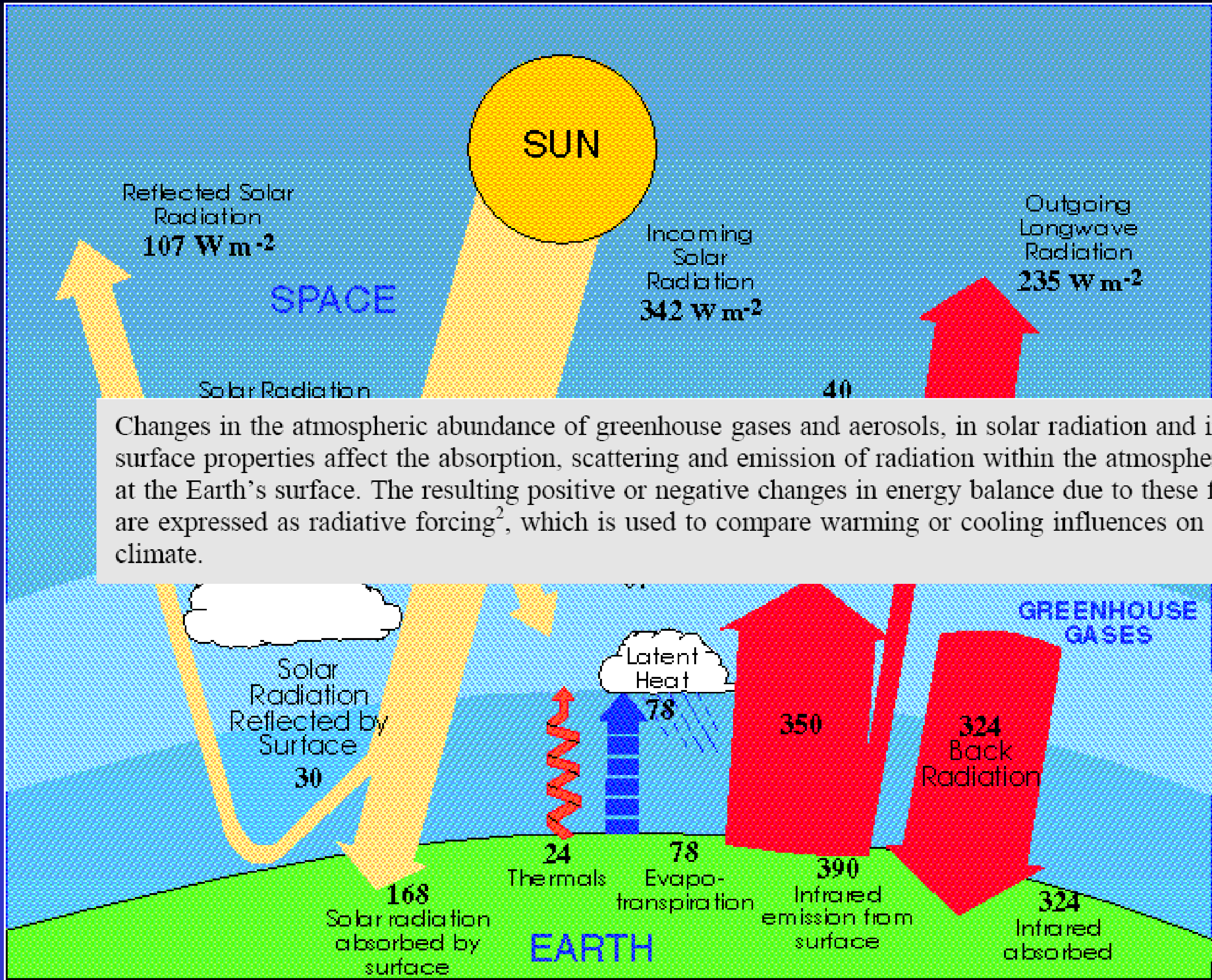
Climate Change is Global



Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in energy balance due to these factors are expressed as radiative forcing[2], which is used to compare warming or cooling influences on global climate.

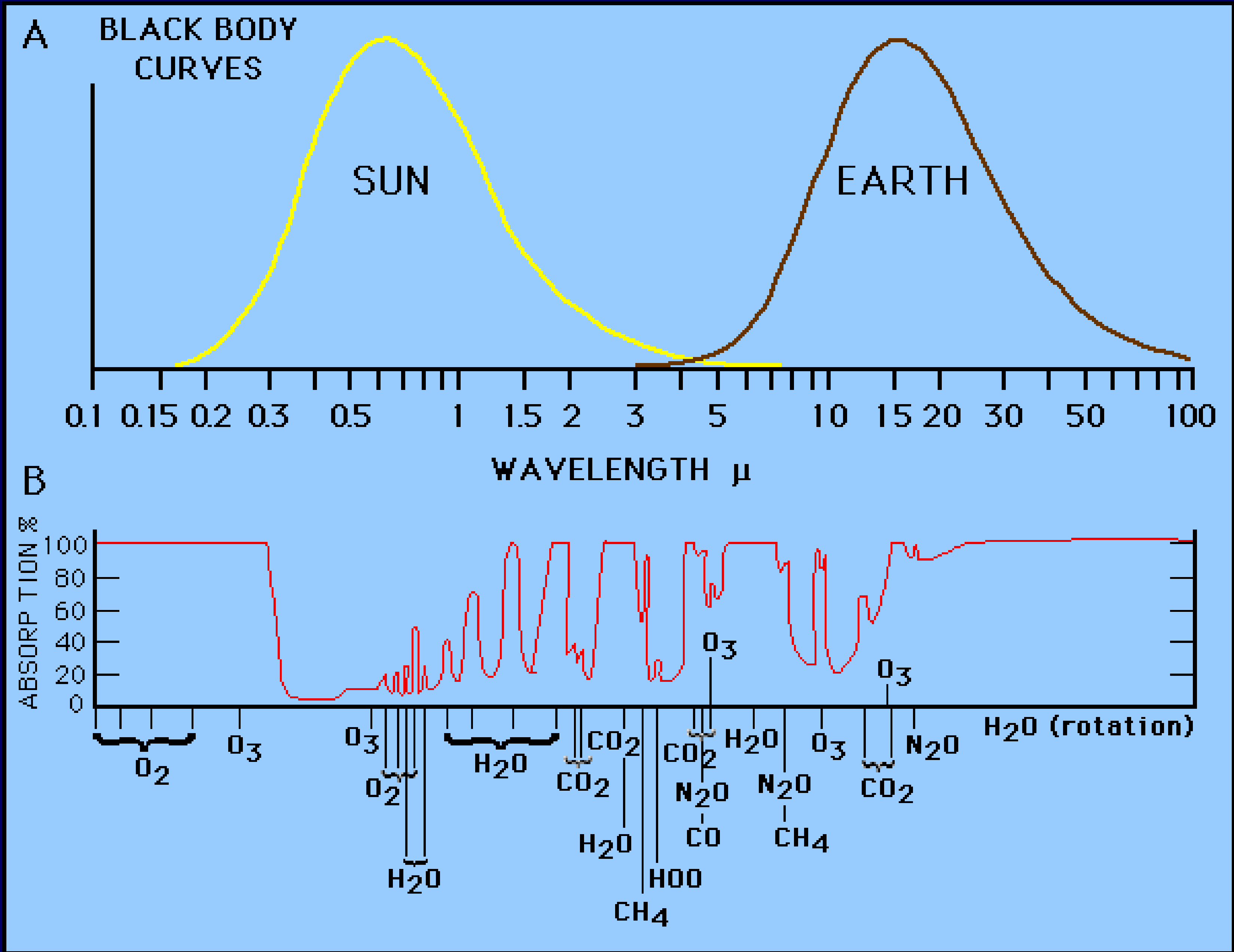
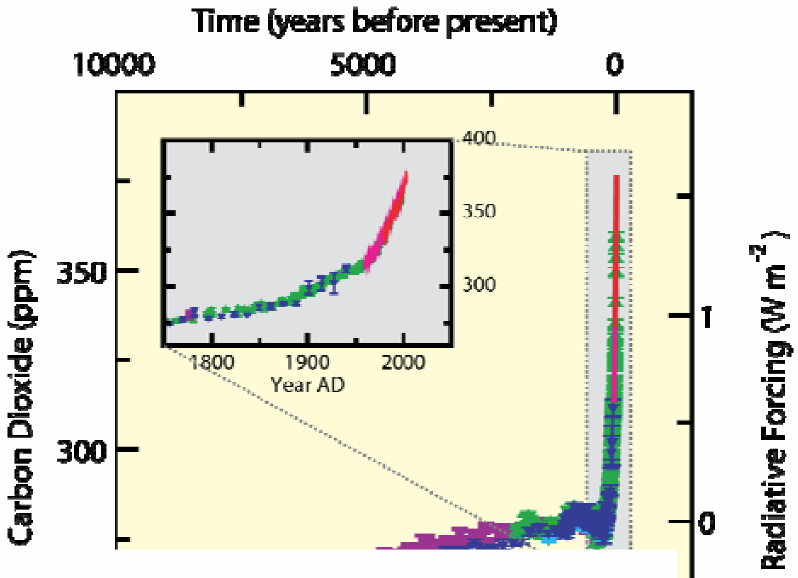
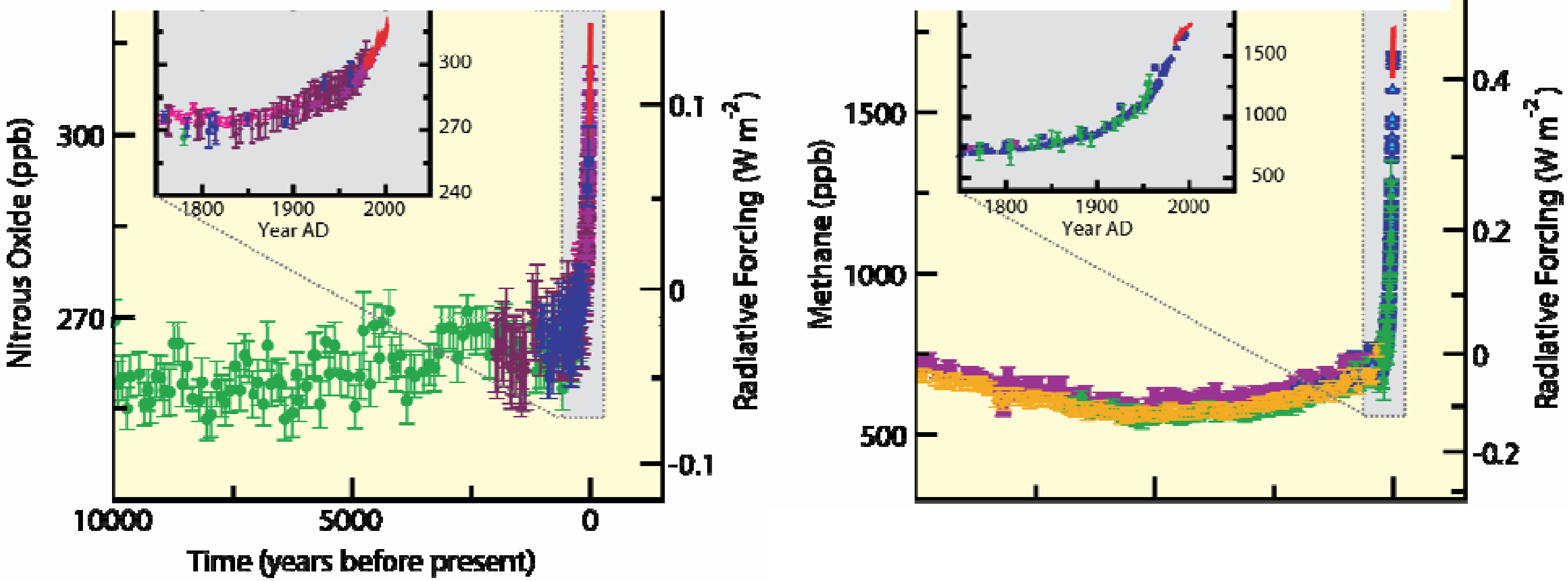
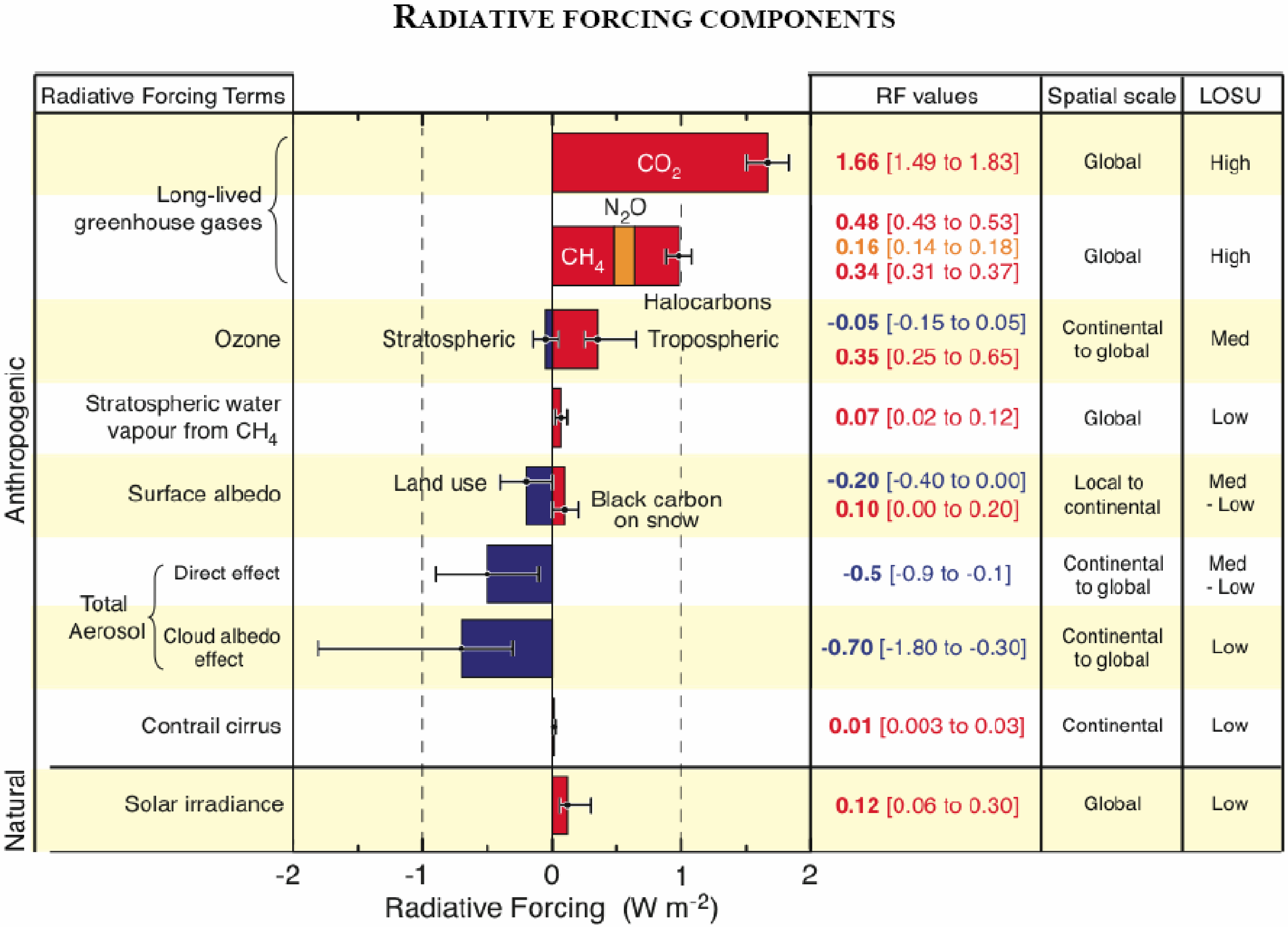

A
BLACK BODY CURVES
SUN
EARTH
0.1 0.15 0.2 0.3 0.5 1 1.5 2 3 5 10 15 20 30 50 100
WAVELENGTH μ
B
ABSORPTION %
100
80
60
40
20
0
O_2
O_3
O_3
O_2
H_2O
H_2O
CO_2
CO_2
H_2O
CH_4
HOO
CO_2
O_3
N_2O
CO
H_2O
N_2O
CH_4
O_3
O_3
CO_2
N_2O
H_2O (rotation)

FIGURE SPM-1.
Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. {Figure 6.4}



Current atmospheric concentrations of carbon dioxide and methane far exceed pre-industrial values determined from ice cores spanning the last 650,000 years. The increases in these greenhouse gases since 1750 (see Figure SPM-1) are due primarily to emissions from fossil fuel use, agriculture, and land-use changes. {2.3, 6.4, 7.3}

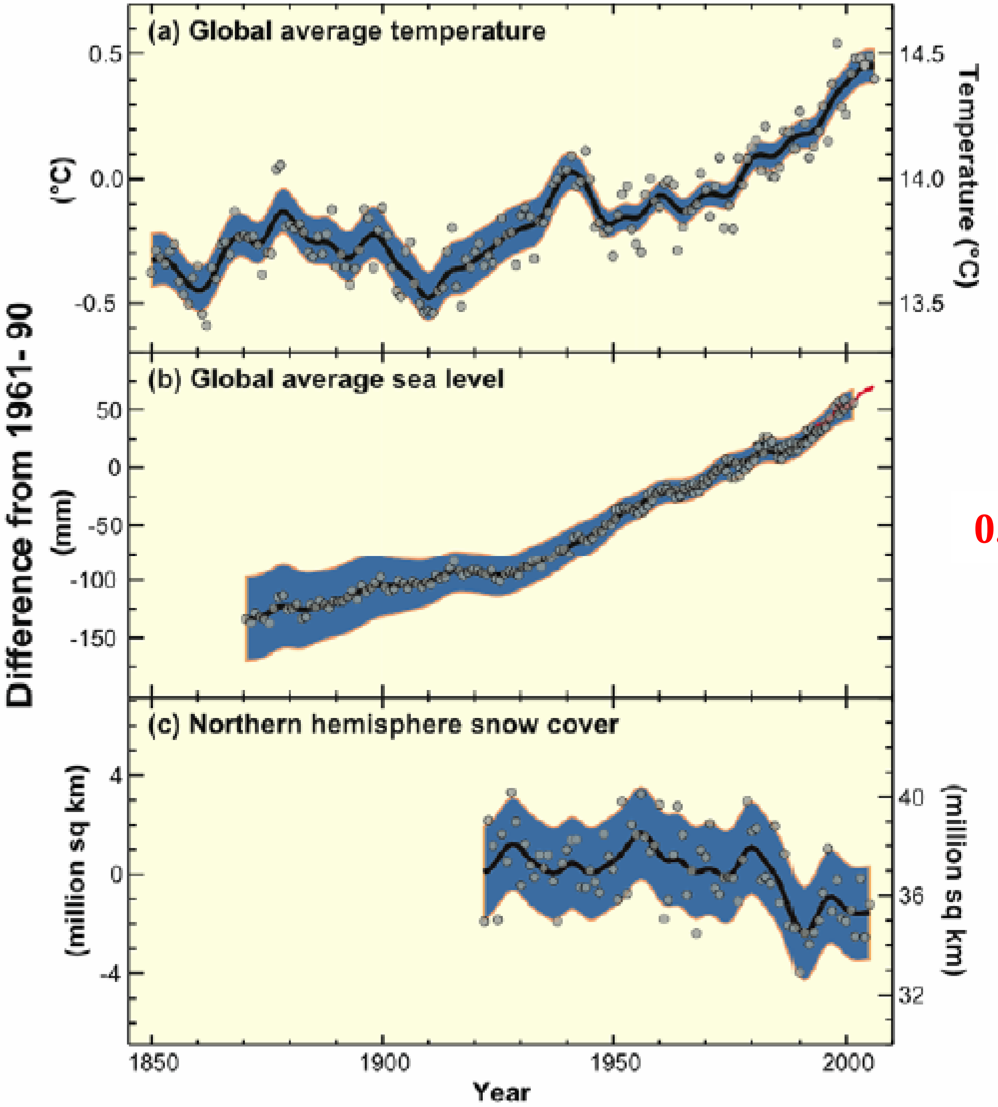




Globally averaged warming effect of human activities since 1750 (1.6 Wm^{-2}), at least 5 times larger than that of solar output changes

FIGURE SPM- … for carbon dioxide (CO_2), methane … , together with the typical geograph… …tific understanding (LOSU). Volcan… …n this figure due to their episodic nature. {2.9, Figure 2.20}

CHANGES IN TEMPERATURE, SEA LEVEL AND NORTHERN HEMISPHERE SNOW COVER



0.74 ^{0}C during 1906-2005

0.17 m during 20th century

FIGURE SPM-3. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves and shaded areas represent decadal averaged values and their assessed uncertainty intervals, while circles show yearly values. {Question 3.1, Figure 1, Figure 4.2 and Figure 5.13}

Warming of the climate system is unequivocal, as is now evident from increases in global average air and ocean temperatures, melting of snow and ice, and rising sea level (see Figure SPM-3). {3.2, 4.2, 5.5}

Numerous changes in climate have been observed at the scales of continents or ocean basins. These include wind patterns, precipitation, ocean salinity, sea ice, ice sheets, and aspects of extreme weather. {3.2, 3.3, 3.4, 3.5, 3.6, 5.2}

It is *very likely* that anthropogenic greenhouse gas increases caused most of the observed increase in globally averaged temperatures since the mid-20th century. Discernible human influences now extend to other aspects of climate, including continental-average temperatures, atmospheric circulation patterns, and some types of extremes (see Figure SPM-4 and Table SPM-1). {9.4, 9.5}

Table SPM-1. Recent trends, assessment of human influence on the trend, and projections for extreme weather and climate events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of discernible human influence on observed trend	Likelihood of continuation of trend based on projections for 21st century using SRES scenarios.
Warmer/fewer cold days/nights over most land areas.	*Very likely*[b]	*Likely*[d]	*Virtually certain*[d]
Warmer/more hot days/nights over most land areas.	*Very likely*[c]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells / heat waves. Frequency increases over most land areas.	*Likely*	*More likely than not*	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas.	*Likely*	*More likely than not*	*Very likely*
Area affected by droughts increases.	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Number of intense tropical cyclones increases.	*Likely*, since 1970	*More likely than not*	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis).	*Likely*	*More likely than not*	*Likely*

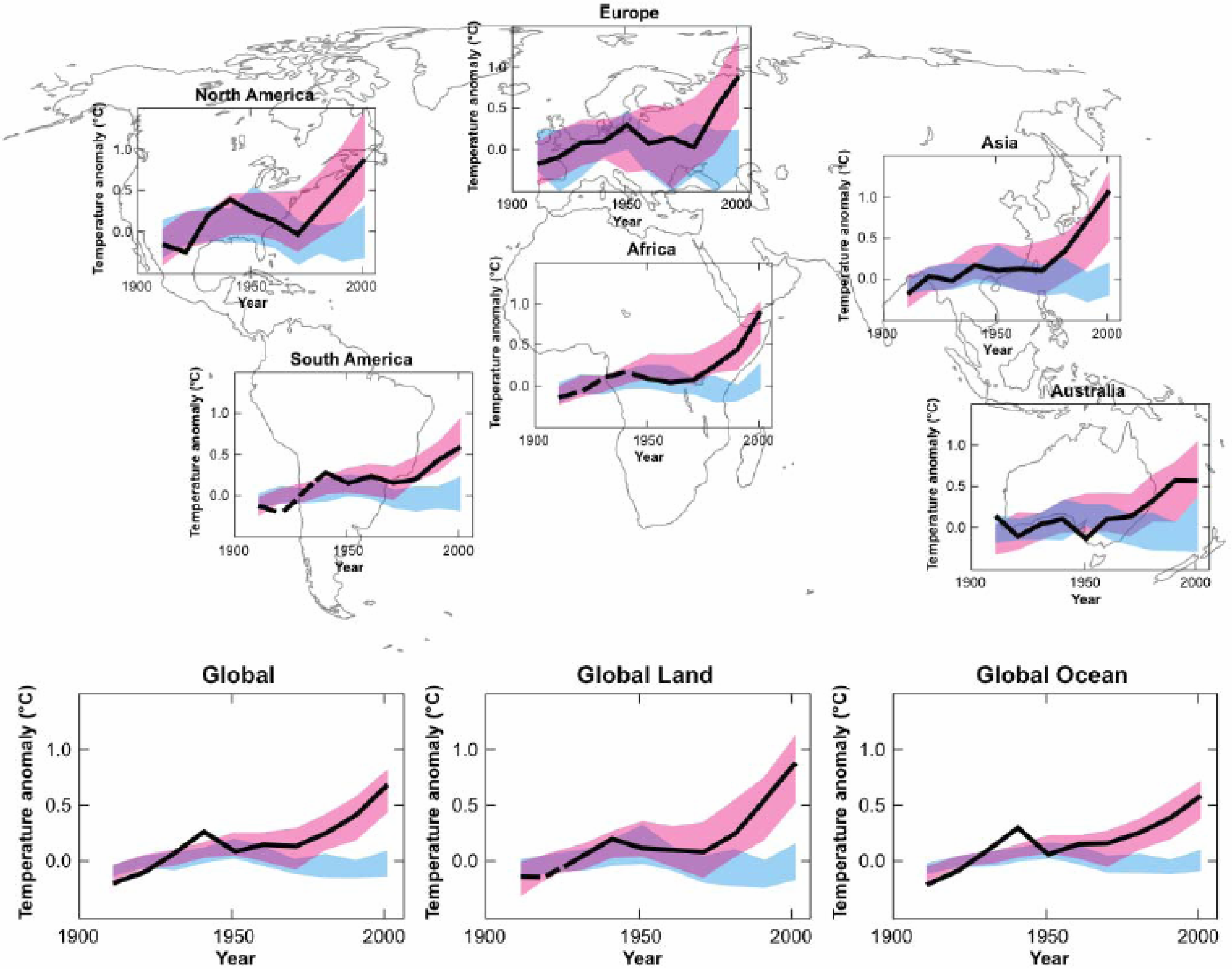
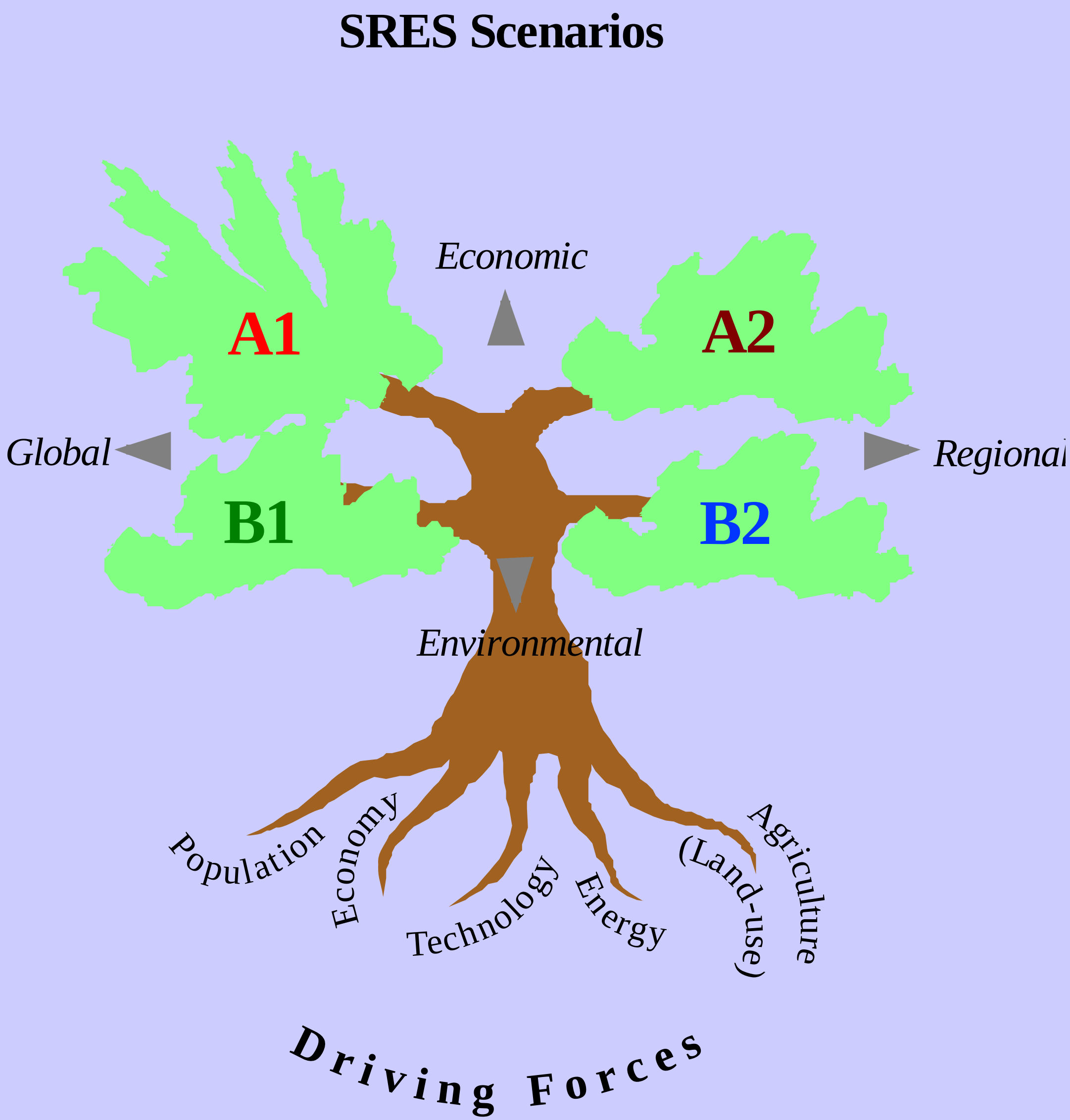


FIGURE SPM-4. Changes in continental- and global-scale decadal surface air temperature for 1906–2005, relative to the corresponding average for the 1901–1950 period, compared with model simulations. Black lines indicate observed changes and are dashed where spatial coverage is less than 50%. Blue bands show the 5–95% range for 19 simulations from 5 climate models using only natural forcings, and red bands show the 5–95% range for 58 model simulations from 14 climate models using both natural and anthropogenic forcings. The changes shown are unadjusted model output in regions where observations are available. {FAQ 9.2, Figure 1}

Schematic Illustration of SRES Scenarios

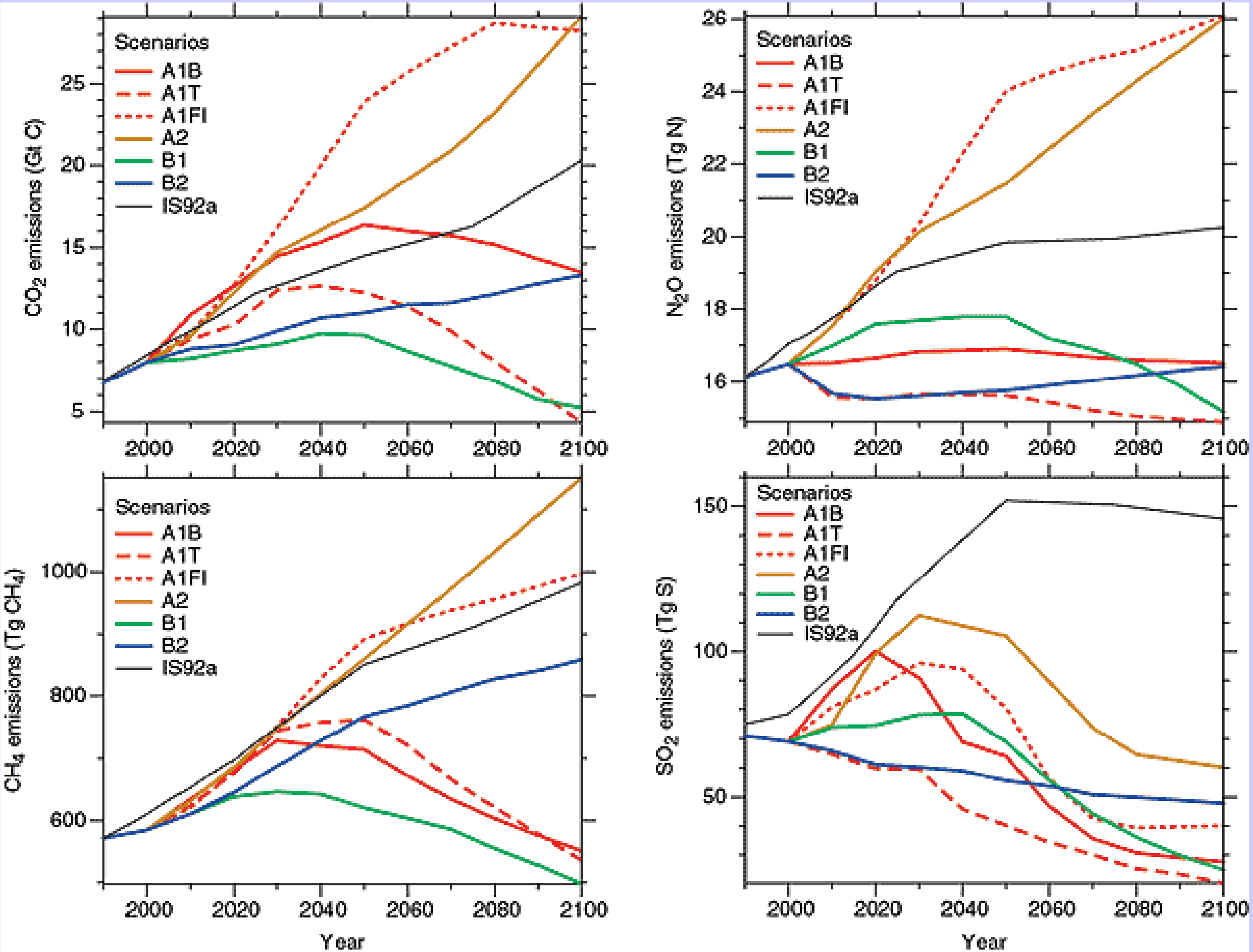


Factors especially:

Population
GDP
Standards of living
Energy use
Carbon/coal usage

Expected greenhouse effect concentration gases

A1B, A1T and A1FI are variations of main A1 SRES: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B)



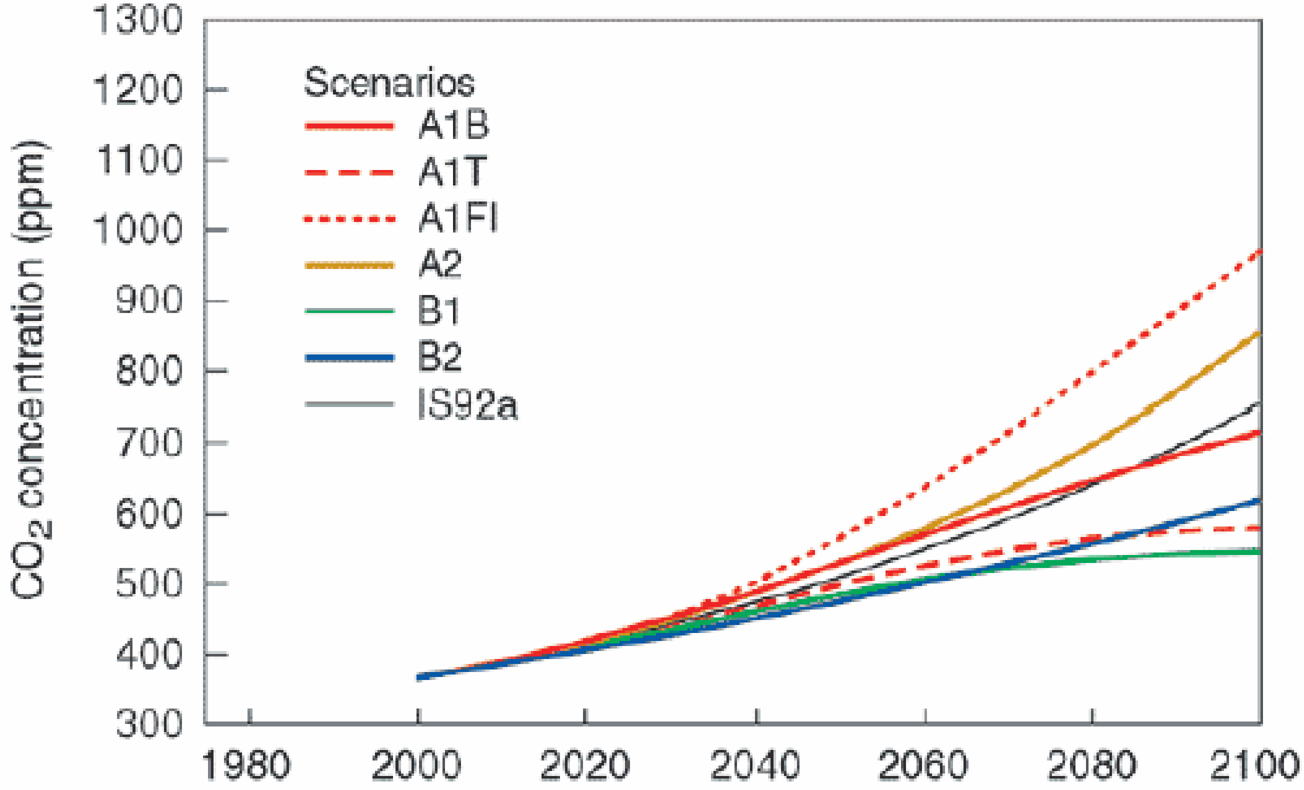


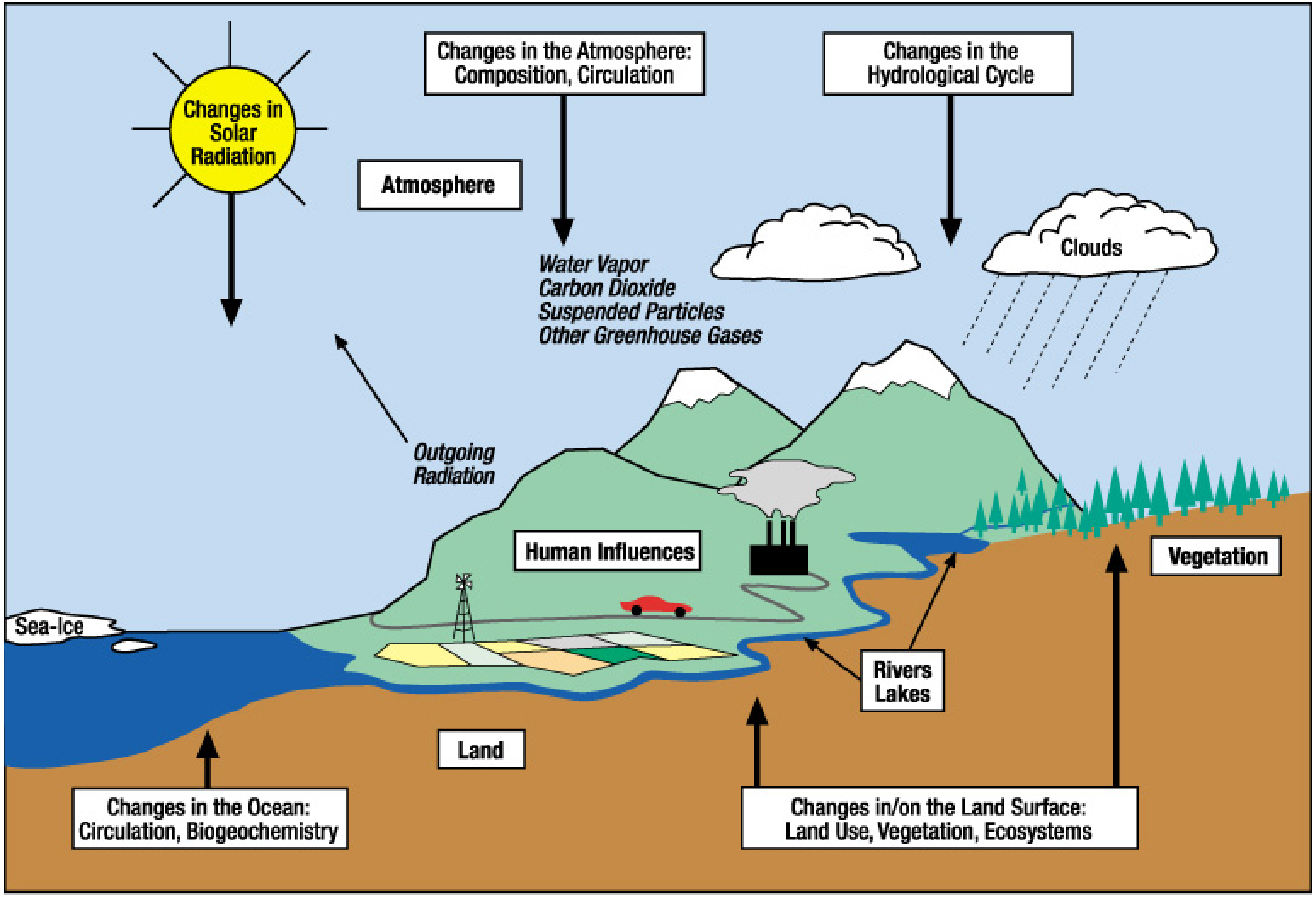
Figura 6.3. La concentració de CO2 a l'atmosfera, com a resultat de les emissions presentades en la figura anterior. Noteu que malgrat en alguns escenaris les emissions comencen a disminuir cap a mitjan de segle, la concentració segueix augmentant, atès que l'escala de temps característica per assolir un nou equilibri en la concentració de CO2 és d'uns 200 anys. [Figura extreta de Houghton *et al.*, 2001]

Which tool ?
Climate Simulation Models (AOGCM)

NOMBRE DEL MODELO	CENTRO (PAÍS)	RESOLUCIÓN ATMOSFÉRICA	RESOLUCIÓN OCEÁNICA	ESCENARIOS SRES SIMULADOS
CCSR/NIES 2	CCSR/NIES (Japón)	5.6 × 5.6 (20)	2.8 × 2.8 (17)	A1,A1FI,A1T,A2,B1,B2
CGCM 1,2	CCC (Canadá)	3.7 × 3.7 (10)	1.8 × 1.8 (29)	A2,B2
CSIRO-Mk2	CSIRO (Australia)	5.6 × 3.2 (9)	5.6 × 3.2 (21)	A1,A2,B1,B2
ECHAM4/OPYC3	MPIM (Alemania)	2.8 × 2.8 (18)	2.8 × 2.8 (11)	A2,B2
GFDL R30 c	GFDL (EEUU)	2.25 × 3.75 (14)	1.875 × 2.25 (18)	A2,B2
HadCM3	UKMO (Reino Unido)	2.5 × 3.75 (19)	1.25 × 1.25 (20)	A1,A1FI,A2,B1,B2

Tabla 1. Características de los AOGCM, y escenarios de emisiones SRES simulados por éstos, cuyos resultados se pueden obtener del DDC-IPCC: http://ipcc-ddc.cru.uea.ac.uk/dkrz/dkrz_index.html. El tamaño horizontal de las celdillas atmosféricas y oceánicas se expresa en grados de latitud-longitud, y entre paréntesis se indica el número de niveles en la vertical.

The Climate System and Influences



AOGCM PROJECTIONS OF SURFACE TEMPERATURES

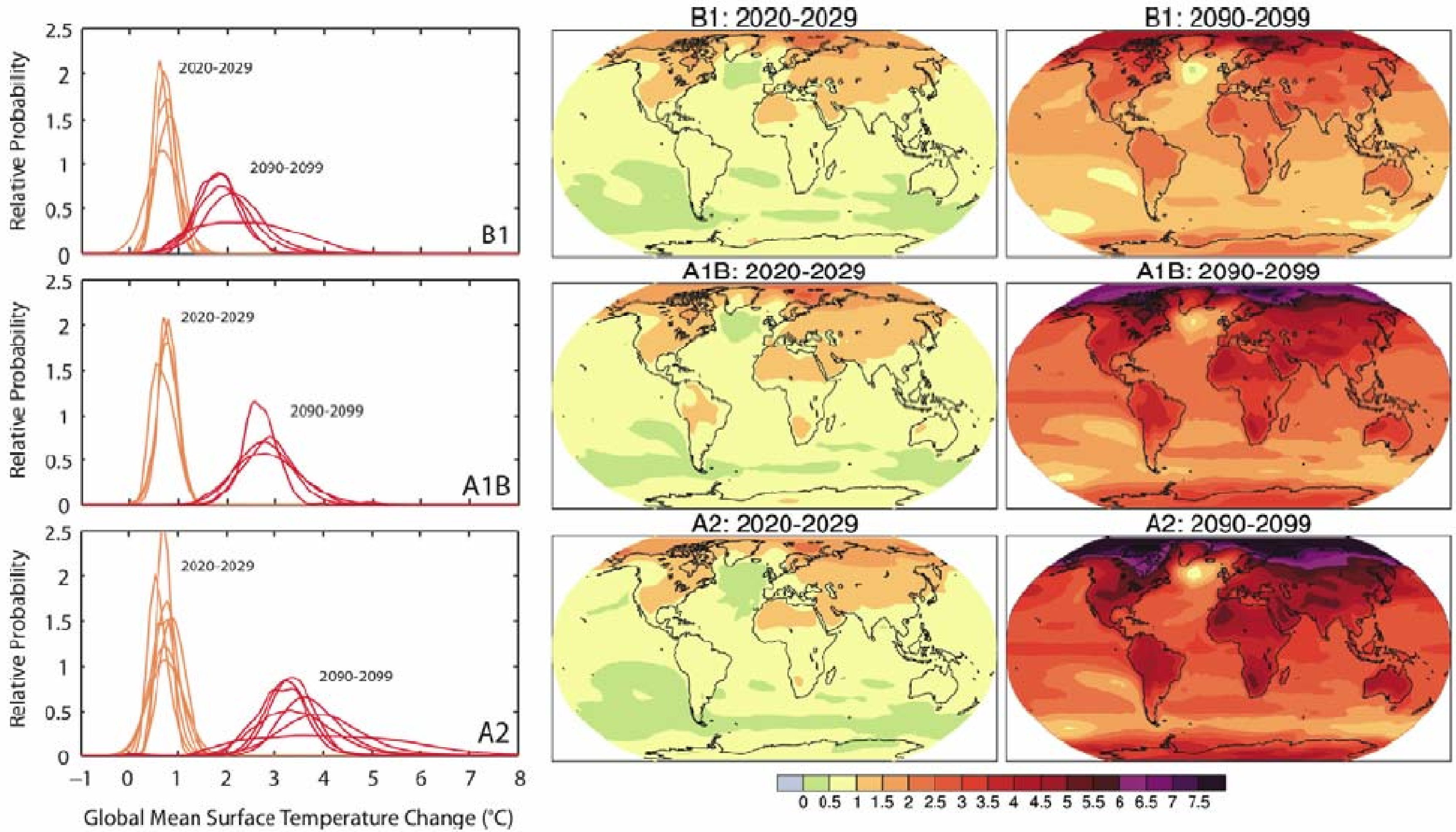


FIGURE SPM-5. Projected global average temperature changes for the early and late 21st century relative to the period 1980–1999. The central and right panels show the AOGCM multi-model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over decades 2020–2029 (center) and 2090–2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming from several different studies for the same periods. {Figures 10.8 and 10.28}

PROJECTED PATTERNS OF PRECIPITATION CHANGES

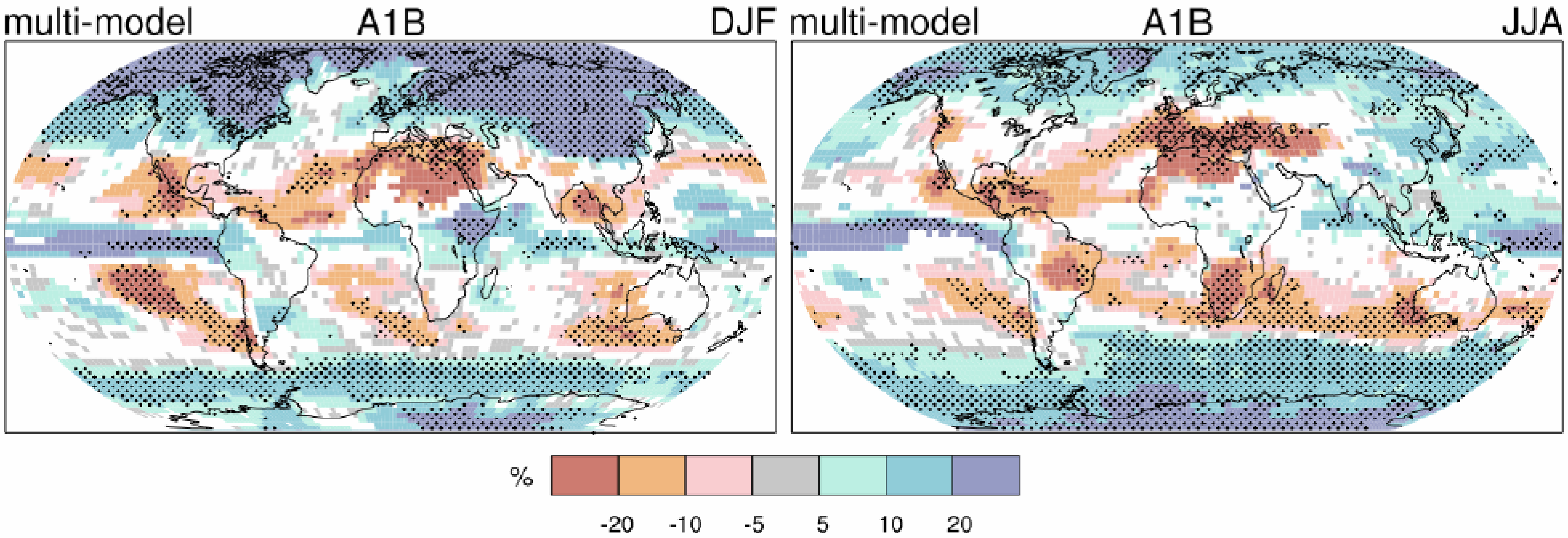


FIGURE SPM-6. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

Climate Change is Global, but …

Climate Change Impacts are Local

Regional Nature of Climate Change

Impacts

- **Water Resources**
- **Ecosystem Vulnerability**
- **Agriculture**
- **Coastal Systems**
- **Human Health**
- **Energy**

Primary Drivers

Precipitation, Winds, and Temperature

Temperature and Precipitation in the Balearic Islands: Recent trends

IPCC Fourth Assessment Report

- The **Mediterranean region** is a very sensitive area to the human-induced climate change

- **Temperature increase** during the period 1979-2005 lays between **2.5 – 3.5 ºC/century**

- **Precipitation decrease** estimated at **5 – 20 %** during the period 1901-2005 (although changes less than 3% are obtained for the period 1979-2005)

- But … large spatial variability: **sub-regional tendencies** are needed

- Great concern for a tourist pole as the **Balearic Islands**

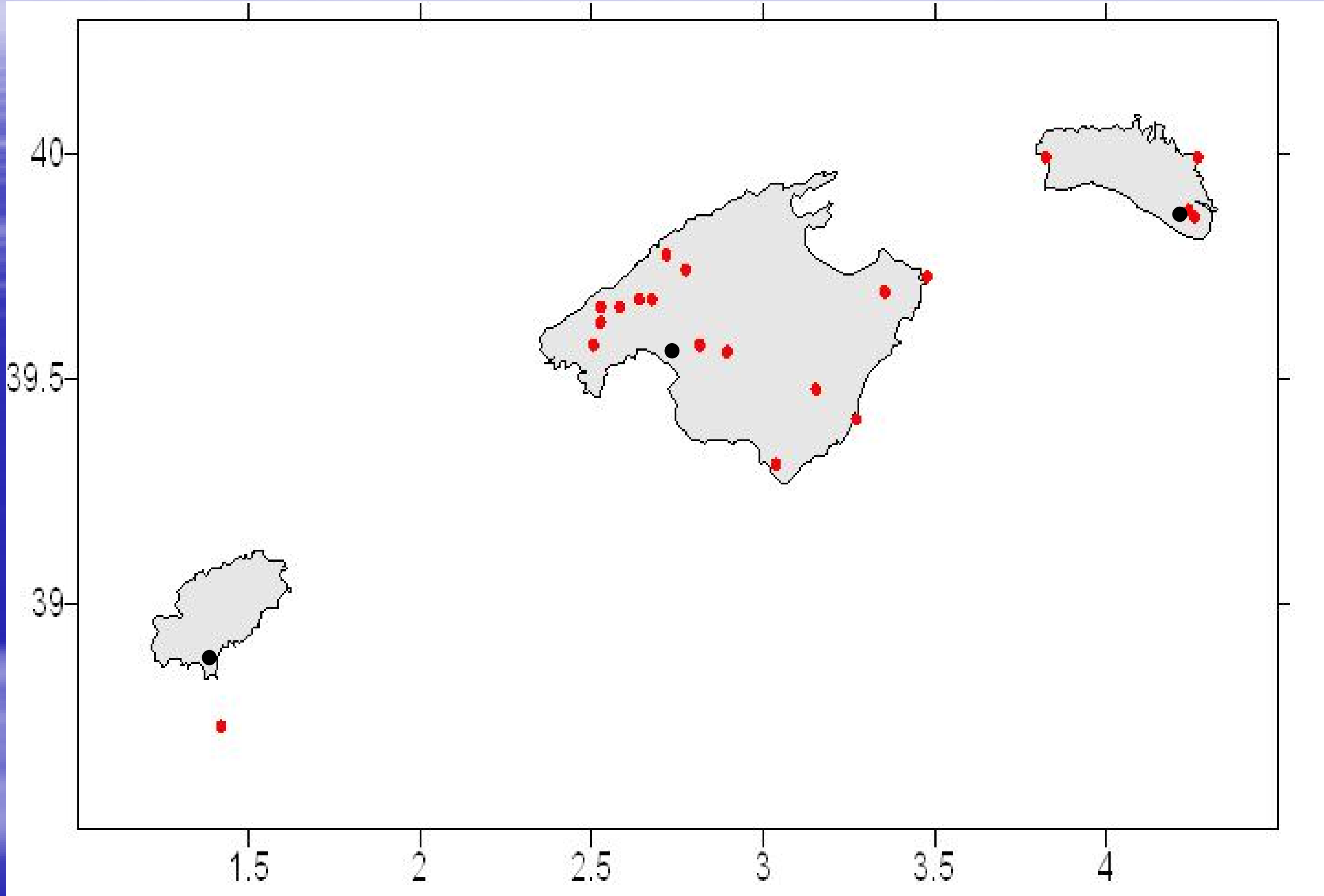
Available observations (INM)

-Temperature (1976-2006)

3 stations

- Precipitation (1951-2006)

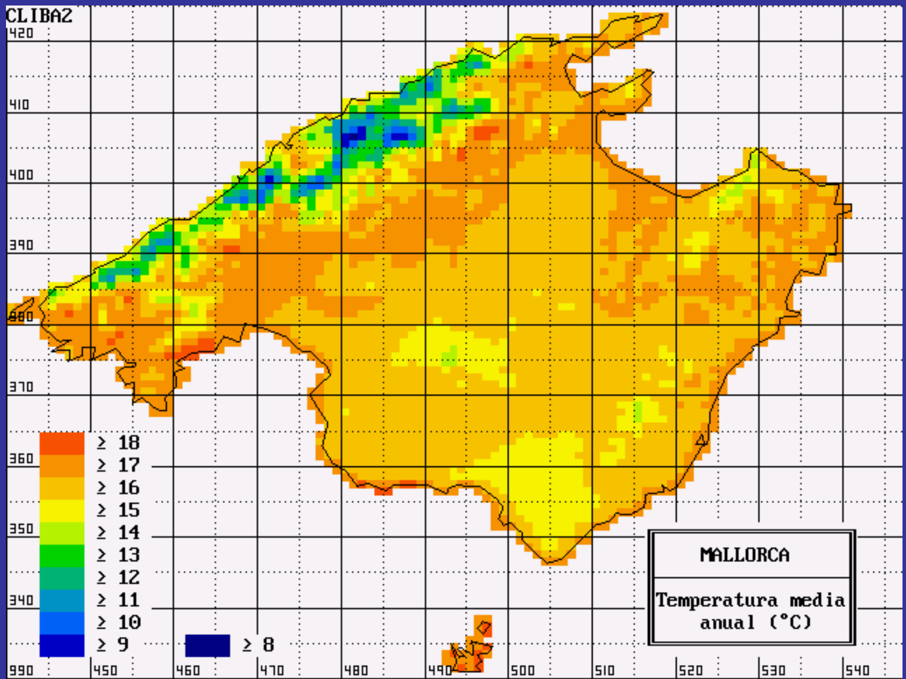
20 stations

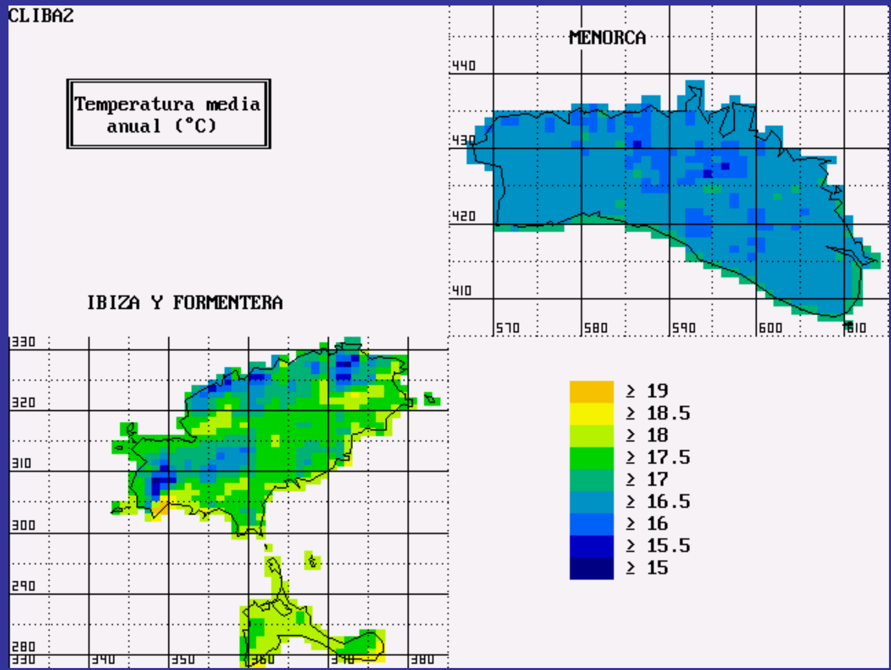


40
39.5
39
1.5
2
2.5
3
3.5
4

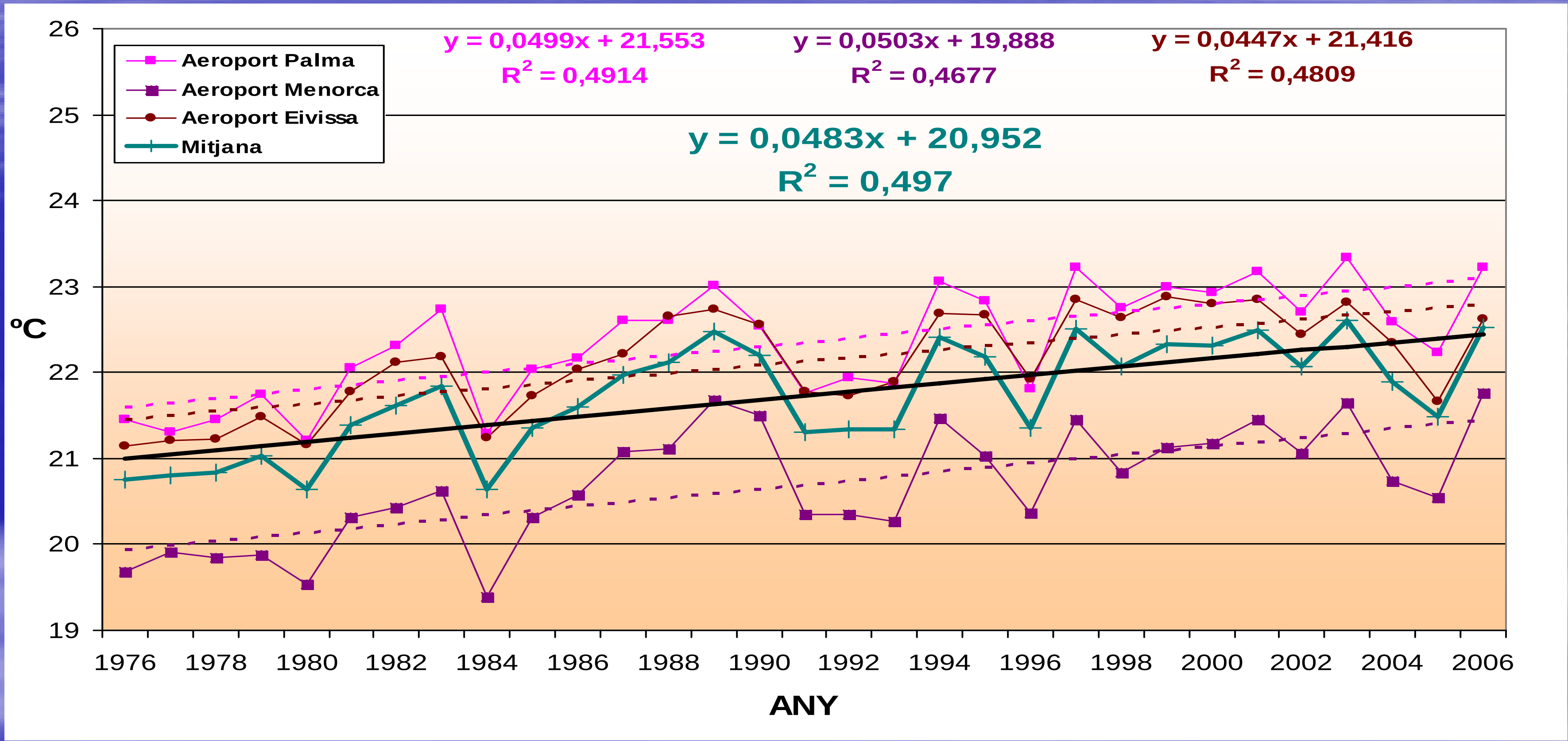
Temperature

TEMPERATURAS MEDIAS ANUALES EN LAS ISLAS BALEARES





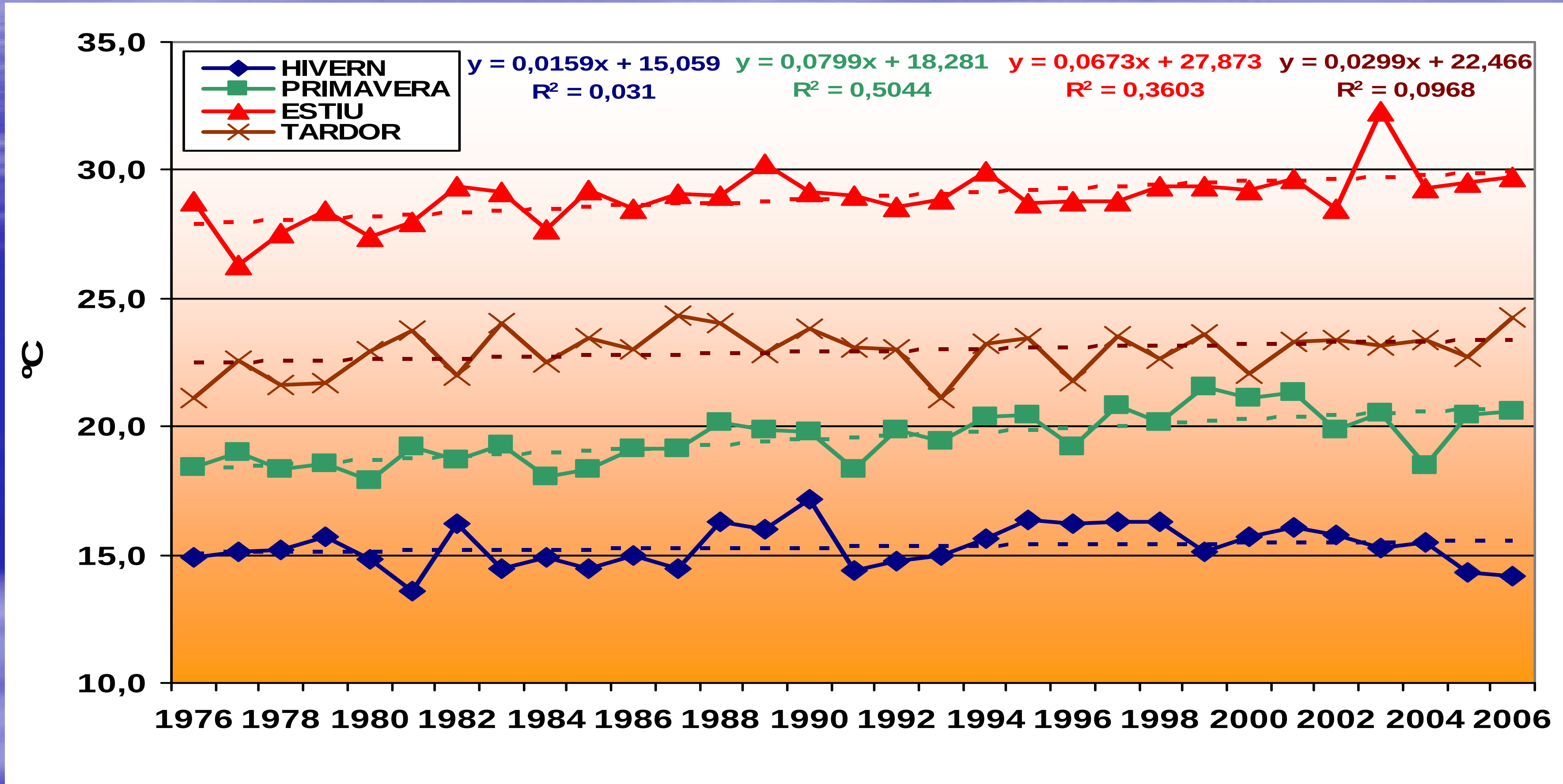
Annual-mean Max. Temp. (Islands)



Annual-mean Max. Temp. (Islands)

Station	Trend (^{O}C / 100 yr)	Statistical Confidence in "Temperature Increase"	Extremely likely range of the trend (^{O}C / 100 yr)	
			Lower limit	Higher limit
Mallorca Airport	+4.99	Virtually certain	+3.43	+6.92
Menorca Airport	+5.03	Virtually certain	+2.99	+7.07
Ibiza Airport	+4.47	Virtually certain	+2.71	+6.23
Mean	+4.83	Virtually certain	+2.98	+6.68

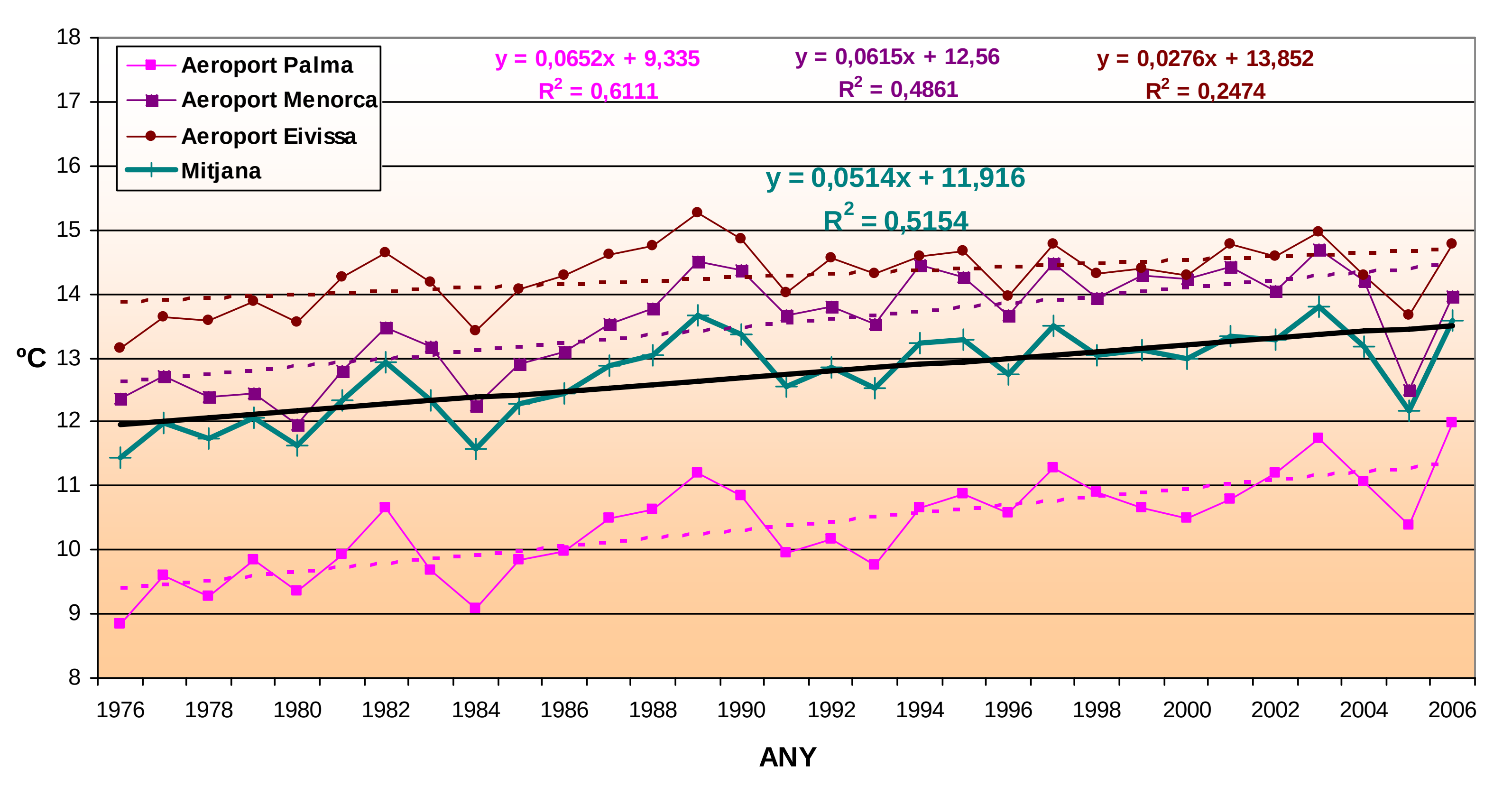
Seasonal-mean Max. Temp.



Seasonal-mean Max. Temp.

Season	Trend (°C / 100 yr)	Statistical Confidence in "Temperature Increase"	Extremely likely range of the trend (°C / 100 yr)	
			Lower limit	Higher limit
Winter	+1.59	Likely	-1.79	+4.97
Spring	+7.99	Virtually certain	+4.98	+11.00
Summer	+6.73	Virtually certain	+3.32	+10.14
Fall	+2.99	Very likely	-0.48	+6.46

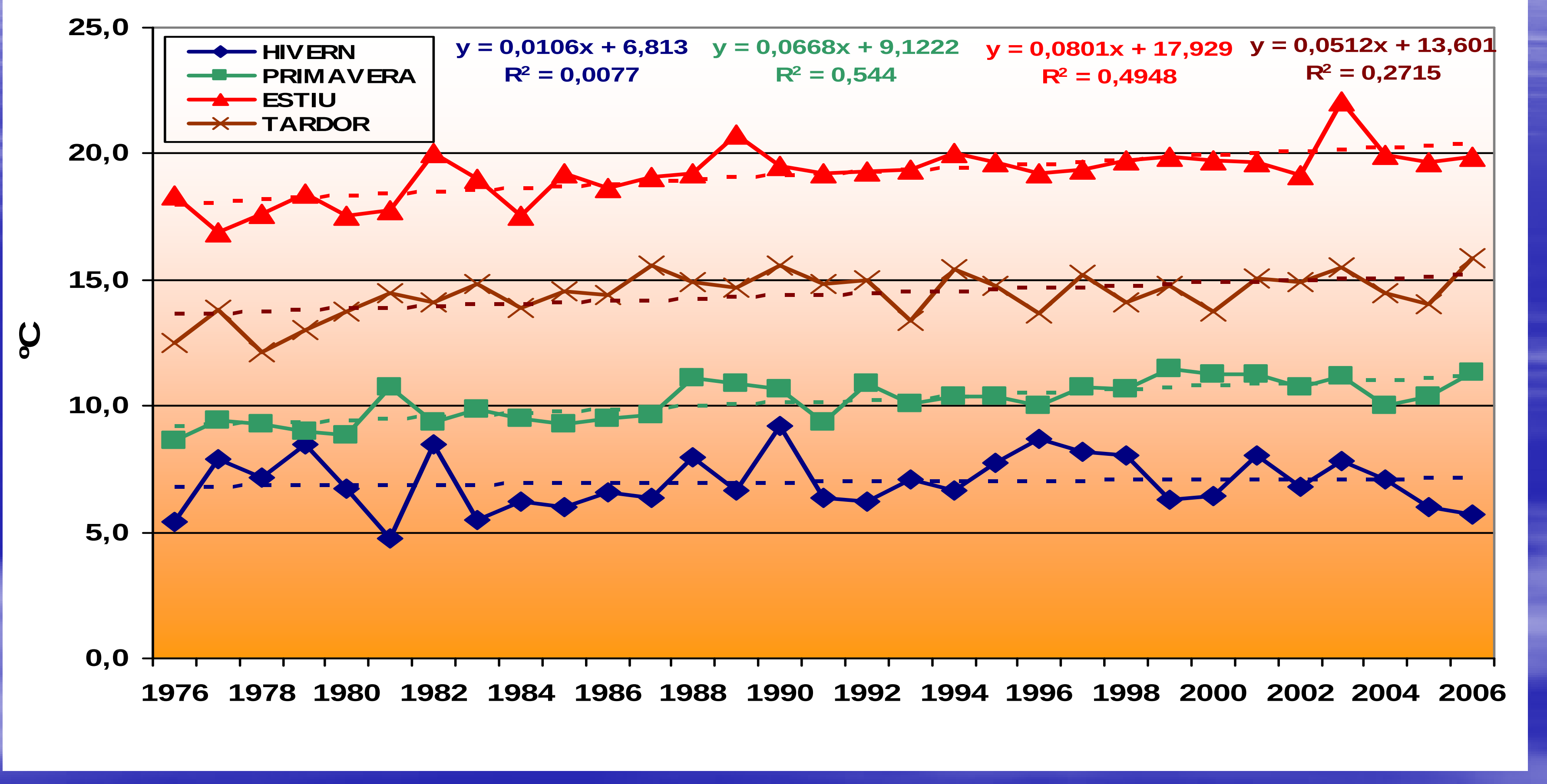
Annual-mean Min. Temp. (Islands)



Annual-mean Min. Temp. (Islands)

Station	Trend (ºC / 100 yr)	Statistical Confidence in "Temperature Increase"	Extremely likely range of the trend (ºC / 100 yr)	
			Lower limit	Higher limit
Mallorca Airport	+6.52	Virtually certain	+4.54	+8.50
Menorca Airport	+6.15	Virtually certain	+3.75	+8.55
Ibiza Airport	+2.76	Virtually certain	+0.93	+4.59
Mean	+5.14	Virtually certain	+3.25	+7.03

Seasonal-mean Min. Temp.

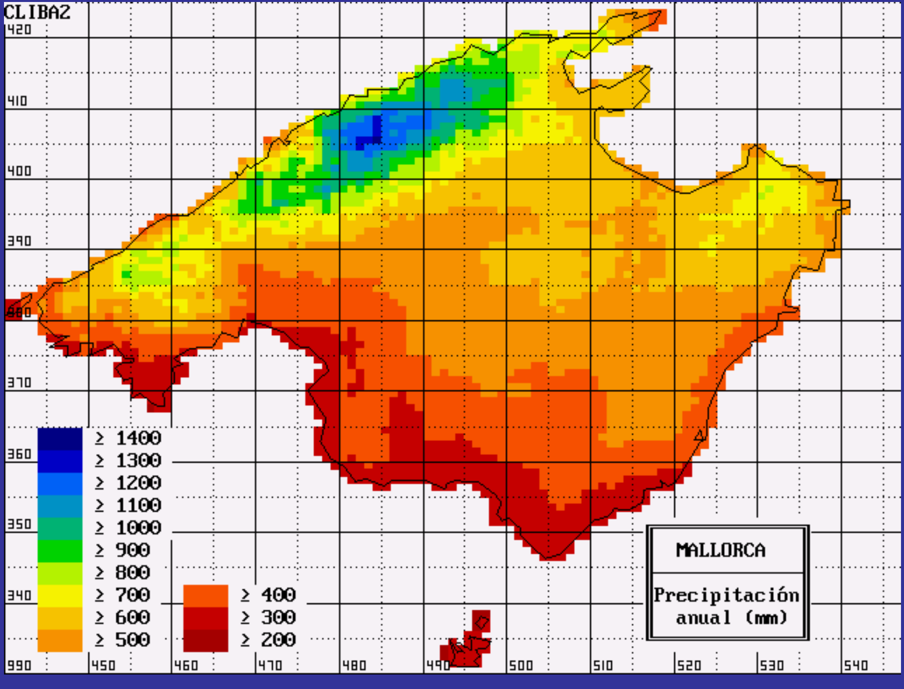


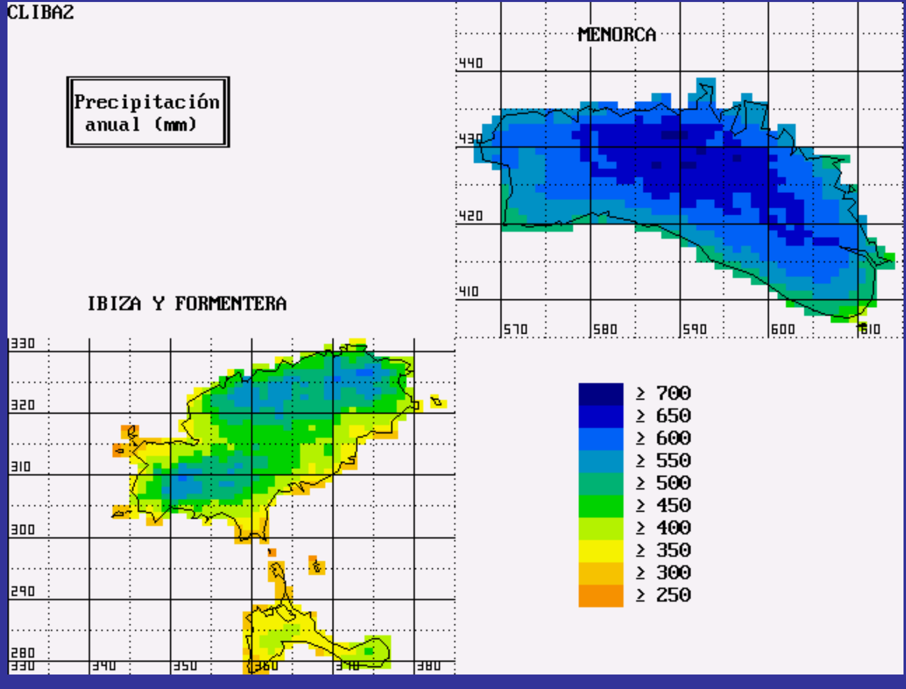
Seasonal-mean Min. Temp.

Season	Trend (°C / 100 yr)	Statistical Confidence in "Temperature Increase"	Extremely likely range of the trend (°C / 100 yr)	
			Lower limit	Higher limit
Winter	+1.06	About as likely as not	-3.51	+5.63
Spring	+6.68	Virtually certain	+4.36	+9.00
Summer	+8.01	Virtually certain	+4.94	+11.08
Fall	+5.12	Virtually certain	+1.95	+8.30

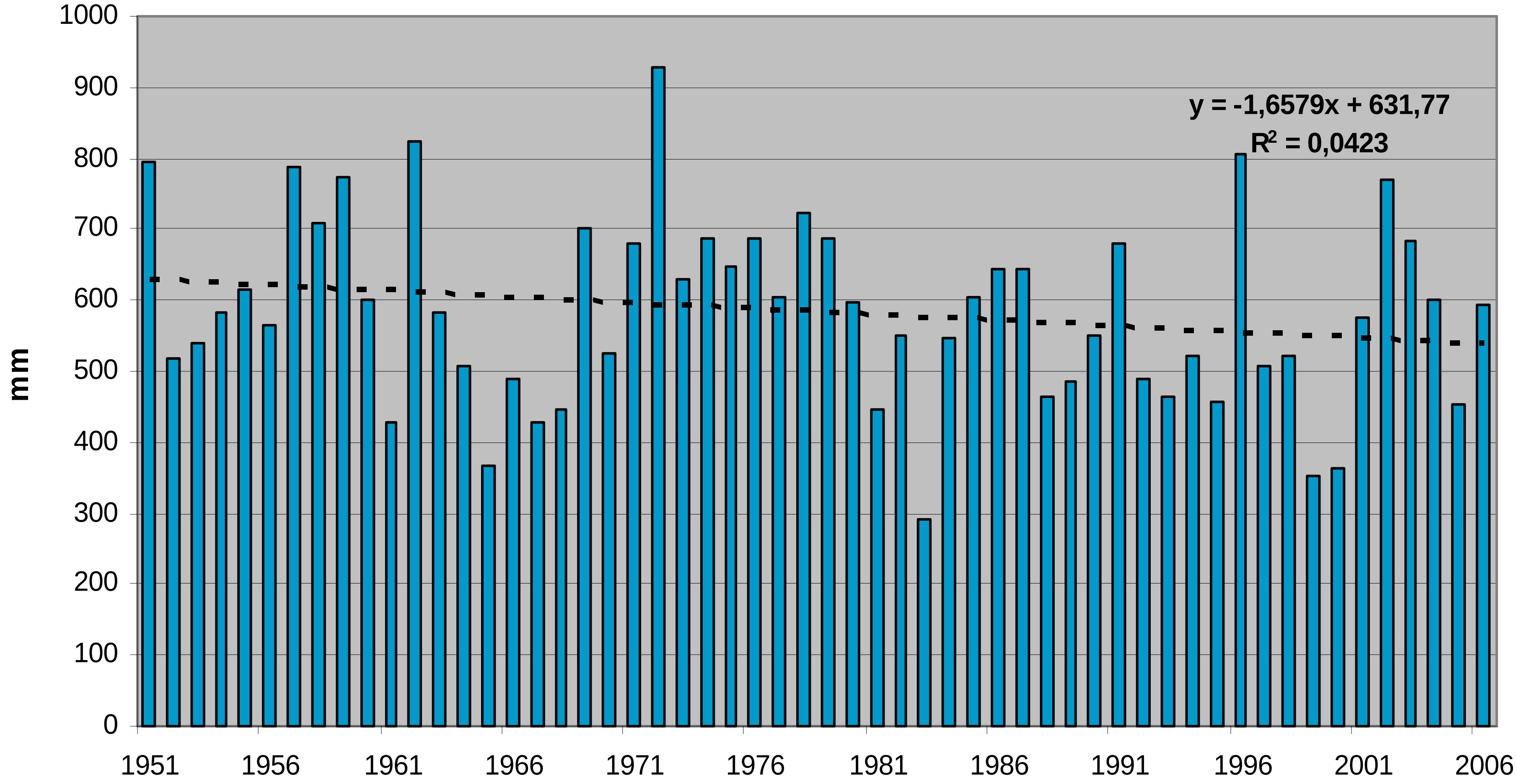
Precipitation

PRECIPITACION ANUAL MEDIA EN LAS ISLAS BALEARES

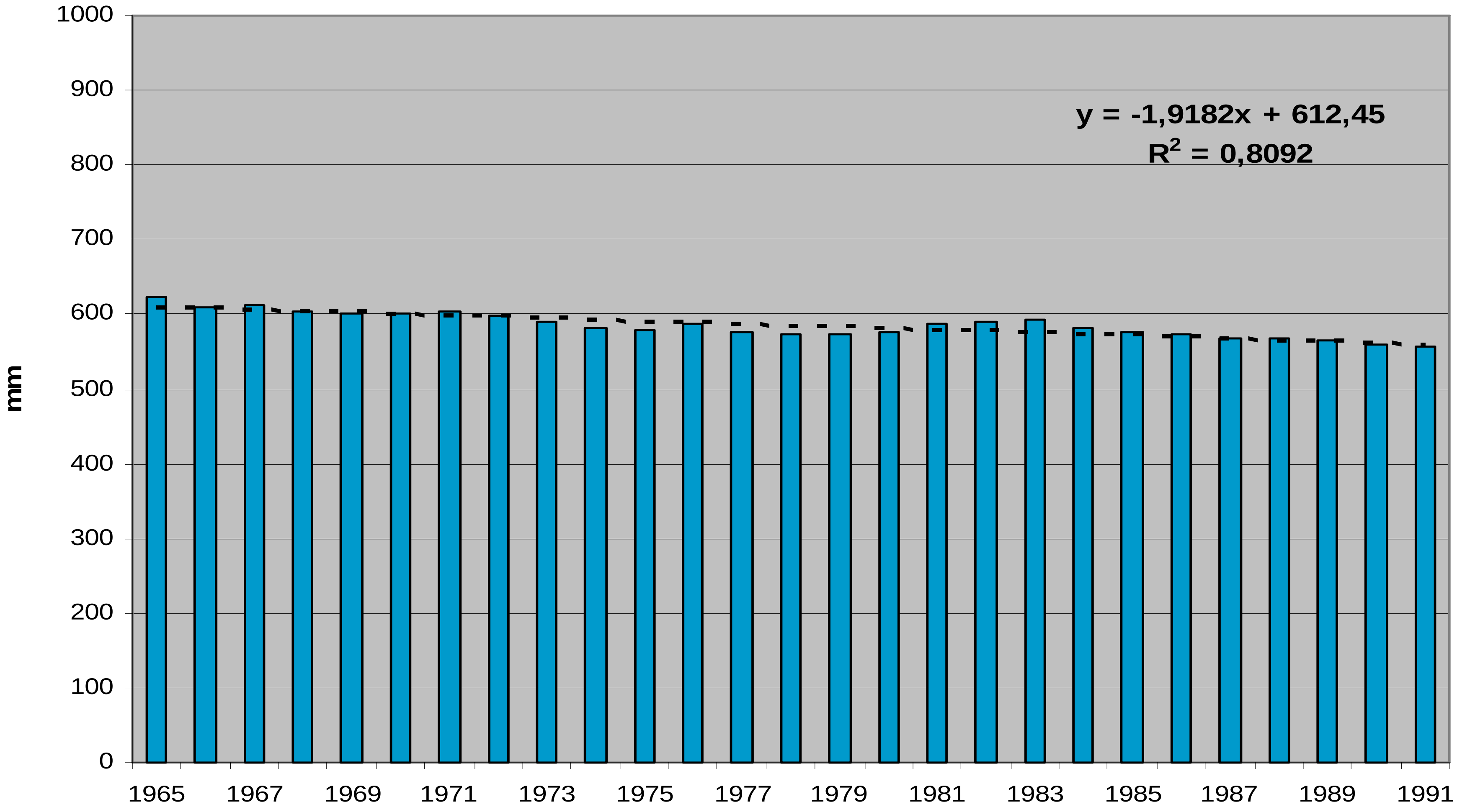




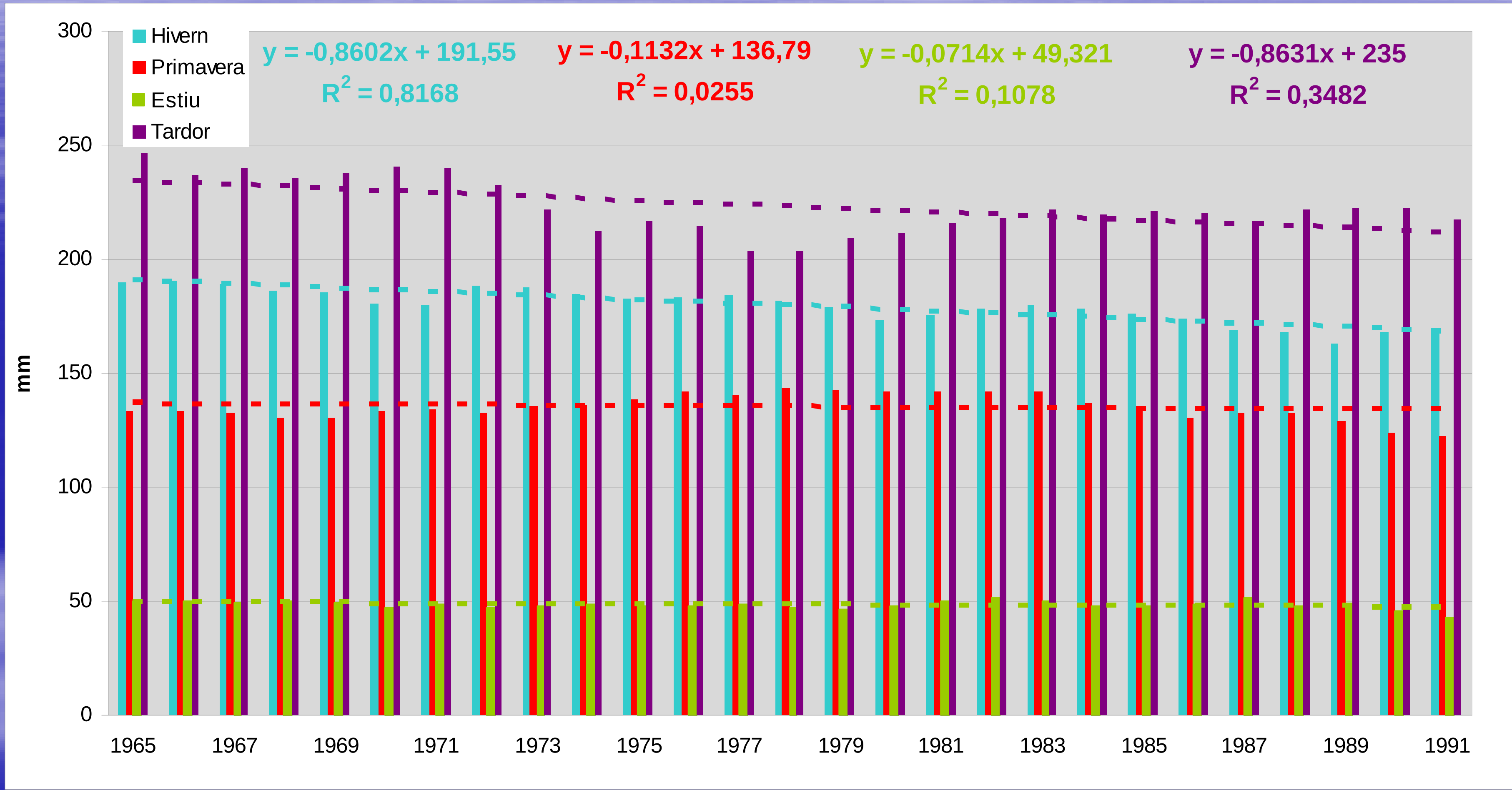
Annual-mean Precip.



Annual-mean Precip. (30-yr filter)



Seasonal-mean Precip. (30-yr filter)



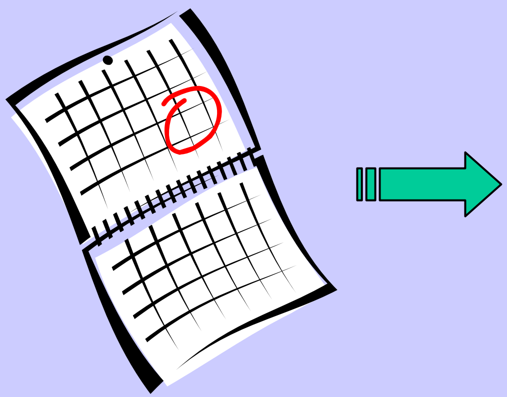
Seasonal-mean Precip. (30-yr filter)

Season	Trend (mm / 100 yr)	Statistical Confidence in "Precipitation Decrease"	Extremely likely range of the trend (mm / 100 yr)	
			Lower limit	Higher limit
Winter	-86	Virtually certain	-102	-69
Spring	-11	About as likely as not	-40	+18
Summer	-16	Very likely	-16	+1
Fall	-86	Virtually certain	-135	-38

The Problem of Scale

- ***Spatial Scales of Importance***
  - Global
  - Regional
  - State/Province
  - Watershed
  - Municipality/Metropolitan

- ***Temporal Scales of Importance***
  - Long-term climate
  - Annual
  - Seasonal
  - Monthly
  - Daily

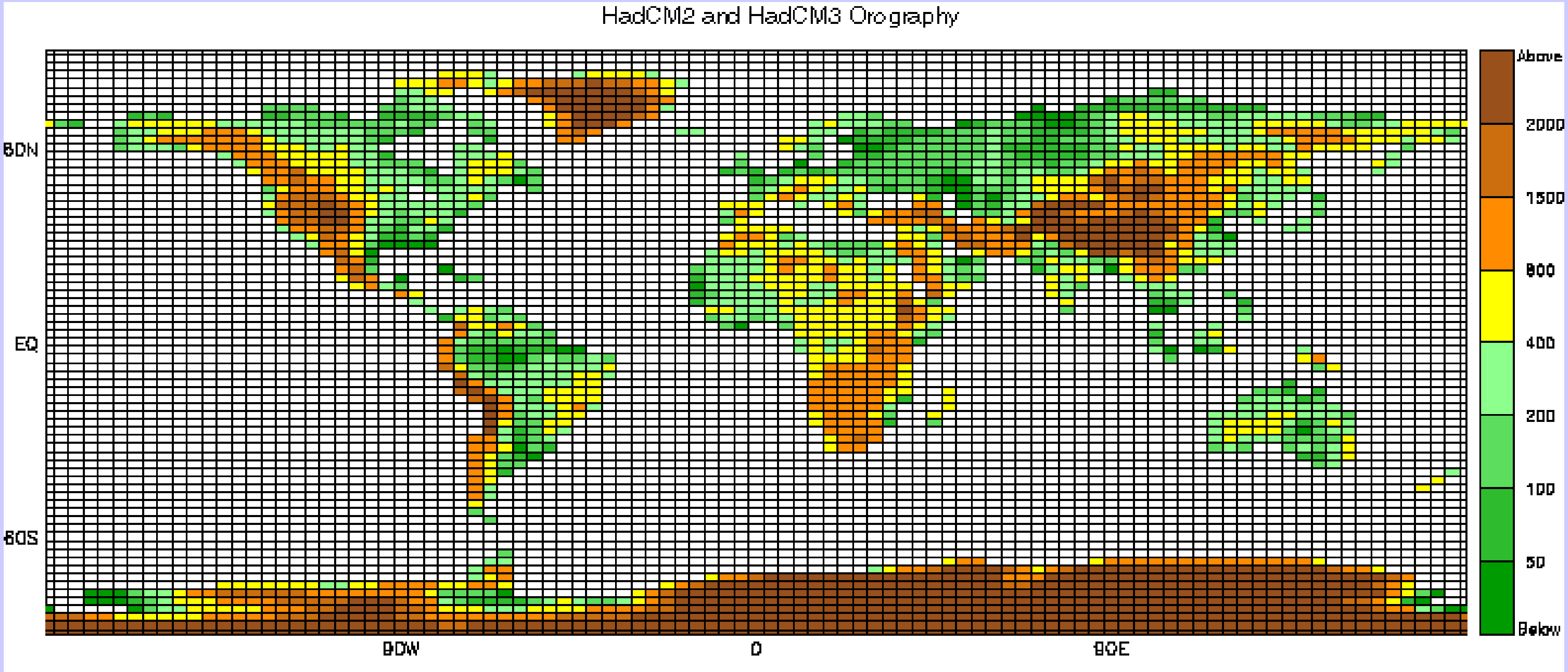


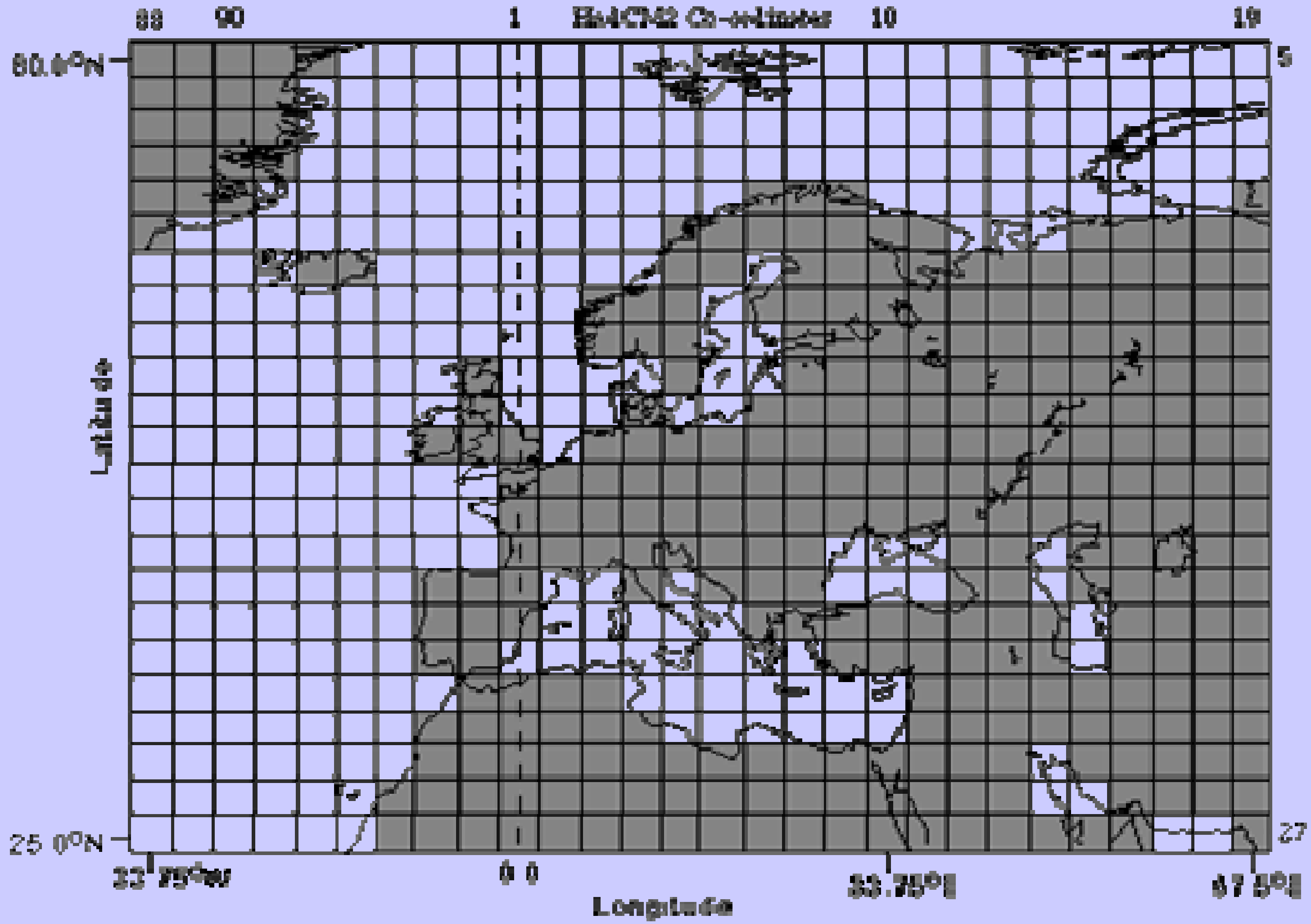
However …

Local climate is strongly influenced by local features such as mountains, sea-land transition and surface characteristics, which are not well represented in global models because of their coarse resolution.

An example: HadCM3 model

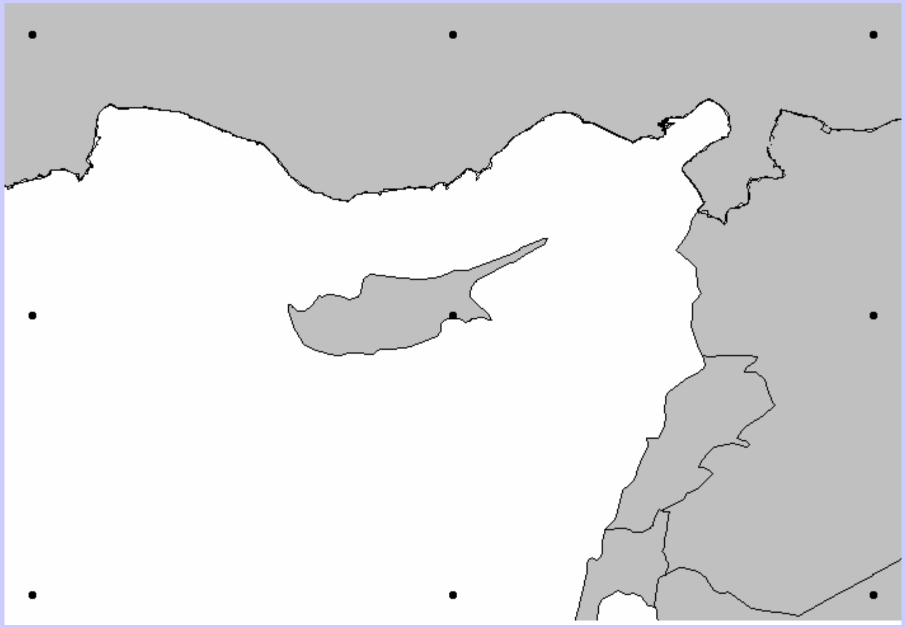
HadCM3 model is the last Hadley centre's coupled ocean-atmosphere GCM with a horizontal resolution of 2.5 x 3.75 degrees and 19 vertical levels, equivalent to a spatial resolution of 278 x 417 km in the equator, and a 278 km x 295 km in the mid latitudes (~ 45º).





Land-sea HadCM3 mask for Europe

Mediterranean islands in the HadCM3 model



What is Downscaling?

- ***Downscaling:***
  - **Direct** prediction of surface variables from GCMs is difficult at sub-continental scales and at high temporal resolutions
  - Downscaling tools combine various output from GCMs with observational data to **improve** spatial and temporal accuracy of climate change scenarios

- ***Types:***
  - **Statistical** Downscaling
  - **Dynamical** Downscaling
  - **Hybrid** Statistical/Dynamical Downscaling

Dynamical Downscaling Assumptions/Methods

- **GCM** output at large aggregate scales is useful for providing boundary conditions for nested models. These nested, higher-resolution models are called **RCM**, and include complex physical parameterizations

- Nesting is usually one-way with no feedback from mesoscale to GCM scale

- Transient run simulations can be accomplished, but are cumbersome

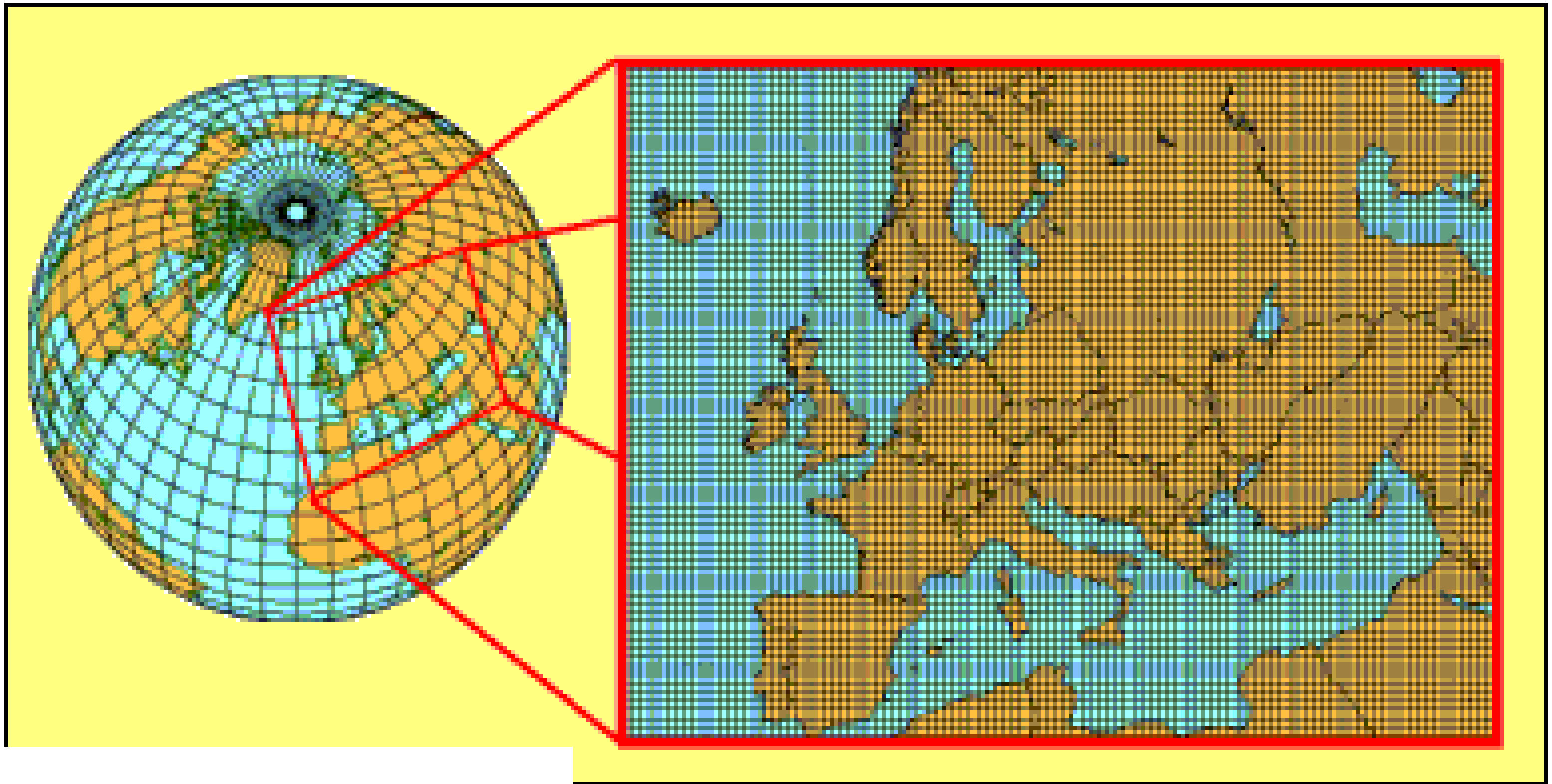
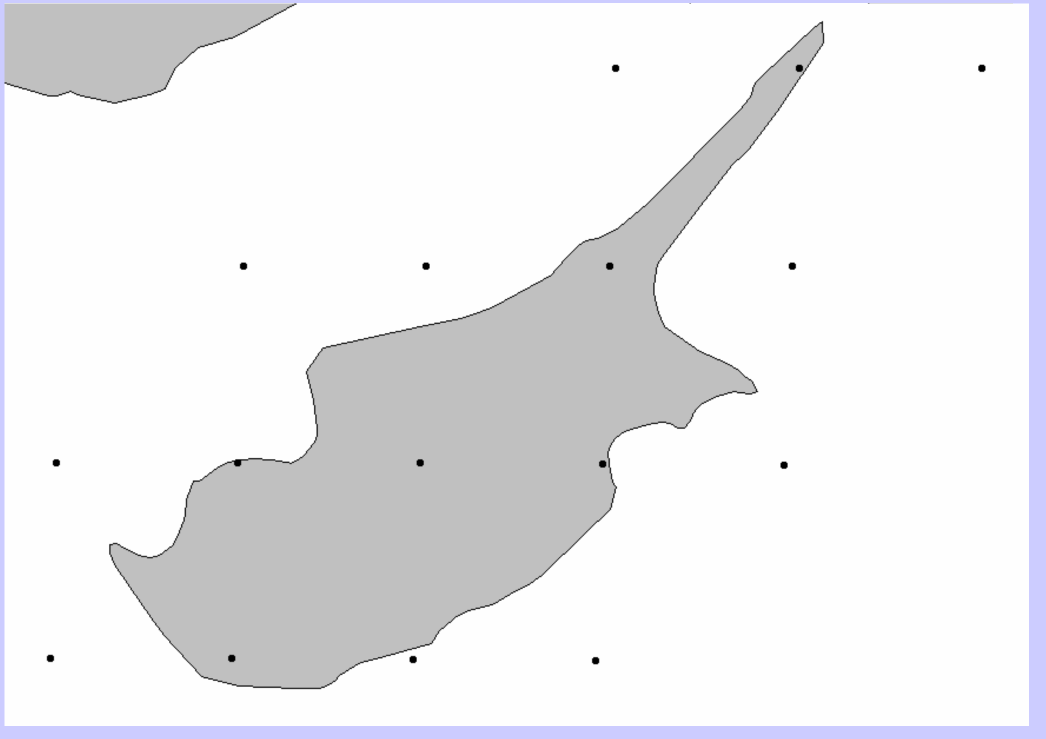


Figura 9. Ejemplo del dominio de aplicación de un RCM sobre Europa con una rejilla de 50 km. La técnica de anidamiento ("nesting") consiste en proporcionar al RCM información de la evolución de las variables atmosféricas en los puntos del contorno del dominio. Dicha información se obtiene previamente de la simulación con un AOGCM que utiliza una rejilla con resolución más baja (celdillas con mayor tamaño)

Mediterranean islands in the HadRM3 (~ 50 km) model

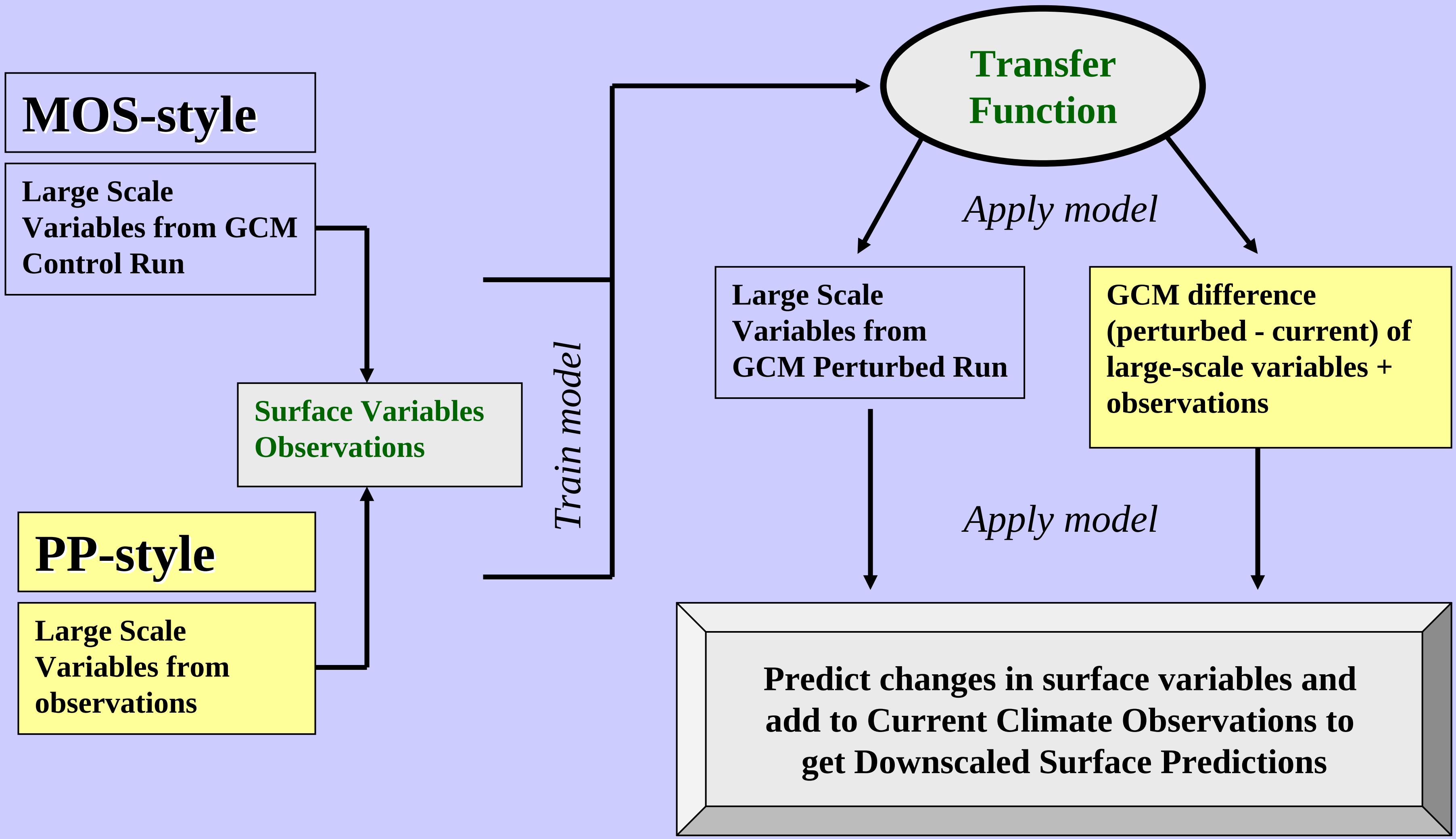


Statistical Downscaling Assumptions and Observations

- Surface parameters are not well-modeled by GCMs.
- High resolution spatial and temporal scales are not well-represented by GCM grid cell output

- Large-scale parameters are well-modeled by GCMs
- Strong physical relationships exist between large-scale forcing parameters and high spatial/temporal resolution surface variables.

Statistical Downscaling Methodologies



Transfer Function Options

- **Multiple Linear Regressions**
  - works well for continuous variables such as temperature
  - simple and relatively easy to interpret
- **Neural Networks**
  - capable of simulating non-linear and unknown functional relationships
  - black box in terms of interpretation
- **Classification and Regression Trees**
  - different types of weather patterns are separated
  - models are generated within weather patterns
  - good for non-continuous variables such as precipitation

Precipitation Downscaling: A Challenge

- **Precipitation events are**
  - Discontinuous with skewed distributions
  - Spatially and temporally non-homogeneous
  - Difficult to model with traditional approaches (precipitation generation depends on many spatial and temporal scales)

Modelos regionales	Anidamiento en HadAM3H			Anidamiento en ECHAM4		
	Control	A2	B2	Control	A2	B2
CNRM	x	x	x			
DMI	x	x	x	x	x	x
ETH	x	x				
GKSS	x	x				
HC	x	x				
ICTP	x	x	x			
KNMI	x	x				
MPI	x	x				
SMHI	x	x	x	x	x	x
UCM	x	x	x			

Tabla II.- Proyecciones regionalizadas basadas en modelos regionales del clima procedentes del proyecto PRUDENCE. Las simulaciones realizadas por cada modelo regional se identifican por el centro o instituto donde se ha desarrollado.

	Modelos globales				
Métodos empíricos	ECHAM4	HadCM3	HadAM3H	CGCM2	HadCM2SUL
Analog(FIC)	A2, B2		A2,B2	A2,B2	
Analog(INM)	A2, B2		A2	A2,B2	IS92a
SDSM		A2,B2			

Tabla I.- Proyecciones regionalizadas con métodos estadísticos disponibles. Los datos diarios de las proyecciones se refieren al periodo 2011-2100 y el periodo de control al periodo 1961-1990 y a las variables: precipitación, temperatura máxima y temperatura mínima. Los métodos Analog(FIC) y SDSM presentan los resultados en las estaciones, mientras que el método Analog(INM) presenta los resultados en una rejilla regular de 50 km.

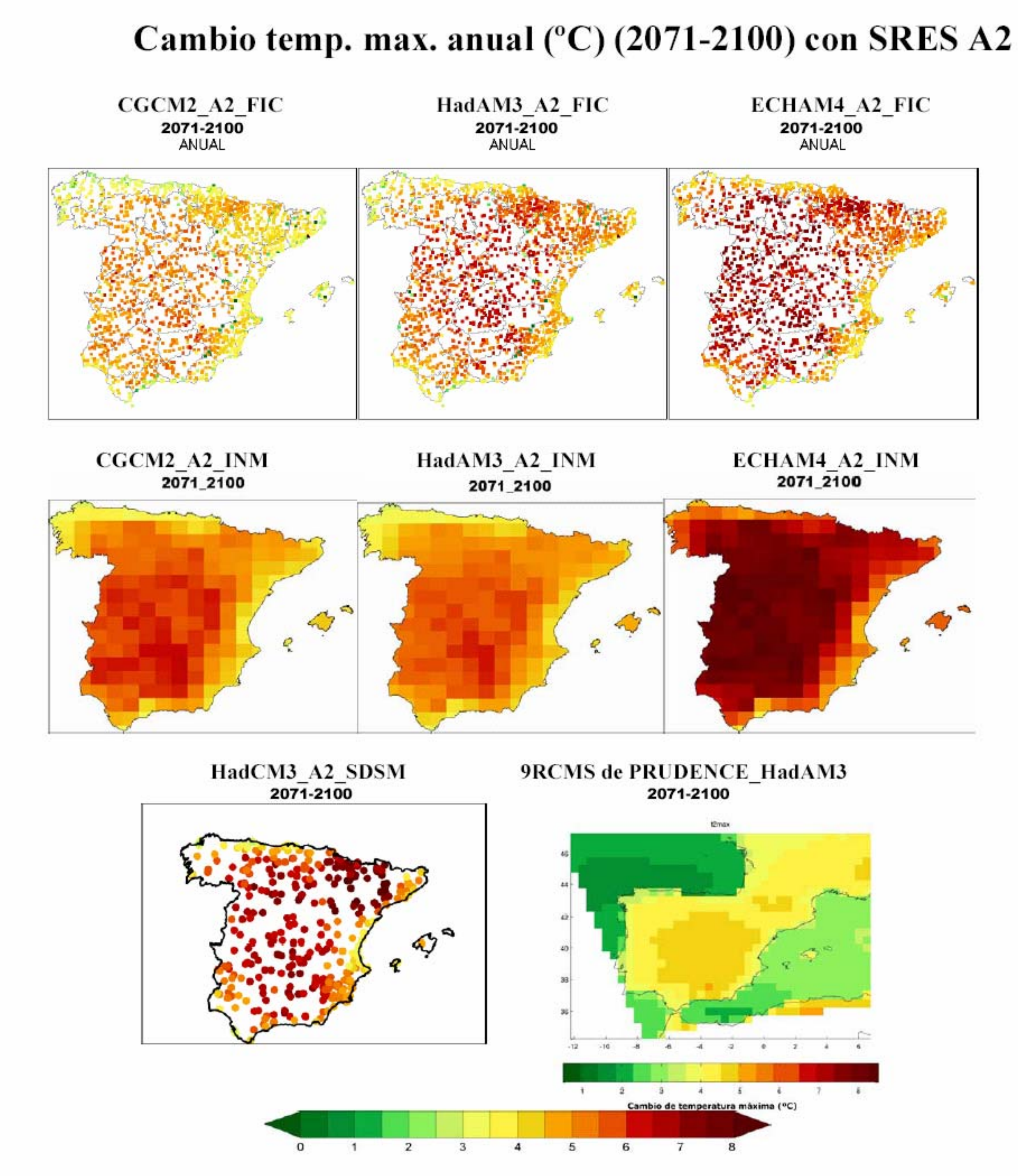


Fig. 1.- Comparación del cambio de temperatura máxima anual para el período (2070-2100) respecto al periodo de control (1961-90) proporcionado por las proyecciones regionalizadas utilizando diferentes modelos globales (HadCM3, HadAM3H, HadCM2SUL, CGCM2, ECHAM4-OPYC), el escenario de emisión A2 del SRES-IPCC y diferentes técnicas de regionalización estadísticas (Anal_FIC, Anal_INM, SDSM) y dinámicas (promedio de los 9 RCMs de PRUDENCE).

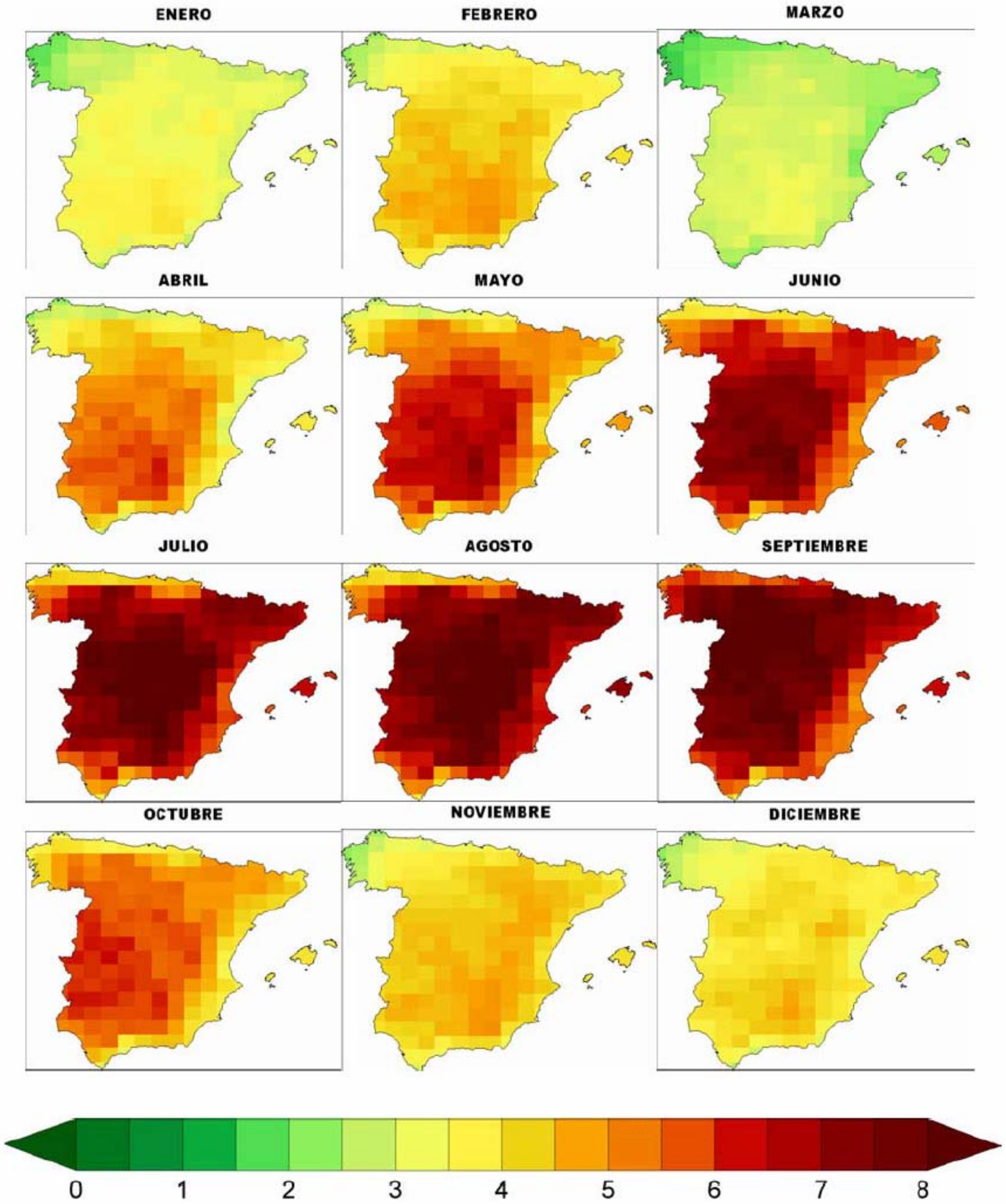


Fig.2.- Cambio medio mensual proyectado para el periodo (2071-2100) respecto al clima actual (1961-1990) por el modelo global HadAM3H y regionalizado con el método de análogos (INM) para la temperatura máxima y el escenario de emisión A2.

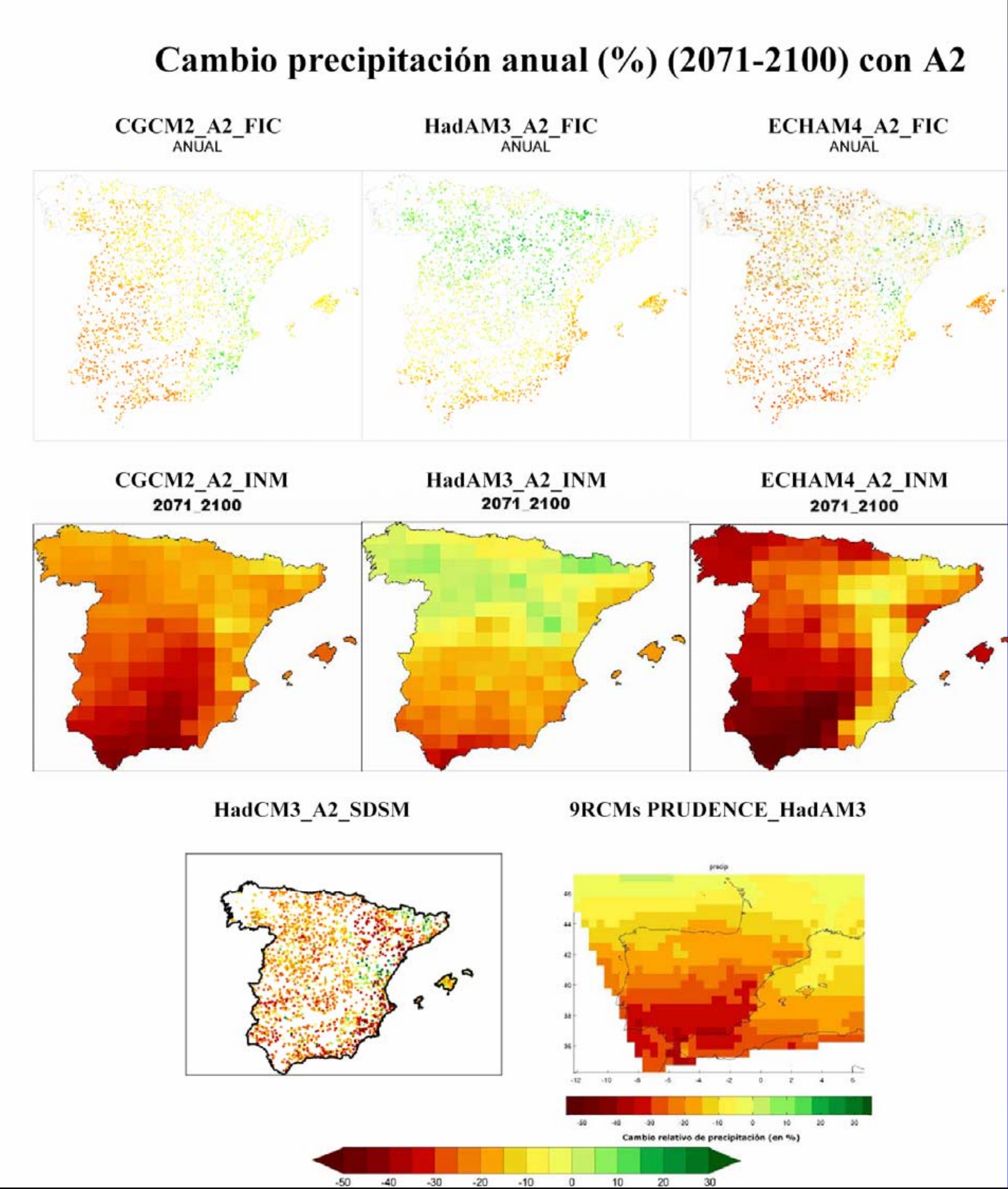


Fig. 3.- Comparación del cambio de precipitación anual para el período (2070-2100) respecto al periodo de control (1961-90) proporcionado por las proyecciones regionalizadas utilizando diferentes modelos globales (HadCM3, HadAM3H, CGCM2, ECHAM4-OPYC), para el escenario de emisión A2 del SRES-IPCC y diferentes técnicas de regionalización estadísticas (Anal_FIC, Anal_INM, SDSM) y dinámicas (promedio de los 9 RCMs de PRUDENCE).

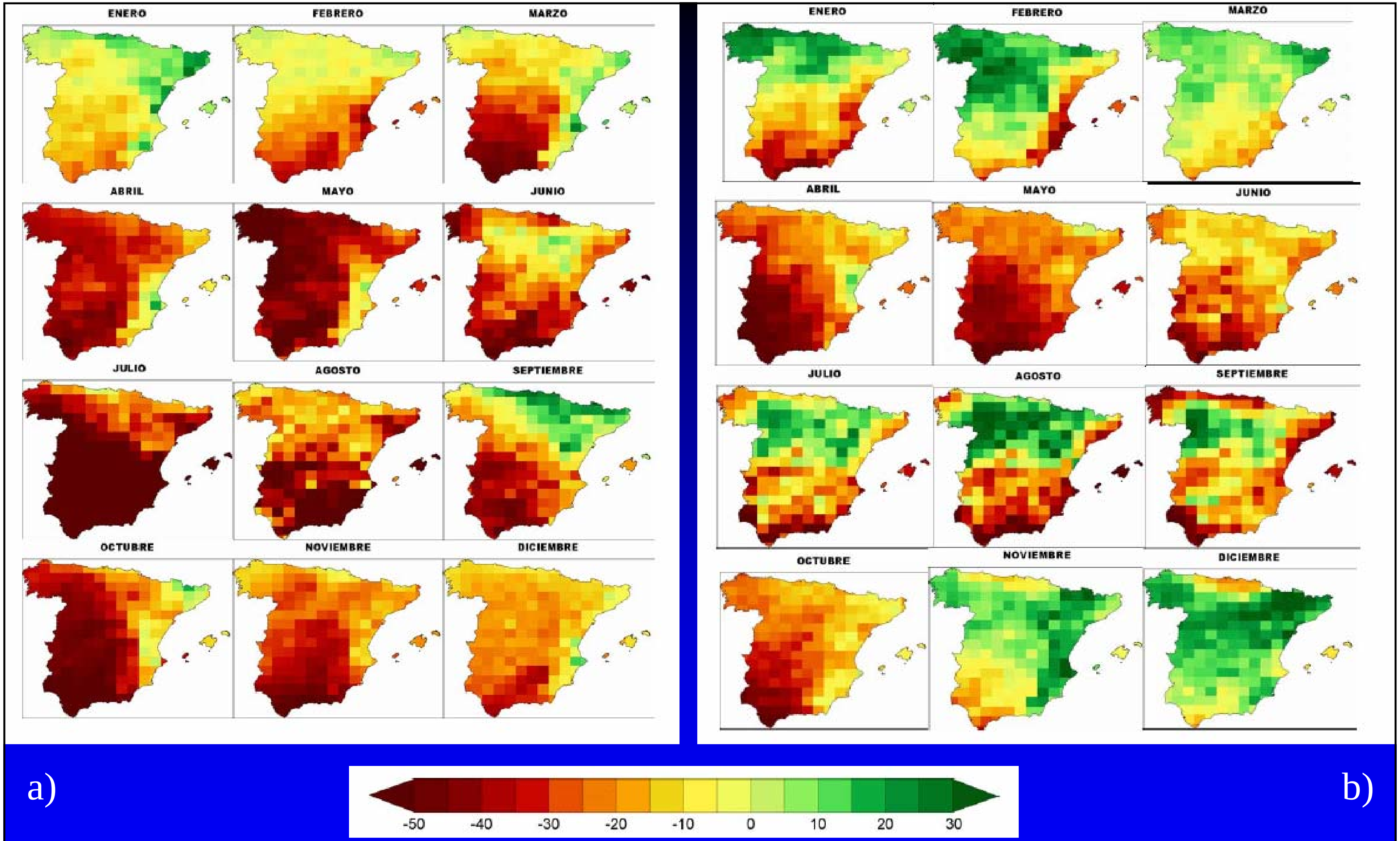


Fig.4.- Cambio de distribución mensual de precipitación (%) para el periodo (2071-2100) respecto al periodo de referencia (1961-1990) para los modelo globales CGCM2 (a) y HadAM3H (b), regionalizados ambos con el método de análogos (INM) con el escenario de emisión A2.

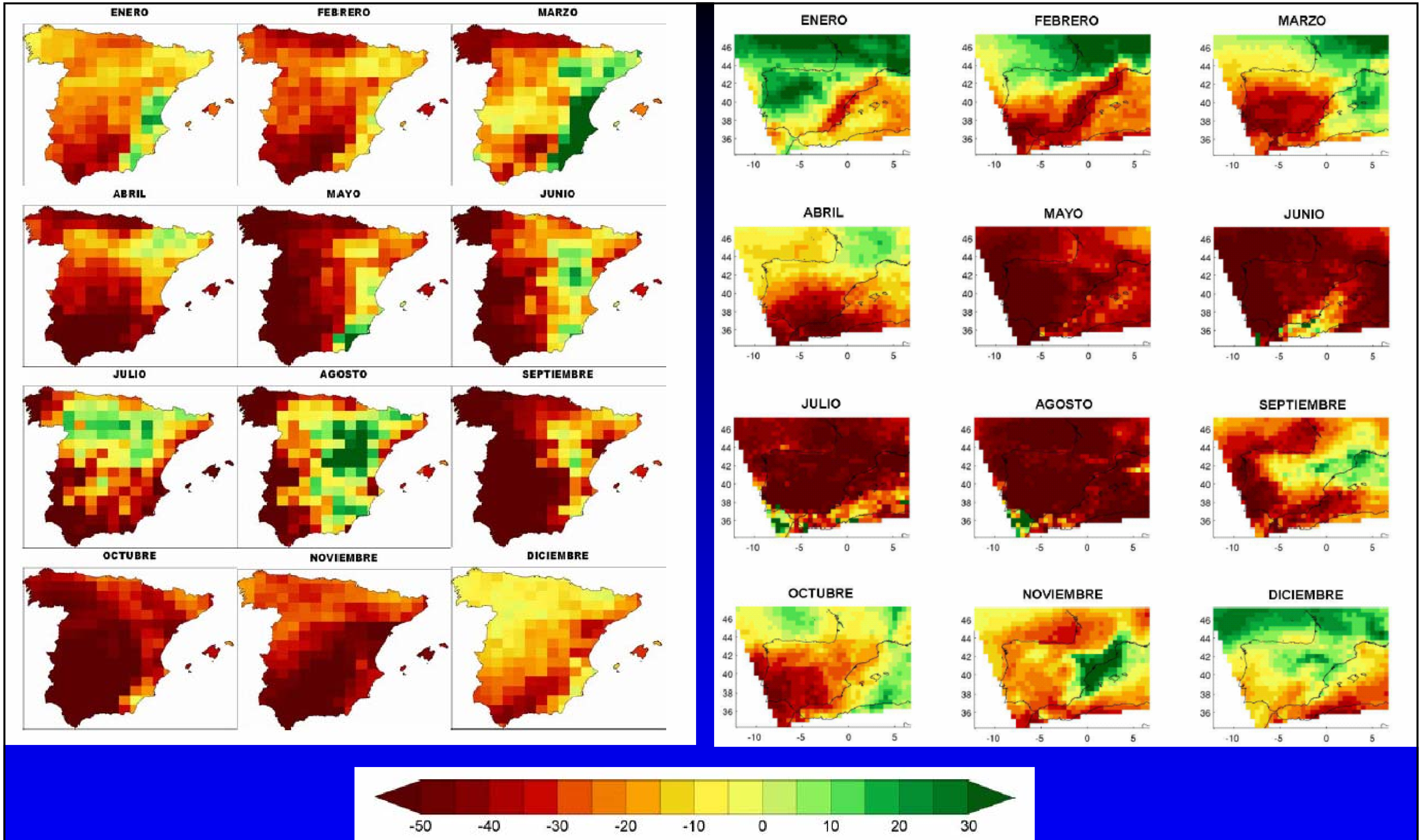


Fig.5.- Igual que fig.4, pero para el modelo ECHAM4-OPYC.

Fig.6.- Igual que fig. 4, pero para el promedio de los 10 modelos regionales de clima de PRUDENCE (incluido el modelo ARPEGE de resolución variable del CNRM).

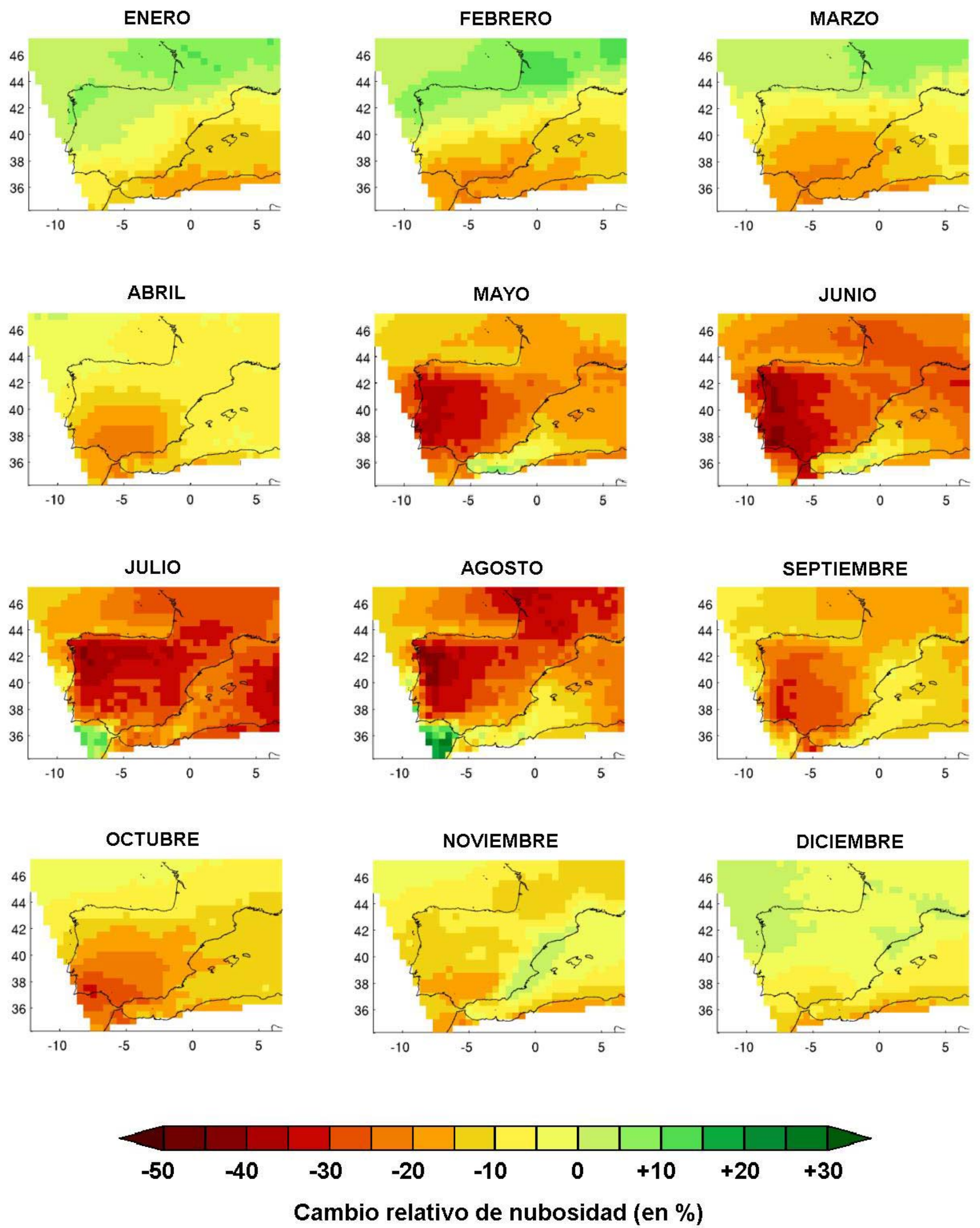


Fig.7.- Distribución mensual del cambio medio porcentual de nubosidad proyectado por los diez modelos regionales PRUDENCE en el escenario A2 (2071-2100) respecto al clima actual (1961-1990).

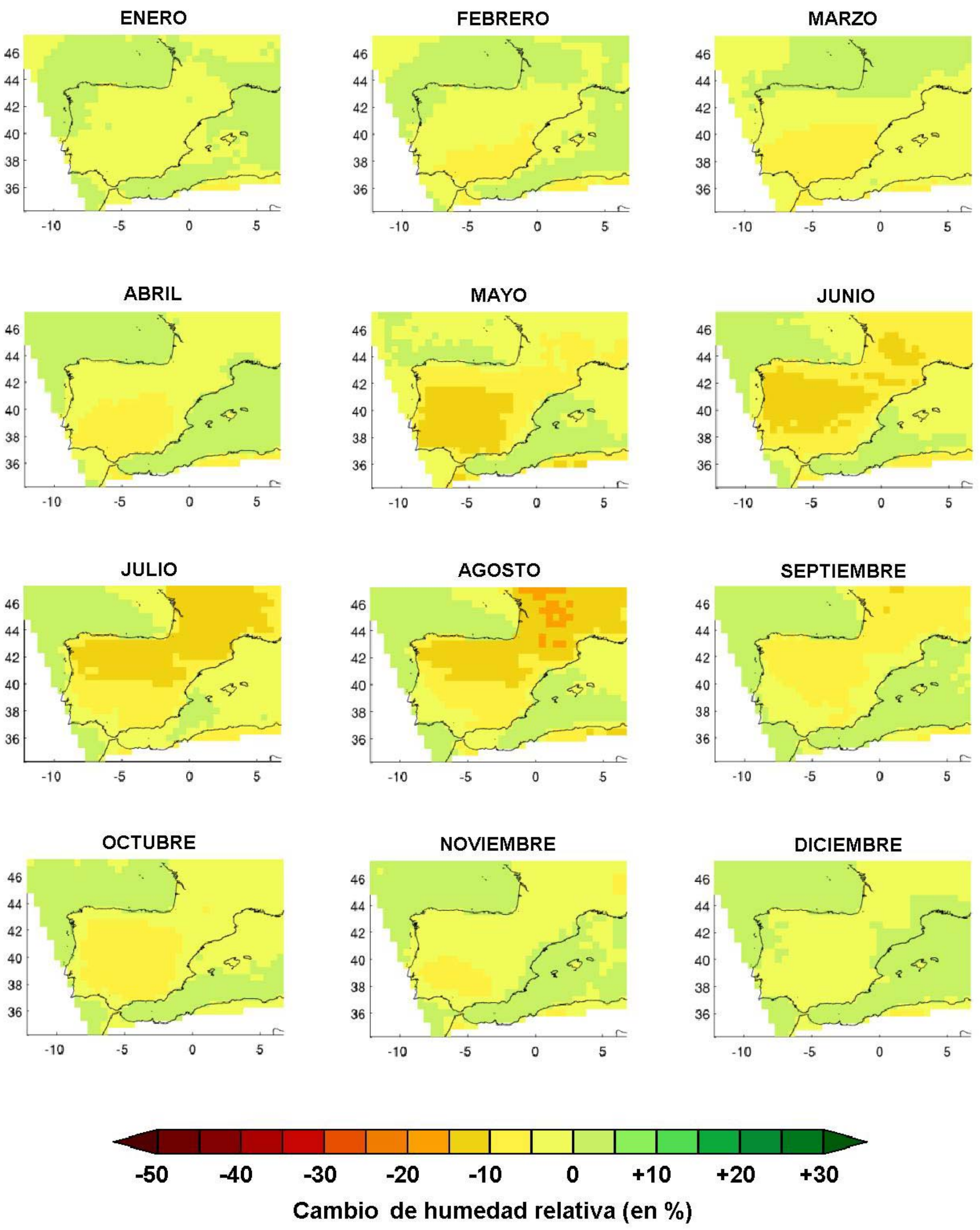
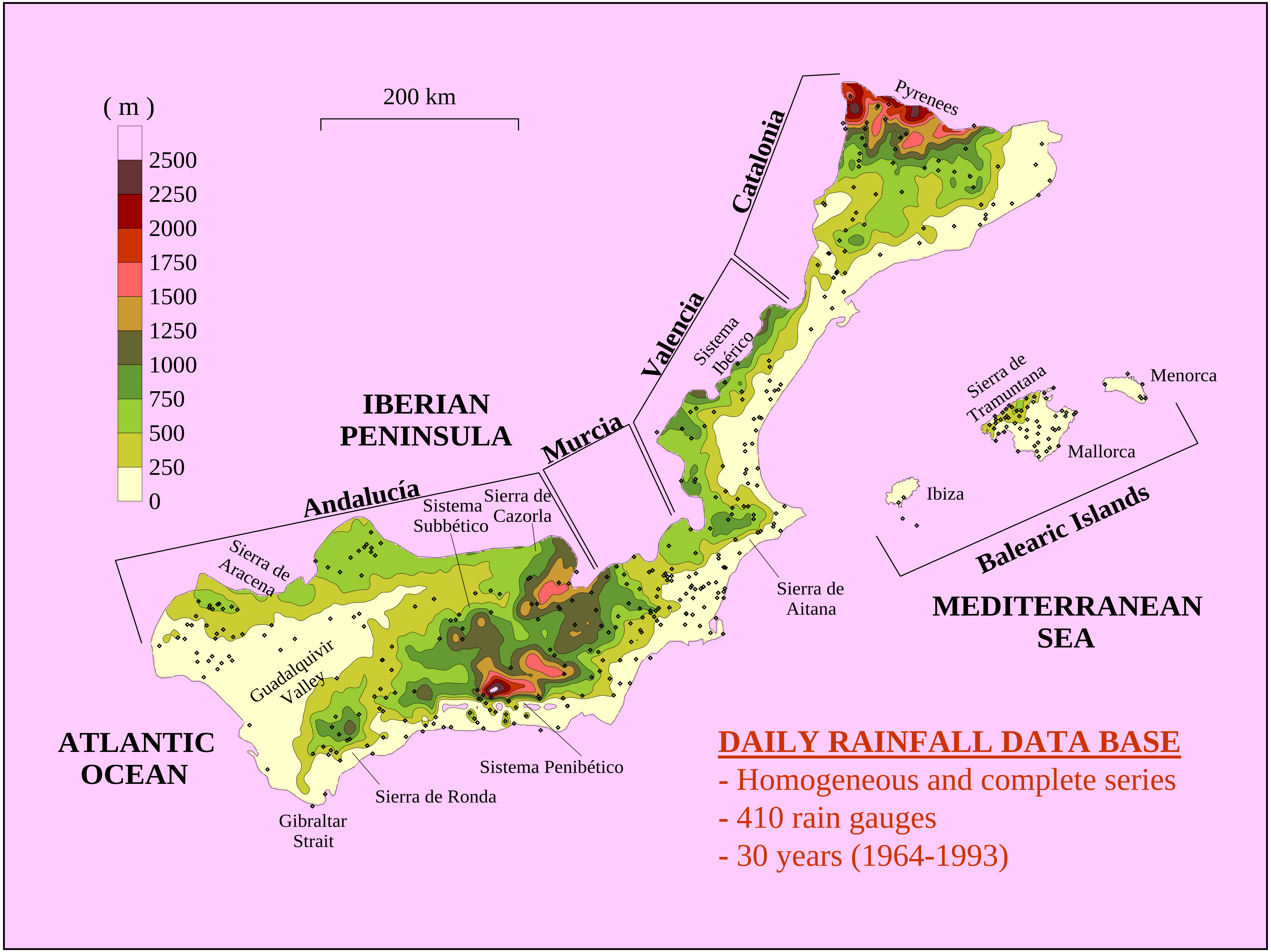


Fig.8.- Distribuciones mensuales del cambio medio de humedad relativa proyectado por los diez modelos regionales PRUDENCE en el escenario A2 (2071-2100) respecto al clima actual (1961-1990).

ATMOSPHERIC CIRCULATION AND PRECIPITATION IN MEDITERRANEAN SPAIN

Trying to find the cause-effect statistical relationship …


(m)
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
200 km
IBERIAN PENINSULA
Catalonia
Pyrenees
Valencia
Sistema Ibérico
Murcia
Andalucía
Sistema Subbético
Sierra de Cazorla
Sierra de Aracena
Guadalquivir Valley
Sierra de Aitana
Sistema Penibético
Sierra de Ronda
Gibraltar Strait
ATLANTIC OCEAN
Sierra de Tramuntana
Menorca
Mallorca
Ibiza
Balearic Islands
MEDITERRANEAN SEA
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

↓

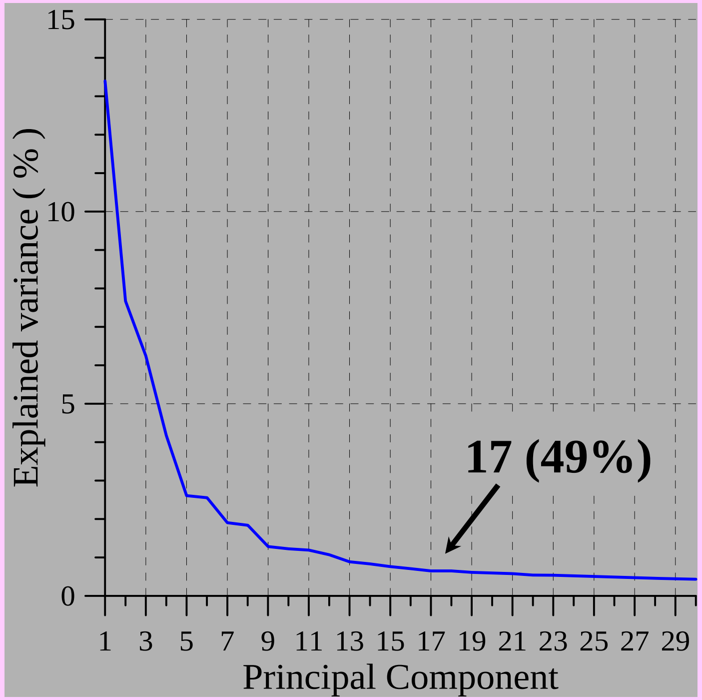
Principal Components Analysis

PCA

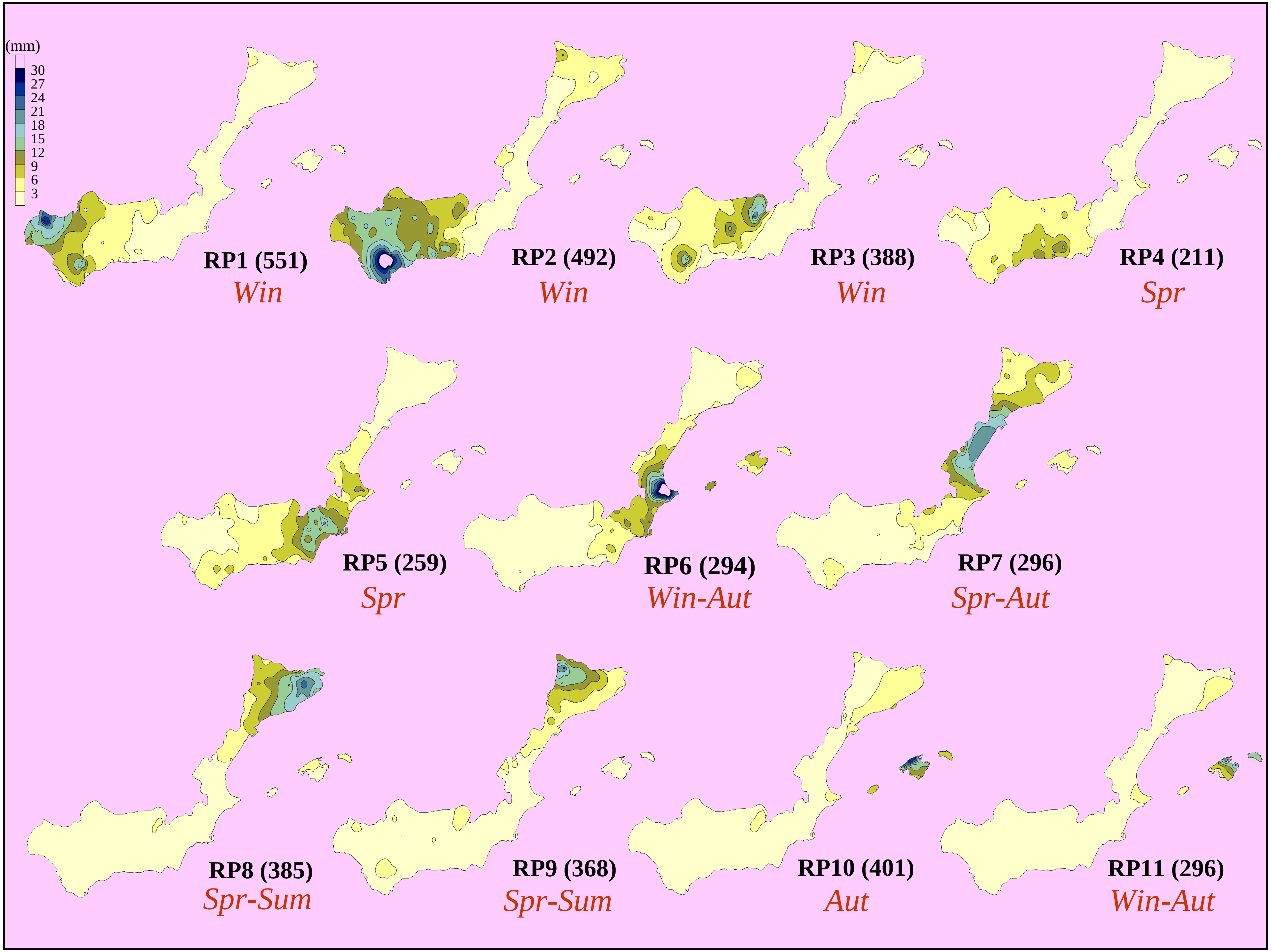
↓

Cluster Analysis (k-means)

CA



11 RPs



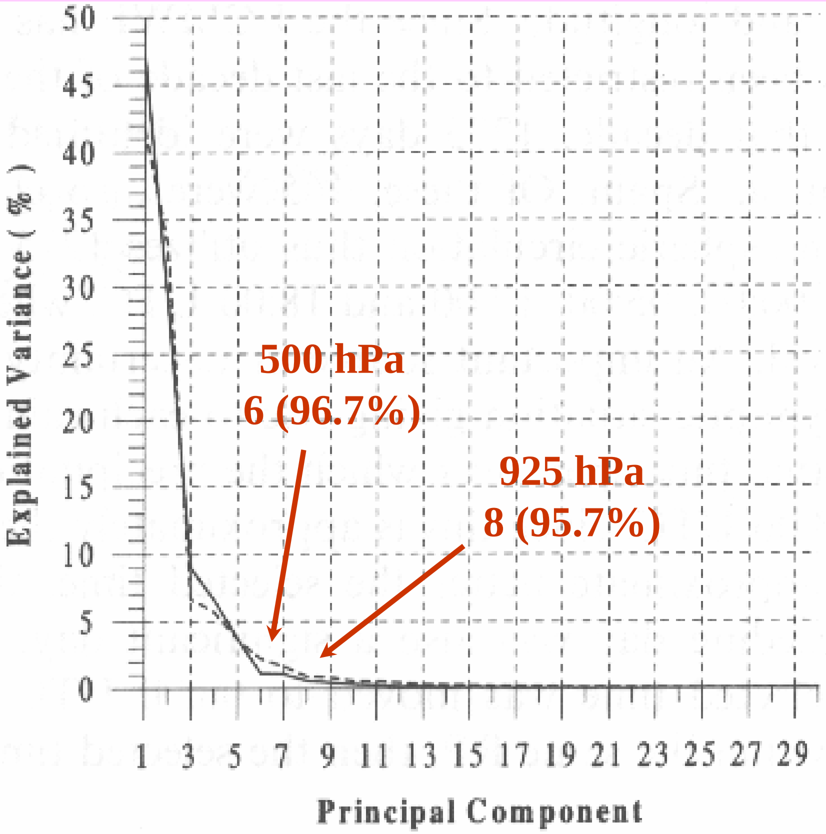
(mm)
30
27
24
21
18
15
12
9
6
3
RP1 (551)
Win
RP2 (492)
Win
RP3 (388)
Win
RP4 (211)
Spr
RP5 (259)
Spr
RP6 (294)
Win-Aut
RP7 (296)
Spr-Aut
RP8 (385)
Spr-Sum
RP9 (368)
Spr-Sum
RP10 (401)
Aut
RP11 (296)
Win-Aut

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)

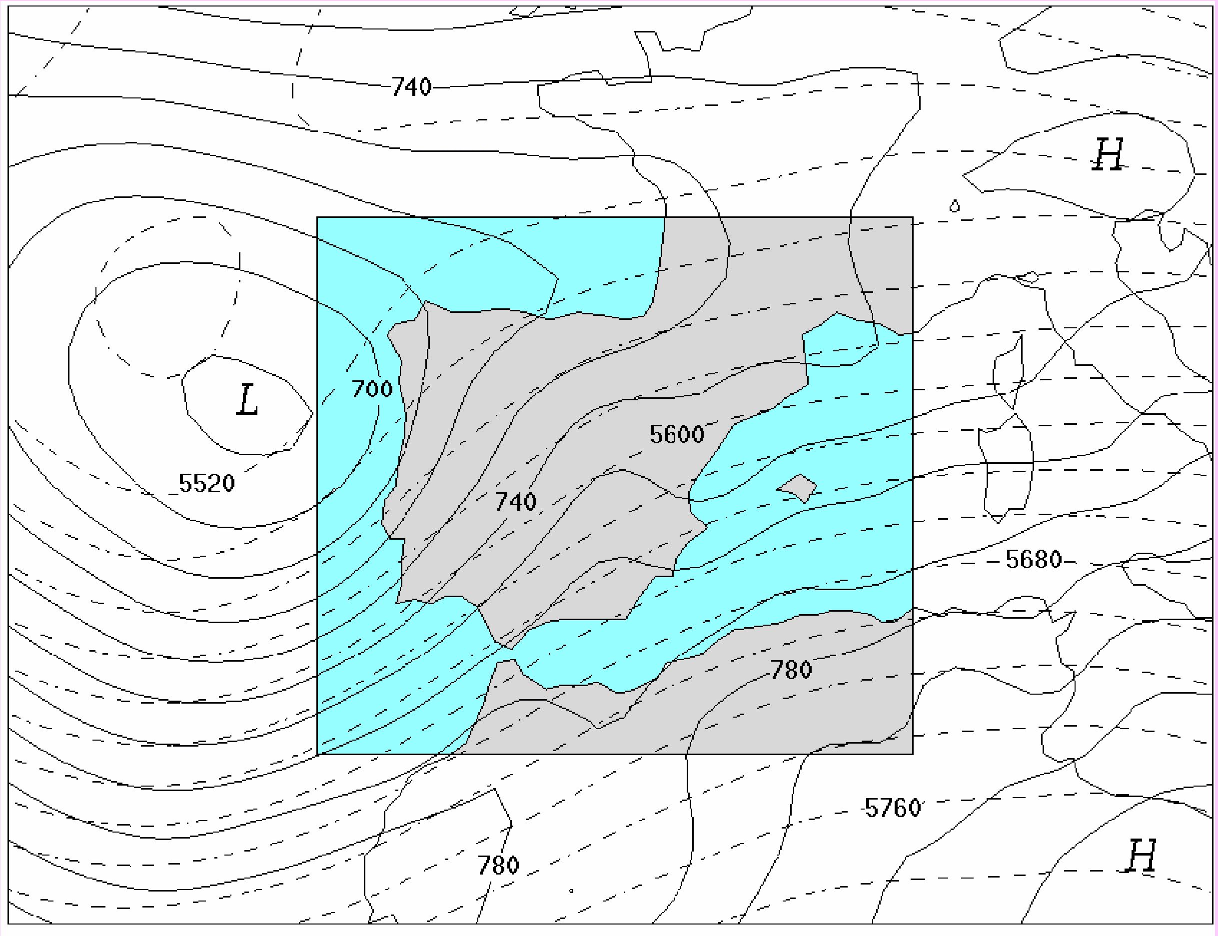
CA

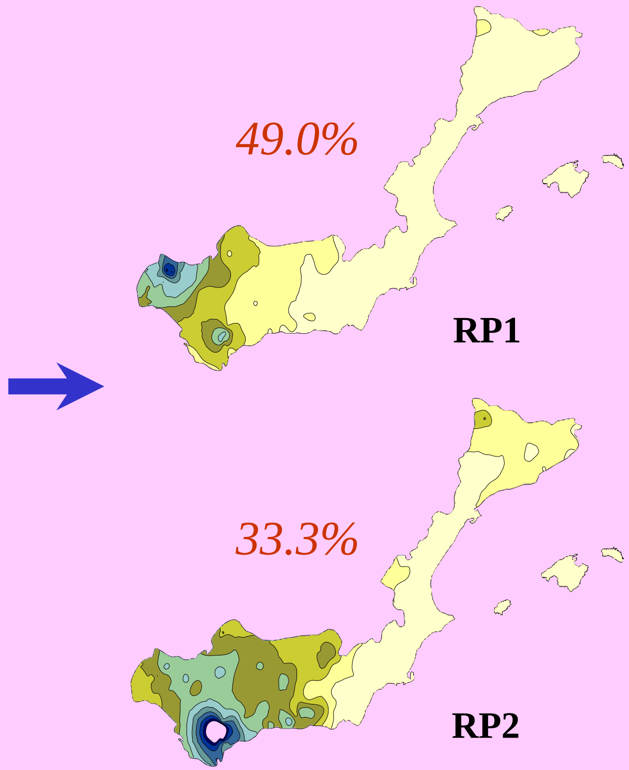
19 APs

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

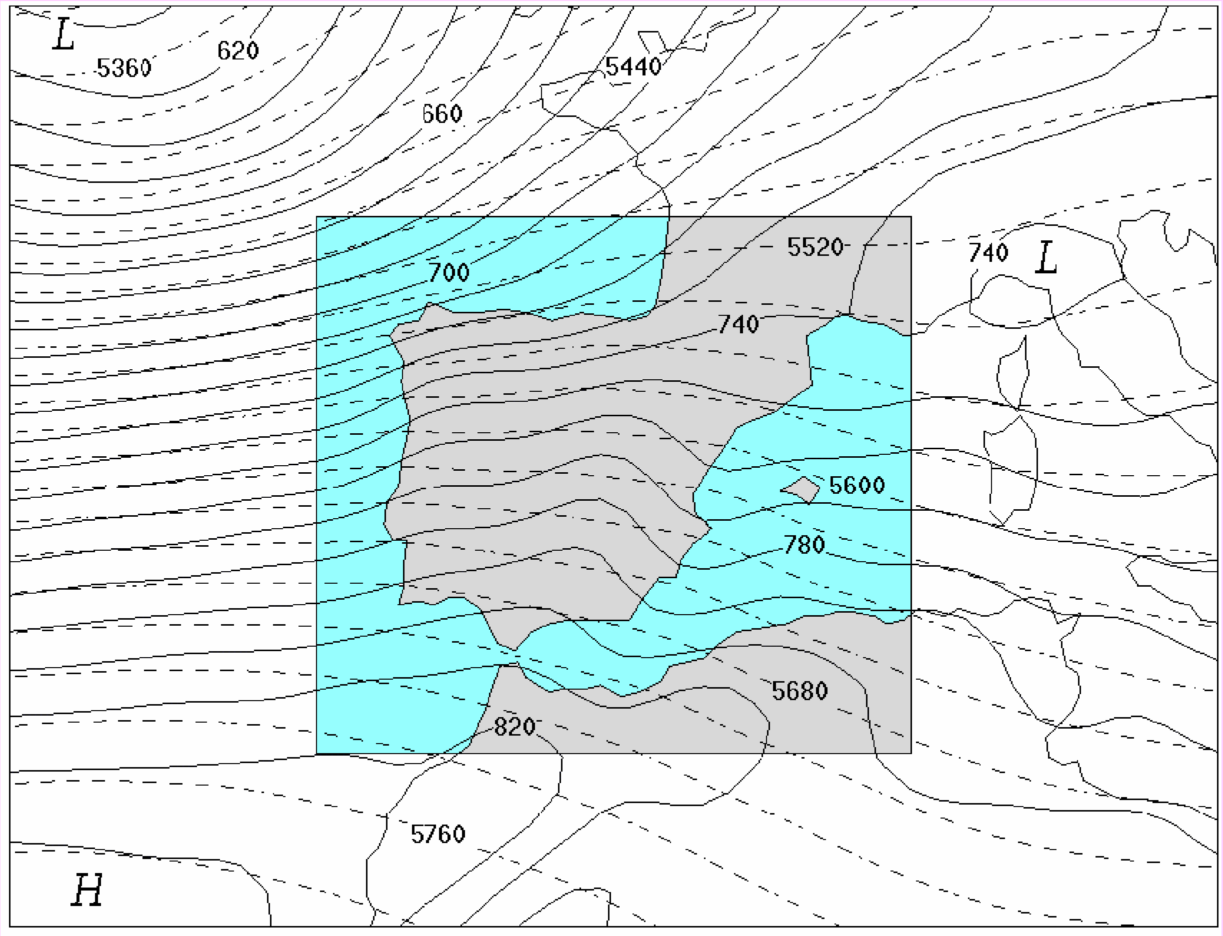
CLEAR ASSOCIATION





AP1

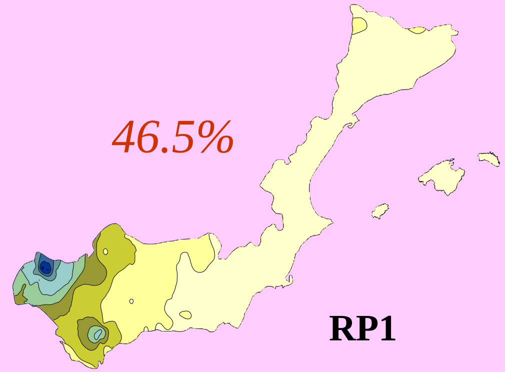
Win 43.1% - Aut 33.4%
Heavy 15.7%



AP2

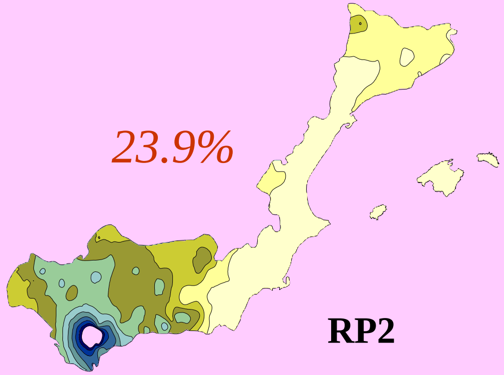
Win 54.9%
Heavy 11.3%

46.5%



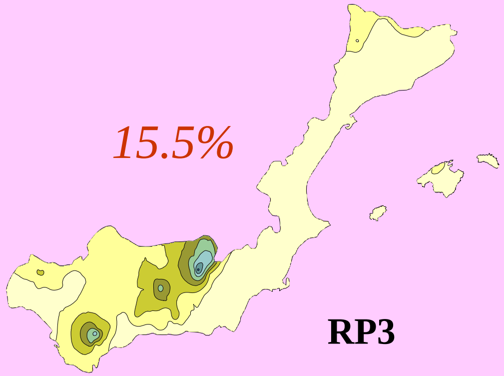
RP1

23.9%

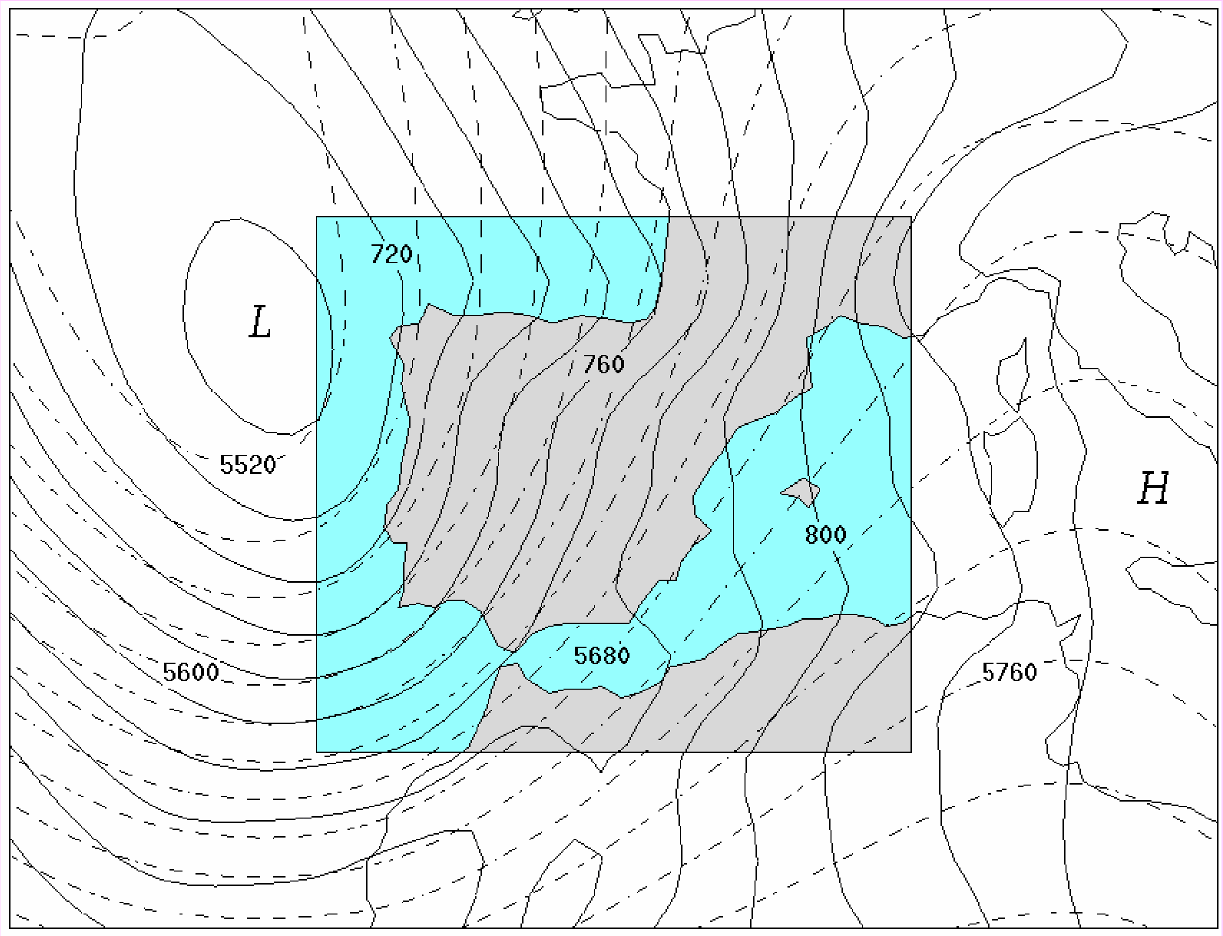


RP2

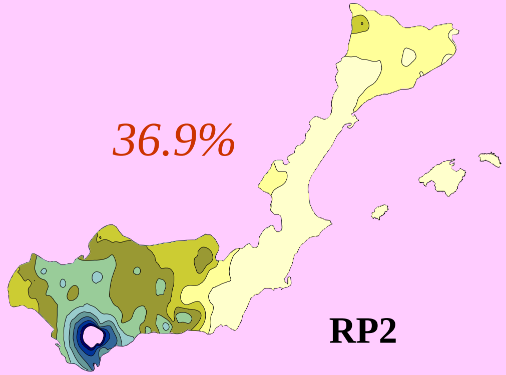
15.5%



RP3

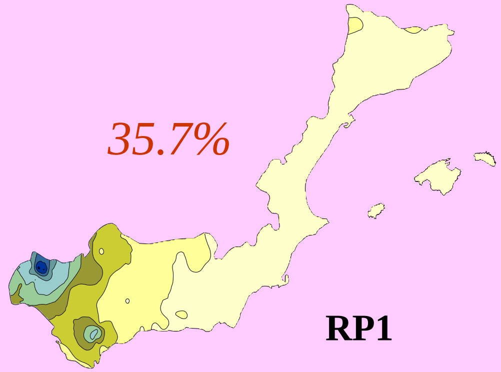


36.9%



RP2

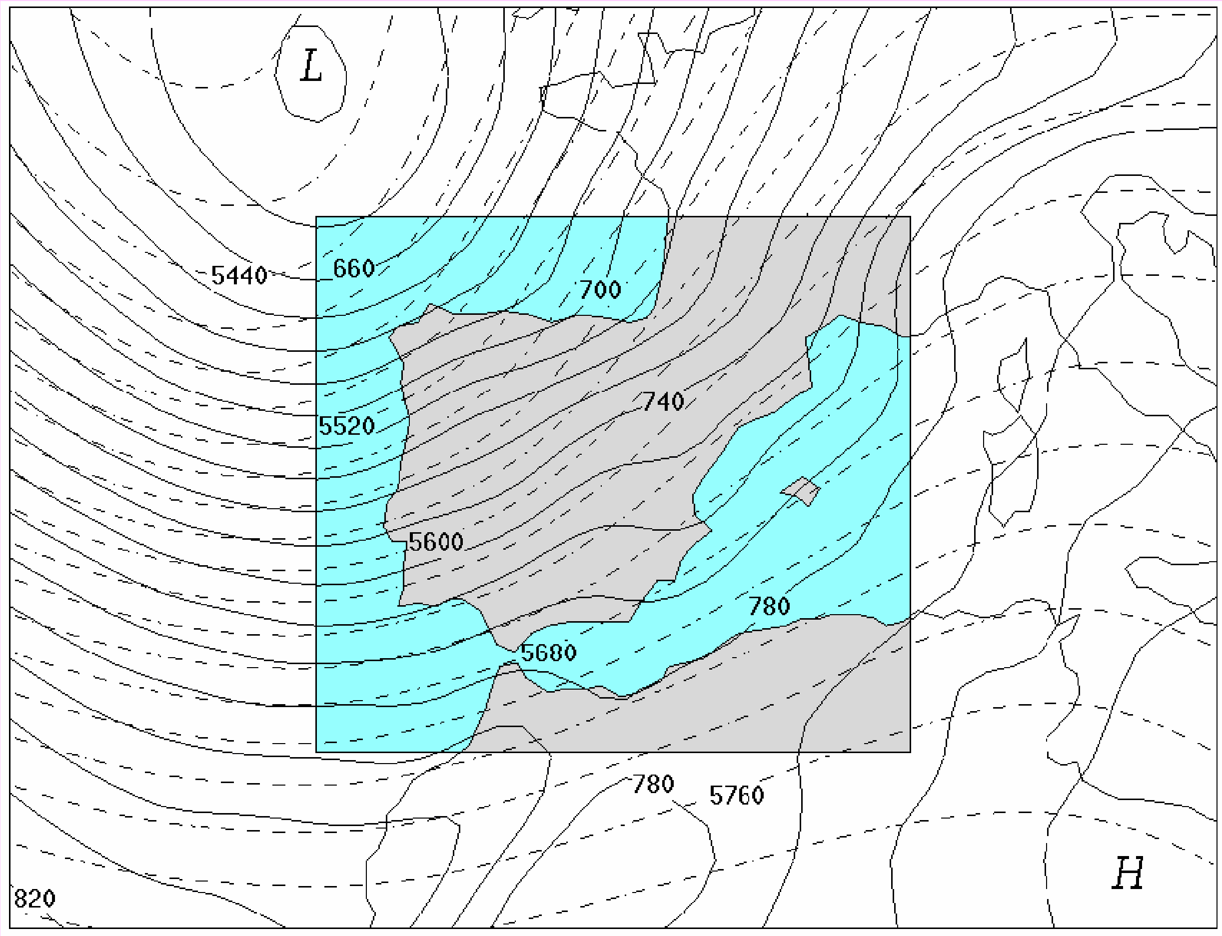
35.7%



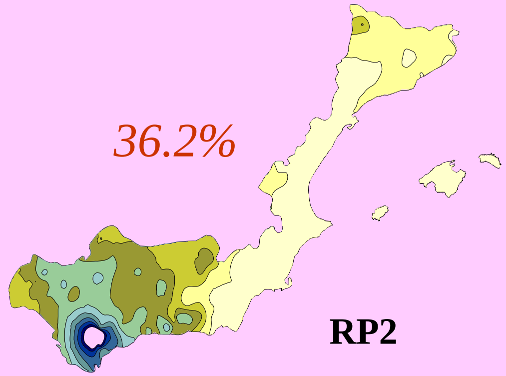
RP1

AP3

Aut *54.8%*
Heavy *25.0%*

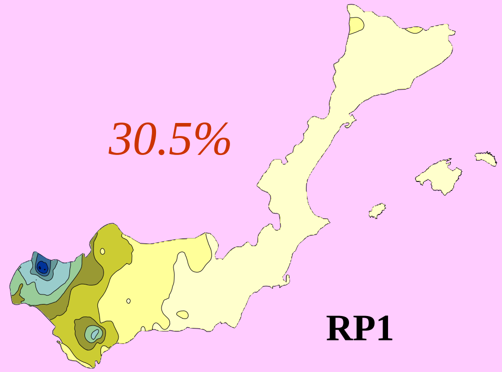


36.2%



RP2

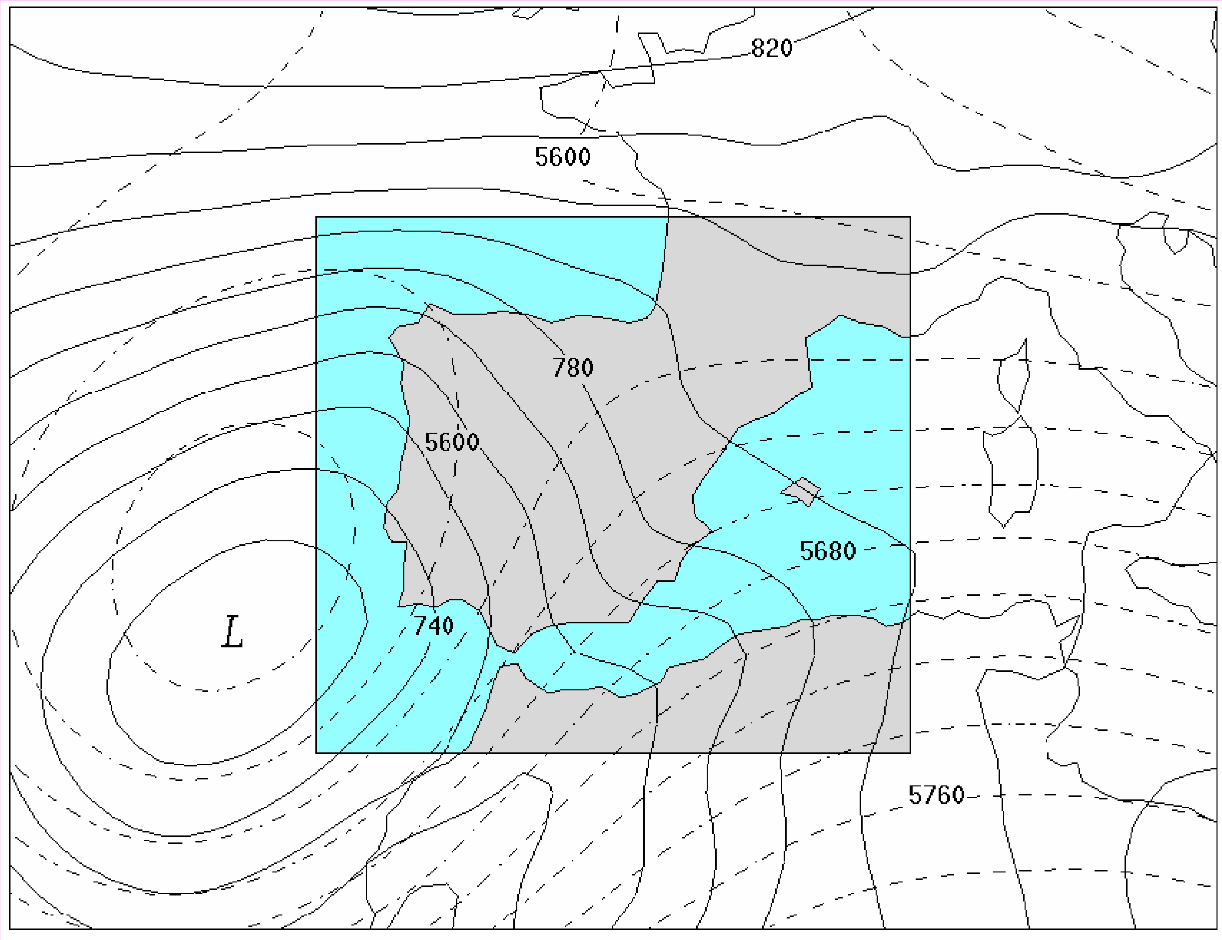
30.5%



RP1

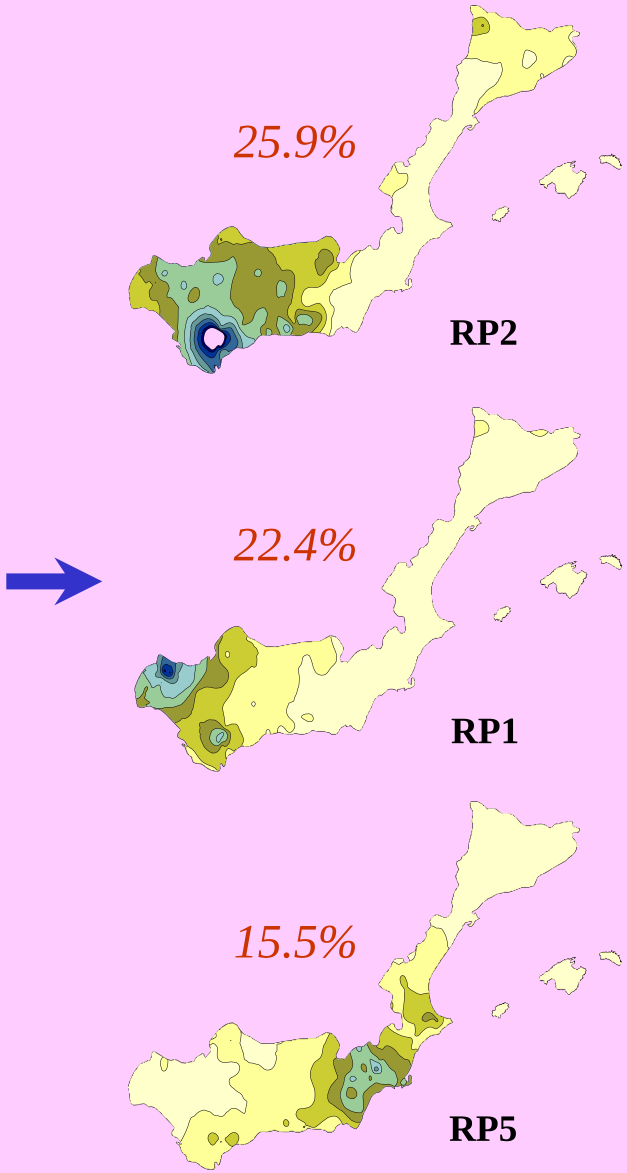
AP4

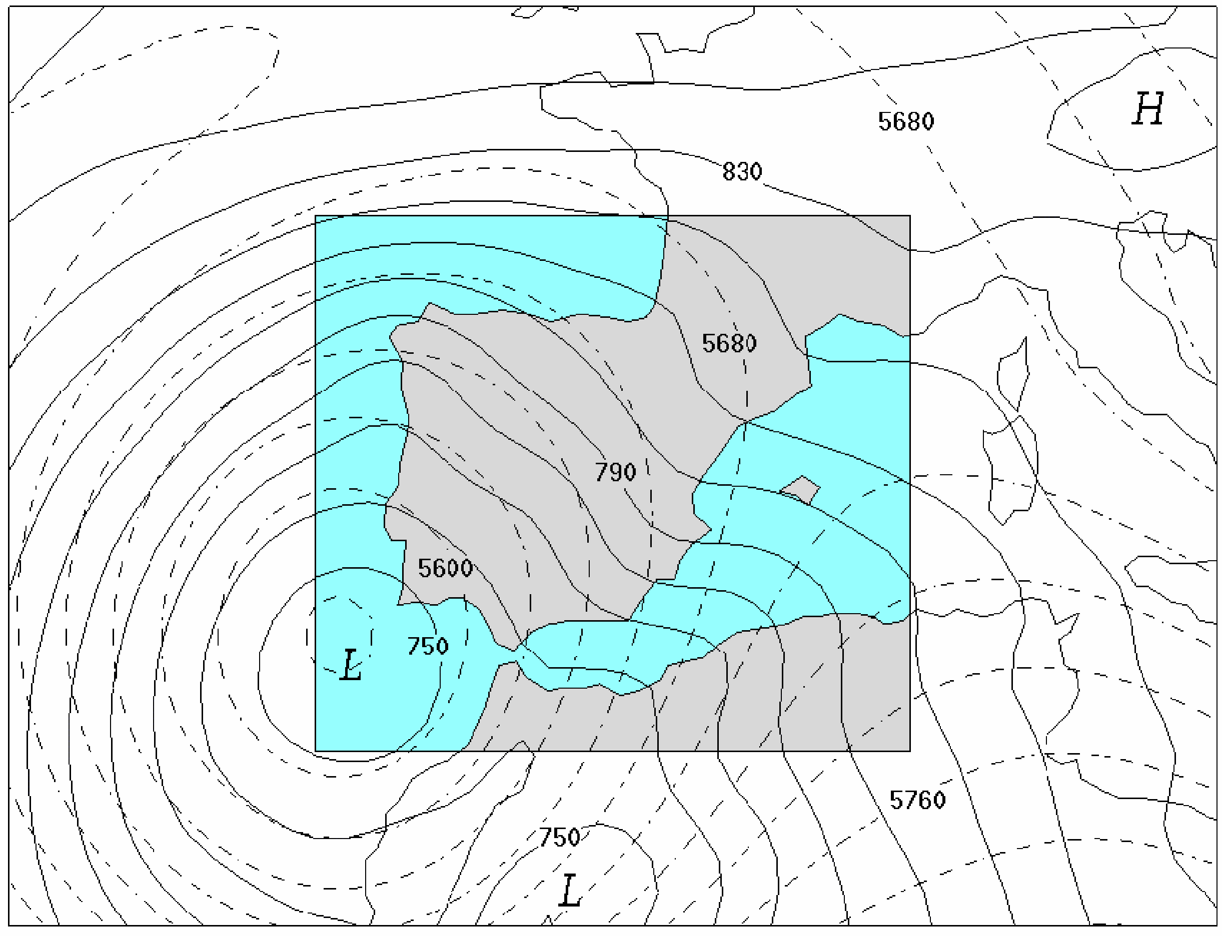
Aut *41.0%*
Heavy *15.2%*



AP5

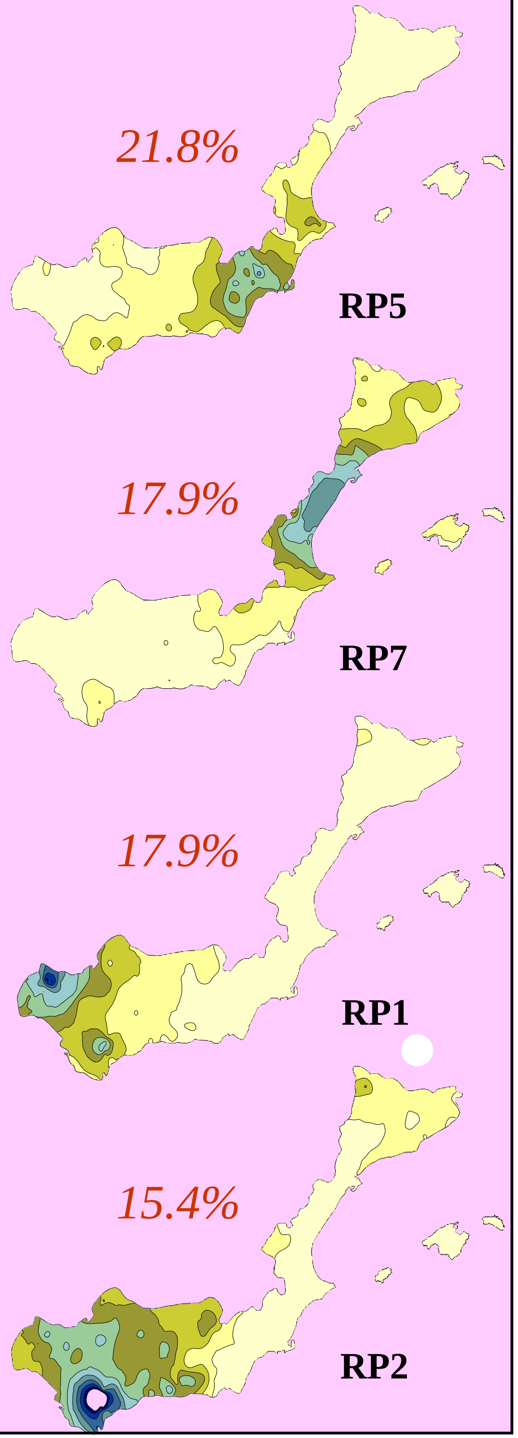
Aut 37.9% - Spr 36.2%
Heavy 17.2%

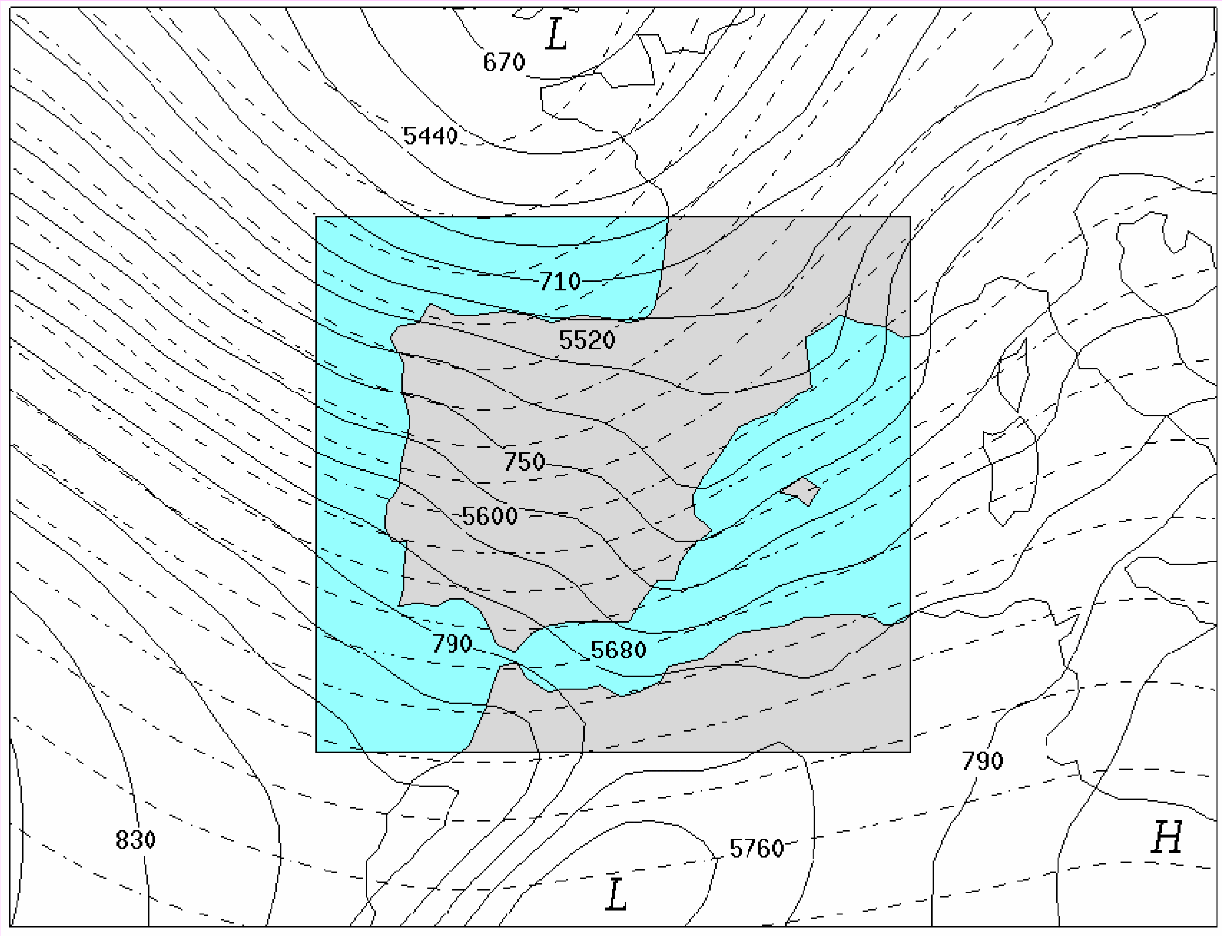




AP6

Spr *33.3%*
Heavy *23.1%*

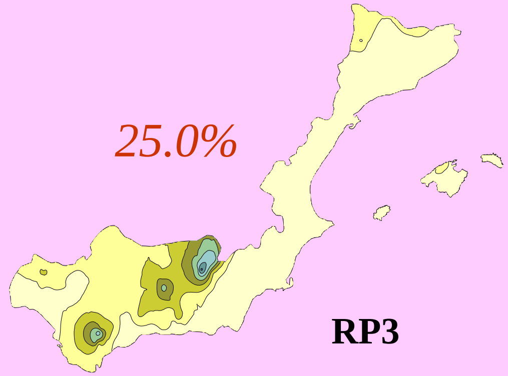




AP7

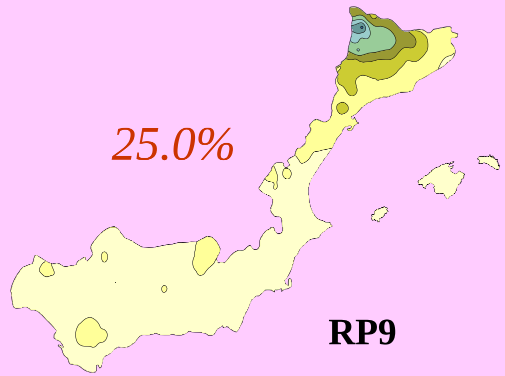
Spr *35.0%* - *Aut* *35.0%*
Heavy *2.0%*

25.0%

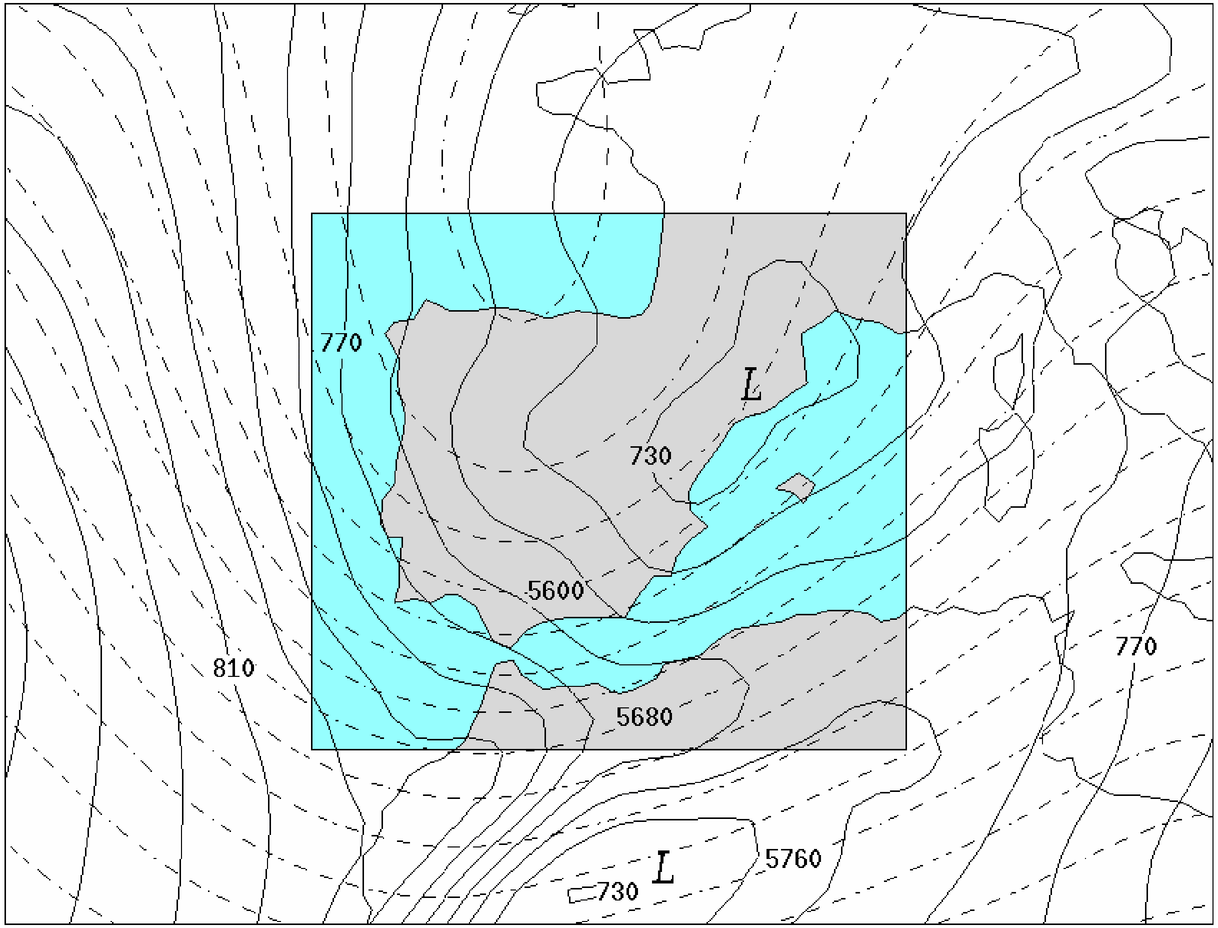


RP3

25.0%



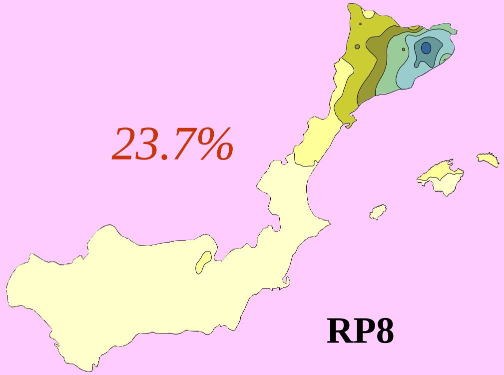
RP9



AP8

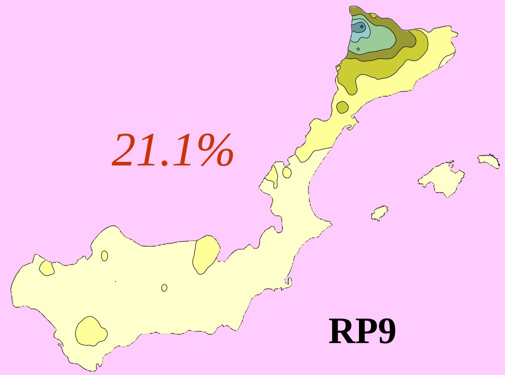
Spr *42.1%*
Heavy *7.9%*

23.7%



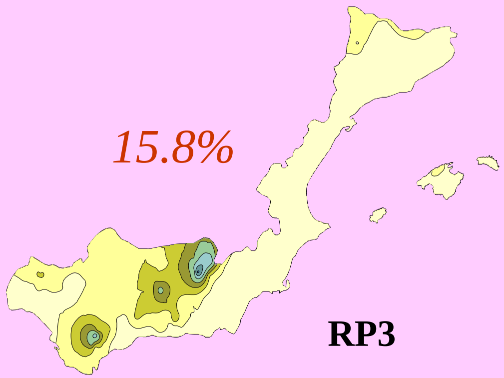
RP8

21.1%

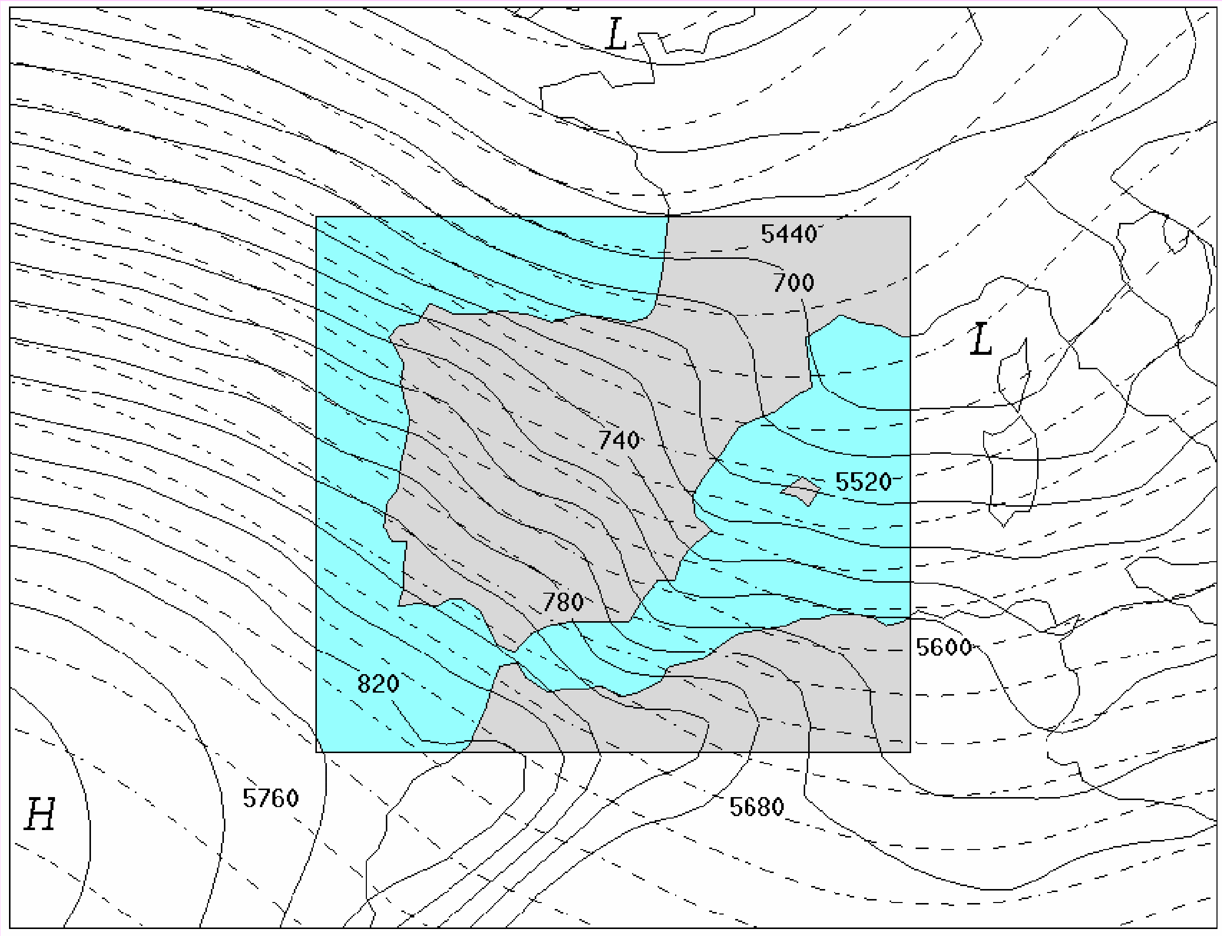


RP9

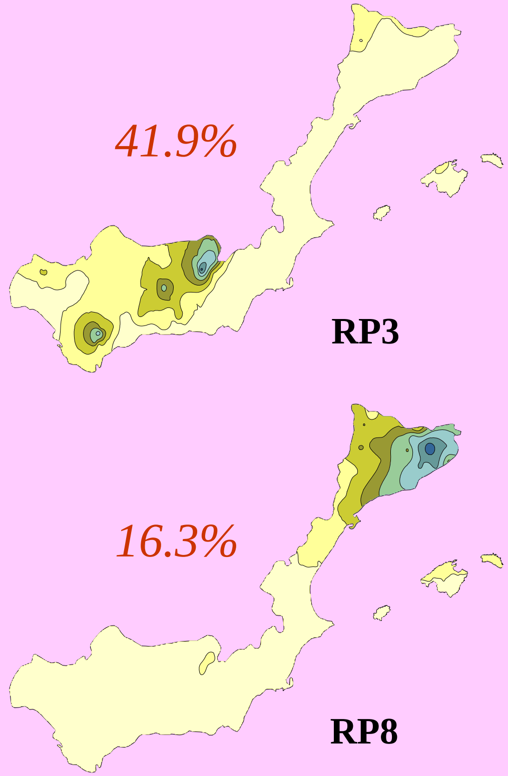
15.8%



RP3

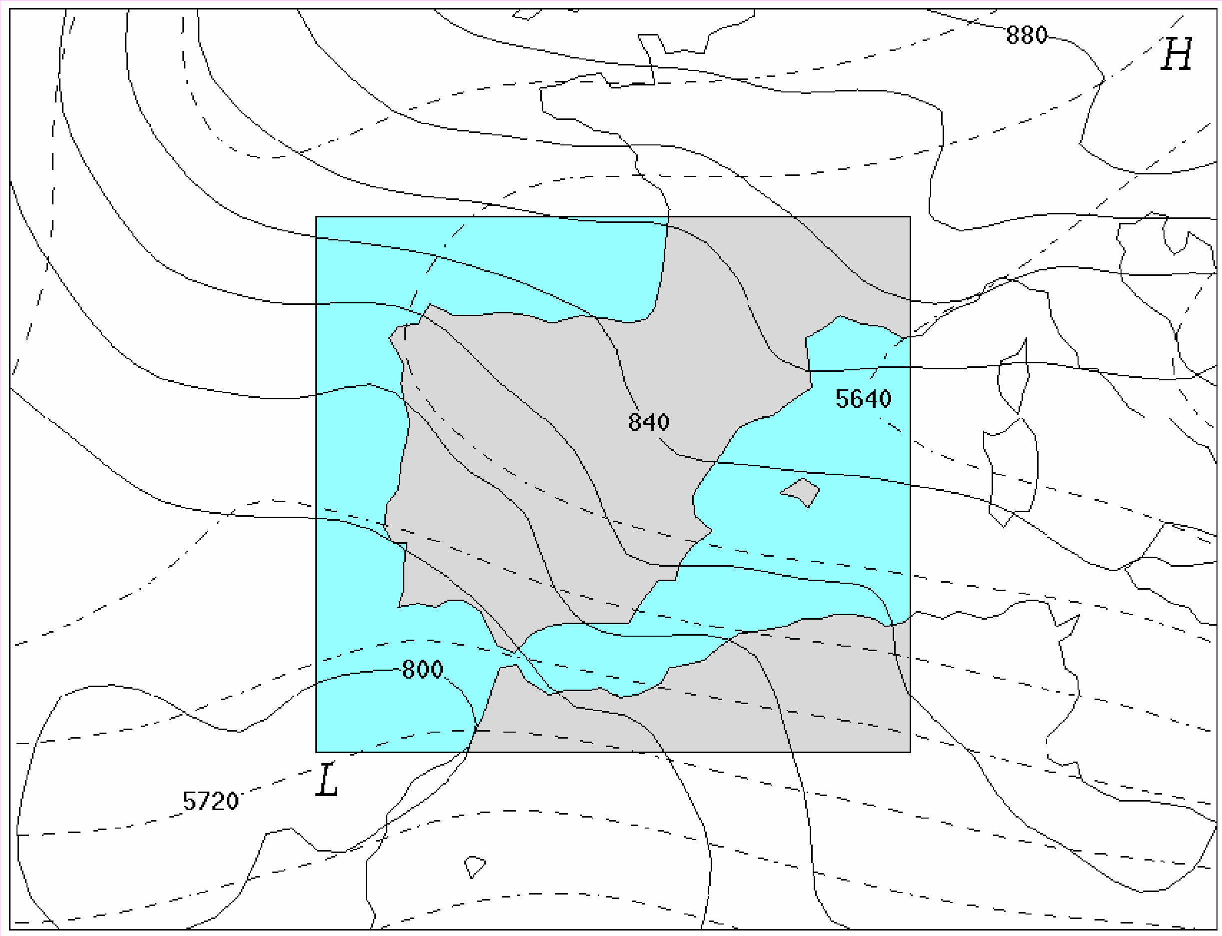


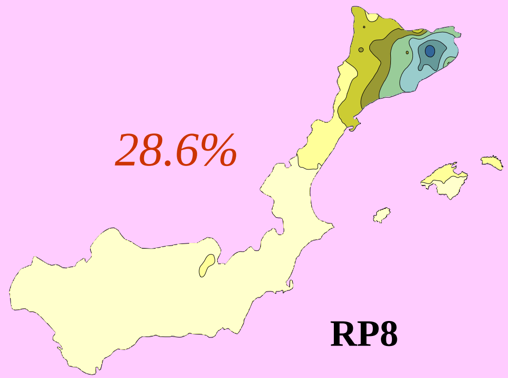
AP9



Win *45.3%*

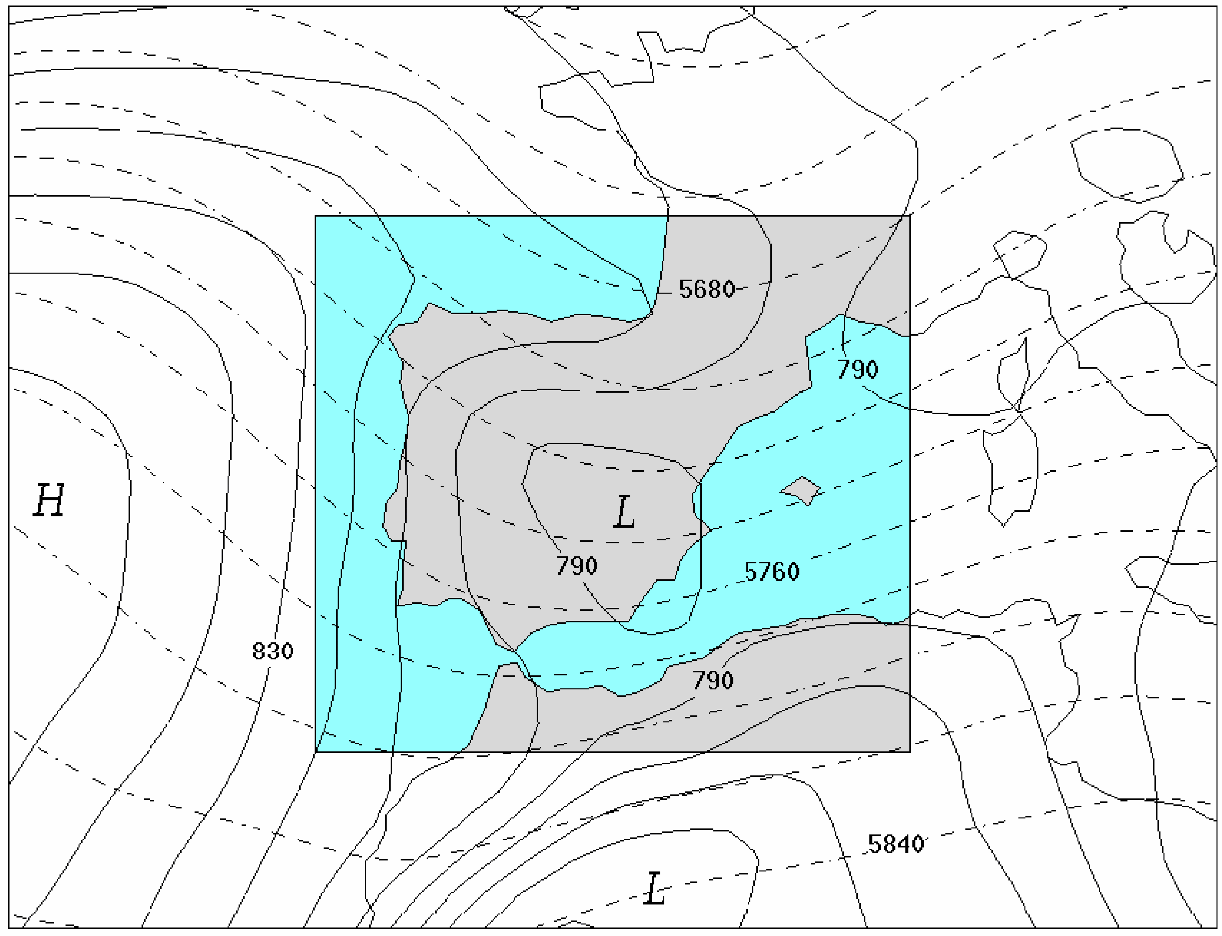
Heavy *3.5%*



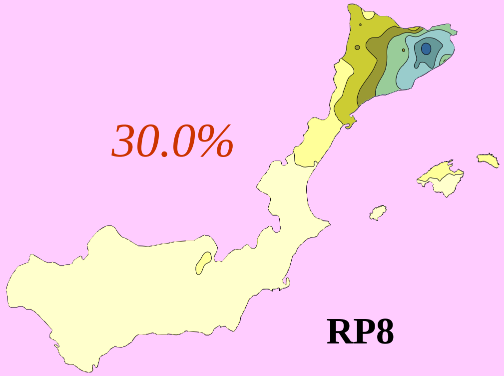


AP10

Win 46.4% - Aut 42.9%
Heavy 10.7%

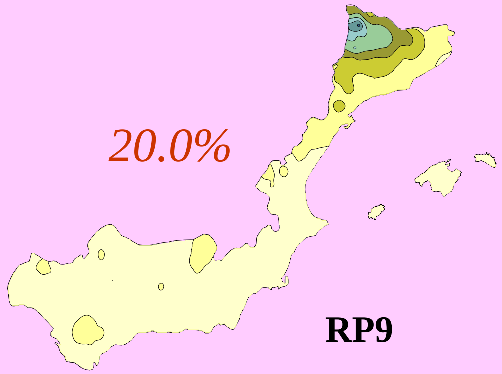


30.0%



RP8

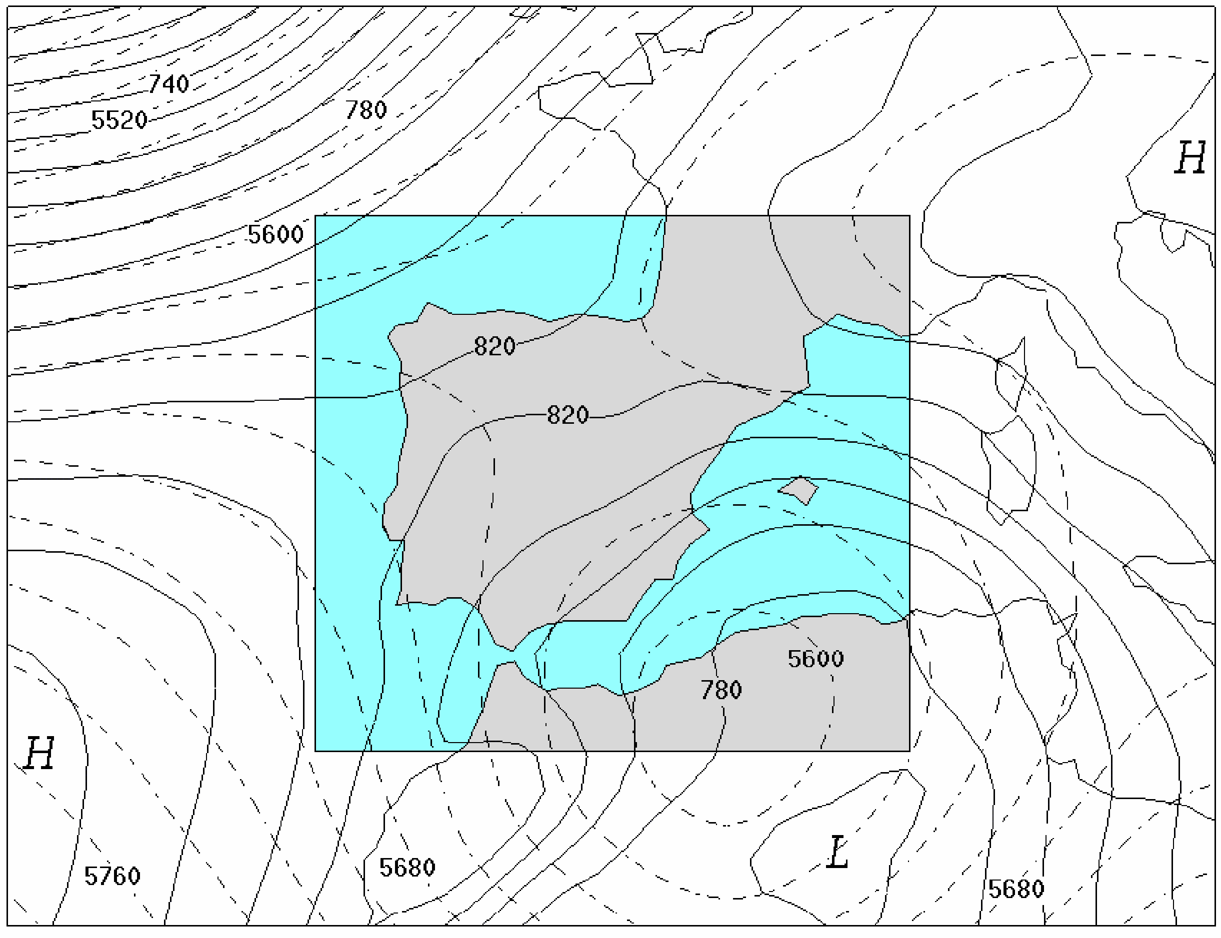
20.0%

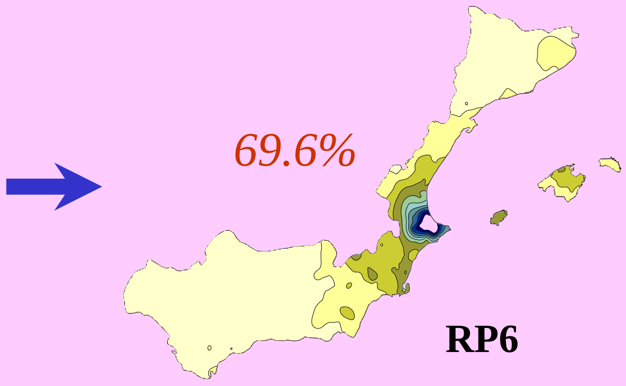


RP9

AP11

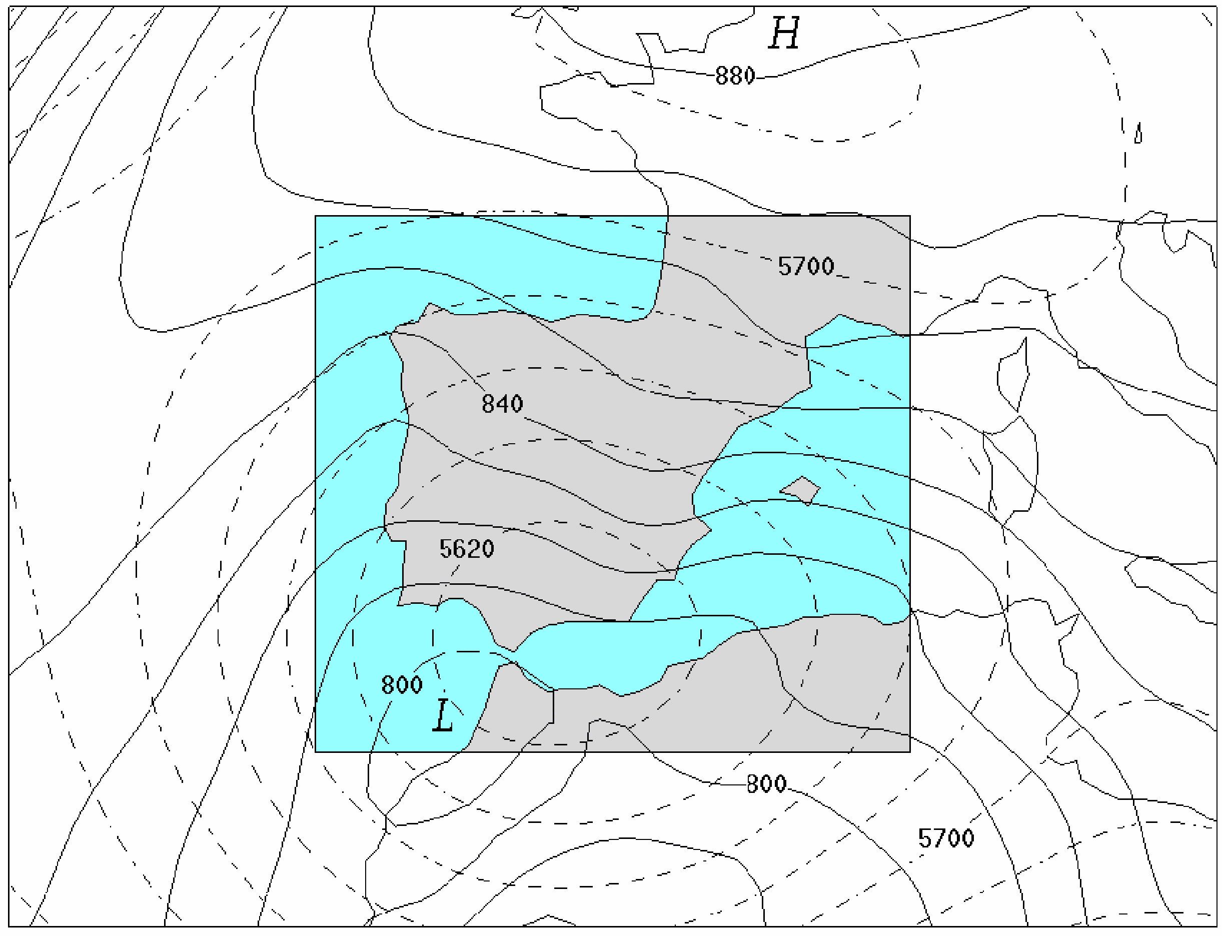
Sum 41.4% - Spr 30.0%
Heavy 0.0%

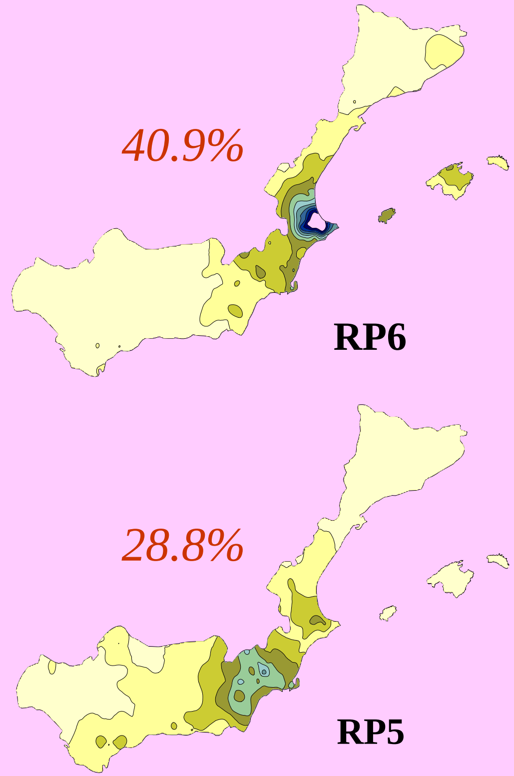




AP12

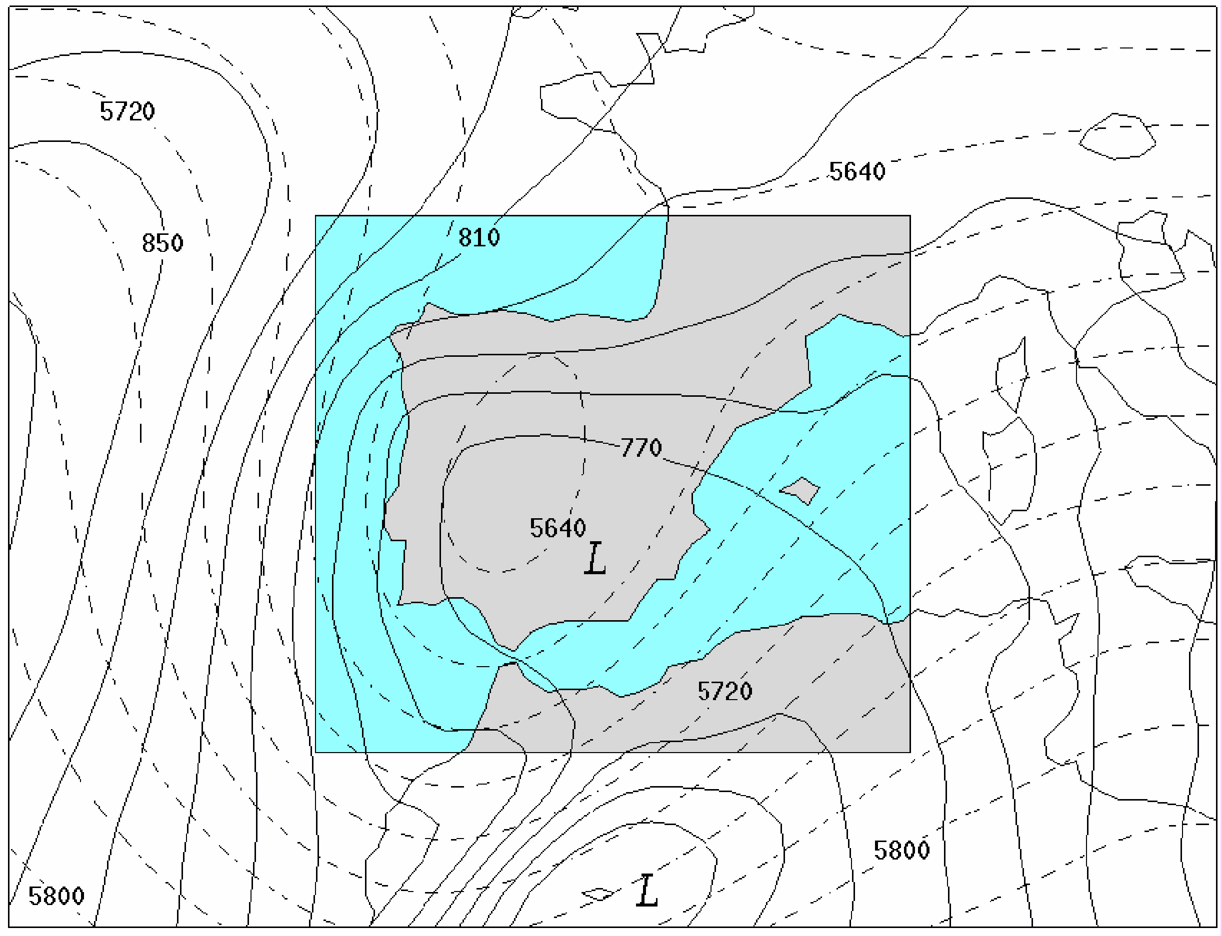
Win 47.8% - Aut 34.8%
Heavy 21.7%



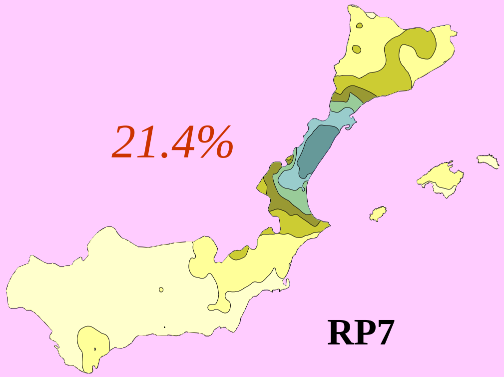


AP13

Win 53.0%
Heavy 37.9%

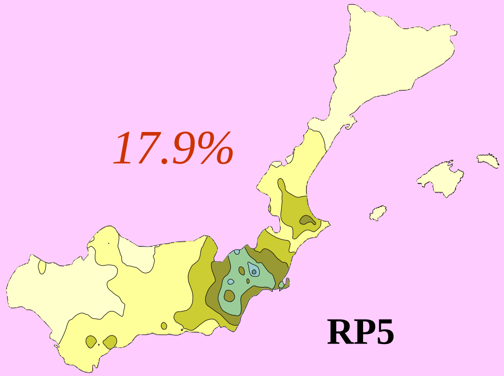


21.4%



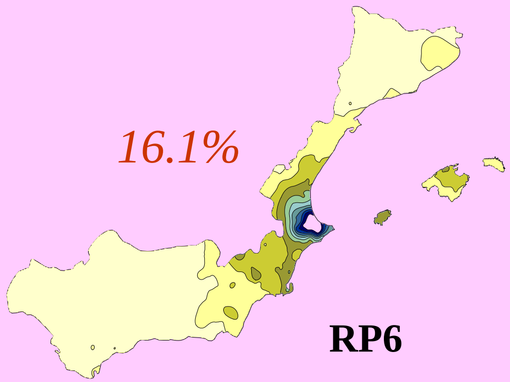
RP7

17.9%



RP5

16.1%

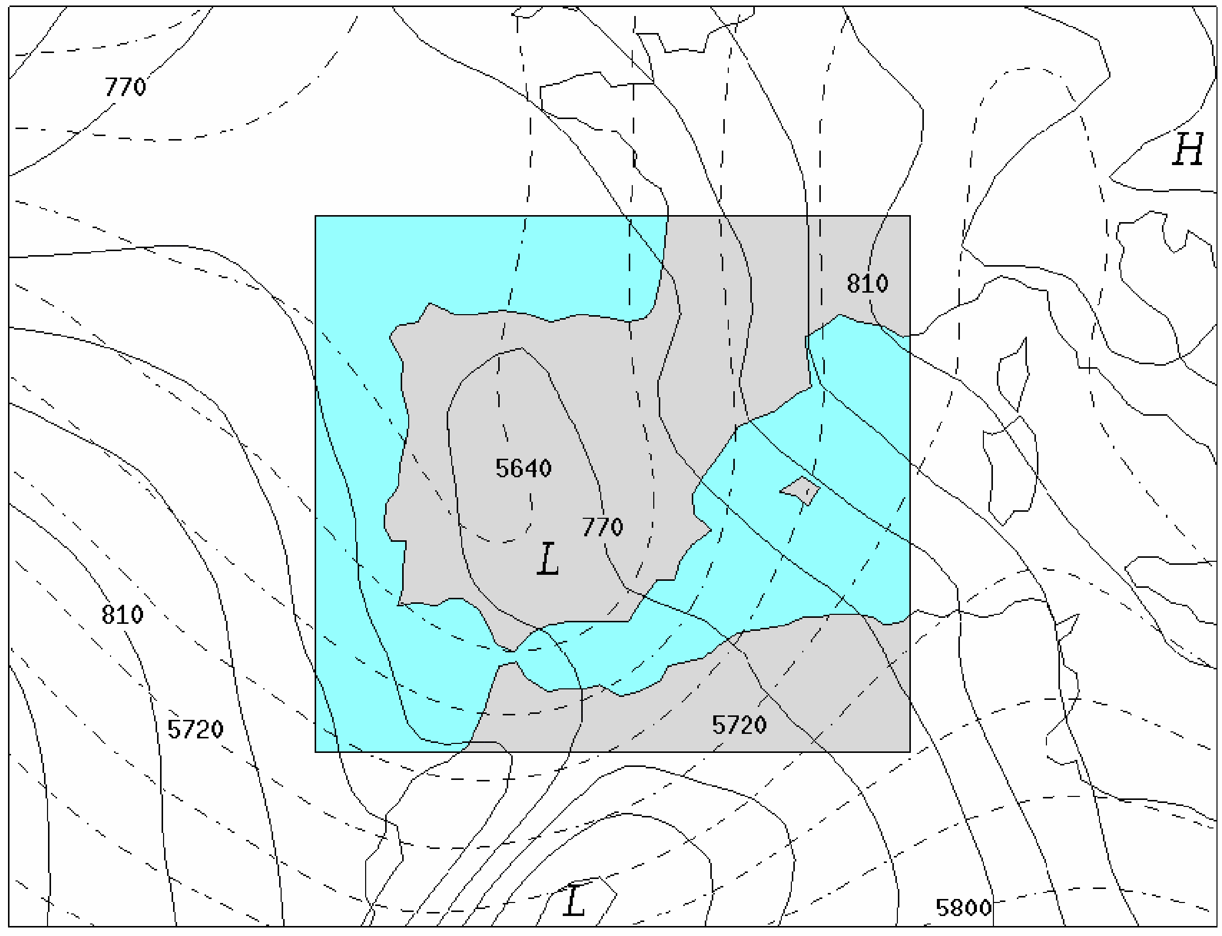


RP6

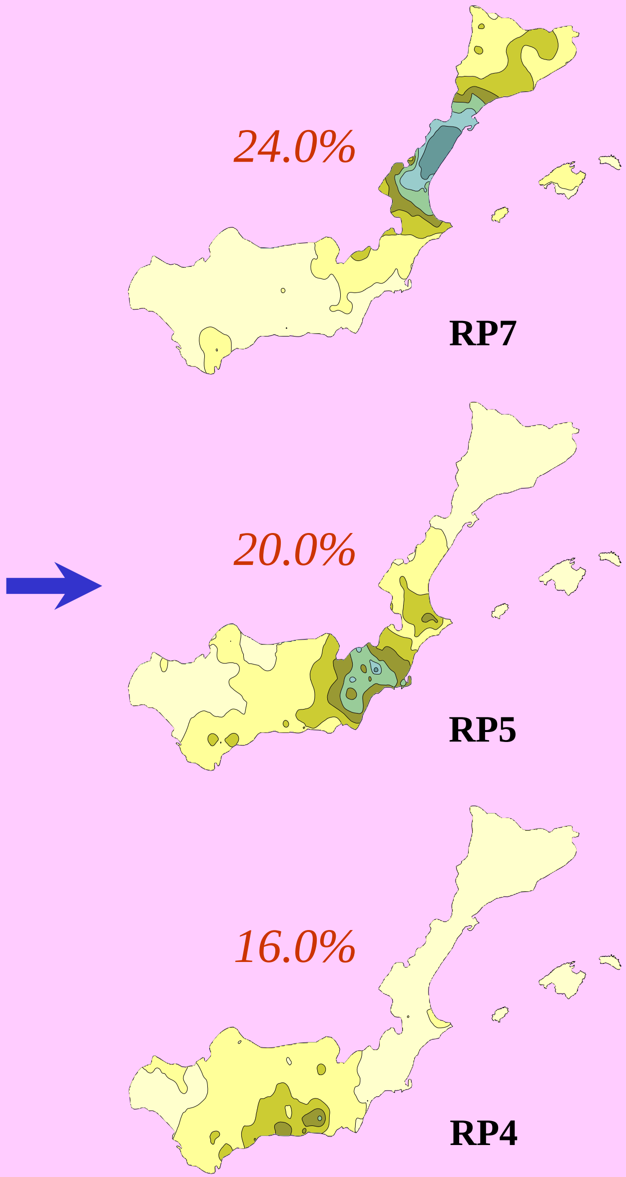
AP14

***Spr** 35.7% - **Sum** 33.9%*

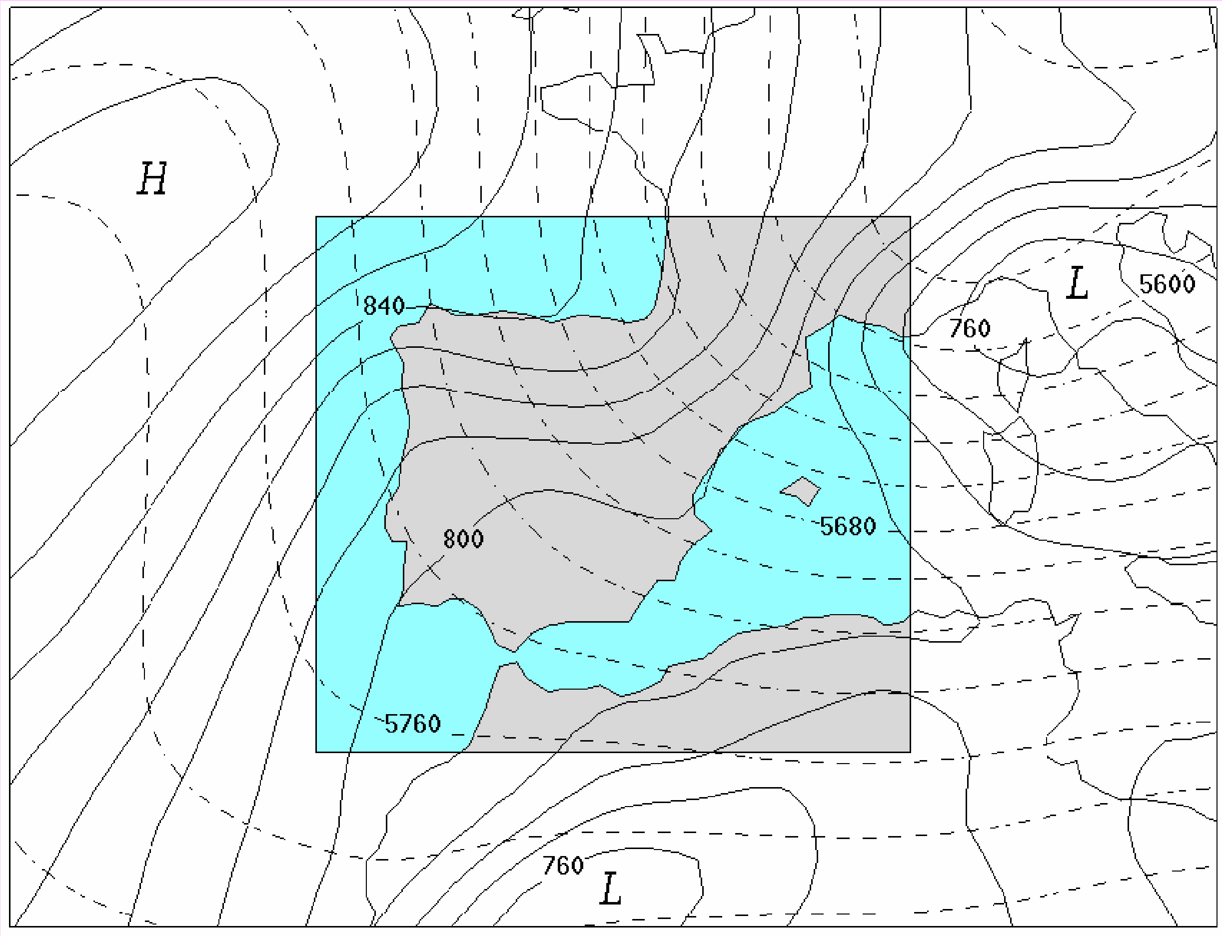
***Heavy** 19.6%*



AP15



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

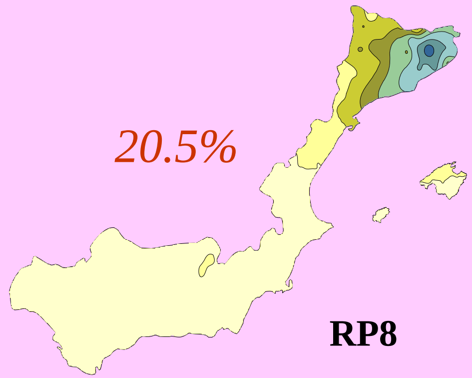


AP16

Sum *38.4%*

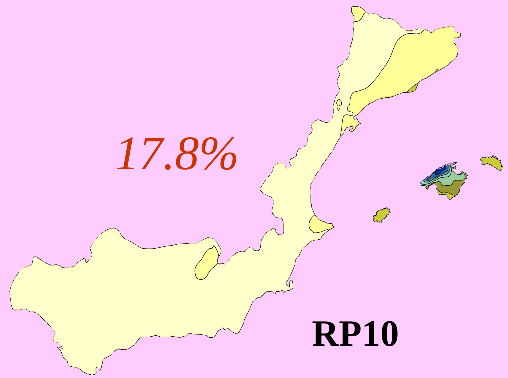
Heavy *0.0%*

20.5%



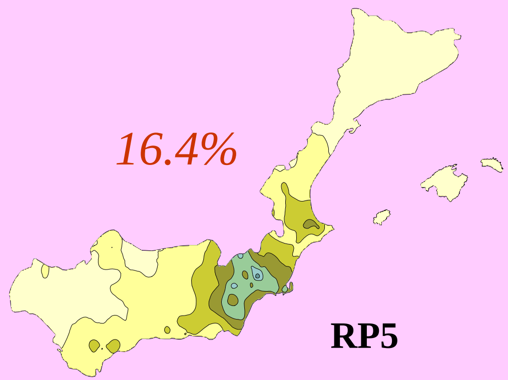
RP8

17.8%

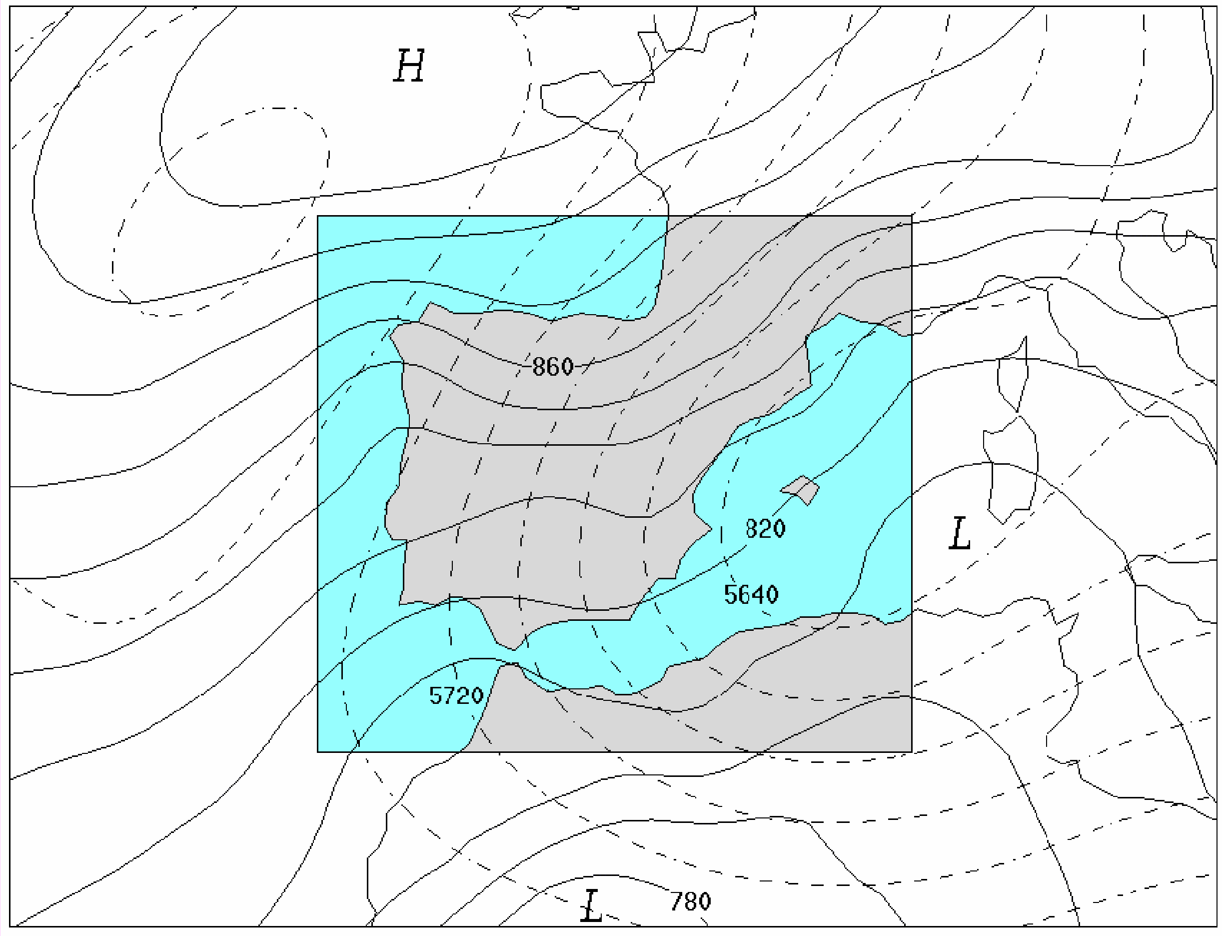


RP10

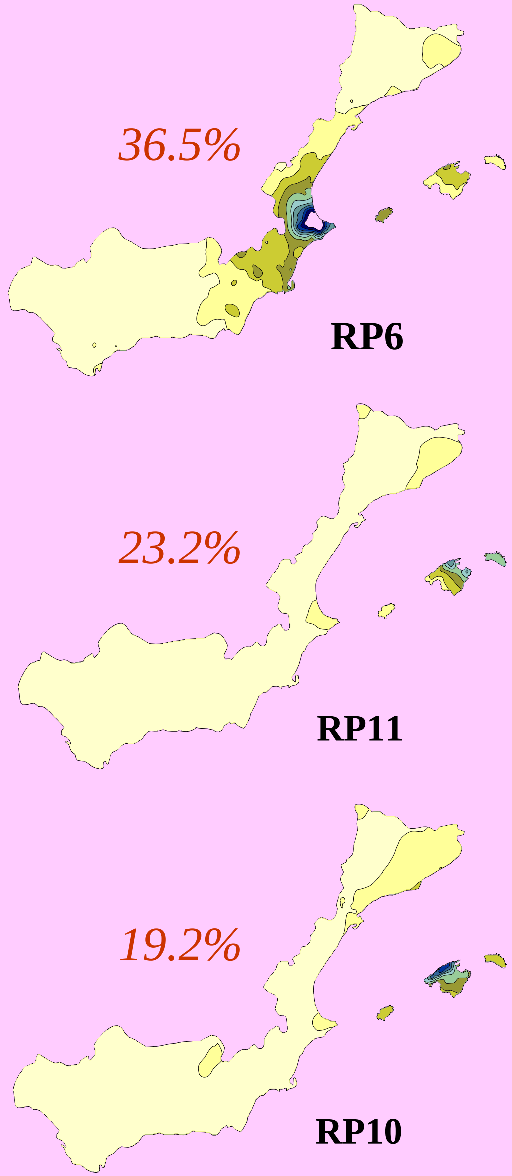
16.4%



RP5

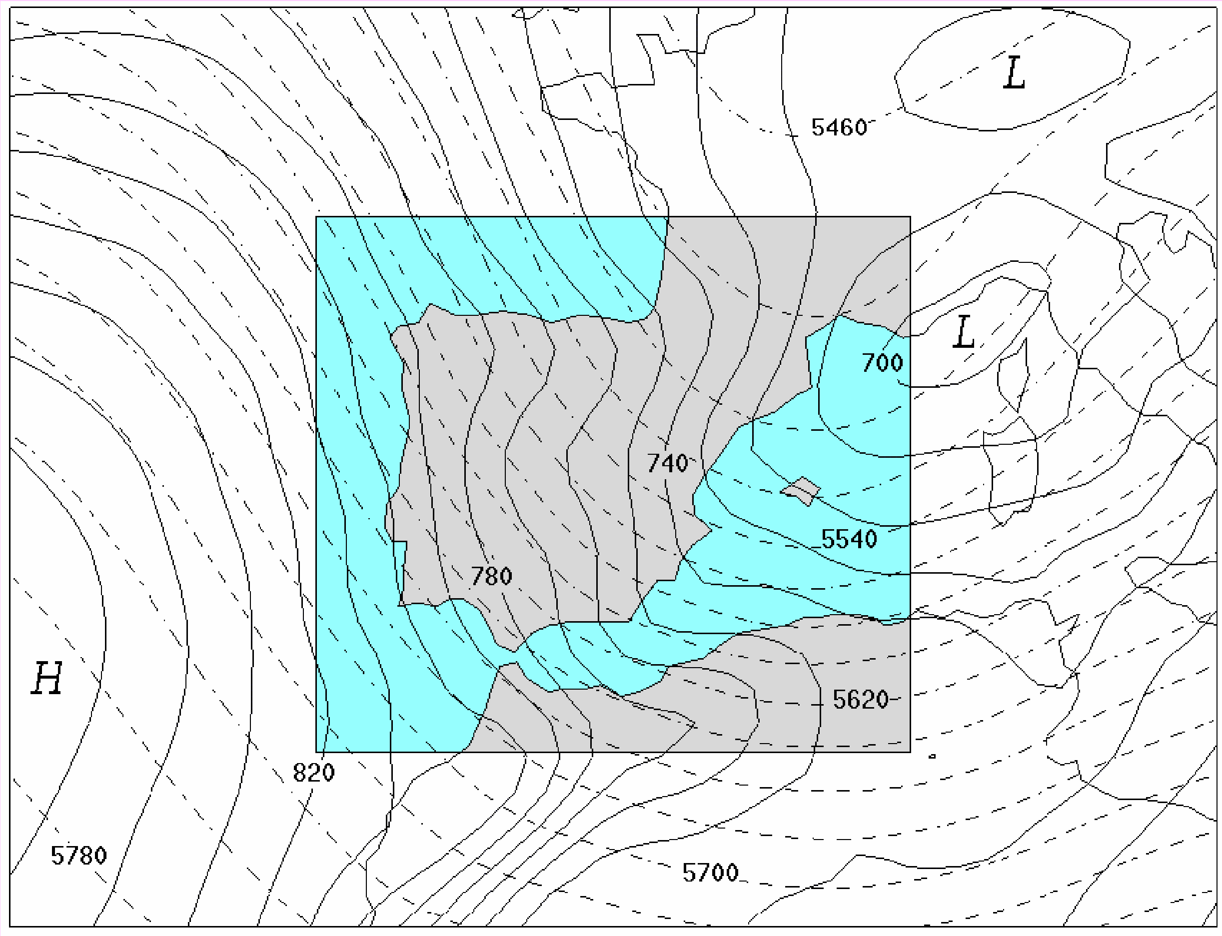


AP17



***Win** 30.8% - **Aut** 30.7%*

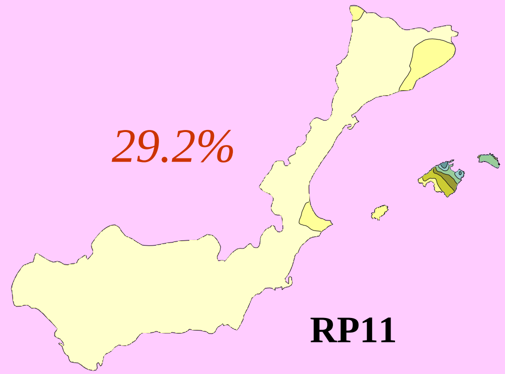
***Heavy** 13.5%*



AP18

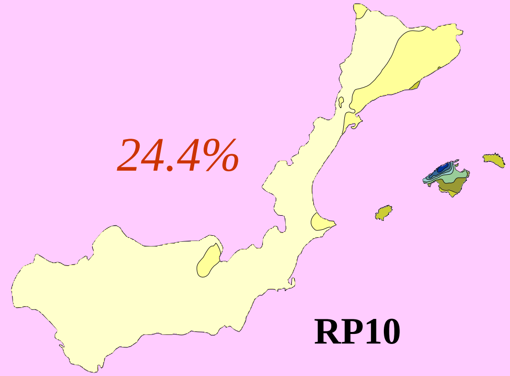
Spr *41.9%*
Heavy *4.7%*

29.2%



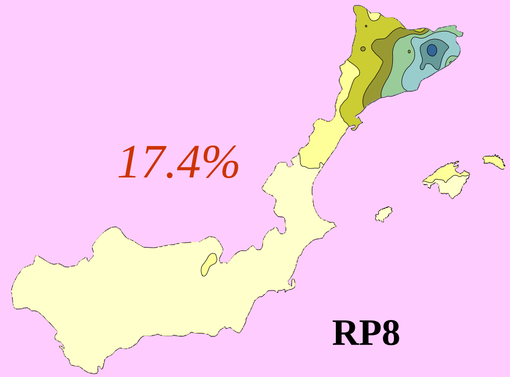
RP11

24.4%

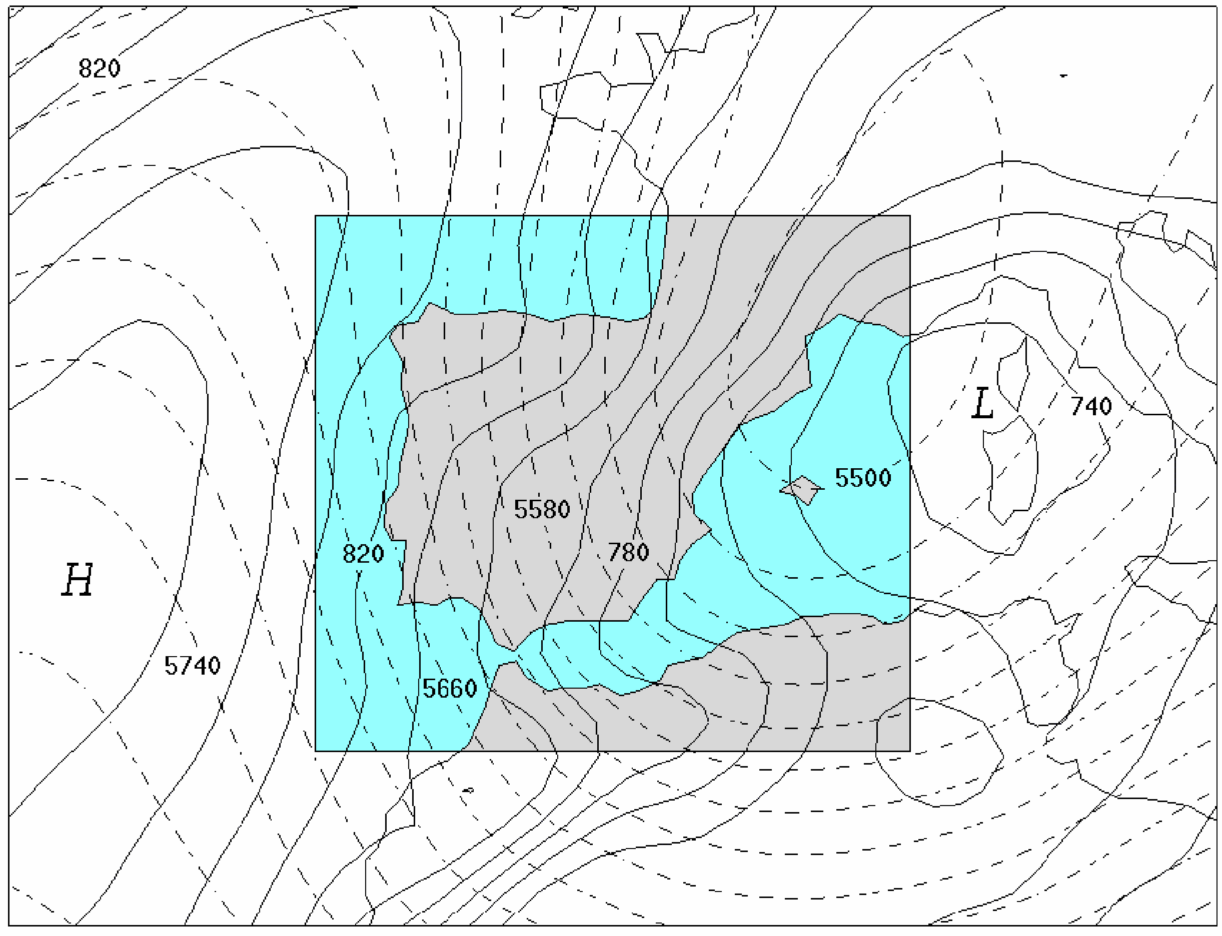


RP10

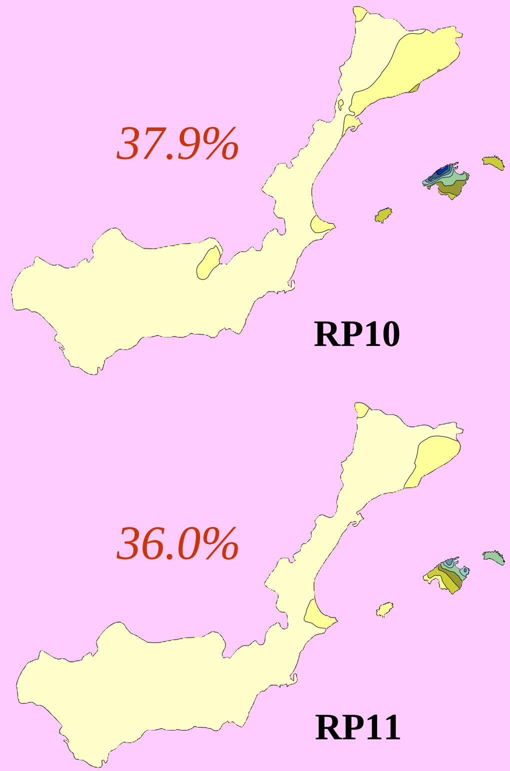
17.4%



RP8



AP19



Spr 40.2% - Win 34.5%
Heavy 11.5%

STATISTICAL DOWNSCALING OF RAINFALL IN MEDITERRANEAN SPAIN BY THE LATE 21st CENTURY

Combining an AOGCM with the previous cause-effect links

"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

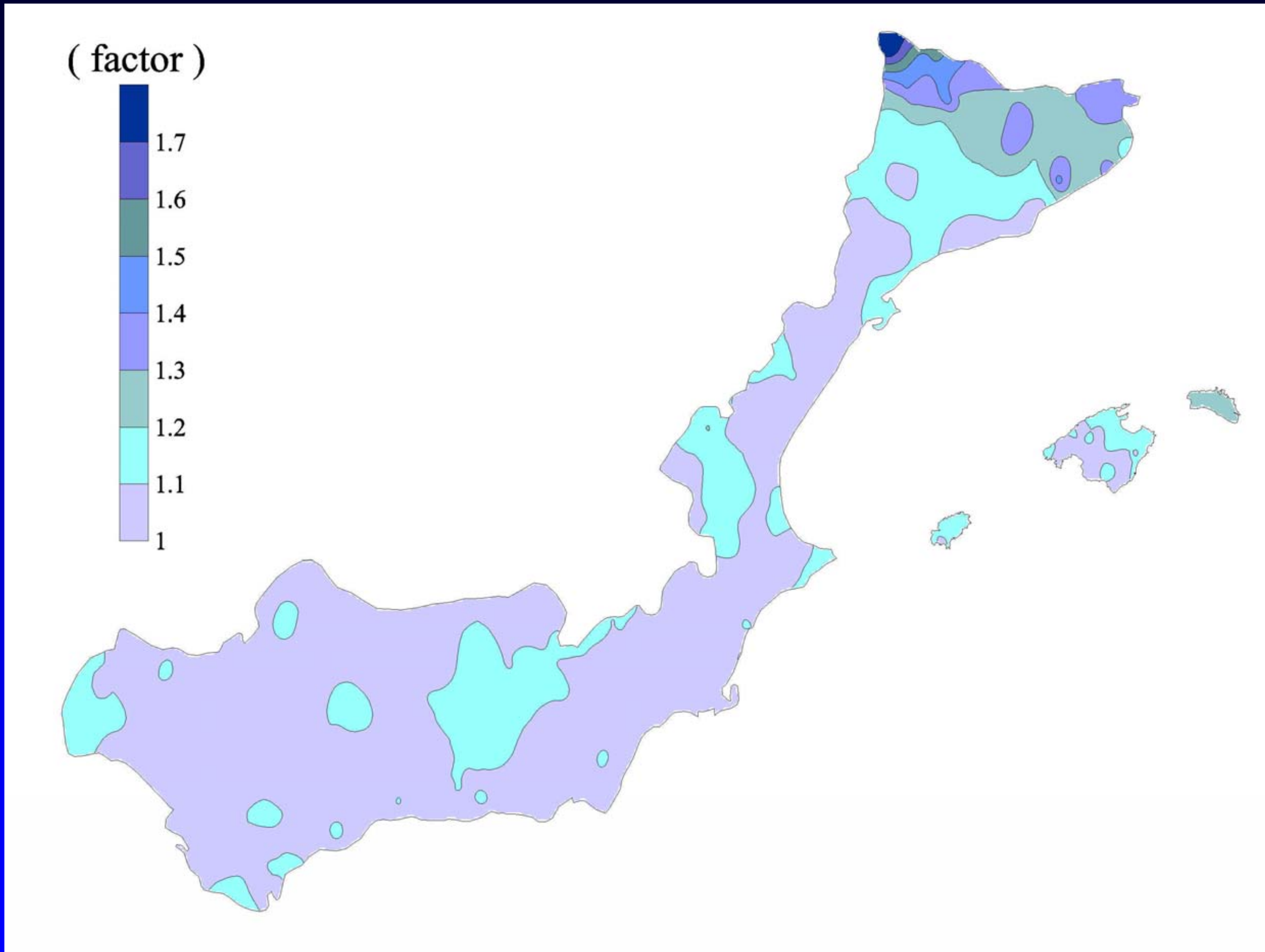
11 décadas móviles

1) Mismas relaciones entre APs y RPs

2) Similar magnitud de la precipitation para cada RP

3) Mismo factor $\phi_i=R_i/S_i$ para la obtención de totales

PRECIPITACIÓN FUTURA


(factor)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1

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	ECHAM PRESNT	**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

1971 – 1990

11 décadas móviles

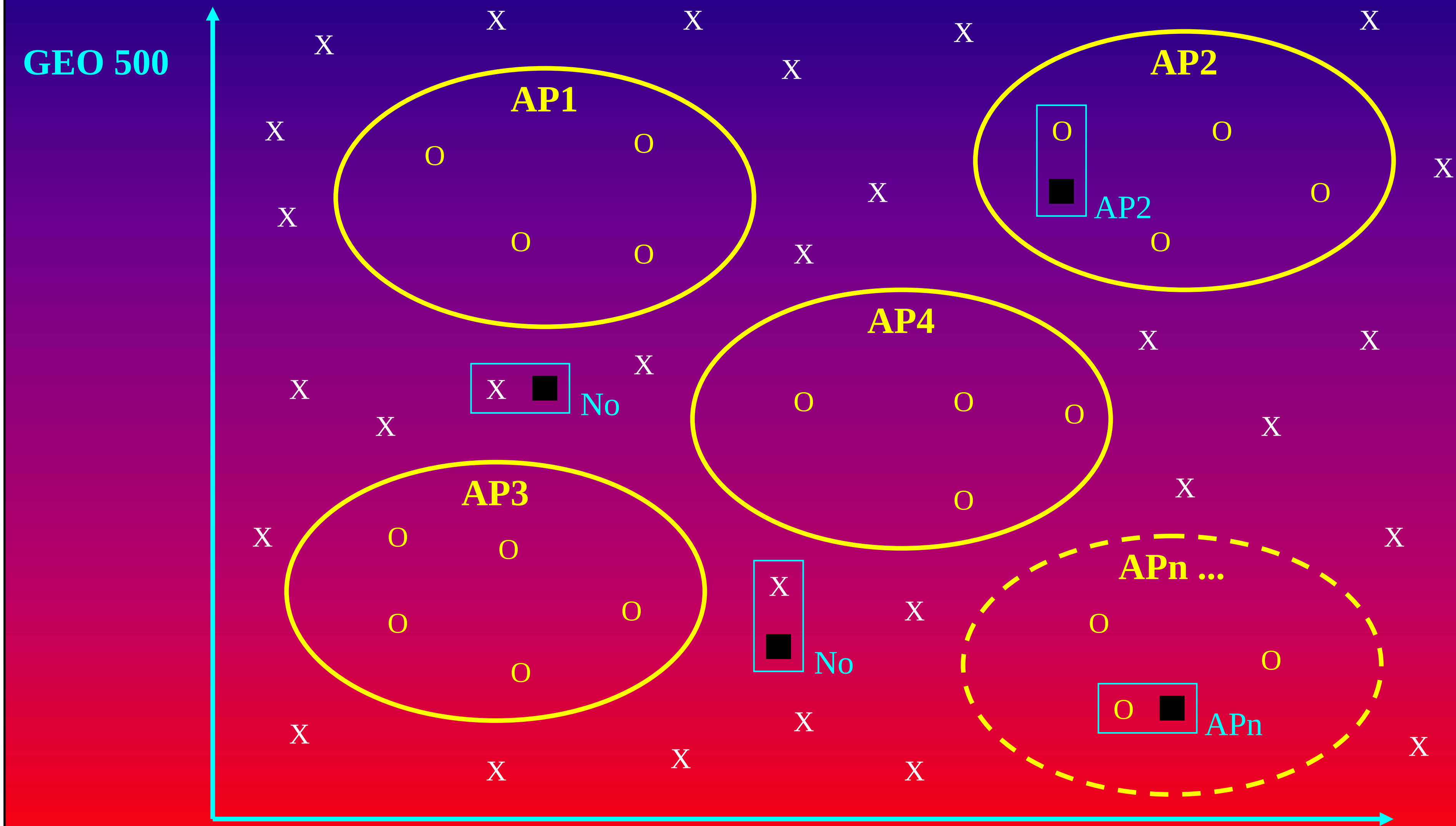
VALIDACIÓN / CALIBRACIÓN DEL MODELO

↓

FUTURO COMPENSADO

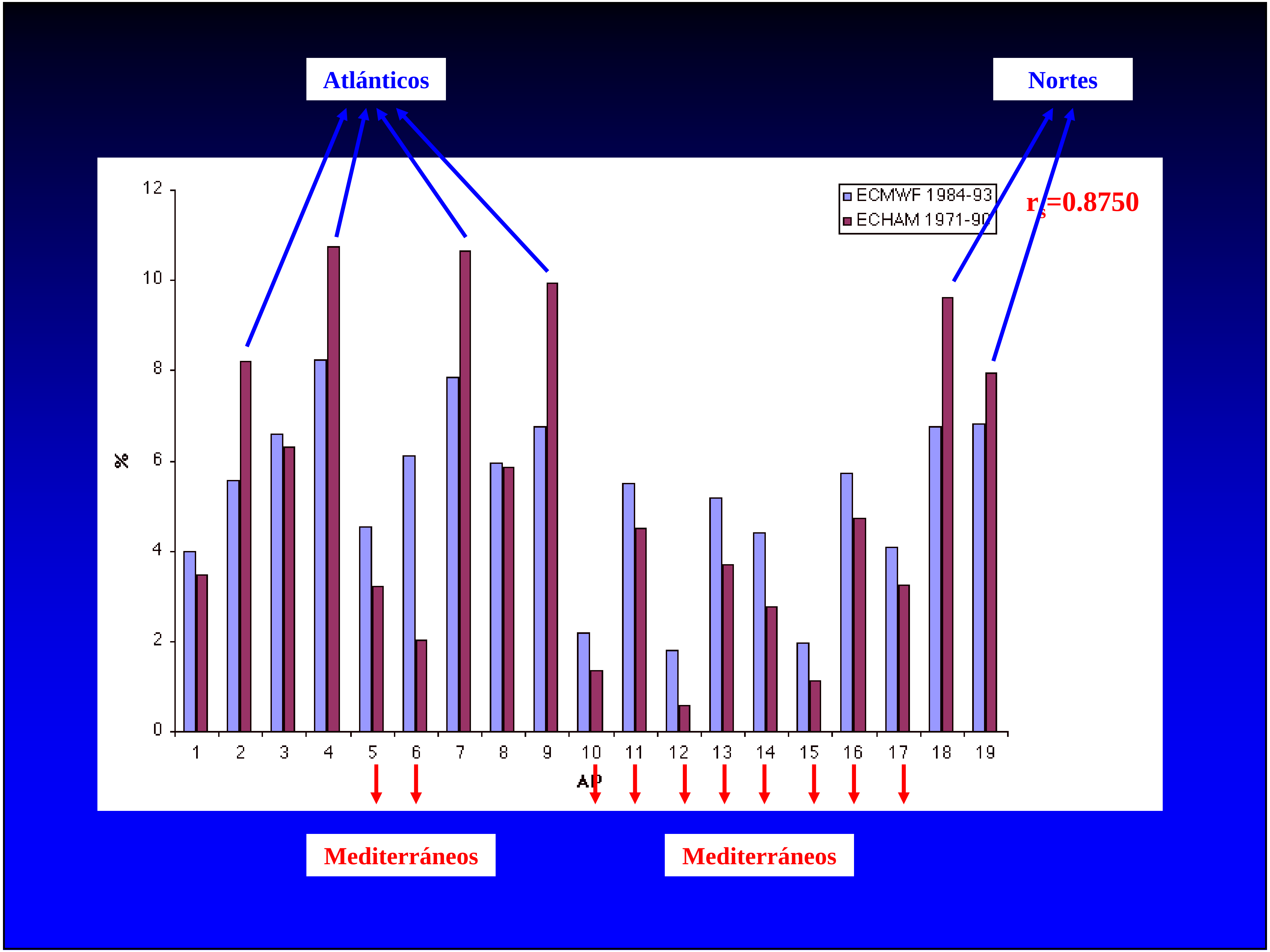
121 décadas (MEDIA + VARIABILIDAD)

TÉCNICA DEL ANÁLOGO

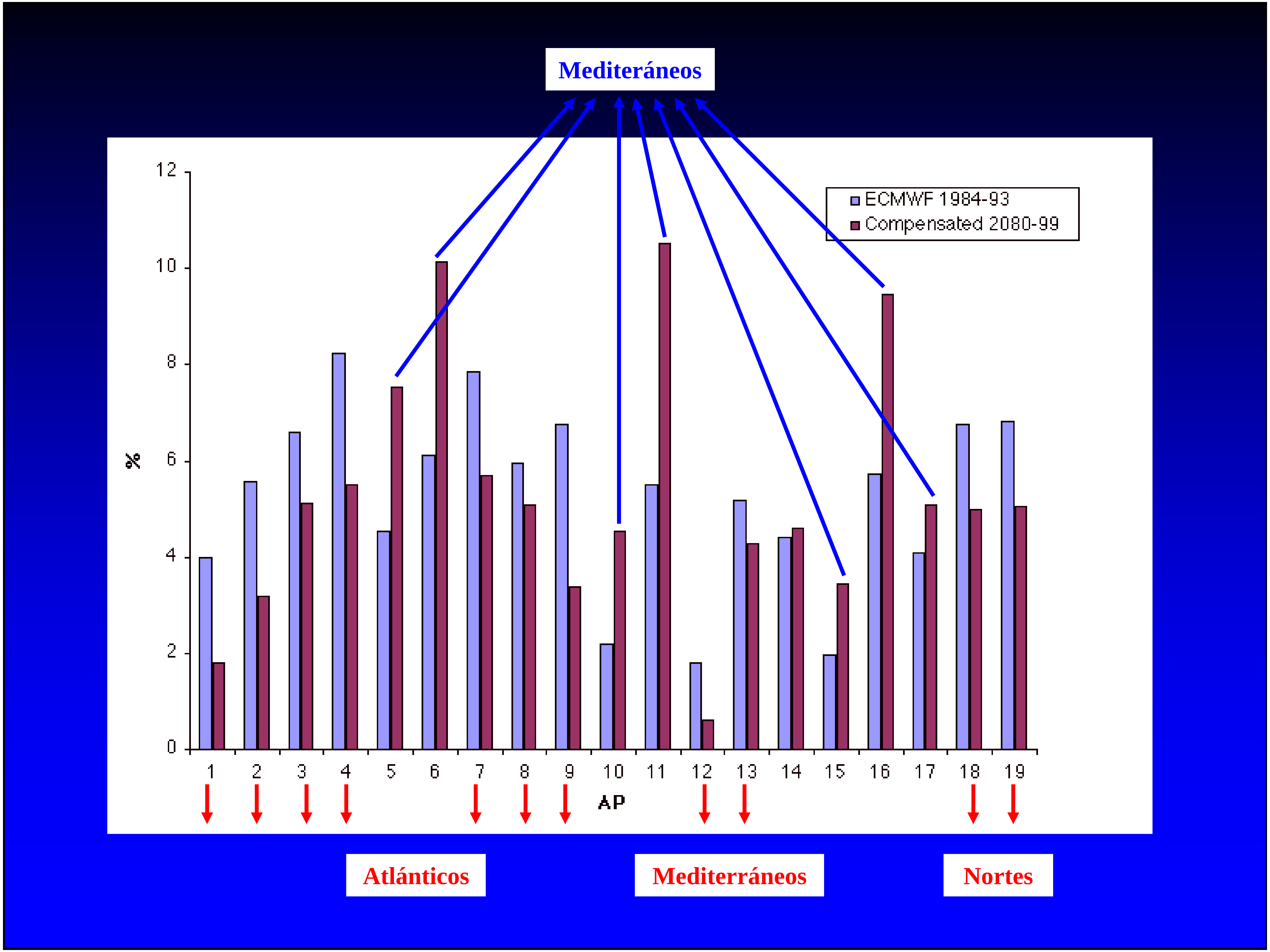


	ECMWF	ECHAM presente	ECHAM futuro
En APs	1275	1317 (media)	1140 (media)

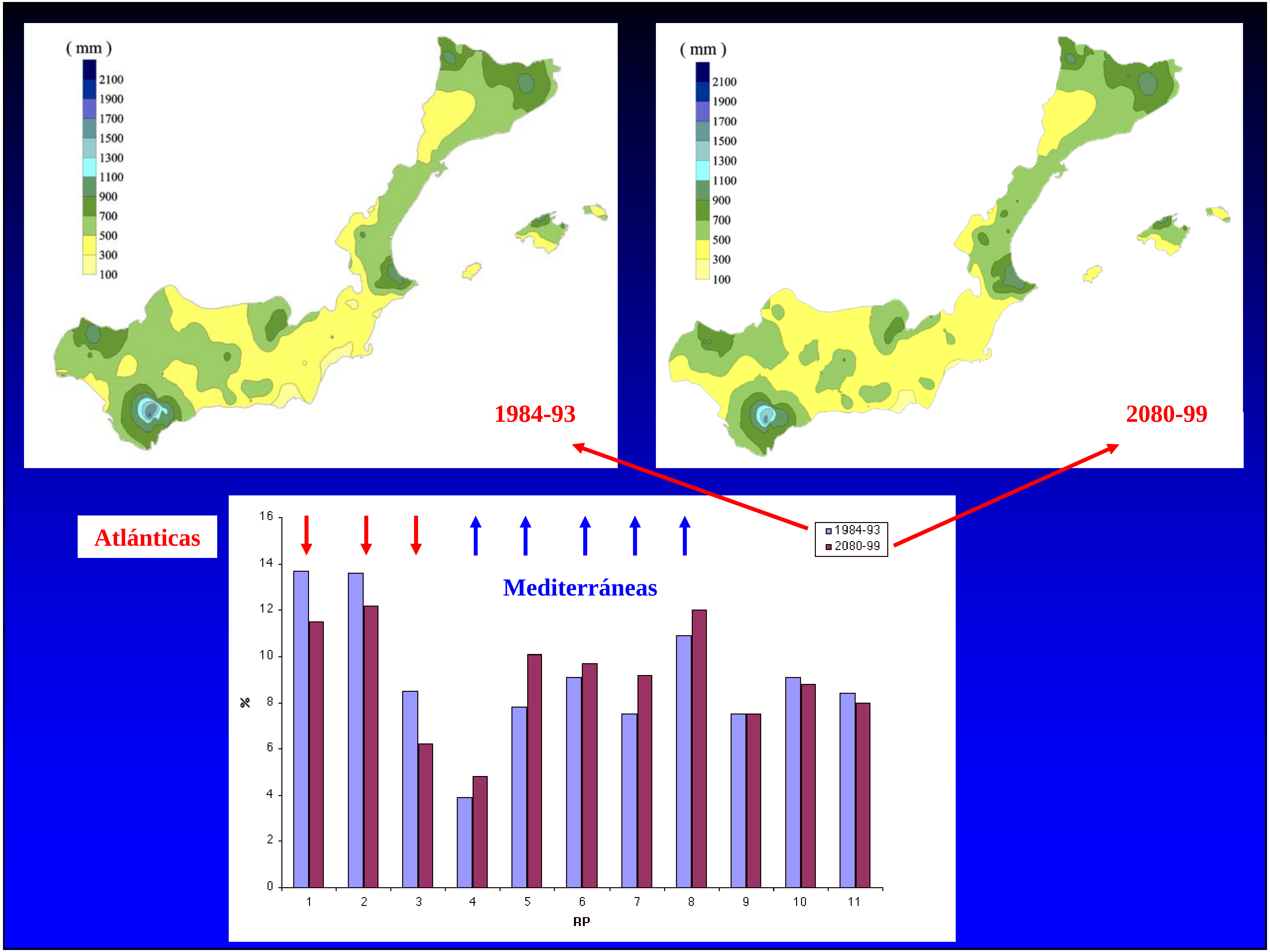
GEO 925



Atlánticos
Nortes
ECMWF 1984-93
ECHAM 1971-90
r_s=0.8750
%
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
AP
Mediterráneos
Mediterráneos

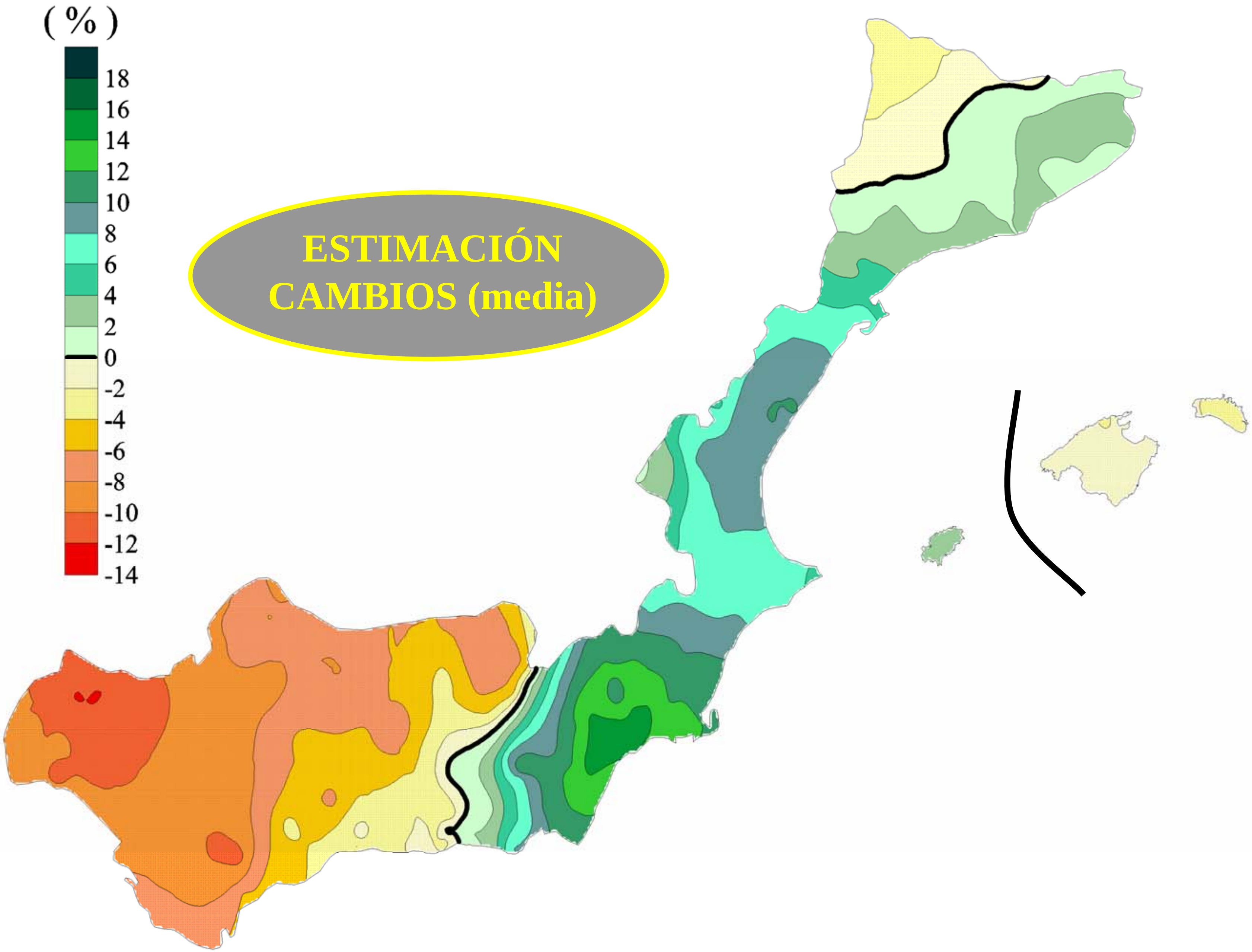


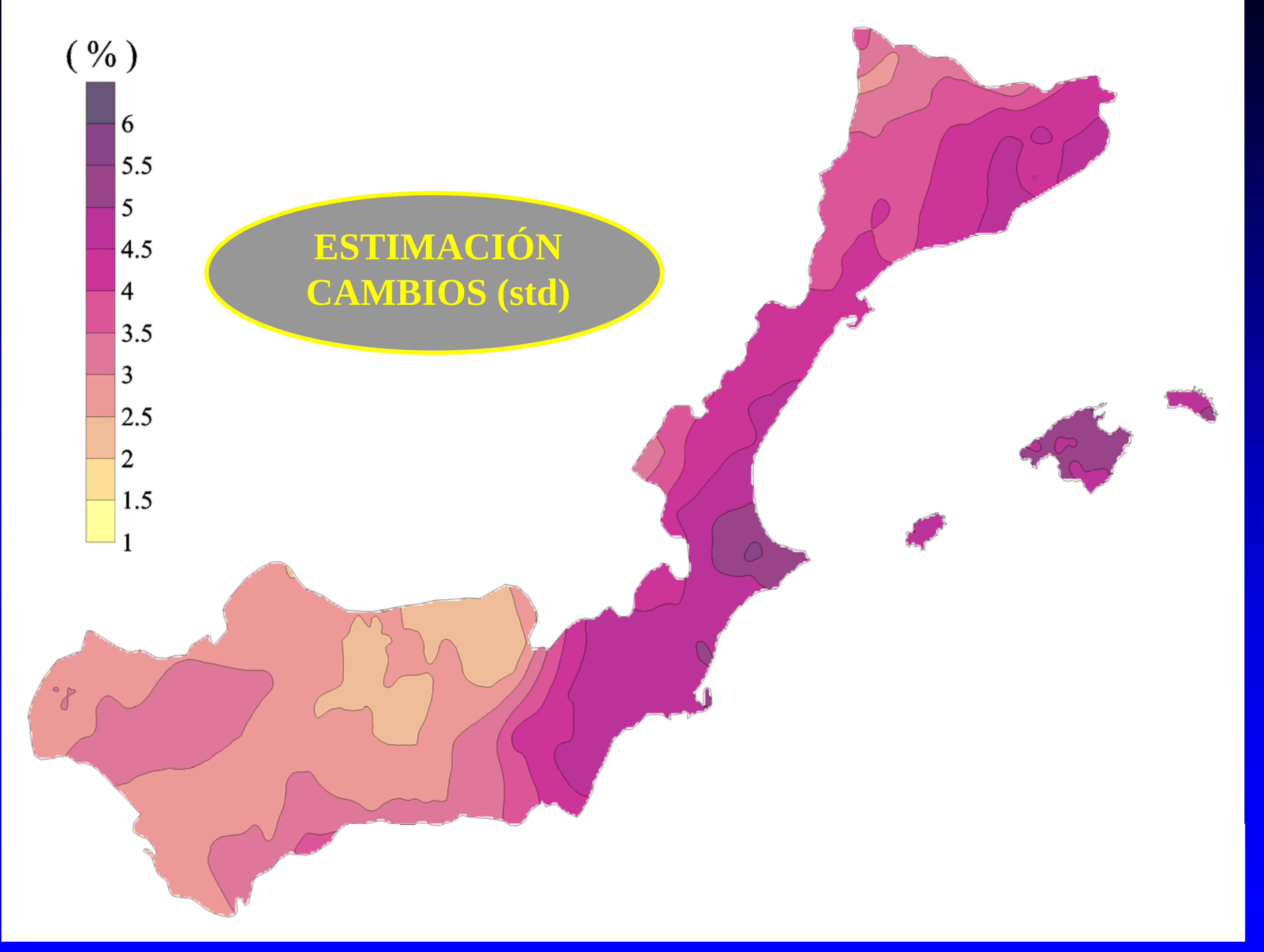
Mediteráneos
12
10
8
6
4
2
0
%
ECMWF 1984-93
Compensated 2080-99
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
AP
Atlánticos
Mediterráneos
Nortes



(mm)
2100
1900
1700
1500
1300
1100
900
700
500
300
100
1984-93
(mm)
2100
1900
1700
1500
1300
1100
900
700
500
300
100
2080-99
Atlánticas
Mediterráneas
1984-93
2080-99
16
14
12
10
8
6
4
2
0
%
1
2
3
4
5
6
7
8
9
10
11
RP

ESTIMACIÓN CAMBIOS (media)




(%)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
ESTIMACIÓN
CAMBIOS (std)

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

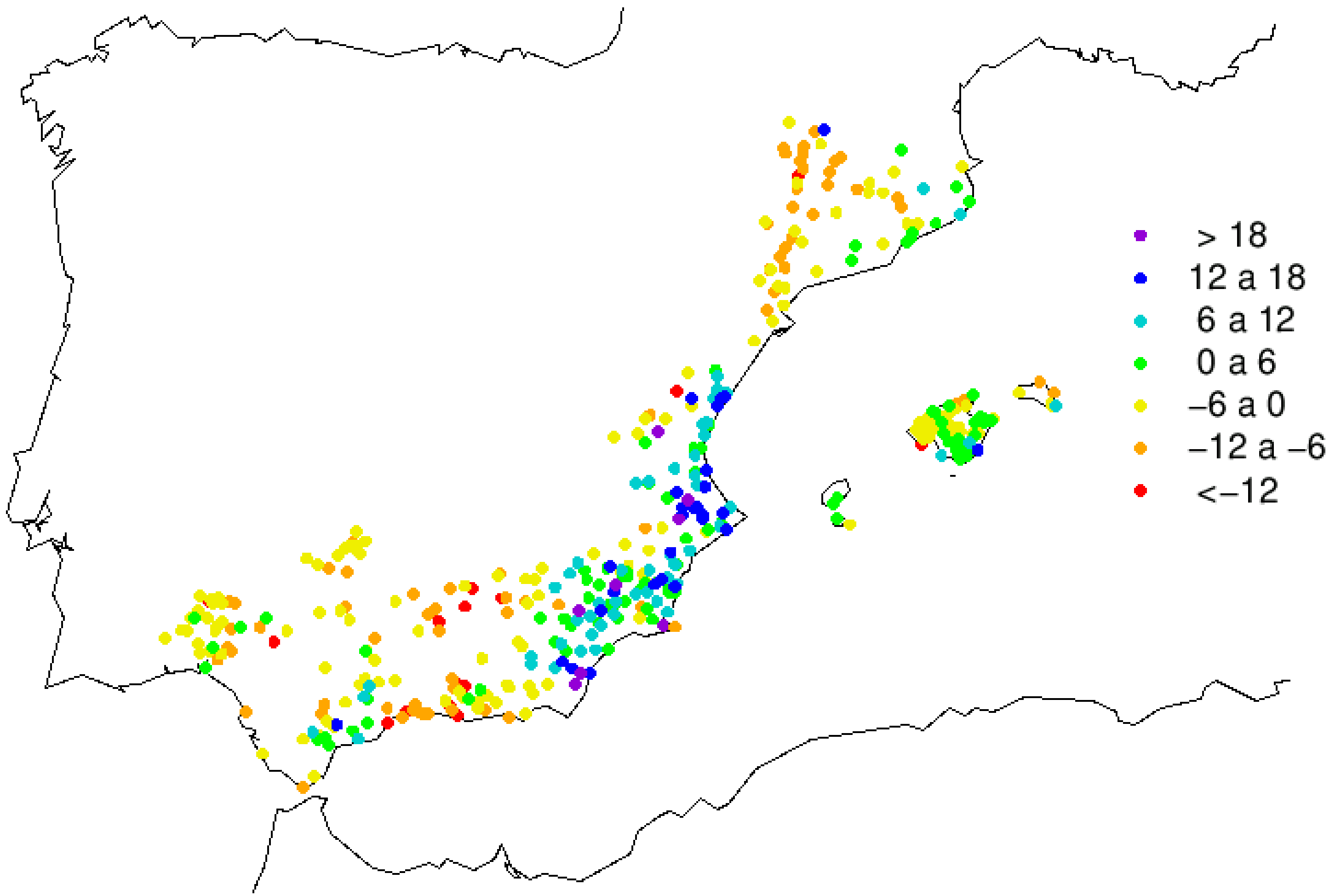


Figura 4: Distribución espacial de las tendencias (% por década) de la precipitación en el área mediterránea española (1964-1993).

Muchas gracias por vuestra atención !!!