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USE OF A CLIMATIC SYNOPTIC CLASSIFICATION TO IDENTIFY AND CHARACTERIZE NO_2 POLLUTION PATTERNS OVER THE IBERIAN PENINSULA

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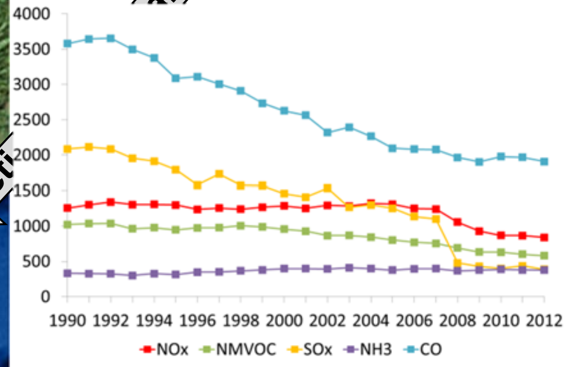
Air pollution in the Iberian Peninsula

Air pollution ► function(meteorology, emissions & topography)

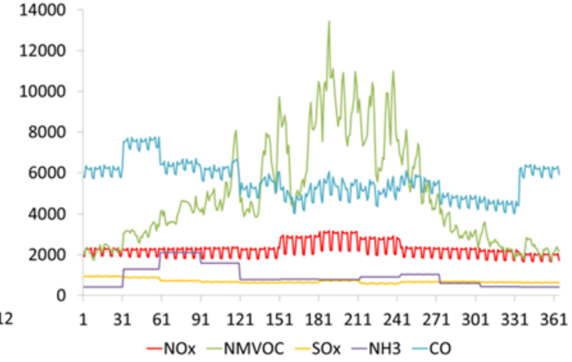
Total Spanish emissions (kt/year)

Environmental Ministry (2014)



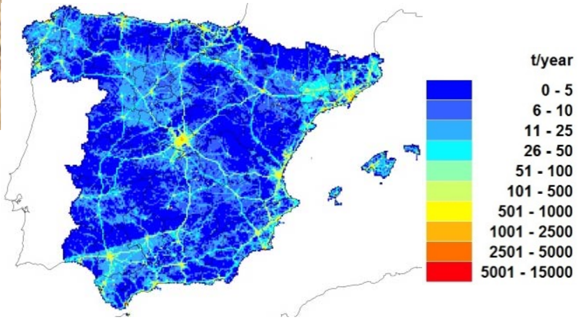
Total daily emissions for Spain (t/day)

Estimated with HERMESv2.0 model (2011)



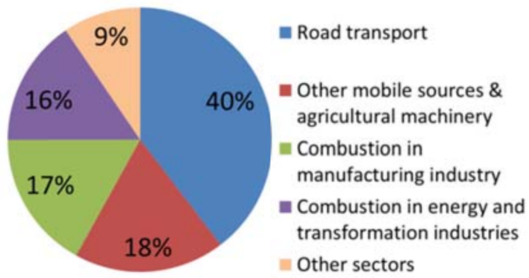
Total annual NO_x emissions for Spain (t/year)

Estimated with HERMESv2.0 model (2011)



Contribution to NO_x emissions in Spain by SNAP activity sector

Estimated with HERMESv2.0 model (2011)



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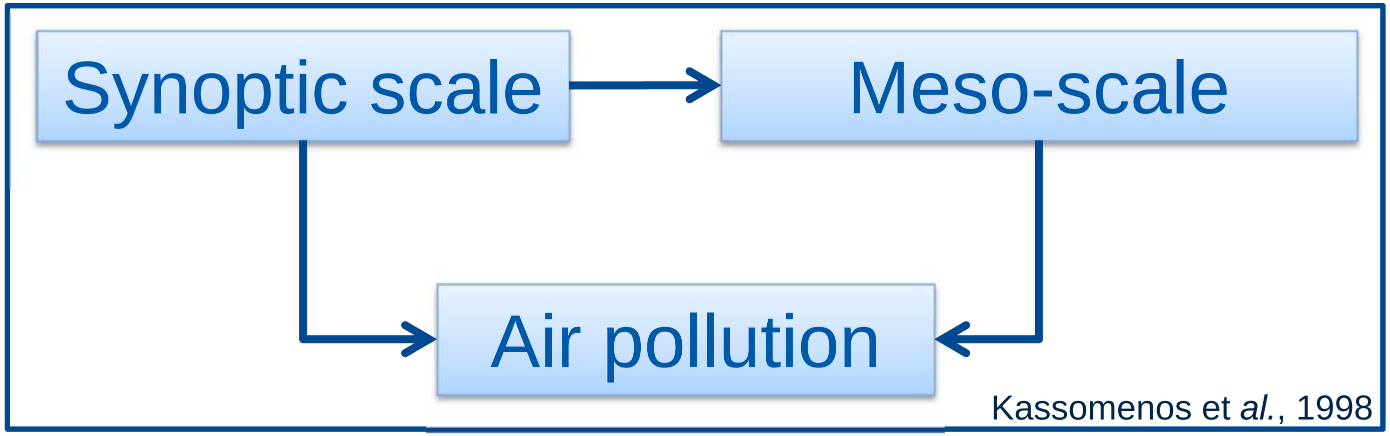
Synoptic, meso-scale meteorology and air pollution



Kassomenos et *al.*, 1998

"*The understanding of the relationship of the pollutants' concentration with the prevailing circulation, both synoptic and local scale, is a key element to explain air pollution dynamics in a given territory. This relationship is primarily examined by classifying the atmospheric circulation*".

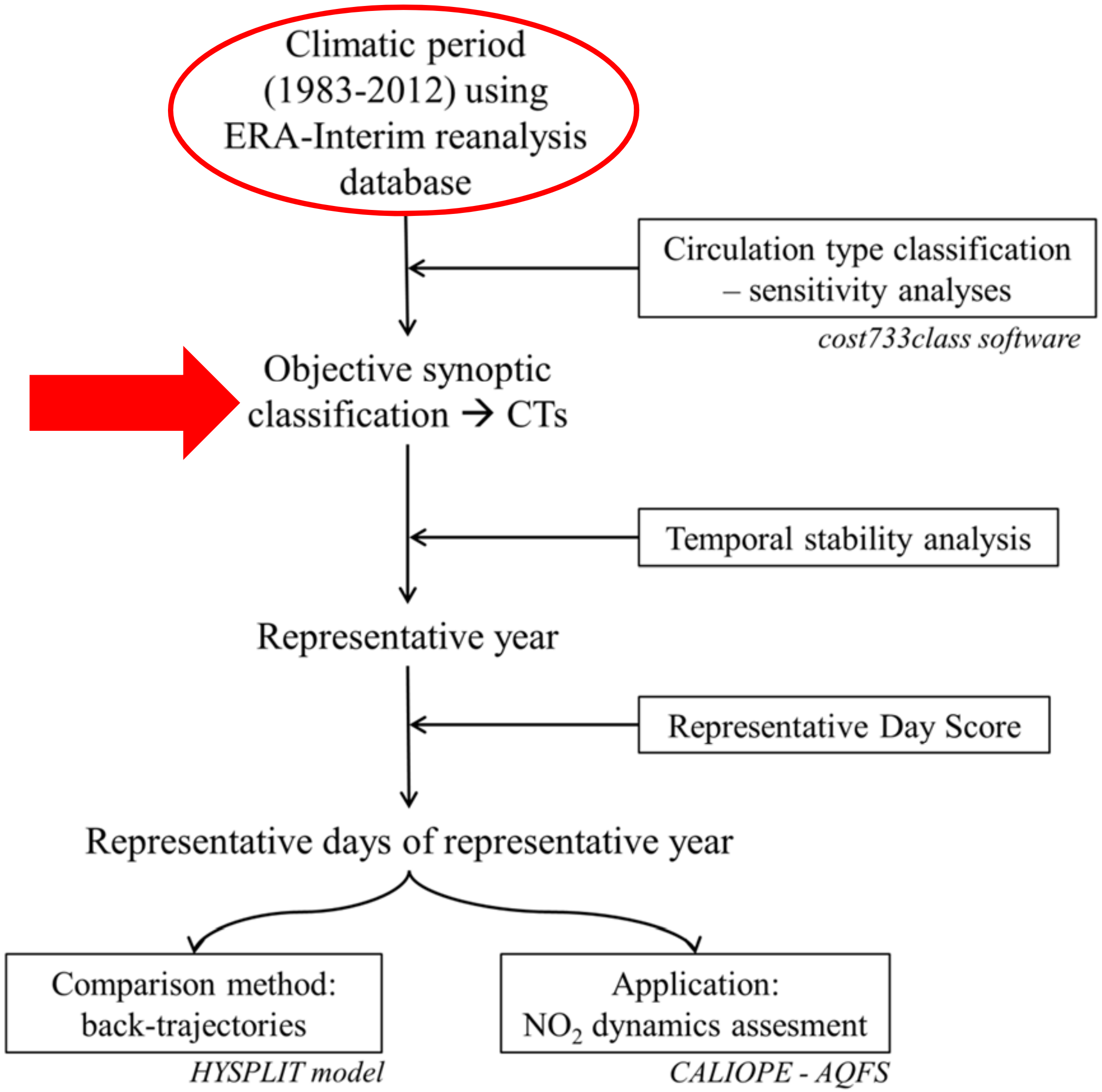
Flocas et *al.*, 2009

Objectives

1. Objectively classify synoptic circulation on a climatic basis (1983-2012) into typical circulation types (CTs)
2. Explain NO_2 surface concentration and dynamics over the Iberian Peninsula

Methodology: synoptic circulation type classification

- **Automatic and objective** classification of synoptic circulation over the Iberian Peninsula
  - Sensitivity tests to classification techniques and other parameters affecting the classification
  - Selection of a reference configuration based on statistical criteria & objective of the classification
- **Characterization of CTs**
  - Pressure and wind fields at surface and 500 hPa geopotential height
  - Climatic and monthly frequency, seasonal distribution, persistence, transitions
- Objective selection of **representative year** and **days** of the CTs



Sensitivity analyses performed

# test	Studied criterion	Variability range
1	Classification technique	Correlation techniques (3); Principal Component Analysis (4); Clustering techniques (5)
2	Number of circulation types	From 2 to 15, 18, 27, 50
3	Meteorological variable used as proxy	Mean sea level pressure (mslp), 10-meter U and V wind components (UV10), 1000-hPa vorticity (Vort1000), 2-meter temperature (T2m), relative humidity (RH)
4	Vertical level	Surface, 11 geopotential levels from 1000 to 1 hPa each 100 hPa
5	Temporal resolution	Data each 6, 12, 24 hours, 06 h mean
6	Seasonality	Winter, spring, summer, autumn, annual (an)
7	Horizontal resolution	0.125º x 0.125º, 0.25º x 0.25º, 0.75º x 0.75º, 1.5º x 1.5º, 3º x 3º
8	Spatial domain	D00 (18.75N – 76.5N / 33.75W – 31.5 E), D01 (24.75N – 62.25N / 25.5W – 20.25 E), D02 (30N – 50.25N / 13.5W – 13.5 E)

Explained Variation criterion + **objective of the classification** enable to select the most useful configuration to identify CTs for air quality applications

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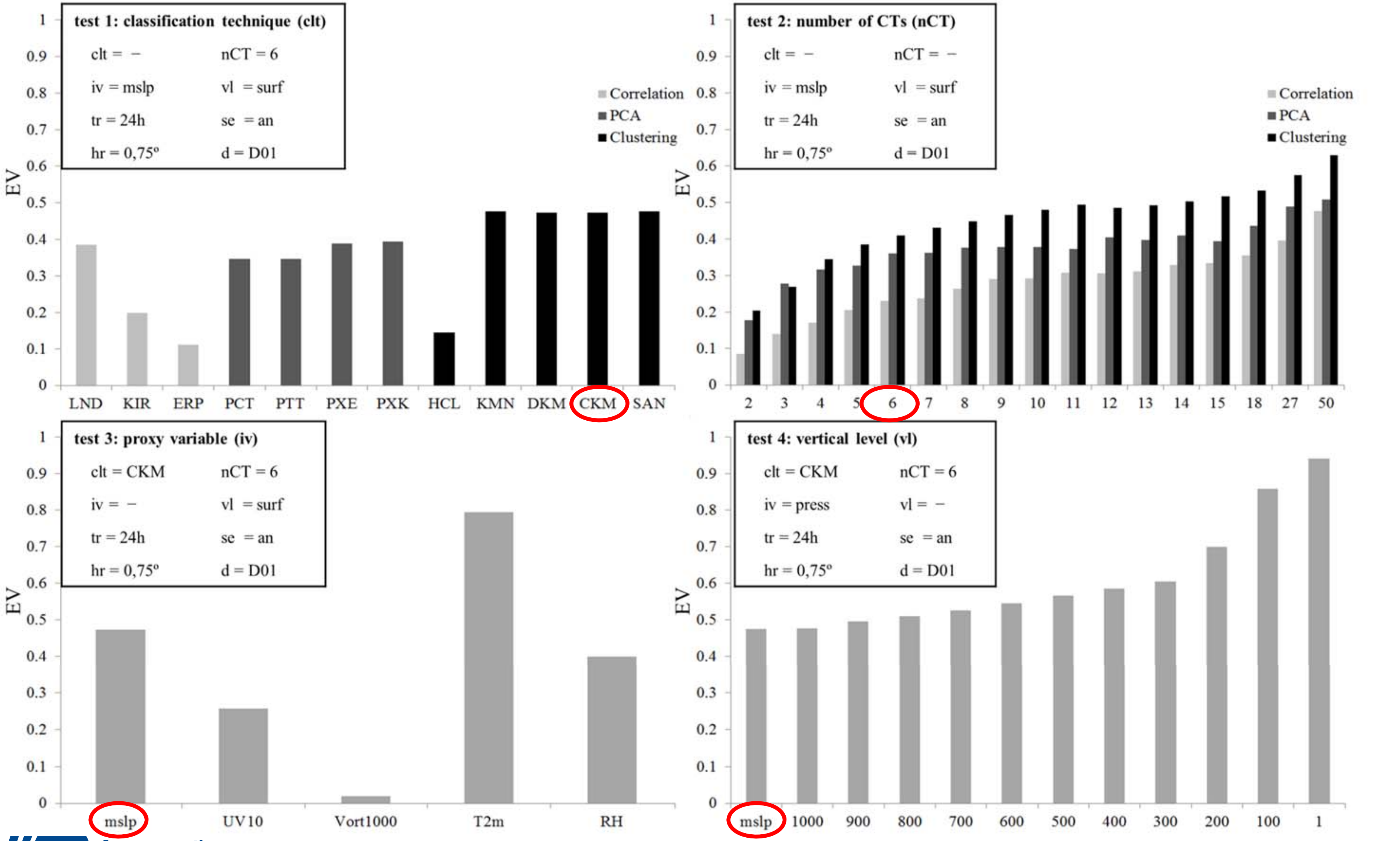
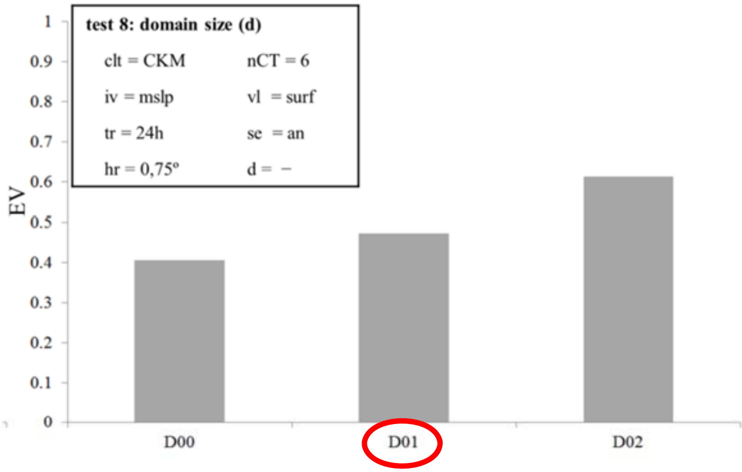
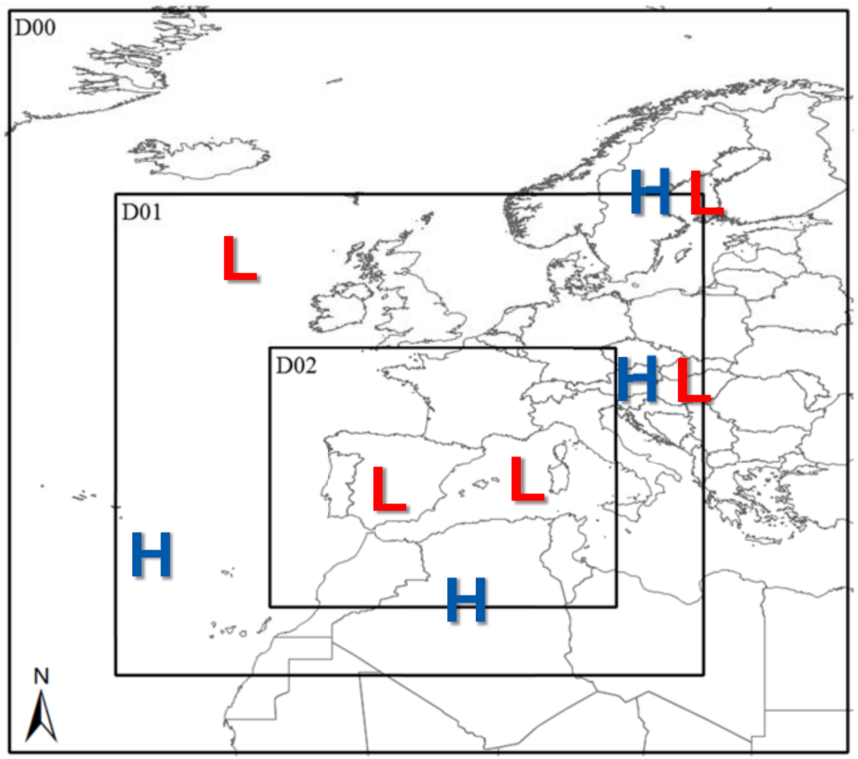
Results of the sensitivity analyses



Results of the sensitivity analyses

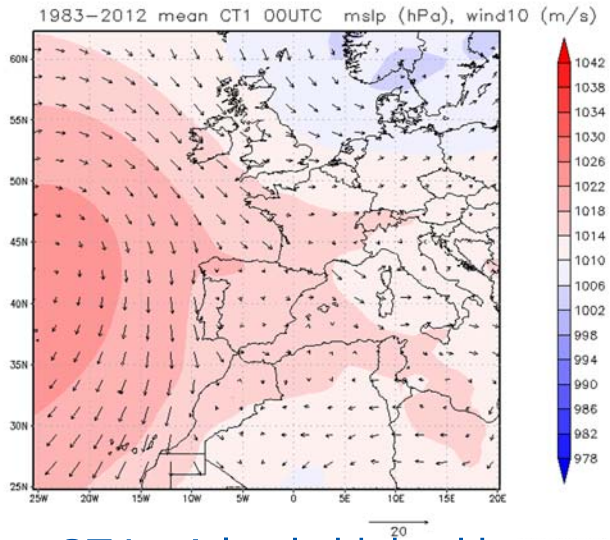




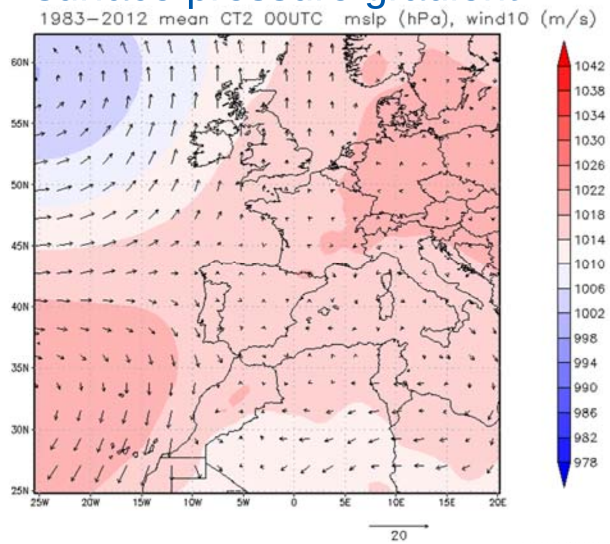
Selected configuration			
Classification technique	C-k means	Temporal res.	6 h
# of CTs	6	Seasonality	Annual
Meteo variable	Atmospheric pressure	Horizontal res.	0.75º x 0.75º
Vertical level	Surface	Spatial domain	D01

Circulation types identified (data base 1983-2012)

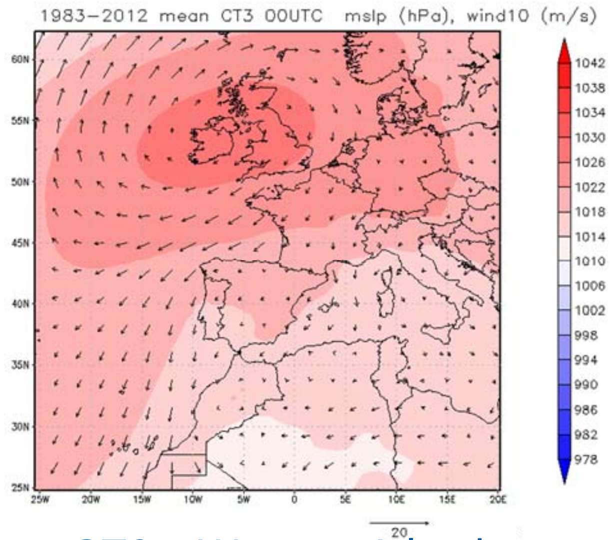
CT1 – NW advection



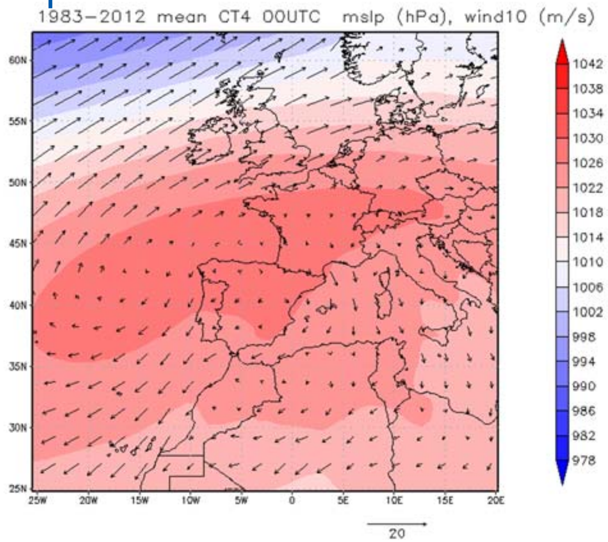
CT2 – Summer reduced surface pressure gradient



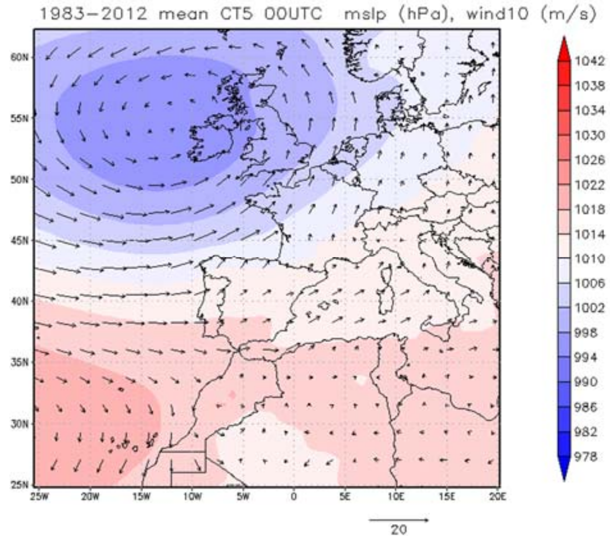
CT3 – E/NE advection



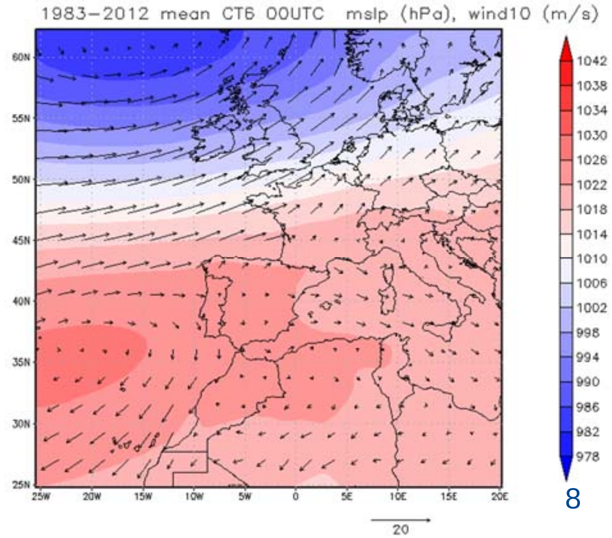
CT4 – Atlantic high with polar maritime advection



CT5 – W/NW advection



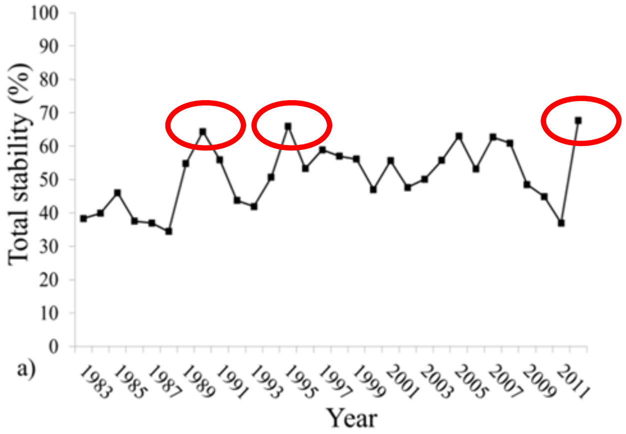
CT6 – Western Atlantic zonal advection



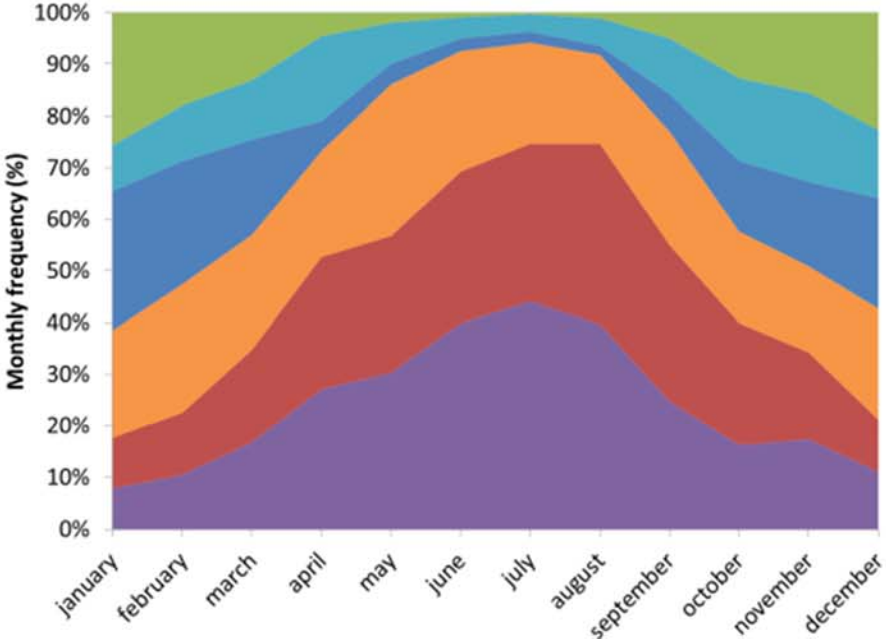
Characteristics of the CTs identified in 1983-2012

	CT1 - NW advection	CT2 - Summer reduced surface pressure gradient	CT3 - E/NE advection	CT4 - Atlantic high with polar maritime advection	CT5 - W/NW advection	CT6 - Western Atlantic zonal advection
Frequency (%)	23.9	22.4	21.3	12.0	10.4	10.1
Most frequent month	JUL	AUG	MAY	JAN	APR/OCT	JAN
Seasonal frequency (%): DJF/ MAM/ JJA/ SON	10.1/26.1/ 43.5/ 20.3	11.7/26.2/ 35.8/ 26.3	25.9/28.5/ 23.5/22.0	49.8/19.9/ 4.4/25.9	26.0/28.7/ 10.4/35.0	54.3/16.4/ 1.9/27.4
Mean / Max persistence (days)	2.9 / 23	2.9 / 22	3.8 / 19	2.7 / 27	3.0 / 17	2.9 / 19
Transitions	CT2	CT1	CT2	CT6	CT1	CT4

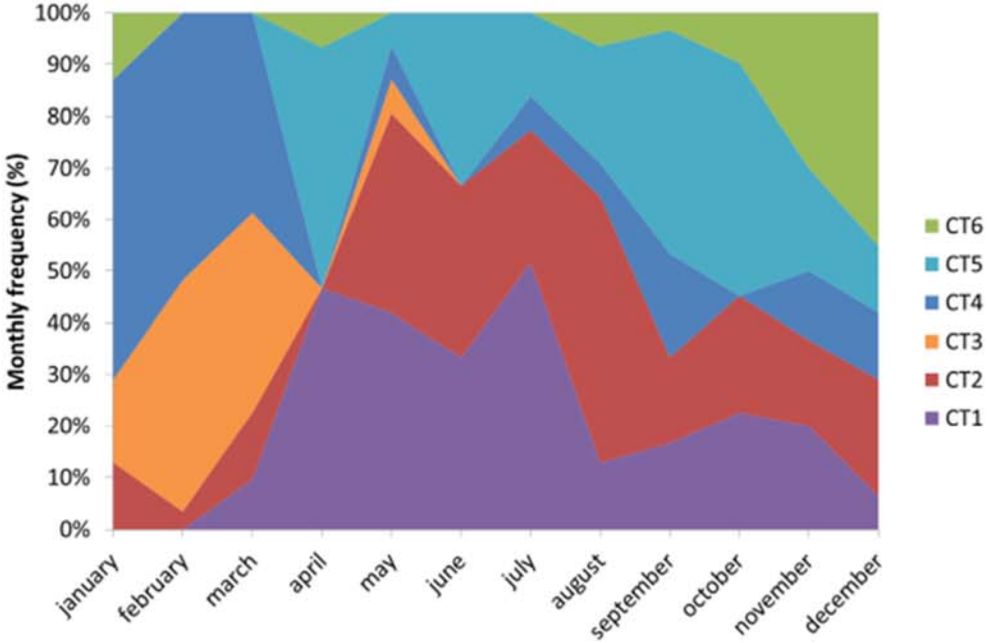
Representative year



CT1	CT2	CT3	CT4	CT5	CT6
NW advection	Summer reduced surface pressure gradient	E/NE advection	Atlantic high with polar maritime advection	W/NW advection	Western Atlantic zonal advection



1983-2012



2012

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Characteristics of the CTs: 1983-2012 vs year 2012

	Period	CT1 - NW advection	CT2 - Summer reduced surface pressure gradient	CT3 - E/NE advection	CT4 - Atlantic high with polar maritime advection	CT5 - W/NW advection	CT6 - Western Atlantic zonal advection
Frequency (%)	1983-2012 2012	23.9 21.9	22.4 21.6	21.3 8.8	12.0 17.8	10.4 20.5	10.1 9.3
Most frequent month	1983-2012 2012	JUL JUL	AUG AUG	MAY FEB	JAN JAN	APR/OCT APR/NOV	JAN DEC
Seasonal frequency (%): DJF/ MAM/ JJA/ SON	1983-2012 2012	10.1/26.1/ 43.5/ 20.3 2.5/37.5/ 37.5/22.5	11.7/26.2/ 35.8/ 26.3 15.2/20.3/ 43.0/21.5	25.9/28.5/ 23.5/22.0 56.3/43.8/ 0.0/ 0.0	49.8/19.9/ 4.4/25.9 56.9/21.5/ 6.2/15.4	26.0/28.7/ 10.4/35.0 5.3/21.3/ 29.3/44.0	54.3/16.4/ 1.9/27.4 50.0/5.9/ 5.9/38.2
Mean / Max persistence (days)	1983-2012 2012	2.9 / 23 3.6 / 10	2.9 / 22 2.6 / 8	3.8 / 19 4.6 /18	2.7 / 27 3.8 / 15	3.0 / 17 3.0 /10	2.9 / 19 3.5 / 10
Transitions	1983-2012 2012	CT2 CT2/CT5	CT1 CT1/CT5	CT2 CT4	CT6 CT2	CT1 CT1/CT2	CT4 CT5

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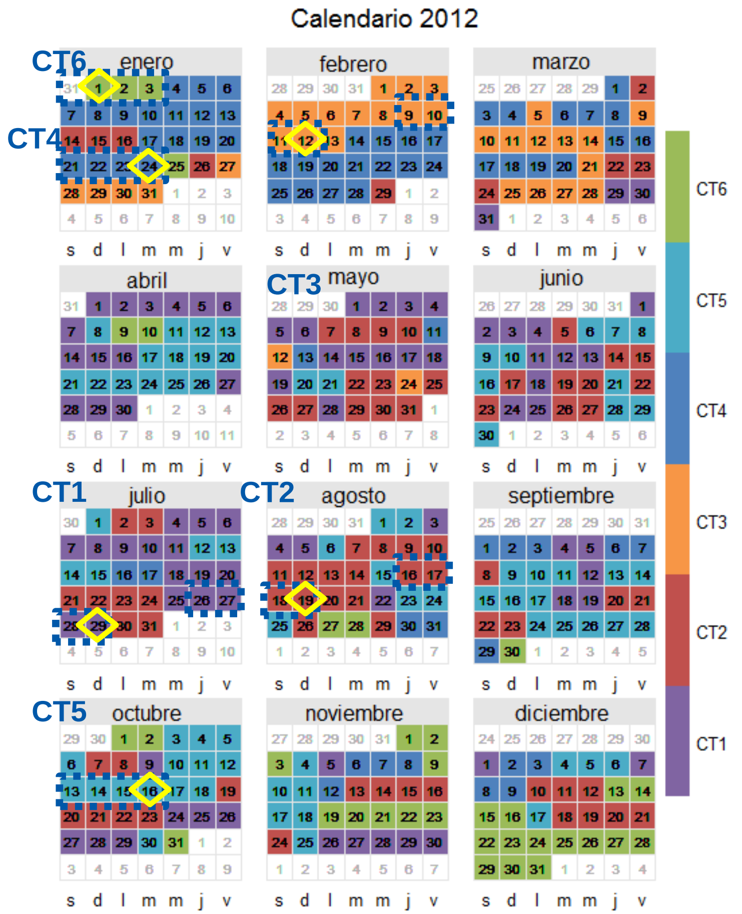
Representative days

Daily score minimizes the differences between the daily grid and the average grid of a given CT.

$$DS_t = \sum_{i=1}^{n} |v_{t,i} - \bar{v}_i|$$

For each day (t) within a given CT, the Day Score (DS) is calculated as the sum of the absolute value of the differences between the daily value and the average value of the meteorological variable of the CT for each cell (i) of the grid.
n is the number of cells of the grid; and $\bar{v}_i$ is the arithmetic mean of the input variable on each i cell of the domain for all days belonging to the CT.



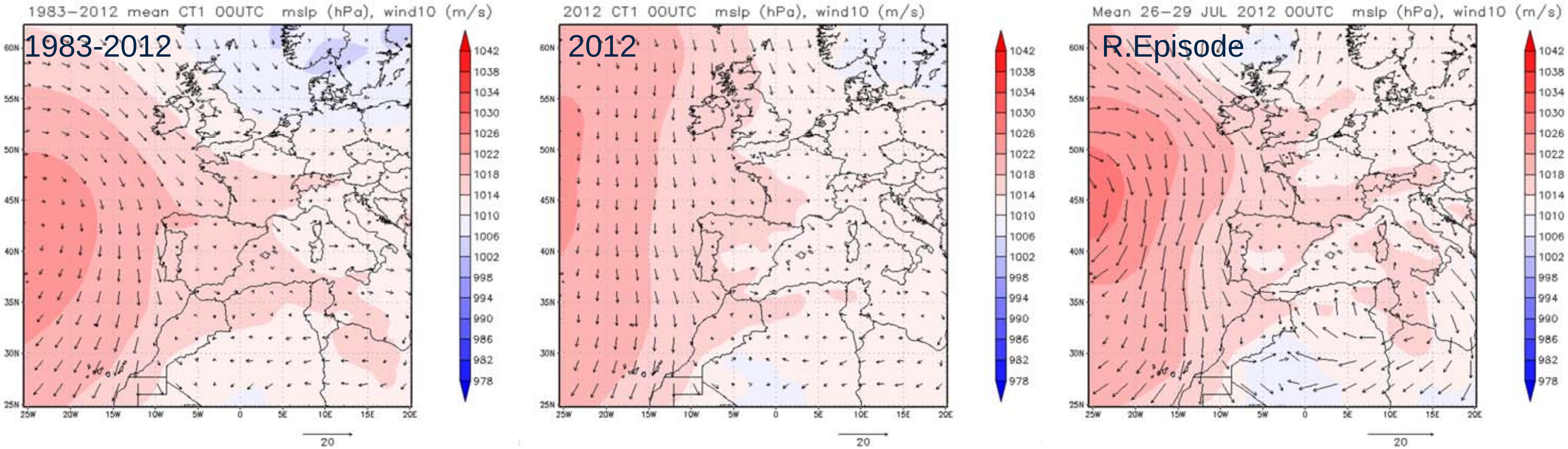
Representative Day Score (*RDS*) minimizes the value of the DS identifying the representative day for each CT.

$$RDS = \min(DS_t)$$

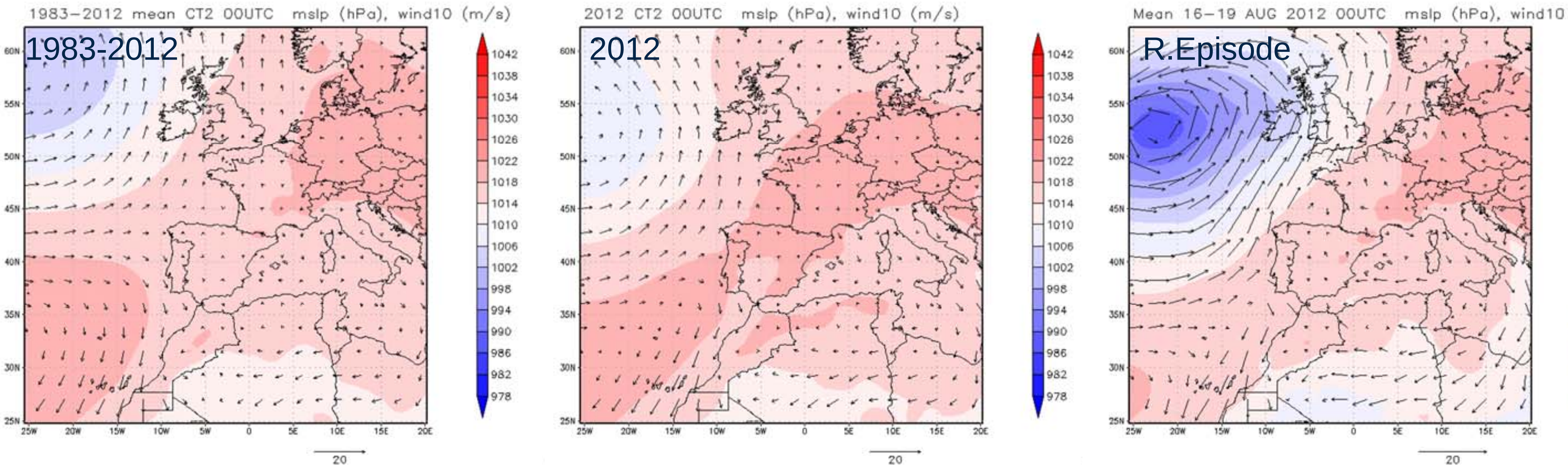
CT1	CT2	CT3	CT4	CT5	CT6
NW advection	Summer reduced surface pressure gradient	E/NE advection	Atlantic high with polar maritime advection	W/NW advection	Western Atlantic zonal advection

Confirmation: 1983-2012 vs 2012 vs mean episode

CT1 – NW advection

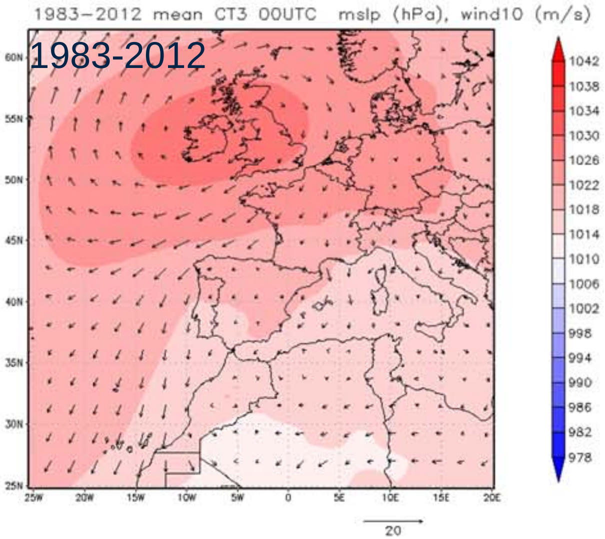


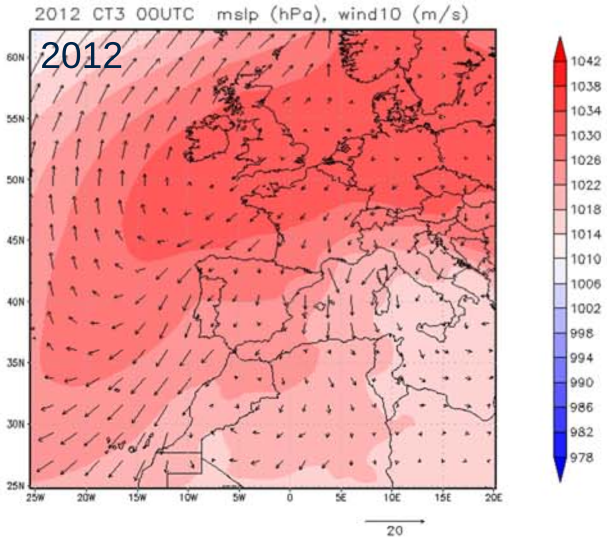
CT2 – Summer reduced surface pressure gradient

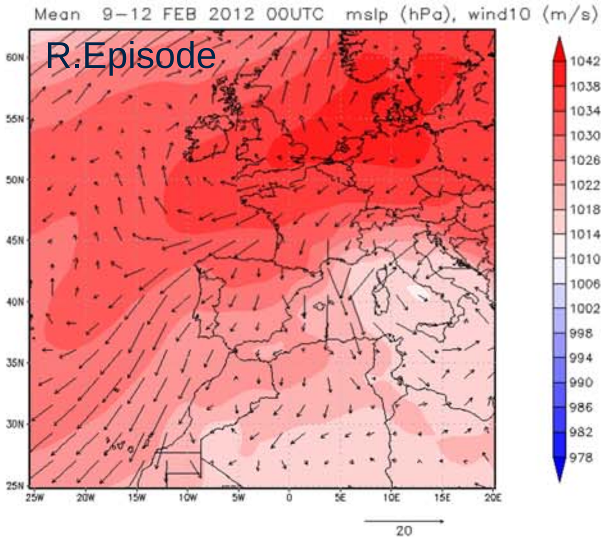


Confirmation: 1983-2012 vs 2012 vs mean episode

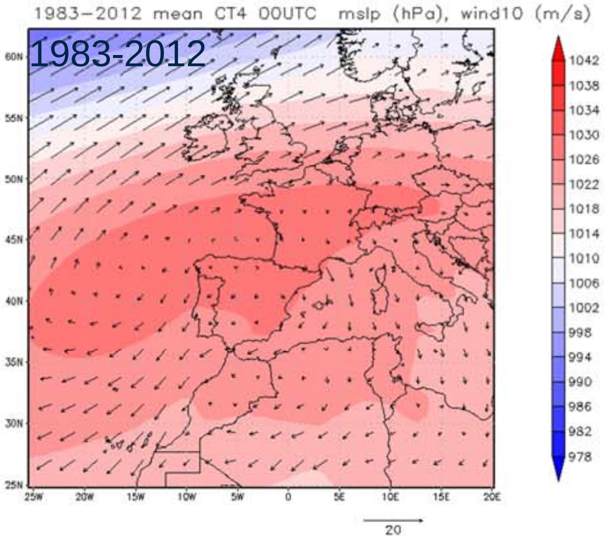
CT3 – E/NE advection

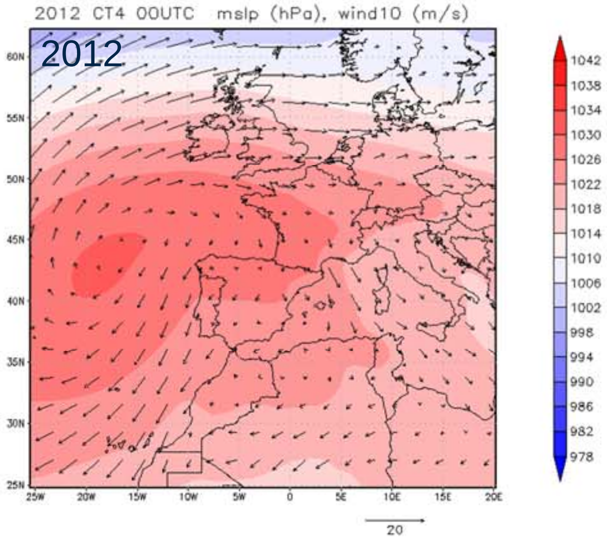


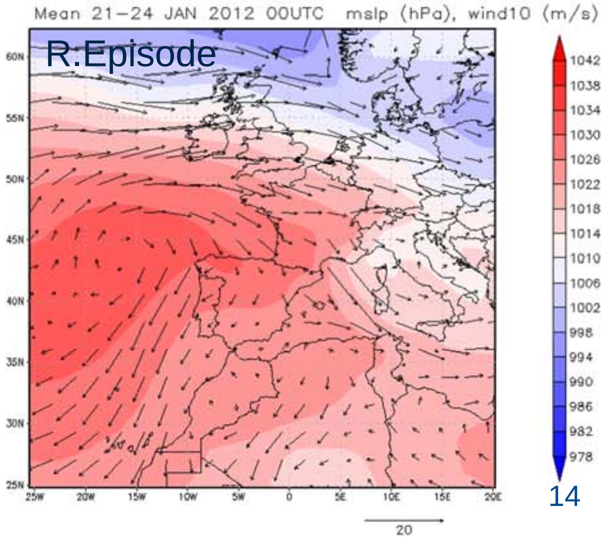




CT4 – Atlantic high with polar maritime advection

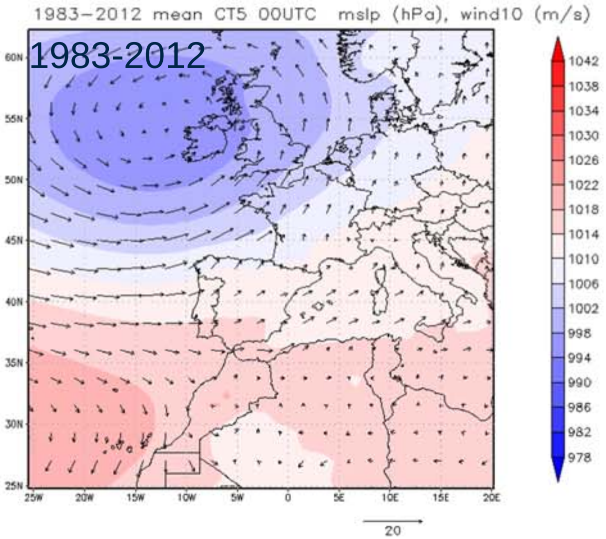


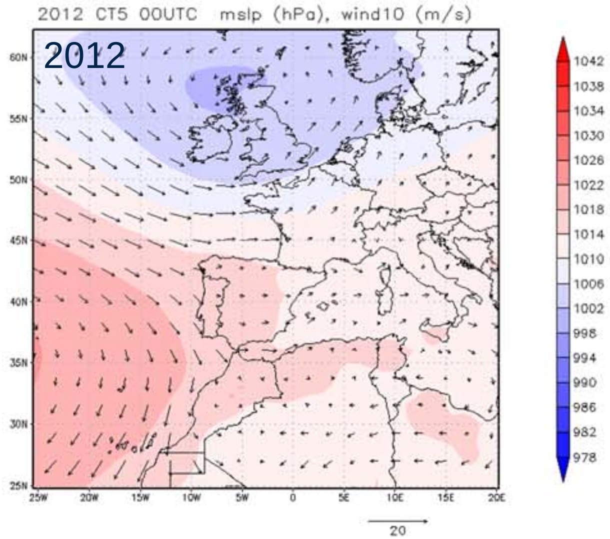


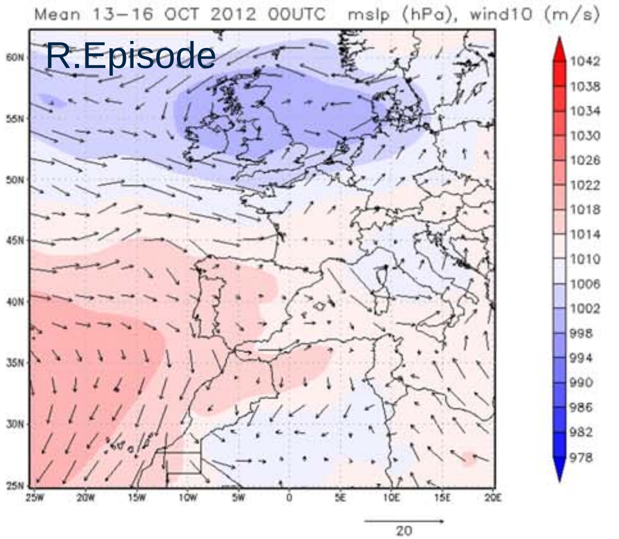


Confirmation: 1983-2012 vs 2012 vs mean episode

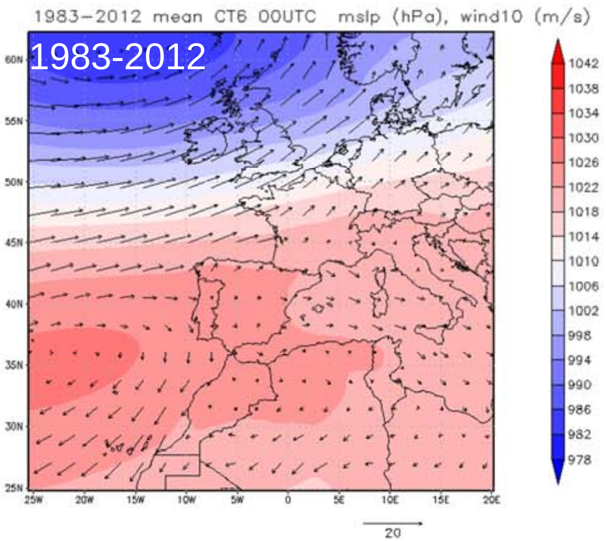
CT5 – W/NW advection

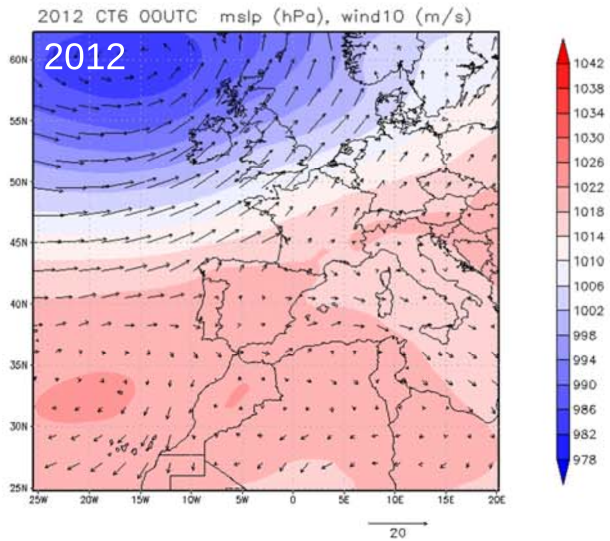


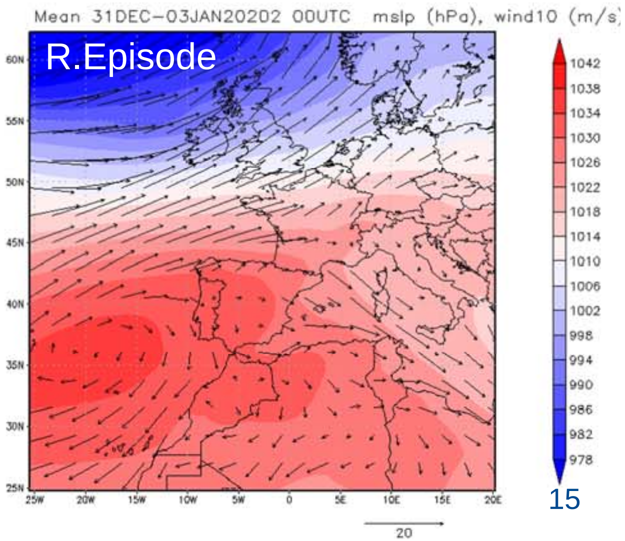




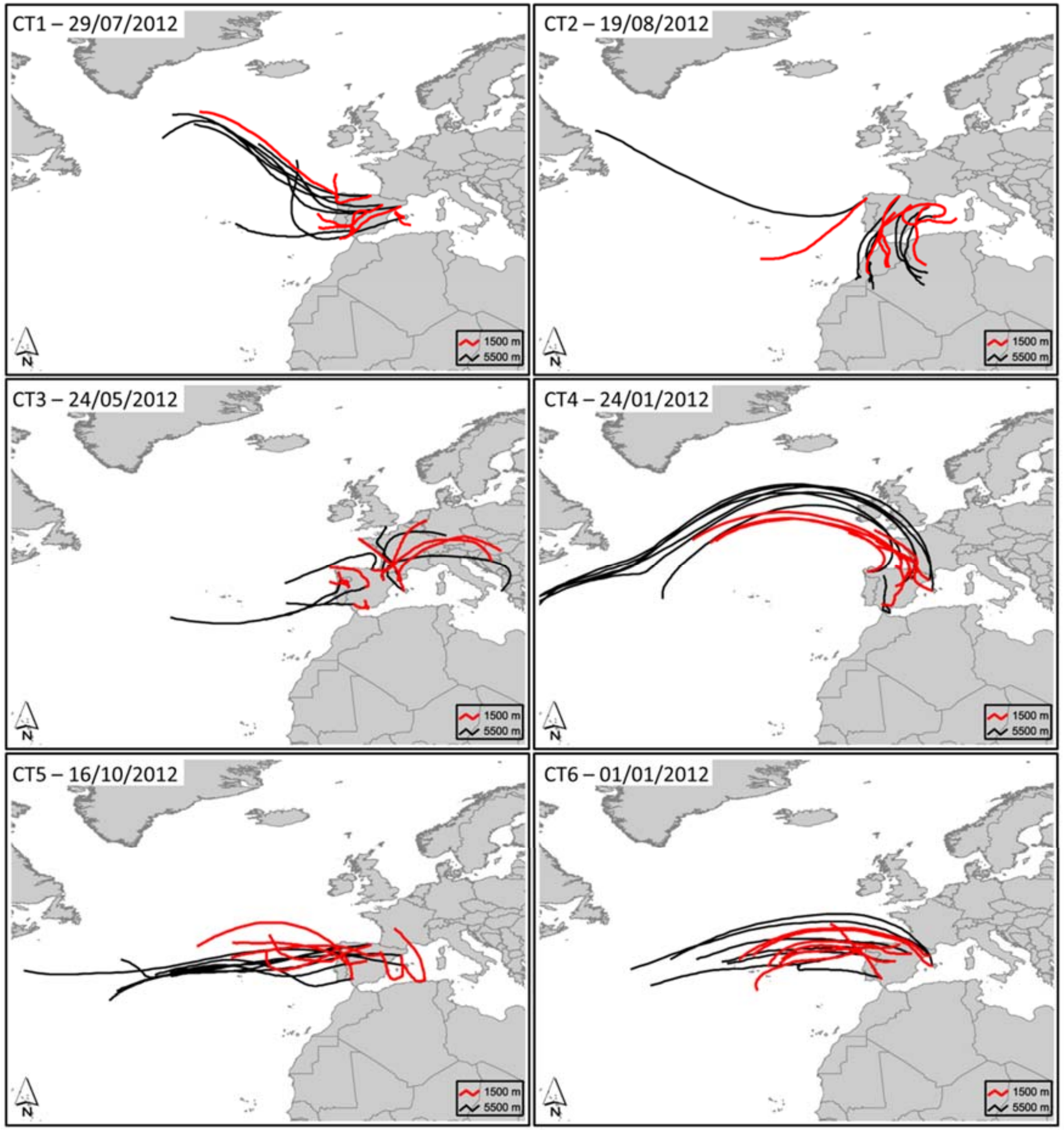
CT6 – Western Atlantic zonal advection







Confirmation: Back trajectories



CT1	NW advection
CT2	Summer reduced surface pressure gradient
CT3	E/NE advection
CT4	Atlantic high with polar maritime advection
CT5	W/NW advection
CT6	Western Atlantic zonal advection

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CALIOPE: Air Quality Forecasting System

CALIOPE modules

Meteorology
- WRF-ARWv3.5
- 38 sigma levels (top 50 hPa)
- IBC: GFS (NCEP)
- 33 layers/50 hPa

Emissions
- HERMESv2
- EU: HERMES-DIS (EMEP data)
- Spain: HERMES-BOUP

Chemistry
- CMAQv5.0.1
- CB05/AERO5
- BC: NCAR MOZART4
- 15 layers/ 50 hPa

Mineral dust
- BSC-DREAM8bv2
- Mineral PM10 and PM2.5

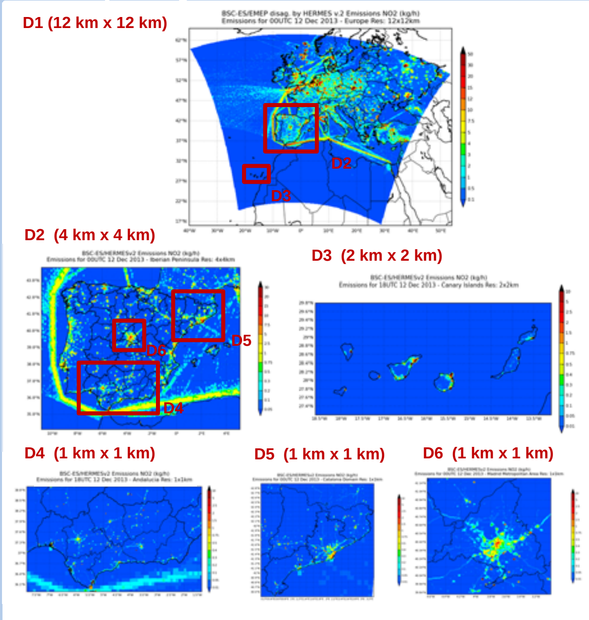
Post-process
- Kalman Filter (puntual y 2D)

Air quality forecast

O_3, NO_2, SO_2, CO, PM10, PM2.5, Benzene

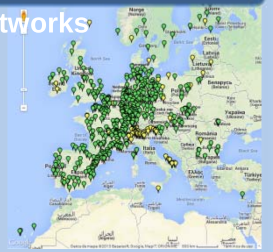
48h forecast

- Concentration maps, emis, meteo
- Air quality indexes



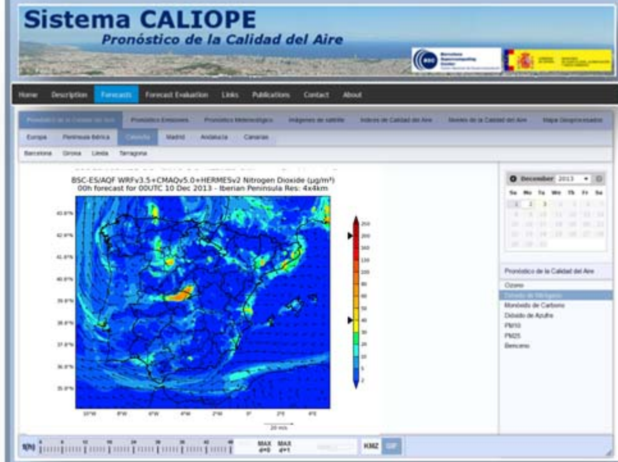
Near real-time evaluation

- Air quality stations networks
- Satellites



Diffusion

- Web (www.bsc.es/caliope)
- Smartphone



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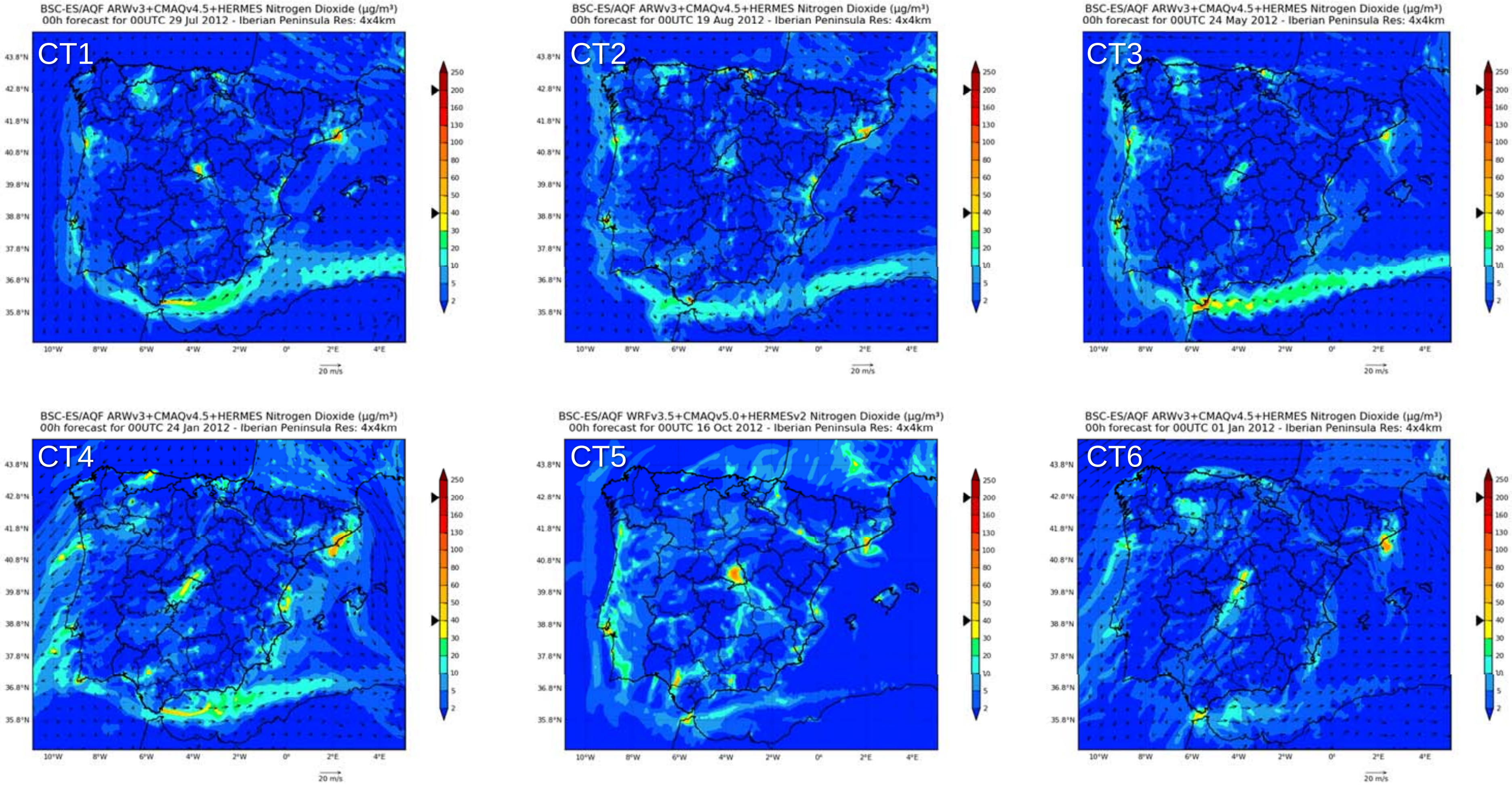
CONSEJERÍA DE MEDIO AMBIENTE Y ORDENACIÓN DEL TERRITORIO

NO_2 dynamics on the RD of each CT



CT1	CT2	CT3	CT4	CT5	CT6
NW advection	Summer reduced surface pressure gradient	E/NE advection	Atlantic high with polar maritime advection	W/NW advection	Western Atlantic zonal advection

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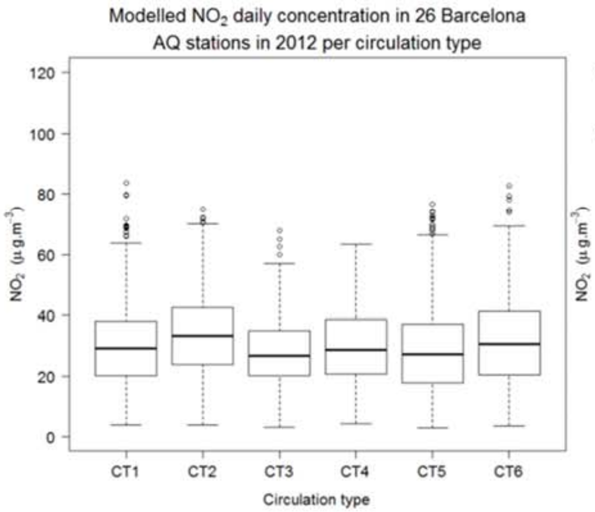
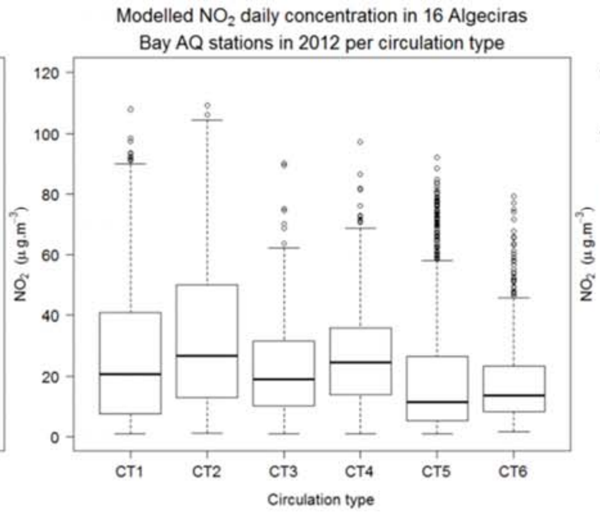
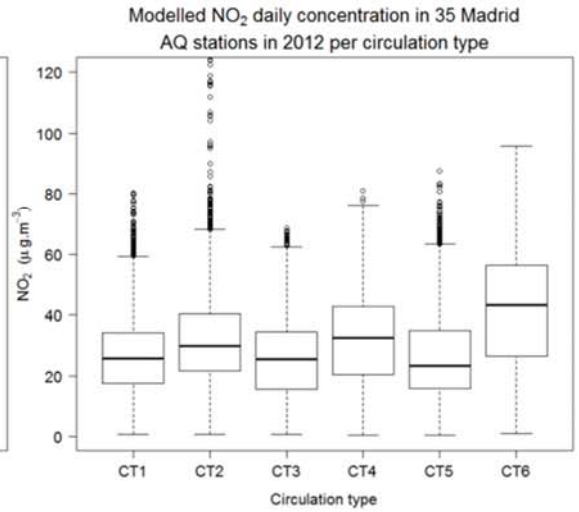
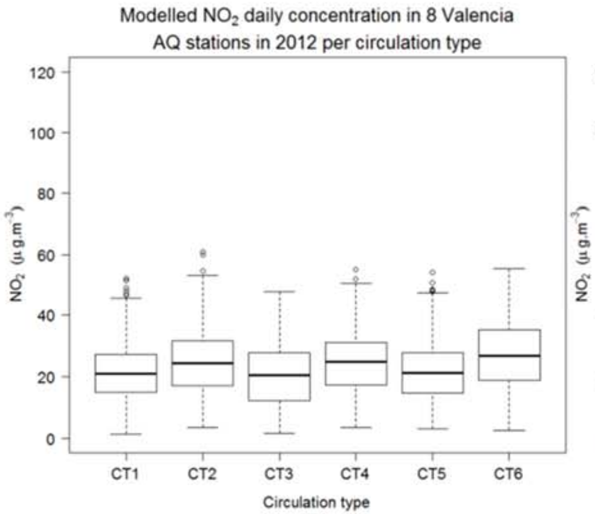
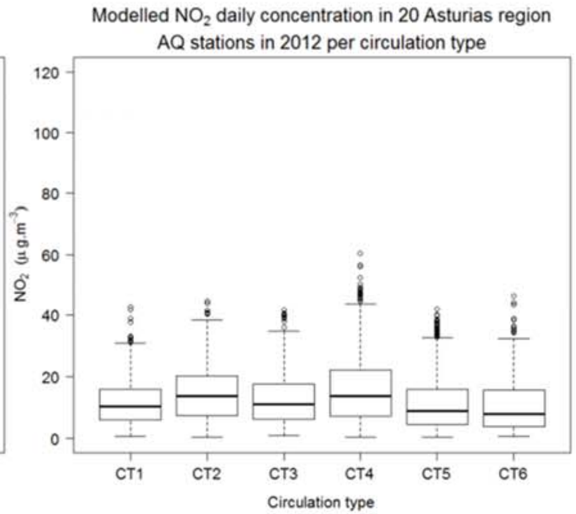
NO_2 per CT











CT1	CT2	CT3	CT4	CT5	CT6
NW advection	Summer reduced surface pressure gradient	E/NE advection	Atlantic high with polar maritime advection	W/NW advection	Western Atlantic zonal advection

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NO_2 dynamic results

- In central, northern, and southern IP: synoptic control of NO_2 concentration in urban and industrial/energy generation areas. In Madrid: synoptic circulation and topography modulate the distance and direction of the urban plume:
  - Central System is a topographic constraint preventing NW winds (CT1) & Reduced surface pressure gradient (CT2) → stagnant conditions, urban plume remains over metropolitan area.
  - Urban plume transported to the SW through the Tajo valley CT3 (~100 km) & CT4 (~250 km).
  - Urban plume transported to the NNE CT5 (~250 km) & NE CT6 (~200 km).
- In Mediterranean coastal areas, synoptic circulation with Atlantic dominance (4 CTs accounting for 69% of climatic frequency) is weakened by topographic barriers (Iberic and Baetic System) and mesoscale meteorology regulates NO_2 dynamics.
  In Barcelona and Valencia:
  - Land-sea and mountain-valley breezes transport urban plume inland/outland and parallel to the coast on a daily cycle CT1, CT2, CT4 & CT6 (20-30 km)
  - Synoptic forcing controls NO_2 transport along Mediterranean coastal areas under CT3 (anticyclonic circulation establishes transport of the urban plume to the E/NE ~40-50 km) and CT6 (zonal winds transport urban plume to the W ~80 km).

Conclusions

- An objective and automatic methodology to classify synoptic circulation is developed.
- The synoptic classification is applied to study air quality patterns over the Iberian Peninsula.
- The three most common CTs account for 67.6% of climatic frequency (CT1, CT2, and CT3) and mainly occur in summertime, replacing one another.
  - CT1 (23.9%) is a NW advective pattern characterized by the arrival of polar maritime air masses towards the IP
  - CT2 (22.4%) depicts a reduced pressure surface gradient, enabling the development of the Iberian thermal low with net advection of North African air masses at 500 hPa geopotential height.
  - CT3 (21%) is especially frequent in spring and summer as a result of a blocking anticyclone over central Europe that leads to E-NE advection towards the IP.

  In winter two CTs are especially frequent, CT4 and CT6.
  - CT4 (12%) is an anticyclonic situation that enables the arrival of Atlantic air masses towards the IP
  - CT6 (10%) is characterised by zonal Atlantic maritime advection.

  CT5 is typical of transitional seasons
  - CT5 (10%) presents unstable conditions over the IP with W-NW winds and precipitation.
- Together with topographic features, synoptic circulation is found to be a key driver of NO_2 urban and industrial/energy-generation-areas plumes in northern, central and southern areas of Spain whereas in Mediterranean coastal areas, mesoscale phenomena dominates NO_2 transport dynamics.

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Thank you for your attention

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Evaluation of the CALIOPE-AQFS for NO_2 in 2013

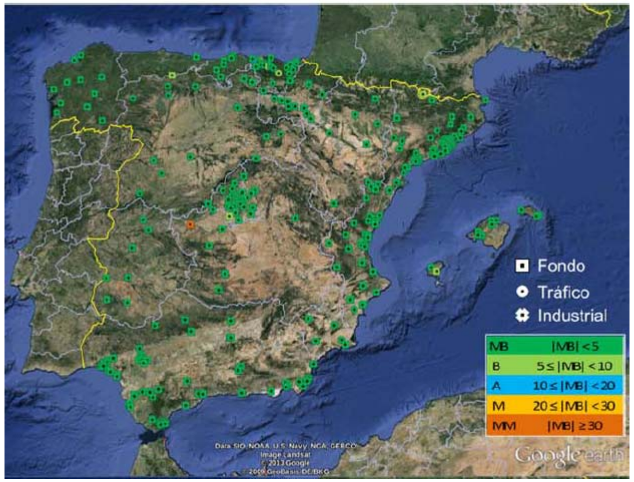
Annual NO_2 evaluation in 2013

CALIOPE-Air quality forecasting system against observations from the Spanish AQ network

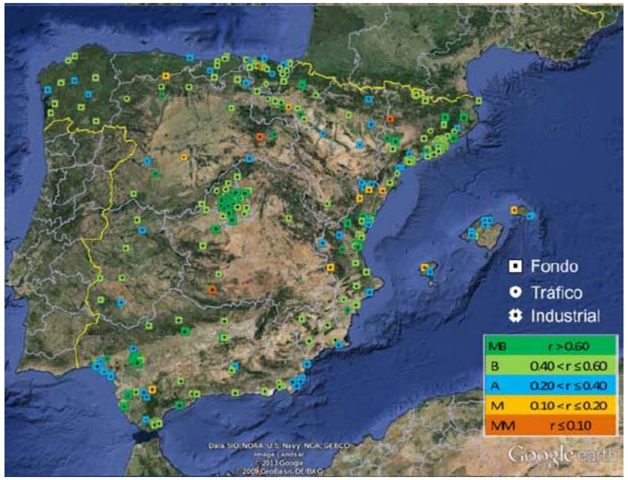
Type of station	# stations	OBS (µg.m^{-3})	MOD (µg.m^{-3})	Bias (µg.m^{-3})	r	RMSE (µg.m^{-3})
All	358	18.9	18.3	- 0.65	0.48	13.9
Urban	167	25.8	24.8	- 1.05	0.55	17.6
Suburban	108	17.3	17.0	- 0.29	0.46	13.8
Rural	83	7.3	7.0	- 0.32	0.37	6.7
Emission	**# stations**	**OBS (µg.m^{-3})**	**MOD (µg.m^{-3})**	**Bias (µg.m^{-3})**	**r**	**RMSE (µg.m^{-3})**
Traffic	73	31.6	29.9	- 1.68	0.54	19.4
Industrial	96	15.7	14.8	- 0.83	0.45	12.3
Background	189	15.7	15.5	- 0.16	0.47	12.7

Evaluation of the CALIOPE-AQFS for NO_2 in 2013

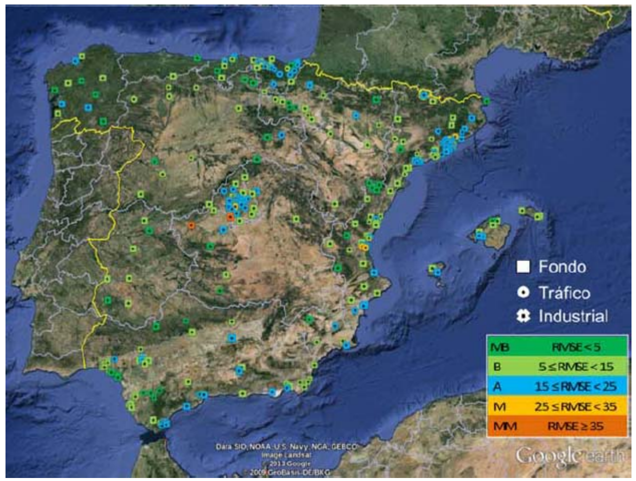
		Bias ($\mu g/m^3$) *MB = 0**	r - *r = 1**	RMSE ($\mu g/m^3$) *RMSE = 0**
NO_2	Muy Bueno (MB)	$\lvert MB \rvert < 5$	$r > 0.60$	$RMSE < 5$
	Bueno (B)	$5 \leq \lvert MB \rvert < 10$	$0.40 < r \leq 0.60$	$5 \leq RMSE < 15$
	Aceptable (A)	$10 \leq \lvert MB \rvert < 20$	$0.20 < r \leq 0.40$	$15 \leq RMSE < 25$
	Malo (M)	$20 \leq \lvert MB \rvert < 30$	$0.10 < r \leq 0.20$	$25 \leq RMSE < 35$
	Muy Malo (MM)	$\lvert MB \rvert \geq 30$	$r \leq 0.10$	$RMSE \geq 35$



Mean Bias



r



RMSE