Assessment of the future climate potential for tourism over Spain using a combination of downscaling approaches and quantitative impact models

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1. Motivations

- **The Mediterranean region** is among the preferred worldwide tourist destinations and it is a highly sensitive area to climate change impacts (Stocker et al., 2013).
- According to the UNWTO (2018), **Spain** occupied the **2nd place** in the ranking of **international tourism destinations** with **81.8 million arrivals and 68$ US billion receipts** only in 2017.

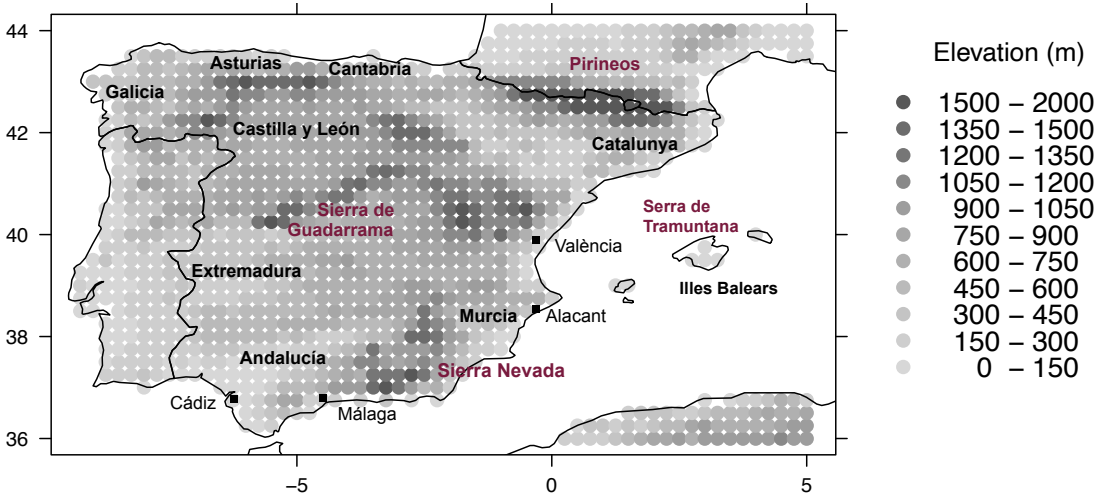
*The weather conditions and environmental assets of Spain enable the development of **several types of tourism**, in addition to the 3S tourism (sun, sea and sand)*






1. Motivations

Climate change will unequally affect tourist activities as they require different weather conditions and show quite diverse physical demand (Bafaluy et al., 2013).



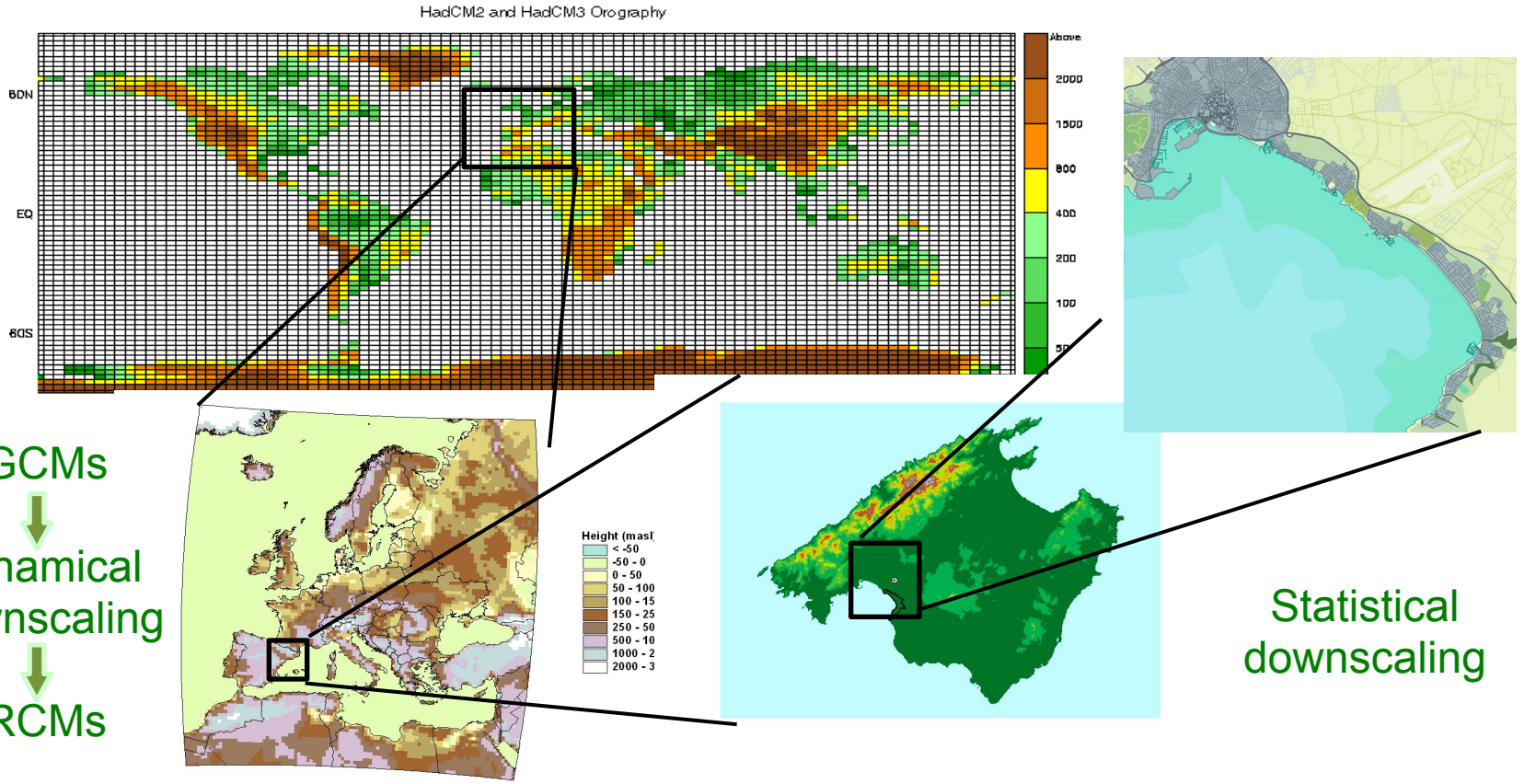
Tourist activity	High season	Number of visitors per year	Spent money (M€/year)	Most visited region
Cultural	All	14,5 million	15.348	Catalunya, Illes Balears and València
Sailing	Summer	1.562 registrations	NA	Illes Balears, Catalunya and València
Golf	Spring	1.6 million	4.640	Andalucía, Castilla y León and Catalunya
Hiking	Spring and autumn	1/2 million	3.283	Pirineos and Serra de Tramuntana (Mallorca)
Cycling	Spring and autumn	160.000*	2.258	Mallorca, Catalunya València and Andalucía
Football	Winter	200 teams	NA	Málaga and Cádiz (Andalucía), Murcia and Alacant

Table 1: Available information about the main socio-economic aspects related to each kind of tourist activity in Spain. *Data correspond only to the Mallorca Island. NA stands for data not available.

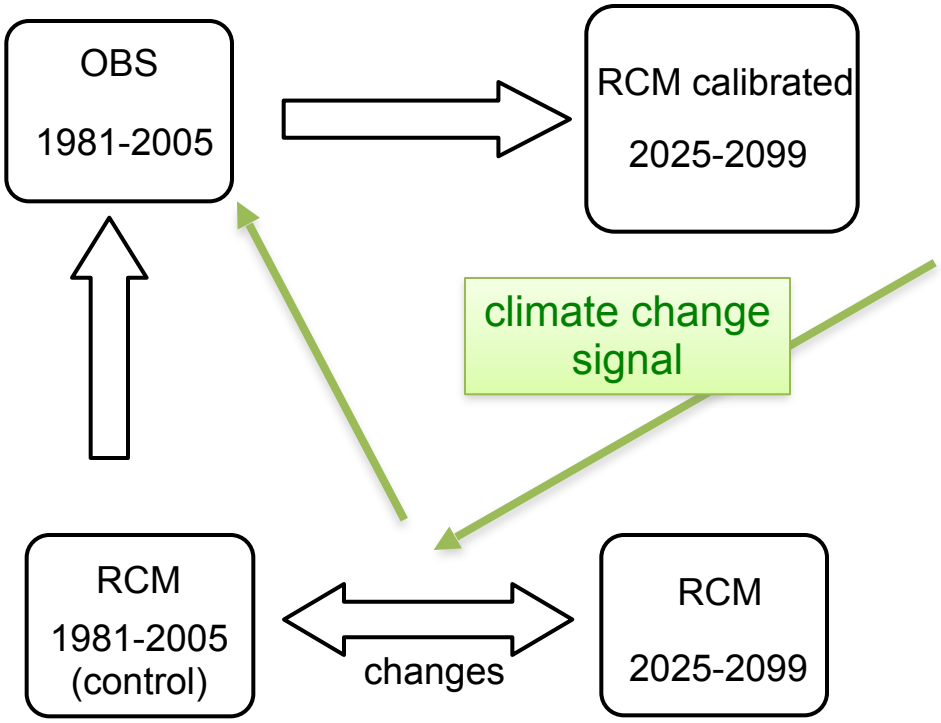
Tools for exploring climate change impacts

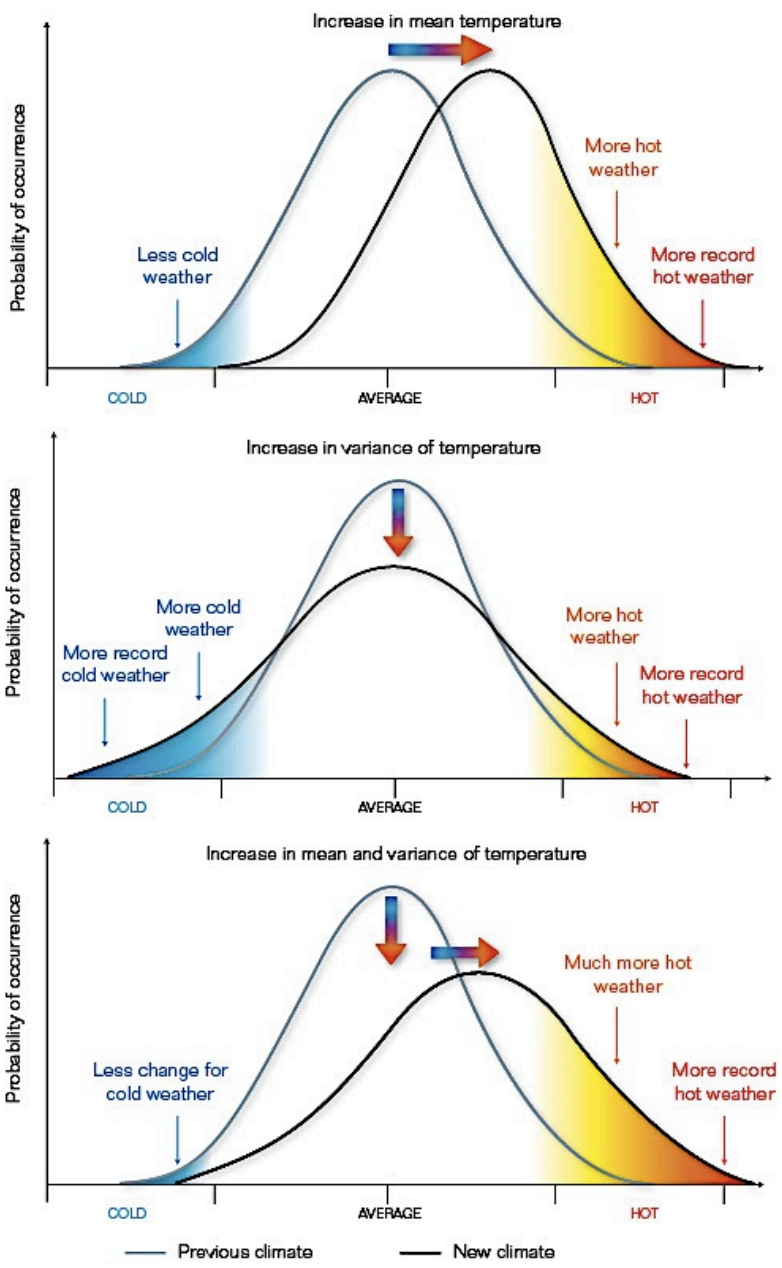
GCMs → RCMs

- Regional scales: Dynamical downscaling. Regional Climate Model (RCMs).
- Local scales: Statistical downscaling and model calibration from RCMs.



Statistical downscaling of RCM outputs

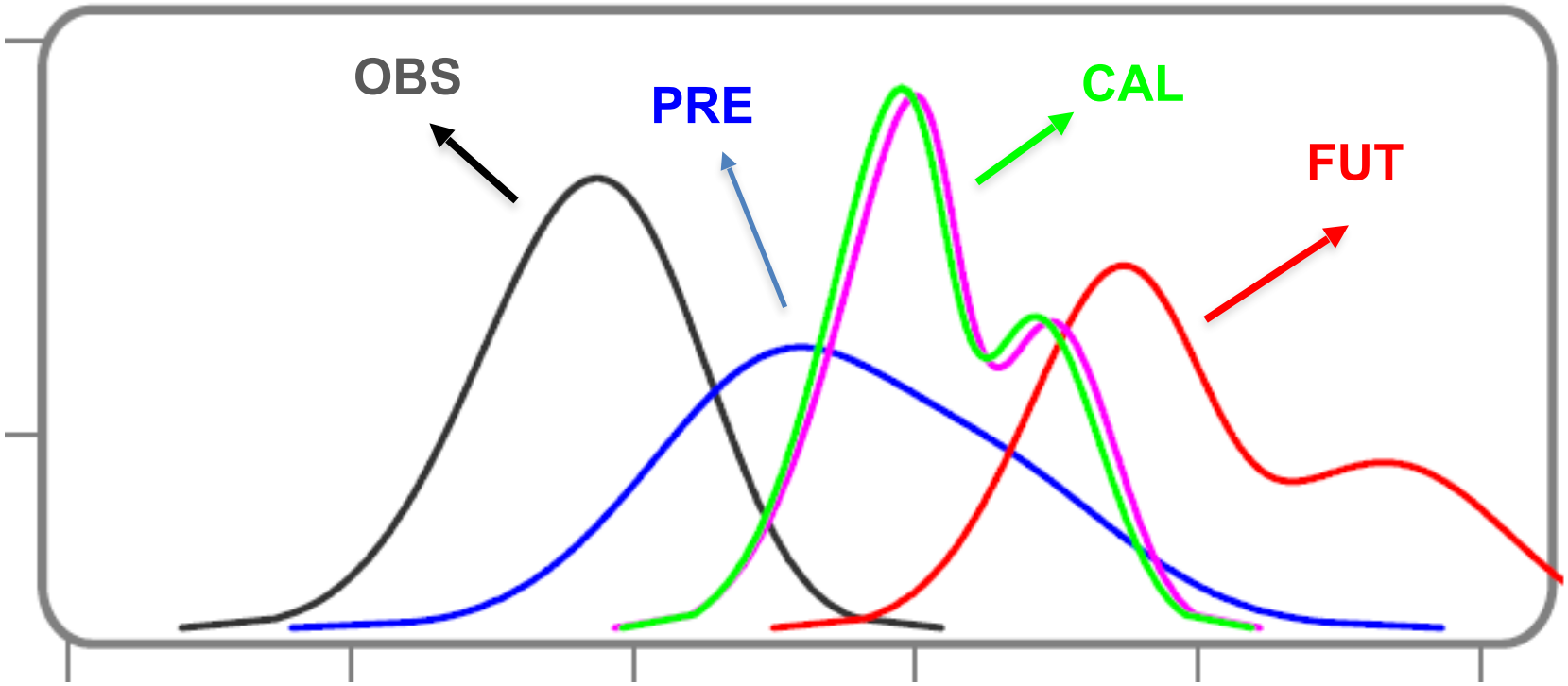




Quantile-Quantile adjustment

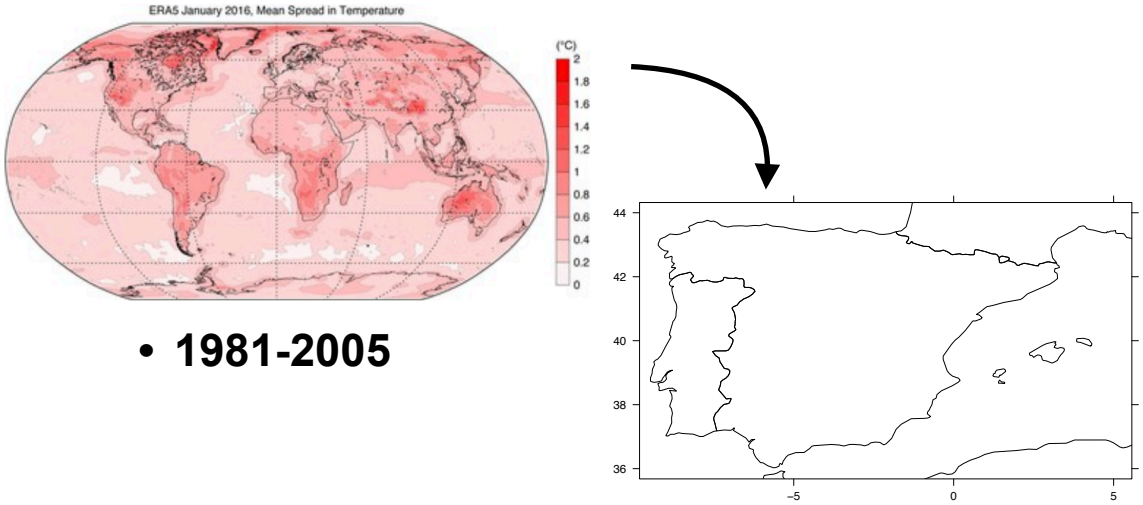
(Cardell et al. 2019)

$$p_i = o_i + g\overline{\Delta} + f\Delta'_i,$$



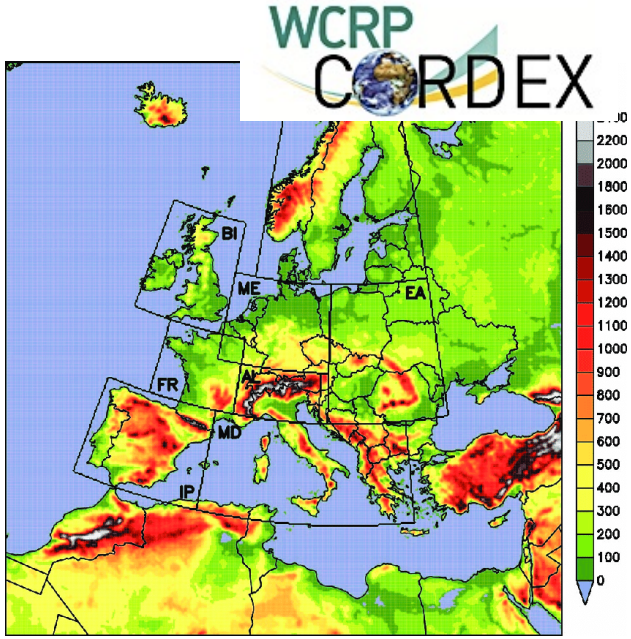
2. Database and methodology

ERA5 (31 km)



- **1981-2005**

EURO-CORDEX (12,5 km)



Future regional scenarios **rcp8.5**

Daily series of **surface**:

1. Maximum temperature
2. Total precipitation
3. Mean wind speed
4. Mean fraction of cloud cover
5. Mean relative humidity

Changes in calibrated CDFs between a 25-year past (i.e. control/observed; 1981-2005) and successive 25-year RCM time-slices (2021-2045; 2046-2070; **2071-2095**).

Driving GCM	RCM	Institute
EC-EARTH	HIRHAM5	DMI

2. Database and methodology

- **Weather typology matrices for the different kinds of tourism and Climate Index for Tourism (CIT) rating scale**

(a)

Cycling	ASHRAE scale TSN [T]	Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥10mm/d) [P]	Wind (≥8m/s) [P]
	Very hot (+4)	3	2	3	2
	Hot (+3)	4	3	3	2
	Warm (+2)	6	5	4	2
	Slightly warm (+1)	7	7	4	3
	Indifferent (0)	7	6	4	2
	Slightly cool (-1)	6	5	3	2
	Cool (-2)	5	4	3	1
	Cold (-3)	4	3	2	1
	Very cold (-4)	3	2	1	1

(b)

Cultural	ASHRAE scale TSN [T]	Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥5mm/d) [P]	Wind (≥10m/s) [P]
	Very hot (+4)	3	3	2	2
	Hot (+3)	4	3	3	3
	Warm (+2)	6	5	4	4
	Slightly warm (+1)	7	6	4	4
	Indifferent (0)	7	6	4	4
	Slightly cool (-1)	6	5	4	4
	Cool (-2)	5	4	3	3
	Cold (-3)	4	4	2	2
	Very cold (-4)	3	2	1	1

(c)

Football	ASHRAE scale TSN [T]	Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥10mm/d) [P]	Wind (≥8m/s) [P]
	Very hot (+4)	3	3	2	2
	Hot (+3)	4	4	3	2
	Warm (+2)	6	6	4	3
	Slightly warm (+1)	7	7	5	4
	Indifferent (0)	7	7	4	3
	Slightly cool (-1)	6	6	3	2
	Cool (-2)	5	5	2	1
	Cold (-3)	4	4	1	1
	Very cold (-4)	3	3	1	1

(d)

Golf	ASHRAE scale TSN [T]	Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥10mm/d) [P]	Wind (≥4m/s) [P]
	Very hot (+4)	3	2	3	1
	Hot (+3)	5	4	3	1
	Warm (+2)	6	5	4	2
	Slightly warm (+1)	7	6	4	2
	Indifferent (0)	7	6	4	3
	Slightly cool (-1)	6	5	3	2
	Cool (-2)	5	4	3	2
	Cold (-3)	4	3	2	1
	Very cold (-4)	3	2	1	1

Hiking	ASHRAE scale TSN [T]	Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥5mm/d) [P]	Wind (≥10m/s) [P]
	Very hot (+4)	3	3	2	2
	Hot (+3)	4	3	3	3
	Warm (+2)	6	5	4	4
	Slightly warm (+1)	7	6	4	4
	Indifferent (0)	7	6	4	4
	Slightly cool (-1)	6	5	4	4
	Cool (-2)	5	4	3	3
	Cold (-3)	4	4	2	2
	Very cold (-4)	3	2	1	1

Sailing	ASHRAE scale TSN [T]	Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥20mm/d) [P]	Wind (≤1.5 or ≥15m/s)
	Very hot (+4)	5	4	3	1
	Hot (+3)	6	5	3	2
	Warm (+2)	7	6	4	2
	Slightly warm (+1)	7	6	4	3
	Indifferent (0)	6	5	4	2
	Slightly cool (-1)	5	4	2	2
	Cool (-2)	4	3	2	1
	Cold (-3)	3	2	1	1
	Very cold (-4)	2	1	1	1

CIT						
1	2	3	4	5	6	7
Unacceptable			Acceptable		Ideal	

De Freitas et al., (2008)

Bafaluy et al., (2013)

- **Universal Thermal Climate Index (UTCI)**

UTCI (°C) range	Stress Category
above +46	extreme heat stress
+38 to +46	very strong heat stress
+32 to +38	strong heat stress
+26 to +32	moderate heat stress
+9 to +26	no thermal stress
+9 to 0	slight to moderate cold stress
0 to -13	slight to moderate cold stress
-13 to -27	strong cold stress
-27 to -40	very strong cold stress
below -40	extreme cold stress

The UTCI (in degree Celsius) is defined as the air temperature (Ta) of the reference condition causing the same human body response as actual conditions.

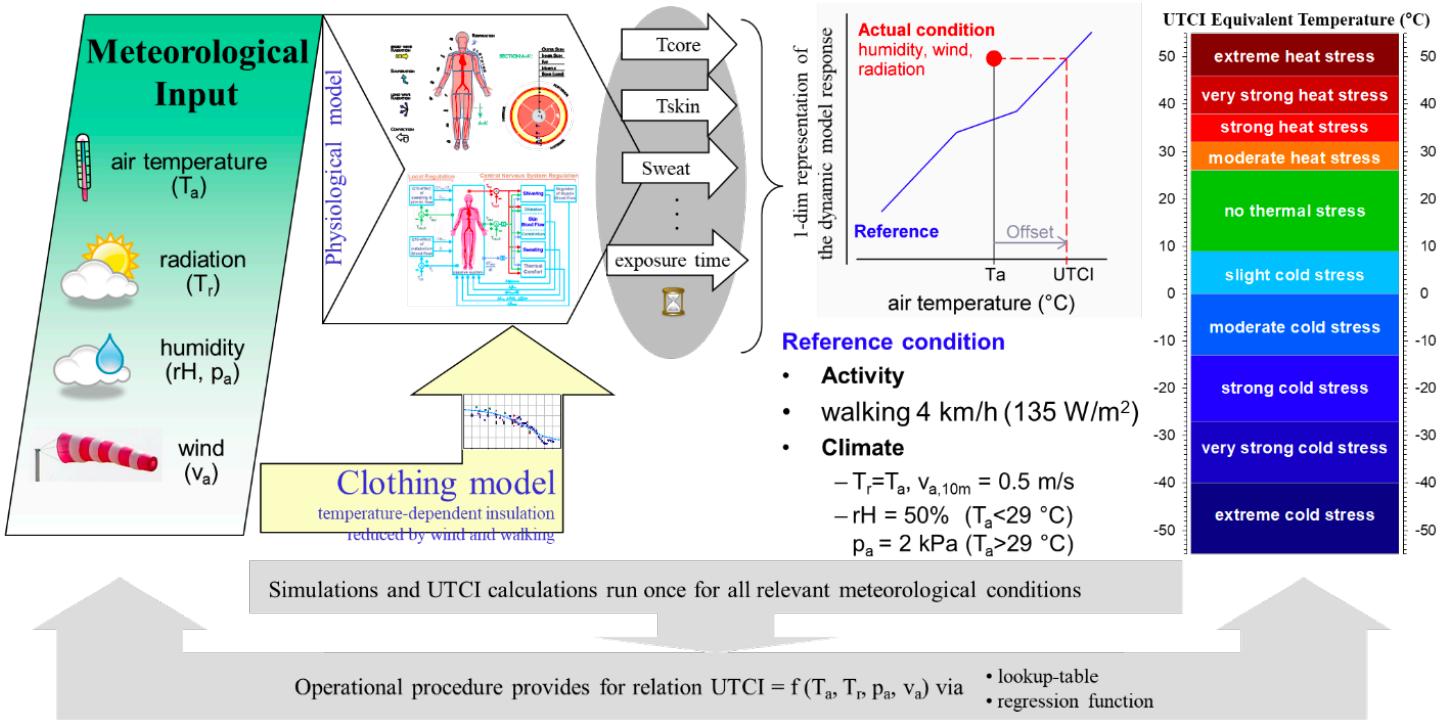
2. Database and methodology

Quantitative analysis of thermal system performance, human comfort and physiological response in:

ERGONSIM
Human Thermal Modelling

- Architecture
- Automotive/aerospace industries
- Clothing research
- Medical engineering
- Biometeorology

- **UTCI-FIALA Model** was created and adapted for UTCI purposes to predict human thermophysiological and calorimetric responses to **outdoor weather conditions** using readily available meteorological data (Fiala et al., 2012)



- **RayMan Pro** A tool for Applied Climatology. Modelling of Mean Radiant Temperature and Thermal Indices

- **UTCI-FIALA Model**

Initial conditions. Thermo-neutral physiological conditions. A steady state exposure of a reclining (nude) person to an environment of 30°C, still air, no thermoregulation.

Simulated person. An average (35 years old, unisex) person weighting 71.4 kg, 169.7 cm tall, with a skin surface area of 1.83 m^2, and body fat content of 22.6% (16.17 kg in total), and an average body density of 1.05 g/cm^3.

Air exposure boundary conditions

- **Mean radiant temperature**
- **Sun elevation**
- **Direct and diffuse solar radiation**
- Maximum temperature
- Mean relative humidity
- Mean wind speed

- **Time exposure (120 min, 25 time steps of 5 min)**
- Clothing
- Activity level (met)

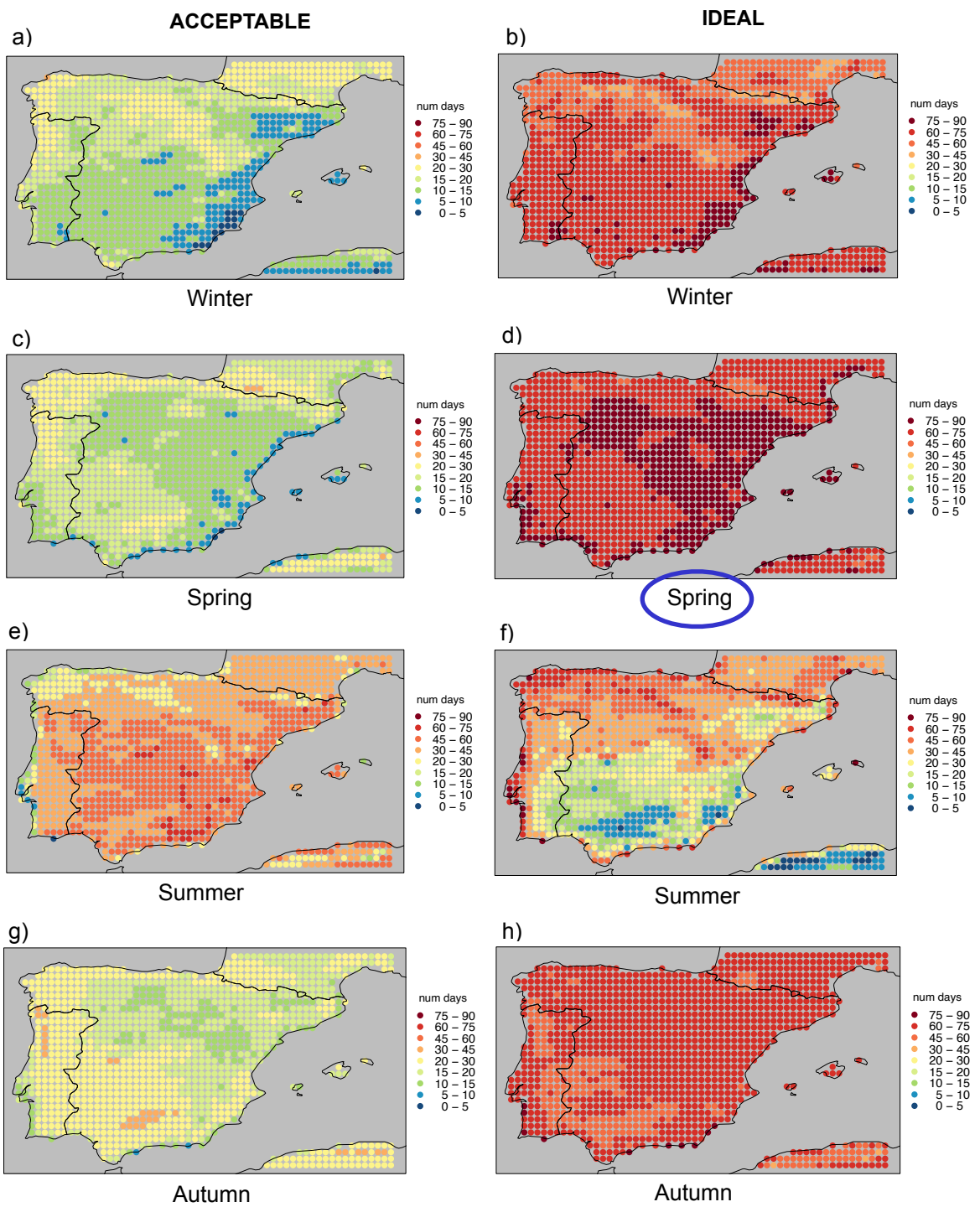
	CULTURAL	SAILING	GOLF	HIKING	CYCLING	FOOTBALL
Activity level (met)	2.0	2.5	2.5	3.0	4.0	5.0
Clothing insulation	0.5	0.3	0.4	0.3	0.3	0.3

3. Results

CULTURAL

Present climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

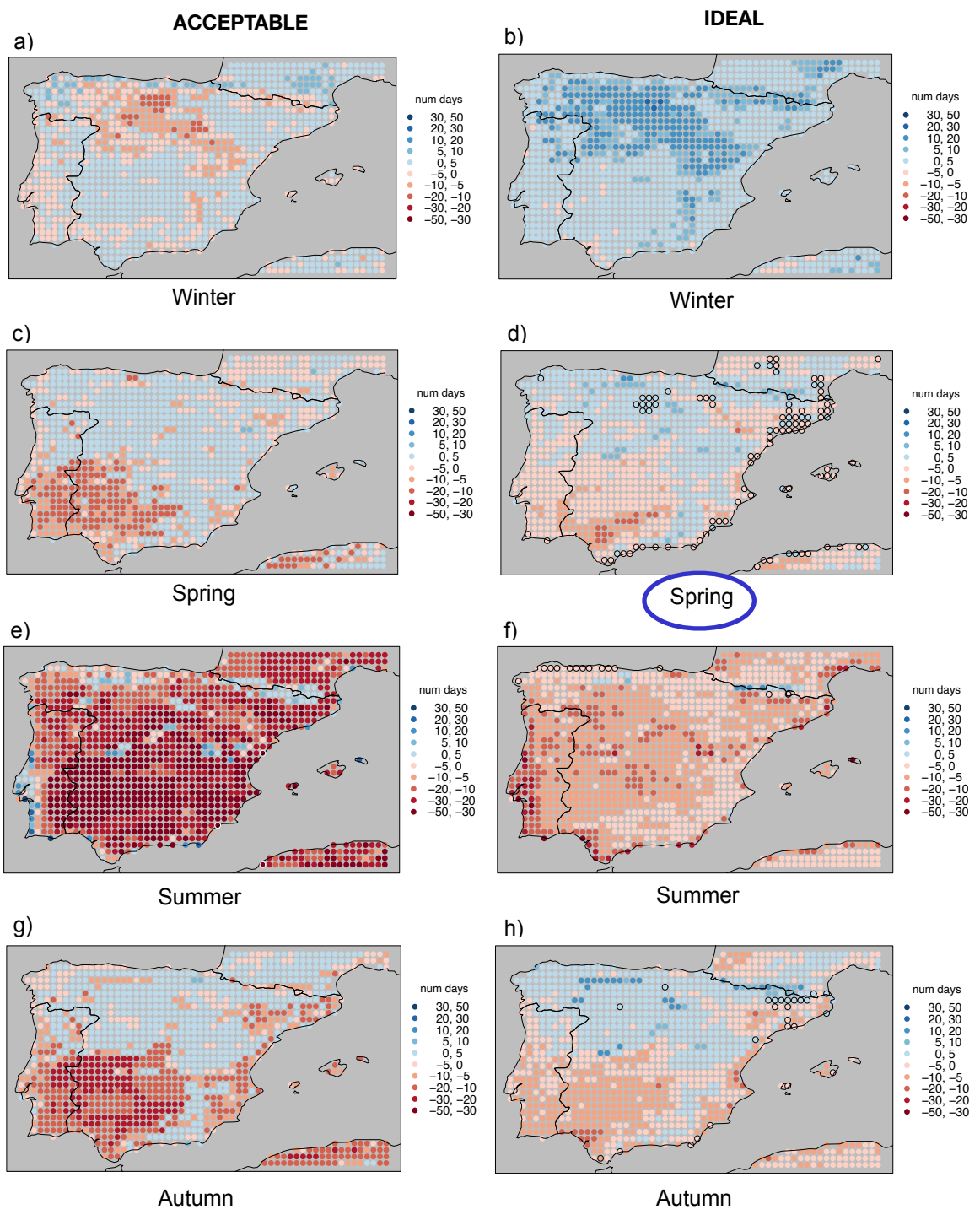


3. Results

CULTURAL

Future change
in climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

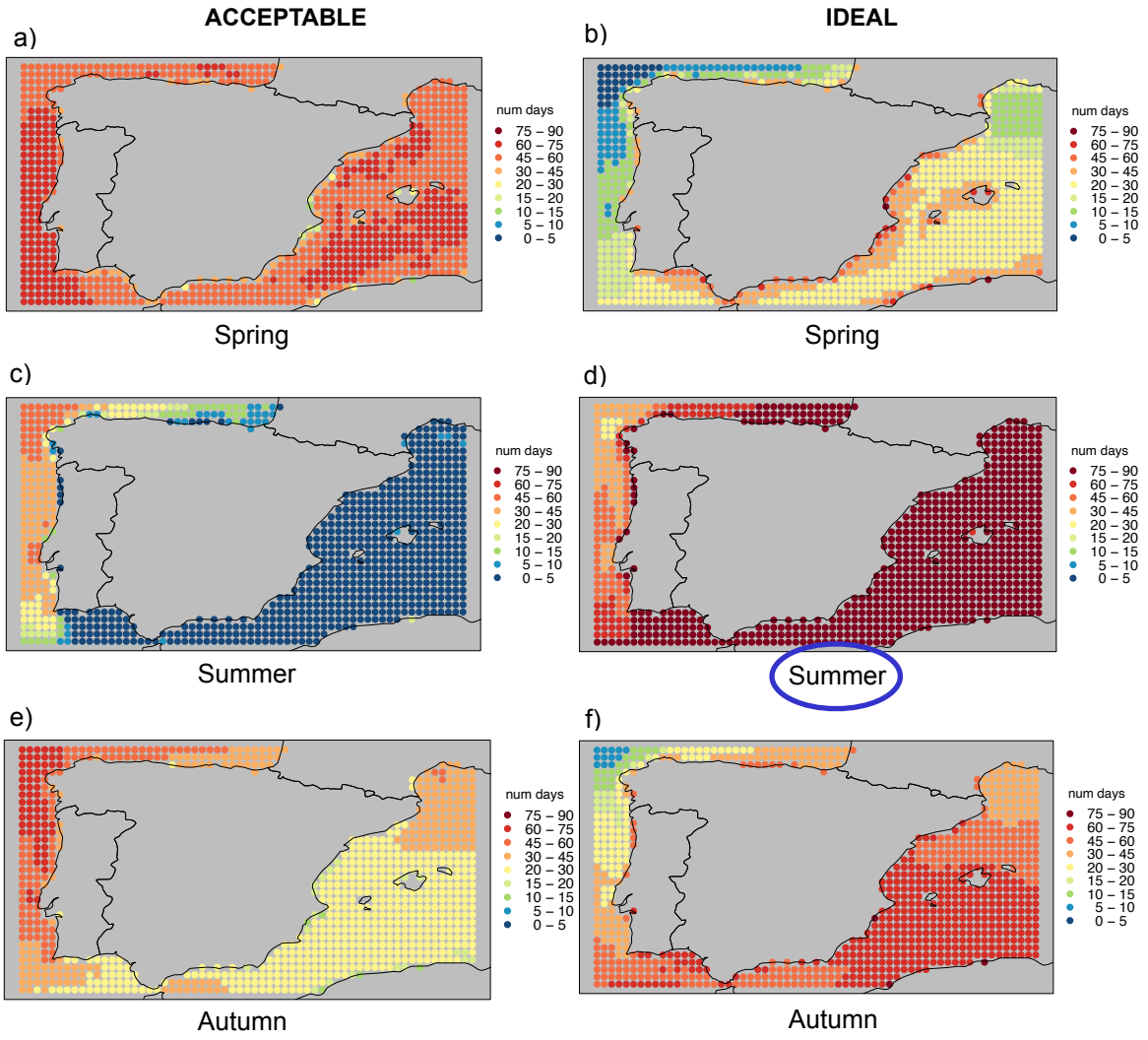


3. Results

SAILING

Present climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

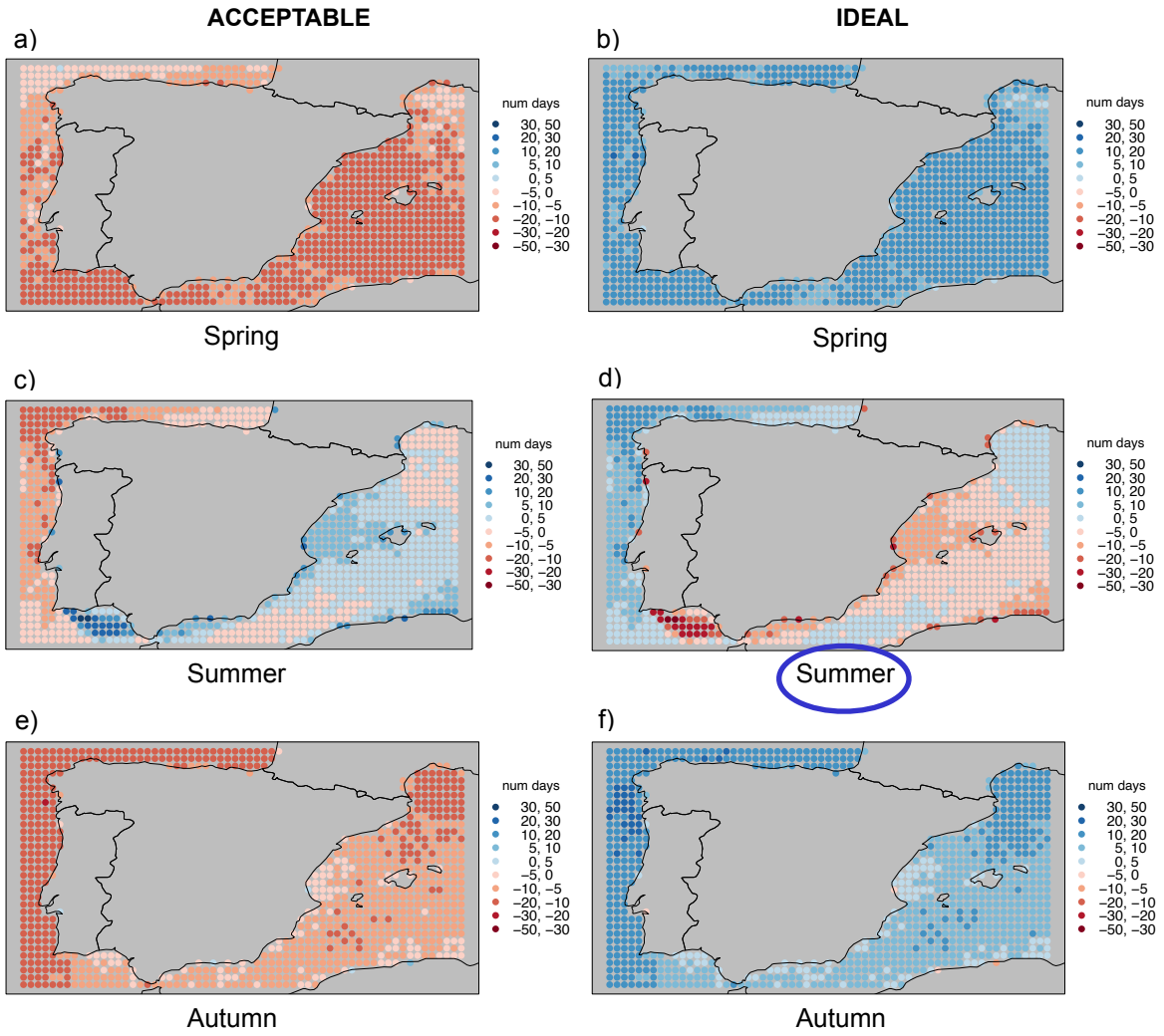


3. Results

SAILING

Future change in climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

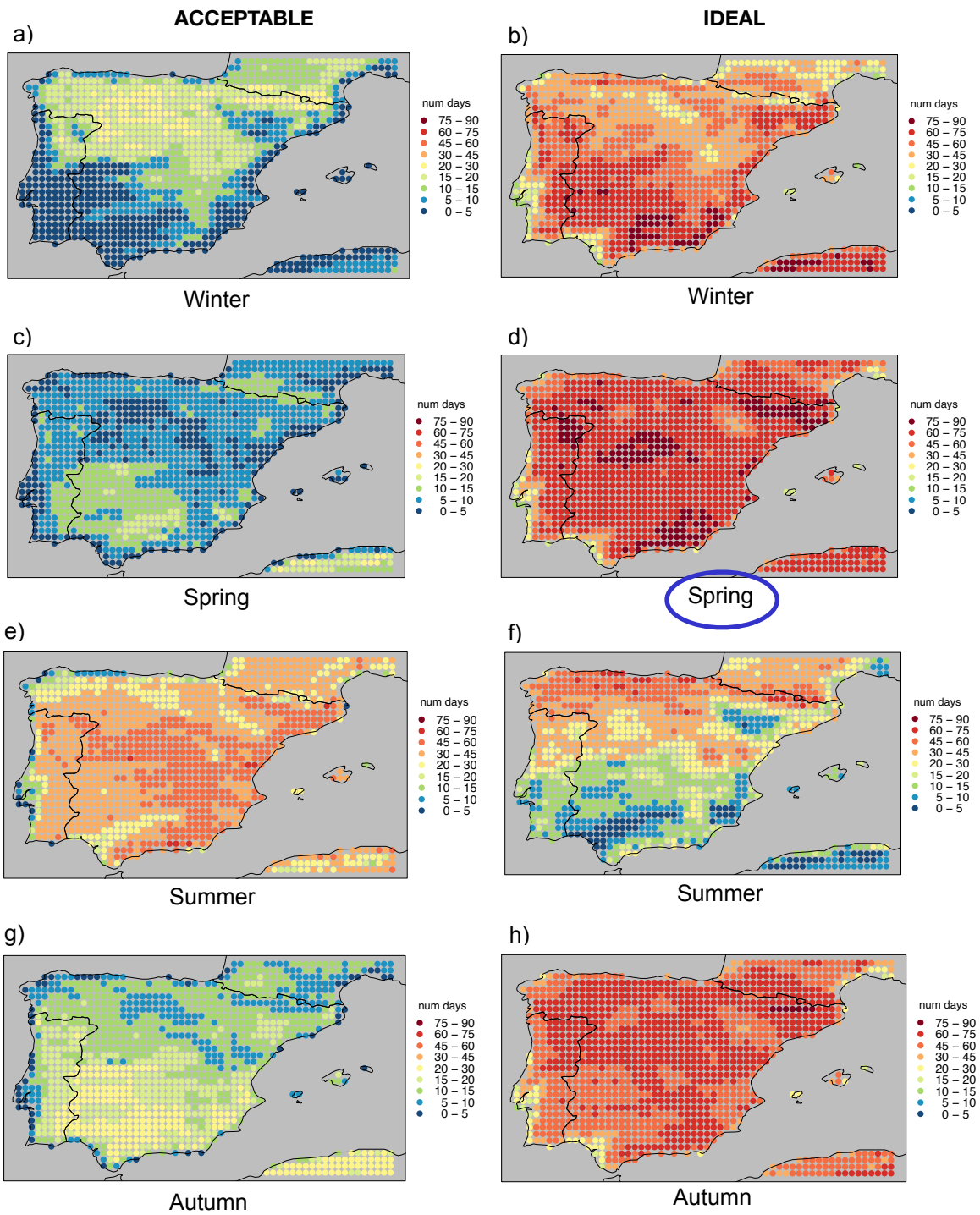


3. Results

GOLF

Present climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

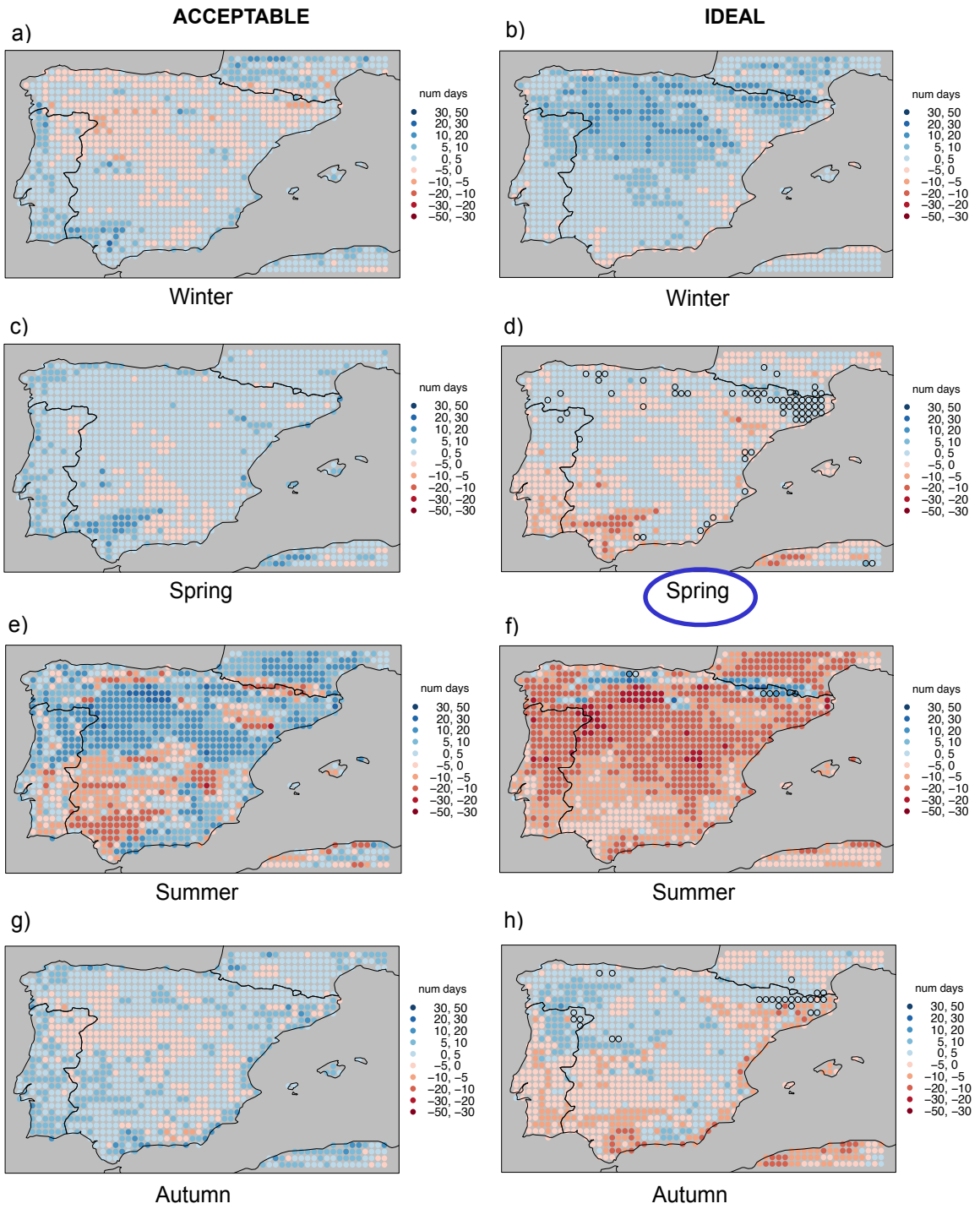


3. Results

GOLF

Future change
in climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

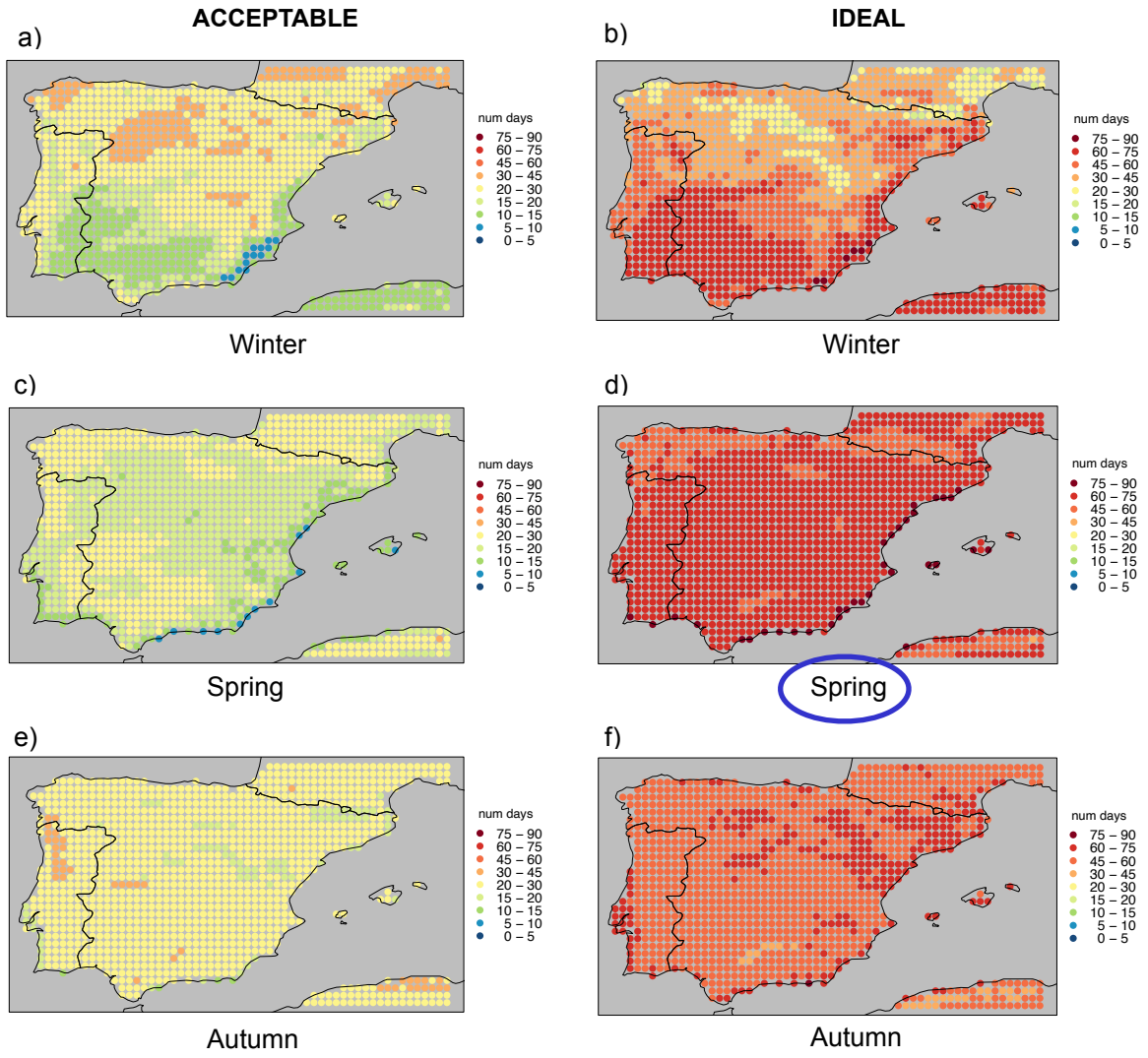


3. Results

HIKING

Present climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

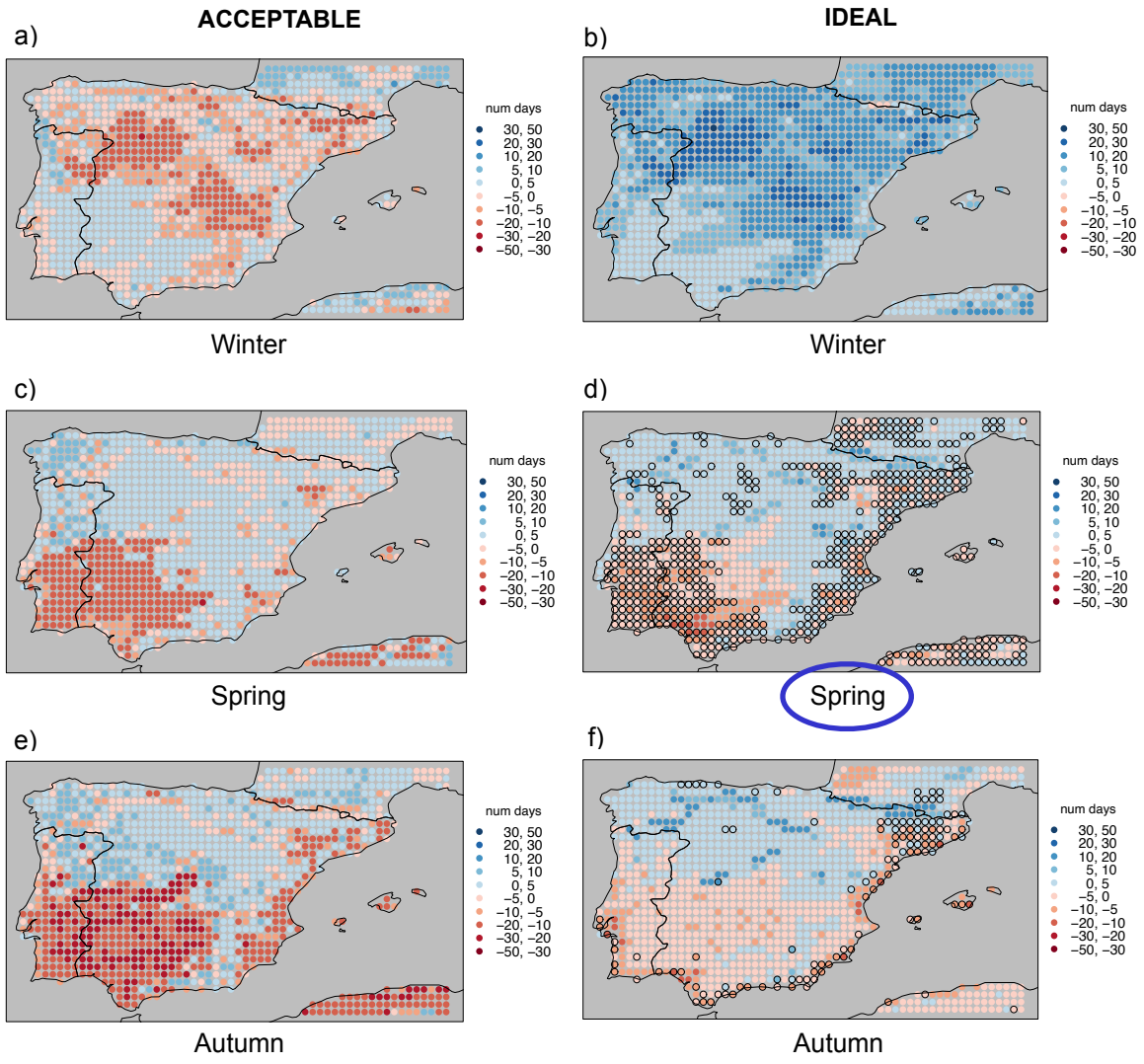


3. Results

HIKING

Future change in climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

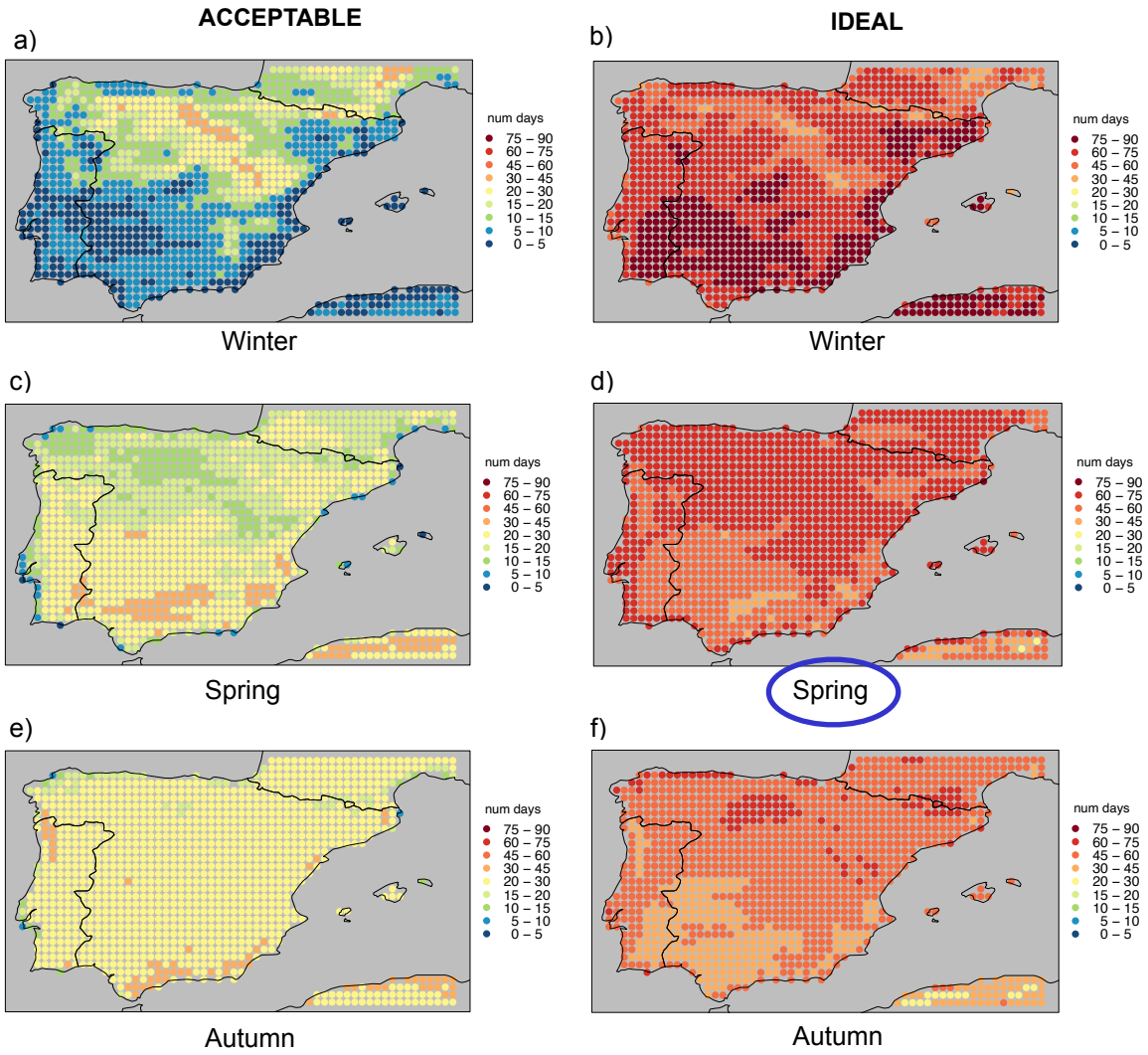


3. Results

CYCLING

Present climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

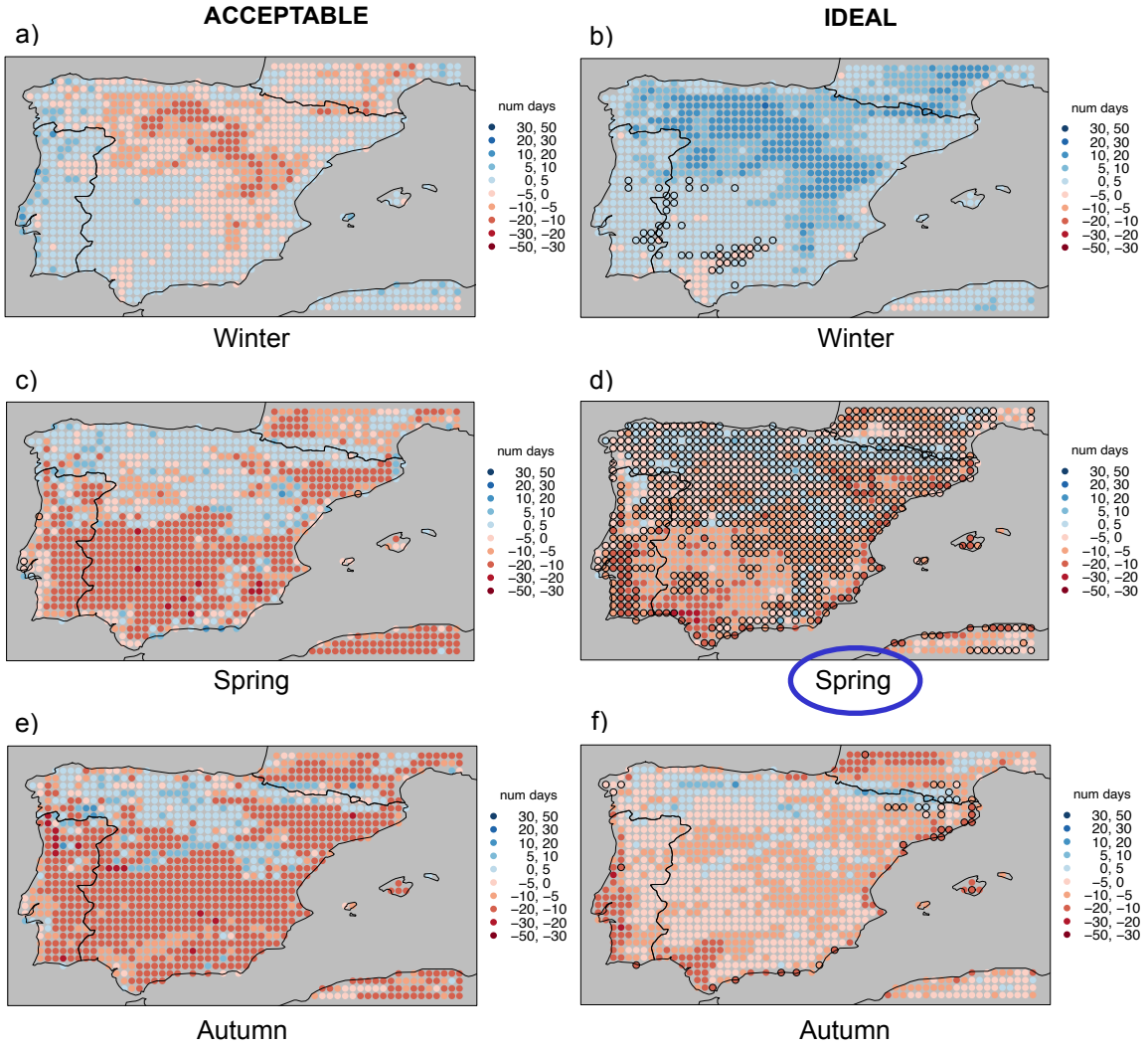


3. Results

CYCLING

Future change in climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

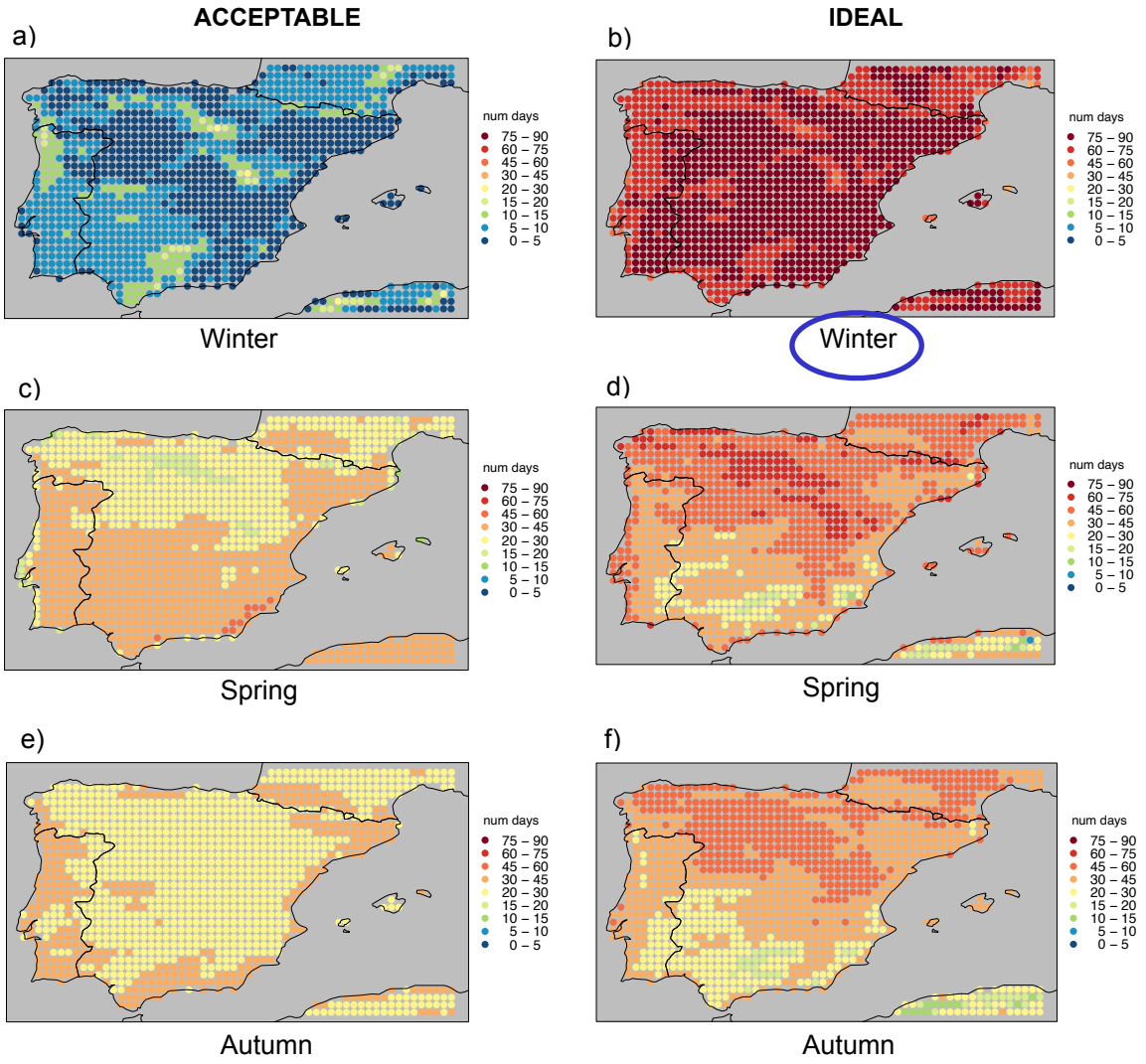


3. Results

FOOTBALL

Present climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	

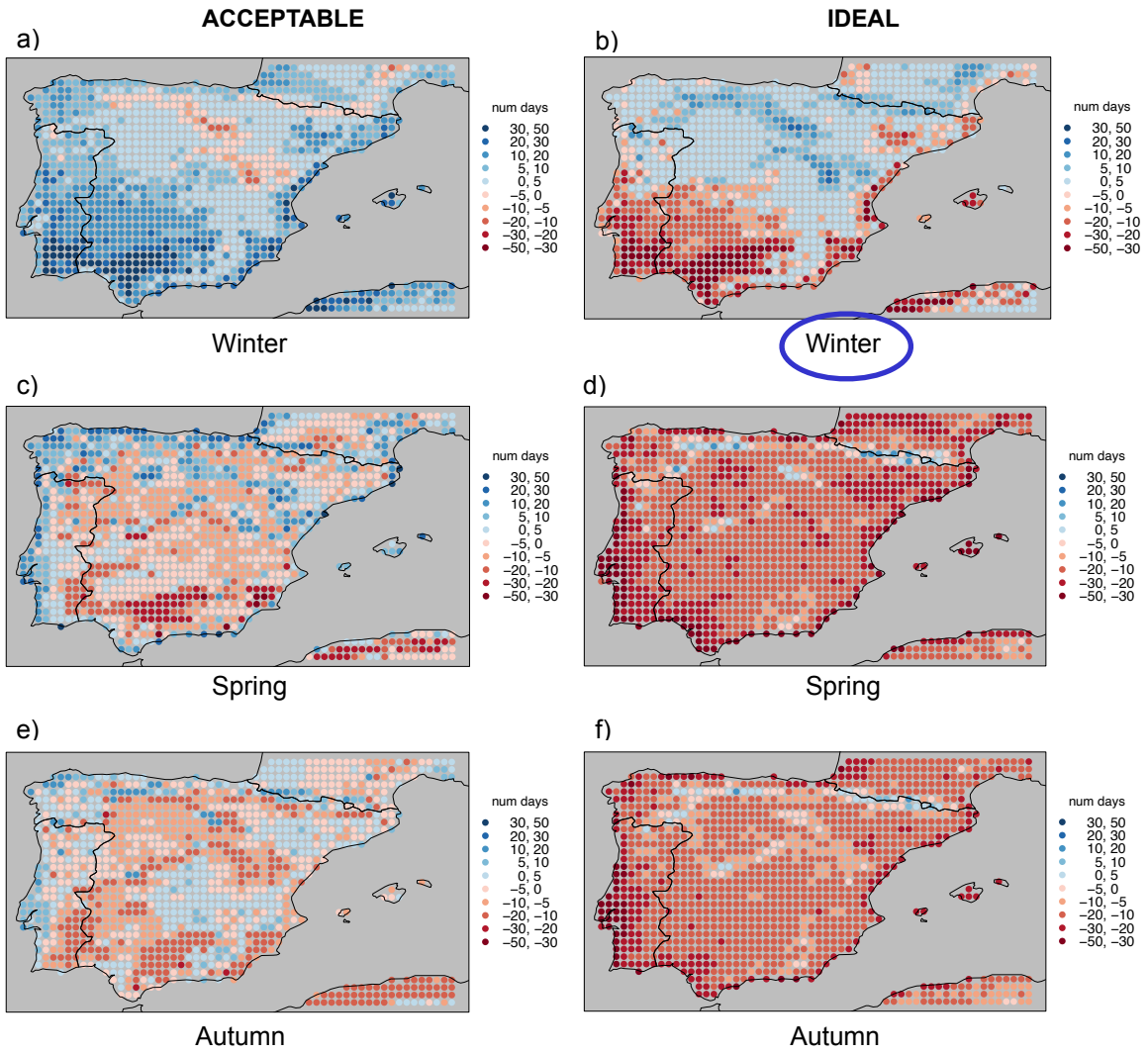


3. Results

FOOTBALL

Future change in climate potential

CIT						
1	2	3	4	5	6	7
	Unacceptable		Acceptable		Ideal	



4. Future work

- Use the whole of RCMs from the EURO-CORDEX project to compute the UTCI and compare shifts through ensemble mean strategies.

- Explore the seasonal CIT distribution across the Mediterranean which is the principal economic centre of the tourist activities in Europe.

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