Explore sustainable European futures

Downscaled Climate Change Scenarios for Europe, Estimation of incremental European Warming

D1.1

June/2018

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Short Description
This deliverable describes the process of selection of climate scenarios, collection of climate data needs from partners (e.g., variables, temporal and spatial resolutions), and the calculation and provision of climate data provided to the EUCalc project team. Given the continuous development of the EUCalc model, the climate data provided might be subject to revision. Accordingly, WP1 will continue exploring the feasibility of providing further climate data, should the need arise later in the project.

Quality check	
Name of reviewer	**Date**
Gino Baudry (Imperial)	**6 June 2018**
Boris Thurm (EPFL)	**5 June2018**

Statement of originality: This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Table of Contents

List of Tables

List of Figures

List of abbreviations

CMIP5	Coupled Model Intercomparison Project Phase 5
CRU	Climate Research Unit
ECS	Equilibrium climate sensitivity
EU	European Union
GCM	General Circulation Model
IPCC	Intergovernmental Panel on Climate Change
UEA	University of East Anglia
RCP	Representative Concentration Pathway
SD	Standard deviation

Executive Summary

This deliverable describes the climate data provided by the UEA partner to the EUCalc project team. Within the calculator, the data is to be used to drive feedback processes that relate to the interaction of climate change with various modules within the calculator (e.g., buildings, energy or agriculture), and also to allow projection of climate change impacts and risks. For each climate variable, projections have been provided as both seasonal and annual, country ensemble means for the 28EU member states + Switzerland for the time frame 2015 to 2100. Historical observational climate data has also been provided for the same variables from 1960-2013. The projected changes in climate identified in Europe are consistent with the findings of IPCC (2013). These include warming and wetting in the north-east, particularly in Scandinavia, and drying in the south-west, particularly in Portugal and other Mediterranean regions.

1 Introduction

This deliverable describes the climate data provided in WP1 by the UEA partner to the EUCalc project team. The UEA team is also committed to exploring the feasibility of providing further climate data should the need arise later in the project.

The EU Calculator aims to build on its predecessors by (among other things) a) providing information about climate change impacts, and b) considering some feedback processes that could not be incorporated in simpler tools. It also differs fundamentally in that as a regional tool, the relationship between the European Union (EU) and the rest of the world (RoW) has to be considered, and an important aspect of that is how the climate in the EU relates to the climate in the rest of the world.

In this deliverable we explain the team’s key decisions relating to these issues, and therefore the implications for the climate data required. We also document the climate data that has been provided by UEA to the rest of the project team.

2 Climate scenarios & data needs in the EU Calculator

There are three reasons why climate data is needed in the EU Calculator project:

(A) To provide a basis for the projection of climate change impacts which will be an output of the Calculator and made available to the user

(B) To drive feedback processes that relate to the interaction of climate change with processes contained solely within WP4 (Land Use) including agriculture and biodiversity

(C) To drive feedback processes that relate to the interaction of climate change with processes in other work packages, such as the Buildings sector (WP2) and the Energy sector (WP5).

Since the EU Calculator takes a dynamic approach to simulation between 2015 and 2050, it became clear that all climate data needed to be provided as time series. Most processes in the model run at either an annual or a 5-yearly time-step, and for this reason it was decided to provide all data as annual time series, and also to provide seasonal time series where required by users.

A questionnaire was circulated to project members to gather information about the attributes of the climate data required for input to other work packages, which is presented in Figure 2.

2.1 Climate scenarios and the relation between EU and the RoW

Climate change impacts within the EU are planned to be taken from existing databases of projected climate change impacts which are themselves driven by global temperature rise.

The question arises as to how to link the emission reductions simulated in the EU Calculator to global temperature change, given that at present the EU's territorial emissions comprise a relatively low proportion (less than 10%) of the global greenhouse gas emissions (49 GtCO2e globally in 2010, with 4.4 GtCo2e emitted by the EU in 2016). Despite this relatively small contribution, it was decided that in the calculator a stronger relationship would be assumed between mitigation action in the EU and global warming than would directly result from the emission reductions themselves: also an indirect effect would be included to reflect the strong leadership role that the EU plays on the global stage in setting a standard and trend for other nations to follow. Furthermore, the EU's consumption emissions are substantial (4366 $MtCO_2$ in 2015, exceeding the territorial emissions of CO2, and comprising around 12% of global CO_2 emissions) and hence the EU has the potential to also directly influence the emissions outside the EU by changing its consumption patterns and behaviour. Hence, one approach is to assume that the rest of the world would make similar emission reductions to the EU, and hence that strong mitigation action in the EU would result in significantly lower climate changes and resultant impacts. The disadvantage of not taking this approach is that the user would not then see a benefit in terms of avoided climate changes from emission reductions within the EU. The approach taken is in line with the commitments made in the Paris Agreement.

RCPs are a set of four radiative forcing time-series (Figure 1) developed for the climate modelling community as the basis for long-term and near-term modelling experiments (van Vuuren *et al.*, 2012): these scenarios cover the range from scenarios consistent with the 2°C goal to high emission futures. Their key parameters are shown in Table 1.

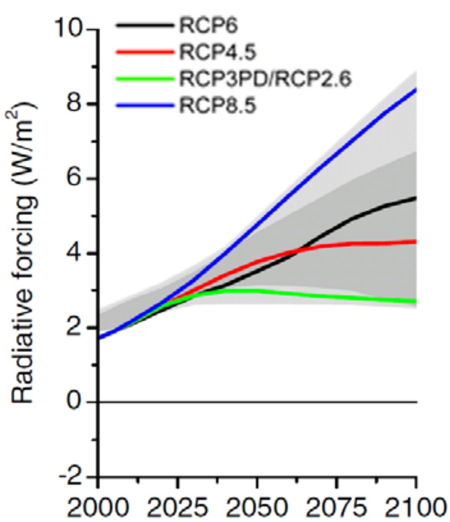

Figure 1 Radiative forcing time series in the Representative Concentration Pathways (http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html).

Table 1 Representative Concentration Pathways: year 2100 parameters

	Radiative forcing (W/m^2)	**CO_2 equivalent concentration (ppm)**	**Rate of change in radiative forcing**
RCP8.5	8.5	1350	Rising
RCP6.0	6.0	850	Stabilizing
RCP4.5	4.5	650	Stabilizing
RCP2.6	2.6	450	Declining

Potential global warming by the 2050s reaches between 1.6ºC and 2.0ºC above pre-industrial levels in RCP's 2.6 and 6.0. We exclude RCP8.5 as being an unlikely scenario given the Paris Agreement, ruling out warming of 2.6ºC by the 2050s. The RCPs differ from the earlier SRES scenarios (Nakicenovich et al 2000) in not being based upon population and GDP data. This means that it is possible for a user of RCPs to choose how emissions are distributed between countries, provided that the global cumulative total of emissions (over time as well as countries) is consistent with the level of global warming. In the case of the Calculator, as mentioned above it is assumed that the EU emissions trends with the global total. Climate data requirements from the team

Climate data has a number of attributes and it is necessary to identify the data needs of the project in terms of these attributes. These attributes are:

- Climate scenario choice
- Variable name (e.g. temperature, precipitation etc)
- Observed data or projected data
- Spatial scale
- Temporal scale
- Temporal resolution
- Changes in climate (anomalies) or absolute climate?
- For changes, which reference climate to use?
- Handling of inter-climate model uncertainty
- Units
- Format

CLIMATE DATA REQUIREMENTS

1. Variables required. Which of these are wanted?
   UEA can provide the following: maximum temperature, minimum temperature, average temperature, vapour pressure, cloud cover, precipitation, wet day frequency.
2. Spatial resolution: we work at half degree (50x50 km) but sometimes it has been downscaled to 20x20 km. Do you want outputs for each grid box, or summed for particular countries or regions?
3. Do you need observed data, and/or projected data? Or do you want just the anomaly (the change between the observed and projected?)
4. Time slice (average climate over a 30 year period a to b) or time series (how temperature varies each year between years x and y. What are the values of a to b and x and y above
5. In the case of EITHER a time slice OR a time series, data can be provided as:
   - Annual average
   - Seasonal average
   - Monthly average
6. How to cope with climate model uncertainty: The way that it works is that we have the four RCPs as temperature time series and they have been run through 21 CMIP5 GCMs. We add the GCM climate anomalies to the observed climate from CRU to create 21 alternative projected climates. Do you want projections for:
   a) all 21 GCM separately
   b) ensemble average across all 21 GCM
   c) ensemble mean and range across all 21 GCM
7. In what format do you want the data (e.g. netcdf)?

INSTRUCTIONS FOR COMPLETING TABLE

1. COLUMN 1: Decide which variables you need.
2. For each variable, you then have to think about what you want within each colour category. Please put your initials in each box if you want that data.
   Please do NOT mark a box at all if you DO NOT want that data. Do NOT mark the boxes in the first row and the first column (where I have already written text).
3. Below the table write your initials, your name, your email address, your work package, the name of your work package leader and your institution.

Figure 2 Questionnaire circulated to team members to assess climate data requirements.

The questionnaire shown in Figure 2 was circulated to team members, to enquire of their requirements.

The questionnaire responses and subsequent discussions at 4th general assembly of the EUCalc project (May 2018) indicated that the requirement was for (a) projected climate change data in the form of time series beginning in 2001 and ending in 2100, with a seasonal or annual temporal resolution (b) observed climate data in the same form, covering the years 1961-2013. EUCalc needs only the projected climate data is from 2014 onwards, as the starting year for the work is 2015 (and observations are not yet available for 2014). The climate model projections are produced based on the 1961-1990 part of the observational data only: the time period, 1961-1990, is one of the standards used for climate modelling results and is a commonly-used baseline for impact models; by this time, our dataset indicates that the world had warmed by 0.35°C since 1861-1890 (see HadCRUT4 dataset of Morice et al., 2012). By the second time period (1984-2013) warming had almost doubled, reaching 0.64°C since 1861-1890. Similarly, IPCC (2013) states that between 1880 and 2012 global average temperature (over land and sea combined) has risen by 0.8°C.

There was interest in both absolute climate projections, and also in levels of change, in relation to natural variability. The main requirements were for temperature and precipitation changes, but all available variables were provided to the team for completeness (and to cater for potential unseen emergent future needs). These comprised maximum temperature, minimum temperature, average temperature, vapour pressure, cloud cover, precipitation, wet day frequency.

Data was requested to be averaged both spatially (over each EU country) and temporally (seasonal or annual averages of monthly values). In dealing with uncertainty between alternative regional projections of climate change, it was also requested that only the ensemble means (across the up to 21 global climate change circulation model patterns utilised) should be provided.

Table 2 Climate variables required by team members.

Climate variable		Unit	Notes
Cloud Cover	cld	percentage (%)	Daily value averaged over the time period
Maximum Temperature	tmx	degrees Celsius	Daily value averaged over the time period
Mean Temperature	tmp	degrees Celsius	Daily value averaged over the time period
Minimum Temperature	tmn	degrees Celsius	Daily value averaged over the time period
Precipitation	pre	Millimetres/month	Monthly total averaged over the time period
Vapour Pressure	vap	hectopascals (hPA)	Daily value averaged over the time period
Wet Day Frequency	wet	Rain days/month	Mohthly total averaged over the time period

The following data sets were therefore provided:

(A) Time series 2001-2100, annual, country ensemble means for the 28+1, EU countries, for each of the climate variables (as anomalies)

(B) Time series 2001-2100, seasonal, country ensemble means for the 28+1, for each of the climate variables (as anomalies)

(C) Observational data, 1960-2013, seasonal and annual, country ensemble means for the 28+1, for each of the climate variables (as absolutes)

In the 4th generally assembly of the EUCalc (May 2018), interest was shown in UEA's ability to present the data as 'signal to noise' that is, to indicate when the climate change signal emerges from the noise of natural variability. For this reason, UEA has provided the ratio of the climate change anomalies above to the natural variability in the observed data set. Specifically, this involves the calculation of the mean and standard deviation (SD) (over time) for each variable in the observed dataset for 1961-1990 (see section 2.3.2), and then for the projected data, calculation the ratio of each anomaly to the SD. The country ensemble means are then recalculated as in (A) above.

Videos were also developed, to help team member less familiar with the climate data to understand the information. These indicate spatially, for the EU, how the climate change signal emerges from the noise as time progresses, beginning with the observed data (Year x – (1961-1990 mean)/SD) from now until 2013; and then showing the same information for 2014-2100. These videos are based on the annual average data only.

2.2 Production of climate data

2.2.1 Global climate change scenarios

The global temperature time series that match the Representative Concentration Pathways (RCPs) used in this project were kindly provided by the UK Met Office Hadley Centre. They are identical time series to those used in the AVOID2 (Avoiding Dangerous Climate Change) project funded by the UK Department of Energy and Climate Change (Bernie and Lowe, 2014). These time series encapsulate the uncertainty in GCMs through the process described below. They are probabilistic outcomes of the modelling system used in AVOID2, which samples scientific uncertainties in the climate system by sampling distributions of physical parameters which have a dominant contribution to uncertainty in climate projections. The three physical parameters used in developing the scenarios are: the equilibrium climate sensitivity (ECS), which is the long-term warming response to a doubling of atmospheric CO2; ocean diffusivity, which affects how quickly heat is removed from the upper ocean, moderating the rates of atmospheric warming; and climate-carbon cycle feedback strength, which accounts for how strongly climate change affects the ability of the carbon cycle to remove CO2 from the atmosphere. The distribution of carbon cycle feedback uncertainty was based on Friedlingstein et al. (2006). The ECS distribution used is based on the IPCC Fourth Assessment Report (IPCC, 2007) and is a simple combination of ECS distributions from a number of alternative lines of evidence (Rogelj et al., 2012)

The Met Office calculated 10%, 50% and 90% probability outcomes for each of the four RCP scenarios as time series over the 21st century, expressing this as the global temperature rise relative to a 1961-1990 baseline. In EUCalc only the 50% projections are used.

2.2.2 European climate change scenarios

Climate change data at the European scale has been produced by the ClimGEN model (Osborn *et al.*, 2016) driven by the global temperature time series (see section 2.3.1). ClimGEN contains a facility to aggregate monthly data to provide seasonal information (Dec-Feb, Mar-May, Jun-Aug, and Sep-Nov) as required in this project. ClimGEN produces output at 0.5x0.5 degree resolution, and this is aggregated to country means as required for this project.

The climate inputs are obtained by scaling patterns of climate change by these global temperature changes (i.e. pattern-scaling; Osborn et al., 2016), combining these with observed monthly variability and then disaggregating the monthly climate series to daily sequences where required by the impact models. The climate change patterns were diagnosed from the twenty-one CMIP5 global climate models (Hurrell et al., 2011). A notable modification to this standard approach is that the monthly precipitation variability is also perturbed according to the changes in precipitation variability simulated by each of the five climate models used here, thus representing increases or decreases in future precipitation variance and distribution skewness (Osborn et al., 2016).

Global Circulation Models provide projections of climate change at a coarse resolution and in order to generate projections at higher resolution for use in this project the ClimGen pattern scaling software application is used (Osborn et al., 2016). Pattern-scaling assumes that there is a linear relationship (possibly after a transformation for precipitation) between the change in a climate variable in a grid cell and the change in the global-mean surface temperature, and that this relationship is invariant under the range of climate changes being considered here. This is a commonly used method; see Tebaldi and Arblaster (2014) for a discussion of its strengths and limitations and James *et al.* (2017) for a review of its specific application to global warming targets in comparison with other methods.

The monthly time-series combine the observational mean climate, the pattern-scaled change in mean climate, and observed monthly anomalies superimposed to provide realistic climate variability. Observational climatic data month-by-month variations in climate over the period 1961-2013 were taken from CRU TS 3.22 (UEA, 2014) for two thirty-year periods 1961-1990 and 1984-2013 on a 0.5° by 0.5° grid. For precipitation, the observed monthly anomalies were first transformed so that their probability distribution changes according to changes projected by GCM climate models (i.e. if a GCM simulates increased, or decreased, variability of monthly precipitation under a future scenario, then this change will be reflected in the monthly time-series generated by ClimGen; see Osborn et al. (2016), for details).

2.3 Climate indices

In this section, the projected climate data are presented. For all variables, values are presented as changes (anomalies) relative to the 1961-1990 observed baseline.

2.3.1 Mean cloud cover

Cloud cover is expected to decrease across Europe except in Northern Scandinavia where hardly any changes are expected. Particularly southern Europe will be affected with decreases up to 4% on the Iberian Peninsula, Southern France, Switzerland, Italy and the area around the Balkan Peninsula (Figure A.1). Losses will predominantly occur in the summer months (JJA, S2) while winter months (DJF, S4) exhibit only slight decreases for Southern Europe, hardly any changes in Central Europe and even an increase in cover for Scandinavia.

2.3.2 Mean precipitation

In Figure 3 changes in annually and seasonally averaged median precipitation for RCP 2.6 are depicted for three thirty year periods. The results show an increase in monthly mean precipitation for Northern Europe and decreases in Southern

Europe, particularly over the Iberian Peninsula. In summer (JJA, S2), only the northern parts of Scandinavia show an increase in precipitation, while increases in winter precipitation (DJF, S4) are projected for most of Europe, except the most southern areas. These areas are likely to be affected by decreases with hotspots in southern France, the Pyrenees, northern Italy and northern Greece.

2.3.3 Surface Air Temperature

Surface air temperature will increase all across Europe but there will be distinct regional differences. Responses between minimum and maximum temperature also differ, indicating that they will not rise at the same rate.

Changes in mean temperature are shown in Figure 4. The north of Sweden and Finland will increase stronger than all the other regions while the British Isles appear to warm slower. This pattern also applies for the minimum temperature (Figure A.3) and maximum temperature (Figure A.2). While the strongest changes for maximum temperature are projected for the summer months (JJA, S2), the strongest changes in minimum temperature are projected for the winter months (DFJ, S4), with Sweden and Finland more affected than other regions.

2.3.4 Vapor Pressure

Vapor pressure is expected to slightly increase throughout Europe and coastlines appear to be stronger affected than the remaining areas (Figure A.4). The strongest changes are expected for the summer months (JJA, S2) with areas in Finland and southern Italy exhibiting the largest increases for the 30 year period around 2050.

2.3.5 Wet Day Frequency

Changes in wet day frequency are depicted in Figure A.5. The north of Europe will experience increases in wet day frequency while the south, particularly the Iberian Peninsula, will experience decreases. There is also a band in which hardly any changes are expected.

The distinct split and band of no changes shifts through the seasons. Winter months and spring months (DJF, S4 and MAM, S1) see an extension of the norther increases to mid France, while decreases in summer (JJA, S2) will be seen as far north as the tip of Denmark.

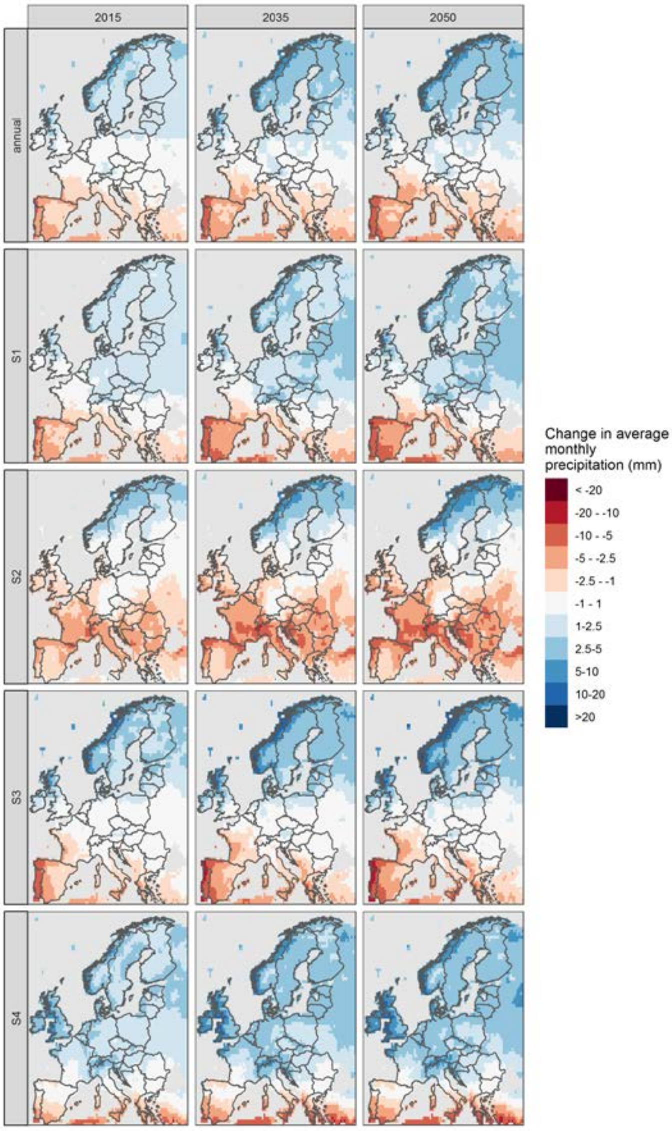

Figure 3 Changes in mean precipitation (mm) relative to 1961-1990 under RCP 2.6 for the 30 year periods centered around 2015, 2035 and 2050

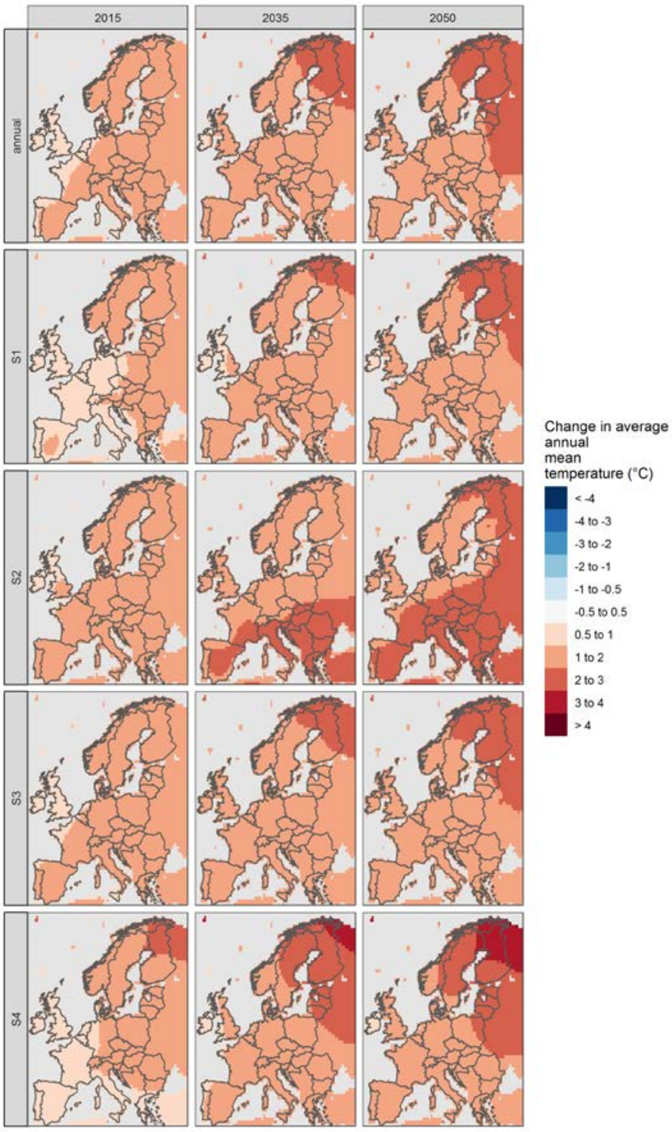

Figure 4 Changes in mean temperature (°C) under RCP 2.6 for the 30 year periods centered around 2015, 2035 and 2050 relative to 1961-1990

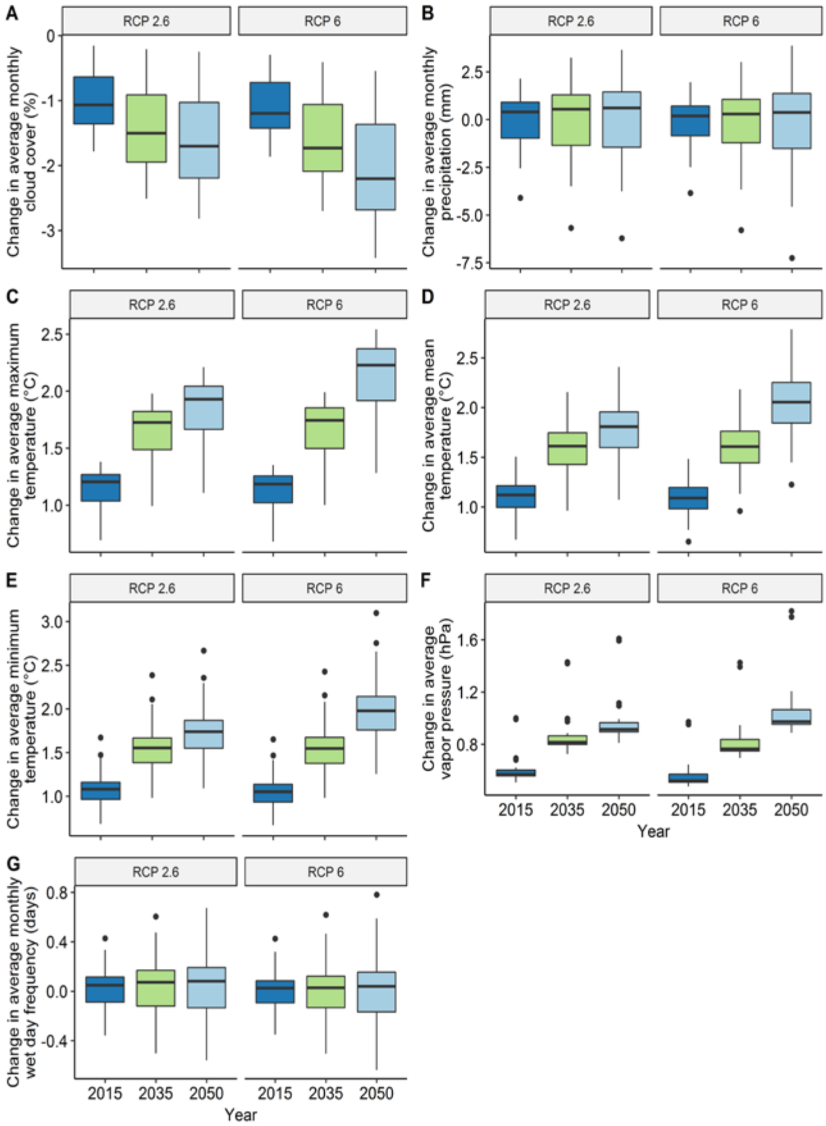

Figure 5 Boxplots showing the ranges of changes (relative to 1961-1990) in A: cloud cover, B: precipitation, C: maximum temperature, D: mean temperature, E: minimum temperature, F: vapor pressure and G: wet day frequency for 29 countries in Europe under both RCP 2.6 and RCP 6 in 2015, 2035 and 2050

2.3.6 Changes on the country level

Table 3 Countries which are projected to be exposed to the smallest and largest changes in climate by the 2050s

Variable	**RCP**	**Country with the smallest change in the climate variable (in absolute terms)**		**Country with largest decrease in the variable (cloud, precipitation, wet day frequency) or smallest increase (temperature related variables and vapor pressure) relative to 1961-1990**		**Country with largest increase in the variable relative to 1961-1990 (or smallest decrease, for cloud cover)**	
Cloud cover	2.6	Finland	-0.3 %	Greece	-6.1 %	Finland	-0.4 %
	6	Finland	-0.5 %	Greece	-7.4 %	Finland	-0.8 %
Precipitation	2.6	Switzerland	0.1 mm	Portugal	-9.0 %	Finland	+7.5 %
	6	Luxembourg	0.4 mm	Malta	-10.9 %	Finland	+8.6 %
Minimum temperature	2.6	Ireland	1.1 °C	Ireland	+1.1 °C	Finland	+2.7 °C
	6	Ireland	1.3 °C	Ireland	+1.3 °C	Finland	+3.1 °C
Mean temperature	2.6	Ireland	1.1 °C	Ireland	+1.1 °C	Finland	+2.4 °C
	6	Ireland	1.2 °C	Ireland	+1.2 °C	Finland	+2.8 °C
Maximum temperature	2.6	Ireland	1.1 °C	Ireland	+1.1 °C	Finland	+2.2 °C
	6	Ireland	1.3 °C	Ireland	+1.3 °C	Finland	+2.5 °C
Vapor pressure	2.6	Ireland	0.8 hPa	Ireland	+8.0 %	Finland	+14.8 %
	6	Ireland	0.9 hPa	Portugal	+8.6 %	Finland	+16.8 %
Wet day frequency	2.6	Slovenia	0.0 d	Portugal	-5.9 %	Finland	+4.0 %
	6	Hungary	0.0 d	Malta	-7.4 %	Finland	+4.7 %

For each indicator, Table 3 presents the countries which are expected to be affected the most/least. Changes in cloud cover, precipitation, vapor pressure and wet day frequency are expressed as percentage change to the 1961-1990 values. Changes in temperature are expressed as absolute values.

Once again, the previously described differences between southern and northern Europe as well as differences between western and Eastern Europe become apparent. In the table we distinguish between impacts in absolute terms and impacts including their directional values. For instance, in case of precipitation und RCP 6, Luxembourg is the country which will be affected by the smallest change, regardless of whether it will be positive or negative. The largest projected decline in precipitation is in Portugal, while Finland has the largest projected increase in precipitation.

3 Conclusions

Important decisions have been made about global climate change scenarios to be considered in the project, and climate data has been provided to the team where possible complying with their expressed user needs. The database created forms the basis of the climate module in the EU calculator. Further data may be provided and added to the database as requests may evolve as the project develops, however limitations exist to the ClimGEN system, for example if projections of future changes in wind are required, it would be necessary to explore freely available data sources outside the Consortium.

The trends identified in Europe are consistent with the findings of IPCC (2013) where wetting in the north-east and drying in the south-west, particularly in Mediterranean regions, is clear (see for example their Figure AI.SM2.6.75).

Climate data is important to the Calculator because changes in climate might affect other module inputs, for example the availability of cooling water for power stations, or the demand for cooling in buildings. It also will in the future enable the emission reductions in the EU to be linked to global changes in temperature and hence reduced climate change impacts, through the assumption of a linkage between emission reductions within and without the EU.

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Annex

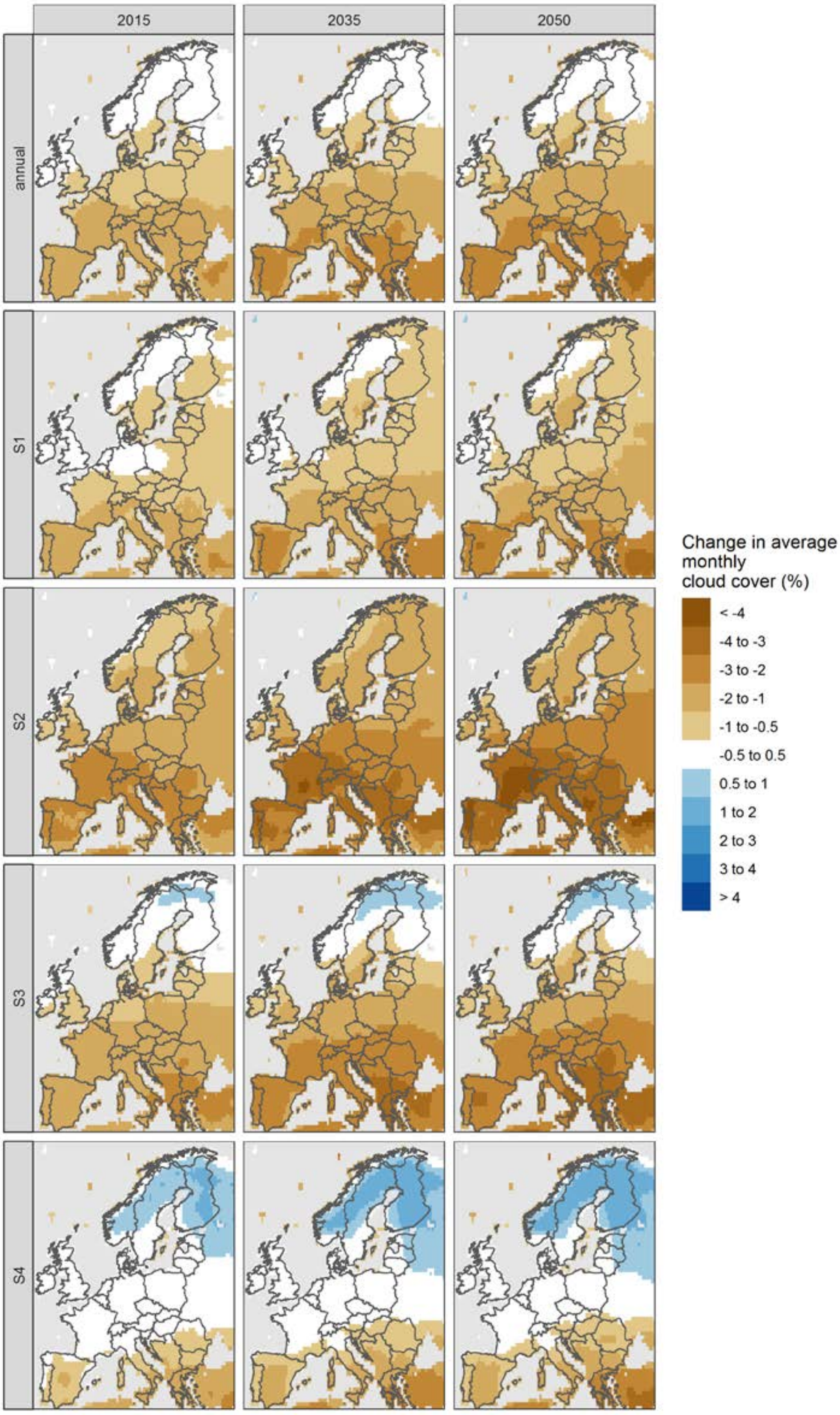

Figure A.1 Projected change in average monthly cloud cover (%) for RCP 2.6 (top row) and RCP 6 (bottom row) relative to 1961-1990 for the years 2015, 2035 and 2050

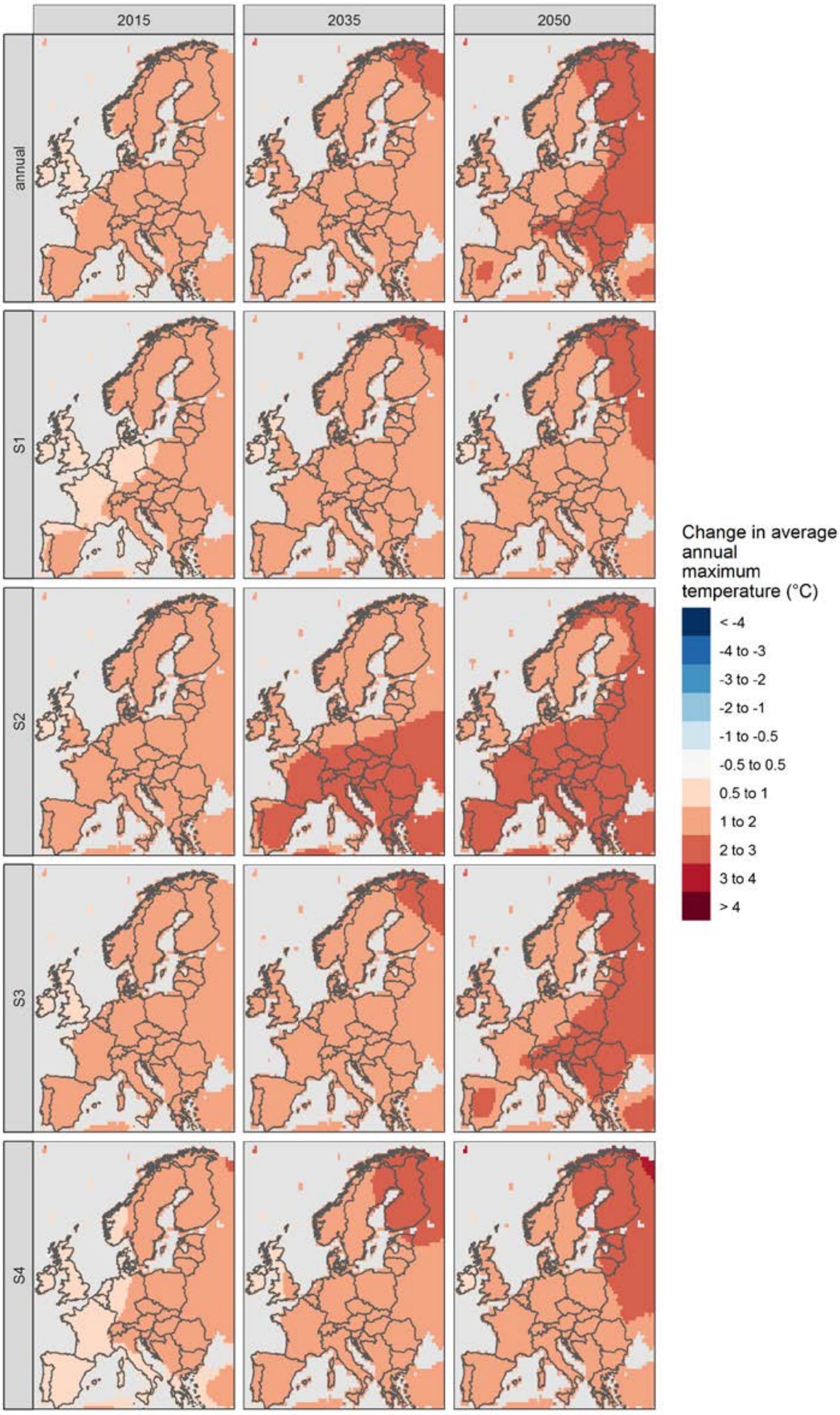

Figure A.2 Changes in maximum temperature (°C) under RCP 2.6 for the 30 year periods centered around 2015, 2035 and 2050 relative to 1961-1990

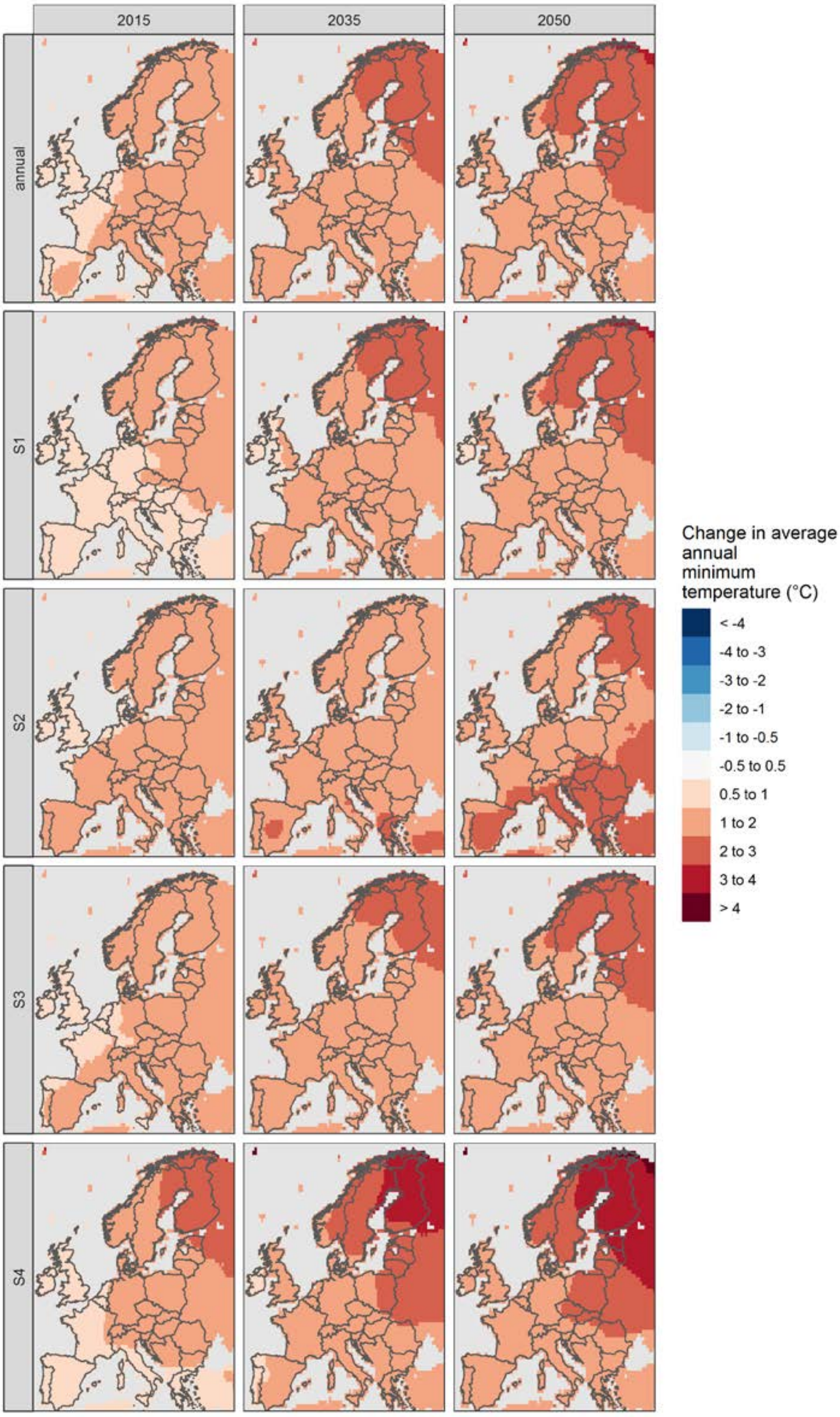

Figure A.3 Changes in minimum temperature (°C) under RCP 2.6 for the 30 year periods centered around 2015, 2035 and 2050 relative to 1961-1990

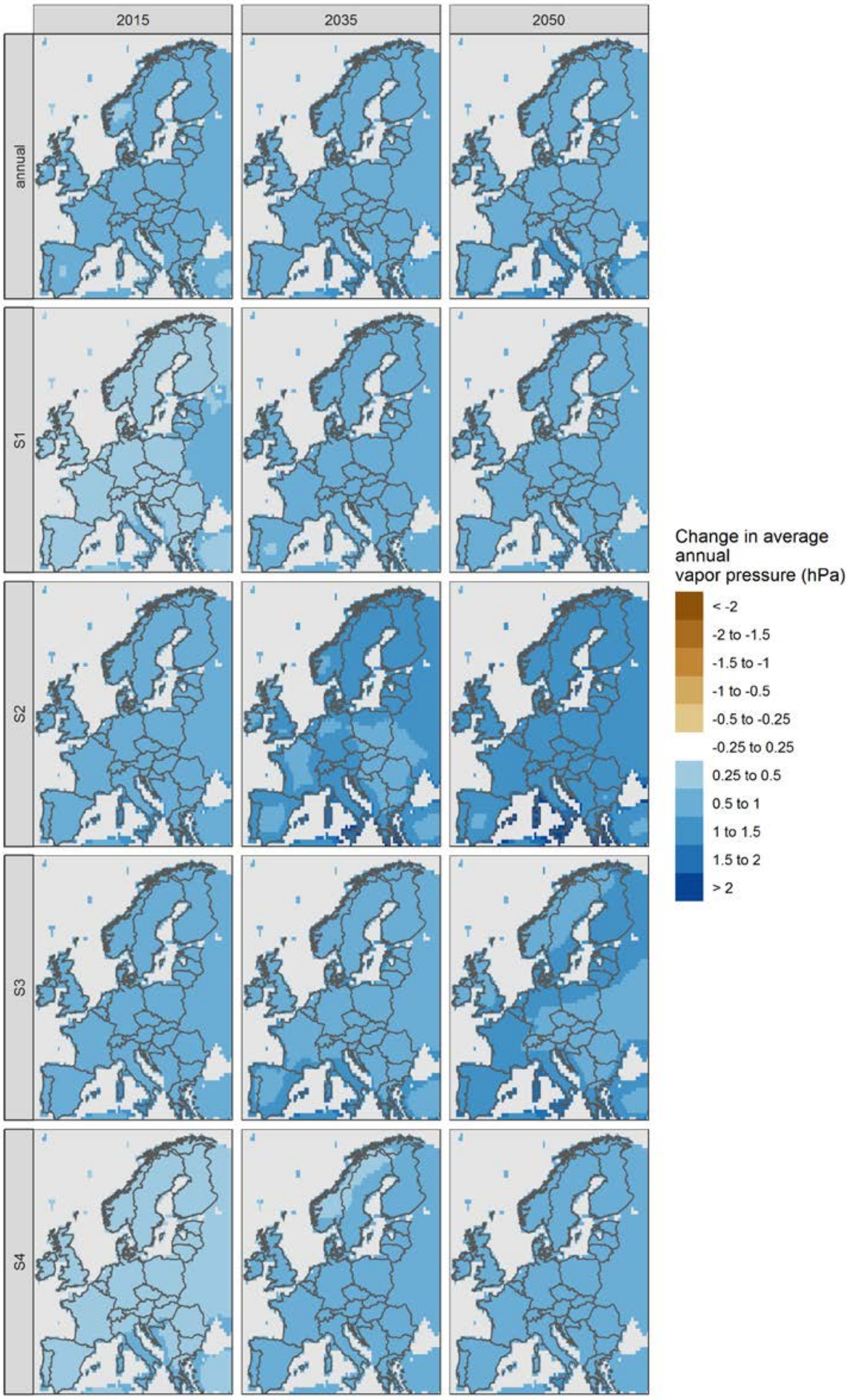

Figure A.4 Changes in vapor pressure (hPa) under RCP 2.6 for the 30 year periods centered around 2015, 2035 and 2050 relative to 1961-1990

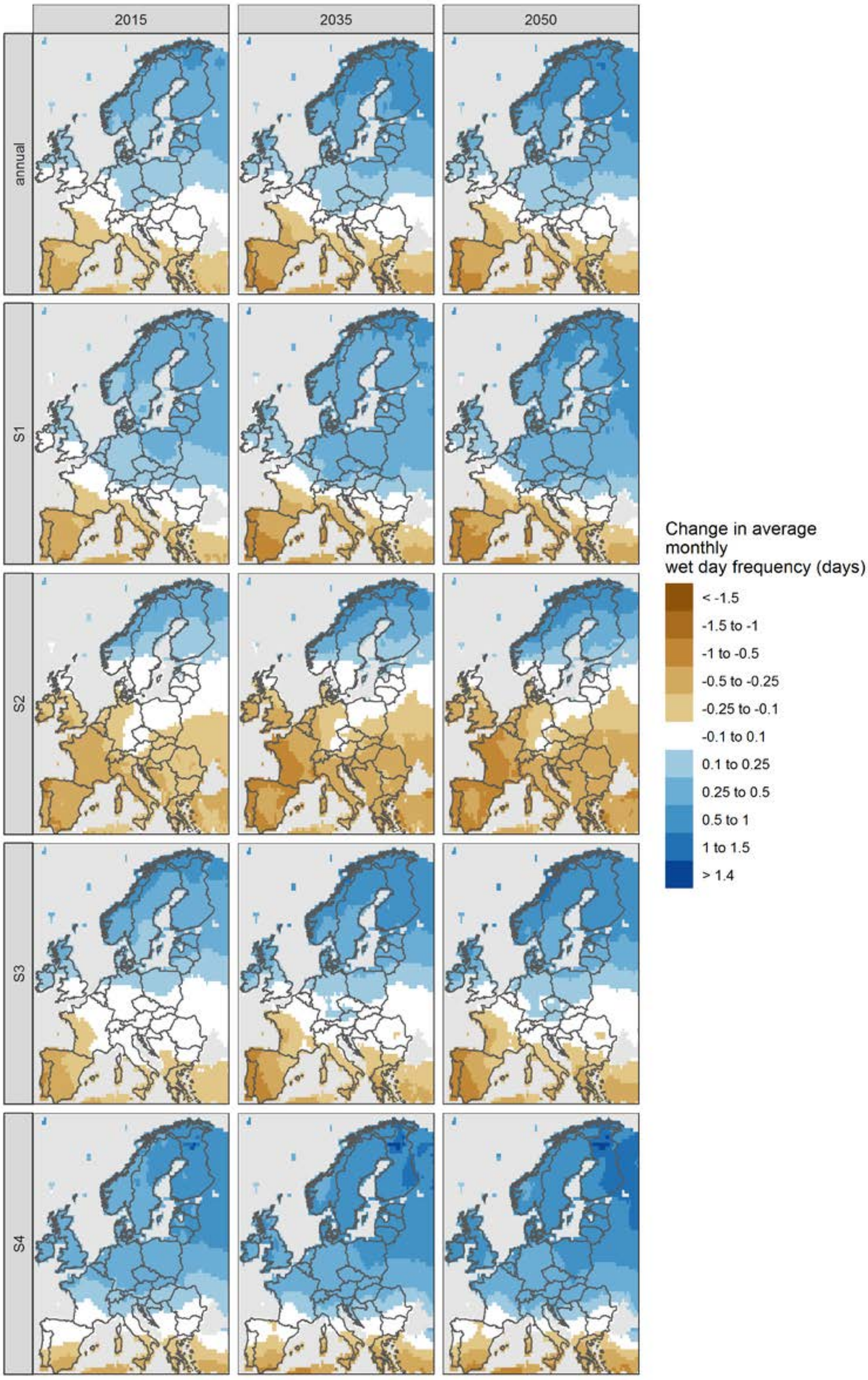

Figure A.5 Changes in monthly wet day frequency (days) under RCP 2.6 for the 30 year periods centered around 2015, 2035 and 2050 relative to 1961-1990