Adv. Sci. Res., 15, 217–230, 2018
https://doi.org/10.5194/asr-15-217-2018

Advances in Science & Research
Open Access Proceedings

Special Issue: 17th EMS Annual Meeting: European Conference for Applied Meteorology and Climatology 2017

Strategy for generation of climate change projections feeding Spanish impact community

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Received: 14 February 2018 – Revised: 6 August 2018 – Accepted: 9 August 2018 – Published: 30 August 2018

Abstract. Over the past decades, the successive Coupled Model Intercomparison Projects (CMIPs) have produced a huge amount of global climate model simulations. Along these years, the climate models have advanced and can thus provide credible evolution of climate at least at continental or global scales since they are better representing physical processes and feedbacks in the climate system. Nevertheless, due to the coarse horizontal resolution of global climate models, it is necessary to downscale these results for their use to assess possible future impacts of climate change in climate sensitive ecosystems and sectors and to adopt adaptation strategies at local and national level. In this vein, the Spanish State Meteorological Agency (AEMET) has been producing since 2006 a set of reference downscaled climate change projections over Spain either applying statistical downscaling techniques to the outputs of the Global Climate Models (GCMs) or making use of the information generated by dynamical downscaling techniques through European projects or international initiatives such as PRUDENCE, ENSEMBLES and EURO-CORDEX. The AEMET strategy aims at exploiting all the available sources of information on climate change projections. The generalized use of statistical and dynamical downscaling approaches allow us to encompass a great number of global models and therefore to provide a better estimation of uncertainty. Most impact climate change studies over Spain make use of this reference downscaled projections emphasizing the estimation of uncertainties. Additionally to the rationale and history behind the AEMET generation of climate change scenarios, we focus on some preliminary analysis of the dependency of estimated uncertainties on the different sources of data.

1 Introduction

Climate change constitutes one of the main global threats we must face in the present century. Even when considering the most optimistic outlooks regarding future greenhouse gas (GHG) emissions, scientific studies reveal that some climate change is inevitable (IPCC, 2013). The increased concentration of GHGs in the atmosphere causes modification of several climate parameters, which in turn are responsible for environmental changes that might result in shifts in the ecosystems and the social and economic systems and sectors. The direction, amount and intensity of climate alterations will, in the end, determine the definitive trends and magnitudes of the impacts at the local, regional and planetary levels.

In this context, society demands more and more climate information at local levels but, at the same time, we are aware that though climate models have experienced great changes, there are still biases with highest impact at small scales (Bruyère et al., 2014). Besides, mainland Spain and Balearic Islands are located in the western part of the Mediterranean Basin, recognized as a “climate change hot spot” that could be strongly affected in the future by significant warming and drying (Giorgi, 2006).

Therefore, to complement the efforts in the reduction of GHG emissions, it is necessary to adopt and implement whatever adaptation measures aimed at reducing the vulnerability of our ecosystems and sectors at the relevant scales and decision levels, in order to minimize its negative impacts. So, studies and measures in climate change adaptation are boosting activity in regionalized climate change projections. Many *ad hoc* institutes have been created to meet this demand and/or National Meteorological and Hydrological Services (NMHSs) are additionally tasked with this new area of activity.

Furthermore, the interest in estimating the potential socioeconomic costs of climate change has led to the increasing use of either dynamical or statistical downscaling methods to produce finer spatial and time scale climate projections for the impact community. In this frame, AEMET, in the division of climate services, has produced a new collection of regionalized climate change projections. In the corresponding web portal users can get an idea of various aspects of climate change from a suite of maps, diagrams, explanatory texts and users' guides. The manuscript is structured as follows. Section 2 gives a comprehensive description of preliminaries and time milestones while the strategy is presented in Sect. 3, focusing on the main contents of the webpage together with the climate projections from CMIP3 and CMIP5 (the third and fifth phases of CMIP) respectively) climate models. Finally, some concluding remarks are summarized in Sect. 4.

2 Preliminaries

In 2006, routine production of regionalized/downscaled climate change projections at century-scale for Spain was launched as a consequence of the international climate change negotiations in the frame of United Nations Framework Convention on Climate Change (UNFCCC) and the commitments there assumed by the Parties. Under the umbrella of the Spanish National Adaptation Plan to Climate Change (PNACC), AEMET was mandated to develop the production and update of such projections in coordination with the academic and research community. PNACC is the general reference frame tool for the coordination of Public Administrations' efforts dealing with the assessment of impacts, vulnerability, and adaptation to climate change in the Spanish sectors acknowledged as potentially affected (water management, agriculture, forests, biodiversity, coasts, health, tourism, etc.).

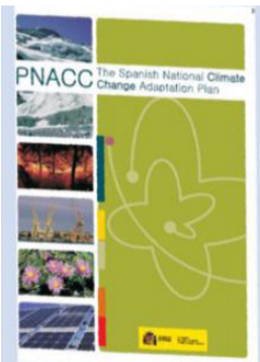
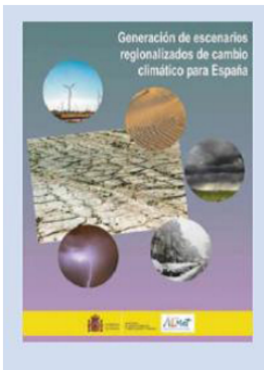
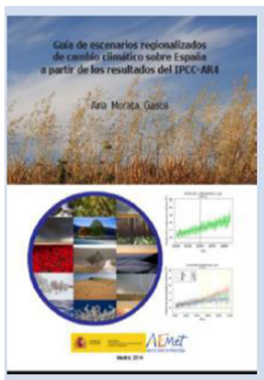
PNACC provides tools for the elaboration of diagnoses and the development of more efficient ways for adaptation and it is actually a process to guide the activities of Public Administrations, enterprises and stakeholders towards a common objective, committing themselves to the fight against climate change. Figure 1 depicts the structure of the PNACC. We must be aware that the PNACC will only be effective if its existence, progress and results are disseminated and communicated in an effective way to all the relevant stakeholders. Its main original objectives include: (a) to develop the future regional climate scenarios for the Spanish geography, (b) to develop and apply methods and tools to evaluate impacts, vulnerability and the adaptation to climate change for all the relevant socioeconomic sectors and ecological systems, (c) to incorporate into the Spanish Research & Development & innovation (R&D&i) system the most relevant needs for climate change impact assessment, (d) to carry out continuous information and communication activities about the projects, (e) to promote the participation of all stakeholders involved in the different sectors and systems, for purposes of mainstreaming adaptation to climate change to sector policies, and (f) to prepare specific reports on the results of the evaluations and projects, and periodical follow-up reports about the projects and the National Adaptation Plan as a whole (see for more details, https://www.mapama.gob.es/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/folletopnacc_tcm30-70394.pdf, last access: 3 August 2018).

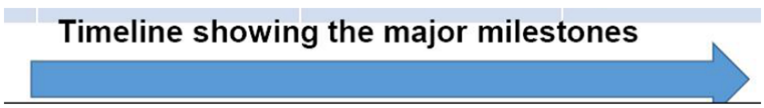
2.1 Milestones

The timelines showing the major milestones are summarized in Table 1. Briefly, in 2006, AEMET was mandated in the frame of PNACC to develop the routine production and update of downscaled climate change projections for Spain at century-scale, in coordination with the Spanish academic and research community.

Our potential users were mainly channelled through the Spanish Climate Change Office (OECC), the Hydrographic Studies Center (CEDEX) (http://www.cedex.es/CEDEX/lang_castellano/, last access: 29 May 2018), the Biodiversity Foundation, and other generic users. In 2008, took place the first delivery (Brunet et al., 2008) of the periodical revision of regional projections with the best data available from climate models contributing to the Third Assessment Report (TAR), observations and regionalization techniques from two international European projects, PRUDENCE (http://prudence.dmi.dk, last access: 29 May 2018), and ENSEMBLES (https://www.ecmwf.int/en/research/projects/ensembles, last access: 30 May 2018). These latter projects aimed at creating state-of-the-art simulations performed with several Regional Climate Models (RCMs) driven by several GCMs that would enable evaluation of uncertainties in RCM outputs and provide data for climate change studies over Europe. The PRUDENCE project was accomplished in 2005 (Christensen and Christensen, 2007; Jacob et al., 2007; Déqué et al., 2007). ENSEMBLES was an EU-funded Integrated Project to develop an ensemble prediction system for climate change based on the principal state-of-the-art, high resolution, global and regional Earth System models developed in Europe, being completed in December 2009. Detailed information about the project and its results, including the RCM simulations, can be found in van der Linden and Mitchell (2009). Apart from providing standardised experiments for model intercomparisons, PRUDENCE and ENSEMBLES were designed to create multimodel ensembles for sampling model uncertainties (https://www.ecmwf.int/en/research/projects/ensembles, last access: 30 May 2018). The second delivery of regional projections took place in

Table 1. Timeline showing the major milestones in the AEMET strategy.

2006	2008	2014	2017
Spanish National Climate Change Adaptation Plan (PNACC) mandated AEMET to develop production and update of downscaled climate change projections in coordination with the academic and research community.	First delivery of periodical revision of regional projections with the best and current data available from GCMs, observations and regionalization techniques (TAR, PRUDENCE)	Second delivery of regional projections (aemet webpage published graphical results and daily and monthly aggregated data. A4 data & ESCENA and ESTCENA data, projects financed by the Spanish Ministery of Environment).	Third delivery of Regional projections by AEMET. Statistical methods of regionalisation (AR5) & dynamical regionalized projections from CORDEX Projects.
	1st Document Brunet et al. (2008)	2nd Document Morata-Gasca (2014)	3rd Document Amblar-Francés et al. (2017)
			



2014 (Morata-Gasca, 2014), when the AEMET webpage published graphical results and daily and monthly aggregated data; from ENSEMBLES project and two Spanish national projects: ESCENA (Jiménez-Guerrero et al., 2013; Dominguez et al., 2013), and ESTCENA (Gutiérrez et al., 2013), funded by the Spanish Ministry of Environment devoted to dynamical and statistical downscaling, respectively as well as downscaled data from CMIP3 climate models feeding the Fourth Assessment Report (AR4). These two strategic actions of Plan Nacional de R&D&i 2008–2011, contributed to the new version of the regional climate change scenarios program PNACC-2012 within PNACC. In 2017, took place the third delivery of regional projections by AEMET (Amblar-Francés et al., 2017), focused mainly on statistical methods of regionalization applied to CMIP5 climate models feeding the Fifth Assessment Report (AR5) and dynamical regionalized projections from the EURO-CORDEX project. In this delivery information aggregated by autonomous communities, provinces and hydrographic basins was introduced.

3 Strategy

In a nutshell, the strategy adopted by AEMET in the generation of Spanish climate change projections (http://www.aemet.es/es/serviciosclimaticos/cambio_climat, last access: 1 August 2018) is based on the exploitation of all relevant information based on either statistical or dynamical downscaling techniques, generated either by AEMET or other projects and international or national initiatives; with strong emphasis on improving visualization together with easy way to access information at appropriate scales (hydrographic basins (HB), provinces, autonomous communities (AC), Spanish Iberia and Balearic and Canary Islands) – see Figs. 2, 3. Table 2 shows the number of projections used in the 3rd delivery obtained by two statistical methods (analog and regression), the EURO-CORDEX dynamical regionalisation based on AR5-IPCC results, and three Representative Concentration Pathways (RCPs): RCP4.5, RCP6.0 and RCP 8.5 for statistical regionalization with two, RCP4.5 and RCP8.5, for dynamical regionalization. RCP4.5 and RCP6.0 represent two in-

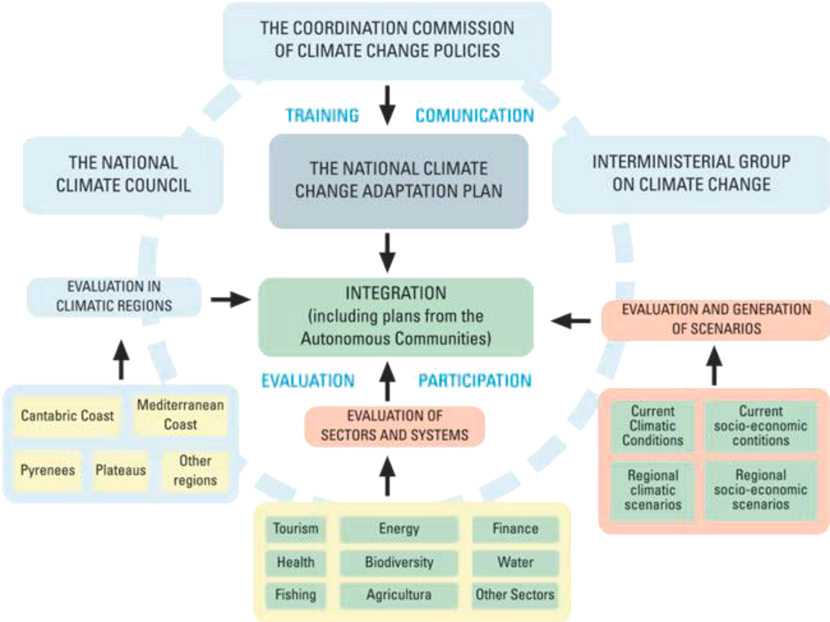


Figure 1. Structure of the National Climate Change Adaptation Plan.

Table 2. Regionalized projections of temperature (Tmax & Tmin) and precipitation obtained by statistical methods (analog and regression) and dynamical regionalisation (EURO-CORDEX) based on AR5-IPCC results. For analog and regression methods, numbers indicate the number of driving GCMs in each case. For CORDEX, number refers to the number of different GCM/RCM combinations.

Scenario	TEMPERATURE				PRECIPITATION			
	Analog	Regression	CORDEX	Total	Analog	Regression	CORDEX	Total
RCP8.5	14	19	10	43	17	19	10	46
RCP6.0	6	7		13	7	7		14
RCP4.5	13	15	10	38	18	15	10	43
Total	33	41	20	94	42	41	20	103

termediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 and 6.0 W m^{-2} after 2100. As regards RCP8.5, radiative forcing reaches >8.5 W m^{-2} by 2100 and continues to rise for some amount of time.

Table 3 depicts the list of global models considered from CMIP5, while the subset of models used from the EURO-CORDEX project is listed in Table 4. In the AEMET webpage numerical information (daily and monthly scales) is available from AR5 and AR4 and from relevant projects (EURO-CORDEX, ENSEMBLES, ESCENA, ESTCENA etc.), different variables and extreme indicators as well as graphic information. Table 5 shows the list of variables and indicators that have been considered taking into account a variety of sources (i.e., suggestions from specialized users, IPCC literature, international projects, etc.).

Bridging the gap between the resolution of climate models and regional and local scale processes represents a considerable challenge. Basically any data can be refined by downscaling techniques (Rummukainen, 2010), this is a crucial step for providing actionable information at the regional and local scales required in impact and adaptation studies (Gutiérrez et al., 2018). The main downscaling approaches are: dynamical downscaling (based on regional climate models (RCM)) and empirical/statistical downscaling (ESD), based on statistical models). As mentioned in Gutiérrez et al. (2018), the relative merits and limitations of both dynamical and statistical downscaling approaches have been widely discussed in the literature and it is nowadays recognized that they are complementary in many practical applications.

Dynamical downscaling represents a group of methods originally used in numerical weather forecasting (Rummukainen, 2010; Maraun et al., 2010). Two major streams are recognizable in dynamical downscaling: in the first, the resolution is increased over the entire domain of the atmospheric global model (e.g. Christensen and Christensen, 2007). The second strategy is based on the utilization of a global model with variable grid size (Déqué et al., 2012). Increasing res-

Table 3. List of CMIP5 models used in the 3rd delivery of Regionalized Projections by AEMET.

Model	Institution	References
ACCESS1.0	Commonwealth Scientific and Industrial Research Org. (CSIRO) y Bureau of Meteorology (BoM), Australia	Bi et al. (2013)
ACCESS1.3	CSIRO BoM, Australia	Bi et al. (2013)
Bcc-csm1.1	Beijing Climate Center, China	Wu et al. (2013), Xiao-Ge et al. (2013)
Bcc-csm1.m	Beijing Climate Center, China	Wu et al. (2013)
BNU-ESM	College of Global Change and Earth System Science (GCESS) Beijing Normal University, China	Ji et al. (2014)
CanESM2	Canadian Centre for Climate Modelling and Analysis (CCCma), Canadá	Arora et al. (2011)
CMCC-CESM	Centro Euro-Mediterraneo per I Cambiamenti Climatici (CMCC), Italy	Hurrell et al. (2013)
CMCC-CM	CMCC, Italy	Scoccimarro et al. (2011)
CMCC-CMS	CMCC, Italy	Weare et al. (2012)
CNRM-CM5	Centre National de Recherches Météorologiques/Centre Européen de Recherche et Formation Avancée en Calcul Scientifique (CNRM-CERFACS), France	Voldoire et al. (2013)
CSIRO-Mk3.6.0	CSIRO in collaboration with Queensland Climate Change Centre of Excellence (QCCCE), Australia	Gordon et al. (2002)
GFDL-ESM2G	NOAA/Geophysical Fluid Dynamics Laboratory (GFDL), USA	Donner et al. (2011)
GFDL-ESM2M	NOAA/GFDL, USA	Donner et al. (2011)
HadGEM2-CC	Met Office, UK	Martin et al. (2011)
Inm-cm4	Institute of Numerical Mathematics, Russia	Volodin et al. (2010)
IPSL-CM5A-LR	Institut Pierre-Simon Laplace (IPSL), France	Dufresne et al. (2013)
IPSL-CM5A-MR	IPSL, France	Dufresne et al. (2013)
IPSL-CM5B-LR	IPSL, France	Dufresne et al. (2013)
MIROC5	Atmosphere and Ocean Research Institute (AORI) National Institute for Environmental Studies (NIES) JAMSTEC, Japan	Watanabe et al. (2011)
MIROC-ESM	AORI NIES JAMSTEC, Japan	Watanabe et al. (2011)
MIROC-ESM-CHEM	AORI NIES JAMSTEC, Japan	Watanabe et al. (2011)
MPI-ESM-LR	Max-Planck-Institut (MPI) for Meteorology, Germany	Giorgetta et al. (2013)
MPI-ESM-MR	Max-Planck-Institut (MPI) for Meteorology, Germany	Giorgetta et al. (2013)
MRI-CGCM3	Meteorological Research Institute, Japan	Yukimoto et al. (2012)

Table 4. List of CORDEX models used in the 3rd delivery of Regional Projections by AEMET.

Institution	Regional Model	Global Model
Climate Limited-area Modelling Community (CLM-Community)	CCLM4-8-17	CNRM-CM5
Swedish Meteorological and Hydrological Institute, Rossby Centre, Sweden	RCA4	CNRM-CM5
Royal Netherlands Meteorological Institute, Nederlands	RACMO22E	EC-EARTH
Swedish Meteorological and Hydrological Institute, Rossby Centre, Sweden	RCA4	IPSL-CM5A-MR
Climate Limited-area Modelling Community (CLM-Community)	CCLM4-8-17	MPI-ESM-LR
Swedish Meteorological and Hydrological Institute, Rossby Centre, Sweden	RCA4	MPI-ESM-LR
Helmholtz-Zentrum Geesthacht, Climate Service Center, Max Planck Institute for Meteorology, Germany	REMO2009	MPI-ESM-LR
Climate Limited-area Modelling Community (CLM-Community)	CCLM4-8-17	MOHC-HadGEM2-ES
Swedish Meteorological and Hydrological Institute, Rossby Centre, Sweden	RCA4	MOHC-HadGEM2-ES
Royal Netherlands Meteorological Institute, Netherlands	RACMO22E	MOHC-HadGEM2-ES

Table 5. List of variables considered in statistical and dynamical regionalisation (daily data) and dynamical regionalisation in AEMET. S (D) stands for statistical (dynamical) regionalisation.

Variable	Daily Data	Monthly Data
Maximum air temperature	SD	D
Minimum air temperature	SD	D
Precipitation	SD	D
Near-surface wind speed (10 m)	D	D
Daily maximum near-surface wind speed of gust (10 m)	D	D
Near-surface relative humidity (2 m)	D	D
95th percentile maximum daily temperature		D
5th percentile minimum daily temperature		D
95th daily precipitation amount		D
Number of frost days		D
Number of tropical nights		D
Maximum precipitation in 24 h		D
Number of days with precipitation <1 mm		D
Number of days with precipitation >20 mm		D
Maximum number of consecutive days with precipitation <1 mm		D
Total cloudiness (fraction)	D	
Evaporation	D	
Downward longwave surface radiation	D	
Net longwave surface radiation	D	
Mean sea level pressure	D	
Surface pressure	D	
2 m specific humidity	D	
2 m relative humidity	D	
Upward latent heat flux at surface	D	
Soil temperature	D	
Maximum soil temperature	D	
Minimum soil temperature	D	
Moisture of upper 0.1 m soil layer	D	
Drainage (deep runoff)	D	
Total runoff	D	
Surface runoff	D	
Down Short wave	D	
Net Short wave	D	
2 m Temperature	D	
2 m Dew point	D	

olution also entails increasing computational cost and data volume. The more recent development proved that RCMs are capable of delivering high resolution results (20 km or less), this adds value in regions with variable orography, land-sea and other contrasts, as well as in capturing sharp, short-duration and extreme events, understanding that added value is usually defined as the ability of RCM simulations to improve some specific aspects of the GCM simulations through the presence of small scale features (Rummukainen, 2010). RCM also require a large expertise in handle. For instance, before using RCM to examine the projected changes, it is useful to evaluate to which extent the RCM outperforms its driving GCM in faithfully simulating climatic features at regional scales. Due to these practical limitations, the regional dynamical downscaling models remain out of reach for a vast majority of impact researchers, involved in geographical, biological, geological fields. Anyway, this is not the case for most climate researchers that have the capacity to handle NetCDF files and daily data.

In the third delivery of climate regional projections by AEMET, dynamical downscaling comes from EURO-CORDEX project (Jacob et al., 2014), since it represents a fine scale set of climate simulations and it is openly available; with multiple variables such as precipitation, maximum and minimum temperatures, relative humidity and wind speed which are of interest for impact studies.

Statistical downscaling is based on the perspective that regional climate is mainly conditioned by two factors: the large-scale climate and the local/regional features such as topography, land-sea distribution or land-use (Fowler et al.,

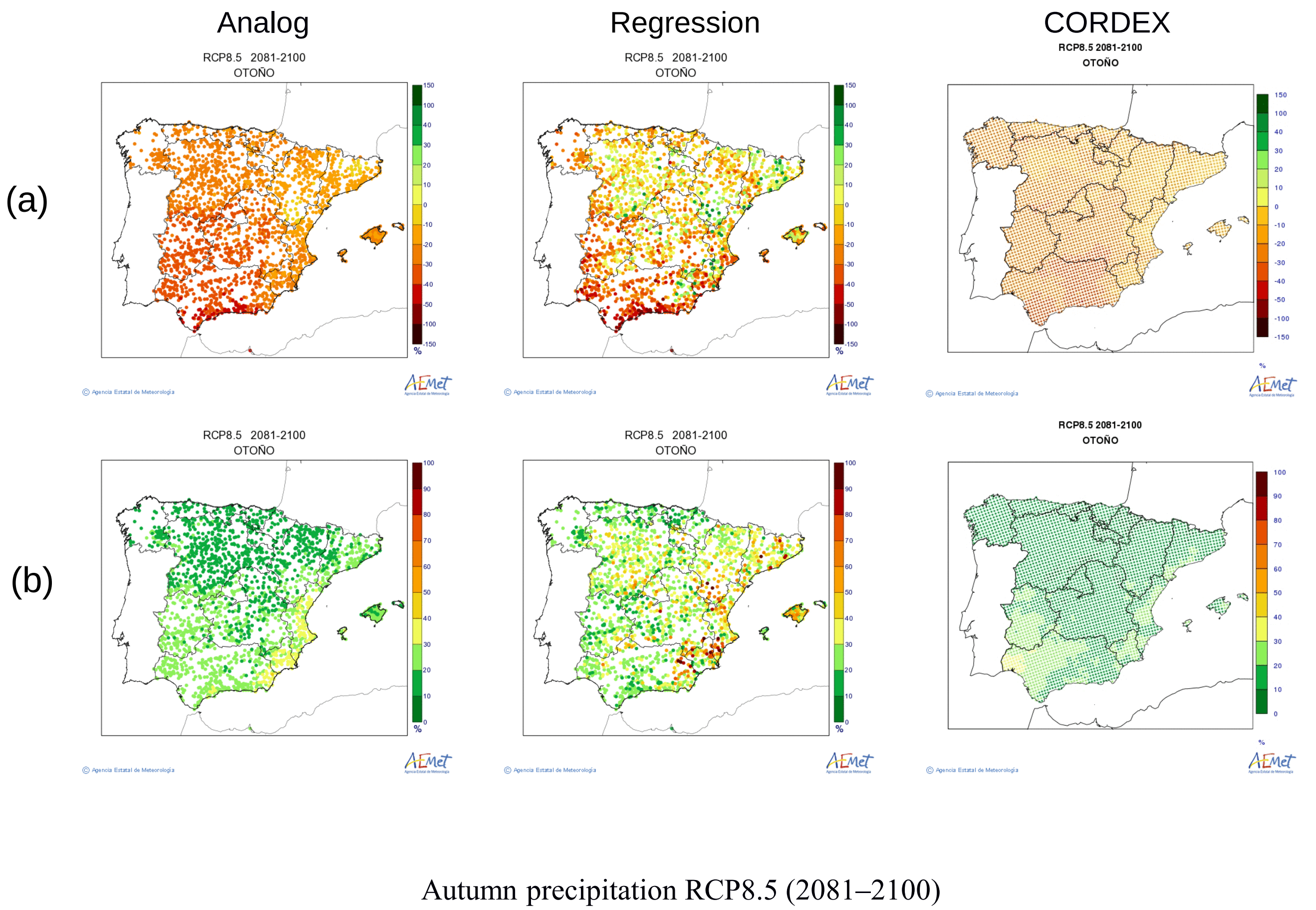


Figure 2. Change of **(a)** autumn mean precipitation (%) and **(b)** uncertainty ($\pm\sigma$) for RPC8.5 scenario in the 2081–2100 period with respect to the reference period (1961–1990).

2007; Wilby et al., 2004). It has the advantages of being computationally cheap and easily adjusted to new areas. A generic weakness of statistical downscaling is the high demand on available data. Therefore, it may appear to be an advantageous alternative for projects where the computational capacity, technical expertise or time represent significant restriction (Trzaska and Schnarr, 2014). In AEMET, two statistical downscaling techniques- analog and regression methods- have been applied to a large ensemble of climate projections released through the World Climate Research Programme (WCRP) Coupled Model Intercomparison project Phase 3 and Phase 5 (CMIP3 and CMIP5). Regression methods are usually applied because they are easy to implement and computationally efficient. Despite the potential problem that point out how statistical relationships derived from observations or simulations of the past will continue to be applicable under future climate conditions, it is considered that statistically downscaled projections are sufficiently robust to make available.

The downscaled projections are developed over (a) Iberian Peninsula and Balearic Archipelago and (b) Canary Islands. Furthermore, regression was used to downscale to the locations of selected weather stations. As regards the analog method, it is based on synoptic analogue selection using sea level pressure and 500 hPa wind components model simulation and application of regression relationships to a selection of predictors (see Petisco de Lara 2008a, b; Amblar-Francés et al., 2017 for more details).

On the other hand, the AEMET portal provides entry information for AdapteCCa (see Fig. 4), which is the Spanish Platform of Interchange and information query about climate change adaptation in Spain (http://escenarios.adaptecca.es, last access: 2 August 2018), with zooming and filtering possibilities and a user friendly interface. AdapteCCa is framed inside the LIFE-SHARA project (http://www.lifeshara.com/, last access: 2 August 2018), which is boosting climate change adaptation in Spain and Portugal. It was created as an initiative of the Spanish Climate Change Office (OECC), the

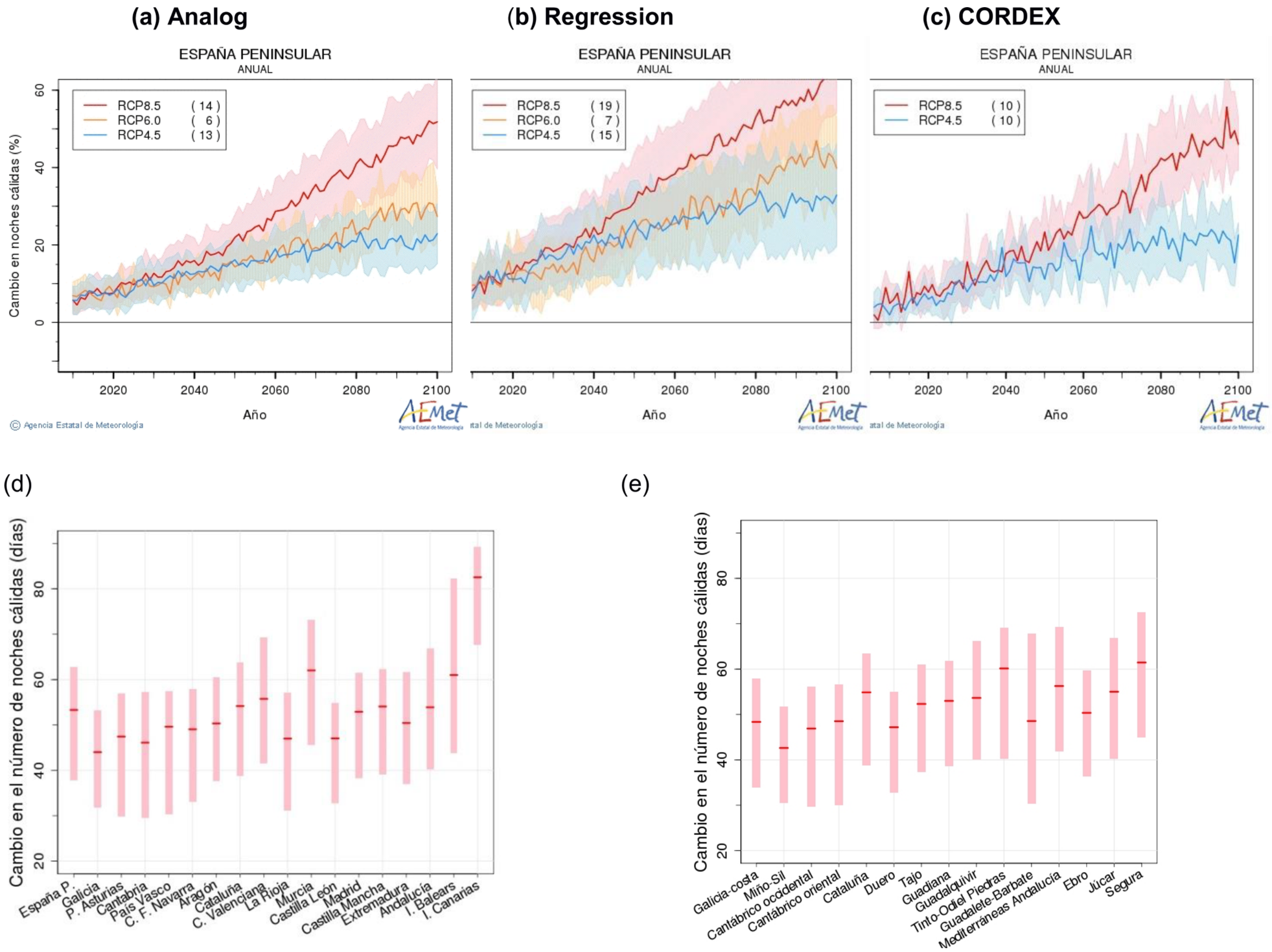


Figure 3. Temporal evolution of the annual change of warm nights for mainland Spain (RCP4.5, RCP6.0, RCP8.5) for: **(a)** Analog, **(b)** Regression and **(b)** EURO-CORDEX methods **(a, b, c)**. In parentheses, numbers of models considered in each RCP. In **(d, e)**, mean variation of this index for Autonomous Communities (AC) and Hydrographic Basins (HB). Central line refers to the median of projections while bar is the range between the 17th and the 83th percentiles.

Biodiversity Foundation and their equivalents in the Spanish autonomous communities.

Moreover, AdapteCCa national platform has been designed taking into full consideration and seeking maximum synergy with the European Climate-Adapt platform (https://climate-adapt.eea.europa.eu/, last access: 27 July 2018), which is an initiative of the European Commission to promote access and exchange of information about adaptation on the different sectors within the European policies and on the different Member States frameworks and initiatives.

As part of AdapteCCa platform, a new visualization tool for climate change scenarios over Spain has been developed. This Climate Scenarios viewer allows to easily visualize and download data of the last generation of regional climate change projections over Spain. There has been a relevant increase in contents, in practice this means that visits and downloads of the webpage have increased very significantly in last months. These evolving needs, over time and focus, have been determined through consultation with a wide range of users and has expanded to larger ensembles of indices and extremes. It should be noted that the National Adaptation Plan to Climate Change (PNACC) is the general framework for the activities of assessing impacts, vulnerability and adaptation to climate change in Spain. In this context, AdapteCCa contributes to reinforce the structure of the PNACC axis of mobilization of actors and the pillar coordination between administrations, being a complementary feature to the AEMET portal (Fig. 5).

AEMET, as a designated national expert agency for weather and climate in Spain, has considerable experience of communicating, conveying key information and concepts regarding climate change and climate scenarios to an audience that is more and more interested and receptive. For the last few years AEMET has worked closely with the Spanish Cli-

Figure 4. AdapteCCa Web portal (http://escenarios.adaptecca.es, last access: 2 August 2018). Date of screenshot: 2 August 2018.

Figure 5. AEMET Web portal (https://www.aemet.es/en/serviciosclimaticos/cambio_climat, last access: 1 August 2018). Date of screenshot: 1 August 2018.

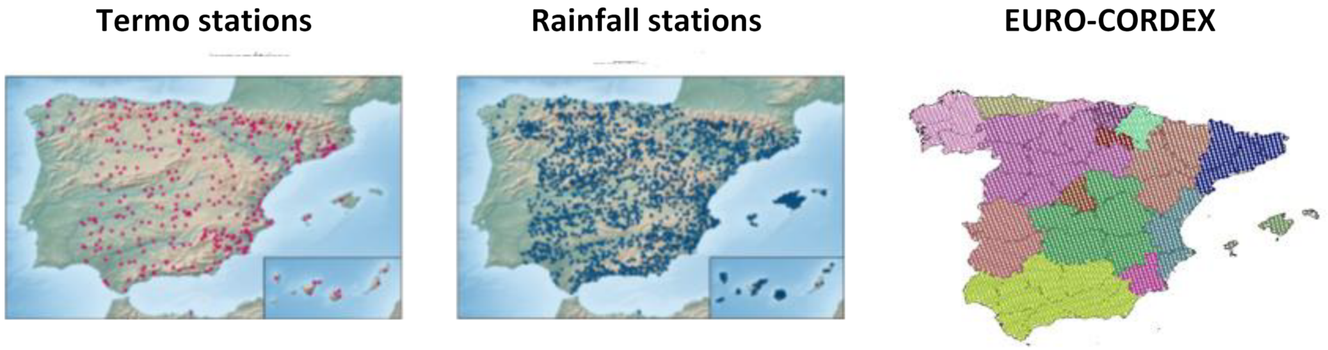


Figure 6. Spatial distribution of climatological stations used in the regionalization of temperature (374) and precipitation (2323) and spatial distribution of gridpoints of Euro-CORDEX.

mate Change Office (OECC) – responsible for the coordination, management and follow-up of the PNACC- and PNACC partners, participating in several of the groups' meetings, an area for intensive and fruitful exchange of knowledge and perspectives.

A major challenge lies in the estimation and later visualization and communication of uncertainties associated to the climate projections generation. Before addressing this problem, we emphasize that a climate projection is the simulated response of the climate system to a scenario of future emission or concentration of GHGs and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized (https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_Glossary.pdf, last access: 25 July 2018).

Uncertainty is a feature that should not be ignored or sidelined, though it is often the case that in science it is misinterpreted by the generic user as ignorance. To address this issue, AEMET has decided to use multiple realizations (ensembles) of regionalized projections, to allow an estimation of uncertainties. In particular, focusing on the available data on the AEMET portal, it is possible to estimate uncertainties associated to three sources: different emission scenarios, different global models simulations, and different regionalization techniques (see Amblar-Francés et al., 2017). In other words, we have to face with the cascade of uncertainty in climate projections, a visual scheme can be found in Wilby and Dessai (2010). They illustrate the various steps in a "top-down" assessment of climate risks, going from future society, through greenhouse gas emissions, GCM simulations, regional scenarios, impact models and local impacts to an actual adaptation response. The relative importance of the different uncertainties will depend on timescale, region, impact, relevant climate variables and other potential factors.

Vautard et al. (2013) argue that the medium term future period of 2050 corresponds to the societal demand of climatic projections useful for adaptation purposes. Regardless of the time scope of the climate projections of the range of possible future scenarios, important is the need for downscaling scenarios and projections at spatial scales that are relevant for adaptation policies. The visualization is potentially complementary to other approaches to describe the relative importance of different sources of uncertainty in climate projections (for instance, uncertainty tubes, as it was referred in Chapter 11, AR5- IPCC representing the probability distribution). The temporal scope of most of the impact studies based on such climate change projections is the end of the century. Additionally, we must account for uncertainties in the reaction of natural ecosystems and human society to estimated climate change when we want to create regional climate change projections and assessment of climate change impacts in various sectors (Giorgi et al., 2009).

Still on the subject, a key factor in the strategy has been devoted to the communication of uncertainties, taking into account that communicating uncertainties to users is not an easy task. In the selection of figures, mainly the evolution plots, we have insisted on the importance of the uncertainties, for instance in Fig. 3, RCP scenario uncertainty is not relevant for the first 50 year period for any RCP considered, but relevant at the end of the century and also depending on the RCP chosen, so this is why it is necessary to focus on the use of all available scenarios. Finally, depending on the variable users are interested in, we guide them to choose dynamical or statistical downscaling.

Focusing on the analysis of our strong points, we would stress the high density of the Spanish climatological observations network (Fig. 6). In contrast with other NMHSs, AEMET has made use for the reference climate change downscaled scenarios of not only dynamical regionalization but also statistical methods benefiting from the high density of the Spanish climatological network. Additionally, the strong links maintained with the main national users (water, energy, biodiversity, tourism) coordinated by the OECC have shaped the way climate change projections are produced, visualized and delivered.

Keeping in mind the importance of regionalized climate change projections for impact studies on climate sensitivity sectors, AEMET in the frame of PNACC-2017 will continue with the machinery of production, improving and updating them applying and analyzing different bias correction methods.

4 Summary and concluding remarks

From 2006 onwards, AEMET has routinely produced or adapted statistical and dynamical downscaled climate projections for the PNACC community (based on data from TAR, AR4, AR5, PRUDENCE, ENSEMBLES and EURO-CORDEX). There has been a steady improvement including updates associated to IPCC cycles and more products. In the future this service aims at complementing the Copernicus Climate Change Service (C3S) in terms of resolution, expression of uncertainty, visualization, tailored adjustments and reinforcement of links with national users. The permanent contact with a wide range of end-users, through e-mail, phone calls and specialized meetings, has allowed us to be fully aware of the frequently need of help with data handling and interpretation of products. The establishment of a long-term bidirectional communication permitting feedback has revealed to be essential for meeting the specific requirements from users. Our experience with users has shown us some major practical difficulties associated with the use of climate projections, such as time and space scale mismatch and the inconsistency between data needs and their availability. The lack of tools supporting decision making in a context of uncertainty prevents a wider use of downscaled climate projections. Finally, we are fully aware of the need to improve and progress on communication and dissemination actions, along with the model improvements associated to new cycles of IPCC and more adequate downscaling techniques.

Data availability. Daily and monthly data generated by AEMET and other producers are available at the AEMET web portal (https://www.aemet.es/en/serviciosclimaticos/cambio_climat).

Author contributions. The AEMET group working on regionalized climate change projections focuses its activity on climate models evaluation, downscaling algorithms and combination/synthesis of regionalized projections for impact and adaptation studies over the Spanish domain. Specifically for this paper, MAPS and PRC adapted and developed algorithms for two statistical methods (Analogs and regression, respectively). MPAF prepared all input data, made most of the calculation for downscaling of climate change projections including process monitoring, quality control and postprocessing. Supervision and final analysis of the projections obtained were conducted by MJCC and ERC, who also verified trends and compared with other published studies. Finally, MAPS selected the information presented in this paper, prepared the first draft and made most of the editorial work.

Competing interests. The authors declare that they have no conflict of interest.

Special issue statement. This article is part of the special issue "17th EMS Annual Meeting: European Conference for Applied Meteorology and Climatology 2017". It is a result of the EMS Annual Meeting: European Conference for Applied Meteorology and Climatology 2017, Dublin, Ireland, 4–8 September 2017.

Acknowledgements. Special thanks are due to people involved in CMIP5, CMIP3, TAR, PRUDENCE, ENSEMBLES, CORDEX and re-analyses projects. Thanks are due to the two anonymous reviewers for their suggestions which improve substantially the manuscript.

Edited by: Andreas Fischer
Reviewed by: two anonymous referees

References

Amblar-Francés, P., Casado-Calle, M. J., Pastor-Saavedra, M. A., Ramos-Calzado, P., and Rodríguez-Camino, E.: Guía de escenarios regionalizados de cambio climático sobre España a partir de los resultados del IPCC-AR5, available at: https://www.aemet.es/documentos/es/conocermas/recursos_en_linea/publicaciones_y_estudios/publicaciones/Guia_escenarios_AR5/Guia_escenarios_AR5.pdf (last access: 27 July 2018), 2017.

Arora, V. K., Scinocca, J. F., Boer, G. J., Christian, J. R., Denman, K. L., Flato, G. M., Kharin, V. V., Lee, W. G., and Merryfield, W. J.: Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases, Geophys. Res. Lett., 38, L05805, https://doi.org/10.1029/2010GL046270, 2011.

Bi, D., Dix, M., Marsland, S., O'Farrell, S., Rashid, H., Uotila, P., Hirst, A., Kowalczyk, E., Golebiewski, M., Sullivan, A., Yan, H., Hannah, N., Franklin, C., Sun, Z., Vohralik, P., Watterson, I., Zhou, X., Fiedler, R., Collier, M., Ma, Y., Noonan, J., Stevens, L., Uhe, P., Zhu, H., Griffies, S., Hill, R., Harris, C., and Puri, K.: The ACCESS coupled model: description, control climate and evaluation, Aust. Meteorol. Ocean., 63, 41–64, 2013.

Brunet, M., Casado, M. J., de Castro, M., Galán, P., López, J. A., Martín, J. M., Pastor, A., Petisco, E., Ramos, P., Ribalaygua, J., Rodríguez, E., Sanz, I., and Torre, L.: Generación de escenarios regionalizados de cambio climático para España, Ministerio de Medio Ambiente Medio Rural y Marino, Madrid, 165 pp., 2008.

Bruyère, C. L., Done, J. M., Holland, G. J., and Fredrick, S.: Bias corrections of global models for regional climate simulations of high-impact weather, Clim. Dynam., 43, 1847–1856, https://doi.org/10.1007/s00382-013-2011-6, 2014.

Christensen, J. H. and Christensen, O. B.: A summary of the PRUDENCE model projections of changes in European climate during this century, Climatic Change, 81, 7–30, https://doi.org/10.1007/s10584-006-9210-7, 2007.

Déqué, M., Rowell, D. P., Lüthi, D., Giorgi, F., Christensen, J. H., Rockel, B., Jacob, D., Kjellström, E., Castro, M., and van den Hurk, B.: An intercomparison of regional climate simulations for Europe: assessing uncertainties in model projections, Climatic Change, 81, 53–70, 2007.

Déqué, M., Somot, S., Sanchez-Gomez, E., Goodess, C. M., Jacob, D., Lenderink, G., and Christensen, O. B.: The spread amongst ENSEMBLES regional scenarios: regional climate models, driving general circulation models and interannual variability, Clim. Dynam., 38, 951–964, https://doi.org/10.1007/s00382-011-1053-x, 2012.

Domínguez, M., Romera, R., Sánchez, E., Fita, L., Fernández, J., Jiménez-Guerrero, P., Montávez, J. P., Cabos, W. D., Liguori, G., and Gaertner, M. A.: Present climate precipitation and temperature extremes over Spain from a set of high resolution RCM, Clim. Res., 58, 149–164, https://doi.org/10.3354/cr01186, 2013.

Donner, L. J., Wyman, B. L., Hemler, R. S., Horowitz, L. W., Ming, Y., Zhao, M., Golaz, J.-C., Ginoux, P., Lin, S.-J., Schwarzkopf, M. D., Austin, J., Alaka, G., Cooke, W. F., Delworth, T. L., Freidenreich, S. M., Gordon, C. T., Griffies, S. M., Held, I. M., Hurlin, W. J., Klein, S. A., Knutson, T. R., Langenhorst, A. R., Lee, H.-C., Lin, Y., Magi, B. I., Malyshev, S. L., Milly, P. C. D., Naik, V., Nath, M. J., Pincus, R., Ploshay, J. J., Ramaswamy, V., Seman, C. J., Shevliakova, E., Sirutis, J. J., Stern, W. F., Stouffer, R. J., Wilson, R. J., Winton, M., Wittenberg, A. T., and Zeng, F.: The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component AM3 of the GFDL global coupled model CM3, J. Climate, 24, 3484–3519, 2011.

Dufresne, J. L., Foujols, M. A., Denvil, S., Caubel, A., Marti, O., Aumont, O., Balkanski, Y., Bekki, S., Bellenger, H., Benshila, R., Bony, S., Bopp, L., Braconnot, P., Brockmann, P., Cadule, P., Cheruy, F., Codron, F., Cozic, A., Cugnet, D., de Noblet, N., Duvel, J.-P., Ethe, C., Fairhead, L., Fichefet, T., Flavoni, S., Friedlingstein, P., Grandpeix, J.-Y., Guez, L., Guilyardi, E., Hauglustaine, D., Hourdin, F., Idelkadi, A., Ghattas, J., Joussaume, S., Kageyama, M., Krinner, G., Labetoulle, S., Lahellec, A., Lefebvre, M.-P., Lefevre, F., Levy, C., Li, Z. X., Lloyd, J., Lott, F., Madec, G., Mancip, M., Marchand, M., Masson, S., Meurdesoif, Y., Mignot, J., Musat, I., Parouty, S., Polcher, J., Rio, C., Schulz, M., Swingedouw, D., Szopa, S., Talandier, C., Terray, P., Viovy, N., and Vuichard, N.: Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5, Clim. Dynam., 40, 2123–2165, 2013.

Fowler, H. J., Blenkinsop, S., and Tebaldi, C.: 2007. Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling, Int. J. Climatol., 27, 1547–1578, https://doi.org/10.1002/joc.1556, 2007.

Giorgetta, M. A., Jungclaus, J., Reick, C. H., Legutke, S., Bader, J., Böttinger, M., Brovkin, V., Crueger, T., Esch, M., Fieg, K., Glushak, K., Gayler, V., Haak, H., Hollweg, H.-D., Ilyina, T., Kinne, S., Kornblueh, L., Matei, D., Mauritsen, T., Mikolajewicz, U., Mueller, W., Notz, D., Pithan, F., Raddatz, T., Rast, S., Redler, R., Roeckner, E., Schmidt, H., Schnur, R., Segschneider, J., Six, K. D., Stockhause, M., Timmreck, C., Wegner, J., Widmann, H., Wieners, K.-H., Claussen, M., Marotzke, J., and Stevens, B.: Climate and carbon cycle changes from 1850 to 2100 in MPI-ESM simulations for the Coupled Model Intercomparison Project phase 5, J. Adv. Model. Earth Sy., 5, 572–597, https://doi.org/10.1002/jame.20038, 2013.

Giorgi, F.: Climate change hot spots, Geophys. Res. Lett., 33, L08707, https://doi.org/10.1029/2006GL025734, 2006.

Giorgi, F., Jones, C., and Asrar, G.: Addressing climate information needs at the regional level: The cordex framework, WMO Bull., 58, 175–183, 2009.

Gordon, H. B., Rotstayn, L. D., McGregor, J. L., Dix, M. R., Kowalczyk, E. A., O'Farrell, S. P., Waterman, L. J., Hirst, A. C., Wilson, S. G., Collier, M. A., Watterson, I. G., and Elliott, T. I.: The CSIRO Mk3 climate system model, CSIRO Atmospheric Research Technical Paper No. 60, CSIRO, Australia, 2002.

Gutiérrez, J., San-Martin, D., Brands, S., Manzanas, R., and Herrera, S.: Reassessing statistical downscaling techniques for their robust application under climate change conditions, J. Climate, 26, 171–188, https://doi.org/10.1175/JCLI-D-11-00687.1, 2013.

Gutiérrez, J. M., Maraun, D., Widman, M., Huth, R., Hertig, E., Benestad, R., Roessler, O., Wibig, J., Wilcke, R., Kotlarski, S., San Martin, D., Herrera, S., Bedia, J., Casanueva, A., Manzanas, R., Iturbide, M., Vrac, M., Dubrovsky, M., Ribalaygua, J., Portoles, J., Raty, O., Raisanen, J., Hingray, B., Raynaud, D., Casado, M. J., Ramos, P., Zerenner, T., Turco, M., Bosshard, T., Stepanek, P., Bartholy, J., Pongracz, R., Keller, D. E., Fischer, A. M., Cardoso, R. M., Soares, P. M. M., Czernecki, B., and Page, C.: An intercomparison of a large ensemble of statistical downscaling methods over Europe: Results from the VALUE perfect predictor cross-validation experiment, Int. J. Climatol., https://doi.org/10.1002/joc.5462, 2018.

Hurrell, J. W., Holland, M. M., Gent, P. R., Ghan, S., Kay, J. E., Kushner, P. J., Lamarque, J.-F., Large, W. G., Lawrence, D., Lindsay, K., Lipscomb, W. H., Long, M. C., Mahowald, N., Marsh, D. R., Neale, R. B., Rasch, P., Vavrus, S., Vertenstein, M., Bader, D., Collins, W. D., Hack, J. J., Kiehl, J., and Marshall, S.: The community earth system model: a framework for collaborative research, B. Am. Meteorol. Soc., 94, 1339–1360, 2013.

IPCC Climate Change: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P. M., Cambridge University Press, Cambridge, UK and New York, NY, USA, 1535 pp., available at: http://www.ipcc.ch/report/ar5/ (last access: 25 May 2018), 2013.

Jacob, D., Barring, L., Christensen, O. B., Christensen, J. H., Castro, M., Déqué, M., Giorgi, F., Stefan Hagemann, S., Hirschi , M., Jones, R., Kjellström, E., Lenderink, G., Rockel, B., Sánchez, E., Schär, C., Seneviratne, S. I., Somot, S., van Ulden, A., and van den Hurk, B.: An inter-comparison of regional climate models for Europe: model performance in present-day climate, Clim. Change, 81, 31–52, https://doi.org/10.1007/s10584-006-9213-4, 2007.

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L. M., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., van Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J. F., Teichmann, C., Valentini, R., Vautard, R., Weber, B., and Yiou, P.: EURO-CORDEX: new high-resolution climate change projections for European impact research, Reg. Environ. Change, 14, 563–578, https://doi.org/10.1007/s10113-013-0499-2, 2014.

Ji, D., Wang, L., Feng, J., Wu, Q., Cheng, H., Zhang, Q., Yang, J., Dong, W., Dai, Y., Gong, D., Zhang, R.-H., Wang, X., Liu, J., Moore, J. C., Chen, D., and Zhou, M.: Description and basic evaluation of Beijing Normal University Earth System Model (BNU-ESM) version 1, Geosci. Model Dev., 7, 2039–2064, https://doi.org/10.5194/gmd-7-2039-2014, 2014.

Jiménez-Guerrero, P., Montávez, J. P., Domínguez, M., Romera, R., Fita, L., Fernández, J., Cabos, W. D., Liguori, G., and Gaertner, M. A.: Mean fields and interannual variability in RCM simulations over Spain: the ESCENA project, Clim. Res., 57, 201–220, https://doi.org/10.3354/cr01165, 2013.

Maraun, D., Wetterhall, F., Ireson, A. M., Chandler, R. E., Kendon, E. J., Widmann, M., Brienen, S., Rust, H. W., Sauter, T., Themessl, M., Venema, V. K. C., Chun, K. P., Goodess, C. M., Jones, R. G., Onof, C., Vrac, M., and Thiele-Eich, I.: Precipitation downscaling under climate change: recent developments to bridge the gap between dynamical models and the end user, Rev. Geophys., 48, RG3003, https://doi.org/10.1029/2009RG000314, 2010.

Martin, G. M., Bellouin, N., Collins, W. J., Culverwell, I. D., Halloran, P. R., Hardiman, S. C., Hinton, T. J., Jones, C. D., McDonald, R. E., McLaren, A. J., O'Connor, F. M., Roberts, M. J., Rodriguez, J. M., Woodward, S., Best, M. J., Brooks, M. E., Brown, A. R., Butchart, N., Dearden, C., Derbyshire, S. H., Dharssi, I., Doutriaux-Boucher, M., Edwards, J. M., Falloon, P. D., Gedney, N., Gray, L. J., Hewitt, H. T., Hobson, M., Huddleston, M. R., Hughes, J., Ineson, S., Ingram, W. J., James, P. M., Johns, T. C., Johnson, C. E., Jones, A., Jones, C. P., Joshi, M. M., Keen, A. B., Liddicoat, S., Lock, A. P., Maidens, A. V., Manners, J. C., Milton, S. F., Rae, J. G. L., Ridley, J. K., Sellar, A., Senior, C. A., Totterdell, I. J., Verhoef, A., Vidale, P. L., and Wiltshire, A.: The HadGEM2 family of Met Office Unified Model climate configurations, Geosci. Model Dev., 4, 723–757, https://doi.org/10.5194/gmd-4-723-2011, 2011.

Morata-Gasca, A.: Guía de escenarios regionalizados de cambio climático sobre España a partir de los resultados del IPCC-AR4, available at: http://www.aemet.es/documentos/es/conocermas/publicaciones/Guia_IPCC/Guia_IPCC.pdf (last access: 25 May 2018), 2014.

Petisco de Lara, S. E.: Método de regionalización de precipitación basado en análogos. Explicación y Validación, Nota Técnica 3A, Área de Evaluación y Modelización del Cambio Climático, AEMET, Madrid, Spain, 2008a.

Petisco de Lara, S. E.: Método de regionalización de temperatura basado en análogos. Explicación y Validación, Nota Técnica 3B, Área de Evaluación y Modelización del Cambio Climático, AEMET, Madrid, Spain, 2008b.

Rummukainen, M.: State-of-the-art with Regional Climate Models, Wires. Clim. Change, 1, 82–96, 2010.

Scoccimarro, E., Gualdi, S., Bellucci, A., Sanna, A., Fogli, P. G., Manzini, E., Vichi, M., Oddo, P., and Navarra, A.: Effects of Tropical Cyclones on Ocean Heat Transport in a High Resolution Coupled General Circulation Model, J. Climate, 24, 4368–4384, 2011.

Trzaska, S. and Schnarr, E.: A Review of Downscaling Methods for Climate Change Projections: African and Latin American Resilience to Climate Change (ARCC), available at: http://www.ciesin.org/documents/Downscaling_CLEARED_000.pdf (last access: 28 May 2018), 2014.

van der Linden, P. and Mitchell, J. F. B.: ENSEMBLES: Climate Change and its impacts: summary of research and results from the ENSEMBLES project, Met Office Hadley Centre, Exeter EX1 3PB, UK, 160, 2009.

Vautard, R., Gobiet, A., Jacob, D., Belda, M., Colette, A., Déqué, M., Fernández, J., García-Díez, M., Goergen, K., Güttler, I., Halenka, T., Karacostas, T., Katragkou, E., Keuler, K., Kotlarski, S., Mayer, S., van Meijgaard, E., Nikulin, G., Patarcic, M., Scinocca, J., Sobolowski, S., Suklitsch, M., Teichmann, C., Warrach-Sagi, K., Wulfmeyer, V., and Yiou, P.: The simulation of European heat waves from an ensemble of regional climate models within the EURO-CORDEX project, Clim. Dynam., 41, 2555–2575, https://doi.org/10.1007/s00382-013-1714-z, 2013.

Voldoire, A., Sanchez-Gomez, E., and Mélia, D. S., Decharme, B., Cassou, C., Sénési, S., Valcke, S., Beau, I., Alias, A., Chevallier, M., Déqué, M., Deshayes, J., Douville, H., Fernandez, E., Madec, G., Maisonnave, E., Moine, M. P., Planton, S., Saint-Martin, D., Szopa, S., Tyteca, S., Alkama, R., Belamari, S., Braun, A., Coquart, L., and Chauvin, F.: The CNRM-CM5. 1 global climate model: description and basic evaluation, Clim. Dynam., 40, 2091–2121, 2013.

Volodin, E. M., Dianskii, N. A., and Gusev, A. V.: Simulating present-day climate with the INMCM4. 0 coupled model of the atmospheric and oceanic general circulations, IZV Atmos. Ocean. Phy.+, 46, 414–431, 2010.

Watanabe, S., Hajima, T., Sudo, K., Nagashima, T., Takemura, T., Okajima, H., Nozawa, T., Kawase, H., Abe, M., Yokohata, T., Ise, T., Sato, H., Kato, E., Takata, K., Emori, S., and Kawamiya, M.: MIROC-ESM 2010: model description and basic results of CMIP5-20c3m experiments, Geosci. Model Dev., 4, 845–872, https://doi.org/10.5194/gmd-4-845-2011, 2011.

Weare, B. C., Cagnazzo, C., Fogli, P. G., Manzini, E., and Navarra, A.: Madden-Julian Oscillation in a climate model with a well-resolved stratosphere, J. Geophys. Res.-Atmos., 117, D01103, https://doi.org/10.1029/2011JD016247, 2012.

Wilby, R. L., Charles, S. P., Zorita, E., Timbal, B., Whetton, P., and Mearns, L. O.: Guidelines for use of climate scenarios developed from statistical downscaling methods, Supporting material of the Intergovernmental Panel on Climate Change, available from the DDC of IPCC TGCIA, 27, TGICA-9: 24–25 September 2004, Laxenburg, Austria, 2004.

Wilby, R. L. and Dessai, S.: Robust adaptation to climate change, Weather, 65, 180–185, 2010.

Wu, T., Li, W., Ji, J., Xin, X., Li, L., Wang, Z., Zhang, Y., Li, J., Zhang, F., Wei, M., Shi, X., Wu, F., Zhang, L., Chu, M., Jie, W., Liu, Y., Wang, F., Liu, X., Li, Q., Dong, M., Liang, X., Gao, Y., and Zhang, J.: Global carbon budgets simulated by the Beijing Climate Center Climate System Model for the last century, J. Geophys. Res.-Atmos., 118, 4326–4347, https://doi.org/10.1002/jgrd.50320, 2013.

Xiao-Ge, X., Tong-Wen, W., Jiang-Long, L., Zai-Zhi, W., Wei-Ping, L., and Fang-Hua, W.: How well does BCC_CSM1.1 reproduce the 20th century climate change over China?, Atmospheric and Oceanic Science Letters, 6, 21–26, 2013.

Yukimoto, S., Adachi, Y., Hosaka, M., Sakami, T., Yoshimura, H., Hirabara, M., Tanaka, T. Y., Shindo, E., Tsujino, H., Deushi, M., Mizuta, R., Yabu, S., Obata, A., Nakano, H., Koshiro, T., Ose, T., and Kitoh, A.: A new global climate model of the Meteorological Research Institute: MRI-CGCM3 – model description and basic performance, J. Meteorol. Soc. Jpn., 90, 23–64, https://doi.org/10.2151/jmsj.2012-A02, 2012.