Strategy for generation of climate change projections feeding Spanish impact community

María Pilar Amblar-Francés¹, María Asunción Pastor-Saavedra², María Jesús Casado-Calle², Petra Ramos-Calzado¹, and Ernesto Rodríguez-Camino²

¹AEMET, Sevilla, 41092, Spain
²AEMET, Madrid, 28040, Spain

Correspondence: María Asunción Pastor-Saavedra (mpastors@aemet.es)

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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.

| Year | Event Description | Related Documents |
|------|-------------------|-------------------|
| 2006 | 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. |  |
| 2008 | First delivery of periodical revision of regional projections with the best and current data available from GCMs, observations and regionalization techniques (TAR, PRUDENCE) | 1st Document Brunet et al. (2008) |
| 2014 | 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 Ministry of Environment). | 2nd Document Morata-Gasca (2014) |
| 2017 | Third delivery of Regional projections by AEMET. Statistical methods of regionalization (AR5) & dynamical regionalized projections from CORDEX Projects. | 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-
Intermediate 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)                  | Ji et al. (2014)                |
|                | Beijing Normal University, China                                            |                                 |
| CanESM2        | Canadian Centre for Climate Modelling and Analysis (CCMa), Canada           | 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 Méteorologiques/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 EUROCORDEX 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.,
Analog Regression CORDEX

Autumn precipitation RCP8.5 (2081–2100)

**Figure 2.** Change of (a) autumn mean precipitation (%) and (b) uncertainty (±σ) for RCP8.5 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.

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
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.
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 needed 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, downsampling 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 downsampling 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.

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