Video resume

Chapter one

Scientific approach to climate change

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Abstract

This chapter provides an overview of the state of the art of the scientific knowledge about climate change. Based on the work done by the Intergovernmental Panel on Climate Change (IPCC), it analyses the concept of climate change, its causes, attributions and evidences, as well as its consequences. This analysis is placed within a general risk framework, which is considered the best to analyse the risks that climate change poses to security, defence, and the Armed Forces.

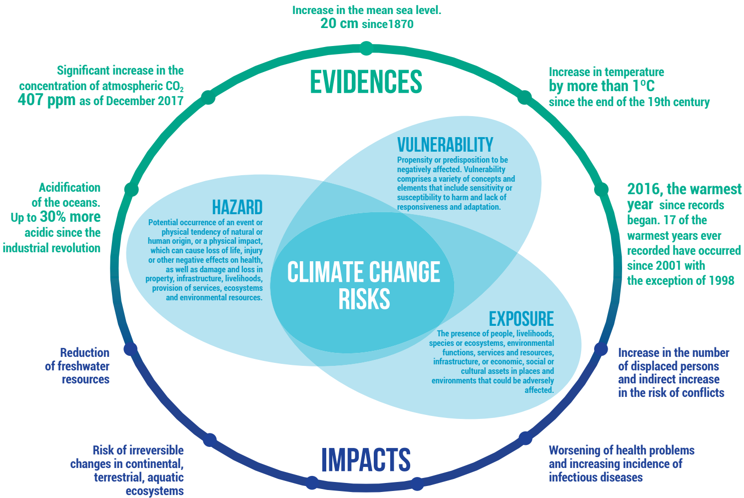
Keywords

Climate change, IPCC, greenhouse gases.

SCIENTIFIC APPROACH TO CLIMATE CHANGE

CLIMATE CHANGE DEFINITION:
Climate changes directly or indirectly attributable to human activity that alter the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

ARTICLE 1 OF THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC) 1992



Increase in the mean sea level. **20 cm** since1870

Increase in temperature **by more than 1°C** since the end of the 19th century

2016, the warmest year since records began. 17 of the warmest years ever recorded have occurred since 2001 with the exception of 1998

Significant increase in the concentration of atmospheric CO_2 **407 ppm** as of December 2017

Acidification of the oceans. Up to **30% more** acidic since the industrial revolution

EVIDENCES

VULNERABILITY

Propensity or predisposition to be negatively affected. Vulnerability comprises a variety of concepts and elements that include sensitivity or susceptibility to harm and lack of responsiveness and adaptation.

HAZARD

Potential occurrence of an event or physical tendency of natural or human origin, or a physical impact, which can cause loss of life, injury or other negative effects on health, as well as damage and loss in property, infrastructure, livelihoods, provision of services, ecosystems and environmental resources.

CLIMATE CHANGE RISKS

EXPOSURE

The presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social or cultural assets in places and environments that could be adversely affected.

IMPACTS

Reduction of freshwater resources

Increase in the number of displaced persons and indirect increase in the risk of conflicts

Risk of irreversible changes in continental, terrestrial, aquatic ecosystems

Worsening of health problems and increasing incidence of infectious diseases

Immersion, flooding and erosion of coastal systems and low-lying areas

Food safety. Negative impact on the production of wheat, rice and corn in tropical and temperate regions

STRATEGIES FOR MITIGATION AND ADAPTATION TO CLIMATE CHANGE

- IMPROVEMENT IN THE EVALUATION OF CLIMATE PHENOMENA
- SUBSTANTIAL REDUCTION OF EMISSIONS IN THE COMING DECADES
- IMPROVEMENT IN SAVINGS AND ENERGY EFFICIENCY
- NEED FOR INTEGRATED RESPONSES THAT LINK ADAPTATION AND MITIGATION WITH OTHER SOCIAL OBJECTIVES
- INTEGRATED PLANNING
- DEVELOPMENT OF STANDARDS AND SPECIFIC ADAPTATION PLANS

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Introduction

This chapter summarises the scientific approach to climate change. In other words, it presents a synthesis of the knowledge that science has about climate change and its impact on natural and socio-economic systems, as a starting point to understand the relationship between climate change, security, defence and the armed forces.

Much of the information comes from the synthesis of the reports of the three working groups (WG) of the Intergovernmental Panel on Climate Change (IPCC) and correspond to the fifth cycle (AR5) prepared by said Group or Panel since its creation in the early 90s. This source is undoubtedly the most rigorous in scientific terms and has also been submitted to the scrutiny of evaluators and governments from more than 190 countries. This initial information has been accompanied by some of the recently published advances and specific information for Spain.

The IPCC is the main international body for the assessment of climate change. It was created by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) in 1988 to provide a scientific overview of the current state of knowledge about climate change and its potential environmental and socio-economic impacts.

The IPCC is a scientific body and, as such, provides comprehensive assessments of the state of scientific, technical and socio-economic knowledge on climate change, its causes, possible impacts and response strategies. But it is also an intergovernmental body, and all member countries of the United Nations and WMO can be part of it. Currently, 195 countries are members of the IPCC.

The IPCC is organised into three working groups and a special group (see figure 1). WGI addresses the physical basis of climate change; WG II, the

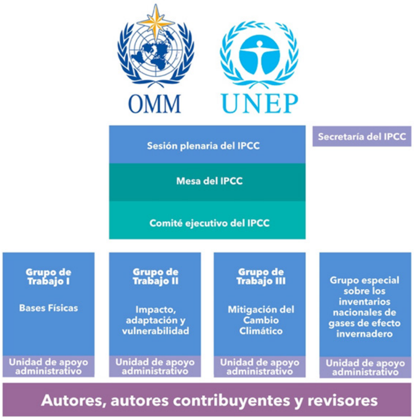


Figure 1. Structure of the IPCC.

impact of climate change and adaptation; and finally the WG addresses the mitigation of climate change. In addition, there is a special additional group dedicated to national inventories of greenhouse gases. Its objective is to formulate and refine a methodology for calculating and reporting national emissions and absorptions of greenhouse gases.

Thousands of scientists from around the world contribute to the work of the IPCC on a voluntary basis as authors, contributing authors and reviewers.

Since its inception, the IPCC has prepared five activity reports. Each new report gives the advances of science with respect to the previous report and also establishes in what areas new research is necessary. Recently, the 5th report (AR5) has been presented, which places special emphasis on the evaluation of the socio-economic aspects of climate change and its consequences for sustainable development, regional aspects, risk management and the preparation of a response through adaptation and mitigation, also showing more than 100 signs of the impacts produced by climate change. The sixth cycle (AR6) has just begun and is expected to see the light in 2020.

Brief description of the phenomenon of climate change

Climate change and its causes

Climate change refers to changes in the state of the climate that can be identified through changes in time, average values and/or variability of its properties. These changes persist typically for decades or longer periods.

Climate change can be caused by internal natural processes or by external forcing such as modulation in solar cycles or volcanic eruptions or by persistent man-induced changes in the composition of the atmosphere or in land uses. In this regard, it should be noted that the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change in its article 1 as «climate changes directly or indirectly attributable to human activity that alter the composition of the global atmosphere and that are superimposed on the natural variability observable in equivalent periods of time». Therefore, UNFCCC clearly distinguishes between, on the one hand, climate change attributable to man, which includes, among others, what is commonly known as global warming and, on the other hand, climatic variability attributable to natural causes.

In this sense, according to AR5 the warming in the climate system is unequivocal, and since the 1950s many of the observed changes have been unprecedented in recent decades to millennia. The atmosphere and the ocean have warmed up, the volumes of snow and ice have decreased and the sea level has risen.

In terms of the physical explanation of the problem, there is general agreement in the scientific community that the fundamental cause of global warming is the result of the expansion of the greenhouse effect, which is a process in which the thermal radiation emitted by the Earth is trapped in the atmosphere due to the presence of a set of gases known as greenhouse gases (GHGs). Solar radiation passes through the atmosphere and heats the Earth's surface. Part of this heat is radiated back. Much of this heat is absorbed by the GHG molecules and radiated in all directions, causing a warming of the Earth's surface and the lower part of the atmosphere. One of the characteristics of these gases is that they remain active in the atmosphere for a long time, which is why they are usually called long-stay gases. Among these gases are: water vapour, methane, nitrous oxide, carbon dioxide and chlorofluorocarbons (CFC).

Water vapour is the most abundant, highlighting its feedback with the weather. As the Earth warms, the water vapour increases and consequently the probability of cloudiness and rainfall. Carbon dioxide is a minor component of the atmosphere, but it is very important since its release into the atmosphere is the product of natural processes such as breathing or volcanic eruptions, but also the product of human activities such as deforestation, change in land uses and the combustion of fossil fuels.

Man has contributed to increasing the concentration of CO_2 in the atmosphere by more than a third since the Industrial Revolution began. This is, without a doubt, the long-stay GHG that is most contributing to climate change. Methane is a hydrocarbon that is also the result of natural processes and human activities, including the decomposition of waste in landfills, agriculture, and especially rice cultivation, as well as the digestion of ruminants and the management of manure in livestock. Nitrous oxide is also closely linked to agricultural activities, especially to the use of commercial and organic fertilisers and the combustion of fossil fuels or biomass. Finally, CFCs are synthetic compounds of industrial origin with different applications. Although they are also considered GHG, their emission is currently firmly controlled thanks to international agreements to avoid their contribution to the destruction of the ozone layer.

The latest IPCC report says that human influence on the climate system is clear, and also shows that recent anthropogenic emissions of greenhouse gases are the highest in history.

Among other conclusions, the report states that anthropogenic emissions of greenhouse gases have increased since the pre-industrial era, largely as a result of economic and demographic growth, and are now greater than ever. This has resulted in atmospheric concentrations of carbon dioxide, methane and nitrous oxide never previously recorded, at least, in the last 800,000 years. The effects of emissions, as well as other anthropogenic factors, have been detected throughout the climate system and it is highly probable that they have been the dominant cause of the warming observed since the second half of the 20th century.

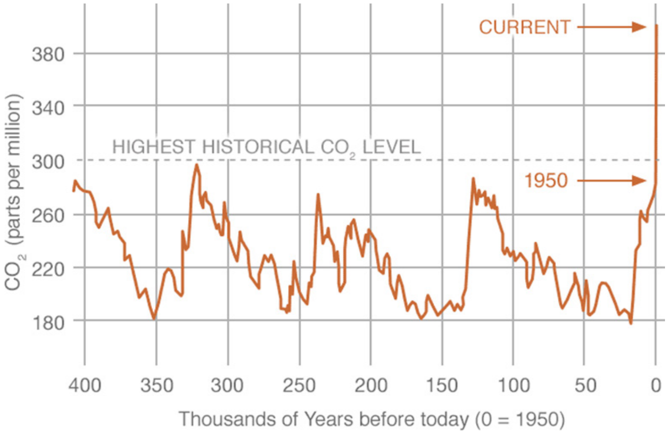
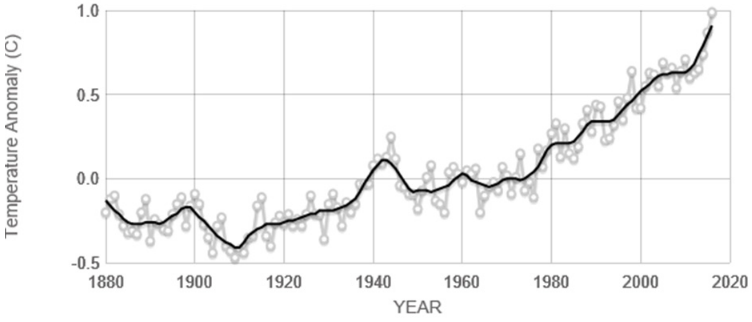


Figure 2: Source: NASA. Evolution of the concentration of CO2 in the atmosphere in parts per million in the last 400,000 years.

Observed signs and impacts

In recent decades, climate changes have caused impacts on natural and human systems on all continents and in all oceans. The impacts are due to observed climate change, regardless of its cause, which indicates the sensitivity of natural and human systems to climate change.

One of the most important impacts observed is the increase in the global mean surface temperature. Figure 3 shows the changes in temperature with respect to the average of the base period 1951-1958. As can be seen, up to 2016, there was an increase of 0.99ºC, and more than one degree since the end of the NINETEENTH century. Seventeen of the hottest years recorded in the 136 years records have been held have occurred since 2001, with the exception of 1998. 2016 was the hottest year registered so far. (Source: NASA/GISS).



Source: climate.nasa.gov

Figure 3. Source: NASA. Evolution of the temperature anomaly (difference with respect to the reference period 1951-1958) observed between 1880 and 2017.

Another indicator of climate change is the increase in the mean sea level, caused mainly by two factors linked to global warming: the increase of water in the ocean basins due to the loss of ice masses in glaciers and at the polar ice caps and the volumetric expansion of sea water due to the increase in its temperature.

Since 1993, when satellite measurements started to be taken, the mean sea level has increased by 84.8 mm (to 7/2017) at a rate of 3.4 mm/year (Source: NASA).

Figure 4 shows the reconstruction of the increase of the mean sea level from tide gauges on the coast, which allows a longer series to be obtained. As can be seen, the rise in the mean sea level since 1870 shows a certain variability, but with a clear long-term trend that has led to a rise of 20 cm from 1870 to today.

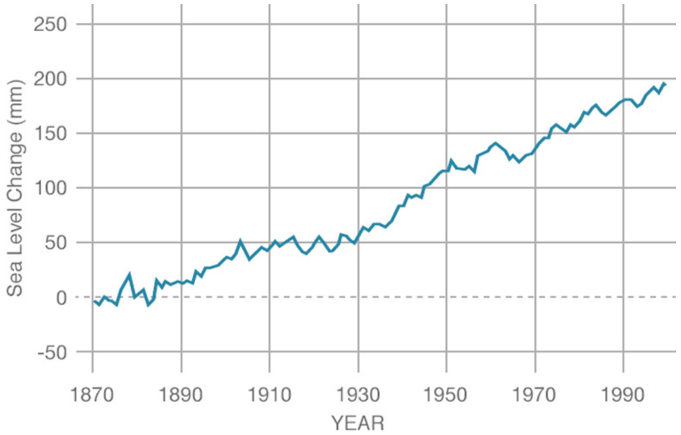


Figure 4: Source NASA/CSIRO: Evolution in mm of the average global sea level between 1870 and the present, obtained from tide gauges on the coast.

Both in the temperature and the sea level, the represented indicator is the result of a global spatial average. It is therefore necessary to consider that in different geographical areas of the world the value of the increases/decreases in temperature and sea level have reached very different values.

But climate change does not only affect average values. Since about 1950 changes have been observed in many extreme weather and climate phenomena. Some of these changes have been linked to anthropogenic influence, such as the fall in the number of extreme cold temperatures, the increase in extreme warm temperatures, the rise in maximum sea levels and the larger number of intense rainfalls in various regions.

This effect is easy to understand if, for example, we think that the displacement of the mean values of the temperature to the right or left of its statistical distribution leads to an increase in the number of extreme events or their intensity. This therefore modifies the number and intensity of cold or heat waves in a given region.

Likewise, the total sea level on the coast, which is the sum of the mean sea level and other short-term components, is increased by the effect of the increase in the average level, resulting in an increase in the frequency of extreme flooding events.

But besides the physical variables, climate change has brought important impacts on the natural and socio-economic systems that have been observed and documented during the last decade. For example, it has been seen that in many regions changes in precipitation or loss of snow pack and ice are altering the hydrological systems, which affects water resources in terms of quantity. Likewise, there is evidence that many terrestrial, freshwater and marine species have modified their geographical distribution areas, seasonal activities, migratory patterns, abundances and interactions with other species in response to the ongoing climate change.

In addition, in this last decade impacts on the socio-economic system have been identified that have also been attributed to climate change.

Figure 5, published in the SPM of the last report of the IPCC, AR5, illustrates a substantially large number of impacts identified in recent decades that are attributable to climate change through scientific evidence supported by publications. The symbols indicate categories of impacts attributed to climate change, the relative contribution of climate change (large or small) to the observed impact and the level of confidence in attribution.

Among the impacts derived from extreme phenomena associated with the climate (for example: heat waves, droughts, floods and forest fires), there is the alteration of ecosystems, the disorganisation of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and the consequences for mental health and human well-being. The greatest warming occurs at higher latitudes than in the tropics, where the pattern of precipitation changes is very complex. Among the observed impacts, a large number are due to the combination of changes in temperature and rainfall. This is the case, for example, in Africa, where glaciers located in the east of the continent are melting, river discharge is falling in the west, and fires are increasing at Kilimanjaro, among others.

The increase in mean sea level is of particular concern in the State Islands (SIDS), where deterioration of coastal vegetation and degradation of groundwater as a cause of saline intrusion are occurring, and flooding and coastal erosion are increasing.

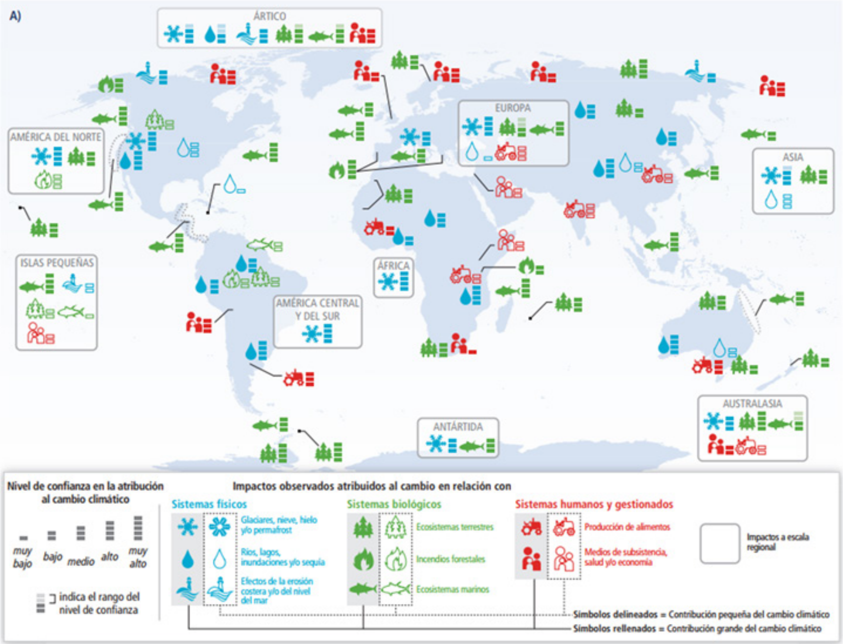


Figure 5. Global patterns of observed climate change impacts (IPCC, 2014).

Some of the impacts detected in Europe are the changes in extreme rainfalls, the alterations in the distribution of species, and the effects that warming is producing on the health and lifestyle of the population of the northern part of the continent.

Figure 5 shows a pattern of heterogeneous climate change across the entire planet as a whole. Some natural and human systems (and the regions in which they are found) are also more vulnerable to climate change than others.

Although the observed records are very heterogeneous in nature since in the countries with lower incomes report fewer impacts than the richer countries, this does not mean that they actually suffer fewer impacts. There are also fewer observations in remote areas, such as deep ocean or mountainous areas with scattered populations and deserts.

The risks of climate change

In order to understand the risks derived from climate change and its possible future evolution, a conceptual framework must be established that allows us to analyse the risk and its consequences from its components. The IPCC therefore introduced, in the AR5 and previously in the Special Report on Extreme Events (SREX), the framework described in figure 6 that integrates the approach followed in the analysis of disaster risks with that corresponding to climate change.

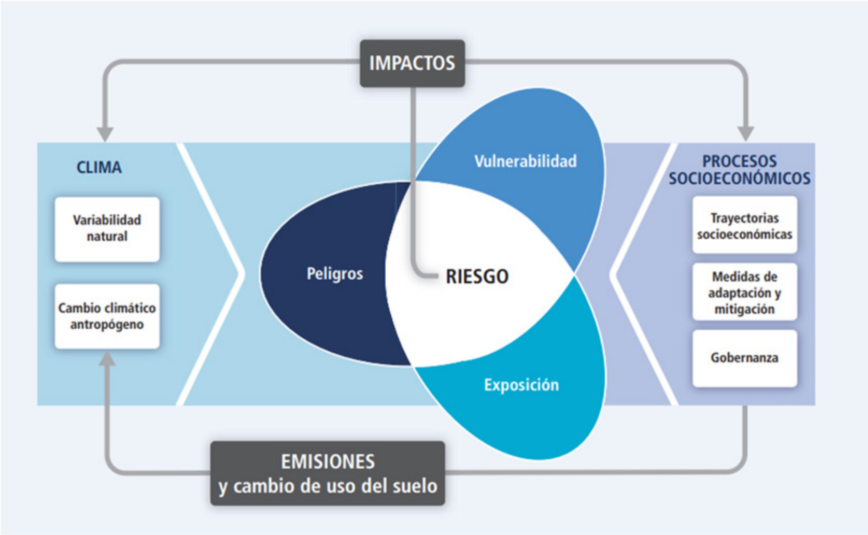


Figure 6. General framework for the analysis of risks derived from climate change (IPCC, 2014).

This scheme allows the analysis of the risks derived from climate change for multiple or individual impacts and their application in different strategic sectors such as water, energy, security, defence, infrastructures or in natural areas such as ecosystems, river basins or on the coast. Likewise, it allows the synergistic effects that climatic forcings have on the risk to be visualised together with those that occur in exposure or vulnerability. Finally, it offers the chance to identify solutions acting on each of the components of the risk individually or through joint mitigation and/or adaptation actions that reduce the risk.

Thus, for example, with flood impacts, the increase in the mean sea level represents an increase in the danger and consequently in the risk to our naval bases, since it contributes to increasing the probability of events that exceed the design limits of existing naval infrastructures. However, this risk will be even greater if the infrastructures, equipment, facilities or assets are deployed and developed in low or little protected areas or the number of assets increases (exposure increase). Also, if existing or future assets are not adequately maintained or measures are not taken to increase their resilience to flooding, there is an increase in vulnerability. Each of these effects individually produces an increased risk in the face of climate change, but their joint action increases the risk even more. In this case, while sea level rise can only be addressed through mitigation, reduction of exposure or vulnerability can be addressed through adaptation.

Also, if the operations of the armed forces are going to take place in geographical regions where an increase in average temperatures and in the frequency and intensity of the extreme events (heat waves) is projected, the reduction of the risks on our units deployed in the region can only be addressed through measures that reduce their exposure and vulnerability to extreme temperatures, since the increase in temperature can only be combated through mitigation.

Therefore, to understand the potential effects of climate change on security and defence, it is necessary to analyse in detail how each of the components of risk can evolve over time and how they can affect both assets and operations linked to these sectors.

The adequacy of placing the consequences of climate change on defence and security in the framework of risk, leads us at this point to consider it necessary to include a set of definitions that will serve to conceptualise the approach to the risks derived from climate change (adapted from IPCC, 2014).

Hazard: potential occurrence of an event or physical tendency of natural or human origin, or a physical impact, which can cause loss of life, injury or other negative effects on health, as well as damage and loss in property, infrastructure, livelihoods, provision of services, ecosystems and environmental resources.

Exposure: the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social or cultural assets in places and environments that could be adversely affected.

Vulnerability: propensity or predisposition to be negatively affected. Vulnerability comprises a variety of concepts and elements that include sensitivity or susceptibility to harm and lack of responsiveness and adaptation.

Impacts: effects on natural and human systems of extreme weather and climate events, and climate change. The impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructures due to the interaction of climatic changes or dangerous weather phenomena that occur in a specific period of time, and to the vulnerability of the companies or the systems exposed to them. The impacts are also called consequences and results. The impacts of climate change on geophysical systems, including floods, droughts and sea level rise, are a subset of the impacts called physical impacts.

Risk: potential consequences in which something of value is in danger with an uncertain outcome, recognising the diversity of values. Often the risk is represented as the probability of occurrence of dangerous events or trends multiplied by the impacts in case such events or trends occur. Risks result from the interaction of vulnerability, exposure and danger (see Figure 6).

Due to their transcendence in the expression of possible solutions to reduce risks, two important concepts such as adaptation and resilience are also introduced here.

Adaptation: process of adjustment to real or projected climate and its effects. In human systems, adaptation seeks to moderate or avoid damage or take advantage of beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to the projected climate and its effects.

Resilience: the ability of social, economic and environmental systems to cope with a dangerous event, trend or disturbance by responding or reorganising to maintain their essential function, identity and structure, while preserving the capacity for adaptation, learning and transformation.

Analysing the derived risks that climate change can bring in the future over any sector or geographical area, it is necessary to determine the evolution of each of the components of the risk, which is what we call projections. In the next section we analyse the scientific knowledge of the projections, fundamentally, of the contributions of the hazard to the risk.

Climate change projections

The climate models

This section mainly analyses the hazard projections. As shown in figure 6, the danger is entirely conditioned by climate, specifically by its natural variability and especially by climate change which in turn is conditioned by the socio-economic trajectories of the future and their impact, for example, on the uses of land, energy policy or GHG reduction agreements that are reached and implemented in the coming decades.

The continuous emission of greenhouse gases will cause greater warming and lasting changes in all components of the climate system, which will increase the likelihood of serious, widespread and irreversible impacts for people and ecosystems and consequently in the sectors of interest for defence and security.

Therefore, accumulated CO_2 emissions will largely determine global warming at the end of the 21st CENTURY and beyond. This has led since the 90s to the generation of largely varying projections of greenhouse gas emissions that depend on socio-economic development and climate policy that are usually represented by different scenarios. These GHG projections are the essential forcing of the general circulation models (GCM) that allow us to obtain projections of the fundamental climate variables for different time horizons. The continuous improvement in our knowledge of the fundamental processes and in our modelling capabilities has allowed us to reach a new generation of GCM significantly improving the quality of the projections that are currently available, and reducing the existing uncertainties. However, the climate projections are the product of numerical modelling and are therefore not exempt from uncertainty.

The GCMs are the basis on which regional circulation models (RCMs) are developed that improve the spatial resolution of the initial models and integrate new processes characteristic of the regions in which they are implemented, considerably improving the quality of the projections. The results of these models are generally those that serve as a basis to project the impacts and risks of climate change. However, there are not RCMs for all regions of the planet, nor are they of the same quality, or cover all the variables necessary to cover the needs of the impact community. This is therefore an important source of uncertainty when assessing the risks arising from climate change.

Description of the RCP. Projections of climate change indicators

In order to understand how the future projections of climate change have been generated, it is necessary to introduce the concept of the Representative Concentration Paths (RCP). Unlike the emission scenarios considered in the previous IPCC reports, the RCPs represent four paths or trajectories of the possible concentrations of greenhouse gases that are used by the community that investigates climate change. They describe four possible climate futures that depend on the emission policy in the years to come. The four RCPs, called RCP2.6, RCP4.5, RCP6 and RCP8.5, receive their acronym based on the value of the radiative forcing expected in 2100 with respect to the pre-industrial era, that is (+2.6; +4.5, +6, +8.5 W/m^2, respectively).

RCPs represent a broad spectrum of options with respect to anthropogenic emissions of greenhouse gases (Figure 7). For example, RCP2.6 assumes that the maximum annual global GHG emissions will occur between 2010 and 2020, with a significant subsequent reduction. This scenario would be compatible with an immediate implementation of the terms of the Paris Agreement, possible but unlikely. The peak of the emissions corresponding to RCP4.5 occurs in 2040 with a subsequent decrease and the RCP8 has its maximum in 2080. However, RCP8.5 considers that emissions will continue to increase throughout the 21st century, corresponding to the most unfavourable scenario.

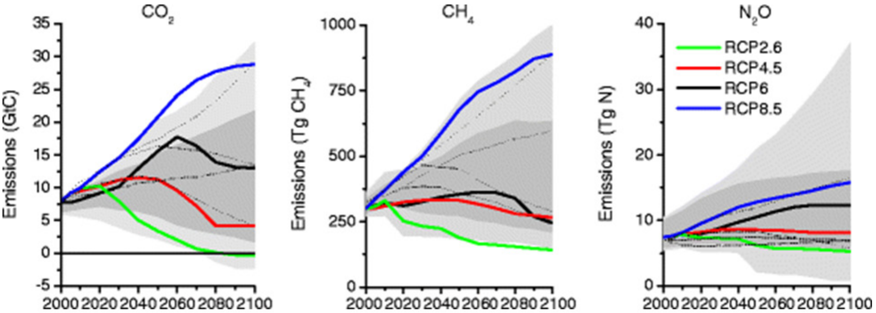


Figure 7. Emissions of the main greenhouse gases through the RCP.

The grey area corresponds to the 98% and 90% percentiles (light and dark grey, respectively) obtained based on the literature. The dashed lines correspond to four of the emission scenarios considered in previous IPCC reports (van Vuuren *et al.*, 2011).

As can be seen in Figure 7, with respect to CO_2 emissions, RCP8.5 shows a trend that corresponds to the upper limit contained in the literature (rapid increase in concentrations). RCP6 and RCP4.5 show a stabilisation of the CO_2 concentration (close to the literature average). Finally, RCP2.6 has a peak CO_2 concentration around 2050 followed by a slight decrease at the end of the century. Regarding the concentrations of CH_4 and N_2O, the order in which the RCPs are located is the direct result of the level of climate policy adopted. The trends in CH_4 concentrations are more pronounced given the short life of the compound. RCP2.6 and RCP4.5 show an emission peak within half a century. With regard to the concentration of N_2O, the scenarios remain in the same order, although in this case the emissions for RCP4.5 remain stable and those corresponding to RCP6 increase with time.

In all emission scenarios evaluated, the projections indicate that the surface temperature will continue to increase throughout the 21st CENTURY. It is very likely that heat waves occur more frequently and last longer, and that episodes of extreme rainfall are more intense and frequent in many regions. The ocean will continue to warm and acidify, and the overall mean sea level will continue to rise.

These conclusions are taken from the modelling with GCM and RCM models within the framework of the Coupled Model Intercomparison Project (CMIP) that began in 1995 and in which more than 30 GCM from different institutions of the world are grouped to perform climate modelling, allowing the comparison of data from the pre-industrial era with different future projections. During the 2010-2014 period, the CMIP5 phase was completed, which served as the basis for all the projections included in the AR5 as well as for most of the research on different aspects of climate change carried out in recent years. The sixth phase, CMIP6, is currently underway, and the results are expected to be released in 2020.

Among the most important results on projections prepared for AR5, it is worth mentioning those in the following table:

Emission scenario	Representative Concentration Pathway (RCP)	2100 CO_2 concentration (ppm)	Temperature Increase (°C)	Mean sea level rise (m)					
			2081-2100	2046-2065	2100	Scenario	2200	2300	2500
Low	2.6	421	1.0 (0.3-1.7)	0.24 (0.17-0.32)	0.44 (0.28-0.61)	Low	0.35-0.72	0.41-0.85	0.50-1.02
Medium low	4.5	538	1.8 (1.1-2.6)	0.26 (0.19-0.33)	0.53 (0.36-0.71)	Medium	0.26-1.09	0.27-1.51	0.18-2.32

Emission scenario	Representative Concentration Pathway (RCP)	2100 CO_2 concentration (ppm)	Temperature Increase (ºC)	Mean sea level rise (m)					
			2081-2100	2046-2065	2100	Scenario	2200	2300	2500
Medium high	6.0	670	2.2 (1.4-3.1)	0.25 (0.18-0.32)	0.55 (0.38-0.73)	High	0.58-2.03	0.92-3.59	1.51-6.63
High	8.5	936	3.7 (2.6-4.8)	0.29 (0.22-0.38)	0.74 (0.52-0.98)				

Table 1. Projections of temperature and mean sea level for different RCP and time periods (IPCC, 2013).

Table 1 is highly illustrative given that it shows different aspects that must be taken into account when analysing the risks derived from climate change in the future. Firstly, it shows how the different associated emission and RCP scenarios are linked to different concentrations of CO_2 in the atmosphere in 2100. Note that NASA's latest measurement of CO_2 in the atmosphere indicates that we have reached 406.94 ppm (09/2017). As a reference, it should be mentioned that in September 2013 the observed value was 396.76 ppm. We can therefore conclude that we are very close to reaching the values of RCP2.6. This RCP leads to a temperature increase of between 0.3ºC and 1.7ºC (1º of average value). Note that, in this table, the projections are shown as the difference between the period reported (for example, 2081-2100) and the control period, which in this case corresponds to 1986-2005. The values that these projections show are the result of an ensemble (aggregation of several models) between various model runs and climate models. This information is expressed as a function of the mean value and the percentiles of 5% and 95% of the distribution (entered in brackets) of the simulated cases.

Likewise, the table reproduces the projections of increase in the mean sea level. This increase is a response to the volumetric expansion of the ocean due to the warming of its waters, to which the contributions of the water volumes from the ice losses in glaciers and ice masses in the continent must be added (e.g. Greenland). Note that there are few differences between the different RCPs until the middle of the century, with mean values between 0.24 and 0.29 m and a variation of the corresponding percentiles of between 0.17 and 0.38 m. In 2100, the most unfavourable RCP suggests an average sea level rise of 0.74 m (the percentiles of 5% and 95% correspond to 0.52 m and 0.98 m, respectively). It is at the end of the century when the differences between mitigation policies are clearly evident.

In this table, very long-term projections (2300-2500) are also included for the first time. Although with great associated uncertainty, it is important to highlight a relevant aspect. Due to the thermal inertia of the ocean, the mean sea level would continue to rise, and could exceed 6 m in the most pessimistic case. That is to say, although the decision to reach a situation of zero emissions will be taken today, the average level of the sea would continue to rise for hundreds of years.

Although a large part of the scientific community works with these projections of an increase in the mean sea level, they are not very conservative in analysing the risks. The IPCC seeks to reduce uncertainties as much as possible, rather than trying to consider all possible scenarios, however unlikely they may be, which is something inherent to risk management. For this reason, AR5 exclusively includes the projections of the mean sea level obtained from simulations of GCM models and although they are cited, the values predicted by other so-called semi-empirical models that have been published in the last decade are not included (Rahmstorf, 2007). All these models coincide in predicting increases in sea level of between 1.5 m and 2.5 m, therefore much higher than those established by the IPCC. This aspect is highly disputed by the community that analyses impacts and risks, since the selection of the temperature or sea level projections can give rise to risk values and therefore to very different adaptation objectives.

The other relevant aspect to consider is that in this section the projections of climate change indicators (temperature and sea level) that are calculated as a global average have been discussed. It is evident that, for the purposes of the analysis of impacts or risks, the search for solutions requires local or at least regional projections since the spatial variability of the behaviour of the climatic variables is very important.

Regional projections. The IPCC Atlas

The climate system can be global in extension, but its manifestations (for example, through atmospheric processes, oceanic circulation, bioclimatic zones, daily time and long-term climatic trends) are regional, or even local, in their occurrence, nature and implications. In this regard, the IPCC has developed an Atlas of global and regional projections as part of the AR5 (IPCC, 2013). This atlas presents a series of figures that show the global and regional climate change patterns that have been generated as part of the CMIP5. Maps of changes in air temperature and relative changes in rainfall (expressed as a percentage of mean rainfall) are presented for different seasons, for the entire globe and for a series of sub-continental regions. The results refer to average changes for periods of 20 years in the short term (2016-2035), medium term (2046-2065) and long term (2081-2100) relative to the reference period 1986-2005. As an example, the results are shown in the Southern European/Mediterranean region.

Temperature is one of the most studied geophysical variables and a clear indicator of global warming. As figures 9 and 10 show (in both, upper left panel) the air temperature increased during the 20th CENTURY and will continue to increase throughout the 21st. In the southern European winter, the projections show temperature increases of between 2ºC and 4ºC by the end of the century for RCP4.5 and RCP8.5 respectively. As regards the summer season, the projections to 2100 are greater, with increases of 3ºC

(RCP4.5) to 7°C (RCP8.5). The spatial maps (see the lower panels of figures 9 and 10) allow us to observe the variability of these changes throughout the region. In Spain, increases of between 2°C and 4°C are projected in summer for 2081-2100 (RCP4.5). In winter, the projected increases are lower, but in all cases considered, from 2050 on, they are above 1°C.

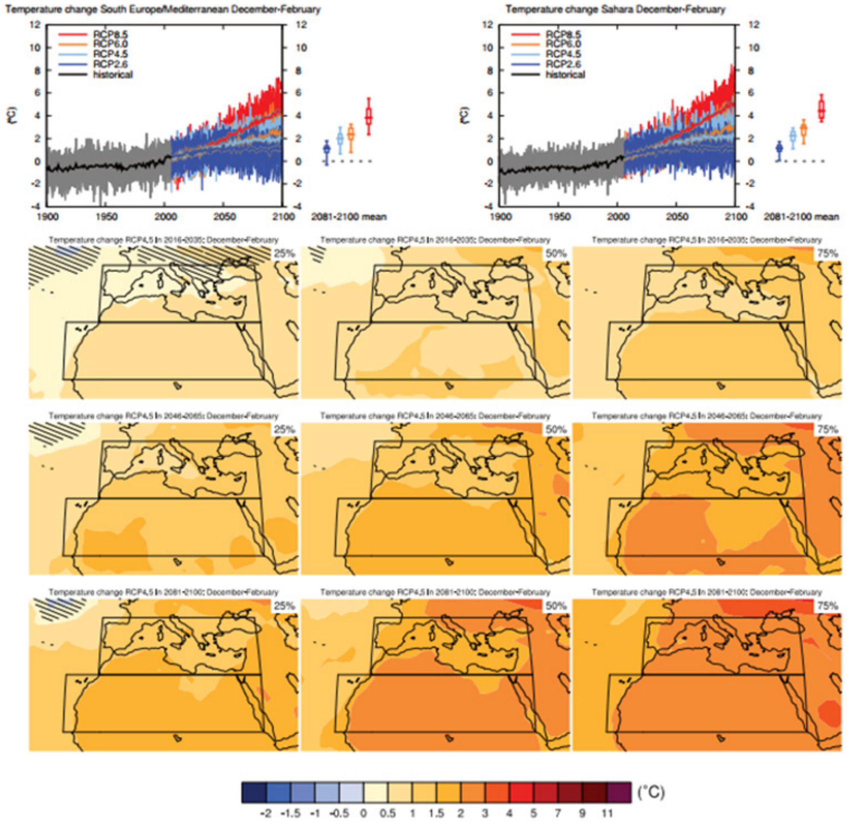


Figure 9. (Top left) Time series of temperature changes relative to 1986-2005 averaged over grid points located on land in the southern European/Mediterranean region (30°N to 45°N, 10°W to 40°E) from December to February. (Top right) The same for grid points located on land in the Sahara (15°N to 30°N, 20°W to 40°E). The fine lines denote one member of the ensemble per model, the thick lines the average of the CMIP5 models. The percentiles of 5%, 25%, 50% (median), 75% and 95% of the distribution of the mean changes for 2081-2100 and for the four RCPs are shown. (Below) Temperature change maps in 2016-2035, 2046-2065 and 2081-2100 with respect to 1986-2005 for scenario RCP4.5. For each point, the percentiles of 25%, 50% and 75% of the CMIP5 ensemble distribution are shown; this includes the natural variability and dispersion of the models. The shading indicates the areas in which the differences of the 20-year average of those of the percentiles are less than the standard deviation of the current natural variability estimated by the models of the 20-year average differences (IPCC, 2013).

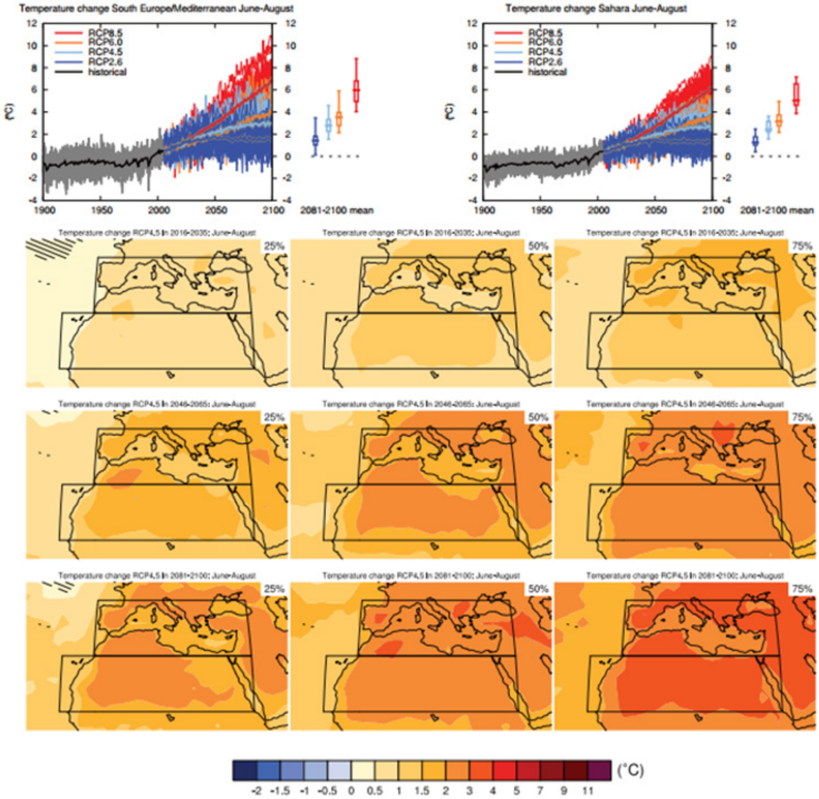


Figure 10. (Top left) Time series of changes in temperature relative to 1986-2005 averaged over grid points located on land in the southern European/Mediterranean region (30°N to 45°N, 10°W to 40°E) from June to August. (Top right) The same for grid points located on land in the Sahara (15°N to 30°N, 20°W to 40°E). The fine lines denote one member of the ensemble per model, the thick lines the average of the CMIP5 models. The percentiles of 5%, 25%, 50% (median), 75% and 95% of the distribution of the mean changes for 2081-2100 and for the four RCPs are shown. (Below) Temperature change maps in 2016-2035, 2046-2065 and 2081-2100 with respect to 1986-2005 for scenario RCP4.5. For each point, the percentiles of 25%, 50% and 75% of the CMIP5 ensemble distribution are shown; this includes the natural variability and dispersion of the models. The shading indicates the areas in which the differences of the 20-year average of those of the percentiles are less than the standard deviation of the current natural variability estimated by the models of the 20-year average differences (IPCC, 2013).

Figures 11 and 12 (upper left panel) represent the time series of changes in relative rainfall (percent change over the mean) in the grid land points representing the southern European/Mediterranean region (30°N-45°N, 10°W-40°E), for October-March (rainy season) and April-September (summer season). You can see how the changes show a slight reduction in rainfall in both cases. Up to mid-century, the projections of the 4 RCPs are very similar, differing more at the end of the century, where, in October-March and for RCP8.5, the projection is 12% less rainfall. In April-September, by contrast, these changes reach 20%. With regard to spatial maps (see bottom panel in figures 11 and 12), we can see how, for the percentiles of 25% and 50%, in Spain a general reduction in rainfall is expected. This reduction is somewhat more pronounced in the summer period (April-September) and in all the percentiles studied, with reductions of between 20% and 30% in some areas for the period 2081-2100. In the rainy season (October-March), a reduction in rainfall of around 10% for the percentiles of 25% and 50% of the distribution is expected at the end of the century, and a slight increase (between 0% and 10%) for the 75th percentile.

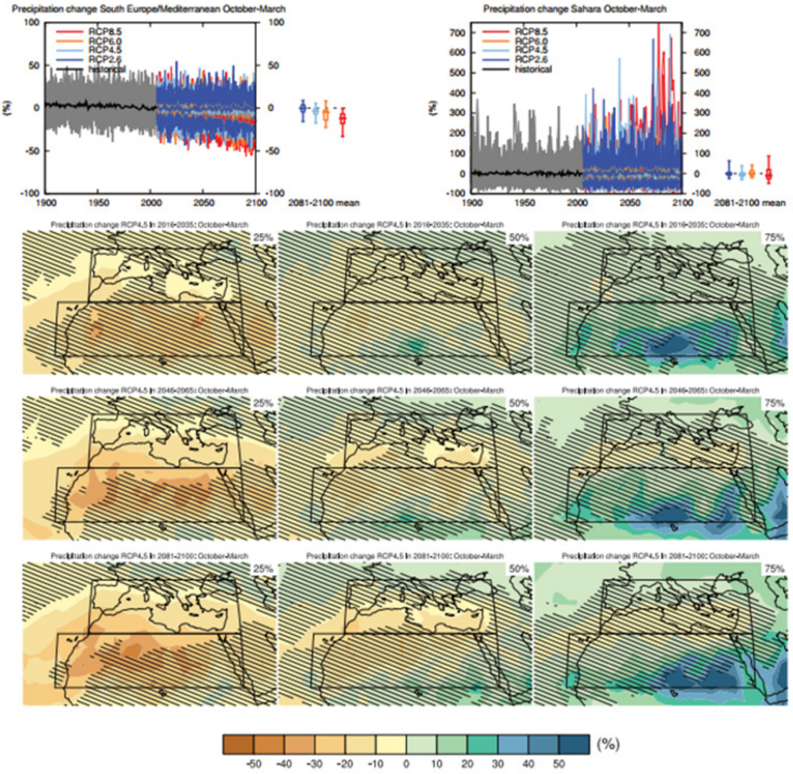


Figure 11. (Top left) Time series of changes in rainfall relative to 1986-2005 averaged over grid points located on land in the southern European/Mediterranean region (30°N to 45°N, 10°W to 40°E) from October to March. (Top right) The same for grid points located on land in the Sahara (15°N to 30°N, 20°W to 40°E). The fine lines denote one member of the ensemble per model, the thick lines the average of the CMIP5 models. The percentiles of 5%, 25%, 50% (median), 75% and 95% of the distribution of the mean changes for 2081-2100 and for the four RCPs are shown. (Below) Maps of change in rainfall in 2016-2035, 2046-2065 and 2081-2100 with respect to 1986-2005 for scenario RCP4.5. For each point, the percentiles of 25%, 50% and 75% of the CMIP5 ensemble distribution are shown; this includes the natural variability and dispersion of the models. The shading indicates the areas in which the differences of the 20-year average of those of the percentiles are less than the standard deviation of the current natural variability estimated by the models of the 20-year average differences (IPCC, 2013).

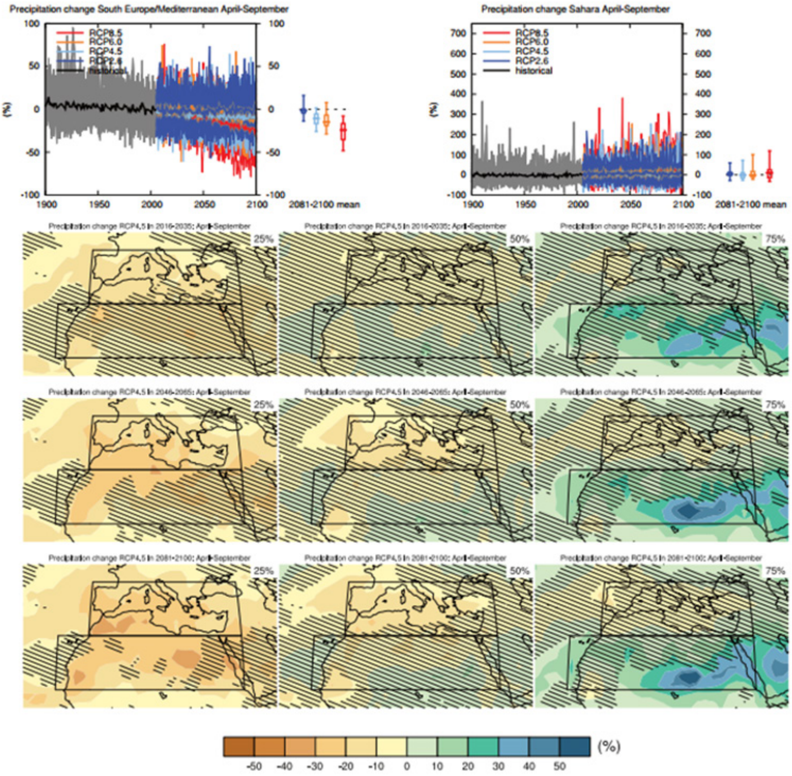


Figure 12. (Top left) Time series of changes in rainfall relative to 1986-2005 averaged over grid points located on land in the southern European/Mediterranean region (30°N to 45°N, 10°W to 40°E) from April to September. (Top right) The same for grid points located on land in the Sahara (15°N to 30°N, 20°W to 40°E). The fine lines denote one member of the ensemble per model, the thick lines the average of the CMIP5 models. The percentiles of 5%, 25%, 50% (median), 75% and 95% of the distribution of the mean changes for 2081-2100 and for the four RCPs are shown. (Below) Maps of change in rainfall in 2016-2035, 2046-2065 and 2081-2100 with respect to 1986-2005 for scenario RCP4.5. For each point, the percentiles of 25%, 50% and 75% of the CMIP5 ensemble distribution are shown; this includes the natural variability and dispersion of the models. The shading indicates the areas in which the differences of the 20-year average of those of the percentiles are less than the standard deviation of the current natural variability estimated by the models of the 20-year average differences (IPCC, 2013).

Note that the atlas only offers information about changes in atmospheric temperature and rainfall. The GCM and RCM offer a lot of other information on atmospheric climatic variables, however, it should be noted that, as of today, they do not provide information on marine variables, so additional modelling is required.

Figure 13 shows projections of wave changes (significant wave height) by seasons by the end of the century with respect to the base period (1979-2005) obtained as an ensemble of 30 GCM models, for RCP8.5.

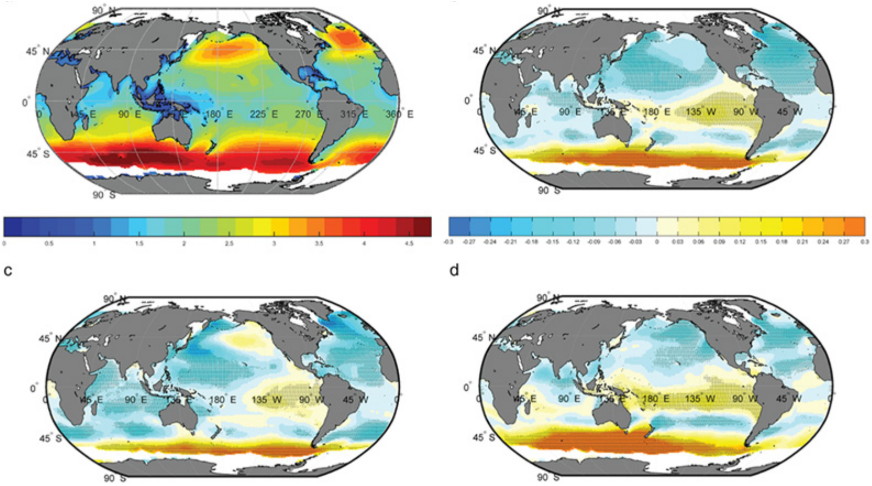


Figure 13 Source: Camus et al. (2017) (a) Significant mean annual wave height (m) for the period 1979-2005. (b–d). Projected changes in annual values, in the EFM, JAS seasons for the period 2070-2100 with respect to (1979-2005) for the RCP8.5.

The results show that the increase in wave height is mainly projected in the southern hemisphere.

Figure 14 shows the relative sea level projections (RSLR) for 2070-2100 for RCP4.5. It must be emphasised that the projection includes the effect of subsidence or isostatic rebound on the coast since what matters in terms of the determination of impacts is the value of the sea level with respect to the coast. Note the great variability along the world's oceans with increases of more than 80 cm and depressions of up to 20 cm in the areas near the Arctic and Antarctic.

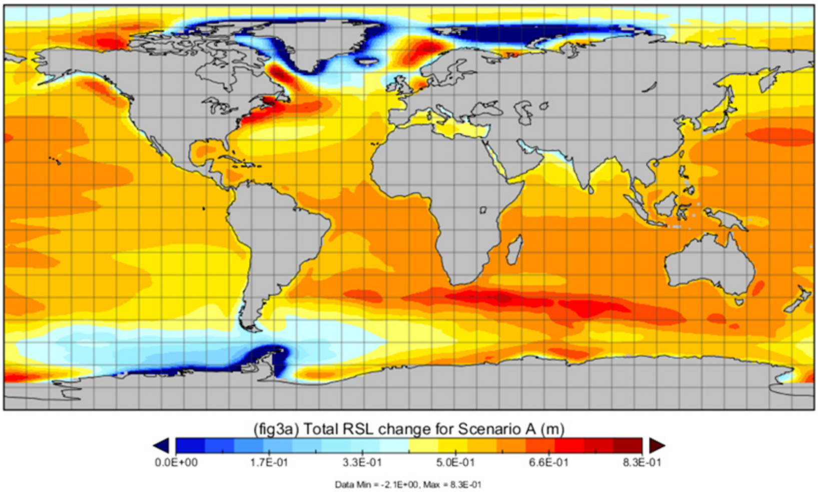


Figure 14. Relative sea level projections (RSLR) at the end of the century for RCP4.5. Source (Slangen, 2014).

Climate projections for Spain

The State Meteorological Agency (AEMET) provides both numerical and graphic information on the projections of climate change for the twenty-first century, regionalised for all of Spain and corresponding to different emission scenarios. These projections are essential for the evaluation of impacts and risks derived from climate change.

The results refer to different emission scenarios (RCP), different global climate models and different regional models, and constitute the most recent source of regionalised projections of climate change available in the European context. The use of sets of evolutions (ensemble/multi-model) allows us to estimate the associated uncertainties, both with the evolution provided by the global models, and by the regionalisation calculated with the regional nested models.

The projection maps of maximum temperature, minimum temperature and rainfall for two periods of the 21st century are shown below as an example: 2046-2061, 2081-2100, regionalised with different techniques.

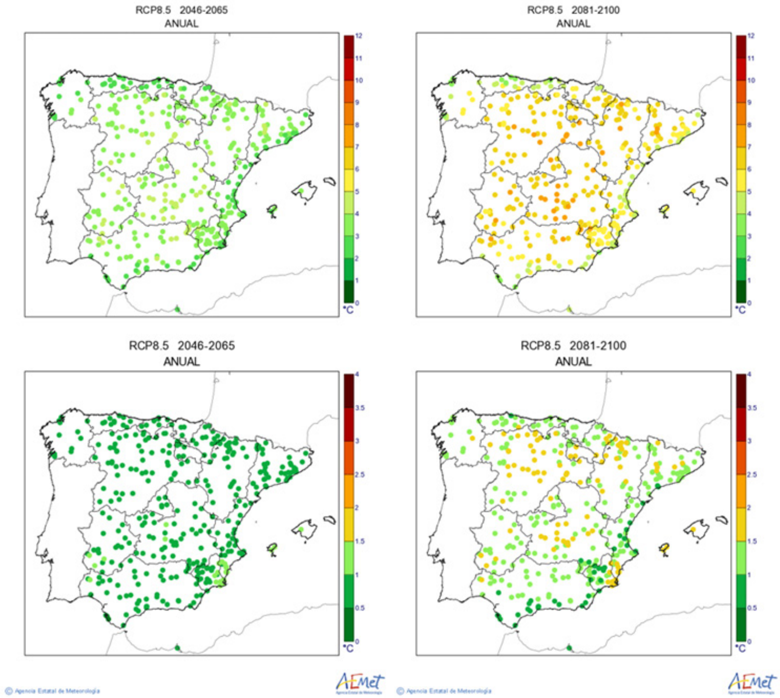


Figure 15. Changes in the maximum annual average temperature (upper panels) and uncertainty (lower panels) for RCP8.5, with respect to the control period 1961-2000 (AEMET).

Figure 15 shows the projections of the change in the maximum annual mean temperature and its uncertainty (obtained as twice the standard deviation) throughout the 21st century for RCP8.5. The results show an increase in temperature of between 1ºC and 5ºC mid-century, and up to 8ºC by the end of the century. These increases are greater in the central zone of the country and much less pronounced on the coast, especially in the regions of Asturias and Cantabria. As can be seen, the uncertainty is greater where the change is greater and as we move away in time, reaching the 2nd by the end of the century.

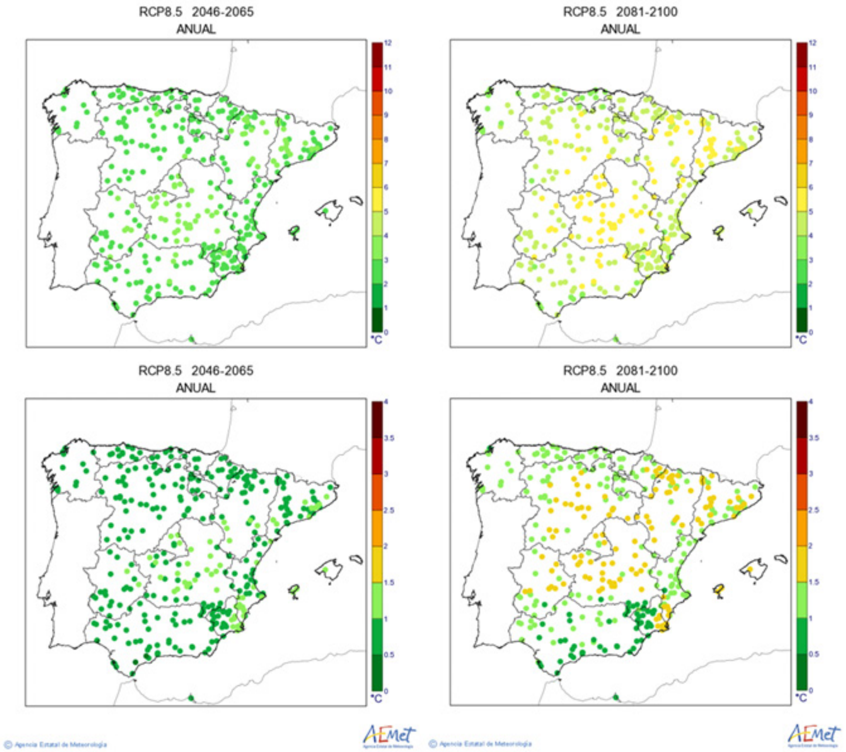


Figure 16. Changes in the minimum annual average temperature (upper panels) and uncertainty (lower panels) for RCP8.5, with respect to the control period 1961-2000 (AEMET).

Figure 16 shows the projections of the change in the minimum annual mean temperature and its uncertainty (obtained as twice the standard deviation) throughout the 21st century for RCP8.5. Although the pattern of change is similar to that observed in the maximum temperature, the spatial variability is smaller. The increase in the minimum temperature by the middle of the century is between 2ºC and 5ºC throughout the country. By the end of the century, the increases are up to 6 degrees, with Castilla La Mancha being the region in which the largest increases will occur.

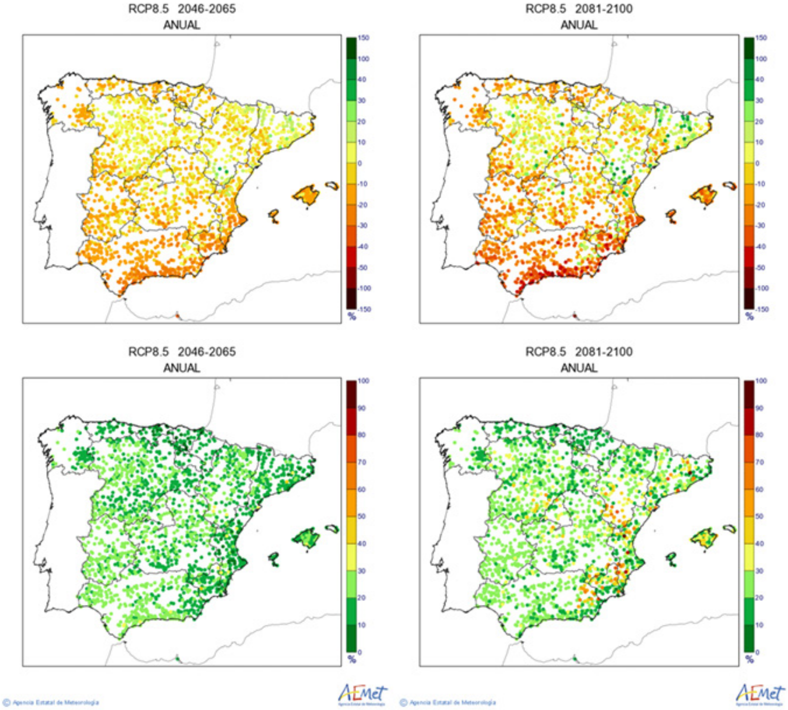


Figure 17. Changes in average accumulated annual rainfall (upper panels) and uncertainty (lower panels) for RCP8.5, compared to the control period 1961-2000 (AEMET).

Figure 17 shows the projections of change in accumulated average annual rainfall and its uncertainty (obtained as twice the standard deviation) throughout the 21st CENTURY for RCP8.5. By mid-century, rainfall will be reduced by up to 40 mm in the coastal areas of Andalusia and Murcia, and 30 mm in the Cantabrian region. On the other hand, it will increase by up to 10 mm in the central-northern area of the country, and up to 40 mm in specific locations in Catalonia and Aragon. By the end of the century, the decreases in rainfall will be more pronounced, more than 50 mm in the south of the country. The increases in the central-northern area will be somewhat higher, reaching 40 mm in some areas, especially in Catalonia and Aragon.

Most of these projections were prepared within the framework of the National Adaptation Plan (PNACC). One of the fundamental instruments for disseminating this plan is AdapteCCA.es (http://www.adaptecca.es), a platform for exchanging and consulting information on adaptation to climate change in Spain. In it you can find all the available information on regionalised climate change projections prepared by the AEMET and some autonomous communities.

For the Spanish coast, MAGRAMA and MINECO jointly financed the project «Climate Change on the Spanish Coast» (C3E) developed by IH Cantabria of the University of Cantabria. One of the results of this project was the C3E viewer (http://www.c3e.ihcantabria.com) in which climatic projections are collected for the variables of marine dynamics on the Spanish coast.

The other components of risk: exposure and vulnerability

As already described above, in addition to the danger, there are other non-climatic factors that influence the level of risk, such as exposure and vulnerability. Both are dynamic, vary in time and space, and depend on economic, social, geographic, demographic, cultural, institutional and environmental factors.

The exposure represents the population, assets and activities at potential risk or that may suffer damage due to an impact. It has dimensions that are physical (buildings and infrastructure), social (people and communities) and economic (activity flows). Therefore, it is highly determined by territorial planning, economic development and overpopulation in cities.

Vulnerability refers to the susceptibility or sensitivity of systems to damage, and is related to concepts such as resilience, fragility and adaptability. It depends to a large extent on the nature of the impact in question, but also on the characteristics of the population (for example, in terms of age and cultural level), of the buildings (for example, as regards the type of foundations and materials), of the ecosystems (for example, as regards their adaptive capacity) and of the rest of the recipients of the impact.

In the analysis of risks associated with climate change, some of these factors are considered: the projection of the population, the migratory processes, the changes in territorial planning and projections in the food or energy demand. However, like the previous, these are not lacking in uncertainty, so it is necessary to analyse the risk in different scenarios.

Impacts and risks of future scenarios of climate change

There is general agreement among the scientific community that climate change will increase existing risks and create new risks for natural and human systems. However, the characteristics intrinsic to risk mean that they are distributed in a disparate way and are generally greater for disadvantaged people and communities (high vulnerability) of the countries, regardless of their level of development.

Another aspect on which there is agreement is that many of the impacts associated with climate change that are now beginning to be observed and that will occur in the near future, will continue for centuries, even if the anthropogenic emissions of greenhouse gases are stopped. In this sense, it must be stressed that the risks of abrupt or irreversible changes increase as the magnitude of the warming increases.

AR5 in its «Summary for policy makers» includes a set of sectoral risks, among which the following stand out. These conclusions are formulated in terms of the language used by the IPCC to describe the uncertainties. These formulations are not included in the following summary, but can be consulted in the previous reference.

Freshwater resources. Projections during the twenty-FIRST CENTURY indicate that renewable resources of surface water and groundwater will be substantially reduced in most subtropical dry regions, thereby intensifying competition for water between sectors.

Terrestrial ecosystems and fresh water. In this century, the magnitudes and rates of climate change associated with medium to high emission scenarios will pose a high risk of abrupt and irreversible change at the regional level in the composition, structure and function of continental terrestrial and aquatic ecosystems, including wetlands.

Coastal systems and low areas. Given the projected rise in sea level throughout the 21st CENTURY and beyond, coastal systems and low-lying areas will increasingly experience adverse impacts such as immersion, coastal flooding and coastal erosion.

Food safety. In relation to the main crops (wheat, rice and corn) in the tropical and temperate regions, projections indicate that climate change without adaptation will have a negative impact on production with increases in local temperature of 2ºC or more above the levels of the late 20th CENTURY, although there may be individual locations that benefit from this increase.

Urban and rural areas. Many global risks of climate change are concentrated in urban areas. Measures that increase resilience and enable sustainable development can accelerate successful adaptation to global climate change. The most important rural impacts in the future are expected to occur in the short term and subsequently in relation to water availability and supply, food security and agricultural incomes, especially regarding changes in food and non-food crop production areas all over the world.

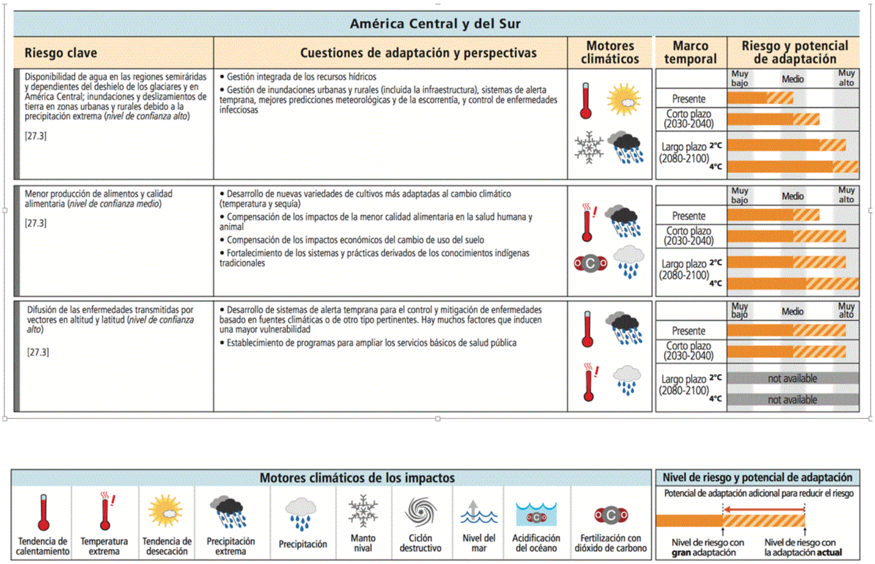
Sectors and key economic services. For most economic sectors, projections indicate that dynamic impacts such as changes in population, age structure, income, technology, relative prices, lifestyle, regulation and governance will be greater than the impacts of climate change.

Health. Until the middle of the century, the impact of projected climate change will affect human health mainly due to the worsening of existing health problems (very high level of confidence). Throughout the 21ST CENTURY, climate change is expected to cause an increase in poor health in many regions and especially in low-income developing countries, compared to the reference level without climate change.

Human security. Projections indicate that climate change throughout the 21st CENTURY will increase the number of displaced people.

Climate change can indirectly increase the risks of violent conflicts in the form of civil war and violence between groups by increasing the intensity of the forces which, according to extensive documentation, drive such conflicts, like poverty and economic crises. The impacts of climate change on the essential infrastructure and territorial integrity of many States are expected to influence national security policies.

In addition, the report includes a summary of what it identifies as key regional risks. Figure 18 shows an example for Central and South America.



América Central y del Sur

Riesgo clave	Cuestiones de adaptación y perspectivas	Motores climáticos	Marco temporal	Riesgo y potencial de adaptación
Disponibilidad de agua en las regiones semiáridas y dependientes del deshielo de los glaciares y en América Central; inundaciones y deslizamientos de tierra en zonas urbanas y rurales debido a la precipitación extrema (*nivel de confianza alto*) [27.3]	• Gestión integrada de los recursos hídricos • Gestión de inundaciones urbanas y rurales (incluida la infraestructura), sistemas de alerta temprana, mejores predicciones meteorológicas y de la escorrentía, y control de enfermedades infecciosas			Muy bajo · Medio · Muy alto
			Presente	
			Corto plazo (2030-2040)	
			Largo plazo (2080-2100) 2°C	
			4°C	
Menor producción de alimentos y calidad alimentaria (*nivel de confianza medio*) [27.3]	• Desarrollo de nuevas variedades de cultivos más adaptadas al cambio climático (temperatura y sequía) • Compensación de los impactos de la menor calidad alimentaria en la salud humana y animal • Compensación de los impactos económicos del cambio de uso del suelo • Fortalecimiento de los sistemas y prácticas derivados de los conocimientos indígenas tradicionales			Muy bajo · Medio · Muy alto
			Presente	
			Corto plazo (2030-2040)	
			Largo plazo (2080-2100) 2°C	
			4°C	
Difusión de las enfermedades transmitidas por vectores en altitud y latitud (*nivel de confianza alto*) [27.3]	• Desarrollo de sistemas de alerta temprana para el control y mitigación de enfermedades basado en fuentes climáticas o de otro tipo pertinentes. Hay muchos factores que inducen una mayor vulnerabilidad • Establecimiento de programas para ampliar los servicios básicos de salud pública			Muy bajo · Medio · Muy alto
			Presente	
			Corto plazo (2030-2040)	
			Largo plazo (2080-2100) 2°C	not available
			4°C	not available

Figure 18. Key risks of climate change and potential for risk reduction through adaptation and mitigation for Central and South America. Each key risk is represented by a value between very low and very high for three time frames: the present, the short term (2030-2040), and the long term (2080-2100). The climate dynamics of the impacts are indicated by icons. Source (IPCC, 2014).

The water-energy-food nexus

As has been observed in the previous sections, climate change presents risks for all sectors of economic activity. But it should be pointed out that these risks are also intertwined through the connections that relate these sectors, and may give rise to generally positive feedback mechanisms that increase the effects of climate change in these sectors.

One of the areas in which this phenomenon occurs in a particularly intense way is known as the water-energy-food nexus. This link can be illustrated by the following figure.

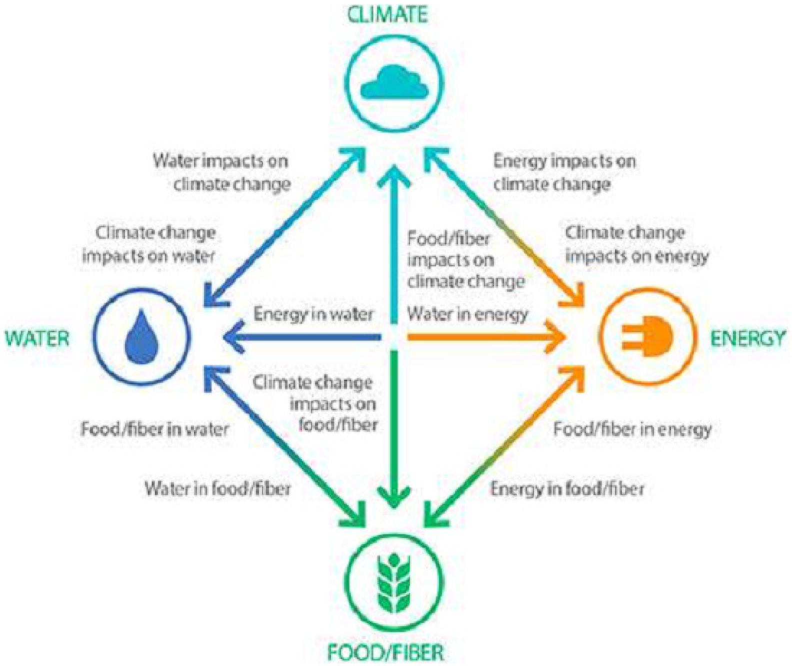


Figure 19. The water-energy-climate-food nexus. Source (WBCSD, 2013).

As you can see, water is necessary for the production of both energy and food. In turn, energy is necessary for the supply of drinking water, and also for food production. Finally, agricultural land may be necessary for energy production (biomass), and forests also affect water availability. And all these elements are influenced by climate change, restricting the volume of water available, altering the demand for energy and also its production, and conditioning agricultural productivity. The relevance of this link is supported by numerous publications, both academic and institutional, on this subject, which can be found summarised in Khan *et al* (2017a).

In Spain, there are few studies that analyse this link. We quote and summarise the three that we know:

Mayor (2016), in his doctoral thesis, studies the water-energy-food nexus for the Duero basin. To do this, she quantifies the water, energy and agricultural production flows that connect these sectors, and analyses the coordination of sectoral policies and institutions. The author concludes that a greater degree of coordination is necessary for the planning of these sectors.

For their part, Willaarts *et al* (2016) extend the analysis of the water-energy-territory nexus for Spain and evaluate the implications of future energy scenarios regarding the use of water and soil or climate change (although without taking into account the feedback between these sectors). The study also retrospectively evaluates to what extent the intensification of agriculture in the last decade has modified the use of natural resources (land, water and energy) and reduced environmental impacts, concluding that the evolution has been positive, except in energy terms, which have increased.

Finally, Zarrar Khan, in his doctoral thesis at the Universidad Pontificia Comillas (Khan *et al*, 2016 and 2017b), developed an integrated water-energy model that allows the evaluation of the impact of different hydrological or energy policies in both sectors jointly. In his works, Khan demonstrates the value of the joint planning of both sectors, which allows water and energy consumption to be reduced as well as the economic costs; and also the interest of taking ex-ante into account the effects of climate change for hydrological and energy planning.

Overall, all the studies analysed underline the need to take into account the interaction between these sectors, which are strategic for our country, when evaluating the impact of climate change. Thus, any strategy to adapt to them should be carried out jointly, something that on the other hand requires collaboration between different institutions at sectoral and territorial level.

Strategies for mitigation and adaptation to climate change

As mentioned in the description of climate change risk analysis, adaptation and mitigation are complementary strategies to reduce and manage the risks of climate change. While adaptation acts on exposure and vulnerability, mitigation is closely linked to the danger, but also to changes in land uses, technology and socio-economic trajectories that are in turn linked to exposure and vulnerability.

There is general agreement in the scientific community that if emissions are substantially reduced in the coming decades, reductions in climate risks can be achieved throughout the 21st CENTURY and beyond. Likewise, it is considered that a reduction in emissions will contribute to making the trajectories of sustainable development resilient to the climate.

What is also clear is that, if no new mitigation efforts are introduced apart from those currently existing, as called for in the Paris Agreement, by the end of the 21ST CENTURY, warming will cause a high to very high risk of serious, generalised and irreversible impacts worldwide. This even assuming that important adaptation strategies are followed in different regions and sectors of the world.

To achieve the goal of reducing warming below 2°C in relation to pre-industrial levels, or even less, significant reductions in emissions would be required over the next few decades, and near zero emissions of CO_2 and other greenhouse gases by the end of the century.

The lack of mitigation strategies that significantly limit emissions requires the implementation of efficient and sustainable adaptation strategies. However, even if the most demanding mitigation strategy was implemented immediately, we would not be exempt from the introduction of adaptation measures.

Experts acknowledge that there are adaptation options in all sectors (water, security, coasts, infrastructures, etc.) but their context of application and potential to reduce climate-related risks is different between different sectors and regions. Therefore, adaptation measures should be considered at the local/regional level and with specific projects for each sector involved, but in an integrated manner. In most cases, adaptation entails important co-benefits, synergies and counterparts for the reduction of other risks, for a significant improvement in the sustainability and quality of life of citizens. The greater the magnitude of climate change, the greater the challenges for many of the adaptation options will be, with situations for which adaptation measures are not viable due to their inefficiency, cost or non-sustainability.

Many adaptation and mitigation options can contribute to tackling climate change, but none suffice alone. For the implementation of the options to be effective, policies and cooperation are needed at all scales; and to strengthen it, integrated responses are required that link adaptation and mitigation to other social objectives (IPCC, 2013).

Mitigation of climate change in Spain

The climate change mitigation strategy for Spain, currently being prepared within the framework of the Law on Climate Change and Energy Transition, is basically determined by the higher level objectives established by the European Commission (and in turn by the Paris Agreement). Thus, very ambitious decarbonisation objectives have been established for 2050 of the economy: between 80% and 95% reduction with respect to the 1990 emissions, equivalent to a total of between 14 and 58 MtCO2eq, which can be compared with the emissions of 2015, which were 340 MtCO2eq.

This basically implies the complete decarbonisation of the electricity sector, which must therefore be completely based on sources without CO_2 emissions (renewable, hydro or nuclear)[1]. Transport or heating and cooling of buildings

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[1] In this regard, it is interesting to note that carbon capture and sequestration (CCS) technologies, which could be used to allow the use of fossil fuels, present numerous uncertainties over their technical viability, not only with respect to capture, but also and above all, to the permanent storage of captured CO_2. In addition, these technologies do not

must also remove CO_2 emission sources almost completely, which can be achieved, inter alia, by the electrification of these end uses, and by managing demand. More complex is the reduction of emissions in industry, because its thermal consumption may not be easy to electrify, and it also has emissions directly associated with its non-energy chemical processes (mainly the production of cement and fertilisers). In these cases, CCS might be a necessary option. Finally, GHG emissions from agriculture and waste, which are also difficult to eliminate completely, especially the first, should be reduced.

The scope of the changes required in the energy and industrial sector will be determined mainly by the requirement of the imposed level of emissions, as well as by the growth of energy and industrial demand. Thus, the 80% reduction scenario allows fossil fuels to continue to have a certain share in the Spanish energy mix, provided that demand is reduced through energy efficiency. On the other hand, if demand grows as pre-2008, or if the reduction target is restricted to 95%, fossil fuels can only make a token contribution, so the rest of the energy supply should be provided by CO_2-free energies.

In this regard, a critical element is the availability or non-availability of nuclear technologies (both for technical reasons and social acceptance), as well as the potential of renewable energy that is available. In scenarios of high demand and low renewable potential, nuclear energy, or another technology without CO_2 emissions, could be necessary to reduce emissions to the required limits. Another critical aspect is the manageability of the energy system with a high penetration of variable renewable energies, which may require a significant volume of backup energy (either by storage, or by dispatchable fossil and renewable technologies). Finally, the economic cost of each of the decarbonisation paths will be determined by the technological evolution of the different energy sources, as well as by the capacity to reduce the energy intensity of the economy, something also essential to improve security of supply.

Lastly, these decarbonisation paths must be guided by appropriate policies. Although the expected technological advance of renewable energies can achieve the decarbonisation of the electricity sector to a large extent without public support, this is not the case of other sectors, which will need appropriate signals (basically a price for CO_2, as well as standards or information policies).

Adaptation to climate change in Spain

As mentioned above, adaptation can reduce the risks of climate change impacts, but its effectiveness is limited, especially when climate change is significant or occurs at an important rate.

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guarantee the capture of 100% of the CO_2 emitted, so they would not be compatible with complete decarbonisation of the electricity sector.

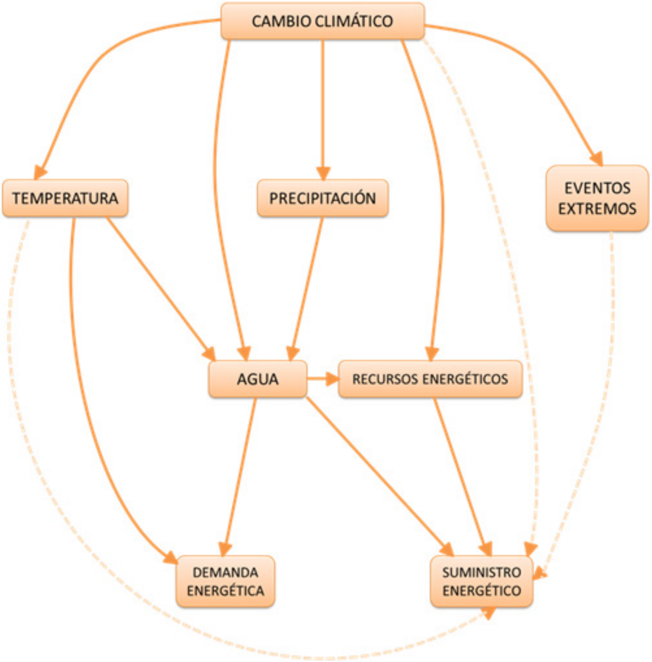
Since 2004, adaptation to climate change has been a priority objective for Spain. In 2006, the National Plan for Adaptation to Climate Change (PNACC) was approved, following a broad process involving the main coordinating bodies on climate change in Spain: the Commission for the Coordination of Climate Change Policies (CCPCC) and the National Climate Council (CNC); the Cabinet took notice of it on 6 October 2006.

The PNACC is a reference framework for coordination among the Spanish Public Administrations on impact assessment, vulnerability and climate change adaptation activities. The PNACC is implemented through work programmes, which specifically define the activities to be carried out. The first work programme of the PNACC, adopted when the Plan was approved, already identified the evaluation of the impact of climate change on the coastal areas among its 4 priority lines. The second work programme was adopted in July 2009, in which all the work that began with the first work programme was assumed and incorporated.

The third work programme 2014-2020, among the areas of work and lines of activity prioritised for different geographical territories, contains the coastal areas and includes the development of the Strategy of Adaptation to Climate Change of the Spanish Coast approved in the *Official State Gazette* in July 2017.

But there are other sectors that have also been or are being analysed. Forests, biodiversity and agriculture are some of them. One of the strategic sectors is also the energy sector.

Climate change will affect the energy sector in different ways, as shown in figure 20.



For Spain, regarding the energy supply, a reduction in the capacity of hydro (approximately 10%) and wind (between 15 and 40%) energy production is expected by 2050. Photovoltaics could increase production by 5%. In terms of demand, an increase is also expected in the demand for cooling (15%), and a fall in the demand for heating.

To deal with these changes, the measures proposed by the experts (see Girardi *et al*, 2015) include improvement in the evaluation of phenomena, joint planning, improvement in energy saving and efficiency, and the preparation of standards and specific adaptation plans.

Summary and conclusions

this chapter offers an overview of the state of the art of scientific knowledge of climate change. Based on the work carried out by the Intergovernmental Panel on Climate Change (IPCC), it analyses the concept of climate change, its causes, attributions and evidence, as well as the analysis of its consequences. This analysis is presented in a general framework of risk that is considered the ideal framework to also analyse the risks that climate change has on security, defence and the armed forces.

The information shows that in a framework of uncertainty we have the necessary databases, methodology and tools to make an assessment of the risks that climate change can generate for defence and makes it possible to identify which regional and sectoral aspects will have a greater impact on it.

References

Agencia Estatal de Meteorología (AEMET). www.aemet.es (last access: October 2017).

CAMUS, P.; LOSADA, IJ; IZAGUIRRE, C.; MIRROR, A.; MENÉNDEZ, M.; PÉREZ, J. (2017). «statistical wave climate projections for coastal impact assessments. Earth's Future», *AGU*, 5, pp. 918-933.

IPCC, 2013. «Annex I: Atlas of Global and Regional Climate Projections», [VAN OLDENBORGH, G. J.; COLLINS, M.; ARBLASTER, J.; CHRISTENSEN, J. H.; MAROTZKE, J.; POWER, S. B.; RUMMUKAINEN, M. and ZHOU, T. (eds.)]. In: «Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change», [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. (eds.)]. *Cambridge University Press*, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014. «Summary for policymakers». In: «Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.

Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change», [FIELD, C.B.; BARROS, V. R.; DOKKEN, D. J.; MACH, K. J.; MASTRANDREA, M. D.; BILIR, T. E.; M. CHATTERJEE, K.; EBI, L.; ESTRADA, Y. O.; Genova, R. C.; GIRMA, B.; KISSEL, E. S.; LEVY, A. N.; MACCRACKEN, S.; MASTRANDREA, P. R. and WHITE, L.L. (eds.)]. *Cambridge University Press*, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

KHAN, Z.; LINARES, P. and GARCÍA-GONZÁLEZ, J. 2016. «Adaptation to climate-induced regional water constraints in the Spanish energy sector: An integrated assessment». *Energy Policy*, 97, pp.123-135.

KHAN, Z.; LINARES, P.; GARCÍA-GONZÁLEZ, J. 2017a. «Integrating water and energy models for policy driven applications. A review of contemporary work and recommendations for future developments». *Renewable and Sustainable Energy Reviews* 67, pp. 1123–1138

KHAN, Z.; LINARES, P.; RUTTEN, M.; PARKINSON, S. C.; JOHNSON, N. and GARCÍA-GONZÁLEZ, J. 2017b. «Spatial and temporal synchronization of water and energy systems: Towards a single integrated optimization model for long-term resource planning». 2017. *Applied Energy SI. Energy-Water-Food Nexus*.

NASA. «Global Climate Change: Vital Signs of the Planet». https://climate.nasa.gov. (last access: October 2017).

MAYOR, B. 2016. *The Water-Energy-Food Nexus*, «Trends, Trade-offs and Implications for Strategic Energies». Doctoral Thesis. Universidad Complutense de Madrid.

RAHMSTORF, S. 2007. «A semi-empirical approach to projecting future sea-level rise». *Science* 315, pp. 368-370, 10.1126/science.,1135456.

SLANGEN, A. B. A.; CARSON, M.; KATSMAN, C.A.; VAN DE WAL, R. S.; KÖHL, W.; VERMEERSEN, A. 2014. «Projecting twenty-first century regional sea-level changes». *Climatic Change* 124, pp. 317-332.

VAN VUUREN, D. P.; EDMONDS, J.; KAINUMA, M. *et al.* 2011. «The representative concentration pathways: an overview», *Climatic Change* 109, p. 5. https://doi.org/10.1007/s10584-011-0148-z.

WBCSD. 2013. «The Nexus for Food, Feed and Fibre, Water and Energy, Co-Optimizing Solutions. World».

Business Council for Sustainable Development. WILLAARTS, B.A; DE LA RÚA, C; CABAL, H; GARRIDO, A; LECHON, Y. 2016. *El Nexo Agua-Tierra-Energía en España*. Fundación Canal Isabel II.