

Chapter 2

Facts and Projections on Climate Change

Abstract This chapter outlines the main facts about changes in the global climate in recent decades and established projections of climate scientists regarding the future evolution of worldwide greenhouse gas emissions, temperature, sea level and precipitation. Apart from the global level, the past and future evolution of key climate variables in Europe, the Mediterranean region and Cyprus is described. Latest available information from international and regional studies is used for this purpose.

Keywords Climate model • Concentration pathways • Precipitation • Radiative forcing • Sea level • Temperature

2.1 Definition of Climate Change, Main Facts and Major Projections

2.1.1 Definitions of Climate Change

According to the official definition given by the United Nations Intergovernmental Panel on Climate Change (IPCC), *climate change* refers to a statistically significant variation in either the mean state of the climate or its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external causes, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC 2007a). The United Nations Framework Convention on Climate Change (UNFCCC) focuses specifically on anthropogenic climate change, i.e. ‘*the change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods*’ (UN 1992).

Some additional definitions associated with climate change that have been addressed by the UNFCCC (1992) are presented below and aim at providing a better understanding of the overall situation:

Climate system means the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions.

Adverse effects of climate change are changes in the physical environment or biota resulting from climate change which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.

Greenhouse gases (GHGs) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation. Their total amount is usually expressed in tonnes of equivalent carbon dioxide ($\text{CO}_{2\text{eq}}$), a metric that takes into account the global warming potential of each gas. The IPCC considers the following GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Emissions denote the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

It is also important to note some additional definitions that are useful to understand fully the aspects of climate change:

Macroclimate: the overall climate of a region (usually a large geographical area).

Microclimate: the essentially uniform local climate of a usually small site or habitat.¹

2.1.2 Main Facts

The vast majority of studies released in the past decade mention clearly that anthropogenic GHG emissions have been increasing substantially in the last decades, thus contributing to large-scale climate change. Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. About half of the cumulative anthropogenic CO_2 emissions between 1750 and 2010 have occurred in the last 40 years.

As shown in Fig. 2.1, greenhouse gas emissions have been increasing from 1970 to 2010, mainly because of man-caused activities. It is widely accepted that total anthropogenic GHG emissions were the highest in human history from 2000 to 2010, reaching 49 (± 4.5) billion tonnes (Gt) $\text{CO}_{2\text{eq}}$ per year in 2010. Of those, CO_2 accounted for 76; 16 % came from CH_4 , 6 % from N_2O and 2 % from fluorinated gases.

¹Definitions of macro- and microclimate according to Merriam–Webster’s dictionary, available online at <http://www.merriam-webster.com/dictionary/>, last accessed in December 2015.

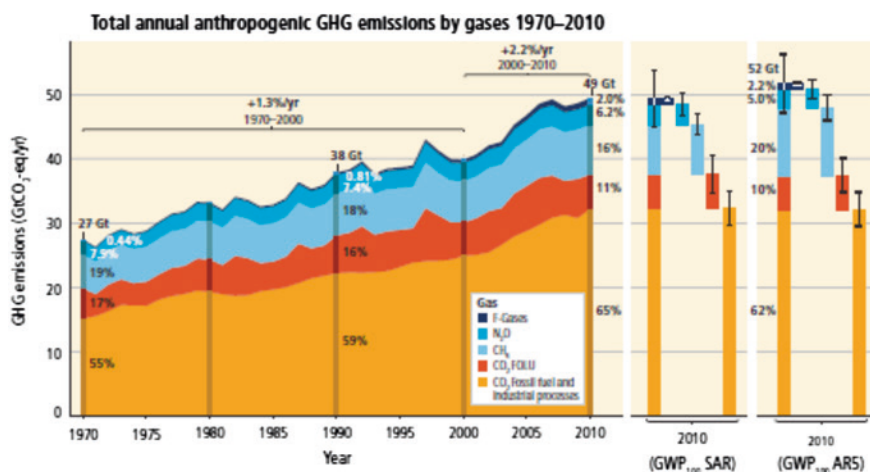


Fig. 2.1 Evolution of anthropogenic GHG emissions since 1970. *Source* IPCC (2014)

On a global scale, economic growth and population growth are the most important reasons for increasing fossil fuel combustion-related CO₂ emissions. Whilst the contribution of population growth has remained roughly the same in the last four decades, the contribution of economic growth to emission growth has risen sharply during the last years. Between 2000 and 2010, both drivers outpaced emission reductions caused by improvements in energy intensity. Moreover, increased use of coal relative to other energy sources has reversed the long-standing trend of gradual decarbonisation of the world's energy supply.

According to the IPCC 5th Assessment Report (or AR5), released in 2014, warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have receded, sea level has risen, and the concentrations of greenhouse gases have increased. New atmospheric temperature measurements show an estimated warming of 0.85 °C since 1880, with the fastest rate of warming in the Arctic (IPCC 2014).

In addition, it is 'virtually certain' that the upper 700 m of the Earth's oceans has warmed during the period from 1971 and 2010. The deep ocean, below 3000 m in depth, 'likely' warmed between 1992 and 2005. Moreover, it can be stated with 'high confidence' that glaciers have shrunk worldwide and that the Greenland and Antarctic ice sheets have lost mass over the past two decades. The report notes with 'very high confidence' that ice loss from Greenland has accelerated during the past two decades. Greenland is now losing about 215 Gt per year of ice, whilst the rest of the world's glaciers lose about 226 Gt per year.

In summary, the conclusion that much of the global warming over the past fifty years is due to human activities is considered *extremely likely* in the IPCC AR5 report, upgraded from *very likely* in the previous IPCC report (4th Assessment Report or AR4; IPCC 2007a).

2.1.3 Projections of GHG Concentrations and Radiative Forcing

IPCC AR5 reports that without additional efforts to reduce GHG emissions, emission growth is expected to persist throughout the twenty-first century. Baseline scenarios, i.e. those without additional emission abatement efforts, forecast GHG concentrations in the atmosphere to exceed 450 parts per million (ppm) $\text{CO}_{2\text{eq}}$ by 2030 and reach concentration levels between 750 and more than 1300 ppm $\text{CO}_{2\text{eq}}$ by the year 2100. For comparison, the $\text{CO}_{2\text{eq}}$ concentration in 2011 is estimated to be 430 ppm (uncertainty range 340–520 ppm). As a result, global mean surface temperature in the 2100 is projected to increase by 3.7–4.8 °C compared to preindustrial levels (IPCC 2014). A set of four scenarios of ‘representative concentration pathways’ (RCPs) has been the basis of these projections and for the assessment of their global impacts. Derived from a very large number of GHG emission projections collected from the international literature, these RCPs assume radiative forcing levels by the year 2100 of 2.6, 4.5, 6.0 and 8.5 watts per square metre (W/m^2), corresponding to GHG concentrations of 450, 650, 850 and 1370 ppm $\text{CO}_{2\text{eq}}$, respectively, covering the range of potential anthropogenic climate forcing in the twenty-first century as reported in the literature. Figure 2.2 illustrates the different scenarios considered in that study.

This kind of scenarios differs somewhat from the approach followed by IPCC in the past. Figure 2.3 compares the four RCPs mentioned above with the modest emission scenario A1B that was used by (IPCC 2007a), which is the basis for many of the climate change impact studies that will be cited in this book. Evidently, the choice of the scenario is not very important until the mid-twenty-first century; for later years, A1B seems to lie between the two most ‘pessimistic’ (i.e. highest) RCPs of IPCC AR5.

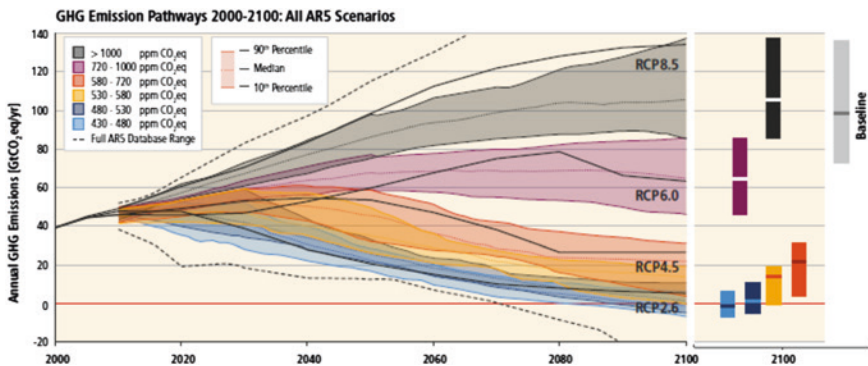


Fig. 2.2 The range of scenarios that were considered in the IPCC 5th Assessment Report. Source IPCC (2014)

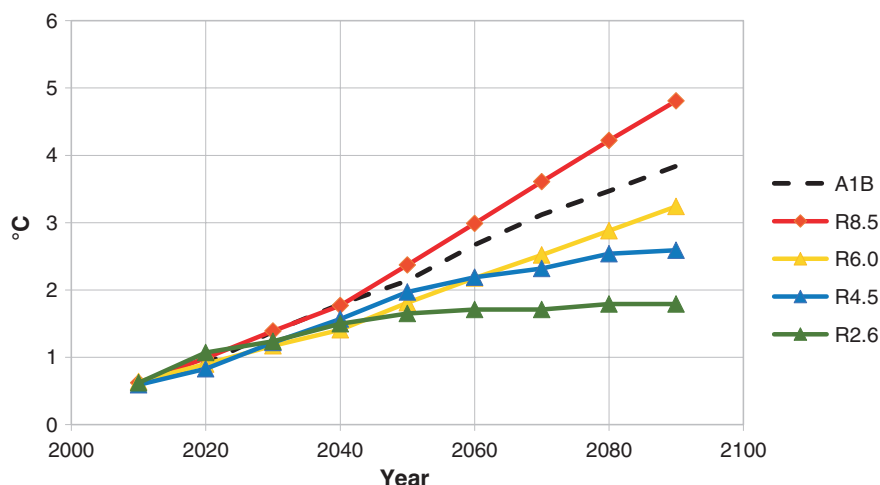


Fig. 2.3 Comparison of predicted changes in global mean surface temperature (compared to the 1986–2005 period) according to the modest A1B emission scenario of IPCC (2007a) and the four different RCPs developed by IPCC (2014). *Source* Panos Hadjinicolaou, The Cyprus Institute, Nicosia, Cyprus (personal communication, 2015)

GHG mitigation scenarios in which it is likely that the temperature increase caused by anthropogenic GHG emissions can be kept to less than 2 °C relative to preindustrial levels (which is a widely stated policy objective) are characterised by atmospheric concentrations in 2100 of about 450 ppm CO_{2eq}. This can only be achieved through substantial cuts in anthropogenic GHG emissions by mid-century, thanks to large-scale changes in energy systems including serious energy efficiency improvements and a substantial shift to low- or zero-carbon energy systems. Scenarios reaching these concentrations by 2100 are characterised by lower global GHG emissions in 2050 than in 2010 and near-zero emission levels by the end of the century.

At the other end of the projections, ‘business as usual’ emission scenarios lead to concentrations that may exceed 650 ppm CO_{2eq} by 2100, and these are very unlikely to limit temperature change to below 2 °C relative to preindustrial levels. This is confirmed by many global emission forecasts. For example, the Organisation for Economic Co-operation and Development (OECD) *Environmental Outlook* baseline scenario envisaged that without more ambitious policies than those in force today, GHG emissions would increase by another 50 % by 2050, primarily driven by a projected 70 % growth in CO₂ emissions from energy use due to an 80 % increase in global energy demand (OECD 2015). More recently, both the International Energy Agency and the OECD, shortly before the start of the international climate summit in Paris in November 2015, stated that national carbon emission mitigation targets and policies up to that date

were clearly insufficient to reach the 2 °C target and that stronger actions were necessary in order to remain on track for a '2 °C world' (IEA 2015; OECD 2015).

2.2 Global Projections

2.2.1 Temperature

Future climate will depend both on warming caused by already existing greenhouse gases in the atmosphere due to past anthropogenic emissions and on future anthropogenic emissions and natural climate variability. The upper part of Fig. 2.4 illustrates the main temperature projections of the IPCC AR5. Assuming that there will be no major event such as volcanic eruptions, changes in solar irradiance or changes in natural sources of GHG emissions, global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will likely be in the range of 0.3–0.7 °C. It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, and it is very likely that heatwaves will occur with a higher frequency and longer duration.

Relative to 1850–1900, global surface temperature change for the end of the twenty-first century (2081–2100) is projected to likely exceed 1.5 °C for RCP4.5, RCP6.0 and RCP8.5 scenarios. Warming is unlikely to exceed 2 °C only for RCP2.6. Moreover, the Arctic region is expected to continue to warm more rapidly than the global mean.

2.2.2 Sea-Level Rise

Recent IPCC AR5 projections of sea-level rise are displayed in the lower part of Fig. 2.4. Global sea level is rising mainly because of:

- thermal expansion of warming ocean water;
- addition of new water from ice sheets of Greenland and Antarctica, from glaciers and ice caps;
- addition of water from land surface run-off (IPCC 2007b).

The new projections show an increase of 0.26–0.55 m by 2100 under a low-emission scenario and 0.52–0.98 m under the high-emission scenario. By contrast, the previous IPCC report (AR4) did not include some of the effects of ice sheet movement due to warming and therefore published much lower estimates in the range of 0.18–0.38 and 0.26–0.59 m under a low- and high-emission scenario, respectively, by 2100.

It is also likely that the Arctic Ocean will be ice-free during part of the summer before 2050 under a high-emission scenario. This represents a large change from

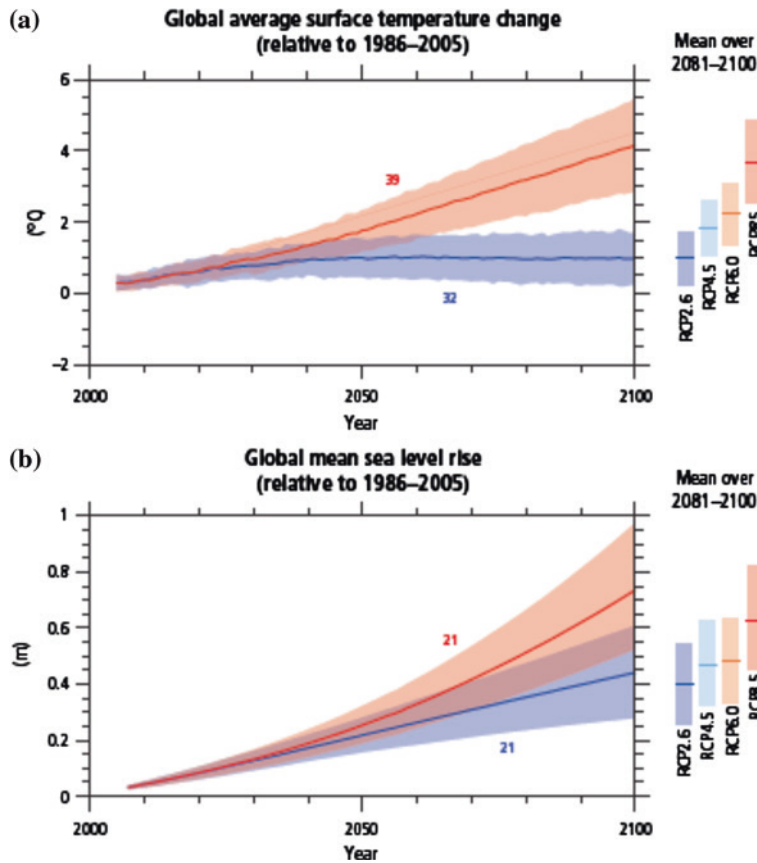


Fig. 2.4 Global average surface temperature change and global mean sea-level rise according to the four RCPs of IPCC (2014)

the AR4, which estimated that the Arctic Ocean would not be ice-free during the summer until late in the twenty-first century. The AR5 finds that Arctic sea ice surface extent has decreased by 3.5–4.1 % per decade (9.4–13.6 % during summer), which is higher than the corresponding AR4 estimate.

2.2.3 Precipitation

Changes in precipitation will not be uniform. The high latitudes and the equatorial Pacific are likely to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation is expected to decrease, whilst in many mid-latitude wet regions, mean precipitation will likely increase (RCP8.5 scenario). Extreme precipitation events

over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent (IPCC 2014).

2.3 Projections for Europe and the Mediterranean

2.3.1 *Past Trends and Projections for Europe*

There is a significant agreement amongst recent studies that all emission scenarios will lead to higher temperatures all over Europe, with strongest warming projected in Southern Europe in summer and in Northern Europe in winter (JRC 2014; Kjellström et al. 2011). Since the 1980s, warming has been strongest over Scandinavia, especially in winter, whereas the Iberian Peninsula warmed mostly in summer (EEA 2012). The decadal average temperature over land area for 2002–2011 is 1.3 ± 0.11 °C above the 1850–1899 average.

Although many features of the simulated climate change in Europe and the Mediterranean are qualitatively consistent amongst models, there are uncertainties that reflect the sensitivity of the European climate to the magnitude of global warming and the changes in atmospheric circulation. The main uncertainty is the substantial natural variability of European climate, particularly for short-term climate projections (IPCC 2007a). The most important projections for Europe are summarised below (EEA 2012; IPCC 2014):

- Temperature increases from 1.0 to 5.5 °C are expected by 2100, which is higher than the projected global warming (1.8–4.0 °C), with the largest warming over Eastern and Northern Europe in winter and over Southern Europe and Mediterranean in summer.
- Changes in precipitation show more spatially variable trends across Europe. Annual precipitation has increased in Northern Europe (up to +70 mm per decade) and decreased in parts of Southern Europe.
- The intensity of precipitation extremes has increased in the past 50 years, and these events are projected to become more frequent.
- High-temperature extremes (hot days, tropical nights and heatwaves) have become more frequent, whilst low-temperature extremes (cold spells, frost days) have become less frequent.
- Winter snow cover has a high interannual variability and an insignificant negative trend over the period 1967–2007 (Henderson and Leathers 2010).
- Europe is marked by increasing mean sea level with regional variations, except in the northern Baltic Sea, where the relative sea level decreased due to vertical crustal motion (Menéndez and Woodworth 2010; Albrecht et al. 2011; EEA 2012).
- Mean wind speeds have declined over Europe over recent decades (Vautard et al. 2010)—although this finding should be treated with caution because of problematic anemometer data and climate variability.

2.3.2 Projections for the Mediterranean

The Mediterranean Sea region, especially the southern and eastern rim, has been identified as one of the main climate change hot spots (i.e. one of the areas most sensitive to climate change) in the world due to water scarcity, concentration of economic activities in coastal areas and reliance on climate-sensitive agriculture. However, the region itself emits low levels of greenhouse gases compared to other areas in the world. CO₂ emission data show that in 2009, the Mediterranean countries together emitted 6.7 % of the world's emissions, equivalent to more than 2 billion tonnes of CO₂. This amount has increased by a factor of 4 in the last 50 years, with an increase in the contribution from countries from the southern region of the Mediterranean from 9 to 30 %. Meanwhile, the contribution of all EU Mediterranean countries has decreased over the same period from 88 to 54 %.

Satellite altimetry data show that the mean sea level of the Mediterranean increased by 2.6 cm in the period 1992–2008. This change seems to be lower than global sea-level rise, which has reached a rate of 3.0–3.5 mm/year since 1992. This different behaviour indicates that being a semi-enclosed basin, the Mediterranean does not respond linearly to the influences of the open ocean on the timescale in question (Vigoda et al. 2011).

The Mediterranean region lies in a transition zone between the arid climate of North Africa and the temperate and rainy climate of Central Europe and is affected by interactions between mid-latitude and tropical processes. Because of these features, even relatively minor modifications of the general circulation in the atmosphere can lead to substantial changes in the Mediterranean climate. This makes the Mediterranean a potentially vulnerable region to climatic changes. In the last decades in the Mediterranean region, temperatures have risen faster than the global average and model projections agree on its future warming and drying, with a likely increase of heatwaves and dry spells, especially since it is expected to experience high temperature increases, reduced precipitation and more frequent droughts—which adds to the already existing water scarcity (Lionello et al. 2014).

Based on the latest comprehensive climate change vulnerability assessment carried out by the European Environment Agency (EEA 2012), the Mediterranean region is projected to experience:

- Temperature increases that will be larger than the European average;
- Lower annual precipitation levels and decreased annual river flows;
- Increased risks of biodiversity loss and desertification;
- Adverse effects on forest fires, summer tourism, agricultural production and public health.

Collaborative research projects have attempted to describe in detail how the climate is expected to change in Europe under various emission scenarios. For example, by using regional climate model simulations, the ENSEMBLES project evaluated many indicators. Projections of the ENSEMBLES project on changes in

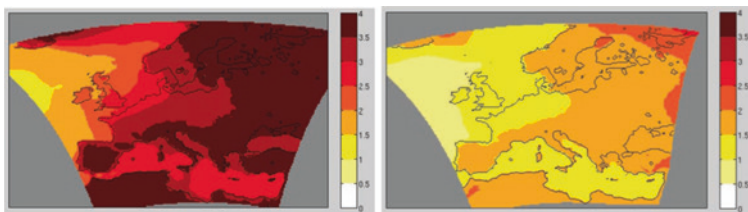


Fig. 2.5 Projected changes in annual mean surface air temperature under the IPCC AR4 A1B scenario, 2021–2050 (*left*) and 2071–2100 (*right*). *Source* van der Linden and Mitchell (2009)

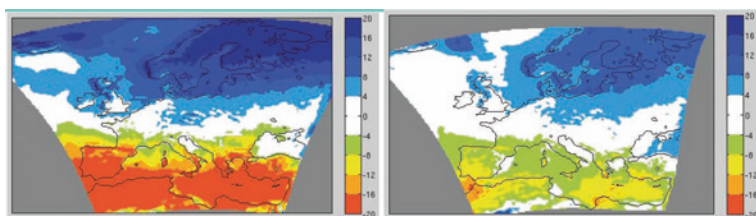


Fig. 2.6 Projected changes in annual precipitation under the IPCC AR4 A1B scenario, 2021–2050 (*left*) and 2071–2100 (*right*). *Source* van der Linden and Mitchell (2009)

annual mean surface air temperature and annual precipitation over Europe are presented in Figs. 2.5 and 2.6, respectively.²

The PESETA project (Projection of Economic Impacts of Climate Change in Sectors of the European Union based on Bottom-Up Analysis) was a major project carried out mainly by the Joint Research Centre of the European Commission. In its first phase (JRC 2009), it examined three important indicators—temperature, precipitation and sea-level rise—and their projected evolution up to the 2071–2100 period based on the IPCC AR4 scenarios A2 and B2, by using data from several standardised high-resolution climate projections. It was clear from the project results that the most adverse effects around Europe (in terms of temperature increase and fall in precipitation) are expected to occur in South Europe.

The PESETA II project (JRC 2014) updated and expanded the previous analysis. Distinguishing between five regions (Northern Europe, UK and Ireland, Central Europe, Central Europe South and Southern Europe), it employed a bottom-up approach to analyse ten biophysical impact categories (agriculture, energy, river floods, droughts, forest fires, transport infrastructure, coasts, tourism, habitat suitability of forest tree species and human health) considering a broad range of climate model simulations. Results for most of these impact categories were

²Graphs and results reproduced here are from the EU-funded project ENSEMBLES (Contract number 2003-505539) (van der Linden and Mitchell 2009)—more details can be found on the website www.ensembles-eu.org.

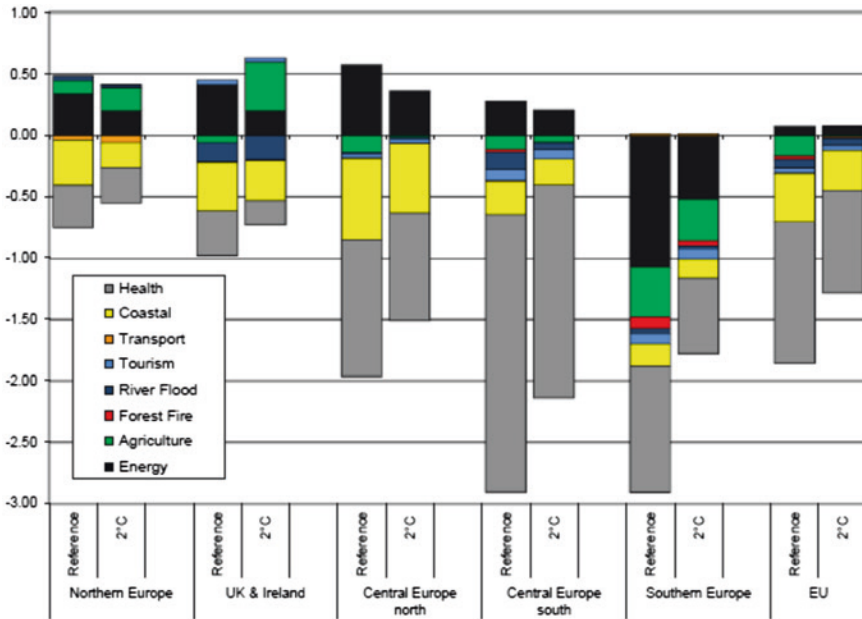


Fig. 2.7 Projected impact on economic welfare (as a percentage of GDP) for two climate change scenarios according to results of the PESETA II project (JRC 2014)

then entered in an economic model to assess economic and welfare effects of the climate scenarios. Impacts were evaluated for three emission scenarios covering a range of low-emission to high-emission pathways.

Results indicate that, for a ‘reference’ scenario without serious mitigation of greenhouse gas emissions, annual climate-related damage around Europe may amount to 190 billion euros or 2 % of EU’s gross domestic product (GDP). The most interesting finding is that the geographical distribution of these climate damages is asymmetric, with a clear bias towards Southern European regions. As shown in Fig. 2.7, welfare losses range from 0.2 % of GDP in Northern Europe to 3 % of GDP in the Central Europe South and Southern European regions, i.e. fifteen times higher than the damage in Northern Europe. The highest welfare losses will occur in Southern Europe (€74 billion) and Central Europe South (€58 billion)—in fact, the damage in the two southern regions will account for more than two-thirds of total EU-wide costs. Most of the economic losses are expected to come from increased mortality, coastal damages and costs of reduced agricultural production.

The MedCLIVAR project (Lionello 2012) has also focused on the Mediterranean’s climate conditions and future changes. In the frame of that project, Dubrovský et al. (2014) have used results from sixteen global circulation models and found that most models agree that there will be an increase in temperature in all seasons and for all parts of the Mediterranean by the end of the twenty-first century. Precipitation is

projected to decrease in almost all parts of the region and in all seasons, but especially in summer. A significant decline of soil moisture is also forecast, with the most significant decrease occurring in summer. Temperature maxima will increase not only because of an overall rise in mean temperature, but to some extent also because of increases in temperature variability and daily temperature range. Higher daily precipitation extremes and longer drought spells are expected all across the region. Regional climate models for the Mediterranean, obtained through ‘downscaling’ of global circulation models, also agree in terms of temperature increases—although there are more discrepancies amongst models as regards projections of precipitation and weather extremes (Jacobeit et al. 2014).

As regards especially the Eastern Mediterranean, two recent studies by Greek and Israeli authorities, based on the IPCC AR4 scenarios, provide valuable information that is of interest to Cyprus.

The report ‘Environmental, economic and social impacts of climate change in Greece’, prepared for the Bank of Greece (2011), assesses the main climatic indicators and presents projections on many important parameters for the Greek territory. According to its findings:

- The mean annual air temperature for the periods of 2021–2050 and 2071–2100 in relation to the reference period 1961–1990 will increase in the entire territory of Greece.
- Precipitation will decrease, with a more intense reduction for the A2 and A1B emission scenarios.
- Mean sea-level rise for Greece has been based on IPCC projections, but the study adds the importance of other factors for the estimation of the vulnerability of a coastal area to sea-level rise, such as tectonics, sediments and coastal geomorphology.

Furthermore, Israel’s Second National Communication on Climate Change (Israel’s Ministry of Environmental Protection 2010) that was prepared for the UNFCCC forecasts:

- A seasonal rise in air temperature of 1.5–2.0 °C in the south-eastern Mediterranean over a thirty-year period.
- An average temperature increase of 5 and 3.5 °C according to projections based on emission scenarios A2 and B2, respectively, in the years 2071–2100, compared to 1961–1990.
- A 10 % decrease in precipitation in Israel by 2020, reaching a 20 % decrease by 2050.
- An increase in the number of days with extreme temperatures and in the number of extreme rainfall events, along with a decrease in the amount of seasonal rain.
- Sea-level rise in the Israeli waters of about 0.5 m by 2050 and approximately 1 m by 2100.

Other climate modelling studies that focused on the Eastern Mediterranean and are of direct relevance for Cyprus are discussed in Sect. 2.4.2.

2.4 Past Trends and Projections for Cyprus

2.4.1 Trends in Major Climate Variables

At a latitude 35° north and a longitude 33° east, Cyprus has an intense Mediterranean climate, with hot dry summers from mid-May to mid-September and rainy, rather changeable, winters from November to mid-March. The meteorology of the island is significantly affected by the two mountainous areas shown in Fig. 1.1: The central Troodos massif, rising to 1951 m, and the long narrow Kyrenia mountain range, with peaks of about 1000 m. The predominantly clear skies and high amounts of sunshine (a typical year includes more than 300 days of sunshine) give rise to large seasonal and daily differences between temperatures of the sea and the interior of the island, which also cause considerable local weather effects. In summer months of July and August, the mean daily temperature ranges between 29 °C on the central plain and 22 °C on the Troodos mountain, whilst the average maximum temperature for these months ranges between 36 and 27 °C, respectively. In January, the mean daily temperature is 10 °C on the central plain and 3 °C on the highest parts of the Troodos mountain, with an average minimum temperature of 5 and 0 °C, respectively (CMS 2015).

Observations from the beginning of the twentieth century show an increasing trend in the annual mean temperature in Cyprus, with a rate of increase of 0.01 °C per year. Overall, a warming of approximately 1–1.58 °C has been observed over the twentieth century. This increase exceeds the mean global temperature rise observed for the same period. The rates of change of precipitation and temperature have been greater during the second half of the twentieth century. According to the Cyprus Department of Meteorology,³ most of the warm years in the century have been recorded after 1990.

As illustrated in Fig. 2.8, a temperature increase has been recorded both in towns and in rural areas of the country. The stronger urban heat island effect played an important role in the temperature increase in towns; however, the increase in temperature in rural areas is indicative of the regional or global climate changes during the last decades. This finding is reinforced by satellite remote sensing data and in situ measurements of sea surface temperatures, which indicate that a general warming has occurred in the Levantine basin (the easternmost part of the Mediterranean Sea) over the period 1996–2006, both at interannual and at seasonal timescales (Samuel-Rhoads et al. 2009).

Moreover, changes in the diurnal temperature range have been recorded during the twentieth century; minimum daily temperatures have generally increased more than the maximum daily temperatures, resulting in a decrease in the long-term diurnal temperature range. This decrease is very similar to some of the coastal

³See the Department's web page (<http://www.moa.gov.cy/ms>) for graphs and brief reports about the climate of Cyprus.

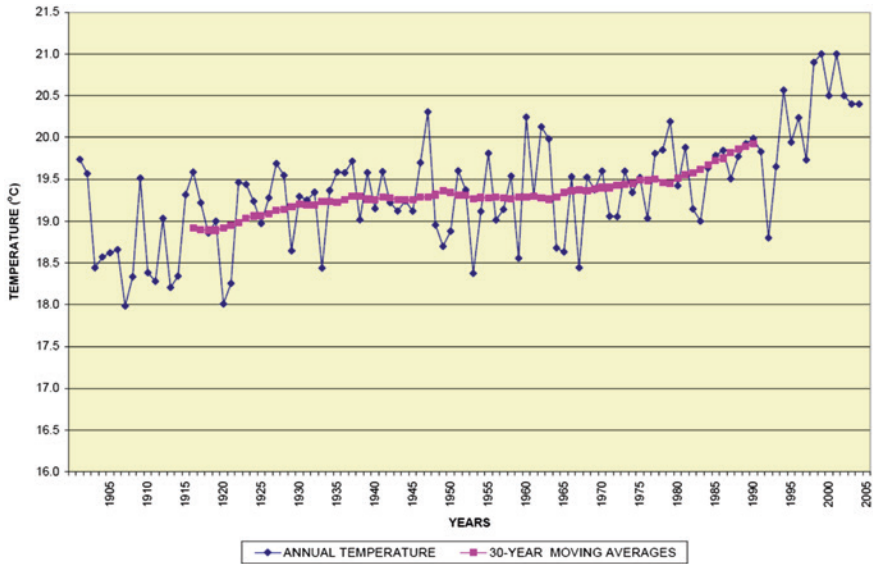


Fig. 2.8 Evolution of annual mean temperature in Nicosia (1901–2005). *Source* Official data cited by Shoukri and Zachariadis (2012)

stations from southern Israel, which show higher minimum temperatures but lower maximum temperatures (Price et al. 1999).

Figure 2.9 displays the evolution of mean annual precipitation in the country, which demonstrated a decreasing trend over the twentieth century. The rate of decrease was 1 mm/year on average. The decrease in mean precipitation was larger during the second half of the twentieth century because years with low precipitation or drought occurred more frequently in comparison with those in the first half of the century: average annual precipitation in the first 30-year period of the twentieth century was 559 mm, whilst average precipitation in the last 30-year period was 462 mm, which corresponds to a decrease of 17 %.

No consistent data series are available for sea-level rise at the coasts of Cyprus. Vertical land movement/tectonics must be taken into consideration, amongst other parameters, for the estimation of sea-level rise for the Cyprus seas, since there is evidence that these parameters are counterbalancing any climate change-induced sea-level rise (Bank of Greece 2011).

2.4.2 Projections

Results of climate models were presented in Sect. 2.3 for Europe or the Mediterranean as a whole need to be refined in order to provide meaningful projections for the island of Cyprus. For several reasons, detailed regional climate

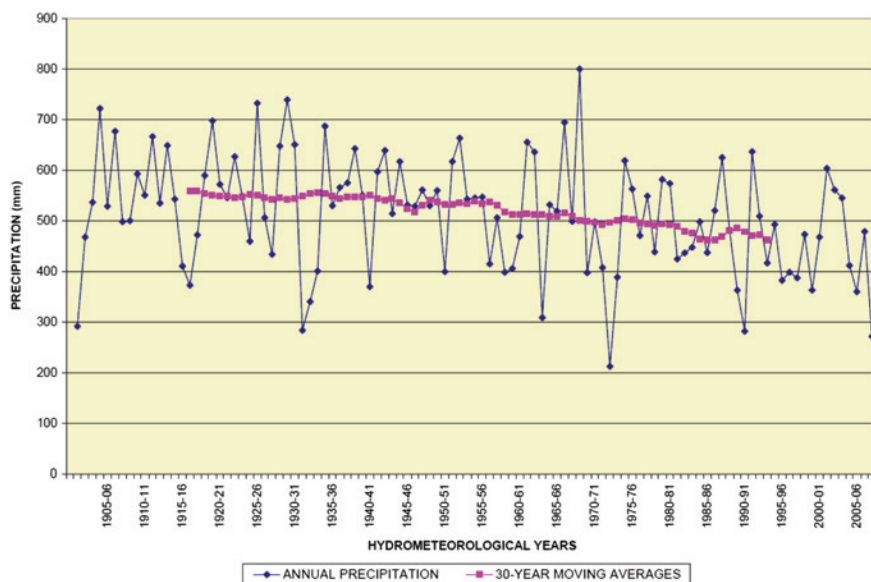


Fig. 2.9 Evolution of annual precipitation in Cyprus (1901–2006). *Source* Official data cited by Shoukri and Zachariadis (2012)

model (RCM) simulations are necessary instead of the more aggregate global circulation models (GCMs). The current horizontal resolution of GCMs used in century-long climate simulations is around 150 km, which does not resolve regional climate forcings associated with orography, coastlines and land surface properties. In order to adequately quantify potential impacts of climate change, climate projections are needed at a much finer resolution than that of GCMs—of a few tens of kilometres or less; this can be achieved through ‘downscaling’ methodologies. These can be classified as ‘statistical downscaling’ approaches, such as the ones reviewed by Jacobeit et al. (2014), or ‘dynamic downscaling’ methods like those mentioned below. Moreover, as Aufhammer et al. (2013) explain in detail, the use of GCMs for examining economic effects of climate change may lead to substantial errors due to aggregation bias; properly developed RCMs greatly improve the reliability of these impact assessments.

There have been some efforts applying different mesoscale models or RCMs to project the effects of anthropogenic global warming in the Eastern Mediterranean (EM) region by the end of this century. Önoğlu and Semazzi (2010) concluded that temperature would increase by 4 °C and precipitation decrease by 20–30 %. Evans (2009) found a temperature increase of 2–4 °C in winter and 2–6 °C in summer. Precipitation decreased strongly (by 30–50 %) in winter along the EM coast. Lelieveld et al. (2012) presented a comprehensive regional climate assessment and discussed potential impacts of future climate change in the EM region based on projections from the PRECIS RCM. With emissions following the IPCC AR4 A1B

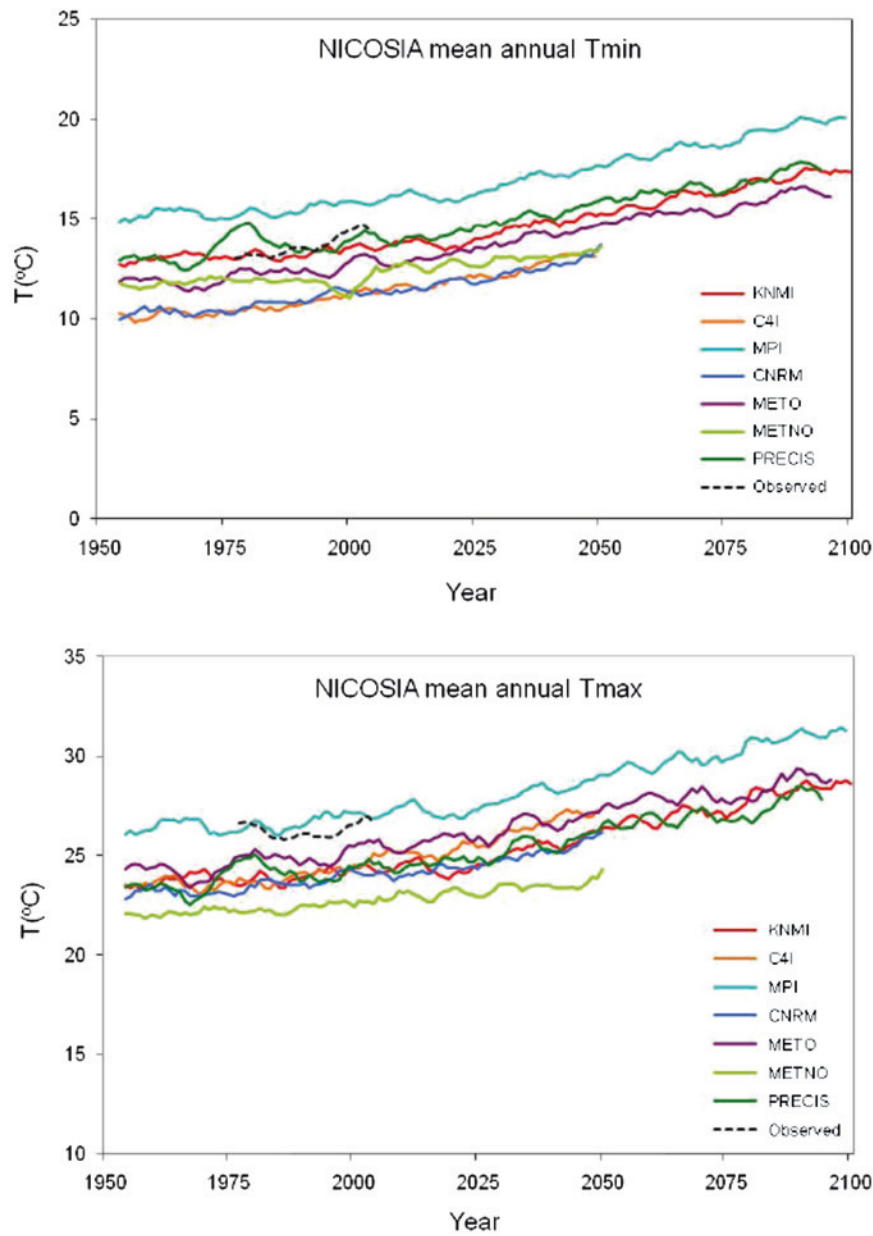


Fig. 2.10 Time series of mean annual minimum (Tmin) and maximum (Tmax) temperatures in Nicosia, according to observations and regional climate model projections. *Source* Giannakopoulos et al. (2012)

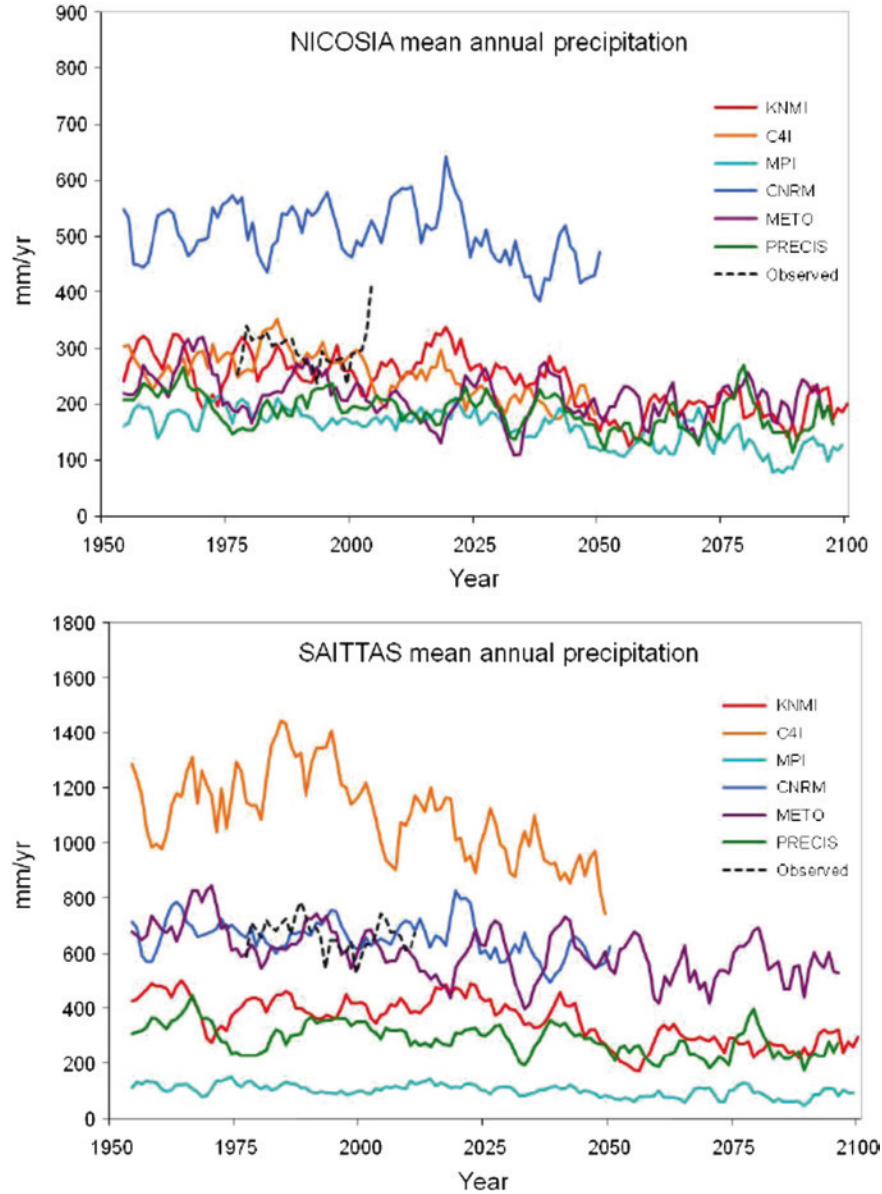


Fig. 2.11 Time series of mean annual precipitation in the city of Nicosia and a semi-mountainous area of Cyprus, according to observations and regional climate model projections. *Source* Giannakopoulos et al. (2012)

scenario, they found a gradual warming of about 3.5–7 °C throughout the twenty-first century compared to 1961–1990. They also demonstrated that this simulation was able to capture the mean climatic conditions as well as the increasing temperature tendency of the twentieth century in the region. For Cyprus, PRECIS projects:

- An almost linear warming throughout the twenty-first century up to +4 °C by the end of the century, with large interannual variability. Summer warming is projected to be approximately 1 °C larger than winter warming (Hadjinicolaou et al. 2011).
- Intense heat extremes. Lelieveld et al. (2014) analysed the PRECIS output for Nicosia (amongst other capitals in the EM region) and found that heatwave duration could increase by 7–10 times by 2099, exceeding 4 months per year, and that the coolest summers at the end of the century will be warmer than the hottest ones in the recent past.
- Rainfall decrease by 2–8 % (although this was not statistically significant).
- Lower precipitation frequency in the areas of Nicosia (inland) and Limassol (coast), whilst mountainous areas could experience a somewhat more frequent rainfall.
- An increase in the number of summer days by more than two weeks per year.
- A significant rise in the number of tropical nights—they are projected to increase by around one month per year.

Further simulations with PRECIS, followed by comparisons with six additional regional climate models used in the ENSEMBLES project mentioned in Sect. 2.3.2, reinforce these findings (Giannakopoulos et al. 2012). Figures 2.10 and 2.11 display the projected evolution of minimum and maximum temperatures and annual precipitation levels in the capital city of Nicosia, respectively, according to the different models employed by the authors. As has already been mentioned in Sect. 2.3, agreement between models is stronger in forecasts of temperature changes rather than in precipitation projections.

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