Review of global change pressures on Urban Water Cycle Systems. Assessment of TRUST Pilots

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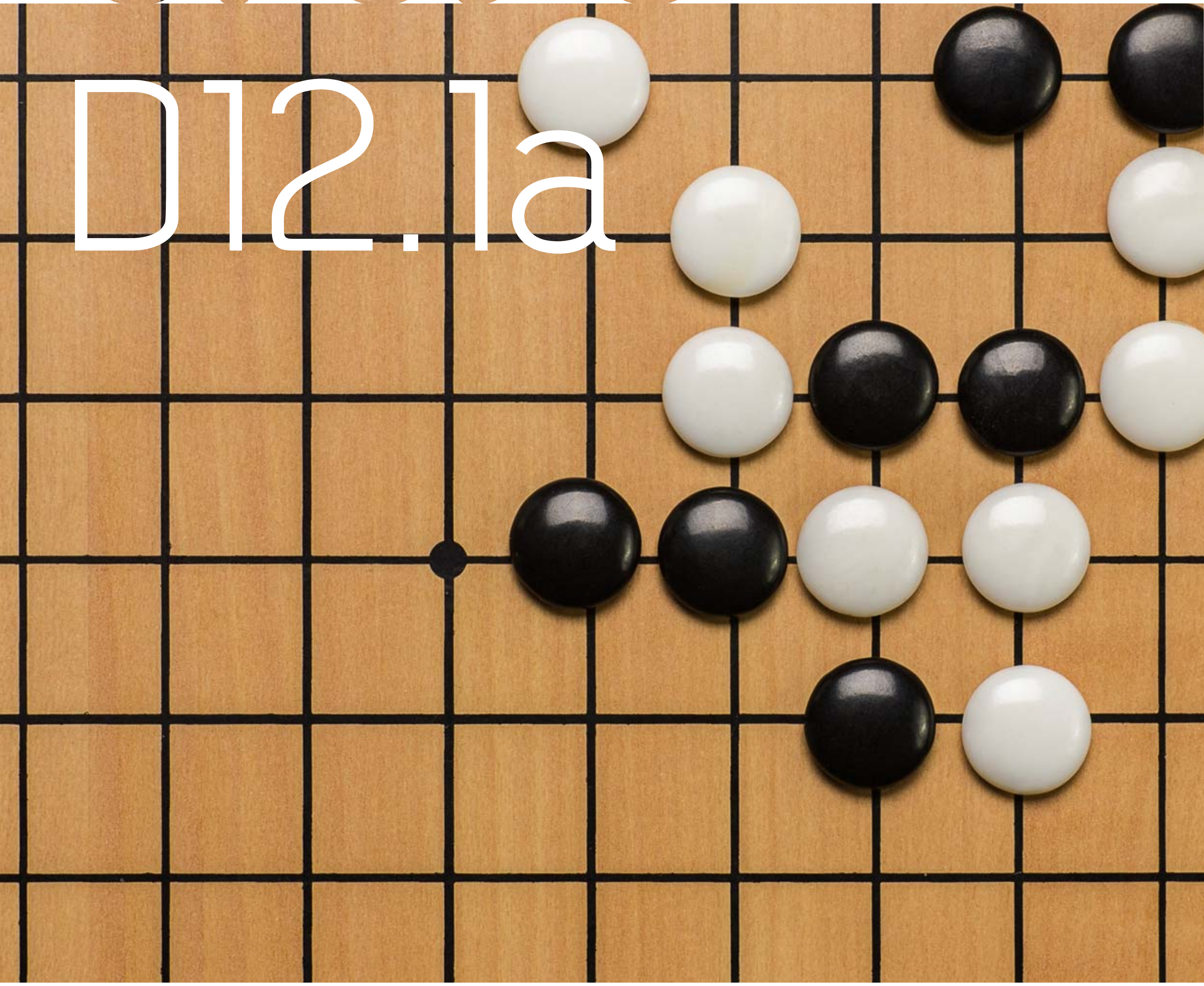

TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

Review of global change pressures on Urban Water Cycle Systems. Assessment of TRUST Pilots - D12.1a

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1. SUSTAINABILITY ON URBAN WATER CYCLE SERVICES

In urban areas, the combined effects of water stress, urbanisation, population growth, as well as economic and other constraints affect natural landscapes and the hydrological response of watersheds. In fact, urban hydrological cycles are becoming more complex because of many anthropogenic influences and interventions. Figure 1 shows a detailed picture of the urban water cycle. Figure 2 presents a schematic view, displaying the major components and pathways of this cycle, as well as the related Urban Water Cycle Services (UWCS) provided to populations: water supply (drinking or non-drinking); collection, treatment and disposal or reuse of wastewater; and management of rain water and other natural water resources.

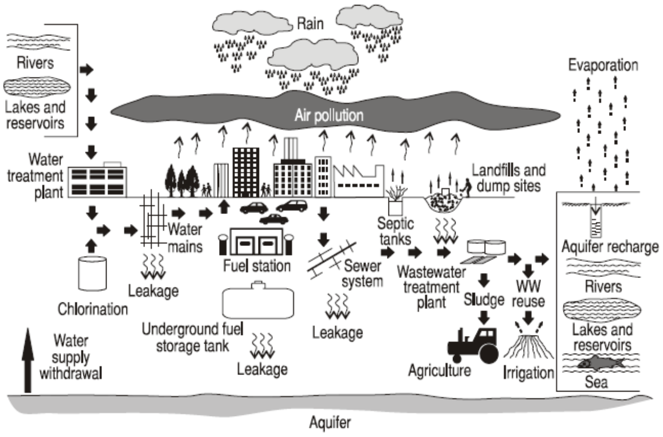


Figure 1 - Urban water cycle (Marsalek et al. 2006)

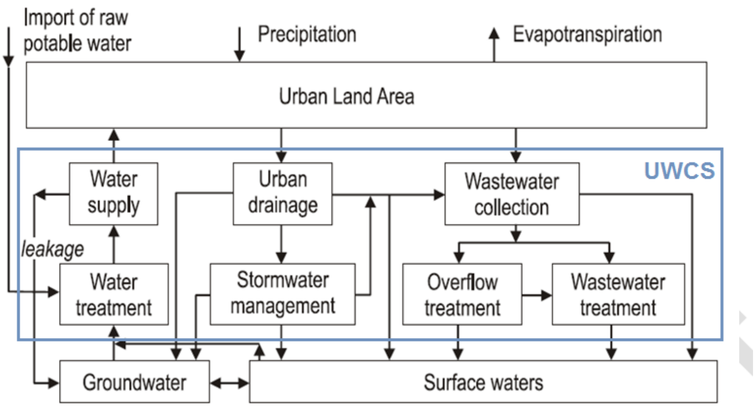


Figure 2 - Urban water cycle – main components and pathways (adapted from Marsalek et al. 2006)

Along with the rest of the world, the water sector is constantly changing through rapid progress or through slow and steady evolution. Either way, different types of pressures with direct or indirect effects on water systems may lead to future risks and stresses, which the sector will have to accommodate. That justifies the importance of considering urban water systems from the point of view of sustainability.

The sustainability concept is frequently associated with the triple bottom line (TBL) approach, comprised by social, environmental and economic dimensions or principles (Figure 3). These dimensions can be seen as aggregated objectives relative to a particular sector that should be developed. However, several authors consider the TBL approach insufficient, defending the need to include other dimensions to the concept of sustainability, like technical, public health, cultural, human rights, infrastructural, governance and others.

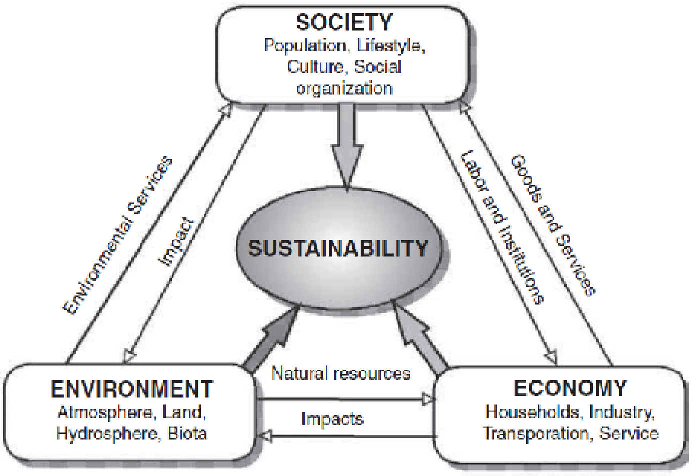


Figure 3- The trinity of factors and impacts determining sustainability (Novotny et al., 2010).

Although the sustainability TBL approach based on the three basic dimensions is not unanimous, all the other approaches include these three basic dimensions. Therefore, for this review it was considered more useful to frame all the pressures that can affect the UWCS in these three TBL basic dimensions: social, environmental and economic. This is clearly in line with the TRUST definition of sustainability, which states that *Sustainability in UWCS is met when the quality of assets and governance of the services is sufficient to actively secure the water sector's needed contributions to urban social, environmental and economic development in a way that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

The rationale for considering the supporting dimensions of assets and governance is to make explicit two important supporting dimensions for complex infrastructure-based systems like UWCS. They are taken into account throughout the report and they will link with the challenges analyzed in the TRUST Report addressing flexible UWCS and transitional pathways (see Smith et al. 2012) (Figure 4).

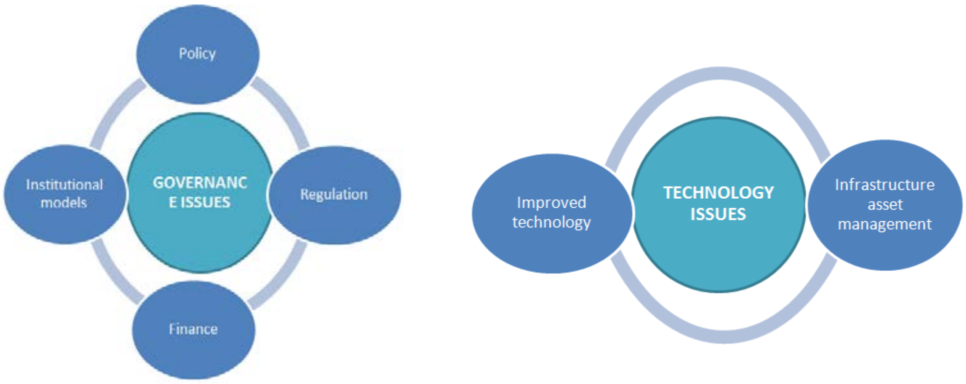


Figure 4 - Main governance and technology components to be considered in Urban Water Cycle Systems

The design of appropriate tools to deal with future stresses requires an understanding of the potential pressures, either opportunities or threats. This report identifies and describes different pressures of critical importance for the water sector, taking into account that global trends often take diverse forms and have dissimilar impacts on a local scale. Chapter 1 introduces the UWCS components and the sustainability approach considered in this context. In Chapter 2 the different pressures affecting UWCS are framed according to the sustainability dimensions: environmental, social and economic. A general description of relevant pressures is presented in terms of context situation, geographic dependency and expected tendencies for the future. Chapter 3 identifies possible future trends on UWCS according to those pressures. Their consideration will allow many countries to undergo considerable changes and to define strategies to solve impending problems and exploit emerging opportunities. Based on the identified trends for the water sector, Chapter 4 presents the prediction of major global change pressures and its impacts on Pilots of TRUST. The two annexes of this report present the principal climatic drivers, in terms of the future projection of weather variables (precipitation and temperature) in the areas of the TRUST pilot cities.

2. FUTURE PRESSURES ON URBAN WATER CYCLE SERVICES

It is important to acknowledge existing and future pressures to Urban Water Cycle Systems as they present major threats to the sustainability of water services. Their early identification maximizes the ability to adapt to them, making possible the development of strategies and the adoption of measures to eliminate or reduce risks at an early stage.

This chapter identifies and describes different pressures of critical importance for the water sector, taking into account that global trends often take diverse forms and have dissimilar impacts on a local scale. Although maintaining a worldwide vision, their identification is focused on the most relevant issues for Europe, as most of the TRUST Pilots are European.

Pressures are framed according to the trinity of sustainability factors, i.e., according to the environmental, social and economic dimensions, and in accordance with the sustainability definition of TRUST. These pressures are further developed in sections 2.1, 2.2 and 2.3, respectively. Figure 5 shows the sub-issues into which pressures were broken down. Environmental pressures comprise water stress, including water quantity and quality problems, and the expected consequences of climate change. Social pressures take demography into account, analyzing the structure and distribution of societies. People's expectations are also mentioned, particularly in what concerns culture, education, preferences and confidence on services. At last, economic pressures focus on globalization in order to analyze its effects on the global economy, escalating and variable costs and increased conflicts. Finance issues are also developed, namely financing difficulties and tariff structures for water services.

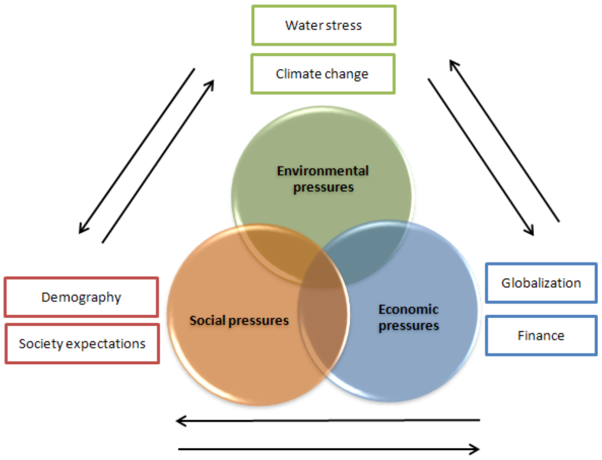


Figure 5 - Global change pressures according to the 3 sustainability dimensions

Although some of these sub-issues belong to more than one of the sustainability dimensions, they were included in the most relevant one, with references to other related factors. The interdependence of pressures is further analyzed in section 2.4. Finally, it has to be noticed that pressures will affect a range of factors such as Governance and Technology components, as presented in Figure 4. Those components were considered throughout the report and they are taken into account throughout the report and they will link with the challenges analyzed in the TRUST Report addressing flexible UWCS and transitional pathways (see Smith et al. 2012).

2.1. Environmental pressures

Water stress occurs when the demand for water exceeds the available amount during a certain period. It may result from a reduction in fresh water resources availability (aquifer over-exploitation, dry rivers, etc.) or from the deterioration of its water quality due to e.g., eutrophication, organic matter pollution or saline intrusion (EEA, 2011a). Global stresses on water are expected to increase and climate change is likely to exacerbate all those pressures. Figure 6 identifies the considered environmental pressures affecting UWCS, which will be further developed in the next section.

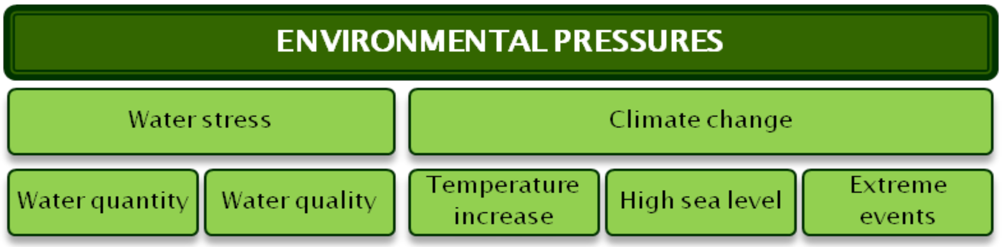


Figure 6 - Environmental pressures affecting Urban Water Cycle Services

2.1.1. Water stress

- **Water quantity**

Agricultural production is currently accountable for 85% of global water consumption (Shiklomanov and Rodda, 2003) and is projected to double by 2050 (Tilman et al., 2002), accelerated not only by increasing population, rising incomes and changes in dietary preferences, but also expanded global production of biological energy sources. Irrigated area is expected to rise by a factor of 1.9 by 2050 (Lobell et al., 2008) and several important agricultural areas are already suffering increasing water scarcity problems (Pfister et al., 2011).

In addition to agricultural production, other activities with a lower impact on water quantity need to be considered. For instance, tourism activities with seasonal characteristics have a special impact on water consumption and therefore on wastewater production. The water consumption per hotel guest is usually much higher than per capita, turning water supply for tourism into a potential pressure in water scarcity areas (Ellis et al., 2006).

By the year 2025, it is predicted that water abstraction will increase by 50 percent in developing countries and 18 percent in developed countries (UN-Habitat, 2003). If current consumption patterns continue, two-thirds of the world's population will live in water-stressed conditions by 2025. As developing countries are addressing problems of hunger and malnutrition, per capita water availability worsens. In fact, scarcity of freshwater is already felt acutely in Africa and West Asia and it is considered an economic constraint in major growth countries like China, India and Indonesia, as well as in commercial centres in Australia and in the western United States (UNESCO, 2009). Furthermore, water scarcity problems are no longer limited to cities located in arid zones. They are also happening in some rapidly growing cities in humid areas that rely on relatively small water resources or draw water from limited groundwater resources (Novotny et al., 2011).

Lastly, it is important to mention that continued efforts against increasing numbers of natural disasters are indispensable. Globally, the number of natural disasters that occur and the cost of the damage they cause are increasing. Regional distribution shows that Asia is the region most prone to water-related casualties like floods, windstorms and slides. Africa comes next, particularly prone to water-borne epidemics, and is followed by the Americas, Europe and Oceania (Adikari and Yoshitani, 2009). In particular, droughts represent a serious and growing threat. In recent years, they have had an estimated total price tag of around 6 billion Euros per year for EU countries (ERCC, 2009).

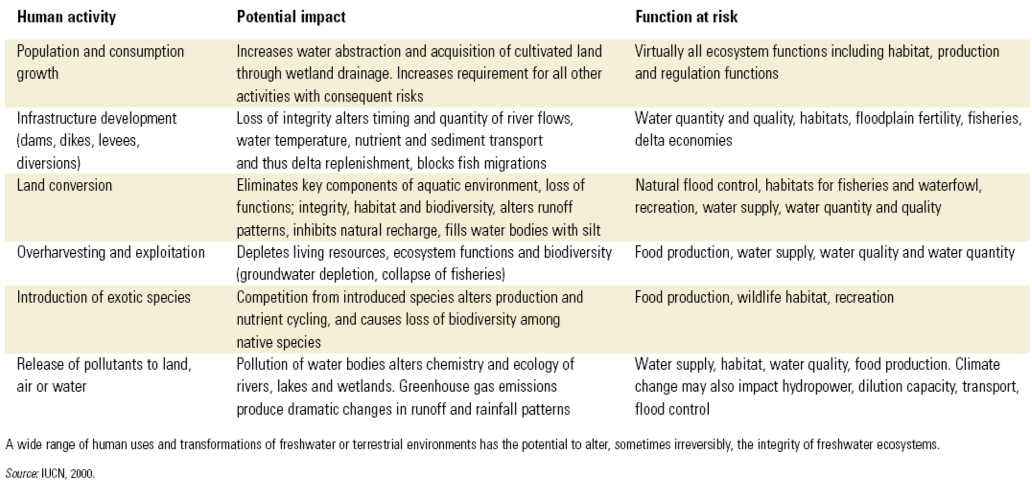
- **Water quality**

Human health requires access to a sufficient amount of good-quality water and it may be impaired via freshwater and marine recreation, the consumption of contaminated freshwater and seafood, inadequate sanitation and a lack of access to safe drinking water (EEA, 2010). Although these sources of health risks are increasingly being dealt with by water services, new challenges keep arising. Different chemicals are being introduced in the industry (e.g. medical pollutants), agriculture and households, creating greater risk to the drinking water system if they contaminate water sources, as a result of accidents or continuous discharging. These pollutants are usually more harmful and more difficult to remove from water than the current known pollutants (Rósen and Lindhe, 2007). New biological pollutants are also receiving more attention, as the case of the avian flu virus showed. Genetically modified bacteria and nano particles are developing rapidly and, while little conclusive research has been conducted for the water sector, many of those products are already on the market (Segrave et al., 2007).

Another challenge are the newly discovered or emerging pathogens with different and variable infection patterns, resulting in new, recurring or drug-resistant infections, These pathogens pose a severe risk to human health if they can overcome the microbial barriers of a water supply system, The factors that are responsible for emerging and re-emerging of pathogens include intensive agriculture, increased growth, migration of human population and climate changes (Dufour et al., 2003). Furthermore, the long-term effects of exposure to small concentrations of some emerging toxic chemicals are unknown. Even though the detection levels might be low, the risks cannot be ignored. On the other hand, new and improved measuring instruments and analytical techniques are able to measure ever lower concentrations, enabling the detection of more and more substances. Those developments can give the impression that an ever increasing number and concentration of chemicals are present in water, which, in turn, will influence the perception of water quality (Segrave et al., 2007).

Water quality should be also viewed from another perspective. Rivers and wetlands with their biota communities are an integral part of our lives and provide the resource base essential to human well-being. Water is paramount to guarantee biodiversity and ecosystems services given its role as a global ecosystem mediator which enables chemical reactions and moves substances among processes (UN-Habitat, 2003). However, human activities like agriculture, urban development, industries and tourism are creating an increasingly large water footprint, resulting in the environmental degradation of aquatic and terrestrial ecosystems, including surface and groundwater contamination (UNESCO, 2009). Air pollution and soil contamination can also influence water quality. For instance, traffic is one of the major sources of stormwater runoff pollution, which is mainly diffuse and difficult to control (Ellis et al., 2006).

Figure 7 stresses some pressures on freshwater ecosystems. It is expected that potential conflicts between the interests of upstream users versus downstream users, and between the goals of different water uses, where biodiversity maintenance is included, will increase.



Human activity	Potential impact	Function at risk
Population and consumption growth	Increases water abstraction and acquisition of cultivated land through wetland drainage. Increases requirement for all other activities with consequent risks	Virtually all ecosystem functions including habitat, production and regulation functions
Infrastructure development (dams, dikes, levees, diversions)	Loss of integrity alters timing and quantity of river flows, water temperature, nutrient and sediment transport and thus delta replenishment, blocks fish migrations	Water quantity and quality, habitats, floodplain fertility, fisheries, delta economies
Land conversion	Eliminates key components of aquatic environment, loss of functions; integrity, habitat and biodiversity, alters runoff patterns, inhibits natural recharge, fills water bodies with silt	Natural flood control, habitats for fisheries and waterfowl, recreation, water supply, water quantity and quality
Overharvesting and exploitation	Depletes living resources, ecosystem functions and biodiversity (groundwater depletion, collapse of fisheries)	Food production, water supply, water quality and water quantity
Introduction of exotic species	Competition from introduced species alters production and nutrient cycling, and causes loss of biodiversity among native species	Food production, wildlife habitat, recreation
Release of pollutants to land, air or water	Pollution of water bodies alters chemistry and ecology of rivers, lakes and wetlands. Greenhouse gas emissions produce dramatic changes in runoff and rainfall patterns	Water supply, habitat, water quality, food production. Climate change may also impact hydropower, dilution capacity, transport, flood control

A wide range of human uses and transformations of freshwater or terrestrial environments has the potential to alter, sometimes irreversibly, the integrity of freshwater ecosystems.

Source: IUCN, 2000.

Figure 7 - Pressures on freshwater ecosystems (UN-Habitat, 2003)

Traditional supply-side approaches to water management which may alleviate these potential conflicts are associated with various negative impacts upon the aquatic environment. For instance, dams interrupt the natural continuity of a river, often with marked ecological consequences, the problem being especially acute for fish such as salmon, trout, eel and sturgeon. Much of the sediment carried into reservoirs becomes trapped and settles to the bottom, and water released by the dam is also depleted in sediment and organic material that would otherwise contribute to the fertility of the floodplains and estuaries downstream, thus reducing the quality of the downstream aquatic habitat. Major changes also often take place in the area to be inundated when the water level in the reservoir rises following the closing of a dam. Water transfers may lead to several drawbacks like reduced river flow, increased concentration of pollutants due to a lower dilution capacity, changes to erosion and sedimentation patterns, changes to the freshwater ecosystem and introduction of alien species to the receiving basin, fragment the landscape and impact adversely upon terrestrial habitats. Excessive abstraction can lead to the drying out of woodland, forests, heathland, dunes and fens, making them less suitable for characteristic plant and animal life. Finally, desalination also causes specific problems by modifying water quantity and quality.

In conclusion, from the water quality and human environmental health perspectives, control of biological pollution is of key significance in protecting ecosystems and UWCS have an important responsibility in this context. For example, rivers require a sufficient amount of water, termed the 'environmental flow', which not only strongly influences water quality, with lower flow diminishing the river's ability to dilute pollutants, but it is also essential to maintain a healthy aquatic ecosystem. Despite the critical importance of flow to aquatic life, abstraction of water from rivers is often excessive and it tends to aggravate, particularly during the summer months or where water scarcity is getting worsen. Those kinds of pressures will have to be further considered (EEA, 2009). Therefore, hydromorphological parameters in the cities may need to be reduced to increase biodiversity, and a greater focus on controls 'at source' and the efficient use of resources including water, energy and chemicals will deserve increasingly more attention.

2.1.2. Climate Change

The International Panel on Climatic Change (2007) outlined the challenges human beings are facing due to the effects of climate change, both at the global and regional scale. In addition to the rise of temperature, climate change is expected to exacerbate extreme events resulting in more frequent flooding and droughts and to cause sea level rise due to the melting of continental glaciers and the thermal expansion of the sea volume.

Morris et al. (2003) outlined that climate change is amplifying water stress by changing patterns of water availability in many parts of the world due to new precipitation and evaporation patterns and due to water quality consequences.

The sea level rise is particularly worrisome. Several large cities already have a portion of their area below the high tide level or even below the mean sea level. Some have built or are building tidal surge dams across the estuaries, as it is the case in London, Boston and Holland. The Dutch situation is especially troublesome because most of the country has a very low elevation, and a large portion of the country was reclaimed from the sea, being below the main seawater level. The sea tide effects are also a problem in the historic city of Venice in Italy, which responded to this threat with a massive project of increasing the grade elevation of all streets and walkways and closing the gaps between the barrier islands and peninsulas that separate the lagoon from the Adriatic Sea (Novotny et al., 2010).

The poorest communities are commonly more vulnerable to those impacts, not only because they lack the capacity to cope with natural disasters, but also because they are usually in fragile areas including unstable hillsides and low-lying coastal areas (UNESCO, 2009).

Policies for adapting water supply and drainage/sanitation systems need to be tested not only with respect to the current situation, but also against future scenarios representing the consequences of changing climatic conditions. A better understanding and knowledge of future hydro-meteorological fluxes is needed to develop techniques for increasing the resilience of urban systems and water dependent ecosystems, and to enable their adaptation to climate change and other global changes. Responses of the catchment to global changes may affect both quantity and quality (mainly due to temperature changes) of urban water delivered to water supply/drainage/sanitation systems.

Methods for assessing possible effects of climate change on meteorological variables and on the hydrological cycle, and therefore on water quality and quantity, are essentially: paleoclimatic similarities, recent meteo-hydrological analogies and meteo-hydrological projections based on the results issued by global climate models or general circulation models (GCM). Palaeoclimatic scenarios usually have limited practical use, for the difficulty of finding reliable data on past eras, and because the current economic and social development can influence climate changes compared to past scenarios, accelerating changes. Recent meteo-hydrological similarities are based on the meteorological data available at the beginning of systematic recording and the limit of this approach is due to the limited availability of historical series of adequate length.

Using estimates provided by GCM allows the analysis of various scenarios of climate change, which take into account the role of the emission in the atmosphere of the so-called greenhouse gases.

The projections of the future climatic conditions, obtained from global and regional fluidodynamics models, show a likely increase of the mean temperature. This would produce a reduction of snowy precipitations (Beniston, 2000) and an increase of the rainfall rate, because of the higher evaporation. However, the changes in precipitation would not be neither geographically uniform, neither positive everywhere. In particular, as far as the European region is concerned, Figure 8 and Figure 9 show the changes in mean annual temperature and precipitation values that are expected by the end of the century, as estimated in the course of recent European projects (see http://peseta.jrc.ec.europa.eu/docs/ClimateModel.html).

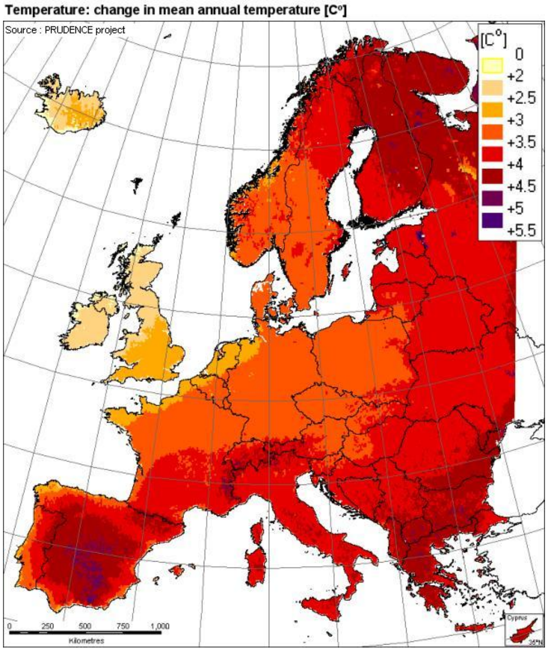
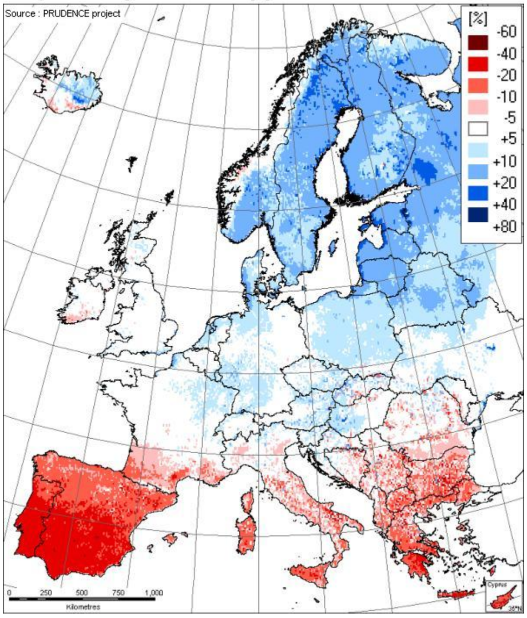


Figure 8 - Change in mean annual temperature by the end of this century. Absolute change in mean annual temperature between control period 1961-1990 and 2071-2100, under the IPCC SRES scenario A2. Data from EC-funded project Prudence (HadCM3 global circulation model, and HIRHAM regional climate model in 12km resolution), map elaboration by EC JRC/IES (source: PESETA project).

Precipitation: change in annual amount [%]



Source : PRUDENCE project

Figure 9 - Change in mean annual precipitation by the end of this century. Relative change in mean annual precipitation between control period 1961-1990 and 2071-2100, under the IPCC SRES scenario A2. Data from EC-funded project Prudence (HadCM3 global circulation model, and HIRHAM regional climate model in 12km resolution), map elaboration by EC JRC/IES (source: PESETA project).

According to the results of the majority of climate models (EEA, 2004; Alcamo et al., 2007), northern and eastern Europe may experience an increase in annual average streamflow and water availability (Figure 10), whereas river basins in southern European, and in particular in the Mediterranean area, may see marked decreases of water availability due to increasing temperature and decreasing precipitation.

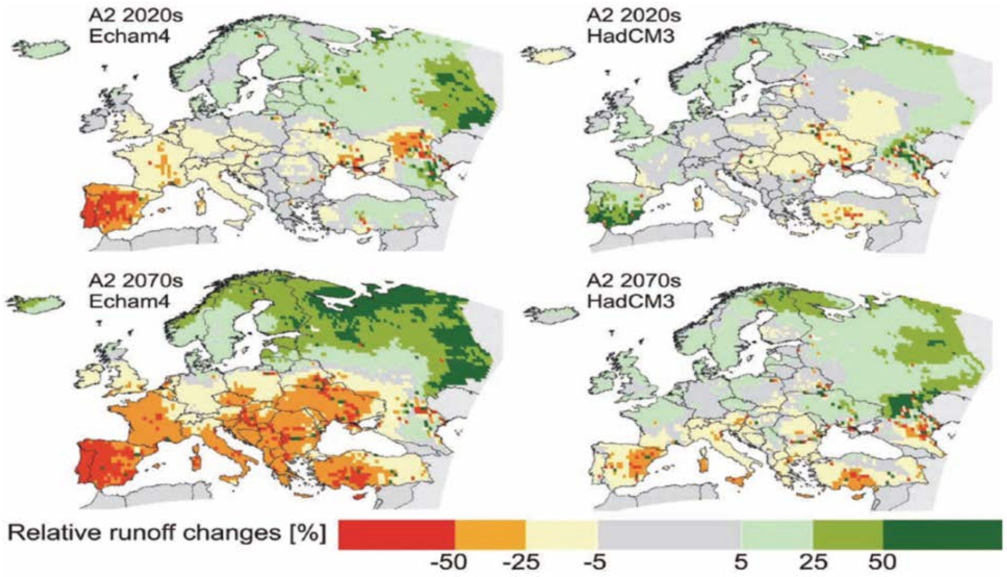


Figure 10 - Change in annual river runoff between the 1961-1990 baseline and two future time-slices (2020s and 2070s) for the A2 scenario (source: figure 12.1, from IPCC AR4 WG2, 2007)

Furthermore, larger seasonal changes may be expected in some regions and, in addition to the trend of ordinary conditions, also the tendency of extreme events and their impacts need to be evaluated at the appropriate temporal scales. These modifications would be significantly dependent on the climatic local behaviour and on the geomorphologic characteristics of each catchment.

The two annexes of this report present the principal climatic drivers, in terms of the future projection of weather variables (precipitation and temperature) in the areas of the TRUST pilot cities. Such scenarios, in the presence of climate change, will influence the states and the impacts on urban water systems, eventually leading to technical and/or management adaptation measures.

The scenarios were developed in two phases, in cascade:

1) Identification of future climate scenarios issued by several GCMs in reference to the areas of the pilot cities, at monthly time-scale (Annex 1).
2) Stochastic generation of future weather scenarios, described by long meteorological (rainfall and temperature) temporal series with a finer time scale, consistent with the monthly results (Annex 2).

Annex 1 presents projections of future climate, referred to each of the ten TRUST pilot cities areas, in terms of the expected change in temperature and precipitation monthly values, being certainly the most important meteorological variables for the management of Urban Water Services. The results show the changes expected (under the A2 SRES scenario, see IPCC 2000) in the monthly values of both temperature and precipitation over the next decades, up to a horizon of fifty years. The analysis is based on the projections of several different GCM models (for two two-decades time-slices up to the 2050's), as far as the progress of temperature and rainfall at monthly time scale is concerned.

Annex 2 presents the estimates of the changes expected at finer temporal scales (i.e. daily or hourly), obtained by using stochastic models that simulate the actual behaviour of the fine-scale time series, on the basis of the available measurements of the above variables. The aim of this analysis is the identification of the modifications that may be expected as far as extreme events are concerned, of particular importance for the design, operation and maintenance of urban water systems. Such kind of modelling is extremely computationally intensive and may be carried out only when extensive time-series of high-resolution observations over the recent past are available. Precipitation and temperature observations at fine time scale were collected for 5 of the 10 pilot cities, i.e.: Amsterdam, Athens, Faro (for the Algarve region), Oslo and Reggio Emilia.

2.2. Social pressures

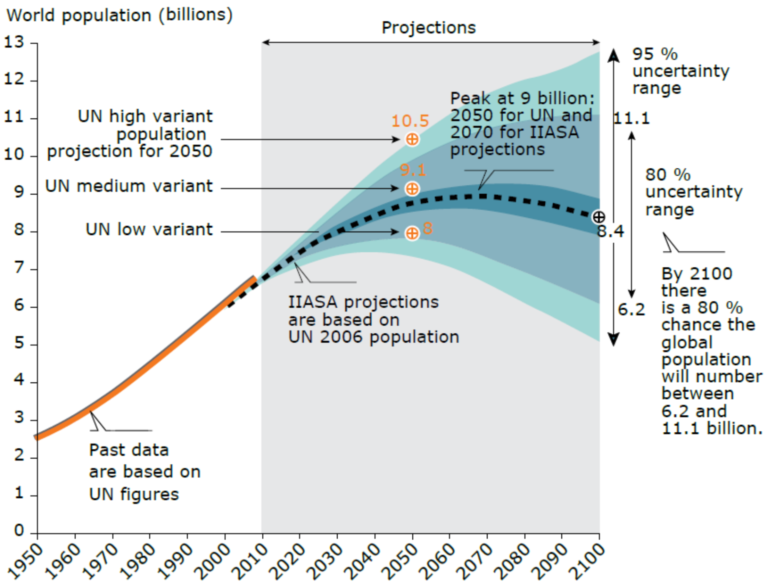
When considering the social pressures on UWCS, it is important to consider the population dynamics, the change in the natural landscape associated with urbanization and the change of the population age distribution, as these affect water demand and consumption patterns. Furthermore, the society culture and education, as well as their preferences and confidence on services, are also changing, with important implications for water-related services. Figure 11 identifies the considered "social pressures" affecting UWCS, which will be further developed in this section.

Figure 11 - Social pressures affecting Urban Water Cycle Services

2.2.1. Demography

- **Population dynamics**

Population dynamics is “the process of numerical and structural change within populations resulting from births, deaths and movements” (Eionet, 2011). Globally, the world’s population is growing by about 80 million people a year (UNESCO, 2009). It has more than doubled since the 1960s and it is expected to continue to growth, although more slowly than in the recent past. Population peak is expected to reach nine billion by around 2050 (UN Population Division, 2009). As Figure 12 shows, there is only a 10 % chance that in 2100 there will be fewer people than today or that the total will exceed 11 billion (Lutz et al., 2008). Population growth is dependent on lifestyles and politics and it is highly context-dependent. It may result in changes in drinking water consumption, which lead to changes in wastewater flows (Ellis et al., 2006).



Note: The UN Population Division studies fertility-evolution scenarios to produce high-, medium- and low-variant figures, whereas IIASA bases its calculations on assumptions for fertility, mortality and migration (with the latter only affecting regional projections).

Source: IIASA, 2007; UN Population Division, 2009.

Figure 12 - World population projections (EEA, 2011)

In addition to population growth, there is an increasing migration arising from individuals searching for better opportunities and refugees fleeing the consequences of war, conflict or natural disasters. A declining and ageing population induces countries to accept migrants, who are typically willing to work at much lower wages than native workers. In 2000 there were 176 million migrants and today this number has reached an estimated 192 million.

Coastal areas, with 18 of the world's 27 megacities (populations of 10 million or greater) are expected to face the largest migration pressures (UNESCO, 2009). The pressure for migration is becoming a vital factor in demographic change over the next 50 years, as migration significantly affects ethnic diversity, age composition and the size of the workforce in recipient countries (EEA, 2011). It is also important to consider the various types of migration, namely the diurnal type of migration between place of work and of residence, the seasonal migration (difficult to predict), the permanent migration, as well as the rural-to-urban migration, common in developing countries, and the urban-to-rural, more common in developed countries. These two latter types of migration are analyzed in the pressure "urbanization". Unexpected migration will strain the capacity of the urban infrastructure (Ellis et al., 2006) and even countries that have been increasing the number of people with access to water supply and sanitation services may see these gains eroded by population growth (UNESCO, 2009).

Taking natural population growth and urbanization into account, future predictions show that population will growth rapidly in some regions and decrease in others, as illustrated in Figure 13.

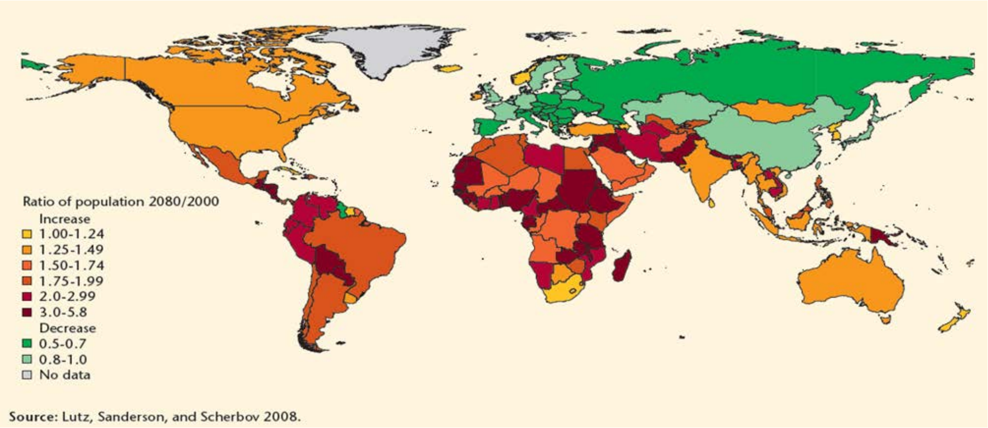


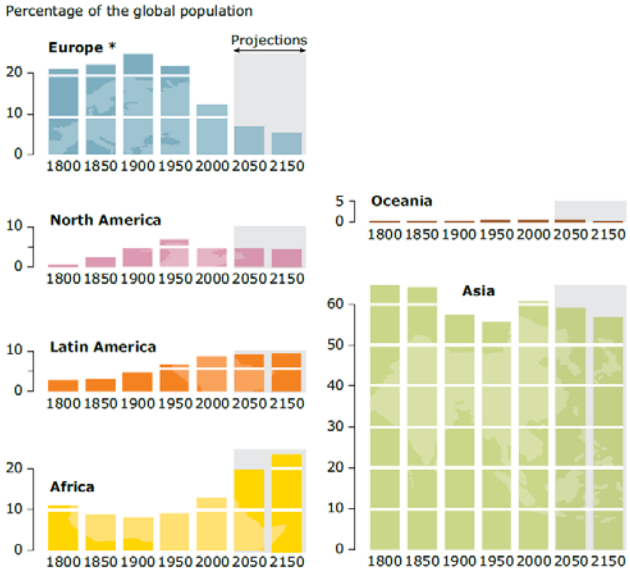
Figure 13 - Expected areas of population growth and decline, 2000-2080 (UNESCO, 2009)

More than 60% of the world's population growth between 2008 and 2100 will be in sub-Saharan Africa (32%) and South Asia (30%) (UNESCO, 2009). In many African countries the population is likely to have doubled by 2100 (IIASA, 2007). Most of the countries of North America and Western Europe may still continue to grow, mostly due to migration, although they might also register declines if policies to attract migrants are not introduced to compensate for the impacts of advanced ageing (EEA, 2011).

Declining populations are also gaining more importance. In the former Soviet Union, the annual population growth is already negative, and in Eastern Europe the population is expected to be less than half today's level by 2100 (IIASA, 2007). This trend is also expected to happen in some developing countries, especially in Asia. Australia, China, Japan, New

Zealand and Western Europe are also expected to shrink in the future (UNESCO, 2009). Most European countries have already reached their peak plateau, and by 2050 the population is expected to stay steady or decline (Novotny et al., 2010).

Figure 14 intends to show regional shares of global population since 1800 until 2150.



Note: * In its geographical definition (including Russia up to the Ural Mountains).

Source: UN Population Division, 1999; Le Monde Diplomatique, 2009.

Figure 14 - Regional shares of the global population (EEA, 2011)

In what concerns population dynamics, it is also important to mention the population age distribution. The world population is younger than ever, as nearly half its inhabitants is under the age of 25 (UNESCO, 2009). Several of the countries with the largest bulges (disproportionate concentrations of people in the 15–29 year-old age group) are located in sub-Saharan Africa and the Middle East and are among the world's most unstable or potentially unstable states (EEA, 2011). Nevertheless, demographers expect the average age of populations to rise in the future. In 2005, 10% of the world's population was 60 years old or older, a number that is expected to increase to 22% and by 2050 (UNESCO, 2009). Figure 15 shows the percentage of the total population aged 60 years or over, in 2009 and the expected percentage in 2050 around the world.

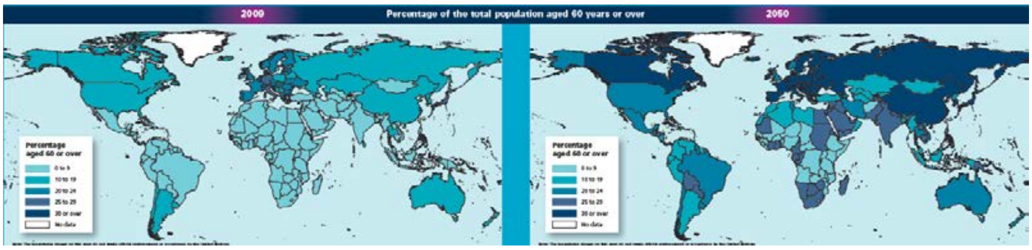


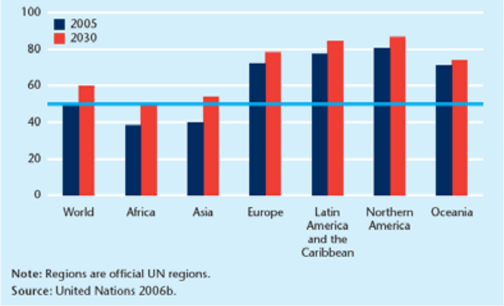
Figure 15 - Percentage of the total population aged 60 years or over (UN Population Division, 2009)

There are obvious differences between developed and developing countries in terms of the speed of ageing (EEA, 2011). Ageing of population is already happening in industrialized countries in Europe and East Asia (UNESCO, 2009). This comes from the population decrease and higher life expectancy rates, which further augments the elderly population (Segrave et al., 2007). Contrary, in developing countries like China, some Pacific islands and central Asian states, populations are expected to have substantial youth bulges until 2025 and only by 2050 are they expected to be ageing as fast as the developed world is now (Jackson and Howe, 2008). From about 2030 to 2050, the trend of population ageing is foreseen to be spread to most regions of the world (Lutz et al., 2008).

Ageing population presents particular challenges. It influences consumption and production patterns, with attendant impacts on natural resource needs, including freshwater (UNESCO, 2009). In addition, the oldest in society are also more vulnerable to disease and are also related to enhanced medical services, placing new demands on water services, particularly on the necessary treatments of water (Ellis et al., 2006).

- **Urbanization**

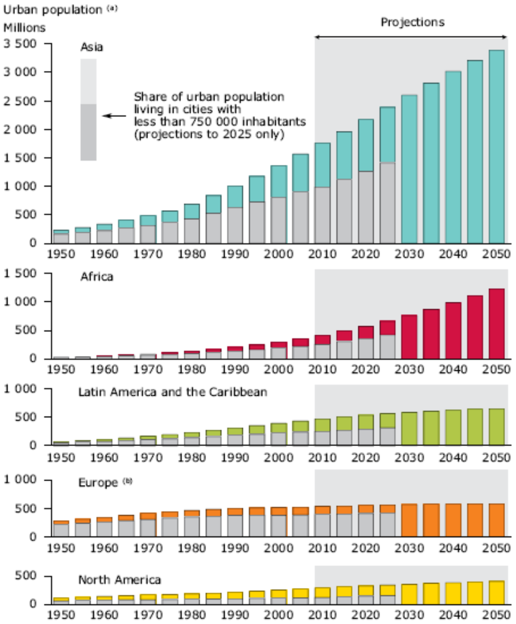
High fertility rates and limited employment opportunities in many rural areas force rural residents to search for a better life in cities, where there is greater access to goods, services and facilities, improved health, education, literacy and quality of life (EEA, 2011). In 2008, the world population was estimated to be equally split between urban and rural areas, marking the transition from a rural dominated to an urban dominated world (UNESCO, 2009). As it is presented in Figure 17, by 2030, the number of urban dwellers is expected to be about 1.8 billion more than in 2005 and to constitute about 60% of the world's population (in some countries, representing more than 90% of the total population (Novotny et al., 2010)), while the number of rural inhabitants is expected to decline slightly from 3.3 billion to 3.2 billion. Almost all (95%) of the increase in urban population is expected to happen in developing countries, especially in Africa and Asia, where the urban population is projected to double between 2000 and 2030. In fact, by 2030 the towns and cities of the developing world will make up an estimated 81% of urban humanity. Most of these areas are already under water stress and do not offer a sustainable access to water and sanitation services to their current population. On the other hand, urbanization rates are much lower in developed countries and are even declining in some countries (UNESCO, 2009).



Note: Regions are official UN regions.
Source: United Nations 2006b.

Figure 16 - Share of population residing in urban areas, 2005 and 2030 (percent) (UNESCO, 2009)

As it has been previously mentioned, urbanization levels vary from region to region and this is likely to continue. Demographers estimate that Asia will be home to more than 50 % of the global urban population by 2050, while Europe's urban population as a percentage of the global total is likely to shrink considerably (EEA, 2011).



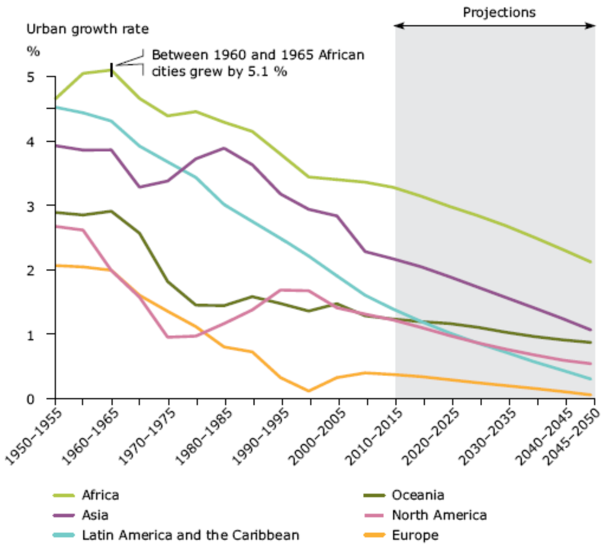
(a) The definiton of 'urban area' varies from one country to the next.

(b) Albania, Andorra, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Channel Islands, Croatia, Czech Republic, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Holy See, Hungary, Iceland, Ireland, Isle of Man, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Montenegro, the Netherlands, Norway, Poland, Portugal, the former Yugoslav Republic of Macedonia, Moldova, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom.
Urban areas of Oceania — not included here for legibility reasons — are projected to reach 38 million people by 2050 (currently 25 million).

Source: UN Population Division, 2010.

Figure 17 - Urban population trends (EEA, 2011)

Nevertheless, all those regions are expected to see their urban growth rate to continue to decrease, as it is illustrated in Figure 18, meaning that although urbanization will continue to grow, it will grow at a lower rate. A key uncertainty on the above results is related to the development of policies, especially on social welfare and health care. Fertility rates can also influence urban growth. Actually, if urban growth decline does not continue as assumed, real urban population growth may strongly exceed projections (EEA, 2011).



Note: 5-year steps.

Source: UN Population Division, 2010.

Figure 18 - Slowing urban growth (EEA, 2011)

Another important factor is the emergence of “megacities” (cities with a population of more than 10 million) in several rapidly growing countries in Asia, Africa, and Latin America. Urban megalopolis agglomerations consist of several cities with suburbs and satellite cities between them, functioning as low-density bedroom communities connected to the city by freeways or by public transportation (Novotny et al., 2010). Despite the rising number of megacities across the globe, most of the world’s urban populations live in cities with fewer than 500,000 inhabitants (UNESCO, 2009). Small- and medium-sized cities are growing even faster than bigger cities (EEA, 2011).

Changes in the natural landscape associated with urbanization can produce additional pressures on local freshwater resources and create the need for more water-related services (EEA, 2011). Urbanization is likely to lead to water demand conflicts and to a tougher resource competition. Some cities are already overpopulated and cannot provide even basic services to a large part of their citizens, especially in developing countries where families live in small crude cardboard or tin houses, on the same level as that in the medieval cities of Europe centuries ago (Novotny et al., 2010). Even in developed countries like the European ones, if urban slum development continues the risks of diseases developing and spreading (for example through tourism) may expose them to new known and unknown diseases (WHO, 2008). On the other hand, urbanization will accentuate the over capacity problems in rural areas that are being progressively abandoned and where water demand has dramatically decreased. This is the case of some rural areas in Central Europe (Segrave et al., 2007).

2.2.2. Society expectations

- **Human rights**

An estimated 884 million people lack access to safe drinking water and a total of more than 2.6 billion people do not have access to basic sanitation. Studies also indicate about 1.5 million children under the age of five die each year and 443 million school days are lost because of water- and sanitation-related diseases. Within this context, on July 2010, the United Nations General Assembly declared that safe and clean drinking water and sanitation is a human right essential to the full enjoyment of life and all other human rights. This accomplishment is expected to push international organizations to offer funding, technology and other resources to help poorer countries scale up their efforts to provide clean, accessible and affordable drinking water and sanitation for everyone (UN, 2011). Furthermore, it will also have impact on the economy of UWCS. By targeting subsidies for the poor and setting minimum levels of service, higher overall revenues will be expected (ERCC, 2009).

However, there are difficulties on allocating taxes to the users, utilities and/or other public entities. Surveys show that in developed countries households connected to urban public systems pay on average 1% of incomes on water bills, including the cost of sewerage. Poorer groups tend to pay a higher share of household income for water (3%–11% of income), which is complicated by the widespread use of informal and small-scale private water distributors (UNDP, 2006). Pressure on governments and service providers to ensure delivery of a minimal supply of potable water to all households at a reasonable price tend to augment, leading to challenges in the use of subsidies and in the setting of tariffs that consider household’s ability to pay and the cost of service delivery. Underpricing of water, the use of water prices to manage water resources or pricing water at the required cost for the delivering to consumers, especially in the politically sensitive segments of agriculture and urban households, are issues increasingly more important. Therefore, reforms including water pricing across the water services industry are urgently needed, with implications for both regulators and consumers. Contrary, if prices cannot adjust to financial realities, stresses emerge as water shortages, inefficient water use, poor water quality, inadequate water infrastructure investments and poor services delivery (UNESCO, 2009).

- **Culture and education**

Culture can be defined as the way of life for an entire society, passing (but also evolving) from generation to generation. It describes the “patterns of human activities and the symbolic structures that impart significance and importance to these activities (such as art, institutions, science, beliefs and moral systems)". Each society has its own culture which should be respected.

In many developing countries, women are not heard about water services despite being among the ones who suffer the most because of inadequate or inexistent services. Another cultural driver is religious belief. Religions that see humanity as a steward of the environment may be a powerful influence in developing the awareness of communities of their roles in using and conserving natural resources, including water. Contrary, religious beliefs can also accelerate the degradation of water resources, as it is the case of the Hindu practice of cremating people in funeral pyres and placing their ashes into the Ganges River, which is a dangerous practice because incomplete cremation results in incompletely burned human remains being put into the river, causing degraded water quality and increasing the potential for the transmission of waterborne diseases. These deeply rooted religious beliefs are difficult to address with a strictly scientific rationale (UNESCO, 2009). Religious or cultural concepts of purity and/or taboo may also impose restrictions on the acceptance of concepts such as re-use of water.

Furthermore, an educated populace typically has a better understanding of the need for sustainable use of aquatic ecosystems and the importance of implementing water conservation practices (UNESCO, 2009). Driven by better education and awareness, individuals may become more demanding as regards quality service levels. That could possible lead more consumer participation because as more people become better educated and informed through newspapers, the internet and other sources of information, there is increasing demand for public information and involvement (Segrave et al., 2007). In conclusion, it is important to have in mind the cultural and educational level of communities to better understand people's actions and their behavioral change.

- **Preferences and confidence on services**

Changes in lifestyles and the aspiration for a better life, reflected in human needs, desires and attitudes, are one of the main social drivers of change. Once people's survival needs are met, their wants become more prominent in term of increasing human comfort and convenience. The general worldwide rise in living standards is generally associated with rising consumption of material goods and non-essential services, as well as changes in eating habits. Millions of people are lifting out from poverty in developing countries, creating a new middle class with increasing demands for food to complement their traditional and less water-intensive diets (UNESCO, 2009). Higher standards of living are also changing European water demand patterns, mainly reflected in increased domestic water use, particularly for personal hygiene (EC, 2007).

One of the emerging issue related to people's preferences concerns studies into the 'real value' of water, incorporated with ideas of 'well being'. The different meanings of water (as the spirit, life, social, connective substance, wealth and power, or others) permeate the interactions that people have with water and influence customer preferences (Strang, 2004). Although a litre of potable water at the tap may be charged at a flat rate for all families, households use water for a variety of purposes, each of which with a different importance or significance to them as individuals or as a family/community. There are two important implications of this. Firstly, it creates real challenges in securing consensus from communities on water management priorities (Syme et al., 2008). Secondly, it may provide opportunities to provide water of different quality to customers for different purposes. In that context, the principle is that utility customers do not necessarily demand for a resource itself (e.g. liters of water) but rather for the services provided by water, such as clothes washing or toilet flushing. This approach opens up supply and demand management options based on developing a mix of solutions (Kayaga and Smout, 2011). A secondary supply pipeline for non-potable water (eg. stormwater, groundwater, recycled wastewater), also called the third pipe system or dual supply, can replace the use of potable water for such uses as toilet flushing, laundry, street cleaning, garden watering and open space irrigation, thus providing a sound basis for promoting a ‘fit-for-purpose’ approach to water use (Wong and Brown, 2008).

Tolerability to water risks is not merely affected by a scientific perspective about water services quality, and particularly on the different substances in drinking water. The population’s own perceptions play an important role, which means that caution is recommended when informing the public to avoid any unnecessary anxiety (Rósen and Lindhe, 2007). Moreover, the best technical solution may not always match with people’s values, making important to ensure that this aspect is taken into account. It is the case of new concepts for stormwater management, e.g. infiltration or re-use, which are dependent on a close involvement of the people, as people cannot be forced to implement source control techniques against their will (Ellis et al., 2006).

Another example of how important people’s preferences are is their appreciation of freshwater and bottled drinking water. With the exception of consumers of bottle water in Western Europe, who are becoming aware of its relatively high price and its potential negative impact on the environment (ecological and resource like energy costs of packaging, transport and waste production), this market is likely to continue to expand worldwide. Most studies find that this trend reflects aesthetic preferences (e.g. taste, odor), convenience or a lifestyle preference for a healthy and low calorie diet. But if consumers are increasingly consuming bottled water as a result of a lack of trust in tap water (e.g. fear of contamination) then it is important to overcome the public relations and comunication deficit between consumers and water supply entities. It is to be noted that improved water treatment technologies may turn tap water less attractive to consumers if they change its taste and odour properties, thereby leading them to favor alternative sources (Kelay et al., 2006). Public water suppliers often tend to ignore this, because the percentage of water they provide for consumption is very low (ca. 5-10%), but it might lead to partially obsolete efforts to improve water resources and treatment (Segrave et al., 2007). Not only policy makers, but also water users will need to better understand the current challenges and their urgency, for example the implications of climate change or the need to reduce water consumption (ERCC, 2009).

Furthermore, what may be deemed as urgent for the water company may be regarded as less important by consumers. Efforts should be made to produce a convergence between consumers interests and priorities with those of the industry (Kelay et al., 2006). That will imply a more participative approach and even joint decision making processes. The implementation of an effective consumer participation has a lot of benefits including the guarantee that decisions are influenced and accepted by the views and concerns of who is affected by them, more transparency and creative decision making, as well as an increase in the trust in suppliers and regulators and acceptance of subsequent decisions. It is also in accordance with the European Water Framework Directive that stipulates stakeholder involvement in the preparation of river basin management plans (SWITCH, 2006). However, engaging the public in the decision making process is likely to slow down the implementation of changes and make it more expensive than simple, one way, communication strategies. Additionally, consumer trust may be eroded if the scientific uncertainty leads to disputes among apparent 'experts' over a topic of concern. Also, it is important to maintain that consumers have the power to influence the outcome of a planning decision, and that they may reject proposals favoured by industry insiders and policy makers (Kelay et al., 2006). In turn, community participation may impact on citizens demanding more information (Segrave et al., 2007).

A final important aspect is consumer trust on quality service and confidence on providers. Most studies show that consumers' primary expectation is that their supplier will provide safe and clean drinking water (Fife-Schaw et al., 2007). Among consumer's demands from their water services company, the following are included: 24 hours accessibility, timely service, flexibility in appointments, transparent bills and multiple payment options, accurate and carefree metering and application of the latest proven technologies (Segrave et al., 2007).

In 2006, an European consumer survey looked at consumer satisfaction in terms of overall satisfaction and expectations, quality, price, image, market and personal factors, complaints and commitment. It concluded that 58% of EU-25 consumers agreed that their water provider offered a good quality service. A North-South gradient is however evident, as most of the northern countries have higher numbers of satisfied consumers (Denmark, Germany, Sweden, Finland), while in most Mediterranean ones, only less than four consumers out of ten showed satisfaction (Italy, Spain, Portugal, Malta). Austria, Cyprus, Luxembourg, Slovenia, Ireland and Hungary also show proportions of satisfied consumers higher than 70% (EC, 2007).

The relationship between trust and acceptance require further study as they might differ. As an example, trust in the motives of a supplier may increase the likelihood of acceptance of a price rise while emotional responses to something like recycling may directly reduce acceptance which, in turn, reduces trust in the supplier (Fife-Schaw et al., 2007a). In fact, public trust is important in determining the acceptability of any proposal and, therefore, agents that are trusted will be able to contain negative public reactions from incidents much more effectively than those that are not. The open collaboration with other trusted information sources may also enhance provider's credibility (Kelay and Fife-Schaw, 2010). In addition, expected stringent regulation will also contribute to consumer's confidence on providers. For instance, the Water Framework Directive (WFD) adopted across the European Union in 2000 (and comparable non-EU legislation) sets quality standards for water at the tap based on microbiological and chemical parameters (EEA, 2010). The basis of the WFD is a requirement for member states to develop integrated management in all 'river basins' in order to achieve 'good' or 'high' ecological status in all water bodies by 2015 (UN-Habitat, 2003). Besides great efforts in water quality driven by this and other legislations, like the Urban Wastewater Treatment Directive (UWWTD), their implementation will be challenged by economic constraints and climate change impacts (EEA, 2010).

2.3. Economic pressures

The following section focus on economic pressures that impact water resources and services. Globalization, meaning the increasing international flows of goods and services, people, investments and finance, is a double-edge issue. It may contribute to the worsening of the current situation but it can also provide some potential solutions. In general, the competition for existing resources and the conflicts among potential users are expected to increase, as well as the costs associated with UWCS. Financing will continue to be a limiting factor for an effective management of the water sector, in particular the lack of funding. These are the main drivers of change that will be analyzed. They are presented in Figure 19.

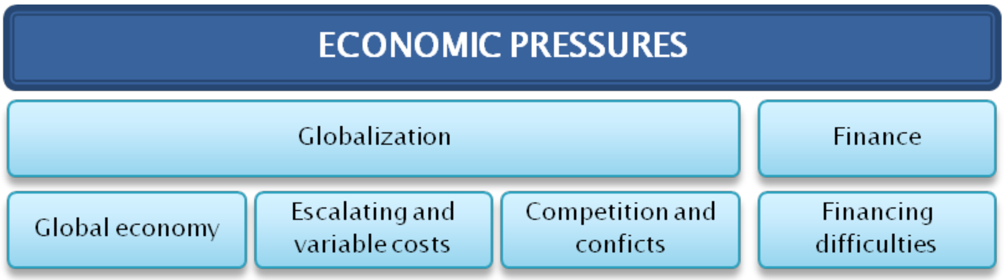


Figure 19 - Economic pressures affecting Urban Water Cycle Services

2.3.1. Globalization

- **Global economy**

Globalization is bringing an increase in economic opportunities to several emerging market economies which are registering continuously high growth rates. According to Goldman Sachs' latest forecast, Brazil, China, India and the Russian Federation are expected to overtake the combined economic strength of the G-8 by 2032. Even sub-Saharan Africa, mainly driven by oil and commodities, is experiencing growth rates of 6% or more. But for a lot of poor people in those rapid economic growth countries, lack of service delivery is still acute and the economic growth output is unevenly distributed, leaving behind the world's poorest people, including indigenous peoples, women in developing countries, the rural poor and children (UNESCO, 2009).

As a consequence of changes in global economic expansion due to the globalization process, the number of consumers and their consumption habits are changing, as well as the location of activities for the production of goods and services (UNESCO, 2009). Furthermore, with increasing interaction, interdependence and integration of different contexts around the world, international standards are becoming a leading influence in regional practices (Segrave et al., 2007). Enterprise structures are also being impacted as they increasingly assume a market logic and offer services to larger areas, resulting from the association of groups of municipalities (Golvan and Bréant, 2007). Consequently, the number of small water companies around the world will fall as they chose to merge together or as larger companies win further concession contracts or take over smaller privatised water companies. The industry will move towards greater domination by a smaller number of large multi-national water companies (especially European) (Kelay et al., 2006). The tendency of the "the rich getting richer" can be a threat, as multinational giants often snatch up the best opportunities. Companies also have to be aware of the risks related to unpatented or regionally patented intellectual property (e.g. copyright laws and patents). On the other side, multi-national companies are well placed to share ideas and best practices, along with the expansion of technological innovation, improvements in productivity and spread of water expertise (Segrave et al., 2007).

- **Escalating and variable costs**

Energy is needed for the construction and operation of all structural water systems (for instance, for the production of concrete for sewer pipes, pumping of wastewater or fuel consumption during grass cutting in infiltration swales) (Ellis et al., 2006). About 60% of water distribution costs and 50% of wastewater treatment costs are related to energy consumption. Energy used worldwide for delivering water (including agriculture) is around 7% of total world consumption. With the continuous expected rise on energy prices, those maintenance procedures will become more expensive, which will most likely lead to increased water prices. Actually, energy demand is expected to continue to increase worldwide as developing countries become industrialized, population growth and resources dwindle (Segrave et al., 2007). According to the International Energy Agency, the world will need almost 60% more energy in 2030 than in 2002, with economic growth in developing countries driving most of the increase (IEA, 2011). The expected rise in energy prices will act as a driving force for a change in the efficiency of the water services sector (Segrave et al., 2007).

Other prices are likely going to increase, as it is the case for land, whose price has to be taken into account when planning water systems, which is complicated by the fact that they vary considerably over time and from area to area (Ellis et al., 2006). In addition, food prices tend to continue to increase as recently happened, mainly because of rising demand, shifting diets, droughts, increased costs of agricultural inputs (such as fertilizers), agricultural policies that encourage non-food commodities (e.g. bioenergy, fibres and narcotics) over food commodities and restriction of exports to help contain prices at home (UNESCO, 2009).

Technologies themselves also have challenges to overcome prices increases. In particular, member states of the European Union are committed to upgrade their water and wastewater treatment systems to comply with EU environmental legislation. However, ageing infrastructures and overdue renovations are expected to augment the problems. The World Business Council for Sustainable Development estimates that the total costs of replacing ageing water supply and sanitation infrastructure in industrial countries may be as high as $200 billion a year. These costs, together with higher required investment in water treatment before use and the operation and maintenance of physical infrastructure so that it meets appropriate standards, are often widely ignored, underestimated or underfunded. It is also worth mentioning the problem related to the fact that current models for depreciation accounting and present value estimation in the water sector are inadequate for illustrating the full picture and economic complexity of long lived water network assets. The result is that some assets are neglected and underprovided, while others deteriorate. Likewise, the pace of growth and urbanization, combined with rising environmental expectations, is creating the need for costly new investments. The decrease of available dam sites, falling water tables and the increase in the distances between the point of abstraction and water use, all raise the costs of exploitation and supply. In addition, the cost of rehabilitating or decommissioning existing infrastructure is also likely to be enormous (UNESCO, 2009). Furthermore, in general, investment in physical infrastructure must be accompanied by the 'soft' infrastructure of policies and legal systems and human capacity.

- **Competition and conflicts**

A lot of cities operate in highly constrained water supply situations, which are likely to continue or even to be aggravated as the competition for water resources and for different water uses is expected to increase, potentially enhanced by globalization. This situation leads to an increase in water value and thus in its price (Segrave et al., 2007).

The search for compromises is further complicated in international situation, as for example in the Nile River basin, shared by 10 riparian countries (Retamal and White, 2011). Other water issues on international rivers include the Niger in Africa and the Mekong in Asia. Trans-boundary conflicts are foreseen to increase in the future and the attempt to obtain a larger share or gain control over another nation's water resources may even result in severe political and military conflicts (Rósen and Lindhe, 2007). Globalization may worsen conflicts among regions and countries, resulting in more international terrorism, exacerbated through migration.

2.3.2. Finance

- **Financing difficulties**

All water-related activities, whether structural (infrastructure) or not (planning, data collection, regulation, public education) require money. Lack of funding will bring necessary actions to a standstill, being a major determinant for adequate water services (Kelay et al., 2006). Financing is an issue that cuts across all of the themes like extension of improved sanitation, upgrading of aging urban systems, actions to improve water efficiency in the face of growing water scarcity and droughts and climate change adaptation (ERCC, 2009). Some of the existing funds are used inefficiently, as it is the case of high payments to informal providers outside the public networks, payments to corrupt operators to obtain water from networks and large public subsidies that end up in the wrong hands (UNESCO, 2009). Furthermore, escalating costs will turn financing difficulties even harder to overcome. It is also trivial that financing of water systems, including rehabilitation and upgrading, is increasingly planned in competition with other priorities, often being rated as less important (Novotny et al., 2010). In particular, sanitation has been severely neglected. The World Health Organization estimates the total annual cost of meeting the Millennium Development Goal at over $9.5 billion, which means that resources will have to double. If the full cost of tertiary wastewater treatment for waste streams in urban areas is added, the total rises to $100 billion, value equivalent to the total annual official development assistance (UNESCO, 2009).

In general, there are three sources of revenue for financing water services: user tariffs, government subsidies or transfers in the form of external aid, from official or philanthropic sources (UNESCO, 2009). In particular, in most countries, the fees citizens have to pay for drinking water supply and urban drainage do not cover the real cost, and it is a challenge to establish fair price policies (Ellis et al., 2006). In Europe, pricing is used to promote a sustainable water use, as foreseen in the framework Directive for Community action in the field of water policy. It promotes incentives for consumers to modify their consumption patterns towards a sustainable level with the aim of recovering the full costs of water services. Users must pay in proportion to their level of consumption and pollution, covering environmental costs, the depletion of limited resources, and the operating and investment costs. The consumers' attitudes towards price varies considerably across the EU. In the EU-25 countries, 38% of consumers think that their water provider prices are fair in comparison with the service provided, ranging from 22% to proportions greater than 50%, which is the case, for example, for Finland, Austria, Slovenia, Denmark and Germany (EC, 2009).

Pinsent Masons Water Yearbook states that an investment of $2.3 trillion will be required worldwide over the next twenty tears, of which only 25 % is likely to be paid by governments, leaving 75% to come from private sources. In fact, in order to overcome financing difficulties several authors have been championing privatization as a means of facilitating investments. This trend has, however, been mitigated in recent years, as involvement of private partners has failed due to inadequate regulatory regimes or ideological reasons (Segrave et al., 2007). It is not commonly agreed whether the private sector is more competent and efficient at mobilizing capital than publicly owned companies (Kelay et al., 2006). On the other hand, many public institutions and political movements are afraid of losing a high quality service, the continued protection of natural resources, and stable, moderate and reasonable prices (Ellis et al., 2006). To avoid this happening, contracts must be well formulated, guaranteeing compliance with environmental standards and protections against excessive profit (Novotny et al., 2010). In Europe, the UK is one of the few countries in the world to fully privatise its water supply. In the Netherlands legislation sets that the privatisation of water is illegal. Efficiency in the Dutch water sector is encouraged by benchmarking rather than privatisation (Kelay et al., 2006). Apart from privatization, liberalization has also been considered. It means the introduction of a market mechanism in the sector (Ellis et al., 2006).

2.4. Pressures interdependency

This section addresses the interrelations between environmental, social and economic pressures. The following diagram intends to show the impacts that the different pressures have on each other.

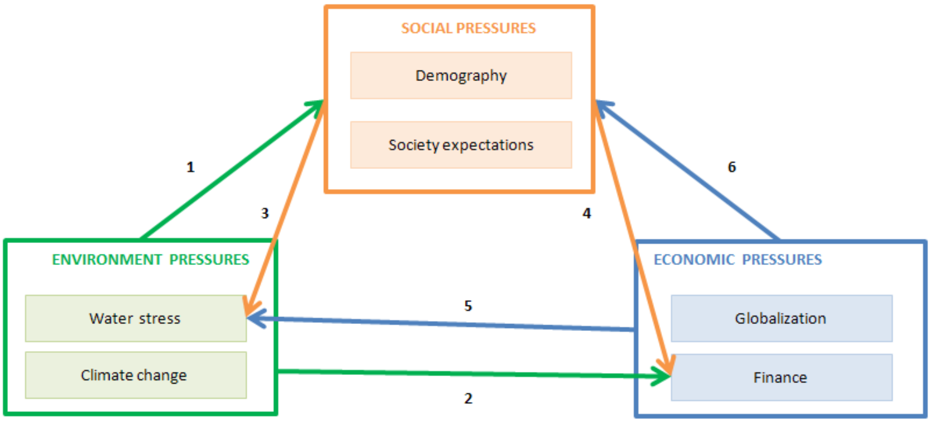


Figure 20 - Pressures interdependence

The different identified environmental pressures put a huge strain on social aspects because the availability and the quality of water influence demographic processes, water use and other society expectations *(arrow 1)*. Water scarcity and flooding, in particular, can trigger migration decisions, particularly where people are directly dependent on the environment for their livelihood. Development projects, including those designed to relieve future water availability stresses, and climate change can also result in an overall acceleration in the displacement of people in the future. Estimates of potential environmentally displaced people range from 24 million to almost 700 million (UNESCO, 2009).

Water resources are increasingly viewed as a potential constraint to economic growth *(arrow 2)*. For instance, China's economic growth has been threatened by serious environmental problems including water pollution (UNESCO, 2009). The energy requirements for drinking water production and wastewater treatment are also rising due to various factors, such as more stringent thresholds and higher ecological standards, more polluted sources, the exploitation of alternative water resources like seawater and the need for adaptation to expected climate change consequences. As a result the costs of providing these services are increasing, affecting water services financial health (Segrave et al., 2007).

Shifts in social pressures also have various impacts on water resources *(arrow 3)*. Freshwater demand as a result of population growth is expected to increase of about 64 billion cubic meters a year. The arrival of additional people through migration can worsen and the growth of small, mid-size and megacities will require natural resources like water resources in quantities that may not be viable. Moreover, a growing population and migration normally put enormous strains in natural resource support systems and increases environmental pollution (EEA, 2011). On the other hand, there are positive impacts that should be mentioned, such the lessening of the pressures on the vacated lands, which may allow some ecosystems to recover. In Europe and North America the rural exodus has actually resulted in the growth of new parklands in some locations (UNESCO, 2009).

Another demographic pressure worth being mentioned is ageing population, occurring in most industrialized societies, because older people are generally more susceptible to diseases and require better water quality (Segrave et al., 2007). Finally, although social expectations lead to environmental pressures, the desire for better water-related services may have the opposite result and actually lead to a better environmental condition. An example of that are tourism activities because pressure exerted by visitors from the industrialized world may support the demand for better water quality in developing countries. Therefore, tourist businesses and institutions are becoming increasingly aware of the importance of a clean environment (Ellis et al., 2006).

Most of the increasing costs arising from the concentration of population in urban areas are usually compensated by economic scale effects. However, in some particular stressed situations, population increase and urbanization can also increase technology costs through the possible need to pump water over greater distances and from deeper in the ground or through the use of sources like desalination and recycling which are more energy intensive (Segrave et al., 2007) *(arrow 4)*. Society expectations may also have impact on economic pressures, mainly due to consumers' Willingness To Pay (WTP) for drinking water or other water-related services. Several studies show that the WTP for water services are usually below the cost of implementing the relevant changes, leading to financing difficulties. In general, WTP is greater for more immediate aspects of the supply (e.g. safe drinking water, better taste and odour) than for more long term or distal supply issues (e.g. infrastructure improvements, decreased river pollution) (Fife-Schaw et al., 2007). WTP can also be affected by existing water quality, affordability and ability to pay, consumers' level of awareness of water management issues, as well as trust in the supplier on how they use funds. On the other hand, Kontogianni et al. (2003) state that self-identity and peoples' pride in their city, as well as moral and ethical concerns increase willingness to pay for the water services. While public becomes more aware of the need for funds to update or modernise the existing water infrastructure, lack of willingness to pay can be changed over time.

Global economy has far-reaching impacts on water resources and their use. In developing countries, people's livelihood is usually dependent on ecosystems. Agricultural practices, overexploitation of inland fisheries and the proliferation of informal settlements all have environmental consequences. Inadequate water resources and sanitation facilities associated with poverty result in water pollution and environmental degradation. Furthermore, the relative importance of meat and dairy products in diets influence the quantity of water used per person for food production. In addition, related to the increasing exchange of goods through international shipping, proliferation of invasive species is expected to cause enormous environmental damage to aquatic and terrestrial ecosystems. Pressure to exploit new sources of oil will lead to new techniques, some of which may have a very high water and environmental footprint. Related to high fuel prices, which are likely to spur the development of alternative energy types like wind and solar, it has to be noted that although these kinds of energy production require little water, expansion of energy supply will affect water resources and related environmental services (UNESCO, 2009). At last, political conflicts could also exacerbate problems (Segrave et al., 2007). Economic insecurity has been associated with rising inequality and political instability. Such situations increase the threat of degrading water resources and reducing environmental services *(arrow 5)*.

Finally, globalization also impacts social aspects. First of all, economic difficulties and political and economic instability can affect migration (UNESCO, 2009). Furthermore, large urban agglomerations (and rural areas) in regions with weak governance structures are vulnerable to social and political unrest, particularly when they are characterized by poor infrastructure and resource (EEA, 2011). Changes in consumption patterns through growing demands and easier access to goods, services and knowledge play a role on water resources and the environment. In fact, globalization has raised living standards of people in the countries that have opened themselves to the global marketplace, transforming the way people view water as a resource (Segrave et al., 2007). For younger people the globalization of trade and advertising tempts those in developing countries to want more and those in developed countries who already have more to want even more. These needs and wants translate into higher consumption and production patterns, requiring additional resources, including freshwater. When actions are taken to reduce poverty, it must also be recognized that increasing the economic well-being of the very poor will ultimately translate into higher demand for natural resources, including water. Globalization, on the other hand, and the concepts of virtual water are leading to growing awareness of water footprints. Growing corporate awareness of a firm's water footprint is leading to greater transparency about the impact of a firm's supply chain on its water environment (UNESCO, 2009). In what concerns finance pressures, the possible increase in private companies can also bring implications on how the companies are perceived by consumers. Private companies are usually seen as having profit as their primary motive, which can lead to a rise in consumer complaints and an increase in consumer awareness about the industry. In particular, privatization may conflict with the commercial interests of private companies which might not be matched to participatory processes of water management. In addition, the private sector involvement will require that water companies would have to rethink their customer relationship management with the aim of maintaining and enhancing consumer confidence and trust (Kelay et al., 2006). Private companies will also have an effect on the willingness to pay (WTP). WTP is lower when the supplier is in the private sector and WTP anything more is close to zero if the private sector supplier is perceived as wasteful or profiteering. Where the state/regional government is responsible WTP can be higher than the status quo (Fife-Schaw et al., 2007).

3. POSSIBLE FUTURE TRENDS

The pressures characterized in the previous chapter and possibly an incalculable number of other unpredictable factors will determine future conditions on a regional scale. The present chapter identifies plausible future trends for the water sector, describes their implications for the UWCS and discusses possible strategies to meet future challenges. The consideration of those aspects will help many water utilities to define strategies in order to solve impending problems and exploit emerging opportunities.

Although Europe has most of the elements of the water services in place to support sustainable development, numerous questions remain. Some of the identified trends represent challenges for Europe (shared with many other regions); others are more related to different realities.

It has to be noted that while there is reasonable confidence over broad trends in the shorter term, substantial uncertainty attaches to the specific trends for a particular country or region. Furthermore, one should keep in mind that trends can be overcome by counter-trends and therefore they should be further developed for each situation.

3.1. Trends induced by Environmental pressures

Based upon these drivers of changes, trends can be defined to facilitate planning and the development of adaptive strategies, as represented in Figure 21 .

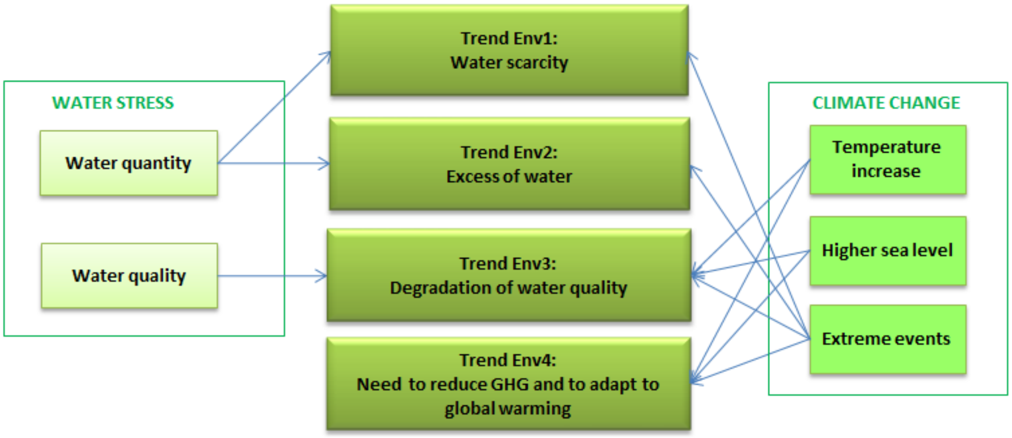


Figure 21 - Possible future trends induced by "Environmental pressures"

Under conditions of water scarcity it can be difficult to meet water demands without compromising on environmental standards (ERCC, 2009). **"Trend Env1: water scarcity"** represents this trend. Many cities face increasing risks of water scarcity because the water resources are not sufficient or contaminated, the capacity to treat and distribute the water is limited or because large losses from the water distribution systems occur (SWITCH, 2006). Where surface water is polluted or limited in terms of availability, groundwater and fossil water may constitute an alternative as a major source for drinking water. Unfortunately overexploitation of groundwater is common in many regions of the world, e.g. in Beijing and in Mexico where depletion of the aquifer has caused a shifting of land to the extent that Mexico City is now sinking (Ellis et al., 2006). Groundwater table lowering due to over abstraction is already a reality in many cities (SWITCH, 2006). Water needs to be managed wisely for satisfying additional needs, namely in agriculture, one of the sectors that consume most water. Possible solutions include drought resistant crop varieties, improved rainwater harvesting, water conservation, improved water productivity and water pollution control (Pfister et al., 2011). Water conservation measures in the domestic sector can lead to a reduction of capita water use rates, as a result of mandatory or voluntary implementation of some water-saving devices or the minimization of the losses in the water distribution systems, even as the population increases (Novotny et al., 2011).

On the contrary, excess of water can also lead to other challenges, which are considered in **"Trend Env2: Excess of water"**. Urbanization leads to various land-use changes, like the elimination of natural flood retention capacity or the interference of new infra-structures with the natural drainage network. Drainage channels in urban areas may be unable to contain the runoff that is generated by intense rainfall events, leading to an increase of flood hazard both in downstream and upstream reaches. Inadequate land use and channelisation of natural waterways, failure of the city protection dikes, inflow from the river during high stages into urban drainage system, surcharge due to blockage of drains and street inlets, soil erosion generating material that clogs drainage system and inlets and inadequate street cleaning practice that clogs street inlets are among causes of urban floods (Seyoum, 2008). Furthermore, in many lowland areas, high groundwater tables are causing problems such as damage to existing building foundations and even flooding of basements. Under these conditions, reductions in groundwater extractions or the supplementing of groundwater through stormwater infiltration can aggravate the situation. Combined stormwater and groundwater management can be a solution (Bandermann et al., 2008). At last, in some areas, water may also tend to cause problems being in excess as it is the case of infiltration and inflow (I/I) in sewer systems.

"Trend Env3: Degradation of water quality" may appear isolated or together with Trend Env1 and Trend Env2. As water quality is being severely affected worldwide, UWCS suffer. It is important to know how to detect emerging pathogens at an early stage, before they cause any harm. Once they are detected, it might be necessary to introduce new treatment steps or improve existing ones (Rósen and Lindhe, 2007). When leaks occur and the surrounding environment is contaminated, water in the distribution systems may be chemically or biologically unstable and undergo deterioration in quality (Alegre et al., 2010). Furthermore, a more detailed knowledge about the processes of sediment formation and sediment mobilisation in a network are necessary to minimise or to avoid deterioration of water quality (Wricke et al., 2007). Water Safety Plans (WSPs), described by the World Health Organization, are promoted as the most effective means of ensuring drinking water safety. WSPs are a comprehensive "source to tap" risk assessment and management approach whose primary aim is to protect public health. Such an approach is needed due to widespread illness and death caused by unsafe drinking water in developing countries and continued outbreaks of waterborne pathogens and contamination incidents in developed countries. They offer an important opportunity to promote preventative risk management within water utilities, although there are some organizational culture aspects that will have to be continually addressed like transparency, accountability, competent workforce, empowerment, poor communication, lack of awareness, interest or reward and coercion (Summerill et al., 2010).

Finally, climate change is predicted to lead to greater frequency and intensity of extreme meteorological events, and the needs for the cities to become more resilient. That is included in **"Trend Env4: need to reduce GreenHouse Gases (GHG) and to adapt to global warming"**. In that case, all water resources problems are exacerbated by the drivers of climate change. Changes in precipitation patterns towards more intense storms lead to an increased risk of flooding, affecting economic damage and the spread of diseases. Cities in delta regions may have to cope with significant sea level rises, which may lead to extreme high water levels and disastrous flooding, or during low discharge periods to the saline water intrusion. While storm events may become stronger, at the same time it is expected that dry periods will become longer, which could lead to an increase of water scarcity risk. Cities located in urbanized river basins may need to compete with agriculture for water allocations during the dry periods (SWITCH, 2006). Strategies will have to be defined and action should be taken at all levels, from individual citizens to local and national governments. This will include research on climate change impacts, mitigation of GHG emissions, adaptation to irreversible impacts and risk management practices for the urban water sector, reducing vulnerability to existing and future disasters and technological developments (Novotny et al., 2010). Increasing frequency and magnitude of water-related disasters, which will cause even more damage to life and property, should also be addressed. In particular, it should be considered a national planning priority and knowledge is needed in what concerns its trends and how it could be projected into the future. Such knowledge is central to plan, manage and mitigate disasters (Adikari and Yoshitari, 2009). Furthermore, when climate change is discussed, the energy-water nexus comes to the discussion. In fact, water supply and wastewater management consume energy to the equivalent of about 5-10 % of total domestic electricity consumption, which means that the urban water system is a small, but still significant energy consumer. Therefore, the water sector cannot be ignored in initiatives to reduce overall energy consumption and to reduce GHG (SWITCH, 2006).

3.2. Trends induced by Social pressures

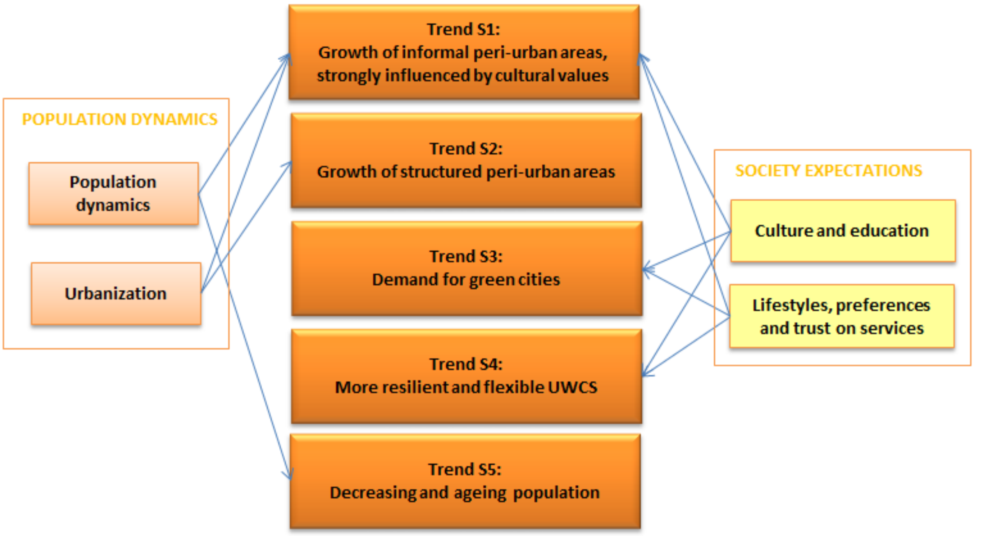


Figure 22 - Possible future trends induced by "Social pressures"

In what concerns population dynamics, a lot of pressures influences UWCS. In the next two decades, the world will have substantially more people in vulnerable urban and coastal areas and the slum formation rate will continue to be close to rate of urban growth (UNESCO, 2009). **"Trend S1: Growth of informal peri-urban areas strongly influenced by cultural values"** addresses this issue, that is particular from developing countries where populations tend to concentrate in some areas, leading to the uncontrolled clustering of urban agglomerations (urban sprawl) and the proliferation of informal communities on the fringes of cities (Ellis et al., 2006). These rapidly growing peri-urban informal settlements constitute huge areas at risk, associated with high levels of water- and sanitation-related diseases (such as schistosomiasis, malaria, trachoma, cholera and typhoid) (SWITCH, 2006). They usually grow without planning, in a disorganized and illegal way. Inhabitants of informal settlements normally do not receive water delivery services from central water supply agencies, but instead, they typically pay exorbitant prices for drinking water (sometimes of dubious quality) from local water dealers. People can spend hours each day fetching water. In this context, cultural and education level is imperative to consider. Cultural perspectives assigned by society will differently reflect UWCS. At the same time, empowerment of women is an important driver in how water services are received and managed, which cannot be forgotten (UNESCO, 2009). Moreover, an informed stakeholder dialogue on policies and the inclusion of local knowledge on the decision process will help to support the implementation of measures and improved solutions. Well-informed consumers can be a driving force for positive change (ERCC, 2009).

In developed countries, the enlargement of established or formal urban usually results from the transformation of natural land surfaces into impervious surfaces, such as roads, streets, parking lots, roofs and other types of structures (UNESCO, 2009). This is represented by **"Trend S2: Growth of structured peri-urban areas"**. In that case, impermeable surfaces increase the magnitude and frequency of floods, therefore increasing the speed of drainage collection, reducing the carrying capacity of the land and, occasionally, overwhelming sewer systems (Seyoum, 2008). In fact, as a result of increased rates of sealing associated with land use patterns, the portion of runoff active areas increases, and due to compaction, infiltration capacity decreases. Consequently, volumes of surface runoff increase and due to the lower roughness of paved or constructed surfaces the concentration times decrease and peak discharges rise. The consequence of this is that the water has a shorter detention time on surfaces and thus evaporation and groundwater recharge are diminishing (Ellis et al., 2006). Furthermore, impervious surfaces block the percolation of rainwater and snowmelt into soil. Such construction increases the flow velocity of water over the land surface, carrying polluting materials into receiving water systems, degrading water quality and causing local pollution problems. This urban drainage effect has increased the frequency of flash floods, causing casualties and infrastructure damage (UNESCO, 2009). All those aspects are paramount for the development of stormwater measures.

As it was mentioned before, some cities will face stronger society expectations, as people expect to achieve better 'quality of life' patterns, which can have a strong impact on the design of urban water management measures. This justifies the definition of **"Trend S3: demand for green cities"**. Actually, people want to walk along natural rivers and swim safely in rivers. In what concerns stormwater, it was common practice to get rid of stormwater as quickly as possible, but nowadays there is renewed emphasis on increasing the visibility of water in urban spaces. Open water bodies are of special value and the sound of flowing water is appreciated (Ellis et al., 2006). Attaining the ecological integrity of urban water resources is increasingly desired by the public. Green and low-impact buildings are also more built because they provide substantial water reuse and energy savings (Novotny et al., 2010). The metabolism model of urban water systems may also be used in order to help to identify and quantify flows of resource inputs (i.e. energy, materials, chemicals) and waste and emission outputs. However, in the context of economic problems, it is possible that the demands for improved water quality will be lowered again (Ellis et al., 2006). In general, transparency, accountability and operational efficiency in service provision are also important factors to user satisfaction. Nonetheless, merely increasing consumers' knowledge about an issue like ecological matters or technology will not necessarily lead to its acceptance, which justifies the need for iterative participatory processes (Kelay et al., 2006). The concept of water footprints may be used to describe the relations among water management, international trade and politics, measuring how much water is used and how much pollution is generated in the production and consumption of goods and services. Motivating companies to assess their water footprints responds to the need for cost control and risk management (UNESCO, 2009).

Highly linked with the previous trend is **"Trend S4: More resilient and flexible UWCS"**, defined to highlight the urgency of water utilities to adopt sustainable urban water systems that are robust and resilient to global change pressures. Strategic planning processes will have to include assessment of future expected global pressures and development of methodologies to respond to the predicted pressures articulated through their future water vision and strategies.

If natural human growth and migration leads to increases in population, it also decreases in other sites. Coupled with the age distribution pressure, it will lead influences in the water systems, represented by the **"Trend S5: Decreasing and ageing population"**. In fact, abandoned regions face difficulties in maintaining supply structures. Population decrease poses problems on sewer systems planned based on population growth predictions. Main challenges include the following aspects: oversized systems, longer times of residence within supply/sewer networks and hence increased potential for biochemical reactions within the transported matter; lower transport velocities and higher sedimentation rates due to lower discharges; reductions in the efficiencies of sewage treatment plants; higher maintenance costs per capita in less densely settled areas; the control of surface runoff in deconstructed areas and projection of decentralized retention for stormwater (Ellis et al., 2006). The age of the population will influence consumption and production patterns, with attendant impacts on natural resource needs, including freshwater (UNESCO, 2009). Ageing population presents particular challenges. The oldest in society are also more vulnerable to disease, placing new demands on water services. Furthermore, when elderly partners lose their spouses, young people delay or reject family formation and divorce rates grown, then the number of single person households increases. As economies of scale are lost, households have higher per capita water consumption (Segrave et al., 2007). At the same time, it is important to remind that it also usually implies a reduction of household consumption, leading to a general reduction of global consumption. On the other hand, ageing of population also often relates to enhanced medical services, which may vary the type of necessary treatments of waste water (Ellis et al., 2006).

3.3. Trends induced by Economic pressures

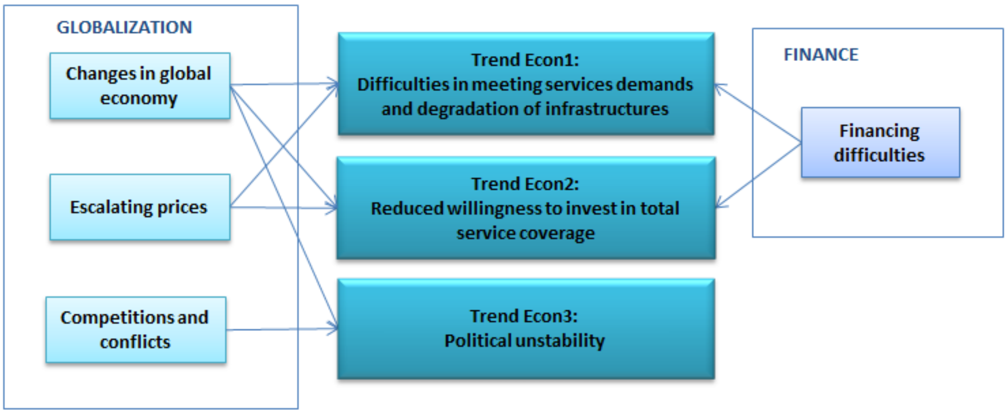


Figure 23 - Possible future trends induced by "Economic pressures"

When water systems charges barely cover the recurrent costs of operation and maintenance, which is quite common, little or no funds remain to recover the capital costs of repairs and upgrades, leading to water infrastructure deterioration over time (UNESCO, 2009). Consequently, water delivery, existing stormwater drainage management and wastewater disposal infrastructure systems require repairs, upgrades and start aging to a level that leads to problems (older components may be more than 150 years old). Some parts of the cities' infrastructures become obsolete, operation, maintenance and rehabilitation remaining critical challenges. The result is that systems can no longer provide reliable access to safe drinking water, leakage losses rates become too high and treating wastewater also fail (Novotny et al., 2010). According to a report by the Task Force for the Implementation of the Environmental Action Program for Eastern Europe, Caucasus and Central Asia, municipal water utilities have now become the main polluters of surface waters (UNESCO, 2009). In addition, as performance standards for pollution control become more stringent, the required sewer maintenance or rehabilitation does not keep pace with the system requirements (Novotny et al., 2010). This context leads to **"Trend Econ1: Difficulties in meeting services demands and degradation of infrastructures"**. For the explained reasons, a particular challenge is the need to revise investments needs by reducing costs (e.g. improving collection efficiency and reducing unaccounted for losses in distribution systems) and finding new sources of funds to close the financing gap. Recurrent costs of service delivery should be minimized and sustainability of water resources and service quality maintained (UNESCO, 2009).

"Trend Econ2: Reduced willingness to invest in total service coverage" is characterized by no willingness to invest in total service coverage. It is most typical from developing countries, where the water sector has been plagued by lack of political support, poor governance, underresourcing, underinvestment non-transparency and accountability, as well as unsustainable economics and low revenue collection (UNESCO, 2009). In those countries, independent service providers can still play an important role in the water sector as they maintain to be the mains supplier of water for the majority of the population. Care must be taken on the quality of service they provide as well as on tariffs charged (Kelay et al., 2006). Moreover, it has to be explained to water utilities and governments that adequate investments in water management, infrastructure and services can yield a high economic return by avoiding other related costs. For example, lack of water storage infrastructure may cause heavy economic losses from flooding and drought, with high costs for human health (UNESCO, 2009). There is also the challenge of applying non-extensive centralized infrastructures. More cost-effective alternatives need to be urgently explored, if the sanitation target is to be met.

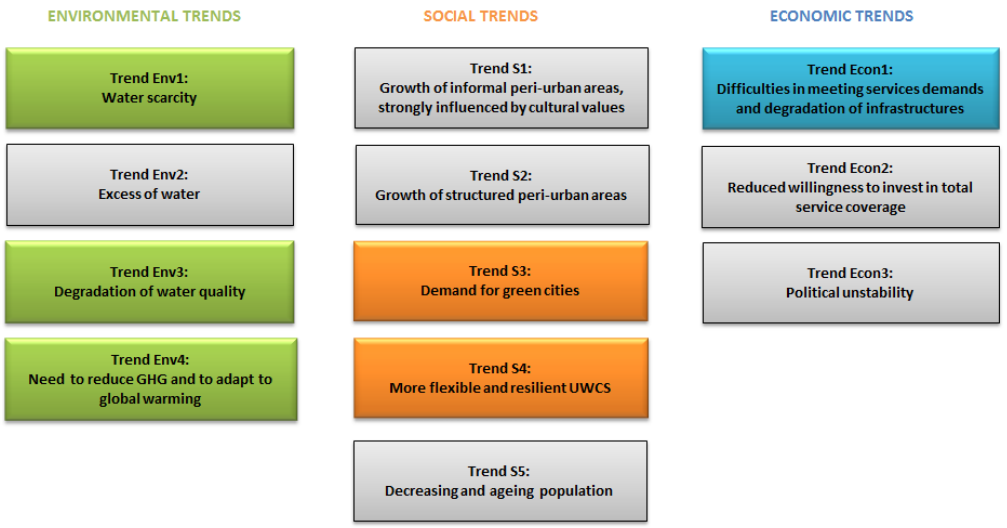
At last, globalization has still another effect, particularly in what concerns competitions and conflicts, leading to the **"Trend Econ3: Political unstability"**. The number and severity of terrorist attacks and sabotage of drinking water systems might increase. The distribution system offers an opportunity of terrorism because it has an extensive character, with severe consequences for the effected people, and because of its unprotected and accessible conditions. It is hard to protect the distribution water systems from deliberately harmful actions like contamination because of the many points where it could be introduced into the system. However, physical destruction of system's assets is more likely than contamination, as it requires fewer resources. It is important to remember that developed countries, although not so highly political unstable like developing ones, are also vulnerable to terrorist attacks. Actually, systems with high source water quality are the most vulnerable since limited treatment is needed, meaning that limited barriers against sabotage or terror events exist. The increased awareness of terrorist and sabotage incidents in some Nordic countries has resulted in more strict security control and restricted accessibility to water production systems, which may pose new operational risks to the systems for its very strong restrictions (Rósen and Lindhe, 2007).

4. EXPECTED MAJOR GLOBAL CHANGE PRESSURES AND ITS IMPACTS ON THE TRUST PILOTS

The main purpose of this chapter was to establish a preliminary framework that can help to identify major global change pressures and its impacts on Pilots of TRUST. This exercise was based on the TRUST pilot partner's main challenges, which were identified taking into account the best information the authors of this report had access to. Gathered information was then reviewed by the Pilots. The trends highlighted in colours in the following Figures correspond to the ones of most significance.

4.1. Algarve

Algarve is a region in the south of Portugal. Water services in that region are managed by the company "Águas de Portugal" (Águas de Portugal Group). Algarve faces limited water resources (low precipitation (↙500mm), ecosystems fragile and critical for the economy and strong building stress on coastal areas. Some opportunities include the insulation level, which is higher than 3000 h/year.



ENVIRONMENTAL TRENDS	SOCIAL TRENDS	ECONOMIC TRENDS
Trend Env1: Water scarcity	Trend S1: Growth of informal peri-urban areas, strongly influenced by cultural values	Trend Econ1: Difficulties in meeting services demands and degradation of infrastructures
Trend Env2: Excess of water	Trend S2: Growth of structured peri-urban areas	Trend Econ2: Reduced willingness to invest in total service coverage
Trend Env3: Degradation of water quality	Trend S3: Demand for green cities	Trend Econ3: Political unstability
Trend Env4: Need to reduce GHG and to adapt to global warming	Trend S4: More flexible and resilient UWCS	
	Trend S5: Decreasing and ageing population	

Figure 24 - Trends expected to influence Águas de Portugal operations (Algarve, Portugal)

One of the heaviest stress factors is tourism pressure, leading to highly seasonal fluctuating water demand, a very wide range of service conditions between low and high season and risks emerging from scarcity of water and energy. Numbers state that there are 15 million night stays per year and 35 golf courses in operation (45 in the future), representing a water demand equivalent to 350 thousand inhabitants. There are also large irrigation areas. In that context, **"Trend Env1: Water scarcity"** has to be considered, along with the challenges of solutions like water management issues, alternative water resources, smart management of existing infrastructure, preference to soft “infrastructure” like eco-hydrology, and others.

The water utility recognizes the importance of reliability and good understanding of cause-effect relationship of water pollution by monitoring, remote sensing or models. That justifies the importance of considering **“Trend Env3: Degradation of water quality”**.

Climate scenarios (Annex 1) show that temperatures are expected to increase annually of ~1.0°C in the 20’s-30’s and of ~1.7°C in the 40’s-50’s, as medians, with higher increasing rate in the late summer months. Some of the models’ projections predict particularly high percentage changes of both signs in the dry summer months, due more to the low absolute amount of the monthly precipitation depths than to lack of reliability; the median values of rainfall depths changes show a falling off during all the months, with an annual decrease of ~ -7% in the 20’s-30’s and ~-14% in the 40’s-50’s. Algarve is therefore likely to experience more frequent drought conditions, which justifies the need to adapt to new climate conditions. A pressure to reduce its carbon footprint by minimizing the energy use and maximize renewable energy production is also foreseen. That is mirrored in “**Trend Env4: Necessity to reduce GHG and the need to adapt to global warming**”.

There is also the recognized need to consider **“Trend S3: Demand for green cities”** and **“Trend S4: More flexible and resilient UWCS”**. Finally, **“Trend Econ1: Difficulties in meeting services demands and degradation of infrastructure”** is also important due to the expected higher standards of service provision and the need to implement cost control measures like asset management, in a context of minimization of infrastructure expansion investment.

4.2. Athens

Generally speaking, Western Greece has all the rain, but Eastern Greece has all the population. Particularly in Athens, a water scarce region, the situation is hampered by transient populations due to holiday seasons (of the order of million visitors per year). Furthermore, Athens corresponds to the major Greece population centre (approx. 5.000.000), being an immigration destination. **“Trend Env1: Water scarcity”** and **“Trend Env3: Degradation of water quality”** must, hence, be addressed in order to ensure the ability to provide high quality water services to an increasing population and manage water and sanitation challenges presented by transient population and immigration. In accordance to what was explained, EYDAP targets include: water losses minimization, alternative water sources development (WWRC, Desal), demand management, environmental impact minimisations and management of wastewater – and especially sludge disposal.

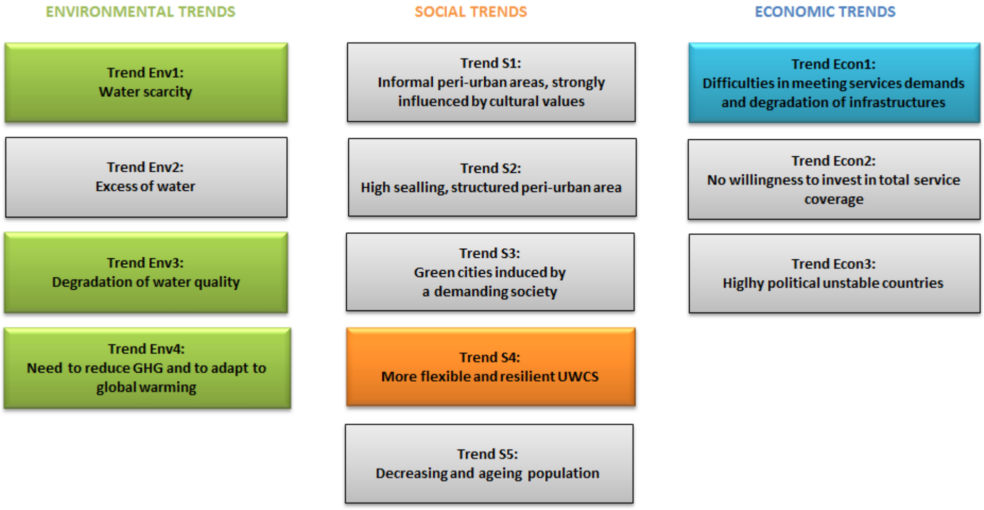


Figure 25 - Trends expected to influence EYDAP operations (Athens, Greece)

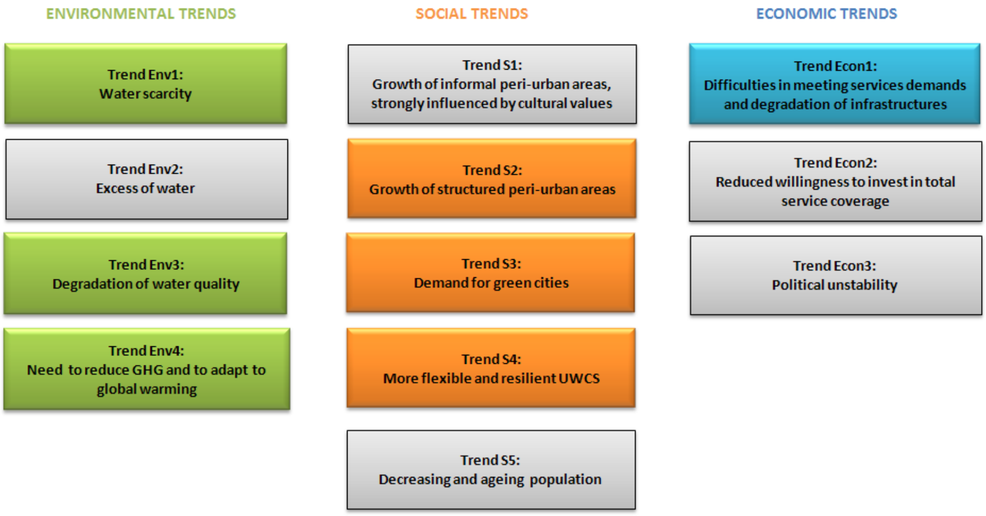
Climate models show that temperatures are expected to increase annually (50% ensemble) of ~1.1°C in the 20's-30's and ~1.8°C in the 40's-50's, with higher rise in the summer months. Overall (50% ensemble), the rainfall depths are expected to decrease throughout all the year (for an annual total decrease of around -7% in the 20's-30's and -14% in the 40's-50's) and of an higher percentage in the drier summer months. Those results confirm the need to consider probable a future accentuation of water scarcity conditions, especially in the summer, justifying **"Trend Env4: Need to reduce GHG and to adapt to global warming"**.

The distribution system is complex and inefficient, with long water transfer schemes, which presents challenges for real time control and long term planning, as well as security. It is running at capacity and even a small increase in demand would require accepting a lower reliability level – at increased costs. Therefore, structural and non-structural measures are urgently required, taking into account the institutional complexity. That justifies **"Trend S4: More flexible and resilient UWCS"**.

Furthermore, EYDAP aims at drastically reducing energy needs for the operation of the water system and turning it into a renewable energy production process as well as increasing energy recovery from system operation (mostly hydro). The water utility also set the ambition to ensure that water prices reflect true (whole life) costs of the operation, maintenance and expansion of its system, including environmental and social policy objectives. It recognizes the limited investment available at this point, which turns privatisation into a real possibility in the near future. From what has been explained, the **"Trend Econ1: Difficulties in meeting services demands and degradation of infrastructure"** needs to be urgently considered.

4.3. Madrid

Canal de Isabel II is a public-sector company responsible for water cycle services to 6 million people in the Madrid Region.



ENVIRONMENTAL TRENDS	SOCIAL TRENDS	ECONOMIC TRENDS
Trend Env1: Water scarcity	Trend S1: Growth of informal peri-urban areas, strongly influenced by cultural values	Trend Econ1: Difficulties in meeting services demands and degradation of infrastructures
Trend Env2: Excess of water	Trend S2: Growth of structured peri-urban areas	Trend Econ2: Reduced willingness to invest in total service coverage
Trend Env3: Degradation of water quality	Trend S3: Demand for green cities	Trend Econ3: Political unstability
Trend Env4: Need to reduce GHG and to adapt to global warming	Trend S4: More flexible and resilient UWCS	
	Trend S5: Decreasing and ageing population	

Figure 26 - Trends expected to influence Canal de Isabel II operations (Madrid, Spain)

Being a water scarce region, a paramount environmental trend corresponds to **"Trend Env1: Water scarcity"**, which is exacerbated by the challenge of integrating the management of resources among all different users and constraints: utilities, river basin organizations, farmers, hydroelectric power companies and stakeholders concerned with ecological issues. This context leads to the need to find and improve non conventional water sources, such as wastewater reuse, greywater recycling, artificial recharge of aquifers, desalination or techniques for increasing precipitation.

Concerning water resources, there is also the objective of minimizing deterioration of drinking water sources, working with causes, risks and impacts. That justifies the need to forecast overexploited and/or contaminated sources, considering **"Trend Env3: Degradation of water quality"**.

Climate models results show that overall (50% ensemble), the temperatures are expected to increase substantially: ~1.5°C in the 20's-30's and of ~2.4°C in the 40's-50's, with particularly high rises in the summer. Considering the median values, the rainfall depths are expected to moderately decrease during all months (total annual decrease: ~ -7% in the 20's-30's and ~ -9% in the 40's-50's). The water utility recognizes the importance of forecasting resource availability and weather conditions, adapting river basin planning and management systems to future precipitation and temperatures scenarios due to climate change as well as harnessing energy and recovery, promotion of renewable energies and carbon dioxide emissions reduction. “**Trend Env4: Necessity to reduce GHG and the need to adapt to global warming”** is therefore considered crucial.

“Trend S2: Growt of peri-urban, structured peri-urban area” might also be important as there exists the recognition of developing new strategies regarding Sustainable Urban Drainage.

Some other special social trends include **“Trend S3: Demand for green cities”** and **“Trend S4: More flexible and resilient UWCS”**. In fact, new sustainable technologies have to be developed in order to meet new standards and regulations on waste water treatment and treated sludge end uses, but also in order to get alternative drinking water sources with different qualities and organoleptic characteristics accepted by public. Closely related to the previous ones, another trend has to be mentioned: **“Trend Econ1: Difficulties in meeting services demands and degradation of infrastructures”** due to the fact that there is the identified need to develop tools like Decision Support Systems to assess, prioritize and manage the risk of failure and rehabilitation works to ensure the sustainability of our hydraulic infrastructures.

4.4. Reggio Emilia

The Province of Reggio Emilia UWCSs is managed by IREN-Acqua Gas, under the supervision of ATO 3 Reggio Emilia. It is a hilly and mountainous area besides the Po river Plain. The capital city is an Italian medium-sized town in a densely populated area with a thriving economy. Its area covers 2,224 km^2 and it has a population of 480,000 inhabitants.

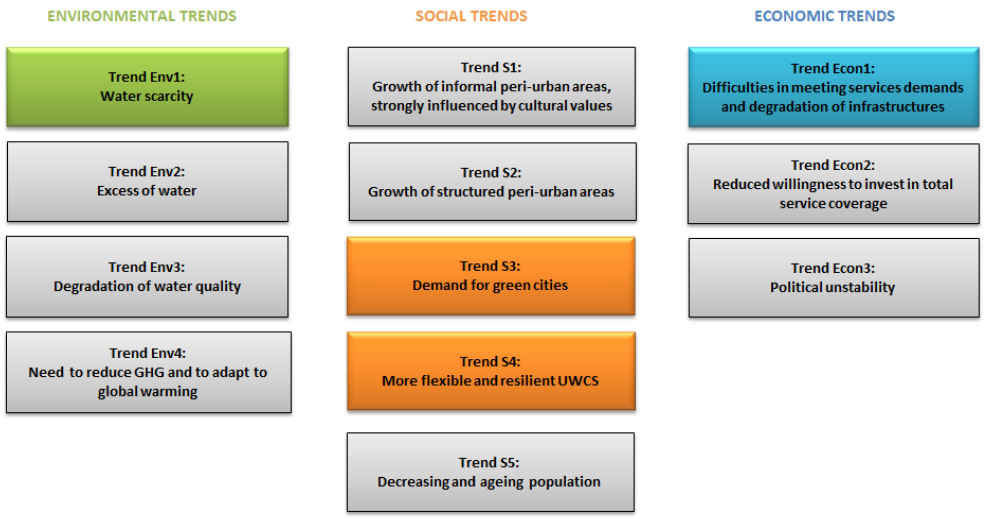


Figure 27 - Trends expected to influence Iren Acqua Gas operations (Reggio Emilia, Italy)

One of the pressures Reggio Emilia will face is water shortages, which justifies the need to give attention to **"Trend Env1: Water scarcity"**.

Climate model results (Annex 1) show that temperatures are expected to increase not negligibly (~1.4°C in the 20's-30's and of ~2.3°C in the 40's-50's) and particularly in the summer months. In what concerns precipitation, the models' projections highlight a minor decrease (not significant) over the entire year. No significant differences are detectable throughout all the seasons when considering the 50% ensemble for the 20's-30's period, and a slight decrease in the spring-summer-autumn, with a slight increase for the winter months, is shown for the following years (-2% annual change for both the two-decades time-slices). "Trend Env4: Necessity to reduce GHG and the need to adapt to global warming" is not considered critical.

Other challenges are related to **"Trend S3: Demand for green cities**" and **"Trend S4: More flexible and resilient UWCS"** as the water utility has to meet the requirements of EU WFD 2000/60, Italian legislation, and regional Master Plan for Water Management, as well as higher service standards to meet increasing customer demands in a context of economic constraints and water scarcity.

That links to another important trend: **"Trend Econ1: Difficulties in meeting services demands and degradation of infrastructure"**. Actually, upgrading the system is a necessity but is has to be in accordance with the budget issued by the local Water Authority. Investment program geared towards infrastructure renewal, optimisation of existing networks, efficient water resources management, energy recovery and production, in a context of shortages of water and finances that cannot be neglected.

4.5. Amsterdam

Waternet is responsible for drinking water supply, sewerage, groundwater control, surface water quality, wastewater treatment and water quality control for the city of Amsterdam. Amsterdam Schiphol Airport has 301 direct destinations, corresponding to 45.2 million passengers and 1.5 million tonnes cargo per year. It provides 170,000 jobs in the region and 60,000 jobs at Schiphol. The water cycle at Schiphol airport includes 1.2 million m^3 drinking water/year, more than 1000 toilets of which 25% water-free urinals, activated sludge WWTP (4000 m^3/d), source-oriented approach to control surface water quality and there is also an ongoing project on glycol treatment (from aircraft de-icing) by algae.

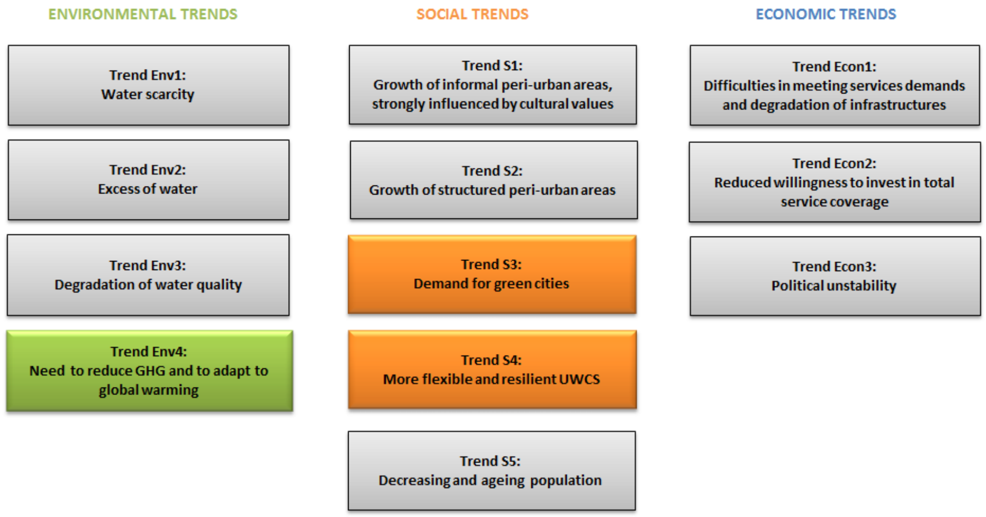


Figure 28 - Trends expected to influence Waternet operations (Amsterdam, Netherlands)

In what concerns climate change scenarios, the temperatures are expected to increase annually of ~1.1°C in the 20's-30's (with a lower increase in the early summer) and of ~1.8°C in the 40's-50's (higher increase during the late winter and the late summer). The rainfall depths are expected to increase during all months, with the exception of the summer ones, where a slight decrease is instead predicted. The mean values of the 50% ensemble indicate an annual moderate increase of ~ 6% in the 20's-30's and ~9% in the 40's-50's. See Annex 1 for details. Furthermore, the urban development in Amsterdam is expected to be climate proof, leading to the **"Trend Env4: Necessity to reduce GHG and the need to adapt to global warming"**. In fact, an important challenge of Waternet utility is achieving a climate neutral water cycle in Amsterdam, and particularly a climate resistant and carbon neutral Airport. Initiatives are already being undertaken to make use of the energy from the water cycle. These include: energy recovery from surface water (heat and cold), sludge digestion and green gas production, thermal energy recovery from drinking water and wastewater, and aquifer thermal energy storage. In 2012, Waternet expects a carbon neutral balance in its own activities. In 2020, it aims to achieve 30% CO_2 reduction (as of 1990) of all activities at location and 20% renewable energy produced at location. Moreover, it wants to be the first carbon neutral mainport in the world in 2040.

Moreover, "**Trend S3: Demand for green cities**" and **"Trend S4: More flexible and resilient UWCS"** in Amsterdam are viewed as future opportunities for application and demonstration of innovative concepts and technologies for urban water cycle. The main objective is to attain the transition to a sustainable city, including the airport. It aims an urban development, liveable and healthy, resilient (with new residential area on islands, coping with urban heat and green roofs) and robust (protecting existing and safe quality low urban areas). Among other sustainability ambitions Schiphol presents the challenge of robust combinations among surface water, wastewater, ground water and drinking water, as well as the closure of the water cycle and biogas production from black water.

4.6. Hamburg

Hamburg Wasser manages water services in the city of Hamburg, which is facing a decreasing water consumption.

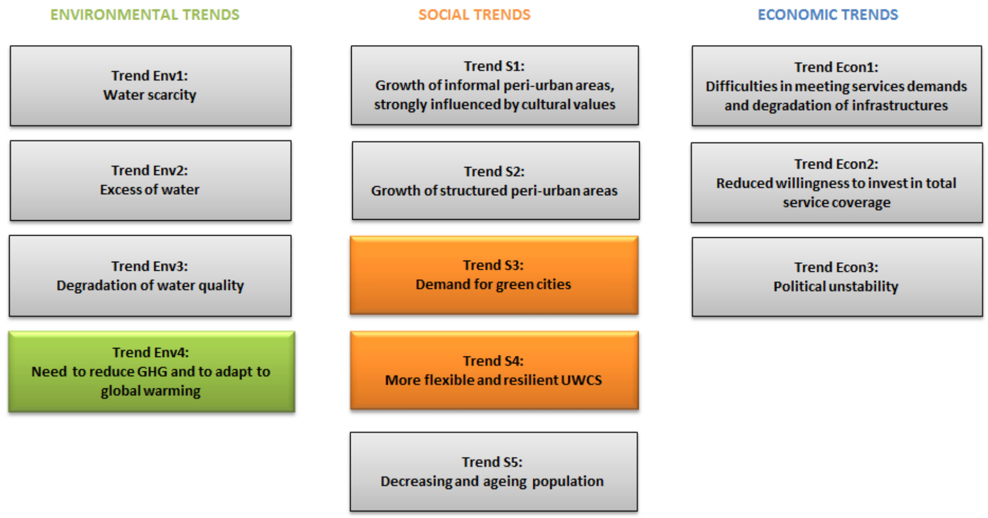


Figure 29 - Trends expected to influence Hamburg Wasser operations (Hamburg, Germany)

Climate models results (Annex 1) show that temperatures (referring to the 50% ensemble) are expected to increase annually of ~1.2°C in the 20's-30's and of ~1.9°C in the 40's-50's, with a larger increase (especially in the 20s-30's) in the winter months. Considering the median values, the rainfall depths are expected to increase during all months, with the exception of the summer ones, where no clear trend in the changes for the 20's-30's and a slight decrease for the 40's-50's are instead predicted. The total annual increase is moderate: ~ 6% in the 20's-30's and ~9% in the 40's-50's. Nevertheless, ambitious goals at Hamburg include further environmental improvement and sustainable development. First of all, the utility is working on Zero-CO_2-Concepts, including solutions like decentralized stormwater management, improved energy efficiency, enhanced power production and awareness on building/demonstration projects. Hamburg's objective on combating global warming is the reduction of greenhouse gas emissions by 40 % until 2020 compared to 1990. Those ambitions are included in **"Trend Env4: Necessity to reduce GHG and the need to adapt to global warming".**

Hamburg has received the "European Green Capital 2011" award for its major achievements in the past years in what concerns excellent environmental standards across the board. That was possible because of the incorporation of water issues in 'green' sustainable urban development initiatives. The city has set very ambitious future plans which promise additional improvements, justifying the need to consider **"Trend S3: Demand for green cities"** and **"Trend S4: More flexible and resilient UWCS"**.

4.7. Oslo area

Oslo receives its water from the surface sources in the 330 km^2 large forest areas surrounding the city. These areas, which consist of forty lakes, are drained by eight major city's watercourses that flow into the Oslo fjord.

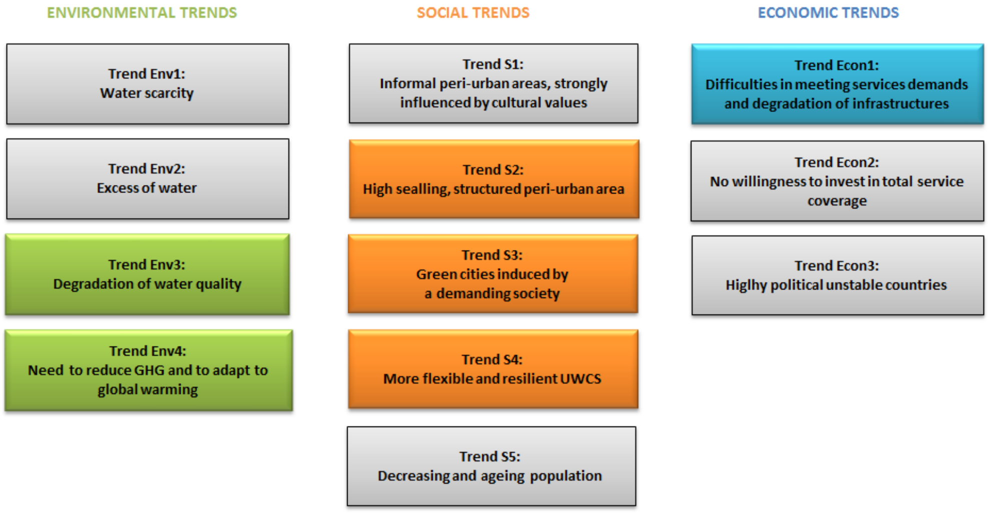


Figure 30 - Trends expected to influence Oslo Water operations (Oslo area, Norway)

First of all, degradation of water quality is an urgent issue for Oslo area, leading to the relevance of considering "**Trend Env3: Degradation of water quality**".

Climate model results (Annex 1) show that temperatures are expected to increase significantly (~1.5°C in the 20's-30's and of ~2.4°C in the 40's-50's when considering the 50% ensemble) and particularly in the winter months. Analysing the median values, the rainfall depths are expected to increase (annually ~ 7% in the 20's-30's and ~12% in the 40's-50's) consistently during all the months, with the exception of the summer ones in the 40's-50's, where no significant change with respect to the control scenarios are predicted. **"Trend Env4: Necessity to reduce GHG and the need to adapt to global warming"** is, therefore, an obvious pressure as development drivers for Oslo urban water systems in coming 30 years include high energy consumption and climate change.

Another expectation is the transition of urban and peri urban area to more sustainable operations, along with the increase in innovational, regulatory, economic, environmental and managerial aspects of urban water systems and services, climate and energy. That corresponds to **"Trend S2: Growth of structured peri-urban areas"**, **"Trend S3 Demand for green cities"** and to **"Trend S4: More flexible and resilient UWCS"**.

Oslo is also expected to face challenges coming from a significant population growth and densification of urban areas, linked with the need for renewal of outdated infrastructure. Therefore, consideration of **"Trend Econ1: Difficulties in meeting services demands and degradation of infrastructure"** might be important.

4.8. Scotland cities

Scottish Water is the 4th largest water company in UK, with 5 million customers and £1bn annual turnover.

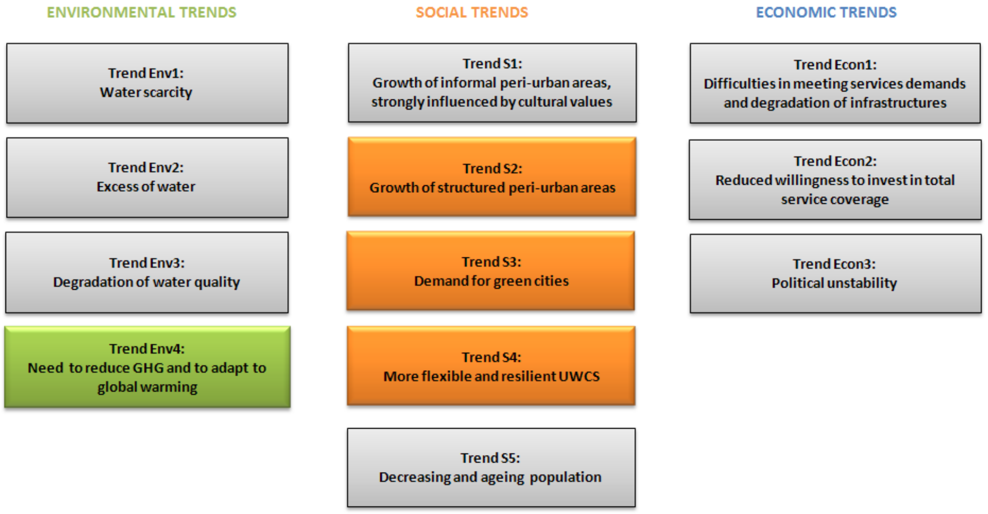


Figure 31 - Trends expected to influence SNBV and Scottish Water operations (Scotland cities, England)

Climate models (Annex 1) show that temperatures (referring to the 50%-ensemble values) are expected to be subject to a very moderate annual increase (~0.9°C in the 20's-30's and of ~1.4°C in the 40's-50's), uniformly distributed over the year. The median values show how the rainfall depths are expected to increase during the autumn, winter and spring months, whereas no significant changes for the 20's-30's and a slight decrease for the 40's-50's are predicted for the summer. The total annual increase is small: ~7% in the 20's-30's and ~8% in the 40's-50's.

Scottish Water operations are mainly affected by **"Trend Env4: Necessity to reduce GHG and the need to adapt to global warming"**, **"Trend S2: Growth of structured peri-urban areas"**, **"Trend S3: Demand for green cities"** and **"Trend S4: More flexible and resilient UWCS"**. In fact, Scottish Water Innovation Priorities include zero disruption to customers, sustainable surface water management, lower carbon water service, “waste to energy” paradigm, nutrient recovery, renewable energy and efficient service delivery. In conclusion, it aims the delivery of recent vision to providing low carbon water services.

4.9. Bucarest

Since 2000, Apa Nova Bucuresti is the dedicated operator in Bucharest for drinking water supply and sewerage services with a concession contract (2000-2025). The responsibility for the water service is assumed by the local authorities, but every municipality may choose its own administration mode (direct or delegation). It has more than 110 000 contractual clients, ~ 1.7 million inhabitants and an annual consumption of approx. 142 Mm^3. Its annual turnover is of about 118.3 M Euros (IFRS) and the annual investment is of approx. 20 M Euros.

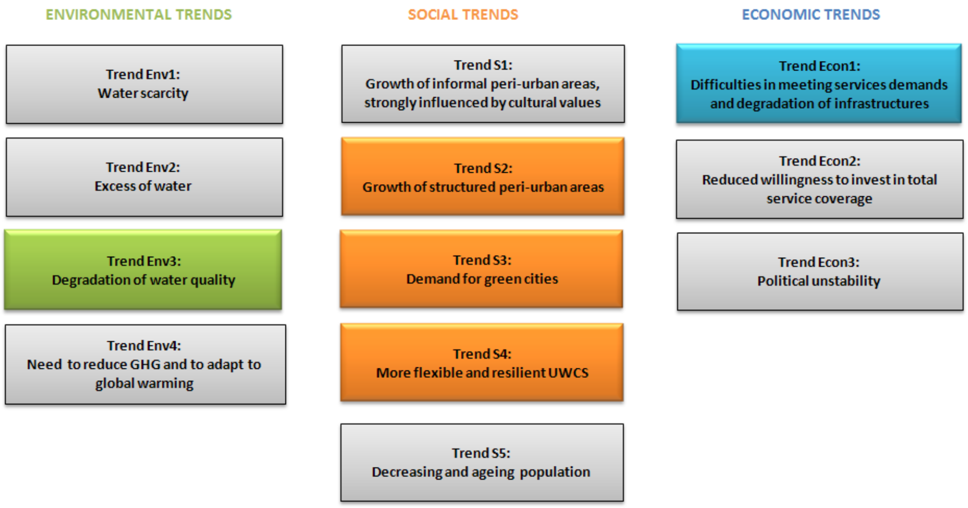


Figure 32 - Trends expected to influence Apa Nova Bucaresti operations (Bucarest, Romania)

One of the key challenges Bucarest faces is the protection of the environment and pollution control, issues clearly related to **“Trend Env3: Degradation of water quality”.** Actually, one of the concerns of the water utility is the quality of treated waste water in 2015.

Climate models results (Annex 1) show that annual temperatures are expected to increase substantially: ~1.3°C in the 20’s-30’s and of ~ 2.3°C in the 40’s-50’s, with particularly high increasing rates during the summer. The overall (50% ensemble) expected change in the precipitation depths is not significant in the 20’s-30’s (corresponding to an annual total decrease of around -1%) and extremely slight also in the 40’s-50’s (-3%) and fluctuating over the different seasons. “Trend Env4: Necessity to reduce GHG and the need to adapt to global warming” is therefore not considered critical.

Within a context of peri-urban development, **"Trend S2: Growth of structured peri-urban areas"** is also paramount to consider. **"Trend S3: Demand for green cities"** and **"Trend S4: More flexible and resilient UWCS"** are justified by the fact that the ANB recognizes the need to move towards more sustainable operations in a transitional economy, including the obligation it has to accomplish on the increase in network efficiency at 67% from the actual 58%.

The last trend **"Trend Econ1: Difficulties in meeting services demands and degradation of infrastructure"** comes from the fact that a vital objective of Bucharest Municipality is the achievement of European standards for the water and sewerage services at the lowest possible tariff. The institutional framework is important to consider as the water utility wants to provide these services independently of the Municipality and/or the state, improve activity's organization, increase operational performance and build a stable and lasting contractual partnership. ANB has also the obligation of extending the Water and Sewerage network.

4.10. Angola

Kilamba-Kiaxi municipality integrates the Luanda province, and possesses 6 counties, 69 sectors and at least 414 blocks, spreading over 135 km^2. One can estimate that the overall population surpasses 900,000 inhabitants.

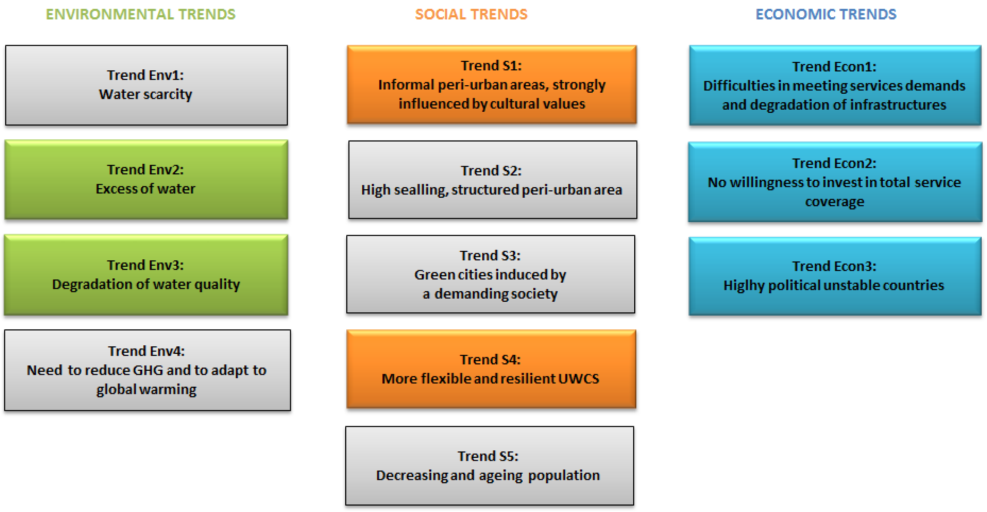


Figure 33 - Trends expected to influence Luanda UWCS operations (Kilamba-Kiaxi, Angola)

In terms of environmental pressures, **"Trend Env3: Degradation of water quality"** is a crucial one. In fact, it is confirmed the existence of groundwater at a depth between 60 and 100 meters. However, the drilling already performed show that it is brackish water, thus needing an appropriate treatment. In addition, wastewater is drained to the streets. There is neither a rainwater draining system, resulting that flooding is normal during rainy season. Draining ditches do exist but they are filled with trash and houses. Since water doesn't flow, it stays there, thus resulting in a source of infectious diseases. Rehabilitation of these ditches seems very urgent, along with the consideration of **"Trend Env2: Excess of water"**.

Climate models results show that temperatures are expected to increase annually, uniformly over the different seasons, of ~1.2°C in the 20's-30's and of ~1.9°C in the 40's-50's. Due to the basically null monthly rainfall amounts in the summer, some of the models' projections seem to predict unrealistic high percentage changes of both signs; examining the absolute - rather than the relative - changes, no clear trend is detectable considering the 50% ensemble of all the models' projections for both the time-slices. "Trend Env4: Necessity to reduce GHG and the need to adapt to global warming" is therefore not identified as critical.

Although there is regular urbanization, some urban patterns should be considered, as it is the case of irregular urbanization with precarious infrastructure and high density slums, some of them located in environmentally sensitive areas. In addition, population has little idea of what sanitation means and its acceptance on new systems remains a challenge. That will make **"Trend S1: Growth of informal peri-urban areas, strongly influenced by cultural values"** very important.

Access to water and energy is very difficult. Most of the municipality does not have access to tap water. Supply is provided by fountains and tanks, some managed by Empresa Pública de Água de Luanda (EPAL), others by some Non-Governmental Organisations. Regarding sanitation, there is no network at all in the Kilamba Kiaxi municipality. For those reasons, is it clear that water and sanitation infrastructures are poor or even inexistent, leading to **"Trend Econ1: Difficulties in meeting service demands and degradation of infrastructure"**, and also justifying the need to consider **"Trend S4: More flexible and resilient UWCS"**.

The African state of development is very different from all the other European case studies. Its medium and long-term vision is certainly not the same as the European ones and solutions to be implemented need to be adapted to their current state of development, organization and human resources. Furthermore, the model of governance (organization, human resources) is very little developed. Therefore, the following trends might also be of relevance: **"Trend Econ2: Reduced willingness to invest in total service coverage"** and **"Trend Econ3: Political unstability"**.

5. CONCLUDING REMARKS

This document presented a review of global change pressures on UWCS in order to establish the most relevant ones influencing the TRUST Pilots.

The most significant pressures affecting UWCS were framed according to the dimensions of the triple bottom line (TBL) sustainability approach: environmental, social and economic dimensions. General descriptions of relevant pressures were presented in terms of context situation, geographic dependency and expected tendencies for the future.

According to those pressures, possible future trends were identified, which may help to further define strategies to solve impending problems and exploit emerging opportunities.

Based on the considered trends for the water sector, major global change pressures and its impacts on Pilots of TRUST were identified. The ones of most significance were highlighted. Such information may be also useful for the development of some of the tasks to be performed in the next months in the TRUST Project (e.g. task 12.3 and WP 13).

Attention should be paid to the fact that pressures and trends, as well as related uncertainties, either due to external conditions or limited knowledge, are context-specific. In any case, it is foreseeable that uncertain future drivers will change the strategic planning of UWCS, taking into account that long-term decisions might have to been taken. Consequently, there is a clear need for more solutions dealing with uncertainty of multiple trends. Furthermore, strategies should also be based around the concepts of flexibility, adaptability and resilience, using measures which can be easily altered or that are robust to changing conditions and to uncertainty. Those considerations are expected to support anticipatory adaptation decision-making. For more information, Report of task 12.2 reviews flexible UWCS and transitional pathways.

Moreover, in UWCS, water supply, wastewater sanitation and drainage systems are strictly connected. Seemingly, governance issues (policy, regulation, institutional models and finance) and technological issues (infrastructure and asset management) are also closely related. Therefore, a final consideration is made in what concerns the close link among the different directions of impacts, which highlights the importance of considering a broad view of interconnections within UWCS.

This analysis is expected to be an useful tool as it offers a wide ranging framework from which to build future scenarios and develop adaptive strategies. It will thus be important to complement work area 1 (WA1) and it will form the basis for developing risk management tools and strategies (WA5). The ultimate goal is to help to translate assessment into action.

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7. ANNEX 1 – SCENARIOS OF EXPECTED TEMPERATURE AND PRECIPITATION CHANGES AT MONTHLY TIME-SCALE FOR PILOT AREAS.

7.1. Introduction

This annex presents the projections of several different GCM models, as far as the progress of temperature and rainfall at monthly time scale is concerned. Two sets of projections are presented, the first one prepared by the UNIBO Research Unit based on results from CMIP3 (Coupled Model Intercomparison Project) and the second one by the IST Research Unit based on results from the ENSEMBLES project.

The UNIBO Research Unit analysed the CMIP3 (Coupled Model Intercomparison Project) projections of future climate (for two two-decades time-slices up to the 2050's), referred to each of the ten TRUST pilot cities areas, in terms of the expected change in temperature and precipitation monthly values, being certainly the most important meteorological variables for the management of Urban Water Services. The analysis is based on the collection of model outputs hosted centrally at the Program for Climate Model Diagnosis and Intercomparison (PCMDI): climate models' output from simulations of the past, present and future climate was collected by PCMDI mostly during the years 2005 and 2006, and this archived data constitutes phase 3 of the Coupled Model Intercomparison Project (CMIP3). In part, the WGCM (the Working Group on Coupled Modelling of the World Climate Research Programme) organized this activity to enable those outside the major modeling centers to perform research of relevance to climate scientists preparing the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC).

The study reports the changes expected (under the A2 SRES scenario, see IPCC 2000) in the monthly values of both temperature and precipitation over the next decades, up to an horizon of fifty years. The projections of the expected monthly changes - with respect to the values modelled for the control run decade (1989-1999) - issued by a set of 16 climate models over the two-decades periods 2020-2039 and 2040-2059, are shown. Along with the outputs of each model, also their overall ensembles values are represented, through the corresponding median (50% percentile) and the 10% and 90% percentiles.

The IST Research Unit analysed the climate projections from ENSEMBLES project which gathered results from climate scenarios produced in several European climate institutes. The project aims "to help inform researchers, decision makers, businesses and the public by providing them with climate information obtained through the use of the latest climate modeling and analysis tools."This way, using an ensemble of runs, is possible to measure the uncertainty in climate projections.

The ENSEMBLES climate runs cover the period between 1950 and 2100, at a grid of 25x25 km. The reference period is 1980-1999, and the projections are made for the periods: 2020-

2039, 2040-2059, 2060-2079 and 2080-2099. The first two periods of projection coincide with the UNIBO study, two additional periods are presented. The reference emission scenario of the ESSEMBLES projections is A1B, a different scenario from the CMIP3 data.

For this report the following variables were analysed: monthly mean temperature, monthly mean precipitation and monthly maximum daily precipitation. The biggest advantage of the ENSEMBLES project is that provides data at the daily and hourly timescale. However, as reported by Mendes and Oliveira (2011), at least for the Portugal region, the data quality of the hourly precipitation is very low, presenting values quite above the expected, when compared to monitoring data.

The GCMs' outputs from both studies are presented in terms of the changes expected in the values of precipitation depths are provided also as the percentage of the change of the mean monthly values of the control run decade (1980-1999). In fact, it must be reminded that the GCM outputs are averaged over relatively large spatial cells (around 450 km^2): because of the uncertainties in the models' outputs at local scale and of the presence of possible climatic differences in the precipitation regime inside each one of the case study areas (for example orographic precipitation for the pilots located in mountainous areas), we believe it may be more useful to have an estimate of the relative expected change, rather than an estimate of the absolute value of the change of monthly rainfall depths.

7.2. Climate Models

Excerpts from: Randall et al., 2007: Climate Models and Their Evaluation, In: Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: The Physical Science Basis, Chapter 8.

Climate models use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the weather and climate system to projections of future climate.

Climate models are mathematical representations of the climate system, expressed as computer codes and run on powerful computers. One source of confidence in models comes from the fact that model fundamentals are based on established physical laws, such as conservation of mass, energy and momentum, along with a wealth of observations. Computer models cannot predict the future exactly, due to the large number of uncertainties involved, but there have been major advances in the development and use of models over the last 20 years and the current models give us a reliable guide to the direction of future climate change. The models are based mainly on the laws of physics, but also empirical techniques which use, for example, studies of detailed processes involved in cloud formation. The most sophisticated computer models simulate the entire climate system. As well as linking the atmosphere and ocean, they also capture the interactions between the various elements, such as ice and land (Climatic Research Unit website: http://www.cru.uea.ac.uk/).

Coupled atmosphere-ocean general circulation models (AOGCMs) combine the two general circulation models, atmospheric and ocean. They thus have the advantage of removing the need to specify fluxes across the interface of the ocean surface. These models are the basis for sophisticated model predictions of future climate, such as are discussed by the Intergovernmental Panel on Climate Change (IPCC).

AOGCMs represent the pinnacle of complexity in climate models and internalize as many processes as possible. They are the only tools that could provide detailed regional predictions of future climate change. However, they are still under development. The simpler models are generally susceptible to simple analysis and their results are generally easy to understand. AOGCMs, by contrast, are often nearly as hard to analyze as the real climate system.

There is considerable confidence that Atmosphere-Ocean General Circulation Models (AOGCMs) provide credible quantitative estimates of future climate change, particularly at continental and larger scales. Confidence in these estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation). Over several decades of development, models have consistently provided a robust and unambiguous picture of significant climate warming in response to increasing greenhouse gases (Randall, 2007).

The large-scale patterns of seasonal variation in several important atmospheric fields are now better simulated by AOGCMs than they were at the time of the previous IPCC Third Assessment Report (TAR 2001). Notably, errors in simulating the monthly mean, global distribution of precipitation, sea level pressure and surface air temperature have all decreased.

Since the TAR, an unprecedented effort has been initiated to make available new model results for scrutiny by scientists outside the modelling centres. Eighteen modelling groups performed a set of coordinated, standard experiments, and the resulting model output, analysed by hundreds of researchers worldwide, forms the basis for much of the current IPCC assessment of model results. The benefits of coordinated model intercomparison include increased communication among modelling groups, more rapid identification and correction of errors, the creation of standardised benchmark calculations and a more complete and systematic record of modelling progress. (Randall et al., 2007)

A statistical ensemble is a set of copies of a system considered at once, where each copy represents a different realization of the system, but with consistent macroscopic properties. A climate ensemble allows to deal with uncertainties in the system, and the output of the several runs can be sum up probabilistically, with probability distribution functions for exemple.

A number of questions may arise from the use of an ensemble:

1) The ensemble has to cover a wide range to be effective
2) It's necessary to consider not only errors in the observations, but also in the models

3) When building probability distribution functions to sum up the different runs, any prior assumptions may influence the results presented.

An ensemble can be a result of different forcing (such as the different emission scenarios), can be the result of different initial conditions, or even of different parameterizations, as the climate models have a large number of adjustable parameters which can have, individually or in group, a significant impact in the simulation.

When different initial conditions are considered, the same model is used, with the same atmospheric physics parameters and forcings, but run from different starting states. Small local changes in variables as temperature or wind in such a chaotic system result in different paths, and therefore, different outputs. A possibility for an ensemble is to do several runs stared with different starting conditions, and then look at the evolution of the group as a whole, as in weather forecasting).

7.3. SRES Emissions Scenarios

Excerpts from: IPCC SRES SPM, 2000, IPCC SRES, 2000, IPCC TAR WG3 (2001)

To produce future climate projections, the atmospheric concentration of greenhouse gases is modified during the simulation according to different scenarios drawn up by economists. The GHG emission scenarios assumed for the 21st century projections follow the special report on emission scenarios (SRES) of the International Panel on Climate Change (2000). The 21st century projections are forced with anthropogenic green-house gas (GHG) emissions only (i.e. volcanic and solar forcing is kept constant at the historic value used for the 20th century simulations).

These emission scenarios follow different storylines for the economic and cultural development of the world. Following these storylines emissions of long-lived greenhouse gases CO2, CH4, N2O, as well as SO2 emissions are derived. The emissions of long-lived greenhouse gases are translated to concentrations using biogeochemical models. For a detailed description of the emission scenarios see also: http://www.grida.no/climate/ipcc/emission.

Since there is no agreement on how the future will unfold, the SRES tried to sharpen the view of alternatives by assuming that individual scenarios have diverging tendencies — one emphasizes stronger economic values, the other stronger environmental values; one assumes increasing globalization, the other increasing regionalization. Combining these choices yielded four different scenario families (see Table A1.1 and Figure A1.1). In the schematic illustration of SRES scenarios (Figure A1.1) the four scenario “families” are shown, very simplistically, for illustrative purposes, as branches of a two-dimensional tree. The two dimensions shown indicate global and regional scenario orientation, and development and environmental orientation, respectively. The four scenarios share a space of a much higher dimensionality given the numerous driving forces and other assumptions needed to define any given scenario in a particular modelling approach. The schematic diagram illustrates the scenarios build on the main driving forces of GHG emissions. Each scenario family is based on a common specification of some of the main driving forces (IPCC TAR WG3, 2001) (Figure 2.11 in IPCC TAR WG3 2001).

Table A1.1 - Overview of SRES scenario quantifications; the four SRES scenario families vs. projected global average surface warming until 2100 (Table 4-2 in IPCC SRES 2000)

	MORE ECONOMIC FOCUS	MORE ENVIRONMENTAL FOCUS
Globalisation (homogeneous world)	**A1** rapid economic growth **1.4 - 6.4 °C**	**B1** global environmental sustainability **1.1 - 2.9 °C**
Regionalisation (heterogeneous world)	**A2** regionally oriented economic development **2.0 - 5.4 °C**	**B2** local environmental sustainability **1.4 - 3.8 °C**

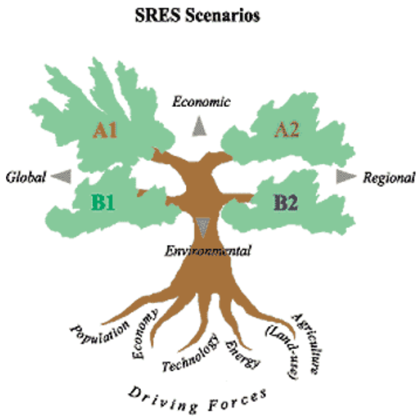


Figure A1.1- Schematic illustration of SRES scenarios.

From the SRES (Special Report on Emissions Scenarios) family of emission scenarios (IPCC SRES 2000, IPCC SRES SPM 2000), only three were used in the CMIP3 climate change simulation runs for the IPCC Fourth Assessment report: SRES-B1, SRES-A1B and SRES-A2.

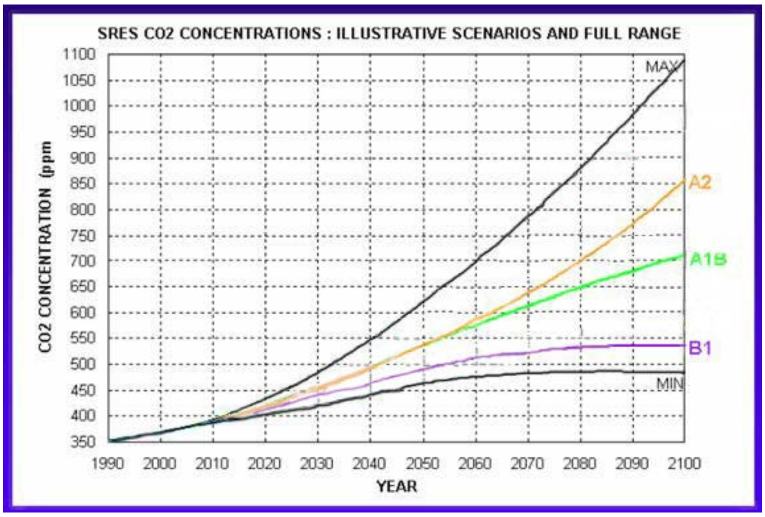


Figure A1.2– CO2 concentration evolution for diferent SRES emissions scenarios

In the present analysis, we considered the A2 scenario and the A1B scenario.

The A2 scenario assumes a moderately free trading world with a regional focus and some sustainability objectives. It describes a largely unchanged behaviour (a "business as usual" scenario) with respect to the current economic trends, assumed in many European studies (see EC DG Regional Policy, 2009). The A2 storyline and scenario family describes a very heterogeneous world and high economic growth and is characterized by:

- A world of independently operating, self-reliant nations.
- Continuously increasing population.
- Regionally oriented economic development.
- Slower and more fragmented technological changes and improvements to per capita income.
- Best estimate temperature rise of 3.4°C with a likely range of 2.0 to 5.4° C.
- Sea level rise likely range: 23 to 51 cm.

The A1 family scenario assumes a future intense economical growth, with the population peak situated mid-century, and posterior decrease, fast growth of efficient technology, increase of the social and cultural interaction and GDP per capita worldwide convergence. The A1B assume a development based in both fossil and non fossil energy.

7.4. Fourth Asssessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), the Program for Climate Model Diagnosis and Intercomparison (PCMDI)

The IPCC Fourth Assessment Report is the fourth in a series of reports on climate change issued by the Intergovernmental Panel on Climate Change, which is based in Geneva Switzerland, and was established in 1988 by two United Nations organisations, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). IPCC has been established to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.

In response to a proposed activity of the World Climate Research Programme's (WCRP's) Working Group on Coupled Modelling (WGCM), PCMDI volunteered to collect model output contributed by leading modeling centers around the world. Climate model output from simulations of the past, present and future climate was collected by PCMDI mostly during the years 2005 and 2006, and this archived data constitutes phase 3 of the Coupled Model Intercomparison Project (CMIP3). In part, the WGCM organized this activity to enable those outside the major modeling centers to perform research of relevance to climate scientists preparing the Fourth Assessment Report (AR4) of the IPCC. (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php)

This unprecedented collection of recent model output is officially known as the "WCRP CMIP3 multi-model dataset". It was meant to serve IPCC's Working Group 1, which focuses on the physical climate system -- atmosphere, land surface, ocean and sea ice -- and the choice of variables archived at the PCMDI reflects this focus. (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php)

By far the most ambitious organised effort to collect and analyse Atmosphere-Ocean General Circulation Model (AOGCM) output from global standardised experiments was undertaken in the last few years.

It differed from previous model intercomparisons in that a more complete set of experiments was performed, including unforced control simulations, simulations attempting to reproduce observed climate change over the instrumental period and simulations of future climate change. It also differed in that, for each experiment, multiple simulations were performed by some individual models to make it easier to separate climate change signals from internal variability within the climate system.

Perhaps the most important change from earlier efforts was the collection of a more comprehensive set of model output, hosted centrally at the Program for Climate Model Diagnosis and Intercomparison (PCMDI). This archive has allowed hundreds of researchers from outside the modelling groups to scrutinise the models from a variety of perspectives. (Randall et al., 2007)

The results of the global climate models that are summarised in the present report are those archived in the CMIP3 dataset and complete models' documentation may be found at the website:
http://www-cmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php

Each model is run with different atmosphere and ocean spatial resolutions: the results here presented for the study areas (pilot city areas) were extracted from a unique spatial modelling grid resampled to a 2°x2° resolution (see World Bank Climate Change Knowledge Portal, http://sdwebx.worldbank.org/climateportal/).

A set of 16 models was considered; the model names, along with the originating groups and country, the main references of the corresponding atmosphere/ocean model coupling study and the related web-site(s) are reported in Table A1.2

Table A1.2 – Global climate models from CMIP3 considered in the analysis

MODEL NAME	ORIGINATING GROUP(S)	COUNTRY	REFERENCE	WEBSITE
BCCR-BCM2.0	Bjerknes Centre for Climate Research	Norway	Furevik et al., 2003	http://www.bjerknes.uib.no/
CCMA-CGCM3.1	Canadian Centre for Climate Modelling & Analysis	Canada	Flato, 2005	www.cccma.bc.ca.gc.ca
CNRM-CM3	Centre National de Recherches Météorologiques (MeteoFrance)	France	Terray et al., 1998	http://www.cnrm.meteo.fr/
CSIRO-MK3.5	CSIRO Atmospheric Research	Australia	Gordon et al., 2002	http://www.csiro.au/
GFDL-CM2.0	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	Delworth et al., 2006	http://gfdl.noaa.gov/
GFDL-CM2.1	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	Delworth et al., 2006	http://gfdl.noaa.gov/
GISS	National Aeronautics and Space Administration (NASA)/ Goddard Institute for Space Studies (GISS)	USA	Schmidt et al., 2006	http://www.giss.nasa.gov/tools/modele/
INGV-ECHAM4	INGV, National Institute of Geophysics and Volcanology,	Italy	Gualdi et al. 2008 (INGV-SXG)	http://www.cmcc.it/data-models/database

INM-CM3.0	Institute for Numerical Mathematics	Russia	Volodin and Diansky, 2004	http://www.inm.ras.ru/
IPSL-CM4.0	Institut Pierre Simon Laplace	France	Marti et al., 2005	http://www.ipsl.jussieu.fr/
MIROC-MEDRES	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies and Frontier Research Center for Global Change (JAMSTEC)	Japan	K-1 Developers, 2004	http://www.jamstec.go.jp/rigc/e/index.html http://www.ccsr.u-tokyo.ac.jp/
MIUB-ECHO	Meteorological Institute, University of Bonn; Meteorological Research Institute of the Korean Meteorological Administration; Model and Data Group at the Max Planck Institute for Meteorology	Germany; Korea	Min et al., 2005	http://www.meteo.uni-bonn.de/
MPI-ECHAM5	Max Planck Institute for Meteorology	Germany	Jungclaus et al., 2005	http://www.mpimet.mpg.de/
MRI-CGCM2.3.2	Meteorological Research Institute	Japan	Yukimoto and Noda, 2003	http://www.mri-jma.go.jp/Welcome.html
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research, Met Office	UK	Gordon et al., 2000	http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadcm3
UKMO-HadGEM1	Hadley Centre for Climate Prediction and Research, Met Office	UK	Johns et al., 2006	http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem1

7.5. ENSEMBLES project

The ENSEMBLES project compiled data provided by several European institutions. The runs considered in this report have a 25 km by 25 km grid and cover the period until the end of the century, between 1950 and 2100. The project gathered data from regional scenarios created specifically for Europe, with daily and sub-daily discretization. In the scope of the present report, the assumption of A1B SRES scenario was seen as convenient add-on which enables the comparison with the A2 projections from CMIP3.

The dataset that provided data to this report can be accessed in the ENSEMBLES project portal: http://ensembles-eu.org/. The set of models analysed for this reports are presented in Table A1.3.

Table A1.3 – Global climate models from ENSEMBLES considered in the analysis

MODEL NAME	ORIGINATING GROUP	COUNTRY	REFERENCE	WEBSITE
CNRM-RM5.1 SCN ARPEGE	Centre National de Recherches Météorologiques	France		http://www.cnrm.meteo.fr/
KNMI-RACMO2 ECHAM5-r3	Koninklijk Nederlands Meteorologisch Instituut	Netherlands	Meijgaard et al., 2008	http://www.knmi.nl/
ETHZ-CLM SCN HadCM3Q0	Eidgenössische Technische Hochschule Zürich	Switzerland	Böhm et al., 2006	http:// www.ethz.ch/
METO-HC HadRM3Q3 HadCM3Q3	Met Office	UK	Collins et al, 2006	http://www.metoffice.gov.uk/climate-change/resources/hadley
METO-HC HadRM3Q16 HadCM3Q16	Met Office	UK	Collins et al, 2006	http://www.metoffice.gov.uk/climate-change/resources/hadley
METO-HC HadRM3Q0 HadCM3Q0	Met Office	UK	Collins et al, 2006	http://www.metoffice.gov.uk/climate-change/resources/hadley
SMHIRCA BCM	Sveriges Meteorologiska och Hydrologiska Institut	Sweden	Kjellström et al., 2005	http://www.smhi.se/

SMHIRCA HadCM3Q3	Sveriges Meteorologiska och Hydrologiska Institut	Sweden	Kjellström et al., 2005	http://www.smhi.se/
ICTP-REGCM3 ECHAM5-r3	International Centre for Theoretical Physics	Italy		http://www.ictp.it
MPI-M-REMO SCN ECHAM5	Max Planck Institute for Meteorology	Germany	Jacob et al., 2001	http://www.mpimet.mpg.de/
C4IRCA3 HadCM3-e1	Community Climate Consortium for Ireland	Ireland	Kjellström et al., 2005	http://www.c4i.ie/
SMHIRCA ECHAM5-r3	Sveriges Meteorologiska och Hydrologiska Institut	Sweden	Kjellström et al., 2005	http://www.smhi.se/
DMI-HIRHAM5 ARPEGE	Danmarks Meteorologiske Institut	Denmark		http://www.dmi.dk
DMI-HIRHAM5 ECHAM5	Danmarks Meteorologiske Institut	Denmark		http://www.dmi.dk
DMI-HIRHAM5 BCM	Danmarks Meteorologiske Institut	Denmark		http://www.dmi.dk

7.6. Future climate scenarios for the A2 SRES emission scenario issued by several GCM models compiled by CMIP

The UNIBO Research Unit has analysed the CMIP3 projections of future climate, referred to each of the TRUST pilot cities areas, in terms of the expected change in temperature and precipitation values, being certainly the most important meteorological variables for the management of Urban Water Services.

In the following, we will present the changes expected in the monthly values of both temperature and precipitation over the next decades, referred to the areas of all the 10 Pilots.

We chose to focus on the projections up to an horizon of fifty years (as above said, under the A2 SRES scenario), reporting the mean values obtained by each of the considered climate models over the following two-decades periods: i) 2020-2039 and ii) 2040-2059, assuming that these time horizons are the most useful for the Decision-Makers in order to implement appropriate adaptation measures.

For such future time-slices, the projections of the expected change of:

- Monthly Mean Temperature (°C)
- Monthly Mean Precipitation depth (mm)

with respect to the values modelled for the control run decade (1980-1999), are shown in the following.

The GCMs' outputs in terms of the changes expected in the values of monthly precipitation depths are provided also as the percentage of the change of the mean monthly values of the control run decade.

The graphs show the mean change values based on the simulations corresponding to

- each of the climate models described in the previous section (considering that, for some of the 16 listed models, the projections are available either for only temperature values - GISS model - or for only the precipitation values – GFDL-CM2.1 and IPSL-CM4.0);
- their overall ensembles values, represented through the median (50% percentile – black thick line), the 10% percentile (lower values – blue thick line) and the 90% percentile (higher values – red thick line).

The values of the annual changes corresponding to the mean of the monthly 50% percentiles are also reported below the graphs, as representative of what may be quantitatively expected when considering all the issued projections, along with a summary comment of the obtained projections concerning the overall temperature and precipitation monthly changes.

Three of the TRUST pilots refer to regions (and a country) rather than to a single city: given the variability of the model outputs over such large regions, we chose to analyse the projections referred to the areas of the main city of the region (Edinburgh for the Scotland cities; Faro for the Algarve region, Luanda for Angola), being representative of the largest, most densely populated and most exploited urban centres of each region.

Amsterdam

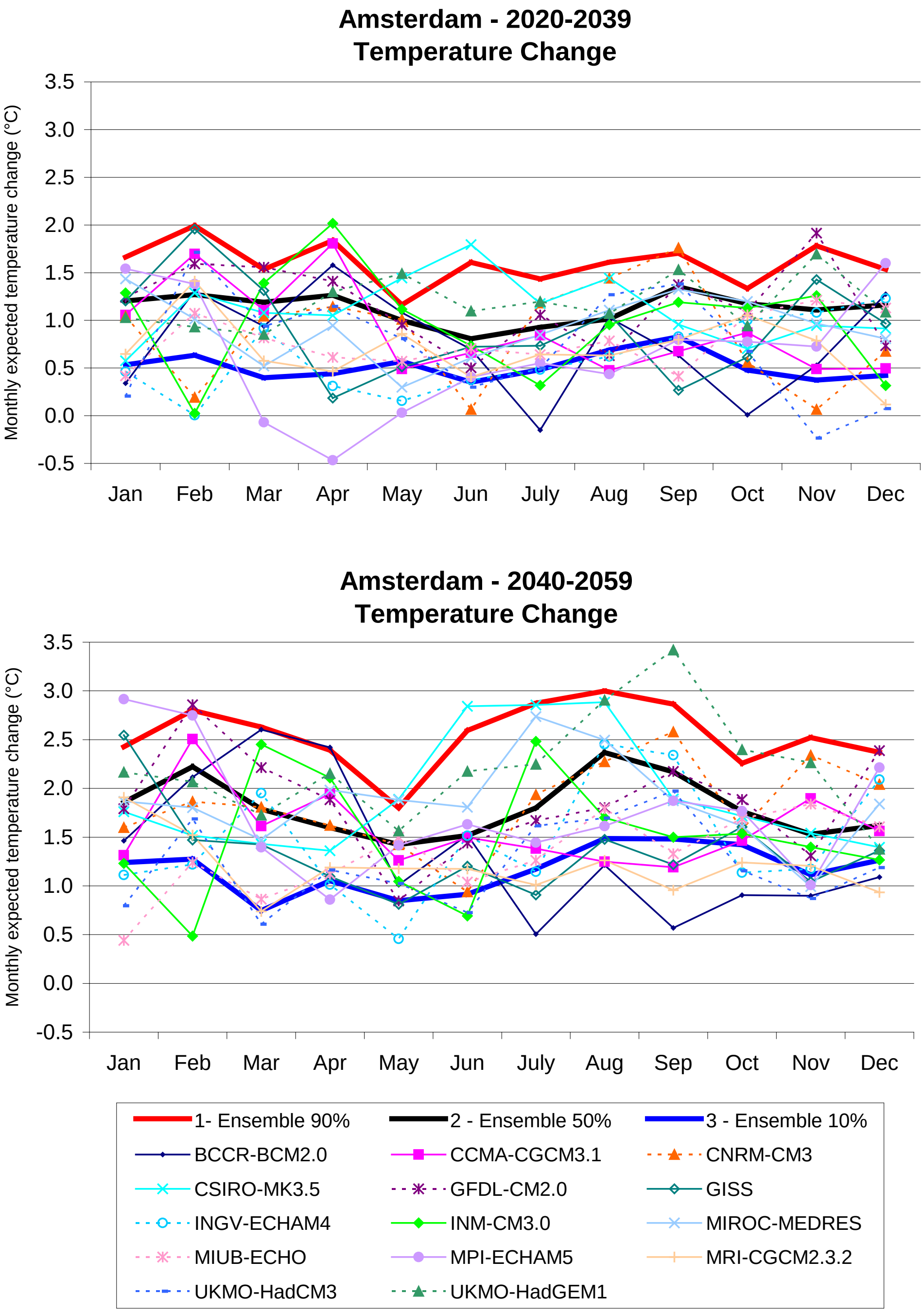


Figure A1.3- Expected temperature change in Amsterdam

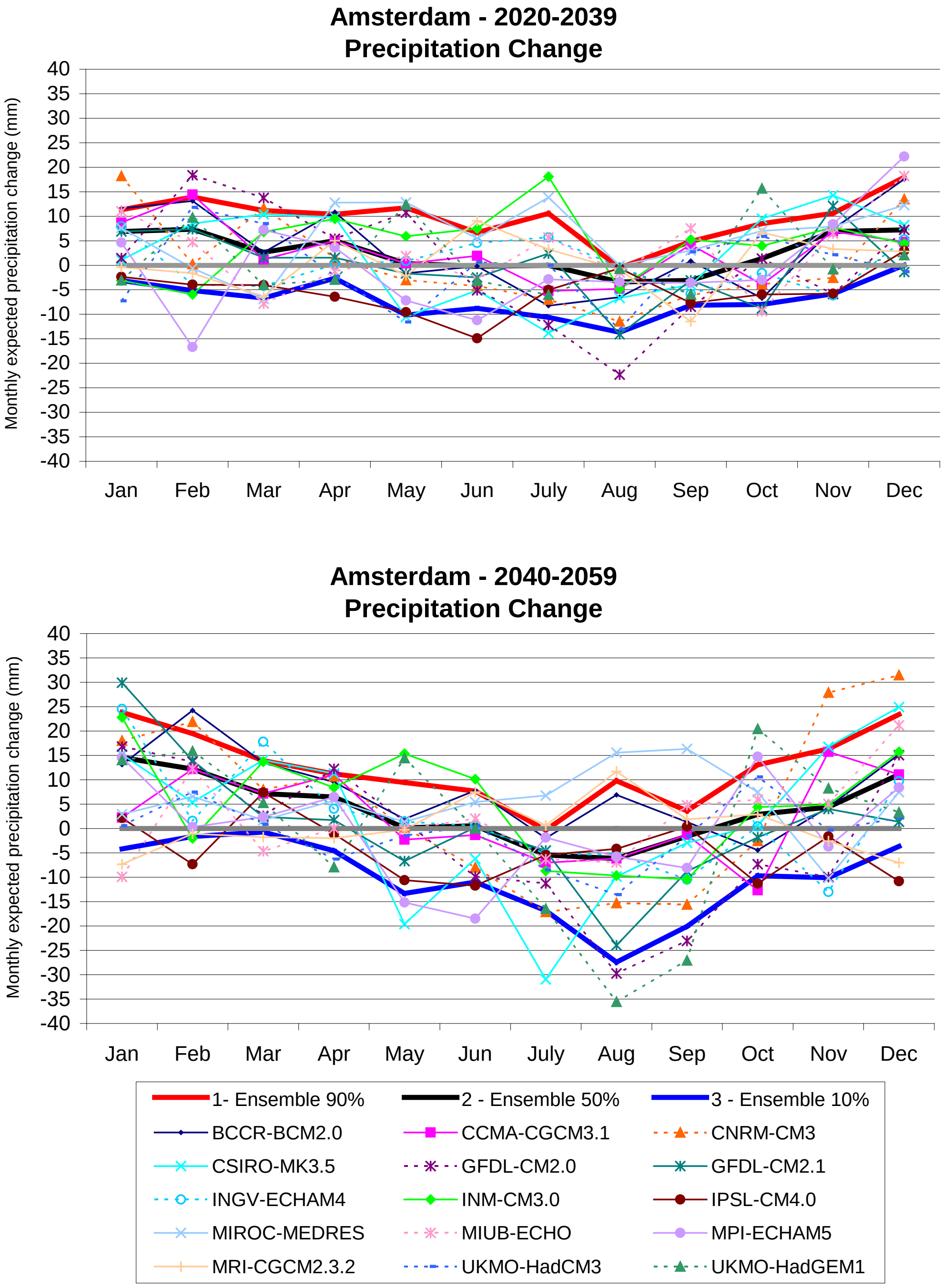


Figure A1.4- Expected precipitation change in Amsterdam (in mm)

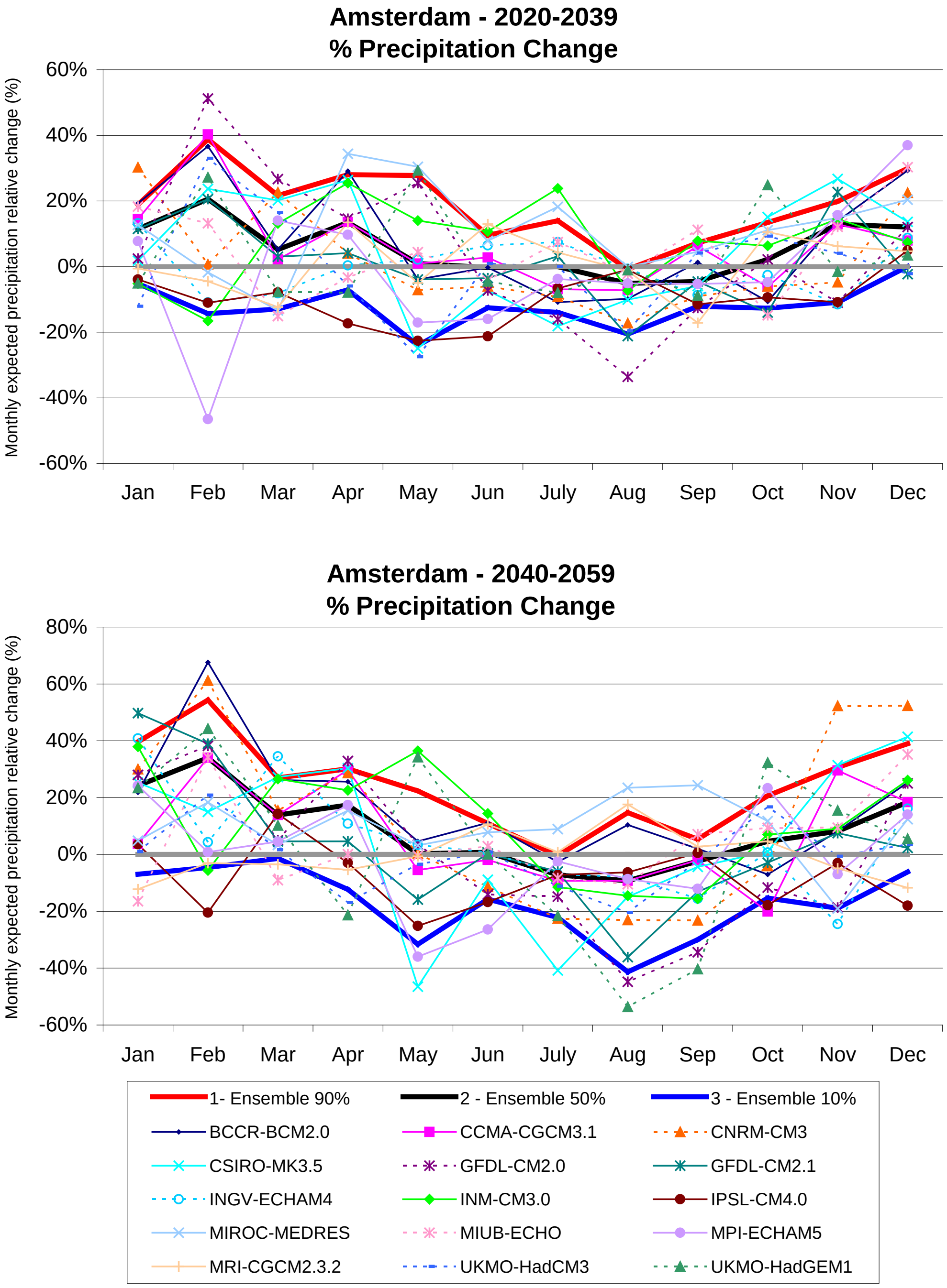


Figure A1.5- Expected precipitation change in Amsterdam (in %)

Athens

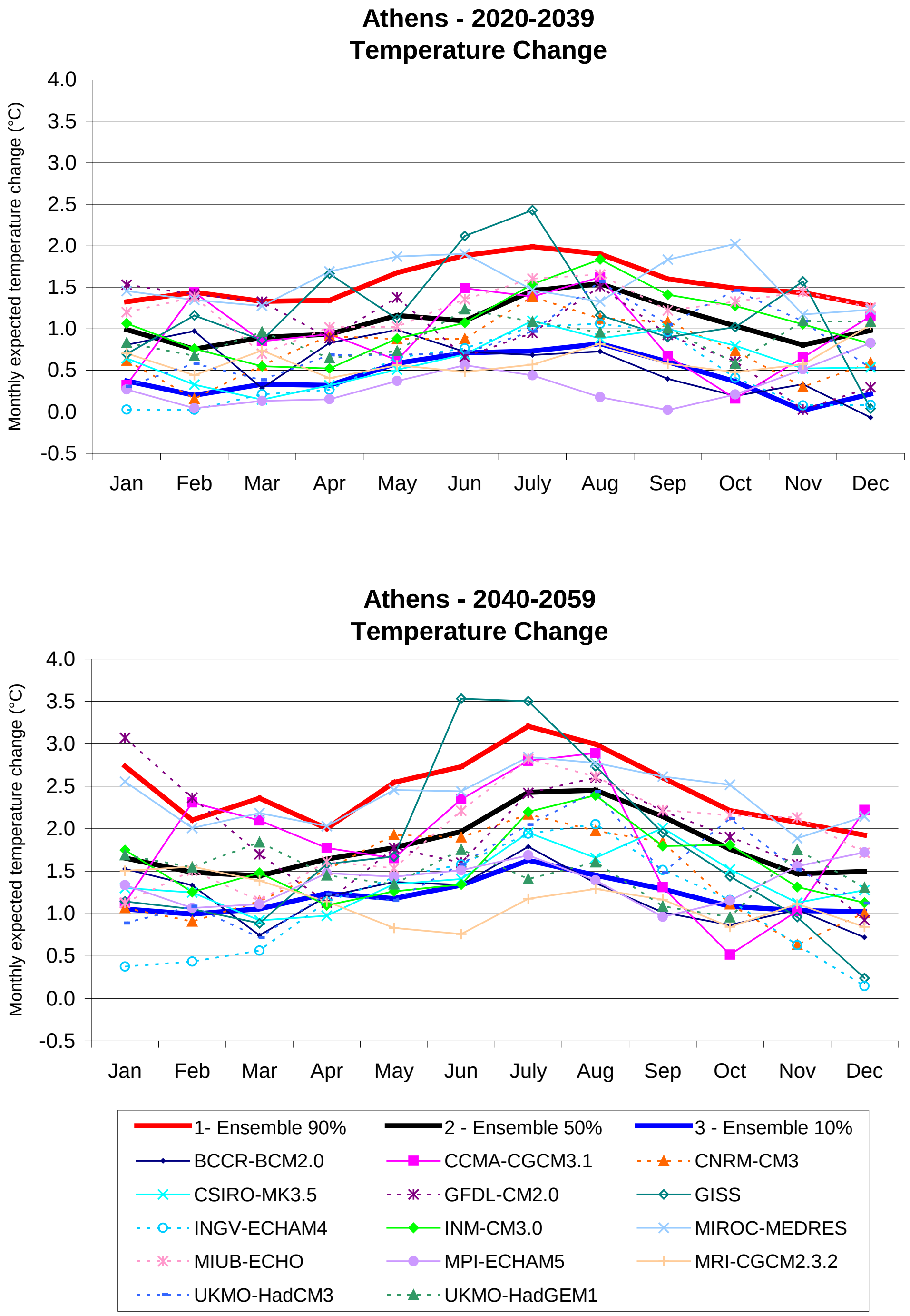


Figure A1.6- Expected temperature change in Athens

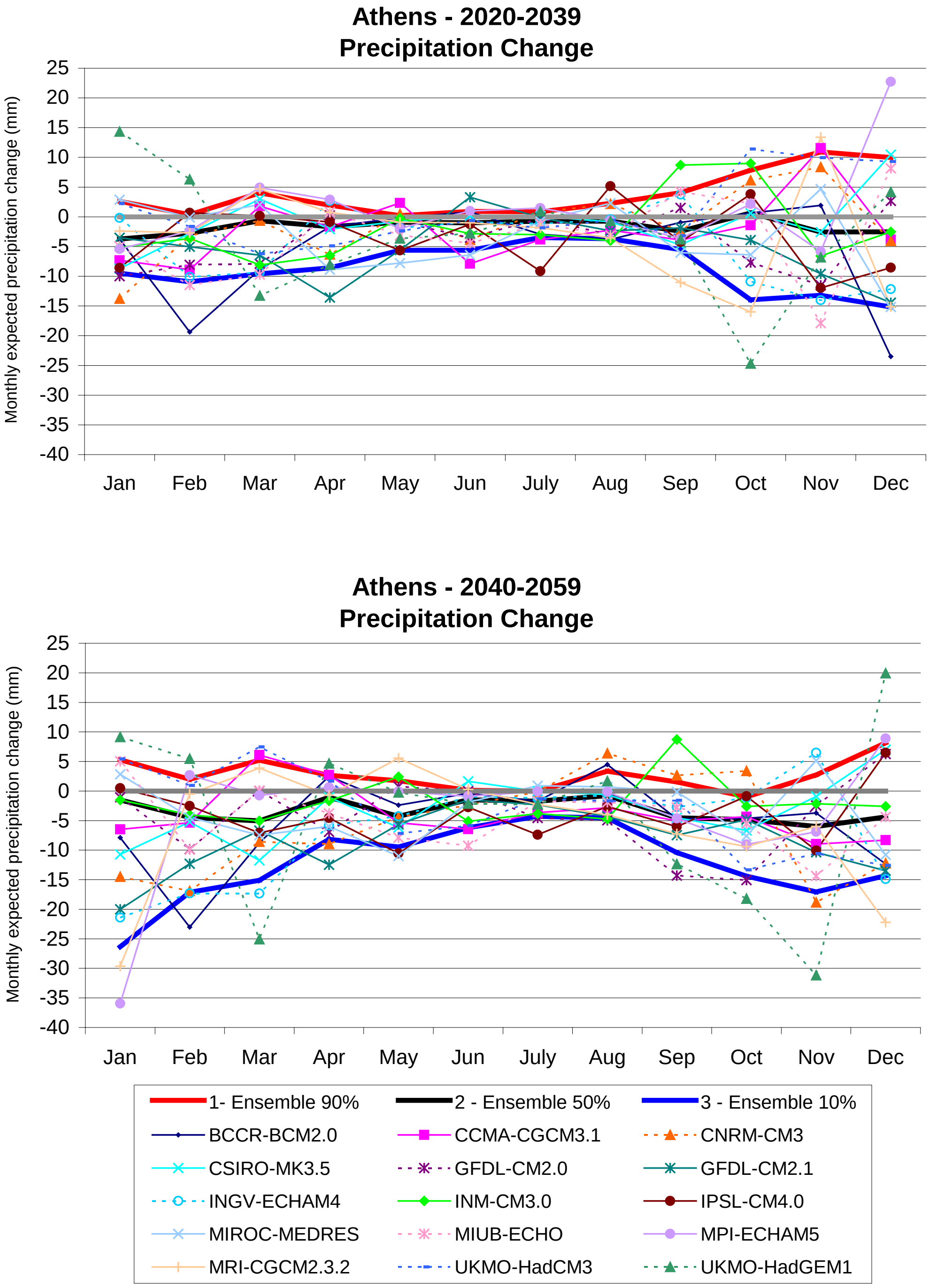


Figure A1.7- Expected precipitation change in Athens (in mm)

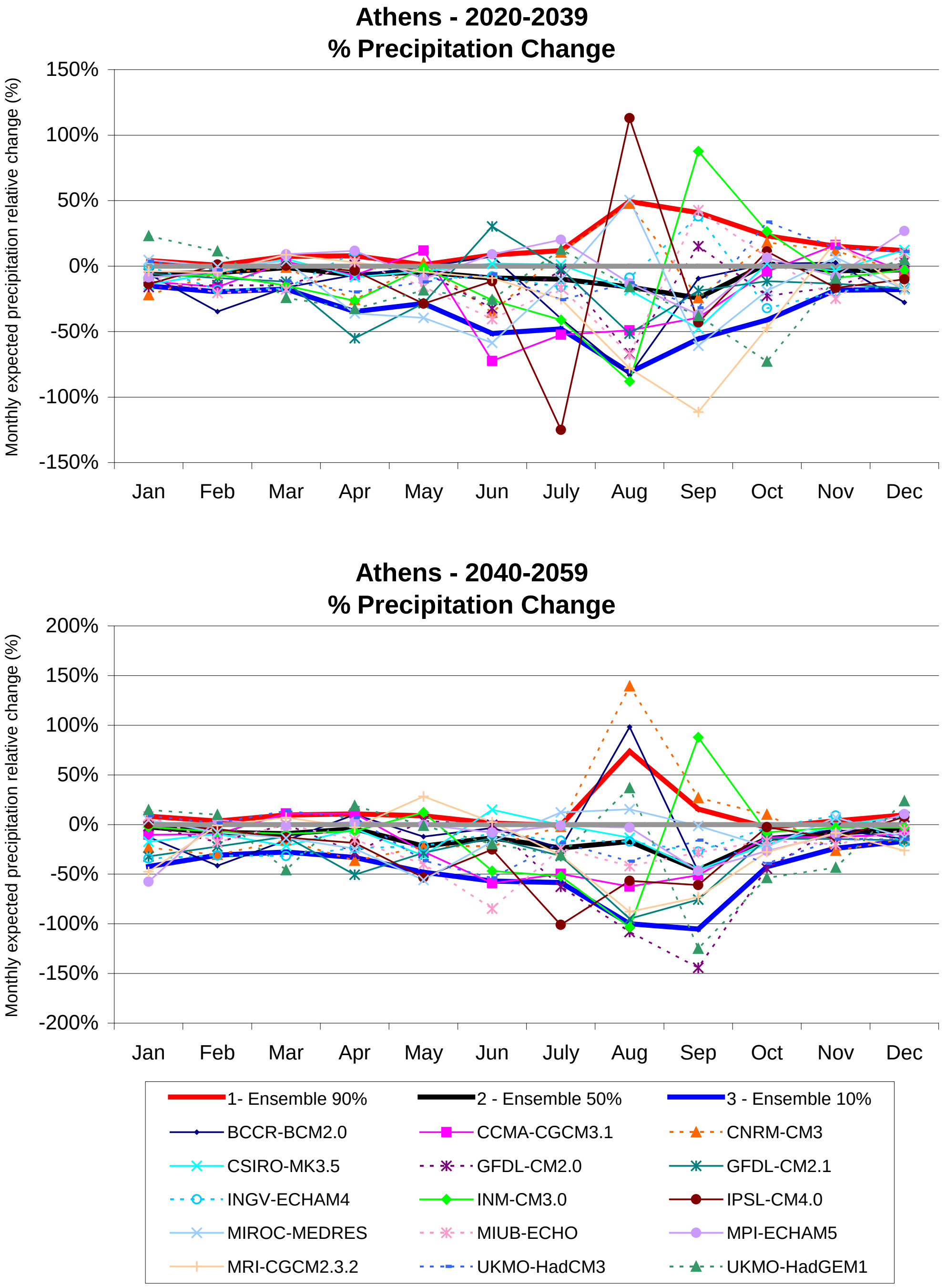


Figure A1.8- Expected precipitation change in Athens (in %)

Bucarest

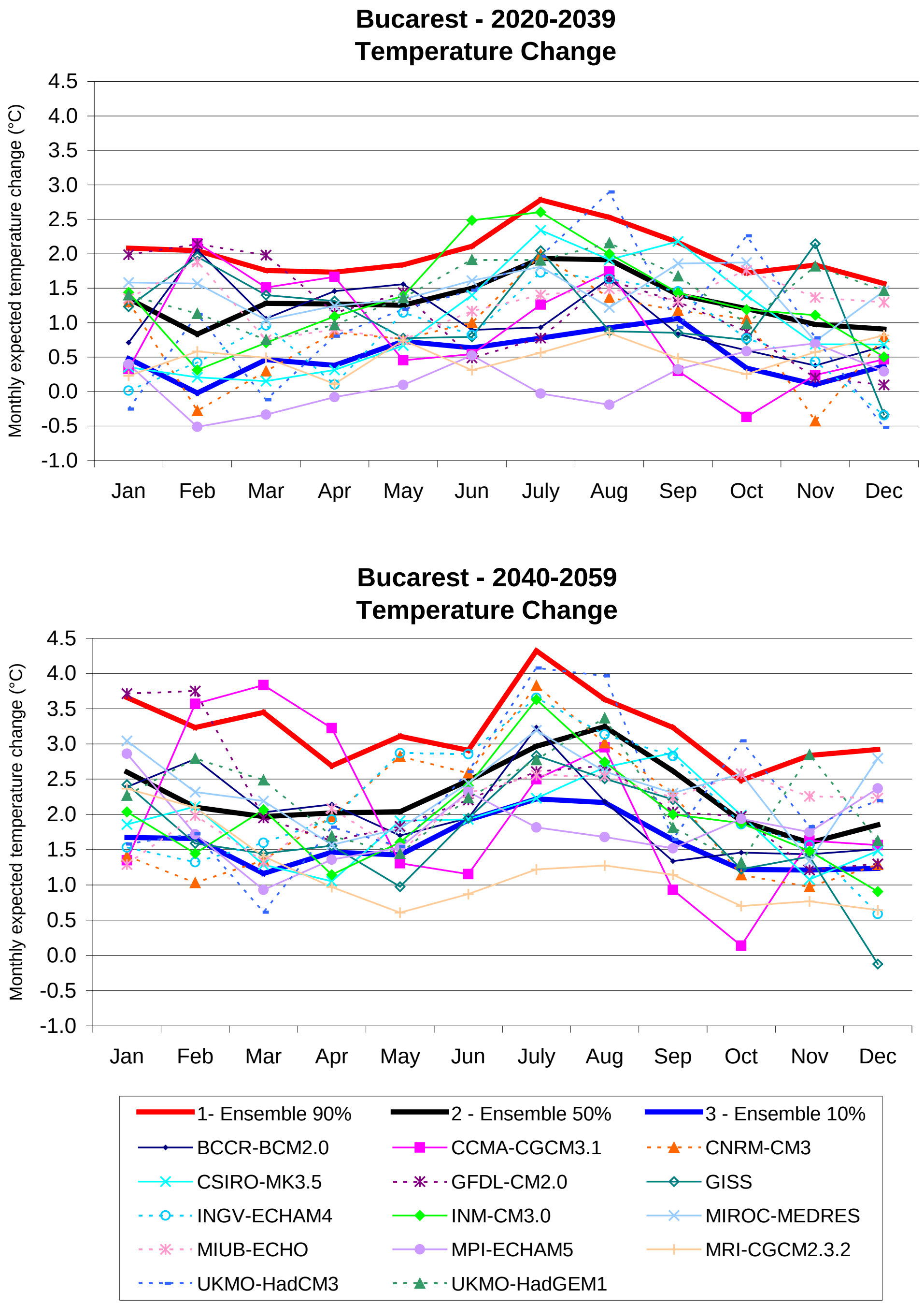


Figure A1.9- Expected temperature change in Bucarest

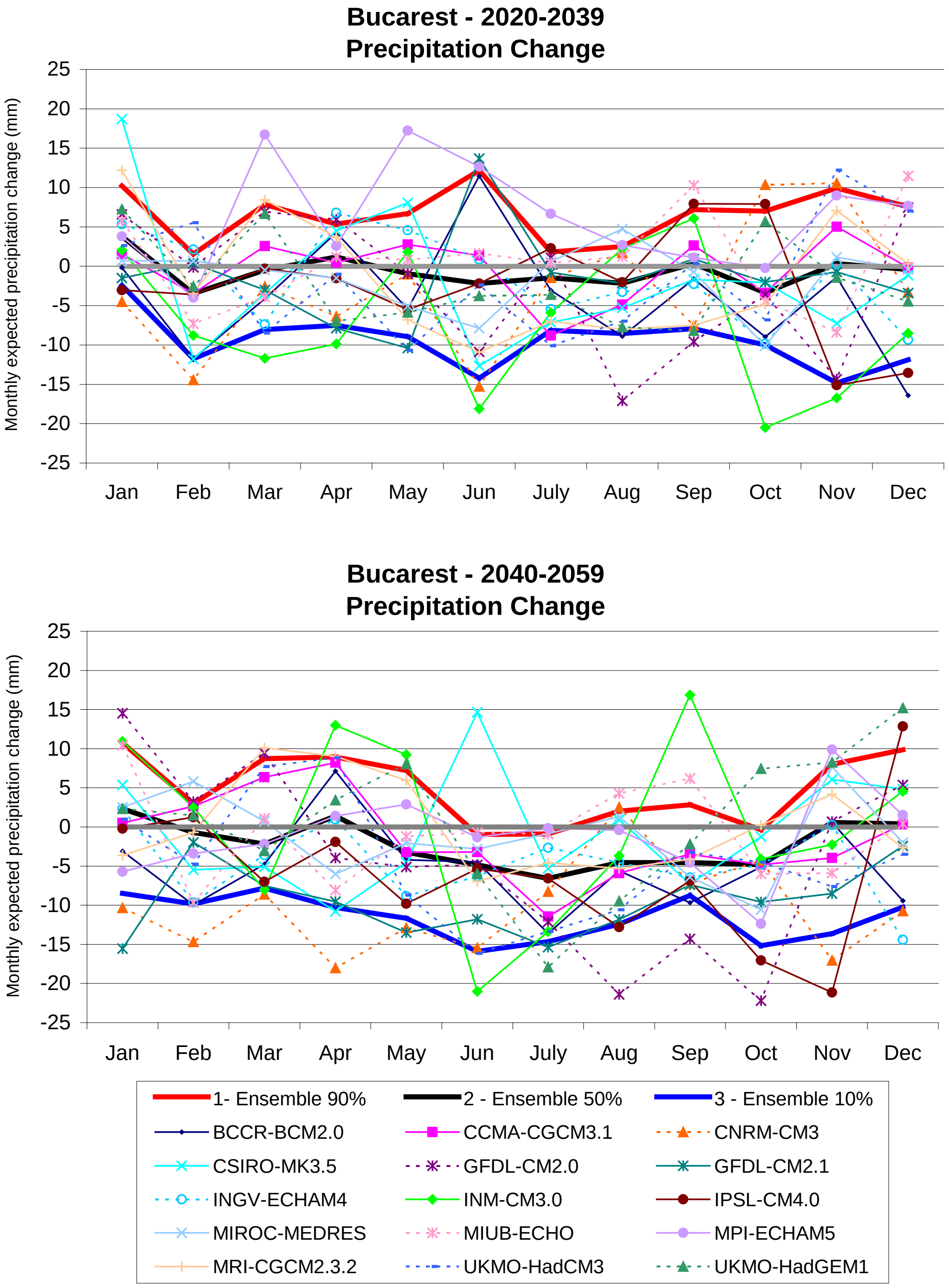


Figure A1.10- Expected precipitation change in Bucarest (in mm)

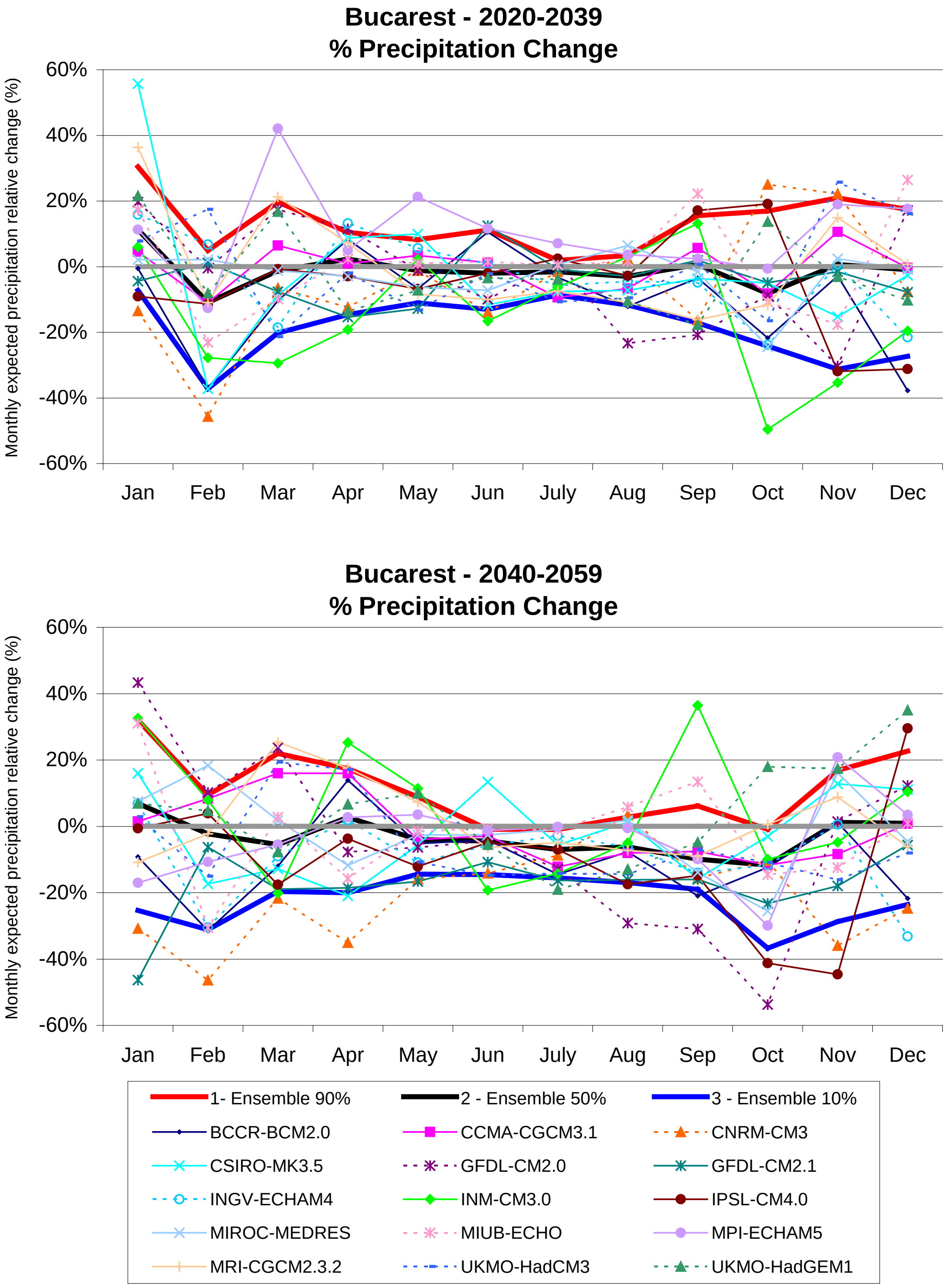


Figure A1.11 - Expected precipitation change in Bucarest (in %)

Scotland cities (Edinburgh)

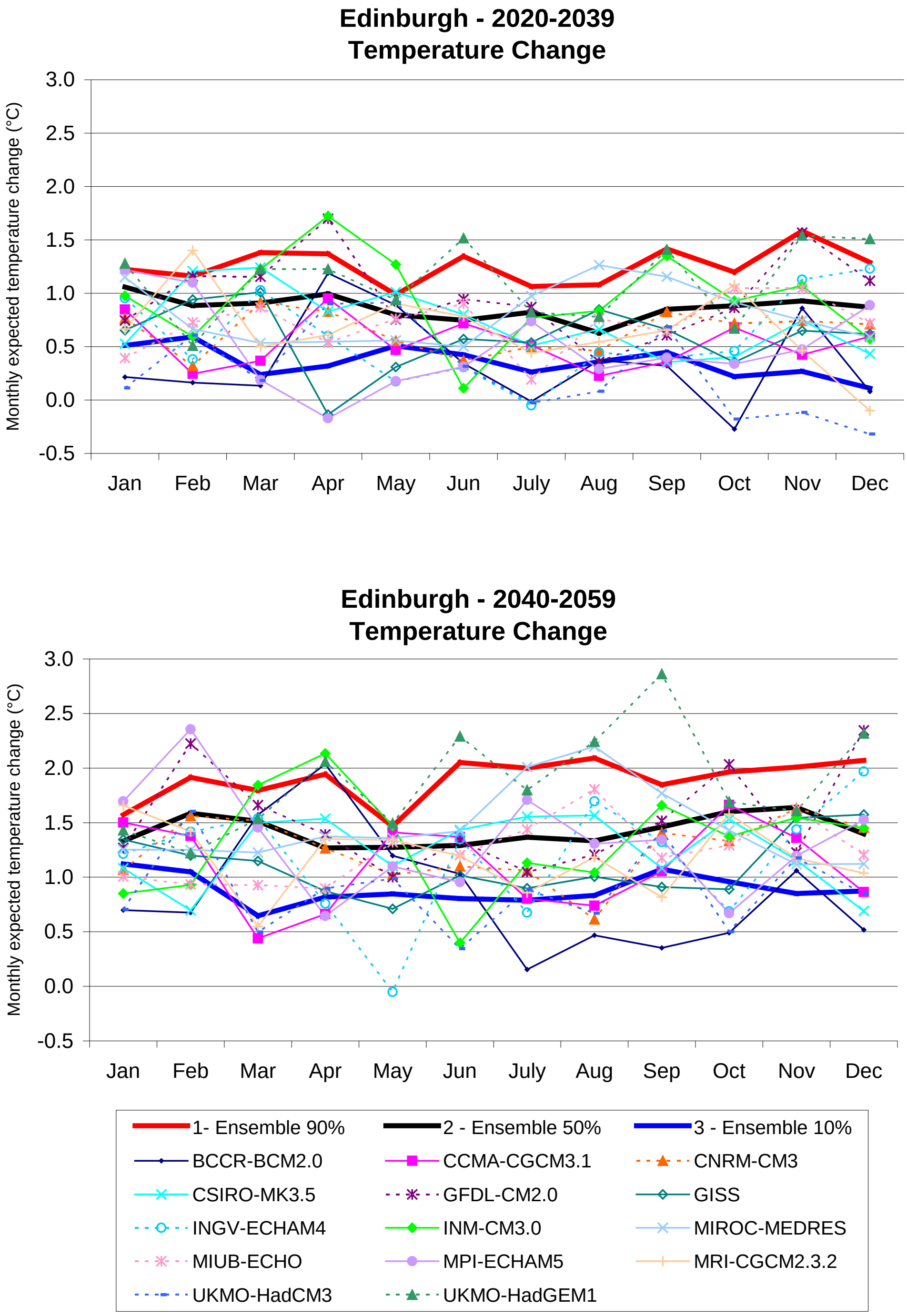


Figure A1.12- Expected temperature change in Edinburgh

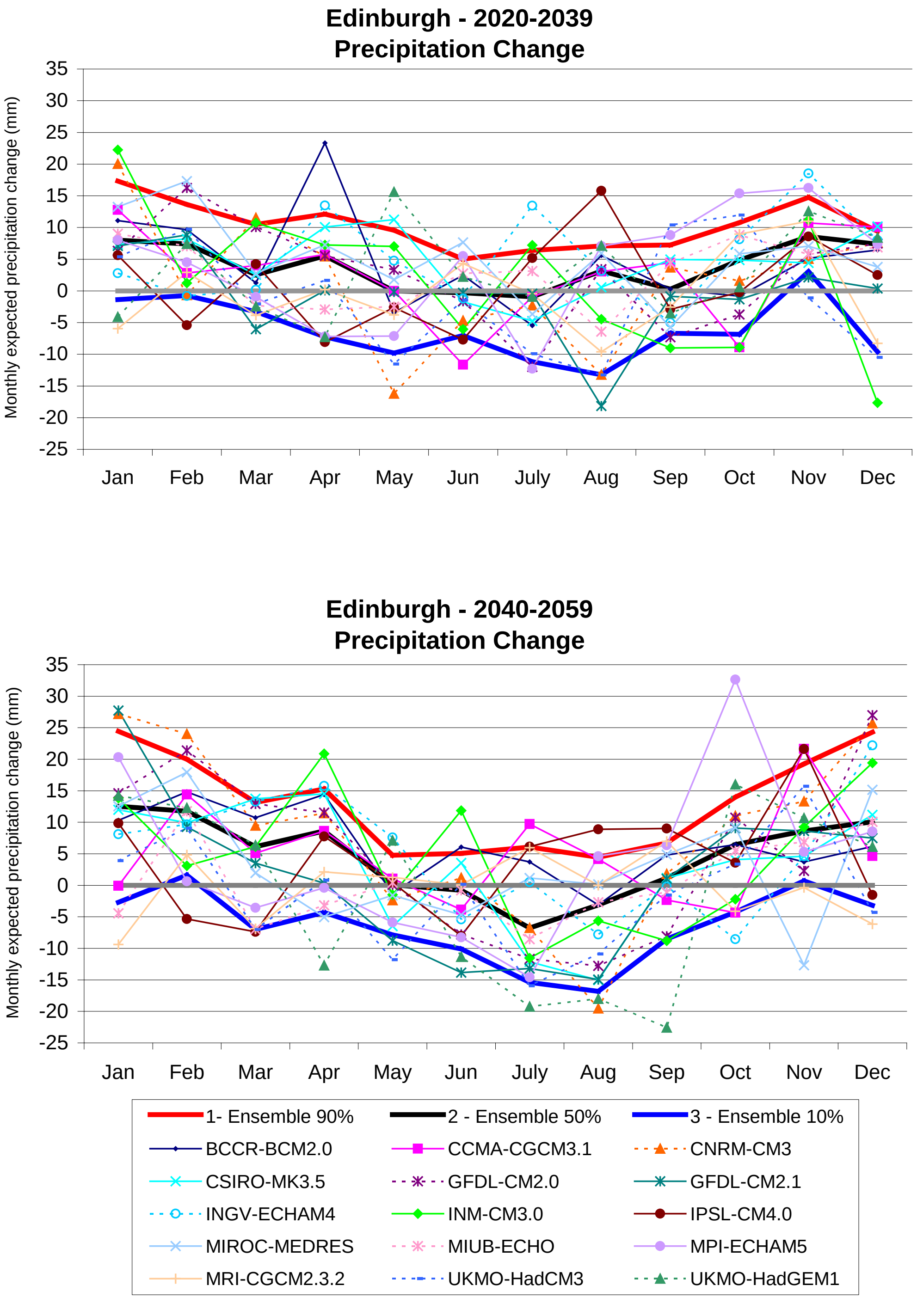


Figure A1.13- Expected precipitation change in Edinburgh (in mm)

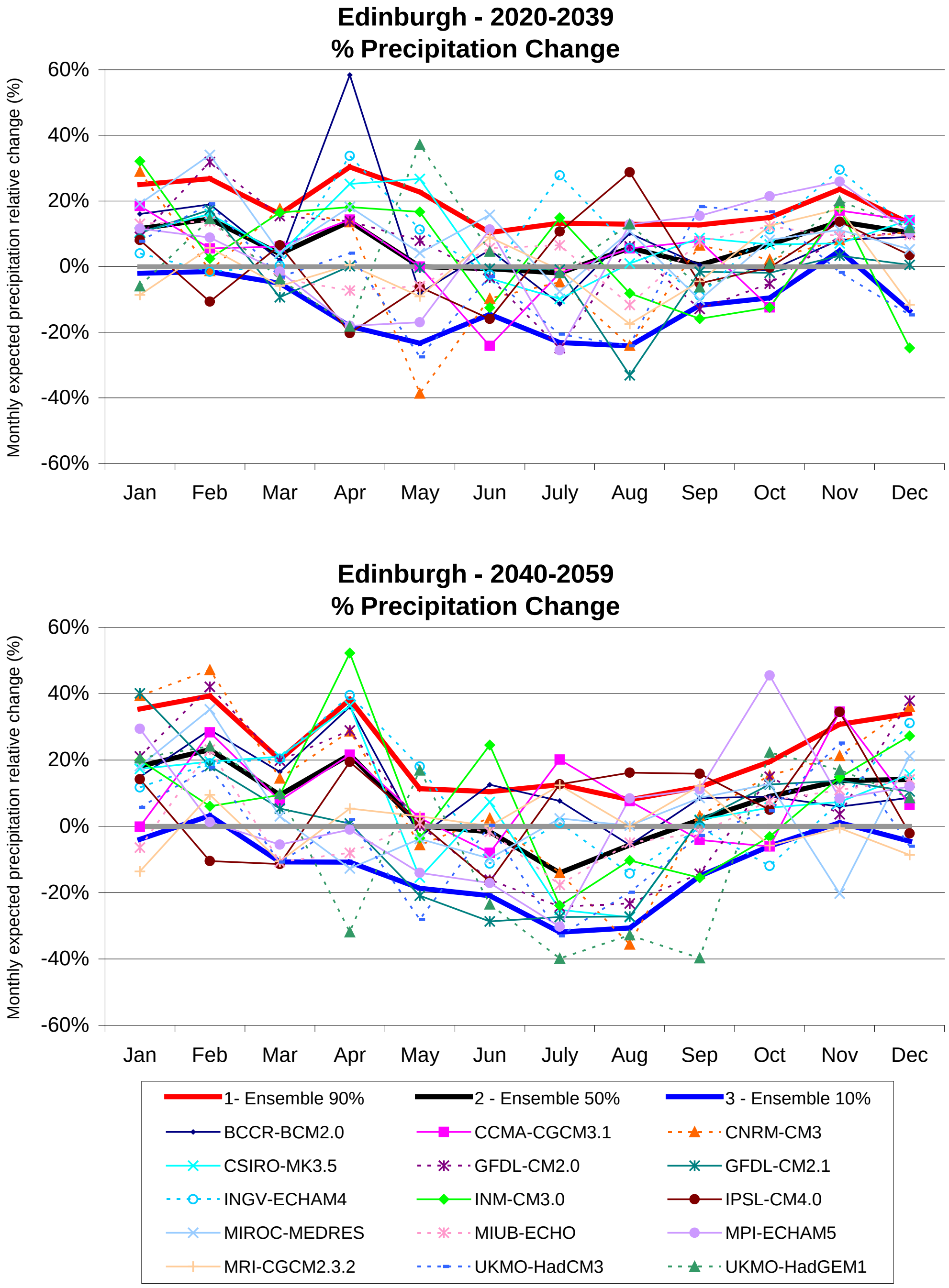


Figure A1.14- Expected precipitation change in Edinburgh (in %)

Algarve (Faro)

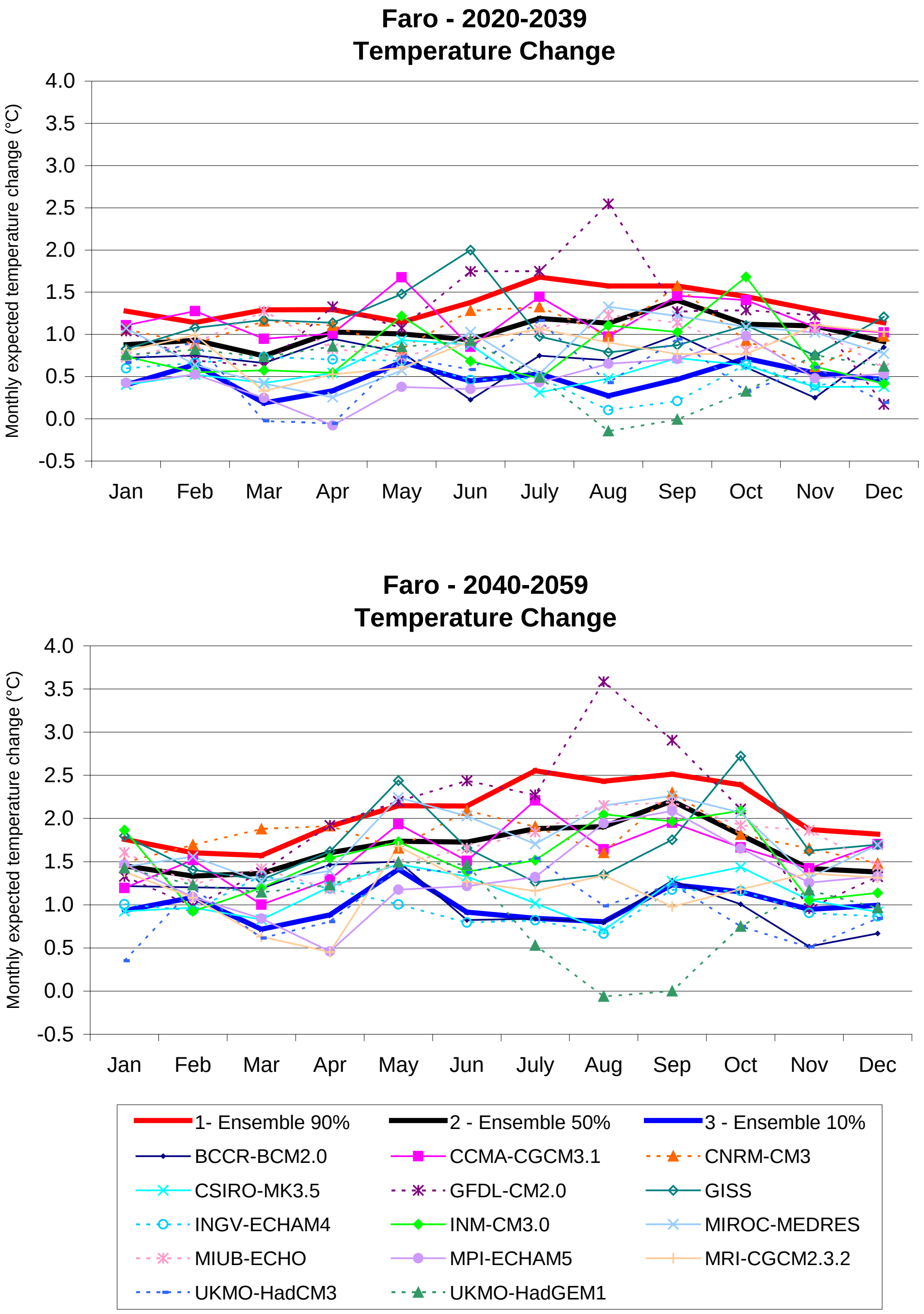


Figure A1.15- Expected temperature change in Algarve (Faro)

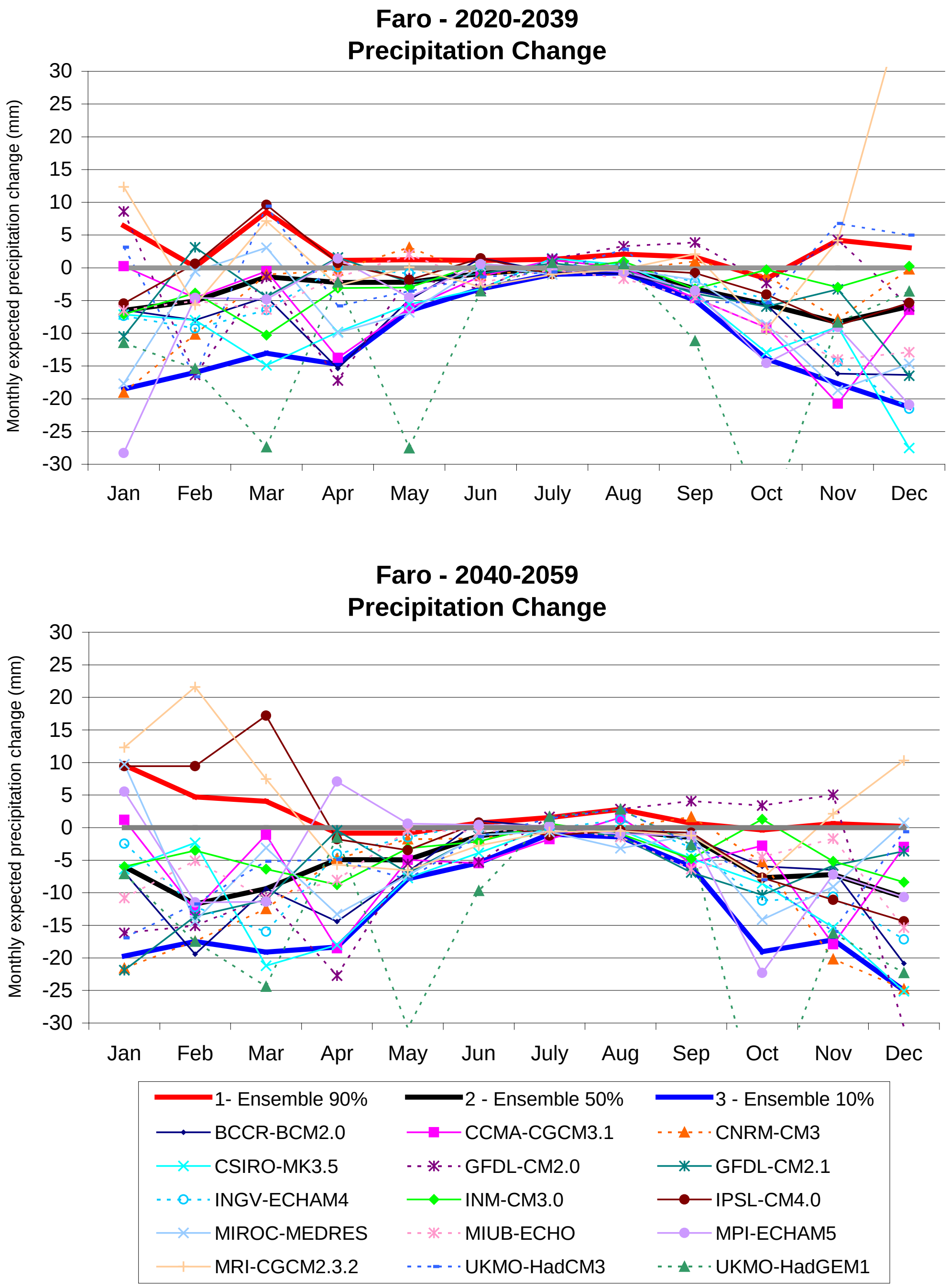


Figure A1.16 - Expected precipitation change in Algarve (Faro) (in mm)

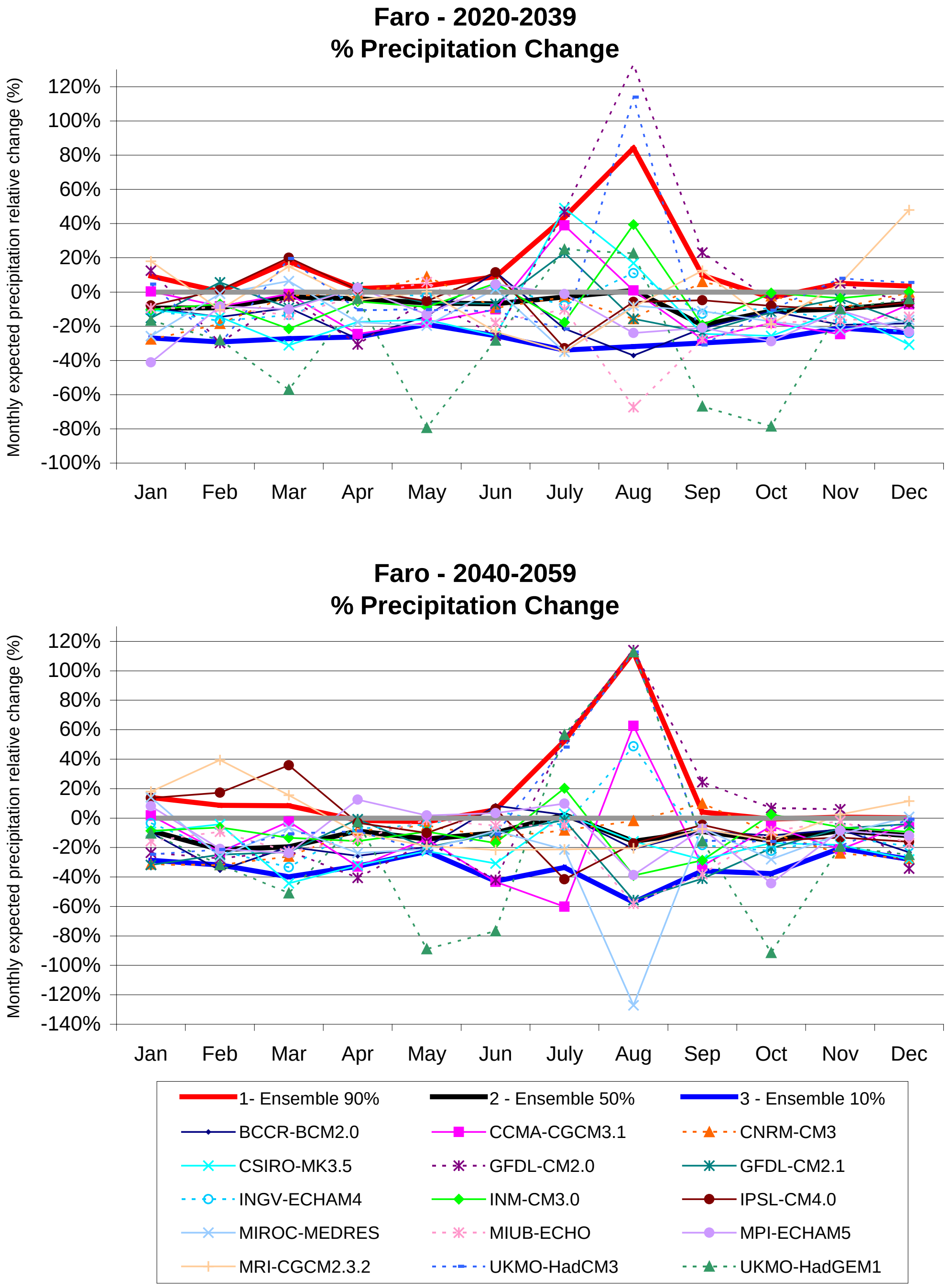


Figure A1.17- Expected precipitation change in Algarve (Faro) (in %)

Hamburg

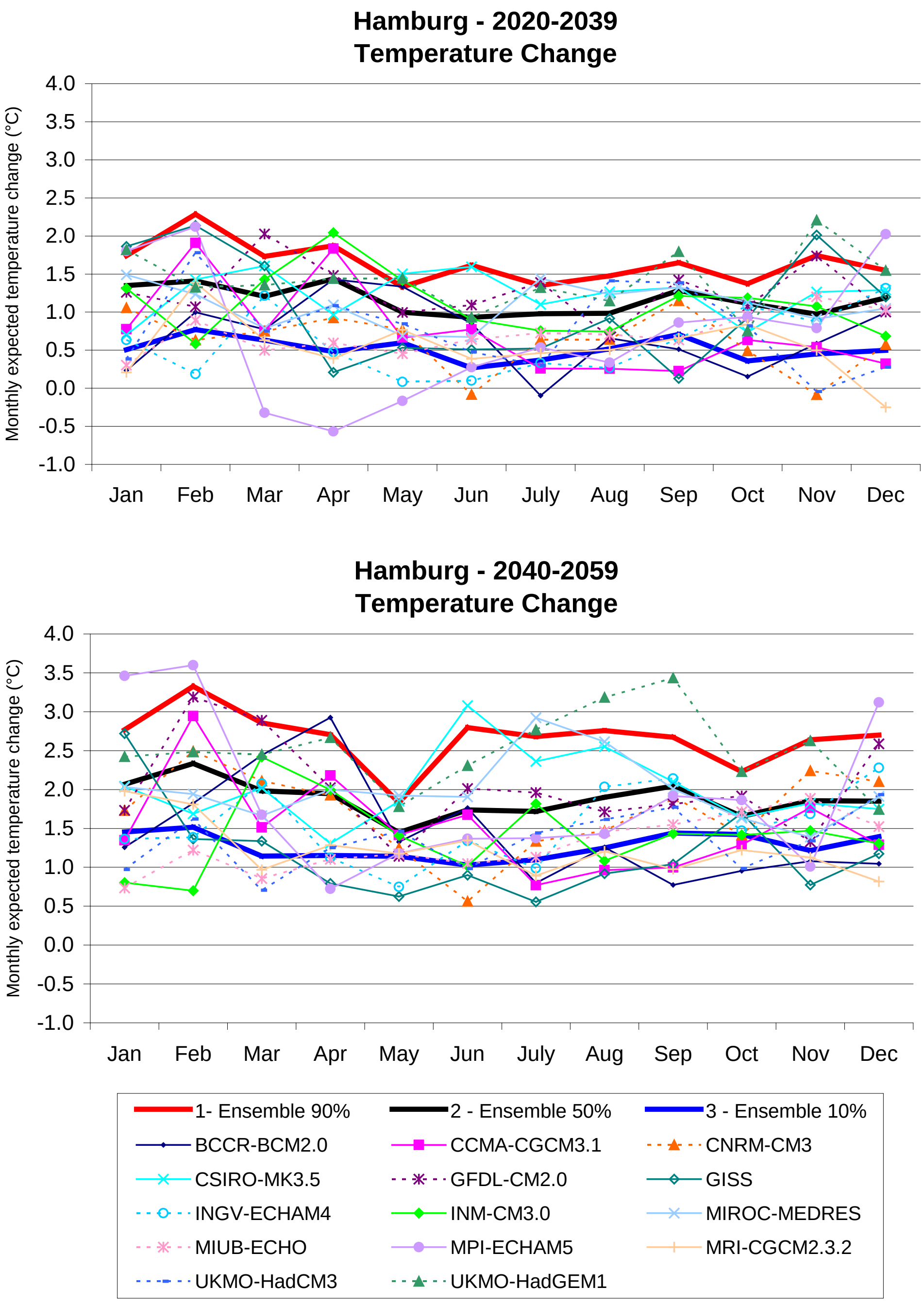


Figure A1.18- Expected temperature change in Hamburg

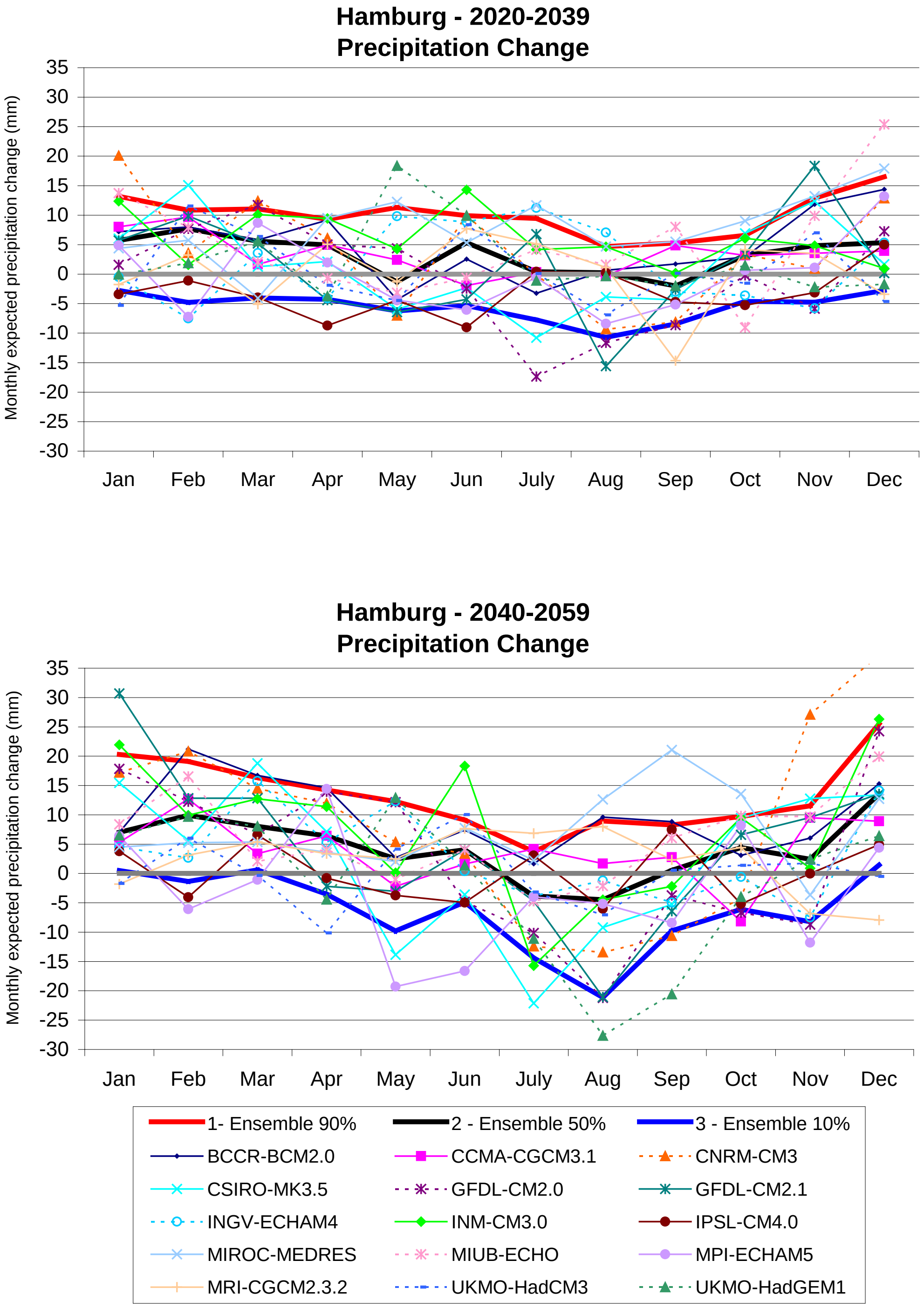


Figure A1.19- Expected precipitartion change in Hamburg (in mm)

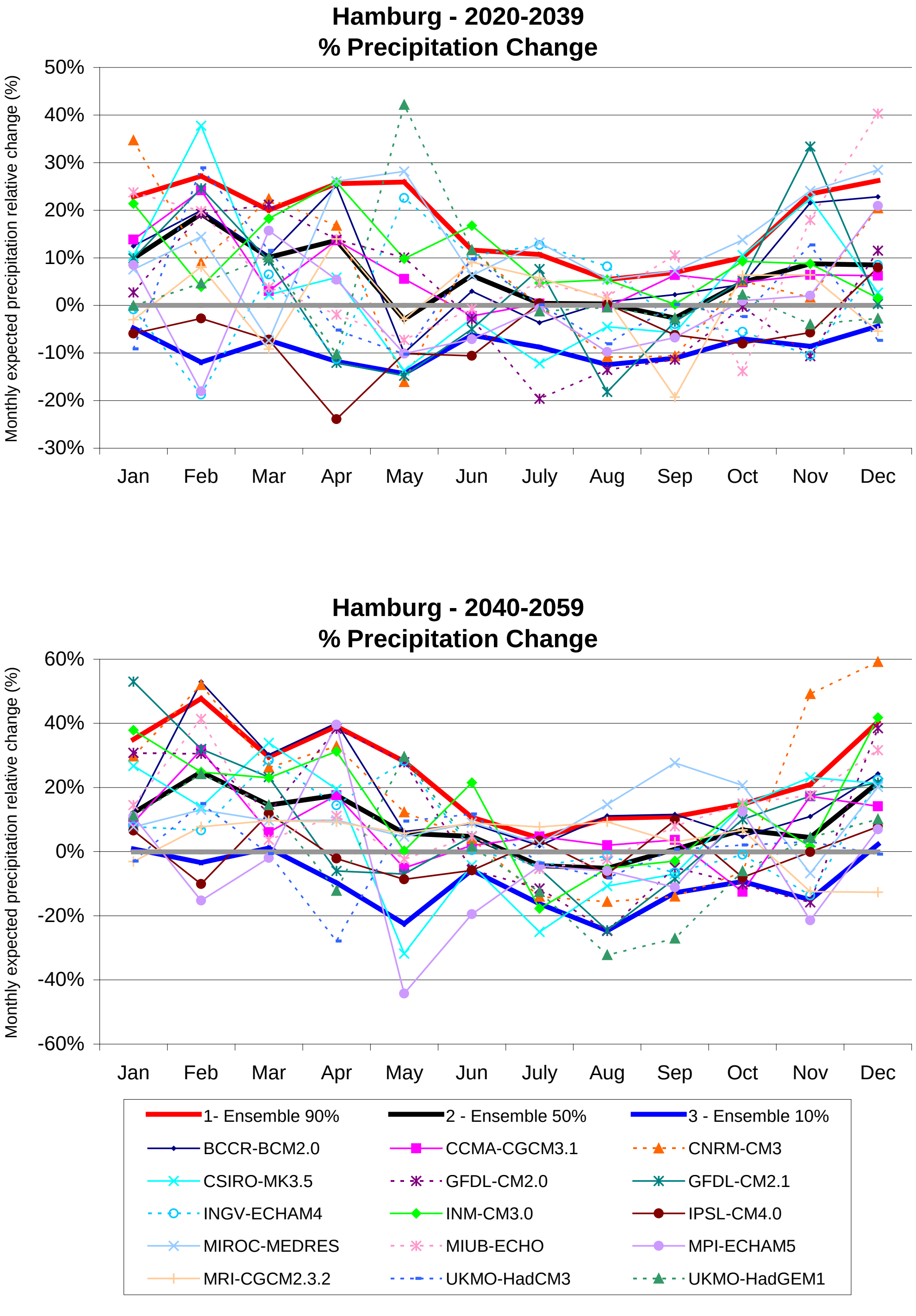


Figure A1.20- Expected precipitartion change in Hamburg (in %)

Angola (Luanda)

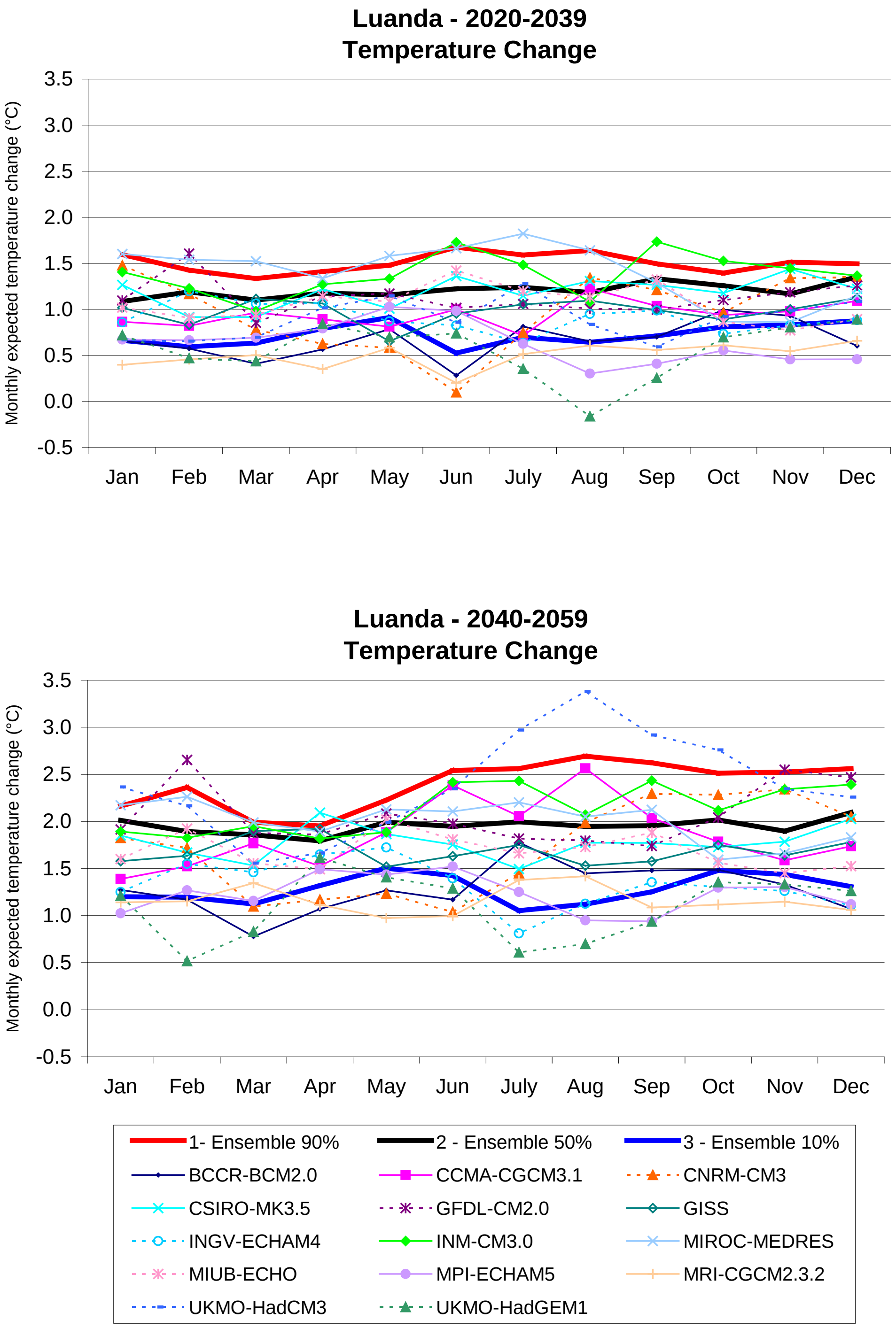


Figure A1.21 - Expected temperature change in Angola (Luanda)

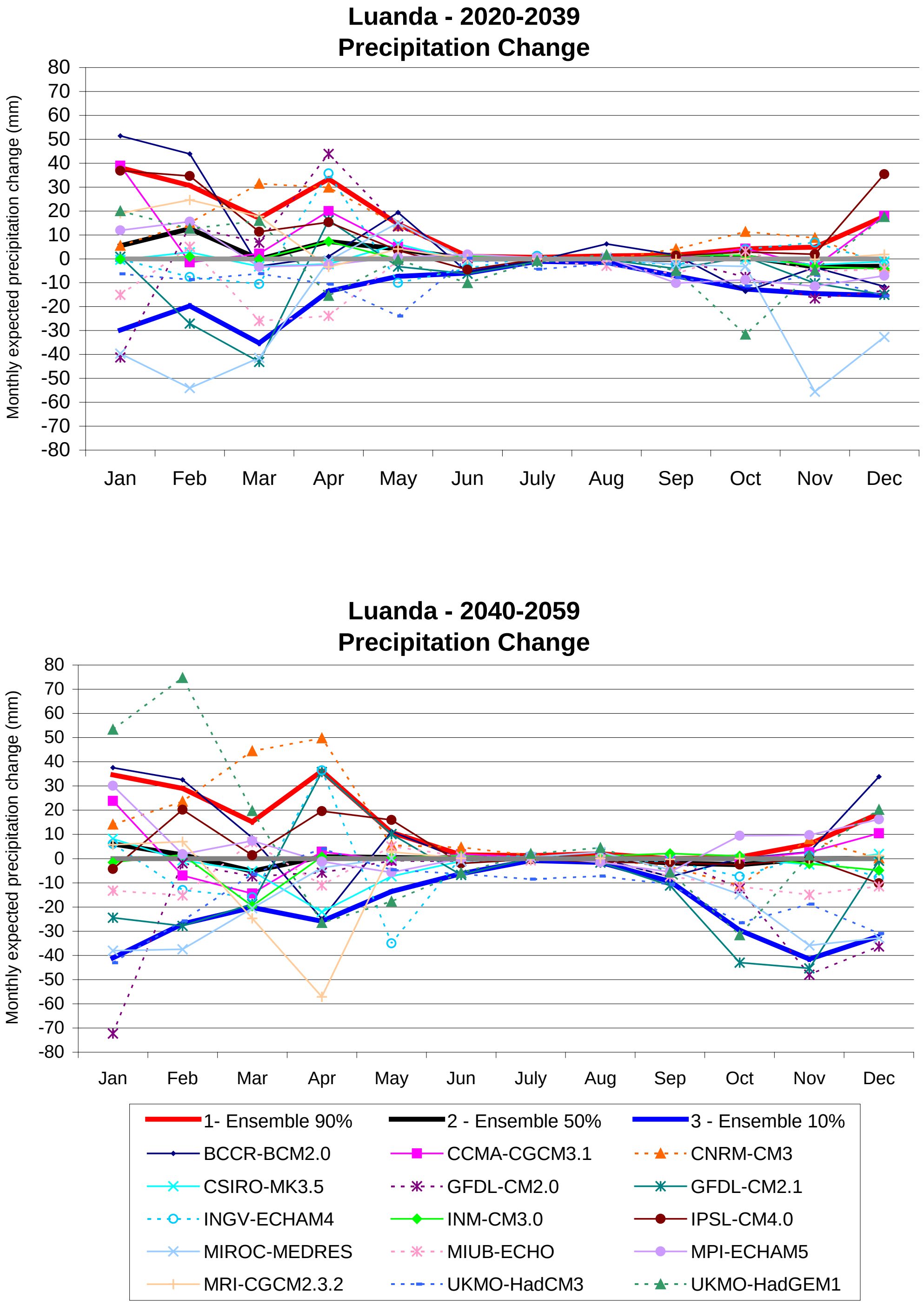


Figure A1.22- Expected precipitation change in Angola (Luanda) (in mm)

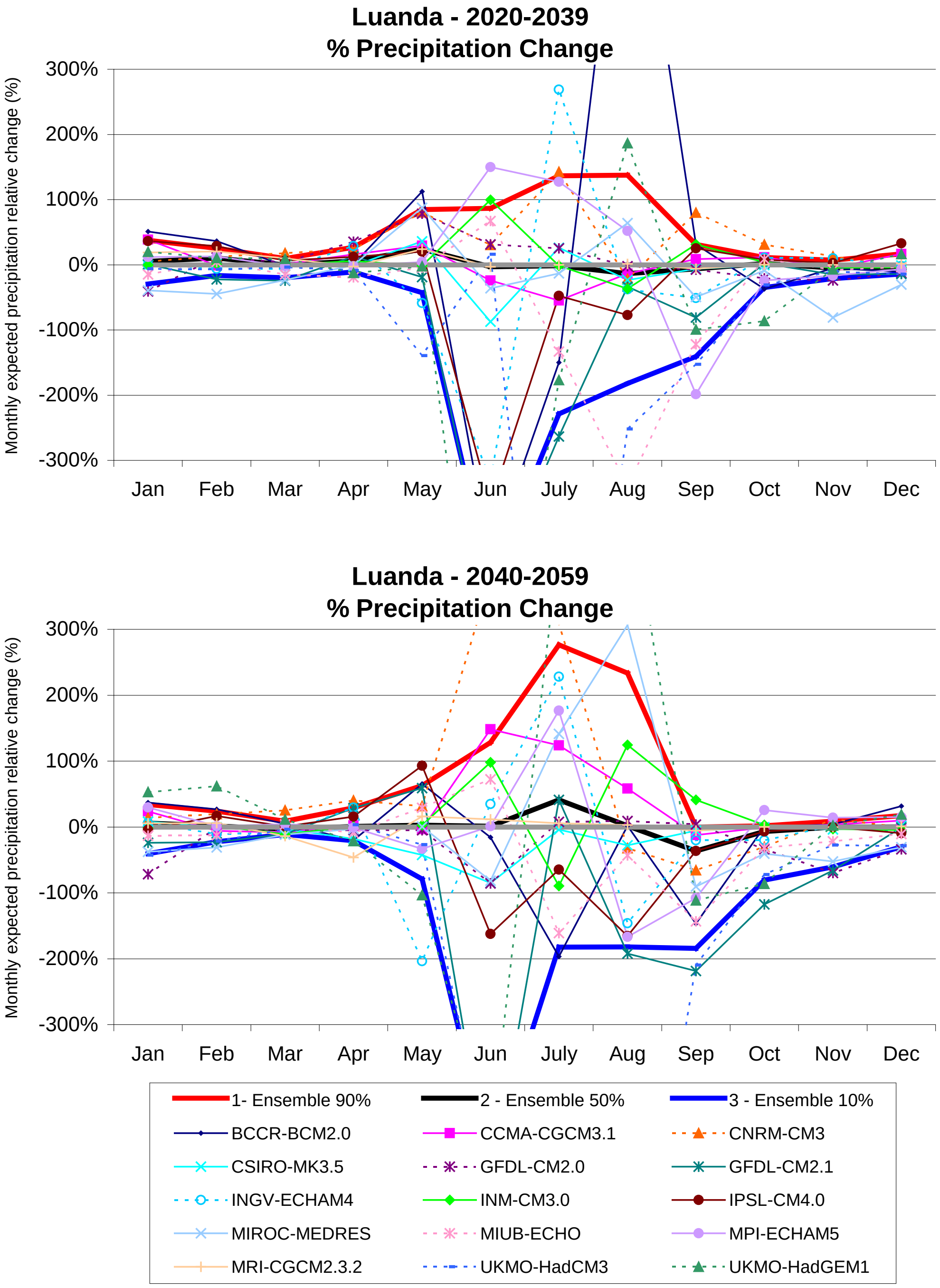


Figure A1.23- Expected precipitation change in Angola (Luanda) (in %)

Madrid

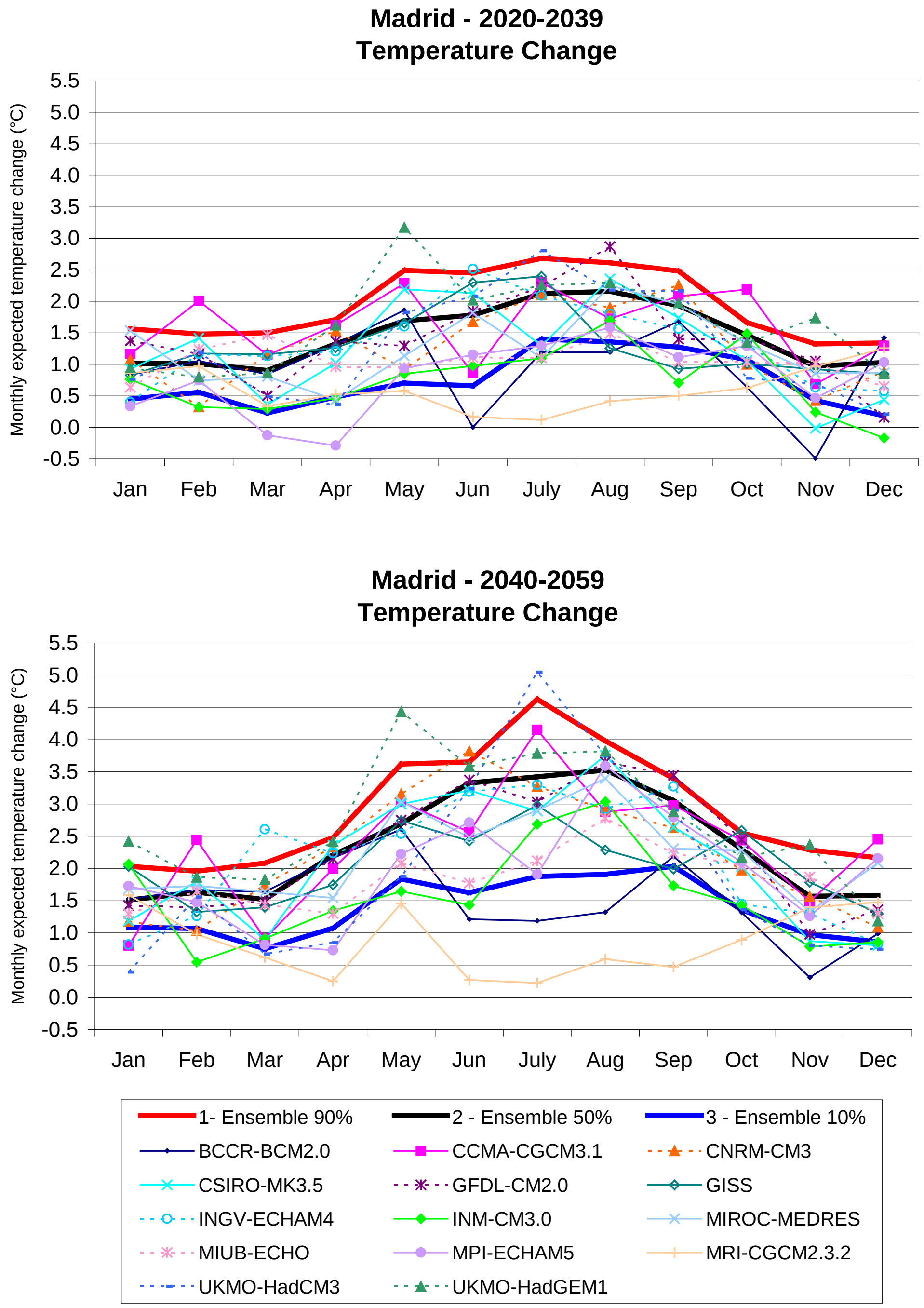


Figure A1.24 - Expected temperature change in Madrid

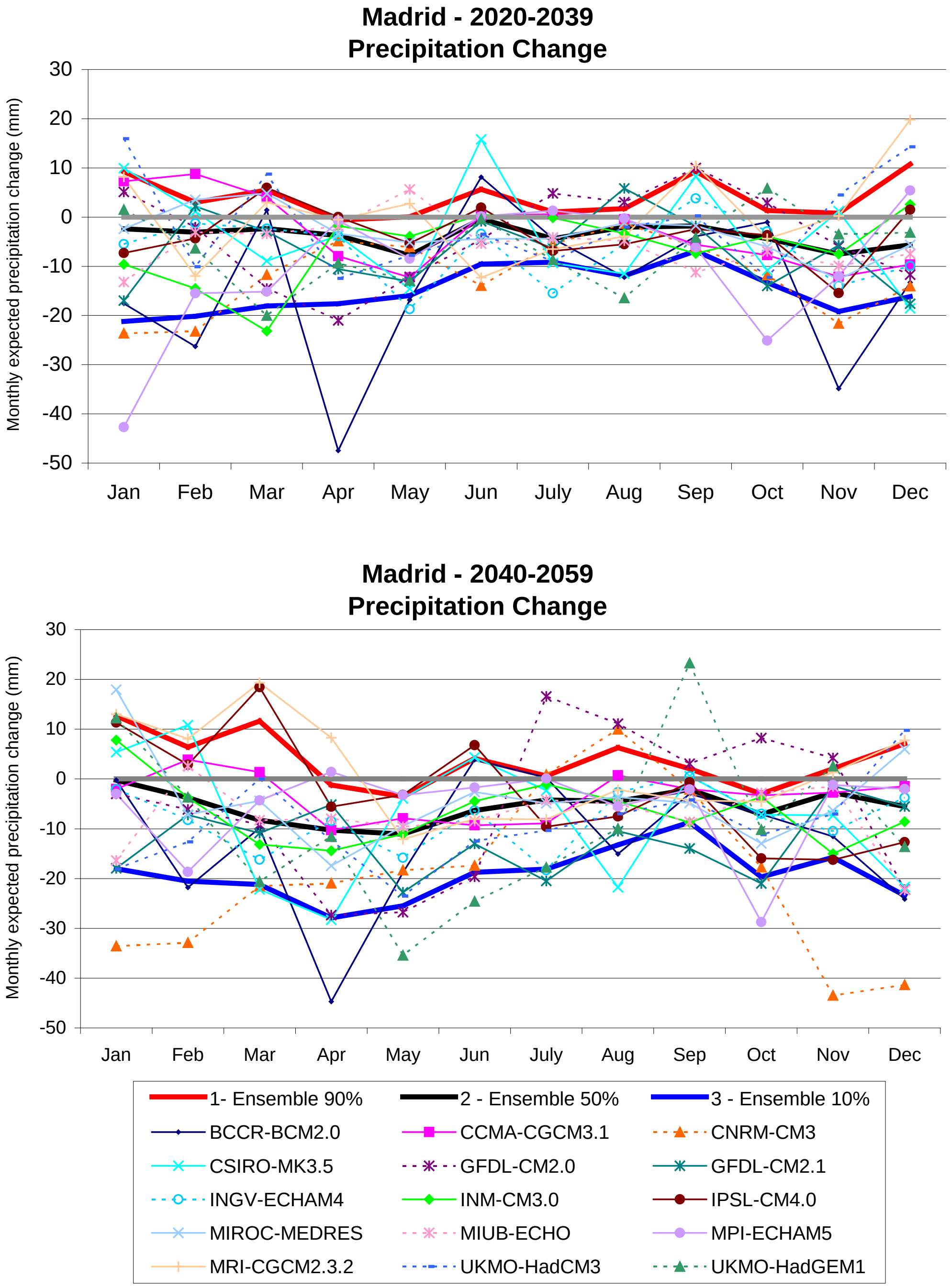


Figure A1.25- Expected precipitation change in Madrid (in mm)

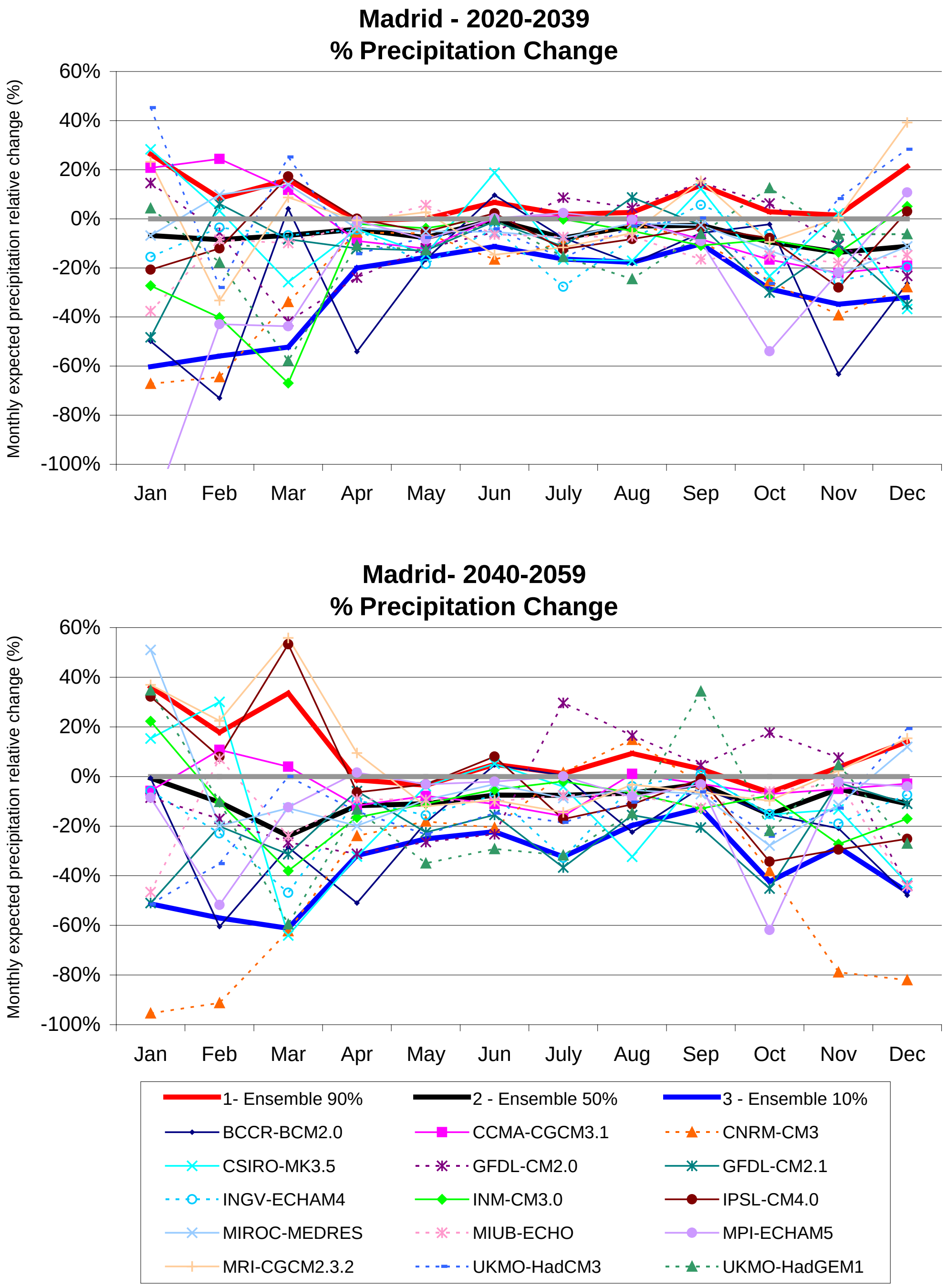


Figure A1.26- Expected precipitation change in Madrid (in %)

Oslo

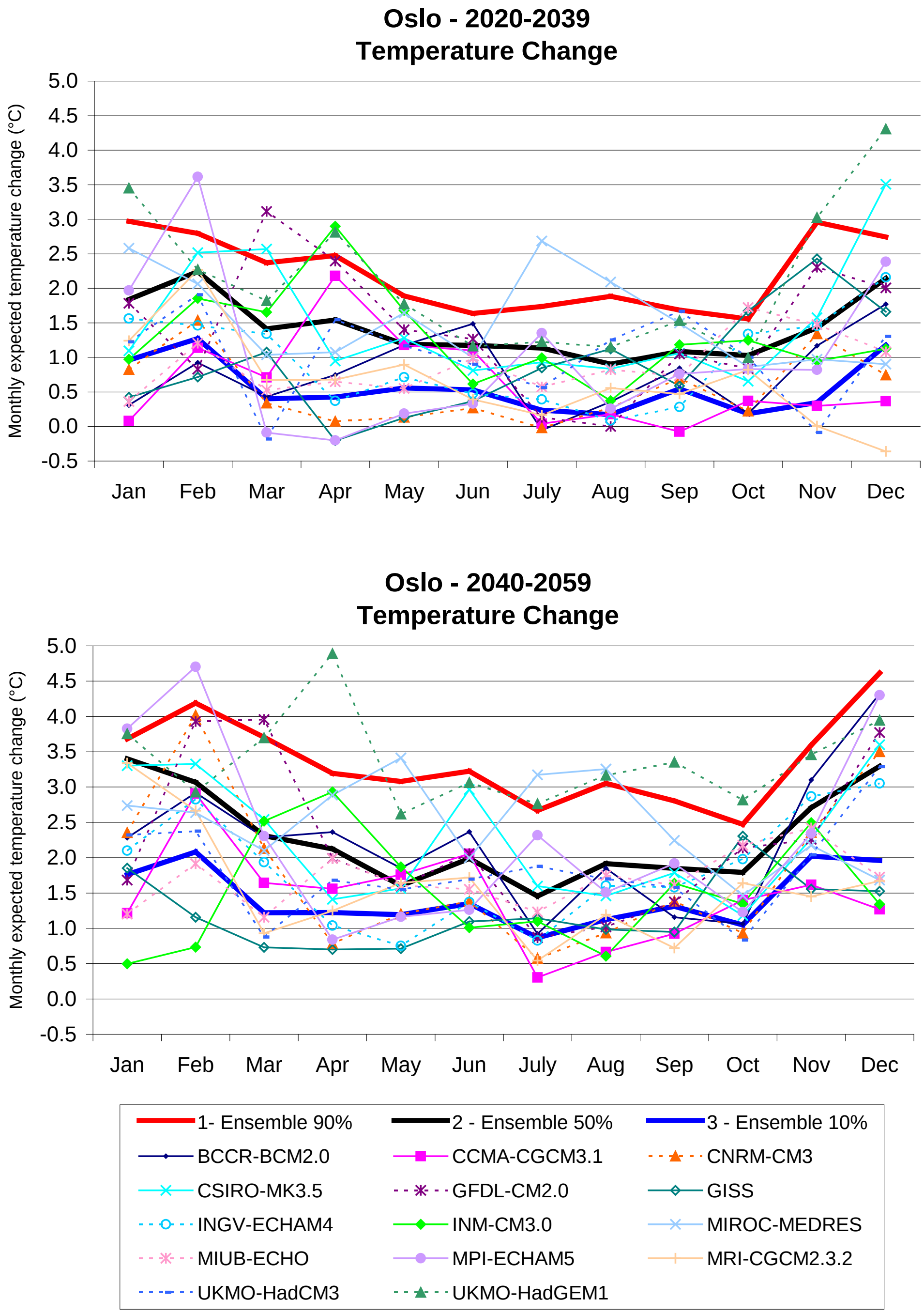


Figure A1.27- Expected temperature change in Oslo

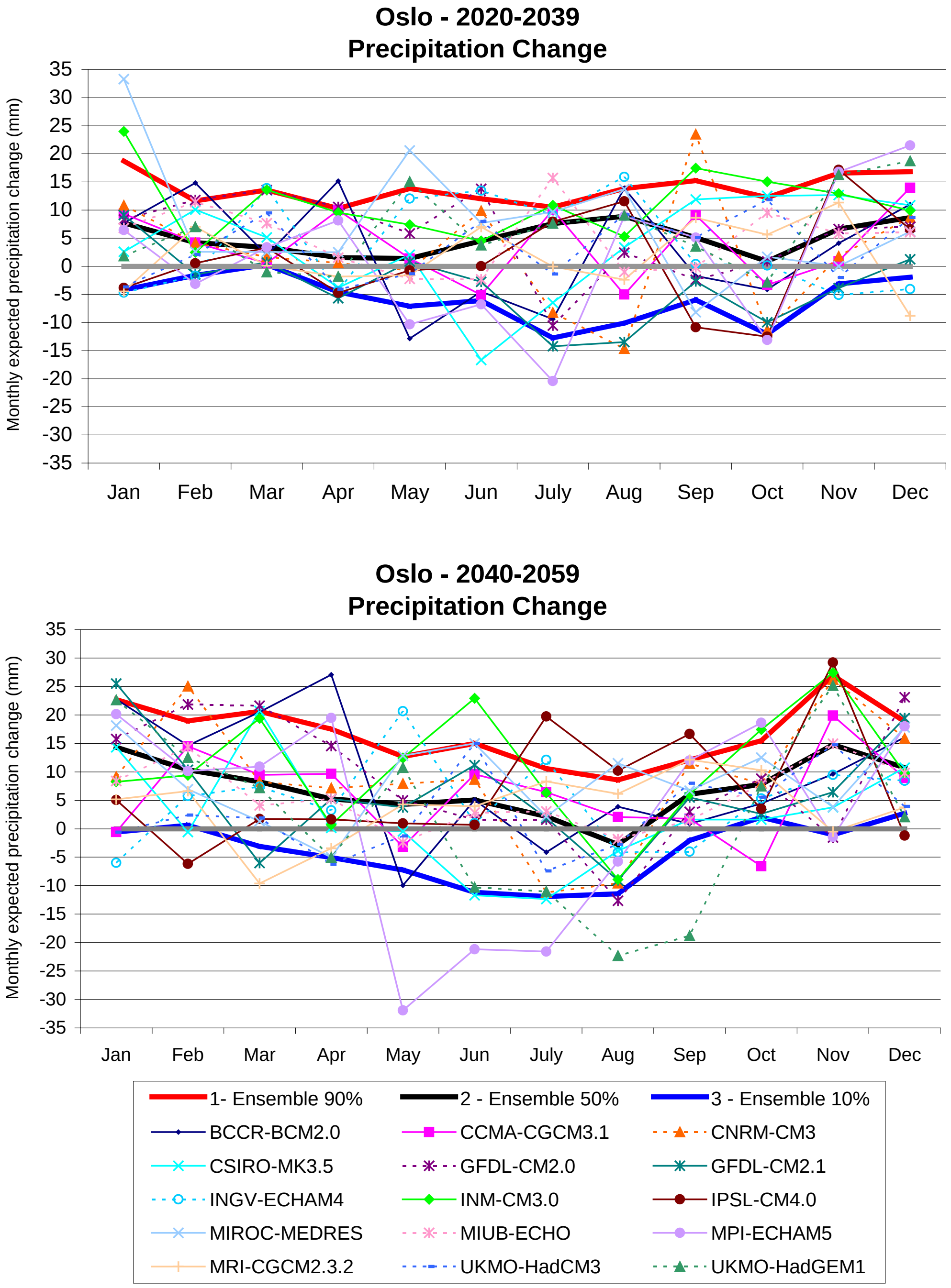


Figure A1.28- Expected precipitation change in Oslo (in mm)

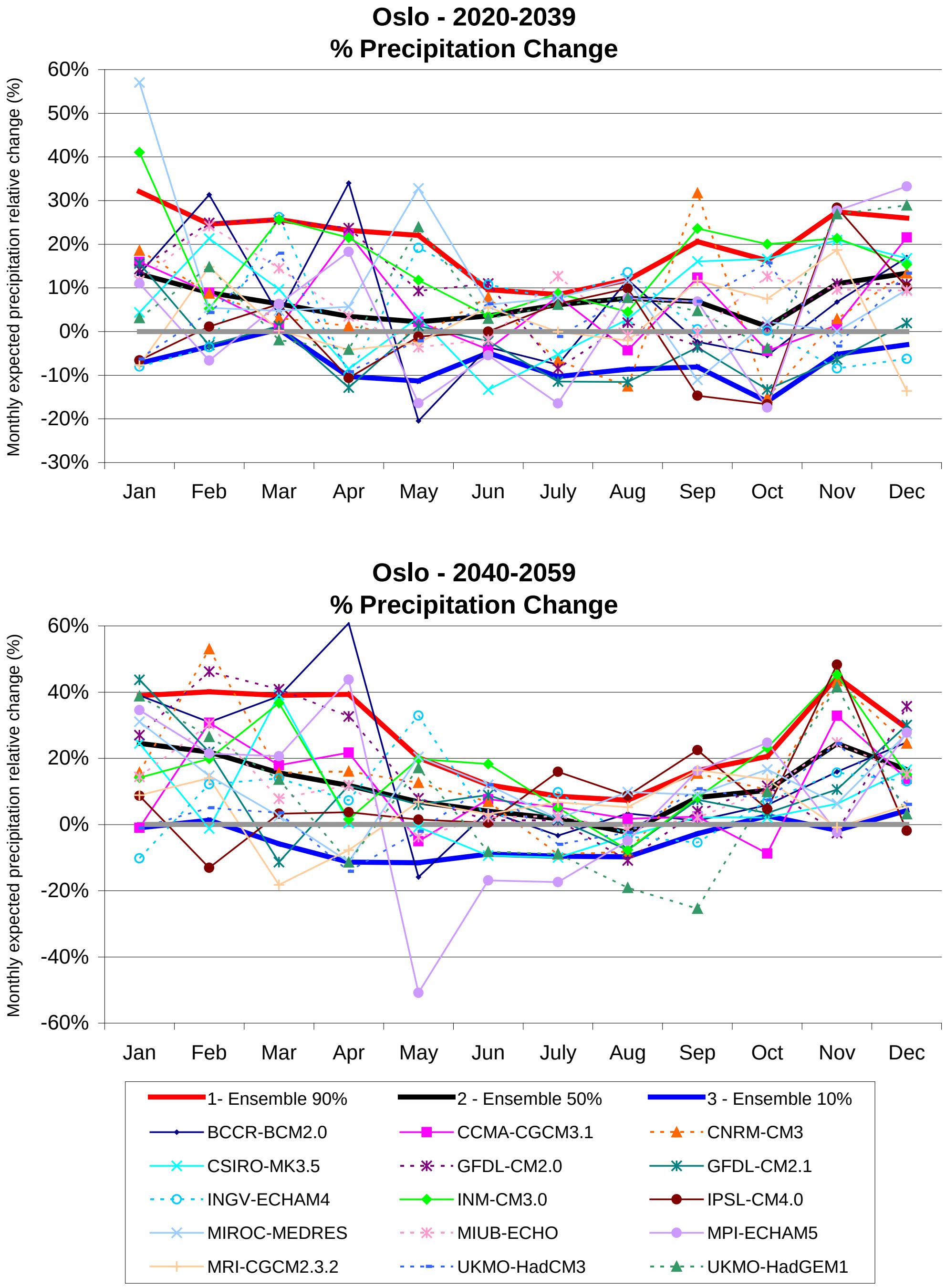


Figure A1.29 - Expected precipitation change in Oslo (in %)

Reggio-Emilia

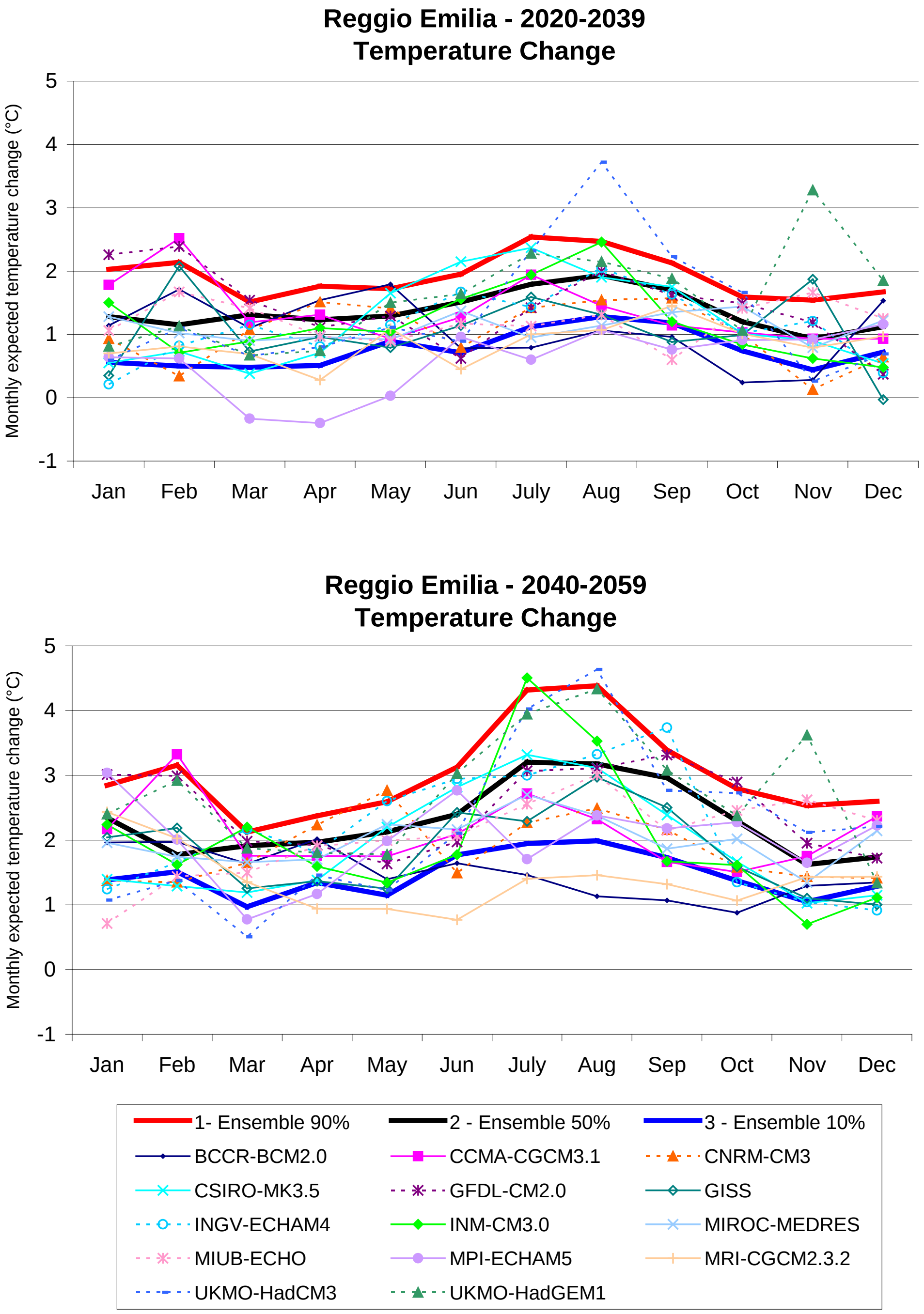


Figure A1.30 - Expected temperature change in Reggio-Emilia

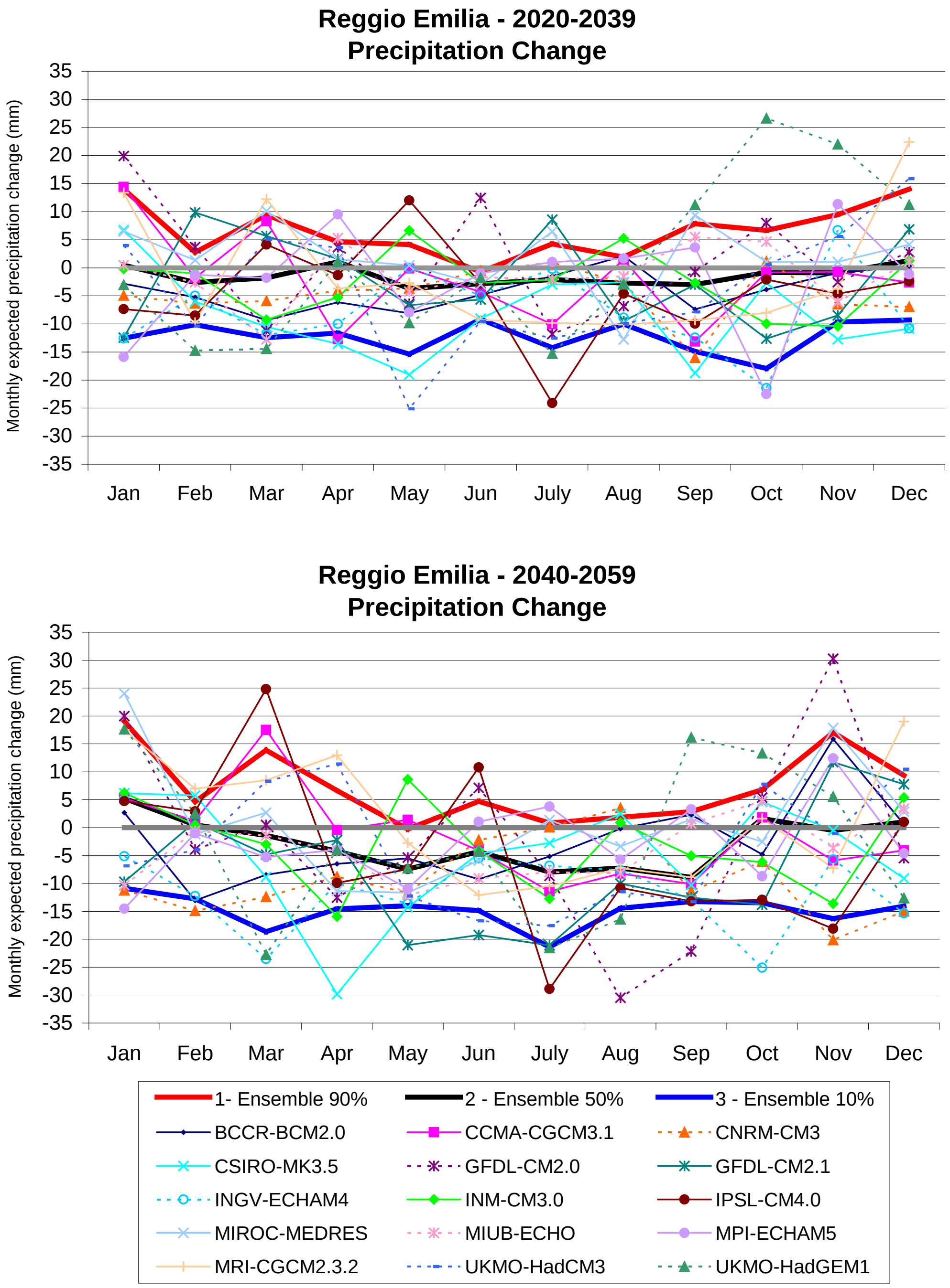


Figure A1.31 - Expected precipitation change in Reggio-Emilia (in mm)

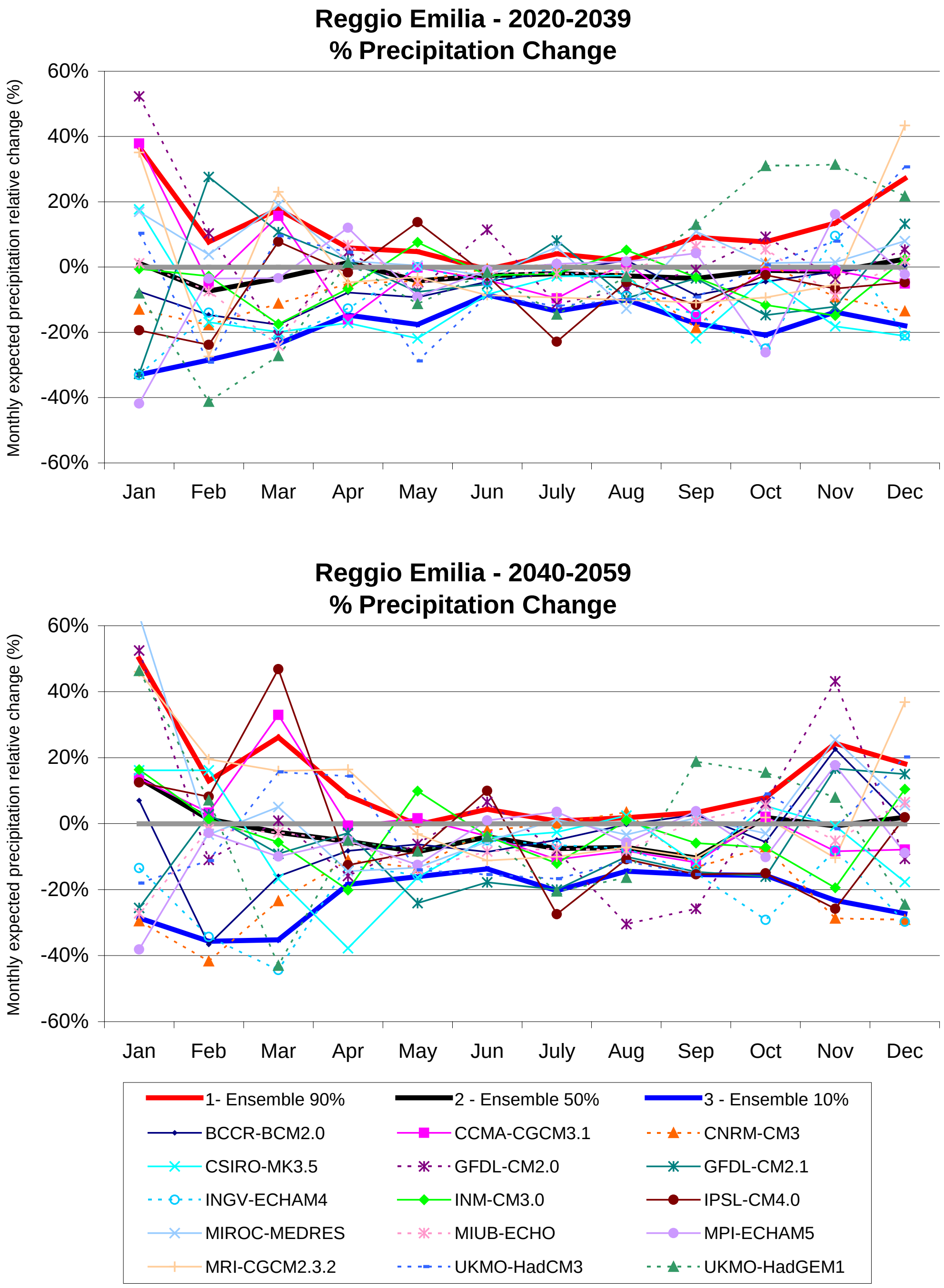


Figure A1.32 - Expected precipitation change in Reggio-Emilia (in %)

7.7. Future climate scenarios for the A1B SRES emission scenario issued by several GCM models compiled by ENSEMBLES project

Overview

We present the changes expected in the 9 European pilots over the next decades in the monthly values of both temperature and precipitation, as well as the maximum daily precipitation. The focus in on the projections up to the end of the 21st century, under the A1B SRES scenario.

The control run was assumed to be from 1980-1999 and mean values obtained by each of the considered climate models over the following two-decades periods: i) 2020-2039, ii) 2040-2059, iii) 2060-2079 and iv) 2080-2099.

Figures A1.3, A1.4 and A1.5 show the evolution of the 50% percentile of 15 model projections from the ENSEMBLES project for the European pilot areas. Figure A1.6 summarises the results. The projects show an increase of mean annual temperature in all pilots, ranging from 1ºC, in Edinburgh, to 4ºC, in Athens up to the end of the century. The precipitation trends vary depending on the region, but southern Europe is expected to observe a decrease in monthly precipitation, while northern Europe will see increase. The trend of the maximum daily precipitation is not clear.

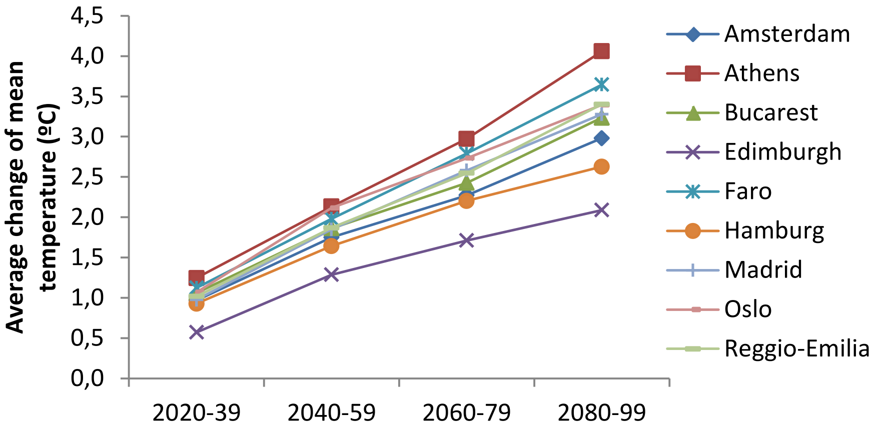


Figure A1.33 - Evolution of the 50% percentile of all model projections of the average mean annual temperature change

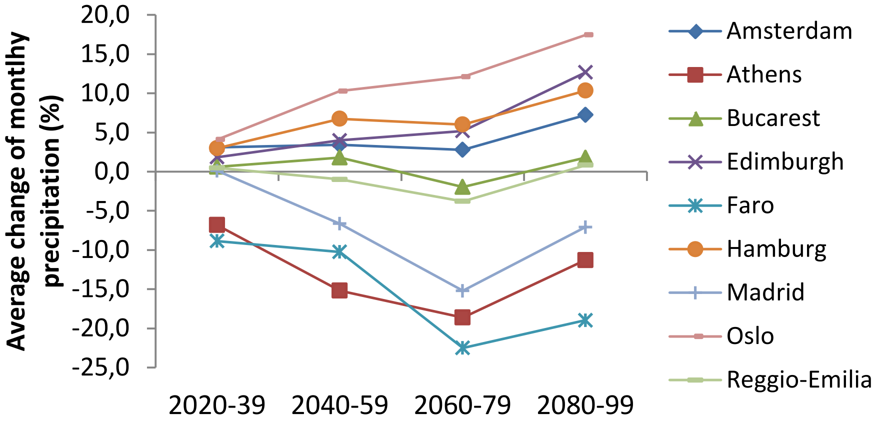


Figure A1.34 - Evolution of the 50% percentile of all model projections of the average monthly precipitation change

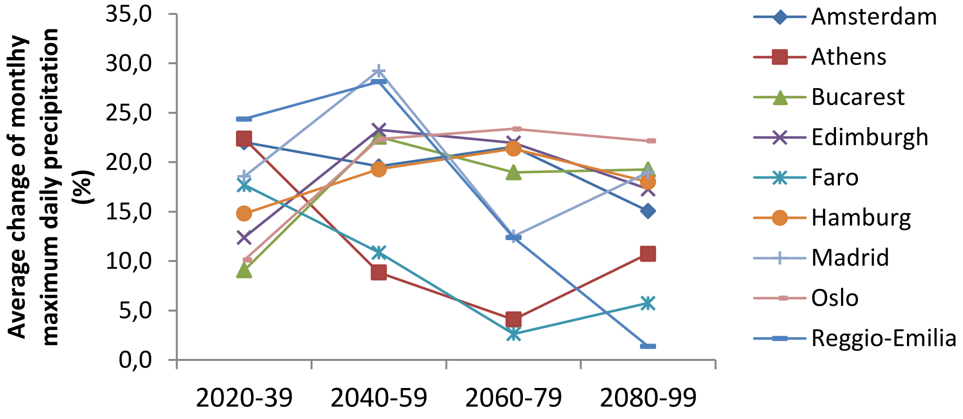


Figure A1.35 - Evolution of the 50% percentile of all model projections of the monthly maximum daily precipitation change

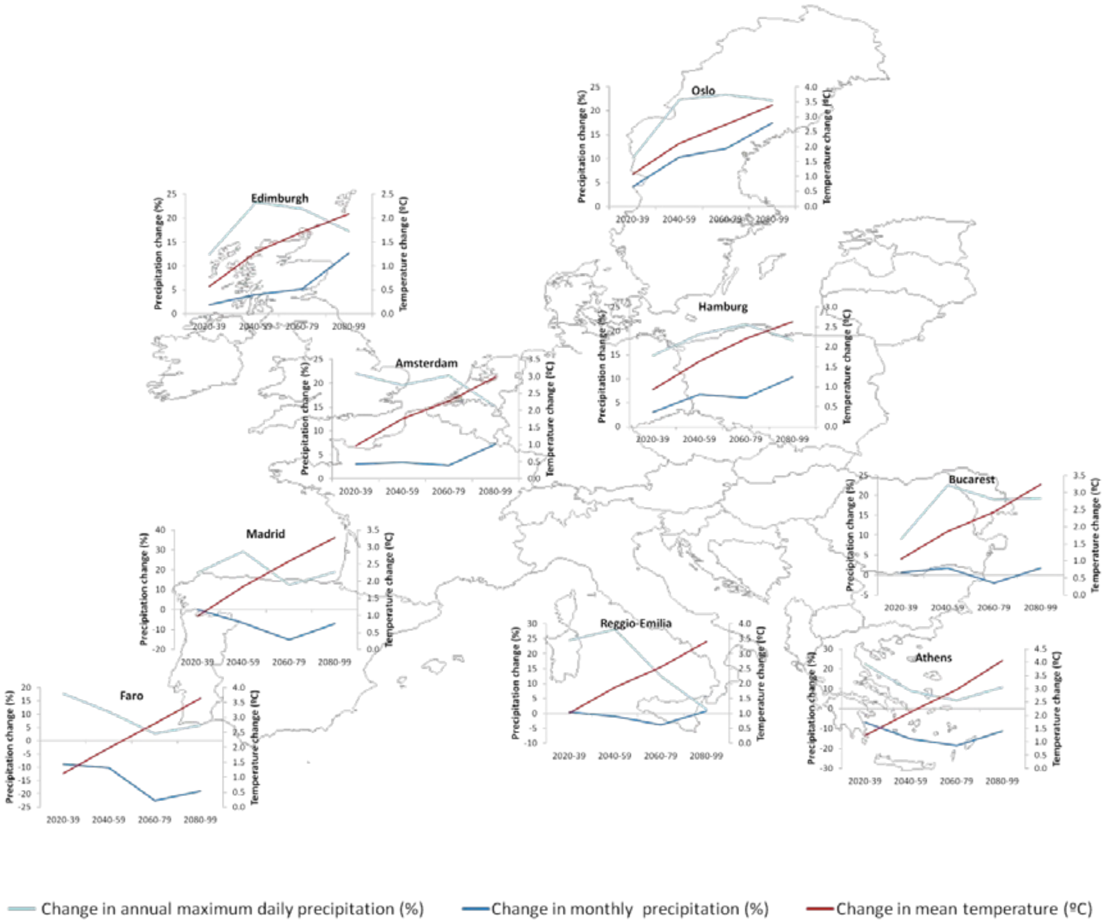


Figure A1.36 - Evolution of the 50% percentile of all model projections

For each pilot city, more detailed information is presented. The graphs show the projections from each model for each two-decade periods, for the following variables:

- Expected average change in monthly mean temperature (°C)
- Expected average change in monthly precipitation depth (mm)
- Expected average change in monthly maximum of daily precipitation depth (mm)

The GCMs' outputs in terms of the changes expected in the values of precipitation depths are provided also as the percentage of the change of the mean monthly values of the control run decade. Three percentiles (10%, 50% and 90%) are also plotted to summarise the variability of the model projections.

In all nine European pilots the projected change in monthly mean temperature is of an increase in all months.

The projections also show a clear decrease in monthly precipitation in Athens and Faro for most of the year. In Amsterdam, Bucarest and Reggio-Emilia a decrease is projected for the summer months and an increase is projected for the remaining months. Oslo is expected to experience a sustainable increase of monthly precipitation in all months along the XXIst. The projected increase is Edinburgh is only observed from mid-century onwards. The trend in Madrid is not clear.

The change projections of monthly maximum daily precipitation are not very clear.

Amsterdam

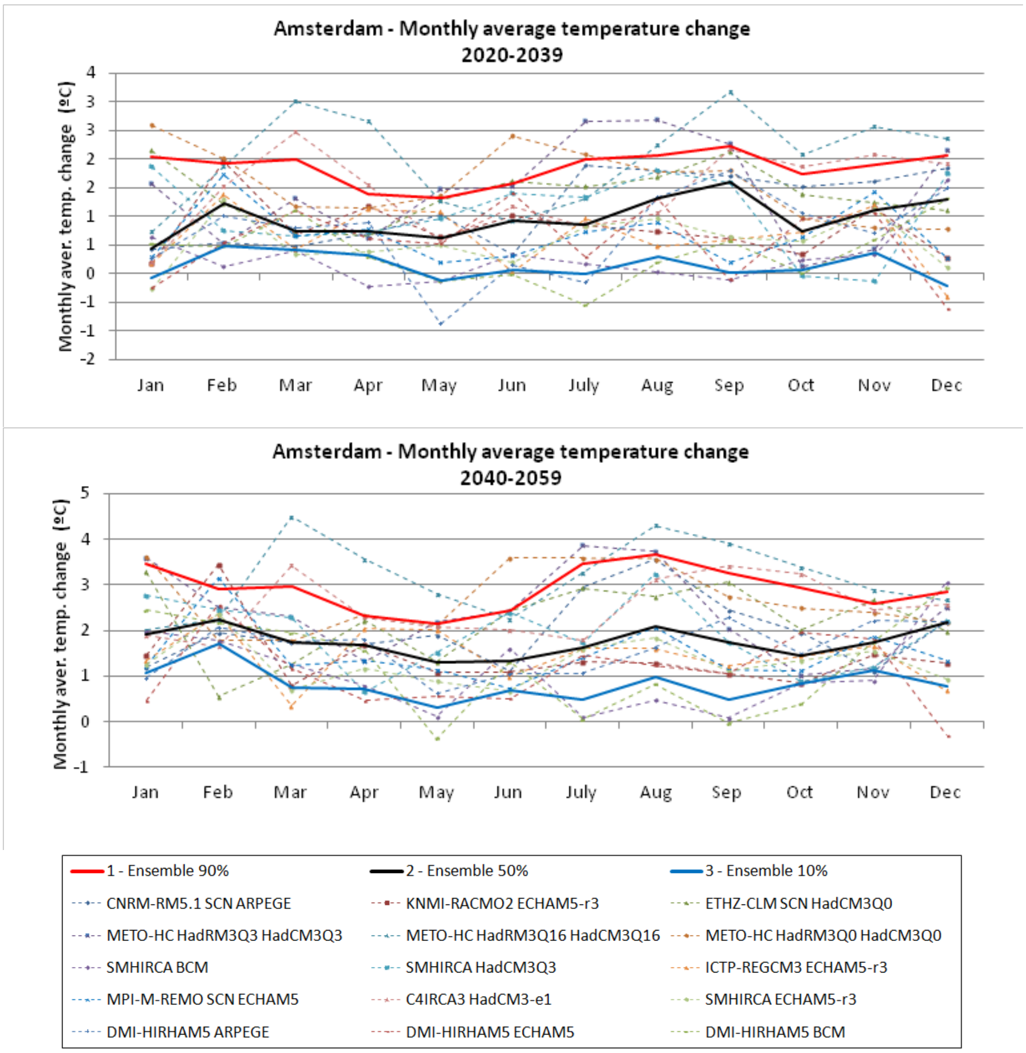


Figure A1.37 – Expected temperature change in Amsterdam (2020-2039; 2040-2059)

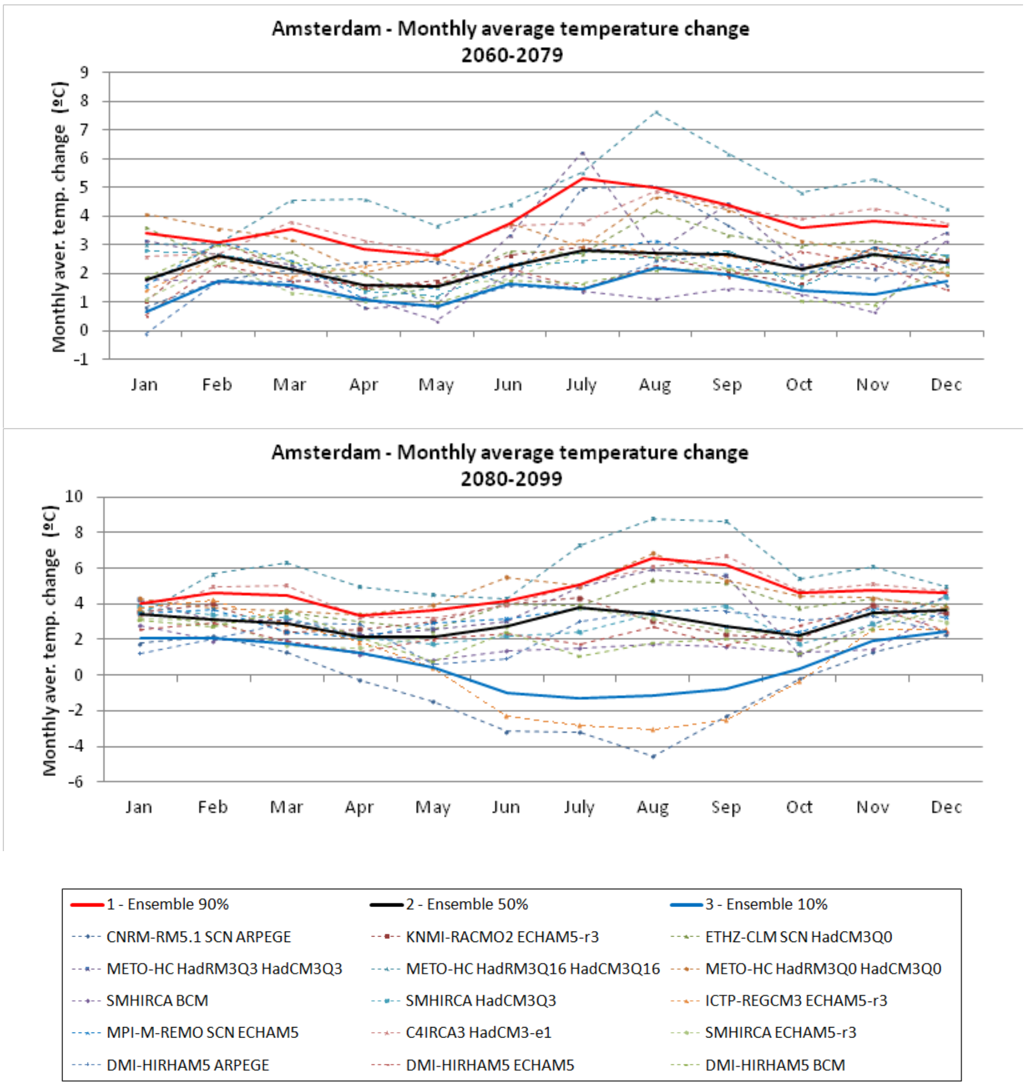


Figure A1.38 – Expected temperature change in Amsterdam (2060-2079; 2080-2079) (in mm)

Figure A1.39 – Expected monthly precipitation change in Amsterdam (2020-2039; 2040-2059) (in mm)

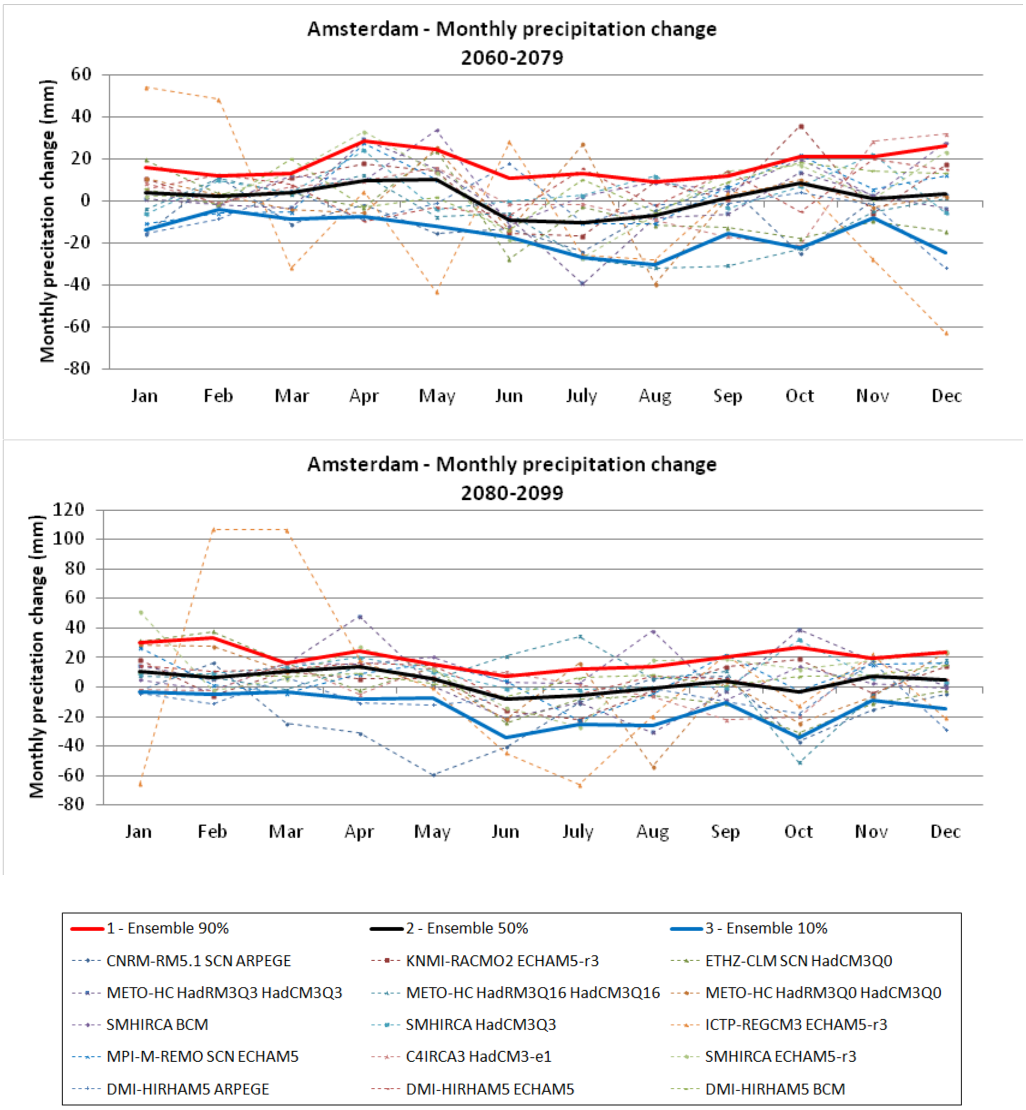


Figure A1.40 – Expected monthly precipitation change in Amsterdam (2060-2079; 2080-2099) (in mm)

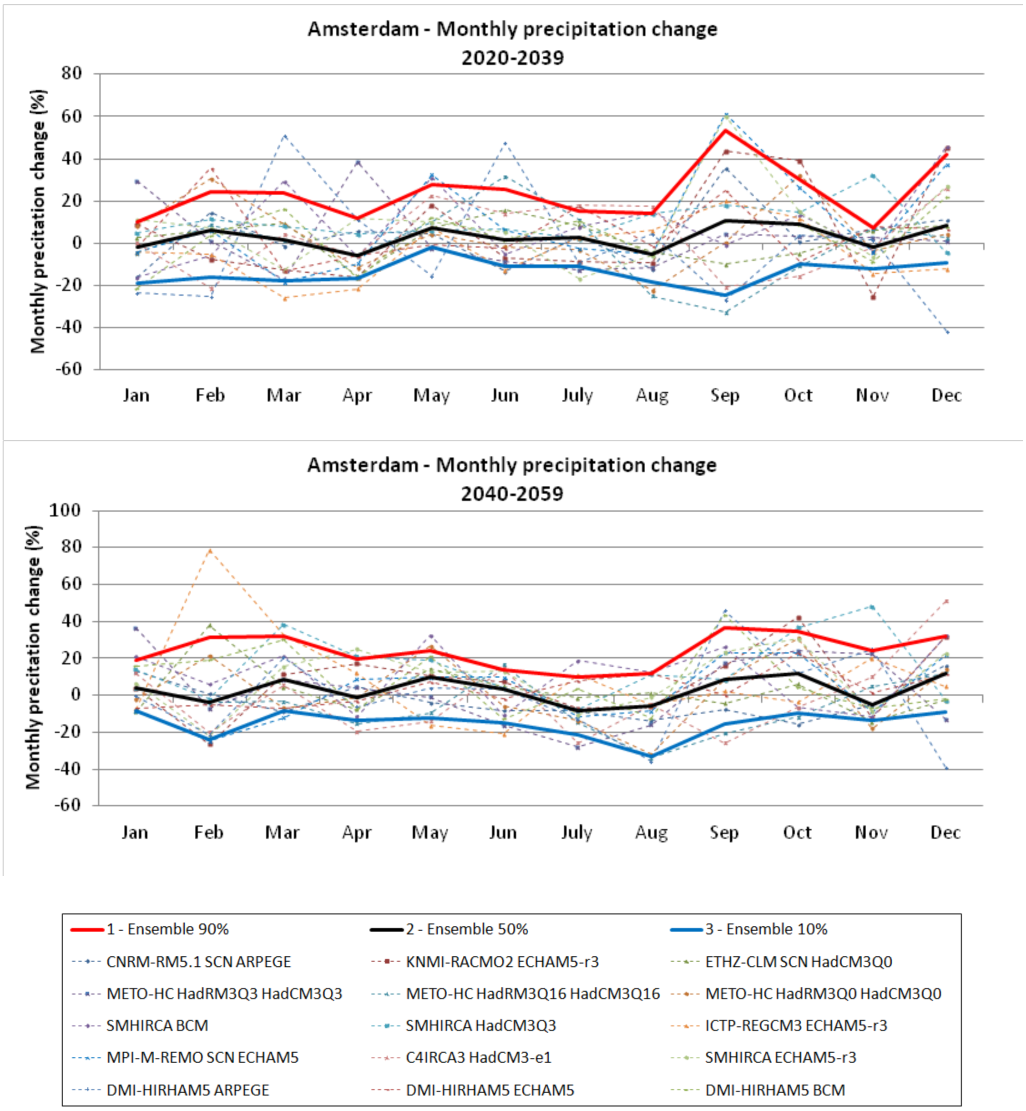


Figure A1.41 – Expected monthly precipitation change in Amsterdam (2020-2039; 2040-2069) (in %)

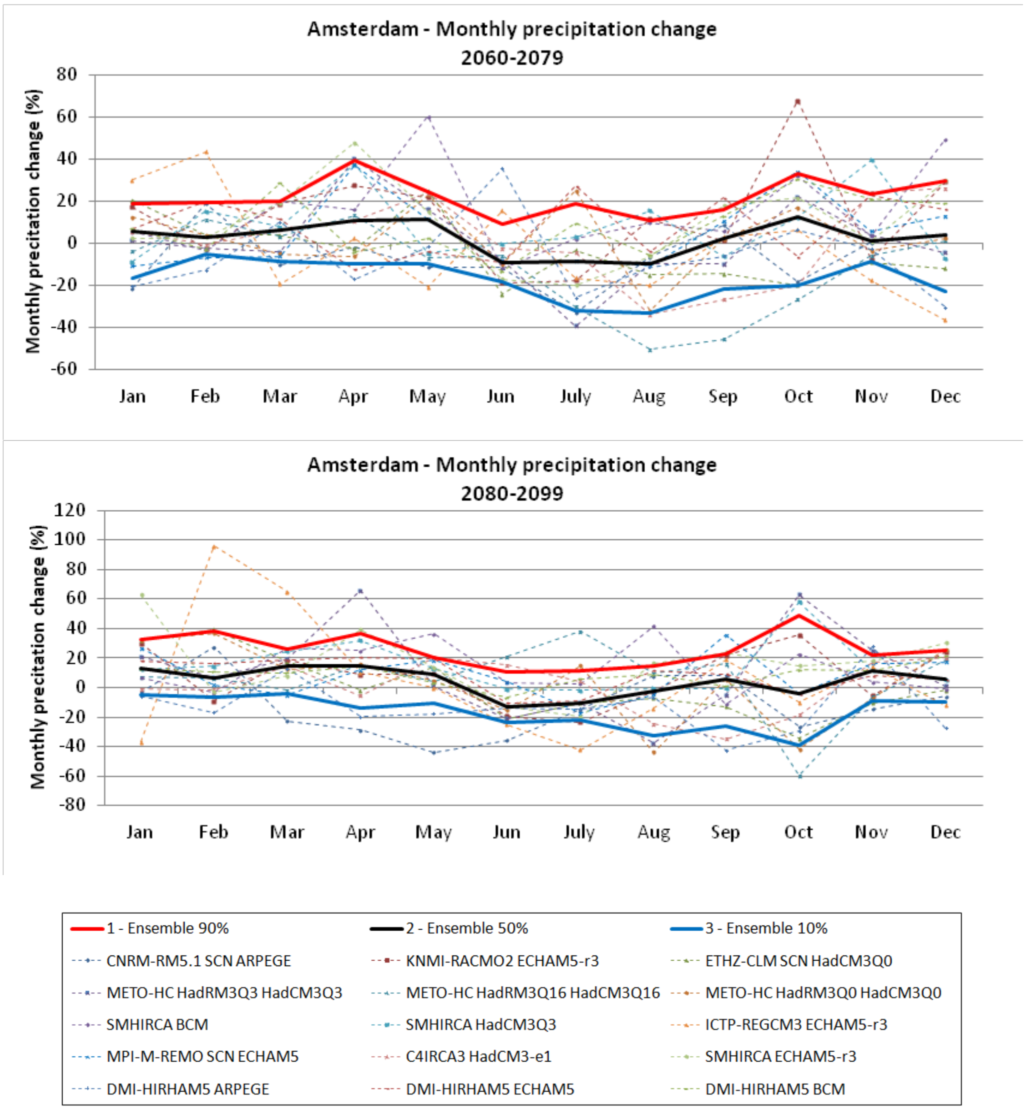


Figure A1.42 – Expected monthly precipitation change in Amsterdam (2060-2079; 2080-2099) (in %)

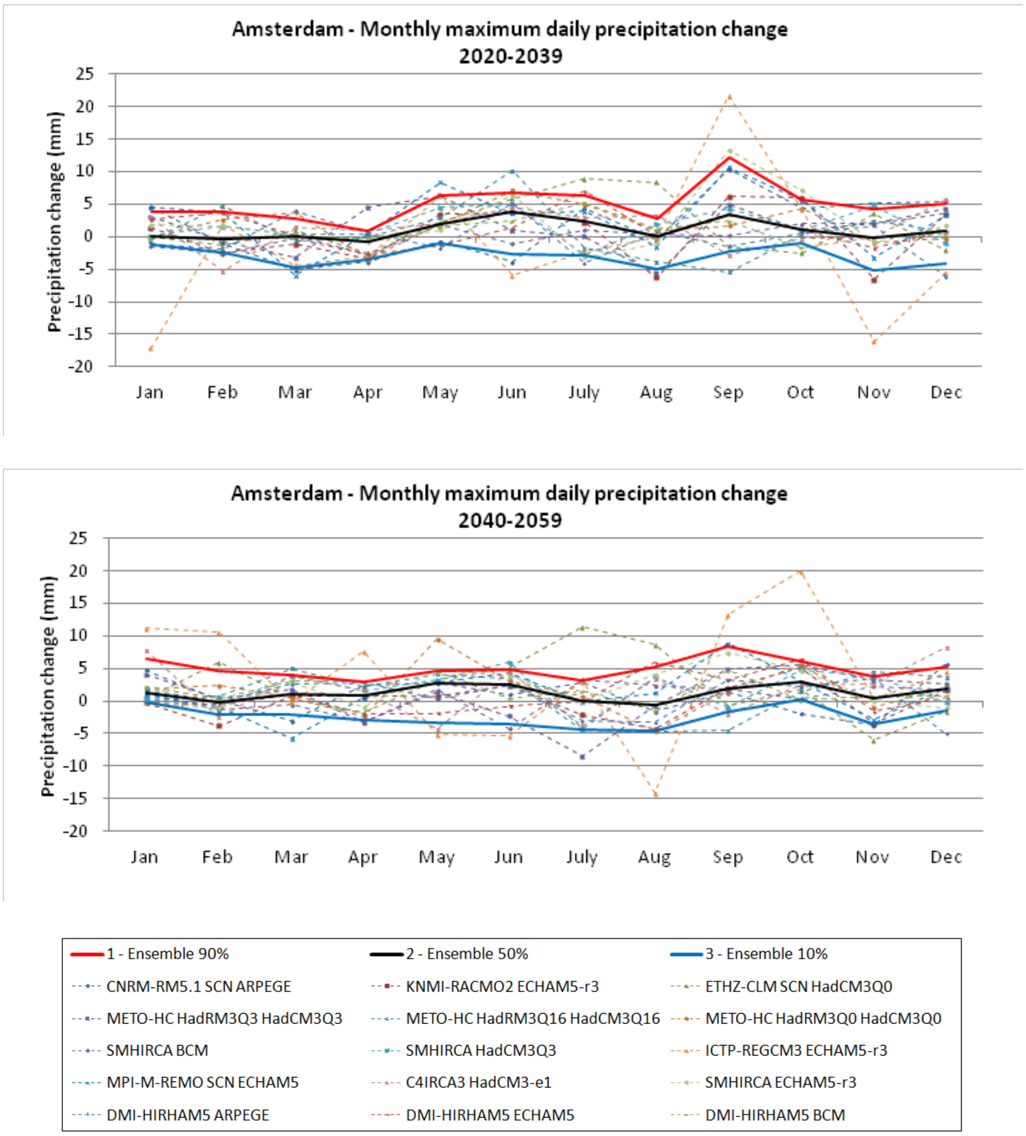


Figure A1.43 – Expected monthly maximum daily precipitation change in Amsterdam (2020-2039; 2040-2059) (in mm)

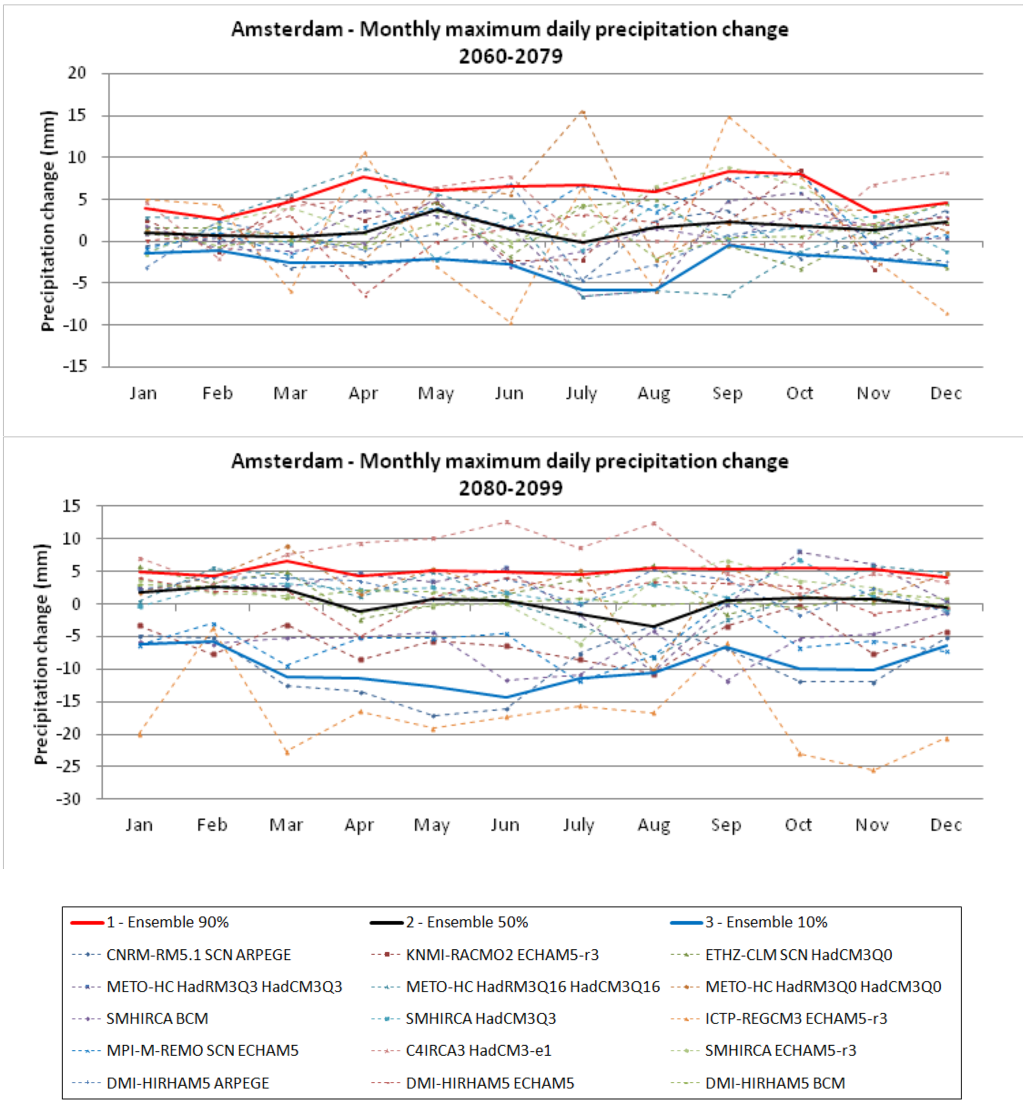


Figure A1.44 – Expected monthly maximum daily precipitation change in Amsterdam (2060-2079; 2080-2099) (in mm)

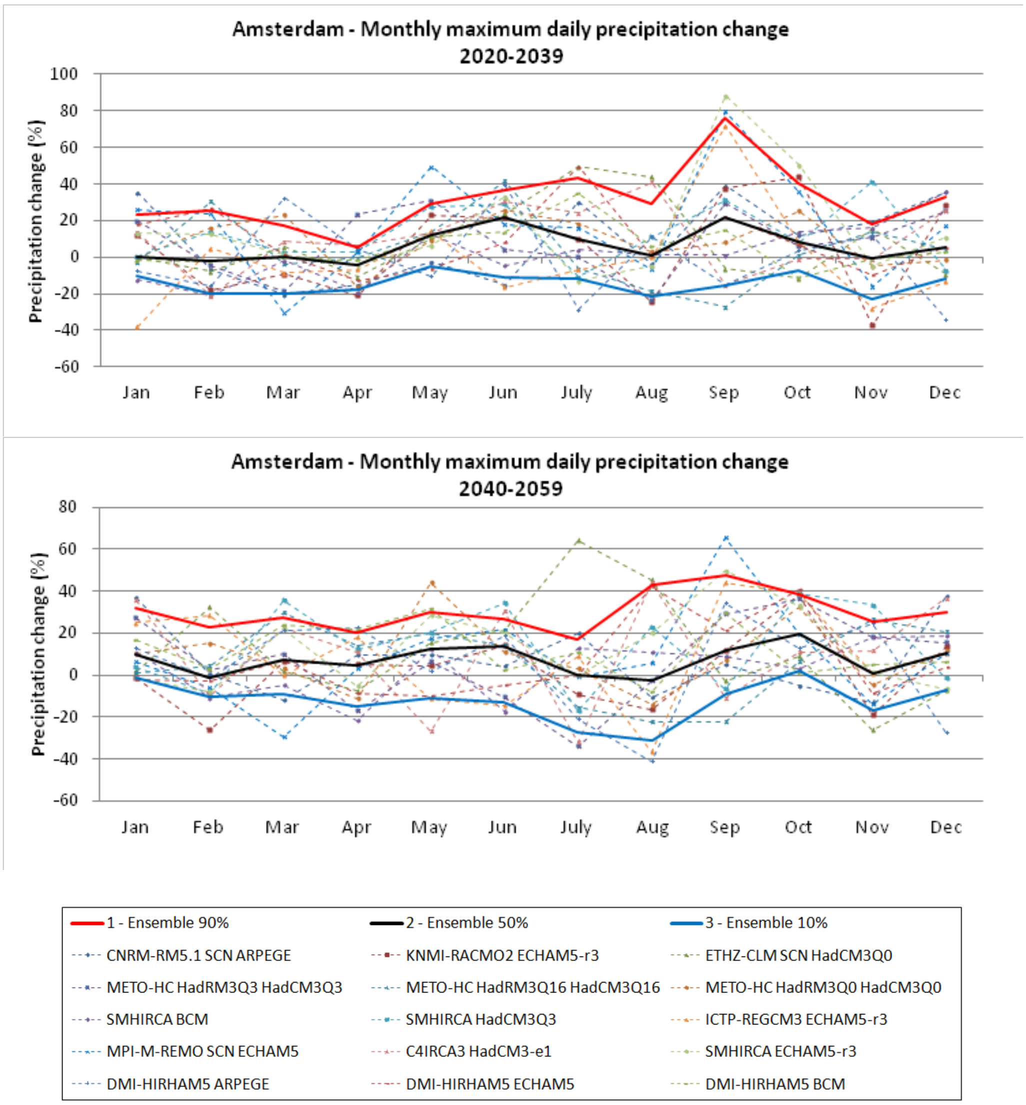


Figure A1.45 – Expected monthly maximum daily precipitation change in Amsterdam (2020-2039; 2040-2069) (in %)

Figure A1.46 – Expected monthly maximum daily precipitation change in Amsterdam (2060-2079; 2080-2099) (in%)

Athens

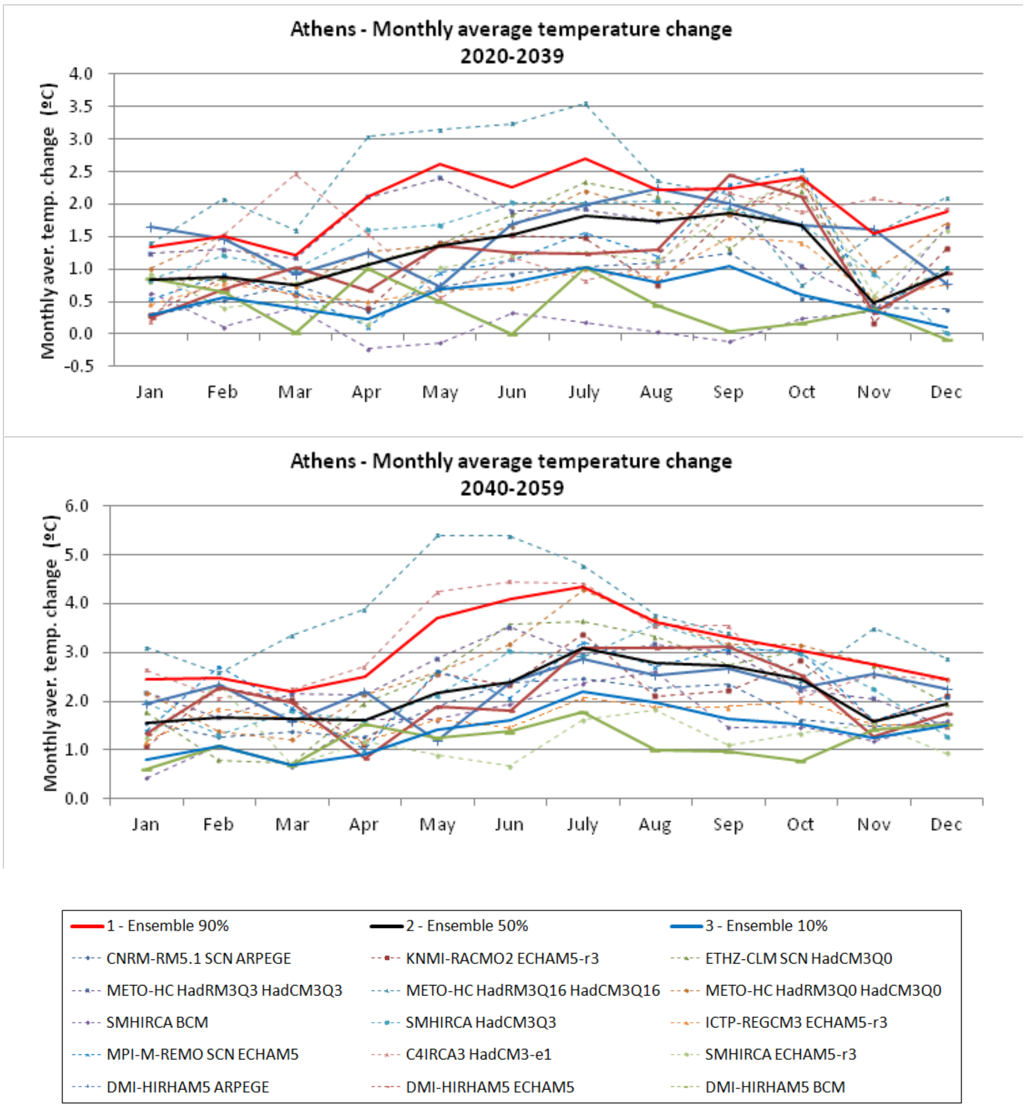


Figure A1.47 – Expected temperature change in Athens (2020-2039; 2040-2059)

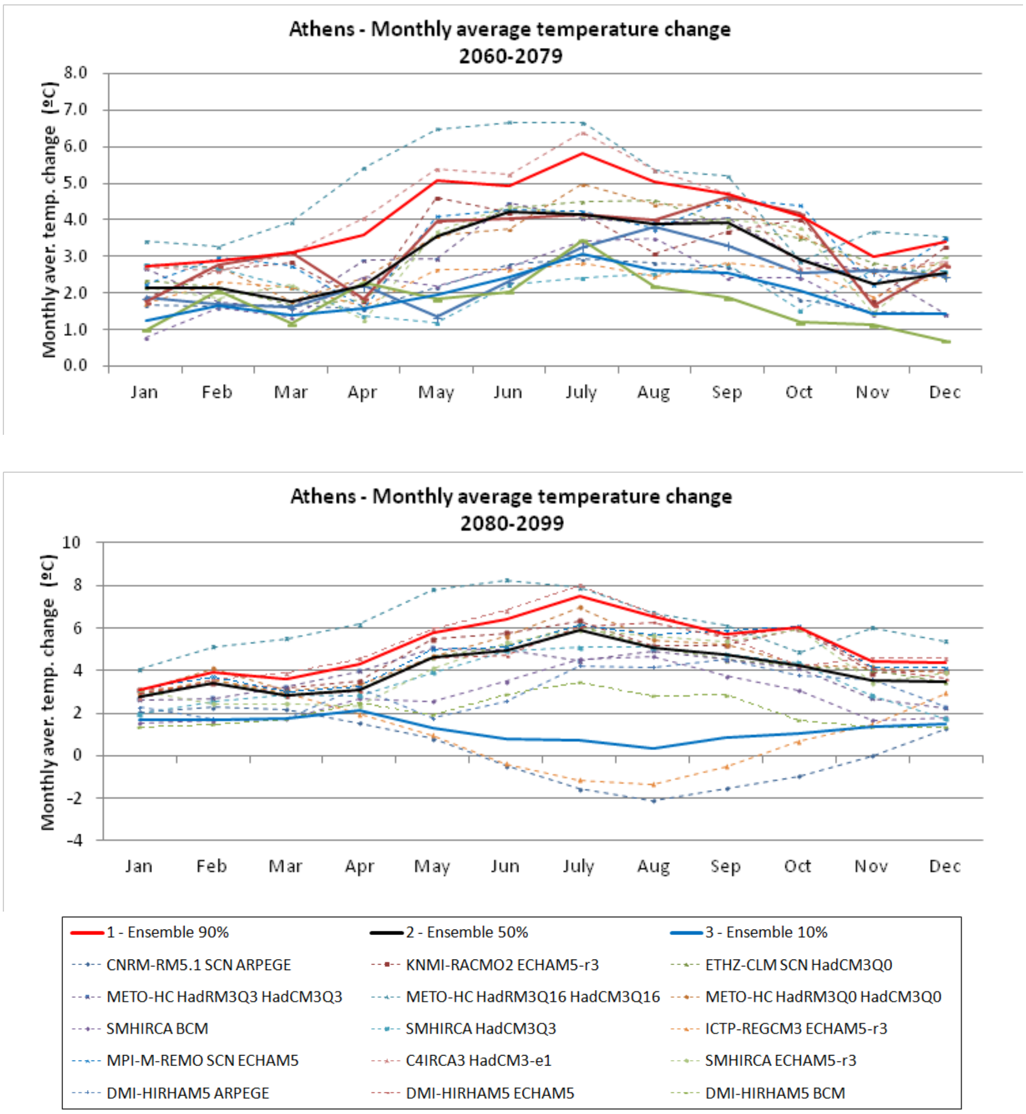


Figure A1.48 – Expected temperature change in Athens (2060-2079; 2080-2099)

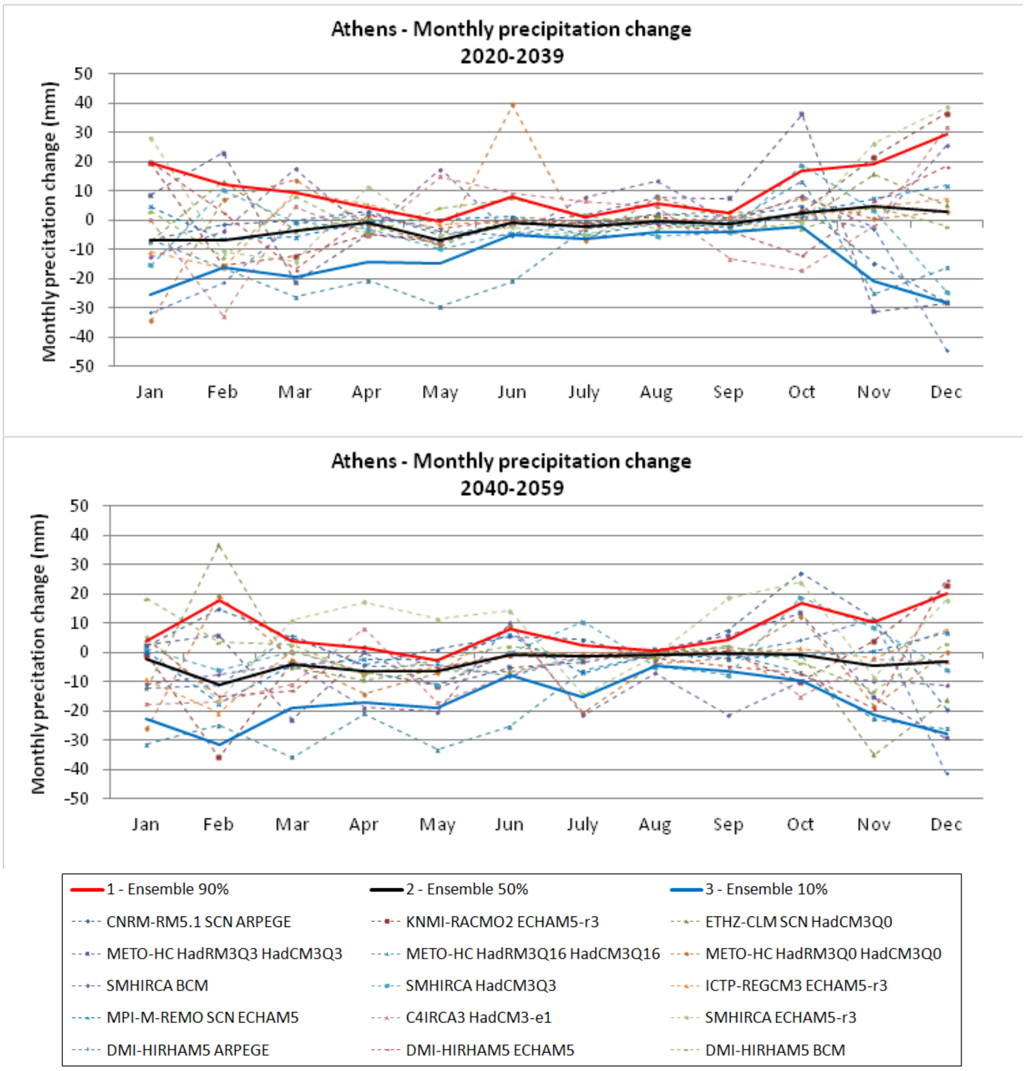


Figure A1.49 – Expected monthly precipitation change in Athens (2020-2039; 2040-2059) (in mm)

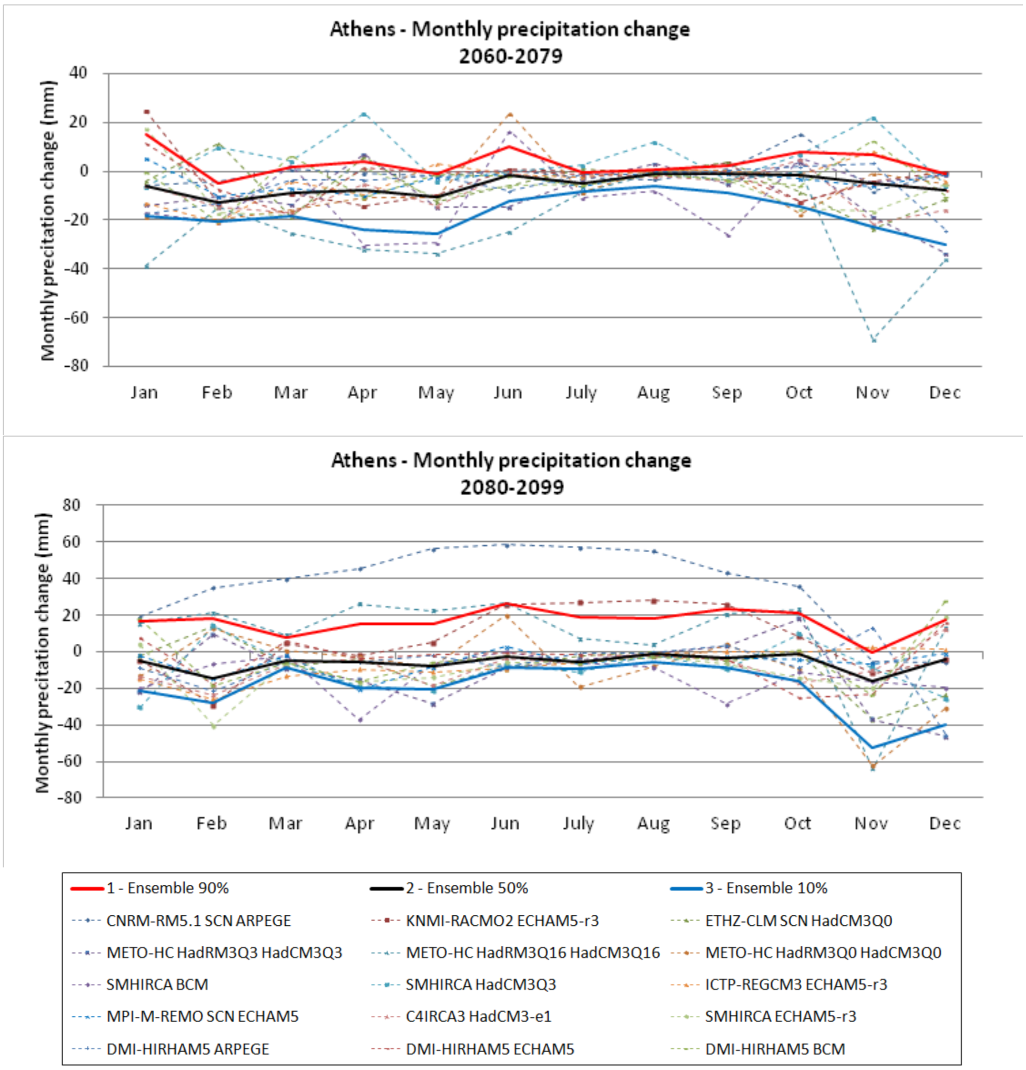


Figure A1.50 – Expected monthly precipitation change in Athens (2060-2079; 2080-2099) (in mm)

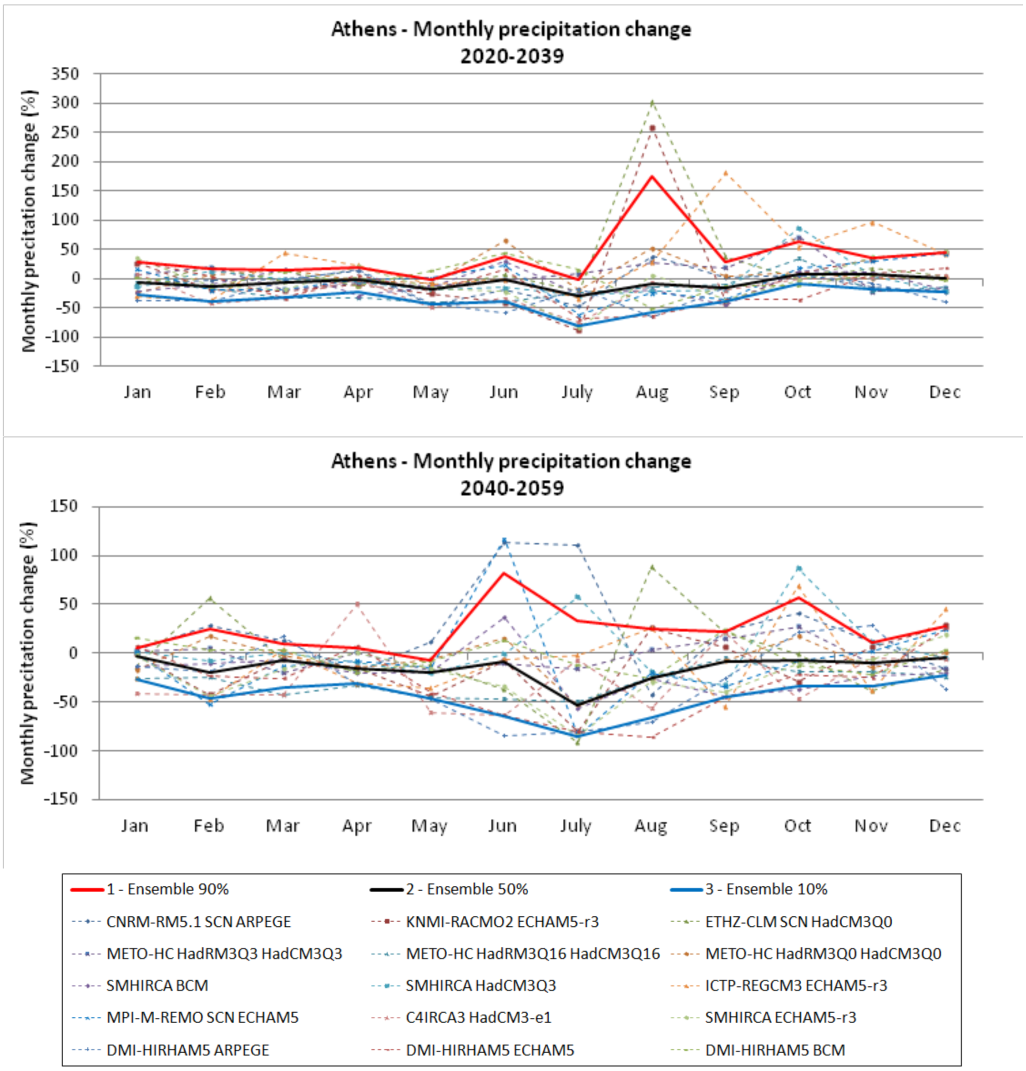


Figure A1.51 – Expected monthly precipitation change in Athens (2020-2039; 2040-2059) (in %)

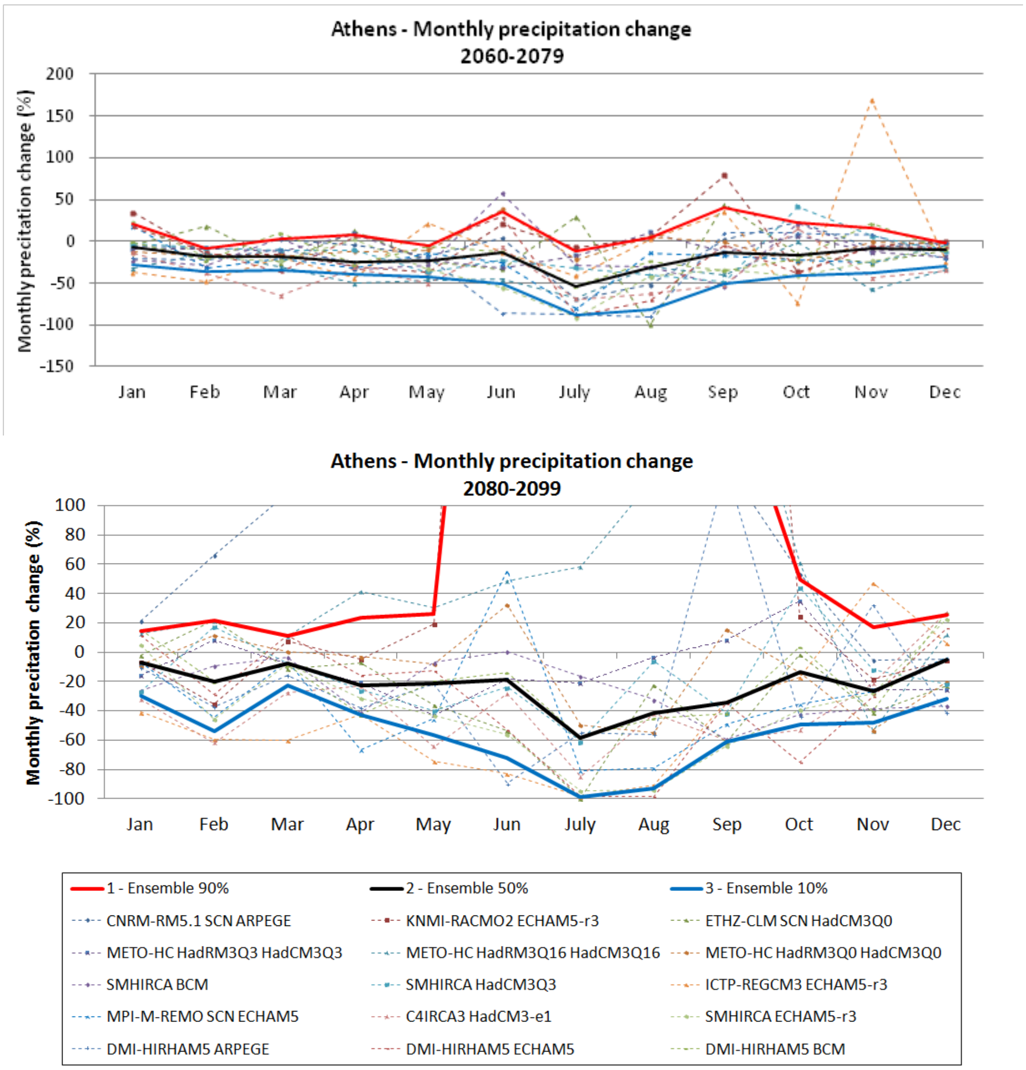


Figure A1.52 – Expected monthly precipitation change in Athens (2060-2079; 2080-2099) (in %)

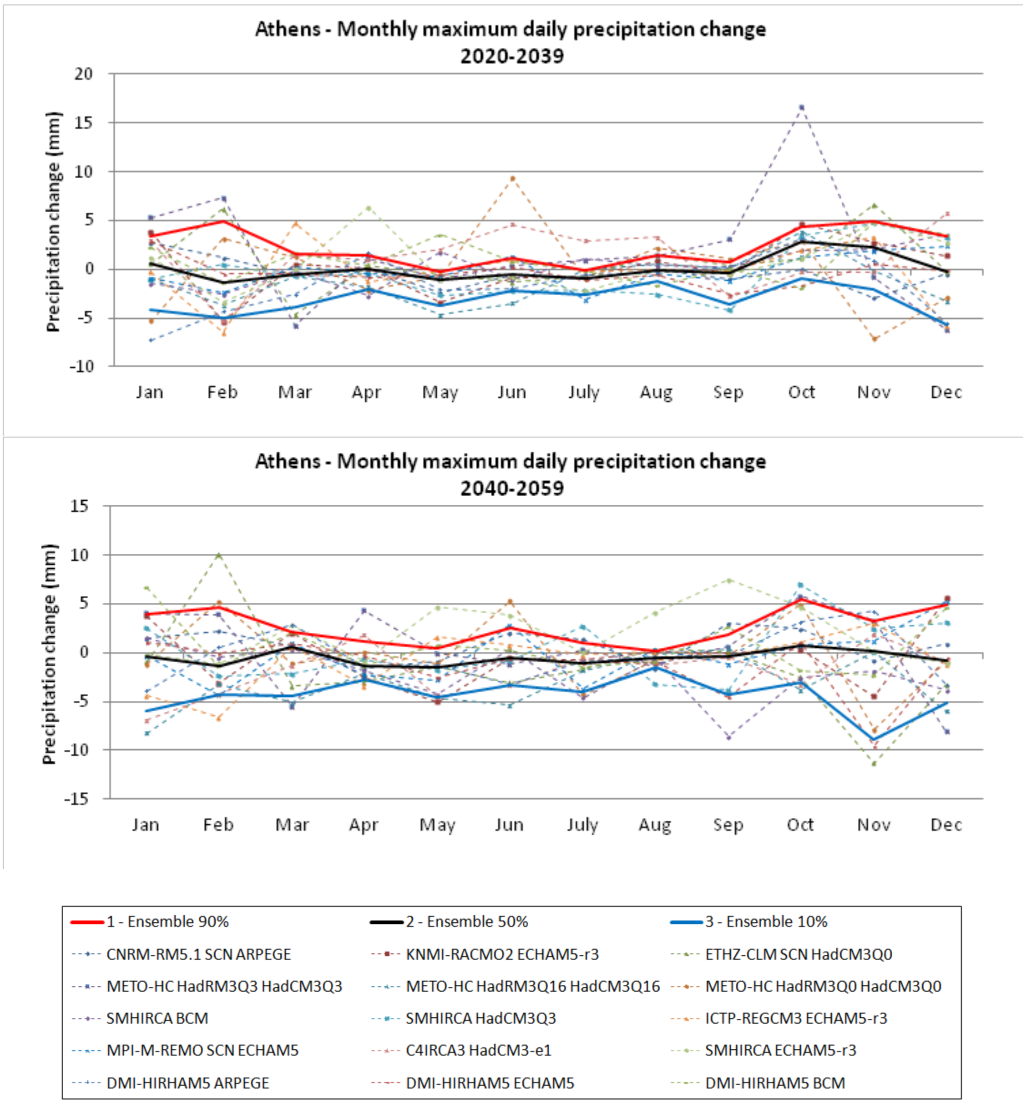


Figure A1.53 – Expected montlhy maximum daily precipitation change in Athens (2020-2039; 2040-2059) (in mm)

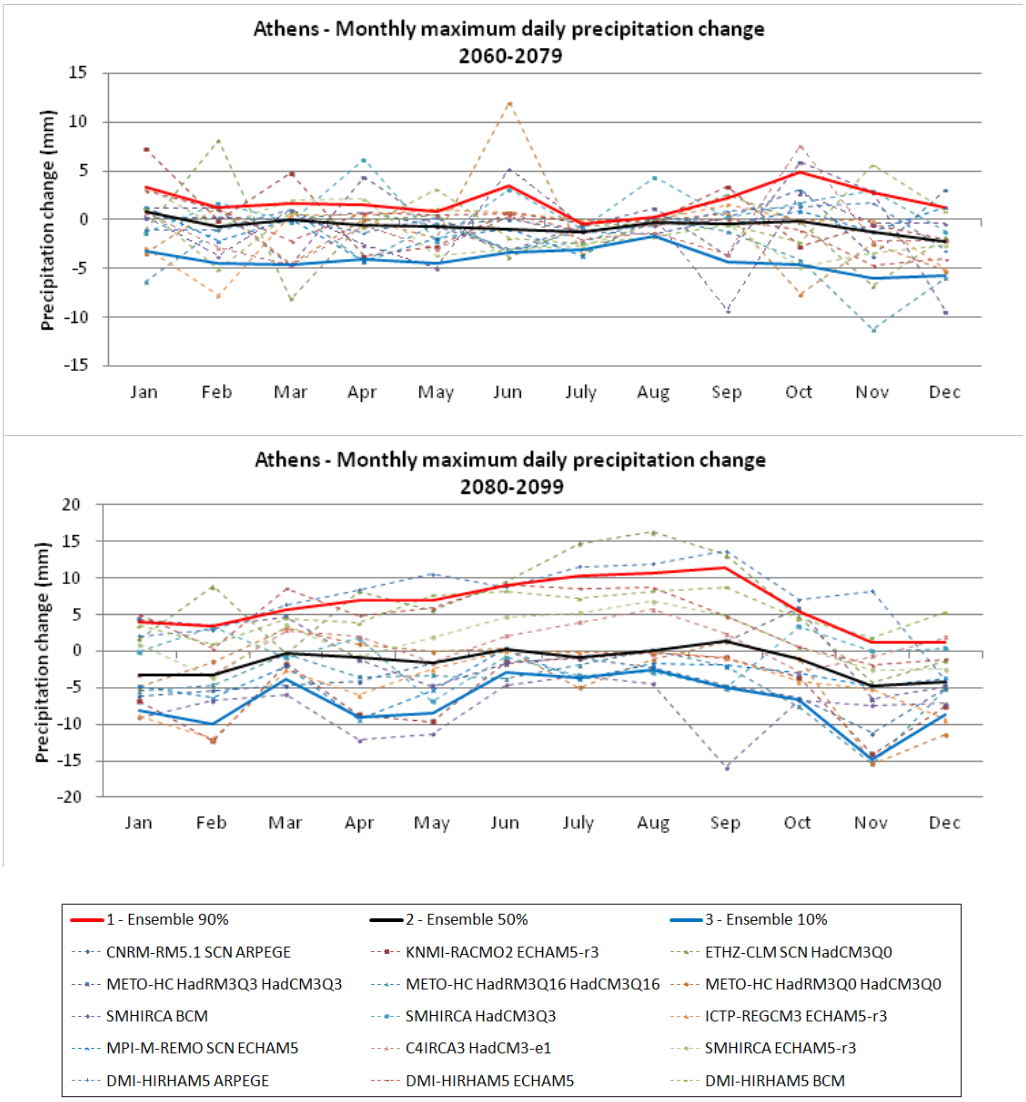


Figure A1.54 – Expected montlhy maximum daily precipitation change in Athens (2060-2079; 2080-2099) (in mm)

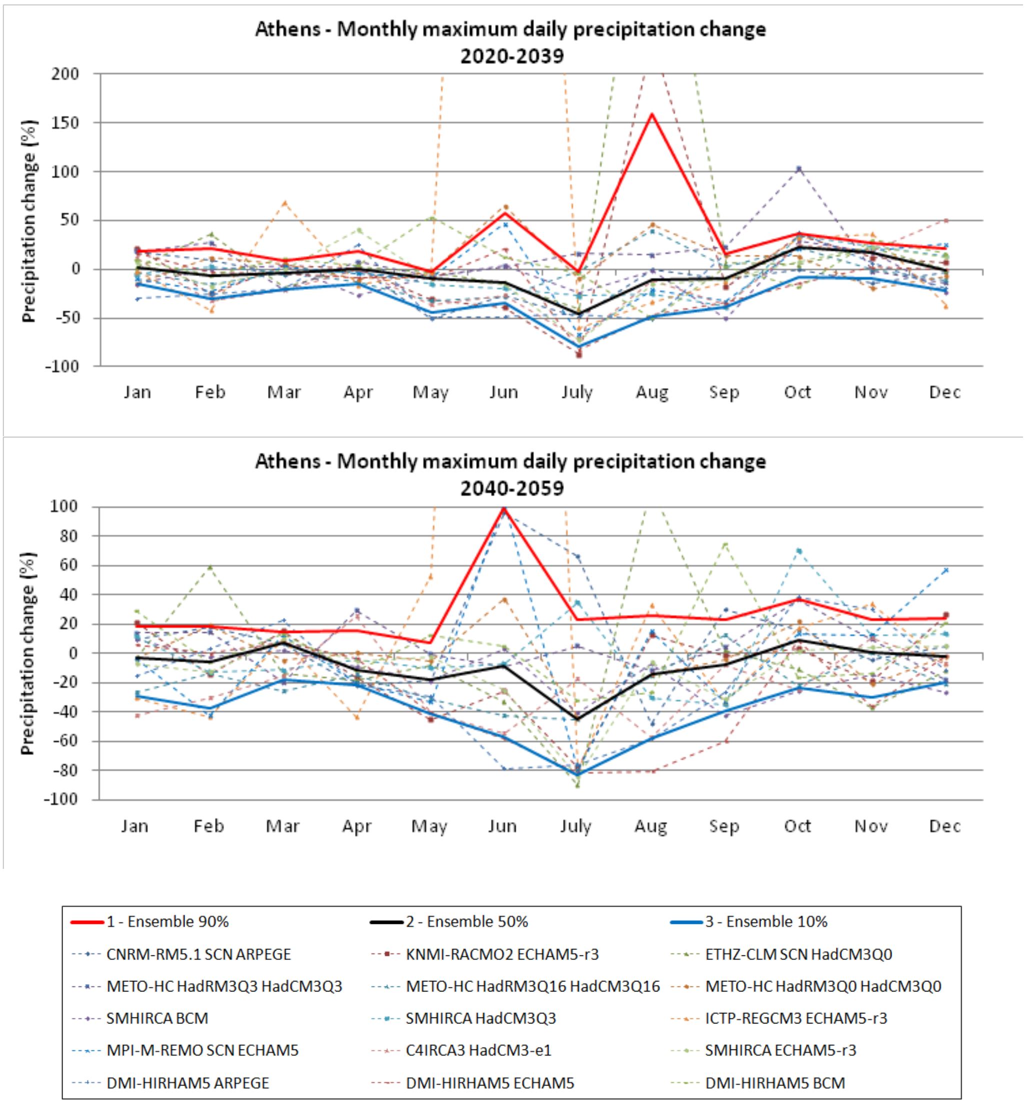
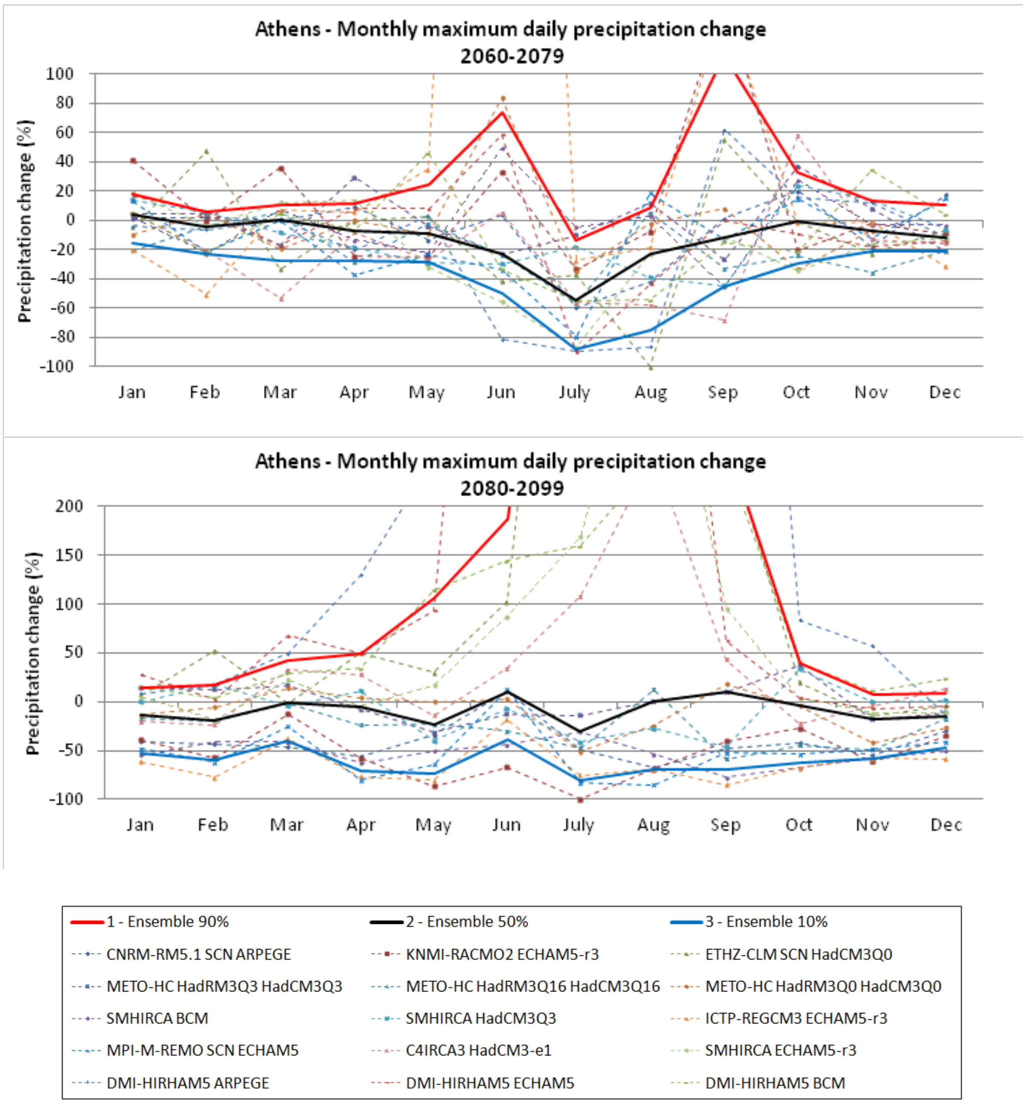


Figure A1.55 – Expected montlhy maximum daily precipitation change in Athens (2020-2039; 2040-2059) (in %)


Athens - Monthly maximum daily precipitation change 2060-2079

Athens - Monthly maximum daily precipitation change 2080-2099

Figure A1.56 – Expected montlhy maximum daily precipitation change in Athens (2060-2079; 2080-2099) (in %)

Bucarest

Figure A1.57 – Expected temperature change in Bucarest (2020-2039; 2040-2059)

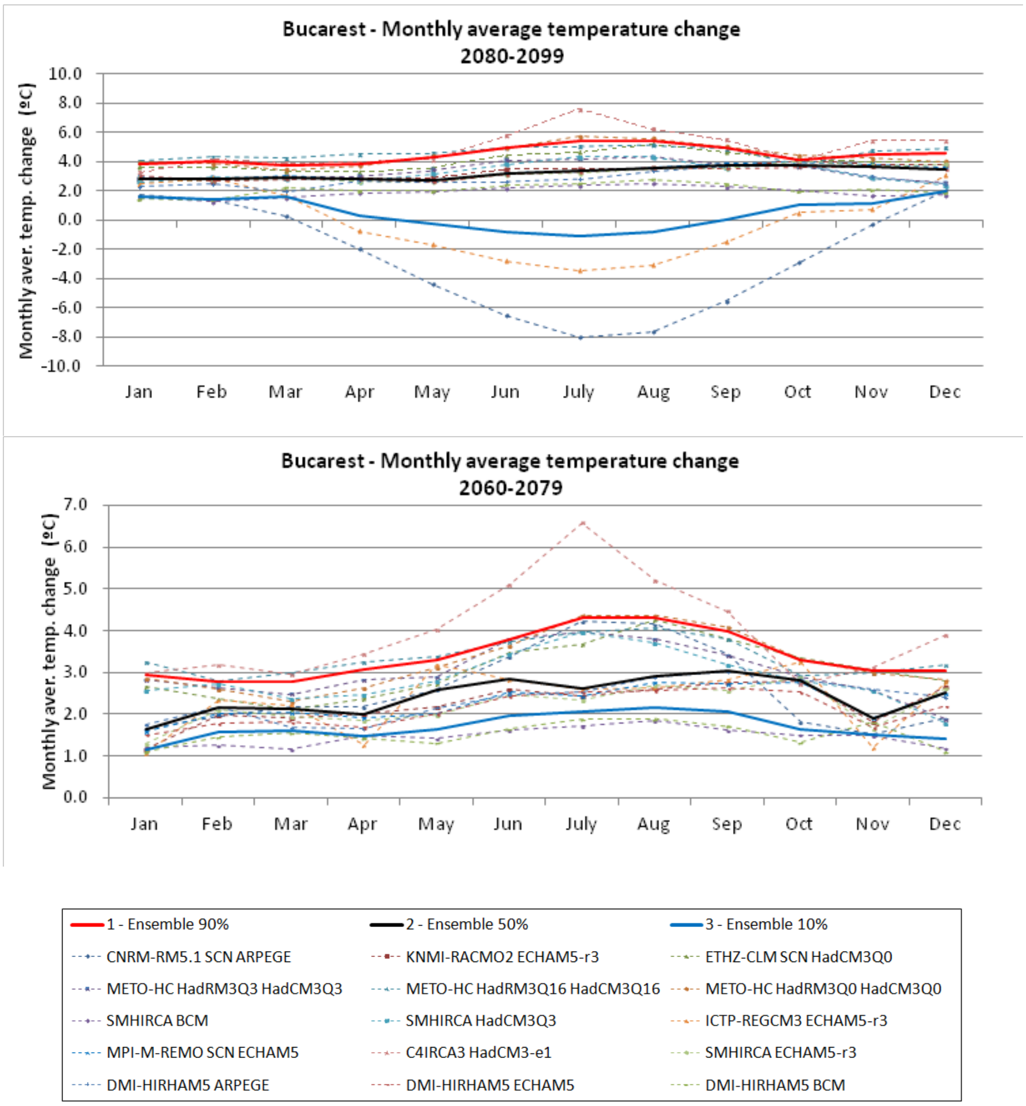


Figure A1.58 – Expected temperature change in Bucarest (2060-2079; 2080-2099)

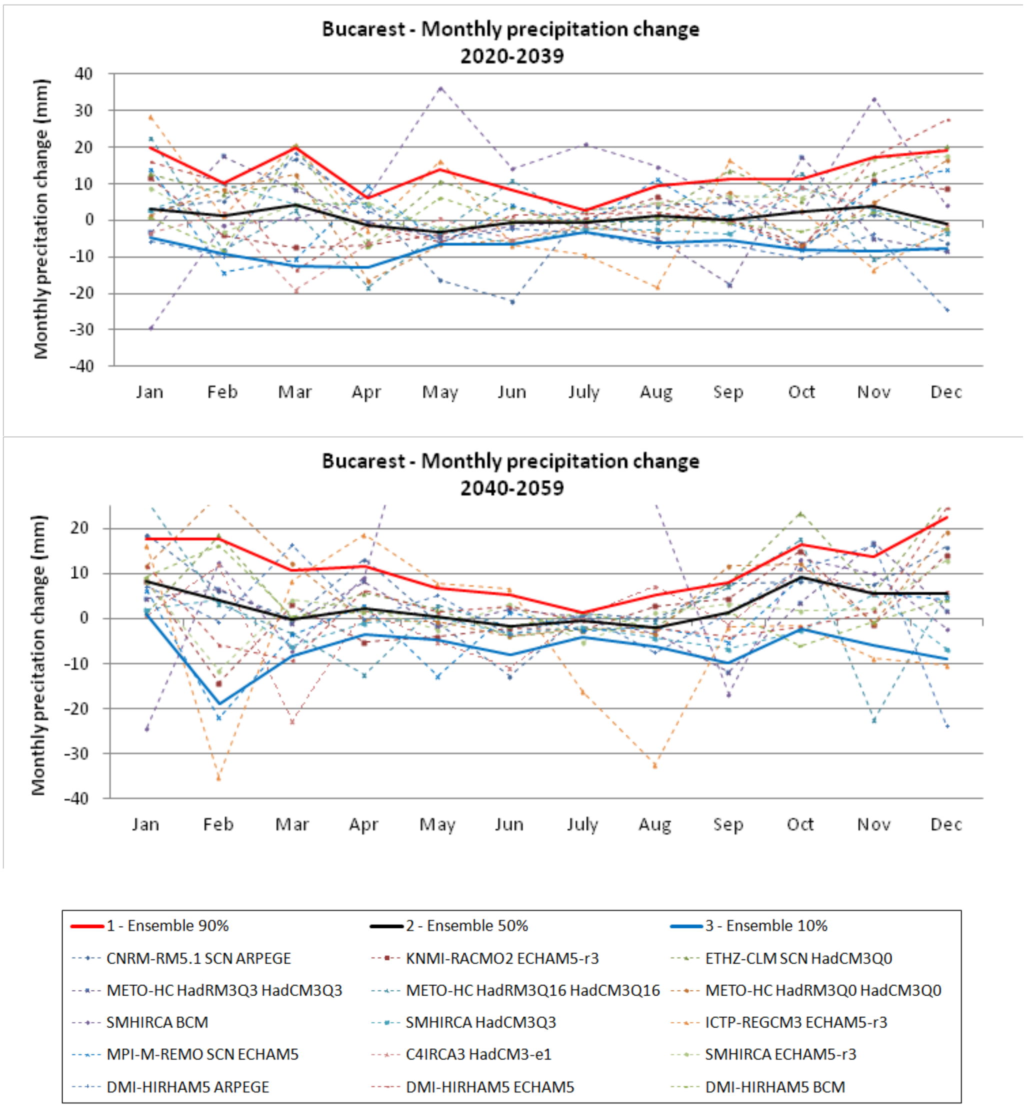


Figure A1.59 – Expected monthly precipitation change in Bucarest (2020-2039; 2040-2059) (in mm)

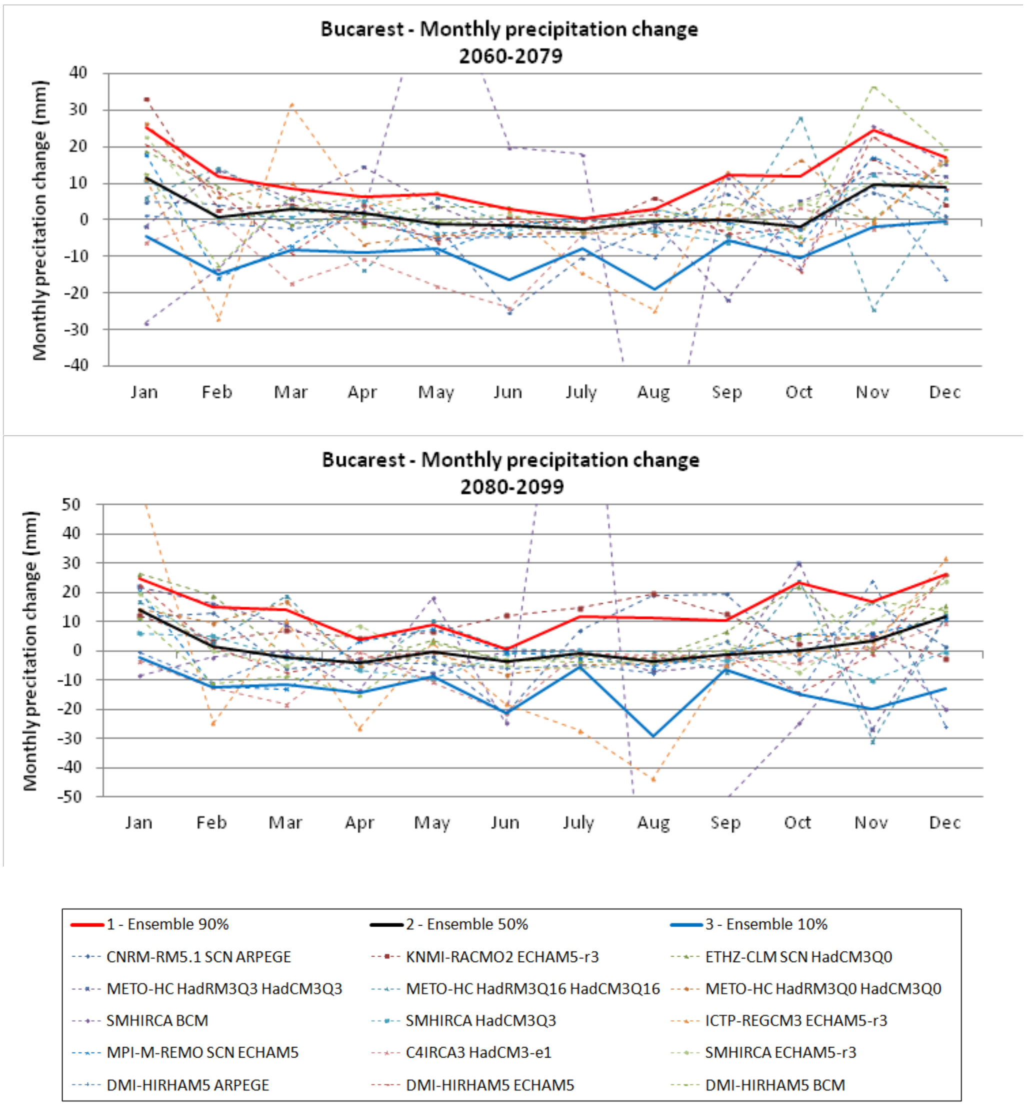


Figure A1.60 – Expected monthly precipitation change in Bucarest (2060-2079; 2080-2099) (in mm)

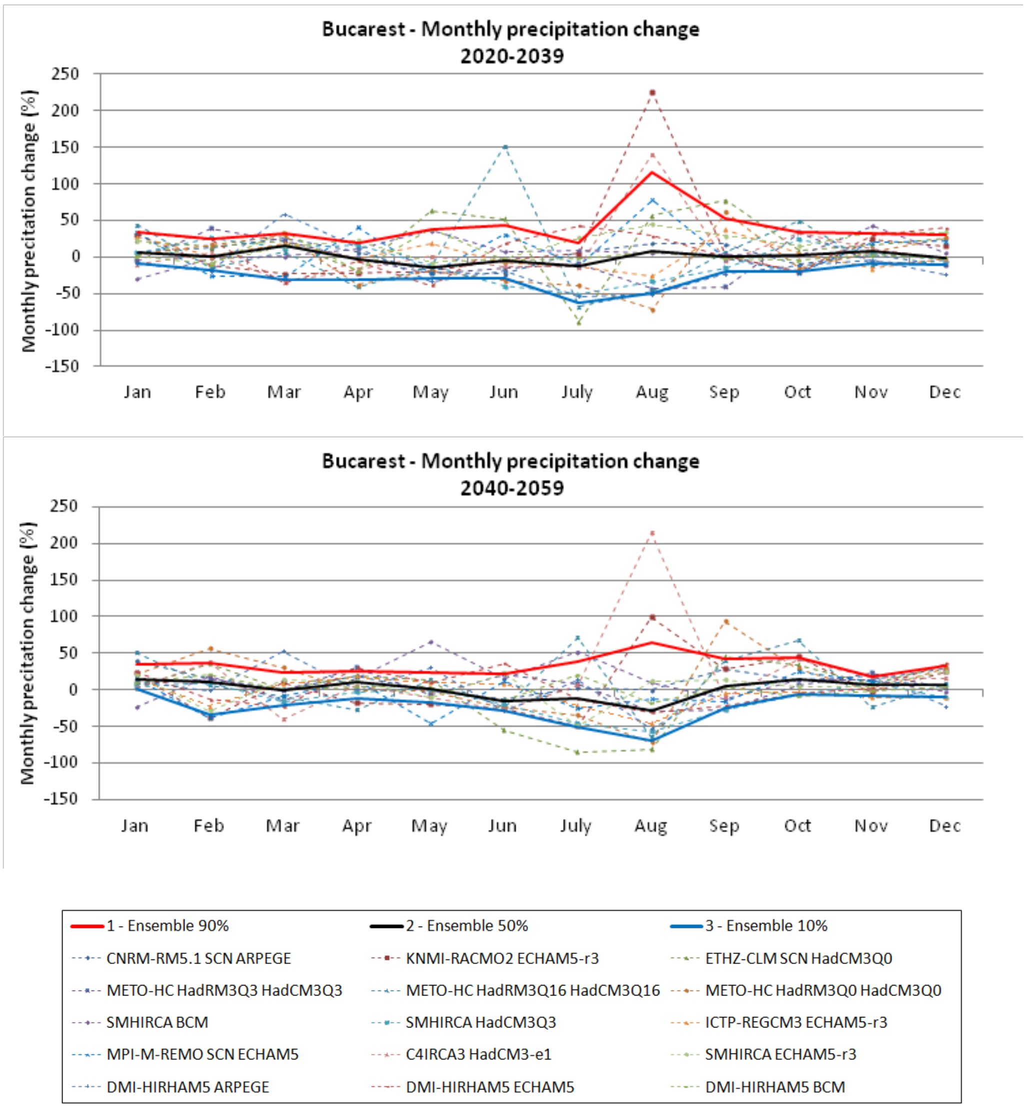


Figure A1.61 – Expected monthly precipitation change in Bucarest (2020-2039; 2040-2059) (in %)

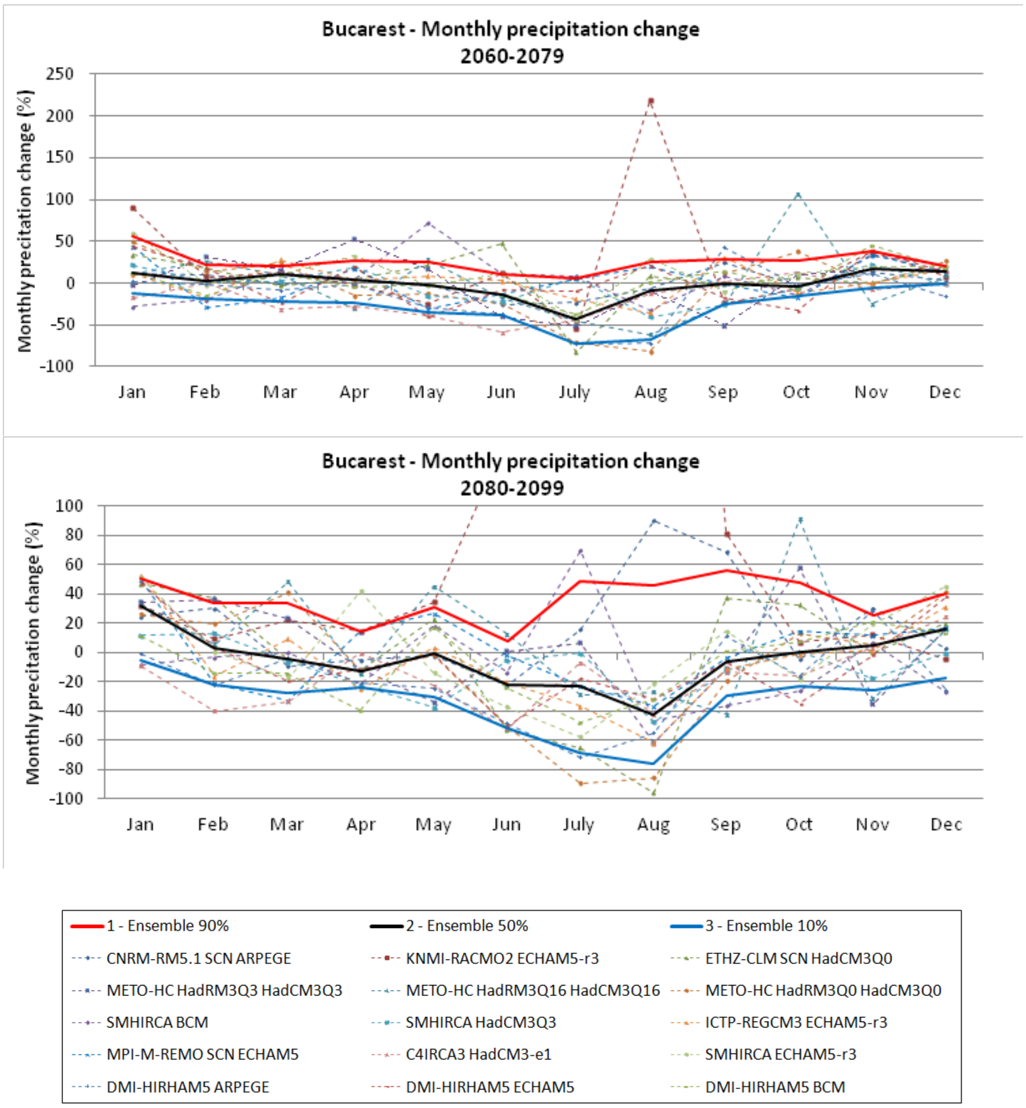


Figure A1.62 – Expected monthly precipitation change in Bucarest (2020-2039; 2040-2059) (in %)

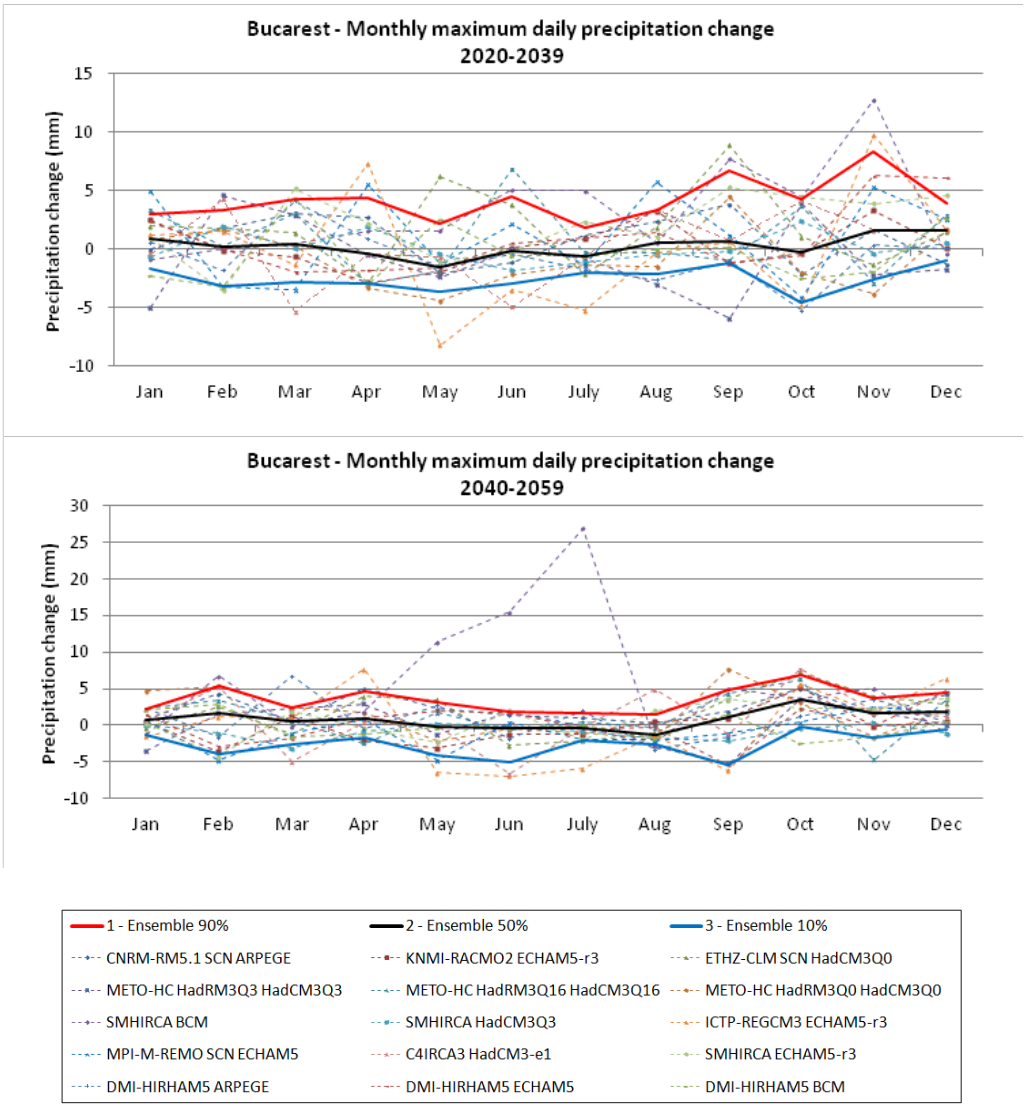


Figure A1.63 – Expected monthly maximum daily precipitation change in Bucarest (2020-2039; 2040-2059) (in mm)

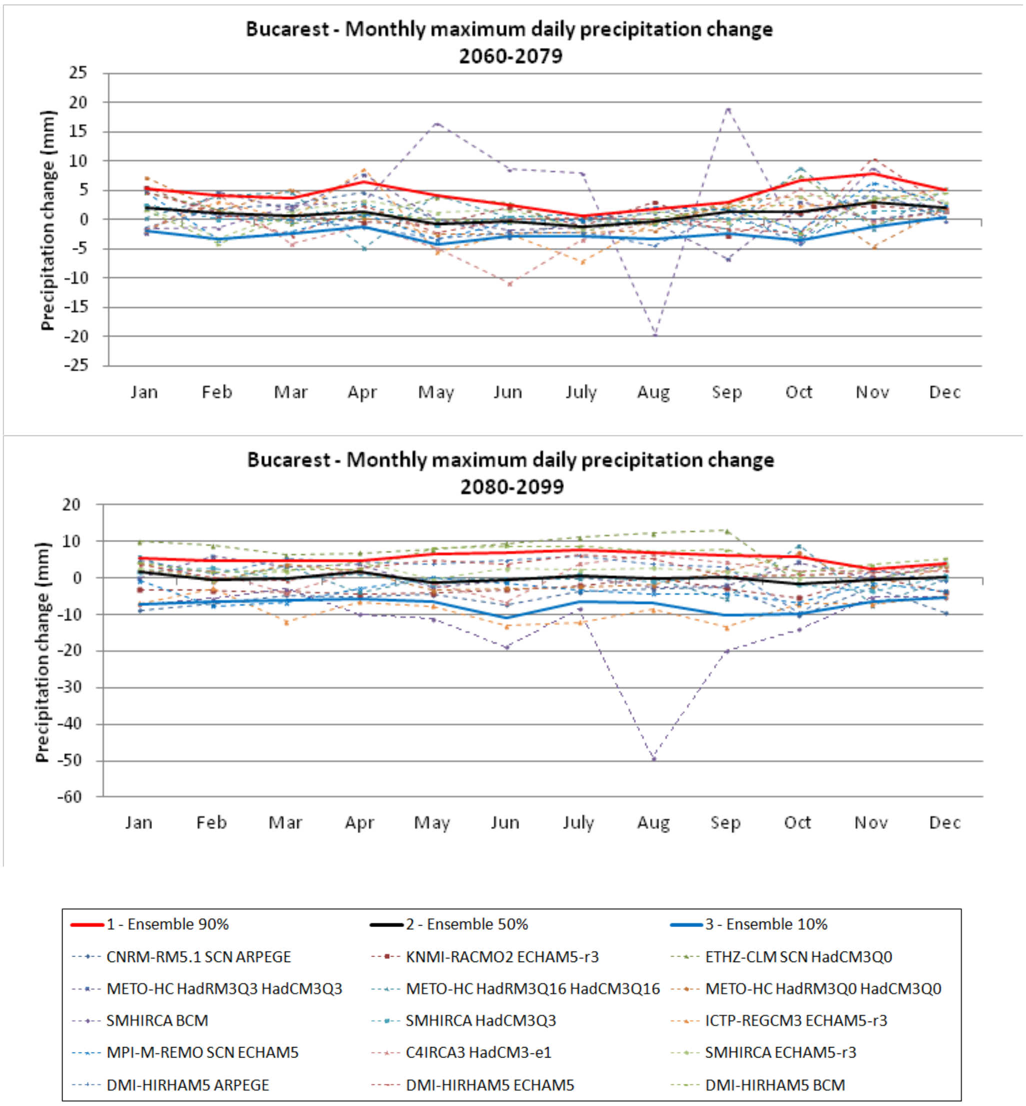


Figure A1.64 –Expected monthly maximum daily precipitation change in Bucarest (2060-2079; 2080-2099) (in mm)

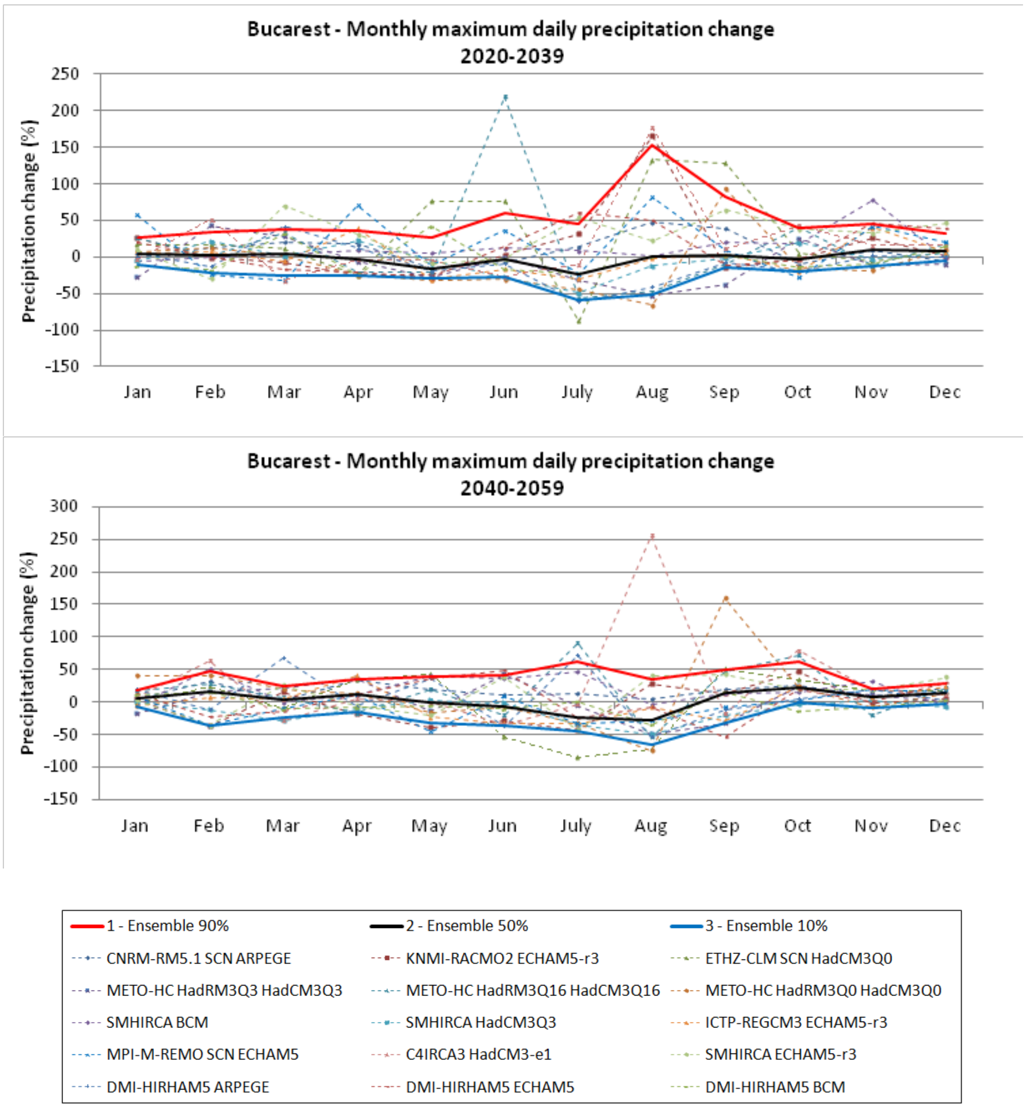


Figure A1.65 –Expected monthly maximum daily precipitation change in Bucarest (2020-2039; 2040-2059) (in %)

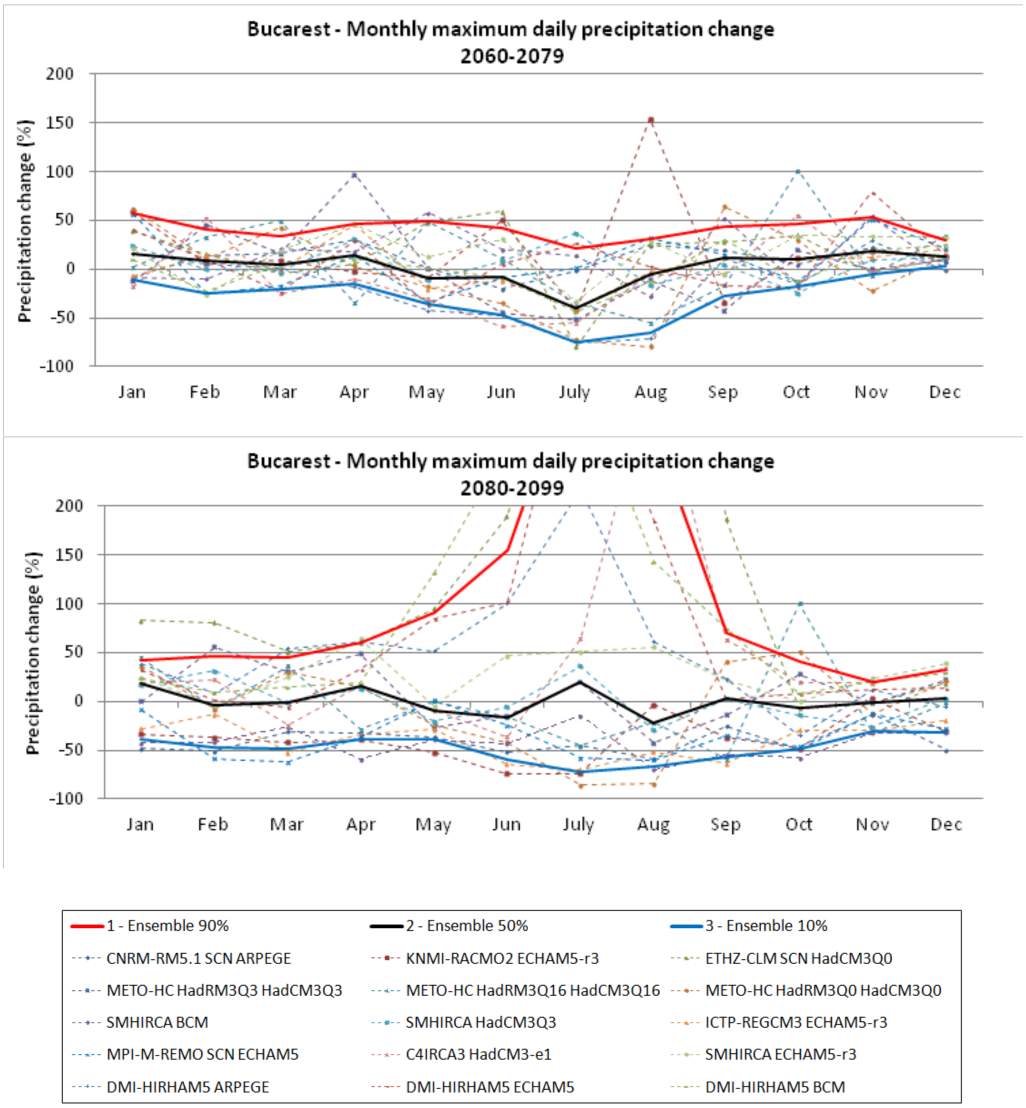


Figure A1.66 –Expected monthly maximum daily precipitation change in Bucarest (2060-2079; 2080-2099) (in %)

Edimburgh

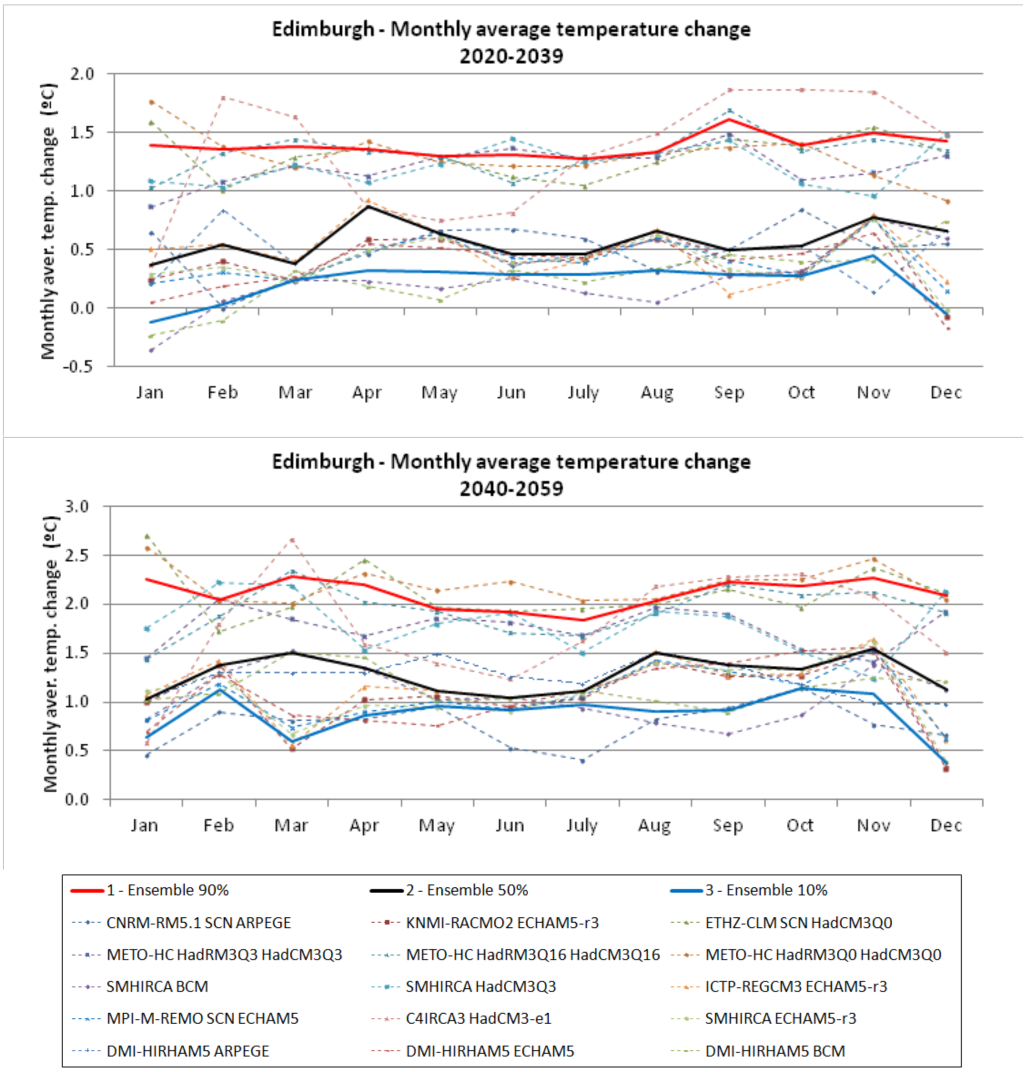


Figure A1.67 – Expected temperature change in Edimbrugh (2020-2039; 2040-2059)

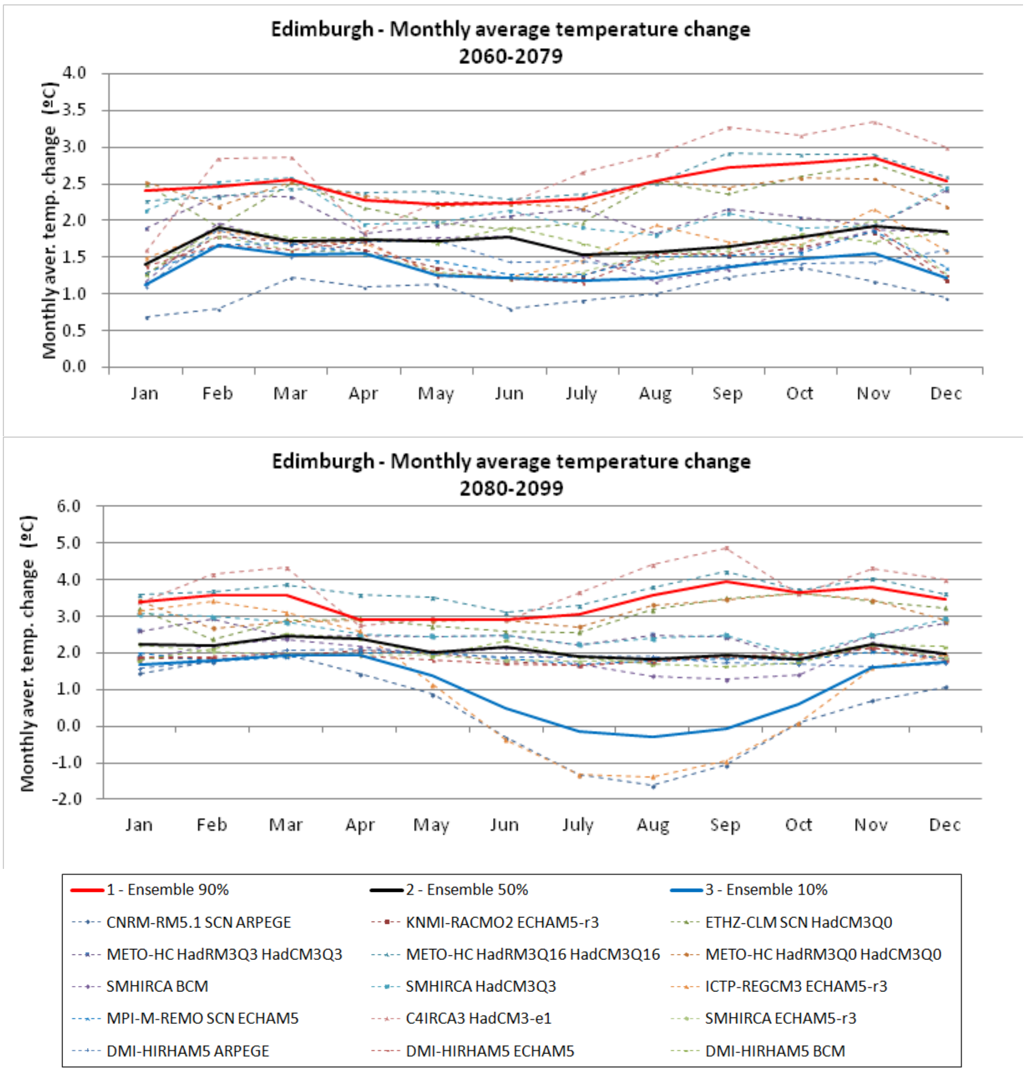


Figure A1.68 – Expected temperature change in Edimbrugh (2060-2079; 2080-2099)

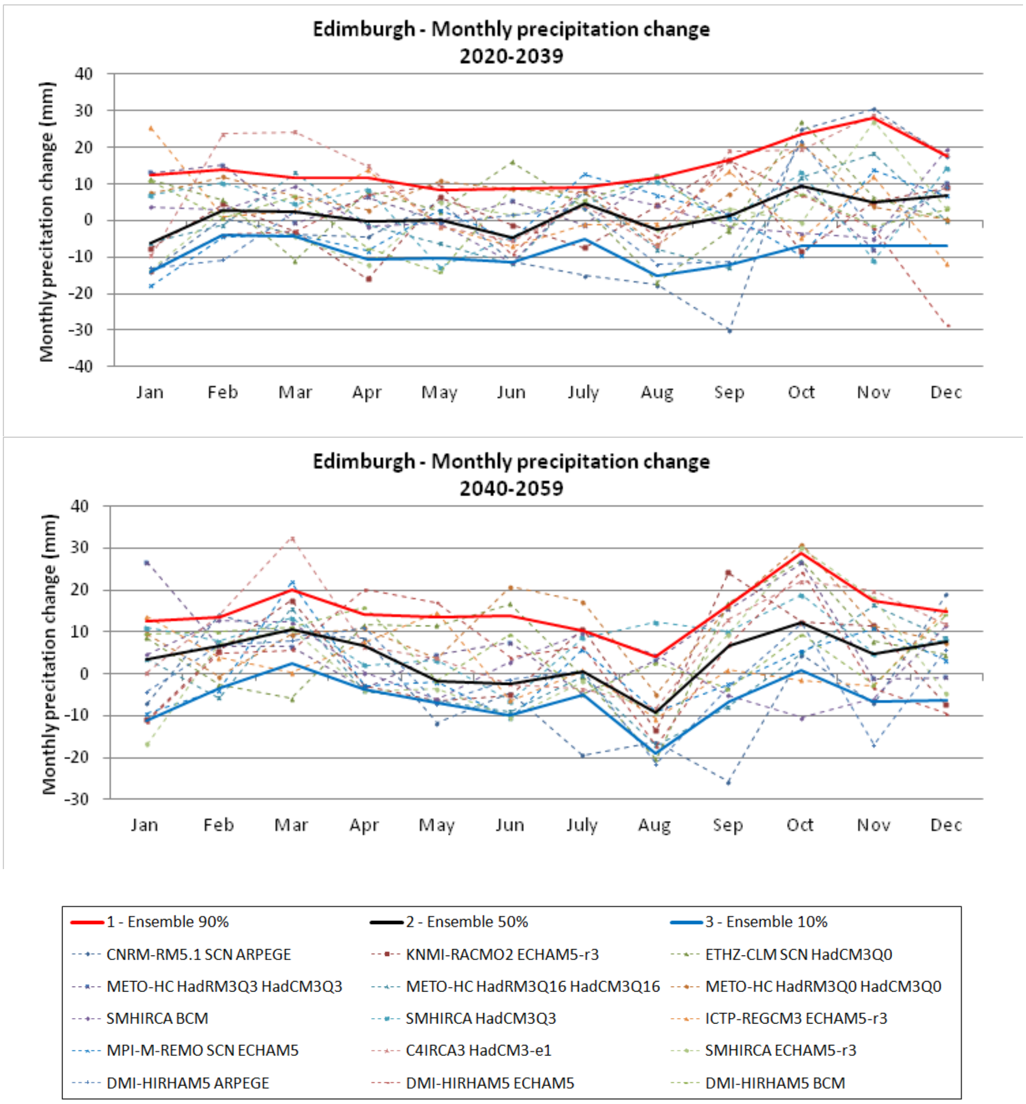


Figure A1.69 – Expected monthly precipitation change in Edimburgh (2020-2039; 2040-2059) (in mm)

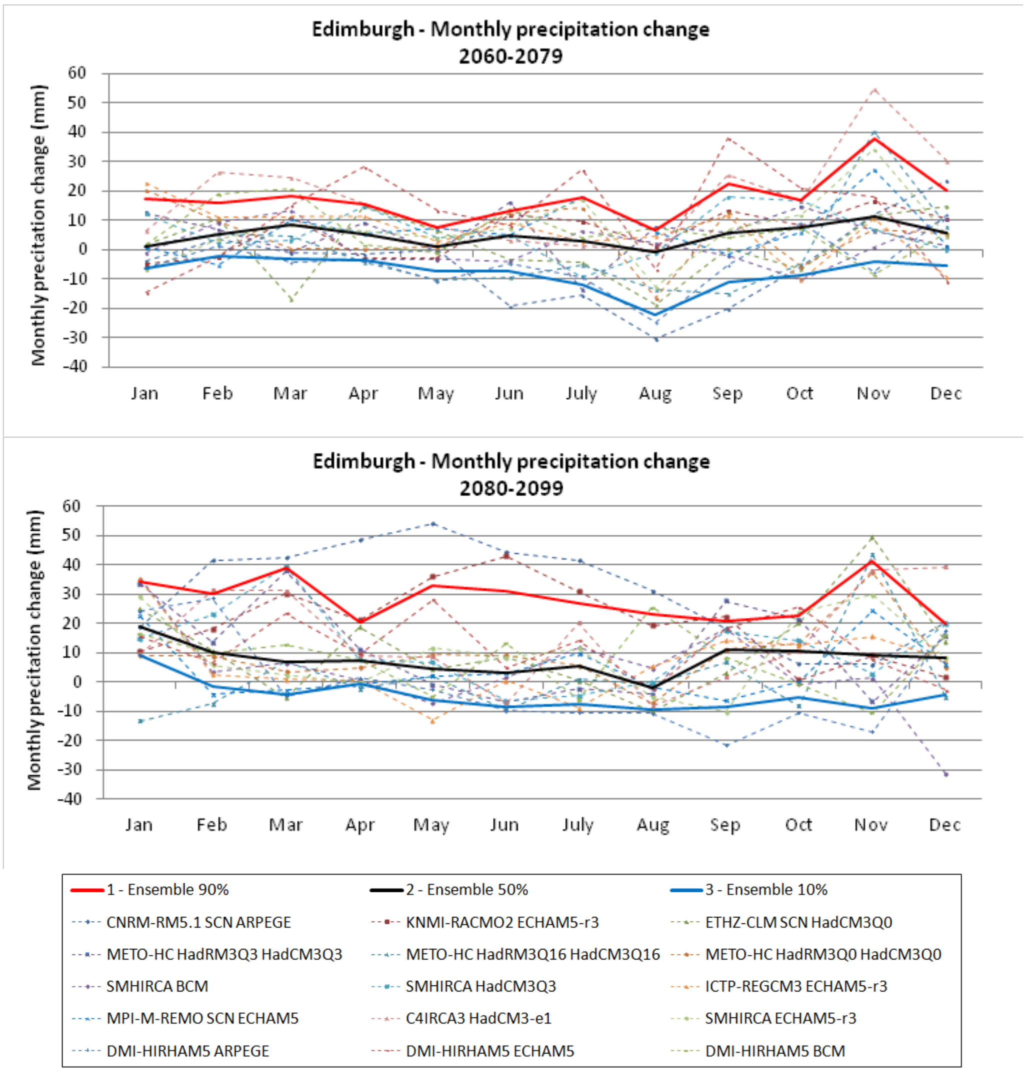


Figure A1.70 – Expected monthly precipitation change in Edimburgh (2060-2079; 2080-2099) (in mm)

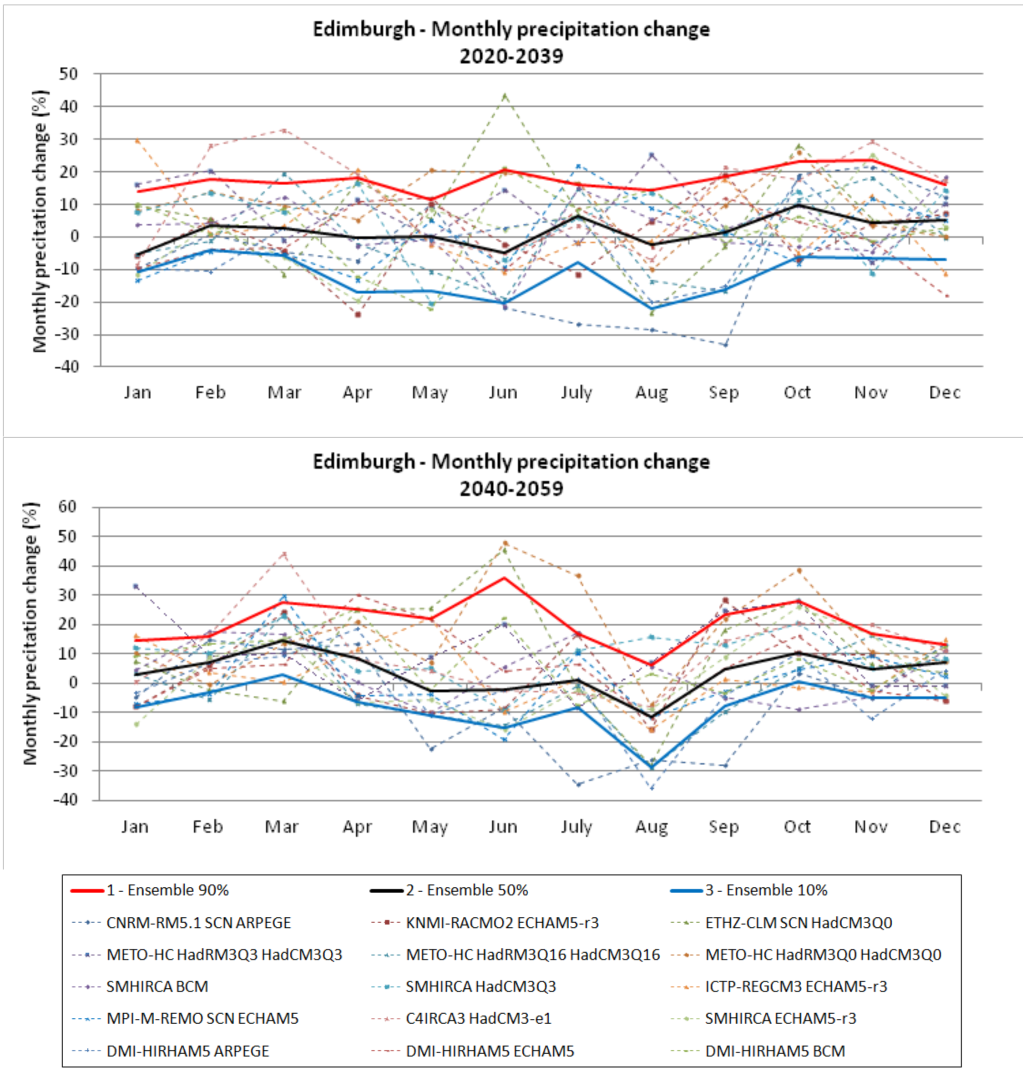


Figure A1.71 – Expected monthly precipitation change in Edimburgh (2020-2039; 2040-2059) (in %)

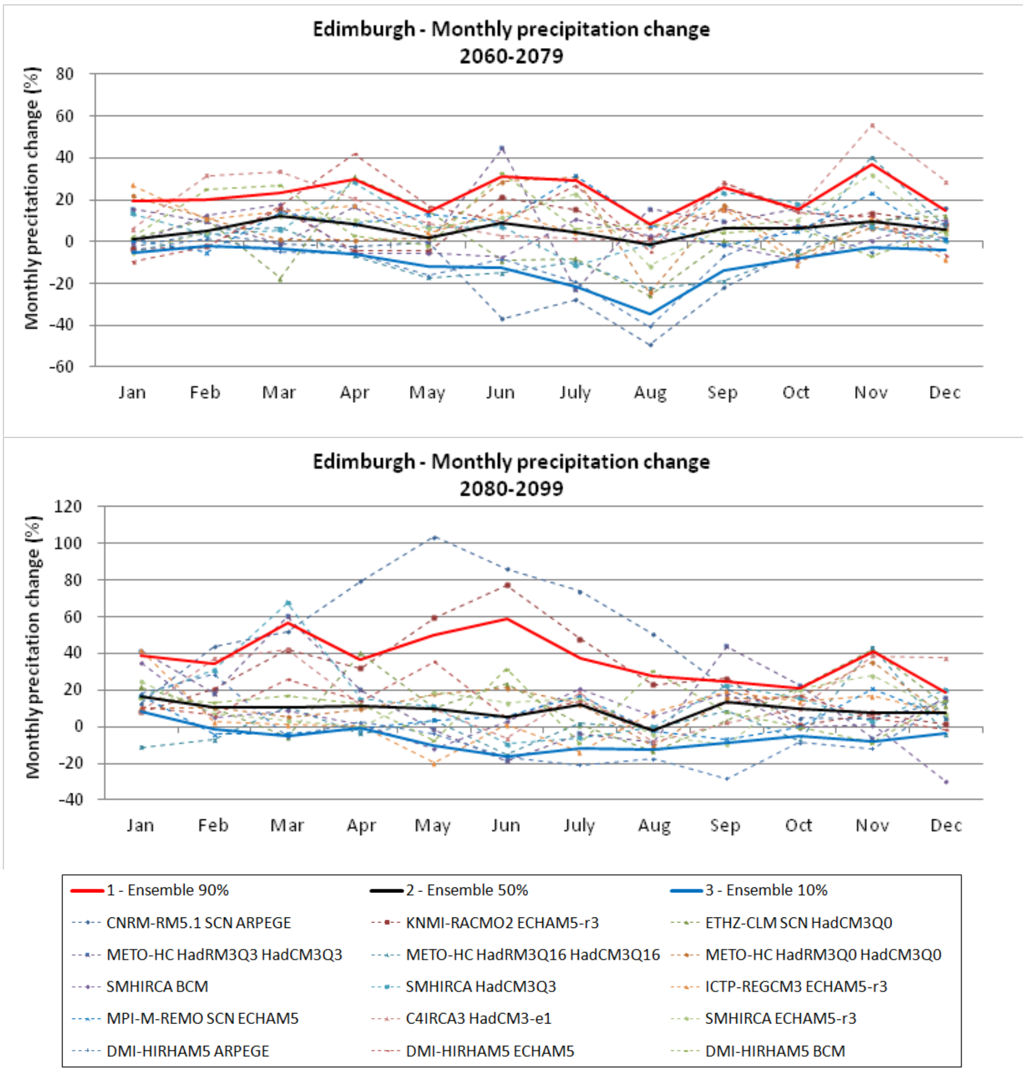


Figure A1.72 – Expected monthly precipitation change in Edimburgh (2060-2079; 2080-2099) (in %)

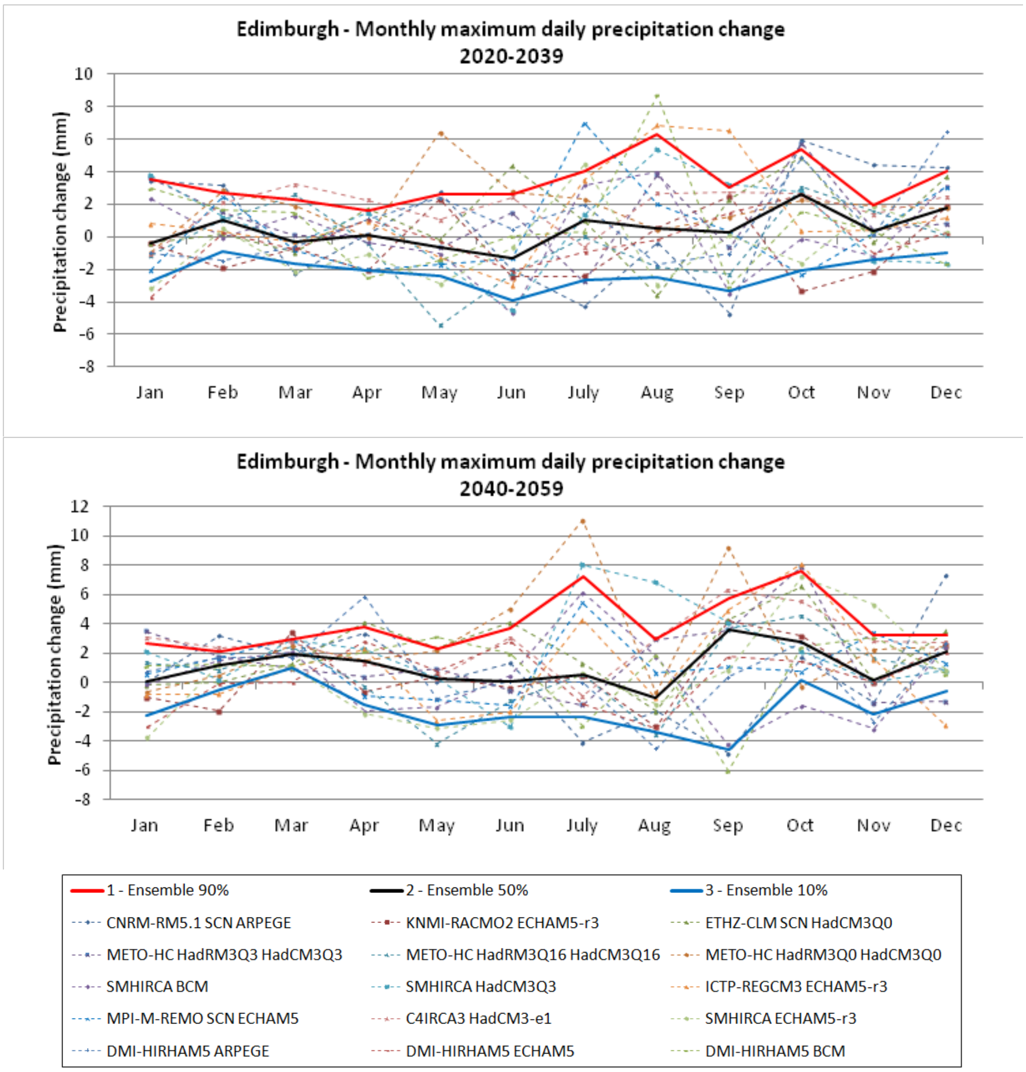


Figure A1.73 – Expected monthly maximum daily precipitation change in Edimburgh (2020-2039; 2040-2059) (in mm)

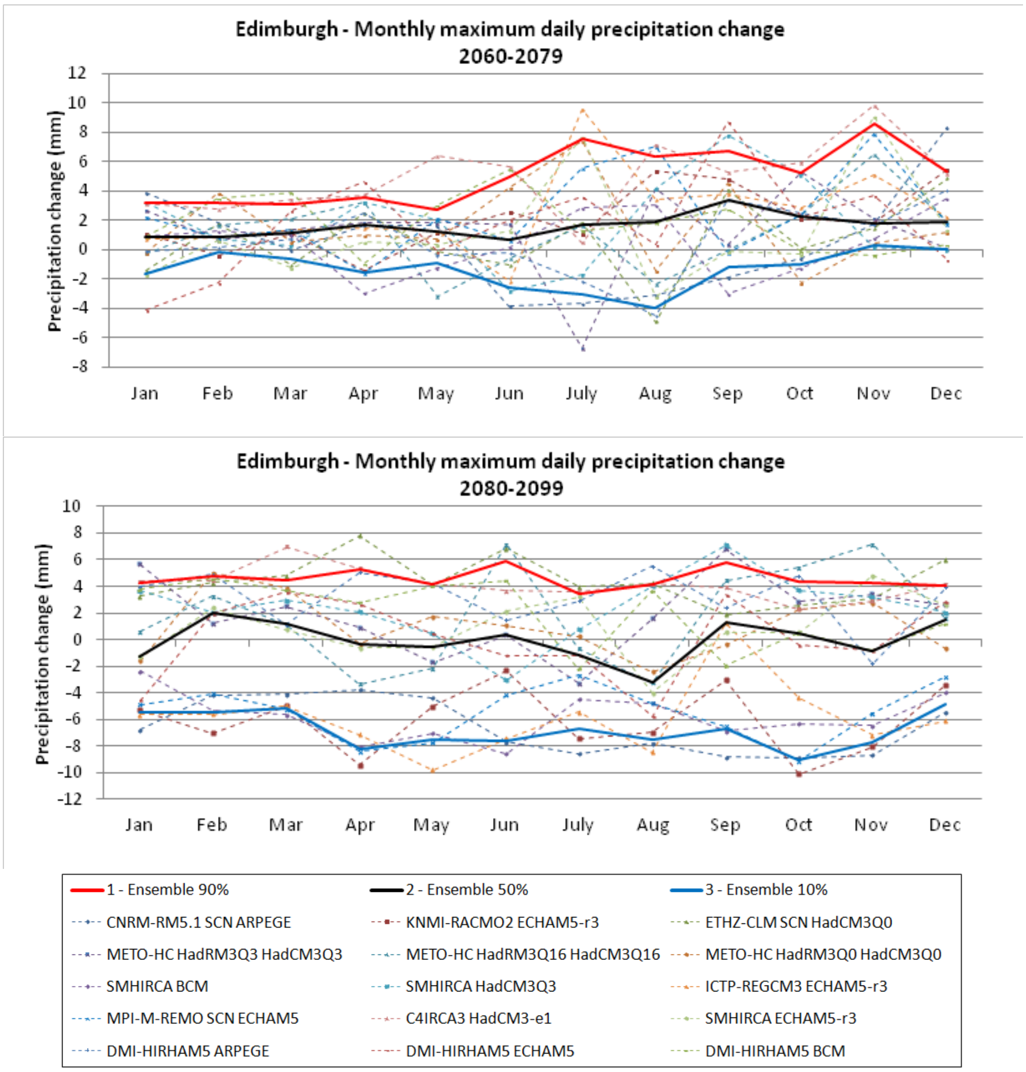
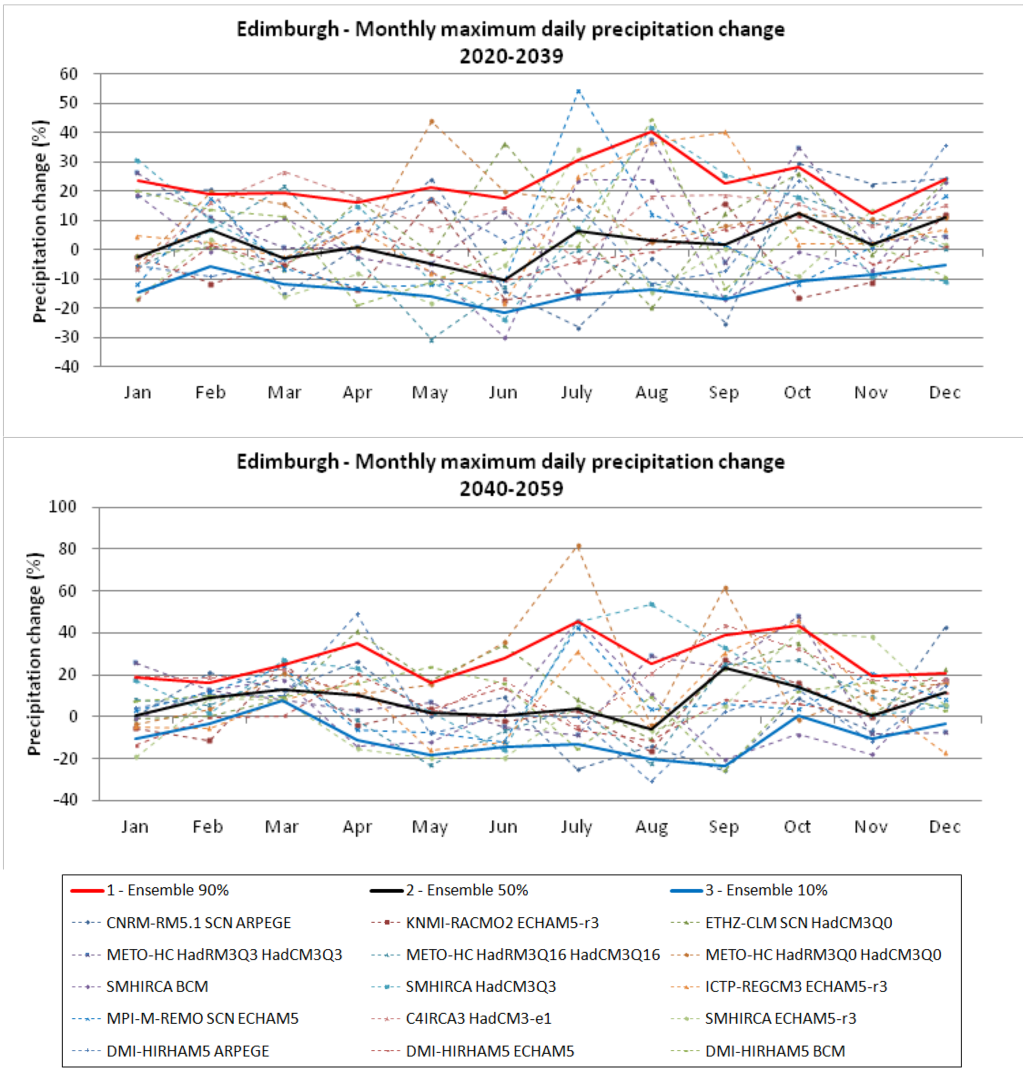


Figure A1.74 – Expected monthly maximum daily precipitation change in Edimburgh (2060-2079; 2080-2099) (in mm)



Edimburgh - Monthly maximum daily precipitation change 2020-2039

Edimburgh - Monthly maximum daily precipitation change 2040-2059

Figure A1.75 – Expected monthly maximum daily precipitation change in Edimburgh (2020-2039; 2040-2059) (in %)

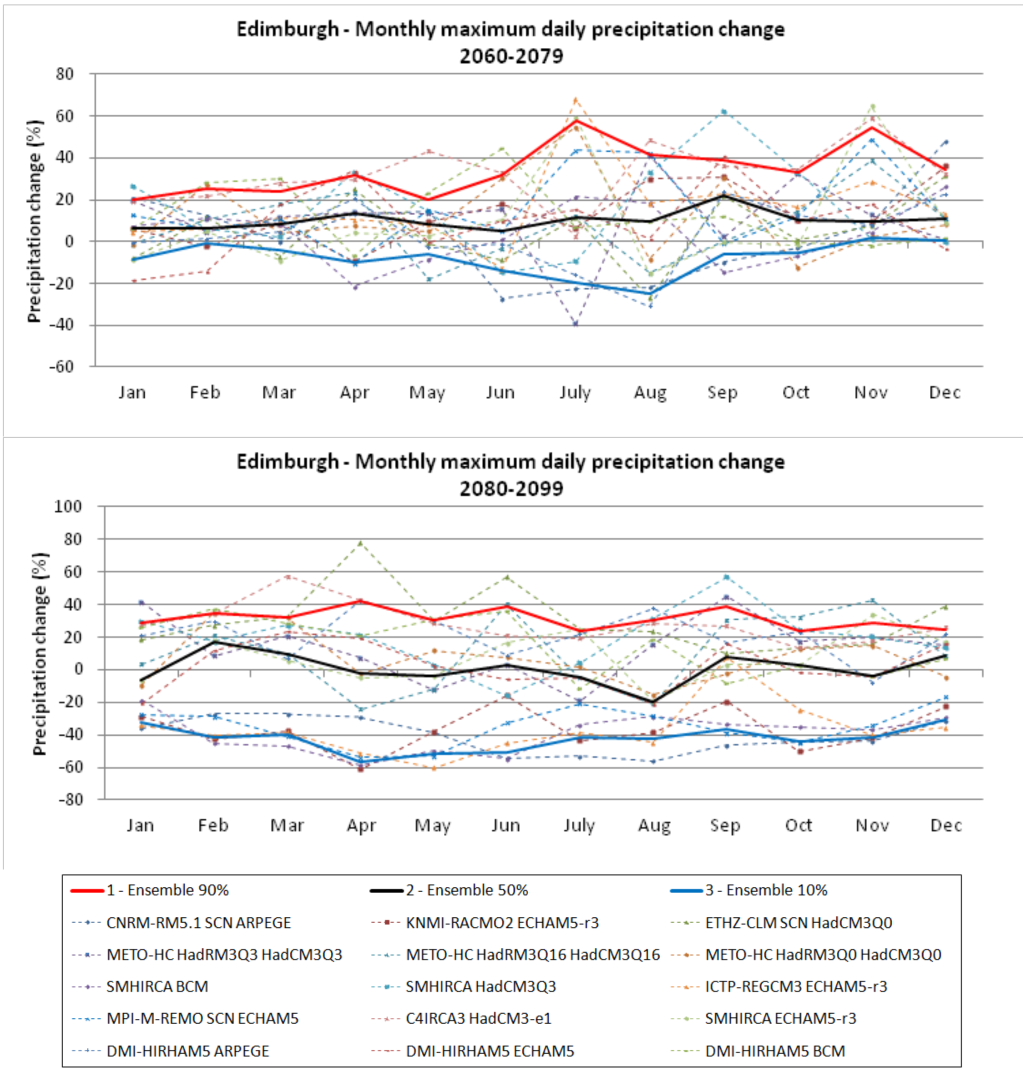


Figure A1.76 – Expected monthly maximum daily precipitation change in Edimburgh (2060-2079; 2080-2099) (in %)

Faro

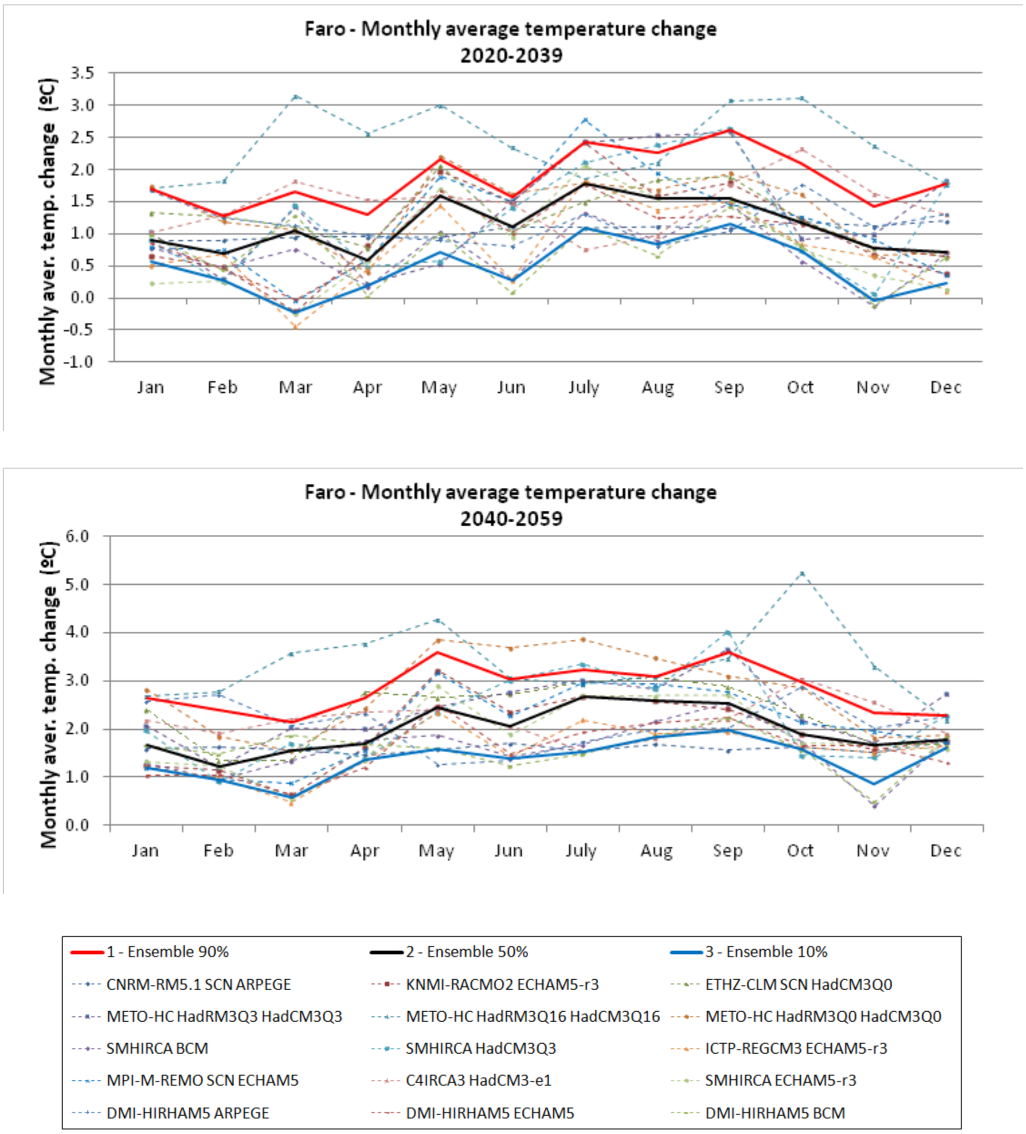


Figure A1.77 – Expected temperature change in Faro (2020-2039; 2040-2059)

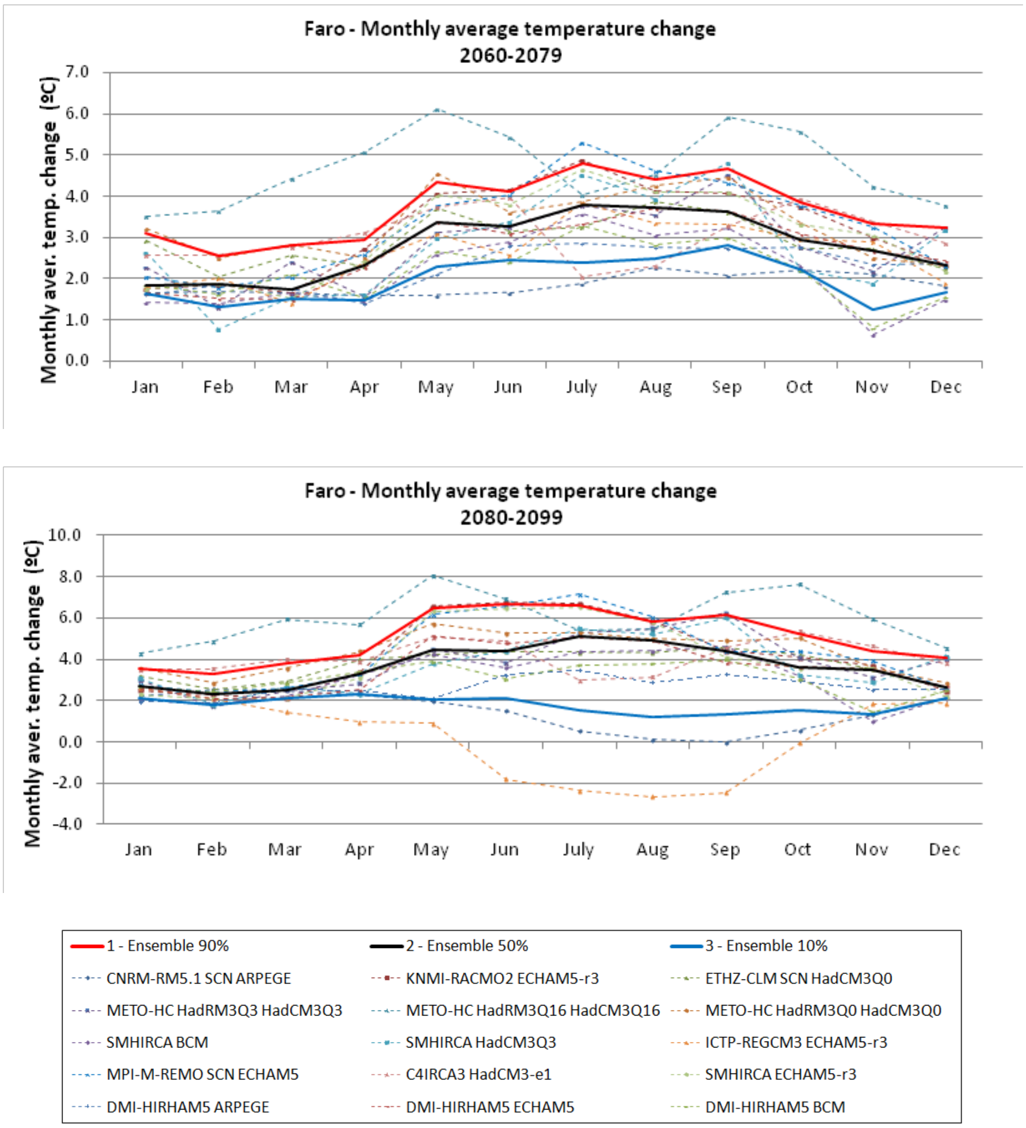


Figure A1.78 – Expected temperature change in Faro (2060-2079; 2080-2099)

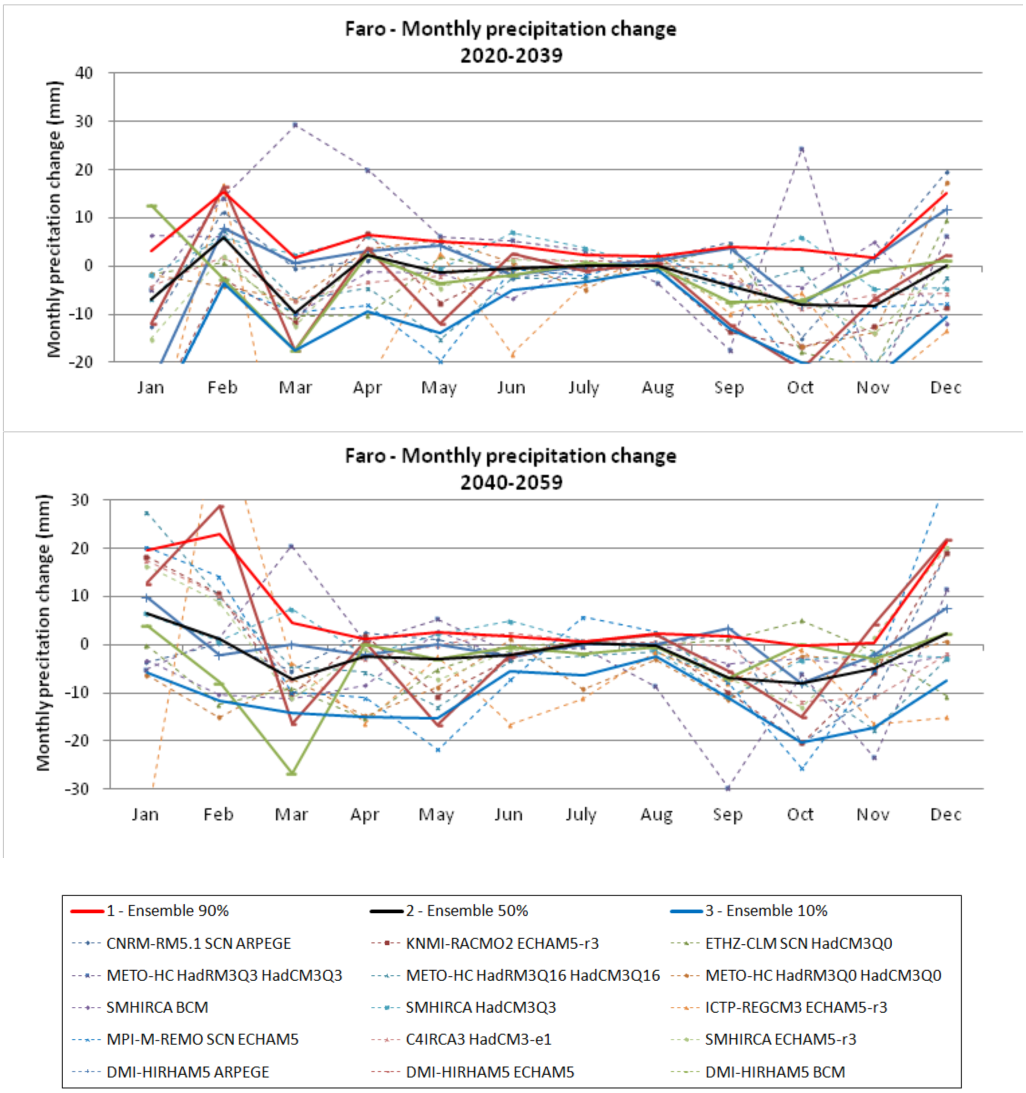


Figure A1.79 – Expected monthly precipitation change in Faro (2020-2039; 2040-2059) (in mm)

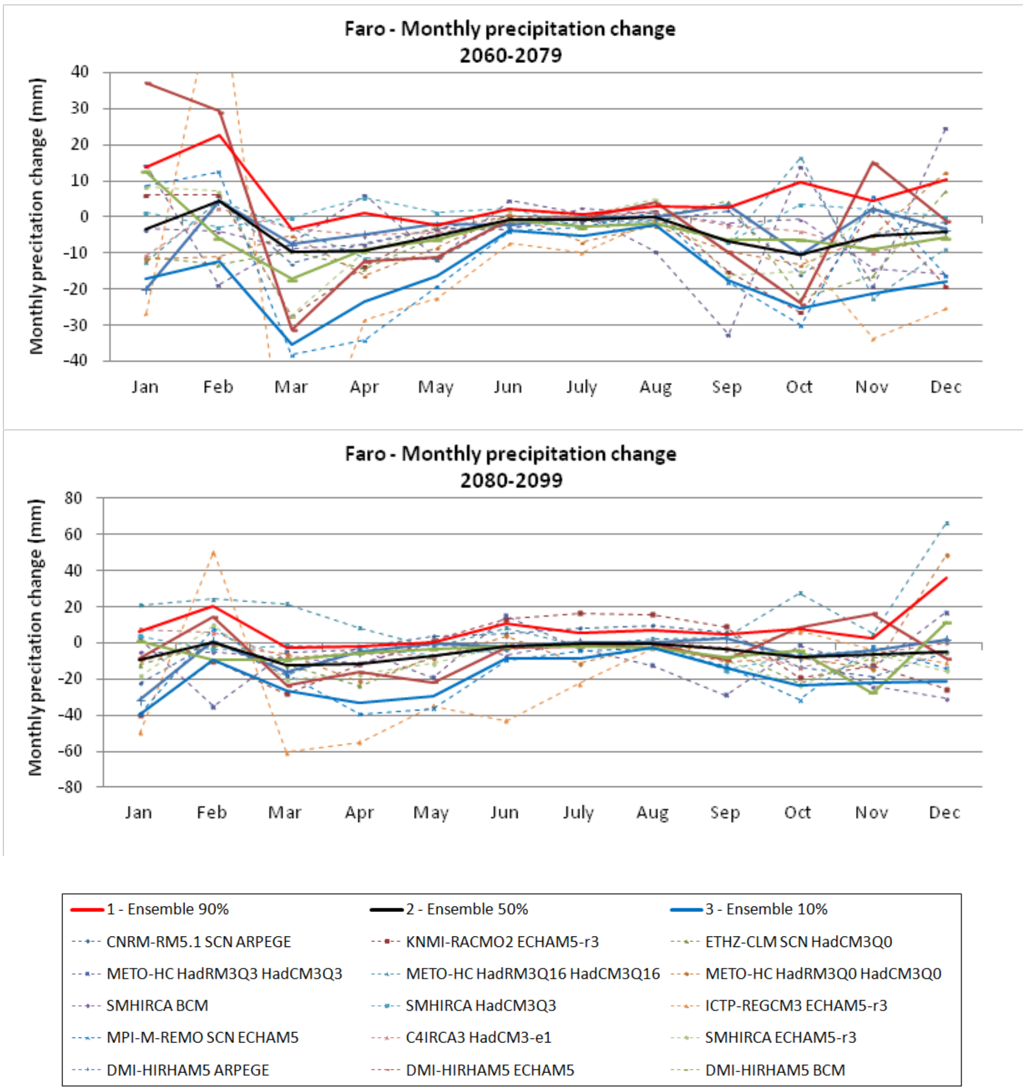


Figure A1.80 – Expected monthly precipitation change in Faro (2060-2079; 2080-2099) (in mm)

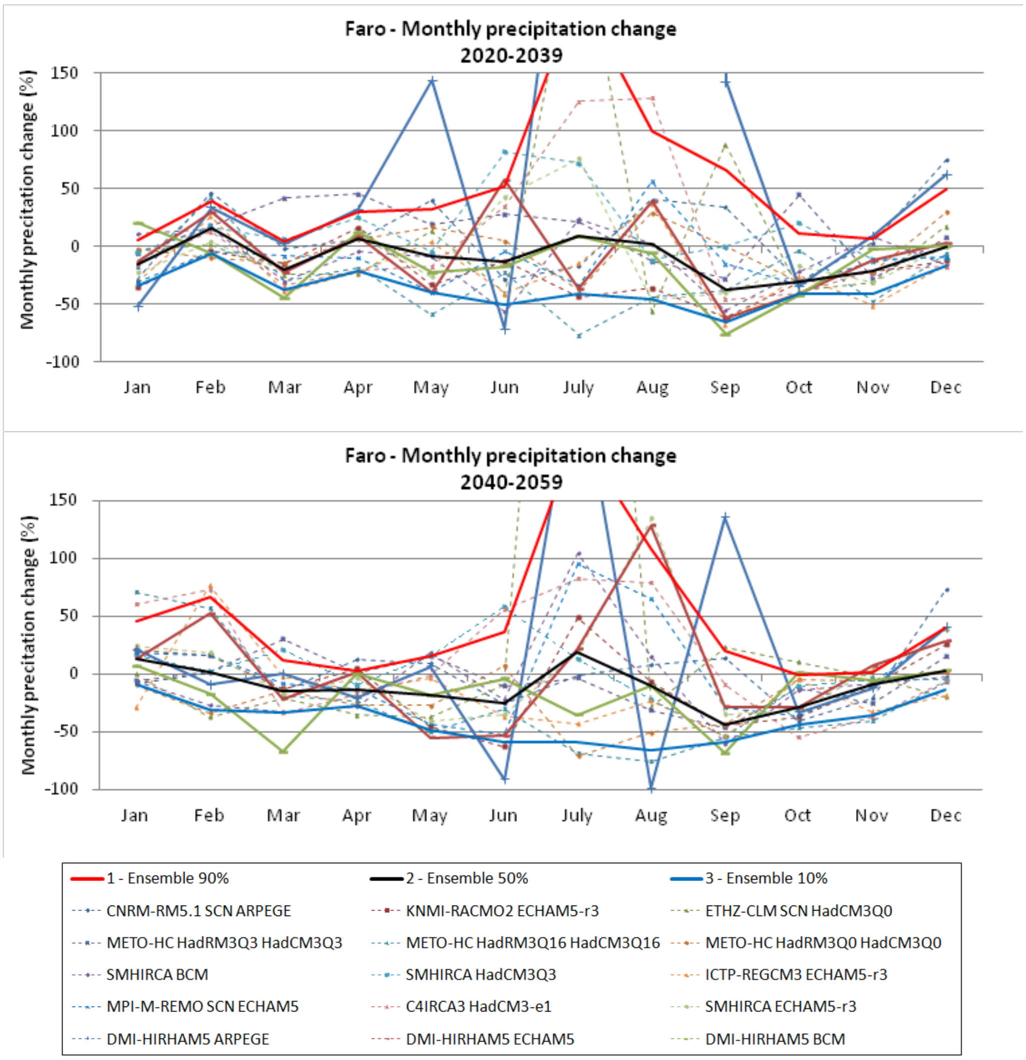


Figure A1.81 – Expected monthly precipitation change in Faro (2020-2039; 2040-2059) (in %)

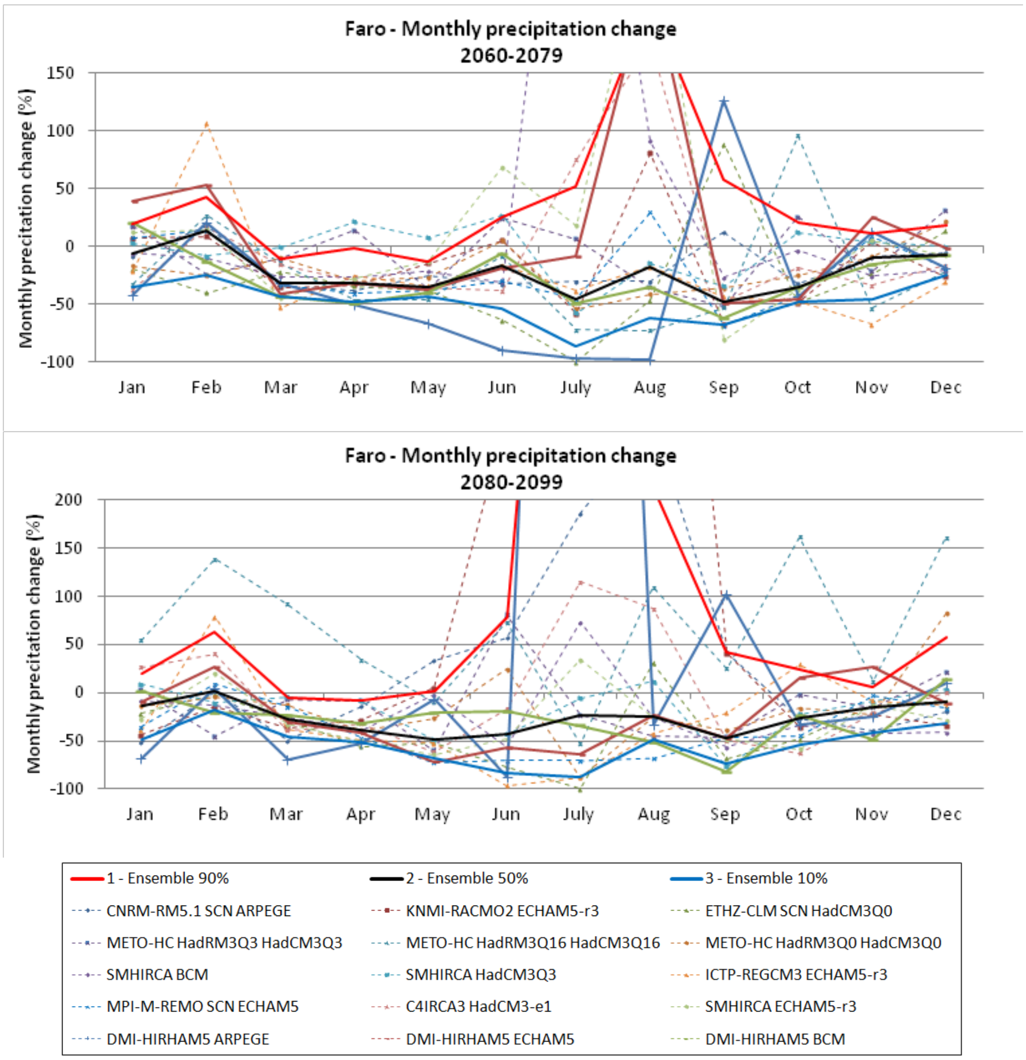


Figure A1.82 – Expected monthly precipitation change in Faro (2060-2079; 2080-2099) (in %)

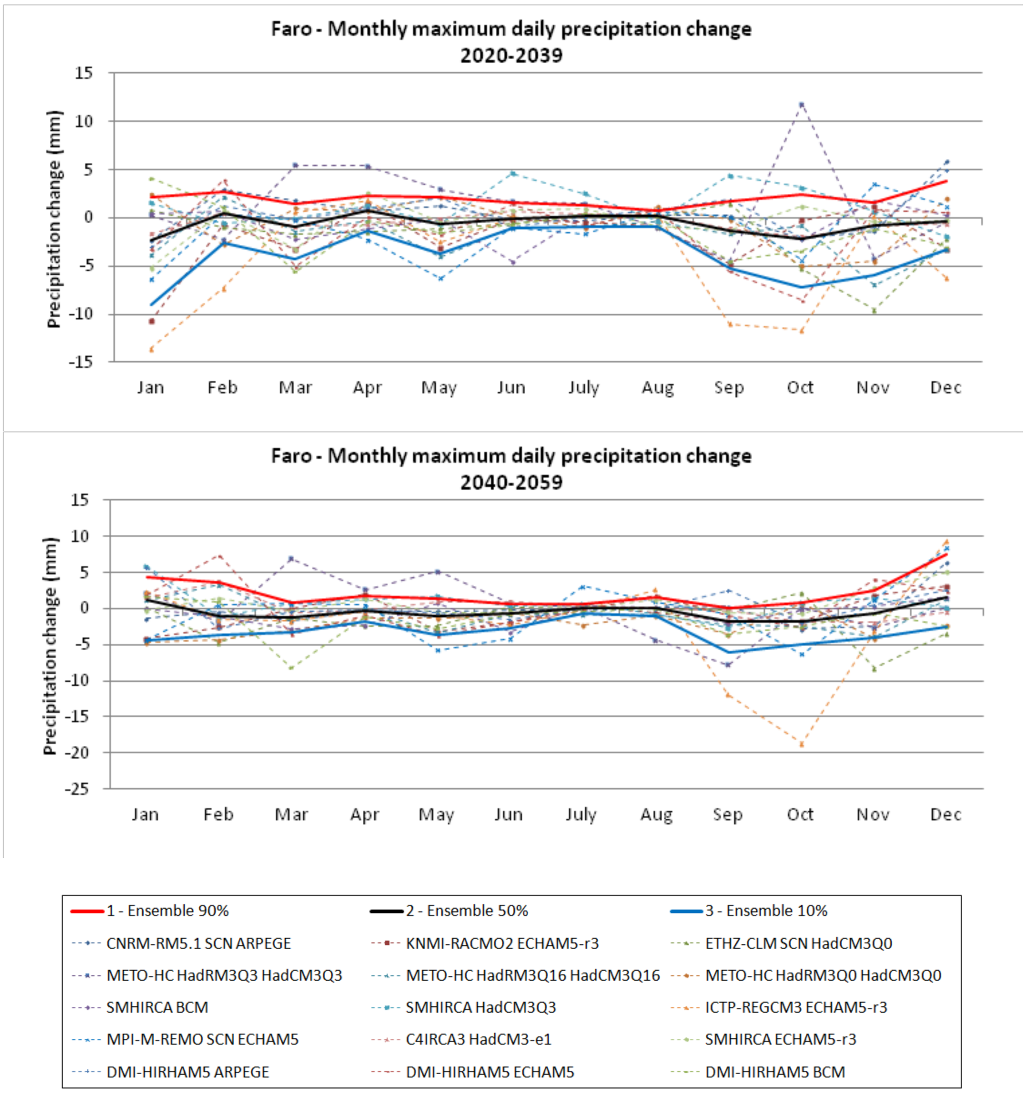


Figure A1.83 – Expected monthly maximum daily precipitation change in Faro (2020-2039; 2040-2059) (in mm)

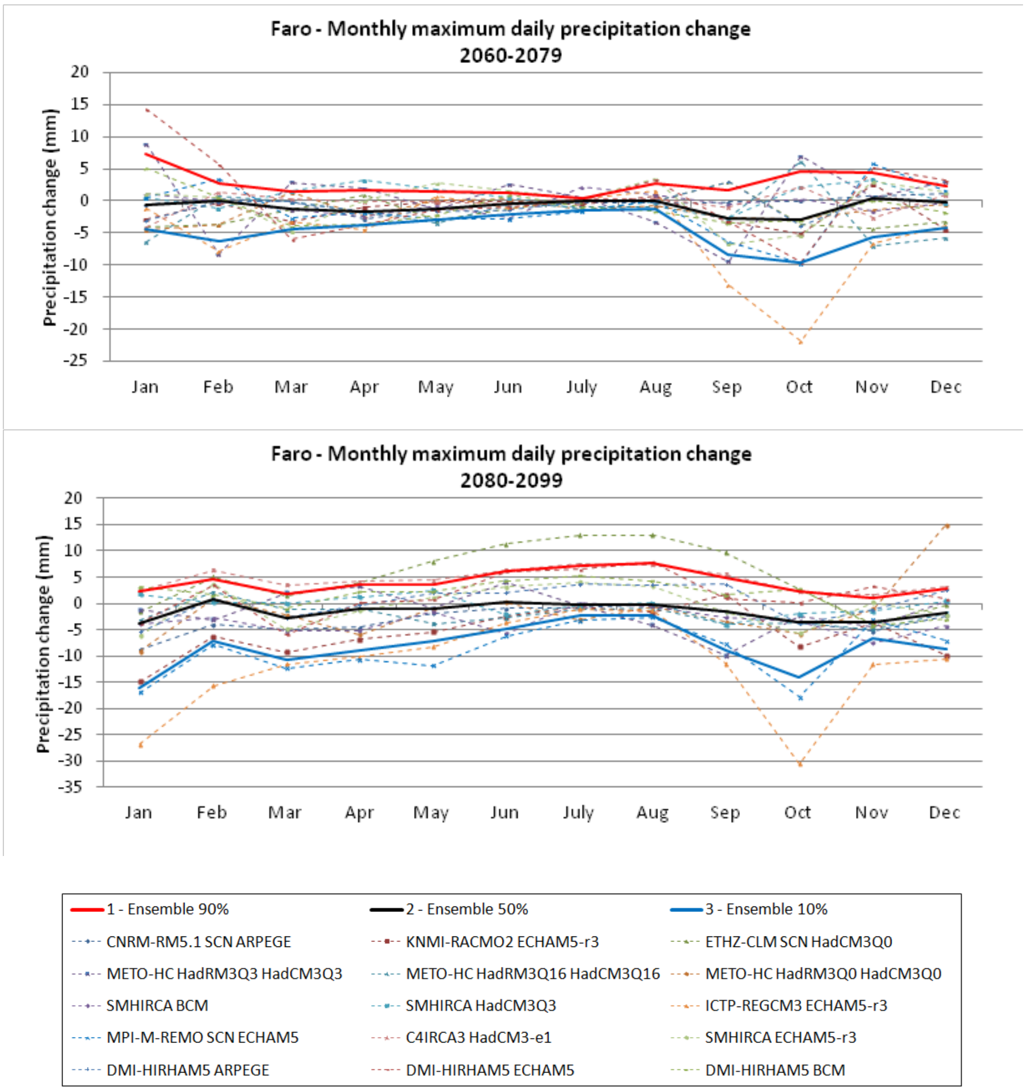


Figure A1.84 – Expected monthly maximum daily precipitation change in Faro (2060-2079; 2080-2099) (in mm)

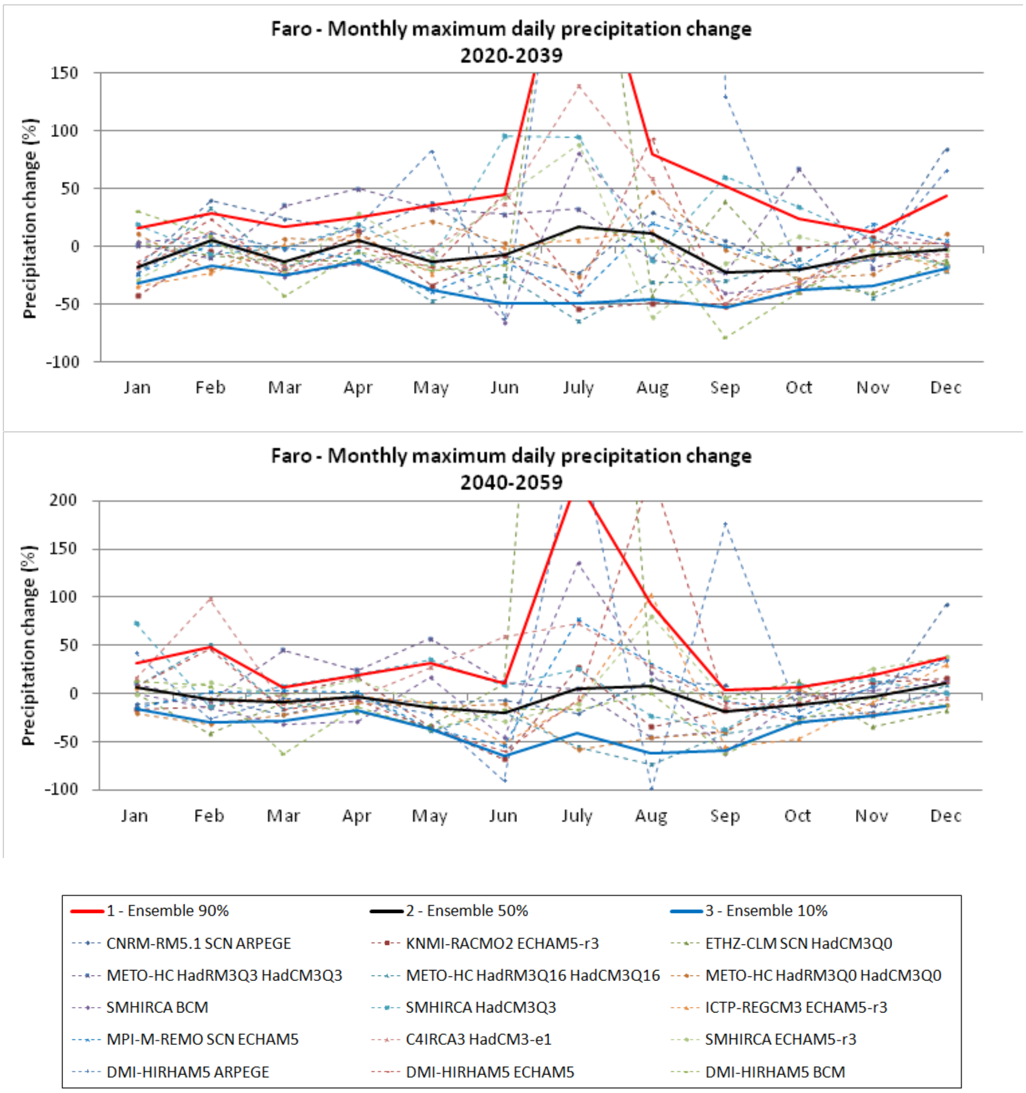


Figure A1.85 – Expected monthly maximum daily precipitation change in Faro (2020-2039; 2040-2059) (in %)

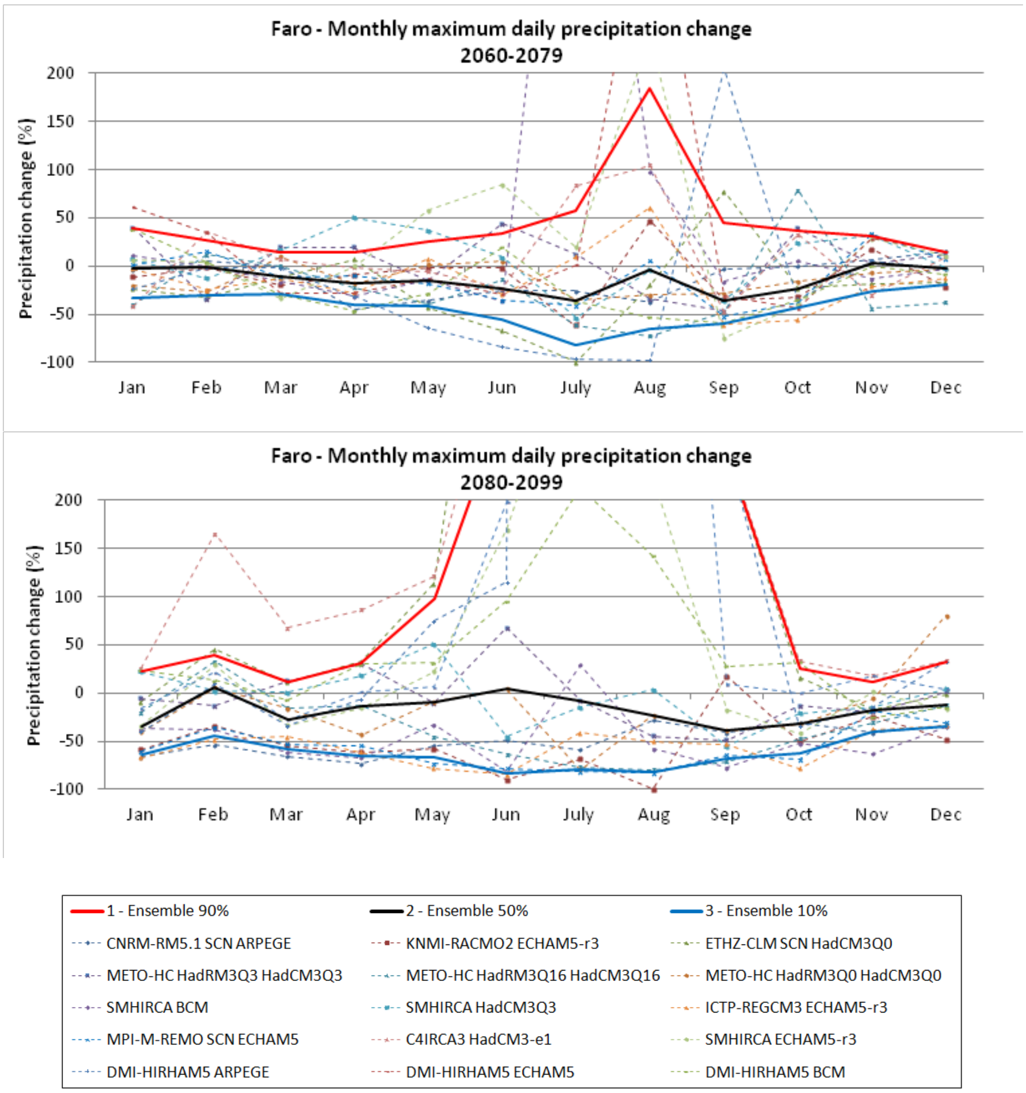


Figure A1.86 – Expected monthly maximum daily precipitation change in Faro (2060-2079; 2080-2099) (in %)

Hamburg

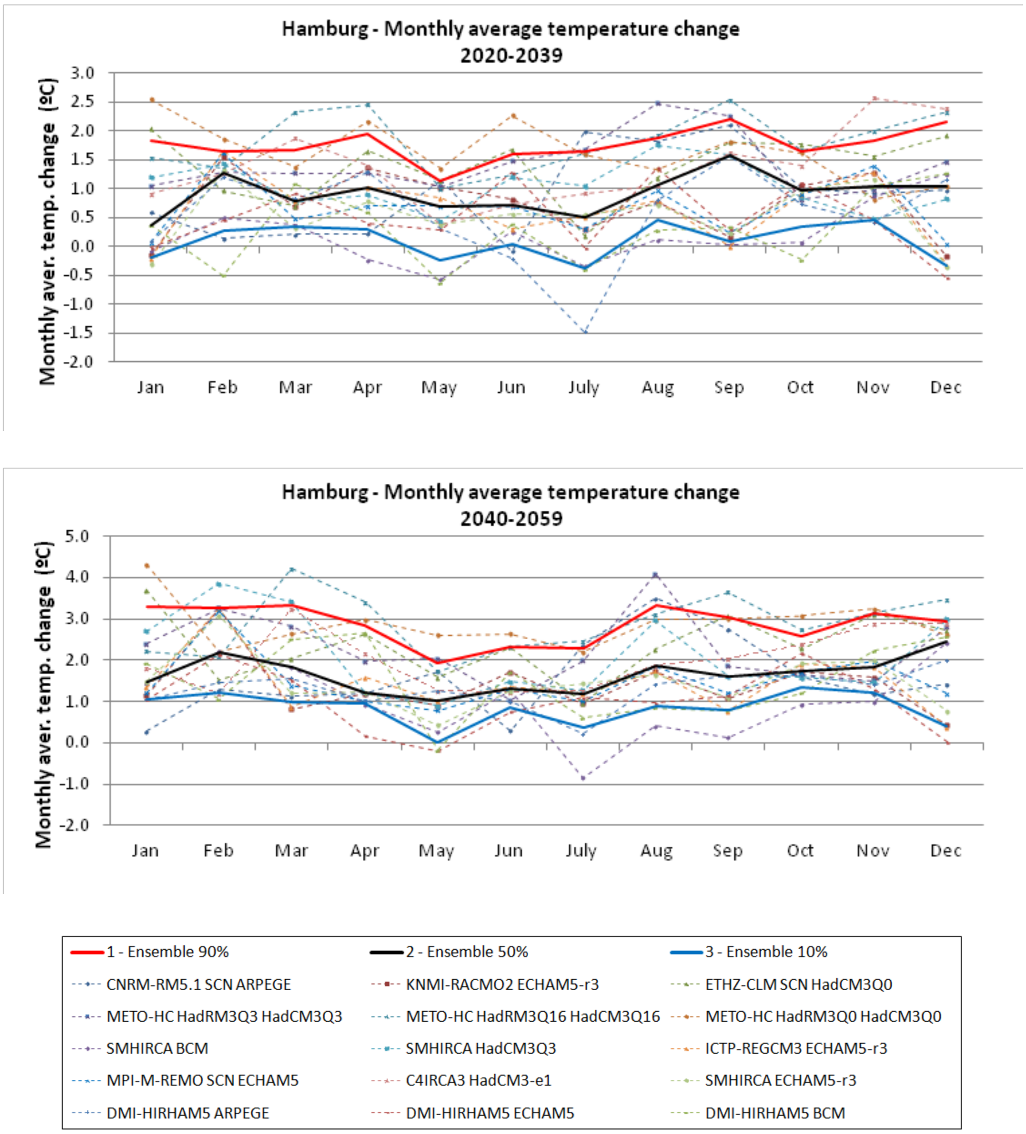


Figure A1.87 – Expected temperature change in Hamburg (2020-2039; 2040-2059)

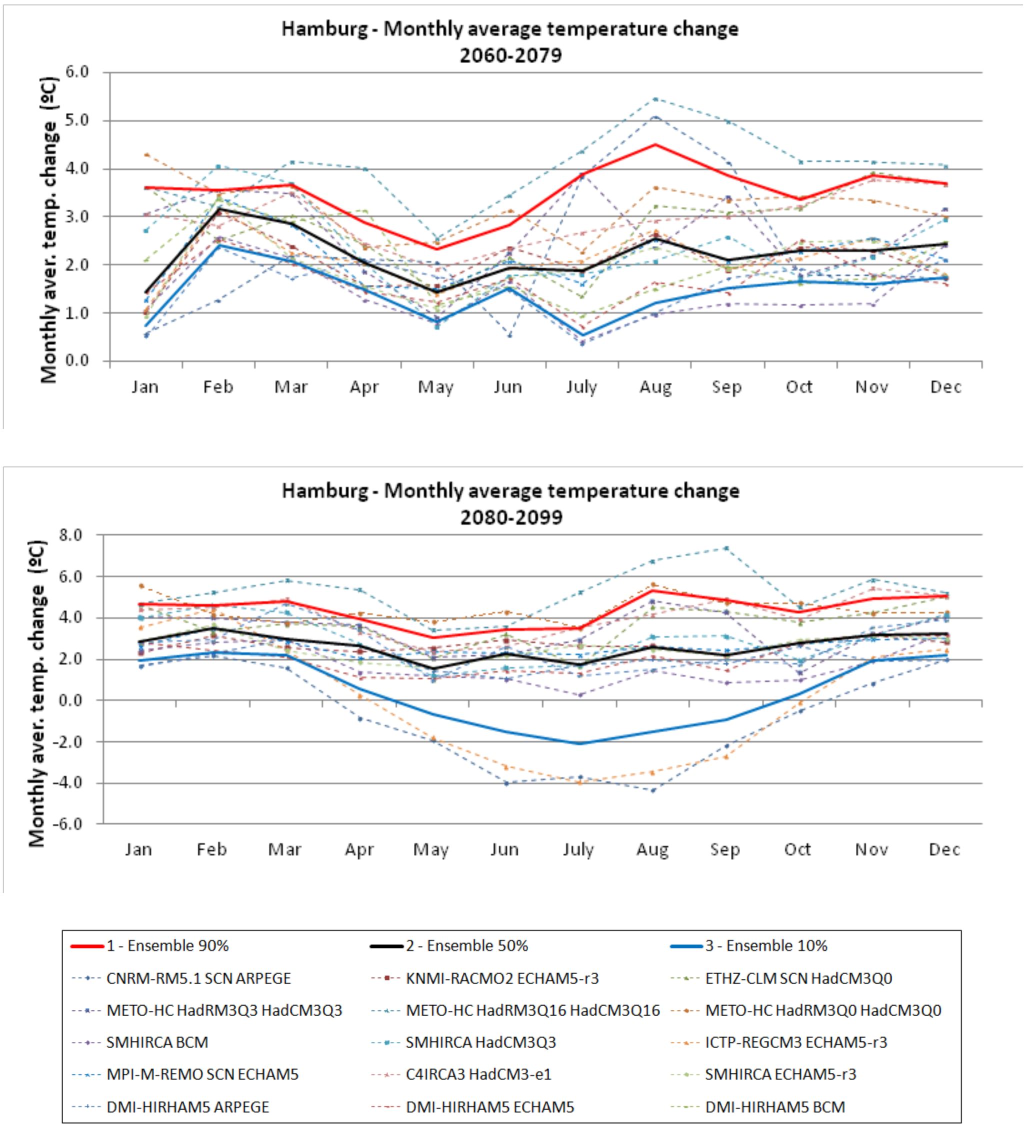


Figure A1.88 – Expected temperature change in Hamburg (2020-2039; 2040-2059)

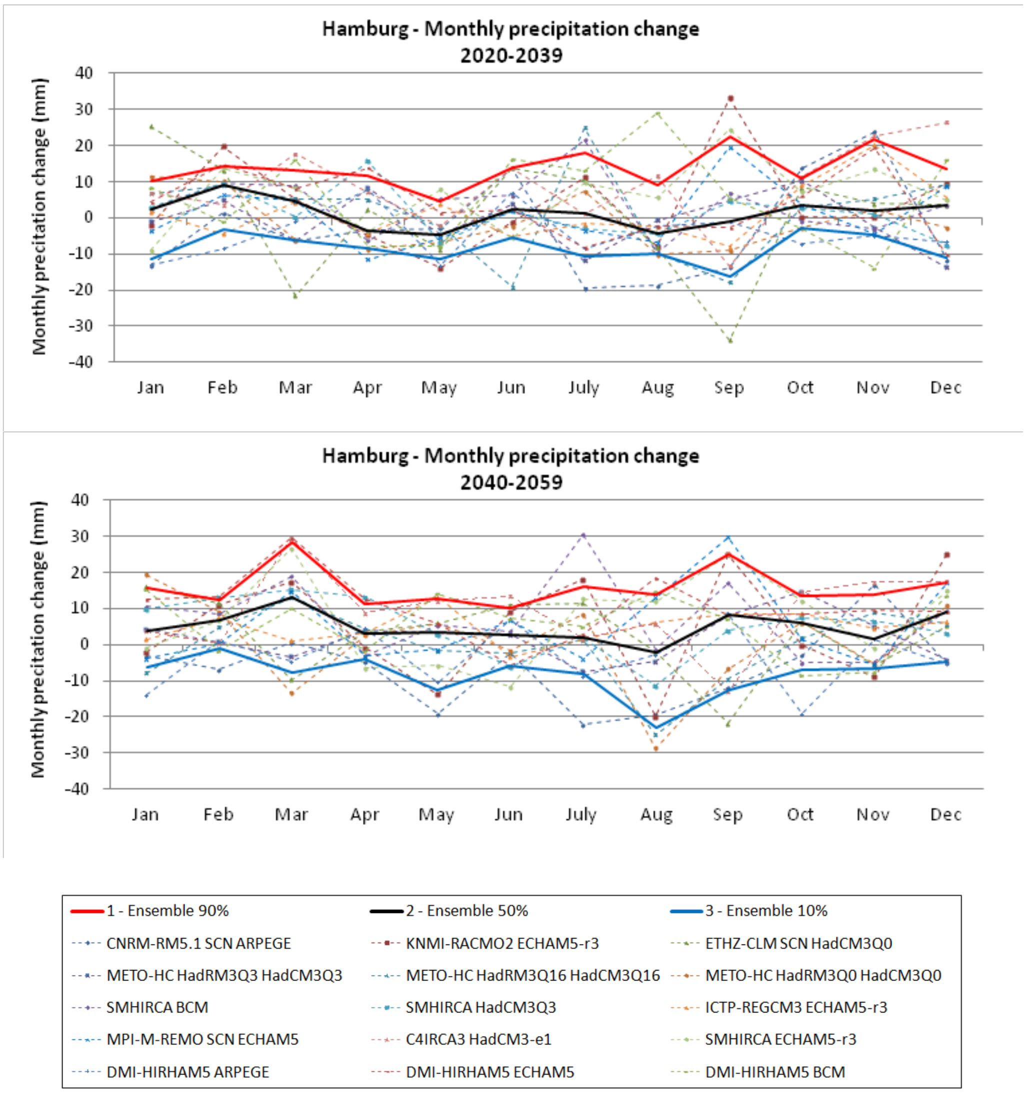


Figure A1.89 – Expected monthly precipitation change in Hamburg (2020-2039; 2040-2059) (in mm)

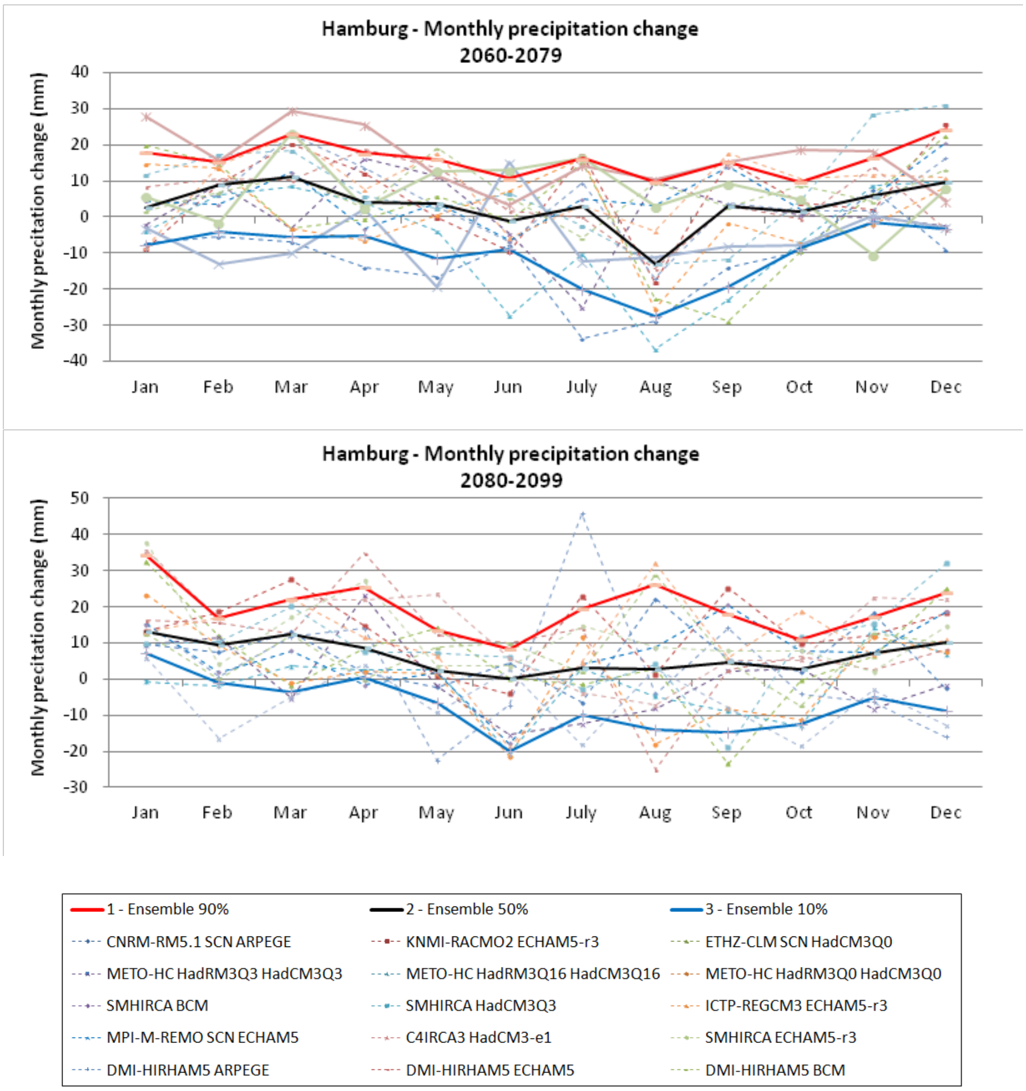
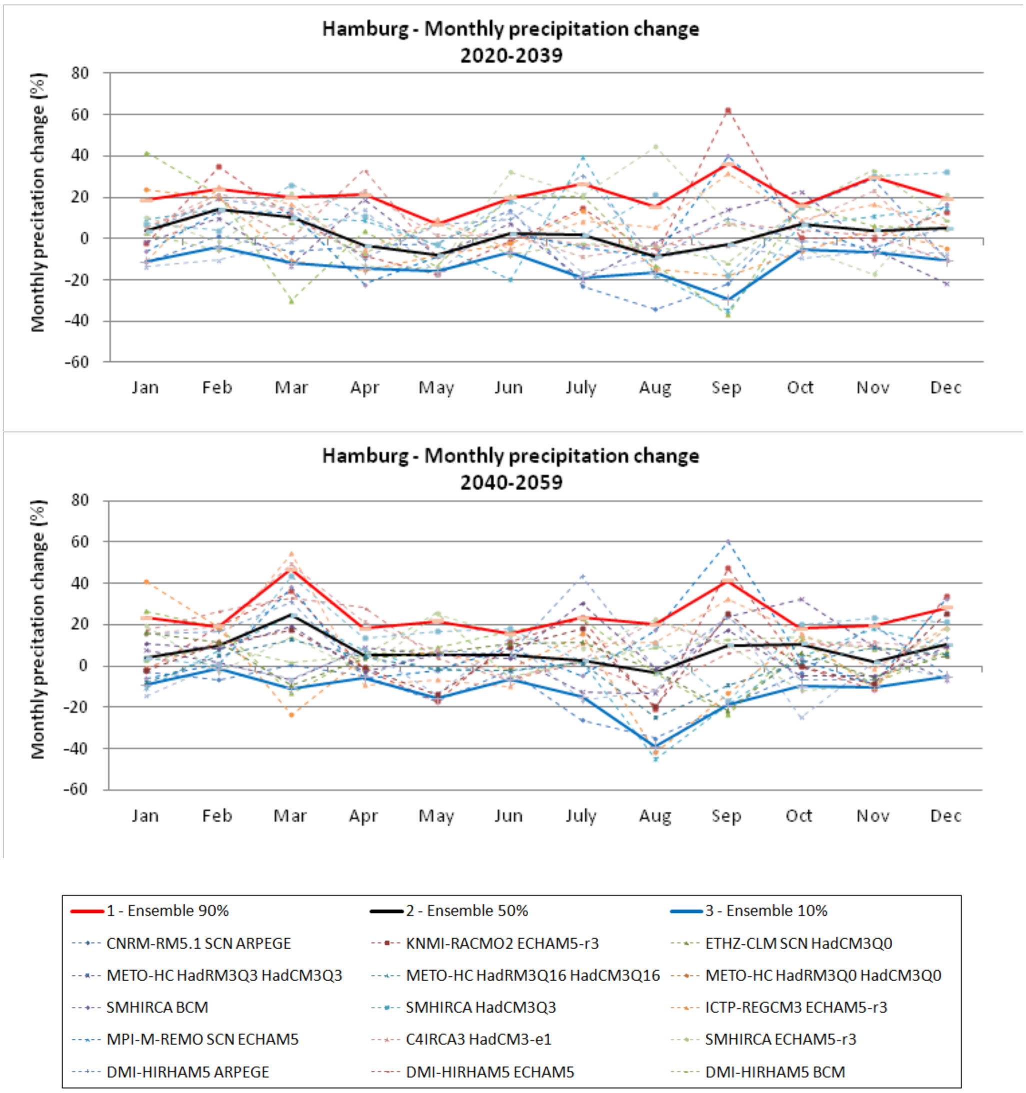


Figure A1.90 – Expected monthly precipitation change in Hamburg (2060-2079; 2080-2099) (in mm)



Hamburg - Monthly precipitation change 2020-2039

Hamburg - Monthly precipitation change 2040-2059

Figure A1.91 – Expected monthly precipitation change in Hamburg (2020-2039; 2040-2059) (in %)

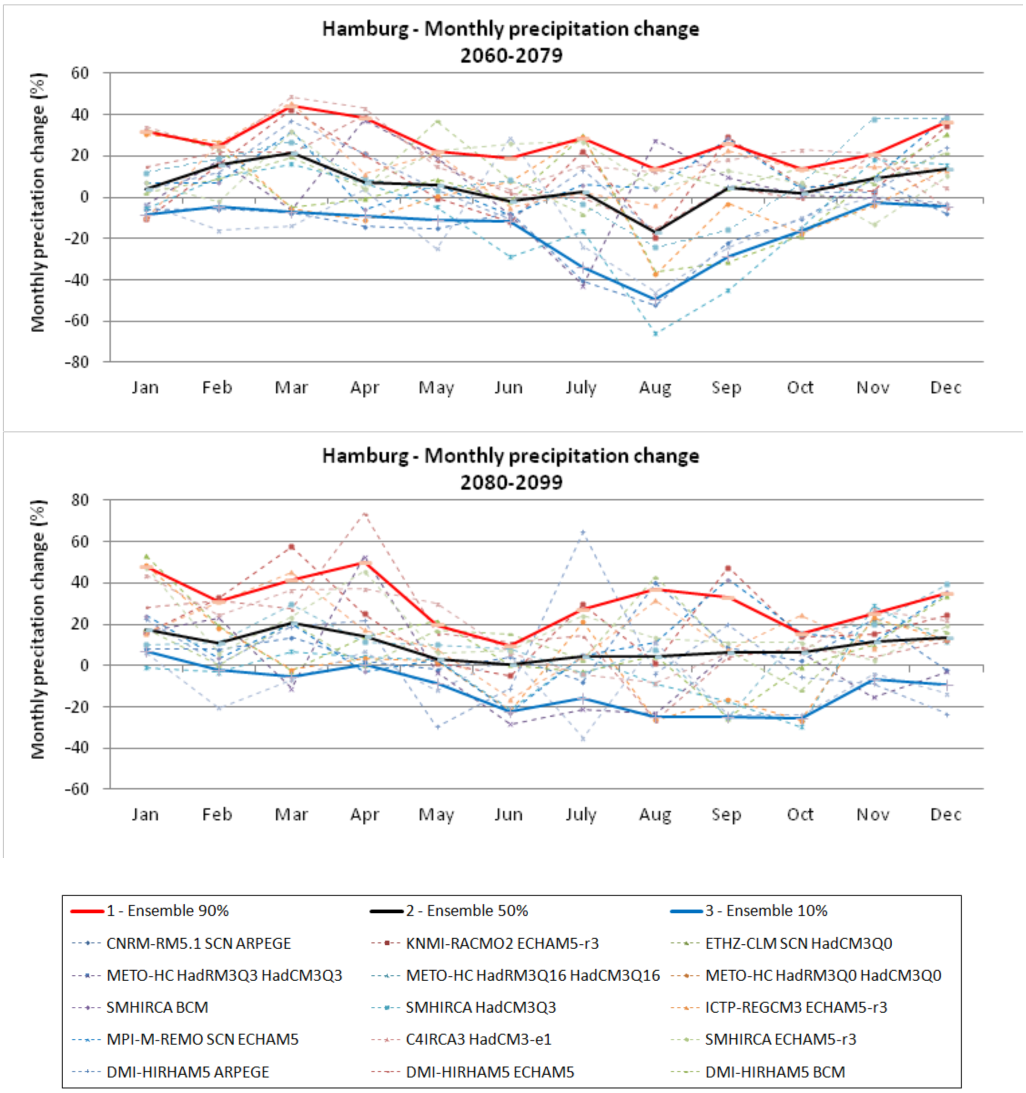


Figure A1.92 – Expected monthly precipitation change in Hamburg (2060-2079; 2080-2099) (in %)

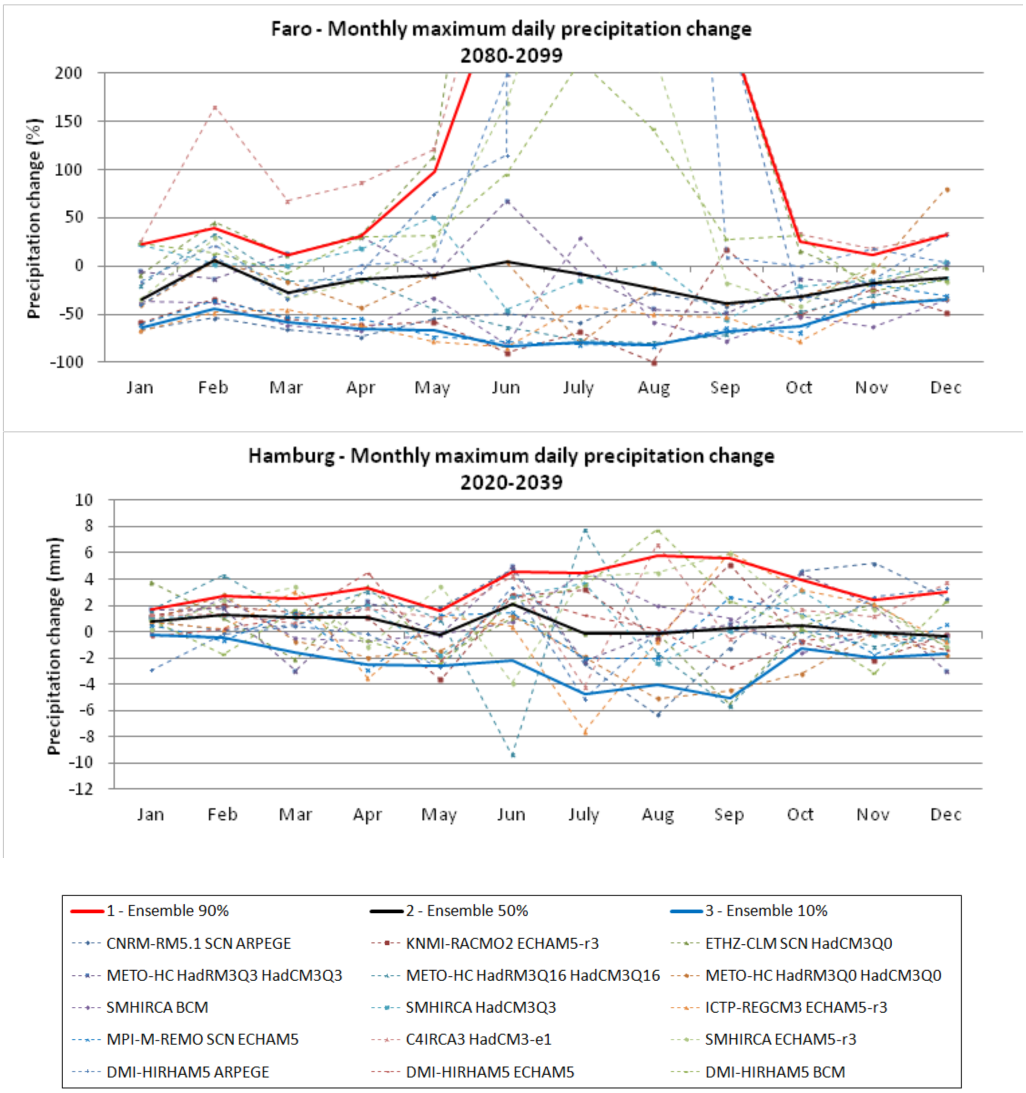


Figure A1.93 – Expected monthly maximum daily precipitation change in Hamburg (2020-2039; 2040-2059) (in mm)

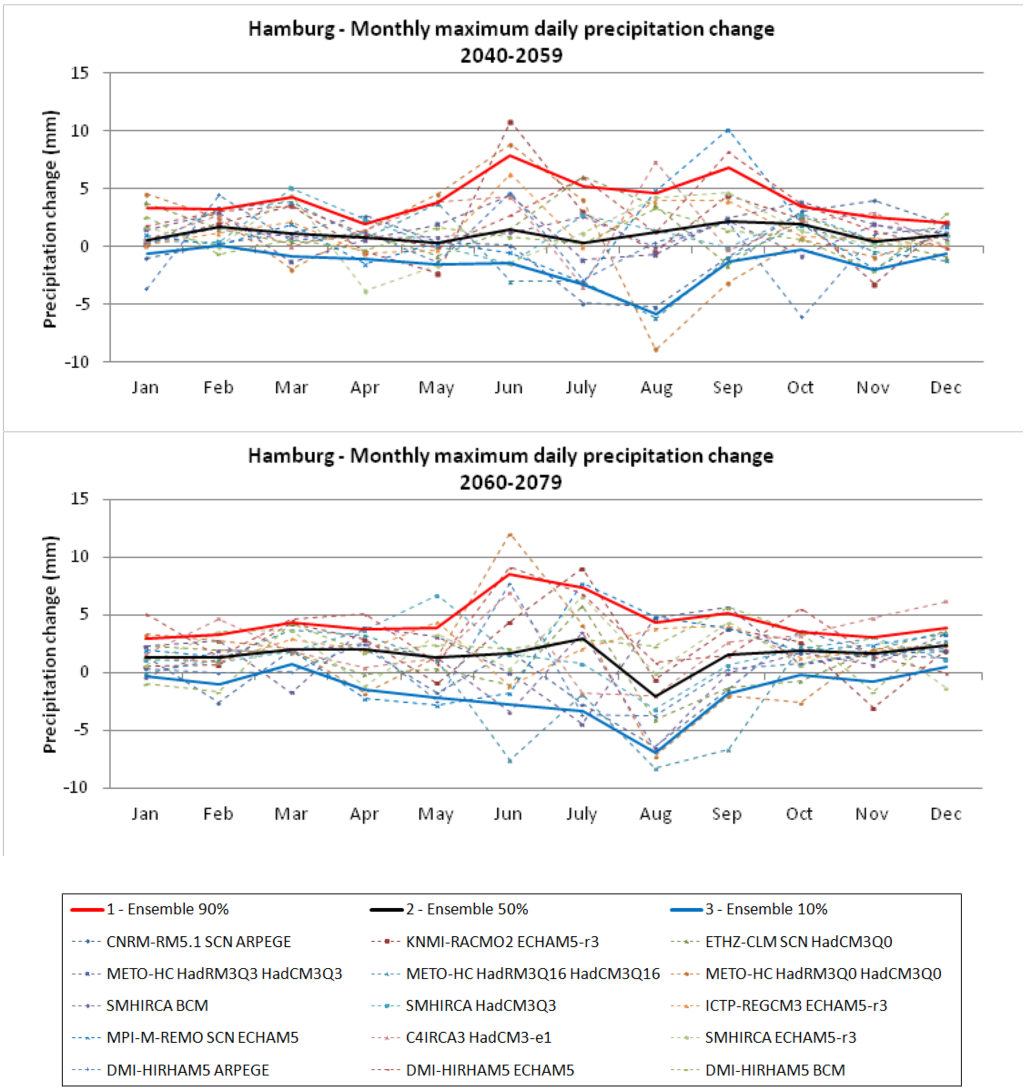


Figure A1.94 – Expected monthly maximum daily precipitation change in Hamburg (2060-2079; 2080-2099) (in mm)

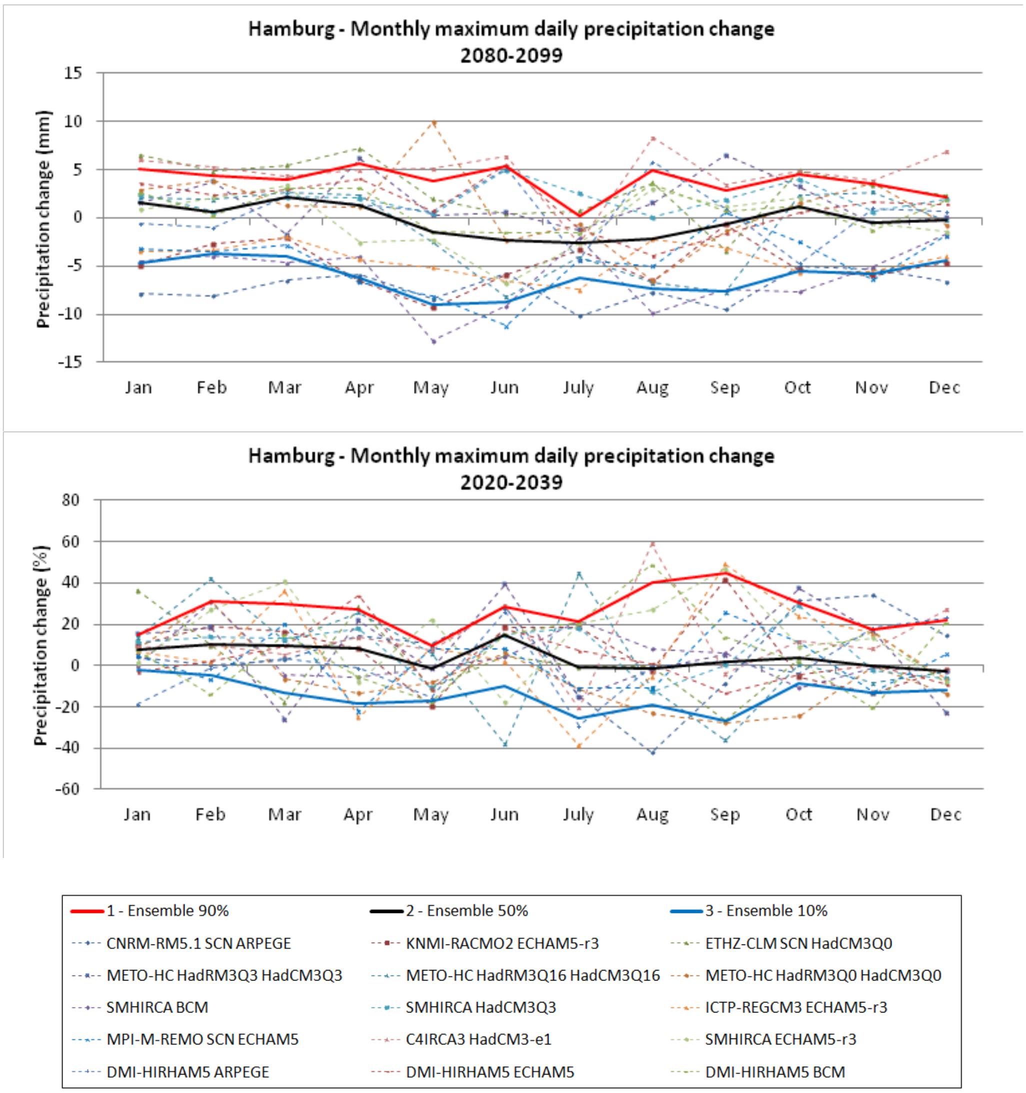


Figure A1.95 – Expected monthly maximum daily precipitation change in Hamburg (2020-2039; 2040-2059) (in %)

Figure A1.96 – Expected monthly maximum daily precipitation change in Hamburg (2060-2079; 2080-2099) (in %)

Madrid

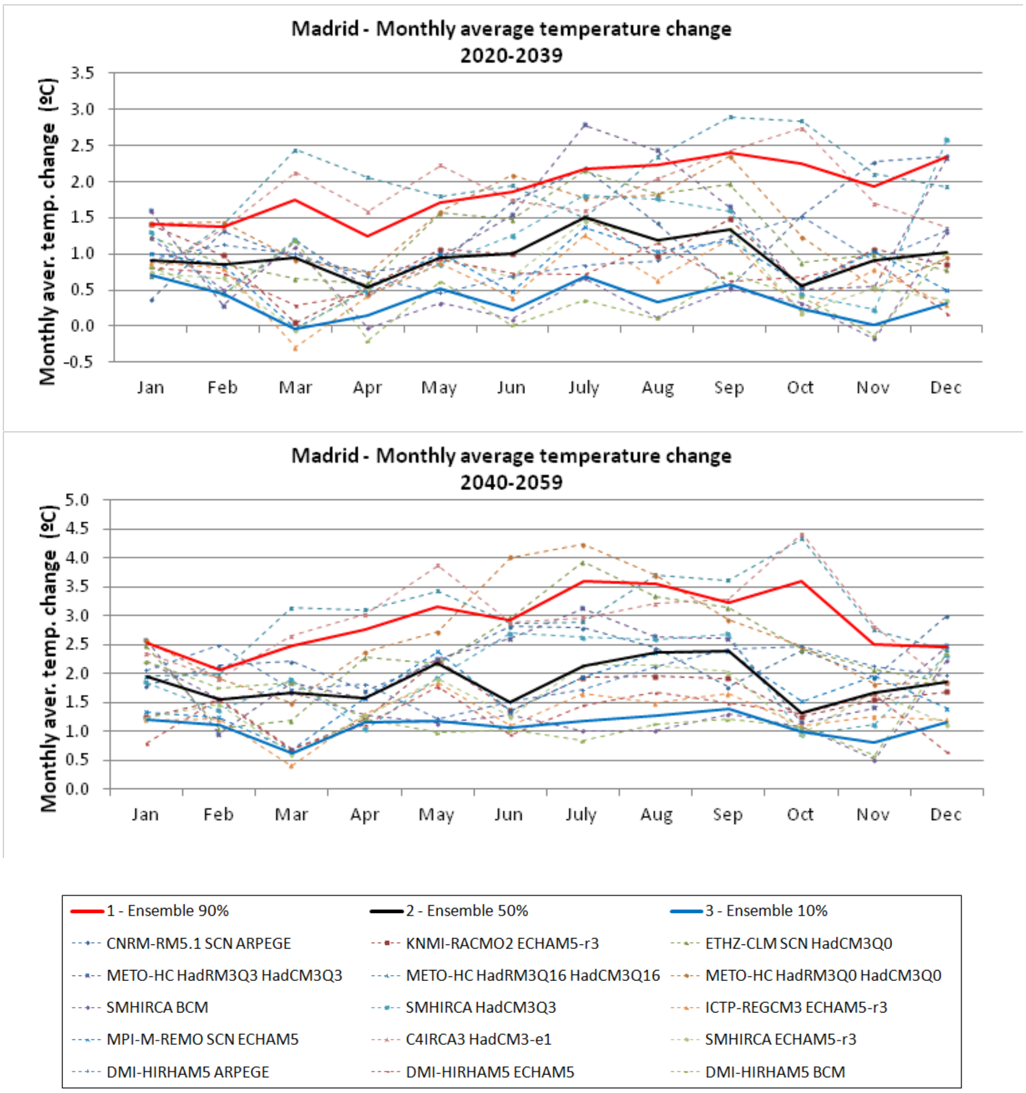


Figure A1.97 – Expected temperature change in Madrid (2020-2039; 2040-2059)

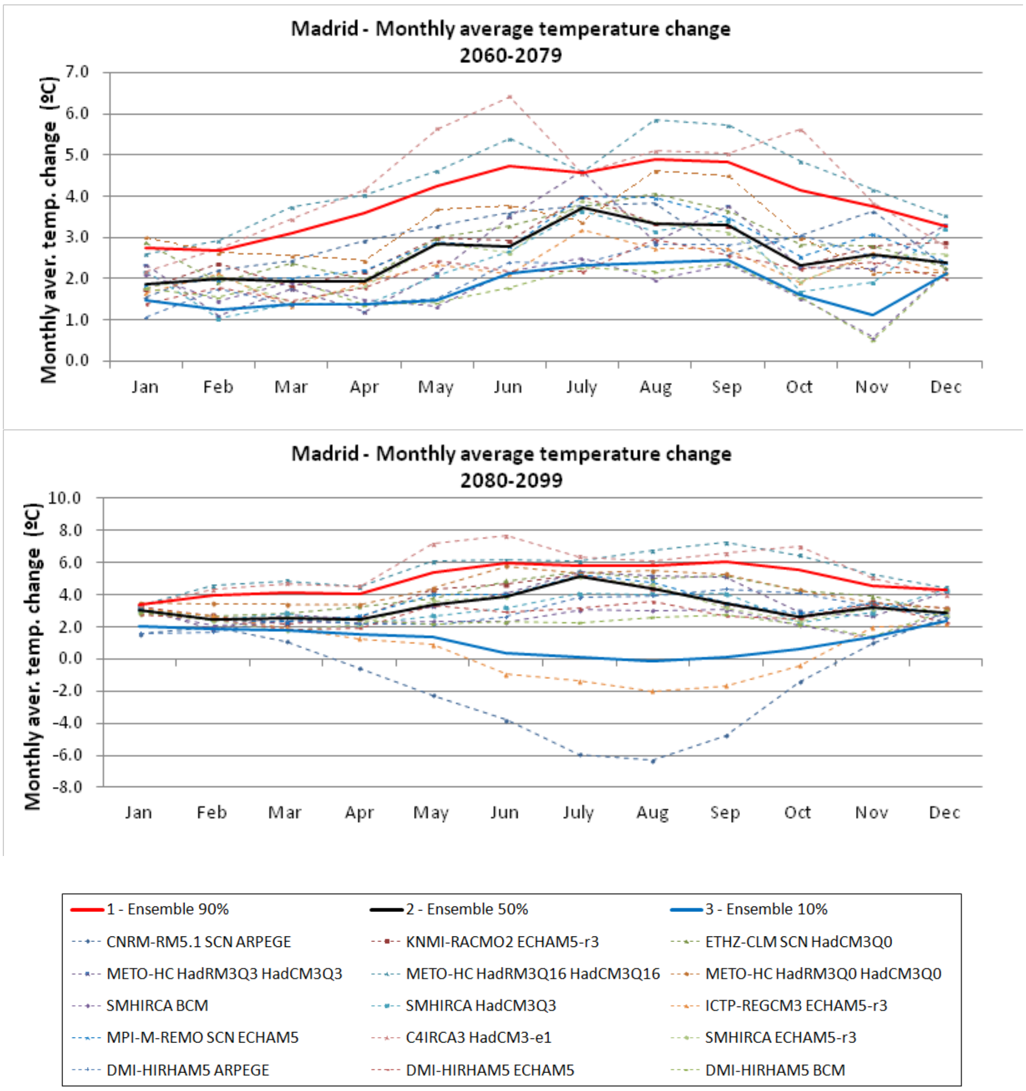


Figure A1.98 – Expected temperature change in Madrid (2060-2079; 2080-2099)

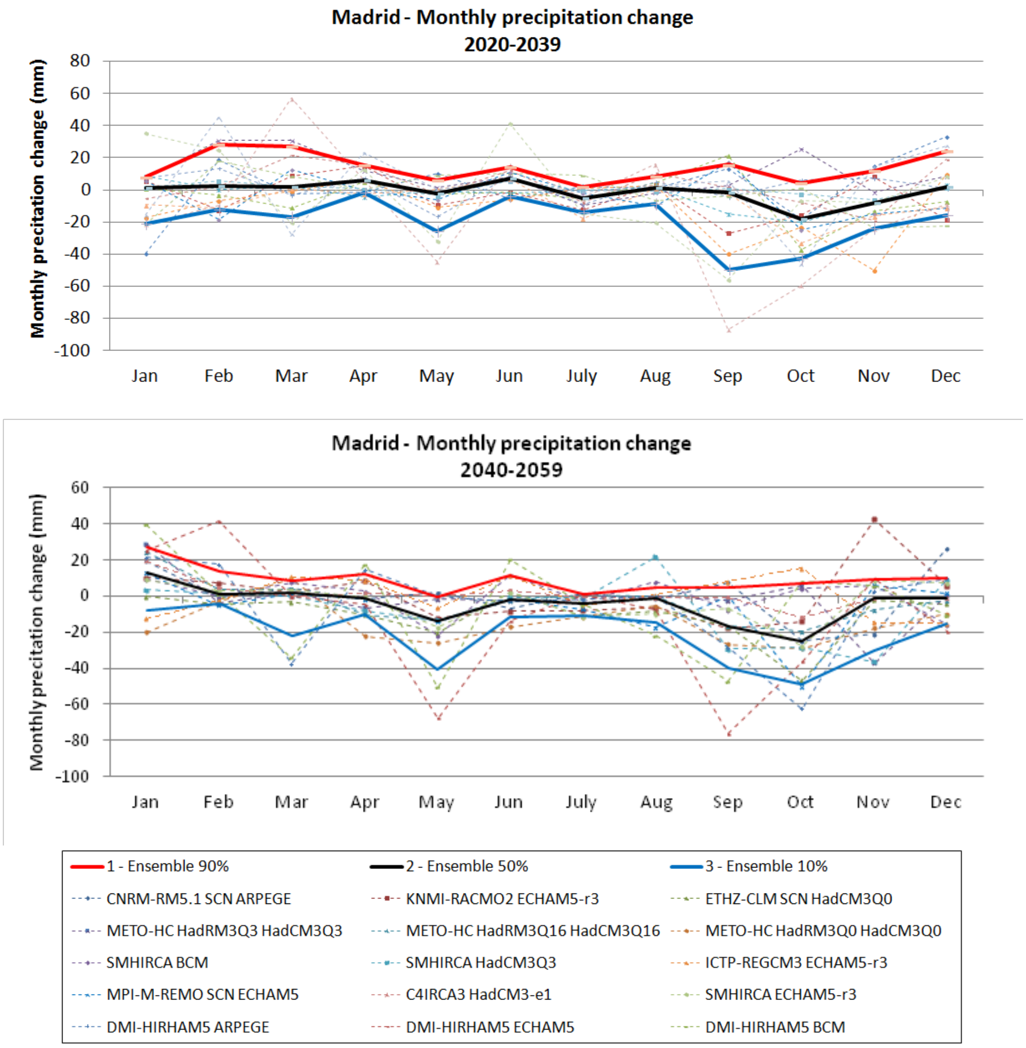


Figure A1.99 – Expected monthly precipitation change in Madrid (2020-2039; 2040-2059) (in mm)

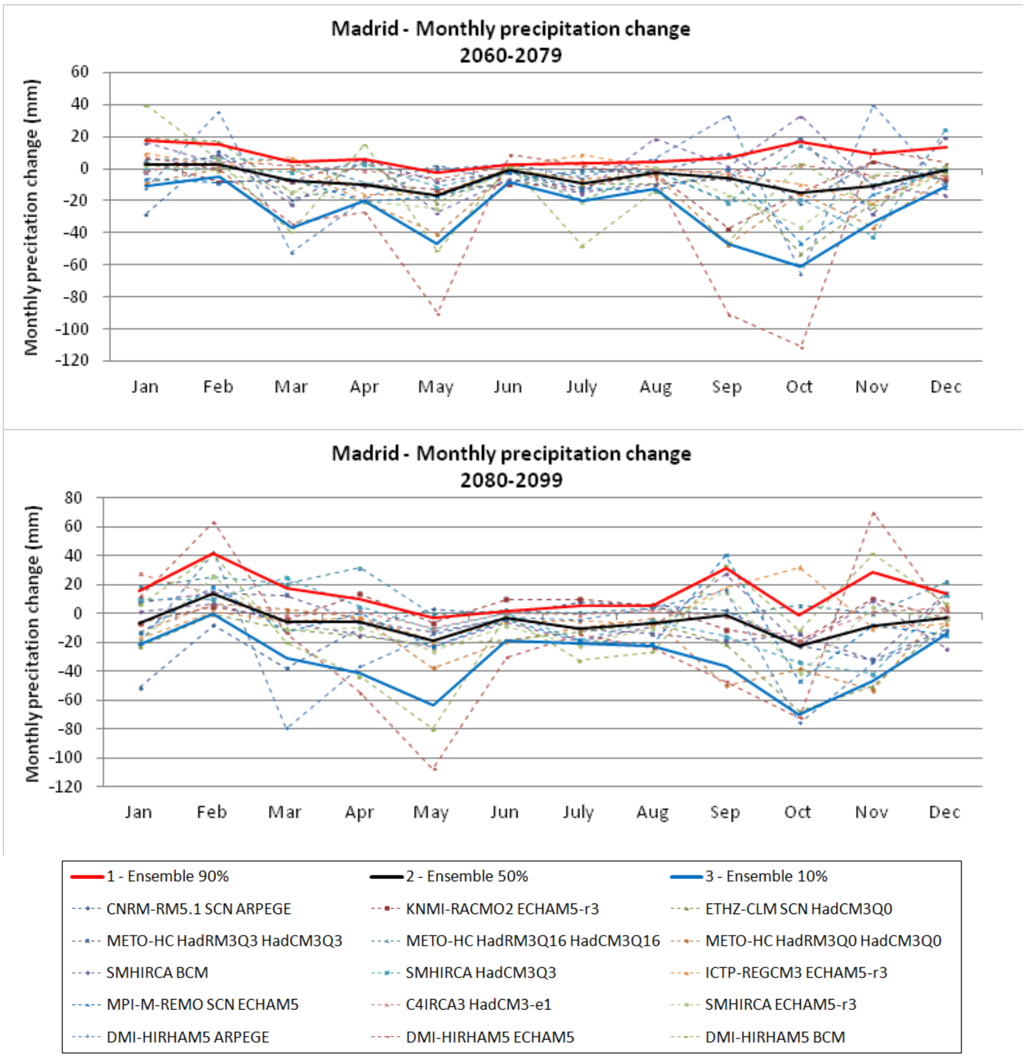


Figure A1.100 –Expected monthly precipitation change in Madrid (2060-2079; 2080-2099) (in mm)

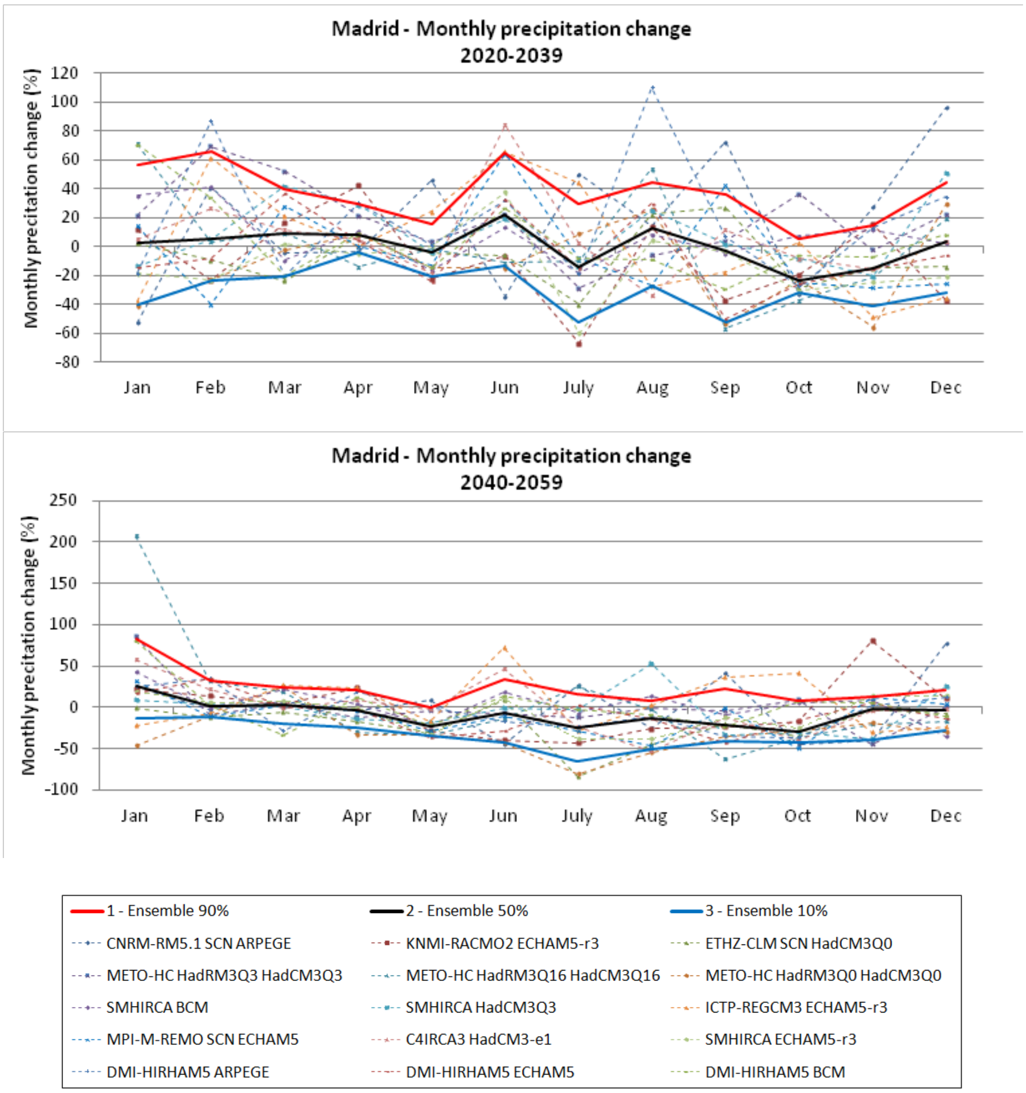


Figure A1.101 – Expected monthly precipitation change in Madrid (2020-2039; 2040-2059) (in %)

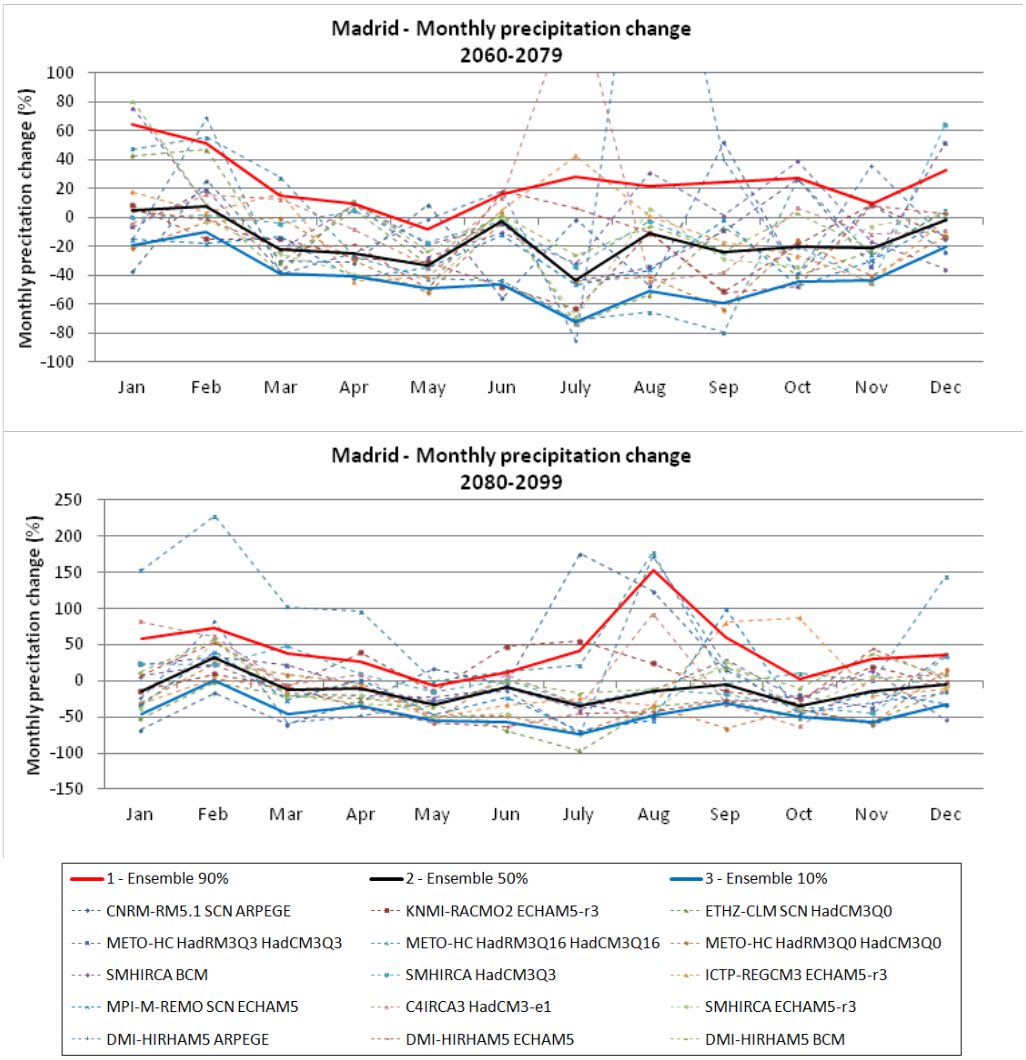


Figure A1.102 – Expected monthly precipitation change in Madrid (2060-2079; 2080-2099) (in mm)

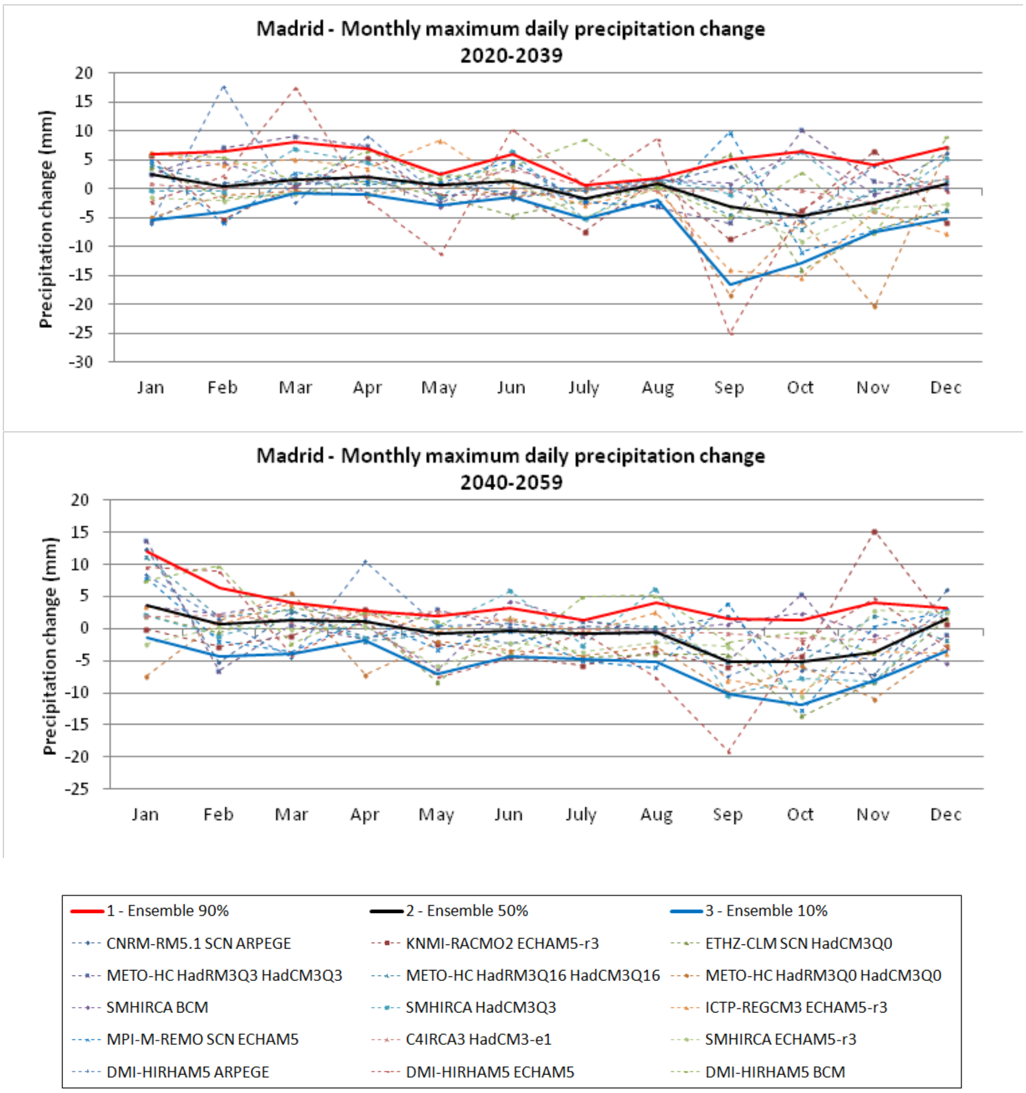


Figure A1.103 – Expected monthly maximum daily precipitation change in Madrid (2020-2039; 2040-2059) (in mm)

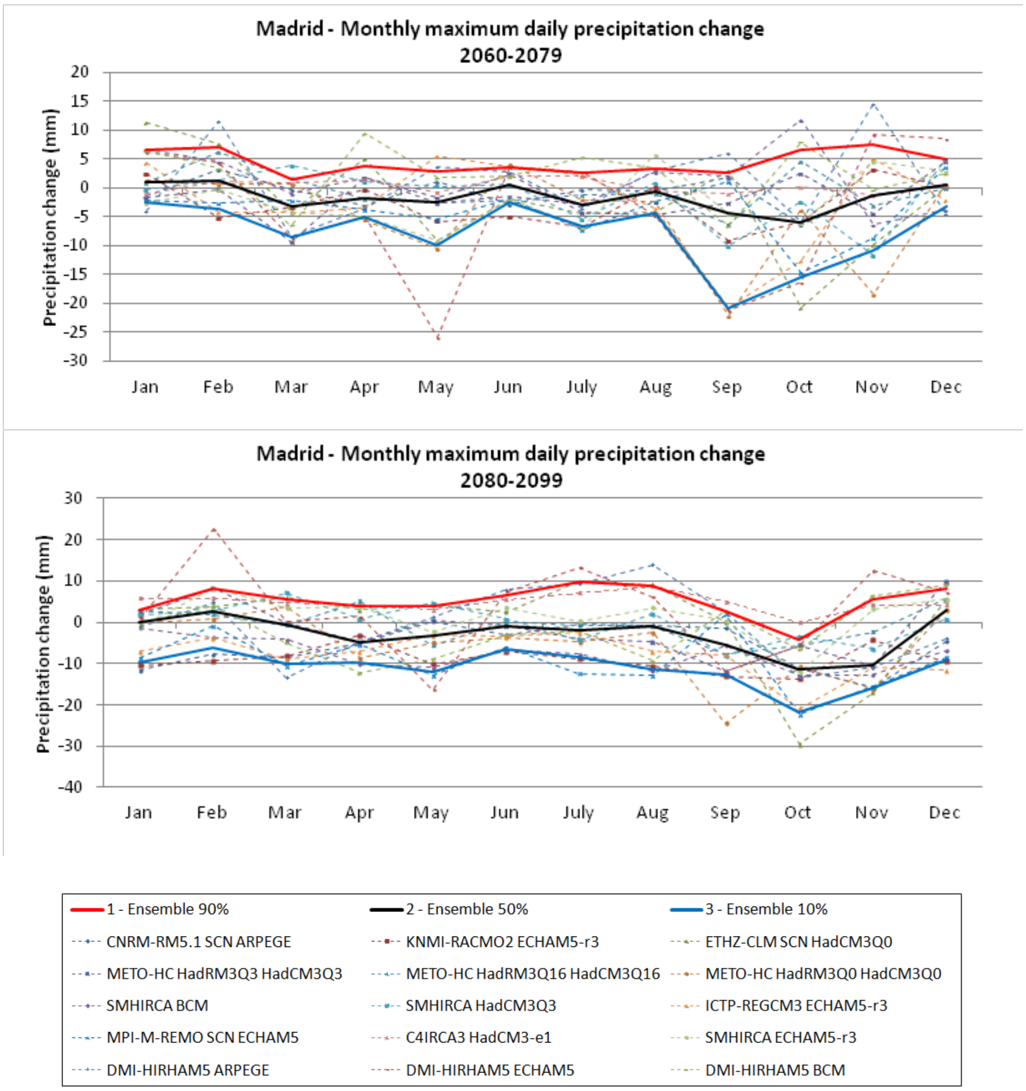


Figure A1.104 – Expected monthly maximum daily precipitation change in Madrid (2060-2079; 2080-2099) (in mm)

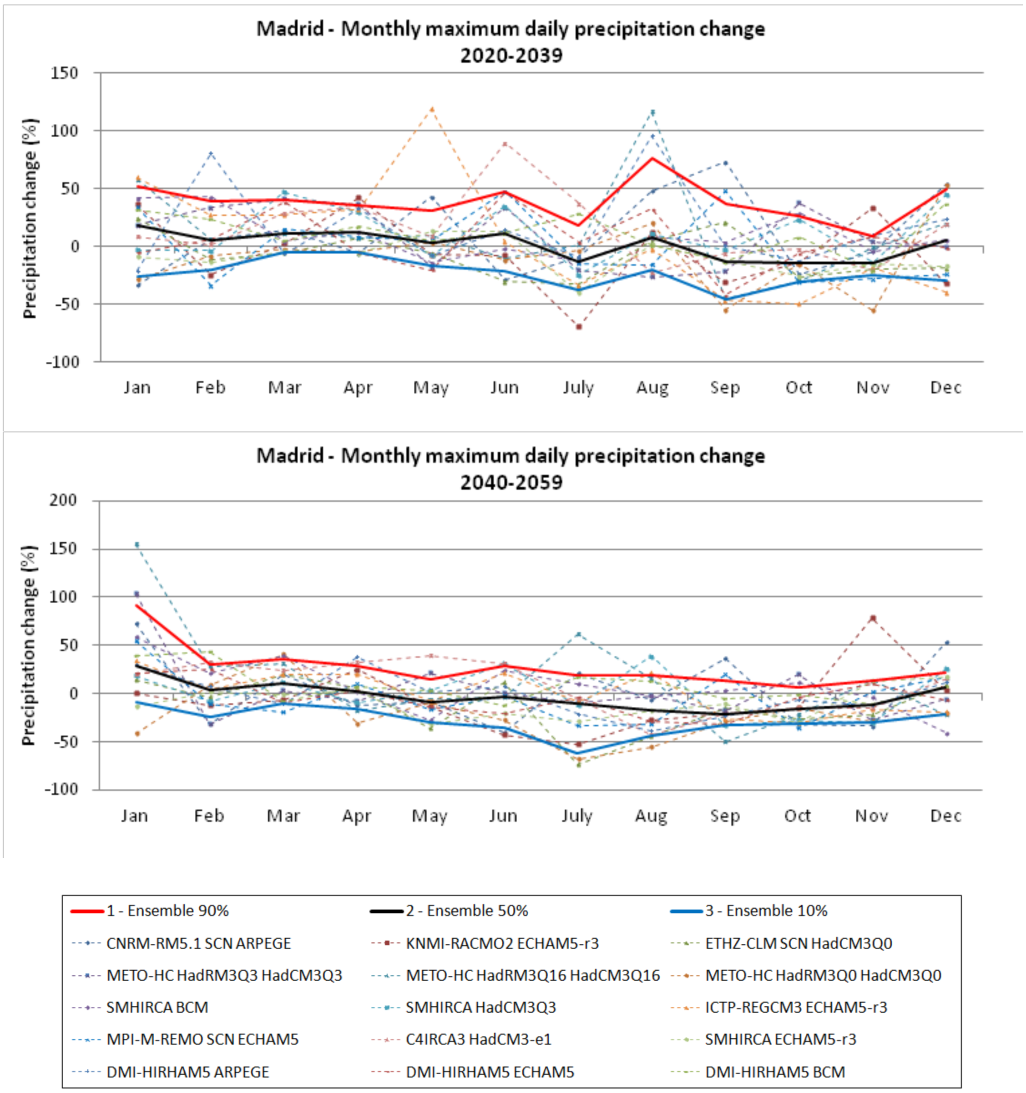


Figure A1.105 – Expected monthly maximum daily precipitation change in Madrid (2020-2039; 2040-2059) (in %)

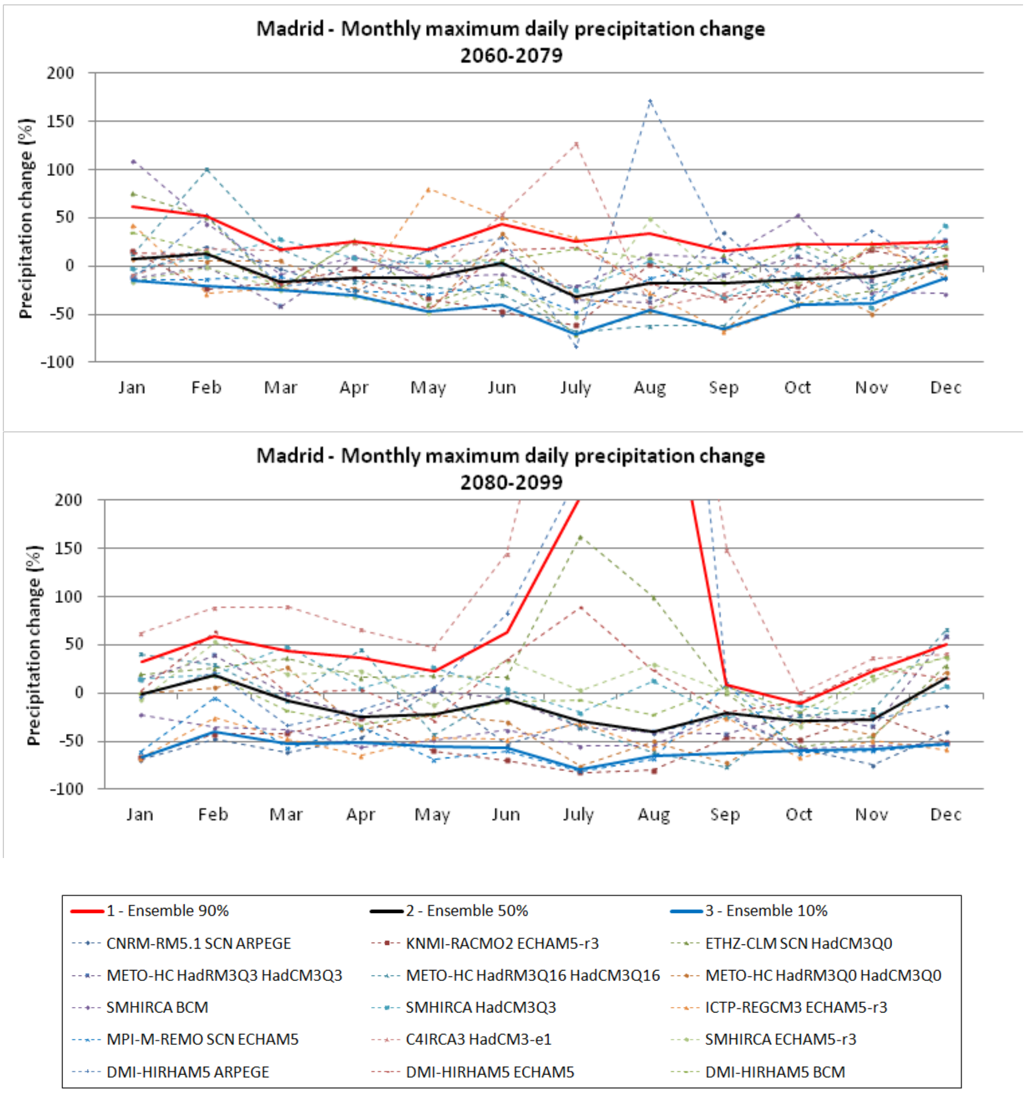


Figure A1.106 – Expected monthly maximum daily precipitation change in Madrid (2060-2079; 2080-2099) (in %)

Oslo

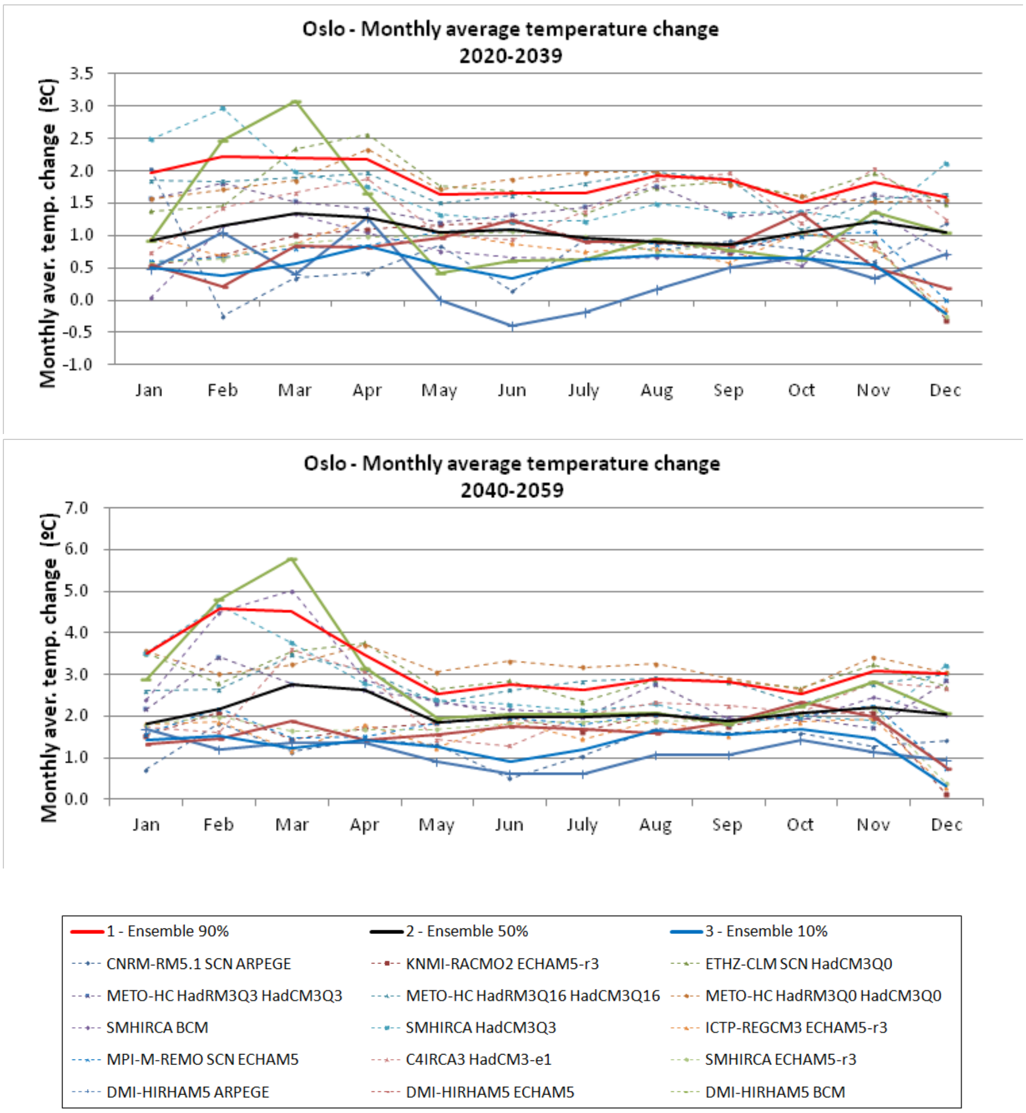


Figure A1.107 – Expected temperature change in Oslo (2020-2039; 2040-2059)

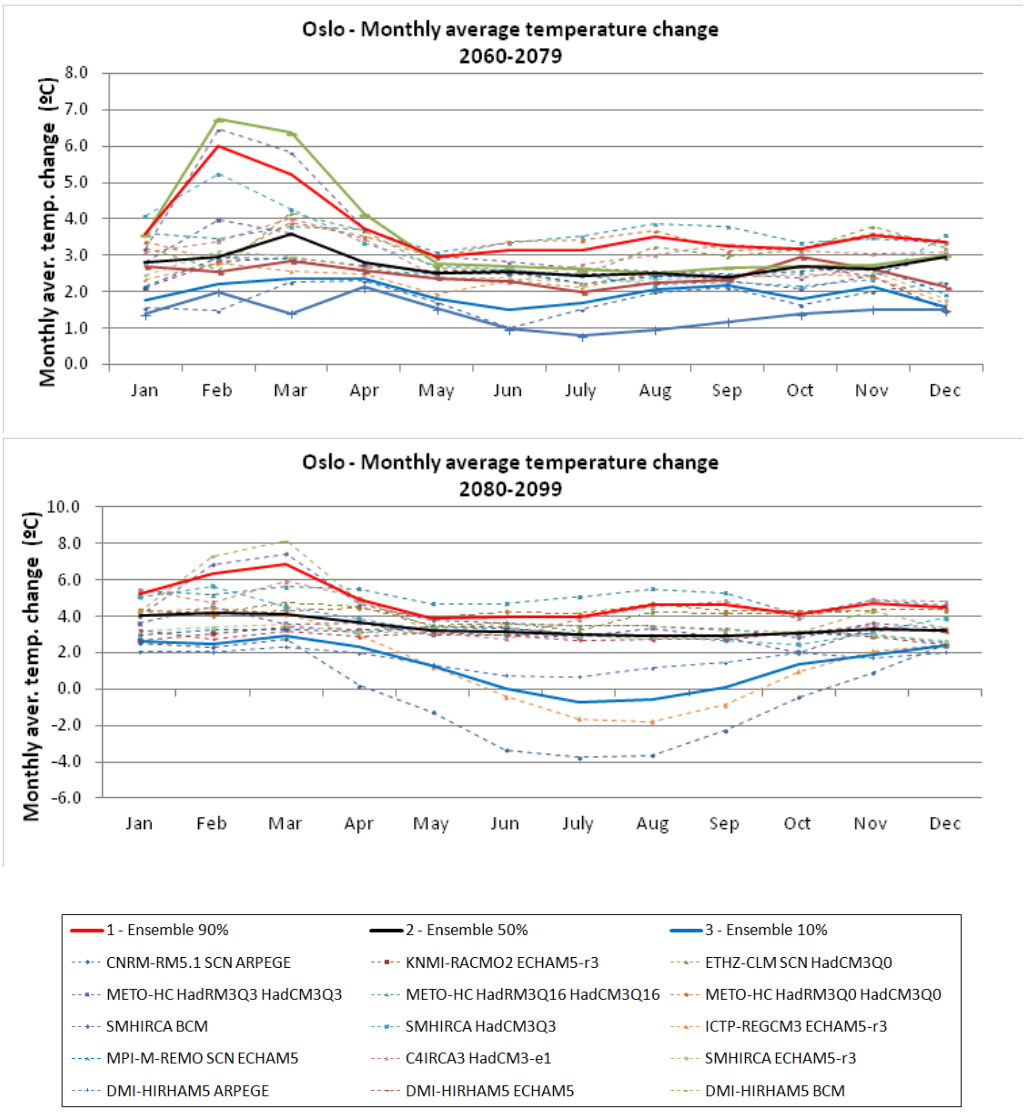


Figure A1.108 – Expected temperature change in Oslo (2060-2079; 2080-2099)

Figure A1.109 – Expected monthly precipitation change in Oslo (2020-2039; 2040-2059) (in mm)

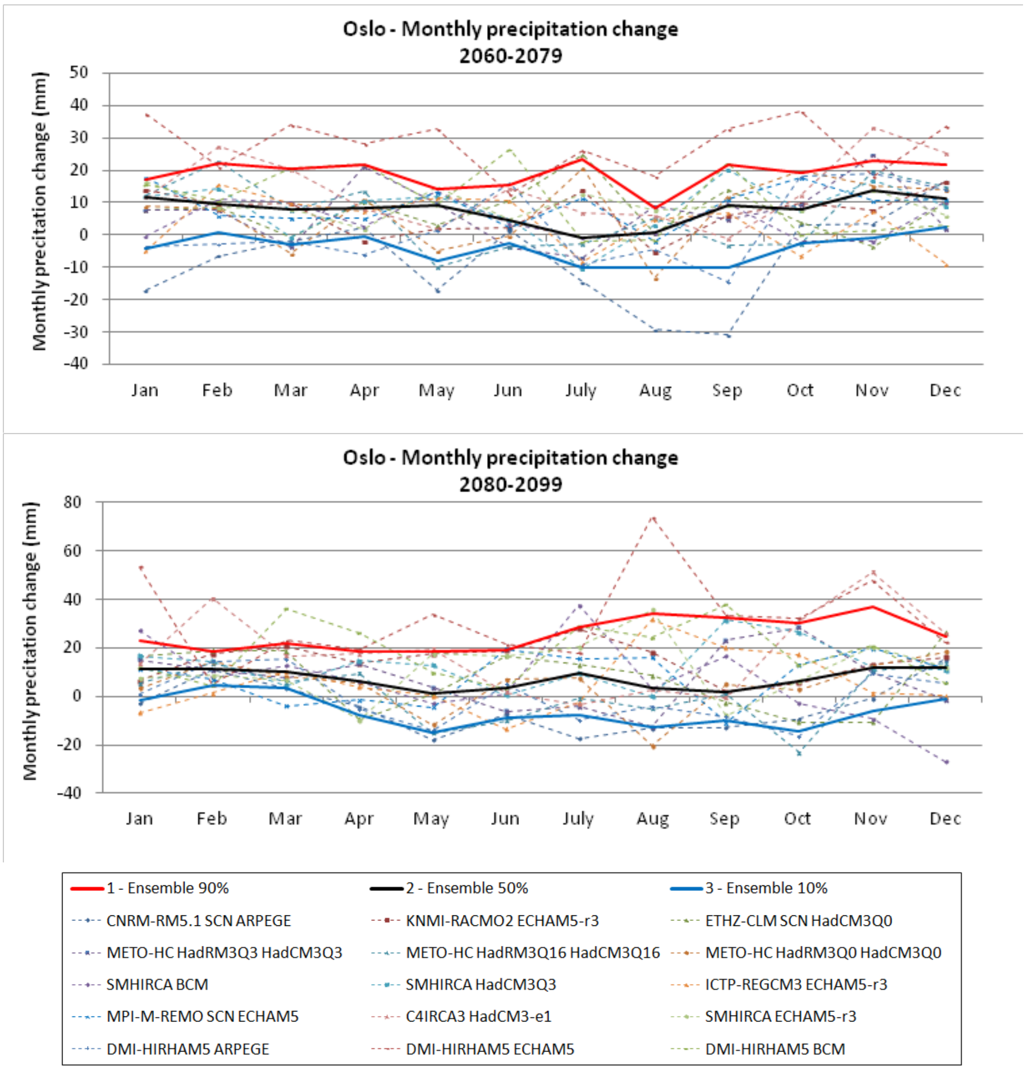


Figure A1.110 – Expected monthly precipitation change in Oslo (2060-2079; 2080-2099) (in mm)

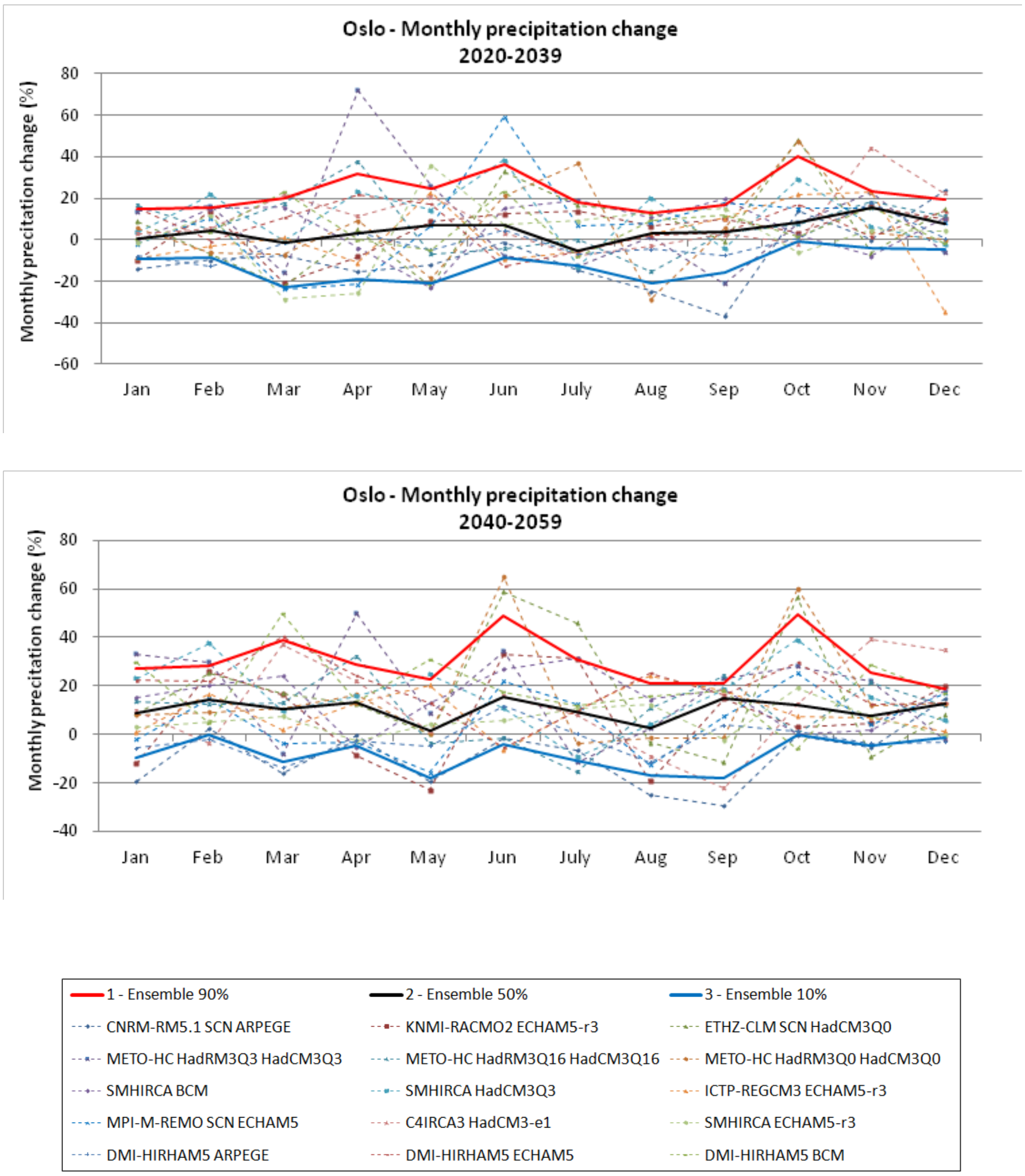


Figure A1.111 – Expected monthly precipitation change in Oslo (2020-2039; 2040-2059) (in %)

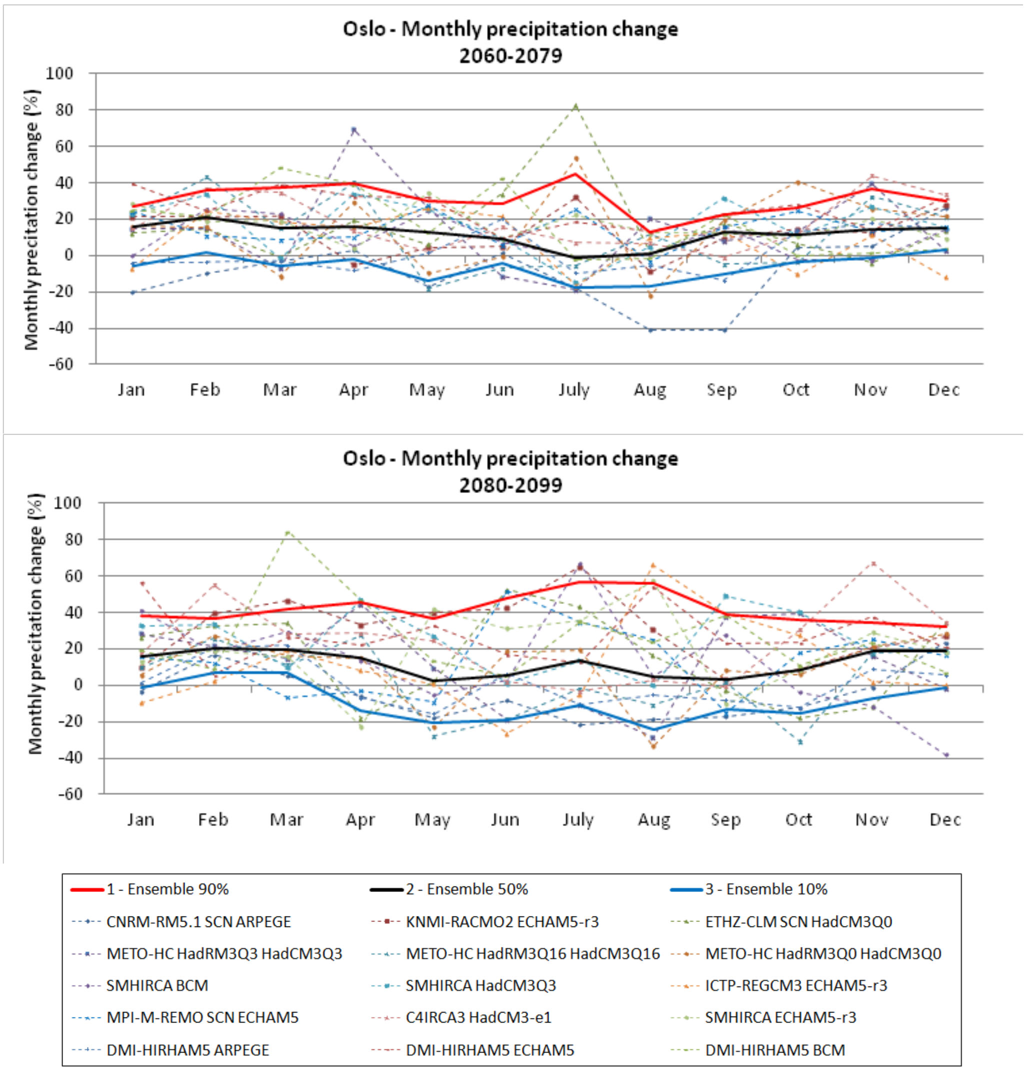
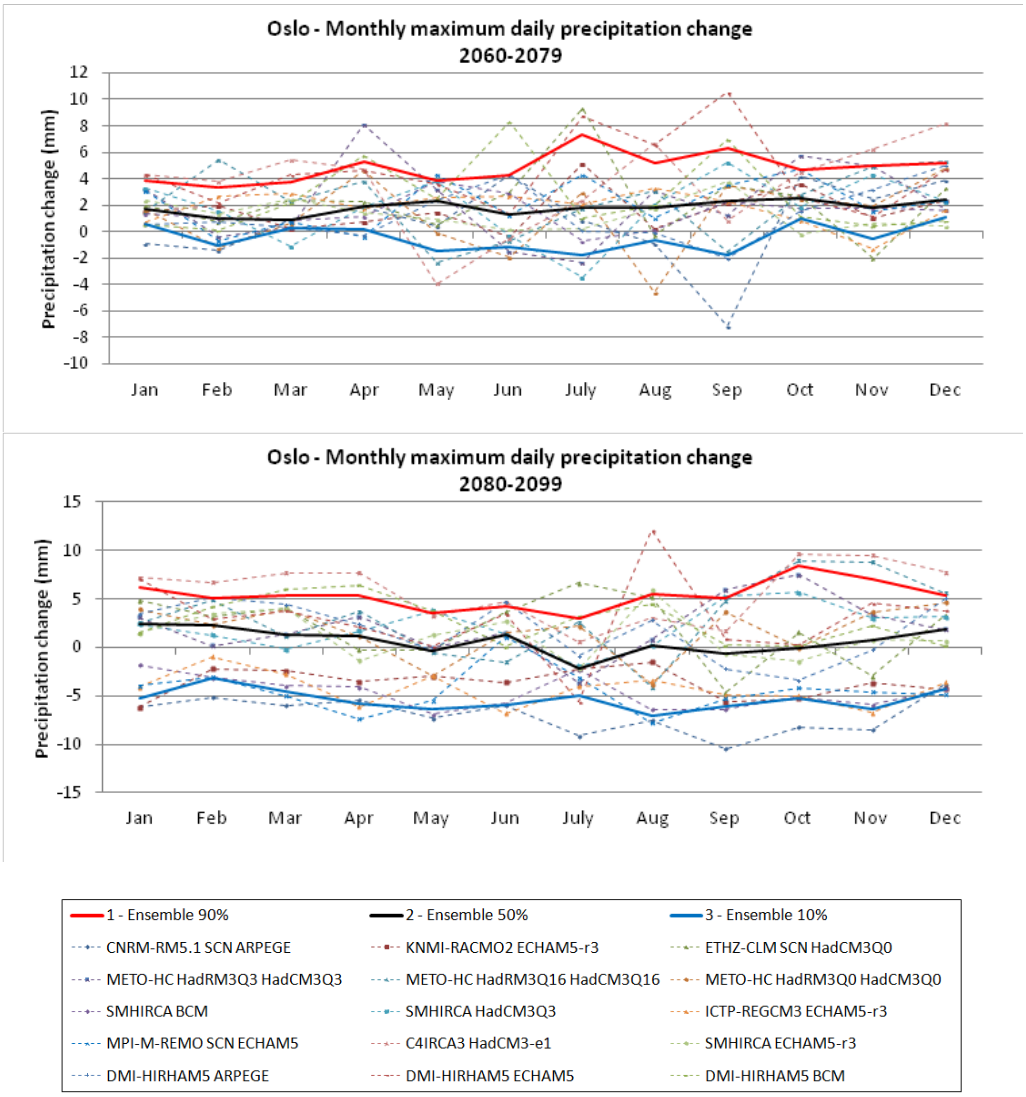


Figure A1.112 – Expected monthly precipitation change in Oslo (2060-2079; 2080-2099) (in %)

Figure A1.113 – Expected monthly maximum daily precipitation change in Oslo (2020-2039; 2040-2059) (in mm)



Oslo - Monthly maximum daily precipitation change 2060-2079

Oslo - Monthly maximum daily precipitation change 2080-2099

Figure A1.114 – Expected monthly maximum daily precipitation change in Oslo (2060-2079; 2080-2099) (in mm)

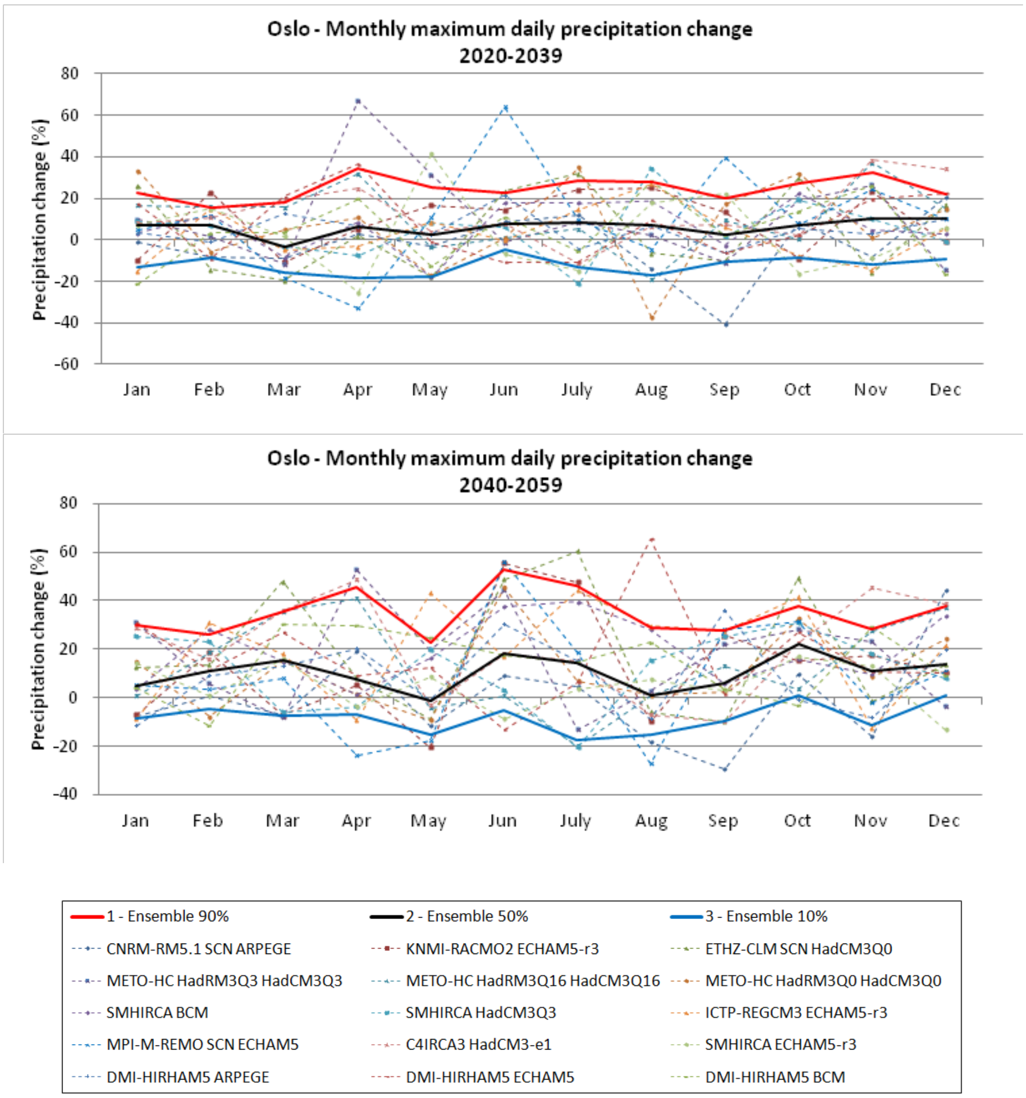


Figure A1.115 – Expected monthly maximum daily precipitation change in Oslo (2020-2039; 2040-2059) (in %)

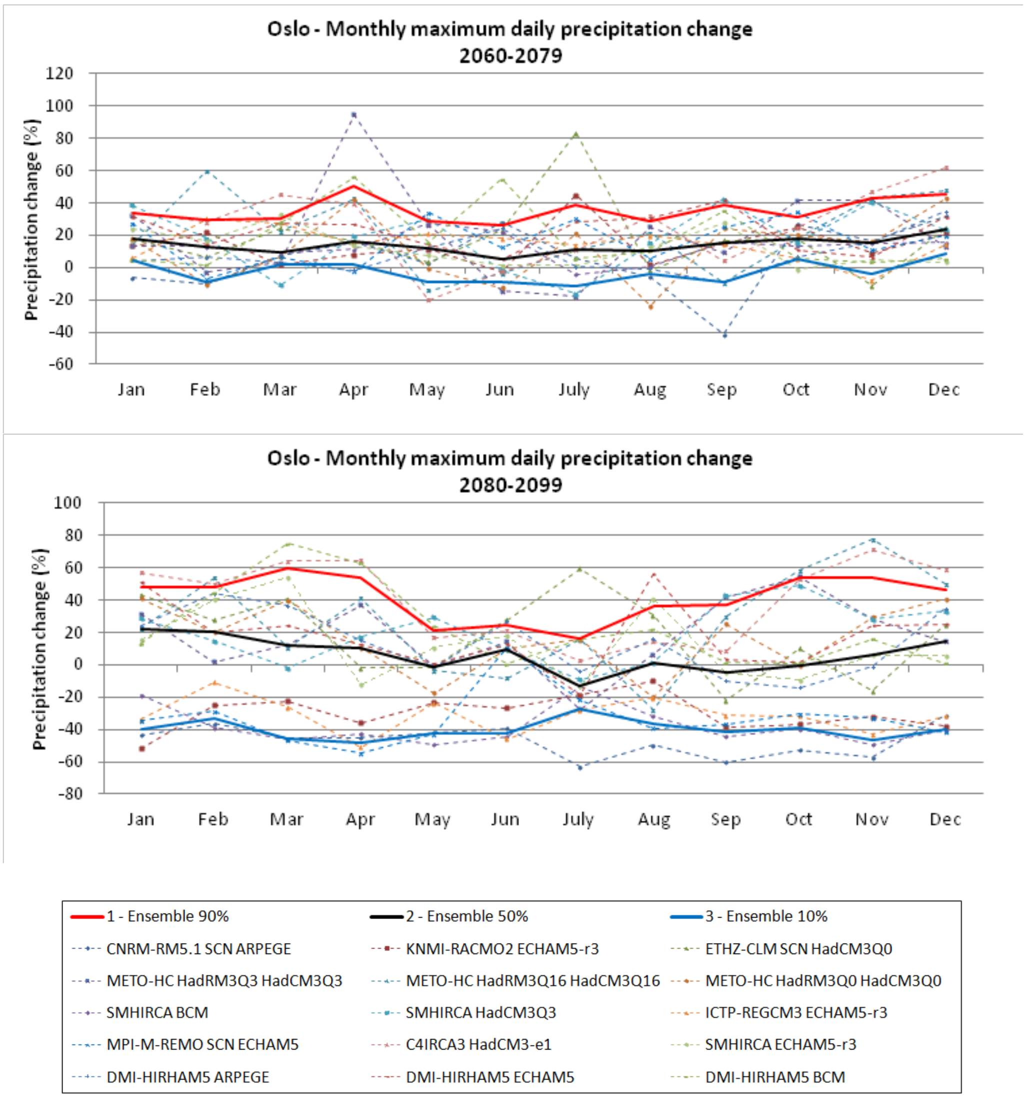


Figure A1.116 – Expected monthly maximum daily precipitation change in Oslo (20770-2039; 2040-2059) (in mm)

Reggio-Emilia

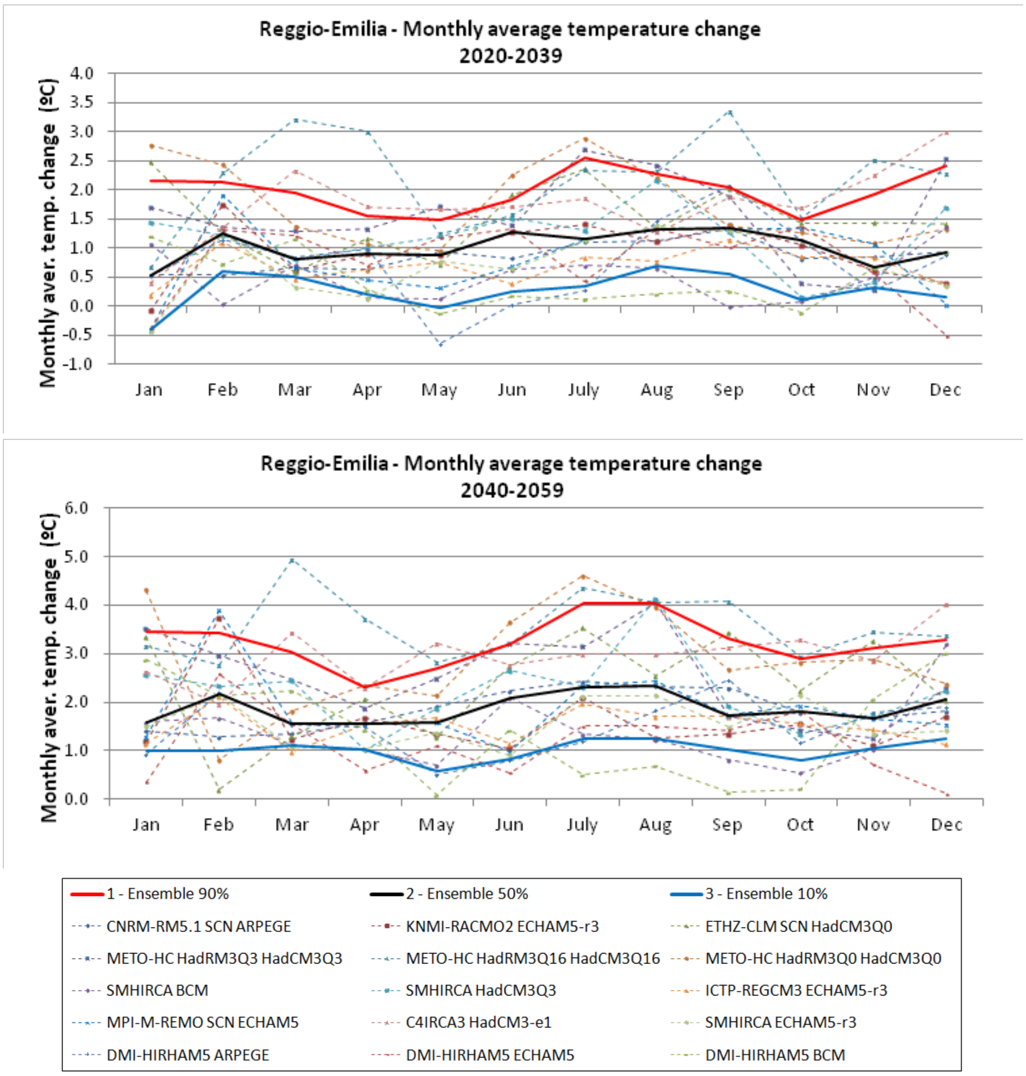


Figure A1.117 – Expected temperature change in Reggio-Emilia (2020-2039; 2040-2059)

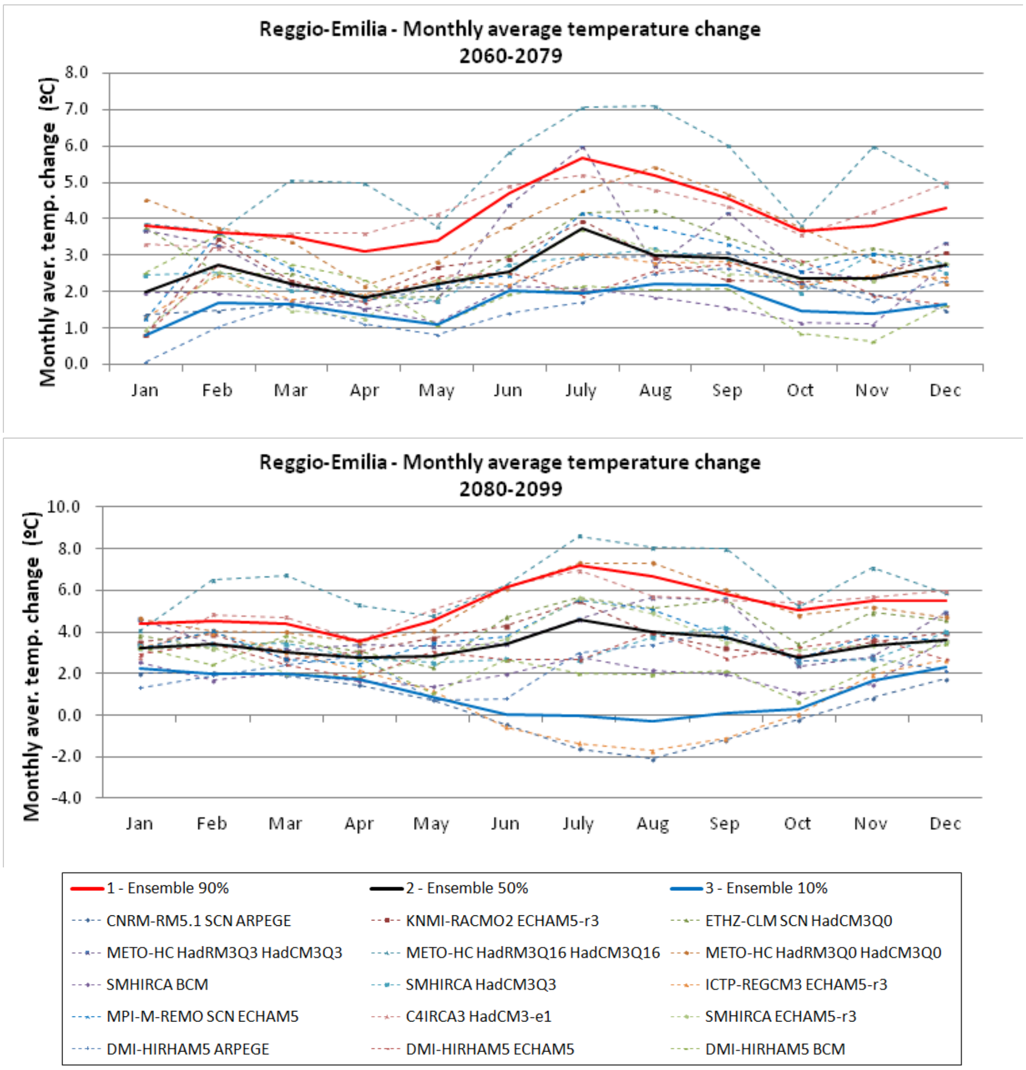


Figure A1.118 – Expected temperature change in Reggio-Emilia (2060-2079; 2080-2099)

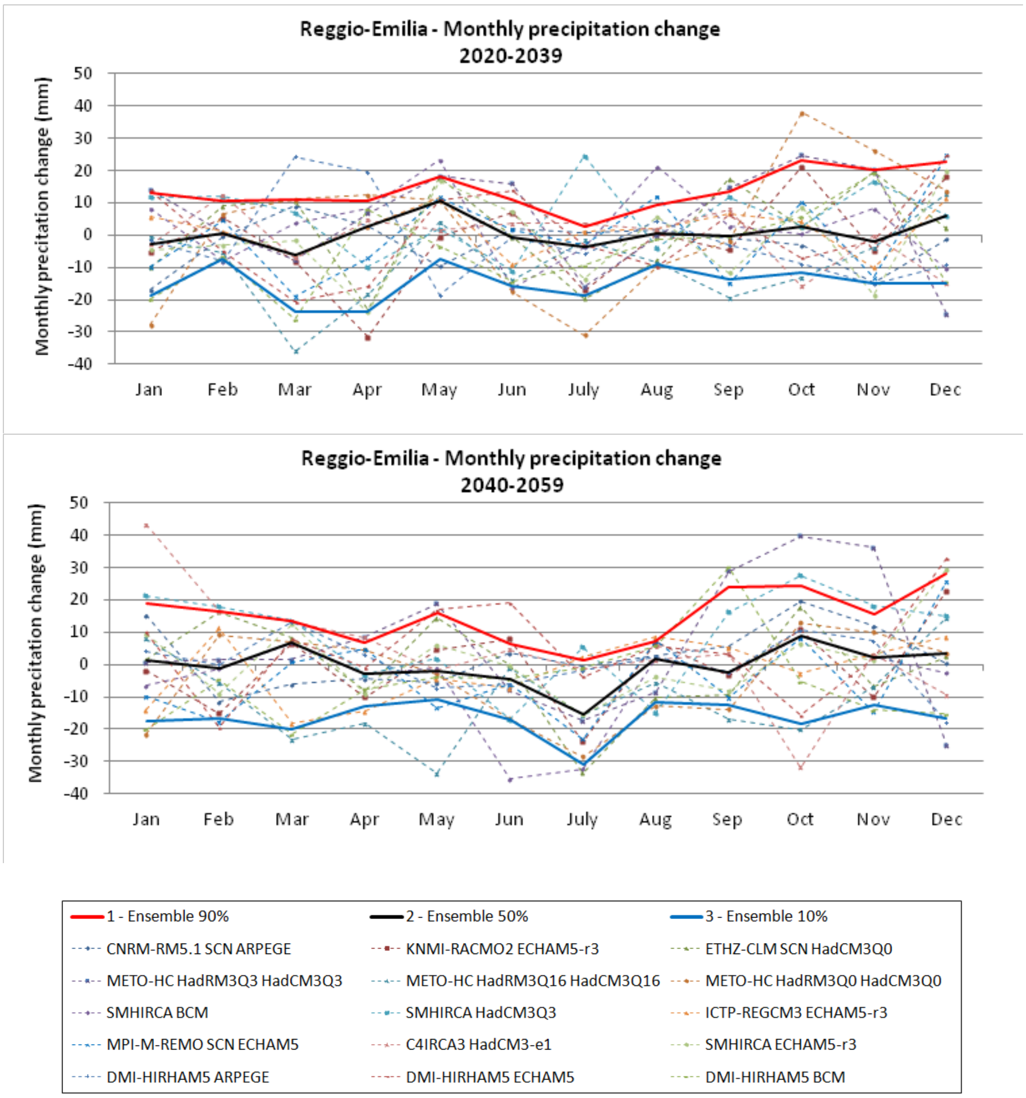


Figure A1.119 – Expected monthly precipitation change in Reggio-Emilia (2020-2039; 2040-2059) (in mm)

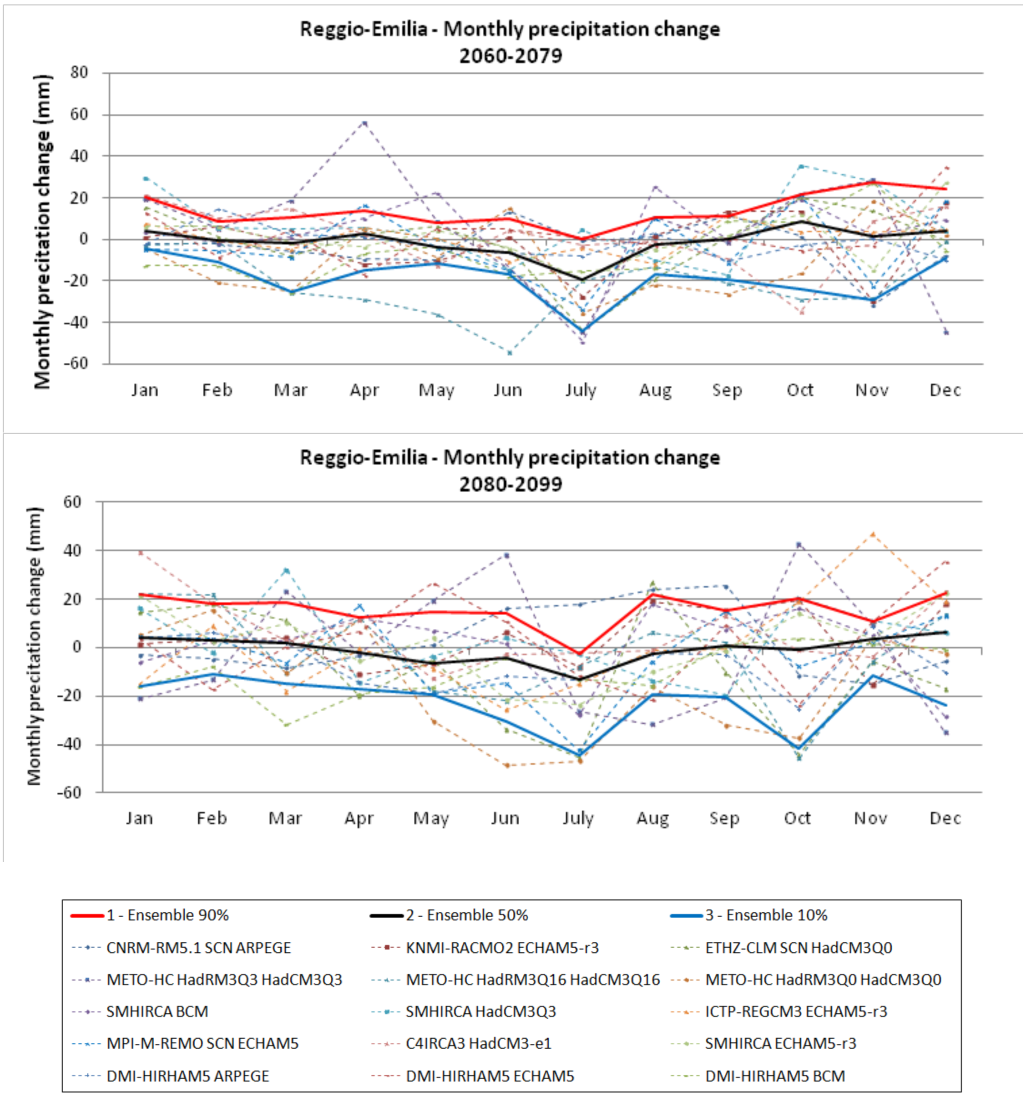


Figure A1.120 – Expected monthly precipitation change in Reggio-Emilia (2060-2079; 2080-2099) (in mm)

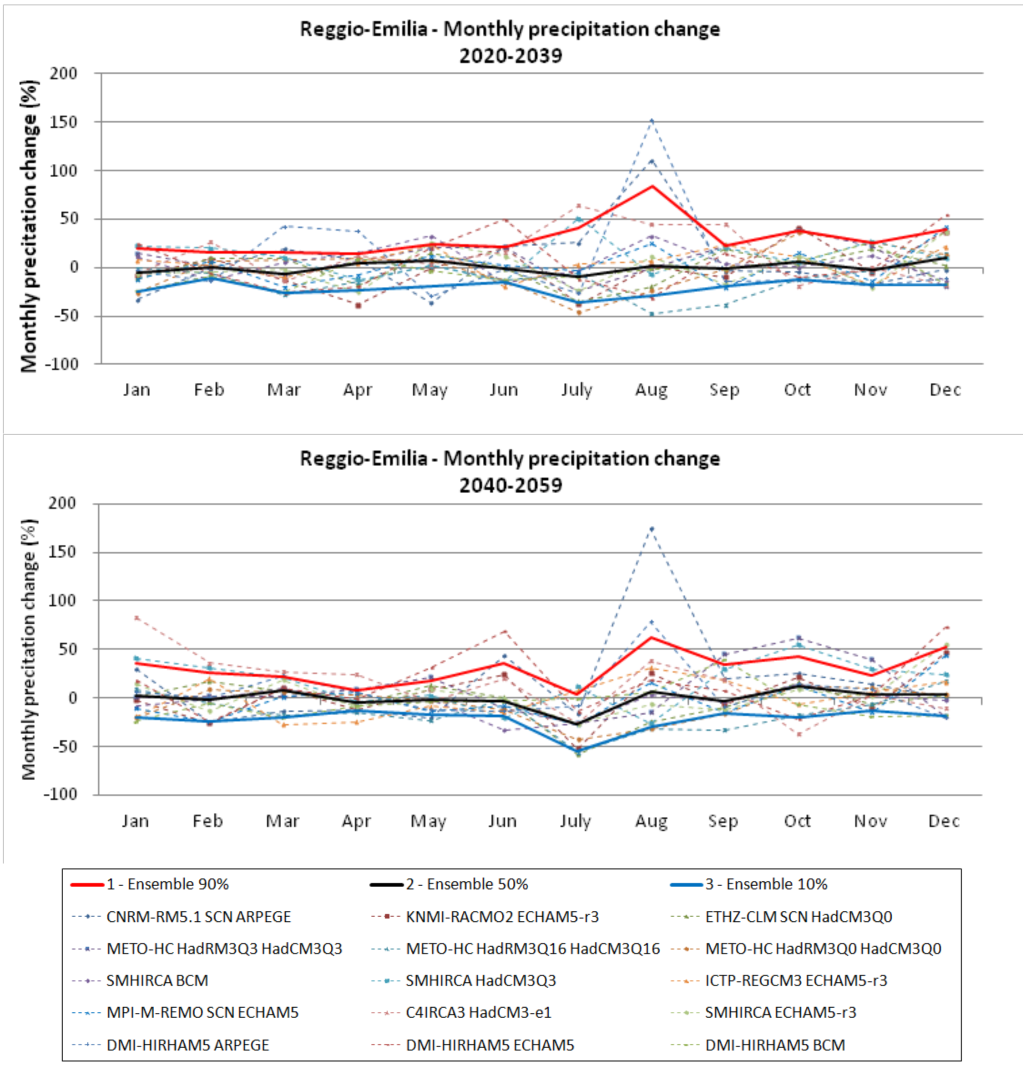


Figure A1.121 – Expected monthly precipitation change in Reggio-Emilia (2020-2039; 2040-2059) (in %)

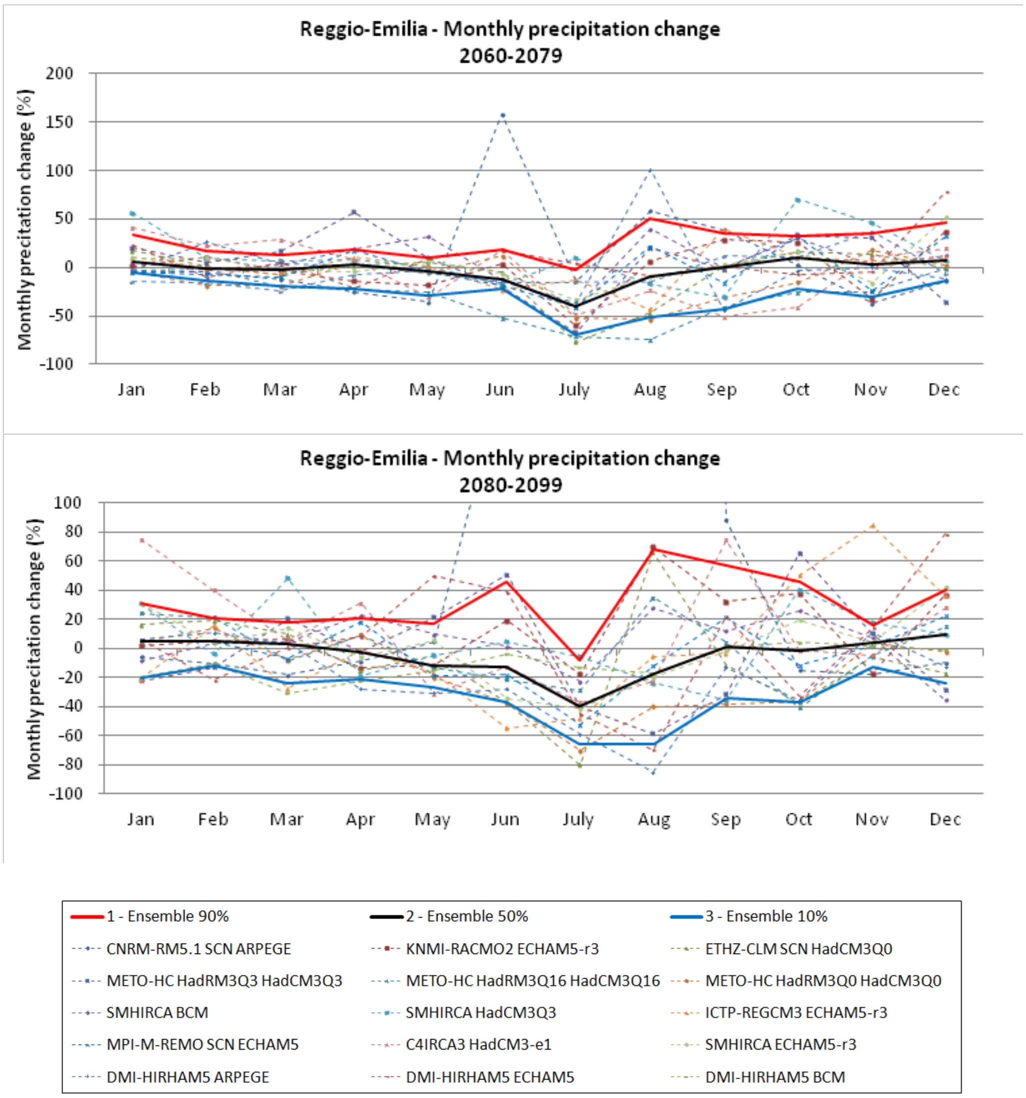
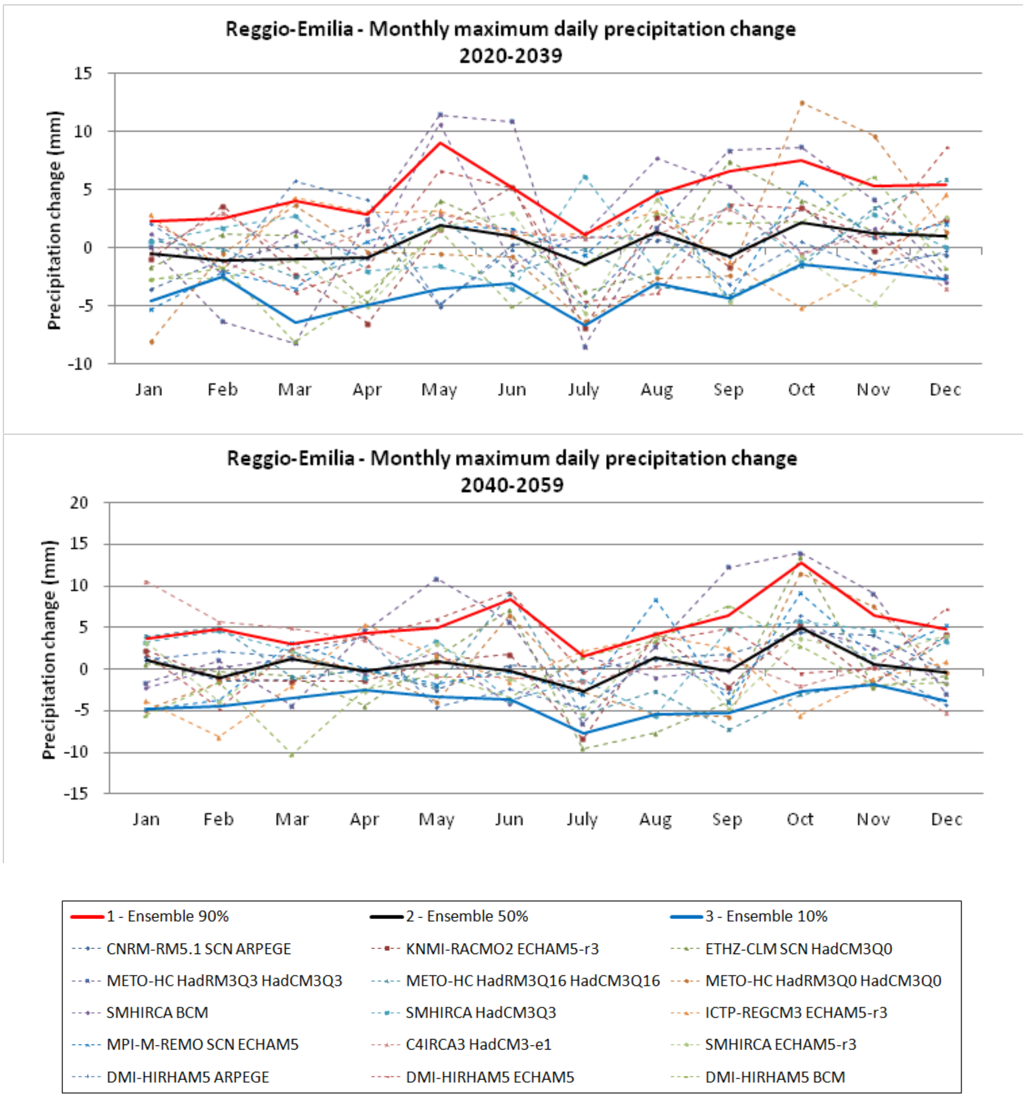


Figure A1.122 – Expected monthly precipitation change in Reggio-Emilia (2060-2079; 2080-2099) (in %)


Reggio-Emilia - Monthly maximum daily precipitation change 2020-2039

Reggio-Emilia - Monthly maximum daily precipitation change 2040-2059

Figure A1.123 – Expected monthly maximum daily precipitation change in Reggio-Emilia (2020-2039; 2040-2059) (in mm)

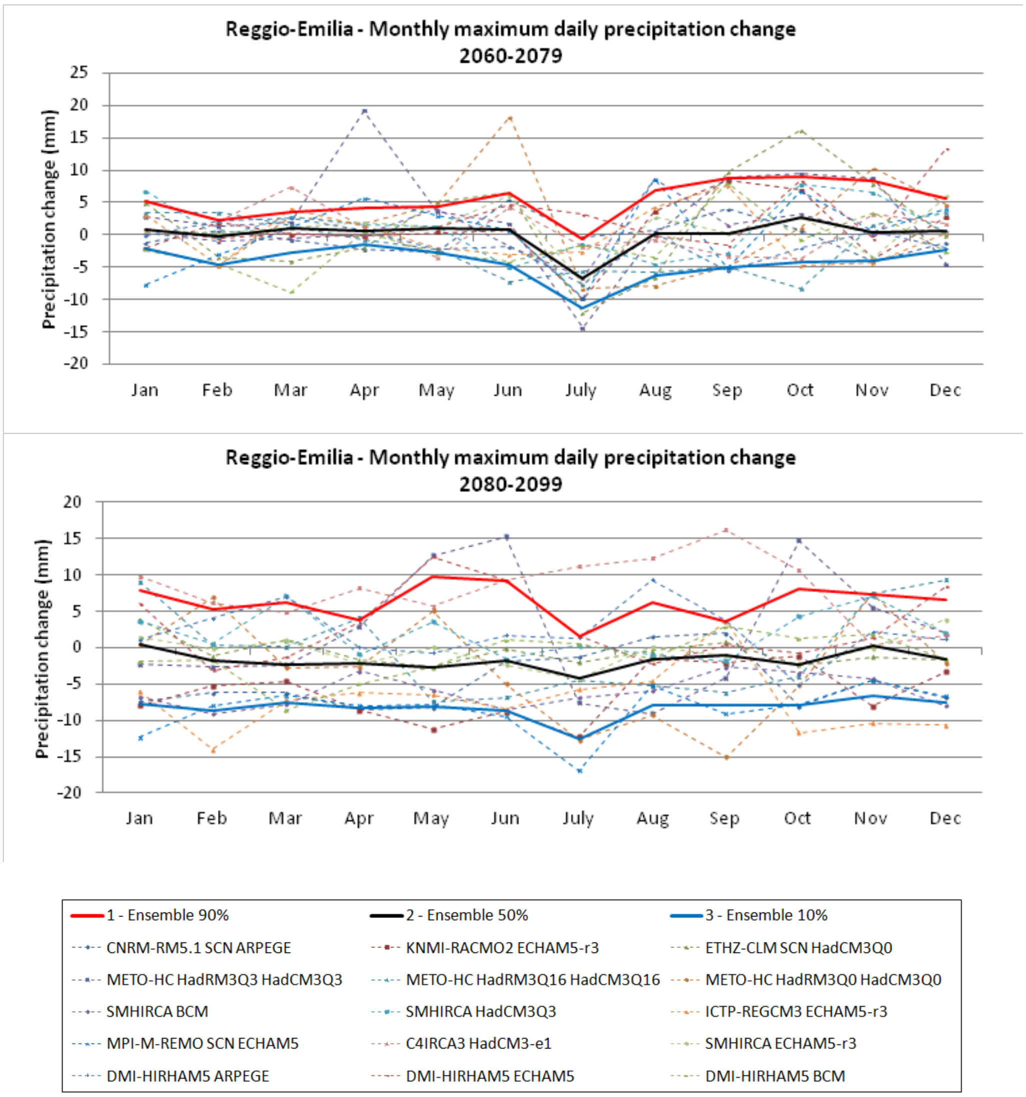


Figure A1.124 – Expected monthly maximum daily precipitation change in Reggio-Emilia (2060-2079; 2080-2099) (in mm)

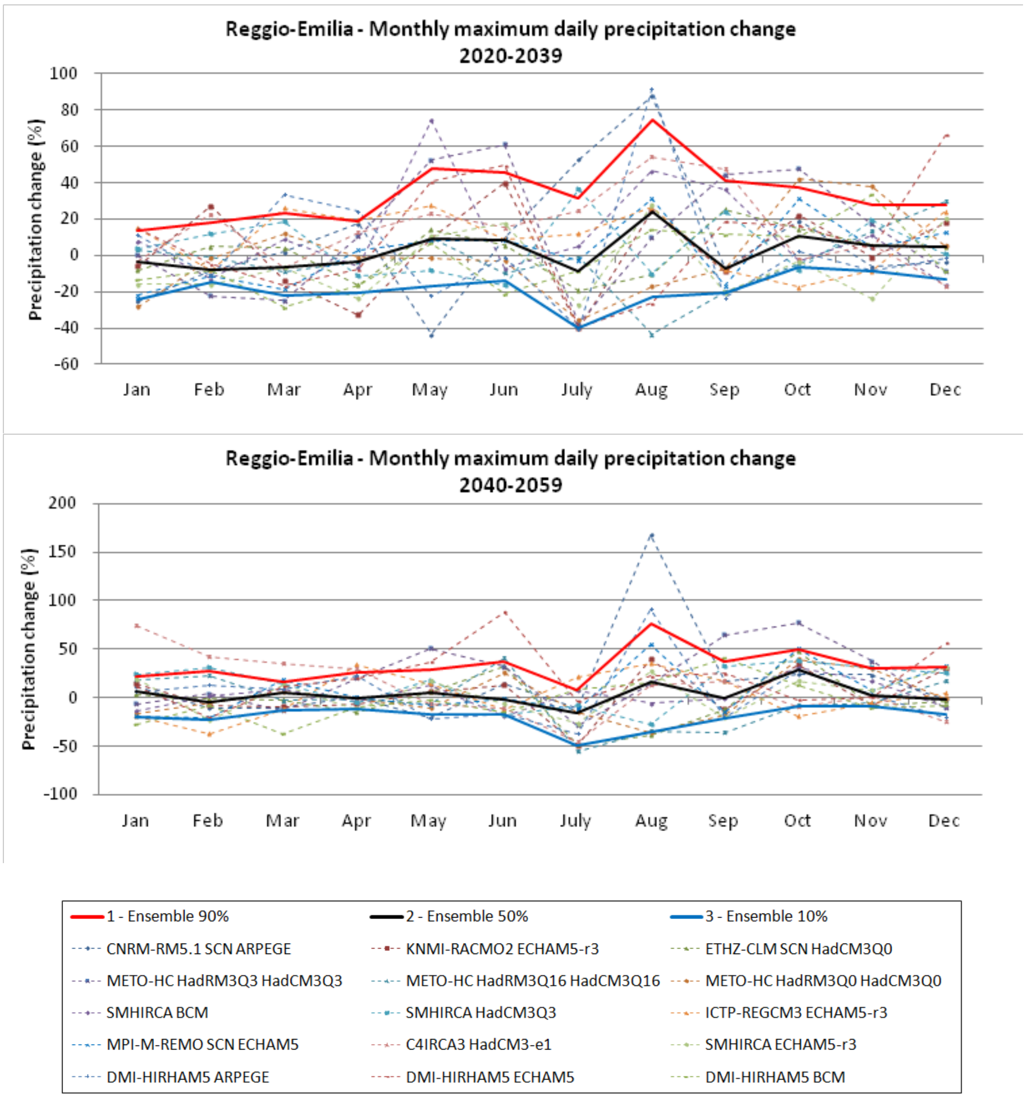


Figure A1.125 – Expected monthly maximum daily precipitation change in Reggio-Emilia (2020-2039; 2040-2059) (in %)

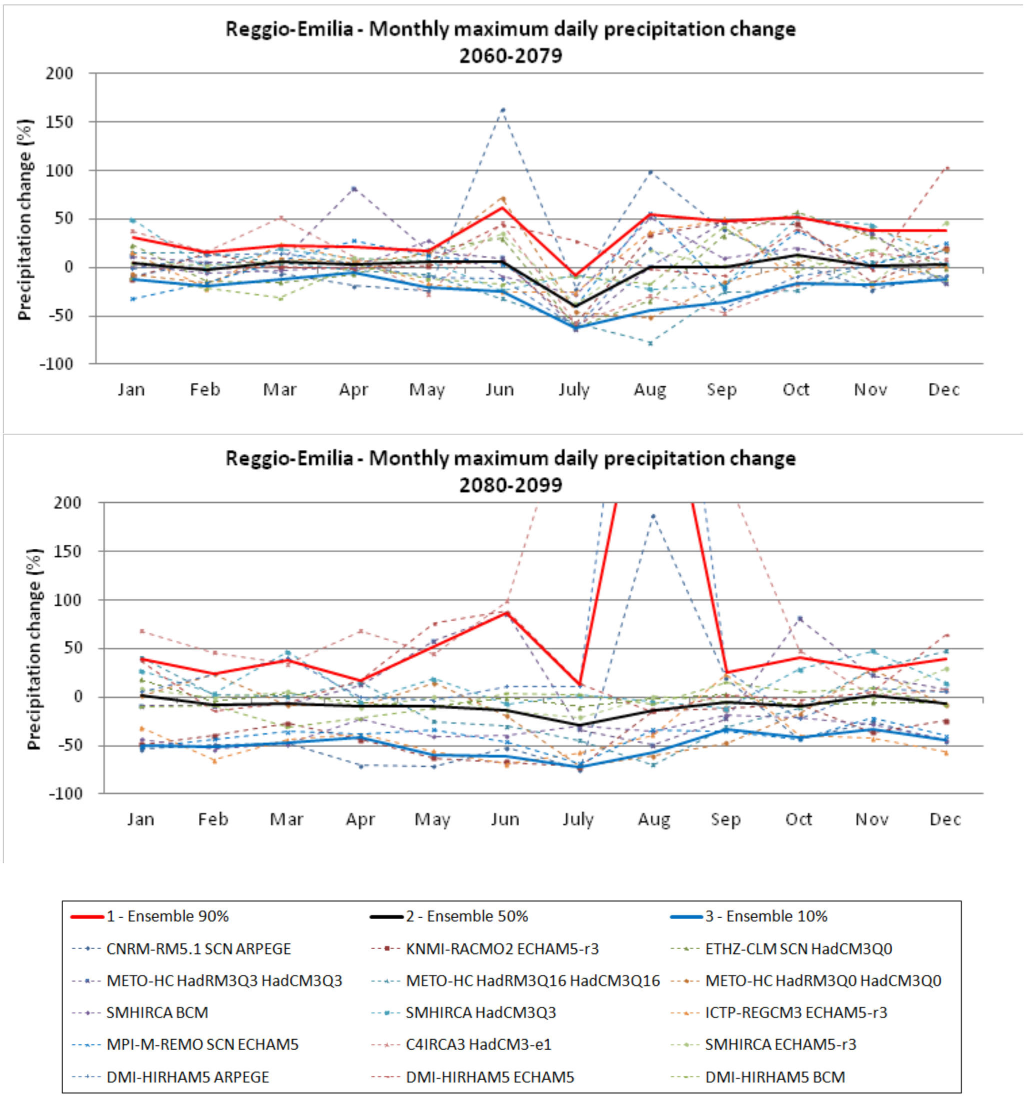


Figure A1.126 – Expected monthly maximum daily precipitation change in Reggio-Emilia (2060-2079; 2080-2099) (in %)

8. ANNEX 2 – STOCHASTIC GENERATION OF FUTURE WEATHER SCENARIOS

8.1. Introdution

Annex 2 presents the estimates of the changes expected at finer temporal scales (i.e. daily or hourly) are obtained by using stochastic models that simulate the actual behaviour of the fine-scale time series, on the basis of the available measurements of the above variables.

Such kind of modelling, extremely computationally intensive, may be carried out only when extensive time-series of high-resolution observations over the recent past are available. In the present analysis, precipitation and temperature observations at fine time scale were collected for 4 of the 10 pilot cities, i.e.: Amsterdam, Athens, Faro (for the Algarve region) and Reggio Emilia.

The approach relies on deriving factors of change for various statistics from control to future scenarios and applying these to observed statistics, rather than using the Regional Climate Models' rainfall climatology directly; such RCM climatology in fact experiences some difficulties in reproducing the spatial patterns of mean rainfall or seasonality accurately (Fowler and Kilsby, 2004) and, more importantly, does not accurately represent (Fowler et al., 2005) extreme dry spells or extreme rainfall events (Kilsby et al., 2007).

The activity consists in the generation of long synthetic rainfall and temperature continuous data series through univariate stochastic models. The models are initially calibrated and verified on the basis of the available hourly or daily historical time series. The models parameters are successively adapted in order to take into account the expected climate changes obtained in the first part of the analysis.

The methods that are considered for stochastic generation are: i) point processes models of the cluster-type (and in particular the Neyman-Scott rectangular pulses model, Cowpertwait et al., 1996, Burton et al., 2008) for the generation of precipitation synthetic time series and ii) AutoRegressive Moving Average models for the generation of temperature series (Brockwell and Davis, 1991).

Both rainfall and temperature stochastic models are initially calibrated and validated on the observations available for a set of climate stations for the past (current or baseline climate). The stochastic models are then used to simulate future rainfall and temperature sequences according to the projection of the statistics previously estimated and - on the basis of such time series – it is possible to estimate the climatic modifications to be expected as far as extreme events are concerned.

Changes in extreme events are in fact of particular importance for the design, operation and maintenance of urban water systems, whose management is generally based on the use of local rainfall Intensity-Duration-Frequency (IDF) curves developed using historical rainfall time series data. This approach implicitly implies that historic hydro-meteorological conditions can be used to represent both the past and the future (stationarity assumption), while such assumption does not hold under changing climatic conditions.

The synthetic rainfall time-series obtained against future climate scenarios will be therefore used for updating the rainfall IDF curves for the areas of the selected Pilot cities.

The present analysis will provide the decision-makers with quantitative estimates of the climatic changes that might be expected for each specific city area, to integrate the qualitative regional framework described in the main W12.1 Internal Report.

Such information may be useful also as input data for the development of some of the tasks to be performed in the next months in the other Work Areas of the Project.

8.2. Generation of future weather scenarios through stochastic simulation in reference to the pilot cities at hourly time-scale

Excerpts from: Jones, P. D., Kilsby, C. G., Harpham, C., Glenis, V., Burton, A. (2009), UK Climate Projections science report: Projections of future daily climate for the UK from the Weather Generator. University of Newcastle, UK, available on-line at http://ukclimateprojections.defra.gov.uk/content/view/1370/500/

Impact and adaptation assessments of climate change often require more detailed information than is available from the climate change projections illustrated above. Extra detail may be needed in terms of higher resolution in space and/or time. For example, projections may be needed at a specific location (like the pilot cities for TRUST) rather than an average for a grid box whose dimension is several kilometres, or the intensity of rainfall may be needed on a time scale of an hour or day, rather than the monthly or seasonal value or the long-term average. This type of information may be further analysed in terms of exceedances of thresholds, or accumulations/deficits: these cannot be derived from climate projections directly. As well as more resolution, some impact assessments are carried out using models which require time series inputs, as they are simulating processes which are sensitive to the history or sequence of events, rather than simply an aggregated average. Examples of such impact models are to be found in numerous applications such as agricultural and ecological studies, or water resource and flood risk assessments.

Such data are also needed for both the current climate and an assigned future period defined by the user, in agreement with different hypotheses of climate change at fine temporal scale. It is desirable that these future scenarios be representative of extreme events such as floods.

In view of the above incapability of climatic projections to deliver such information, a complementary approach has been developed here using a weather generator to provide high resolution time series of weather variables for the selected pilots and an average (over different GCMs) climatic condition predicted by GCMs for the year 2059.

Principles of weather generators (WGs)

The methodology uses stochastic models to generate synthetic time series of weather variables. These series may be thought of as plausible and possible sequences which may happen but have not been observed. A stochastic process (sometimes known as a random process) is one where the state of the system at one time (e.g. the weather today) does not completely determine the state at the next time (e.g. tomorrow's weather). This is the opposite of a deterministic process. Such stochastic processes are not completely random, as some paths are more probable (e.g. a wet day following a wet day) and others less allowing us to ensure that some overall statistical properties of the weather variables are conserved. So, instead of dealing with only one possible 'reality' of the weather, there are many possible and plausible realisations of not only the future, but also of the past/present.

A WG allows us to generate many different (but statistically equivalent) series. Such generated series will be stationary, a very useful statistical property. Stationarity means that they will contain weather variability, but there will be little variability in their statistical measures of climate. We can also use such very long series for studies of extremes when observed series are not long enough, or are subject to some change over time. In our context, stationarity refers only to one user-defined future period. Combining generated series from two different future time periods will remove this assumption.

Stochastic models and weather generators have been used for many years in fields such as flood risk estimation and water resources engineering, in a process known as Monte Carlo simulation. This allows many different eventualities and designs to be evaluated (often for specific future time horizons), and they form the basis for much of modern risk management.

The weather generator that is used herein is based around a stochastic rainfall model that simulates future rainfall sequences and a stochastic Fractionally Difference ARIMA model (FARIMA) to generate temperature data. Statistical measures within the weather generator are then modified according to the probabilistic projections.

The general approach herein taken is as follows:

- Observed hourly or daily rainfall totals and temperatures for the current climate are used to calibrate the WG for each pilot city (i.e. the calculation of the necessary statistics);
- Changes at the monthly time scale for each pilot are taken from the above GCM projections to define the possible future climate change (on average over the different GCMs);
- The stochastic model is then refitted using perturbed future statistics;
- Future weather variables are then generated conditioned on modified statistics above.

The changes refer to the average monthly values of rainfall and temperature for the year 2059.

The rainfall generator

The success of the above described procedure in producing realistic weather sequences therefore depends to a large extent on the method of weather generation (Hutchinson, 1986). The well-known WG developed by Richardson (1981) incorporates the simplest method, a first order Markov chain model.

However, it is now widely recognised that the clustered nature of rainfall occurrence is better modelled by more complex clustered point process rainfall models. Therefore, the Neyman- Scott Rectangular Processes (NSRP) model is herein used to generate synthetic rainfall series. The NSRP model is the basis for standard UK urban drainage design software (Cowpertwait et al., 1996). This model has been shown to realistically reproduce extreme values for engineering impact studies, using multi-site data of intense events (Cowpertwait et al., 2002) and for single-site data under present and future climates (Kilsby et al., 2007).

The Neyman-Scott rectangular pulses rainfall model introduced by Rodriguez-Iturbe et al. (1987) is a particular form of stationary and clustered point process. Storm origins (shown in Figure 4 as squares) occur accordingly to a Poisson process with arrival rate λ, so that the time between adjacent storm origins is an exponential random variable with mean $1/\lambda$. Each storm origin generates a random number C (C = 1, 2, 3, ?) of rain cells. The number of rain cells associated with a certain storm is usually assumed to be a Poisson random variable with mean ν. The waiting time, after a storm origin, for the starting of a single rain cell (shown in Figure 4 as circles) is an exponential random variable with parameter β. Each rain cell has a random duration and a random intensity, where the intensity is held constant throughout the cell duration. Both the intensity and the duration are assumed to be exponentially distributed with parameter δ and η respectively. The total rainfall intensity at time t is the sum of the intensities of all active rain cells at that time. Figure A2.1 reports a sketch of the schematisation of the hyetograph operated by the model.

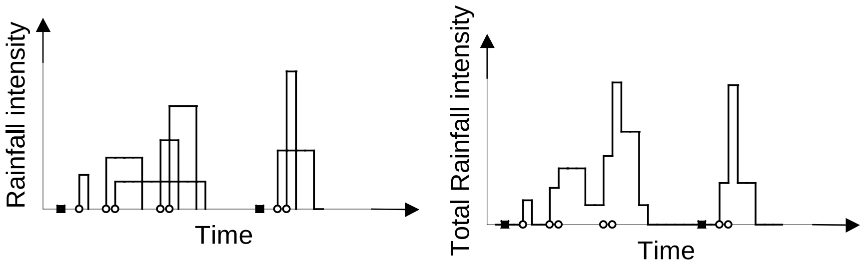


Figure A2.1 - Schematisation of the hyetograph operated by the Neyman-Scott model. Storm origins and cell origins are marked with squares and circles respectively.

The Neyman-Scott model provides a continuous-time representation of the rainfall process. The resulting rainfall depths are often aggregated over assigned time steps. The model can be used for modelling rainfall data on a wide range of time scales, provided the time step between successive observations is fine enough in order the intermittence of the process to be preserved.

The model structure is characterised by five parameters which are to be estimated by fitting historical rainfall data. Model estimation is performed by using the method of moments, which consists in equating estimates of various combinations of first- and second-order statistics from historical precipitation time series to their theoretical expressions, which are dependent on the model parameters. Least squares techniques are usually employed to minimise the differences between theoretical and computed values of the above statistics.

In order to account for seasonality, the model parameters are usually estimated on a seasonal basis. Accordingly, the year is divided into periods (seasons) and stationarity of the process is assumed in each of them. The estimation procedure is then performed for each period and thus the model parameters can assume different values in different seasons. Further details on the Neyman-Scott model can be found in Rodriguez-Iturbe et al. (1987).

In general, the parameters of the NSRP model can be estimated by selecting a set that matches, as closely as possible, the expected statistics of the generated time series with the corresponding statistics estimated from an observed rainfall time series. These statistics are derived in the first instance from observed rainfall and might typically include, for example, the mean rainfall, variance of hourly/daily rainfall and proportion of dry days. Future climate scenarios can be generated by changing rainfall statistics accordingly to the GCMs projections.

The temperature generator

The generation of the synthetic hourly temperature record was performed by referring to the pilot cities and was carried out by applying a fractionally differenced autoregressive integrated moving average (FARIMA) model. On many occasions, this class of models turned out to be able to fit the autocorrelation structure of temperature series, which is very often affected by a slow decay, which may suggest the presence of long-term persistence, implying this way the presence of the Hurst effect (Montanari, 2003). More details on FARIMA models and the simulation procedure herein applied are given by Montanari et al. (1997), Montanari et al. (2000) and Montanari (2005).

8.3. Calibration of the weather generator model for the pilot city of Reggio Emilia

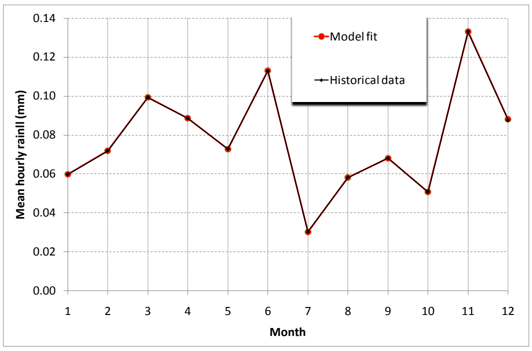
Calibration of the rainfall generator

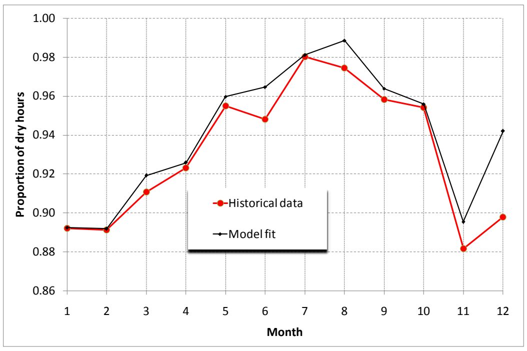
The rainfall generator was calibrated by using an historical hourly rainfall record observed at Reggio Emilia in the period May 2004 – August 2011. A few missing values are present. The historical series is not very long and therefore could not be fully representative of the current climate. Ideally, a longer observation period would be desirable.

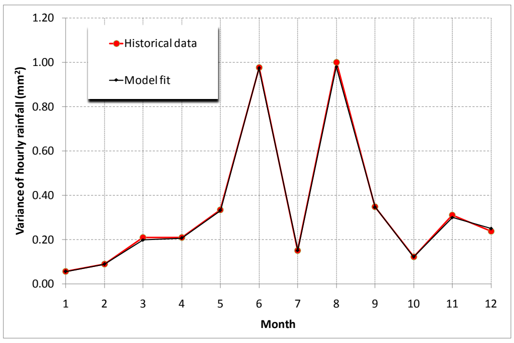
For the purpose of rainfall generation, it was decided to subdivide the year in 12 periods (seasons) corresponding to the 12 calendar months. The NSRP model was applied by using the software RAINSIM, that was kindly provided by the University of Newcastle Upon Tyne (Burton et al., 2008; 2010a; 2010b).

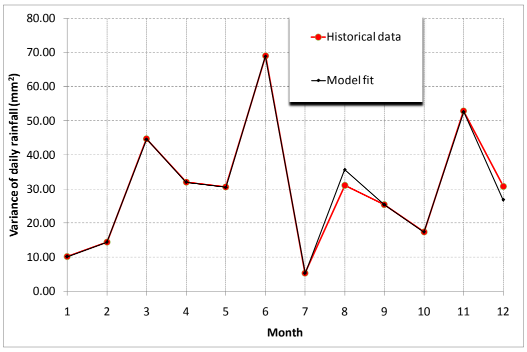
The NSRP model was calibrated by optimising the fit of the following statistics:

- Mean hourly rainfall for each month;
- Proportion of dry hours for each month;
- Variance of hourly rainfall for each month;
- Variance of daily rainfall for each month;
- Lag-one correlation of daily rainfall for each month.









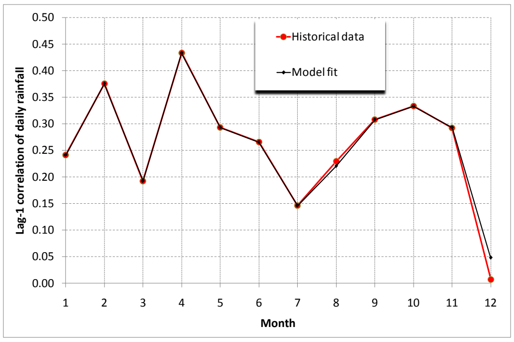


Figure A2.2 reports a comparison between observed and fitted statistics. It can be seen that the model provides a very good fit.

A 10-year long simulation of hourly rainfall data was performed in order to compare historical, fitted and simulated statistics. The results are shown in Figure A2.3.

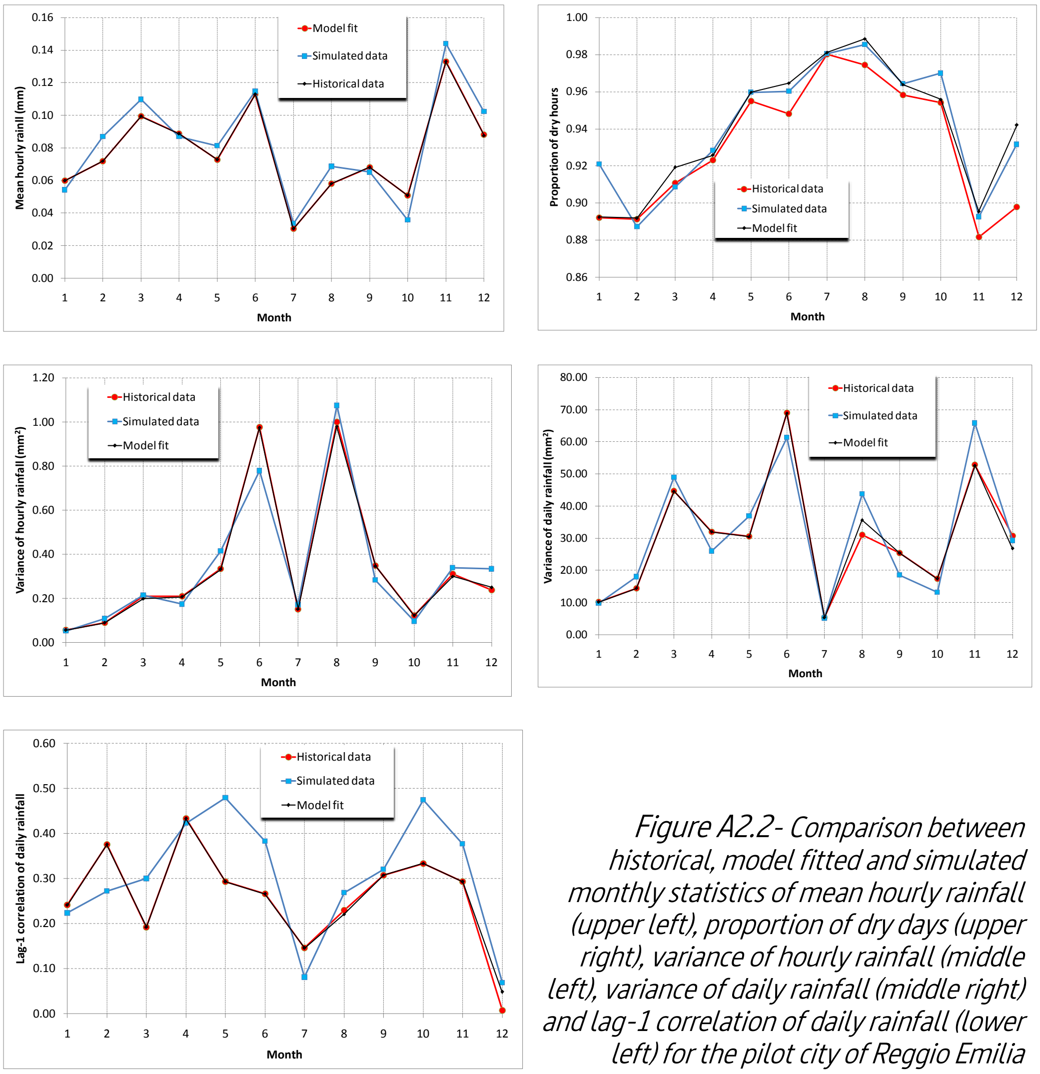


Figure A2.2- Comparison between historical, model fitted and simulated monthly statistics of mean hourly rainfall (upper left), proportion of dry days (upper right), variance of hourly rainfall (middle left), variance of daily rainfall (middle right) and lag-1 correlation of daily rainfall (lower left) for the pilot city of Reggio Emilia

The agreement is very satisfactory in consideration of the length of the observed record. In fact, the considered statistics are affected by uncertainty induced by the limited sample size, which is particularly significant for correlation. Therefore the simulated values are in good agreement with the historical ones. However, it is to be considered that these simulated data refer to the actual climate. The file of the simulated data can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-current-climate-reggio-emilia.zip .

In order to get an indication on the fit of the extremes, it is useful to compare depth-duration-frequency curves computed on historical and simulated data. The comparison, that is reported in Figure A2.4, shows that the agreement is indeed very good. However, it appears that the curves are underestimating the extremes for the longer rainfall duration, with respect to what local expert knowledge suggests. Underestimation is due to the limited length of the historical record.

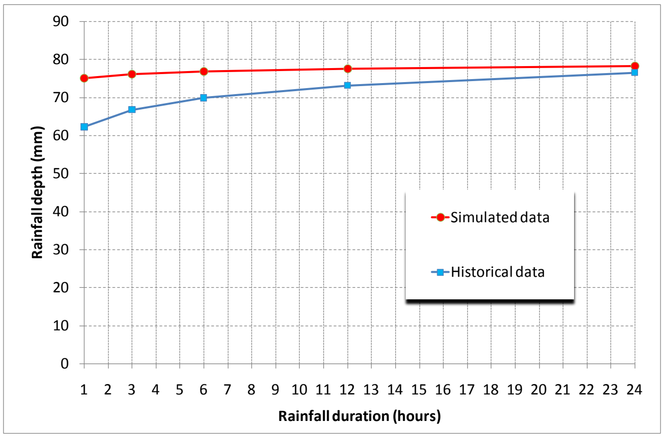


Figure A2.3- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using historical and simulated data for the pilot city of Reggio Emilia

Calibration of the temperature generator

The temperature generator was calibrated by using an historical hourly temperature record observed at Reggio Emilia in the period Jan 2005 – Dec 2010. A few missing values are present. Temperature data are affected by seasonality. It is usual practice in stochastic modelling of non-intermittent series to deal with seasonality by performing a preliminary deseasonalisation of the mean value of the data. Deseasonalisation was performed by using the method proposed by Grimaldi and Montanari (2000). Figure A2.5 reports the seasonal component as well as autocorrelation functions, for lag up to one year, of original and deseasonalised data. It can be seen that the deseasonalisation was successful.

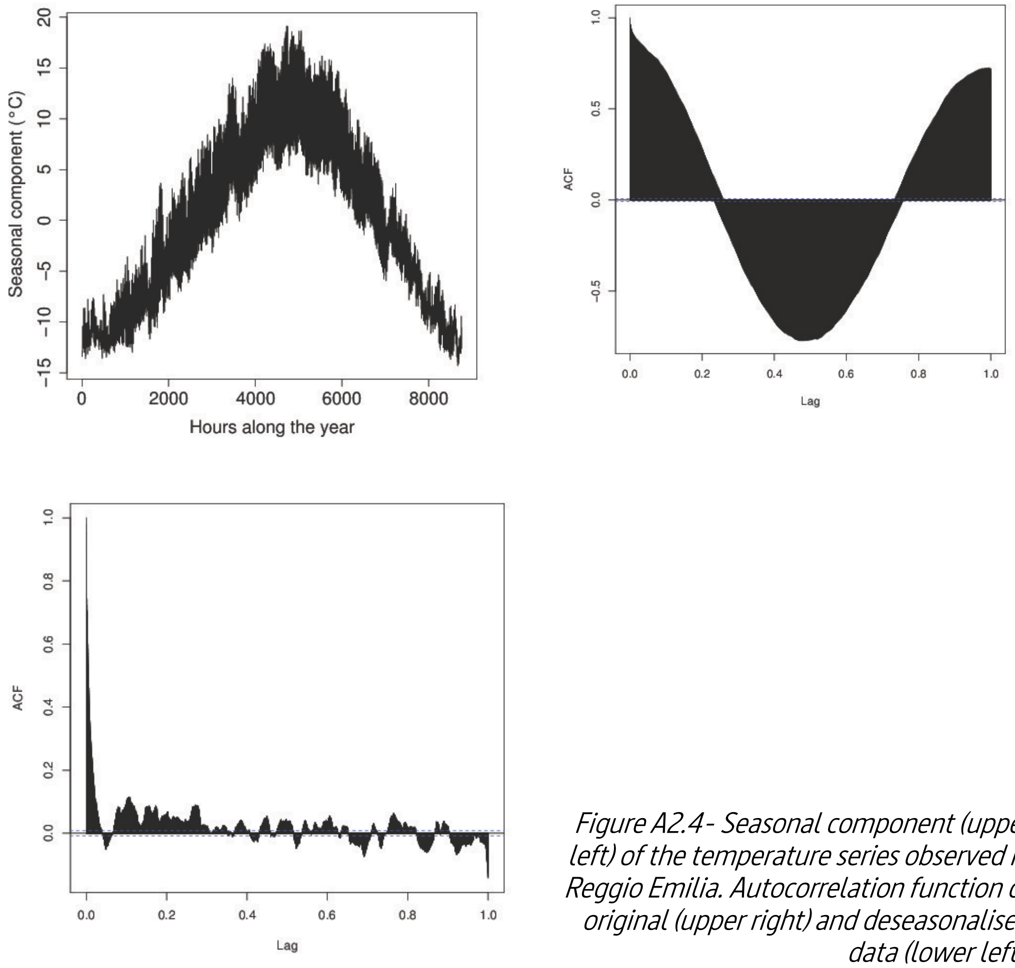


Figure A2.4- Seasonal component (upper left) of the temperature series observed in Reggio Emilia. Autocorrelation function of original (upper right) and deseasonalised data (lower left).

The best FARIMA model was identified accordingly to the procedure proposed by Montanari et al. (1997), which suggested the use of a FARIMA(1,d,0) model. Figure A2.5 reports the autocorrelation function of the residuals for lags up to one year. It can be seen that the residual correlation is scarcely significant, with the only exception of the lags around 24 hours. However, in consideration of the amount of variance that is explained by the seasonal component, the fit provided by the FARIMA model can be considered satisfactory.

The autoregressive parameter is 0.84 (with 95% confidence limits [0.83-085]) while the fractional differencing parameter is 0.32 (with 95% confidence limits [0.30-0.34]).

8.4. Generation of synthetic weather scenario referred to the year 2050 under climate change for the pilot city of Reggio Emilia

Rainfall generation

To generate future weather scenarios one needs to perturb the parameters of the Neyman-Scott model accordingly to changes in mean rainfall predicted by GCMs. In detail, for Reggio – Emilia changes as predicted by the 50% ensemble are used, which are summarised in Table A2.1.

Table A2. 1. Percentage changes in mean rainfall in Reggio Emilia up to the year 2059.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
+17%	0%	-3%	-5%	-10%	-3%	-5%	-5%	-10%	+3%	0%	+3%

The above variation in mean rainfall can be obtained, in the weather generator, accordingly to two hypotheses:

- Hypothesis 1: changes are obtained by varying the mean number of rainfall events in each month (HP 1).
- Hypothesis 2: changes are obtained by varying the rainfall intensity in each event (HP 2).

Generation is done accordingly to both hypotheses.

- **Generation accordingly to HP 1**

A 10-year run of rainfall in the future scenario was generated accordingly to the HP 1. Figure A2.6 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

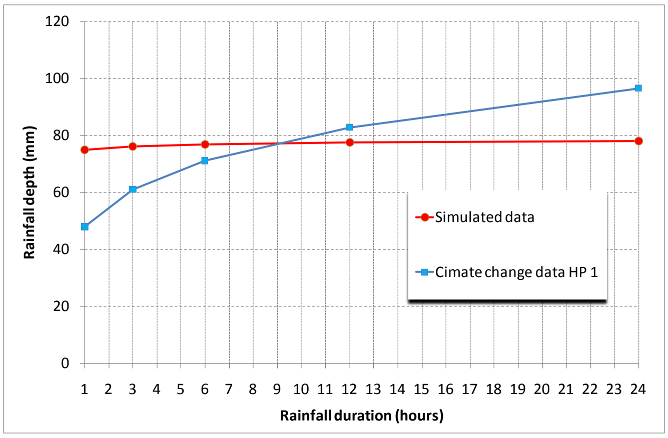


Figure A2.5- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 1) for the pilot city of Reggio Emilia

The results show an increase of the extreme rainfall for the longer durations which is compensated by a decrease for the shorter durations. This effect can be ascribed to the superimposition of some events in the winter months for the increases of the number of events themselves in the months of December and January. While the decrease of the extreme rainfall for the shorter durations is probably due to the summer decrease of the number of events. These simulated data under the HP 1 hypothesis can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-reggio-emilia-HP1.zip

- **Generation accordingly to HP 2**

A 10-year run of rainfall in the future scenario was generated accordingly to HP 2. Figure A2.7 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

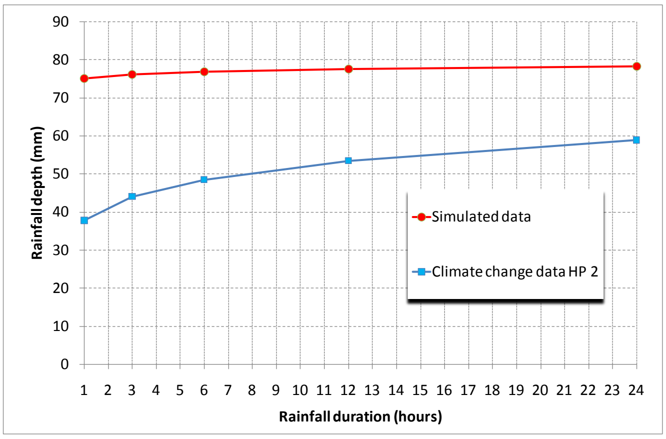


Figure A2.6 - Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 2) for the pilot city of Reggio Emilia

The results show a general decrease of the extreme rainfall which is more significant for the shorter durations. This effect can be ascribed to the general decrease of rainfall intensity in the months where the intensity itself is much more sizeable. These simulated data under the HP 2 hypothesis can be downloaded here:
http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-reggio-emilia-HP2.zip

One should note that the limited sample size that was used for the generation (which was selected in view of the limited sample size of the historical data) introduces some sample variability which may have an influence on the results. Moreover, one should also note that the two hypotheses above are not exhaustive of all the possible climate change combinations that might end up with a given change in the mean rainfall. For instance, a decrease in mean rainfall could be originated by a significant decrease of the number of events and a corresponding increase in their intensity. In this case, the extreme events may result more severe, even if the number of events and the mean rainfall are decreased.

Accordingly to the above hypotheses, one can conclude that the projected climate changes should not originate concerning situations for the management of urban drainage systems that are usually designed on the basis of short-term extreme rainfall.

Temperature generation

To generate future weather scenarios the seasonal component estimated above was perturbed accordingly to changes in mean temperature predicted by GCMs. In detail, for Reggio – Emilia changes as predicted by the 50% ensemble are used, which are summarised in Table A2.2.

Table A2. 2. Changes in mean temperature in Reggio Emilia up to the year 2059.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2.4	1.8	1.9	2.0	2.2	2.4	3.2	3.1	3.0	2.3	1.7	1.8

Generation was performed for a 10-year long temperature record. Figure A2.8 reports a comparison between the autocorrelation functions of simulated data in the current climate and the future scenario. Given that mean temperature only, at monthly time scale, was changed, one would expect a good agreement between the 2 autocorrelations. Figure 12 in fact confirms the good fit provided by the model.

These simulated temperature data can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-reggio-emilia-tem.zip

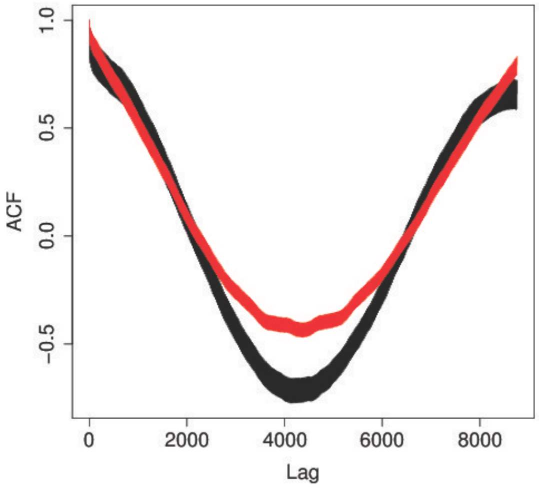


Figure A2.7 - Comparison between autocorrelation functions of simulated hourly temperature data in the current climate (black line) and the 2059 scenario (red line) for the pilot city of Reggio Emilia. The maximum lag is 8760 hours (one year). Lines look thick for the 24-hour oscillation of the autocorrelation.

8.5. Calibration of the weather generator model for the pilot city of Faro (Algarve Region)

Calibration of the rainfall generator

The rainfall generator was calibrated by using an historical hourly rainfall record observed at Faro in the period March 2001 – December 2009. A few missing values are present. The historical series is not very long and therefore could not be fully representative of the current climate. Ideally, a longer observation period would be desirable.

For the purpose of rainfall generation, it was decided to subdivide the year in 12 periods (seasons) corresponding to the 12 calendar months.

- The NSRP model was calibrated by optimising the fit of the following statistics:
- Mean hourly rainfall for each month;
- Proportion of dry hours for each month;
- Variance of hourly rainfall for each month;
- Variance of daily rainfall for each month;
- Lag-one correlation of daily rainfall for each month.

Figure 12 reports a comparison between observed and fitted statistics. It can be seen that the model provides a very good fit.

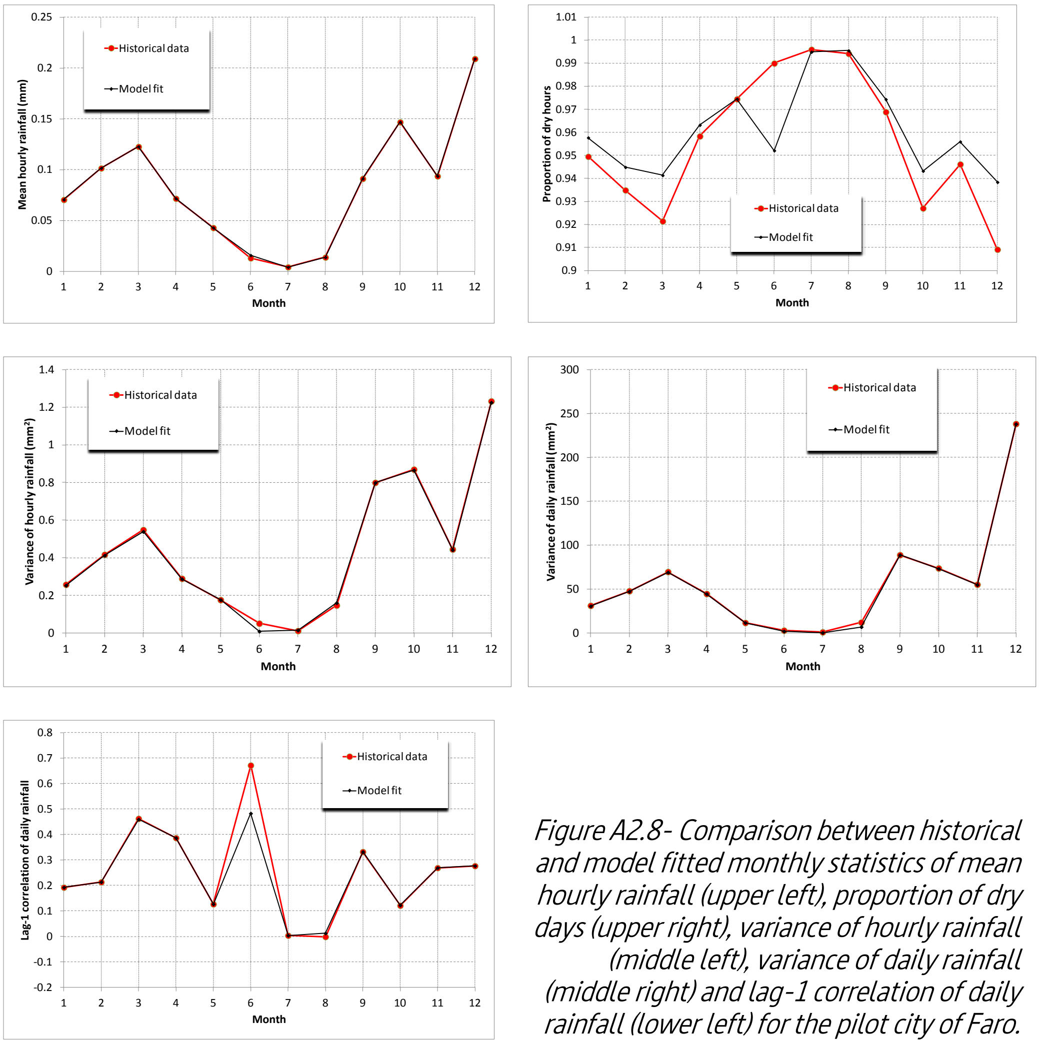


Figure A2.8- Comparison between historical and model fitted monthly statistics of mean hourly rainfall (upper left), proportion of dry days (upper right), variance of hourly rainfall (middle left), variance of daily rainfall (middle right) and lag-1 correlation of daily rainfall (lower left) for the pilot city of Faro.

A 10-year long simulation of hourly rainfall data was performed in order to compare historical, fitted and simulated statistics. The results are shown in Figure 13.

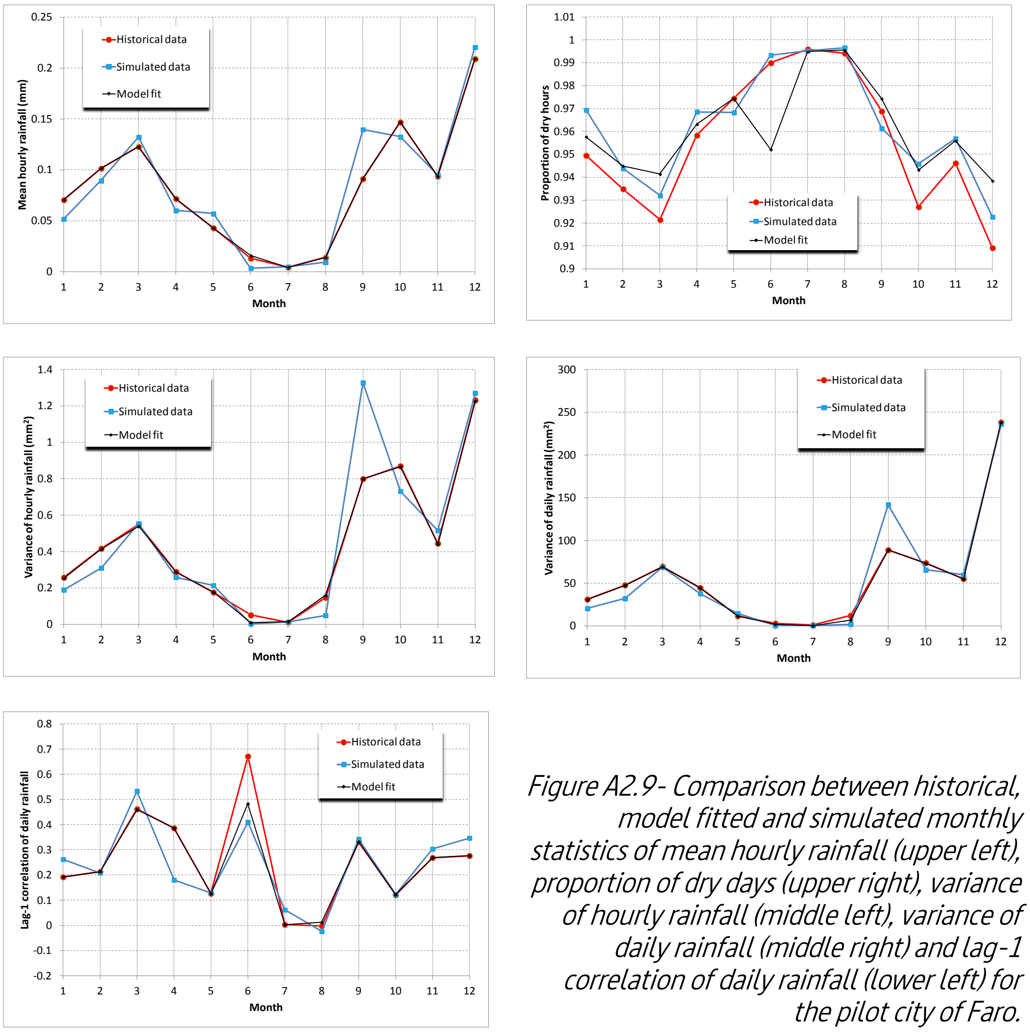


Figure A2.9- Comparison between historical, model fitted and simulated monthly statistics of mean hourly rainfall (upper left), proportion of dry days (upper right), variance of hourly rainfall (middle left), variance of daily rainfall (middle right) and lag-1 correlation of daily rainfall (lower left) for the pilot city of Faro.

The agreement is very satisfactory in consideration of the length of the observed record. In fact, the considered statistics are affected by uncertainty induced by the limited sample size, which is particularly significant for correlation. Therefore the simulated values are in good agreement with the historical ones. However, it is to be considered that these simulated data refer to the actual climate. The file of the simulated data can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-current-climate-FARO-Algarve.zip.

In order to get an indication on the fit of the extremes, it is useful to compare depth-duration-frequency curves computed on historical and simulated data. The comparison, that is reported in Figure 14, shows that the agreement is indeed very good. However, it appears that the curves are underestimating the extremes for the longer rainfall duration, with respect to what local expert knowledge suggests. Underestimation is due to the limited length of the historical record.

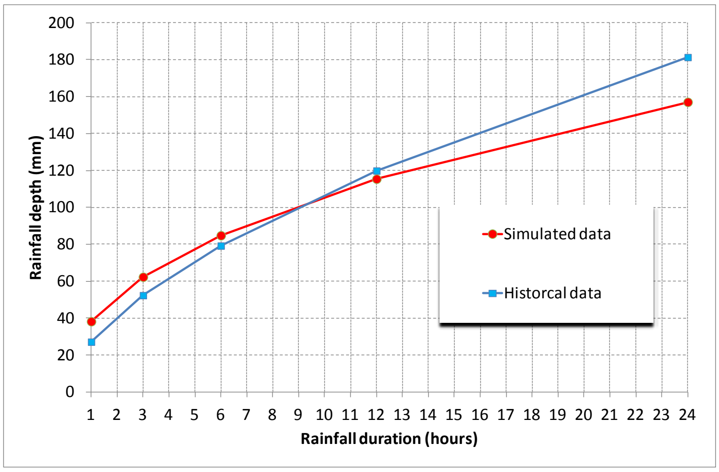


Figure A2.10- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using historical and simulated data for the pilot city of Faro.

Calibration of the temperature generator

The temperature generator was calibrated by using an historical hourly temperature record observed at Faro in the period Jan 2006 – Dec 2010. A few missing values are present. Figure 15 reports the seasonal component as well as autocorrelation functions, for lag up to one year, of original and deseasonalised data. It can be seen that the deseasonalisation was successful.

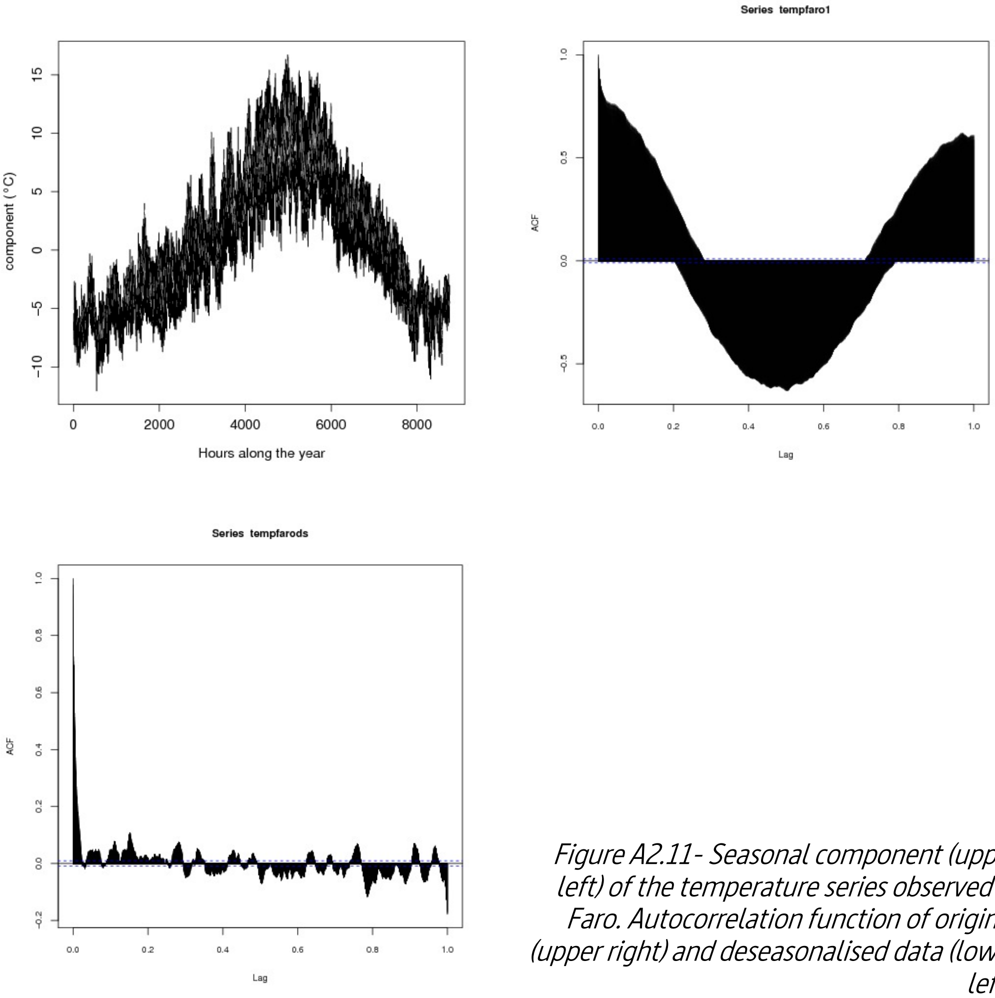


Figure A2.11- Seasonal component (upper left) of the temperature series observed in Faro. Autocorrelation function of original (upper right) and deseasonalised data (lower left).

The best FARIMA model was identified accordingly to the procedure proposed by Montanari et al. (1997), which suggested the use of a FARIMA(2,d,1) model. The residual correlation is scarcely significant. Therefore, the fit provided by the FARIMA model can be considered satisfactory.

The autoregressive parameters are 0.42 and 0.29, while the moving average parameter is -0.42. The fractional differencing parameter is 0.44 (with 95% confidence limits [0.41-0.47]).

8.6. Generation of synthetic weather scenario referred to the year 2050 under climate change for the pilot city of Faro

Rainfall generation

To generate future weather scenarios one needs to perturb the parameters of the Neyman-Scott model accordingly to changes in mean rainfall predicted by GCMs. In detail, for Faro changes as predicted by the 50% ensemble are used, which are summarised in Table 5.

Table A2. 3. Percentage changes in mean rainfall in Faro up to the year 2059.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
-9%	-21%	-20%	-9%	-14%	-10%	2%	-16%	-9%	-15%	-9%	-12%

The above variation in mean rainfall can be obtained, in the weather generator, accordingly to two hypotheses:

- Hypothesis 1: changes are obtained by varying the mean number of rainfall events in each month (HP 1).
- Hypothesis 2: changes are obtained by varying the rainfall intensity in each event (HP 2).

Generation is done accordingly to both hypotheses.

- **Generation accordingly to HP 1**

A 10-year run of rainfall in the future scenario was generated accordingly to the HP 1. Figure 16 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

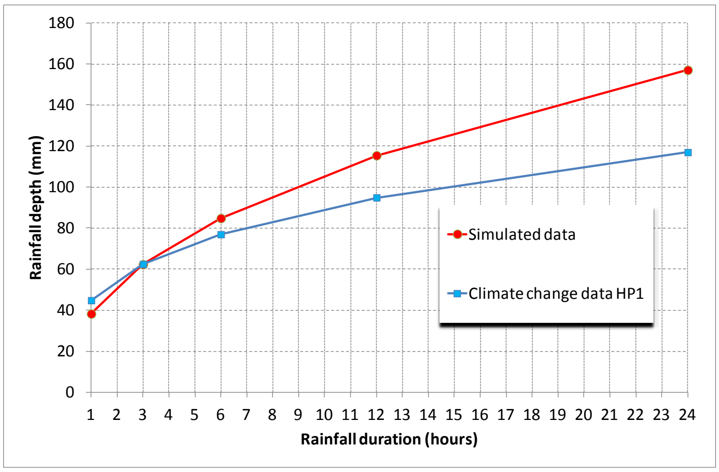


Figure A2.12- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 1) for the pilot city of Faro.

The results show an increase of the extreme rainfall for the longer durations which is particularly significant for the 24-hour rainfall for which a 25% increase is noticed. These simulated data under the HP 1 hypothesis can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-FARO-Algarve-HP1.zip

- **Generation accordingly to HP 2**

A 10-year run of rainfall in the future scenario was generated accordingly to HP 2. Figure 17 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

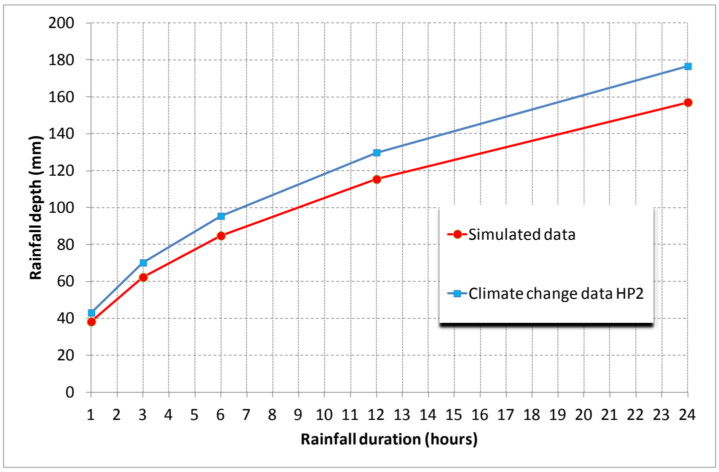


Figure A2.13- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 2) for the pilot city of Faro.

The results show a general increase of the extreme rainfall which, however, is not pronounced. These simulated data under the HP 2 hypothesis can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-FARO-Algarve-HP2.zip

One should note that the limited sample size that was used for the generation (which was selected in view of the limited sample size of the historical data) introduces some sample variability which may have an influence on the results. Moreover, one should also note that the two hypotheses above are not exhaustive of all the possible climate change combinations that might end up with a given change in the mean rainfall. For instance, a decrease in mean rainfall could be originated by a significant decrease of the number of events and a corresponding increase in their intensity. In this case, the extreme events may result more severe, even if the number of events and the mean rainfall are decreased.

Accordingly to the above hypotheses, one can conclude that the projected climate changes should not originate concerning situations for the management of urban drainage systems, that are usually designed on the basis of short-term extreme rainfall.

Temperature generation

To generate future weather scenarios the seasonal component estimated above was perturbed accordingly to changes in mean temperature predicted by GCMs. In detail, for Faro changes as predicted by the 50% ensemble are used, which are summarised in Table 6.

Table A2. 4. Changes in mean temperature in Faro (Algarve) up to the year 2059.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1.5	1.4	1.4	1.6	1.7	1.7	1.9	1.9	2.2	1.8	1.4	1.4

Generation was performed for a 10-year long temperature record. Figure 18 reports a comparison between the autocorrelation functions of simulated data in the current climate and the future scenario. It confirms the good fit provided by the model.

These simulated temperature data can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-faro-tem.zip.

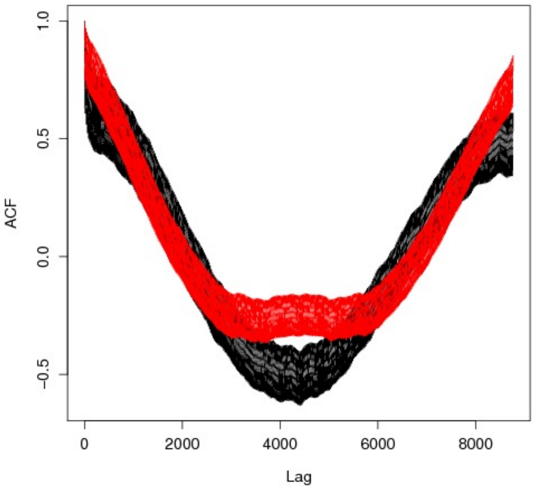


Figure A2.14- Comparison between autocorrelation functions of simulated hourly temperature data in the current climate (black line) and the 2059 scenario (red line) for the pilot city of Faro. The maximum lag is 8760 hours (one year). Lines look thick for the 24-hour oscillation of the autocorrelation.

8.7. Calibration of the weather generator model for the pilot city of Athens

Calibration of the rainfall generator

The rainfall generator was calibrated by using an historical hourly rainfall record observed at Athens in the period January 2001 – July 2011. A few missing values are present. The historical series is not very long and therefore could not be fully representative of the current climate. Ideally, a longer observation period would be desirable.

For the purpose of rainfall generation, it was decided to subdivide the year in 12 periods (seasons) corresponding to the 12 calendar months. The NSRP model was calibrated by optimising the fit of the following statistics:

- Mean hourly rainfall for each month;
- Proportion of dry hours for each month;
- Variance of hourly rainfall for each month;
- Variance of daily rainfall for each month;
- Lag-one correlation of daily rainfall for each month.

Figure 19 reports a comparison between observed and fitted statistics. It can be seen that the model provides a very good fit.

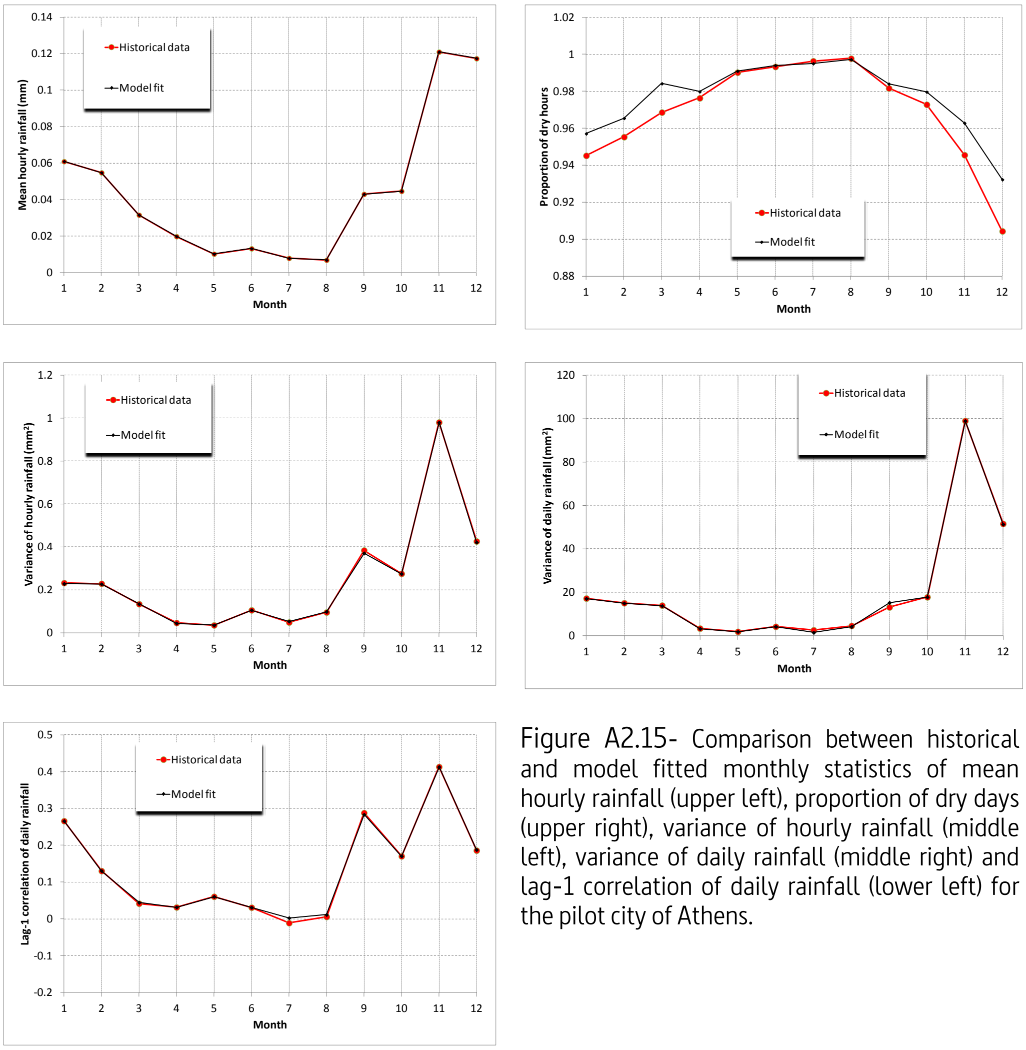


Figure A2.15- Comparison between historical and model fitted monthly statistics of mean hourly rainfall (upper left), proportion of dry days (upper right), variance of hourly rainfall (middle left), variance of daily rainfall (middle right) and lag-1 correlation of daily rainfall (lower left) for the pilot city of Athens.

A 10-year long simulation of hourly rainfall data was performed in order to compare historical, fitted and simulated statistics. The results are shown in Figure 20.

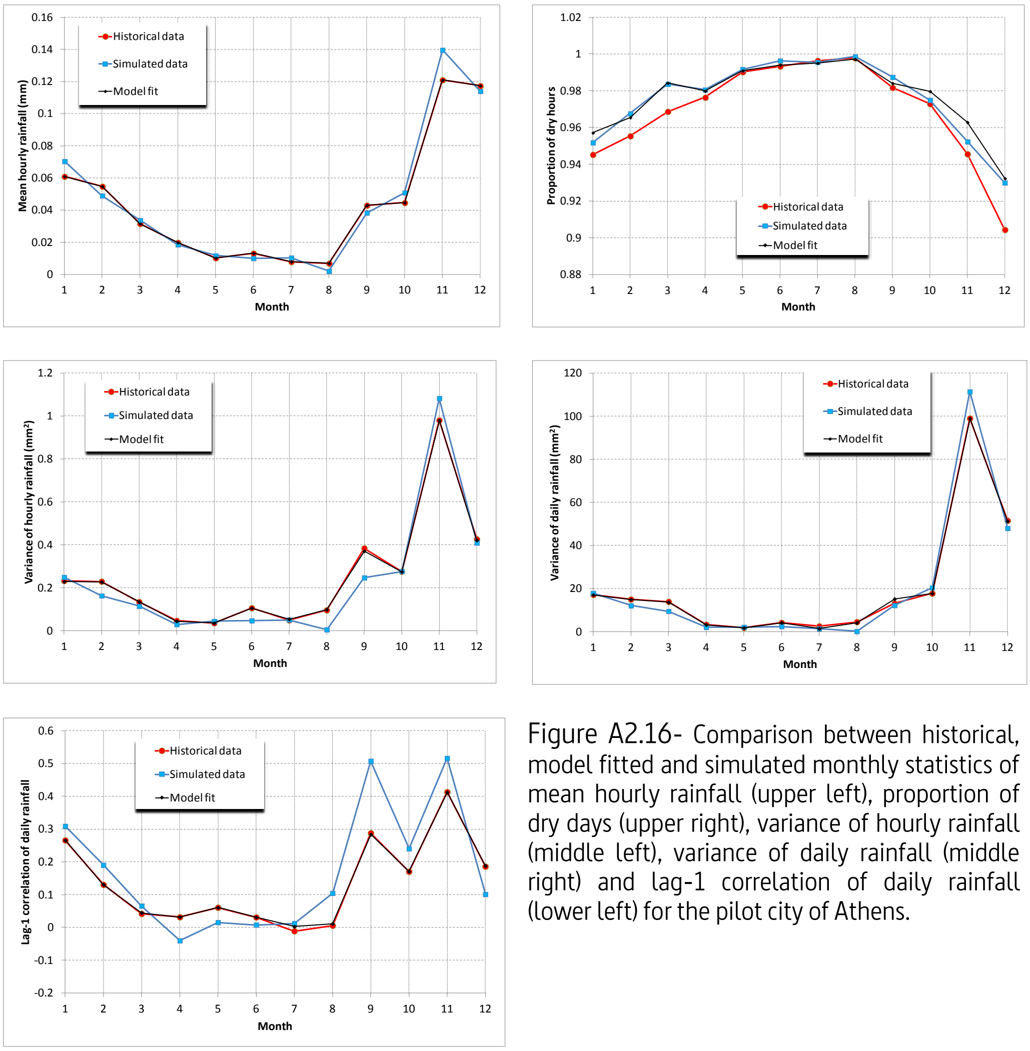


Figure A2.16- Comparison between historical, model fitted and simulated monthly statistics of mean hourly rainfall (upper left), proportion of dry days (upper right), variance of hourly rainfall (middle left), variance of daily rainfall (middle right) and lag-1 correlation of daily rainfall (lower left) for the pilot city of Athens.

The agreement is very satisfactory in consideration of the length of the observed record. In fact, the considered statistics are affected by uncertainty induced by the limited sample size, which is particularly significant for correlation. Therefore the simulated values are in good agreement with the historical ones. However, it is to be considered that these simulated data refer to the actual climate. The file of the simulated data can be downloaded here:

http://distart119.ing.unibo.it/alberto/trust/ sim-current-climate-Athens.zip.

In order to get an indication on the fit of the extremes, it is useful to compare depth-duration-frequency curves computed on historical and simulated data. The comparison, that is reported in Figure 21, shows that the agreement is indeed very good. However, it appears that the curves are underestimating the extremes for the longer rainfall duration, with respect to what local expert knowledge suggests. Underestimation is due to the limited length of the historical record.

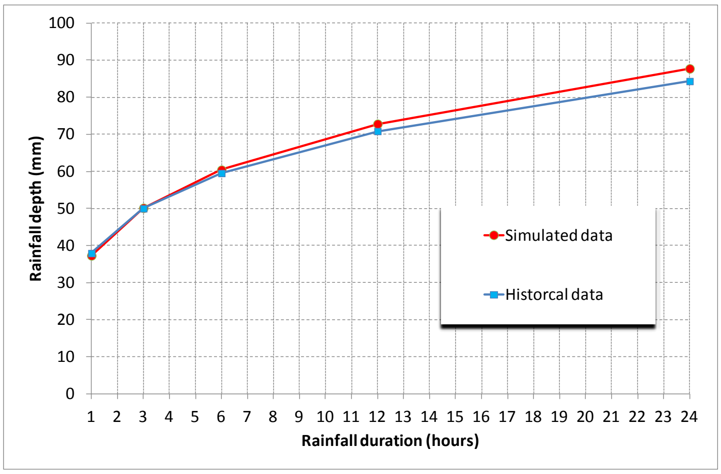
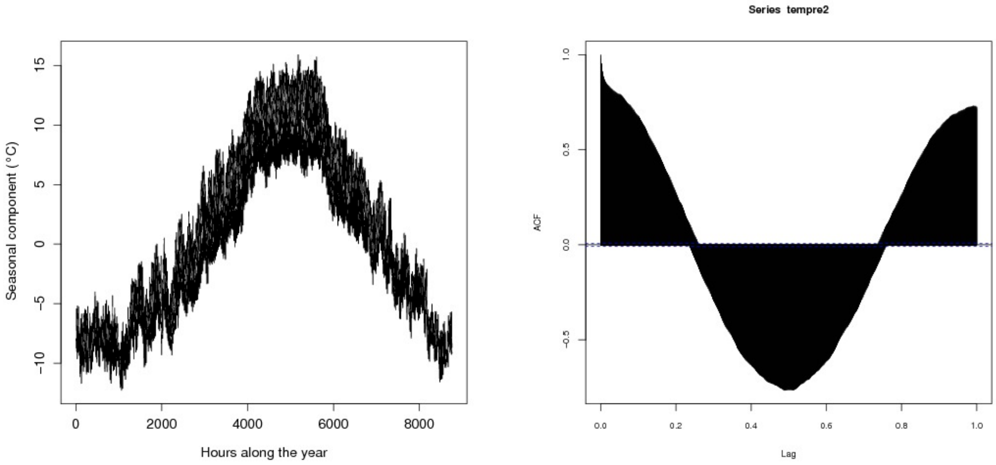


Figure A2.17- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using historical and simulated data for the pilot city of Athens.

Calibration of the temperature generator

The temperature generator was calibrated by using an historical hourly temperature record observed at Athens in the period Jan 2001 – Dec 2008. Figure 22 reports the seasonal component as well as autocorrelation functions, for lag up to one year, of original and deseasonalised data. It can be seen that the deseasonalisation was successful.



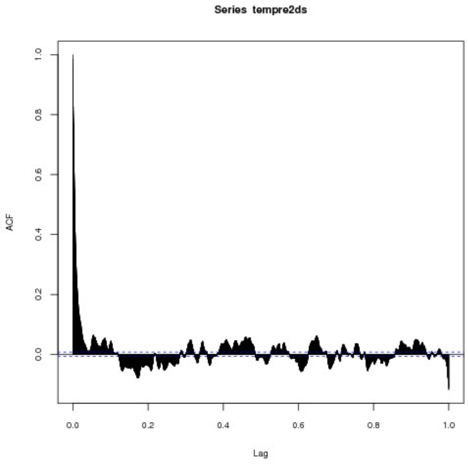


Figure A2.18- Seasonal component (upper left) of the temperature series observed in Athens. Autocorrelation function of original (upper right) and deseasonalised data (lower left).

The best FARIMA model was identified accordingly to the procedure proposed by Montanari et al. (1997), which suggested the use of a FARIMA(2,d,0) model. The residual correlation is scarcely significant and therefore the fit provided by the FARIMA model can be considered satisfactory.

The autoregressive parameters are 0.84 and -0.03, while the fractional differencing parameter is 0.42 (with 95% confidence limits [0.40-0.44]).

8.8. Generation of synthetic weather scenario referred to the year 2050 under climate change for the pilot city of Athens

Rainfall generation

To generate future weather scenarios one needs to perturb the parameters of the Neyman-Scott model accordingly to changes in mean rainfall predicted by GCMs. In detail, for Athens changes as predicted by the 50% ensemble are used, which are summarised in Table 7.

Table A2. 5. Percentage changes in mean rainfall in Athens up to the year 2059.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
-2%	-8%	-9%	-4%	-22%	-13%	-24%	-17%	-46%	-14%	-8%	-5%

The above variation in mean rainfall can be obtained, in the weather generator, accordingly to two hypotheses:

- Hypothesis 1: changes are obtained by varying the mean number of rainfall events in each month (HP 1).
- Hypothesis 2: changes are obtained by varying the rainfall intensity in each event (HP 2).

Generation is done accordingly to both hypotheses.

- **Generation accordingly to HP 1**

A 10-year run of rainfall in the future scenario was generated accordingly to the HP 1. Figure 23 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

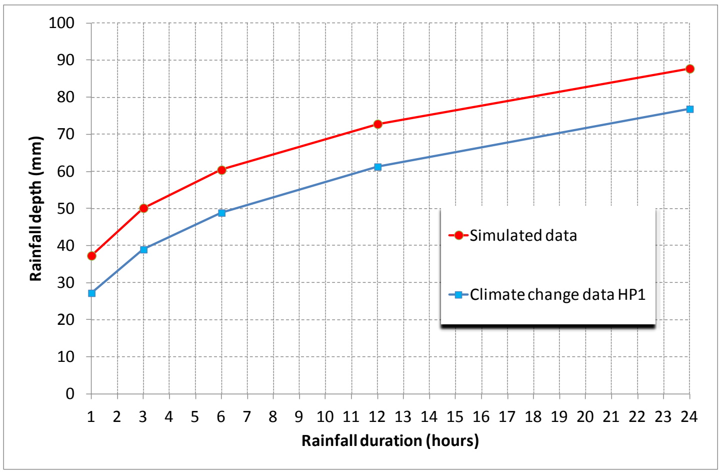


Figure A2.19- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 1) for the pilot city of Athens.

The results a decrease of the rainfall intensity. These simulated data under the HP 1 hypothesis can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/ sim-changing-climate-Athens-HP1.zip

- **Generation accordingly to HP 2**

A 10-year run of rainfall in the future scenario was generated accordingly to HP 2. Figure 24 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

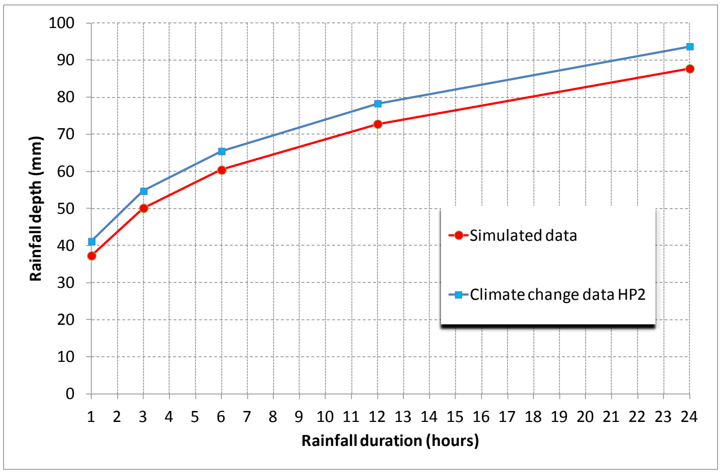


Figure A2.20- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 2) for the pilot city of Athens.

The results show a general increase of the rainfall intensitywhich is more significant for the shorter durations. This effect can be ascribed to the general decrease of rainfall intensity in the months where the intensity itself is much more sizeable. These simulated data under the HP 2 hypothesis can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-Athens-HP2.zip

One should note that the limited sample size that was used for the generation (which was selected in view of the limited sample size of the historical data) introduces some sample variability which may have an influence on the results. Moreover, one should also note that the two hypotheses above are not exhaustive of all the possible climate change combinations that might end up with a given change in the mean rainfall. For instance, a decrease in mean rainfall could be originated by a significant decrease of the number of events and a corresponding increase in their intensity. In this case, the extreme events may result more severe, even if the number of events and the mean rainfall are decreased.

Accordingly to the above hypotheses, one can conclude that the projected climate changes should not originate concerning situations for the management of urban drainage systems, that are usually designed on the basis of short-term extreme rainfall.

Temperature generation

To generate future weather scenarios the seasonal component estimated above was perturbed accordingly to changes in mean temperature predicted by GCMs. In detail, for Athens changes as predicted by the 50% ensemble are used, which are summarised in Table 8.

Table A2. 6. Changes in mean temperature in Athens up to the year 2059.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1.6	1.5	1.45	1.6	1.7	1.9	2.4	2.45	2.1	1.7	1.5	1.5

Generation was performed for a 10-year long temperature record. Figure 25 reports a comparison between the autocorrelation functions of simulated data in the current climate and the future scenario. Figure 25 in fact confirms the good fit provided by the model.

These simulated temperature data can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-athens-tem.zip.

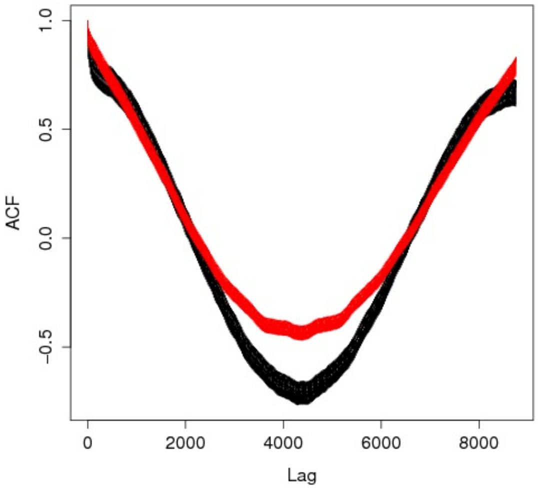


Figure A2.21- Comparison between autocorrelation functions of simulated hourly temperature data in the current climate (black line) and the 2059 scenario (red line) for the pilot city of Athens. The maximum lag is 8760 hours (one year). Lines look thick for the 24-hour oscillation of the autocorrelation.

8.9. Calibration of the weather generator model for the pilot city of Amsterdam

Calibration of the rainfall generator

The rainfall generator was calibrated by using an historical daily rainfall record observed at Amsterdam in the period January 1971 – 31 Oct. 2011. A few missing values are present. The historical series is quite long and therefore it could be considered fully representative of the current climate.

For the purpose of rainfall generation, it was decided to subdivide the year in 12 periods (seasons) corresponding to the 12 calendar months. The NSRP model was calibrated by optimising the fit of the following statistics:

- Mean daily rainfall for each month;
- Proportion of dry hours for each month;
- Variance of daily rainfall for each month;
- Variance of daily rainfall for each month;
- Lag-one correlation of daily rainfall for each month.

Figure 26 reports a comparison between observed and fitted statistics. It can be seen that the model provides a very good fit.

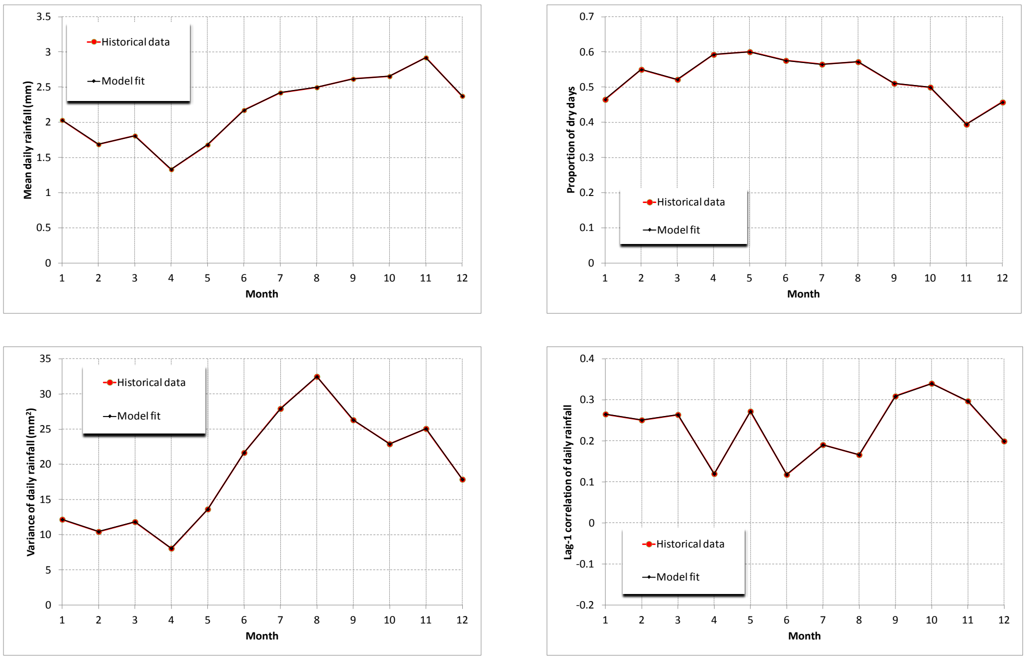


Figure A2.22- Comparison between historical and model fitted monthly statistics of mean daily rainfall (upper left), proportion of dry days (upper right), variance of daily rainfall (lower left) and lag-1 correlation of daily rainfall (lower right) for the pilot city of Amsterdam

A 10-year long simulation of hourly rainfall data was performed in order to compare historical, fitted and simulated statistics. The results are shown in Figure 27.

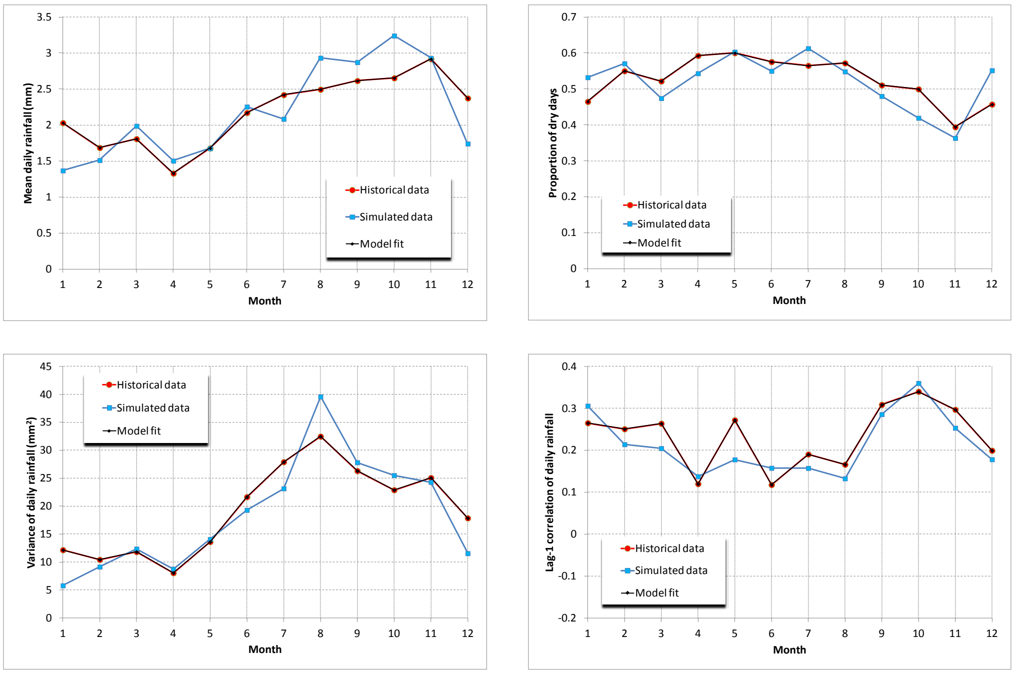


Figure A2.23 - Comparison between historical, model fitted and simulated monthly statistics of mean daily rainfall (upper left), proportion of dry days (upper right), variance of daily rainfall (lower left) and lag-1 correlation of daily rainfall (lower right) for the pilot city of Amsterdam

The agreement seems quite satisfactory in consideration of the length of the observed record. In fact, the considered statistics are affected by uncertainty induced by the limited sample size, which is particularly significant for correlation. Therefore the simulated values are in good agreement with the historical ones. However, it is to be considered that these simulated data refer to the actual climate. The file of the simulated data can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-current-climate-Amsterdam.zip.

In order to get an indication on the fit of the extremes, it is useful to compare depth-duration-frequency curves computed on historical and simulated data. The comparison, that is reported in Figure 28, shows that the agreement is indeed very good.

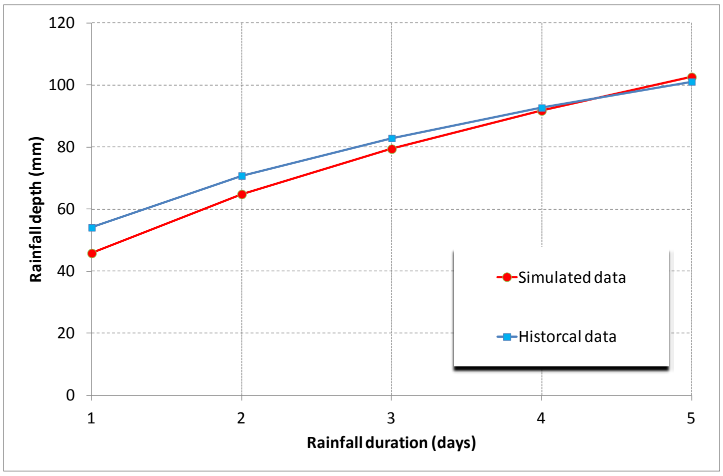


Figure A2.24- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using historical and simulated data for the pilot city of Amsterdam

8.10. Generation of synthetic weather scenario referred to the year 2050 under climate change for the pilot city of Amsterdam

Rainfall generation

To generate future weather scenarios one needs to perturb the parameters of the Neyman-Scott model accordingly to changes in mean rainfall predicted by GCMs. In detail, for Athens changes as predicted by the 50% ensemble are used, which are summarised in Table 9.

Table A2. 7. Percentage changes in mean rainfall in Amsterdam up to the year 2059.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
24%	34%	14%	17%	0%	1%	-7%	-9%	-2%	5%	8%	18%

The above variation in mean rainfall can be obtained, in the weather generator, accordingly to two hypotheses:

- Hypothesis 1: changes are obtained by varying the mean number of rainfall events in each month (HP 1).
- Hypothesis 2: changes are obtained by varying the rainfall intensity in each event (HP 2).

Generation is done accordingly to both hypotheses.

- **Generation accordingly to HP 1**

A 10-year run of rainfall in the future scenario was generated accordingly to the HP 1. Figure 29 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

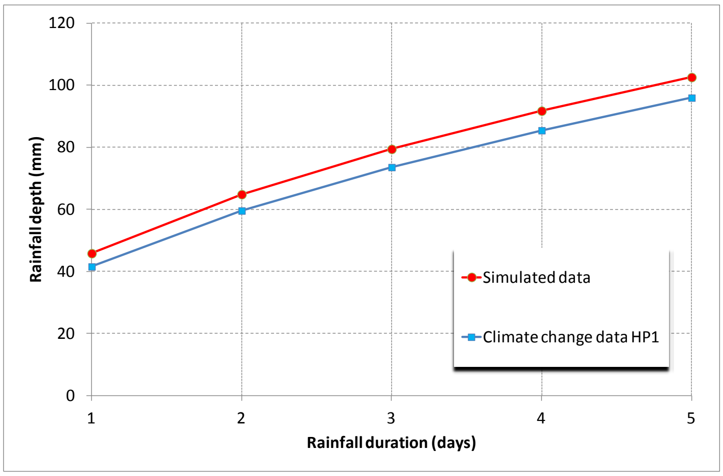


Figure A2.25- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 1) for the pilot city of Amsterdam

The results show that rainfall intensity is slightly decreased. These simulated data under the HP 1 hypothesis can be downloaded here:

http://distart119.ing.unibo.it/alberto/trust/ sim-changing-climate-Amsterdam-HP1.zip

- **Generation accordingly to HP 2**

A 10-year run of rainfall in the future scenario was generated accordingly to HP 2. Figure 30 reports a comparison between simulated depth-duration-frequency curves in the current and 2059 scenarios.

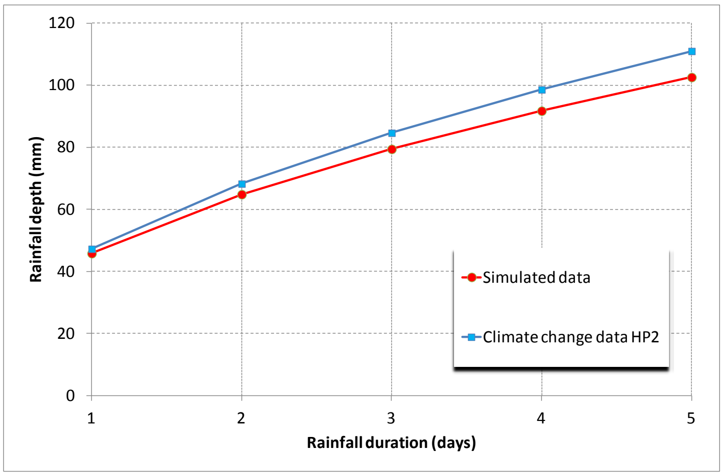
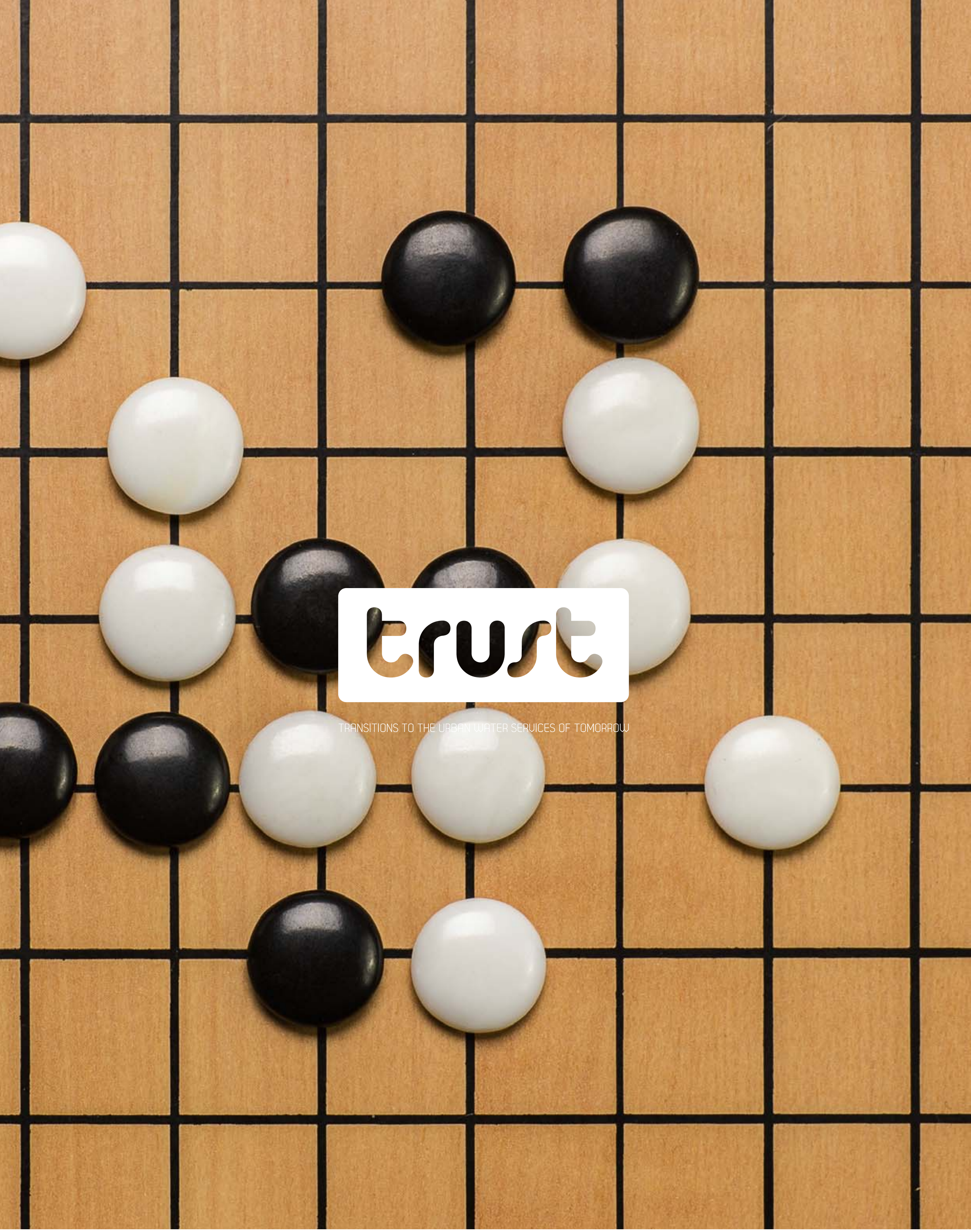


Figure A2.26- Comparison between 50-year return period depth duration frequency curves for rainfall computed by using simulated data in the current and changed climate (HP 2) for the pilot city of Amsterdam.

The results show a slight increase of the extreme rainfall. These simulated data under the HP 2 hypothesis can be downloaded here: http://distart119.ing.unibo.it/alberto/trust/sim-changing-climate-Amsterdam-HP2.zip

One should note that the limited sample size that was used for the generation (which was selected in view of the limited sample size of the historical data) introduces some sample variability which may have an influence on the results. Moreover, one should also note that the two hypotheses above are not exhaustive of all the possible climate change combinations that might end up with a given change in the mean rainfall. For instance, a decrease in mean rainfall could be originated by a significant decrease of the number of events and a corresponding increase in their intensity. In this case, the extreme events may result more severe, even if the number of events and the mean rainfall are decreased.

Accordingly to the above hypotheses, one can conclude that the projected climate changes should not originate concerning situations for the management of urban drainage systems, which are usually designed on the basis of short-term extreme rainfall.



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