MULTIPLE DEMANDS ON WATER AND NEEDS FOR ADAPTATION TO CLIMATE CHANGE

A DEMONSTRATION FOR ANKARA

Thesis is submitted in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

Master on Environmental Sciences – Soil, Water, Biodiversity (EnvEuro)

University of Natural Resources and Applied Life Sciences, Vienna

Submitted by
Hasan Hüseyin Miraç Gül

May 2012
Vienna, Austria

UNIVERSITY OF NATURAL RESOURCES AND APPLIED LIFE SCIENCES, VIENNA

GRADUATE COMMITTEE APPROVAL OF A THESIS SUBMITTED BY
Hasan Hüseyin Miraç Gül

This is to certify that I have examined this copy of my master's thesis and have found that it is complete and satisfactory in all respects, and that any and all revisions required by the final examining committee have been made.

Thesis Advisory:
Prof. Dr. Helga Kromp-Kolb
Department of Meteorology, University of Natural Resources and Applied Life Sciences, Vienna, Austria

Prof. Dr. Andreas Fangmeier
Institute for Landscape and Plant Ecology, University of Hohenheim, Stuttgart, Germany

Third Reader:
Prof. Dr. Helmut Schume
Institute of Forest Ecology, University of Natural Resources and Applied Life Sciences, Vienna, Austria

I affirm that I have written the master thesis and have not used any sources or aids other than those indicated.

Date:

Acknowledgements

First, I want to express my gratitude to Doruk and Aslı Aydın Özdemir, and Ahmet Hakan Koç for inviting me to their home as well as to their heart. Without their support, this thesis would not be possible. Moreover, I want to thank to my relatives in Ulm who made Germany home.

Later, I thank the following people for their valuable help at critical times: Nurettin Şimşek, Dr. Çağatay Dikmen, Sezar Gülbaz, Cemal Gül, Emel Bilgen, Şeyma Bilgen, Yaşar Yücel Yeşilbağ, İdil Kaya, Patrick Haas, Imran Nadeem, Prof. Dr. Ali Ünal Şorman, Dr. Elçin Kentel, Dr. Thomas Bauer, Gülce İğneli, Burak Akbaba, Barış Özüdoğru, Tuğba Cücemen, and Serhat Şensoy.

Special thanks are to my unofficial adviser Dr. Herbert Formayer, whose effort and patience made this study possible and less painful. His contribution to the pleasure in the last period of this master study with his consideration is undeniable. Moreover, I am thankful to Prof. Dr. Helga Kromp-Kolb for her invaluable guidance and scrutiny, and to Prof. Dr. Andreas Fangmeier for his understanding and remote support.

Finally, I want to thank the following people for their help, consideration, interest and time: Deniz Akten Hülagü, Sinan Fındık, Özgül Çakın, and Prof. Dr. Yahya Sezai Tezel.

And to EnvEuro Team for their great effort!

And to My Family...

Abstract

The aim of this study is to identify options for climate change adaptation regarding water use of Ankara. Climate change is a multidimensional issue also affecting security of water resources through exacerbating the current problems of water availability and reliability of supply systems by increasing variability and uncertainty. Therefore, identification of impacts of climate change on water resources is the crucial point to base adaptation measures on. General impacts on the hydrologic cycle and water resources are assessed through available literature. Observed and expected impacts of climate change on Turkey are compiled and effects on Ankara are deduced. To observe past climatic change in Ankara, 25 meteorological station records obtained from Turkish State Meteorological Service (DMİ) are analysed in terms of temperature and precipitation. Besides, information from the high-resolution gridded Europe-wide data set (E-OBS) is controlled for reliability. The contribution of precipitation to runoff in Ankara is investigated through correlation analysis between meteorological records of DMİ and streamflow gauging logs of State Hydraulic Works (DSİ). The expected impacts of climate change on temperature and precipitation in Turkey are identified by referring to the results of available climate models. In addition to these, water resources, supply and use of Ankara are investigated. Finally, the effect of demographic changes on water demand is analysed.

Temperature exhibits a slight rising trend since 1975. This increasing trend for temperature is expected to continue during the 21st century. Precipitation is expected to decrease, although some regional models claim the opposite. Considering the relationship between precipitation and runoff, correlation ($R^2 \leq 0.5$) was found to be weak. This might be attributed to the importance of evapotranspiration for availability of water. These results indicate that climate change will have negative impacts on Ankara. However, the city is more sensitive to climate variability and uncertainties including extremes in terms of water resources and supply than to climate change as such. Adaptation options are proposed and an assessment of adaptive capacity is provided. Ankara exhibits rather strong adaptive capacity with major drawbacks considering information/knowledge gap of the general public and lack of high-qualified and trained personnel within public and private institutions.

Zusammenfassung

Das Ziel dieser Studie ist es, Möglichkeiten zur Anpassung der Wasserversorgung in Ankara an den Klimawandel aufzuzeigen.

Der Klimawandel ist ein multidimensionales Thema, dass auch die Sicherheit von Wasserressourcen beeinflusst. Dies erfolgt einerseits durch eine Verschärfung bestehender Probleme bezüglich der Verfügbarkeit von Wasser und andererseits durch eine Gefährdung der Versorgungsnetze aufgrund von stärkeren Schwankungen und Extremen. Die Identifizierung der Einflüsse des Klimawandels auf Wasserressourcen ist eine grundlegende Basis zur Identifizierung von Anpassungsmaßnahmen.

Generelle Einflüsse des Klimawandels auf den hydrologischen Kreislauf und Wasserressourcen wurden durch eine Literaturanalyse zusammengetragen. Darauf aufbauend wurden beobachtete und erwartete Auswirkungen des Klimawandels auf die Türkei erarbeitet und die Auswirkungen speziell auf Ankara hergeleitet. Darüber hinaus wurden Aufzeichnungen von 25 meteorologischen Stationen, die vom Staatlichen Türkischen Meteorologischen Dienst (DMI) zur Verfügung gestellt wurden hinsichtlich Temperatur und Niederschlag analysiert, um den Klimawandel in der Vergangenheit in Ankara zu beschreiben. Zudem wurden Informationen vom hochauflösenden europaweiten Rasterdatensatzes (E-OBS) zur Plausibilitätsanalyse herangezogen. Darüber hinaus wurde der Beitrag des Niederschlages zum Abfluss im Einzugsgebiet von Ankara durch eine Korrelationsanalyse zwischen den meteorologischen Daten des DMI und Aufzeichnungen des Wasserdurchflusses – bereitgestellt vom Staatlichen Hydraulischen Amt – untersucht.

Die erwarteten Auswirkungen des Klimawandels auf Temperatur und Niederschlag werden aus den Ergebnissen von greifbaren Klimamodellen innerhalb der Türkei abgeleitet. Zusätzlich dazu werden Wasserressourcen, Wasserbereitstellung und Wassergebrauch von Ankara untersucht. Zum Schluss wird die Auswirkung des Bevölkerungswachstums auf den Wasserbedarf analysiert.

Die Temperatursanalyse zeigt, dass seit 1975 einen leicht ansteigenden Trend aufweist. Es wird erwartet, dass dieser während des 21. Jahrhunderts bei der Temperatur weiter ansteigen wird. Eine Abflussschätzung allein aus den Niederschlagsdaten ist nicht möglich, da zwischen Niederschlag und Abfluss keine gute Wechselbeziehung ($R^2 \leq 0.5$) festgestellt wurde. Hingegen wurde eine Abhängigkeit von der Evapotranspiration festgestellt. Durch die oben aufgeführten Ergebnisse kann festgestellt werden, dass Ankara eher empfindlich hinsichtlich Klimaschwankungen und Extremen bezüglich der Wasserressourcen und –bereitstellung ist, als gegenüber dem Klimawandel. Folglich werden notwendige Anpassungsmöglichkeiten vorgeschlagen und eine Bewertung der anpassungsfähigen Kapazität erstellt. Ankara weist eine starke Anpassungskapazität auf, die allerdings bedeutende Mängel hinsichtlich der Informations- und Wissenstransfer an die Allgemeinheit sowie einem Mangel an hochqualifiziertem und trainiertem Personal in öffentlichen und privaten Institutionen aufweist.

Table of Contents

List of Figures

List of Tables

Abbreviations

AÇOB	Ankara Directorate of Environment and Forestry
ASKİ	Ankara Metropolitan Municipality Department of Water and Sewage
ATO	Ankara Trade Chamber
DMİ	Turkish State Meteorological Service
DSİ	General Directorate of State Hydraulic Works
EC	European Commission
ENSO	El Niño Southern Oscillation
E-OBS	European High-Resolution Gridded Data Set
EU	European Union
FAO	Food and Agriculture Organization
FNCCC	First National Communication on Climate Change
GHG	Greenhouse Gas
GIS	Geographical Information Systems
IPCC	Intergovernmental Panel on Climate Change
İTÜ	Technical University of İstanbul
MKEK	Mechanical and Chemical Industry Corporation
NAO	North Atlantic Oscillation
NAOI	North Atlantic Oscillation Index
NAPA	National Action Plan of Adaptation
NGO	Non-governmental Organisation
OECD	Organisation for Economic Co-operation and Development
SPI	Standardised Index Method
TAI	Turkish Aeronautical Institution
TMMOB	Union of Chambers of Turkish Engineers and Architects
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNRRO	United Nations Relief and Rehabilitation Administration
WMO	World Meteorological Organisation

1. Introduction

There are numerous examples from history illustrating how the success of civilization and human welfare is intimately linked to climate. Natural warming or cooling periods of only 1^{o}C or 2^{o}C have influenced human activities, resulted in population migrations, or altered settlement patterns. For instance, the warm period around 950 AD enabled the settlement of Greenland, and briefly North America, by Nordic people; but at about the same time, severe droughts in Central America caused the collapse of the Mayan Civilisation. During the Little Ice Age (1550 to 1850 AD), global average temperature 1^{o}C to 2^{o}C lower than now contributed to fishing and crop failures and repeated famine in Europe. Moreover, in 1815, a large volcanic eruption in Indonesia emitted huge quantities of dust and soot into the atmosphere. The resultant cooling in the following year became known as, “the year without summer,” and crop failures in Europe led to widespread food riots, political unrest, and migration (Hardy, J. T., 2003, pp. 153).

Thus, one can easily deduce that climate can either bring opportunities or become a threat for human survival. In our age, human interaction with climate has an unprecedented form: we are now able to substantially intervene the atmospheric processes. Nevertheless, our ability to control these mechanisms is not still superficial and we are not able to precisely predict the result of this intervention. In other words, what is waiting ahead is yet unknown and human survival is a question addressed to humans themselves. Our attitude towards the giant we have created is one of the prime issues determining our future on this world. The shape and structure that this attitude needs to develop against the giant, climate change, are the concerns initiated this study. The interest is towards the interaction between climate change and water resources, and their use according to changing conditions. Thus, the aim of this study is to analyse climate change impacts on water resources and identify adaptation options to lessen these impacts. Furthermore, a demonstration of options of adaptation to climate change for Ankara to improve its conditions regarding water resources is provided.

In historical time, only at the end of the 19th century climate variability became an important research topic above all. However, it soon retreated into the background again. Only in our age the issue of possible climate changes and their causes turned into one of the central objects of climate research. We faced an intensive and controversial discussion among scientists about the climate change caused by humans. Some scientists drew the attention of public to the issue and demanded measures to prevent further climate changes with negative economic, social and political effects. The Intergovernmental Panel on Climate Change (IPCC) was put in place by governments to assess the scientific evidence on climate change. Their periodic assessments have become a major source of information on the issue and the hypothesis of man-induced climate change is generally accepted as the hypothesis explaining observed features best. The position of other scientists, convinced that the observed changes are a natural phenomenon, possibly associated with cosmic processes (Stehr, N., von Storch, H., 2010, pp. 65-66), has become a minority position.

What is the cause of the current warming? The evidence indicates that it is a result of the rising levels of greenhouse gases in the atmosphere. Several lines of evidence lead to this conclusion. First, the absorption of infrared radiation by greenhouse gases within the atmosphere can explain a large part of the observed warming. Second, there are no other known natural external forces to climate system, e.g. changes in the amount of solar irradiance reaching Earth, which might account for any significant fraction of the warming (Mathez, E. A., 2009, pp. 8). IPCC (2007, pp. 10) states that most of the observed rise in global average temperatures since 1950s is very likely because of the detected increase in anthropogenic greenhouse gas concentrations. Current concentrations of carbon dioxide and methane exceed pre-industrial values by far. It is confirmed that the post-industrial rise of these gases does not stem from natural mechanisms. For instance, main sources of increased atmospheric carbon dioxide are the emissions from fossil fuels and from the effects of land use change on plant and soil carbon. The total radiative forcing of climate due to increases of the greenhouse gas concentrations is the highest in more than 10,000 years. This must have effects on climate. IPCC Fourth Assessment Report (2007) provides evidence concerning temperature rise, such as the fact that 2005 and 1998 were the warmest two years in the records of global surface air temperature since 1850. The warming on land in the last 30 years is widespread over the globe and greatest in Northern Hemisphere (Solomon, S. et al, 2007, pp. 24, 25, 36, 37). Furthermore, the Summary for Policymakers states that there is high agreement and much evidence that global greenhouse gas concentrations will continue to rise over the next decades (IPCC, 2007b, pp.7), in spite of current climate change mitigation policies and related sustainable development practices. In other words, the Earth will continue to warm.

As the globe gets warmer and climate changes, new strategies to lessen these impacts on societies are required. In other words, systems need to adapt themselves to the continuously changing conditions created by climate change. Adaptation to climate change is a rather less recognised issue. Berrang-Ford et al (2011) state that only 87 of 1,741 climate change studies deal with it. However, the expectation is that with the recent scientific, social, and political progress concerning climate issue, adaptation will soon be widely perceived to be as important as mitigation.

In the climate change context, adaptation means modifications of ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts, referring to changes in processes, practices, and structures to average potential damages or to benefit from opportunities associated with climate change. Adaptation is important as it connects evaluations of impacts and vulnerabilities, and because it helps to develop and evaluate response options (IPCC, 2001, pp. 879, 881). The main reasons for adaptation are the inevitability of climate change, providing more effective and less costly anticipatory and precautionary measures, uncertainty regarding climate change, possible immediate benefits from adaptation to variability and extreme events, and removing maladaptive policy and practices, and possible future benefits from climate change (IPCC, 1990, IPCC, 2001, pp. 890).

Adaptation has the potential to both alleviate negative impacts and capitalise on new opportunities introduced by climate change. Planned, anticipatory adaptation may decrease vulnerability and realise opportunities associated with climate change effects and hazards. Considerable reductions in damages due to climate change can be achieved through timely implementation of adaptive measures. However, there are limits, related with magnitude and rate of climate change, as well as financial, institutional, technological, cultural and cognitive. Within and across regions, countries, sectors, and communities, adaptive capacity and processes widely differ. Policy and planning processes need to take these aspects into account in the development and implementation of adaptation. High priority should be given to increasing the capacity of countries, regions, communities, and social groups to adapt to climate change in synergistic ways with wider societal goals of sustainable development (IPCC, 2001, pp. 902, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 737).

Adaptive capacity is an important concept within the adaptation issue. It refers to the capability, ability or potential of a system, region, or community to successfully adapt to the effects or impacts of climate change or variability, and comprises alterations in behaviour, resources, and technologies. Adaptive capacity is associated with vulnerability of a given system or society that is a function of physical exposure to effects of climate change and its capability to adapt to these conditions, which is determined by development path, the distribution of resources, prior stresses, and social and governmental institutions. Determinants of adaptive capacity are economic resources, technology, information and skills, infrastructure, institutions, and equity (IPCC, 2001, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007).

Adaptation is also an important issue for water sector. Changes in precipitation patterns affecting water distribution are important for many sectors, but especially agriculture, energy and health (IPCC, 1995, pp. 412). To cope with climate change impacts on water resources systems, many of the standard water resources criteria, e.g. reliability, safe yield, probable maximum flood, resilience, and robustness, need to be addressed. It is necessary to separate physical effects of climate change from impacts having a societal value. Characteristics of the water use system determine the impact: for some cases a large climate change effect could have a small impact, whereas for others a small change may result a large impact (IPCC, 1995, pp. 471-473). The most significant impact of climate change on the water supply system is the rise of uncertainty, substantially complicating rational water resource planning (Mukheibir, P., 2010). Therefore, the aim of water resources management is to mitigate the effects of extremes in climate variability and supply a dependable source of water for multiple societal purposes. Water resources managers, especially in developing countries, should be concerned with the results of climate change scenarios, affirming significant effects on freshwater resources in many regions of the world. Research to identify key vulnerabilities and appropriate responses will support the design and implementation of climate change adaptation options. Water management is a continuously adaptive enterprise because it has to respond changes in demands, hydrological input, technologies, the structure of economy, and society's approach on the economy and the environment. There are four interrelated approaches regarding this adaptation: (a) to expand capacity, new investments; (b) operation of existing systems considering optimal use (instream and offstream); (c) system maintenance and rehabilitation modifications in processes and (d) demands, e.g. conservation, pricing, institutions. The water management practices, intending to adjust to the present climate variability, could also help to mitigate perturbations as droughts. However, there are social, economic, and environmental costs associated with adaptation (IPCC, 1995, pp. 471, Ziervogel, G., Johnston, P., Matthew, M., Mukheibir, P., 2010).

Water is the basis of life on Earth and foundation of all civilisations. For instance, the ancient Persians named water as the first word in their dictionary, *ab*, to show its importance for their culture. The Egyptian civilisation used a wavy line to represent the word for water, which became later the Hebrew letter *mem* and eventually the Latin letter M (Cech, T. V., 2009, pp. 1-2). Water preserves the same rank today and availability is getting more important with the increasing world population and climate change. The number of people without safe water and sanitation is more than it was at the turn of the century. More than one third of the world population live in countries with moderate to severe water stress regions. This number is expected to almost double by 2025. The main factor behind this fact is higher demand due to population growth. The problem caused by climate change is altering distribution of water resources around the world, altering the timing, variability and reliability of rainfall; increasing the occurrence of extremes and affecting water quality. (Jones, J. A. A., 2010, pp. 2, 3). Therefore, water resources management is becoming more challenging, especially for the urban areas. Changes in the material and energy fluxes and in the amount of precipitation, evaporation, and infiltration in urban areas result in changes in water cycle characteristics. The interaction between large urban areas and climate has long recognised and is because of changes in the energy flux, air pollution, and air circulation patterns (Karamouz, M., Moridi, A., Nazif, S., 2010, pp. 2, 4). Considering climate change, these interactions are expected to broaden and influence availability of water in urban areas.

Consequently, understanding the impacts of climate change on hydraulic cycle is crucial to take necessary precautions considering availability of water in cities.

There are observations of changes in hydrologic processes such as precipitation, evaporation, and transpiration. These changes exhibit different trends in various parts of the world and have impacts on precipitation. During the last century, a general increase in precipitation between 30^{o}N and 85^{o}N, and a decrease between 10^{o}S and 30^{o}N were observed on land. In the 21st century, similar patterns are expected. As a result of these changes, there will be both negative and positive impacts on water resources. In general, the availability of water towards the poles is projected to rise, whereas a decrease in the lower mid-latitudes and subtropics is expected. Increased annual runoff may raise the renewable water resources, however, it also brings increased flood risk. On the other hand, decreased precipitation may result in increased depletion of water resources, which would prompt quality degradation of freshwater and conflicts among users and sector (Bates, B. C., Kundzewicz, Z. W., Wu, S., Palutikof, J. P., 2008, pp. 44).

One aim of this study is to understand changes in the hydrologic cycle in Turkey. Hence, an effort was made to compile available studies concerning the impacts of climate change on Turkey. Till recent years, climate change was an elite subject discussed within academic environment in the country (Karakaya, E., 2008). Therefore, the number and quality of studies concerning the issue is limited but they indicate temperature fluctuations causing cool and warm periods since 1930s. A more significant temperature increase is observed during the last two decades. Temperature fluctuations differ according to the seasons and geographic scale, however, a decrease in winter and an increase in spring mean and maximum temperatures are clear. These changes were more pronounced in western and eastern regions. Precipitation follows the periodical changes in temperature, resulting in dry and wet periods. In general, precipitation is observed to decrease, however, not uniformly. This negative trend is apparent in winters and in western and southern regions of Turkey. Moreover, there are studies indicating the impacts of ENSO and NAO events on the cool and dry, and warm and wet periods in the country. Some scientists claim that these events could be used to predict availability of water. Considering the water resources, all the studies mentioned above reveal more negative trends in streams than positive ones, pointing to the importance of precipitation for runoff. The future scenarios forecast that climate change will be more influential during the 21st century creating a warmer and drier Turkey. However, the expected changes are not uniform through the country and model results are not fully consistent. In general, southern and eastern parts will be more negatively influenced, whereas the northern regions may have positive results. Therefore, water stress, especially in western and southern urban areas, is anticipated to increase. Nonetheless, more investigations are required to precisely determine possible impacts of climate change on water resources of Turkey.

Ankara is the area of interest in this study. Capital of Turkish Republic since 1923, Ankara is an ever growing city with a large area and a large population. It lies on 39^{o}57' N and 32^{o}53' E in Central Anatolia. The dominant climate over Ankara is continental with hot and dry summers, and cold and wet winters (AÇOB, 2008). According to the 2010 census, the total population of Ankara is 4,771,716 (URL 1), 97% of which lives in the urban area. To satisfy water needs of such a big population a large mass of water is required. Main water resources of Ankara are the rivers and streams of the Sakarya and Kızılırmak basins. Currently, there are 8 dams servicing the city with an average capacity of 375 hm^3/a for drinking water, industrial water, and irrigation needs (URL 2).

As stated above, Ankara is expected to be considerably influenced by climate change. The intensity of the impacts is of concern for the city and, thus, a detailed analysis is necessary to understand the scale of sensitivity, which means the degree to which a system is affected by or responsive to climate stimuli. However, sensitivity is not only a function of impacts but also determined by the properties of the system of concern. The city is well-supplied and plans to meet the future water demand are ready, yet, the question is if this adaptive capacity is enough to exhibit resilience and flexibility. Resilience is the ability of a system to rebound, recoup or recover from a stimulus. Flexibility, on the other hand, is the degree to which a system is pliable or compliant. In this scope, water resources of Ankara and impacts of climate change on them are investigated through available data to assess climate sensitivity of the city. The ultimate aim of this study is to propose climate change adaptation options for water resources of Ankara.

As it is discernible from above, there are three main factors addressed in this study: climate change, water resources, and adaptation. Figure 1.1 depicts the flow of the thesis. Observed and expected impacts of climate change on the hydrologic cycle, in general, and, specifically, impacts on Turkey are investigated. Afterwards, Ankara is the focus to identify changes in temperature and precipitation patterns. This is achieved by literature search and use of available model results, and data analysis. Two groups of climate model results are used. The first group consists of regional models for Turkey which are ECHAM5 RegCM3, HadAMP3. The second group is the result of the PRUDENCE project. The data set employed at this level consists of meteorological data obtained from Turkish State Meteorological Service (DMİ). 25 meteorological station records are used to inspect homogeneity among meteorological data through a correlation analysis. In addition to stations of DMİ, temperature and precipitation data from 258 grid points belonging to E-OBS are employed. This is a European-wide data set composed of daily, high-resolution, land-only grids for precipitation, and maximum, minimum and mean temperature. Data of E-OBS are tested for their reliability.

Water resources are the second main issue considered. Through identifying the impacts on the hydrologic cycle, alterations in water availability are addressed. Water resources of Turkey and Ankara are described and water demand and use of Ankara is examined. This analysis is conducted with the data supplied by Ankara 5th Regional Directorate of State Hydraulic Works (DSİ) that include the monthly values of 8 dams providing water to Ankara with information about monthly volumes of the water in the dams, amount of inflows and amounts of outflows in different categories from 1972 to 2010. Then, observed and expected impacts of climate change on water resources of Ankara are assessed. The assessment contains also analysis of streamflow records of streams in Ankara. The gauging stations belong to DSİ and contain monthly total flows of tributaries of Sakarya and Kızılırmak rivers in and around Ankara, and the data are recorded for the 1957 – 2000 period. A correlation between precipitation and streamflow data, and inflow to dams is investigated to reveal runoff patterns and significance of precipitation for Ankara. Moreover, the population factor for demand on water is analysed. Increase in population is compared with the change in water consumption, i.e. annual per capita water use, and a forecast is made according to the expected population.

Considering the results of the above two main categories, i.e. climate change and water resources, a climate sensitivity assessment for Ankara is provided. Combining the impacts on water resources of the city and the properties of the water supply system, Ankara's situation in face of climate change is evaluated.

The third category is the adaptation issue. Related background information about adaptation is provided through literature search, mainly IPCC reports and options for adaptation on water resources are identified. Besides, adaptive capacity of Ankara is assessed considering economic resources, technology, information and skills, institutions, and equity.

Finally, all the information and outcome obtained through literature and data analysis are synthesised to propose climate change adaptation measures for Ankara on water resources.

The above verbalised information flow is detailed in different parts of the study. Part 2 gives brief information about the hydrologic cycle and, later, summarises climate change effects on it through changes in temperature, precipitation, evaporation and transpiration. Based on these changes, the significance of climate change for water resources is explained. Later on, observed and expected climate change impacts on Turkey are compiled through available studies and an assessment of the water resources of the country is provided under the changing climatic conditions. Part 3 describes water potential of Turkey, comprised of groundwater, lakes and rivers. Amongst, rivers have the prime importance as they comprise 87% of available water resources. Afterwards, water demand, use and future projections for the country are given. Part 4 is reserved for explanation of adaptation issue in the climate change context. First, the definition of adaptation is provided and the concept is explained with related approaches, types and processes, scales, and supporting and inhibiting factors. Second, adaptation options concerning natural resource management are discussed. Definitions and factors of adaptive capacity and vulnerability are given and their interaction is investigated. Finally, options for climate change adaptation for water sector are covered. Part 5 presents Ankara with brief information about its history, geography, climate, land use, economic activities, and population. Part 6 provides information about the history of, and current and future water resources of Ankara. Part 7 deals with data analysis. First, the data used are listed and related information is provided. Later, a summary for Ankara from regional climate model results is given to exhibit expected future changes in temperature and precipitation. Water use of Ankara in different sectors is investigated. Following this, meteorological data are analysed to reveal temperature and precipitation patterns in Ankara and E-OBS data set is checked for reliability. Finally, the relationship between precipitation and surface runoff is investigated through comparing the meteorological data and streamflow records of DSİ. The conclusion of the whole process of analysis is given in the last section assessing climate sensitivity of Ankara. In Part 8, the solution of the research question is presented considering the factors identified in Part 7. Options for climate change adaptation of Ankara on water resources are proposed and the adaptive capacity of the city is assessed.

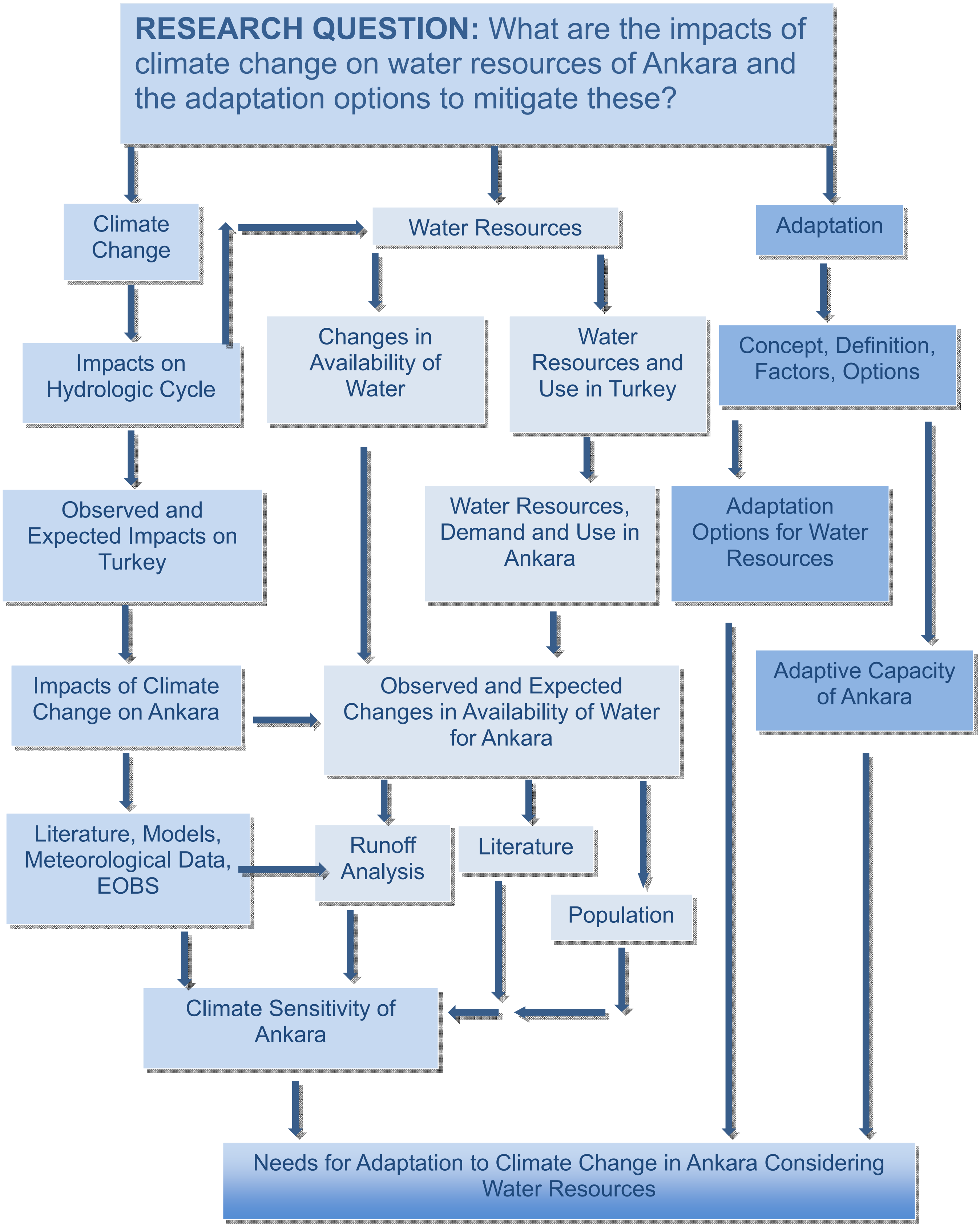


Figure 1.1 Flow Diagram of Thesis

2. Climate Change Impacts on the Hydrologic Cycle, Water Resources and Turkey's Waters

This part aims to provide brief information about the hydrologic cycle and, later, to summarise climate change effects on it through changes in temperature, precipitation, evaporation and transpiration. Based on these changes, the significance of climate change for water resources is explained. Later, observed and expected climate change impacts on Turkey are compiled through available studies and an assessment of the water resources of the country is provided under the changing climatic conditions.

2.1 Climate Change Impacts on Hydrologic Cycle

2.1.1 Hydrologic Cycle

Water can move from the atmosphere to the Earth´s surface, accumulate as snow or ice, evaporate, penetrate through soil to aquifers, or be taken up by plants and transpired back to the atmosphere (Hardy, J. T., 2003, pp. 78). Oceans and the atmosphere are the major reservoirs of water on the Earth. Others include groundwater, streams, lakes, and plants (Barnes, B. V., Zak, D. R., Denton, S. R., Spurr, S. H., 1997). The hydrologic cycle is the continuous circulation of the water through the reservoirs, and includes reservoirs where water is stored, and processes that transfer water between them (Hudak, P. F., 2000, pp. 2-3). In other words, it is the movement of water through oceans, atmosphere, and land.

Energy from the sun is the power source of the system, causing water to evaporate from the surface of the world's oceans which then vaporizes to form large cloud masses. Global wind system drives these clouds and, under the right conditions, the water precipitates, falling back to the surface again as rain, snow or hail. Some of the water falling on the land collects to form streams and rivers which eventually flow back into the sea, from where the process starts all over again. However, some of the rainfall is returned to the atmosphere without contributing to the flow of streams and rivers through evaporation from surface, and transpiration from the soil to reach the water table, which is the hydraulic gradient causing groundwater to flow through saturated rock. Unless the groundwater is removed by pumping from wells, it will flow through an aquifer towards natural discharge points, e.g. springs, seepages into streams and rivers, and discharges directly into the sea (Brassington, R., 1998, pp. 2-3).

The amount of water in movement within the hydrologic cycle every year is equivalent to an almost 1-meter-deep layer of water over the entire Earth (Mathez, E. A., 2009, pp. 49). Evaporation, precipitation, transpiration, infiltration, groundwater flow, and runoff are the processes of the hydrologic cycle. Transfer of water from liquid to vapour state is evaporation. Plants transpire water vapour through small leaf openings called stomata, a process called transpiration. Precipitation occurs when water vapour in the atmosphere condenses on condensation nuclei. The precipitated water may be intercepted by vegetation, become flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow, or discharge as surface runoff. Runoff is the various ways by which water moves across the land. This includes surface and channel runoff. Infiltration is the flow of water from the ground surface into the ground. Infiltrated water may percolate deeper to recharge groundwater and later joins into streams to become streamflow. Groundwater flow is the movement of water in the vadose zone and aquifers. It may return to the surface or seep into oceans. Groundwater tends to move slowly and is replenished slowly. Therefore, it can remain in aquifers for thousands of year (Hudak, P. F., 2000, pp. 2-3, Mays, L. W., 2001, pp. 191, Han, D., 2010, pp. 12).

Evaporation is the transformation of liquid water into vapour by wind action and solar radiation. Evaporation occurs from open water bodies and land surfaces. To determine availability of water or loss in a region, evaporation rates are extremely important. Transpiration is the process through which water molecules leave living plant tissue and enter the atmosphere. Transpiration is almost constant in areas of abundant rainfall, however, there are variations mainly in the length of each plant's growing season. On the other hand, transpiration in dry areas differs largely according to root depth. Shallow-rooted plants often wither and die due to a lack of moisture, yet, deep-rooted plants survive as they are able to reach into deeper groundwater and continue to transpire (Cech, T. V., 2010, pp. 27-45).

Condensation is the cooling of water vapour till it changes into a liquid. Cooling water vapour ascending in the atmosphere initiates this process. As it occurs, the water vapour undergoes a phase change into liquid or ice. With existence of other atmospheric conditions, condensation process may form clouds at higher elevations, or fog close to ground (Cech, T. V., 2010, pp. 27-45).

Precipitation occurs when atmospheric moisture becomes too great to be suspended in clouds. Small, weakly linked water molecules form droplets under proper conditions. These molecules undergo coalescence and fall as rain, snow, sleet, hail, or virga, which is the evaporating rain before it reaches to ground. After reaching the Earth's surface, precipitation may become surface water runoff, surface water storage, glacial ice, water for plants, groundwater, salty water in the oceans, or it may evaporate and immediately return to the atmosphere (Cech, T. V., 2010, pp. 27-45).

Runoff is the amount of water that flows across the land surface after a storm event. Climate, terrain, precipitation intensity, and volume play an important role in surface water runoff. Moreover, land-use has a significant effect. Water seepage into the soil on barren land surfaces is hindered and, thus, runoff moves rapidly downhill. However, dense vegetative cover increases seepage rate as it slows surface water flow. Urban areas with paved streets and parking lots, side-walks, and roof tops prevent seepage and increase runoff. Therefore, after major storm events areas downstream of urban areas usually experience increased stream flow (Cech, T. V., 2010, pp. 27-45).

Oceans, the largest store of water on Earth and fundamental source of evaporation and precipitation, dominate the water cycle. They store 97% of all water on Earth, and 86% of all evaporation occurs over them (Jones, J. A. A., 2010, pp. 223). Lakes and reservoirs are important components of the hydrological cycle. The former are large bodies of inland water mostly formed by glacial activity or surface water runoff, while the latter may be natural or artificial water bodies to store, regulate, and control water. Lakes and reservoirs are collection points for storage of surface water runoff and groundwater seepage, sources of evaporation, and they can replenish the flow in streams. Landslides, tectonism, glaciation, river action, animal activity, meteorite impact, volcanism, and human activity may create lakes and reservoirs, which rely on precipitation, snowmelt, groundwater infiltration and glacial melt as water sources. Evaporation, groundwater recharge, and outflow are ways stored water is lost. Another important storage element is groundwater storage. Under the force of gravity, surface water seeps downward through porous soils into underlying geological material. The principle method of replenishing groundwater is precipitation. Through seepage from streams, lakes, wetlands, and salt water, surface water also feeds groundwater. Groundwater resides beneath the land surface in sand and gravel, rocks, fine clay material, and cracks in large rocks. Groundwater movement is under the force of gravity through capillary action and geologic material to lower elevations till an underground barrier such as clay or rock is reached. If it reaches lower elevation, groundwater can arrive at land surface, or it can infiltrate into a stream, lake, wetland, or ocean (Cech, T. V., 2010, pp. 27-45).

2.1.2 Climate Change Impacts on Hydrologic Cycle and Water Resources

Due to global warming acceleration in oceanic evaporation and increase in overall global precipitation are foreseen. Precipitation seasons are getting shorter, coupled with overall larger annual precipitation and a shift from snow to rain. Larger volumes of runoff will occur in short times. Regional and seasonal changes are important and could differ greatly from the global mean. Thus, climate change will affect water availability, water demand, and water quality (Hardy, J. T., 2003, pp. 77-78, Loaiciga, H. A., et al, 1996).

Ocean processes are substantially important in regulating the climate. Oceans are the main source of atmospheric moisture, and storage and transporter of heat. There are two specific aspects of ocean circulation under focus: the thermohaline circulation and El Niño. They operate at different ends of the time spectrum. The former is continuous and takes centuries to complete, whereas the latter has a life-time of one year, recurring approximately every five years. The thermohaline circulation occurs due to salt and heat gradients, e.g. Gulf Stream and North Atlantic Drift, which are responsible for the mild and wet climates in West Europe. Thermohaline circulation is affected by the introduction of colder water and the increase in evaporation. As the colder water sinks, the excessive evaporation makes it saltier. On short term, oxygen distribution and life in the deep ocean are expected to be disrupted. In the long run, a slowdown in the North Atlantic Drift is expected with the introduction of more polar water, which in turn is anticipated to weaken effects of global warming across Europe. Additionally, El Niño is becoming more important, with impacts on atmospheric circulation, precipitation and temperature (Bates, B. C., Kundzewicz, Z. W.,Wu, S., Palutikof, J. P., 2008, pp. 22). It is driven by the difference in temperature changes in eastern and western tropical Pacific (Hardy, J. T., 2003, pp. 86) and peaks near the end of the year and mostly affects the west coast of Central and South America. Moreover, it creates heavy rains in the Americas and drought in Indonesia and India.

Warming increases evaporation and more moisture means more **precipitation** (Mathez, E. A., 2009, pp. 138). Over the 20th century precipitation increased over land between 30^{o}N and 85^{o}N, and decreased notably in the past four decades from 10^{o}S and 30^{o}N (after an increase in the decades before). Similar changes were observed on the oceans with effects on salinity. Inverse variations between northern Europe and the Mediterranean area are observed, associated with changes in the North Atlantic Oscillation. Over the Amazon Basin and south-east of South America positive trends were observed, yet, over Chile and partly on the western coast of the continents, negative trends prevailed. The western part of Africa part and the Sahel showed decreases in mean precipitation since 1901 (Global Historical Climatology Network data). Furthermore, north-western India showed a decrease, whereas north-western Australia exhibited moderate to strong increases (Bates, B. C., Kundzewicz, Z. W.,Wu, S., Palutikof, J. P., 2008, pp. 15, 16). Considering the future impacts, climate projections forecast increases in globally averaged mean water vapour pressure, evaporation and precipitation during the 21st century. At high latitudes in winter and summer seasons increase in precipitation is expected. There are notable increases over the tropical oceans and in some of the monsoon regimes (Asian monsoon in summer and Australian monsoon in winter), yet general decreases in mid-latitude summer precipitation (except for Eastern Asia) and over many tropical areas. Besides, many sub-tropical areas are projected to face clear precipitation loss, particularly in Caribbean and the Mediterranean. According to SRES A1B scenario, during 2080 – 2099 there are going to be substantial increases up to 20% in most high latitudes, in eastern Africa, the northern part of central Asia, and the equatorial Pacific Ocean, whereas decrease of the same amount in the Mediterranean and Caribbean, and sub-tropical western coasts of each continent. In the low- and mid-latitudes summer drying poses drought risk. Over land a 5% increase has been projected, accounting for a net change of 24% of the global mean increase, and over the oceans a 4% (Bates, B. C., Kundzewicz, Z. W.,Wu, S., Palutikof, J. P., 2008, pp. 25).

Along with changes in mean precipitation, large increases in heavy precipitation events were also observed, however, there is a limited number of sufficiently long and reliable data series (in Europe and North America). Heavy precipitation events are expected to become more frequent, especially in tropical and high latitude areas with the increase in mean precipitation. (Bates, B. C., Kundzewicz, Z. W., Wu, S., Palutikof, J. P., 2008, pp. 16, 26, Hardy, J. T., 2003, pp. 86).

Consistent with observed warming and almost constant relative humidity, in recent decades tropospheric **water vapour** content has risen. Over the global oceans, total column water vapour has increased by 1.2 ± 0.3% per decade between 1988 and 2004. For the 21st century climate models project a change in global mean evaporation balancing global precipitation change. With higher temperatures annual average evaporation tends to increase over much of the ocean and water content of the atmosphere is projected to increase accordingly, with an almost-constant relative humidity. Increases in atmospheric moisture are expected to be especially pronounced over the equatorial oceans and high latitudes (Bates, B. C., Kundzewicz, Z. W.,Wu, S., Palutikof, J. P., 2008, pp. 18, 25-26).

Evapotranspiration has augmented since the 1950s, caused by increasing temperatures and abundant availability of surface moisture due to increased precipitation. It is observed that there was a trend of increasing soil moisture content (top 1 m) during summers in the former Soviet Union, China and central USA. During the 21st century potential evaporation is expected to increase due to increased water holding capacity of atmosphere at higher temperatures, and an almost constant relative humidity. A forecast of the future evapotranspiration under enriched-CO_2 conditions is not possible. The higher is the CO2-concentration, the lower is the pH in stomata, leading to a closing of the pore openings. This “stomatal resistance” slows water loss, and evapotranspiration. On the other hand, increased carbon dioxide may increase plant growth, and, hence, evapotranspiration. Therefore, to estimate the effect of CO_2 enrichment, global scale dynamic vegetation models are required (Bates, B. C., Kundzewicz, Z. W., Wu, S., Palutikof, J. P., 2008, pp. 21, 29, Hardy, J. T., 2003, pp. 78).

Regarding **runoff** and river discharge, there is a global, broadly coherent changing pattern with increase in high-latitudes and large parts of the USA, and with decrease in West Africa, southern Europe, and southernmost South America. Moreover, regions where winter precipitation is shaped by snow showed alterations in timing of river flows. In the future, it is expected that climate change will influence river flows, as well as lake and wetland levels. Those are mainly dependent on timing, volume and type of precipitation. Changes in evaporation also impact river flows, on which warming would cause changes in seasonality. At lower elevations, where snowfall is seldom, the effect is expected to be greater. Moreover, in the middle of the 21st century peak flows would occur at least a month earlier. Changes in runoff are much more related to changes in rainfall in regions with no or little snowfall (Bates, B. C., Kundzewicz, Z. W., Wu, S., Palutikof, J. P., 2008, pp. 29, Hardy, J. T., 2003, pp. 22, 29-30).

The described changes in the hydrological cycle have many and far reaching effects. Considering groundwater levels, positive changes are expected at high latitudes, arid and semi-arid regions. However, increase in precipitation may not contribute to **groundwater recharge** in wet regions. In average, groundwater recharge is projected to increase by 2% until 2050s compared to 1961 – 1990, whereas, in north-eastern Brazil, south-western Africa, and the southern part of Mediterranean Sea, a decrease more than 70% is computed. On the other hand, the Sahel, the Near East, northern China, Siberia and western USA are the regions with an increase of more than 30% expected. Furthermore, it is highly likely that **drought** will influence large areas. Mid-continental areas are under greater risk of drought. It is claimed that extreme droughts, frequency of extreme drought events, and the mean drought duration experienced by the land surface will increase by 10 to 30 fold, 2 fold, and 6 fold, respectively. Earlier melting of snowpack is also important. If reservoirs are not large enough to hold this early water, the supply for late summer and autumn will be lost to oceans. About one-sixth of the population of the world dwells in such regions, therefore, the early runoff may become a serious issue for those areas. **Water quality** is also foreseen to be altered by climate change with introduction of many forms of pollution including sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution. Increased precipitation intensity is expected to enhance transport of pathogens and dissolved pollutants. Moreover, more frequent heavy rainfall will cause overloading of sewer systems and water and wastewater treatment plants more often, deteriorating process quality. On the other hand, decreased flows will result in less dilution of contaminants. In semi-arid and arid areas, salinization of groundwater and surface water will be a problem due to increased evapotranspiration. On coastal regions, sea intrusion would be a concern for safety of freshwater reservoirs. Floods, e.g. river floods, flash floods, urban floods, sewer floods, glacial lake outburst floods and coastal floods, are due to processes including intense and/or long-lasting precipitation, snowmelt, dam break, reduced conveyance due to ice jams or landslides, or by storm. It is indicated that globally the number of great flood catastrophes per decade during 1996 – 2005 was twice as high as between 1950 and 1980. Therefore, climate change might already have had impacts on the intensity and frequency of floods (Bates, B. C., Kundzewicz, Z. W., Wu, S., Palutikof, J. P., 2008, pp. 37-43, Mathez, E. A., 2009, pp. 143).

As a summary, there are observations of changes in hydrologic processes such as precipitation, evaporation, and transpiration. These changes exhibit different trends in various parts of the world and have impacts on precipitation. During the last century, a general increase in precipitation between 30^oN and 85^oN, and a decrease between 10^oS and 30^oN were observed on land. In the 21^{st} century, similar patterns are expected. As a result of these changes, there will be both negative and positive impacts on water resources. In general, the availability of water towards poles is projected to rise, whereas a decrease in the lower mid-latitudes and subtropics is expected. Figure 2.1 briefly depicts the negative impacts. Increased annual runoff may raise the amount of renewable water resources, however, it also brings increased flood risk. On the other hand, decreased precipitation may result in increased depletion of water resources, which would prompt quality degradation of freshwater and conflicts among users and sector (Bates, B. C., Kundzewicz, Z. W., Wu, S., Palutikof, J. P., 2008, pp. 44).

2.2 Impacts of Climate Change on Precipitation, Temperature and Water Resources in Turkey

Climate change was not a public concern till 2006. It was only discussed by academic people in their own environment. Along with lack of public interest, the uncertainty regarding Turkey's role in international climate policy was another factor of this situation. However, in 2006, natural disasters and seasonal abnormalities drew attention to the issue. Later, the Ministry of Agriculture, and Ministry of Environment and Forestry gave climate change warning and the first commission to study climate change impacts on the country was established by Parliament in 2007. Thus, public attention was aroused (Karakaya, E., 2008). However, this rise of awareness did not bring any solid result for the investigation of impacts of climate change.

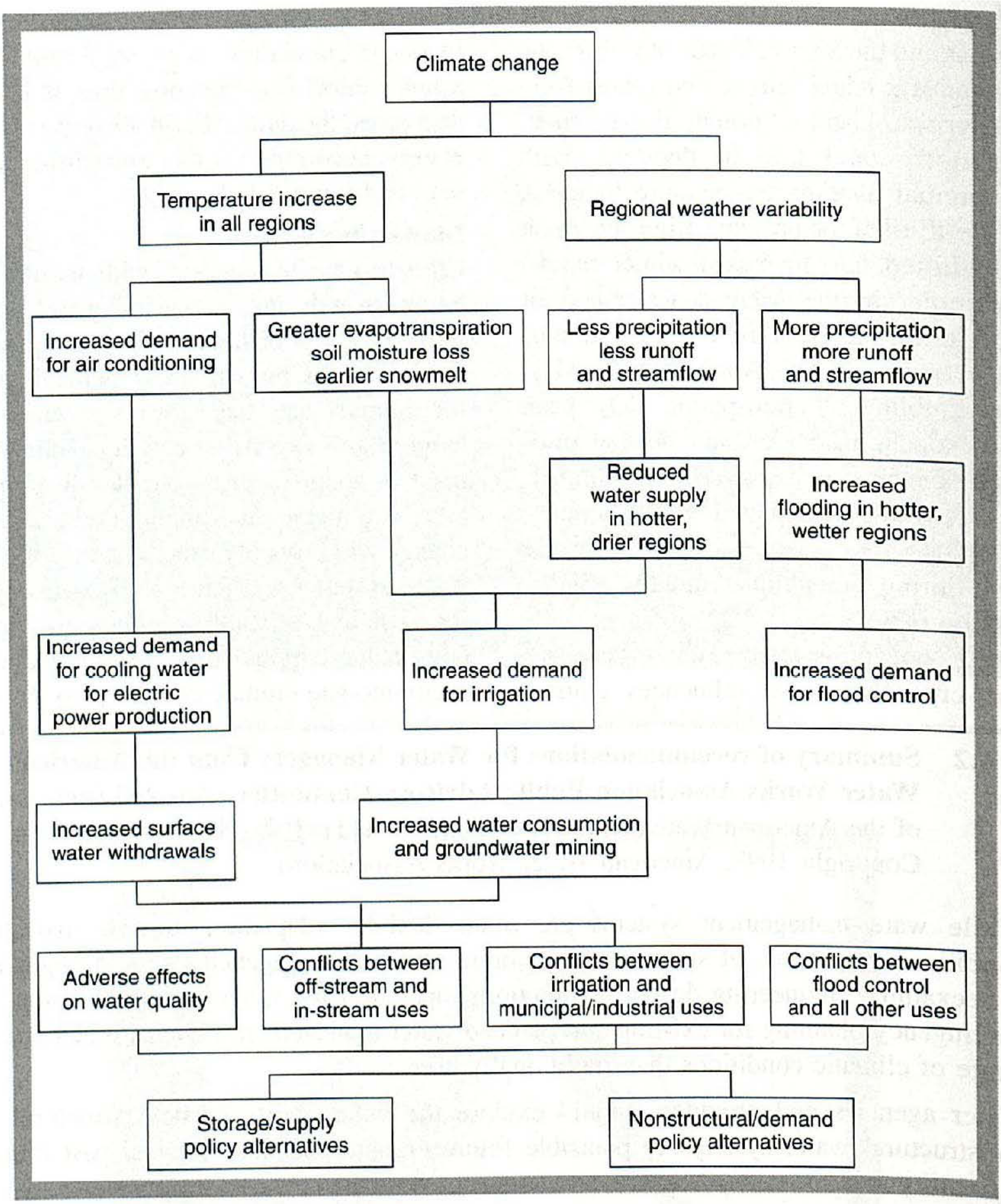


Figure 2.1 Climate Change Influence on Water Supply and Water Demand (Hardy, J. T., 2003, pp.94)

This section is concerned with the few published studies about observed temperature and precipitation changes, and available future projections on climate change impacts for Turkey. Along with meteorological changes, hydrologic alterations are also compiled and availability of water in Turkey is assessed under these conditions.

There are some studies concerning the earlier changes in temperature. For the period 1930 – 1993, a clear decrease in summer and fall, and a slight increase in spring for the mean maximum temperatures over the country were reported. Summer decrease was significant in Mediterranean and Central Anatolia regions. There was a long-term warming trend in mean minimum temperature series for all regions in winter, spring and summer, among which the spring warming was the most distinct. Considering diurnal temperature ranges, a decreasing trend in all seasons other than fall was observed (larger increase in night-time temperatures than daytime temperatures). The decrease in summer was significant in all regions except for East and Southeast Anatolia regions, whereas winter decreasing trend was apparent over Black Sea and Central Anatolia regions (Türkeş, M., Sümer, U. M., Kılıç, G., 1996). Kadıoğlu (1997) investigated data of 18 stations (1939 - 1989) over Turkey and analysed annual mean, maximum and minimum temperatures. Trend analyses revealed that night minimum temperatures had increased during spring especially at 37 N and 41 N latitudes. The mean annual minimum temperature increase was calculated as 0.0012^{o}C/year. In contrast, the seasonal and annual mean maximum temperatures showed a decreasing trend which was not statistically significant. Winter and spring maximum temperature increases were determined as 0.36^{o}C and 0.66^{o}C, respectively. Summer and autumn maximum temperatures revealed decreases by 0.2^{o}C and 0.71^{o}C, respectively. Considering mean annual temperatures, increase per year was calculated as 0.006^{o}C, and total increase was 0.32^{o}C. Besides, Kömüşçü (1998) analysed fluctuations in the annual mean air temperature in the period 1930 – 1995. He noted cooling periods until early 1950s, late 1970s, during early 1990s, and warm periods until mid-1960s, early 1980s, and after 1993. However, he did not denote any significant trend for the annual mean temperature. According to another study concerning the meteorological data of the period 1929-1999, there was a small but significant decreasing trend in winter average temperatures in West and East Black Sea, however, small increasing trend (0.07-0.34^{o}C/decade) in Central Anatolia and west of South-east Anatolia. Most stations showed an increasing trend in spring. Summer temperatures had the tendency to rise slightly at west, and a general cooling at other regions. In fall, there was a significant cooling trend in Black Sea and East Anatolia. About maximum temperatures, there was a small increasing trend in east and west regions, yet, Central Anatolia faced a small decreasing trend. Spring maximum temperature rose like those in summer, yet, some parts showed a decreasing trend in summers. Winter minimum temperatures exhibited an increase in regions other than Black Sea. This trend was general in spring and summer. Significant night temperature rise was seen especially in urban areas (0.12-0.49^{o}C/decade). Concerning fall, there was a significant increasing trend in west and south regions. Cooling trends were seen in East Black Sea, and mid- and north parts of East Anatolia (Türkeş M, Sümer, U. M., Demir, İ., 2002). First National Communication of Turkey on Climate Change analysed data covering the period 1951-2004 from 113 appropriate stations. Concerning average annual temperature, there was a widespread increase in summer temperatures, mostly in western and south-western parts. However, this widespread increase might be related with urban heat island effect. On the other hand, there was a decreasing tendency in winter temperatures, most significant at coasts. For spring and fall, the trends were sporadic, i.e. they did not show any coherent regional behaviour. The maximum temperatures for winter showed a significant decreasing trend at coastal areas of Black Sea, and in Central Anatolia. However, there was a contrary tendency in summer. Particularly in western parts, there is a widespread increase. Minimum temperatures in winter exhibit significant decrease only at northern and southern coasts. Summer minimum temperatures show significant increasing trends at all stations (FNCCC, 2007, pp. 165). Finally, Tayanç et al (2009) observed urban temperatures between 1950 and 2004. They concluded the existence of a general warming trend over Turkey considering annual maximum, annual minimum and annual mean temperatures, however, not significant. They reported a cooling period between 1960 and

1992, and an increasing temperature after that.

The findings above generally agree on presence of an increasing trend in annual mean temperature and mean minimum temperature. The decrease in winter maximum temperatures is the other point of agreement. Climate change as well as urbanisation and measurement errors are the proposed reasons for these trends. Therefore, more detailed and up-to-date observations are required to study climate change in the near meteorological history of Turkey. Nevertheless, Türkeş (2008) provided a general picture of temperature change in Turkey:

1. Annual, winter and spring mean temperatures have a tendency to rise, especially in the South, while there is a decrease in average temperatures in the North and continental regions in summers and falls.
2. The increasing trends of the night minimum temperatures are statistically significant.
3. The increase in night minimum temperature is significantly greater in summer than in spring and fall. Rise in spring and summer night temperatures are stronger than the rise in day maximum temperatures during these seasons.
4. The changes regarding temperate or hotter climates of Turkey's temperature regime are closely related with the statistically significant increasing night temperatures of summers and springs.
5. When compared with the significant increase in minimum night temperatures, some stations show a small increase, some show a small decrease regarding maximum day temperatures.
6. Increasing trends concerning night temperatures have caused strong decreasing trends in the difference between maximum-minimum temperatures at most stations in spring and summer, and at some in winter and fall.

Along with temperature, past changes in precipitation were also investigated. Analysing spatial and temporal variations of annual and seasonal precipitation, and annual aridity index series between 1930 and 1993, and normalised precipitation anomalies for the period 1994 – 2000 revealed that normalised annual and winter precipitation series had showed large variations over a considerable part of Turkey starting from 1970s. Wet conditions for the normalised annual and winter precipitation anomaly series were observed in 1940s, 1960s, late 1970s, early 1980s and mid-late 1990s, and dry conditions prevailed in the early-mid 1930, early-mid 1970s, mid-late 1980s, early 1990s, and 1999/2000 periods [coinciding with the above mentioned cool and warm periods, respectively.] Between mid-1940s and late 1960s, spring precipitation series exhibited an upward trend over most of the country. Moreover, a shift from humid conditions to dry sub-humid conditions appeared in the aridity index values by 1960s. During the period between the end of spring and beginning of fall, generally hotter and drier conditions were prevalent in regions other than Black Sea and north of East Anatolia (Türkeş, M., 1996, Türkeş, M., 2003, Türkeş, M., 2008). According to First National Communication on Climate Change, there were coherent areas of significant change in precipitation in winter and fall. In the last five decades the western regions had a significant decrease in winter precipitation. On the other hand, fall precipitation in northern parts of Central Anatolia increased. However, the reasons behind those changes were not clear. For spring and summer, there was no coherent areal change, although some stations show significant changes in precipitation (FNCCC, 2007, pp. 161-162). Türkeş, Koç and Sariş (2009) analysed daily precipitation totals of 97 stations over the country to assess the long-term trends and variations in precipitation series. In the Mediterranean type rainfall regimes, low frequency fluctuations and strong decreasing trends were observed. A long-term decreasing trend prevailed in all regions in winter. In spring, a general trend in precipitation totals in all regions other than Black Sea was seen. Yet, a high year-to-year variability in spring precipitation in the total series was clear. In spite of a general weak increasing trend over the country, except for Mediterranean and Marmara regions in summer, a slightly decreasing trend at many stations was found. January, February and September revealed a decreasing trend in monthly precipitation values, however, April, August and October showed an increasing one. The former trend was evident in Mediterranean, Central and East Anatolian regions, whereas the latter was in Mediterranean, Marmara, and Central Anatolian regions. Furthermore, Toros (2011) analysed daily precipitation data of 271 stations over Turkey for the period 1961 – 2008. He reported a general decrease in annual total precipitation during the last decades. Regions with increasing precipitation were Marmara, Aegean, Mediterranean, and South-east Anatolia. In winter a general negative trend was determined. Moreover, on basin scale, Büyükyıldız and Berktay (2004) analysed the precipitation information from 25 meteorological stations on Sakarya Basin. They have detected a significant downward trend in 12 of them, located in north and west of the basin. 9 of those stations also exhibit a decreasing trend, however, insignificant. Additionally, they observed an insignificant increasing trend in 4 stations. Finally, Tayanç et al (2009) indicated larger urban precipitation variability than in rural areas, signalling more frequent and severe droughts and floods in the former.

Analysing and understanding the large scale climatic conditions, such as ENSO and NAO patterns, is regarded useful to predict the potential of any water resources system (Karabörk, M. Ç., Kahya, E., Karaca, M., 2005). Kahya and Karabörk (2001) investigated the relationship, if any, between stream-flows of Turkey and El Niño and La Niña signals. A total of 76 stream-flow gauging stations, belonging to the General Directorate of Electrical Power Resources Survey and Development Administration (EİE), from over 22 river basins were selected. Each stream-flow observation spanned the period 1964 – 1994, i.e. 31 years. Data list also included seven El Niño (1965, 1969, 1972, 1976, 1982, 1986, and 1991) and six La Niña events (1964, 1970, 1971, 1973, 1975, and 1988). They concluded that there was a potential for long-range prediction of stream-flow associated with the extreme phases of Southern Oscillation. North-western Anatolia (NWA) and Eastern Anatolia were identified as the two core regions with signals revealing the sign and magnitude of stream-flow responses to ENSO events. Following this, Karabörk and Kahya (2003) analysed monthly total precipitation records at 94 meteorological stations of State Meteorological Service (DSİ) whose records contained the period 1940-1993, i.e. 54 years. Eleven El Niño (1941, 1951, 1953, 1957, 1965, 1969, 1972, 1976, 1982, 1986, and 1991) and eight La Niña (1950, 1955, 1964, 1970, 1971, 1973, 1975, and 1988) events were included to the data set. The authors concluded a clear presence of teleconnections between precipitation regimes over Turkey, and El Niño and La Niña events. Furthermore, Karabörk, Kahya, and Karaca (2005) analysed impacts of SO and NAO on precipitation, stream-flow, and maximum and minimum temperatures. The data consisted of information from 76 stream-flow gauging stations over a 31-year period (1964 – 1994), and 94 meteorological stations over a 43-year period (1951 – 1993). Ten El Niño events between 1951 and 1988 occurred in this period. It was seen that with maximum temperatures all the stations had a similar response to El Niño and La Niña. Considering minimum temperatures and El Niño, two candidate regions were identified in the East and the West. It was found that NAOI and winter precipitation were negatively correlated. Moreover, 50 of 76 stream-flow stations, located in western and southern Anatolia, showed negative correlation with NAOI. 14 of these, majority located in Sakarya basin, showed a lower significance level ($\alpha \leq 0.01$). The conclusion was that positive NAO resulted in dryer and cooler conditions in Turkey. Türkeş and Erlat (2005) examined winter precipitation (DJFM) of 78 meteorological stations of Turkey and their response to North Atlantic Oscillation (NAO) between 1930 and 2001. The conclusions of the study follow as: 1) Among the three compared indices of NAO the Ponta Delgada-Reykjavik (PD-R) index, followed by Lisbon-Stykkisholmur/Reykjavik (L-S(R)) are the best ones with respect to the ability to explain year-to-year variability in long-term winter precipitation series. 2) A negative relationship between normalised winter precipitation and the NAO was observed through correlation analysis at all stations for PD-R and almost all stations for the L-S(R). 3) Winter composite precipitation amounts mainly had an increasing trend during the weak NAOI phase and a decreasing one during the strong NAOI phase. 4) A link between extreme low- and high-index NAO winters, and the individual widespread strong wet conditions and drought events in winter seasons were observed. 5) There was also a possibility for an individual strong NAO to induce widespread wet conditions rather than widespread drought in winters. 6) A significant resemblance between spatial pattern and magnitude of negative correlation coefficients with the NAOIs and spatial pattern and severity of wet (dry) conditions related to the weak (strong) NAOI phase in winter was detected. The resemblance was specific for the PD-R and the L-S(R) NAOIs. Sönmez, Kömüşçü, Erkan and Turgu (2005) argued in their study dealing with drought in Turkey that winter droughts in the country could be connected to positive NAO anomalies. Finally, Karabörk, Kahya, and Kömüşçü (2007) analysed 212 meteorological stations over a 30-year period (1973 – 2002) to quantify shifts in probability distribution of precipitation data in connection with SO extremes. Previously determined core regions were investigated and it was found that in West Anatolia region (including Ankara) there were upward shifts in the amount of April – July precipitation during El Niño event years. A similar tendency was observed in East Anatolian region for February – June period. Moreover, La Niña related shifts in East Anatolia were determined to be significant during April – October as dryness. The writers claimed that ENSO patterns could be a tool for water resources management in the country. Keskin and Şorman (2010) also affirmed that ENSO and NAO indices values could support runoff values to construct a drought or flood management plan.

In brief, the studies dealing with ENSO and NAO suggested that there were connections between these events and precipitation and stream-flow regimes in Turkey. North-western (including Ankara) and Eastern Anatolia revealed clear links. Moreover, NAO impacts were claimed to be observable as dryer and cooler periods in the country. Specifically, decreases in winter precipitation were associated with these atmospheric events. Therefore, writers suggested that ENSO and NAO patters could be a tool for water managers in Turkey.

The above information is about the observed changes in climate. The paragraphs below are dealing with the projected effects.

First National Communication on Climate Change also provides a general look to the changes in temperature. Future simulation with RegCM3 is run by the general circulation model FVGCM (Finite Volume General Circulation Model) based on SRES A2 emission scenario. For the whole country, an increase in the average temperatures is projected in winter. This increase is higher in the east part of the country. In summer western parts will have a higher increase, especially Aegean Region, which is foreseen to be up to 6^{o}C. The average increase in average temperatures for the entire country is expected to be 2-3^{o}C (FNCCC, 2007, pp. 165).

In another study conducted using a regional climate model, PRECIS (Providing Regional Climates for Impact Studies), developed by the Hadley Centre for Climate Prediction and Research, a detailed climate prediction for Turkey was done (see Appendix A). The model was run on the HadAMP3 results of the Hadley Centre and comparisons were made between the reference period simulations (1961-1990) and future period simulations (2071-2100). According to A2 scenario, average temperatures will rise by 4-5^{o}C at coasts, and 5-6^{o}C at inner regions during 2071-2100 compared to 1961-1990 period. The average increase is expected to be 5.12^{o}C. In winters, from West to East, an increase in average temperatures is expected. This increase is 3-4^{o}C in West, whereas 4-6^{o}C in East. In springs, a general 4-5^{o}C temperature difference will be seen. This difference will be 3-4^{o}C at Black Sea coast, and 5-6^{o}C in East Anatolia. The change in summer is expected to be opposite to winter, i.e. West regions will have more change than East. South-east Anatolia will face 4-5^{o}C difference, however, inner Aegean, inner West Black Sea may have differences up to 6-7^{o}C. Other regions will face 5-6^{o}C temperature change. The difference during fall is determined as 4-5^{o}C for the whole country. The annual difference in maximum temperature according to Turkey's spatial average is calculated as 5.36^{o}C during 2071-2100 compared to the period 1961-1990. The highest change in maximum temperatures is seen at inner East Anatolia in winters. The change in summers is expected to be 5-6^{o}C at South-east Anatolia, and will increase towards west. The change in minimum temperatures is expected to be 5-6^{o}C at East and South-east Anatolia, inner Aegean, north-west and south of Central Anatolia, and 4-5^{o}C elsewhere. The annual difference in minimum temperature according to Turkey's areal average is calculated as 5.02^{o}C during 2071-2100 compared to the period 1961-1990 (Demir, İ., Kılıç, G., Coşkun M., 2008).

The most recent study is the project called "Climate Change Scenarios for Turkey", which is a collaboration of The Scientific and Technological Research Council of Turkey, Ministry of Environment and Forestry, İstanbul Technical University, and Turkish State Meteorological Service during 2006-2008 (URL 3). The model was constructed by downscaling A2 and B1 ECHAM5 results using RegCM3 (URL 4). It was run for 2011-2099 with 30-year-periods for each season and with reference period 1961-1990 (see Appendix B).

According to the A2 scenario results, concerning temperature changes, for the period 2011-2040, an increase about 0.4^{o}C is expected for winter except for South-east Anatolia, where the change is 1^{o}C. For spring, a general cooling trend is seen everywhere except East and South-east Anatolia. The decrease, about 1^{o}C, is more significant at Marmara, Aegean, and west and mid-Mediterranean parts. On the other hand, East and South-east Anatolia will face an increase 0-1^{o}C. During summer, Marmara, north and mid-Aegean, Black Sea regions show a decrease of 0-1^{o}C. The increase in remaining parts is 0-3^{o}C. For fall there is a similar tendency with summer. Yet, only the south of Marmara, West and East Black Sea show a decrease, which is 0-1^{o}C. Other regions exhibit an increase of 0-3^{o}C. The most significant increase is at South-east Anatolia in summer and fall. For the period 2041-2070, there is an increasing trend for all the seasons and for the entire country, and is more than the last period. The most significant changes are projected for winter and fall, 1.5-3^{o}C. In spring, west and Central Anatolia has a change about 1^{o}C. East and South-east Anatolia, however, show a trend of 0.8-2.5^{o}C. For summer, majority of the country faces an increase of 1.5-3^{o}C. The northern parts are relatively less hot than southern and central regions. The temperature increase in 2071-2099 is higher than the previous periods. In general, the change is more than 3^{o}C. The most significant increase is in East and South-east Anatolia. In winter, Aegean and Marmara Regions exhibit an increase about 2^{o}C. The change at other parts is 3-5 degrees. In spring, Aegean, Marmara, north of Central Anatolia, and Black Sea regions show a less hot temperature increase than the other parts, where the change is 2-5^{o}C. The most significant increase is projected for summer. The entire change is expected to be 2-6^{o}C. Not as summer but fall also faces important temperature increase, which is about 2-5^{o}C.

Considering B1 scenario, there is almost no or slight temperature increase in all seasons in the period 2011-2039. The clearest change is a decrease in spring about 1^{o}C at regions different than East and South-east Anatolia. However, the situation for 2040-2069 is not that soft. For winter and fall significant changes are projected. In winter, majority of the country faces an increase of 2.5^{o}C. Only Aegean region has a lower increase which is about 1.5^{o}C. In fall, the general increase is about 2^{o}C except for south of Marmara and mid-Black Sea, where the change is about 1^{o}C. In spring, only in eastern parts an increase 1-2^{o}C, is foreseen. In summer east and south regions face an increase of 1.5-3^{o}C. Other regions exhibit 0.5-1.5^{o}C. 2070-2099 is a severe period. Except for spring, there are important increases in all seasons. In winter, East Anatolia, South-east Anatolia, and east Mediterranean will have 2.5°C higher temperatures than in 1961-1990. 2°C of change is expected in other parts. In spring, Aegean, Marmara and Black Sea exhibit 1°C increase. Mediterranean, Central Anatolia show an increase of 1.5°C. The change at East Anatolia and South-east Anatolia is 2-3.5°C. In summer, the increase is significant in west Mediterranean and east parts, where the change is more than 3°C. In fall, west parts will have an increase of 2°C, whereas east 3°C.

Aksoy et al (2008) projected future trends in Thrace Region using SCENGEN GCM outputs for HadCM2 and ECHAM4. For annual temperature, the expectation of rise according to ECHAM4 is 1°C, 2°C, and 3.9°C for 2025, 2050 and 2100, respectively. HadCM2 predicts an increase of 0.8°C, 1.5°C, and 3.2°C for 2025, 2050, and 2100, respectively. The results are in agreement with the above projections.

Regarding precipitation, in general, for winter and spring, precipitation decreases along the Aegean and Mediterranean coasts, and increases on the Black Sea coast. The East Black Sea will have more precipitation. Central Anatolia shows little or no change. The most severe reductions are expected at the south-western coast. In summer not much change is expected, while in fall a slight increase in the whole country is foreseen. The Euphrates-Tigris basin will have substantially higher precipitation in fall. The snow water equivalent change is expected to be up to 200 mm over the high plains of East Anatolia, East Black Sea Mountains. Therefore, major changes in stream flows are expected in the country (FNCCC, 2007, pp.164).

According to A2 scenario of PRECIS in the period 2071-2100 a general decrease in precipitation with regional differences is expected. In East Black Sea, Aegean, Mediterranean, and Taurus Mountains line, 100-400 mm/a less precipitation is foreseen. The percentage of decrease in precipitation is growing from East to West. A 30-40% decrease is expected at the Aegean, Thrace, west and mid-Mediterranean, some parts of South-east Anatolia, and Central Anatolia. On the other hand 5% less precipitation will be seen at East Anatolia and East Black Sea regions. During winters, Aegean, Mediterranean, Taurus Mountains line will have dramatic decreases. However, there will be an increase at East Black Sea and north of East Anatolia. During spring, a general decrease in the country is expected. In summer, precipitation decreases significantly in Central Anatolia and Black Sea Region. Especially in the East, an increase in precipitation in fall compared to other seasons is expected. During 2071-2100, snow cover will be less compared to 1961-1990 at East Anatolia and East Black Sea. This decrease reaches 300 mm in some parts. Due to increase in heat, evaporation, and decrease in precipitation, water loss will be higher. Although there is no significant areal result concerning Turkey, more losses are expected at south of Marmara, Aegean, East Black Sea, north of South-east Anatolia and Taurus Mountains line (Demir, İ., Kılıç, G., Coşkun M., 2008).

The results of A2 scenario of the "Climate Change Scenarios for Turkey" project show that there is a percentage increase in the entire country for the period 2011-2040 in all seasons. In winter and spring, this increase is mainly about 30%. However, north-east parts are expected to receive at least 50% more precipitation. In summer, the regions with minimum or no precipitation are parts of Central and South-east Anatolia, and mid-Mediterranean. In fall, the most significant increase is in the central parts. During 2041-2070, in winter a general slight increase in precipitation in the central regions is projected. In spring, the increase is about 20-50% in the entire country. The central parts will face a decrease up to 150% in summer. South-east Anatolia is expected to have an increase of about 200%. In fall, Marmara, Aegean, and east and mid-Mediterranean show a decrease up to 50%, whereas remaining regions will receive about 30% more precipitation. Winter and spring of 2071-2099 will have a rise of about 30% except for Mediterranean. Mediterranean is projected to exhibit 50% loss. In summer, the entire country but South-east Anatolia will face a decrease up to 200% in central regions. South-east Anatolia, however, exhibits an increase of about 200%. In fall Central Anatolia, Mediterranean, majority of South-east and East Anatolia, and mid and east Black Sea show an increase about 30%. In the remaining regions the loss is up to 50%.

According to the B1 scenario of the "Climate Change Scenarios for Turkey" project, winter, spring and fall will receive about 1.2 mm/day more precipitation in 2010-2039 than in 1961-1990. There is no or slight change in summer. Similar results are observed for 2040-2069. Winter and spring generally receive 0.8 mm/day more precipitation. In the north-eastern parts the increase is more than this value. In the whole country a decrease about 0.8 mm/day is expected. There is a slight decrease in the entire country in summer. In fall, central regions will receive about 0.8 mm/day more precipitation. There is no or slight change in remaining regions. The situation in 2070-2099 is slightly different. In winter, Mediterranean will face a decrease of about 2.5mm/day. The Black Sea coast is expected to have more precipitation, up to 3.2 mm/day. In spring there is slight increase in all regions other than Mediterranean coast and South-east Anatolia. In summer the whole country will face a slight decrease in precipitation. Precipitation behaviour in fall is similar to spring, yet, the decrease is at eastern side and Marmara.

Aksoy et al (2008) predict a decrease in precipitation with 3.7%, 6.8%, and 13.8% for 2025, 2050, and 2100 respectively, according to ECHAM4 in Thrace Region. This will be 5.4%, 10%, and 20.1% in 2025, 2050, and 2100, respectively, according to HadCM2. A summary of the model results are presented in Appendix C.

To sum up, the effect of climate change on Turkey is expected to be increasing in terms of temperature with the most significant increase in the Mediterranean. Although different values have been provided by different studies, the consensus is that the eastern parts will have more increase than western parts in winter. This trend will be opposite in summer, i.e. the change in temperature is expected to be higher in the west than east. On precipitation, however, it is hard to reach a consensus. In the long term, a general increase is expected in winter and spring, however, especially east and south regions exhibit sharp declines. Summer and fall will become more arid. These changes will be observed after the first half of the 21st century and get severe through the next century. It is also necessary to note that the majority of model runs cited by IPCC reveal a general decrease in precipitation for Turkey (URL 5). The precipitation increase is mainly found in ECHAM5 models. This raises uncertainty and emphasises the need for more regional climate runs for Turkey. In view of the aims of this study, it is on the safe side to assume that climate change will have negative impacts on precipitation in all regions except Black Sea.

There are quite a few studies investigating climate change impacts on water resources of Turkey. One of them assessed the 31-year long monthly mean stream-flow records of 83 gauging stations over 26 basins and revealed downward trends in west, south and south-east parts of the country. The only upward trend was observed in central part of Black Sea and north-east part of Central Anatolian Region. No trend was seen in the rest. However, it was not certain that those trends were primarily a consequence of climate change, although changes in precipitation and surface temperature were expected to be influential (Kahya, E., Kalaycı, S., 2004). Another analysis dealing with the 31-year long monthly records of 78 stations aims to investigate relationships between precipitation anomalies and stream-flow changes. The conclusion was that precipitation had been the basic driving factor in the stream-flow processes. Moreover, the analysis revealed decreasing trends in 1970 – 1974, 1982 – 1986, and 1989 – 1994, which were considered to be a consequence of the mean temperature and evapotranspiration increase (Kalaycı, S., Kahya, E., 2006). Albek and Albek (2009) analysed stream-flows and stream temperatures and found that more streams experienced a decrease in yearly and seasonal flows than an increase. They stated the changes in precipitation and increasing water use for irrigation as the primary factors. Considering stream temperatures, more positive trends were present, signalling a warming trend. Furthermore, another analyses of the data supplied by 130 flow measurement gauges over 25 basins revealed a general decreasing trend during the last 75 years on stream-flow in Turkey (more than 10% in Sakarya, and more than 15% in Kızılırmak basins). This trend was significant in the west of Marmara Region, Aegean Region, west of Central Anatolian Region, Mediterranean Region, and South-east Anatolian Region (Yıldız, M., Özkaya, M., Uçar, İ., Ayhan, Ö., 2010). To summarise, precipitation was determined to be the primary factor affecting stream-flow processes. All observations revealed that the streams with negative trends were larger in number than those with positive trends. The decreasing trends were more significant in west, north-west, and south-east parts of Turkey. The results comply with the observed changes in precipitation described before.

To provide a **general summary** of the impacts of climate change on Turkey, it is possible to indicate temperature fluctuations causing cool and warm periods beginning from 1930s. It is observed that there is a more significant temperature increase during the last two decades. Temperature fluctuations differ according to the seasons and geographic scale, however, a decrease in winter and an increase in spring mean and maximum temperatures were clear. These changes took place more in western and eastern regions. Precipitation followed the periodical changes in temperature, resulting in dry and wet periods. In general, the precipitation was observed to decrease, however, not uniformly. This negative trend was apparent in winters and in western and southern regions of Turkey. Moreover, there are studies indicating the impacts of ENSO and NAO events on the cool and dry, and warm and wet periods in the country. Scientists claim that these events could be used to predict availability of water. Considering the water resources, all the studies mentioned above reveal more decreasing trends in streams than positive ones, pointing to the importance of precipitation for runoff. The future scenarios forecast that climate change will be more influential during the 21st century creating a warmer and drier Turkey. However, the expected changes are not uniform throughout the country. In general, southern and eastern parts will be more negatively influenced, whereas the northern regions may experience positive effects. Water stress, especially in western and southern urban areas, is anticipated to increase. Nonetheless, more investigations are required to precisely determine possible impacts of climate change on water resources of Turkey.

Türkeş et al (2000) summarised the expected impacts of climate change on hydrologic cycle on Turkey as below:

1. As the climate belts are moving towards the poles, Turkey is expected to be under influence of a drier and hotter climate covering North Africa and Middle East now.
2. More problems may occur in water supply in dry and semi-dry regions, especially in urban areas, and more water may be required for agricultural and drinking purposes.
3. Along with the enlargement of arid and semiarid regions, increase in intensity and duration of summer aridity may contribute to desertification, increase in salinity, and erosion.
4. Especially in the big cities, due to urban heat islands, night temperatures during hot periods will significantly rise.
5. Infections due to changes in amount of water and heat stress may result in immense health problems.
6. Low delta and coastal plains, and estuaries, generally places of dense settlement, tourism, and agriculture, may be flooded due to sea level rise.

7. The area under seasonal and permanent snow-ice cover and the length of the snow cover period may decrease. Sudden snow melts and avalanches may occur.
8. The change in timing and volume of flow due to snow melt may affect water resources, agriculture, transport, and recreation sectors.

3. Water Potential, Need and Use in Turkey

This part describes water potential of Turkey, comprised of groundwater, lakes and rivers. Amongst these, rivers are of prime importance as they comprise 87% of available water resources. Later, water demand, use and future projections are given.

3.1 Water Potential of Turkey

Annual mean precipitation is about 643 mm which creates a mean flow of about 501 hm^3/a, of which 274 hm^3 is evaporated back to atmosphere through water and soil surfaces and by evapotranspiration, 69 hm^3 feeds groundwaters, and 158 hm^3 turns into surface flow and reaches seas and lakes through rivers. 28 hm^3 of 69 hm^3, feeding groundwaters, become surface waters through springs. Moreover, an amount of 7 hm^3/a enters Turkey cross-border. Therefore, gross surface water potential of Turkey is 193 hm^3/a. Considering the 41 hm^3/a feeding groundwaters, total renewable gross water potential is calculated as 234 hm^3/a. However, the amount of technically available and economically feasible water is 98 hm^3/a, 95 hm^3/a from surface waters and 3 hm^3/a cross-borders. With the 14 hm^3/a of extractable groundwater, total amount of available water is 112 hm^3/a (URL 6, Toprak, S., et al, 2007, Şener, S., et al, 2007).

Table 3.1 Potential of Water Resources of Turkey

Annual Mean Precipitation	643 mm/a
Annual Mean Flow	501 hm^3/a
Evaporation	274 hm^3/a
Infiltration	41 hm^3/a
Surface Waters	
Annual Surface Flow	193 hm^3/a
Available Surface Flow	98 hm^3/a
Groundwaters	
Annual Extractable Amount	14 hm^3/a
Total Amount of Available Water	*112 hm^3/a*

3.1.1 Groundwater

According to hydro-geological investigations conducted by DSİ till the end of 2009, groundwater extraction was 13.66 km^3, of which 4.064 km^3 was used by the state for irrigation, 5.776 was used as drinking and industrial water, and 2.971 km^3 was used by individuals (URL 7).

3.1.2 Lakes

There are more than 120 natural lakes, including the small ones in the mountains. Van Lake, which is one of the largest and deepest lakes is at an altitude of 1,646 m and has an area of 3,712 km^2. Second largest is Salt Lake in Central Anatolia. Salt Lake has an area of 1,500 km^2. The lakes are mainly located in four regions: Göller Yöresi (Eğirdir, Burdur, Beyşehir, and Acıgöl), South Marmara (Sapanca, İznik, Ulubat, Kuş), Van Lake and surroundings, Salt Lake and surroundings. Some of the lakes are deeper than 30 m. Along with the natural lakes, 656 reservoirs exist in Turkey. Some of them are Atatürk Dam (817 km^2), Keban Dam (675 km^2), Karakaya Dam (268 km^2), Hirfanlı Dam (263 km^2), Altınkaya Dam (118 km^2), Kurtboğazı Dam (6 km^2) (URL 7).

3.1.3 Rivers

Turkey is rich of rivers and those are more important than the above mentioned resources. Therefore, detailed information about them is supplied below, based on Akbulut, N. E. et al. (2009).

Turkey has many rivers entering the surrounding seas and neighbour countries of Iraq, Iran and Armenia as the country has complex geological, geomorphological and climatic settings. Overall, there are 26 main drainage basins in the country, of which 4 are endorheic, i.e. lacking an outflow to the sea.

The river basins, shown on Figure 3.1, can be characterised as follows: The Euphrates, Kızılırmak, Kura and Aras drain large basins (> 70,000 km^2). Most other rivers drain catchments <30,000 km^2. Rivers that drain the Pontid and Taurid Mountains have the highest specific runoff (l/m^2/year) due to high precipitation and low evaporation rates. Rivers that drain into the eastern Mediterranean Sea (Seyhan, Ceyhan) and some Eastern Anatolian (Euphrates, Tigris) also have high specific runoffs. Less well-endowed are the basins of north-eastern Turkey (Çoruh, Aras), Central Anatolia (Sakarya, Yeşilırmak, Kızılırmak), and the Marmara Region.

Turkey is drained by 107 major rivers, each with a catchment area >1,500 km^2. The longest river is Kızılırmak (1,355 km). After the Euphrates (1,263 km in Turkey), Tigris (523 km in Turkey), Seyhan (560 km), Aras (548 km in Turkey), Yeşilırmak (519 km), Ceyhan (509 km), Çoruh (442 km in Turkey), Gediz (400 km), Susurluk (321 km), Greater Meander (307 km), and Smaller Meander (174 km) follow. As seen, the Euphrates, Tigris, Meriç, Çoruh, Aras and Asi are transboundary rivers.

The Sakarya River, Sangarios in ancient Greece, is the third largest river with a catchment area of 58,160 km^2. It originates from five springs in the western Anatolian Plateau, the Sakarbaşı. The catchment mostly consists of neogene-lacustrine and volcanic sedimentary bedrock in the headwaters, whereas palaeogene and mesozoic bedrock of metamorphic and detritic origin dominate in the lower part. Major tributaries are Porsuk, Kirmir, Ankara, Göynük and Mudurnu rivers. The mean basin relief is about 1,160 m.

The Kızılırmak River, starting at Kızıldağ, Sivas, flows across the central Anatolian plain, cuts the Pontid Mountains and discharges into the Black Sea. The catchment area, 78,180 km^2, includes sedimentary, magmatic and metamorphic bedrocks from the Mesozoic to Neogene periods.

The catchment of the 519 km long Yeşilırmak drains an area of 36,114 km^2 and contains a complex mosaic of sedimentary, magmatic and metamorphic bedrock formed during the Mesozoic to Neogene periods. Originating in the Central Anatolian Plateau, Yeşilırmak flows first through inter-mountain valleys before it cuts Pontid Mountains and enters the Black Sea.

Seyhan River, 560 km long, with a basin area of 20,450 km^2 originates in the Tahtalı Mountains (Sivas and Kayseri provinces). Cutting the Taurid Mountains, it passes the Çukurova coastal plain and reaches Mediterranean Sea in a vast delta. The plain consists of quaternary and neogene sediments. Primary components of the headwaters are mesozoic carbonates and ophiolitic bedrocks as well as neogene sediments and volcanic sedimentary bedrock. Major tributes are Göksu, Zamantı, Çakıt and Körkün rivers.

The Ceyhan River, 510 km, drains a mountainous catchment of 21,982 km^2 in the eastern Taurids, which primarily consists of palaeozoic, mesozoic, and tertiary bedrock. The river originates at an elevation of ~3000 m above sea level. The Ceyhan River enters to the Mediterranean Sea at İskenderun Bay after flowing from Çukurova floodplain.

The Euphrates (Fırat) drains the largest basin, 127,304 km^2. It originates in the highlands of north-east of the Anti-Taurid Mountains (~3,000 m above sea level) and enters Syria. The major tributes in Turkey are Karasu and Murat rivers. The basin is mostly covered by neogene volcano-sedimentary bedrock.

The Tigris (Dicle) drains an area of 57,614 km^2 located at South-east Anatolia. The Batman, Garzan, Botan, and Hezil rivers are the major tributes in Turkey. The basin is covered by sedimentary and karstic carbonate rocks and of Palaeozoic to tertiary origin. The headwaters are dominated by metamorphic rocks. The Tigris enters Iraq and forms Shatt-el-Arab at southern Iraq with Euphrates and reaches Persian Gulf.

The Aras River drains an area of 27,548 km^2 in Turkey, covered by neogene-sedimentary, volcano-sedimentary, and volcanic rocks. It originates in mountains 3000 m above sea level. Before entering Iran, the river joins with Arpaçay, a major tributary, and forms the Turkish-Armenian boundary.

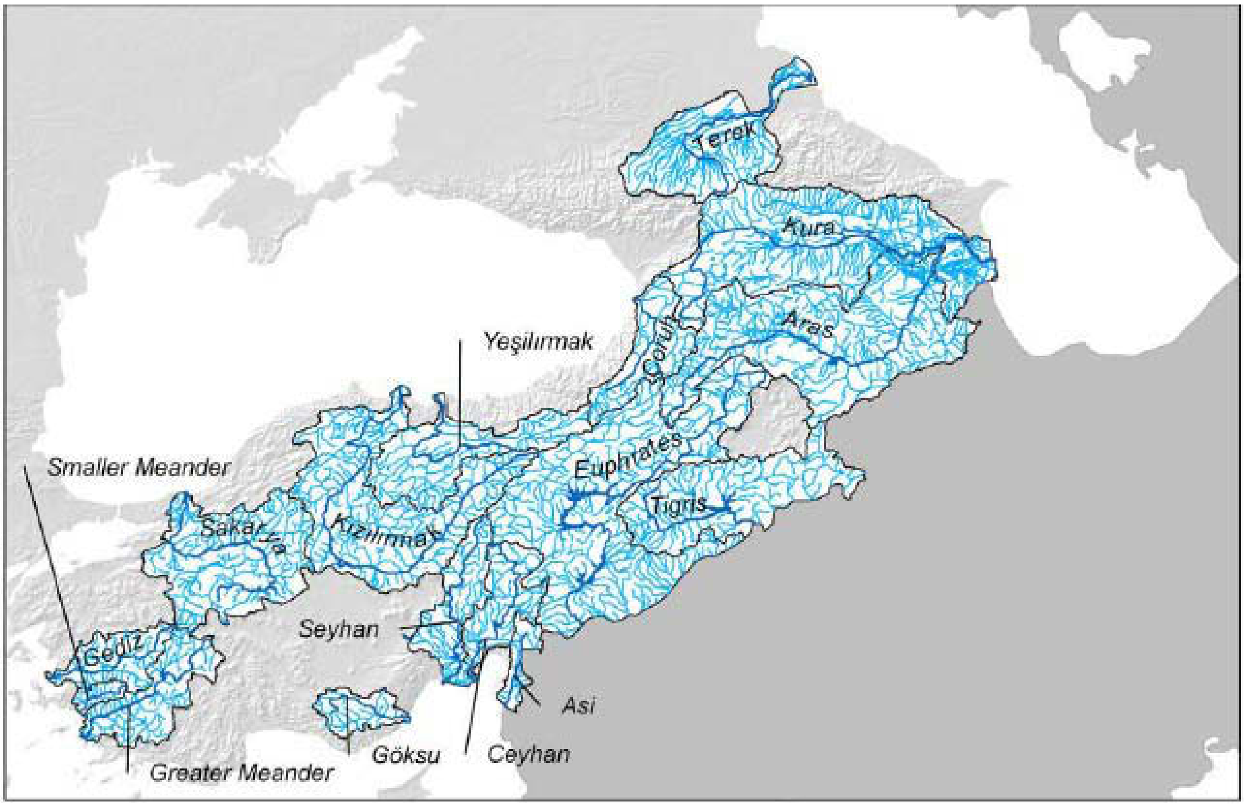


Figure 3.1 Drainage Network of Rivers in Turkey

3.2 Water Need and Use in Turkey

Turkey's current water potential per capita is 1,500 m^3/a, which is expected to drop to 1,220 m^3/a in 2030 assuming the same water availability (Şener, S., et al, 2007) or 1,000 m^3/a mainly due to population increase (Akbulut, N. E., et al, 2009). The main use of water (75%) is irrigation (Şener, S., et al, 2007). The second largest water use is for drinking water needs (15%). These ratios are expected to be 65% and 15% in 2030, respectively as shown below (Toprak, S., et al, 2007).

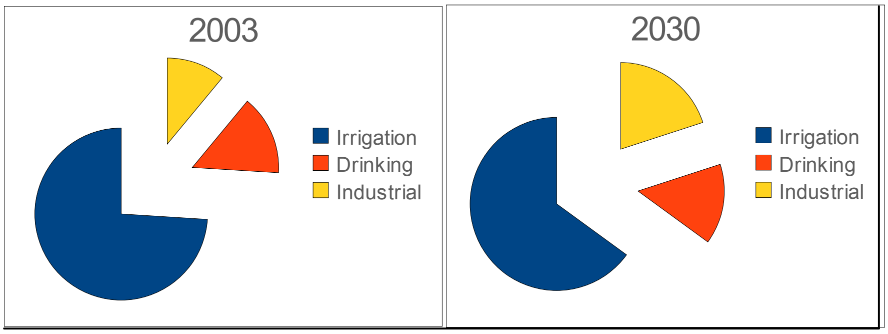


Figure 3.2 Water Use of Turkey in 2003 and 2030 (Toprak, S., et al, 2007)

DSİ plans to open up new areas for irrigation. However, the water use for this sector is expected not to rise as there are projects to increase use of pressurized irrigation, which is not widespread currently. The table below shows projection of water use in 2023 considering different sectors (URL 6).

Table 3.2 Increase of Water Use in 2023 compared to 2009 (URL 6)

	2009		**2023**		**Development Ratio (%)**
	Amount	**Unit**	**Amount**	**Unit**	
Irrigation	5.42	Million ha	8.5	Million ha	157
Hydroelectric Power	50	Billion kWh	140	Billion kWh	280
Drinking and Industrial	10.62	Billion m^3	38.5	Billion m^3	362

Another area of water use is power production. The total mean annual runoff all Turkish rivers is 186 km^3, corresponding to an average runoff coefficient of 0.37 (total annual precipitation is 500 km^3). Gross annual hydro power potential is 433 TWh, 50% of which is technically exploitable. 28% of this portion is economical. Currently, 34% of this economically exploitable potential is in use. 120 power plants with 11,588 MW installed capacity are in operation. More than 480 power plants are expected to be installed by 2020 (Akbulut, N. E., et al, 2009).

If the per capita water availability is below 1000 m^3 or the ratio of withdrawals to long-term average runoff is above 0.4, basins are called water-stressed. Such conditions are presently found in Northern Africa, the Mediterranean Region, the Middle East, the Near East, southern Asia, northern China, Australia, the USA, Mexico, north-eastern Brazil, and the west-coast of South America (Bates, B. C., Kundzewicz, Z. W.,Wu, S., Palutikof, J. P., 2008, pp. 21). The water availability in Turkey is still above this level, but due to population growth and climate change water stress could occur if no measures are taken.

4. Climate Change Adaptation, Adaptive Capacity, and Response Options for Water Sector

Part 4 is reserved for explanation of adaptation issue in the climate change context. First, the definition of adaptation is provided and the concept is explained with related approaches, types and processes, scales, and supporting and inhibiting factors. Adaptation options concerning natural resource management are discussed. Definitions and factors of adaptive capacity and vulnerability are given and their interaction is investigated. Finally, options for climate change adaptation of water sector are covered.

4.1. Climate Change Adaptation

In climate change context adaptation means modifications in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to average potential damages or to benefit from opportunities associated with climate change (IPCC, 2001, pp. 879). Adaptation consists of deliberate actions to limit negative outcomes as well as to benefit from any opportunities (OECD, 2009, pp. 48) and is critical as a required complement to mitigation actions because, first, it is likely that a lag time between emissions and consequent climate change exists. Therefore, adaptive actions against unavoidable adverse effects may be necessary irrespective of any mitigative action. Second, adaptation is necessary for natural climate variability. Hence, development of planned adaptation strategies to cope with these risks is required (IPCC, 1990, IPCC, 2001, pp. 881, OECD, 2009, pp. 48, Mukheibir, P., 2010), “Adaptation is unavoidable.” (Berrang-Ford, L., Ford, J. D., Paterson, J., 2011).

Moser and Ekstrom (2010) deviate from this definition in recognition that adaptation must consider climate change but it can be initiated or realised in the context of non-climatic windows of opportunity. They also criticise the implicit assumption of effectiveness in the outcome. Stemming from these issues, the definition for adaptation they offer is that “adaptation involves changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes. Adaptation strategies and actions can range from short-term coping to longer-term, deeper transformations, aim to meet more than climate change goals alone, and may or may not succeed in moderating harm or exploiting beneficial opportunities.”

Adaptations differ according to systems, people undertaking them, prompting climatic stimuli, and their timing, functions, forms, and effects. In natural systems, adaptation is reactive, autonomous, whereas in human systems, private decision-makers and public agencies or governments undertake adaptation (IPCC, 2001, pp. 879, OECD, 2009, pp. 50). However, also in human systems autonomous or spontaneous adaptations are observed: they are generally reactive and take place without intervention of a public agency. They tend to be incremental and specific, and in response to multiple stimuli, to take multiple forms, to be limited by economic, social, technological, institutional and political conditions. On the other hand, planned adaptations can be reactive or anticipatory, i.e. undertaken before impacts are observed. In addition, adaptations can vary in time and scale (geographic, functional etc.). (IPCC, 2001, pp. 883). Governments and public agencies play a crucial role in adaptation issue because, first, they are the custodians for public assets and provide services and, second, they establish the rules and regulations which may improve or limit the ability of other actors to adapt to the impacts of climate change. Finally, they are important as governments and public agencies are responsible for investments in public goods, monitoring of weather and climate, provision of weather forecasts, and research and development to enable other actors to better adapt to climate change (OECD, 2009, pp. 52).

Adaptation to environmental and climatic changes and conditions is not a new concept. Historically, accumulated knowledge on adaptation through a range of practices that include crop diversification, irrigation, water management, disaster risk management and insurance, societies have a long list of adaptive measures to the weather and climate impacts. However, climate change is a novel risk often going beyond the range of experience related to e.g. drought, heatwaves and accelerated glacier retreat (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 719, OECD, 2009, pp. 50).

Rather than changed average values, factors related with variability and extremes are the key features for climate change vulnerability and adaptation. Communities tend to be more vulnerable and less adaptable towards extremes, changes in the frequency and/or magnitude of conditions different than average. Therefore, climatic variations and extremes are important and the losses due to them are increasing. These losses signal that to offset negative impacts of temporal climatic variations, autonomous adaptation has not been sufficient (IPCC, 2001, pp. 879).

Regardless of autonomous adaptation, planned anticipatory adaptation may reduce vulnerability and realise opportunities associated with climate change. As well as future benefits, implementing adaptation policies, programs, and measures are to bring immediate benefits, only if they are consistent or integrated with decisions or programs addressing non-climatic stresses (IPCC, 2001, pp. 63, 879). In other words, adaptation aims to reduce vulnerability of societies to hazards by enhancing the capability to better predict, resist, and recover from their consequences (OECD, 2009, pp. 48). Success in adapting to climate change, variability, and extremes will be determinant for the range of successful future adaptations offsetting negative impacts associated with climate change (IPCC, 2001, pp. 879).

Within international negotiations, adaptation is a relatively recent concern. Although UNFCC in 1992 and Kyoto Protocol in 1997 mentioned adaptation, it has come to focus in the Seventh Conference of the Parties (CoP-7) in Marrakesh in 2001. There, three funds to deal with adaptation were established. Those are the Least Developed Countries Fund (LDC), the Special Climate Change Fund, and the Adaptation Fund. LDC aims at countries with particularly low adaptive capacity. The Special Climate Change Fund finances both mitigation and adaptation activities in all developing countries. Finally, the Adaptation Fund provides financial means only to the parties to the Protocol (OECD, 2009, pp. 49).

Before moving further, the definitions of a number of terms relevant to the following discussion of adaptation as given by IPCC (2001) should be viewed:

Sensitivity: Degree to which a system is affected by or responsive to climate stimuli (sensitivity includes responsiveness to both problematic and beneficial stimuli)
Susceptibility: Degree to which a system is open, liable, or sensitive to climate stimuli (similar to sensitivity, with some connotations toward damage)
Vulnerability: Degree to which a system is susceptible to injury, damage, or harm (problematic or detrimental part of sensitivity)
Impact Potential: Degree to which a system is sensitive or susceptible to climate stimuli (essentially synonymous with sensitivity)
Stability: Degree to which a system is not easily moved or modified
Robustness: Degree to which a system is not given to influence; strength

Resilience: Degree to which a system rebounds, recoups, or recovers from a stimulus
Flexibility: Degree to which a system is pliable or compliant (similar to adaptability, but more absolute than relative)
Coping Ability: Degree to which a system can successfully grapple with a stimulus (similar to adaptability but includes more than adaptive means of grappling)
Responsiveness: Degree to which a system reacts to stimuli (broader than coping ability and adaptability because responses need not be successful)
Adaptive Capacity: The potential or capability of a system to adapt to (to alter to better suit) climatic stimuli or their effects or impacts
Adaptability: The ability, competency, or capacity of a system to adapt to (to alter to better suit) climatic stimuli (essentially synonymous with adaptive capacity) (IPCC, 2001, pp. 894).

Regions, countries, socio-economic groups have considerably varying capacity to adapt. The most vulnerable regions and communities are those highly exposed to hazardous climate change impacts and limited adaptive capacity. Countries with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources possess little capacity to adapt and are highly vulnerable. Particularly for the most vulnerable regions, nations, and socio-economic groups, to decrease vulnerability, enhancement of adaptive capacity is a required condition. Modifying the adaptive capacity of communities and regions, development decisions, activities, and programs have important roles but they generally do not consider risks related with climate variability and change, inclusion of which in the design and implementation of development initiatives is required to decrease vulnerability to improve sustainability (IPCC, 2001, pp. 879-880).

Under the light of above statements, the below may be considered as the main reasons for adaptation:

1. Climate change cannot be totally avoided.
2. Forced, last-minute, emergency adaptation or retrofitting are more costly and less effective than anticipatory and precautionary adaptation.
3. Climate change may be faster or more noticeable than the available estimates suggest, i.e. unexpected events may take place.
4. Immediate benefits are possible from better adaptation to climate variability and extreme atmospheric events.
5. Immediate benefits are also possible through removing maladaptive policies and practices.
6. Future benefits can result from climate change (IPCC, 1990, IPCC, 2001, pp. 890).

Planned anticipatory adaptation aims reducing a system's vulnerability by diminishing risk or strengthening adaptive capacity. The below objectives are generated from this aim (IPCC, 2001, pp. 891).

1. Modifying robustness of infrastructural designs and long-term investments, e.g. extending the range of temperature or precipitation a system can resist without failure and altering the tolerance of loss or failure (for instance by increasing economic reserves or by insurance)
2. Strengthening the flexibility of vulnerable managed systems, e.g. allowing mid-term adjustments, and decreasing economic lifetimes
3. Enhancing the adaptability of vulnerable natural systems, e.g. reducing non-climatic stresses and removing barriers to migration (including eco-corridors).
4. Reversing trends which increase vulnerability, e.g. defining setbacks for development in vulnerable areas such as floodplains.
5. Improving societal awareness and preparedness, e.g. informing the public about the risks and

likely consequences of climate change.

Even if there is an urgent need to begin implementing adaptation options, it is suitable to start planning to avoid actions that could increase vulnerability to the impacts of climate change. It could take at least a decade for necessary analyses, training people, developing plans and mobilising public and political awareness and support. Therefore, the process should begin immediately. There are two main priorities of adaptation: information exchange, and education and community participation. The exchange of data and information among related institutions is necessary in this highly interdisciplinary set of problems. Moreover, models and assessment techniques should be developed to support decision-makers' perception on the complicated interactions and conflicting interests. Educating public and decision-makers on impacts of climate change is essential to let everybody understand the risks. Inclusion of local communities and members in deciding and implementing response options is also substantial to realise adaptive responses (IPCC, 1990).

Moser and Ekstrom (2010) identify three cyclic phases with sub-processes. The phases are understanding, planning, and managing. Understanding phase comprises problem detection, information gathering, and defining the problem. The next phase, planning, involves development of options, their evaluation, and selection. The final phase of adaptation, managing, covers implementing options, monitoring of them and environment, and evaluation. OECD (2009) accepts a fourth step for the monitoring and evaluating the success of the adaptation implemented.

According to the above classification, vulnerability of the system of interest and risks associated with climate change should be identified first in addressing adaptation to climate change. Socio-economic and environmental conditions, biophysical and socio-economic impacts, and the ability of systems to respond to climate change through autonomous adaptation could be the baseline for vulnerability assessment (OECD, 2009, pp. 55-60). Available knowledge of adaptation, adaptive capacity and vulnerability is not enough for reliable estimations of adaptation and for stringent assessment of governments' planned adaptation, options, measures, and policies (IPCC, 2001, pp. 880) due to absence of measurable outcomes or indicators to assess adaptation (Berrang-Ford, L., Ford, J. D., Paterson, J., 2011). Improved knowledge about processes shaping adaptation decisions is required to predict autonomous adaptations and provide input to adaptation policies. This knowledge consists of information on steps in the processes, decision rationales, handling of uncertainties, choices of adaptation types and timing, conditions stimulating or inhibiting adaptation, and the consequences or performance of adaptation strategies or measures (IPCC, 2001, pp. 884-885).

Strengthening perception of adaptation processes, and information about the conditions under which various types of adaptations are to occur is crucial. Through several types of analysis such as listing possible adaptation measures, impact assessment models, adaptation process models, historical and spatial analogues, and empirical analysis of contemporary adaptation processes insights have been gained. Predictions of probable future adaptations are important parts of climate change impact models. Those models are based on climate scenarios focusing on adaptation to changed average conditions, with little attention given to interannual variations and extremes. Conceptual models of adaptation processes define sequential relationships and feedback concerning climatic and non-climatic stimuli, system sensitivities and impacts, tactical and strategic adaptations, and net or residual impacts. They reflect conditions that constrain or facilitate various kinds of adaptation (IPCC, 2001, pp. 885-888).

Even without human induced climate change, climate is extremely variable, indicating that humans and living things have some built-in ability to adapt to climate change. Now societies have higher ability to cope with climatic events than before, due to technology, e.g. better communication, transportation, food storage, and increased wealth. All the experience gained through these events can be employed in formulating and implementing responses to anthropogenic climate change. Moreover, people in one area can learn from those in other places. Especially if analogues exist anywhere in the world, there is potential for such adaptation (IPCC, 1990).

Decision tools to evaluate adaptation options include risk-benefit and multi-criteria analyses. Such evaluations are more complicated by the existence of secondary impacts related to adaptation itself. For instance, water development projects may have important impacts on local transmission of parasitic diseases. Nevertheless, it is broadly accepted that planned adaptations to climate risks are generally to be implemented as components of (or as modifications to) existing resource management programs or as part of national or regional strategies for sustainable development (IPCC, 2001, pp. 893).

Under guidance of UNFCCC, nations have started developing National Adaptation Programmes of Action (NAPA). With NAPA, a country determines priority activities which need to be implemented in the near future to address urgent national climate change adaptation requirements. Evidence reveals that as other national planning processes, NAPAs face the same constraints on effectiveness and legitimacy (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 731-732). For instance, the EU White Paper considering climate change adaptation is a framework to reduce EU's vulnerability to the impacts of climate change (EC, 2009). Biesbroek et al (2010) compared NAPA of nine European countries (Denmark, Finland, France, Germany, Hungary, Netherlands, Romania, Spain, and UK) according to six common issues to all the reports. Identified driving factors are pressures, compelling information or key events forced governments to take action. In other words, the extreme events, rapid increase in knowledge on region-specific vulnerabilities and impacts are the major triggers. The action plans were prepared according to expected future developments, vulnerable sectors, risks and opportunities of climate change, scale of the problem, and paradigm dominating adaptation debate. Three phases of research focus were determined in common: climate system research, impacts and mitigation research, and vulnerability and adaptation research. Considering information dissemination and awareness-raising for adaptive practices, it was observed that those issues were among the long-term visions including both hard and soft measures. The National Adaptation Action Plans suggested bottom-up approaches for adaptation, given the multitude of variables, context dependencies and cultural settings. Moreover, there is a need for a strong leading department, such as a ministry or institution to initiate the development procedure with the inclusion of subunits in leading vulnerable sector departments. Also, interdepartmental units may prove a valuable role in managing the integration of adaptation into sectoral policies. Finally, a bottom-up input from other scales of governance is needed for a coherent and integrated adaptation strategy.

“Mainstreaming” in climate change context refers to integration of climate change vulnerabilities or adaptation into some aspect of related government policy such as water management, disaster preparedness and emergency planning or land-use planning. Integration of climate information into environmental data sets, vulnerability or hazard assessments, wide development strategies, macro policies, sector policies, institutional or organisational structures, or in development project design and implementation are the actions promoting adaptation. It is contemplated that by implementing mainstreaming initiatives, adaptation to climate change will be part of or consistent with other well-established programmes, particularly sustainable development planning (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 732). Investigating several major development agencies, it is found that those consider climate change as a real but uncertain threat, however, they have not examined effect of their activities on vulnerability to climate change. Thus, mainstreaming should cover a wider set of measures to decrease vulnerability (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 732).

Governments face some **constraints** in implementing adaptation actions. Those constraints can be listed as a) relevance of climate information for development-related decisions, b) uncertainty regarding climate information, c) compartmentalisation with governments, d) segmentation and other barriers within development-cooperation agencies, e) trade-offs between climate and development objectives. The United Nations Development Programme (UNDP) provides guidance to overcome these obstacles and barriers in mainstreaming. In short, as part of government planning, the opportunities for implementing adaptation depend on effective, equitable and legitimate actions to overcome barriers and limits. Initial signals of impacts created the so-called "policy windows hypothesis" as a demand and political area for implementing adaptation, yet, it is not certain whether weather-related catastrophic events can facilitate adaptation or be a barrier (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 732, 733).

It is mostly argued that there are both **limits and barriers** for specific adaptation plans and actions as a response to climate change. Limits are the conditions or factors rendering adaptation ineffective as a response to climate change and are widely insurmountable. These are naturally subjective and dependent upon the values of diverse groups and are closely related to the rate and magnitude of climate change as well as associated key vulnerabilities. Moreover, significant barriers to action in financial, cultural and policy realms on adaptation process are identified and those bring questions about the efficacy and legitimacy of adaptation responses to climate change. Adaptation is not able to make aggregate impacts of climate change negligible or beneficial, nor is it likely that all adaptation measures will be taken. Moreover, high adaptive capacity may not directly translate into accomplished adaptations to climate change. Furthermore, there is a less understanding of feasibility, costs, effectiveness, and the likeliness of implementation of adaptation (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 733).

Physical and ecological limits

The rate and magnitude of climate change are expected to determine the resilience of coupled socio-ecological systems to climate change, and there are some critical thresholds expected beyond which some systems may not be able to adapt to changed climatic conditions without radically altering their functional state and system integrity, and which may limit possibilities for adaptation of a physical environment or region (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 733).

Technological limits

Technological adaptations are considered as potent means of adapting to climate variability and change. UNFCCC sees development of new technologies and technology transfer to developing countries, to protect human life by increasing resilience, and to protect the biological and physical environments in natural systems (Tessa, B., Kurukulasuriya, P., 2010), as an important component of adaptation to climate change. Nonetheless, limits exist for technology use as a response to climate change. First, uncertainties may inhibit adoption or development of technological solutions under social context and decision-making. Second, some possible technologies may not be economically feasible or culturally acceptable. Finally, transfer of technology may not be equal for all groups or individuals, regardless of the extent technology transfers among countries (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 734). In order to deliver adaptation technologies in full promises to developing countries, significant challenges, such as lack of political will from developed nations, concerns regarding intellectual property rights, the market-driven technology transfer, and the weak capacity of absorption from inadequate institutions and policies, need to be overwhelmed. Moreover, the differences in approaches of developed and developing nations hinder the technology transfer. The former is focused on markets whereas the latter is concerned with the accession of technologies (Tessa, B., Kurukulasuriya, P., 2010).

To overcome political barriers hindering technology transfer, Tessa and Kurukulasuriya (2010) suggest developing countries to increase voluntary contributions to the various adaptation funds, to transfer climate-smart intellectual property rights to the public good domain, and to formulate suitable policy instruments. They also recommend developing countries to improve skills and knowledge, to increase funding and amount of efficiency, to strengthen cooperation among research institutions, to improve business environment.

Financial barriers

Preliminary estimates of adaptation measures from World Bank are US$10 billion – US$40 billion/yr at the international level. At local levels, lack of adequate financial resources would limit individuals and communities. Especially, low-income groups may not afford suggested adaptation mechanisms (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 735). For instance, at the local-level, lack of financial resources with stretched-budgets limits governments and organisations to take necessary actions for adaptation (OECD, 2009, pp. 178).

Informational and Cognitive Barriers

The decision of the best adaptation option requires having access to reliable data on the impacts of climate change. With the knowledge of climate change impacts and vulnerability, the most appropriate policy responses can be developed (EC, 2009). OECD (2009, pp. 178) emphasises lack of awareness and information as well as competing priorities and needs for local development of adaptation measures. It is shown that uncertainty about future climate change incorporates with individual and social understanding of risk, opinions and values to influence judgement and decision-making regarding climate change. Interpretations of danger and risk associated with climate change are context specific and that adaptation responses to climate change can be limited by human cognition. Four main perspectives on informational and cognitive constraints on individual responses are

1. Knowledge of climate change causes, impacts and potential solutions does not necessarily lead to adaptation.
2. There is no unique perception of climate change risks.
3. Perceptions of vulnerability and adaptive capacity are important.
4. Appropriate adaptive behaviour is not motivated by appeal to fear and guilt (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 735).

It is indicated that an individual's awareness of an issue, knowledge, personal experience, and a sense of urgency of being personally affected, make up necessary but inadequate conditions for behaviour or policy change. Behavioural change is also affected by perception of risks, of vulnerability, motivation and capacity to adapt. These perceptions differ among individuals and groups and some can act as barriers to adaptation to climate change, of which policy-makers need to be aware and they should provide structural support to overcome those (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 735-736). To forecast impacts of climate change and to identify vulnerability associated with it, methods, models, data sets and predictions tools, enabled with information and communication technologies, are deemed helpful. European “Clearing House Mechanism” is an example of tools to improve accession to data and knowledge base. This is an IT tool and database on climate change impacts, vulnerability, and best practices of adaptation across Member States. Moreover, pro-active research and education policy is required to enhance impacts of climate change and the development of skills, methods and technologies to cope with the consequences of climate (EC, 2009).

Social and Cultural Barriers

In different situations people and groups experience, interpret and respond to climate change differently, therefore, social and cultural limits to adaptation can be related to various ways. Depending on their world views, values, and beliefs, individuals and groups may have different risk tolerances and preferences on adaptation to climate change. Conflicting understandings can impede adaptive actions. Differential power and access to decision makers may favour some adaptation responses while limiting for others. In addition, adaptive responses may be limited due to diverse understandings and prioritisations of climate change issue across different social and cultural groups (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 736).

Many analyses of adaptation propose that successful adaptations contain marginal changes to material circumstances than wholesale changes in location and development paths. Moreover, it is suggested that the scale and novelty of climate changes are not the only determinants of degree of impact. Societies also alter their own vulnerability to climate fluctuations by changing their environments. Problems of indeterminacy (weakly understood structures and processes), discontinuity (novelty and surprise in social systems), reflexivity (the capacity of people and organisations to reflect on and adapt their approach), and framing (legitimately-diverse views about the state of the world) are the elements of accounting for future economic and social trends (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 736, 737).

Depending on the before-mentioned adaptation phase, Moser and Ekstrom (2010) identifies the barriers for adaptation. In the understanding phase, they first list the barriers limiting detection of a problem, which are related with existence and detection or perception of a signal, threshold of concern and response need and feasibility. Barriers in the information gathering are interest and focus, availability and accessibility, salience or relevance, credibility and trust, receptivity of information, and willingness and ability to use. In the problem definition phase, threshold of concern, response need and feasibility, and level of agreement or consensus are the defined barriers. There are also obstructions within planning phase. In option development process, lack of leadership, ability to identify and agree on goals, range of criteria and range of options to meet those, and control over processes and options may hinder adaptation. In assessing options, availability of and accession to data and information, availability of methods to evaluate and compare options, perception of credibility, salience, and legitimacy of information and methods, agreement on assessment approach, and level of agreement on goals, criteria and options define the limits for succession. Considering the selection process, agreement on selecting options, sphere of responsibility or control over option, threshold of concern over possible negative consequences and perception of option feasibility, and clarity of authority and responsibilities concerning the options are the barriers identified. Finally, barriers in the managing phase are also distinguished according to sub-processes. During implementation of options, threshold of intent, authorisation, sufficient resources, accountability, clarity or specificity of option, legality and procedural feasibility, sufficient mobility against institutional stickiness may pose limits. In the monitoring process, lack of a plan, agreement and clarity on monitoring targets, availability of methods, technology, sustainable economic resources and human capital, and ability to handle data are the recognised barriers. Evaluation process may be hindered by the factors such as threshold of need and feasibility of evaluation, availability of expertise, data and methodology, willingness to learn and revisit previous decisions, existence of legal limitations, and social and political of revising previous decisions.

4.1.1 Options for Climate Change Adaptation

Risks associated with projected climate change need to be incorporated with natural resource management planning to initiate adaptation to climate change. Yet, decision on timing and methods of this integration is both complex and difficult because of the uncertainty of, and need for constant adjustments for projected impacts (Bardsley, D. K., Sweeney, S. M., 2010). In many cases, the adaptive options have to be realised on small scales, e.g. regions or watersheds, and the specific social, economic, and environmental context has to be considered. In other words, the choice of adaptation measures has to be based on costs, benefits, equity, efficiency and implementability. This is required to accomplish a balance between various competing social objectives, and thereby create maximum net social well-being. (IPCC, 1990, IPCC, 2001, pp. 885, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 720).

Possible adaptation measures are based on experience, observation, and speculation about alternatives that can be created. In many sectors and regions, lists of possible adaptations exist, indicating the range of strategies and measures for possible adaptations to risks of climate change in particular sectors and regions. Many of these adaptations represent improved resource management that would also bring benefits in dealing with current climatic hazards as well as future climatic risks (IPCC, 2001, pp. 886).

The uncertainties of climate change limit the analysis of response strategies in terms of their effectiveness and intercomparisons of the social, economic, and environmental consequences of implementing those vs. doing nothing. Yet, there are several criteria to evaluate those strategies (IPCC, 1990):

- Flexibility: As the climate change effects are uncertain, responses are required to be successful under a variety of conditions, including no change. Therefore, flexibility is the issue of keeping options open.
- Economically Justifiable Based on Other Benefits: Policies like these are expected to be justifiable in their own right, i.e. without climate change. Addition to climate change, they shall meet other social goals. In other words, benefit should be gained from them even there is no change in climate.
- Timing: As there may be lag-time to feel effects of climate change, the same is applicable for realisation of benefits of adaptive policies. Therefore, expensive anticipatory actions will be justified if the expected costs due to climate change are very high. To assess timeliness, following factors to be considered: a) existence of a critical point in time before the adaptation strategy should be implemented, and b) the time necessary to efficiently develop the response (and required technology), and educate and spread it to users/implementers
- Feasibility: Adaptive strategies to be consistent with legal, institutional, political, social, cultural, and financial arrangements, which are critical for their do-ability. However, policies may aim to modify or remove such barriers.

- Compatibility: Response actions for one sector should not be inhibiting to adaptive strategies in other sectors or activities. Likewise, they should not defeat or negate limitation strategies, and vice versa.

In addition to those, the below are supplementary characteristics of, or criteria for, the identification of adaptation options (IPCC, 2001, pp. 891):

- The measure generates benefits to the economy, environment, or society under given conditions.
- The measure tackles high-priority adaptation issues like irreversible or catastrophic impacts of climate change, long-term planning for adaptation, and unfavourable trends.
- The measure directs at current areas of opportunity, e.g. land purchases, revision of national environmental action or development plans.
- The measure is feasible, that is, its employment is not highly hindered by institutional, social/cultural, financial, or technological barriers.
- The measure is consistent with, or complementary to, adaptation or mitigation efforts in other sectors.

In brief, potential adaptations' success is considered to be dependent on the flexibility or effectiveness of the measures, such as their capability to meet decided objectives within a range of future climate scenarios, and their potential to create benefits that overwhelm costs (IPCC, 2001, pp. 891).

OECD (2009) divides adaptation measures into the following generic categories.

- Bear losses. This is the option of “doing nothing”, i.e. bearing or accepting losses, which theoretically occurs under situations with no capacity to respond, especially in poor communities.
- Share losses. This option involves sharing the losses among a wider community both in traditional and complex societies.
- Modify the threat. There is a possibility to control the risk to a degree.
- Prevent effects. This is a frequently used set of adaptation measures involving steps to prevent effects of climate change and variability.
- Change use. If the climatic threat makes the continuation of an economic activity impossible or extremely risky, the change of use may be contemplated.
- Change location. This is a more extreme response considering the change of location of economic activities.
- Research. The process is advanced by research into new technologies and methods of adaptation.
- Encourage behavioural change through education, information and regulation. This type of adaptation includes dissemination of knowledge through education and public information campaigns, leading to behavioural change.

A different type of characterisation is proposed by IPPC (1990):

- Category A: responses that improve our knowledge base to let reasoned judgement on response strategies concerning climate change and that should be realised in advance of accurate regional predictions.
- Category B: comprised of responses that are economically feasible under present-day conditions and, thus, could be implemented in short-term.
- Category C: More costly responses that should be considered in the long-term. Because of high

cost, considering those responses under reduced uncertainties regarding climate change would be wise.

Furthermore, below options would be useful to reduce critical lead times and planning horizons for design and implementation of specific actions regarding climate change and its impacts (IPCC, 1990).

Short-term research related options: Actions to augment knowledge base to make better judgements about response strategies (IPCC, 1990):

- creating inventories, data bases, monitoring systems, and catalogues of the current state of resources, their use and management practices,
- improving our scientific understanding of and predictive tools for critical climatic factors, their impacts on natural and human systems,
- initiating studies and assessments to guess the resilience and adaptability of resources and their vulnerability to climate change,
- supporting public and private research and development for more efficient resource use and innovation, and allowing innovators to benefit from their work

Short-term policy options: There are economically feasible options to improve natural resource use efficiency, fuller utilisation of harvests, and waste reduction. Such measures include (IPCC, 1990):

- emphasizing the development and adoption of technologies to increase the productivity of efficiency of crops, forests, livestock, fisheries, and human settlements,
- promoting and strengthening of resource conservation and sustainable resource use,
- accelerating economic development efforts in developing countries because those usually own largely resource-based economies. Thus, improving natural resources use could be beneficial. Such efforts could create capital, which in turn would make adaptation to climate change more feasible,
- creating methods to involve local population and resource users to gain a stake in conservation and sustainable resource use
- decentralising decision making on resource use and management

Long-term options: Those could be implemented if they get feasible or the uncertainties regarding climate change are reduced (IPCC, 1990):

- building large capital structures (e.g. dams) to sustain enhanced availability of water,
- strengthening and enlarging protection areas to intensify prospects for unmanaged ecosystems to adapt to climate change,
- examining and terminating direct and indirect subsidies and incentives for inefficient resource use, and other institutional barriers to efficient resource use

In more detail, IPCC (1990) states that the knowledge base relevant to making policy decisions needs to be expanded (A). It is necessary to initiate the requisite research to decrease uncertainties related with forecasting of the status of resources, their use and management at various geographical scales and their socio-economic consequences, which requires coordinated research efforts to a) augment the understanding and predictions of changes in critical climatic factors, the direct and non-climatic effects of changes in GHG concentrations on the terrestrial and marine biosphere, b) improve and/or create methodological tools for anticipation of these climatic and non-climatic impacts on the supply and demand of resources, and the socio-economic consequences of climate change and alternative adaptive response strategies, c) estimating costs and benefits for both adaptation and limitation measures to reach the optimal mix to maximise social well-being.

It is necessary to document, catalogue and make more accessible resource use and management practices under the widely different climatic conditions (A). With sufficient confidence on future climatic regimes predictions, it would be possible for one area to more easily locate analogues for its future climate. Independent of climate change, resource managers need inventories of the state of resources (A). Inventories precisely describing the condition and use of resources would be valuable. Moreover, they would enable managers to predict future state of resources (IPCC, 1990).

Studies and assessments to estimate the resilience of resources and their vulnerability to climate change may be useful for decision of priorities related to areas and resources within them to be focused by authorities (A). Therefore, current adaptive capacity of localities, nations or systems would be identified. Moreover, such assessments would provide information concerning adaptability to various rates of climate change. Such assessments require considerable effort on research, improving, and/or developing appropriate methodological tools to predict the effects of climate change on resource use and management, and socio-economic impacts associated. To maintain early warning regarding any potential changes and trends, monitoring systems on status of resources needs to be established (A). Designing such systems to observe changes in resources in different locations that may indicate the effects of climatic perturbation (IPCC, 1990).

To assist rational use and management of natural resources, and to help localities, nations, and regions better deal with any climate change, existing institutions should be improved or, if appropriate, new ones to be established. Technology development and transfer mechanisms shall be supported and improved (A, B, C). Such efforts could be realised via existing institutions such as FAO, UNEP, WMO, UNRRO, UNDP, and other multi- and bilateral agencies as well as national institutions. It is necessary to strengthen efforts to educate and inform the public and decision makers on the scientific, policy, and economic aspects of issues related with climate change (B) (IPCC, 1990). Bardsley and Sweeney (2010) offer four distinct approaches to guide decision-making on natural resources. These are scenario modelling, applied and participatory Geographical Information Systems (GIS) modelling, environmental risk analysis, and participatory action learning. If applied to the land and groundwater studies, the scenario modelling approach can assist to adjust previous resource condition assessment regarding expected changes in precipitation. GIS modelling aims to maximise engagement with stakeholders in various sectors to highlight key vulnerabilities and responses by decision-makers. Environmental risk analysis may be helpful to guide stakeholders through an examination of the risks within their systems. With participatory action learning, the aim is to provide stakeholders the means to realise their local vulnerabilities even without presence of significant information, e.g. scientific or other public materials.

Research and development efforts concerning more efficient resource use needs to be initiated (A) to help cope with climate change related new stresses. Public and private enterprises should cooperate in such facilities regarding more efficient forestry, agricultural, and water use practices, and biotechnological innovation. The responsibility to encourage R&D efforts could belong to governments, while they direct such work in consistence with public health and safety. It could be wise for nations to consider developing new or modified institutional, legal, and financial measures a) enabling innovators to profit from their R&D, and b) motivating individuals and communities to create an economic share in conservation and efficient and sustainable use and management of resources. Along with the available methods for reducing the negative impacts to resources, more research and technology development could be required to deal with the potentially worst consequences (A). Such progress is already in evolution and is contemplated to be useful even if climate change does not occur (IPCC, 1990).

To reduce pressures on resources, which are expected to rise due to population growth, independent of anthropogenic climate change, increasing the efficiency, productivity and intensity of resource use consistent with sustainable growth principles are necessary. Along with research and technological improvements (A, B), identifying and reviewing subsidies for resource use would improve efficiency (B, C). Subsidies encourage use of marginal resources. Yet, societies have the right to determine what to subsidise among various activities due to equity and other social benefits that may not be easily compliant to monetisation. In such circumstances, it could be worthy to assess if subsidies could be reformulated so that they accomplish their social goals with minimum the environmental impact (IPCC, 1990).

Promoting resource conservation and sustainability of resource use (A, B, C). Conservation practices could be useful to resist climatic stresses through helping moderate local climates, water use, and soil erosion, increase genetic variability, and reduce other stresses from environmental degradation. Strengthening protection and conservation of highly vulnerable areas (A, B, C) (IPCC, 1990).

It is necessary to maintain or improve flexibility for resource management (A, B, C). This is because, with greater flexibility, there will be increased opportunities to adjust land and water uses to a wide range of possible climatic conditions. Therefore, it is a required condition for successful adaptation. There are several implications to this (IPCC, 1990, pp. 179).

To practical extent, decentralising decisions on resource use and management should be considered (B, C), i.e. those may be left to individuals and local authorities since it is more likely that they have a better understanding of the local context and, thus, less likely to make mistakes in their evaluations. Furthermore, decentralisation could help to avoid any error in judgement to be universal. On the other hand, decentralisation should not fail coordination between adjacent jurisdictions. Moreover, sometimes local concerns could overwhelm the broader good, leading to “not in my backyard” mentality. Thus, methods should be investigated to figure out how smaller segments of society may agree on taking actions benefiting larger society even at some additional risk or burden to themselves. In addition to decentralisation, to maintain flexibility, quick and accurate information and technology transfer is critical (A). Finally, it is necessary to search for methods of increasing the flexibility of land and water use for various purposes (A) (IPCC, 1990).

4.1.2 Lessons from Adaptation Experiences

All socio-economic systems are constantly in response to changing circumstances, including climatic conditions. There is human capacity to adapt to long-term mean climate conditions but not to extremes and to year-to-year variations in climatic conditions. Human settlements and agricultural systems, for instance, have adapted to be in harmony with a huge variety of climatic zones, however, those are usually vulnerable to temporal deviations from normal conditions. Thus, adaptations according to mean conditions may or may not be helpful in dealing with the variability of climate. There is evidence showing the existence of considerable potential for adaptation to reduce climate change impacts and to realise new opportunities. These include proactive measures such as crop and livelihood diversification, seasonal climate forecasting, community-based disaster risk reduction, famine early warning systems, insurance, water storage, supplementary irrigation, and reactive adaptations such as emergency response, disaster recovery, and migration. Adaptation options come generally in socio-economic sectors and systems of turnover of the capital investment and operation costs that are shorter or less frequent where long-term investment is necessary. “Wait and see” or reactive approach is often inefficient and could be unsuccessful to address irreversible damages, such as species extinction or unrecoverable ecosystem damages (IPCC, 2001, pp. 889, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 721).

A number of mechanisms have been established to serve proactive adaptation to seasonal to interannual climate variability. These include institutions to generate and disseminate regular seasonal climate forecasts, and the regular regional and national forums and implementation projects worldwide to engage with local and national decision makers to design and implement anticipatory adaptation measures in agriculture, water resource management, food security and some other sectors. Even though across sectors and regions a variety of adaptation initiatives have been employed, the responses are not universally or equally available. Many response strategies are less available, whereas many others have become more available (IPCC, 2001, pp. 889). For instance, it is shown that technological solutions such as seasonal forecasting are not sufficient to cover the underlying social drivers of vulnerabilities to climate. Social inequities in access to climate information and the lack of resources to react can also severely limit anticipatory adaptation (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 721).

Not only is there seldom only one adaptation option available to decision-makers but also seldom do people choose the best responses – among those available that would most effectively lessen losses – generally because of an established preference for, or aversion, to certain options. There is limited knowledge of risks or alternative adaptation strategies for some cases, while in others, adoption of adaptive measures is limited by other priorities, limited resources, or economic or institutional barriers. There is evidence showing that the costs of adaptation to climate conditions are growing, which signals, at least partially, increases in populations and/or improvements in standards of living, with more available income used to improve comfort, health, and safety levels in the short run. Findings reveal that problems demanding early or long-term attention usually fail to receive it, and the most efficient responses are not taken. There is little evidence that efficient and effective adaptations to climate change risks will be undertaken autonomously (IPCC, 2001, pp. 889, 890).

With vulnerability to climate risk, many adaptations reduce the vulnerability to current climate variability, extremes, and hazards. Although climate change is a significant source of stress, and probably with opportunities, it has always been only one factor among others. From only physical dimensions alone, the results of a shift in climate are not calculable, therefore, attention to human dimensions through which those results are experienced is necessary. The importance of climate change for regions is shaped largely by the ability and likelihood of those regions to adapt (IPCC, 2001, pp. 889, 890).

Nevertheless, there are some examples of adaptation measures. Actions concerning public health have been implemented through combining weather monitoring, early warning, and response measures in some places. Weather and climatic extremes have also directed a number of adaptation responses in the financial sector. Moreover, there are some adaptation measures that take the scenarios of future climate change and associated impacts into account, which is necessary for long-lived infrastructure or forests, because those are expected to be exposed to climate change impacts during their long lifetimes. Along with specific infrastructure projects, examples of comprehensive risk management policies and plans considering climate change scenarios at the city, regional, and national level exist. There are efforts to combine adaptation to current and future climate within the environmental impact assessment procedures in several countries like Caribbean, Canada, and within OECD countries. A key feature of these procedures is direct consideration of several climate variables, uncertainties, and time horizons for different adaptation responses (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 721-724).

Assessment of nine NAPAs (Denmark, Finland, France, Germany, Hungary, Netherlands, Romania, Spain, and UK) shows that institutional problems pose greater challenges than technical solutions for adaptation actions. Adaptation must become an integral part of all relevant policies, i.e. mainstreaming is necessary. Moreover, unlike other environmental policies, self-interest and voluntary motivation are required to take adaptive actions. Most barriers seem to be related to policy co-ordination and implementation. Therefore, not only the uncertainty of the climate issue but also the uncertainties regarding the strategies of stakeholders in the adaptation process and the institutions involved are important. Furthermore, there are fundamental knowledge gaps considering the design of flexibility of mechanisms, connection of research to policy needs, understanding the roles of institutions, options to share knowledge in the international area, identification of responsibilities of stakeholders, evaluation of vulnerabilities in sectors, and adaptation policies (Biesbroek, G. R., Swart, R. J., Carter, T. R., Cowan, C., Henrichs, T., Mela, H., Morecroft, M. D., Rey, D., 2010).

4.2. Adaptive Capacity and Vulnerability

Adaptive capacity is the capability, ability or potential of a system, region, or community to successfully adapt to the effects of or impacts of climate change or variability, and comprises alterations in behaviour, resources, and technologies. It determines adaptation to deal with the climate change effects and risks and highly influences the vulnerability of communities and regions to effects and hazards of climate change. Enhancement of adaptive capacity is a functional tool for coping with changes and uncertainties in climate, including variability and extremes. The presence of it is necessary for the design and implementation of effective adaptation strategies to reduce possibility and the magnitude of negative outcomes of climate issue. Therefore, improvement of adaptive capacity decreases vulnerability and promotes sustainable development (IPCC, 2001, pp. 879, 882, 894, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, p. 727, Mukheibir, P., 2010).

The capacity to adapt **differs widely** among regions, countries, and socio-economic groups and will vary over time. The most **vulnerable regions** and communities are highly affected by dangerous impacts of climate change and are able to exhibit limited adaptive capacity. Wealth, scientific and technical knowledge, information skills, infrastructure, institutions, and equity are the parameters of ability to adapt and cope with climate change impacts. Groups or regions with limited adaptive capacity along any of these dimensions are more vulnerable as they are to other stresses, i.e. they are said to be sensitive to climate to the degree that they can absorb its impacts and vulnerable to the degree that they can be harmed. Understanding the dynamics of vulnerability is as important as understanding climate itself since vulnerability and causes of it have vital roles in impact determination. On the other hand, high adaptive capacity does not have to translate into actions to reduce vulnerability. There are significant barriers including both the inability to natural systems to adapt to the rate and magnitude of climate change, and technological, financial, cognitive, and behavioural, and social and cultural constraints. There are also constraints on availability and flow of knowledge and information for adaptation decisions (IPCC, 2001, pp.63, 894, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 719).

Considering climate change, the **vulnerability o**f a given system or society is a function of physical exposure to effects of climate change and its capability to adapt to these conditions. Two aspects of differential vulnerability are distinguished: physical exposure to the hazardous agent and the ability to deal with its effects. Hence, vulnerability recognises the role of socio-economic systems in magnifying or curbing the climate change impacts and stresses the degree that the climate catastrophe risks can be softened or improved by adaptive actions that can be brought within the reach of populations at risk (IPCC, 2001, pp. 894, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 720).

4.2.1 Determinants of Adaptive Capacity

Main features of communities or regions that may be determinants for their adaptive capacity are economic wealth, technology, information and skills, infrastructure, institutions, and equity. Some of these determinants are generic, while others are specific to particular impacts of climate change. Generic indicators may include factors as education, income and health. Indicators for particular effects, e.g. drought or floods, may relate to institutions, knowledge and technology (IPCC, 2001, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 727).

Economic Resources
It is clear that adaptive capacity is determined by the economic condition of nations and groups whether it is expressed as the economic assets, capital resources, financial means, wealth, or poverty. It is broadly accepted that wealthy nations are better prepared to hold the costs of adaptation to impacts and risks of the climate change than poorer nations (IPCC, 2001, pp. 895). Even though economic development may provide substantial access to technology and resources to invest in adaptation, per capita high income is neither a necessary nor a sufficient indicator of the adaptive capacity (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 728).

Technology
Technology has the potential to take an important part in adapting to climate change (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 727). Limiting the range of possible options, lack of technology can hinder seriously a nation's ability to implement adaptive responses. With availability and access to technology at different levels, adaptive capacity is expected to vary. To improve adaptive capacity, willingness to develop and utilise new technologies for sustainable extraction, use, and development of natural resources is essential (IPCC, 2001, pp. 896). Usually, research programmes undertaken by governments and by the private sector lead technological adaptations and innovations, which are the creation of new strategies or technologies, or the improvement of old ones in response to new conditions. (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 728).

Information and Skills
Recognition of the necessity to adapt, knowledge about available options, the capacity to assess them, and the ability to implement the most suitable ones are factors of a successful adaptation. Building adaptive capacity necessitates a solid and unifying vision, scientific approach to problems, openness tackle challenges, pragmatism in developing solutions, and involvement of community at the highest political level. To implement adaptation options, a nation also needs skilled and trained personnel

(IPCC, 2001, pp. 896).

Infrastructure
Adaptive capacity is dependent on social infrastructure. It is also regarded as a function of availability and access to resources by decision-makers and vulnerable population groups. At the community level, lack of flexibility in formal housing areas with more fixed dwelling form and drainage infrastructure decreases the response capacity to contemporary environmental conditions (IPCC, 2001, pp. 896).

Institutions
The role of institutions is defined as “a means for holding society together, giving it sense and purpose and enabling it to adapt.” It is widely accepted that countries with well-developed social institutions have greater adaptive capacity than those with less efficient institutional organisations (IPCC, 2001, pp. 896). Established institutions in developed countries can manage both contemporary risks of climate change and those associated with future. “The accumulation of numerous small changes in the present range of water resources management practices and procedures increases the flexibility for adaptation to current climate uncertainty and serves as a precursor to future possible responses with an ill-defined, changing climatic regime. The time has come for innovative thinking on the question of how our water allocation institutions should function to improve our capacity to adapt to the uncertain but potentially large impacts of global climate change on regional water supplies. Given the climatic uncertainties and the very different institutional settings that have developed in this country, there is no prescription for adaptation.” (IPCC, 2001, pp. 897)

Equity
The capacity to adapt to climate change is not equal across and within societies, according to age, class, gender, health and social status (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 728, 729). The weight of local-level studies builds broad lessons on adaptive capacity of individuals and communities. The critical point is the nature of the relationships between community members, as in the access to and participation in decision-making processes. Successful community-based resource management has the potential to improve resilience of communities as well as to maintain ecosystem services and ecosystem resilience (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 729).

The determinants of adaptive capacity are either dependent of each other or they are mutually inclusive (IPCC, 2001, pp. 897). It is expected that adaptive capacity at any one scale may be served or limited by factors outside the system in question. At the local scale, such limitations may be in the shape of regulations or economic policies determined at the regional or national level constricting the freedom of individuals and communities to act, or that turn certain potential strategies unviable (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 730).

There is not enough number of simple cause-effect relationships between climate change risks and the capacity to adapt. Adaptive capacity varies over time and is under influence of multiple processes of change. The distribution of adaptive capacity within and across societies forms a major challenge for development and an important constraint to the effectiveness of any strategy for adaptation. Some adaptations that address changing economic and social conditions may reduce vulnerability to climate change, as adaptations to climate change may increase vulnerability to other changes (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 731). Determinants and their influence on adaptive capacity have been identified, however, there are no agreed criteria or variables to quantitatively measure and compare it globally. Empirical local-level studies on vulnerability are complex and context-specific but attempts to describe patterns or guess trends globally or regionally are very difficult. The effects of changes in the determinants of adaptive capacity are not direct or clear, thus, developing systematic indices for measurement and comparison is a difficult task (IPCC, 2001, pp. 898, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 729).

Considering their adaptive capacity to climate change, countries differ at the global scale because there are multiple processes of change interacting to influence vulnerability and shape outcomes from climate change. Developed nations with their economic affluence and stability, their institutions and infrastructures, and access to capital, information, and technology are expected to have greater capacity to adapt than developing countries. Mostly, countries with strong social institutions supported by higher levels of capital and human knowledge are considered to have high adaptive capacity. Although adaptation options are available in developing countries and countries in transition, their infrastructure and economic means may not provide the capacity to initiate response actions in time. The main barriers for these are (IPCC, 2001, pp. 897, Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 729).:

- Financial/market: uncertain pricing, availability of capital, lack of credit
- Institutional/legal: weak institutional structure, institutional instability
- Social/cultural: inflexibility in land-use practices, social conflicts
- Technological: lack of existence and access
- Informational/educational: lack of information and trained personnel

Moreover, due to their reliance on climatic resources, developing countries have a lower adaptive capacity compared to industrialised nations (IPCC, 2001, pp. 898).

At different scales and levels of society, the vulnerabilities and expected impacts to climate change will be observed, and adaptive capacity strengthening may be initiated. Examples of initiatives to enhance adaptive capacity at various scales follow as (IPCC, 2001, pp. 899-902).:

- Global scale
    - To adjust global and local priorities, better cooperation between industrialised and developing countries by enhancing political and scientific interactions and working.
    - Inclusion of global institutions for global-level adaptation, including research and policy, funding, and monitoring at all levels.
    - Removal of barriers to international trade so as to improve market conditions, to reduce exploitation of marginal land, to accelerate transfer of technology, and to contribute to overall economic growth for sustainability and adaptive capacity.
    - Effective global economic participation. Benefits go beyond direct financial gain and include technology transfers, technical and managerial skills transfers, and other skills transfers associated with the learning and doing process.
- National level
    - With an emphasis on poverty reduction, developing climate change policy to improve more vulnerable sectors in the country.
    - Establishment of broadly based monitoring and communication systems.

    - Establishing a public policy to encourage and support adaptation at local or community levels and in private sector.
    - Motivation towards sustainable economic growth to result a greater dedication or resources to development of adaptive technologies and innovations.
- Local means
    - To prevent concentration of power in a few hands and marginalisation of sections of local population, establishment of social institutions and arrangement, considering representativeness of decision-making bodies and maintenance of flexibility in the functioning of local institutions
    - Encouragement of diversification of income sources for poorer sectors of society.
    - Supporting formal or informal arrangements for collective security
    - Determination and prioritisation of local adaptation measures and enabling feedback to higher level of government. Such efforts need adequate provision of knowledge, technology, policy, and financial support to be supported.

Furthermore, the below requirements may help a system or a nation to enhance its adaptive capacity (IPCC, 2001, pp. 898-899):

- To have a stable and prosperous economy. Industrialised nations are more capable than developing countries in holding the costs of adaptation, regardless of biophysical vulnerability to the impacts of climate change.
- High degree of access to technology at various levels and sectors. Furthermore, willingness to develop and utilise new technologies for sustainable extraction, use, and development of natural resources is important for enhancing adaptive capacity.
- The roles and responsibilities for implementation of adaptation strategies are well defined and distributed by central governments and are clearly understood at national, regional, and local levels.
- Transmission of information regarding climate change and adaptation is provided nationally and regionally, and forums for the discussion and innovation of adaptation strategies at various levels exist.
- Equitable access to resources within a nation, region, or community is guaranteed by social institutions and arrangements governing the allocation of power since the existence of power differentials may reduce adaptive capacity.
- Existing systems with high adaptive capacity are preserved.

A preliminary assessment based on IPCC (2001) for adaptation and adaptive capacity in Turkey leads to the following points of interest:

- Priority areas for adaptation are land and water resources, food productivity, and disaster preparedness and planning, especially for poorer, resource-dependent regions.
- Adaptations are necessary to cope with vulnerabilities related with climate variability, in human health, coastal settlements, infrastructure, and food security.
- Climate change is only one of the problems. Adaptation responses are tightly linked to development activities, which should be considered in assessing adaptation options.
- The coming 1 or 2 decades have to be used to avoid upheavals. Long-term adaptation needs anticipatory actions.
- A wide range of precautionary measures, including awareness rising and expansion of insurance industry, needs to be available at the national and regional level to limit economic and social

impacts of disasters.

- Development of effective adaptation strategies requires local involvement, i.e. inclusion of community perceptions, and recognition of multiple stresses on sustainable management of resources.
- To improve adaptive capacity, social structure, culture, economic capacity, and level of environmental disruptions, resource and infrastructure bases, equity issues, institutions, and technology have to be enhanced.
- A more systems-oriented approach, emphasizing multiple interactive stresses, with less dependence on climate scenarios would be useful for adaptation strategies.

4.3. Response Options for the Water Sector

Changes in precipitation patterns affecting water distribution are important for agriculture, energy, and health (IPCC, 1995, pp. 412). In Europe, for example, more than 80% of agricultural land is rain-fed. Food production is dependent on availability of water resources for irrigation. Limited water availability is already a problem in many parts of Europe and climate change is expected to exacerbate the situation. Share of water-stressed areas are expected to rise to 35% in the continent by 2070s (EC, 2009). Price, income, technology, and other influences affect demand for water. Other things kept equal, more water is used as temperature increases (IPCC, 1995, pp. 412). To cope with climate change impacts on water resources systems, many of the standard water resources criteria, e.g. reliability, safe yield, probable maximum flood, resilience, and robustness, are practical indicators. It is necessary to separate physical effects of climate change from the impacts of having a societal value placed on a change in some physical quantity. Characteristics of the water use system determine the impact: for some cases a large climate change effect could have a small impact, whereas for others a small change may result a large impact (IPCC, 1995, pp. 471-473).

In the coming decades, demand increases, mainly for municipal water supply in rapidly urbanising areas, energy production, and agricultural water supply, will be the issue for water resources management. Demand management, regulatory controls, legal and institutional changes, and economic instruments will be the focus for water management strategies (IPCC, 1995, pp. 471-473):

- Watersheds and river basins located in arid and semi-arid regions are the most sensitive to temperature and precipitation changes.
- To increase flexibility of water resources systems to meet increasing uncertainties regarding climate change, water demand management and institutional adaptation are the fundamental components.
- For water systems to meet their goals, increased streamflow regulation and water management regimes could be useful.
- Isolated single-reservoir systems are less adaptable to climate change than integrated multiple-reservoir systems.
- To mitigate many of the negative impacts of climate change, future technological changes are likely to be useful.
- Engineering design criteria, operation rules, contingency plans, and water allocation policies need to be examined due to changes in the mean and variability of water supply.

The most significant impact of climate change for water supply system is the rise of uncertainty of input through precipitation, substantially complicating rational water resource planning (Mukheibir, P., 2010). The aim of water resources management is to mitigate the effects of extremes in climate variability and supply a dependable source of water for multiple societal purposes. Water management is a continuously adaptive enterprise because it has to respond changes in demands, hydrological information, technologies, the structure of economy, and society's approach on the economy and the environment. The water management practices, intending to help the present climate variability, could also help to mitigate perturbations as droughts. However, there are social, economic, and environmental costs associated with adaptation (IPCC, 1995, pp. 471, Ziervogel, G., Johnston, P., Matthew, M., Mukheibir, P., 2010).

Various types of water supply systems exist around the world. The simplest system extracts water from a river or a village borehole, which are very sensitive to climate change as they do not have any storage. The next level of system contains a single managed source, e.g. river, reservoir, aquifer, coupled with a distribution network supplying water to users, and possibly a waste treatment system. The characteristics such as storage-runoff ratio, seasonal distribution of supply and demand of water determines the sensitivity of the system to climate change. The most elaborate systems are integrated networks with several sources and a large water transfer distance. The climate change sensitivity of such systems depends on system structure and the degree of utilisation (IPCC, 1995, pp. 473).

There are various possibilities for individual adaptation measures or actions. The formulation of a series of credible development scenarios stemming from different combinations of population growth assumptions along with economic, social, and environmental objectives is necessary for a long-term strategy. After those are established, a set of alternative long-term strategies for water management considering climate change must be developed including water management measures, policy instruments, or institutional changes. The range of response strategies should be evaluated with different levels of service reliability, costs, and environmental and socio-economic impacts. Some will be able to better cope with climate change, while others will be useful for environmental sustainability. In reality, selection of an optimal path after the application of engineering design criteria to different alternatives is a conclusion shaped by social preferences and political realities. Engineering design criteria evolve accordingly with new meteorological and hydrological records and performance of water management systems tested under different conditions (IPCC, 1995, pp. 481-482).

Future water resources management strategies should contain the combinations of the following many cost-effective management measures:

- direct measures to control water and land use (regulatory, technological)
- indirect measures affecting behaviour (incentives, taxes)
- for improved management of resources institutional change
- modifications in the operation of water management systems
- direct measures increasing availability of supply (reservoirs, pipelines)
- measures to ameliorate technology and the efficiency of water use (IPCC, 1995, pp. 482).

There is a trend to plan management systems that balance supply development with demand management. Without decreasing the overall reliability of a system, non-structural management measures have been relied on to supply necessary robustness. Nevertheless, it must be remembered that the combination of various design factors, operating rules, reservoir storage allocation decisions, flood forecasting and evacuation plans, and drought contingency plans provide an important range of robustness, resiliency, and flexibility to cope with uncertainty and surprises. Water management systems of this scale, coupled with demand management and institutional and regulatory changes to deal with expected impacts on population and demands, are able to provide a well-balanced strategy for dealing with risk and uncertainty. Therefore, the aim is to lower, if possible to minimise, the negative social, economic, and environmental results due to any kind of changes in water resources. The fundamental reality is that water resources management is a progressive adaptive activity (IPCC, 1995, pp. 483).

Developing countries, where water demand is increasing rapidly and the institutional system and water supply facilities are not sufficient, are highly vulnerable to climate change and intense imbalances are foreseen since most of them are situated in arid and semi-arid regions mainly with isolated reservoir systems. Moreover, it is likely that in many temperate regions, adaptation measures are needed for also floods and associated damages and rising concerns about dam and levee failures. Therefore, socioeconomic-driven increases in water demand and the possible decrease in availability of water resources must be considered in the future management. Minimising net water use, developing new water resources such as reuse of wastewater could be solutions for those imbalances. To provide satisfactory enough potable water, prevention of water pollution is important. Two key principles for sustainable development and water use in developing countries: 1) Management at the lowest appropriate levels. Mostly centralised and top-down approaches to water resource development and management are not sufficient, although they ensure national economic and social interests. 2) To consider water as an economic good. There are various opportunities for improved management of water infrastructure, pricing policies, and demand-side management of supply. Charging for water may stimulate conservation and protection of water resources and creates consciousness of water management (IPCC, 1995, pp. 420, 471).

Considering the strengths and the challenges mentioned above, some of the key findings of IPCC in water sector regarding adaptation and adaptive capacity are listed below:

- Water managers are experienced in adapting to change. There are many techniques to assess and implement adaptive options. Yet, range of climate change may eliminate some traditional adaptive strategies, and available adaptations are generally not used.
- Adaptation can be on both supply side, e.g. altering infrastructure or institutional arrangements, and demand side management, e.g. changing demand or risk reduction. Many policies, creating net social benefits independent of climate change, exist.
- Water managements do not make decisions to solely cope with climate change, although it will be very important for future resource management. Some vulnerabilities are not within the conventional responsibility of water managers.
- Assumptions made on adaptation significantly determine the economic costs of climate change impacts. Economically optimum adaptation may not be implemented due to limits associated with uncertainty, institutions, and equity.
- Exposing vulnerabilities and raising awareness of climate risks, extreme events are generally driving factors for change in water management. Climate change modifies indicators of extremes and variability, which complicates adaptation decisions.
- Institutional capacity, wealth, management philosophy, planning time scale, organisational and legal framework, technology, and population mobility affect ability to adapt.
- Research and management tools aimed at adapting to uncertainty and change rather than improving climate scenarios are necessary for water managers.
- Rather than improving climate scenarios, water managers need research and management tools aimed at adapting and change (IPCC, 2001, pp. 64, 900).

4.3.1 Response Strategies for Water Sector

OECD (2009, pp. 52) seeks adaptation measures considering water sector into two main groups:

prevention of losses (structural/technological, institutional/administrative, and market-based) and education/behaviour. Examples of structural or technological prevention of losses are leakage control, conservation plumbing, and capacity increase (new reservoirs, desalination facilities). Institutional or administrative losses may be prevented by water allocation and risk management to deal with rainfall variability. Market based preventions may be managed by water permits and water pricing. Finally, educational or behavioural measures may be supported by rational water use and rainwater collection, for instance. However, the following broad response strategies of IPCC, referring to Part 4.1.1, may provide a better path to shape adaptation options considering water sector.

Timing of strategies: It is not known if the changes related with climate would occur gradually or suddenly. Considering the uncertainties regarding the extent, magnitude, and timing of climate change and its impacts on water resources, it could be suitable to postpone the more costly adaptation measures (C) till these uncertainties are reduced. Instead, less costly strategies (A, B), especially with other social benefits, could be appropriate. During the short-term, some response strategies and programs e.g. flood warning, evacuation, disaster relief loans or subsidies, and emergency operations, can be implemented. Other strategies such as conducting studies of altered reservoir operations to meet changing demands under climatic uncertainty require a longer lead time (IPCC, 1990).

Determining the flexibility and vulnerability of current water supply systems (A, B). Under the presence of uncertainty regarding hydrologic changes to be expected in any particular region and the cost of making any important change in existing water supply systems, a reasonable first step would be to assess their flexibility to the type of alterations due to climate change. Models could be useful to estimate sensitivity of water supply systems to increased aridity or runoff (IPCC, 1990).

As the vulnerability and/or inflexibility in a particular water system, and the effects on human population and on ecosystems are getting greater, monitoring relevant parameters to identify trends, to strive to reduce uncertainties regarding the effects of climate changes on water resources, and to consider measures to improve the flexibility of the water supply systems are gaining importance (IPCC, 1990).

System optimisation (A, B). System operation may not be optimised according to existing jurisdictions and agencies. If different jurisdictions or agencies are willing to execute agreements including exchange of storage and flood control capacity between reservoirs of different times of year, determining rules for joint operation, fundamental increases in system yield can be obtained by joint use and revised operating rules. More up-to-date data on meteorological and soil moisture conditions, application of more sophisticated computer models could help to enhance increases obtainable from such measures. If, in the long-run, the understanding of the flexibility and vulnerability of a water supply system regarding its response to a variety of hydrologic alterations is improved, the next step to be optimising the water yield, hydropower production, flood control, recreational use, maintenance of fish and wildlife habitat, and other outputs available from existing facilities under different climate change scenarios as well as current climate (IPCC, 1990).

Improving scientific measurement, monitoring, knowledge, and forecasting (A). One of the initial challenges for planners under the uncertainty regarding hydrologic conditions could be to decide whether the long-term changes are occurring or are expected to be experienced in a region under focus. Such assessments are based on wide and precise monitoring of hydrological and meteorological factors. A continued study of the interaction of the hydrologic system with the rest of the climatic system should be maintained to enable area or basin-specific predictions, or detection of trends, concerning changes in water availability and other parameters necessary for water resources management, which, as a result, enable planners, designers, and managers to consider anticipated climate trends in their use of stream flow and other time-dependent data series (IPCC, 1990).

Water conservation (A, B). Conservation measures would be more important under prolonged aridity conditions. Conservation of municipal and industrial water supplies can be accomplished through education, improved measurement and metering, technological improvements, specifying the use of more efficient water-using appliances in building codes, and, in arid climates, use of low-water-use landscaping rather than grass lawns. Moreover, under extreme drought conditions over one or two dry years, voluntary rationing and mandatory restrictions of domestic use, e.g. allowing water during certain hours, could be effective. Addition to those, pricing has a better potential as a motivator for conserving water (IPCC, 1990).

Managing demand through pricing (B). Water prices could be signals and incentives to conserve water, develop new supplies, and allocate limited water supplies among competing uses. As water use is sensitive to price, higher prices will generally direct users to conserve water and modify technologies. Hence, water supply authorities could use pricing to reflect real or replacement costs to promote efficient use. Utilisation of pricing as a means of conserving water by applying marginal-cost pricing (charging for the cost of the last-added and most expensive increment of supply) or progressive-rate pricing (charging more per unit to users of large amounts) could be an important opportunity for cities and irrigation districts. Moreover, during drought periods, pricing would be a possible means of allocating water use. To some extent this is realised: a two-tier rate structure is employed as some areas, where lower rates are charged for interruptible supplies of water (IPCC, 1990).

Voluntary water transfers or markets (B). There should be institutional arrangements for more arid conditions to assure that water is directed to where it is most needed and where it will be the most productive (IPCC, 1990).

Natural resources management (B, C). To promote the sustained yield and conservation of natural resources, to address deforestation and desertification, such programs are implemented in many regions of the world. Those may mitigate the impacts of climate change on water resources if potential impacts and risks of climate change are considered. Integrated river basin or watershed management programs are examples of such measures (IPCC, 1990).

Flood management. Flood management strategies are widely based on computed magnitude and frequency of flood events considering largely historic data. In addition to studies on systems operation designed to comply with a wider range of climatic conditions, potential response strategies include the following:

- Enhancing flood forecasting (A). Real-time information on hydro-meteorological data such as rainfall, streamflow/stage, and reservoir levels is available by GEOS satellites and other advanced systems. Wide collection and employment of real-time data with advanced quantitative precipitation forecasting techniques could enable water managers to respond better to potential flooding.
- Evacuation plans (B). Broad flood preparedness plans may include activities for temporary evacuation of flood plain occupants during flood events. Improved flood warning and forecasting abilities could enable additional actions like removing or raising building contents to reduce flood losses.
- Floodplain zoning (B). Zoning flood plain areas to forbid construction of structures and

activities prone to floods is another means to reduce or avoid losses.

- Flood insurance (B). This may have a double function. The flood insurance premiums can be price signals to the insured to deter locating in flood-prone areas. Second, insurance can be potent to reduce economic impacts of losses, once flooding has occurred (IPCC, 1990).

Design modifications (B, C). When cost effective, designing more capacity into spillways at times of project construction and other modifications, like increased capacity of dikes, can be helpful in dealing larger flows of water. (IPCC, 1990)

Education, technology transfer, and financial assistance and special considerations for developing countries (A). In many cases, developing countries fail to cope with adverse water resource conditions under current climate. Therefore, additional efforts may initially needed to raise standards of water resource management. Education, training, and technical assistance efforts directed at water manager and user could be a factor to promote more efficient water use in responding to climate change. To improve strength and resilience of water systems, determining appropriate technologies would be significant, considering the regional economic base and level of economic development, cultural and institutional factors, international and bilateral trade and debt policies, and guidelines for development projects (IPCC, 1990).

Modification of storage and other augmentation measures (C). In spite of costs, additional storage could be a measure to react climate change to accommodate changes in magnitude and timing of precipitation and/or snow melt, either by increasing existing dams, construction of new facilities, inter-basin transfers, or recharge of underground aquifers with available surface supplies. It is necessary to take into consideration potential adverse and beneficial environmental and economic impacts while planning such measures. Under drought conditions threatening public health and well-being, transportation of emergency water supplies could be supplied (IPCC, 1990).

Dam safety and other design criteria (B, C). Increased runoff because of climate change could be a potential risk for the safety of existing dams with design deficiencies. Thus, it is necessary to re-evaluate design criteria for dams to include climate change impacts (IPCC, 1990).

Adjustments for preserving water quality in rivers and reservoirs (B, C). Inadequate levels of freshwater could fail to dilute contaminants and salts, to dissipate heat, to leach salts from agricultural soils, and to regulate water temperatures to sustain aquatic life, and ecosystems of lakes, rivers, and streams. Moreover, dissolved oxygen concentrations could be influenced and eutrophication problems could worsen. Climate change could indirectly influence quality of underground water supplies by affecting the recharge rates of aquifers. Therefore, efficient operation of systems for managing water quality may become more critical. To mitigate negative changes in water quality, various in-place technologies such as aeration and destratification and localised mixing systems could be utilised. Modifying the operation of reservoirs with multi-level withdrawals, or adding this capability to existing reservoirs could be two of the factors improving the ability to manage changes in water-quality conditions. Water-quality issues may arise by the level of discharges into a stream, including non-point source runoff from the watershed. Thus, watershed management programs should consider non-point sources as well as point sources (IPCC, 1990).

4.3.2 Practical Examples of Adaptation in Water Resources Management

At national level, Turkey has not published any action plan regarding adaptation, however, it is mentioned in documents such as National Climate Change Strategy 2010 – 2020 (2010) and Climate Change Action Plan (2011). Strategy document states the necessities in the short-, mid-, and long-term and action plan specifies the activities towards adaptation. Considering water sector, the strategy document indicates the needs for dealing with agricultural drought and improvement of water quality in the short-term; development of legislations on water and integration of climate change issue to them, water conservation, flood control in the mid-term; pricing, system optimisation, recycling of wastewater, development of water-efficient building codes and technologies for the long-term. In the Climate Change Action Plan activities towards mainstreaming, capacity enhancement of water management bodies, development of financial and technical policies, and integrated basin management are defined.

New York City integrated climate change scenarios in the review of its water supply system. Changes in temperature and precipitation, sea-level rise, and extreme events were recognised as significant parameters for water supply impacts and adaptation in New York region (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 724).

Boston metropolitan region water supply system was assessed under climate change scenarios. With a stable climate, the reliability of water supply was calculated as 93% by 2100 with expected water demand growth. Introducing climate change, the reliability decreased to 82%. However, demand side management could increase it to 83%. If the local system would be connected to the main state river system, the reliability would reach 97% (Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, pp. 726).

Wesselink et al (2009) emphasized the role of hydrology and hydraulic experts in climate change adaptation in the Netherlands. They deemed water expertise is indispensable in decision-making in water sector.

Ziervogel et al (2010) searched the importance of availability and accessibility of climate forecasts for water resource managers in South Africa. It was stated that the water management sector did not recognise the importance of information about changing intra-annual precipitation conditions in a systematic manner, which was accepted as a critical step towards long-term change. This was believed to be due to lack of awareness of available products or unsuitability of the products for users' needs. Using the information about climate variability would better equip the water managers to adapt to climate change. Moreover, it was considered crucial to provide the exact information they needed. For daily management of water resources and extreme events, short-term climate information was deemed sufficient. Seasonal forecasts were employed for tactical decisions over medium-term. For long-term time scales, planning issues, information on decadal variability and climate change were required. It was observed that bulk water managers benefit short-term forecasts to manage the water in dams, whereas seasonal forecasts were used for drought management. However, they required rainfall intensity predictions, more specific location forecasts, and longer forecast lead times. It was concluded that water resource managers would be supported towards adapting to climate variability and change, if there were necessary and sufficient information from climate forecasts.

In summary, regarding water resources, the most significant effect of climate change for water supply systems is the rise of uncertainty (Mukheibir, P., 2010). Water resources systems should be reliably performing over a wide range of foreseen hydrological variability. This reliability criterion is dependent on risks, costs, benefits, environmental impacts, and societal preference (IPCC, 1995, pp. 482).

Possible response strategies for water sector can be listed as follows: determining the flexibility and vulnerability of current water supply systems (A, B), system optimisation (A, B), improving scientific measurement, monitoring, knowledge and forecasting (A), water conservation (A, B), managing demands through pricing (B), voluntary water transfers or markets (B), natural resources management (B, C), education, technology transfer, and financial assistance (A), modification of storage and other augmentation measures (C), dam safety and other design criteria (B, C), and adjustments for preserving water quality in rivers and reservoirs (B, C) (IPCC, 1990).

5. History and Description of Ankara

This part presents Ankara with brief information about its history, geography, climate, landuse, economic activities, and population.

5.1. History of Ankara

The origin of the name Ankara is unknown. According to the undocumented sources, the first name was Ankyra, meaning anchor in Greek, which was given by the Galatians. The tales tell that Midas of Phrygia established the city at a place with an anchor. One of the later names Engürü is the Persian word for grape. Therefore, it is claimed that the city was rich of vineyards. The name has changed in time from Ankyra to Ancyre, Engüriye, Engürü, Angora, Angara and, finally, to Ankara (AÇOB, 2008, URL 8).

Although there is no certain evidence of the first establishment of Ankara, archaeological investigations reveal that the area is under settlement since the palaeolithic era. Those searches are able to date back the settlements to the Hittites. Later, the Phrygians, the Cimmerians, the Persians, the Lydians, the Macedonians, the Galatians, the Romans, and the Seljuks occupied it (AÇOB, 2008, URL 8).

In 8 B.C. Ankara was under control of Phrygians and was an important settlement. Evidence shows that there were dwellers outside of the castle, on the hillside to the castle and plains. During 522 – 486 B.C., the city was a small trade centre where the Lydians and the Persians were supreme. Galatians were on stage during 278 – 277 B.C. Under Roman reign, the city was the capital of Galatia area and, thus, was promoted to metropolis degree. Those were the times that Ankara had its most powerful and important age. In the first two centuries after Christ, Ankara became a major crossroad of Roman road web in Anatolia and improved its governmental, military, and economic functions. Therefore, the settlements were grown outside of the castle, to the plains and were twice as bigger as in the previous century. The population is claimed to have been 100,000 and the city had an open view without any surrounding walls. However, in the third century A.D., due to instabilities, protecting walls were constructed and the city lost its open view. Later in 334, Byzantine ruling started on the city. In 1075 Byzantine lost its control to Seljuks. However, the reign changed hands among Seljuks, Byzantine, Turkish begliks and Mongols till the appearance of the Ottoman's. The Ottoman's occupied the land in 1354 to establish their reign over Anatolia. Ankara had another important age under the House of Osman as a trade city. The existence of more than 30 hostelries is the proof of this significance. In the 16^{th} and 17^{th} centuries, the city's population was doubled. However, starting in the 18^{th} century, Celali Revolts, shaking the Ottoman Empire, made the city lose its population. In spite of the turmoil and loss in trade, Ankara was an important city till the 19^{th} century. Long after, Ankara had a major role in the Independence War. On December 27, 1919, Mustafa Kemal and his comrades came to Ankara and declared it as the centre for the campaign. Since October 13, 1923 Ankara is the capital of Turkish Republic (Ankara Metropolitan Municipality, 2006, AÇOB, 2008).

5.2. *Geography of Ankara*

Ankara lies on 39°57' N and 32°53' E and two geographic regions. A small north part of the city is in the Black Sea Region and the main area is in north-west of Central Anatolia Region. East border of Ankara is determined by two cities, Kırşehir and Kırıkkale. At west, Eskişehir and Bilecik are located. Çankırı is the north, and Bolu is the north-west neighbourhood of the city. Konya and Karaman are located at south of Ankara. Surface area of Ankara is 26,326 km^2 and average altitude is 890 m

(AÇOB, 2008). Figure 5.1 gives borders of the city and its districts.

Figure 5.1 Map of Ankara (URL 9)

Ankara is an area on plains formed by tributaries of Kızılırmak and Sakarya rivers. Forests and steppe are present together. The north part of the province is shaped by the plains of Mid-Anatolia and Pontid Mountains. South of Ankara is surrounded by Salt Lake, plains like Kepez and Hacıbekiroğlu. Among them volcanic mountains Karadağ and Karasimir, and Paşa and Teke mountains rise. From mid-part through north, mountain ranges connecting to Pontid Mountains sprawl. Close to them, İdris and Elmadağ mountains are located. Because of this south-west north-east direction of mountains, there are many depression areas and, thus, Balaban, Mogan lakes, and Çubuk, Mürted, Babayakup plains have been formed. Other lakes in the province are Eymir, Karagöl, Kurumcu, and Samsun (AÇOB, 2008).

5.3. Climate and Weather

5.3.1 Overview

The dominant climate over Ankara is continental with hot and dry summer and cold and wet winters. The north part of the city is under influence of Black Sea climate. Through south and south-east parts of the province, temperature difference between night and day increases and the amount of precipitation decreases. The hottest period is July – August, and the coldest month is January. The mean temperature is 10 – 13°C. The hottest temperature measured is 40.8°C. According to yearly mean values, insolation is 7.4 h/day. The mean precipitation is 370 – 565 mm. The number of frost days is 60 – 110, and that of snowy is snow cover 17 – 42 days. The mean relative humidity is 61.2%. Evaporation values reach their highest values in July and August. Mean evaporation is 162.5 mm/year (AÇOB, 2008). Detailed information concerning weather and climate parameters is presented by below figures and tables.

5.3.2 Precipitation

May is the month during which the most precipitation is seen. Between June and November, dry season prevails. Daily maximum precipitation is high in December. Mean precipitation is 397.4 mm. The number of mean snowy days is 31.6, whereas the number of the mean days of snow cover is 23.8 (AÇOB, 2008).

Table 5.1 Mean Values of Some Weather Parameters for Ankara (AÇOB, 2008)

	Relative Humidity (%)	Temperature (°C)	Evaporation (mm)
January	73.9	0.3	-
February	70.8	1.8	-
March	63.8	5.9	-
April	60.8	11.2	92.5
May	58.2	15.9	149.8
June	53.4	19.9	188.6
July	47.7	23.3	239.0
August	47.4	23.0	226.2
September	51.2	18.5	156.1
October	61.4	12.8	85.5
November	70.4	6.6	-
December	76.0	2.2	-
Average	61.2	11.8	162.5

Table 5.2 Mean Precipitation Values for (AÇOB, 2008)

	Mean Precipitation (mm)	Mean Maximum Precipitation (mm/day)	Mean Snowy Days	Mean Days of Snow Cover	Mean Maximum Snow Depth (cm)	Mean Days of Frost
January	40.6	27.9	9.5	9.8	30.0	20.5
February	32.9	26.9	7.4	7.0	30.0	17.7
March	35.5	22.1	5.2	2.3	20.0	11.4
April	52.2	29.4	1.2	0.2	7.0	1.7
May	49.5	41.6	0.1	-	-	-
June	33.5	88.9	-	-	-	-
July	14.9	62.6	-	-	-	-
August	12.6	35.6	-	-	-	-
September	16.5	32.2	-	-	-	-
October	30.3	29.0	-	-	-	0.7
November	37.4	36.0	2.4	0.5	10.0	8.1
December	41.5	36.7	5.8	4.0	25.0	17.4
Average	397.4	88.9	31.6	23.8	30.0	77.5

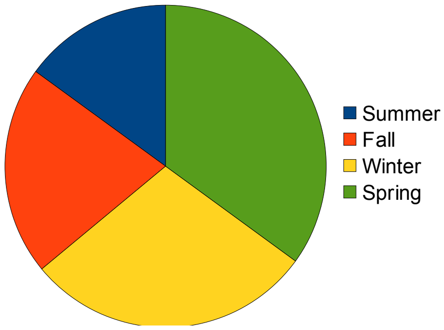


Figure 5.2 Distribution of Precipitation among Seasons (AÇOB, 2008)

5.3.3 Drought

Using Standardised Precipitation Index Method (SPI), drought in Ankara is investigated. This method is employed to track lack of precipitation for different time intervals. Monthly precipitation series of minimum 30 years are prepared and wet and dry periods are identified within the given time span. Index values below zero are accepted as the beginning of drought, whereas positive values indicate the end of dry period. Below are the monthly SPI values for Ankara (AÇOB, 2008).

Table 5.3 Standardised Precipitation Index Values for Ankara (AÇOB, 2008)

Month	Value	Category
January	0.73	damp-dry
February	-1.89	heavy drought
March	0.88	damp-dry
April	-0.40	light drought
May	-0.01	light drought
June	-1.04	moderate drought
July	-1.64	heavy drought
August	-0.85	light drought
September	1.50	very wet
October	-0.12	light drought
November	0.65	damp-dry
December	-0.40	light drought

The table shows that light to moderate drought conditions prevail in Ankara in 8 months, and the other months are "damp-dry", with only September ranging as very wet. This illustrates the need for water management in Ankara very well.

5.4. Land Use and Agriculture

5.4.1 Overview

Land area of Ankara is 2,570,600 ha. 50% of that (1,284,000.75 ha) is agricultural land, 12% (358,261 ha) is forest and shrubbery, 17% (390,577 ha) is meadow land, and 21% is non-agricultural land

(AÇOB, 2008). Only 15% (193,837 ha) of the agricultural land can be irrigated. The actual irrigated portion is 93,140 ha, which is only 7.25% (Ankara İl Tarım, 2006, pp. 79).

The below figure and tables provide impression about agricultural land use of the province. As seen with 70%, croplands have the highest share among other agricultural land uses. The smallest portion belongs to vineyards.

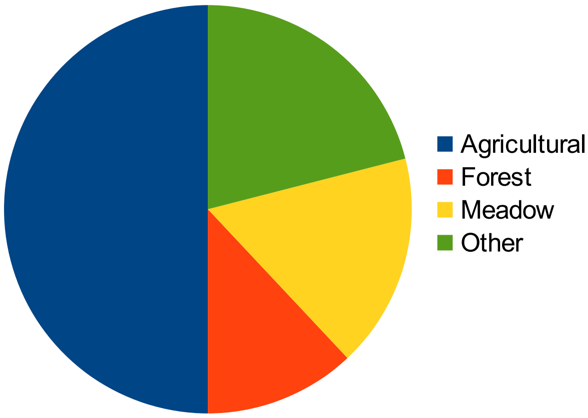


Figure 5.3 Land Use of Ankara (AÇOB, 2008)

Table 5.4 Cultivated Land Use Distribution of Agriculture (AÇOB, 2008)

Use	Area (ha)	Percentage in Total Land Area
Cropland	896,162.40	70.4
Vegetable	36,527.40	2.8
Orchard	10,315.00	0.9
Vineyard	6,026,45	0.5
Fallow	323,839.60	25.4
Total	1,272,870.85	100

Table 5.5 Non-cultivated Land Use Distribution of Agriculture (AÇOB, 2008)

Use	Area (ha)	Percentage in Total Land Area
Meadow	394,931.00	30.5
Forest and Shrubbery	357,961.00	27.5
Non-agricultural	544,837.15	42.0
Total	1,297,729.15	100

5.4.2 Crop Production

All cereals such as barley, wheat, rye, and oat found in Central Anatolia Region are produced in Ankara. These are planted as seeds before winter and harvested in July – August by reaping machine. Pulses, including bean, chickpea, masoor, are the second agricultural production group. Those are planted by sowing machine or manpower and harvested in June by manpower or using mower. The third group of cultivation is fodder crop. In autumn vetch and triticale, in spring common vetch, alfalfa, sainfoin, and corn are cultivated. Corn and alfalfa are produced in irrigated land. Last group of crops is industrial plants, some of which are sugar beet, sunflower, cumin, and potato (AÇOB, 2008).

5.4.3 Horticultural Crop Production

The major fruits produced in Ankara are apple, pear, grape, peach, apricot, cherry, walnut, mulberry, and strawberry. Tomato, cabbage, leek, spinach, bean, pea, onion, broad bean, broccoli, and carrot are the examples of vegetable production. There is also ornamental plant production in the province (AÇOB, 2008), however, that is not significant.

5.4.4 Animal Husbandry

In Ankara bovine animal husbandry is based on dairy production. Such activities are concentrated in villages of Ayaş, Kazan, and Güdül with a capacity of 10 – 30 animals. Stock farming is intensive in Çubuk, Sincan, Akyurt, and Polatlı with a capacity varying between 20 and 250 animals. Moreover, there are also family farms having 1 – 7 animals. There is not a live-stock trade in Ankara (AÇOB, 2008).

5.5. Industry

As before the republic era, Ankara is still a notable trade, industry, and conference tourism centre. In the early days of the new state, one brewery, one cement plant, and one powder mill used to constitute industrial life of Ankara. However, currently quantity and variety of industrial facilities are considerable. Within the province, macaroni, flour, vegetable oil, dairy, sugar, cement, tractor, agricultural equipment, engine, dye, brick and tile, forest, furniture, hardware, and textile products are generated. Nevertheless, the facilities are mostly small and medium size enterprises, employing average 10 – 14 workers (AÇOB, 2008).

Along with those mentioned above, defence industry is an important asset of the economy of Ankara. Mechanical and Chemical Industry Corporation (MKEK), HAVELSAN, ROKETSAN, and ASELSAN, Turkish Aeronautical Industry (TAI) are the main drivers of the sector. Moreover, there are some private enterprises as FMC-Nurol Defence Industry, Aremsan Electrics and Machine Industry, Barış Electrics Industry, and Marconi Communication belonging to defence industry. Their presence has reinforced machine and metal industry in the city. Moreover, there are more than 50 R&D facilities within the techno-cities and organised industrial sites (AÇOB, 2008).

As stated above, most of the industrial production, about 40% comes from the metal and machine industry. The second largest sector in Ankara is food production. The third is wood processing. In 2008, the number of industrial facilities in Ankara was 4,327 with 369,256 employees (AÇOB, 2008).

5.6. Settlement and Population

5.6.1 Settlement

Area of Ankara Metropolitan Municipality covers about 855,000 ha. The borders were identified by drawing a circle with centre Ankara Governor's Building and a radius of 50 km. This is the largest municipal border in the whole country and contains 15 districts and total 36 municipalities (AÇOB, 2008).

According to 2005 values, the metropolitan urban housing area of Ankara is about 61,000 ha. 16,000 ha of this is housing, 70% of which (11,000 ha) constitutes planned residential areas, where 77.5% of the population dwells. Unplanned residential areas occupy 30% of the total dwelling area and the population living here is 27.5%. Total urban housing area of Ankara is about 80,000 ha (AÇOB, 2008).

The below table gives some values for urban areas per capita for Ankara. As expected, public institutions have the highest share. Second is the area of universities and the third is the green areas.

Table 5.6 Per Capita Urban Areas in Ankara (AÇOB, 2008)

Urban Structure	Area (m^2/c)
Public institutions (without military)	17
Primary and secondary schools	2.9
Health facility	1.12
Green areas (active)	4
Green areas (all)	12.8
Socio-cultural facility	0.48
University	16
Trade facility	3.3

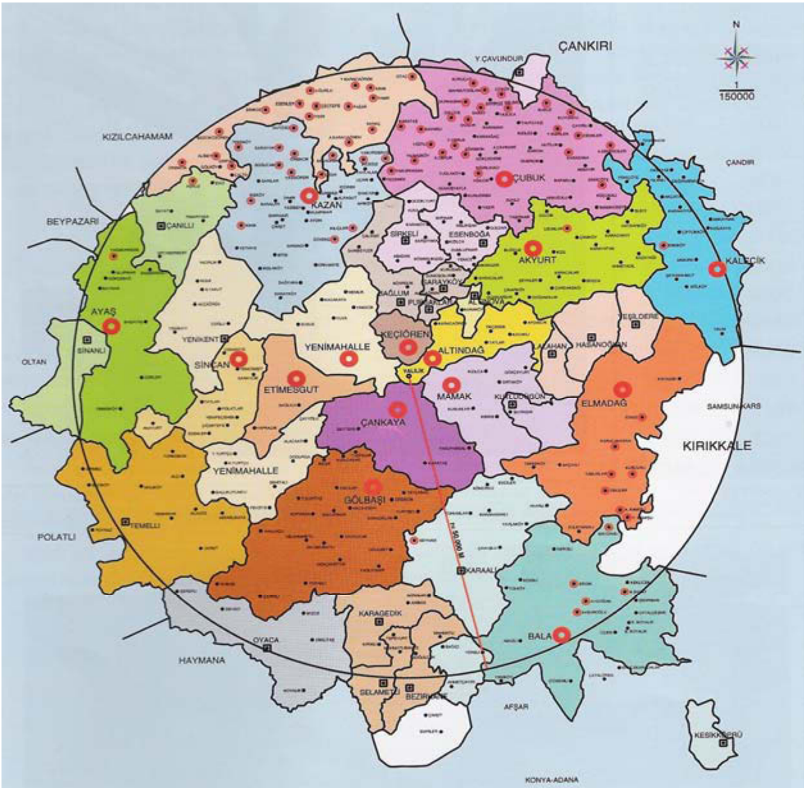


Figure 5.4 Borders of Ankara Metropolitan Municipality

5.6.2 Population

According to 2010 census, urban population of Ankara is 4,641,256. The number of males is 2,314,795, females is 2,326,461. With the 130,460 people living in rural areas, the total population of the province is 4,771,716, of which 2,379,226 are male and 2,392,490 are female (URL 1). The following table details the population in the different districts (Table 5.7).

Table 5.7 2007 Population Density of Ankara's Districts (AÇOB, 2008)

District	Population	Area (km^2)	Population Density (c/km^2)
Total	4,007,860	24,521	163
Altındağ	407,101	167	2,438
Çankaya	769,331	268	2,871
Etimesgut	171,293	49	3,496
Gölbaşı	62,602	735	85
Keçiören	672,817	190	3,541
Mamak	430,606	471	914
Sincan	289,783	344	842
Yenimahalle	553,344	274	2,020
Akyurt	18,907	212	89
Ayaş	21,239	1,108	19
Bala	39,714	2,530	16
Beypazarı	51,841	1,800	29
Çubuk	75,119	1,350	56
Elmadağ	43,374	568	76
Kalecik	24,738	1,340	18
Kazan	29,692	408	73
Kızılcahamam	33,623	1,744	19
Ankara Metropolitan Municipality	3,609,660	10,014	360.46

Since the beginning of the republic era, Ankara has experienced a population increase greater than the average of Turkey. This increase was 34.7‰ between 1927 and 1935, whereas 21.4‰ between 1990 and 2000 (Figure 5.5) (AÇOB, 2008). A population increase of 2 to 3% indicates a doubling of the population every 23 to 35 years.

The Future population of Ankara was projected via different methods including grid, arithmetical increase, compound interest and etc. By 2023, the smallest and largest projections are calculated as 5,652,852 and 9,172,936, respectively. Considering all the results, the population of Ankara is projected to be 6,034,708 by 2023. The decrease in the population increase rate of last 20 years is taken into account. Moreover, other growing cities in Central Anatolia are expected to attract people more than Ankara. It is uncertain that to what extent migration to the city will continue (Ankara Metropolitan Municipality, 2006).

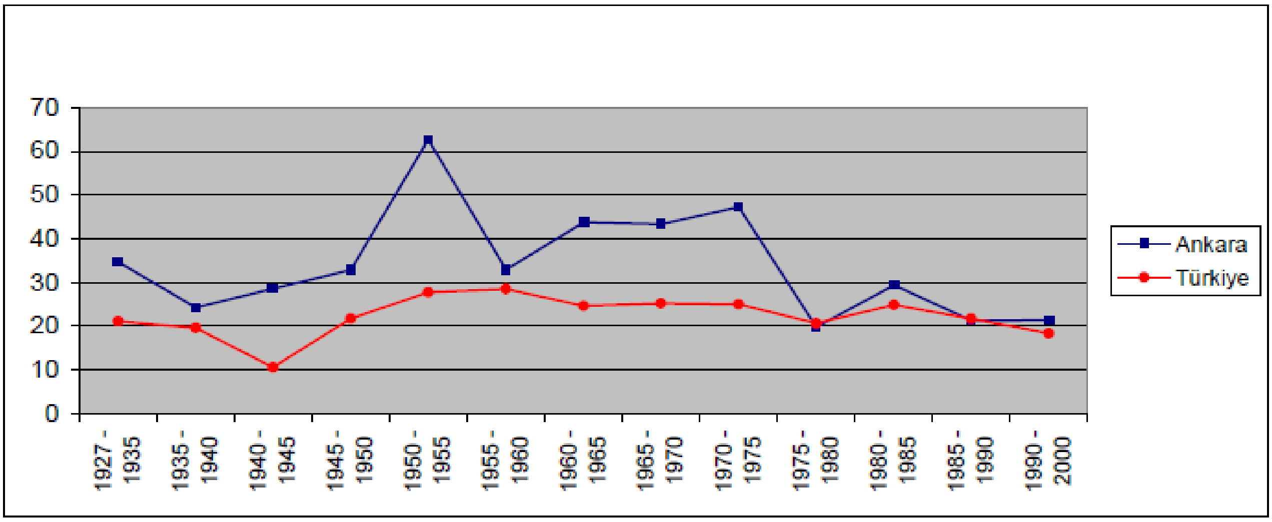


Figure 5.5 Rate of Population Increase (‰) of Turkey and Ankara between 1927 and 2000 (Ankara Metropolitan Municipality, 2006)

Water for drinking is the single most important use of the managed water in Ankara. The amount needed is highly dependent on the number of people that need to be provided for. This is discussed in more detail in part 7.3.4.

6. Investigation of Current and Future Water Resources of Ankara

This part provides information about the history of water supply, and current and future water resources of Ankara.

The earliest historical information about water system of Ankara is the water supplied by the Governor Abidin Paşa in 1890. He diverted waters of Elmadağ and Hanım Pınarı by masonry-lined canals, and connected to the fountains by iron and cement pipes. After becoming the capital, population of Ankara rose to 75,000. Thus, the municipality took necessary precautions to meet water demand in the coming years. A catchment close to Kusunlar Village was constructed and water was supplied to the city by 600 mm radius pipes. Moreover, two pump stations at Şahande and Hanım Pınarı, and a collection tank of 1,000 m^3 at Kocatepe were built. Later, to supply water from Çubuk Dam, a filtering station with a capacity of 24,000 m^3, 9 tanks with a total volume of 1,200 m^3 were installed. Additional to those, 123 123 km of pipe lines were laid. The management responsible for water resources was operating as a department belonging to the Municipality. Later, in 1949, it became a corporate body subjected to a special statute and named “Ankara Directorate of Waters”. In 1964 Çubuk II Dam, in 1965 Bayındır and in 1967 Kurtboğazı dams were put into service. During 1968 – 1969, the Master Plan for Ankara's Water and Sewage to meet demands till 2020 were prepared by Camp Harris Mesara Company. According to this plan, in 1984 the first unit of İvedik Water Treatment Plant and in 1985 Çamlıdere Dam were put into service. After 1980, water and sewage organisations under municipalities were reorganised according to the newly constituted Metropolitan Municipality Management Models. In 1987 “Ankara General Directorate of Water and Sewage” (ASKİ) was founded (ASKİ, 2011). Since then, ASKİ is the main responsible body for the issues related with water supply system of Ankara.

Ankara is located on the intersection of three watersheds, which are Sakarya, Kızılırmak, and Konya Closed Basin. Within the province the area of surface waters is 4,385 ha. The dams are constructed on Kızılırmak and Sakarya rivers and their tributaries. Main surface waters of Ankara and their flowrates are (AÇOB, 2008):

1. Kızılırmak River and tributaries Terme and Balaban streams, 2,900 hm^3/a
2. Sakarya River and tributaries Aladağ, Nalderesi, Girmir and Ankara streams, 2,500 hm^3/a
3. Peçenek Stream, 30 hm^3/a

The total flowrate on the borders of the province is 5,430 hm^3/a (AÇOB, 2008). Please refer to Appendix D and Appendix E for the maps of Kızılırmak and Sakarya watersheds, respectively. The below tables give information about water resources of Ankara and the dams.

Table 6.1 State of Water Resources of Ankara (AÇOB, 2008)

Resources	Capacity
Annual precipitation	493.6 mm
Total water potential	11,618 hm^3/a
Surface water	11,260 hm^3/a
Groundwater	358 hm^3/a

Considering the surface area of the city, annual precipitation constitutes an amount of 12,994.5 hm^3/a, which is larger than the total water potential. However, to find the contribution of this amount to the availability of water needs more analysis.

Currently, there are 8 dams providing about 375 hm^3/a water to Ankara (see Table 6.2 and Figure 6.1). These are Çubuk I and II, Bayındır, Kurtboğazı, Çamlıdere, Eğrekkaya, Akyar, and Kesikköprü dams. There are additional 2 more supporting those, which are Asartepe and Kavşakkaya (URL 2).

Table 6.2 Dams in Ankara (URL 2)

Dam	Location	Influent	Use	Total Volume (hm^3)	Active Volume (hm^3)	Irrigated Area (ha)	Service Year
Çubuk I	Çubuk	Çubuk	Drinking water + flood control	5.6	2.49		
Çubuk II	Çubuk	Çubuk	Drinking water	24.6	22		1964
Bayındır	Kayaş	Bayındır	Drinking water + flood control	6.97	6.2		1972
Kurtboğazı	Kazan	Kurt	Drinking water + irrigation	96.9	93	2,800	1973
Çamlıdere	Çamlıdere	Bayındır	Drinking water	1,220	840		1987
Eğrekkaya	Kızılcahamam	Sey	Drinking water	113	86		1993
Akyar	Kızılcahamam	Bulak	Drinking water	56	47		2000
Asartepe	Ayaş	İlhan	Irrigation	20		1,500	1989
Kesikköprü	Bala	Kızılırmak	Irrigation + energy	95	57	6,600	2008
Kavşakkaya	Kazan	Ovaçayı	Drinking water	64			2007

Figure 6.1 Dams in Ankara (ASKİ, 2008)

There are also natural and constructed ponds mainly for irrigation purposes. Below is a list of them.

Table 6.3 Ponds in Ankara (URL 10, AÇOB, 2008)

Pond	Location	Influent	Use	Active Volume (hm^3)	Irrigated Area (ha)
Çanıllı	Ayaş	İlhan	Irrigation	0.642	142
Kızılca	Çubuk	Ortakuyu	Irrigation	372	40
Kösrelik	Çubuk	Uludere	Irrigation	0.207	28
Kızık	Çubuk	Kırha	Irrigation	0.71	94
Susuz	Eryaman	Slope water	Recreation		
Bucuk	Sincan	Yukarıbağ	Irrigation	0.28	162
Üçbaş	Kızılcahamam	Kavgalının deresi	Irrigation	0.428	76
Aşağıkaraören	Kızılcahamam	Kuzoğlu	Irrigation	0.213	49
Kırköy	Kızılcahamam	Eneğim	Irrigation	0.304	64
Karagüney	Kızılcahamam	Karagüney	Irrigation	0.505	131
Çeştepe	Kızılcahamam	Bostan	Irrigation	0.392	143
Çeltikçi	Kızılcahamam	Akdere	Irrigation	0.201	43
İğdir	Kızılcahamam	Kayacık	Irrigation	0.033	15
Çamalan	Nallıhan	Beydili	Irrigation	1,026	437
Örencik	Kazan	Karanlık	Irrigation	0.2	31
Evren-Köprüdere	Şerefli Koçhisar	Köprü	Irrigation	1.5	215
Bayındır	Çamlıpınar	Gökçepınar	Livestock irrigation	0.137	11.5
Tekirler	Nallıhan	Gelence	Irrigation	1,333	233
Ozanköy	Nallıhan	Kurugöl	Irrigation	2.11	181
Kösrelik	Keçiören		Irrigation		24

As shown above, surface waters are the basic resource for Ankara. However, there is an increasing demand on groundwater in the last years, yet its share in the total is still small. There are many drilled wells mainly for irrigation in Ayaş, Beypazarı, Polatlı, Kazan, Gölbaşı and Çubuk districts (AÇOB, 2008). Table 6.4 shows a list of groundwater basins in use.

Table 6.4 Groundwater Basins Used in Ankara (AÇOB, 2008)

Location	Reserve (hm^3/a)	Location	Reserve (hm^3/a)	Location	Reserve (hm^3/a)
South Ankara	4.5	Mürted plain	15.5	Bala	1.5
Ayaş – Beypazarı - Güdül	5.5	Temelli	0.5	Kızılcahamam	0.4
Çubuk plain	9.0	East of Salt Lake and Peçenek	3.0	Elmadağ	8.2
Hatip plain	33.0	Bursal valley	1.5	Kalecik	1.6
Kurakçöl	2.0	Gölbaşı	2.23	Polatlı	0.1
Yenimahalle	1.85	Kazan	0.54		

To meet the increasing demand in the future, till 2033, two new dams are planned: Kuruçay and Gerede-Işıklı. Kuruçay Dam is designed to supply 8.68 hm^3/a from Çubuk stream. Gerede-Işıklı, on the other hand, is a far bigger project, through which 226.05 hm^3/a water is planned to supply to Ankara (Yüzer, M., 2011).

7. Investigation of Climate Change Impacts on Water Resources of Ankara and Assessment of Climate Sensitivity

The aim of the data analysis introduced here is to identify future impacts of climate change on water resources of Ankara and to assess climate sensitivity of the city. Therefore, the data used are listed and related information is provided. A summary of regional climate model results for Ankara is given to exhibit expected future changes in temperature and precipitation. Water use of Ankara in different sectors is investigated. Meteorological data obtained from DMİ are analysed to reveal temperature and precipitation patterns in Ankara and E-OBS data set is checked for reliability. Finally, the relationship between precipitation and surface runoff is investigated through comparing the meteorological data and streamflow records of DSİ. The conclusion of the whole process of analysis is given in the last section assessing climate sensitivity of the city.

7.1. *Data Sets and Methodology*

The investigation of impacts of climate change on water resources of Ankara is conducted in two directions: referring to available regional climate models for and including Turkey, and data analysis.

Available regional climate models for Turkey are exploited to explore effects in Ankara. The first group of models consists of regional models for Turkey - ECHAM5 RegCM3 and HadAMP3 - described in Part 2.2. The second group of models are those involved in the PRUDENCE project which uses two atmosphere-only general circulation model ensembles and four regional models and with two different emission scenarios, giving results relative to 1971 – 2000 (Christensen, J. H., Christensen, O.B., 2007).

The data set analysed is composed of water consumption data, meteorological logs, and streamflow records. The aim is to determine water use patterns, and search for climate change impacts of the past through handling of logs of meteorological and streamflow gauging stations located in and around the city. The location of both meteorological and streamflow gauging stations on land is displayed in Appendix F, the time periods for which data are available, as well as some additional information on the stream-flow gauging stations is depicted in the Tables 7.1 and 7.2.

- First, the data supplied by Ankara 5^{th} Regional Directorate of State Hydraulic Works (DSİ) is used to assess water consumption of the city. The data set contains the monthly values of 8 dams, described in the previous part, supplying water to Ankara with information about volumes of the water in the dams, amount of inflows and amounts of outflows in different categories from 1972 to 2010 in different time ranges shown by Table 7.1.
- The meteorological data are a set of logs from 25 stations belonging to Turkish State Meteorological Service (DMİ) and contain monthly mean temperature and monthly total precipitation information of 1975 – 2010 period in varying time range. Table 7.2 summarises the information about these stations.
- In addition to stations of DMİ, temperature and precipitation data from 258 grid points of the E-OBS data set are employed. This is a European-wide data set composed of daily, high-resolution, land-only grids for precipitation, and maximum, minimum and mean temperature for the 1950 – 2006 period (Haylock, M. R., 2008). It was hoped that these data would provide a better areal coverage with precipitation data.
- Along with meteorological data, there are streamflow records of the streams in Ankara. The gauging stations belong to DSİ and contain monthly total flows of tributaries of Sakarya and Kızılırmak rivers in and around Ankara, and the data are recorded during 1957 – 2000 period again

in varying time periods. Table 7.3 gives the properties of these gauging stations.

Table 7.1 Time Range of the Data of Dams

Dam	Asartepe	Bayındır	Çamlıdere	Çubuk I	Çubuk II	Kavşakkaya	Kesikköprü	Kurtboğazı
Range	1989-2010	1972-2010	1987-2010	1972-2010	1972-2010	2007-2010	2007-2010	1972-2005

Table 7.2 General Information about the Meteorological Stations Used (DMİ)

Name	Number	City	Altitude	Status	Range	Basin	Location
Ankara	17130	Ankara	890.52	Active	1975-2010	Sakarya	39.95N, 32.88E
Avanos	17833	Nevşehir	950	Active	1986-2010	Kızılırmak	38.44N, 34.51E
Ayaş	3000	Ankara	910	Passive	1975-1990	Sakarya	40.01N, 32.35E
Bala	3920	Ankara			1987-1993	Kızılırmak	39.33N, 33.07E
Beypazarı	17680	Ankara	682	Active	1975-2010	Sakarya	40.10N, 31.56E
Çamlıdere	2042	Ankara	1175	Passive	1986-1999	Sakarya	40.48N, 32.48E
Çandır	2560	Ankara	1000	Passive	1989-1996	Kızılırmak	40.43N, 33.80E
Çeltikçi	2375	Ankara	775	Passive	1986-1994	Sakarya	40.32N, 32.45E
Çubuk	9643	Ankara	940	Passive	1975-1993	Sakarya	40.14N, 33.02E
Elmadağ	3182	Ankara			1984-2002	Kızılırmak	39.55N, 33.14E
Etimesgut	17667	Ankara	806.15	Passive	1975-1991	Sakarya	39.57N, 32.41E
Gülşehir	5335	Nevşehir	885	Passive	1985-1986	Kızılırmak	38.74N, 34.62E
Güvem	1886	Ankara	1050	Passive	1986-1993	Sakarya	40.66N, 32.79E
Hacıbektaş	4993	Nevşehir	1200	Passive	1975-1997	Kızılırmak	38.93N, 34.40E
Haymana	4092	Ankara			1975-1991	Sakarya	39.26N, 32.30E
İkizce	3731	Ankara	925	Passive	1986-2004	Sakarya	39.65N, 32.72E
Kalecik	3011	Ankara			1985-2002	Kızılırmak	40.06N, 33.25E
Kaman	17756	Kırşehir	1075	Active	1976-2010	Kızılırmak	39.22N, 33.43E
Kayaş	3180	Ankara	950	Passive	1986-1988	Sakarya	39.90N, 32.97E
Kızılcahamam	17664	Ankara	1033	Active	1975-2010	Sakarya	40.28N, 32.39E
Nallıhan	17679	Ankara	650	Active	1975-2010	Sakarya	40.11N, 31.22E
Peçenek	2200	Ankara	1500	Passive	1989-1998	Sakarya	40.42N, 32.30E
Polatlı	17728	Ankara	886	Active	1975-2010	Sakarya	39.35N, 32.09E
Sarıyar	2992	Ankara	405	Passive	1975-1998	Sakarya	40.02N, 31.25E
Sivrihisar	17726	Eskişehir	1070	Active	1975-2010	Sakarya	39.27N, 31.32E

The data analysis has four steps:

1. Water consumption patterns and sectors in Ankara are investigated to figure out how much water is used and in which sector, e.g. agricultural, drinking water, including industrial use or energy.
2. The data from the stations of DMİ are inspected for homogeneity in terms of temperature and precipitation trends. Then the E-OBS data are compared with the station data and tested for their reliability. These inspections are done with scatter graphs by comparing the data in pairs.
3. Correlations between precipitation and streamflow data, as well as inflow to dams are

investigated again by using scatter graphs. They are intended to reveal runoff patterns and to help determine the significance of precipitation for Ankara.

4. The relationship between population and water use is investigated. Increase in population is compared with the change in water consumption, i.e. annual per capita water use, and a forecast of water needs is made according to the expected population.

Table 7.3 Properties of the Streamflow Gauging Stations

Station No.	Name	Stream	Service Date	End of Service	Precipitation Area (km^2)	Altitude	Basin
15-029	Uzunlu	Arsızözü	26.10.1962	31.01.1984	597	1130	Kızılırmak
15-033	Tatlar Brj.	Acısu	10.09.1963	08.02.2002	219.5	1058	Kızılırmak
15-038	Sarayözü	Sarıöz	21.09.1963	19.01.1976	186	795	Kızılırmak
15-057	Kılıçlar	Balaban	12.09.1963	17.09.2001	1240.8	716	Kızılırmak
15-070	Arifeoğlu	İnandık	17.09.1964		367.4	739	Kızılırmak
15-133	Tüney	Terme	07.01.1967		1326.9	687	Kızılırmak
15-177	Koyunbaba	Terme	01.10.1977		754	778	Kızılırmak
15-195	Kuşçuali	Balaban	04.09.1981		997	850	Kızılırmak
12-008	Aş. Çavundur	Çubuk	01.04.1960	31.08.1974	190.4	1020	Sakarya
12-009	Karaköy	Çubuk	13.12.1957	01.08.1962	958.4	906	Sakarya
12-017	Mandıra	Kızılcahamam	01.01.1959		907.5	903	Sakarya
12-023	Nenek	Hatip	01.03.1960	23.08.1966	210	1000	Sakarya
12-026	Yağmurdere	Elmalı	18.03.1960	05.09.1994	266	800	Sakarya
12-030	Saray	Sey	15.03.1960	30.01.1992	384.2	957	Sakarya
12-075	Karşıyaka	Sirkeli	10.07.1964		59.20	1002	Sakarya
12-081	Derince	Bulak	01.09.1965	30.09.1993	274	1007	Sakarya
12-083	Ravlı	Ravlı	12.12.1965		65.30	1051	Sakarya
12-126	Pazar	Mera	17.12.1974		197.2	965	Sakarya
12-129	Yenice	Çubuk	22.10.1974		824	935	Sakarya
12-134	Yeşildon	Porsuk	03.09.1974	06.10.2003	7580	750	Sakarya
12-176	Hasan Köprü	Akgöl outlet	01.10.1984			890	Sakarya
12-188	Yakapınar	Nal	01.05.1986		618	654	Sakarya

7.2. Compilation of Available Climate Model Results for Ankara

ECHAM5 RegCM3, according to A2 scenario, forecasts a general temperature increase between 2011 and 2040 except for spring and partly in summer compared to the 1961 – 1990 period. The increase is between 0.4°C – 0.8°C, highest in fall. In spring a cooling about 0.8°C is foreseen. During the next thirty years there is a general rise between 0.4°C – 1.5°C, highest in winter and lowest in spring. Between 2071 and 2099, temperature rise is more than the previous period with a range of 2°C – 4°C, again lowest in spring but highest in summer. The same model projects a general increase in precipitation in the 2011 – 2040 period, ranging from 4 to 25%, highest in fall and lowest in summer. The 2041 – 2070 period exhibits a slight increase except for summer. In summers up to 35% precipitation loss is anticipated, yet, particularly in spring, an increase up to 16% is expected. During

2071 – 2099 precipitation decrease in summer and fall, and increase in winter and spring, less than 8%, are foreseen.

Regarding the B1 emissions scenario, the model results give no temperature change except a temperature decrease of 1°C in spring in the 2010 – 2039 period. Spring continues to be slightly colder during 2040 – 2069 but a rise up to 2°C (highest in winter) is projected for the same period. During 2070 – 2099 the temperature rise is sharp, 1°C – 3.5°C, lowest in spring and highest in fall. The model foresees a general rise in precipitation during the 21st century, between 0 to 1 mm/day, which is expected to be the highest during 2010 – 2039.

HadAMP3 A2 focuses on the 2071 – 2100 period. The forecast is a 5°C rise in the mean temperatures. For winter and summer, the expected increase is 4°C and 7°C, respectively. Decrease in annual total precipitation for 2071 – 2100 is 200 mm. The projected decrease in winter is up to 10 mm/a, whereas for summer, almost no change is expected. HadAMP3 provides estimations for snow cover and annual precipitation – evaporation difference. Snow cover in 2071 – 2100 is estimated to decrease up to 30 mm and precipitation – evaporation difference is expected to develop 20 to 30 mm/month towards evaporation.

Figures below provide a summary of the results of the models for scenarios A2 and B1.

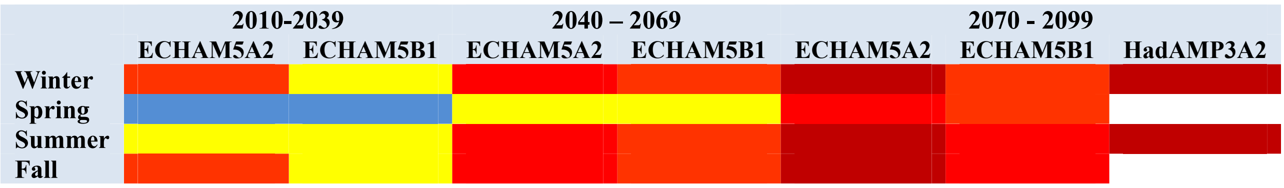


Figure 7.1 Summary of Regional Model Results for Temperature Change in Ankara (blue represents “decrease”, yellow represents “no or slight change”, and red represents “increase”)

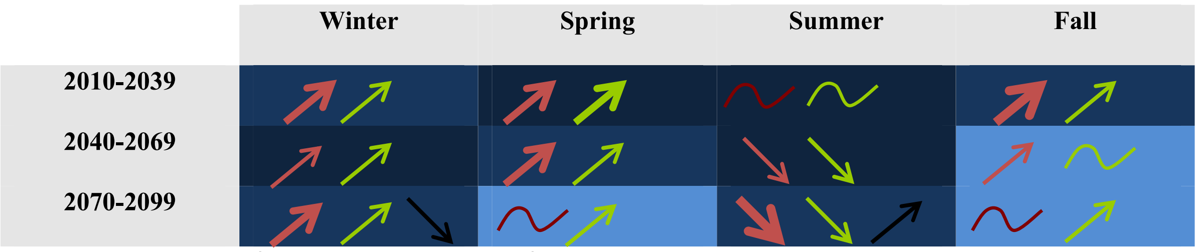


Figure 7.2 Summary of Regional Model Results for Precipitation Change in Ankara (red represents ECHAM5 A2, green represents ECHAM5 B1, black represents HadAMP3 A2)

Referring to the PRUDENCE project, the results (please refer to Appendix G) are presented in Table 7.4 and Table 7.5. The results contain changes in Annual, SUMMER (April – September), WINTER (October – March), DJF (December – January – February), MAM (March – April – May), JJA (June – July – August) and SON (September – October – November) temperatures for the 21st century based on 1971 – 2000. The results indicate a significant temperature rise after 2011 which reaches dramatic levels at the end of the 21st century. Summer temperature is expected to rise more than winter period and annual temperature. JJA is the period with the highest increase, which may result in more evaporation. SON temperature also deserves attention according to the projected results.

Table 7.4 Results of PRUDENCE Project for Temperature Change (^oC)

	Model	2011 – 2040	2036 – 2065	2071 - 2100
Annual Temperature	CNRM-ARPEGE	1.5	2.5	4
	ICTP-RegCM3	1	2.5	4
	MPI-REMO	1.5	2	4
SUMMER Temperature	CNRM-ARPEGE	2	2.5	4 – 4.5
	ICTP-RegCM3	1.5	2.5	4
	MPI-REMO	1	2 – 2.5	4 – 4.5
WINTER Temperature	CNRM-ARPEGE	1	2 – 2.5	2.5 – 3
	ICTP-RegCM3	1	1.5 – 2	3.5
	MPI-REMO	1.5	2	4

Table 7.5 Comparison of Results of Regional Models and PRUDENCE Project (^oC)

	Model	2011 – 2040	2036 – 2065	2071 - 2100
DJF Temperature	CNRM-ARPEGE	0 - 1	2	2 – 2.5
	ICTP-RegCM3	0.5	2	3.5
	MPI-REMO	1.5	2 – 2.5	4
	ECHAM5 A2	0.4	1	3
	ECHAM 5 B1	0	2	3
	HadAMP3 A2	-	-	4
MAM Temperature	CNRM-ARPEGE	1.5 – 2	2.5	3 – 4
	ICTP-RegCM3	1	2	3.5
	MPI-REMO	0 – 1	2.5	3.5
	ECHAM5 A2	-0.4 - -0.8	0.4	0.8 – 1.5
	ECHAM 5 B1	-1	0 – 1	1 - 2
JJA Temperature	CNRM-ARPEGE	2.5	3 – 3.5	5
	ICTP-RegCM3	1 – 1.5	2 – 2.5	4.5 - 5
	MPI-REMO	1.5	2.5 – 3	4.5 – 5
	ECHAM5 A2	-0.4 – 0.4	1 – 2	3 - 4
	ECHAM 5 B1	0 – 1	1.5	2.5
	HadAMP3 A2	-	-	7
SON Temperature	CNRM-ARPEGE	1.5	2 – 2.5	3.5
	ICTP-RegCM3	1.5	2	4
	MPI-REMO	2	2.5	4.5
	ECHAM5 A2	0.8	1.5	3
	ECHAM 5 B1	0 – 1	2	2 - 3

As observed from Figure 7.1, three models indicate a general increasing trend in temperature with differences in seasons. However, they do not agree in the degree of rise. The HadAMP3 A2 forecasts the highest increase. ECHAM5 A2 also predicts more increase in temperature than ECHAM5 B1. The highest rise is expected in the last period of the 21st century. In all seasons, spring is expected to exhibit the lowest temperature difference. It is observed that the PRUDENCE group also predicts more temperature increase than ECHAM5 RegCM3. The second may be more reliable as it was run on regional level for Turkey. As shown in Figure 7.2, for the 21st century according to ECHAM5 model results winter and spring precipitation are expected to rise with varying intensities, whereas there is decrease in summer. HadAMP3 opposes this rising trend for the last 30 years of the 21st century. For fall, ECHAM5 A2 and B1 scenarios indicate precipitation increase between 2010 and 2039 but fail to reach an agreement for the later periods. In brief, the three sets of models fail to reach an acceptable agreement, which emphasises the need for more or better model runs for the country.

If the model runs compiled by IPCC (URL 5) are regarded, as indicated in Part 2.2, there is also no agreement on the future changes in precipitation. As shown above, the regional runs predict a general increase for Ankara but IPCC projects the opposite. This situation increases uncertainty in climate change and has to be taken into account.

7.3. Results of Data Analysis

7.3.1 Water Use in Ankara

Information about the dam volumes, amount of inflow and outflow of water are used in this section. As seen from Table 7.1, the longest data sets belong to Çubuk I and II, and Bayındır dams from 1972 till 2010 and the shortest are concerning Kavşakkaya and Kesikköprü dams. As observed from Figure 7.3, the volume held in dams increases as new dams are put into service. In 1972 Bayındır Dam, in 1973 Kurtboğazı Dam, in 1987 Çamlıdere Dam, in 1989 Asartepe Dam, in 2007 Kavşakkaya Dam, and in 2008 Kesikköprü Dam were put into service. With sharp rises, fluctuations in volumes are observed. This can be attributed to the difference between amount of inflow to the dams and total water use shown on Figure 7.4. Till 1987, the difference is almost equal to zero, in other words, the whole amount of water coming to the reservoirs is consumed. Starting from 1987, there are clear differences between the incoming and outgoing volumes. When water use is higher than the influent, e.g. 1989 – 1993, 2000, 2003 – 2007, it is seen that average dam volumes are decreasing. The decrease in the amount of influent coincides with the dry periods such as mid-late 1980, early 1990s, and 1999/2000 discussed in Part 2.2. This would indicate a connection between precipitation and the amount of water entering to the reservoirs. However, it is not possible to prove any such relationship in this study as discussed in Part 7.3.2. The dramatic decrease after 2005 is also striking. The reason for this reduction is the severe drought, especially experienced during 2007 – 2008.

The dramatic rise on Figure 7.4 is because of inclusion of Kesikköprü Dam in 2008. The main purpose of Kesikköprü Dam is energy production (Table 6.2). The huge amount it receives from Kızılırmak is used to produce energy. As explained above, it is observed that till 1987 the inflow is almost enough to meet water demand. After 1987, fluctuations are seen in the amount of incoming water, which has impacts on availability of water. This indicates the need for careful management of surface waters.

Figure 7.5 shows the water use according to sectors and loss due to flood control and evaporation. Here water use for energy production is not included since it only has data for 3 years starting in 2008. Figure 7.6 provides information for energy production. If this figure is compared with the later ones, it can be observed that water use for energy production is the highest in all seasons among sectors after 2007. On the other hand, Figure 7.7 shows that between 1972 and 2010 water is mainly used for drinking purposes including industrial water use. Later follows energy sector. The figure enables us to observe the high amount of loss of water due to flood control. It is even higher than drinking water in

1981. As the volume of reservoirs is increased, the loss due to excessive inflow decreases. This draws attention to importance of storage capacity. Considering the changes in precipitation time, type and intensity, and early timing of peak flows due to climate change, which are discussed in Part 2, storage capacity of a water supply system becomes crucial to hold such possible shock loads for availability of water. One other important issue is the sharp rise of irrigation use in 2007 and 2008. These were years of severe drought and water managers had to provide water for agriculture. It is stated in Part 5.4.1 that 85% of the agricultural land is rain fed. Therefore, it is clear that under lack of precipitation, water for irrigation becomes an important matter.

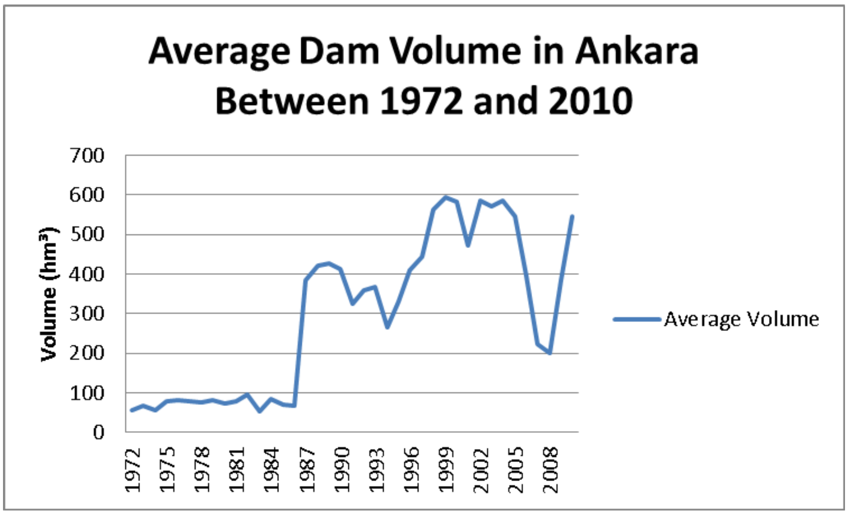


Figure 7.3 Average Dam Volume in Ankara between 1972 and 2010

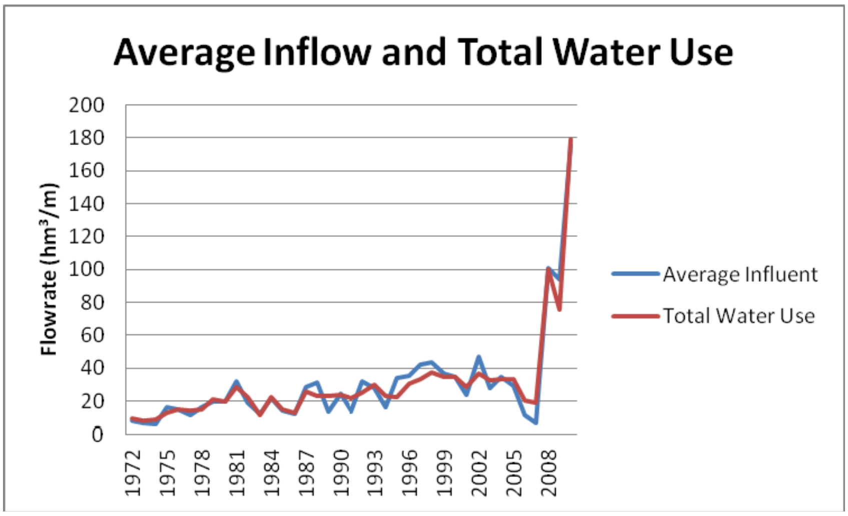


Figure 7.4 Average Inflow to Dams and Average Total Water Use in Ankara between 1972 and 2010

Figure 7.7 presents the distribution of total water use from 1972 till 2010. Drinking water use has the highest share with 53%. The second rank belongs to energy sector, 23%, which appears first in 2008 with the allocation of Kesikköprü Dam. The share of water released for flood control is 14%, whereas irrigation and loss due to evaporation are 5% each. Therefore, it is apparent that the main concern for water managers in Ankara is to supply drinking water to the city, which is definitely different than the average use of water for the whole country, discussed in Part 3.2.

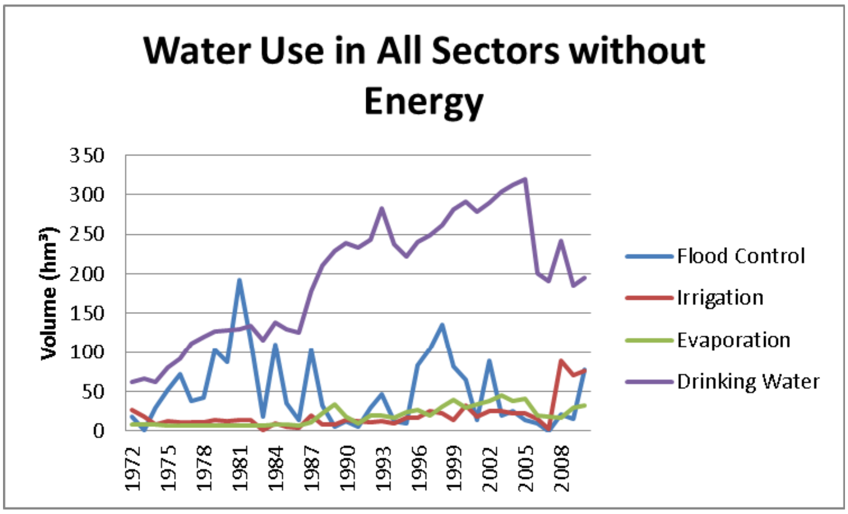


Figure 7.5 Water Use in All Sectors without Energy

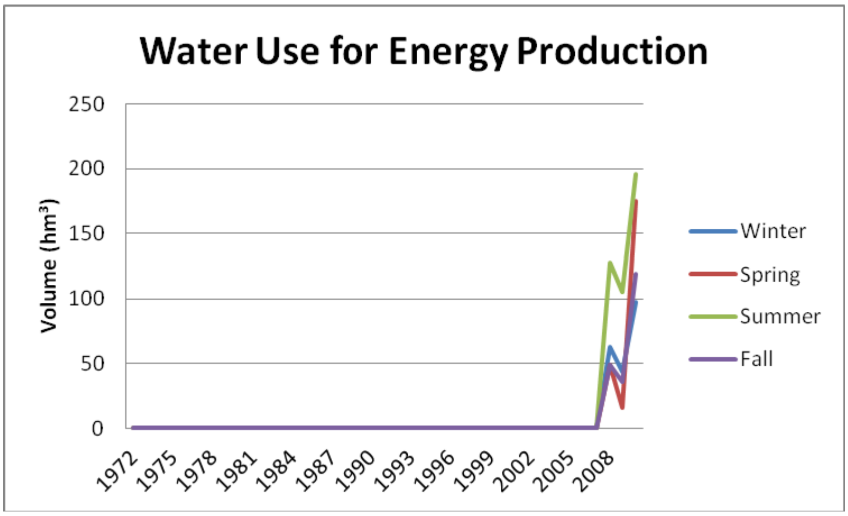


Figure 7.6 Water Use for Energy Production in All Seasons

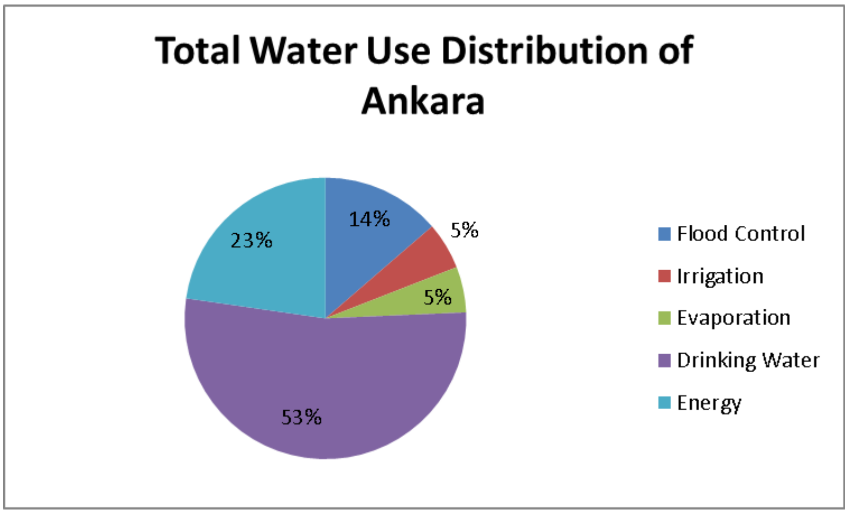


Figure 7.7 Distribution of Total Water Use in Ankara between 1972 and 2010

Figures 7.8 to 7.16 give information about the situation at the dams and water use of Ankara. Water volumes are generally lowest in winter seasons and highest in summers. This is because; the wet period feeds the dams, the effect of which is observed in summers although the amount of inflow to the reservoirs is almost zero in this season. In other words, there is a contribution of inflow during winter and spring, resulting in the highest volume in summer. Figure 7.8 shows the amount of inflow and total water use in winter. As expected, the water incoming to the dams is more than the water leaving. Figure 7.9 depicts winter water loss in all sectors. Except for 1974 and 1979, drinking water use is the highest. Water use for irrigation and loss due to evaporation are all zero except for 2005 - this could be a recording error.

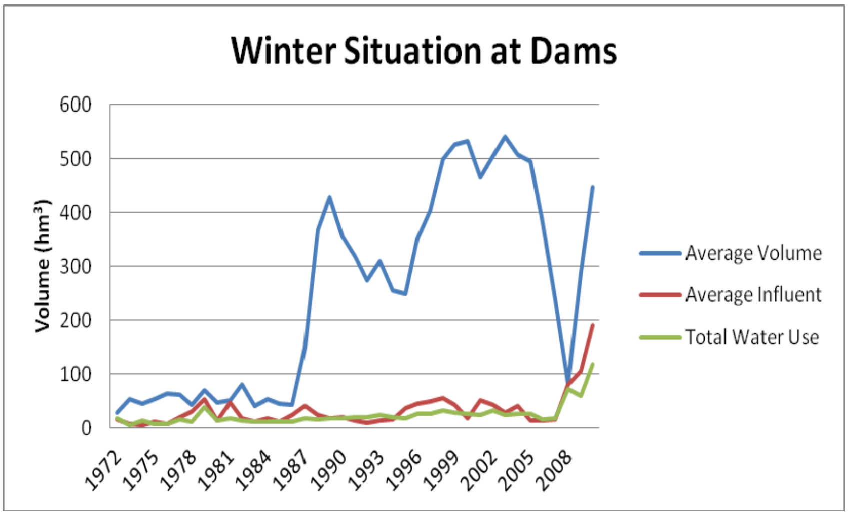


Figure 7.8 Situation at Dams in Winter

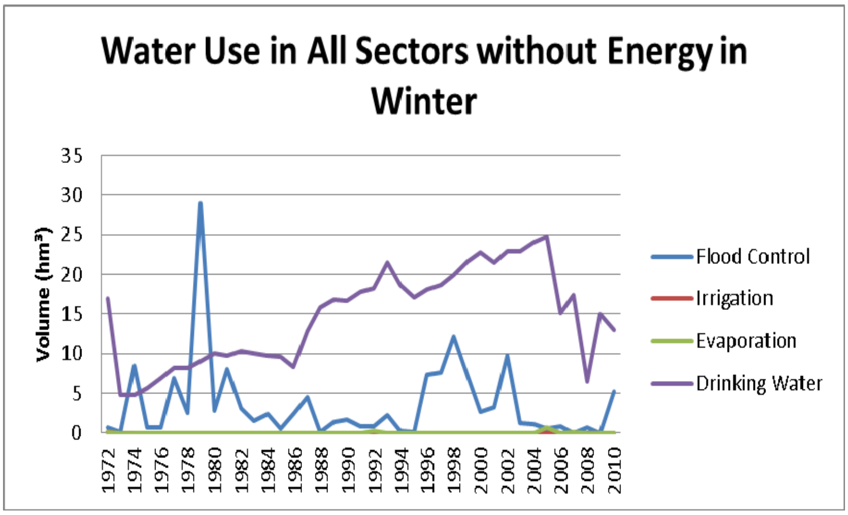


Figure 7.9 Water Use in All Sectors without Energy in Winter

Figure 7.10 provides information about the situation at dams in spring. As in winter, the amount of inflow is higher than the total water use in all years except for 2007 and 2008. Figure 7.8 and Figure 7.10 show once more the importance of surface runoff in winter and spring for the availability of water in Ankara. Figure 7.11 gives information about water use in all sectors in spring. Unlike in winter, water loss due to flood control is higher than drinking water use till 1987, the year in which Çamlıdere Dam was put into service. Nevertheless, the amount of water lost due to shock loads is still high. This again indicates the need for more storage capacity, especially in spring. Figure 7.12 supports this issue. It is clearly shown that the water loss due to flood control is the highest in spring. As discussed above, storage capacity would become a major issue during the 21st century with climate change impacts on precipitation.

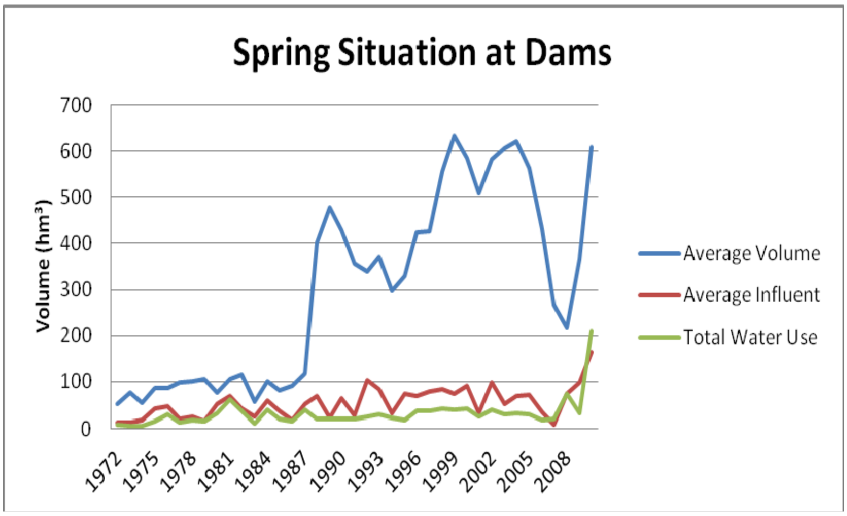


Figure 7.10 Situation at Dams in Spring

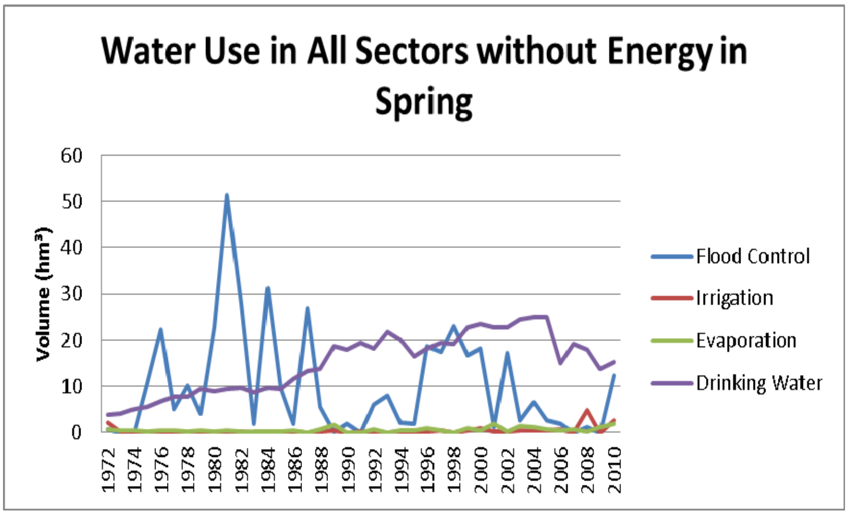


Figure 7.11 Water Use in All Sectors without Energy in Spring

Figure 7.13 illustrates summer situation at dams. The volume held in the reservoirs is the highest, as mentioned above. It is no surprise that total water use is higher than the amount of inflow in summer. Figure 7.14 shows water use in sectors in summer. Drinking water use has the highest share in all sectors except in 2008 – 2010. Here irrigation is the sector that consumed the most of the water stored, which indicates that during drought periods decision on priority of water demand could be a challenge. If we keep in mind that the amount for drinking water also comprises the use by industry, the importance of the problem gets clearer. Water managers may have to decide on priority among households, agriculture and industry. Evaporation is also high during summers. In some years it is more than the amount used for irrigation. With the increase in temperature, more water is expected to evaporate in the future. Hence, water managers have to consider this deficiency-creating factor more in their supply plans. Finally, it is also necessary to note that there is considerable amount of water lost due to flood control, although there is almost no precipitation, as discussed in Part 7.3.2. This can be attributed to snow melt, shifts in wet period or storm events.

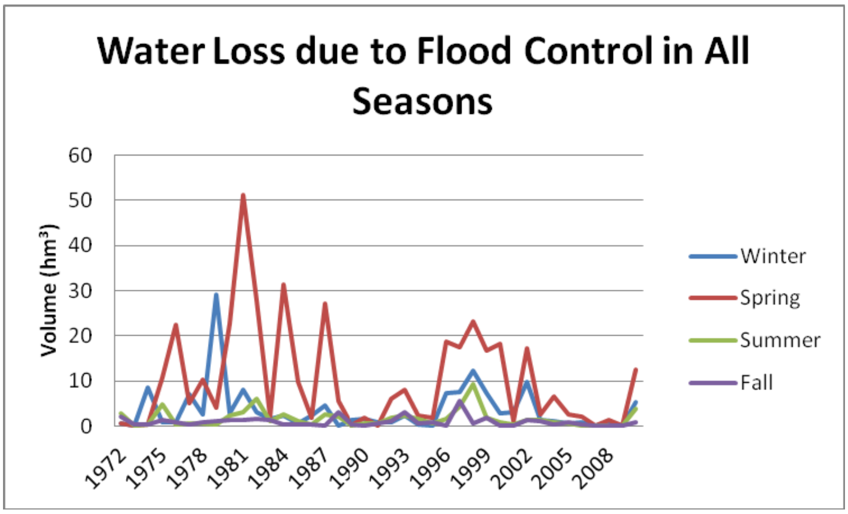


Figure 7.12 Water Loss due to Flood Control in All Seasons

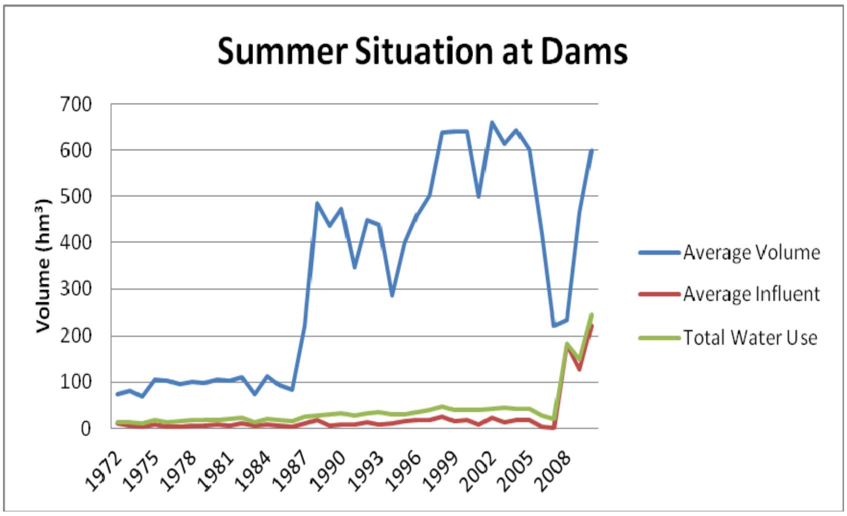


Figure 7.13 Situation at Dams in Summer

Figure 7.15 gives information about the situation at dams in fall. As in summer, total water use is higher than the amount of inflow. Figure 7.16 depicts water use according to sectors. Again in fall, water used for drinking purposes is the highest. This, in fact, is the only sector that water managers need to care about in this season. As in summer, evaporation in fall is quite high, especially since 1990.

Figure 7.17 compares drinking water use in all seasons. As mentioned above, in general drinking water use is highest in summer. Along with high temperatures, the industrial water needs may be another factor increasing the demand in summer. Due to lack of data, it is not investigated in this study, however, careful observation is deemed necessary for a better water management. Such information could also be useful for demand-side management. In some periods, fall drinking water use is more than or almost equal to summer, possibly because of the end of the holiday season. Residents and university students returning to Ankara after summer vacation could be the main factor causing the rise of water demand.

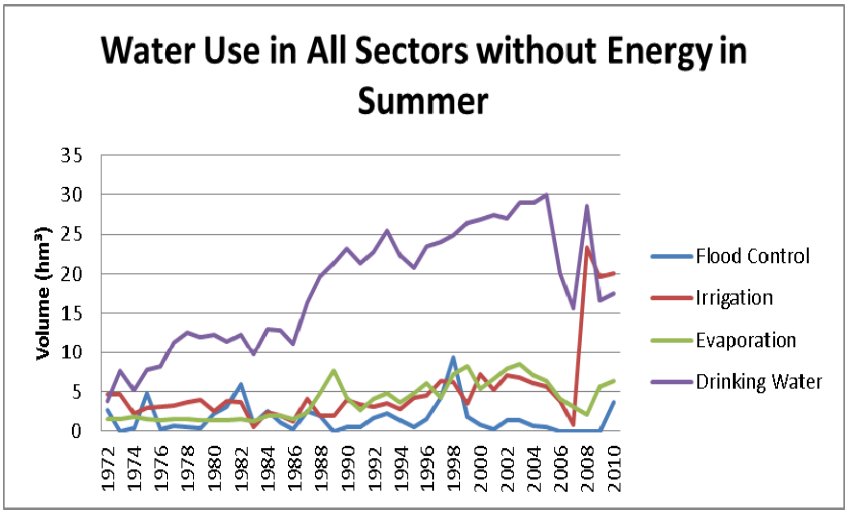


Figure 7.14 Water Use in All Sectors without Energy in Summer

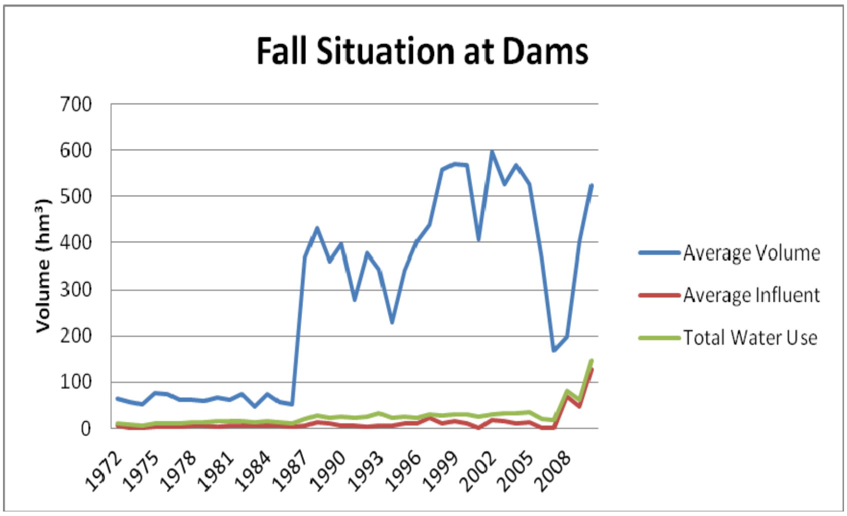


Figure 7.15 Situation at Dams in Fall

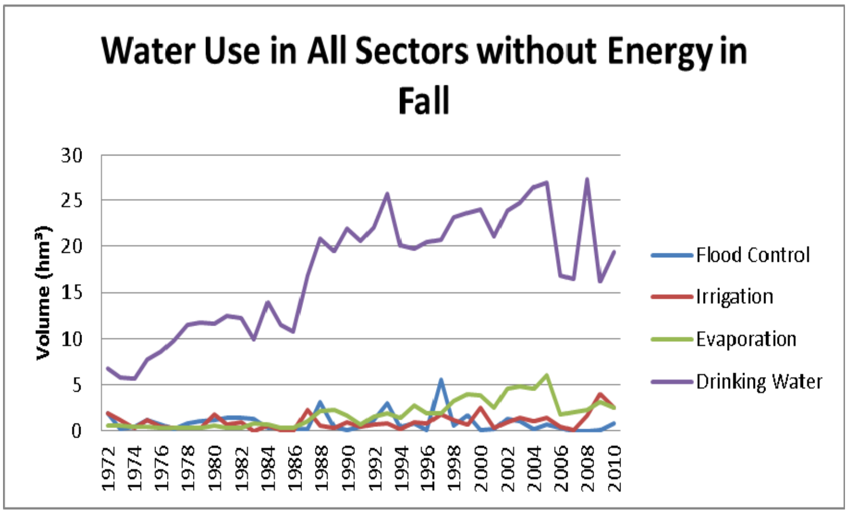


Figure 7.16 Water Use in All Sectors without Energy in Fall

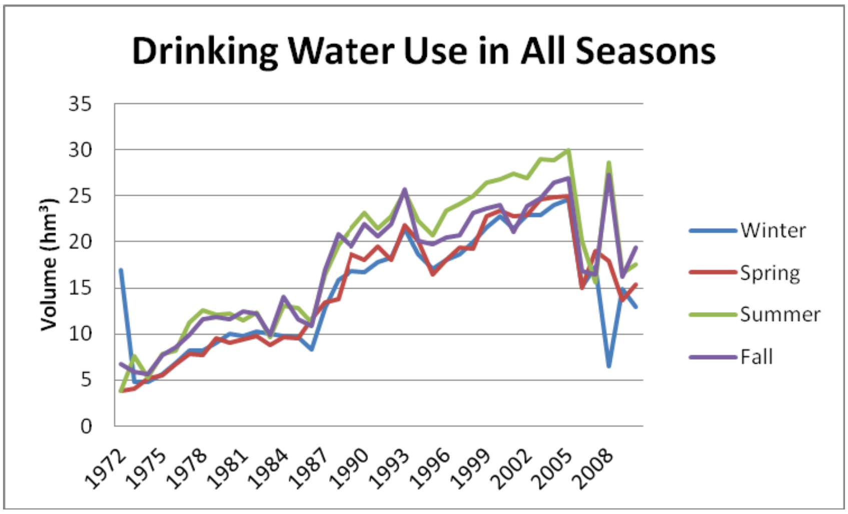


Figure 7.17 Drinking Water Use in All Seasons

To sum up, since 2008 water consumption for energy production has been the most important sector. On the other hand, total water used for drinking purposes is the highest among sectors between 1972 and 2010. It comprises more than 50% of the total water volume leaving the reservoirs. Like energy production, drinking water reaches its maximum in summer. The amount of water wasted for flood control is generally the highest in spring, however, with a decreasing trend. This may be because of the increased capacity of the reservoirs. As expected, irrigation water use reaches its highest level in summer. Even after 2008, it is more than drinking water. This shows that the water managers gave the priority to agriculture during drought periods, which indicates that the two sectors may be competitive in the coming years in case of drought. It should be noted that drinking water use includes industrial demand, which aggravates the issue. Water managers should consider this problem in their plans. Finally, observation of evaporation during summer and fall reveals an increasing trend, in agreement with the temperature increase discussed in Part 2 and below. It is no surprise that evaporation is highest in summer. The loss of water through evaporation may become more serious in the future with the expected rise in temperature and a possible decrease in precipitation.

7.3.2 Analysis of Meteorological Data

As stated above, the aim of the data analysis in this part is to test homogeneity among meteorological data in order to see whether there is a spatially uniform temperature development. Therefore, for every station monthly temperature and precipitation values as averages over all years and monthly anomalies for each log were calculated. Average values show a wet period from October till May. Using temperature and precipitation anomalies, a correlation analysis was conducted among stations in pairs, which resulted in 5 groups of stations that have similar precipitation patterns. For each group, a station providing good correlation ($R^2 \geq 0.5$) with others was determined. Finally, values of E-OBS are compared with the real data of DMİ.

To inspect homogeneity temperature logs are compared in pairs. It is observed from the correlation analysis that temperature shows a homogeneous distribution over the land covered by this study. The Figure 7.18 gives some examples of this analysis. The samples chosen are from the four corners of the area depicted in Appendix F. As seen all the correlation factors (R^2) are greater than 0.5, therefore, it is concluded that temperature change is uniform and increasing throughout the region. The observed increase is in agreement with the discussion in Part 2.2.

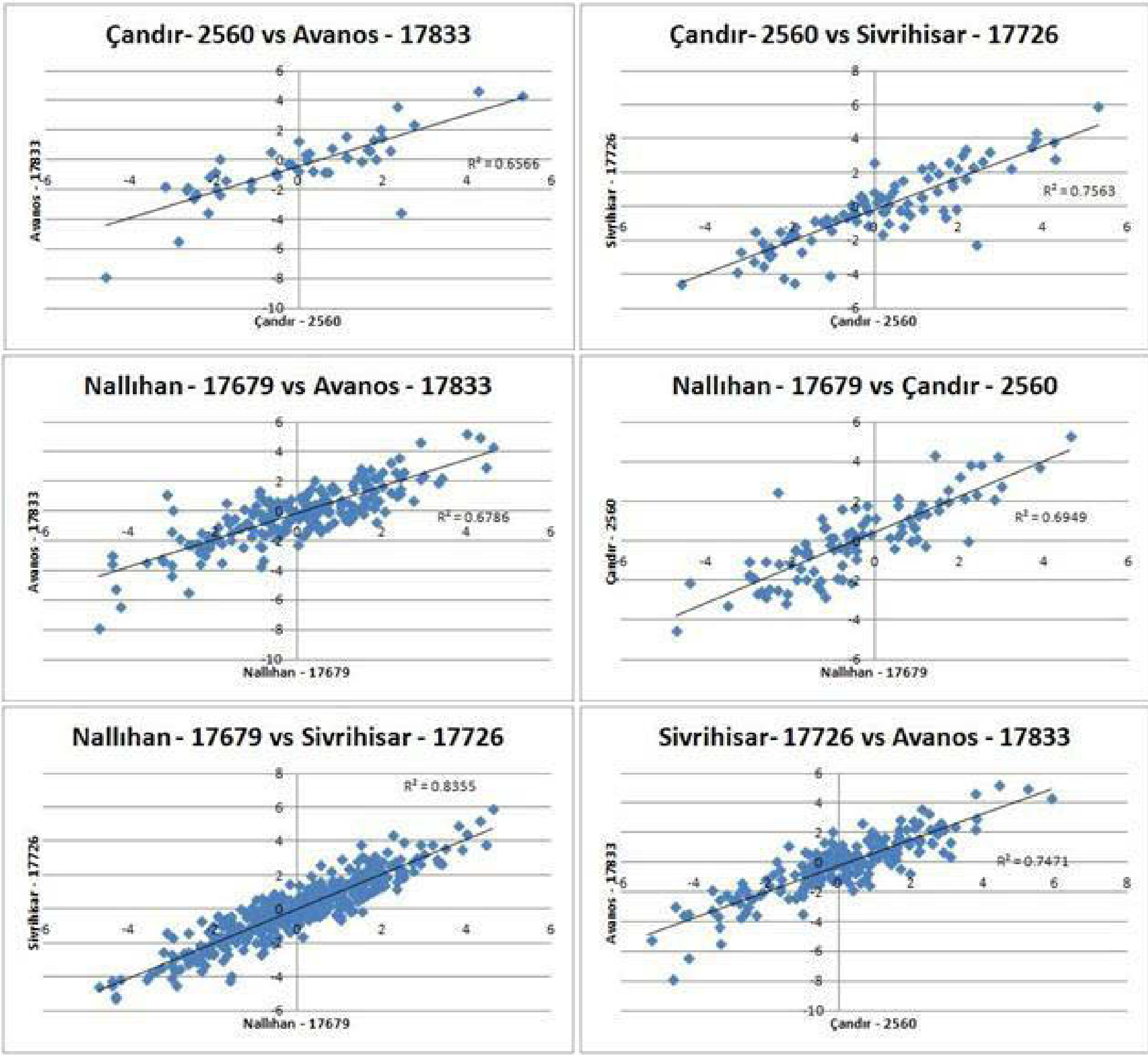


Figure 7.18 Results of Correlation Analysis for Temperature among Meteorological Stations

Precipitation was analysed in the same manner. Unlike the uniform behaviour of temperature, precipitation analysis provided 5 sub-regions of the study area with different precipitation patterns. In each group a station which gives good correlation with others was determined. These 5 stations are Beypazarı (17680), Kalecik (3011), Kaman (17756), Polatlı (17728), and Gülşehir (5335). The Figures from 7.19 to 7.32 provide information about these stations as representatives. Each displays mean temperature and precipitation, precipitation anomalies, and contribution of wet season to the precipitation total. Figure 7.33 shows the location of these stations and the 5 groups of sub-regions.

Figure 7.19 shows monthly mean temperature and precipitation values for Beypazarı. As seen, precipitation has higher values between October and May, whereas temperature is higher out of this range. Therefore, the north-western climate regime is like a Mediterranean climate with wet winters. Mean temperature in summer and mean precipitation in wet season reaches 25^{o}C and 55 mm, respectively. Figure 7.20 gives information about monthly precipitation anomaly of Beypazarı. There is no clear trend in change of precipitation. The anomalies follow the wet and dry conditions again mentioned in Part 2.2. It is possible to say that storm events are frequent in north-western region by observing the jumps on Figure 7.20. On Figure 7.21 one can examine the contribution of wet season to total precipitation. On average the share of wet season is 72% and with fluctuations raging between 55% (1983) to over 90% (2009), showing a predictable pattern.

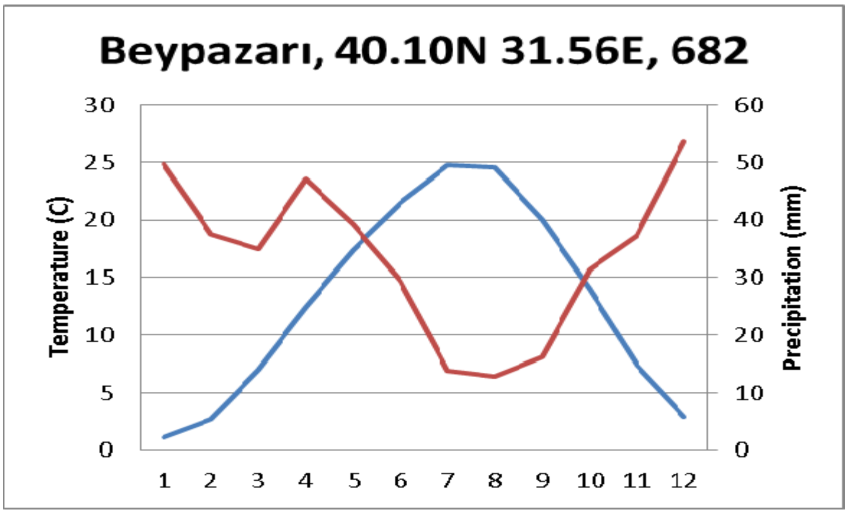


Figure 7.19 Monthly Mean Temperature (blue) and Precipitation (red) Values of Beypazarı

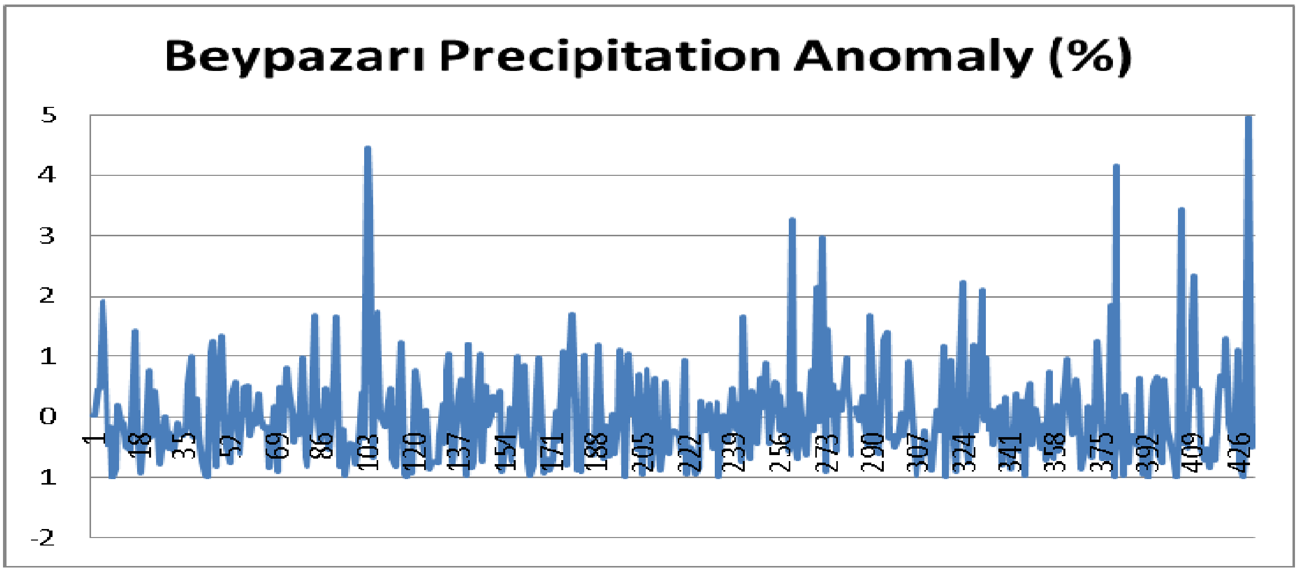


Figure 7.20 Monthly Precipitation Anomaly of Beypazarı as Percentage between 1975 and 2010

Figure 7.22 provides information about mean monthly temperature and precipitation values of Kalecik, representing the central and eastern parts of the study area. Here a Mediterranean-like climate with wet winters prevails with average summer temperature less than 25°C and average precipitation as high as 60 mm during wet season. Figure 7.23 gives information about the precipitation anomalies in Kalecik. The figure also does not provide a trend for change in precipitation. As no high jumps are seen on the graph, it can be concluded that the precipitation in central and eastern regions was uniform throughout the log period (1983 – 2002). On Figure 7.24 one can observe the contribution of wet season in total precipitation for Kalecik. It is possible to conclude that precipitation exhibited shifts in seasons during the record period.

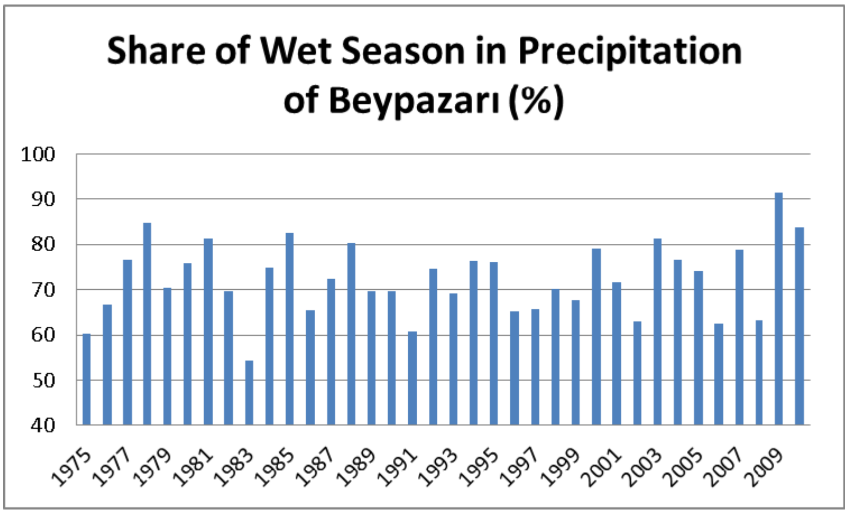


Figure 7.21 Share of Wet Season in Total Precipitation of Beypazarı as Percentage

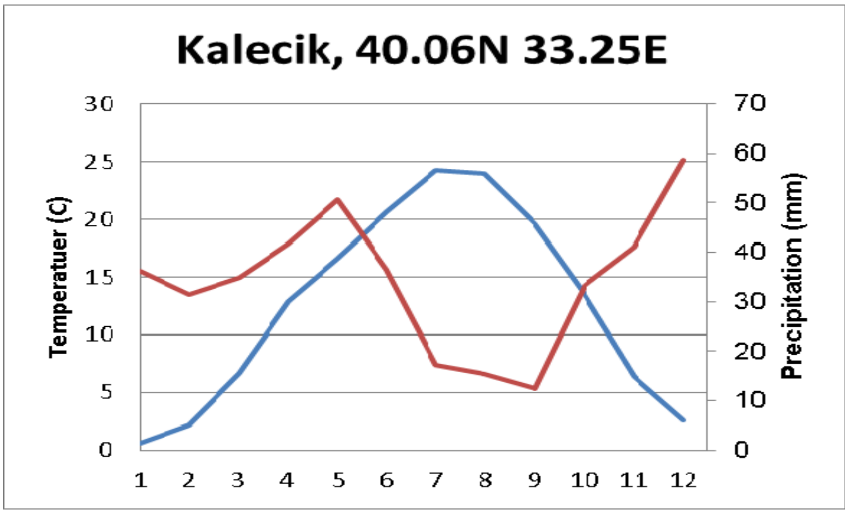


Figure 7.22 Monthly Mean Temperature (blue) and Precipitation (red) Values of Kalecik

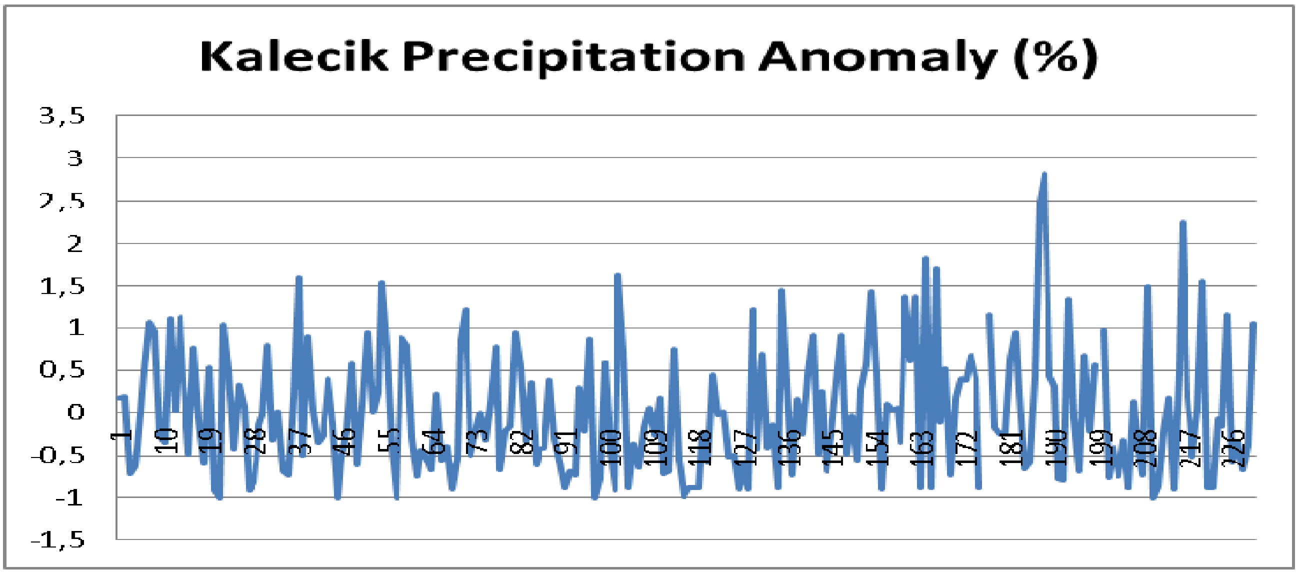


Figure 7.23 Monthly Precipitation Anomaly of Kalecik as Percentage between 1983 and 2002

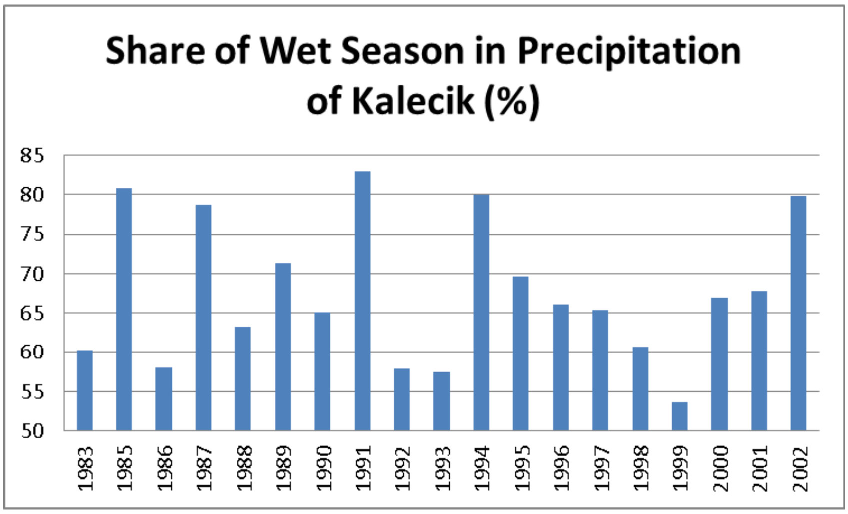


Figure 7.24 Share of Wet Season in Total Precipitation of Kalecik as Percentage

Figure 7.25 shows monthly mean temperature and precipitation values for Polatlı representing the south-western part of the study area. As in other regions, the climate is dominated by a Mediterranean-like regime with wet winters. Mean summer temperature is less than (< 25^{o}C) both Beypazarı and Kalecik. The main difference from the above mentioned groups is that the highest value of precipitation, which is about 45 mm, is observed in spring rather than in winter. Figure 7.26 presents precipitation change in Polatlı, south-western part of the study area. The first impression is the high frequency of recurring excess rain events. Therefore, it is possible to conclude that the amount of precipitation was not uniform between 1975 and 2010. Moreover, there is not any significant change in precipitation in Polatlı like other stations. The contribution of wet season to total precipitation is provided by Figure 7.27. As mentioned above, it is also possible to observe wet and dry periods, discussed in Part 2.2, in Polatlı. After 2000, the difference between subsequent years, i.e. degree of fluctuation, is becoming larger. This indicates a clear shift in wet season for south-western region of the study area.

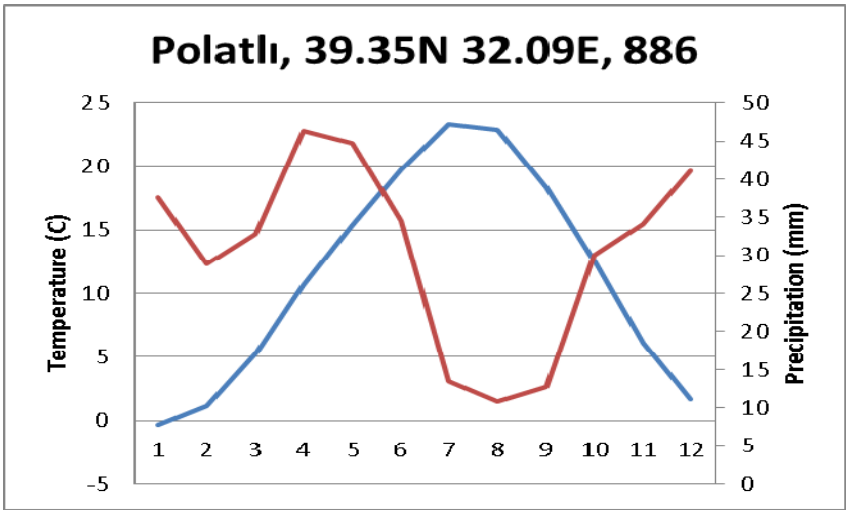


Figure 7.25 Monthly Mean Temperature (blue) and Precipitation Values (red) of Polatlı

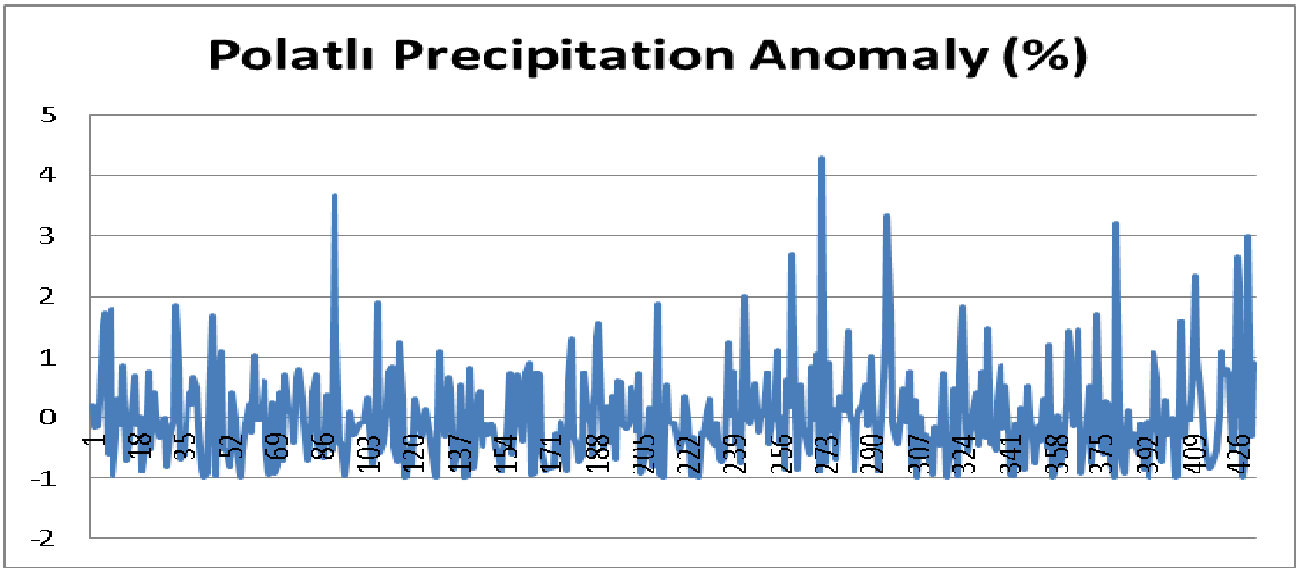


Figure 7.26 Monthly Precipitation Anomaly of Polatlı as Percentage between 1975 and 2010

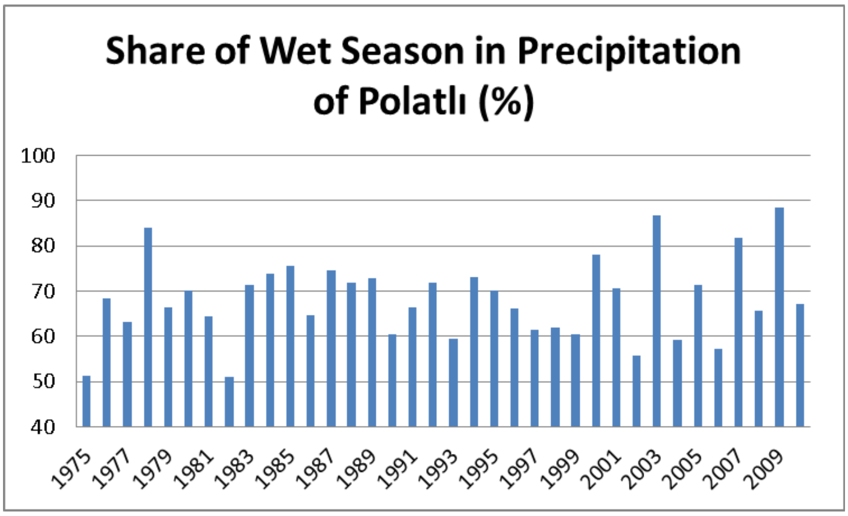


Figure 7.27 Share of Wet Season in Total Precipitation of Polatlı as Percentage

In Figure 7.28 monthly mean temperature and precipitation values are depicted for Kaman, representing south part of study area. Again a Mediterranean-like climate with wet winters is observed. It has the smallest mean summer temperature (~20^{o}C) among others. The major difference of Kaman and other stations is the large area between summer temperature and summer precipitation on Figure 7.28. This indicates a larger precipitation – evaporation gap. Figure 7.29 gives information about the precipitation anomaly of Kaman. It is possible to say that storm events with decreasing intensity are getting more frequent after 2000. Figure 7.30 provides information about the share of the wet season in total precipitation of Kaman. The impact of observation mentioned for Figure 7.28 is visible here. As the summer precipitation remained less than the other stations, the contribution of wet season to total precipitation (76.6%) is clearer and higher for Karaman. Thus, it is possible to conclude that precipitation has changed less compared to other sub-regions mentioned above.

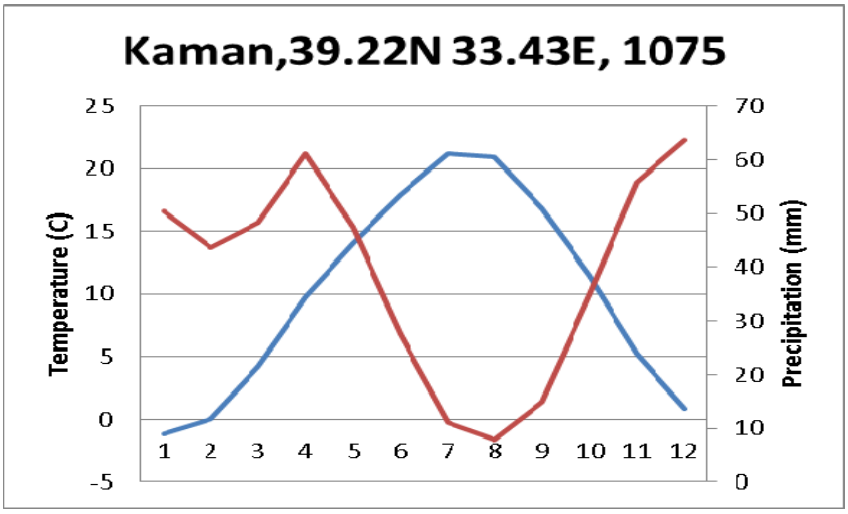


Figure 7.28 Monthly Mean Temperature (blue) and Precipitation (red) Values of Kaman

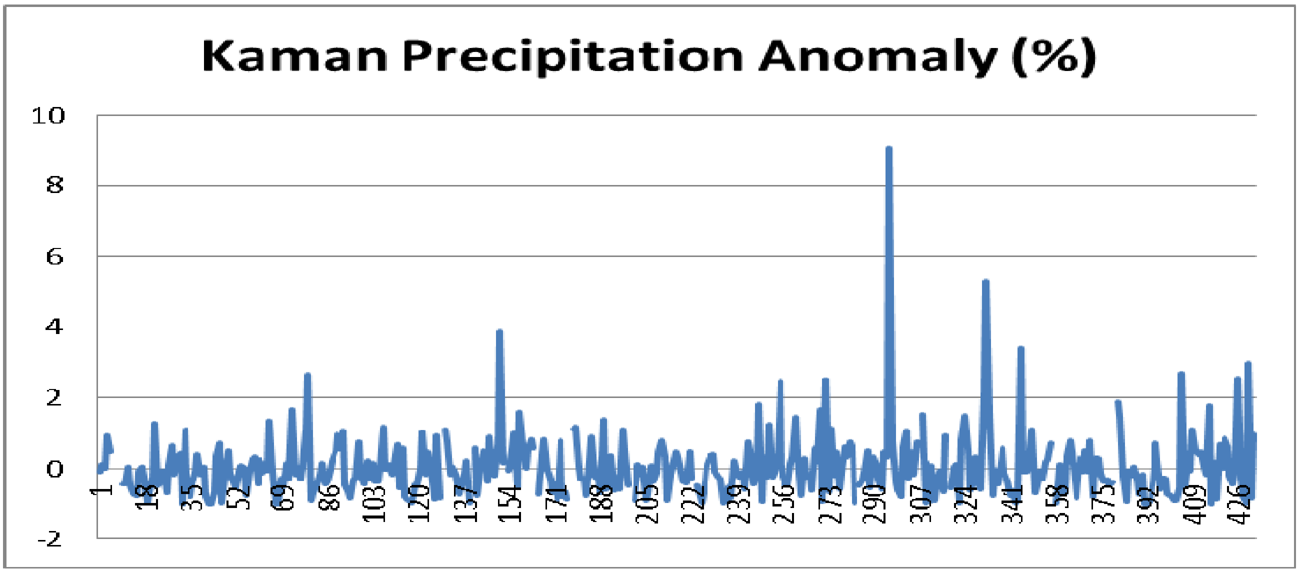


Figure 7.29 Monthly Precipitation Anomaly of Kaman as Percentage between 1975 and 2010

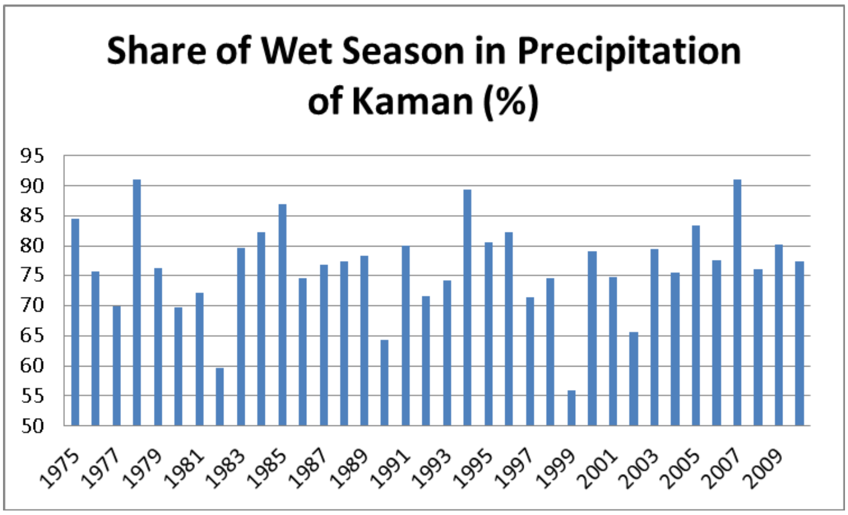


Figure 7.30 Share of Wet Season in Total Precipitation of Kaman as Percentage

Figure 7.31 depicts monthly mean values for precipitation and temperature of Gülşehir which represents the south-eastern region of the area of interest. A Mediterranean-like climate with wet winters prevails over the region as in all other sub-regions. The mean summer temperature reaches 25^{o}C. Like Polatlı, the maximum amount of precipitation of Gülşehir is in spring and is up to 60 mm. From Figure 7.32, it is possible to discern more positive values than negative ones for precipitation change. This is not enough to draw any conclusion about the behaviour of precipitation in south-eastern region of the study area.

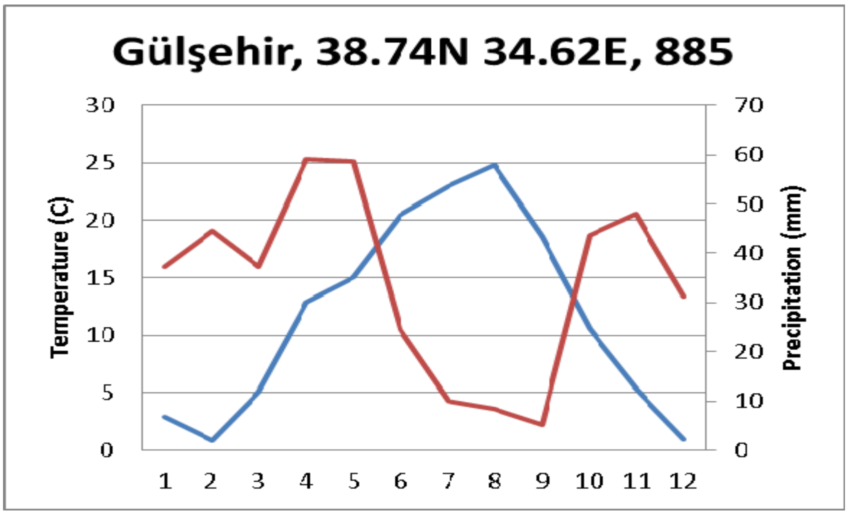


Figure 7.31 Monthly Mean Temperature (blue) and Precipitation (red) Values of Gülşehir

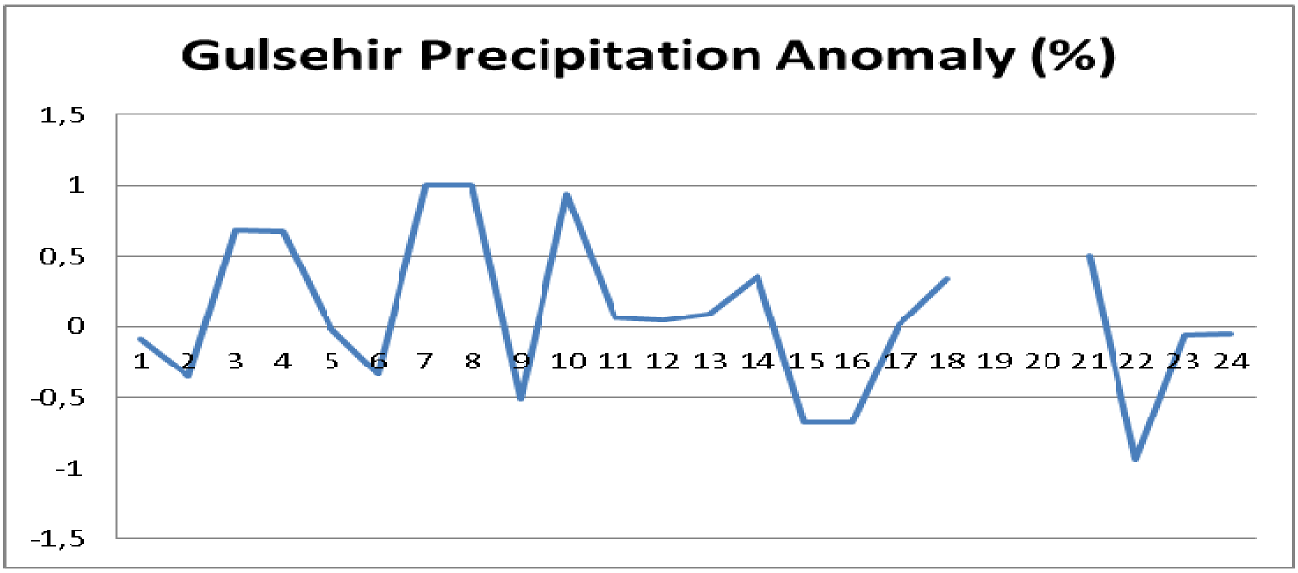


Figure 7.32 Monthly Precipitation Anomaly of Gülşehir as Percentage between 1985 and 1986

The location of these stations and the 5 groups of sub-regions can be seen in Figure 7.33. As the above figures depict, all stations exhibit a Mediterranean-like climate regime with wet winters. Temperatures reach the highest values in summer and coldest in winter, whereas precipitation has the minimum values in summer. Considering the monthly anomalies, it is not possible to comment on the behaviour of the precipitation whether there is a decrease or increase. The contribution of wet season to total precipitation each year gives an idea about the importance and variability of this period. On average, the share of precipitation between October and April is 72% for Beypazarı, 67.7% for Kalecik, 68.6% for Polatlı, and 76.6% for Kaman.

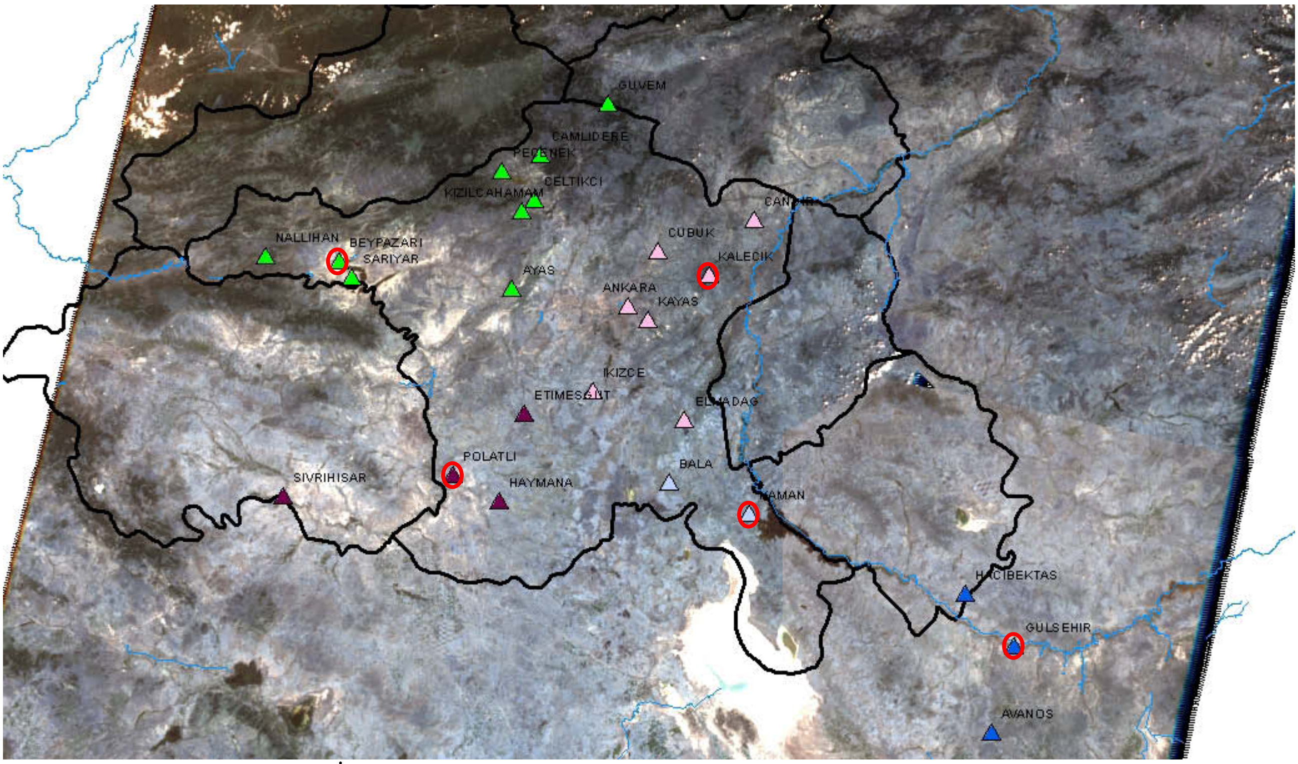


Figure 7.33 Distribution of DMİ Station Groups

The contribution of wet period in north-western region (Beypazarı) is less non-uniform compared to other regions. Here the correlation between input of precipitation and availability of water in the dams may be more predictable. Storm events are observed frequently here. Considering the contribution of the wet period, it can be concluded that an important amount of water is wasted for flood control due to lack of storage capacity, as discussed in Part 7.3.1. Regarding precipitation anomalies, Kalecik (central and eastern regions) has a more uniform precipitation distribution but wet period exhibits more variability. Therefore, the contribution of the wet season to water storage may not be as high as in northern parts. In south-western parts (Polatlı) the mean maximum precipitation is lowest (45 mm/month) with a minimum in spring. Storm events are more frequent in this region than in north-western parts. As discussed in 7.3.3, the contribution of precipitation to water storage is expected to be a minimum in south-western regions. Spring precipitation is expected to be lost through evapotranspiration. Also, fluctuation in the wet period of Polatlı is clearer after 2000. Among the regions the south (Kaman) exhibits the lowest summer mean temperature (~20^{o}C) and precipitation. The area between these values on Figure 7.28 is the largest among all similar graphs. This means the largest evaporation – precipitation difference. As in south-western regions, there are more frequent storm events with decreasing intensity after 2000. However, the most uniform wet period distribution (76.6% on average) is observed in the south, which has the smoothest precipitation pattern among all regions. Therefore, precipitation in south might have made the highest contribution to surface runoff, however, this study is unable to provide proof for such a relationship. The reasons behind this subject are discussed in Part 7.3.3. As in the case of Polatlı, the region represented by Gülşehir (south-eastern) has the highest precipitation, reaching 60 mm in spring. Yet, this amount is expected to be mainly consumed by vegetation. To conclude, considering the dam locations (Figure 6.1) the larger portion of water supplied to Ankara's water system may be provided by northern and central precipitation during fall and winter. Detailed investigation of the hydrological system here could supply the necessary information for the measures to cope with climate change impacts.

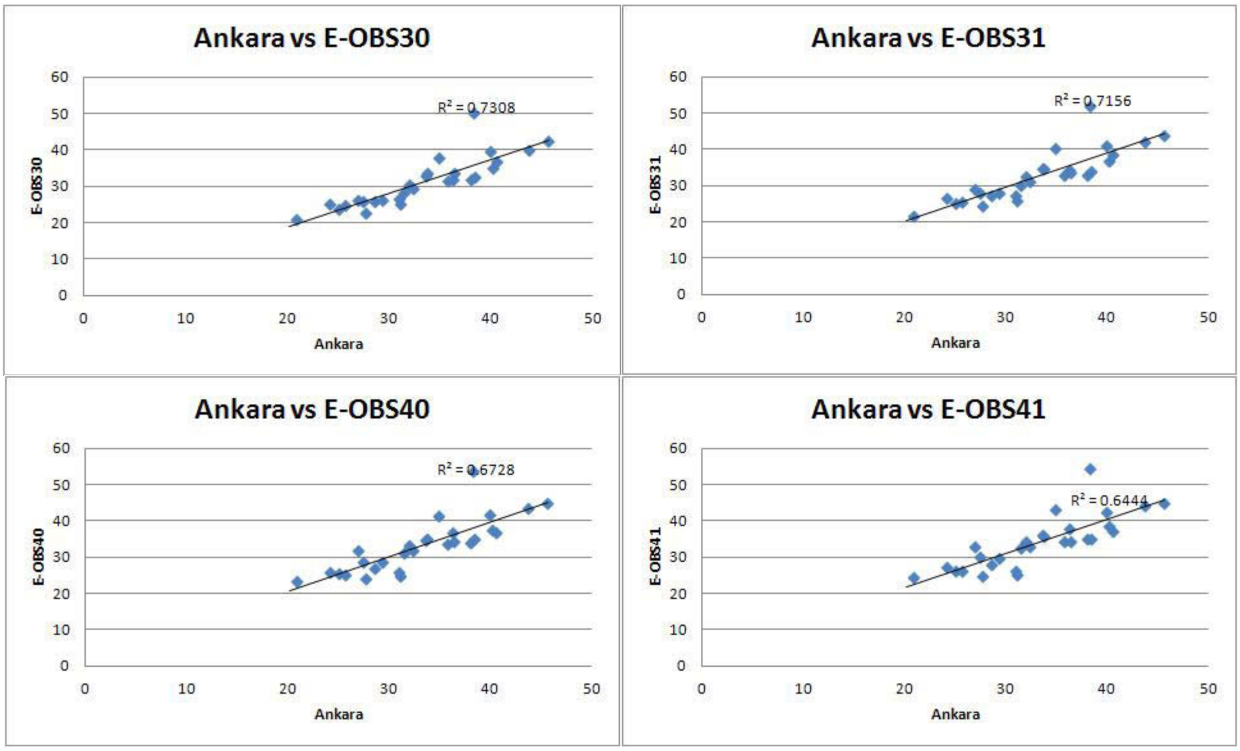


Figure 7.34 Examples of Correlation Analysis among Ankara Station and E-OBS Grids for the Period 1975 - 2009

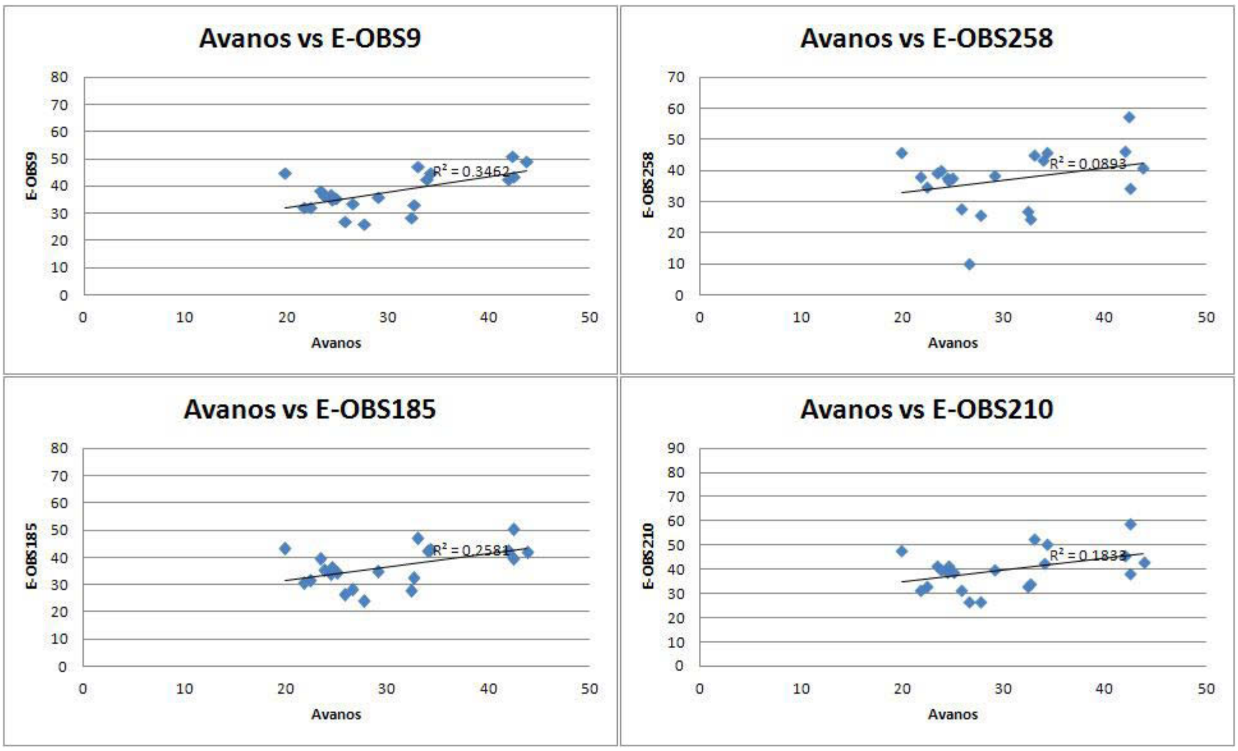


Figure 7.35 Examples of Correlation Analysis among Avanos Station and E-OBS Grids for the Period 1975 - 2009

The E-OBS data is a daily gridded observational dataset for precipitation, temperature and sea level pressure in Europe and the Mediterranean area based on daily series of observations at meteorological stations, with uniform quality control, analysis of extremes. If sufficiently reliable, this data set could be helpful in obtaining e.g. spatially integrated precipitation data. Therefore, a correlation analysis between DMİ stations and E-OBS grid point data was conducted. While E-OBS grids close to the centre of Ankara exhibit a good correlation with DMİ stations adjacent to them (Figure 7.34), only a very low correlation is seen as the distance to the centre increases (e.g. Figure 7.35). Comparison of E-OBS station around Ankara station with the station itself provides satisfactory results ($R^2 > 0.5$). Most probably the data taken for derivation of E-OBS data came from Ankara station. The correlation coefficients in Figure 7.35, however, are very low, which is attributed to the distance between Avanos and Ankara stations and true for all the less distant stations. Therefore, E-OBS data set for Turkey and models based on them are not sufficiently reliable for this analysis. This indicates a lack of information/data and a need for efforts to fill the gap.

7.3.3 Analysis of Streamflow Data

Comparison of monthly mean precipitation and streamflow (basin-wise), shown below by Figure 7.36 and Figure 7.37, reveals that they have the same pattern, i.e. the runoff also rises in winter and starts decreasing after April, which is surprising, as the precipitation maximum generally occurs in winter for Sakarya and in spring for Kızılırmak. This is probably the effect of the additional water uptake by vegetation in spring and indicates significant importance of evapotranspiration.

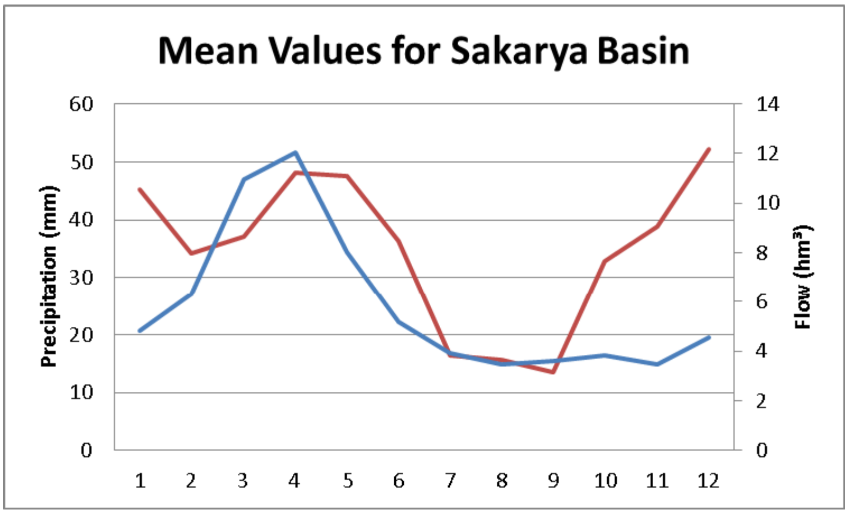


Figure 7.36 Monthly Mean Precipitation (red) and Streamflow (blue) Values for Sakarya Basin

To analyse the importance of precipitation for surface runoff, correlation analysis for the wet period (October – April) between meteorological logs and streamflow records was conducted for 6-months total, weighted precipitations and with lag-times. Surprisingly, all the correlations (R^2) are far from being satisfactory. Figure 7.38 depicts a few of the correlation analysis results for Sakarya Basin. In the final trial, an average basin precipitation was calculated and used to generate distributions. It is seen that the highest R^2 value is 0.35 (< 0.5). Figure 7.39 shows some of the results for Kızılırmak basin. Again an average basin precipitation was used for the analysis. Here again all the coefficients of correlation are less than 0.5. As a result no further calculations were carried out regarding the basin areas of Kızılırmak (78,180 km^2) and Sakarya (58,160 km^2). The gauging stations used in this study are concentrated on central and northern parts of the area of interest. A better choice of these would hopefully show the expected relationship between precipitation and surface runoff.

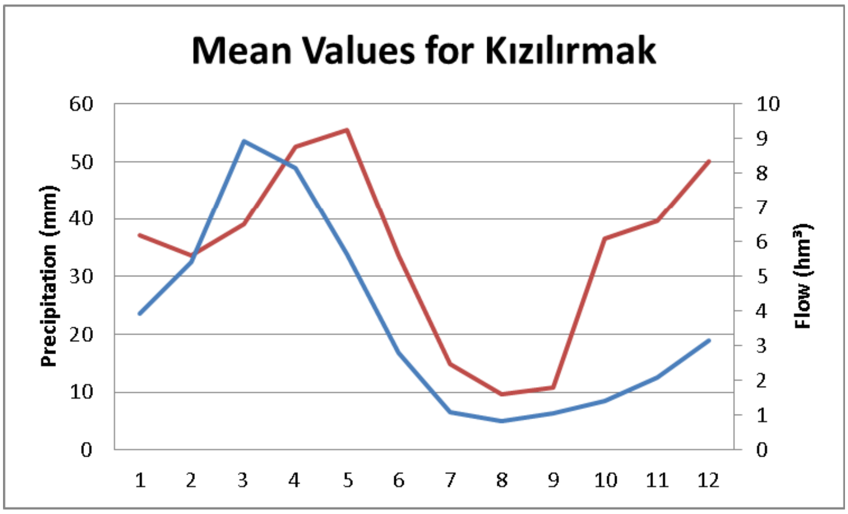


Figure 7.37 Monthly Mean Precipitation (red) and Streamflow (blue) Values for Kızılırmak Basin

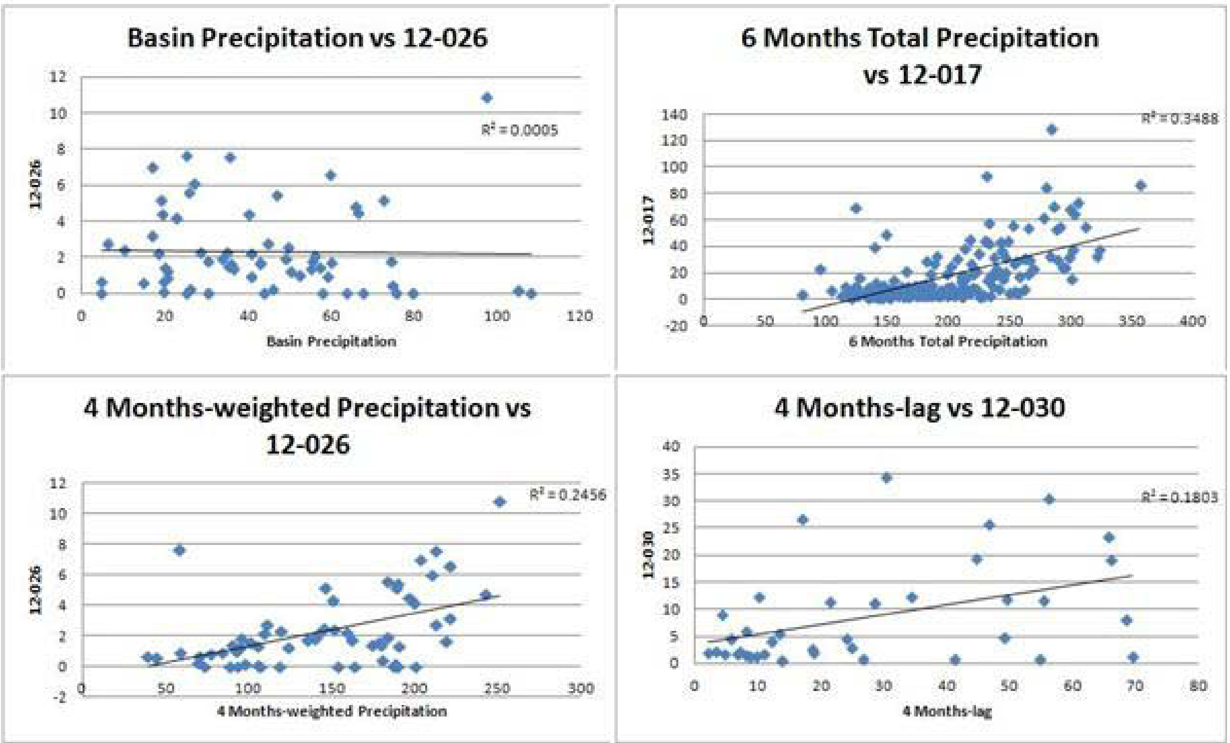


Figure 7.38 Examples of Correlation Analysis of Precipitation and Streamflow Data in Sakarya Basin

After recognition of this lack of correlation, the question arose whether natural vegetation growth in fall could influence the amount of surface runoff. To answer this, available studies concerning the phytology of Ankara and surroundings were referred to and scientists knowledgeable in this field were asked. Three of the available studies (Şahin B., 2007, Çalışkan G., 2008, Akdeniz, S., 2009) showed that sampling had generally been done in spring - of 1,232 total samplings 908 had been done between April and June, whereas only 27 between September and October. The enquiry displays the existence of a vegetation growth in fall, however, it may not be large enough to have a noticeable effect on surface runoff (Holzner, W., 2012).

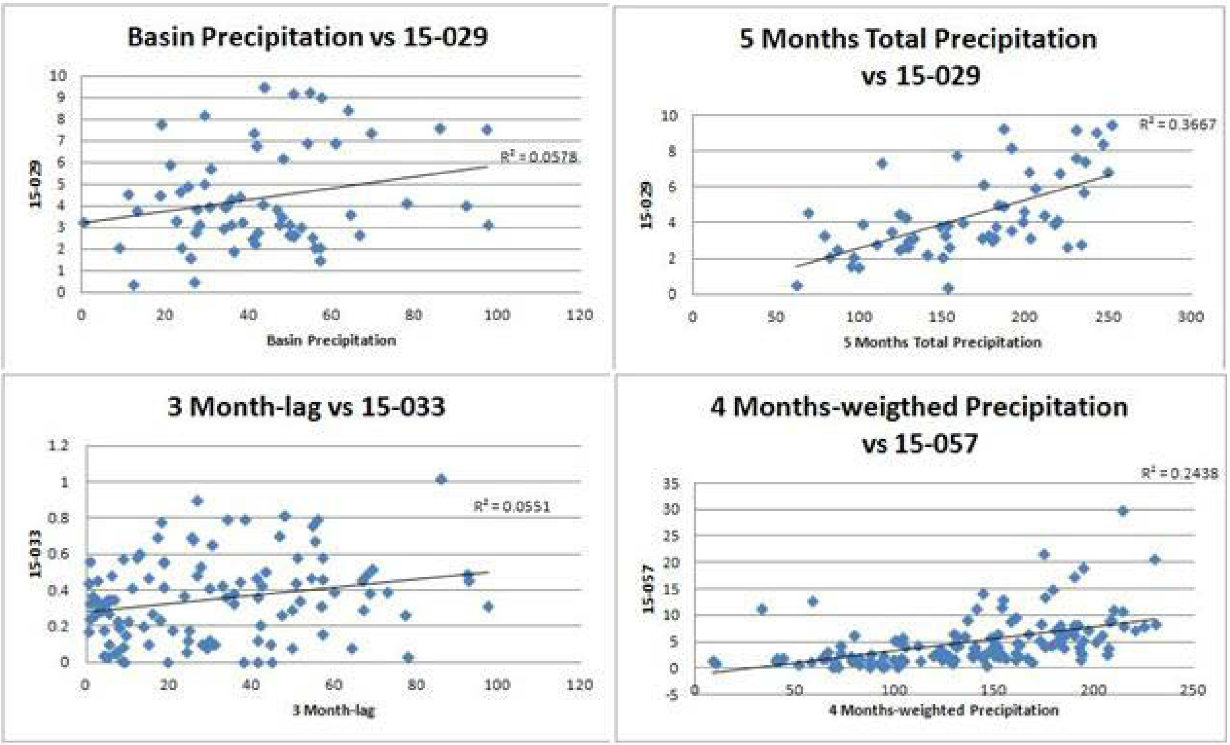


Figure 7.39 Examples of Correlation Analysis of Precipitation and Streamflow Data in Kızılırmak Basin

7.3.4 Population Factor on Water Demand in Ankara

It is shown in Part 7.3.1 that the prime use of water in Ankara is to meet drinking water demand. Hence, population increase is the main factor affecting the demand rise for water in the city. Table 7.6 shows the population change from 1980 till 2010. According to the values, the average population and water consumption increases are about 596,000 and 50.5 hm^3 every ten years, respectively.

Table 7.6 Population Increase in Ankara between 1980 and 2010 (Ankara Metropolitan Municipality, 2006)

Year	**1980**	**1990**	**2000**	**2010**
Population (mil.)	2.85	3.23	4.01	4.64
Water Use (hm^3)	235.65	284.43	417.96	387.21

Figure 7.40 and 7.41 give information about the relationship between population and water use (without energy). Water consumption for energy is excluded here because it does not appear until 2008 and the energy produced in Kesikköprü Dam is not only used in Ankara. Moreover, no water is supplied to the city from this dam currently (URL 11) because it was put into service under severe drought conditions as an emergency solution. As seen, till 2010 water use rises with population. The trend for water consumption is steeper than that of population increase. It can be concluded that the residents' use of water is increasing. To understand the drop in water use in 2010, one must turn to Figure 7.6 which shows that water use continues to increase till 2005. With the start of the dry period in 2006, water use levels are low mainly because of lack of available water. The main reason in the decrease of water consumption in 2010 despite the population growth could be this dry period. Nevertheless, detailed information about the water use in Ankara is necessary to find a conclusive

explanation for this low value.

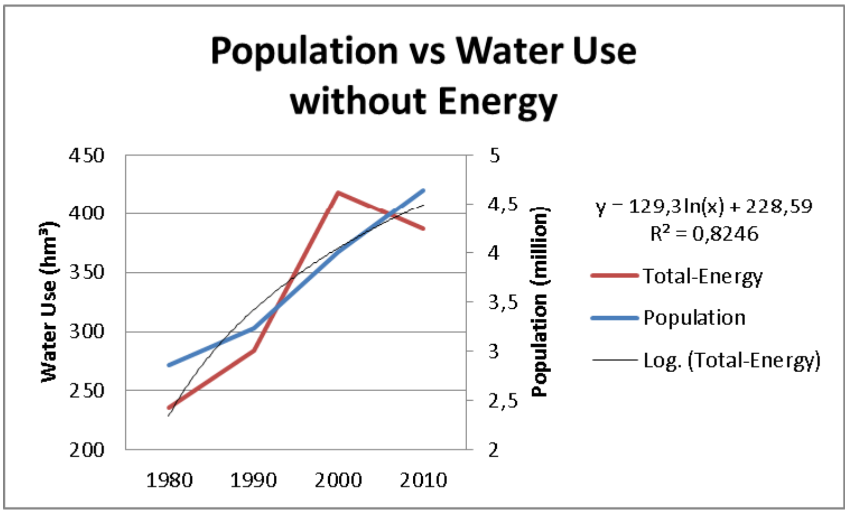


Figure 7.40 Population Growth and Water Use Increase in Ankara between 1980 and 2010

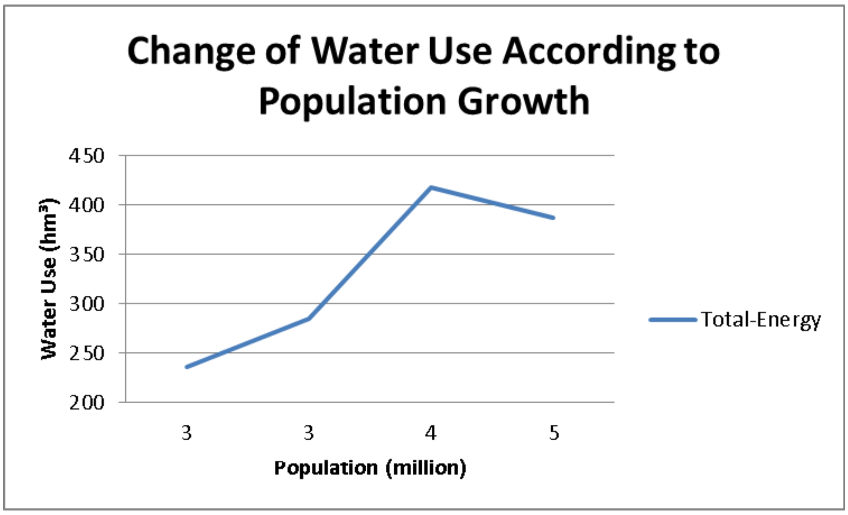


Figure 7.41 Change of Water Use According to Population Growth between 1980 and 2010

The total water holding capacity of the dams is 1,110.69 hm^3 (Part 6). Based on the 2010 water consumption, 387.21 hm^3/a, the time required to consume all the water (that is the period for which the need can be sustained) is

1,110.69 hm^3/387.21 hm^3/a = 2.62 years.

However, as shown in Figure 7.2, the dam volumes generally do not reach their maximum capacity. For instance in 2010 the volume was 550 hm^3, which is half of the potential. Therefore, a better estimate would be that the amount of water stored in the reservoirs of Ankara can sustain the needs for about 15 months.

Ankara Landuse Plan Report (Ankara Metropolitan Municipality, 2006) forecasts a population of 6.03 million in 2023 if the current trend continues. 5.65 million is the expectation if the population growth is below the trend, and 9.17 million with an above-trend-growth. Assuming a water consumption of

250 L/d/c (Yüksel, E., et al, 2004) and 6.03 million people in 2023, the necessary amount of water is

$6.03x10^6c$ x 250 L/d/c x 10^{-9} hm^3/L x 365 d/a = 550 hm^3/a

Therefore, for at least during the coming decade, available water holding capacity of the dams is enough to meet the future water demand of the city. With additional projects planned for 2033, the capacity is going to rise to 1,345.42 hm^3/a, which is expected to maintain the current population and capacity ratio.

However, if the water used for energy is included to the calculation, total water consumption in 2010 rises to 2,146.68 hm^3/a, which means that the supply lasts for

1,110.69 hm^3/2146.68 hm^3/a x 365 d/a = 188.6 days.

This result may indicate a future conflict between energy and other sectors.

The amount used to meet drinking demand contains industrial water use. Due to lack of data, the calculations in this study are not able to differentiate the effect of industry on water demand. Investigation of both factors separately would be more useful for deciding climate change adaptation measures discussed in Part 8.

7.4 Assessment of Climate Sensitivity for Ankara

Adaptation issue and related concepts in the climate change context is discussed in Part 4. In climate change context sensitivity means the degree to which a system is affected by or responsive to climate stimuli. The characteristics such as storage-runoff ratio, seasonal distribution of supply and demand of water, system structure and the degree of utilisation determine the sensitivity of a water supply system to climate change (IPCC, 1995, pp. 473).

Putting together the results on water resources and consumption, meteorological trends, and streamflow conditions as well as climate model scenarios on the future of the climate, sensitivity of the water supply of the city of Ankara can now be assessed.

The regional model results show that the temperatures are expected to substantially increase, particularly through the end of the 21^{st} century. Surprisingly, precipitation is also estimated to rise, although with a decreasing trend. On the other hand, global circulation models (URL 5) project a decrease in precipitation. The ensuing uncertainties hinder a clear conclusion regarding future water supply. Yet some aspects can be addressed: evaporation needs more consideration, as it currently causes a 5% water loss, equal to the amount used for irrigation. With increasing temperature, evaporation from the total surface area of 6,275.5 km^2 of the dams will further increase. Temperature rise may also change the form of precipitation: the amount of snow fall and snow cover will decrease. This may result in an early peak level of streamflows, which may be a problem, if there is not sufficient space for the water. Yet, on the whole, the results indicate that climate change at present does not pose a high risk in terms of water resources of Ankara. One important factor of concern might be increasing climate variability and extreme events as recent droughts or floods have proved. However, uncertainties in climate models in this respect even exceed those of overall precipitation.

The outcome of the analysis of water resources and use is that the city is well-supplied, thanks to DSİ, to meet the current and future demands, at least for the next two decades. In other words, the capacity is maintained with a strong infrastructure for beyond 2033. If a 25-year of life-time for such projects is assumed, it is appropriate to be convenient till the mid-century. This holds true for average conditions. However, severe droughts can cause extreme water constraints in the city, as experienced in 2007 and 2008 even though the water managers of Ankara Metropolitan Municipality managed to connect Kesikköprü Dam to the city grid at short term with a great effort (ASKİ, 2011). The problem in the city arose because the water management did not foresee this extreme event and did not have any plan or solid strategy to meet it. With the attempt to save the situation, the problem became more severe as short-term decisions caused infrastructural problems (URL 12, URL 13). Therefore, flexibility, robustness and resilience of the water system are well founded concerns. Furthermore, it became clear that under drought conditions irrigation competes with drinking water. Keskin and Şorman (2010) also draw attention to the issue of groundwater levels and water quality in dry periods. They have determined that water withdrawals were substantially increased to feed agricultural land, deteriorating both height of water table and water quality. If energy production is coupled with these, specifying priorities and allocating water could be a conflictual issue for the water authorities.

Other practical result of the analysis concern meteorological and hydrological data: the E-OBS gridded meteorological data has proven inappropriate for Turkey. Any models based on this data set probably fail to deliver reliable predictions for the country. To overcome this problem, either the data set should build on a higher density of stations or Turkey should rely on different models and/or put some effort in developing its own. Second, the precipitation during fall and winter seasons over northern and central parts of the study area is likely to provide the most of the water stored in the reservoirs. Detailed analysis of the hydrological system of these sub-regions could be essential to decide on adaptation measures.

A possibly important aspect results from the comparison of streamflow and precipitation data. No trace for any contribution of precipitation to streamflow was detected, and evapotranspiration, evincing particularly after April, appeared as a key factor determining availability of water. This has to be carefully analysed in view of possible shifts in precipitation periods due to temperature rise. Temperature rise is important because it may draw vegetation period forward, resulting in less water accumulation for the dry season. Furthermore, with climate change conditions, a second period of vegetation might develop in fall, creating a risk for water supply in winter.

Finally, except for the 2006 – 2010 period, water consumption in Ankara shows an increasing trend with population growth. The main aim for water management is to meet the rising demand due to population growth. As shown in Part 7.3.1, more than half of the water is used as drinking water (including industrial use). Currently, Ankara is the second most populated city in Turkey and it will probably preserve this rank. As mentioned above, the water supply infrastructure is well-designed to meet the present demand and the demand of the near future, nonetheless, such a large population is very vulnerable to any water shortage unless there is good planning and management.

To sum up, the city of Ankara exhibits a strength considering the infrastructure and water allocation plans for the future with a high storage/runoff ratio, even under climate change conditions. Yet, there seems to be deficits in water management stemming from insufficient scientific data, inventories and forecasts and, as a result, weaknesses in policy and planning. Moreover, this immense population has the potential to magnify any negative consequence of a climatic event as the recent drought and flood events have proved (URL 14). Thus, Ankara exhibits more sensitivity to climate variability and uncertainties, including extreme events, rather than to climate change as such: a sensitivity that is aggravated by institutional, political, and knowledge gaps as well as lack of trained people.

8. Needs for Climate Change Adaptation and Improvement of Adaptive Capacity

As discussed in Part 4, in the climate change context, adaptation means modifications of ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts, referring to changes in processes, practices, and structures to average potential damages or to benefit from opportunities associated with climate change. Adaptation is important as it connects evaluations of impacts and vulnerabilities, and because it helps to develop and evaluate response options (IPCC, 2001, pp. 879, 881). The main reasons for adaptation are the inevitability of climate change, providing more effective and less costly anticipatory and precautionary measures, uncertainty regarding climate change, possible immediate benefits from adaptation to variability and extreme events, and removing maladaptive policy and practices, and possible future benefits from climate change (IPCC, 1990, IPCC, 2001, pp. 890).

Adaptation is an important issue for water sector. Changes in precipitation patterns affecting water distribution are important for many sectors, but especially agriculture, energy and health (IPCC, 1995, pp. 412). It is necessary to separate physical effects of climate change from impacts which have a societal value. Characteristics of the water use system determine the impact: for some cases a large climate change effect could have a small impact, whereas for others a small change may result a large impact (IPCC, 1995, pp. 471-473). The most significant impact of climate change on the water supply system is the rise of uncertainty, substantially complicating rational water resource planning (Mukheibir, P., 2010).

In Part 7.4, the conclusion is that the water supply system of Ankara exhibits more sensitivity to climate variability and uncertainties including extremes rather than climate change considering the climate model results and data analysis. This sensitivity arises from institutional, political, and knowledge gaps as well as lack of trained personnel in public and private institutions. Therefore, the suggested responses below are focused on these factors. In fact, the listed issues are also determinants of adaptive capacity. As a result, proposed actions for adaptation could also facilitate improving adaptive capacity.

Before discussing the possible adaptive responses, a brief stakeholder analysis is necessary to state clearly the reasoning behind them. The Republic of Turkey has a central governance model in which all decisions are taken, initiated, and implemented at the national level. All public institutions in the country are only responsible to carry out and monitor the directions given by the central government. One of the fundamental results of this model is that local authorities are not able to develop political directives or regulations according to their needs. For instance, if the central government has not made any legislation on climate change adaptation, any action plan can only be issued as a guideline by the local authority.

In view of this, stakeholders in Ankara for adaptation actions focusing on water resources may be Ankara Metropolitan Municipality and other municipalities, local directorates of Ministry of Forestry and Water, Ministry of Environment and Urbanisation, State Hydraulic Works, Turkish State Meteorological Service and universities. Along with public institutions, civil society groups such as Union of Chambers of Turkish Engineers and Architects (TMMOB), Ankara Trade Chamber (ATO), and national and international environmental groups and institutions should be part of this process, which would be initiated, directed, and managed by Ankara Metropolitan Municipality since it is the main responsible body for the well-being of the city and dwellers. Other public authorities would be responsible for supporting Ankara Municipality in terms of conveyance of directives and regulations, and their enforcement, data and knowledge provision, and technical and human resources. The universities would play an advisory role and provide scientific data and knowledge. Finally, TMMOB and ATO, and other NGOs could contribute in technical, sectoral/financial, and social issues, respectively.

8.1 Needs for Climate Change Adaptation

Proposed actions are classified according to IPCC (1990, 2001) reports, analysed in Part 4. There are three categories, A, B and C, depending on their timing, costs, scale and response type.

Category A: Responses under this category aim at enhancing data, information and knowledge resources to enable decision-makers to have better judgements on climate issue, which are generally short-term measures.

To deal with climate uncertainty and variety in the most efficient way, the knowledge base has to be improved for better evaluation of water resources. In other words, research to identify key vulnerabilities to climate uncertainty and variability will serve for design and implementation of response options (Ziervogel, G., Johnston, P., Matthew M., Mukheibir, P., 2010). Principally, creating data bases, monitoring systems, and catalogues, and providing information concerning meteorological and hydrologic events and their assessments are the responsibility of the central government and these are implemented by the local representatives. Therefore, Ankara Metropolitan Municipality has to identify the type and form of data and information necessary, and request those from the state institutions. On the other hand, the Municipality has to create its own data base concerning the water supply system, e.g. developing monitoring systems to observe timing, amount and form of inflows to and outflows from the system. With the help of scientists, models and simulations can be developed for short-term planning and preparedness, which could be crucial to cope with floods or droughts. Finally, flexibility, resilience and vulnerability assessment studies should be initiated with a long-term approach regarding hydro-meteorological events, particularly floods and droughts, water resources, and supply, use and conservation.

Besides closing the knowledge gap, steps towards educating public and personnel need to be realised. First, water managers and all the staff assisting them should be informed and convinced about the significance of the climate issue. Then they have to get well-equipped or qualified, to receive, understand, and process the data, information or knowledge serviced to them in order to make the most appropriate decisions. The local directorates, universities and NGOs could cooperate and prepare education material, courses, and workshops targeting at these personnel. Moreover, the Municipality needs to consider employing high-qualified people to be able to operate in the near-term. Not only educated personnel but also an aware public is required to achieve adaptation. Therefore, again with the involvement of the local directorates, universities, NGOs and media, campaigns to attract public attention should be organised. They could be supported with informative and educational materials, both soft and hard, with easy access.

Finally, the Municipality needs a road map for the adaptation issue. Thus, a Municipal Adaptation Action Plan should be prepared with one part dealing with water resources to plan, assess, manage and implement the decisions taken. This municipal level plan may refer to the national documents concerning climate change.

Category B: The response options listed below are mainly long-term and bear some costs.

If the knowledge and skilled personnel gap is closed, one next step concerning system optimisation is development of sophisticated models and simulations considering the uncertainties and variability related to climate. Predicting hydro-meteorological events could improve the decisions on water allocation and use. Later, water conservation options should be implemented regarding aridity conditions. Such options may consist of development and application of new technologies and consumer appliances, implementation of new efficiency codes for buildings, metering and pricing, design and planning of the landscape and urban to allow less water use. Particular emphasis needs to be on improving irrigation water efficiency because water is wasted with the flooding method. Instead, drip or sprinkler irrigation has to be employed. Moreover, industry could be oriented into water conservation with process changes or better technologies. Public should also be directed to use water efficiently. Campaigns or initiatives should be taken to replace old home appliances with newer ones, which, however, require financial support. Demand management is an important component for water conservation. Pricing could be a practical option to promote less water use at user level. Over proportionately higher prices for higher water consumption to assure equity, citizens and industry could be induced to conserve water. Lastly, recycling of wastewater, or use of grey water, could be considered as an option for conservation. Urban planning is a crucial issue for Ankara with a high population growth. The enlargement of urban area needs to be under control to have a sustainable and manageable infrastructure. Moreover, housing in or close to nature and water conservation areas should not be allowed. Flood management plans should also consider water resource issues because it threatens the sustainability and safety of the water supply system as well as water quality.

Category C: Options under this category are costly and long-term. Their realisation needs careful assessment not to prevail any capacity, capital or resource loss.

Regarding Ankara and the climate sensitivity, major options should be concerned with enhancing storage capacity of the whole system. This is necessary if the change in precipitation form and timing, possibility of early runoff, extreme events, change in evapotranspiration, and population growth are considered. In brief, the best response of Ankara to climate uncertainty and variety could be to broaden the range of capability of the water system so that both shock-loads are buffered and long dry periods are resisted. Therefore, construction of new reservoirs, dams, and ponds is necessary, and safety improvement for those structures needs to be developed.

8.2 Adaptive Capacity Assessment for Ankara and Needs for Improvement

Adaptive capacity is the potential of a system to adapt to impacts of climate (IPCC, 2001). To assess adaptive capacity of Ankara, the determinants listed by IPCC (2001) are referred. These are economic resources, technology, information and skills, infrastructure, institutions, and equity, which are evaluated with their major strengths and weaknesses, and solutions to overcome barriers are proposed. One essential aspect that should be highlighted is that Ankara is a capital of a developing country where climatic issues will add to current problems, the majority of which are related with awareness and priorities of both decision-makers and public more than economic and financial aspects, availability of information, technological and human resources.

Economic Resources

The contribution of Ankara to National Gross Domestic Product in 2009 was 9%. On average, 12% of all the tax revenues are collected in Ankara (URL 15). Such figures show the economic capacity of the city. Moreover, the Municipality has the potential or ability to create financial sources depending on the image and importance of the city. Therefore, claiming a strong adaptive capacity for Ankara in terms of economic resources would be reasonable. Nevertheless, allocation of this financial source for climate change adaptation could be a problem.

Technology

Technologies related to observation, monitoring, and prediction of the water systems are needed. Being the capital, Ankara needs to be well-equipped for the safety of governmental services. Moreover, the majority of the data collected nation-wide is processed in Ankara. Finally, the city has good prerequisites for technological innovation with 10 universities, public institutions, and local industrial facilities. Thus, the city has high adaptive capacity in terms of technologies or technology development for water resources.

Information and Skills

Being the capital enables Ankara to avail itself of all necessary information and skills easily within all public institutions. However, as expressed in previous parts and above sections, the majority of adaptation responses need address the education of water managers and related staff. Along with the lack of consideration of climate change by the state, as the direct responsible body of water supply for the city, Ankara Metropolitan Municipality has displayed a less than optimal approach and response to the climatic events that occurred in the last 5 years. Hence, Ankara, as a governing structure, shows a low adaptive capacity to climate change. To overcome this barrier, governors should be informed about the importance of adaptation, besides climate change and its mitigation, and their perception needs to be changed as well as their priorities. Only after that, the required increase in information and skills at the management level can be accomplished because of the top down governmental structure. Otherwise, lack of awareness at the level of government authorities can impede climate change responses (OECD, 2009).

Institutions

As emphasised before, being the capital, Ankara is provided with potential benefits. Existence of strong institutions, both public and private, is one of those. All the public institutions that could play a vital role in adaptation, e.g. local directorates of State Hydraulic Works, Turkish State Meteorological Service, Ministry of Urbanisation and Planning, Ministry of Water and Forestry, universities, TMMOB, ATO, and other NGOs, exist and up to a degree well-organised and equipped technically, and have a certain capacity, especially DSİ, to deal with the water issue. Therefore, Ankara also exhibits high adaptive capacity considering institutions. However, the lack of necessary information and skills, coordination among them, lack of communication, clarity of responsibility areas, and willingness could lower capacity to adapt. Moreover, Ankara Metropolitan Municipality does not have any department dealing with climate change, which is considered to be important.

Equity

Water is available to the poor as well as the rich. The number of households subscribed to ASKİ is 1,511,135 (ASKİ, 2011). If 4 people per household is assumed, then it is seen the number of subscribers cover the whole population of the city (4,641,256 (URL 1)). On the other hand, assuming

150 L/d/c (URL 16) water use, the volume of water a 4-peopled-household spends per month is

$$150 \text{ L/d/c} \times 4 \text{ c} \times 30 \text{ d/month} \times 10^{-3} \text{ L/m}^3 = 18 \text{ m}^3\text{/month}$$

Considering the minimum wage, 701.44 TL/month (URL 17) and 2.7 TL/m^3 of charge (URL 18), the ratio of the expenditure on water with VAT to the total income of this household is

$$((18 \text{ m}^3\text{/month} \times 2.7 \text{ TL/m}^3) \times (1 + 0.08)) / 701.44 \text{ TL/month} = 0.075$$

7.5% of income of a 4-membered poor family is spent for water needs in Ankara. Although this is a high ratio, equity in adaptation to climate change for water resources is not a practical determinant of adaptive capacity. The measures offered above should basically be undertaken by institutions rather than individuals. The only issue that might raise equity problems may be the tariffs to manage demand. Water managers need to pay attention to this matter. About the rest, equity is not expected to determine adaptive capacity of Ankara on water resources and should be considered in socio-economic aspects of climate change issue.

To sum up, it is concluded that Ankara shows a strong adaptive capacity to overcome impacts of climate uncertainty and variability on water resources. It has considerable potential and benefits due to being the capital city. Nevertheless, the success of any adaptation measure is dependent on the awareness of governors, decision-makers, and water managers of climate change, because only they are able to shape any kind of action. Moreover, the key determinant for adaptive capacity is identified as availability of information and skills. Even though all other determinants are perfectly strong, lack of information and necessary skills affect, as Moser and Ekstrom (2010) specifies, the potential to observe, assess and define problems, create and manage response activities, and monitor and evaluate those. Therefore, measures to raise the adaptive capacity in terms of information and skills need to be immediately realised, which, in fact, is the key adaptation response issue for the short-term and will determine outcomes for the long-term.

Conclusion

Taming the giant or taming ourselves... Both are essential in the context of climate change but the focus in the world is primarily on mitigation of climate change and less on adaptation to it. However adaptation is unavoidable because climate change is inevitable. Therefore, it is reasonable to take measures to lessen the degree and scale of the expected impacts. Moreover, benefits would be gained by timely action. Thus, societies need to consider adaptation to climate change to improve their capacity and resilience against, and to decrease sensitivity and vulnerability to climate change as well as to create means to gain advantages.

One of the issues arising with climate change is the availability of water. Water scarcity is already a concern for the world and climate change just intensifies the current problems. Thus, understanding the impacts of climate change on hydrologic cycle, and, therefore, on availability of water resources is of immense value to properly deal with the issue.

Turkey is not different from the rest of the world in that impacts of climate change are observed and will be observed in the future. Nevertheless, the country does seem to understand and react to climate change properly. There are a few steps towards addressing the issue in some academic papers or even a national level strategy plan, however, more effort is required to grasp what is ahead.

Ankara was chosen as area of interest for the above considerations with the aim of providing a first assessment of adaptation options for the city. Therefore, general impacts of climate change on the hydrologic cycle and their effects on water resources are. For this purpose climatic conditions (temperature and precipitation of 25 meteorological stations in and around Ankara) and water resources and use in Ankara, supplied by Ankara 5th Directorate of State Hydraulic Works, were analysed. For future water supply and demand climate scenarios and population forecasts were consulted. The study was hampered by lack of high quality data and some analyses, such as the E-OBS data set proved too unreliable to be of use. In other cases, such as the lack of correlation between precipitation and run-off, the issue might be related with data quality but there could also be other effects that have not been quantified so far – e.g. evapotranspiration. Uncertainty regarding the future is great due to very divergent results of climate scenarios calculated by different models. While temperature rises in all models, precipitation development differs, from an increase to decreases. Thus the study revealed a number of research needs, such as:

- Quality of meteorological and hydrological data needs to be improved. Longer time series would be necessary and might possibly be available in an undigitalised form.
- Climate model results should be downscaled to Turkey and evaluated and corrected for biases to provide a more reliable basis for the evaluation of future developments.
- Hydrological models should be developed and evaluated for the rivers in question to be coupled to the climate models.
- With an improved data base, climate variability and extreme events could be studied.
- Precipitation during fall and winter seasons over northern and central parts of the study area is likely to provide the most of the water stored in the reservoirs. Detailed analysis of the hydrological system of these sub-regions could be essential to decide on adaptation measures.
- Possible shifts in precipitation periods due to temperature rise should be carefully analysed. Temperature rise is important because it may draw vegetation period forward, resulting in less water accumulation for the dry season and make a second vegetation period in fall possible, creating a risk for water supply in winter.

- More than 50% of the water in Ankara is used as drinking water. This, however, includes industrial uses. More detailed information would be necessary to suggest more precise adaptation measures.

Due to the high storage/runoff ratio, the water system infrastructure and water allocation plans of the city of Ankara are appropriate and well suited even for the future even under climate change conditions. Yet, there seem to be deficits in water management stemming from insufficient scientific data, inventories and forecasts, and, therefore, weaknesses in policy and planning. Moreover, this immense population has the potential to magnify any negative consequence of a climatic event as the recent drought and flood events have proved. Thus Ankara exhibits more sensitivity to climate variability and uncertainties, including extreme events, rather than to climate change as such; a sensitivity that is aggravated by institutional, political, and knowledge gaps as well as lack of trained people.

Hence, closing the knowledge/information gap regarding data bases, monitoring systems, and catalogues, and providing information regarding meteorological and hydrologic events, water resources and their assessments is the first measure to be taken (Category A according to IPCC). Flexibility, resilience and vulnerability assessment studies should be initiated with a long-term approach regarding hydro-meteorological events, particularly floods and droughts, water resources, and supply, use and conservation (A). Also, steps towards educating public and personnel needs to be realised (A). Employing high-qualified people to be able to operate in the near-term should be considered (A). A Municipal Adaptation Action Plan should be prepared with a part dealing with water resources to plan, assess, manage and implement the decisions taken (A). Development of sophisticated models and simulations considering the uncertainties and variability related to climate are necessary to achieve system optimisation (B). Water conservation options should be implemented regarding aridity conditions. Such options may consist of development and application of new technologies and consumer appliances, implementation of new efficiency codes for buildings, metering and pricing, design and planning of the landscape and urban to decrease use (B). Pricing could be a practical option to promote less water use at user level. Through better pricing of higher water consumption, considering equity, dwellers and industry could be forced to conserve water (B). Recycling of wastewater, or use of grey water, could be considered as an option for conservation (B). Enhancing nature and water conservation areas are to be concerned (B). Flood management plans should also consider water resources issues because it threatens the sustainability and safety of the water supply system as well as water quality (B). Enhancing storage capacity of the whole system, i.e. construction of new reservoirs, dams, and ponds, should be considered (C).

The assessment of the adaptive capacity for Ankara was conducted in terms of economic resources, technology, information and skills, institutions, and equity. Regarding economic resources, Ankara is claimed to exhibit strong capacity if one considers the 9% contribution from Ankara to National Gross Domestic Product in 2009. On average, 12% of all the tax revenues are collected in Ankara (URL 12). Such figures show the economic capacity of the city. Moreover, the Municipality has the potential or ability to create financial sources depending on the image and importance of the city. Nevertheless, allocation of these could be a problem. Considering technology, Ankara provides a reliable view as the city is well-equipped with necessary water resources management tools. Thus, in terms of technology, Ankara again has strong capacity. However, there is a lack regarding information and skill. This is because the majority of adaptation responses depend on the education of water managers and related staff. Along with the lack of consideration of climate change from the state, as the direct responsible body of water supply for the city, Ankara Metropolitan Municipality has not responded well to the climatic events occurred in the last 5 years. In terms of institutions, Ankara is again claimed to show high capacity. As emphasised before, being the capital, Ankara is provided with potential benefits. Existence of strong public and private institutions is one of these. All the public institutions that could play a vital role in adaptation exist and up to a degree well-organised and equipped technically, and have a certain capacity, especially DSİ, to deal with the water issue. However, the lack of necessary information and skills, coordination among institutions, lack of communication, clarity of responsibility areas, and willingness could lower the capacity to adapt. Equity is assessed to be irrelevant in water access issue because every citizen has the right and opportunity to reach water in Ankara. This is also provided by the municipality. . To conclude, Ankara shows a strong adaptive capacity to overcome impacts of climate uncertainty and variability on water resources. It has a considerable potential and benefits due to being the capital city. Nevertheless, the success of any adaptation measure is dependent on the approach of governors, decision-makers, and water managers because only they are able to shape any kind of action.

References

AÇOB, 2008, Ankara İl Çevre Durum Raporu, İl Çevre ve Orman Bölge Müdürlüğü, Ankara, Turkey

Adger, W. N., Agrawala, S., Mirza, M. M. W., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit B., Takahashi, K., 2007, Assessment of Adaptation Practices, Options, Constraints and Capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O. F. Canziani, J.P. Plutikof, P.J. Van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, pp. 717-743

Akbulut, N. E., et al, 2009, Rivers of Turkey, Rivers of Europe, Elsevier, Italy, pp. 643-672

Akdeniz, S., 2009, Ayaş-Kazan-Yenikent Arasında Kalan Bölgenin Florası (Ankara/Türkiye), Master Thesis, Ankara, Turkey

Aksoy, H., Ünal, N. E., Alexandrov, V., Dakova, S., Joon, J., 2008, Hydrometeorological Analysis of Northwestern Turkey with Links to Climate Change, International Journal of Climatology, vol. 28, pp. 1047-1060, DOI: 10.1002/joc.1599

Albek, M., Albek, E., 2009, Stream Temperature Trends in Turkey, Clean, vol. 37 (2), pp. 142-149, DOI: 10.1002/clen.200700199

Ankara İl Tarım, 2006, İl Tarım ve Kırsal Kalkınma Master Planlarının Hazırlanmasına Destek Projesi: http://www.agri.ankara.edu.tr/fcrops/1289__ANKARA_TARIM_MASTER_PLANI.pdf

Ankara Metropolitan Municipality, 2006, Nazım İmar Planı Plan Açıklama Raporu, İmar ve Şehircilik Dairesi Başkanlığı, Ankara, Turkey

ASKİ, 2011, Ankara Metropolitan Municipality, General Directorate of Water and Sewage, Ankara, Turkey

Barnes, B. V., Zak, D. R., Denton, S. R., Spurr, S. H., 1997, Forest Ecology, 4th Edition, John Wiley and Sons, Inc., New York, U.S.A

Bardsley, D. K., Sweeney, S. M., 2010, Guiding Climate Change Adaptation within Vulnerable Natural Resource Management Systems, Environmental Management, vol. 45, p. 1127-1141, doi:10.1007/s00267-0109487-1

Bates, B. C., Kundzewicz, S. Wu, and J. P. Palutikof, Eds., 2008, Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva

Berrang-Ford, L., Ford, J. D., Paterson, J., 2011, Are We Adapting to Climate Change, Global Environmental Change, vol. 21, p. 25-33, doi:10.1016/j.gloenvcha.2010.09.012

Biesbroek, G. R., Swart, R. J., Carter, T. R., Cowan, C., Henrichs, T., Mela, H., Morecroft, M. D., Rey, D., 2010, Europe Adapts to Climate Change: Comparing National Adaptation Strategies, Global Environmental Change, vol. 20, p. 440-450, doi:10.1016/j.gloenvcha.2010.03.005

Brassington, R., 1998, Field Hydrogeology, 2nd Edition, John Wiley and Sons Ltd., West Sussex, England

Büyükyıldız, M., Berktay, A., 2004, Parametrik Olmayan Testler Kullanılarak Sakarya Havzası Yağışlarının Trend Analizi, J. Fac. Eng. Arch. Selcuk Univ., v. 19, n. 2, p. 23-39

Cech, T. V., 2010, Principles of Water Resources, History, Development, Management, and Policy, 3rd Edition, John Wiley and Sons, Inc. New York, U.S.A.

Christensen, J. H., Christensen, O.B., 2007, A Summary of the PRUDENCE Model Projections of Change in Europe Climate by the End of This Century, Climate Change, vol. 81, p. 7-30, doi: 10.1007/s.10584-006-9210-7

Çalışkan, G., 2008, Kurtboğazı Barajı Havzası (Ankara) Florası, Master Thesis, Ankara, Turkey

Demir, İ., Kılıç, G., Coşkun M., 2008, PRECIS Bölgesel İklim Modeli ile Türkiye İçin İklim Öngörüleri: HadAMP3 SRES A2 Senaryosu, IV. Atmosfer Bilimleri Sempozyumu, Bildiriler Kitabı, İTÜ Uçak ve Uzay Bilimleri Fakültesi Meteoroloji Mühendisliği Bölümü, İstanbul, pp. 365-373

EC, 2009, White Paper: Adapting to Climate Change: Towards a European Framework for Action, COM(2009) 147 Final

FNCCC, 2007, First National Communication of Turkey on Climate Change

Han, D., 2010, Concise Hydrology, Dawei Han and Ventus Publishing ApS, http://bristol.academia.edu/DaweiHan/Books/126981/Concise_Hydrology

Hardy, J., T., 2003, Climate Change Causes, Effects, and Solutions, John Wiley and Sons Ltd, West Sussex, England

Haylock, M. R., Hofstra, N., Klein Tank, A. M. G., Klok, E. J., Jones, P. D., New, M., 2008, A European Daily High-resolution Gridded Data Set of Surface Temperature and Precipitation for 1950 – 2006, Journal of Geophysics Research, Vol. 113, D20119, doi:10.1029/2008JD010201

Holzner, W., 2012, personal communication on January 9, 2012

Hudak, P. F., 2000, Principles of Hydrogeology, 2nd Edition, CRC Press LLC, Florida, U.S.A.

IPCC, 2007a: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., Miller, H. L., Summary for Policymakers. 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, Cambridge University Press, Cambridge, U.K., and New York, U.S.A.

IPCC, 2007b: Climate Change 2007: Synthesis Report Summary for Policymakers

Jones, J. A. A., 2010, Water Sustainability, A Global Perspective, Hodder Education, London, UK, pp. 223

Kadıoğlu, M., 1997, Trends in Surface Air Temperature Data Over Turkey, International Journal of Climatology, vol. 17, pp. 511-520

Kahya E., Karabörk, M. Ç., 2001, The Analysis of El Niño and La Niña Signals in Stream-flows of Turkey, International Journal of Climatology, vol. 21, pp. 1231-1250

Kahya, E., Kalaycı, S., 2004, Trend Analysis of Streamflow in Turkey, Journal of Hydrology, vol. 289, pp. 128-144

Kalaycı, S., Kahya, E., 2006, Assessment of Streamflow Variability Modes in Turkey: 1964 – 1994, Journal of Hydrology, vol. 324, pp. 163-177

Karabörk, M. Ç., Kahya, E., 2003, The Teleconnections between the Extreme Phases of the Southern Oscillation and Precipitation Patterns over Turkey, International Journal of Climatology, vol. 23, pp. 1607-1625

Karabörk, M. Ç., Kahya, E., Kömüşçü, A. Ü., 2007, Analysis of Turkish Precipitation Data: Homogeneity and the Southern Oscillation Forcings on Frequency Distributions, Hydrological Processes, vol. 21, pp. 3203-3210, DOI: 10.10002/hyp.6524

Karakaya, E., 2008, Küresel Isınma ve Kyoto Protokolü, İklim Değişikliğinin Bilimsel Ekonomik ve Politik Analizi, Bağlam Yayıncılık, Ankara, Turkey, pp. 11-20

Karamouz, M., Moridi, A., Nazif, S., 2010, Urban Water Engineering and Management, CRC Press, Danvers, USA

Keskin, F., Şorman, A. Ü., 2010, Assessment of the Dry and Wet Period Severity with Hydrometeorological Index, International Journal of Water Resources and Environmental Engineering, vol. 2(2), pp. 29-39

Kömüşçü, A. Ü., 1998, An Analysis of the Fluctuations in the Long-term Annual Mean Air Temperature Data of Turkey, International Journal of Climatology, vol. 18, pp. 199-213

Loaiciga, H. A., et al, 1996, Global Warming and the Hydrological cycle, Journal of Hydrology, vol. 174, pp. 83-127

Mays, L., W., 2001, Water Resources Engineering, John Wiley and Sons Inc., New York, USA

Mathez, E. A., 2009, Climate Change the Science of Global Warming and Our Energy Future, Columbia University Press, New York, U.S.A.

Ministry of Environment and Forestry, 2010, Republic of Turkey National Climate Change Strategy Document 2010 - 2020, Ankara, Turkey (in Turkish)

Ministry of Environment and Urbanisation, 2011, Climate Change National Action Plan 2011 – 2023, Ankara, Turkey (in Turkish)

Moser, S. C., Ekstrom, J. A., 2010, A Framework to Diagnose Barriers to Climate Change Adaptation, PNAS, vol. 107, p. 22026-22027, doi:10.1073/pnas.1007887107

Mukheibir, P., 2010, Water Access, Water Scarcity, and Climate Change, Environmental Management, 2010, vol. 45, p. 1027-1039, doi:10.1007/s00267-010-9474-6

OECD, 2009, Integrating Climate Change Adaptation into Development Co-operation: Policy Guidance – ISBN-978-92-64-05476-9

Solomon, S., Qin, D., Manning, M., Alley, R. B., Berntsen, T., Bindoff, N. L., Chen, Z., Chidtaisong, A., Gregory, J. M., Hegerl, G. C., Heimann, M., Hewitson, B., Hoskins, B. J., Joos, F., Jouzel, J., Kattsov, V., Lohmann, U., Matsuno, T., Molina, M., Nicholls, N., Overpeck, J., Raga, G., Ramasmawy, V., Ren, J., Rusticucci, M., Somerville, R., Stocker, T. F., Whetton, P., Wood, R. A., Wratt, D., 2007, Technical Summary. 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, Cambridge University Press, Cambridge, U. K., and New York, U.S.A.

Sönmez, F. K., Kömüşçü, A. Ü., Erkan, A., Turgu, E., 2005, An Analysis of Spatial and Temporal Dimension of Drought Vulnerability in Turkey Using the Standardized Precipitation Index, Natural Hazards, vol. 35, pp. 243-264, DOI: 10.1007/s11069-004-5704-7

Stehr, N., von Storch, H., 2010, Climate and Society Climate as Resources, Climate as Risk, World Scientific Publishing Co. Pte. Ltd, Singapore

Şahin, B., 2007, Tarla Bitkileri Merkez Araştırma Enstitüsü İkizce Araştırma ve Uygulama İstasyonu'nun (Haymana/Ankara) Flora ve Vejetasyonu, Master Thesis, Ankara, Turkey

Şener, S., et al, 2007, Küresel Isınma ve Tarımda Suyun Etkili Kullanımı, III. Ulusal Su Mühendisliği Sempozyumu, İzmir, Turkey, pp. 645-654

Tayanç, M., İm, U., Doğruel, M., Karaca, M., 2009, Climate Change in Turkey for the Last Half Century, Climatic Change, vol. 94, pp. 483-502, DOI: 10.1007/s10584-008-9511-0

Tessa, B., Kurukulasuriya, P., 2010, Technologies for Climate Change Adaptation: Emerging Lessons from Developing Countries Supported by UNDP, Journal of International Affairs, vol. 64, No.1, pp. 17-30

Toprak, S., et al, 2007, İçme Suyu Dağıtım Sistemlerindeki Kayıplar, III. Ulusal Su Mühendisliği Sempozyumu, İzmir, Turkey, pp. 601-610

Toros, H., 2011, Spatio-temporal Precipitation Change Assessments over Turkey, International Journal of Climatology, DOI: 10.1002/joc.2353

Türkeş, M., 1996, Spatial and Temporal Analysis of Annual Rainfall Variations in Turkey, International Journal of Climatology, vol. 16, pp. 1057-1076

Türkeş, M., Sümer, U. M., Kılıç, G., 1996, Observed Changes in Maximum and Minimum Temperatures in Turkey, International Journal of Climatology, vol. 16, pp. 463-477

Türkeş M, Sümer, U. M., Demir, İ., Çetiner, G., 2000, Küresel İklim Değişikliği ve Olası Etkileri, Çevre Bakanlığı, Birleşmiş Milletler İklim Değişikliği Çerçeve Sözleşmesi Seminer Notları, pp. 7-24, http://www.dmi.gov.tr/iklim/iklim-degisikligi.aspx

Türkeş M, Sümer, U. M., Demir, İ., 2002, Türkiye'nin Günlük Ortalama, Maksimum ve Minimum Hava Sıcaklıkları ile Sıcaklık Genişliğindeki Eğilimler ve Değişiklikler, http://www.dmi.gov.tr/iklim/iklim-degisikligi.aspx

Türkeş, M., 2003, Spatial and Temporal Variations in Precipitation and Aridity Index Series of Turkey, Mediterranean Climate Variability and Trends, Springer-Verlag, Berlin – Heidelberg, 2003, pp.181-213

Türkeş M., Erlat E., 2005, Climatological Responses of Winter Precipitation in Turkey to Variability of the North Atlantic Oscillation during the period 1930-2001, Theoretical and Applied Climatology, vol. 81, pp. 45-69

Türkeş, M., 2008, İklim Değişikliği ve Küresel Isınma Olgusu: Bilimsel Değerlendirme, Küresel Isınma ve Kyoto Protokolü, İklim Değişikliğinin Bilimsel Ekonomik ve Politik Analizi, Bağlam Yayıncılık, Ankara, Turkey, pp. 21-57

Türkeş, M., Koç, T., Sariş, F., 2009, Spatiotemporal Variability of Precipitation Total Series over Turkey, International Journal of Climatology, vol. 29, pp. 1056-1074, DOI: 10.1002/joc.1768

Wesselink, A., de Vriend, H., Barneveld, H., Krol, M., Bijker, W., 2009, Hydrology and Hydraulic Expertise in Participatory Processes for Climate Change Adaptation in the Dutch Meuse, Water Science and Technology, vol. 60.3, p. 583-595, doi:10.2166/wst.2009.412

Yıldız, M., Özkaya, M., Uçar, İ., Ayhan, Ö., 2010, Türkiye'nin Yüzeysel Su Potansiyeli, VI. Ulusal Hidroloji Kongresi, Denizli, pp. 892-944

Yüksel, E., Eroğlu, V., Sarıkaya, H. Z., Koyuncu, İ., 2004, Current and Future Strategies for Water and Wastewater Management of İstanbul City, Environmental Management, vol. 33, No. 2, p. 186 – 195, doi: 10.1007/s00267-003-2852-6

Yüzer, M., 2011, personal communication on April 4th, 2011

Ziervogel, G., Johnston, P., Matthew, M., Mukheibir, P., 2010, Using Climate Information for Supporting Climate Change Adaptation in Water Resource Management in South Africa, Climatic Change, vol. 103, p. 537-554, doi:10.1007/s10584-009-9771-3

URL 1: http://report.tuik.gov.tr/reports/rwservlet?adnksdb2=&ENVID=adnksdb2Env&report=turkiye_il_koy_sehir.RDF&p_il1=6&p_kod=2&p_yil=2010&p_dil=1&desformat=html, last access: June, 2011

URL 2: http://www2.dsi.gov.tr/bolge/dsi5/ankara.htm, last access: March, 2011

URL 3: http://gaia.itu.edu.tr/, last access: April, 2011

URL 4: http://www.dmi.gov.tr/iklim/iklim-degisikligi.aspx?s=s1, last access: April, 2011

URL 5: http://www.ipcc-data.org/maps/, last access: March, 2012

URL 6: www.dsi.gov.tr/topraksu.htm, last access: March, 2011

URL 7: www.dsi.gov.tr/hizmet/tarim.htm, last access: March, 2011

URL 8: http://www.cankaya.bel.tr/oku.php?yazi_id=5590, last access: May, 2011

URL 9: http://www.turkiyerehberi.gen.tr/sehirler/ankara-haritasi, last access: May, 2011

URL 10: http://www.dsi.gov.tr/bolge/dsi5/ankara.htm#golet, last access: March, 2011

URL 11: http://www.aski.gov.tr/m.asp?tid=10&pn=1&tpn=1, last access: January, 2012

URL 12: http://www.radikal.com.tr/haber.php?haberno=229317, last access: May, 2012

URL 13: http://www.peyzajmimoda.org.tr/resimler/ekler/c3b1830513cc3b8_ek.pdf?tipi=2&turu=&sube=0, last access: May, 2012

URL 14: http://www.hurriyet.com.tr/gundem/18046531.asp, last access: May, 2012

URL 15: http://hurarsiv.hurriyet.com.tr/goster/haber.aspx?id=7666693&p=2, last access: January, 2012

URL16:http://www.mmo.org.tr/resimler/dosya_ekler/ed33392d3a48aa1_ek.pdf?dergi=159, last access: May, 2012

URL 17: http://www.asgariucret.org/, last access: May, 2012

URL 18: http://www.aski.gov.tr/Yukle/Resim/tarife_27-08-2009.gif, last access: May, 2012

Appendices

Appendix A	Results of PRECIS Climate Model
Appendix B	Results of ECHAM5 A2 and ECHAM5 B2 Climate Models
Appendix C	Summary of Regional Model Results for Turkey
Appendix D	Map of Sakarya Watershed
Appendix E	Map of Kızılırmak Watershed
Appendix F	Layout of Meteorological and Streamflow Gauging Stations
Appendix G	Results of PRUDENCE Project

Appendix A Results of PRECIS Climate Model

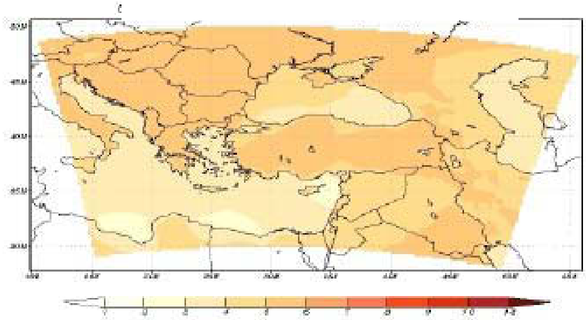


Figure 1a. Average Temperature Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (°C)

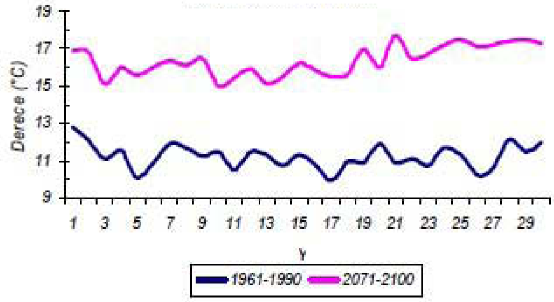


Figure 1b. Average Temperature Difference During 2071-2100 and 1961-1990 According to HadAMP3 A2 Scenario

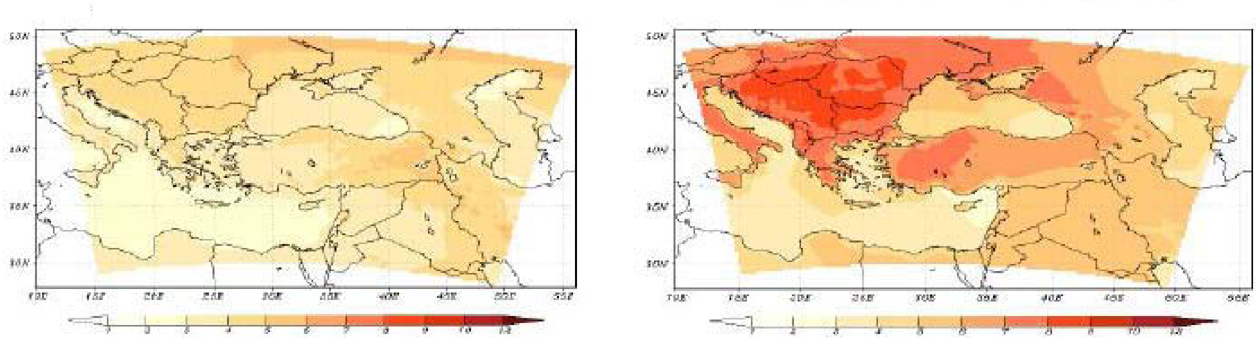


Figure 2. Winter (left) and Summer (right) Average Temperature Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (°C)

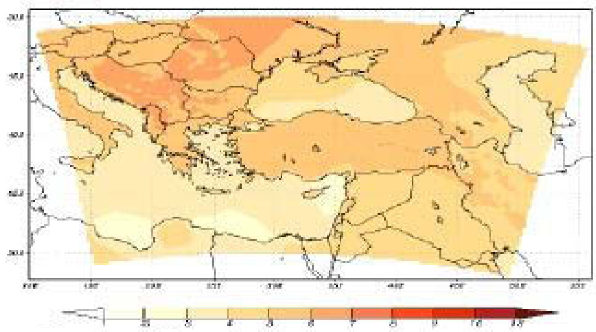


Figure 3a. Maximum Temperature Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (°C)

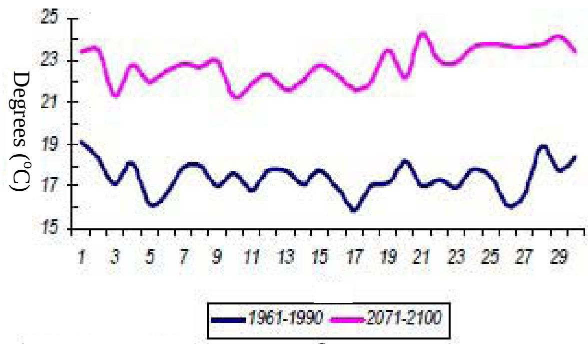


Figure 3b. Maximum Temperature Difference During 2071-2100 and 1961-1990 According to HadAMP3 A2 Scenario

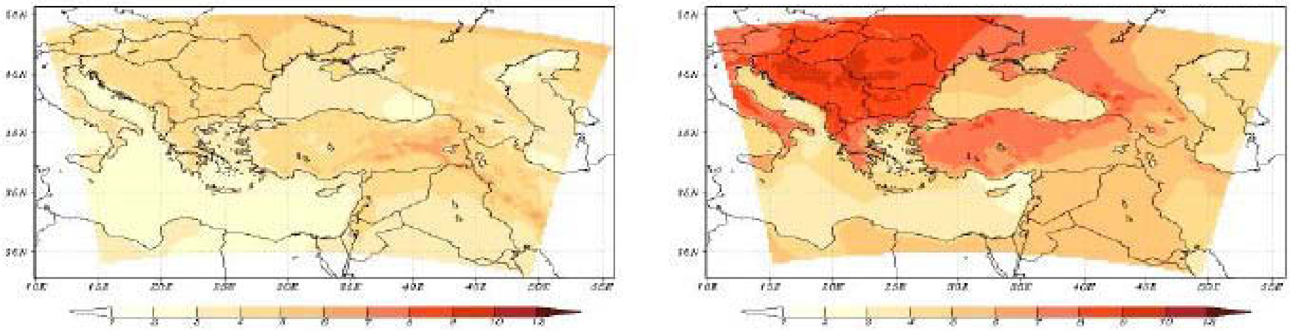


Figure 4. Winter (left) and Summer (right) Average Maximum Temperature Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (^oC)

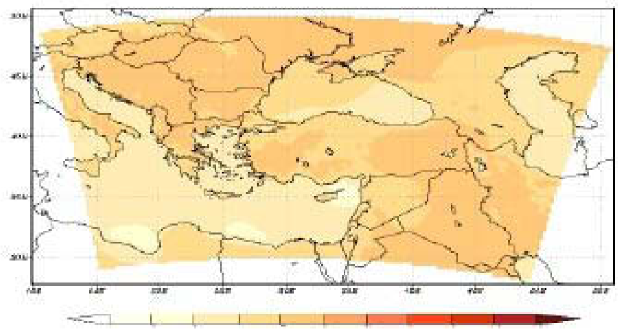


Figure 5a. Minimum Temperature Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (^oC)

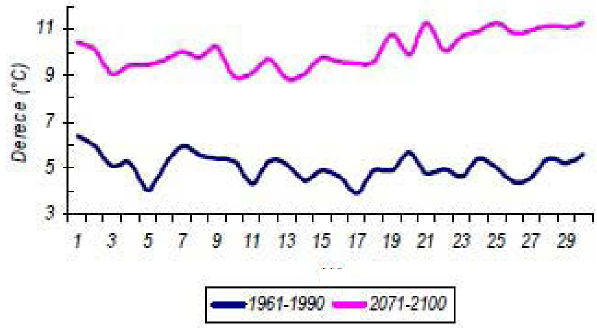


Figure 5b. Minimum Temperature Difference During 2071-2100 and 1961-1990 According to HadAMP3 A2 Scenario

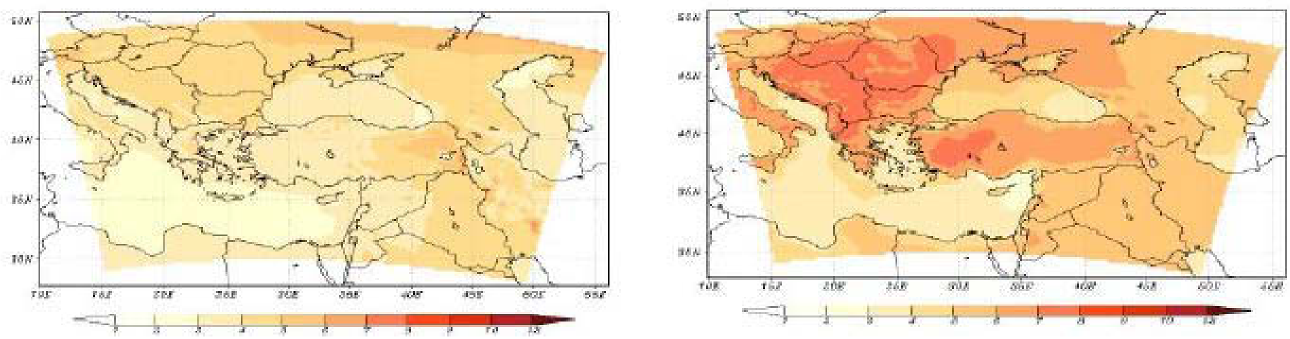


Figure 6. Winter (left) and Summer (right) Average Minimum Temperature Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (^oC)

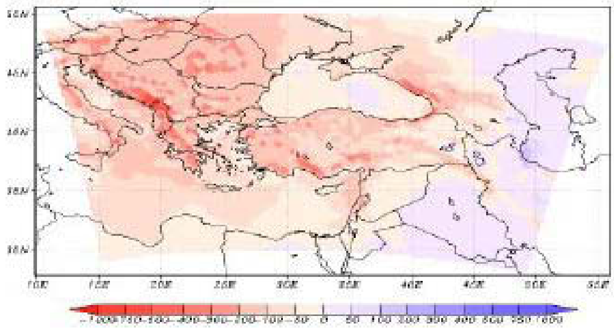


Figure 7a. Annual Total Precipitation Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (mm/a)

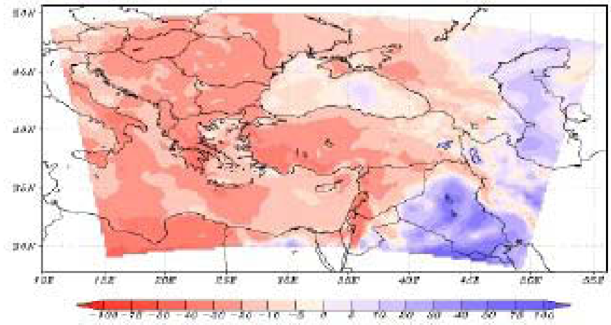
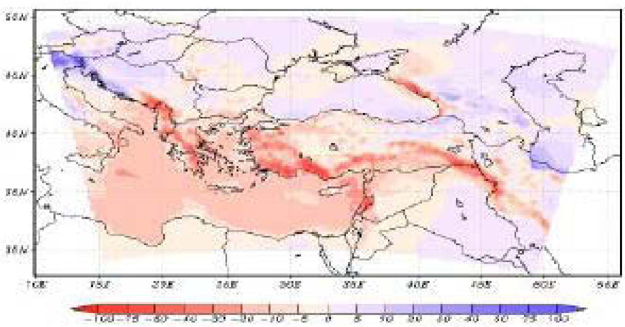


Figure 7b. Annual Total Precipitation Difference Rate During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (%)



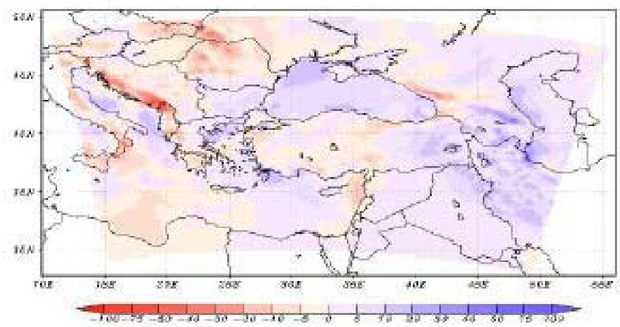


Figure 8. Winter (left) and Summer (right) Precipitation Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (mm/a)

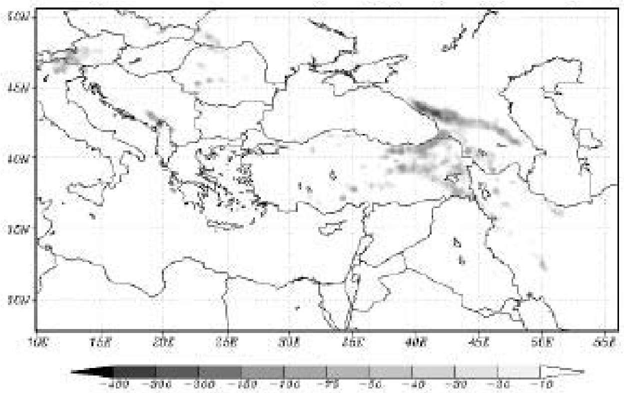


Figure 9a. Winter Snow Cover Difference During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (mm)

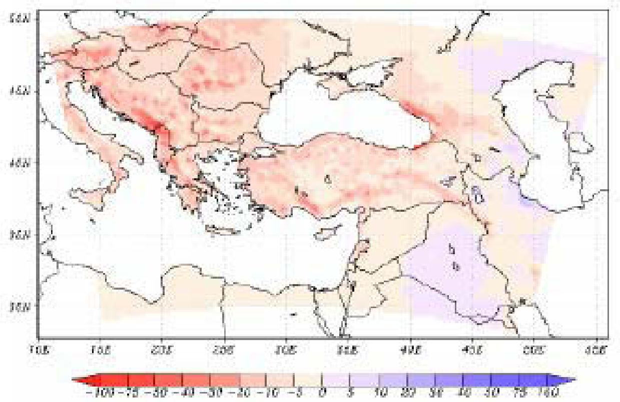
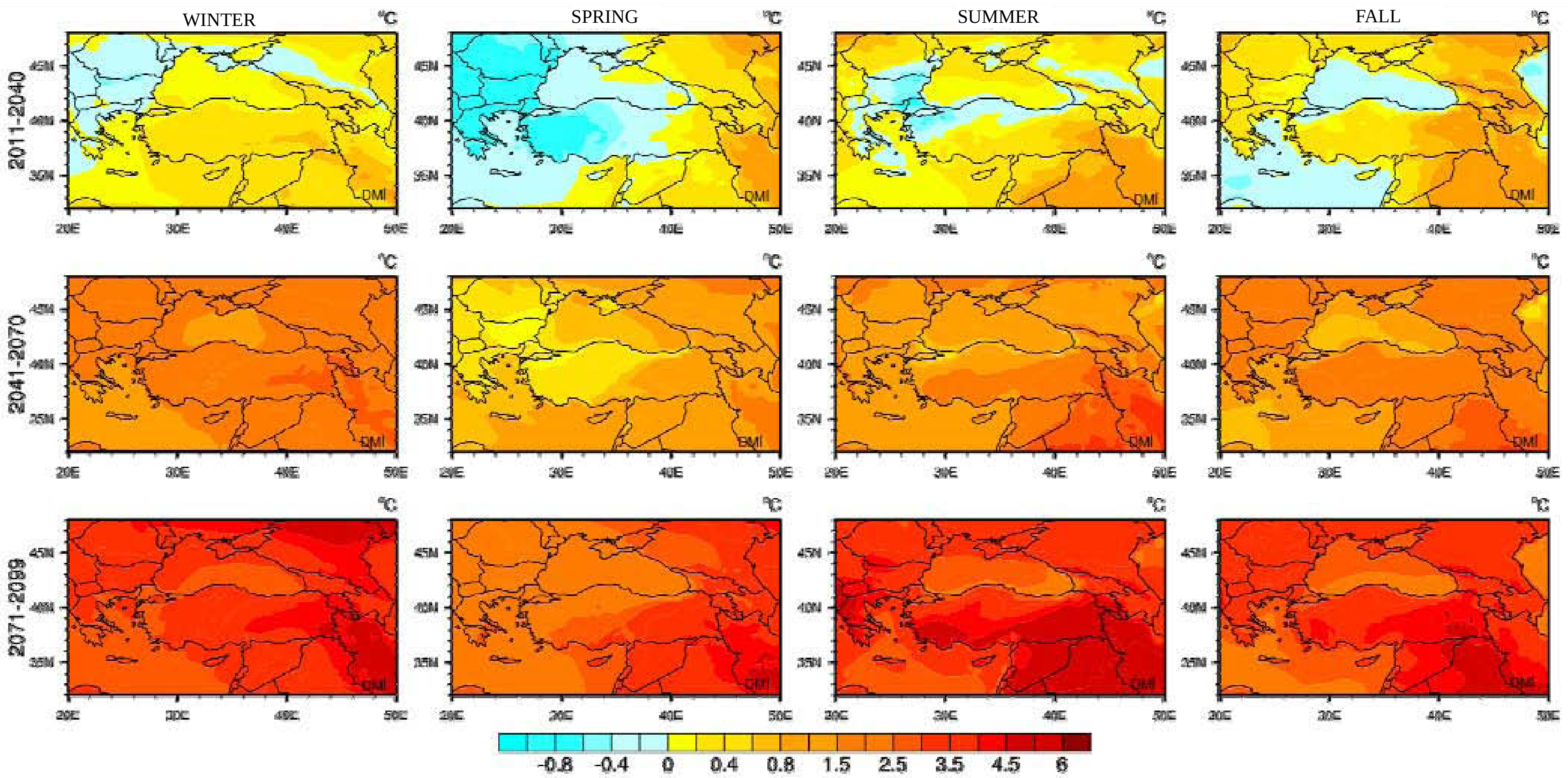


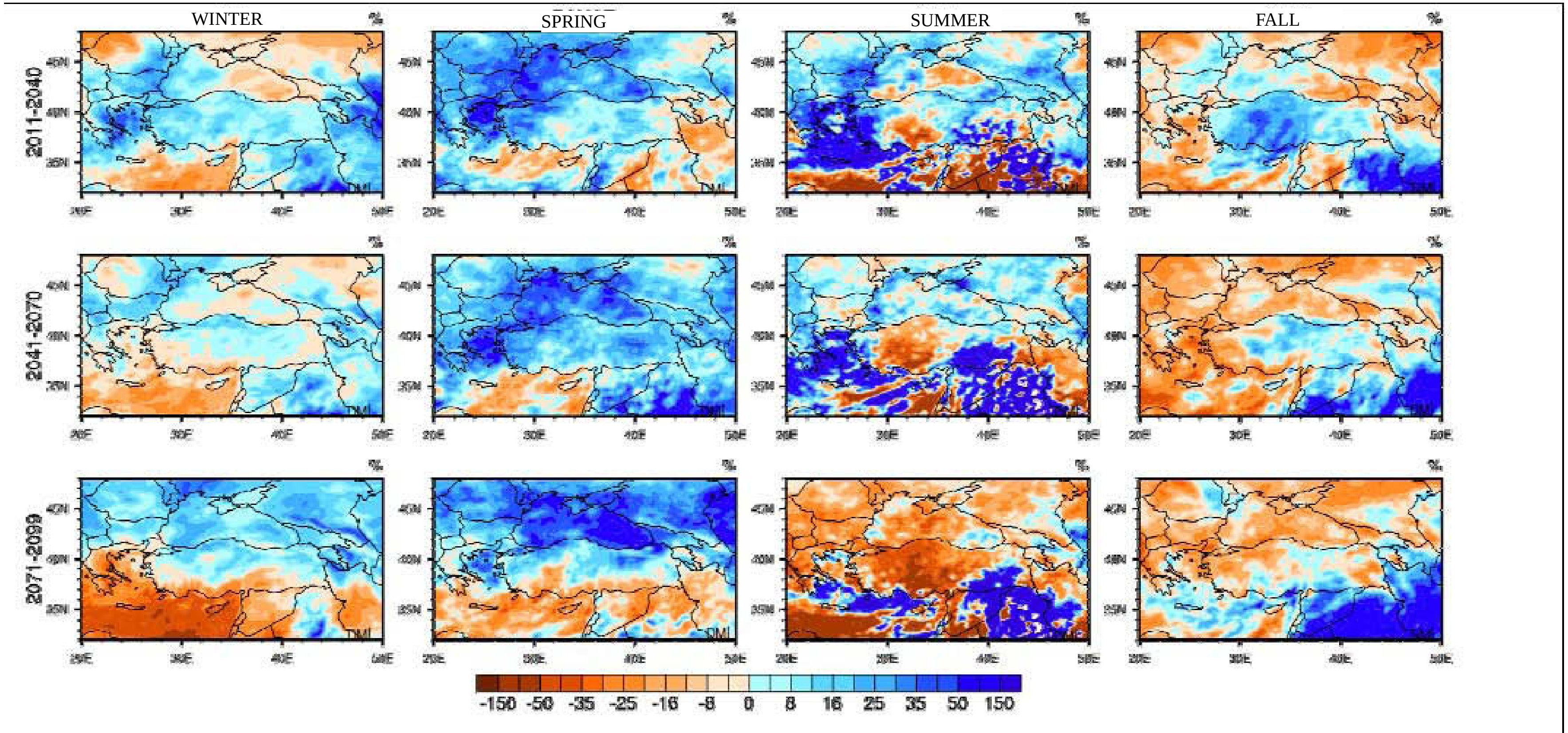
Figure 9b. Annual Average Precipitation-Evaporation Difference Rate During 2071-2100 than 1961-1990 According to HadAMP3 A2 Scenario (mm/month)

Appendix B Results of ECHAM5 A2 and ECHAM5 B1 Model Results

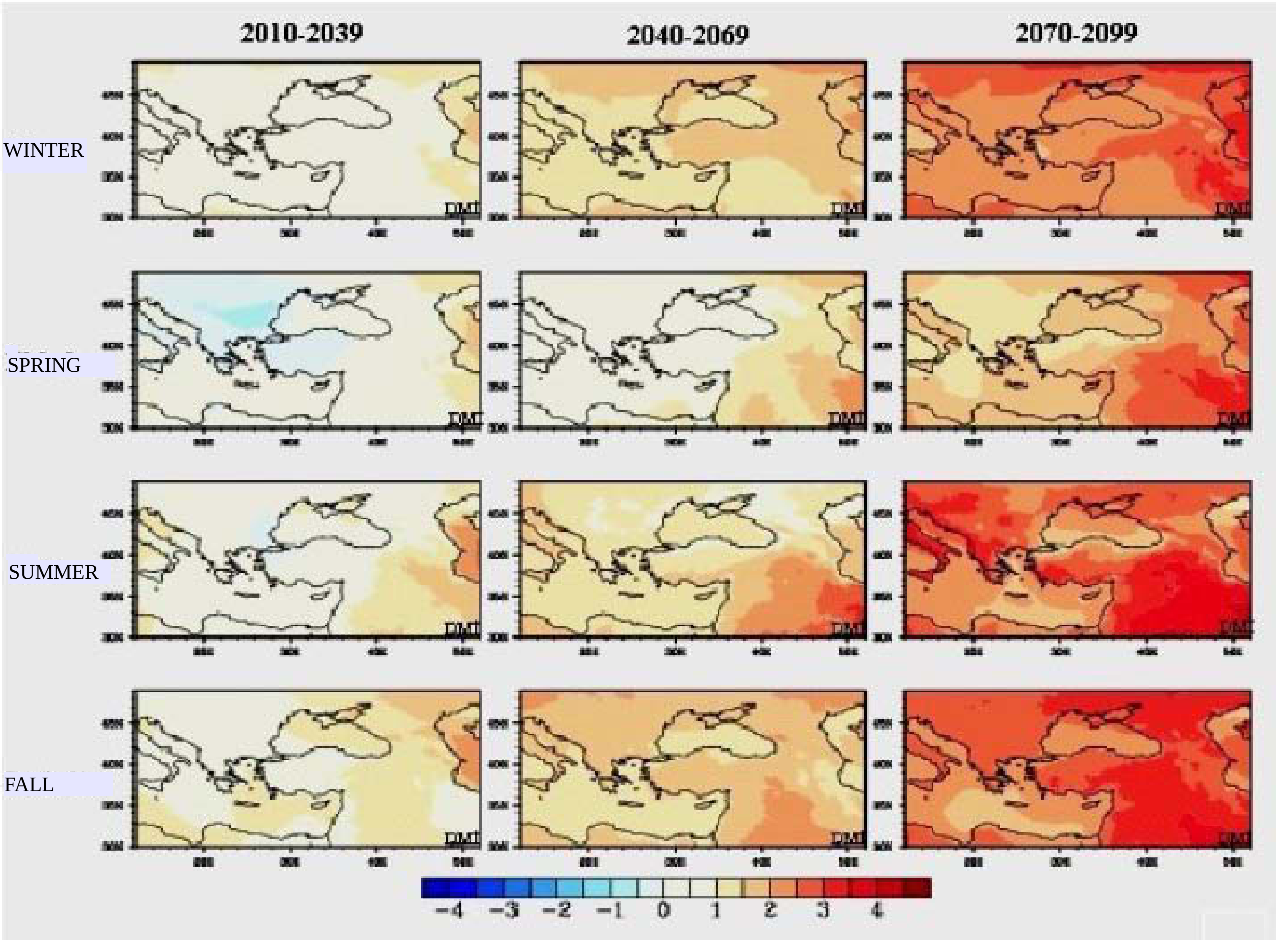
Seasonal temperature changes for Turkey (^oC) obtained by downscaling ECHAM5 global climate model results for A2 scenario according to RegCM3 regional climate model. The results were obtained by comparing the differences at 2011-2099 in 30-year-periods with reference period 1961-1990.



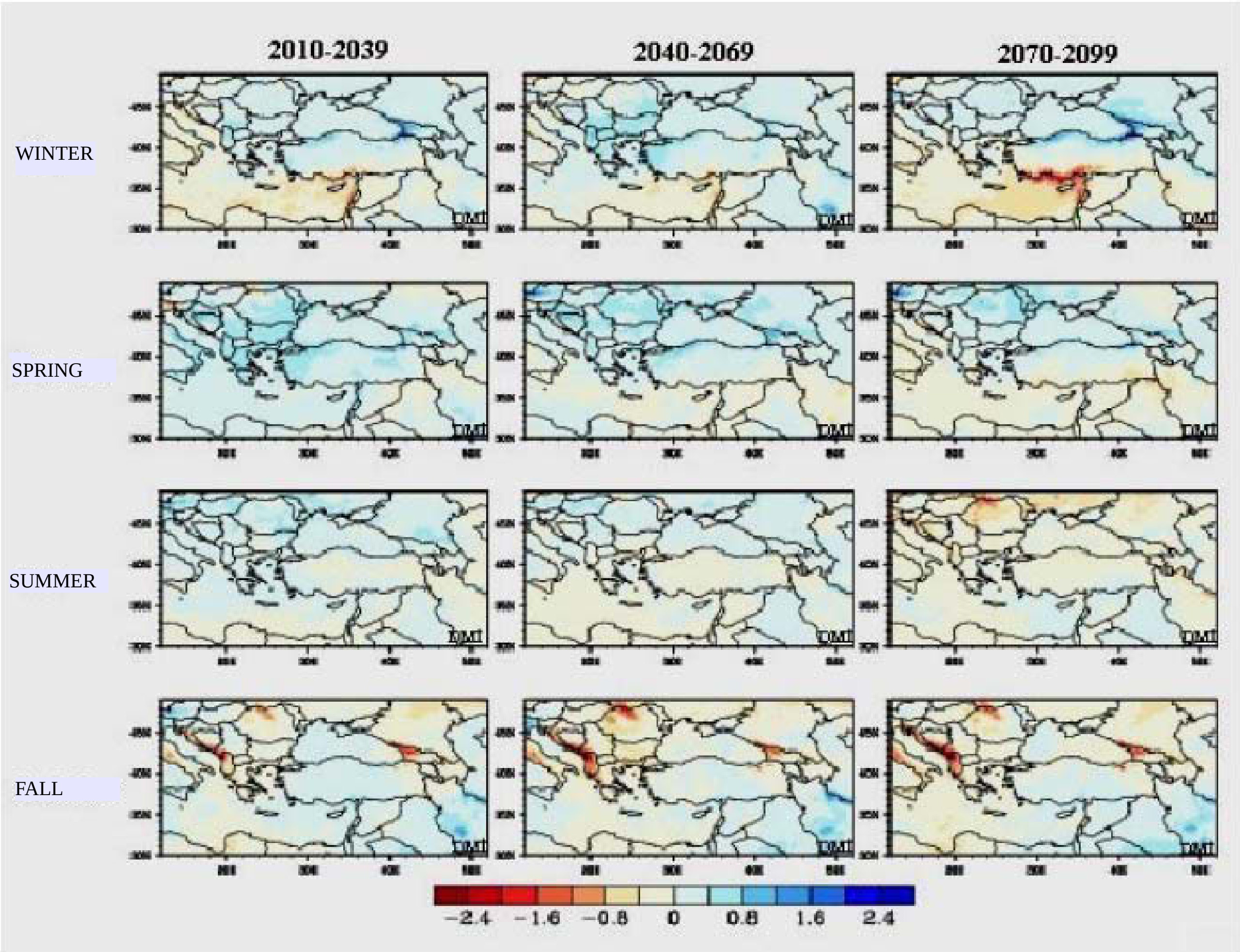
Seasonal total precipitation changes for Turkey (%) obtained by downscaling ECHAM5 global climate model results for A2 scenario according to RegCM3 regional climate model. The results were obtained by comparing the differences at 2011-2099 in 30-year-periods with reference period 1961-1990.



Seasonal temperature changes for Turkey (°C) obtained by downscaling ECHAM5 global climate model results for B1 scenario according to RegCM3 regional climate model. The results were obtained by comparing the differences at 2010-2099 in 30-year-periods with reference period 1961-1990.

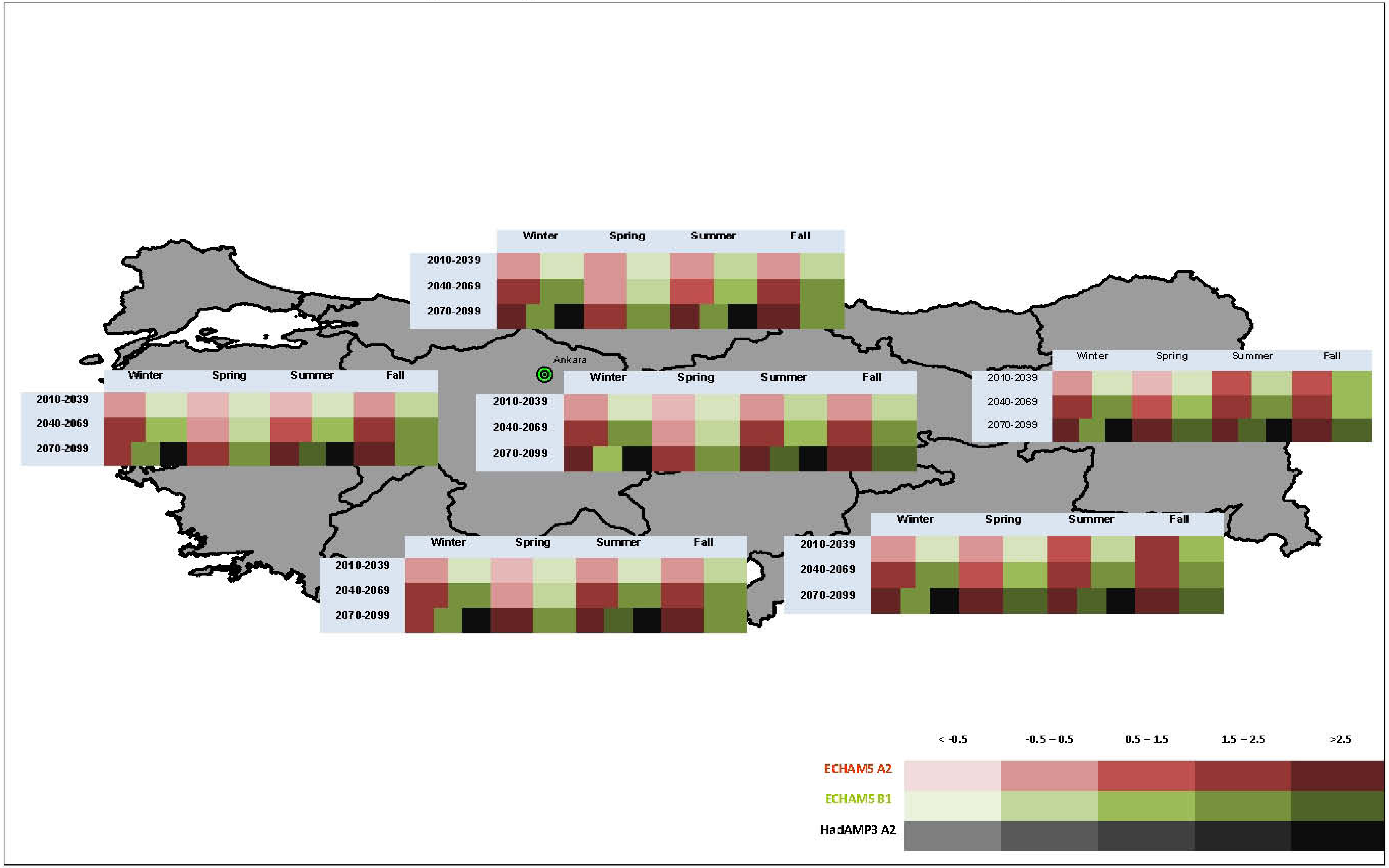


Seasonal total precipitation changes for Turkey (mm/day) obtained by downscaling ECHAM5 global climate model results for B1 scenario according to RegCM3 regional climate model. The results were obtained by comparing the differences at 2010-2099 in 30-year-periods with reference period 1961-1990.

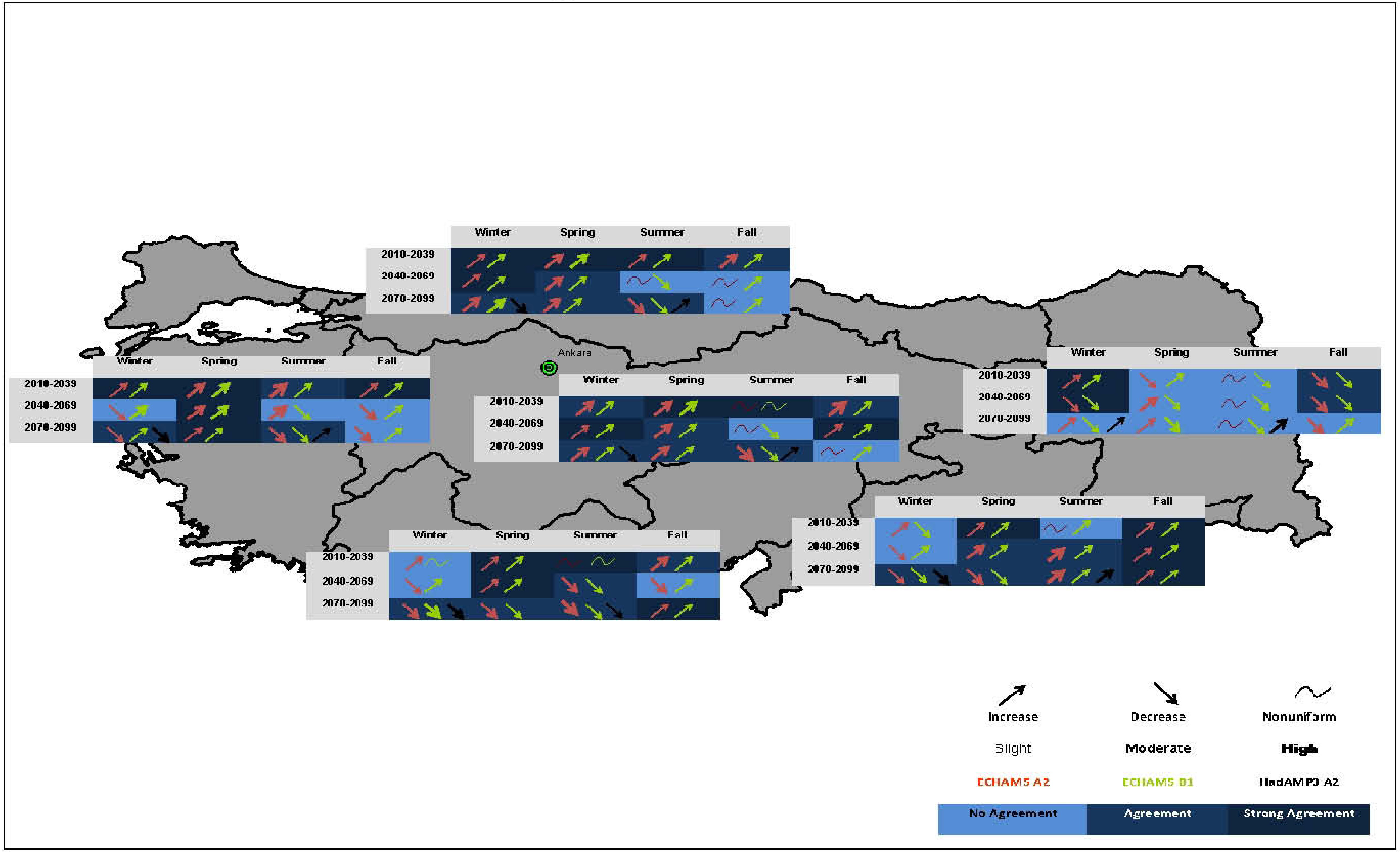


Appendix C Summary of Regional Model Results for Turkey

Summary of Regional Model Results for Temperature (C)

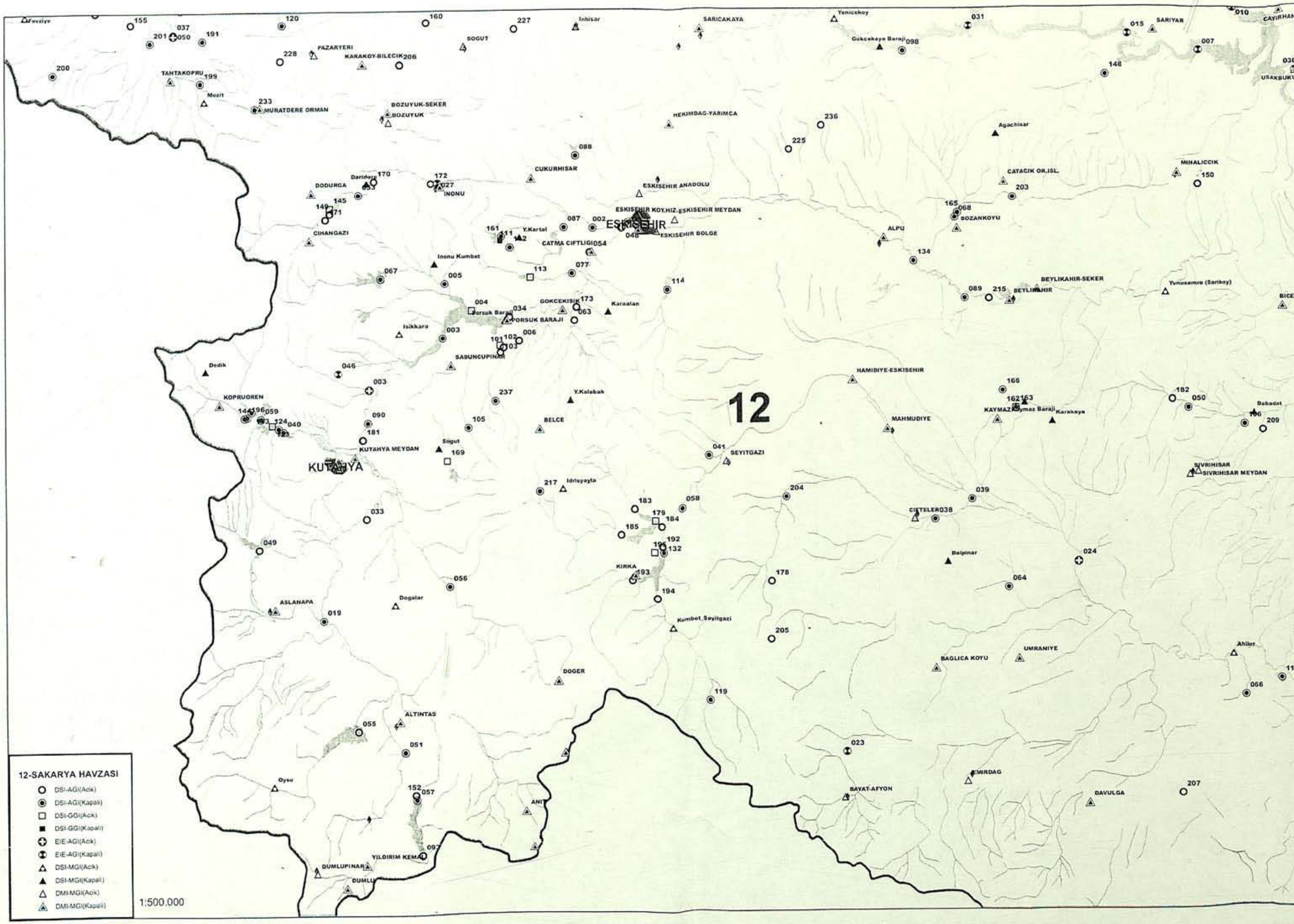


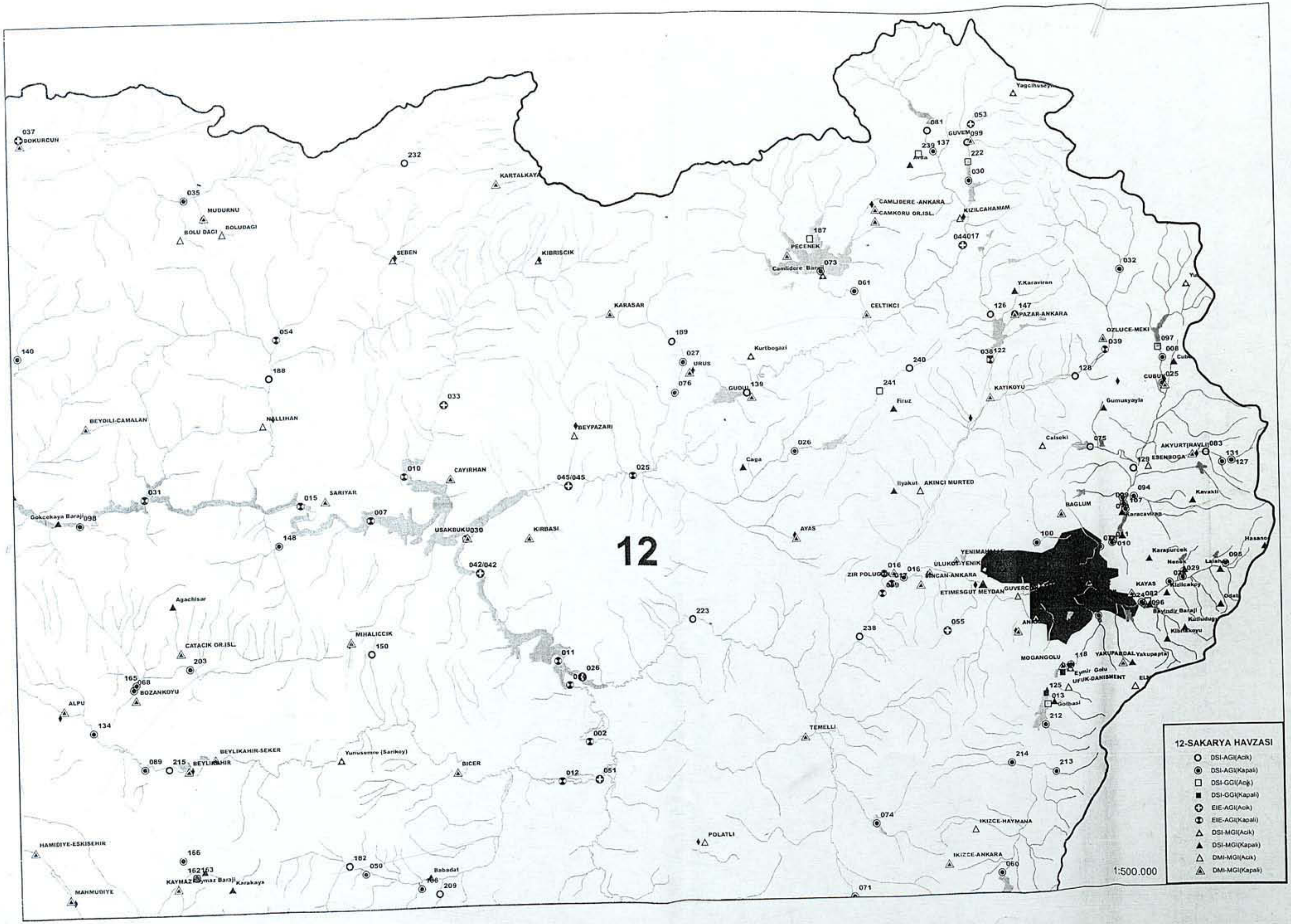
Summary of Regional Model Results for Precipitation



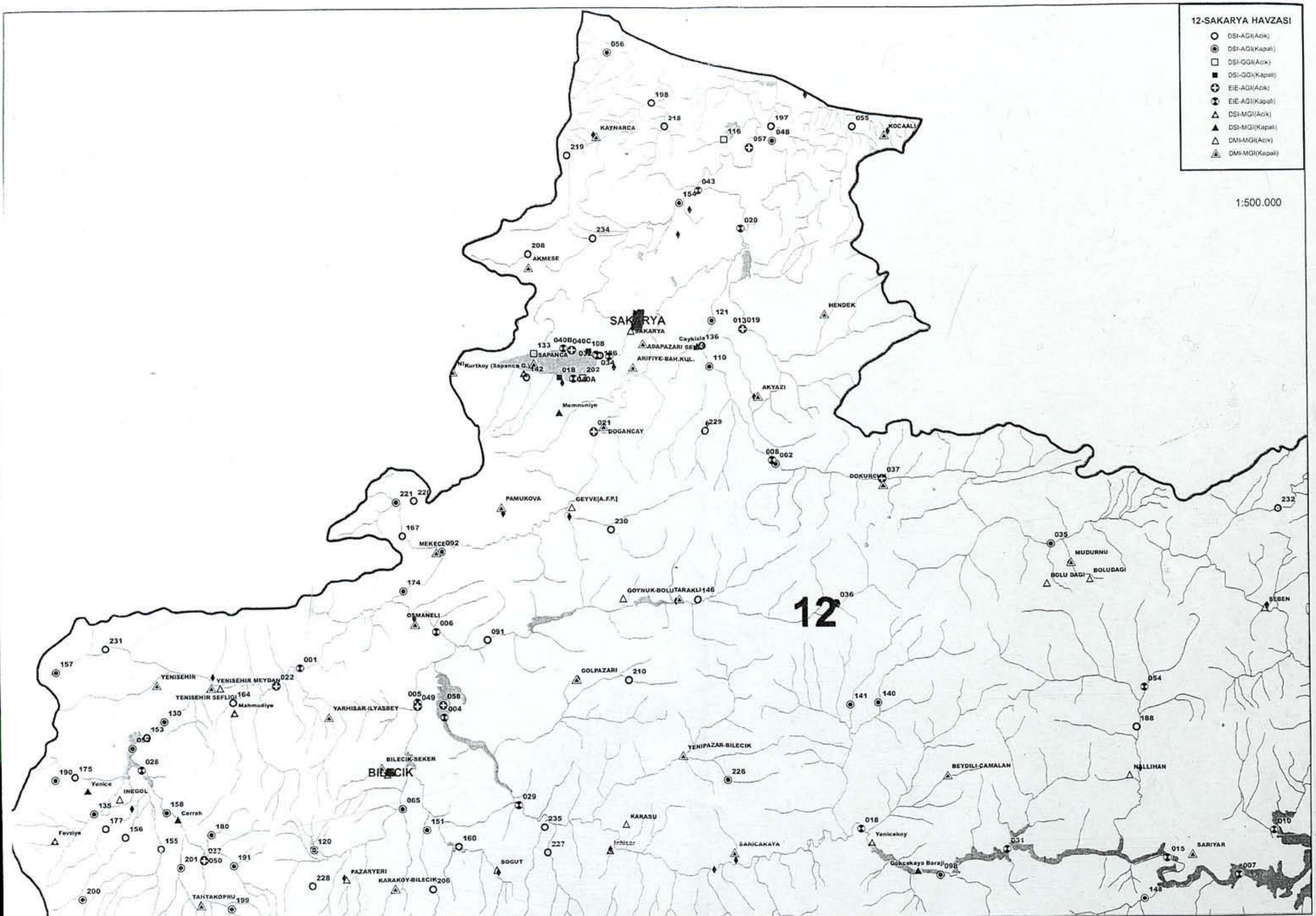
Appendix D Map of Sakarya Watershed


12
12-SAKARYA HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:600.000
SIVRIHISAR
HAYMANA
Emirler
YENIMEHMETU
GUNYUZU-KOZAGACI
Gumuskonak (Yorme)
CIFTELER038
Belpinar
Kirazlioglu
POLATLI TAR.ISL.
Ahiler
BAGLICA KOYU
UMRANIYE
Seyhler138
Kumbet_Seyitgazi
KIRKA
Dogalar
DOGER
ALTINTAS
YILDIRIM KEM
BAYAT-AFYON
EMIRDAG
DAVULGA
CELTIK
Adakasim
YUNAK
ALTINOVA TAR.ISL.
TURGUT-KONYA
CESMELISEBIL
Buyukoba
GOZLU TAR.ISL.
KONUKLAR D.U.C.
SARAY
KADINHANI
ILGIN
ARGITHANI
DOGANHISAR
ASAGICIGIL

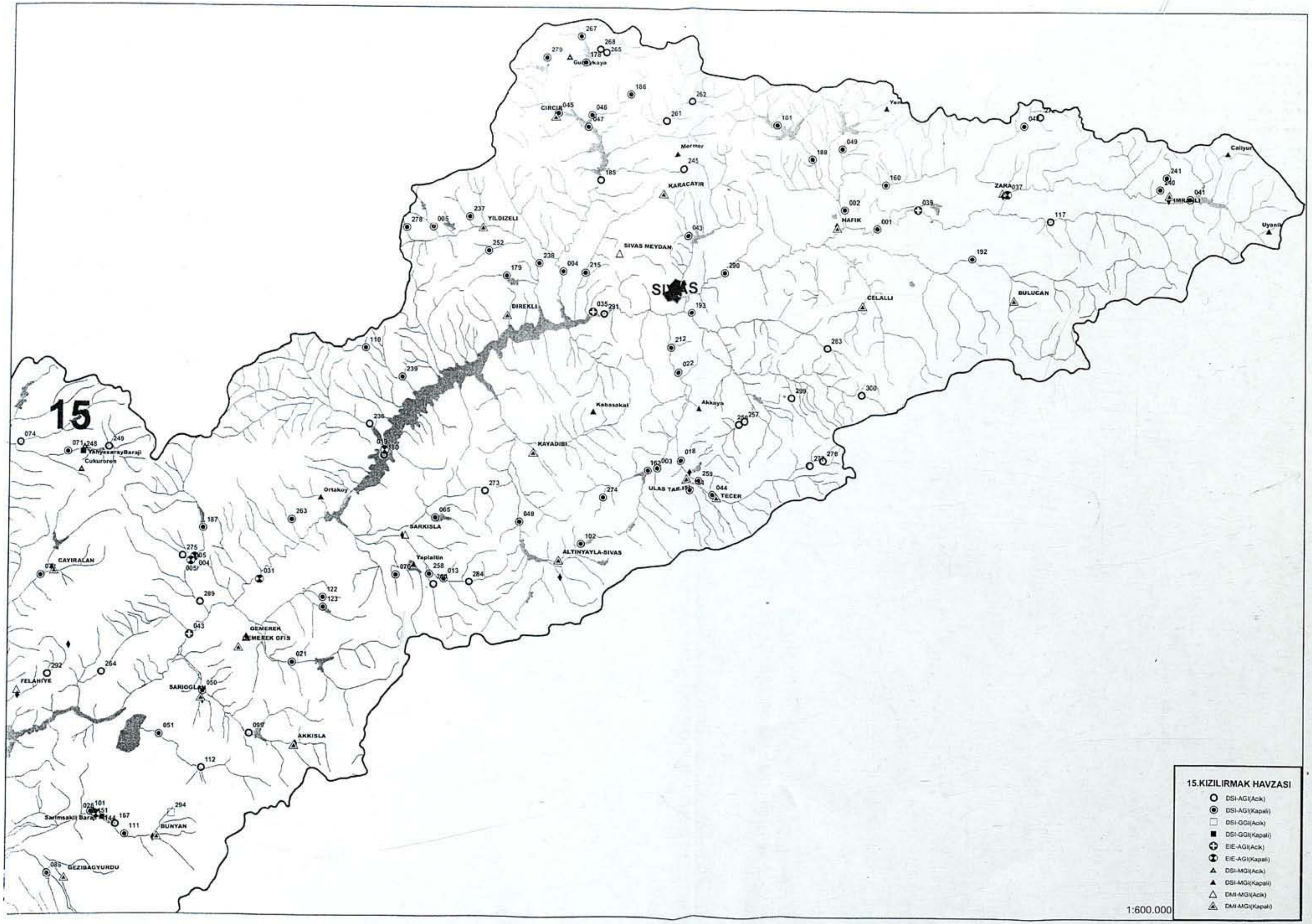

12-SAKARYA HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:500.000
12
ESKISEHIR
KUTAHYA
PAZARYERI
KARAKOY-BILECIK
TAHTAKOPRU
MURATDERE ORMAN
BOZUYUK-SEKER
BOZUYUK
SOGUT
Inhisar
SARICAKAYA
Yenicekoy
Gokcekaya Baraji
SARIYAR
CAYIRHAN
USAKBUKU
HEKIMDAG-YARIMCA
Agachisar
CUKURHISAR
DODURGA
CIHANGAZI
INONU
ESKISEHIR ANADOLU
ESKISEHIR KOY.HIZ.
ESKISEHIR MEYDAN
ESKISEHIR BOLGE
Y.Kartal
CATMA CIFTLIGI
Inonu Kumbet
MIHALICCIK
CATACIK OR.ISL.
BOZANKOYU
ALPU
BEYLIKAHIR-SEKER
Yunusemre (Sarikoy)
GOKCEKISIK
Porsuk Baraji
PORSUK BARAJI
Karaalan
Isikkara
SABUNCUPINAR
Dedik
KOPRUOREN
Y.Kalabak
BELCE
HAMIDIYE-ESKISEHIR
MAHMUDIYE
Karakaya
Babadat
KUTAHYA MEYDAN
Sogut
SEYITGAZI
Idrisyayla
SIVRIHISAR
SIVRIHISAR MEYDAN
CIFTELER
Belpinar
KIRKA
ASLANAPA
Dogalar
Kumbet_Seyitgazi
UMRANIYE
BAGLICA KOYU
Ahiler
DOGER
ALTINTAS
EMIRDAG
BAYAT-AFYON
DAVULGA
Oysu
DUMLUPINAR
YILDIRIM KEMAL

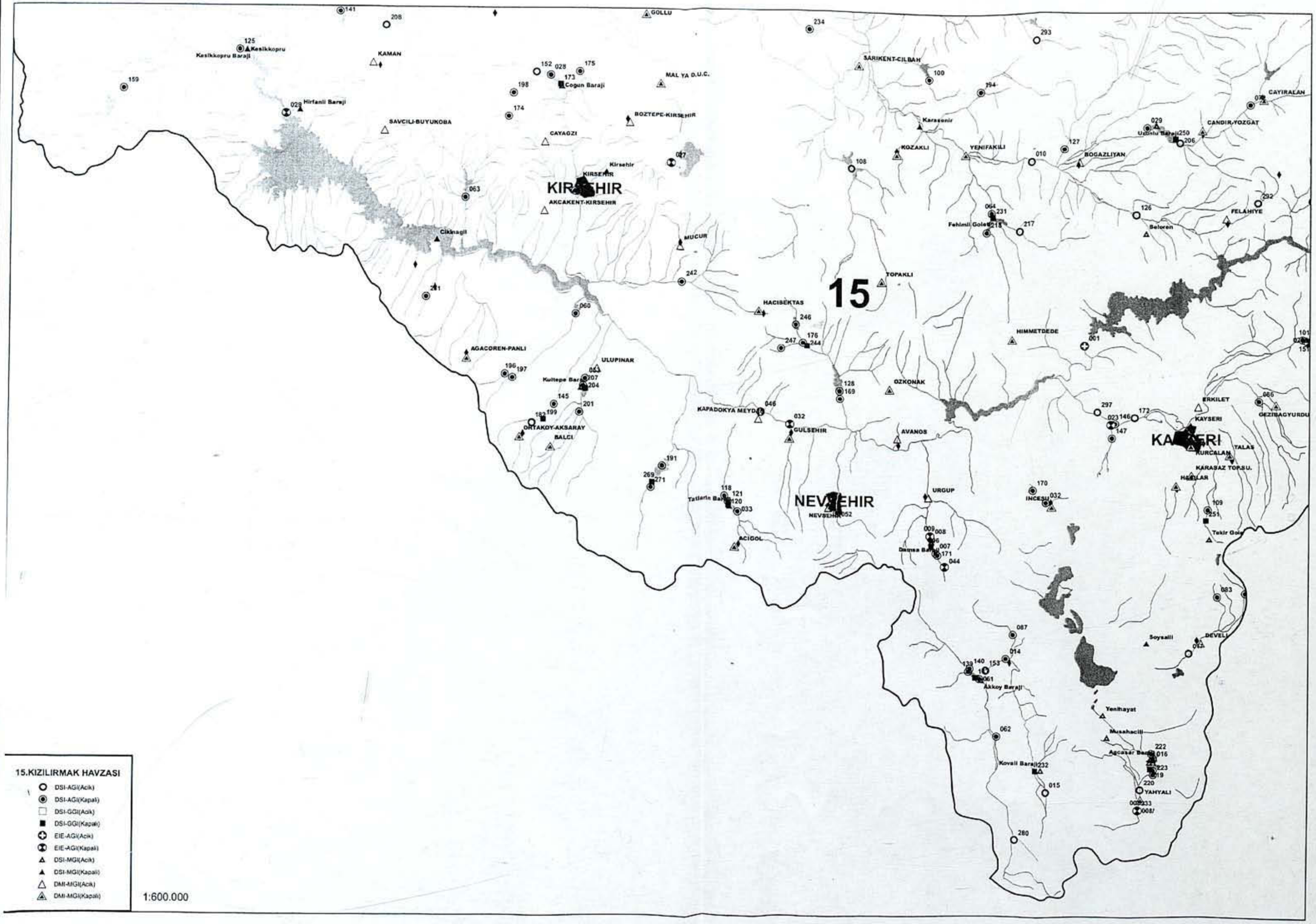


12-SAKARYA HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:500.000
12
SOKURCUN
MUDURNU
BOLU DAGI
BOLUDAGI
KARTALKAYA
SEBEN
KIBRISCIK
KARASAR
URUS
GUDUL
PECENEK
Camlidere Baraji
CAMLIDERE -ANKARA
CAMKORU OR.ISL.
KIZILCAHAMAM
CELTIKCI
Kurtbogazi
PAZAR-ANKARA
Y.Karaviran
KAYIKOYU
OZLUCE-MEKI
Gumusyayla
Firuz
BEYDILI-CAMALAN
NALLIHAN
BEYPAZARI
CAYIRHAN
SARIYAR
Gokcekaya Baraji
USAKBUKU
KIRBASI
Caga
Iiyakut
AKINCI MURTED
AYAS
BAGLUM
Calseki
ESENBOGA
Kavakli
Karacaviran
Karapurcek
KAYAS
Kizilcakoy
Bayindir Baraji
Kutludugun
Hasanoglan
YENIMAHALLE
ZIR POLUGU
SINCAN-ANKARA
ETIMESGUT MEYDAN
Agachisar
MIHALICCIK
CATACIK OR.ISL.
BOZANKOYU
ALPU
MOGANGOLU
Eymir Golu
UFUK-DANISMENT
Yakupabdal
Golbasi
TEMELLI
BEYLIKAHIR-SEKER
BEYLIKAHIR
Yunusemre (Sarikoy)
BICER
POLATLI
IKIZCE-HAYMANA
IKIZCE-ANKARA
HAMIDIYE-ESKISEHIR
MAHMUDIYE
KAYMAZ
Kaymaz Baraji
Karakaya
Babadat

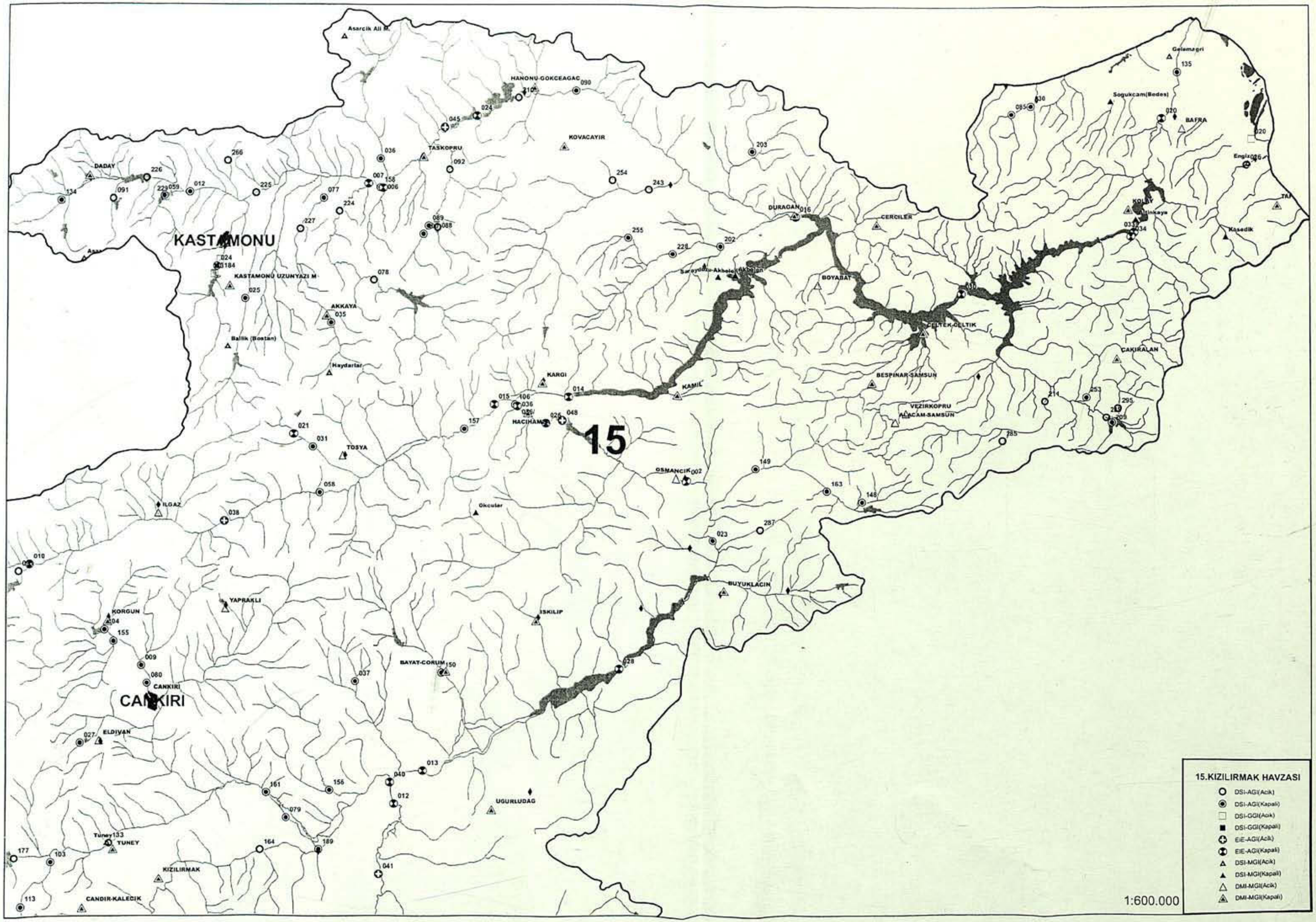

12-SAKARYA HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:500.000
12
SAKARYA
BILECIK
KAYNARCA
KOCAALI
AKMESE
HENDEK
SAPANCA
ADAPAZARI
ARIFIYE-BAH.KUL.
Caykisla
AKYAZI
Memnuniye
DOGANCAY
DOKURCUN
PAMUKOVA
GEYVE[A.F.P.]
MEKECE
MUDURNU
BOLU DAGI
BOLUDAGI
GOYNUK-BOLU
TARAKLI
OSMANELI
SEBEN
YENISEHIR
YENISEHIR MEYDAN
YENISEHIR SEFLIGI
Mahmudiye
YARHISAR-ILYASBEY
GOLPAZARI
BILECIK-SEKER
YENIPAZAR-BILECIK
BEYDILI-CAMALAN
NALLIHAN
Yenice
INEGOL
Cerrah
Fevziye
KARASU
Yenicekoy
SARICAKAYA
Gokcekaya Baraji
SARIYAR
SOGUT
PAZARYERI
KARAKOY-BILECIK
TAHTAKOPRU

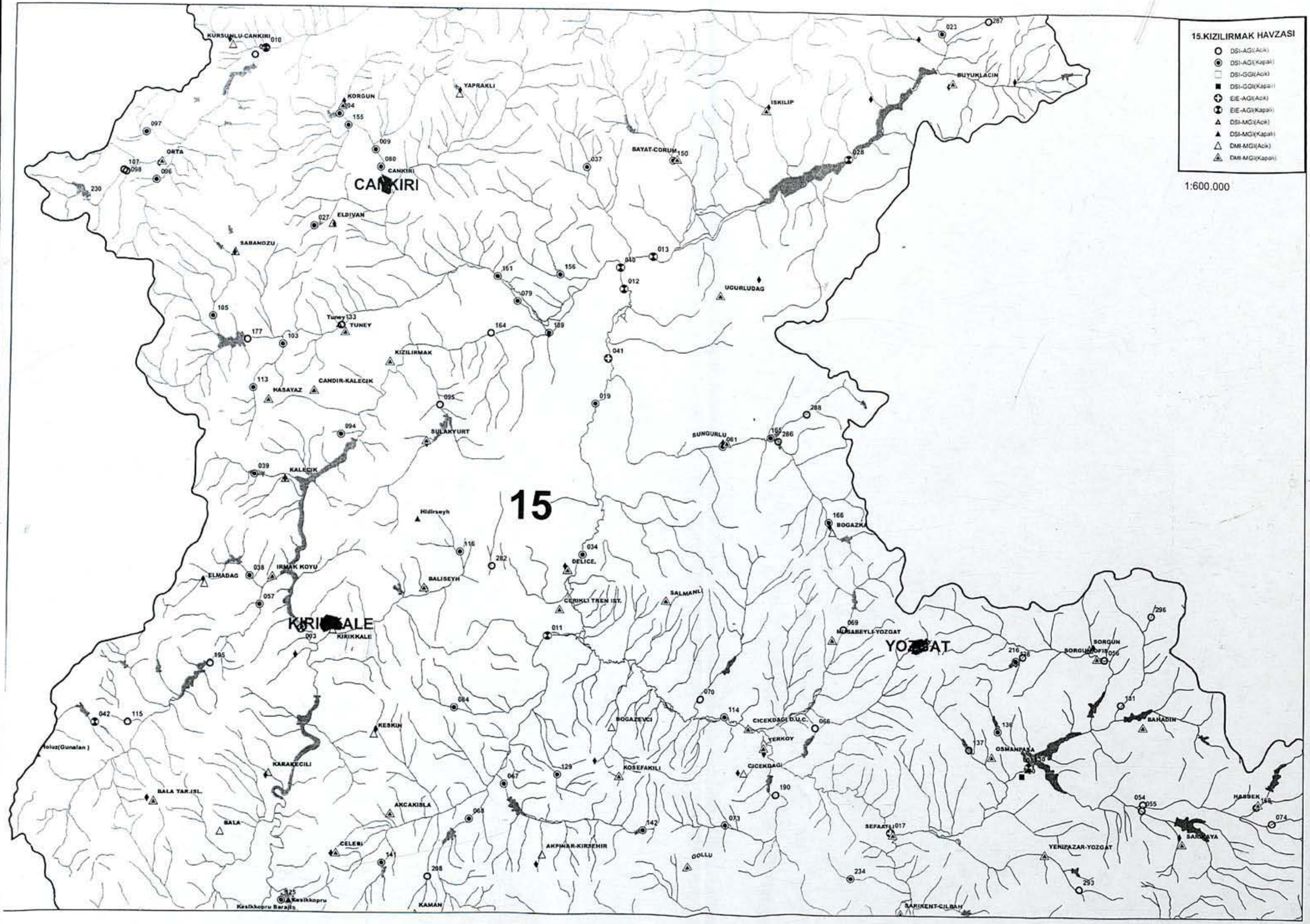
Appendix E Map of Kızılırmak Watershed


15
SIVAS
YILDIZELI
CIRCIR
KARACAYIR
SIVAS MEYDAN
HAFIK
ZARA
IMRANLI
CELALLI
BULUCAN
DIREKLI
KAYADIBI
ULAS TAR.
TECER
SARKISLA
Yapialtin
ALTINYAYLA-SIVAS
Ortakoy
Kabasakal
Akkaya
Mermer
Caliyurt
CAYIRALAN
GEMEREK
GEMEREK OFIS
SARIOGLAN
AKKISLA
FELAHIYE
Sarimsakli Baraji
BUNYAN
GEZIBAGYURDU
YahyasarayBaraji
Cukuroren
15.KIZILIRMAK HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:600.000



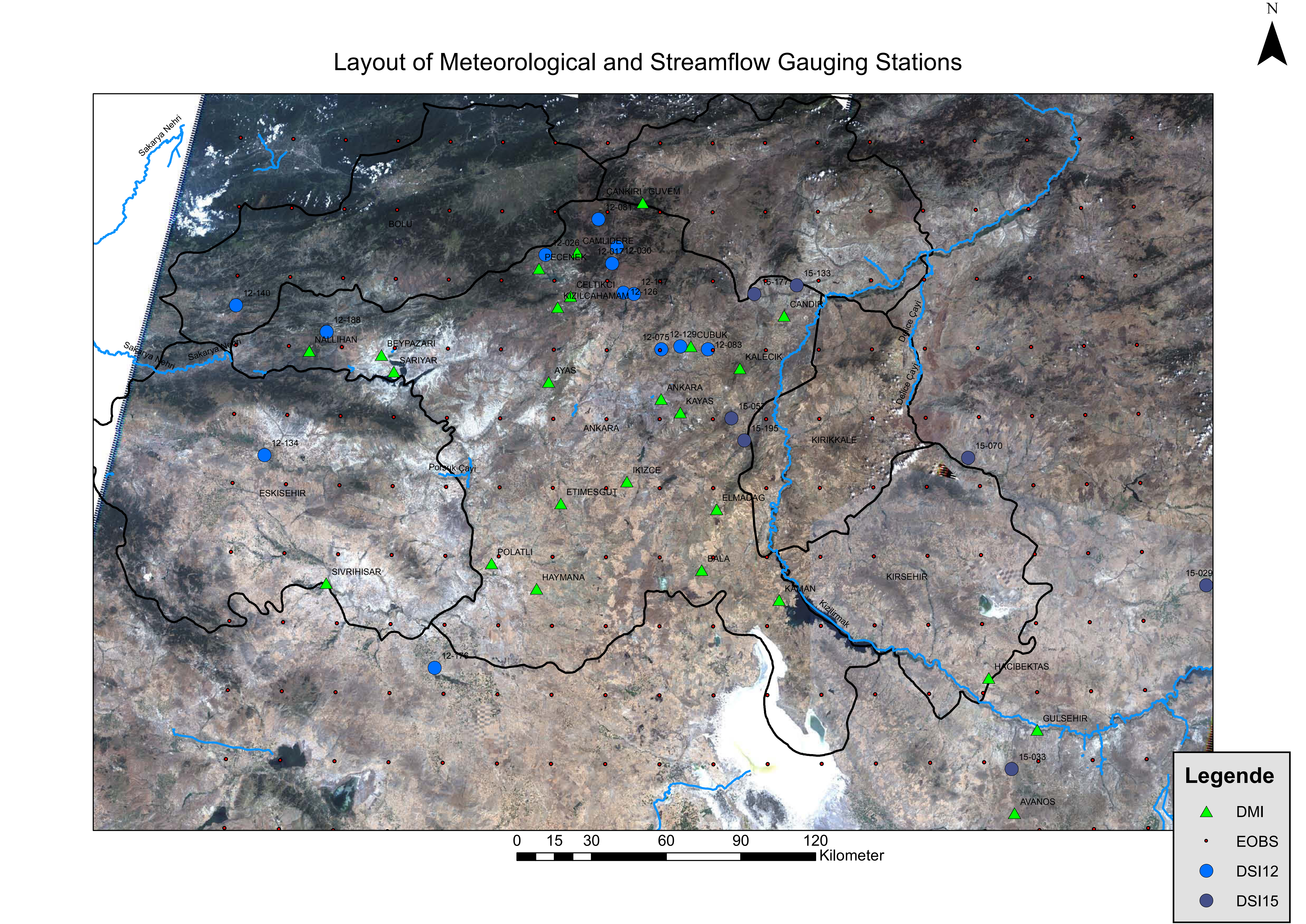
15.KIZILIRMAK HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:600.000
15
KIRSEHIR
NEVSEHIR
KAYSERI
KAMAN
GOLLU
Kesikkopru
Kesikkopru Baraji
Hirfanli Baraji
SAVCILI-BUYUKOBA
CAYAGZI
Cogun Baraji
MAL YA D.U.C.
BOZTEPE-KIRSEHIR
AKCAKENT-KIRSEHIR
Cikinagil
MUCUR
AGACOREN-PANLI
ULUPINAR
Kultepe Baraji
ORTAKOY-AKSARAY
BALCI
HACIBEKTAS
KAPADOKYA MEYDANI
GULSEHIR
OZKONAK
AVANOS
URGUP
Tatlarin Baraji
ACIGOL
Damsa Baraji
SARIKENT-CILBAH
Karasenir
KOZAKLI
YENIFAKILI
TOPAKLI
Fehimli Golet
HIMMETDEDE
BOGAZLIYAN
Uzunlu Baraji
CANDIR-YOZGAT
CAYIRALAN
FELAHIYE
Seloren
ERKILET
GEZIBAGYURDU
TALAS
KURCALAN
KARASAZ TOP.SU.
HASILAR
Tekir Golet
INCESU
DEVELI
Soysalli
Akkoy Baraji
Yenihayat
Musahacili
Agcasar Baraji
Kovali Baraji
YAHYALI


15
KASTAMONU
DADAY
TASKOPRU
KOVACAYIR
HANONU-GOKCEAGAC
KASTAMONU UZUNYAZI M
AKKAYA
Ballik (Bostan)
Haydarlar
KARGI
HACIHAMZA
TOSYA
ILGAZ
Okcular
OSMANCIK
KAMIL
DURAGAN
CERCILER
BOYABAT
CELTEK-CELTIK
BESPINAR-SAMSUN
VEZIRKOPRU
ALACAM-SAMSUN
CAKIRALAN
BAFRA
Gelemzgri
Sogukcam(Bedes)
Kasedik
BUYUKLACIN
YAPRAKLI
KORGUN
ISKILIP
BAYAT-CORUM
CANKIRI
ELDIVAN
UGURLUDAG
TUNEY
KIZILIRMAK
CANDIR-KALECIK
15.KIZILIRMAK HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:600.000


15.KIZILIRMAK HAVZASI
DSI-AGI(Acik)
DSI-AGI(Kapali)
DSI-GGI(Acik)
DSI-GGI(Kapali)
EIE-AGI(Acik)
EIE-AGI(Kapali)
DSI-MGI(Acik)
DSI-MGI(Kapali)
DMI-MGI(Acik)
DMI-MGI(Kapali)
1:600.000
15
CANKIRI
KIRIKKALE
YOZGAT
KURSUNLU-CANKIRI
KORGUN
YAPRAKLI
ISKILIP
BUYUKLACIN
ORTA
ELDIVAN
SABANOZU
BAYAT-CORUM
UGURLUDAG
TUNEY
KIZILIRMAK
CANDIR-KALECIK
HASAYAZ
SULAKYURT
SUNGURLU
KALECIK
Hidirseyh
BOGAZKALE
ELMADAG
IRMAK KOYU
BALISEYH
DELICE
CERIKLI TREN IST.
SALMANLI
BEKISARAYLI-YOZGAT
SORGUN
SORGUN OFIS
KESKIN
BOGAZEVCI
CICEKDAGI D.U.C.
YERKOY
CICEKDAGI
OSMANPASA
BAHADIN
KARAKECILI
BALA TAR.ISL.
BALA
KOSEFAKILI
AKCAKISLA
CELEBI
AKPINAR-KIRSEHIR
GOLLU
SEFAATLI
YENIPAZAR-YOZGAT
SARIKAYA
HASBEK
KAMAN
Kesikkopru
Kesikkopru Barajı
SARIKENT-CILBAH
Holuz(Gunalan)

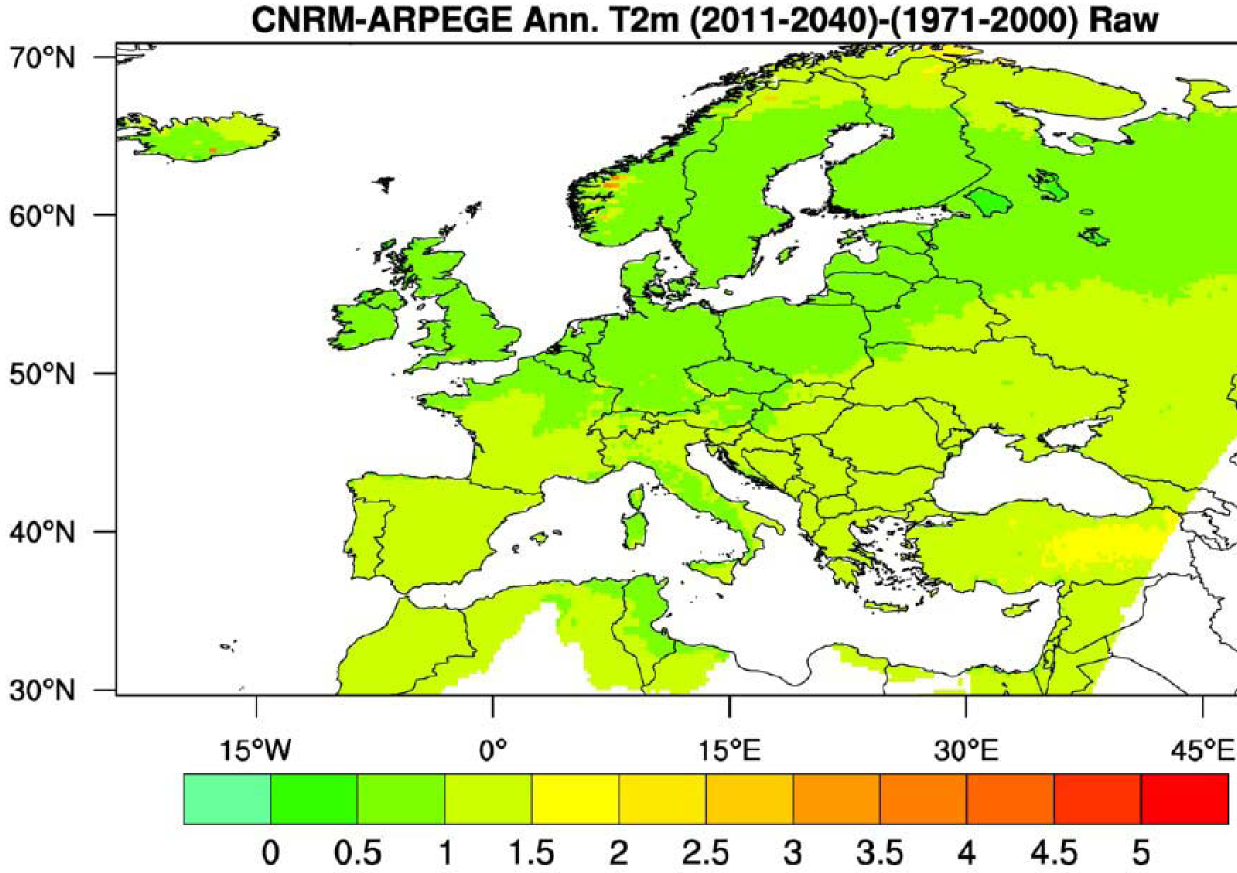
Appendix F Layout of Meteorological and Streamflow Gauging Stations

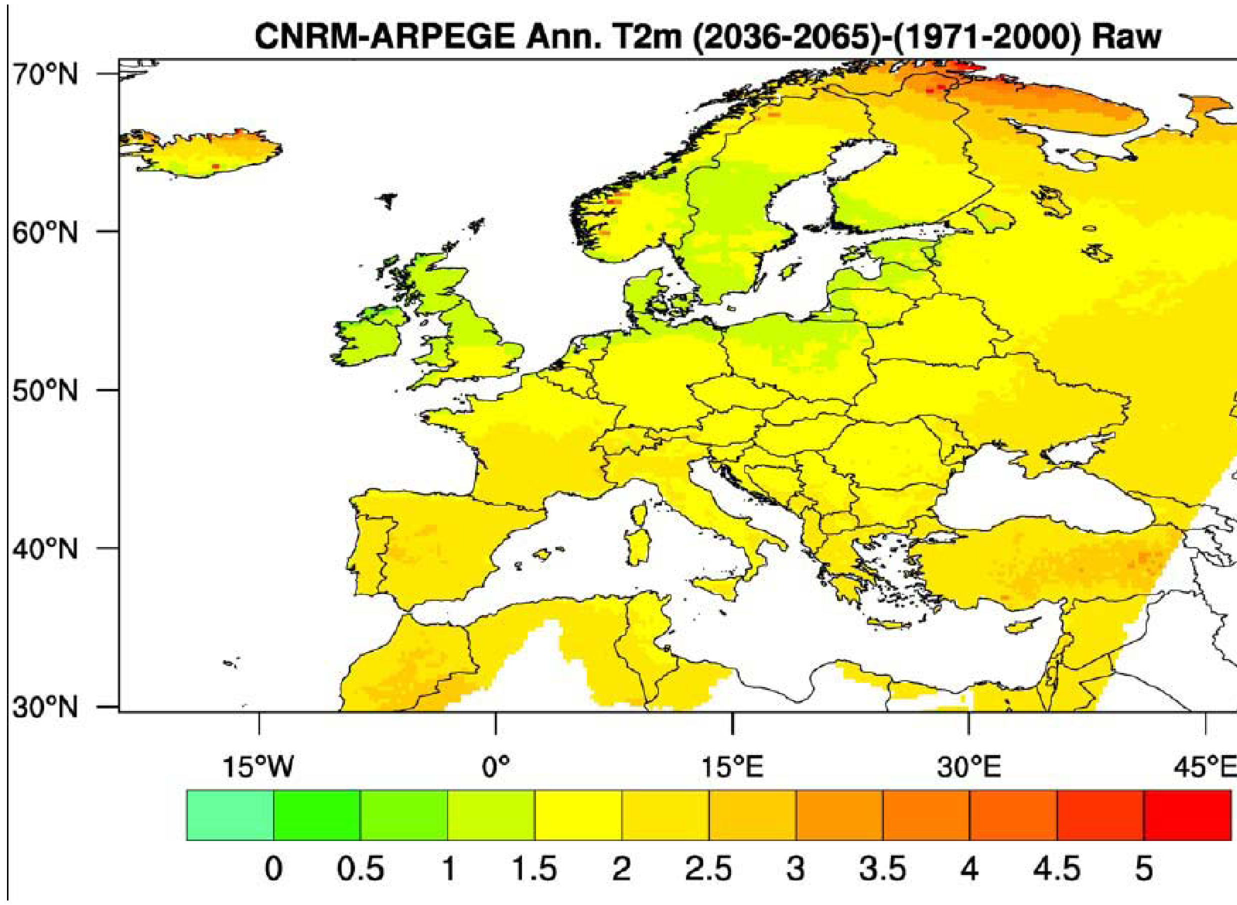
Layout of Meteorological and Streamflow Gauging Stations

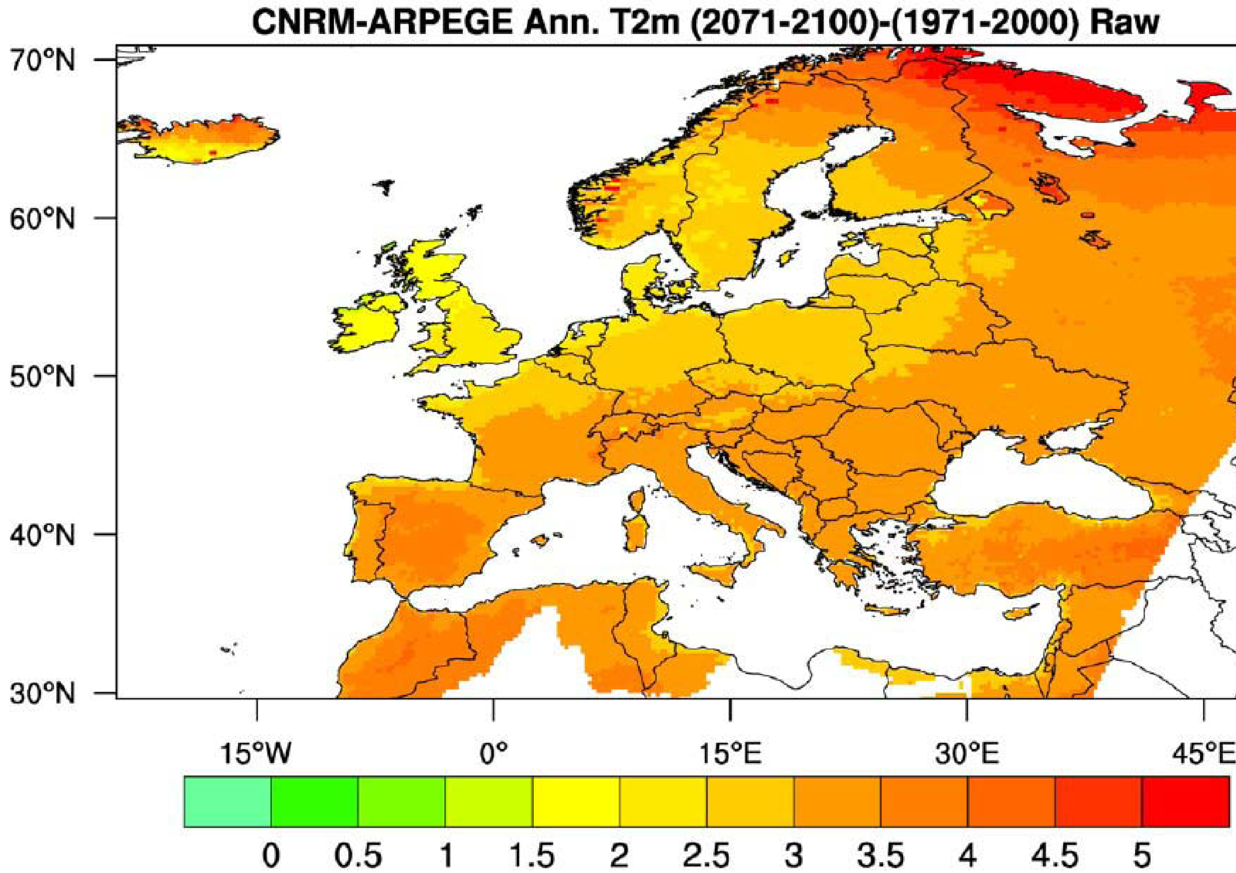


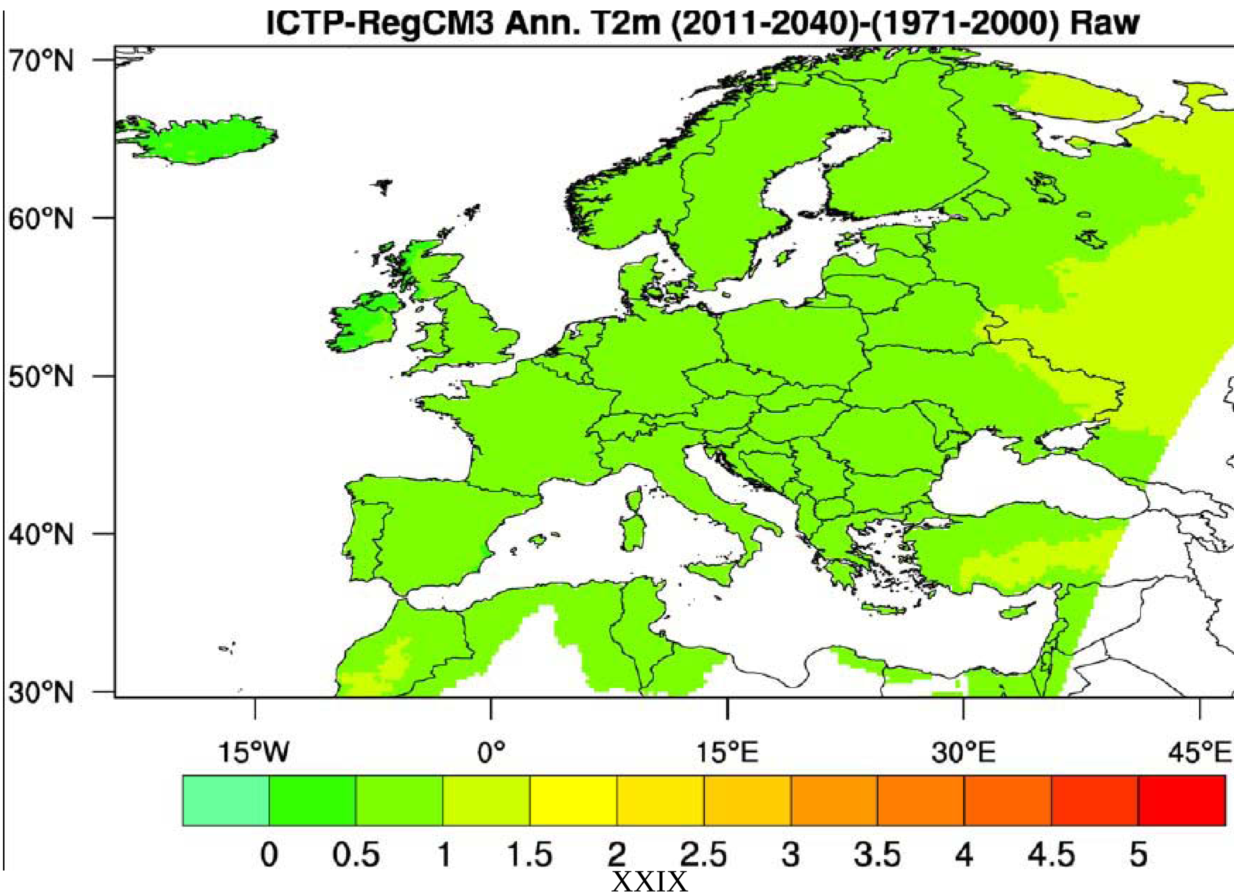
Appendix G Results of PRUDENCE Project

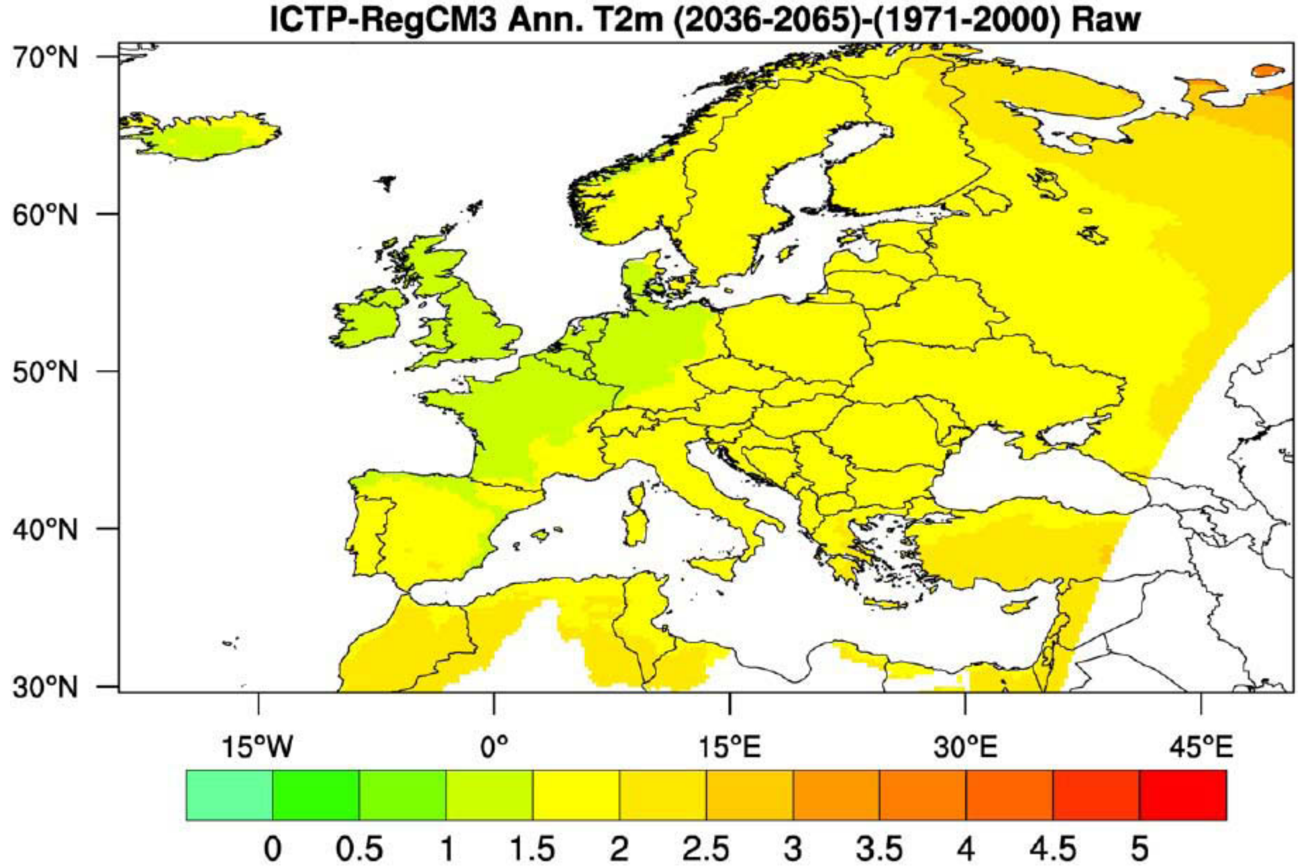
Annual Mean Temperature

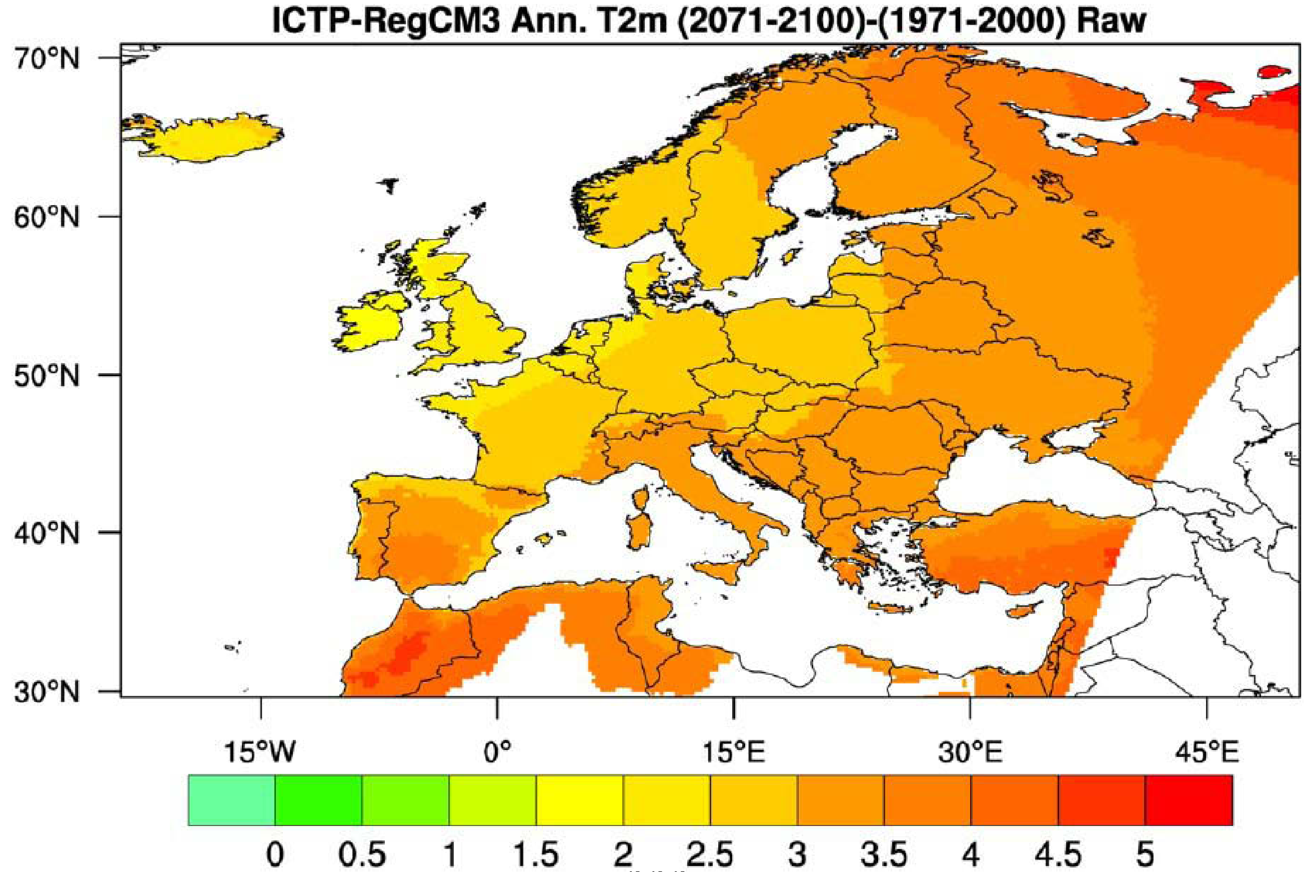

CNRM-ARPEGE Ann. T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

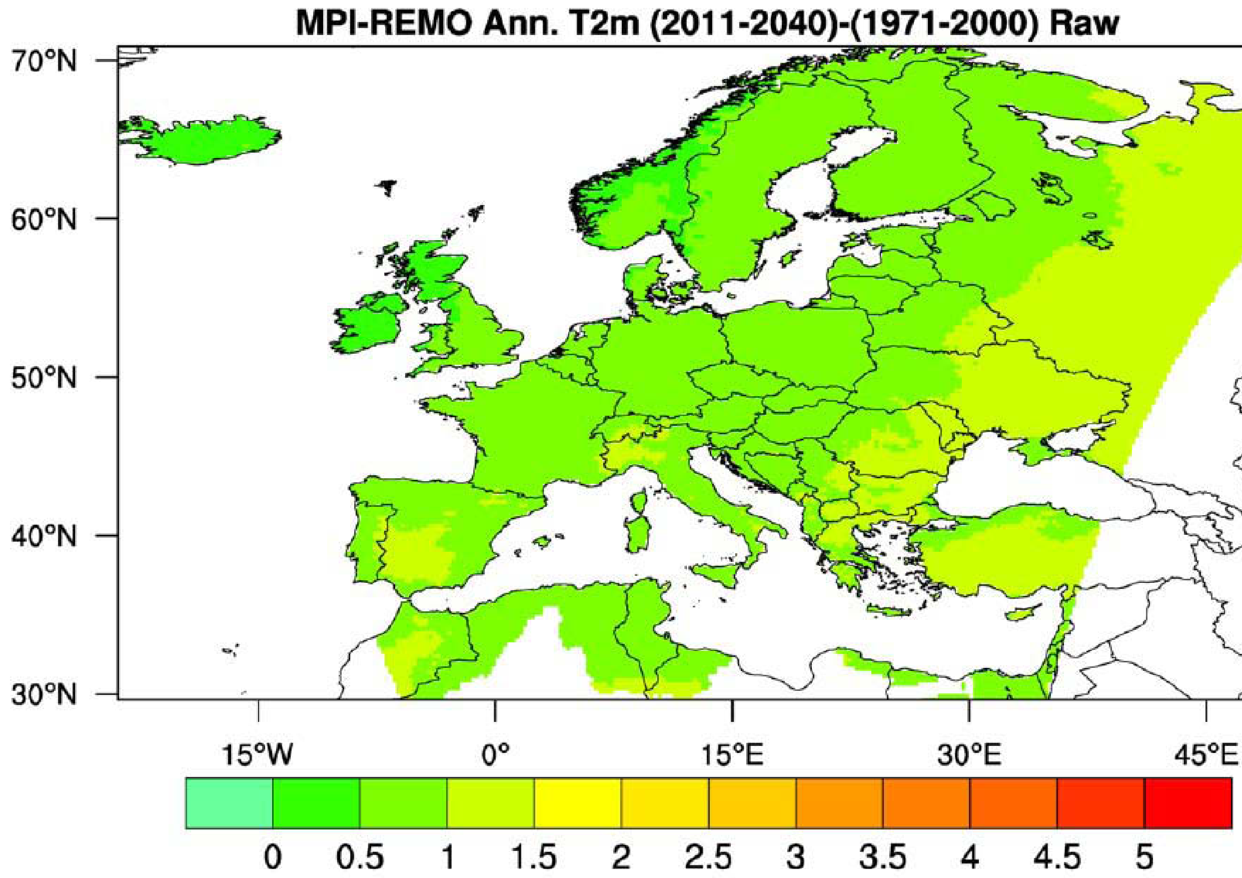

CNRM-ARPEGE Ann. T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

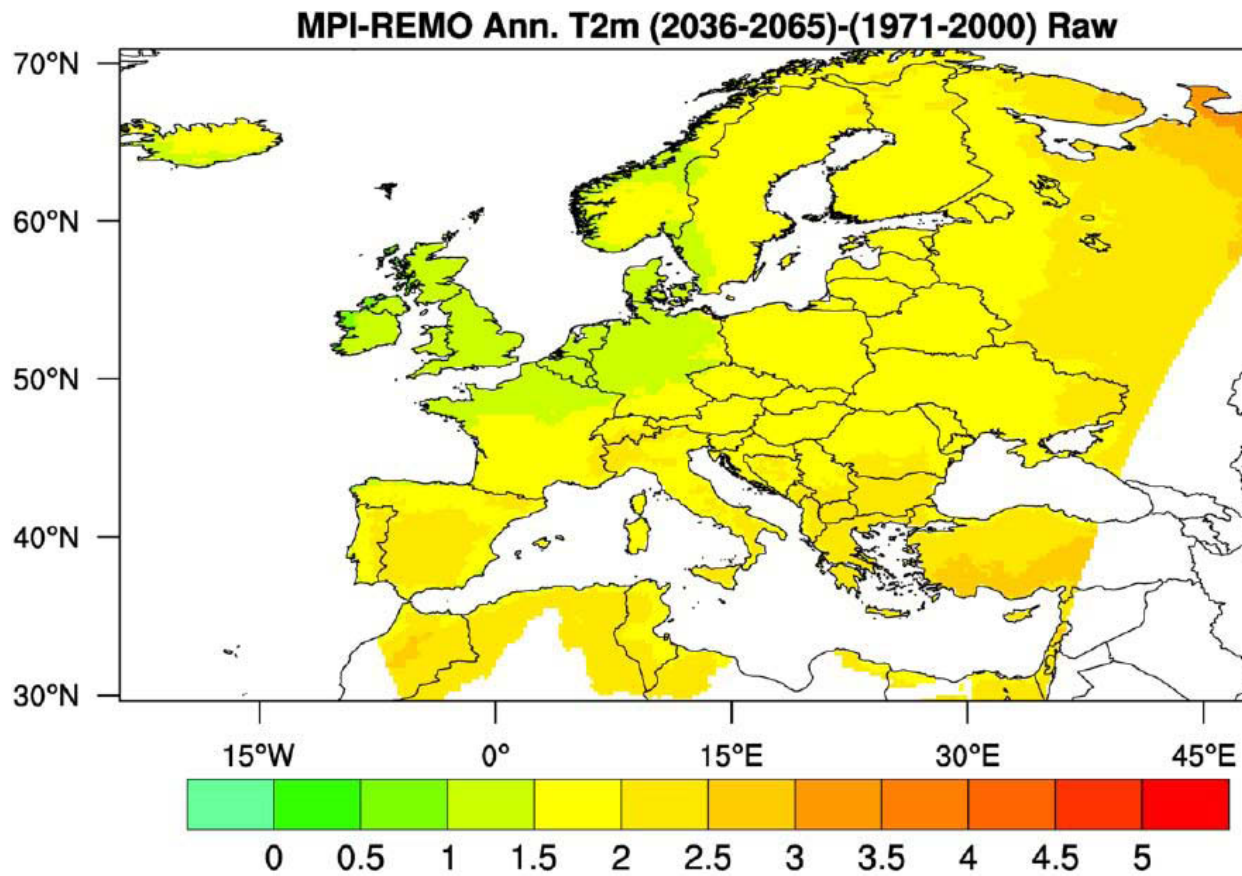

CNRM-ARPEGE Ann. T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

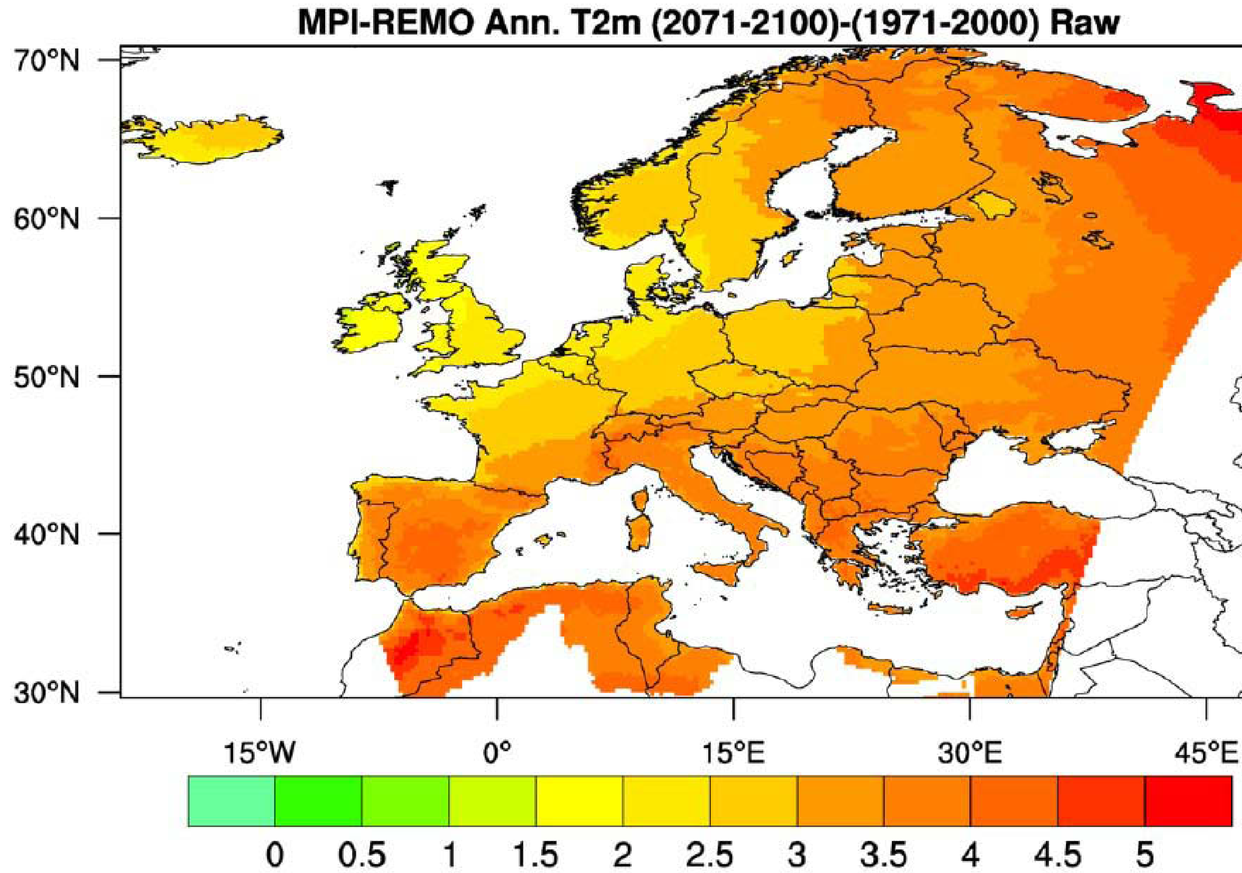

ICTP-RegCM3 Ann. T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


ICTP-RegCM3 Ann. T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

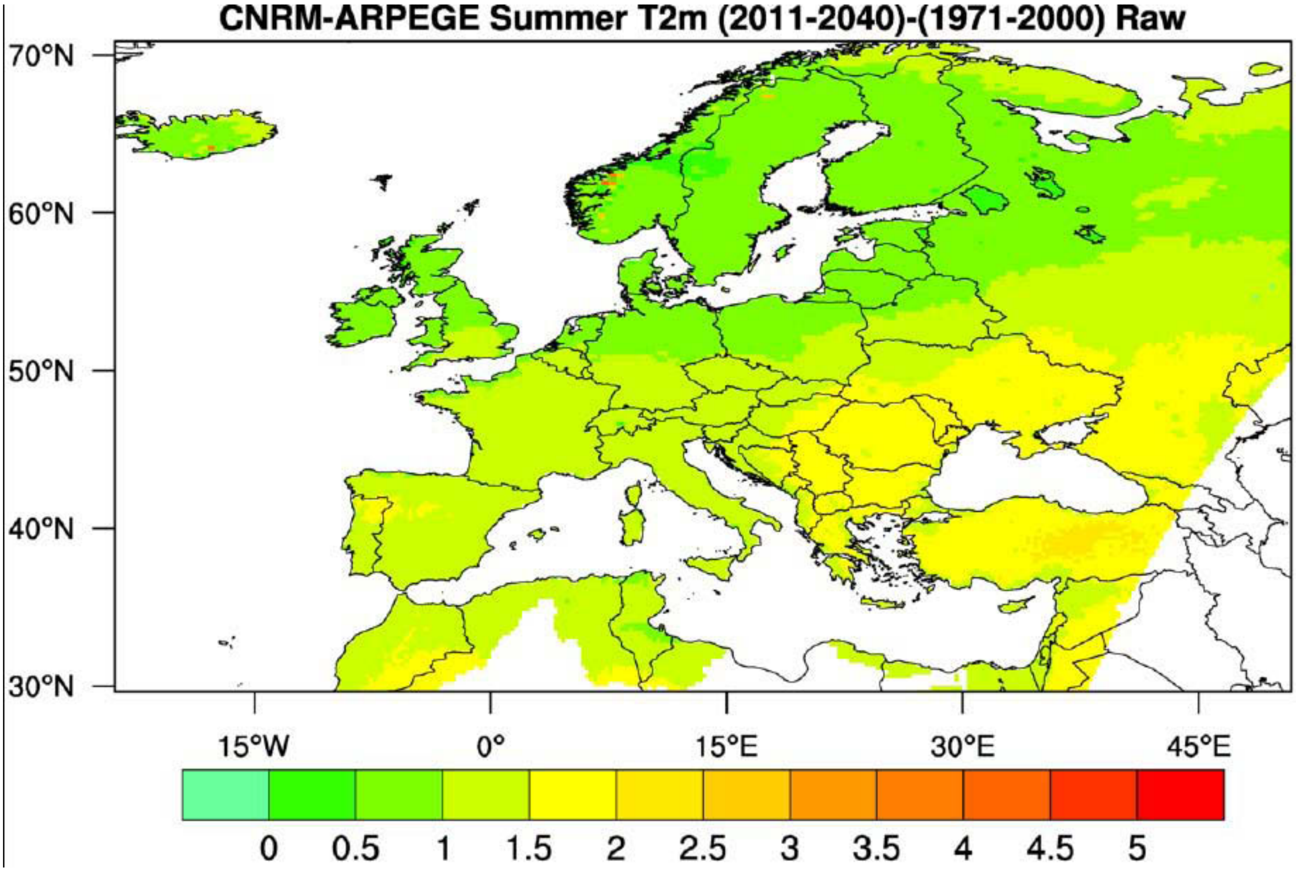

ICTP-RegCM3 Ann. T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

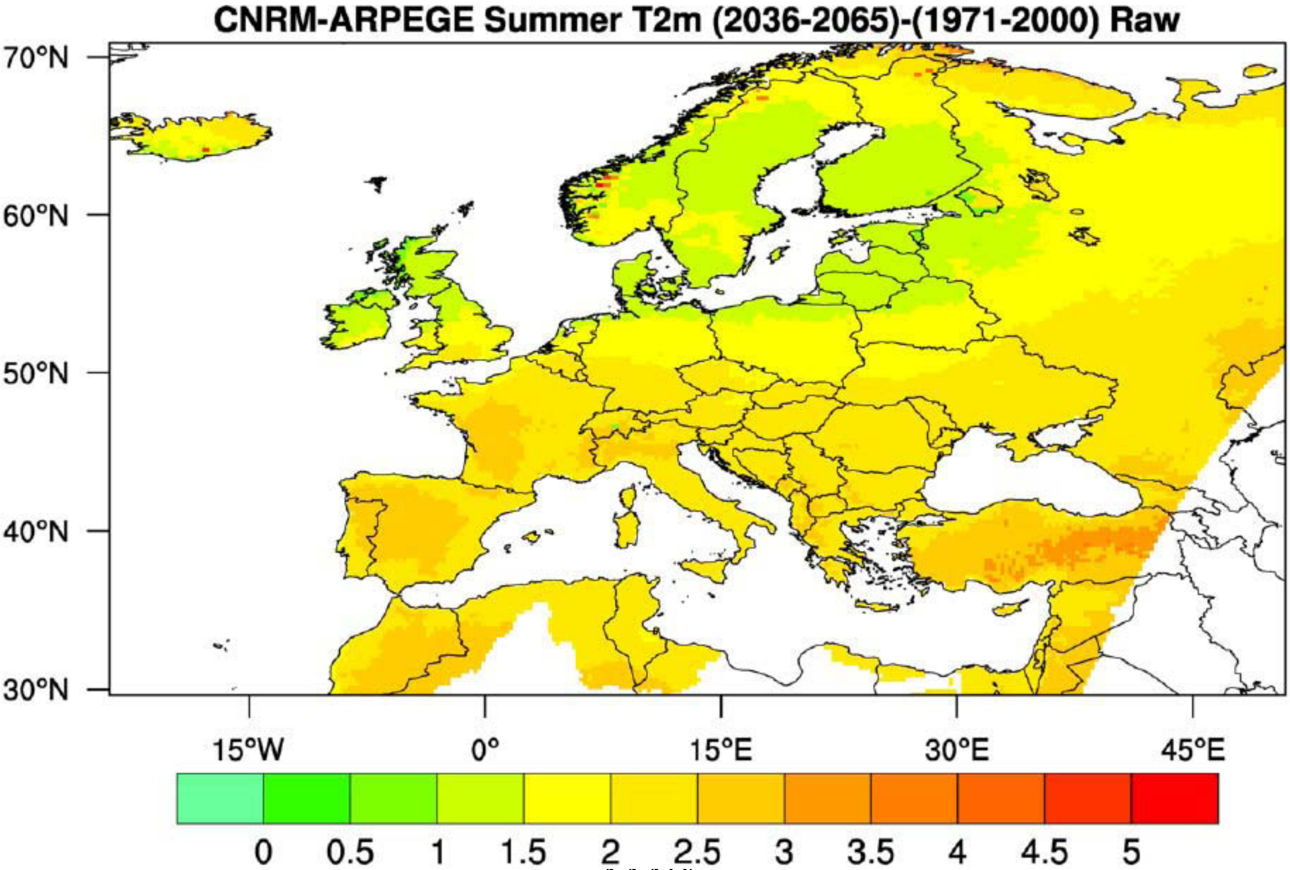

MPI-REMO Ann. T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

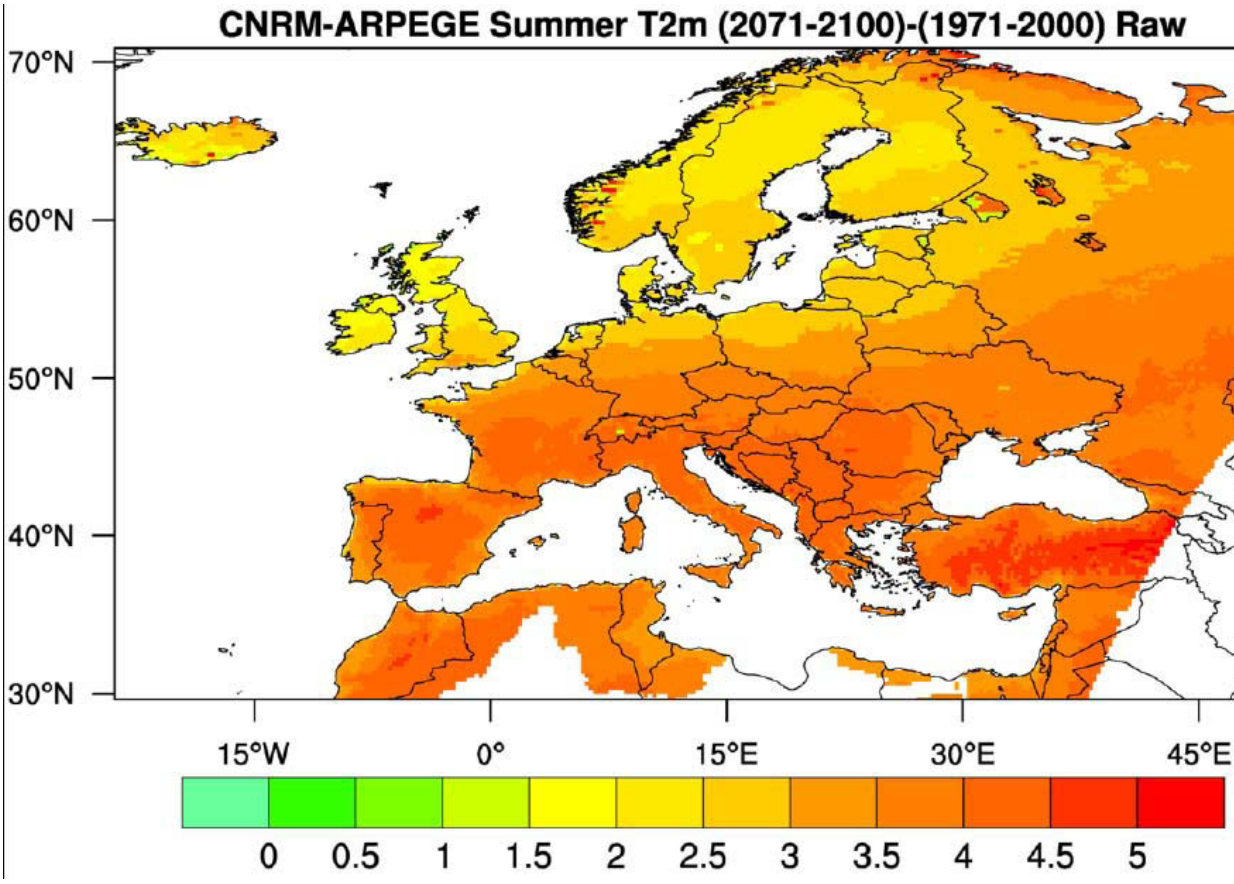

MPI-REMO Ann. T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

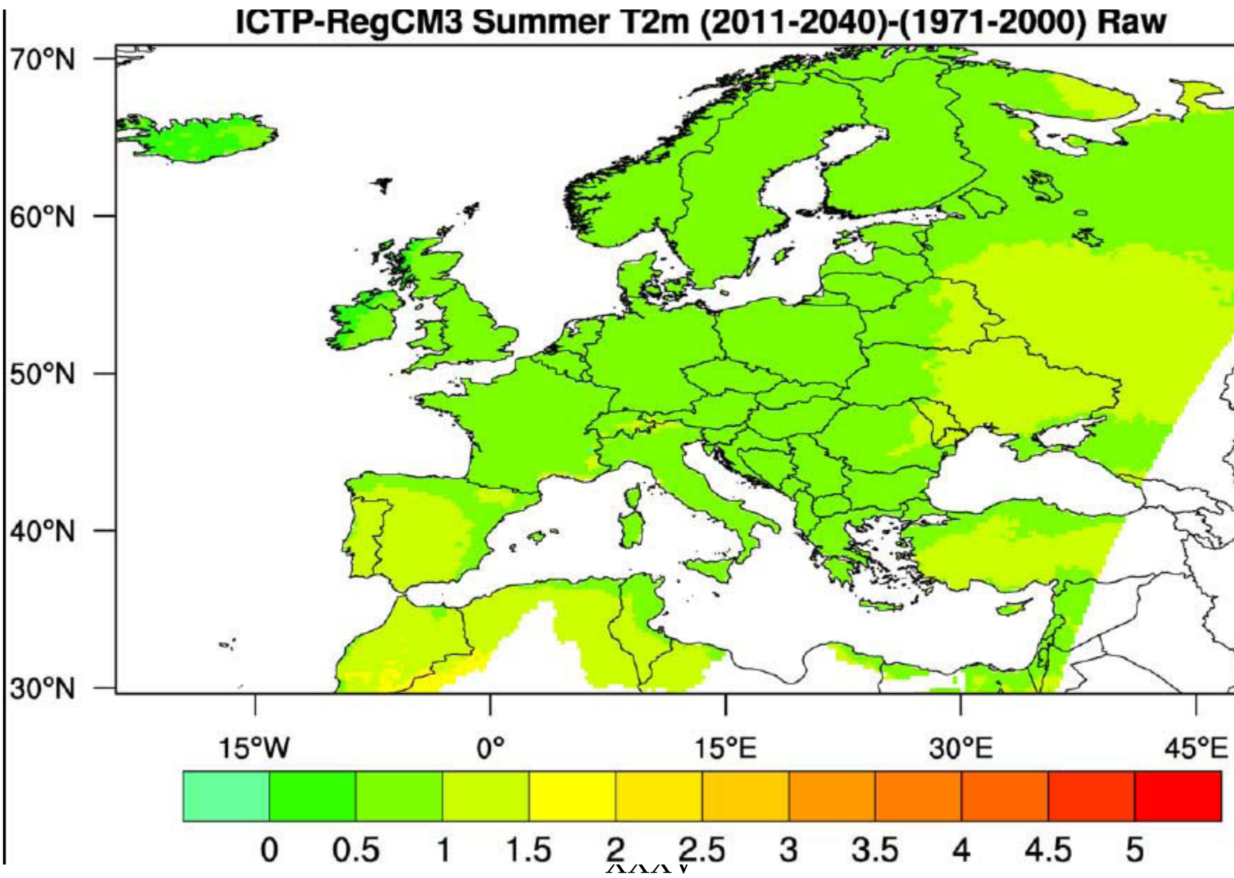

MPI-REMO Ann. T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

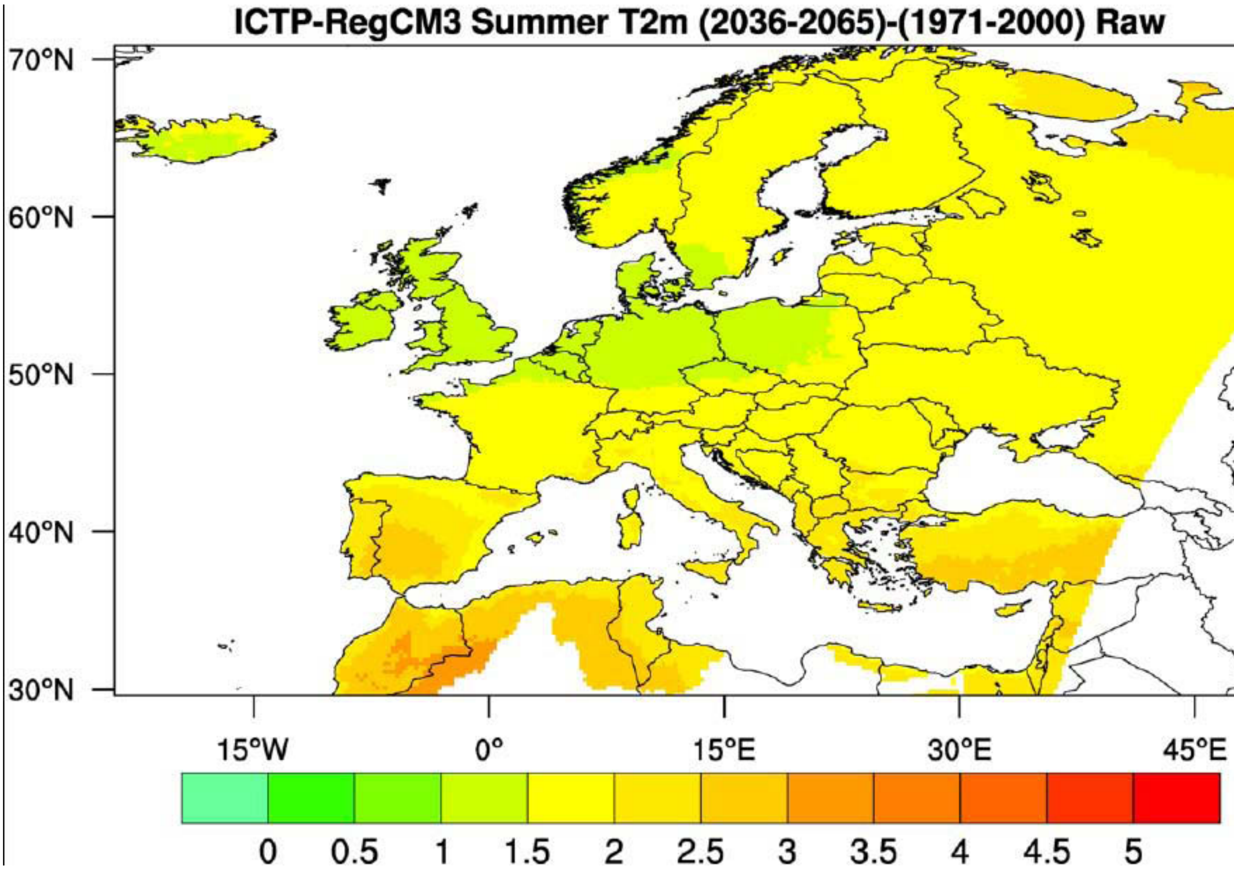
Summer Temperature

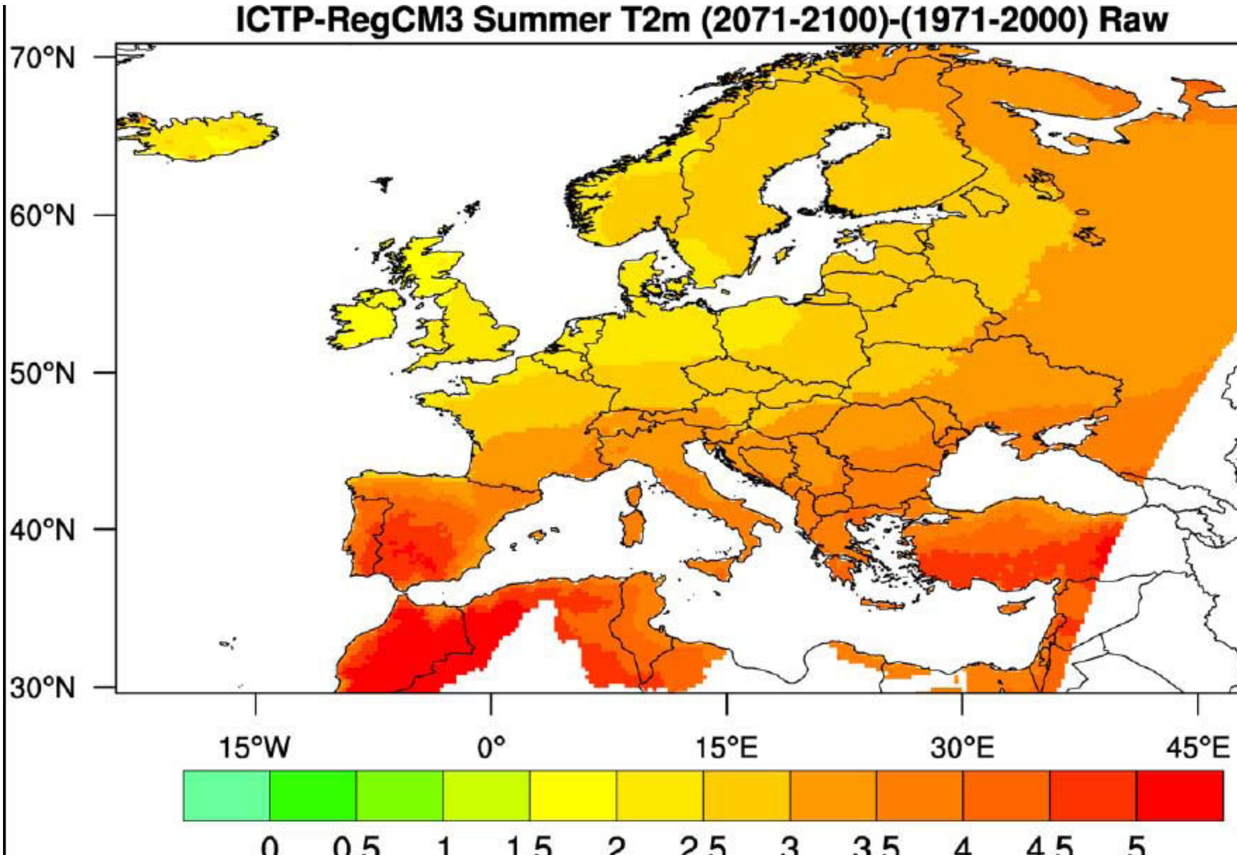

CNRM-ARPEGE Summer T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

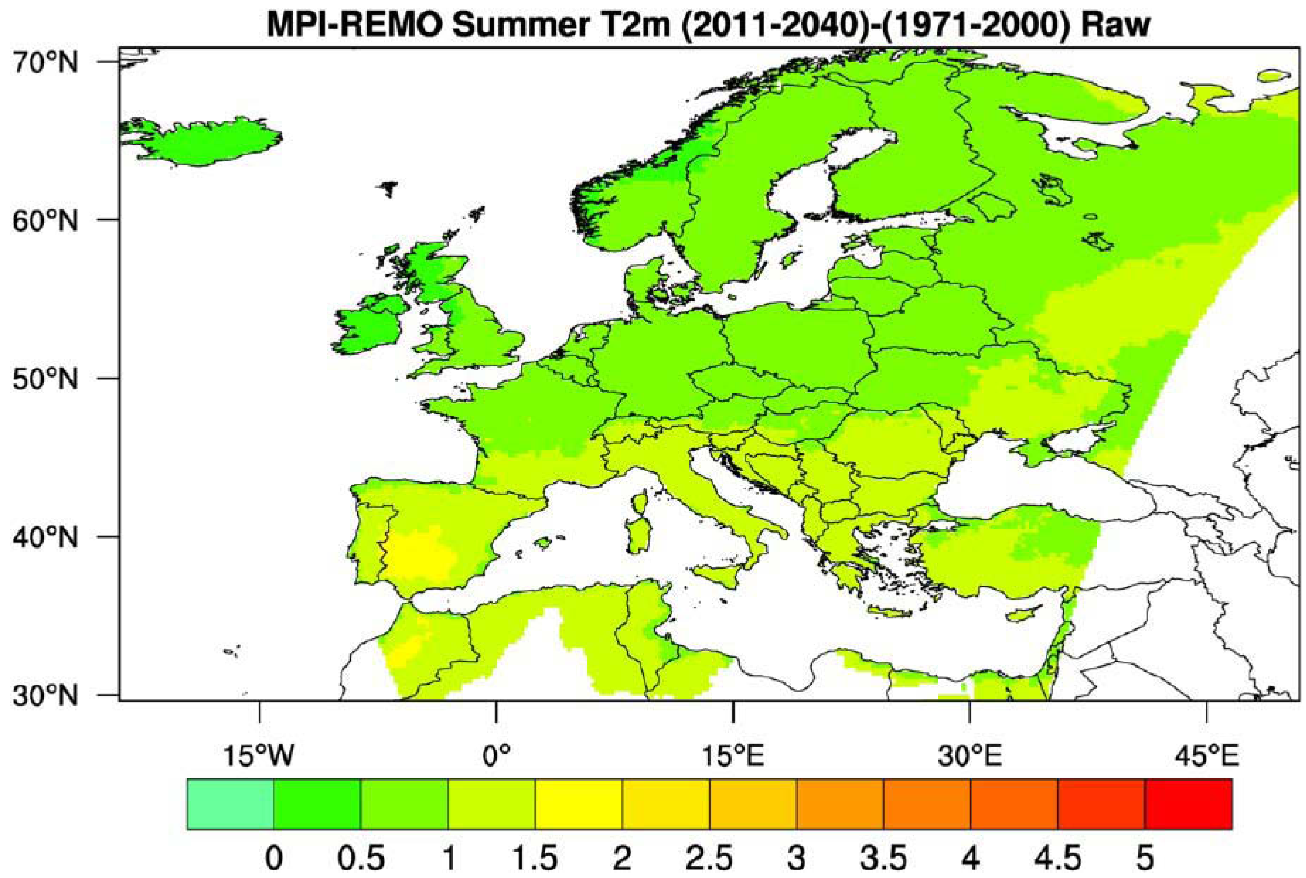

CNRM-ARPEGE Summer T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

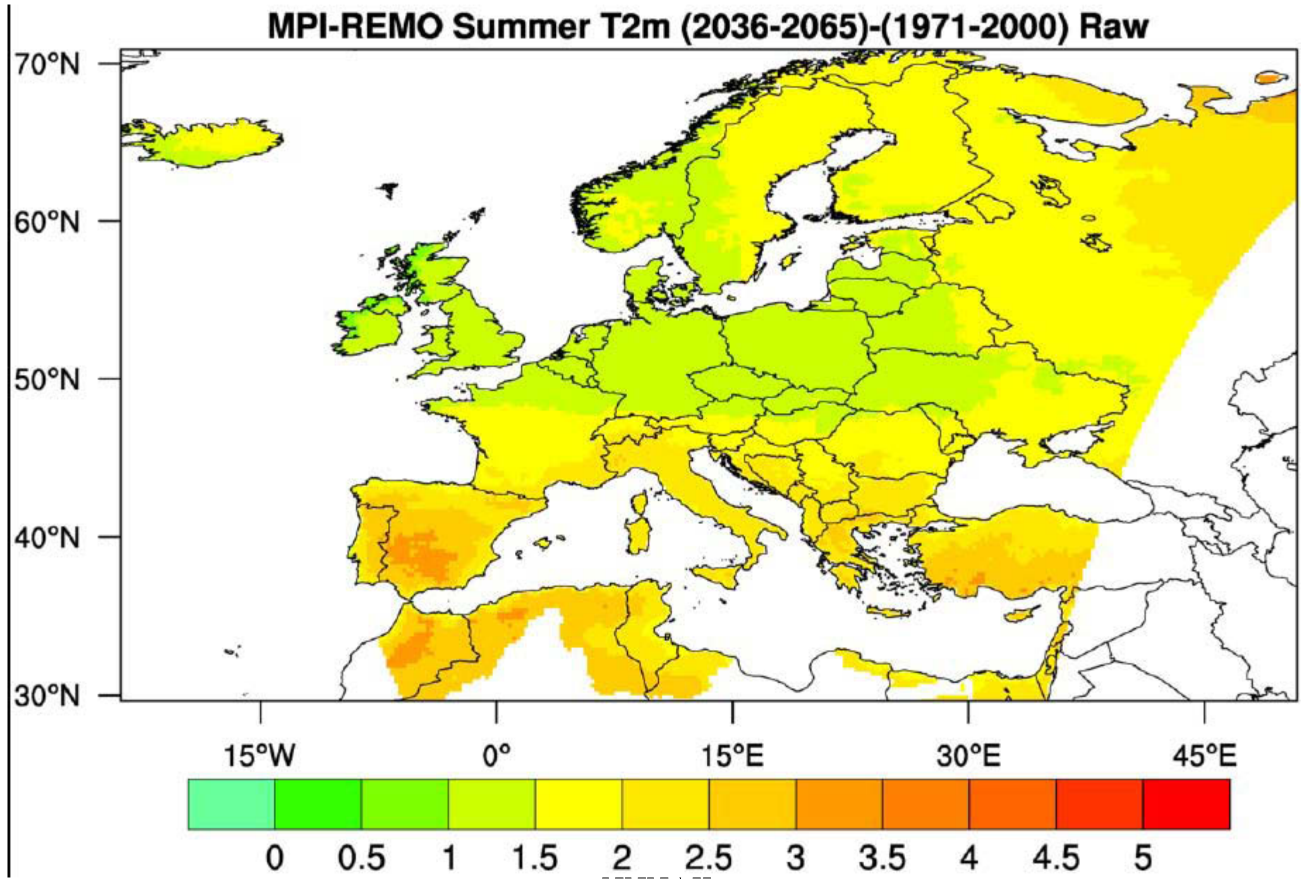

CNRM-ARPEGE Summer T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

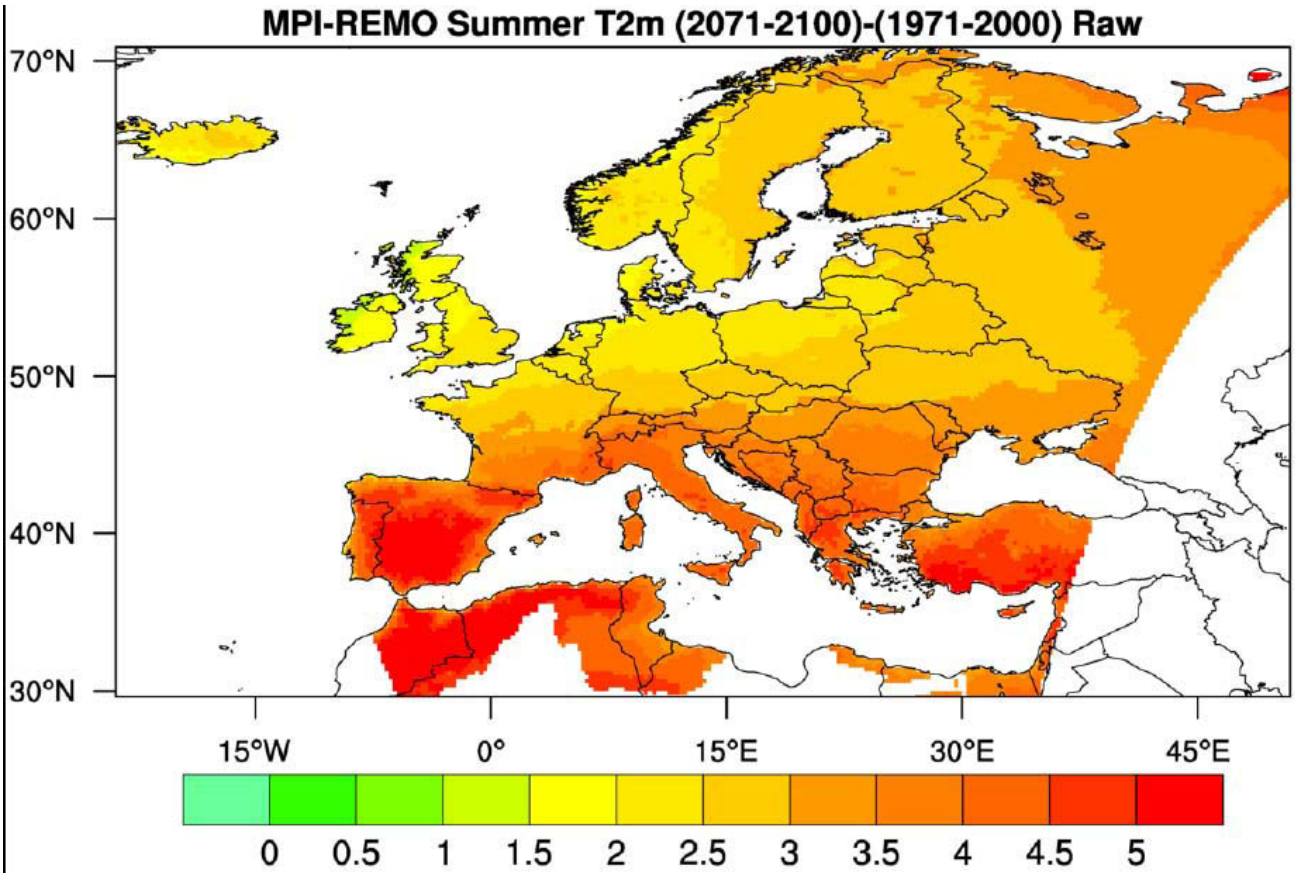

ICTP-RegCM3 Summer T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


ICTP-RegCM3 Summer T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

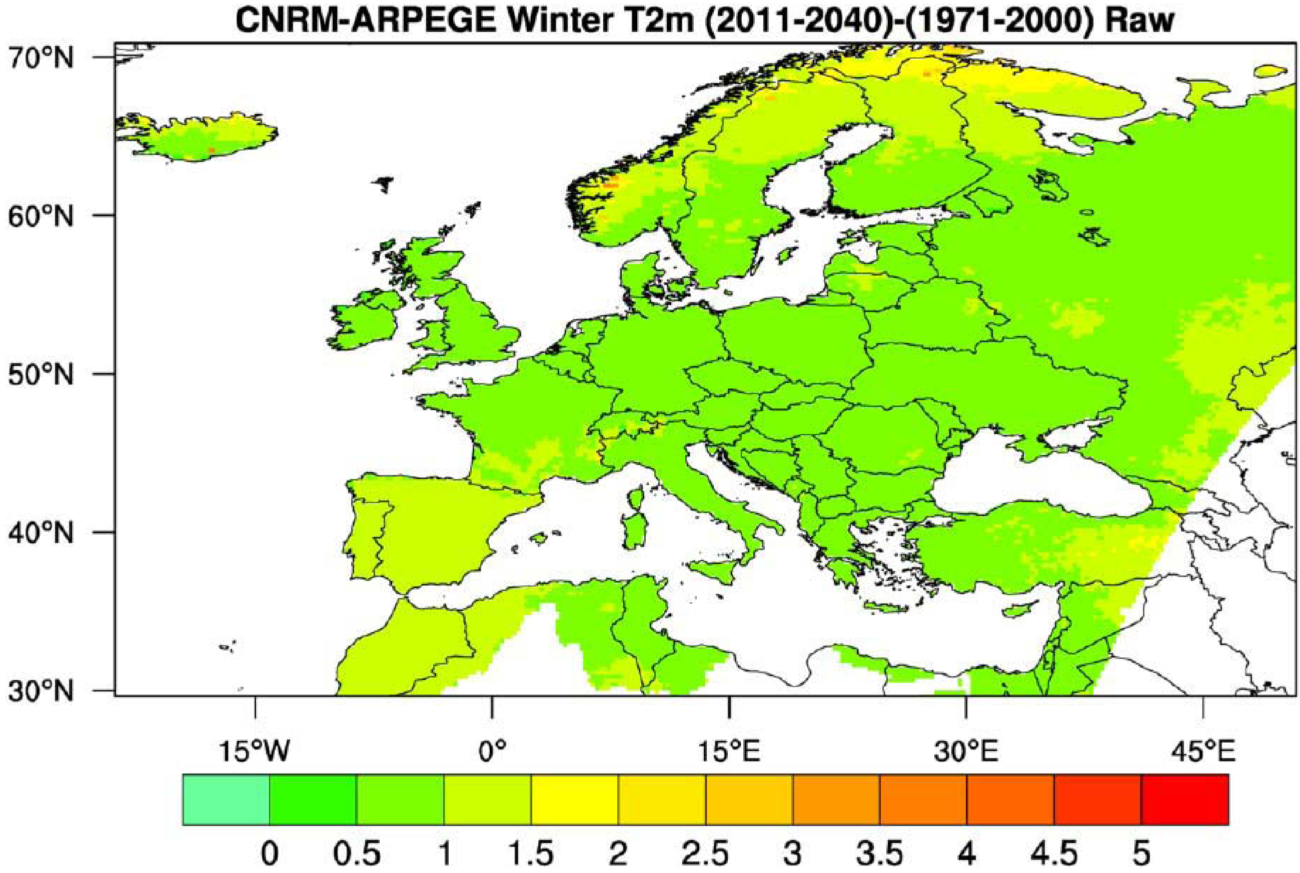

ICTP-RegCM3 Summer T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

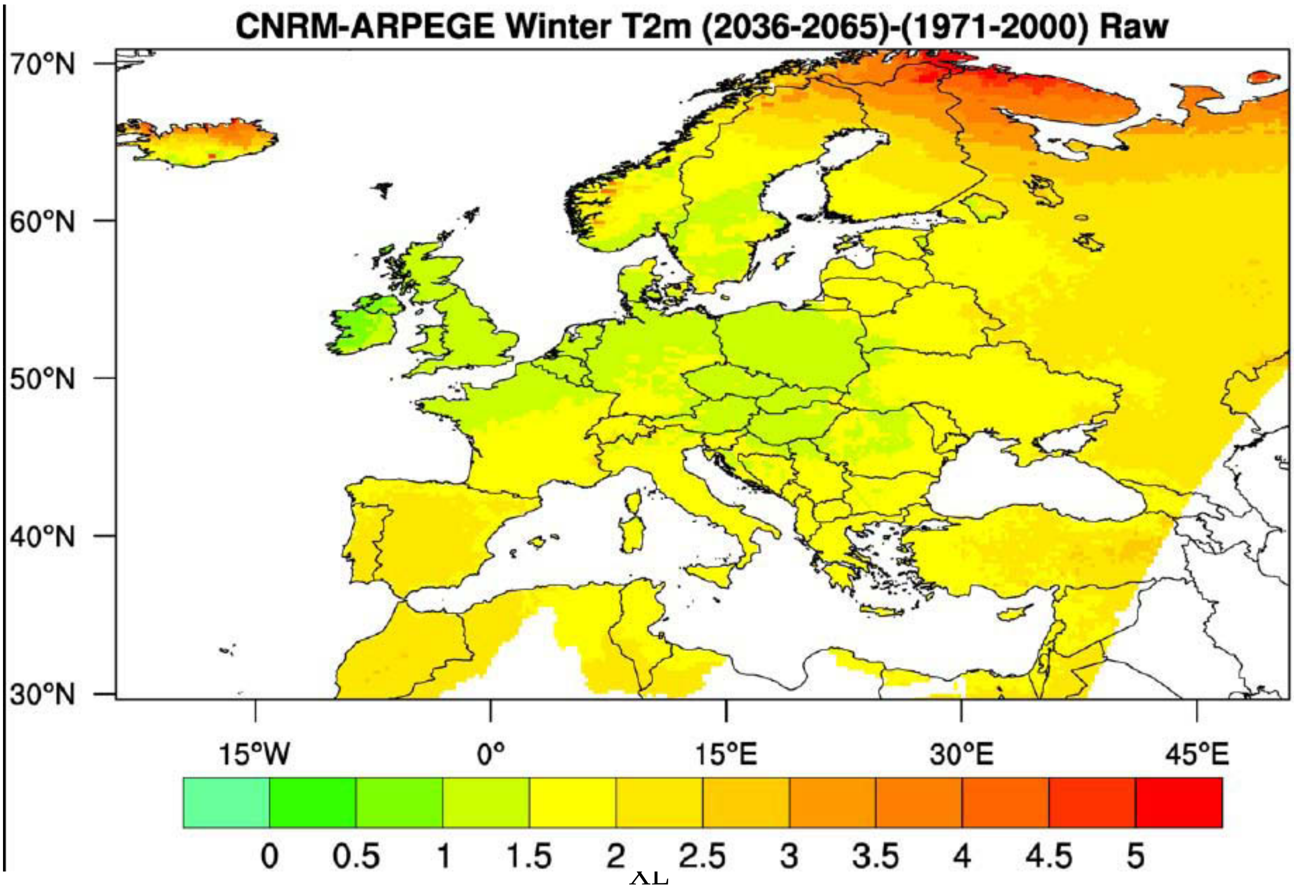

MPI-REMO Summer T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

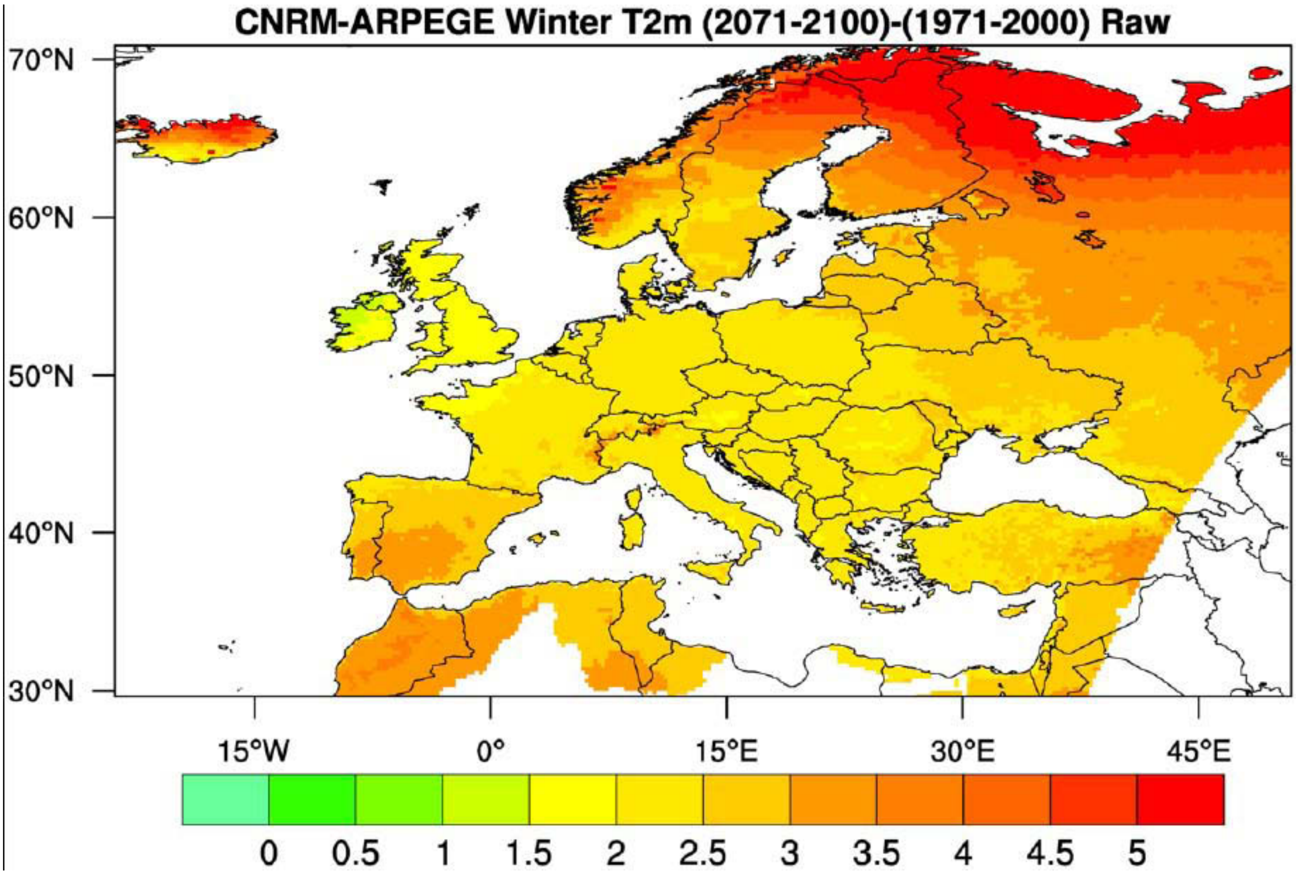

MPI-REMO Summer T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

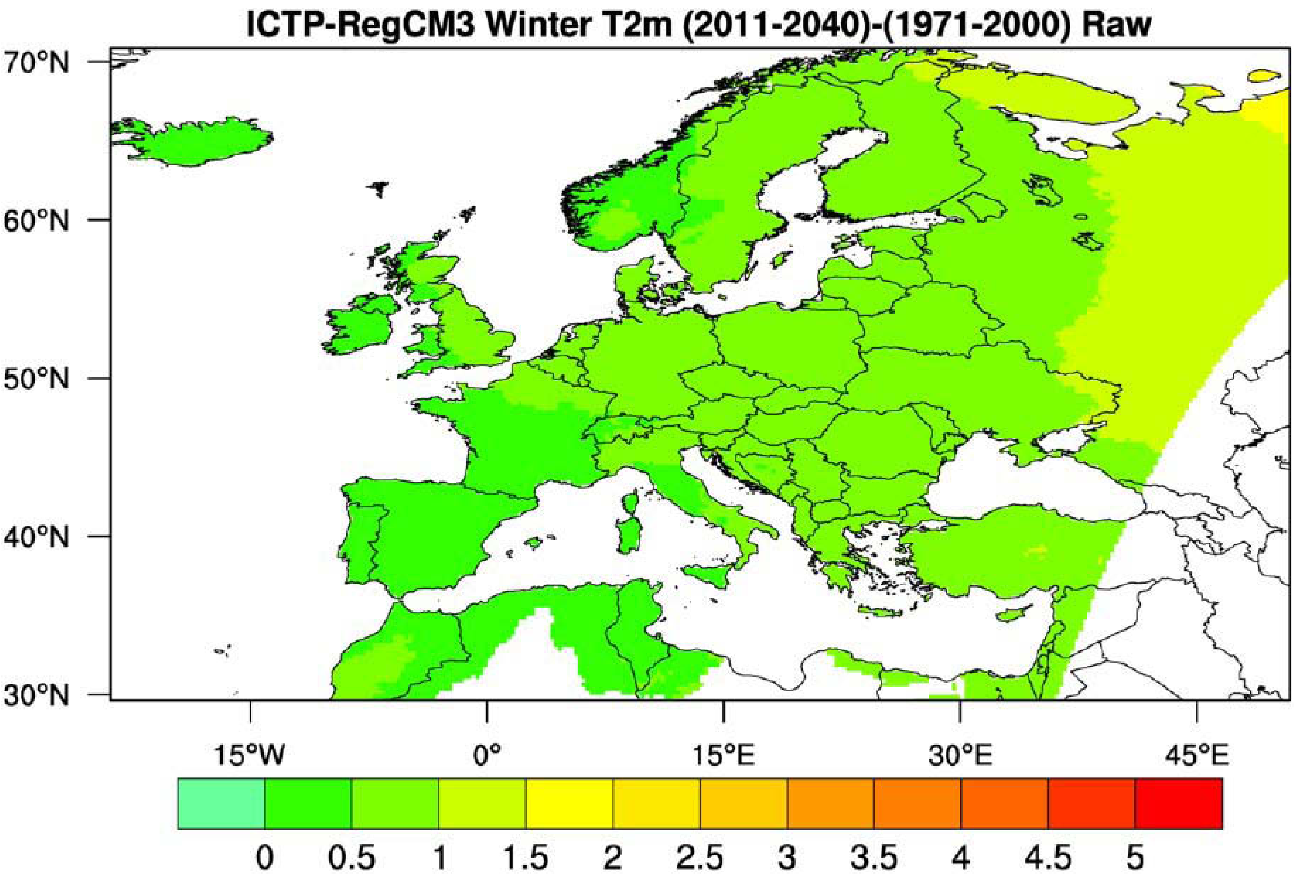

MPI-REMO Summer T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

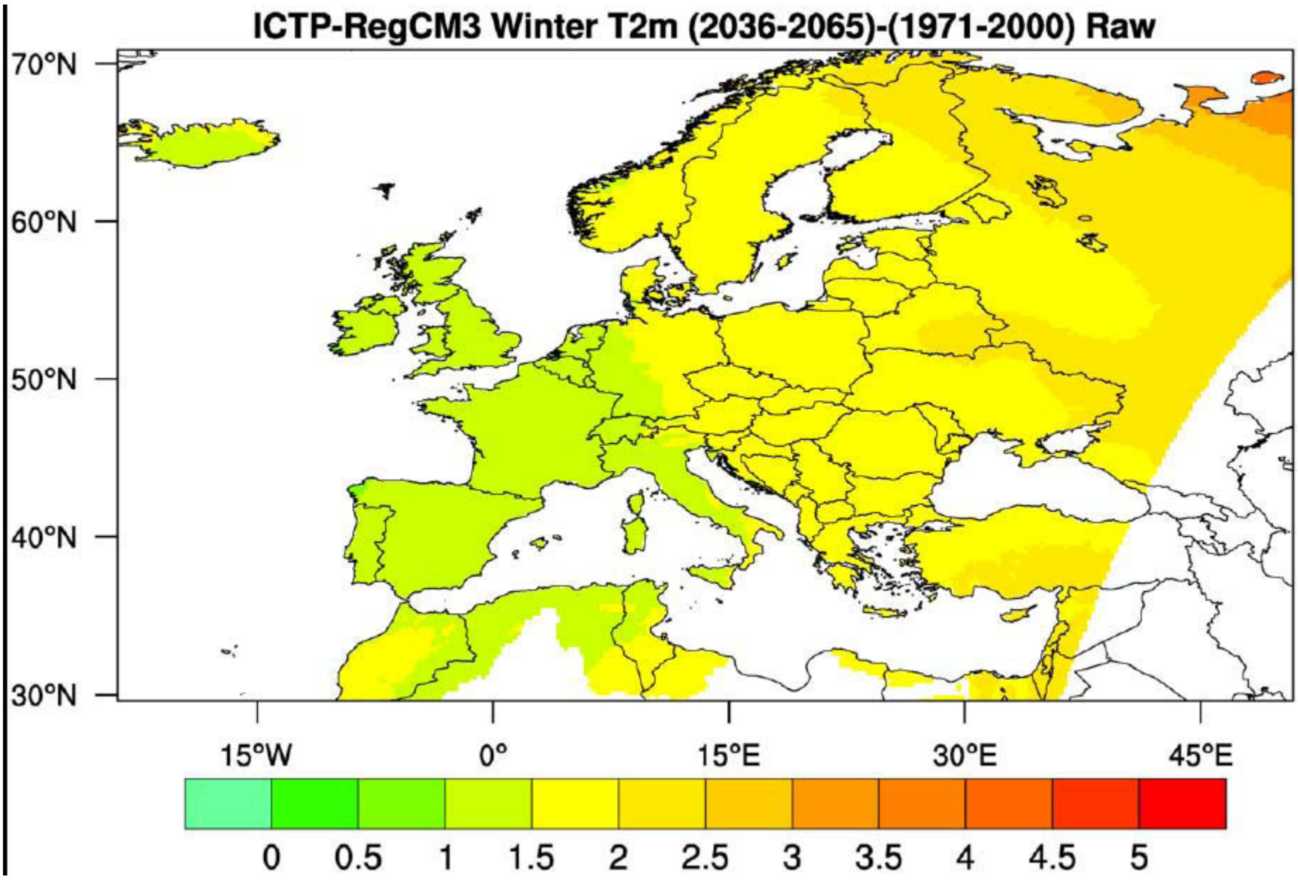
Winter Temperature

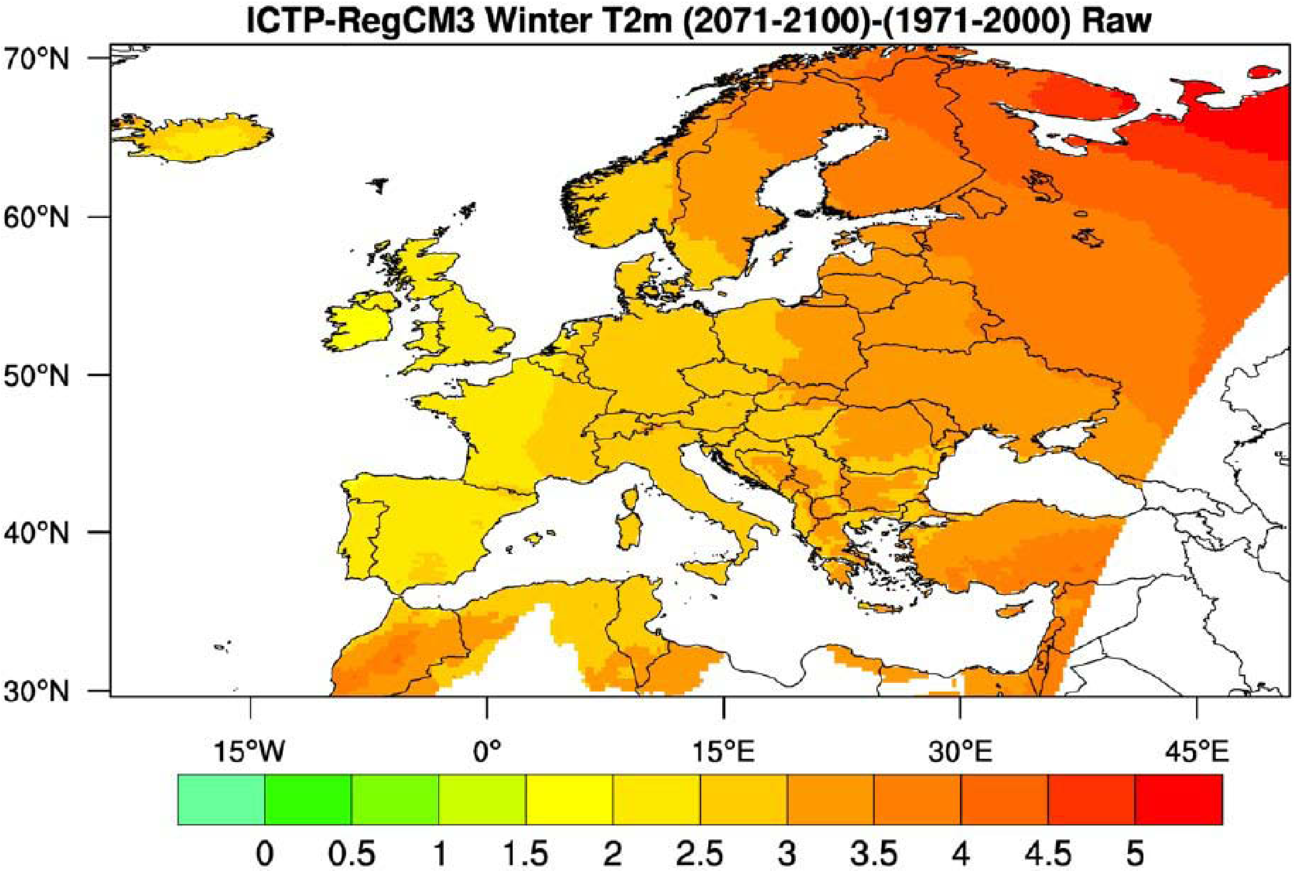

CNRM-ARPEGE Winter T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

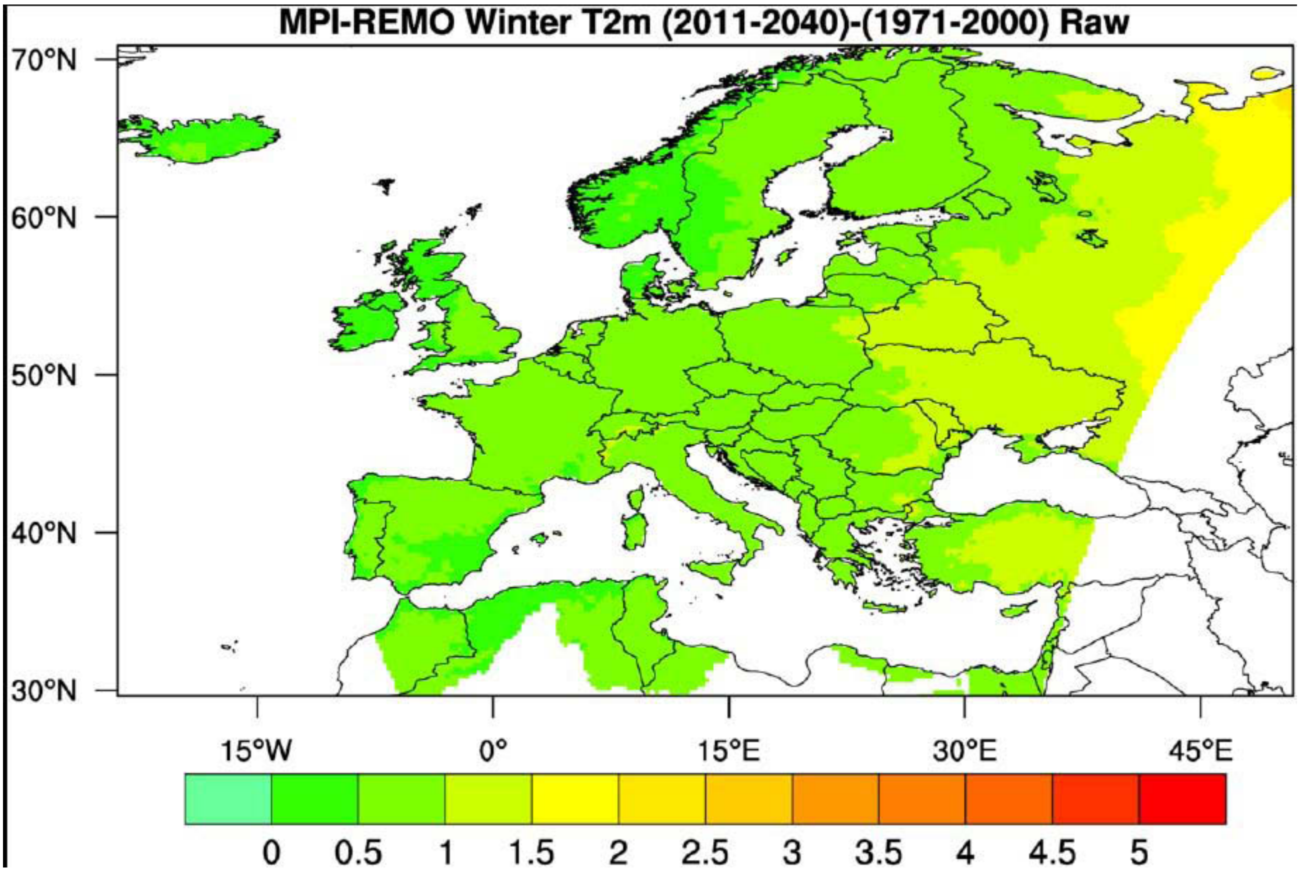

CNRM-ARPEGE Winter T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

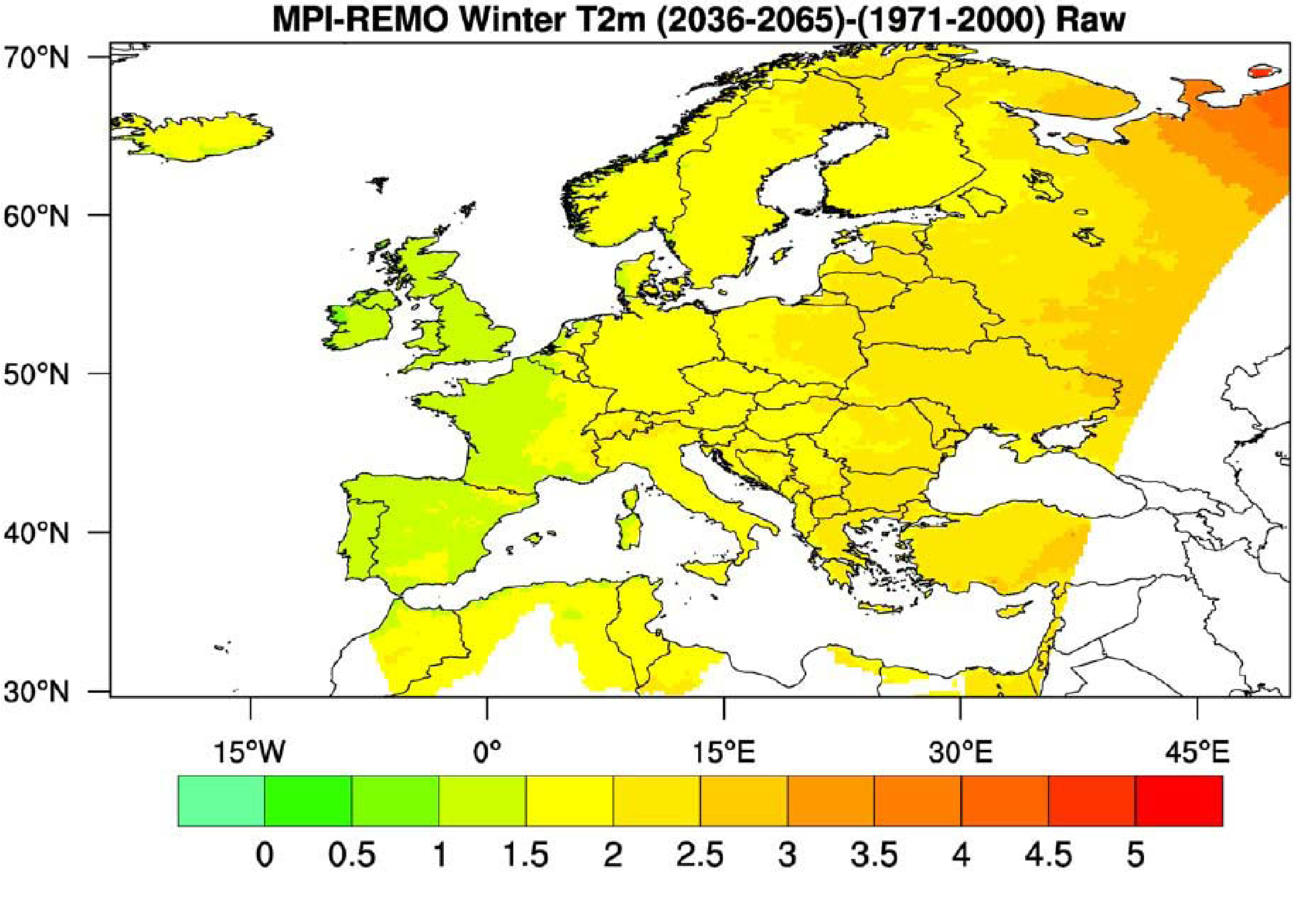

CNRM-ARPEGE Winter T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

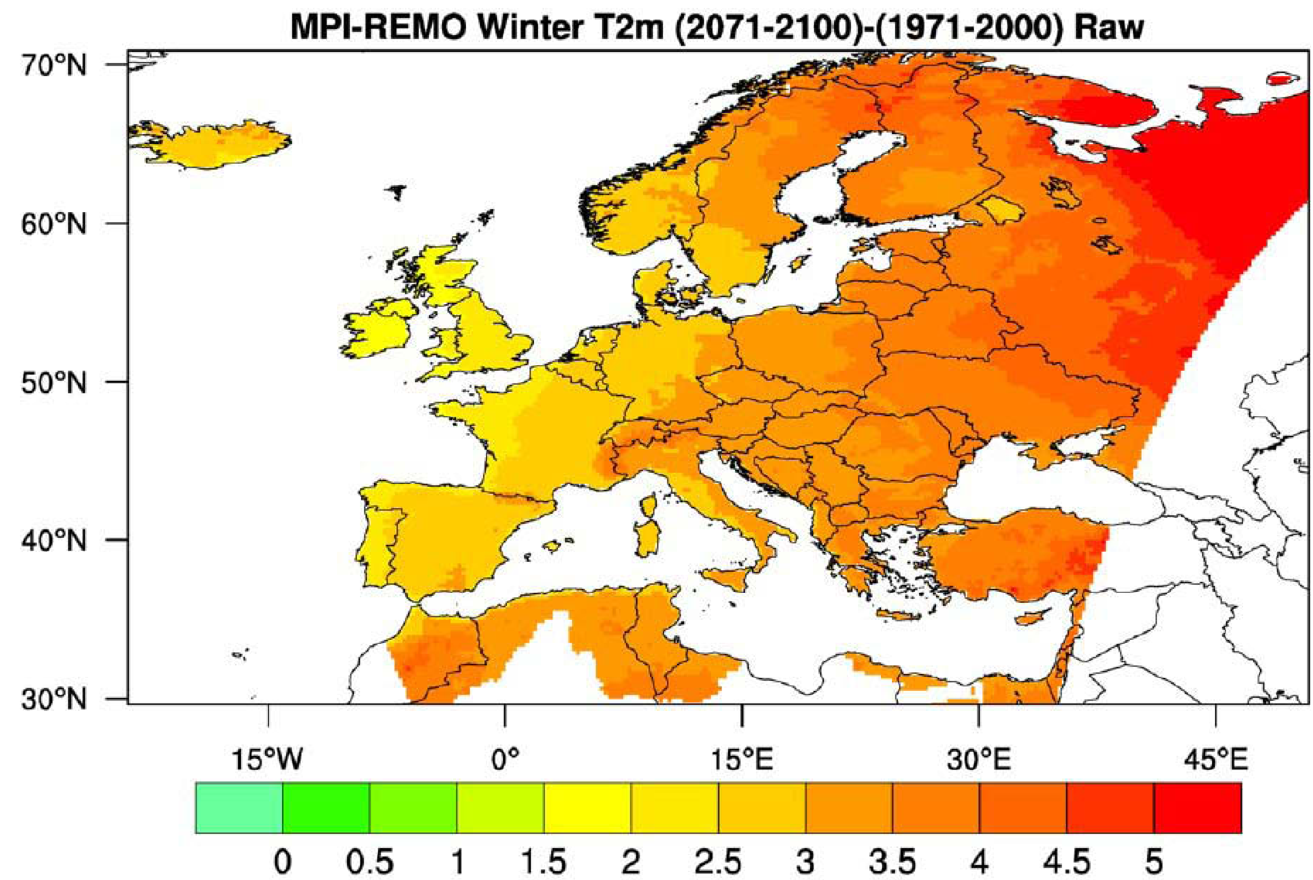

ICTP-RegCM3 Winter T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


ICTP-RegCM3 Winter T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

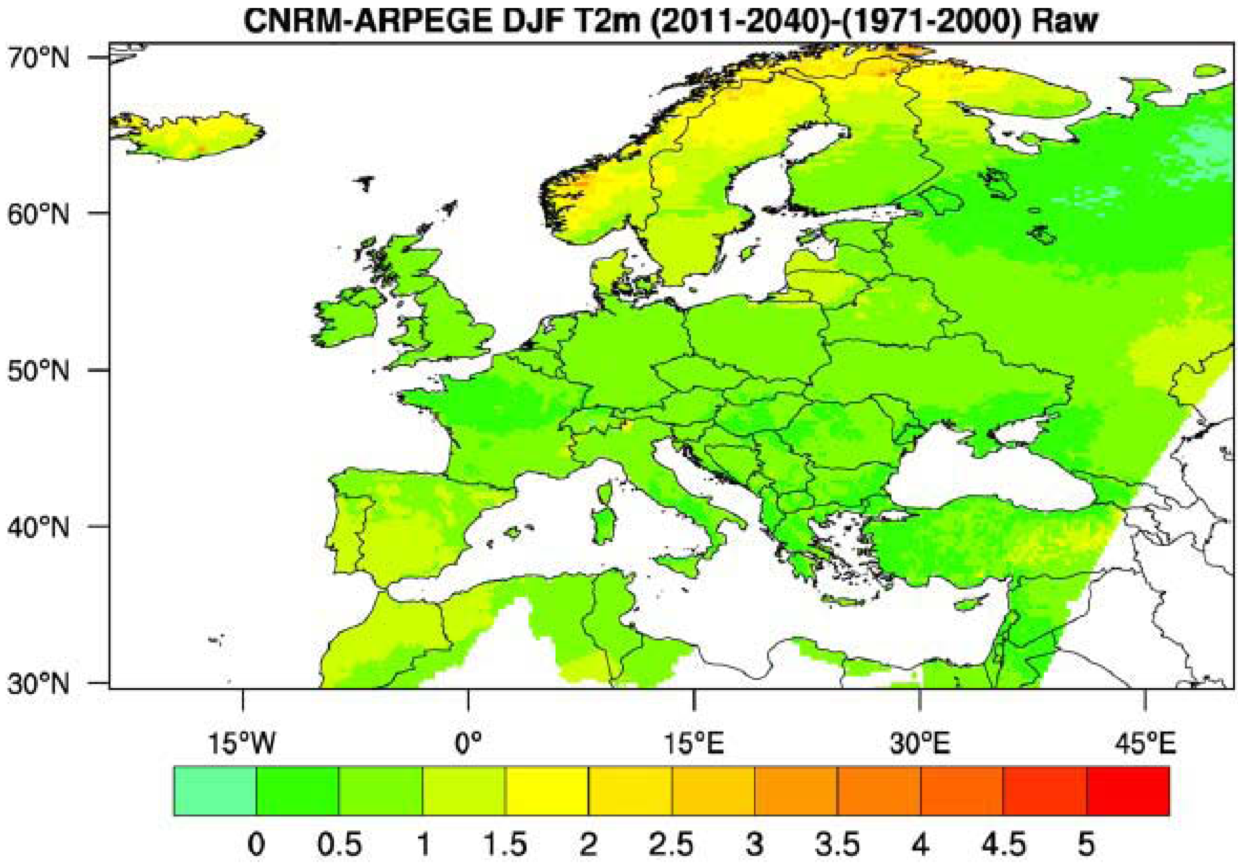

ICTP-RegCM3 Winter T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

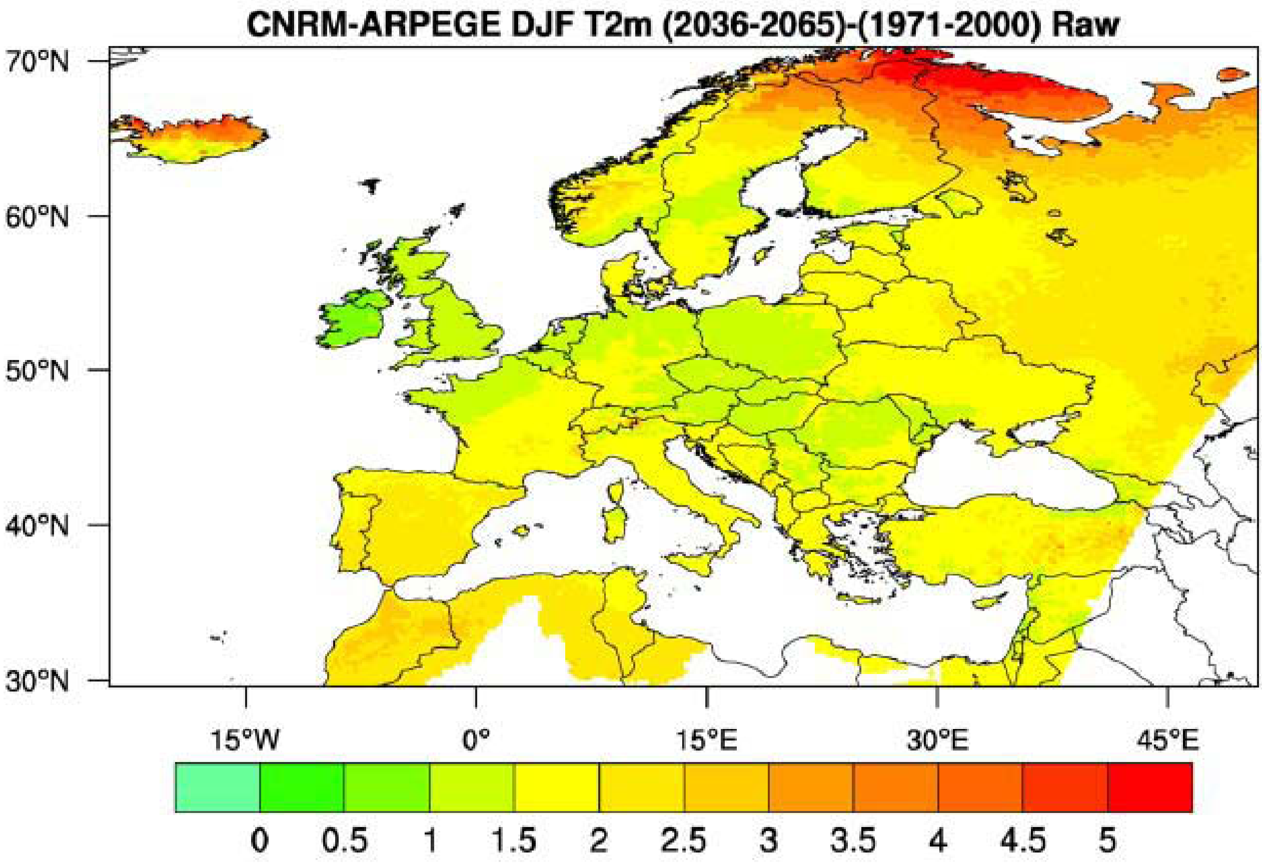

MPI-REMO Winter T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

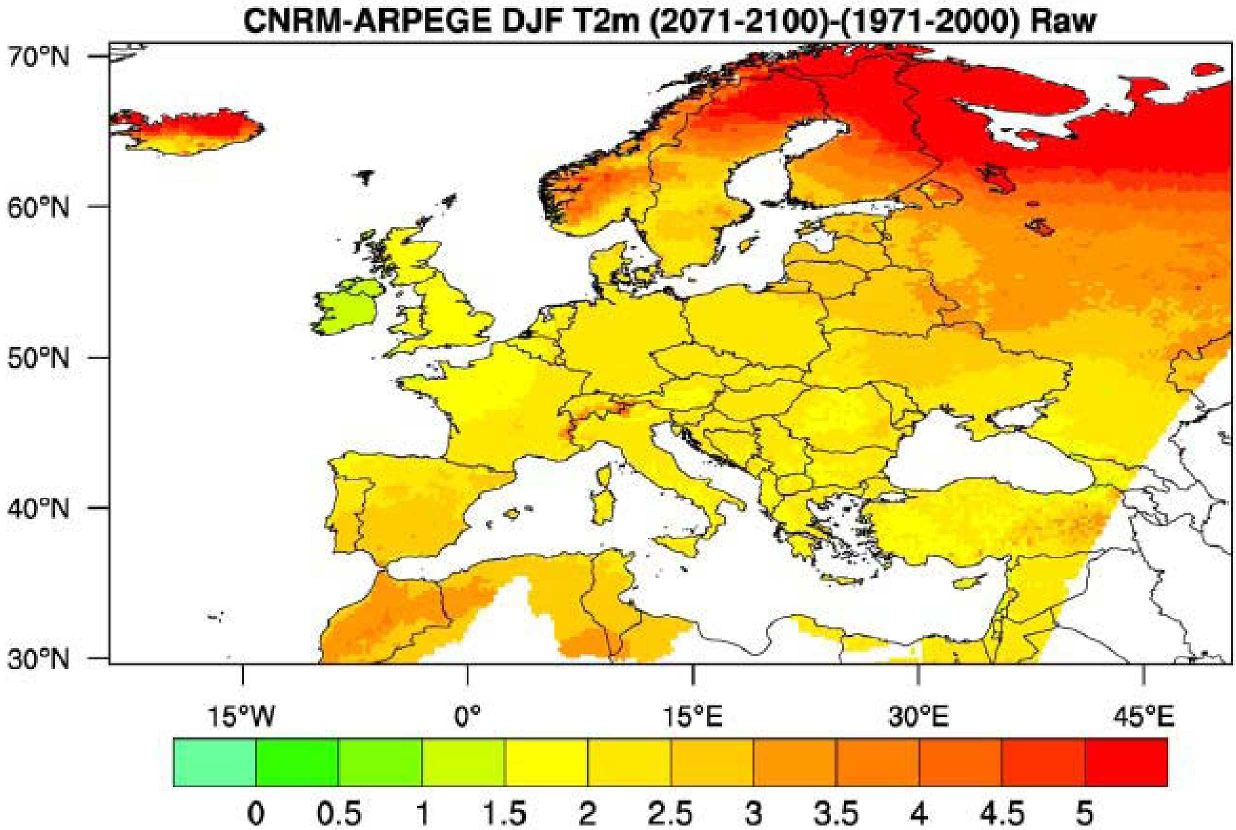

MPI-REMO Winter T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

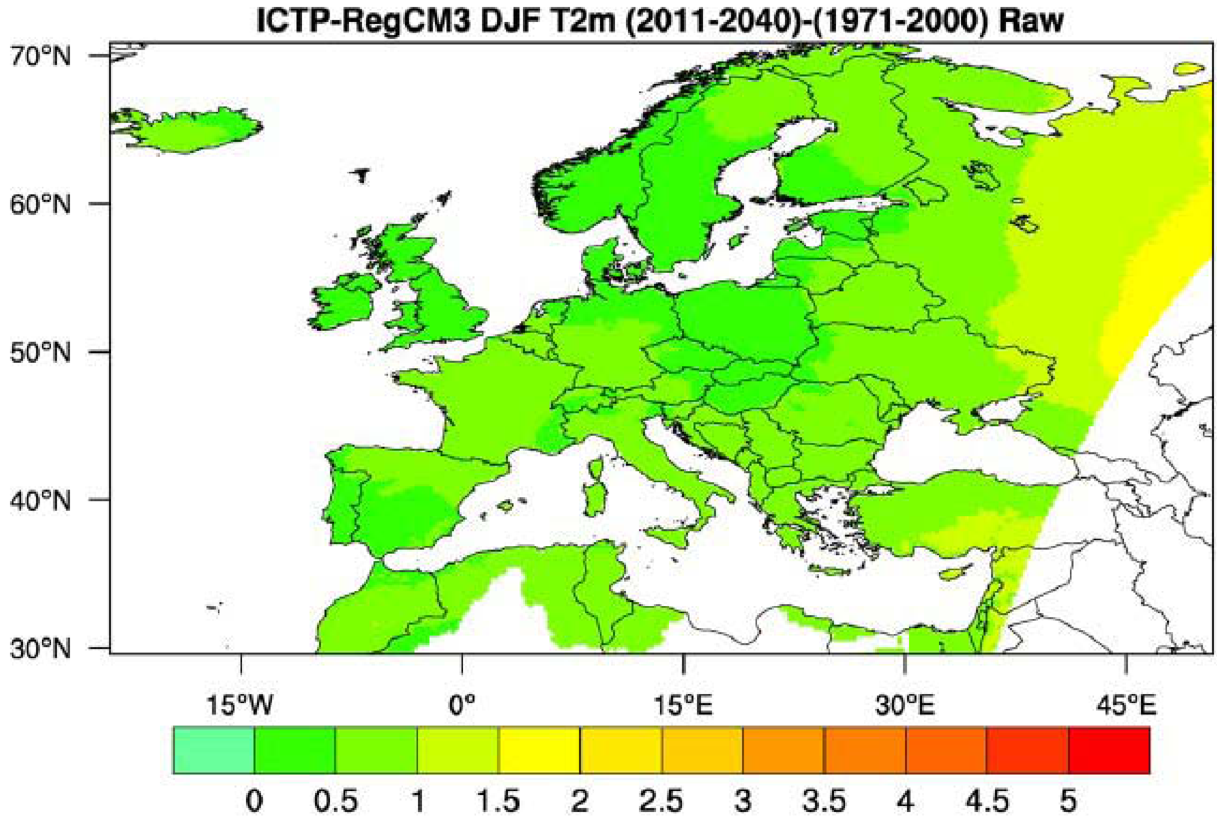

MPI-REMO Winter T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

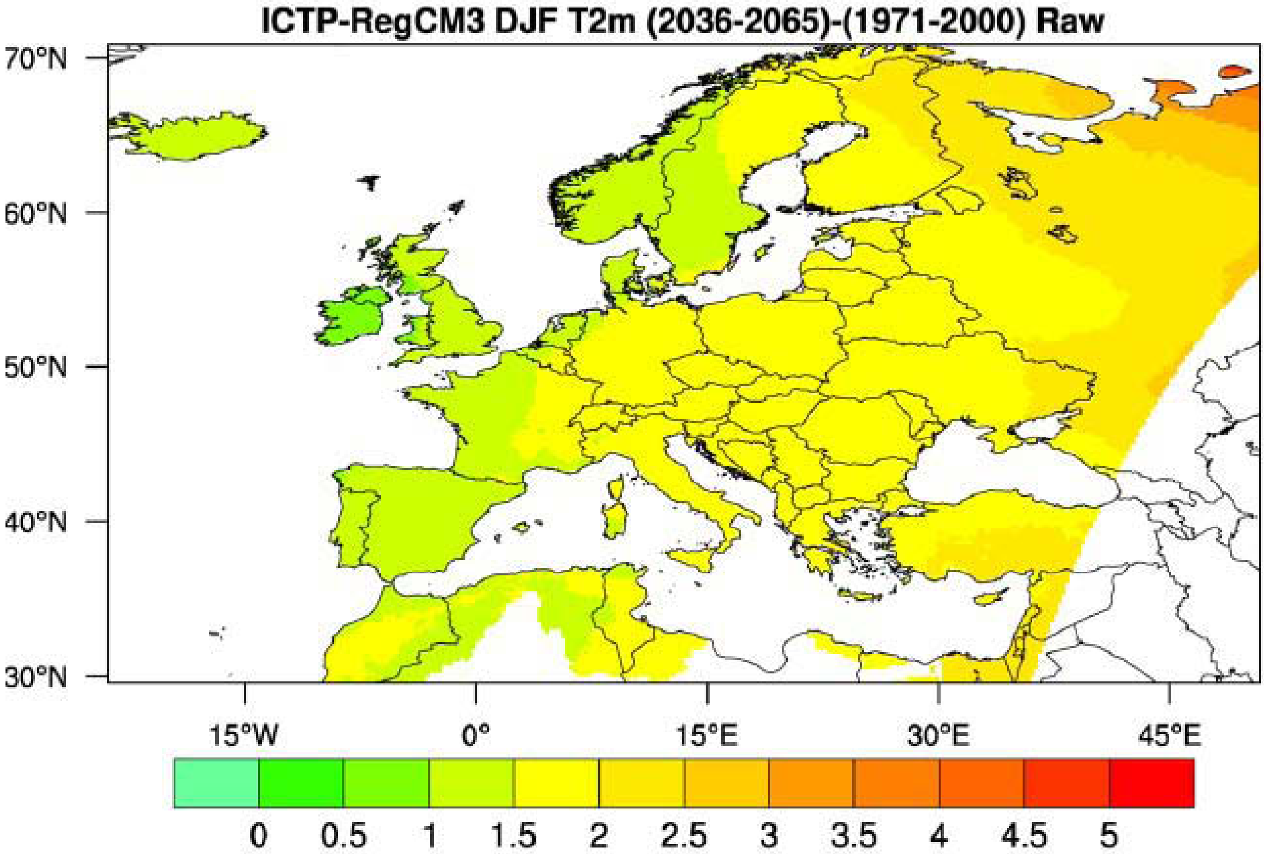
DJF Temperature

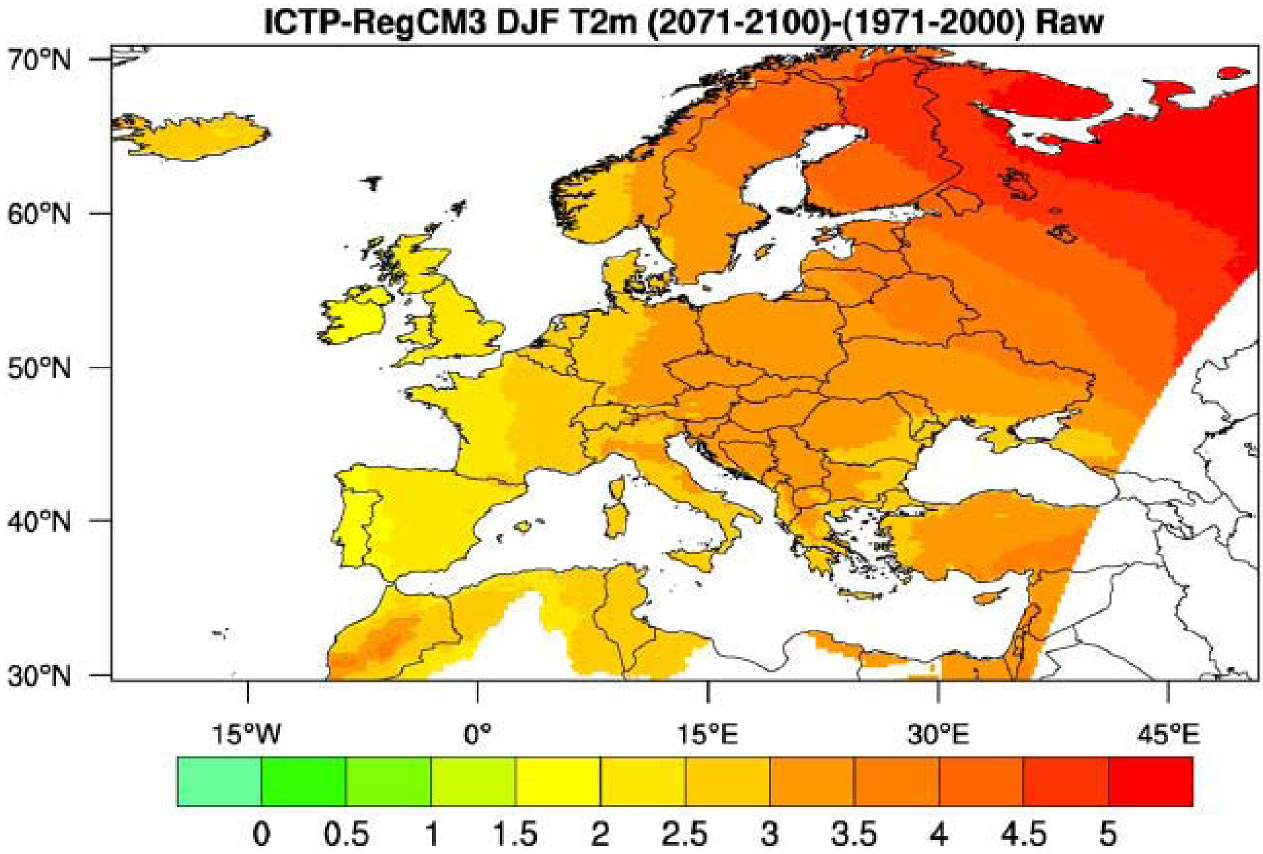

CNRM-ARPEGE DJF T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

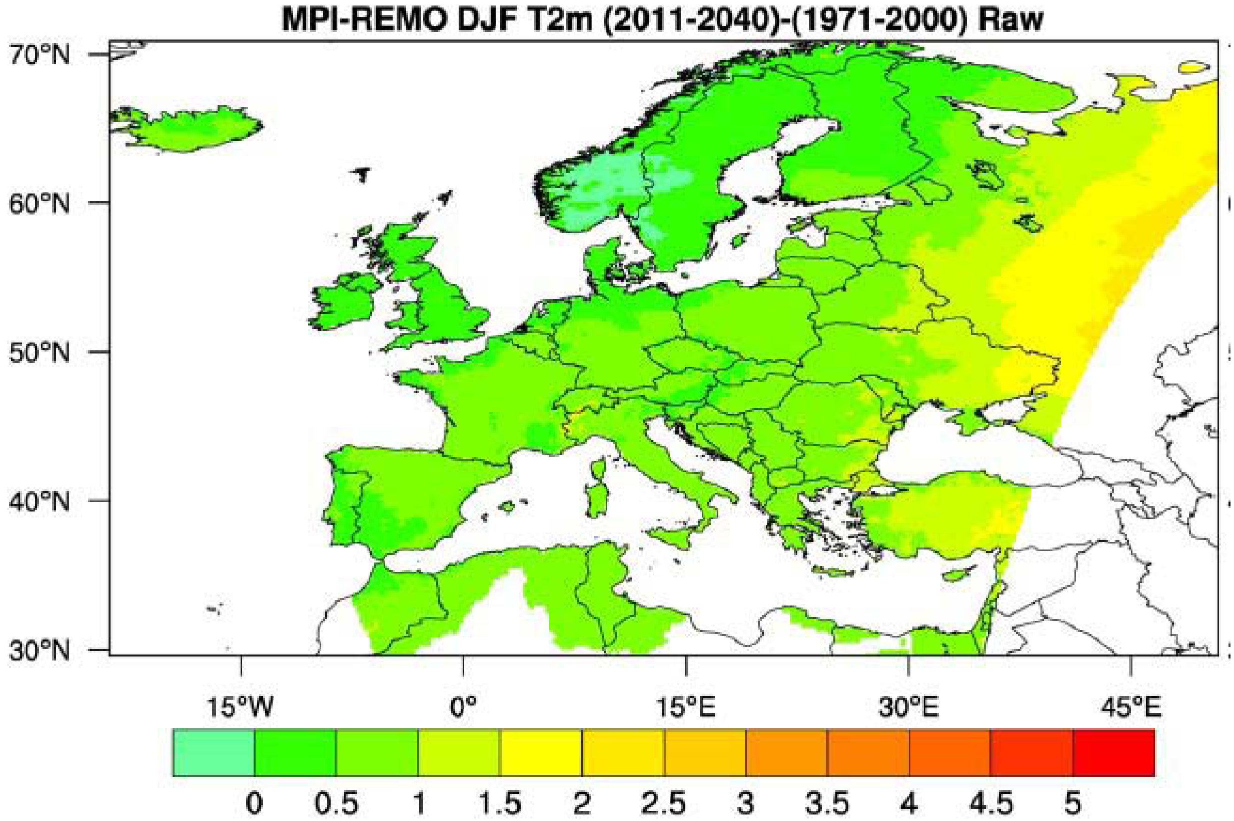

CNRM-ARPEGE DJF T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

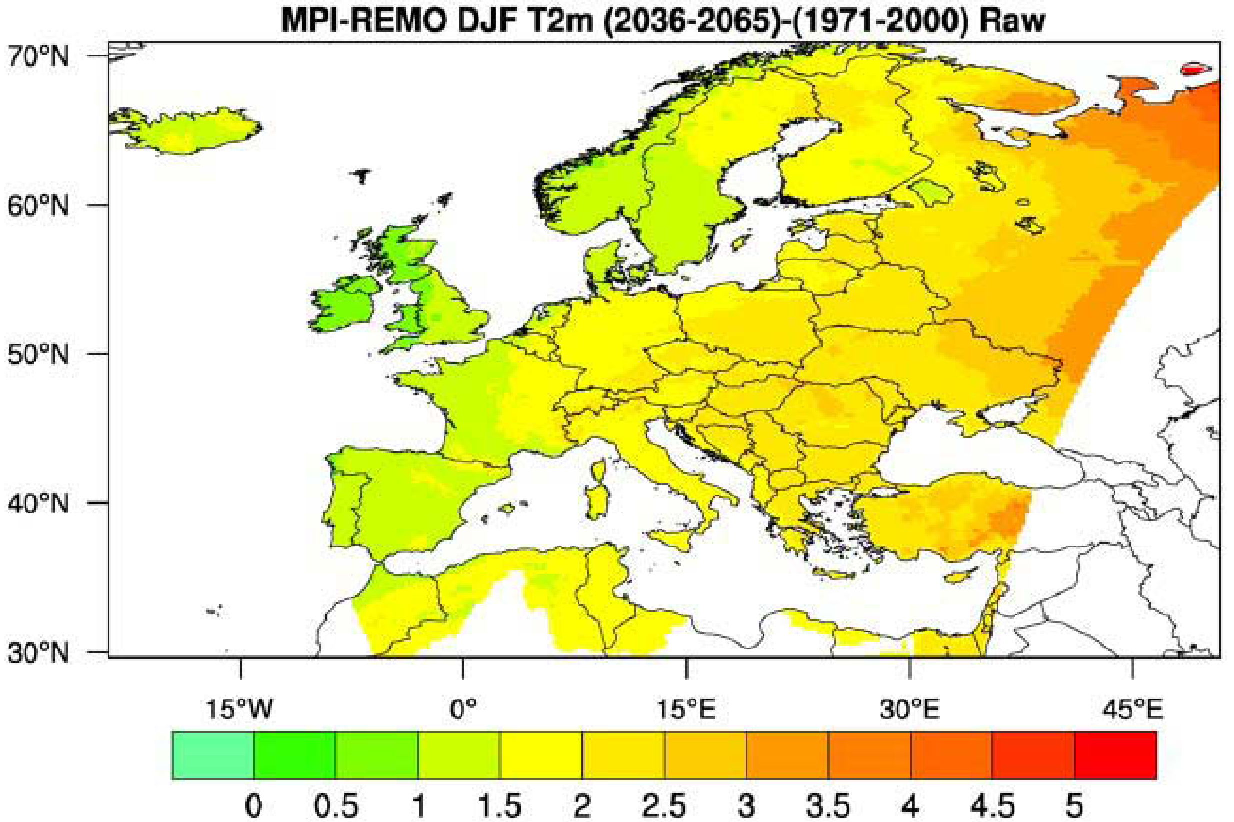

CNRM-ARPEGE DJF T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

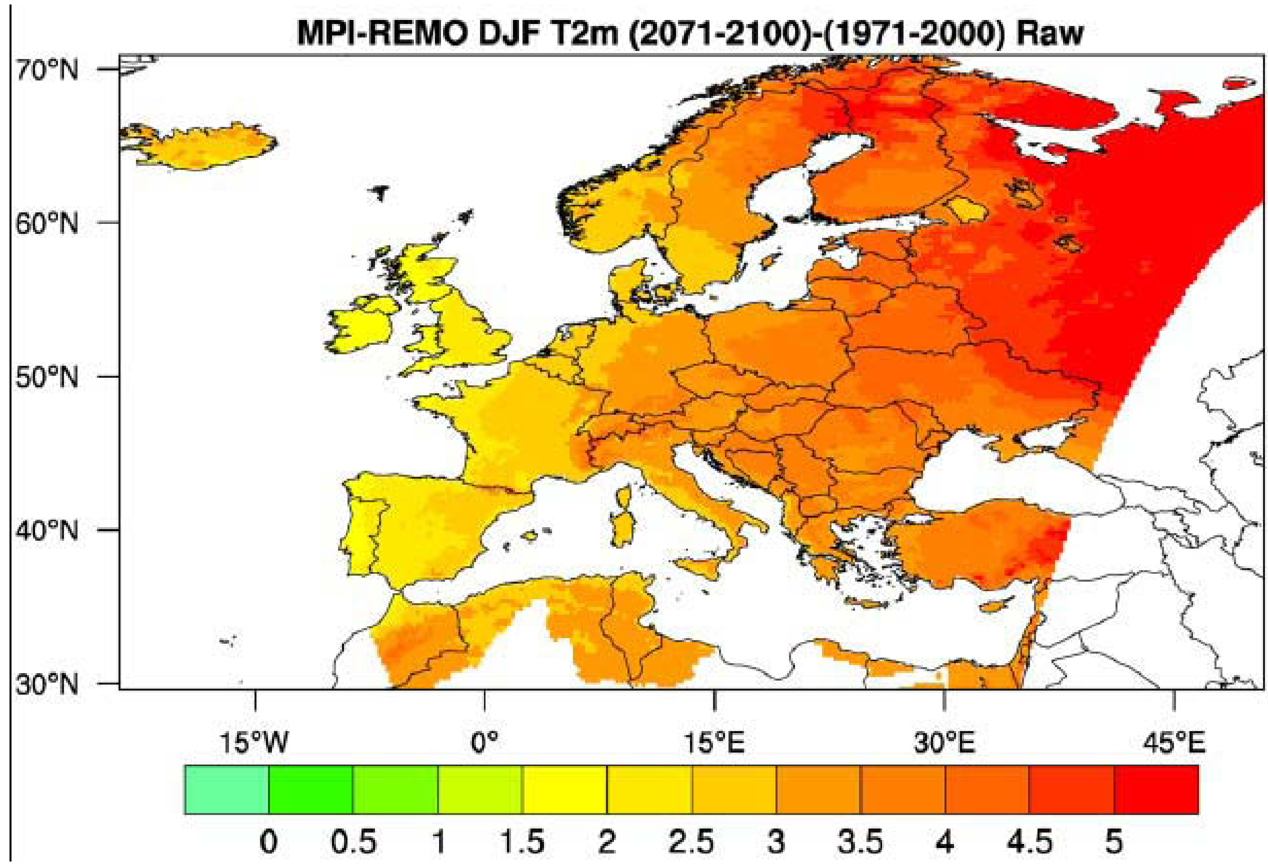

ICTP-RegCM3 DJF T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


ICTP-RegCM3 DJF T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5


ICTP-RegCM3 DJF T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5


MPI-REMO DJF T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

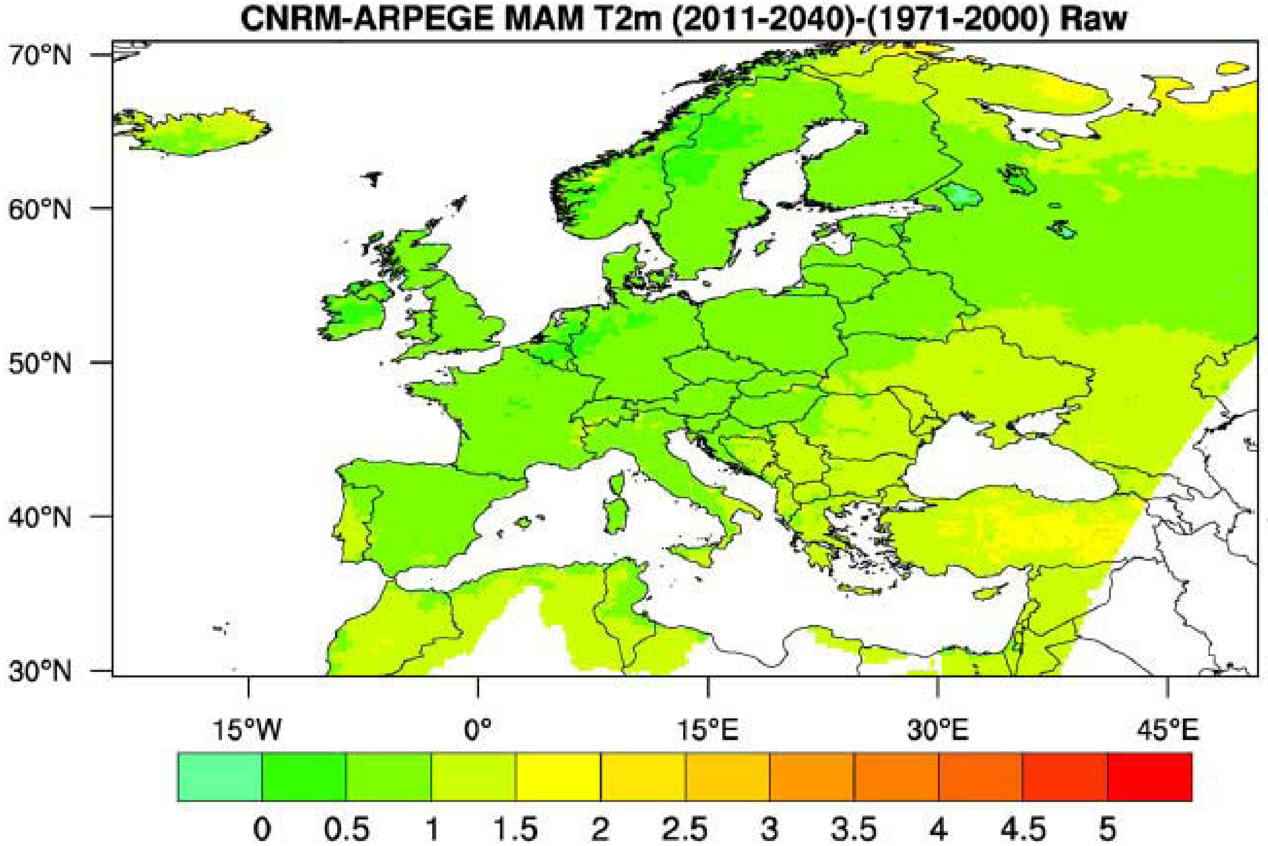

MPI-REMO DJF T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

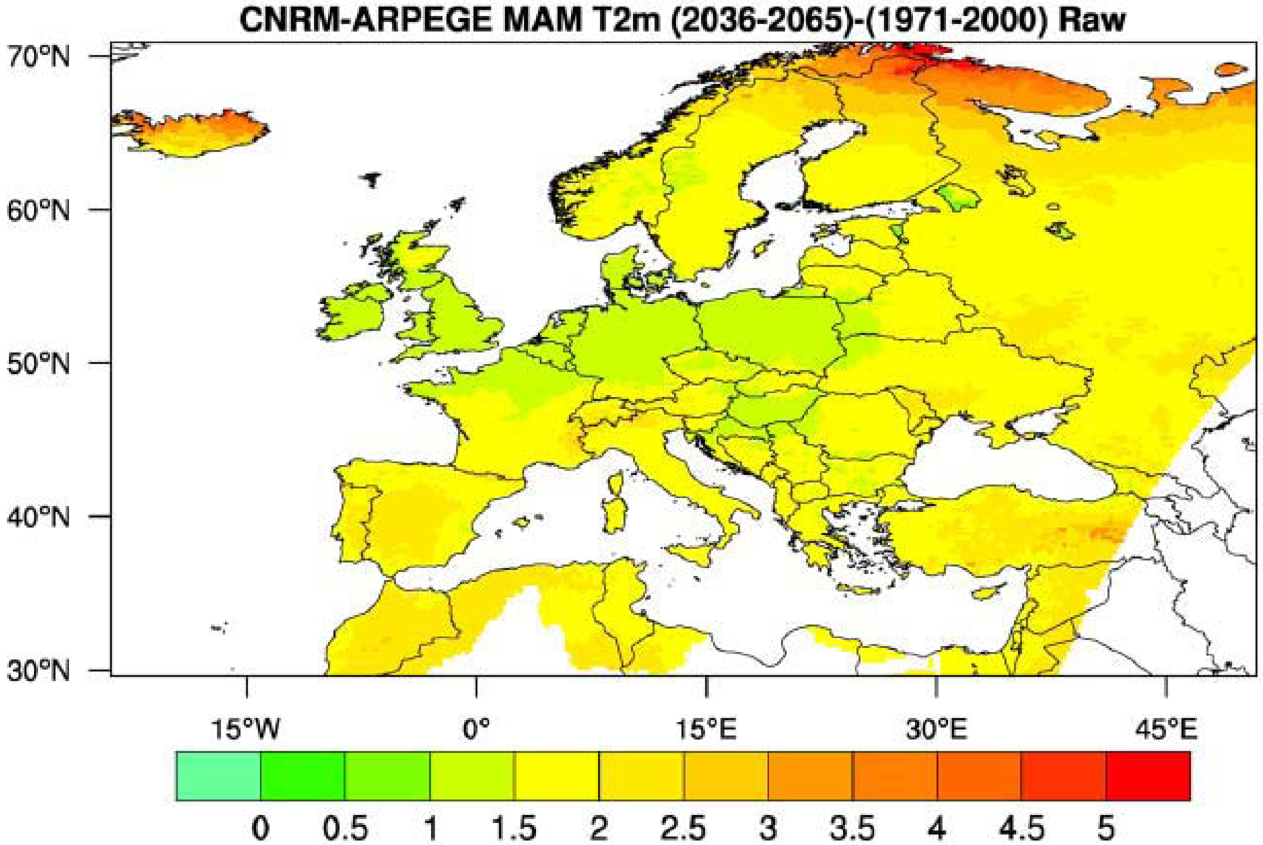


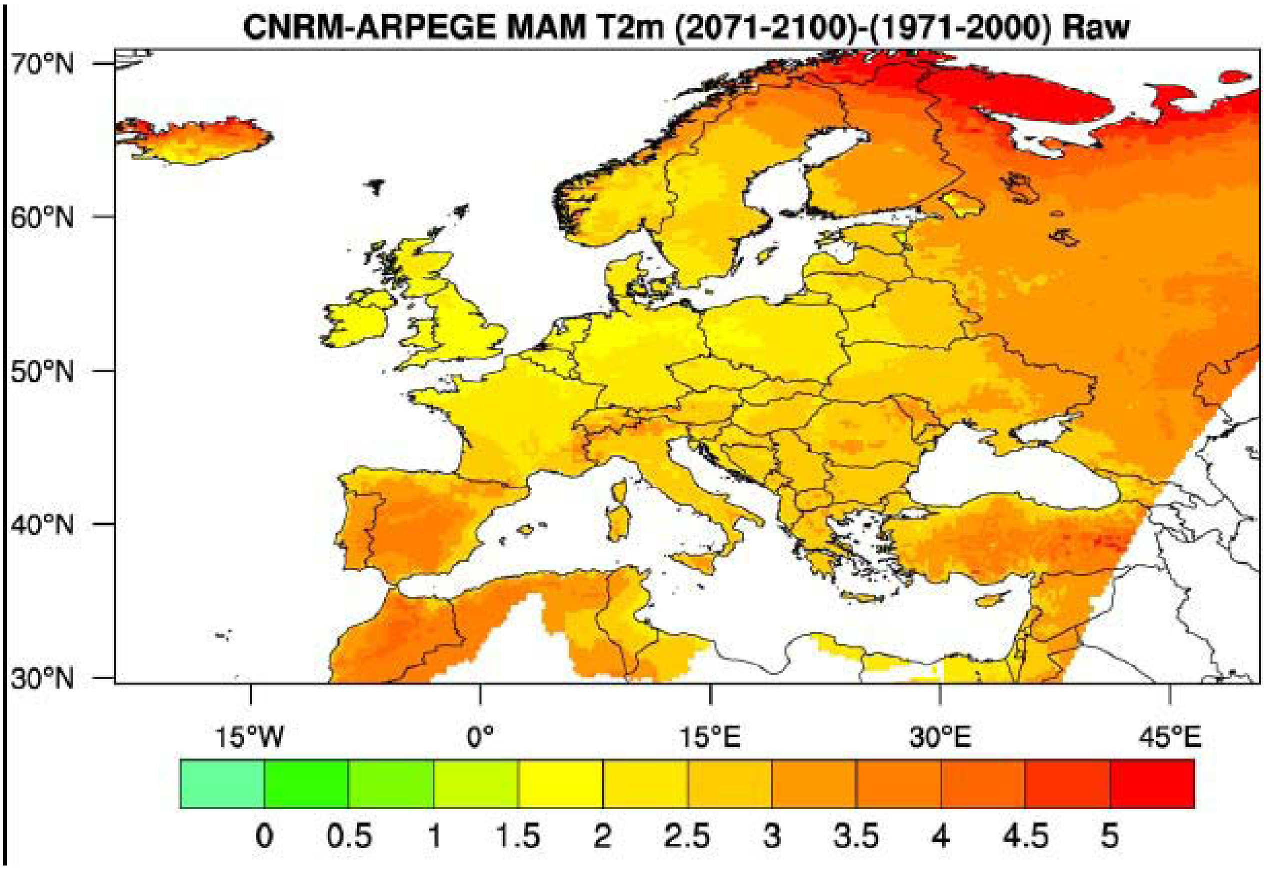
MPI-REMO DJF T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

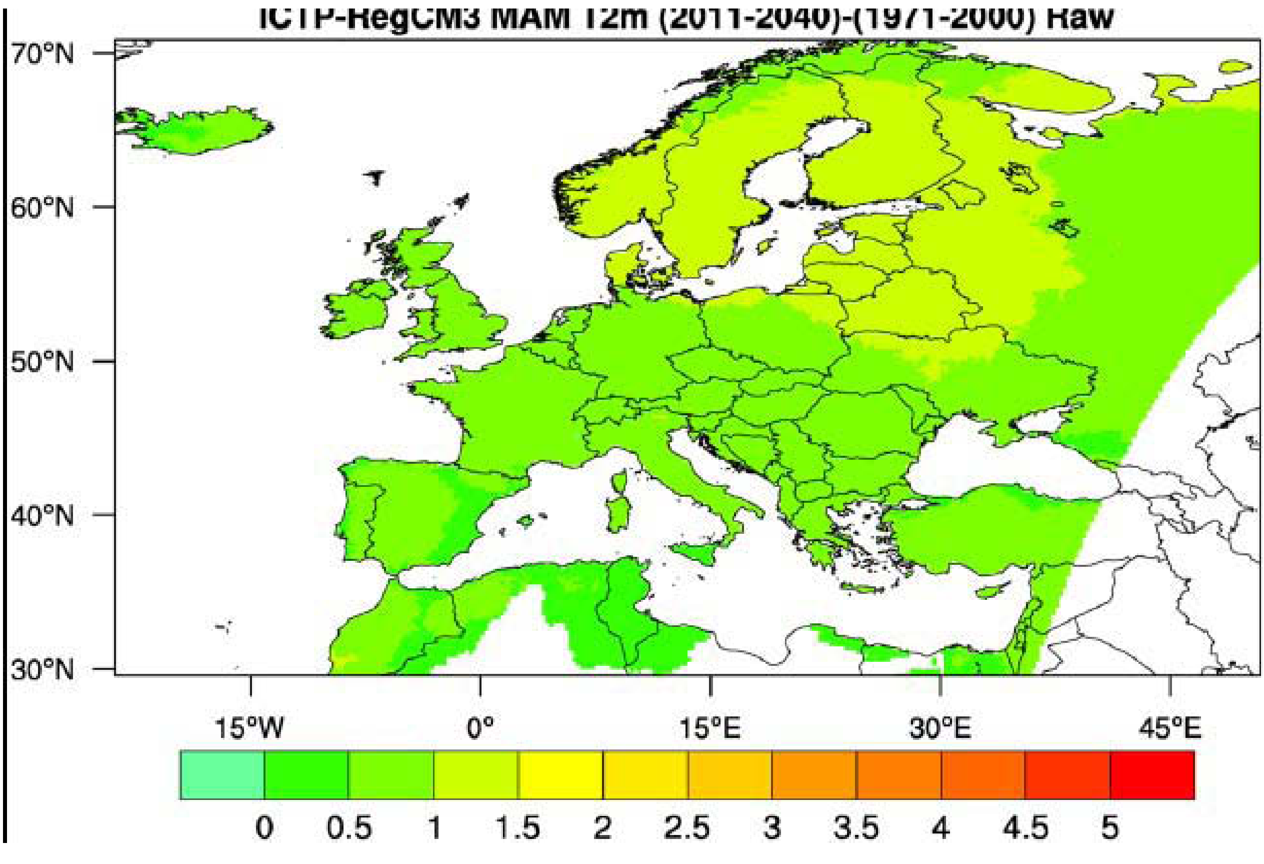
L

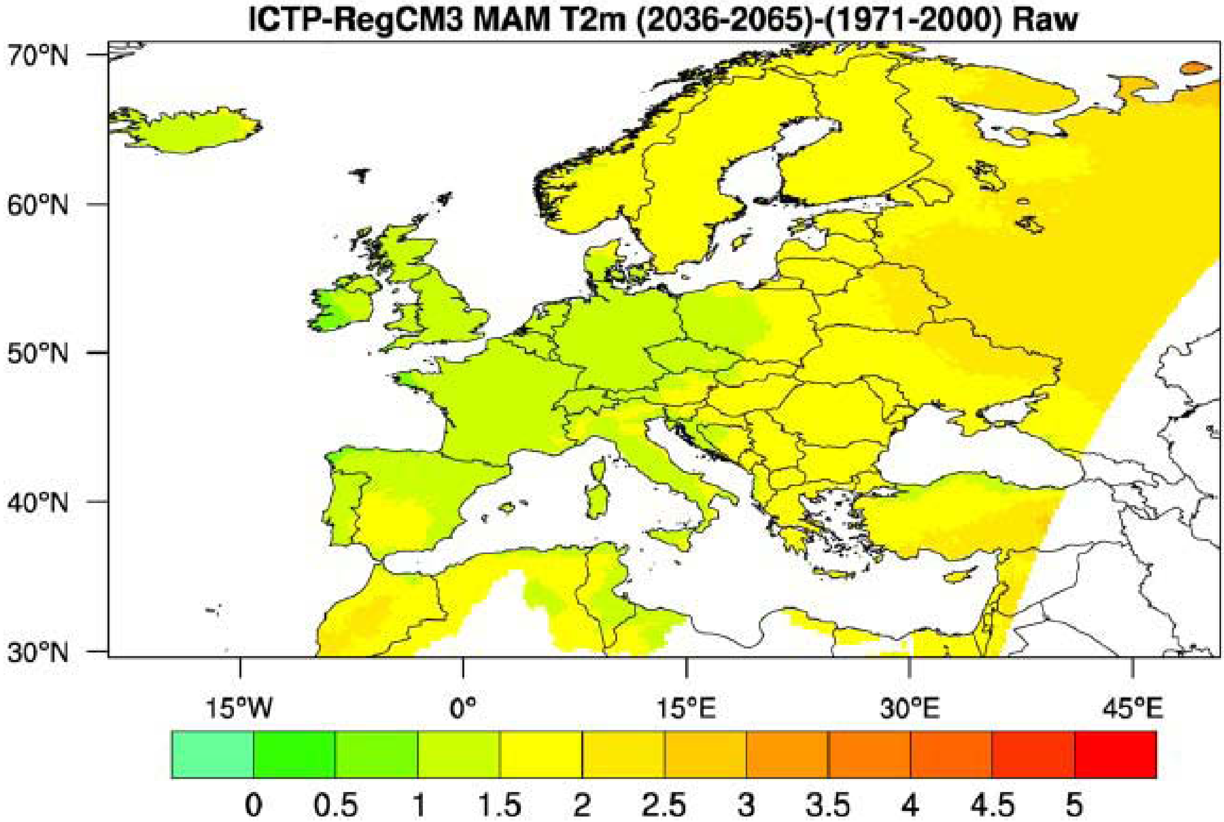
MAM Temperature

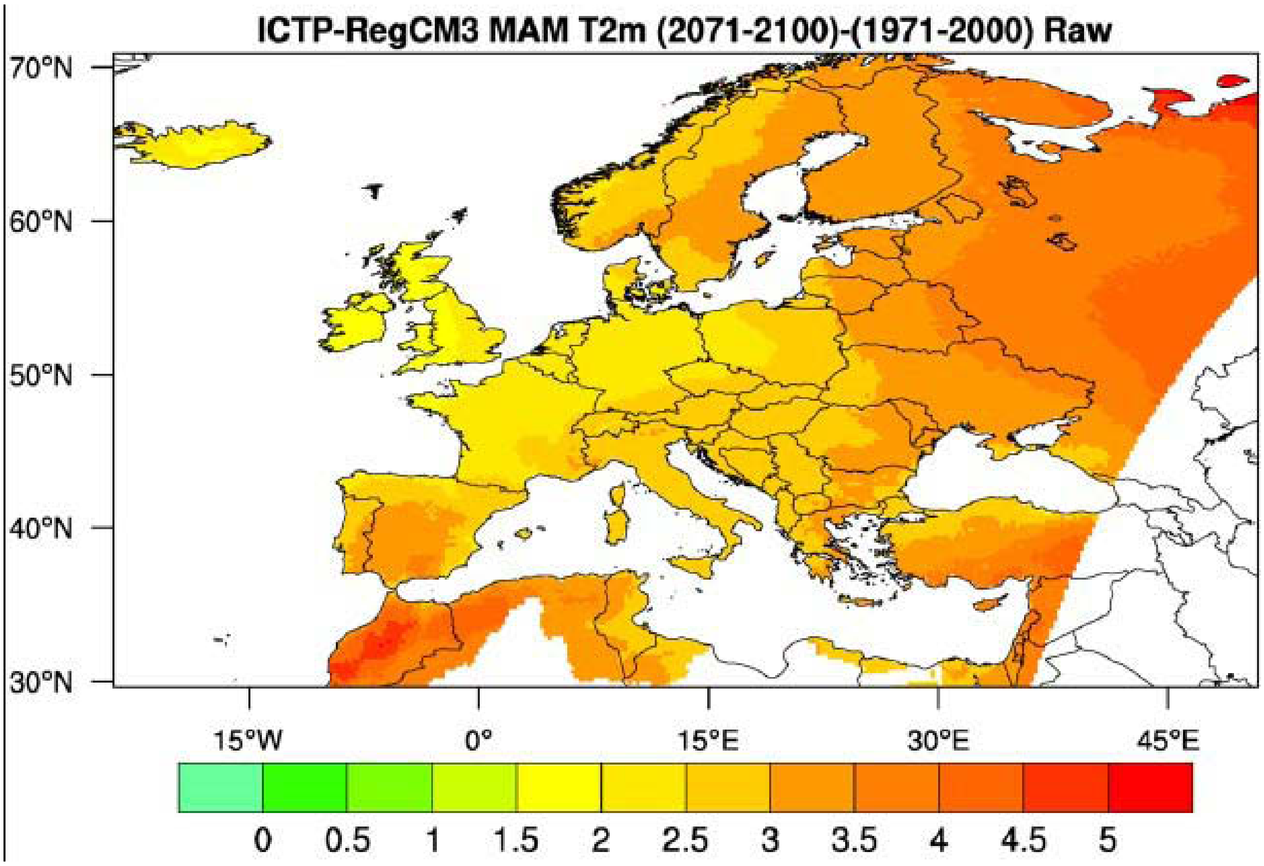

CNRM-ARPEGE MAM T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

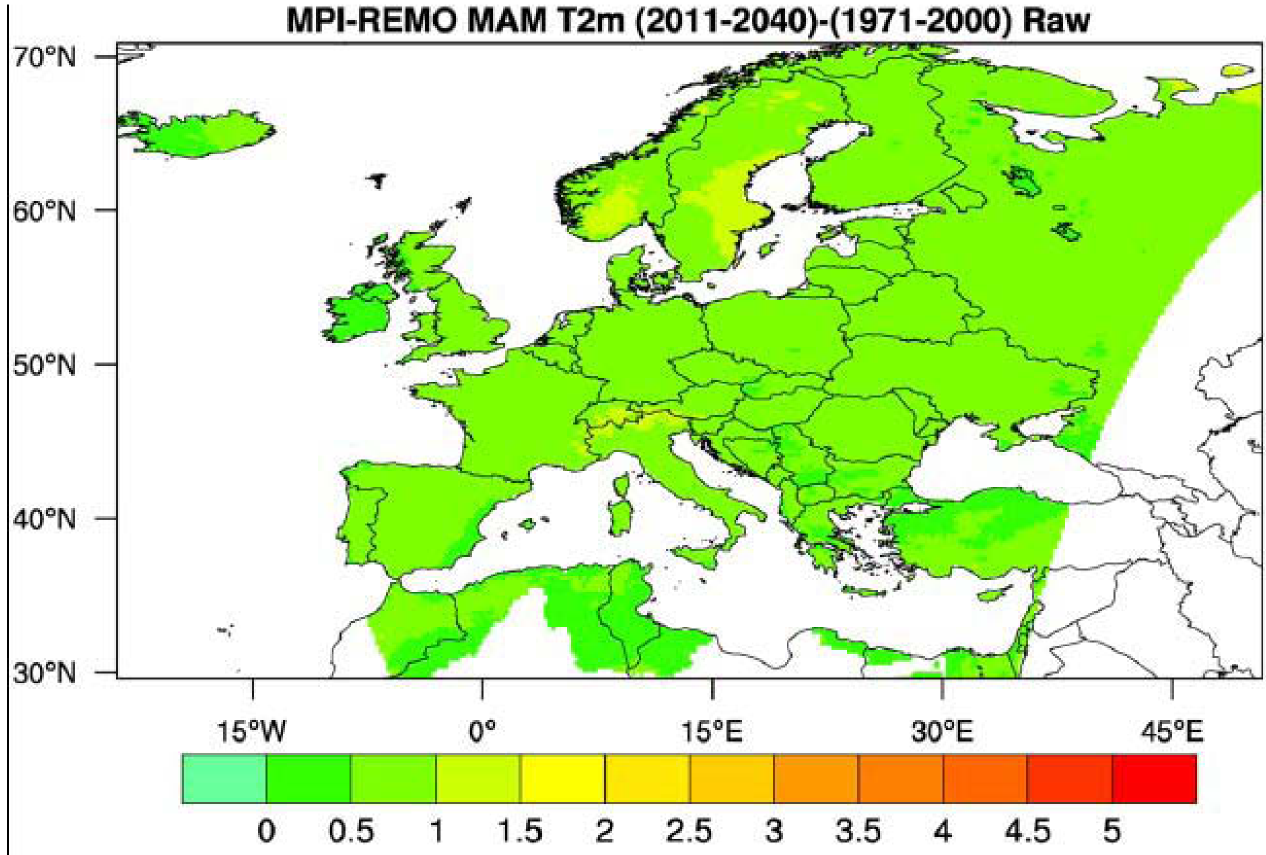

CNRM-ARPEGE MAM T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

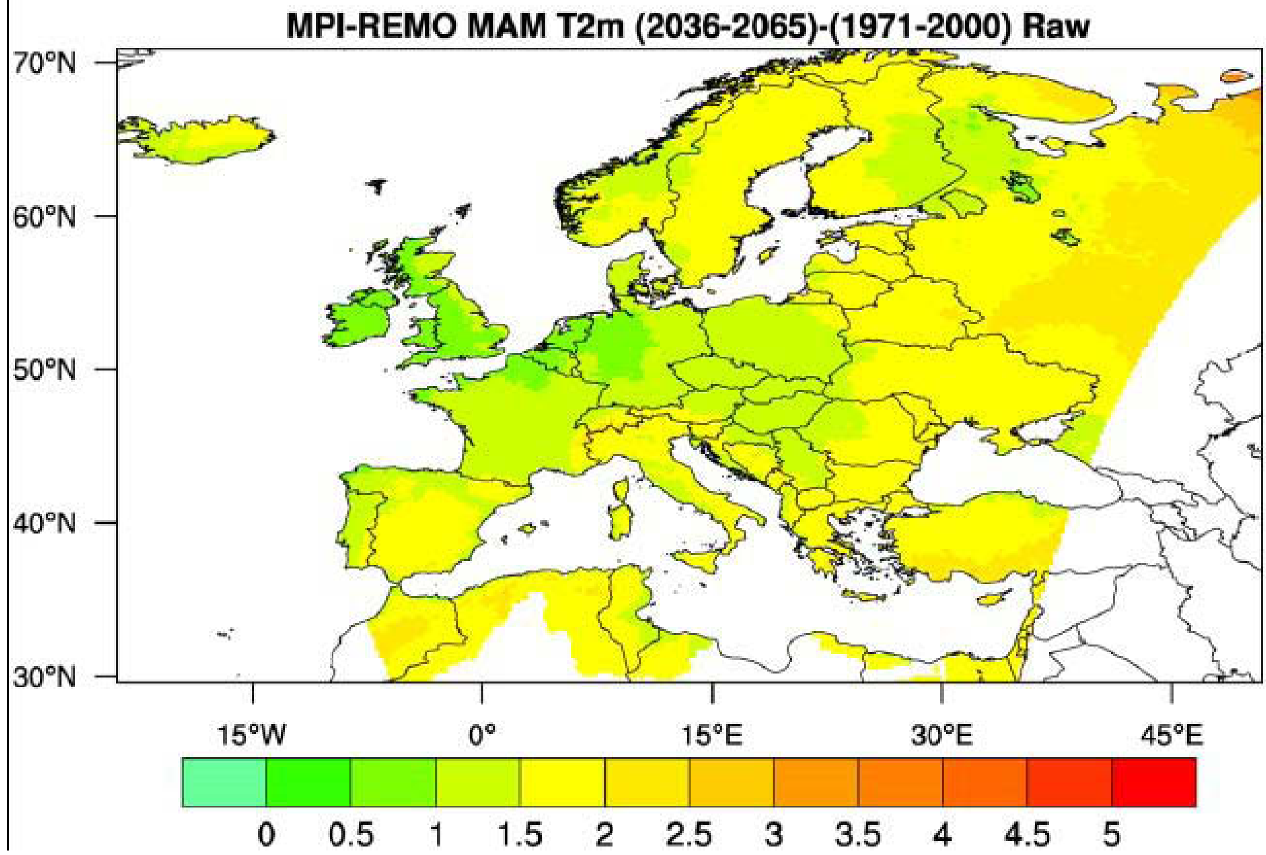

CNRM-ARPEGE MAM T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

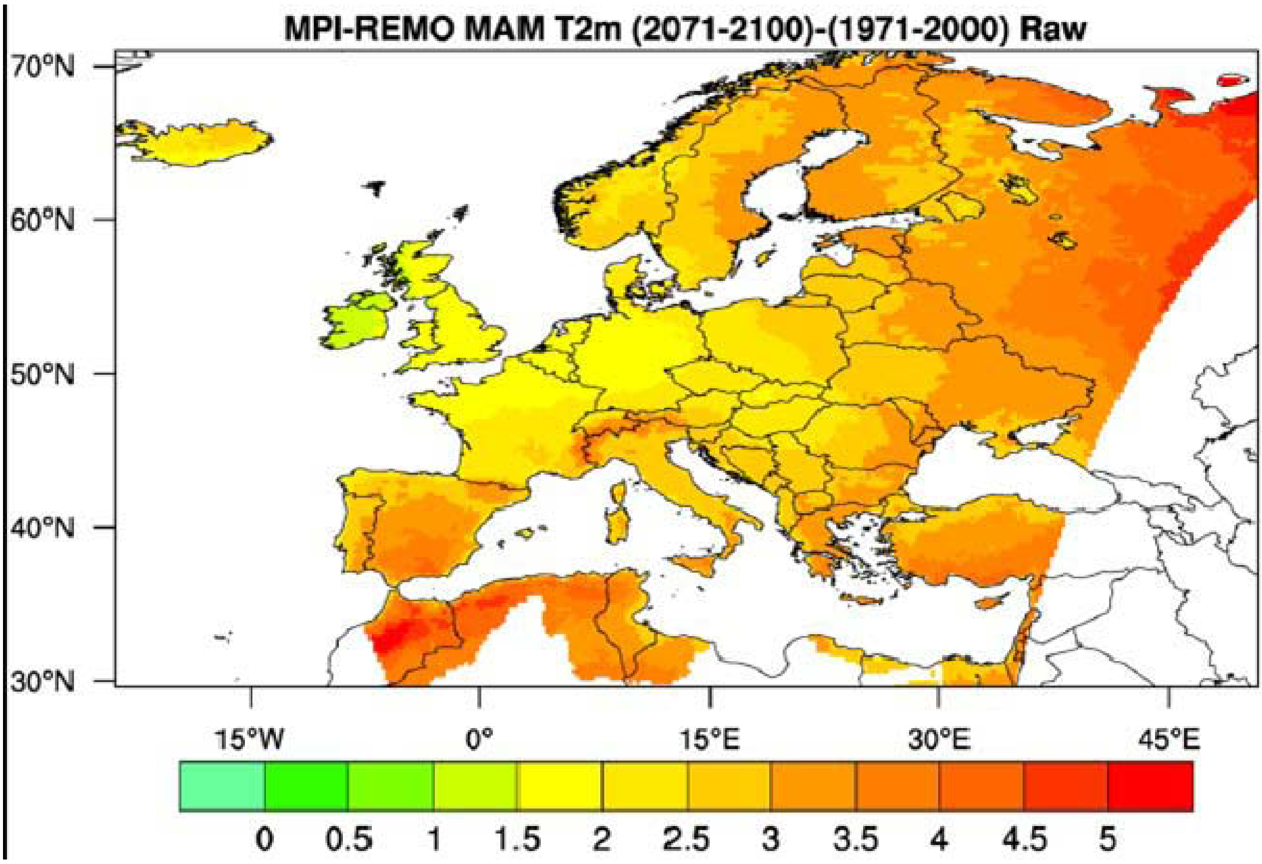

ICTP-RegCM3 MAM T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5


ICTP-RegCM3 MAM T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

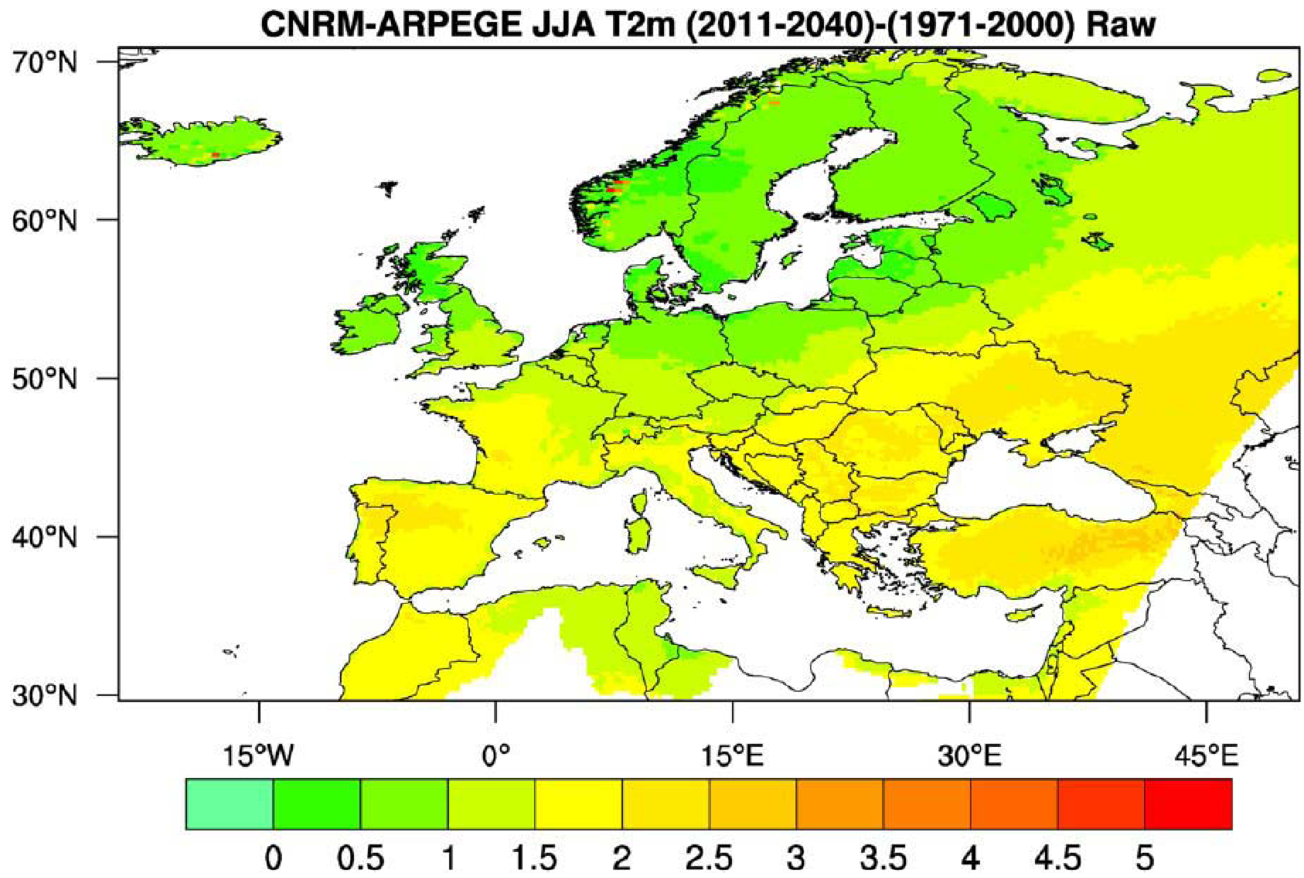

ICTP-RegCM3 MAM T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

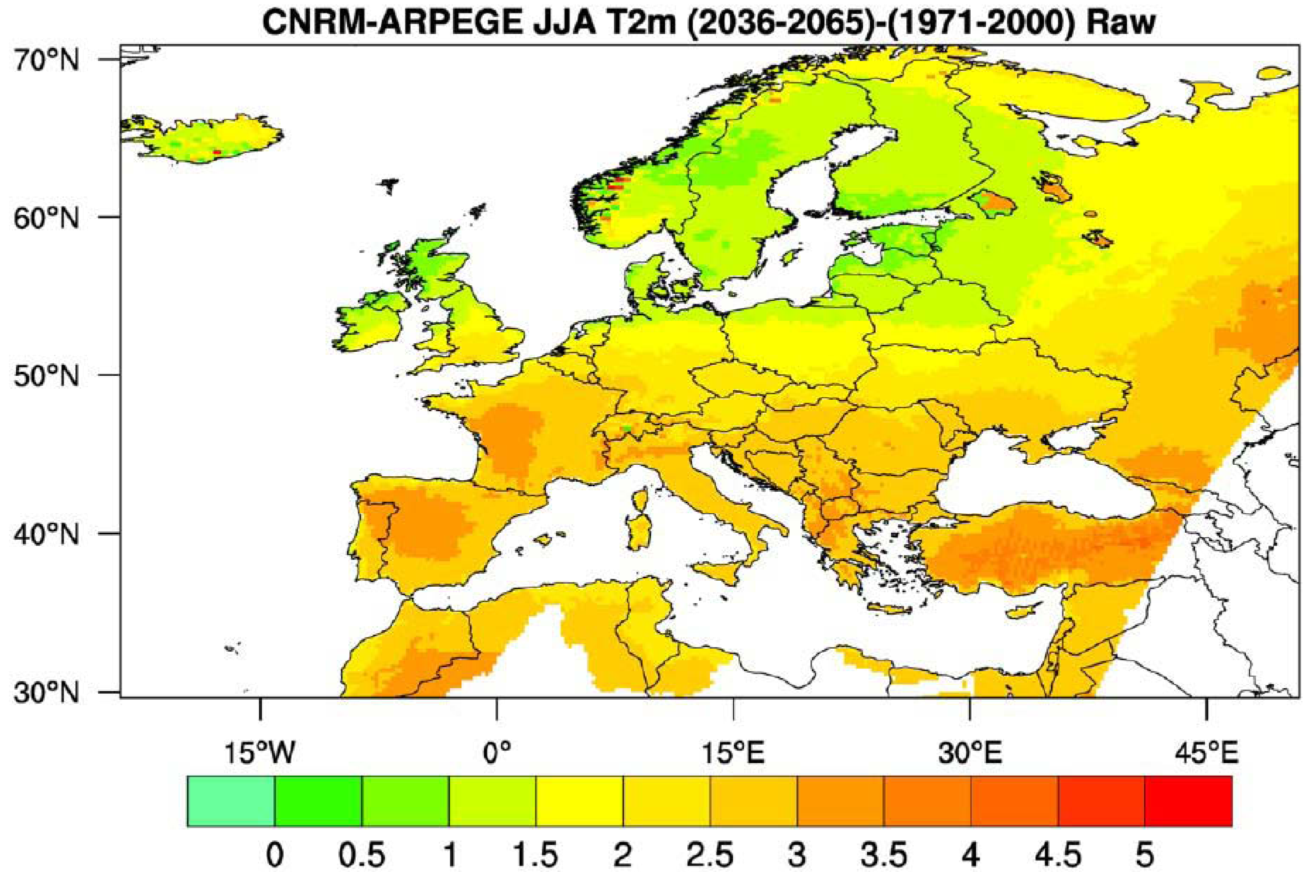

MPI-REMO MAM T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

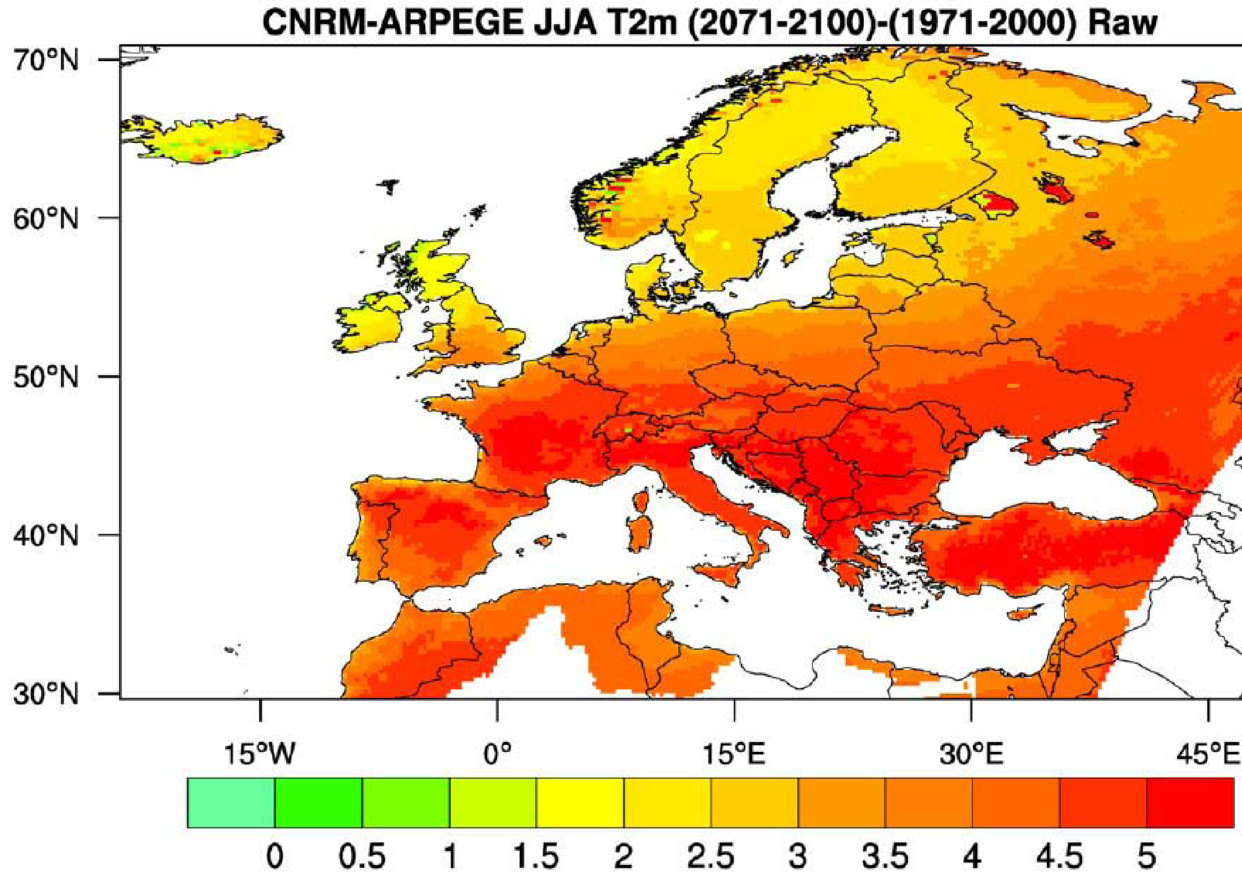

MPI-REMO MAM T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

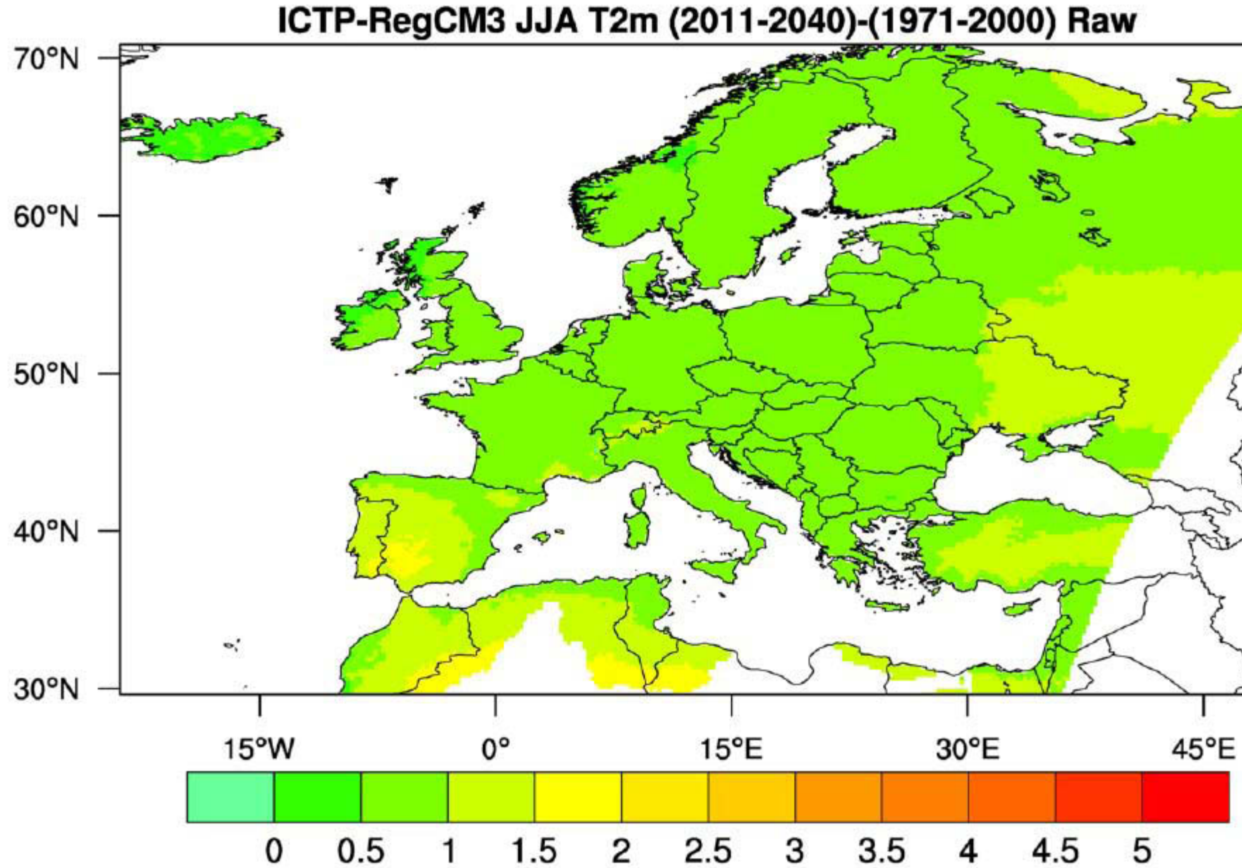

MPI-REMO MAM T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

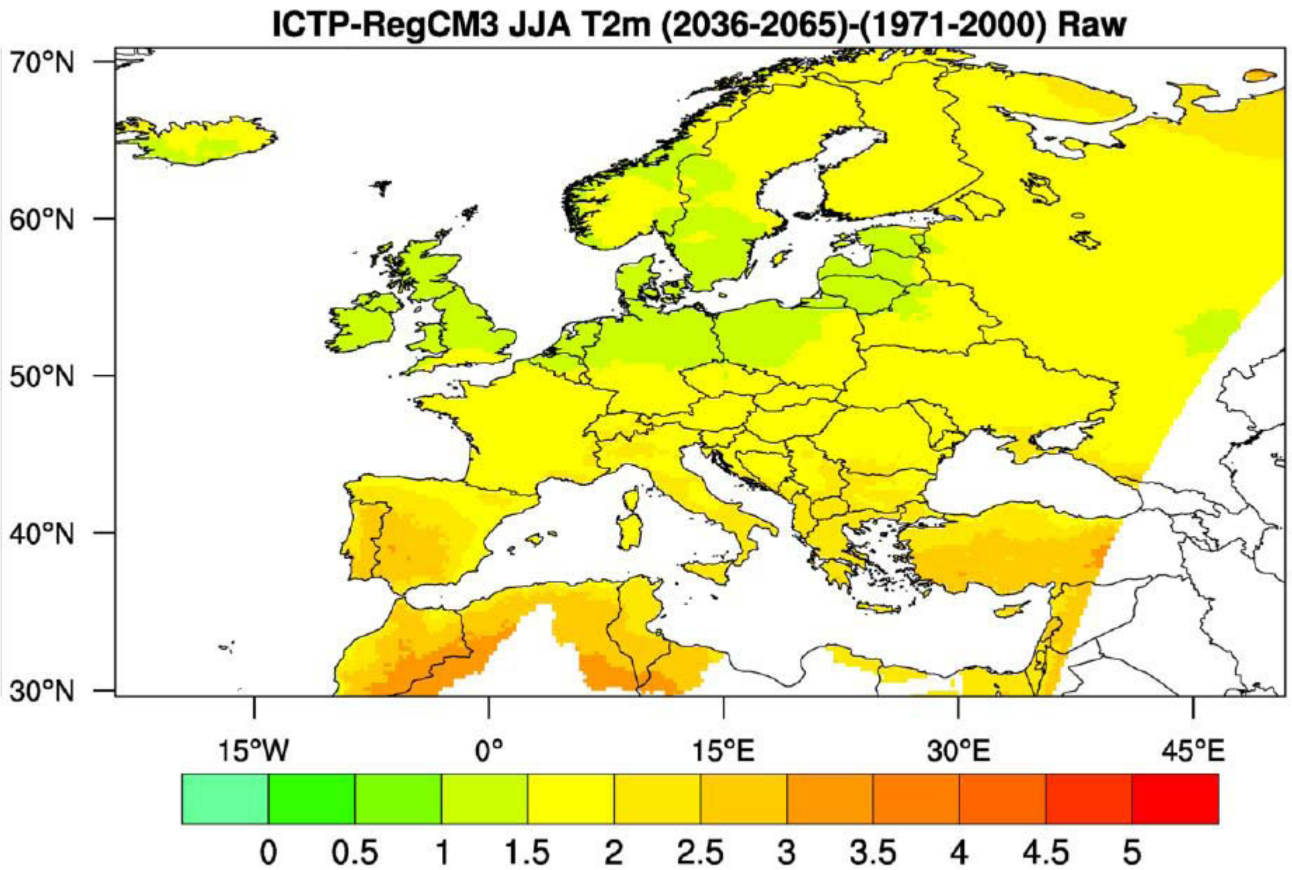
JJA Temperature

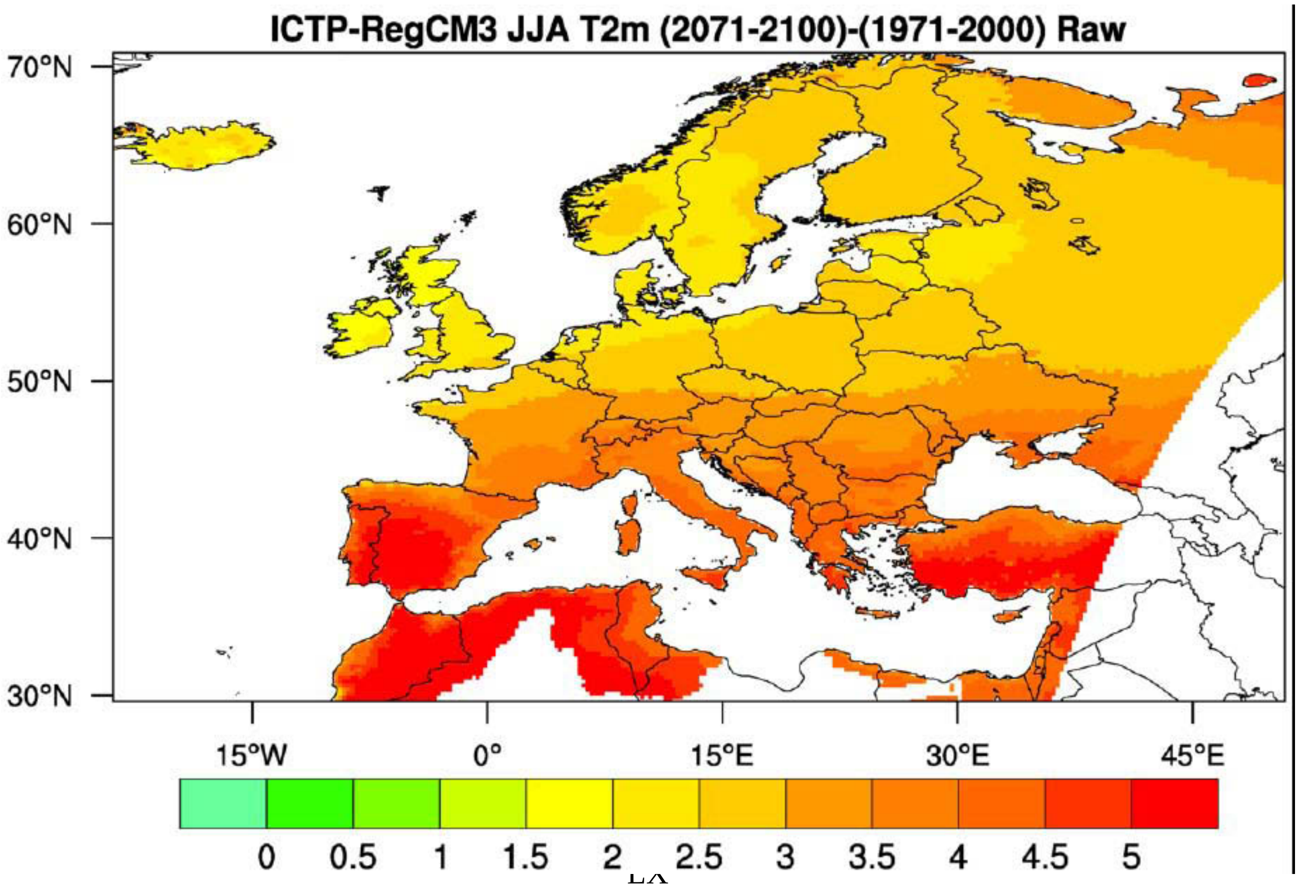

CNRM-ARPEGE JJA T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

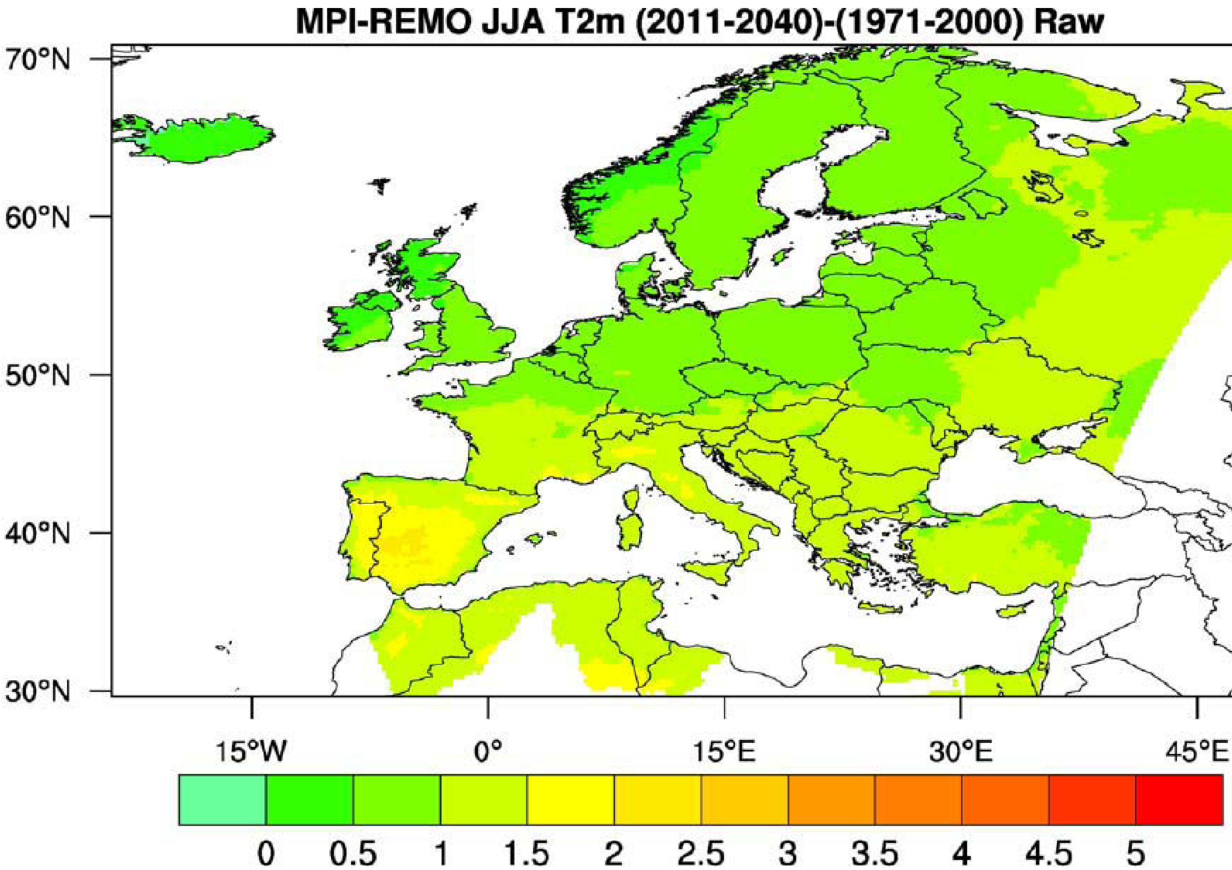

CNRM-ARPEGE JJA T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

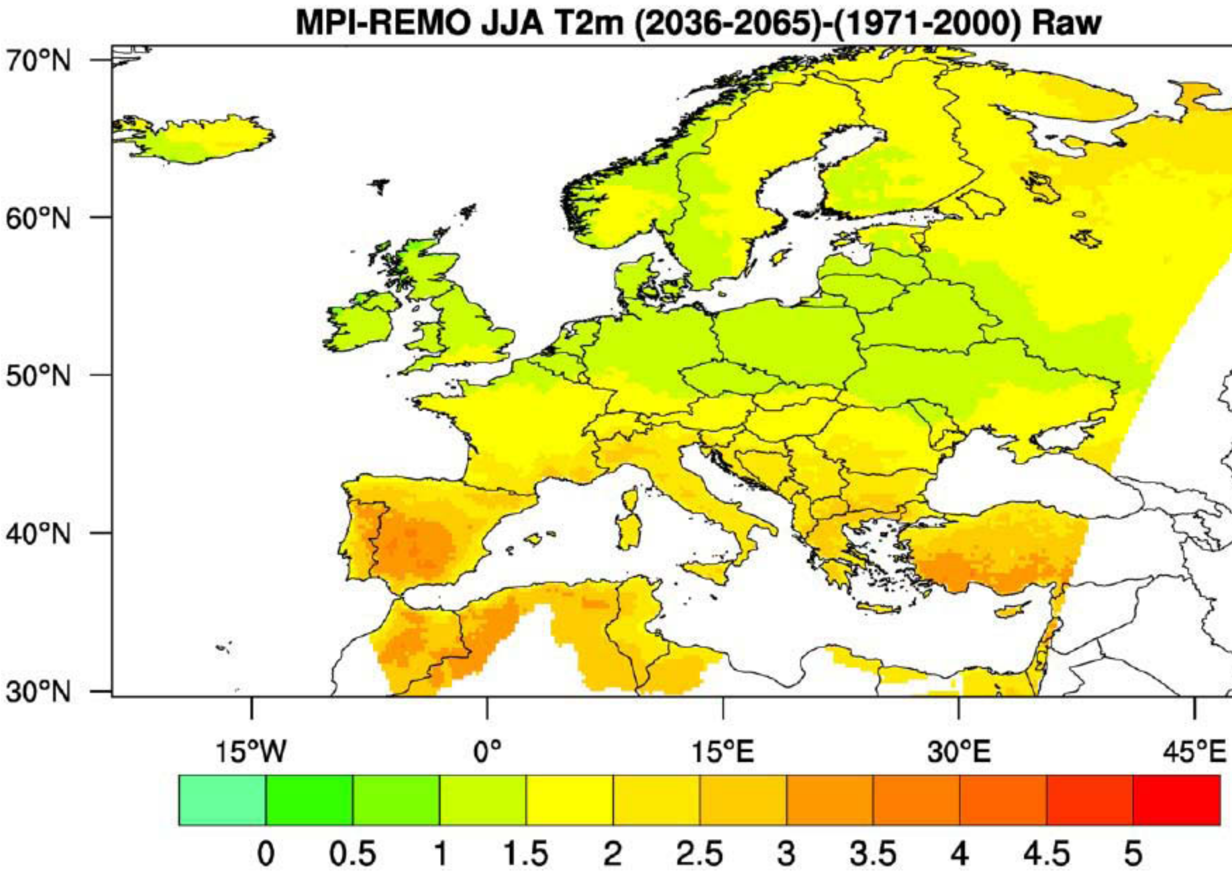

CNRM-ARPEGE JJA T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

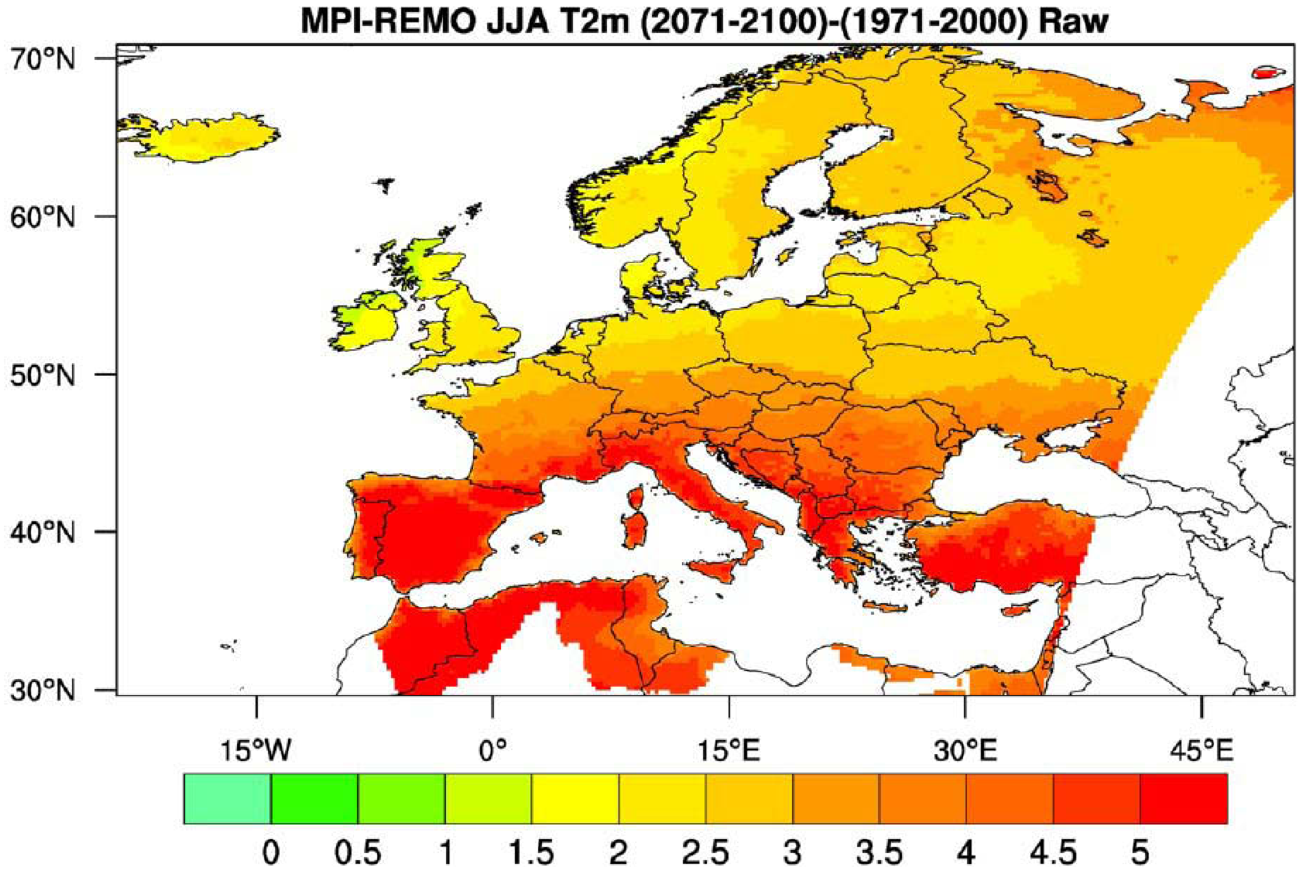

ICTP-RegCM3 JJA T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


ICTP-RegCM3 JJA T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

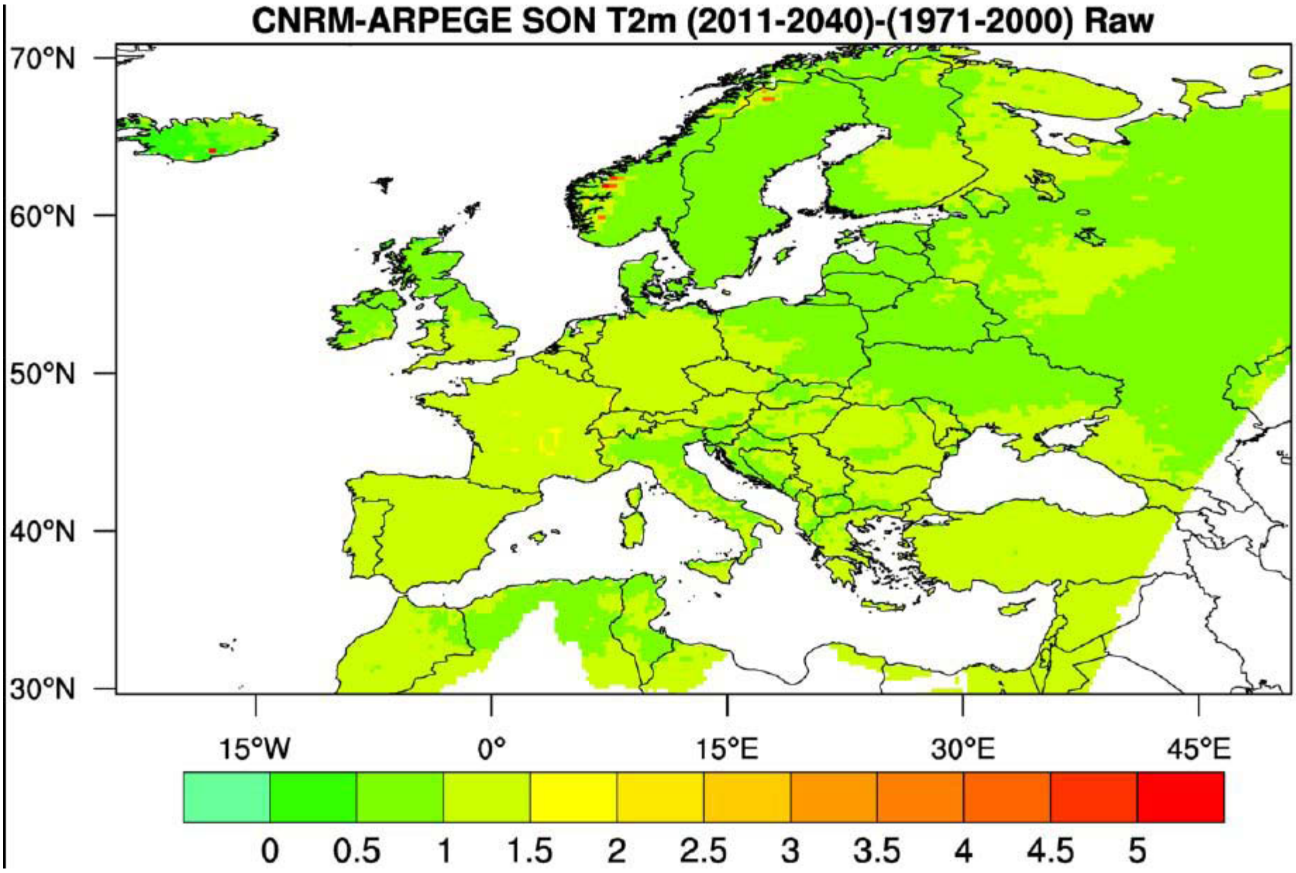

ICTP-RegCM3 JJA T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

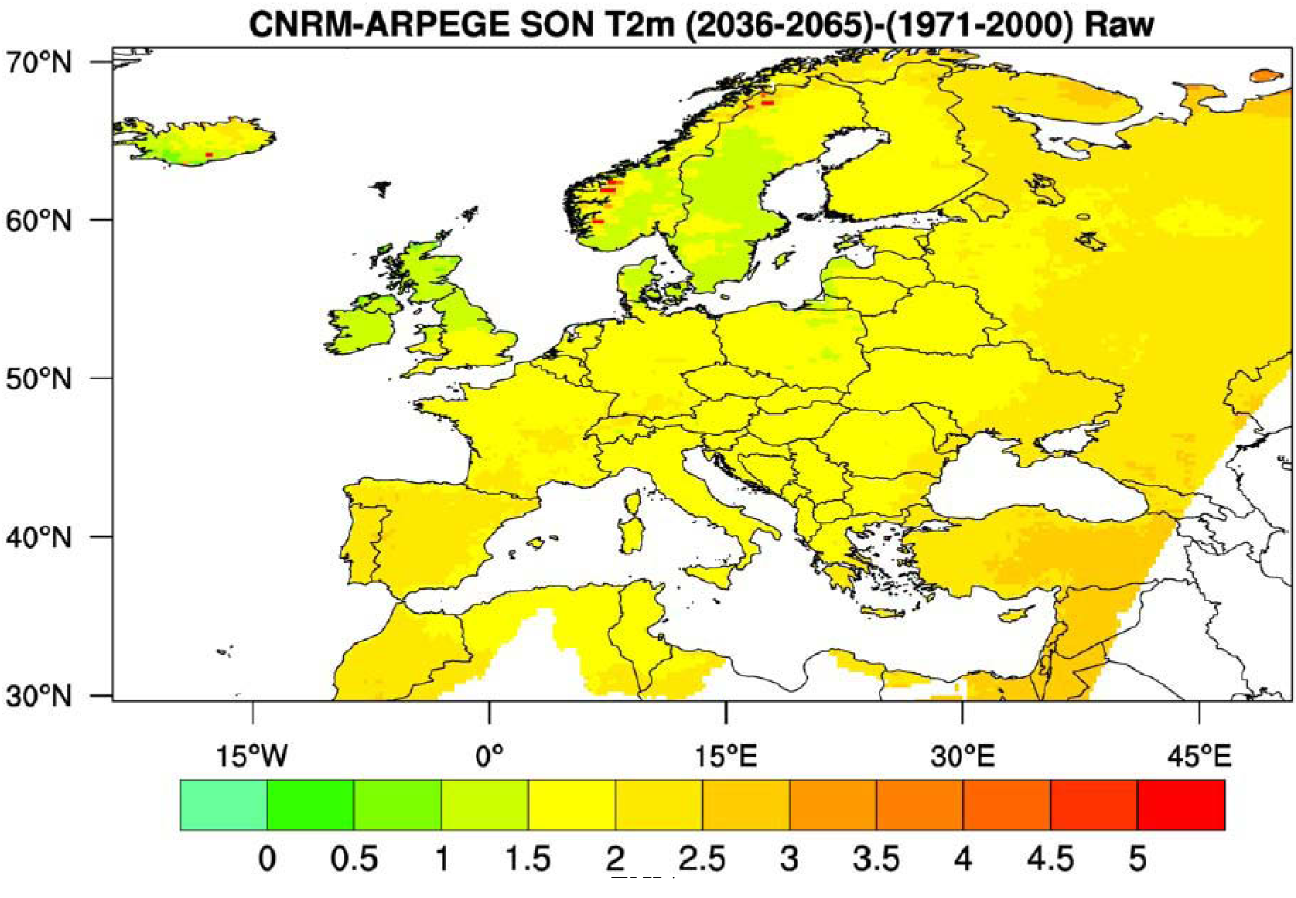

MPI-REMO JJA T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

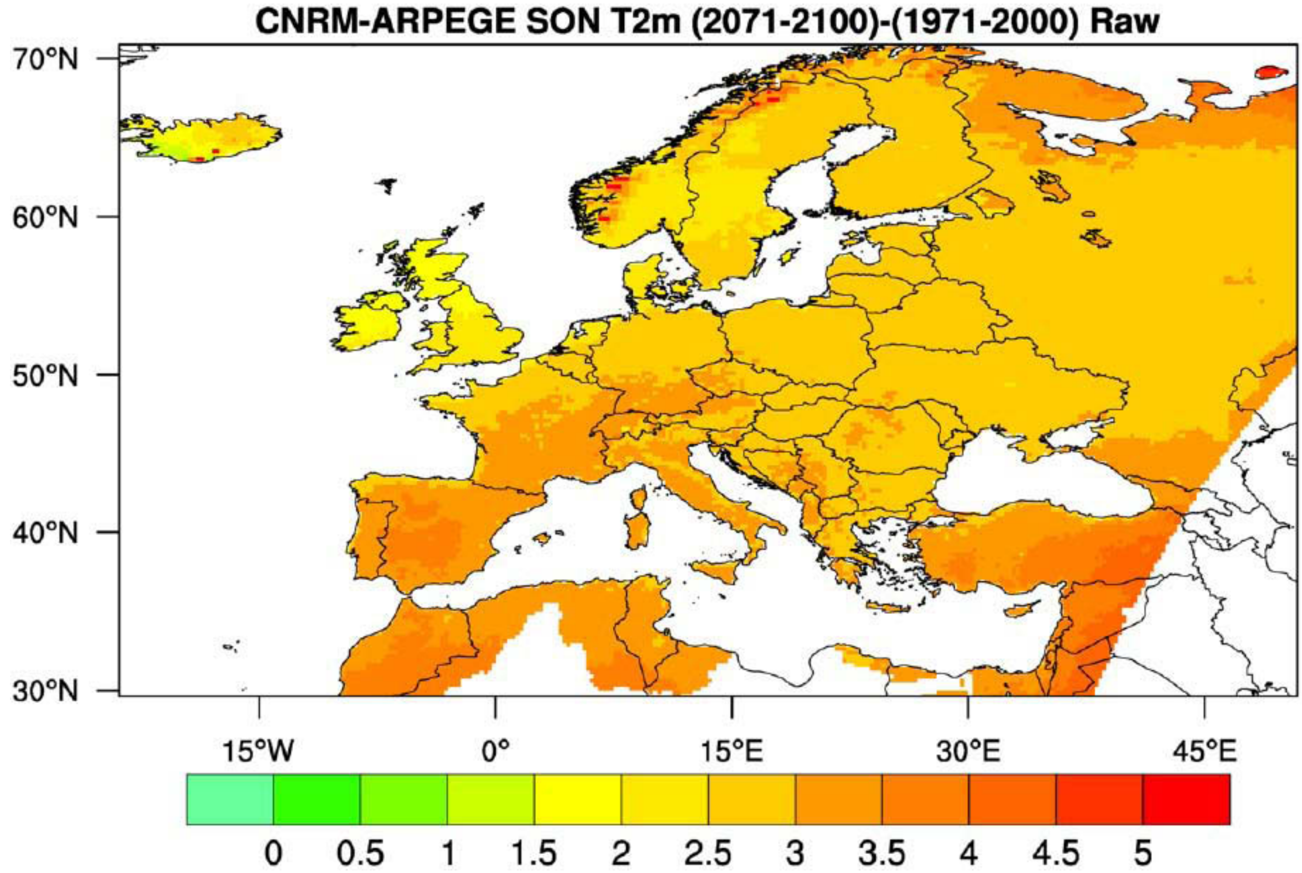

MPI-REMO JJA T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

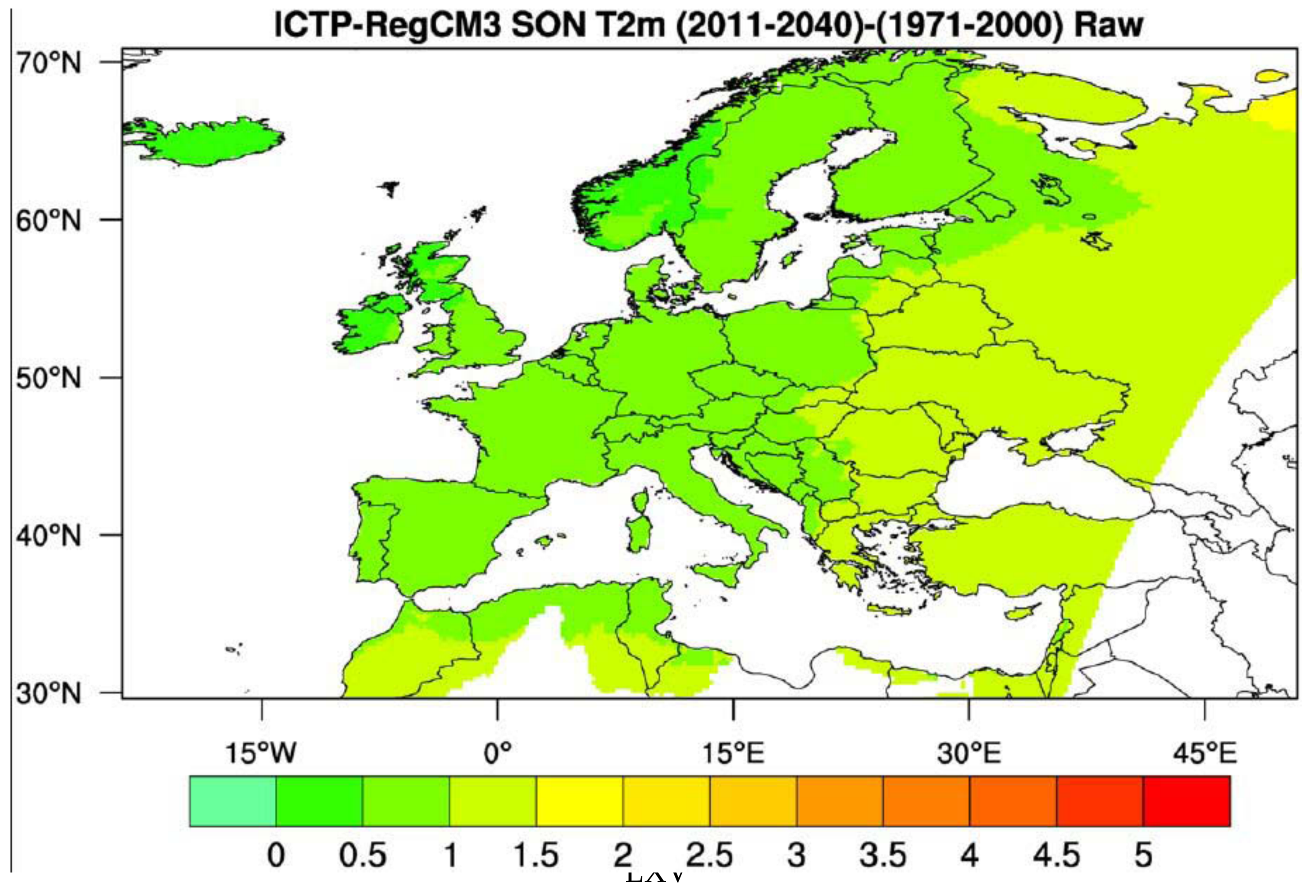

MPI-REMO JJA T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

SON Temperature

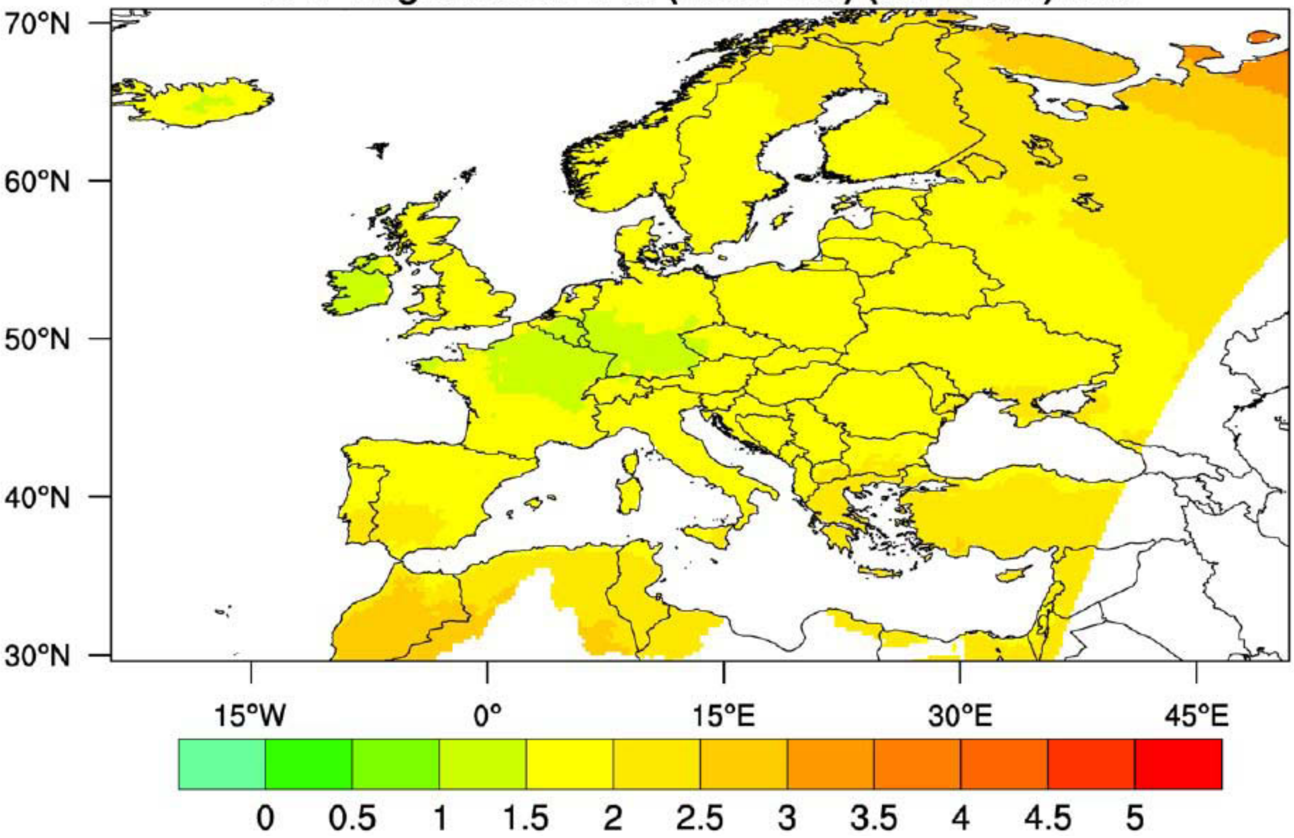

CNRM-ARPEGE SON T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


CNRM-ARPEGE SON T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

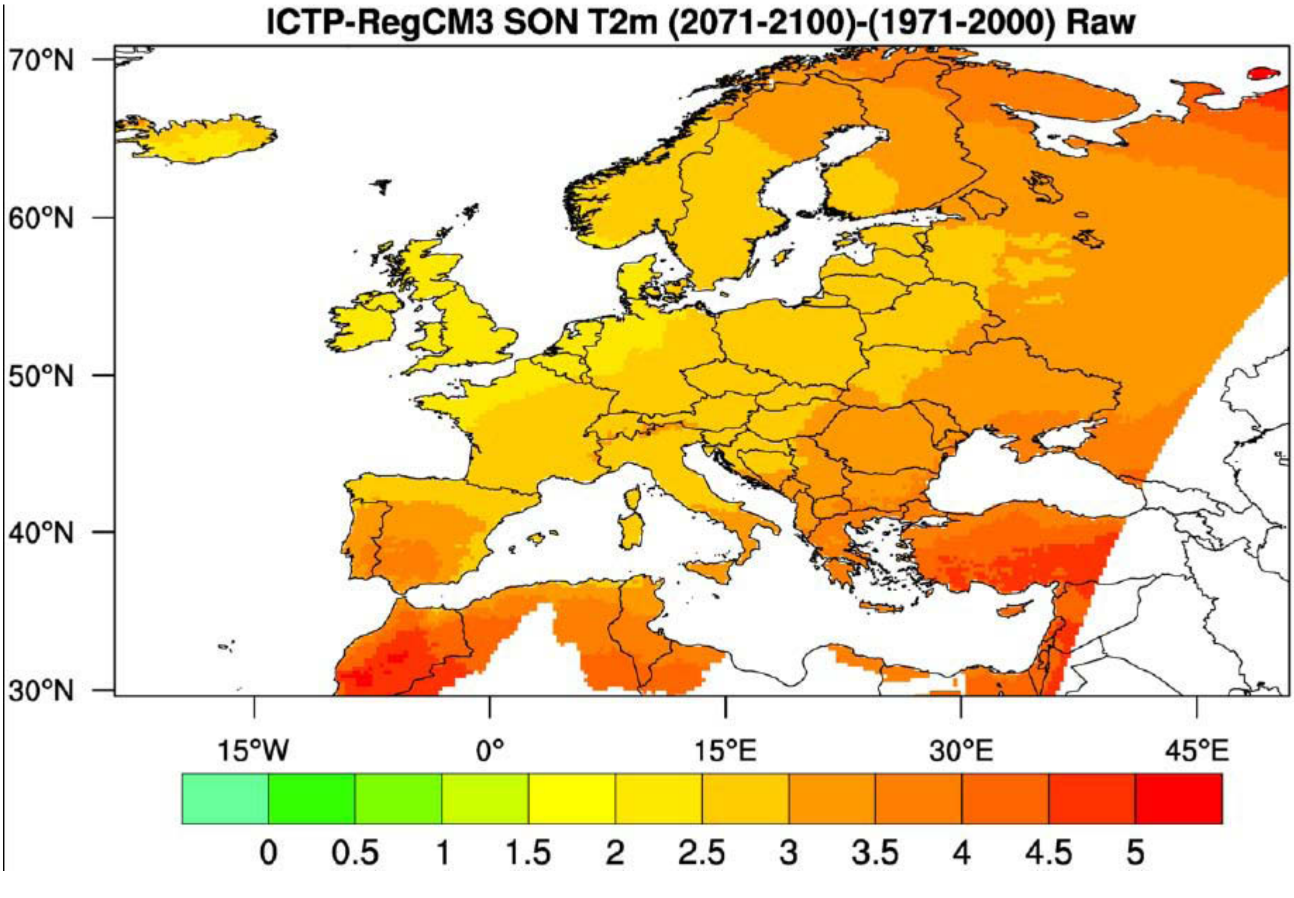

CNRM-ARPEGE SON T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

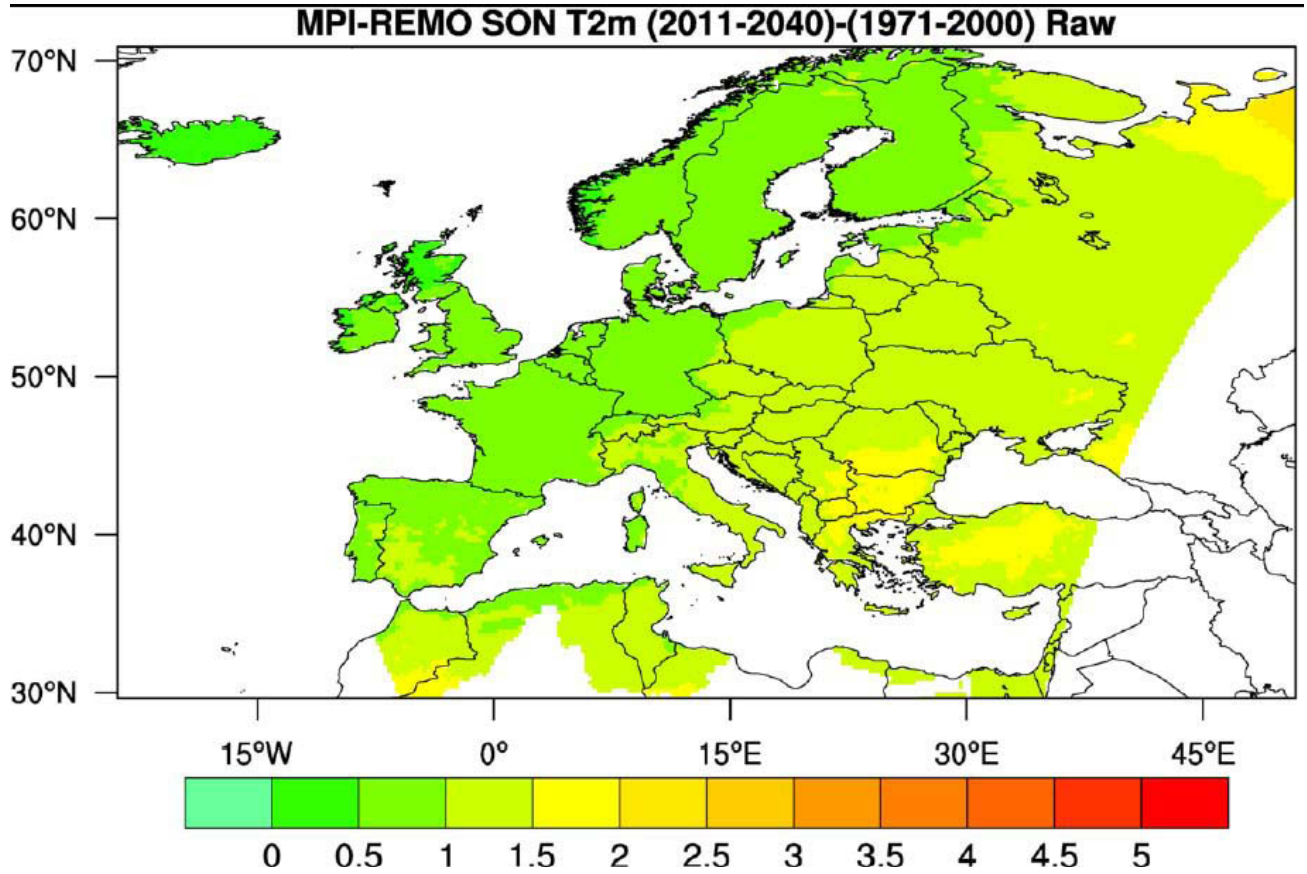

ICTP-RegCM3 SON T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

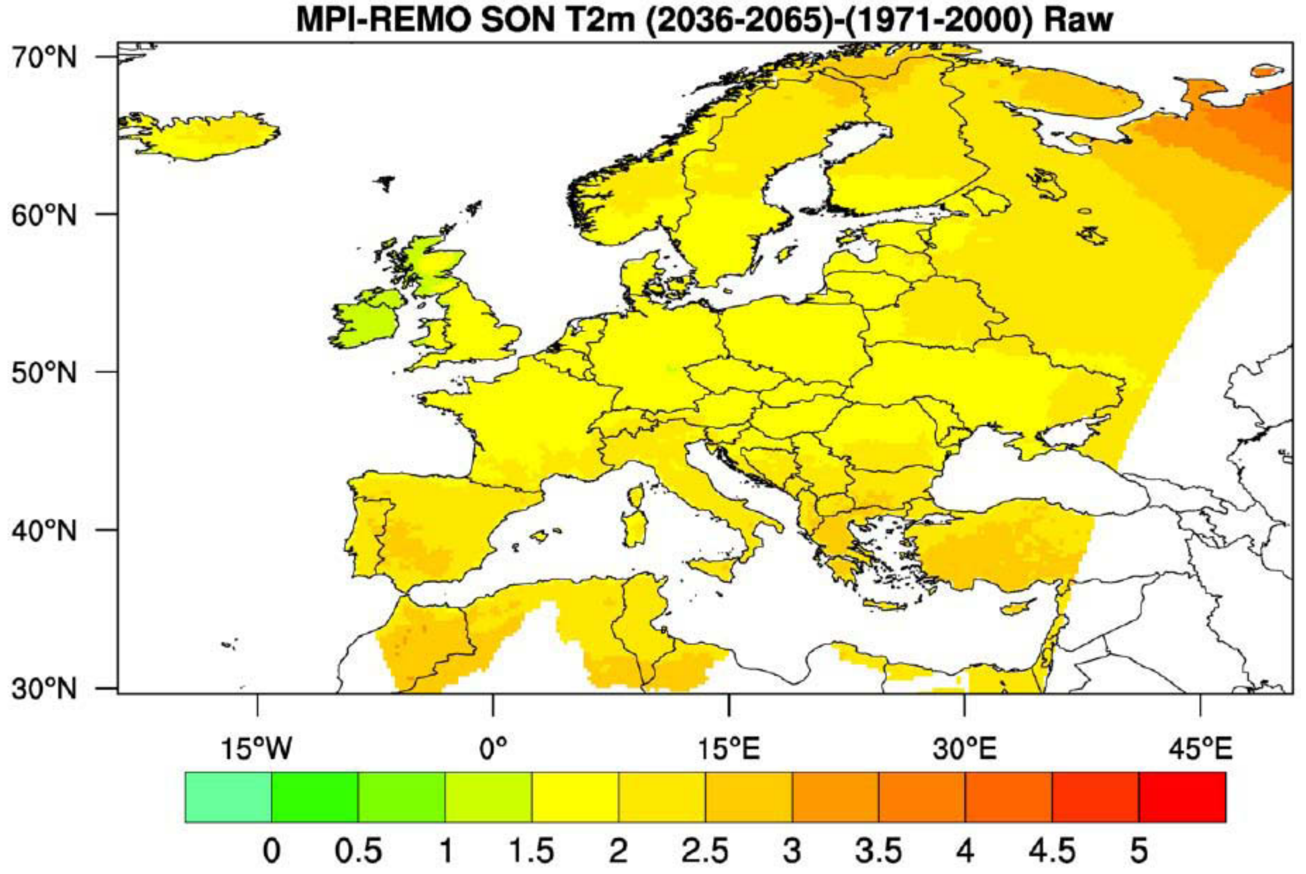
ICTP-RegCM3 SON T2m (2036-2065)-(1971-2000) Raw

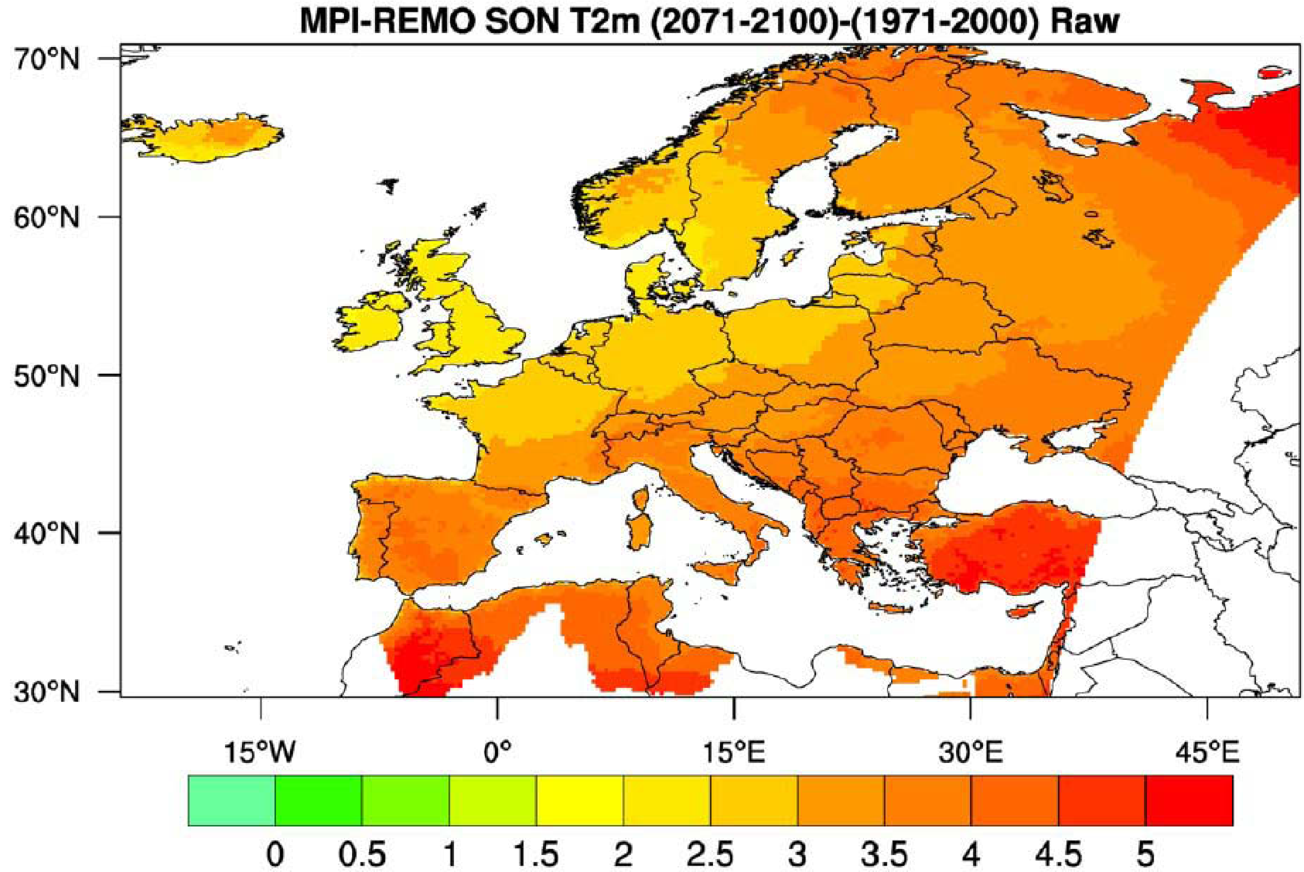


ICTP-RegCM3 SON T2m (2071-2100)-(1971-2000) Raw




MPI-REMO SON T2m (2011-2040)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5


MPI-REMO SON T2m (2036-2065)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5


MPI-REMO SON T2m (2071-2100)-(1971-2000) Raw
70°N
60°N
50°N
40°N
30°N
15°W
0°
15°E
30°E
45°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5