CLIMATE CHANGE PROJECTIONS OF CYPRUS USING RegCM4.4

by

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ABSTRACT

CLIMATE CHANGE PROJECTIONS OF CYPRUS USING RegCM4.4

The scientific motivation of this thesis is a substantial presence of climate change which is one of the most significant issues in the world. There have been happening many natural disasters because of climate change. In particularly, coastal regions and islands, such as Cyprus, are more vulnerable to any possible hazards.

Humankind start to contribute the climate change, especially, after industrial revolution. Burning fossil fuels causes the increase of CO2 emission to the atmosphere. In fact, at the beginning of the 18th century, before the Industrial Revolution, CO2 concentration in the atmosphere was 280 ppm; however, today, this value is 410 ppm. The unprecedented CO2 increase in the atmosphere since Industrial Revolution gives rise to global climate change. The Mediterranean region is predicted to be affected by climate changes in terms of air temperature rise.

In this study, air temperature (°C) and precipitation (mm/day) estimations of Cyprus were investigated with the regional climate model. The climatology model is run for the three periods of 2011–2040, 2041–2070, and 2071–2100, with respect to the control period of 1971–2005 for Cyprus domain via regional climate model simulations. Regional Climate Model (RegCM4.4) of ICTP (International Centre for Theoretical Physics) was run by using two different global climate models. MPI- ESM-MR global climate model of the Max Planck Institute for Meteorology and HadGEM2 of the Met Office Hadley Center were dynamically downscaled to 10 km resolution by using double nesting. RCP4.5 and RCP8.5, the emission scenarios, of the IPCC (Intergovernmental Panel of Climate Change) were used for projections.

ÖZET

KIBRIS'IN GELECEK HAVA SICAKLIĞI VE YAĞIŞ KLİMATOLOJİSİNİN BÖLGESEL İKLİM MODELİ İLE İNCELENMESİ

Bu tezin bilimsel motivasyonu dünyanın en önemli sorunlarından birinin iklim değişikliği olması ve bundan kaynaklı birçok doğal afet ve ekstrem olaylardır. Özellikle Kıbrıs gibi ada ülkeleri ve kıyı bölgeleri oluşabilecek anomalilere karşı daha kırılgan bir coğrafyaya sahiptir.

İnsanoğlunun iklim değişikliğine etkisi özellikle Endüstri Devrimi'nden sonra arttı. Fosil yakıt tüketimi atmosferdeki CO2 konstantrasyonunun ani şekilde artmasına sebep olmaktadır. 18. yüzyılın başlarında, Endüstri Devrimi öncesi 280 ppm olan atmosferdeki CO2 miktarı, günümüzde 410 ppm'i bulmaktadır. Daha önce görülmemiş bu artış dünyanın atmosferinin hızla değişmesine sebep olmuştur. Akdeniz havzasının iklim değişikliğinden, sıcaklık artışı gibi yönlerden olumsuz şekilde etkilenmesi öngörülmektedir. Bu çalışmada Kıbrıs'ın iklim tahminleri 1970-2005 verileri referans alınarak 2010-2100 dönemi için ortalama hava sıcaklığı ve yağış değişiklikleri bölgesel iklim modeli ile araştırıldı. İklim modeli 2011-2040, 2041-2070 ve 2071-2100 zaman periyotlarında ayrı ayrı çalıştırıldı. Uluslararası Teorik Fizik Merkezi (ICTP)'ndeki bilim insanları tarafından geliştirilen Bölgesel İklim Modelleme 4 (RegCM4.4) programını iklim modellemek için kullanıldı. ICTP'nin bölgesel iklim modeli iki farklı global iklim modeli ile koşuldu. Bunlardan biri Max Planck meteoroloji enstitüsünün MPI-ESM-MR, diğeri ise Met Office Hadley merkezine ait olan HadGEM2 global iklim modelidir ve 10 km çözünürlüklü tahmin sonuçları, Uluslararası İklim Değişikliği Paneli'ne (IPCC) ait RCP4.5 ve RCP8.5 emisyon senaryoları ile koşulmuştur.

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LIST OF ACRONYMS/ABBREVIATIONS

AR4	IPCC Fourth Assessment Report, 2007
AR5	IPCC Fifth Assessment Report, 2014
CDO	Climate Data Operators
CFC	Chlorofluorocarbons
CO2	Carbondioxide
COAMPS	Coupled Ocean/Atmosphere Mesoscale Prediction System
ESP	Earth System Physics
FAR	First Assessment Report
GCM	General Circulation Model
GrADS	Grid Analysis and Display System
GRIB	General Regularly-distributed Information in Binary form
HDF	Hierarchical Data Format
ICTP	The Abdus Salam International Centre for Theoretical Physics
IPCC	The Intergovernmental Panel on Climate Change
MPI-ESM-MR	Max Planck Institute Earth System Model, medium resolution
NCAR	National Center for Atmospheric Research
NWP	Numerical Weather Prediction
ppm	parts per million
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RegCM4	Regional Climate Modeling 4
RF	Reference
SAR	Second Assessment Report
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
TAR	Third Assessment Report
UNEP	United Nations Environment Programme

WMO	World Meteorological Organization

1. INTRODUCTION

In recent years, atmospheric events such as extreme hot weather and hurricanes have become more frequently. Therefore, climate change is a well known phenomenon.

After the invention of the steam engine, the Industrial Revolution began in the 18th century. This development brought along the fossil fuel consumption such as oil, coal and natural gas which causes the carbon dioxide concentration rise in the atmosphere unprecedentedly. With the dependence on the use of fossil fuels that have begun after the Industrial Revolution, the gaseous waste coming out of these fuels is stuck in the atmosphere and this may cause the greenhouse effect. The main promoters of climate change are the gases such as carbon dioxide (CO2), nitrous oxide N2O, water vapour (H2O), methane (CH4), ozone (O3) and chlorofluorocarbons (CFC) accumulated in the atmosphere. These gases have caused greenhouse effect in the atmosphere. Carbon dioxide and these kinds of greenhouse gases are a good absorbing radiation resources from the surface of the earth. The increase of concentration CO2 behaves like a blanket over the surface of the earth and it makes the earth even warmer [1].

The concept of greenhouse effect first introduced by the French scientist Jean-Baptiste Fourier in the first half of the 19th century. It was strengthened by the study of Swedish scientist Svante Arrhenius which revealed the significant relationship between the amount of CO2 in the atmosphere and temperature [1].

While solar radiation reaches the earth's surface, the earth radiates back to the space. The balance of incoming and outcome energy must be equal. It can be seen in Figure 1.1. However, most of the solar radiation, which comes to the sun, stays in the earth's atmosphere instead of reflecting.

The main reason for climate change is the warming of the earth in this way. Heating of the atmosphere may cause global sea-level rise and the melting of glaciers make it clear that climate change is an undeniable fact.

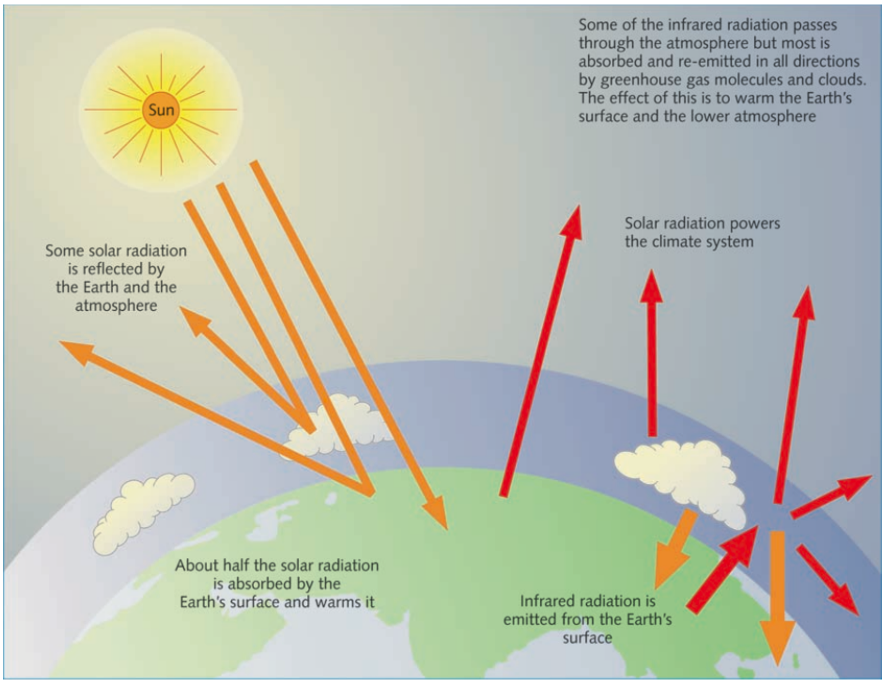

Figure 1.1: The Greenhouse Effect

The most important environmental problem of the world is carbon dioxide emissions due to the use of the fossil fuels that has maintained its importance since then. The amount of carbon dioxide in the atmosphere, which is the most important among the greenhouse gases, has increased unparalleled from 280 ppm to over 400 ppm. To predict the future impact of this increase is modeled with various emission scenarios.

One of the most dangerous consequences of climate change is sea level rise and it is being felt more severely in certain regions [2]. The first countries affected by this increase are of course island nations and coastal regions. Moreover island nations are in danger because of inundation and flooding especially low-lying islands [3]. Cyprus is one of the these critical countries. The future climate projections help to examine the adaptive options.

2. CLIMATE CHANGE

For decades, people have always asked the following question: Is the climate changing? In fact, the answer is in the question. Because if the climate did not change, we should still be living in the ice age. We would have been living in the same meteorological conditions as 1000 years ago. The actual question is "How fast the climate should be changing?" This change, which was very slow at times before the Industrial Revolution, has increased dramatically in recent years.

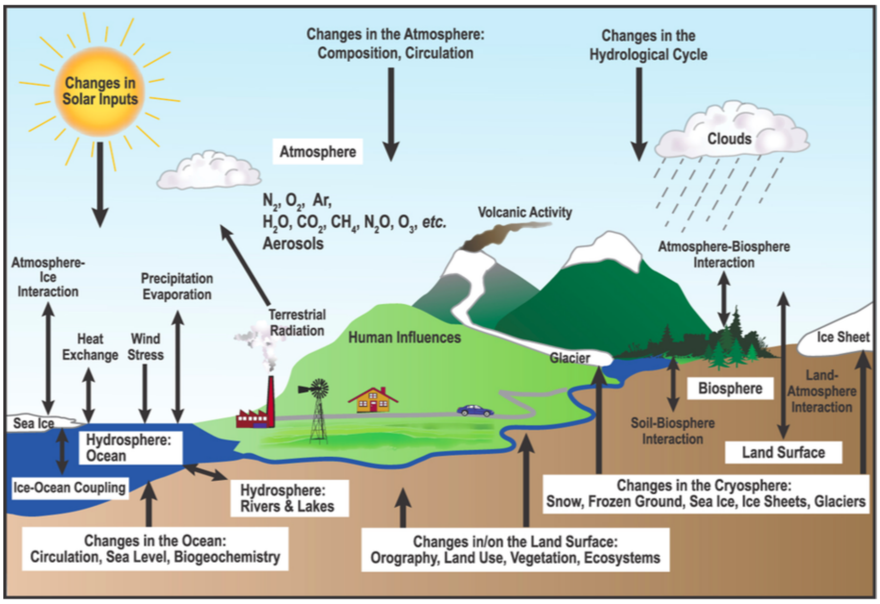

Figure 2.1: Interactions between the components of the global climate systems [4]

Climate is defined as the weather conditions in a specific time period and specific regions [1]. Unlike meteorology, the climate is the average weather conditions of longer time intervals. Therefore, climate change projections focus on longer time intervals in future or past (usually thirty years). These estimates make it clear the fact that climate has been undeniably changing over the last 200 years. Certainly, the main source of this change is human beings. The increasing amount of fossil fuel consumption and devastating deforestation causes the climate change rapidly.

The climate is an interactive system which includes relation between the atmosphere, land, ocean, ice on the surface and radiation from the sun. The interaction of the systems can be seen in the Figure 2.1. According to the UK Met Office, there are seven fundamental sources of climate change: ”higher temperatures, changing rainfall, changes in nature, sea level rises, retreating glaciers, sea ice, and ice sheets” [5].

When it comes to sea level rise, which is one of the most visible consequences of climate change, island nations are the most vulnerable ones. There is a high concurrence that sea level has been rising over the last century at 1 to 2 mm/yr [6]. Moreover, satellite data records of NASA shows that the rate of sea level rise is 3.4 mm per year.

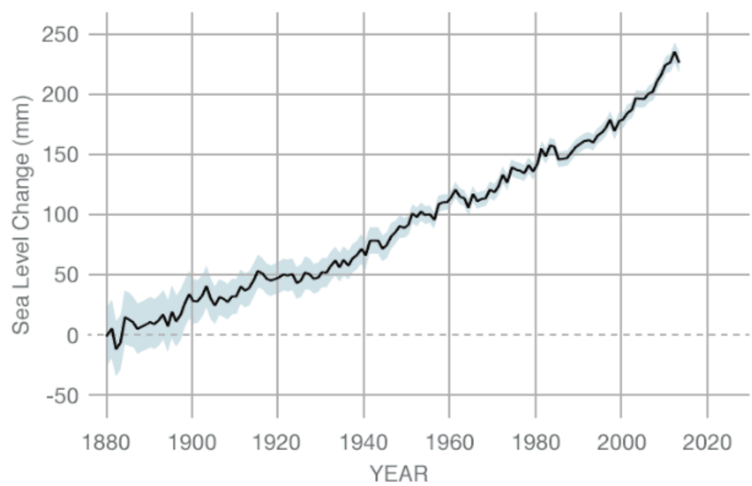

Figure 2.2: Sea Level Change by Coastal tide gauge records [7]

Arctic ice sheets and The Greenland glaciers that contain a large part of fresh water, the resources have started to melt year by year. The rate of change for the Antarctica is 125 gigatons per year and for the Greenland, it is 287 gigatons per year [7].

2.1. Climates of the Past

The fact that the climate has been changing since the beginning of the recorded history is an undeniable fact and investigation in some past climate change periods plays a key role to project the future climate change. This chapter will focus on especially a few time periods in the past.

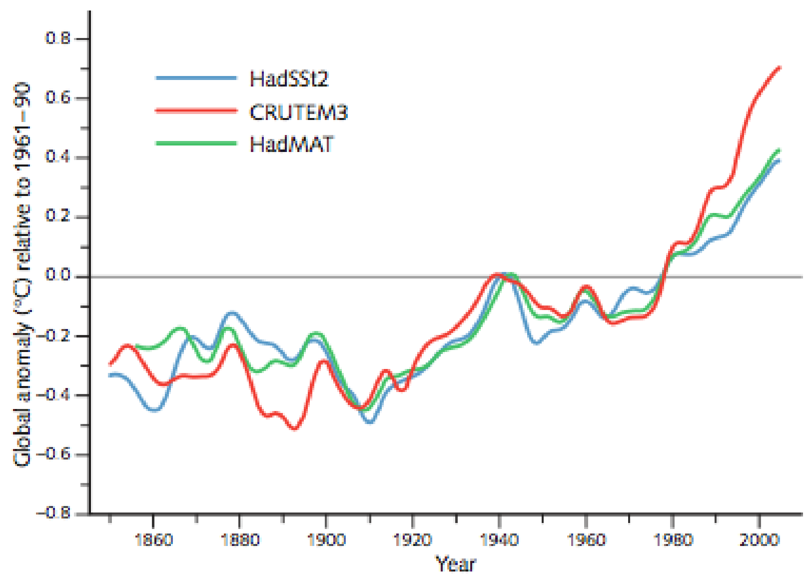

Figure 2.3: Decadally smoothed annual anomalies of global average sea surface temperature (blue), night marine air temperature (green) and land surface air temperature (red) relative to their 1961–90 means [1].

Climate data has been recorded since 1880, and the average temperature over the last hundred years has increased by 0.89 °C. As shown in the Figure 2.3, the warm-up grew faster than usual in the early years of twenty-first century. The Fifth Scientific Assessment Report of the Intergovernmental Panel on Climate Change [8] states that each of the last successive three decades has been getting hotter since 1850.

In addition, the earth's natural warming and cooling cycles have always existed, but it is something else we are living at right now. The hottest five years recorded in history are 2017, 2018, 2016, 2015, 2014, 2013 and 2010. The increase in temperatures does not mean that the air is heated. The world has a complex climate system: even a small increase in average global temperature causes a lot of changes with a lot of dangerous side effects.

For the last glacial maximum 18,000 years ago, it is very likely that the warming was between 4 and 7°C which was ten times slower than the last twentieth century [1]. In other words, the climate has already been changing but it is happening so fast in last few decades. There has never been a rapid temperature rise so far. It is almost impossible for living things to adapt to this severe increase.

To interpret of past climates (Paleoclimate), researchers obtain information from organisms, such as diatoms, forams, and coral serve. Moreover, ice cores, tree rings, and sediment cores are other favorable proxies. The information obtained from these proxies indicates that the last major ice age began 120,000 years ago and it came to an end 20,000 years ago [1]. Then these records can be integrated with earth's modern climate analyses and inserted in a climate model to infer past as well as predict future climate.

When interpreting climate change over time, it is vital to understand scale. Generally, four major time scales are considered, including:

- Long term- Hundreds of millions of years;
- Medium term- One million years;
- Short term- 160,000 years;
- Modern period- Hundreds of years.

When it comes to the modern periods, sea level rise is another consequence of climate change.

Thermal expansion of the sea water because of ocean warming and water mass input from land ice melt and land water reservoirs are two main reasons of sea-level rise [4]. The shore line change in island nations is important because they are vulnerable to sea level rise.

2.2. Human and Natural Drivers of Climate Change

There are many reasons of the climate change. First of all, the climate has been changing for many years.

2.2.1. Human Factor

After Industrial Revolution, the fossil fuel use has risen unpredictably and it has caused the high carbon dioxide emission.

The Intergovernmental Panel on Climate Change (IPCC) [8] publishes reports about climate change latest scientific, technical and socio-economic information, with the participation of a large number of scientists at regular intervals. The last report was announced in 2014, AR5 report, and it pointed out that it is very likely that (at least ninety five percent confidence level) climate change is caused by human beings. Furthermore, climate change in the climate system is definite and the climatic changes have not been preceded for many years since the 1950s. During this period, the atmosphere and the ocean warmed, snow and ice amount decreased and sea level and the concentration of greenhouse gases increased. Absolutely, there were many other natural reasons besides the human impact.

2.2.2. Natural Drivers

There are natural drivers of the climate changes such as sun spots, volcanic and geologic activities, volcanic and geologic activities, ocean cycles and change in solar temperature because of earth's orbit changes.

2.2.3. The Sun

The sun is ultimate external energy resource of the earth and this energy makes the earth inhabitable. The real problem is that the energy which comes from the sun is not constant. The scientists call the Sun "variable star" by reason of changing brightness in time.

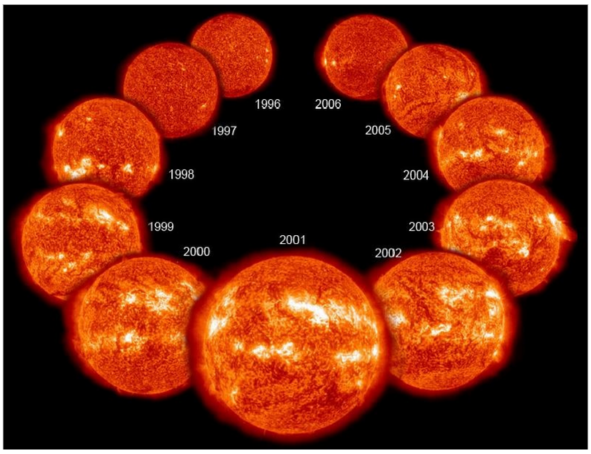

Figure 2.4: Sunspot variations in 11-years solar cycle [9].

In 1843, the scientists discovered that the sun has many sun spots (dark areas) and bright spots (called faculae). The energy that the sun emits into the earth decreases or increases depending on these spots. It can be seen clearly in Figure 2.4 these variations of the spots. Throughout these cycles, however, the variation in solar energy is not high, varying only by about 0.1 percent.

2.2.4. Volcanic and Geologic Activities

In a few ways, volcanoes and associated geological activity can affect global and regional temperatures. First, powerful volcanic eruptions blow out ash, dust, and sulfur particles all the way up to the stratosphere, where they may last for months (or longer) and accumulate in the atmosphere.

On the other hand, sulfur gases can react with water vapor in the stratosphere to form a fog of droplets of sulfuric acid that disperses at high altitudes around the globe. Some incoming solar radiation is blocked by the residues of these volcanic emissions, which works to temporarily cool the troposphere for up to a few years. After the Mount Pinatubo eruption in 1991, the global temperature drop was about 0.6 degrees Celsius and, for instance, lasted for about two years. However, this kind of cooling is temporary. Also, volcanic eruption emits greenhouse gases such as carbon dioxide and methane.

2.2.5. Ocean Cycles

Vast ocean currents accelerate and slow down over time, and different parts of the oceans have their own cycles of heating and cooling. When the amount of the area occupied by the oceans is taken into account, the effect of such cycles on the climate cannot be denied. El Niño is a basic example of these cycles.

The winds blowing continuously from east to west of the Pacific Ocean cause accumulation of hot water in the east and cold water in the west. High sea surface temperature causes atmosphere to become more unstable. While humid and warm weather accumulate in the west, dry and cold weather prevail in the east of the ocean. This airflow strengthens the winds from the east. But, once sea surface temperatures increase over an extended period of time in the tropical Pacific Ocean to above-normal levels, the difference between the east and west region is closed.

This situation, El Niño, affects many climatic events such like floods, drought, heat waves, seasonal changes.

La Nina is an ocean phenomenon caused by atmosphere that is the opposite of El Nino. In the case of La Nina occurring in the eastern Pacific ocean, the degree of sea water should be between three and five degrees, but it is colder. La Nina takes about five months and has tremendous effects on the climate of North America. Sometimes it even affects the Atlantic Hurricane. In general La Nina occurs by following years of El Niño [1].

2.2.6. Earth's Orbit Changes

The orbital properties of earth is not steady, just like the sun. These changes are named the Milankovitch cycles. Some astronomical calculations show that the periodic changes in the earth's orbit are closely controlled by the seasonal and latitude distribution of the incoming solar radiation reaching the top of the atmosphere. Seasonal

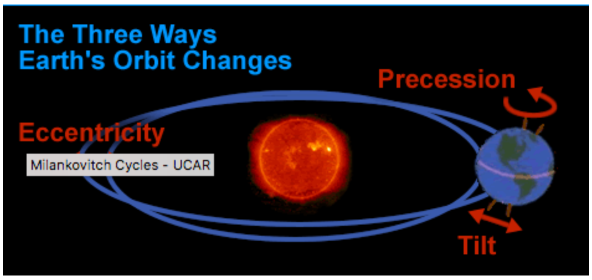

Figure 2.5: Milankovitch Cycles

changes in the incoming solar radiation are larger than the annual average changes and can reach 60 W/m^2. The axis inclination of the earth varies between about 22° and 24.5° with two semi-periodicities of about 41,000 years adjacent to each other [10].

2.3. Vulnerability of Island Nations

The first question that comes to mind when it comes to climate change is what the fate of the island countries because of sea level rise and changing climatic extreme events will be. The availability of freshwater in small island conditions has always presented obstacles and the main reasons of this issue are fast growing demand, urbanization, tourism.

Furthermore, climate change affects land based biodiversity on islands, often interacting with many other drivers such as;

- Ecosystem and species horizontal shifts and range decline;
- Altitudinal species range shifts and decline mainly due to temperature increase on high islands;
- Exotic and pest species range increase and invasions mainly due to temperature increase in high-latitude islands [11].

By all means, climate change has adversely effects on human health directly or indirectly. Morbidity and mortality from extreme weather events, certain vector and food-borne and waterborne diseases and climate-sensitive health problems are some issues of the island countries. Extreme climate events such as tropical storms, coastal flooding, and drought can both have short- and long-term adverse effects on human health, including drowning, injuries, increased transmission of disease, and health issues associated with worsening water quality and quantity [12].

2.3.1. Cyprus

Cyprus is an island country which is located in Eastern Mediterranean and it is the third biggest island in the Mediterranean sea by area, is 3,572 square-mile. The population of the island is about 1.1 million. Cyprus has always been a desirable island for strategic, political, commercial and religious reasons. There are two mountain ranges and the plains between them in this country; the climate is subtropical in nature [13]. The climate of the island is suitable for holidays during the whole year. Island is a product of rich nature, also, there are many endemic plants and animal species, beaches along the Mediterranean Sea, culture and history.

Tourism sector in Cyprus is highly developed so that there has become the major tourist destination of the Mediterranean region [14]. Moreover, Cyprus is a popular destination for people interested in mythology. There is the birthplace of the mythological beautiful Aphrodite, the Greek goddess of love and passion. Aphrodite was born and raised on an island near Paphos, the capital of western Cyprus, before becoming a goddess.

There are two different countries in Cyprus region. When these conditions are taken into account, the future climate change projections play a key role in the fate of tourism sector.

Figure 2.6: Cyprus region

3. METHODOLOGY

3.1. IPCC

Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by two specialized organizations operating under the United Nations, World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). The aim of the panel is to evaluate the current scientific, technical and socio-economic knowledge and studies on climate change, and to guide decision-makers on climate change adaptation in the light of scientific outputs. IPCC has 195 member countries and it establishes the objective and transparent reports. All IPCC officials and the authors contributing to the reports, except for the technical and administrative staff of the IPCC, voluntarily work for the IPCC. They are nominated by governments, selected by the IPCC secretariat according to their scientific and academic qualifications as a result of extremely challenging and transparent processes [15].

The assessment reports compiled on the current situation of the world's climate system are shared with the press and policymakers in five or seven years periods and reports offer the mitigation and adaptation options. Therefore, the assessments play a key role to the international negotiations to cope with climate change. The assessment reports are completely scientific. Instead of giving advice to decision makers about what they should do, they project the future climate change based on specific scenarios.

The first of these reports was published in 1990 (FAR), the second in 1996 (SAR), the third in 2001 (TAR) and the fourth in 2007 (AR4). The Fourth Assessment Report indicated that climate change probably (90 percent chance) was caused by human activities.

The Fifth Assessment Report increased the level of certainty in previous assessments and the most up-to-date report, (AR5), was announced in 2014. Their next report, that is Assessment Report 6 (AR6) is anticipated to be published in 2022 [17].

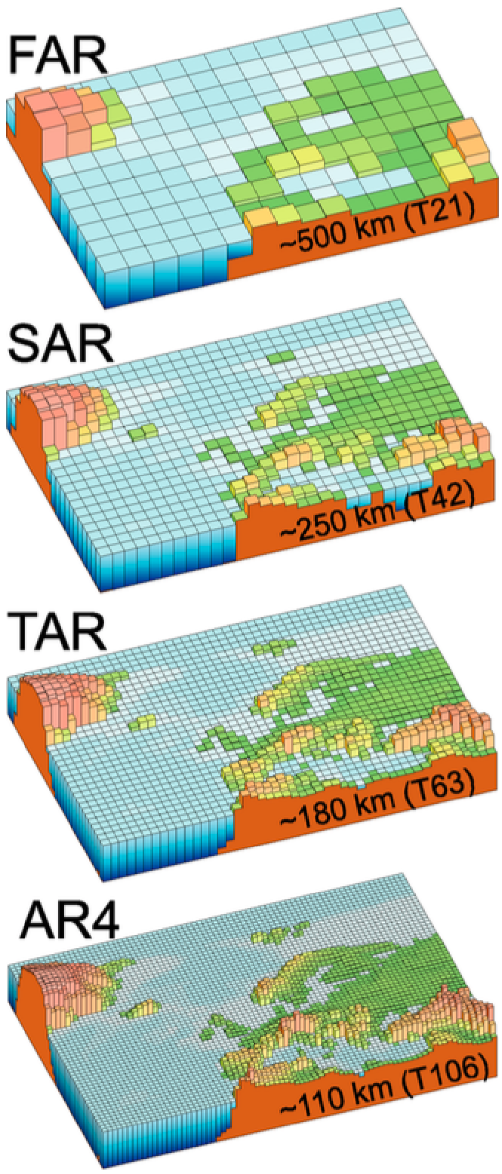

Figure 3.1: Resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001), and AR4 (2007) [16].

3.2. RegCM4

In recent decades, the use of regional climate models (RCMs) in the future projections of climate change has become widespread. The RegCM is one of these regional climate models. It has been developed in 1989 by F. Giorgi at the National Center for Atmospheric Research (NCAR) - Pennsylvania State University (PSU) and maintained in the Earth System Physics (ESP) section of the Abdus Salam International Center for Theoretical Physics (ICTP). More advanced versions of RegCM were released in the 1993 (Regcm2) and then in 1999 RegCM2.5 was developed. The model was further developed into the following years, in 2006 (RegCM3) and the most recent version is upgraded in 2010 (RegCM4) [18].

To project the regional impacts of climate change, higher resolution simulations and the resolution of General Circulation Models (GCMs) are needed. The resolution of general Circulation Models is low (150-200 km) and The GCMs are mathematical models of the atmospheric and ocean circulation. Moreover, atmospheric and oceanic GCMs together with sea ice and land-surface components are key components of global climate models. On the other hand, RCMs are numerical models which initial boundary conditions are provided by the output of the GCMs. In addition, the requirement input of RegCM is time-dependent lateral boundary conditions, such as vertical profiles of wind, temperature, and humidity, surface pressure and sea surface temperature (SST). The model is responsive and user-friendly.

It can be applied other regions easily. It can be applied to any region in the world with a grid positioning of up to one km, which is hydrostatic limit, and for a broad range of research, from process studies to paleoclimate and future climate projections [19].

3.2.1. Components of RegCM

A numerical climate model includes the descriptions of the basic dynamics and physics of the various components and their interactions. Parameterisation is a physical process and it is described in terms of an algorithm (a process of step-by-step calculation). There is need dynamical equations to do this.

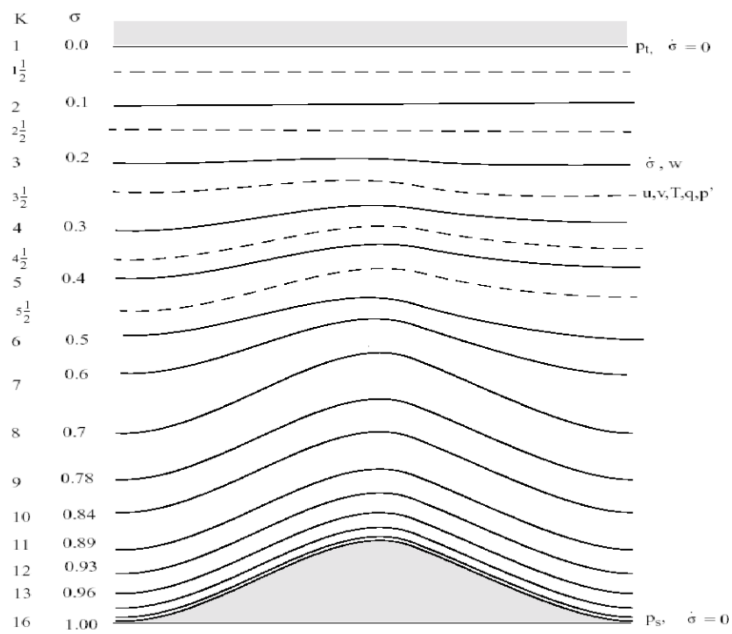

Figure 3.2: Schematic representation of the vertical structure of the model. This example is for 16 vertical layers. Dashed lines denote half-sigma levels, solid lines denote full-sigma levels (Adapted from the PSU/NCAR Mesoscale Modeling System Tutorial Class Notes and User's Guide) [20].

Four components of the RegCM modeling system are Terrain, ICBC, RegCM, and Postprocessor. Terrain and ICBC are ingredients of the RegCM which is pre-processor. Terrestrial parameters (containing sea level, soil and temperature of sea surface) and horizontally interpolated three-dimension projections, which are isostatic pressure, are latitude longitude combine a high-resolution domain on both a slewed (and normal) Mercator, Lambert Conformal, or Polar Stereographic prediction. Vertical interpolation is also practiced from pressure levels to RegCM's σ coordinate system. The surfaces close to the ground are closely aligned with the trend of terrain, and the higher-level σ are approximate [20].

Domain size and horizontal-vertical resolution may differ, because parameters, that require a varying amount of core memory are used in the modeling package programs, and the required amount of hard disk storage varies accordingly.

3.2.2. The RegCM Model Horizontal and Vertical Grid

First start introducing the grid configuration of the model is beneficial. Generally the system of the model obtains and analyses on pressure surfaces, however these must be interpolated to the vertical coordinate of the model before the model is entered. The vertical coordinate is terrain-following (Figure 3.2) meaning that the lower grid levels follow the terrain while the upper surface is flatter. While the pressure reduces toward the top of the model, intermediate levels smooth step by step.

The hydrostatic solver uses a dimensionless σ coordinate to define the model levels where p is the pressure, p_t is a specified constant top pressure, p_s is the surface pressure.

$$\sigma = \frac{p - p_t}{p_s - p_t} \tag{3.1}$$

where we can define:

$$p^*(x, y) = p_s(x, y) - p_t \tag{3.2}$$

A similar scalar coordinate uses the Non-hydrostatic solution, but it is defined completely from the reference point. The atmospheric characteristics:

$$p(x, y, z, t) = p_0(z) - p'(x, y, z, t) \tag{3.3}$$

$$T(x, y, z, t) = T_0(z) - T'(x, y, z, t) \tag{3.4}$$

$$\rho(x, y, z, t) = \rho_0(z) - \rho'(x, y, z, t) \tag{3.5}$$

the vertical sigma coordinate is defined as:

$$\sigma = \frac{p_0 - p_{\mathrm{t}}}{p_{\mathrm{s}} - p_{\mathrm{t}}} \tag{3.6}$$

where $\mathrm{p_s}$ is the surface pressure, $\mathrm{p_t}$ is a specified constant top pressure and $\mathrm{p_0}$ is the reference pressure profile. The total pressure at each grid point is hereby given as:

$$p = p^{*}\sigma + p_{\mathrm{t}} + p' \tag{3.7}$$

with p^* defined as in the hydrostatic solver. σ is zero at the highest point's of the surface as it is represented in equation and Figure 3.2, and the model levels are shown as σ. A list of standards between zero and one that non-necessarily to need. Being evenly spaced defines the vertical resolution of the model. The resolution in the boundary layer is usually much better than the others, and the amount of concentrations may differ depending on the user requirement.

The horizontal grid has an Arakawa-Lamb B-staggering of the speed variables with respect to the scalar variables (T, q, p, etc). This is shown in Figure 3.3 that is

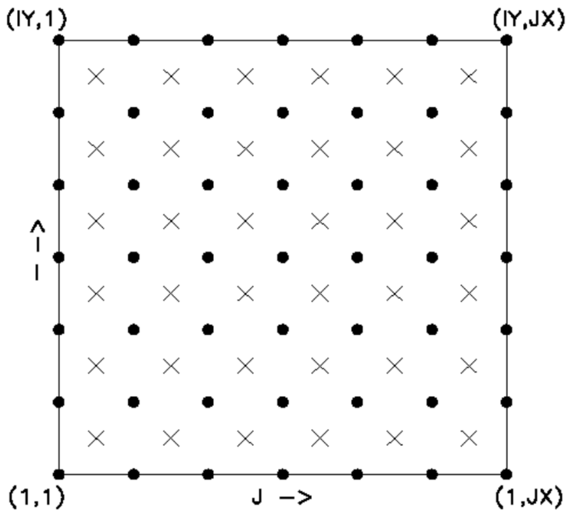

Figure 3.3: Illustration of the displaying the dot and cross grid points scaling horizontal Arakawa B-grid.

illustrated in the middle of the grid box, also, east and north velocity components are collected at the corner.

The grid center points are pointed to as cross points, and the corner points are dot points. Therewith horizontal velocity is defined at dot points. Data is input to the model, the preprocessors do the necessary interpolation to warrant compatibility with the grid points.

All of these factors are described in the center of each vertical layer of the model, given to as semi-levels and inferred by the dashed lines in Figure 3.6. Vertical velocity is performed at complete (solid lines) levels.

The complete levels are mentioned in the definition of the sigma concentrations, including concentrations at σ 0 and 1. The number of model layers is therefore always one less than the number of full sigma levels.

The finite difference method in the model is, absolutely, significantly dependent upon the grid staggering all mean or grads are implied operand in the equation.

Detailed information given in the Reference Manual of RegCM4.4 by ICTP [21].

3.2.3. RCP Scenarios

Four greenhouse gas concentration simulations embraced by the IPCC for its Fifth Assessment Report (AR5) are representative concentration methods (RCPs). It substitutes for the projections published in 2000 for the Special Report on Emissions Scenarios (SRES). Climate modeling and research use the pathways that describes four possible climate futures and all considered possible outputs depend on how much greenhouse gasses will be emitted in the coming years.

There are four basic scenarios of Representetive Concentration Pathways (RCPs), RCP2.6, RCP4.5, RCP6, and RCP8.5 that are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively) [22]. Moreover, RCP scenarios are studied in detail by van Vuuren et al [23].

At Table 3.1, we can see the overview of the RCP Scenarios and related publications.

CO2 concentration at the atmosphere is over 410 ppm today. In this study, RCP4.5 and RCP 8.5 scenarios were used for the accuracy of future projections trying to tell us that atmospheric CO2 concentration will significantly increase the maximum projected concentration level before 2100 [33].

Table 3.1: RCP Scenarios

Scenario	**Description**	**Citation**
RCP 8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100	Riahi et al. (2007) [24] Rao and Riahi (2006) [25]
RCP 6	Stabilization without overshoot pathway to 6 W/m^2 at stabilization after 2100	Fujino et al. (2006) [26] Hijioka et al. (2008) [27]
RCP 4.5	Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100	Smith and Wigley (2006) [28] Clarke et al. (2007) [29] Wise et al. (2009) [30]
RCP 2.6	Peak in radiative forcing at 3 W/m^2 before 2100 and decline	van Vuuren et al. (2006; 2007) [31], [32]

3.2.4. ERA-Interim Data set

ERA-Interim is produced by European Centre for Medium-Range Weather Forecasts. It is a data set which includes global climate reanalysis and observations. Moreover,this atmospheric reanalysis data has been being continuously updated in real time since 1979 [34]. To generate reanalyzed data, ERA-Interim uses a fixed version of a numerical weather prediction (NWP) system. The fixed version guarantees that an evolving NWP system does not cause any false and misleading trends, although such trends can be created by the changing observing system.

Moreover, this data set includes the instantaneous, surface parameters like sea ice fraction, snow albedo, sea surface temperature, soil moisture and snow depth. Cumulative forecast, surface and single-level parameters are also saved on the Gaussian grid of the model. These predictions are available in the twenty eight steps up to ten days. It can be downloaded most archived ERA-Interim data from the European Centre for Medium-Range Weather Forecasts (ECMWF) Data Server [35].

3.3. General Circulation Models

General Circulation Models play a key role to understand climate, weather forecasting and projection of climate change. It uses a numerical analyses of a planetary atmosphere or ocean's general circulation. The first of its kind General circulation model was developed by Syukuro Manabe and Kirk Briyan at the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey. This model combines oceanic and atmospheric processes. Scientists could now comprehend how the ocean and atmosphere are interacted to climate effect [36].

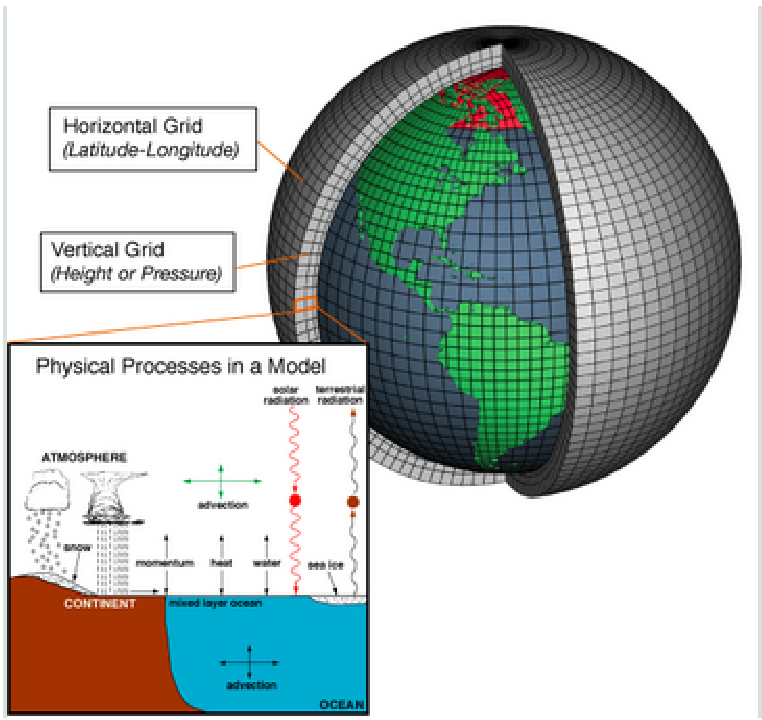

Figure 3.4: Schematic representation of the 3-Dimensional grids of the planet. The reason of the dividing to grids is applying basic equations. The calculation includes winds, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluate interactions with neighboring points.

Many research institutes around the world are working to develop models to simulate the current climate and its coming years evolution under different scenarios of greenhouse gas and aerosol [34]. In this study, The Max Planck Institute for Meteorology Earth System MPI-ESM-MR and the Hadley Centre Global Environment Model HadGEM2 are used for time period 1971-2000. Additionally, RCP4.5 and RCP8.5 emission scenarios are used for the future periods.

3.3.1. MPI-ESM-MR

MPI-ESM-MR is a detailed Earth-System Model, and it includes the ocean, atmosphere, and surface area components. Through the exchange of energy, momentum, water and significant trace gases such as carbon dioxide, these elements are combined. The model is created by Max Planck Institute and MPI-ESM1 comprises of general circulation models (ECHAM6), which is included ocean, sea ice, the land surface model and arbitrarily contains dynamical land vegetation parameters.

3.3.2. Met Office Hadley Centre Earth System Model

HadGEM2-ES is a coupled Earth System Model used by the Met Office Hadley Center for the 100-year prediction of Coupled Model Intercomparison Project Phase 5 (CMIP5). HadGEM2 is a Met Office Unified Model (UM) configuration that was developed from UM version 6.6. HadGEM2-ES was the first model of the Met Office Hadley Center to provide components of the Earth system as standard. The Unified Model is also used for operational weather forecasting and climate research by a number of institutions around the world. For a seamless range of uses from short-range numerical weather prediction to seasonal, decadal and centennial climate prediction, the Met Office develops and uses the Unified Model atmospheric model. The Met Office collaboration twiki [37] offers a wide range of scientific and technical information on the Met Office Hadley Center Earth System Models [38].

4. RESULTS AND DISCUSSIONS

In this research, the change of climate variables such as surface air temperature and precipitation have been investigated. The comparison of seasonal mean changes in surface air temperature and precipitation have been analyzed for four seasons separately with a spatial resolution of ten km. To get this high resolution outputs, we received fifty km resolution data as input file and by doing double-nested, we got the ten km resolution output.

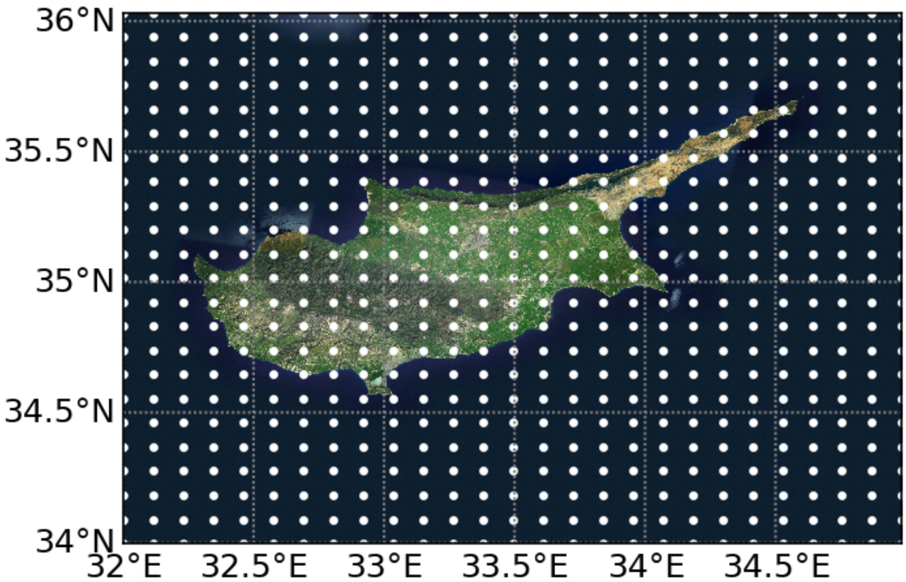

Figure 4.1: Representation of the grid points of the model on the Cyprus map

4.1. Biases of the HadGEM2 and MPI-ESM-MR

Differences between HadGEM and MPI-ESM-MR are noticeably high, in particular monthly average precipitation data shows different outputs. The reason of this bias is difference of the dissimilar Global Circulation Models. MPI-ESM-MR is a model used and created by Germans, while HadGEM is created by British scientists.

While Germany and the surrounding climatic conditions are taken into account by MPI-ESM-MR, Britain and the surrounding climatic conditions are taken into consideration by HadGEM.

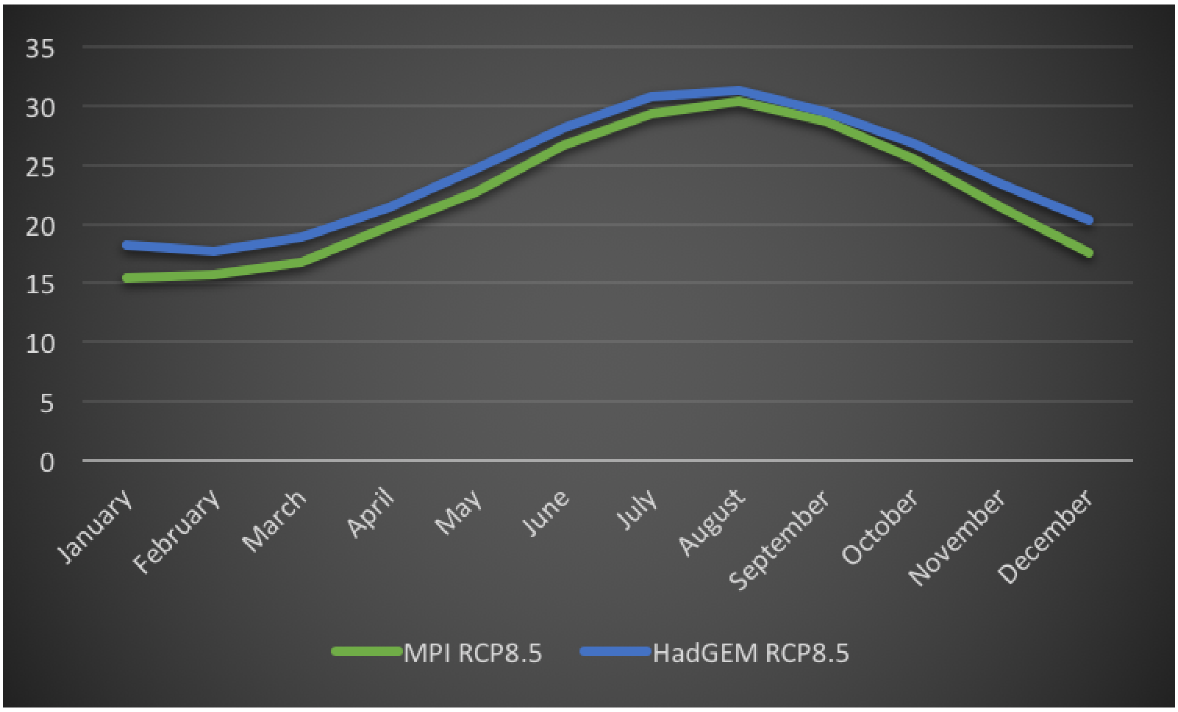

Figure 4.2: Monthly mean air temperature projection biases from RegCM4.4 by forcing HadGEM2 and MPI-ESM-MR according to RCP8.5 scenario data for the period 2071-2100

The fact that England is an island country is similar to Cyprus, yet it has a much colder climate than Cyprus. On the other hand, the region of Germany has similarities and contradistinctions with the climate of Cyprus. As it shown in the Figure4.2, there are no such variation in air Surface temperature.

Cyprus is located in the Mediterranean region and has the hottest summer and winter climates of the European Union. In Cyprus there are 300 to 340 sunny days a year. The average temperature of the air is 27°C (81°F), and only a few degrees warmer is the water. Temperature leaps are sometimes up to 35-37°C (95-99°F). But fresh breezes and comparatively low moisture smooth out heat in Cyprus.

Relative air humidity of Cyprus in winter is on average between sixty percent and eighty percent and in summer between forty percent and sixty percent with even reduced values over inland regions around midday. [39]. When it comes to Great Britain's weather, it is usually mild and temperate owing to the Gulf Stream's impact. while determine the initial boundary conditions, Gulf streams impact may play a key role in results of HadGEM2. Moreover Germany's climate and humidity may differ from the Mediterranean region. As it can be seen in Figure 4.3 the bias of precipitation case is more than the case of air surface temperature.

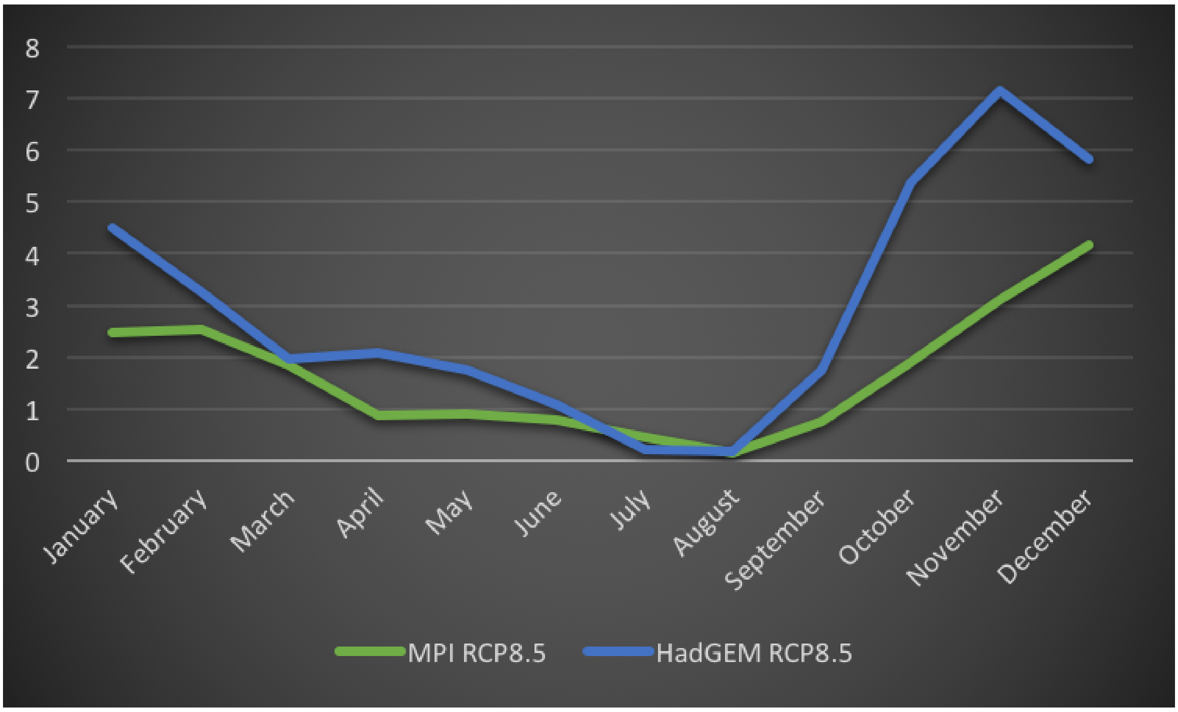

Figure 4.3: Monthly Average Precipitation projection biases from RegCM4.4 by forcing HadGEM2 and MPI-ESM-MR according to RCP8.5 scenario data for the period 2071-2100

Because of initial boundary conditions variation, results of Global Circulation Models differ from each other. Ultimately, combining and comparing more Global circulation models can lead to more reliable results.

4.2. Seasonal Climate Analysis

In this study, to compare the seasonal mean changes in surface air temperature and precipitation, four climate seasons were evaluated individually with a spatial resolution of ten km.

3-month lead time (seasonal time periods) air temperature and precipitation forecasts are both extremely statistically significant and beneficial to users.

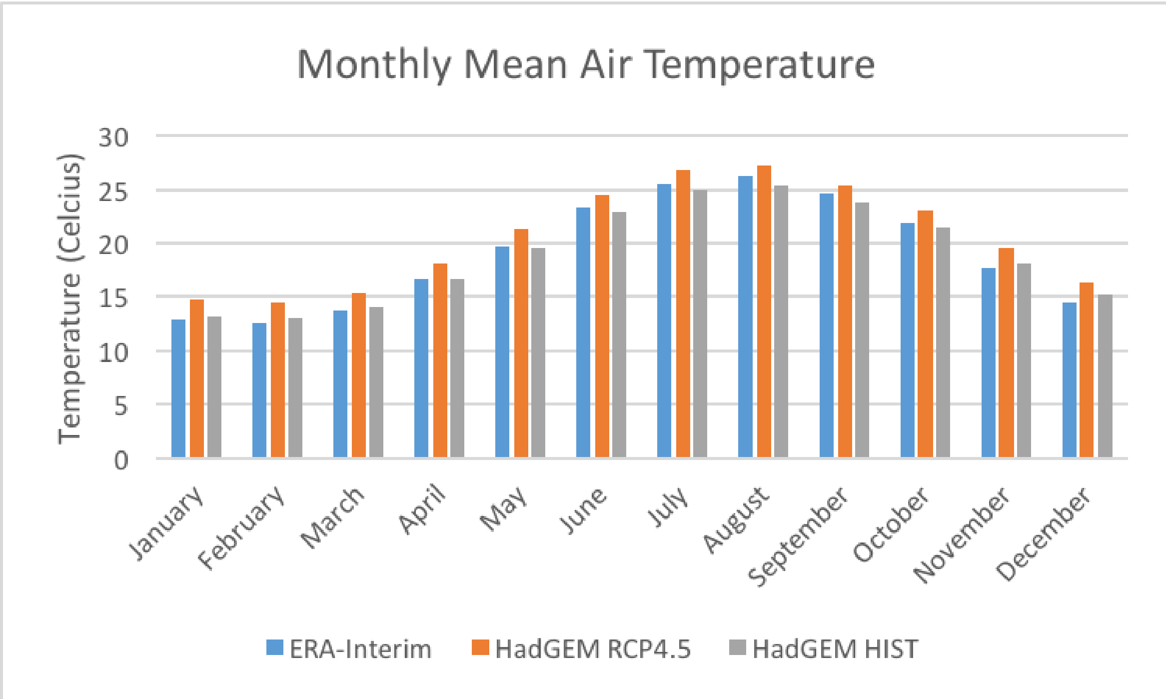

Figure 4.4: Monthly mean air Temperature projection from RegCM4.4 by forcing HadGEM2 according to RCP4.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

We assessed surface air temperature change and precipitation projections for the future periods of 2011–2040, 2041–2070 and 2071–2100 on the basis of the IPCC RCP4.5 and RCP8.5 scenarios for the current period of 1971–2000. and we use two different Global Circulation Models that HadGEM2 and MPI-ESM-MR. In this study, to compare results, we use different scenarios and different GCMs.

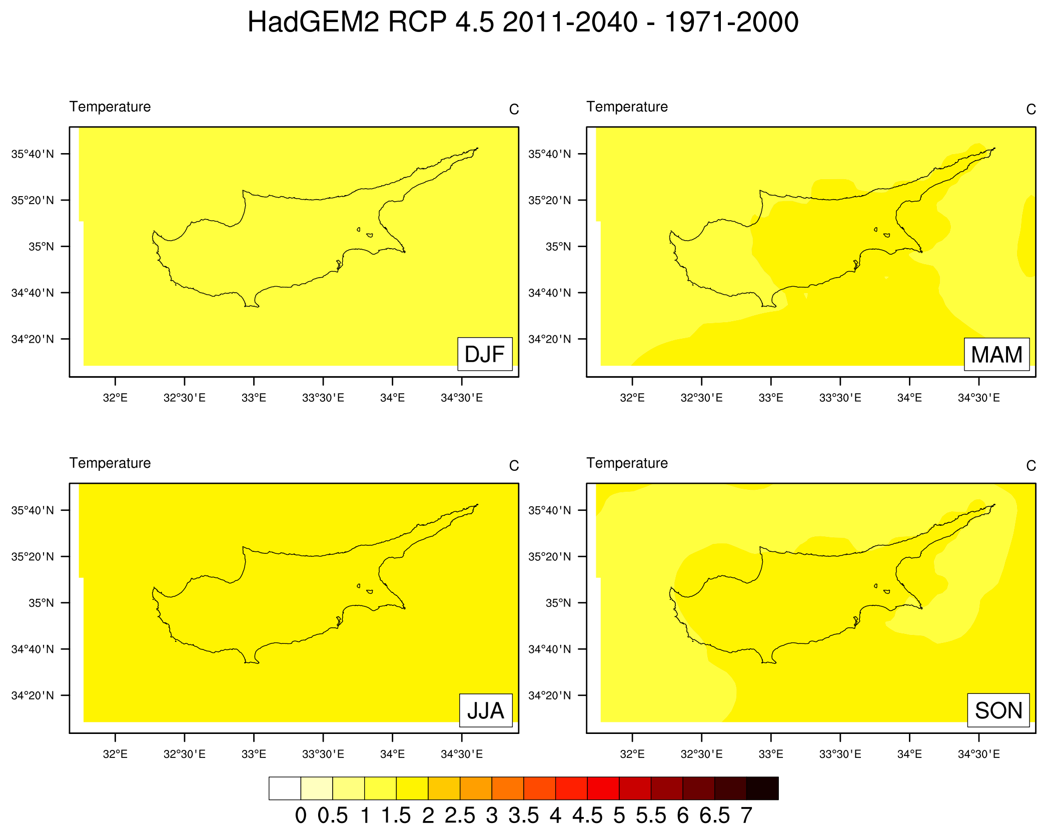

Figure 4.5: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by HadGEM2 Global Climate Model with RCP4.5 scenario in the future, 2011-2040 time period, which is respect to reference time interval 1971-2000

First, we tested regional climate model's ability to simulate observed climatology by using ERA-interim reanalysis dataset for the period 1971-2000 and global climate models of HadGEM2 and MPI-ESM-MR for the same reference time period as a forcing data to the model. Then we compare the Global Circulation Models hist data and ERA-interim dataset with the represented future time periods.

After taking the field mean of the outputs, we determined the monthly mean air temperature and monthly average precipitation amounts to compare hist data of the same Global Circulation Model and ERA-interim dataset.

As it can be seen in Figure 4.4, future climate projection ,for the 2011-2040 time period, will be higher than both HadGEM HIST and ERA-interim outputs.

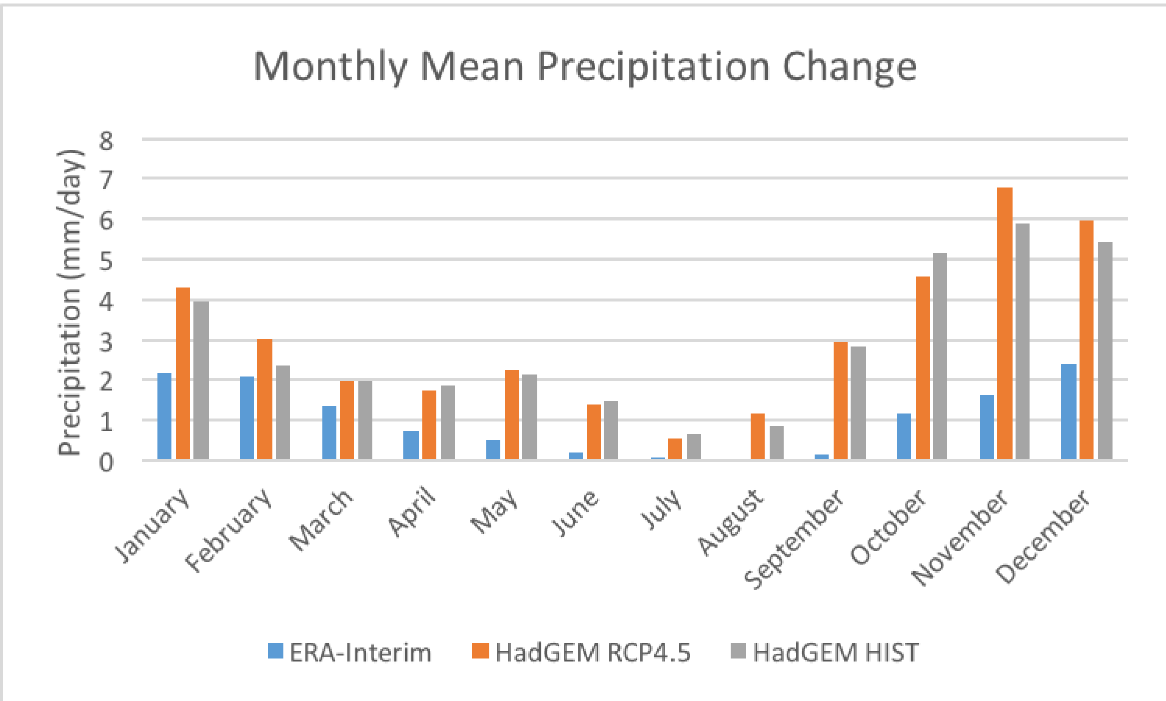

Figure 4.6: Monthly Average Precipitation projection from RegCM4.4 by forcing HadGEM2 according to RCP4.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

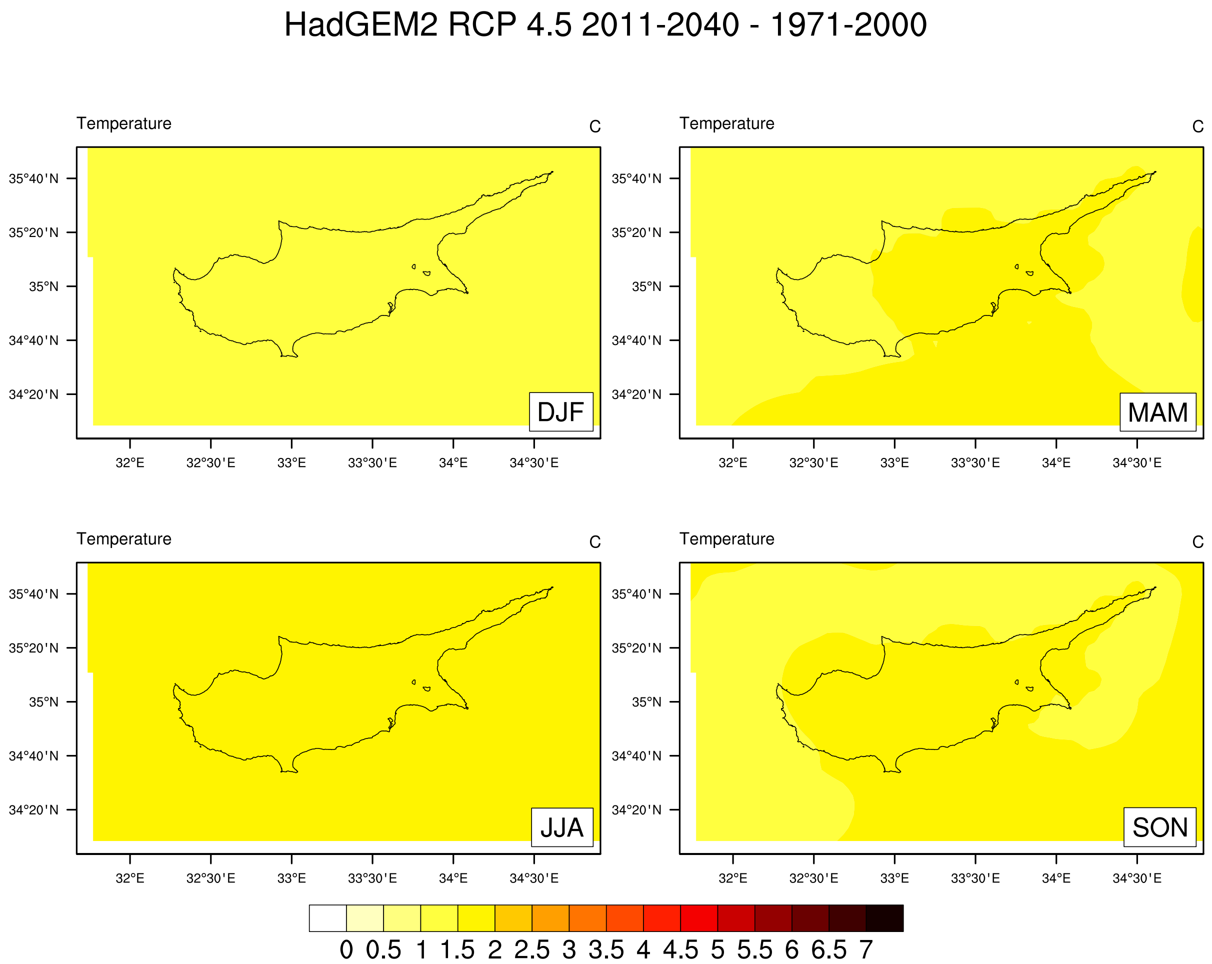

Figure 4.7: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by HadGEM2 Global Climate Model with RCP4.5 scenario in the future, 2011-2040 time period, which is respected to reference time interval 1971-2000

Especially, this air temperature rise will be severe in winter months. Although RCP4.5 is a more optimistic scenario, temperature and precipitation changes are severe in the results.

Figure 4.5 shows the outcomes of RegCM which is operated by using the output of global circulation model,HadGEM2, with IPCC's RCP4.5 scenario. It represents that the air surface temperature will increase around 2°C in 2011-2040 time period.

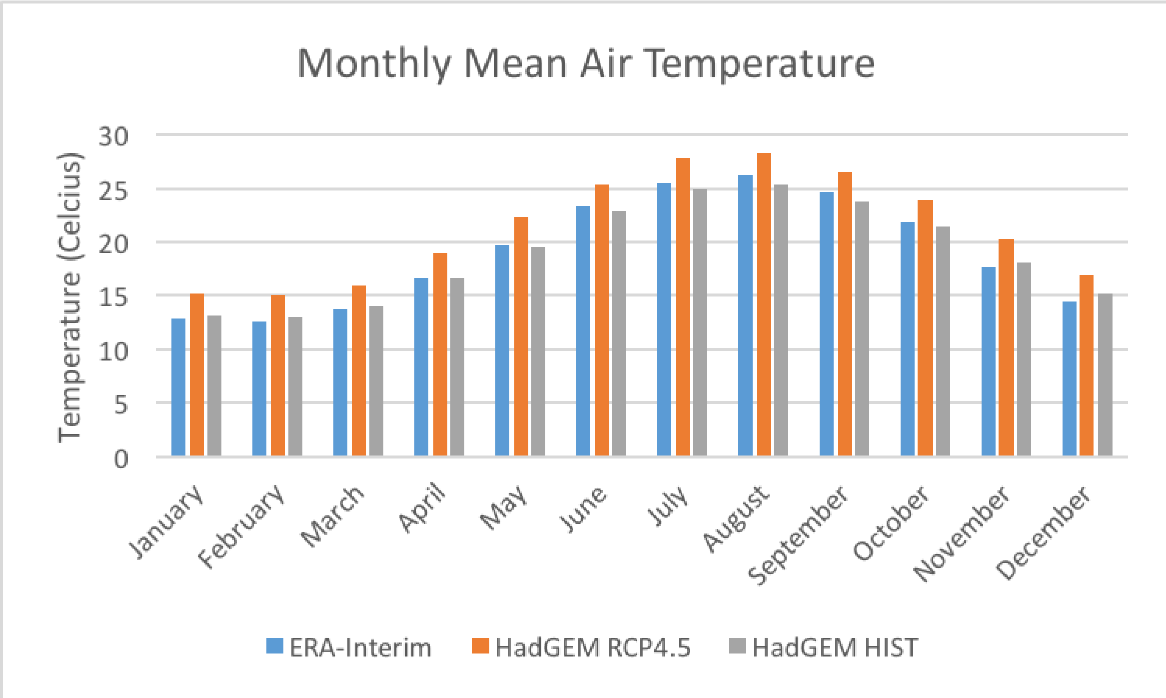

Figure 4.8: Monthly mean air Temperature projection from RegCM4.4 by forcing HadGEM2 according to RCP4.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

When it comes the compare of the results of HadGEM HIST data, ERA-interim and future projection of HadGEM which is run by RCP4.5 scenario it can be seen ,in Figure 4.6, that the precipitation increase will be 2 mm/day in winter months.

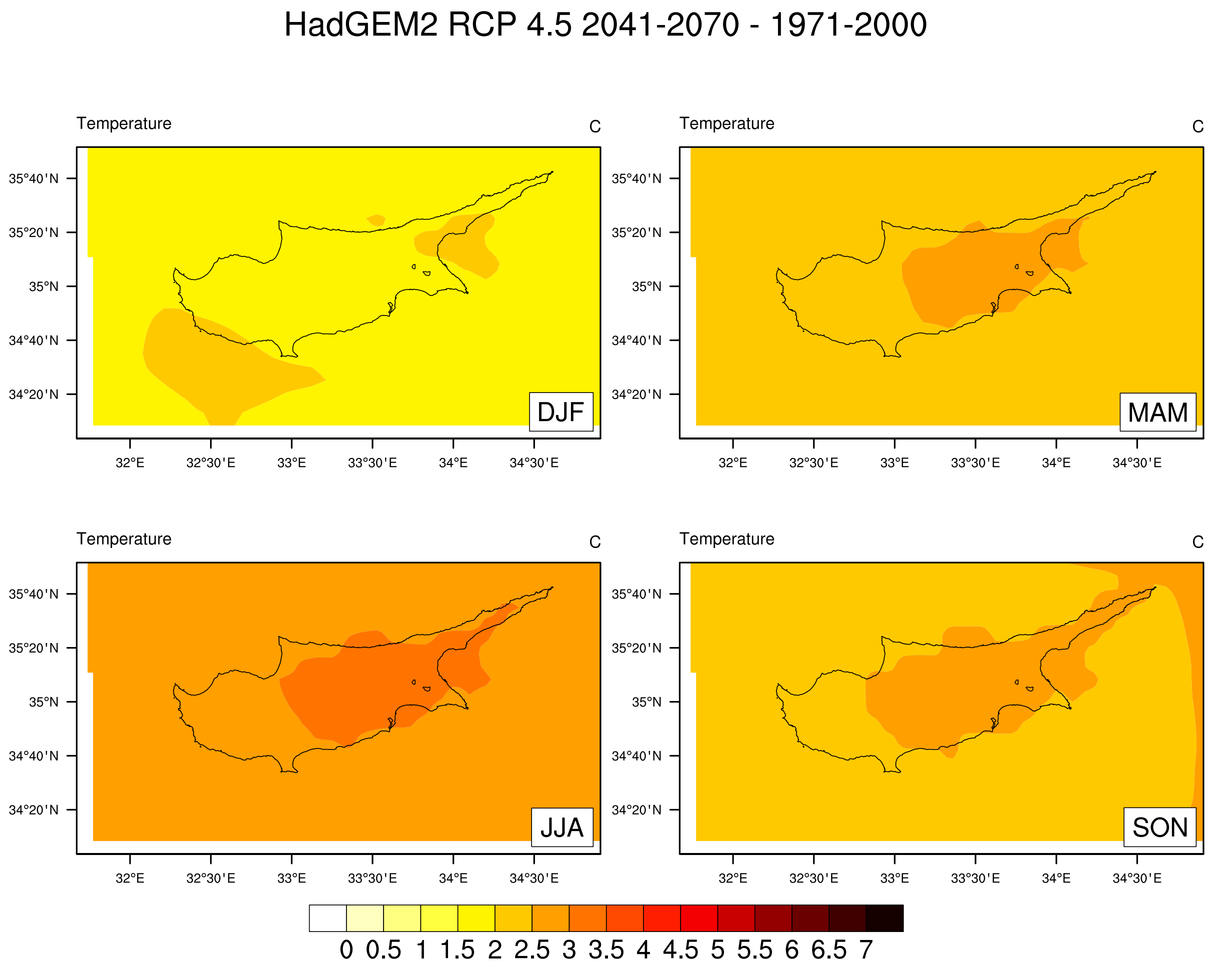

Figure 4.9: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by HadGEM2 Global Climate Model with RCP4.5 scenario in the future, 2041-2070 time period, which is respect to reference time interval 1971-2000

Figure 4.7 shows that the precipitation pattern will change in the 2011-2040 time period. Particularly, the middle of the island will suffer from the drought in winter and spring months.

Especially in summer months (as it can be seen in Figure 4.8) the increase of air temperature will reach almost five degrees. The second future time period is 2041 to 2070 and Figure 4.9 represents the air surface temperature change. As it can be seen, this increase is almost homogeneous in all regions and seasons except the winter season.

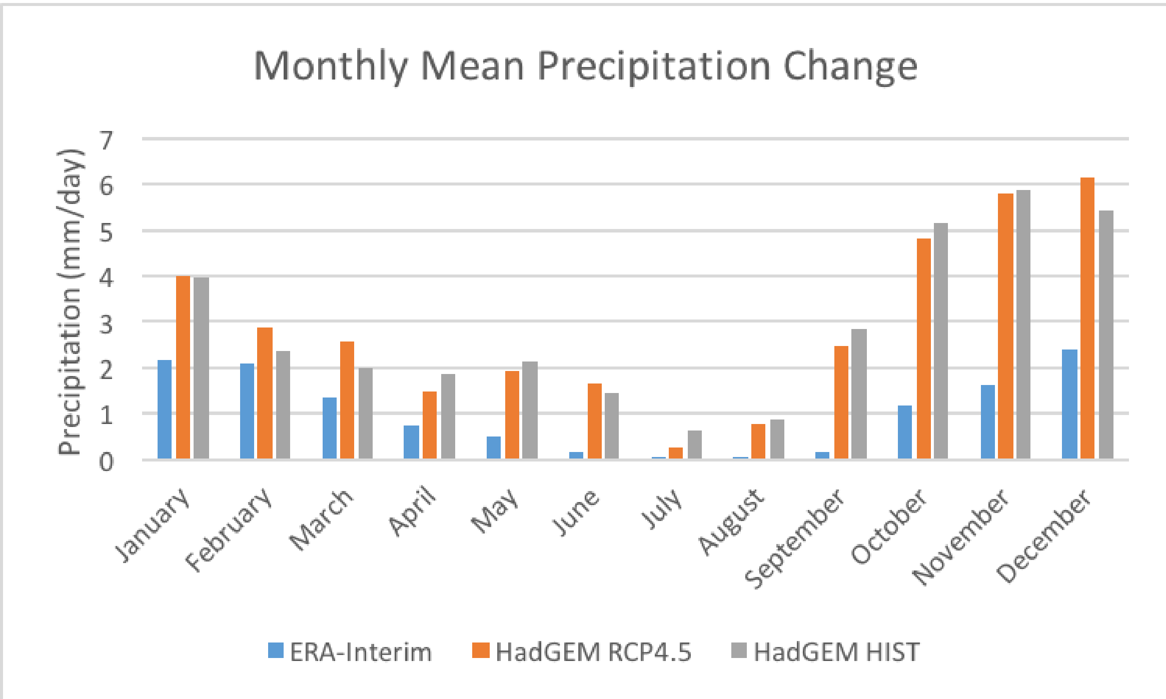

Figure 4.10: Monthly Average Precipitation projection from RegCM4.4 by forcing HadGEM2 according to RCP4.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

When it comes the precipitation case of the second time period 2041-2070 (which is seen in Figure 4.10) precipitation decrease will be 1.2mm/day in Spring months. Moreover, same model output of the seasonal average precipitation change is represented in the Figure 4.11. Average precipitation decrease can be seen especially in spring months.

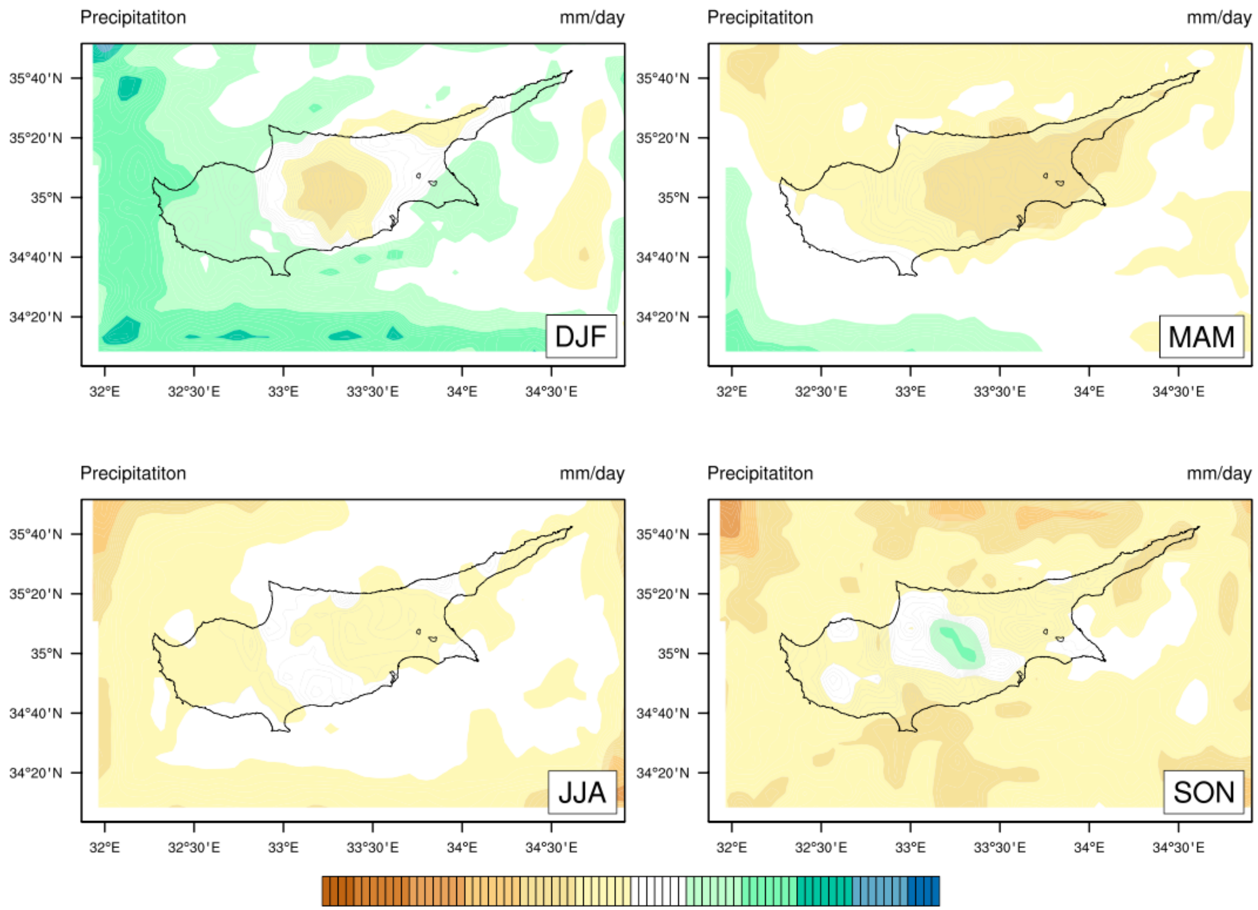

Figure 4.11: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP4.5 scenario in the future, 2041-2070 time period, which is respected to reference time interval 1971-2000

The result of RCP4.5 scenario outputs of HadGEM2 global model dataset for the period of 2071-2100 is presented in Figure 4.12. Monthly mean surface air temperature outputs show almost four degrees increase in all round the year.

As can be seen in the Figure 4.13 model outputs show that more than 4°C temperature rise is inevitable in particular summer months.

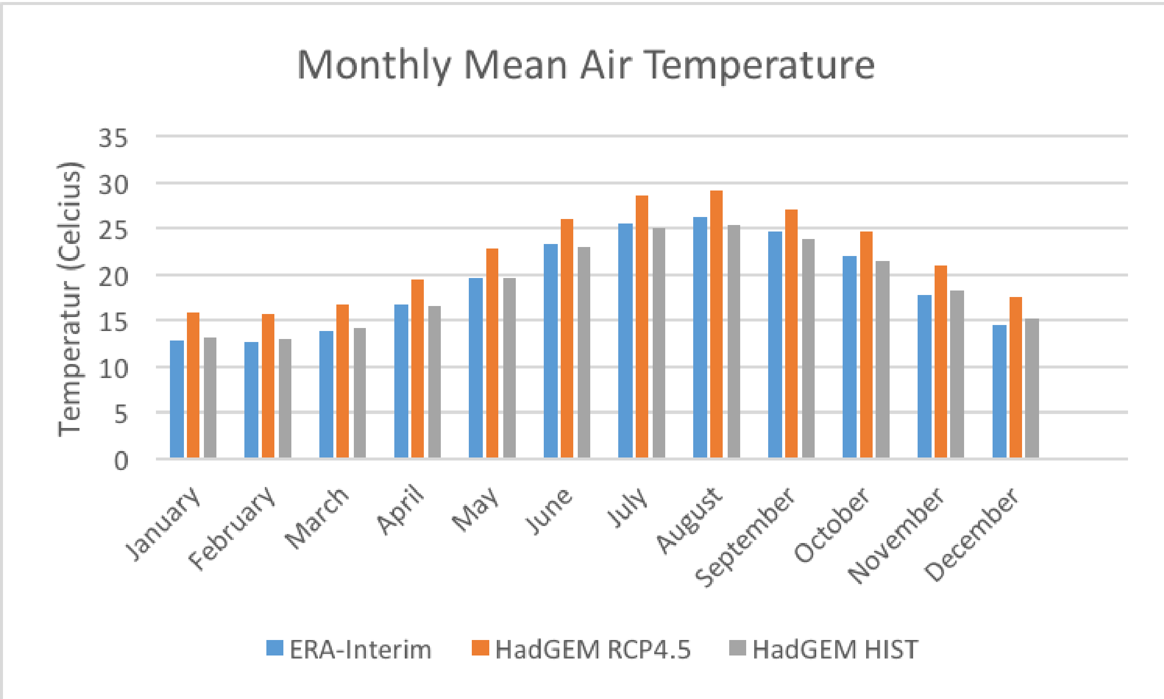

Figure 4.12: Monthly mean air Temperature projection from RegCM4.4 by forcing HadGEM2 according to RCP4.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

Moreover, the the precipitation case of the RCP4.5 scenario shows that a monthly basis the amount of precipitation will increase up to 1 mm/day in December, as shown in Figure 4.14.

On the other hand, Figure 4.15 shows that this increase will be especially in coastal region of the island in the last time period of 2071-2100. It may also be very important to project extreme events in these areas for this case.

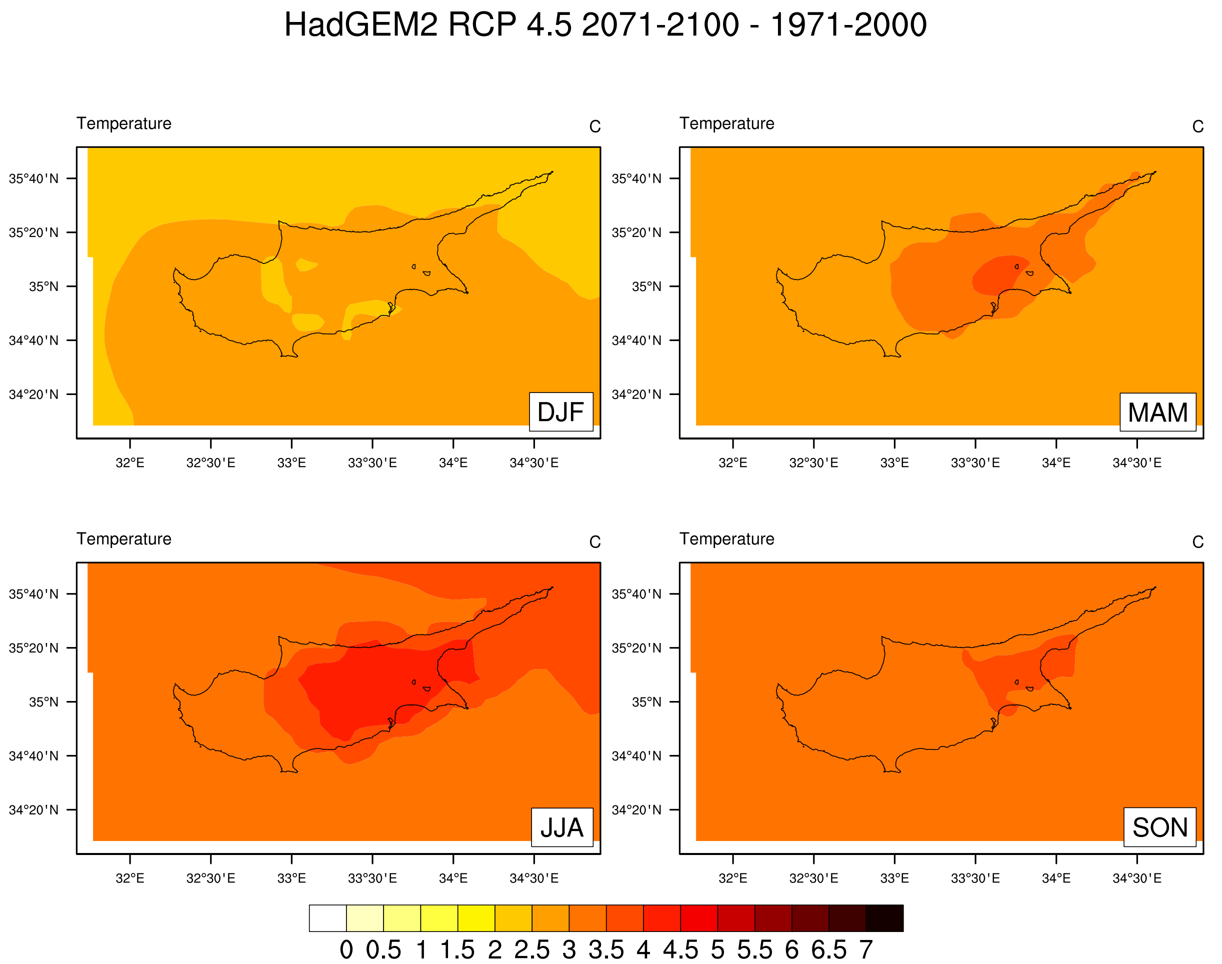

Figure 4.13: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP4.5 scenario in the future, 2071-2100 time period, which is respect to reference time interval 1971-2000

If we look at the first time period in the Figure 4.16, 2011-2040 in the monthly mean air temperature case, it is observed that the difference in temperature over Cyprus will increase at the south coastal regions in winter months, whereas in the middle regions will decrease in winter and spring months and increase around 0.7 mm/day.

Consequently, these results clearly show that the pattern of precipitation in Cyprus will change considerably for this time interval.

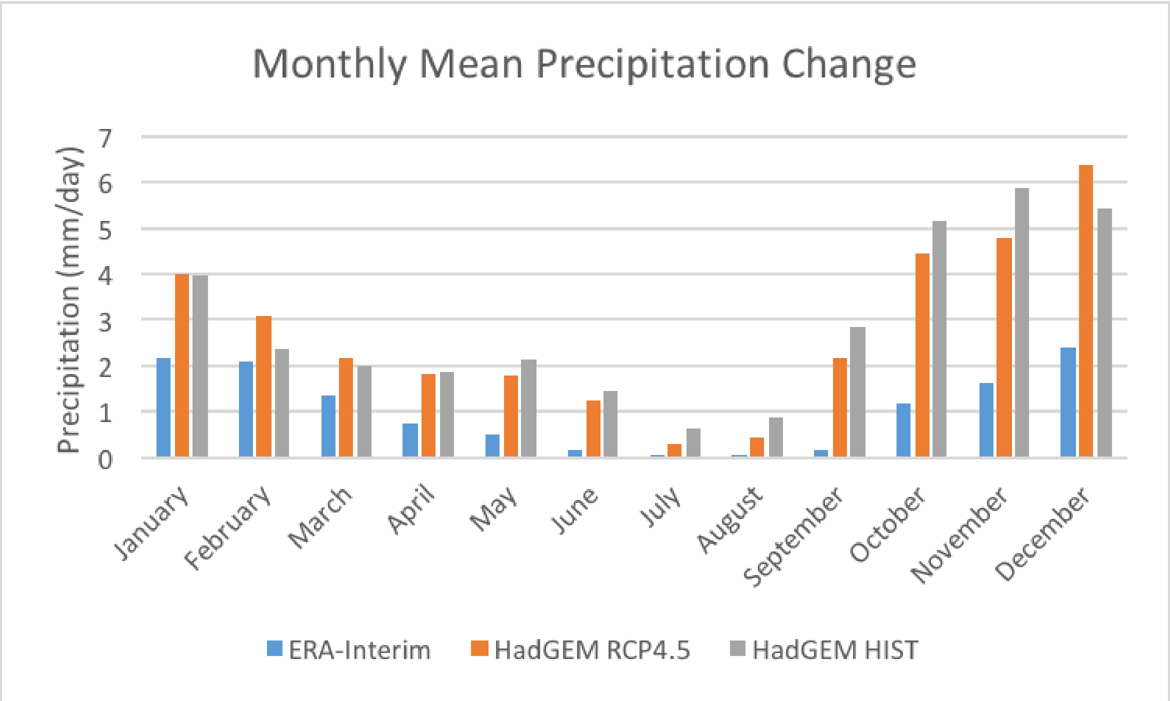

Figure 4.14: Monthly Average Precipitation projection from RegCM4.4 by forcing HadGEM2 according to RCP4.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

Within the RCP8.5, outputs of the regional climate model RegCM based on the HadGEM2 global model dataset for the time interval 2011-2040 is shown in Figure 4.16. obviously, temperature increase will be almost four degrees in every months of the year.

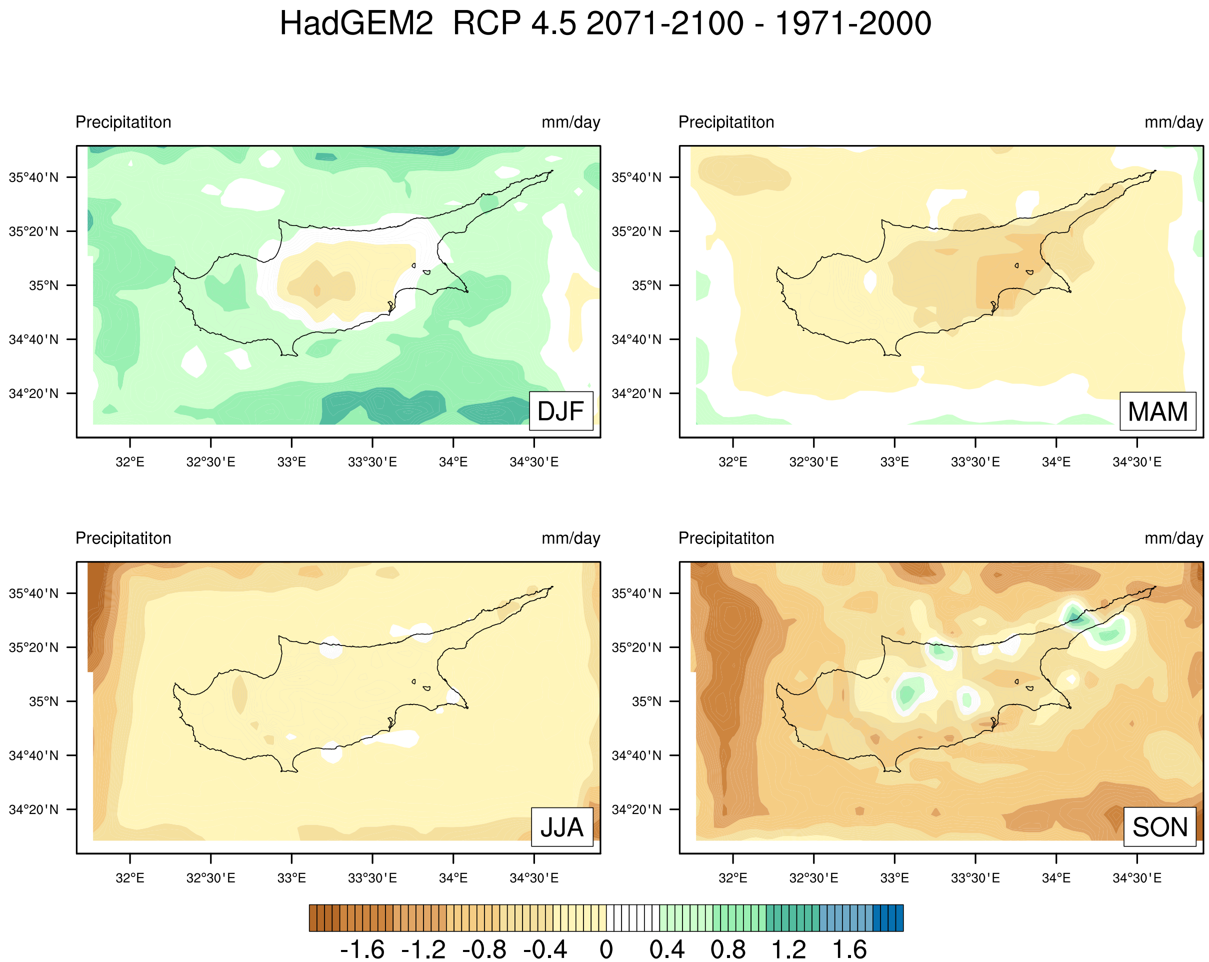

Figure 4.15: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP4.5 scenario in the future, 2071-2100 time period, which is respected to reference time interval 1971-2000

According to the Figure 4.17, this increase will be coastal region of the island, particularly, in summer season and there will be approximately 2-3°C increase in surface air temperature seasonally. Nevertheless, the temperature rise in winter season will be around 1°C for this time period. Surely, the warming is higher than the outputs of RCP4.5 scenario.

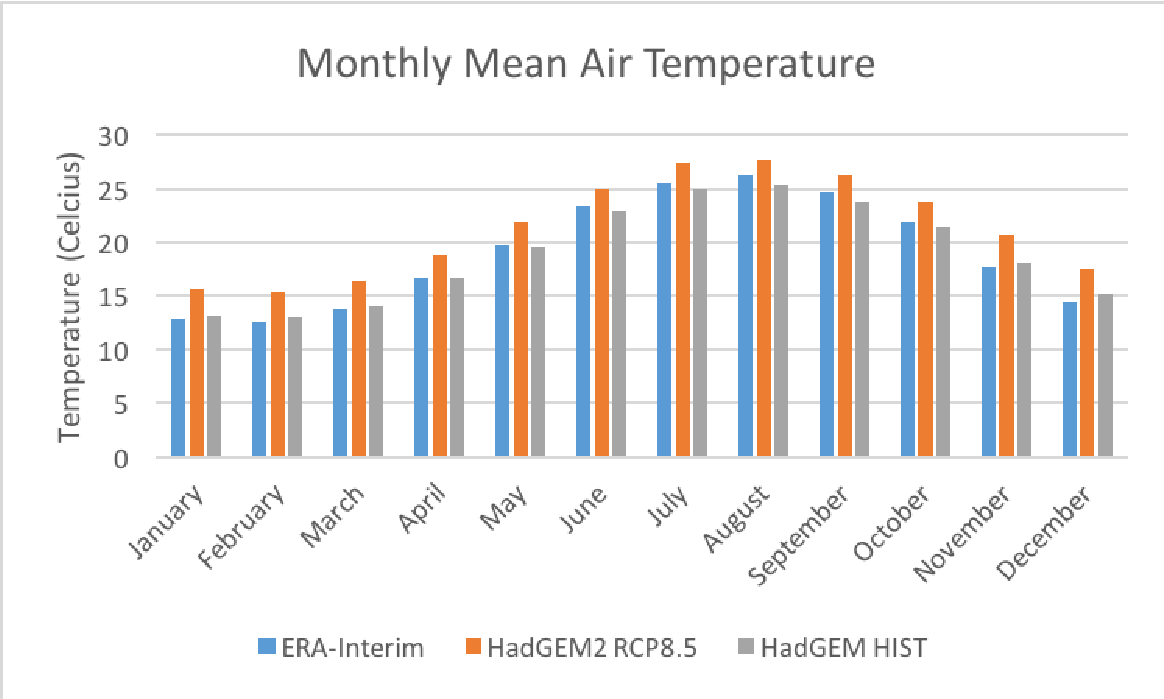

Figure 4.16: Monthly mean air Temperature projection from RegCM4.4 by forcing HadGEM2 according to RCP8.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

The projected data of RCP8.5 scenario, mean precipitation change will be 1 mm/day on February for the time interval 2011-2040 (which is shown in Figure 4.18). In other months of the year, there will be no change in precipitation compared to model's hist outputs and ERA-interim dataset.

As it can be seen in Figure 4.19, not only the precipitation pattern, but the amount of rainfall also increase sharply. Obviously, the risk of flood disaster in this region is quite high ,especially, in winter (DJF) and autumn (SON) months.

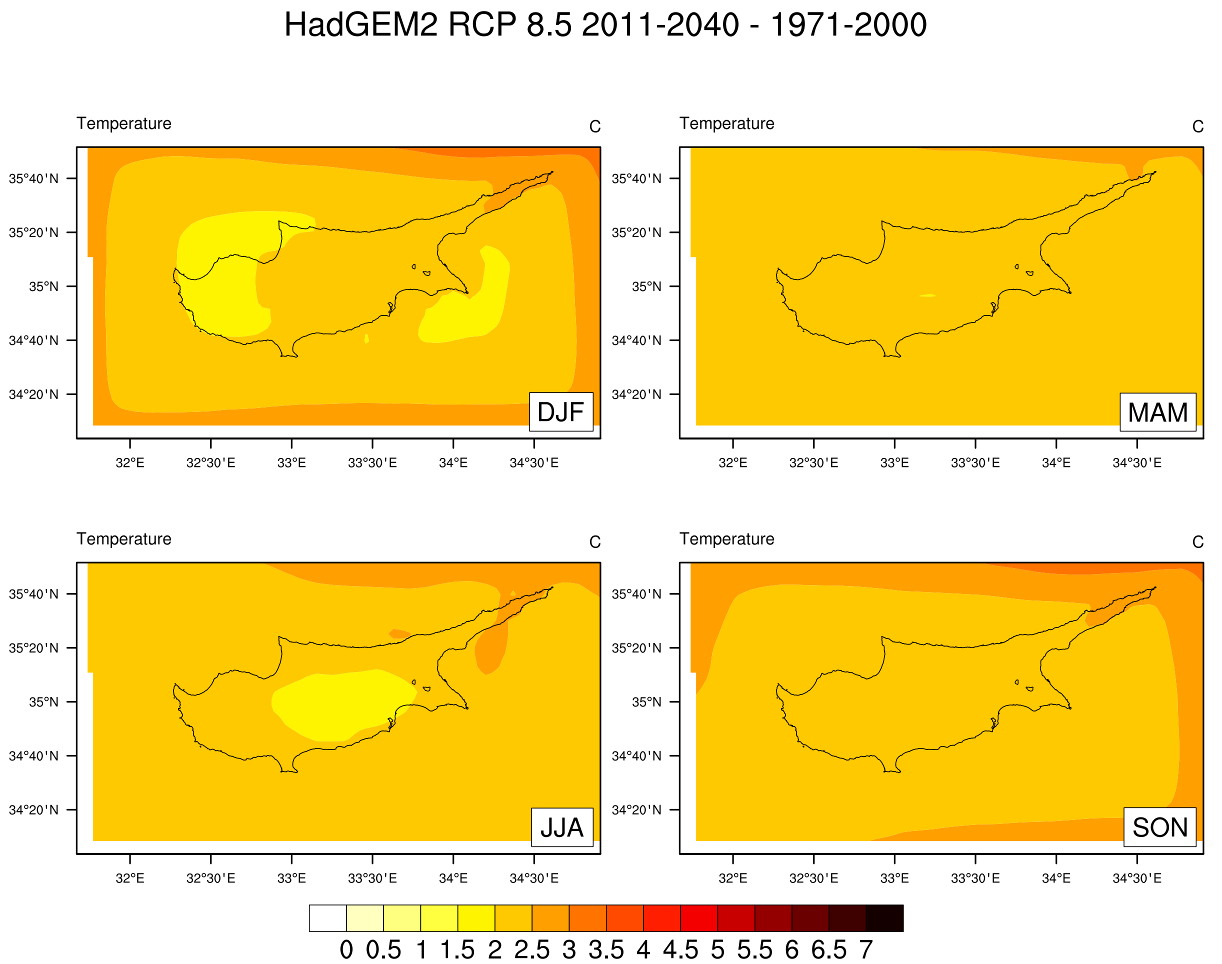

Figure 4.17: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP8.5 scenario in the future, 2011-2040 time period, which is respect to reference time interval 1971-2000

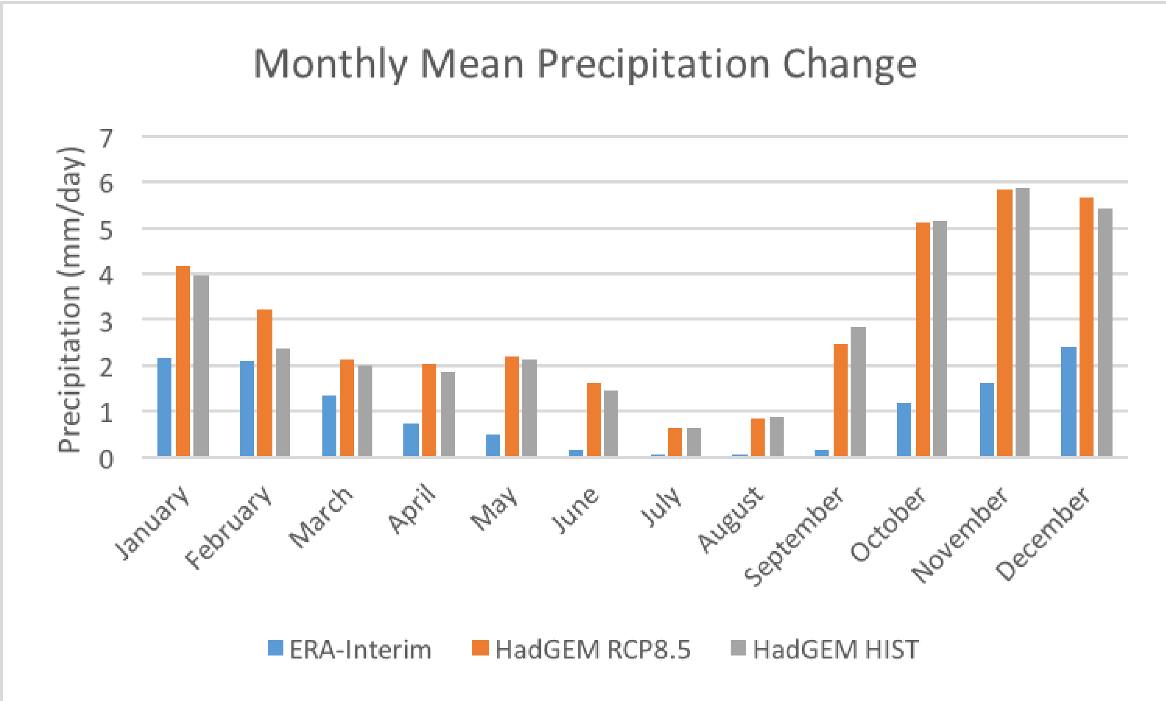

Figure 4.18: Monthly Average Precipitation projection from RegCM4.4 by forcing HadGEM2 according to RCP8.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

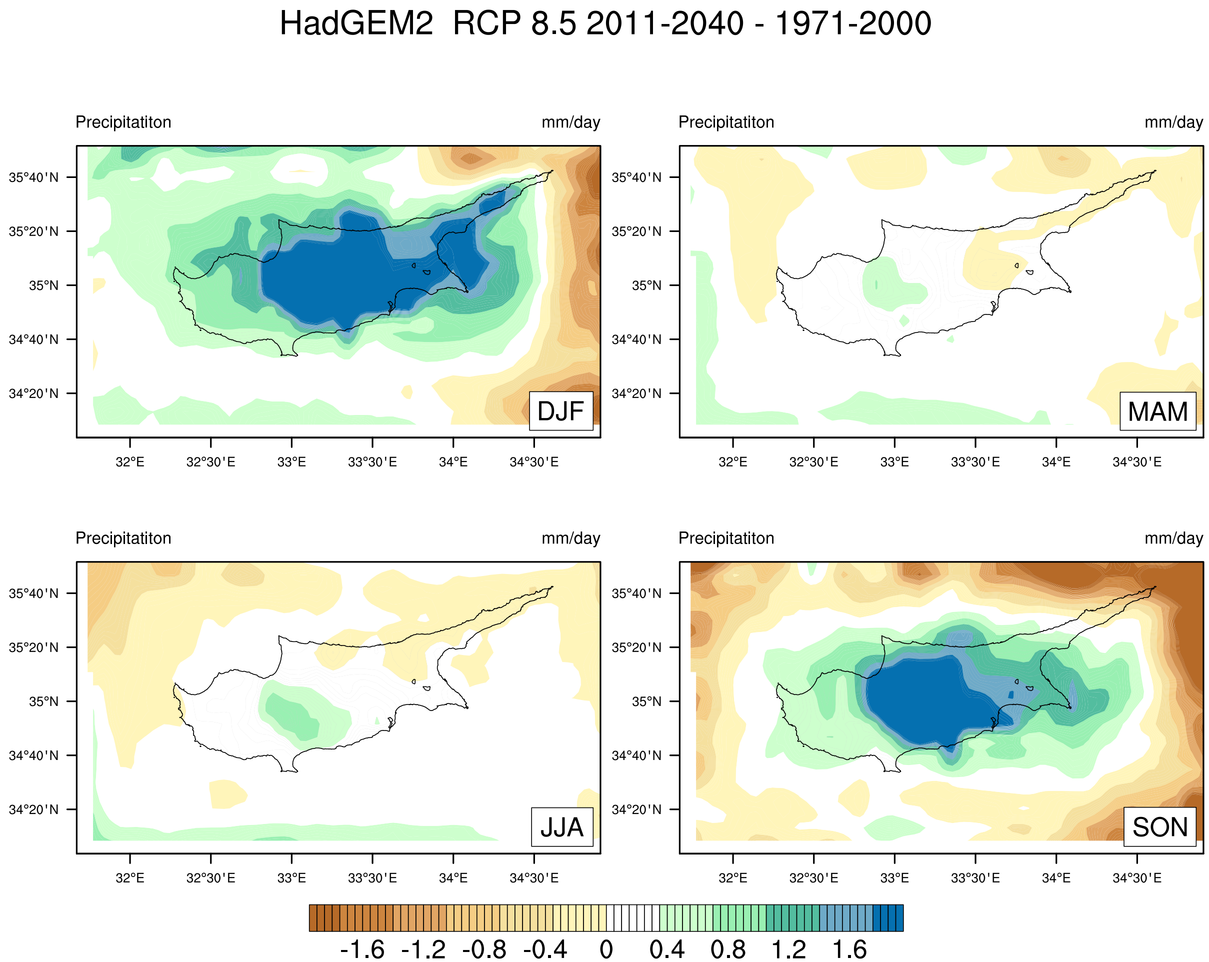

Figure 4.19: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP8.5 scenario in the future, 2011-2040 time period, which is respected to reference time interval 1971-2000

On the other hand, rise of precipitation in summer months can influence the tourism sector, which is very significant for island economy.

When it comes to the time period of 2041-2070, which is shown in Figure 4.20 monthly mean air temperature will increase all round the year. Also, Figure 4.21 shows that this temperature rise will be severe in autmn and summer seasons and it will be up to five degrees.

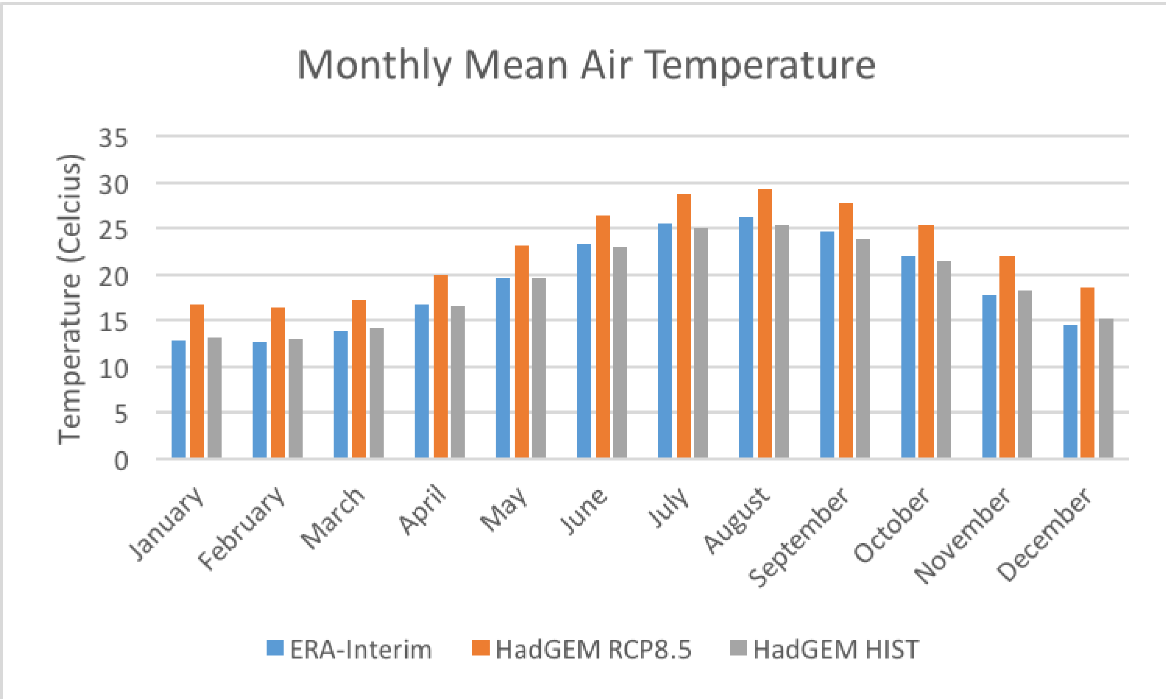

Figure 4.20: Monthly mean air Temperature projection from RegCM4.4 by forcing HadGEM2 according to RCP8.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

Comparing the precipitation case, which is shown in Figure 4.22, while the change of precipitation will be further in winter and autmn seasons.

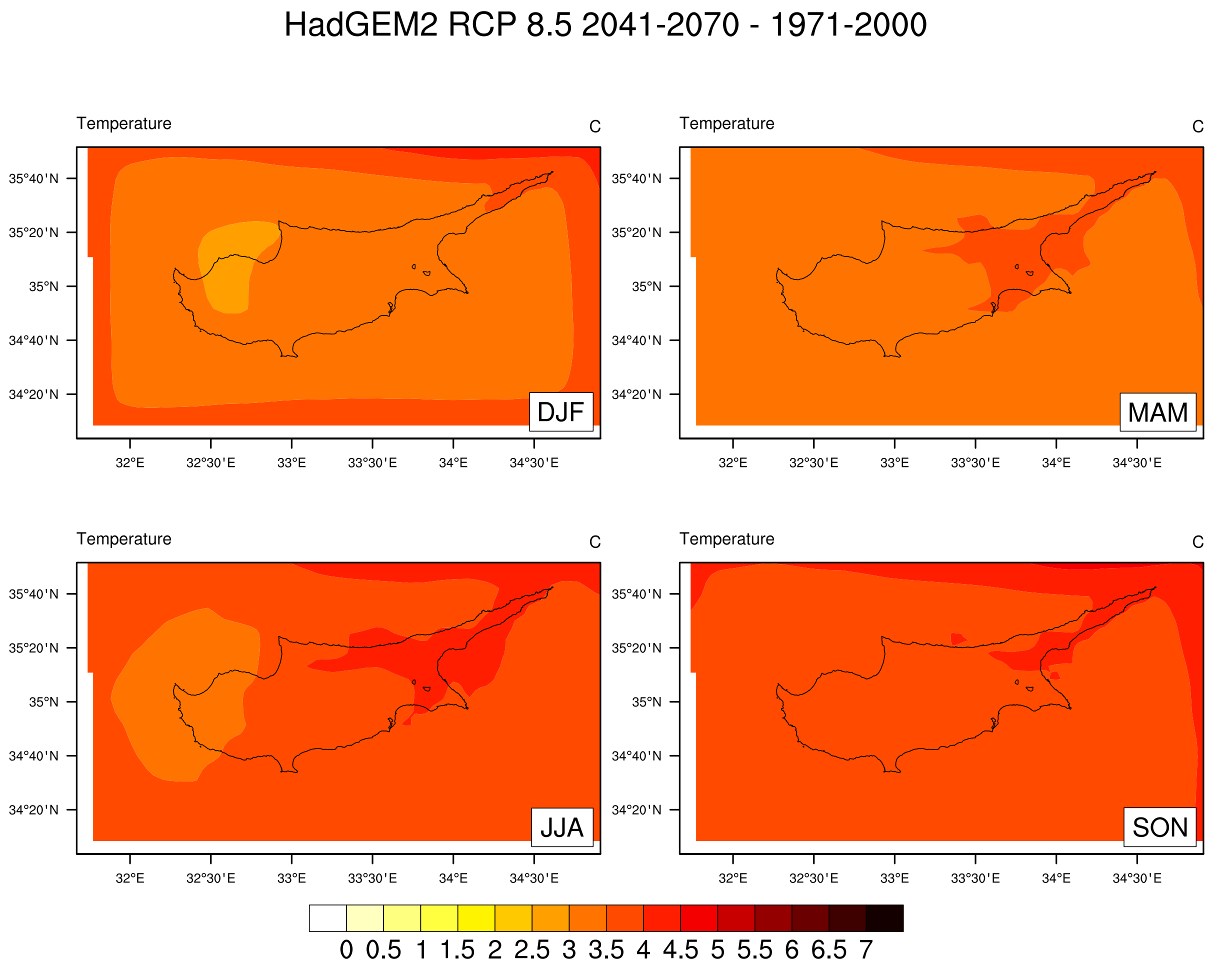

Figure 4.21: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP8.5 scenario in the future, 2041-2070 time period, which is respect to reference time interval 1971-2000

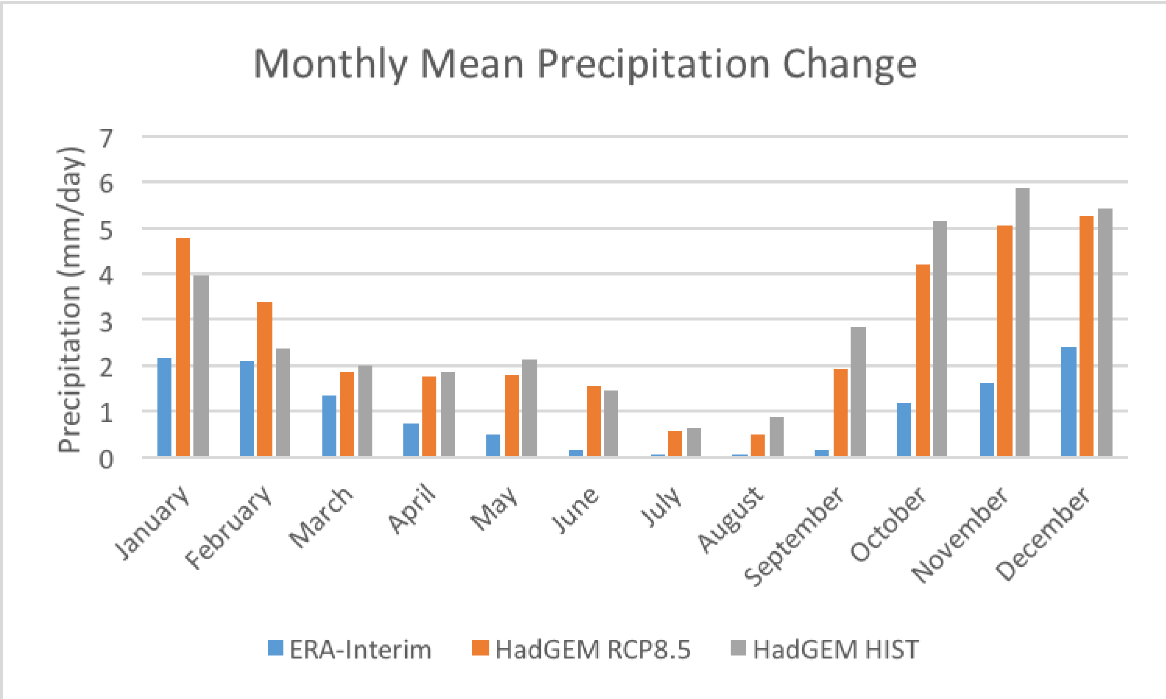

Figure 4.22: Monthly Average Precipitation projection from RegCM4.4 by forcing HadGEM2 according to RCP8.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

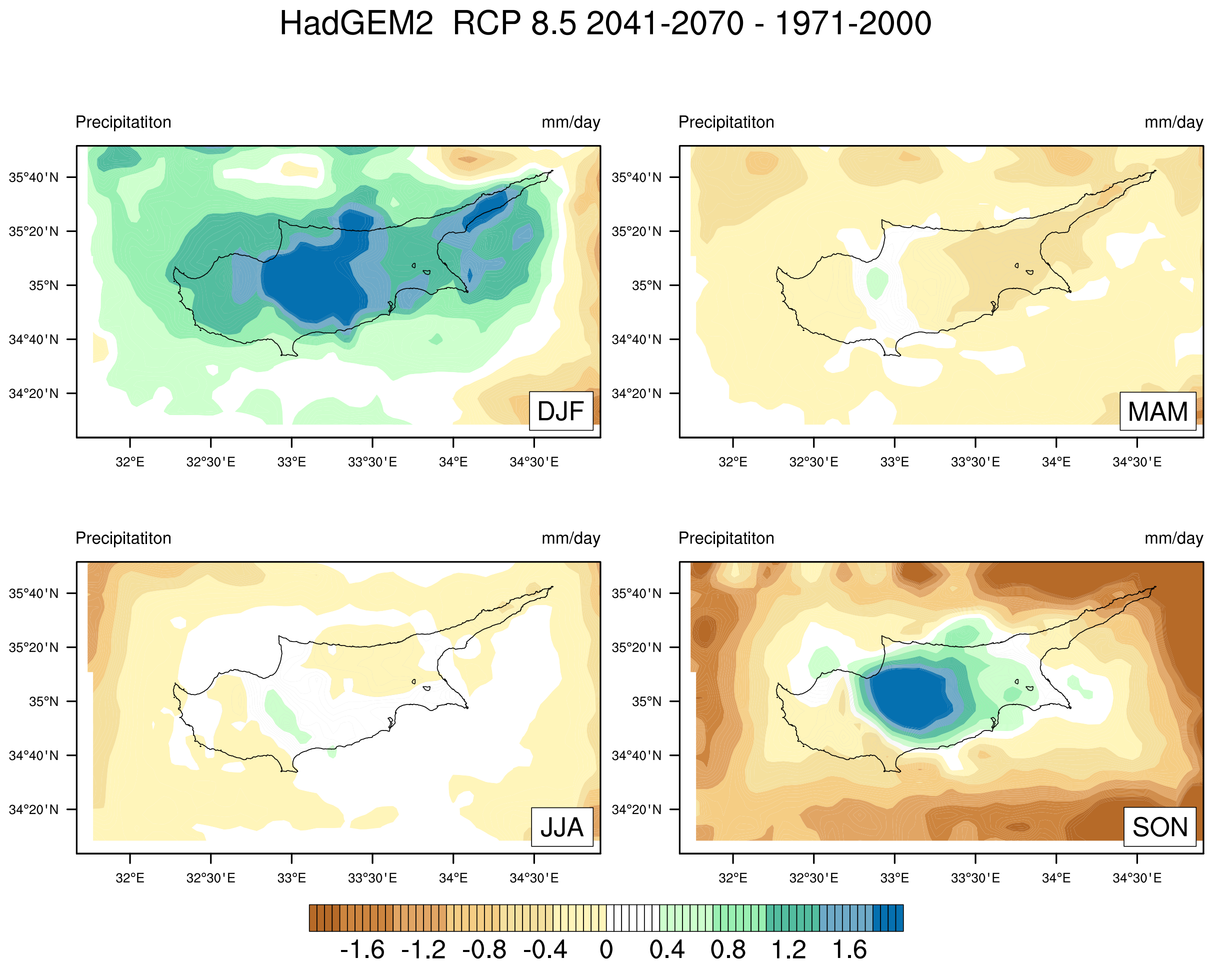

Figure 4.23: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP8.5 scenario in the future, 2041-2070 time period, which is respected to reference time interval 1971-2000

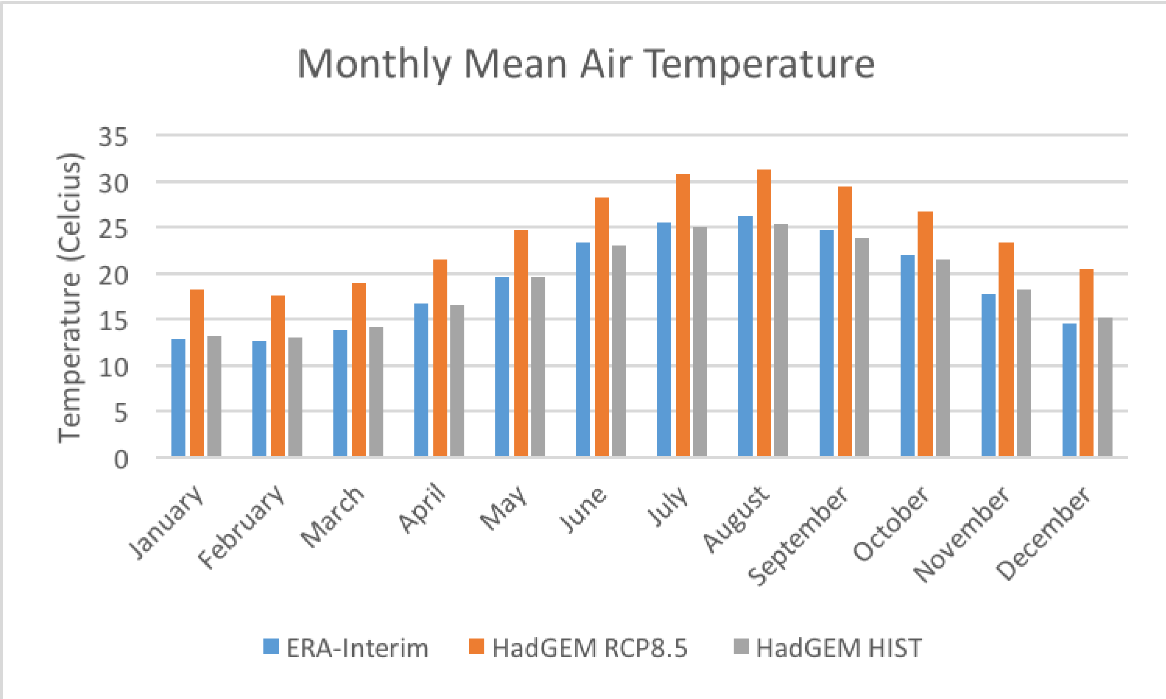

Figure 4.24: Monthly mean air Temperature projection from RegCM4.4 by forcing HadGEM2 according to RCP8.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

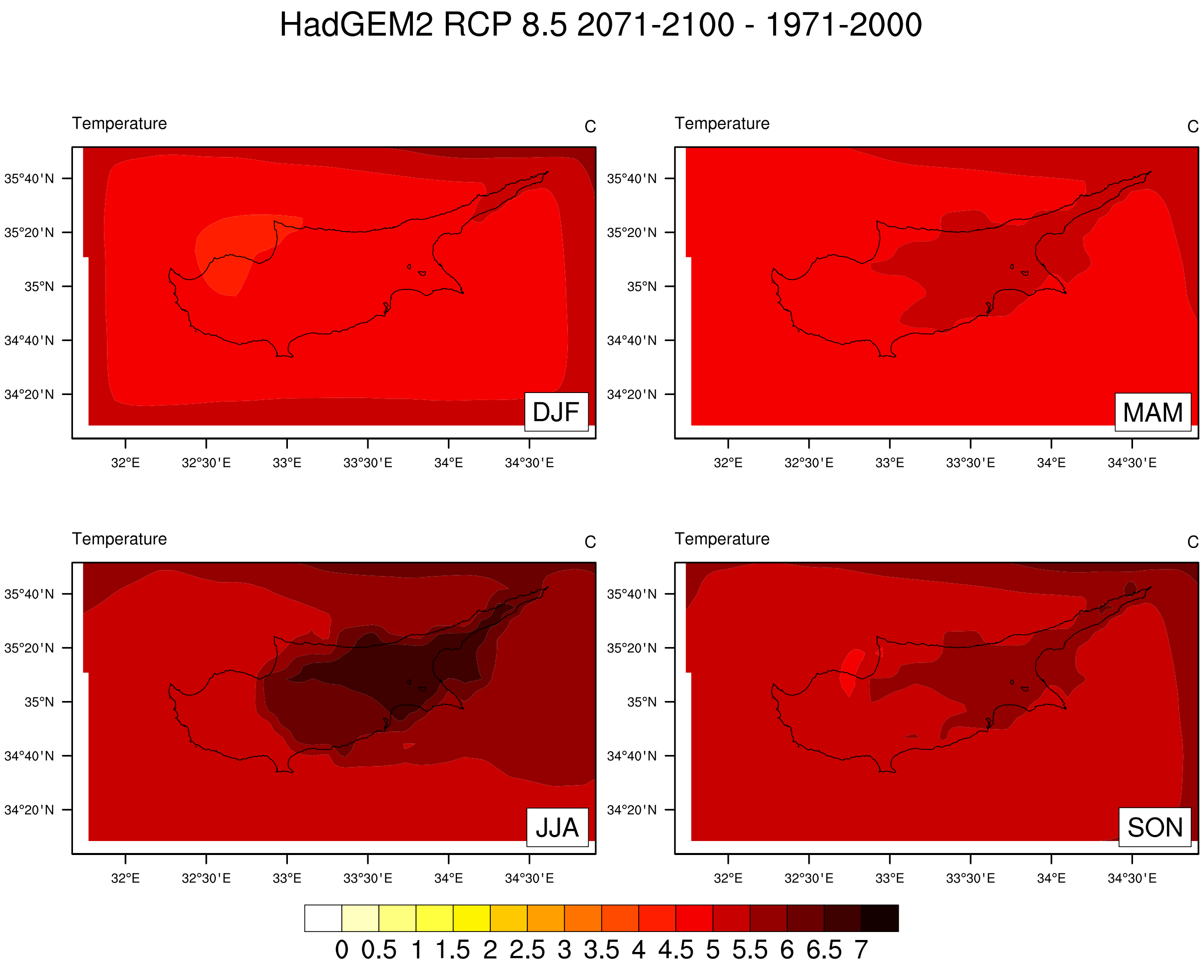

Figure 4.25: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP8.5 scenario in the future, 2071-2100 time period, which is respect to reference time interval 1971-2000

Figure 4.23 shows that the same result's seasonal average case and precipitation rise obviously seen in the graphs. Particularly, the northern part of the region can suffer from drought, in spring months (MAM) owing to the decrease of rainfall, the precipitation amount will be almost 0.6 mm/day. Furthermore, the increase in the amount of the mean precipitation rise will be severe in winter season (DJF). For the

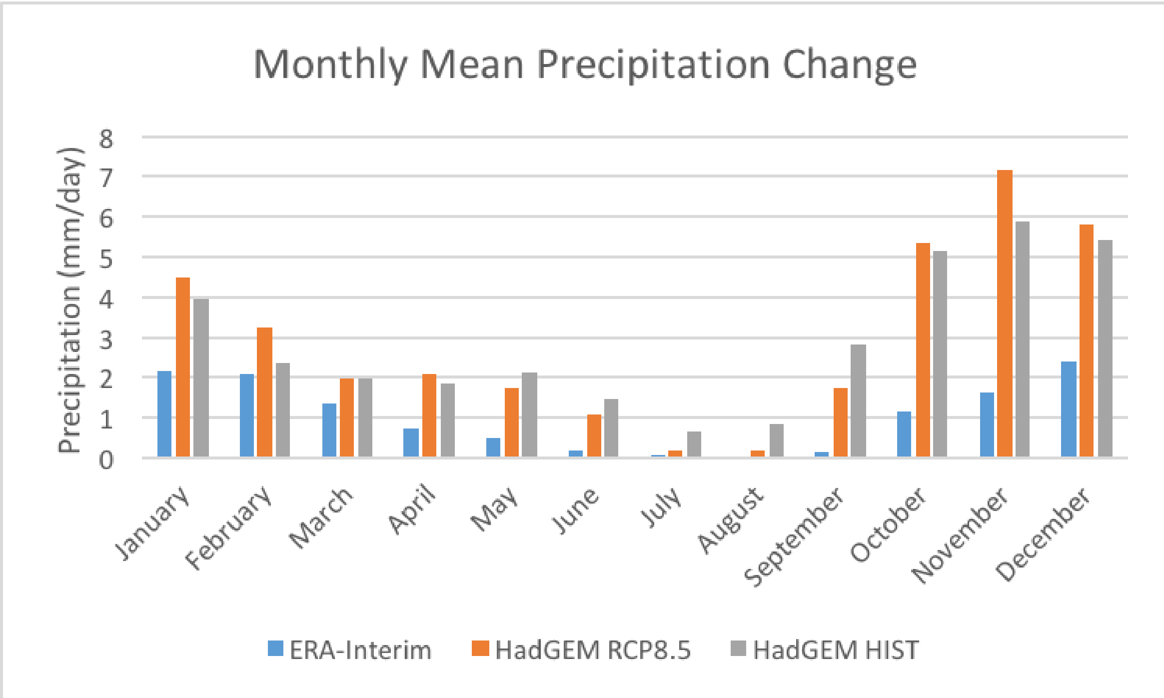

Figure 4.26: Monthly Average Precipitation projection from RegCM4.4 by forcing HadGEM2 according to RCP8.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

last time period 2071 to 2100 which is shown in the Figure 4.24, the air temperature increase will reach seven degrees. Monthly mean cahnges show that the peak point will be in August.

According to the projection which forced by global climate model HadGEM2 with RCP8.5 outputs, the air temperature will rise considerably in summer (6-7 °C warmer) compared to the reference time interval. As it can be seen in Figure 4.25, this temperature increase will be felt in almost every region of the island in all the seasons.

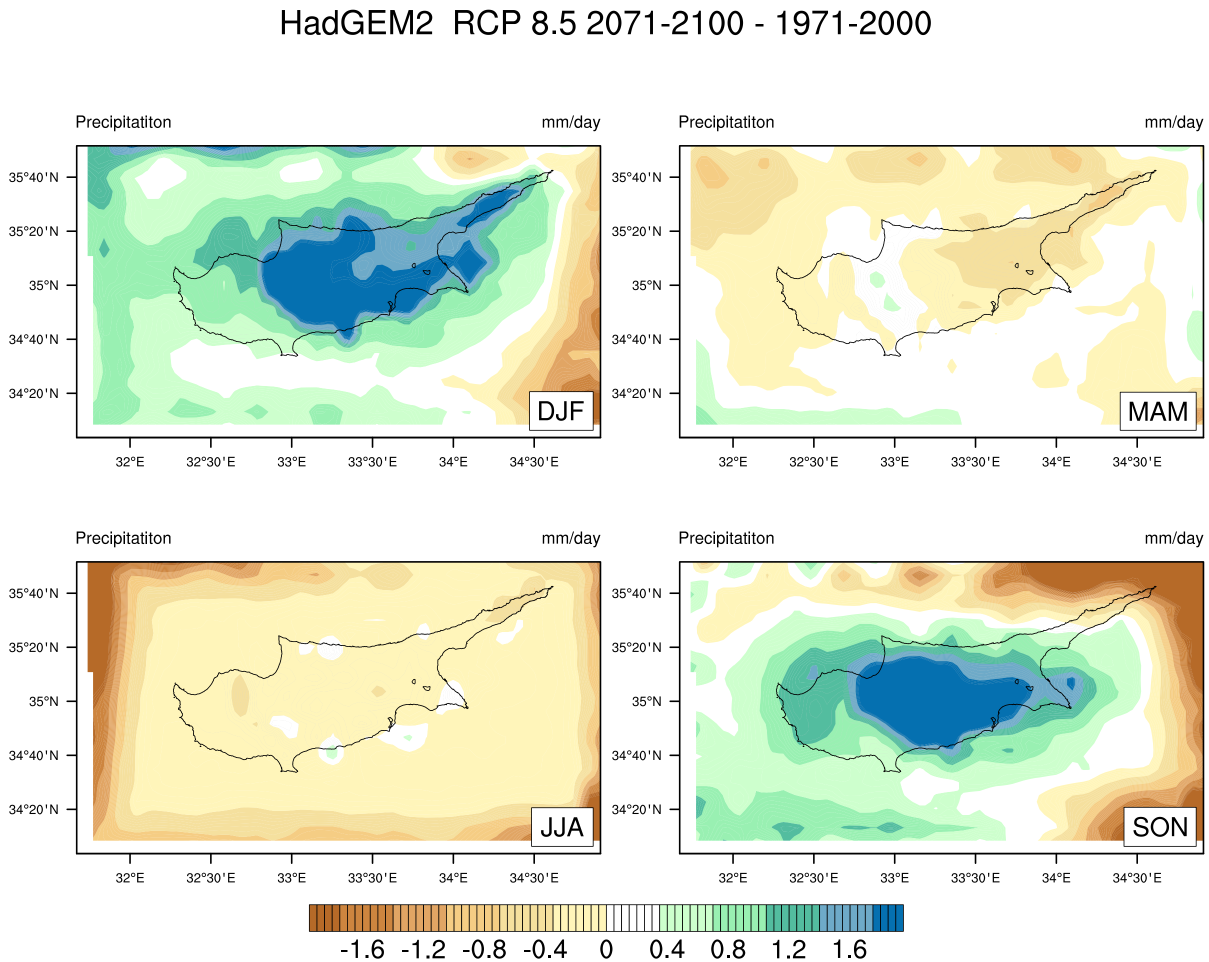

Figure 4.27: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by Hadley Centre Global Environment Model version 2 (HadGEM2) General Circulation Model with RCP8.5 scenario in the future, 2071-2100 time period, which is respected to reference time interval 1971-2000

Monthly mean precipitation case for the last time period is represented in Figure 4.26. It can be seen apparently the precipitation change will be severe almost all round the year.

In Figure 4.27, whereas the average amount of precipitation will decrease by up to 0.9 mm/day in spring, compared to the reference time interval 1971-2000, it will rise up to 0.9 mm/day in winter and fall seasons.

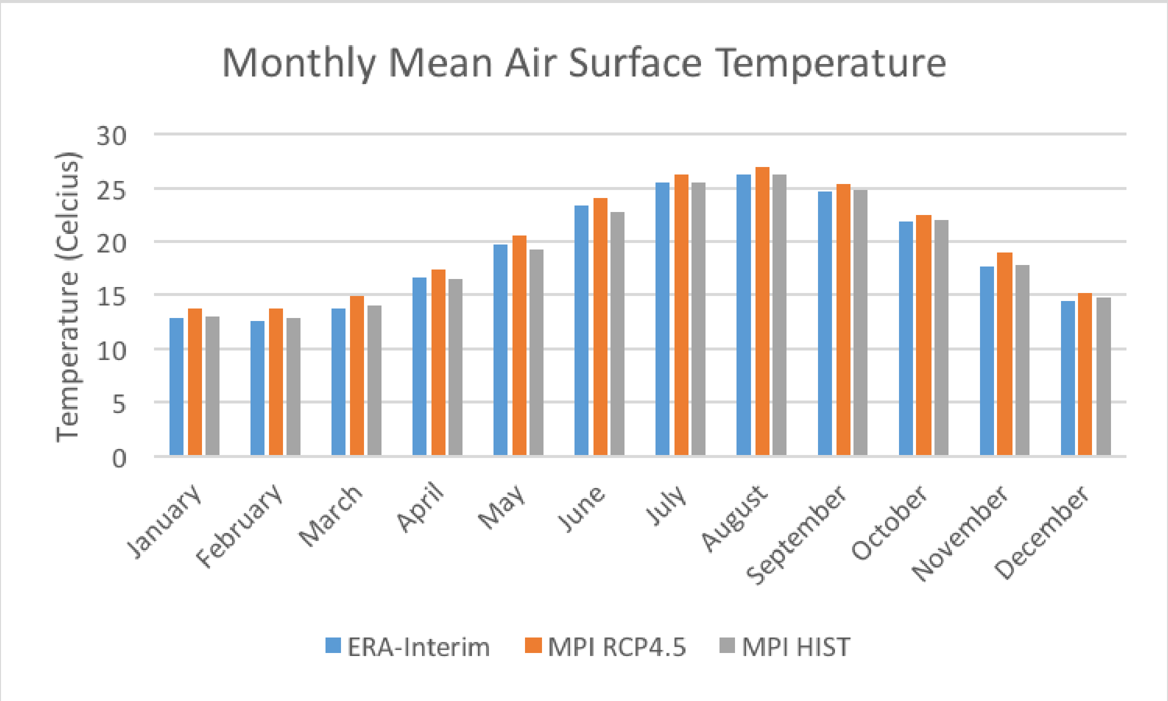

Figure 4.28: Monthly mean air Temperature projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP4.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

Global Circulation Model MPI-ESM-MR results shows that, just like HadGEM2, the 2011-2040 time period is slightly better than the later times. According to the result,as shown in the Figure 4.28, surface air temperature is expected to increase between 1-2 °C respect to the reference time period 1971-2000.

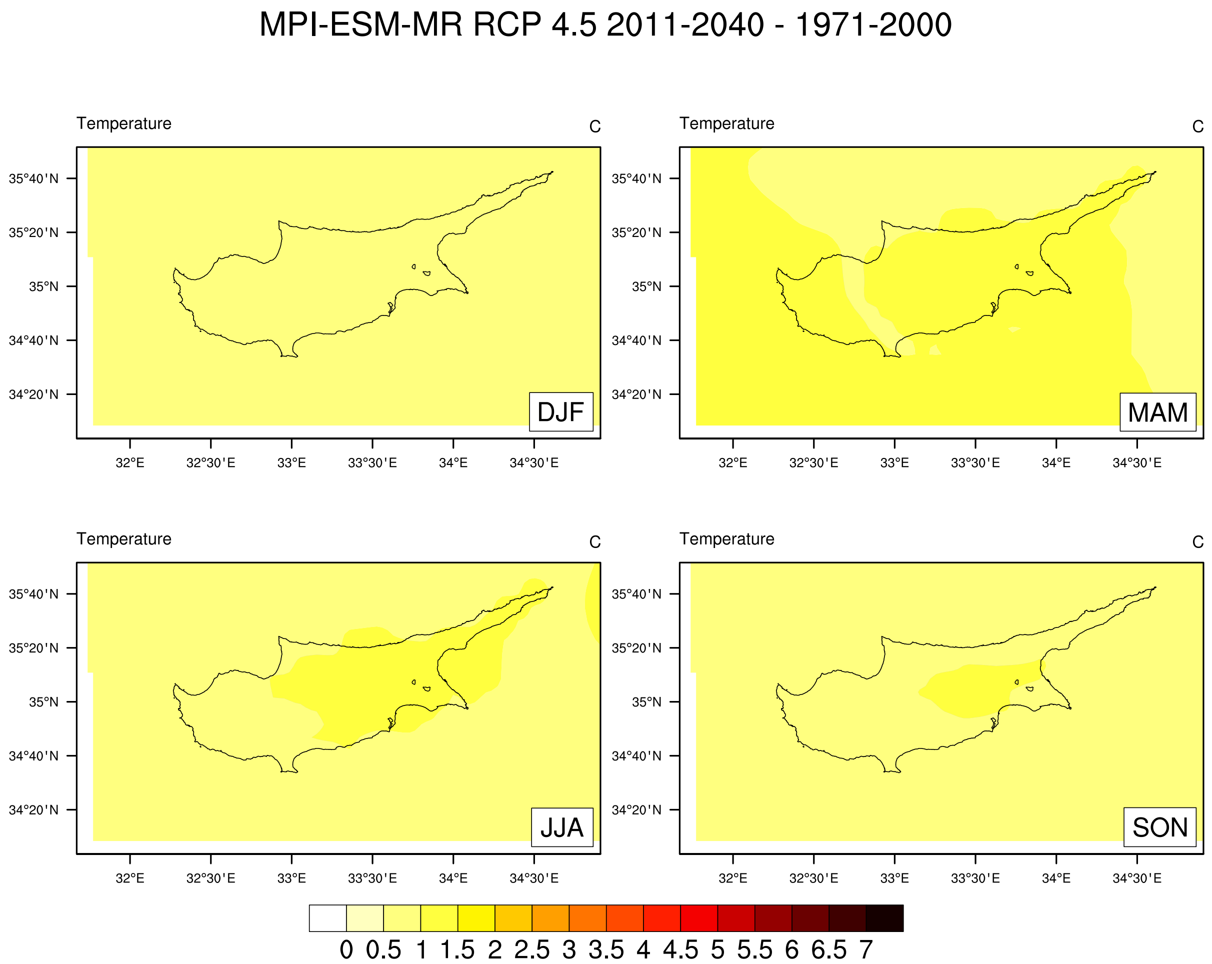

Figure 4.29: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP4.5 scenario in the future, 2011-2040 time period, which is respect to reference time interval 1971-2000

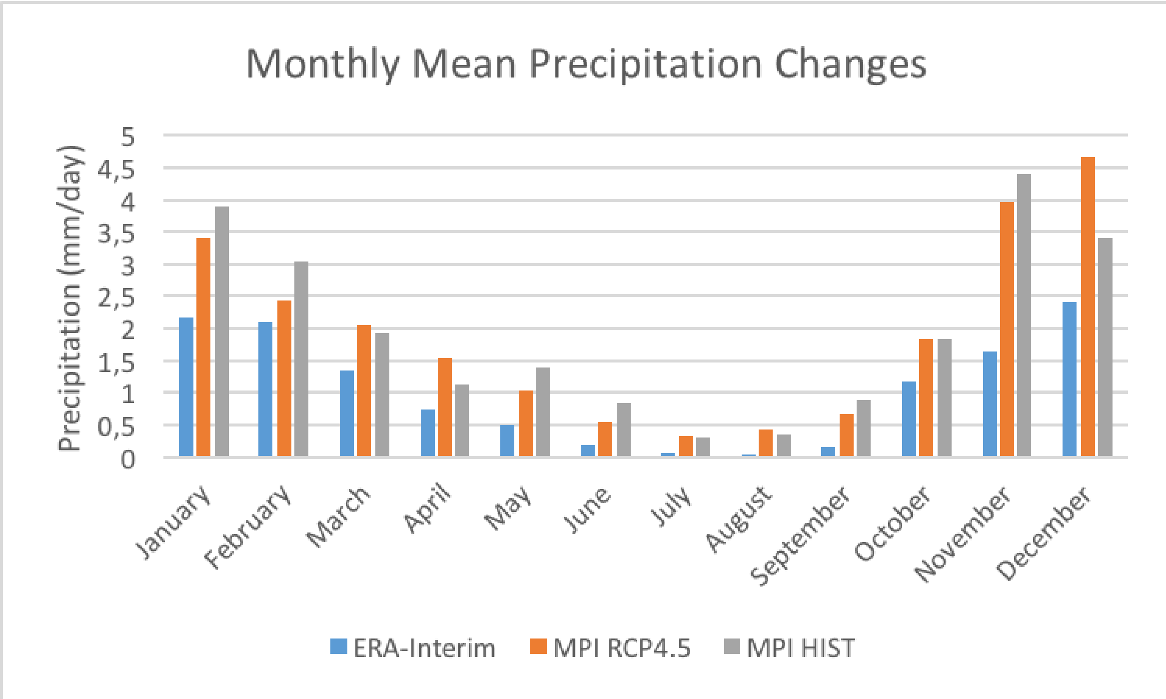

Figure 4.30: Monthly Average Precipitation projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP4.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

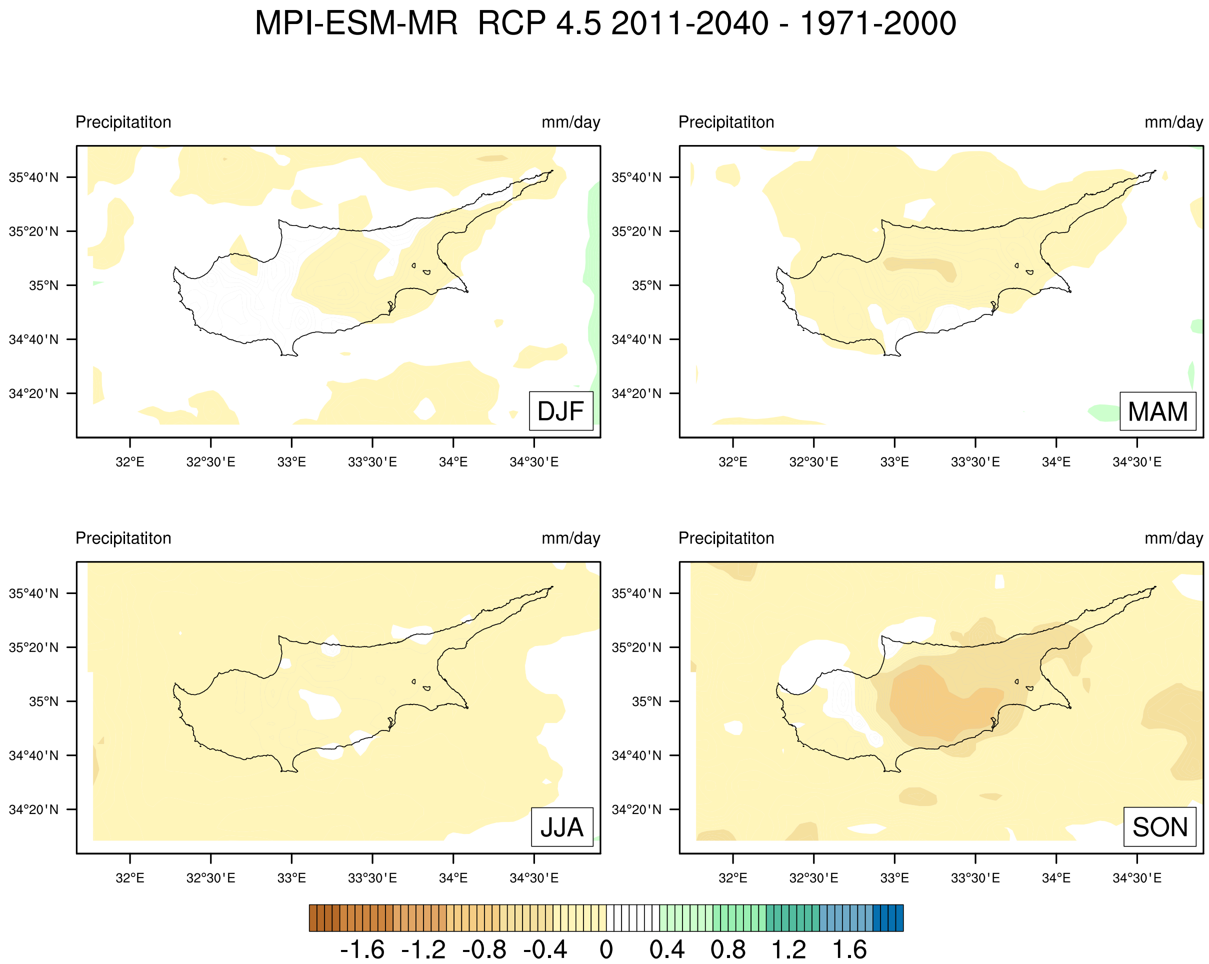

Figure 4.31: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP4.5 scenario in the future, 2011-2040 time period, which is respected to reference time interval 1971-2000

Figure 4.29 shows that the temperature change will be homogeneously. Especially the temperature rise will reach two degrees on summer and spring months. Figure 4.30 shows that the comparison MPI-ESM-MR HIST, ERA-interim and the model's future period. The temperature increases in December compared to the model's own past output. It is predicted that the temperature will decrease in January and February.

According to the results of the model, which is represented in Figure 4.31, there is a decrease of 0.6 mm/day in precipitation between 2011-2040 in the autumn months (SON), while the average rainfall amount will remain the same in other seasons.

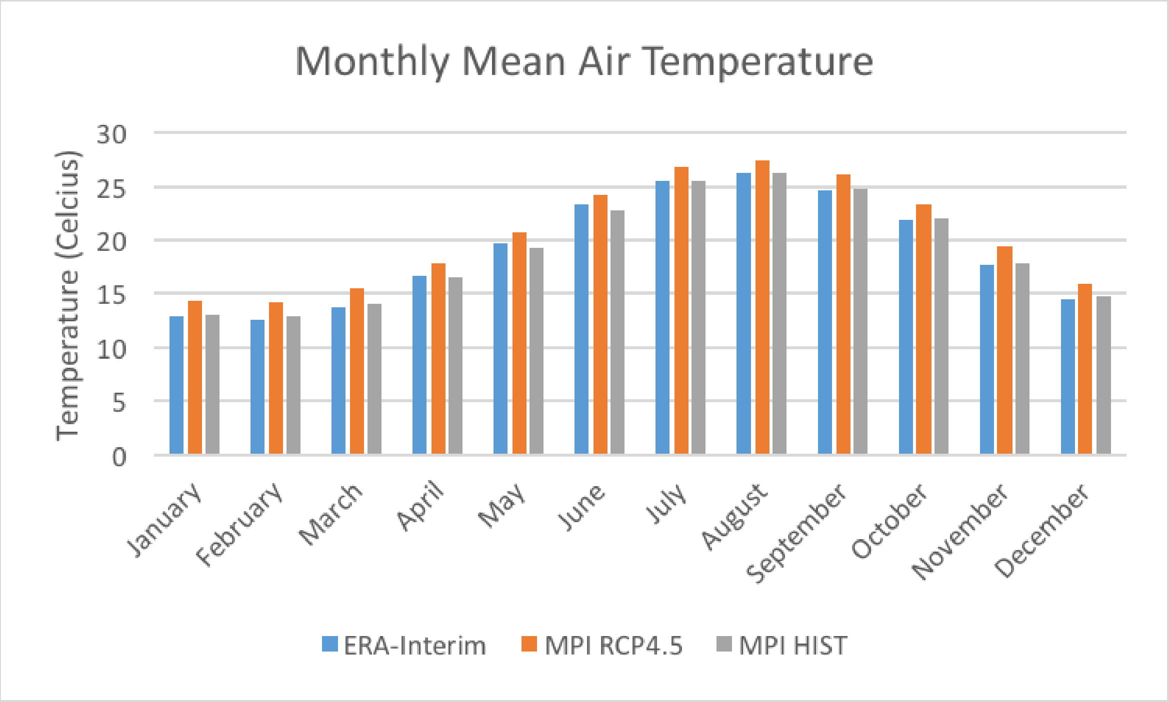

Figure 4.32: Monthly mean air Temperature projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP4.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

Figure 4.32 represents the change of air temperature for the RCP4.5 scenario which is run by MPI-ESM-MR. As it is shown in the Figure 4.33, for the time period 2041 to 2070, there will be an increase between 1 or 2 °C in all seasons and all over the region of the island.

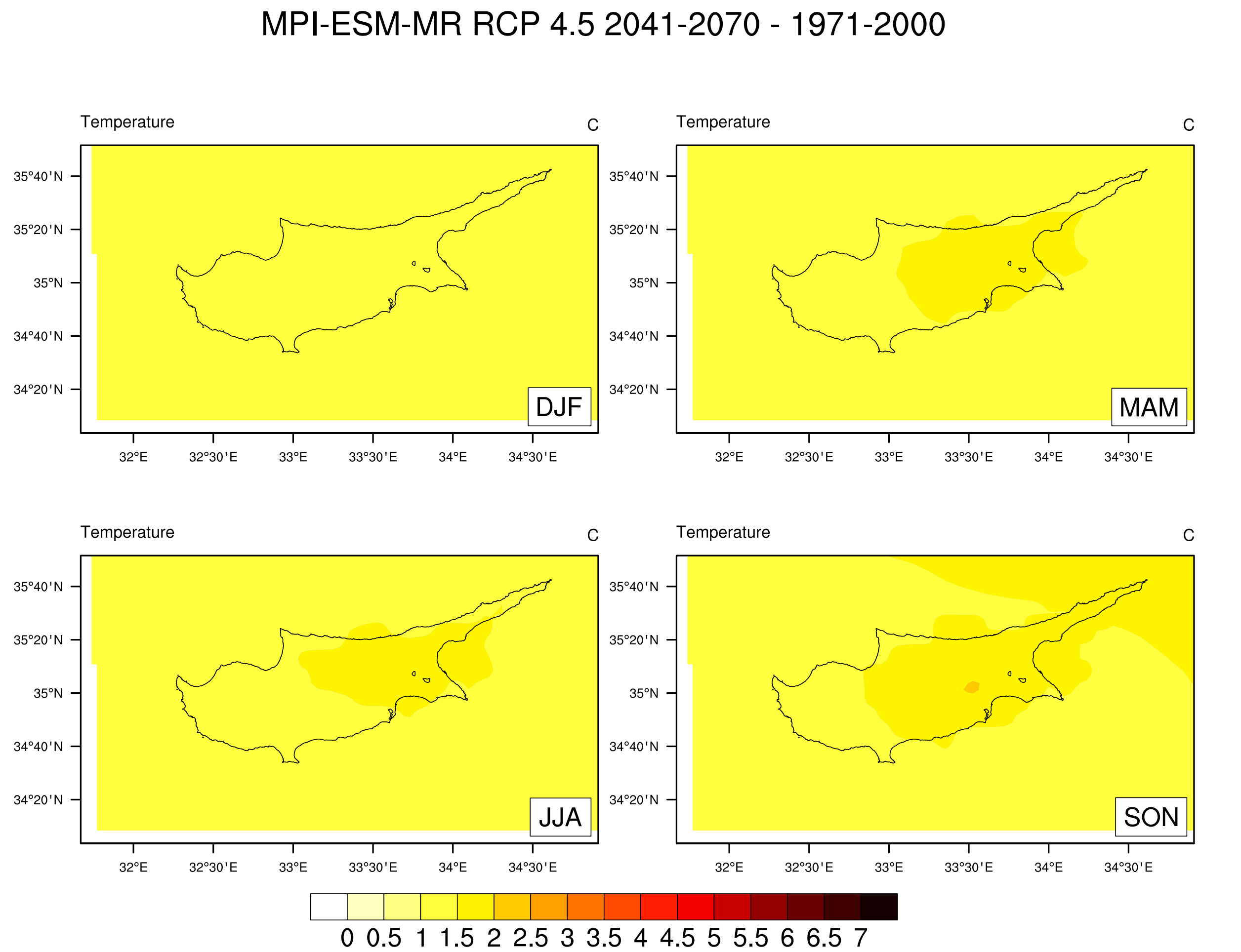

Figure 4.33: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP4.5 scenario in the future, 2041-2070 time period, which is respect to reference time interval 1971-2000

As for the change in the amount of precipitation shown in Figure 4.34, for time period 2041-2070 in the RCP4.5 case, there is again a very fast changing pattern. According to the Figure 4.35, the amount of precipitation decreased up to 0.9 mm/day in winter and autumn seasons, yet did not change in other seasons.

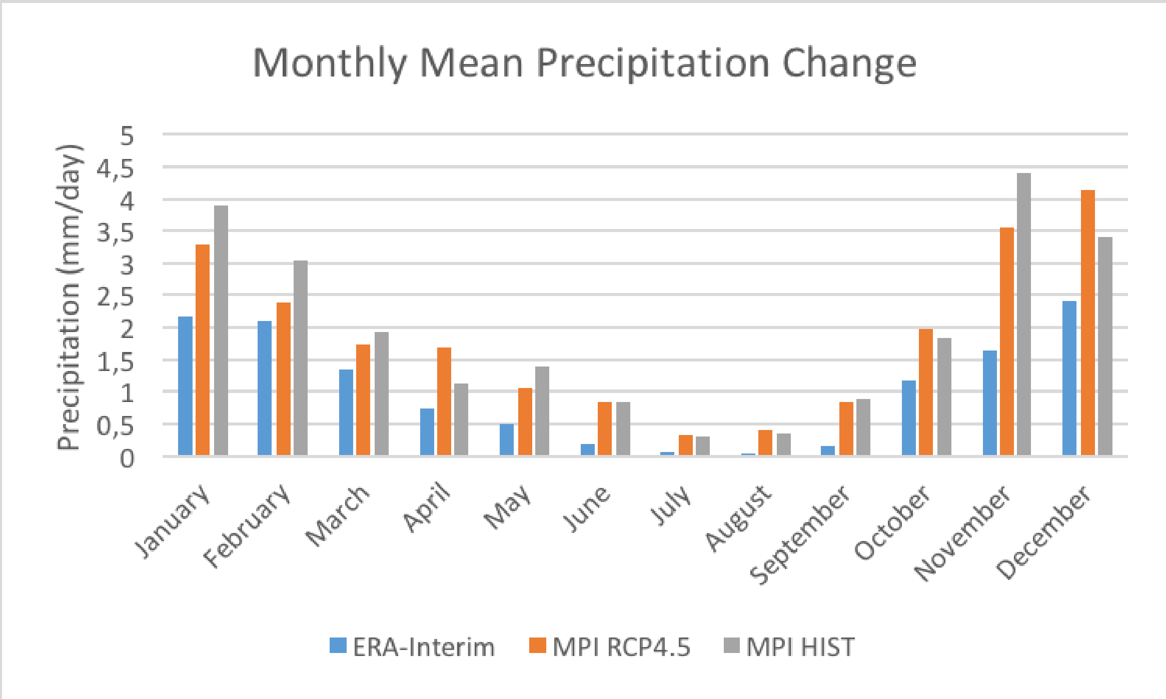

Figure 4.34: Monthly Average Precipitation projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP4.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

When it comes the last time period 2071-2100, as shown in Figure 4.36, there are absolute an air temperature rise in between 1 to 3 °C respect to the 1971-2000 time interval. and Figure 4.37 shows that the temperature increase will be homogeneously.

According to the precipitation change outputs of the RCP4.5 scenario, in Figure4.38, which is run with global climate model MPI-ESM-MR, mean precipitation change will be decrease up to 0.9 mm/day in fall season. Moreover, as it is shown in Figure 4.39, winter and spring seasons' rate of decrease is almost the same.

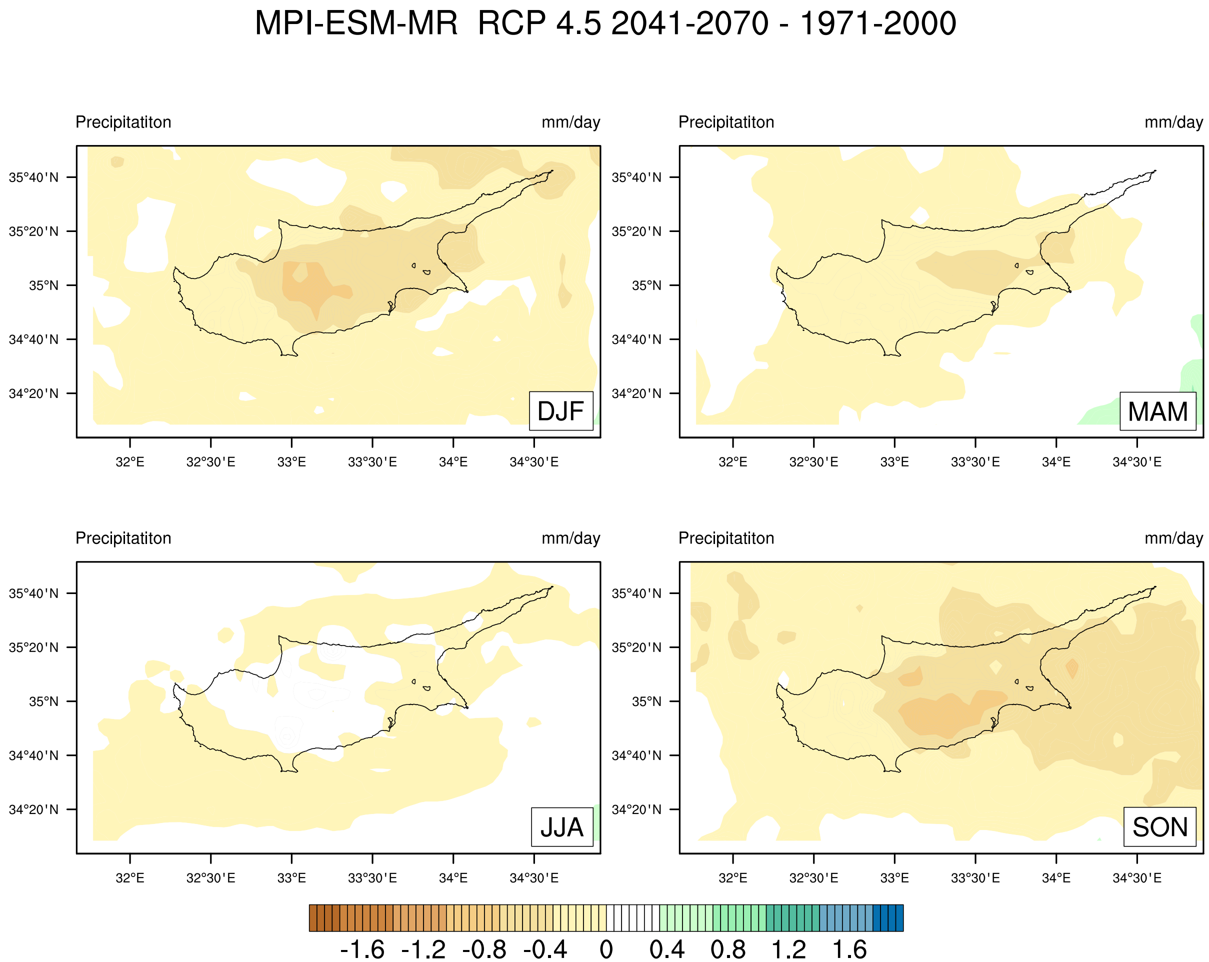

Figure 4.35: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP4.5 scenario in the future, 2041-2070 time period, which is respected to reference time interval 1971-2000

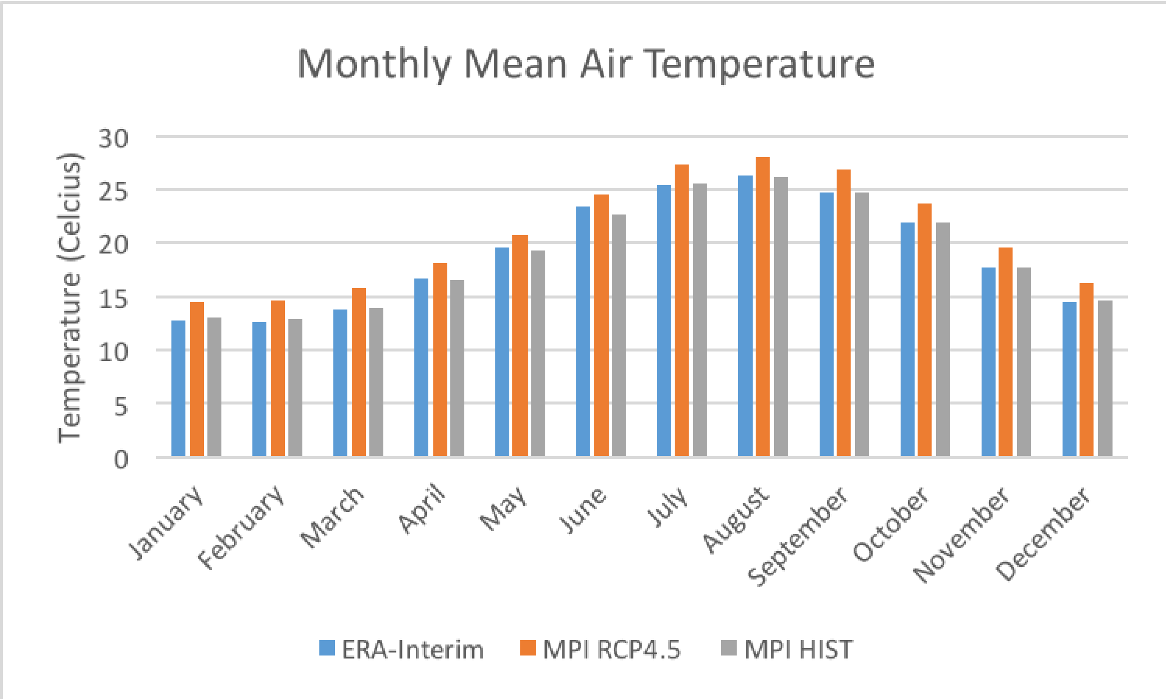

Figure 4.36: Monthly mean air Temperature projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP4.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

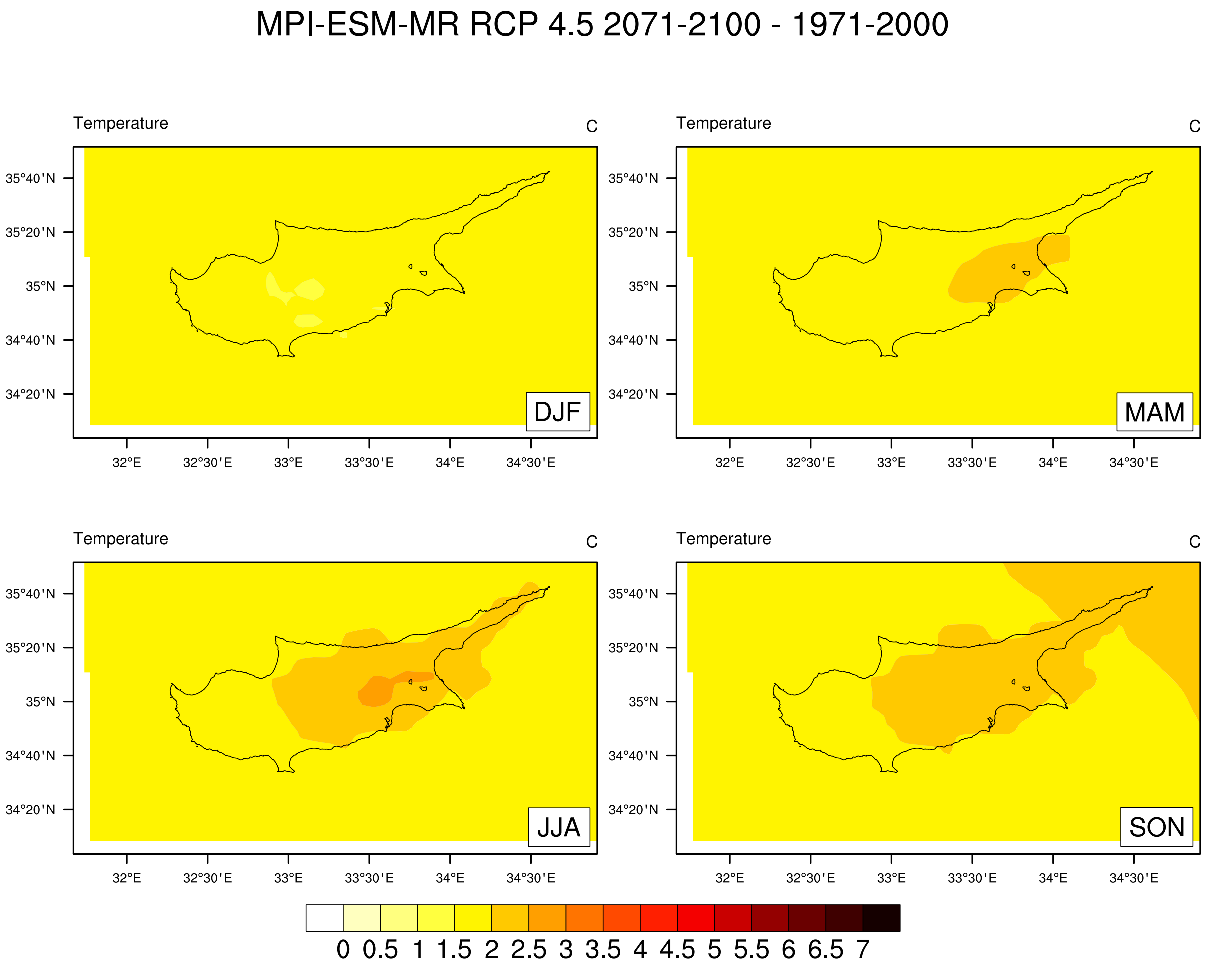

Figure 4.37: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP4.5 scenario in the future, 2071-2100 time period, which is respect to reference time interval 1971-2000

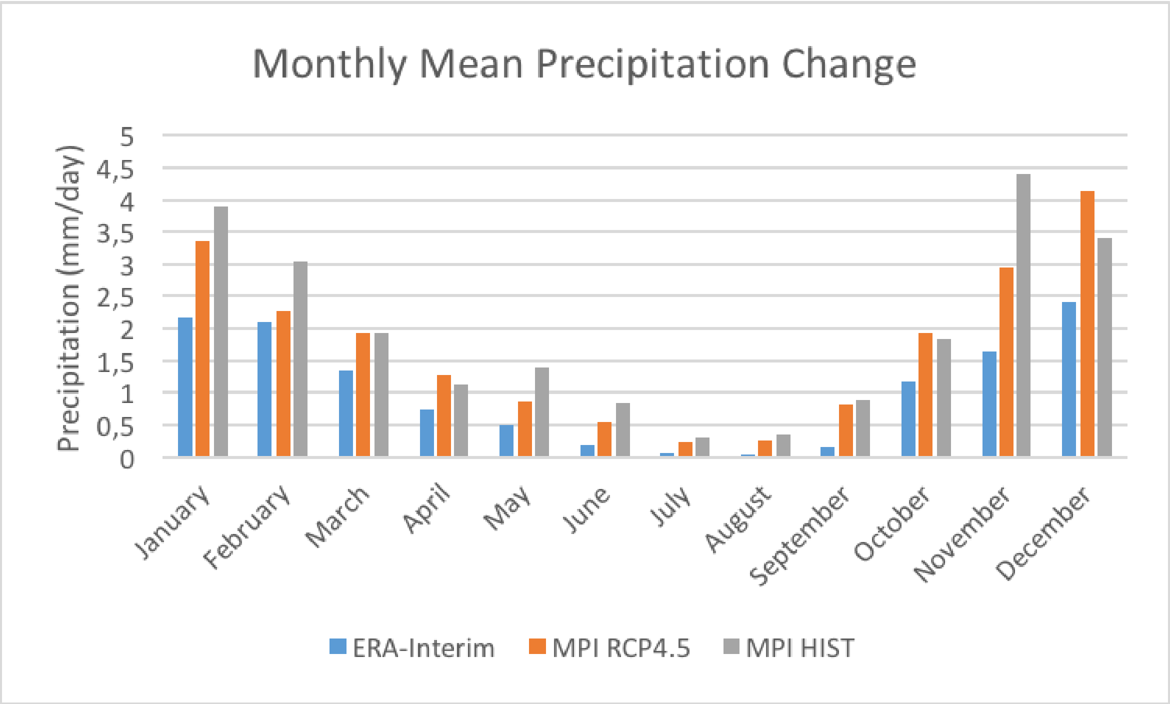

Figure 4.38: Monthly Average Precipitation projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP4.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

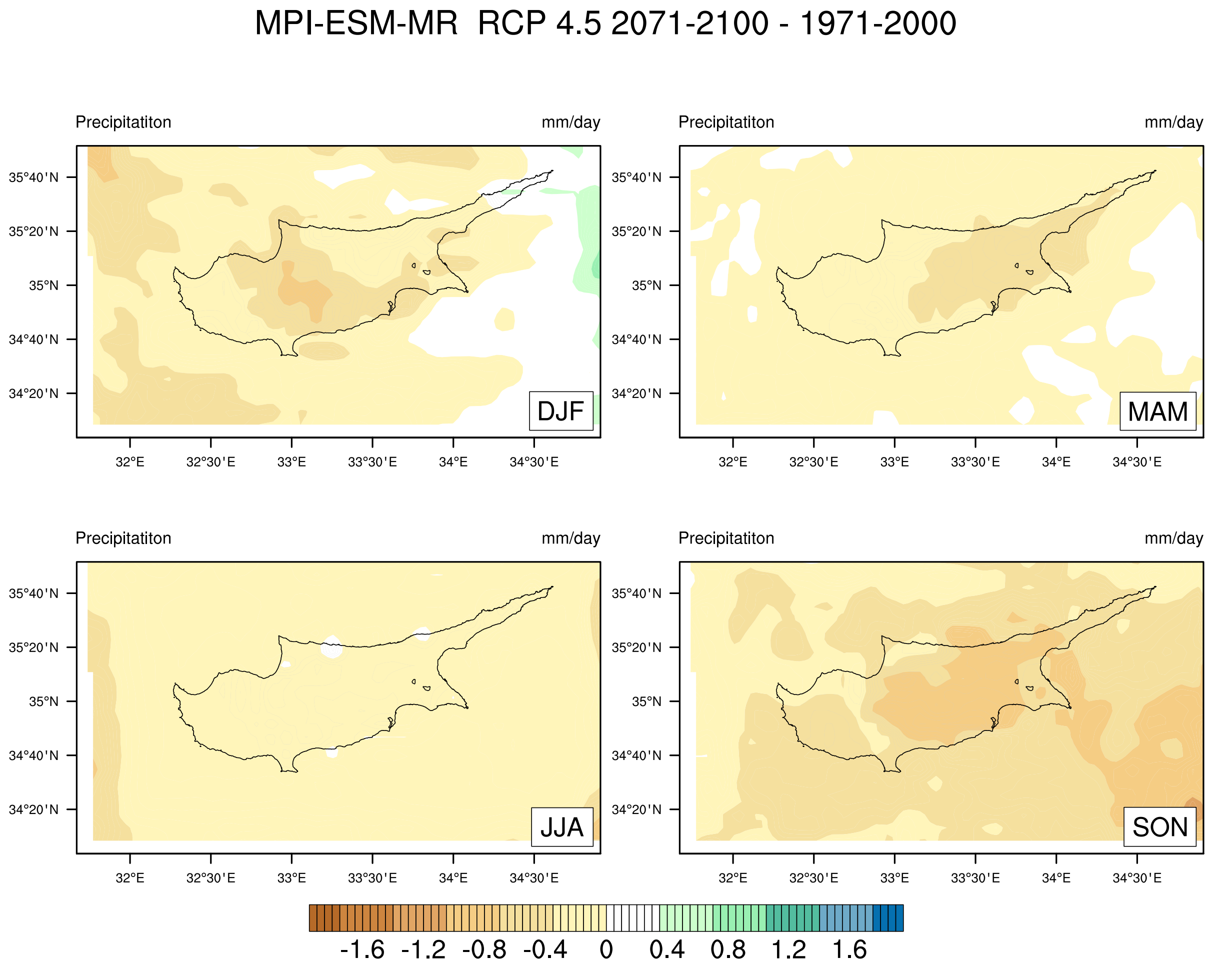

Figure 4.39: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP4.5 scenario in the future, 2071-2100 time period, which is respected to reference time interval 1971-2000

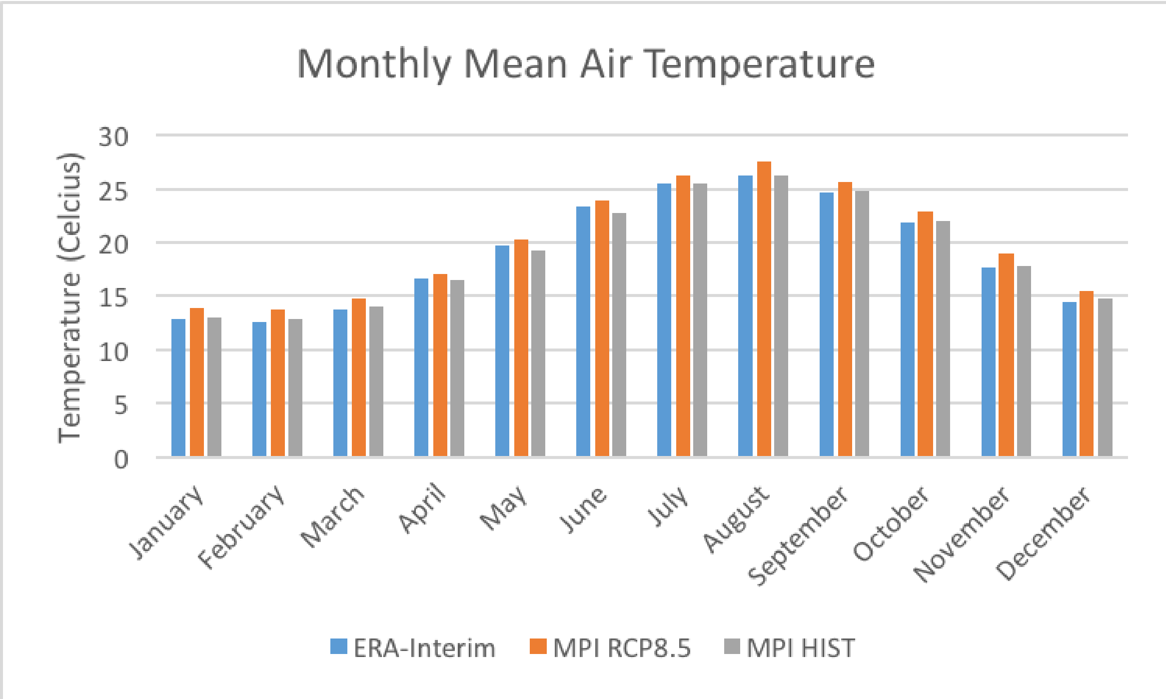

Figure 4.40: Monthly mean air Temperature projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP8.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

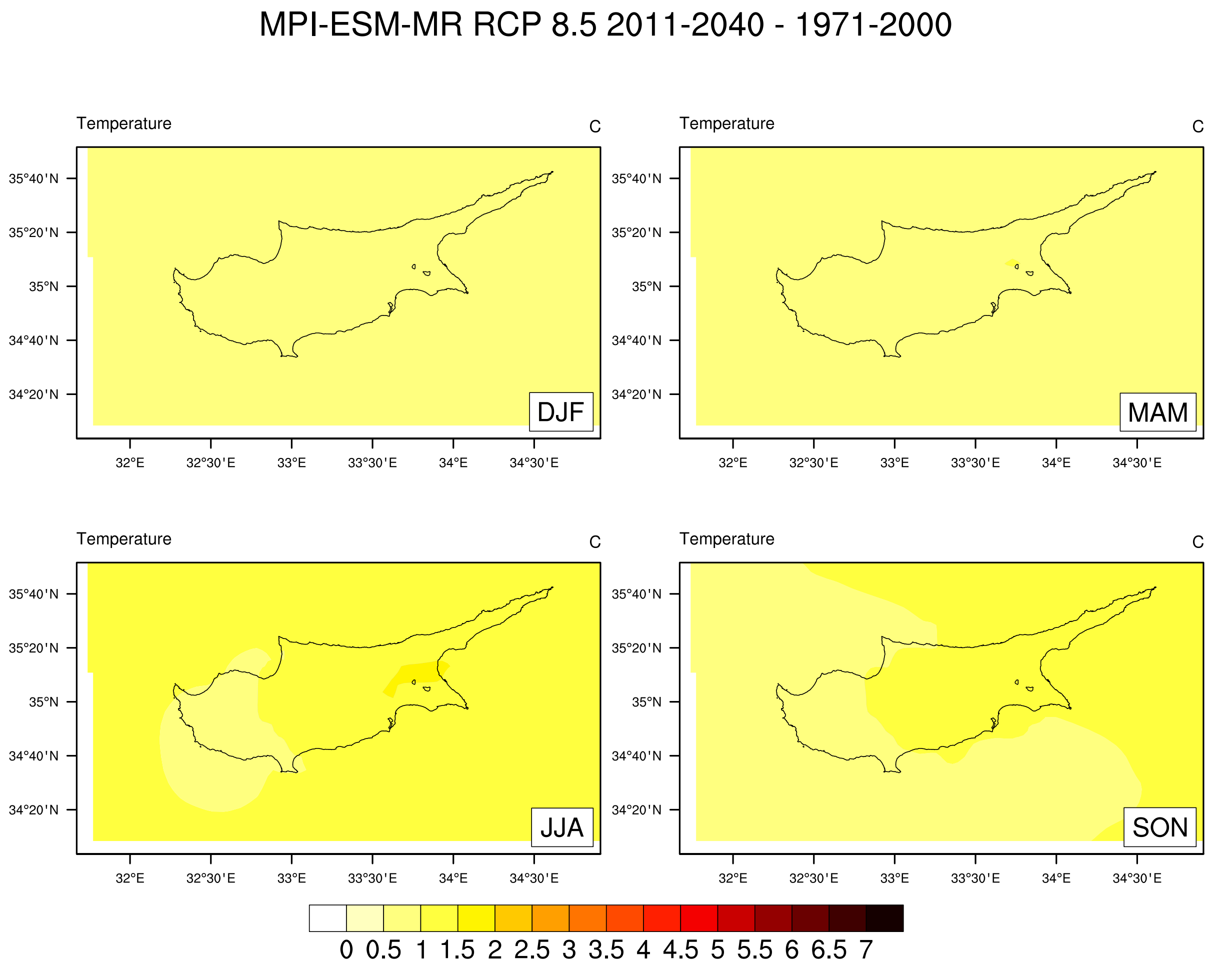

Figure 4.41: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP8.5 scenario in the future, 2011-2040 time period, which is respect to reference time interval 1971-2000

If we examine the results of scenario RCP8.5, of course the results are worse than RCP4.5. When we look at the first time period between 2011 and 2040 (Figure 4.40 and Figure 4.42), air surface temperature and mean precipitation changes are less than other time intervals.

Outputs of the RegCM for the second time period of 2041-2070 is represented in Figure 4.44.Especially temperature rise will be on July and August. Also, as it is shown in the Figure 4.45, the air temperature rise will be homogeneous in region and will be 2°C except the winter season respect to the reference time period.

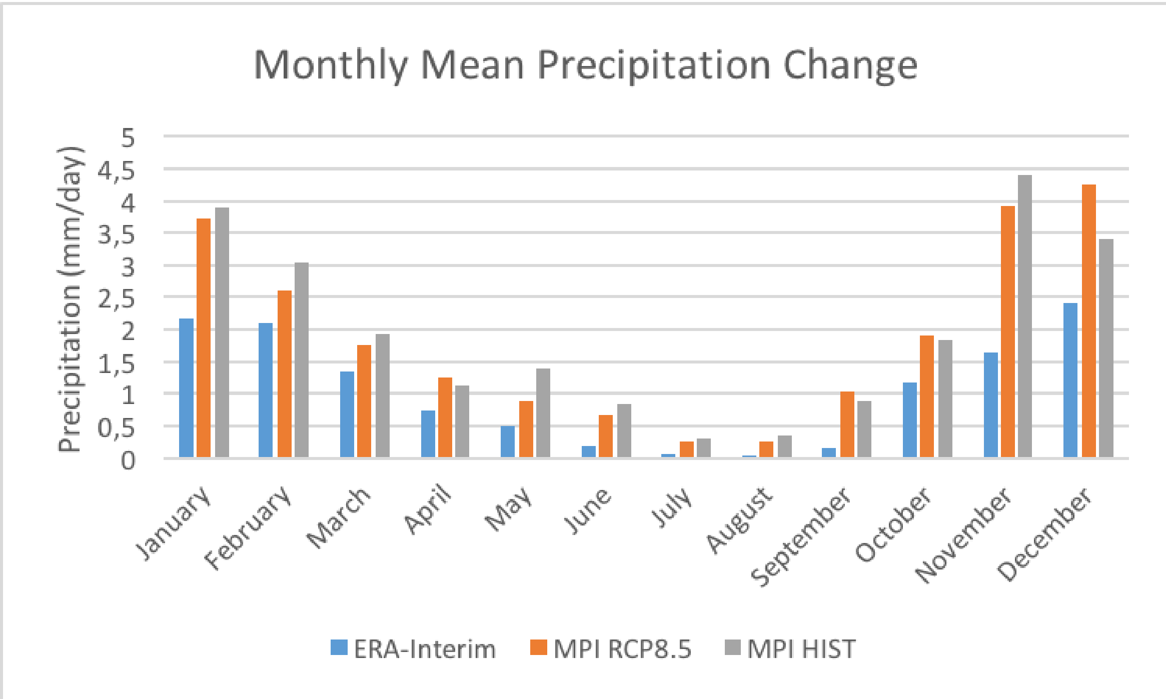

Figure 4.42: Monthly Average Precipitation projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP8.5 scenario data for the period 2011-2040 with respect to the reference time period 1971-2000

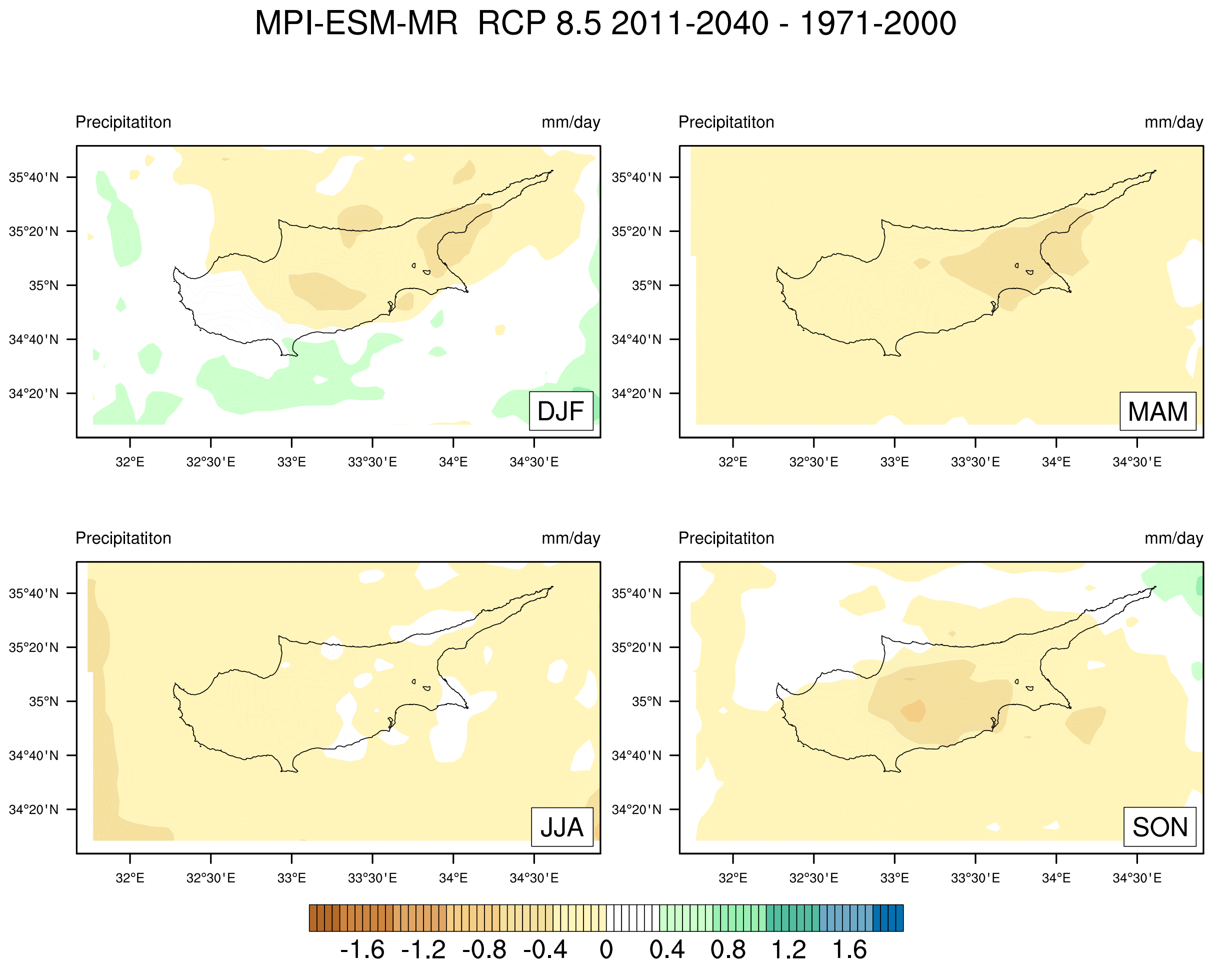

Figure 4.43: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP8.5 scenario in the future, 2011-2040 time period, which is respected to reference time interval 1971-2000

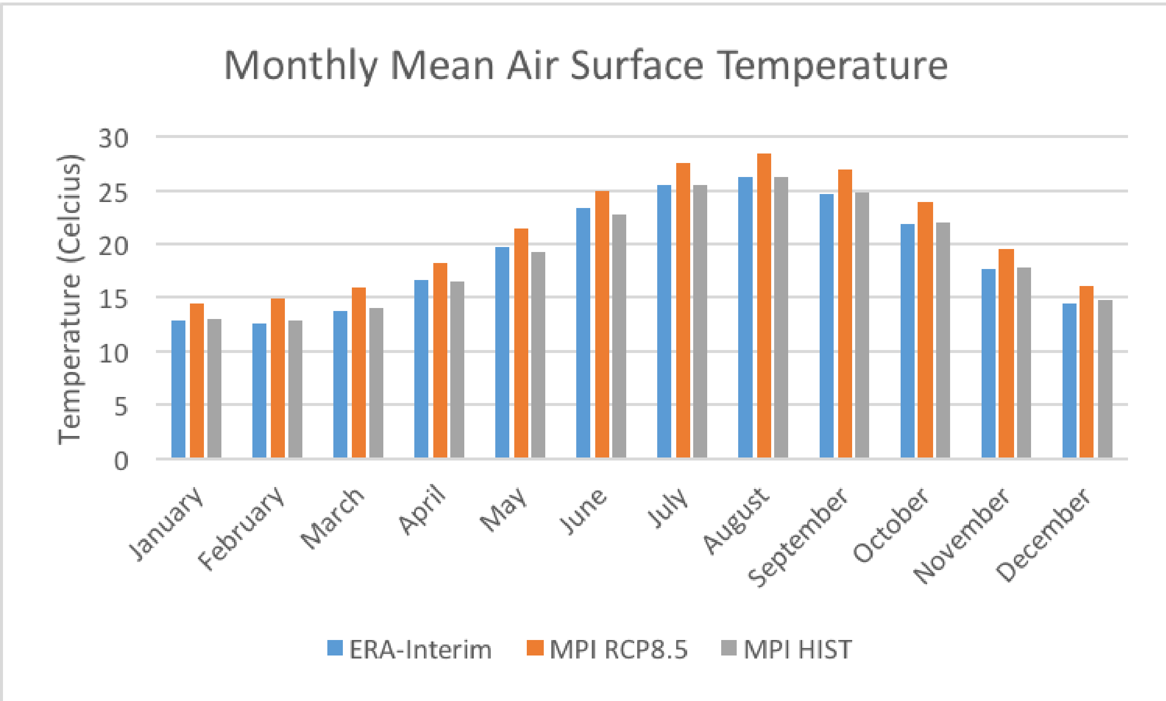

Figure 4.44: Monthly mean air Temperature projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP8.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

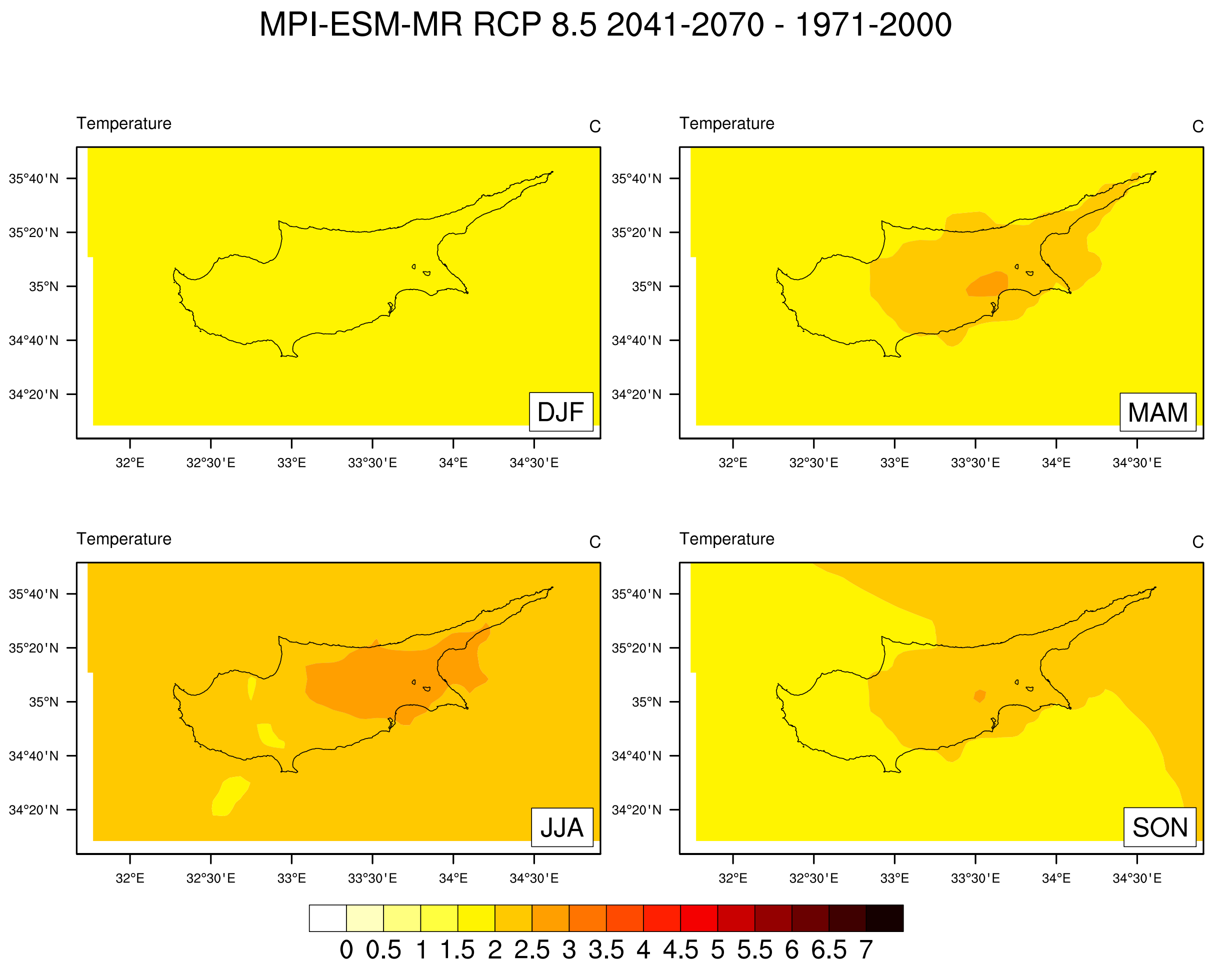

Figure 4.45: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP8.5 scenario in the future, 2041-2070 time period, which is respect to reference time interval 1971-2000

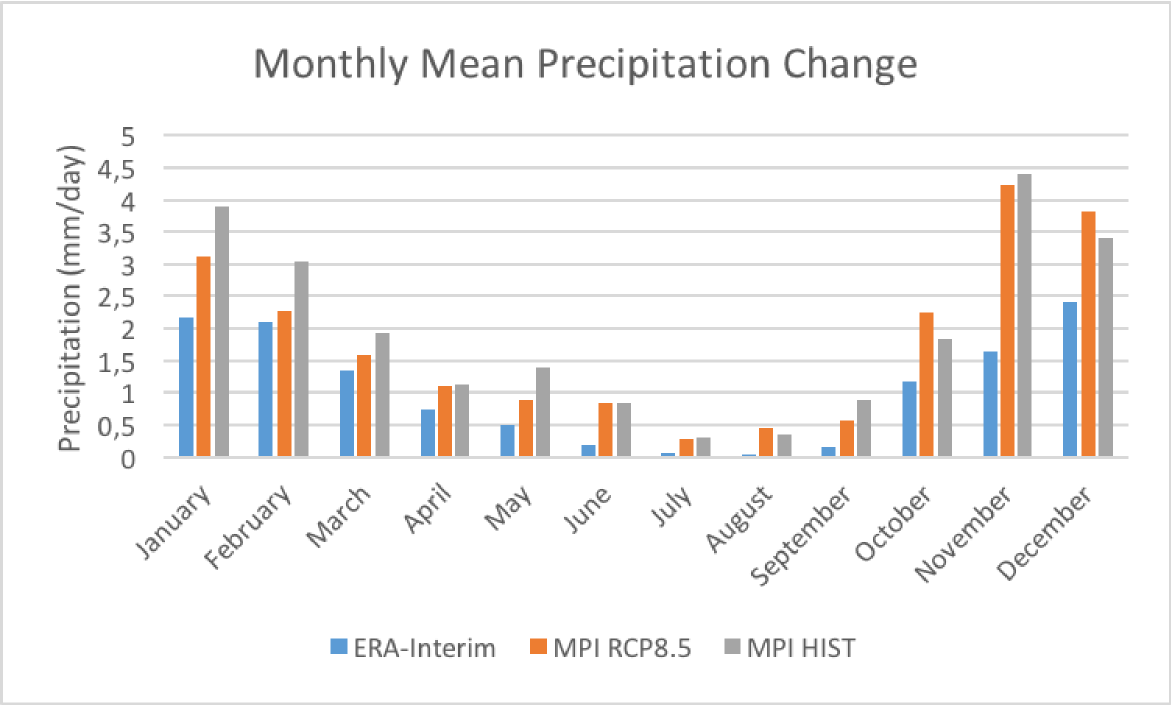

Figure 4.46: Monthly Average Precipitation projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP8.5 scenario data for the period 2041-2070 with respect to the reference time period 1971-2000

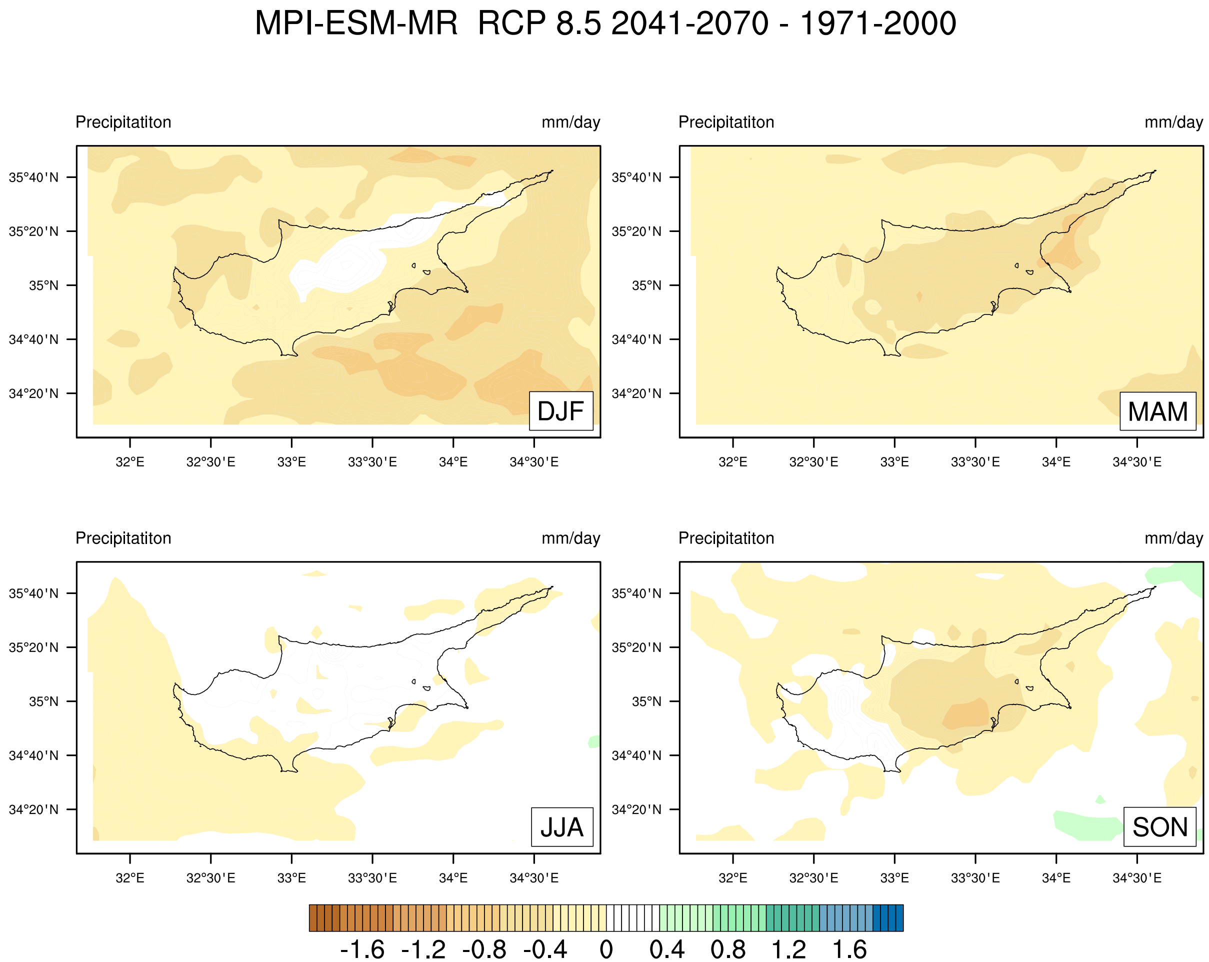

Figure 4.47: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP8.5 scenario in the future, 2041-2070 time period, which is respected to reference time interval 1971-2000

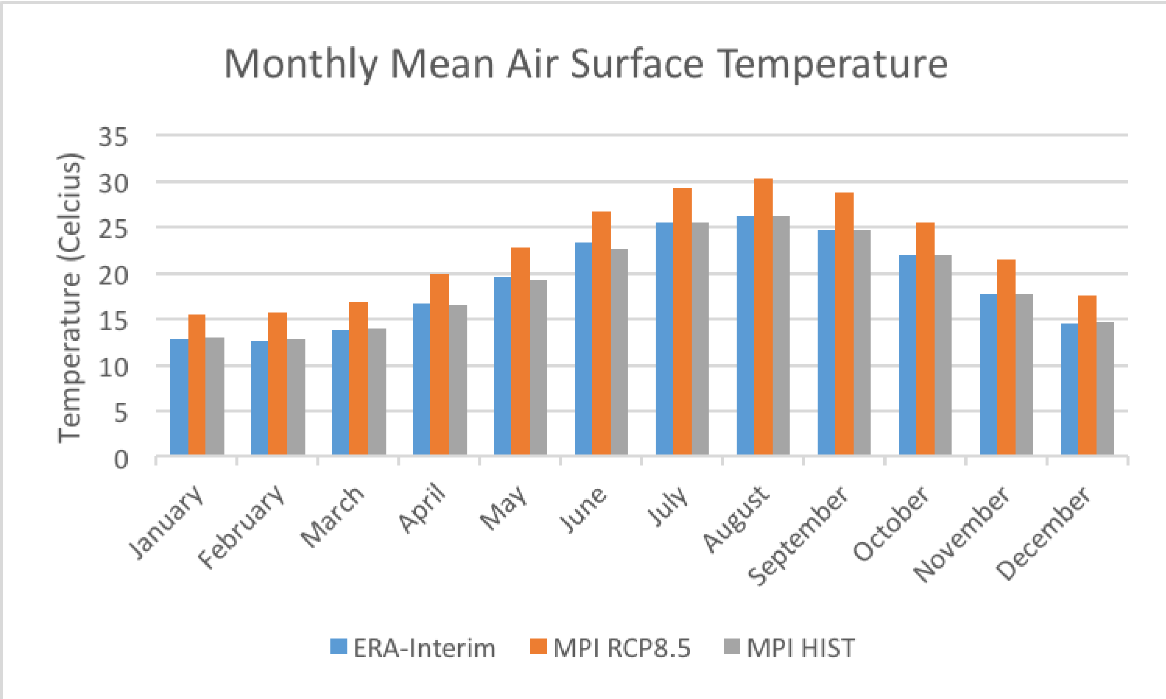

Figure 4.48: Monthly mean air Temperature projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP8.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

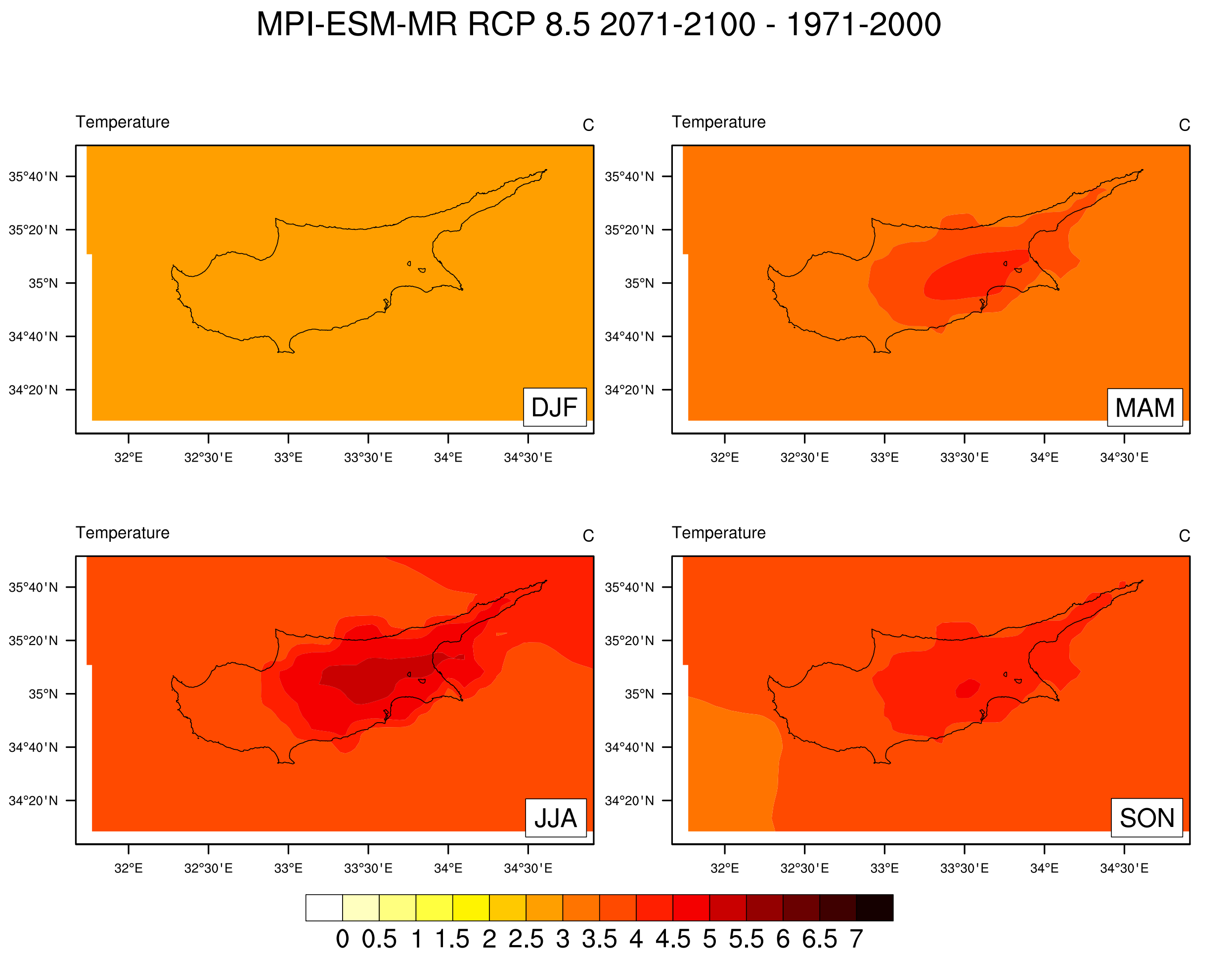

Figure 4.49: Range of the projected mean air temperature difference over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP8.5 scenario in the future, 2071-2100 time period, which is respect to reference time interval 1971-2000

The third time interval (2071-2100) outputs are the severe ones (in Figure 4.49). The projected air temperature increase goes up to 6°C in summer months particularly in the middle of the island region. As it is seen in Figure 4.50, the same region seems to under danger of drought in winter and fall seasons because of the mean precipitation decrease up to 1.5 mm/day.

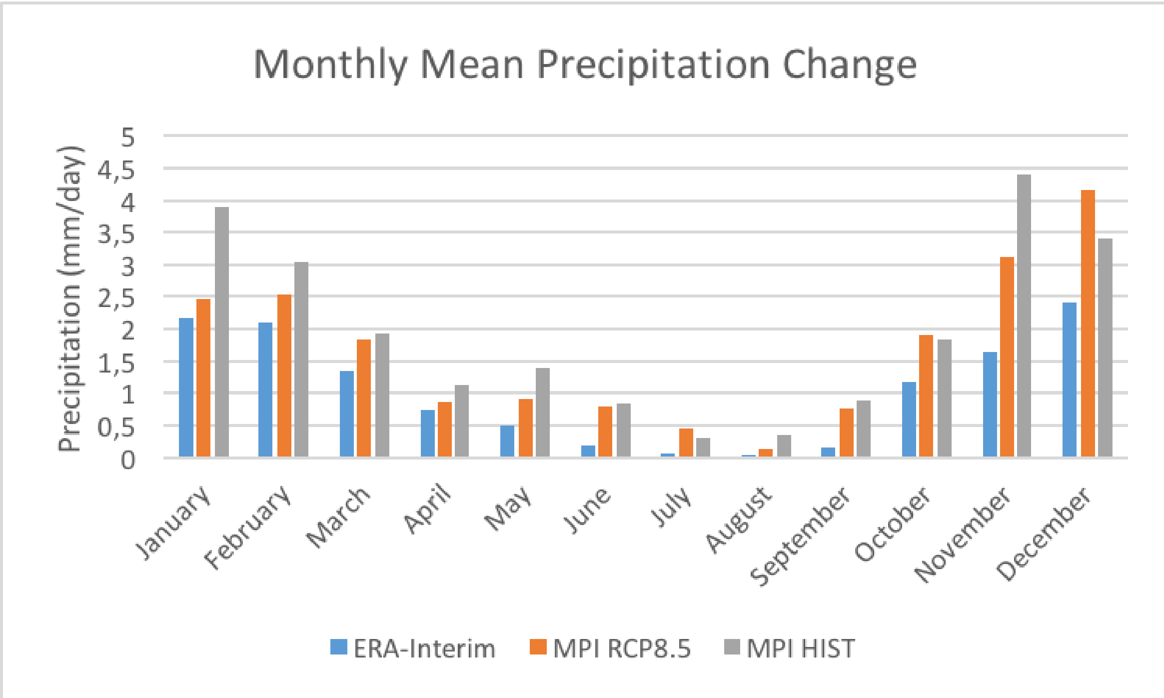

Figure 4.50: Monthly Average Precipitation projection from RegCM4.4 by forcing MPI-ESM-MR according to RCP8.5 scenario data for the period 2071-2100 with respect to the reference time period 1971-2000

Figure 4.51 shows that this precipitation deplete will be severe particularly in winter and spring seasons. Moreover, middle region of the island may suffer from drought.

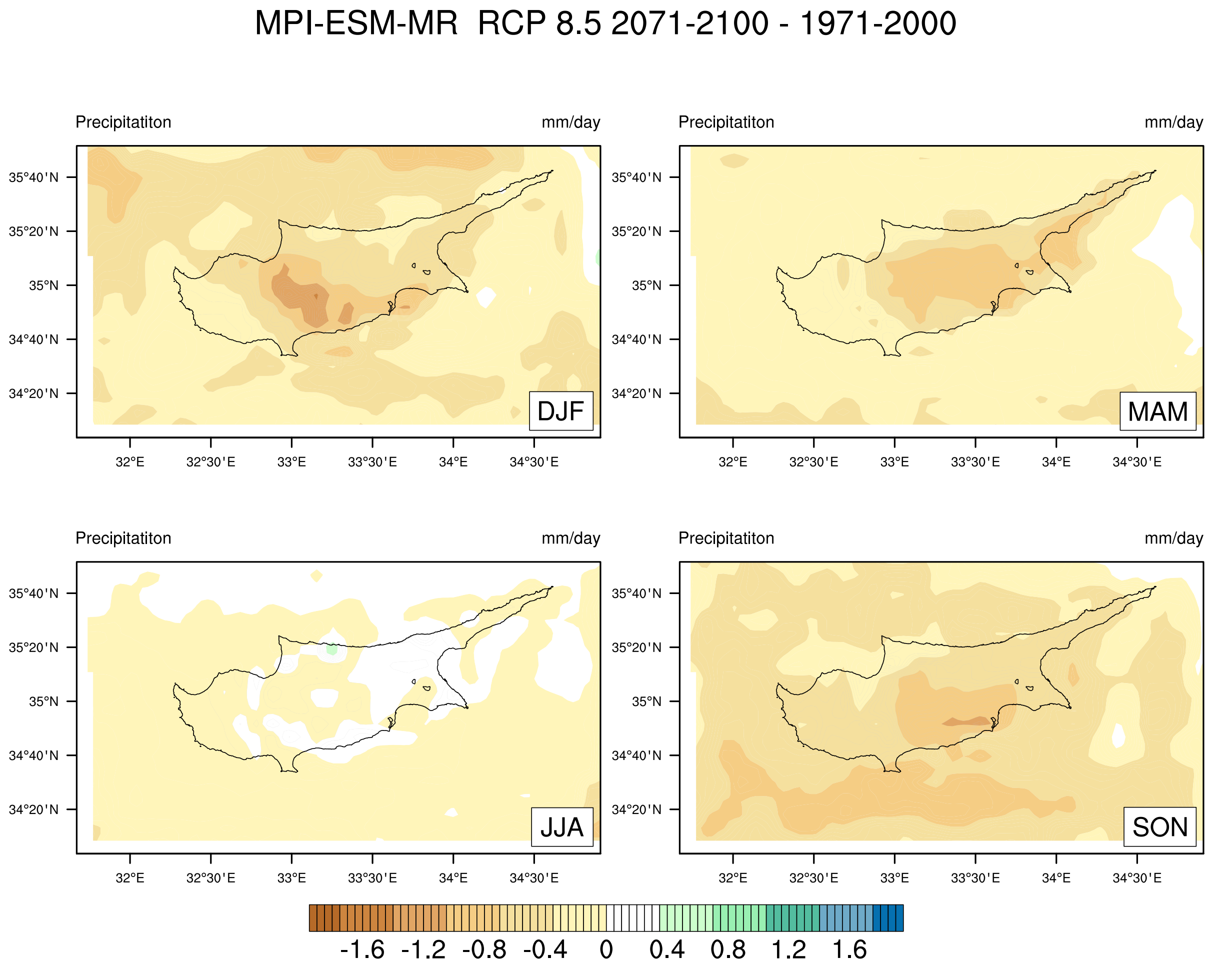

Figure 4.51: The difference of the projected average precipitation over the Cyprus region. Outputs of the regional climate model, RegCM4.4, run by MPI-ESM-MR Global Climate Model with RCP8.5 scenario in the future, 2071-2100 time period, which is respected to reference time interval 1971-2000

5. CONCLUSION

In this research, we projected the future climate forecasts. Our model took into account different parameters as solar radiation, thermal radiation, density, motion and composition. Moreover, global forecasting parameters are wind velocity, humidity, temperature and pressure.

In this study we used the outputs of the global climate models HadGEM2 and MPI-ESM-MR as an input file of the Regional Climate model (RegCM) and investigated in two different case scenario RCP4.5 and RCP8.5. Also, we divided the time intervals into 29-year period so that we could see the seasonal differences respect to the reference time interval 1970-2000.

A minimum increase of 1°C is observed even in RCP4.5 case, on the other hand results of the RCP8.5 show that the temperature rise will go up to 6°C. Furthermore, precipitation pattern changes can be seen in both scenarios and both of global climate model outputs. Running this region at one km resolution can be much more illuminating to observe changes in more detail. By using double-nested method, we got the ten km resolution output from the fifty km resolution model output.

Ten km resolution regional climate simulations showed that the air surface temperature will increase at least 1°C in every region of the island, in every scenario case. The case of precipitation results carry another risk. There may be under the flood risk in the future. There is a significant increase in rainfall, in autumn and winter months especially, according to model outputs. Projecting the extreme events such as consecutive dry days or consecutive heavy raining days can be very useful for Cyprus region.

Initial boundary conditions and regional climate parameters are taken into account according to the Mediterranean basin. As it represented IPCC's AR5 Synthesis Report, Mediterranean region is not resilient enough and the vulnerability of Mediterranean basin will increase and climate will change in the coming years. Our model outputs showed the almost same results, severe air temperature increase and heavy rainfall in winter, drought in summer months will affect the quality islander's.

Cyprus is an island country located in the eastern Mediterranean region and it is a very important island region from the geopolitical point of view. When the importance of this island ecologically and politically is taken into account, projecting the future climate extremes of this region plays a crucial role. It is very informative about what precautions should be taken. Not only because of including two different nations, but also the climate of the island plays a key role in tourism, which is the biggest source of livelihood of the island.

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