Evapotranspiration projections in Austria under different climate change scenarios

EnvEuro Master's thesis

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Abstract

Evapotranspiration (ET) is one of the most relevant components in the water cycle and known to be defined by a wide variety of local and seasonal biophysical factors, vulnerable to climate change. The present study aims to broaden the knowledge of potential evapotranspiration (ETp) in Austria, through geographical representations of evapotranspiration and water balance for historical and future periods. Raster ETp data from observations (2003-2015) and three different climate models (for the periods: 1981-2010, 2036-2065 and 2071-2100) were calculated by the Penman-Monteith formula, and further treated with Geographical Information Software (ArcGIS) to produce figures representing the changing situation. One model represents the mean climate signal out of 13 different regional climate models forced with RCP4.5 emission scenarios and the other two for the RCP8.5 scenario, representing the mean and an extreme situation out of 13 models. Results show that elevation has an important influence on ETp due to its relation to climatological parameters. ETp is found to be higher with lower humidity levels and warmer temperature, then, eastern and southern regions of Austria (Pannonian and Illyrian climates) show the highest values of ETp (~900mm), whereas lower values are found in the north (Atlantic climate) and the mountains (Alpine climate). Climate change effects are studied and higher ETp values were found for all models by the end of the century. These outcomes show that climate signals (between 1981 and 2100) display a 6.8% increase for the mean RCP4.5, 12.6% for mean RCP8.5 and 25.3% for the extreme RCP8.5 scenario. For the mean models, a greater increase of ETp was found in the lower altitudes (Lower Austria, Vienna and Burgenland) where temperatures would increase the most. However, a completely different distribution is seen for the extreme case, where ETp raises the most at higher elevations. The major changing factors of ETp were further analyzed, and the greatest changes were found for temperature and precipitation. Water balance is also considered, and outcomes manifest that water deficit would potentially be stressed in all climate change scenarios, but especially for the extreme RCP8.5 for which precipitation drastically decreases during summer by the end of the century. Although being specific for Austria, this project aims to portray the relevance of the local effects of climate change in ETp -directly affecting agriculture, land use and water supply- and it aims to inspire international evapotranspiration assessment to motivate further development of mitigation/adaptation solutions and better water management.

Key words:

Evapotranspiration, Potential Evapotranspiration, Penman-Monteith, Water Balance, Climate Change, Climate models, Drought, Austria, Alps, Europe.

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1. Introduction

The late 1800's industrial revolution triggered the massive emission of CO_2 that, acting as a greenhouse gas (GHG), has accumulated in the atmosphere and influenced the Earth's radiative forcing towards an increase since. Over 100 years the global average surface temperature has warmed up by approximately 0.7ºC (Kelemen et al., 2009), and for Austria temperatures have risen close to 2ºC since 1880 and most of this warming has happened in the last 30 years. Moreover, a national increase of 3-5ºC by the end of the 21th century is expected if no action is taken (Austrian Panel on Climate Change, 2014).

Climate change, is one of the main challenges of our current society as stated in the United Nations Sustainable Development Goals (SDGs) (United Nations, 2015). However, the issue is complex to tackle, because despite being a global problem, impacts are not homogeneous throughout the territory and it makes it difficult to coordinate collective action. Such impacts would depend on the magnitude, exposure and ability to adapt of the systems (Kelemen et al., 2009).

Evapotranspiration is a complex mechanism influencing the water cycle, which is dependent on climatological factors, and conditions the availability of water from the soil. Therefore, it is relevant to consider how changes in climate might affect this variable so that assessment of risks in sectors dependent on weather, such as agriculture, can be done. Then, getting to know the global warming's impacts on the hydrological cycle is not only important for water management but also management of forests and agricultural ecosystems (Calanca, Roesch, Jasper, & Wild, 2006).

This study aims to assess the potential impact of evapotranspiration with climate change in the site of interest, to see which are the most relevant factors influencing the potential of the soil to lose water, and how this will vary depending on two different emission pathways considering three scenarios.

Objectives

The purpose of the present work is to estimate the main characteristics that determine the distribution of evapotranspiration in Austria; assess the regional impacts of climate change in evapotranspiration and water balance for the three different scenarios studied; consider the influence of the Alps in the regional climate; and evaluate which can be the main influencing factors triggering such changes in evapotranspiration with expected climate change.

Relevance

Evapotranspiration is of great importance when managing water. Hence, a better understanding of the implications of this potential impact could increase the capacity of adaptation of the region, help save water, as well as, preserve food security and sovereignty for the future.

This project is framed in the context of Europe and is aimed also to be of use for other countries. Nevertheless, the outcomes of the work are of direct significance for policy-makers or development-planners in Austria.

1.1. Evapotranspiration

The combined process of water loss from the soil surface through evaporation and from the plant canopy through transpiration, is addressed as evapotranspiration (ET).

Evaporation consists in the removal of water from a surface by the conversion of liquid water into water vapor. This process is directly bound to climatological parameters such as solar radiation, air temperature, air humidity and wind speed (Allen, Pereira, Raes, & Smith, 1998b).

Transpiration is a concept that explains the loss of water through the plants' stomata. Physical parameters like radiation, temperature, humidity and wind, as well as evaporation, affect transpiration. However, since it is a physiological process it also depends on the soil water content, the ability of the soil to conduct water to the roots, crop characteristics, environmental aspects and cultivation practices (Allen et al., 1998b). Surface air temperature seems to be the atmospheric parameter that influences transpiration the most, strongly related to solar radiation (Thornthwaite & Mather, 1951).

Evapotranspiration, then, is the flow of water and latent heat energy returning to the atmosphere (Oki & Kim, 2016). This process, considered to be the reverse of precipitation, is a key factor to determine the water balance of a watershed (Oki & Kim, 2016; Thornthwaite & Mather, 1951). Precipitation and evapotranspiration are both important factors for climate, but they are not dependant on the same meteorological variables and thus do not share the same distribution throughout the year (Thornthwaite & Mather, 1951). That means that in some months not all rainfall might be transferred back to the atmosphere with evapotranspiration, but become a surplus in form of groundwater recharge or runoff. On the other hand, other months may present higher evapotranspiration than precipitation, possibly triggering a drought situation. The month of maximum ETp in Europe coincides in July, according to Thornthwaite & Mather (1951).

The rate at which ET occurs depends on four things: climate, soil moisture supply, plant cover, and land management; being the two first the most important ones (Thornthwaite & Mather, 1951).

Considering the meteorological factors determining ETp, radiation is the limiting one since it restricts how much energy is available for the vaporization of water. Together with air temperature, radiation is the main driving force of ETp, whilst air humidity and wind speed are the factors determining the rate at which vapor would be removed (Abtew, 1996; Richard G Allen, Pereira, Raes, & Smith, 1998c).

Humidity represents the vapor content of air and it lowers the rate of ETp from a surface, the higher it is (Abtew & Melesse, 2013). A way of expressing humidity is through *vapor pressure*, that is a measure of partial pressure applied by water vapor molecules in the air. This is relevant since the vapor gradient between two environments define how fast the process will be performed, in that transport of molecules from one to the other will be stronger the bigger the gradient is and will get weaker the closest it gets to an equilibrium state of water vapor pressure (Oke, 1978).

The pressure at which the air saturates is called saturation vapor pressure (SVP), and depends on temperature, logarithmically increasing with it (see **Figure 1**). Considering that temperature would be kept constant, the amount of water vapor needed to reach the saturation point is called *vapor pressure deficit.* This concept is of relevance since it represents the "drying power of air" relative to a saturated surface, like a leaf or pond. Considering same temperature for both environments, the bigger the deficit the bigger the vapor gradient will be (Oke, 1978).

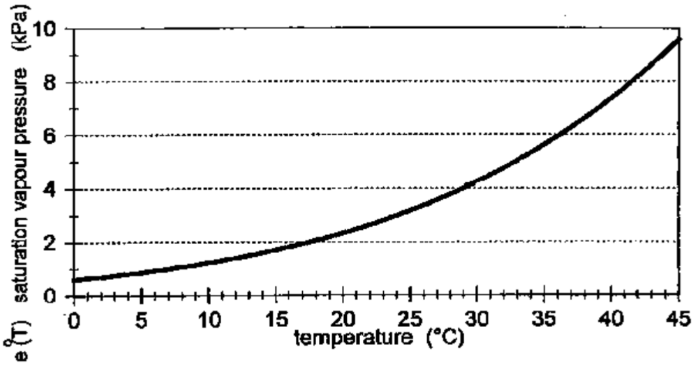

Figure 1 - Saturation vapor pressure curve (Allen et al., 1998c).

Wind leverages ETp by removing vapor saturated air from above the evaporating surface thus increasing, in conditions of a dry environment, the vapor pressure gradient and rising the evapotranspiration rate (Allen et al., 1998c).

It has been extensively said in the scientific community that climate change is expected to modify the global water cycle, both by affecting precipitation and the rate of evapotranspiration, impacting regional water demand and availability (Wada, 2008). This makes it relevant to consider evapotranspiration projections for different future scenarios, not only for ecological purposes but also social. Agricultural production could be heavily affected by ETp, especially in the views of a possible future where food demand increases, and better planning in irrigation could play a crucial role when attempting to reach food security for all (Oki, 2006). Crop yields can be influenced by good water management, then, a better understanding of crop evapotranspiration is of relevance (Hargreaves & Allen, 2003). Estimating ET can be a first important step to calculate crop water requirements for good rationalization of water consumption in future conditions (Khalil, 2013).

Since both processes, evaporation and transpiration, happen simultaneously, it is a complex task to distinguish between them (Allen et al., 1998b; Zotarelli, Dukes, Romero, Migliaccio, & Morgan, 2010). Evaporation, which mainly depends on physical characteristics can be quite accurately estimated, however, transpiration is different depending on the type of plant. That makes it difficult to homogenize ET results for a whole area.

Despite precipitation and ET being quite closely related, they have both been studied by two different scientific communities. On the one hand, precipitation has been broadly studied by meteorologists due to its physical nature. On the other hand, ET has been developed generally by biologists for it is driven by plant physiology (Thornthwaite & Mather, 1951). Studies have been carried out in the US since early 1900s, but the complexity of the process is still evolving nowadays with the introduction of new measurement technologies (Hargreaves & Allen, 2003; Jensen, Burmann, & Allen, 1990). ET has been attempted to be measured through many different techniques, like the measuring of vapor transfer, water soil moisture change, etc. (Thornthwaite & Mather, 1951). However, nowadays one of the most widely accepted methods is the usage of the Penman-Monteith equation, the one adopted for the present work (see sections 1.1.1. and 2.2.).

In an attempt of understanding such a complex process, ET definitions were made to simplify the concept. Actual evapotranspiration (ETa), potential evapotranspiration (ETp) and reference evapotranspiration (ETo) are some of the most commonly used definitions:

Actual evapotranspiration

ETa is the closest-to-reality term used in the literature, for it is considered to be the actual evapotranspiration of a specified crop at a designed time, and the soil water content is taken into consideration (Burman & Pochop, 1994).

Potential evapotranspiration

ETp is a term that has been used for a considerable period of time, since mid-1900 (Burman & Pochop, 1994; Irmak & Haman, 2014), and according to Burman & Pochop (1994) is the rate of ET that can occur in case all soil and plant surfaces are well supplied with water; as long as plants are not limited by diseases or fertility. Since ETp depends only on climatic conditions, it does not represent the real transfer of water to the atmosphere but the possible one in ideal conditions of soil moisture and vegetation (Thornthwaite & Mather, 1951). Both potential and reference ET were defined with the objective to eliminate the crop specific changes in the evapotranspiration process (Irmak & Haman, 2014), however, ETp is usually considered to be ambiguous (Allen et al., 1998b). For this reason, in this project ETp is be understood the same way as ETo, defined in the FAO guidelines, where the Penman-Monteith equation is explained (see section 2.2.) (Allen, Pereira, Raes, & Smith, 1998a).

Reference evapotranspiration

ETo is a similar term to the ETp but applied to an identifiable reference crop, usually alfalfa or grass (Burman & Pochop, 1994). For the usage of the Penman-Monteith equation, such reference crop is assumed to have a height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23. It is assumed that the crop completely shades the ground and closely resembles a surface of actively growing green, well-watered grass of uniform height (Allen et al., 1998a). A schematic representation of the variable is represented in **Figure 2**.

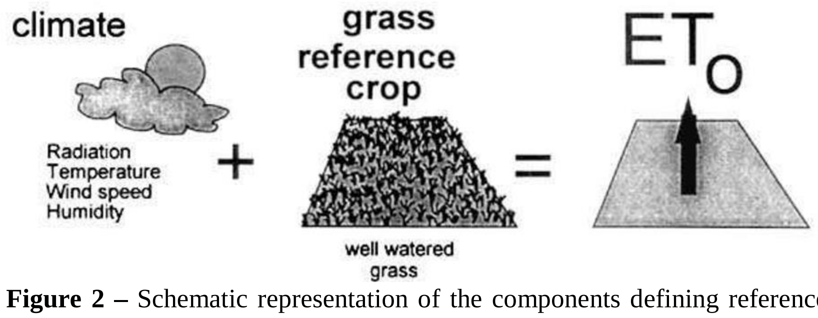

Figure 2 – Schematic representation of the components defining reference evapotranspiration, ETo (Allen et al., 1998b).

1.1.1. Evapotranspiration determination

Evapotranspiration can be either measured directly, by empirically estimating values from pan evaporation, or by computing the numbers from meteorological data. However, ET is not an easy parameter to directly measure, since specific and accurate devices are needed to quantify all the physical parameters (of energy balance or soil water balance), and those are usually costly (Allen et al., 1998b).

Empirical estimation of ET is commonly done from pan evaporation methods, which consist in measuring the water loss of a vessel containing water. Since such evaporation is induced by the physical factors of the surrounding environment, the monitored environmental conditions can be used to locally calculate ET.

Moreover, ET is widely computed from weather data. After many years of worldwide research, the Food and Agricultural Organisation (FAO) organised a consultation of experts, together with the International Commission of Irrigation and Drainage and the World Meteorological Organization (WMO) to review methodologies. From that consultation, a consensus was made with the selection of the Penman-Monteith equation, which allows it to calculate an ETo value from weather data. The method was selected because it provides the most consistent ETo results for all regions and climates (Allen et al., 1998a).

For the present work, estimation of ET has been done by means of computed meteorological data and the application of the FAO Penman-Monteith equation (as seen in section 2.2.).

1.1.2. Effects of Climate Change on ETp

Climate change is widely acknowledged and expected to intensify the water cycle (Huntington, 2006), however, its effects in evapotranspiration have not still been conclusive due to the complexity of quantification and lack of research (Abtew & Melesse, 2013; Serrat-capdevila, Scott, Shuttleworth, & Valdés, 2011).

As stated by Abtew & Melesse (2013), ET increases with rising temperature, more radiation, decreasing humidity and increase of wind speed. Therefore, lower precipitation will contribute to an increase of ET, as that would mean less cloud cover which, in turn, would increase radiation and temperature, while lowering humidity.

ET represents the amount of water lost by a surface into the atmosphere, thus it affects the moisture factor of the environment and is a parameter related to drought. The IPCC considers drought to be one of the impacts of recent climate-related extremes, posing an important threat to ecosystems and human systems (IPCC, 2014). Therefore, a better understanding of ET has the potential to enable us to avoid drought (Thornthwaite & Mather, 1951), as it is also a key component in the widely used Palmer Drought Severity Index (PDSI) for estimation of dryness (Rind, Goldberg, Hansen, Rosenzweig, & Ruedy, 1990). Some studies have been made to find out that there is an increased likelihood of drought as climate warms (IPCC WG I, 2013b). And as recently published in Nature, an extended increase in estimates of ETp, due to global warming, contribute to drying processes (Milly & Dunne, 2016).

Further research on hydrologic and phenological processes (relation between climate and periodical biological phenomena) suggests that the growing season has already enlengthened substantially in humid regions, which also implies an affection in ET (Huntington, 2006). Some studies explain that in mid-latitudes and some subtropical regions, runoff could decrease, possibly due to an increase in ET that would outweigh the precipitation rise (Huntington, 2006). Also, others state that ET will not increase as much as global precipitation due to the higher CO_2 concentration leading to stomata closure, reducing like this the transpiration rate (Oki, 2006).

One of the most relevant issues to consider in future scenarios is that the SVP, or water-holding capacity of the atmosphere, is directly affected by temperature as seen in **Figure 1** (Rind et al., 1990). Therefore, the water-holding capacity is likely to increase as air temperature rises due to global warming, triggering an increment of vapor gradient thus greater ETp.

Affections on ET are not just relevant for purely water supply issues but the water cycle in general. The influence of water vapor on the energy balances could lead to the overheating of the land and to a stronger increase in temperatures (Novák, 2005).

Conclusively, future climate change projections in the sight of global warming might have heavy implications on ET, which affects the water cycle, and would pose a potential threat of drought for some regions of the globe. However, ET is a difficult parameter to study and more research should be addressed to acknowledge what specific implications that might have in the future.

1.2. Study site: Austria

Austria is a landlocked country located in central Europe, covering the coordinates 47º-49ºN and 10º-17ºE, with neighbouring Czech Republic, Germany, Hungary, Italy, Liechtenstein, Slovakia, Slovenia and Switzerland. Approximately a population of about 8.5 million people lives in the territory, which has a surface is of 83,871 km^2 (United Nations Statistics Division, 2017). Austria has a federal system of government, conforming a Republic of nine federal states: Vienna, Upper Austria, Lower Austria, Burgenland, Styria, Carinthia, East Tyrol, Tyrol and Vorarlberg (shown

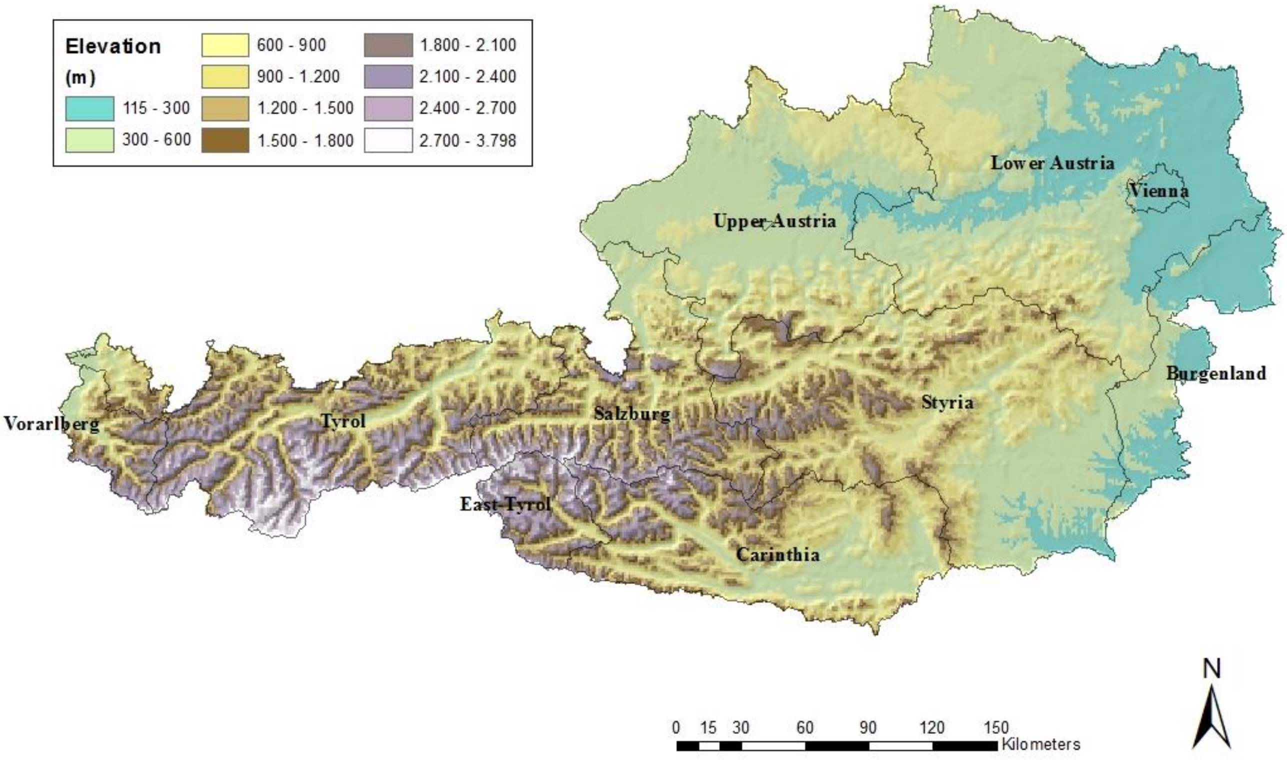

Figure 3 – Geographical representation of the elevation in the Austria, divided into its nine federal states.

in **Figure 3**). Its main economic activity is the services sector, together with small and medium-sized businesses, and despite not having the most predominance in economy, agriculture and/or forestry take up most of the country's area (Umweltbundesamt, 2010).

The Austrian territory is known for being a rather mountainous region with an elevation range between 115 m and 3,798 m, shown in **Figure 3**, finding the Pannonian plane in the East and the Alps rising towards the West (Umweltbundesamt, 2010). The presence of the Alps' mountain ridge not only affects the development of local winds, but also considerably influences general circulation in Europe (Schüepp & Schirmer, 1977). About 60% of Austria is covered by mountains, thus this irregular topography and high elevations influence the overall climate in the country, which varies over the region.

1.2.1. General factors conditioning climate

Climate is subject to local characteristics of the terrain and relative location in the globe. The following section introduces some key factors to understand climate as described by Whiteman (2000): (1) latitude, (2) altitude, (3) continentality and (4) regional circulation.

1) **Latitude** of a given place determines the day length and the angle of incoming sunlight, then, it defines the input solar radiation of the site. Also, the latitudinal position in the globe influences the exposure to the circulation belts of surface high and low pressure.
2) **Altitude** is a very important factor to consider since temperature, atmospheric moisture, precipitation, winds, incoming solar radiation, and air density, will vary according to it. Temperature decreases with altitude typically following the dry adiabatic lapse rate, of 10ºC/km. Atmospheric moisture decreases with altitude due to a lack of water moisture sources the higher the site is. Despite the decrease in moisture, precipitation is higher with elevation because of the low temperatures that make air masses condensate into rainfall. Also, windspeed increases with height because of the lack of friction comparing with large lowlands. Finally, air density decreases because air pressure, determined by gravitational forces, is lower with altitude.
3) The distance from the sea, or **continentality**, is also a relevant factor due to the thermal behaviour of big water masses. The difference in heat capacity between sea water and soil, being of almost double for salty water, causes differences in the amount of heat absorbed and released by a surface thus creating a phase lag of the annual temperature extremes of surface water and air (Schüepp & Schirmer, 1977). This way, territories closer to water masses do not have such an abrupt temperature change as inland zones, for the sea buffers those changes by releasing latent heat. The more inland areas are found, the lesser the sea buffering is and the more drastic temperature changes will be. Apart from moderating temperatures, the maritime influence has higher humidity and thus more cloudiness and precipitation, due to the direct source of moist that air masses represent.
4) **Regional circulations**, are the regional wind and ocean currents that represent a determinant factor of climate. Such derived regional winds are associated with the *semipermanent atmospheric high and low-pressure systems* formed in different latitude belts because of radiation input and surface interactions, and they are named after their stagnant nature although having a slight shift throughout the year (Ahrens & Henson, 2016). Air masses are moved around the globe by wind systems, which are determined by

the global atmospheric circulation and its cells and the relation between continents and oceans, mountains and ice fields (Ahrens, 2008). The air masses' flow tends to remain constant due to the pressure systems, defining this way the regional circulation of a site and thus its climate.

1.2.2. Main drivers of Climate in Europe

Europe with its 10.000.000 km^2 and 50 countries, is the most maritime of the continents due to its many peninsulas and islands. It is a territory that locates itself in the globe comprising the 29ºW in the Azores Islands to the 60ºE in the Ural mountains, and from passed the Arctic circle until the Mediterranean islands in the South, at approximately 35ºN (Boucher, 2005; 'Europe', n.d.). Because of its geographical position and topographic diversity (see **Figure 4**), the climate in Europe is not homogeneous but comprised of several climatic regions.

The European regional circulation, which defines the different climates, depends on how global winds drive air masses and how those are affected by topographical obstacles. The relation land-ocean has, also, an important influence on a region's climate due to the different heat capacity of such surfaces.

The Icelandic low, the Azores (or Bermuda) high and the Siberian high are the *semi-permanent air pressure systems* that influence Europe's weather the most (Ahrens, 2008). On the one hand, the Icelandic low and the Azores high are systems originated from the convection and subduction of the circulation cells, Hadley and Ferrell, which trigger such subpolar lows and the subtropical highs (Ahrens & Henson, 2016; Hordon, 2005a; Hordon & Binkley, 2005). On the other hand, the

Figure 4 - Topographic map of Europe (Wikimedia Commons, 2011).

Siberian high, mostly present in winter, is formed because of the intense cooling of the land (Ahrens & Henson, 2016; Hordon, 2005b).

The anticyclonic and cyclonic activities of the Azores High and the Icelandic Low are of importance, since they create the westward main wind direction (westerlies) that move polar maritime air masses towards the continent. Those air masses are moist, cool and unstable that, once colliding with highlands, are sensitive to trigger rainfall. Precipitation is enhanced with height when orographic lift pushes moist air into colder layers of the atmosphere, making it condense (Ahrens, 2008). In that sense, mountain ranges have an important role for the climate system, although accounting for a small proportion of surface on the globe. They are one of the middle latitudes' mechanisms for cyclogenesis, acting as a physical barrier to air masses and disturbing synoptic conditions (Marty, Philipona, Fröhlich, & Ohmura, 2002).

Closeness to the Ocean means higher humidity and thus lower capacity for temperature to have drastic changes, defining like this the characteristic **maritime/oceanic climate** with seasonal mild temperatures. In contrast, the furtherer away from coastal areas the lower the humidity level and more change is found between seasons due to extreme temperature changes, creating the typical **continental climate** (Oliver, 2005; Snow, 2005).

All the above-mentioned factors, from general circulation to region-specific interactions, are key to further understand how climate is in the site of interest.

1.2.3. The Austrian Climates

Understanding the general factors that condition the climate of a region, and having considered the main drivers that define it in Europe, a closer look to the Austrian situation show the climatic reality of the country.

Central Europe is strongly influenced by maritime air masses, which decrease its influence on the weather as they drive east. Throughout the region, topography plays a key role while defining the local climate. The relative location of the country from the ocean and highlands have an influence on its climate, which shows lower temperatures in winter and higher temperatures in Summer than what it would be expected from a similar region closer to the ocean (like western Switzerland).

According to the Hydrological Atlas of Austria (HAA), the country's range of average annual temperatures goes from -8ºC to 12ºC and a mean yearly precipitation of 400mm up to 3500mm, for the period 1961-1990 (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2003). Precipitation development has changed over the last 150 years, showing regional differences, with an increase of annual precipitation in the west of the country while rainfall decreased in the southeast (APCC, 2014).

The heterogeneity of the terrain implies different climatic regions within the territory. According to Whiteman (2000), those are:

- **Alpine climate**: typical climate found in highlands, like the Alps, where temperature decreases with elevation. Precipitation is high and snow common for winter months. Such climate is characteristic for great variation in temperature, precipitation, and vegetation in a relatively short vertical elevation change.

- **Atlantic** (Oceanic) **climate**: in the north-western side of the mountain ridge, the climate is strongly influenced by the air masses coming from the Atlantic Ocean. Having moist subtropical mid-latitude climate characteristics, it has humid mild winters and long cool summers.
- **Illyrian** (Mediterranean/Continental) **climate**: characteristic of the southern side of the Alps (Styria and Carinthia), closer to the equator where the influence of the subtropical highs is greater. Such climate shows cold winters with relatively high precipitation, influenced by the Mediterranean, however, summers are characteristically continental dry and hot.
- **Pannonian** (Continental) **climate**: found in the eastern flat part of the country, the Pannonian Basin, consisting on the flat area enclosed between the Carpathians, the Alps and the Dinaric Alps. It is a clearly continental climate, where changes are large with annual temperature ranges controlled by landmasses. In such topographic characteristics climate is expected to have hot, dry summer and cold winters. However, it shows complex weather patterns due to the convergence of wet air coming from the west and the drier warm winds from the Mediterranean, together with the cold temperatures falling in the basin from its mountainous surroundings (European Commission, 2009).

Effect of the Alps

The major air circulation in Europe is coming from the westerlies (Schüepp & Schirmer, 1977), wind flow that bring moist cold air on shore. The presence of topographic interferences in the flow of such air mases forces them to rise, cooling such ascending air and enhancing the formation of clouds and precipitation. Some cloud types are specifically associated with mountainous terrains, such as the Föhn walls (called Chinook in America). Such clouds are formed in the windward side of a long mountain barrier, where moist air is forced to rise and condensate, leading to the characteristic formations together with precipitation (Whiteman, 2000).

The Föhn effect is of relevance because it implies a drastic temperature difference between the windward and the leeward side. That happens when the air mass increases its temperature via the moist adiabatic lapse rate (6ºC/1000 m), but once it reaches the top the mass is not wet anymore and descends the leeward slope of the mountain through the dry adiabatic lapse rate (10ºC/1000 m). That means that the air in the leeward side of the ridge is to be dryer and warmer than a position in the same elevation on the windward side (Ahrens & Henson, 2016; Whiteman, 2000).

Another relevant implication of the presence of such mountain range in the territory is the shading of sunlight, together with the effect of inclination and orientation of land which will trigger different thermal wind systems due to difference in sunshine duration. The weather in valleys then, is extremely variable on the radiation reaching the surface, which directly affects the wind and temperature of the area (Whiteman, 2000).

Finally, the Alps are a mountain range covering several countries and its effects in the Austrian territory are derived, also, from the obstacles they generate to air circulation in other countries like Switzerland or France.

Climate change expected in Austria

Research is being done in the matter of climate change for the Austrian territory and most of the results are summarized in the Austrian Assessment Report for Climate Change 2014, carried out by the Austrian Panel on Climate Change (APCC) (2014).

Since the 1880, Austria has warmed up about 2ºC and half of such increase in temperatures has happened over the last 30 years (see **Figure 5**). Therefore, an increase of 3-5ºC by the end of the century is expected, for scenarios without extensive measures to reduce emissions, compared to the early 1900s. Such change in temperature is prone to reinforce processes that might release more GHG.

In what concerns to precipitation, no clear trend is seen for annual averages due to important regional differences. Austria is in a transition region between Northern Europe and the Mediterranean regions, and both territories show drastically different trends concerning precipitation. Northern Europe would present an increasing trend for rainfall, but a decrease would be expected for Mediterranean areas.

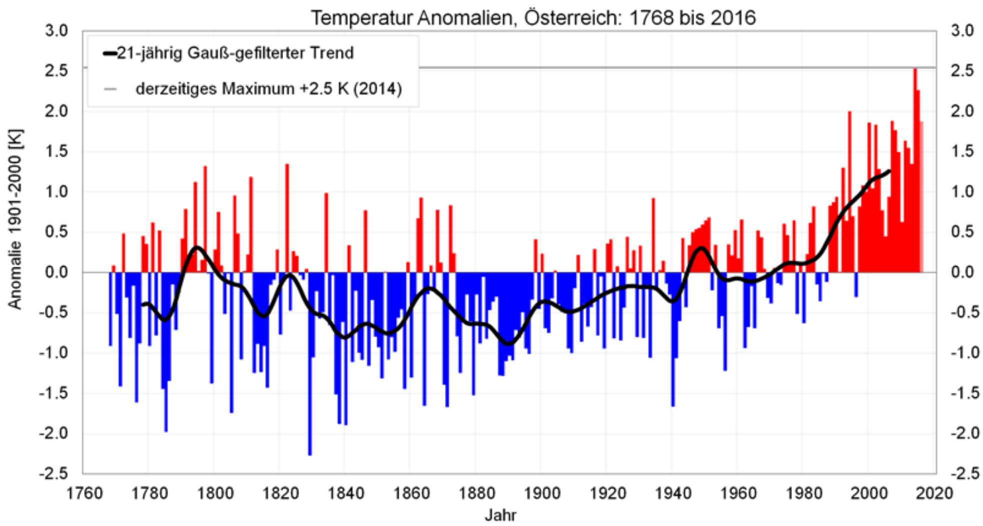

Figure 5 – Temperature development is Austria since the start of early measurements. Showing, with the black line, a clear increase in temperatures over the last 30 years (Zentralanstalt für Meteorologie un Geodynamik, 2017).

1.3. Climate Models

In this section, a basic introduction on the climate change research communities is made, with further development on the climate models (CM), both global (GCM) and regional (RCM).

Three primary research communities of climate change are the ones responsible for the progress in long term climate forecasting, those are: climate models (CM), Integrated Assessment Models (IAM) and Integrated Adaptation and Vulnerability (IAV).

The climate system's scales are too big in size and long in time to be studied by experimental methods, however, climate modelling was originated with the objective of understanding the system, firstly derived from conceptual models. Further improvement of those into mathematical models, in the 19th century, led to the final development of Numerical Weather Prediction (NWP) models in the 20th century, possible due to the newly gained digital computation. NWP was ground-breaking for short-term forecasting and further progress lead to the consolidation of the early CMs. The first GCM was launched in 1955, by Norman Phillips, and triggered a scientific revolution worldwide focusing on such models, searching for better ways to predict climate. Together with the technological evolution of computers, this trend in science prevails today (Edwards, 2011; Weart, 2017a).

CMs are constantly being developed and perfected, simulating the results of precise scenarios for the evaluation of our future climate (see section 1.4.). For that, collaboration with IAMs and IAV is needed. While climate models specialize in numerically representing the Earth's natural system and its interactions with human activity, IAMs specify the features of such human systems, adding necessary information for coherent future scenarios (from fossil fuel emissions to representations of land use change and energy systems) (Nakicenovic, Lempert, & Janetos, 2014). Finally, IAV models work with the outcome of the combination between IAMs and GCMs to evaluate the vulnerability and adaptation capacity of the scenarios.

CMs must firstly simulate the global circulation for further study of regional areas, then GCMs and RCMs are produced in a combined climate modelling chain, explained as follows.

1.3.1. Global Climate Models

The Earth's complicated system can be better studied since climate models were first developed, around mid-1900s (Edwards, 2011) and they are one of the sources of evidence that humans are having an influence on global climate. These so called general circulation models (GCMs), or global climate models, consist on computer-based simulations re-creating the chemical and physical processes that drive the planet's climate through mathematical formulas. GCMs work on three dimensions and are conformed by a horizontal (Cartesian) and vertical grid of cells (a schematical representation is shown in **Figure 6**) (Coley, 2008).

Equations based on the fundamental laws of physics, chemistry, and fluid motion are solved per cell with the use of powerful computers. GCM need an initial situation and forcings to start 'running'. All these factors include atmospheric dynamics, oceans, land surface, ice, etc. and they are included in form of mathematical equations. Then, results from each virtual station are shared with the neighbouring ones and equations are solved again, giving an integrated calculation of the system with its interactions for a defined period of time (NOAA, n.d.). The accuracy of a model is limited by how detailed processes are, the spatial resolution and the computer's capacity (Coley, 2008). The complexity of the models will limit the resolution and/or time of calculation, it is for this reason that currently GCMs have a coarse resolution, of around 250 km spacing. However, scientific research and technology advances are making it more feasible to calculate more complex systems in higher resolution and lesser time (Edwards, 2011; Treut et al., 2007).

Early GCMs started by simulating atmospheric circulation but a key factor was separating the models from reality, the ocean. It was not until 10 years after the first GCM was developed, that the first results from a coupled Atmosphere-Ocean General Circulation Model (AOGCM) were released (Edwards, 2011). Nonetheless, climate is not only defined by the physics of radiation and fluids but, also, biological and chemical processes. Then, this need of integrating atmosphere, hydrosphere, cryosphere and biosphere, triggered the creation of Earth system models (ESMs), which considers all the above mentioned (Edwards, 2011; Heavens, Ward, & Mahowald, 2013).

The community of modelers grew larger by the end of the 20th century and became better organized, with the aim of providing an enhanced global forecasting. In that regard, the World Climate Research Programme (WCRP) initiated in 1995 the Coupled Model Intercomparison Project (CMIP), addressing to unify formats and compare information from the worldwide community of climate researchers (Weart, 2017a; WCRP, 2017). The latest phase of the CMIP was the CMPI5, which collaborated in the development of the IPCC Fifth Assessment Report (5AR) (WCRP, 2017).

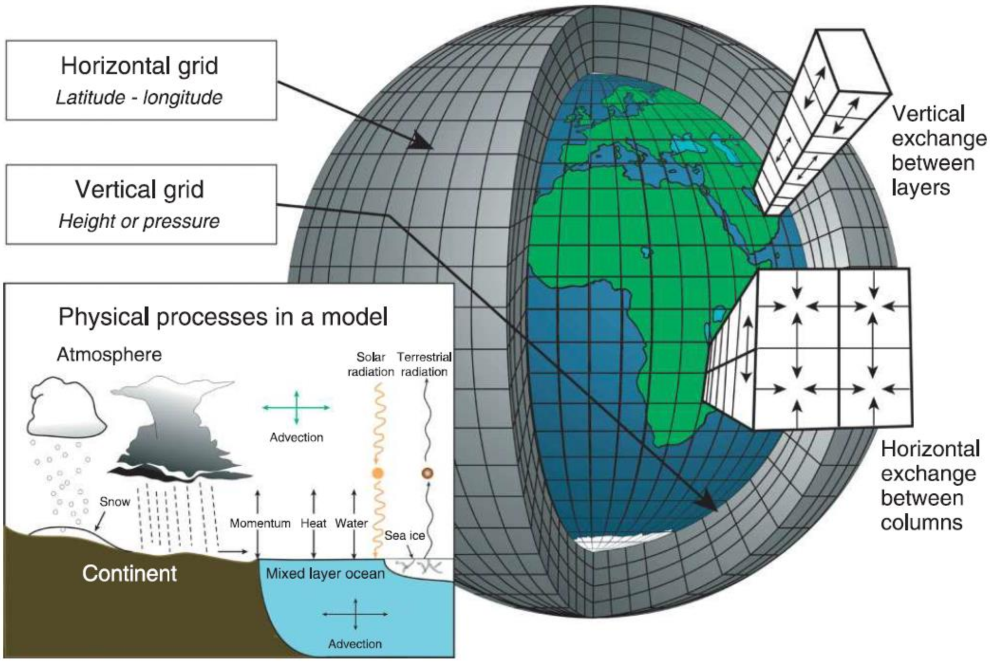

Figure 6 - Schematic representation of a GCM's grid structure, which shows the interactions between cells and the involved physical drivers (Edwards, 2011).

1.3.2. Regional Climate Models

There is high confidence of AOGCMs being a credible source of large scale quantitative estimates for a future climate (Randall et al., 2007). Nevertheless, many impact applications need finer scale models which include complex topography, island locations or places with variable topography. To correct the clear limitation of GCM having a coarse horizontal resolution of hundreds of kilometres, Regional Climate Models (RCMs) were introduced. These run calculations, in a process called 'downscaling', to transpose the GCMs data into higher resolution grids of tens of kilometres (climateprediction.net, 2014; Wilby et al., 2004).

Downscaling is the usage of information from the GCM's output by relating it to regional parameters, through dynamical or statistical models (Storch, 1995). In the case of statistical downscaling, low resolution outputs from the global models are introduced to the statistical models to estimate the local climate characteristics (Wilby et al., 2004).

RCMs fit the associated weather at a fine scale than the GCMs, that focus on the atmospheric circulation at a synoptic scale, considering that topography is a key factor for weather and climate (van Meijgaard et al., 2012).

1.4. Climate Scenarios

Already in 1896 Arrhenius published for the first time the idea of fossil fuels' derived gases being the driver for a possible climate change, but it was not until Keeling's Mauna Loa measurements, around mid-1900, that the idea started to be taken seriously (Weart, 2017b). Finally, in 1988 the Intergovernmental Panel on Climate Change (IPCC) was established as a scientific basis tool of climate change, and it was its Third Assessment Report (IPCC WG I, 2001) the one stating that it was *extremely likely* that anthropogenic emissions influenced the warming of the climate since 1750 (Foster et al., 2007). From that, and to predict what future situations to expect, climate scenarios started to develop.

Scenarios for climate change are needed to help understand how the Earth's system might react to human activities, how much could different anthropogenic contributions affect climate change or to evaluate future possible impacts of our current actions. All these efforts to forecast future scenarios are driven by the will of mitigating or adapting against imaginable fatal situations, however, this is not an easy task for complex socioeconomic, technological and environmental conditions must be taken into consideration. In order to merge all those conditions together, communities like the IAM and the IAV, cooperate together with the climate modelers so that results can better coincide with what would be expected in reality (Moss et al., 2010).

Early scenarios developed with the progress of climate modeling, and experiments were carried out by changing carbon dioxide concentrations to see how climate would respond to such forcings. Currently, models consider a wide variety of conditions, not just physical but also economic and political (Moss et al., 2010).

Due to its complexity, a scenario scheme had to be done to make sure that worldwide scientific results were homogenized. Since its starts, the IPCC has proposed several emission scenario frameworks to work with on its reports and to make it comprehensible for others. The first set was the SA90, used in the First Assessment Report (1990), and defined five emission pathways. Because of the emerging of new information relevant for scenario designs, the IS92 appeared and was used in Second Assessment Report (1995) with six scenarios that revised population forecasts, and included issues such as the amendments of the Montreal Protocol (Leggett et al., 1992). The IS92 were pathbreaking for being the first global scenarios providing estimates of the full ensemble of greenhouse gasses. However, in 1995 they were put under revision and the evaluation recommended significant changes, triggering the creation of the Special Report on Emission Scenarios (SRES) used in Third Assessment Report (2001) and 4th Assessment Report (2007). In order to make scenarios more understandable for policy makers the SRES were complemented with narratives about the future (Nakicenovic et al., 2000). Finally, in sight of not having any emission scenario considering policy making actions to mitigate climate change, the Representative Concentration Pathways (RCPs) were developed (Moss et al., 2010). This is the current system of climate scenarios, already applied in the 5th Assessment Report of the IPCC in 2013.

Representative Concentration Pathways

The RCPs are a product of collaboration between IAMs, climate modelers, terrestrial ecosystem modelers and emission inventory experts, producing a comprehensive data set of high spatial resolution for a period extending up to 2100. Such scenarios are the ones currently used in the IPCC reports (Moss et al., 2010; van Vuuren, Edmonds, et al., 2011).

The idea behind it is that rather than generating emissions based on socioeconomic story lines, like in the SRES, the process develops the models by setting important characteristics that trigger radiative forcing, aiming to get four different levels of it by the end of the century, relative to those of 1750 (Moss et al., 2010). Radiative forcing is understood as the disturbance of the Earth-atmosphere system energy balance, and its units are Wm^{-2} (IPCC WG I, 1996). The trajectories of the new system are associated with different combinations of economic, technological, demographic, policy and institutional futures instead of a unique socioeconomic or emissions scenarios (Moss et al., 2010). This different radiative forcing trajectories are pictured in **Figure 7**.

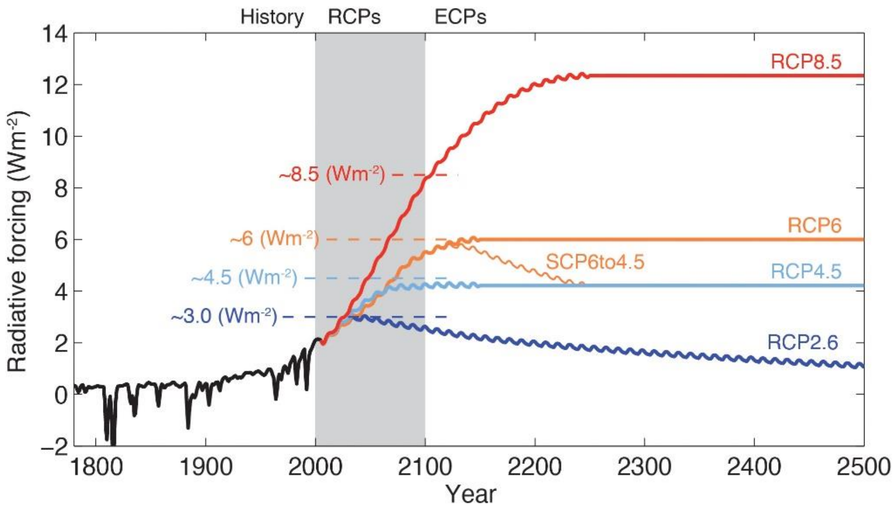

Figure 7 - Representation of the evolution of the radiative forcing over time for the different RCPs scenarios (IPCC WG I, 2013a).

The pathways are created for the whole century having clear radiative forcing endpoints by 2100. Those depend on the forcing of GHG or other forcing agents, then, numerous socioeconomic pathways could trigger each of the RCPs (Nakicenovic et al., 2014; van Vuuren, Edmonds, et al., 2011). The new scenarios pose a new starting point for research, since they map a wide range of climate outcomes without being forecasts nor policy recommendations (Moss et al., 2010).

Table 1 – Representation of the RCPs radiative forcing with their corresponding CO2 equivalent and future trends (Masui et al., 2011; R. Moss et al., 2008; Riahi et al., 2011; Thomson et al., 2011; van Vuuren, Stehfest, et al., 2011)

Name	Radiative forcing	CO2eq	Rate of change in radiative forcing
RCP8.5	8.5 W/m2	1350 ppm	Rising
RCP6.0	6.0 W/m2	850 ppm	Stabilizing without overshoot
RCP4.5	4.5 W/m2	650 ppm	Stabilizing without overshoot
RCP2.6	2.6 W/m2	450 ppm	Peak and decline

There are four different scenarios, each of them named after their radiative forcing by the end of the century, which can also be represented in form of CO_2 equivalent (see **Table 1**). Those are the RCP2.6 (van Vuuren, Stehfest, et al., 2011) representing one mitigation scenario with a very low forcing level; the RCP4.5 (Thomson et al., 2011) and RCP6 (Masui et al., 2011), being two medium stabilization scenarios; and the RCP8.5 (Riahi et al., 2011), which is the high emission scenario with continuous rise. In this project, just RCP4.5 and RCP8.5 were considered.

1.4.1. RCP4.5

RCP4.5 is a scenario of long-term, global stabilization of the Earth's radiative forcing at 4.5Wm^{-2} (approximately 650ppm CO_2-equivalent), due to the control of GHG emissions, short-lived species, and land-use-land-cover. This scenario considers that climate policies will take action to limit emissions and stabilize radiative forcing, also, nuclear is considered to be the major energy source by the end of the century (Thomson et al., 2011).

The SRES scenario that would represent a similar median temperature increase by 2100 would be the SRES B1 (Rogelj, Meinshausen, & Knutti, 2012), which represents the storyline of a connecting world having the same global population peaking in mid-century and then declining. The B1 scenario aims to find global solutions to economic, social and environmental problems and supports equity (Nakicenovic et al., 2000).

1.4.2. RCP8.5

Based in a scenario of high emissions and vulnerability, RCP8.5 represents the 'baseline scenario', where no specific climate mitigation target is considered and a radiative forcing of 8.5 Wm^{-2} (more than 1,350 CO_2 equivalent in 2100) is assumed as the endpoint (Moss et al., 2010; Riahi et al., 2011; Riahi, Grübler, & Nakicenovic, 2007). It is a high-emission business as usual scenario, with a socio-economic development pathway characterized by slow rates of economic development, little convergence between regions, quick population increase and slow technological change. One of the comparable scenarios of the SRES that would fit with RCP8.5 would be the A2 (Nakicenovic et al., 2000; Riahi et al., 2011; van Vuuren, Edmonds, et al., 2011).

The RCP8.5 could, also, represent a similar case of the SRES A1F1 storyline, in what regards to the median temperature increase by 2100 (Rogelj et al., 2012). However, in A1F1 the situation represents a fast-economic growth and rapid introduction of new efficient technologies, as well as a global population that peaks in the middle of the century and then declines. The main characteristic of the A1F1 shared with the RCP8.5 pathway is the fossil fuel intensity of the technology (Nakicenovic et al., 2000).

2. Methodology

The study of climate change impacts requires methods to be able to forecast what the situation might be like, in a hypothetical future scenario. Since no measurements of the future can be done, models that simulate the weather conditions of a specific site or region are needed to produce the forecasted data and then calculate ETp. For of this project, data from climate modelling was provided by the Institute of Meteorology of the University of Natural Resources and Life Sciences (BOKU) in Vienna. Finally, further treatment of the applied data was made with Geographic Information Systems (GIS) and Statistical software (Excel).

Tools

Computational tools were needed for the elaboration of this project, to geographically present the data and further analyse the values. Those are:

ArcGIS – ArcMap 10.5

ArcGIS is a GIS software developed by the Environmental Systems Research Institute (ESRI), with ArcMap being its main component to view, edit, create and analyse geospatial data. For the present work, the version 10.5 of ArcMap was used.

Microsoft Excel

Spreadsheet like computer software, for organization, storage and analyses of data, developed by Microsoft. Excel 2016 was used.

2.1. Data Collection

The data was facilitated by the Institute of Meteorology (BOKU). Observational INCA data was given for the period of 2003-2015 and model data was obtained for different climatological periods throughout the 21st century.

2.1.1. Observation data

Observation data was needed to be able to assess the performance of the models, as well as, to have real data from which to obtain the ETp dependent factors of the territory.

The applied data was given by the Integrated Nowcasting through Comprehensive Analysis (INCA), estimated by the Central Institute for Meteorology and Geodynamics (ZAMG). This is a high-resolution analysis and nowcasting system that combines surface station data, remote sensing data (from radars and satellites), high-resolution topographic data, and NWP outputs. INCA works with a horizontal resolution of 1 km and analyses hourly 3D forecasts for temperature, humidity, wind, 2D 15-minute frequency results of cloudiness, precipitation rate, and precipitation type. The result is a spatially quasi-continuous grid of weather fields in the territory (Kann & Haiden, 2011).

This nowcasting system is still under development, since it just started obtaining data in 2003 and its operative phase was not established until 2005. INCA was stimulated by the rising demand for immediate variable forecasts, in relation to the improvement of real-time warning systems and transportation planning. Unlike other Austrian evaluation systems, INCA analysis use NWP model information in order to make interpolations between observations (Haiden, Kann, Pistotnik, Stadlbacher, & Wittman, 2010; Kann & Haiden, 2011).

Due to the early stage of the project, the range of available observational data is of 12 years. That represents a limitation, because the data cannot be used to make strong climatic conclusions, for which 30 years of continuous data would be needed.

2.1.2. Models data

Obtaining data about future scenarios requires computer modelling. These models are created by worldwide research Institutes, downscaling GCMs to get RCMs that most accurately adequate the results to the study site. With such computing techniques, a suite of physical variables was estimated and, from these, ETp calculation was done by applying the Penman-Monteith equation (see section 2.2.).

The EURO-CORDEX project facilitated the initial data[1]. This initiative conforms part of the Coordinated Regional Downscaling Experiment (CORDEX), that aims to provide a framework of international coordination for the improvement of regional climate scenarios. The specific case of EURO-CORDEX provides regional projections for the European territory at a resolution of 50 km (EUR-44) and 12.5 km (EUR-11) (Jacob et al., 2014). Regional simulations are based on the downscaling of the global climate projections of the new CMIP5 (Taylor, Stouffer, & Meehl, 2012) and the new emission scenarios, the RCPs (Moss et al., 2010; Rogelj et al., 2012).

Selection of models

Since 26 model ensembles were available for the Austrian territory, a selection of three of them was done with the objective to show two mean models for RCP4.5 and RCP8.5, and an extreme scenario for RCP8.5. All ensembles can be seen in **Figure 8** and the election of the models was done by the Institute of Meteorology (BOKU)**.**

From each emission scenario dataset, RCP4.5 and RCP8.5, the mean climate signal was calculated between all the models (13 of each scenario). Then, the shortest distance between that mean value and the models in the dataset was considered and the shortest-distance one was selected. Finally, the model presenting the most critical situation was selected to have a representation of what could one of the extreme situations be like.

The two model-chains for the ICHEC represent the means of the datasets (RCP4.5 and RCP8.5) and have a similar precipitation climate signal, increasing around 5% for the period 1981-2100. On the contrary, the third model ensemble shows a precipitation decrease of around 8% by the end of the century, representing as well, the worst-case scenario of emissions (RCP 8.5).

Models description

The applied GCMs are ESMs, which, in contrast to other coupled climate models can simulate the carbon cycle of the earth system. This is made by including the interactions of the atmosphere and

[1] Available from: https://esg-dn1.nsc.liu.se/search/cordex/

oceans, with the biosphere (Heavens et al., 2013; SOCCOM, 2017). Also, both models are participating in the CMIP5. These are:

EC-EARTH is a GCM developed by the Irish Centre for High-End Computing (ICHEC), in Ireland. This coupled climate model is an ESM developed to promote international cooperation and accessibility to knowledge and data base, forming part of a Europe-wide consortium ('EC-Earth Home Page', n.d., 'ICHEC Home Page', n.d.).

HadGEM2-ES is a GCM developed by the Met Office Hadley Centre (MOHC), in the United Kingdom. The Hadley Centre Global Environmental Model version 2 was developed to simulate and understand centennial scale climate evolution by including biogeochemical feedbacks (Collins et al., 2011; Jones et al., 2011).

To have a spatial scale relevant to assess the impacts of a changing climate, downscaling of the GCM to regional scale is necessary (Renate & Bärring, 2016). The data used in this project was produced by the following RCMs:

KNMI-RACMO22E *(in combination with EC-EARTH)* was developed by the Royal Netherlands Meteorological Institute (KNMI), from the Netherlands, and it is a European based model with a resolution between 10 and 50 km (van Meijgaard et al., 2012).

CLMcom-CCLM4-8-2 *(in combination with HadGEM2-ES)* was developed by the Climate Limited-area Modelling Community (CLMcom), formed by an open, international network of scientists. The COSMO model in Climate Mode (CCLM) is an RCM developed from the local model of the German Meteorological Service, that can perform 100-year simulations and has a spatial resolution between 1 and 50 km ('CLMcom Home Page', n.d.).

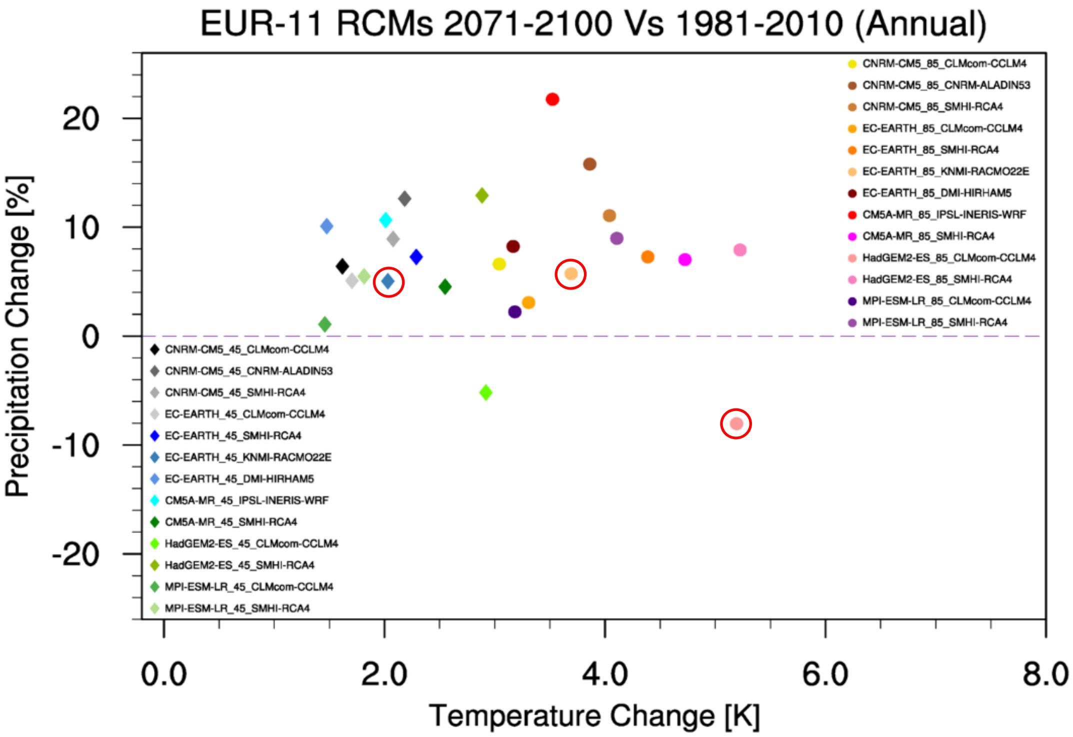

Figure 8 - Graphical representation of the Austrian EURO-CORDEX model ensembles depending on their climate signals of precipitation and temperature (Institute of Meteorology BOKU, 2017).

Output data from downscaled climate models

The calculation of the models was undertaken by the Institute of Meteorology (BOKU) applying the three abovementioned models. The applied scenarios are based on a unification of RCPs and different precipitation change projections.

The full relationship of the model ensembles and the scenarios can be seen in **Figure 9**. Two of the scenarios present the same precipitation changes, where rainfall would increase around 5% over time, and they only differ in what RCP they represent (4.5 and 8.5). The third scenario shows an extreme case where precipitation would decrease in the future by 8% over a century, and which is considered a worst-case scenario for the RCP (8.5).

The data was produced in each scenario for four different 30 year climatologies: 1981-2010, 2011-2040, 2036-2065 and 2071-2100. Of which the 1981-2010, 2036-2065 and the 2071-2100 periods were considered sufficient for the present study, naming them: historical data, mid-century, and century; respectively.

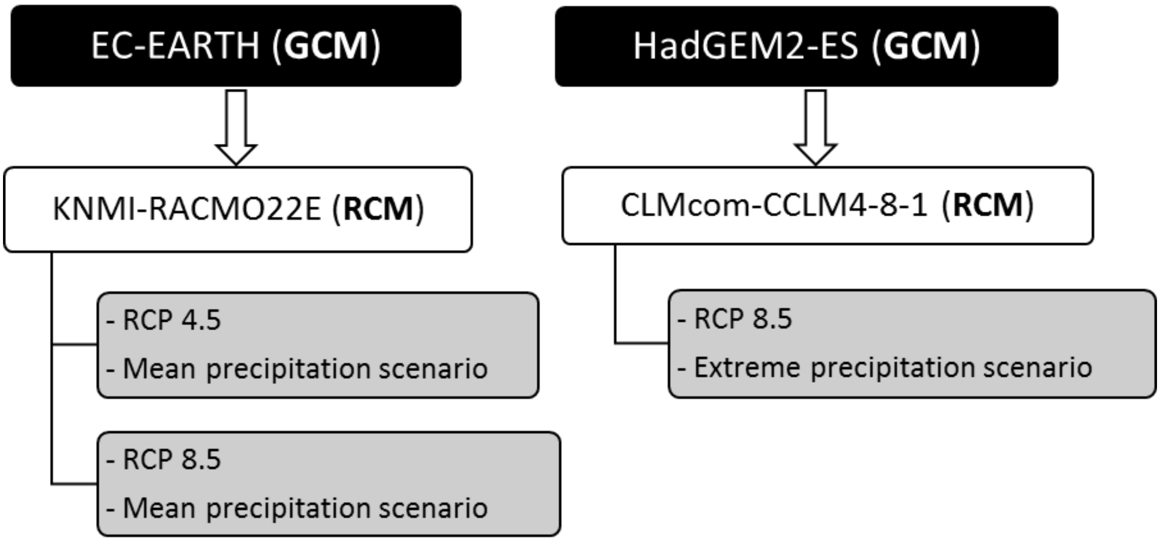

Figure 9 - Schematic representation of the relation between the model ensembles between GCMs and RCM, and the precipitation scenarios.

Then, for each scenario there were three data sets from different time periods. To summarize, the initial data used was:

- (x1) Observational data (2003-2015)
- (x3) Model data:
  - Historical data (1981-2010)
  - Mid-century data (2036-2065)
  - Century data (2071-2100)

An example of the labelling of the applied initial data is given here:

EvaPotranspiration_ICHEC-EC-EARTH_rcp45_r1i1p1_KNMI-RACMO22E_1981_2010_01

Institute GCM RCP RCM Time period Month

Throughout the document, further references to the models previously described will be the following:

- ICHEC-EC-EARTH_rcp45_r1i1p1_KNMI-RACMO22E → mean RCP4.5
- ICHEC-EC-EARTH_rcp85_r1i1p1_KNMI-RACMO22E → mean RCP8.5
- MOHC-HadGEM2-ES_rcp85_r1i1p1_CLMcom-CCLM4-8-1 → extreme RCP8.5

2.2. Penman-Monteith calculation

Evapotranspiration is subjective to a series of physical and physiological variables; however, physiologic factors are standardized when ETp is considered (see section 1.1.). Many empirical methods were developed over the last half-century to calculate ET from various climatic variables, one of them is the Penman-Monteith equation. Such equation is a blend of the Penman equation (Penman, 1948), which determines ET from a combination of an energy balance and an aerodynamic formula, and the inclusion of the bulk surface resistance term that Monteith made to the first (Monteith, 1965). The final formula including both physical and physiological factors was simplified by the FAO (Allen, Pereira, Raes, & Smith, 1998), assuming some constant parameters for a defined grass reference crop (Zotarelli et al., 2010); that is the FAO-56 Penman equation (Allen et al., 1998a):

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

Where ET_o = reference evapotranspiration rate (mm d^{-1}); Δ = slope of the saturation vapor pressure temperature relationship (kPa $°C^{-1}$); R_n = net radiation flux (MJ $m^{-2}d^{-1}$); G = sensible heat flux into the soil (MJ $m^{-2}d^{-1}$); γ = psychometric constant (kPa $°C^{-1}$); e_s = saturation vapor pressure (kPa); e_a = actual vapor pressure (kPa); T = mean air temperature (ºC); and u_2 = wind speed (m s^{-1}) at 2 m above the ground.

The equation needs standard climatological records of sunshine (solar radiation), air temperature, relative humidity and wind speed. Then, the calculation of ETp was made out of such weather data provided by INCA and the models following Zotarelli et al. (2010).

As explained in the section 1.1., the usage of ETp throughout the text is based on the same ET_o definition described by the FAO (Allen et al., 1998a).

2.3. Climate model's data treatment

The data initially given had to be treated by converting, projecting and displaying it, with the objective of obtaining comprehensive results in the form of maps. Data organisation was important for further analysis, which was made in combination of excel and GIS calculations.

2.3.1. Organisation

The initial ETp and Precipitation data was provided in a non-compatible format to work with in the GIS software so conversion, projection and aggregation was needed before starting with the calculations.

1. *Conversion:* To be able to use the provided data sets given in text format (.asc), a conversion of those into raster was done, by means of ArcToolbox:
   `Conversion tools >> To Raster >> ASCII to Raster`
2. *Projection:* Once the data was converted into Rasters, it was defined into the right projection for a uniform geographical representation. The Coordinate System used for this project's data was the Lambert conformal conic (LCC). Also, with the ArcToolbox:
   `Data Management Tools >> Projections and Transformations >> Define Projection`
3. *Aggregation:* Since all data was given per month, aggregation of the information into years was made with the function `Map Algebra`, inside the `Spatial Analyst Tools` section of ArcToolbox. Sum of the month's data, for both ETp and precipitation, was made for observations and for each scenario with its time intervals.
4. *Display:* For all geographical representations of the results, intervals and colours of display were self-defined, with the help of some default colour palettes of ArcMap 10.5.

2.3.2. Calculations

For further analysis, calculations were done with the objective of assessing the observation/model data biases, identifying elevation-ETp relation residuals, finding the Austrian water balance and obtaining the relative changes of ETp between historical and century period.

Relative Bias

Bias had already been done by the Institute of Meteorology (BOKU), however, a consideration on how good the models represented the observations was needed to assess how reliable the models' data was. Using ArcToolbox and `Map Algebra` the relative bias could be calculated by:

$$Relative\ Bias = -\left(\frac{Observational\ data - historical\ model\ data}{Observational\ data}\right)$$

ETp-elevation relation

Files with the monthly ETp sorted by elevation was provided by the Institute of Meteorology (BOKU) for each scenario and period. Then, treatment of such data was done with Microsoft Office Excel 2016 by: importing the text format (.asc), filtering unwanted values, and representing the relation of the ETp and elevation variables in form of a scatter plot. Finally, the linear regression of the plot was found.

Once the linear regressions had been found for all datasets, a geographical representation was done for each, using the ArcMap Toolbox and the function `Map Algebra`. The ETp-elevation relation maps were found by applying the regression formula into the GIS software.

Then, by substracting those ETp-elevation relation results to the yearly ETp raster files, for each dataset, a map of residuals was produced. The objective behind the extraction of such residuals was to be able to more clearly identify the factors that may affect ETp, since those maps would not be considering the influence that elevation has on the variable of study.

Water Balance

Water balance was calculated with the ETp and Precipitation datasets of all scenarios. This was done by deducting from the precipitation raster files the respective ETp for the same situation, using of the `Map Algebra` function of ArcMap.

Relative change of ETp

Finally, with the objective of obtaining maps representing the relative change of ETp throughout the century, the percentage of ETp difference between the two periods was calculated. Using the `Map Algebra` from ArcToolbox and the operation:

$$Relative\ change = \left(\frac{Century\ model\ data - Historical\ model\ data}{Historical\ model\ data}\right) * 100$$

3. Results

Evapotranspiration is one of the main components of the hydrological and energy cycle, heavily affecting water availability, and thus potentially influencing ecological and social dimensions. In the following section, results from observation data are presented and compared to the models' ones. Moreover, the outcomes of the different scenarios' changes are presented between the historical and century periods for ETp, water balance and other climatological factors.

3.1. Observation data

Observation (INCA) data is used to represent what the current situation in the Austrian context is, by showing the mean monthly distribution of ETp, as well as, the geographical distribution of ETp, precipitation and water balance; which is pictured to spot the arrangement of such variables throughout the territory.

3.1.1. Monthly distribution

Results from the observation, represented in **Figure 10**, show how mean ETp is variable throughout the year, having its maximum in July and minimum in the winter months, with a total sum of approximately 750 mm/y for the observation data. From the models, the mean annual sum is of approximately 700 mm/y, as seen in **Figure 17**.

The ETp difference throughout the year could be due to the change in solar radiation from summer to winter, affecting temperature that would, in turn, also affect ET. Considering INCA's data, summer represents 76.44% of the mean yearly ETp, for a period from April to September.

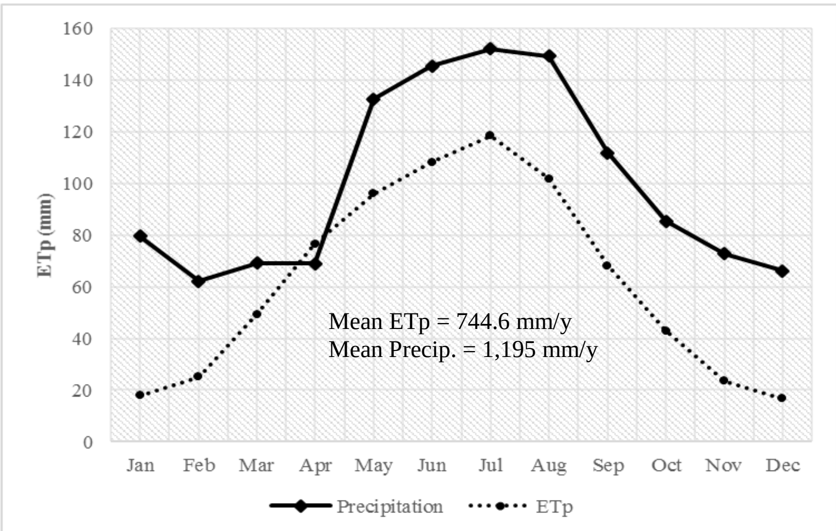

Figure 10 - Mean ETp and precipitation monthly distribution of the observation data (2003-2015).

Moreover, **Figure 10** shows that precipitation tends to increase in the summer months and decline in winter, where the minimums are found. ETp represents 62.30% of the total yearly precipitation for the territory, hence it is a rather relevant contributor to the water cycle.

Representation of the monthly ETp distribution is also available for each of the scenarios in the Annexes, in **Figure 17**. There, a clear water deficit period from May to October appears for the extreme RCP8.5 scenario, however, all the other scenarios keep the same yearly structure with values shifted to be higher.

3.1.2. Geographical distribution

A general picture of the geographic distribution of potential evapotranspiration, precipitation and water balance for Austria is shown in **Figure 11**, representing the observation data from 2003 to 2015.

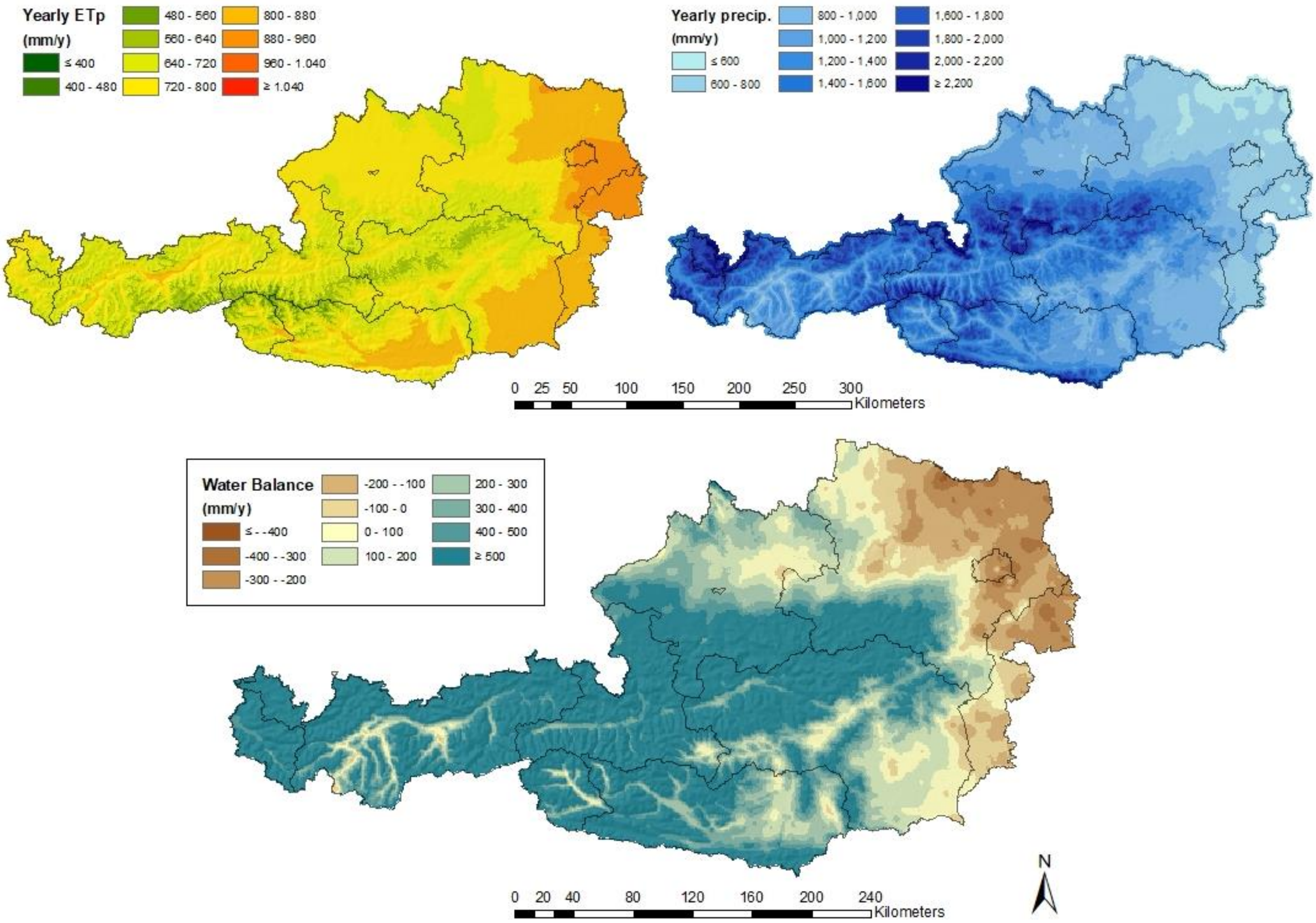

Figure 11 – Maps of Austria showing the distribution of yearly ETp (top-left), precipitation (top-right) and water balance (bottom), for observation data (2003-2015).

Evapotranspiration

ETp, with a mean value of 744.6mm/y overall the territory, appears to be higher in the Southern face of the Alps than in the Northern one (shown in the top-left map in **Figure 11**). Also, it is in the easternmost area of the country where the highest ETp values are found showing a decreasing pattern when going west; which coincides with the increase in elevation (seen in **Figure 3**).

Therefore, the territorial distribution of ETp seems to significantly correlate with the height of the topography, showing higher ETp for lower lands. This can be evident in the east of Vienna and

Lower Austria and the north of Burgenland. Then, the Alpine region shows the lowest values of about 350 mm, while the Austrian's lowest plains present the highest numbers of 1,000 mm of yearly soil water loss.

With the objective to decouple the elevation relation so that the remaining influencing factors of ETp are more visible, **Figure 12** was made. This shows residual maps of the historical data independent from elevation.

Figure 12 shows the distribution of ETp without the effects of elevation in form of a map. This makes it feasible to consider the importance of other factors influencing the potential water loss of the country. The distribution seems to be similar between observation and the models and displays higher ETp (purple colours) in the East and South of the territory. ETp is greater in the eastern and southern part of the territory, with also high values for the southern territories of Tyrol.

Lowest values of ETp are shown for the regions of central and North Austria (green colours), specially in the confluence zone of Upper Austria, Styria and Lower Austria.

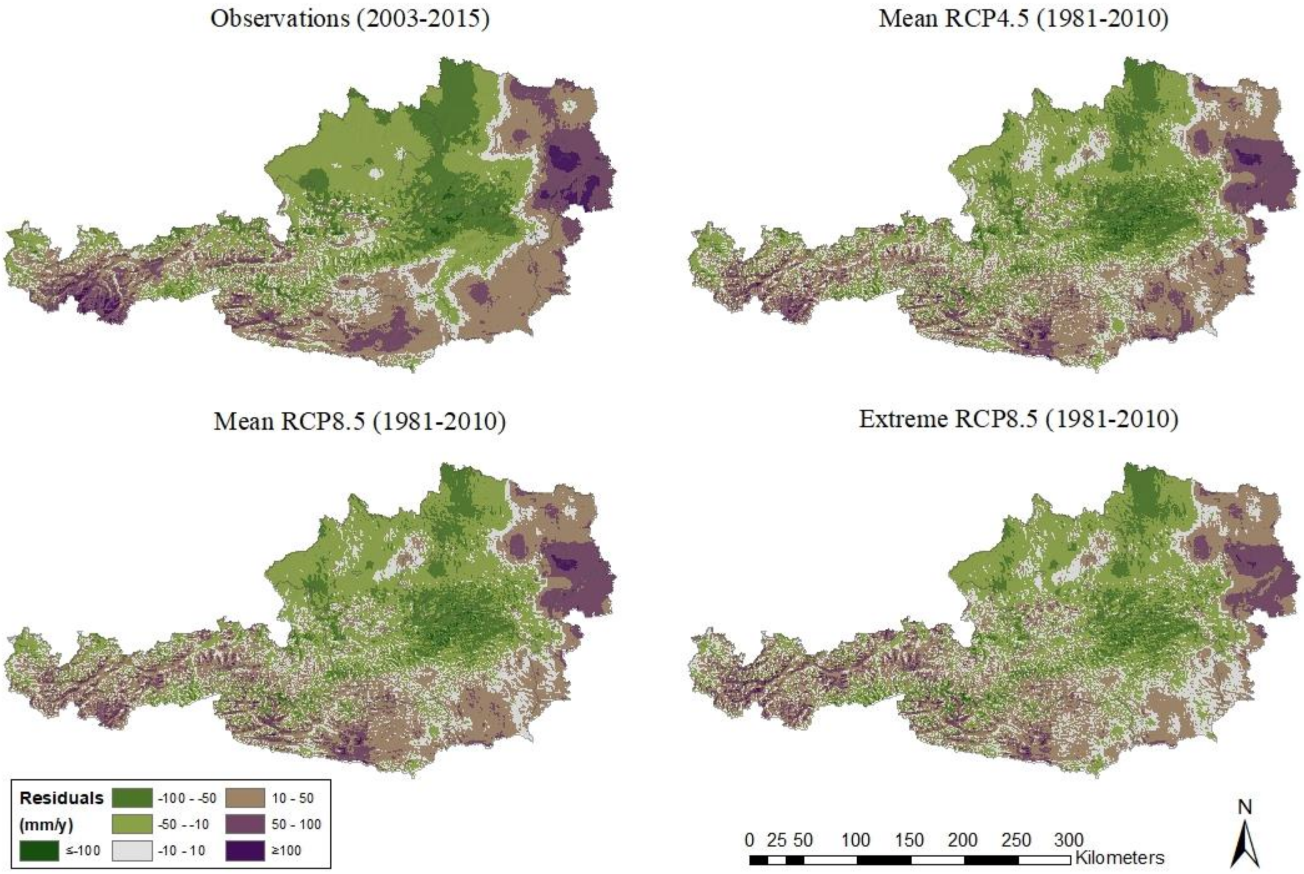

Figure 12 - ETp Residual representation of observation data and the historical period of the models. This distribution shows in which areas ETp is higher for factors independent from elevation.

Precipitation

The geographical distribution of precipitation in Austria is shown in the top-right map of **Figure 11**. The total annual precipitation is 1,195 mm for whole Austria and it appears that rainfall decreases from west to east. Maximum values are of over 2,500mm, and minimum ones of circa 500mm.

The highest values are seen to be in the north-western region of the Alps, which coincide with an abrupt change in elevation, from 300-600m up to approximately 2,000m, for air masses coming from the North-West of the country. The lowest precipitation is found in north-eastern Austria, coinciding with the low lands of the territory in Lower Austria and Burgenland.

Water Balance

Subtracting the evapotranspiration to the precipitation of the territory, the water balance is represented in the bottom map of **Figure 11**. This shows a total 450mm/y in surplus of water that can potentially be stored in the soil. Despite the mean value for the period being positive, there are some areas in Austria where water balance shows to be negative. This happens in the East of the territory, where precipitation has its lowest values and evapotranspiration the highest. Most of the water deficit is seen for elevations lower than 500m and it covers the whole Burgenland and Vienna region, as well as about half of Lower Austria.

None of the mountainous areas are suffering from water deficit, but some Tyrolean valleys have close to negative values due to the lesser precipitation and high ETp.

3.2. Comparison between observation and model data

Comparison of the observation data and the models is relevant to assess the good performance of the scenarios' forecasts, then, a first analysis of the fitting of the model's historical data with observations was done. Moreover, as seen in the previous section, elevation dependency of ETp seems like a relevant factor that is considered and compared between the scenarios and observations.

3.2.1. Performance of the models

A bias correction of the models was already done by the Institute of Meteorology at BOKU, however, to check whether the models used fit with reality, a representation of the relative bias was performed and presented in **Figure 13**.

The percentage in difference of the models is considered from the observation data, showing that all models present a lower value than what it is represented for the observations. The values of difference are of -6% for the mean RCP4.5 and extreme RCP8.5 and -7% for the mean RCP8.5; comparing to the observations. The distribution of the difference between datasets appears to be quite homogeneous, underestimating the most the values in high western elevations. Models seem to underestimate observation data homogeneously throughout the rest of the territory, with maximum change of -15% of observation values.

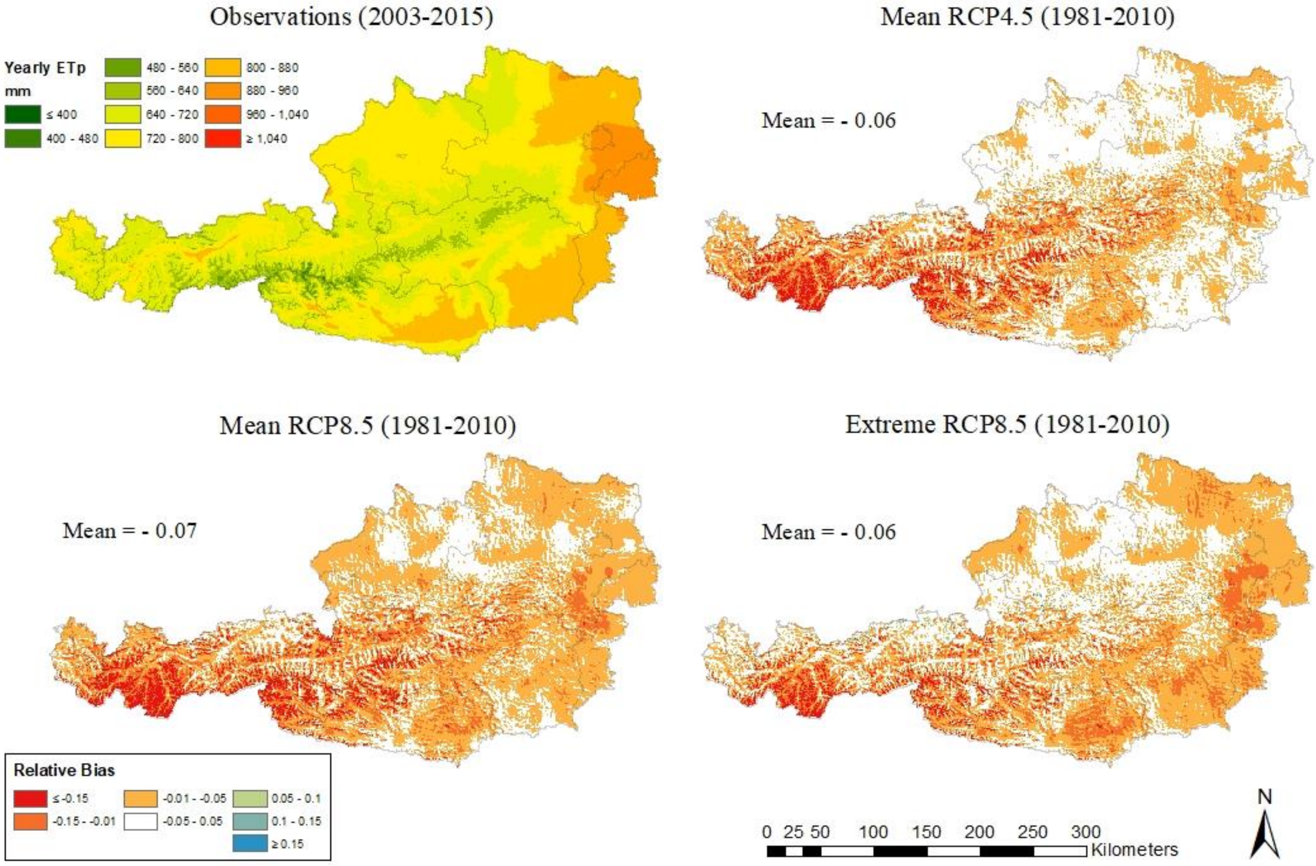

Figure 13 – Evaluation of bias correction of the observation and the model historical data, represented as a coefficient. On the top left map, the previous representation of the observations ETp is shown as a reference, and the rest of the maps present the coefficient of change between the already bias corrected model data and the observations.

Elevation dependency

As seen in the section 3.1.2, ET decreases with elevation. Then, the relation between ETp and elevation was found for observations and models, which are hereafter compared.

The importance of such elevation dependency can be assessed by considering the R^2 coefficients of the linear regressions, represented in **Table 2**. These values show the percentage of variance that can be explained by the elevation dependency observed previously. Results show that stronger effect of elevation appears for the historical period of the models, with approximately 75%, than for the observation data, with around 60%.

Table 2 - Coefficient of determination R^2 of the linear regressions between ETp and elevation.

	R2			
	2003-2015	1981-2010	2036-2065	2071-2100
Observations	0.62			
Mean RCP4.5		0.77	0.78	0.81
Mean RCP8.5		0.77	0.78	0.79
Extreme RCP8.5		0.74	0.68	0.51

If the linear regression itself is considered, the models seem to underestimate the observations, as can be seen in **Figure 14**. That underestimation was already seen with the relative bias, in the previous section.

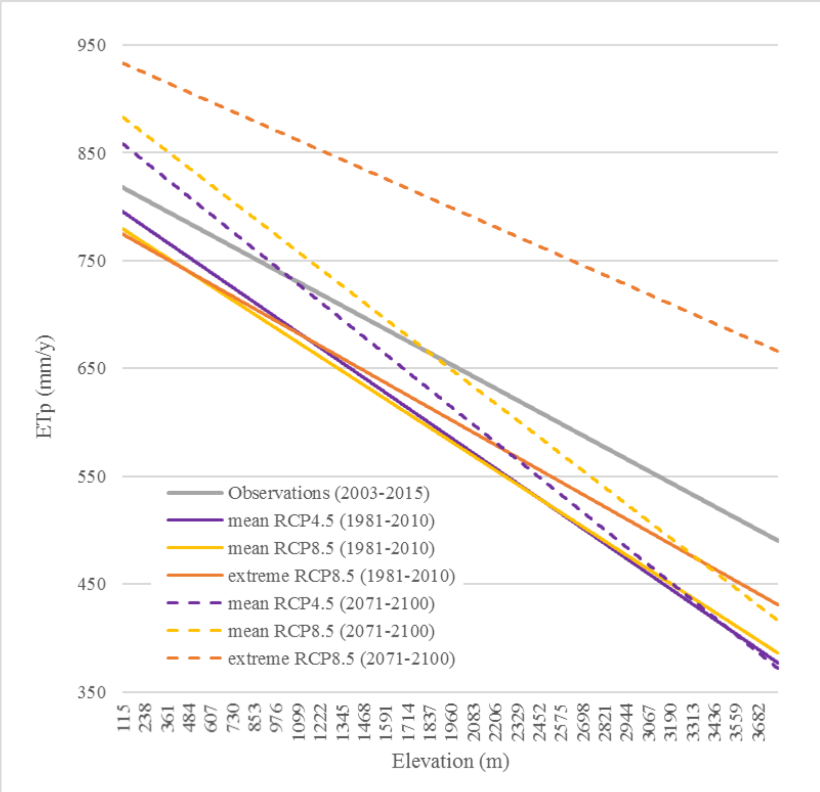

Figure 14 – Graphical representation of the linear regressions found between ETp and elevation, for all scenarios and both historical and century periods.

The slopes of the linear regression represent the rate at which elevation affects ETp (represented for 100m increase in elevation in **Table 3**). Considering the slopes of each data set, the historical estimation of the extreme RCP8.5 model is the one showing the most similar one to the INCA data. The rest of the models (mean RCP4.5 and mean RCP8.5) clearly underestimate observation values the greater the elevation is, therefore, performance of the ETp-elevation relation is not optimal for high altitudes. This could be possibly due to the way in which the bias correction was done for the relative humidity variable, where a simple scaling approach was used instead of quantile mapping, triggered by a lack of observation data. That could represent a systematic underestimation in elevations above 1,500m, where clouds are frequently formed (Formayer, 2017).

Concerning the evolution of elevation dependency in the future climate change scenarios, it seems that in future periods approximately the same variance could be explained because of elevation,

Table 3 – Rate of ETp decrease per 100m increase in elevation.

	Rate of Etp decrease with elevation (mm/100m)		
	2003-2015	1981-2010	2071-2100
Observations	-9		
Mean RCP4.5		-11	-13
Mean RCP8.5		-11	-13
Extreme RCP8.5		-9	-7

for the mean RCP4.5 and the mean RCP8.5 scenarios, with a slight increase of R^2 of 4% and 2%, respectively. On the contrary, for the extreme RCP8.5 scenario a drastic decrease of 23% in the coefficient is observed, meaning that other factors would become more important determiners of ETp than elevation. However, for all scenarios and periods, altitude explains at least 50% of the variance in ETp (as it appears in **Table 2**).

Figure 14 shows that slopes are quite similar for the historical extreme RCP8.5 and observation data, whereas for mean RCP4.5 and RCP8.5 they appear to be steeper. By the end of the century, the slopes in the regression become steeper for mean RCP4.5 and RCP8.5, however, it comes to be flatter for the extreme RCP8.5.

Representation of the scatter plots with the elevation relation can be individually seen for all scenarios in **Figure 18** in the Annexes.

3.3. Models data

Data obtained from computational models is useful to further predict future situations. Change in ETp is assessed by considering how it changes for each scenario, presenting the geographical relative change between the end of the 21st century and the reference period. Moreover, consequences of such climate signals to the water balance are considered and a presentation of the change in the key factors defining ETp is done.

3.3.1. Change in Potential Evapotranspiration

Potential evapotranspiration, as shown in **Table 4**, increases for all models as climate change happens. Displaying that the scenario with the least climate signal is the mean RCP4.5 with a 6.78% of change from historical to century records, whilst the model with the most affection is the extreme RCP8.5 with 25.27% change. The mean RCP8.5 shows an intermediate affection of 12.62% change. Also, higher change is found between the first half of the century than in the

Table 4 – Model's values of mean, minimum and maximum ETp values of the overall Austrian territory, for each period and scenario, with its relative change from 1981 to 2100).

Yearly Mean ETp (mm)				
Model	1981-2010	2036-2065	2071-2100	*Rel. Change*
mean RCP4.5	700.41	731.08	747.89	*6.78%*
mean RCP8.5	690.07	727.31	777.14	*12.62%*
extreme RCP8.5	696.49	784.58	872.49	*25.27%*

Yearly Minimum ETp (mm)				
Model	1981-2010	2036-2065	2071-2100	*Rel. Change*
mean RCP4.5	369.48	374.4	376.15	*1.81%*
mean RCP8.5	369.42	376.33	389.63	*5.47%*
extreme RCP8.5	384.74	450.17	520.99	*35.41%*

Yearly Maximum ETp (mm)				
Model	1981-2010	2036-2065	2071-2100	*Rel. Change*
mean RCP4.5	911.08	946.25	972.16	*6.70%*
mean RCP8.5	894.08	945.62	1005.83	*12.50%*
extreme RCP8.5	881.95	966.02	1089.94	*23.58%*

second for mean RCP4.5 and extreme RCP8.5, which is not the case for mean RCP8.5. A graphical representation of the evolution of ETp in Austria is shown in **Figure 15**.

Table 4, also, shows the minimum and maximum values of the yearly average values for the Austrian territory, there it can be seen that the increase throughout the century is approximately the same between the overall mean and the maximum. However, the change is not the same for the minmum values, being smaller than the mean change for mean RCP4.5 and mean RCP8.5 but higher for the extreme RCP8.5.

The maximum and minimum values of the models show which scenario has the highest range and how it would change over time. The mean RCP4.5 followed by the mean RCP8.5 would present the bigger range for the reference period and through the century, such ranges would grow wider for all models, specially for the mean RCP8.5.

The individual geographical evolution of ETp throughout the century is pictured in the Annexes with **Figure 19** for the mean RCP4.5, **Figure 21** for mean RCP8.5 and **Figure 23** for the extreme RCP8.5.

A geoprahical representation of the relative change of ETp between 1980 and 2100 for each scenario is shown in **Figure 16**. There, a similar pattern is seen for mean RCP4.5 and RCP8.5, although with different percentages of change since RCP8.5 shows changes approximately 10% higher than RCP4.5. Both scenarios appear to have the least change in the alpine area, and the highest change in some areas in the North (in Salzburg and Upper Austria) as well as some southern Austria territories (south Styria and Carinthia).

While mean RCP4.5 and RCP8.5 show a rather similar geographical pattern, where change appears to be lower the higher the elevation elevation is, in the extreme RCP8.5 a complete different arrengement is seen. For the critical scenario, change is greater in the mountainous area, dimnishing as it goes west. Its minimum values are of 15% change in the easternmost part of the country, coinciding with the lowest elevation.

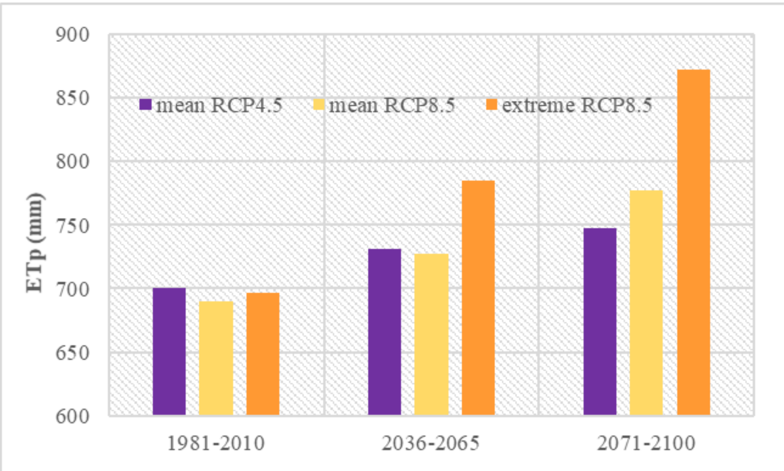

Figure 15 – Graphical representation of the evolution in the yearly mean ETp for each scenario and period, throughout the 21st century.

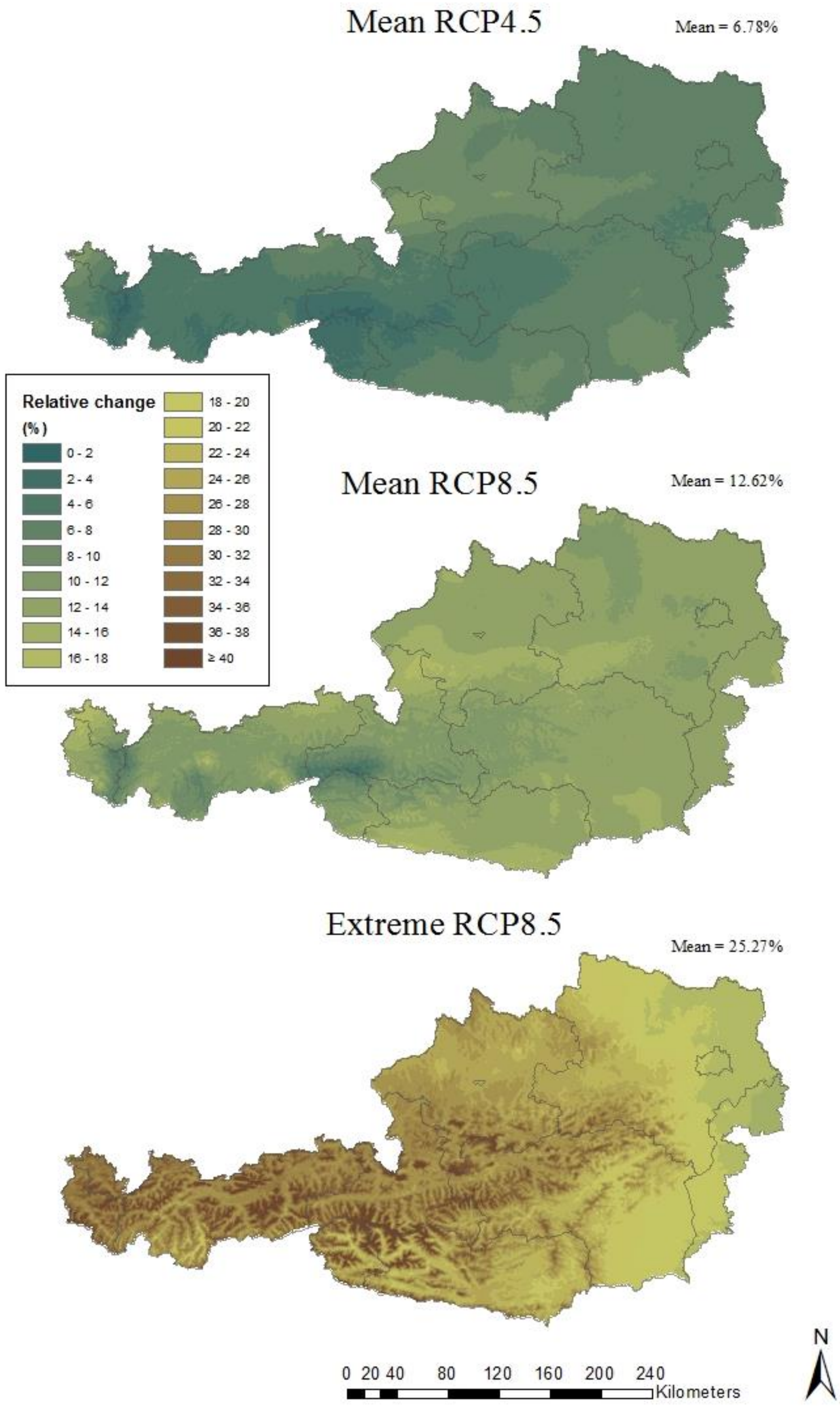

Figure 16 - Geographical representation of the relative change (in percentage) between the reference and the century ETp data, for all models considered in the present work. Whilst mean RCP4.5 and RCP8.5 show a similar distribution of change, the extreme situation presents a complete different picture; in which ETp increases the most in the mountainous areas.

3.3.2. Change in Water Balance

The distribution of water balance in all three periods studied is shown in the Annexes, in **Figure 20**, **Figure 22** and **Figure 24** for mean RCP4.5, mean RCP8.5 and extreme RCP8.5; respectively.

In such maps, where only precipitation and ETp are considered, water deficit is spotted in the North-East of the country (Lower Austria, Burgenland, Vienna and eastern Styria). Projections predict, according to the Figures abovementioned, that water deficit could potentially increase for both RCP8.5 scenarios and further spread from East to West following the lowlands and, also, in some Tyrolean valleys.

As shown in **Table 5**, for mean RCP4.5 the average water balance stays quite constant or even slightly increases over time. However, for mean RCP8.5 and extreme RCP8.5 that average decreases circa 20mm and 85mm, respectively.

Table 5 - Model's values of mean yearly water balance for each period, and the relative change between the reference and century data.

	Yearly Water Balance (mm)			
Model	1981-2010	2036-2065	2071-2100	*Rel. Change*
mean RCP4.5	413.2	389.3	421.2	*1.9%*
mean RCP8.5	433.6	425.6	410.9	*-5.2%*
extreme RCP8.5	413.2	433.6	327.9	*-20.7%*

The mean water balance not being negative in any of the scenarios by the end of the century, means that within the territory enough rainfall covers the increase in evapotranspiration. Nevertheless, if looking at the regional distribution it appears clear that depending on the area, the situation can be completely different with either water deficit or relevant surplus of water.

Changes are seen, for the case of mean RCP8.5, showing that by the end of the century Styria, Burgenland, Lower Austria, Vienna and some valleys of Tyrol lower values could be found. A more critical situation is shown by the extreme RCP8.5, displaying a heavy increase of the area affected by water deficit, which in 2100 would even include Carinthia apart from the regions abovementioned.

3.3.3. Change in Factors determining ETp

Evapotranspiration has been said to depend on a cluster of climatological variables, then, those are presented to show which of them is to vary the most with climate change. In **Table 6** the mean values of the variables considered to be determinant of ETp are presented for each period and scenario. Moreover, actual and relative change are represented as general information and to show which of the parameters suffers from major perturbance in the different climate change scenarios.

The mean relative humidity keeps in the order of 75-80%. For mean RCP4.5 and RCP8.5 an actual change of -0.14% and -0.59% respectively happens for the period between 1981 and 2100; -5.54% for the extreme scenario RCP8.5. Relative humidity, also, appears to be higher for the mean RCP values than for the extreme.

Mean global radiation, understood as the incoming solar radiation reaching the ground, has a global value in Austria of 128W/m^2 and shows no significant changes from the reference period to the end of the century. By just presenting a slight increase for the extreme scenario and a small decrease for the mean scenarios.

Mean wind speed is of approximately 2.2 to 2.5 m/s in Austria, and values appear to be higher for mean RCP4.5 and RCP8.5 than extreme RCP8.5. Throughout the century, no changes are seen for the scenarios.

Mean yearly temperature overall the Austrian region is of about 7ºC for the reference period and this variable is the one that presents the greatest change, with even an increase of 2ºC for the least GHG intensive scenario (mean RCP4.5). Mean RCP8.5 shows an increase of 3.5ºC and the extreme RCP8.5 appears to increase 5ºC by the end of the century. The change in temperature is greater in the first half of the century for mean RCP4.5, whilst being bigger in the second half for mean RCP8.5. The extreme scenario shows an equal warming for the first and second half of the 21st century.

Finally, total yearly precipitation for the territory is approximately 1,100mm for the historical period, and it is also one of the most heavily changed variables throughout the century. For both mean RCP4.5 and RCP8.5, rainfall increases 5% and 6%, respectively. On the contrary, the critical scenario of RCP8.5 shows a decrease in precipitation of around 8.5% by the end of the century, comparing to the historical period.

Table 6 - Mean values of Relative Humidity, Global radiation, Wind speed, Temperature and Precipitation with their actual and relative changes, for the period 1981-2100.

	1981-2010	**2036-2065**	**2071-2100**	***Change***
		Rel. Hum. (%)		***(%)***
mean RCP4.5	79.1	78.6	79.0	*-0.14%*
mean RCP8.5	79.7	79.5	79.3	*-0.59%*
extreme RCP8.5	77.6	75.4	73.3	*-5.54%*
		Global Rad. (W/m2)		***(%)***
mean RCP4.5	128.8	129.2	127.9	*-0.69%*
mean RCP8.5	128.6	128.8	127.1	*-1.21%*
extreme RCP8.5	128.6	128.7	129.0	*0.32%*
		Wind speed (m/s)		***(%)***
mean RCP4.5	2.5	2.5	2.5	*1.22%*
mean RCP8.5	2.3	2.3	2.3	*1.32%*
extreme RCP8.5	2.2	2.2	2.2	*-1.79%*
		Temperature (ºC)		***(ºC)***
mean RCP4.5	6.7	7.8	8.8	*2.03*
mean RCP8.5	6.8	8.4	10.5	*3.69*
extreme RCP8.5	6.8	9.4	11.9	*5.18*
		Precipitation (mm/y)		***(%)***
mean RCP4.5	1,121	1,127	1,176	*4.97%*
mean RCP8.5	1,131	1,160	1,195	*5.72%*
extreme RCP8.5	1,031	981	944	*-8.45%*

4. Analysis and discussion

In this section, a previous consideration on the good performance of the models is presented, with further development on what are the factors conditioning ETp throughout the territory of Austria, and expanding on the relation between elevation and potential evapotranspiration. Then, the effects of climate change are assessed and compared for each of the scenarios. Also, the vulnerability of the region is considered with focus on agriculture, and further suggestions for policymakers. Finally, the limitations of study are presented.

4.1. Performance of the models

The datasets from the models were bias corrected by the Institute of Meteorology (BOKU), however, evaluation of the good performance of those for the present work was made.

As seen in **Figure 13**, a comparison between the observations and the models in the reference period shows how the models have lower values, of about 6-7%. This difference could be attributed to the fact that the observations consider data for 18 years less than the models' historical data, and that the period is set in 2003-2015. It was said in the 1.2. section that the heaviest increase in temperatures in Austria has occurred over the last 30 years, with a warming of 1ºC (APCC, 2014). Therefore, the fact that observations consider a small portion of a late period of these 30 years, can be the reason why values are greater than the model's interval. The observations data represents a fraction of time when the effect of global warming already shows a significant increase of ETp.

Since the INCA data set was not initiated until 2003, information in such a high resolution and complexity previous to that year is not available. Then, limitations of the analysis must be acknowledged in that observation data does not represent the real climatological values (that should consider 30 years, according to scientific standards) of Austria. The comparison between observations and the bias corrected historical model's data show that although values are lower for the models, geographical distribution is kept quite constant.

The difference could be attributed to the fact that the calculation of ETp requires the consideration of several variables, which were computed by the models and then bias corrected mainly by means quantile mapping. However, not enough observation values of relative humidity were available and a simple scaling approach had to be used instead. This could have triggered a systematic bias that would explain the underestimation of values, especially for higher elevations as seen in **Figure 14**.

4.2. Factors of ETp distribution in Austria

ETp, is mainly conditioned by physical properties of the atmosphere, since the aspects dependant on plant physiology are standardized as constants. ETp is positively dependent on temperature, radiation and wind speed, and inversely dependent on humidity. Then, an estimated relation of such factors within the territory is discussed in the following sections to identify what are the main reasons defining ETp distribution in the Austrian territory.

The different climates of Austria explained in section 1.2.3. have a crucial influence in determining ETp, mainly due to the humidity conditions. Most of the ETp happens in the summer months, then, dryer and warmer summer areas would appear to have the highest values. This matches with the the Illyrian and Pannonian climate regions.

All the different phenomena spotted as relevant to explain why ETp happens in the region, is categorized into different sections for further discussion. Those are: (1) Elevation, (2) Sheltering effect of the Alps and (3) Radiation shadowing.

4.2.1. Elevation

As explained by Calanca, Roesch, Jasper, & Wild (2006), the Alps show a decrease of evapotranspiration as elevation increases. This relation can be seen in the top-left map of **Figure 11**, there a decreasing relation of ETp with elevation is shown while going west, matching the elevation profile of **Figure 3**.

For the INCA data, elevation is an explanation for about 62% of the variance in ETp whilst it does for more than 75% in the rest of the models (**Table 2**). That means that the bias corrected model data presents too much of a dependency on elevation compared to the observation data, maybe due to the limitation of bias correction for the humidity factor, as commented in the previous section.

In the linear regression between the two variables, shown in **Figure 14**, it appears that observation data has higher values than the rest of the model's historical period (seen, also, for the mean ETp values and representation of bias). Nevertheless, the rate at which ETp diminishes with elevation is presented by the slope of the regression, and observation data has a similar one to the extreme RCP8.5. Contrarily, mean RCP4.5 and RCP8.5 have a steeper slope, meaning that those models might be underestimating ETp at higher elevations.

Although several factors influence this ETp-elevation relation, the predominant ones are the decrease in temperature related to altitude and the lower amount of solar radiation that reaches the ground (affected by the presence of clouds, thus relative humidity and precipitation).

Big elevations present higher global radiation (Marty et al., 2002), however, the frequency of cloud cover related to mountainous areas turns the high solar radiation into the lowest sunshine duration region of the country. Therefore, instead of radiation having a crucial role for ETp at elevation, temperature, vapor pressure deficit and wind speed would be factors with a much importance when defining the maximum rate of evapotranspiration (Calanca et al., 2006).

Following the moist or dry adiabatic lapse rate, temperature decreases at a constant rate with elevation which in turn affects the SVP, lowering the vapor pressure gradient, that means that the rate at which evaporation happens will also decrease due to lower vapor pressure deficit (Oke, 1978). Moreover, the higher cloud cover frequency might influence ETp by limiting income solar radiation that hits the ground, which can potentially lower temperatures even more.

4.2.2. Sheltering effect of the Alps

Mountain ranges, as previously stated in section 1.2.2, can have an important impact determining a region's climate since they act as barriers for air masses. Austria is mainly influenced by moist air coming from the Atlantic, however, the Alps are the key mouldering element of the country's climate. This is for the sake of the longitudinal orientation of the mountain chain, which creates differentiated conditions between the northside and southside of the mountain range.

Wet and cold air comes from the northern part of the country, stemming from the Atlantic, and is forced to rise and condense because of the orographic lift. It is for this reason that the northern side of the Alps tends to present higher humidity, thus higher chances of cloud and fog formation than the southern part. On the contrary, and because of the mountain barrier precipitating most of the moist air, the South of the Alps presents lower humidity levels and thereby less cloud cover.

In dryer environments SVP increases and ETp will tend to increase too, resulting from an increase in vapor pressure gradient that triggers faster exchange rate of vapor from the surface to the atmosphere.

Looking at the map of elevations (**Figure 3**) and the map of residuals (**Figure 12**), a clear match can be seen between the Southern area of the Alps and the higher values of the residuals. Hence, Illyrian and Pannonian climates coincide with the greater ETp values. The lowest values are found in the Northern region from the mountains where humidity is higher, typical in Oceanic influenced climates.

Furthermore, the Alps' sheltering means that a greater part of the air masses would have precipitated in the windward side of the mountain range, therefore, big clouds are less likely to be formed in the leeward side and solar radiation would be higher there, increasing ETp.

Finally, in some of the Tyrolean valleys it appears that values of ETp (see **Figure 11**) are high as well. This could be due to the Föhn effect and/or sheltering of humid masses which result in very dry areas where precipitation is scarce, as can be seen in the top-right map of **Figure 11**.

4.2.3. Radiation shadowing

Incoming solar radiation determines the amount of energy available to vaporize water and it varies on the cloud cover and sunshine duration throughout the year. In that sense, mountain ranges have an important effect by changing the shading of sunlight throughout the year as the sun's angle switches, affecting temperature as well.

The presence of the Alps cause shading during the winter months triggering global incoming yearly radiation to be the lowest in some Alpine regions where ETp, also, appears to be smallest. However, it seems that ETp is most prominent in summer (shown in **Figure 10**), therefore cloud cover frequency would have more of an influence than the sunshine duration over the year.

Cloud cover is more frequent the more humid an area is. Then, in the north-western part of Austria, where the Alps are still not blocking the humid air masses from the Atlantic, it is more probable to find the clouds blocking the incoming shortwave radiation. Contrarily, in the South-East and eastern part of the country it appears that radiation is the highest, which could be related to the Pannonian climate being a rather dry area with less cloud cover.

A relation can be seen in the geographical distribution between the yearly global radiation and the ETp in Austria. The spots with major income radiation in the South-East match with the scattered areas of higher ETp seen in the historical data of the models (**Figure 19, Figure 21, Figure 23**) and the map of residuals (**Figure 12**).

4.3. Effects of climate change

Climate change is said to have had already an influence of approximately 2ºC of warming in Austria since 1880 and predictions expect a further increase, in sight of impassivity towards it (APCC, 2014). For this reason, scenarios are being developed and studied with the objective of knowing what to expect in the future, finding ways to adapt if possible. And although not all scenarios considered in the present work show the same results, some tendencies can be spotted, which gives a glance estimation of what can be expected.

As shown in **Table 6**, temperature appears to be the factor that changes the most with the GHG increase. This warming affects ETp not only by directly influencing the energy forcing of vaporization, but also by increasing the vapor pressure gradient that drives the rate at which water is vaporized, relative to the SVP curve.

Figure 19, **Figure 21** and **Figure 23** show the distribution of ETp throughout the territory, which appears to keep a similar distribution for mean RCP4.5 and RCP8.5, where values are the smallest the lowest the elevation is. In mid-century/century periods, also, ETp increases by advancing following the low lands towards the west. Still, a clear difference between the northern and southern side of the alps show how the presence of humid air masses from the Atlantic influence ETp in the North, by limiting it into lower values than the South.

Regarding the extreme scenario, in the mid-end century period, distribution is also kept by elevation but there is no clear distinction between North and South of the Alpine barrier. This could be due to the decrease in precipitation because of less humid air coming from the Atlantic. Such dryer air could mean a reduction in cloud cover, which would increase the global radiation that limits the energy of vaporization. This is especially relevant for the mountains, where radiation is higher. Cloud cover formed by the low temperatures in elevation seems to be the reason of the elevation-dependency relation of ETp seen in the historical period, however, this relation is lost throughout the century with climate change for the extreme scenario (see **Table 2**). Then, cloud cover diminishing due to dryer air masses could be one of the reasons of the rupture in the ETp-elevation dependency.

Evapotranspiration's energy of vaporization is bound to the global radiation and air temperature of the locality, then an increase in the radiative forcing due to more GHG is going to trigger a rise the ETp values. It is for this reason that for all scenarios ETp increases throughout the century. Nevertheless, because of RCP8.5 following an emission intensive pathway, the mean and extreme scenarios present higher change in ETp than RCP4.5, because radiative forcing keeps on increasing. On the other hand, the RCP4.5 scenario aims for the stabilisation of emissions and thus radiative forcing is not overshooting.

One of the most relevant potential problems of ETp raise is the threat of drought, however, this direct increase of water vapor in the atmosphere could also be a threat by triggering a positive feedback loop for climate change. Water vapor, alike carbon dioxide, is one of the most important greenhouse gases on Earth, therefore, a substantial increase in atmospheric vapor could double the climate warming begot by CO_2 emissions (Texas A&M University, 2009). An increase in water vapor in the atmosphere could mean that the effects of global warming could be continuously amplified.

In this study three different scenarios were considered, and each of them triggered a series of changes in the factors defining ETp (see **Table 6**). The following sections firstly assess the change on ETp-elevation dependency, followed by a more detailed comparison between the models. On the one hand, mean RCP4.5 and mean RCP8.5 represent similar precipitation forecasted situations, therefore a clearer assessment of the changes due to emissions can be done. On the other hand, since mean RCP8.5 and extreme RCP8.5 share the same radiative forcing scenario a comparison on the effects of precipitation predictions can be done.

4.3.1. Elevation influence

The elevation is a relevant factor in understanding ETp for Austria, and this ETp-elevation relation has been seen to change over the century. As seen in **Table 2**, the influence of elevation in ETp is kept constant for mean RCP4.5 and mean RCP8.5, but drastically decreases for extreme RCP8.5. This indicates that, for the moderate models, elevation as an understanding factor of ETp is kept relevant throughout the century, a situation that would not apply for extreme changes.

For the extreme case of RCP8.5, elevation diminishes its capability to explain the distribution of ETp in Austria. This might be due to the increase in SVP set off by the decrease in humidity and increase in temperatures. Such SVP triggers an increase in the vapor water deficit and thus more water could potentially be lost from the soil. Temperature very much depends on the elevation, however, an overall decrease in humidity would affect all the territory and, since SVP has such a strong influence in ETp, elevation would lose influence.

Finally, mean RCP 4.5 and mean RCP8.5, seem to underestimate values in great heights as seen in the bias consideration (**Figure 13**) and comparing observations to historical linear regressions (**Figure 14**). Then, values of ETp in high elevations could possibly be greater than the ones shown in **Figure 19**, **Figure 21** and **Figure 23**.

4.3.2. Comparison between RCP4.5 and RCP8.5

A closer look is taken to compare the effects of the different radiative forcing scenarios, with diverse GHG emissions pathways. The RCP4.5 represents a world where action is taken globally, with the objective of limiting emissions and stabilizing the radiative forcing by the end of the century. RCP8.5, portrays a more regional world with slow technological change continuing to emit “business-as-usual” throughout the century.

Observing **Figure 17**, where monthly evolution of ETp and precipitation is shown, it is visible that both scenarios have approximately the same mean monthly distribution throughout the years and that the only significant change is an enlargement of the ETp curve and a slight decrease of precipitation in summer and increment in winter, for the mean RCP8.5 scenario.

Both scenarios appear to present a similar distribution of ETp increase, however, RCP8.5 shows higher mean values than RCP4.5. Difference in ETp relative change is shown in **Figure 16**, with a mean difference of approximately 8% between both models, being the mean RCP8.5 the scenario with the most change. For both, the lowest change is seen in the mountainous regions, whilst higher alterations are manifest for most of Upper Austria, northern Salzburg, West of Lower Austria and scattered patches in the South of the country.

Looking at the yearly mean ETp (**Figure 19** and **Figure 21**) it is specially in the eastern territory, like Lower Austria, Wien and Burgenland, that values are bigger. That is because of the lowlands being warmer and the influence of the Continental climate, that has dryer conditions in summer, with warm temperatures and little precipitation (and cloud formation blocking incoming radiation).

The greatest change occurs during the first half of the century for RCP4.5, stabilizing by the end of the century, however, in the case of RCP8.5 ETp values continue to increase throughout the periods and most of the change happens in the second half of the 2000. This could be, as previously mentioned, due to the stabilization of radiative forcing implied by the scenario RCP4.5, which does not mean that emissions are stable but that action has been taken to control the effect of such in the warming of the planet.

ETp is often referred as the opposite to precipitation, therefore its increase suggests the possibility of a negative water balance for the future, in case precipitation is not abundant enough. Yearly average water balances, as seen in **Figure 20** and **Figure 22**, show that for RCP4.5 values keep constant throughout the century or even slightly increasing, whilst they slowly decrease for RCP8.5. The stable water balance for RCP4.5 could be because of precipitation increasing at approximately the same rate at which ETp also increases (~ 5-6%). However, for the case of RCP8.5 precipitation increases at half the rate at which ETp increases (6% for precipitation and 12% for ETp), therefore not being able to compensate the water loss executed by the increase of temperature.

Since radiative forcing is higher for RCP8.5 than to RCP4.5, it makes sense to see higher values for ETp in the first than the second. Higher radiative forcing pushes global temperature to increase, which in turn increases regional air temperature. This rising of air temperature directly affects ETp calculation, as well as indirectly other determining factors of ETp such as SVP. RCP8.5 does not consider limiting the effects of human activity in the climate system, but continues to follow a carbon intensive approach of development, then, the results of this emission scenario would represent the most critical outcome expected for ETp by the end of the century (considering a precipitation increase scenario).

4.3.3. Comparison between extreme and mean RCP8.5

The two models considering RCP8.5 as their emission pathway show very different precipitation outcomes, and the effect of this is discussed. In contrast to the mean RCP4.5 and RCP8.5, which show similar results of the geographical distribution of ETp in the mid-century period, the case of the extreme RCP8.5 presents a rather different one.

The mean monthly distribution of ETp and precipitation show, in **Figure 17**, a similar shape of the ETp curve for all scenarios in the historical period, having the highest values in summer months and the lowest in winter. ETp shows higher account for the extreme RCP8.5 in the summer months than for the mean RCP8.5, however, the figures appear to be very different not because of the ETp curve but due to precipitation change. It appears that rainfall distribution throughout the year drastically changes, heavily decreasing from April to October in the extreme case. Austria is characteristic of having its precipitation peak over summer, and such a switch might be due to a disruption in the circulation patterns that no longer bring humid air masses towards the Alpine barrier. The monthly rainfall scheme looks like being heavily influenced by the Mediterranean climate, in which summer is the season in which it rains the least and Autumn and Spring the more abundant ones.

Comparing both RCP8.5's relative change, in **Figure 16**, the pattern at which ETp changes is completely different from one model to the other. For the mean RCP8.5, change is greater the lower the terrain is (as explained in the previous section), however, for the extreme RCP8.5 case ETp changes the most in the higher elevations. The pattern followed by the critical precipitation model shows a decrease in relative change the lower elevation is, with a change of circa 14% since the time of reference. Difference between ETp at historical and end-of-century periods is greater for the extreme RCP8.5 than the mean one, since 12% of the relative change for the critical scenario already happens for the period of 2036-2065, whereas such change only happens by the end of the century for the mean RCP8.5. Hence, how precipitation patterns will develop with climate change is crucial to understand while tackling ETp.

Regarding the yearly mean ETp (**Figure 21** and **Figure 23**), both scenarios show about the same distribution, by which in elevated areas ETp will tend to have lower values. However, in extreme RCP8.5 there is no difference between the northern part of the country (above the alps) or the southern, unlike the other scenarios. This could be due to the decrease in humidity and precipitation, mostly expected from the North-West as the main air masses hitting the country come from the Atlantic. This can be seen in **Table 6**, where relative humidity decreases 5%, and precipitation 8% since 1981 values for the extreme model. In the century data of the mean RCP8.5 case, the average ETp value overall Austria is 777mm, which is lower than the same value for mid-century in the extreme model (785mm). Also, both maps of those situations, also, show similar distributions. However, the extreme RCP8.5 presents a rather radical situation where even in elevated areas, values are in the order of 800mm.

Water balance is positive for both models yet for the two of them, contrarily to the mean RCP4.5, the balance decreases all along the century. Mean RCP8.5's balance decreases 5% between 1981 and 2100, on the other hand mean RCP8.5 decreases up to 20% since the reference period. Such a harsh change is mainly triggered by the rise of ETp. This can be clearly seen in the last period in **Figure 24**, where water deficit expands following the pattern of drastic increase in ETp, in the northern and southern Alps. Although water balances have been seen to be positive, when the geographical distribution is considered (**Figure 22** and **Figure 24)** water deficit can be spotted from early periods in the eastern part of Austria, coinciding with the areas where ETp is greater. The situation of water deficit, expands dramatically throughout the century for the case of extreme RCP8.5, perhaps fitting with the areas where precipitation diminishes the most (in the southern slope of the Alps) and specially with the increase of ETp in the order of 120mm for flat areas, comparing historical and century periods. The distribution of water balance for mean RCP8.5 does not show such a spread over the territory, like the extreme case, but an increase of deficit in the areas where it was already present.

Changes in temperature for these models are of 3ºC and 5ºC increase by 2100 from 1981, for mean and extreme respectively. Then, scenarios like this could be expected in case no action is taken to try limit GHG emissions. Although both models considered in this section had the same radiative forcing, results appeared to be truly different just by having variant precipitation evolution, triggered by the model's differences. Extreme RCP8.5 would represent the worst-case scenario, not only in the business-as-usual approach of emissions, but also all the consequences coming from it. All models under the selection process seen in section 2.1.2. are considered to have the same probability, therefore all possibilities should be considered and further studied to better understand future challenges.

4.4. Vulnerability of agriculture in Austria

Consideration and analysis of climate projections is done with the objective of bringing possible futures into discussion, knowing that the actions today might lead to the foresights estimated. All the effects of climate change in ETp abovementioned represent impacts for society and environment, and may pose a threat that should be evaluated.

Although three different scenarios are considered to have the same quality, given by the EURO-CORDEX project, the two mean models are the models recommended to show the more suitable prediction of the future. That is due to the better fitting of the precipitation curve between the reference period of the models and the observation data, seen between the monthly distribution figures **Figure 10** and **Figure 17**. Considering that the observation period coincides with the end of the historical time-interval, when global warming has already had some effect in the territory, reality is seen to be more closely fitting with the expected mid-century mean RCP4.5 and RCP8.5 than the extreme situation. Also, a trend has been stated by the IPCC WG I (2013) saying that already an overall increase in precipitation has happened for northern hemisphere mid-latitude territories.

Nevertheless, it should be noted that Austria is in a transition region between Mediterranean and Continental influenced climate that show contrary trends regarding precipitation, with an expected increase in Northern Europe and a decrease in the South (APCC, 2014). That poses an added uncertainty on what might happen in the territory and further research should be done, to better understand the probabilities.

The present work does not have enough information to assume whether the RCP4.5 or the RCP8.5 is more likely to happen, due to the complexity of global emissions' share per country and the international policies developed to limit those. Then, it is considered that to minimize impacts of climate change in Austria special attention to the worst-case scenario (RCP8.5) should be paid.

Vulnerability is a term widely used to consider how dangerous a certain situation might be for something or someone. Hereafter, vulnerability is considered as it is defined by the IPCC WG II (2014) as "the propensity or predisposition to be adversely affected" (the rest of terms utilized in this matter will also be understood with the IPCC definitions). The combination of vulnerability, exposure and hazards result into risks. Then, since ETp is a component of the water cycle, changes in the normal distribution could lead to impacts in water supply and pose risks for ecosystems and society, if the systems are not resilient enough.

Agriculture is one of the sectors that could more harshly be struck by climate change and its effects on ETp. The Austrian Panel on Climate Change (2014) already stated that if no efforts are made to adapt to climate change, Austria could be prone to increase its vulnerability in decades (specially for agriculture, forestry, tourism, hydrology, energy, health and transport). It is for that reason, that the country has already adopted a national adaptation strategy since 2012, however, ETp has not still been incorporated into the agenda.

While atmospheric carbon dioxide, light and temperature appear to be determining factors of the rate of growth in a plant, it is the soil moisture which sets the upper limit of the actual productivity (Calanca et al., 2006). Since ETp is mainly affecting the potential of soils to lose water, it seems to be a crucial variable to take into consideration for agricultural planning. Good estimation of ETp in the future, could mean better adaptation to climate change effects and thus impacts could be minimized.

Agriculture in Austria is mainly found in the east (Styria, Burgenland, Lower Austria and Carinthia), cultivating crops like sugar beets, wheat, maize, barley, potatoes, apples and grapes. Stockbreeding is also done by raising pigs and cattle (Encyclopedia Britannica, n.d.). Some of these areas have already been seen, in **Figure 11**, to have water deficit due to excessive ETp compared to localized precipitation. Nevertheless, the country's overall water balance is positive, meaning that recharge of water courses and aquifers is a reality. Then, redistribution of water resources for irrigation, in the regions where agriculture is more abundant, is already needed. Nevertheless, the increased water deficit, for the case of mean RCP8.5, poses an added stress to agriculture in those regions where irrigation methods are already taking place and makes them more dependant of such monitored water supply. Moreover, in the hypothetical situation of the extreme RCP8.5 happening, areas where water deficit was not present before, like Carinthia (see **Figure 24**), could find themselves in social and infrastructural challenges for adaptation.

ETp increase is not the only factor that could represent a risk for the sector, the increase in temperature and precipitation could potentially influence the natural cycle of organisms (phenological changes) and thus the whole system might be affected. Early greening and fruiting could lead to a shift in the irrigation system and warmer temperatures could lead to the introduction of new pests (APCC, 2014). The proof of increase of ETp with climate change should serve of warning to increase the studies estimating it per regions, which should be incorporated in water management strategies (Abtew & Melesse, 2013).

Plant physiology and geophysical factors are closely interrelated and dependant on many variables, which makes it difficult to fully understand all processes, and although climate change is expected to lead to future risks it might also result in some opportunities. This is due to the higher CO_2 levels likely to thrive vegetation productivity, for plants could potentially store more carbon in the future, thus higher photosynthetically activity would be expected (Abtew, 1996; IPCC WG I, 2013b). Also, this increment of carbon dioxide could reduce transpiration requirements, counteracting the increase of transpiration due to the warming environment (Abtew

& Melesse, 2013). This increase in productivity could help the agricultural sector to be more resilient, although an increase in yield might also trigger an increase in water requirements.

Some of the solutions proposed by the Austrian Panel on Climate Change (2014) could be the improvement of irrigation systems, but also the usage of more water-efficient crops fitting with the climatological characteristics of each site (also proposed by Azam & Farooq (2005)). Moreover, efficient mulch cover, reduced tillage or wind protection could be some measures to control evapotranspiration in crops. Finally, measures to protect soil and avoid erosion, strategies for water retention and improvement of irrigation infrastructure (with warning, monitoring and forecasting systems) would be key to lower the country's vulnerability.

The presence of the Alps, and the wide grid of water courses throughout Austria, is an asset for the adaptive capacity of the country since it works as an important water storage system, of snow and groundwater. However, without region-specific planning considering the foresighted scenarios, some areas could not be resilient enough to cope with the effects of climate change. Then, more research, monitoring and improved water planning is needed.

4.5. Limitations of the study

The present work dealt with ongoing researched fields, such as climate models and evapotranspiration, therefore, limitations of the results should be mentioned.

As presented in sections 1.3. and 1.4. climate models and scenarios are in constant evolution, improving with technology and being constantly redefined to fit the changes in society. The climate system is complex to simulate and the variety of models developed by the EURO-CORDEX network of research centres, shown in **Figure 8**, give different outcomes. Therefore, an intrinsic limitation must be contemplated when results are obtained from models. It should also be stated that values gotten to calculate ET had been previously bias corrected from climate models, then, a certain bias degree is possible. Sections 3.2. and 4.1. aimed to explain such differences for a critical insight of the results.

Another limitation is found considering that evapotranspiration is a complex concept that, as seen in sections 1.1. and 2.2., involves a wide number of climatic variables and the overestimation of one or another can bias considerably the conclusions obtained. In addition, the reader should be aware that in the present work no actual ET was presented, due to the difficulty of quantifying ET (complex soil and vegetation heterogeneity), but a reference or potential ET was given from calculating the variable with the Penman-Monteith calculation.

Nevertheless, despite all the limitations of modelling and dealing with evapotranspiration, computational foresights are an important source of information, setting a reference point for present planning. The outcomes can explain certain trends on how ETp could potentially change in sight of climate change, and can be of use as a reference prediction for policy-makers and development planners.

5. Conclusion

In conclusion, the work of this report shows that the distribution of ETp in the Austrian territory is mainly determined by the influence of Alps in the incoming Atlantic air masses, determining the different climatological regions of the country as well.

ETp is directly affected by temperature, radiation, windspeed and humidity and mostly happens in summer, when radiation is at its maximum. Dryer and warmer climates, then, are the ones presenting the highest values. In Austria, the Pannonian and Illyrian climates found in the East and South of the country show the higher potential of soil water loss. On the contrary, humid regions like Atlantic influenced climates, in the North, or cold and cloudy regions, in the Alps, show the lowest ETp values.

Also, ETp in the territory is likely to increase with climate change even for the scenario where climate action is taken, and temperature is probable to be the most influenceable factor. Relative changes of ETp between the period 1981 and 2100 are of 7% for the mean RCP4.5 scenario, 13% for mean RCP8.5 and 25% for extreme RCP8.5. For the two mean scenarios, ETp increases following the elevation profile, however, for the extreme situation ETp rises the most at higher elevations and resembles to be due to a combination of lesser humidity levels, increasing radiation, and warmer temperatures.

Elevation is the main reason explaining the distribution of ETp in the territory, possibly because of the effect that altitude has on temperature. Such relation is kept constant throughout the century for mean RCP4.5 and mean RCP8.5, yet in the extreme scenario elevation could lose its importance in detriment of humidity, which is assumed to gain importance.

Moreover, this work shows how yearly water deficit increases with climate change for the regions where negative water balance is already present, like in the eastern part of Austria. This is seen for both RCP8.5 scenarios, although more prominently in the extreme one. Distribution of negative water balance grows following the lower lands in the North and South of the Alps, potentially affecting Vienna, Burgenland, Lower Austria, Styria and Carinthia. Clearly, the extreme RCP8.5 scenario would show the most critical situation of drought, for water balance would be negative for most of the summer months.

Finally, the outcomes of this project aim to proof that water distribution is likely to be modified by climate change and encourages sectors, like agriculture, to monitor and incorporate ETp into their planning, so that water is better managed and planned. This is of importance for the adaptive capacity of Austria, to be able to face whatever scenario may happen in the future.

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Annexes

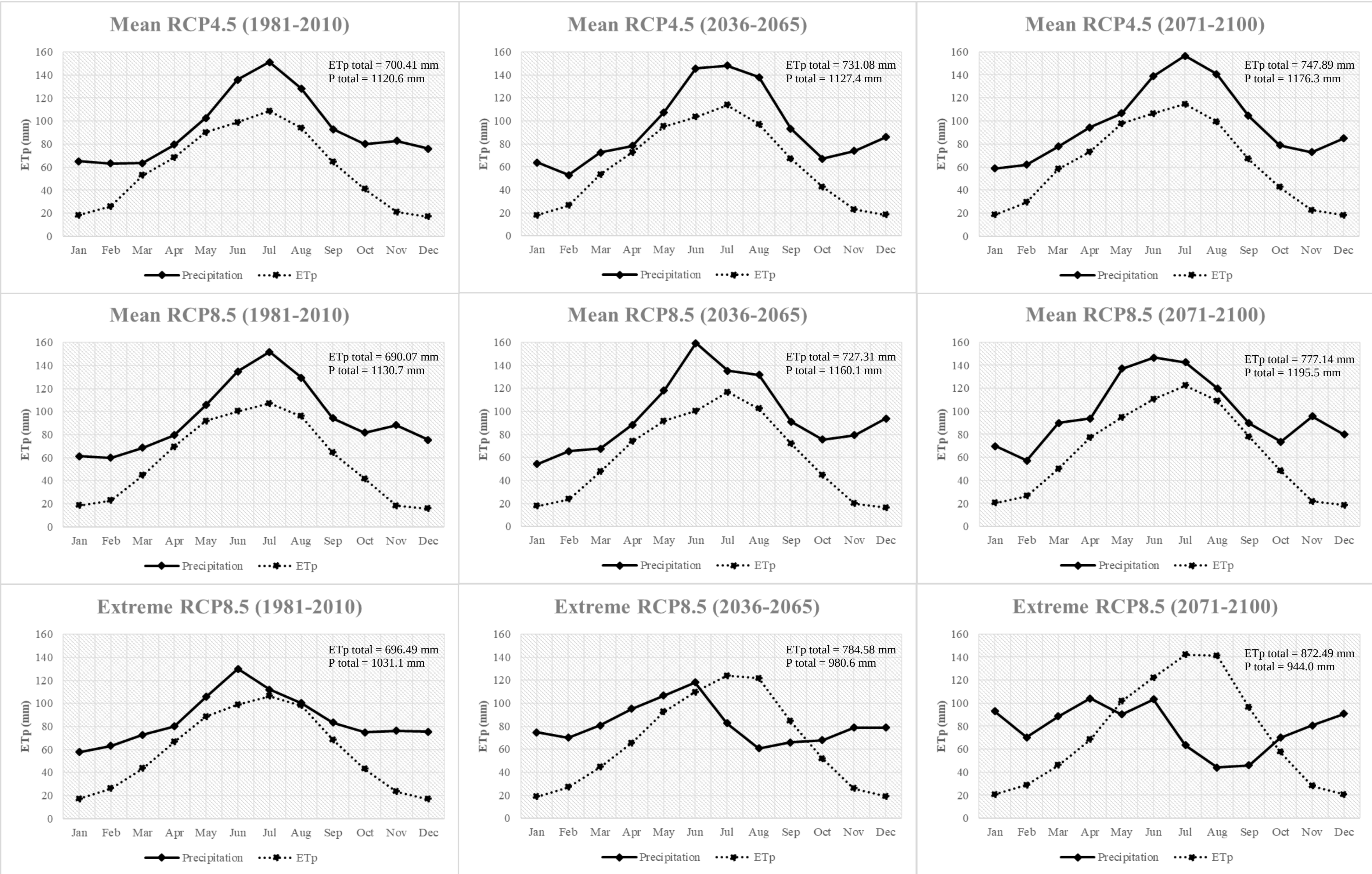

Figure 17 - Mean ETp and precipitation monthly distribution for each of the scenarios in the reference (1981-2010), mid-century (2036-2065) and century (2071-2100) periods. Both mean models show an increase in precipitation, keeping the same yearly pattern throughout the century. However, in the extreme case rainfall diminishes substantially for the summer months. In all cases, ETp rises also in the period between May and September.

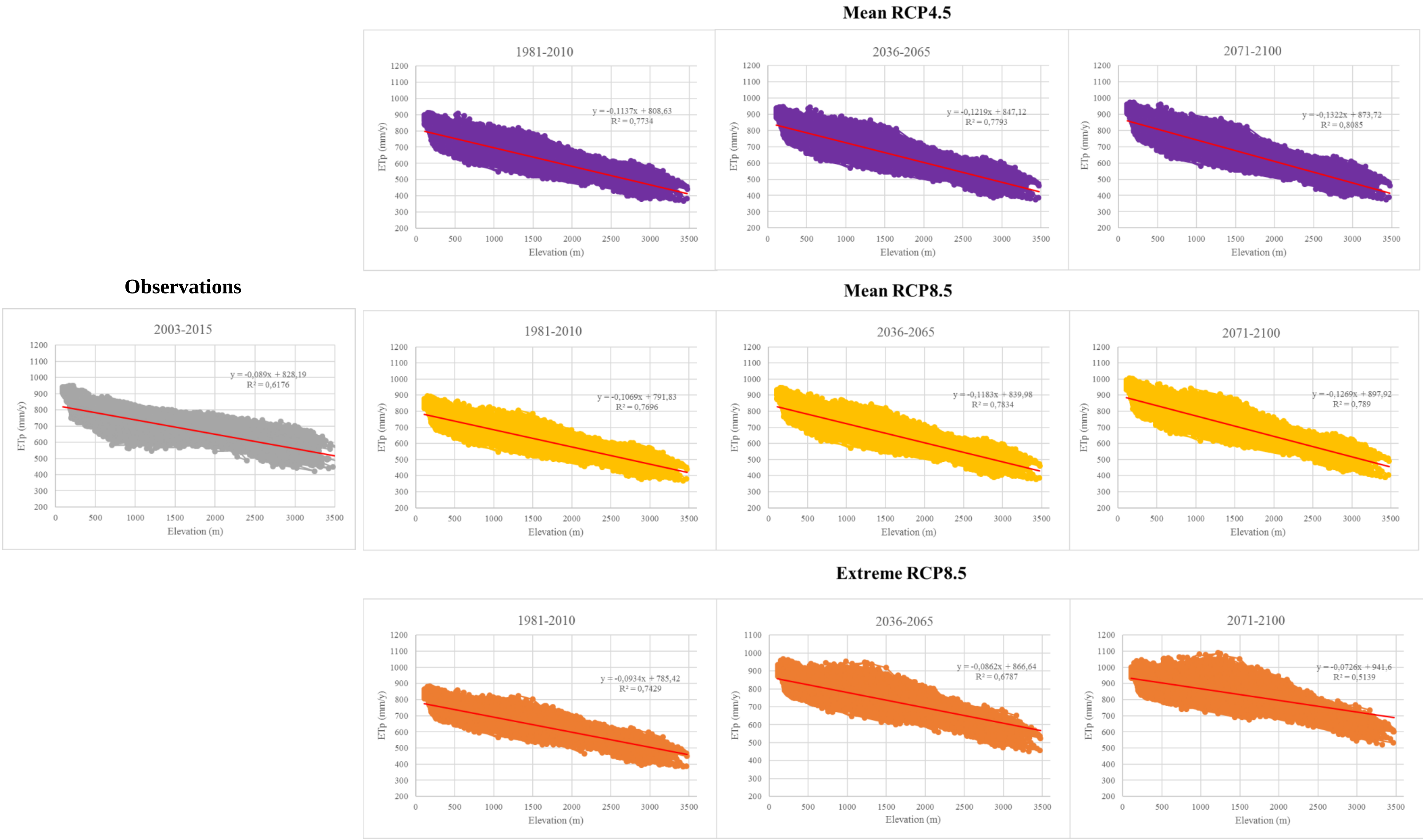

Figure 18 – Scatter plots of the relation between ETp and elevation for the observations and all scenarios. The Linear regression is also represented in the graphs, together with the equation and the coefficient of determination (R^2). Influence of elevation in the distribution of ETp in Austria is likely to be kept constant for the mean scenarios, however, in the extreme RCP8.5 it would lose significance.

Mean RCP4.5

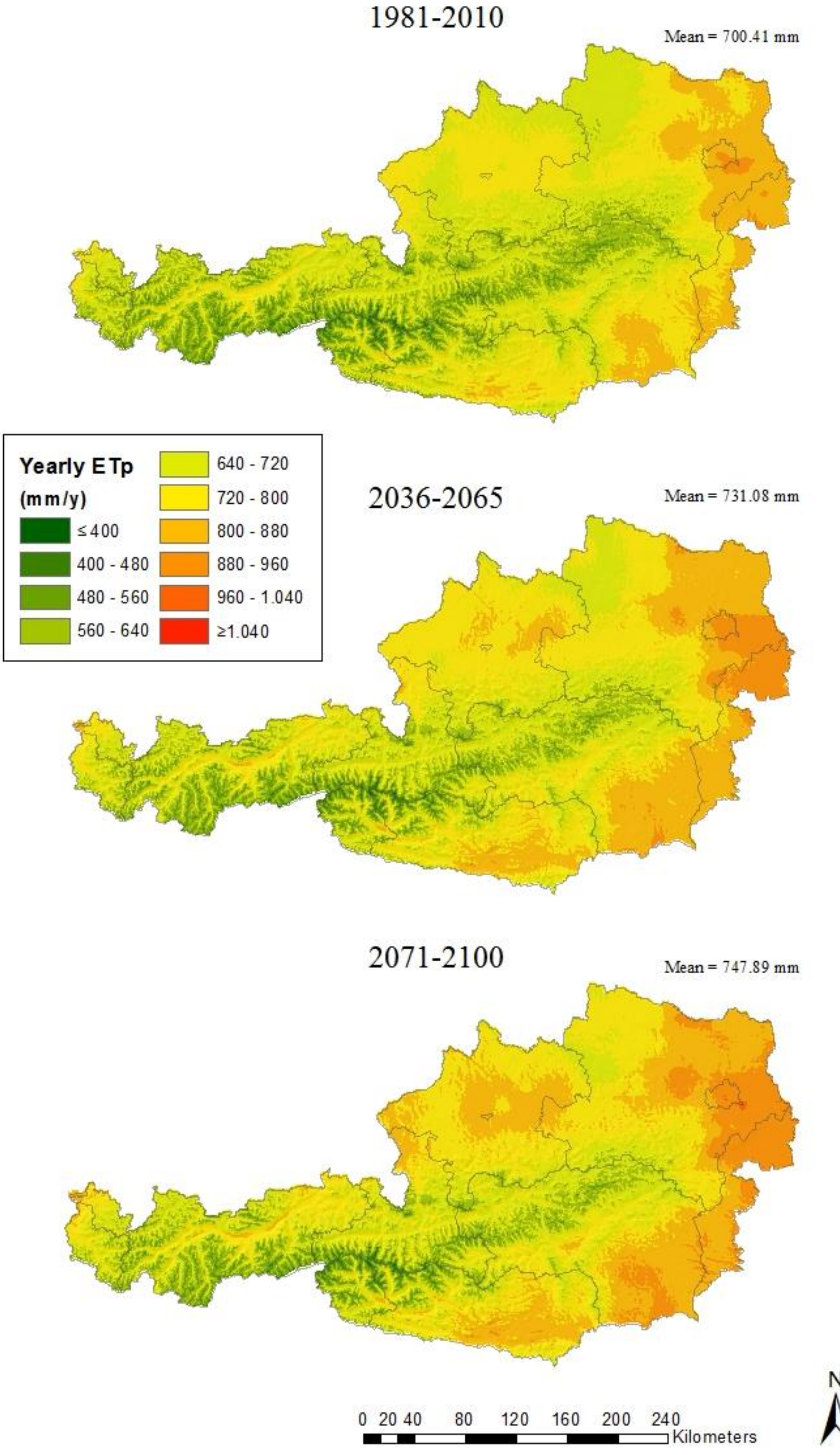

Figure 19 – Geographical distribution of ETp in Austria for the mean RCP4.5 scenario. In the East of the territory, where ETp values are higher, it is likely that warming temperatures will worsen the situation. Then, high values would also expand west following the lowest elevations towards the North and South of the Alps. More affection would be expected for the South of the territory than the North.

Mean RCP4.5

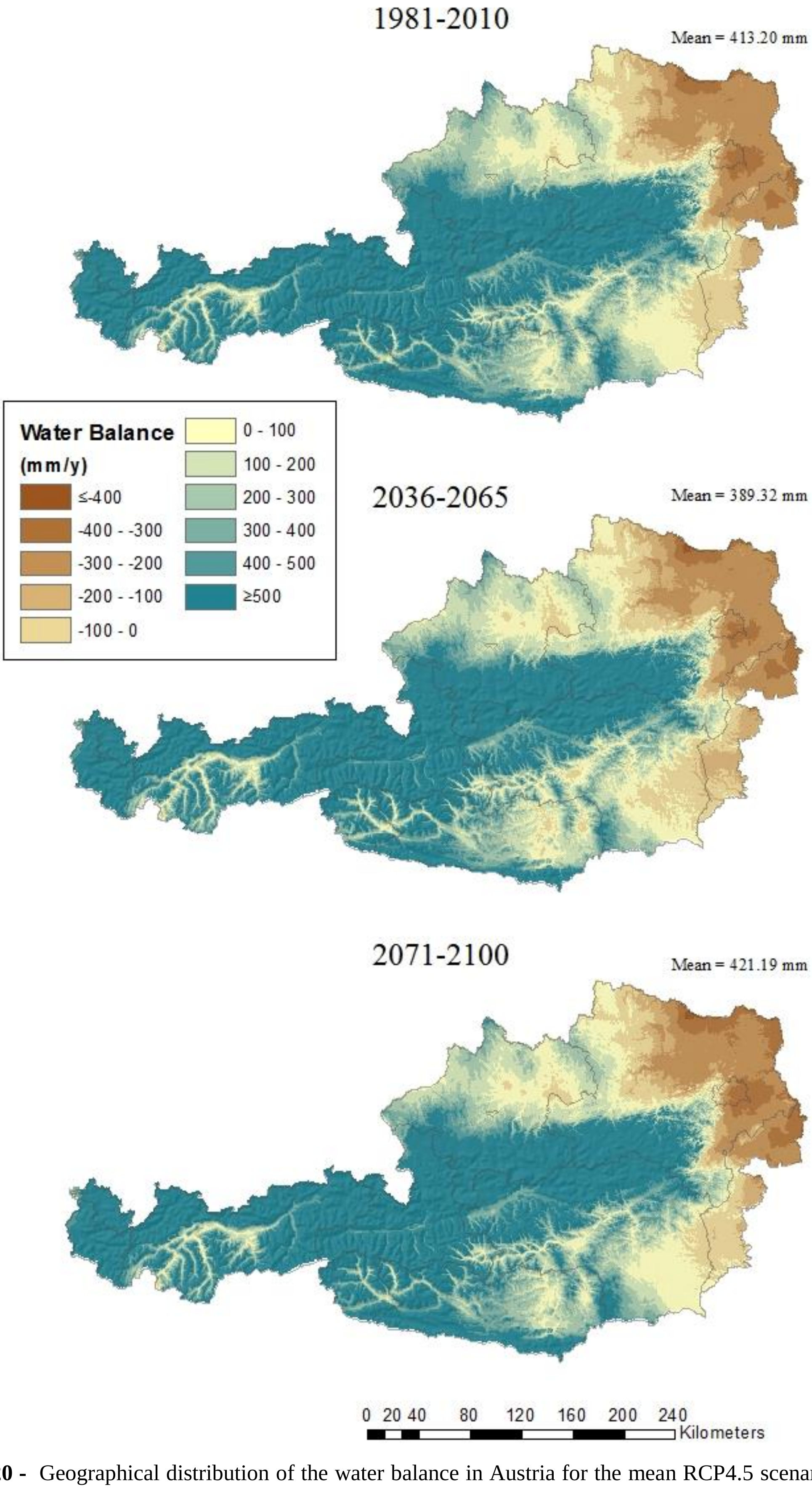

Figure 20 - Geographical distribution of the water balance in Austria for the mean RCP4.5 scenario. Clear water deficit is seen in the East of the territory, where ETp values are higher and precipitation lower. The increase of precipitation with climate change might counteract the drying trend of higher ETp, leaving an end situation similar to the reference period.

Mean RCP8.5

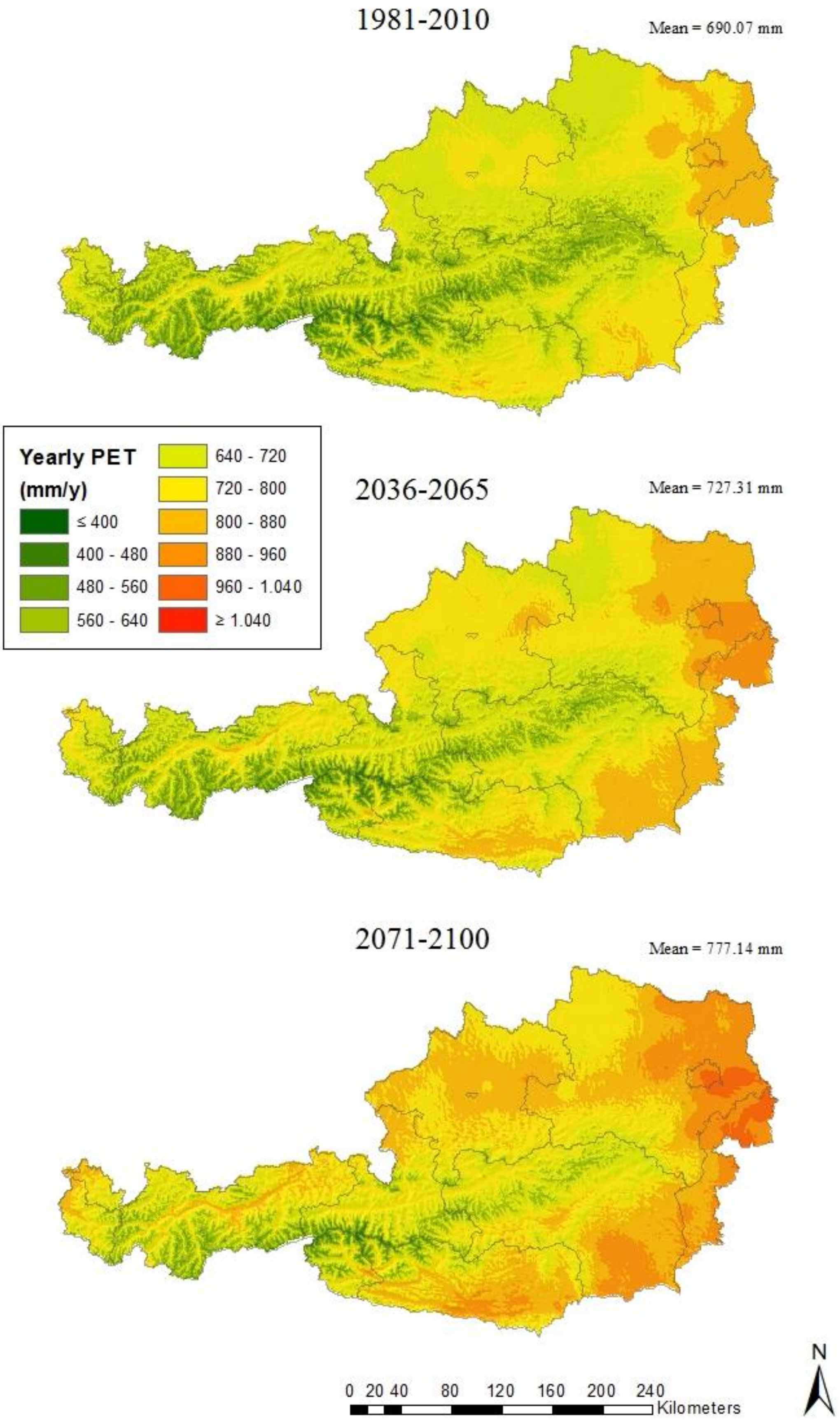

Figure 21 - Geographical distribution of ETp in Austria for the mean RCP8.5 scenario. Higher ETp values in the East are likely to expand west, following the lower elevations. Increase in ETp would even influence 1,000m elevations.

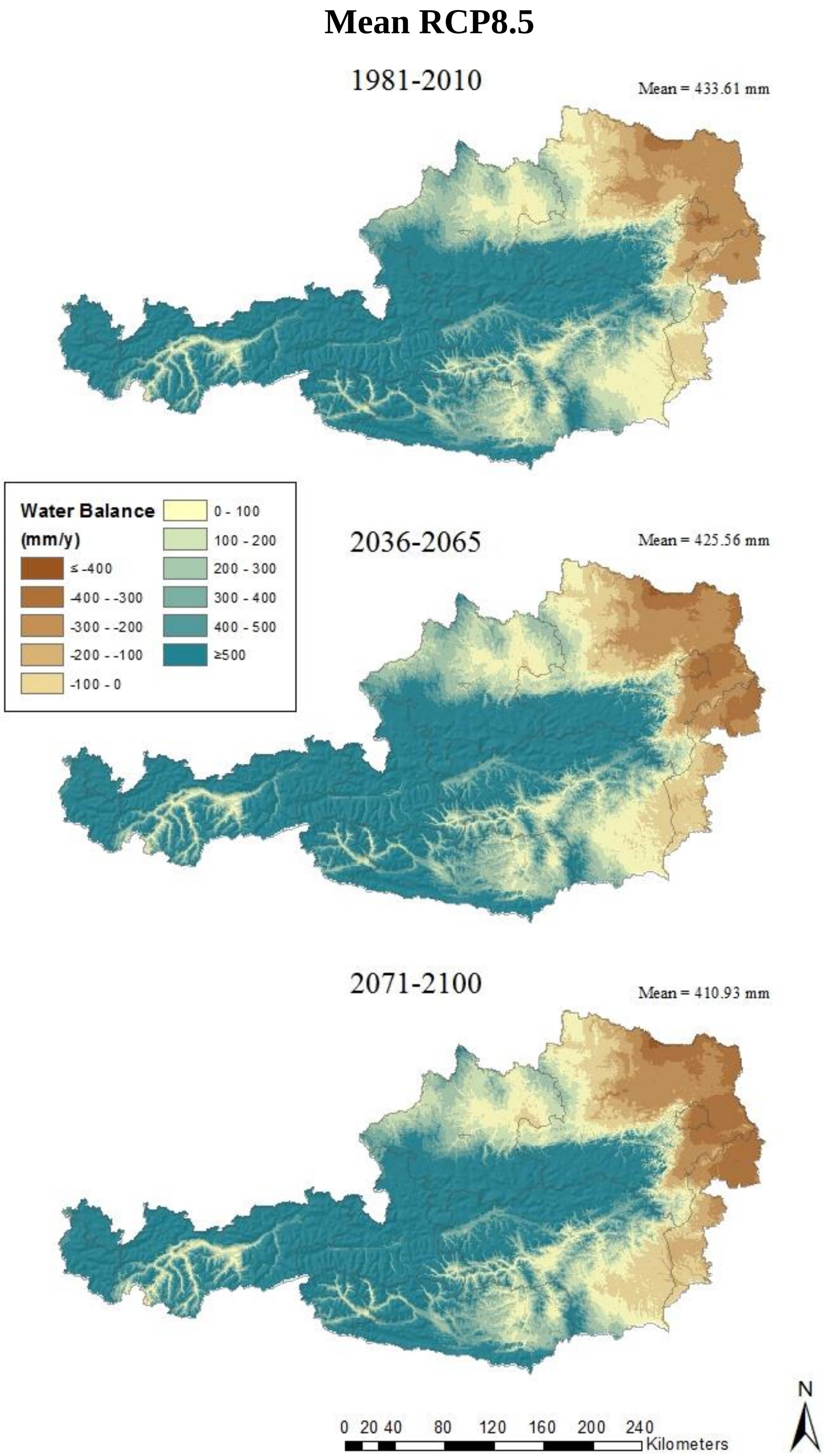

Figure 22 - Geographical distribution of the water balance in Austria for the mean RCP8.5 scenario. In the East of the territory, where ETp values are higher and precipitation lower, water deficit is spotted and expected to worsen. This poses a significant threat for agriculture (mainly present in such lowlands).

Extreme RCP8.5

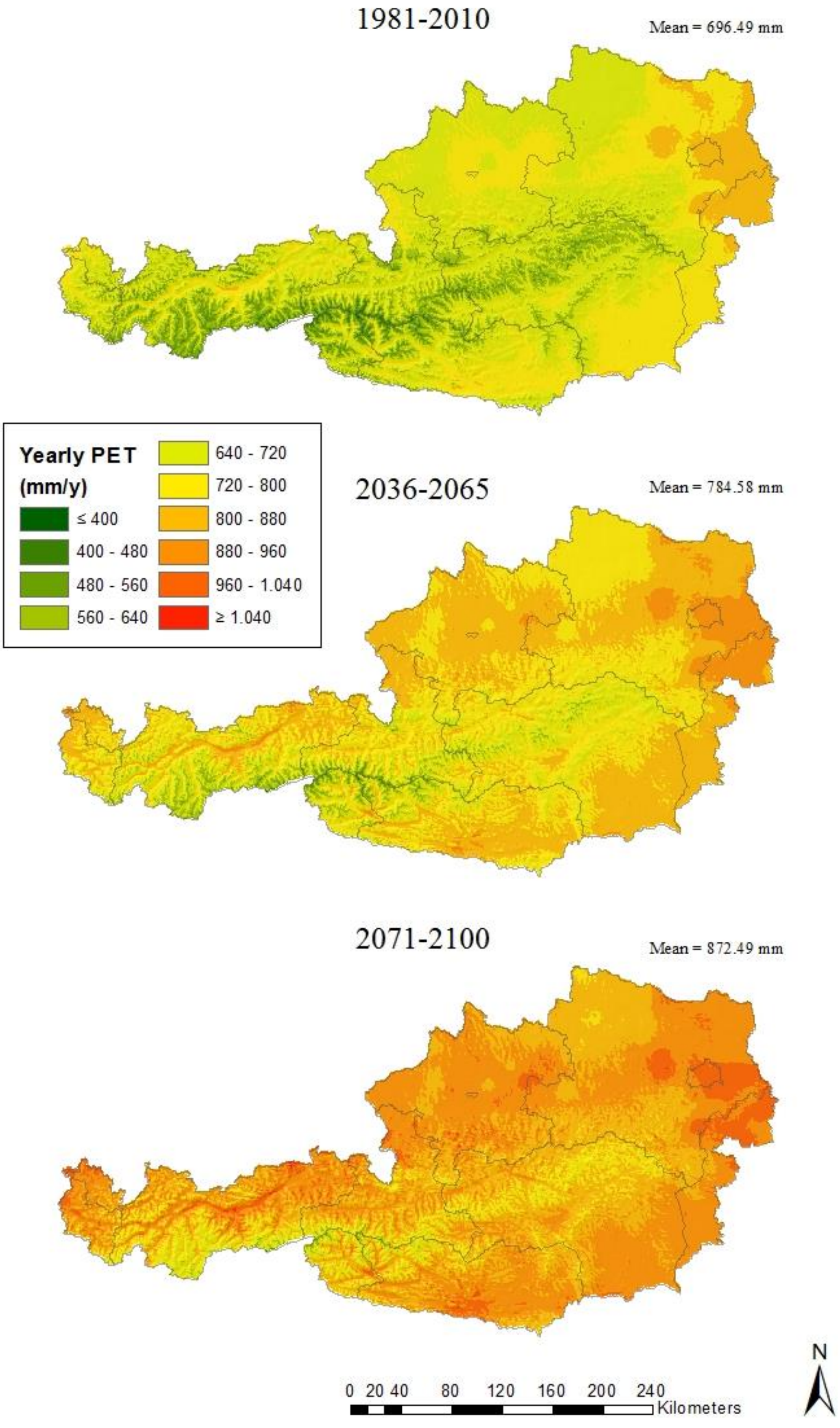

Figure 23 - Geographical distribution of ETp in Austria for the extreme RCP8.5 scenario. High values of about 900mm, which are just seen in the East of the territory for the reference period, are expected to be found overall the country by the end of the century in such business-as-usual scenario.

Extreme RCP8.5

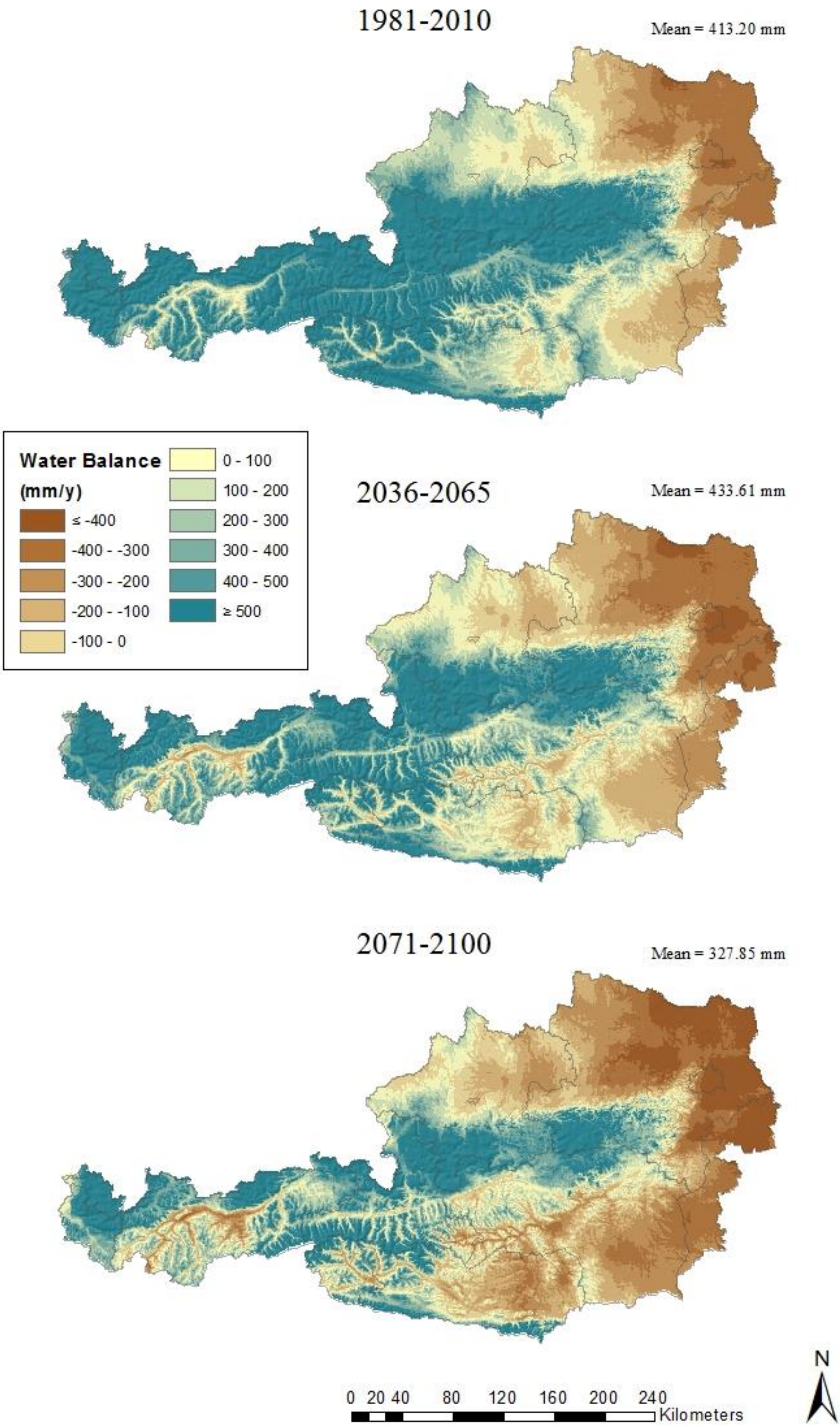

Figure 24 - Geographical distribution of the water balance in Austria for the extreme RCP8.5 scenario. Water deficit matches the East, where ETp is higher and precipitation lower. However, throughout the century precipitation is expected to decrease, threatening greater part of the country to be close to a drought situation.