INFLUENCE OF EVAPOTRANSPIRATION FORMULAS ON HYDROLOGICAL PROJECTIONS IN AUSTRIAN CATCHMENTS

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Affidavit

I Saga Palmquist hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

Abstract

Evapotranspiration (ET) is a primary part of the water cycle and essential in calculations of the water balance at catchment scale. Input data of potential evapotranspiration (PET) are commonly used for calculation of actual evapotranspiration (AET) in hydrological models. PET is likely to change with future climate conditions and these changes are expected to be important in defining changes in future discharge. Several current hydrological models and climate models do not calculate PET when applying data from climate models in hydrological modelling when considering impacts of climate change. Calculation of PET, hence has to be derived outside these hydrological models and from several available PET formulas. This paper aims to study the sensitivity in PET depending on the formula applied and its possible impact on hydrological projections in future time periods with changing climate conditions. Four PET formulas (Penman, Priestley-Taylor, McGuinness-Bordne and Thornthwaite) with diverse formula complexity are applied for calculation of PET and compared against each other in response to future climate changing conditions over two catchments in Austria. PET data is calculated from climate model data, for the time periods 1985-2014 (REF), 2021-2050 (FUT(MID)) and 2071-2100 (FUT(CEN)), driven by ÖKS15 (mean climate data derived from two different climate models over Austria). The climate model data are according to three different emission scenarios, RCP4.5, RCP8.5 and RCP8.5 hot (extremely dry scenario). AET and discharge projection were simulated by a conceptual semi-distributed model, applying PET data from the Penman formula according to RCP8.5 hot in the Ybbs catchment. Results illustrate that PET will increase in both future time periods according to all three RCPs, with the largest increases for FUT(CEN) and emission scenarios with stronger climate signal. Furthermore, the study indicates that large differences are seen in PET among the formulas in both catchments. The sensitivity due to PET formula are demonstrated to be higher in periods more distant in the future, FUT(CEN), compared to near future, FUT(MID), and with extreme emission scenarios. Salzach catchment illustrate higher uncertainty depending on the formulas in RCP8.5 and RCP8.5 hot compared to Ybbs catchment in annual relative change. The increased change in PET in the Salzach catchments seems to be connected to increased relative range in changing temperature. AET is found to increase in future time periods, however, demonstrated to strongly decrease compared to PET. Annual discharge projections are only expected to decrease for time periods more distant in the future. However, discharge decreases are seen in the summer months for both time-periods. The difference in PET data among the formulas might influence discharge projections in the two catchments. Examining annual values, higher sensitivity in discharge due to PET formulas are illustrated in time-periods more distant in the future according to emission scenarios with stronger climate signal. However, investigating individual months, presents the largest uncertainty in discharge due to PET formulas to be spread over different time periods and RCPs. Consideration of uncertainty connected to PET estimation by different formulas are proposed by this study when modelling hydrological projections in changing climate conditions due to the range in PET extent among the PET formulas applied in the two catchments. Special attention should be given to periods where PET and precipitation are in closer balance.

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1 Introduction

Since the late 19th century the global average temperature has risen by about 1°C (IPCC, 2018). The past decade (2006-2015) has been warmer than the average temperature between 1850-1900. A common understanding between the leading climate scientists is that the climate change is almost certainly caused by anthropogenic forces. A 0.2°C increase per decade is estimated to be caused by human global warming. Impacts from global warming on natural and human system has already been observed and is expected to cause large changes in the future (IPCC, 2018).

One of the most complex and least understood natural hazards, impacting a great extent of people is drought (Hagman, 1984). Drought is usually divided into four connected categories: meteorological, agricultural, hydrological, and socioeconomic (Mishra & Singh, 2010; Van Loon, 2015; Wilhite & Glantz, 1985). In Europe have recent trends of meteorological and hydrological droughts been seen (EEA, 2016). Some of the more recent severe events of these kind were recorded in 2007, 2011-2012, 2015 (Hanel, Rakovec, Markonis, Máca, Samaniego, Kyselý, & Kumar, 2018; Možný et al., 2016) and 2018 (Di Liberto, 2018). The drought events are projected to increasingly cause more damage and rise in frequency by the end of the 21st century due to global warming (Spinoni, Vogt, Naumann, Barbosa, & Dosio, 2018).

Central Europe is expecting an intensification in drought frequency, duration and severity as a direct effect of climate change. As a whole, water resources, biodiversity and the landscape will be affected by this, as well as key sectors like energy production, tourism, agriculture and forestry. However, before studying the impact caused by meteorological drought events, it is essential to understand the regional features of meteorological drought. Mozny et al. (2016) showed that a consistent drying trend between 1961-2014 was found in Central Europe. The main driver of the meteorological drought was an increase in evaporation demand rather than changes in precipitation. The increased evapotranspiration was driven by increasing temperature and incoming solar radiation plus decreasing relative humidity (Možný et al., 2016).

On planet Earth are climate and water closely linked. Climate changes in the climatic system evoke changes in the water system, and vice versa (Kundzewicz, 2008). Water extracted from rivers or indirect water reservoir, supplies over half of the worlds potable water stock (Barnett, Adam, & Lettenmaier, 2005). Except water resources being an essential part of human substance, water plays a key role in the mix of renewable energy sources such as hydropower. Hydropower supplies about 20 % of the global electricity demand, making it the most important renewable energy source in the world (Panwar, Kaushik, & Kothari, 2011). Austria's largest contributor to electricity is hydropower, providing approximately 60 % of the electricity (Bundeministerium Nachhaltigkeit und Tourismus, 2018). The rivers and water resources supplying hydropower systems are already being changed by anthropogenic impacts such as land use changes and are projected to be further affected by climate change (Lobanova, Liersch, Nunes, Didovets, Stagl, Huang, Koch, Rivas López, Maule, Hattermann, & Krysanova, 2018; Van Vliet, Franssen, Yearsley, Ludwig, Haddeland, Lettenmaier, & Kabat, 2013). It is indicated by observational evidence that an intensification of the water cycle, with increasing rates of evapotranspiration is ongoing (Kundzewicz, 2008).

Evapotranspiration is an important mechanism of the water cycle and one of the major processes returning water vapor to the atmosphere. It is composed of two sub-processes, removal of water from soil, vegetation surfaces and open water bodies as evaporation and transpiration from plants (Senay et al., 2014). Evapotranspiration is dependent on several of climatological variables such as air temperature, wind speed, net radiation, soil moisture and soil hydraulic properties, thus is an efficient indicator, reflecting the climate change (Xie & Zhu, 2013). Valuation of evapotranspiration is an essential variable in assessment of climate change impacts on water resource (Yates, D., Strzepek, 1994). Within hydrological modelling the accounting of evapotranspiration estimation is a necessity. The input variables rainfall and potential evapotranspiration (PET) is mostly required as a minimum in continuous simulation hydrological models. Where PET could be described as the amount of water that would be transferred to the atmosphere in form of evapotranspiration if enough water at all time is available (Kay & Davies, 2008).

Considering of associated uncertainty in hydrological systems and climate change impact studies is an essential step though the usefulness of hydrological projections otherwise could be limited (Georgakakos, Seo, Gupta, Schaake, & Butts, 2004; Wagener & Gupta, 2005). Investigation of four levels of uncertainties is considered in most studies for a thorough uncertainty analysis on hydrological projections. First greenhouse gas emission scenarios, second global climate model (GCM) outputs, third downscaling techniques and last the hydrological model (Maurer, 2007; Wilby & Harris, 2006). Inner uncertainties exist in all four sources of uncertainty. Last mentioned uncertainty, hydrological model, is partly dependent on inputs (measurements and estimations). Evapotranspiration estimations, rainfall, temperature and other meteorological data are all part of these input uncertainties. The first mentioned hydrological modelling input uncertainty, evapotranspiration estimations, is a key part when studying the future climate change on water resources (Seiller & Anctil, 2016).

Even if the impact of different evapotranspiration estimations in hydrological projections in a climate change context, not have been largely researched, there are some studies which has studied this area. In one of the studies, comparing two different PET methods, applying climate model data according to SRES A2 emission scenario, developed by Nakicenovic & Swart (2000), for the period 2071-2100, great differences in calculations of PET were shown (Kay & Davies, 2008). The result was pointed out as to possible have a big impact on water resource projections in changing climate conditions. Additional studies has suggested that when looking at hydrological projection in a climate change context the choice of PET formulas could play an important role (Donohue, McVicar, & Roderick, 2010; Seiller & Anctil, 2016). The impact of difference in PET estimations to hydrological projections in conditions of changing climate could have a particular effect in areas where the magnitude of precipitation and PET is in close balance (Kingston, Todd, Taylor, Thompson, & Arnell, 2009).

Aim

This thesis aims to study the sensitivity in PET projection and its application in hydrological projections, depending on the choice of PET formula, with the consideration of climate change according to different emission scenario and time periods, in the sites of interest.

- To illustrate four different available options for evapotranspiration estimation for future scenarios
- Analyse the various evapotranspiration estimations in relation to different emission scenario, future periods and catchments applied
- Discuss how hydrological projections potentially varies depending on the PET formula

Relevance

Evapotranspiration (ET) plays an important part in the hydrological cycle and is found to be the variable with largest impact on drought in Central Europe. Additionally, climate change is projected to impact the hydrological cycle, further elevating ET as a consequence of rising temperature. As a result, ET is an important variable in hydrological modelling during periods and geographical regions where potential evapotranspiration (PET) is close to the amount of precipitation. ET estimations are one of the input uncertainties in hydrological modelling and several studies have suggested the choice of evapotranspiration formulas in hydrological projection, highlighting its importance in a changing climate.

This thesis is part of a larger project called Powerclim, which initial started 2011 and examined possible effects of climate change on water balance and potential hydropower energy projections over 10 catchments in Austria (Holzmann, Formayer, Massmann, & Becsi, 2018). The project is conducted in collaboration between the Institute for Hydrology and Water Management (HyWa) and Institute of Meteorology and Climatology (BOKU-Met) at the University of Natural Resources and Life Sciences, Vienna (BOKU). Because of recent dryer years, BOKU has extended the project Powerclim, to investigate the effects on water balance in future more extreme climates conditions. This study takes part in the extended part of the project.

1.1 Objective

To achieve the aim, this paper analyses the sensitivity in PET projections and its application in hydrological projections depending on the choice of different PET formulas in a changing climate by:
1) providing four available options for evapotranspiration estimations
2) consider the four PET estimations methods at two catchments
3) evaluate this in the context of climate change for two future time periods according to three different emission scenarios RCP4.5, RCP8.5 and RCP8.5 hot, with climate data derived from two different climate models
4) providing AET and discharge projections applying PET data from one formula and one catchment according to RCP8.5 hot
5) Discuss the PET results in relation to hydrological projections, in comparison with earlier findings in the field

The study is completed over two catchments in Austria, based on climate data for the reference period 1985-2014 and two future periods, 2021-2050 and 2071-2100 according to three different emission scenarios. Three of the four PET estimations methods are calculated in a package called Evapotranspiration package comprised in the software program for statistical analysis called Rstudios and one is given. PET results are compared and illustrated in Excel and Rstudios. Following, AET and discharge projections are simulated for Ybbs catchment applying PET data for the Penman formula, according to RCP8.5 hot in the conceptual, semi-distributed hydrological model (BOKU- IWHW). Next, PET, AET and discharge results are analysed and discussed.

1.2 Evapotranspiration

Evapotranspiration is the reverse of precipitation, representing the transport of water from earth surface back to the atmosphere (Thornthwaite, 1948). It has a major role in the exchange of mass and energy between the soil-water-vegetation system and the atmosphere (Senay et al., 2011). Evapotranspiration is represented as the combination of evaporation from soil surface and transpiration from plants, which involves the exchange of moisture between the plant and the atmosphere through plant stomata (Senay et al., 2014; Thornthwaite & Mather, 1951).

1.2.1 Evaporation

Evaporation is the process which occurs when liquid water is converted into water vapor and removed from a surface to the atmosphere. Input of energy either from the sun or from the atmosphere itself need to be present for the process to occur naturally (Shuttleworth, 1979). Evaporation is driven by climatological variables such as solar radiation, air temperature, wind speed and vapour pressure and is thereby directly affected by climate change (Helfer, Lemckert, & Zhang, 2012). Other factors effecting the process is the amount of water available at the surface and the degree of shading of the crop canopy (Allen, Luis, RAES, & Smith, 1998).

1.2.2 Transpiration

The physical process transpiration consists of the removal of water vapor from liquid water contained in the plants and the transfer to the atmosphere. The major part of this process is through stomata (Allen et al., 1998; Kozlowski & Pallardy, 2007). Transpiration is affected by both external physical and physiological factors. Radiation, air temperature, air humidity and wind speed, are all part of the physical factors influencing transpiration. Further, the physiological process is affected by the soil water content, the ability of the soil to conduct water to the roots as well as crop characteristics, environmental aspects and cultivation practices (Allen et al., 1998). Vapour pressure between the inside leaves and the humidity of its surrounding air, is the major force driving the transpiration (Kirschbaum, 2004).

1.2.3 Factors effecting evapotranspiration

Evapotranspiration (ET) is a continuous process which commonly is presented in a similar way to that of precipitation, such as water transfer over a specific time period, usually in units of millimetres/day (Brown, 2000).

A variety of soil features, plant and meteorological factors affect ET in a complex way (Akerman, 2016). The main factors affecting evapotranspiration are soil moisture, meteorological (climate variables), plant type and development, land management and environmental factors, where the primarily factor being soil moisture (Allen et al., 1998; Brown, 2000). If the total amount of water in the soil is less than the wilting point, the process cannot take place.

Meteorological conditions play a key role in evapotranspiration, providing the amount of energy of vaporization and transfer of water vapor from the surface (Allen et al., 1998; Brown, 2000). The two fundamental components energy balance (determines the latent heat of the vaporization) and mass transfer (influences the rate of transfer of water vapor away from the evaporating surface) drive the ET process. The four key climate variables connected to ET, solar radiation ($R_{s)}$, wind speed (U_z), air humidity (RH) and temperature (T), combines the two components energy balance and mass transfer (Guo, Westra, & Maier, 2016).

Solar radiation
The quantity of energy available, for altering liquid water into water vapor, determines the ET process (Allen et al., 1998). Solar radiation is the main source of energy on earth, it is the meteorological variable with the greatest impact on ET during most days of the year (AI-Barrak, 1964; Akerman, 2016). It contributes with great amounts of energy, able to vaporize water. Radiation varies at diverse latitudes and various seasons, due to difference in the position of the sun. As well, turbidity of the atmosphere and the cloud cover has effect on the actual solar radiation reaching the ET surface (Allen et al., 1998). Important is that, not all the accessible solar energy is used to vaporize water, but is part of the energy used to heat up the atmosphere, the soil and vegetation (AI-Barrak, 1964; Allen et al., 1998).

Wind
Wind and air turbulence transfer great amount of air masses over the evapotranspiration surface and has an important role in the removal of water vapour. The air above the evaporating surface becomes

increasingly moist of water vapour in the process of vaporizing water. By enhancing removal of water vapor from the saturated surface to the dryer atmosphere, wind acts as driving force in the transfer of water vapor. If the moist air not continuously is transferred and replaced with dry air, the evapotranspiration rate will decrease (Allen et al., 1998; Brown, 2000). In a dry, hot and windy day, the rate of evapotranspiration will be larger than in a cool, damp and still day (AI-Barrak, 1964)

Air Humidity

Together humidity and temperature determine the dryness or the drying power of the atmosphere. Air humidity can be expressed in several of ways, including vapor pressure, dewpoint temperature and relative humidity. Air humidity or the difference between the water vapor pressure of the surrounding air and at the evapotranspiring surface, is the most vital factor for removal of water vapour. The meteorological variable vapor pressure deficit (VPD) is a precise indicator for the actual evaporative capacity of the air and is influenced by air temperature and air humidity. That means the difference between the actual vapor pressure in the air and the saturation vapour pressure. The saturation vapour pressure is the corresponding pressure at which water molecules, transferring back and forth between the water surface and the air, has reached an equilibrium. When the air is not saturated, the actual vapor pressure will be lower than the saturation vapour pressure. In hot dry arid regions, the evaporative demand is high over a watershed while in tropical (warm) humid areas, the demand is reduced even if the temperature is high due to the high humidity of the surrounding air (Allen et al., 1998; Brown, 2000).

Air Temperature

Air temperature impacts VPD, thereby ET, as stated in the former paragraph. Higher air temperature leads to higher storage capacity of water molecules in the air and thereby higher saturation vapour pressure, see **figure 1**. Adding to this, air temperature has influence on ET by the transferring of energy to crop from the heat in the surrounding air. Less energy is needed for evapotranspiration when the vegetation is warm compared to cool. Consequently will ET be higher in sunny warm weather than in cloudy and cool weather (Allen et al., 1998; Brown, 2000).

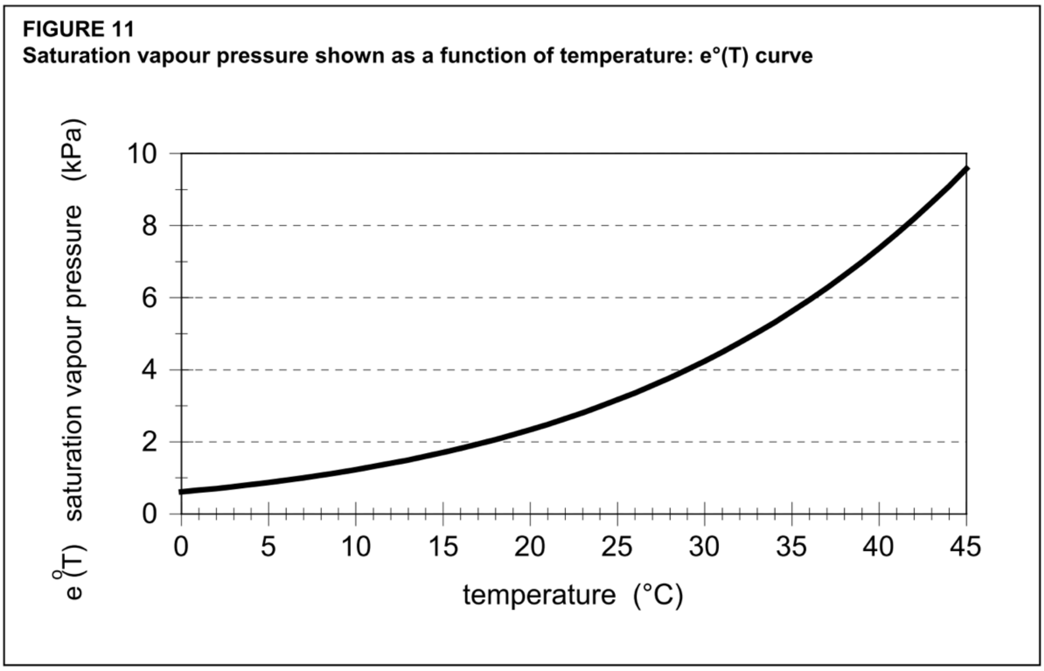


Figure 1. Temperature and saturation vapour pressure (Allen et al., 1998).

As weather variables change over the year, due to seasonal shift, the amount of evapotranspiration also shifts depending on the season. Runoff is produced from the water remaining after the ET process is satisfied. The extent of PET, **section 1.2.5**, is important for areas and seasons where the addition of water through precipitation are close to the degree of PET. Though, soil water might result in being a limiting factor to actual evapotranspiration, **section 1.2.6**, with small changes in PET magnitude (Prudhomme & Williamson, 2013).

1.2.4 Reference evapotranspiration

Reference evapotranspiration (ET_{ref}) is the rate of evapotranspiration from a reference surface with sufficient water at all time (Allen et al., 1998). ET_{ref} is a type of standardized PET, ET_{ref} is the evapotranspiration from a surface covered by crops with specific characteristics (McMahon, Peel, Lowe, Srikanthan, & McVicar, 2013; McVicar, Van Niel, Li, Hutchinson, Mu, & Liu, 2007). Precisely, a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23 composes the reference surface. The reference surface closely mimic a large-scale surface of green, with grass of similar height and well-watered, actively growing and fully shading the ground (Allen et al., 1998). ET_{ref} in combination with the crop coefficient offers a practical parameter for hydrological, agricultural and environmental models to evaluate the global water cycle impacts of climate change (McVicar et al., 2007).

1.2.5 Potential Evapotranspiration

The concept PET was first introduced by (Thornthwaite, 1948) and the first method for calculation of PET was developed by Penman (1948), in in middle of the 2000 century. The concept has since played an essential part of many water balance, drought and vegetation growth studies (Lockwood, 1999). Thornthwaite (1948) defined PET as the amount of water that could evaporate and transpire from a surface entirely covered by vegetation and with, at all time, sufficient soil moisture for the use of the vegetation. No crop with specific characteristics is included in calculation of PET. Potential evapotranspiration also includes evaporation from open-water, which e.g. can be calculated from pan evaporation multiplied with a pan coefficient, see **section 1.2.7** (McMahon et al., 2013). In contrast to actual evapotranspiration (AET), PET is dependent only on climate conditions. It signifies not the real but the possible removal of water in ideal conditions of soil moisture and vegetation (Thornthwaite & Mather, 1951). AET and PET will be equal if sufficient water is available for both sub-processes in evapotranspiration. If not fulfilled, PET will be higher than AET (Seiller & Anctil, 2016).

1.2.6 Actual Evapotranspiration

AET is the amount of water that evaporate and transpire, under natural conditions where the process is limited by available soil moisture. In addition to the limitation of the available amount of water, AET is also dependent on climatic factors (Thornthwaite & Mather, 1951; Xu, Singh, Chen, & Chen, 2008). For estimations in a general case, AET is mainly determined by PET, soil moisture and vegetation statues also referred to as the crop coefficient (Labedzki, 2011).

1.2.7 Estimation of Evapotranspiration

To determine evapotranspiration directly, particular devices and precise measurements of several physical parameters or the soil balance in lysimeters, are needed. These procedures can only be properly done by educated research personnel and are commonly expensive and challenging in terms of correctness and measurement. This makes direct measurement of evapotranspiration difficult to obtain (Allen et al., 1998).

An easier and successful estimation of evapotranspiration is usually done by empirical measurement using the pan evaporation method. Firstly, the method contains observation of evaporation loss from a water surface, which delivers directory of the joined effect of evapotranspiration from the meteorological variables' radiation, air temperature, air humidity and wind. Secondly, a pan coefficient multiplied with the evaporation estimations from the pan (Allen et al., 1998). The coefficient is included to adopt the estimation to a specific climate region and water losses from crop (Allen et al., 1998; Karlsson & Pomade, 2004)

A further generally applied method is calculation of ET from climate data (Allen et al., 1998). Several numbers of empirical or theoretical formulas has been developed for calculation of PET. Some of the most frequently used are Penman, Thornthwaite and Turc (Karlsson & Pomade, 2004). Estimations of PET by Penman and Turc formulas has been showed to obtained the same kind of accuracy as lysimeters or evaporation pans (Rijtema, 1959).

In this study PET is calculated from climate data by four different PET formulas, Penman, McGuiness-Bordne, Priestley- Taylor and Thornthwaite, see **section 4.2.1.**

1.3 PET and climate change

The global warming is expected to increase further during the next century. If it increases at the current rate the global temperature is likely to reach 1.5 °C above the pre-industrial level, between 2030 and 2052. Big differences in regional climate conditions are projected to be caused by future climate change. Mean temperature in most land and ocean regions (*high confidence*), hot extremes in most inhabited regions **(***high confidence***)**, heavy precipitation in several regions **(***medium confidence***)**, and the probability of drought and precipitation deficits in some regions **(***medium confidence***)**, are some of the differences in regional climate conditions expected to increase (IPCC, 2018).

Trends of increase in climate and weather extremes intensity and frequency has already been detected at which global warming of 0.5 °C has occurred (IPCC, 2018). Over the last 20 years several of dryer years has occurred over Europe, as example the years 2007, 2011-2012 and 2015. The dryer periods in future climate is expected to affected several industries, including agricultural and energy production (Možný et al., 2016).

1.3.1 Climate change effects on PET

An intensification of the water cycle is expected with climate change (Huntington, 2006; Oki & Kanae, 2006). Evapotranspiration, as one of the main components in the water cycle is also affected by climate change. Further, the climate variables, which PET is dependent on, solar radiation, air temperature, vapor pressure, wind speed and humidity are also effected by climate change (Donohue et al., 2010; Jahanbakhsh-Asl, Dinpashoh, Singh, Rasouli, & Foroughi, 2018).

However, the climate variables are found to have diverse effects on the evaporation demand in a changing climate. First, with higher temperature the ET rate is known to increase (Snyder, Moratiel, Zhenwei Song, Swelam, Jomaa, & Shapland, 2011). The temperature has a direct effect on the surface vapor pressure deficit (VPD), when the temperature rises and there are small changes in air humidity, the VPD increase leading to increased evaporation demand (Dai & Zhao, 2017; Dai, Zhao, & Chen, 2018). In contrast to air temperature, both greater CO_2 concentrations and increased humidity tend to decrease transpiration and thereby ET. To maintain CO_2 concentrations inside the stomata, leaf stomata partly close, consequently as CO_2 concentrations rise. Leading to, transpiration from the plants will decrease. In future climate change the air temperature is expected to increase and the CO_2 levels elevate. Global humidity is also likely to increase as the oceans and other water bodies warm and evaporate more water into the atmosphere (Snyder et al., 2011).

It has amplified that the effect of increased CO2 concentrations will have a significant reducing effect on the predictions of future continental drying (Swann, Hoffman, Koven, & Randerson, 2016). Other analysis showed that the drying effect due to increase in air temperature dominates and will lead to a rise in ET (Dai et al., 2018; Scheff & Frierson, 2014).

Evapotranspiration is one of the parameters influencing drought and the most significant component of the hydrologic budget apart from precipitation (Hanson, 1991). Higher evaporative demand is leading to increased aridity and more drought if not balanced by precipitation (Sheffield & Wood, 2012). Drought cause damage on people and several of sectors including agriculture and energy production (Možný et al., 2016; Wilhite, 2000). In future changing climate conditions, drought is one of the likely consequences in several of region of the world (IPCC, 2018; Sheffield & Wood, 2012). In the widely used drought index, Palmer Drought Severity Index (PDSI)(Palmer, 1965), precipitation and PET are estimations applied to estimate the water balance equation. Understanding evapotranspiration is therefore essential for understand and quantifying drought (Scheff & Frierson, 2014). Dai and Zhao (2017) find that increased PET after the 1980s, significant has enriched drying. In consensus has, several studies put forward increased evapotranspiration due to increased future global warming as a one of the main variables driving a strong global trends toward drought or aridity (e.g Dai, 2013; Feng & Fu, 2013; Scheff & Frierson, 2014). Though, indicated is that historical and future tendencies towards continental drying may have been overstated, due to overestimations of potential evapotranspiration by the Penman–Monteith, in calculations of offline-computed runoff and other PET-dependent metrics (Milly & Dunne, 2016). However, in an recent study has evapotranspiration been stated as the driving factor of drought in central Europe (Možný et al., 2016).

Climate change effects on ET, also influence regional discharge and runoff. Some studies project that runoff could decrease due to increased ET in mid-latitudes and subtropical regions (Huntington, 2006). Further, decreases in discharge due to increased PET in Europe (e.g river Danube) are also projected in the future (Nohara, Kitoh, Hosaka, & Oki, 2006).

To conclude, climate change will have an effect on ET, which in turn will affect the water cycle and water balance, as well as most probably enhance drought. The exact effect on ET is not agreed on. Yet, ET is projected to impact future discharge in Europe (Danube), leading to decrease in runoff. In addition, stated as the most important parameter driving drought in Central Europe. This making ET an important factor in hydrological projection modelling in a changing climate in Austria.

1.3.2 Expected climate change in Austria

The Austrian temperature has risen almost by the double, close to 2 °C compared to the increases in global temperature of 0.85 °C since 1880. The much large increase of temperature could be notice predominantly from the period after 1980. Approximately a further increase of 1.4 °C is predicted in Austria until around year 2050. Because of the permanency of greenhouse gas in the atmosphere and the slowness in the climate system, the temperature increase is not largely affected by the emission scenario adapted. However, in years after 2050 is the temperature development very influenced by anthropogenic global warming and therefore also by the emission scenario (APCC, 2014).

Substantial regional differences in precipitation patterns has been showed in the last 150 years in Austria. Increases of annual precipitation of around 10-15 % was noted in the western parts, while decreases of around the same degree was recorded in the southeast. Because Austria is situated in a transition zoon between to areas with opposite trends, stretching from decreases in the Mediterranean to increases in

Northern Europe, no clear trend signal of annual average precipitation in Austria for 21st centaury is showed (APCC, 2014).

For all Alpine stations has the annual sunshine duration increased over the last 130 years. The increase is measured to about 20% or 300 sunshine hours. Cold nights have been rarer while the hot days have become more frequent due to change patterns of temperature extremes.
In the future, climate warming trends are expected, as well as increasing probability of extended summer droughts. Leading to increased risk of forest fires in Austria. Further, the development of temperature extremes, which already has been seen, are predicted to intensify and as a consequent the frequency of heat waves will likewise increase during the 21st century (APCC, 2014).

The changing climate conditions will most likely impact the weather-dependent sectors such as; agriculture and forestry, tourism, hydrology, energy, health and transport and the sectors linked to these (APCC, 2014).

1.4 Climate models

A short overview of climate models is presented in this section. Climate models provides climate data for calculation of evapotranspiration in this study, thus are these an important part of the paper.

The climate system extent over a large size and works on long time scales, owing to this can the system not be studied by experimental methods (Edwards, 2011). Thus, to investigate earth climate, climate models are applied. They represent the climate system mathematically and includes known physical, chemical and biological properties as well as interactions and feedback processes of the climate system (IPCC, 2007a).

For estimations of future climate projections for the current century and further, creating climate prediction on long- and short-time scales, as well as for examining the climate systems response to different forcing's, climate models are an essential tool (Edwards, 2011). Climate models are additionally used in stimulating the paleo or historical climate data, for attribution and for physical knowledge through application in sensitivity and process studies. Last, provides climate models more details at regional and local scale, through downscaling of global climate projection (Flato et al., 2013).

The climate models are grounded in well-established physical principles (IPCC, 2007b). From the range of simple climate models such as energy balance models to models demanding high-performance computing, such as complex Earth system models (ESMs), are used in studies of the climate (Flato et al., 2013).

For examining climate systems on a larger scale global climate models (GCM) are applied, while regional climate models (RCM), are used for smaller regions. Further, models are also used for integrated assessment and are called Integrated Assessment Models (IAM). The typical spatial resolution of GCM and RCMs are illustrated in **table 1.**

Table 1. Typical spatial resolution for GCM and RCM (Sørland, Schär, Lüthi, & Kjellström, 2018).

	GCM	RCM
Spatial resolution (km)	100-300	10-50

1.4.1 Global climate models (GCM)

The GCM cover the whole atmosphere, including the complete surface of earth and the air above it. Several of climate aspects are included, counting; the temperature of the atmosphere and the oceans, precipitation, winds, clouds, ocean currents and sea-ice extent (IPCC, 2014; SMHI, 2019). The atmosphere, over and above the earth surface, is divided into a 3-dimensional grid. The 3-dimensional grid includes land surfaces, sea and ice cover. A quantity of meteorological, hydrological and climatological parameters is computed over time for every grid point of the model. The 3-dimensional grid is limited because of the huge computer power needed for the climate model. Commonly, the grid spacing is rather large in global models. This contributes, when looking at regional scale, to low levels of detail (SMHI, 2019). Two of the commonly used GCM is Atmosphere–Ocean General Circulation Models (AOGCMs) and Earth System Models (ESMs).

Some of the major function of the use of AOGCMs is to produce projections based on future greenhouse gas (GHG) and aerosol forcing, as well as to comprehend the physical parameters (atmosphere, ocean, land and sea ice) of the climate systems. Further, AOGCMs are used where biogeochemical feedbacks are not too important, for climate predictions on a seasonal to decadal scale. More, in process studies or applications with emphasis on a specific area are high-resolution or variable-resolution AOGCMs also applied (Flato et al., 2013).

EMSs are the current best developed tools for simulating past and future response of the climate system to external forcing, where the biogeochemical feedbacks are crucial. The models is an expansions of the AOGCMs containing representation of different biogeochemical cycles and are the existing state-of-the art models (Flato et al., 2013).

1.4.2 Regional climate models (RCM)

RCMs are applied in studies, investigating particular geographical regions on earth, in more detail. The climate processes representations are similar to those of the atmospheric and land surface components of the AOGCMs (Flato et al., 2013). A smaller grid spacing can be applied in RCM, giving a model with more details without the need for more computer power. This is possible though the RCM grid is located over a smaller area (e.g. country or continent), compared to the GCM. Occurrence outside the RCM has to be taken into account. These changes are regulated by results from GCM (SMHI, 2019). Similar regional and local details provided by RCM can also be delivered by empirical and statistical downscaling methods (SMHI, 2019).

1.4.3 Integrated assessment models (IAM)

These models implement a joint analysis assessing the position and the consequences of the environmental change and the response of policy implementation to it. The combination of physical, biological, economic and social sciences results and models is integrated in the analysis (IPCC, 2007a). The current used Representative Concentration Pathways (RCPs), described in **section 1.5.1.1**, are produced from IAMs. These IAMs include the representation of the full economy land use and land-use change and the climate system (IPCC, 2014; Moss et al., 2010).

1.5 Climate scenarios

The climate research community uses scenarios to better understand the complex interaction between the climate system, eco-systems and human activities and conditions. With respect to numerous of parameters; socioeconomic, technological, environmental conditions, emissions of greenhouse gases and aerosols, gives climate scenarios a plausible description of how the future might progress(Moss et al., 2010).

Scenarios are applied in several of areas within the climate research, including as input to climate models and in assessment of uncertainty and impacts of anthropogenic contributions to climate change and Earth system as well as basis for mitigation and adaptation options (Moss et al., 2010; van Vuuren et al., 2011).

In the climate research several different scenarios are used including: emission scenarios, concentration scenarios and climate scenarios. Emission scenarios are based on a consistent set of expectations about driving forces (e.g development of economy, demographic and change in technology) of emissions and their main interactions, representing a plausible future development of emissions like greenhouse gases and aerosols (IPCC, 2007a). Driven from emission scenarios, concentration scenarios are given possible representation of the future radiative forcing measured in (W/m2). The combination of emission scenarios or concentration scenarios, global and- regional climate models and the modelled time period creates a climate scenario which represent plausible future climate conditions (SMHI, 2019). For the creation of climate scenarios is often both information about the observation current climate and climate projection needed, even if the climate projections serves as the basic material (IPCC, 2007a).

It is preferred to use a shared set of scenarios in the scientific community to have improved an easier comparison of climate model results as well for a smoother communication between different studies. The first common set of global emission scenarios offering estimations of the complete set of greenhouse gases was IS92 scenarios (Leggett, Pepper, & Swart, 1992) used in the Second Assessment Report produced by the Intergovernmental Panel on Climate Change(IPCC, 1995) (van Vuuren et al., 2011).

In the next assessment report (Third Assessment Report, 2001) was the Special Report on Emission Scenarios (SRES), developed by Nakicenovic & Swart (2000), used as basis of the climate projections. The emission scenarios SRES are classified into four scenario families and was also applied in the Forth Assessment Report by IPCC (2007) (IPCC, 2007a). Today the SRES scenario is usually used as a reference to the currently used set of scenarios, RCPs (Moss et al., 2010; SMHI, 2019). The scenarios were applied in the Fifth Assessment Report of IPCC (2014) and are also the set of scenarios applied in this study (IPCC, 2014).

1.5.1.1 Representative Concentration Pathways (RCPS)

The development of new scenarios was left to the research community, since IPCC decided not to commission additional sets of emission scenario on its twenty-fifth session in 2006 (Moss et al., 2010). Through a collaboration of the use of IAMs, climate models, terrestrial ecosystem models and by emission inventory experts was the RCPs developed. The RCPs is established as a basis for long-term and near-term climate modelling experiments (van Vuuren et al., 2011).

The RCPs contain radiative forcing pathways which can be the outcome of various of combination of economic, technological, demographic, policy and institutional futures, thereby not connected to specific emission scenarios or socioeconomic situations. The making of the radiative forcing pathways is developed by identification of specific characteristic which generate radiative forcing in climate modelling for different time periods, where the levels of radiative forcing for year 2100 is the most important. This process gives the opportunity to make a parallel study of the climate development, emission scenario and socioeconomic, rather than starting with describing a certain socioeconomic state to produce emission levels and thereafter the climate scenarios (SMHI, 2019). Compared to previous scenarios (e.g SRES and IS92 scenarios) which are generated through specific socioeconomic or emission scenario, the RCPs covers a wider range (Moss et al., 2010).

The RCPs include four different trajectories of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use, global surface temperature change according to the RCPs is illustrated in **figure 2**. All pathways span over the period 1850–2100. The four pathways are named after each radiative forcing in the end of the 21st century, as RCP2.6 (radiative forcing of 2.6 W/m^2 in 2100), RCP4.5 (radiative forcing of 4.5 W/m^2 in 2100), RCP6.0 (radiative forcing of 6.0 W/m^2 in 2100) and RCP8.5 (radiative forcing of 8.5 W/m^2 in 2100), higher radiative forcing represent stronger climate signal. They are representatives of greenhouse gas emission in the wider literature and can also be characterised as CO2 equivalent. RCP2.6 is a strict mitigation scenario, with the goal to stay below global warming of 2°C above pre-industrial temperatures. RCP4.5 and RCP6.0 are two intermediate scenarios and RCP8.5, a scenario with very high GHG emissions (IPCC, 2014). Further, the pathways has been described for an extended period between 2100-2300 (Moss et al., 2010).

This paper only includes RCP4.5 and RCP8.5, these two emission scenarios will therefore be further described in the next sections.

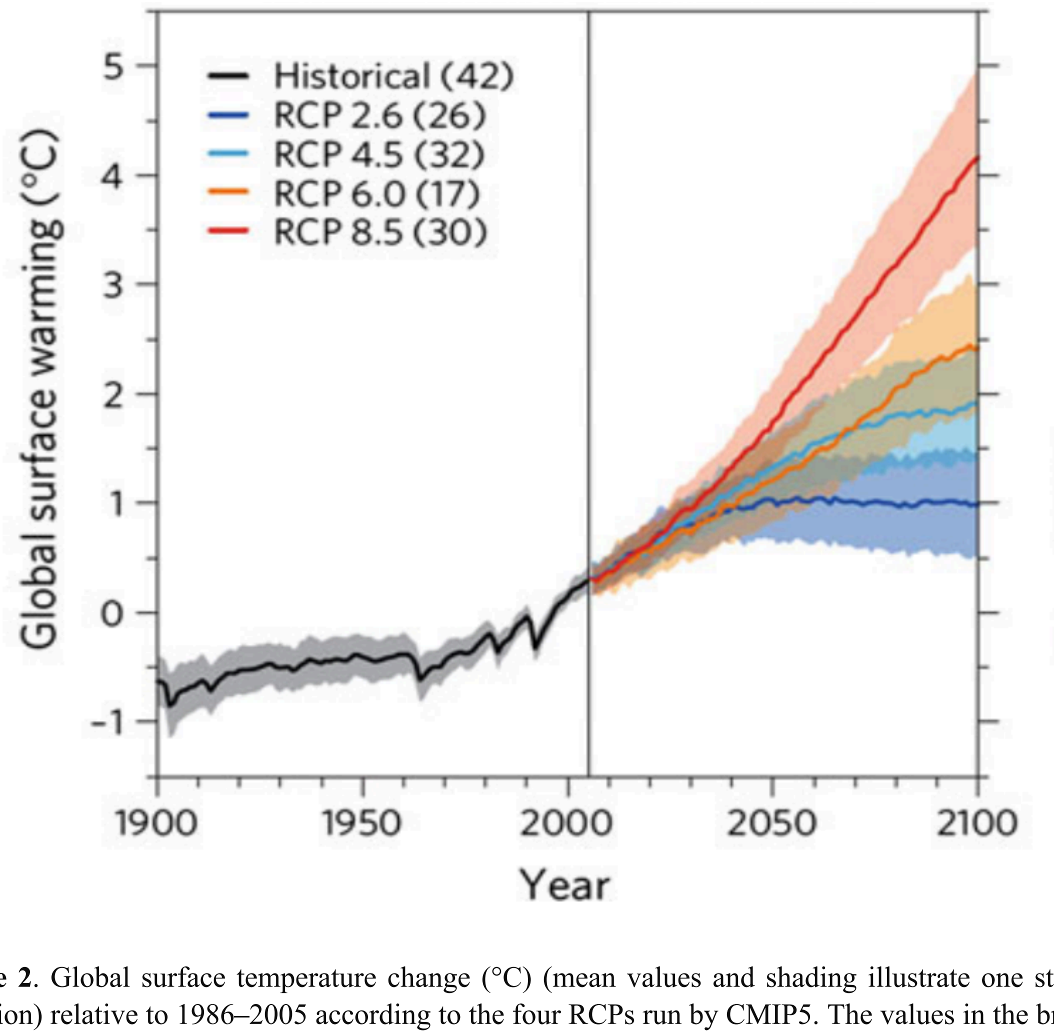


Figure 2. Global surface temperature change (°C) (mean values and shading illustrate one standard deviation) relative to 1986–2005 according to the four RCPs run by CMIP5. The values in the brackets gives the number of models (Quante & Bjørnæs, 2016).

1.5.1.2 RCP4.5

RCP4.5 is a stabilization scenario of long-term global emissions of greenhouse gases and land-use-land-cover. The scenario stabilizes in the year of 2100 at the radiative forcing at 4.5 W/m^2, at around 650 ppm CO_2-equivalent, and never exceed that rate. RCP4.5 assumes the implementation of mitigation climate politics to reach the target of emission limitation and radiative forcing stabilization (Thomson, Calvin, Smith, Kyle, Volke, Patel, Delgado-Arias, Bond-Lamberty, Wise, Clarke, & Edmonds, 2011).

Several mitigation politics and different possible pathways could be taken to reach the target. Some examples of the actions for reaching RCP4.5 are changes in the energy system, including transformation into electricity, energy technologies with lower emissions and organisation of carbon capture and geologic storage technology (Thomson et al., 2011).

1.5.1.3 RCP8.5

RCP8.5 is the pathway with highest emissions and radiative forcing of the total set of RCPs. RCP8.5 do not incorporate any certain climate mitigation target and is therefore a supposed 'baseline' scenario. The radiative forcing in 2100 is of 8.5 W/m^2 with over 1350 ppm CO_2-equivalent, with significant GHG increases over time (Riahi, Rao, Krey, Cho, Chirkov, Fischer, Kindermann, Nakicenovic, & Rafaj, 2011).

Assumptions including a high population and income growth at a relative slow pace, together with technological change and energy intensity development at uncertain rates, leads the RCP8.5 to high energy demand and GHG emission in the long term, due to the lack of climate change politics (Riahi et al., 2011).

1.6 PET and hydrological models

PET is one of the essential component's in the determination of the water balances and an important input in hydrological models. The range of techniques for estimation of water balance and discharge, is wide, from very simple to highly complex model.

1.6.1 Water balance

Water and moisture movement over earth ground, vegetation and atmosphere are essential for all living things (Ivezic, Bekic, & Zugaj, 2017). Water circulates naturally, creating closed hydrologic cycles (Oki & Kanae, 2006). The ratio between water inflow (water input) and outflow (water output), measured for different space and time scales, is the water balance (Sutcliffe, 2004). Studies differs from global water cycle to the humidity around a leaf, in the field of water balance (Ghandhari & Alavi Moghaddam, 2011).

For understanding of present and future available water storage and assistance in creation of water management strategy the knowledge of the water balance is important. Calculations of water balance are used in several of research and applied problems such as

- For estimation of regional water balance
- In assessment of the impact of human activity and climatic variations on basin runoff
- In planning and allocation of fresh water resources

The demand for more detailed knowledge of the water balance is clearly needed, due to the expected more frequent and longer drought periods and intensity of floods (Ivezic et al., 2017).

All water balance expressions have in general the form (Goldscheider, 2010):

Output = Input + Δ in storage (1-1)

Basic components determining the water balance is: precipitation, evapotranspiration, river runoff and ground water outflow not drained by river systems (Shiklomanov, 2009). Precipitation is probable to be the main input, but river inflow or groundwater inflow could also be included. Evapotranspiration, river outflow and groundwater outflow are part of the output. Included in storage changes are increases in soil moisture and groundwater storage (Sutcliffe, 2004).

Annual global river discharge, including direct ground water discharge, are estimated to around 45 500 km^3/year (Oki & Kanae, 2006). An illustration of the global water balance is exemplified in **figure 3**. In studies of the hydrological cycle or water circulations in the atmosphere-hydrosphere-lithosphere system, examination of these components for specific areas and time intervals are of high significance (Shiklomanov, 2009).

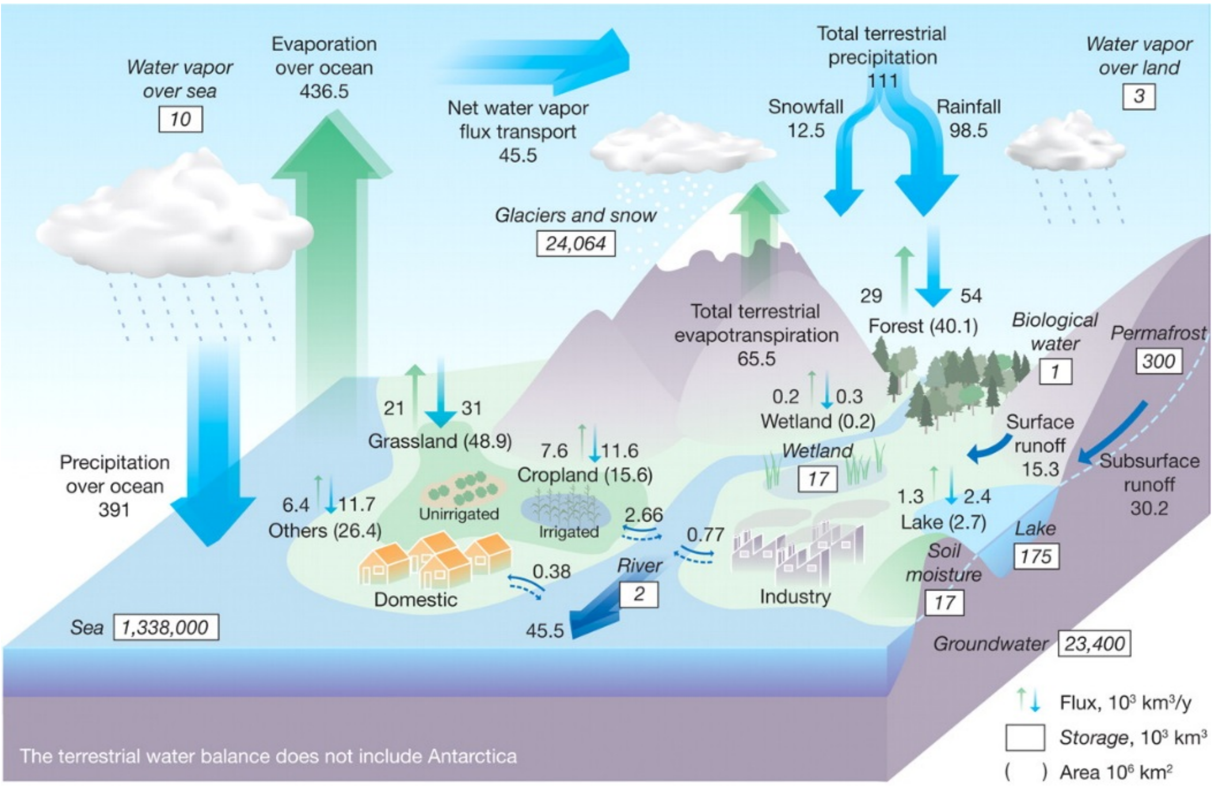


Figure 3. Global water balance (Oki & Kanae, 2006).

The general water balance equation, where no external inflows form nearby catchments and territories reach the system, could be written as following:

P = ET + R ± ΔS (1-2)

P - precipitation

ET - evapotranspiration;

R - runoff (surface, subsurface and groundwater)

ΔS - water storage change

Throughout the time period considered, enter water the system via precipitation. The water converts into evaporation and/or runoff including surface, subsurface or groundwater and connected storage or change in storage during, see **equation 1.2** (European Commission, 2015). A further simplification for long time intervals could be written as:

Precipitation - Discharge = Evapotranspiration (1-3)

(Holden, 2013)

In theory the concept of water balance could seem simple, when applicated practically, several complications could be found. Accurate measurement of the different components:

- evapotranspiration
- precipitation
- various forms of runoff

are some of the most obvious difficulties in water balance calculations. In addition, problems with the regionalization of hydrological data (Goldscheider, 2010).

In calculations of different water balance components and the impact of climate and soil properties on hydrology and water resources, various water balance models and hydrological models have been developed (Devia, Ganasri, & Dwarakish, 2015; Ivezic et al., 2017).

In this paper the water balance component evapotranspiration is studied closer.

1.6.2 Hydrological models

A model system represents a simplified demonstration of the real world (Wheater, Sorooshian, & Sharma, 2007). The use of the model is mainly for predicting system behaviour and understanding different hydrological processes. The characteristics of a model is defined by the many parameters used and contained in a model. The model using least parameters and complexity, as well as given results close to reality is a good model (Devia et al., 2015). A hydrological model can be defined as a set of equations, containing various parameters for describing watershed characteristics, which assists in the estimation of discharge (Devia et al., 2015).

To recognize how climate and soil properties impacts hydrology and water resources, numerous of hydrological models, with specific special characteristics, have been developed. For water and environmental resource management is hydrological models considered an important and necessary tool. Rainfall data and drainage area are the two most important input variables and required for all hydrological models. Accompanied by these are several of other inputs considered as, water shed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, evapotranspiration and characteristics of ground water aquifer as well as temperature (Devia et al., 2015).

The classification of rainfall-runoff models is based on input and parameters and the extent of physical principles applied. Lumped and distributed model is one classification, based on the model parameters as a function of space and time. Further, rainfall-runoff model can be classified based in time as either a static or a dynamic model. Last, classifications of empirical model, conceptual models and physically based models is one of the most important. This classification is based on several of variables. A list of some of the characteristic of the three different models is illustrated in **table 2** (Devia et al., 2015).

In studies where the purpose is to investigate projections of climate change impact on water resources and hydrological patterns of river basins is hydrological modelling a primary tool (Lobanova et al., 2018). In this study is a semi-distributed conceptual rainfall-runoff model used, see explanation in **section 4.3.1.**

Table 2. Characteristics of the three rainfall-runoff models Empirical, Conceptual and Physically based (Devia et al., 2015).

Empirical model	Conceptual model	Physically based model
Data based or metric or black box model	Parametric or grey box model	Mechanistic or white box model
Involve mathematical equations , derive value from available time series	Based on modeling of reservoirs and Include semi empirical equations with a physical basis.	Based on spatial distribution, Evaluation of parameters describing physical characteristics
Little consideration of features and processes of system	Parameters are derived from field data and calibration.	Require data about initial state of model and morphology of catchment
High predictive power, low explanatory depth	Simple and can be easily implemented in computer code.	Complex model. Require human expertise and computation capability.
Cannot be generated to other catchments	Require large hydrological and meteorological data	Suffer from scale related problems
ANN, unit hydrograph	HBV model, TOPMODEL	SHE or MIKESHE model, SWAT
Valid within the boundary of given domain	Calibration involves curve fitting make difficult physical interpretation	Valid for wide range of situations.

1.6.3 PET application in hydrological modelling

Of the global terrestrial precipitation around 40 % is converted into runoff, while more then 60 % is transferred back to the atmosphere through evapotranspiration (Rodell et al., 2015). In over 77 % of earth land surface does ET exceed runoff (Harrigan & Berghuijs, 2016). Making evapotranspiration an essential parameter in the understanding of the hydrological cycle and regional water balance (Knipper, Hogue, Scott, & Franz, 2017). Consequently, in hydrological modelling is the understanding of evapotranspiration also of great importance (Kay & Davies, 2008).

In simulation of conceptual models, provides PET input data for estimation of AET which is used for direct calculation of discharge. PET issue input data for the upper limit of water losses through evapotranspiration. AET can differ between zero and PET, conditional on the amount of available water in the soil stores. In this type of models, it is especially important with accurate estimations of PET changeability of the year and in various locations. Wrongfully estimations of PET could lead to inaccurate estimations of AET and thus runoff and river discharge. Underestimation of runoff and discharge will result in overestimations of PET and contrary overestimation of runoff and discharge of PET will be underestimated (Prudhomme & Williamson, 2013)

1.6.4 PET impact on hydrological modelling

Some studies, focusing on assessing the effects of PET on hydrological models. Both PET inputs and the choice of a specific formula could possible play a role in the efficiency of the model.

A comprehensive evaluation of the impacts of improved PET inputs, done by Andréassian, Perrin & Michel (2004), shows that the hydrological models are very sensitive to PET inputs but that this is adjusted with adaptation of the input parameters during the calibration method. In agreement with Andréassian et.al (2004), is an earlier study concluding that calibration methods are able to counterweigh for the bias in PET input and thereby have little effect on the hydrological precision (Paturel, Servat, & Vassiliadis, 1995). Isabelle, Nadeau, Rousseau, & Anctil (2017) asses the performance of three ET formulas and their hydrological modelling influence of a small boreal peatland-dominated watershed. The study concludes that, calibration of model parameters compensates for the sensitivity in the evapotranspiration inputs. The assumption that PET input, with improved temporal precision, do not or not strongly influence the hydrological modelling performance on hydrological modelling, was put forward by Fowler (2002) and Oudin, Michel, & Anctil (2005).

In a study by Oudin, Hervieu, et al. (2005), 27 different PET estimation methods were tested, over a sample of 308 catchments, to assess their impact on discharge simulation. The report illustrates that hydrological models has low sensitivity to the choice of PET formula, though the supreme part of the PET selection lead to the same efficiency of the hydrological model (Oudin, Hervieu, et al., 2005). In contradiction to Oudin, Hervieu, et. al. (2005), seems the choice of PET method to have an influences on the model performance, in the span of discharge predictions (Raúl F. Vázquez Z. & Jan Feyen, 2013). However, Isabelle et al. (2017) mentions the same finding as Oudin, Hervieu, et al. (2005), stating that the difference in the presentation of the PET formulas tested have no considerably effect on the hydrological model performance. The same conclusions has also been put forward by Andersson (1992).

Further, even though studies e.g. Andersson (1992) and Oudin, Hervieu, et al. (2005), state that the performance of the hydrological models have low sensitivity to the selection of PET, types of formulas which provide the best streamflow simulations is illustrated, even though the differences are small. Penman-Monteith is recommended as the best options for ET calculation by the Food and Agricultural Organization (FAO) (Allen et al., 1998). However , temperature and radiation-based formulas are the ones which tend to provide best discharge simulation (Oudin, Hervieu, et al., 2005). Furthermore, Andersson (1992) founds, in a study where seven PET methods were assessed on the sensitivity of an HVB model, that temperature-based estimation options give a slightly better precision of the model. The preferred use of simpler formulas, compared to Penman-Monteith, in streamflow simulations was also put forward by Kannan, White, Worrall, & Whelan, (2007). Moreover, the Penman-Monteith formula is states as the best option for estimation of PET in studies looking at sensitivity of hydrological simulation to PET (Zhao, Xia, Xu, Wang, Sobkowiak, & Long, 2013). Contradictory, other studies have illustrated that offsets in hydrological predictions can occur with the use of simple air temperature-based PET formulas (Hoerling, Eischeid, Quan, Diaz, Webb, Dole, & Easterling, 2012; Lofgren, Hunter, & Wilbarger, 2011). Lofgren et al. (2011) shows, when using an energy budget-based formula instead of an air temperature based, that the PET predictions has reduced magnitude and Hoerling et al. (2012) finds evidence that, simplified temperature assumption on PET, could compromise its ability as drought indicator in future climate.

1.6.5 PET formulas in hydrological projections in a climate change context

Evaporative demand is projected to change along with changes in the hydrological cycle due to climate change. The understanding of PET including choosing the relevant PET method for application in hydrological projection in changing climate conditions might be vital.

In a research where five PET formulas were examined for how good they captured the dynamics in evaporative demand, the Penman formulation was found to be the most promising (Donohue et al., 2010). The study stresses the importance of the choice of PET formula and how it is parameterised for projections in: energy-limited catchments, catchments that seasonally switch between energy- and water-limited states and irrespective of the climate type when actual evaporation is estimated as a fraction of PET. However, a simpler formula was preferred over the more complex formula by Sperna Weiland, Tisseuil, Dürr, Vrac, & Van Beek, (2012). Yet, stresses the study, similar to that of Donohue et al. (2010), the necessity to test formulas in climate impact assessment and hydrological projection in climate change context, even if related biases to PET method incline while going from PET to AET and runoff to discharge.

Further, the choice of PET methods was stated to possible have great influence on the runoff stimulation in future climate change, more for periods 2071–2100 than for 2011–2040 by Bae, Jung, & Lettenmaier, (2011). Additional, in a study investigating PET formula sensitivity of historical climate change of 18 PET methods compared over six climate stations in Germany, all PET formulas were found to be influenced by trends in climate data. However different sensitivities were showed for every formula (Bormann, 2011).

In a recent study, SWI (Surface Wetness Index) with PET (Thornthwaite and Penman–Monteith equation), was examined to compare spatiotemporal characteristics of global drylands. The results showed that with increases in global warming, PET changes contributed to variations in continental drylands and under climate change was the simpler formula Thornthwaite increasingly less appropriated (Yang, Ma, Zheng, & Duan, 2017). Furthermore, the selecting of PET method was stated as the second most important uncertainty when looking at impact of climate change on water resource projections by Troin, Arsenault, Martel, & Brissette (2017).

Thompson, Green, & Kingston (2014) analyzed six PET formulas in one model, investigating seven scenarios for an increase in global warming. The results showed that scenario discharges are impacted by the PET method but that precipitation uncertainties are stronger than the PET method uncertainties. However, in changes of high and low flows, occurs uncertainties related to PET methods in all scenarios tested (Thompson, Green, & Kingston, 2014).

The significance of testing PET formulas in hydrological models was also stressed by Seiller & Anctil, (2016), testing 24 potential evapotranspiration formulas over 20 ensemble models and two catchments. They provide clear evidence that the PET method influences hydrological projections in a climate change context. In addition, a study examining six PET methods to an increase in global warming of 2 degrees, demonstrated that global projections of PET in future climate change varies depending on the formula used (Kingston et al., 2009). In the same study, similar indicates of differences in water balance, dependent on different PET estimates, were found with calculations of annual aridity index and regional water surpluses. Yes, in a study examine six PET methods effect on climate change impacts on river flows at mid-latitudes were only very small uncertainties in the PET method related to runoff found (Koedyk & Kingston, 2016).

According to above, hydrological modelling is found to be sensitive to the choice of PET formula in several of studies and a large spread in findings regarding the best performing PET formula. Furthermore, great difficulty even in specific location and climate conditions to choose a correct and only formula. Therefore, study the sensitivity in hydrological projections due to different PET formulas is important. The four PET formulas studied in this paper are described in **section 4.2**.

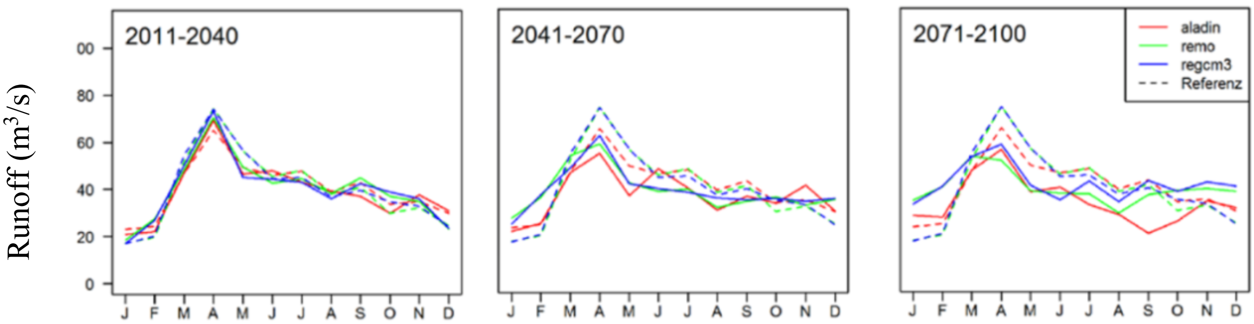
2 Study site

PET calculation of the four formulas has been studied over two catchments. Both catchments are situated in Austria, named Ybbs (Traisen) and Salzach (Pinzgau) catchments, in this study only referred to as Ybbs and Salzach. Austria is located in central Europe with boarders connecting to Czech Republic, Germany, Hungary, Italy, Liechtenstein, Slovakia, Slovenia and Switzerland. The country´s terrain consist to a large extent of higher elevations and mountain areas, where less than a third of the state is below 500 meters (above sea level) and has a temperate and alpine climate (Austrian Embassy Washington, 2018).

The two catchment areas were selected from the four test areas (Inn, Salzach, Isel and Ybbs) previous studied in the Powerclim project (Holzmann et al., 2018). Ybbs and Salzach were chosen for their different hydrological regime, **figure 4**.

Ybbs is located at lower elevation close to mountainous areas, with high variability of discharge throughout the year. The highest peak is seen in spring. The regime could be quantified as a mix pluvial-nival regime. Salzach catchment is situated on higher altitudes within the mountain area of the Alps. The catchment could be defined as a glacier-nival regime, with great discharge in summer and considerable low flows in winter (Parriaux, 2011). The boundaries of the catchment areas are sourced from the predecessor project POWERCLIM, and can be found in the **figure 5** (Holzmann et al., 2018).

a)



b)

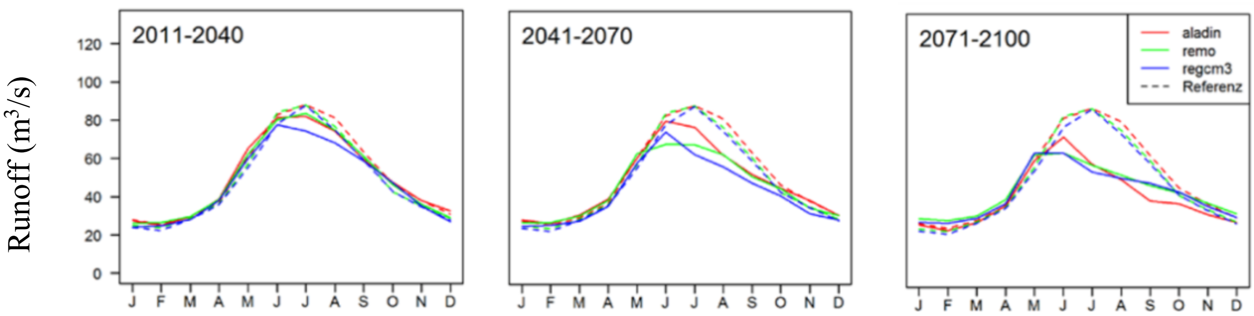


Figure 4. Annual discharge for three time-periods according to three different climate scenarios and one reference scenario, for (a) Ybbs and (b) Salzach catchment (Holzmann et al., 2018).

The basin Ybbs is located in the federal state of Lower Austria with an area of 1116 km^2 and an altitude between 263-1841 m, seen in **figure 5**. The average precipitation per year is around 1440 mm and the mean annual evapotranspiration about 600 mm. The basin has a mean annual discharge of 860 m^3/s (Frey, 2015). The catchment area defines northern Alpine foreland conditions (Holzmann et al., 2018).

The catchment Salzach is located in an alpine dominated region, with elevation from 742 to 3649 meters. It is part of the federal state Salzburg with an area of 1166 km^2, seen in **figure 5**. The basin has an higher annual average precipitation compared to the average precipitation for whole Austria, at around 1640 mm. Evapotranspiration for the catchment is about 350 mm per year in average and a mean annual discharge of approximately 1360 m^3/s (Frey, 2015). The characteristics of high alpine reservoirs, is well described in the Salzach catchment (Holzmann et al., 2018). Furthermore, the discharge from the area is the main source of energy for existing power plants in Salzburg (Verbund, 2019).

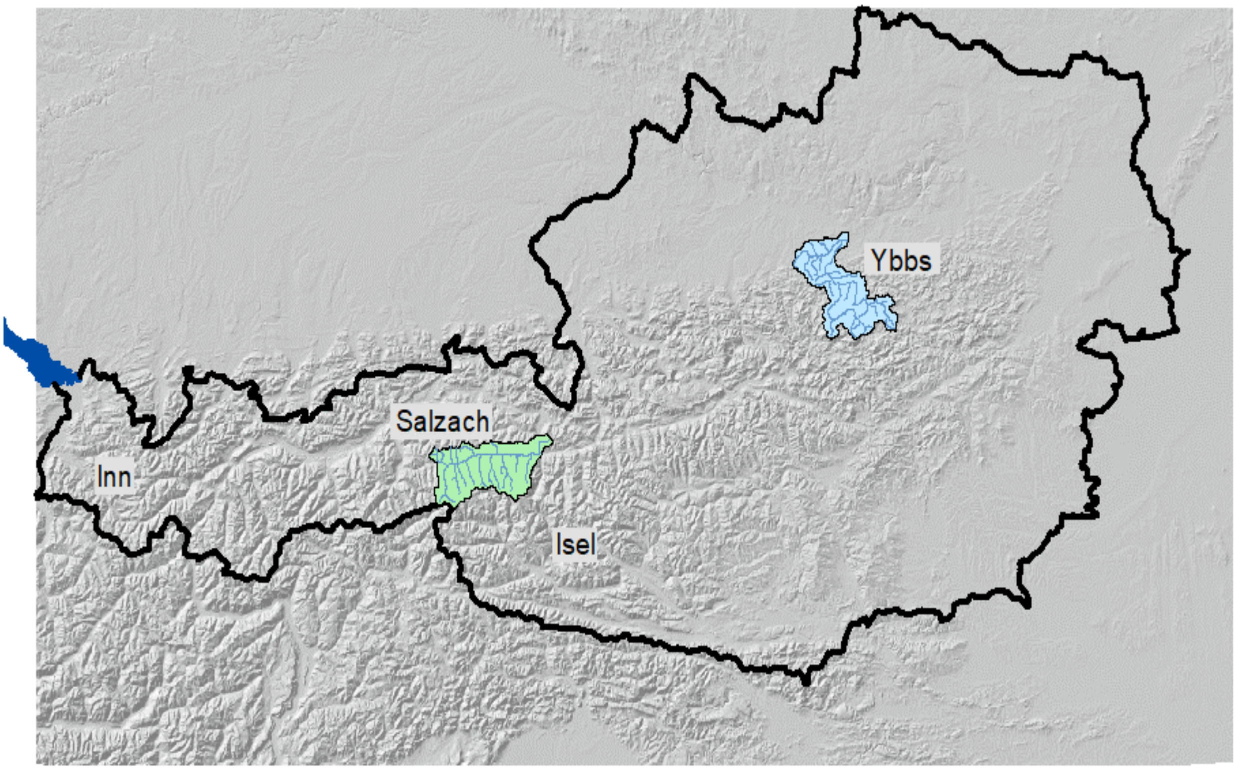


Figure 5. Map of Austria with location and area of Ybbs and Salzach catchments.

3 Data basis

The climate and precipitation data were facilitated by the Institute of Meteorology and Climatology (BOKU-Met) at BOKU. The data for comparison of modelled climate data are given by the multivariable analysis and nowcasting system, Integrated Nowcasting through Comprehensive Analysis (INCA) and provides climate data for the period 2003-2015. Both modelled reference data and modelled future data of climate and precipitation data used for PET and discharge calculation is provided from ÖKS15 – (Klimaszenarien für Österreich/climate scbarios for Austria). The reference data are specified for the period 1985-2014 and future data obtained for two future diverse climatological periods.

3.1 Spatially distributed data

The data set used for comparison of climate modelled data, were provided by the multivariable analysis and nowcasting system, Integrated Nowcasting through Comprehensive Analysis (INCA), estimated by the Central Institute for Meteorology and Geodynamics (ZAMG).

For the fields: temperature, humidity, wind, global radiation, precipitation, precipitation type, snowfall line, ground temperature and cloudiness, delivers INCA near-real-time analyses and forecasts. INCA system combines surface station observation data, NWP model output, radar and satellite data and high-resolution topographic data. INCA analyses hourly data for the forecast fields, temperature, humidity and wind and 15-min analyses for precipitation, precipitation type, ground temperature and cloudiness (Haiden, Kann, Wittmann, Pistotnik, Bica, & Gruber, 2011).

INCA has been specially developed for use in mountainous terrain and to improve and complement output variables for numerical weather prediction (NWP) models (Haiden et al., 2011). The system contributes with value for NWP forecast by delivering: high-resolution analyses, nowcasts, and improved forecasts both within and beyond the nowcasting range (Haiden, Kann, Pistotnik, Stadlbacher, & Wittmann, 2010). Between the analysis part of INCA and the Austrian Vienna Enhanced Resolution Analysis system (VERA), is the key difference that INCA interpolate between observations, relying on NWP model output and high-resolution remote sensing data (Haiden et al., 2011).

In Central Europe there exists various of different INCA domains. In this study is data provided by the Austrian INCA domain, which works with high-resolutions of 1 km and covers an area of 600 km x 350 km (Haiden et al., 2011).

The climate variables provided by INCA and applied in this study are: min daily air temperature (in °C), max daily air temperature (in °C), daily solar radiation (in W/m^2), humidity (in %) and wind speed (in m/s). Daily data are provided in separated text files for each climate variable, including a date column and a climate variable column for the period 2003-2015. The INCA data are aggregated to catchment areas by BOKU-Met, for the two catchments Ybbs and Salzach, see **figure 5** for area boundaries. The data are given for mean values.

There are limitations thus the INCA data only exists for 12 years, where 30 years of continuous data are need for making strong climatic conclusions.

To ensure very accurate weather analyses, the INCA system process data from numerous of sources (e.g. surface weather stations, radar and satellite observation and forecasts of numerical models), which are as close to the real state of the atmosphere as possible. In addition, statistical methods and information about the climate are used. INCA data are therefore justified as valid and used for direct comparison with ÖKS15 climate data, see **figure 7**.

3.2 Model data

Modelled reference and future data in this study is obtained from data sets of computer modelling data from ÖKS15 (climate scenarios for Austria). It contains climate scenarios and has been developed by the Central Institute for Meteorology and Geodynamics (ZAMG), the Wegener Center for Climate and Global Change at the University of Graz, and the Interfaculty Department of Geoinformatics – Z_GIS at the University of Salzburg (CCCA Data Server, 2016). ÖKS15 estimations are carried out on the basis of the up-to-date scientific standards and based on the presently best data.

ÖKS15

ÖKS15´s regional climate projection data are specially arranged, interpolated and bias-corrected (see next paragraph), for the Austrian region. It contains data sets of regional climate projections for the period 1971-2100 commissioning RCP4.5 and RCP8.5. The data set provides the meteorological variables: air temperature, precipitation, radiation, wind speed and air humidity and the downscaled scenarios is provided for a regular grid with a 1kmx1km resolution.

The bias correction of the climate scenarios in ÖKS15 is accomplished in four steps:

- Selection of relevant models and data sets for bias-correction
- Regridding models and observations
- Bias correction of the models using Scaled Distribution Mapping (SDM)
- Downscaling

The data sets of bias-corrected regional climate scenarios from ÖKS15 are based on regional climate models (RCM) scenario data from EURO-CORDEX. EURO-CORDEX delivers regional climate change projection for Europe at a resolution of 50 km (0.44°) and 12.5 km (0.11°). The global climate projection of the CMIP5 and the emission scenarios RCPs are the basis of the regional projections. EURO-CORDEX is part of the global Coordinated Regional Downscaling Experiment (CORDEX) which is based on the internationally coordinated framework for improving regional climate scenarios (Gobiet & Jacob, 2012; Jacob et al., 2014).

For bias-correction are three observational data sets SPARTACUS (period 1961-2015), GPARD1(period 1961-2011) and STRAHLGRID (period 1980-2012) with a resolution of 1 x 1 km and station data from five “flagship stations” in Austria used (Chimani et al., 2016).

- SPARTACUS (Spatiotemporal Reanalysis Data set for Climate in Austria)
  The spatial distribution of daily air temperature is described in the gridded observation data set for the period 1961-2015.

- GPARD1 (Gridded Precipitation for Austria at Daily 1 km Resolution)
  The data set consists of daily precipitation measurements for the period 1961-201.

- STRAHLGRID (Global radiation and sunshine extracted from disturbance data set)
  For the period 1980-2012 provides the data set daily data for the incident shortwave radiation and the sunshine duration.

- Austrian station data

Provide close to complete daily measurement time series of the variables air temperature, precipitation and sunshine duration between the period 1900-2015.

Even though ÖKS15 has been comprehensively bias-corrected by the latest tools and scientific standards a perfect copy of the reality is not possible. Possible errors in measuring of the observation data as well as in the meshed data sets owing to resolution could be found. Contributing to existing uncertainties in the climate data. However, the data are found reliable due to its bias correction and is used in this study for reference and future climate and precipitation data.

The data sets of climate and precipitation data, given by ÖKS15, were calculated for the boundaries of the two catchments by BOKU-Met, applied in PET calculation by the four PET formulas Penman, Priestley-Taylor, McGuinness-Bordne and Thornthwaite and in discharge simulation.

Reference (REF) and Future (FUT) data

The REF and the FUT data were provided by BOKU-Met and modelled by ÖKS15. It contains daily data sets for five climate variables and one for precipitation of mean daily values. The variables included in the data set are: min daily air temperature (in °C), max daily air temperature (in °C) daily solar radiation (in W/m^2), humidity (in %), wind speed (in m/s) and precipitation (mm).

Data for both REF and FUT were given for both catchments, Ybbs and Salzach. Three data sets of 30 years intervals were provided, one for REF data for the period 1985-2014 called REF, and two for FUT data including one climate and precipitation data set for period 2021-2050 here named FUT(MID), and one for the period 2071-2100 called FUT(CEN). Data for REF, FUT(MID) and FUT(CEN) were produced according to the three emission scenarios RCP4.5, RCP8.5 and RCP8.5 hot.

Two different climate models in ÖKS15 provides the data according to the three emission scenarios. Data according to RCP4.5 and RCP8.5 are provided by one climate model, which represent a close mean ensemble of all the climate models in ÖKS15 data set. Data according to RCP8.5 hot illustrate an extremely dry scenario, simulated from a climate model within ÖKS15, which provides the driest scenario according to RCP8.5. The evaluation of, what is mean and what is extreme dry, is based on data for the whole of Austria, not on the catchment areas specifically. See **section 1.5.1.1** for explanation of RCPs.

The climate and precipitation data were given in text file format for every variable including two columns, one compromising the dates and one the data values. The climate and precipitation data were given for each of the three emission scenarios (RCP4.5, RCP8.5 and RCP8.5 hot) for the three different time periods (REF, FUT(MID) and FUT(CEN)) and the two catchments. In total given 18 individual data sets for each of the three time periods (REF, FUT(MID) and FUT(CEN)) in one catchment. The five climate data sets for each emission scenario, time-period and catchment were listed as one combined data set in Rstudios for calculation of PET, see **section 3.2.1.** and **table 4**. Precipitation data were analysed separately and included in the discharge model.

An overview of the time period, data set provider, emission scenario and INCA and modelled climate and precipitation variables used in the different data sets are illustrated in **table 3**. An individual data set are the combination of (Time period, climate or precipitation variable, emission scenario and catchment), as an example REFTminRCP4.5YBBS. A detailed description of the data treatment for application in Rstudios can be found in **section 3.2.1.**

Table 3. Overview of the four time-periods INCA, REF, FUT(MID) and FUT(CEN).

Name of data sets	INCA	REF	FUT(MID)	FUT(CEN)
Data set provider	INCA	ÖKS15	ÖKS15	ÖKS15
Time period	2003-2006	1985-2014	2021-2050	2071-2100
Climate variables and precipitation	T_{min}, T_{max}, RH, R_s, U_z	T_{min}, T_{max}, RH, R_s, U_z Precipitation	T_{min}, T_{max}, RH, R_s, U_z Precipitation	T_{min}, T_{max}, RH, R_s, U_z Precipitation
Data given for emission scenario		RCP4.5 RCP8.5 RCP8.5 hot	RCP4.5 RCP8.5 RCP8.5 hot	RCP4.5 RCP8.5 RCP8.5 hot
Catchment	Ybbs Salzach	Ybbs Salzach	Ybbs Salzach	Ybbs Salzach
Total amount of individual data sets for both catchments	10	36	36	36

Area elevation data

A digital elevation model (DEM) filefor each catchment provided by HyWa to calculate the mean elevation. The mean elevation is used as one of the constants in Rstudios for calculations of PET, see constants in **table 6**.

The file contains the hypsometric distribution of the two catchments. Starting at 300 m above sea level (absl), Ybbs and 800 m absl, Salzach. The area is estimated for every 100 m elevation up to 1900 m and higher and 3800 m and higher for Ybbs and Salzach respectively. The area for every elevation step is cumulated in Rstudios and plotted against the elevation, to measure the mean elevation of the catchment. Ybbs mean elevation is calculated to 638 m absl and Salzach to 1779 m absl.

Summary of input data provided by ÖKS15 for PET and the discharge calculation

Climate input data given by ÖKS15 for PET calculation is given in daily time step, following:

- Max air temperature
- Min air temperature
- Solar radiation
- Ait humidity
- Wind speed

The hydrological input data, for discharge simulation, are given in daily time step. Input data includes

- PET calculated from ÖKS15 data
- Precipitation data provided by ÖKS15
- Temperature data provided by ÖKS15
- Solar radiation data provided by ÖKS15

The methodology of climate and precipitation data, including providing and application, are illustrated in **figure 6.**

1) The three existing emission scenarios given
2) Modelling and providing of climate and precipitation data by GCM and RCM according to the emission scenarios
3) Import of data in Rstudios for comparison of model and INCA data and for PET calculation
4) Application of PET data and modelled data (ÖKS15) in hydrological model

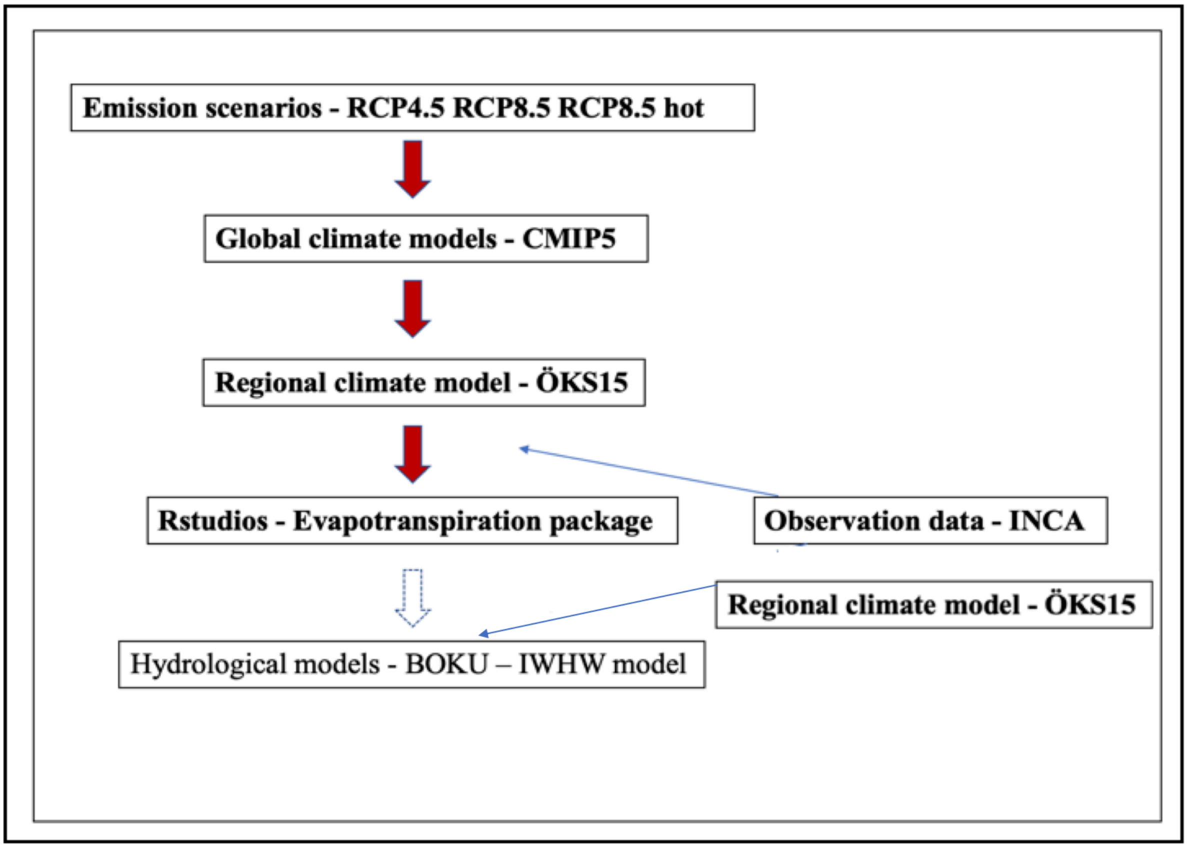


Figure 6. Methodology for the providing and application process of climate and precipitation data.

3.2.1 Data treatment

The data sets of climate variables (INCA and ÖKS15) provided by BOKU-Met had to be organised and converted for application in the Evapotranspiration package in Rstudios. PET data calculated in RStudios were thereafter exported for application in the hydrological model.

The 5 climate data sets of INCA, for each catchment area and the 5 climate data sets of REF and the two FUT data sets, for each emission scenario, and each catchment given in the format of text files could be directly imported into Rstudios. For application in the Evapotranspiration package, described in **section 4.1.1**, was it necessary to re-organize, alter the data into a new format, and last list the data. The Evapotranspiration package requires a list of 11 variables displayed in **table 4**.

Table 4. Overview of the required list in the Evapotranspiration package.

Variable number	Variable name	Variable description
1	*Date.daily*	date in daily time step
2	*Date.monthly*	date in monthly time step
3	*J*	julian days ordered by date
4	*i*	month number (1-12)
5	*ndays*	Days in a month
6	*Tmin*	daily maximum temperature in degree Celcius,
7	*Tmax*	daily minimum temperature in degree Celcius,
8	*RHmax*	daily maximum relative humidity in percentage,
9	*RHmin*	daily minimum relative humidity in percentage
10	*uz*	daily wind speed in meters per second,
11	*Rs*	daily solar radiation in Megajoule per square meter.

The first five variables were derived from the date column from each climate data set, by coding in Rstudios. The column with climate data variables was ordered by the date column, through coding in Rstudios, variable 6 to 11. The variable Julian day, 3 variables were order by the date column in the same way. Climate data were only provided for a mean RH value. The data for mean RH were therefore used as both RHmin and RHmax. Following, were all variables, with exception of variable 2 and 3 converted in to zoo format by coding in Rstudios. Last, were the data listed as a combined file including all climate variables, **table 4**.

The total number of combined climate data sets for modelled ÖKS15 data and INCA data are illustrated in **table 5**. Ybbs and Salzach containing 10 combined data set respectively. Subsequent, re-organization, deriving, conversion and listing of data could the Evapotranspiration package be run applying ÖKS15 data. Link for download of RStudios and installation of Evapotranspiration package is found in **appendix.**

Table 5. Combined climate data sets for application in Rstudio and calculation of PET.

	INCA	REF	FUT(MID)	FUT(CEN)
Emission scenario (RCPs)		RCP4.5 RCP8.5 RCP8.5 hot	RCP4.5 RCP8.5 RCP8.5 hot	RCP4.5 RCP8.5 RCP8.5 hot
Ybbs	1	3	3	3
Salzach	1	3	3	3

3.2.2 Input data comparison

Comparison of monthly daily mean input data including the five climate variables for INCA, REF, FUT(MID) and FUT(CEN) for the two catchment areas are illustrated in **figure 7**. Small variations in intra annual variation is illustrated in application of monthly daily mean, larger fluctuation over the year would have been seen if daily mean values were applied. Data of monthly daily mean were chosen for comparison of different data seats to easier illustrate differences among the data sets.

Tmax and Tmin increases in both FUT scenarios compared to INCA data for mutually Ybbs and Salzach catchments. The modelled variables for the temperature variables are well accorded with the INCA values, following a similar yearly pattern. Similar, does wind speed and solar radiation variables for the three modelled data sets monitor the INCA yearly distribution and values quite well. The solar radiation decreases in all model data sets compared to INCA, in Salzach catchment. For Ybbs catchment, illustrate solar radiation model data in comparison to INCA, a changing pattern of both higher and lower values over the year. However, the difference among the data sets are small. The wind speed variable shows no clear increase or decrease for future periods compared to INCA for neither of the catchments. In addition, wind speed does not demonstrate any great monthly fluctuation in monthly daily mean, the data set is therefore also illustrated as a distribution function in **figure 8,** to illustrate existing fluctuation in daily mean values.

Humidity in contrast to the other four variables fluctuates and departs strongly from INCA distribution for both catchments. This indicate uncertainty in humidity data, needed to be take into consideration in calculation of PET. The modelled humidity values in Ybbs catchment show, lower measurement for the period end of February to beginning of April and August, compared to INCA data. But show peak increases in values from January to end of February and beginning of April to end of May. The modelled humidity data for Salzach catchment increases almost over the whole year compared to INCA, illustrating strong peaks in increases in the period April and June, July to September and January to February.

The modelled data compared to INCA data show similar intra annual patterns, in all RCPs, for the variable's temperature, solar radiation and wind speed. However, clear increases in Tmax and Tmin for future data sets are seen when RCPS with stronger climate signal is applied. Humidity data show strong fluctuation with different monthly patterns depending on emission scenarios applied, **see appendix** for input data comparison for all RCPs.

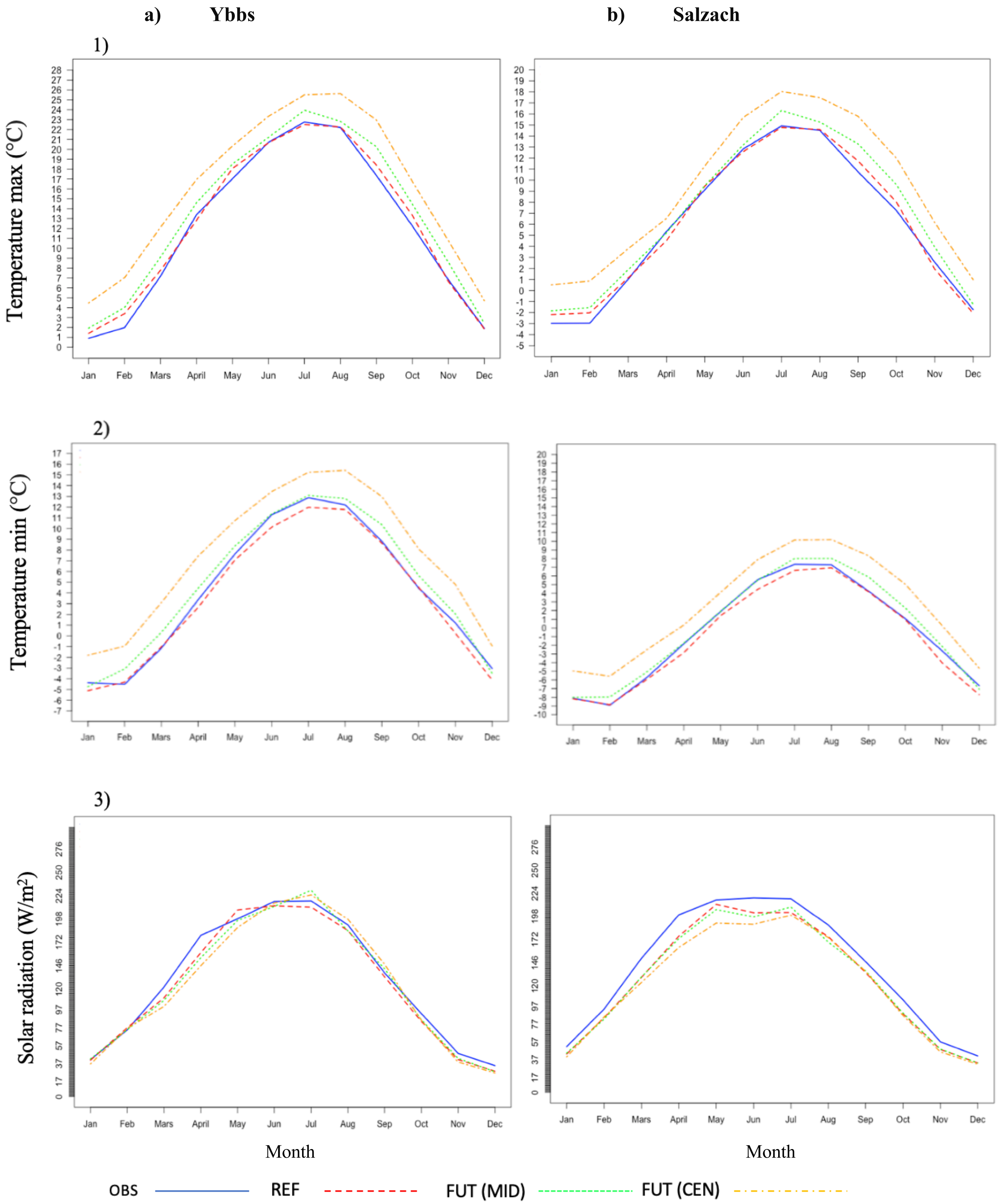


Figure 7.1. Comparison of mean daily climate input data (1) Tmax, (2) Tmin, (3) Solar radiation, (4) Air Humidity, (5) Wind speed. For a) Ybbs and b) Salzach of INCA year (2003-2015), REF (1985-2014), FUT(MID) (2021-2050) and FUT(CEN) (1971-2100). REF, FUT(MID) and FUT(CEN) climate data are according to RCP8.5.

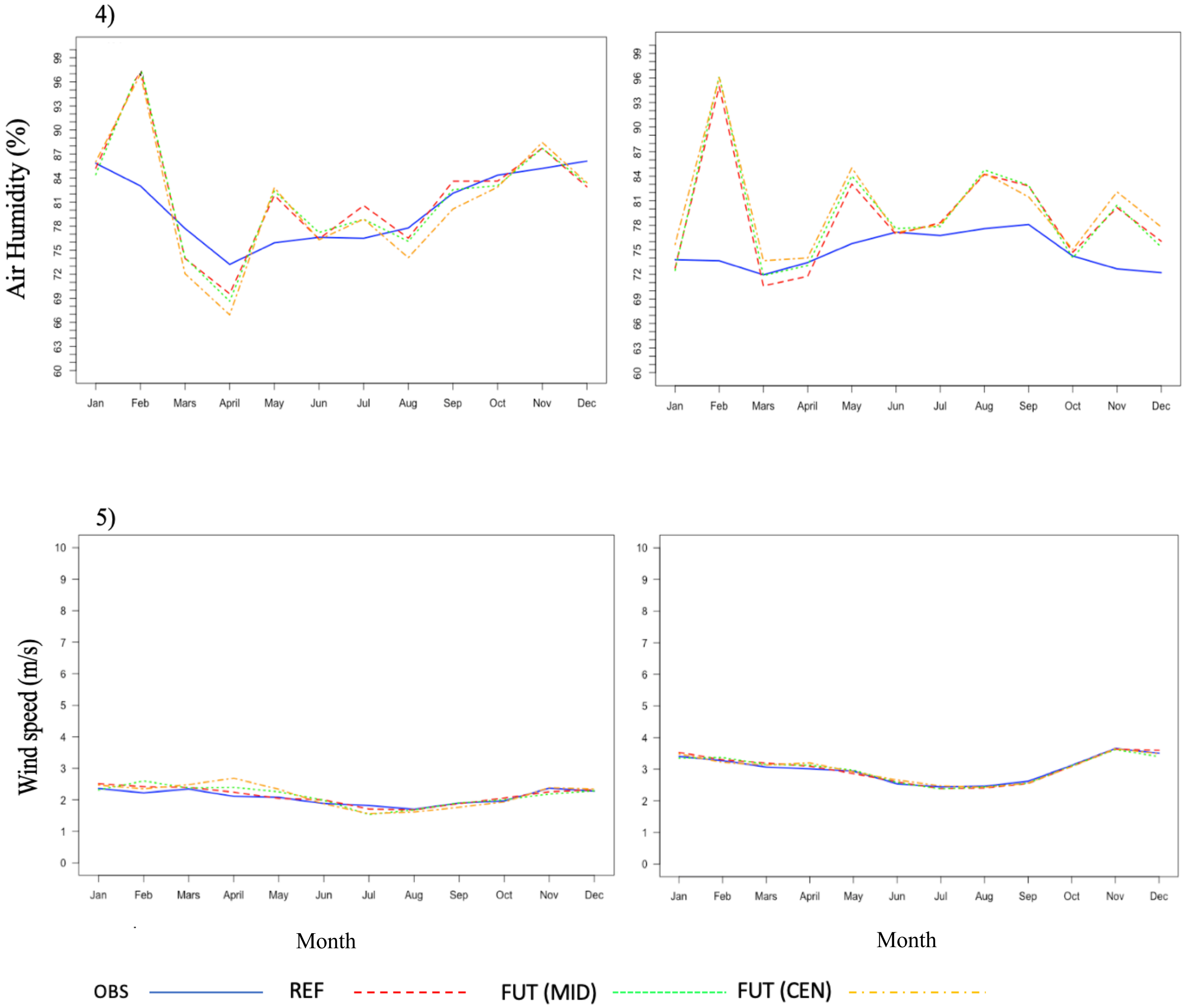
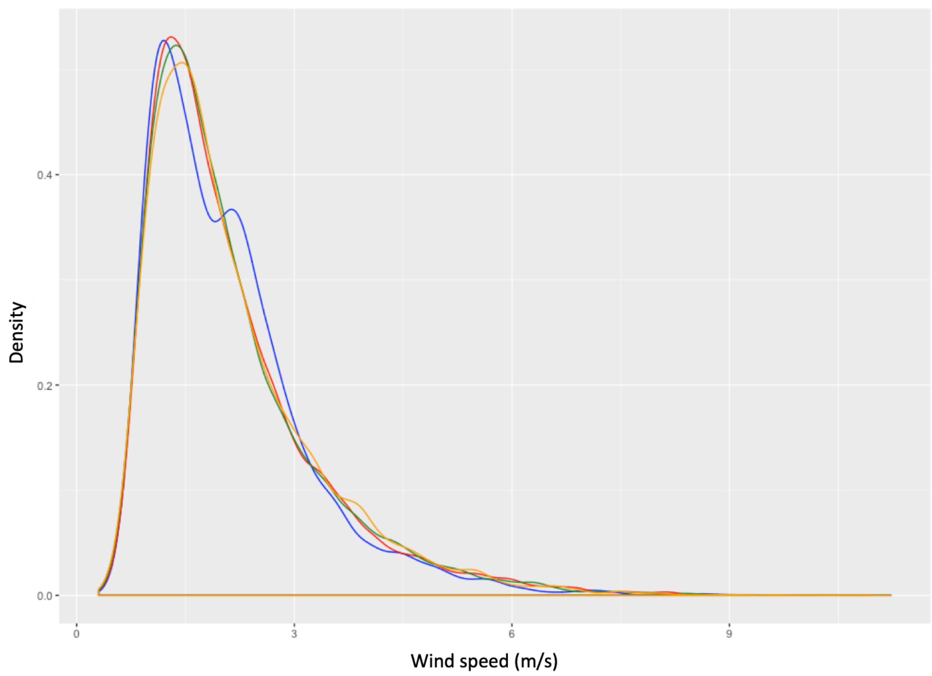


Figure 7.2. Comparison of mean daily climate input data (1) Tmax, (2) Tmin, (3) Solar radiation, (4) Air Humidity, (5) Wind speed. For a) Ybbs and b) Salzach of INCA year (2003-2015), REF (1985-2014), FUT(MID) (2021-2050) and FUT(CEN) (1971-2100). REF, FUT(MID) and FUT(CEN) climate data are according to RCP8.5.

The distribution functions for the wind speed variable displays a similar distribution between all four data sets, for both Ybbs and Salzach. Where the data set for Ybbs catchment have a mean distribution between 2.08 and 2.15. INCA data have the lowest mean of 2.08 (m/s). For Salzach catchment show modelled data a higher and earlier peak than the INCA data, indicating a larger amount of lower wind speed values for the modelled data in this catchment. The mean values of the four data sets are very similar reaching in the span of 3.00 to 3.02.

a) Ybbs



b) Salzach

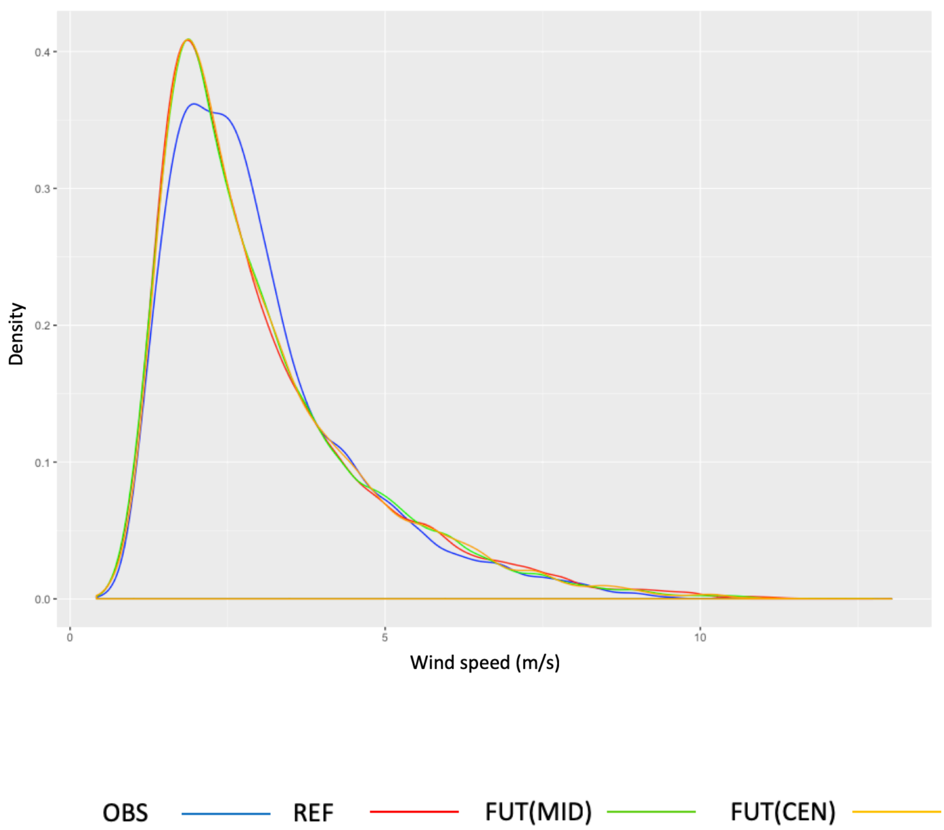


Figure 8. Distributions function of Wind for a) Ybbs and b) Salzach.

4 Methodology

4.1 R and Rstudios

Rstudios was used to run the climate data and calculate evapotranspiration by the three of the four PET formulas (Penman, Priestley-Taylor and McGuinness-Bordne) for the two catchments used in this study, see **section 4.2.1** for description of PET formulas. In addition, for comparison among the four formulas and for further simpler calculations used in the study, link for download of R is found in **appendix**

R is a software program and a language for statistical analysis which. It is a GNU project (operating system of free software) and complies on several of platforms including window and MacOS(R Foundation, n.d.).

R can be recognised as a different implementation of S, similar to the language and environment. However, some important differences exist, yet most of the code written in S can be used for R runs. Extensive variety of statistical (linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering, …) and graphical techniques, is provided by R. The ease of producing well-designed publication-quality plots, including mathematical symbols and formulae, is one of strengths with R. In R, the packages are the essential unit of shareable code. Code, data, documentation, and tests are bundles together in a package and over 6000 packages are available (R Foundation, n.d.).

Rstudios is an open source IDE (integrated development environment) for R. In Rstudios, users can clearly view graphs, data tables, R code, and output all at the same time. In addition, CSV, Excel, SAS (*.sas7bdat), SPSS (*.sav), and Stata (*.dta) files can directly be import into R without having to write the code (Kent state University, 2019).

A package in Rstudios called "Evapotranspiration" was used to calculate PET for the three ET formulas over both catchments. The climate data were altered to the correct format to run the package, see **section 3.2.1**. The correct data were thereafter run in the package for every formula and for the two catchments. Results of ET.Daily, ET.Monthy, ET.Annual, ET.MonthlyAverage and ET.AnnualAverage was given. The results of ET.Daily for Ybbs catchment and RCP8.5 hot, were subsequently after conversion to text file, applied to the hydrological model.

4.1.1 Evapotranspiration package

Included in the Evapotranspiration package from RStudios are 17 different ET estimation methods. The formulas estimate either PET, AET or ET_{ref} at a particular location using one or several of climate variables at sub-daily, daily or monthly resolution. In hydrological modelling are often PET used as input to the hydrological models. All the ET formulas are based on the fundamental components which drives ET: Energy balance (determines the latent heat of vaporization) and Mass transfer (effecting the rate of water vapor movement leaving from the evaporating surface) (Guo et al., 2016).

The ET models included in the package have different data requirements of climate variables and related units because they are based on different physical developments and dependent on diverse climate variables. In total, eight ET-methods estimates PET. The PET methods consider Tmin, Tmax, RHmin, RHmax, Rs, Uz and dewpoint temperature, at different sets of ET sub-processes (Guo et al., 2016).

All the equations in the package except two (Jensen-Haise and McGuinness-Bordne) are taken from (McMahon et al., 2013). The two remaining formulas Jensen-Haise and McGuinness-Bordne are sources from (Prudhomme & Williamson, 2013).

The packages consists of the functions ReadInputs(), ET…(), ETPlot(), ETComparison() and ETForcing(). Daily raw climate data or sub-daily raw climate data, as well as a list of constants are required as input for the package. There are requirements for the variable names, units and the input data file format for the raw climate input data (find in supplementary material to the report of GUO). The essential variables for the input data are (year, month and day), defining the time of the data set. Furthermore, additional input data requirements are needed. However, differ depending on which ET model that is used. Constants suggestions and compulsory definitions (naming) of the constants are summarized in the package under “constants” (Guo et al., 2016). Selected constants are needed to be specified by hand depending on the location of the calculated area and the instruments used. The constants which is space and tool dependent are: latitude, portion of extraterrestrial radiation reaching the planets ground on days with no sun, difference between fraction of extraterrestrial radiation reaching the earth ground in days with no sun and days with full-day sun, ground elevation above mean sea level and height of wind instrument. Constant included for PET calculations in this study is displayed in **table 6**.

The ReadInputs() is a pre-processing function established for loading and processing the input data. Data availability and identification of missing entries and errors in the input data are checked by the function. First, availability of date data (year, month and day) are tested, after which available raw climate data inputs is reported. The function then asses missing entries in the climate variable and the quality is evaluated against two threshold values. Further, abnormal values in the climate variables are simply checked. Finally, the raw data are combined into daily time-step and ready to use in the ET models (Guo et al., 2016).

The generic function ET…() achieves calculations for all the different 17 ET methods and produces summary of the results. The specific ET formula can be called by writing the function name after ET. (e.g ET.Penman for the Penman formula). The function can be called when the required data and constants are provided. The choice of model and sub-model, along with the corresponding versions, amounts calculated (mean, max and min), options for alternative calculations and assumptions as well as the time-series used are printed on the screen. The full results including the calculation summary and the whole times series of output are stored automatically in Rstudios working directory as an R list file and as a cvs file (Guo et al., 2016).

The results can be visualised and plotted by the three plotting functions ETplot(), ETComparison() and ETForcing. ETPlot() preforms plots at different time scales (daily, monthly and annual) for the original estimated results, aggregations and averages. Comparison of results and imagining of uncertainties from divers ET formulas and different input data can be done by calling ETComparison(). For every call of the function can three kinds of plots be produced: time- series plots, non-exceedance probability plots and box plots. ETForcing() generates plots picturing the relationship between the calculated ET and the four climate variables (Guo et al., 2016).

Table 6. PET constants.

Constants	Penman	Priestley–Taylor	McGuinesse-Bordne
lat_rad - latitude in (radians)	0.8360 (Ybbs) 0.8240 (Salzach)	0.8360 (Ybbs) 0.8240 (Salzach)	0.8360 (Ybbs) 0.8240 (Salzach)
z - height of wind instrument (m)	10		
sigma - Stefan-Boltzmann constant (MJ/K^4/m^2/day^1)	$4.903*10^{-9}$	$4.903*10^{-9}$	
alphaPT - Priestley-Taylor coefficient		1.26	
Gsc - solar constant (MJ/m^2/min^1)	0.0820	0.0820	0.0820
lambda - latent heat of vaporisation (MJ/kg)	2.45	2.45	2.45
Elev - ground elevation above mean sea level in (m)	638 (Ybbs) 1779 (Salzach)	638 (Ybbs) 1779 (Salzach)	638 (Ybbs) 1779 (Salzach)

4.1.1.1 Output data

Results for the whole time series applied is given. Estimation of PET for Daily, Monthly, Annual, Monthly Average and Annual Average is summarised and stored as R list file and as a CVS file. The results of monthly average and annual average are used for illustration of PET difference among the formulas and for calculation of absolute and relative change of PET. The daily PET estimations in the result file, was after conversion to text file applied in the hydrological model.

4.2 Selection of evapotranspiration formulas

The purpose of this study was to test four different formulas used in hydrological modelling. The formulas were to be based on diverse number of inputs climate variables and if possible, from diverse PET classes. The PET classes represented in this paper originates from the PET classes presented in Seiller et al. (2016). The three classes are: combinational, radiation-based and temperature-based formulas. The idea of development of the formulas has more influence on the classification then on which input variables is included. The combinational formulas mix energetic and mass-transfer concepts while the temperature-based and radiation-based formulas are empirical. Penman and Priestley-Taylor are two of the well-known combinational formulas(Penman, 1948; Priestley & Taylor, 1972). Where's McGuinness-Bordne (Oudin, Hervieu, et al., 2005), Turc (Turc, 1961) and Jensen-Haise (Jensen &

Haise, 1963) are three radiation-based formulas (Seiller & Anctil, 2016). Part of the temperature-based class are e.g Thornthwaite (Thornthwaite, 1948) and Blaney-Criddle (Allen & Pruitt, 1986),

Eight out of 17 ET formulas, in the evapotranspiration package, produce quantitative estimations of PET. From the set of available formulas producing PET was Penman (combinational), Priestley-Taylor (combinational) and McGuinness-Brodne (radiation-based) chosen. However, of the optional eight formulas where neither a simple temperature-based ET formula (Guo et al., 2016). To include a temperature- based formula was calculation for the Thornthwaite equation given by the IWHW. The PET results given by Thornthwaite was imported and plotted in Rstudios. The outcomes were thereafter compared with the other three formulas calculated in the package. An overview of the four PET formulas, belonging PET class and climate variables included in the equation and in calculations in Rstudios is illustrated in **table 7**.

Table 7. Overview of the four ET formulas.

PET class	PET formula name and related function name in ET package	Time step (Guo, Westra, & Maier, 2016)	Climate variables included in equation	Climate input data required in package (Guo et al., 2016)
Combinational	Penman (Penman, 1948) *ET.Penman*	Day	T RH R_s U_z	T_{min} T_{max} RH_{max} RH_{min} R_s U_z
Combinational	Priestley-Taylor (Priestley & Taylor, 1972) *ET.Priestley-Taylor*	Day	T RH R_s	T_{min} T_{max} RH_{max} RH_{min} R_s
Radiation-based	McGuinness-Bordne (Oudin, Michel, Hervieu, Andréassian, Anctil, Loumagne, & Perrin, 2005; Prudhomme & Williamson, 2013) *ET. McGuinnessBordne*	Day	T R_s	T_{min} T_{max}
Temperature-based	Thornthwaite(C. Thornthwaite, 1948)	Day	T	

All four selected formulas are applied in hydrological modelling (Oudin, Michel, & Anctil, 2005; Seiller & Anctil, 2016). The Penman equation is a widely applied formula and used in several of hydrological studies (e.g Isabelle et al., 2017; McMahon, Peel, Lowe, Srikanthan, & McVicar, 2013; Oudin, Hervieu, et al., 2005; Oudin, Michel, et al., 2005). Further, the modified version Penman- Monteith is presented by FAO as the most satisfactory formula (Allen et al., 1998; Murage & Ongoma, 2015). Priestley-Taylor was chosen as the second formula in the hierarchy of complexity after Penman. Because of its similarities to Penman but with empirical simplification. Further, the method is used in several of hydrological studies (e.g Cai, Yang, Zhao, Zhou, & Hou, 2017; Devia et al., 2015). The McGuinness-Bordne formula was selected for its simpler structure and for its class belonging (Radiation-based). McGuinness-Bordne were one of two radiation-based formulas producing PET estimations in the Evapotranspiration package. McGuinness-Bordne was selected in favour of the other (Jensen-Haise) because of its capacity to calculate PET for lower temperature without producing negative PET values (Guo et al., 2016). The formula is included in several of studies testing evapotranspiration formulas including (Oudin, Michel, Hervieu, et al., 2005; Seiller & Anctil, 2016; Xu & Singh, 2000).

Thornthwaite formula was chosen as an alternative to the temperature-based group. The formula is wildly used in calculation and comparison studies of PET (Kay, Bell, Blyth, Crooks, Davies, & Reynard, 2013; Prudhomme & Williamson, 2013; Seiller & Anctil, 2016). Furthermore, PET calculation of Thornthwaite had earlier been applied in studies at the institution, including as the original formula to BOKU-HYWA(Frey, 2015).

4.2.1 PET formula description

The formulation of the Penman equation, Priestley-Taylor equation and McGuinness-Bordne equation in this study, is source from Guo et al., (2016). Guo et al., (2016) obtained the two first mentioned equation from (McMahon et al., 2013), thus is the Penman formula and the Priestley-Taylor formula sourced from the same paper here. The McGuinness-Bordne formula has (Guo et al., 2016) obtained from (Prudhomme & Williamson, 2013) hence is the equation in this study sourced from there. The applied Thornthwaite formula is sourced from (Bretschneider, Lechner, & Schmidt, 1982).

Penman

The Penman equation was developed in 1948 (Penman, 1948) and was the first to create a formula which included the combination of energy-balance and aerodynamic equations for calculations of PET (McMahon et al., 2013). The formula includes all the four weather variables T, RH, R_s and U_z (Murage & Ongoma, 2015) and is part of the combinational class (Oudin, Hervieu, et al., 2005; Seiller & Anctil, 2016). The method excludes the no standard meteorological measurement, the surface temperature variable. Furthermore, heat exchange with the ground, change in heat storage, and water-advected energy is not assumed in the PET method. In practical hydrological applications is the assumption acceptable for monthly or daily estimations (McMahon et al., 2013). In this study is the equation used as:

$$PET = \frac{\Delta}{\Delta + \gamma} \times \frac{R_s}{\lambda} + \frac{\gamma}{\Delta + \gamma} \times E_{uz} \qquad (4\text{-}1)$$

PET (mm/day) - is the daily potential evaporation from a saturated surface
Rs (MJ/m^2/ day)- is the net daily radiation at the evaporating surface and dependent on the surface albedo
E_{uz} (mm/day) - is the function which is the aerodynamic component of the formula which include the average daily wind speed (m/s)
Δ (kPa/◦C) - is the slope of the vapour pressure curve, at air temperature, which include the saturation vapour pressure (kPa) and the average vapour pressure (kPa),
γ (kPa/ ◦C) - is the psychrometric constant
λ (MJ/kg) - is the latent heat of vaporization

Several of other ET equations has been inspired by the Penman formula. Including the extended version called Penman – Monteith where cropped surfaces by introducing resistance factor was included by (Monteith, 1965). Further, Penman did lay out the path for the evolution of the Priestley-Taylor method, described next.

Priestley-Taylor

The Priestley-Taylor equation is applicable for wet surfaces under conditions of limited advection and is an empirical simplification of the Penman model. The formula does not include an aerodynamic component but calculate the PET in terms of energy fluxes. The formula is part of the combinational class and include the input weather variables: T, RH and R_s (Oudin, Hervieu, et al., 2005; Seiller & Anctil, 2016). The Priestley-Taylor constant αPT included in the formulas was set to 1.26 for advection-free saturated surfaces (Priestley & Taylor, 1972). The constants have after 1972 been examined and tested. Where large seasonal and spatial variations in αPT was show in Castellvi et al. (2001). Pereira (2004), illustrated that αPT should not be seen as a constant but rather as a decoupling coefficient. Daily time step is adopted in the Priestley-Taylor formula and the formulas used in this study is as follow:

$$\mathrm{PET} = \alpha_{\mathrm{pt}} \left(\frac{\Delta}{\Delta + \gamma} \times \frac{\mathrm{R_s}}{\lambda} + \frac{\mathrm{G}}{\lambda} \right) \tag{4-2}$$

PET (mm/day) - is potential evapotranspiration,
R_s (MJ/ m^2/ day) - is the net daily radiation at the evaporating surface,
G (MJ/m2/day) - is the soil flux into the ground,
Δ (kPa/ ◦C1) - is the slope of the vapour pressure curve at air temperature,
γ (kPa/ ◦C1) - the psychrometric constant
λ (MJ/kg1) - is the latent heat of vaporization
αPT is the Priestley–Taylor constant.

McGuinness-Bordne

The PET estimation method is included in the PET class radiation-based formulas (Oudin, Michel, & Anctil, 2005; Seiller & Anctil, 2016). However, the formula has also been defined as a temperature-based equation by (Tanguy, Prudhomme, Smith, & Hannaford, 2018). In this study the formula is define as a radiation-based. The method was developed in USA and is based on an analysis of lysimeter data in Florida. It was proposed as an additional formula more suitable for humid regions (McGuinness & Bordne, 1972). The foundation formula uses Fahrenheit as the describing unit for temperature. The formula has however been described in different version applying °C as unit for temperature. The version used in this paper applies °C and is described as:

$$\mathrm{PET} = \frac{\mathrm{R_e}}{\lambda p} \times \left(\frac{\mathrm{T} + 5}{68} \right) \tag{4-3}$$

PET (mm/day) – is potential evapotranspiration
λ (MJ/ kg) - latent heat of vaporization
T_a (C) - temperature
R_e (MJ/m^2/day) - extraterrestrial radiation
ρ (1000 kg/L) – water density

One limitation with the McGuinness-Bordne equation is when calcualting PET for temperature under minus 5 °C, though the second part of the equation is calculated to a negative number. This limitation could be traced back to the deveopment of the formula which orginally was established using Farenhait as the unit for temperature.

Thornthwaite

Thorntwaite is part of the temperature-based PET class (Oudin, Hervieu, et al., 2005; Seiller & Anctil, 2016**).** The formulas was developed in the middle of the twentieth century. For valleys in the estern USA, with supply of surface water, correlated Thornthwaite (1948) monthly mean temperatue with PET, determinded from the water balance. The original approch was later modified, presenting parameterization for a regulated range of average air temperature T (◦C) by (Willmott, Rowe, & Mintz, 1985). The Thornthwaite is empirical and depends only on temperature and latitude.

The formulas and associated parameters, in this paper, is sourced from (Bretschneider et al., 1982). The daily PET values for respectively month, is given by the mean values from each month. Meaning that each thay in the same month has the same value.

$$PET = 16{,}0 \left(\frac{10T}{I} \right)^{a} \qquad (4\text{-}4)$$

PET (mm/month) – potential evapotranspiration

T (°C) – average monthly temperature
I – heat index for the 12 months of the year, with I = Σ i
i – heat index for every single month, i= $(T/5)^{1.514}$
a – characteristic value as a function of I

The monthly PET values, after calculation, are corrected according to sunshine duration for each month and latitude, see **table 8**.

Table 8. Sunshine duration according each month for Ybbs and Salzach catchments.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sunshine Duration	0.76	0.8	1.02	1.14	1.31	1.33	1.34	1.23	1.05	0.93	0.77	0.72

4.3 Hydrological model for PET application

Calculation of hydrological projections in changing climate condition is completed according to one emission scenario (RCP8.5 hot) and for Ybbs catchment. However, all PET results in this report are discussed in relation to application in the hydrological model referred to as BOKU-HYWA. The choice of hydrological model was done by the Institute of Hydrology and Water management (HyWa) and is the same model which earlier has been used in Powerclim project. It is presented and developed by (Holzmann, Lehmann, Formayer, & Haas, 2010) specifically for Austrian conditions. The model has been used in recent papers for studying possible impacts of climate change on the hydrological system (e.g Frey, 2015; Holzmann et al., 2010).

4.3.1 BOKU-HYWA model

BOKU-HYWA is a conceptual, semi-distributed rainfall-runoff model, based on the ideas of the broadly used HBV model. Fast surface flow components are accounted in the model induced as infiltration excess (HOF), saturation overland flow (SOF), interflow (subsurface flow, SSF) and ground water flow (GWF). **Figure 9** illustrate a scheme of the model.

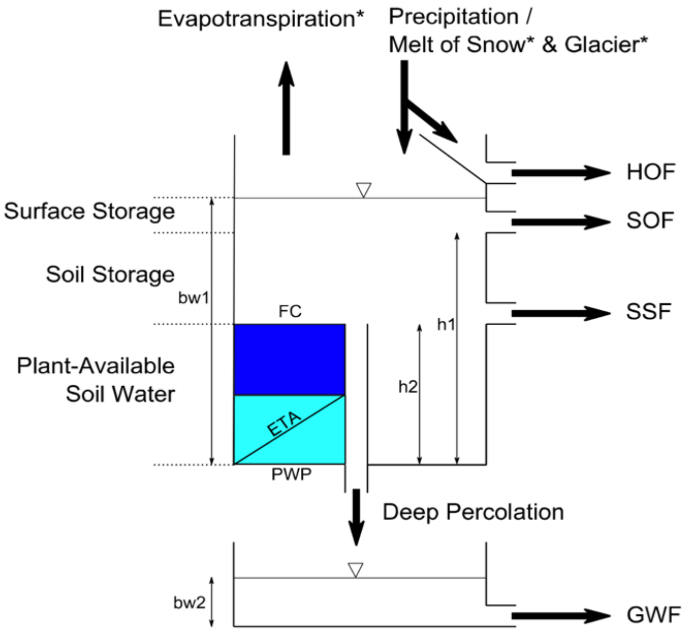


Figure 9. Illustration of the hydrological model BOKU-HYWA (Frey, 2015).

The model is capable of temporal resolution up to one hour. However, in this study is daily time step used. Daily precipitation is one of the input variables and treated as lumped input. Melt of snow and glaciers are internally computed for different elevation levels. All the temperature-dependent variables including temperature, marked with * in **figure 9**, could be applied for seven different altitude levels: 250 m, 500 m, 750 m, 1000 m, 1250 m, 1500 m and 2500 m above sea level or as mean values. In this study are mean PET values applied. The modelled catchments are subdivided into 100 m elevation levels by a digital elevation model (DEM). Air temperature information is gotten by interpolating. However, if temperature at elevations above 2500 m above sea level or below 250 m above sea level has to be gained, extrapolating using a lapse rate of 0.0065 °C m-1 is done. A simple temperature index model is used to calculate the ice- and snowmelt (Frey, 2015).

Soil in the model is treated as lumped storage in the watershed. In the bucket-type storage of the model enters water only by liquid precipitation or by melt of snow and ice. There are four ways in the model which water can exit the soil either as water vapor through evapotranspiration, due to percolate into a deep groundwater storage or as SOF or SSF runoff. If the capacity of the storage, limited by infiltration capacity of the soil, is exceeded and intense precipitation or snow and ice melt tries to enter the storage will HOF happen (Frey, 2015).

Potential evapotranspiration is estimated outside the model by an alternative PET formula, e.g Penman, Priestley-Taylor, McGuinness-Bordne or Thornthwaite, see **section 4.1.1** for PET calculation in Rstudios, evapotranspiration package. The model calculates the AET from the input values of PET when the soil water level drops. PET linearly reduces to AET when the soil level falls below 50 % of the field capacity (Frey, 2015).

In the calibration process, the hydrological model gets data of observed discharge, which it should be matched to. The model further has some parameters that can be adjusted, including correction factors for PET and precipitation. During the calibration process a program tests different values for the parameters, PET and precipitation, and exams which discharge that is coming out, with each of these adjusted parameter values. This discharge is compared to the measured discharge. The result of the calibration are the parameters of PET and precipitation that result in the simulated discharge having the best agreement with the measured discharge. However, precipitation is not adjusted if the water balance equation, $Q=P-(AET*C_{aet})$, (Q= discharge, P= precipitation, C_{aet}= AET correlation factor) requirement is meet.

4.3.1.1 Output data

The results from the model are daily total discharge at the outlet of the modelled basin. It is the sum of all the generated runoff processes included in the model: overland flow represented by QHOF and QSOF, the interflow QSSF, baseflow as QGWF and direct runoff from ice- and snowmelt as QMELT.

4.4 Calculation

Relative change of PET

Mean annual PET difference between the future time-slices, was compared through relative change (%). The change was calculated for FUT(MID) and FUT(CEN) relative to REF. The calculation of relative change for mean annual PET was estimated in excel and operated by:

$$\text{Relative change} = \left(\frac{\text{(Future time-slice - Reference data)}}{\text{Reference data}} \right) \text{x } 100$$

Standard deviation

Standard deviation was calculated for mean annual PET values to illustrate the possible range of annual variations, listed in **table 12 and 13**. The calculations were completed in Rstudios using command sd().

5 PET results and model intercomparing

5.1 PET depending on RCPs

Figure 10 and **11** illustrate PET development for each modelled data set according to the three RCPs for Ybbs and Salzach catchments respectively.

In FUT(CEN) increases PET according to RCPs with higher climate signal, for all PET methods, in Ybbs catchment. Greatest change in PET is seen for McGuinness – Bordne, from 982 mm/year to 1138 mm/year, according to RCP4.5 and RCP8.5 hot respectively. The smallest increase between RCP4.5 and RCP8.5 hot is illustrated for Priestley-Taylor, from 808 mm/year to 855 mm/year. See **table 9** for PET change between RCP4.5 and RCP8.5 hot in FUT(CEN) and all estimation methods.

The changes among RCPs in FUT(MID) illustrate small differences compared to FUT(CEN). A small positive change between RCP4.5 and RCP8.5 hot is seen for McGuinness – Bordne, Penman and Thornthwaite, while a negative change is showed for Priestley-Taylor.

For all PET methods expect Penman are the lowest PET calculations showed for RCP8.5 hot and the highest values for RCP8.5 in REF data. A quite constant outline of PET among the RCPs is illustrated for the Penman formula.

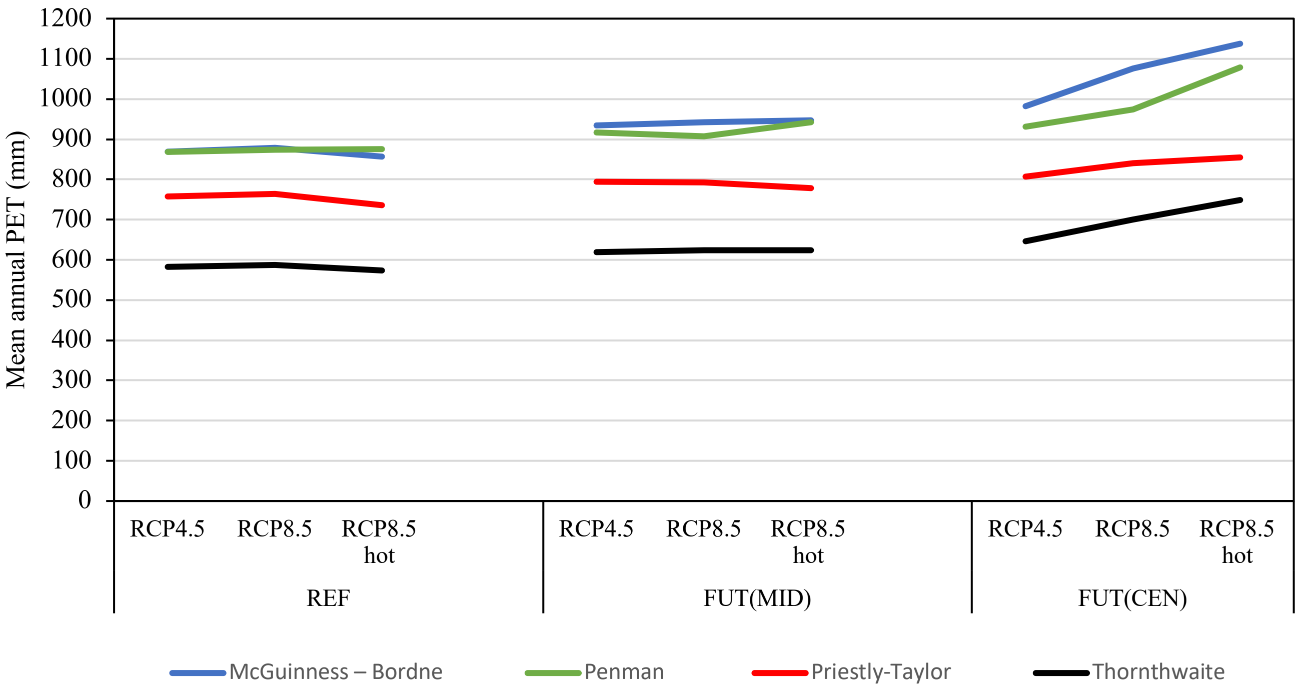


Figure 10. Mean annual PET variation depending on emission scenario. Illustrating RCP4.5, RCP8.5 and RCP8.5 hot for REF, FUT(MID) and FUT(CEN) and Ybbs catchment.

Table 9. Change (RCP8.5 hot minus RCP4.5) in mean annual PET values (mm) for each formula and both catchments according to FUT(CEN).

Catchment	McGuinness – Bordne	Penman	Priestley-Taylor	Thornthwaite
Ybbs	155	148	47	103
Salzach	212	231	94	116

For Salzach catchment increase PET calculations according to RCP with higher radiative forcing in FUT(CEN). With lowest values for RCP4.5 and highest for RCP8.5 hot. This is true for all PET estimation methods. The increase in PET according to RCPs is largest for the Penman. With an increase, comparing RCP4.5 to RCP8.5 hot, of 231 mm/year, see **table 9**.

An increase in PET from RCPs with weaker to stronger climate signal could also be seen in FUT(MID) for McGuinness – Bordne, Penman and Thornthwaite. Priestley-Taylor, show the highest PET calculations for RCP8.5 hot and lowest for RCP8.5. However, the difference between RCP4.5 and RCP8.5 is quite small laying between 710 mm/year and 708 mm/year for the PET method.

For REF data there are a quite unchanging outline between the RCPs for all PET formulas seen. Displaying the highest PET values for RCP8.5 for all PET methods except Penman.

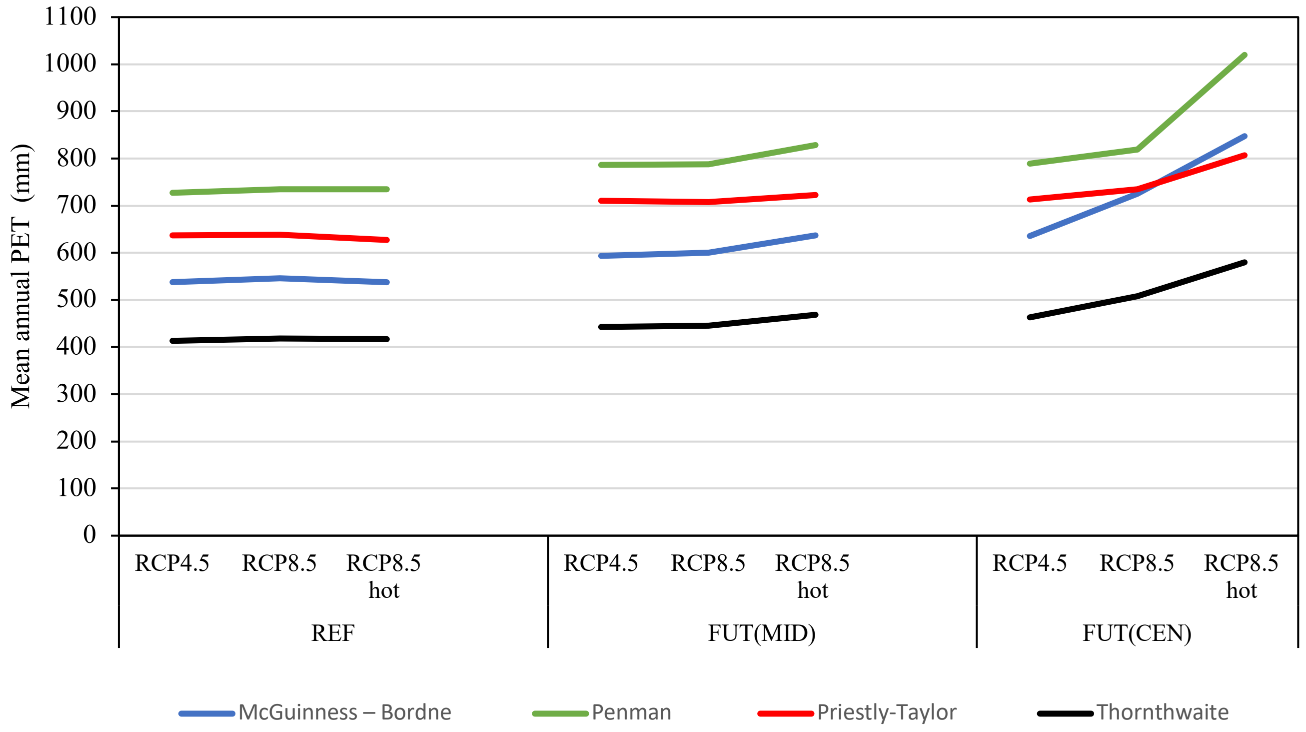


Figure 11. Mean annual PET variation depending on emission scenario. Illustrating RCP4.5, RCP8.5 and RCP8.5 hot for REF, FUT(MID) and FUT(CEN) and Salzach catchment.

5.2 PET variability

Annual distribution

PET results of annual mean, for the various formulas, show different patterns in both catchments. In **figure 12** (Ybbs) and **figure 13** (Salzach) is PET calculations for REF, FUT(MID) and FUT(CEN), for all RCPs and the four PET formulas illustrated.

In Ybbs catchment gives McGuinness – Bordne the maximum mean annual PET for all time periods and RCPs, despite in REF and RCP8.5 hot, where Penman gives a higher PET. Subsequent, a pattern can be seen, of highest PET given by McGuinness – Bordne, followed by Penman, Priestley- Taylor and Thornthwaite. For all PET formulas and RCPs increases PET from REF to FUT(MID) and to FUT(CEN). Highest PET is illustrated in FUT(CEN) for RCP8.5 hot for all formulas. This is demonstrating a pattern of rising PET with future time periods.

Strong variation in mean annual PET among the four formulas is presented for all time periods, with a great difference between the highest and lowest PET. In FUT(MID) and FUT(CEN) is the utmost biggest difference seen in RCP8.5 hot between McGuinness – Bordne and Thornthwaite, with PET of 947 mm (FUT(MID) and 1138 mm (FUT(CEN) for McGuinness – Bordne and 623 mm (FUT(MID) and 749 mm (FUT(CEN) for Thornthwaite. This is corresponding to an absolute change of 324 mm and 389 mm for FUT(MID) and FUT(CEN), **table 10**.

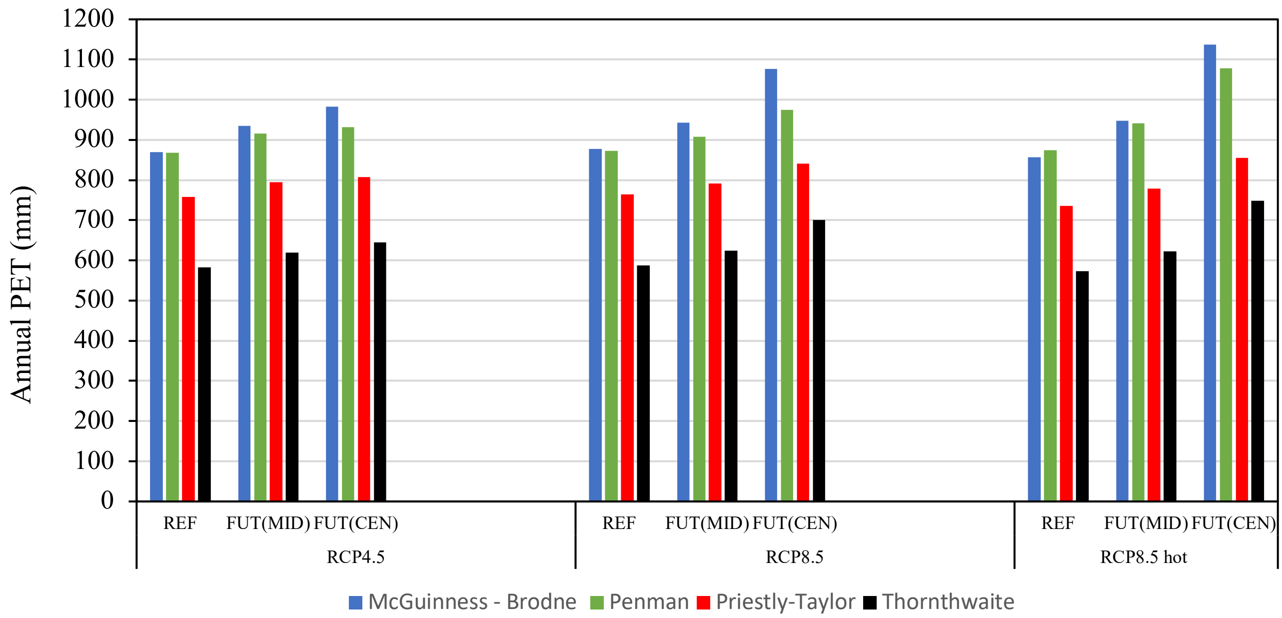


Figure 12. Mean annual PET variation subject to the different time periods REF, FUT(MID), FUT(CEN). Displayed for all emission scenarios for Ybbs catchment.

In the Salzach catchment, a continues pattern for all data sets and all RCPs can be seen, where the Penman PET method at all time give the highest PET calculations. The Penman results are followed by the Priestley-Taylor PET calculations which gives the second highest PET, third McGuinness – Bordne and last Thornthwaite which gives the lowest values of PET. This outline is true for all scenarios and data sets with the exception of FUT(CEN) and RCP8.5 hot, where McGuinness – Bordne gives higher PET results than Priestley-Taylor.

Mean annual PET increases when going from REF to FUT(MID) and FUT(CEN). This is true for all RCPs and for all PET formulas.

The mean annual PET varies essentially between different formulas in the same time period and RCP. The biggest variation in absolute PET among the different formulas is between, 1020 mm to 580 mm concerning Penman and Thorthwaite respectively, for the period FUT(CEN) and RCP8.5 hot. This response to an absolute change of 440 mm. The maximum change for FUT(MID) is seen in RCP8.5 hot between Penman and Thorthwaite, with an absolute change of 360 mm, see **table 10**.

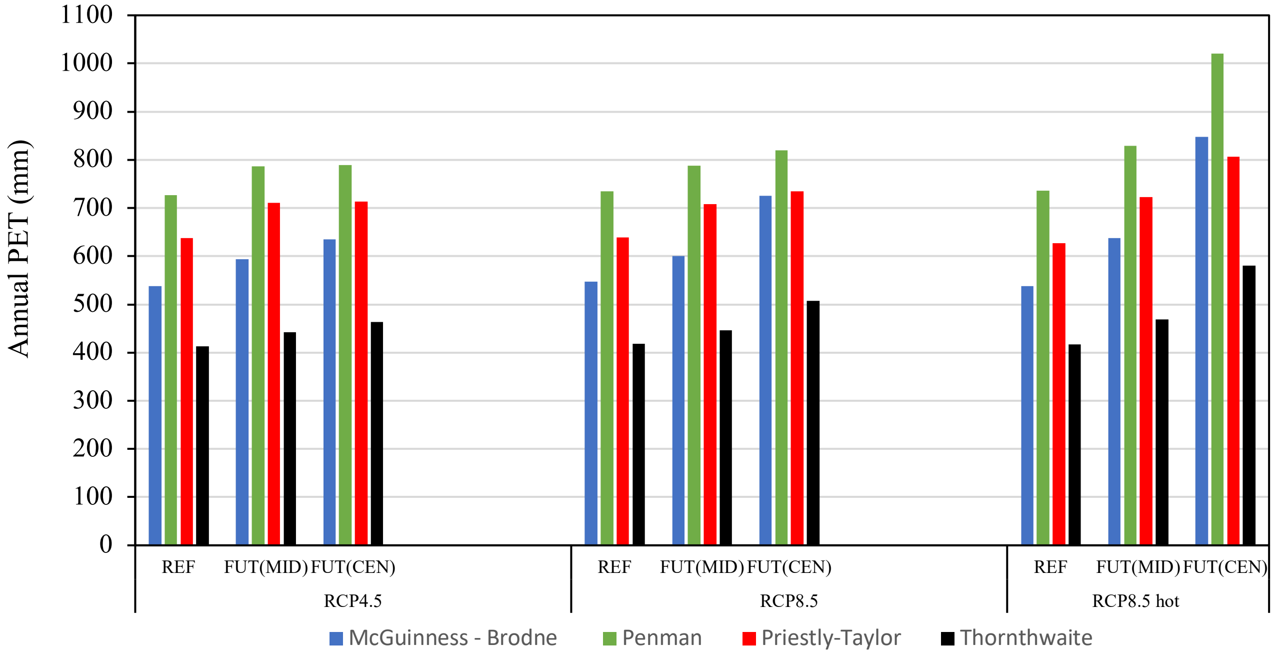


Figure 13. Mean annual PET variation subject to the different time periods REF, FUT(MID), FUT(CEN). Displayed for all emission scenarios for Salzach catchment.

Table 10. Maximum absolute difference in annual mean PET (mm) among PET formulas.

Time period	Emission scenario	Ybbs	Salzach
		Annual (mm)	Annual (mm)
FUT(MID)	RCP4.5	315	344
	RCP8.5	319	342
	RCP8.5 hot	324	360
FUT(CEN)			
	RCP4.5	337	325
	RCP8.5	375	311
	RCP8.5 hot	389	440

Annual relative change

The change in annual mean for FUT(MID) and FUT(CEN) relative to REF, according to each RCPs is pictured in **figure 14** for (a) Ybbs and (b) Salzach catchments. All PET formulas, in each scenario and catchment has a positive relative change, implying increased PET with climate change in both Ybbs and Salzach catchment.

a) Ybbs b) Salzach

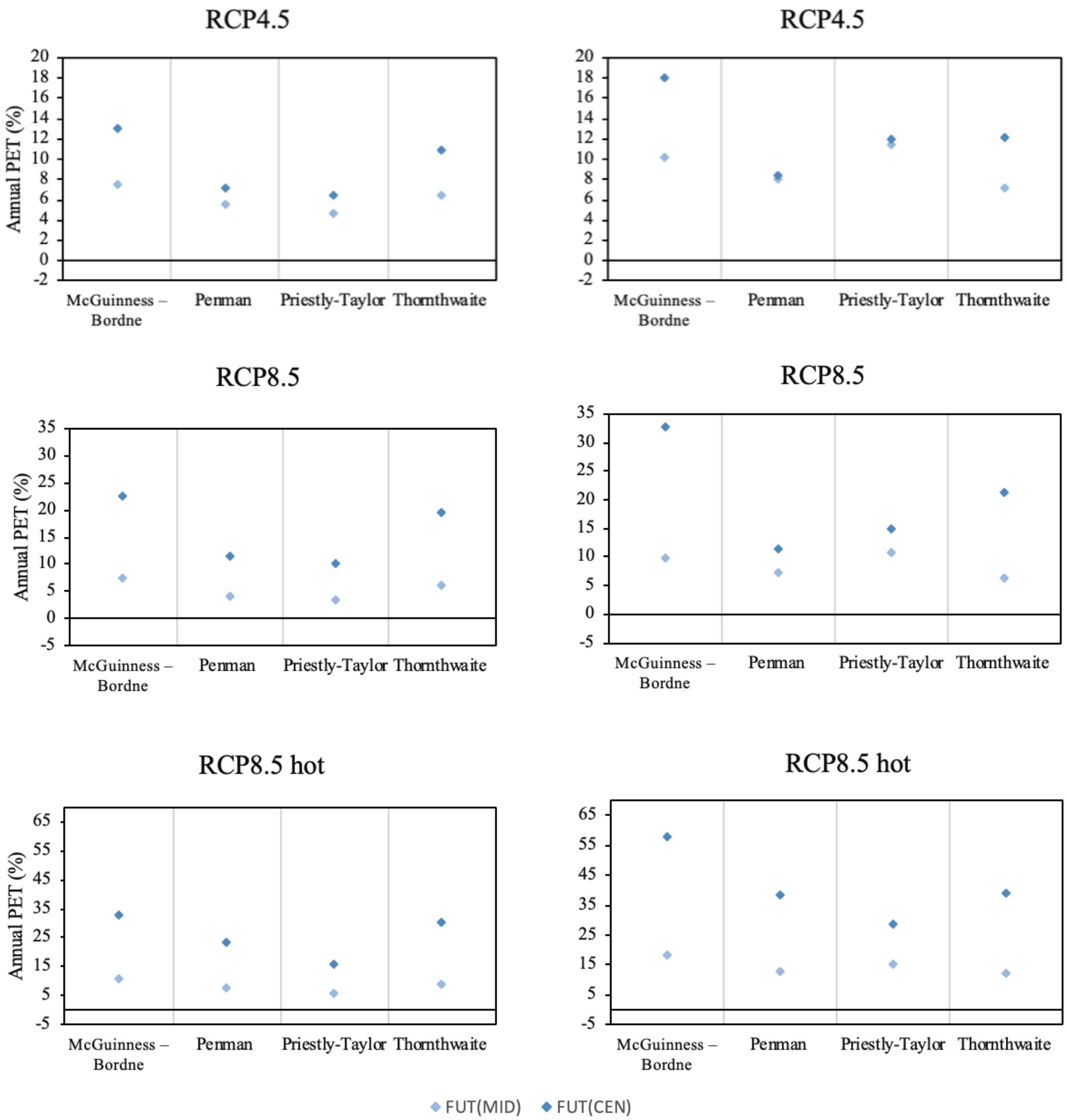


Figure 14. Changes in annual mean of potential evapotranspiration for FUT(MID) and FUT(CEN) relative to the REF (1981–2010) according to RCP4.5, RCP8.5 and RCP8.5 hot for a) Ybbs and b) Salzach catchment.

Time periods

The highest relative change is given by McGuinness- Bordne for all emission scenarios and both time periods in Ybbs catchment, followed by Thornthwaite, Penman and Priestley – Taylor. The greatest change in annual PET values is illustrated in RCP8.5 hot for all PET formulas, where the relative change for each estimation method are within 11% for PET FUT(MID) and 32 % for PET in FUT(CEN).

Looking at FUT(MID) in Salzach catchment, the smallest relative change is calculated by Thornthwaite in all RCPs. Priestley- Taylor presents the highest relative change in RCP4.5 and RCP8.5. While, for RCP8.5 hot is the largest change given by McGuinness- Bordne. Similar to Ybbs, the highest change is showed in RCP8.5 hot for all formulas. In this emission scenario the relative change, among the formulas, are within 19%.

The display of formulas in FUT(CEN) in Salzach catchment, has a different outline compared to FUT(MID). In all RCPs McGuinness- Bordne shows the highest relative change, followed by Thronthwaite. Penman gives the lowest annual mean change in RCP4.5 and RCP8.5. However, a change between Priestley- Taylor and Penman is illustrated in RCP8.5 hot, where Priestley- Taylor gives the smallest change. In RCP8.5 hot, the greatest change can be seen for all four formulas, in the range of 28 - 58 %.

RCPs

Smaller difference occurs in relative change among RCP4.5 and RCP8.5, in both catchments for FUT(MID). However, a quite clear increase can be seen in RCP8.5 hot compared to the other emission scenarios. For FUT(CEN), a pronounced pattern is obvious, where the relative change increases from RCP4.5 to RCP8.5 and to RCP8.5 hot. This is true for the four formulas and both catchments.

PET formulas

The change range between the formulas increases in FUT(CEN) compared to FUT(MID) in all emission scenarios and in both catchments. In RCP8.5 hot, FUT(CEN), the change range among the formulas is 17% for Ybbs and 29% for Salzach, see **table 11**. This can be compared to FUT(MID), with the maximum span of 5 % and 6 % for Ybbs and Salzach respectively. This points in the direction of an increased sensitivity in PET among difference formulas, in climate projection in a distant future compared to the near future.

Table 11 . Maximum differences of relative annual PET (%) among PET formulas.

	Ybbs		Salzach	
	FUT(MID)	FUT(CEN)	FUT(MID)	FUT(CEN)
RCP4.5	2	6	4	6
RCP8.5	4	13	4	21
RCP8.5 hot	5	17	6	29

Monthly distribution

In **figure 15** are the monthly distribution of PET calculation of the four PET formulas, for REF and FUT data, according to RCP8.5, and both catchments illustrated. For modelled data there are a spread, of monthly daily mean PET calculation, between the formals seen.

In Ybbs catchment follow the Penman and the Priestley-Taylor time series a similar pattern, where McGuinness – Bordne and Thornthwaite show a small different outline. McGuinness – Bordne gives a noticeably higher monthly daily mean for all data sets, for the period May to September compared to the other formulas. In the period January to August, the monthly daily mean PET calculations for Thornthwaite show the lowest values compared to the other formulas, in all data sets.

The maximum difference between the PET formulas is seen in June, for all data sets between McGuinness – Bordne and Thornthwaite. With a difference in average daily PET of 1.69 mm/day for REF, 1.85/day mm FUT(MID) and 2.12/day mm for FUT(CEN) data. High difference in average PET between Penman and Thornthwaite is displayed in April, with differences according to 1.68 mm/day, 1.61 mm/day and 1.60 mm/day for REF, FUT(MID) and FUT(CEN) respectively. The daily PET data also show large difference among the formulas. An example of the variation in daily PET data between the formulas is the first of June 2080 according to RCP8.5 hot, the calculations vary from 1.95-4.5 mm /day. Smaller absolute difference for Ybbs catchment, in the period October to November for all data sets, is illustrated.

The behaviour of daily average PET calculation by the different formulas in Salzach show a different pattern compared to Ybbs catchment. Thornthwaite presents the lowest average daily PET calculations for the period March to September for all data sets. Followed by McGuinness – Bordne as the second lowest PET in the period March to May. For the colder month January and February, in REF, gives McGuinness – Bordne visibly negative results of PET. This might depend on the properties of the formula which calculates negative results when temperature below minus 5 degrees are applied, see **section 4.2.1** for PET method description. Penman gives the highest average daily PET calculations for the period January to June in all data sets except FUT(CEN). In FUT(CEN) is a distinctive increase in PET by McGuinness – Bordne seen from June to September.

The maximum difference in average daily PET among formulas is seen in April for the Salzach catchment between Penman and Thornthwaite in all modelled data sets. Where a variance of 2.0 mm/day for REF, 2.13/day mm for FUT(MID) and 2.04 mm/day for FUT(CEN) is showed. Daily PET calculation also varies depending on the formulas applied. On the 15 of April 2080 and RCP8.5 hot, lays the daily PET calculation in the range from 0.42 - 3.22 mm/day.

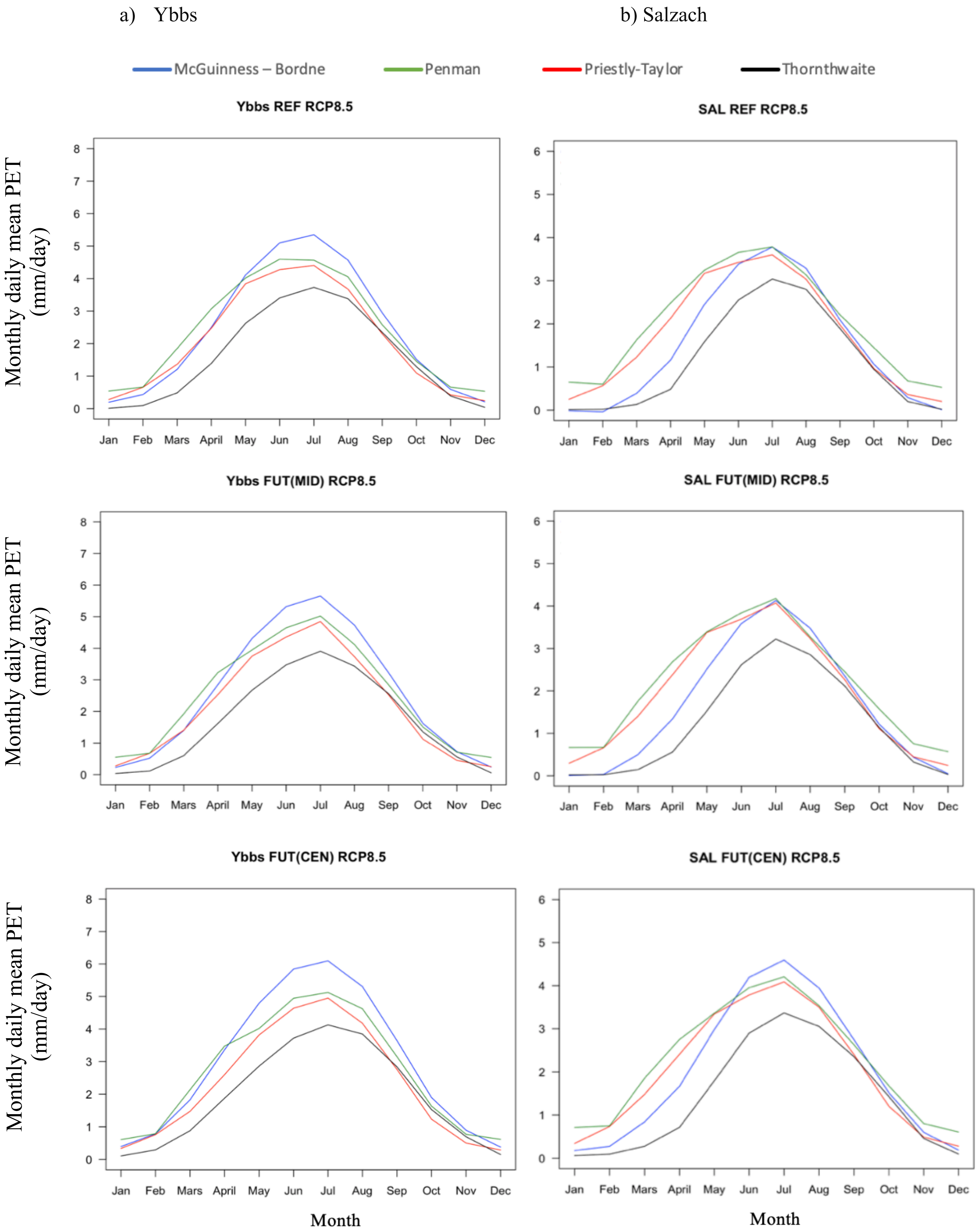


Figure 15. Monthly daily mean PET series for REF, FUT(MID) and FUT(CEN) according to RCP8.5, for a) Ybbs and b) Salzach catchments.

Monthly absolute change

The absolute change in monthly daily mean PET for FUT(MID) and FUT(CEN) relative to REF period, for Ybbs and Salzach catchments, is illustrated in **figure 16** and **17**. The absolute change is displayed for all three emission scenarios (a) RCP4.5, (b) RCP8.5 and (c) RCP8.5 hot in absolute values.

A very large increase in FUT(CEN) according to RCP8.5 hot, in both catchments is illustrated. The absolute change in monthly daily mean PET is in the majority of month larger in FUT(CEN) than in FUT(MID), this is especially clear for RCP8.5 and RCP8.5 hot in both catchments. The difference among PET formulas increase in FUT(CEN) compared to FUT(MID) for most month. Larger absolute change in monthly daily mean PET among the formulas are illustrated in FUT(CEN), from April to October RCP8.5 hot. With a maximum difference in August of 0.94 mm/day and 1.13 mm/day for Ybbs and Salzach respectively. Furthermore, quite clear increase in PET change is also seen from RCP4.5 to RCP8.5 in FUT(CEN) from July to September in both catchments.

The absolute change is positive for all formulas and each month in FUT(CEN) in Ybbs catchment. Except, for Priestley-Taylor in May according to RCP8.5, where a small negative change is given. A similar positive pattern in change is seen for FUT(MID), with a few more exceptions of negative values. Both RCP8.5 and RCP8.5 hot show negative values in May for two and three formulas respectively.

In Ybbs are lower absolute change seen in January and December in all emission scenarios and both time periods. For FUT(CEN) and RCP8.5 and RCP8.5 hot, big changes are seen between July to August. While, the largest change is given in May for RCP4.5 and FUT(CEN). Indicating different monthly behaviour and sensitivity in PET depending on the emission scenario applied.

For all formulas and each month in FUT(CEN), a positive absolute change in Salzach catchment is seen. FUT(MID) also illustrate a positive change with two exceptions for Thornthwaite, in May, RCP8.5 and January RCP8.5 hot.

December, January and February give lower PET values for the three RCPs and both FUT(MID) and FUT(CEN) in Salzach. Similar to Ybbs, no significant pattern of a month with the highest PET over the time periods and all RCPs is seen. From June to August in FUT(CEN) according to RCP8.5 and RCP8.5 hot, and in FUT(MID) according to RCP8.5 hot, a greater positive change in PET values are seen. This pattern is however, not showed in RCP4.5.

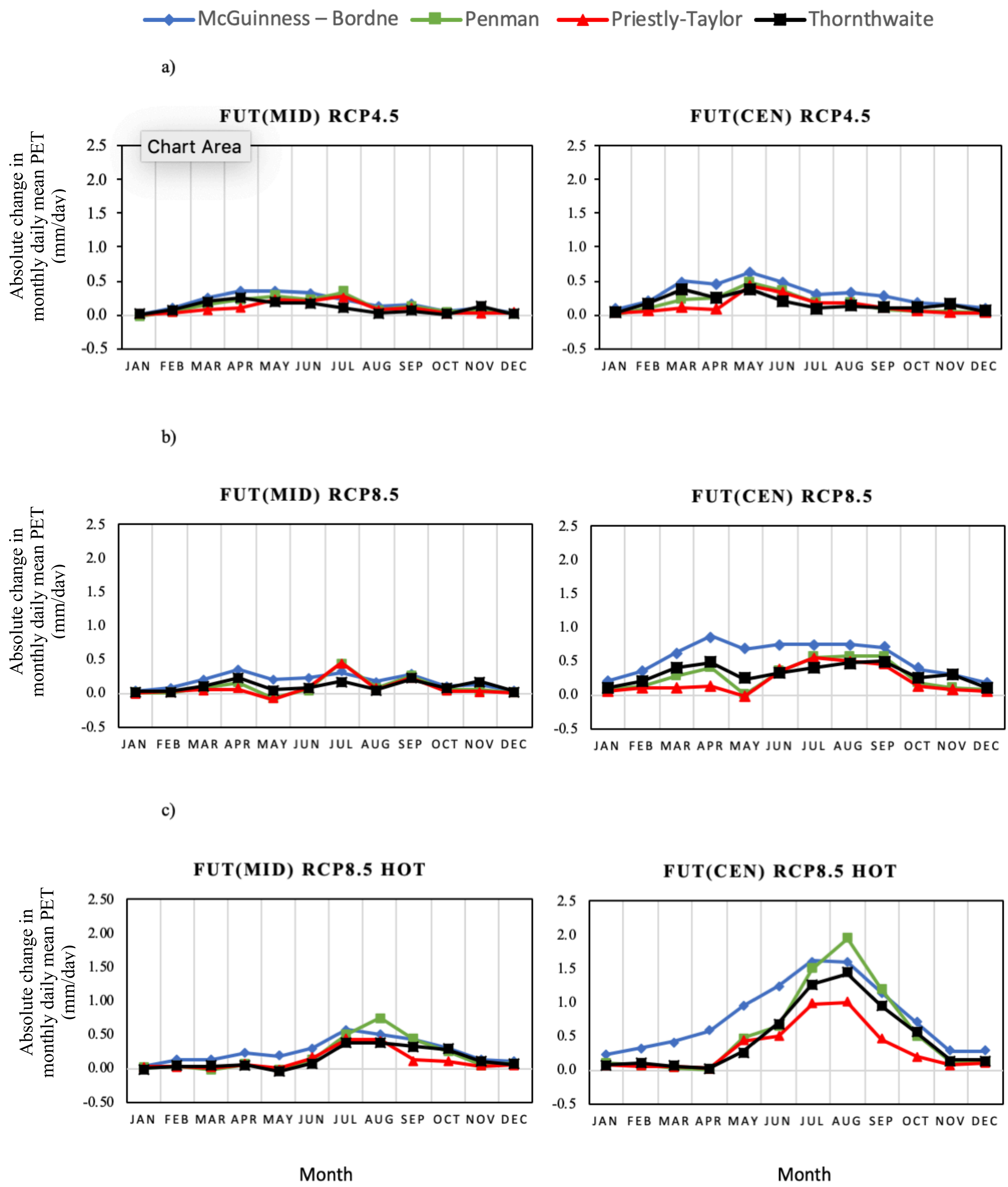


Figure 16. Absolut change in monthly daily mean PET for FUT(MID) and FUT(CEN) relative to REF according to (a) RCP4.5, (b) RCP8.5 and (c) RCP8.5 hot in Ybbs catchment

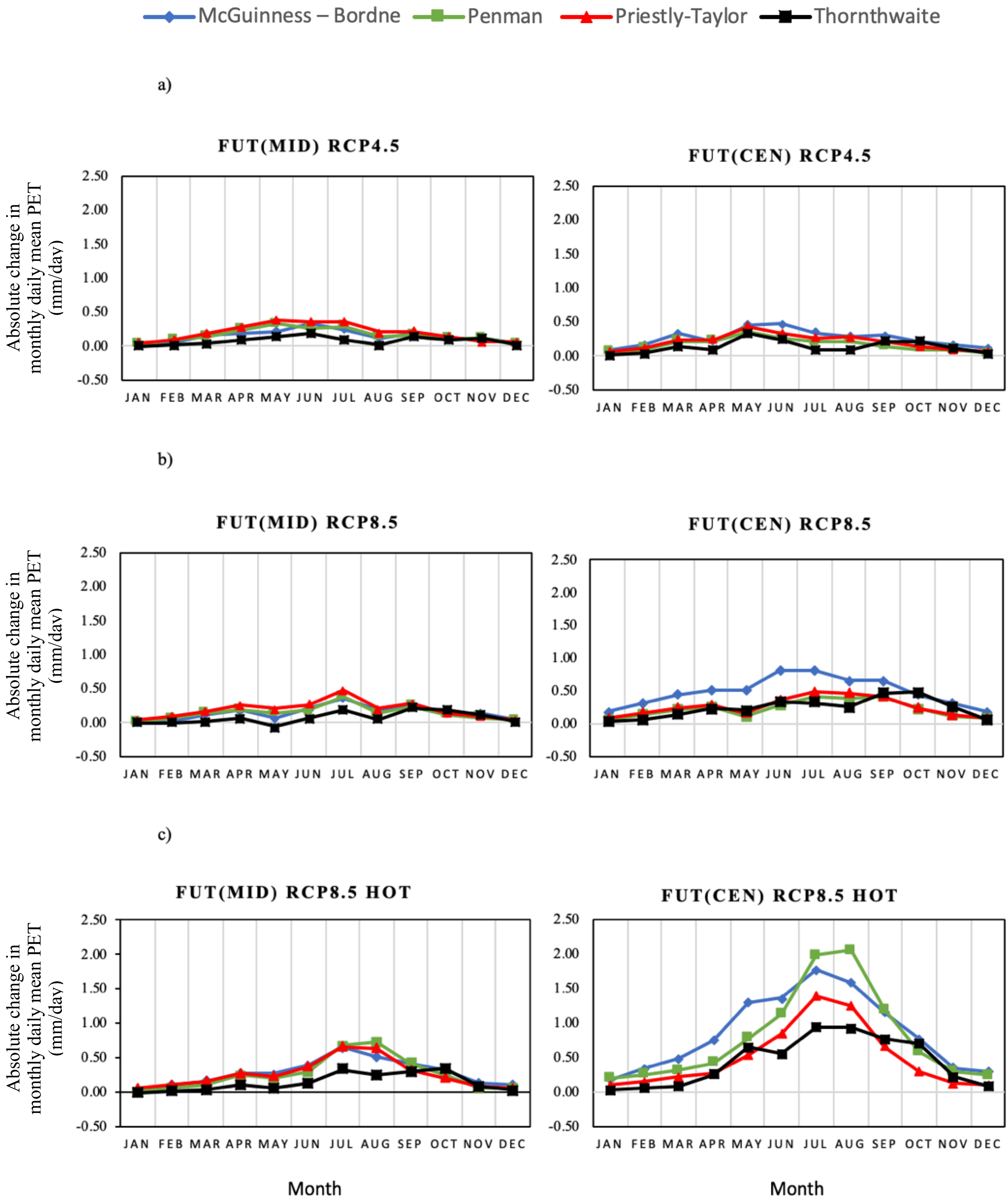


Figure 17. Absolute change in monthly daily mean PET for FUT(MID) and FUT(CEN) relative to REF according to (a) RCP4.5, (b) RCP8.5 and (c) RCP8.5 hot in Salzach catchment**.**

Summary table of mean annual PET values and standard deviation

In **table 12** and **13,** the annual mean and standard deviation calculated for interannual variations, for REF, FUT(MID) and FUT(CEN) according to the three RCPs and the two catchments is illustrated.

For all RCPs and time-periods can fluctuation from year to year be seen. When looking at relative change among standard deviation and mean annual values, a small difference, depending on scenario and time-slice, occurs. Change difference between emission scenarios lies in the range of 1-4 % and among time-periods 1-3%.

Quite similar relative standard deviations are also seen among the different formulas, ranging from 3.5-9 % in Ybbs and 3-8% in Salzach catchment.

Table 12. Overview of annual mean and standard deviation for Ybbs catchment.

Emission Scenario	REF	FUT(MID)	FUT(CEN)	REF	FUT(MID)	FUT(CEN)
	Annual mean	Annual mean	Annual mean	Standard deviation	Standard deviation	Standard deviation
RCP4.5						
McGuinness-Bordne	870	934	982	37.9	40.15	47.8
Penman	868	916	931	39.5	50.0	48.1
Priestley-Taylor	758	794	808	30.5	33.5	32
Thornthwaite	582	619	646	20	22.7	27.4
RCP8.5						
McGuinness-Bordne	878	942	1076	41.7	35.6	49.2
Penman	873	908	974	40.6	49.9	49.3
Priestley-Taylor	765	792	841	31.5	33.1	32.6
Thornthwaite	587	624	701	23.6	19.8	29.2
RCP8.5 hot						
McGuinness-Bordne	857	947	1138	44.7	54.2	64.0
Penman	875	942	1079	73.5	77.7	94.2
Priestley-Taylor	736	778	855	34.7	33.0	37.8
Thornthwaite	574	623	749	23.5	31.3	50.8

Table 13. Overview of annual mean and standard deviation for Salzach catchment.

Emission Scenario	REF	FUT(MID)	FUT(CEN)	REF	FUT(MID)	FUT(CEN)
	Annual mean	Annual mean	Annual mean	Standard deviation	Standard deviation	Standard deviation
RCP4.5						
McGuinness-Bordne	538	594	635	32.2	43.0	47.3
Penman	727	787	789	23.4	28.5	29.1
Priestley-Taylor	637	710	713	20.3	23.7	24.6
Thornthwaite	413	443	464	18.5	23.8	26.0
RCP8.5						
McGuinness-Bordne	547	601	725	38.8	36.7	45.8
Penman	734	788	819	25.6	29.8	27.7
Priestley-Taylor	639	708	734	21.6	24.9	24.2
Thornthwaite	419	446	508	25.1	20.8	23.2
RCP8.5 hot						
McGuinness-Bordne	538	637	847	40.2	50.8	63.3
Penman	735	829	1020	40.9	46.1	82.1
Priestley-Taylor	627	722	807	25.7	27.1	39.2
Thornthwaite	417	468	580	22.3	26.2	35.6

5.3 Precipitation and PET comparison

Monthly PET in comparison with precipitation for FUT(MID) and FUT(CEN) is illustrated in **figure 18** for Ybbs catchment and **figure 19** for Salzach catchment.

In both future time periods according to RCP8.5 and RCP4 and in Ybbs catchment, precipitation exceeds PET data over the whole year, with the exception of individual months. Where PET data calculated by McGuinness-Bordne exceeds precipitation. Looking at FUT(MID) and FUT(CEN) according to RCP8.5 hot, are a quite different rain pattern illustrated. Precipitation surpass the PET between January to April and from October to December in both time periods. Over the warmer periods are precipitation strongly decreased and PET exceeds precipitation, with stronger decreases and over more month in FUT(CEN).

Over both time periods according to all RCPs, exceeds precipitation clearly PET data applying all four formulas, with the exception of FUT(CEN) according to RCP8.5 hot in Salzach catchment**.** Precipitation is evidently decreased from July to September. During this period illustrate PET higher values in comparison to precipitation.

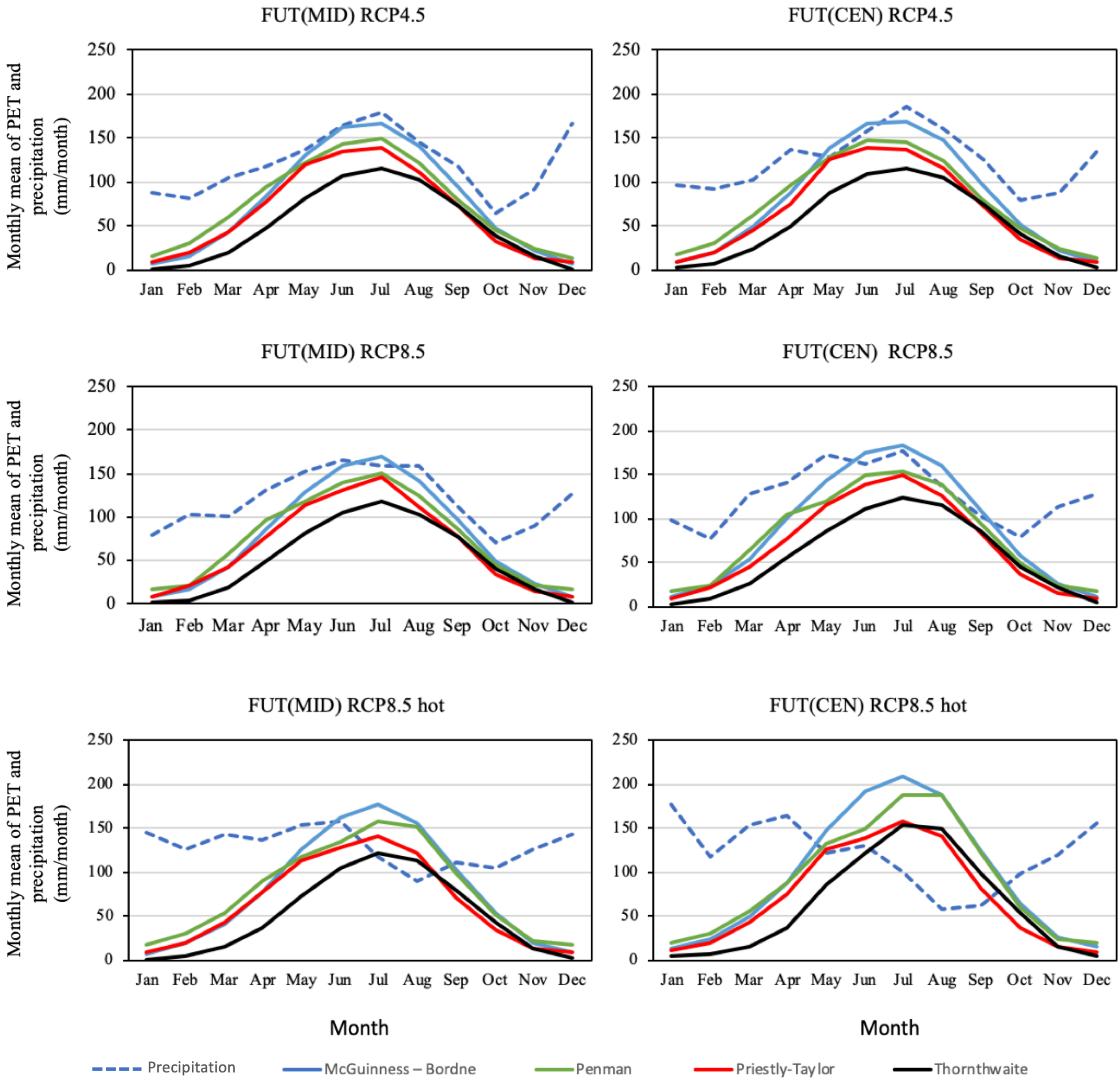


Figure 18. Monthly PET and precipitation comparison for FUT(MID) and FUT(CEN) according to RCP4.5, RCP8.5 and RCP8.5 hot for Ybbs catchment.

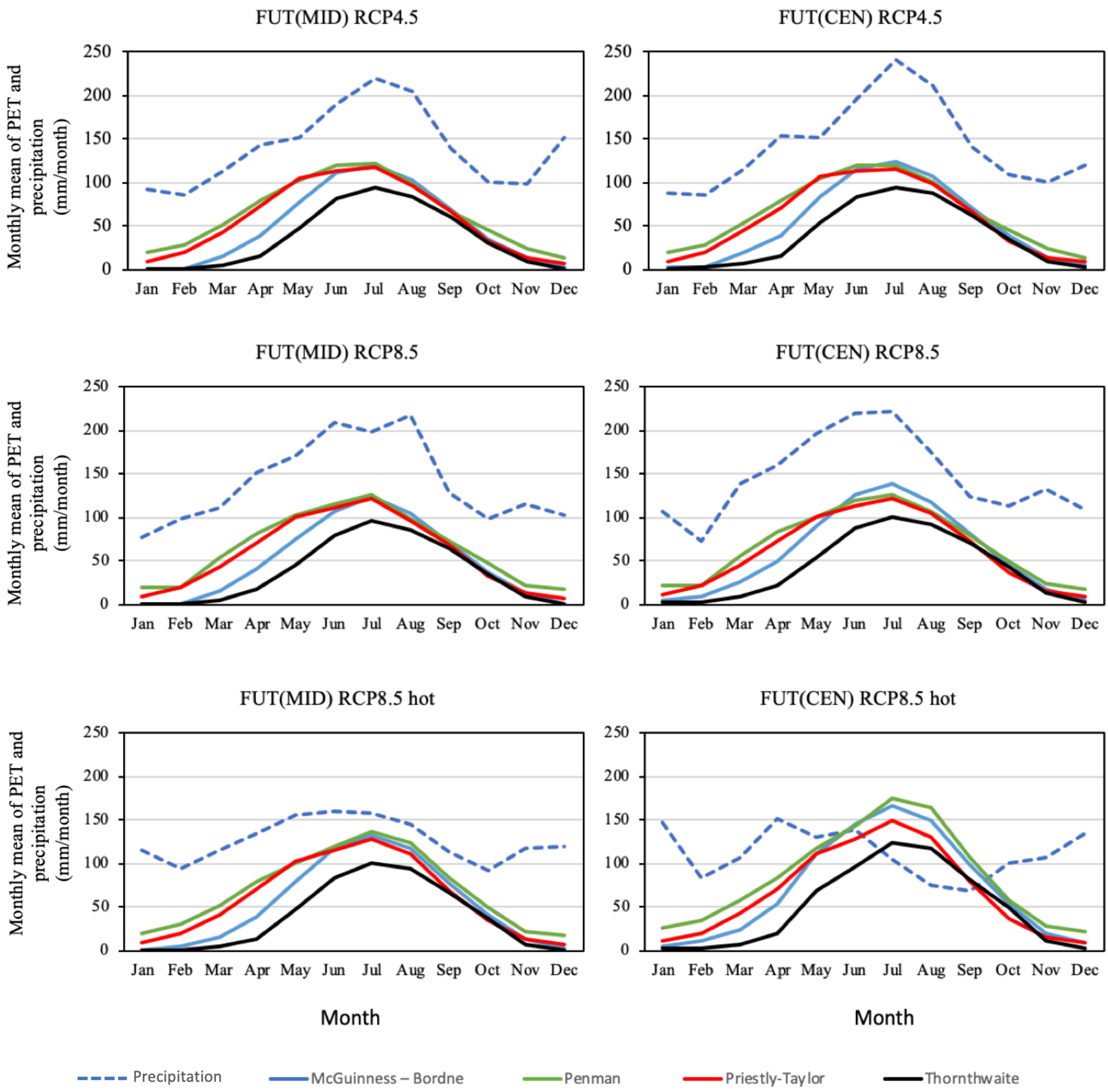


Figure 19. Monthly PET and precipitation comparison for FUT(MID) and FUT(CEN) according to RCP4.5, RCP8.5 and RCP8.5 hot for Salzach catchment.

5.4 AET and discharge

5.4.1 AET

Actual evapotranspiration and discharge are stimulated for Ybbs catchment, for the three time periods and RCP8.5 hot, applying PET by the Penman method. AET and discharge are calculated from hydrological calibrated PET results.

AET increases with time in more distant future, with highest values in FUT(CEN) followed by FUT(MID) and REF, **figure 20**. Indicating a positive trend in AET, in periods more distant future, similar the pattern of PET. However, when comparing PET with AET, is strong decreases in AET illustrated, **figure 21**. AET is reduced by more than a third in all time periods during the calibration.

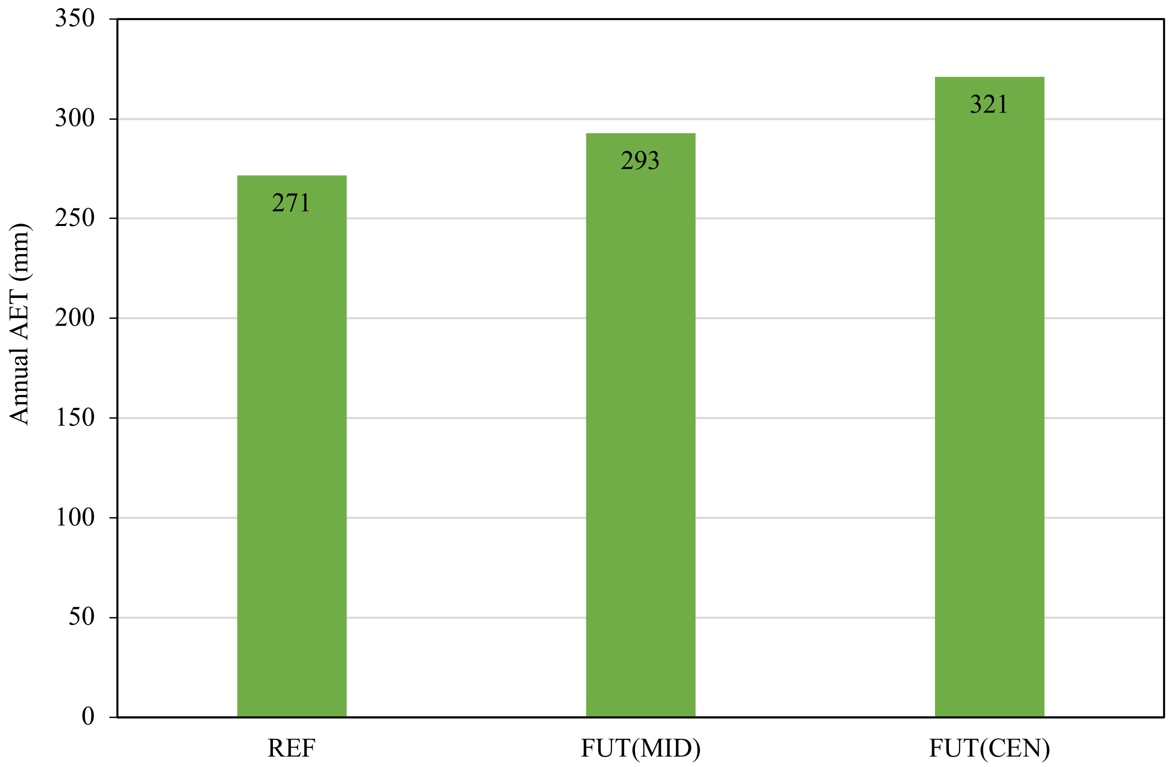


Figure 20. Annual mean AET for REF, FUT(MID) and FUT(CEN), in Ybbs catchment and RCP8.5 hot.

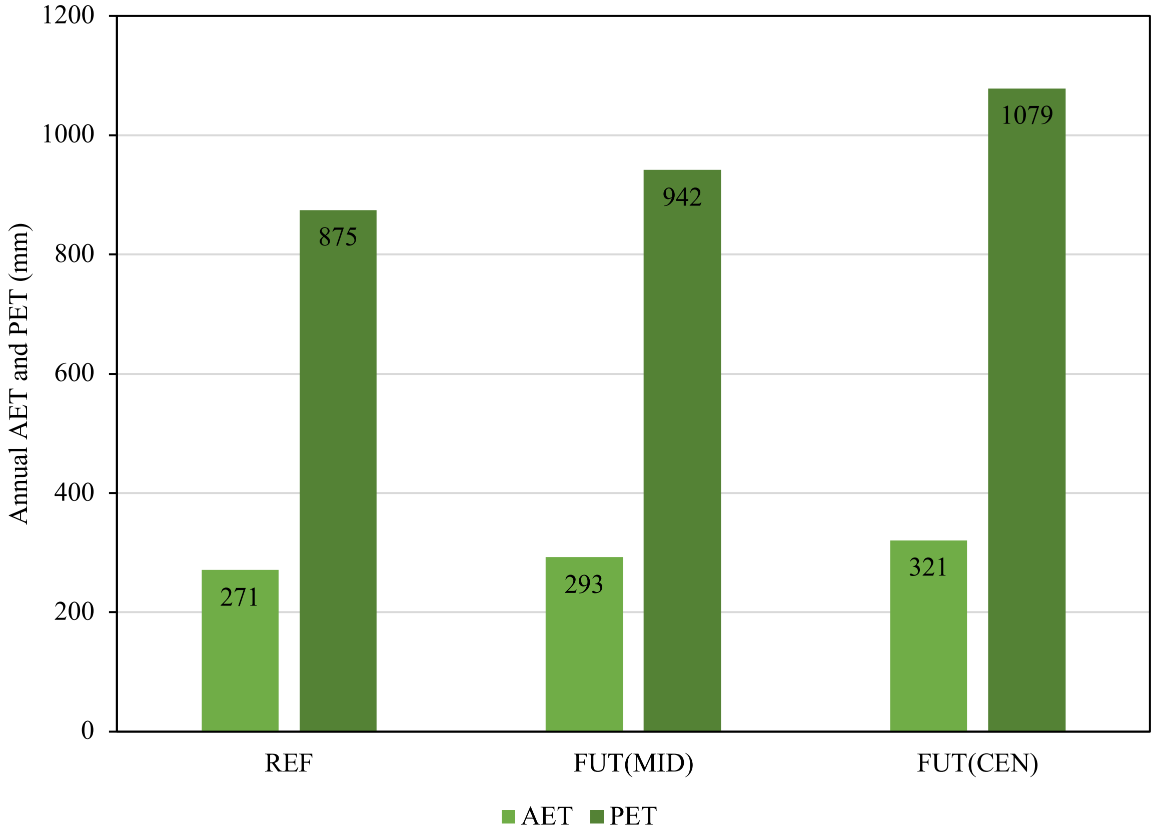


Figure 21. Comparison of annual AET and PET for REF, FUT(MID) and FUT(CEN).

The monthly distribution of AET is illustrated in **figure 22**. Increases in FUT(CEN) compared to REF is seen in all month, except for March and April. Stronger increases are illustrated from May to October in this time period. In FUT(MID) relative to REF, increases are given in February and from April to December, with the exception of May. The rises in AET in FUT(MID) is smaller compared to FUT(CEN) in most of the months.

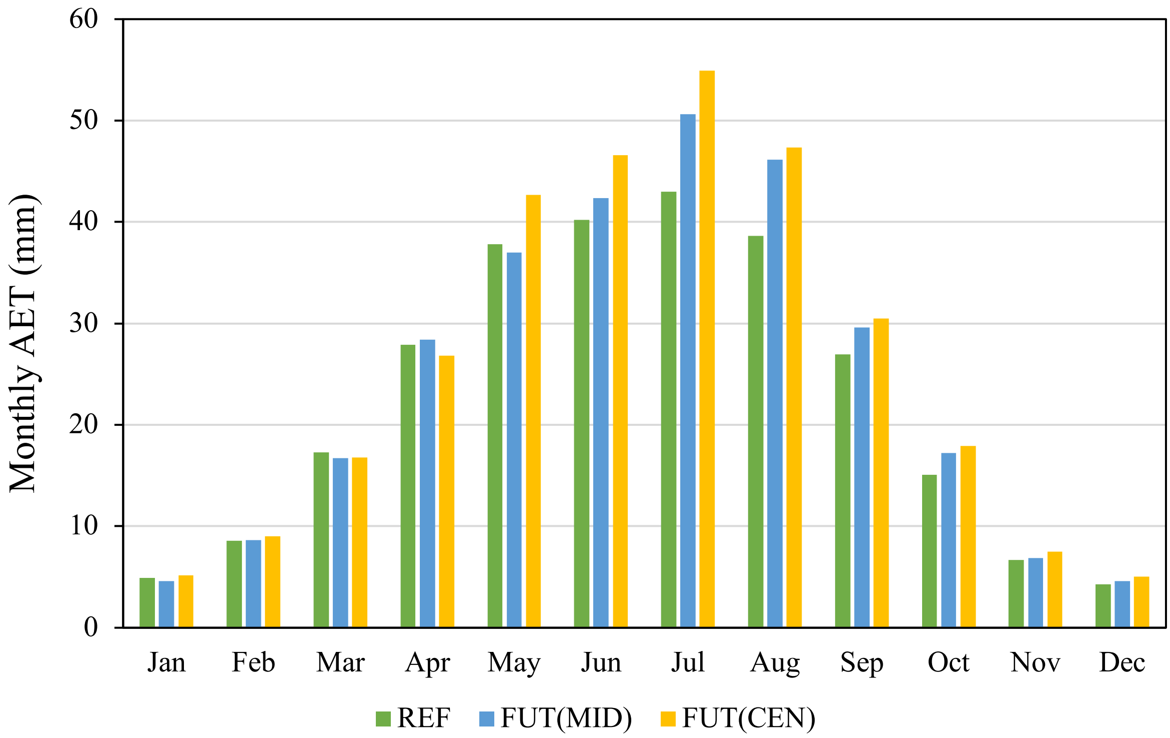


Figure 22. Monthly AET comparing REF, FUT(MID) and FUT(CEN).

5.4.2 Discharge

Annual mean discharge gives the lowest values for the FUT(CEN) period and the highest for FUT(MID), **figure 23**. The difference is around 60 mm/year between FUT(MID) and FUT(CEN) and is around 40 mm/year between REF and FUT(CEN).

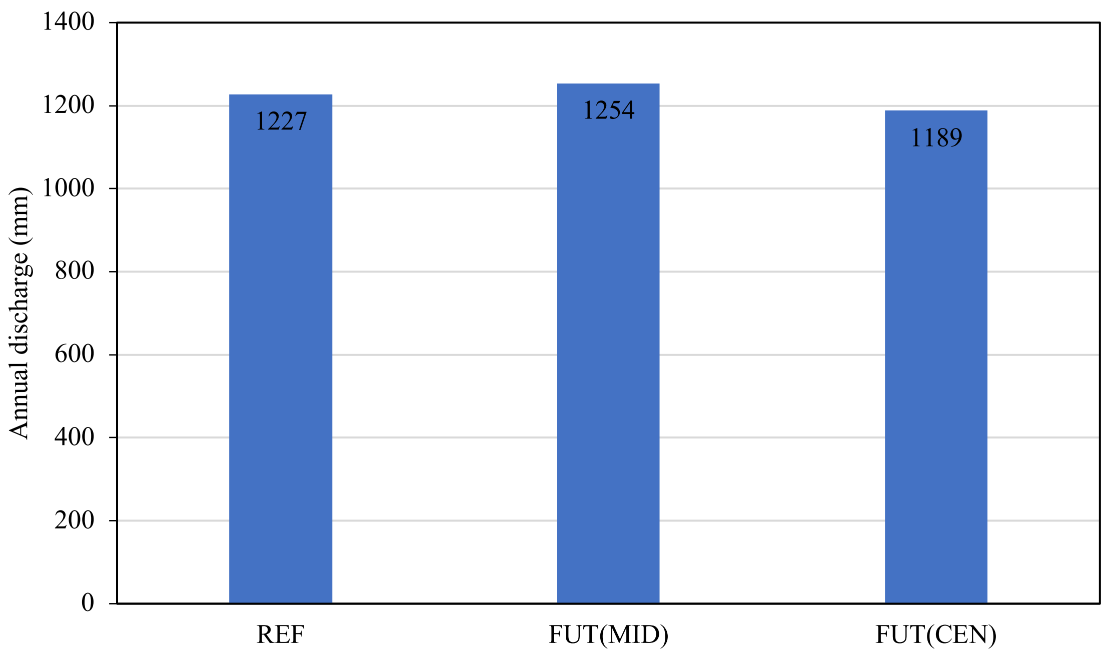


Figure 23. Annual discharge depth in (mm) for REF, FUT(MID) and FUT(CEN), in Ybbs catchment and RCP8.5 hot.

The monthly distribution of discharge for the three time periods are illustrated in **figure 24**. Decreases in discharge, comparing FUT(CEN) to REF, are seen from April to October. With largest difference in August and September. Opposite, quite big increases in discharge for FUT(CEN) are showed in January and December. Comparing FUT(MID) and REF, decrease is seen in April and from June to September, while increases are seen the rest of the year. The difference in runoff among REF and FUT(MID) are in most months smaller compared to discharge differences between REF and FUT(CEN).

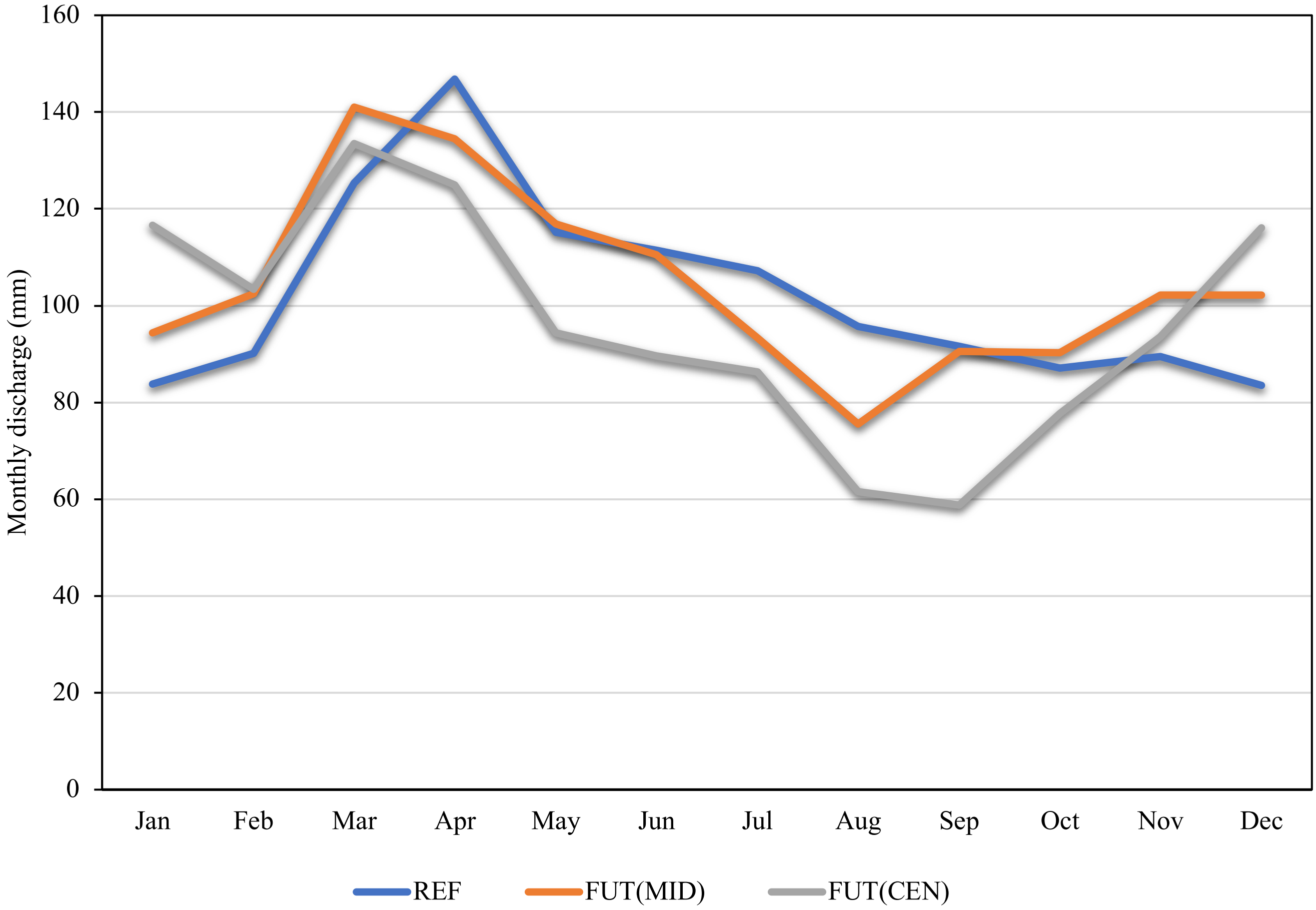


Figure 24. Comparison of mean monthly discharge depth of REF, FUT(MID) and FUT(CEN) in Ybbs catchment, according to RCP8.5 hot.

AET and discharge in comparison to precipitation

Comparison of AET and discharge to precipitation is illustrated in **figure 25.** As can be seen, precipitation equal AET and discharge very well in both future time periods, for filling the water balance equation. In FUT(MID) is annual mean precipitation 1553 (mm) and the sum of AET and discharge 1547 (mm) and in FUT(CEN) correspond precipitation to 1511 (mm) and the amount of AET and discharge to 1510 (mm). In REF are a difference of 50 mm between precipitation and the sum of AET and discharge seen.

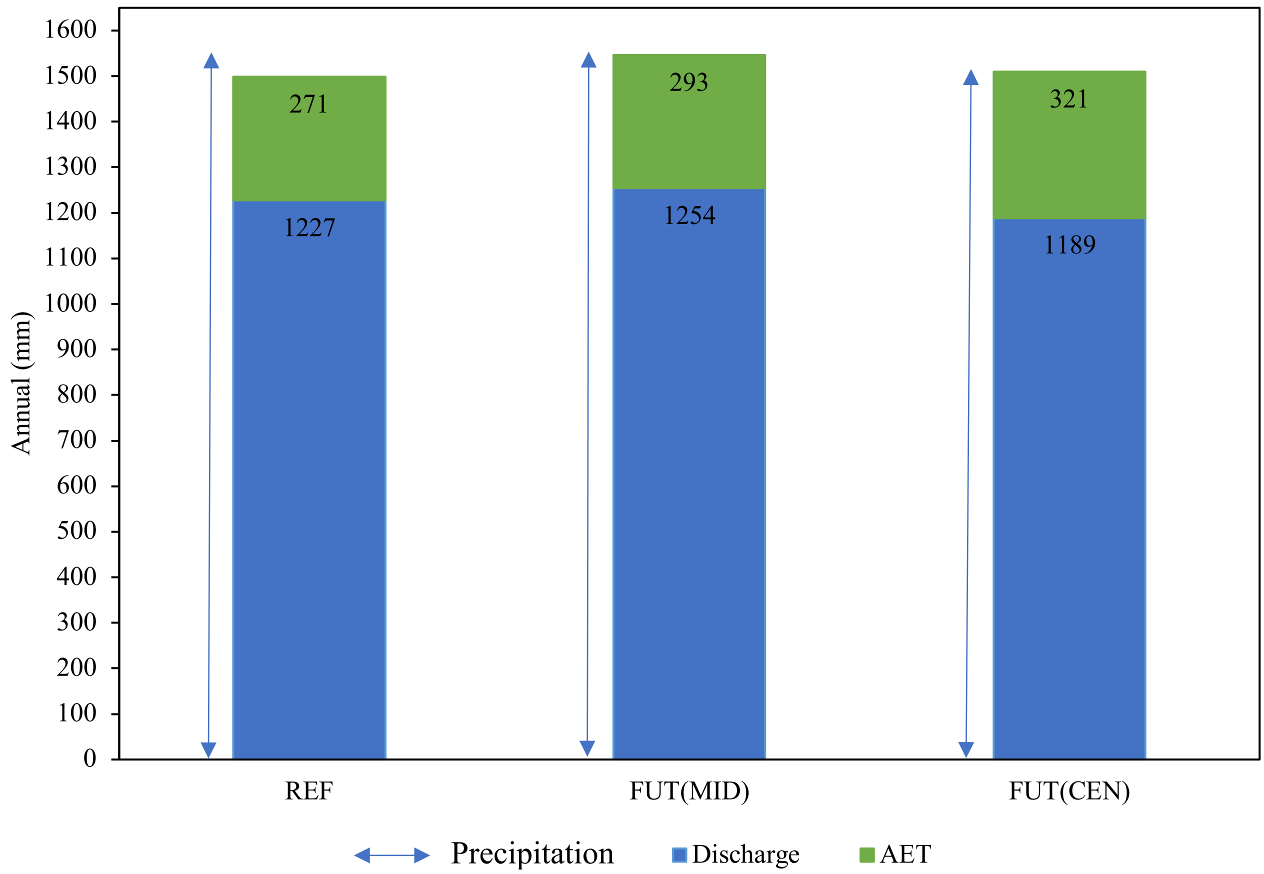


Figure 25. Annual precipitation compared to annual AET and discharge for REF, FUT(MID) and FUT(CEN).

5.4.3 Precipitation

Monthly precipitation illustrates different pattern depending on the RCP applied. In **figure 26** is the monthly distribution of precipitation displayed for FUT(CEN) according to RCP4.5, RCP8.5 and RCP8.5 hot for Ybbs and Salzach catchments.

In Ybbs catchment illustrate precipitation a similar pattern according to RCP4.5 and RCP8.5, with higher values from April to August and lower precipitation in February and October. Similar outline is seen in Salzach catchment according to the same emission scenarios, but with higher precipitation results for the majority of months.

The precipitation pattern shows a quite different pattern according to RCP8.5 hot in both catchments. In Ybbs catchment is lower values illustrated from May to October and higher value in January, December and from March to April. Minor values are seen from July to November and from February to March in Salzach catchment. Highest values are illustrated for January and December and from April to June.

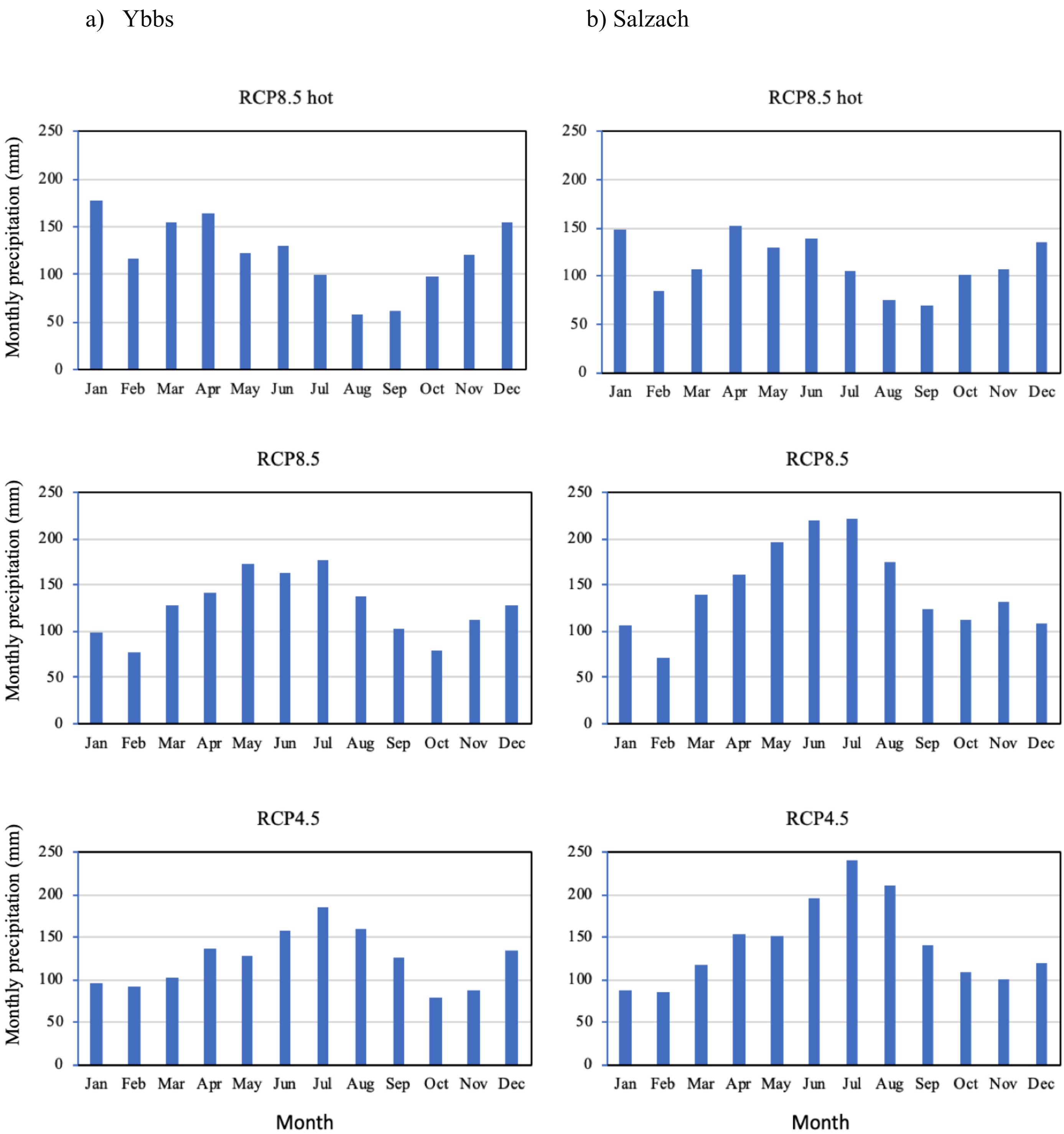


Figure 26. Monthly precipitation for FUT(CEN) according to RCP4.5, RCP8.5 and RCP8.5 hot, for a) Ybbs and b) Salzach catchments.

6 Discussion

This chapter will discuss the effects of climate change based on the aforementioned PET calculations from the two catchments. As such, this section will look at the different emission scenarios and critically discuss the different time frames in the analysis and the implications of its outcome. Moreover, the sensitivity of the PET calculations in relation to its discharge will also be mentioned. Conclusively, this section will introduce the limitations of the study.

6.1 Climate change effect on PET values

The climate change effect on PET values, made visible in figure 12 and figure 13, are projected to increase in the future independent of formula, RCP and time period. The annual mean PET for all formulas increases consistently with RCPs that have stronger climate signal as well as in time periods in more distant futures. This illustrate some tendencies about the future change in PET for the two catchments in Austria even though the emission scenarios tested do not show the same results. One reason for the positive PET increase in all emission scenarios could stem from the rising energy of vaporizations, which is a main driving force of evapotranspiration. The energy of vaporization is connected to air temperature and solar radiation which is impacted by increases in radiative forcing owing to increased greenhouse gases. As greenhouses gases are projected to rise in the RCPs, rises in temperature is also expected. Similar increases in PET along with future changing climate is also illustrated by Ekström (2007), Kingston et al. (2009) and Galí (2017). Air temperature seems to be the main driver of the increases in PET, thus this variable is increasing most and over the whole year and as such it impacts all formulas in this study (**figure 7**). Additionally, when RCP8.5 hot is applied, in both catchments, there are great decreases in the level of humidity from July to September as well as increases in radiation in the same period of the year, see **appendix.** This change in the two variables are likely to be contributing factors for the large increase in the PET data under theses months and for the same scenario, see **figure 16** and **17**. The change in radiation could be connected to PET data calculated by all formulas with the exception of Thornthwaite formula, while humidity changes can also< be associated with PET changes given by Penman and Priestley-Taylor.

In comparison between the Ybbs and Salzach catchments, higher PET values are given for Ybbs. This is probably due to the difference in elevation between the two catchments. As temperature decreases along with increasing elevation this is effectively contributing to minor temperatures at higher altitudes which, in turn, leads to lower PET values. Decreasing PET values as an outcome of rising elevation in Austria is also found by Galí (2017). Additionally, decreasing PET values along with rising altitudes in the Alps are found by Calance, Roesch, Jasper and Wild (2006).

6.1.1 Emission scenario

PET is expected to change according to the applied RCP for both catchments and all formulas. In Ybbs catchment, the difference between the RCPs in FUT(MID) are very low and show no clear pattern for all PET formulas. In Salzach, a more distinct pattern is visible where all PET values for all formulas is highest in the RCP8.5 hot simulation. However, small difference in PET among RCP4.5 and RCP8.5 can be seen. This indicate that there is a low sensitivity in PET change to RCPs, especially if the extreme emission scenario is excluded in the first part of the century for both catchments. This is in agreement with earlier papers studying PET changes between RCP4.5 and RCP8.5 (Galí, 2017; Obada, Alamou, Chabi, Zandagba, & Afouda, 2017).

Changing PET values among the RCPs are more distinct in FUT(CEN) where a clear pattern in increasing PET from RCP4.5 to RCP8.5 and to RCP8.5 hot in both catchments can be seen, **figure 10** and **11**, The same findings that is, stronger diverting PET values beginning around year 2070 and among RCPs, has been presented by Obada et al., (2017) and for reference evapotranspiration by Tao, Chen, Xu, Hou, & Jie, (2015).

The gradually increasing PET is more distinct in the Salzach catchment as compared to the Ybbs catchment, where a larger difference between RCP4.5 and RCP8.5 hot in FUT(CEN) can be seen for all PET formulas, **table 9**. The absolute higher increase in mean annual temperature in Salzach, 3.2-3.7 °C, compared to Ybbs, 2.5-3 °C, among the two emission scenarios RCP4.5 and RCP8.5 hot could be a contributing factor to this.

6.1.2 Time period

In this study, depending on the applied future time period (FUT(MID) and FUT(CEN)), various changes within PET value can be identified. For all emission scenarios, formulas and catchments an increase from FUT(MID) to FUT(CEN) can be seen. This strongly implies an increase in PET values in more distant future time periods (FUT(CEN)). Similar results have been reached by Bae et al. (2011) and Rajabi and Babakhani (2018). Larger changes in PET over Europe, in more distant future is also demonstrated by Deszsi et al. (2018), Galí (2017) and Wilby and Harris (2006). These findings correlate with the expected rises in the mean annual temperatures in the more distant future compared to near future. For example, the difference in temperature between FUT(CEN) and RCP8.5 hot is around 17.0 °C and 14.8°C compared to FUT(MID) at 14.8 °C and 8.3 °C in the same RCP and for Ybbs and Salzach respectively. A similar pattern of temperature differences can be seen for RCP4.5 and RCP8.5. Important to note, is how temperature seems to be the major parameter effecting the increase in PET. This variable increases the most compared to the other variables, which positively affects PET and is also strengthened by Bae et al. (2011) and Galí (2017). Additionally, Goa (2017) finds that temperature is the most influential parameter in two tested PET formulas namely; Penman–Monteith and Priestley–Taylor.

6.1.3 Variation over time

Monthly variation

From a monthly distribution pattern and perspective, PET seems to differ depending on the RCPs and time period used. A monthly absolute change in PET is illustrated in **figure 16** for the Ybbs catchment and in **figure 17** for the Salzach catchment.

In Ybbs and for RCP4.5 a positive monthly daily mean PET change is visible in all months except for January in the FUT(MID) time period and for one formula. According to RCP8.5, the one formula and both time series, small decreases in PET can be seen in May. A similar result has also been obtained for May and March according to the RCP8.5 hot for FUT(MID), where decreases is illustrated for some of the formulas. For the remaining months, positive PET values are given. For Salzach, the same distribution of results has been obtained where they show the same outline of positive change in PET for most months and formulas. However, a negative PET change is given for Thornthwaite in the FUT(MID) time period, in May according to RCP8.5 and in January according to RCP8.5 hot.
These findings differ somewhat from Galí (2017) who find increases from May to September in all emission scenario in Austria. The differences of these results might depend on the time period chosen for the 'middle century', which is between 2021-2050 (this study) versus 2036-2065. It could also be connected to differences in the specific location used for the calculations, all of Austria compared to smaller catchments. These differences in PET calculations can vary depending on the location of the

catchment, as seen between Ybbs and Salzach from this study as well as illustrated by Bormann (2011). Additionally, the variations in the results could depend on the specific formula applied.

In the Ybbs catchment a distinct variation in the seasonal change can be seen in FUT(CEN) according to RCP8.5 hot where greater increases are seen from June to August and relative smaller increases from November to February. Similar to Ybbs, the greatest differences between absolute monthly daily mean PET change are seen in RCP8.5 hot FUT(CEN) in Salzach, with the absolute highest change from June to September and relative smaller in the colder month.

These results, of high increases in monthly daily mean during the summer months from June to August is also found by Ekström et al. (2007) where PET for the future time period (2071-2100) in Europe, according to SRES A2, is studied. Positive PET change in July in the future period (2040-2069), according to SRES A1, is also found in Great Britain by Prudhomme and Williamson (2013). Nonethelss, the highest changes can be seen in January for most of the formulas tested, which does not correlate with the results of this study. This might depend on different locations studied (England vs Austria). However, it is more likely that the large increases in January seen in Prudhomme and Williamson (2013), and not in this study, depends on the comparison of relative change in there study. Relative change comparison can give large change range also in months with low absolute change values of PET.

Overall, the intra-annual pattern of positive PET values is seen for the majority of months and for both catchments, reinforcing the mean annual results. This indicates an increasing PET with future climate change and emission scenario.

Interannual variation

Even if water availability on a long-term catchment scale is often controlled in mean annual PET, its importance in interannual fluctuation studies in water balance been put forward by Cheng, Xu, Wang and Cai (2011). The variation in annual PET from year-to-year within the 30-year periods, showed by the standard deviation, are illustrated in **table 12 and 13** for both the Ybbs and Salzach catchment. Small differences in fluctuations dependent on RCPs, time-slice and formula is showed in both catchments.

ET variability is found to be strongly connected to precipitation (Ukkola & Prentice, 2013). PET, however, is not connected to precipitation and can therefore not explain the variability in PET. Inter-annual variabilities in ET has also been found to be connected to temperature change (Yuan, Bai, Li, Kurban, & De Maeyer, 2017). The mean annual temperature shows similar relative standard deviation variability in future time periods compared to REF but increase a little with emission scenario with stronger climate signal. Because PET is dependent on temperature, this might explain the small variation difference among time periods and RCPs.

The small variance in annual variability among the formulas could possibly be connected to different influence of the temperature variable among the formulas. For instance, the combinational formulas are dependent on fluctuation in other variables such as radiation and humidity.

6.1.4 PET formulas

In this study, large differences in PET values among the formulas have been obtained, both annually and monthly, where the mean annual differences are illustrated in **figure 12** and **13**. The difference in PET depending on the formula illustrate larger variances than PET values among various RCPs and time-slices. The maximum difference in PET among estimation method, RCPs and time periods is shown in **table 14**.

Table 14. Comparing maximum absolute difference (mm/year) of RCPs, time-slice and PET formulas.

	RCP4.5 to RCP8.5 hot	Time-slice RCP8.5 hot	PET formula RCP8.5 hot
Ybbs	155	191	389
Salzach	231	191	440

Differences in PET depending on formulas and discussion on its possible impact on hydrological projections is elaborated on in **section 6.3 and 6.4.**

6.2 Discharge change

The annual discharge results for FUT(CEN) and FUT(MID) are both illustrated in **figure 23**, which are not expected to decrease to a much larger extent, for either of the other emission scenarios or PET formulas in Ybbs. First, the highest PET values are given for RCP8.5 hot and precipitation is predicted to be lowest. Secondly, the Penman give high PET values at all time periods and emission scenario compared to the other formulas. The only formulas which gives higher PET compared to Penman is McGuinness-Bordne in the Ybbs catchment. However, this difference will probably not affect the annual discharge to a greater extent after calibration and PET translation to AET.

The discharge increase from REF to FUT(MID) even though AET is increasing. This contradicting result may depend on several factors. First, this might stem from small increases in the precipitation in the middle of the century. Even if the increase is smaller than the increase in AET, this could have an impact on the results. Second, various monthly precipitation patterns could also be a contributing factor. If a larger part of increased precipitation for FUT(MID) falls in the months where the energy for PET and AET is limited for both time periods, this could lead to relatively higher annual discharges, even if the annual AET increases. This distribution of precipitation is seen in the Ybbs catchment (from January to March and from November to December), where an increased magnitude of the precipitation in FUT(MID) falls and AET is low or in similar magnitude for both periods, see **figure 22** for AET and **appendix** for precipitation. Lower amounts of precipitation can be seen from June to September compared to REF. During these months a lower discharge can also be seen for FUT(MID) compared to REF. However, the decrease in these months is not as large as the increase in the other periods, see **figure 24**.

The annual discharge in FUT(CEN) decreases compared to REF. This is in line with the increased AET as well as the decreased precipitation for this time period. However, monthly precipitation increases from January to April and from October to December in FUT(CEN). During the same months, small differences in AET can be seen among REF and FUT(CEN) and runoff show increases in all months except for April and October compared to REF. This indicates a stronger influence of the precipitation than of the AET on the discharge throughout these time periods. However, in April and October, clear decreases in the discharge can be seen, indicating an influence of evapotranspiration throughout these months. In October, increases in AET is in line with decreases in the discharge for FUT(CEN) compared to REF, see **figure 22 and 24**. Although, decreases in AET in April for FUT(CEN) compared to REF becomes contradicting to the discharge results.

The decreases in the discharge from May to September appears to be connected to both precipitations decreases and AET increases, illustrated in **figure 22 and 24**. The influence of the precipitation might be larger since there is a greater difference in precipitation compared to increases in AET. This may be connected to water limitations in the catchment during the period. However, Možný et al. (2016) testing drought index including precipitation and evapotranspiration in central Europe, finds that changes in evapotranspiration seems to be the driving factor for change in drought severity.

The AET is strongly decreased compared to PET in both future time periods. This is possible due to the water limitation from May to September, where the largest increase in PET occur. The more severe impacts of the decreases in AET compared to PET, also seems to be during the calibration process, discussed further in **section 6.4.**

6.3 PET difference among formulas

The four formulas tested belongs to three different classes namely; combinational, radiation-based and temperature-based. None of the formulas have been chosen over the other and as such they will be discussed in relation to each other and not in relation to a specific formula or any "best practice" since such a formula has not been encountered. The PET change between the formulas could possibly have an impact on the hydrological projections in a changing climate which will be discussed in relation to earlier findings.

Large changes in PET among different formulas is found for both catchments in this study as previously stated in **section 6.1.4.** Similar differences in PET depending on the choice of estimation method have also been found in several other studies (Kay & Davies, 2008; Kingston et al., 2009; Seiller & Anctil, 2014, 2016; Yang et al., 2017). The PET difference among the formulas is possibly due to different properties of the formulas, the different inputs and the relative sensitivity to temperature as elaborated on by other studies (Allen et al., 1998; Bae et al., 2011; Bormann, 2011). For example, Bormann (2011) states that "valid" PET methods should, generally, be expected to project similar PET values when the same climate data is applied. However, variation among PET values are possible though the formulas are dependent on various input data. Furthermore, Allen et.al (1998) states that, variation in PET values among formulas could arise due to different inputs and assumptions in the formulas. Furthermore, the formulas are calculated separately. If, however, all formulas where calculated simultaneously in one climate model with the same feedback mechanisms, the outcome might be different.

In both catchments and all emission scenarios the temperature-based formula Thornthwaite gives the smallest annual PET values. The radiation-based formula, McGuinnes, gives the highest PET values closely followed by the Penman formula in the Ybbs catchment. For Salzach, the highest PET is given by Penman, followed by Priestley-Taylor. Lower PET results is given by the Thornthwaite formula compared to Penman in one of the basin, which has a similar monthly distribution as in this study (Yates, D., Strzepek, 1994). Furthermore, similar results of different PET values for temperature-based (Thornthwaite), combinational (Penman) and radiation-based (McGuinness-Bordne) formulas, are found in a study testing 18 different PET formulas in 6 German basins (Bormann, 2011). In the study, it is showed that all or two out of three temperature-based formulas gives lower PET values than Penman in the two catchments areas, Zugspitze and Hohenpeißenberg. The two aforementioned basins from the report are also the most similar to the ones tested in this study. Furthermore, the radiation based formula, Jensen and Haise, which is similar in structure to McGuinnesse and Bordne, show high PET values (Bormann, 2011). However, Priestley-Taylor gives a higher PET than Penman in the report which do not correspond to the findings in this study. Moreover, this outline of PET results is contradicting to findings from a similar report by Yang et al. (2017) who compare PET values between Penman-Monteith and Thorntwaite. In that study, small differences are seen between the formulas in Austria. These smaller differences in PET among the formulas could be due to the calculation of PET globally and the selection of different elevation bands. Thereby not showing site specific pattern of PET calculation among formulas, which could differ from catchment to catchment as for example seen in Bormann (2011).

The tendency of larger relative PET change in (FUT(CEN) relative to REF for the temperature-based and radiation-based formulas compared to the combinational formulas is somewhat ambiguous, see **figure 14**. A negative change in radiation and a positive change in humidity would possibly explain this ambiguity, since both combinational estimation methods takes these two climate parameters into account. Yet, no clear annual decrease in radiation nor increase in humidity is captured in the catchments. Instead, the somewhat smaller changes in the climate variables (except temperature) might have an effect on the minor relative change in the combinational methods compared to the radiation- and temperature-based formulas. This stem from the fact that, the temperature- based method and radiation-based method are more sensitive to changes in temperature and do not take into account the other variables. Both Seiller et.al (2016) and Bae et.al (2011) show higher sensitivity to temperature changes for the temperature- and radiation- based methods in relation to formulas taking several variables into account.

As shown in **figure 12 and 13,** the lowest PET values can be found for the Thronthwaite formula in both catchments. As such, it could be argued that the temperature-based method clearly underestimates PET. In addition to this, if PET values calculated by Thornthwaite is compared to PET given by Penman, large difference among these formulas appear which strengthen the abovementioned underestimation. Since, the Penman-Monteith, a modification of the Penman formula, is asserted by FAO as the most promising formula (Allen et al., 1998). However, Ekström et.al (2007) finds unrealistic future PET estimation with application of the FAO formula.

The change range in PET among formulas in changing climate, will hereafter be discussed in relation to the emission scenario applied, the time period investigated and seasonal variation.

6.3.1 Emission scenario and time period

When looking at the relative change, the change among formulas increase from RCP4.5 to RCP8.5 and to RCP8.5 hot and from FUT(MID) to FUT(CEN) in both catchments. However, the difference among RCPs are significant in FUT(CEN). This finding is in line with Bae et al. (2011), where the change range among various emission scenarios are clear in distant future time-periods.

The difference among time periods increase with emission scenarios characterized by increasing temperatures where the biggest maximum relative change among formulas is found in FUT(CEN) RCP8.5 hot and for both catchments. This finding is also consistent with Bae et.al. (2011). Similarly, Bormann (2011) identify a larger change in the PET estimation among different PET models the stronger the observed climate change. This relationship seems to be correlated with changing temperatures which increase with RCPs with stronger climate signal and time periods in more futures.

The maximum relative change range among the formulas in FUT(CEN) according to RCP8.5 and RCP8.5 hot, is notably higher in Salzach compared to the Ybbs catchment. This might be related to relatively higher temperature change (FUT(CEN) compared to REF) in Salzach. Since, the temperature variable influence the various formulas different as discussed above. The mean annual relative temperature change in Salzach is 130% and 210% compared to Ybbs 40% and 62% for RCP8.5 and RCP8.5 hot respectively. The temperature increase in the Salzach catchment is only larger in RCP8.5 hot compared to Ybbs when looking at absolute temperature change between FUT(CEN) and REF. This is visible in the temperature difference of 3.0 °C (RCP8.5) and 5.2 °C (RCP8.5 hot) for Salzach and 3.4 °C (RCP8.5) and 4.3 °C (RCP8.5 hot) for Ybbs. The absolute temperature change seems to well corresponding to the outline of maximum absolute PET differences among the formulas. Since larger spread among the formulas in Salzach compared to Ybbs, only is given for FUT(CEN) according to RCP8.5 hot.

6.3.2 Variation over time

Looking at the monthly absolute change for FUT(MID) and FUT(CEN) relative to REF according to all RCPs, larger change ranges among formulas can be seen for all months in FUT(CEN) compared to FUT(MID), with the exception of June in RCP4.5, **figure 16 and 17**. During the period from March to July the range is larger compared to the November to February period in all RCPs in the Ybbs catchment. A similar pattern is seen for the Salzach catchment with a smaller change range in the November to February time period as compared to the spring and summer months. Higher change ranges are also spotted in August, September and October when RCP8.5 hot is applied. This indicates a higher sensitivity in the PET estimation among formulas during these months. Therefore, it might be more important to give attention to the choice of estimation method in some parts of the year than others. Similar large changes in PET estimations, up to 40% at certain points of the year, is also found by Prudhomme and Williamson (2013). These further stresses the point of uncertainty in PET methods, especially in specific periods of the year. No uniform pattern in response to climate change among formulas was evident for different seasons by Bromann (2011). Differences in PET response to climate change was showed in both winter and summer seasons, no period was however stressed as being more or less sensitive.

The change range for the different month in FUT(CEN) differ depending on the emission scenario applied. Pointing to the fact that the sensitivity of the choice of PET formulas changes when different RCPs are applied and tend to be more sensitive in emission scenarios with stronger climate signal for most months. This further supports the results showed in annual PET values.

6.4 Possible impact on discharge due to PET formulas – discussed in comparison to earlier findings

The change range in PET among formulas discussed above will possibly have an impact on runoff projection in a changing climate, especially in time periods where large PET differences among formulas is seen and where PET and precipitation is in close balance. With strong changes in PET it can be expected that AET will also change, which possibly could affect the discharge (Andréassian, Perrin, & Michel, 2004). Sensitivity in discharge projection in a changing climate due to difference in PET among formulas has been illustrated by several other studies as well (Bae et al., 2011; Bormann, 2011; Kay & Davies, 2008; Kingston et al., 2009; Seiller & Anctil, 2014, 2016). Furthermore, Sperna Weiland et al. (2012) finds that the choosen PET method could have partical effect on runoff in specific catchments. However, contradicting findings has also been found in recent studies (Koedyk & Kingston, 2016), where the choice of PET method not partially affects the runoff in a changing climate. Yet, Koedyk & Kingston (2016) state that, these finding stands in contrast to previous work and that further work is needed in order to gain knowledge of this uncertainty.

Shared for studies, either finding hydrological projections sensitivity to PET method or not, is that the uncertainty is decreases with calibration (Bai et al., 2016; Seiller & Anctil, 2016; Sperna Weiland et al., 2012). More specifically, the sensitivity seems to decrease from PET to AET and to runoff (Sperna Weiland et al., 2012). Based on this, it can also be expected that the change range among PET formulas used in this study should also decrease after calibration in the hydrological model. Even if no direct comparison is conducted in this study it can be seen from the discharge stimulation by applying the

Penman formulas, how the PET values more or less is halved after calibration to fit the observed discharge. Thereafter, the AET is further decreased due to the water availability, **figure 21**. This indicates that the higher PET values will decrease in calibration while the lower values might increase a little, leading to a much smaller change range among formulas after calibration.

The level of PET could have a significant impact in areas and for seasons where the magnitude of PET is similar to that of precipitation. Where small changes in PET in those locations could lead to soil water being a limiting factor to evapotranspiration (Prudhomme & Williamson, 2013). PET formulas with the lowest values might overestimate the discharge and the formula with the highest PET values could underestimate the flow. In FUT(CEN), according to RCP8.5 hot, the average annual precipitation is approximately 1511 mm and 1353 mm for the Ybbs and Salzach catchments respectively. PET for the Ybbs catchment, with the same emission scenario and time period are; 1138 mm, 1079 mm, 855 mm and 749 mm for and for the Salzach catchment; 847 mm, 1020 mm, 807 mm and 580 mm for the McGuinness-Bordne, Penman, Priestley-Taylor and Thornthwaite formulas for both catchments. According to the aforementioned outcome, it can be argued that the runoff might be sensitive to the change range in PET in FUT(CEN) according to RCP8.5 hot, since PET is quite close to the amount of precipitation on an annual basis in both catchments. However, PET and precipitation are not in close balance over all months and seasons according to RCP8.5 hot, see **figure 18 and 19**. It is therefore difficult to say if the hydrological projections in the Ybbs and Salzach catchments would be sensitive to differences in PET over the entire year. However, as proposed by Bormann (2011), the examination of sensitivity to the choice of PET formula for a specific site could be done by calculating the change in annual climatic water budget (annual precipitation minus annual PET), between the reference period and the future period.

The actual annual evapotranspiration stands for 18%, 19% and 21% of the annual precipitation for REF, FUT(MID) and FUT(CEN) respectively, in the Ybbs catchment and for RCP8.5 hot. This could indicate that a change in PET plausibly would have a bigger effect in time periods in a more distant future compared to a nearer future. Since, evapotranspiration constitutes a bigger part of precipitation in FUT(CEN) compared to FUT(MID). Increasing maximum change range in runoff, due to application of different formulas, for periods in a more distant future was illustrated by Bae et al. (2011). The study also states how hydrological projections could be sensitive to different emission scenarios, though quite various change among runoff due to different changes in PET range was found for specific emission scenarios (Bae et al., 2011). Larger changes in runoff, when applying different PET methods (for some GCM), for distant future periods and emission scenarios with high climate signal was also found in Kay and Davies (2008). Correspondingly, smaller change in runoff due to different PET formulas was found for emission scenarios with lower radiative forcing (Bae et al., 2011; Koedyk & Kingston, 2016; Thompson et al., 2014).

The largest absolute difference in monthly mean daily PET between REF and future time periods can be seen between July and September in both catchments for RCP8.5 hot, **figure 16 and 17**. However, PET exceeds precipitation in most cases during this season, see **figure 18 and 19** for precipitation and PET comparison for FUT(CEN) according to RCP8.5 hot. In these months the water is limited and AET cannot take place at the rate of PET. Thereby change among PET formulas might not have large effects on AET and therefore not on the discharge during this period. This minor effect of the change in PET during the warmer season due to limited water availability in central Europe is discussed by Bornmann, Diekkrüger and Richter (1996). Additionally, Koedyk and Kingston (2016) brings up how limited water availability in the basin is one reason for the insensitivity in runoff to PET change in their report. They find, however, that this is not a cause to the insensitivity. Nevertheless, PET formulas are found to be influenced by low flows in the summer in both of the studied catchments by Seiller and Anctil, (2016).

Conversely, as visible in **figure 18** and **19**, PET values are lower than precipitation from January to April and from October to December in the Ybbs catchment and from January to June (for some of the formulas) and from October to December in the Salzach catchment for FUT(CEN) according to RCP8.5 hot. In these months the difference in PET values among the formulas might have a bigger impact on the discharge than during the summer month, because the catchments are not water limited. Several studies point to this fact, Bae et.al (2011), Seiller et.al. (2016), Kay et.al. (2013) and Kingston et.al. (2009), that varying sensitivity in hydrological projection due to different PET formulas stem over different seasons. First, a larger range in the relative monthly runoff in the wet season (May to November) compared to the dry season was found by Bae et al. (2011). Additionally, Seiller et al. (2016) find that a change in PET has impacted on spring high flows in one of the catchments studied and autumn high flows in the other. In a study looking at historical trends and future projections of evaporation in Britain, it is found that energy-water balanced catchments are more sensitive to PET changes. Energy-water balanced time periods could also be found over the year when precipitation and PET are in close balance (Kay et al., 2013). Similar findings were also stressed by Kingston et.al (2009), where the sensitivity in PET difference due to the choice of formula in hydrological models is especially high when the evapotranspiration is in close balance with the precipitation.

As discussed above, the annual PET difference among formulas seems to have the largest impact in FUT(CEN) according to RCP8.5 hot for both catchments. Moreover, for most months, the highest difference among PET formulas in absolute change in monthly daily mean PET values, are illustrated in FUT(CEN) according to RCP8.5 hot. Thus, it is expected that the largest influence on runoff due to difference in PET formulas is found in FUT(CEN).

However, as AET is limited by water the AET will be influenced by differences among PET formulas when sufficient water is present. As illustrated in figure 18 and 19 and mentioned above, this is not true for all months in either of the catchments in FUT(CEN) and according to RCP8.5 hot. However, when considering PET and precipitation in both time periods and according to RCP8.5 and RCP4.5, water is sufficient over the entire year in the Salzach catchment and over almost the entire year in the Ybbs catchment. In FUT(MID) and according to RCP8.5 hot, sufficient water is given from January to June and from September to December in the Ybbs catchment and for the entire year in the Salzach catchment. As previously mentioned, discharge is most sensitive to differences in PET and in periods where PET and precipitation are in closer balance (Kay et al., 2013; Kingston et al., 2009). Considering the AETs limitation to water availability together with PET/ precipitations balance and differences among the formulas in all time periods and RCPs, the discharge sensitivity to PET formulas in specific months seems to be found in different RCPs and time periods. In the Ybbs catchment, from May to June, PET is in close balance with the precipitation and sufficient water is present for all RCPs and time periods except for FUT(CEN) according to RCP8.5 hot,. Similar to the above scenario, from July to August, higher sensitivity in discharge to the choice of PET formulas are likely to be found in both time periods applying RCP4.5 and RCP8.5. However, in April and October, the uncertainty seems to be similar in all time periods and emission scenarios. In the Salzach catchment the largest sensitivity appears to be found from May to June and in October in FUT(CEN) according to RCP8.5 hot, though PET and precipitation is in close balance and AET not is limited by water. Yet, the largest sensitivity is probably found, from August to September, in FUT(MID) according to RCP8.5 hot.

In several studies, climate models has been stated as having high uncertainty in discharge projections (Bae et al., 2011; Kay et al., 2013; Kay & Davies, 2008; Koedyk & Kingston, 2016). So, it should be mentioned that only two climate models are applied for climate and precipitation data in this study. The pattern and comparison among PET and precipitation in specific months might therefore change if data from other climate models are applied.

6.5 Constraints

Some broader general limitations apparent in the study should be mentioned and elaborated on. First, the study applies data from the current developing research field climate models and emission scenarios. Secondly, calculations of evapotranspiration, is a complex natural process including several input data. Last, application of a smaller part of available PET formulas.

An important limitation stem from the results provided by the climate model since simulations of the climate system is complex and various climate models provide different outcomes. Additionally, the models are in constant progress, developing with technology improvements to better suit the locations simulated. Only two climate models have been used in this study, however the model data has been corrected for bias with the latest standard and scientific methods. Moreover, the emission scenarios used, like the climate models, are in constant development. Several changes over the years imply a limitation in its application. Nonetheless, the latest accepted emission scenarios from the scientific community have been applied.

The large number of climate variables and the complexity in estimating evapotranspiration is an additional limitation. Significant limitations in the results could stem from over- or underestimation of one or several of parameter. Furthermore, AET was only calculated from one catchment and emission scenario due to time constraints. However, potential evapotranspiration was calculated for four formulas, two catchments and all emission scenarios, providing a good ground for the first step of PET sensitivity and its sensitivity in hydrological projection, and last for its application in future work.

Further constraints stem from the application of a restricted amount of PET formulas since only four out of a large amount of available formulas has been tested. A larger number of formulas would present a greater range of possible outcomes of the PET calculation, which might have led to a different change range among the formulas. However, as for the scope of this research has been to illustrate the difference in PET result depending on the choice of formula associated with various PET classes has been fulfilled. Important to note is the fact that the maximum change range would in any case not become smaller by including more formulas.

7 Summary and conclusions

This study has set out to explore the sensitivity in PET projections and the uncertainty in hydrological projections belonging to the choice of PET formulas in a climate change context. As such, this study can conclude how PET has been proved to increase in both catchments independent of the emission scenario applied. Temperature rises due to global warming is found to be the most influencing factor to these increases, however, it seems that radiation and humidity are important contributing factors to this in FUT(CEN) according to RCP8.5 hot. Higher PET calculations are showed in Ybbs compared to the Salzach catchment. Greater increases in PET could be projected for RCPs with stronger climate signal in both catchments in FUT(CEN). Furthermore, maximum increases for both annual and monthly results could be expected in time periods in more distant futures combined with the extreme scenarios. Differences in PET values is seen among RCPs, time periods and the PET formulas applied whereas the biggest difference is seen among the different PET formulas applied.

The study also shows that great difference in annual PET can be expected depending on the formula applied in each catchment. It is found that both annual absolute maximum difference and the maximum change range in percent of annual PET is large among the four estimation methods. Similar differences are found in both catchments in terms of absolute difference. However, Salzach compared to Ybbs show a significantly greater change range in the annual percentage among formulas when RCP8.5 and RCP8.5 hot is applied in FUT(CEN). This demonstrates that sensitivity in PET estimation due to different formulas could be expected in both catchments subject to climate change, where a higher degree of sensitivity is apparent in the Salzach catchment. The added sensitivity in the Salzach catchment could be connected to higher temperature change range.

It is showed that the annual PET percent change range is sensitive to time periods when RCPs with a stronger climate signal is applied. The difference in range among PET formulas is also found to be sensitive to RCPs in FUT(CEN). Considerably higher maximum change ranges are found in FUT(CEN) and RCP8.5 hot compared to FUT(MID) and the same emission scenario. Likewise, when comparing change range between RCP8.5 hot and RCP4.5 in FUT(CEN) large differences are found. This demonstrates that different time periods and emission scenarios applied should to be considered in evaluation of PET. Furthermore, the choice of estimation method is more sensitive in simulations with stronger climate change and increasing temperatures.

Discharge decreases is only expected in more distant time periods (FUT(CEN)). The same pattern is expected independent of which emission scenario is applied in the Ybbs catchment. The increases in discharge during the colder months in both future time periods seems to be more connected to precipitation changes than changes in AET. However, in April and October as well as during the summer months in FUT(CEN), AET is found to have a bigger influencing factor to changes in discharges. AET strongly decreases compared to PET, to less than a third of PET. The calibration process in the hydrological model appears to be a large influencing factor.

No direct conclusion is stated in this study regarding if the difference in PET estimations will impact discharge in climate change. However, this paper, owing to the variety in quantity of PET among formulas, suggest that PET uncertainty is important. Periods with precipitation and PET in close balance should be given special attention. It is likely that the sensitivity to the choice of PET formula is greater in projections for time periods in more distant futures in combination with emission scenarios with strong climate signals when considering annual values in both catchments. However, this was not clear when looking at monthly patterns of PET and precipitation, especially in the Ybbs catchment. In this case, the largest uncertainty in discharge belonging to PET formulas, in specific months, seemed to be spread over different RCPs and time-periods.

This paper implies uncertainties in PET estimation depending on the choice of formula and the sensitivity could compose an impact on hydrological projections in climate change. It is therefore suggested to be quantified to limit the uncertainty and improving such projections. Furthermore, this study aims to constitute as a basis for further research of different PET formulas influence on hydrological projections for various catchments in Austria. As such, it contributes to the quite limited amount of research regarding the uncertainty of PET formulas in hydrological modelling.

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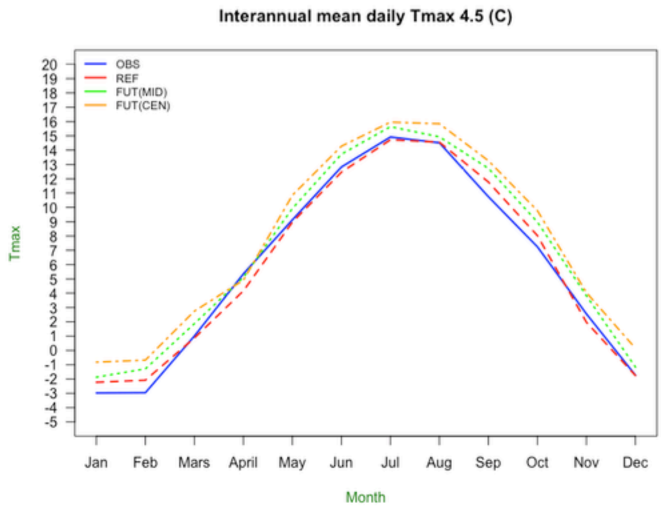
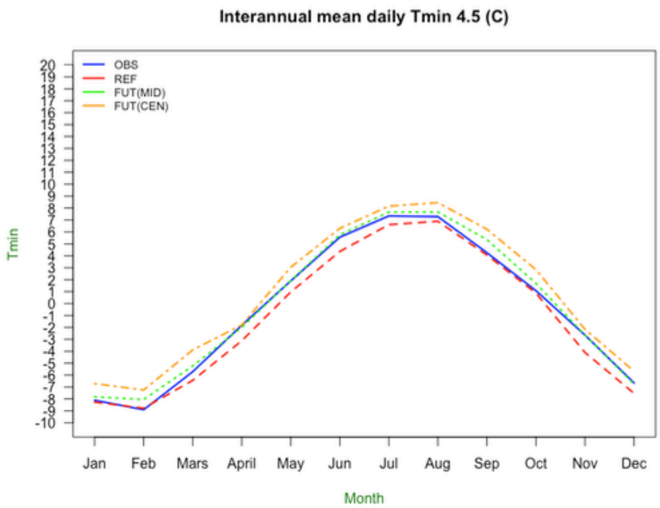
9 Appendix

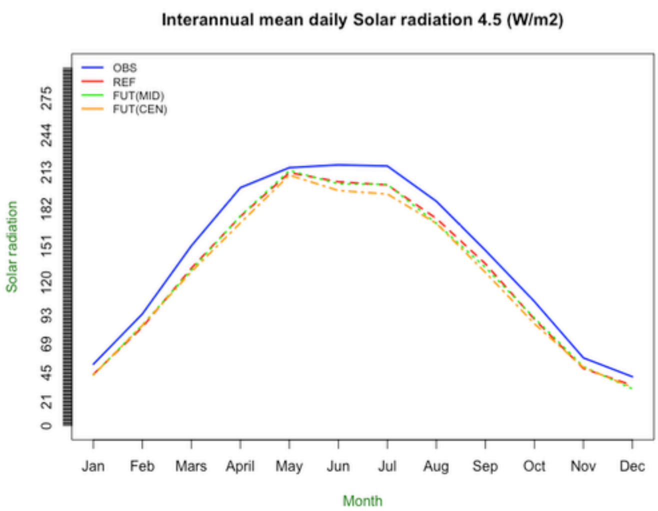
Links for download of R, RStudio and installation of the Evapotranspiration package.

- **R**: https://www.r-project.org
- **Rstudio**: https://www.rstudio.com/products/rstudio/download/
- **Evapotranspiration package**: https://rdrr.io/cran/Evapotranspiration/

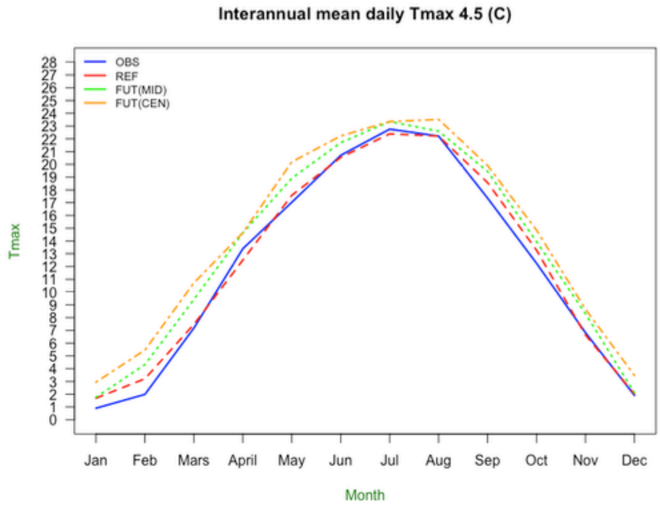
a) Salzach

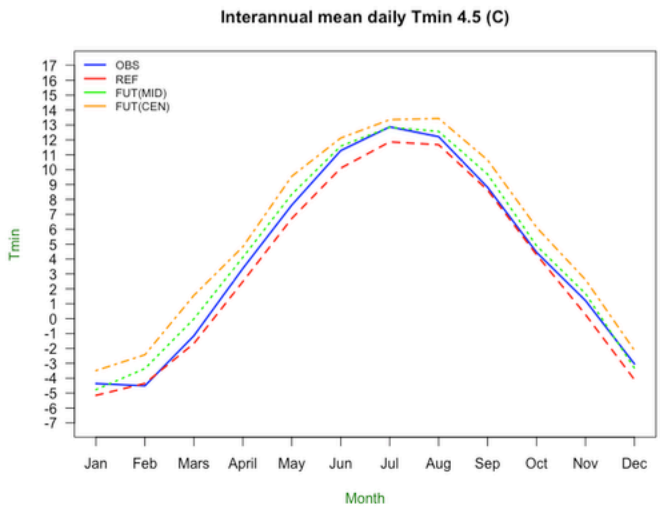


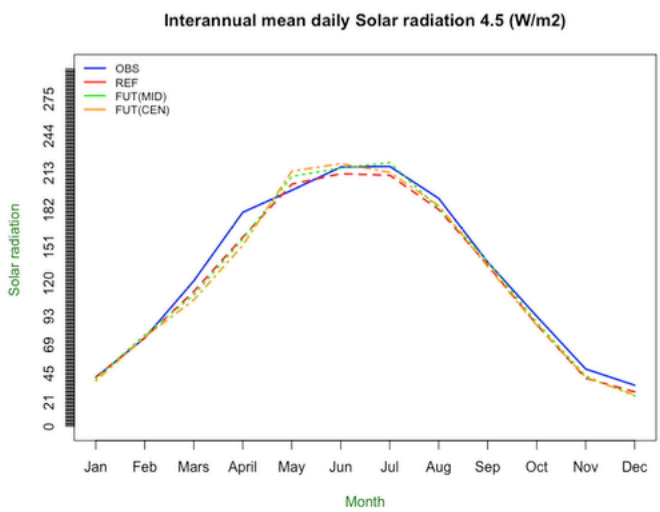




b) Ybbs







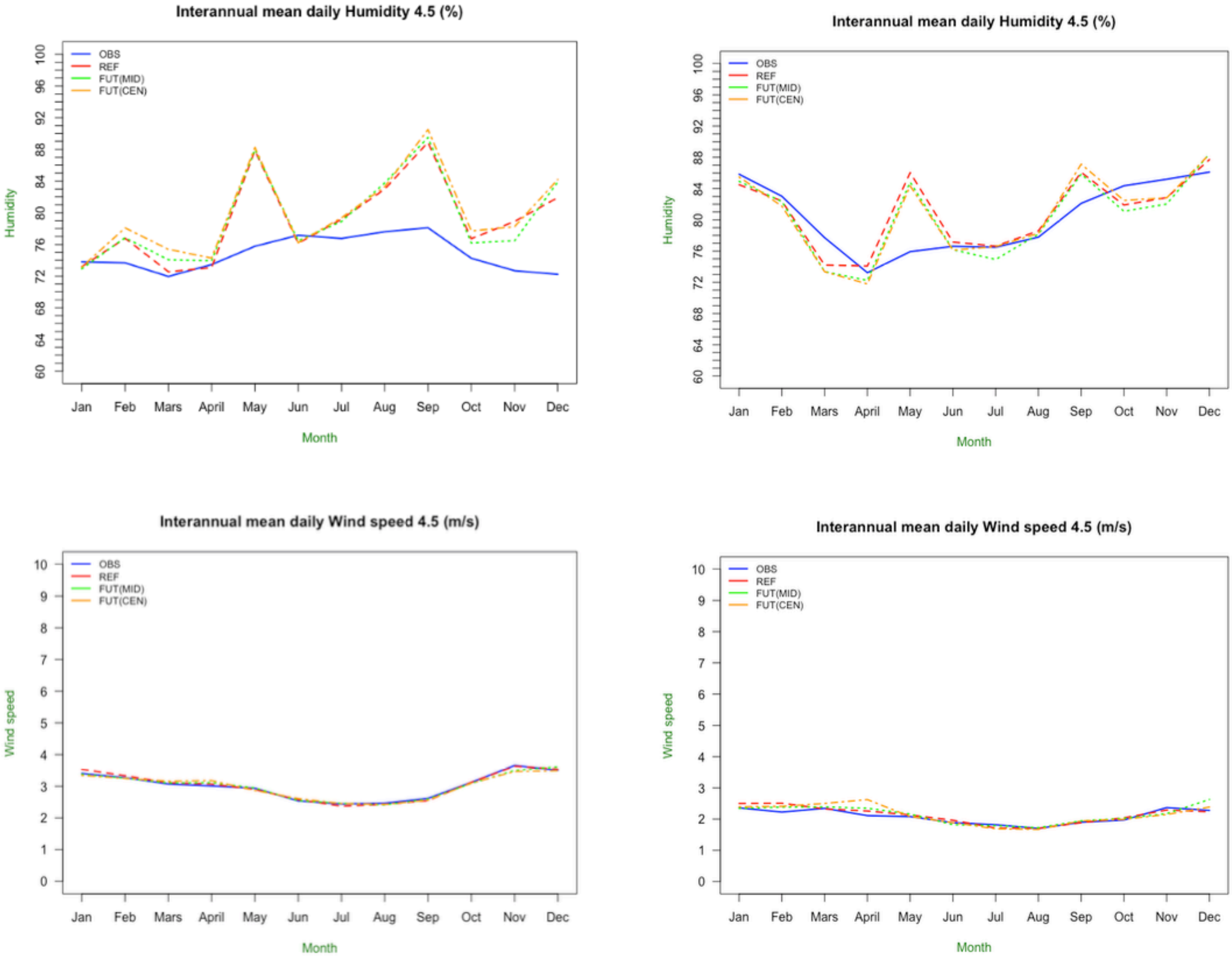
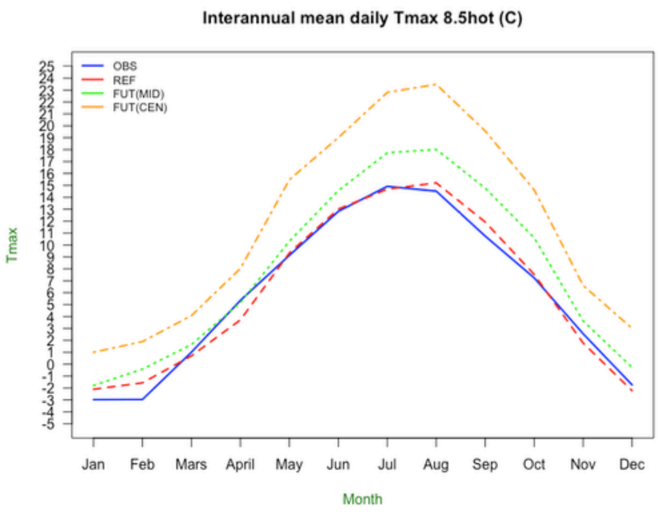
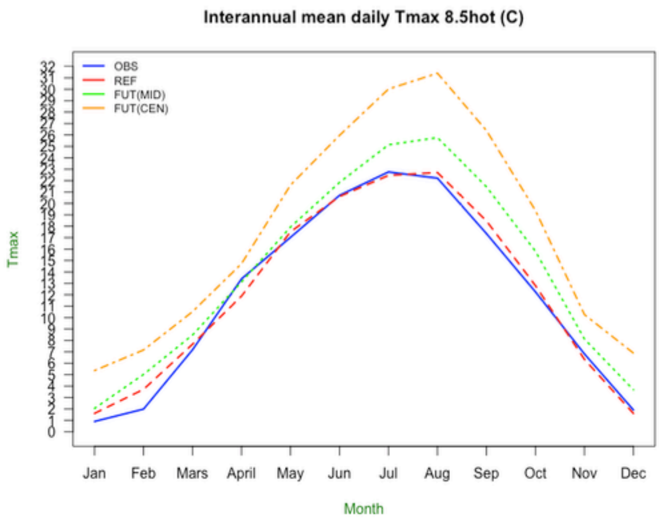
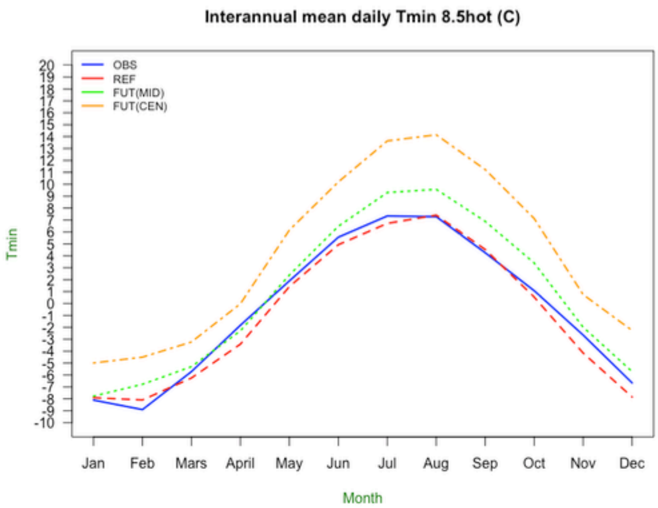


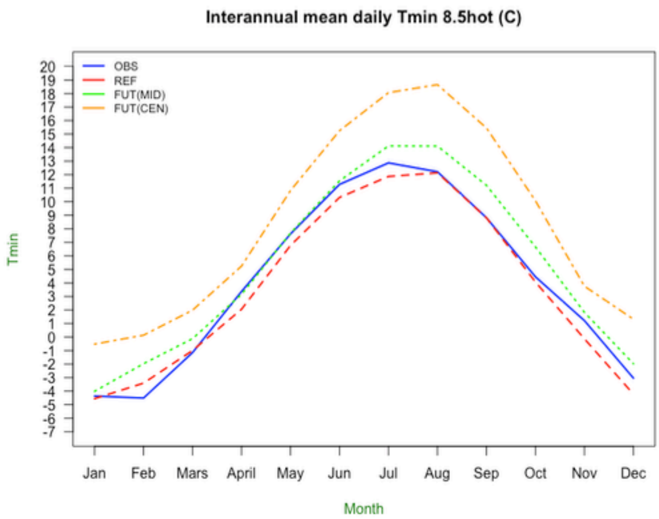
Figure 27. Comparison of mean daily climate input data (1) Tmax, (2) Tmin, (3) Solar radiation, (4) Air Humidity, (5) Wind speed. For a) Salzach and b) Ybbs of INCAyear (2003-2015), REF (1985-2014), FUT(MID) (2021-2050) and FUT(CEN) (1971-2100). REF and FUT climate data are according to RCP4.5.

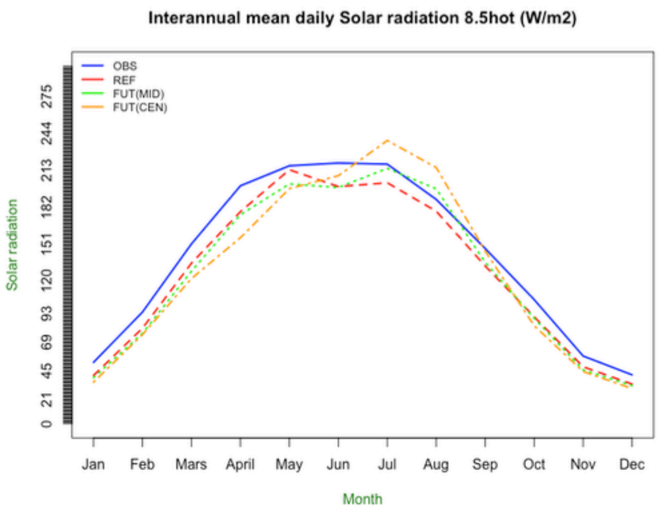
a) Salzach b) Ybbs











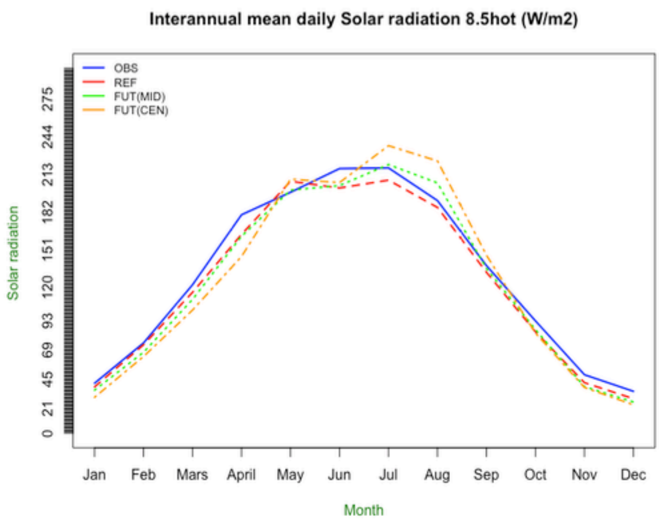


Figure 28. Comparison of mean daily climate input data (1) Tmax, (2) Tmin, (3) Solar radiation, (4) Air Humidity, (5) Wind speed. For a) Salzach and b) Ybbs of INCAyear (2003-2015), REF (1985-2014), FUT(MID) (2021-2050) and FUT(CEN) (1971-2100). REF and FUT climate data are according to RCP8.5 hot.

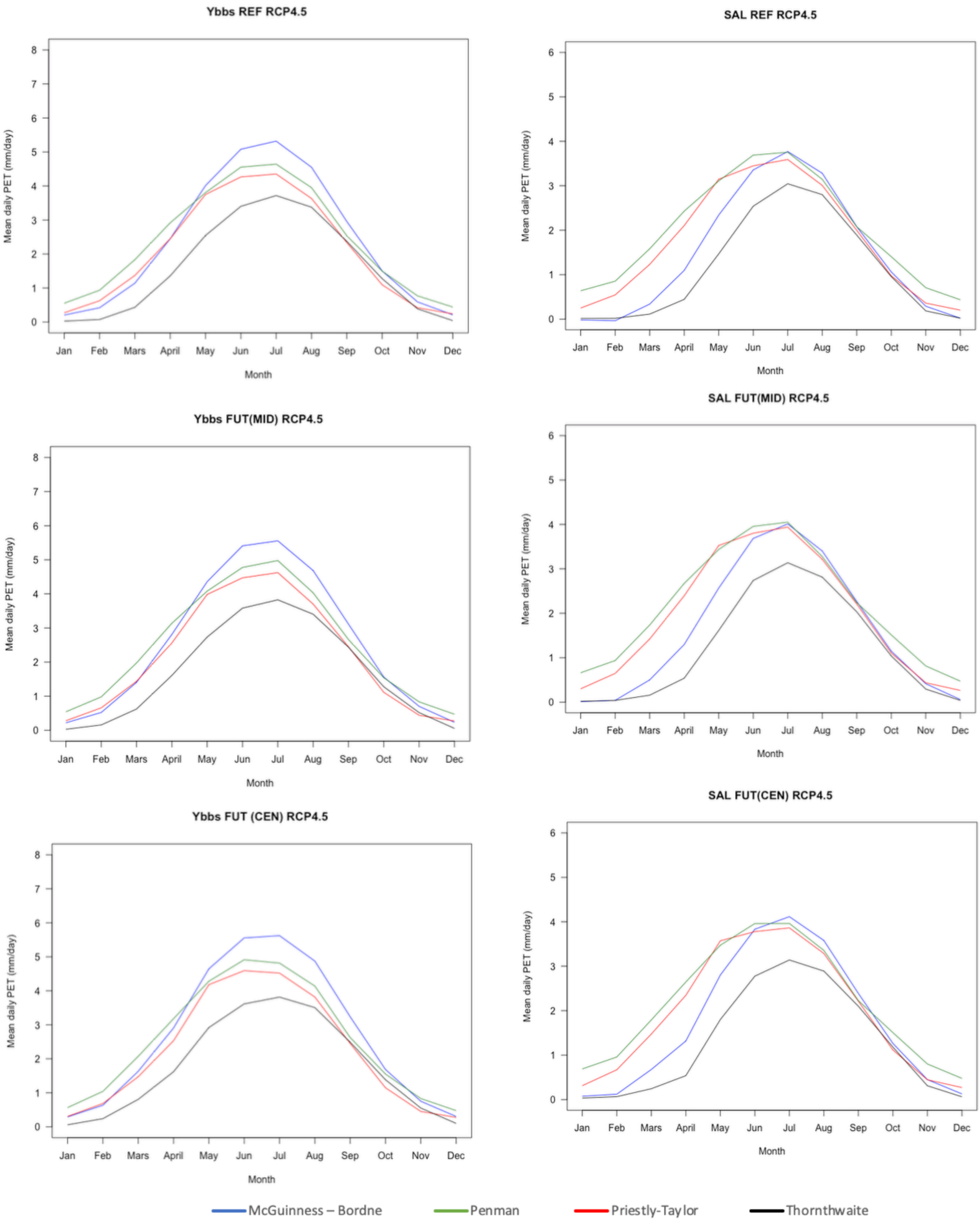


Figure 29. Mean daily PET series for (1) REF, (2) FUT(MID) and (3) FUT(CEN) according to RCP4.5, for Ybbs and Salzach catchments.

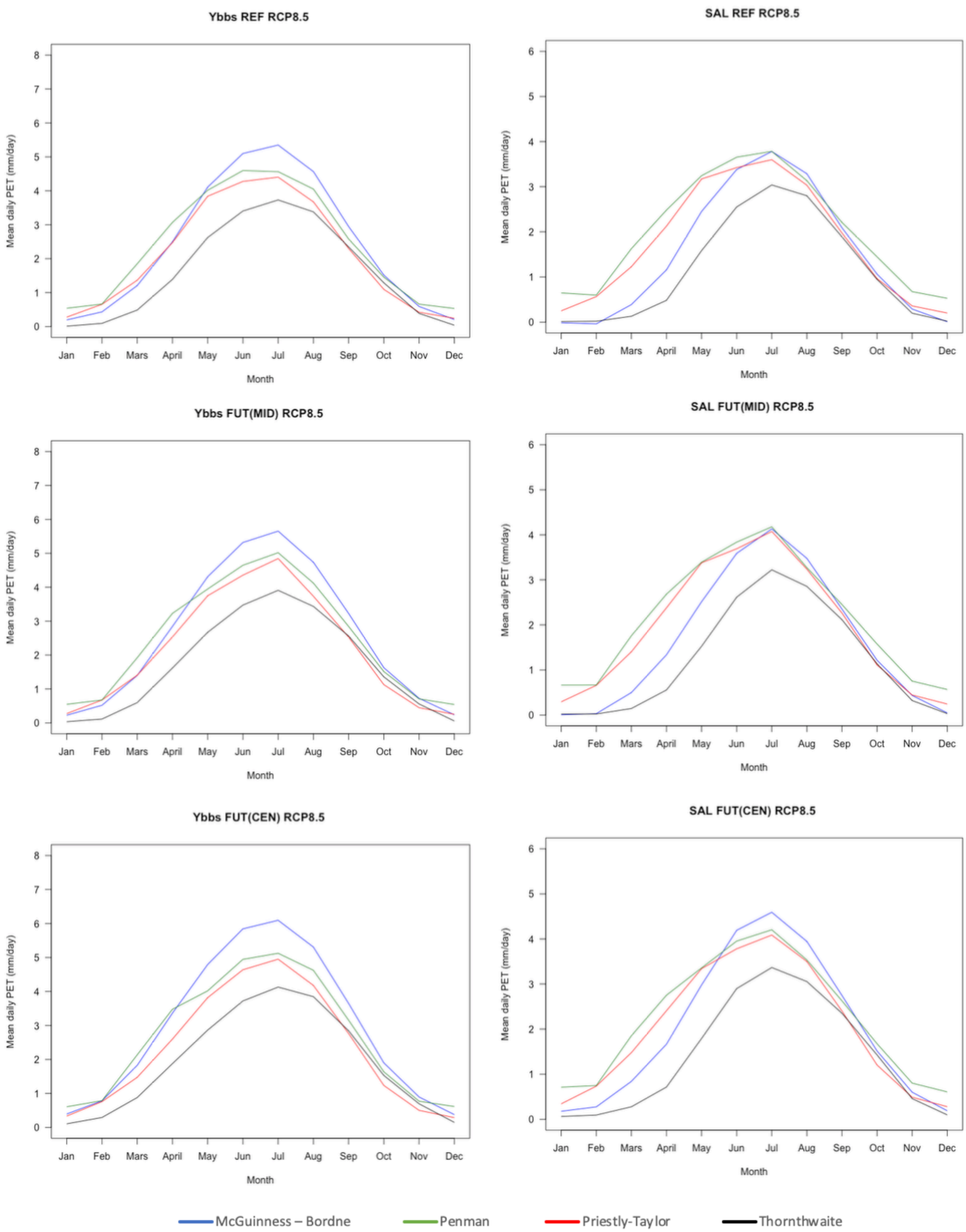


Figure 30. Mean daily PET series for (1) REF, (2) FUT(MID) and (3) FUT(CEN) according to RCP8.5, for Ybbs and Salzach catchments.

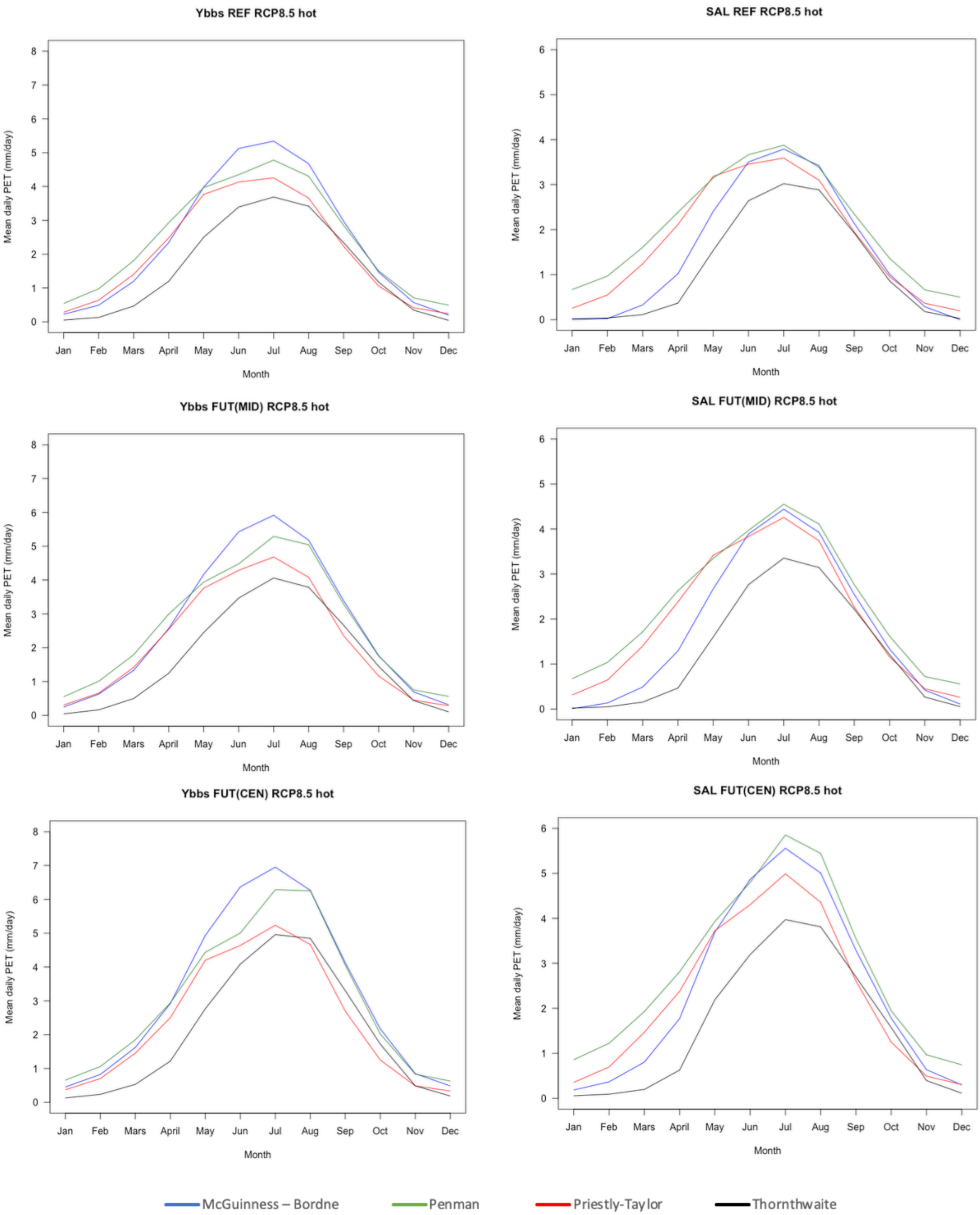


Figure 31. Mean daily PET series for (1) REF, (2) FUT(MID) and (3) FUT(CEN) according to RCP8.5 hot, for Ybbs and Salzach catchments.

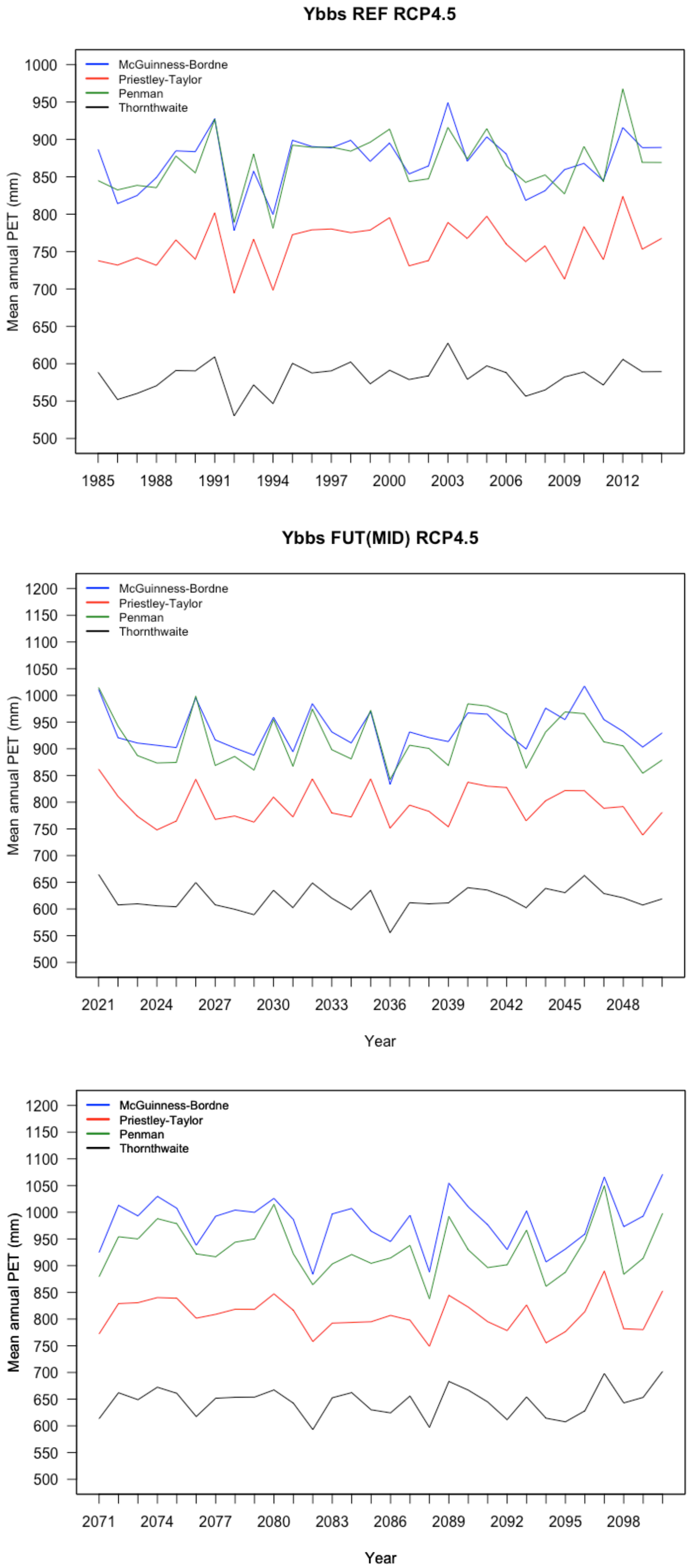


Figure 32. Inter- annual difference in Ybbs catchment according to RCP4.5

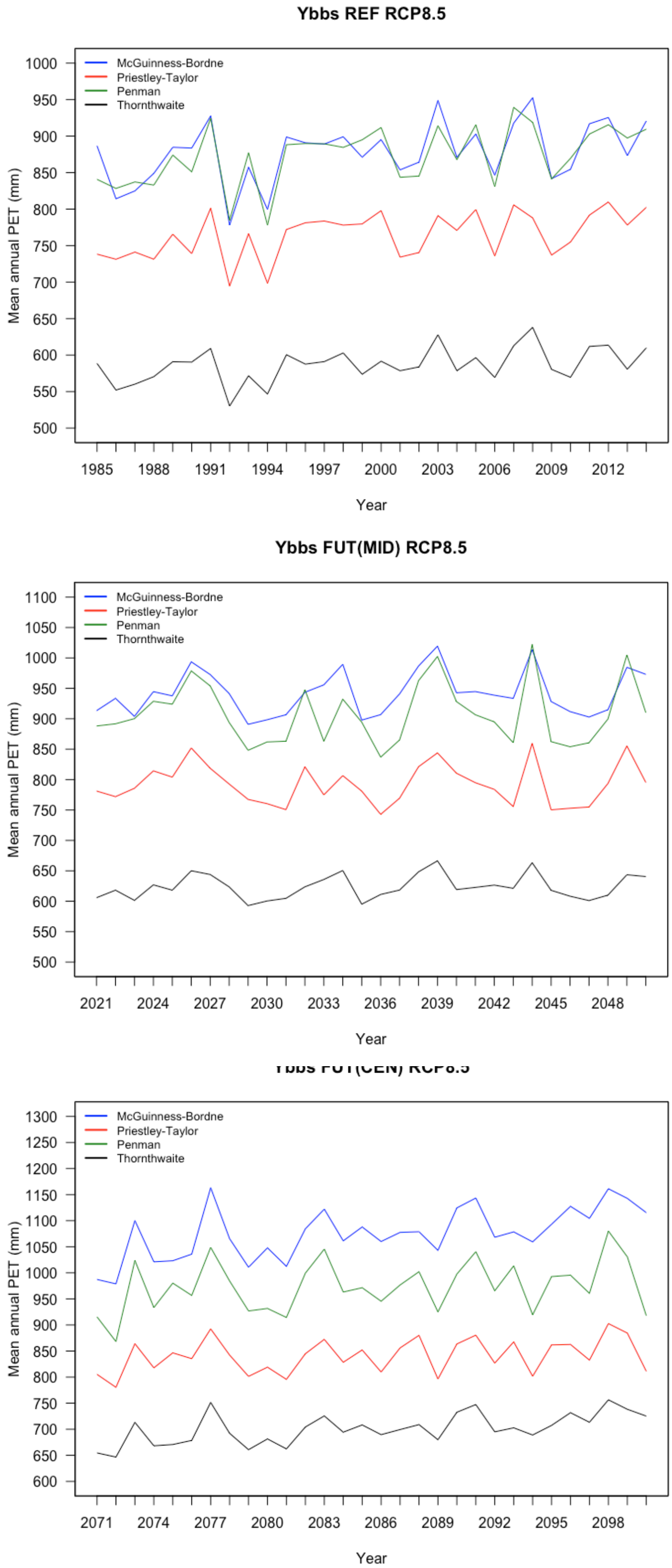


Figure 33. Inter- annual difference in Ybbs catchment according to RCP8.5

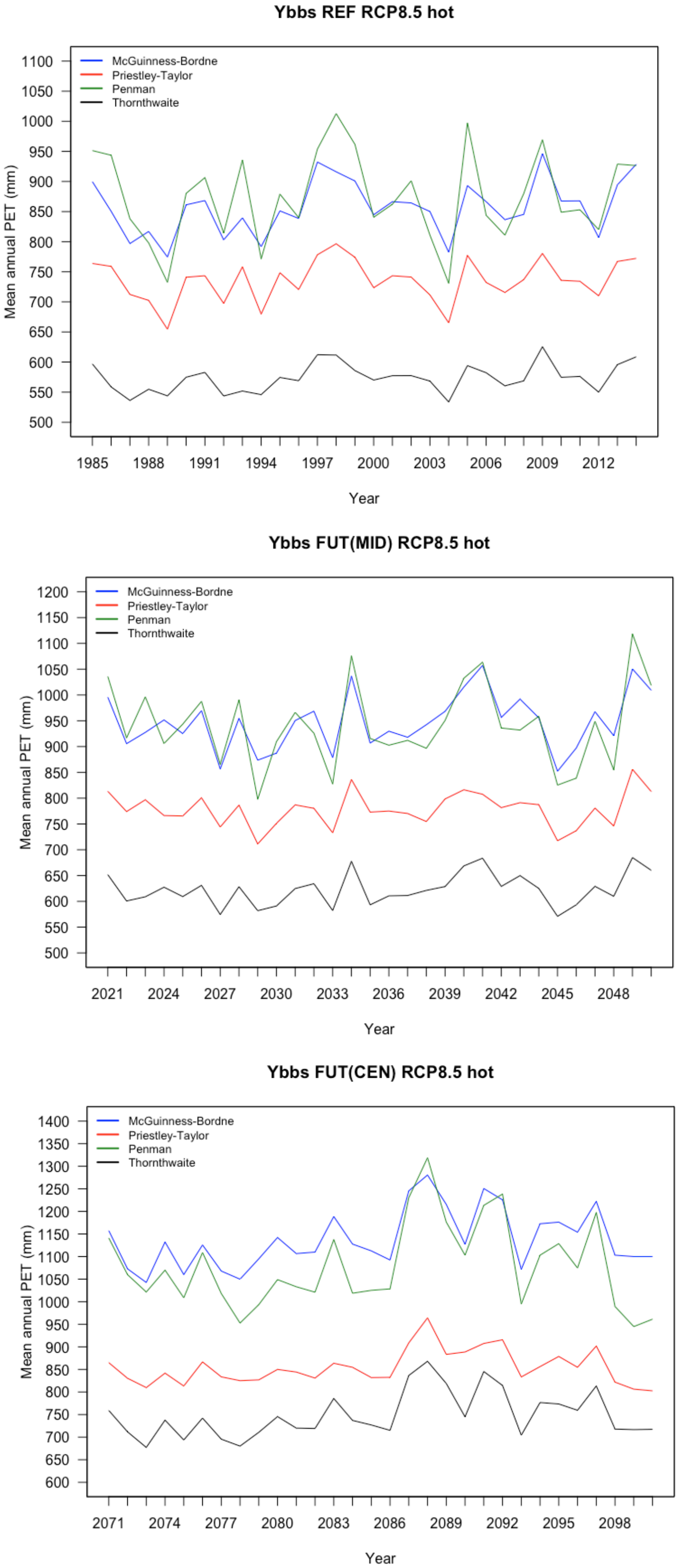


Figure 34. Inter- annual difference in Ybbs catchment according to RCP8.5 hot

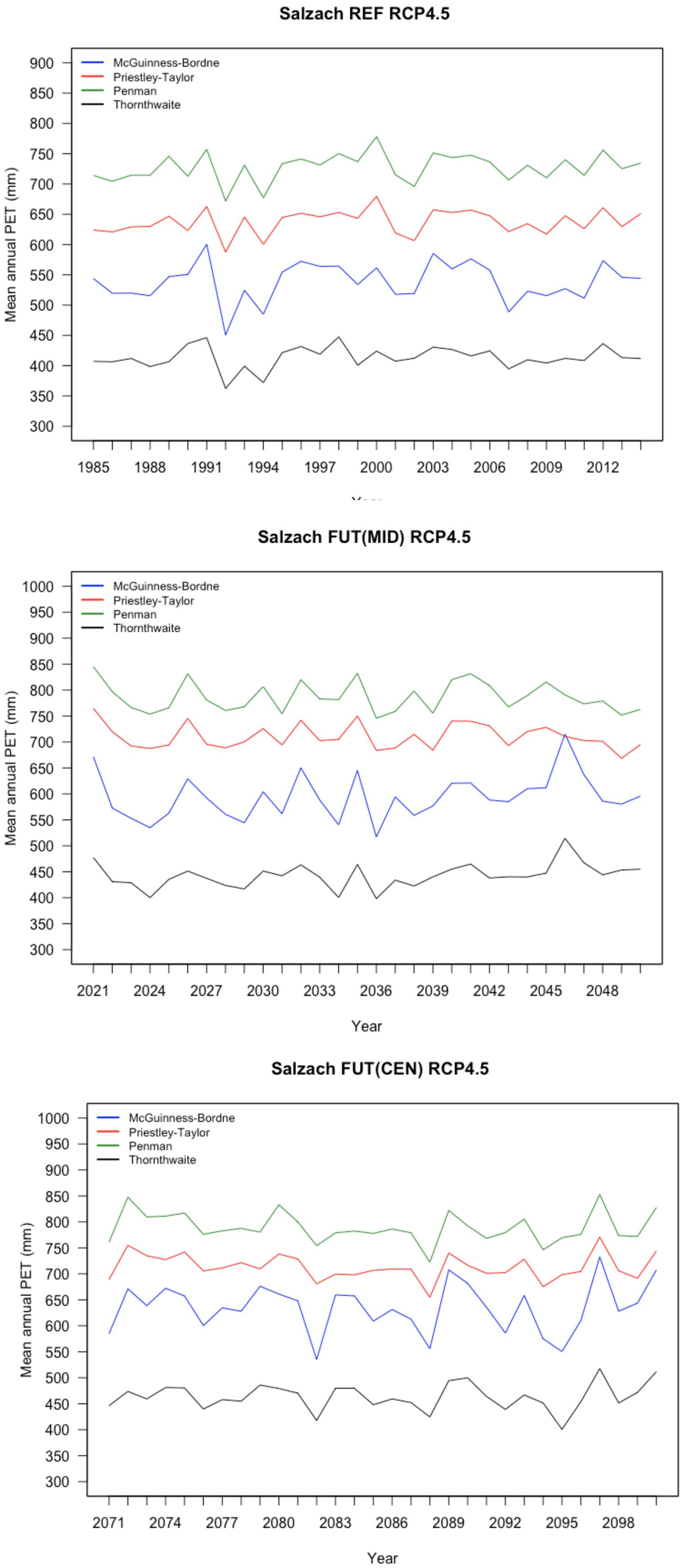


Figure 35. Inter- annual difference in Salzach catchment according to RCP4.5.

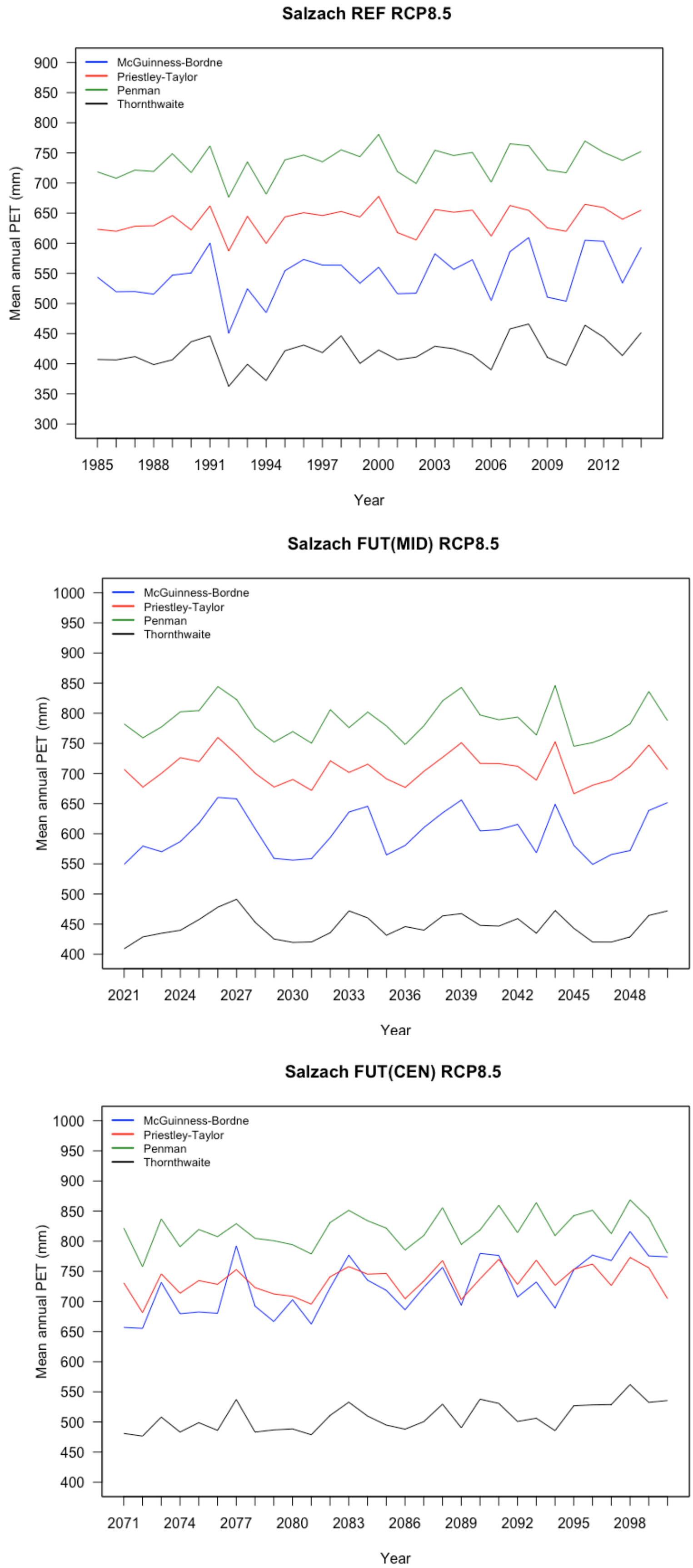


Figure 36. Inter-annual difference in Salzach catchment according to RCP8.5.

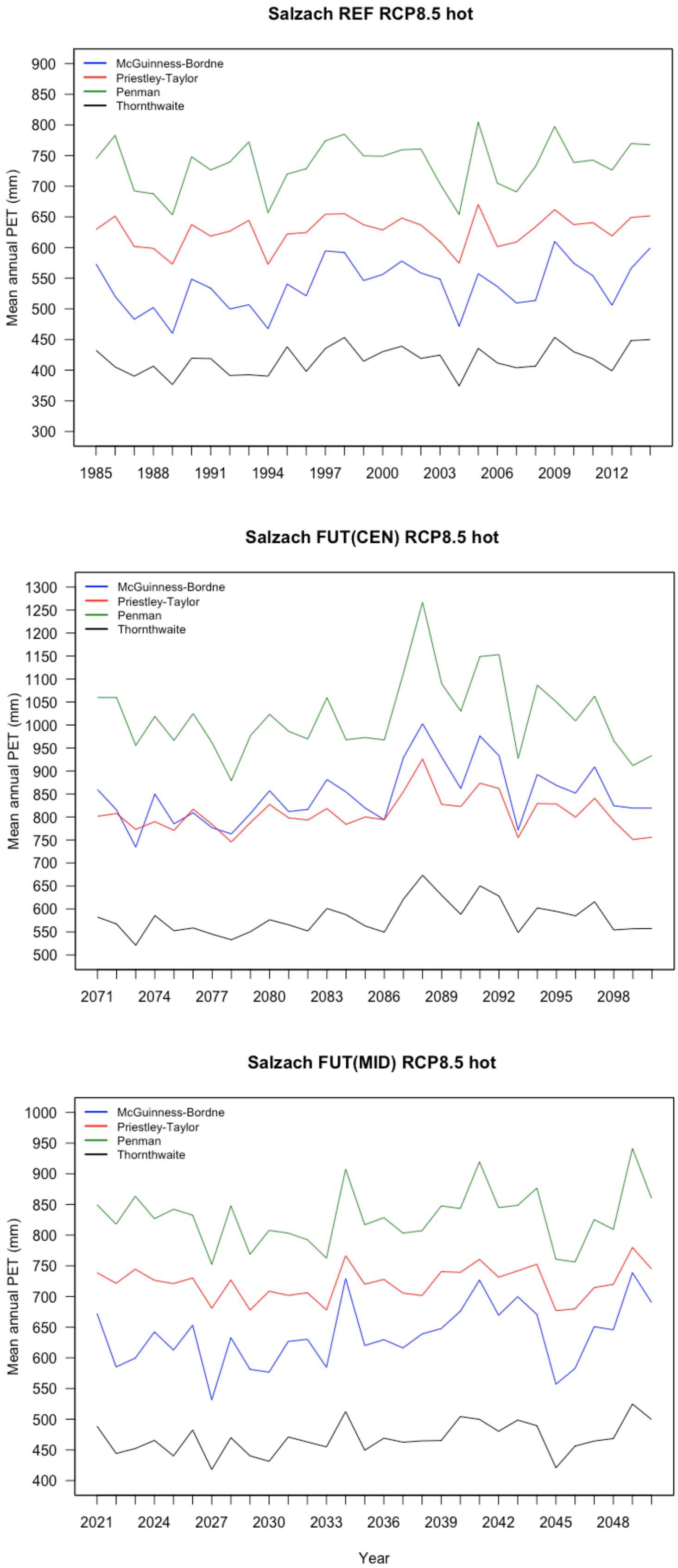


Figure 37. Inter-annual difference in Salzach catchment according to RCP8.5 hot.

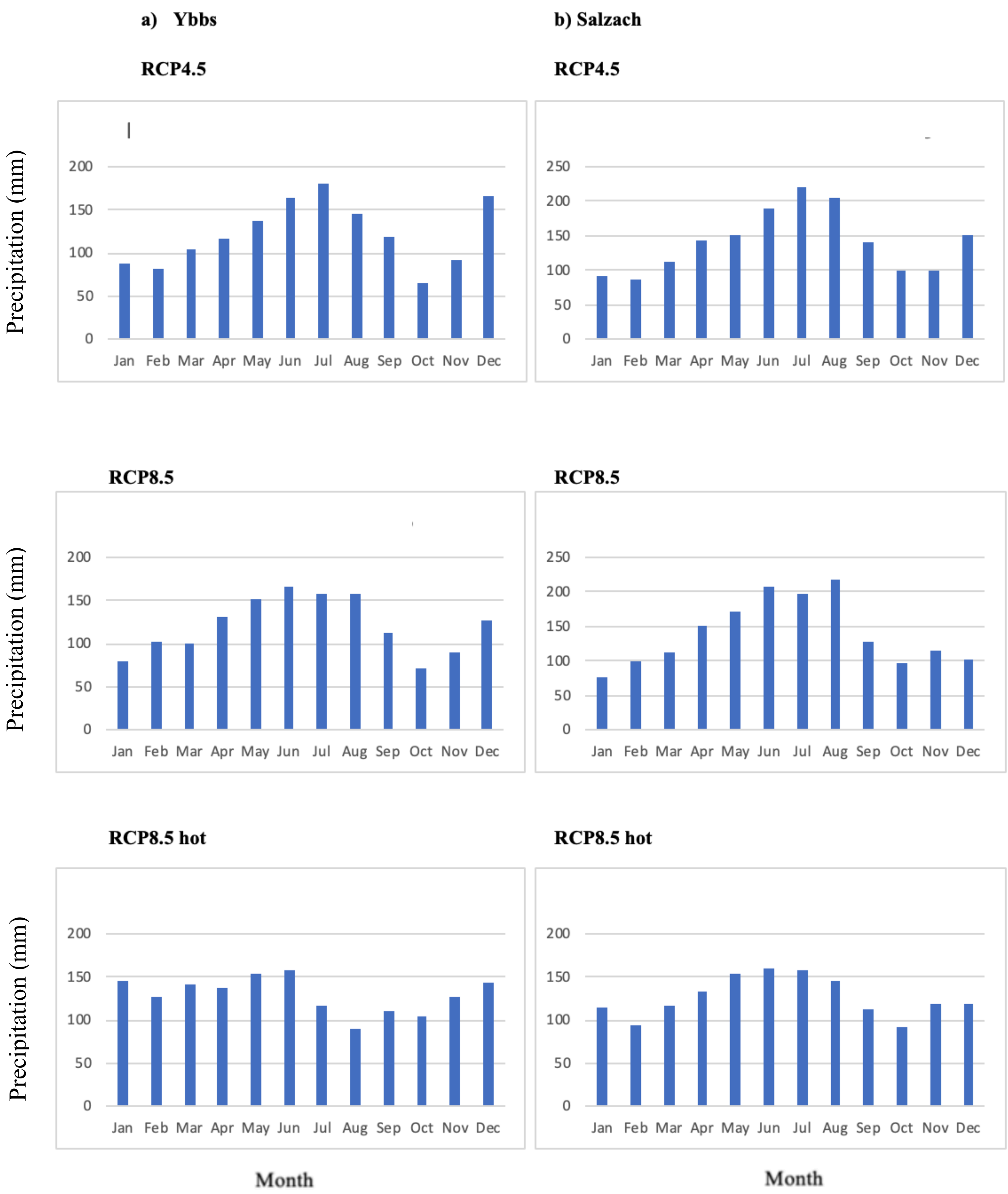


Figure 38. Monthly precipitation in (mm) for FUT(MID) according to RCP4.5, RCP8.5 and RCP8.5 hot a) Ybbs and b)Salzach.

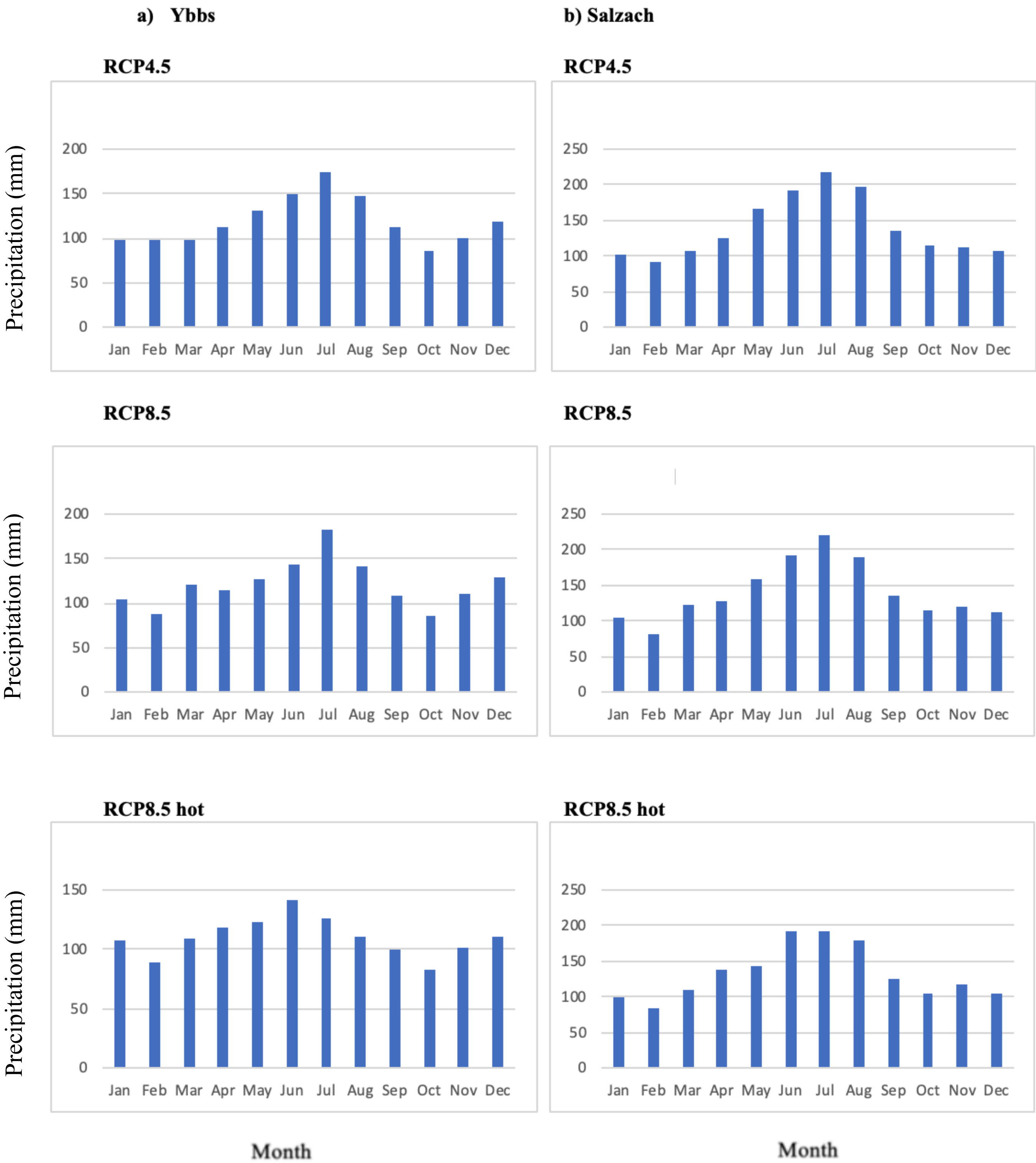


Figure 39. Monthly precipitation in (mm) for REF according to RCP4.5, RCP8.5 and RCP8.5 hot for a) Ybbs and b) Salzach.