METEOROLOGICAL APPLICATIONS
Meteorol. Appl. **23**: 462–469 (2016)
Published online 16 May 2016 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/met.1570

Royal Meteorological Society

Climate change effects on crop evapotranspiration in the Carpathian Region from 1961 to 2010

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ABSTRACT: In this study, the annual and seasonal crop evapotranspiration at the spatial level of the Carpathian Region were evaluated over 1961–2010. The temperature, precipitation and actual evapotranspiration grid monthly climate data and land cover were analysed and processed on a seasonal basis to compute the annual crop evapotranspiration. The land cover evapotranspiration rate was assigned through evapotranspiration coefficients from the literature. Geographical Information System (GIS) techniques, such as conversions from vector to raster data and the 'Raster Calculator' function, were used to assess the spatial distribution of the crop evapotranspiration at a regional scale.

In particular, two datasets from different periods (1961–1990 and 1990–2010) were used to compute the seasonal and annual crop evapotranspiration for the Carpathian region. The results of climate parameters indicate a rise in temperature and crop evapotranspiration values between the first and the second period. In addition, significant spatial changes were observed with a shift of maximum values from south to north.

KEY WORDS crop evapotranspiration; climate change; land cover; seasonal; Carpathian Region

Received 5 November 2015; Revised 14 January 2016; Accepted 23 January 2016

1. Introduction

The quality and quantity of water resources depend on climate regime and land cover. Many papers describe the impact of land use on watersheds (Tong and Chen, 2002) and water supply (Thanapakpawin *et al.*, 2006; Nistor *et al.*, 2015), whereas others describe the impact of land use on the chemical composition of infiltration water and hydrological processes (DeFries and Eshleman, 2004).

The Carpathian Range is an important mountain catchment area, with diversified land cover and climate influences. This article proposes an assessment of annual and seasonal crop evapotranspiration (ET_c) for the Carpathian Region during 1961–1990 and 1991–2010. Both absolute and relative differences in ET between the two time periods were determined. The region of the Carpathian Mountains was chosen for this study for the following reasons: (1) future tourism development is planned so it is important to know how the land cover could influence the ET_c in this region; (2) its geographical position means it experiences an Atlantic marine climate influence in the west, a Baltic climate influence in the north, a continental influence in the east and a climate transition influence in the south; and (3) there is a lack of literature regarding ET_c in the Carpathian Region.

Shaver *et al.* (2000), Oerlemans (2005), Dong *et al.* (2013) and Xie *et al.* (2013), amongst others, claimed a warming of the global climate. The most striking climate changes can be seen in falling precipitation levels and in global temperature rises of up to 3 °C (Stocks *et al.*, 1998; IPCC, 2001; Stavig *et al.*, 2005; Canadian Centre for Climate Modelling and Analysis, 2014), which are putting pressure on available food crops and water resources for a fast-growing global population (Nistor and Porumb-Ghiurco, 2015). The literature presents a large number of publications that claim the negative impact of climate change on ecosystems and on groundwater recharge (Parmesan and Yohe, 2003; Campos *et al.*, 2013; Prăvălie *et al.*, 2014). In this context, evapotranspiration has an important impact on regional water balance and is a valuable parameter for climate, hydrology and agriculture studies (Nistor and Porumb-Ghiurco, 2015).

In recent years, many studies have analysed evapotranspiration for water resources investigations (Li *et al.*, 2007; Rosenberry *et al.*, 2007; Gowda *et al.*, 2008; Abtew and Melesse, 2013). In the literature generally, potential evapotranspiration (ET_0) is approximated by evaporation (Penman, 1948; Thornthwaite, 1948; Allison and Barnes, 1985; Lhomme, 1997) and ET_c is approximated by crop absorption because of vegetation evapotranspiration rate (Allen *et al.*, 1998). Until now, only a few authors (e.g. Allen, 2000; Gowda *et al.* 2008; Gerrits *et al.* 2009) have demonstrated the impact of ET_0 and actual evapotranspiration (AET_0) on agriculture and water balance (Nistor and Porumb-Ghiurco, 2015). Ambas and Baltas (2012) assessed the so-called sensitive parameter using different evapotranspiration methods and they estimated the reference evapotranspiration in the Prefecture of Florina, western Macedonia. Gao *et al.* (2007, 2012) defined the AET_0 as a useful indicator for changes in water cycle and climate.

The goals of the present paper were to determine the annual and seasonal ET_c in the Carpathian Region over 1961–2010. Using the climate data and land cover distribution of 10 classes of the

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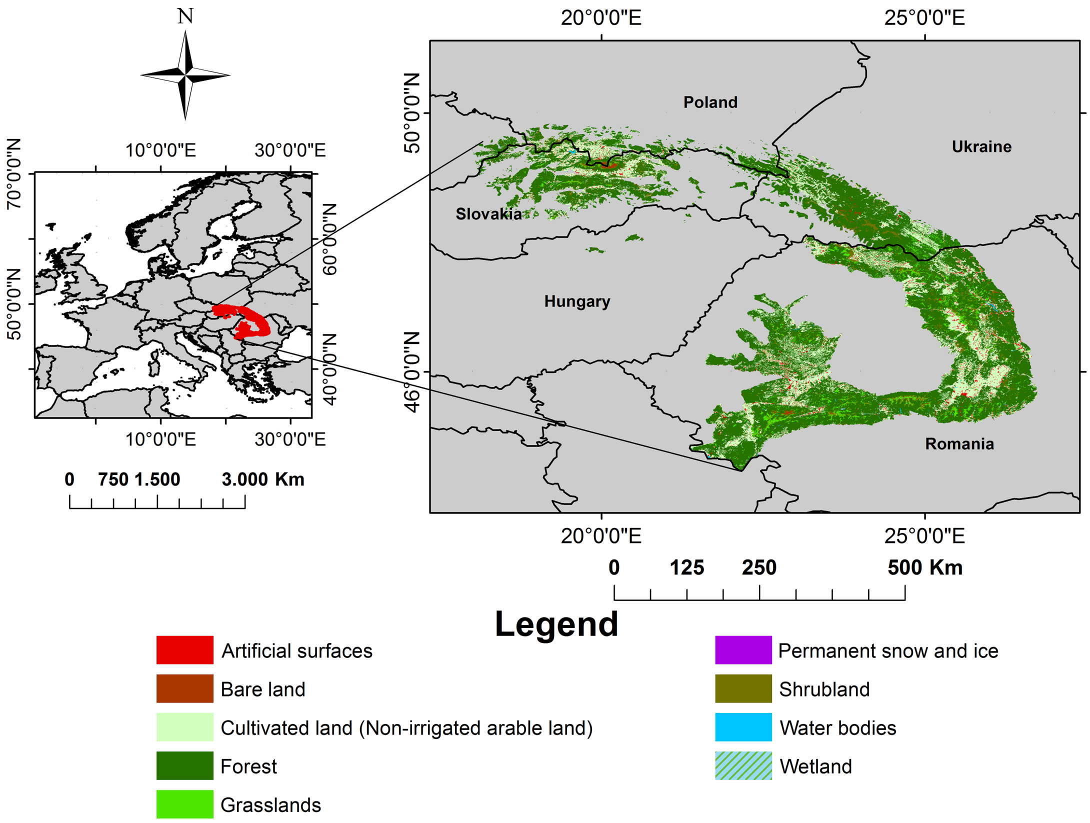

Figure 1. Location of the Carpathian Mountains region in Europe and its land cover.

region, the space–time ET_c computation was determined using a Geographical Information System (GIS).

2. Study area

The Carpathian Region extends from 44°28′ to 49°51′N and 18°00′ to 26°46′E (Figure 1). It is positioned in the centre of Europe and represents the most important ecosystem in this part of the continent. The region, within national borders of over 8 countries, is the main source of drinking water for central Europe and also represents a huge reserve of surface water and groundwater. After the Köppen–Geiger climate classification, the Carpathian Region has Dfb climate over the largest part of its total area, characterized by fully humid climate conditions and warm summers (Kottek *et al.*, 2006). Exceptions are the eastern sectors of the Romanian and Ukrainian Carpathians, the central parts of the Slovakian Carpathians as well as a small part of south Poland, which have a Dfc climate type, with fully humid precipitation conditions and cool summers (Kottek *et al.*, 2006). The annual average temperature over the last 20 years in the region ranged from −0.6 to 12.1 °C and the precipitation exceeded 1800 mm year^{-1}. The ET_0 ranged from 373 mm up to 700 mm. The maximum values of ET_c are found in the western extremity of the southern Carpathian Region and are influenced by the high temperatures and lower altitudes of the area. Figure 2 shows the annual averages of temperature, Figure 3 the annual averages of precipitation and Figure 4 the annual averages of ET_0 registered in the Carpathian Region during the two investigated the periods (1961–1990 and 1991–2010). The vegetation cover of the Carpathian Region is predominantly forest and pasture, although a smaller percentage of agricultural cultivated lands is present. Urban areas and villages are located in the depression areas, whereas the high elevation of the mountain chain is occupied by bare soils and rocks, as well as alpine hay.

3. Materials and methods

3.1. Climate data

Annual climate data grids of temperature and precipitation, completed with monthly ET_0, dating from 1961 to 2010 were used in the present study to determine ET_c. The grids had a 10 × 10 km resolution. For this study, the maps were transformed to a resolution of 1 × 1 km because of the spatial resolution of 1 × 1 km of the land cover.

3.2. Land cover data

Land cover data were extracted from the World Land Cover 30 m database. This database was assembled by China in collaboration with the United Nations and was applied to the Carpathian land cover. The Global data base comprises 10 classes and has a 30 × 30 m resolution. For this study, the land cover was transformed to 1 × 1 km, because a finer resolution is difficult to observe at the regional scale.

3.3. Evapotranspiration coefficient (K_c)

Each type of crop and vegetation has an evapotranspiration rate, called the evapotranspiration co-efficient (K_c) in the literature (Allen *et al.*, 1998). The K_c varies from crop to crop and also from place to place. At the same time, for the same crop, K_c oscillates within the same time span of a given year. Four stages

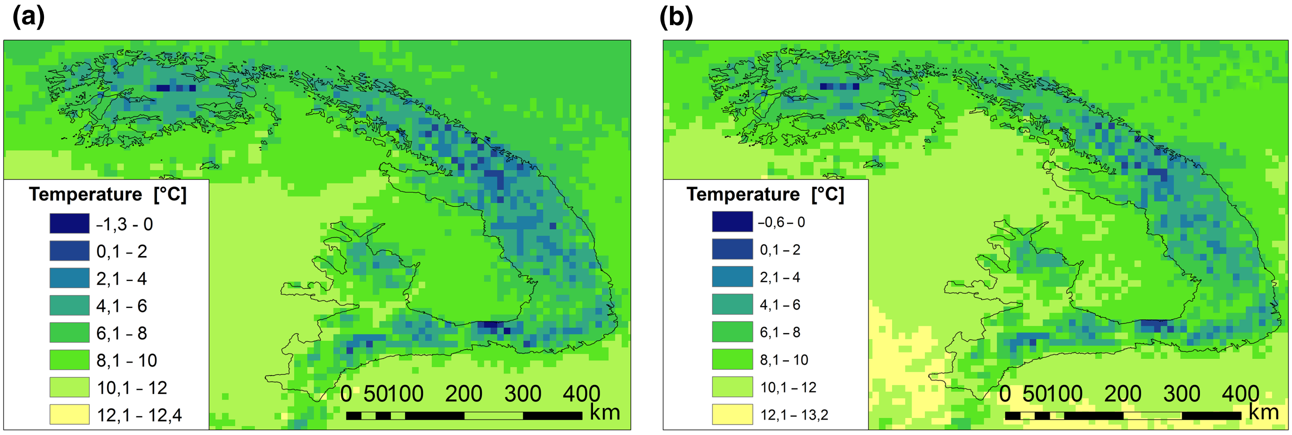

Figure 2. (a) The average of mean annual air temperature between 1961 and 1990. (b) The average of mean annual air temperature between 1991 and 2010.

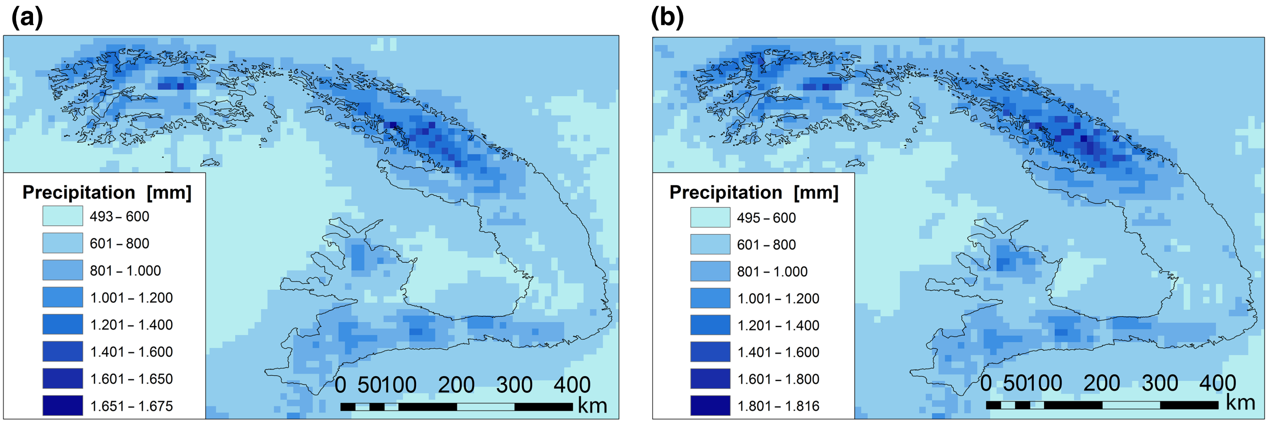

Figure 3. (a) The average of mean annual precipitation between 1961 and 1990. (b) The average of mean annual precipitation between 1991 and 2010.

of crop growth were used in the present paper. For each stage, the K_c values were determined for each crop identified in the Carpathian land cover. Grimmond and Oke (1999) published K_c values for urban areas and bare soil from different places in the United States. The present study adopted these appropriate K_c values related to urban areas and bare soil for the Carpathian Region considering the similar latitude in the present survey and the different locations from United States studied by Grimmond and Oke (1999). In addition, the work presented in the present study also adopted the methodology presented by Nistor and Porumb-Ghiurco (2015) related to land cover evapotranspiration in the Emilia-Romagna region. They analysed the ET_c in four time shifts during one year. These shifts were chosen based on the four seasons of growth of the crops. Also, they calculated the ET_c at the spatial scale using a mathematical operation with raster data in ArcGIS environment. Based on FAO Paper 56 (Allen *et al.*, 1998), for each type of crop and for each season a K_c was identified. In the present paper, because of the large extension of the region, it was decided to assign the initial season from March to May, the mid-season from June to August, the late season from September to October and the cold season from November to February. Following the above seasonal divisions, the appropriate values of initial season co-efficient ($K_{c\ ini}$), mid-season co-efficient ($K_{c\ mid}$), end season co-efficient ($K_{c\ end}$) and cold season co-efficient ($K_{c\ cold}$) were assigned to land cover of the Carpathian region. The seasonal K_c values were assigned vector data of land cover and furthermore the vector data of each set season were transformed into raster data with 1×1 km spatial resolution (Figure 5). This set was done by Nistor and Porumb-Ghiurco (2015) for their study about land cover evapotranspiration in the Emilia-Romagna region. For particular crops or in local situations, a fifth season called the development season could be inserted between the initial season and the mid-season. Table 1 provides the values of K_c Corine Land Cover (CLC) European Environmental Agency (2007) used for the ET_c calculation in the Carpathian region.

3.4. Crop evapotranspiration

The ET_c was obtained by multiplying K_c with ET_0 (Equation (1)). The calculations were done on raster data using the ArcGIS 10.1 environment, 'Raster Calculator' function. The climatological data were divided into averages of 30 years (from 1961 to 1990) and 20 years (from 1991 to 2010) with the aim of identifying climate changes, defined by ET_c, during a period of 50 years. The seasonal ET_c was calculated for each season by multiplying the monthly raster data of ET_0 with raster data of K_c (Equations (2)–(5)). Consequently, the annual ET_c could be obtained by summing the seasonal ET_c values (Equation (6)). The ET_0 grid map was calculated using the Thornthwaite method for evapotranspiration and these data

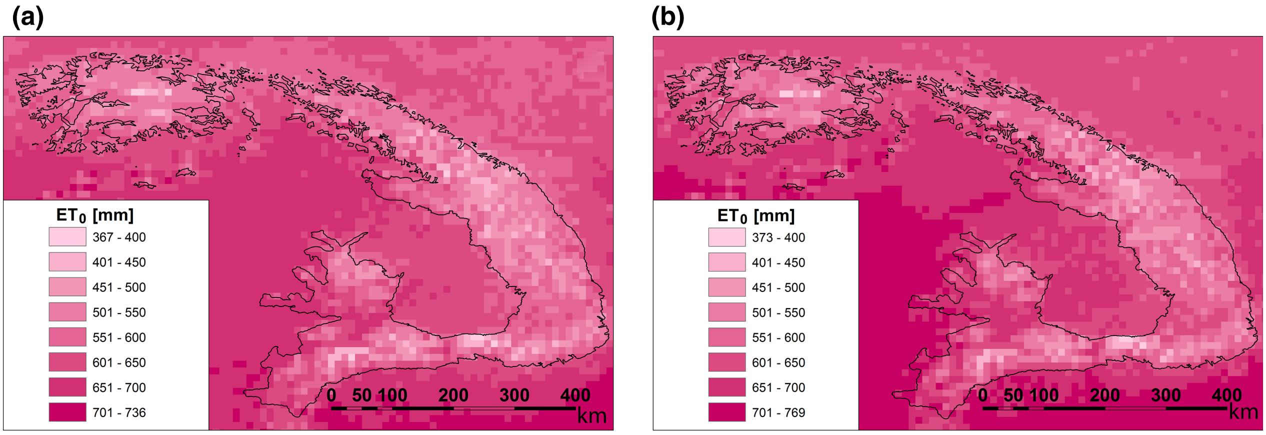

Figure 4. (a) The average annual ET_0 between 1961 and 1990. (b) The average annual ET_0 between 1991 and 2010.

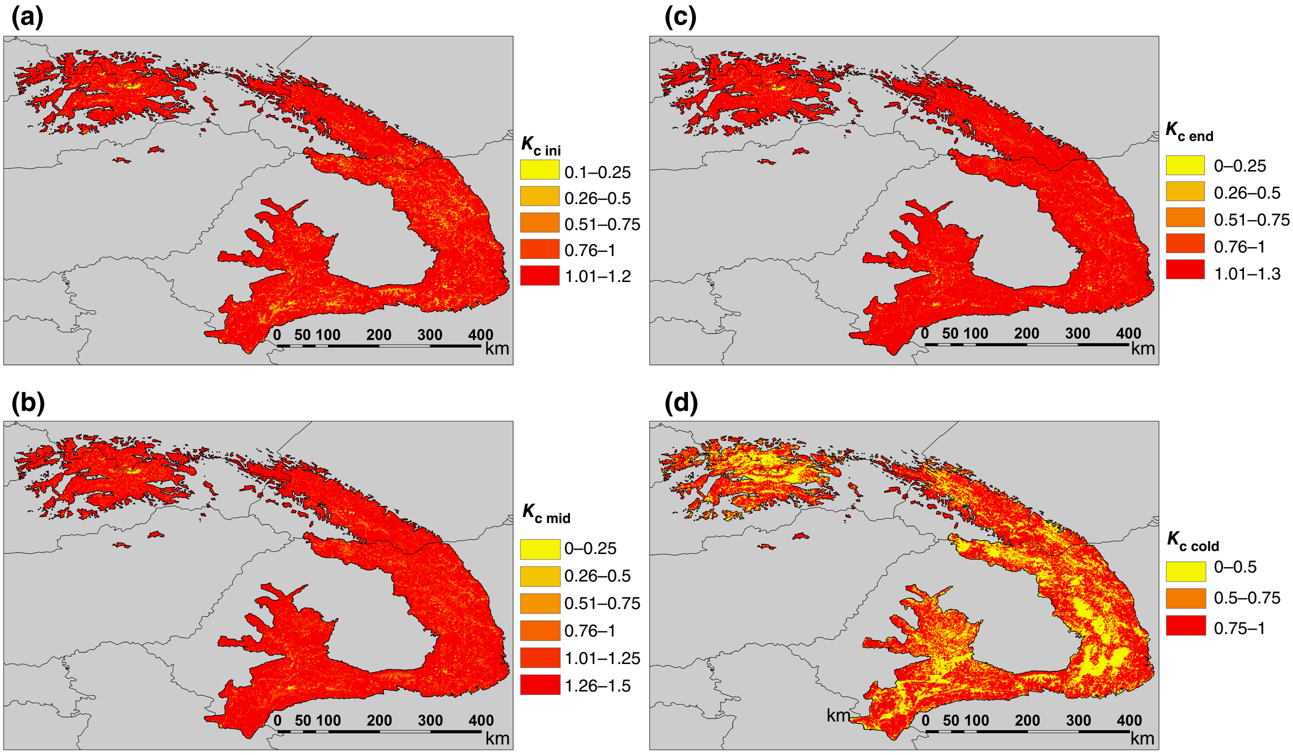

Figure 5. Spatial distribution of K_c in the Carpathian Mountains region. (a) $K_{c\ ini}$ for the initial stage. (b) $K_{c\ mid}$ for the mid-season stage. (c) $K_{c\ end}$ for the late stage. (d) K_c cold for the cold stage.

grids are the results of the Project CARPATCLIM (Szalai *et al.*, 2013):

$$ET_c = ET_0 \times K_c \quad (1)$$

$$ET_{c\ ini} = ET_{0\ ini} \times K_{c\ ini} \quad (2)$$

$$ET_{c\ mid} = ET_{0\ mid} \times K_{c\ mid} \quad (3)$$

$$ET_{c\ end} = ET_{0\ end} \times K_{c\ end} \quad (4)$$

$$ET_{c\ cold} = ET_{0\ cold} \times K_{c\ cold} \quad (5)$$

$$\text{Annual } ET_c = ET_{c\ ini} + ET_{c\ mid} + ET_{c\ late} + ET_{c\ cold} \quad (6)$$

4. Results

A general view of the annual ET_c map (Figure 6) over two set periods in the Carpathian Region shows that ET_c increased in the southern and eastern parts of the region in 1991–2010. The annual ET_c values in the 1961–1990 period ranged from 61 mm to 973 mm and the maximum values are registered in the southwestern part of the Carpathian Region. The minimum values of ET_c are found in some locations of the southern and western Carpathian region. This spatial distribution is a consequence of the high elevations of the peaks and low temperatures. In addition, a contributing factor is the lack of significant vegetation areas. At the same time, the realms with maximum values of ET_c show land cover patterns with deciduous type forest. This is due to high values of K_c, leading to an increase of ET_c. Areas in which lower ET_c are found are

Table 1. Corine Land Cover coefficients used for ET_c in the Carpathian Mountain region.

Corine Land Cover		K_{ini} season					K_{mid} season					K_{end} season					K_{cold} season				
CLC30 m	CLC Description	Kc	Ks	Ku	Kw	Kclc	Kc	Ks	Ku	Kw	Kclc	Kc	Ks	Ku	Kw	Kclc	Kc	Ks	Ku	Kw	Kclc
10	Cultivated land (Nonirrigated arable land)	1.1	–	–	–	1.1	1.4	–	–	–	1.35	1.25	–	-	–	1.25	–	–	–	–	–
20	Forest	1.2	–	–	–	1.2	1.5	–	–	–	1.5	1.3	–	–	–	1.3	0.8	–	–	–	0.8
30	Grasslands	0.3	–	–	–	0.3	1.2	–	–	–	1.15	1.1	–	–	–	1.1	–	–	–	–	–
40	Shrubland	0.8	–	–	–	0.8	1	–	–	–	1	0.95	–	–	–	0.95	–	–	–	–	–
50	Wetland	–	–	–	0.15	0.15	–	–	–	0.45	0.45	–	–	–	0.8	0.8	–	–	–	–	–
60	Water bodies	–	–	–	0.25	0.25	–	–	–	0.65	0.65	–	–	–	1.25	1.25	–	–	–	–	–
80	Artificial surfaces	–	–	0.1	–	0.1	–	–	0.3	–	0.3	–	–	0.2	–	0.2	–	–	–	–	–
90	Bare land	–	0.2	–	–	0.15	–	0.2	–	–	0.2	–	0.05	–	–	0.05	–	–	–	–	–
100	Permanent snow and ice	–	–	–	0.48	0.48	–	–	–	0.52	0.52	–	–	–	0.52	0.52	–	–	–	0.48	0.48

K_c, coefficient used for the crops, plants, and tree; K_s, coefficient used for the rocks and bare soils; K_u, coefficient used for urban area; K_w, coefficient used for free water and marshes; K_{clc}, coefficient used for land cover in Emilia-Romagna.
Source: From Allen *et al.* (1998); Nistor and Porumb-Ghiurco (2015).

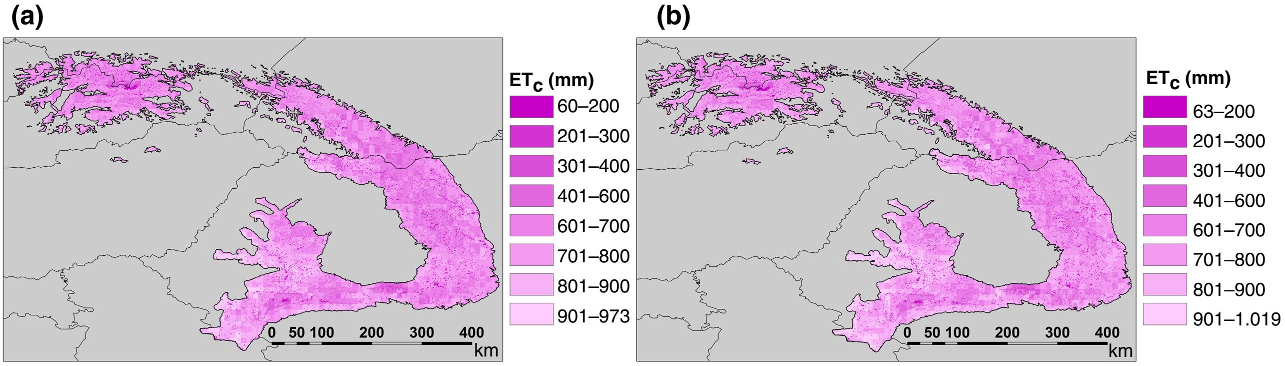

Figure 6. Spatial distribution of annual ET_c in the Carpathian Mountains region. (a) Annual ET_c for the period 1961–1990. (b) Annual ET_c for the period 1991–2010.

characterized by temperatures lower than 0 °C and bare land cover areas.

The annual ET_c during the 1991–2010 period ranged from 63 mm to 1019 mm and show maximum values in the southwestern part of the Carpathian Region. These high values are attributed to the high temperatures and to the presence of forests and cultivated lands. The lower values of ET_c are found in the southern and western Carpathians. This spatial distribution is due to temperatures above 8 °C in the southwestern part of the region and below 0 °C in the other. The minimum values of the annual ET_c were identified in the western Carpathian Region and are due to the lower temperatures and higher elevations of the region, and the lower K_c of the crops. The areas with maximum values of ET_c show land cover patterns with mixed forest with high values of K_c, leading to an increase in ET_c.

The spatial distribution of the seasonal ET_c for the periods 1961–1990 and 1991–2010 was analysed. For both periods, the seasonal ET_c map indicates maximum values during the mid-season stage. This is due not only to high temperatures and ET_0 in the summer, but also to the high values of K_c (>1.4).

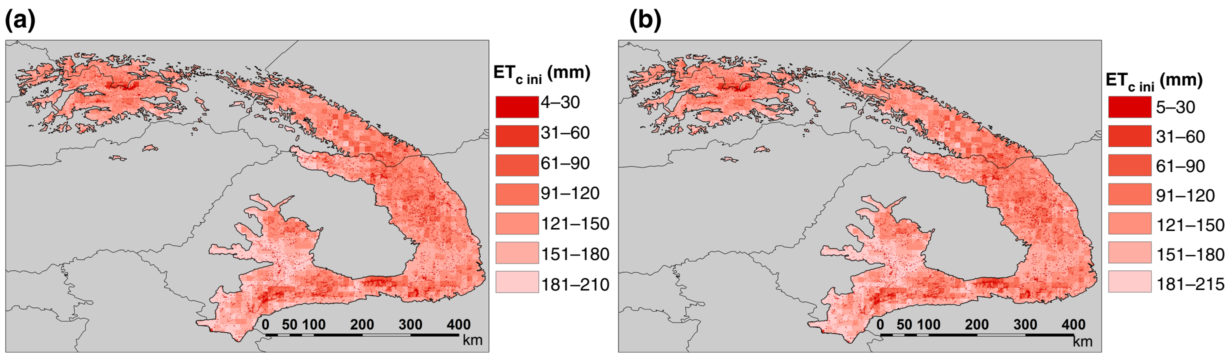

Figure 7. Spatial distribution of $ET_{c\ ini}$ in the Carpathian Mountains region. (a) $ET_{c\ ini}$ for the initial stage (1961–1990). (b) $ET_{c\ ini}$ for the initial stage (1991–2010).

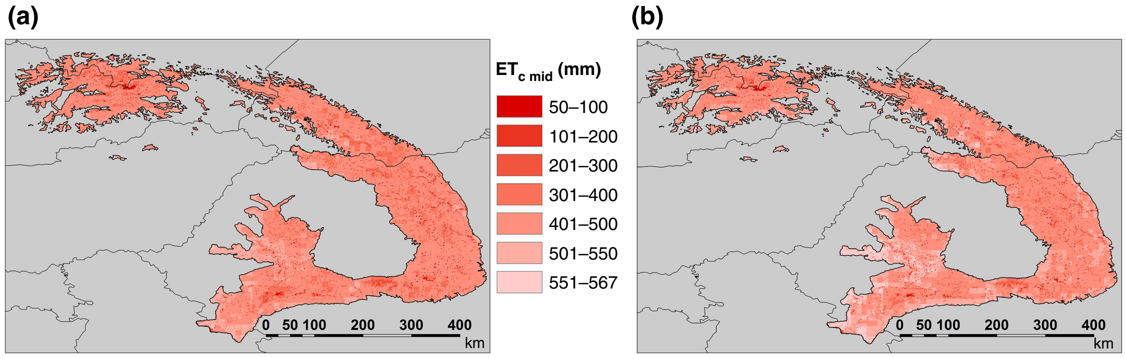

Figure 8. Spatial distribution of $ET_{c\ mid}$ in the Carpathian Mountains region. (a) $ET_{c\ mid}$ for the mid-season stage (1961–1990). (b) $ET_{c\ mid}$ for the mid-season stage (1991–2010).

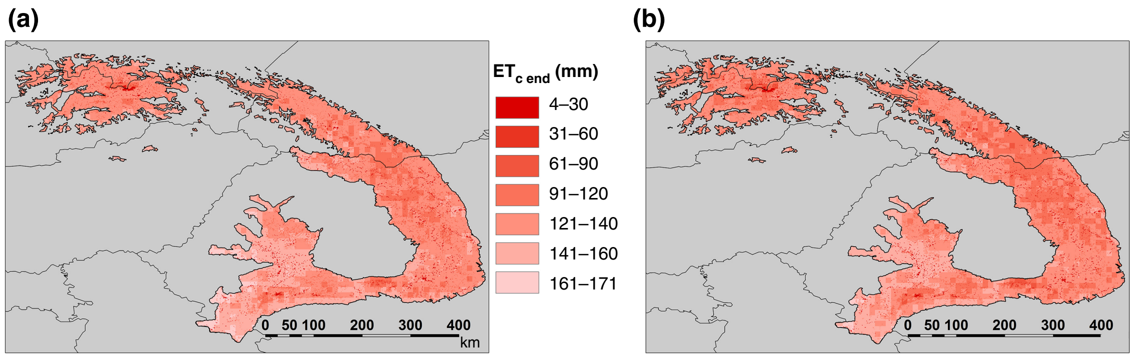

Figure 9. Spatial distribution of $ET_{c\ end}$ in the Carpathians Mountains region. (a) $ET_{c\ end}$ for the late stage (1961–1990). (b) $ET_{c\ end}$ for the late stage (1991–2010).

In the first period (1961–1990) the values of $ET_{c\ ini}$ ranged from 4 mm to 210 mm, whereas in the last period (1991–2010) the $ET_{c\ ini}$ ranged from 5 mm to 215 mm (Figure 7). This discrepancy could be explained by climate changes contributing to an increase of the evapotranspiration (ET_0 and $ET_{c\ ini}$) during the spring months (March–May).

The values of $ET_{c\ mid}$ in the 1961–1990 period varied between 50 mm and 567 mm, whereas the values of $ET_{c\ mid}$ in the 1991–2010 period varied between 53 mm and 611 mm (Figure 8). The maximum values of $ET_{c\ mid}$ in the earlier period spread over the western border of the southern Carpathians whereas in the later period the maximum values of $ET_{c\ mid}$ spread over the northern sides of the Romanian Carpathians and the southwestern sides of the Ukrainian Carpathians. The sides with lower $ET_{c\ mid}$ are located in the south and northwestern parts of the region and overlap with territories with high altitudes covered by cultivated lands and where the ET_0 values are below 400 mm year^{-1}.

Analysing the end seasons, $ET_{c\ end}$ values were lower than 10 mm and higher than 160 mm in both periods. During 1961–1990 the $ET_{c\ end}$ had a maximum value of 171 mm in the southwestern part of the Carpathian Region and a minimum value of 4 mm in the northwestern part of the region. In the period 1991–2010, the $ET_{c\ end}$ reached maximum values that exceeded 165 mm in the southwestern sides of the Carpathian Region (Figure 9) and the minimum values of $ET_{c\ end}$ drop to 3 mm in the Western Carpathians. Essential differences are found in the spatial distribution of the $ET_{c\ end}$: in the first set period,

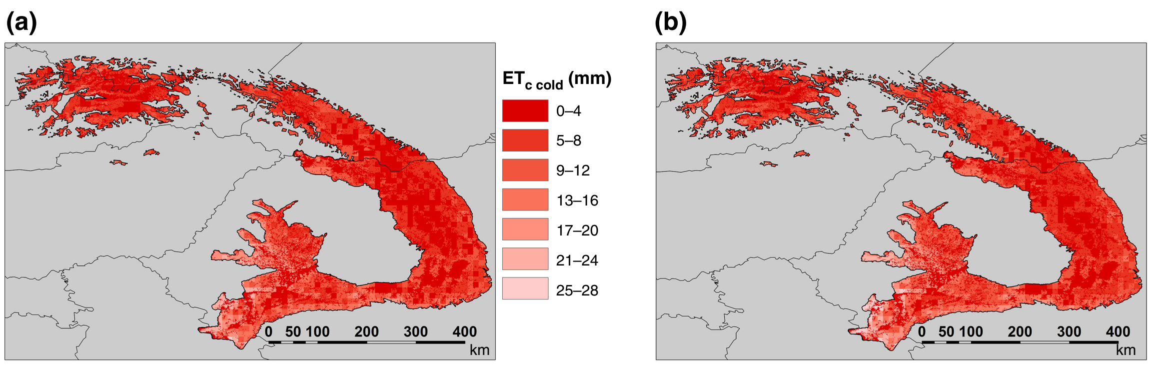

Figure 10. Spatial distribution of $ET_{c\ cold}$ in the Carpathians Mountains region. (a) $ET_{c\ cold}$ for the cold stage (1961–1990). (b) $ET_{c\ cold}$ for the cold stage (1991–2010).

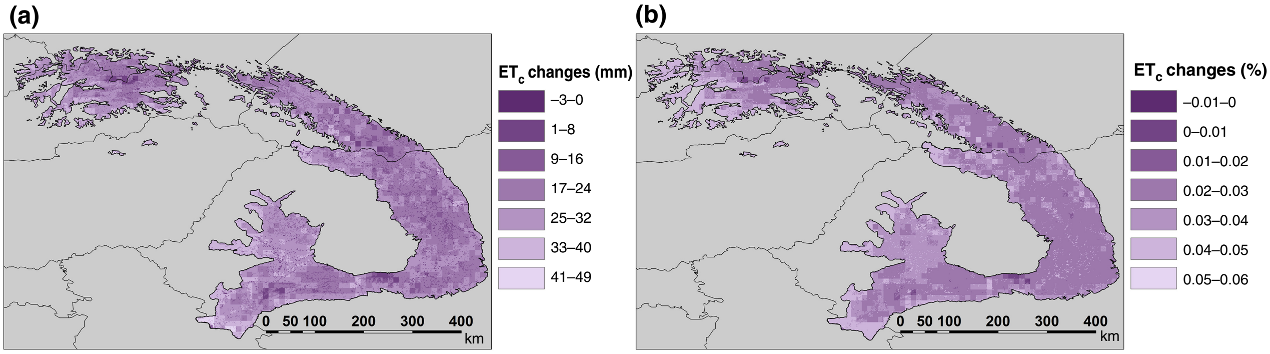

Figure 11. (a) Absolute changes of annual ET_c in the Carpathian Mountains region between present and past periods. (b) Relative changes of annual ET_c in the Carpathian Mountains region between present and past periods.

the highest values of $ET_{c\ end}$ (>170 mm) are found in the south and west areas, whereas in the last set period the highest values of $ET_{c\ end}$ (>160 mm) are found in some locations situated in the western and southern parts of the region.

The lower temperature in the cold season explains the low values of the $ET_{c\ cold}$. Between 1961 and 1990 the $ET_{c\ cold}$ ranged from 0 to 28 mm, whereas between 1991 and 2010 the $ET_{c\ cold}$ ranged from 0 to 29 mm (Figure 10). In both periods, the maximum values were found in areas covered by forest, shrubland and cultivated lands. The land cover pattern indicates that the $K_{c\ cold}$ values of forest contribute to an increase of ET_c even if the annual temperatures fall below 10 °C.

Interestingly, the spatial distribution of $ET_{c\ cold}$ shows that higher values are found in the elevated areas. This is in line with the results carried out by Nistor and Porumb-Ghiurco (2015) for the Emilia-Romagna region. The reason is that the elevated areas of mountains are covered by coniferous forest and the $K_{c\ cold}$ of these areas is positive.

Figure 11 depicts the differences of annual ET_c values between the 1961–1990 and 1991–2010 periods. The absolute and relative differences of ET_c were determined between past and recent climate with the aim of observing the most affected areas and the areas with smaller changes in ET_c. The absolute difference map of ET_c highlights that the central and south-western sides of the Carpathian Region registered a maximum value of 49 mm between 1961–1990 and 1991–2010. The insignificant absolute changes are verified in the eastern part of the region. The relative changes indicate that southern part of the Carpathian Region registered changes larger than 0.06% between both analysed periods.

5. Conclusions

The work presented here has shown that recent climate change has had a negative impact on the ET_c in the Carpathian Region. The geographical position of the mountain chain, which spreads over 5° N, determines the spatial distribution of temperature, precipitation and the ET0 climatic parameters. Together with these parameters, the land cover data and crop evapotranspiration coefficients contribute to a seasonal and annual increase of ET_c.

The values of annual ET_c determined in the present study and the seasonal ET_c trend in recent years are close to annual and seasonal ET_c reported for the northern Apennines. This demonstrates that the applied methodology was adapted successfully to the Carpathian Region case study. The maps of seasonal and annual ET_c, derived by calculation from raster maps, are new pieces of information that contribute to the specific literature about the Carpathian Region. The limitations of the research are related to the field measurements of each type of crop. Because of a complicated assessment system of the evapotranspiration for each kind of vegetation and inexpedient methods with lysimeters, the present study was based on literature standard K_c and empirical equations. This shortcoming does not affect the survey, because the study was focused on a regional scale and over long time periods. Moreover, the variation of moisture, soils and K_c from place to place prompted us to choose the standard values for K_c.

Based on this study, future work will focus on water balance and groundwater vulnerability assessment under climate and land use change. The findings of the paper should be useful for climatologists and hydrologists and workers in agriculture and forestry management.

Acknowledgement

The authors would like to thank the members of the project: CARPATCLIM Database © European Commission – JRC, 2013.

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