Climatology and trends of reference evapotranspiration in Spain

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1. Abstract

This study presents a climatology and trend analysis of reference crop evapotranspiration ($ET_o$) over continental Spain and the Balearic Islands. Geographic features of the study region play a substantial role in the climatology of $ET_o$. The highest values (in excess of 1200 mm y$^{-1}$) are found at lower elevations in the south, while the lowest values (less than 900 mm y$^{-1}$) are found in the highest elevations in the north. A deep analysis reveals: i) a low interannual variability; ii) summer accumulates more than 50% of annual values; and iii) the radiative component contribution is higher than 50%. A positive long-term trend (1961-2014) has been detected for most of the study area, but showing contrasting situations when shorter periods (20-30 years) are analyzed. A short initial period of negative trend was followed by a longer period of positive trend. We argue that global dimming/brightening played a role in this process, as these two contrasting periods are clearly guided by the radiative component. A seasonal analysis of the trends reveals that spring and summer are the seasons showing the long-term positive trends. Interestingly, a monthly analysis shows that spring trends are guided by March and April and summer trends are mostly guided by June, which is the month showing the highest relative changes. This could have important consequences for agriculture and natural ecosystems since this month represents the start of the summer (dry) period.

1. Introduction

Reference crop evapotranspiration, $ET_o$, is a climatic variable that represents the evaporative demand of the atmosphere at a specific location and time of the year, assuming a reference surface. It is therefore independent of soil characteristics, crop type, crop development, management practices or other non-climatic factors. The Food and Agriculture Organization of the United Nations (FAO) version of the Penman-Monteith equation (FAO-PM) is the most recommended method to calculate $ET_o$, since it is physically-based and includes physiological and aerodynamic components (Allen et al., 1998). $ET_o$ has an important role in the surface water and energy balances, and is also the basis for calculating crop evapotranspiration under standard and non-standard conditions (Allen et al., 1998).

Obtaining reliable estimations of $ET_o$, therefore, is relevant for a variety of disciplines, and many studies have used $ET_o$ in applications related to climatology (Hobbsin et al., 2016; Vicente-Serrano et al., 2017), hydrology (Prudhomme and Williamson, 2013; Coppola et al., 2014; Seiler and Anctil, 2016) agriculture (Katerji and Rana, 2014; Pereira et al., 2015; Saadi et al., 2015), and ecology (Jucker et al., 2016; Chitra-Tarak et al., 2018). Nevertheless, these studies face two relevant challenges: i) obtaining all the necessary data to compute $ET_o$ using FAO-PM, and ii) obtaining $ET_o$ climate grids at the required spatial resolution, which is very high for some of the disciplines (e.g. ecology: Franklin et al. (2013); Karger et al. (2017); Abatzoglou et al. (2018)).
Furthermore, the analysis of the impacts of ET\(_o\) on different systems could be considered as the last one of a 4-levels hierarchical pyramid, in which each level is based in the lower ones and addresses a specific knowledge gap: 1) development of better methodologies to estimate ET\(_o\); 2) computation of ET\(_o\) datasets, preferably in the form of climate grids; 3) climatic analysis of ET\(_o\); and 4) analysis of the impacts of ET\(_o\) anomalies, such as impacts on droughts, crops, ecosystems or water resources. Thus, to study the impacts of ET\(_o\) it is first necessary to understand the climatology of ET\(_o\), and that in turn requires a good dataset of ET\(_o\).

Because of that, there is great interest in obtaining high spatial resolution climate grids of ET\(_o\) for the recent decades, but also for longer periods (Haslinger and Bartusch, 2016; Lewis and Allen, 2017; Robinson et al., 2017; Tanguy et al., 2018). Furthermore, the relevance of these studies increases in the context of climate change as the relevance of the possible changes in ET\(_o\) comes into play prominently (Scheff and Frierson, 2014; Vicente-Serrano et al., 2020). The sign and magnitude of ET\(_o\) trends in the recent past and in future projections have been the subject of intense scientific debate in the last years. The existence of ET\(_o\) trends can be of especial relevance in climate regions ranging from semi-arid to sub-humid conditions, in which changes in ET\(_o\) can critically modify the aridity conditions even with no changes in rainfall amounts, with huge impacts on the environment, crops and water resources. Temperature has a direct influence on ET\(_o\), and the recent temperature increase contributes to an increase of ET\(_o\). Nevertheless, the contribution of the rest of variables is regionally dependent, as their trends vary largely between regions (Wang et al., 2017a). Thus, both positive and negative trends in ET\(_o\) have been described, which imply drier or wetter conditions, respectively. Negative trends were detected, for instance, in India (Jhajharia et al., 2012), China (Wang et al., 2017b), several regions of the USA (Irmak et al., 2012; Kulal and Irmak, 2016), and Iran (Dinpashoh et al., 2011). On the other hand, positive trends were detected in Europe (Stagge et al., 2017), Great Britain (Robinson et al., 2017), or Spain (Vicente-Serrano et al., 2014b).

As a region characterized by semi-arid conditions, the interest of ET\(_o\) in Spain is apparent, and many studies addressed different topics related with this variable. Until now, ET\(_o\) studies in Spain focused on a limited number of locations (Vicente-Serrano et al., 2014b; Azorin-Molina et al., 2015; Tomás-Burguera et al., 2017), or used only temperature to estimate ET\(_o\) following the Hargreaves and Samani (Hargreaves and Samani, 1985) approach (Berengena and Gavilan, 2005; Vanderlinden et al., 2008; Aguilar and Polo, 2011; Giménez and García-Galiano, 2018; Yeste et al., 2018).

These previous studies have already shown some features of the spatial distribution and temporal variability of ET\(_o\) in Spain, such as a strong seasonal component with peak values in summer or a clear latitudinal gradient with the highest values in the south. Moreover, a positive trend affecting most of the Spanish territory since 1961 was also previously detected (Espadafor et al., 2011; Vicente-Serrano et al., 2014b).

Nevertheless, Spain shows a high spatial climate variability due to its com-
plex topography but also due to its position in the mid-latitudes close to the Atlantic Ocean and the Mediterranean Sea (Azorin-Molina et al., 2014). Hence, some of the climate variables influencing ET\textsubscript{o}, such as wind speed (Lorente-Plazas et al., 2015) and temperature (Peña-Angulo et al., 2015), also show high spatial variability. Therefore, to correctly analyse ET\textsubscript{o} in Spain, a high spatial ET\textsubscript{o} climate database available to capture this high spatial variability is required. A new ET\textsubscript{o} grid (SPETO) based on FAO-PM covering continental Spain and the Balearic Islands for the 1961-2014 period with a high spatial resolution of 1.1x1.1 km has been recently made available (Tomas-Burguera et al., 2019).

This paper aims at filling the gap of ET\textsubscript{o} studies in Spain. The spatial distribution of mean annual and monthly ET\textsubscript{o} will be analysed, as well as the absolute and relative contributions of its two components: radiative (linked to the available energy to force evapotranspiration) and aerodynamic (linked to the capacity of air to store additional water vapour). The inter-annual variability of ET\textsubscript{o} will also be studied at the annual and monthly scales, as well as the contribution of the two components. Finally, temporal trends of ET\textsubscript{o} will be assessed. In addition, all of these analysis will also be reproduced for the two components of ET\textsubscript{o} in an effort to better understand the role of each component in the trends of ET\textsubscript{o}.

2 Data and methods

We used raw data of maximum and minimum temperature, wind speed, relative humidity and sunshine duration provided by the Spanish national weather service (AEMET), to develop a gridded database of ET\textsubscript{o}. Quality control, gap filling and homogenization were implemented on the raw data before interpolating the grids (Vicente-Serrano et al., 2017). The Interpolate-then-Calculate strategy was used, in which climate grids of each one of the variables of interest are obtained in a first step, and then the Penman-Monteith equation is used to calculate ET\textsubscript{o}. The resulting database (SPETO) has a spatial resolution of 1.1 km and a temporal resolution of one week covering the 1961-2014 period for the Spanish mainland and the Balearic Islands. More details on the development of SPETO can be found in Tomas-Burguera et al. (2019). The complete dataset can be downloaded from http://digital.csic.es/handle/10261/176701, and data for a given location can be retrieved from the interactive viewer at http://speto.csic.es. We used data of ET\textsubscript{o} and its two components (radiative and aerodynamic) from the SPETO database.

We computed annual and monthly mean ET\textsubscript{o} and its two main components (radiative and aerodynamic), as well as their standard deviation (SD) and coefficient of variation (CV), considering the 1981-2010 reference period. The 1981-2010 period was used to follow the recommendations of the World Meteorological Organization regarding the computation of climatological standard normals (WMO, 2017).

We conducted a trend analysis of annual and monthly ET\textsubscript{o} and their components, considering the entire period 1961-2014. The Sen’s slope statistic
(Sen, 1968) was used to estimate the magnitude of the temporal trend (in mm decade\(^{-1}\)), and the Mann-Kendall test (Mann, 1945; Kendall, 1948) was used to check its significance, at an \(\alpha = 0.05\) significance level. Trends were computed using the pre-whitening method proposed by Yue et al. (2002), as implemented in the Rsyp package (Bronaugh and Werner, 2019). In order to increase the spatial and temporal comparability of the results of the trend analysis, the relative trend was also calculated (in % decade\(^{-1}\)) by dividing the absolute magnitude of the trend by the mean value of ET\(_o\) over 1981-2010.

These analyses were conducted for each grid cell, preserving the 1.1x1.1 km spatial resolution of the original dataset. For the trend analysis, a regional scale was also considered. Thus, in spite of calculating only one regional trend for the whole study area, three regions were considered. The number of regions and the allocation of each basin into each group was decided according to the magnitude of the mean annual ET\(_o\) at each basin. The three regional time series are the following (Figure 1): i) High (ET\(_o\) higher than 1100 mm), including Tajo, Guadiana, Guadalquivir, Júcar, Segura, Mediterranea Andaluzas and Baleares basins; ii) Medium (ET\(_o\) in the range of 900-1100 mm), with Duero, Ebro and C.I. Cataluña basins; and iii) Low (ET\(_o\) lower than 900 mm), including Galicia Costa, Miño-Sil, Cantábrico, and C.I. Pais Vasco.

3 Results

3.1 Annual and seasonal ET\(_o\)

Mean annual ET\(_o\) ranged between 700 mm and 1300 mm (Figure 2a). Two geographical patterns can be clearly identified, following latitudinal and altitudinal gradients. The latitudinal pattern shows higher values in the southern region, and lower values in the northern region. On the other hand, an altitudinal pattern is also present with higher values in the lowlands and the center of the main river valleys and lower values in the mountain ranges, coinciding with the main watershed borders. The combination of these two patterns explains the location of the highest values of ET\(_o\) in the lowlands of the south and the lowest values in the mountain regions of the North. The central Ebro Valley represents an anomaly to the latitudinal pattern, as it shows higher ET\(_o\) than its geographical context despite being located in the northern area of the Iberian Peninsula.

The seasonal analysis (Figure 2b to 2e) reveals a strong pattern with the three summer months accounting for nearly 50 % of the annual ET\(_o\). Autumn and spring show intermediate values, with spring having slightly higher values than autumn. The same spatial patterns found in the mean annual values are more apparent in summer than in the other seasons, due to its highest values and the high spatial gradients detected in this season.

The radiative component of ET\(_o\) has the largest contribution to the annual ET\(_o\) with a relative contribution to the mean annual ET\(_o\) always greater than 50 % (Figure 3a), and even reaching percentages as high as 65-70 %. The seasonal analysis of the two components reveals interesting differences between
summer and winter (Figure 3b). While in summer the radiative component clearly has the highest contribution, in winter the contribution is slightly higher for the aerodynamic component. Not surprisingly, the seasonality of the radiative component is higher, as it is mainly guided by the available radiation, which is highly seasonal in the mid-latitudes.

3.2 Inter-annual variability

The inter-annual variability of ET₀ is low, with most of the territory showing CV between 2% and 6% (Figure 4a). Only a few spots in mountainous areas have CV higher than 6%. On the contrary, the lowest CV, 2% or less, are restricted to a small area at the southeast. In general, ET₀ CV is higher in the north than in the south. The seasonality is also high in the CV (Figure 4b to Figure 4e). Opposite to the mean values, winter shows the highest CV while summer reaches the lowest CV.

The analysis of the CV of the two components reveals differences (Figure 5). While the radiative component show values between 2% and 6%, the aerodynamic component of ET₀ shows higher variability with some values higher than 10% and most of the territory showing values higher than 6%.

Therefore, the low inter-annual variability of ET₀ is explained to a large part by the low inter-annual variability of the radiative component, which at the same time influences the low values of CV in summer. On the other hand, the high contribution of the aerodynamic component in winter guides the higher winter values of CV.

3.3 Trends

Positive trends of annual ET₀ were found in most of the study area (Figure 6a), with up to 69.5% of the territory showing significance. Linear trends between 15 and 30 mm decade⁻¹ were found in the Northeast of the Iberian Peninsula, the center and the South. On the other hand, in the northwestern region of the Iberian Peninsula no statistically significant trends were found, and a region of negative (but not statistically significant) trend was detected in mountainous areas of that region. A region of positive but non statistically significant trend close to the Mediterranean Sea also exists, affecting the Júcar and some spots of the Ebro basins.

The positive trend was also detected in the two components of ET₀, but with relevant differences in the spatial distribution among them (Figure 6b and c). The radiative component showed positive and statistically significant trends in the southern and eastern parts of the study area, while the northwestern region was dominated by statistically non-significant trends (both positive and negative). The aerodynamic component, on the other hand, showed positive trends in the northeastern region and in a north-to-south corridor located close to 3°W of longitude which coincides, more or less, with the central part of the Iberian Peninsula. Some spots with negative trends in the aerodynamic component appeared in the Mediterranean region.
Thus, both annual and components trend analysis reveals that the positive trend affect the High and Medium regions, while not statistically significant trends dominate in the Low region. Figure 7a shows the annual evolution of \( ET_o \) in the three regions. The three regions show similar temporal pattern, with the detection of two contrasting periods. A first period of decreasing \( ET_o \) is followed by a second period of increasing \( ET_o \). Due to the decreasing period being much shorter than the increasing period, the long-term trend is positive in most of the territory.

The running window trends (Figure 7b) represent the relative slope of the trends (in \( \% \text{ decade}^{-1} \)) for different starting years and different time windows. The maximum possible time window for each starting year is located in the hypotenuse of the resulting triangle. The top vertex corresponds to the linear trends for the whole period, showing positive and statistically significant values in the High and Medium regions and positive but not statistically significant in the Low region, as seen previously. However, the positive trend also dominates the hypotenuse of the Low region, being statistically significant if the starting year is moved to the 1970's.

The first period of decreasing \( ET_o \) has a short duration in the High and Medium regions. In the Low region, on the other hand, it can be detected even with a time window of 40 years. This persistence helps to explain why the positive trend is not statistically significant for the whole period in this region.

The real magnitude of this first period of decreasing \( ET_o \) is really unknown since this trend most likely started before the analyzed period.

For short time windows an oscillation is detected, presenting sequential but asymmetric decreasing and increasing pulses. In the High and Medium regions, the increasing trends are clearly larger than the negative ones. In fact, the Medium region has the highest trend with values slightly higher than \( 5 \% \text{ decade}^{-1} \) (p-value of 0.02) considering the 70's as starting year.

The component analysis (Figure 8) shows differences between the aerodynamic and radiative components, but a similar evolution in the three regions. The two components show an increasing trend in the long-term but with many differences in the mid and short-term periods. The aerodynamic component shows a higher frequency oscillation in the annual values, implying that short pulses of negative and positive trends alternate during the study period. On the other hand, the radiative component shows a low frequency oscillation, with a starting period of negative trend followed by a long-lasting positive trend. Thus, it could be argued that the low frequency oscillation of \( ET_o \) is guided by the radiative component while the high frequency oscillation is guided by the aerodynamic component.

Differences also emerge at the seasonal level (Figure 9). In general, spring and summer are dominated by a long-term positive trends, especially in the High and Medium regions. In the Low region only spring shows a long-term positive trend. Spring and autumn are the two seasons showing higher low frequency trends, alternating periods of decrease with periods of increase. In the late years of the study period a high positive trend in the short term was detected in Medium and Low regions in autumn. The magnitude of the trend
Finally, the spatial analysis of the long-term trends of monthly values (Figure 10) also reveals interesting results. The high trend of summer is mostly due to the high relative trend of June, which shows a large area with values higher than 3 mm decade$^{-1}$. Interestingly, June is the month with the highest relative trend in the whole year. On the other hand, July and August only show high relative trends in the south and northeast of the Iberian Peninsula. At the same time, July shows negative trends in the northwest. March and April are the two months guiding the positive trend of spring, showing large areas affected by a relative trend higher than 2%, while May almost has no areas with statistically significant positive trends.

4 Discussion and conclusions

4.1 Climate normals

Although the general distribution of ET$_o$ in the study area, with higher values in the southern region and lower values in the northern region, has been described in previous studies (Espadafor et al., 2011; Vicente-Serrano et al., 2014a; Azorin-Molina et al., 2015), the high spatial resolution of the database used on this study offers a deeper insight on the spatial distribution of the variable. The maximum ET$_o$ in the inner part of the Mallorca island or the contrast of ET$_o$ within the basins, showing maximum values in the center of the main river valleys and minimum values in the mountain areas, are only two examples of this enhanced detail. The spatial distribution also reflects the contrasting conditions prevailing in the more humid and energy-limited climate of the northern Iberian Peninsula and the semi-arid south (Martin-Vide and Olcina, 2001). The detection of the differences in ET$_o$ in basins confirmed the presence of an elevation gradient in the study area, previously described by Vanderlinden et al. (2008) in Andalusia, by Yang et al. (2019a) in China or by Robinson et al. (2017) in Great Britain.

Some interesting results emerged from the separate analysis of the two components of ET$_o$. The radiative component is the most dominant, meaning that it shows a contribution higher than 50% in the whole study area. This result is in accordance with previous results obtained in the study area (Vicente-Serrano et al., 2014c) and other regions (Wang and Dickinson, 2012; Maes et al., 2019). Interestingly, as a consequence of the low interannual variability of the radiative component and its highest contribution to ET$_o$, ET$_o$ also has low variability. This is in accordance with Mendicino and Senatore (2013) and Samani (2000), who argued that temperature and radiation account for 80% of the variability of ET$_o$. This is the basis for some of the methods to estimate ET$_o$ using temperature and/or radiation data, such as Priestley-Taylor (Priestley and Taylor, 1972) or Hargreaves and Samani (Hargreaves and Samani, 1985).

Nevertheless, the aerodynamic component plays a key role in the mean values of ET$_o$ as well as in the interannual variability. In some windy regions of the
country, such as the Ebro Valley, its contribution is close, or even higher, to 40%.

In addition, during winter the contribution of the aerodynamic component is highest, which is related with the low radiation available during this season. This was also detected in Great Britain by Robinson et al. (2017). A consequence is that winter is the season showing the highest interannual variability of ET$_o$.

In terms of atmospheric circulation, the high interannual variability of winter could be related with two contrasting atmospheric situations that dominate the regional weather in winter: i) the Azores anticyclone, often with an extension toward the Iberian Peninsula (ridge of high pressure) or to Central Europe (anticyclonic bridge), characterized by a stable atmosphere, without rain; and ii) the zonal west circulation, with fronts and extratropical cyclones by latitudes close to the Iberian Peninsula, or the presence of a low in the southwest of IP (sometimes only in mid-troposphere, cut-off low), characterized by an unstable atmosphere and rainy weather. These situations could be linked to positive and negative phases of the North Atlantic Oscillation (NAO), respectively. As explained by Zubiate et al. (2017), NAO has a strong influence on wind speed anomalies in the Iberian Peninsula. While the negative phase influences positive wind speed anomalies, a positive phase influences negative anomalies. While these two situations can also take place in the other seasons, the fact that the radiation component dominates ET$_o$ during the rest of the year diminishes the effect of the contrasting effects in the aerodynamic component.

4.2 ET$_o$ trends

The detection of a long-term positive trend coincides with the results of previous studies in the region and in other countries in Europe, such as Great Britain (Robinson et al., 2017), France (Chaouche et al., 2010), Southern Italy (Palumbo et al., 2011) or Poland (Labedzki et al., 2014). The obtained results, ranging from 7.0 to 12.6 mm decade$^{-1}$ depending on the region, are quite lower than previous trends reported by Vicente-Serrano et al. (2014c) (23 mm decade$^{-1}$) and Espadafor et al. (2011) (24 mm decade$^{-1}$) in the Iberian Peninsula. While we calculated the regional trends based in a climate grid data, the previous studies computed a regional trend based on a small number of weather stations. This means that we computed the trend using ET$_o$ data for the whole territory, while previous studies focused only on some of the first order weather stations in Spain, usually located in the main cities. This could be the source of some differences as Spain is characterized by a complex topography, which is taken into account in the climate grid used in this study but not in previous studies.

Despite the difference in the magnitude, the temporal distribution of the trend is quite similar, with a high trend in summer like Espadafor et al. (2011) mostly centered in June, as it was also detected by Vicente-Serrano et al. (2014c). The high increase of ET$_o$ values in June could be related with the early onset of summer (Peña-Ortiz et al., 2015), as temperatures show a relevant positive trend in spring (Gonzalez-Hidalgo et al., 2015). But this could also be influenced by the negative trend in air humidity also affecting this month (Vicente-Serrano et al., 2014a). In the normal course of summer, enhanced val-
ues of actual evapotranspiration during June could mean that vegetation dries
the soil moisture earlier, increasing the natural stress conditions of the late sum-
mer in most of the region. On the other hand, if soil water availability cannot
support an increase of actual evapotranspiration, an increase in the sensible heat
would occur, possibly activating a positive feedback due to an increase in the
temperature and a decrease in the air humidity (Miralles et al., 2019) occurring
simultaneously.

While the trends in $ET_o$ are commonly assessed as monotonic trends, a
running windows trend analysis of $ET_o$ in the region reveals two contrasting
periods. A first period of decreasing trend, which starts in 1961 and ends in
the late 70s, is followed by a second period of increasing trend, which ends at
the end of the study period. Furthermore, for windows shorter than 30 years
different pulses alternating between decreasing and increasing trends are also
detected. In general, the increasing pulses are more relevant both in magnitude
and in significance than the negative ones. The Low region, corresponding to
the watersheds located in the northwest of the Iberian Peninsula, is an anomaly
to this pattern. While the same pulses can be identified in this region, the first
period of decreasing trend in $ET_o$ is longer than in the other two regions. In
this regard, it is very complex to attribute these results to the different climate
variables. Nevertheless, the use of the running windows trend approach for the
two components help to clarify the origin of the two contrasting periods and
also of the short pulses.

The radiative component is the one with similar long-term changes than
$ET_o$. This means that the radiative component is the one guiding the alter-
nation between the first decreasing period and the second increasing period.
Nevertheless, the aerodynamic component plays a relevant role as it seems to
be the responsible for the shortest pulses. It is also interesting to point out
that the aerodynamic component also shows an increasing long-term trend in
the three analyzed regions.

The trend in the radiative component is consistent with the global dim-
ming/brightening. A decrease in the solar radiation in the decades previous to
the 1980’s was followed by an increase in the solar radiation after that date.
Both changes in aerosols and cloud cover guide this process, with relative im-
portance of each factor changing from one region to another (Wild, 2009). Al-
though sunshine duration was used as a proxy of the solar radiation in the
SPETO database (Tomas-Burguera et al., 2019), it could be possible to detect
the effects of this process in the obtained radiative component and $ET_o$. This
coincides with Sanchez-Lorenzo et al. (2009), who showed that dimming and
brightening processes were well captured by sunshine duration data in Spain.
In Spain, dimming is characterized by a discrepancy between sunshine dura-
tion and cloud cover trends (Sanchez-Lorenzo et al., 2009, 2012), suggesting
that dimming is guided by changes in aerosols. On the other hand, the pos-
terior recovery in the radiation (global brightening) was showed to be highly
influenced by a decrease in cloud cover in Spain (Mateos et al., 2014) as well
as in the Mediterranean area (Sanchez-Lorenzo et al., 2017) and in Europe
(Wild et al., 2009). In addition, the relation between the atmospheric evap-
orative demand and dimming/brightening was previously proposed in Greece (Papaioannou et al., 2011), Austria (Düthmann and Böschl, 2018) or Great Britain (Robinson et al., 2017). It is worth mentioning that the radiative component of the Penman-Monteith equation is also influenced by temperature and wind speed. However, we hypothesize that these two variables play a more relevant role in the trends of the aerodynamic component than in the trends of the radiative component.

The aerodynamic component also plays a key role to correctly assess the trends of ET$_{o}$ (Irmak et al., 2012; McVicar et al., 2012; Vicente-Serrano et al., 2020). This relevance increases in warm and dry regions like Spain, as the combination of high temperature with high vapor pressure deficit increases the role of the aerodynamic component (McKenney and Rosenberg, 1993). The trend of the aerodynamic component depends on the combination of the trends of air temperature, air humidity and wind speed, which results in a complex situation. However, the impact of air temperature and air humidity is commonly assessed via the vapor pressure deficit, which globally showed an increase as a consequence of global warming (Wang et al., 2012; Yuan et al., 2019), therefore contributing positively to the trends of the aerodynamic component. Nevertheless, in many regions of the World wind is the most influencing variable regarding the role of the aerodynamic component. This is mainly because the wind stilling, which is a process that caused a decreasing trend in wind speed during the last decades, proved to guide the decrease of the atmospheric evaporative demand in many regions (Jiang et al., 2019; McVicar et al., 2012; Roderick et al., 2007; Zhang et al., 2007). In Spain this counteracting effect also exists. While the increase of air temperature (del Río et al., 2006; Gonzalez-Hidalgo et al., 2016) and the decrease in the relative humidity (Vicente-Serrano et al., 2014a) contribute to increasing the aerodynamic component, the decrease in wind speed (Azorin-Molina et al., 2014) contributes to its decrease. However, in the long-term, the effect of air temperature and relative humidity prevail and the aerodynamic component shows a long-term increase. The situation is more complex when the alternation between negative and positive pulses in the short-term trends has to be explained. Interestingly, the first alternation of decreasing and increasing pulses of the aerodynamic component of the 1960’s and the 1970’s is in accordance with the alternation of temperature trends detected by Gonzalez-Hidalgo et al. (2016). Nevertheless, running trend analysis of the other variables are missing yet. For future scenarios the situation of the aerodynamic component could be even more complex, as changes in CO2 also implies changes in the surface conductance (Yang et al., 2019b), which is commonly assumed as constant.

To conclude, the analysis of ET$_{o}$ using the new SPETo database showed the non-stationarity of the trends of ET$_{o}$ and the differences in the role of the two components. While the trends of ET$_{o}$ are commonly assessed as monotonic trends, the results of this work reveals that future studies should focus on the non-stationarity of these trends. Furthermore, unraveling the role of each climate variable in these trends should be prioritized in future research. Finally, the detection of high relative trends in spring (March and April) and early summ-
mer (June) could be very relevant for crops and ecosystems, and further research should also focus on this specific point.

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Figure 1: Topography of the study area with most important rivers and basins of the Continental Spain (a) and the three different regions considered in this study (b).
Figure 2: Annual (a) and seasonal mean values of ET₀ for the 1981-2010 period. Winter (b), spring (c), summer (d) and autumn (e).
Figure 3: Percentage contribution of radiative component (a) to annual ET$_s$. Whisker plot of the radiative (Ra) and aerodynamic (Ae) seasonal values (b).
Figure 4: Interannual variability of annual (a) and seasonal values of ET₀ for the 1981-2010 period in terms of coefficient of variation. Winter (b), spring (c), summer (d) and autumn (e).
Figure 5: Interannual variability of radiative (a) and aerodynamic (b) components of ET$_o$ for the 1981-2010 period in terms of CV.
Figure 6: Magnitude of the linear trend of the annual ET\textsubscript{o} (a), radiative (b) and aerodynamic (c) components over the period 1961-2014. Black dots represent statistical significant trends at p-value<0.05 and at spatial resolution of 20 km.
Figure 7: a) Temporal evolution of annual ET$_o$ for three different regions and b) trend slope of annual ET$_o$ for three different regions and different periods. Black dots represent statistically significant trends (p-value<0.05).
Figure 8: a) Temporal evolution of aerodynamic (AE) and radiative (RA) components of $ET_o$ for three different regions and b) trend slope of annual AE and RA components of $ET_o$ for three different regions and different periods. Black dots represent statistically significant trends (p-value<0.05)
Figure 9: a) Temporal evolution of seasonal ET$_o$ for three different regions and b) trend slope of seasonal ET$_o$ for three different regions and different periods. Black dots represent statistically significant trends (p-value < 0.05).
Figure 10: Relative trends of monthly ET$_o$ over the period 1961-2014.
References


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