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Spatio-temporal changes of the climatic water balance in Romania as a response to precipitation and reference evapotranspiration trends during 1961–2013

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ABSTRACT

Changes in precipitation (P), evapotranspiration (ET) and, implicitly, in the climatic water balance (CWB), are imminent effects of climate warming. However, changes in the CWB, as a response to changes in P and ET, have not yet been analysed thoroughly enough in many parts of the world, including Romania. The present study explores the spatio-temporal changes of the CWB (difference between P and reference evapotranspiration, ET_o) in Romania, based on a wide range of climatic data (P, as well as temperature, relative air humidity, sunshine duration and wind speed, necessary for computing ET_o with the FAO-56 Penman-Monteith method) recorded at 70 weather stations across the country in the 1961–2013 period. As a secondary objective, the study attempts to identify the possible connections between the index's trends and large-scale atmospheric circulation, assessed based on the dynamics of certain European-scale relevant teleconnection indices. Thus, the Mann–Kendall test and *Sen's slope* methods were used to analyse CWB trends (but also P and ET_o trends, in order to explain CWB pattern changes) annually, seasonally and in the maize and wheat growing seasons. Also, the Spearman correlation procedure and a composite analysis between interannual series of teleconnection indices and CWB were used to assess the influence of atmospheric circulation on the index's variability for all analysed time scales. The results generally showed CWB decreases (for the most part of up to −2 mm/yr, yet with a relatively low statistical significance) and highlighted an overall amplification of drier conditions on all time scales, except for autumn (CWB increases, generally of up to 1 mm/yr, but with low statistical significance). Moreover, net changes of even under −200 mm/53 yrs annually and −175 mm/53 yrs in summer and for the maize and wheat growing seasons were found in the CWB. Spatially, it was found that the country's southwestern and southeastern regions are the main epicentres of drier trends, while the northwest appears to have become wetter. Overall, the negative CWB trends are due to partial P decreases (statistically insignificant) and general ET_o increases (highly statistically significant, even 100% in summer). It seems that the amplification of the climatic water deficit across the country is especially linked to the positive phases of the Arctic Oscillation and North Atlantic Oscillation, but also, in part, to those of several other teleconnection indices that affect Europe. Our results signal the necessity to adapt anthropic and ecological systems to future dryness trends countrywide, which will most likely intensify against the background of climate change expected to occur by the end of the century.

1. Introduction

We are living in the climate change era, which is one of the greatest environmental challenges of our time. While the increase in mean global temperatures has reached ~0.9 °C since the beginning of the 20th century (IPCC, 2013), global warming, the most important type of climate change, is particularly alarming when considering temporal and spatial differences of temperature pattern changes. For instance, the

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increase rate of mean global temperatures doubled after 1979 over land compared to ocean areas (Diffenbaugh and Field, 2013), anthropic systems and terrestrial ecosystems therefore becoming all the more vulnerable to this environmental perturbation. However, the most important threat of increasing temperatures in this century consists of the interaction between the atmosphere and other Earth systems possibly triggering positive feedbacks. Instances of numerous global warming autoacceleration mechanisms (e.g. snow cover decline in the arctic region that will trigger additional warming by drastically reducing albedo, or boreal forests dieback/permafrost thawing that will release large amounts of carbon/methane into the atmosphere, thus amplifying the greenhouse effect) have been well documented (Lenton et al., 2008). Theoretically, these positive feedbacks could generate an increase in mean temperatures of up to 6 °C for doubled CO_2 in the atmosphere (Hansen et al., 2008). This hypothetical scenario can however become highly unlikely if governments worldwide manage to rapidly curb down CO_2 emissions, according to the Paris Agreement that aims to stabilize warming under the 2 °C threshold throughout this century, relative to preindustrial levels (Fawcett et al., 2015).

Global warming itself is a major driving force of many environmental changes, including precipitation (P) and evapotranspiration (ET). In a warmer world, the entire Earth's water cycle changes as a result of the overall increase in rainfall, surface evaporation and plant transpiration (or evapotranspiration). However, there currently are numerous differences between such changes occurring in various global regions – certain global land areas are experiencing an increase in atmospheric humidity, while others are becoming increasingly dry (IPCC, 2013). While the additional energy that warming adds to the climate system is already activating in many regions of the globe (e.g. in the tropics) a higher amount of water in the atmosphere that influences precipitation amounts (IPCC, 2007), the net changes of the atmospheric water cycle also depend on ET dynamics. Although a warmer atmosphere will cause ET to increase especially in terrestrial areas with significant water content, the state of affairs can become significantly more complicated in a possible future scenario with higher amounts of atmospheric carbon, where plants will be likely to transpire less due to the decrease in stomatal conductance (against the background of atmospheric CO_2 excess) and, implicitly, to the decrease in the gas exchange between the biosphere and atmosphere (Bonan, 2008).

Over the past decades, significant changes in P and ET (or in climatic water balance – CWB, computed based on P and ET values) have occurred across the globe. After 1951, an apparent overall increase in annual P amounts was noted in the mid- and higher-latitudes of Northern (e.g. in the United States or in central-northern region of Europe) and Southern (Argentina and northern Australia) Hemispheres (IPCC, 2013). However, in the same period and at the same time, decreases in P amounts were recorded in Mediterranean Europe, the Sahel region, southern and eastern Africa, eastern and, in part, southeastern Asia and southeastern Australia. It can therefore be concluded that these regions experienced an increasingly intense overall humidity deficit, but, in order to obtain an accurate assessment of the climatic water deficit, ET trends must be taken into account as well, which have generally been recorded over a more recent period of time (after 1980) globally (Jung et al., 2010; Wang et al., 2010). However, based on the results of a relatively recent study that analysed global ET trends starting with the second half of the 20th century (Sheffield et al., 2012), it can be concluded that these lower P global areas have indeed experienced an intense water deficit, considering the overall increase in ET in most of the aforementioned regions.

In many instances, it is however difficult to conduct a general analysis of the CWB dynamics, in part due to the fact that ET trends are not necessarily positive in a warmer world, given the interferences of other causes (lower wind speed or decreased solar radiation in areas with higher aerosol concentrations) that appear to be responsible for the lower values this parameter has had in recent decades in many countries worldwide. Relevant examples that can illustrate this include the United States, China, India, Thailand or Australia (IPCC, 2007; Roderick et al., 2007; Fu et al., 2009). Moreover, it appears that, after 1998, soil moisture decreases in Southern Hemisphere were a major determining factor in slowing the increase of global ET (Jung et al., 2010), which highlighted other variables that can influence the ET regime on a large scale.

Advanced climate models suggest a significant possible future increase in global ET, which, despite a similar trend expected for precipitation, will strongly amplify the climatic water deficit in extensive global areas (Feng and Fu, 2013). Given these conditions, an expansion of arid environments is likely to occur especially in northwestern and southwestern North America, eastern Latin America, southern and central Europe, the Sahel region and southern Africa, eastern and northeastern Asia, and eastern Australia (Feng and Fu, 2013; Huang et al., 2016). Overall, it has been suggested that, by 2100, drylands (delimited based on the P/ET ratio) will cover as much as 56% of the global land area under the pessimistic scenario RCP8.5 (or 50% considering RCP4.5) (Huang et al., 2016), as opposed to their current share of 45%, according to the latest estimations (Prăvălie, 2016). Therefore, considering the far more aggressive expansion of land systems that will become drier compared to those expected to become wetter, it was suggested the unanimously acknowledged statement "dry gets drier, wet gets wetter" should be rephrased to "dry gets drier, but more than wet gets wetter" (Prăvălie, 2016).

The Mediterranean European region is therefore a past global hotspot of CWB change towards a humidity deficit, as certain studies directly or indirectly signalled the increasing aridity in various countries such as Spain (Vicente-Serrano et al., 2014), Italy (Colantoni et al., 2015) and Greece (Nastos et al., 2013). It is at the same time a projected epicentre of these drier trends, which also reaches the southeastern region of the continent, where Romania is located (Gao and Giorgi, 2008; Cheval et al., 2017). One of the major economic and ecological implications of these restrictive and persistent climatic conditions relate to the extensive land degradation in numerous countries in southern and southeastern Europe, including Romania (Prăvălie et al., 2017a).

Over the past ~50 years, Romania has experienced various forms of climate change (Busuioc et al., 2010; Ionita et al., 2013; Cheval et al., 2014; Marin et al., 2014; Spinoni et al., 2014; Dumitrescu et al., 2015; Croitoru et al., 2016a; Prăvălie et al., 2016a), including changes in key P (Marin et al., 2014; Dumitrescu et al., 2015; Croitoru et al., 2016b) and ET (Croitoru et al., 2013a) parameters. While national annual precipitation amounts generally remained stable (trends without statistical significance), except for certain areas in the northwest/southeast where statistically significant positive/negative trends were recorded (Marin et al., 2014), ET values had different dynamics. A relatively recent analysis showed that, after 1961, the parameter's trends have been largely positive and, for the most part, statistically significant (Croitoru et al., 2013a). Although based on this reasoning it can be indirectly deduced that, in Romania, the CWB evolved towards deficit values, this hypothesis is uncertain considering that, to date, no concrete national statistical analyses have been conducted on this index's dynamics.

Such country-wide analyses are essential for the management of agricultural systems, water resource planning or for adapting ecological systems to future climate change. In fact, many anthropic and natural systems are already vulnerable to CWB changes. For instance, it was proven that agricultural crops in several parts of the Romanian Extra-Carpathians region have lately had lower yields against the background of an amplified climatic water deficit (Prăvălie et al., 2014a; Prăvălie et al., 2016b). Other studies also signalled lower streamflow rates in numerous catchments countrywide, especially during summer, when the climatic water deficit has grown constantly over the past decades (Birsan et al., 2014). These examples signal, directly or indirectly, the importance of the CWB as a regulating variable in the dynamics of natural processes or anthropogenic activities. However, in order to analyse similar connexions in future interdisciplinary studies, it will be