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Variation of reference evapotranspiration in the central region of Argentina between 1941 and 2010

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ABSTRACT

Study region: Changes in reference evapotranspiration (ET_o) may have important consequences for agricultural suitability in the central region of Argentina. Annual ET_o variation was assessed, in terms of both territory and time, for the 7 decades between 1941 and 2010, analyzing the behavior of the 4 atmospheric variables which determine it: temperature, vapor pressure, wind speed and cloud cover.

Study focus: The influence of each variable on ET_o was evaluated from a multiple regression model and a simple correlation analysis, using climate data from the observation network, and repeating this analysis using interpolated variables. In this grid scheme, linear relationships were determined between ET_o and the different key atmospheric variables, plus precipitation (PP), and the *t* test was applied to establish the statistically significant sectors ($P < 0.1$). Then, those areas with a significant trend change ($P < 0.1$) were determined by the Mann–Kendall test. Finally, the interception of the grids was performed to establish their joint occurrence.

New hydrological insights for the region: Most of the region analyzed (>91%) presents a non-significant variation of ET_o over time, with a mostly non-significant change of each driving variable, regarding both its relationship with ET_o and its own trend of change. The beneficial change in agricultural suitability reported for this water-limited region was found to be produced almost exclusively by increasing PP.

1. Introduction

The worldwide rise in air and ocean temperatures, widespread melting of snow and ice and increased sea levels are evidence of climate system warming in recent decades (Bates et al., 2008). Despite the close link between the energy balance and the water budget, however, while the rate of atmospheric evaporative demand has increased in some regions, matching the warming (Tabari et al., 2011), Hobbins et al. (2004) paradoxically reported decreasing rates in other territories (Bandyopadhyay et al., 2009; Chattopadhyay and Hulme, 1997; Xu et al., 2006). Changes in evapotranspiration (ET) are of great importance because this is not only one of the components of the hydrological cycle in a region (Wang and Dickinson, 2012), but also has a direct impact on agricultural suitability (de la Casa and Ovando, 2014). Knowledge of ET variations in time and space is crucial for understanding the interactions between different vegetation covers and the atmosphere (Keane

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et al., 2002), better managing a territory's water resources (Raupach et al., 2009), or assessing the phenomenon of drought and its associated environmental impacts (McVicar and Jupp, 1998).

The evaporative demand of the atmosphere, represented either by the potential ET (PET) (Penman, 1948; Thornthwaite, 1948) or the reference ET (ET_o) (Allen et al., 1998, 2006), is a complex biophysical process influenced by four major meteorological variables: net radiation, vapor pressure, wind speed and air temperature (Donohue et al., 2010). A conceptual entity more than an operative one, the PET or ET_o (hereinafter ET_o only) is difficult to measure directly, and so different calculation methods have been developed, for models with one or more of these variables. Comparing the performance of different predictive models that estimate ET_o, Penman's combined method with the use of this complete set of variables was the one that produced the most convincing estimates of the dynamics of potential evaporation (Donohue et al., 2010).

In a comprehensive review of trends in global rates of evaporation and evapotranspiration, McVicar et al. (2012) argue that these generally tend to decrease, mainly due to the aerodynamic component (resulting from the combined effects of wind speed (u_2) and vapor pressure (e_a)) and, secondly, as a result of changes in the radiative component. Through a worldwide meta-analysis, they consider it very likely that decreased u_2 is widespread, although, in order to assess its influence on ET_o reduction, they argue the need to comprehensively analyze the variation of the four major meteorological elements involved in atmospheric water demand.

There have been numerous changes in weather conditions worldwide during the twentieth century, shown by long-term trends in global average air temperature (Trenberth et al., 2007), vapor pressure (Durre et al., 2009), precipitation (New et al., 2001), net radiation (Wild, 2009) and wind speed (McVicar et al., 2010, 2012). In Australia, both temperature and precipitation have increased on average in the last 3 or 4 decades (Bureau of Meteorology, 2007), as well as vapor pressure, while wind and net radiation have decreased (Roderick et al., 2007; McVicar et al., 2008). All these atmospheric changes may explain changes in evaporative demand (Donohue et al., 2010).

The relative importance of the four primary meteorological variables that control the trend of evaporative demand may change both absolutely and relatively, and very probably vary both spatially and temporally. Tang et al. (2011) determined that the decline in ET_o in the Haihe River Basin in China can be attributed to variations of net radiation, e_a, u_2 and temperature (T). While the increase in temperature determines a significant increase in ET_o over time, the negative rates of the other variables that regulate the process explain the general negative trend of ET_o. Thus, Zheng et al. (2009) interpret the paradox of pan evaporation in the Haihe River Basin, noting that, while the increase in temperature may have increased evaporation, this was offset by the decrease in wind speed and solar radiation, combined with the increase of water vapor pressure in the region.

One of the main advantages of Penman's method is its ductility to represent atmospheric water demand under different climatic conditions and to translate the complex combination of the constituent elements. Among the disadvantages, the model presents operational difficulties in terms of the availability of information needed for its implementation. This is exacerbated when seeking to simultaneously evaluate the temporal and spatial variation of ET_o, since meteorological networks change over time with the appearance and disappearance of some stations, or because the availability of instruments is not uniform, etc. Recognizing this difficulty, Irmak et al. (2012) developed a method for estimating the full set of variables required to calculate Penman-ET_o, using only daily values of maximum temperature (T_{max}), minimum temperature (T_{min}) and precipitation (PP). The ET_o obtained in this way for Platte River Basin (Nebraska, USA) presented a linear trend of $-0.36\,\text{mm}\,\text{yr}^{-1}$ between 1893 and 2008, a decline that was attributed to a significant increase in PP (100 mm during the same period), reducing solar and net radiation.

In a study of agricultural potential variation in the central region of Argentina, de la Casa and Ovando (2014) consider that the greatest potential at present can be attributed to increased precipitation since the 1940s. In contrast, the change of ET_o was not significant in more than 90% of this territory and, where it was significant, the variation was ambiguous because in some sectors the trend is positive and in others negative.

To further analyze ET_o behavior in the central region of Argentina, a territory that is limited in its evaporative capacity primarily by water availability (Donohue et al., 2007), this study evaluates ET_o variation between 1941 and 2010. The temporal and spatial changes in atmospheric demand are assessed through the variation of the four meteorological variables responsible (T, e_a, u_2 and cloud cover (N)) and also of PP. In addition to assessing the influence of using cloud cover instead of sunshine duration to determine radiation balance, the analysis proceeds in two spatial scales: local, which strictly uses meteorological data recorded by the observation network, and the other regional, with information obtained from a process of geographic interpolation.

2. Materials and methods

2.1. Data

The climate data used in this study were provided by the National Weather Service of Argentina (Smn, 1958, 1975, 1981, 1986, 1992, 2007, 2012 the last 2 series published digitally). These statistics present monthly mean values of weather variables for a ten-year period, with a complete series from 1941. Thus, time series of climatic values were available for 7 consecutive periods (i.e., 1941–1950, 1951–1960, 1961–1970, 1971–1980, 1981–1990, 1991–2000 and 2001–2010). Fig. 1 shows the study area in the central region of Argentina, with the geographic location of the weather stations used in the period 2001–2010, and Table 1 shows the list of weather stations from which data were used in each decade.