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FOREWORD: DROUGHT COMPLEXITY AND ASSESSMENT UNDER CLIMATE CHANGE CONDITIONS

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Drought is one of the most complex climate hazards, affecting several natural systems and socioeconomic sectors (Wilhite, 2000). This makes that although several studies have focused on droughts conceptual issues (Wilhite and Glantz, 1985), it is really impractical to establish an unique definition of this phenomenon (Lloyd-Hughes, 2014). Drought is usually detected when an impact is recorded. It may refer to damages in agriculture (crop yield reductions), ecological impacts (tree decay and/or mortality), but it may also be related to a hydrological dimension, associated to reductions in streamflow, reservoir storages or groundwater decreases (Van Loon, 2015). Drought conditions in different systems may coincide or not in space and time, which makes even more complex the drought characterization and analysis.

There are several problems for drought quantification. Drought is usually recognized by the impacts that drought produces in a variety of sectors, but in opposition to other hydroclimatic hazards, droughts cannot be directly measured by any instrument. There is not a unique variable that may provide an absolute assessment of the drought severity in a region given the multidimensional character of droughts. An important characteristic of drought is that may occur on different time-scales. In recent years the concept of time scales has been widely used by drought scientists, and it is explained in several reports [e.g., the pioneer study by McKee *et al*. (1993)]. This term allows taking into account the different periods from the arrival of water inputs to availability of a given usable resource. This was illustrated by Changnon and Easterling (1989), showing that a precipitation anomaly propagates to soil moisture levels, runoff, streamflow, groundwater, lakes, etc., in a very different way. Thus, it is common to find drought conditions in a hydrological system, whereas other systems in the same region may have normal or even humid conditions. As a simple and illustrative example, four years of low precipitation will probably produce a severe hydrological drought in terms of river discharge and reservoir storages, but during the drought period high precipitation events may produce high levels of soil moisture. Drought usually occurs in only a part of the hydrological cycle and the use of methodologies to quantify drought severity on different time-scales is essential to cover this issue.

Given strong complexity of droughts, the assessment of drought severity is usually based on climatic information (e.g., Sheffield *et al*., 2012), since the origin of most drought events is related to the climate variability. For these reasons, and also given the available climate information with a wide spatial and temporal perspective, drought trend analyses have been usually based on climatic drought indices, which try to be synthetic measures of drought severity that are calculated using time series of different climate variables, mainly precipitation (McKee *et al*., 1993) or precipitation and the atmospheric evaporative demand (Vicente-Serrano *et al*., 2010). A number of the so called "drought indices" has been developed to quantify this phenomenon, and to know the onset, end, duration, magnitude and spatial extent of individual drought events (e.g., Heim, 2002). In general, these indices are good proxies to determine drought conditions in a variety of environmental, hydrological and agricultural systems (Vicente-Serrano *et al.,* 2012).

In relation to the variables that determine drought, precipitation deserves independent mention given its primary importance to define drought severity. Nevertheless, under the current global warming scenario other meteorological variables may be gaining importance in the drought occurrence. Climate change is not only characterized by strong temperature rise (Hartmann *et al*., 2013), but it also affects the evolution of other climate elements like cloudiness and sunshine duration (Wild *et al*., 2013), the atmospheric water content (Willet *et al.,* 2014) and wind speed (McVicar *et al.,* 2012a). Evolution of all these elements should be considered together to understand current climate change effects on drought severity (McVicar *et al.,* 2012b).

The impact of a reduction in precipitation on drought severity is evident. Whereas, much less is known on the possible effects of the other major climate component of drought severity, i.e. the Atmospheric Evaporative Demand (AED). Observations show that AED may show contrasting trends among regions and periods as a consequence of the evolution of the different climate factors that control this variable. Some studies suggest that the vapour pressure deficit, (i.e. the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated, and determined by warming processes and available air humidity), is driving the evaporative demand of the atmosphere, mainly in semiarid regions (Wang *et al*., 2012). Other studies have argued that the effect of climate warming on AED is minimal, and other meteorological variables (including solar radiation and wind speed) are more important (Roderick and Farquhar, 2002; McVicar *et al.,* 2012a). Brutsaert (2006) indicated that current AED processes may not be linked to any individual process, and their changes are partially attributed to modifications in solar irradiance, relative humidity and wind speed changes. Therefore, there are strong uncertainties in current AED trends and their driving factors worldwide and given these uncertainties, it is not surprising to find no consensus on the evolution of drought severity in the last decades under a global warming scenario. Thus, the most recent IPCC report on climate extremes indicates only low-to-medium confidence of drought trends at the global scale (Seneviratne *et al.,* 2012). For example, Sheffield *et al.* (2012) used two different methods to estimate the AED at the global scale, and showed very different results, stressing the limitations of using temperature-based methods to estimate the AED and the need of considering the whole aerodynamic and radiative components of the reference evapotranspiration. Moreover, Van der Schrier *et al*. (2013) showed that uncertainties in drought severity trends are not only related to the AED methodology but to the use of different calibration periods to calculate drought indices. The different sensitivity of the available drought indices to the precipitation and the AED is also another source of uncertainty (Vicente-Serrano *et al*., 2015), and finally the quality of the long-term climate information available at the global scale (Trenberth *et al.,* 2014). All these problems stress the need of working with high quality data to increase the goodness of drought severity trends, being this possible only at the regional scale. An example of the evolution of drought severity based on high quality and homogenized data of the different variables necessary to obtain accurate evolution of the AED is found in the Iberian Peninsula. In this region drought severity and the surface affected by drought has increased in the last decades associated to increased AED (Vicente-Serrano *et al*., 2014). The current availability of detailed studies with high-quality data is not enough to have definitive conclusions on recent drought trends at the global scale and more regional studies are needed.

In summary, there are still large uncertainties in the evolution of drought severity given the complexity of the drought phenomenon, the difficulties for drought quantification and the large existing data gaps for both objective drought quantification based on impacts and the assessment based on climate variables, mainly for the AED assessment. In any case, the results of regional studies from different areas of knowledge and the evidences related to an increase of the drought impacts suggest that the severity of drought may be increasing in recent decades as a consequence of global warming (Van Loon *et al*., 2016). The state-of-the-art climate change projections for the 21st century predict enhanced warming at the global scale with low uncertainty among models (Hartmann *et al*., 2013). It is expected that under these projections drought will be a more complex and severe phenomenon.

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