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A climatological assessment of drought impact on vegetation health index

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ABSTRACT

The Vegetation Health Index (VHI) has been widely used for monitoring and characterising droughts. This index takes into account ecosystem features in terms of fluctuations between prescribed maxima and minima of NDVI (Vegetation Condition Index, VCI) and of Land Surface Temperature (LST; Thermal Condition Index, TCI), and is estimated as the weighted sum of these two contributions. Since there is no a priori knowledge about vegetation and temperature contributions, VHI is typically taken as the average of both contributions, i.e., a weight of 0.5 is assumed. In this work climatologies of NDVI and LST – spanning the period between 1982 and 2009 – are used to estimate VCI, TCI and VHI on a Mediterranean geographic window, which are then correlated with the multi-scalar drought indicator SPEI (Standardized Precipitation-Evapotranspiration Index) with the aim of assessing the effect of drought on each contribution. Results of the correlations between VCI-SPEI and TCI-SPEI show that the relative contributions of VCI and TCI to vegetation health depend on vegetation cover: the effect of drought is more evident in the case of VCI in semiarid climate classes (regions where the limiting factor to vegetation growth is water); while the effect of drought is more obvious in TCI for moistier climate classes (regions where the limiting factor is solar radiation). This leads to the conclusion that by maximising the correlations between VHI and SPEI, over a climatological period, it is possible to evaluate the relative roles of VCI and TCI to VHI for different climate regions.

1. Introduction

Drought episodes are a recurrent feature of climate with a wide-range of impacts on the planet and society (Klos et al., 2009; Mishra and Singh, 2010; Phillips et al., 2009; Wilhite et al., 2007). Droughts rank among the deadliest (Hillier and Dempsey, 2012) and costliest (Cook et al., 2007; Ding et al., 2011) of all natural disasters. Moreover, the observed intensification of evaporative demand associated with the impacts of climate change on temperature and precipitation regimes, have contributed to a widespread increase in drought severity (Dai, 2012; Diffenbaugh et al., 2015; Trenberth et al., 2013; Vicente-Serrano et al., 2014). However, a universally accepted definition of drought is still missing (Mishra and Singh, 2010; Smakhtin and Schipper, 2008; Wilhite and Glantz, 1985), which contributes to an even more difficult monitoring of drought episodes and the assessment of their severity. Thus, there is a growing need for a better understanding of the various aspects of drought events that help consolidating monitoring strategies.

The Mediterranean region is known for its vegetation dependence on water availability (Gouveia et al., 2009; Lindner et al., 2010). This region is commonly characterised by a Mediterranean climate (Strahler, 1975, Lionello et al., 2006, Bolle et al., 2006) where, under normal conditions, water availability is low and water demand is high (sometimes surpassing the former). In these regions, the increase of temperature together with the decrease of precipitation will enhance evapotranspiration rate (Hartmann et al., 2013; Iglesias et al., 2009). Also, large areas in this region are dedicated to agriculture, implying a strong consumption of water supplies (Hoerling et al., 2012). Therefore, the role of evapotranspiration on drought frequency and severity has been assessed during the last decades over several areas of the Mediterranean region (Coll et al., 2017; Dai, 2012; Páscoa et al., 2017; Sheffield et al., 2012; Vicente-Serrano et al., 2014). Furthermore, according to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) major changes in the mean precipitation and its variability are projected over this area. When combining all these factors with the increased drought frequency observed over the region in the last years (Hoerling et al., 2012; Mariotti, 2010; Vicente-Serrano et al., 2014), the need for a proper drought monitoring over the Mediterranean basin becomes a key issue to be dealt with.

Several different indices have been developed during the last decades aiming at characterizing the different types of drought, namely meteorological, hydrological and agricultural droughts (Mishra and Singh, 2010; Zargar et al., 2011). The Palmer Drought Severity Index

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(PDSI) (Palmer, 1965), the Standardized Precipitation Index (SPI) (Mckee et al., 1993), and the more recent Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010) are worth being mentioned among others (Heim, 2002; Mishra and Singh, 2010). SPEI was specifically designed to assess drought taking into account the climatic balance between precipitation and potential evapotranspiration (Beguería et al., 2014; Vicente-Serrano et al., 2010). Due to the inclusion of the effect of temperature, and therefore evapotranspiration, in drought assessment SPEI has revealed to be very useful for monitoring and characterizing drought in climate change context (Vicente-Serrano et al., 2010).

In the last years, remote sensing data have also been used for drought monitoring and drought index development (Gouveia et al., 2017; Kogan, 1997; Vicente-Serrano et al., 2015). Indeed, spaceborne observations allow the retrieval of both atmospheric and surface variables – from precipitation, to soil moisture, vegetation indices, amongst others – that have proven useful in this field (Lakshmi, 2017; Wardlow et al., 2012). The current availability of accurate satellite-based Climate Data Records (CDRs; Bento et al., 2017; Duguay-Tetzlaff et al., 2015; Martins et al., 2016) opens the way to the application of drought indices derived from remotely-sensed information at large spatial and temporal scales with the aim of better understanding the past behaviour of drought episodes and better anticipating the future.

The vegetation health index (VHI) (Kogan, 2001, 1997) is a widely used drought index based on remote sensing information (Bhuiyan et al., 2006; Kogan et al., 2012; Quiring and Ganesh, 2010; Singh et al., 2003). It consists of a linear combination of two components, namely the Vegetation Condition Index (VCI) incorporating information on the visible (VIS) and near infrared (NIR) portions of the electromagnetic spectrum and the Thermal Condition Index (TCI) relying on the thermal infrared (TIR). The VCI component is commonly estimated using the Normalized Difference Vegetation Index (NDVI) and aims to account for the vegetation water stress; the TCI, in turn, is used to assess the temperature stress of vegetation and is estimated based on either top-of-atmosphere brightness temperature or on Land Surface Temperature (LST). The rationale behind the formulation of VHI rests over the following two assumptions:

i) VHI is defined such that the lower the NDVI and the higher the LST, the poorer is vegetation health;
ii) Since there is no a priori knowledge about vegetation and temperature contributions to vegetation health, the latter index is commonly computed by simply averaging VCI and TCI.

The first assumption was verified in a number of studies focusing regions located in Mongolia and the USA (Karnieli et al., 2010, 2006; Sun and Kafatos, 2007). Results indicate that the way LST and NDVI contribute to vegetation health depends on location, season and vegetation type. For instance, a concurrent contribution of both variables was found when the limiting factor for vegetation development is solar energy (typically at high latitudes and elevations), while opposite contributions occur where water is the limiting factor (typically at arid and semiarid regions).

The aim of this study is to assess the relative contribution of NDVI and LST when characterizing vegetation health over a Euro-Mediterranean region, composed of different ecosystems and vegetation landscapes. To accomplish that, VHI and its two components are correlated to SPEI at different time scales, in order to understand the response of vegetation to drought events over different biomes. VHI was chosen, as it allows the quantification of vegetation health under thermal conditions whereas SPEI was selected since it integrates the risen evaporative demand, as obtained through evapotranspiration. The relative contributions of NDVI and LST on vegetation health were then associated to the different aridity regions within the Euro-Mediterranean area.

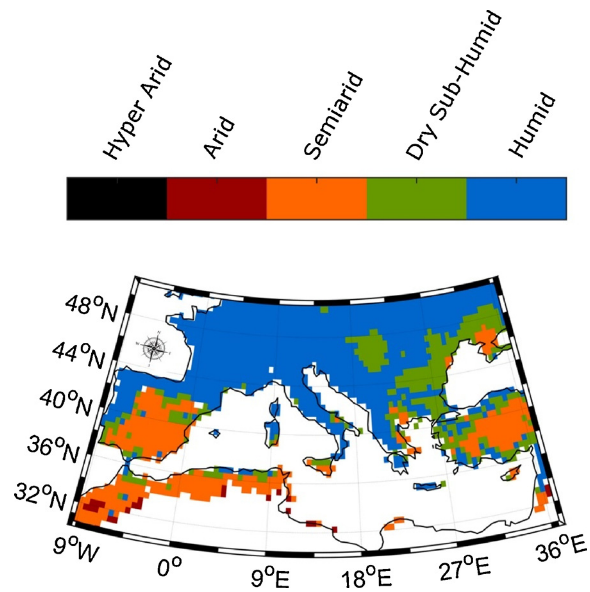

Fig. 1. Geographical domain of the study area over Europe. Colours represent the aridity index classes (based on the CGIAR-CSI Global-Aridity and Global-PET Database). Desert zones are masked (in white) according to the IGBP land cover.

2. Data

2.1. Study area

This work focuses on the Euro-Mediterranean region encompassed by the geographical window between 30.25 N–51.25 N and 9.75 W–37.25 E (Fig. 1). Desert regions were masked based on land cover data from the International Geosphere-Biosphere Programme (IGBP) (Loveland et al., 2000), while irrigated pixels were masked with the Advanced Along-Track Scanning Radiometer (AATSR) LST biome classification version 2 (ALB-2) derived from the Globcover classification (Ghent et al., 2017). Fig. 1 shows the aridity index (Zomer et al., 2008, 2006) from CGIAR-CSI Global-Aridity and Global-PET Database (http://www.cgiar-csi.org) – which uses estimates of evapotranspiration based on the Hargreaves equation (Hargreaves, 1994) – divided into different aridity interval values (UNESCO, 1979): hyper arid (< 0.03), arid (0.03–0.2), semiarid (0.2–0.5), dry sub-humid (0.5–0.65), and humid (> 0.65). The study area is characterised by an arid climate in some scattered pixels over north Africa; semiarid climate over north Africa, southern and eastern Iberia, central Turkey and southern Ukraine; dry sub-humid climate is to be found in some regions of north Africa (closer to the Mediterranean), Iberia, Turkey, Ukraine, and the Balkans region; and finally, humid climate, which is the prevailing climate in the area of study, spreads from northern Iberia to eastern Europe.

2.2. NDVI and LST

Data of NDVI (Myneni et al., 1995) were extracted from NASA/Goddard Space Flight Center's Global Inventory Modelling and Mapping Studies (GIMMS) Group (Tucker et al., 2005). With an 8-km spatial- and a bi-monthly temporal- resolution, the GIMMS NDVI dataset is the longest (starting in 1982) and most complete NDVI record available. It is widely used to assess both global and local vegetation dynamics and impacts of climate on the vegetation (Detsch et al., 2016; Ding et al., 2015; Fensholt and Proud, 2012).

NDVI data were linearly interpolated to a 0.5° spatial resolution. Then, a centred moving average, with a span of 3 bi-monthly values, was applied to remove high frequency noise. The NDVI trend associated