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Interactive Comment

Interactive comment on "A global analysis of the impact of drought on net primary productivity" *by* T. Chen et al.

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I have read: A global analysis of the impact of drought on net primary productivity by Chen et al. and the three reviews.

I am not going to make comments on the different issues related to the drought impacts on net primary production. In Vicente-Serrano et al. (2013) we made an extensive analysis and discussion on the drought impacts on worldwide vegetation using different parameters. Here I am going to respond to some of the reviewers which comment different issues related to the Standardized Precipitation Evapotranspiration Index (SPEI).

For example, reviewer 2 suggests the use of SPEI instead PDSI following Zhang and

Running (2010). In Vicente-Serrano et al. (2011) we reviewed the limitations of the PDSI for drought quantification and drought monitoring providing solid arguments for this (I include some paragraphs from that article):

"It is widely recognized that the PDSI has numerous deficiencies (e.g. Alley, 1984). Karl (1986) showed that the PDSI is highly affected by the selected calibration period. In addition, the parameters necessary to calculate the PDSI were determined empirically and mainly tested in the U.S.A., which restricts its use in other regions (see Akimremi et al., 1996). It has been shown that the PDSI is not spatially comparable because the weighted factors were obtained from data for nine climatic divisions in the U.S.A., which were aggregated at an annual level (Heim, 2002). Guttman et al. (1992) illustrated that severe or extreme drought events recorded by the PDSI are not spatially comparable, as the cumulative frequencies of the index vary spatially (Karl et al., 1987; Nkemdirim and Weber, 1999). Redmond (2002) noted that the creator of the PDSI, W.C. Palmer, did not intend or foresee significant use of the index beyond the Great Plains, in the central U.S.A. Other problems with the PDSI have been reported. Karl (1983) analyzed the sensitivity of the PDSI to the water field capacity parameter, and reported that areas of greater capacity are more likely to be affected by drought, in agreement with the findings of Weber and Nkemdirim (1998). Alley (1984) also noted subjectivity of the PDSI in terms of assigning real drought conditions to the values of the index."

"The problems of monitoring drought on different time scales are linked to deficiencies in the ability of the PDSI to make spatial comparisons. The problems of spatial comparability in the PDSI were clearly illustrated by Vicente-Serrano et al. (2010b), who investigated correlations of the PDSI at a global scale with different time scales of the SPEI. This showed large spatial variability because the PDSI represents water deficits at different time scales depending on the region under consideration. This was initially investigated by Guttman (1998), who showed that the spectral characteristics of the PDSI vary from site to site. In other words, the time scales of the PDSI and the sc-PDSI are not fixed because they depend on the characteristics of the sites and vary

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spatially, making it difficult to assess what kind of deficit the index is representing and making spatial comparisons between sites."

"One reason one cannot say that the PDSI is superior to the SPI and the SPEI is mainly because it lacks flexibility to adapt to the intrinsic multi-scalar nature of drought. 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 studies by McKee et al., 1993 and 1995; or Hayes et al., 1999)."

In Vicente-Serrano et al. (2013) we clearly detailed how vegetation is responding differently to drought time scales according vegetation types, aridity conditions, etc., Then, it is essential to consider a flexible drought index that can be calculated on different time scales to adapt the different times of response of vegetation types to water deficit. In a recent global comparison of different drought indices (SPEI, SPI and four version of the PDSI) we have showed the strong limitations of PDSI to identify drought impacts on forest growth, soil moisture, streamflows and crops worldwide in comparison to SPI and SPEI. Thus SPEI providing the best results at the global scale (see details in Vicente-Serrano et al. 2012).

Reviewer 3 made some criticisms to the SPEI:

1. There are areas on the globe where the monthly accumulated rainfall is less than the monthly accumulated potential evapotranspiration. This means that negative values are entered into the SPEI calculations. Can the authors comment on the physical realism of using negative net precipitation values in a drought index?

Addressed in Vicente-Serrano et al. (2011): "It has been argued that unrealistic water balances are obtained when Potential Evapotranspiration (PE) is used instead of actual evapotranspiration (E). This is especially the case when PE exceeds the water available in the soil, which limits the evapotranspiration rate. This would be a major shortcoming of the SPEI if the index was aimed at estimating the soil water balance, but this is not its purpose. On the contrary, the SPEI is defined in a relative way (in

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standardized units), and consequently the magnitude of PE is not relevant even if the difference between precipitation and potential evapotranspiration (P–PE) is negative. In other words, the SPEI measures deviations with respect to normal conditions of P-PE, and therefore the magnitude of this balance is of less importance. We see this as an advantage rather than a shortcoming. In fact, in using the PDSI it is assumed that when the soil water content is close to zero the magnitude of PE does not have an effect on the magnitude of drought. It could be argued, however, that increasing evapotranspiration demand when the soil water reserve is already minimal could have a very negative impact on plants. In other drought-vulnerable systems including surface water resources (rivers, lakes and reservoirs), it is known that increasing PE affects water loss by direct evaporation (Hostetler and Bartlein, 1990; Elsawwaf et al., 2010). The widely analyzed 2003 and 2010 summer droughts in Europe are excellent examples of how, independently of the available soil moisture, increased PE rates as a consequence of extremely high temperatures have a marked impact on vegetation activity, and in this case led to tree mortality and wild fires (Ciais et al., 2005; Lobo and Maissongrande, 2006; Granier et al., 2007; Barriopedro et al., 2011). Therefore, we consider that the use of PE estimates in the calculation of a drought index is very useful, has a theoretical justification, and it is an efficient and easy way to include the effect of evapotranspiration demand on a variety of systems."

2. The SPEI uses the Thornthwaite parameterization for potential evapotranspiration. This parameterization is only related to temperature (and the latitude of the grid square) while radiation is the principal factor in determining potential evapotranspiration. This can be justiïňĄed by observing that temperature data is much more abundantly available than radiation data, although the Climatic Research Unit also makes the more physically realistic Penman-Monteith-based estimate for potential evapotranspiration available. Nevertheless, the authors should comment on the use of the Thornthwaite parameterization and quantify (or discuss using results from the literature) where this parameterization overestimates or underestimates potential evapotranspiration.

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I agree with the comments by the reviewer. The original formulation of the SPEI was based on PET estimated by means of the Thornthwaite (Th) equation. Motivation for preferring the Thornthwaite equation was to avoid that data availability constrains, since it is one of the least data demanding methods requiring only mean monthly temperature values. Nevertheless, we were aware of the alleged deficiencies of the Thorthwaite equation to obtain reliable PET estimates. The Thorthwaite equation has been reported to underestimate PET in arid and semiarid regions while overestimating it in humid equatorial and tropical regions. As better is the PET estimates it is expected to have better SPEI values. The SPEI is not constrained to be obtained by the Th equation. Thus, in http://sac.csic.es/spei/tools.html there is available a R library to obtain SPEI using different PET parameterizations (Thtornthwaite, Hargrevaes –recommended by the FAO when data availability is low- and Penman-Monteith –according to different available data, see details in the help of the R package-). In addition, the SPEI global dataset from 1901 to 2011 is now created from monthly precipitation and potential evapotranspiration from the Climatic Research Unit of the University of East Anglia. Currently the version 3.2 of the CRU dataset has been used and the SPEIbase is based on the FAO-56 Penman-Monteith estimation of potential evapotranspiration from CRU (see details in http://sac.csic.es/spei/database.html). Currently there is a manuscript under review in which comare globally (using gridded adatasets and stations) the role of using different PET parametrizations on SPEI variability and trends.

3. The SPEI uses potential evapotranspiration rather than actual evapotranspiration. There is an inverse relation between these two in areas which are moisture stressed (). This will increase the potential evapotranspiration. How does this phenomenon inïňĆuence the results of this paper?

This is partially addressed above: increased evaporative demand by the atmosphere under low soil water availability is increasing plant water stress. Moreover, in Vicente-Serrano et al. (2011) we also widely discussed limitations of using actual evapotranspiration given low accuracy of estimations: “Many believe that the soil water balance

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cannot be accurately simulated using only climatic data and the soil water capacity, while completely neglecting other soil properties and the complex role of vegetation in the calculation of E. In practice, the PDSI cannot be considered a robust water balance model as it oversimplifies soil surface hydrological processes. The best way of obtaining accurate soil water balance calculations is by using highly complex physically-based hydrological models such as TOPMODEL (Beven, 1997), TOPKAPI (Ciarapica and Todini, 2002), or RHESSys (Tague and Band, 2004). Moreover, soil-moisture estimations are very complex and model dependent (Mo, 2008), which makes the multi-model soil moisture estimates more confident than using just a single model (Wang et al., 2009). State-of-the-art models including the above typically require a high degree of parameterization to provide accurate estimates of the soil water balance, and its horizontal and vertical distribution over a catchment. The parameters include the soil saturated hydraulic conductivity and porosity, factors that influence the water balance (including topography, surface roughness), and the physiological and phenological characteristics of the vegetation. In contrast, the PDSI only requires the water field capacity. Despite the parsimony of the PDSI, available information on soil water capacity is very poor; this has led to the use of inaccurate values when applying the PDSI in most regions of the world. Therefore, the PDSI is affected by both model uncertainty and the propagation of input data errors. Because of over-simplification of soil water processes in the PDSI, it has been reported that climatic components (precipitation and potential evapotranspiration) explain most of the spatial and temporal variability of the index. This explains why numerous reports have been made of strong correlations of the PDSI with the SPI and SPEI at various time-scales (e.g. Guttman, 1998; Redmond, 2002; Ntale and Gan, 2003; Ceglar and Kajcef-Bogataj, 2008; Vicente-Serrano et al., 2010b), which show that the PDSI behaves more as a climatic drought index than a measure of soil water balance. It is important to appreciate that E, which is a very difficult variable to measure, cannot be accurately computed using a simplistic water balance model like the PDSI. Although specific instrumentation (e.g. lysimeters and eddy-covariance towers) is available, the measurements are usually highly depen-

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dent on very specific characteristics of the plant cover (e.g. type of vegetation, root depth, sap flow, stomatal conductance), and the strategies and efficiency of vegetation physiological mechanisms to cope with water stress (McDowell et al., 2008). Therefore, the reliability of estimates of E at regional scales, only using climate data, is quite low. The calculation of distributed E values is commonly based on remote sensing data because it accounts for the vegetation cover and type, which are the main variables involved in the determination of E (e.g. Bastiaanssen et al., 1998; Jacob et al., 2002; Zhang et al., 2010). Although some models combining climatic, hydrological and plant physiology information have been proposed to provide estimates of E, their use is limited because of the high degree of uncertainty in the simulation of water consumption by vegetation (e.g. Choudhury and DiGirolamo, 1998; Morales et al., 2005; Alton et al., 2009). In addition, even with application of the most complex procedures the models typically consider vegetation cover to be static, and do not incorporate vegetation cover changes, which are common and can occur abruptly (deforestation, forest fires, reforestation, desertification, irrigation), markedly affecting the magnitude of E. Given the difficulties in accurately estimating E, an operative way to incorporate the effect of evaporative demand on drought indices is to use an estimate of the potential evapotranspiration (PET) from empirical or physical models."

More details about the potentials and limitations of the SPEI, tools and datasets can be found at the SPEI site (http://sac.csic.es/spei/index.html) and in different articles:

Vicente-Serrano S.M., Santiago Beguería, Juan I. López-Moreno, (2010) A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index – SPEI. Journal of Climate 23: 1696-1718.

Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I., Angulo, M., El Kenawy, A. (2010): A new global 0.5° gridded dataset (1901-2006) of a multiscalar drought index: comparison with current drought index datasets based on the Palmer Drought Severity Index. Journal of Hydrometeorology. 11: 1033–1043

Beguería, S., Vicente-Serrano, S.M. y Angulo, M., (2010): A multi-scalar global drought data set: the SPEIbase: A new gridded product for the analysis of drought variability and impacts. Bulletin of the American Meteorological Society. 91, 1351-1354

Vicente-Serrano, S.M., Beguería, S. and Juan I. López-Moreno (2011). Comment on "Characteristics and trends in various forms of the Palmer Drought Severity Index (PDSI) during 1900-2008" by A. Dai. Journal of Geophysical Research-Atmosphere. 116, D19112, doi:10.1029/2011JD016410

Vicente-Serrano, S.M., Santiago Beguería, Jorge Lorenzo-Lacruz, Jesús Julio Camarero, Juan I. López-Moreno, Cesar Azorin-Molina, Jesús Revuelto, Enrique Morán-Tejeda and Arturo Sánchez-Lorenzo. (2012) Performance of drought indices for ecological, agricultural and hydrological applications. Earth Interactions 16, 1–27.

The different references cited in this comment can be consulted in Vicente-Serrano et al. (2011).

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