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Interactive Comment

Interactive comment on "Global trend analysis of the MODIS drought severity index" *by* P. I. Orvos et al.

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Reply to the comments

We thank the careful reading of the manuscript and the supporting general comments. Please find here our responses to the critical remarks. For the sake of clarity, we quote the related sentences of the Referee in italic.

"(1) When introducing the DSI data set, please spend some words on what high/low index values mean in terms of drought conditions. Since DSI is no "classical" drought index, the corresponding information would be helpful to easier assess what the trends observed in this study actually mean (...)."

Indeed, the interpretation of this DSI is not an easy task, therefore we increased substantially the description of the index in the second Section (Data and methods), as follows.

"In order to better exploit the strengths of continuous satellite observations, Mu et al. (2013) have recently developed a remotely sensed global drought severity index (DSI), and compiled an open access data base spanning 12 years between 2000 and 2011 at a temporal resolution of 8 days. The highest spatial resolution is around 5 km $(0.05° \times 0.05°)$ with an almost global coverage. The definition of DSI incorporates the normalised difference vegetation index (MOD13 NDVI product), together with the evapotranspiraton and potential evapotranspiraton ratio data (MOD16 ET/PET product).

The NDVI vegetation index measures the fraction of photosynthetically active radiation absorbed by plant canopies, basically the amount of vegetation present on the ground (???). By design, the dimensionless NDVI is a transformation of the near-infrared/red spectral reflectance ratio, and it varies between -1.0 and +1.0. Relatively large negative values occur when red reflectance exceeds near infrared one corresponding to water surfaces, values around zero are characteristic for barren areas, while positive values span from grasslands trough midlatitude forests up to tropical jungles.

Terrestrial evapotranspiration (ET) is the sum of evaporation and plant transpiration from land surface to the atmosphere. The computation algorithm of MOD16 ET is based on the theory of Penman-Monteith energy balance by using remote sensing inputs of the leaf area index, land cover, albedo, and enhanced vegetation index, furthermore meteorological parameter values of radiation, air temperature, pressure, and humidity (??). Over a sufficiently long time period, ET is less than or equal to precipitation for most vegetated geographic locations, apart from sites where irrigation or subsurface water supply may shift the balance. Tropical forests have the highest ET values, dry areas and areas with short growing seasons exhibit low ET, while values for temperate and boreal forests lie between the two extremes. Potential evapotranspiration (PET) is the amount of water that would be evaporated and transpired in case of hypothetically infinite water availability, incorporating the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from the land surface. ET and PET are expressed in terms of depth of water (mm) for a given time period (day, week, month, etc.), thus the ratio ET/PET has a value of 1.0 where evapotranspiration fully satisfies potential conditions, and declines toward zero where the surface dries.

A given DSI value is obtained by standardisation of the sum of previously and separately standardised NDVI index and ET/PET ratio (?):

$$Z = \frac{NDVI - \langle NDVI \rangle}{\sigma_{NDVI}} + \frac{ET/PET - \langle ET/PET \rangle}{\sigma_{ET/PET}} \quad , \tag{1}$$

$$DSI = \frac{Z - \langle Z \rangle}{\sigma_Z} \quad . \tag{2}$$

Temporal mean values $\langle * \rangle$ and standard deviations σ_* are determined over the available time period for each gridpoint separately. It is an important detail that DSI is derived using ET/PET without NDVI during the classified dormant season, because of greater noise in the non-growing season NDVI signal (?). Permanently non-vegetated locations such as deserts, high mountains, extended lakes, or large cities cannot provide useful input for DSI data, therefore such gridpoints are filtered out by a quality assessment procedure (?). Note that zero DSI values are not equivalent with missing data, standardisation procedure defined by Eqs. (1) and (2) shifts local mean values to this level by definition. There are two essential aspects to be also emphasise at this point: (i) Standardisation enhances small fluctuations or seasonal changes with the normalisation by the local standard deviations σ_*, and (ii) standardisation does not remove any trend existing in the time series, furthermore it does not change the statistical significance of trends in any sense. ”

Related paragraphs are inserted in the next Section:

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“Condensation of the multitude of information into a single number such as DSI has the drawback that a given numerical value does not carry any explicit meaning. Two zeros at two distant gridpoints convey the message only that the situations at both sites are compatible with the local twelve-year mean state of the very sites considering the functional status of the ecosystems. Nonzero DSI values of distant locations cannot be compared numerically, their magnitudes can only be interpreted in a statistical sense with respect to the particular records. Nevertheless standardisation is a useful tool to compare various signals of very different measures facilitating trend analyses or revealing cross-correlations. For example, in a semiarid region where the ET/PET ratio is low, a weak absolute trend might correspond to a significant change in wetness demonstrated clearly by a slope given in units of the local standard deviation.”

“As for an interpretation of the observed trends, a further complication arises from the composite aspect of DSI defined by Eq. (1). NDVI and ET/PET are far from being independent characteristics, however they are not strictly coupled. Therefore a given trend can be resulted in a dominating tendency of changes in one of the two terms, or in both of them. Peculiar situations can occur when the two partial trends cancel each other, and this is not a pure theoretical possibility.”

(2) “The authors state that the observed trends reveal decadal-scale climate variability rather than long-term global climate change (e.g., last paragraph of the introduction). I agree that 12 years of observations are insufficient to claim long-term trends, but the observed tendencies could still be due to either long-term trends or decadal-scale oscillations or a superposition of both. One way to further disentangle this might be allowing for non-linear trend models. I agree that this might be beyond the scope of the present work. However, being more precise in what could be the reasons for the observed linear slopes is definitely appreciated. ”

If we understand properly this comment, the Referee suggests non-linear trend models in order to separate natural climate variability from global climate change. However, this is a very general problem, and it is not solved yet in spite of many related efforts on much longer records:

“The relatively short period of 12 years is not enough to connect the results with global climate change. We think that the observed significant DSI trends over extended geographic areas are related to a decadal mode of the natural climate variability. Apart from time-span limitations, recent studies on drought trends (???) lead to somewhat controversial conclusions, as noticed by ?. One major issue in determining reliable long-term trends in drought due to climate change is to separate the effects of natural variability, especially El Niño/Southern Oscillation (ENSO) (?). During El Niño events, the main rainfall systems in the tropics move eastward over the tropical Pacific ocean leaving weakened monsoons behind (??). In the La Niña phase, dry areas are more common in places where it is wet during El Niño events. Indeed, as ? pointed out in a recent study, ENSO dominated the multi-decadal variability of terrestrial evaporation at the global scale. Their main conclusion is that the recent decadal decline in global average continental evaporation is not the consequence of a persistent reorganisation of the terrestrial water cycle, but rather it is an indication of transitions to El Niño conditions (?). ”

(3) “Regarding to the previous comment, it would be interesting to see how the global trend patterns (Fig. 4) compare with the outcomes of similar analyses applied to classical drought-related indices like PDSI, SPI or others. These indices are available, though on coarser spatial resolution, for the same period as DSI (and even far beyond) and might therefore be very helpful to assess the actual climatological implications of the results of the present study. To repeat the point already raised above, I feel that the practical use of DSI for climatological studies (i.e. the analysis of large-scale trend patterns) might be rather limited, whereas this index appears more suited for studying local effects due to human activity.”

Repeating the extended trend analysis with different data sets is beyond the scope of the present work. Instead, we give a detailed comparison with similar recent trend analyses on remotely sensed vegetation indices, which helps to understand DSI, but illustrates also the difficulties of a proper interpretation of tendencies. In general, our patterns are highly consistent with the results of Fensholt and Proud (2012), differences are discussed as follows:

"Fortunately, Fensholt and Proud (2012) performed a linear trend analysis of monthly MODIS NDVI data over the period 2000-2010. They found significant slopes for 11.8% of the pixels (the same spatial resolution as for DSI) on a global scale: 5.4% characterised by positive and 6.3% with negative trends. The comparison of Fig. ?? and Fig. 2a of Fensholt and Proud (2012) reveals a high level of correspondence, however DSI is definitely more sensitive indicator of negative trends. The most important difference already mentioned is that ? evaluated NDVI data in the growing seasons, while DSI provides continuous records by means of ET/PET ratio. For this reason, the areas indicated by blue rectangles in Fig. ??b can be considered as exhibiting ET/PET dominated trends. The majority of such gridpoints indicating statistically significant negative DSI tendencies are located in the middle of the Eurasian continent, in South-East Asia, in the northern part of South-America, and in the eastern part of Middle-Africa. Three smaller regions denoted by brown rectangles in Fig. ??b (Northern Mexico, South Africa, and Northern Australia) show significant NDVI trends, however DSI records do not obey similar (or exhibit much weaker) tendencies. These are candidate areas where NDVI and ET/PET terms cancel each other, however further local studies are necessary to get a clear interpretation."

(4a) "When presenting numerical values of trends, the authors use the unit "DSI / year". Since DSI is dimensionless, this does not seem to be appropriate, so just "per year" should be correct."

Thanks, we changed all the units to be year^{-1}.

(4b) "However, given the authors' statement that numerical values of DSI at different grid points should not be compared quantitatively, I wonder what one can learn from comparing numeric trend values at all. This particularly refers to Fig. 3 and the discus-

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sion in the final paragraph of Section 2. Specifically, giving mean slopes for all drying and wetting trends as well as corresponding standard deviations (p. 23) seems to be quite pointless if values are mutually inconsistent by definition. I may have missed the point here, so some clarification would be helpful."

This is an important point, and we try to explain the problems of DSI definition in details (see the responses above). Shortly, standardisation is widely used as a tool of visualization, where time series of very different measures are to be compared. In our case, the rescaling by local sigma values (local standard deviations) provide information on the statistical significance of trends, slopes should be interpreted in units of the ensemble standard deviation. From this point of view, percentage values of sites where either positive or negative trends are significant convey useful information, and mapping by using the appropriate colour scale helps to identify geographically connected regions.

(5) "Finally, some aspect that I would recommend for further considerations is seasonality. From a climatological perspective, it appears highly relevant to study the seasonal pattern of trends. Even though the authors emphasize that their analysis does not provide trends in a long-term global change context, the results of such an exercise (possibly in combination with other related indices) would allow for a more detailed climatological interpretation. Note that also the brief review of existing findings on existing findings and possible mechanisms related to the observed regional trend patterns in South America and India almost exclusively refers to seasonal phenomena."

Thanks, we agree. Now we inserted several related comments to make this point clear, see above.

" Example time series and linear trends are shown in Fig. 1 for three nearby locations (at the same latitude) in Argentina, where significant negative trends are identified (see below). Note that the time series exhibit apparently weak seasonal and annual variations, in spite of the fact that the climate of province of Córdoba is humid subtropical with four marked seasons. This is mostly because the ET/PET term in DSI [see Eq. (1)]

has a feeble seasonal variability in many places (?), moreover NDVI is incorporated only during the classified snow-free growing seasons as noticed before."

"Minor comments (...)"

Thanks, we corrected the formulation.

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