Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-467-AC7, 2016


Hydrology and Earth System Sciences
Open Access
Discussions

# *Interactive comment on* "Reliability of meteorological drought indices for predicting soil moisture droughts" *by* D. Halwatura et al.

**D. Halwatura et al.**

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Received and published: 13 November 2016

We would like to thank Dr Ryan Teuling and his students Danny Heuvelink, Judith Poelman and Heleen Westerveld for their critical and constructive comments on our manuscript. We appreciate the time and effort taken to review our manuscript. We would like to address the major issues identified by all the reviewers in a compiled response, and address the minor comments in a revised version of the manuscript. We are confident that the reports will make a positive contribution to the quality of our manuscript.

All three reports emphasise the relevance and novelty of our topic for the research community as well as practical applications and the fit within the aims and scope of HESS. While the introduction is deemed to be well written, all reviewers stress the



lack of explanation around some fundamental assumptions made in the methods that would certainly help to better understand the implications of our findings. Specifically, the reviewers' concerns are related to (1) the use of the minimum over the average monthly soil water pressure as reference for potential plant water stress, (2) the use of SPI/RDI and Hydrus-1D over other indices or numerical soil water models, and (3) the comparison of standardised indices with simulations of a physically based model or empirical measurements (including the use of the 75th percentile threshold). We note that concerns (2) and (3) are in line with that of Reviewer #1 and would like to further expand on our earlier response to Reviewer #1 below.

(1) Use of the minimum over the average monthly soil water pressure as reference for potential plant water stress

The decision to use the minimum rather than average monthly soil water pressure as reference for potential plant water stress is based on the assumption that one incidence of exceeding a species-specific water pressure threshold causes irreversible plant water stress. This reference point is more biologically relevant than average monthly soil water pressure as averages may mask high variability. In this regard, we make a very strong assumption about the (lack of) mechanisms plants may have developed to overcome short periods of water stress. We acknowledge the alternative assumption, in which case the average monthly soil water pressure would provide the better metric for comparing between SPI/RDI and Hydrus-1D. We will address this in a revised version of the manuscript by discussing the results obtained using the alternative approach.

Please find below plots of the two alternative metrics for the three locations in our study (Figs. 1.1 – 1.3), as well as the web plot of correlations between the indices and the average monthly soil water pressure (Figure 2). Though there is a good qualitative correlation between monthly average and monthly minimum soil water pressure (Figure 1.1-1.3) the correlation values between drought index and average soil water pressure are always lower than the monthly minimum soil water potential except for Melbourne (compare Fig. 2 below and Fig. 5 in the manuscript). Further, there is no interesting/significant trend or variation between the monthly average soil water pressure with two soil depths and two drought indices compared to monthly minimum soil water pressure.

(2) Use of SPI / RDI and Hydrus-1D over other indices / numerical soil water models

The objective of our study is to test the capability of a simple meteorological drought index to detect relevant periods of deficits in soil water availability. Note that the objective was not to compare the performance of drought indices amongst each other or to compare alternative soil water models. We realise that, in order to make this more explicit in the manuscript, we have to carefully rephrase parts of the introduction and methods.

In order to meet this objective, we selected the SPI as a representative index out of the great pool of meteorological drought indices from the literature as it considers rainfall as the only input variable. Also the SPI is one of the most commonly used indices and tends to be used for more than just meteorological droughts in practice. Acknowledging the critical impact of evaporation on the soil water balance we selected the RDI as an alternative simple drought index using evaporation as an additional input variable to rainfall. Any additional input variables or the use of a generic two-layer soil model (as in the PDSI proposed by one reviewer) would compromise our objective and be out of scope.

In regards to the numerical soil water model, we selected Hydrus-1D because it is a well-established soil water flow model that is freely available, which ensures the reproducibility of our work. We acknowledge that the model selection is a somewhat random process. However, any numerical model is, to some degree, a simple representation of physical processes and would have limited predictive power. The uncertainty in the model is addressed using parameter sensitivity analysis, as is common practice in the environmental modelling literature. Ideally, indices such as the SPI or RDI are compared with empirical field data. However, such empirical data are often not available



(such as in our study locations) for a variety of reasons, though primarily because long-term monitoring programs are restricted due to limited funding and time. The lack of empirical data is an issue across the world especially in developing nations or nations such as Australia with little history of long-term monitoring programs. A logical step before implementing any long-term campaigns is to test their feasibility in a desktop study using physically based models such as Hydrus-1D with available empirical data such as rainfall/evaporation and soil water retention characteristics, as demonstrated in our work. That said, the model is used as a reference/control similarly as any empirical soil moisture data would be used and, hence, calibration/validation with empirical data (as requested by one reviewer) is deemed to be redundant (otherwise we would have used the empirical data as a reference in the first place).

(3) Comparison of standardised indices with simulations of a physically based model or empirical measurements (including the use of the 75th percentile threshold)

The main concern of all reviewers is that the indices are standardised quantities whereas the modelled soil water pressure is an absolute physically relevant metric. As emphasised in our response to Reviewer #1, the SPI is standardised using the long-term average rather than the seasonal averages. Therefore, the standardisation in SPI rescales the data and does not remove seasonal variability, so it is not expected to make much difference to the correlations (only insofar as changing from a skewed to a normalised distribution of values) and cannot affect the FR/FAR values (as the scaling is monotonic). We will emphasise this fact in the revised paper. The use of non-seasonally-standardised indices is not uncommon, (e.g. Martínez-Fernández et al., 2015; Wang et al., 2015; Wang et al., 2016)

Regarding the use of the 75th percentile, our underlying assumption is that native plants have been established over long periods and are adapted to the local environmental condition and would suffer similar levels of water stress at the 75th percentile soil water pressure across the three locations. Of course this implies different absolute quantities of soil water pressure. For example, the 75th percentile corresponds to pF

3.4 in Bourke, but is only pF 2.3 and 2.1 in Melbourne and Cairns, respectively (Fig. 5 in the manuscript). In order to address the issue of an arbitrarily selected threshold, we tested our methods within the range of 45-95% (Fig. 3 in the manuscript).

Standardisation and/or normalisation of soil water pressure (be it modelled or measured) would require further assumptions of which we have already made a lot (as pointed out by some reviewers). For example, a distribution function would be required for the standardisation process, which involves further uncertainty. Likewise, in the normalisation process the scale of the normalized interval is significantly affected by any outliers.

For the Reviewers' and Editor's information, we have transformed the modelled pF based on the mean and standard deviation of a normal distribution (Fig. 3). Yet the strength of the relationship remains the same as for the correlation presented in the manuscript (compare Fig. 4 below and Fig. 5 in the manuscript).

At the Editor's discretion, we would prefer to keep the study reasonably simple rather than adding further arbitrary transformations of the data and hope our findings will be considered as useful desktop study to justify further work on the capability of simple drought indices to detect plant water stress related soil moisture deficits, including the establishment of long-term monitoring networks for the verification/falsification of our findings.

Further comments that will be addressed in the revised manuscript:

J. Poelman, comment 2.1: Emphasise the effort made in former studies and further stress the novelty of our study in the introduction. J. Poelman, comment 2.4: Further references to justify the step-by-step description of methods. J. Poelman, comment 3: Expand discussion on when to use the indices over the model in relation to uncertainty in the water retention curves. All reviewers: All minor comments/issues, including references. Thank you!



References

Martínez-Fernández, J., González-Zamora, A., Sánchez, N., Gumuzzio, A., 2015. A soil water based index as a suitable agricultural drought indicator. Journal of Hydrology 522 265-273. Wang, H., Rogers, J.C., Munroe, D.K., 2015. Commonly Used Drought Indices as Indicators of Soil Moisture in China. Journal of Hydrometeorology 16(3) 1397-1408. Wang, H., Vicente-serrano, S.M., Tao, F., Zhang, X., Wang, P., Zhang, C., Chen, Y., Zhu, D., Kenawy, A.E., 2016. Monitoring winter wheat drought threat in Northern China using multiple climate-based drought indices and soil moisture during 2000–2013. Agricultural and Forest Meteorology 228–229 1-12.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-467/hess-2016-467-AC7-supplement.pdf

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-467, 2016.

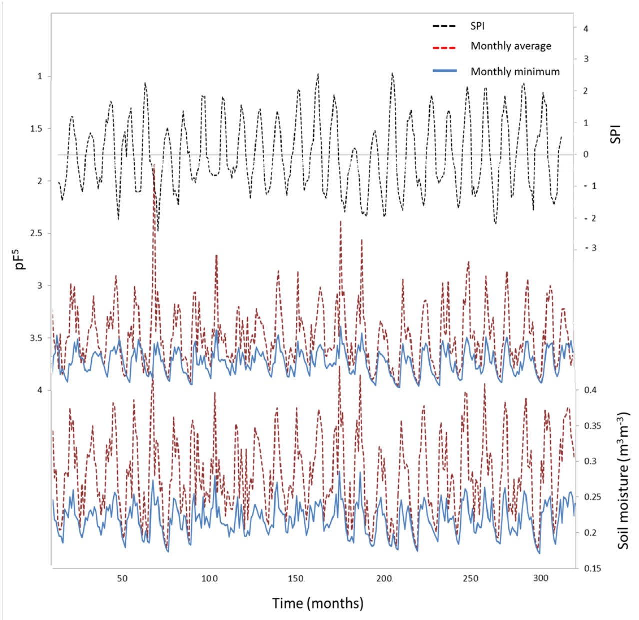


Figure 1.1: Time series of the SPI, the simulated monthly minimum soil water pressure and monthly average soil water pressure, and the monthly minimum soil moisture and monthly average soil moisture in 5 cm depth in Cairns. Note: average and minimum soil moistures are also included to this figure aligned with the reviewer #3 comments.

**Fig. 1.**



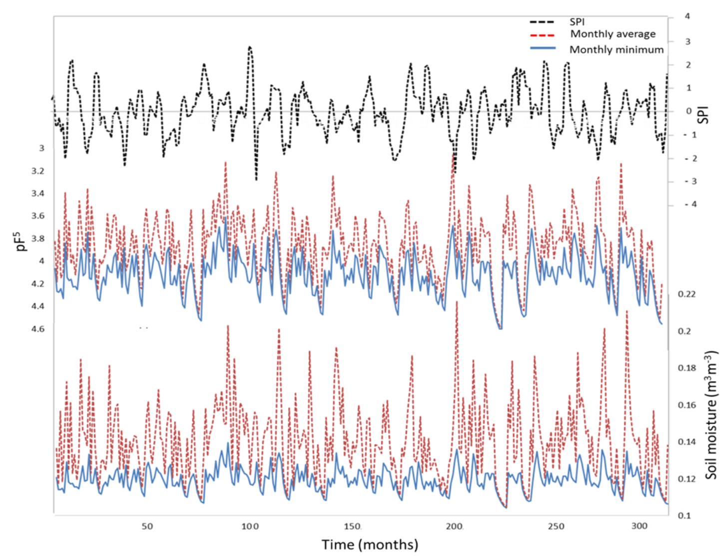


Figure 1.2: Time series of the SPI, the simulated monthly minimum soil water pressure and monthly average soil water pressure, and the monthly minimum soil moisture and monthly average soil moisture in 5 cm depth in Bourke. Note: average and minimum soil moistures are also included to this figure aligned with the reviewer #3 comments.

**Fig. 2.**

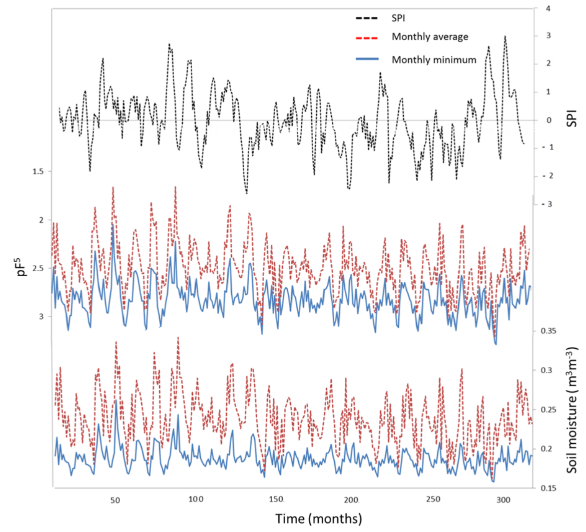


Figure 1.3: Time series of the SPI, the simulated monthly minimum soil water pressure and monthly average soil water pressure, and the monthly minimum soil moisture and monthly average soil moisture in 5 cm depth in Melbourne. Note: average and minimum soil moistures are also included to this figure aligned with the reviewer #3 comments.

**Fig. 3.**



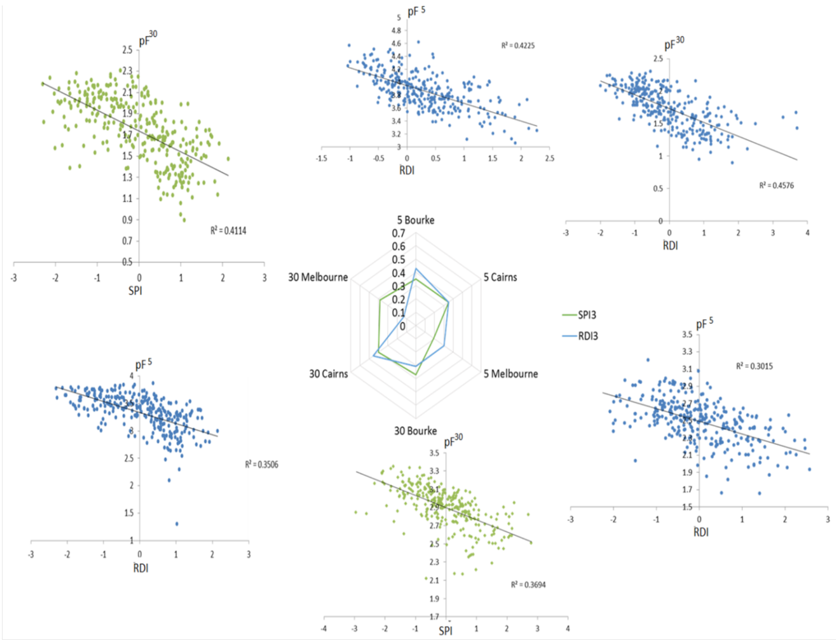


Figure 2: Correlations between simulated monthly average soil water pressure pF Vs three month time scale of SPI and RDI for 5 cm and 30 cm soil depth. The scatter plots represent the highest correlation for each location

**Fig. 4.**

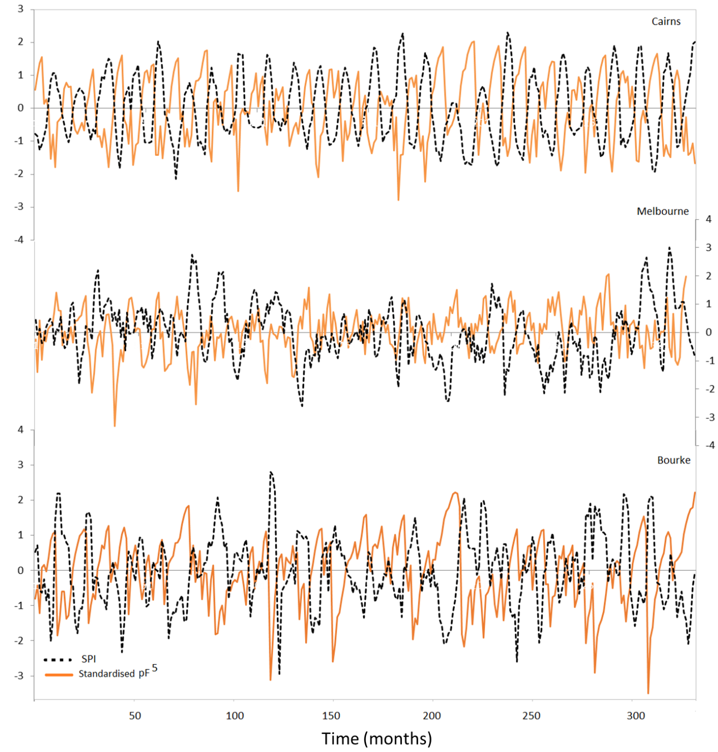


**Fig. 5.** Figure 3: Standardised monthly minimum soil water pressure in 5 cm depth and SPI for Cairns, Bourke and Melbourne.



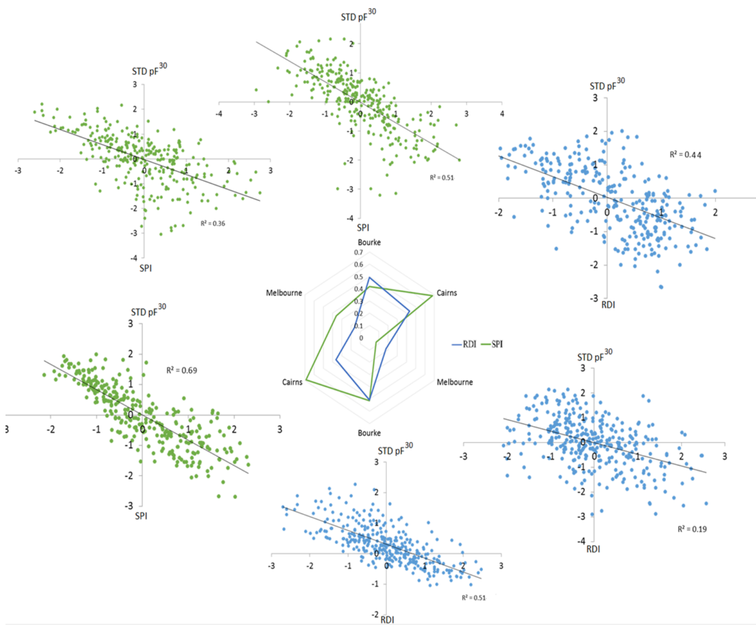


Figure 4: Correlations between standardized monthly minimum soil water pressure STD pF Vs three month time scale of SPI and RDI for 5 cm and 30 cm soil depth. The scatter plots represent the highest correlation for each location

**Fig. 6.**