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VERIFICATION OF SOIL MOISTURE FROM LAND SURFACE MODELS AND TRADITIONAL SOIL DRYNESS INDICES

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ABSTRACT

The McArthur Forest Fire Danger Index (FFDI) used in Australia has a component representing fuel availability called the Drought Factor, which inturn is partly based on soil moisture deficit, commonly calculated as either the Keetch–Byram Drought Index (KBDI) or Mount's Soil Dryness Index (SDI). The KBDI and SDI are essentially simplified water balance models to estimate soil moisture depletion in the upper soil levels, and are driven by precipitation and maximum temperature analyses. In this study, we compare these two old empirical models against an emerging new approach in soil moisture estimation in the form of land surface modelling. Validation of these models are carried against *in situ* observations of soil moisture from OzNet and CosmOz networks in Australia. The results indicate that soil moisture from land surface model employed within Bureau of Meteorology's operational numerical weather prediction (NWP) model produce a better skill than KBDI and SDI. The average correlations obtained over all sites are 0.77, 0.62 and 0.74 for NWP, KBDI and SDI respectively.

INTRODUCTION

The ignition, spread and temporal variations in fire danger depend heavily on fuel availability (FMC; Chandler *et al.*, 1983). Because fuel availability measures are not always readily available, fire danger rating systems include sub-models to estimate this quantity from weather observations. The McArthur Forest Fire Danger Index (FFDI; McArthur 1967) used in Australia for instance, has a component representing fuel availability called the Drought Factor, which inturn is partly based on soil moisture deficit which is commonly calculated in Australia as either the Keetch–Byram Drought Index (KBDI; Keetch and Byram, 1968) or Mount's Soil Dryness Index (SDI; Mount 1972). These two empirical water balance models are, however, over-simplified and may lead to large uncertainties in the estimated soil moisture deficit. With the advancement in the science of soil moisture estimation and prediction in the form of physically based land surface models, more comprehensive and systematic measures of soil moisture is now available. Research is already started to deliver a better provision of soil dryness products with greater accuracy at a much higher spatial and temporal resolution for use in fire danger ratings. This study intends to be of a preliminary nature to this research and describes the comparison between soil moisture from old empirical models (KBDI and SDI), a land surface model and *in situ* observations.

DATA AND METHODOLOGY

For the present study, KBDI and SDI are generated for the whole of Australia at 0.05o x 0.05o resolution using the Australian Water Availability Project (AWAP) daily rainfall and daily maximum temperature data (Jones *et al.*, 2007) for a period of 40 years, from 1974 – 2014. The two sources of *in situ* data used for this study are from the OzNet and Australian Cosmic Ray Sensor Network (CosmOz) soil moisture monitoring networks. OzNet data used in this study consists only observations from the Murrumbidgee Soil Moisture Monitoring Network (Smith *et al.*, 2012). CosmOz is the first national network of cosmic ray soil moisture probes and comprise of 13 sites situated at different locations over different climate zones in Australia (Hawdon *et al.*, 2014). The numerical weather prediction (NWP) soil moisture dataset used in this study are analyses from the old (called Australian Parallel Suite – 0; APS0) and current (Australian Parallel Suite – 1; APS1) versions of the Australian

Community Climate and Earth Simulator (ACCESS) global modelling system employed operationally by the Bureau of Meteorology. APS0 had a horizontal resolution of about 80 km and APS1 that of about 40 km.

Since the different soil moisture datasets mentioned above are represented in different forms and units, to enable a fair product comparison, all are scaled between [0, 1] using their own maximum and minimum values from the respective lengthy time series. In order to match the daily time steps of the KBDI and SDI fields, the NWP model and *in situ* data are averaged over each day. A spatially collocated sub-set using the nearest neighbour technique with respect to the *in situ* observation locations are then made from these daily averaged gridded model (NWP, KBDI and SDI) fields. For all stations, correlations, bias, and root mean square difference are calculated for the whole period in which the comparing data overlaps.

RESULTS AND DISCUSSIONS

COMPARISON WITH OZNET

In order to assess the accuracy of the soil moisture estimates from APS1, KBDI and SDI, an evaluation is made against the soil moisture observations from OzNet hydrological network. The verifications are made with datasets which span for a period of 21 months, i.e. from September 2009 to May 2011. OzNet provides soil moisture observation for the top 30 cm layer (0 – 30 cm deep) which is used in this study for comparisons.

The correlation, bias and RMSD calculated for APS0, KBDI and SDI with respect to the OzNet sites are given in Table 1. The values represent an average taken over 30 stations. The results show that, in general, the APS0 correlations are higher than that from both KBDI and SDI. The average correlation values across all OzNet sites for APS1, KBDI and SDI are 0.72, 0.60 and 0.71 respectively. The APS0 soil moisture usually correlates very well with the observations, where 90% of sites showing a correlation of 0.6 or more. Biases are in average of 0.02, -0.39 and -0.02 for APS0, KBDI and SDI respectively. KBDI in general display a large wet bias, which suggest that the evapotranspiration estimates in KBDI are rather under-estimated. Though SDI presents on an average a wet bias, it doesn't systematically exhibit any wet bias at all stations. Averaged RMSD for APS0, KBDI and SDI are 0.19, 0.43 and 0.23 respectively. The higher RMSD in KBDI signify that the errors in soil moisture are larger in KBDI compared to APS0 and SDI.

Table 1. Comparison of normalized soil moisture between OzNet *in situ* observations located at Murrumbidgee catchment area and ACCESS NWP model (APS0), KBDI and SDI. The values represent an average over 30 sites.

Correlation [-]			Bias [-]			RMSD [-]		
APS0	**KBDI**	**SDI**	**APS0**	**KBDI**	**SDI**	**APS0**	**KBDI**	**SDI**
0.72	<u>0.60</u>	0.71	0.02	-0.39	-0.02	0.19	0.43	0.23

COMPARISON WITH COSMOZ

The three modelled root-zone soil moisture estimates from APS1, KBDI and SDI are evaluated against daily average measurements from CosmOz cosmic ray probe sites across Australia. Since APS1 dataset had the shortest span among the four data types, a subset of CosmOz, KBDI and SDI data set were produced based on APS1 time period for sensible verification. This period spans about 31 months, from May 2012 to Dec 2014. The statistical scores of this verification is presented in Table 2. The verifications results using CosmOz data displays a similar pattern to that from the OzNet, where the NWP soil moisture product exhibit a good skill over the KBDI and SDI products. The mean correlations obtained for APS1, KBDI and SDI in this case are 0.8, 0.63 and 0.76 respectively. The average bias obtained for APS1, KBDI and SDI are 0.01, -0.35 and -0.07 respectively. KBDI again shows a rather large wet bias over all stations. Since the CosmOz observations are scattered all over Australia, this implies that KBDI under-predict the soil moisture deficit substantially, regardless of the climate zone. SDI doesn't exhibit any consistent wet or dry pattern spatially, similar to APS1. RMSD are in average of 0.15, 0.42 and 0.20 respectively for APS1, KBDI and SDI.

Table2. Comparison of normalized soil moisture between CosmOz observations and APS1, KBDI and SDI. The values represent an average over 13 sites.

Correlation [-]			Bias [-]			RMSD [-]		
APS1	**KBDI**	**SDI**	**APS1**	**KBDI**	**SDI**	**APS1**	**KBDI**	**SDI**
0.80	0.63	0.76	0.01	-0.35	-0.07	0.15	0.42	0.20

SUMMARY

The validation study done in this work use *in situ* observations from OzNet and CosmOz network to assess the reliability of NWP, KBDI and SDI soil moisture products. In general, the NWP soil moisture gives a better performance compared to KBDI and SDI, and as depicted by the correlation, bias and RMSD values. This is despite the fact that NWP soil moisture were calculated at a much coarser resolutions (~ 40 – 80 km) and use its own precipitation estimates - which are generally associated with lot of errors - to drive the soil moisture. As compared to this, KBDI and SDI soil moisture estimations use observation based precipitation analysis and are done at a much higher resolution (~5 km). Over most of the sites on which comparisons were made, KBDI soils are significantly wetter than other three datasets. This wet bias seen in KBDI could have its implication for fire danger ratings, where it is used, as this would potentially downgrade the fire potential. SDI, although displays a much better temporal soil moisture variation than KBDI, usually fail to catch the rapid drying / wetting phases seen in the observations.

It is worth noting that there is still a lot of scope to improve soil moisture products from land surface models used in NWP by using advanced data assimilation techniques (Dharssi *et al.*, 2013). As the next step, research will be performed to calculate soil dryness using satellite remote sensing measurements, land surface model simulations and data assimilation techniques. Consequently, this research is intended to lead to the provision of soil dryness products with greater accuracy at a much higher spatial and temporal resolution.

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