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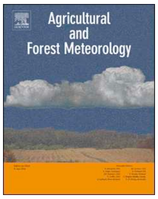

Evaluation and calibration of a high-resolution soil moisture product for wildfire prediction and management

Vinodkumar[a,b,*], Imtiaz Dharssi[a]

[a] Bureau of Meteorology, Docklands, Melbourne, VIC-3008, Australia
[b] Bushfire and Natural Hazard Cooperative Research Centre, East Melbourne, VIC-3002, Australia

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ABSTRACT

Soil moisture deficit is a key variable used in operational fire prediction and management applications. In Australia, operational fire management practices use simple, empirical water balances models to estimate soil moisture deficit. The Bureau of Meteorology has recently developed a prototype, high-resolution, land surface modelling based, state-of-the-art soil moisture analyses for Australia. The present study examines this new product for use in operational fire prediction and management practices in Australia. The approach used is twofold. First, the new soil moisture product is evaluated against observations from ground based networks. Among the results, the mean Pearson's correlation for surface soil moisture across the three in-situ networks is found to be between 0.78 and 0.85. Secondly, the study evaluate a few different calibration methods to facilitate the ready utilization of the new soil moisture product in the current operational fire prediction framework. The calibration approaches investigated here are: minimum-maximum matching, mean-variance matching and, cumulative distribution function matching. Validation of the calibrated products using extended triple collocation technique shows that the minimum-maximum method has the highest skill. Evaluation of the calibrated products against MODIS fire radiative power data highlights that large fires correspond to a drier soil in minimum-maximum outputs compared to other calibration results and the current operational method.

1. Introduction

The risk of a forest fire inception is influenced by the amount and type of fuel (dead and live biomass) available and its susceptibility to burn (San-Miguel-Ayanz et al., 2003). Fuel moisture content is a critical variable affecting fire interactions with fuel and partly controls the efficiency of fire ignition and burning. For example, Dowdy and Mills (2012) showed that fuel moisture content influences the risk of ignition from lightning. However, estimating fuel moisture over a large region is still a challenge (Matthews, 2014). Soil moisture is found to be a key factor that influence fuel moisture content (Walsh et al., 2017; Pellizzaro et al., 2007; Krueger et al., 2016). Consequently, operational forest fire prediction systems typically include soil moisture as one of the inputs for fire behaviour calculations. The soil moisture status to these fire prediction models are usually provided in the form of moisture deficit, defined as the amount of water required to bring the soil up to field capacity. For instance, the McArthur Forest Fire Danger Index (FFDI; McArthur, 1967) used operationally in Australia for fire prediction use soil moisture deficit information from either Keetch–-Byram Drought Index (KBDI; Keetch and Byram, 1968) or Mount's Soil Dryness Index (SDI; Mount, 1972) models, depending on the fire jurisdiction.

The KBDI and SDI data are not just used as mere inputs to FFDI, but they also play a critical role in the risk management decisions and activities carried out by Australian fire and environment agencies. For example, prescribed burning conducted on button grass moorlands in Tasmania use SDI to determine the flammability of moorland boundaries (Marsden-Smedley, 2009). SDI is also used in the states of South Australia and Western Australia to plan fuel reduction activities (Bain et al., 2016; Finkele et al., 2006). KBDI is a key tool to support the formation of fire strategies, burn proposals and on-ground implementation in Queensland (Blaik et al., 2013). The prescribed burning risk assessment tool for Victoria include KBDI as a key component for decision making (Slijepcevic et al., 2007).

There are evidences that the KBDI and SDI performs poorly in predicting near-surface soil moisture (Kumar and Dharssi, 2017; Holgate et al., 2016). This is critical in a fire prediction stand point, given the relationship between moisture states in forest litter and surface soil (Hatton et al., 1988). Soil moisture from land surface models within a numerical weather prediction system can provide more

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[*] Corresponding author at: Science to Services Branch, Bureau of Meteorology, 700 Collins Street, Docklands, Melbourne, Victoria 3008, Australia.
E-mail address: vinod.kumar@bom.gov.au (Vinodkumar).

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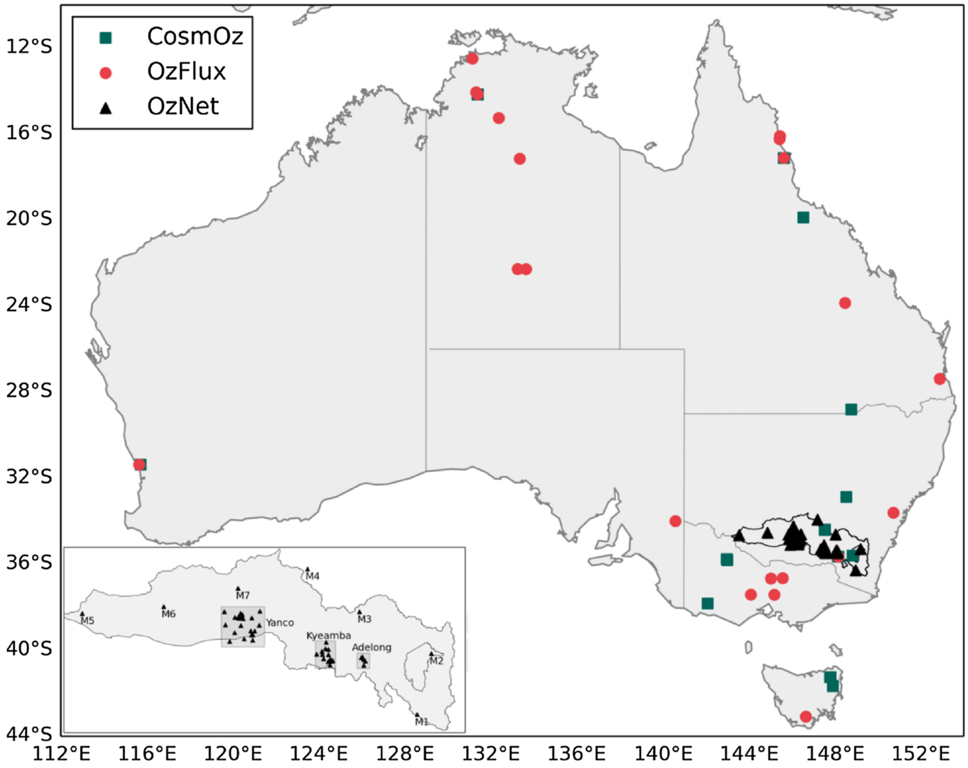

Fig. 1. Location of in-situ observations. The Murrumbidgee catchment is represented by the black boundary. A zoom-in on the Murrumbidgee catchment and the OzNet network is shown in the inset.

accurate estimates than that from the above indices (Vinodkumar et al., 2017). In Australia, the soil moisture analyses from operational NWP systems run by the Bureau of Meteorology are coarse in resolution (~25 km), and the skill can be limited by large uncertainties that exist in NWP forcing - especially precipitation. Hence, a prototype, high resolution, offline land surface modelling system has been developed by the Bureau of Meteorology (Dharssi and Vinodkumar, 2017). This prototype system is based on the Joint UK Land Environment Simulator (JULES; Best et al., 2011) land surface model and is forced mainly by observation based meteorological analyses. The new system is called the JULES based Australian Soil Moisture Information (JASMIN) and estimates soil moisture at a spatial resolution of 5 km.

The present study aims to support the development and utilization of JASMIN for application in operational fire prediction and risk management practices in Australia. The first objective in this regard is to systematically validate JASMIN using in-situ data. The need for a spatially and temporally extensive ground truthing of JASMIN is addressed by using three large-scale soil moisture networks. This study also complements the traditional ground-truthing methodologies with a relatively new validation technique called extended triple collocation (McColl et al., 2014).

The second objective is to illustrate the effective adoption of JASMIN in current operational practices by applying simple calibration methods. We apply the calibration methodology to convert native JASMIN soil moisture content available in Kg m^{-2} to soil moisture deficit values specified in a range between 0–200 mm, as required by FFDI. The calibration offers a simple, faster and cost-effective way to make significant upgrades to the existing operational systems used by fire and other environment agencies. Similar calibration (also referred as rescaling/matching) problems are of high interest in soil moisture data assimilation, where the elimination of systematic differences between model data and observations need to be achieved. Calibration techniques are also applied in soil moisture studies to convert observed data into model-equivalent form for various analyses. A considerable number of studies have explored several calibration techniques for verification (Draper et al., 2009; Su et al., 2013; Vinodkumar et al., 2017) and for data assimilation (Houser et al., 1998; Walker and Houser, 2001; Sabater et al., 2007). The calibration methods applied here are: minimum-maximum matching, mean-variance matching and cumulative distribution function matching. The calibrated data is evaluated against observations using Pearson's product-moment correlation and extended triple collocation methods. A qualitative evaluation of the traditional indices and JASMIN rescaled products against Moderate resolution Imaging Spectro-radiometer (MODIS) fire radiative power (FRP) data is also carried out. Finally, a comparison between the FFDI calculations based on each calibrated product is presented.

2. Data sets

2.1. JASMIN

The JASMIN system runs at 5 km resolution with an hourly time interval (Dharssi and Vinodkumar, 2017). The soil column extends from the surface to 3 m and is divided into four layers of thickness 100 mm, 250 mm, 650 mm and 2 m. JASMIN use the van Genuchten soil hydraulic model to define the relationship between soil moisture and soil hydraulic conductivity. Except for tree heights, JASMIN use the default ancillary information provided along with JULES to account for spatial variability in soil and vegetation properties horizontally. The tree height information used in JASMIN is based on a global dataset of canopy height derived from space-borne light detection and ranging instrument (Simard et al., 2011).

The BoM's Mesoscale Surface Analysis System (MSAS; Glowacki et al., 2012) data available near-real-time at 4 km resolution is converted and re-gridded to provide the JULES driving data for air temperature, specific humidity, wind speed and surface pressure. The downward surface solar radiation data is from a near-real-time BoM product derived from the Himawari Geostationary Meteorological Satellites and is available at about 5 km resolution. The downward surface longwave radiation data is obtained from BoM's regional NWP model at