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# EVALUATION AND CALIBRATION OF A LAND SURFACE BASED SOIL MOISTURE FOR FIRE DANGER RATINGS

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# ABSTRACT

## EVALUATION AND CALIBRATION OF A LAND SURFACE BASED SOIL MOISTURE FOR FIRE DANGER RATINGS

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We present the evaluation of high-resolution, JASMIN soil moisture analysis developed for Australia. The prototype JASMIN system has been developed primarily for use in fire and land management. JASMIN produce hourly soil moisture estimates over four soil layers at 5 km horizontal resolution. We evaluate JASMIN against three ground-based networks in Australia. Among the results, the median Pearson's correlation obtained for surface soil moisture across the observation networks for JASMIN is between 0.78 and 0.85. JASMIN generally has a better skill than the Keetch-Byram Drought Index and Soil Dryness Index models used operationally in Australia.

We also apply and evaluate a few rescaling approaches to the JASMIN soil moisture to facilitate its use in the current operational fire danger rating system. Minimum-maximum matching, mean-variance matching, and cumulative distribution function (CDF) matching are the rescaling approaches applied. Validation of the rescaled products is performed using ground-based observations and MODIS fire radiative power data.

The rescaling readily enables fire agencies to utilize the JASMIN product in their existing fire prediction models. However, the potential of JASMIN is greatest in the National Fire Danger Rating System (NFDRS), currently being prototyped across Australia. Particularly, the ability of JASMIN to estimate soil moisture at several levels is expected to be advantageous in the NFDRS. For example, the Spinifex fuel model implemented in the current NFDRS prototype uses 0-10cm soil moisture as an input. This soil moisture information is available natively in JASMIN.

# INTRODUCTION

Accurate estimation of soil moisture is of great importance in fire danger assessment, given the close relationship between soil moisture and fuel dryness. To that extent, the operational fire danger rating system in Australia employs soil moisture deficit models to estimate fuel availability (McArthur, 1967). Soil moisture exhibits high variability in space and time, driven by several parameters, such as vegetation, soil type, topography, and meteorology. The current operational soil moisture deficit models, the Keetch-Byram Drought Index (KBDI; Keetch and Byram, 1968) and the Mount's Soil Dryness Index (SDI; Mount, 1972), are rather simplified methods that neglect most of these influencing factors.

Rapid scientific progress has been made in the past few decades on accurate soil moisture estimation using modern techniques like satellite remote sensing and land surface modelling. Land surface models (LSMs) provide a detailed representation of thermal and hydrological processes (Best et al., 2011). Soil wetness from LSMs within a numerical weather prediction system (NWP) is found to provide more accurate estimates than that from KBDI or SDI (Vinodkumar et al., 2017). However, soil moisture analysis from operational, global NWP systems run by the Bureau of Meteorology have a coarser resolution (~25 km). Also, their skill can be limited by the large uncertainties that exist in NWP forcing - especially precipitation. Hence, a high resolution offline land surface modelling system that will be driven mainly by observation based meteorological forcing has been developed.

The new soil moisture analyses system, referred to as the JULES based Australian Soil Moisture INformation (JASMIN; Dharssi and Vinodkumar, 2017), is based on the Joint United Kingdom Land Environment Simulator (JULES; Best et al. 2011) land surface model. The JASMIN system covers whole Australia at a spatial resolution of 5 km. The system is run with an hourly time step and output is stored at every third time step. The soil column in JASMIN is 3 m deep and is divided into four layers of 0.1, 0.35, 0.65 and 2 m depth from the surface. The present study briefly describes the verification of JASMIN against ground observations and comparisons with current operational methods.

We apply three rescaling methods to calibrate the native JASMIN soil moisture outputs so that they are compatible for use in fire prediction models used by the fire agencies. The rescaling approaches applied and validated are: minimum-maximum (MM) matching, mean-standard deviation (μ–σ) matching, and cumulative distribution function (CDF) matching. Validation of the rescaled products is performed here using the MODIS fire radiative power data.

# RESULTS AND DISCUSSION

## VERIFICATION OF JASMIN AGAINST GROUND OBSERVATIONS

The skill of JASMIN, KBDI and SDI is assessed using ground observations from the CosmOz, OzNet and OzFlux networks. Figure 1 represents each model's skill over different land use / land cover (LULC) for shallow soil layers. The LULC classification is made based on the types over which the observation sites are located. We broadly classify the land cover types into forests, woodlands, grasslands and croplands. The northern Australian savannahs are classified as woodlands. All pasture and grazing paddocks are included under grasslands. Of the 81 sites in total across three networks, 16 are classified as croplands, 11 as forests, 9 under woodlands and the remaining 45 under grasslands.

From a forest fire prediction perspective, it is interesting to note that KBDI and SDI show a strong correlation with observations over forested sites (Fig 1a). Forested regions generally receive a high annual rainfall total, which explains the better performance of KBDI in terms of correlation. However, KBDI exhibits a relatively large wet bias over these forested sites (Fig 1c). Also, the median anomaly correlation of KBDI is less than 0.60 (Fig. 1d). This highlights the moderate skill of KBDI in capturing the high frequency changes in moisture of forest litter layer. SDI skill is generally better than KBDI for all land cover types. The most probable reason for this is the use of a vegetation classification in SDI to estimate soil dryness. Also, the assumption of evapotranspiration (ET) water loss as a linear function of maximum temperature seems to be a more reasonable one than that used in KBDI.

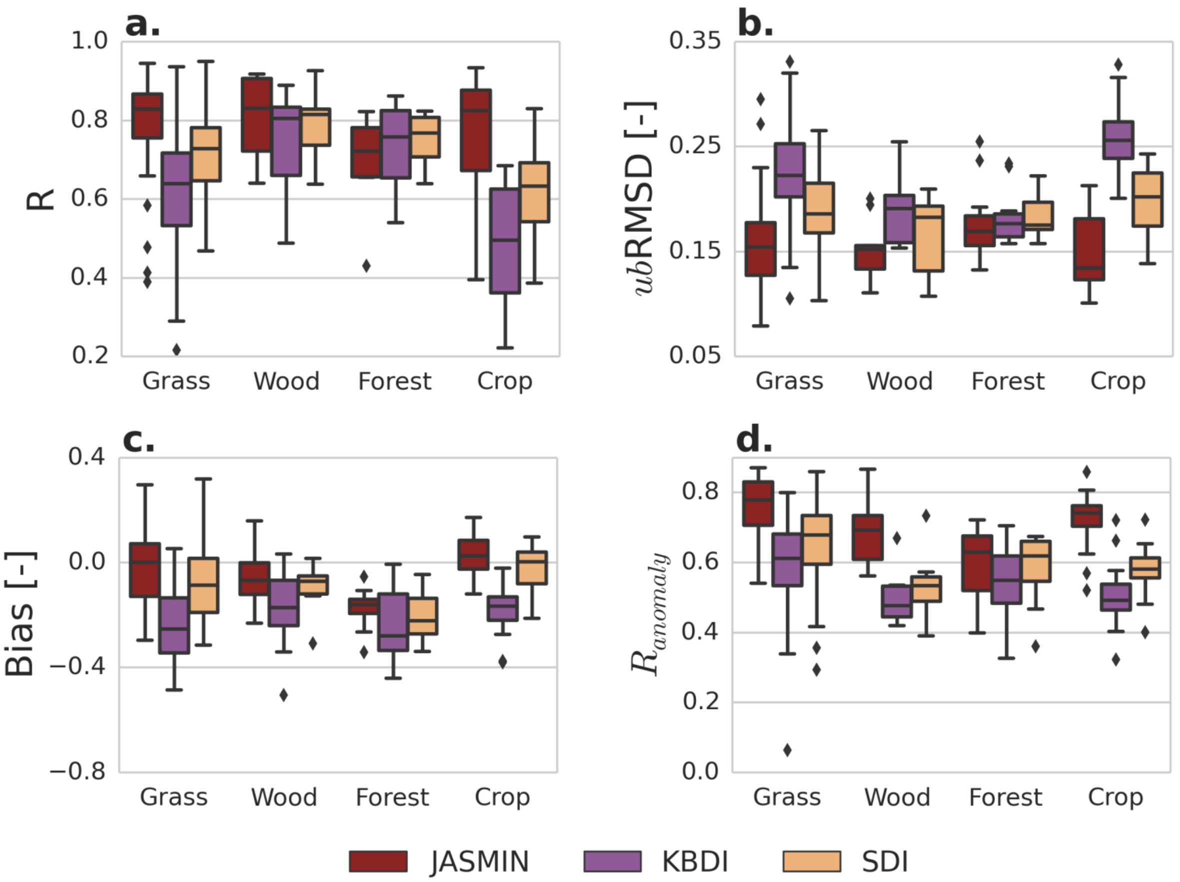


**Figure 1.** Skill of each model over various land cover types: a) Pearson's correlation, b) unbiased RMSD, c) bias, and d) anomaly correlation. The red, blue and green boxes and whiskers represent JASMIN, KBDI and SDI respectively. The grouping is done based on the land cover type of the observing site. The outliers are marked as diamonds.

JASMIN performs consistently better overall land cover types considered here. The skill of JASMIN over grasslands is quite remarkable. The median correlation between JASMIN and observations over grassland is about 0.83. The corresponding anomaly correlation is 0.78. It also has better skill in simulating moisture regimes over woodlands and croplands. Though KBDI and SDI have slightly higher median correlation than JASMIN over forest sites (Fig. 1a), JASMIN has lower unbiased RMSD (Fig. 1b), lower bias (Fig. 1c) and higher anomaly correlation (Fig 1d) than the traditional models. These results arguably underline the potential of JASMIN to be used in a variety of land related applications.

## CALIBRATION OF JASMIN SOIL MOISTURE

The key aim of rescaling methods is to calibrate JASMIN outputs in units of moisture excess to moisture deficit values with a dynamic range from 0 – 200 mm in depth. As a demonstration of each calibration technique, a qualitative evaluation of KBDI and rescaled JASMIN products against Moderate resolution Imaging Spectro-radiometer (MODIS) fire radiative power (FRP) data are presented in Fig. 2. The JASMIN product corresponds to the 0 – 350 mm soil profile.

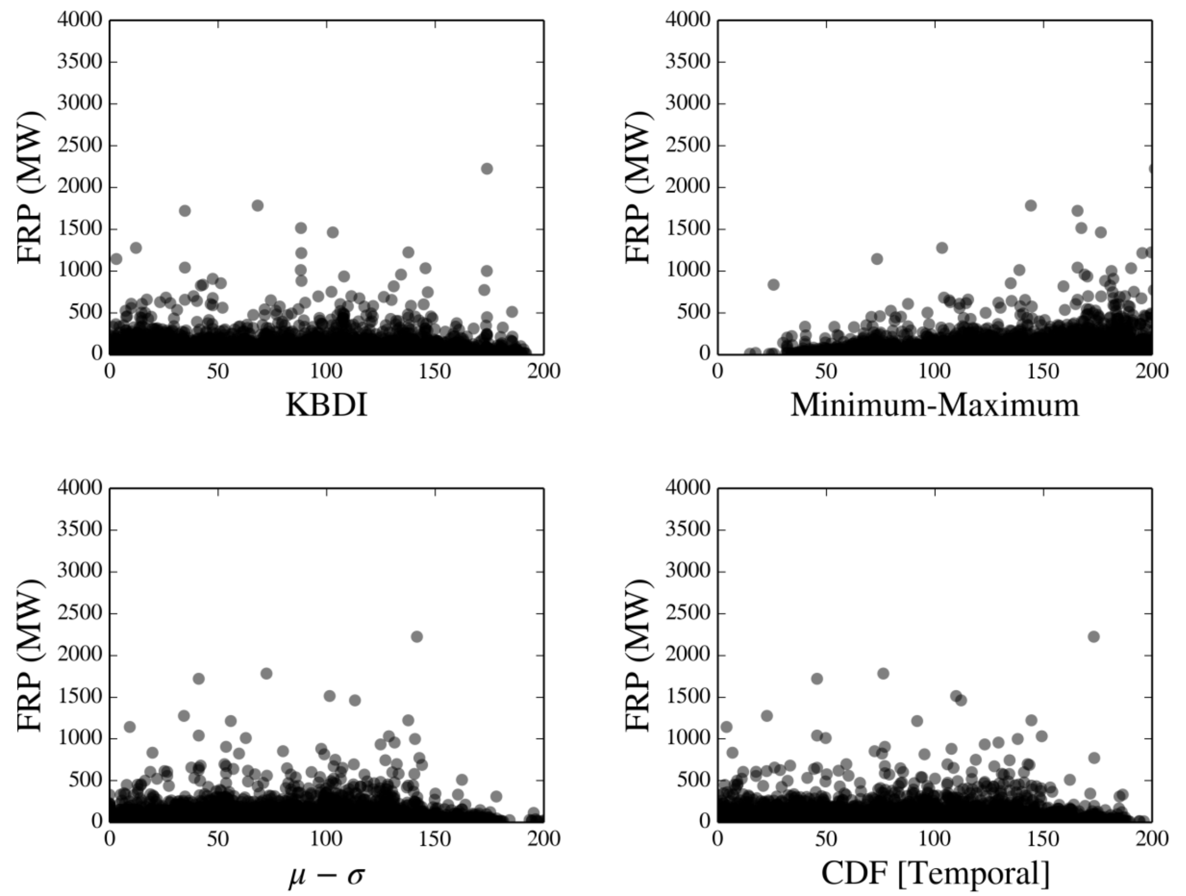


**Figure 2.** Scatter plot depicting MODIS FRP product against a) KBDI, JASMIN rescaled using b) MM, c) μ–σ, and d) CDF matching methods. The selected area corresponds to the state of Victoria. JASMIN products correspond to 0-350 mm model soil profile. The datasets span from January 2010 to February 2015.

The evaluation against MODIS FRP product reveals some characteristics of each soil dryness datasets. For example, the MM method (Fig. 2b) generally produces a drier soil than KBDI and other two methods. This causes the fires with high intensity to correspond to drier soils One of the features of μ-σ (Fig. 2c) and CDF (Fig. 2d) techniques is that they preserve the climatology of the dryness index to which they are matched. This is apparent from the scatter plots (Fig. 2). Some of the systems which use the soil dryness products may be tuned to offset the bias in traditional indices. For such systems, μ-σ and CDF techniques thus offer a product with improved correlations while preserving the climatology of the traditional dryness index. The scatter plot of KBDI (Fig. 2a) shows that higher FRP values occur over wet soils as well as dry soils. Generally, large intense fires are associated with sufficiently dry live fuels and larger dead fuels. The drying of these large fuel loads is associated with prolonged drought and hence large soil moisture deficit. In that respect, it could be argued that the drier soils in MM method corresponding to large FRP values present a more realistic scenario.

The results from the correlation analysis (Table 1) indicate that MM matching, μ–σ matching and CDF matching methods have similar skill. The negative values indicate that the model fields are in deficit form whereas observations are given as soil moisture contents. The correlations of JASMIN products decrease when the 0 – 1 m soil profile is used. This highlights the representativity differences in model and observation soil horizons. CosmOz observation depths are usually below 400 mm. Also, about 42% of the "deeper" probes in OzFlux are located at 500 mm. Only 16% of the total sites have probes located at 1 m. This possibly made the 0 – 350 mm model profile more representative of observations than the 1 m profile.

| **In situ network** | **Correlation** | | | | **Anomaly correlation** | | | |
|---|---|---|---|---|---|---|---|---|
| | *KBDI* | *MM* | $\mu - \sigma$ | *CDF* | *KBDI* | *MM* | $\mu - \sigma$ | *CDF* |
| **0-350 mm profile** | | | | | | | | |
| CosmOz (Surface) | -0.69 | -0.84 | -0.82 | -0.79 | -0.47 | -0.66 | -0.61 | -0.59 |
| OzFlux (Surface) | -0.75 | -0.80 | -0.80 | -0.79 | -0.58 | -0.70 | -0.68 | -0.66 |
| OzFlux (Root zone) | -0.86 | -0.85 | -0.85 | -0.85 | -0.65 | -0.63 | -0.63 | -0.62 |
| **0-1 m profile** | | | | | | | | |
| CosmOz (Surface) | -0.69 | -0.73 | -0.70 | -0.67 | -0.47 | -0.57 | -0.55 | -0.54 |
| OzFlux (Surface) | -0.75 | -0.74 | -0.73 | -0.71 | -0.58 | -0.64 | -0.61 | -0.60 |
| OzFlux (Root zone) | -0.86 | -0.82 | -0.82 | -0.82 | -0.65 | -0.63 | -0.62 | -0.60 |

**Table 1.** Pearson's product-moment correlations of KBDI and JASMIN based soil moisture deficit products against in-situ soil moisture observations. The values represent a network average.

## SUMMARY

The present study underlines some of the limitations of traditional soil dryness indices in producing accurate soil moisture estimates, particularly for a shallow soil layer. One limitation of the traditional indices is that they use a single soil horizon to represent variations in both surface and root zone layers. The new JASMIN system can address gaps in the present operational methods by providing accurate soil moisture information in different layers. The JASMIN has shown to provide good skill in estimating soil moisture at both surface and root zone layers.

Considering the significant effort required to adopt any new source of information in operations, the calibration provides an opportunity to make a substantial improvement to the existing system with the least amount of resources. However, in the longer term, we envisage the adoption of JASMIN soil moisture in its native form for operational fire danger ratings. This will potentially reduce the loss of information arising from any form of calibration. The new Australian national fire danger rating system plans to incorporate JASMIN soil moisture information in its native form to estimate fuel availability.

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