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MITIGATING THE EFFECTS OF SEVERE FIRES, FLOODS AND HEATWAVES THROUGH THE IMPROVEMENTS OF LAND DRYNESS MEASURES AND FORECASTS

Annual project report 2014-2015

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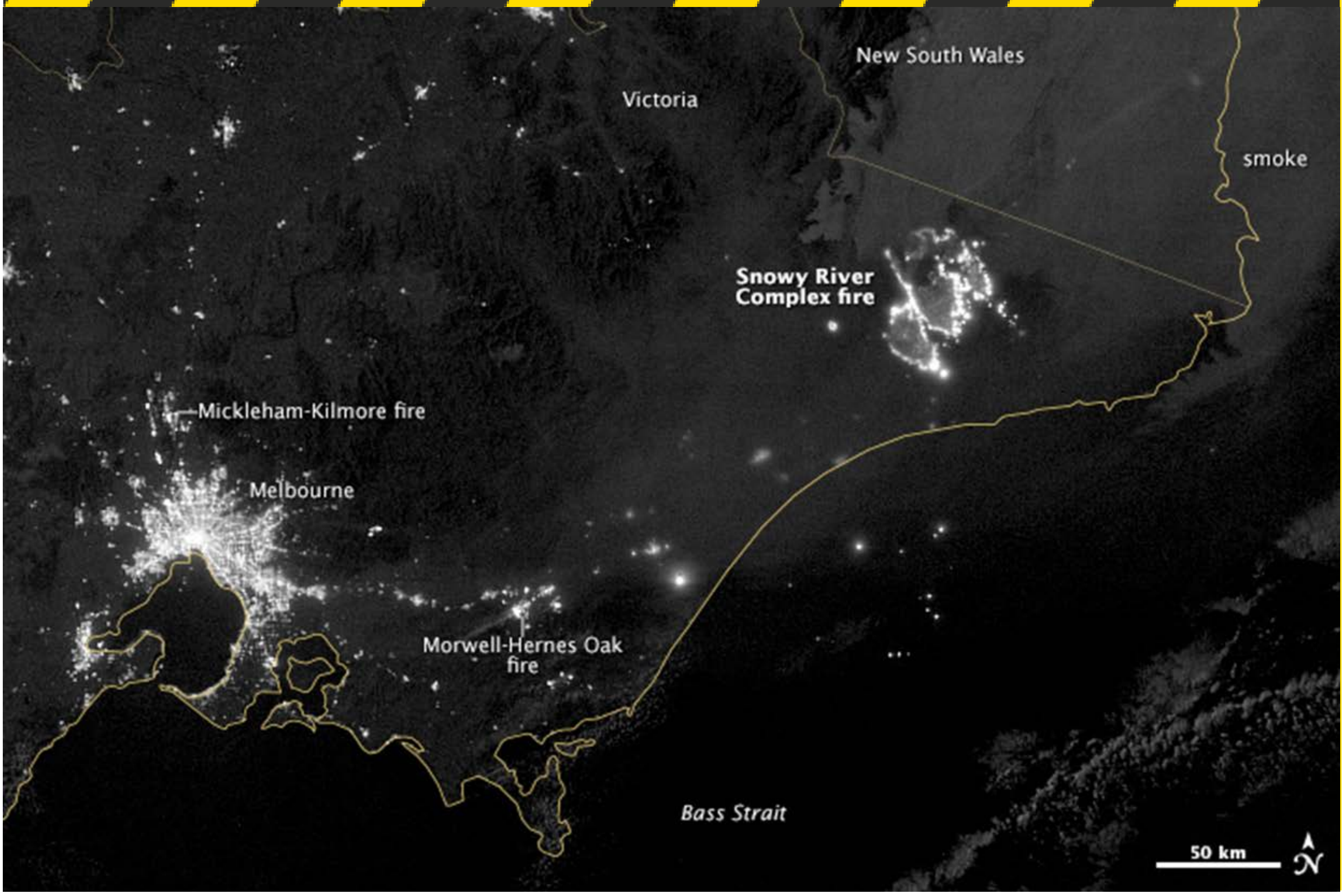

Version	Release history	Date
1.0	Initial release of document	26/10/2015

Australian Government
Department of Industry and Science

Business Cooperative Research Centres Programme

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Publisher:
Bushfire and Natural Hazards CRC

October 2015

Citation: Dharssi I, Kumar V, 2015, Mitigating the effects of severe fires, floods and heatwaves through the improvement of land dryness measures and forecasts: Annual project report 2014-2015, Bushfire and Natural Hazards CRC

Cover: Night time satellite image of a fire in East Gippland, Victoria, showing the fire to be approximately the same size as Melbourne during February 2014.

Source: NASA Earth Observatory

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EXECUTIVE SUMMARY

The Australian people, businesses and environment are all vulnerable to wildfires, floods and other natural hazards. Deloitte Access Economics estimate the 2012 total economic cost of natural disasters in Australia exceeded $6 billion. Some examples of recent extreme events are the Millennium drought spanning from 1998 to 2009, the 2009 Black Saturday bushfires, the 2011 cyclone Yasi and the summer 2010/2011 floods in eastern Australia.

Knowledge of landscape dryness is critical for the management and warning of fires, floods, heatwaves and landslips. This project will address fundamental limitations in our ability to prepare for these events. Currently landscape dryness is estimated using simplified soil moisture accounting systems developed in the 1960's. Similarly, flood prediction, runoff potential and water catchment/dam management also are not using the best available science and technology.

The McArthur Forest Fire Danger Index used in Australia for operational fire warnings has a component representing fuel availability called the Drought Factor (DF). The DF is partly based on soil moisture deficit, calculated as either the Keetch-Byram Drought Index (KBDI) or Mount's Soil Dryness Index (MSDI). The KBDI and MSDI are simplified water balance models driven by observation based daily rainfall and temperature. The KBDI and MSDI models oversimplify the parameterisations of evapotranspiration and runoff leading to significant errors.

A verification study has performed an inter-comparison of the traditional KBDI and MSDI with weather prediction models, satellite measurements and ground based measurements. The verification shows that soil moisture analyses from weather models have greater skill and smaller biases than the KBDI and MSDI. This is despite the weather prediction models having a coarse horizontal resolution and not using observed rainfall. Verification also shows that the remotely sensed Advanced Scatterometer soil wetness product is of good quality. This study suggests that analyses of soil moisture can be greatly improved by using physically based land surface models, remote sensing measurements and data assimilation.

The outputs of this project will improve Australia's ability to manage multiple hazard types and create a more resilient community, by developing a state of the art, world's best practice in soil moisture analysis that underpins flood, fire and heatwave forecasting.

END USER STATEMENT

GARY FEATHERSTON, AUSTRALASIAN FIRE AND EMERGENCY SERVICES AUTHORITY COUNCIL PROJECT BACKGROUND

Knowing the underlying soil moisture is critical in determining fire behaviour and fire danger. This project has the right mix of underpinning science and operational application. The improved soil moisture estimation processes based on models and data assimilation will provide fire agencies nationally with the tool to ``monitor and predict the moisture content of bushfire fuels. This is pivotal to the application of the revised National Fire Danger Rating system.

PAUL FOX-HUGHES, SEVERE WEATHER SECTION, HOBART, BUREAU OF METEOROLOGY PROJECT BACKGROUND

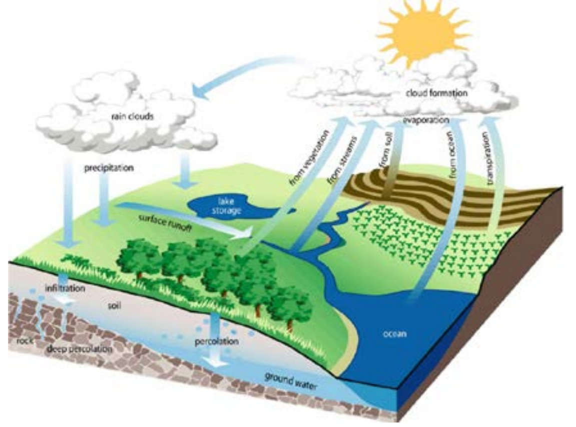
This project stands to contribute some very substantial benefits for emergency and land managers, both directly, through better assessments of soil moisture across the landscape, and Indirectly, by improving the quality of weather and other environmental forecasts. The progress to date has been very encouraging and highlights the advantages of this work, with improved soil moisture estimates already demonstrated.

ROB SANDFORD, DIRECTOR STATE OPERATIONS, SA COUNTRY FIRE SERVICE PROJECT BACKGROUND

With a greater focus on improving community resilience through preparation and planning for bushfire events, this project will improve the accuracy of the likely impact and severity of fires on the community. The further benefits for other hazards including flood and heatwave will again allow the development of greater community resilience and minimise the impacts of these events.

INTRODUCTION

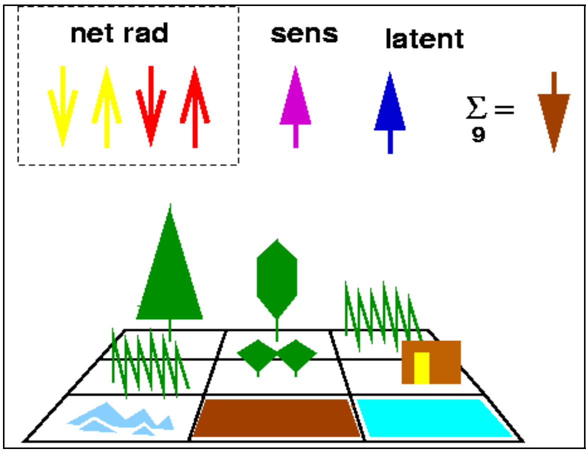
Good estimates of landscape dryness underpin fire danger rating, fire behaviour models, flood prediction and landslip warning. Soil dryness also strongly influences heatwave development by driving the transfer of solar heating from the soil surface into air temperature rise.



Strong positive feedbacks between soil moisture and rainfall give the Earth system a long memory allowing extreme conditions to persist for long periods. Accurate knowledge of soil moisture conditions is crucial for accurate prediction of fires, heatwaves, droughts and floods. Soil moisture is important both for short term forecasting, from a few hours to a few days, as well as long range seasonal forecasting.

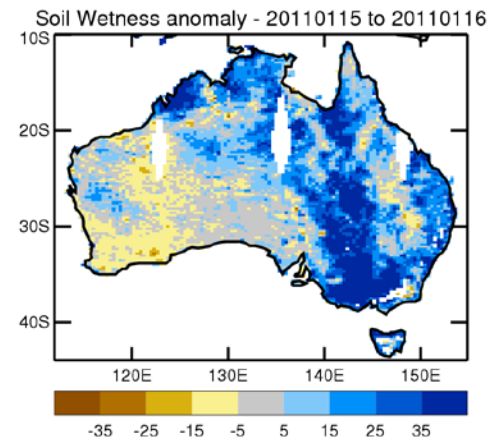
Fire intensity, spread rate and ignition are very sensitive to the fuel dryness which is strongly linked to soil moisture content. For example, Dutta et al. (2013) show using a neural network that knowledge of soil moisture is essential for the accurate prediction of wildfire incidence. Moreover, Gellie et al. (2010) shows that the occurrence of large destructive fires corresponds to very large soil moisture deficit values. Estimates and forecasts of fuel and soil moisture are the foundation of the fire danger calculations used to rate and manage wildfires and to warn of developing fire danger. Similarly estimates and forecasts of soil moisture are essential ingredients to be able to forecast with accuracy river flows on seasonal scales (one to three months), which is very much in demand by water managers and reservoir operators.

Currently landscape dryness is estimated using very crude models developed in the 1960's. The most prominent of those used in Australia are the Keetch-Byram Drought Index (KBDI; Keetch and Byram, 1968) developed by the US Forest Service, and the related Soil Dryness Index (MSDI; Mount, 1972) developed by Forestry Tasmania. These simple empirical soil moisture models are designed for easy hand calculation once per day for a small number of points across the landscape. These empirical calculators do not work effectively in dryer environments, which are typical in the Australian landscape and which are predicted to become more widespread as the climate changes. They do not take into account different soil types, slope, aspect and many other factors. They are poor drivers of the sophisticated fire models used by fire agencies and the Bureau of Meteorology to manage and warn for dangerous fire conditions. Flood prediction, runoff potential and water catchment/dam management also are not using the best available technology and use simplified soil moisture accounting systems.



Modern land models calculate landscape dryness with greater sophistication and account for details such as soil texture, solar insolation, root depth, vegetation type and stomatal resistance. The Australian Community Climate and Earth System Simulator model has four soil layers. The topmost layer from the surface to 10cm is critical for the exchange of moisture between the soil and forest litter fuels. The lowest layer extends down to 3 metres.

The current fire systems only use landscape dryness assuming one soil layer, soil type and vegetation, at one point in the day. It is imperative to the Australian community that the best science and technology that is available to Emergency Management is used effectively and incorporated into warnings systems.



There are few ground based observations of soil moisture and temperature. However, a number of new satellite systems have been launched that can provide information about surface soil moisture, soil temperature and vegetation properties such as leaf area index. The advantage of these satellite systems is that they provide national coverage on a daily timescale. Advanced land data assimilation schemes can be used to blend the satellite measurements with model forecasts.

PROJECT BACKGROUND

RESEARCH PROBLEM

The problems being addressed by this research are:

1. The need to calibrate Numerical Weather Prediction (NWP) and remotely sensed measures of landscape dryness so that they can be incorporated into operational prediction models for fire, flood and water resource management, while maintaining the calibration of the application of the original operational systems.

2. Applying corrections to measures of landscape dryness for a range of natural hazard types to improve the monitoring and prediction of events.

3. Exploring the relationship between soil dryness measures and litter fuel moisture content.

IMPORTANCE OF THIS RESEARCH

This project will address a fundamental limitation in our ability to prepare for fires, floods and heatwaves and is directly linked to pre-event planning as well as forecasting of events. Both of these aspects are core elements of a resilient community. The outputs of this project will improve Australia's ability to manage extreme events by developing a state of the art, world's best practice in soil moisture analysis that makes use of many different sources of observations and cutting edge land surface modelling and data assimilation.

This research will examine the use of detailed land surface models, remotely sensed satellite measurements and ground based observations for the monitoring and prediction of landscape dryness. The new information will be calibrated with the old scheme so that it can be used within existing fire and flood forecasting prediction systems. This will be achieved through partnerships between the fire prediction, numerical weather prediction, climate modelling and flood forecasting communities within the Commonwealth and State agencies, and universities who all require accurate estimates of landscape dryness, delivering research outcomes with wider social and environmental benefits to Australia and the broader community.

RESEARCH METHODOLOGY

In the first year, the work has focused on:

1. Production of a historical dataset of the KBDI and MSDI at 5 km horizontal resolution using analyses of rainfall and maximum temperature. This new gridded dataset of MSDI and KBDI will be compared with the much used, lower 25 km resolution, Finkele-Mills dataset (Finkele et al. 2006) and will be a valuable resource for researchers working on fire climatologies across Australia.

2. Calibration and rescaling of NWP soil moisture measures. This will retain the accuracy, temporal and spatial resolution of NWP based soil moisture without

changing the overall climatology of Fire Danger Index and other calculations based on soil moisture.

3. Inter-comparison of traditional soil dryness models (KBDI, MSDI) with soil moisture/dryness from:

    a. Numerical Weather Prediction models (ACCESS and others);
    b. Satellite measures of landscape dryness;
    c. Ground based soil moisture observations.

A full eight year program will be developed to follow up progress in the first year by:

1. Adaptation of remotely sensed, NWP and numerical seasonal prediction model dryness measures to support operational short and medium time frame forecasts by providing more accurate data of soil moisture deficits and runoff potential.

2. Explore the use of multi-model ensembles to forecast soil dryness indices. This work will support objective risk based forecasts and management of fires by informing emergency managers about the probability of reaching soil moisture thresholds based on a range of weather forecast scenarios.

3. Develop downscaling techniques for landscape moisture measurements and forecasts using a range of statistical and full model based approaches. The benefits will be improved local-scale estimates and forecasts of landscape moisture that better match local soil type and depth, slope, aspect vegetation and other factors.

4. Use data assimilation methods (e.g. Dharssi et al. 2015) to extract the maximum amount of useful information by optimally blending remotely sensed and model land surface data. The only practical way to observe the land surface on a national scale is through satellite remote sensing. Unfortunately, such satellite data is prone to biases and corruption. Therefore, it is essential to quality control and bias correct the satellite data. In addition, satellite measurements are infrequent with measurement repeat times of about one day and contain gaps. Data assimilation can filter the random errors from the satellite measurements and fill in both the spatial and temporal gaps in the measurements.

5. Extend current land surface models to include a wider range of vegetation types, and better matching of model vegetation characteristics to Australian vegetation. Explore the relationship between soil dryness and litter fuel moisture content using land surface models.

6. Calculating a high resolution Fire Danger Index (FDI) dataset based on land surface reanalyses and calibrated, rescaled NWP soil dryness measures. This will supplement the SDI and KBDI datasets and be a valuable resource for other researchers in the Emergency Service sector and at universities working on fire danger climatologies, fire danger rating schemes and fire impact models.

POTENTIAL OUTCOMES

The benefits of this project will be:

- ✓ More accurate, detailed and confident estimates and forecasts of soil moisture, and hence an expectation of more accurate predictions of fire danger and fire behaviour, flood forecasting, landslip warning and heatwave events.
- ✓ Benefits extend from landscape management and fuel reduction burns to the highest intensity wildfires.
- ✓ Benefits extend to water resource management, dam catchment monitoring and function of dams in flood mitigation.
- ✓ Datasets of landscape dryness to support a wide range of other research in fire, flood and heatwave prediction.

VERIFICATION OF SOIL MOISTURE FROM MULTIPLE MODELS OVER AUSTRALIA FOR FIRE DANGER RATING APPLICATION

Australia has a long history of frequent forest fires, owing to its hot and dry climate. The McArthur Forest Fire Danger Index (FFDI; McArthur, 1967) was introduced in 1958 for operational fire warnings over Australia and is still used operationally, albeit with continuous development. The formulation of FFDI is based on air temperature, wind speed, relative humidity, and a component representing fuel availability called the Drought Factor (DF). The DF is defined on the assumption that the fuel moisture content (FMC) is affected by both long term and short term drying effects. The short term drying effects are based on the time since recent rain and past 20 days rainfall amount. The long term drying effects are based on either the Keetch-Byram Drought Index (KBDI; Keetch and Byram, 1968) or Mount's Soil Dryness Index (MSDI; Mount, 1972). KBDI and MSDI are estimates of the cumulative soil moisture deficit (SMD) and represent the degree of drought in the landscape. Studies show that the occurrence of large destructive fires corresponds to very large SMD values. SMD therefore is a key variable in the FFDI calculations with accurate estimates of soil moisture crucial for effective wildfire management, rating and warning. The KBDI is widely used in the Australian states of Victoria, New South Wales and Queensland while MSDI is used in the states of Tasmania, South Australia and Western Australia (Finkele et al., 2006b).

KBDI and MSDI are simple water balance models that do not take into account the majority of physical factors which affect soil moisture dynamics such as soil type, vegetation type, terrain or aspect. They over-simplify the evapotranspiration and runoff processes, which are critical in calculating accurate soil moisture states, leading to large errors. Recent progress in the remote sensing of soil moisture, data assimilation techniques and physically based land surface models has led to the development of new soil moisture products. Two examples of such datasets are the soil moisture analyses produced from the Bureau of Meteorology's operational Numerical Weather Prediction (NWP) system, and remotely sensed soil wetness measurements from the Advanced Scatterometer (ASCAT; Wagner et al., 2013) instrument. This study undertakes an evaluation of the latter two datasets along with KBDI, MSDI and another simple water balance model called the Antecedent Precipitation Index (API; Crow et al., 2005). In-situ observations of soil moisture from the OzNet hydrological monitoring network (Smith et al., 2012) and Australian national cosmic ray soil moisture monitoring facility (CosmOz; Hawdon et al., 2014) are used to validate the modelled and remotely sensed soil moisture datasets.

The verification shows that the NWP soil moisture analyses have greater skill and smaller biases than the KBDI, MSDI and API analyses. This is despite the NWP system having a coarse horizontal resolution and not using observed precipitation. The average temporal correlations between observed and modelled soil moisture are 0.77, 0.62, 0.74 and 0.70 for NWP, KBDI, MSDI and API. Verification also shows that the remotely sensed Advanced Scatterometer soil wetness product is of good quality. This study suggests that analyses of soil moisture can be greatly improved by using physically based land surface models, remote sensing measurements and data assimilation.

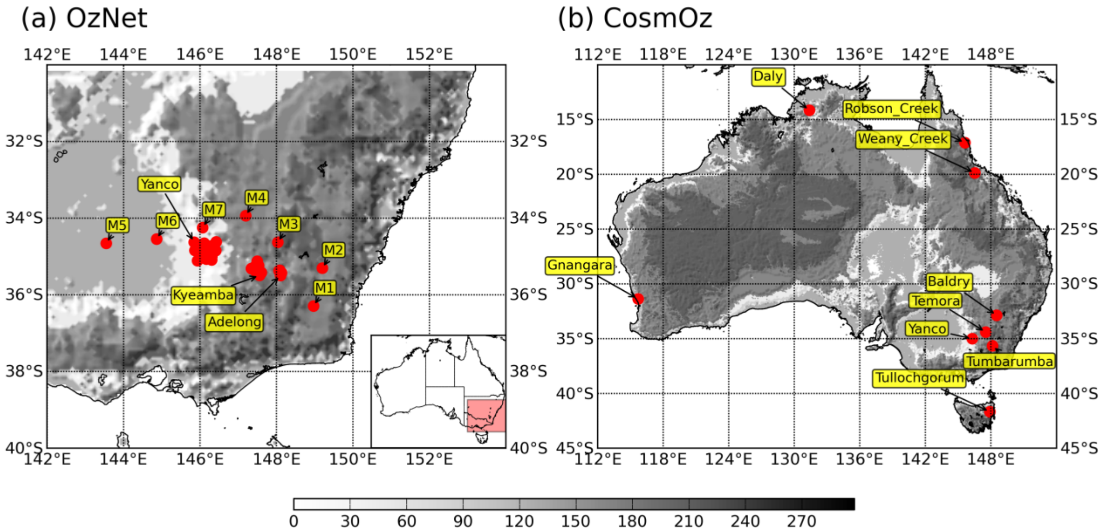


Figure 1: Site locations of (a) OzNet and (b) CosmOz network observing stations. Spatial extent of OzNet is shown by the map of Australia in the inset of (a). The filled contours represent surface elevation (m) at 10 km resolution.

DATA AND METHODOLOGY

This study calculates gridded daily analyses of KBDI and MSDI using the same methodology as Finkele et al. (2006b). The primary difference is that this study calculates KBDI and MSDI at a resolution of about 5 km while Finkele et al. (2006b) calculated KBDI and MSDI at a resolution of about 25 km. KBDI and MSDI are calculated using gridded analyses of daily rainfall and daily maximum temperature from the Australian Water Availability Project (AWAP; Jones et al., 2009).

Keetch-Byram Drought Index. The KBDI (Keetch and Byram, 1968) is a simple water balance model to estimate soil moisture depletion. The assumptions of KBDI are that (i) the rate of moisture loss due to evapotranspiration is a function of vegetation cover density, which itself is an exponential function of mean annual rainfall, (ii) the evapotranspiration rate is also assumed to be an exponential function of the daily maximum temperature, and (iii) the depth of the soil layer is such that the maximum moisture available is 203 mm.

Mount's Soil Dryness Index. MSDI (Mount, 1972) was developed for the Tasmanian Forestry Commission as an alternative to KBDI. Rainfall interception and runoff in MSDI are based on seven vegetation categories. For each vegetation class, parameter values are defined for canopy rainfall interception fraction, canopy storage capacity, canopy loss per wet day, and flash-runoff fraction (Finkele et al., 2006b). The regression coefficients used to calculate evapotranspiration are the same as those used operationally by the Bureau of Meteorology's MSDI calculations.

Antecedent Precipitation Index. API is another simple water balance model (Crow et al., 2005) and is based on the assumption that the amount of moisture in a soil column is related to precipitation at earlier times.

OzNet. The OzNet hydrological monitoring network is managed together by Monash University and University of Melbourne in Australia. Soil moisture observations from the Murrumbidgee river catchment (Fig. 1a; Smith et al., 2012) are available online for the period 2001 to 2011. Soil moisture observations from the top 30 cm are used in this study for comparisons with models. The Murrumbidgee catchment is characterised by significant spatial variability in climate, soil, vegetation and land use.

CosmOz. CosmOz is a network of cosmic ray soil moisture probes established at thirteen locations around Australia. A cosmic-ray probe measures the number of fast neutrons near the land surface. Fast neutrons are strongly moderated by the presence of hydrogen and soil moisture represents the largest and most variable source of hydrogen near the surface. The data processing and calibration methods used by the CosmOz network are described by Hawdon et al. (2014).

NWP Soil Moisture. The operational global NWP system employed by the Bureau of Meteorology is part of the Australian community Climate and Earth System Simulator (ACCESS). The ACCESS Global NWP system first became operational in September 2009 with a horizontal resolution of about 80 km. The ACCESS Global NWP system was updated in March 2012 with an increase in horizontal resolution to about 40 km. The ACCESS Global NWP system does not use observations of precipitation. This study refers to the old ACCESS Global NWP system as ACCESS_80km and the newer ACCESS Global NWP system as ACCESS_40km.

ACCESS NWP incorporates a physically based land surface model (LSM). Both ACCESS_80km and ACCESS_40km use the Met Office Surface Exchange Scheme version 2 LSM. The MOSES2 soil is 3 m thick and is discretised into four layers. ACCESS Global NWP employs a physically based soil moisture nudging technique (Best et al., 2007) that adjusts the model soil moisture to minimise the errors in six hour forecasts. The soil moisture nudging scheme only uses observations of screen level temperature and humidity and doesn't use any remotely sensed observations or any observed precipitation.

The ACCESS_80km soil moisture analyses are only available from 2009 to 2012. ACCESS_40km soil moisture analyses are only available from 2012. ACCESS_40km soil moisture analyses can be compared with CosmOz observations which are available in near real-time (NRT) since 2011.

ASCAT Soil Water Index. The Advanced Scatterometer (ASCAT) instruments on board EUMETSAT meteorological satellites MetOp-A (launched 2006) and MetOp-B (launched 2012) provides NRT estimates of surface soil wetness. A third ASCAT instrument is expected to be launched on the MetOp-C satellite during 2017, thereby providing a continuous and long-term source of NRT soil moisture measurements. This study uses the EUMETSAT NRT 12.5 km resolution product from MetOp-A. The ASCAT surface soil wetness product represents soil moisture in a thin surface layer of ~1 cm thickness (Albergel et al., 2012). However, the in-situ observations and model analyses of soil moisture used in this study are for a deeper layer of soil. Therefore, the exponential filter (Wagner et al., 2013) is applied to the time-series of ASCAT surface soil wetness measurements to approximate the soil wetness profiles (SWI) for a deeper layer of soil.

Verification Metrics. The approach of Albergel et al. (2012) is used to calculate the soil moisture verification statistics. To enable a fair comparison, all soil moisture time-series are normalised between [0, 1] using their own maximum and minimum values from their own long time series, as also done by many other soil moisture verification studies. The anomaly correlations between models and observations are also calculated. Anomalies are computed for each time-series by using a 31-day sliding window.

RESULTS

Verification against OzNet is only carried out for ACCESS_80km, API, KBDI and MSDI, since their temporal availability overlaps with that of the OzNet observations. The verifications statistics are calculated from September 2009 to May 2011 when all the data are available. The evaluation against CosmOz is undertaken for ACCESS_40km, ASCAT, API, KBDI and MSDI. Since ACCESS_40km dataset has the shortest availability, the verification period spans from May 2012 to Dec 2014.

Data Set	Normal Time Series						Anomaly Series	
	Correlation		Bias		RMSD		Correlation	
	OzNe	CosmO	OzNe	CosmO	OzNe	CosmO	OzNe	CosmO
ACCESS 80k	0.72	X	0.02	X	0.19	X	0.68	X
ACCESS 40k	X	0.81	X	-0.03	X	0.15	X	0.68
KBDI	0.60	0.63	-0.39	-0.35	0.43	0.42	0.56	0.28
MSDI	0.71	0.76	-0.02	-0.07	0.23	0.20	0.75	0.50
API	0.66	0.73	0.14	0.14	0.26	0.23	0.71	0.68
ASCAT	X	0.76	X	-0.01	X	0.19	X	0.67

Table 1: Verification scores for the ACCESS NWP models (ACCESS_80km and ACCESS_40km), KBDI, MSDI, API and ASCAT against OzNet and CosmOz in situ soil moisture observations. Scores for both normal and anomaly time series are presented. The values represent an observing network average. The ACCESS_40km uses the dynamic weighting method. A x symbol represents an unavailable value.

Comparison with OzNet. The verification with respect to the OzNet sites is given in Table 1 and represents averages over 30 stations. Results show that ACCESS_80km soil moisture analyses have the best overall agreement with the OzNet soil moisture observations. The ACCESS_80km soil moisture analyses have the smallest bias and RMSD and the highest temporal correlation. KBDI in general display a large wet bias, which suggest that KBDI underestimates evapotranspiration. MSDI shows a small average wet bias, but doesn't systematically exhibit a wet bias at all stations. These results suggest that the MSDI analyses are more accurate than KBDI primarily because KBDI shows a significant wet bias. Figure 2 shows a Taylor diagram comparing model soil moisture against OzNet soil moisture observations at the 30 stations. The model skill, defined as the temporal correlations between observed and modelled soil moisture (R), varies considerably from station to station and no single model is always best or worst. At some observing stations all the models have high skill. Such as station A1 where (R) values are 0.90 (ACCESS_80km), 0.84 (KBDI), 0.87 (MSDI) and 0.71 (API). KBDI has higher skill than the other models at stations M1 and M2. At stations M3, M4, M5, M6, M7, A1, A3, A4, K2 and K3 ACCESS_80km has higher skill than the other models. MSDI has higher skill than the other models at all but one of the Yanco stations and station A5. API has higher skill than the other models at stations A2, K1 and Y13. At station Y13, no model performs particularly well with R values of 0.26 (ACCESS_80km), 0.10 (KBDI), 0.50 (MSDI) and 0.63 (API). Site Y13 is characterised by very few observations.

The short term variation in model soil moisture is assessed through verification of anomaly time-series. Such short term soil moisture variations may be significant for calculation of fire danger, particularly for Australia, where heatwaves can cause rapid drying. Finkele et al. (2006b) find that the DF in FFDI increases too quickly during periods of prolonged dryness after a significant rain event. They show that this problem can be addressed by using SMD rather than past rainfall to calculate short term drying. Mean soil moisture anomaly correlation between model and in-situ observations are presented in Table 1. MSDI has higher anomaly correlation than the other models at 18 OzNet sites, while KBDI has lower anomaly correlation than the other models at 25 OzNet sites. The results suggest that ACCESS_80km is better able to capture the soil moisture seasonal variations rather than the short term variations.

Site	Sensing Depth (m)			Correlation		RMSD		Anomaly Correlation	
	Mean	Max	Min	SW	DW	SW	DW	SW	DW
Baldry	0.22	0.38	0.11	0.89	0.87	0.11	0.13	0.83	0.80
Daly	0.40	0.55	0.16	0.82	0.84	0.13	0.13	0.60	0.61
Gnangara	0.40	0.56	0.24	0.57	0.66	0.21	0.19	0.52	0.66
Rob Creek	0.13	0.21	0.08	0.80	0.82	0.16	0.15	0.40	0.45
Temora	0.17	0.27	0.09	0.90	0.90	0.12	0.13	0.72	0.77
Tullochgorum	0.20	0.47	0.08	0.76	0.75	0.18	0.16	0.66	0.71
Tumbarumba	0.10	0.14	0.06	0.81	0.81	0.16	0.16	0.49	0.54
Weaney Ck	0.23	0.35	0.11	0.74	0.75	0.15	0.17	0.77	0.78
Yanco	0.20	0.37	0.08	0.87	0.88	0.13	0.13	0.76	0.77
Mean				**0.80**	**0.81**	**0.15**	**0.15**	**0.64**	**0.68**

Table 2: Verification scores for normalised ACCESS_40km soil moisture analyses against ground based CosmOz observations. SW (DW) represents the static (dynamic) weighting method.

Comparison with CosmOz. The soil moisture analyses from ACCESS_40km, KBDI, MSDI, API and ASCAT are evaluated against daily average measurements from the CosmOz cosmic ray probes. Although there are a total of 13 sites in the CosmOz observing network, only the nine sites which are fully calibrated and are not subjected to irrigation are selected (Fig. 1b) for this study. Measurements from Gnangara are included even though there are major issues with site calibration (Hawdon et al., 2014). Table 2 shows the verification scores at CosmOz locations using either the static (ACCESS SW) or dynamic (ACCESS DW) weighted ACCESS_40km NWP soil moisture. The scores for ACCESS SW and ACCESS DW are similar at most locations. ACCESS SW only uses information from the top two model soil layers while ACCESS DW can also use information from the third model soil layer, when the CosmOz sensing depth is greater than 0.35 m. The verification shows that ACCESS NWP (ACCESS_40km) soil moisture analyses have the best overall agreement with the CosmOz soil moisture observations. The ACCESS_40km soil moisture analyses have the smallest bias and RMSD and the highest temporal correlation. The results also suggest that ACCESS_40km soil moisture analyses agree more closely with the in-situ observations than ACCESS_80km soil moisture analyses. Since, the difference in temporal correlation between ACCESS_40km and MSDI (0.81 vs 0.76) is greater than the difference in temporal correlation between ACCESS_80km and MSDI (0.72 vs 0.71). 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-predicts the soil moisture deficit substantially, regardless of the climate zone. API, unlike KBDI, exhibits a dry bias at all CosmOz sites. MSDI doesn't exhibit any consistent wet or dry bias. API has similar, but slightly worse, skill to MSDI. API gives an average correlation of 0.73, which is greater than KBDI (0.63) but less than MSDI (0.76). ASCAT skill is generally very good with temporal correlations greater than 0.8, except at the Tumbarumba and Tullochgorum observing stations. The Tumbarumba site is located in a eucalyptus forest and the Tullochgorum site is surrounded by high terrain. ASCAT has difficulties in measuring soil moisture accurately in regions with high vegetation density or complex terrain (Dharssi et al., 2011).

Table 1 shows mean anomaly correlation between CosmOz observations and models. The ACCESS DW, API and ASCAT best captures the short term soil moisture variations. The mean anomaly correlations are 0.68 (API), 0.68 (ACCESS DW), 0.50 (MSDI) and 0.28 (KBDI). The mean anomaly correlation between CosmOz and ASCAT is 0.67. Mean anomaly correlation between KBDI and CosmOz observations is significantly lower than the mean anomaly correlation between KBDI and OzNet observations. Most likely, this is due to sensor locations. The OzNet Y10 site and CosmOz Yanco sites are located nearby and show similar anomaly correlation values. Anomaly correlation values are 0.28 (OzNet Y10 vs KBDI) and 0.31 (CosmOz Yanco vs KBDI).

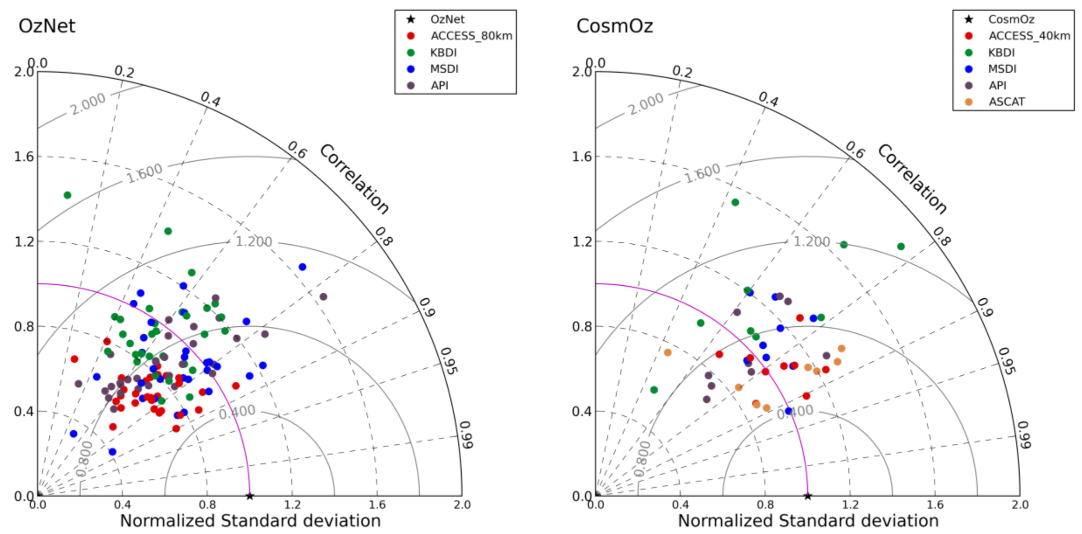


Figure 2: Taylor diagrams. Left Panel shows the verification scores of ACCESS 80km (red dots), KBDI (green dots) and MSDI (blue dots) against soil moisture observations at 30 OzNet observing stations. Right panel shows the verification scores of ACCESS 40km (red dots), KBDI (green dots), MSDI (blue dots), API (greyish purple dots) and ASCAT (orange dots) against soil moisture observations from nine CosmOz sites. ACCESS 40km uses the dynamic weighting method.

CONCLUSIONS

This is the first study to compare and verify KBDI and MSDI against ground based soil moisture observations. It is already widely known that KBDI indicates significantly wetter conditions than MSDI (Finkele et al., 2006b). However, until now, it has not been known which is less accurate. The verification results in this study clearly shows that KBDI has a large wet bias and that MSDI agrees more closely with ground based soil moisture observations. KBDI is found to have a large wet bias at all the OzNet and CosmOz observing stations used for verification. The results also show that overall MSDI has a small wet bias. However, at many observing stations MSDI has a dry bias. Moreover, the verification results show that KBDI and MSDI have limited skill.

This is the first study to verify ACCESS NWP soil moisture analyses against ground based observations. This is also one of the first studies to use CosmOz soil moisture observations for verification. Comparison against observations shows that ACCESS NWP soil moisture analyses have more skill than KBDI and MSDI. This is despite the fact that KBDI and MSDI are computed on a much higher resolution grid and use observation based rainfall and temperature analyses. ACCESS NWP has a much coarser resolution and doesn't use any observations of precipitation. Results show that the ACCESS NWP soil moisture analyses have small biases and are particularly good at capturing the seasonal variations. Results also indicate that the more recent ACCESS_40km model soil moisture analyses agree more closely with the in-situ observations than the older ACCESS_80km model. This is likely to be due to the higher spatial resolution of ACCESS_40km as well as improvements to the model and data assimilation. As well as higher accuracy, the ACCESS NWP system is much more flexible and provides analyses of soil moisture on four clearly defined soil layers over a 3 m depth of soil. In contrast, the simple water balance model outputs are ambiguous since the assumed depth of soil is not clearly defined. Another significant advantage of ACCESS NWP is the ability to produce 10 day forecasts of soil moisture. Such forecasts will be very useful for medium range forecasting of fire risk. Future work is planned to assess the skill of the 10 day soil moisture forecasts. The ACCESS NWP system is in the midst of an upgrade that will increase the horizontal resolution to 25 km.

The best way to improve the analyses of soil moisture for operational fire warnings is to combine the strengths of the different systems. The major strength of ACCESS NWP is that it uses a physically based land surface model and data assimilation which allows ACCESS NWP to accurately capture the soil moisture seasonal variations and minimise biases. The simple water balance models, particularly API, do a good job of capturing the short term soil moisture variations because they have a high spatial resolution and use observations based rainfall and temperature analyses. Therefore, we propose to develop a soil moisture analysis scheme that uses: (i) A physically based land surface model driven by observation based rainfall and temperature, running at a high spatial resolution of about 5 km, (ii) A land surface data assimilation scheme to assimilate remotely sensed observations such as ASCAT.

NEWS

PHD STUDENTS

The project welcomes two new PhD students this year.

Alex Holmes

Alex is studying at Monash University, Melbourne. His supervisors are Dr Chris Rudiger, Professor Nigel Tapper and Dr Imtiaz Dharssi. His research project is *Investigating the effect of Soil Moisture, Temperature and Precipitation Extremes on Fire Risk and Intensity in Australia.* His End user supporters are Mark Chladil, John Bally, Rob Sandford, Liam Fogarty and Paul Fox-Hughes.

Zeinab Yazdanfar

Zeinab is studying at Monash University, Melbourne. Her supervisors are Professor Jeff Walker and Dr Imtiaz Dharssi. Her research project is *Assimilation of ASMR-2 soil moisture and vegetation data into Australian Land Surface models for Natural hazard monitoring and prediction.* Her End User supporter is Dr Paul Fox-Hughes.

SEMINARS, WORKSHOPS AND CONFERENCES

Australasian Fire and Emergency Services Authorities Council (AFAC) Conference 2014

Dr Imtiaz Dharssi gave a talk on *Mitigating the effects of severe fires, floods and heatwaves through the improvements of land dryness measures and forecasts* at AFAC 2014, Wellington, New Zealand.

Australian Energy and Water Exchange Initiative (OzEWEX) Workshop 2014

Dr Imtiaz Dharssi was an invited speaker at OzEWEX 2014, CSIRO Discovery Centre, Canberra and gave a talk on *Are we improving weather forecasts through better initialisation of the land surface state?*
The talk included a description of the work performed for the BNHCRC.

Agricultural Soil Water Workshop 2014

Dr Imtiaz Dharssi and Dr Vinodkumar gave two talks at the Agricultural Soil Water Workshop at the University of Melbourne. Dr Dharssi gave a talk on *Land surface data assimilation for ACCESS and Bushfires and Natural Hazards CRC.* Dr Kumar gave a talk on *Verifying ACCESS soil water against ground based observations (OzNET and CosmOz).*

Bureau of Meteorology R&D Seminar

Dr Vinodkumar gave a presentation titled *Verification of soil moisture from multiple models for bushfire danger rating applications* at Melbourne. The seminar was also open through Video Conferencing to End-users and others at sites outside the Bureau of Meteorology.

PUBLICATIONS LIST

V. Kumar, I. Dharssi, J. Bally, P. Steinle, D. McJannet, and J. Walker, 2015: Verification of soil moisture from multiple models over Australia for fire danger rating application. Water Resources Research, Submitted

Dharssi, I., V. Kumar, C. Yeo, J. Bally, and J. Kepert, 2014: Mitigating the effects of severe fires, floods and heatwaves through the improvements of land dryness measures and forecasts. Australasian Fire and Emergency Service Authorities Council Conference. Wellington, New Zealand

Dharssi, I. and V. Kumar, 2015: Sources of soil dryness measures and forecasts. Australasian Fire and Emergency Service Authorities Council Conference. Adelaide, Australia

V. Kumar and I. Dharssi, 2015: Verification of soil moisture from land surface models and traditional soil dryness indices. Australasian Fire and Emergency Service Authorities Council Conference. Adelaide, Australia

Zeinab, Y., J. Walker, and I. Dharssi, 2015: Towards the assimilation of asmr-2 soil moisture and vegetation data for natural hazard monitoring and prediction. Australasian Fire and Emergency Service Authorities Council Conference. Adelaide, Australia

Holmes, A., C. Rudiger, N. Tapper, and I. Dharssi, 2015: Improving fire risk estimation through investigating fire intensity, moisture and temperature anomalies. Australasian Fire and Emergency Service Authorities Council Conference. Adelaide, Australia

CURRENT TEAM MEMBERS

Imtiaz Dharssi Scientist Centre for Australian Weather and Climate Research	Claire Yeo Scientist Bureau of Meteorology
Vinod Kumar Scientist Centre for Australian Weather and Climate Research	Jeff Walker Scientist University of Monash
Alex Holmes PhD Student Monash University	Jeff Kepert Scientist Centre for Australian Weather and Climate Research
Zeinab Yazdanfar PhD Student Monash University	Peter Steinle Scientist Centre for Australian Weather and Climate Research
John Bally Lead End User Bureau of Meteorology	Adam Smith Scientist Bureau of Meteorology
Adam Leavesley End User ACT Parks	Ian Grant Scientist Bureau of Meteorology
Paul Fox-Hughes End User Bureau of Meteorology	
Mark Chladil End User Tasmania Fire Service	
Rob Sandford End User Country Fire Service, South Australia	
Ralph Smith End User Department of Fire and Emergency Services, Western Australia	
David Taylor End User Parks Tasmania	

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