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

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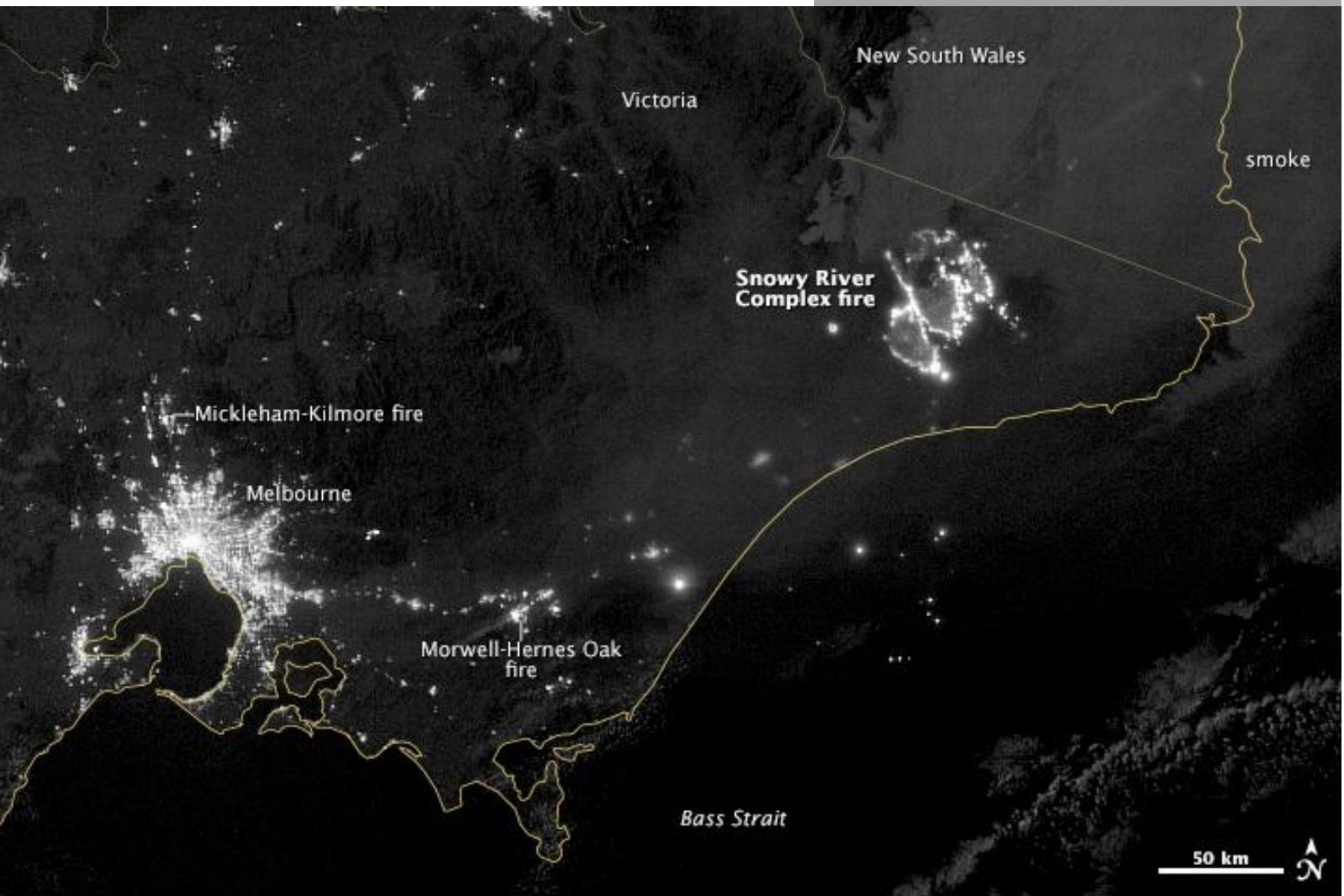
Mitigating the effects of severe fires, floods and heatwaves through the improvements of land dryness measures and forecasts.



Imtiaz Dharssi et al.,
Centre for Australian Weather and Climate Research

Cover Image: Night time satellite image of a city sized fire in Victoria, Australia during February 2014. Source NASA Earth Observatory.

Summary

The Australian people, businesses and environment are all vulnerable to wildfires, floods and other natural hazards. A recent Bureau of Meteorology study concludes that extreme weather events cost the Australian economy about $65 Billion every year. 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. A recent United Kingdom Meteorological Office report concludes that investment in weather services provides an at-least seven fold return.

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.

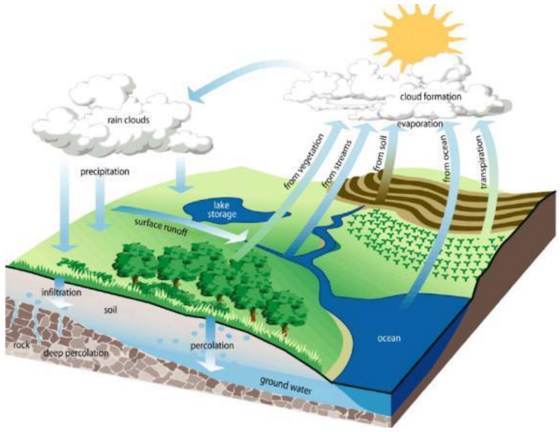
This research will examine the use of detailed land surface models, satellite measurements and ground based observations for the monitoring and prediction of landscape dryness. The new information will be calibrated for use within existing fire and flood forecasting systems.

An inter-comparison will be performed of the traditional Keetch-Byram Drought Index and Soil Dryness Index with weather prediction models, satellite measurements, ground based measurements, and rainfall-runoff models. Soil moisture from weather prediction and reanalysis will be calibrated for the calculation of a high resolution historical dataset of KBDI and SDI. These datasets will be a valuable resource for researchers working on fire climatologies across Australia. 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.

Longer term work will explore the use of multi-model predictions and data assimilation to forecast soil dryness indices for operational application to fire, flood and heat wave hazards. The vegetation and soil parameterisations in current land surface models will be developed to match Australian conditions.

1. 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.

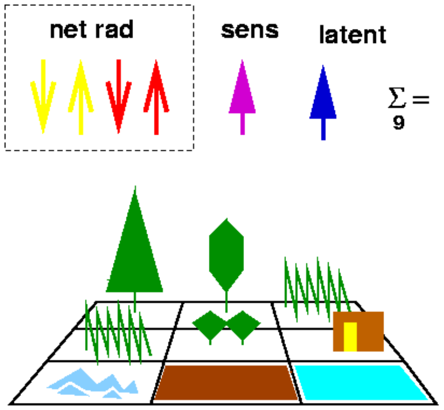


Strong positive feedbacks between soil moisture and rainfall give the Earth system a long memory allowing extreme conditions to persist for long periods. Accurate knowledge of soil moisture conditions is crucial for accurate prediction of fires, heatwaves, droughts and floods. Soil moisture is important 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. 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 a seasonal scales (one to three months), which is very much in demand by water managers and reservoir operators.

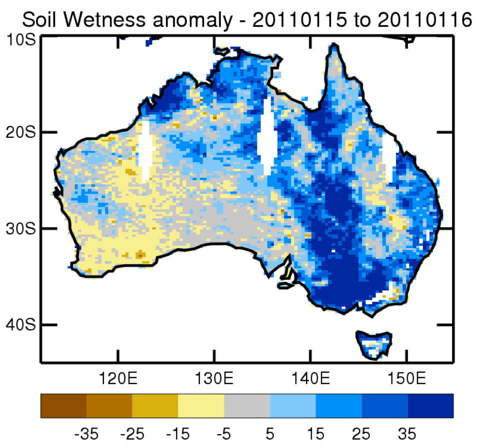
Currently landscape dryness is estimated using very crude models developed in the 1960’s. The most prominent of those used in Australia are the Keetch-Byram Drought Index (KBDI; Keetch & Byram 1968) developed by the US Forest Service, and the related Soil Dryness Index (SDI; Mount 1972) developed by 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 is predicted to become worse 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 as the science is out-dated and has been verified as not effective in fire spread prediction. 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 Numerical Weather Prediction (NWP) systems also calculate landscape dryness. For example, the Australian Community Climate and Earth System Simulator (ACCESS; Puri et al. 2013) NWP system uses 5 vegetation classes, 4 non-vegetation surface types and 3 soil texture classes. The ACCESS NWP model soil moisture is adjusted each model run, every six hours, to better match the recent history of surface air temperature and moisture patterns.

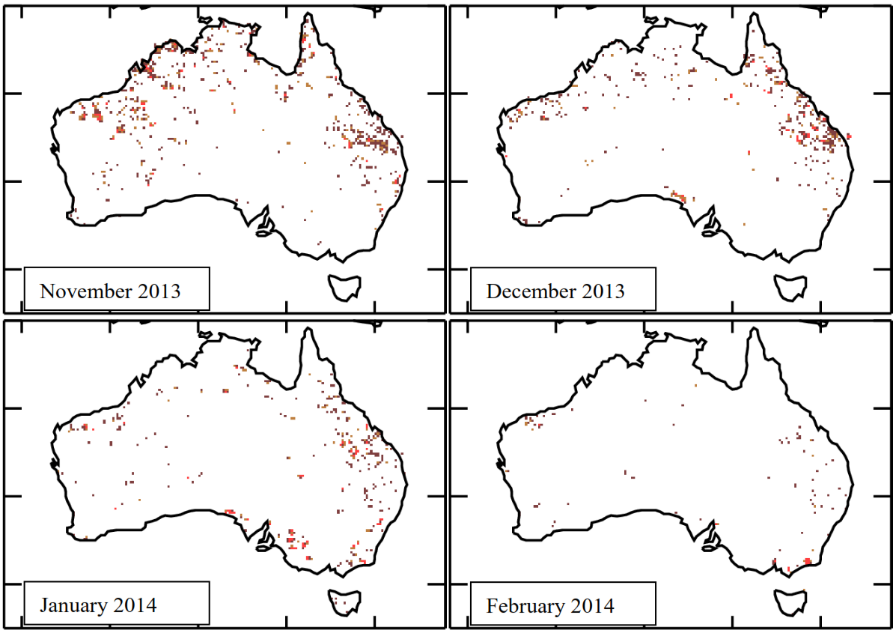


Modern land models calculate landscape dryness with greater sophistication and account for details such as soil texture, solar insolation, root depth, vegetation type and stomatal resistance. The Australian Community Climate and Earth System Simulator model has four soil layers. The topmost layer from 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 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.



Active fire detected by the NASA Moderate Resolution Imaging Spectroradiometer instrument.

2. Project objectives

The problems being addressed by this research are:

1. The need to calibrate 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.

In the first year, the work will focus on:

1. 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.
2. Inter-comparison of traditional soil dryness models (KBDI, SDI) with soil moisture/dryness from:

   a. Numerical Weather Prediction models (ACCESS and others);
   b. Satellite measures of landscape dryness;
   c. Water resource assessment models (Australian Water Resources Assessment and Australian Water Availability Project/WaterDyn);
   d. Rainfall-runoff models used for flood and river flow prediction; and in situ measurements of soil moisture.

3. Produce a historical dataset of the KBDI and SDI from reanalysis. This new gridded dataset of SDI and KBDI will be compared with the much used Finkele-Mills dataset (Finkele et al. 2006) and will be a valuable resource for researchers working on fire climatologies across Australia.

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. 2013) 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.

Proposed strategy

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.

3. 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.

4. Project News

The current status of the project is that the contract between the Bureau of Meteorology and the Bushfire and Natural Hazard CRC (BNHCRC) to initiate and fund this project was signed on 29 May 2014. Funds from this project will support one science researcher to work full time on this project. Dr Vinod Kumar was recruited for this project in June 2014. Dr Kumar has good experience of land surface science and data analysis methods and has worked for the Bureau of Meteorology since 2012. The project management plan has been finalised.

Dr Dharssi, Professor Jeff Walker, Dr Jeff Kepert, Dr John Bally, Dr Paul Fox-Hughes, Adam Leavesley and Rob Sandford attended the BNHCRC research advisory forum held in Adelaide during March 2014. There were three days of wide ranging discussions between the science researchers and the end users. Dr Dharssi explained that the project priority is to produce operational ready products that would be of direct benefit to the end user community. The end users explained their priorities and explained that they wanted an operational ready system operating on a national scale with near real- time daily updating. Dr Dharssi, Professor Jeff Walker, Dr Adam Smith and Dr Ian Grant attended a soil moisture workshop at Monash University, Melbourne during July 2014. This workshop allowed science researchers from all over Australia to discuss their projects and find opportunities to collaborate and avoid any duplication of effort. Dr Dharssi will attend the AFAC/BNHCRC conference to be held at Wellington, New Zealand in September 2014 and give a talk describing this BNHCRC project.

5. Project Team

Imtiaz Dharssi, Scientist, Centre for Australian Weather and Climate Research Vinod Kumar, Scientist, Centre for Australian Weather and Climate Research John Bally, Lead End User, Bureau of Meteorology

Adam Leavesley, End User, ACT Parks

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 Use,r Department of Fire and Emergency Services, Western Australia

David Taylor, End User, Parks Tasmania Claire Yeo, Scientist, Bureau of Meteorology Jeff Walker, Scientist, University of Monash

Jeff Kepert, Scientist, Centre for Australian Weather and Climate Research Peter Steinle, Scientist, Centre for Australian Weather and Climate Research Adam Smith, Scientist, Bureau of Meteorology

Ian Grant, Scientist, Bureau of Meteorology

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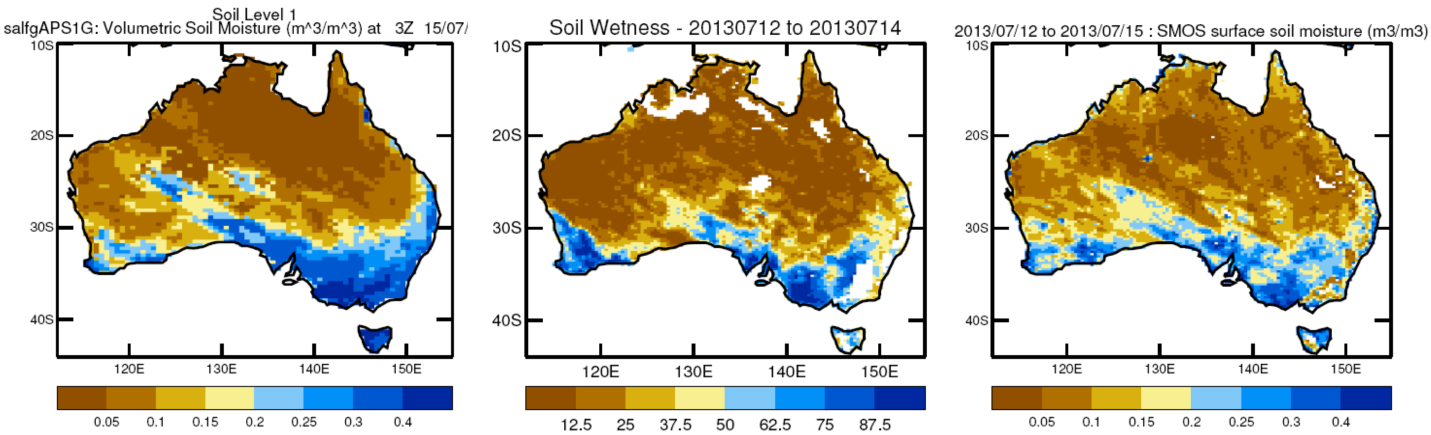

Comparison of Model surface soil moisture (left) with ASCAT surface soil wetness (middle) and SMOS (Soil Moisture Ocean Salinity) surface soil moisture (right).