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High resolution passive microwave response to landscape controls influencing soil moisture patterns: A case study for the Livingstone Creek Catchment

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Abstract:

The 46km^2 Livingstone Creek Catchment in south-eastern Australia was flown with a passive microwave airborne remote sensor (Polarimetric L-band Multibeam Radiometer, PLMR) as part of the National Airborne Field Experiment in 2006 with a spatial resolution of ~ 200m. The catchment was experiencing extreme drought conditions leading up to the experiment and as a result ground cover in the catchment was minimal with many paddocks consisting of sparse dry stubble and grass. The PLMR image captured surface wet soil moisture conditions after a 30mm rainfall event. This paper looks at the conceptualizations of our current understanding of landscape controls that influence the soil moisture patterns in the landscape. Passive microwave is becoming more widely available on various satellite platforms, and will be a valuable data source for catchment water balance and climate change science modelling. Downscaling of passive microwave satellite imagery data is the current challenge. The use of the high resolution PLMR data flown in this study allows for examination of the current data sources that provide surrogate information on terrain, land cover and soil properties that could potentially be used in downscaling procedures. Three indexes were used for a visual comparison. (1) A weathering index (2) Topographic Wetness Index (TWI) and (3) SPOT satellite imagery for land cover. The weathering index matched certain areas of the PLMR data where it was known that the soil properties were driving the soil wetness patterns. The topographic wetness index represented broad areas of hilly landscapes from flat alluvial areas in the PLMR images. The land cover appeared to show localised areas of high contrast in PLMR image however these areas are generally vegetated with trees as the landforms are steep with shallow infertile soils. It is proposed that further studies will look at multi criteria analysis of terrain and land cover indexes to try and find the correct mix of variables needed to represent the PLMR images so that downscaling studies from coarser PLMR data can occur.

Keywords: *PLMR, Soil Moisture, NAFE, downscaling*

1. INTRODUCTION

Understanding soil moisture distribution patterns allows for the different water storage characteristics of catchments to be identified and modelled, increasing our understanding of process connectivity for water balance studies, and weather forecasting as soil moisture significantly drives weathering patterns. Current methods for mapping soils use multiple techniques as no individual technique can adequately identify all the processes that lead to soil formation and distribution. These methods usually consist of sourcing existing surrogate information such as geological maps, utilising aerial photography and remote sensing techniques, and field mapping. Remote sensing techniques for mapping soils range from multi-spectral scanning, airborne gamma-ray spectrometry, hyper-spectral remote sensing, gravity, electromagnetics, and radiometrics (Papp, 2002). All these methods measure different physical characteristics of the regolith, from mineralology to reflectance and conductance properties. Previous studies have demonstrated the benefits of using passive microwave data for estimating soil hydraulic properties as it is sensitive to moisture variations (Peters-Lidard *et al.* 2007, Santanello *et al.* 2007, Mattikalli *et al.* 1998). With additional surrogate information on terrain, soil properties, rainfall patterns and vegetation cover, downscaling of the original data is possible (Reichle *et al.* 2001) allowing for increased application potential at catchment scales. The high resolution PLMR data used in this study is providing a unique opportunity to identify which terrain indices should be explored to assist downscaling techniques. Recent studies with this PLMR data have shown that changes in moisture responses observed by the airborne passive microwave sensor were field verified to reflect the different geology, soil, and landform elements of the catchment (Summerell et al 2008).

Gwangseob and Barros (2002) indicated that (1) topography appeared to be the dominant spatial structure of soil moisture during and immediately after rainfall, (ie slope, aspect (solar radiation) landscape position etc) followed by (2) the soil moisture evolving into patterns that reflected soil hydrological properties, (ie Soil/regolith type - porosity and permeability characteristics) and then finally (3) vegetation dominating the soil moisture patterns through evapotranspiration as the landscapes dry down. Aspects of (1) and (2) will be explored in this paper. Figure 2 shows the common conceptualisation of factors effecting soil moisture characteristics.

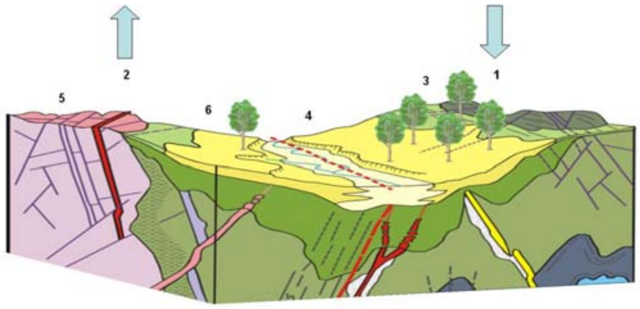

Figure 1. Factors influencing soil moisture 1. Rainfall amount and intensity 2. evaporation 3. Transpiration 4. landforms (position in landscape, aspect and slope) 5. Regolith/soil type (porosity and permeability) 5. geology (structure and fabric)

1. STUDY AREA

The Kyeamba Creek catchment is south east of Wagga Wagga in central New South Wales, Australia. It covers an area of 600 km^2 and flows into the Murrumbidgee River. The major surface drainage features are Kyeamba, O’Briens and Livingstone Creeks. Average annual rainfall is 650 mm, with a gradient decreasing from the highlands in the south to the confluence with the Murrumbidgee River in the north. Land use is dominated by cattle grazing, limited sheep grazing and some pasture irrigation. The geology of the area is characterised by granitoids in the higher regions of the catchment, and deformed metasediments in the lower regions.

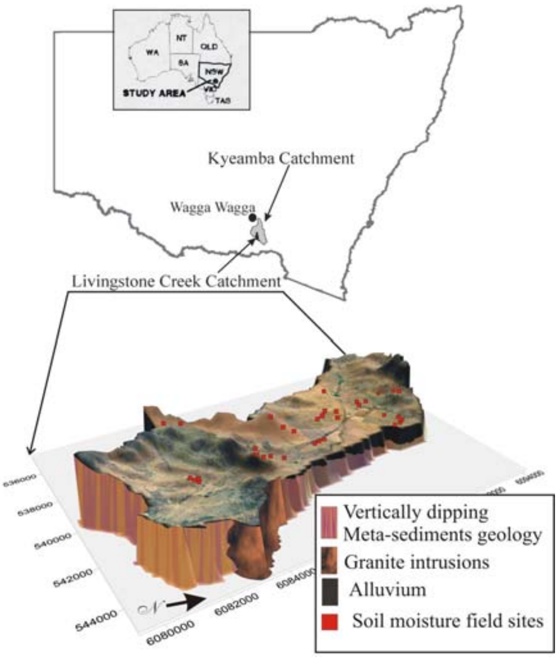

Figure 2. Location of the Kyeamba Creek and Livingstone Creek catchments showing the major geologies and field verification soil moisture sites.

2. DATA

The data used in this study was the high resolution PLMR microwave brightness mounted onboard a small aircraft during the National Airborne Field Experiment in 2006 (NAFE’06; Merlin et al. 2008) and was field verified at soil moisture sampling sites. The focus study area for this paper is the Livingstone Creek sub-catchment (see Figure 2), which covers an area of 46km^2. The landforms, geology, vegetation and landuse in Livingstone creek are common to the whole Kyeamba Creek catchment.

The PLMR used in this study measured both vertical (v) and horizontal (h) polarisations at incidence angles +/–7°, +/–21.5° and +/–38.5° in across track configuration. For this study the (h) polarisation was used as it is best suited to soil moisture sensing (Njoku *et al.* 2002). As the flight occurred within a 2 hour period during the day when temperature variation was minimal there was no need to correct for temporal variations in temperature.

Airborne gamma-ray radiometrics is a passive remote sensing technique that measures the natural emission of gamma-ray radiation from the upper 30 cm of the earth’s surface. The principle gamma-ray emitting isotopes used in airborne geophysical surveys are ^{40}K, and the ^{232}Th and ^{238}U decay series. These are used to estimate potassium, thorium and uranium abundances respectively. Gamma rays emitted from the earth’s surface mainly relate to the mineralogy and geochemistry of the bedrock and weathered materials (eg. soils, saprolite, alluvial and colluvial sediments). Gamma-ray imagery therefore provides a surface geochemical map showing the distribution of the radionuclides in rocks and soil.

The 25m resolution DEM used in this study was supplied by the NSW Land Information Centre (NSW LIC 1999) and used for processing of the terrain indices TWI using standard GIS procedures.

3. METHODS

Data acquired by PLMR was processed for the whole of the Livingstone Creek catchment and was converted to a common incidence angle by using the ratio of each PLMR beam average to the beam 1 average (7^{o}) multiplied by the actual beam observation.

The radiometric data was processed to derive a surface geochemical weathering index over the study area using the method described by Wilford *et al.* (2007.). During weathering or regolith/soil formation the concentration of radioelements are altered from there primary bedrock source. In general K is leached during weathering (assuming the bedrock contained K originally) whereas Th and U tend to increase due to their affinity with iron oxides and clays in the weathering profile. The index highlights these relationships to predict the intensity of surface weathering. Highly weathered granites and metasediments in the Kyeamba catchment are more clay rich with associated high water holding capacities than less weathered landscapes.

The Topographic Wetness Index (TWI) of Beven and Kirkby [1979] was calculated. It aims to represent water flow paths across the landscape and hence is often used as a surrogate for soil moisture potential.

Recently captured SPOT satellite imagery was visually assessed to look for any correlations between vegetation cover and soil moisture responses.

4. RESULTS AND DISCUSSION

The PLMR images used for this study were flown immediately after 30 millimetres of rain (Figure 3). Summerell *et al.* (2008) showed an area of metasediment geology where Chen and McKane (1996) mapped out two separate soil landscapes during field surveying and aerial photo interpretation. These are “li” the Livingstone landscape and “ly” the Lloyd landscape. The “li” soil landscape is typically more resilient to weathering with a lot more quartz material and shallower soils, while the “ly” is more weathered with deeper soils. The PLMR brightness temperature pattern has reflected these soil landscapes with the “li” soil landscape unit, showing a drier signal than the “ly” unit which is reflective of the soil types and their water retention properties (Figure 4). However detailed soil landscape mapping is not widely available to allow this to be used as a common data set especially for downscaling. The detail of the weathering index (Figure 3) does not appear to have a strong catchment wide correlation with the PLMR however in certain areas it is picking up some of the spatial patterns of the soil landscapes (Figure 4) where as described above the soil properties are influencing the soil moisture characteristics. The TWI index (Figure 3) is showing general areas such as the alluvial flats compared to the hill slopes. At the southern end of the catchment a SPOT image was used to indicate land cover. Very strong contrasting patterns in vegetation from very bare (white colours) to vegetated (green colours) do appear in some areas on the PLMR brightness image (Figure 5). Although the heavily vegetated areas are stands of trees on shallow rocky and less fertile soils which in turn relates to landscape processes.

5. CONCLUSIONS

The flights of PLMR (200m) over the Livingstone Creek catchment after 30mm of rainfall have shown strong spatial relationships with features within the catchment. This study has started to assess high resolution terrain / geophysical / land cover to soil moisture with the aim of determining appropriate data sets to be used to downscaling coarser PLMR data. The weathering index showed some areas where it represented soil wetness well, and at these locations it was identified that soil properties were the driver for the wetness conditions. The TWI index appeared to disseminate the hilly areas from the flats. Vegetation cover did appear to explain some of the more contrasting changes in the PLMR image but not the generalized patterns throughout the catchment. The next challenge will be to objectively assess these and other terrain and land cover attributes against the soil moisture PLMR data most likely in a multi criteria approach. This will then be use downscale coarse 1km^2 PLMR data over the Kyeamba valley (also flown by the NAFE campaign). Eventually the process will be applied to passive microwave data from satellite platforms that have even larger pixel sizes. This study appears to be following the downscaling process identified by Reichle *et al.* (2001). In countries like Australia that are experiencing increased drought effects from climate change, better mapping of soil water availability will significantly improve scientific development for natural resource management such as catchment water balance, soil and wind erosion modeling, and ultimately weather forecasting. Passive microwave is a remote sensing technique that is capable of this task and is becoming more widely available on various satellite platforms. Sensible downscaling procedures will be the limiting factor to the successful use of such data.

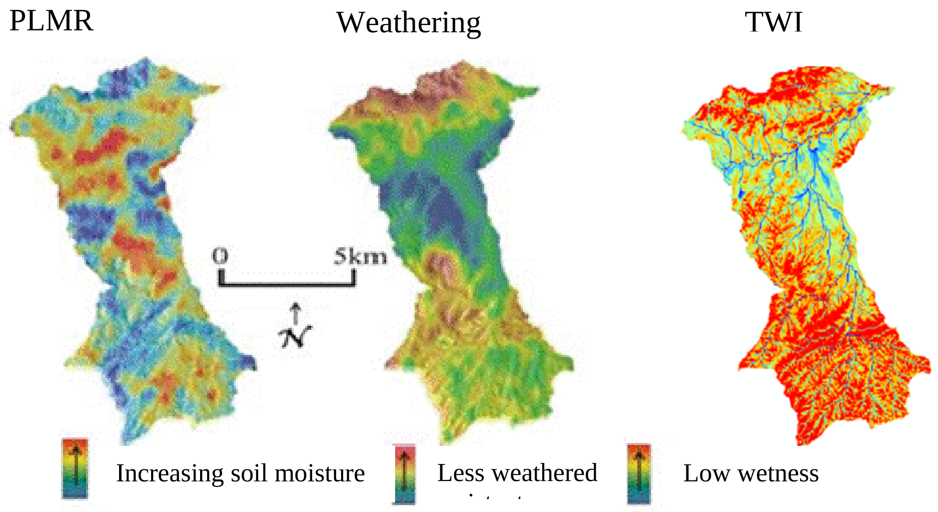

Figure 3. PLMR brightness of soil moisture compared to the weathering index and TWI.

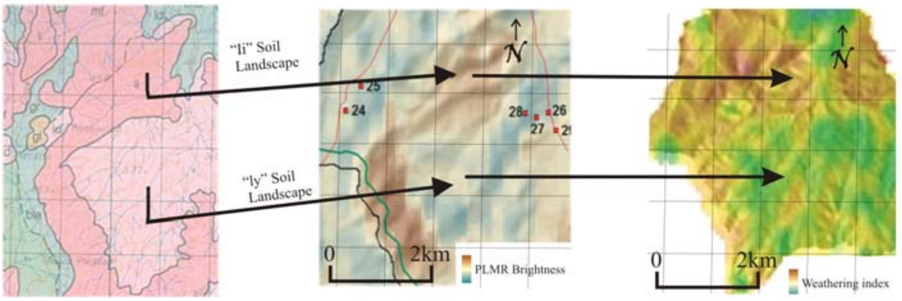

Figure 4. Different soil landscapes within the same metasediment geology are reflecting soil moisture and temperature differences. Image to the left is from the soil landscapes of the Wagga Wagga 1:100, 000 map sheet. (Chen and McKane 1996). Image in the middle is the PLMR brightness temperature on the after 30mm of rainfall. Image to the left is the weathering index. (Modified from Summerell *et al.* 2008).

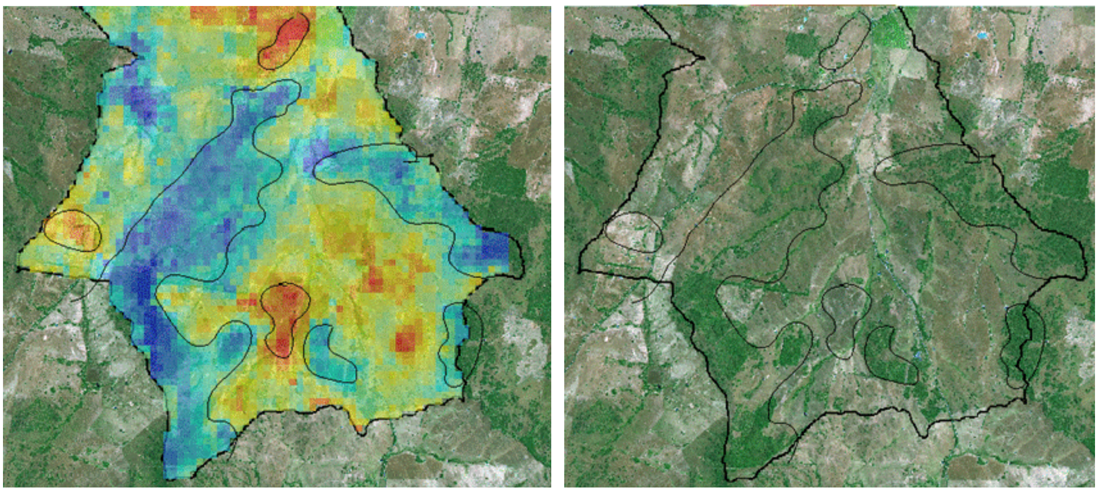

Figure 5. Assessing the impacts of vegetation on PLMR brightness (Blues in this image to the right are drier, redder colours are wetter).

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