Estimating Soil Moisture at High Spatial Resolution with Three Radiometric Satellite Products: A Study from a South-Eastern Australian Catchment

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Abstract

Long-term soil moisture datasets at high spatial resolution are important in agricultural, hydrological, and climatic applications. The soil moisture estimates can be achieved using satellite remote sensing observations. However, the satellite soil moisture data are typically available at coarse spatial resolutions (˜ several tens of km), therefore require further downscaling. Different satellite soil moisture products have to be conjointly employed in developing a consistent time-series of high resolution soil moisture, while the discrepancies amongst different satellite retrievals need to be resolved. This study aims to downscale three different satellite soil moisture products, the Soil Moisture and Ocean Salinity (SMOS, 25 km), the Soil Moisture Active Passive (SMAP, 36 km) and the SMAP-Enhanced (9 km), and to conduct an inter-comparison of the downscaled results. The downscaling approach is developed based on the relationship between the diurnal temperature difference and the daily mean soil moisture content. The approach is applied to two sub-catchments (Krui and Merriwa River) of the Goulburn River catchment in the Upper Hunter region (NSW, Australia) to estimate soil moisture at 1 km resolution for 2015. The three coarse spatial resolution soil moisture products and their downscaled results will be validated with the in-situ observations obtained from the Scaling and Assimilation of Soil Moisture and Streamflow (SASMAS) network. The spatial and temporal patterns of the downscaled results will also be analysed. This study will provide the necessary insights for data selection and bias corrections to maintain the consistency of a long-term high resolution soil moisture dataset. The results will assist in developing a time-series of high resolution soil moisture data over the south-eastern Australia.

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1. INTRODUCTION

- Soil moisture is a key variable in a number of environmental processes. Therefore, soil moisture data plays an important role in hydrological, climatic and agricultural applications.
- SMOS (launched in Nov-2009) [1] and SMAP (launched in Jan-2015) [2] are two recent missions dedicated to soil moisture mapping. Both SMOS and SMAP consist of 1.4 GHz L-band radiometers. SMAP radar (1.26 GHz) failed after ~3 months of operation. Both missions have a 3-day revisit time and an expected accuracy of RMSE = 0.04 m^3/m^3 V.
- The point-scale in-situ observations and coarse resolution (~10s of km) satellite soil moisture products are unable to capture the high spatial variability of soil moisture as required by many of its regional-scale applications. Therefore, downscaling satellite soil moisture products is often required.
- A long-term dataset of high spatial resolution soil moisture can assist in improving the outputs of a number of regional-scale applications.
- Soil moisture products of multiple satellites are required in developing a long-term time-series of high spatial resolution soil moisture dataset. However, soil moisture products of different satellites exhibit inconsistencies due to the differences in their spatial resolutions, band widths, retrieval algorithms, overpass times, penetration depths, etc.

(Source: NASA)

2. OBJECTIVES

This study focusses on downscaling three satellite soil moisture products; **SMAP 36-km, SMAP enhanced 9-km and SMOS 25-km**, into 1 km resolution across the Krui and Merriwa River catchments in the Upper Hunter Region of, New South Wales, Australia over 2015.

This work includes:

I. Validation of the coarse-resolution satellite soil moisture products with the in-situ data.

II. Inter-comparison of the satellite soil moisture products.

III. Downscaling the satellite soil moisture products and validation of the downscaled data.

3. THERMAL INERTIA THEORY

- Thermal inertia relationship between the diurnal soil temperature difference (ΔT) and the daily mean soil moisture ($\theta\mu$) has been used in this work to downscale coarse-scale satellite soil moisture products.
- Thermal inertia (TI) is a property that characterizes the degree of resistance of a body to the change of its surrounding temperature. TI is a function of the material's density (ρ), thermal conductivity (K) and specific heat capacity (c). i.e. $TI = \sqrt{\rho.K.c}$ [3].
- Presence of moisture increases the thermal inertia of soil. Therefore, higher the soil moisture content, lesser the diurnal temperature difference of soil (ΔT) [4]. This relationship between $\theta\mu$ and ΔT has been employed in this study to estimate soil moisture at high spatial resolution.

3. THE STUDY AREA – GOULBURN RIVER CATCHMENT

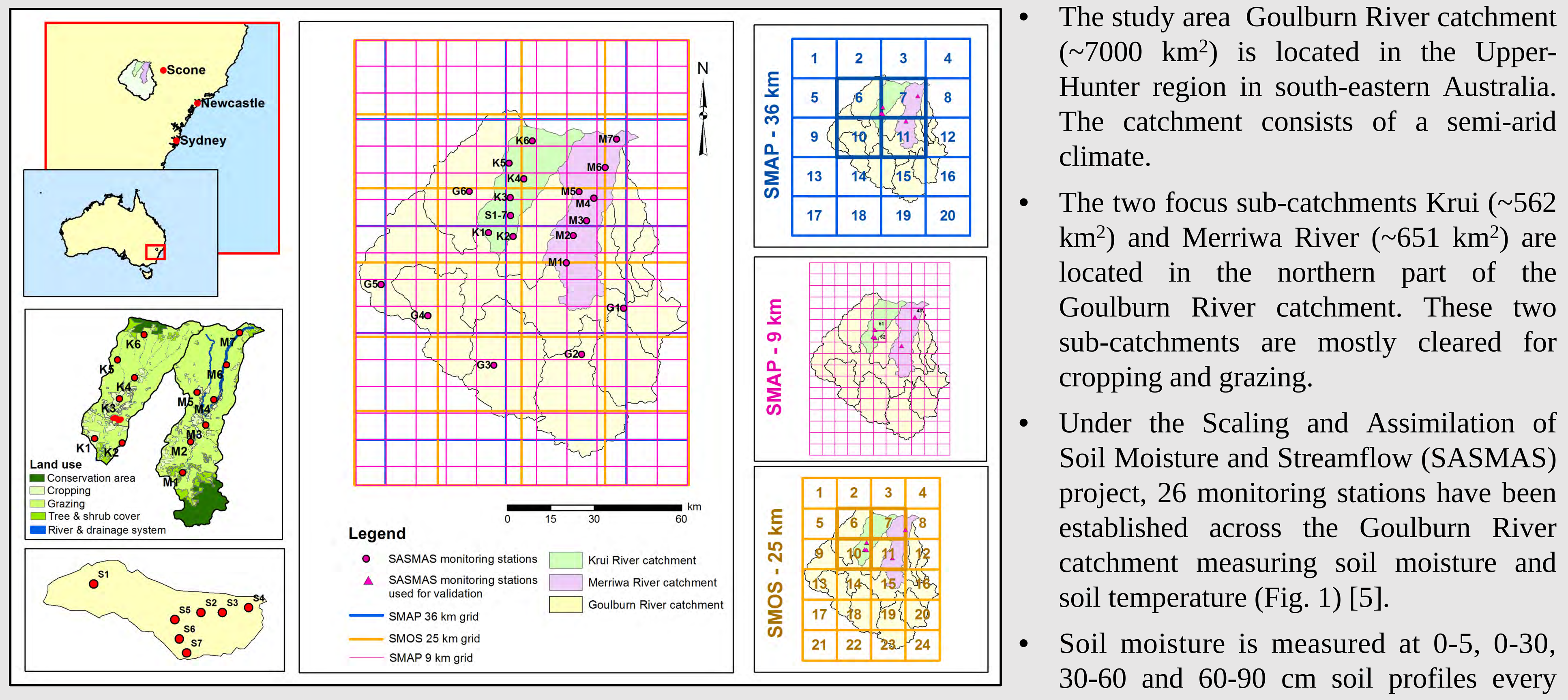

Fig. 1: The study area, Goulburn River catchment and SASMAS soil moisture monitoring stations along with SMAP 36 km, SMAP-E 9 km and SMOS 25 km grids.

- The study area Goulburn River catchment (~7000 km^2) is located in the Upper-Hunter region in south-eastern Australia. The catchment consists of a semi-arid climate.
- The two focus sub-catchments Krui (~562 km^2) and Merriwa River (~651 km^2) are located in the northern part of the Goulburn River catchment. These two sub-catchments are mostly cleared for cropping and grazing.
- Under the Scaling and Assimilation of Soil Moisture and Streamflow (SASMAS) project, 26 monitoring stations have been established across the Goulburn River catchment measuring soil moisture and soil temperature (Fig. 1) [5].
- Soil moisture is measured at 0-5, 0-30, 30-60 and 60-90 cm soil profiles every minute and averages are logged at every 20 minutes. The dataset is available from 2003 to 2015 with some data gaps.

4. DATA AND METHODOLOGY

4.1 Data

- **SMAP (L3_SM_P) data (2015/2016)**
  - Soil moisture (36 km resolution) (θ_{SMAP})
  - *National Snow and Ice Data Center (NSIDC)*
- **SMAP (L3_SM_P_E) data (2015/2016)**
  - Soil moisture (9 km resolution) ($\theta_{SMAP\text{-}E}$)
  - *National Snow and Ice Data Center (NSIDC)*
- **SMOS (L3 SM 3-DAY) data (2015/2016)**
  - Soil moisture (25 km resolution) (θ_{SMOS})
  - *Centre Aval de Traitement des Données SMOS (CATDS)*
- **MODIS (MYD11A1) data (2015)**
  - Day and Night Land Surface Temperature (LST) data (1 km resolution)
  - *Land Processes Distributed Active Archive Center (LP DAAC)*
- **MODIS (MYD13A2) data (2003-2015)**
  - 16-Day NDVI data (1 km resolution)
  - *Land Processes Distributed Active Archive Center (LP DAAC)*
- **SASMAS in-situ data (2003-2015)**
  - Daily mean soil moisture ($\theta\mu$) (0-5 cm soil profile)
  - Diurnal Soil Temperature difference (ΔT) (0-5 cm soil profile) ($\Delta T = T_{13:30} - T_{01:30}$)
  - *http://www.eng.newcastle.edu.au/sasmas/SASMAS/sasmas.htm*
- **National Soil and Landscape Grid**
  - Clay content (90 m resolution)
  - *Commonwealth Scientific and Industrial Research Organisation (CSIRO)*

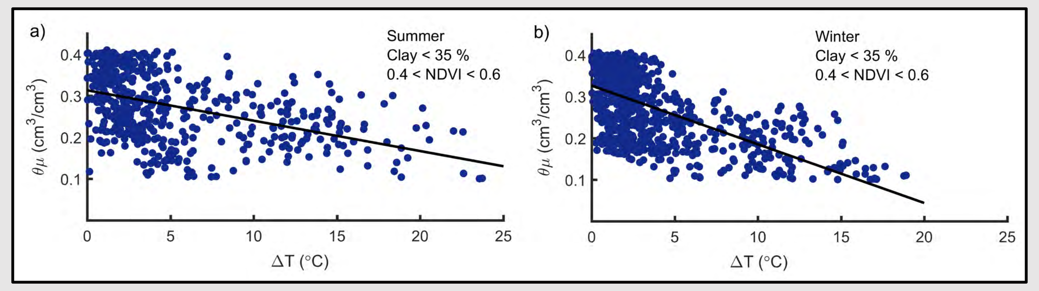

Fig. 2: Linear regression fits developed for the summer and winter with soil clay content< 35% and 0.4< NDVI< 0.6.

4.2 Methodology

Validating SMAP and SMOS soil moisture products by using SASMAS in-situ data.

↓

Inter-comparison between SMAP and SMOS soil moisture products.

↓

Bias correction of SMOS 25-km soil moisture products.

$$AdjSMOS = (SMOS - \mu SMOS) + \mu SMAP$$

↓

Developing $\Delta T - \theta\mu$ regressions using SASMAS in-situ data. Regressions were classified into 24 classes based on NDVI, season and soil clay content [4].

Season: *Spring, Summer, Autumn, Winter*

NDVI: *NDVI<0.4, 0.4<NDVI<0.6, NDVI>0.6*

Soil clay content: *Clay<35%, Clay>35%*

↓

Calculating ΔT values using MODIS LST products.

↓

Estimating $\theta\mu$ values at 1 km by fitting the ΔT values into regression tree algorithms.

↓

Downscaling satellite soil moisture products.

$$\theta_{ds}(x,y) = \theta_{est}(x,y) + [\theta_{sat} - \frac{1}{N}\sum_{x,y}\theta_{est}(x,y)]$$

↓

Downscaling satellite soil moisture products and validation.

5. RESULTS

5.1 Comparison between satellite soil moisture products and SASMAS in-situ observation

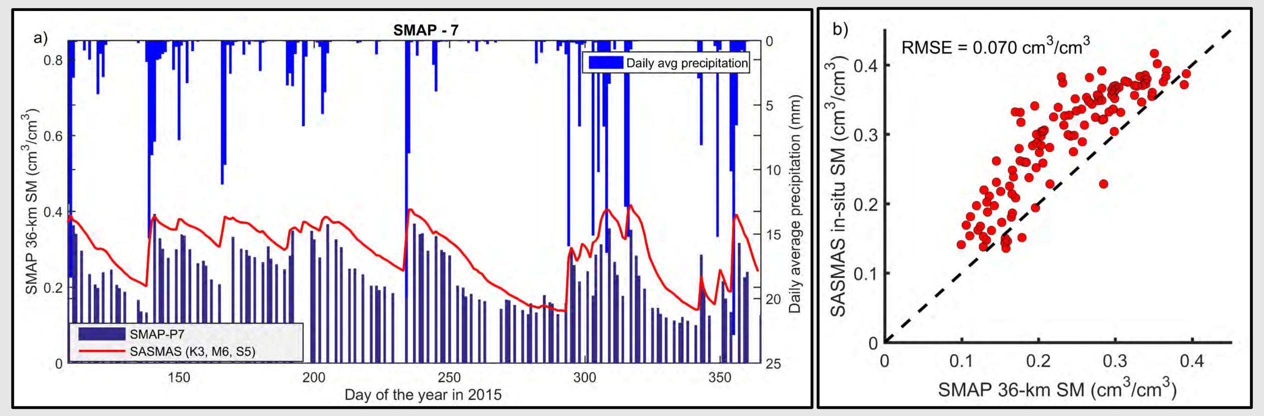

Fig. 3: a) Agreement between SMAP 36-km soil moisture products and SASMAS in-situ data at SMAP 36 km pixel no. 7. b) Comparison between SMAP 36 km soil moisture products and SASMAS in-situ observation.

Table 1: Comparison between coarse-resolution satellite soil moisture products and SASMAS in-situ observations over Krui and Merriwa River catchments in 2015.

Satellite soil moisture product	RMSE (cm^3/cm^3)	Pixel number
SMAP 36-km	0.07	SMAP-7
SMAP-E 9-km	0.10, 0.06, 0.05	SMAP-E 43, 51, 62
SMOS 25-km	0.22	SMOS-10

5.2 Inter-comparison between satellite soil moisture products

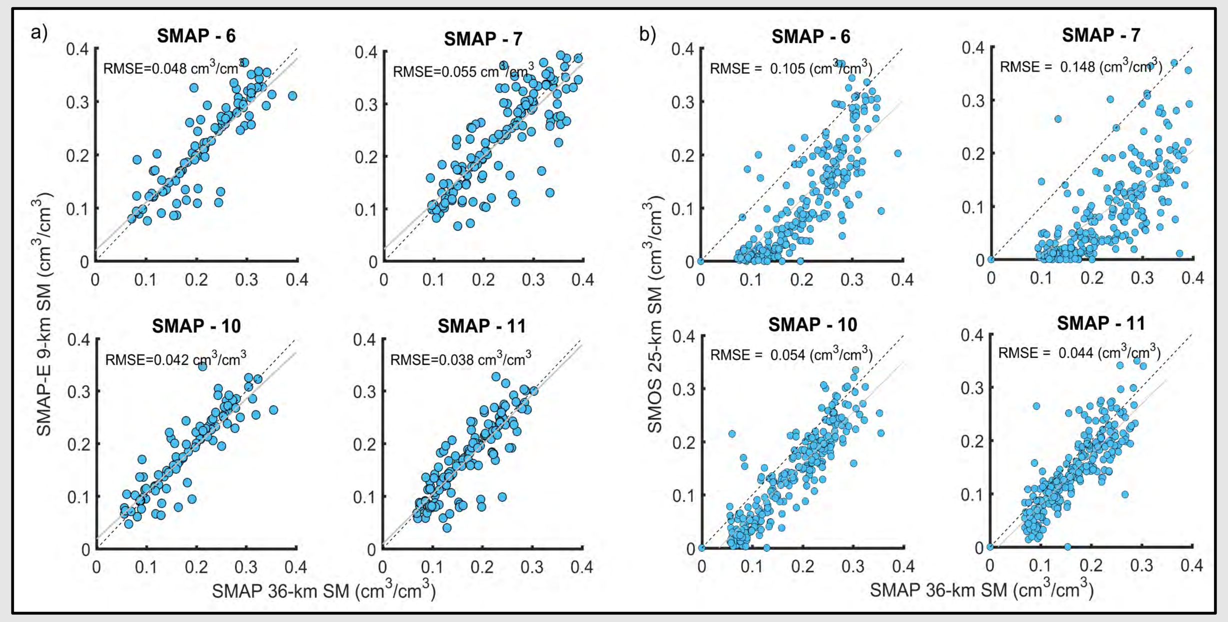

Fig. 4: Inter-comparison between a) SMAP 36 km and SMAP-E 9 km, b) SMAP 36 km and SMOS 25 km soil moisture products across Krui and Merriwa River catchments in 2015/16.

Table 2: Inter-comparison between coarse-resolution satellite soil moisture products across Krui and Merriwa River catchments in 2015/16.

Satellite soil moisture products	RMSE (cm^3/cm^3)	Pixel number
SMAP 36 km - SMAP 9 km	0.048 0.055 0.042 0.038	SMAP-6 SMAP-7 SMAP-10 SMAP-11
SMOS 25 km - SMAP-E 9 km	0.144 0.144 0.146 0.147	SMOS-6 SMOS-7 SMOS-10 SMOS-11
SMAP 36 km - SMOS 25 km	0.105 0.148 0.054 0.044	SMAP-6 SMAP-7 SMAP-10 SMAP-11
SMAP 36 km - Adj. SMOS 25 km	0.071 0.100 0.046 0.057	SMAP-6 SMAP-7 SMAP-10 SMAP-11

5.3 Validating downscaled soil moisture products

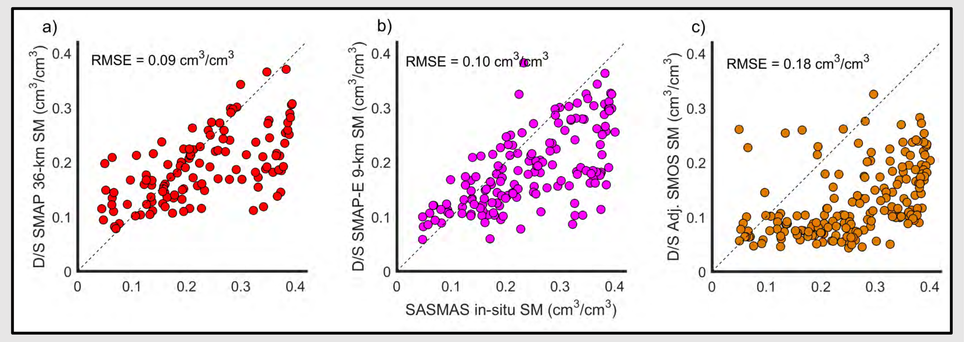

Fig. 5: Validation of downscaled a) SMAP 36 km, b) SMAP-E 9 km and, c) Adjusted SMOS 25 km, soil moisture products using SASMAS in-situ observations in 2015.

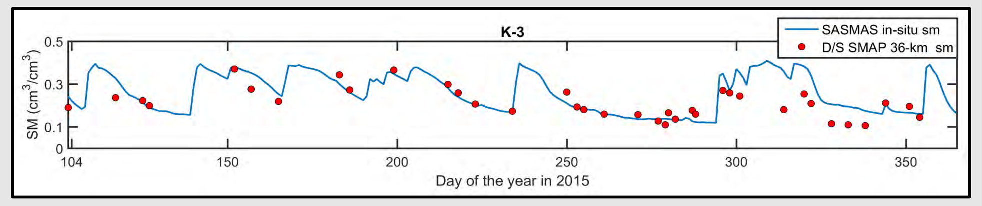

Fig. 6: Agreement between downscaled SMAP 36 km soil moisture ,data and SASMAS in-situ observations at K-3 station.

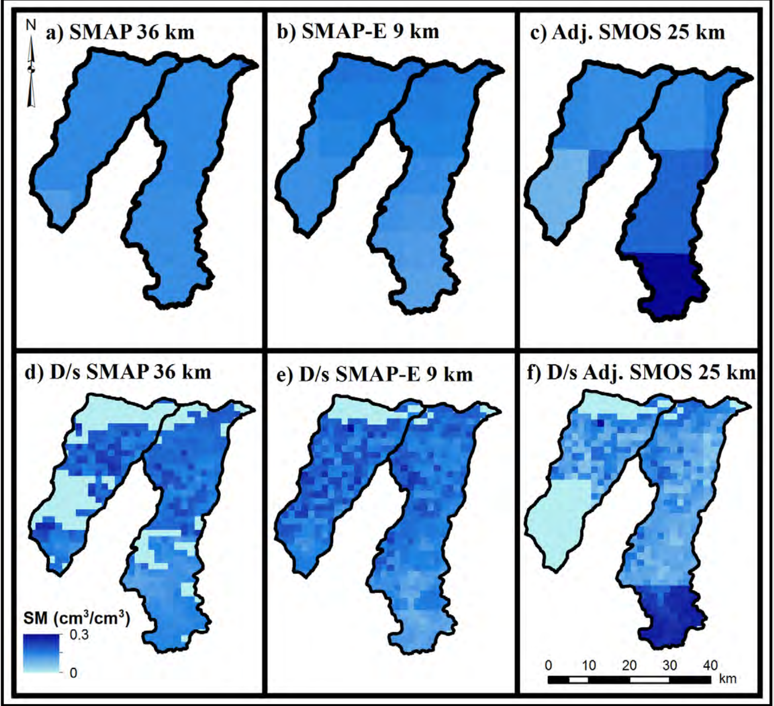

Fig. 7: Spatial variability of soil moisture across Krui and Merriwa River catchments as captured by;

a) SMAP 36-km,
b) SMAP-E 9-km,
c) Adjusted SMOS 25-km,
d) downscaled SMAP 36-km,
e) downscaled SMAP-E 9-km, and
f) downscaled adjusted SMOS data,
on 28th June 2015.

6. CONCLUSIONS

- SMAP soil moisture products exhibit a good correlation with SASMAS in-situ observations (avg. RMSE= 0.07 cm^3/cm^3). SMOS soil moisture products exhibits a general under-estimation over the study area compared to in-situ data (0.22 cm^3/cm^3).
- The accuracy of the downscaled data is highly dependent on the accuracy of the coarse-resolution satellite soil moisture products.
- Downscaled soil moisture products were able to capture the spatial variability of soil moisture in more detail.
- Unavailability of high resolution in-situ observations for validation and the data gaps due to the effect of the cloud cover on MODIS LST data can be identified as two major limitations.
- Future studies will be focussed on improving the regression algorithms and on applying the algorithms over other soil moisture monitoring fields in south-eastern Australia.

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