Remote Sensing of Environment 215 (2018) 33–43

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Surface rock effects on soil moisture retrieval from L-band passive microwave observations

N. Ye[a], J.P. Walker[a,*], C. Rüdiger[a], D. Ryu[b], R.J. Gurney[c]

[a] Department of Civil Engineering, Monash University, Australia
[b] Department of Infrastructure Engineering, University of Melbourne, Australia
[c] Environmental Systems Science Centre & National Centre for Earth Observation, University of Reading, United Kingdom

ARTICLE INFO

Keywords:
Passive microwave
Soil moisture
Remote sensing
Rock fraction
SMOS
SMAP

ABSTRACT

The L-band (1.41 GHz) passive microwave remote sensing technique is the approach used by the first satellites dedicated to soil moisture measurement, the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS), and the Soil Moisture Active Passive (SMAP) mission developed by the National Aeronautics and Space Administration (NASA). These satellites aim to provide global soil moisture maps for the top ~5 cm layer of soil with an accuracy better than 0.04 m^3/m^3. However, with a passive microwave observing resolution of ~40 km, non-soil targets such as surface rock may possibly confound the brightness temperature observations and degrade the accuracy of retrievals for many SMOS and SMAP pixels across the world. Since the microwave contribution of rock is not well accounted for in current soil moisture retrieval algorithms, simply ignoring its existence may be detrimental to the performance of resultant soil moisture products. Using a combination of model simulations and airborne field campaign data from central Australia, this study has determined that a rock cover fraction threshold of up to 0.4 can be tolerated before the 0.04 m^3/m^3 soil moisture target accuracy is potentially exceeded under extreme dry or wet conditions. However, this threshold reduces to 0.2 when assessed in terms of a brightness temperature impact > 4 K. These rock fraction thresholds have subsequently been applied to the Ecoclimap rock cover map, identifying the SMOS and SMAP pixels globally that are likely to be adversely affected if rock is unaccounted for. The results show that approximately ~3.3% of all SMOS and SMAP pixels may have brightness temperature impacts exceeding 4 K from surface rock, with Asia being the most affected, having ~6.0% affected pixels. These values reduce to ~1.5% of SMOS and SMAP pixels globally, and ~3.1% for Asia, when assessed in terms of soil moisture errors expected to possibly exceed 0.04 m^3/m^3 when not accounting for surface rock.

1. Introduction

Soil moisture is a key variable in global water, energy, and carbon cycling, which is fundamental to hydrology, meteorology, and agriculture (Sellers et al., 1997). Due to its high variability in time and space, it is difficult to measure or predict the spatial and temporal distribution of soil moisture at regional and global scales (Crow et al., 2012; Ryu and Famiglietti, 2006). However, the first satellite dedicated to measuring global soil moisture was launched on November 2nd, 2009. This Soil Moisture and Ocean Salinity (SMOS) mission, led by the European Space Agency (ESA) in collaboration with the Centre National d'Etudes Spatiales (CNES) in France and the Centro para el Desarrollo Tecnologico Industrial (CDTI) in Spain, measures soil water content in the top ~5 cm soil every 2 to 3 days with a target accuracy of better than 0.04 m^3/m^3, using a 2-D interferometric radiometer operating at L-band (1.413 GHz; Kerr et al., 2010). Likewise the National Aeronautics and Space Administration (NASA) developed the Soil Moisture Active Passive (SMAP) mission to measure soil moisture using a combination of L-band (1.41 GHz) radiometer and L-band (1.26 GHz) radar to increase the resolution of soil moisture products from 40 km to 10 km (Entekhabi et al., 2010). Since the approach was to first downscale the brightness temperature measurements according to the spatial patterns in the radar data, with the soil moisture then retrieved using the standard passive microwave algorithms, any errors in the radiometer data at the native resolution would be carried through to the higher resolution products. Even though the radar unfortunately malfunctioned shortly after launch, this same issue applies to the alternative downscaling approaches currently being proposed.

The passive microwave remote sensing technique has been adopted for soil moisture measurement as it is unaffected by cloud, has a direct

* Corresponding author.
E-mail address: jeff.walker@monash.edu (J.P. Walker).

https://doi.org/10.1016/j.rse.2018.05.025
Received 12 September 2017; Received in revised form 24 May 2018; Accepted 25 May 2018

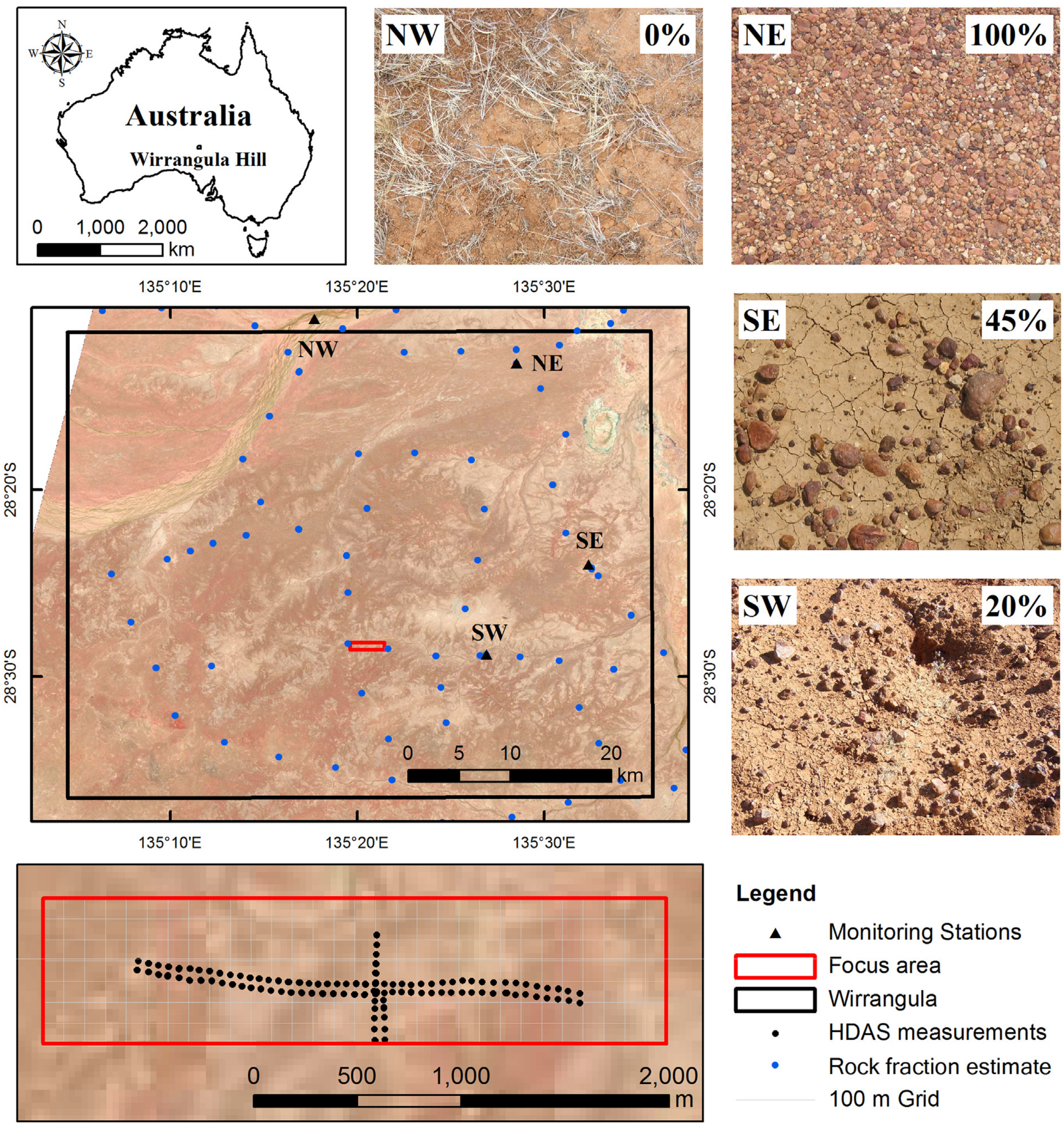

Fig. 1. Location of the Wirrangula Hill study area within Australia (top left), the focus area (red box, middle left), temporal monitoring stations (black triangles, middle left), and the HDAS measurements (black dots, bottom left). Also shown are ground level photographs of the land surface at the monitoring stations as labelled in the top left corner of each picture. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

relationship with soil moisture through the soil dielectric constant, and has a reduced sensitivity to land surface roughness and vegetation canopy, compared with optical, infrared, and active microwave techniques (Jackson and Schmugge, 1989; Njoku et al., 2002). However, the spatial resolution of L-band space-borne radiometer measurements is restricted by the size of antenna, meaning that a resolution on the order of ~40 km is achieved based on the current level of antenna technology. For the SMOS mission, 69 elementary radiometers are distributed along three Y-shaped arms of 4.5 m in length, to produce an elliptical shaped footprint of ~43 km in size using synthetic aperture techniques. In contrast, the SMAP mission uses a rotating mesh antenna of 6 m (20 ft) in diameter to directly observe a single brightness temperature of ~40 km spatial resolution.

The volumetric soil moisture of each SMOS and SMAP radiometer pixel is subsequently retrieved from the brightness temperature observations through the use of radiometric transfer models. Although the SMOS soil moisture retrieval algorithm is capable of three different surface types (bare soil, vegetated soil, and forest) within the SMOS footprint (Kerr et al., 2010; Kerr et al., 2012), the accuracy of the SMOS and SMAP soil moisture retrieval will suffer from land surface heterogeneity at such a coarse scale. In addition, the impacts of surface rock, standing water, and urban areas within the sensor's field of view have not been well studied and accounted for in the current soil moisture retrieval models, causing an uncertainty in the soil moisture retrieval accuracy (Delwart et al., 2008). While a few model simulation studies have been performed to explore the rock cover fraction threshold for the SMOS target soil moisture accuracy of 0.04 m^3/m^3 (Kerr et al., 2010; Loew, 2008), there has been no rigorous assessment of the expected rock impact globally. The rock fraction thresholds of 0.11 and 0.15–0.20 were obtained from Kerr et al. (2010) and Loew (2008)