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High-Resolution Near-Surface Soil Moisture Mapping for Precision Irrigation Using a UAV

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Abstract: Population growth and acceleration of climate change have severely impacted the world's global water supply and its availability for irrigation. Precision irrigation enables efficient irrigation management; however, it requires timely and accurate high-resolution near-surface soil moisture information. Passive microwave remote sensing at L-band is well recognized for soil moisture monitoring but current satellite missions such as SMOS and SMAP are limited by their coarse spatial resolution. This study demonstrates a UAV-mounted Polarimetric L-band Single-beam Radiometer (PLSR) with thermal infrared sensing for high-resolution (10 m) near-surface soil moisture mapping. Multi-angular (0° and 40°), dual-polarized brightness temperature observations were employed to concurrently retrieve near-surface soil moisture and vegetation optical depth, reducing the need for ancillary inputs. Two physically-based retrieval strategies, snapshot and time-series, are compared to identify the more robust approach, while a machine learning approach is also explored to evaluate its potential for near-surface soil moisture estimation as compared to physically-based models.

Keywords: *Soil moisture, UAV, passive microwave radiometry, machine learning, precision irrigation.*

1. INTRODUCTION

Global population growth and climate change threaten the world's limited freshwater resources, with irrigation responsible for ~70% of global freshwater withdrawals (Campbell et al. 2017). Automatic precision irrigation enables precise application of just the right amount of water to the soil and crops at the desired location but relies on timely and accurate near-surface (top 5 cm) soil moisture information. Passive microwave remote sensing, especially at L-band (1.4 GHz), has been recognized as the most efficient technique for soil moisture monitoring due to its all-weather capability and direct sensitivity to soil dielectric properties (Entekhabi et al. 2014). Current satellites such as SMAP (Soil Moisture Active-Passive) and SMOS (Soil Moisture and Ocean Salinity; Kerr et al. 2010) provide global coverage but at coarse (40 km) spatial resolution every 2 to 3 days. Fortuitously, using a radiometer at lower altitudes (30 m), such as from a UAV (Unmanned Aerial Vehicle), high (10 m) spatial resolution can be achieved on a daily basis.

One challenge for passive microwave soil moisture mapping is the need for ancillary data such as soil surface roughness, vegetation water content, and soil temperature, which are crucial in the soil moisture retrieval models, and acquiring them can be laborious, time consuming and spatial extrapolation may be uncertain. Using multiconfiguration measurements (dual-polarization, multi-angular, multi-temporal), ancillary information about the soil and vegetation may be retrieved concurrently with the near-surface soil moisture (known as the N-parameter retrieval), hence reducing the need for ancillary datasets. Consequently, this study investigates the use of multiconfiguration passive microwave observations from a UAV-based L-band radiometer to enable concurrent retrieval of near-surface soil moisture and vegetation optical depth, thereby reducing reliance on ancillary datasets and improving retrieval accuracy.

2. METHODOLOGY AND RESULTS

The Polarimetric L-band Single-beam Radiometer (PLSR) was integrated with a UAV platform to collect dual-polarized, multi-angular (0° and 40°) brightness temperature observations along with thermal infrared observations across varying soil moisture conditions and land covers, including grass, corn, bare soil, and oats at a study site located at Newry, Victoria (Figure 1a). The PLSR-UAV platform and the flight plan used in this study are shown in Figures 1c-d. Installed weather and soil moisture stations enabled continuous field monitoring (Figure 1b). In-situ measurements were also collected during each flight day, including near-surface soil moisture measurement with the Hydraprobe Data Acquisition System (HDAS; see Figure 2; Merlin et al. 2007), soil temperature, gravimetric soil moisture sampling, soil texture analysis, surface roughness, and destructive vegetation sampling, which were used for soil moisture retrieval model validation. PLSR-UAV derived dual polarized brightness temperature and thermal infrared maps at 0° and 40° incidence angles are shown in Figure 3. Methods for

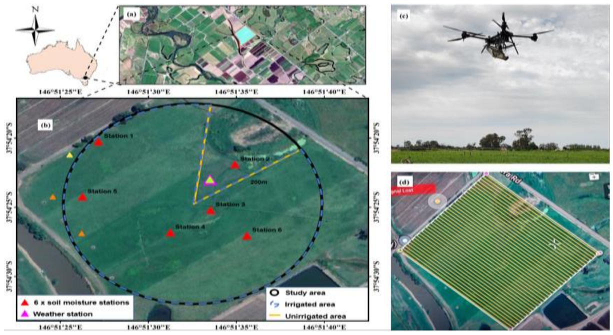

Figure 1:(a) Location of the case study at Newry, Victoria. (b) Installed weather and soil moisture monitoring stations. (c) PLSR-UAV platform. (d) PLSR-UAV flight plan.

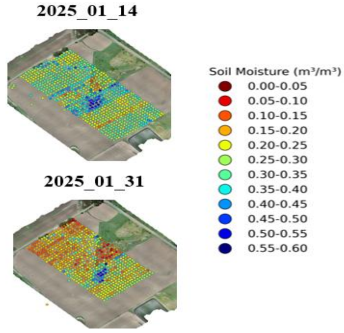

Figure 2:Example of soil moisture data collected using HDAS.

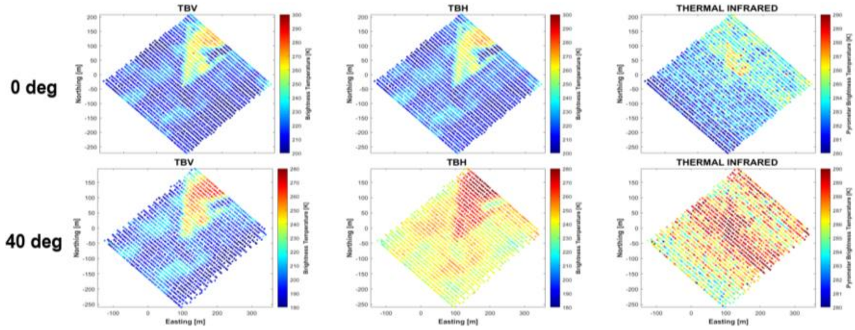

Figure 3:Example of PLSR-UAV derived dual polarized brightness temperature and thermal infrared maps at 0° and 40° incidence angles.

simultaneous near-surface soil moisture and vegetation optical depth retrieval are being developed using the Tau-Omega model (Mo et al. 1982). Key operational questions being investigated include, the importance of radiometer calibration and the role of field measured versus globally available or calibrated parameters for robust retrieval. Two retrieval strategies, the snapshot and a time-series approach will be presented to advise the most robust approach. Moreover, machine learning algorithms will be compared to physically-based models to assess their potential for estimating near-surface soil moisture data using UAV based passive microwave observations.

3. CONCLUSIONS

This study deployed a UAV-based L-band radiometer for high resolution routine near-surface soil moisture monitoring for precision irrigation. Unlike previous studies that provide coarse spatial resolution or rely heavily on ancillary datasets, this work combines multi-angular and dual-polarized brightness temperature observations to simultaneously retrieve near-surface soil moisture and vegetation optical depth to provide accurate high-resolution maps of near-surface soil moisture and vegetation water content. Two physically-based retrieval strategies, snapshot and time-series retrieval are being evaluated for robust retrieval. Machine learning based estimations will be compared against physically-based model retrievals. This enables operational UAV-based soil moisture mapping for site-specific irrigation management, with reduced water use and thus advance sustainable agriculture.

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