FY2023 Progress Report To:

the

Japan Aerospace Exploration Agency

Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using AMSR3 and GCOM-W data

Specification No: **JX-PSPC-550551**; Contract No: **23RT000291**

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March 2024

MONASH University
Engineering

Executive Summary

This report presents the findings and activities of the project "Validation of GCOM-W1 Products Using Global Water and Energy Balance Monitoring in the Australian Murray-Darling Basin" for the fiscal year 2023. The primary objective of the project is to sustain the operation of the JAXA flux tower located in Yanco, New South Wales, facilitating the collection of soil moisture data for validation of satellite products.

Maintenance activities for JFY 2023 ensured proper functioning of the JAXA flux tower, addressing challenges like insect control and sensor replacements. Tower safety inspections were conducted, revealing good conditions overall, and necessary sensor replacements were carried out to maintain data accuracy.

The JAXA flux tower provided crucial half-hourly measurements, although some connectivity issues with soil moisture sensors were noted. Real-time data was accessible online, aiding continuous monitoring. The ASSH-T weather station also provided valuable data, with most sensors operating normally.

The report analyzed AMSR2 soil moisture products, revealing consistent underestimation of soil moisture levels compared to flux tower measurements. The inclusion of SMAP data highlighted differences, with SMAP showing closer agreement with ground truth, especially during wet seasons. Validation efforts using time series plots showed consistent underestimation by AMSR2 products compared to tower measurements, particularly during wet periods. The addition of

SMAP data underscored the importance of considering satellite frequency and footprint size for accurate soil moisture estimates.

Preliminary analysis of AMSR2 research products suggested slightly higher values compared to standard products, but significant disparities remained when compared to tower and SMAP data. Further analysis is planned to understand and address these discrepancies.

Evaluation of AMSR2 VWC products against MODIS NDVI-derived VWC highlighted discrepancies between the two, with AMSR2 VWC showing potential overestimation. Analysis of different versions of the VWC product revealed variations in performance, emphasizing the need for more in-depth analysis once the official research product is available.

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Chapter 1: Introduction

The aim of this report is to outline the research activities and findings from the project "Validation of GCOM-W1 Products Using Global Water and Energy Balance Monitoring in the Australian Murray-Darling Basin" for the fiscal year 2023. A primary objective of the project is to sustain the operation of the JAXA flux tower situated at the central validation site in Yanco, New South Wales. This endeavor facilitates the collection of spatially distributed soil moisture data covering an area equivalent to an AMSR2-sized footprint. Additionally, the project endeavors to contribute significantly, both independently and collaboratively, to the validation of the AMSR2 soil moisture product. This includes intercomparisons with complementary satellite soil moisture products from missions such as SMAP and validation of the Vegetation Water Content (VWC) research product against MODIS-derived vegetation indices and field samplings.

Throughout JFY 2023, the project will carry out site maintenance activities, including the calibration of the JAXA tower Gas Analyzer (IRGA) and routine site visits and upkeep of the JAXA flux tower. Compliance with Australian regulations will necessitate a tower inspection in 2023. The soil moisture data collected will be utilized to validate the AMSR2 soil moisture products at resolutions of 10 km and 25 km. Moreover, the project has identified instances of erroneous data, potentially indicative of sensor malfunctions, prompting the procurement of replacement sensors from JAXA. These replacement sensors arrived at Monash University in late January 2023 and were subsequently installed over the course of the year.

Chapter 2: Flux Tower Maintenance

2.1 Flux Tower Maintenance for JFY 2023

Regular site maintenance completed during 2023-2024 was undertaken by a dedicated Monash University Field Technician. This occurred every 4-6 weeks and included the following activities:

i) Cleaning of all environmental sensors within the enclosure
ii) Insect control and grass cutting;
iii) Cleaning and checking of Rain Gauge.
iv) Downloading of data and battery health checks.

Access to the tower has been quite difficult over the year, with flooding in the paddocks occurring over the spring and summer months. Vegetation inside the enclosure has been very difficult to maintain, as high growth has occurred in the area due to high rainfall events. Grass both in the local pasture and within the tower enclosure has proliferated, making it very thick and tall, and difficult to maintain, however the grass was slashed in December and January, which has helped to keep the growth down. Insect control has also been difficult to manage, as spider webs have covered the optical path of the gas analyser frequently.

Battery performance for all loggers is working well, however there is a slow decline in charged capacity. Replacements and upgrades should potentially be considered in future budgets.

Figure 1: Slashed grass within the enclosure

2.2 Tower Safety Inspection

The tower safety inspection of the tower was completed on 19/07/2023 by Wave1. Previous inspection was on 03/12/2019. It is recommended that a safety inspection should be done every 2 years according to Australian regulations.

The Mast, Ladsaf system, guy wires and associated rigging, footings, mounts and brackets are in good condition. During the inspection the sensors were all cleaned of cobwebs, the 8m Windset was replaced and the gas analyser windows were cleaned. During the inspection, the NDVI camera lens was also cleaned, and it was reported that condensation was observed on the inside of the lens. An inspection report has been provided by Wave1 and forwarded to JAXA.

Figure 2: Bow shacle, Ladsaf spring, Mast base, Guy point of the tower

2.3 Sensor Condition and Replacement

The following sensors was ordered and provided by JAXA (received in January 2023):

JAXA Tower:

- Wind speed/direction (Met One 034B), 2 pcs
- Soil Moisture (Trime-pico32-110), 2pcs
- Soil Temperature (WST110-L5), 2pcs
- Soil Heat Flux (HF-HFP-01), 2pcs

ASSH-T weather station:

- Soil Moisture (Trime-pico32-110), 2pcs
- Soil Temperature (WST110-L5), 2pcs

- Soil Heat Flux (HF-HFP-01), 2pcs

The following sensor replacement works were completed:

JAXA tower

1. MetOne windset at 2m replaced in April 2023, then cables replaced in September 2023 due to erroneous readings.
2. Heat flux plate at 4cm (Serial #19278) in April 2023, then repositioned to ensure close contact with the soil in January 2024, as the readings were abnormal.

Figure 3: Replacement of 5cm Heat flux plate

3. Trime PICO #33264 at 10cm replaced with new sensor (serial #50746) in May 2023, however readings were incorrect for some time while the field technician diagnosed the issue. Readings were corrected in November 2023.

4. MetOne windset at 8m replaced as part of tower safety inspection in July 2023.

5. The modem at JAXA was replaced in June 2023, along with a new battery to run it.

6. The Trime Pico sensor and temperature sensor at 75cm was replaced in November 2023.

Figure 4: Replacement of 75cm Trime Pico soil moisture sensor.

7. The Vaisala humidity sensor at 8m still required replacement as it has failed. The dust caps on all the humidity sensors also need replacing and should be part of an annual budget to keep them functioning well and to combat degradation due to dust/insects.

8. The NDVI camera has not been functioning correctly for some time. As reported during the tower inspection the camera has condensation on the inside of the lens which indicates the seals are not working. This will need to be removed and checked. There has also been issues with the camera not recording images, which also needs to be investigated when the camera is removed.

ASSH-T weather station

1. Trime Pico soil moisture (#32266) at 45cm replaced with #40663 in October 2023.
2. Trime Pico soil moisture at 10cm was replaced in January 2024.

2.4 Servicing and Calibration of IRGA sensor

The gas analyser started recording zero values in mid-September of 2023. It was removed from the tower and the internal chemicals were changed, the firmware updated and gas bottles transported to site in order to calibrate the Li-7500. The head, however, was still reading zero values, and required servicing and repairs from Licor, USA. The gas analyser was put back up on the tower in January 2024, fully functioning and calibrated.

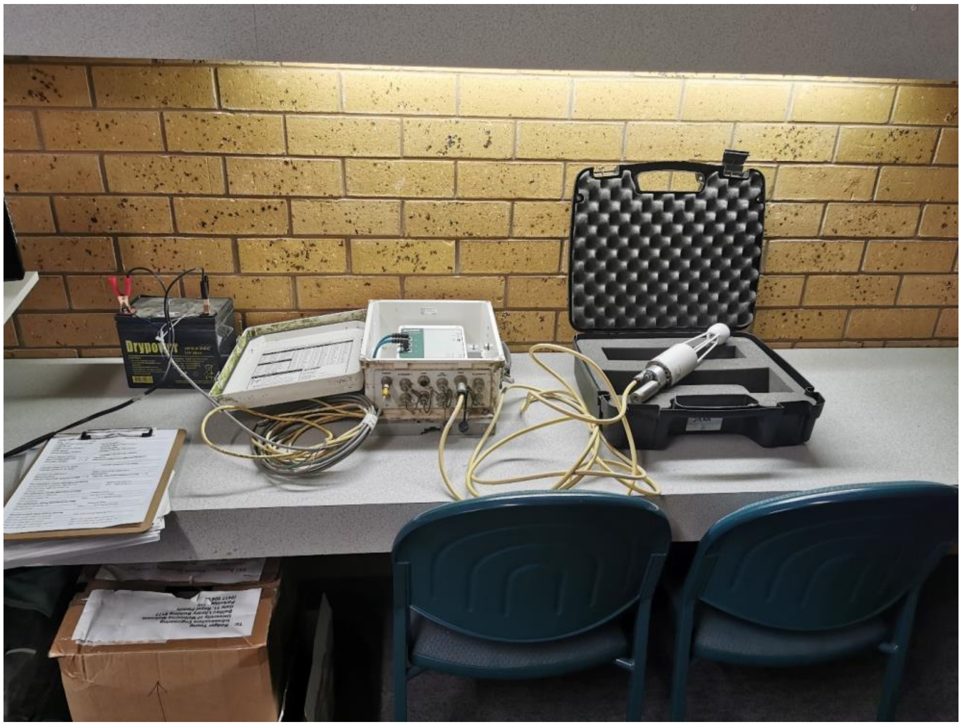

Figure 5: Calibration of IRGA sensor.

Chapter 3: Flux Tower Data

3.1 JAXA Tower Data Archive

Half-hourly measurements from the JAXA flux tower are uploaded from the JAXA station to a Monash server on a weekly basis. Figures below show some example of the key data collected in JFY2023.

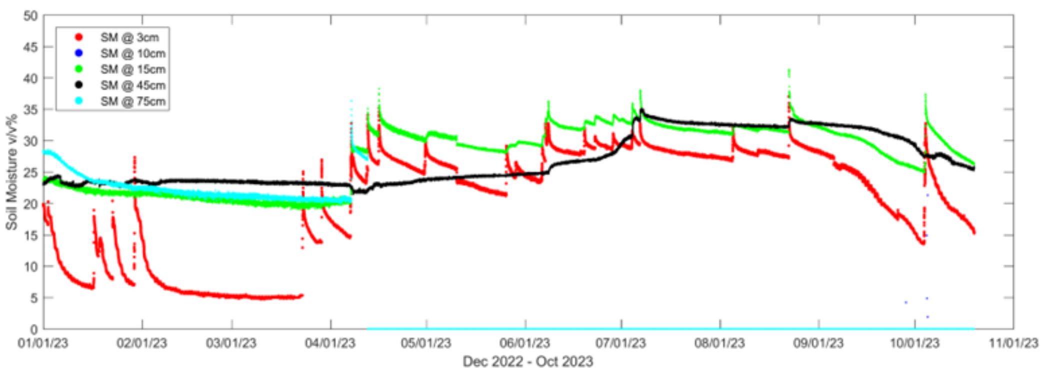

Figure 6: Soil moisture measured at JAXA Tower for 2023.

There are some connectivity issues with the junction boxes and plugs for the @10cm and @75cm soil moisture sensors. The Trime PICO #33264 at 10cm was replaced with new sensor (serial #50746) in May 2023, however readings were incorrect for some time while the field technician diagnosed the issue. Readings were corrected in November. The Trime Pico sensor and temperature sensor at 75cm was also replaced in November 2023.

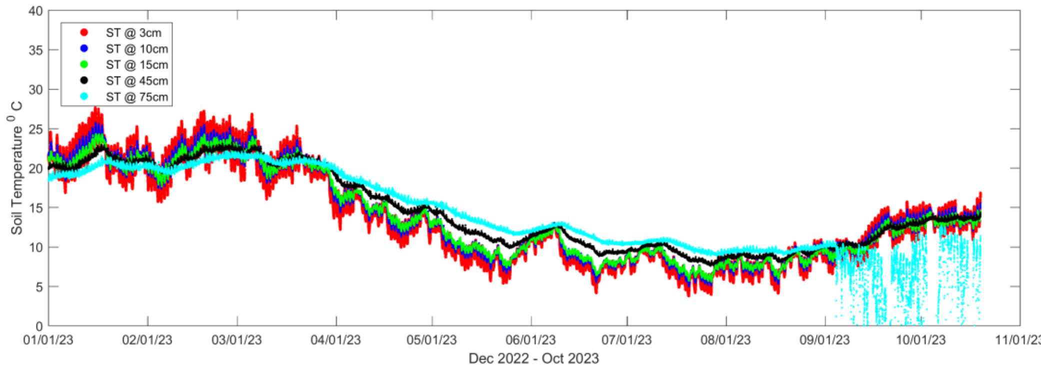

Figure 7: Soil temperature measured at JAXA Tower for 2023.

Soil temperature @75cm started giving erroneous data since Sept 2023 which was checked and fixed in January 2024.

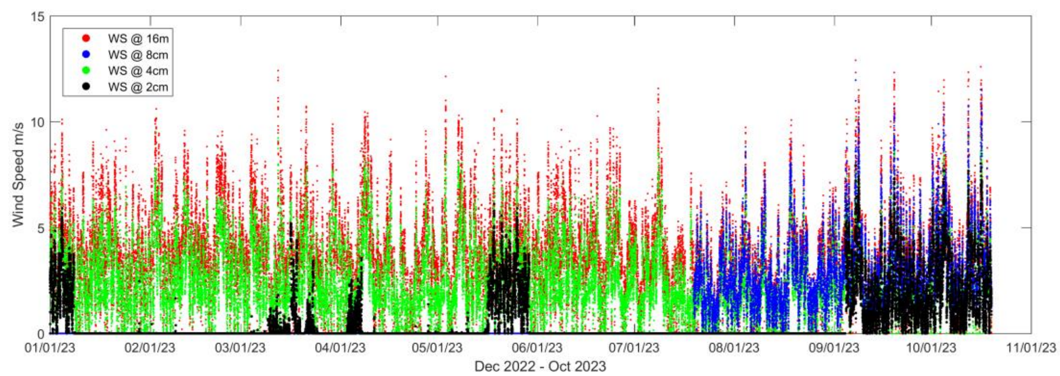

Figure 8: Wind speed measured at JAXA Tower for 2023.

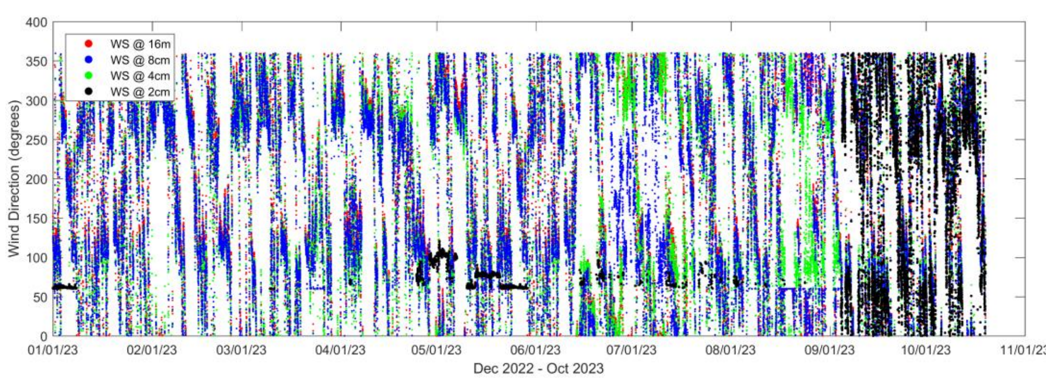

Figure 9: Wind direction measured at JAXA Tower for 2023.

MetOne windset at 2m was replaced in April 2023, then cables replaced in September 2023 due to erroneous readings. MetOne windset at 8m was replaced as part of tower safety inspection in July 2023.

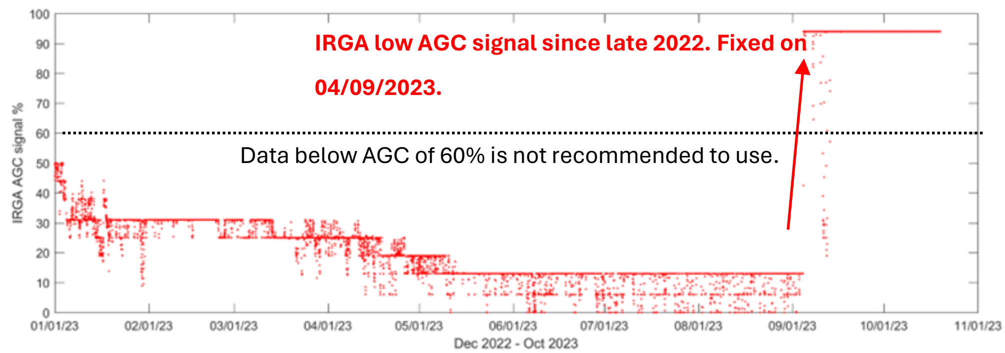

Figure 10: IRGA AGC signal for 2023.

IRGA has been having low AGC signal since late 2022. It was fixed on 04/09/2023.

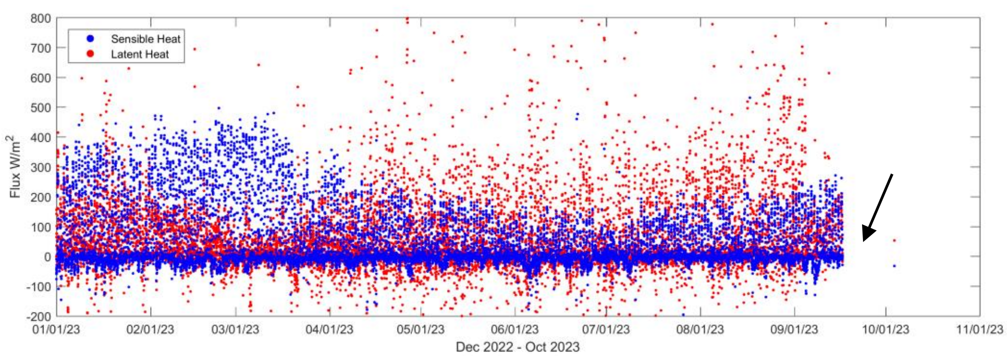

Figure 11: Flux density measured at JAXA Tower for 2023.

However, after the signal was fixed, IRGA completely stopped working on 16/09/2023. It was taken off the tower on 19/10, attempted calibration but no response from IRGA. The head was reading zero values, and was sent to be serviced and repaired from Licor, USA. The gas analyser now has been put back up on the tower in January 2024, now fully functioning and calibrated.

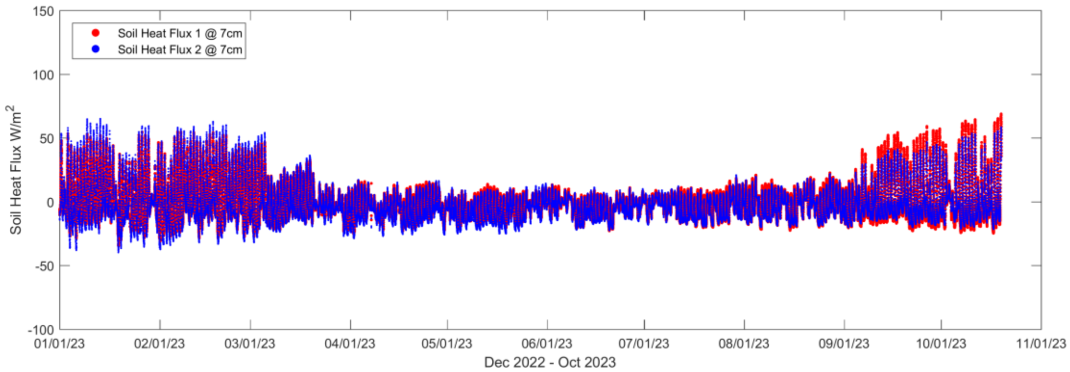

Figure 12: Soil Heat Flux at 7cm depth for 2023.

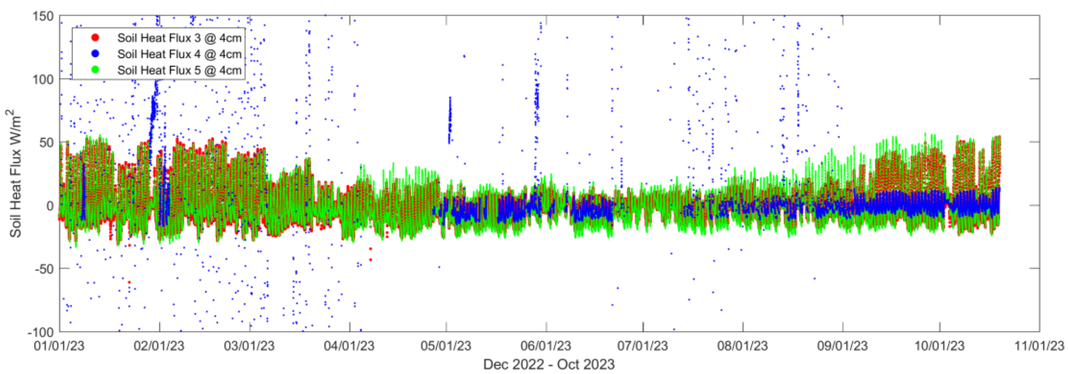

Figure 13: Soil Heat Flux at 4cm depth for 2023.

Heat flux plate at 4cm (Serial #19278) in April 2023, then repositioned to ensure close contact with the soil in January 2024, as the readings were abnormal.

3.2 Real-time Figures Archive

Real-time figures from the flux tower is also produced and available at http://www.science.uwa.edu.au/centres/land/yanco. The website is maintained by

Prof. Jason Beringer' s team in Faculty of Science, the University of Western Australia (jason.beringer@uwa.edu.au).

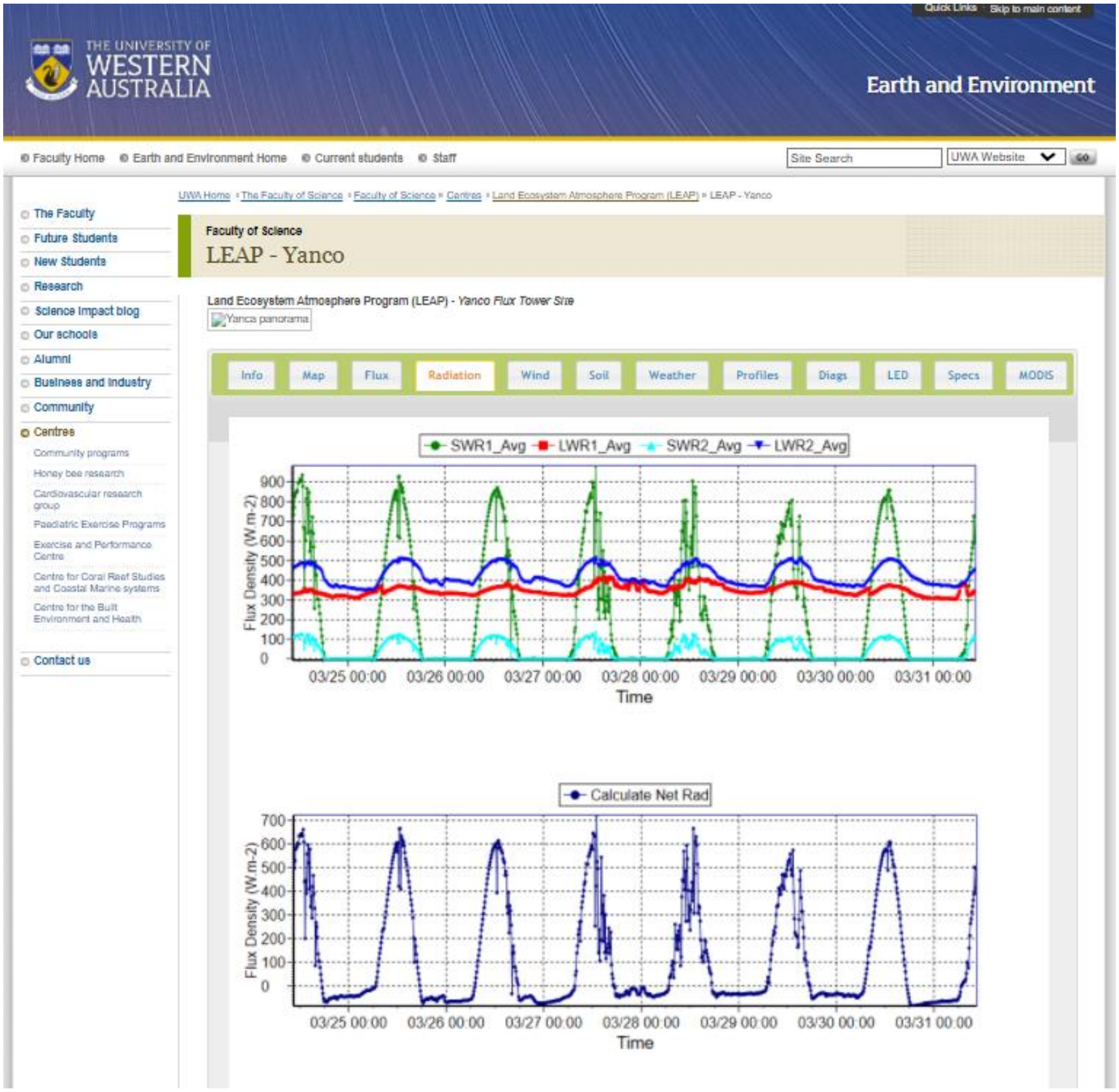

Figure 14: Real-time tower data interface on http://www.science.uwa.edu.au/centres/land/yanco.

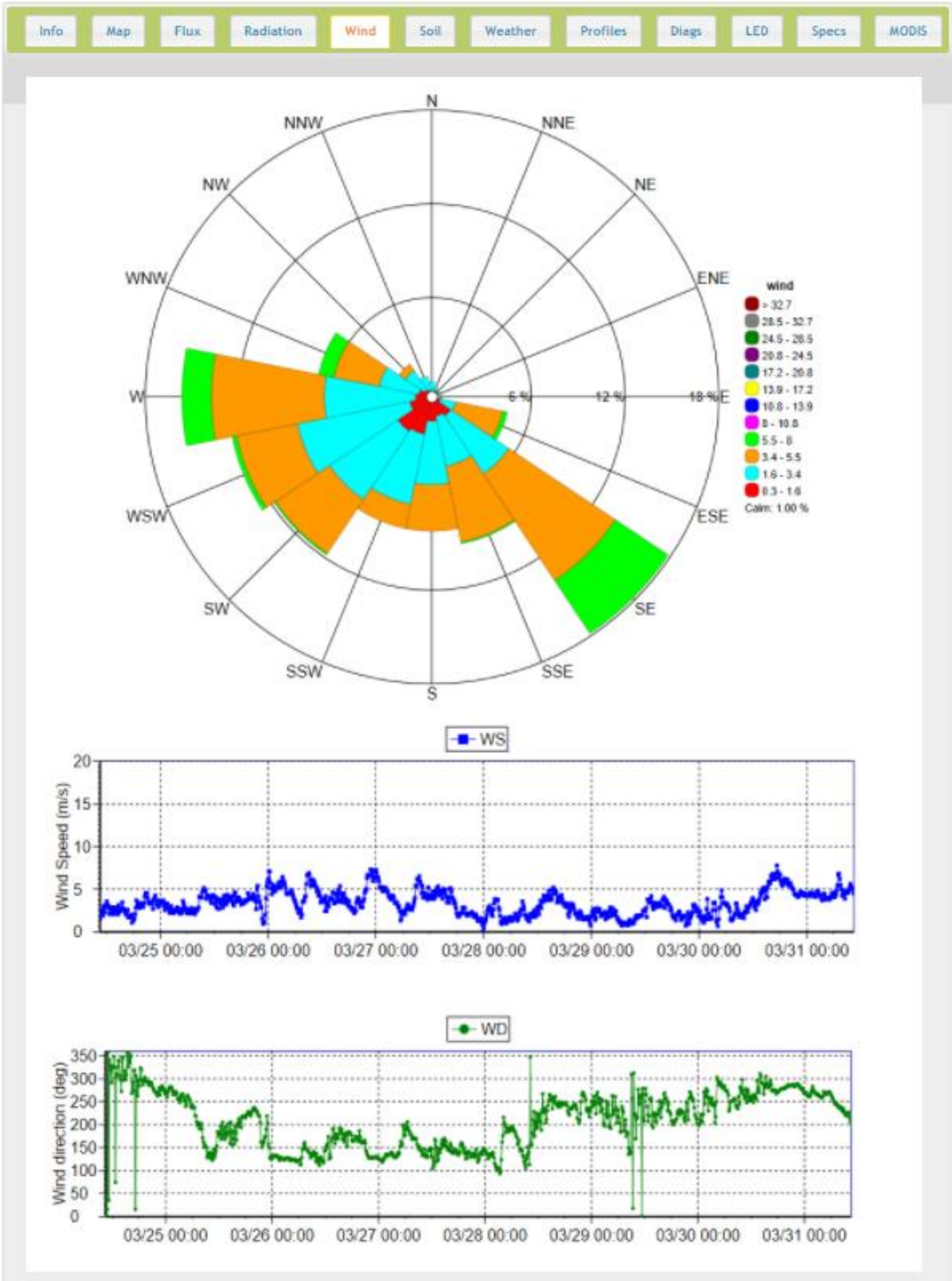

Figure 15: Examples of real-time figures for wind speed and wind direction.

3.3 ASSH-T weather station data

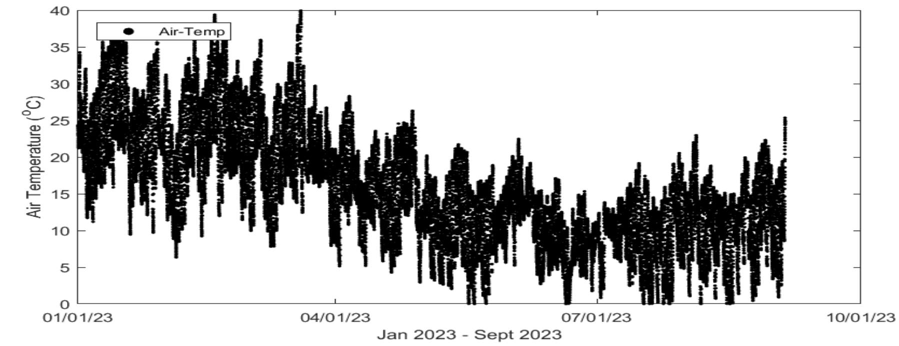

Figure 16: Air temperature data for ASSH-T station in 2023.

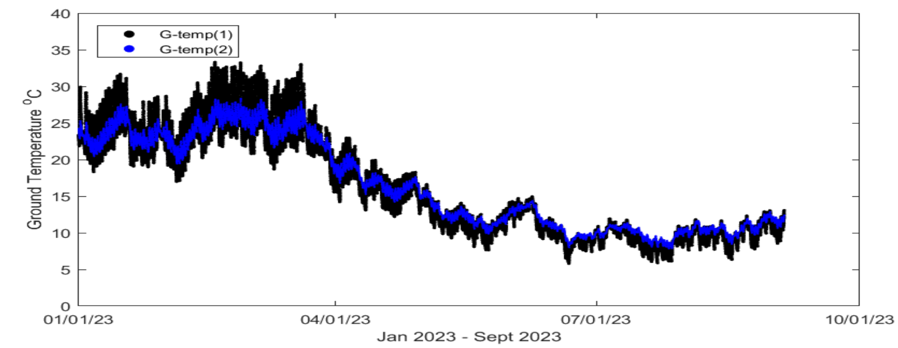

Figure 17: Soil temperature data for ASSH-T station in 2023.

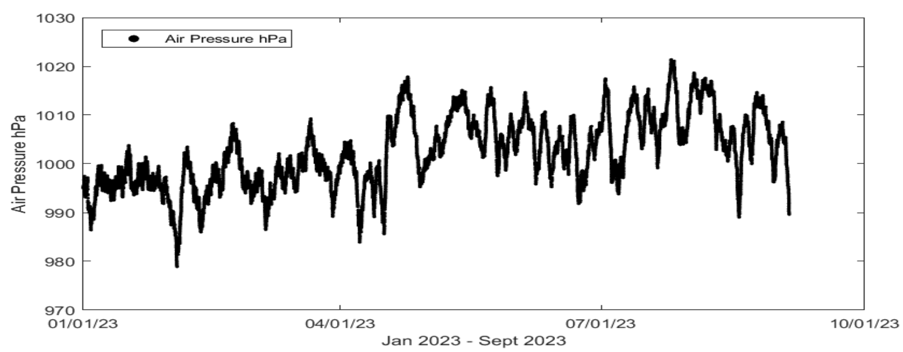

Figure 18: Air pressure data for ASSH-T station in 2023.

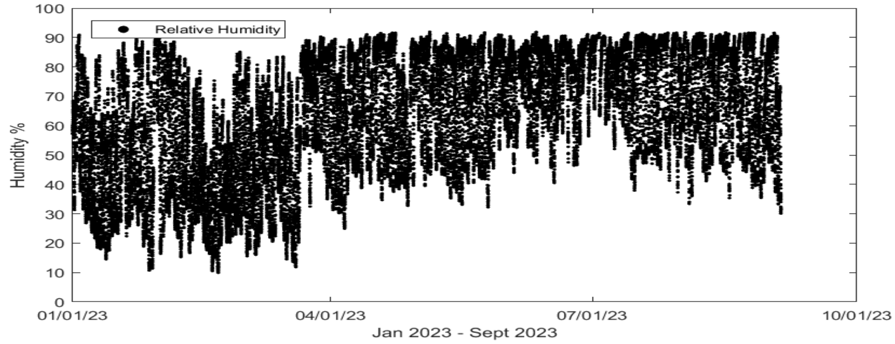

Figure 19: Relative humidity data for ASSH-T station in 2023.

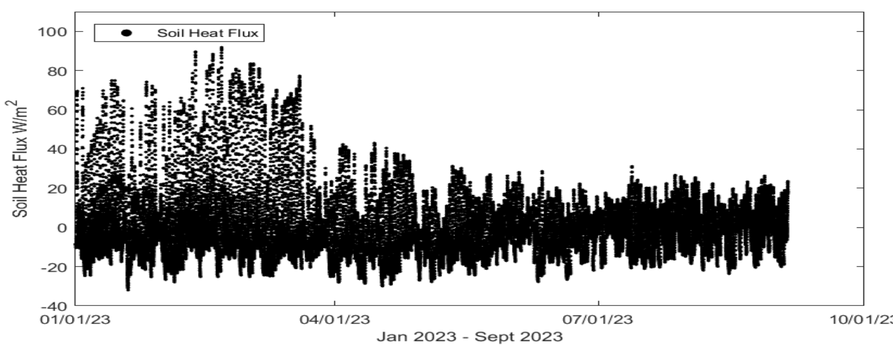

Figure 20: Soil heat flux data for ASSH-T station in 2023.

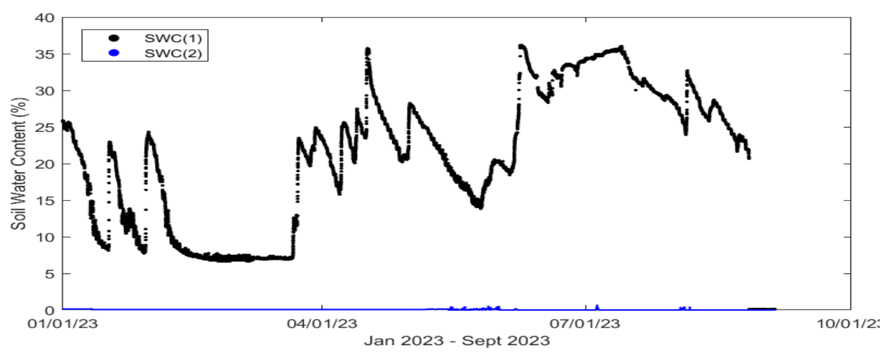

Figure 21: Soil moisutre data for ASSH-T station in 2023.

All sensors at the ASSH-T weather station are operating normally except for the two soil moisture sensors. Trime Pico soil moisture (#32266) at 45cm was replaced with #40663 in October 2023. Trime Pico soil moisture at 10cm was replaced in January 2024.

3.3 OzNet monitoring network data

Similar with previous years, soil moisture and soil temperature over 20-min interval of measurements from the OzNet monitoring stations are collected from each station. All raw data have been archived and downloadable at http://www.oznet.org.au.

Data were separated and named according to the southern hemispheric seasons, i.e. spring (September – November), summer (December – February), autumn (March – May) and winter (June – August). Simple quality checks have been applied to these data whereby out of range values have been removed.

Some recent sample data after the station upgrades are shown as follows:

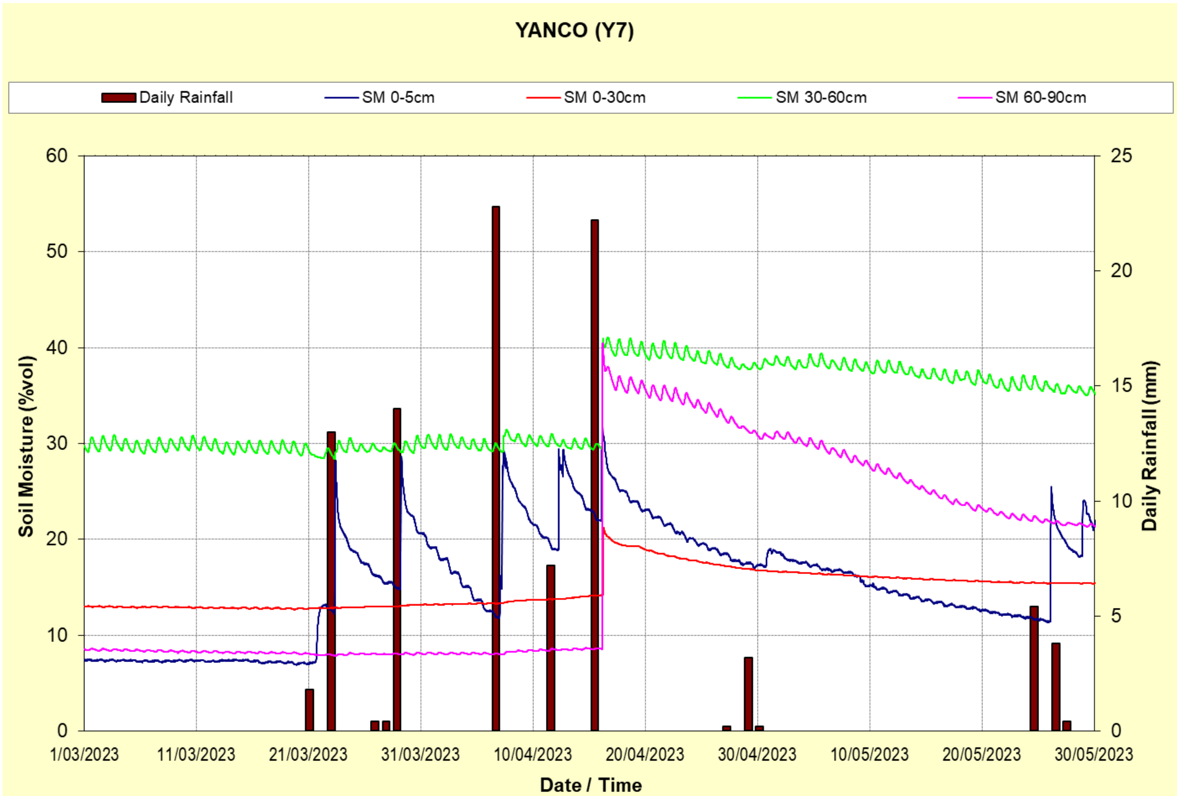

Figure 22: Sample data – Y7 Station 2023 Autumn soil moisture data.

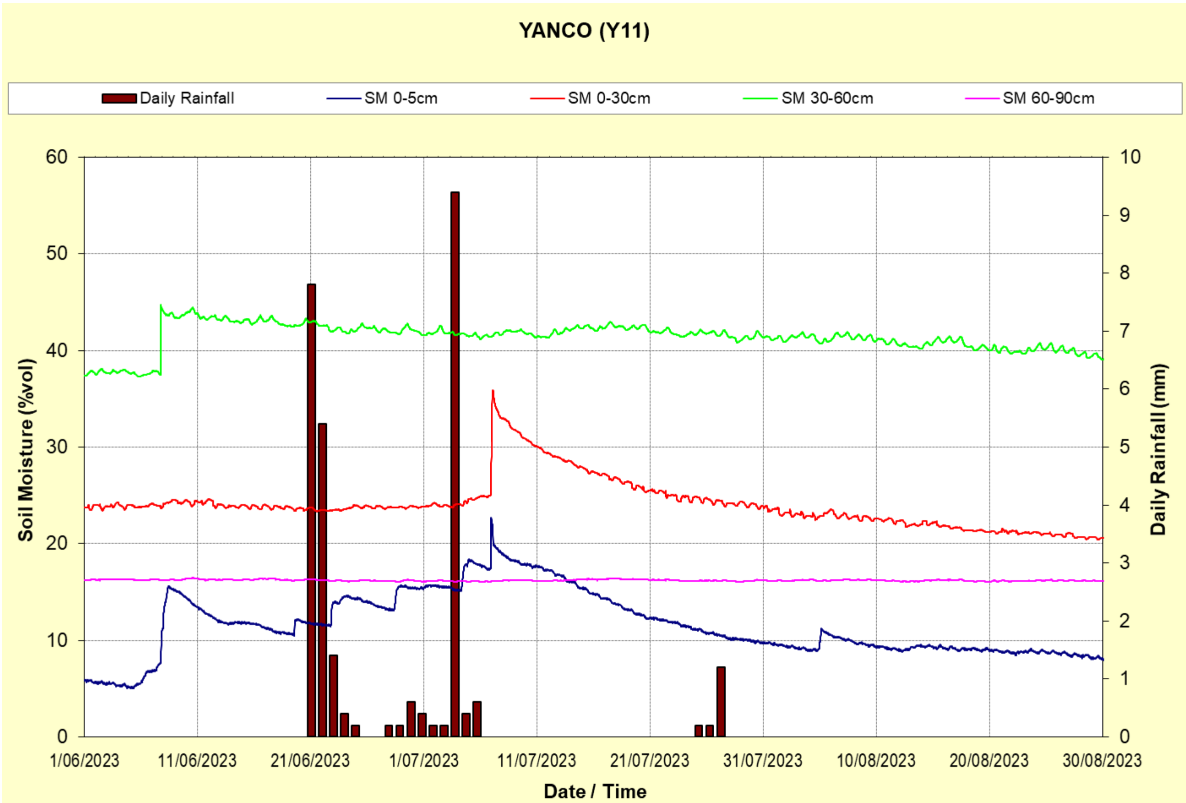

Figure 23: Sample data – Y11 Station 2023 Winter soil moisture data.

Chapter 4: AMSR-2 Level 3 soil moisture products

4.1 The Murrumbidgee Catchment

Located in southern NSW, Australia, the Murrumbidgee catchment is bordered by the Great Dividing Range to the east, the Lachlan catchment to the north, and the Murray catchment to the south. The Murrumbidgee Catchment exhibits a significant spatial variability in climate, soil, vegetation and land cover because of its distinctive topography (Figure 23).

Due to the diversity within this area, the large amount of complementary data from long-term monitoring sites, and past airborne field experiments, this region is an ideal test-bed for the comprehensive validation of satellite soil moisture from missions such as GCOM-W1 and is highly complementary to validation sites in Mongolia and Thailand. Considering the size of the satellite footprint, there are regions in the catchment that are relatively homogeneous in regard to climate, soil type, vegetation, and consequently radiometric response (Rüdiger et al., 2011) when compared to many other countries.

Temporal climatic variations of the catchment are primarily associated with elevation, varying from semi-arid in the west to temperate in the east. The total average annual rainfall for the entire Murrumbidgee River catchment is about 530

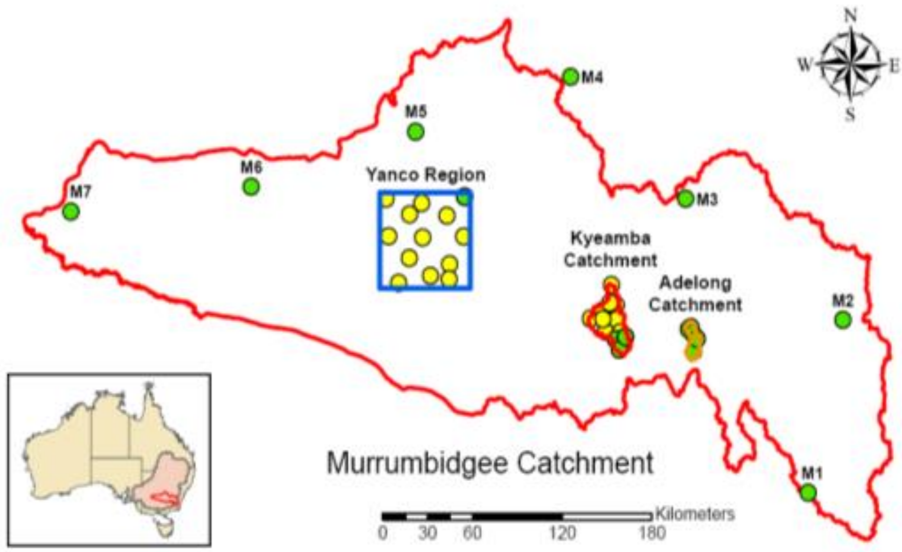

Figure 24: Location of the Yanco core validation site within the Murrumbidgee Catchment. Also shown is the location of the Murrumbidgee Catchment within the Murray-Darling Basin (inset) and the locations of sparse network soil moisture stations.

mm, with a mean annual precipitation of 300 mm in the west and about 1,900 mm towards the east in the Snowy Mountains. The actual evapotranspiration is equivalent to precipitation in the west but represents only half of the precipitation in the east. Long term averaged precipitation data for the Murrumbidgee Catchment shows a relatively constant rate of rainfall across the year, with a slight increase in winter. The Murrumbidgee catchment is characterised by plains in the west with an elevation around 50 m, to steep mountainous regions towards the east with elevations more than 2,100 m in the Snowy Mountains. Soils in the Murrumbidgee Catchment vary from sand to clay, with the western plains being dominated by finer-textured soils and the eastern slopes being dominated by medium-to-coarse textured soils (McKenzie et al., 2000).

Land use in the catchment is predominantly agricultural with the exception of steeper parts, which are dominated by a mixture of native eucalypt forests and exotic forestry plantations. Agricultural land use varies greatly in intensity and includes pastoral, more intensive grazing, broad-acre cropping, and intensive agriculture in irrigation areas along the mid-lower Murrumbidgee. Grazing is predominant in the west and scattered in the east, whereas dryland cropping dominates the mid Murrumbidgee catchment. Irrigation sites are mainly located in western part of the Yanco core validation site. The catchment is comprised of about 52% pasture, followed by about 21% arable and 18% silvicultural land use. The other land use types represent less than 9% of the total catchment area.

4.2 The Yanco Site – location of flux tower

The Yanco area is a 60 km x 60 km area located in the western plains of the Murrumbidgee Catchment where the topography is flat with very few geological outcroppings (Figure 13). Soil types are predominantly clays, red brown earths, transitional red brown earth, sands over clay, and deep sands. Approximately one-third of the core validation site is irrigated during summer when sufficient water is available. The Coleambally Irrigation Area (CIA) is a flat agricultural area of approximately 95,000 hectares that contains more than 500 farms. The principal summer crops grown in the CIA are rice, corn, and soybeans, while winter crops include wheat, barley, oats, and canola. Rice crops are usually flooded in November by about 30 cm of irrigation water.

A total of 24 surface soil moisture sites were installed in late 2009 to develop a nested soil moisture monitoring configuration for the SMAP mission at scales of approximately 3 km, 9 km and 36 km. These stations continuously monitor the soil moisture over the 0-5 cm layer with a Hydraprobe and soil temperature sensors (Unidata® 6507A/10) at 1, 2.5 and 5cm depths. The 24 sites are concentrated on two

9 km x 9 km focus areas (areas YA and YB), corresponding to two pixels of the SMAP grid at which the active passive soil moisture product (SMAP L3_SM_A/P product) was to be produced. Finally, 10 of the sites within areas YA and YB are concentrated on a further two 3 km x 3 km sub-areas (each) with at least 4 stations measuring the distribution of soil moisture across each, corresponding to a total of four of the SMAP radar pixels (see zoomed in figure in Figure 24 for details of the YB area). Unfortunately, the SMAP radar failed shortly after commissioning. However, sentinel data are being used to replace the SMAP radar observations for locations such as the Murray Darling Basin.

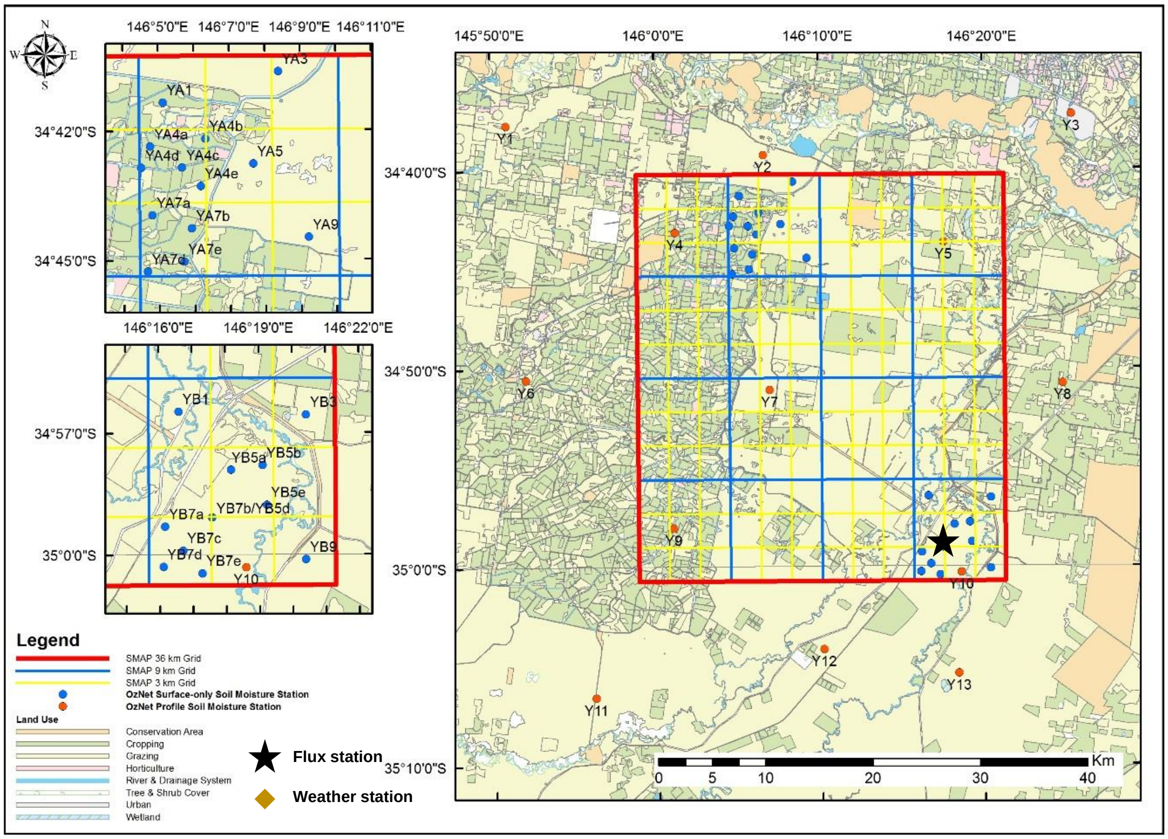

Figure 25: Locations of the JAXA flux station, weather station and soil moisture monitoring stations within the Yanco core validation site. Also shown are the YA and YB focus areas with intensive soil moisture stations, and the locations of intensive ground sampling areas.

This intensive network is also an ideal core validation site for AMSR2, as it i) monitors soil moisture across an AMSR2 sized pixel with approximately 30 stations, and ii) can be used to validate AMSR2 downscaling algorithms through the nested sampling design and supplementary intensive ground sampling activities that have been undertaken. Moreover, extensive airborne data sets and supplementary ground data (see www.smapex. monash.edu) have been used to assess the representativeness of soil moisture sites for each of the 9 km x 9 km focus areas

(areas YA and YB), corresponding to two pixels of the SMAP products at 3 km for radar, 9 km for radar-radiometer and 36 km for radiometer pixels (Yee et al. 2016). These stations have also been used to validate AMSR2 soil moisture products based on the JAXA and LPRM algorithm of different versions, and SMOS soil moisture products (Yee et al., 2016), and provide a perfect source of data for the passive-passive downscaling work proposed here.

4.3 AMSR2 Level 3 soil moisture product

The AMSR2 L3 soil moisture product was downloaded from the GCOM-W1 Data providing Service (the G-Portal: https://gportal.jaxa.jp/gpr/). To cover the whole

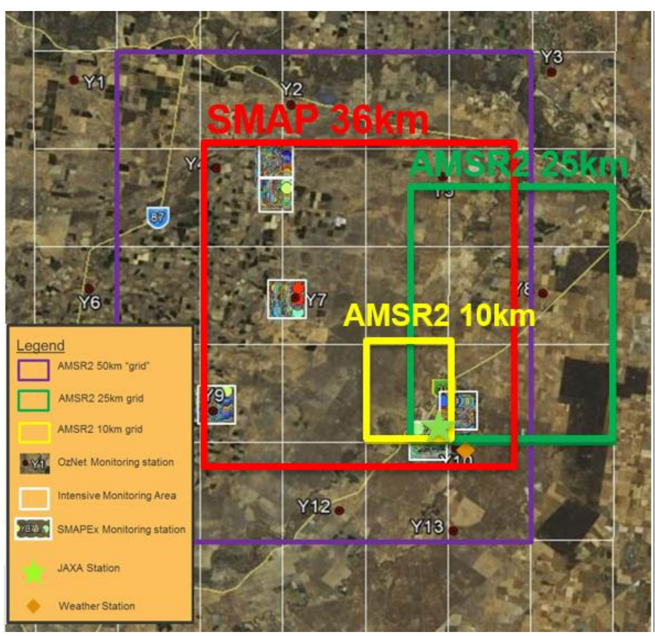

Figure 26: Location of the 10-km and 25-km AMSR2 L3 SMC pixel, SMAP 36-km pixel with respect to the flux tower location.

period in which AMSR2 data is available, the analysis covered a time series from July 2012 to December 2023 (see Figure 27). Both the high resolution 10-km product and the low resolution 25-km product were considered in the analysis. The product identifier for the 10-km and 25-km resolution data products are 'GW1AM2_YYYYMMDD_01D_EQMD_L3SGSMC**H**F3300300' and 'GW1AM2_ YYYYMMDD_01D_EQMD_L3SGSMC**L**F3300300', respectively.

The AMSR2 pixel in which JAXA tower (-34.99S, 146.29E) is located was extracted. The pixel location of the L3 SM data scene is Row 1250, Column 1463 for the 10-km product, and Row 500, Column 586 for the 25-km product. The pixel boundaries with respect to the flux town location is shown in Figure 25.

The time series of the AMSR2 Level 3 SMC 10-km and 25-km products are shown in Figure 27. It is seen that from 2012 to 2020, 2013-2014 and 2017 are relatedly dry years while the rest of the period are wetter. For the wetter years, comparing with 2015-2016, 2018-2021 experienced a slightly dryer condition throughout the period.

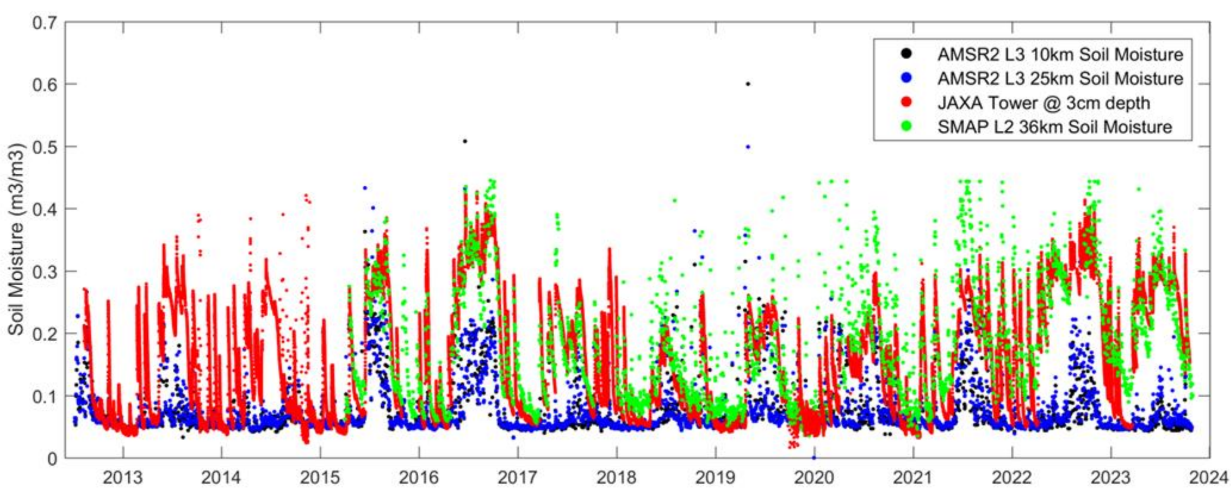

Figure 27: Year 2012 to 2023 time series of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site.

But the higher values of 2018-2021 are more scattered. The wet season (May to August) in 2019-2021 is less obvious and has extreme values in rainfall events pretty much throughout the years.

Similar with previous years, the updated 2020-2023 data show that the high-resolution soil moisture almost coincide with the low-resolution data, especially during the dry season. For the wet season, however, the low-resolution soil moisture has a slightly larger dynamic range. This could be due to the reason that 25-km pixel contains a larger area and thus include mixed land cover types such as pasture, crops and forest, while within the 10-km pixel it is almost pasture.

Figure 29 shows the box plots of the AMSR2 L3 low- and high- resolution soil moisture for year 2023 only. Most of data fall in the range of approximately 0.03 m^3/m^3 to 0.12 m^3/m^3 and the median value is only slightly above 0.05 m^3/m^3. Very few data exceed 0.1 m^3/m^3.

Figure 28 shows the box plots of the AMSR2 L3 low- and high- resolution soil moisture for all data from 2012 to 2023. It is seen that most of data fall in the range of approximately 0.05 m^3/m^3 to 0.12 m^3/m^3 and the median value is only slightly above 0.05 m^3/m^3. Very few data exceed 0.3 m^3/m^3 which mostly happened in the winter season of 2015-2016 and 2018-2021, with the highest reaching 0.6 m^3/m^3 for 10km data and 0.5 m^3/m^3 for 25km data.

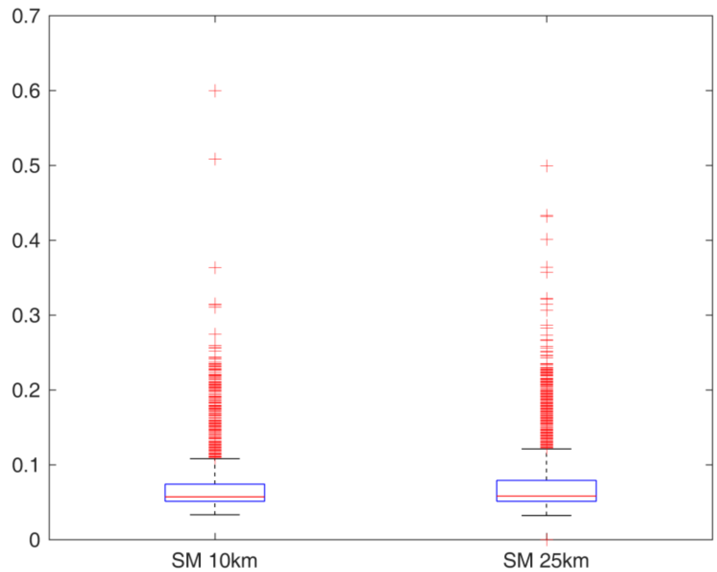

Figure 28: Box plot of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site: 2012-2023.

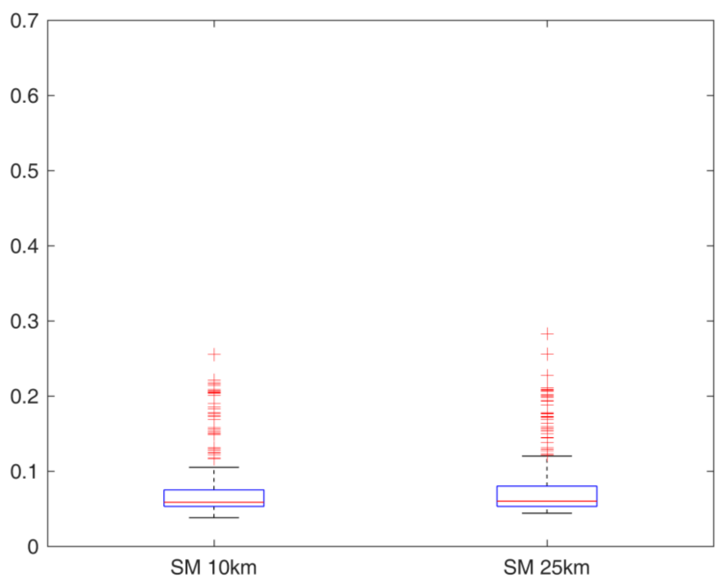

Figure 29: Box plot of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site: year 2023 only.

Chapter 5: Validation of AMSR-2 Level 3 Soil Moisture Products

5.1 Time Series Plots

The soil moisture data provided by the AMSR2 Level 3 products, offered at resolutions of 10km and 25km, have been subjected to thorough validation procedures using two independent data sources: the in-situ soil moisture measurements from the JAXA flux tower and data from the SMAP satellite mission. The validation results are illustrated in Figure 30, showcasing a time series analysis spanning a decade from 2012 to 2023. Notably, the flux tower's soil moisture sensor, utilized for validation, was positioned 3 cm below ground level, representing surface soil moisture.

Upon examining Figure 30, it becomes evident that the AMSR2 products consistently exhibit a tendency to underestimate soil moisture levels compared to the flux tower sensor readings, depicted by the red curve. Intriguingly, a stronger correlation between the two datasets emerges during dry periods throughout the years. Moreover, lower values in AMSR2 data tend to align more closely with the flux tower measurements than higher values, a trend observed consistently from 2020 to 2023.

During the wet seasons of 2022 and 2023, a noticeable disparity between the tower and AMSR2 soil moisture values becomes apparent, resembling a pattern observed in 2015-2016. Additionally, a noteworthy trend of fluctuating soil moisture levels throughout the wet season, observable in the flux tower measurements, is not distinctly captured in the AMSR2 product.

In summary, while the AMSR2 Level 3 soil moisture products generally provide accurate estimates, they consistently exhibit a tendency to underestimate soil moisture levels compared to flux tower measurements. Further investigation is required to understand and address this discrepancy to enhance the accuracy of AMSR2 soil moisture estimations.

The analysis also includes the SMAP Level 2 36km product, derived from L-band (1.4 GHz) brightness temperature observations using a passive-only algorithm (Figure 29). In contrast to the AMSR2 products, the SMAP product, represented by green dots, demonstrates a closer alignment with flux tower soil moisture measurements, particularly during wet seasons (May-Sept). This observation is unsurprising, considering the larger footprint of the SMAP product (36 km), which may provide a more representative estimate of soil moisture conditions surrounding the flux tower.

Interestingly, during dry seasons, the SMAP product tends to overestimate soil moisture levels compared to the "truth," while AMSR2 products exhibit slightly better alignment. This behavior could be attributed to the higher frequency of C-band utilized in AMSR2 soil moisture retrieval, rendering it more sensitive to vegetation cover and surface roughness effects. Vegetation cover, especially during the wet season, can significantly influence the AMSR2 signal, complicating the separation of vegetation effects from true soil moisture signals.

Conversely, L-band observations in SMAP are more sensitive to soil moisture variations, making it better suited for accurate surface soil moisture retrieval. Hence, it is understandable that the SMAP product shows closer agreement with the "truth" soil moisture levels, particularly during wet seasons. Overall, the inclusion of the SMAP product underscores the importance of considering satellite frequency and footprint size when interpreting soil moisture estimates.

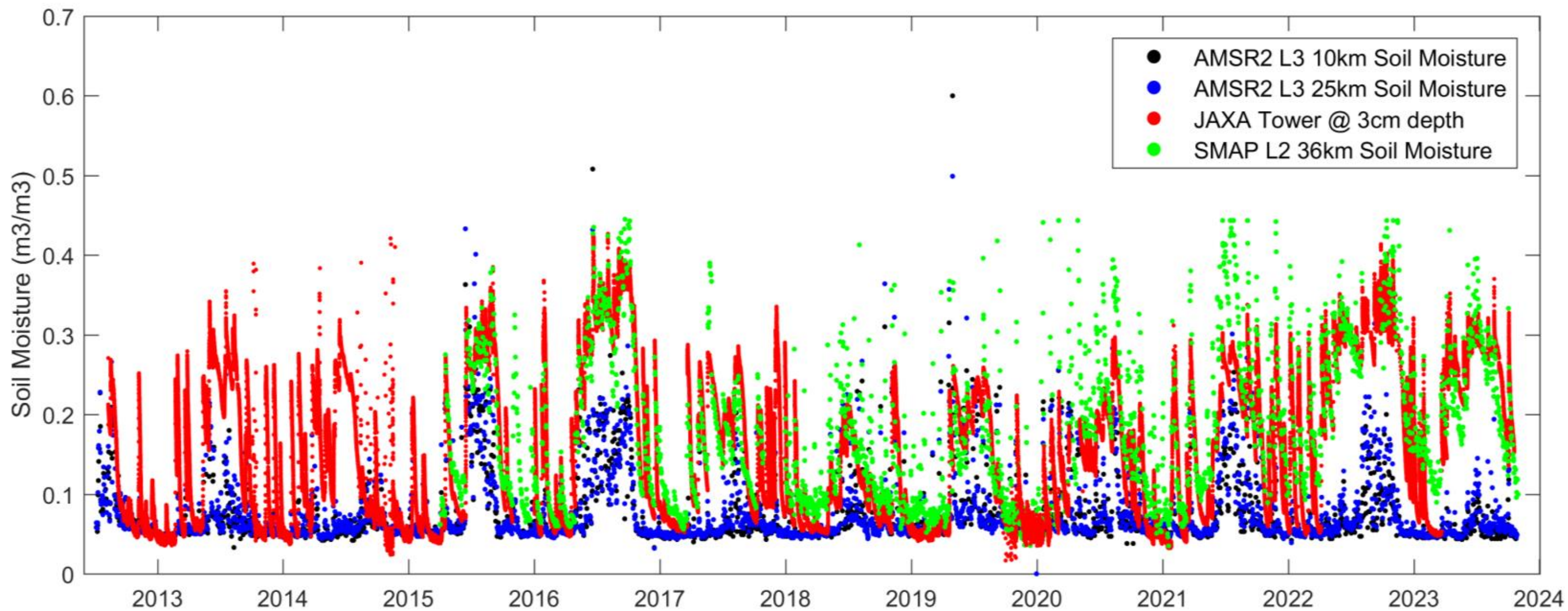

Figure 30: Same time series plot as Figure 19 with added SMAP L2 36km soil moisture product from 2012 to 2023.

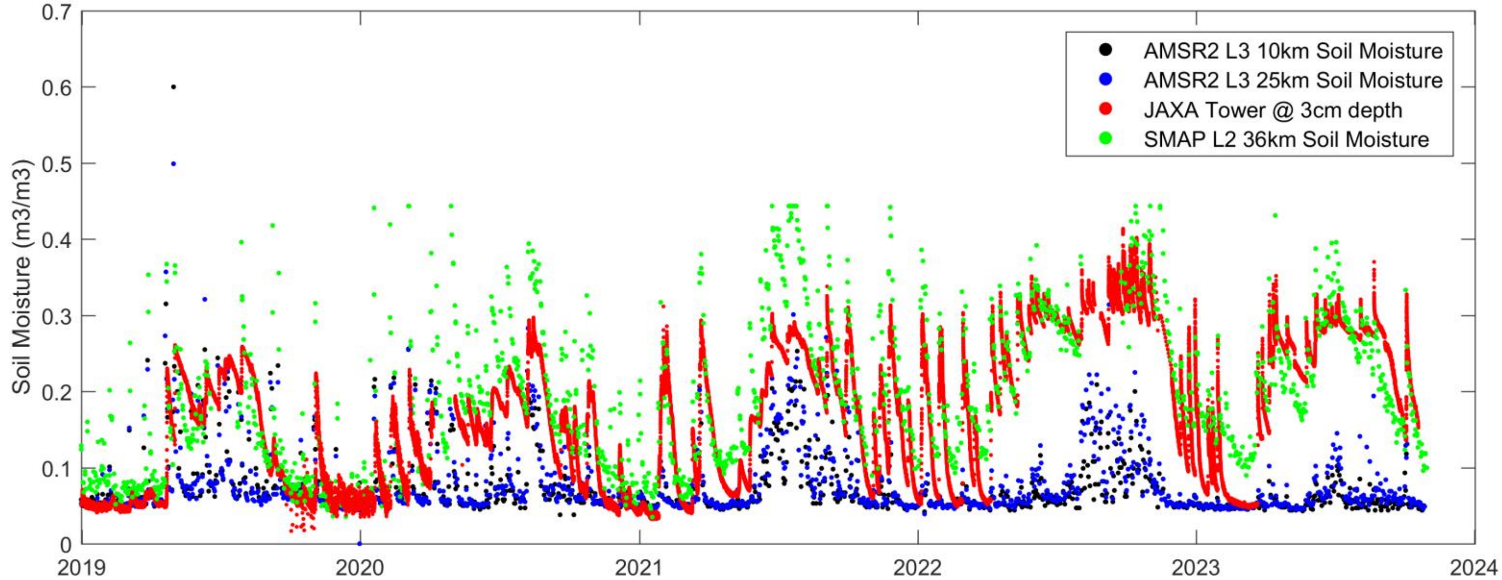

Figure 31: Zoom-in view of time series of AMSR2 products, tower SM and SMAP SM for 2019-2023.

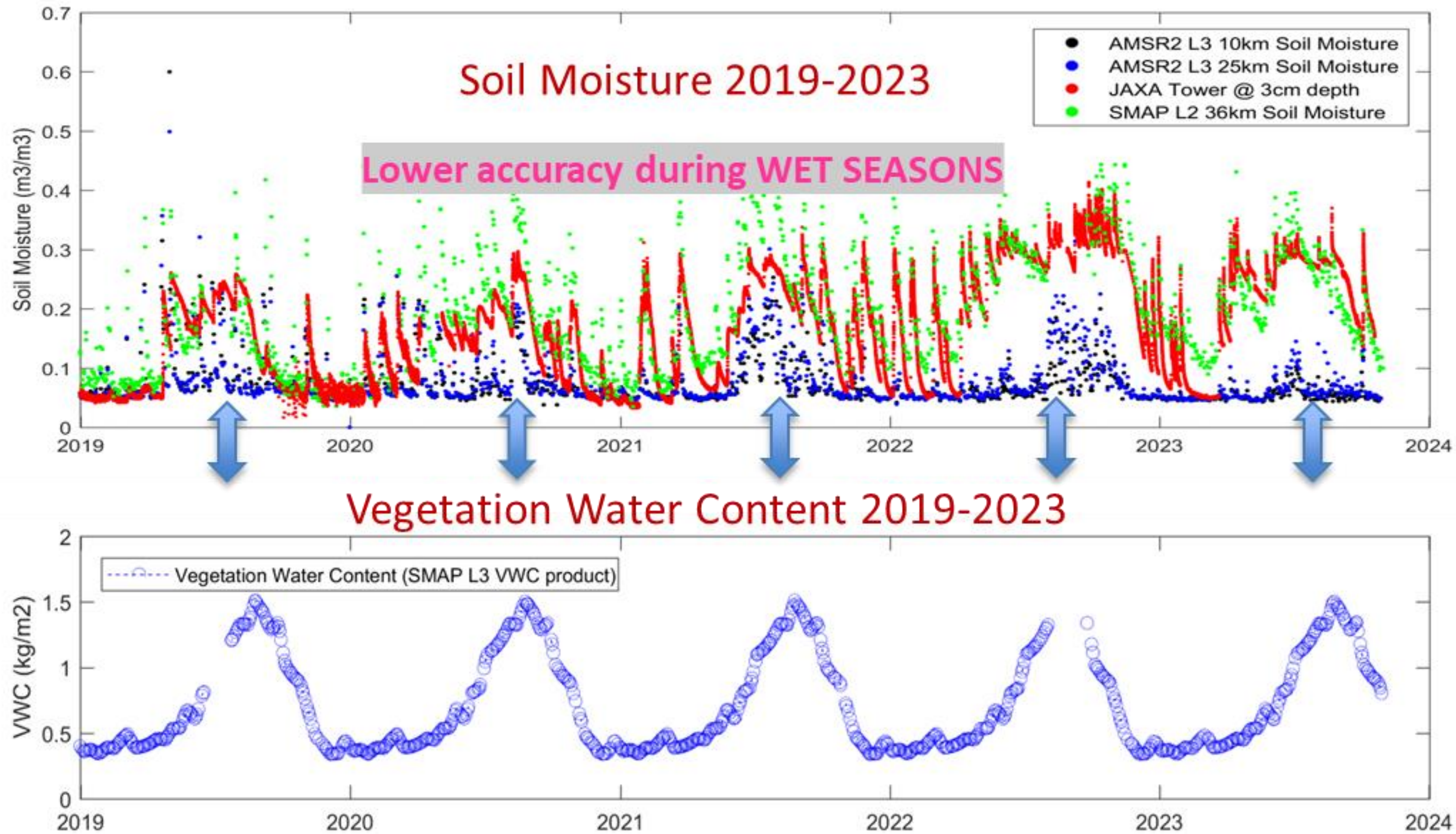

Figure 32: Comparison of the wet-season higher soil moisture against VWC (MODIS NDVI Climatology) for 2019-2023.

Figure 31 illustrates a focused time series analysis spanning the recent four-year period from 2019 to 2022. This plot presents a comparison between AMSR2 soil moisture products (10 km in black and 25 km in blue) and tower soil moisture readings (in red). A clear observation emerges: the AMSR2 products consistently underestimate the tower soil moisture levels. Interestingly, the correlation between the two datasets is stronger during the dry season (October to December) compared to the wet season (May to September).

According to the annual reports of JFY 2022, a potential strategy to enhance the accuracy of the AMSR2 soil moisture product involves employing a simple regression technique against in-situ measurements, utilizing historical data profiles. This regression method can be implemented on the original product when the soil moisture surpasses a certain threshold, such as 0.1 m3/m3, beyond which the disparity between the product and in-situ measurements becomes more evident.

Moving to Figure 32, it showcases the soil moisture time series for the same 2019-2023 timeframe alongside the volumetric water content (VWC) derived from the MODIS 10-year NDVI climatology. The VWC plot is included to contrast with the soil moisture trend. Notably, the accuracy of the AMSR2 soil moisture product diminishes during the wet season, consistent with previous findings. The VWC trend closely mirrors the soil moisture trend, with peaks in VWC correlating well with peaks in soil moisture levels. However, due to the retrieval of AMSR2 soil moisture from C-band, which operates at a higher frequency, the signal is notably influenced by the vegetation layer, posing challenges in separating vegetation effects from soil moisture. Consequently, the AMSR2 product exhibits less sensitivity to soil moisture changes.

5.2 Scatter Plots and Statistics

Figure 33 presents a comparative analysis between the AMSR2 L3 soil moisture product at 10-km resolution and soil moisture observations from tower (Figure 33a) and SMAP (Figure 33b) through scatter plots. These plots reveal a consistent negative bias (-0.08 and -0.11 m^3/m^3), aligning with the findings from the time series plot. Furthermore, tower soil moisture is juxtaposed against AMSR2 SM (Figure 33c) and SMAP SM (Figure 33d) in separate scatter plots.

Upon scrutinizing the comparison between SMAP SM and tower SM, it becomes evident that the bias was relatively smaller (-0.04 m^3/m^3) compared to AMSR2 SM. Additionally, both the root mean square error (RMSE) and correlation (0.80) exhibited superior performance. These results strongly suggest that the SMAP product offers more accurate estimations of soil moisture levels compared to the AMSR2 product.

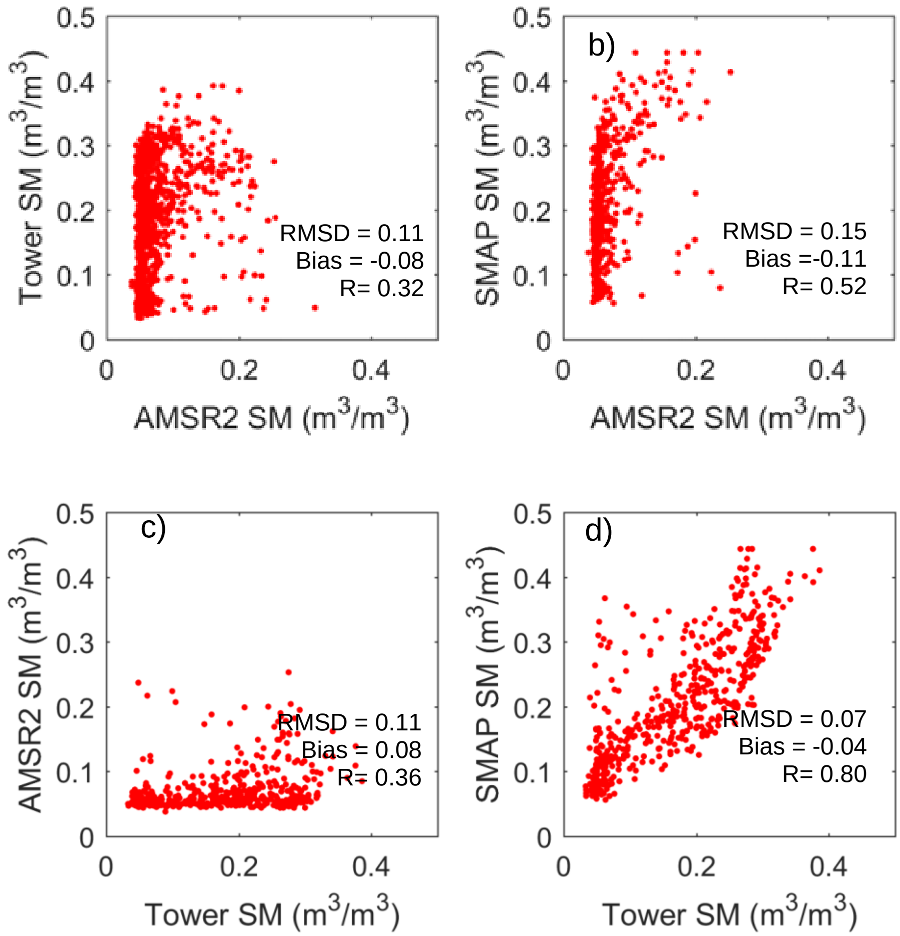

Figure 33: Scatter plots of AMSR2 SM (10-km) against a) tower soil moisture, b) SMAP SM (36km), c) tower SM against AMSR2 SM and d) tower SM against SMAP SM.

Chapter 6: Validation of AMSR-2 Research Soil Moisture Products

A preliminary analysis was performed with the AMSR2 soil moisture research product. Unlike the soil moisture standard product, the research product uses the algorithm for AMSR3. The research product for 10km and 25km were plotted against tower soil moisture and SM product together with the AMSR2 standard product for 2022-2023 in figure 34.

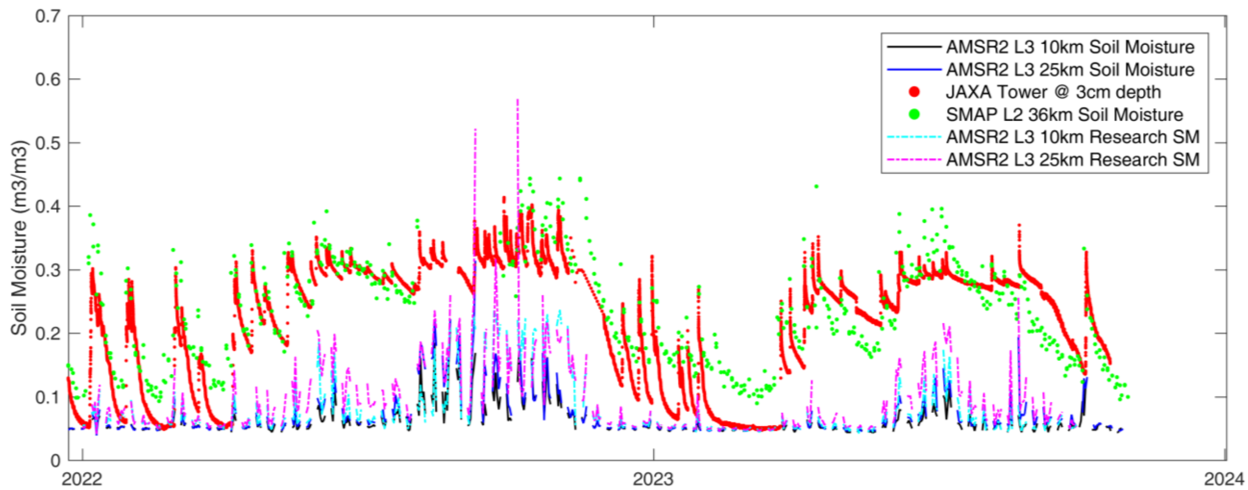

Figure 34: Validation of both AMSR2 standard and research SM product against tower and SMAP SM for 2022-2023.

In the time series plot, it is noticeable that the research product consistently registers slightly higher values compared to the standard product. Despite this, there remains a significant disparity between the research product and the tower/SMAP data. Particularly noteworthy are the occurrence of some extreme values in late 2022, exceeding 0.5 m^3/m^3, while the actual soil moisture truth hovers around 0.4 m^3/m^3. Despite these discrepancies, it's worth noting that the research product demonstrates a slightly reduced bias when compared with the standard soil moisture product.

Analysis will continue in the coming FY with longer periods of time series.

Chapter 7: Validation of the AMSR2 beta VWC product

7.1 The AMSR2 beta VWC product

JAXA introduced the beta VWC product, encompassing two data versions: v001, employing semi-empirical retrieval algorithms utilizing X and Ka bands, and v002, employing the ANN algorithm utilizing C, X, and Ka bands. In previous years, both versions underwent evaluation by validating the VWC products against calculated VWC derived from MODIS vegetation indices VWC-NDVI relationships, as outlined in Gao et al., 2015.

Given that the product provided was available until the conclusion of 2020, a preliminary analysis was conducted utilizing three years of data spanning 2018 to 2020. Table 1 furnishes a summary of the data versions utilized in the analysis. The VWC official research product is not yet available on the server. More in-depth analysis will be performed once the product is officially ready.

Table 1. AMSR2 VWC research products from 2012-2020 provided

Product version	Algorithm
v001	Semi-empirical retrieval algorithm using X and Ka bands
v002	ANN algorithm using C, X and Ka bands

Table 2. VWC-NDVI equations suggested by Gao et al. (2015)

Land cover type	Empirical Relationships
Corn	$VWC = 0.098\ e^{4.225NDVI}$
Cereal grains	$VWC = 0.078\ e^{3.51NDVI}$
Grassland	$VWC = 0.017\ e^{5.866NDVI}$

7.2 The Validation against MODIS NDVI-derived VWC

Figure 35 illustrates a comparative analysis between the calculated VWC derived from MODIS NDVI using the Gao equation and the AMSR2 VWC products. Notably, v001 values generally exhibit higher levels compared to v002. Specifically, when VWC values surpass 3 kg/m^2, both versions tend to align, whereas discrepancies emerge at lower VWC values. This phenomenon may be attributed to the increasing influence of vegetation, which becomes more discernible as VWC rises and is more readily detected by the frequency bands.

However, the calculated VWC from MODIS NDVI markedly differs from the AMSR2 VWC products, with MODIS VWC only corresponding with AMSR2 VWC at very low VWC values (0-1 kg/m^2). In the year 2020, MODIS VWC follows a similar trend as AMSR2 VWC while exhibiting a negative bias of approximately 1-2 kg/m^2. Additionally, it's noteworthy that MODIS VWC remained relatively constant throughout the years 2018-2019, maintaining a low value of less than 1 kg/m^2.

Based on our team's on-site field experience, AMSR VWC v001 appears to be potentially overestimating VWC levels for grassland conditions. The actual VWC condition likely lies somewhere between AMSR VWC v001 and MODIS VWC. Nonetheless, these products necessitate field VWC data for accurate verification of their performance.

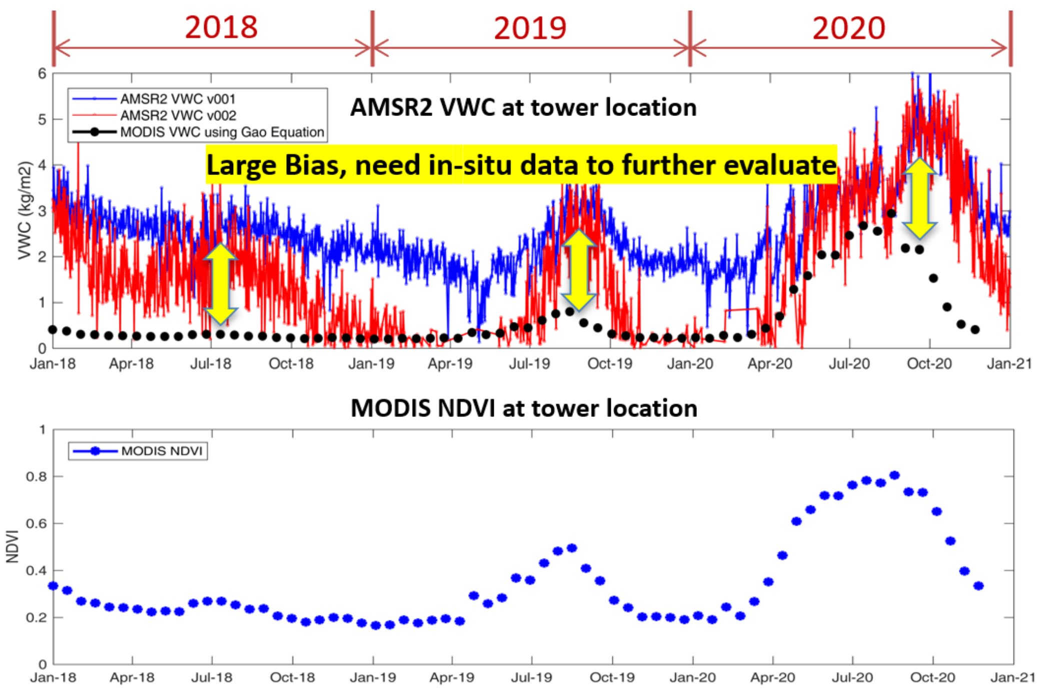

Figure 35: Top: AMSR2 VWC product v001 and v002 together with Calculated VWC from MODIS NDVI using Gao equation; Bottom: MODIS NDVI used to calculate VWC.

7.3 The Validation against field campaign sampling

To further validate the accuracy of AMSR-2 VWC products, we collected field sampling data from various field campaigns conducted in the Yanco area. These campaigns include SMAPEx-4 (May 2015), SMAPEx-5 (Sept 2015), PRISM2019 (Oct 2019) and PRISM2021 (Mar 2021). These campaigns provided us with ground-truth measurements of VWC, which we can compare with the VWC values derived from AMSR-2 data. Through this validation process, we aim to assess the accuracy of the AMSR-2 VWC products and ensure that they provide reliable information for future studies and applications in the field of remote sensing.

Based on the information gathered from the SMAPEx-4, SMAPEx-5, PRISM2019, and PRISM2021 field campaigns at Yanco area, it has been determined that the VWC values obtained from the AMSR2 product are likely overestimated. Specifically, the VWC values obtained from SMAPEx-4 and SMAPEx-5 were found to be below 1 kg/m^2 (Figure 36, up), which is more in line with the VWC values obtained using the MODIS derived VWC. Similarly, the VWC values obtained from PRISM2019 were even lower, measuring less than 0.5 kg/m^2 (Figure 36, bottom), which again aligns better with the MODIS derived VWC. These findings confirm that the AMSR2 VWC product is likely too high when compared to the actual VWC 'truth'. Further research and analysis are needed to determine the exact degree of overestimation and to identify appropriate solutions to address this issue.

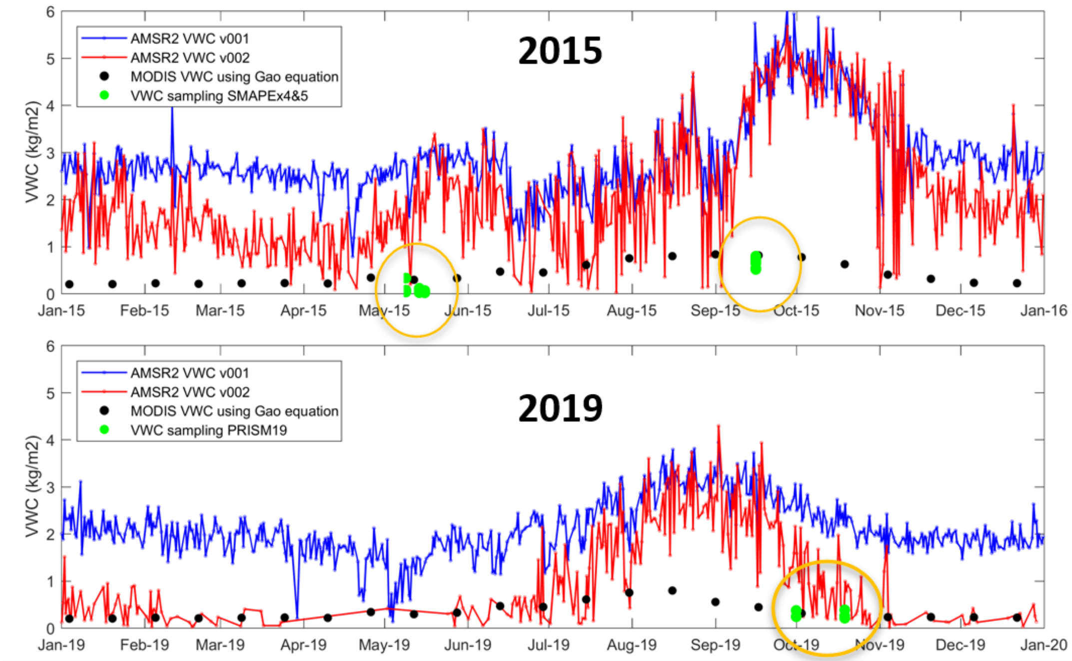

Figure 36: Top: AMSR2 VWC product v001 and v002 together with VWC samplings from SMAPEx 4&5; Bottom: same with up but with VWC samplings from PRISM19.

Chapter 8: Summary and Conclusion

In conclusion, the project "Validation of GCOM-W1 Products Using Global Water and Energy Balance Monitoring in the Australian Murray-Darling Basin" for the fiscal year 2023 has made significant progress towards its primary objective of sustaining the operation of the JAXA flux tower in Yanco, New South Wales. Maintenance activities undertaken during the fiscal year ensured the proper functioning of the flux tower, addressing challenges such as insect control and sensor replacements. Additionally, tower safety inspections confirmed satisfactory conditions overall, with necessary sensor replacements carried out to maintain data accuracy.

The data collected from the JAXA flux tower, supplemented by the ASSH-T weather station, provided valuable insights into soil moisture dynamics in the study area. However, some connectivity issues with soil moisture sensors were noted, although real-time data remained accessible online, facilitating continuous monitoring efforts.

Analysis of AMSR2 soil moisture products revealed consistent underestimation of soil moisture levels compared to flux tower measurements, with SMAP data showing closer agreement with ground truth, especially during wet seasons.

Validation efforts using time series plots further confirmed the underestimation by AMSR2 products, particularly during periods of elevated soil moisture. Preliminary analysis of AMSR2 research products suggested slightly higher values compared to standard products, but significant disparities persisted when compared to tower and SMAP data, warranting further investigation.

Evaluation of AMSR2 VWC products against MODIS NDVI-derived VWC indicated discrepancies, with AMSR2 VWC potentially overestimating values. Variations in performance were observed among different versions of the VWC product, highlighting the need for more comprehensive analysis once the official research product becomes available.

In summary, the findings presented in this report contribute to a better understanding of soil moisture dynamics in the Australian Murray-Darling Basin and underscore the importance of accurate satellite-derived products for water and energy balance monitoring. Future research will focus on addressing discrepancies and refining validation methodologies to enhance the reliability of satellite-based soil moisture estimates.

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Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using AMSR3 and GCOM-W data

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