FY2022 Progress Report To:

the

Japan Aerospace Exploration Agency

Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using GCOM-W1 data

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Engineering

Executive Summary

The present report aims to provide a detailed overview of the research activities and outcomes of the project titled 'Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using GCOM-W1 data' during the Japanese Fiscal Year (JFY) 2022. One of the primary research objectives was to continue operating the JAXA flux tower located in Yanco, New South Wales, Australia, within the core validation site. This was done to obtain spatially distributed soil moisture data from across an AMSR2- and AMSR3-sized footprint.

The project made significant independent and collaborative contributions towards accomplishing three main targets during JFY 2022:

Firstly, the validation of the AMSR2 standard soil moisture product was continued. Secondly, intercomparison of the AMSR2 soil moisture product with the Soil Moisture Active Passive (SMAP) Level 2 soil moisture product was carried out. Thirdly, the vegetation water content (VWC) research product was validated against field sampling from the 4th and the 5th Soil Moisture Active Passive Experiments (SMAPEx-4 and -5) conducted in Yanco, Australia, and VWC calculated from MODIS-derived vegetation indices.

It is worth noting that all three targets were achieved in JFY 2019 to JFY 2020 and were continued in JFY 2021 and JFY2022, as they will also serve as a reference for the research after the launch of AMSR3. Before JFY 2021, the research focused on validating the land surface model simulated soil moisture and flux data using AMSR2 products, and validation of satellite-based Kc factor due to the unavailability of the AMSR2 VWC research product. However, since the AMSR2 VWC research product became available, the primary task during JFY 2021 and 2022 was to focus on the third target.

The results of the research activities and outcomes presented in this report demonstrate the significant contributions of the project towards the validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using GCOM-W1 data, while also providing a guideline for the research targets after AMSR3 is launched (schedule in JFY 2023). The project's findings can be utilized to improve the accuracy of soil moisture measurements and vegetation water content estimates in the region. Overall, the project has significantly contributed to the advancement of scientific knowledge and understanding of global water and energy balance monitoring, and its findings can be used to support sustainable management of water resources.

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Chapter 1: Introduction

The purpose of this report is to present the research activities and outcomes of the project "Validation of GCOM-W1 Products Using Global Water and Energy Balance Monitoring in the Australian Murray-Darling Basin" during JFY 2022. One of the main objectives of the project is to continue the operation of the JAXA flux tower at the core validation site in Yanco, New South Wales, to collect spatially distributed soil moisture data across an AMSR2-sized footprint. The project also aims to make significant independent and collaborative contributions to the validation of the AMSR2 soil moisture product, including intercomparison with complimentary satellite soil moisture products from other missions like SMAP, and validation of the Vegetation Water Content (VWC) research product against MODIS-derived vegetation indices and field samplings.

In JFY 2022, the project will conduct site maintenance activities, including the calibration of the JAXA tower Gas Analyzer (IRGA) and regular site visits and maintenance of the JAXA flux tower. The collected soil moisture data will be used to validate the 10-km and 25-km resolution AMSR2 soil moisture products. Additionally, the project identified erroneous data, indicating possible broken sensors, and requested replacement sensors from JAXA. The replacement sensors have arrived at Monash University in late January, 2023. Due to the special training requirement to climb the tower and the appointment of a new technician in our group, the replacement sensors will be installed in March-April 2023.

In June 2021, JAXA provided a beta version of the VWC product, which includes two data versions: v001, using semi-empirical retrieval algorithms using X and Ka bands, and v002, using the ANN algorithm using C, X, and Ka bands. Both versions were evaluated against calculated VWC from MODIS vegetation indices VWC-NDVI relationships from Gao et al, 2015. The main research activity for JFY 2022 is to continue validating the VWC products against field sampling collected from SMAPEx-4 and SMAPEx-5 field campaigns in the Yanco area.

Chapter 2: Flux Tower Maintenance

2.1 Flux Tower Maintenance for JFY 2022

This section details the field site maintenance work done in 2022. The maintenance work involved standard field checks, battery checks, investigation into problems with the NDVI camera, purchasing of CO_2 and nitrogen gas, receiving replacement sensors, and dealing with difficulties in accessing the site.

<u>Standard Field Checks</u>:

The standard field checks were completed as planned. This included rain gauge cleaning, regular battery health checks, pest, and grass maintenance.

<u>Battery Checks</u>:

The battery checks were overdue, and it was determined that they needed to be replaced as they were over 10 years old. The replacement of the batteries was scheduled and completed.

<u>Problems with NDVI Camera</u>:

Some problems were starting to occur with the NDVI camera. It was found that it was recording fewer photos but a full data file. This issue requires further investigation to determine the cause.

<u>CO2 and Nitrogen Gas</u>:

CO_2 and nitrogen gas were purchased for next year's IRGA calibration.

Replacement Sensors:

Replacement sensors were received in late January 2023, including HFP, wind sensors, temperature and soil moisture sensors. These sensors will be replaced in March-April 2023, providing that our new technician is trained for safely climbing the tower.

Difficult Weather Patterns:

Due to difficult weather patterns, site visits were not as regular as hoped. The consistent La Nina and wet paddocks are creating wet conditions making the site hard to access.

Vegetation Growth and Pest Species:

There is more vegetation growth in the last two years, causing more pest species. This creates problems with insects and spiders making nests on sensors and inside cabinets, threatening the reliability of stations to collect clear and concise data. This problem seems to be starting to get worse and needs to be kept in mind for future planning and fieldwork activities.

Future Tower Inspection to be Scheduled:

Another tower inspection needs to be scheduled by the end of JFY2023, since The Australian Standard requires inspection of Guyed masts every 2 years and free-standing towers every 3 years to be compliant. The LadSafe (fall arrest system) perhaps annually. The last tower inspection was done at the end of 2019.

Overall, the standard field checks were completed, and necessary maintenance and replacements were carried out. The investigation into the NDVI camera issues needs to be done and the issue with pest species needs to be addressed for future planning and fieldwork activities.

2.2 JAXA Asset Check at Yanco site

We received a request from JAXA GCOM RA office for checking assets and asset labels for JAXA annual stocktaking. We also received some help from Dr. Fujii in identifying some of the assets. The sensors include AMSR2 Land Surface Observation System, GCOM-W1 Soil Moisture Station, AWS/GCOM-W1 Heliograph, COM-W1/AWS Infrared Radiometer, NDVI Sensor, and AMSR-2 Australian Atmosphere Observation System.

They are detailed in the following:

1. AMSR2 Land Surface Observation System - Asset Number: 2410286863 This system includes a whole tower system, including a solar module, soil sensors, pyranometer, pyrgeometer, and other sensors.

2. GCOM-W1 Soil Moisture Station - Asset Number: 2910279308 This AWS (Automatic Weather Station) system measures soil moisture and is installed in Australia.

3. AWS/GCOM-W1 Heliograph - Asset Number: 2910304116 This system includes a pyranometer (CMP21) and is used as a calibration reference. It was sent to Monash University in February 2014 and is usually kept in the laboratory.

4. COM-W1/AWS Infrared Radiometer - Asset Number: 2910304128 This system includes a pyrgeometer (CGR4) and is used to measure infrared radiation. Item No.3 and No. 4 were sent to Monash University in February 2014. Their purpose is to be used as a calibration reference. Therefore, they would normally be kept in the laboratory. The data logger has a port to connect the reference. By connecting a reference there, you can compare three

sensors side by side: the reference, downward radiation, and upward radiation. It can also be used as a replacement in case of sensor failure.

5. NDVI Sensor (SKR1850D) - Asset Number: 2910304834 This system includes four-channel sensors (SKR1850D, SKR1870D) and was sent to Monash University in February 2014. It is mounted on the radiometer frame of the tower system along with the pyranometer/pyrgeometer.

6. NDVI Sensor (SKR1850ND) - Asset Number: 2910304840 This system includes four-channel sensors (SKR1850ND, SKR1870ND) and was sent to Monash University in February 2014.

7. AMSR-2 Australian Atmosphere Observation System - Asset Number: 2910393621 This system includes a weather transmitter (WXT530), infrared radiation thermometer (SI111-L20), temperature and humidity probe (HMP155-L3.5). These are replacement sensors sent to Monash University in 2017.

These sensors are essential for environmental monitoring and provide valuable data for research and scientific purposes. Regular maintenance and calibration are necessary to ensure their accuracy and reliability. The information obtained from these sensors can be used for a variety of applications, including agriculture, climate research, and weather forecasting.

During the December 2022 field trip, photos were taken to identify some of the assets. These photos are shown below were taken on Nov 30 and Dec 1, 2022:

Figure 1: The whole tower observation system.

Figure 2: The radiometer frame of the tower system.

Figure 3: The Infrared radiometer (the square box in the middle).

Figure 4: The NDVI camera on the top of the tower.

Figure 5: The soil moisture station of the tower system.

Figure 6: Loggers with asset labels on the cabinet and lid of the cabinet.

2.3 Sensor Condition and Replacement

During site visits general duties are regularly undertaken including the cleaning of all environmental sensors and removal of spider webs. However, more preventative measures are being investigated as a reaction to these increased insect numbers.

Difficulty surrounding reduced staff numbers has been a problem after pandemic related cuts among technical staff. However, more technicians are being trained for field activities rather than relying on one staff member. This should result in more regular field visits/maintenance work and sensor calibrations.

As identified by our project CI Jason Beringer, there has been a number of sensors either failed or failing since early 2022. Some of these have been pointed out in the 2021 annual report. The tower is starting to show its age. The following problems and shown with highlight in purple boxes.

1. Licor IRGA AGC signal strength has dropped below 60% (Figure 7 green box) at Christmas 2022 and may well have continued to decline and really anything below 50% we would have to exclude. This was a big problem last year and into this year (Figure 7purple box). The windows need to be cleaned.

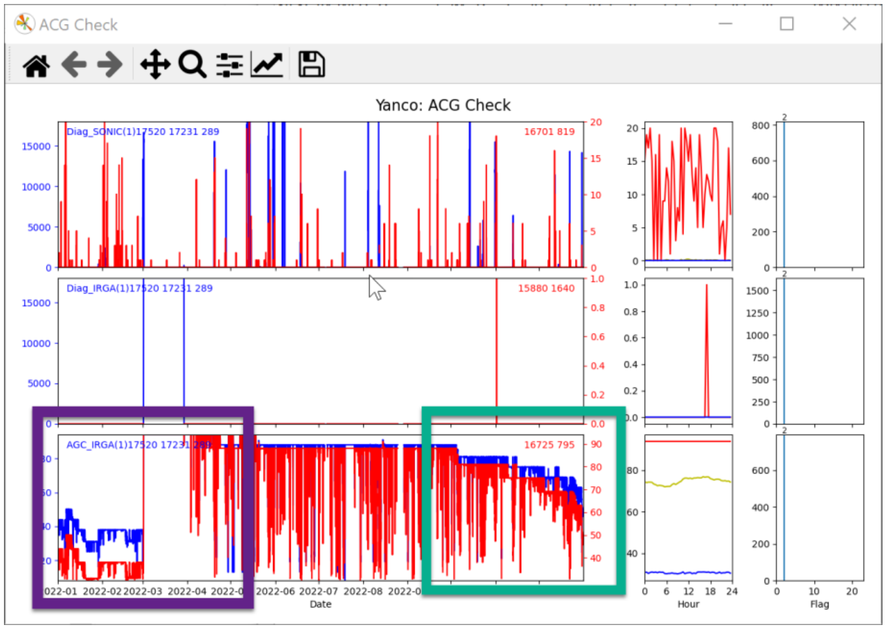

Figure 7: AGC signal strength during 2022.

2. Wind sensors Wind direction and Wind speed at 2m failed (Figure 8). Wind speed at 8m failed (Figure 9). These are believed to be the analogue sensors and have bearings in them and a finite life. It was considered to bring them all in and replacing bearings and service them in house as they are very likely to continue to get worse over time.

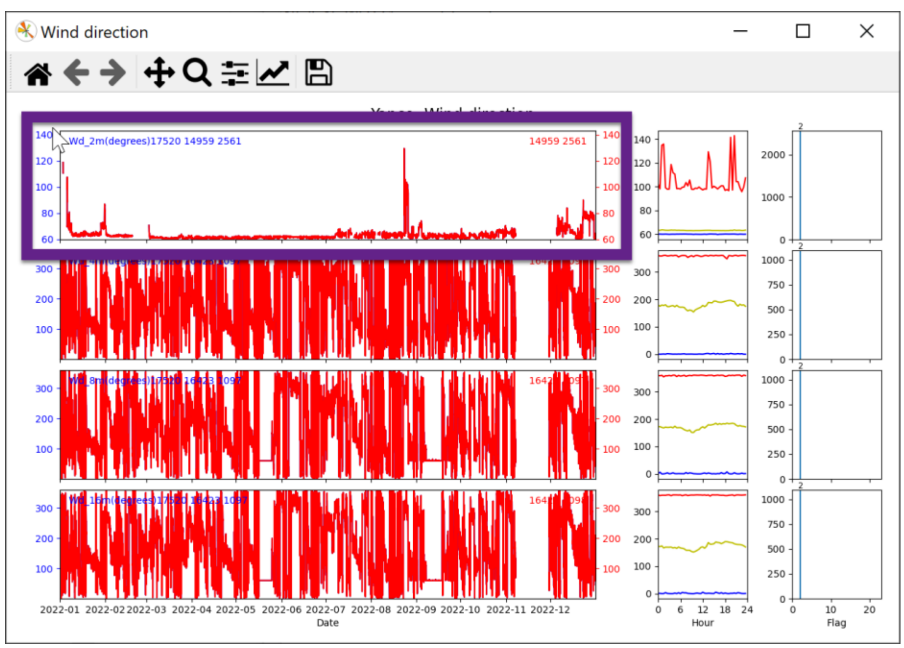

Figure 8: Wind direction for the four different heights during 2022.

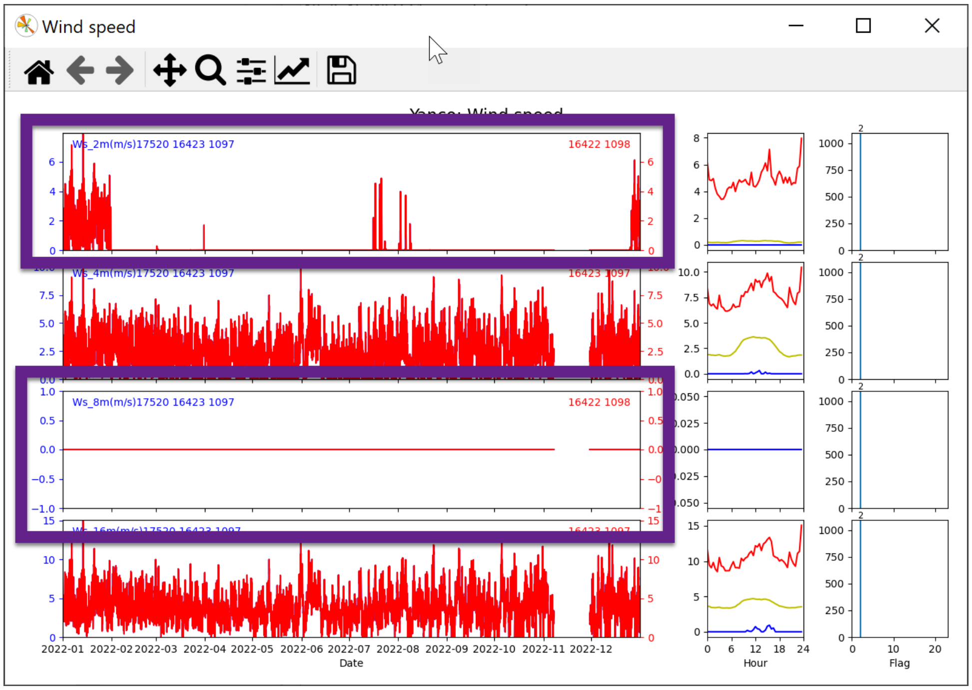

Figure 9: Wind speed for the four different heights during 2022.

3. One out of 2 Soil heat flux plates has failed. was recommended to install another one to replace the faulty one. (Figure 10)

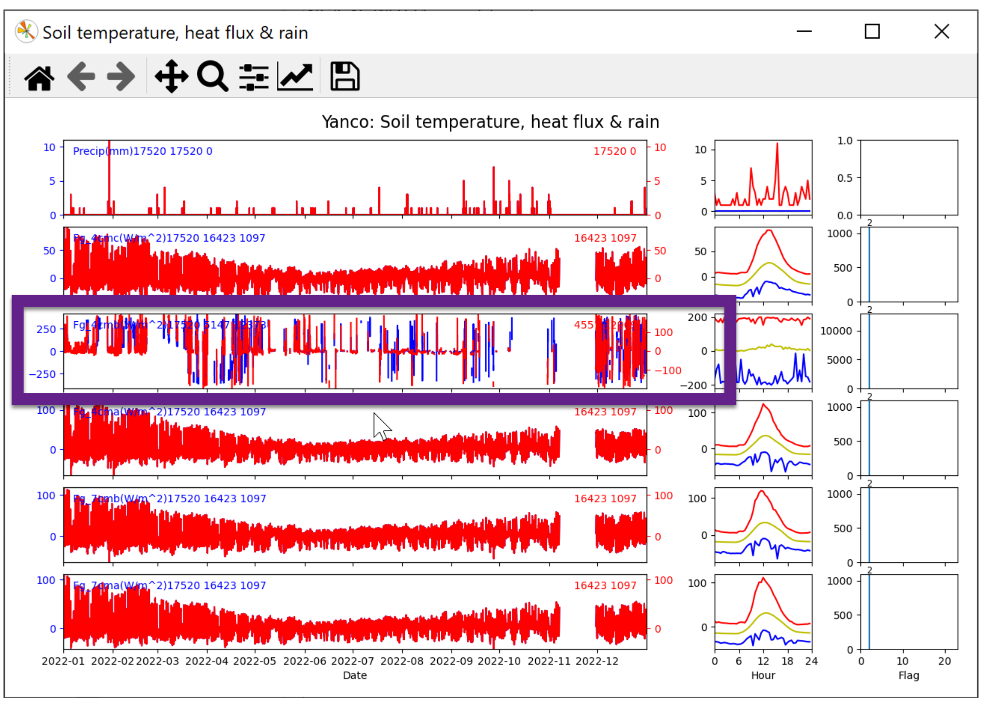

Figure 10: Wind speed for the four different heights during 2022.

4. Soil moisture probe at 10cm has intermittent failures so needs replacement too (Figure 11)

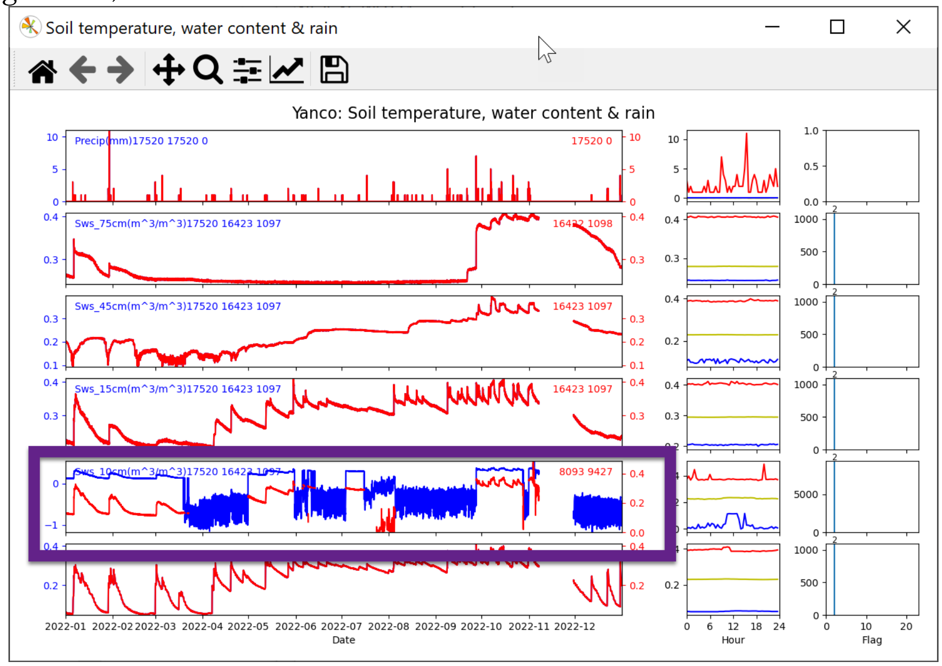

Figure 11: Soil moisture for the five different depth and precipitation during 2022.

5. Temperature and Humidity probe at 8m mostly failed (Figure 12). They would need to be replaced. Also they probably all need a clean and check at site, especially the dust cap. These are replaceable.

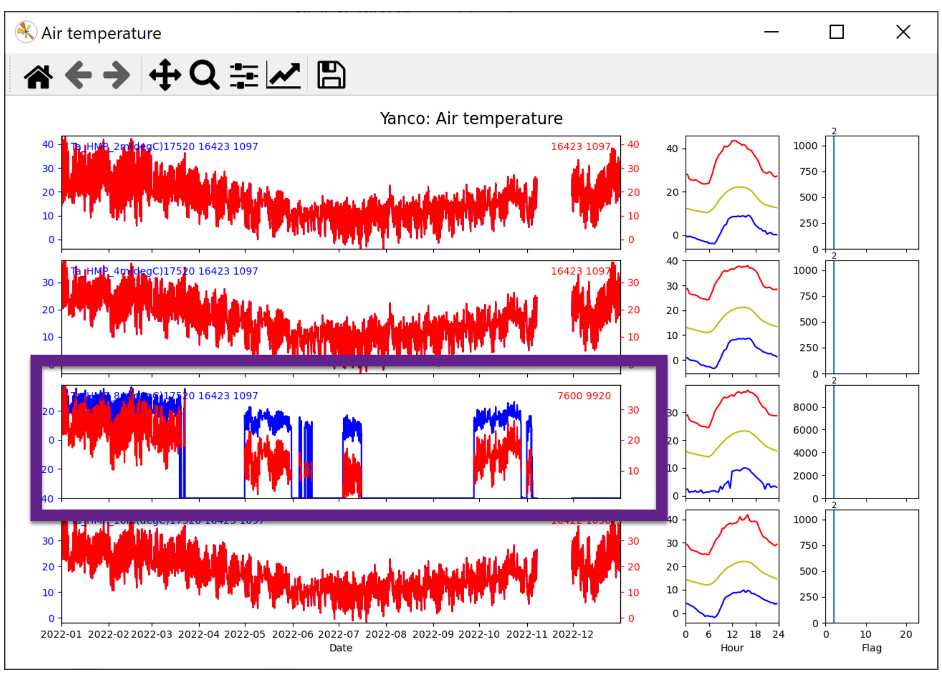

Figure 12: Air temperature at four different heights during 2022.

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

These sensors will be replaced in March-April 2023, providing that our new technician is trained for safely climbing the tower.

The following sensor is newly identified to be faulty and need replacement, and this will be requested to be provided by JAXA at their earliest convenience.

- Temperature and humidity sensor, 1 pc

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 from 2020 to 2022 (the 3-year contract period) from the JAXA tower.

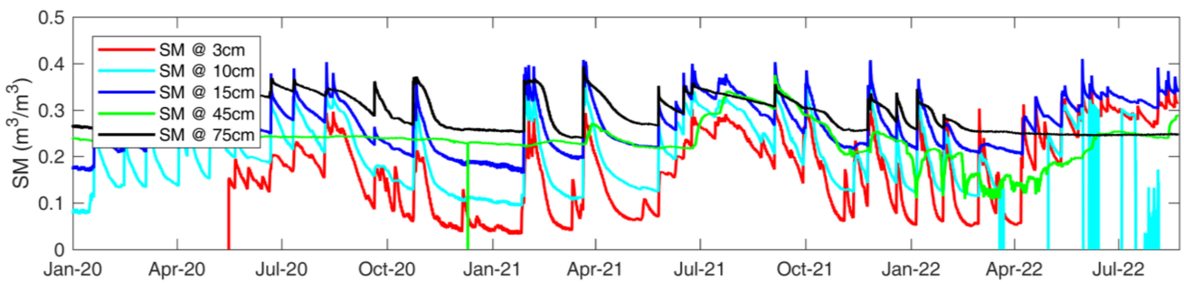

Figure 13: Soil moisture measured at JAXA Tower for 2010-2022.

It can be seen that 3cm sensor was replaced in May 2020 and the data have been performing well after sensor replacement. The 10cm sensor becomes faulty since April 2022.

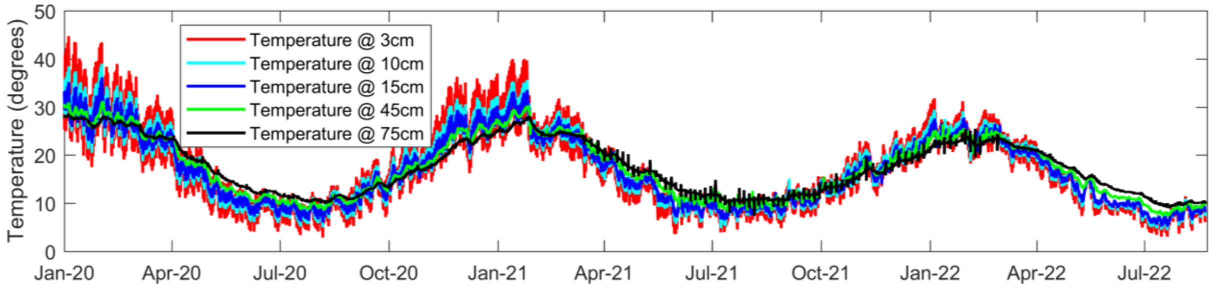

Figure 14: Soil temperature measured at JAXA Tower for 2020-2022.

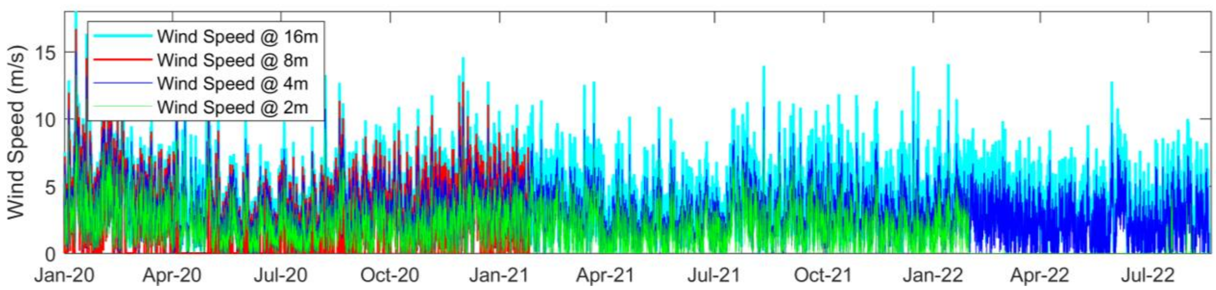

Figure 15: Wind speed measured at JAXA Tower for 2020-2022.

The 8m sensor (red) resumed functioning in January 2020 but stopped working again in February 2021. The 2m (green) stopped working in February 2022.

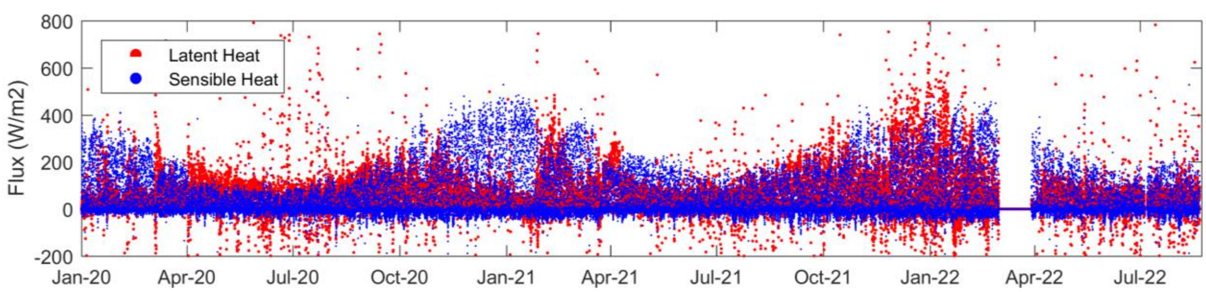

Figure 16: Flux density measured at JAXA Tower for 2020-2022.

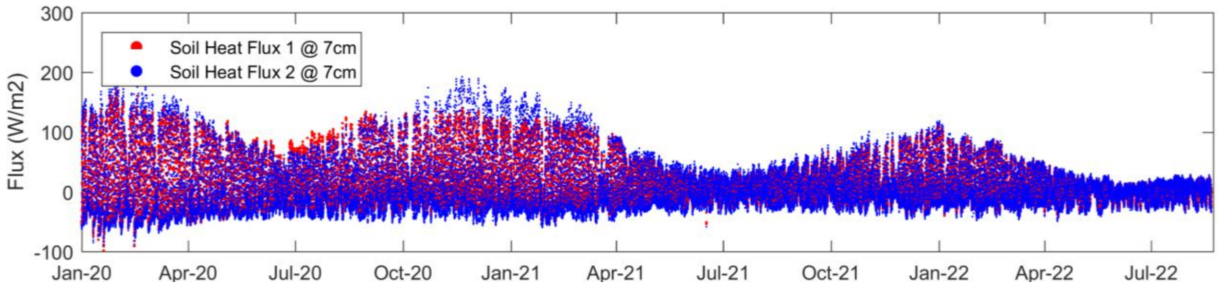

Figure 17: Soil Heat Flux at 7cm depth for 2020-2022.

One soil heat plate at 4cm (Figure 18, red) has significantly larger ranged compared with the other two plates. The sensor is considered to be faulty and will be replaced.

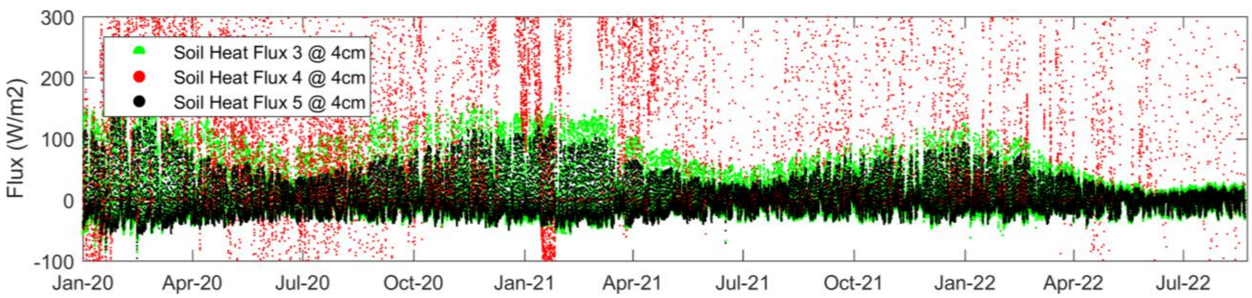

Figure 18: Soil Heat Flux at 4cm depth for 2020-2022.

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).

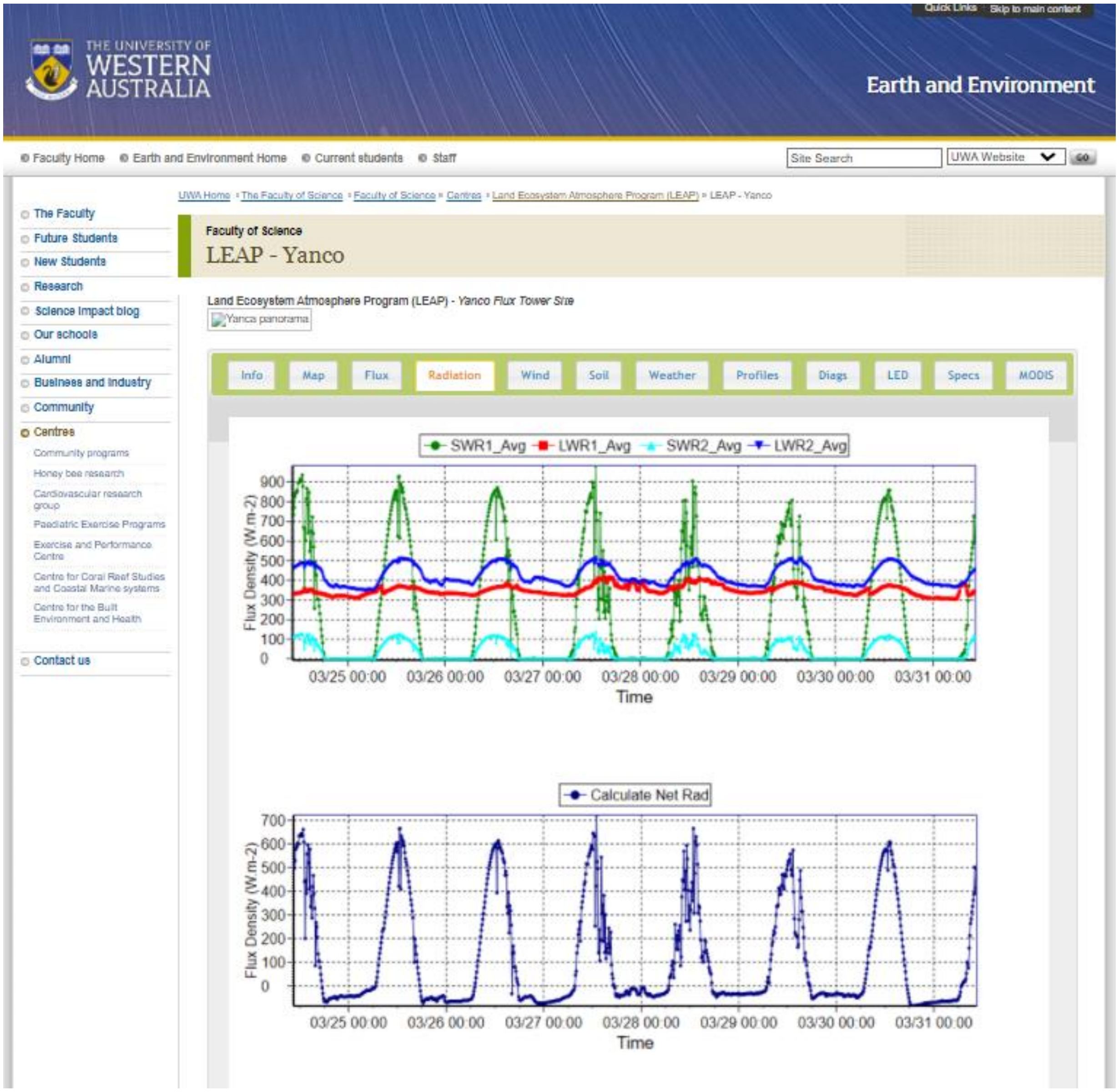

Figure 19: Real-time tower data interface on

http://www.science.uwa.edu.au/centres/land/yanco.

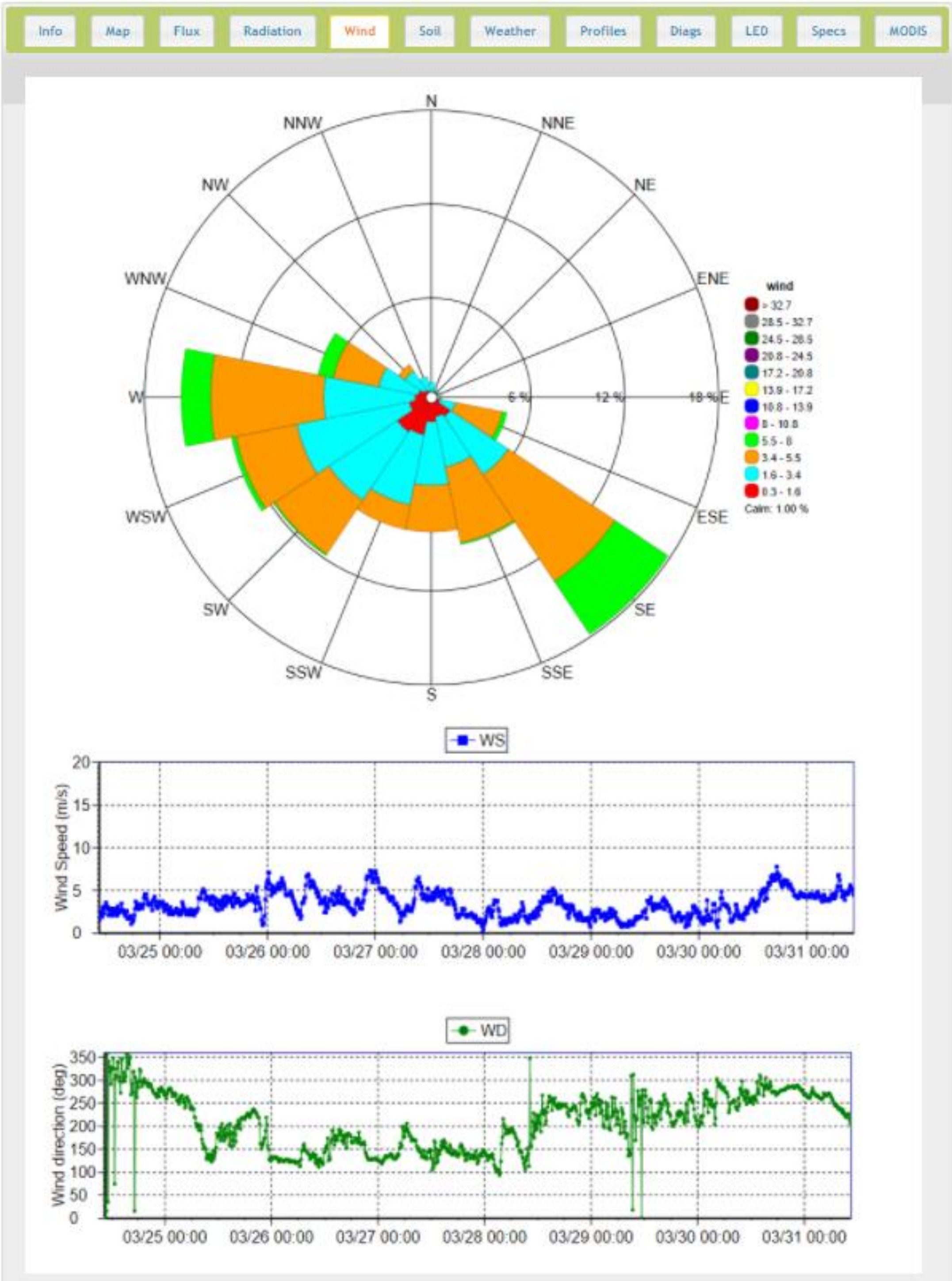

Figure 20: Examples of real-time figures for wind speed and wind direction.

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:

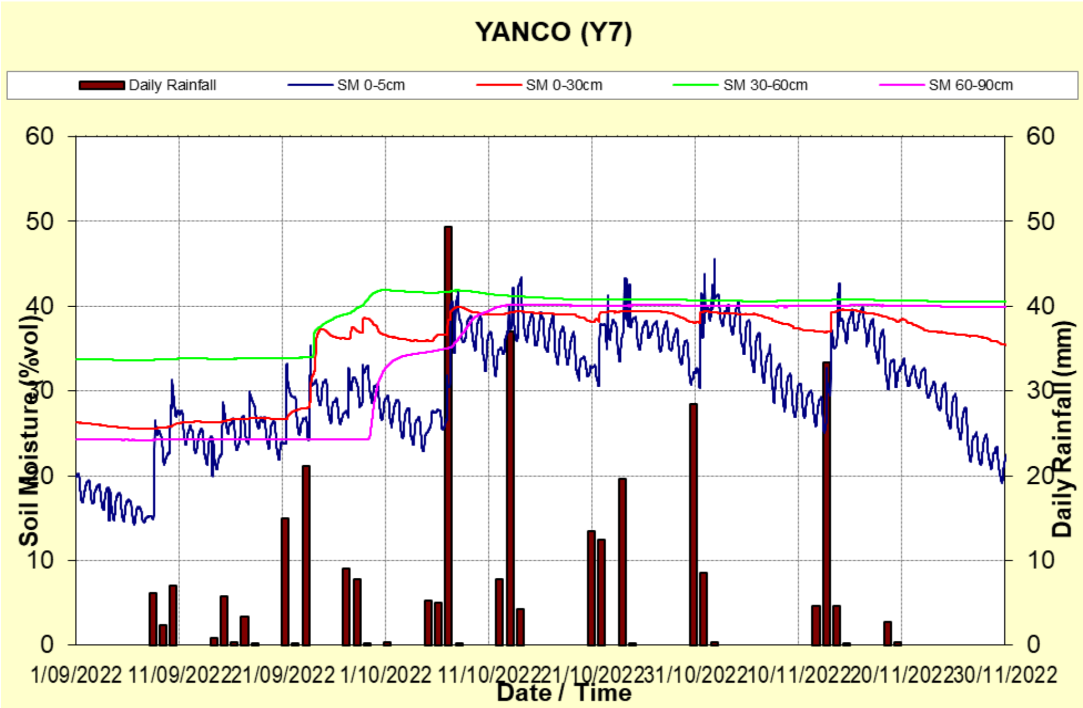

Figure 21: Sample data – Y7 Station 2022 Spring soil moisture data.

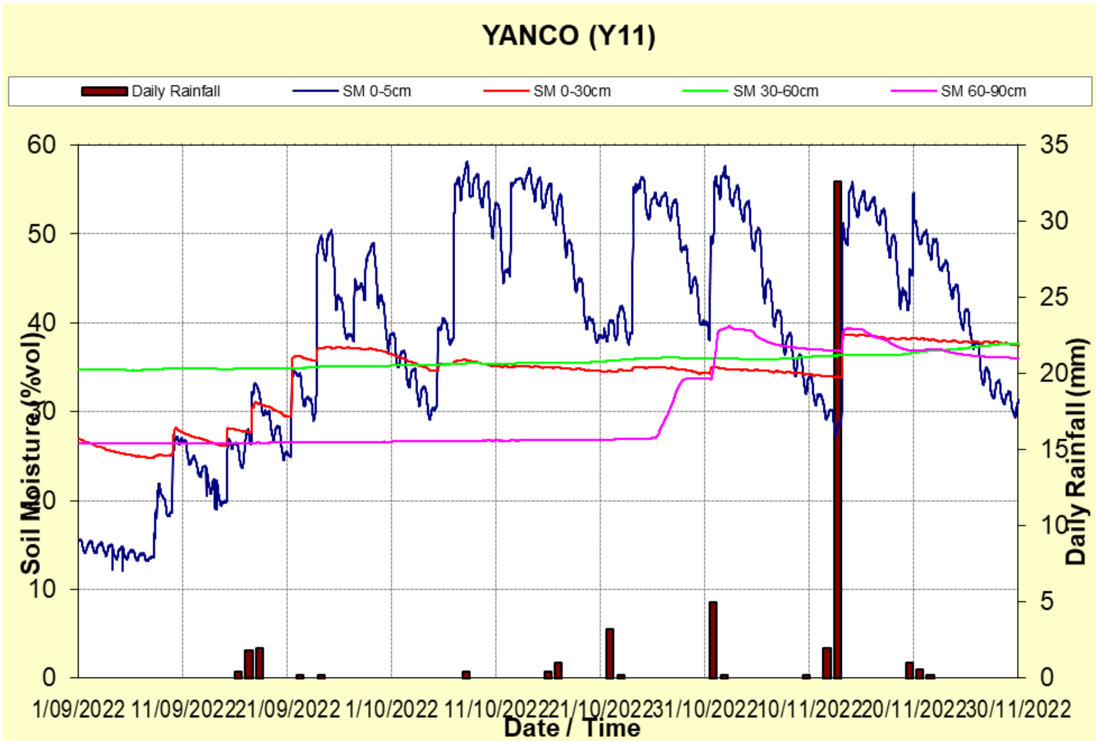

Figure 22: Sample data – Y11 Station 2022 Spring soil moisture data.

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

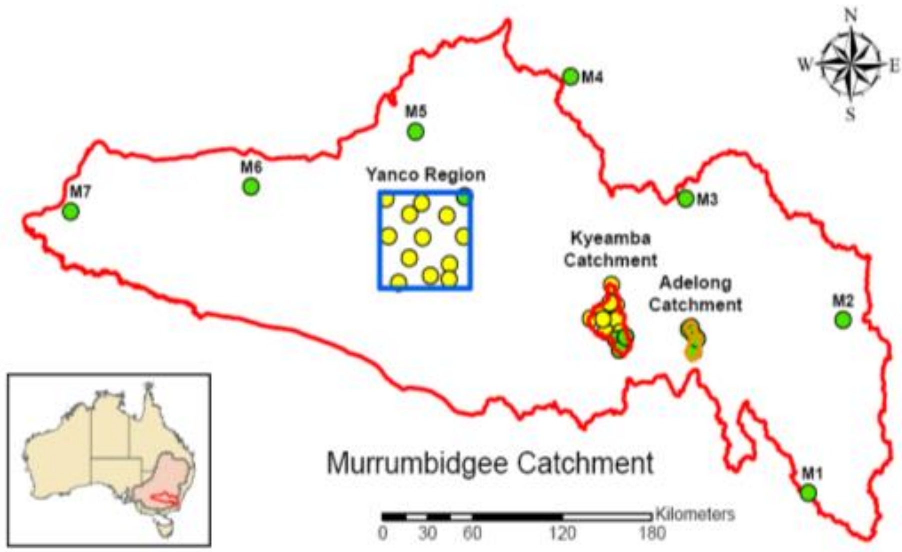

Figure 23: Location of the Yanco core validation site within the Murrumbidgee Catchment. Also shown is the location of the Murrumbidgee Catchment within the Murray-Darling Basin (inset) and the locations of sparse network soil moisture stations.

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.

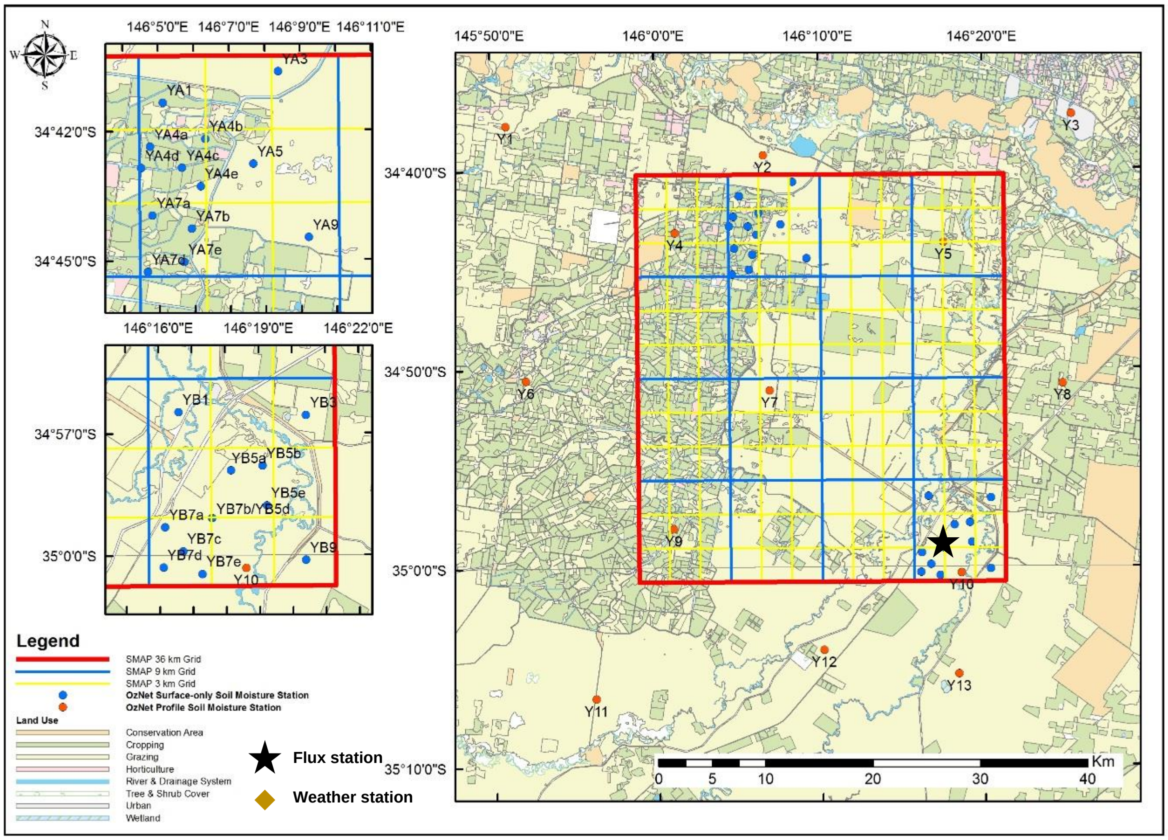

Figure 24: Locations of the JAXA flux station, weather station and soil moisture monitoring stations within the Yanco core validation site. Also shown are the YA and YB focus areas with intensive soil moisture stations, and the locations of intensive ground sampling areas.

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

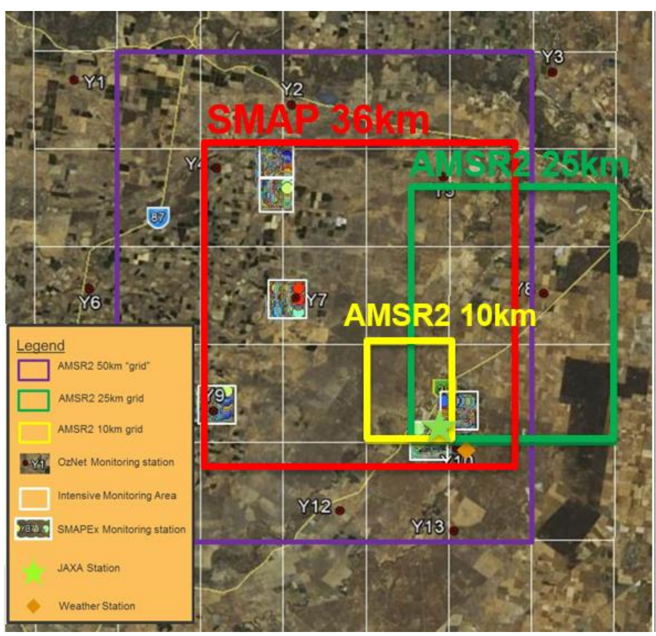

Figure 25: Location of the 10-km and 25-km AMSR2 L3 SMC pixel, SMAP 36-km pixel with respect to the flux tower location.

period in which AMSR2 data is available, the analysis covered a time series from July 2012 to December 2022 (see Figure 26). 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 26. 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.

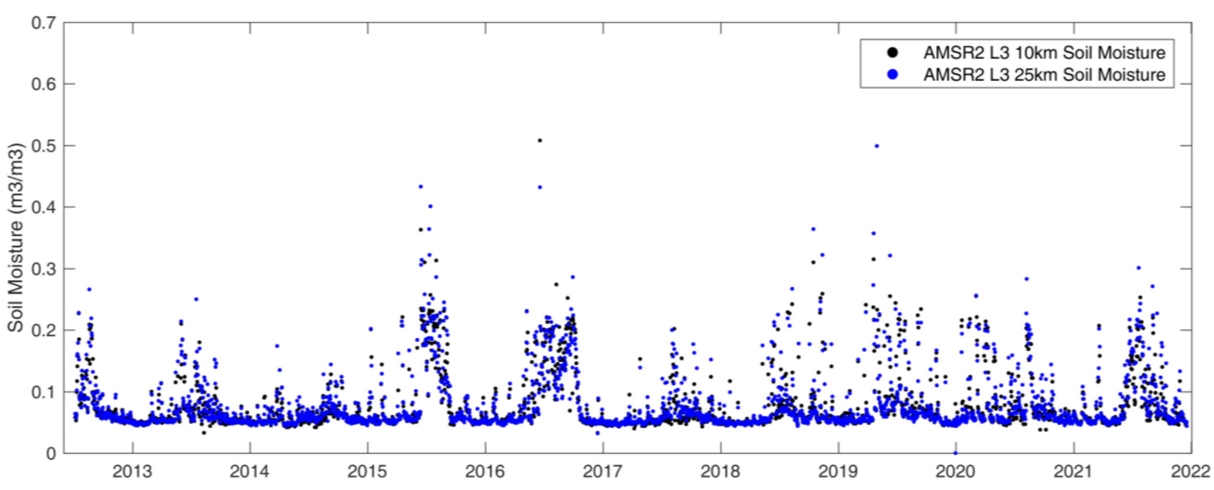

Figure 26: Year 2012 to 2020 time series of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site.

But the higher values of 2018-2022 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 2020-2022 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 28 shows the box plots of the AMSR2 L3 low- and high- resolution soil moisture for year 2022 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 27 shows the box plots of the AMSR2 L3 low- and high- resolution soil moisture for all data from 2012 to 2022. 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.

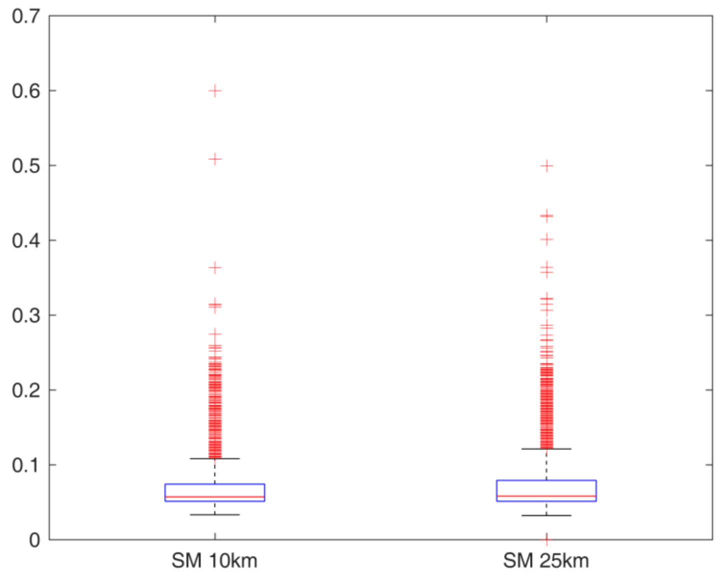

Figure 27: Box plot of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site: 2012-2022.

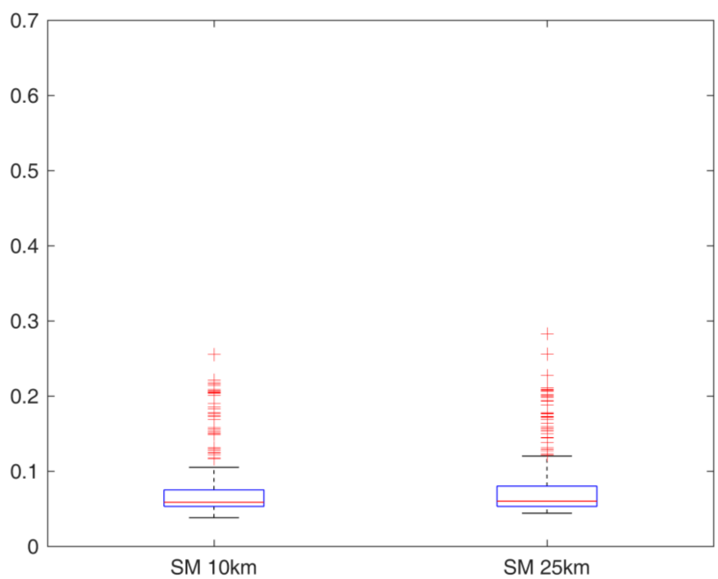

Figure 28: Box plot of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site: year 2022 only.

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

5.1 Time Series Plots

The AMSR2 Level 3 soil moisture products, available at 10km and 25km resolution, have undergone rigorous validation against two independent data sources: in-situ soil moisture measurements from the JAXA flux tower, and observations from the SMAP satellite mission. The results of this validation are presented in Figure 29, which depicts a time series plot of the comparison between AMSR2 and flux tower soil moisture measurements and SMAP product over a 10-years period spanning from 2012 to 2022. It should be noted that the flux tower soil moisture sensor used for validation was installed at a depth of 3 cm below ground level, representing the ‘surface’ soil moisture.

Upon inspection of Figure 29, it is apparent that the AMSR2 products tend to underestimate the soil moisture levels measured by the flux tower sensor, as indicated by the red curve. Interestingly, a stronger correlation between the two datasets is observed during dry periods across all years. Furthermore, when comparing AMSR2 to the flux tower measurements, lower values tend to match better than higher values, a pattern that has been observed in previous years and persists from 2020-2022.

In wet seasons from 2020-2022, a clear gap between the tower and AMSR2 soil moisture values is evident, which is similar to the pattern observed during 2015-2016. Another noteworthy observation is the trend of increasing and decreasing soil moisture levels throughout the wet season, which is evident in the flux tower measurements but not clearly apparent in the AMSR2 product.

Overall, the results of this validation exercise indicate that while the AMSR2 Level 3 soil moisture products are generally accurate, they tend to underestimate soil moisture levels when compared to flux tower measurements. Further investigations are necessary to identify the reasons for this discrepancy and to improve the accuracy of AMSR2 soil moisture estimates.

The Soil Moisture Active Passive (SMAP) Level 2 36km product, derived from L-band (1.4 GHz) brightness temperature observations using a passive-only algorithm, is also included in this analysis (Figure 29).

Compared to the AMSR2 products, the SMAP product (indicated by the green dots) appears to match better with the flux tower soil moisture measurements, particularly during wet seasons (May-Sept). This observation is not surprising, given that the SMAP product has a larger footprint of 36 km, compared to the 10km and 25km resolutions of the AMSR2 products. This larger footprint may provide a more representative estimate of the soil moisture conditions over the region surrounding the flux tower.

Interestingly, during dry seasons, the SMAP product overestimates the "truth" soil moisture levels, while the AMSR2 products match slightly better. This behavior may be attributed to the fact that the AMSR2 soil moisture is retrieved from C-band, which has a higher frequency and is more sensitive to the effects of vegetation cover and surface roughness. During the wet season, in particular, the vegetation cover can significantly impact the AMSR2 signal, making it more challenging to decouple the vegetation effect from the true soil moisture signal.

In contrast, L-band has been shown to be more sensitive to soil moisture content variation and better suited to retrieve accurate surface soil moisture. Thus, it is not surprising that the SMAP product appears to be closer to the "truth" soil moisture levels, especially during wet seasons. Overall, the inclusion of the SMAP product in this comparison highlights the importance of considering the impact of satellite frequency and footprint size when interpreting soil moisture estimates.

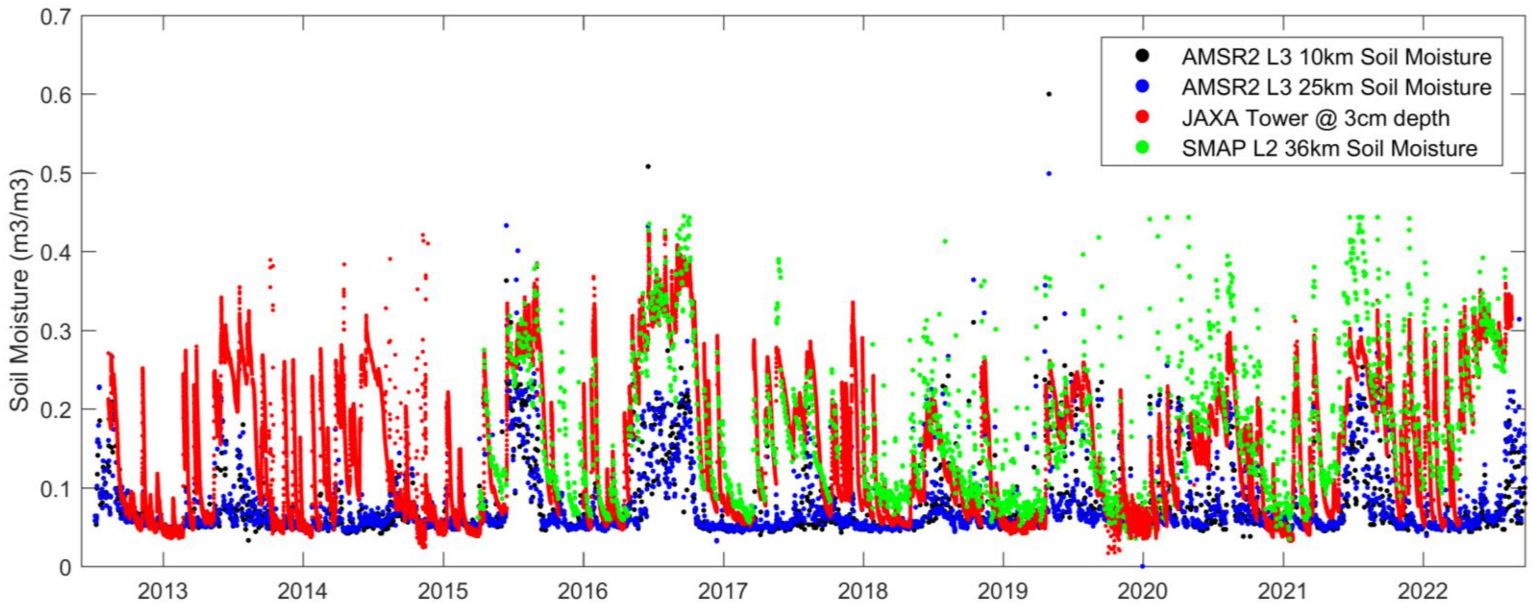

Figure 29: Same time series plot as Figure 19 with added SMAP L2 36km soil moisture product from 2012 to 2022.

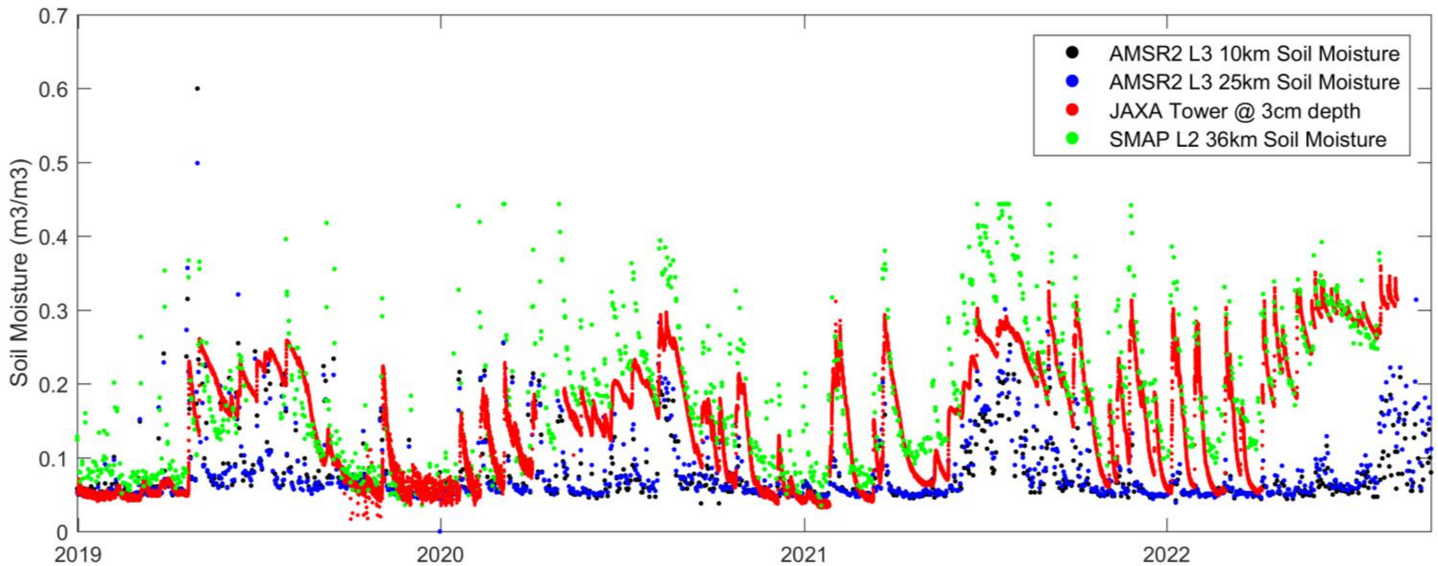

Figure 30: Zoom-in view of time series of AMSR2 products, tower SM and SMAP SM for 2019-2022.

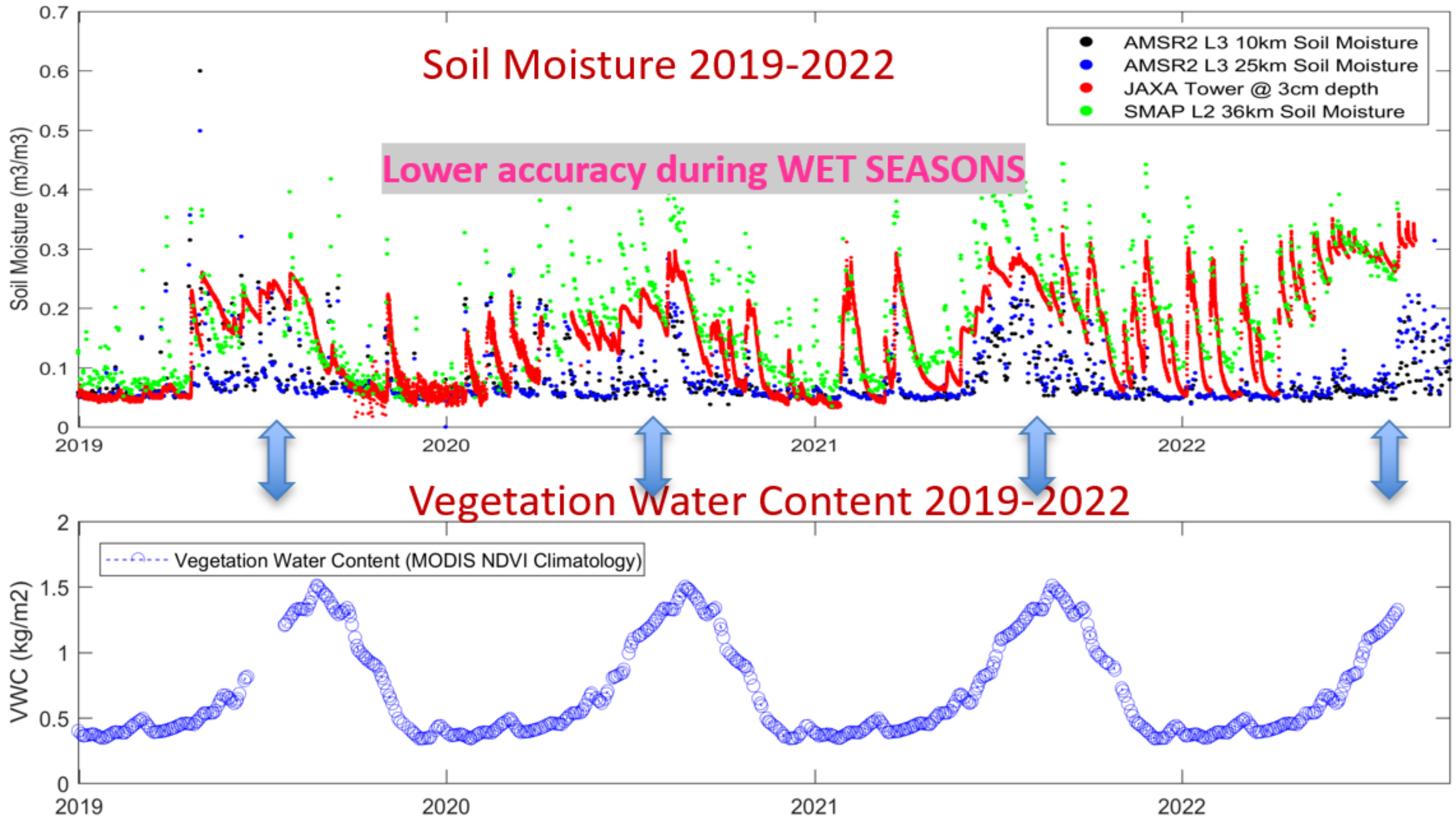

Figure 31: Comparison of the wet-season higher soil moisture against VWC (MODIS NDVI Climatology) for 2019-2022.

In Figure 30, we can observe a zoomed-in time series plot for the recent four-year period of 2019-2022. The plot depicts the comparison between the AMSR2 soil moisture products (10 km in black and 25 km in blue) and the tower soil moisture (in red). It is evident that the AMSR2 products generally underestimate the tower soil moisture. The correlation between the two is better during the dry season of October to December than in the wet season of May to September.

As mentioned in the annual reports of JFY 2020 and 2021, one possible way to improve the accuracy of the AMSR2 soil moisture product is by applying a simple regression of itself against in-situ measurements based on the historical data profile. This regression can be applied to the original product once the soil moisture exceeds a certain level, such as 0.1 m^3/m^3, beyond which the discrepancy between the product and in-situ measurements becomes more pronounced.

Figure 31 displays the soil moisture time series plot for the same 2019-2022 period in comparison to the volumetric water content (VWC). The VWC is derived from the MODIS 10-year NDVI climatology and is plotted to compare with the soil moisture trend. It is evident that the accuracy of the AMSR2 soil moisture product is lower during the wet season, which is consistent with the findings in previous reports. The trend of VWC matches well with the soil moisture trend, and the peaks of VWC correlate well with the peaks of soil moisture. However, since the AMSR2 soil moisture was retrieved from C-band, which is a higher frequency, the signal is more influenced by the vegetation layer, making it more difficult to separate the effect of vegetation from soil moisture. Consequently, it is less sensitive to soil moisture changes.

5.2 Scatter Plots and Statistics

Figure 32 provides a comparison between the AMSR2 L3 soil moisture product at 10-km resolution and soil moisture observations from tower (Fig 32a) and SMAP (Fig 32b) through scatter plots. The scatter plots show a negative bias (-0.08 and -0.11 m^3/m^3), which is consistent with the results obtained from the time series plot. Additionally, tower soil moisture is compared against AMSR2 SM (Fig 32c) and SMAP SM (Fig 32d) in separate scatter plots.

Upon comparing SMAP SM to tower SM, it is evident that the bias was relatively smaller (-0.04 m^3/m^3) in comparison to AMSR2 SM. Moreover, both the root mean square error (RMSE) and correlation (0.80) were relatively superior. The results indicate that the SMAP product is more accurate in estimating soil moisture levels than the AMSR2 product.

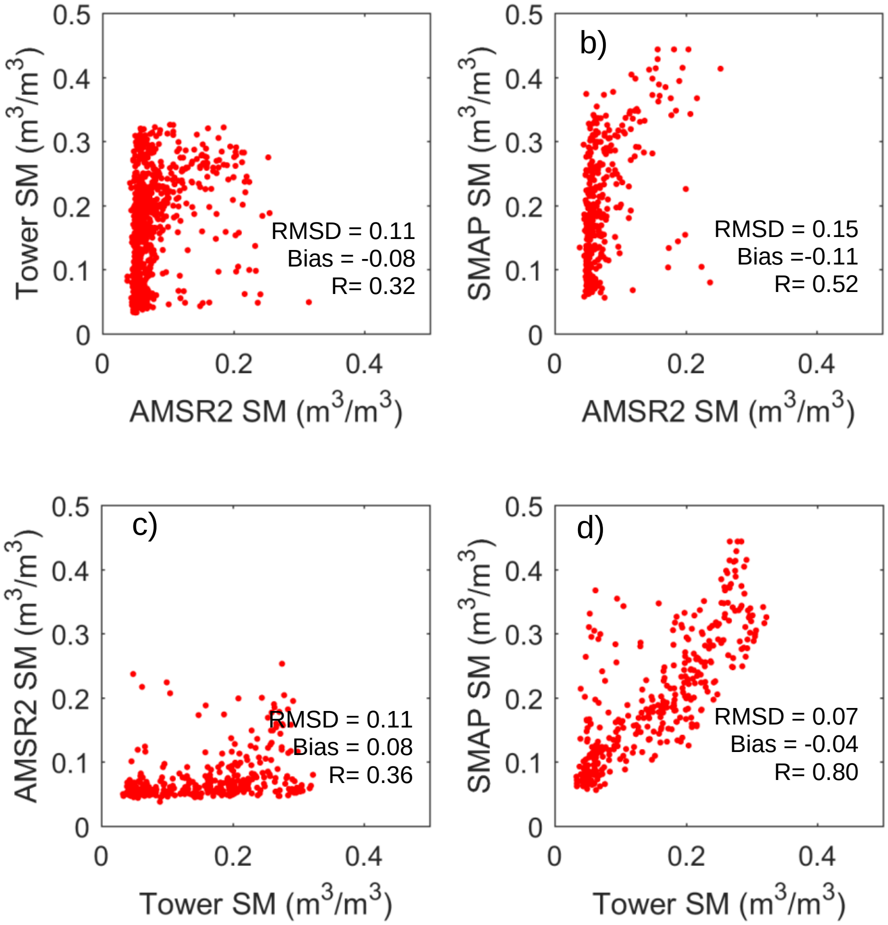

Figure 32: Scatter plots of AMSR2 SM (10-km) against a) tower soil moisture, b) SMAP SM (36km), c) tower SM against AMSR2 SM and d) tower SM against SMAP SM.

Chapter 6: Validation of the AMSR2 beta VWC product

6.1 The AMSR2 beta VWC product

In late June 2021, JAXA provided the beta VWC product, which included two data versions: v001, which utilizes semi-empirical retrieval algorithms using X and Ka bands, and v002, which uses the ANN algorithm using C, X, and Ka bands. In JFY2021, both versions were evaluated by validating the VWC products against calculated VWC from MODIS vegetation indices VWC-NDVI relationships from Gao et al, 2015. Although the validation of VWC against field sampling collected from SMAPEx-4 and SMAPEx-5 field campaigns at Yanco area is still underway, it is expected to be completed by the end of April this year.

Since the product was provided until the end of the year 2020, a preliminary analysis was conducted using three years of data from 2018, 2019, and 2020. Table 1 provides a summary of the data version used in the analysis. Further analysis will be conducted once the validation against field sampling is complete.

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

Figure 33 depicts the time series plot of AMSR2 VWC, with v001 shown in blue and v002 shown in red. The plot reveals that the values of v001 tend to be higher than those of v002. Notably, when VWC values surpass 3 kg/m2, the two versions tend to overlap, whereas larger discrepancies between the two datasets appear when VWC values are below 2 kg/m2. This is because when VWC is high, vegetation effects are more pronounced and can be more readily detected by the frequency bands.

Moreover, it is apparent that the VWC values in 2018 remain relatively stable throughout the year. In 2019, however, VWC levels are significantly higher during winter months compared to summer months. In 2020, vegetation levels are highest among the three years, peaking at 5-6 kg/m3. However, it is important to note that such high VWC levels are more commonly associated with forests or very dense vegetation rather than grasslands, which warrants further validation of these products.

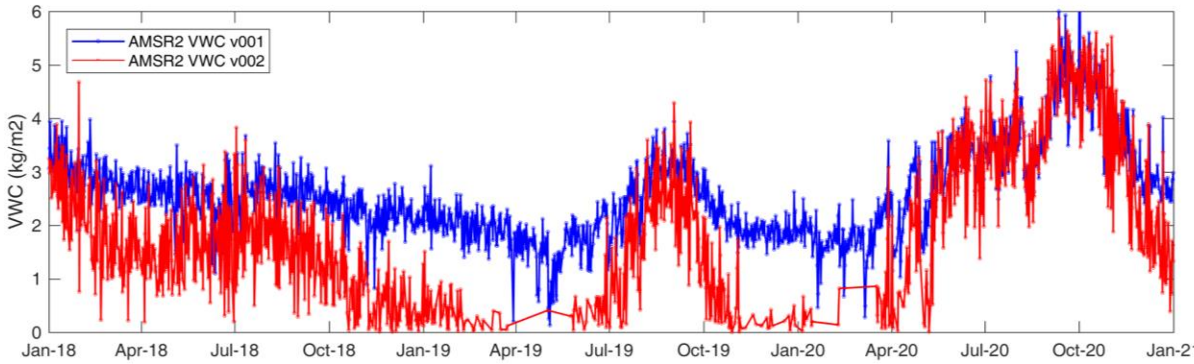

Figure 33: AMSR2 VWC product v001 and v002 time series from the year 2018 to 2020.

6.2 The Gao et al equations

Gao et al. (2015) conducted a comprehensive study on deriving vegetation water content (VWC) from normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) using satellite data and ground samples from field campaigns. The study focused on four vegetation types: corn, cereal grains, legumes, and grassland. The authors proposed new equations based on the compiled data sets and found them to be superior to the existing ones based on statistical analysis. The study also identified NDVI and NDWI1640 as the preferred indices for VWC estimation based on the availability and error statistics of the data sets. The authors recommended that the new equations can be used in future global remote sensing applications for VWC retrieval.

In Figure 34, the data sets and equations for VWC estimation using NDVI for different vegetation types are presented, with the recommended equations indicated by red dotted lines. Table 2 summarizes the recommended VWC-NDVI equations by Gao et al. for different land cover types.

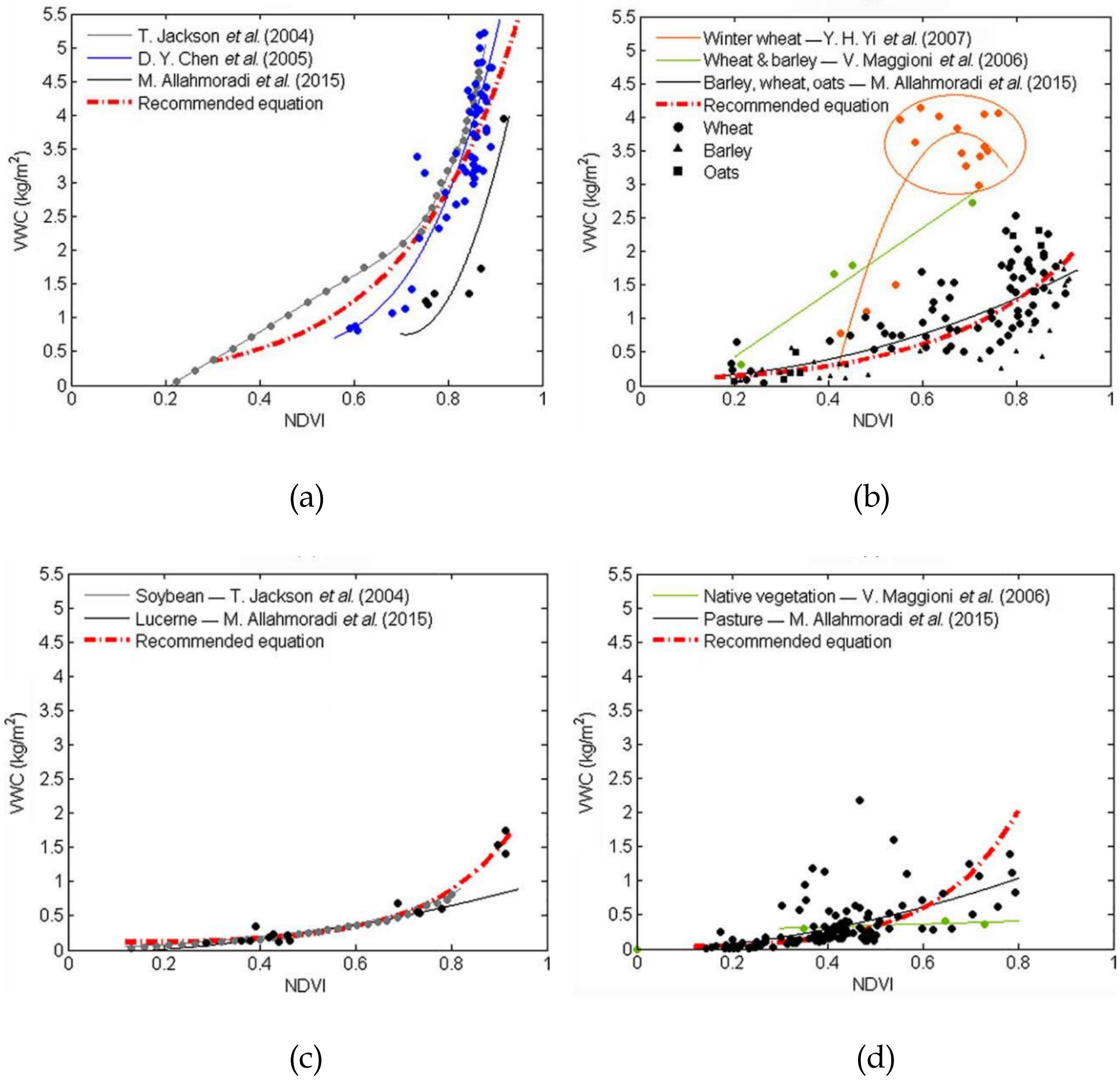

Figure 34: Data sets and equations for VWC estimation using NDVI from Gao et al (2015).
(a) Corn. (b) Cereal grains. (c) Legumes. (d) Grassland.

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	$VWC = 0.017\ e^{5.866NDVI}$

As in the tower site the dominant land cover is **grassland**, the last equation in Table 2 was applied to MODIS NDVI to calculate VWC.

6.3 The Validation against MODIS NDVI-derived VWC

Figure 35 displays a comparison between the calculated VWC from MODIS NDVI using the Gao equation and the AMSR2 VWC products. It is evident that v001 values are generally higher compared to v002. Specifically, when the VWC values exceed 3 kg/m^2, the two versions tend to coincide, whereas gaps tend to occur at lower VWC values. This observation could be attributed to the vegetation effect, which becomes more pronounced as the VWC increases and is easier to detect by the frequency bands. However, the calculated VWC from MODIS NDVI is significantly lower compared to the AMSR2 VWC products, with the MODIS VWC only coinciding with AMSR2 VWC at very low VWC values (0-1 kg/m^2). For the year 2020, the MODIS VWC follows the same trend as AMSR2 VWC while exhibiting a negative bias of around 1-2 kg/m^2. It is also worth noting that the MODIS VWC

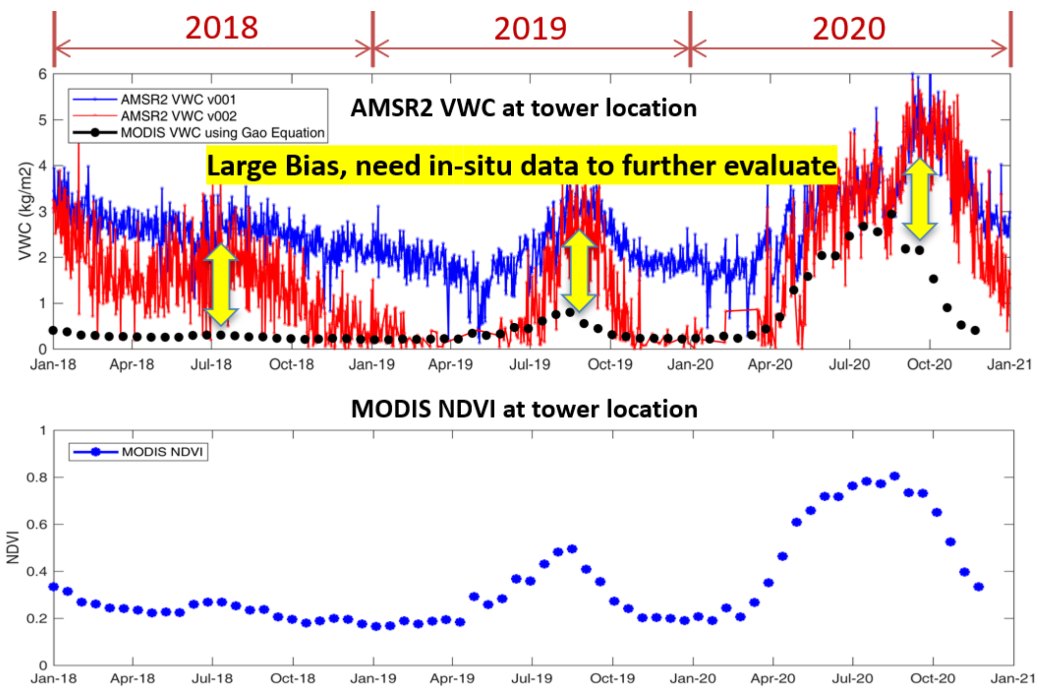

Figure 35: Top: AMSR2 VWC product v001 and v002 together with Calculated VWC from MODIS NDVI using Gao equation; Bottom: MODIS NDVI used to calculate VWC.

remained nearly constant throughout the two years 2018-2019, maintaining a low value of less than 1 kg/m^2.

Our team's on-site field experience suggests that the AMSR VWC v001 is likely too high for grassland conditions. The real VWC condition is probably somewhere between AMSR VWC v001 and MODIS VWC. However, these products still require field VWC data to verify their accuracy.

6.4 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.

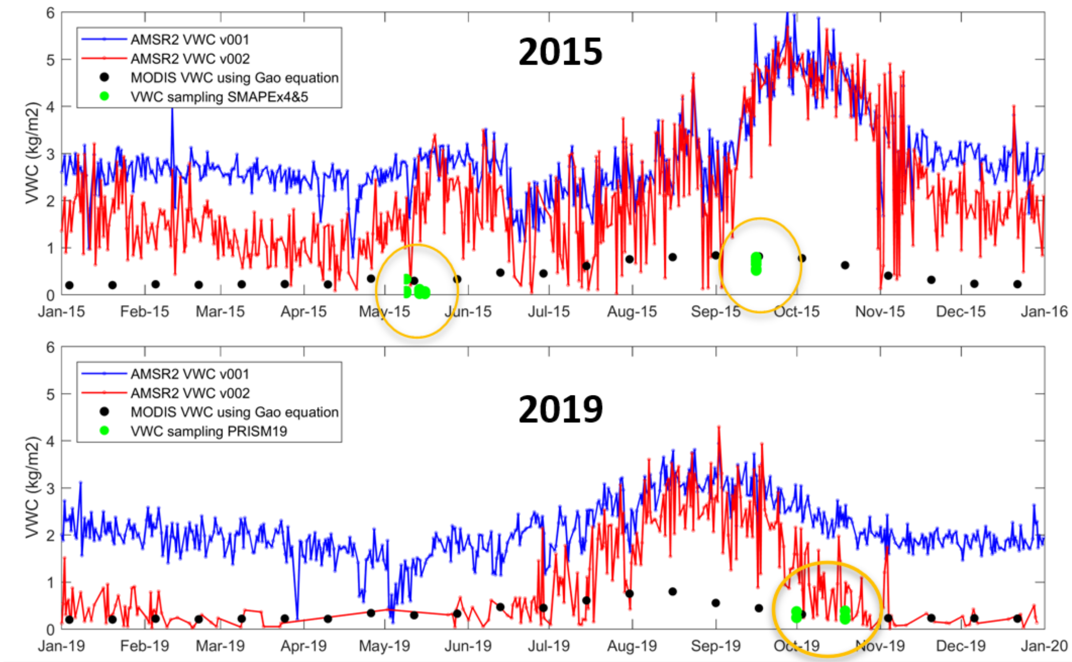

Figure 36: Top: AMSR2 VWC product v001 and v002 together with VWC samplings from SMAPEx 4&5; Bottom: same with up but with VWC samplings from PRISM19.

Chapter 7: Future Work

The estimation of the in-situ Kc will be continued in JFY2022 and this will be compared to the satellite Kc. Calculation of in-situ Kc:

Kc = ETc / ETo. ETc is crop evapotranspiration, which can be obtained from the flux tower EC; ETo is reference evapotranspiration, which can be calculated from FAO Penman-Monteith equation, with flux tower data such as wind speed, air T, soil heat fluxes etc.

$$ET_0 = \frac{0.408\Delta(R_n - G)\gamma \frac{C_n}{T_a + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + C_d U_2)}$$

eq (10)

Rn: net radiation at the crop surface

G: soil heat flux density (MJ m^2/day)

T: air temperature at 2m height (^oC)

U_2: wind speed at 2m height (m/s)

e_s: saturation vapor pressure (kPa)

e_a: actual vapor pressure (kPa)

e_s- e_a: saturation vapor deficit (kPa)

Δ: slope vapor pressure curve (kPa/ ^oC)

γ: psychometric constant

C_n: numerator constant

C_d: denominator constant

Chapter 8: Summary and Conclusion

This report outlines the research activities and outcomes of the JFY 2022 project "Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using GCOM-W1 data". One of the main objectives of this project was to continue operating the JAXA flux tower located in Yanco, NSW, Australia, and provide spatially distributed soil moisture data from an AMSR2-sized footprint.

Throughout the project, the AMSR2 standard soil moisture product was validated and compared with the Soil Moisture Active Passive (SMAP) Level 2 soil moisture product. The findings indicated that the AMSR2 products tended to underestimate tower soil moisture, and the correlation was better during the dry season than the wet season. To improve the AMSR2 soil moisture product, a regression approach could be applied based on the historical data profile.

The vegetation water content (VWC) research product was validated against field sampling data from SMAPEx-4 and -5 and VWC calculated from MODIS-derived vegetation indices. The AMSR2 VWC values were generally higher in version v001 compared to v002, and the calculated VWC from MODIS NDVI using Gao equations was significantly lower than the AMSR2 VWC products. However, based on the on-site field experience of the research team, the AMSR VWC v001 was likely too high for a grassland condition. Further field data verification is needed to establish the real VWC condition. Overall, the findings suggest that the AMSR2 VWC product is probably too high compared to the VWC 'truth' and that further research is necessary to refine the products.

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Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using GCOM-W1 data

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