FY2021 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

---

Specification No: **JX-PSPC-530198**; Contract No: **21RT000218**

Investigators: Jeffrey Walker (ER2GWF106), Jason Beringer, Christoph Rüdiger, Ying Gao

Contributor: Kiri Mason, Luisa White Murillo

March 2022

MONASH University
Engineering

Executive Summary

This report presents the research activities and research outcomes for the project 'Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using GCOM-W1 data' during JFY 2021. One of the main research activities aimed to continue operating the JAXA flux tower within the core validation site located in Yanco, New South Wales, Australia. This provides spatially distributed soil moisture data from across an AMSR2 sized footprint. It was proposed that during JFY 2021, this project would make significant independent and collaborative contributions to:

i) Continuing the validation of the AMSR2 standard soil moisture product.

ii) Intercomparing the AMSR2 soil moisture product with the Soil Moisture Active Passive (SMAP) Level 2 soil moisture product.

iii) Validating the vegetation water content (VWC) research product against a) field sampling from the 4th and the 5th Soil Moisture Active Passive Experiments (SMAPEx-4 and -5) conducted in Yanco, Australia, and b) VWC calculated from MODIS-derived vegetation indices.

The first two targets were accomplished each year from JFY 2019 to JFY 2020 and was continued in JFY 2021. In JFY 2019 and JFY 2020, due to the unavailability of research product of the AMSR2 VWC, the target was focused on validating the land surface model simulated soil moisture and flux data using AMSR2 products, and validation of satellite-based Kc factor. Since the AMSR2 VWC research product became available in early 2021, the main task was focused on the 3rd target.

Table of Contents

List of Figures

Chapter 1: Introduction

This report presents a range of research activities and research outcomes of the project Validation of GCOM-W1 products using global water and energy balance monitoring at the Murray-Darling Basin in Australia during **JFY 2021**. The project seeks to continue operating the JAXA flux tower within the core validation site located in Yanco, New South Wales, and provide spatially distributed soil moisture data from across an AMSR2 sized footprint. Importantly, this project will also make significant independent and collaborative contributions to i) continuing the validation of the AMSR2 soil moisture product against in-situ observations; ii) Intercomparing the AMSR2 soil moisture product with complimentary satellite soil moisture products from other missions, such as SMAP; and iii) validating the Vegetation Water Content (VWC) research product against VWC calculated from MODIS-derived vegetation indices and field samplings.

During JFY2021, the main site maintenance activities include calibration of the JAXA tower Gas Analyzer (IRGA). Other activities include regular site visit and maintenance of the JAXA flux tower, data downloading and processing. The processed soil moisture data was used to validate the 10-km and 25-km resolution AMSR2 soil moisture products. On the other hand, erroneous data which indicates possible broken sensor was identified and we are waiting for JAXA to provide replacement sensors (request has been sent to Dr. Fujii Hideyuki).

The beta VWC product was provided by JAXA in late June 2021. Two data versions were available: v001 which is the semi-empirical retrieval algorithms using X and

Ka bands; v002 is the ANN algorithm using C, X and Ka bands. Both versions were used for evaluation in JFY2021. The main research activity was to validate these VWC products against calculated VWC from MODIS vegetation indices VWC-NDVI relationships from Gao et al, 2015. The validation of VWC against field sampling collected from SMAPEx-4 and SMAPEx-5 field campaigns at Yanco area is still underway and will be finished by the end of April this year.

Chapter 2: Flux Tower Maintenance

2.1 Flux Tower Maintenance for JFY 2021

Travel Restrictions due to the COVID-19 pandemic were in place again during the latter half of 2021. This reduced the number of possible site visits and prevented a large amount of upgrade work from happening over the course of the winter months. However, no data loss (gaps) for the JAXA Tower resulted during all of 2021 and early 2022.

In preparation for a February Field Campaign upgrades to stations in the YA and YB Area were made during November/December 2021 and January/Feburary 2022. These upgrades included the addition of 5 Stevens Hydra Probe sensors to each station to measure soil moisture and temperature across the following depths: 5-10cm, 10-15cm, 15-20cm, 20-25cm and 40cm (including the 0-5cm surface probe already in-situ).

Other maintenance work and upgrades to be made on the existing Y-stations were postponed due to the priority being preparation for the Field Campaign.

Calibration on the JAXA Tower Gas Analyzer (IRGA) has been completed in late March 2022. The instrument was removed from the tower and the technician was awaiting the delivery of replacement scrubber chemicals from Licor in early March. New calibration gases have been quoted for and ordered. These include 1 x bottle of 450ppm CO_2 span gas and 1 x bottle of Ultra High Purity Nitrogen (N5) gas to zero the sensor. The calibration was completed during the last week of March 2022 and the Gas Analyser has been returned and re-installed to the tower.

Maintenance work was recently done on the tower (February 2022) where the lowest horizontal steel bar which carries the Temperature and Humidity Sensor at 2m had fallen off by the shearing of attachment brackets. It is not completely clear how this occurred. However, it is highly likely a result of a weather event or general wear and tear on attachment brackets themselves. These have now been replaced and re-attached. Data will be checked upon the next site visit.

Figure 1: Broken horizontal bar on the tower.

Figure 2: Horizontal bar after it had been reattached

A lot of vegetation growth has occurred in the area due to increased rain events and moisture in the soil during the 2021/2022 summer period. Grass both in the local pasture and within the tower enclosure has grown considerably making it harder to maintain. The increase in vegetation and water availability has in turn brought more insects to the area resulting in some problems with spider populations on the tower structure. In particular where strong webs can interfere with measuring equipment. Namely the lower-level anemometer (2m) which at times has been covered in webs and the gas analyzer where webs have blocked the optical path.

2.2 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 outlined in the last annual report, together with recent confirmation and data check with the broken sensors, the following sensors will be ordered and provided by JAXA (updated in January 2022):

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

Future upgrades are planned upon receipt of these new sensors that JAXA decided to provide.

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 of the key data collected from 2019 to 2021 (the 3-year contract period) from the JAXA tower.

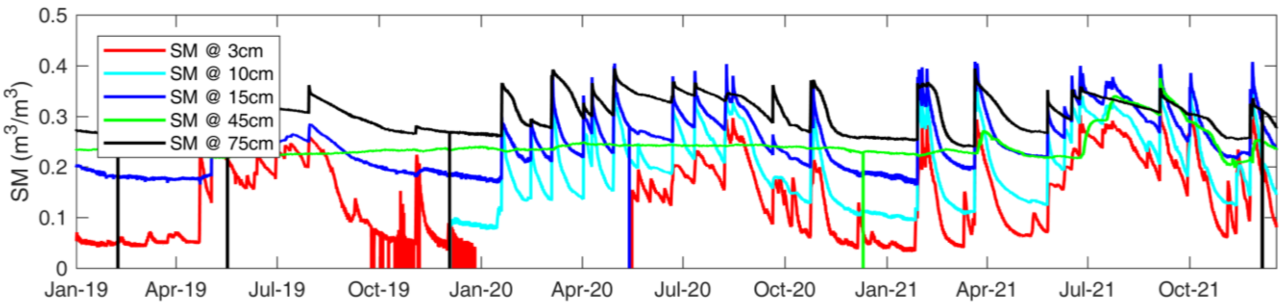

Figure 3: Soil moisture measured at JAXA Tower for 2019-2021.

It can be seen that 3cm sensor was replaced in May 2020 and the 10cm sensor was replaced in December 2019, and both data have been performing well after sensor replacement.

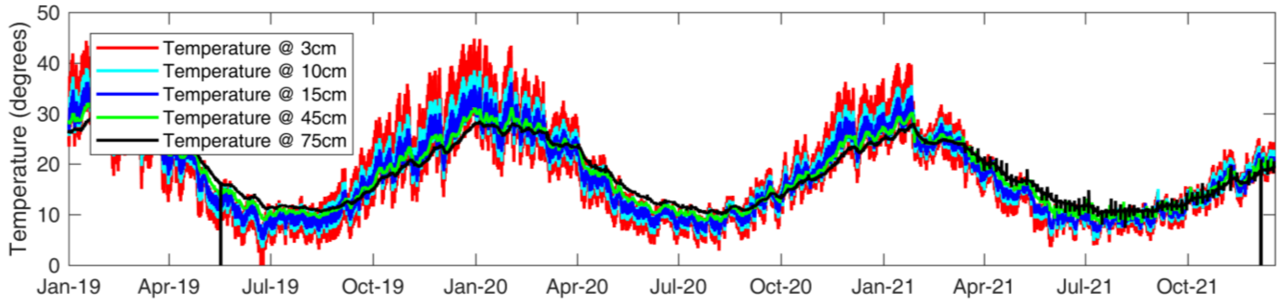

Figure 4: Soil temperature measured at JAXA Tower for 2019-2021.

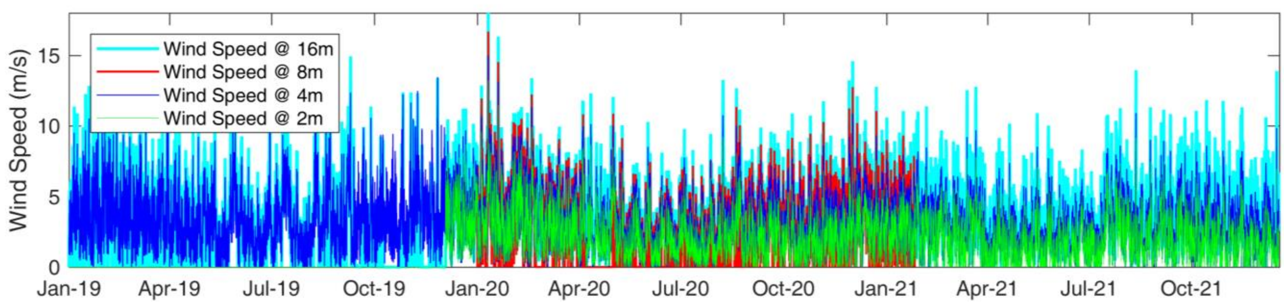

Figure 5: Wind speed measured at JAXA Tower for 2019-2021.

It can be seen that 2m sensor was replaced in December 2019 and has been working well since then. The 8m sensor resumed functioning in January 2020 but stopped working again in February 2021, this is to be replaced upon the arrival of the replacement sensors.

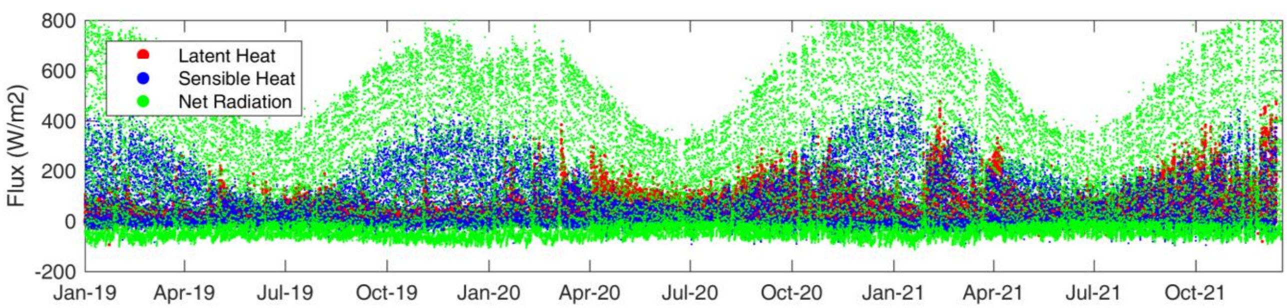

Figure 6: Flux density measured at JAXA Tower for 2019-2021.

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).

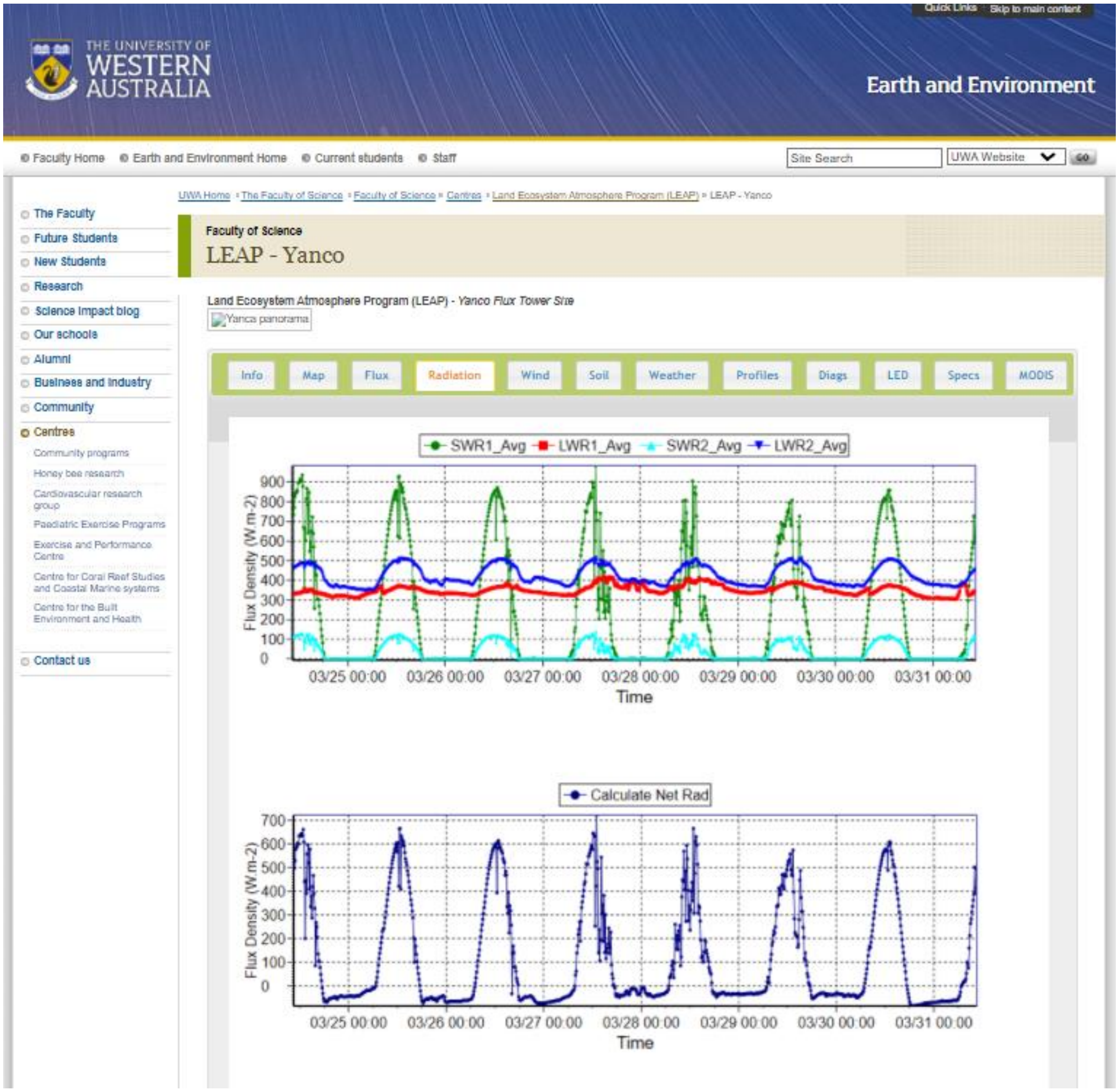

Figure 7: Real-time tower data interface on http://www.science.uwa.edu.au/centres/land/yanco.

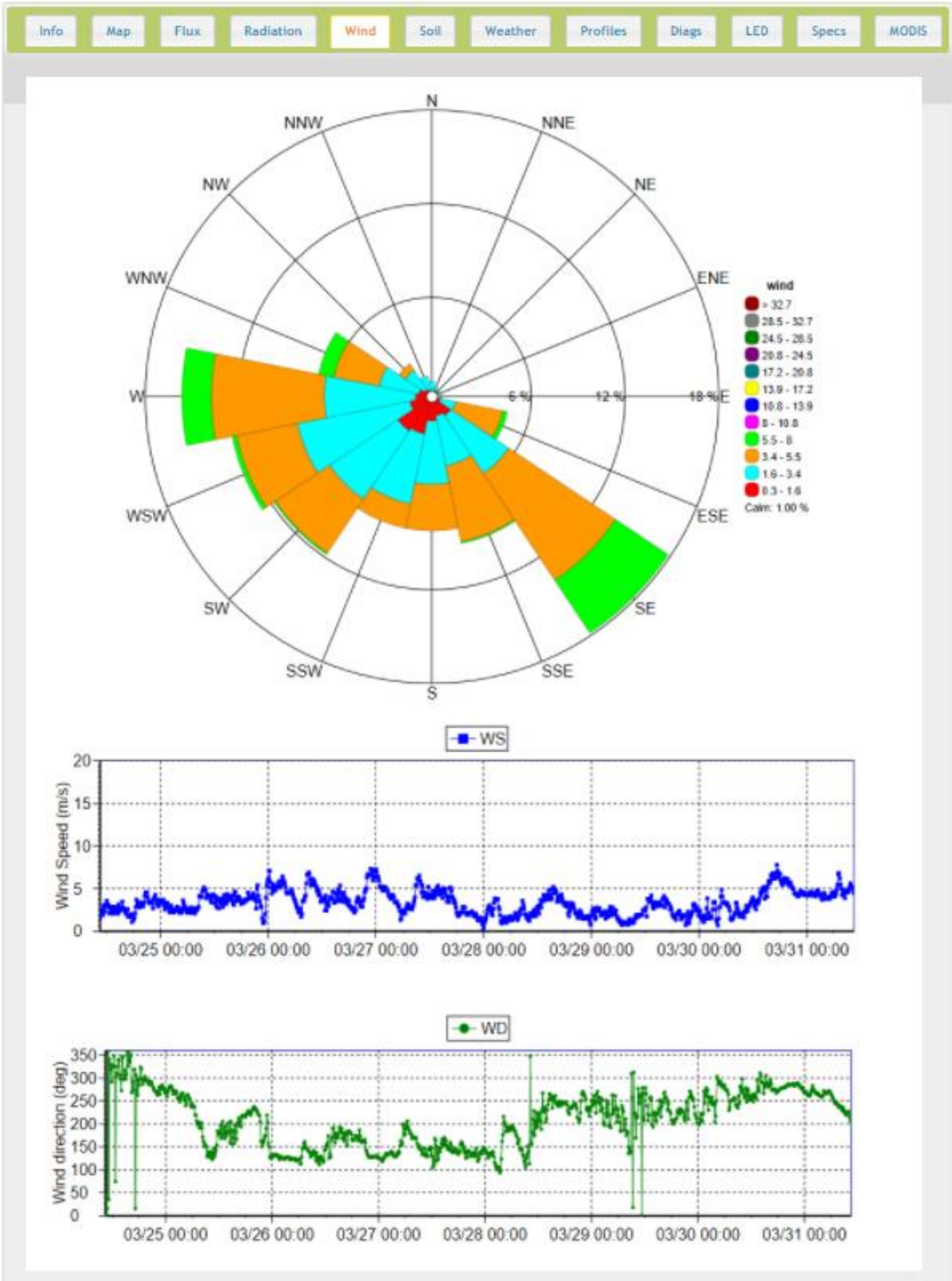

Figure 8: Examples of real-time figures for wind speed and wind direction.

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.

Recently, the YA and YB stations has been upgraded by including soil moisture probes at 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-25cm, and 40 cm depth. Within the upgrades, seven stations were placed in the Tubbo site, located at the YA area (see Figure 9). These stations collected data for the 2021-2022 summer season. Currently, the station 36 is the only one installed due to harvesting working, but it is planned to reinstall the other six stations.

Some recent sample data after the station upgrades are shown in Figure 10 and Figure 11.

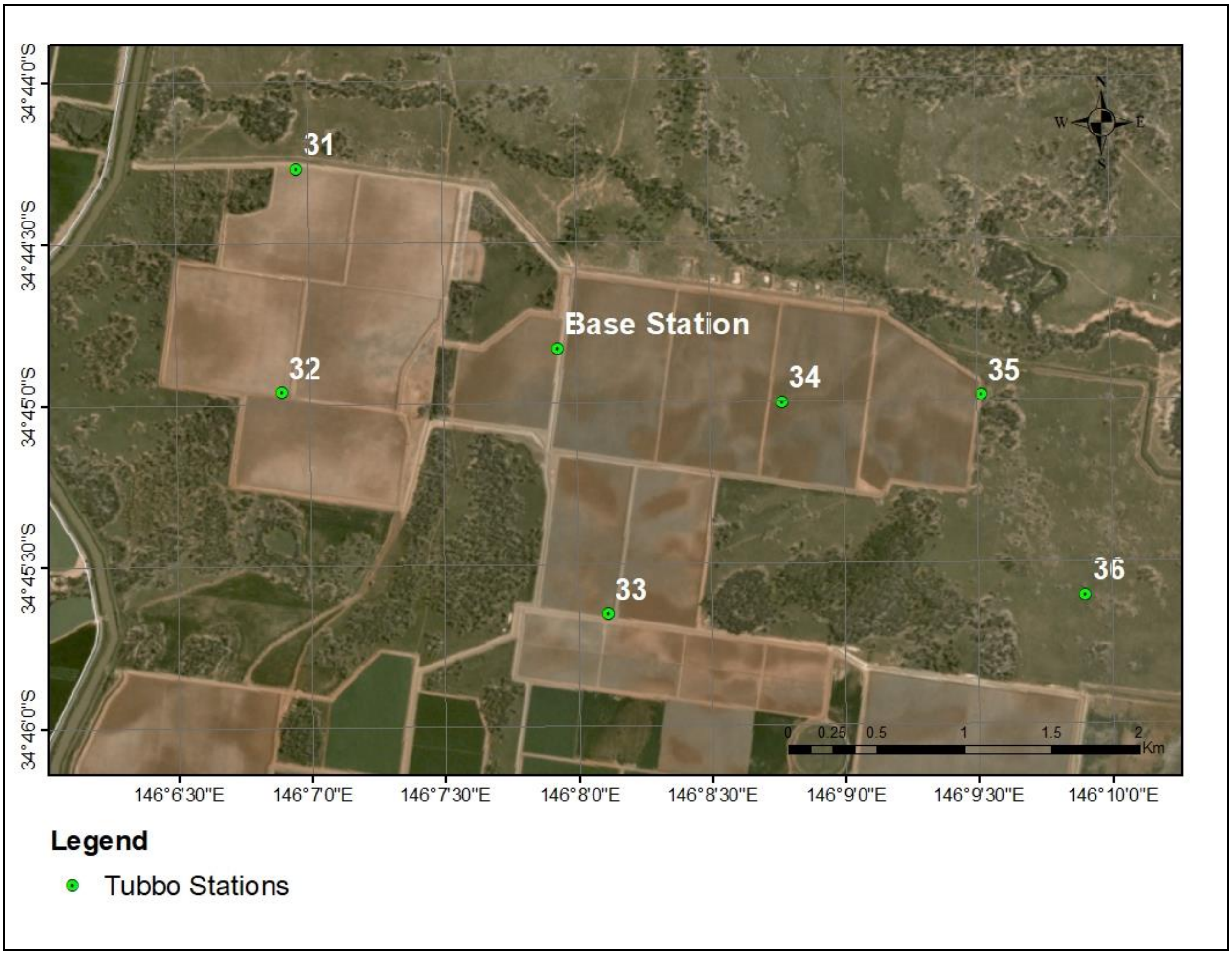

Figure 9: The location of the Tubbo Stations.

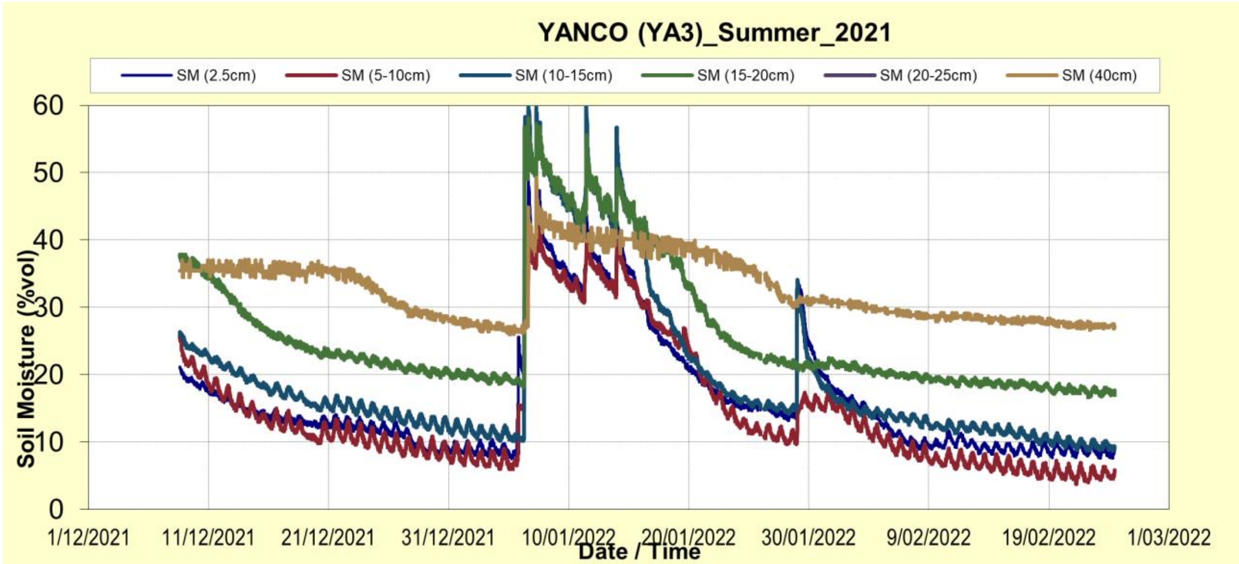

Figure 10: Sample data – YA3 Station 2021 Summer data.

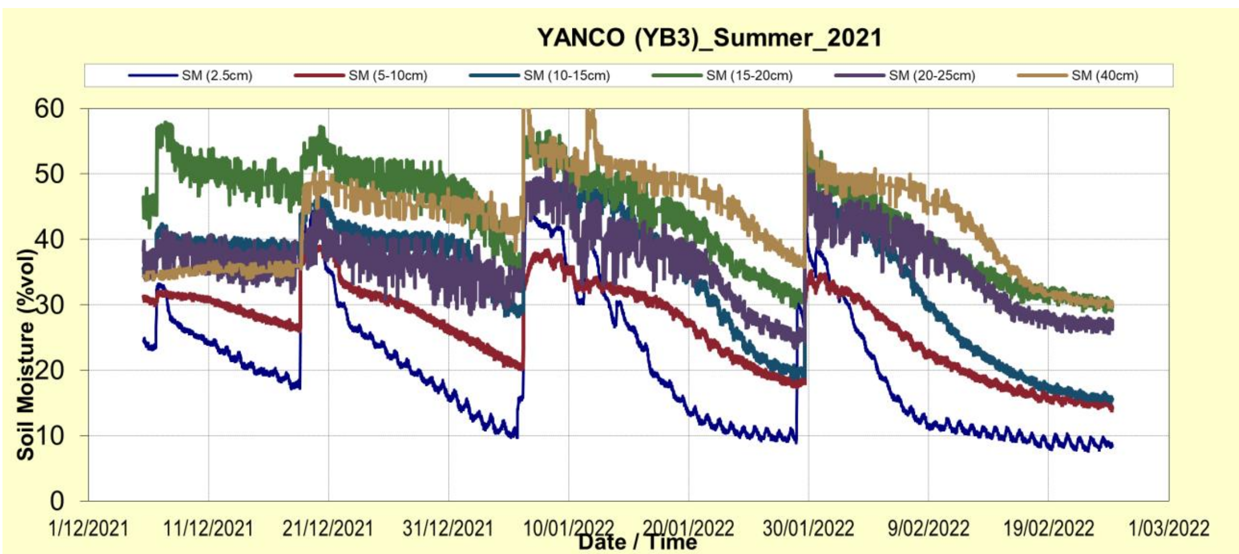

Figure 11: Sample data – YB3 Station 2021 Summer data.

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 12).

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

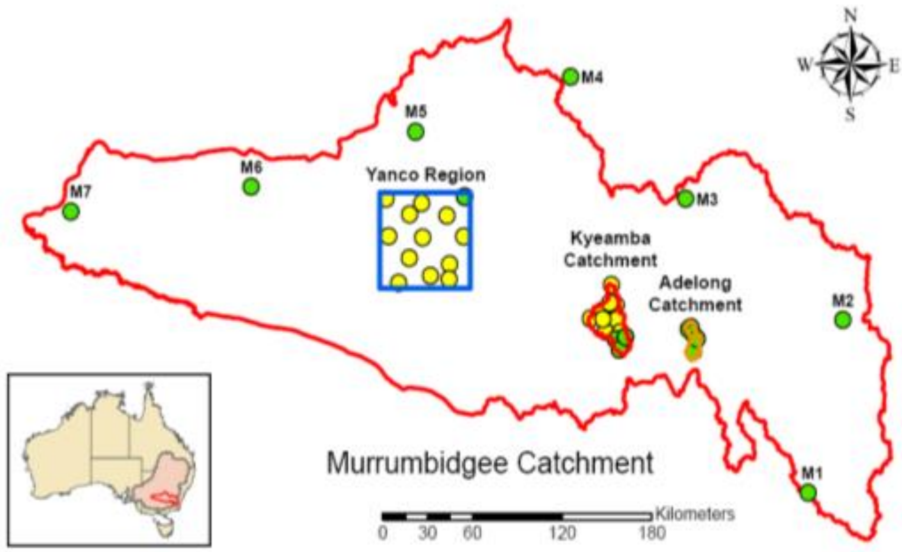

Figure 12: Location of the Yanco core validation site within the Murrumbidgee Catchment. Also shown is the location of the Murrumbidgee Catchment within the Murray-Darling Basin (inset) and the locations of sparse network soil moisture stations.

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 13 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.

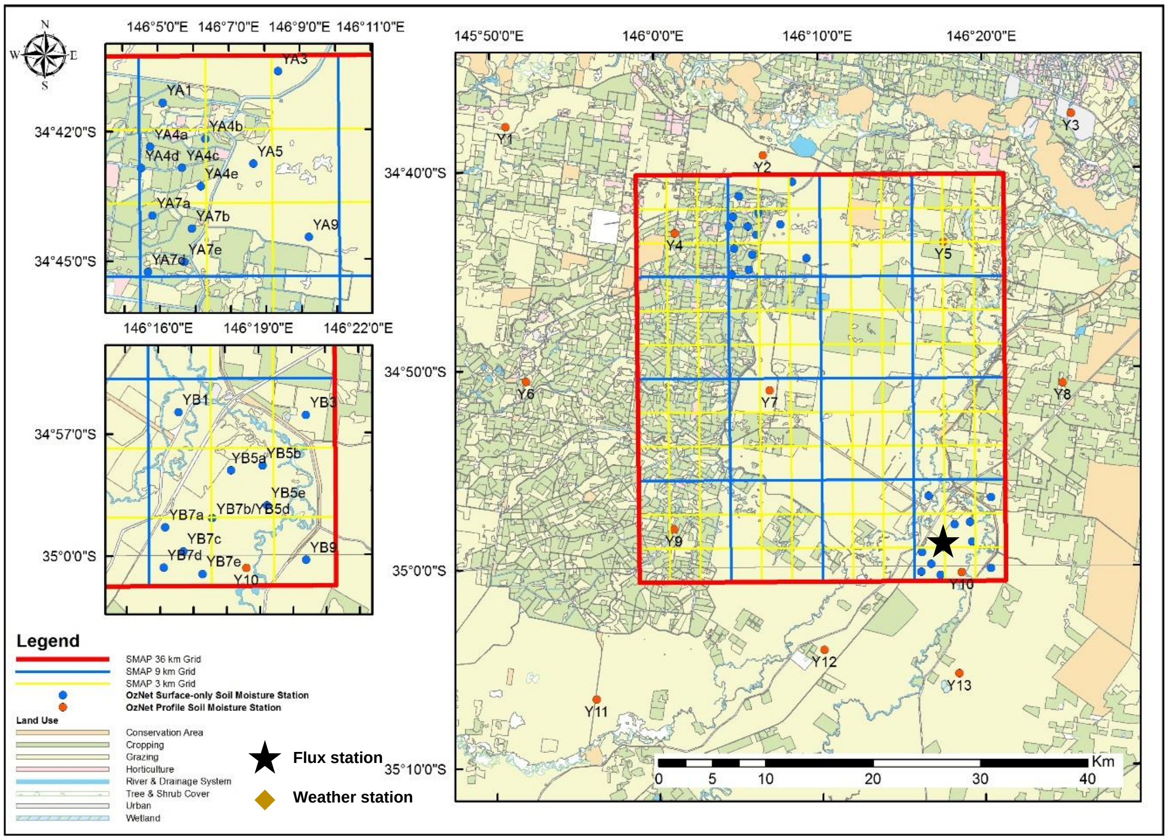

Figure 13: Locations of the JAXA flux station, weather station and soil moisture monitoring stations within the Yanco core validation site. Also shown are the YA and YB focus areas with intensive soil moisture stations, and the locations of intensive ground sampling areas.

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

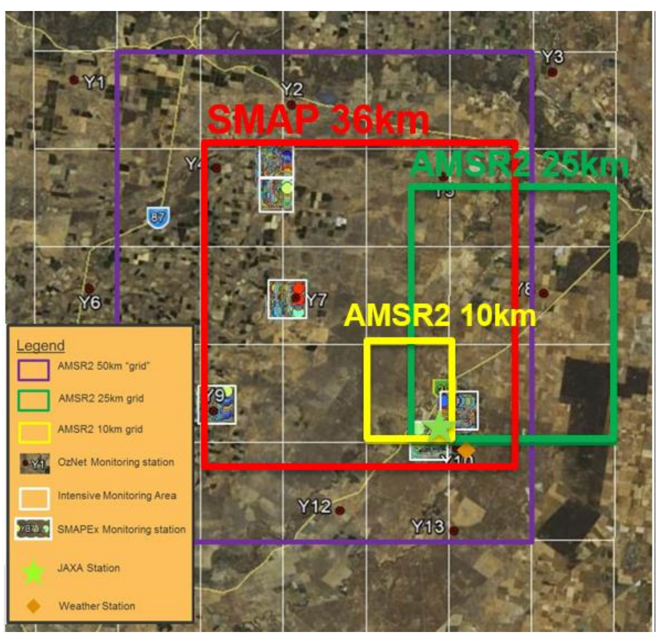

Figure 14: Location of the 10-km and 25-km AMSR2 L3 SMC pixel, SMAP 36-km pixel with respect to the flux tower location.

period in which AMSR2 data is available, the analysis covered a time series from July 2012 to December 2021 (see Figure 16). 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 14.

The time series of the AMSR2 Level 3 SMC 10-km and 25-km products are shown in Figure 15. 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.

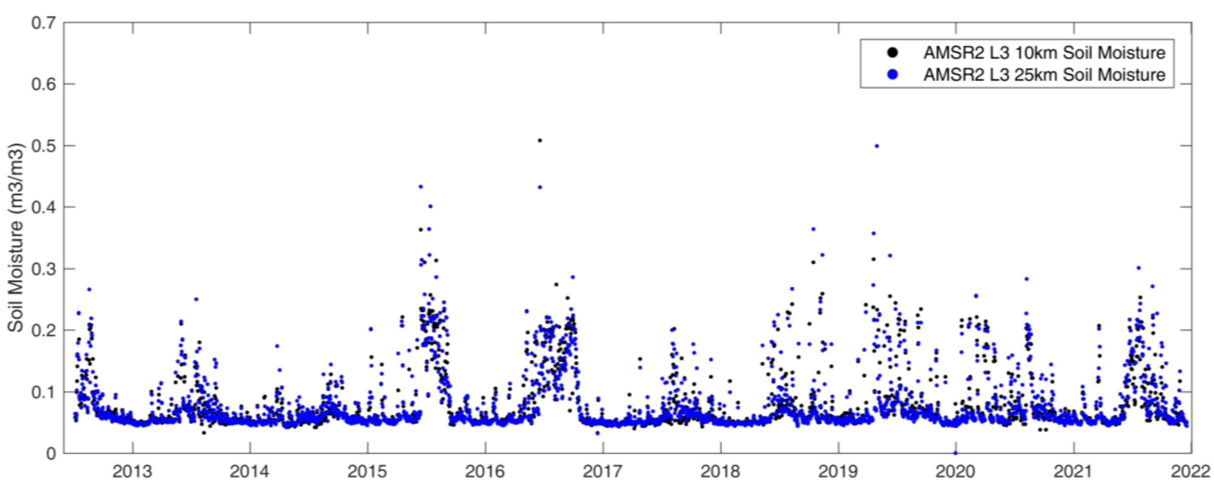

Figure 15: Year 2012 to 2020 time series of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site.

But the higher values of 2018-2021 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 2020-2021 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 17 shows the box plots of the AMSR2 L3 low- and high- resolution soil moisture for year 2021 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 16 shows the box plots of the AMSR2 L3 low- and high- resolution soil moisture for all data from 2012 to 2021. 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.

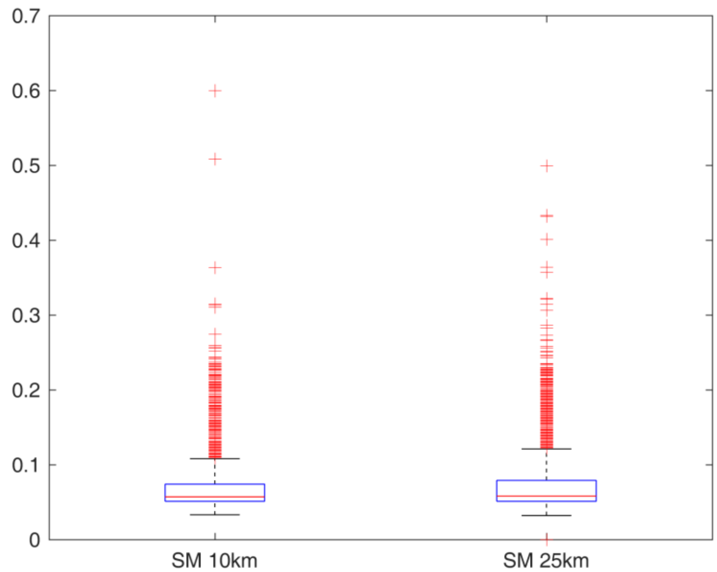

Figure 16: Box plot of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site: 2012-2021.

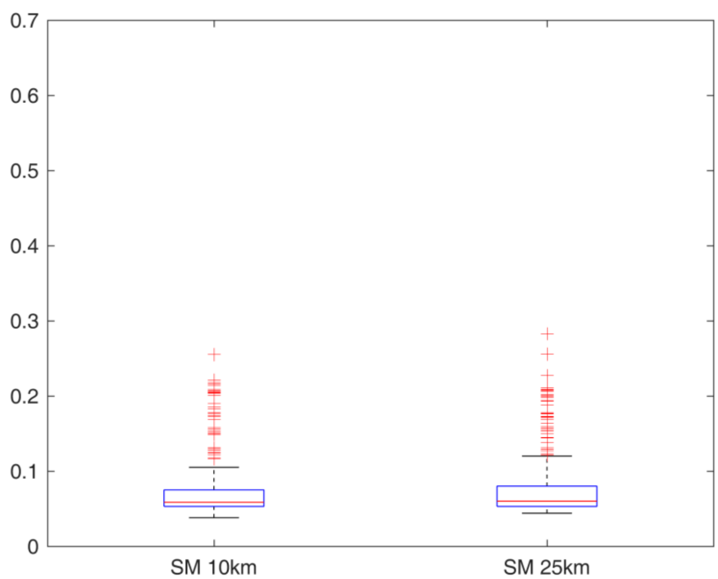

Figure 17: Box plot of the AMSR2 L3 10-km and 25-km soil moisture in the Yanco site: year 2021 only.

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

5.1 Time Series Plots

The AMSR2 L3 10km- and 25km- soil moisture products are validated against 1) the in-situ soil moisture measurements from the JAXA flux tower, and 2) SMAP observations.

Figure 18 shows a time series plot of the comparison of AMSR2 SM against flux tower SM from July 2012 to December 2021 (flux tower SM data missing for the first couple of months in 2020 due to broken TRIME-PICO sensor). On the flux tower, soil moisture sensor was installed at 3 cm depth below ground. It can be seen that the AMSR2 products are underestimating the tower soil moisture (red) in general. The correlation is relatively higher during the dry period of all years. Compared to tower SM, similar with previous years, from 2020-2021, lower values match better than the higher values. For 2019-2021, there was clear gap between tower and AMSR2 in wet season, similar to 2015-2016. There is also a clear trend of increasing and decreasing in tower SM throughout the wet season, while trend is not clear in the AMSR2 product.

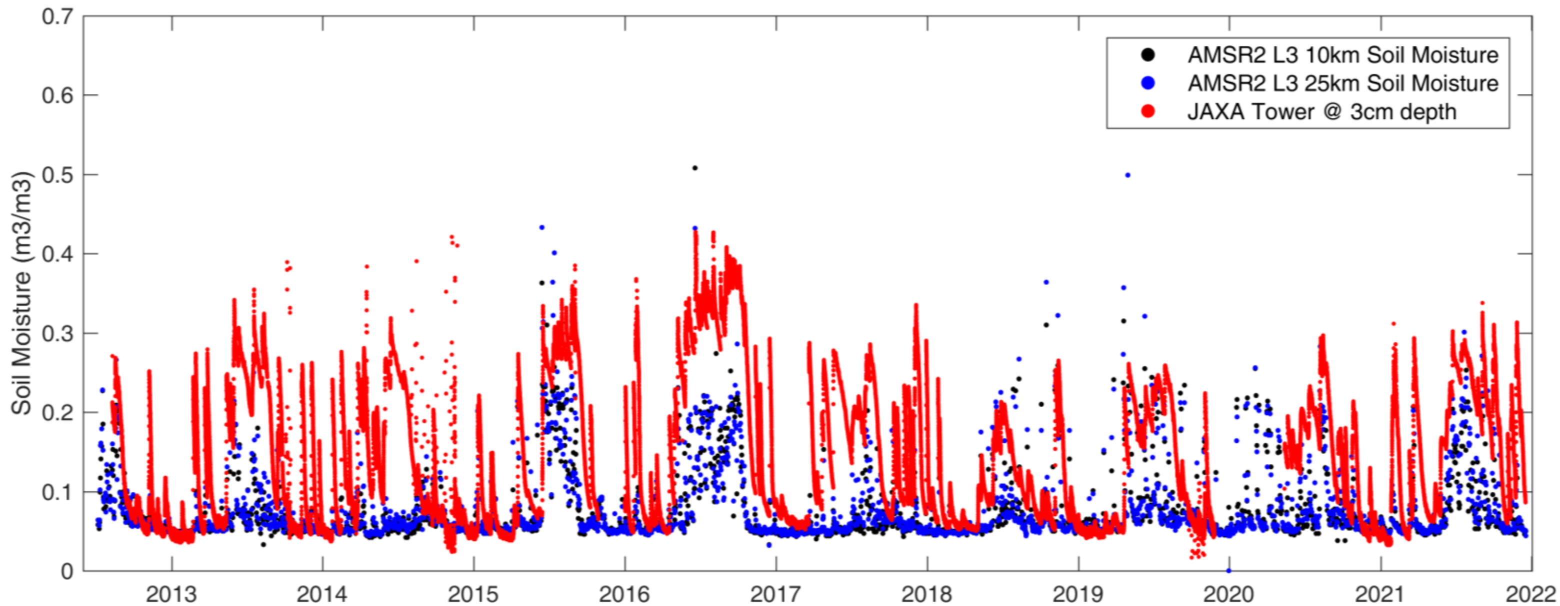

Figure 18: Time series plot of AMSR2 L3 10- and 25-km soil moisture product against JAXA flux tower soil moisture measured at 3-cm depth from 2012 to 2021.

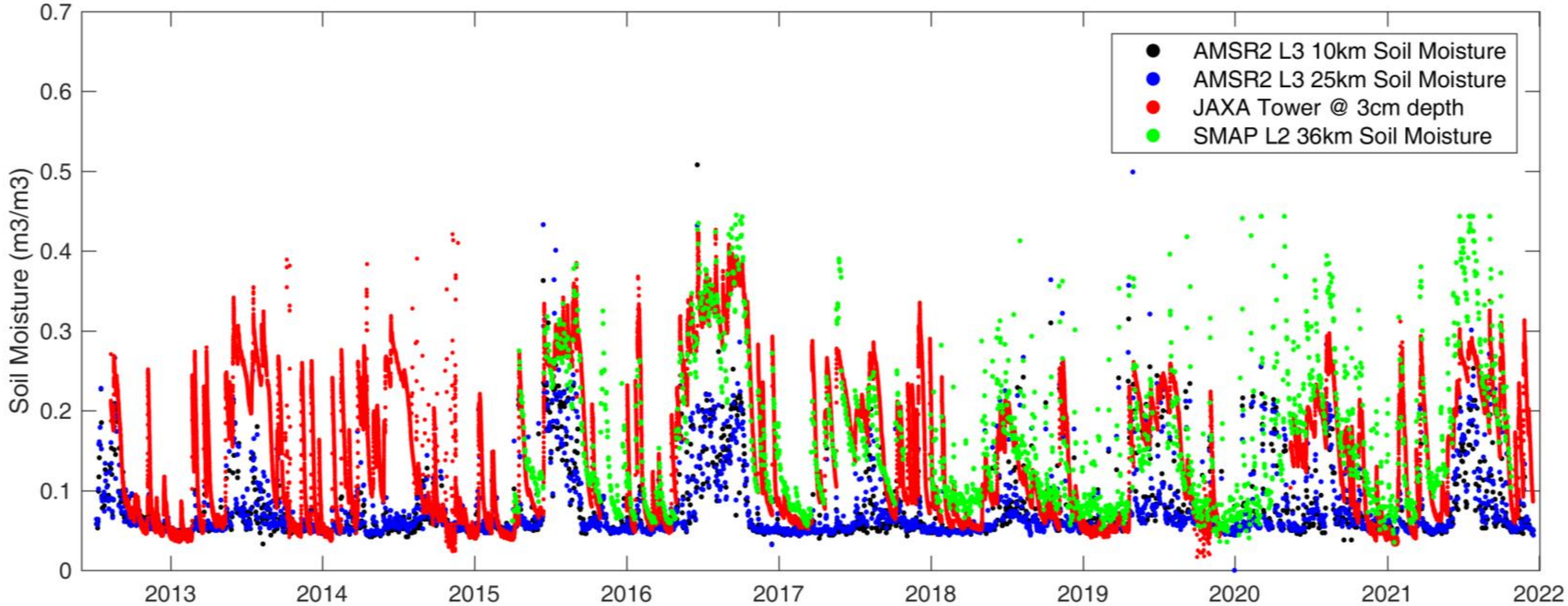

Figure 19: Same time series plot as Figure 19 with added SMAP L2 36km soil moisture product from 2012 to 2021.

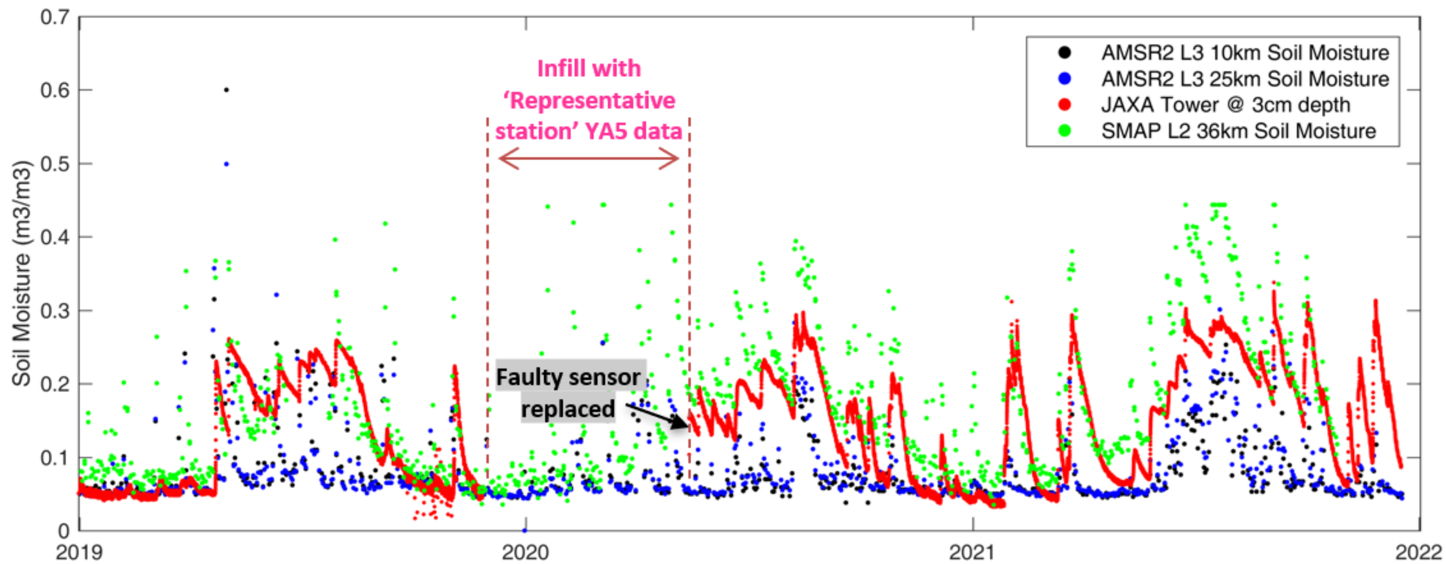

Figure 20: Zoom-in view of time series of AMSR2 products, tower SM and SMAP SM for 2019-2021 (3-year contract period).

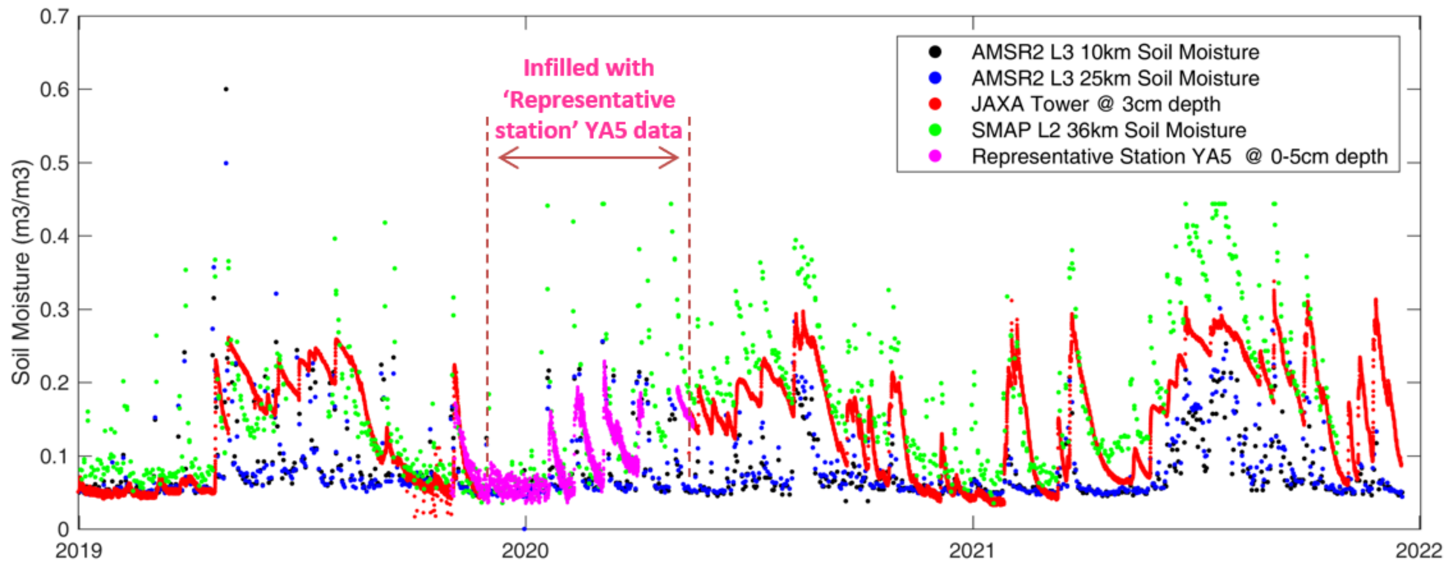

Figure 21: Zoom-in view of time series of AMSR2 products, tower SM and SMAP SM for 2019-2021 with infilled in-situ soil moisture from YA5 station.

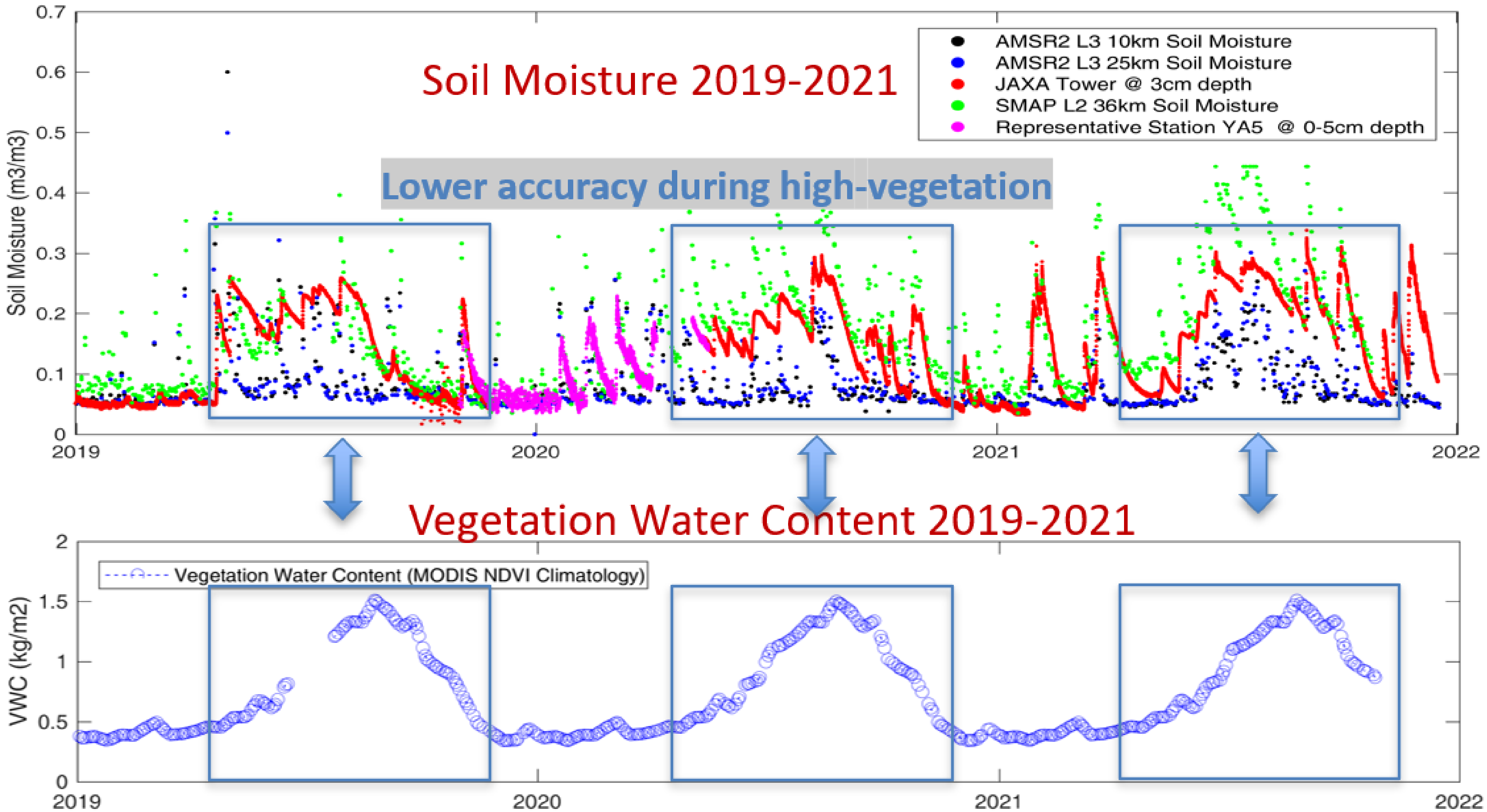

Figure 22: Comparison of the wet-season higher soil moisture against VWC (MODIS NDVI Climatology) for 2019-2021.

Figure 19 added the Soil Moisture Active Passive (SMAP) L2 36km (passive-only algorithm) product to Figure 18. The product was retrieved from L-band (1.4 GHz) brightness temperature observations.

Having a larger footprint of 36 km compared with the AMSR2 products, it can be seen that the SMAP product (green) matches better with tower soil moisture compared to AMSR2 itself, especially for wet seasons (May-Sept). For dry season, however, SMAP overestimates the soil moisture 'truth' while AMSR2 matches slightly better. Since the AMSR2 soil moisture was retrieved from C-band, which is a higher frequency, the signal is more affected by the vegetation layer and thus it is more difficult to decouple the effect of vegetation (more pronounced during wet season) from soil moisture.

As it has also been widely demonstrated in the past that low frequency (L-band) has higher sensitivity to the moisture content variation and more capable to retrieve accurate surface soil moisture, it is suggested that the SMAP product should be closer to the ground 'truth',

For the 3-year contract period 2019-2021 in particular, Figure 20 shows a zoom-in time series plot for the these three years. Is it seen that we lost some data from December 2019 to May 2020 for the 3cm tower soil moisture. After doing some research on the Oznet station data, it has been found that the YA5 (previously identified to be one of the representative stations for the Yanco regional area) has very similar time series patterns with the 3cm tower soil moisture data. Therefore, the YA5 data was used to infill the tower missing data to make the full data record complete. The infilled gap is shown in Figure 21.

It can be seen that in general the AMSR2 products (black for 10 km and blue for 25 km) are underestimating the tower soil moisture (red). The correlation is relatively better during the dry period (Oct-Dec) compared with the wet season (May-Sept).

As also mentioned in the annual report of JFY 2018 and 2019, one possible way for improving the AMSR2 soil moisture product is through applying a simple regression of itself against in-situ measurement based on the historical data profile. This regression could be set to apply to the original product once soil moisture exceeds certain level, e.g. 0.1 m^3/m^3, beyond which the product/in-situ discrepancy starts to become more pronounced.

Figure 22 shows the soil moisture time series plot during 2019-2021 in comparison with VWC for the same period. Looking at the 3 years data, it is more obvious that the accuracy is lower during wet seasons. The VWC derived from MODIS 10-year NDVI climatology is also plotted to compared with the soil moisture trend. Similar with discussed in the previous reports, here the VWC trend matches well with the soil moisture trend; the peaks of VWC also correlate well with the soil moisture peaks. Since the AMSR2 soil moisture was retrieved from C-band, which is a higher frequency, the signal is more affected by the vegetation layer and thus it is more difficult to decouple the effect of vegetation from SM. Therefore, it is less sensitive to the soil moisture change.

5.2 Scatter Plots and Statistics

The AMSR2 L3 soil moisture product at 10-km resolution are also plotted in Figure 23 as scatters against soil moisture observations from tower (Fig 23a) and SMAP (Fig 23b). It shows negative bias in the scatter plots (-0.06 and -0.09 m^3/m^3) which are consistent to the time series plot. Tower soil moisture is also plotted against AMSR2 SM (Fig 23c) and SMAP SM (Fig 23d). When comparing SMAP SM to tower SM, the bias was smaller (-0.04 m^3/m^3) compared to AMSR2 SM, and both RMSE (0.07 m^3/m^3) and correlation (0.81) were relatively superior.

a)

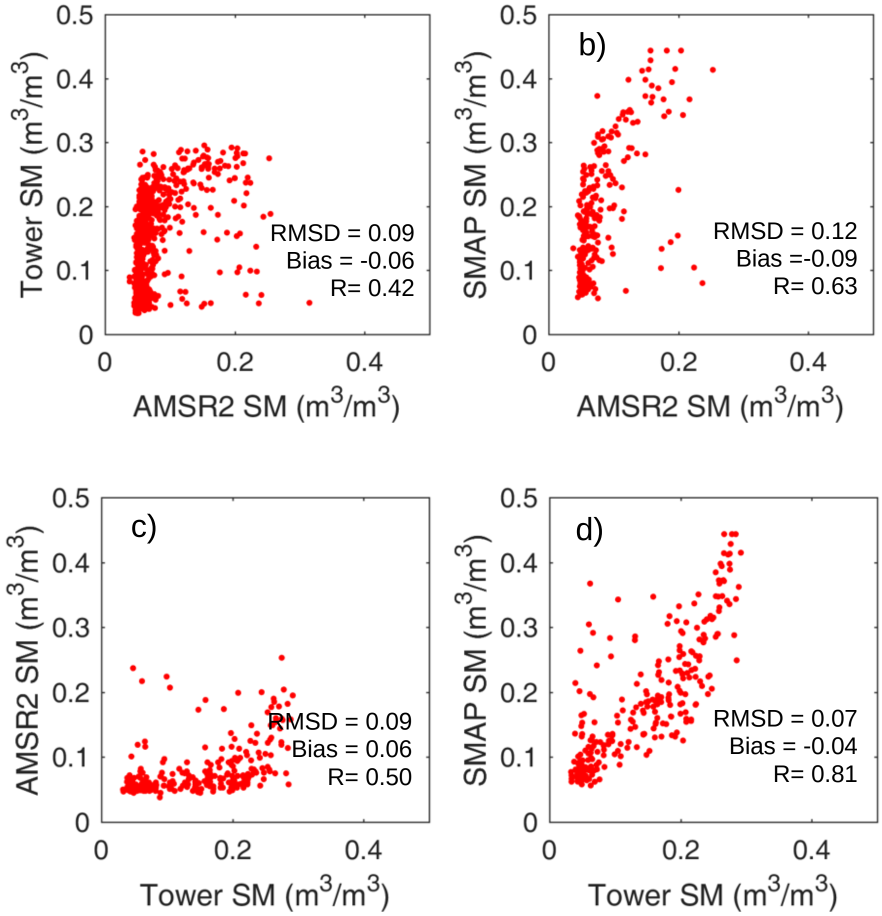

Figure 23: Scatter plots of AMSR2 SM (10-km) against a) tower soil moisture, b) SMAP SM (36km), c) tower SM against AMSR2 SM and d) tower SM against SMAP SM.

Chapter 6: Validation of the AMSR2 beta VWC product

6.1 The AMSR2 beta VWC product

The beta VWC product was provided by JAXA in late June 2021. Two data versions were available: v001 which is the semi-empirical retrieval algorithms using X and Ka bands; v002 is the ANN algorithm using C, X and Ka bands. Both versions were used for evaluation in JFY2021. The main research activity was to validate these VWC products against calculated VWC from MODIS vegetation indices VWC-NDVI relationships from Gao et al, 2015. The validation of VWC against field sampling collected from SMAPEx-4 and SMAPEx-5 field campaigns at Yanco area is still underway and will be finished by the end of April this year.

As the product was provided until end of the year 2020, 3 years of data including 2018, 2019 and 2020 are selected to perform some preliminary analysis.

A summary of the data version used can be found in Table 1.

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 24 shows the AMSR2 VWC time series. v001 was indicated in blue v002 was indicated in red.

It is clear that the values of v001 are generally higher compared to v002. More specifically, when the VWC values reach above 3 kg/m^2, the two versions tend to coincide with each other; while the VWC values are below 2 kg/m^2, there tend to be larger gaps between the two versions of data. This could be the reason that when VWC become higher, the vegetation effect tend to be more pronounced and easier to be detected by the frequency bands.

It can also be seen that year 2018 has relatively consistent VWC throughout the whole year. In 2019 the VWC is significantly higher during the winter months compared with the summer months. In 2020, the vegetation level is highest among the three years, reaching 5-6 kg/m^3 at the largest. However, this level of VWC is more of a scale of forest or very dense vegetation, instead of grassland. Therefore, these products needs to be further validated.

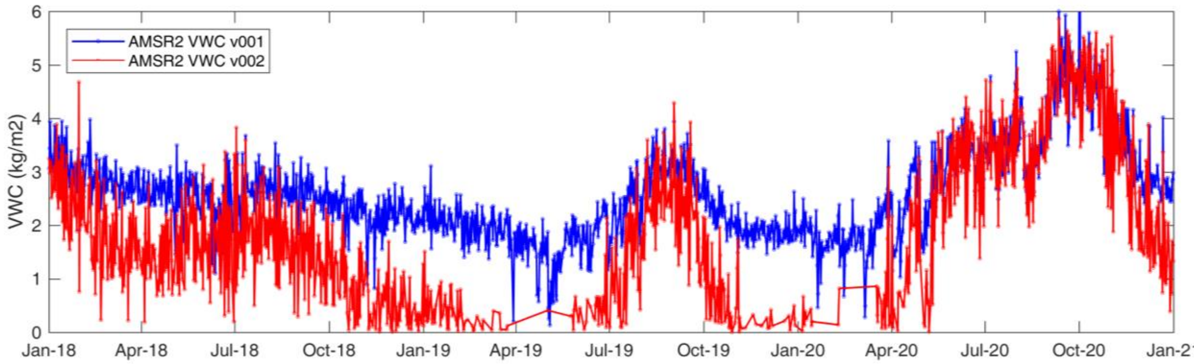

Figure 24: AMSR2 VWC product v001 and v002 time series from the year 2018 to 2020.

6.2 The Gao et al equations

The work done by Gao et al. (2015) complied and inter-compared a number of equations developed for VWC derivation from NDVI and NDWI using satellite data and ground samples collected from field campaigns around the globe. Four vegetation types were considered: corn, cereal grains, legumes and grassland. New equations were proposed based on the entire compiled data sets. Results showed superiorities for these new equations based on statistical analysis. In their work, it was found that NDVI and $NDWI_{1640}$ are the preferred indices for VWC estimation based on the availability and the error statistics of the compiled data sets. It was also recommended that these new equations can be applied in the future global remote sensing application for VWC retrieval.

Figure 25 shows the data sets and equations for VWC estimation using NDVI from Gao et al (2015) for Corn, Cereal grains, Legumes and Grassland, respectively. The recommended equations that were considered in this study are indicated in red dotted line.

Table 2 summarizes the recommended VWC-NDVI equations by Gao et al. for different land cover types.

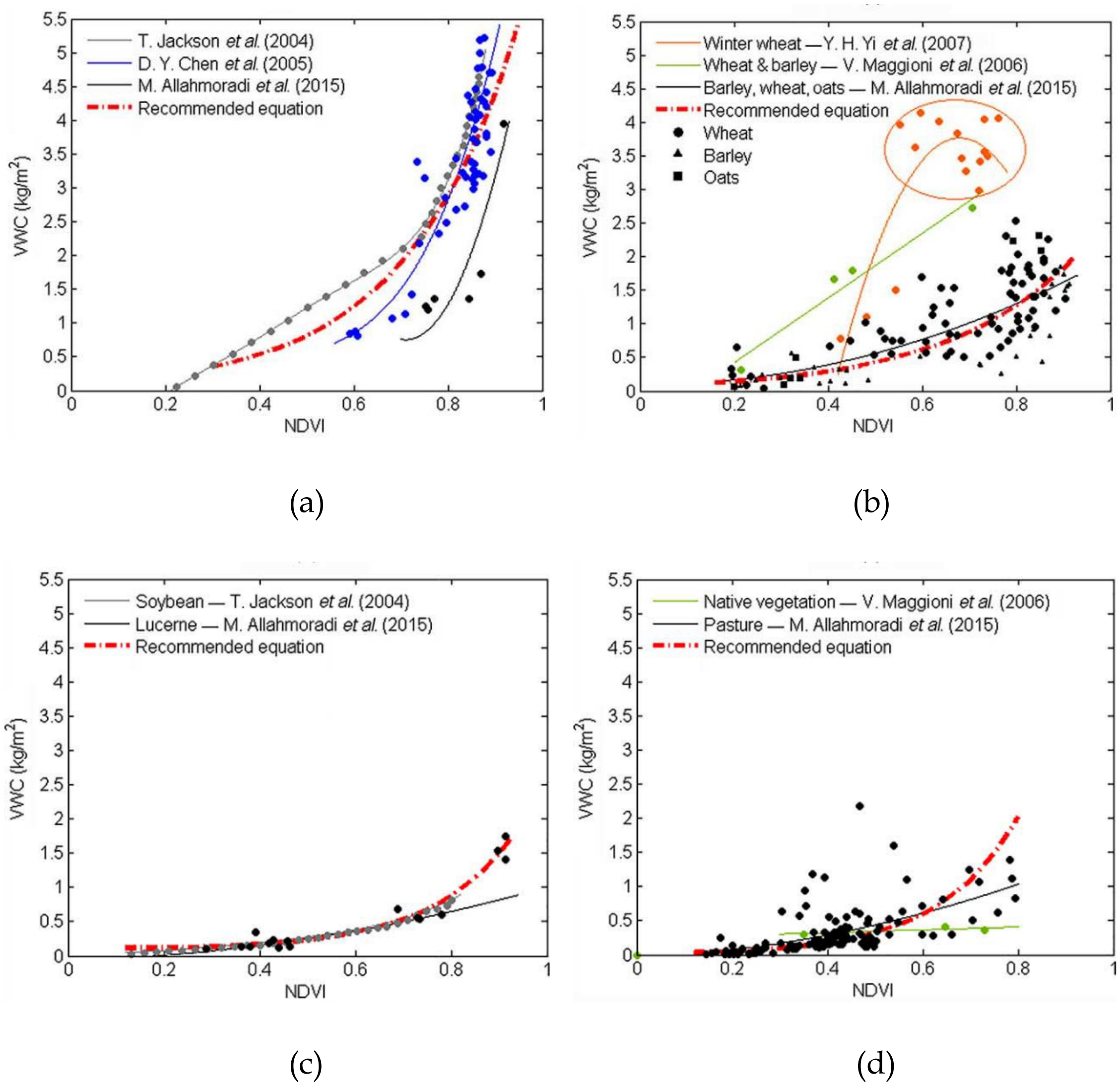

Figure 25: Data sets and equations for VWC estimation using NDVI from Gao et al (2015). (a) Corn. (b) Cereal grains. (c) Legumes. (d) Grassland.

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 Results

As shown in Figure 26, the calculated VWC from MODIS NDVI using Gao equation was plotted on top of the AMSR2 VWC products.

It is clear that the values of v001 are generally higher compared to v002. More specifically, when the VWC values reach above 3 kg/m^2, the two versions tend to coincide with each other; while the VWC values are below 2 kg/m^2, there tend to be larger gaps between the two versions of data. This could be the reason that when VWC become higher, the vegetation effect tend to be more pronounced and easier to be detected by the frequency bands.

However, the calculated VWC from MODIS NDVI is significantly lower compared to AMSR2 VWC products. More specifically, the MODIS VWC only coincide with

AMSR2 VWC at the very low VWC values, i.e. 0-1 kg/m^2. For the year 2020, the MODIS VWC catches the same trend with the AMSR2 VWC while having a negative bias of around 1-2 kg/m^2. It is also interesting to see that for the year 2018 to 2019, the MODIS VWC is almost constant throughout the two years while keeping a very low value of less than 1 kg/m^2.

According to the on-site field experience from our team, it is suggested that the AMSR VWC v001 is probably too high for a grassland condition. The real VWC condition is more like to be between AMSR VWC v001 and MODIS VWC. However, we will still need some field VWC data to verify these products.

As the field VWC data from the SMAPEx campaign are from 2014 and 2015, we will need to further extract some earlier AMSR2 VWC products to make such comparison. This work is still underway. More results of the validation of year 2014-2015 data against field samplings will be updated in April 2022.

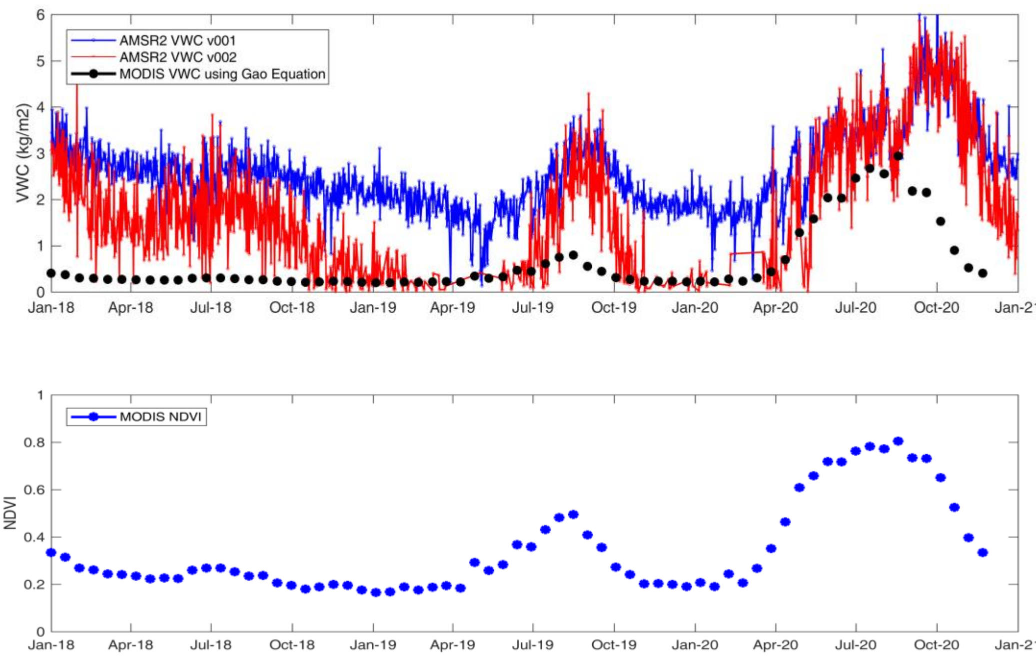

Figure 26: Top: AMSR2 VWC product v001 and v002 together with Calculated VWC from MODIS NDVI using Gao equation; Bottom: MODIS NDVI used to calculate VWC.

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 (^{o}C)

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/ ^{o}C)

γ: psychometric constant

C_n: numerator constant

C_d: denominator constant

Chapter 8: Summary and Conclusion

This report presents the research activities and research outcomes for the project 'Validation of global water and energy balance monitoring in the Australian Murray-Darling Basin using GCOM-W1 data' during JFY 2021. One of the main research activities aimed to continue operating the JAXA flux tower within the core validation site located in Yanco, New South Wales, Australia. This provides spatially distributed soil moisture data from across an AMSR2 sized footprint. It was proposed that during JFY 2021, this project would make significant independent and collaborative contributions to:

i) Continuing the validation of the AMSR2 standard soil moisture product.

ii) Intercomparing the AMSR2 soil moisture product with the Soil Moisture Active Passive (SMAP) Level 2 soil moisture product.

iii) Validating the vegetation water content (VWC) research product against a) field sampling from the 4th and the 5th Soil Moisture Active Passive Experiments (SMAPEx-4 and -5) conducted in Yanco, Australia, and b) VWC calculated from MODIS-derived vegetation indices.

In general the AMSR2 products are underestimating the tower soil moisture. The correlation is relatively better during the dry period (Oct-Dec) compared with the wet season (May-Sept).

As also mentioned in the annual report of JFY 2019 and 2020, one possible way for improving the AMSR2 soil moisture product is through applying a simple regression of itself against in-situ measurement based on the historical data profile. This regression could be set to apply to the original product once soil moisture exceeds certain level, e.g. 0.1 m^3/m^3, beyond which the product/in-situ discrepancy starts to become more pronounced. The VWC trend matches well with the soil moisture trend; the peaks of VWC also correlate well with the soil moisture peaks. Since the AMSR2 soil moisture was retrieved from C-band, which is a higher frequency, the signal is more affected by the vegetation layer and thus it is more difficult to decouple the effect of vegetation from SM. Therefore, it is less sensitive to the soil moisture change.

For the AMSR2 VWC, the values of v001 are generally higher compared to v002. More specifically, when the VWC values reach above 3 kg/m^2, the two versions tend to coincide with each other; while the VWC values are below 2 kg/m^2, there tend to be larger gaps between the two versions of data. This could be the reason that when VWC become higher, the vegetation effect tend to be more pronounced and easier to be detected by the frequency bands.

The calculated VWC from MODIS NDVI using the Gao equations is significantly lower compared to AMSR2 VWC products. According to the on-site field experience from our team, it is suggested that the AMSR VWC v001 is probably too high for a grassland condition. The real VWC condition is more like to be between AMSR VWC v001 and MODIS VWC. However, we will still need some field VWC data to verify these products.

References

Draper, C. S., and R. H. Reichle (2019), Assimilation of satellite soil moisture for improved atmospheric reanalyses. *Mon. Wea. Rev.*, in press, doi:10.1175/MWR-D-18-0393.

De Jeu, R. A. M., Holmes, T. R. H., Parinussa, R. M. & Owe, M. (2014). A spatially coherent global soil moisture product with improved temporal resolution. *Journal of Hydrology*, 516: 284-296.

Gao, Y., Walker, J., Allahmoradi, M., Monerris-Belda, A., Ryu, D. & Jackson, T. J. (2015). Optical Sensing of Vegetation Water Content: A Synthesis Study. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 8, 4, p. 1456 - 1464 9 p.

Gevaert, A. I., Parinussa, R. M., Renzullo, L. J., Van Dijk, A. I. J. M. and De Jeu, R. A. M. (2015). Spatio-temporal evaluation of resolution enhancement for passive microwave soil moisture and vegetation optical depth. *International Journal of Applied Earth Observation and Geoinformation*.

Liu, Q., and Coauthors (2011). The contributions of precipitation and soil moisture observations to the skill of soil moisture estimates in a land data assimilation system. *Journal of Hydrometeorology*, 12, 750–765, doi:10.1175/JHM-D-10-05000.1.

McKenzie, N.J., D.W. Jacquier, L.J. Ashton and H.P. Cresswell (2000), "Estimation of soil properties using the Atlas of Australian Soils," *CSIRO Land and Water Technical Report* 11/00.

Parinussa, R. M., Yilmaz, M. T., Anderson, M. C., Hain, C. R. & De Jeu, R. A. M. (2014) An intercomparison of remotely sensed soil moisture products at various spatial scales over the Iberian Peninsula. *Hydrological Processes*, 28: 4865-4876.

Rudiger, C., Walker, J.P., Kerr, Y.H. (2011) On The Airborne Spatial Coverage Requirement for Microwave Satellite Validation. *IEEE Geoscience and Remote Sensing Letters*, 8(4):824-828. doi:10.1109/LGRS.2011.2116766.

Santi, E. (2010). An application of the SFIM technique to enhance the spatial resolution of spaceborne microwave radiometers. *International Journal of Remote Sensing*, 31: 2419-2428.

T. Mo, B. J. Choudhury, T. J. Schmugge, J. R. Wang, T. J. Jackson, "A model for the microwave emission of vegetation-covered fields", *J. Geophys. Res.*, vol. 87, no. 11, pp. 229-237, Dec. 1982.

Yee, M., Walker, J. P., Monerris, A., Rudiger, C. and Jackson, T. J. (2016). On the identification of representative in situ soil moisture monitoring stations for the validation of SMAP soil moisture products in Australia. *Journal of Hydrology*, 537,, 367-381. doi:10.1016/j.jhydrol.2016.03.060

Yee, M., Walker, J. P., Rüudiger, C., Robert M. Parinussa, Kerr, Y. and Koike, T. (2016). A comparison of SMOS and AMSR2 soil moisture using representative sites of the OzNet monitoring network. *Remote Sensing of Environment*. Manuscript in review.

Validation of GCOM-W1 products using global water and energy balance monitoring at the Murray-Darling Basin in Australia

MONASH University
Engineering