Downscaling Advanced Microwave Scanning Radiometer 2 Surface Soil Moisture Using Normalized Multi-Band Drought Index And Leaf Area Index

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ABSTRACT: Soil moisture is one of the most significant variables for various applications in meteorology, climatology, hydrology, and ecology. To monitor surface soil moisture (SSM) for large scale, Advanced Microwave Scanning Radiometer 2 (AMSR2) provides SSM data with a spatial resolution of 10 km and 25 km. Experiments from previous studies have revealed that SSM can be possibly functionalized by normalized multi-band drought index (NMDI) and leaf area index (LAI). Since NMDI and LAI are both acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) data, with resolutions of 0.5 km and 1 km respectively, a downscaling method by incorporating AMSR2 and MODIS data is therefore expected to generate SSM data with a finer resolution of 1 km. The main objective of this study is to formulate relationships between AMSR2 SSM and MODIS-derived NMDI and LAI. The study area is located in Central America, and we mainly focus on the dry season, which extends from January to April. The period of acquisition for image data of AMSR2 and MODIS is from January to February, 2014. The study was conducted by first generating a transformation function based on the observations each day, and the results confirmed the validity of the method for AMSR2 SSM downscaling. Furthermore, the method is expected to develop the analysis for the rainy season in order to finalize the method, and is also expected to be transferable to other regions to obtain the SSM data in finer scale.

1. INTRODUCTION

Surface soil moisture (SSM) is very important in the Earth. To monitor SSM for large scale, Advanced Microwave Scanning Radiometer 2 (AMSR2) provides SSM data at a spatial resolution of 10 km and 25 km. According to Wang et al (2007), SSM could be estimated using the normalized multi-band drought index (NMDI) and leaf area index (LAI). Specifically, when LAI is lower than 4, NMDI decreases while SSM increase rapidly. On the other hand, when LAI is higher than 4, there is no significant relationship between NMDI and SSM could be identified. This observation provides a possible practice that since NMDI and LAI can be acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) data, with resolutions of 0.5 km and 1 km respectively, a downscaling method by incorporating AMSR-2 and MODIS data is therefore expected to generate SSM data with a finer resolution of 1 km.

This study aims to generate a formularized relationship that can be used to retrieve a SSM map with resolution of 1 km. The study area is located in Central America, and we mainly focus on the dry season, which extends from

January to February. The study was conducted by first generating a transformation function based on the observations each day, and confirmed the validity of the method for AMSR2 SSM downscaling.

2. STUDY AREA

Figure 1. Study area. Left) Global map with study area which is boxed by red. Right) Study area with country name which is between Pacific Ocean and Caribbean Sea.

The study area is located at Central American Isthmus, including south Mexico, Belize, Guatemala, Honduras, El Salvador, and Nicaragua. The area is around 570,000 km^2. There are only rainy season and dry season in whole year, and the dry season is from December to May. Since there is a stable dry reason in this area, SSM is always close to saturation in rainy season, and that is why we selected the area as study area.

3. METHODS

The period of acquisition for image data of AMSR2 and MODIS is from January to February, 2014. First of all, water and cloud pixels are removed, and the three maps are resampled into the same coordinate system and scale. Secondly, remove noise. There are many types of soil in Central America Isthmus, and each types of soil may have different respond regression. Therefore, which type of soil is quite different with most point will be considered as noise and removed. All points will be distinguished to data points (95 %) and check points (5 %). The third step is using data points to regression the relationship of SSM, NMDI and LAI. Forth, the Kringing interpolation is applied to downscale the residual of AMSR2 SSM and retrieval SSM which resolution is 10 km to 1 km, and it will combined with retrieval SSM in 1 km. Finally, using the check points to validate this study. The work flow is shown in figure 2.

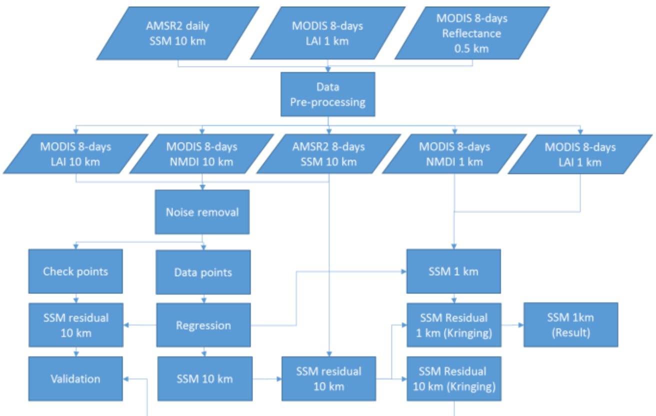

Figure 2. Flow chart of this study.

3.1 Data pre-processing

The resolution of MODIS reflectance is 0.5 km, to fit with the other data format, so it need to resample to 1 km first. Then, the coordinate transformation, cloud removal, and water mask are applied, because MODIS is an optical sensor which cannot receive surface data if that pixel filled with cloud. Extract band 2, 6, and 7 to calculate NMDI, which is defined as follow:

$$\text{NMDI} = \frac{R_{860mm} - (R_{1640mm} - R_{2130mm})}{R_{860mm} + (R_{1640mm} - R_{2130mm})} \quad (1)$$

where R_{860mm} , R_{1640mm} , and R_{2130mm} are the apparent reflcetances observed by a satellite sensor.

The NMDI and LAI maps are in a grid of 1 km without cloud and water pixel. And, resample to 10 km which is the resolution of AMSR2 SSM as the regression data. The AMSR2 SSM is a radar retrieval data, so there is no need to mask the cloud of it, we just only processed the coordinate transformation and water mask. Because AMSR2 provides a daily data and MODIS provides an 8-days data, AMSR2 data needs to take an average of 8 days which period is the same with MODIS data. Due to water surface effects, SSM around coastline and large lakes often show erroneously high value (Koike, 2013). If SSM reaches over 20%, the soil will be almost a flow. Therefore, SSM must be removed if it is larger than 20%.

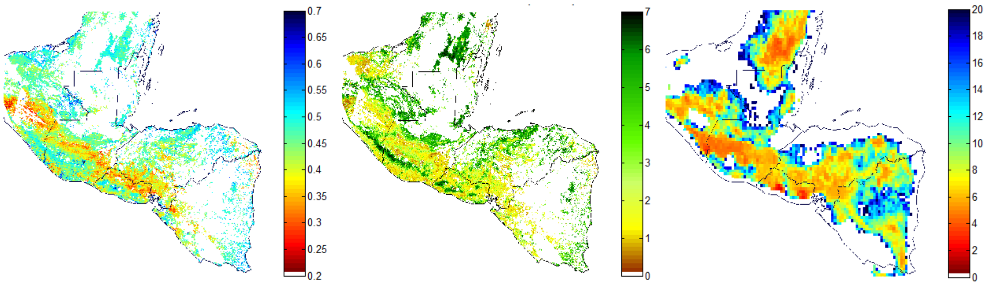

Figure 3. Original input data on 1st of January, 2014. Left) MODIS NMDI. Mid) MODIS LAI. Right) AMSR2 SSM.

After the pre-processing of MODIS NMDI, LAI and AMSR2 SSM, the resampled maps of this study are all grid of 10 km data format, as the same scale of MODIS. Then, if the ratio of data pixels and total pixels in a grid is larger than 80 percent, this grid makes a data grid. If not, this grid regard as an empty grid. The data still need to remove the points with LAI value is larger than 4. Figure 4. shows the 10 km data with overlapping area, and Figure 5. shows the scatter figure of three data of Figure 4.

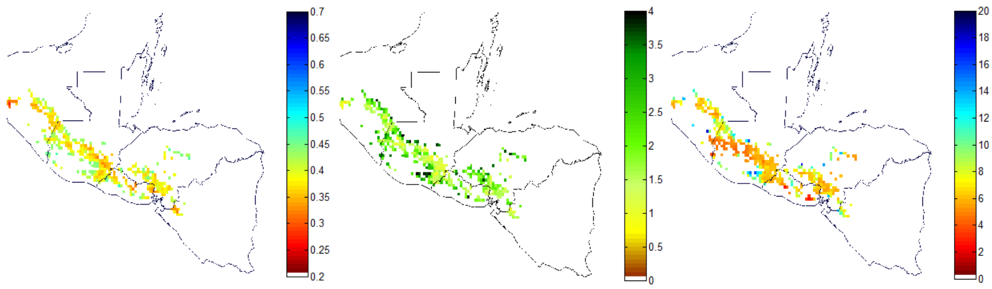

Figure 4. Overlapping data in 10 km grid on 1st of January, 2014. Left) MODIS NMDI. Mid) MODIS LAI. Right)

AMSR2 SSM.

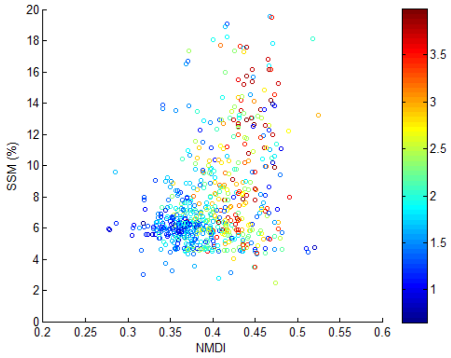

Figure 5. The combination with 10 km resolution data on 1st of January, 2014. X axis is NMDI. Y axis is SSM, and the unit is %. Z axis and color bar shows LAI value.

3.2 Respond surface

We can find some data close in a center of special surface in Figure 5, and the ideal data usually distribute closely. Therefore, the reference surface needs to fit this surface. Then, set a threshold that the data is far from this surface will be mark as a noise data. After noise removal, 95 % of the points are data points which will be applied to regression to a new surface by Respond Surface Methodology, and 5 % of the points are check points which will be applied to verify the study. The data after noise removal will be used in Respond Surface methodology. We can get one other surface which is fitted better to the data. The equation is designed as equation (2) with the knowledge of previous study.

$$SSM = \beta_0 + \beta_1 \times LAI + \beta_2 \times NMDI + \beta_3 \times LAI \times NMDI + \varepsilon \quad (2)$$

Where $\beta_0, \beta_1, \beta_2,$ and β_3 are the coefficients of equation (2). ε is the residual.

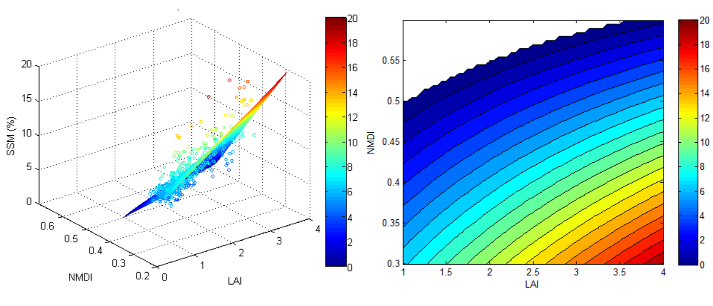

Figure 6. Respond surface with noise removal result on 1st of Jan., 2014. Left) Reference surface with scatter of noise removal result with reference surface. Right) Contour map of reference surface.

3.3 Kringing Interpolation

SSM with 1 km resolution can be estimated if the coefficients of respond surface were obtained, but the reliability of this estimation is uncertain. Therefore, the verification would be applied with 10 km resolution. Using the coefficients obtained from respond surface methodology, SSM estimation can be applied to 10 km resolution which is the same scale with AMSR2 SSM data.

The residual can be obtained by comparison with a grid of 10 km SSM estimation and AMSR2 data, and the root mean square error (RMSE) can be verified. The RMSE usually can be better when combines with the Kringing interpolation of the residual. Kringing interpolation which performs better in environmental applications is applied to make a residual map with 1 km resolution to make SSM result much better and with 10 km resolution to verify the Kringing interpolation result.

4. RESULTS AND DISCUSSION

4.1 SSM formulization

In Table 1, first group of $\beta_0, \beta_1, \beta_2,$ and β_3 at the 2nd to 5th column shows the coefficients of the reference surface, and the other group of $\beta_0, \beta_1, \beta_2,$ and β_3 shows the coefficients of the respond surface at specified day. The 6th to 8th column shows the amount of points after each process. The 6th column means the points count after resample to 10 km with 80 % grid. The 7th column means the points count after removing the points with LAI value is larger than 5. The 8th column means the points count after noise removal by reference surface. The 9th column shows the ideal data ratio which is the percentage of the 8th column divide by the 7th column. $\beta_0,$ and β_1 are positive, and $\beta_2,$ and β_3 are negative. This phenomenon fits the relationship between LAI, NMDI, and SSM. And, the RMSE value is less than 2 %.

Table 1. Result table of this study.

Date	Jan. 1	Jan. 9	Jan. 17	Jan. 25	Feb. 2	Feb. 10	Feb. 18	Feb. 26
β_0	10.111	16.481	16.481	10.111	8.556	13.241	5.564	16.463
β_1	27.778	15.037	15.037	27.778	28.089	18.719	9.480	18.074
β_2	-44.444	-59.259	-59.259	-44.444	-44.444	-53.704	-15.859	-59.259
β_3	-51.111	-21.481	-21.481	-51.111	-51.111	-32.593	-16.748	-31.481
Resample	853	2233	1898	833	1048	1083	1537	2578
LAI < 5	639	1130	965	473	579	275	575	1353
Reference Surface	394	782	551	286	330	159	354	815
Ratio (%)	61.66	69.20	57.10	60.47	56.99	57.82	61.57	60.24
β_0	11.182	8.935	7.264	5.034	13.521	12.108	8.661	5.879
β_1	6.720	4.353	8.165	9.806	6.241	5.375	2.733	5.410
β_2	-26.964	-18.698	-15.149	-9.870	-36.210	-32.994	-17.329	-8.065
β_3	-8.829	-4.698	-13.638	-17.626	-7.367	-6.434	-2.377	-9.693
RMSE(%)	1.78	1.77	1.71	1.74	1.96	1.77	1.64	1.47

4.2 Validation of downscaled SSM data

In Table 2, using the check points verify the estimation at 10 km grid which is the same with AMSR2 SSM data, and combine the estimation and Kringing interpolation result which is produced by data points not check points. We can find out that all the statistics results of the second solution are better than first one. So we could inferred that the Kringing interpolation does improve the estimation of SSM. Figure 7. shows the estimation result with Kringing interpolation is close to the trend of AMSR2 SSM on 1st of January, 2014.

Table 2. Validation of Check Points.

Date		Jan. 1	Jan. 9	Jan. 17	Jan. 25	Feb. 2	Feb. 10	Feb. 18	Feb. 26
RMSE	Estimation	1.67	1.28	1.92	1.23	0.94	0.70	0.83	0.88
	Estimation + Kringing	0.73	0.77	0.52	0.98	1.06	1.10	0.81	0.49

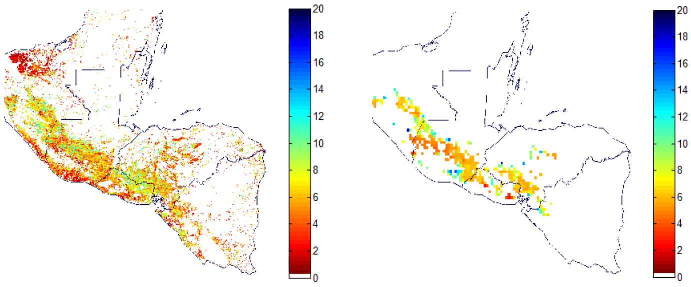

Figure 7. Comparison between the estimation SSM with 1 km resolution and AMSR2 SSM with 10 km on 1st of Jan., 2014. Left) Estimation SSM with 1 km resolution. Right) AMSR2 SSM with 10 km resolution.

5. CONCLUSION

The study was conducted by first generating a transformation function based on the daily observations, and Table 2. shows that the RMSE is reduced after using Kringing interpolation at most of dates and all values are small confirmed the validity of the method for AMSR2 soil surface moisture downscaling. Furthermore, the method is expected to develop the analysis for the rainy season in order to finalize the method, and is also expected to be transferable to other regions to obtain the SSM data in finer scale. But there still exists some problems need to solve, such as the input points are too few so that the respond surface does not behave in a good trend. In addition, the cloud mask is another problem, because MODIS is an optical sensor so that the data didn't reflect signal from surface.

REFERENCE

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