ESTIMATION OF SURFACE SOIL MOISTURE USING MODIS IMAGERY

C. F. Chen[*†], Y.J, Lin[†], L.Y. Chang[†], N. T. Son[*]
[*] Center for Space and Remote Sensing Research
[†] Department of Civil Engineering
National Central University, Jhongli City, Taoyuan County 32001, Taiwan
Email: cfchen@csrsr.ncu.edu.tw, eugenelin151121@yahoo.com.tw, lychang@csrsr.ncu.edu.tw, ntsonait@hotmail.com

KEY WORDS: MODIS, AMSR-E, surface soil moisture, Taiwan.

ABSTRACT: This study aimed to develop an algorithm to retrieve surface soil moisture in Taiwan from the moderate resolution imaging spectroradiometer (MODIS) data (1-km resolution) and AMSR-E (advanced microwave scanning radiometer-earth observing system on-board aqua satellite) soil moisture data (25-km resolution). Data were processed for 2009 comprising three main steps: (1) computing the temperature vegetation dryness index (TVDI) by empirical analysis of the relationship between land surface temperature (LST) and normalized difference vegetation index (NDVI) data. Because the climate was altered by elevation, the study area was divided into two regions (using a threshold of 1000 m) based on the digital elevation model (DEM) analysis. The TVDI was thus processed separately for each region, (2) converting TVDI to the same unit with AMSR-E soil moisture data (mg cm^{-3}) by regression analysis of the two datasets, and (3) validating the results of retrieved soil moisture. The retrieved soil moisture showed the comparable spatiotemporal patterns with the AMSR-E soil moisture data. The goodness of the methods was assessed by comparing the TVDI results with the retrieved soil moisture using root mean square error (RMSE) indicated that the methods in which the study area was partitioned into two regions produced slightly better results (RMSE = 36.7 mg cm^{-3}) than the methods in which the study area was not partitioned into two regions (RMSE = 39.8 mg cm^{-3}).

1. INTRODUCTION

Surface soil moisture is an important parameter for various applications including agricultural and environmental management. This parameter is especially important for crop management because it affects the transpiration rate of crops (Kramer, 1969). Information on soil moisture is thus important because planners need such information for monitoring purposes. Soil moisture can be calculated from meteorological data using indices, such as Palmer drought severity index (PDSI) (Palmer, 1965) and standardized precipitation index (SPI) (McKee et al., 1993). However, the use of these indices for regional soil moisture monitoring is likely infeasible because the climatic data acquired over a large region were costly and often insufficient. Satellite-based indices, such as AMSR-E (Advanced Microwave Scanning Radiometer-Earth Observing System on-board Aqua satellite) index (g cm^{-3}, 25-km resolution), have been developed and used for large-scale monitoring of soil moisture in the top few cm of soil. This index is however unsuitable to be applied in small regions such as Taiwan for monitoring purposes due to its coarse spatial resolution.

Because of this limitation, studies often used satellite data to develop indices for soil moisture monitoring (Chen et al., 2011; Mallick et al., 2009; Patel et al., 2008; Sandholt et al., 2002; Wang et al., 2004). One of the commonly-used satellite-based indices used for soil moisture investigation is the temperature vegetation dryness index (TVDI) (Sandholt et al., 2002). This index is constructed based on the empirical interpretation of the relationship between the normalized difference vegetative index (NDVI) and land surface temperature (LST). The NDVI and LST were used to derive TVDI because NDVI characterizes the greenness of vegetation indicating water stress, whilst LST reflects soil moisture. Thus, the combination of these two NDVI and LST can provide more complete information on soil moisture (Carlson, 2007).

The main objective of this study was to develop an approach to retrieve surface soil moisture (mg cm^{-3}) from moderate resolution imaging spectroradiometer (MODIS) data in Taiwan.

2. STUDY AREA

The study area (Taiwan) covers approximately 36,000 km^2, lying between 23°46′ N−121°00′ E (Figure 1). The elevation ranges from 0 to 3,952 m above the mean sea level. The study area has subtropical monsoonal climate with the mean annual precipitation of approximately 2,500 mm. The hottest month is July with the mean temperature of 27−28 °C and the coolest month is February (15 °C). The more frequent occurrence of climatic extremes in recent years has affected the region. Thus, there was an urgent need to develop methods to retrieve soil moisture for agricultural and environmental monitoring purposes.

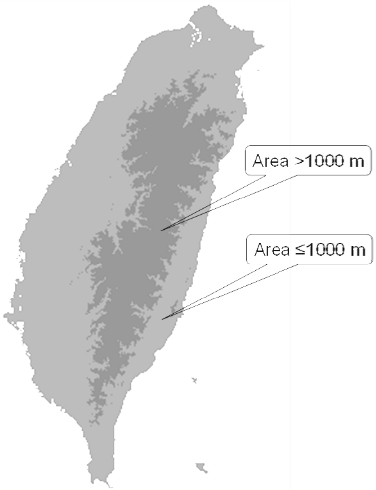

Figure 1. The study area showing the two elevation levels.

3. DATA

MODIS and AMSR-E data for 2009 were acquired from NASA. The daily MODIS products used to compute TVDI include MYD09GQ (250-m resolution) and MYD11A1 (1000-m resolution). 12 images less influenced by cloud were selected. The TVDI was computed using LST and NDVI data. The spatial resolution of the NDVI data (derived from MYD09GQ) is different from LST (extracted from MYD11A1). Re-sampling NDVI data (250-m resolution) to the same resolution as the LST data (250-m resolution) was necessary. Daily volumetric surface soil moisture from AMSR-E data for 2009 (Figure 2) were acquired and used for linear regression analysis between the TVDI results and AMSR-E data. The purpose of doing so was to convert TVDI to the real soil moisture data that had the same unit as the AMSR-E soil moisture data (mg cm^{-3}). The AMSR-E data are given as surface volumetric soil moisture (mg cm^{-3}) in 25-km spatial resolution acquired in ascending pass (1:30 pm). The AMSR-E data formatted using cylindrical equal-area were reregistered through a geometric look-up table using latitude and longitude information.

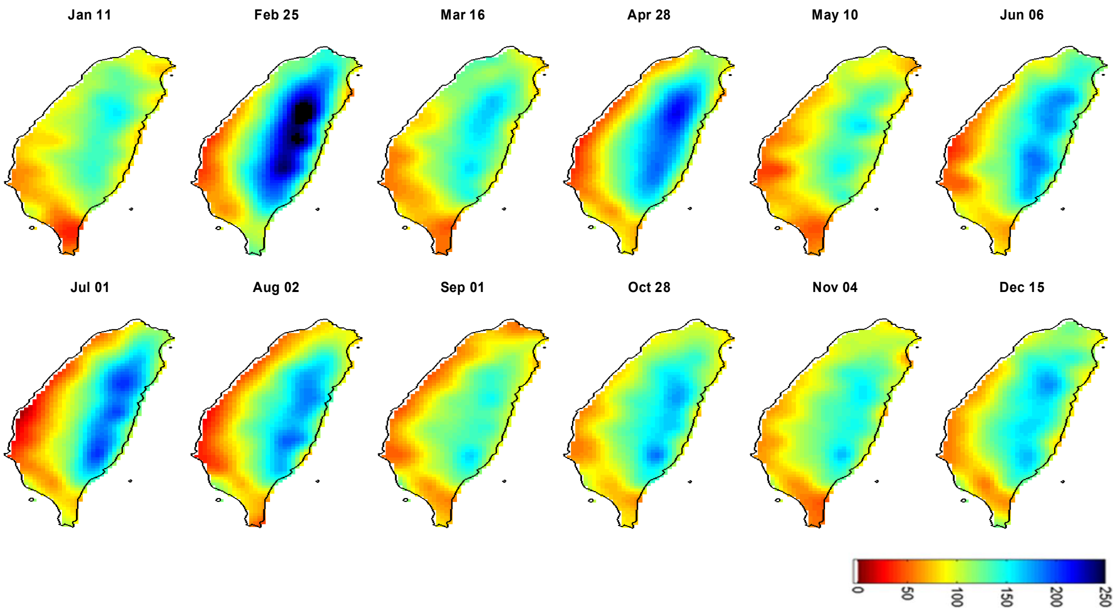

Figure 2. Evolution of resampled 1-km AMSR-E soil moisture (mg cm^{-3}) in 2009.

4. METHODS

The TVDI method (Sandholt et al., 2002) was used to retrieve surface soil moisture from MODIS and AMSR-E data. The index is calculated based on the empirical analysis of NDVI-LST data. The NDVI and LST were used because the combination of these two indices normally shows a strong negative relationship. The data could form a triangle shape if the study area is large enough to provide a wide range of NDVI and LST conditions (Gillies et al., 1997). The TVDI for each pixel can be calculated as follows.

$$TVDI = \frac{T_{s_{obs}} - T_{s_{\min}}}{T_{s_{\max}} - T_{s_{\min}}},$$

where $T_{s_{obs}}$ is the observed surface temperature at a given pixel. $T_{s_{\max}}$ is temperature of the dry edge (the upper straight line in the triangle). $T_{s_{\min}}$ is the temperature of the wet edge (lower horizontal line of the triangle). The dry and wet edges were calculated from the NDVI-LST space regression with small intervals of NDVI. Because the climate in the region was affected by the elevation, parameters including temperature and pressure are altered by the changes of elevation. Based on the digital elevation method (DEM) analysis, we divided the study area into two regions: plain (elevation ≤ 1000 m), and mountain (elevation > 1000 m). Thus, the TVDI was also processed separately for each region. The real soil moisture was retrieved by regression analysis between the TVDI results and AMSR-E soil moisture data. Thus, the transformation function between the two datasets was computed to convert the TVDI to the real soil moisture data that had the same unit as AMSR-E soil moisture data (g cm^{-3}).

3. RESULTS AND DISCUSSION

3.1 Evolution of TVDI

The spatiotemporal evolution of TVDI (values from 0 − 1) showed a large degree of variation in TVDI values over space and time. In general, The higher TVDI values (0.4 – 0.6) were found in plains and lower elevation parts of the study area, and the TVDI values (0.6–0.8 and 0.8 – 1.0) were mainly observed in coastal and residential areas (Figure 3a). The low TVDI values (0 – 0.4) were observed for water surfaces and high elevation mountain areas (Figure 3b).

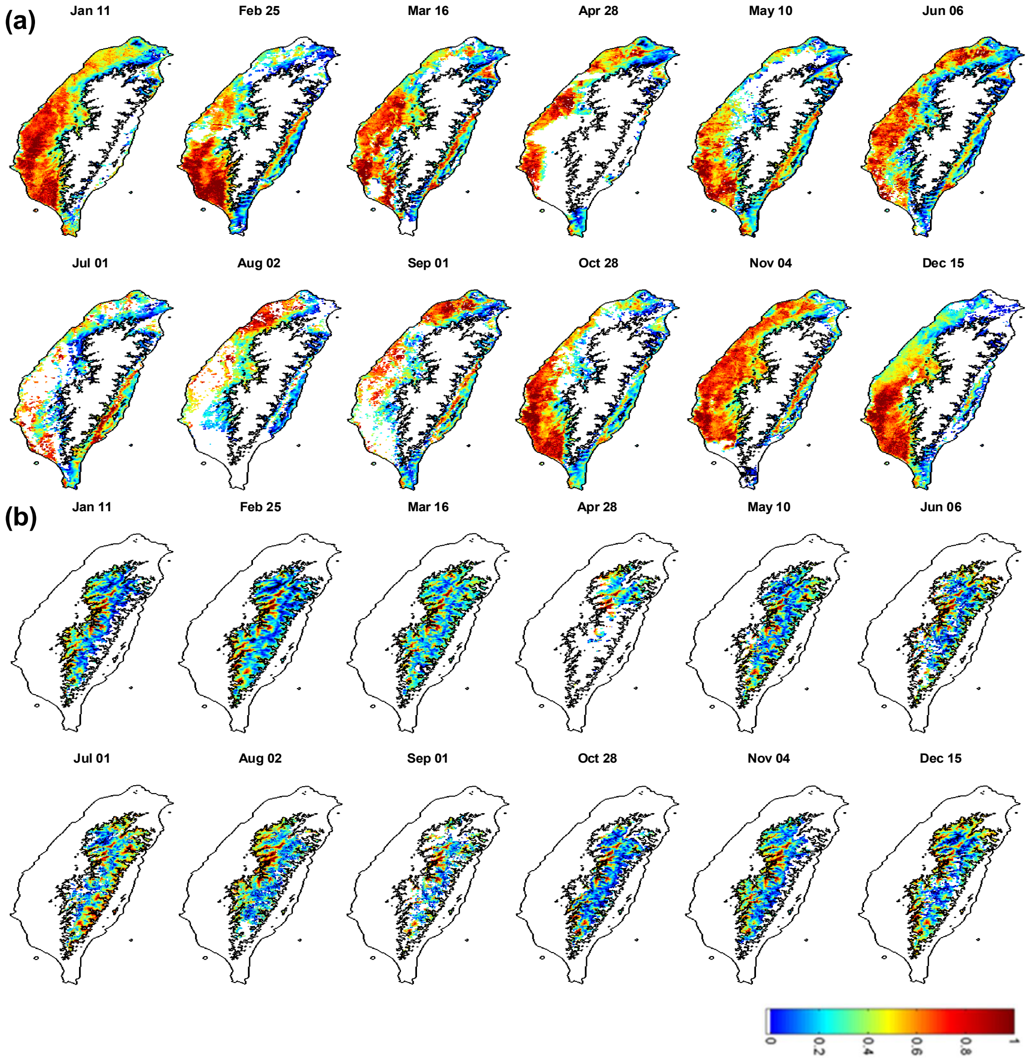

Figure 3. Evolution of monthly TVDI: (a) elevation ≤ 1000 m, and (b) elevation > 1000 m.

3.2 Evolution of surface soil moisture

The real soil moisture maps (mg cm^{-3}) retrieved for two regions (region ≤ 1000 m, and region > 1000 m) by using transformation functions (derived from regression analysis between the TVDI results and AMSR-E soil moisture data) were combined into one image scene (Figure 4). The spatio-temporal evolution of soil moisture generally showed the comparable patterns with those from the AMSR-E data (Figure 2) throughout the year. The areas of low soil moisture were more concentrated in the west part of the region where most residents settled in the cramped plains. The areas of low soil moistures were expanded from April but likely returned to wet conditions by the end of September due to the monsoonal influence.

We assessed the goodness of the methods by comparing the TVDI results with the real soil moisture (obtained from TVDI results and AMSR-E soil moisture data) using the root mean square error (RMSE). Two cases were investigated: Case 1, the study area was partitioned into two regions (region ≤ 1000 m, and region > 1000 m), and Case 2: the study area was not partitioned into two regions, and only one transformation function was derived to retrieve the real soil moisture for the entire region. The results (Table 1) indicated that the mean RMSE (used to quantify the difference between the two datasets) achieved for Case 1 was 36.7 mg cm^{-3}, while the value for Case 2 was 39.8 mg cm^{-3}. The comparisons performed for each partitioned region (region ≤ 1000 m and region > 1000 m) also confirmed the slightly better results obtained for Case 1. The RMSE values for the region ≤ 1000 m and region > 1000 m were 38.6 and 32.3 mg cm^{-3}, while the values for Case 2 were 39.8 and 40.9 mg cm^{-3}, respectively.

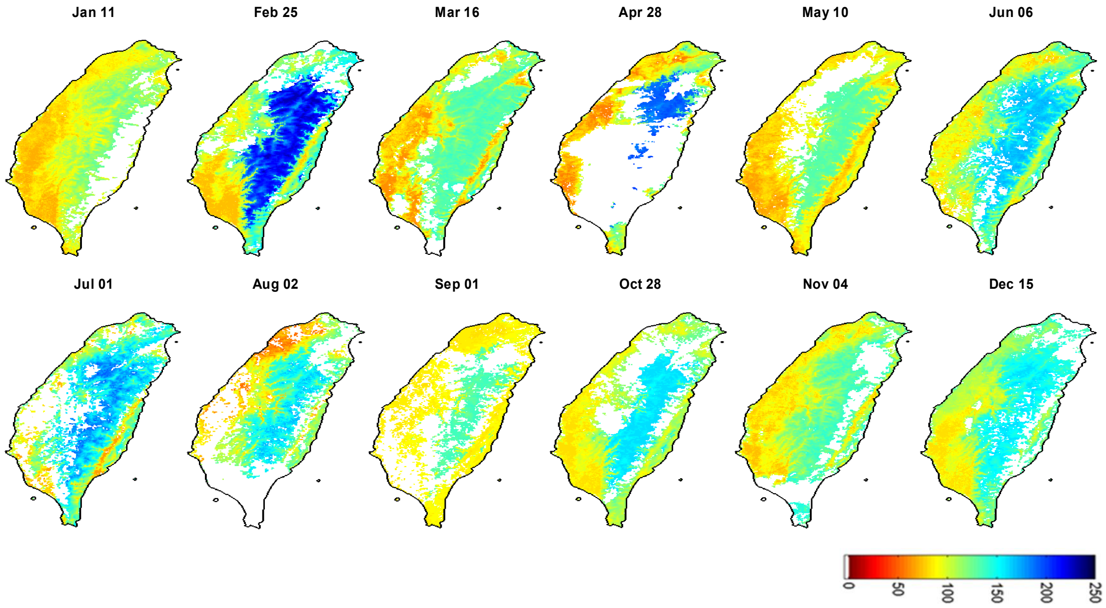

Figure 4. Evolution of 1-km surface soil moisture (mg cm-3) retrieved from the TVDI results and AMSR-E soil moisture data.

Table 1. Mean RMSE results derived from the analysis between the real soil moisture and the AMSR-E soil moisture data.

Cases	Mean RMSE (mg cm^{-3})
Case 1: partition	
Entire region	36.7
Region ≤ 1000 m	38.6
Region > 1000 m	32.3
Case 2: without partition	
Entire region	39.8
Region ≤ 1000 m	40.9
Region > 1000 m	32.4

4. CONCLUSIONS

The objective of this study was to develop an approach to retrieve surface soil moisture from MODIS TVDI and AMSR-E soil moisture data. The study area was divided into two regions based on the DEM analysis. The real soil moisture was retrieved by regression analysis between the TVDI results and the AMSR-E soil moisture data. The goodness of the methods was assessed by comparing the TVDI results and the real soil moisture using RMSE. The results showed that the methods in which the study area was divided into two regions based on DEM analysis (Case 1) yielded slightly better results than the other (Case 2). The mean RMSE achieved for Case 1 was 36.7 mg cm^{-3}, while that for Case 2 was 39.8 mg cm^{-3}, respectively. The low soil moisture areas were mainly distributed in western part of the study area. The evolution of low soil moisture expanded from April and typically returned to wet conditions by the end of September. This study demonstrated the use of MODIS data and AMSR-E soil moisture data (25-km resolution) to retrieve the higher resolution surface soil moisture (1-km resolution). The methods can be applied to the other regions to retrieve surface soil moisture for agricultural and environmental monitoring purposes.

REFERENCES

Carlson, T., 2007. An Overview of the "Triangle Method" for Estimating Surface Evapotranspiration and Soil Moisture from Satellite Imagery. Sensors 7, 1612-1629.

Chen, C.-F., Son, N.-T., Chang, L.-Y., Chen, C.-C., 2011. Monitoring of soil moisture variability in relation to rice cropping systems in the Vietnamese Mekong Delta using MODIS data. Applied Geography 31, 463-475.

Gillies, R.R., Kustas, W.P., Humes, K.S., 1997. A verification of the “triangle” method for obtaining surface soil water content and energy fluxes from remote measurements of the Normalized Difference Vegetation Index (NDVI) and surface radiant temperature. International Journal of Remote Sensing 18, 3145–3166.

Kramer, P.J., 1969. Plant and soil water relationship. McGraw Hill Inc.

Mallick, K., Bhattacharya, B.K., Patel, N.K., 2009. Estimating volumetric surface moisture content for cropped soils using a soil wetness index based on surface temperature and NDVI. Agricultural and Forest Meteorology 149, 1327-1342.

McKee, T.B., Doesken, N.J., Kleist, J., 1993. The relationship of drought frequency and duration to time scales, The 8th conference of applied climatology. American Meteorological Society, Anaheim, CA, p. 179−184.

Palmer, W.C., 1965. Meteorological drought. US Weather Bureau, Washington, D.C. .

Patel, N.R., Anapashsha, R., Kumar, S., Saha, S.K., Dadhwal, V.K., 2008. Assessing potential of MODIS derived temperature/vegetation condition index (TVDI) to infer soil moisture status. International Journal of Remote Sensing 30, 23-39.

Sandholt, I., Rasmussen, K., Andersen, J., 2002. A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status. Remote Sensing of Environment 79, 213-224.

Wang, C., Qi, S., Niu, Z., Wang, J., 2004. Evaluating soil moisture status in China using the temperature–vegetation dryness index (TVDI). Canadian Journal of Remote Sensing 30, 671-679.