Passive microwave soil moisture evaluations by ground based measurements in Korea

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ABSTRACT:

Passive microwave sensors have many advantages including the ability to directly measured soil moisture at large spatial scales regardless of weather conditions or time of day. However, microwave-sensed soil moisture's inevitable limitation is that it cannot describe hydrology at the watershed because its retrieved soil moisture scale is too large. Thus, microwave-sensed soil moisture requires validation. Even if there have been great developments for microwave-sensed soil moisture with validation efforts using ground based measurements and land surface models, the validations of the remotely sensed soil moisture in Korea are very limited. This study validated Advanced Microwave Scanning Radiometer E (AMSR-E) soil moisture productions with ground based measurements at eight sites from rural development administration in Korea. The relationship between AMSR-E soil moisture and Normalized Difference Vegetation Index (NDVI) retrieved from Moderate Resolution Imaging Spectroradiometer (MODIS) for estimating soil moisture is also investigated. Overall there was a reasonable agreement between the AMSR-E and ground data, but unreliable replication was found in winter season. More intensive validation efforts should be conducted with other AMSR-E soil moisture products with vegetation information. This type of estimation provides the utility of the AMSR-E soil moisture products and MODIS NDVI as an alternative of the ground based measurements and improves soil moisture retrieval algorithms.

1. INTRODUCTION

Fresh water recognized as abundant on our planet is now drastically becoming a scarce natural resource (Falkenmark and Rockstrom, 2004). The fresh water resources stress may be more deteriorated by increasing climate change and population growth scenarios in the world including East Asia (Milly et al, 2005). To better understanding of fresh water availability linked between the land surface and the atmosphere, accurate estimation of the soil moisture is required even if its amount in water resources systems is relatively small. Soil moisture determines the partitioning of precipitation into runoff, infiltration, and surface storage, as well as the partitioning of incoming solar radiation and long wave radiation into outgoing long wave radiation, latent heat flux, ground heat flux, and sensible heat flux (Pachepsky et al., 2003).

Recently, larger spatial scaled mean surface soil moisture is available from aircraft and satellite instruments comprised of various active and passive microwave sensors (Schmugge et al., 2002). The brightness temperature (T_B) as intensity of natural thermal emission on the land surface was measured by these passive microwave sensors and surface soil moisture is successfully retrieved from the T_B observations (Jackson et al., 1995). Even if there are many advantages of monitoring soil moisture at larger scales including the ability to directly measurement soil moisture regardless of weather conditions or time of day (Jackson, 1993; Jackson and Schmugge, 1995), its inevitable limitations are existing. One of the major limitations is that it cannot describe hydrology at the watershed or field scale because its retrieved soil moisture scale is too large (Mohanty and Skaggs, 2001; Jacobs et al., 2004). Thus, retrieved soil moisture estimates require validation.

Validation studies for the AMSR-E soil moisture products have been conducted over different continents, Europe (Wagner et al., 2007), the United States (McCabe et al., 2005; Crow and Zhan, 2007; Owe et al., 2008; Choi et al., 2008), and Australia (Drape et al., 2009). Even if AMSR-E evaluation efforts in many regions around the world to estimate the potential of the AMSR-E surface soil moisture, there have not been any evaluation efforts in Korea. This study was conducted for the initial evaluation of the AMSR-E soil moisture products in Korea. We used land parameter retrieval model products by NASA and Vrije Universiteit Amsterdam (VUA), the Netherlands following Owe et al. (2001) using ground based measurements at Korean monitoring network sites.

2. MATERIALS AND METHODS

2.1 Study Region and Ground Data

In order to validate AMSR-E retrieved soil moisture, ground measured data were obtained from 60 sites with Time Domain Reflectometry (TDR) in 10 cm depth from rural development administration in Korea (http://weather.rda.go.kr). Data from eight sites among the sixty sites were selected (Figure 1).

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Figure 1. Study region

2.2 AMSR-E

The AMSR-E instrument provides global microwave measurements using different bands (56 km for the C band, 38 km for the X band, and 12 km for the Ka band) over two passes: ascending (1:30 pm) and descending (1:30 am). The Vrije Universiteit Amsterdam (VUA) AMSR-E soil moisture products are retrieved from the Land Surface Parameter Model (LPRM) (Owe et al., 2008). The model is based on a three-parameter forward retrieval procedure which uses one dual polarized channel (e.g., C or X band) to optimize soil moisture and Vegetation Water Content (VWC) (Owe et al., 2008). Land surface temperature is derived from the vertical polarized Ka band (e.g., 36.5 GHz). The LPRM parameterizes vegetation optical depth using Polarization ratios, Microwave Polarization Difference Index (MPDI) described as

$$MPDI = (T_{bV} - T_{bH})/(T_{bV} + T_{bH}) \qquad (1)$$

where T_{bV} and T_{bH} are the brightness temperature at vertical and horizontal polarizations, respectively.

2.3 MODIS-NDVI

Terrestrial vegetation greatly influences on the energy balance, hydrologic and biogeochemical cycle on earth. Vegetation can also serve as an indicator of anthropogenic influences on the environment (Huete et al., 1999). Vegetation Index (VI) was developed to understand the roles of vegetation as a contributor to maintain biophysical systems and as an indicator of global environmental change (Huete et al., 1999). Many VIs have been developed, and most of them are expressed as the relationship between light reflection in the red and near infrared (NIR) section of the spectrum to separate the landscape into water, soil, and vegetation (Glenn et al., 2008). Normalized Difference Vegetation Index (NDVI), one of the most common among those Vis, was developed by Rouse et al. (1974). There is a global record of NDVI data since 1981from Advance Very High Resolution Radiometer (AVHRR) mounted on the National Oceanic and Atmospheric Administration (NOAA) satellites. This AVHRR-NDVI is currently inter-calibrated with NDVI data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the terra and aqua satellites (Glenn et al., 2008). NDVI can be described as (Glenn et al., 2008):

$$NDVI = (\rho NIR - \rho Red) / (\rho NIR + \rho Red)$$

where ρNIR and ρRed are reflectance values of Near Infrared and Red light received at the sensors. Recently, Several researchsers investigated the potential use of MODIS-driven NDVI to estimate soil moisture with some success (i.e., Schnur et al., 2010). Based on their suggestions, we tested this possibility of MODIS-NDVI for estimating soil moisture at the eight selected sites in Korea. MYD13A2 product from Aqua satellite with 1km-16 day of spatio-temporal scale was used in this study.

3. EVALUATION

In this study, we validated the AMSR-E products from land parameter retrieval model products by National Aeronautics and Space Administration (NASA) and Vrije Universiteit Amsterdam (VUA), the Netherlands for ground measurements from selected Korean monitoring network sites during 2004 study period. The relationship between AMSR-E and MODIS NDVI was also tested.The ground based measurements were extracted at Aqua overpass time: 1:30 pm EST to match the time of the AMSR-E soil moisture products. Figure 2 shows that there were reasonable temporal patterns respond with precipitation events (not shown here).
Overall, VUA AMSR-E soil moisture and MODIS NDVI showed the reasonable agreement with ground based measurements (RMSE = 8-26% and BIAS = 0-24%) (Table 1). However, we found that AMSR-E soil moisture products showed relatively higher temporal variability. These patterns may likely due to vegetation transmissivity as a function of the vegetation optical depth. The vegetation tramsmissivity was very uncertain in densely vegetated areas because microwave polarization difference indices became very small (Owe et al., 2001).

y: AMSR-E soil moisture, x: ground based soil moisture

	Equation	R^2	BIAS	RMSE
Chuncheon	y= 1.1523x+10.092	0.2031	-22	26
Pyeongchang	y=0.4145x+37.016	0.0436	-24	26
Bonghwa	y=-0.1505x+42.148	0.0032	-16	20
Sangju	y=0.1059x+31.446	0.0215	12	17
Andong	y=0.5569x+22.383	0.0869	-8	11
Cheongsong	y=0.7131x+19.841	0.1195	-14	16
Nonsan	y=0.0473x+36.457	0.0019	0	8
Cheongju	y=0.326x+25.816	0.0996	2	10

Table 1. A comparison of the ground based soil moisture with AMSR-E soil moisture

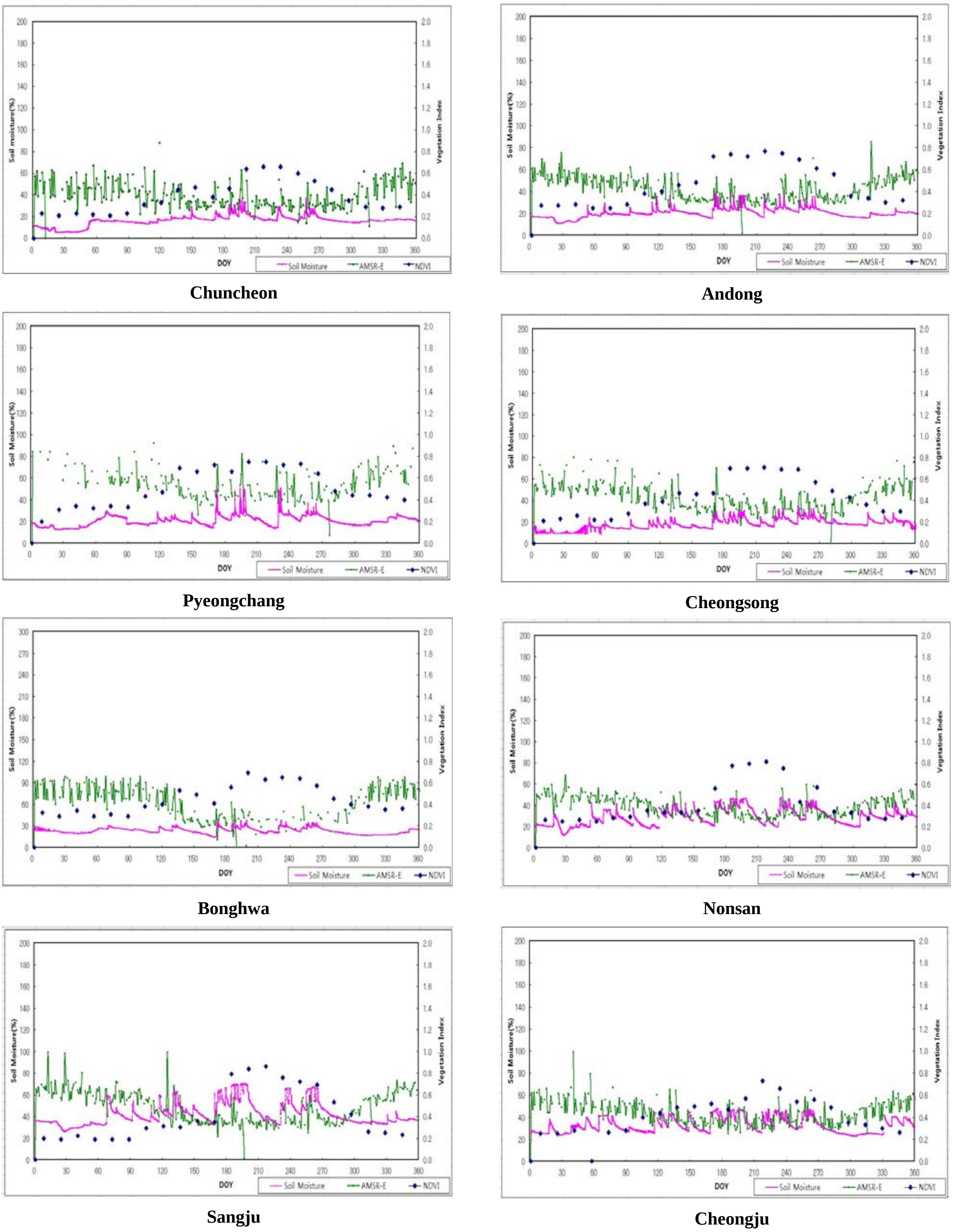


Figure 2. A comparison of the ground based and AMSR-E soil moisture with Normalized Difference Vegetation Index (NDVI)

Even if ground measuring sites are grass, highly vegetated area like forest may be included within the AMSR-E pixel (~25 km by 25 km). In addition, there were relatively larger soil moisture differences between two different systems during the winter season likely due to frozen soils.

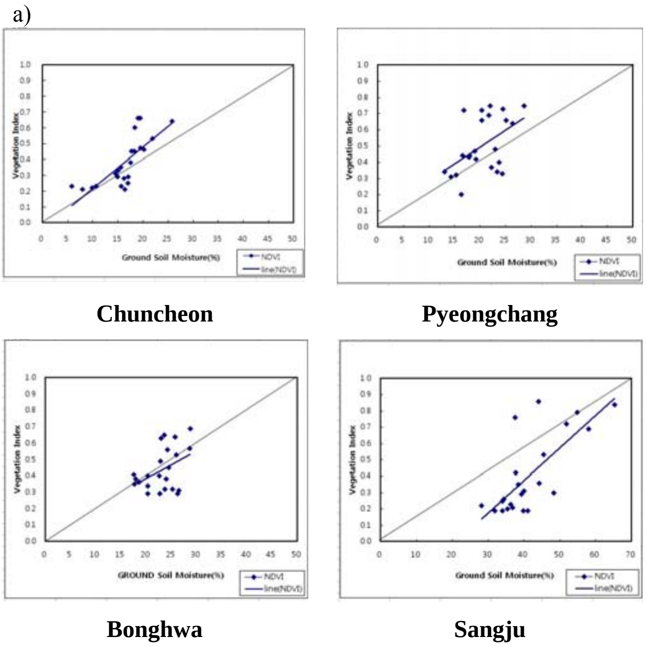
y: MODIS NDVI, x: ground based soil moisture

	Equation	R^2
Chuncheon	y=0.026x-0.0444	0.5664
Pyeongchang	y=0.0211x+0.071	0.2463
Bonghwa	y=0.0169x+0.0482	0.1825
Sangju	y=0.0199x-0.4214	0.5475
Andong	y= 0.0362x-0.2708	0.4849
Cheongsong	y=0.0281x-0.0638	0.4665
Nonsan	y= 0.0165x-0.0658	0.2858
Cheongju	y=0.0112x+0.0383	0.1467

Table 2. Relationship between meanground based soil moisture and MODIS NDVI

We investigated the temporal variation of the AMSR-E soil moisture with MODIS NDVI. Based on the Figure 2, the VUA AMSR-E soil moisture showed better correlations with the ground data when the NDVI is higher than 0.4. These patterns were contrast with the previous finding of Choi and Jacobs (2008) that National Snow and Ice Data Centre (NSIDC) AMSR-E showed very uncertain temporal variation for dense canopies due to increased attenuation with increasing vegetation.

a)



b)

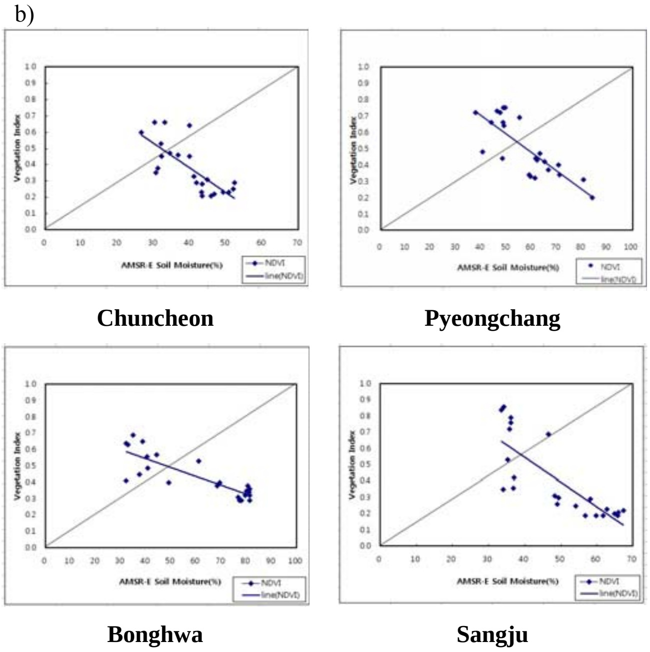


Figure 3. Relationship between mean soil moisture and NDVI a) ground based soil moisture and MODIS NDVI b) AMSR-E soil moisture and MODIS NDVI

Figure 3 showed ground soil moisture data had positive patterns with NDVI. However, there were negative relationships between the VUA AMSR-E soil moisture and MODIS NDVI. Those patterns were clear mirror even if both soil moisture data had reasonable correlations with vegetation indices (Tables 2 and 3).

y: MODIS NDVI, x: AMSR-E soil moisture

	Equation	R^2
Chuncheon	y= -0.0151x+0.9833	0.5676
Pyeongchang	y=-0.0113x+1.1554	0.6327
Bonghwa	y=-0.0054x+0.76	0.7087
Sangju	y=-0.0153.x+1.156	0.6314
Andong	y=-0.0177x+1.2146	0.6598
Cheongsong	y=-0.0145x+1.0664	0.674
Nonsan	y=-0.017x+1.0731	0.4001
Cheongju	y=-0.0166x+1.1357	0.5957

Table 3. Relationship between meanAMSR-E soil moisture and MODIS NDVI

Current results suggest that validation efforts need to be further conducted in light of various geophysical conditions such as land cover and climate types. Especially, comparison using the NSIDC AMSR-E and VUA AMSR-E soil moisture product should be conducted with vegetation indices to find reasonable validation period to replicate ground data. If we can find the appropriate relationship between MODIS NDVI and soil moisture through extensive validation efforts, NDVI can be another alternative to estimate soil moisture at various spatial scale.

4. CONCLUSION

The soil moisture products from the VUA AMSR-E were validated using ground based measurements at eight sights from rural development administration in Korea. While there were reasonable agreements between the AMSR-E and ground soil moisture, unreliable relationships were found in winter season. More intensive validation efforts should be conducted with other AMSR-E soil moisture products with vegetation information.

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