Estimation of vegetation optical depth and single scattering albedo using multi-angular microwave vegetation indices (MVIs)

Qian Cui[1,2], Jiancheng Shi[1]

[1] State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, 100101, China; Email: shijc@radi.ac.cn (J.C.Shi)

[2]University of Chinese Academy of Sciences, Beijing 100049, China; Email: cuiqian@radi.ac.cn (Q.Cui)

Abstract

This paper introduces an approach for estimating vegetation optical depth and single scattering albedo using multi-angular microwave vegetation indices (MVIs). Through analysis of Advanced Integral Equation Model (AIEM) simulation database, which includes a wide range of surface roughness and soil dielectric conditions, bare soil emissivities at different incidence angles can be characterized by a linear function with parameters only dependent on the pair of incidence angles used. Based on these relationships, soil signals can be eliminated from radiometer measurements and multi-angular MVIs which are only related to vegetation parameters are derived. Then, vegetation optical depth and single scattering albedo can be estimated using radiometer measurements with multiple pairs of incidence angles. Retrievals of vegetation optical depth from Yanco Region and Little Washita watershed are compared with MODIS NDVI products.

1. Introduction

Vegetation properties are key elements in the study of global carbon cycle and ecosystems [1]. In contrast to optical satellite sensors, microwave sensors are sensitive to vegetation properties of a thicker layer. Microwave vegetation indices (MVIs) are developed based on multi-frequency data of AMSR-E radiometer, and they are independent of soil emission signals and depend only on vegetation properties. The Soil Moisture and Ocean Salinity (SMOS) mission, which is the first operational L-band passive microwave space-borne sensor using synthetic aperture techniques, was launched in November, 2009. It provides global L-band brightness temperature for a range of incidence angles from 0o to 60o at a spatial resolution of about 43 km [2]. Due to its capability to penetrate vegetation canopy, we can expect obtaining more vegetation information from it.

Vegetation canopies have significant influence on the observed microwave emission signals, since it attenuates and scatters the radiation emitted by the soil and it also emits its own radiation. In zero-order radiative transfer model ($\tau-\omega$ model), vegetation optical depth τ and single scattering albedo ω are used to parameterize the effect of vegetation. Single scattering albedo is found to be rather low at L-band. Recent studies also found that vegetation optical depth could be linearly related to the vegetation water content (VWC) using the so-called b parameter [3].

In this paper, a new approach to estimate vegetation optical depth and single scattering albedo using multi-angular MVIs based on SMOS data is introduced. The most uniqueness of this approach is it explores the relationships of soil emissivities at different incidence angles and eliminates soil emission signals from radiometer measurements.

2. Methodology

For vegetation-covered surfaces, the observed brightness temperature at low-frequency band as L-band can be described as:

$$TB_p(\theta) = V_{ep}(\theta) + V_{attp}(\theta)\varepsilon_p^s(\theta) \tag{1}$$

$$V_{ep}(\theta) = (1-\omega_p)\cdot(1-\gamma_p(\theta))\cdot(1+\gamma_p(\theta))\cdot T_C \tag{2}$$

$$V_{attp}(\theta) = \gamma_p(\theta)\cdot T_s - (1-\omega_p)\cdot(1-\gamma_p(\theta))\cdot\gamma_p(\theta)\cdot T_C \tag{3}$$

where p represents the polarization (V or H), T_s and T_c stand for physical temperatures of the soil and the canopy respectively, ω is the vegetation single scattering albedo, $\varepsilon^s(\theta)$ is the emissivity of rough soil surface and

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

$\gamma = \exp(-\tau / \cos(\theta))$ is the vegetation transmissivity. θ and τ are incidence angle and vegetation optical depth respectively. V_e and V_{att} are vegetation emission component and vegetation transmission component [1], respectively.

2.1 Characteristics of bare soil emission signals at two incidence angles at H-polarization

In order to characterize the incidence angle dependence of soil emission signals at L-band, a simulated soil emission database was generated using Advanced Integral Equation Model (AIEM) [4]. This database covers a wide range of volumetric soil moisture and surface roughness parameters. Gaussian, 1.5-Power and Exponential correlation function were all used in the simulation. The parameters and their range included in the database are summarized in Table 1.

Table 1 Parameters and their range used in AIEM simulations

Parameter	Min	Max	Interval	Unit
Incidence angle	5	55	5	degree
Soil moisture	2	44	2	%
rms height	0.25	3.5	0.25	cm
Correlation length	2.5	35	2.5	cm
Correlation function	Gaussian ,1.5-Power and Exponential			

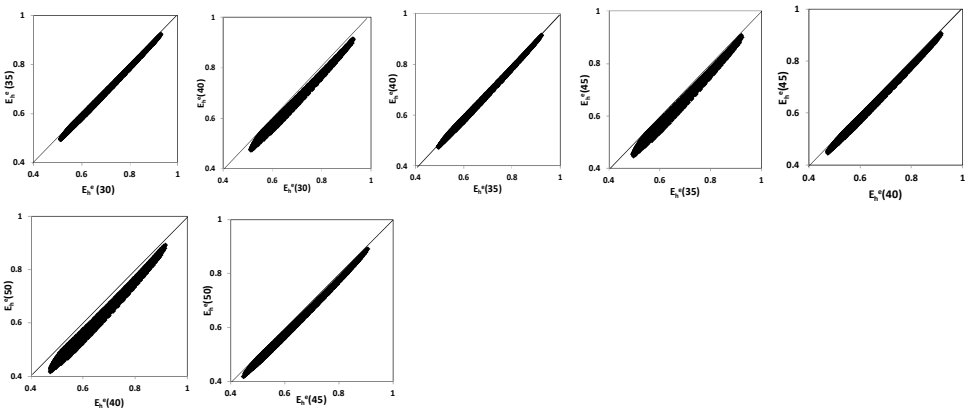

Fig. 1 Relationships of AIEM simulated soil effective emissivities at two incidence angles at H-polarization.

From Fig. 1, we note that the bare soil effective emissivities at two incidence angles at H-polarization are highly correlated and can be characterized as a linear function. These relationships are neither dependent on soil moisture nor roughness properties:

$$\varepsilon_h^s(\theta_2) = a_h(\theta_1, \theta_2) + b_h(\theta_1, \theta_2) \cdot \varepsilon_h^s(\theta_1) \tag{4}$$

where a and b are only dependent on the pair of incidence angles used. They can be easily determined by regression analysis using AIEM simulated database. Table 2 gives a and b with different pairs of incidence angles and the correlation coefficients (R^2).

Table 2 Parameters a and b for different pairs of incidence angles

(θ_1, θ_2)	a	b	R^2
(30°,35°)	-0.0242	1.0114	0.9989
(30°,40°)	-0.0514	1.0208	0.9958
(35°,40°)	-0.0276	1.0103	0.9986
(35°,45°)	-0.0576	1.0163	0.9944
(40°,45°)	-0.0307	1.0073	0.9982
(40°,50°)	-0.0632	1.0069	0.9925
(45°,50°)	-0.0337	1.0015	0.9978

2.2 Estimation of vegetation optical depth and single scattering albedo

Eq. (1) at a given incidence angle at H-polarization can be rearranged as:

$$\varepsilon_h^s = \frac{TB_h(\theta) - V_{eh}(\theta)}{V_{atth}(\theta)} \tag{5}$$

By inserting Eq. (5) into Eq. (4) with two incidence observations at H-polarization, the surface emissivity can be canceled out and it is derived:

$$TB_h(\theta_2) = A_h(\theta_1, \theta_2) + B_h(\theta_1, \theta_2) \cdot TB_h(\theta_1) \tag{6}$$

where

$$A_h(\theta_1, \theta_2) = a(\theta_1, \theta_2) \cdot V_{atth}(\theta_2) + V_{eh}(\theta_2) - B_h(\theta_1, \theta_2) \cdot V_{eh}(\theta_1) \tag{7}$$

and

$$B_h(\theta_1, \theta_2) = b(\theta_1, \theta_2) \cdot \frac{V_{atth}(\theta_2)}{V_{atth}(\theta_1)} \tag{8}$$

Eq. (6) indicates that brightness temperature with two incidence angles at H-polarization can be approximated by a linear function. The intercept A and slope B are called Microwave Vegetation Indice (MVIs) which was first developed based on AMSR-E multi-frequencies configuration. The derivation of the MVIs described in this paper is similar to that in Ref. [1]. Both of them have the same theoretical basis and similar derivation procedure. However, the MVIs here are derived from multi-angular channels all at L-band. MVIs are not affected by surface signals and only depend on vegetation properties and temperature. Thus, given soil temperature and vegetation temperature, seven equations like Eq. (6) can be obtained using seven pairs of incidence angles (showed in Table 2). The vegetation optical depth τ_{NAD} and single scattering albedo ω can be optimized using a least squares iterative algorithm where the initial guess p_{ini} of each vegetation parameters at the date of t is set to be the retrieved value at the date of t-1, and p_{ini} is set to be 0.0 at the first day of radiometer observations (t=0).

3. Result

The SMOS Level 1c (L1c) brightness temperature product of 2010 are used in this study. The multi-angular observations are not obtained at fixed incidence angles, and it does not meet our requirements. To conquer this problem, a mixed objective function [5] is used to fit SMOS L1c brightness temperatures to expected incidence angles. Yanco Region (Australia) and Little Washita watershed (USA) are chosen as the study areas. In Yanco Region, the land use is irrigation area with rice and crops in the west, dry land cropping in the north and native pasture in the south. For Little Washita watershed, the land cover is dominated by rangeland and pasture, but including winter wheat and cropland. The details of these two study areas can be found in Ref. [6] and [7]. All of the SMOS footprints within study area were processed using the approach.

The time series of vegetation optical depth retrievals for both study sites are illustrated in Fig.2 and SMOS L2 optical depth products are also demonstrated. In addition, MODIS 0.05 Deg 16-day composite NDVI product (MOD13C1) are added for comparison. As we can see from Fig.2, the three parameters show similar seasonal variations trend. However, both optical depth obtained from our new algorithm and that from SMOS algorithm have a certain time lag (about 16 days) compared with NDVI. The possible explanation is that NDVI and microwave optical depth respond to different vegetation properties. The optically-based vegetation index NDVI is related to a thin layer of leaves and is influenced by the chlorophyll. However, microwave measurements especially at low frequency are more sensitive to the stems and woody parts of vegetation properties. The microwave optical depth is a function of vegetation dielectric properties, which is determined by the vegetation water content and may show different pattern from chlorophyll. In addition, the NDVI data used for comparison here are 16-day composite data, which means only one value within 16 days is selected to represent the first day of the 16-day period.

Retrieved vegetation single scattering albedo shows relatively stable pattern with a minimal value of 0.03 and 0.0322, maximal value of 0.0567 and 0.0543 and averaged value of 0.042 and 0.043 for Yanco Region and Little Washita, respectively.

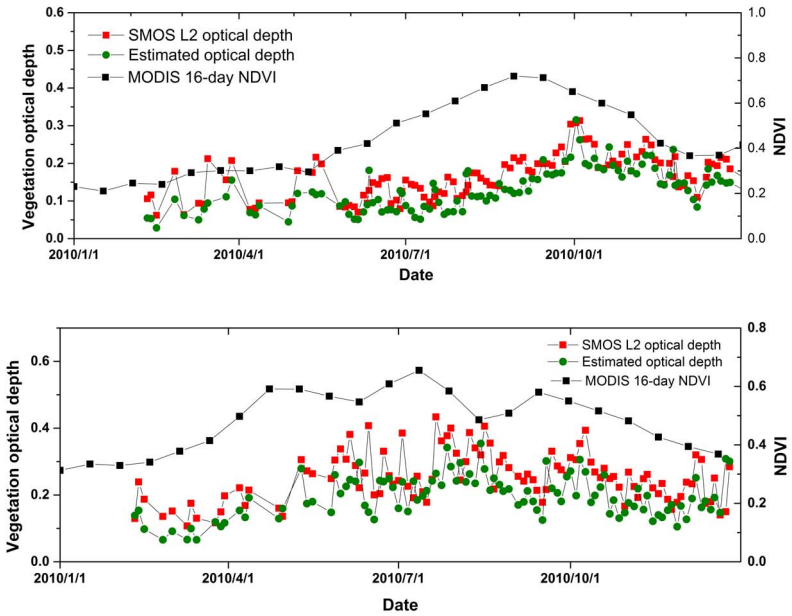

Fig.2 Temporal plots of retrieved averaged optical depth and SMOS L2 averaged optical depth product over Yanco Region (top) and Little Washita watershed (bottom). MODIS 16-day composite NDVI data are added to compare.

4. Conclusion

An approach for estimating vegetation optical depth and single scattering albedo using multi-angular microwave vegetation indices (MVIs) is presented in this paper. The basis of this approach is that the soil emissivities at two adjacent incidence angles are highly correlated and can be described as linear functions with parameters independent on soil dielectric and surface roughness and only dependent on the pair of incidence angles. Multi-angular microwave vegetation indices (MVIs) can be derived and they depend only on vegetation properties. Vegetation optical depth and single scattering albedo can be estimated using multi-pair of radiometer measurements. This approach is applied on SMOS L1c brightness temperature data. Using Yanco Region and Little Washita watershed as study areas, retrievals of vegetation optical depth are compared to SMOS L2 optical depth product and MODIS 16-day composites NDVI product. In this paper, we only discuss the short vegetation. More researches about dense vegetation such as forest will be done in future.

5. References

1. J. Shi, T. Jackson, J. Tao, J. Du, R. Bindlish, L. Lu and K. S. Chen, “Microwave vegetation indices for short vegetation covers from satellite passive microwave sensor AMSR-E,” Remote Sens. Environ. 2008, pp. 4285-4300.
2. Y. H. Kerr, P. Waldteufel, J. P. Wigneron, J. M. Martinuzzi, J. Font and M. Berger, “Soil moisture retrieval from space: The Soil Moisture and Ocean Salinity (SMOS) mission,” IEEE Trans. Geosci. Remote Sens. 2001, pp. 1729-1735
3. T. J. Jackson and T. J. Schmugge, “Vegetation effects on the microwave emission of soils,” Remote Sens. Environ. 1991, pp. 203-212.
4. K. S. Chen, T. D. Wu, L. Tsang, J. Shi and A. K. Fung, “The emission of rough surface calculated by the integral equation method with a comparison to a three-dimensional moment method simulations,” IEEE Trans. Geosci. Remote Sens. 2003, pp. 90-101.
5. T. J. Zhao, J. Shi, R. Bindlish, T. J. Jackson, Y. H. Kerr, Q. Cui, Y. Q. Li, T. Che and X. Li, “Refinement of SMOS Multi-angular brightness temperature and its analysis over reference calibration targets,” In Proceedings of International Geoscience and Remote Sensing Symposium , IGARSS2013, 49-52,Melbourne, Australia.
6. A. B. Smith, J. P. Walker, A. W. Western, R. I. Young, K. M. Ellett, R. C. Pipunic, R. B. Grayson, L. Siriwardena, F. H. S. Chiew and H. Richter, “The Murrumbidgee soil moisture monitoring network data set,” Water Resources Research. 2012, W07701.
7. T. J. Jackson, M. H. Cosh, R. Bindlish, P. J. Starks, D. D. Bosch, M. Seyfried, D. C. Goodrich, M. S. Moran and J. Du, “Validation of Advanced Microwave Scanning Radiometer soil moisture products,” IEEE Trans. Geosci. Remote Sens. 2010, pp. 4256-4272.