ANAYLYSIS ON TEMPORAL CHANGE OF SOIL MOISTURE WITH SAT IMAGES FOR AGRICULTURAL DROUGHT MONITORING IN NORTHEASTERN PART OF THAILAND

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KEYWORDS: Soil moisture, IEM model, Drought monitoring

ABSTRACT: Soil moisture is one of the most effective indicators of drought. Active microwave remote sensing can detect backscatter from surface at any weather condition. Based on the backscatter coefficient and other parameters such as surface roughness, soil moisture can be estimated. The current research examined fundamental techniques required to estimate soil moisture from synthetic aperture radar (SAR) data, which is one of active microwave remote sensing data. Authors have measured volumetric soil moisture at 5-cm depth at several points of paddy fields, Burirum Province, northeastern part of Thailand from November, 2005. JERS1/SAR images observed from 1992 to 1998 were available around field measurement sites. Firstly, Integral Equation Method (IEM) model is focused on, which models scattering of microwave between different matters. Several parameters of IEM model were calibrated with the ground measured data and backscatter coefficients obtained from JERS1/SAR images. In fact, dates of available JERS-1 SAR images are different from dates of field measurements. However, because of the limitation of available JERS1/SAR data, it was assumed that ground measured data can be applied for the calibration. Then, volumetric soil moisture distribution was mapped from 1992 to 1998. The map was examined from a viewpoint of precipitation around the area of SAR images. It was found that IEM model is useful to estimate volumetric soil moisture as long as it is well calibrated.

1. INTRODUCTION

North and northeastern parts of Thailand faced severe drought in 2005, and have suffered from drought periodically. Drought can be defined according to meteorological, hydrological, or agricultural criteria. Meteorological drought is usually based on long-term precipitation departures from normal. Hydrological drought refers to deficiencies in surface and subsurface water supplies. Agricultural drought occurs when there is insufficient soil moisture to meet the needs of a particular crop at a particular time. Agricultural drought is typically evident after meteorological drought but before a hydrological drought. While drought monitoring, especially agricultural drought monitoring, around Thailand, Laos and Cambodia is getting more and more important, it has not been achieved. In order to mitigate the impact of drought, an early warning system for drought should be developed. Remote sensing is capable of monitoring drought because it enables to simultaneously detect spectral data from the surface of wide area. Microwave sensor is better to detect volumetric soil moisture and water body rather than optical sensor because dielectric constant of water in microwave region can be easily discriminated from dielectric constants of other matter. In the present research, methodology to detect volumetric soil moisture using active remote sensing data for drought monitoring is examined.

2. ESTIMATION OF SOIL MOISTURE FROM SAR DATA

2.1 Study area

Burirum province, located in northeastern part of Thailand and affected by drought recently, is selected as study area, shown in Figure 1.The paddy fields area is 6,765 km^2, which cover about 66.8% of total land area 10,128 km^2. Its position is between latitude 14.13-15.79^{o}N, longitude 102.36 - 103.50^{o}E. The average temperature ranges from 22.7^{o}C in winter to 33.3^{o}C in summer. Average annual precipitation is 1394.8 mm from 2001-2004 and average annual precipitation days is 100 days. Authors have installed probes of volumetric soil moisture and soil temperature at 5-10 cm depth in several rain-fed and irrigated paddy fields in Burirum Province since November, 2005. One of the sites, named as site 1 (15.636^{o}N, 102.899^{o}E), was focused on in the present research.

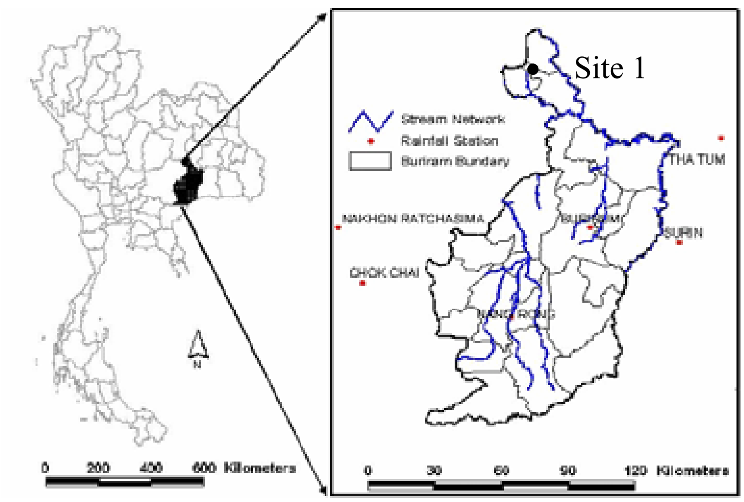

Figure 1: Location of the study area

2.2 JERS1/SAR data

JERS1/SAR images, product level 2.1 around site 1 (path 123, row 174) from 1992 to 1998 were obtained for the analysis. The list is shown in Table 1. Firstly, these images were geometrically corrected with topographic map of Thailand. And then, normalized radar cross section (NRCS) was calculated from digital number (DN) value of JERS1/SAR product level 2.1 data by applying equation (1) (User's Guide, 2001).

$$NRCS = 20 \log_{10}(I) + CF \text{ [dB]} \qquad (1)$$

where I denotes DN, and CF denotes conversion factor. As a result of validation, CF to be used depends on processing date of data. As the available data were processed in 2006, "-85.34" was used as CF. Calculated $NRCS$ was used as backscattering coefficient for the analysis using the IEM model. In order to remove speckle noise, which is one of features of SAR image, median filter was applied. The size of filter window was examined, and empirically determined as 13x13.

Table 1: Available JERS-1 SAR images around Site 1

No.	Observation date (yyyy/mm/dd)
1	1992/10/31
2	1993/03/12
3	1994/01/14
4	1994/04/12
5	1994/08/22
6	1994/11/18
7	1995/03/30
8	1995/08/09
9	1996/07/26
10	1996/12/05
11	1997/01/18
12	1997/04/16
13	1997/05/30
14	1997/11/22
15	1998/01/05
16	1998/04/03
17	1998/05/17

2.3 IEM model

Radar backscattering response from soil surfaces is widely used to retrieve surface properties as surface roughness or volumetric soil moisture (Loew, *et al.*, 2006). The sensitivity of the active microwave backscatter response to surface parameters has been extensively studies so far. The small perturbation model (SPM) and Kirchhoff approximation (KA) (Ulaby, *et al.*, 1982) are traditional theories of wave scattering from rough surfaces. The SPM is valid for slightly rough surfaces while the KA is applicable for a rough surface with a large surface curvature. They are restricted to a very limited range of surface roughness conditions. Integral equation method (IEM) surface scattering model (Fung, *et al.*, 1994) is valid for a broader range of surface roughness conditions. While several improvements of IEM model have been made, one of which is proposed as advanced IEM (Chen, *et al.*, 2003), IEM model is focused on in the present research because its results are reported to be stable and many knowledge and results to apply the IEM model are available. Hereafter, the brief explanation of the IEM model is described.

Fung, *et al.* proposed the final integrated scattering results for two cases, that is, $k\sigma < 3$ or not where $k = \omega\sqrt{\varepsilon_1\mu_1}$, ω is the radian frequency, ε_1 is the permittivity of medium 1, μ_1 is the permeability of medium 1 and σ^2 is the variance of the surface. In the present research, it was found that $k\sigma < 3$. As HH backscattering coefficients are available, previously mentioned in subsection 2.2, following IEM model was used the present research.

$$\sigma_{hh}^0 = \sigma_{hh}^1 + \sigma_{hh}^M , \quad \sigma_{hh}^1 = 8k^4\sigma^4 \left| R_\perp \cos^2\theta \right| W(-2k_x, 0)$$

$$\sigma_{hh}^M = \frac{8k^4\sigma^4\cos^2\theta}{\pi}\exp(-2k_z\sigma^2)\int \frac{u^2v^2}{q^2} W(u-k_x, v)W(u+k_x, v)dudv$$

where σ_{hh}^0 is the total HH-backscattering coefficient, σ_{hh}^1 is the single-scattering HH-backscattering coefficient, σ_{hh}^M is the multi-scattering HH-backscattering coefficient, θ is the incident angle of radar, $k_x = k\sin\theta$, $k_z = k\cos\theta$, W^n is the Fourier transform of the nth power of the surface correlation function, and $q = (k^2-u^2-v^2)^{1/2}$.

2.4 Measurement of surface roughness


Figure 2: Measurement of surface roughness (No. 4 in Table 2)

Surface roughness strongly affects surface scattering, and is a sensitive parameter for the IEM model as well as soil moisture. Surface roughness of rain-fed paddy field was measured, which is located in 15.366°N, 103.012°E. The paddy field is different from site 1 (15.636°N, 102.899°E) because accessibility to site 1 was limited.

Geolocational data of points along a profile on surface of paddy field were measured using total station GPT-7005 produced by TOPCON, Japan (TOPCON Pulse Total Station GPT-7000 series, 2006). Authors measured data in prism mode, i.e. with prism perpendicular to the target point. The GPT-7005 can measure up to 3,000-m distance in prism mode. The distance accuracy is 3 mm + 2 ppm x (distance). Surface roughness was estimated as root mean square of height difference. On two dates (May 30, 2006 and July 25, 2006), the measurements were conducted. Regarding measurements No. 1 and No. 4, measurements were conducted on the same paddy field before and after planting, respectively. The details on measurements are shown in Table 2.

Table 2: Measured surface roughness of paddy fields in Burirum Province
(σ denotes root mean square of height difference)

No.	Date (yyyy/mm/dd)	Condition	Interval (Profile)	Samples	σ (cm)
1	2006/05/30	Before planted	50 cm (20 m)	41	5.07
2					5.53
3		After planted			3.17
4	2006/07/25	After planted	5 cm (10 m)	201	3.65

2.5 Estimation of soil moisture & mapping of soil moisture

First, temporal change of backscatter coefficients in paddy field of Site 1 from 1992 to 1998 was obtained from JERS1/SAR. Before estimating volumetric soil moisture from backscatter coefficient by the IEM model, calibration of parameters used in the IEM model were conducted. As a result to examine sensitivities of parameters, autocorrelation length of surface roughness was calibrated as 0.5 m with reference to volumetric soil moisture in dry season measured in Site 1. Even though this autocorrelation length of surface roughness might not be optimized because of lack of actual volumetric soil moisture during 1992 to 1998, this tentatively optimized parameter was used in the current research. Then, a semiempirical dielectric constant model (Peplinski *et al.*, 1995) was used, which can be applied for simulation in 0.3 – 1.3 GHz range of wavelength. Finally, volumetric soil moisture was estimated from backscatter coefficient by the IEM model. Urban areas show higher backscatter coefficients, the urban areas should be separated from other areas. As it was found that the urban areas can be classified using the image observed on Jan 14, 1994, the mask image for urban areas were produced from the image on Jan 14, 1994 and applied for all SAR images. Figure 3 shows temporal change (from 1993 to 1998) of volumetric soil moisture of Burirum Province, Thailand in 1994 estimated from JERS1/SAR with IEM model.

3. DISCUSSIONS AND CONCLUSIONS

As a result to apply the IEM model for temporal JERS1/SAR images, temporal change of volumetric soil moisture were estimated. It was found to be easy to calibrate parameters of the IEM model estimating as long as there are not so many sensitive parameters. In the present research, surface roughness was obtained from surveying results. Therefore, autocorrelation length of surface roughness, which is quite difficult to actually measure, was stably calibrated. However, this calibration technique should be improved even though actual volumetric soil moisture data at the same date are not available. The lack of actual volumetric soil moisture affects not only calibration but also validation of estimated results. However, precipitation data can be applied for the validation. Least annual precipitation data can be obtained from the Web page of The Meteorological Department of Thailand (TMD Web page, 2006). During 1992 to 1998, Northeastern part of Thailand had 10% less precipitation in 1992 than normal year's precipitation, 17% less precipitation in 1993 and 16% less precipitation in 1998. Authors will collect daily precipitation data in province from TMD. A methodology to validate soil moisture with such existing statistics or other meteorological parameters should be examined in near future.

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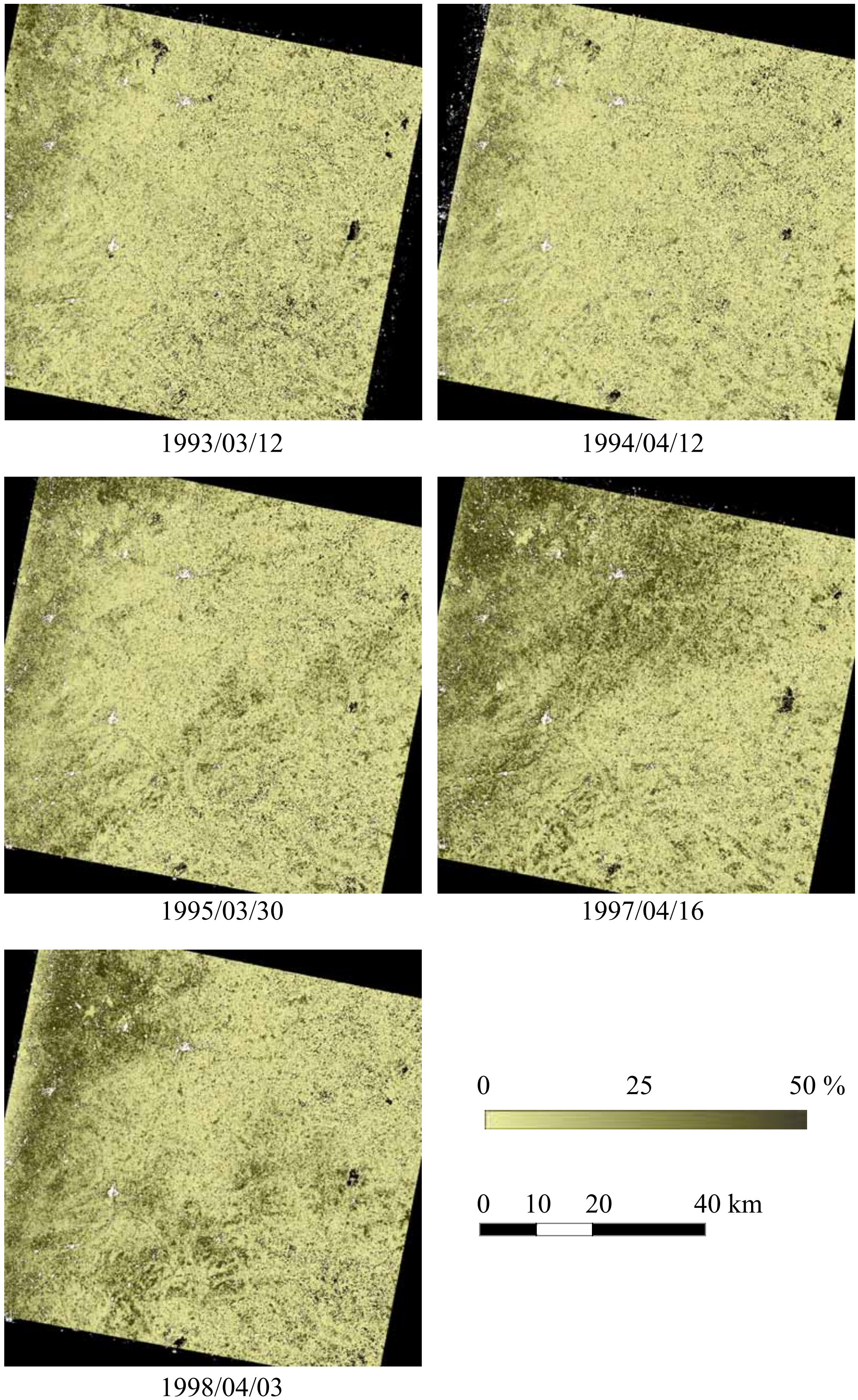

Figure 3: Temporal change of volumetric soil moisture of Burirum Province, Thailand from 1994 to 1998 estimated from JERS1/SAR with IEM model