Land Surface Soil Moisture Effect on DInSAR

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Abstract: Differential interferometric phases from JERS-1 L-band data sets show spatial variation of path-length ranging from a few mm to several cm. The variation may be caused by changes in soil moisture contents, i.e. variation of penetration depth and the swelling of soils. Although the amount of total effect caused by soil moisture is not measurable, it is clear that the soil moisture according to precipitation is another factor to be considered in DInSAR analysis. We also discuss DInSAR characteristics in a rice paddy according to irrigation conditions, and discrimination of hydrological features such as stream channels and watershed boundaries by applying DInSAR technique.

Keywords: DInSAR, JERS-1 SAR, soil moisture, penetration depth, rice paddy, hydrological features.

1. Introduction

Synthetic Aperture Radar (SAR) interferometry has become a powerful method for topographic mapping and monitoring surface changes caused by earthquakes, subsidence, volcanic activities, mining, ground water pumping, etc. Differential SAR interferometry (DInSAR) has been applied successfully to estimate subtle crustal deformation of natural and artificial causes. DInSAR results are recently considered to be sensitive to changes in soil moisture due to the large difference in dielectric properties between water and soil [1]. Soil moisture is closely related to the success or failure of agricultural crops, forest fires, global climate dynamics and hazards such as flooding [2]. Soil moisture affects penetration depth and clay swelling in soil that occurs to changing path length of returned radar signal [3]. A change in penetration depth occurs regardless of soil composition and clay content [4]. In this paper, we discuss the effect of soil moisture in the study are to the interferometric phase.

2. Data processing and Analysis

1) Data

To examine the relationship between SAR interferometeric phase and soil moisture, we obtained twenty-nine JERS-1 SAR data sets from 1992 to 1998 and processed a time-series of seventy-five differential interferograms. We adopted 2-pass DInSAR methods using digital elevation model (DEM) from 1:25,000 digital map by National Geographic Information Institute

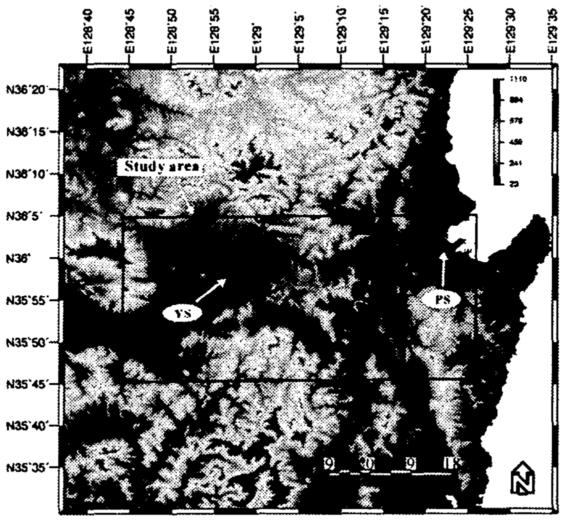

Fig. 1. Color slice of DEM with the location of Young-chon (YS) and Po-hang (PS) meteorological stations. Black line is the study area.

(NGII). We acquired precipitation data from two meteorological stations at Young-chon and Po-hang area (Fig. 1) operated by Korea Meteorological Administration (KMA).

2) Effects of Precipitation

Penetration depth and the swelling of soils affect DInSAR phase in the land surface without surface deformation. These two factors are due to change in soil moisture [2]. Soil moisture is dependent on precipitation, snow melt and ground thawing. If the soil moisture of surface layer is drier than the average, penetration depth will increase, and if wetter it will decrease [4]. Soil moisture also increases clay swelling. Both of penetration depth and clay swelling affect phase with the same sign. Wetting the soil both increases surface elevation and decreases penetration, both of which decrease path length [2]. Fig. 2 summarizes the precipitation and data acquisition dates. A change in penetration depth to soil would be a smoothly varying function of soil moisture. However, this relationship (penetration depth and soil moisture) is considered as nonlinear. Fig. 3 shows nonlinear statue of penetration depth as each wavelength (X, C and L-band) [3]. Fig. 4 shows phase variation in differential interferograms

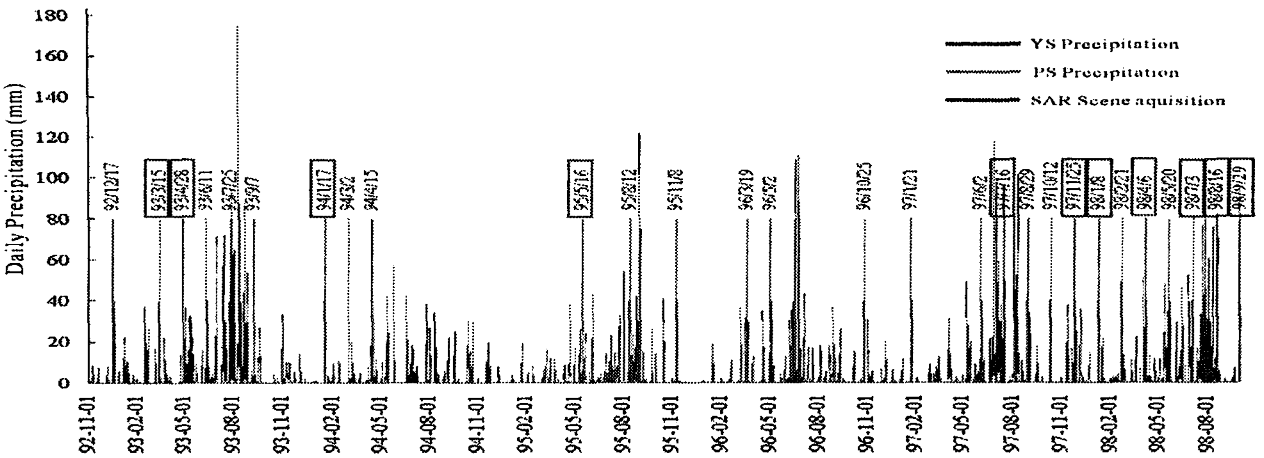

Fig. 2. Daily precipitation data for SAR image acquisition period. Blue bars are precipitations at Young-chon, green bars are those at Pohang station. Pink bars correspond to SAR image acquisition dates, and pink rectangles are rainy days on SAR data acquisition.

according to precipitation (or presumably volumetric water content) in the land surface. Fig. 4(A) shows phase variation under different soil moisture conditions. This differential interferogram must be affected by precipitation. Master image (Mar. 15, 1993) was obtained only 1 hour after raining, while slave image (Jun. 11, 1993) under clear sky condition (Fig. 4). The rainfall decreases penetration depth to zero for all wavelengths on the day of the rain event [4]. The residual interferometric phase in Fig. 4(A) would be caused by different penetration depths between master and slave images. Note that non-zero phases distribute along a main drainage system. If the abnormal phases were caused by atmospheric effects, their pattern should be random rather than being correlated with drainage pattern. Therefore, it can be explained by saturated conditions near main channel areas while relatively

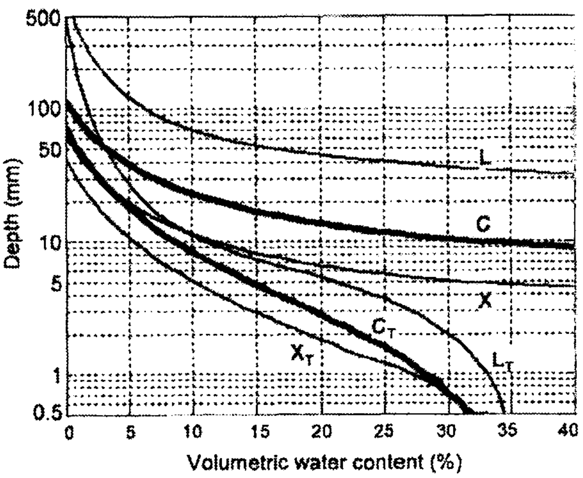

Fig. 3. Penetration depth of SAR microwaves as a function of soil moisture for each band. The subscript T indicates penetration depths when transmission losses at 0.1 mm increments [3].

lower soil moisture in hills and mountains. In Fig. 4 (B), differential interferomeric phase is rarely seen. There

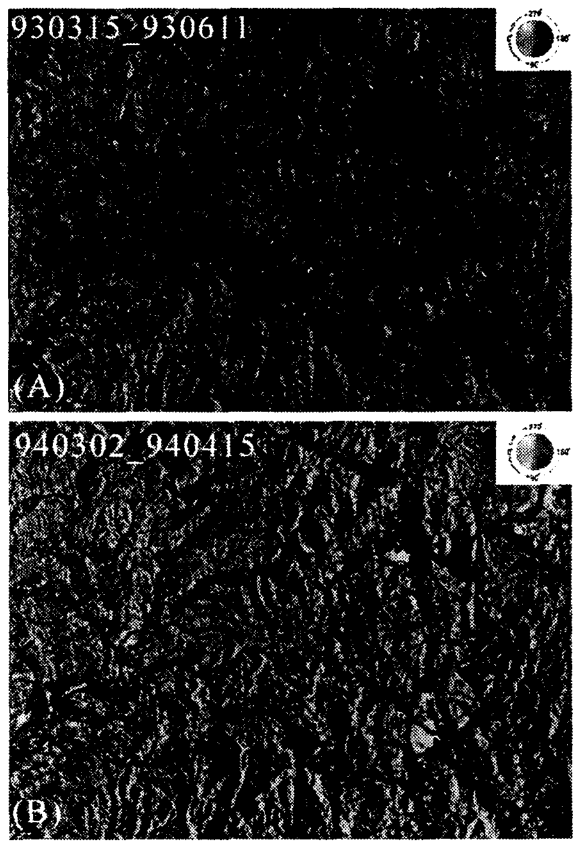

Fig. 4. (A) Differential interferogram of Mar. 15, 1993 (precipitation: 12.5 mm by 10 a.m. and stopped, temperature: 6.3 °C, scene center time: 11:03 a.m.) and June 11, 1993 (precipitation: none, temperature: 22.4 °C, scene center time: 11:03 a.m.). (B) Differential interferogram of Mar. 2, 1994 (precipitation: none, temperature: 1.7 °C , scene center time: 11 a.m.) and Apr. 15, 1994 (precipitation: none, temperature: 13.4 °C , scene center time: 10:59 a.m.)

were no raining events for both images (Mar. 2, 1994 and Apr. 15, 1994) (Fig. 2), and the interferogram implies there had been no significant surface deformation in the period.

3) Characteristics of DInSAR in a Rice Paddy

In a rice paddy field, differential interferometric phase varies with seasons. Fig. 5 shows typical differential interferometric phases in spring (Fig. 5 (A), (C), and (E)) and late summer (Fig. 4 (B), (D), and (F)). In Figs. 5 (A), (C) and (E), decorrelation is severe as denoted by yellow elliptic lines. In the early spring, the rice paddy field is nothing but a flat bare soil or filled with water. The rice paddy in spring (Fig. 4 (A), (C) and (E)) cannot occur strong backscattering. On the contrary, the rice paddy in summer season (Fig. 4 (B), (D) and (F)) between July to August is filled with grown rice and water. Single-bounced backscattering from rice plant is not significant by L-band. However, double-bounced signals on water surface produce coherent interferomeric phase. More interesting feature is that the interferometric phases are different at different rice paddy. It implies that the interferometric phase in a rice paddy in summer contains information on the height of irrigated water in a rice paddy. Unfortunately, we do not have ground-truth data of water level in the studied rice paddy field during the data acquisition period. However, it will be a good application topic of DInSAR to observe a rice paddy field.

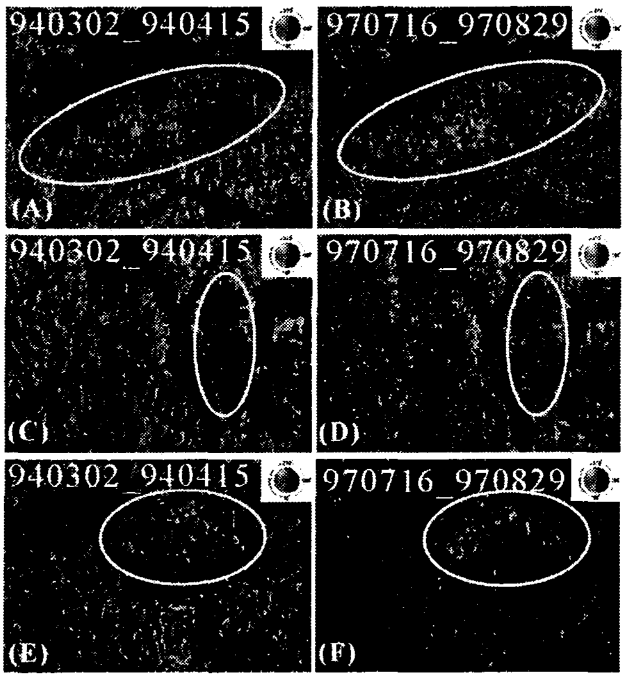

Fig. 5. Differential interferograms of (A), (C) and (E) obtained in early spring do not show coherent fringe patterns in yellow elliptic lines. Interferometric pairs of (B), (D) and (F) in summer are coherent due to double-bounced scattering from water and rice plant.

4) Hydrgeologic Features in DInSAR Interferomgrams

Since the penetration depth of microwave depends on the soil moisture, some hydrological features can be detected in DInSAR interferograms. As in Fig. 6, Differential interferograms correlate hydrological features such as drainage, stream channels and watershed White circles and ellipses (Fig. 6) highlight locations where fine scale changes in phase difference corresponding to stream channels, watershed and ridge. These phase variations on differential interferograms caused by changes in penetration depth of the SAR microwaves according to volumetric water content. Atmospheric phase delays alone are not sufficient to explain the entire variations in the interferograms.

To delineate hydrogeologic features from DInSAR interferograms, precipitation with respect to data acquisition date is critical. In Fig. 6(A), the raining with a mount of 12.5 mm was stopped just one-hour before the data acquisition of the master scene. Fully saturated soil near to the stream channels and surface flow of the water produced shorter path lengths. Interferogram in Fig. 6(B) is more useful to delineate hydrogeologic features than Fig. 6(A). Both master and slave images were obtained one day after raining of 1.5 and 0.5 mm,

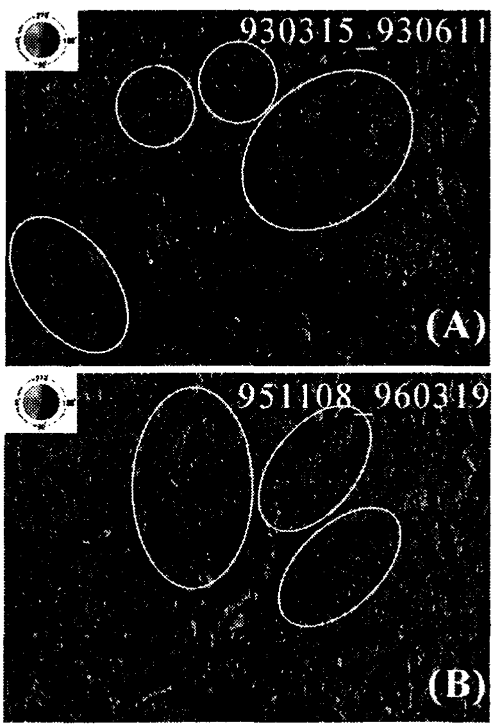

Fig. 6. Differential interferograms (A) and (B) render drainage, stream channels, ridge and watershed. (A) Differential interferogram of Mar. 15, 1993 (precipitation: 12.5 mm by 10 a.m. and stopped, temperature: 6.3 °C, scene center time: 11:03 a.m.) and June 11, 1993 (precipitation: none, temperature: 22.4 °C, scene center time: 11:03 a.m.). (B) Differential interferogram of Aug. 8, 1995 and Mar. 19, 1996 images has rain event the day before each 1.5 and 0.5 mm.

respectively. Because the amount of raining was relatively small and one day had passed since the rain events, no surface water is expected and soil not so wet. However, the resulting interferogram in Fig. 6(B) still shows drainage pattern well. We can delineate drainage and stream pattern between including rain event interferogram and no-rain event interferogram.

3. Conclusions

Soil moisture governs the penetration depth of radar signal, and affects clay swelling of the soil. Two factors (penetration depth and clay swelling of the soil) result in variation in differential interferometric phase even without surface deformation. Although the total effects of the two factors are not as significant as those of crustal deformation or atmosphere, they must be considered in the interpretation of differential interferometric phase over land mass.

It is also found that water level specifically in summer is an important parameter for differential interferomeric phase in a rice paddy field. It would be a good topic of future application of DInSAR to measure water level variation in a rice paddy. Some hydrogeologic features such as drainage pattern, watershed and ridge can also be detected in DInSAR interferogram. Data acquisition dates in terms of precipitation are critical for the application.

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