Measurement of Land Subsidence and Microwave Penetration of Drying Mudflat by using Radarsat-1 DInSAR and PolScat Laboratory Experiment

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Abstract— **Lee and Chi (2004) have reported maximum 30mm subsidence that have occurred on Hwaong reclaimed mudflat, west coast of Korea, during September to October 2003 by Radarsat-1 DInSAR analysis. DInSAR observation of land subsidence, however, should consider the effect of microwave penetration into soil which occurs in the same direction with subsidence. To discriminate the subsidence and microwave penetration into a drying mudflat, we performed a laboratory experiment with a polarimetric scatterometer (PolScat). The PolScat is composed of 5.0-5.6GHz dual-polarization square horn antenna and Agilent 8753ES vector network analyzer. Fully polarimetric data were acquired from the saturated mud state (gravimetric soil water content of 60%) to dry mud state (5%) on a sample (2m×2m×0.2m) for six weeks. Among the total phase change of -155° (17mm vertical shift), the initial -105° was due to 11mm subsidence and the later -50° was due to 6mm microwave penetration into dry mud. It was shown that the microwave penetration is not a negligible parameter in conjunction with soil moisture and subsidence, and can be compensated for using a PolScat observation.**

Keywords; DInSAR, polarimetric scatterometer, subsidence, penetration

I. INTRODUCTION

DInSAR technique has been widely used to monitor the natural or artificial coherent surface movements with homogeneous accuracy of up to cm or even mm over a large area. However, the applicability of this technique is seriously limited by other factors such as sensor geometry, incoherent scatterers, atmospheric effect and volume scattering.

Lee and Chi [1] have shown that there was maximum 30mm subsidence on Hwaong tidal mudflat, west coast of Korea, which was reclaimed recently. They used DInSAR technique on two Radarsat-1 SAR images acquired on September and October 2003, respectively over the reclaimed mudflat blocked by a 10km-long embankment in March 2002 (Fig. 1). Atmospheric effect was precluded because the area is virtually flat and the DInSAR phase anomaly correlates strongly with surface water feature: strong anomaly in the area far from the lake and remnant water channels inside the reclaimed mudflat. Soil moisture is a crucial factor for microwave backscattering coefficient and phase signal in this barren land. It was suggested that contraction of a drying mudflat was a prime cause of the subsidence and thus the phase anomaly observed in DInSAR signal, but they also argued that microwave penetration into soil might have caused the phase anomaly in the same direction as that of land subsidence. A laboratory experiment was therefore suggested to see how deep microwave can penetrate into a dry mudflat if any.

In this paper, we report our laboratory experiment on a drying mud sample with a polarimetric scatterometer. A complicated M-shaped change of radar backscattering coefficient with drainage, evaporation, mud crack, and continued evaporation sequence of a drying mud has been reported separately by [2]. We report the phase change of the drying mudflat caused by subsidence and microwave penetration.

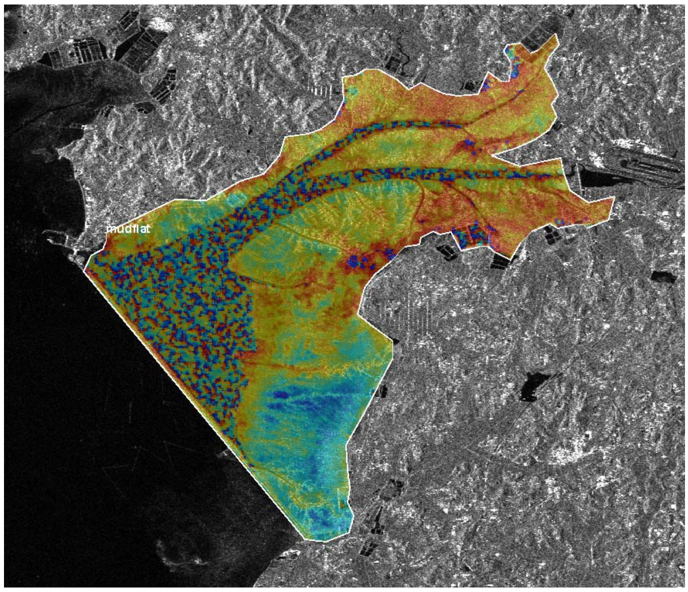

Figure 1. DInSAR measurement of subsidence rate from zero (red) to 3cm per month (blue) obtained from Radarsat-1 InSAR pair acquired at September 27 and October 21, 2003, overlying time-averaged SAR amplitude image (16km × 15km). Maximum subsidence rate occurs at lower part of mudflat possibly due to lower supply of surface or ground water, finer mud composition, or thicker mud volume (equivalently, deeper subsurface bedrock). Note the lower subsidence rate along the river or drainage system due to constant surface water supply preventing volume contraction of mud [1].

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II. LABORATORY EXPERIMENT

A. Polarimetric Scatterometer

We constructed a polarimetric scatterometer (PolScat) system mainly composed of a C-band antenna and a vector network analyzer (VNA) [3]. The antenna is a dual-polarimetric square horn antenna with dual-mode transducer. It has frequency range of 5.0-5.6GH, 13° E-plane and 17° H-plane beam width, 20.5dB gain, 1.4 VSWR, 50dB port isolation, 50Ω impedance, and 3.1kg in weight. Agilent 8753ES VNA was used for RF control together with Agilent 85032B Type N Calibration Kit. A notebook computer was connected to the VNA via a GPIB-USB connector and to a digital camera system, both for fully automatic control.

The VNA-based polarimetric scatterometer operates in a stepped-frequency sweep mode. Using an inverse chirp-Z FFT algorithm installed in the VNA, the PolScat provides a time-domain radar return from a target as a fully polarimetric (HH, HV, VH, VV) amplitude and phase data. The range resolution is determined by $\Delta R = c/2B$. The maximum resolution (smallest ΔR) of 25cm is achieved when the antenna's bandwidth B of 600MHz is fully used. The maximum range of the radar system is related to the maximum sampling number of the VNA (N =1601) and the range resolution via $R_{\max} = (N-1)\Delta R$. This value could be arbitrary large with narrow use of B but the actual operating range is limited by the power of the VNA (10dBm) to no more than a hundred meters.

The returned phase signal is a function of range from the antenna to a target with a range error R_{error} defined by

$$R_{error} = \frac{\lambda}{4\pi}\phi_{error} , \qquad (1)$$

where λ is the wavelength and ϕ_{error} is the phase error. From a test data with a trihedral corner reflector (50cm hypotenuse) and some stable natural targets, the instantaneous phase error was found to be less than 1° which corresponds to R_{error} of 0.08mm. Compared with a conventional satellite SAR interferometry where the nominal phase error is 10° and R_{error} =0.8mm, the PolScat interferometry can provide a sub millimeter accuracy of range change so that it can be used for the calibration and validation of satellite DInSAR signal.

To ensure a long term signal stability of PolScat system, a laboratory test was performed with the trihedral corner reflector in an isolated room with no temperature control. There was a subtle monotonic increase of amplitude of 5% for 10 days mainly due to the room temperature and humidity fluctuations. Phase were extremely stable within 1° change for the first six days, but it showed a monotonic decreased up to 6° for the later four days. The temperature and humidity from outside weather might have caused this change but no data were available to prove it. However, this experiment was enough to found that a subtle change of the target, PolScat system, and environmental factors such as temperature and humidity should be under control to obtain a valid long-term data. A fully automatic measurement in an isolated laboratory environment with a full control of temperature and humidity was sought after for the following laboratory experiment.

B. Experiment Setup

Fig. 2 and 3 show the schematic diagram and photo of the laboratory experiment with PolScat on a drying mud. A ton of mud sample was collected from natural mudflat nearby the study area. The sample was kept in a 2m×2m×0.2m Styrofoam frame covered with vinyl. It was flooded with water and kept calm until mud particles precipitate completely (Fig. 4a). The antenna height was 205cm from the floor with 45° look angle. The $R_{\max}$ was 25m with N =1601 and ΔR =25cm. PolScat data was automatically obtained every 10 minute together with digital photo every hour for six weeks. We also measured vertical subsidence and horizontal shrink of the mud body. Occasionally we have sampled the mud, dried it in a 90°C oven to calculate gravimetric soil moisture content by;

$$m_g\,(\%) = \text{ water mass / dry soil mass} \times 100. \qquad (2)$$

Room temperature was kept 20°C with humidity of 30% constantly for the initial four weeks, and changed to 28°C and 20% later on to speed up the evaporation process.

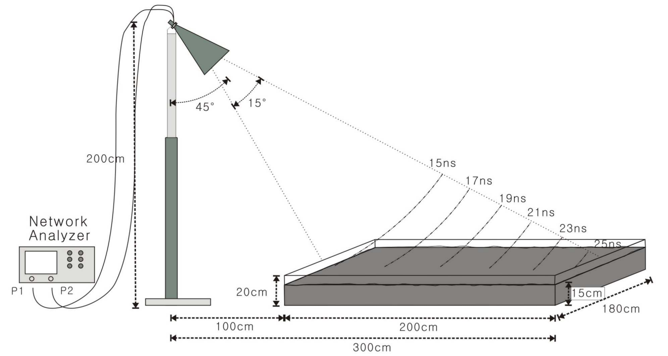
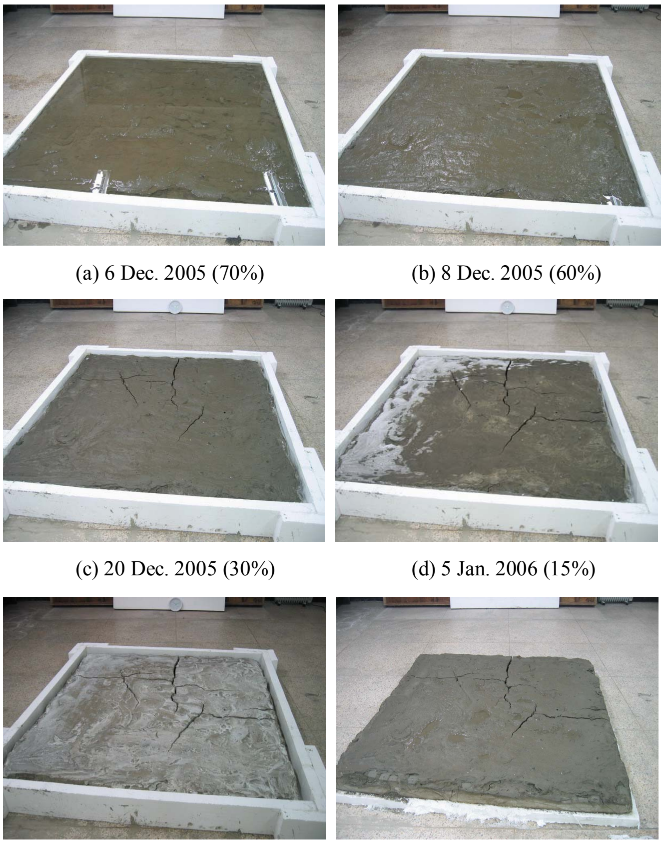


Figure 2. Schematic diagram of laboratory experiment on drying mud sample using a polarimetric scatterometer.

Figure 3. Photo of PolScat laboratory experiment on drying mud. The notebook computer automatically controls the the Agilent 8753ES network analyzer and the digital camera. This temperature controlled room was secured for 6 weeks.

C. Data Interpretation

The experiment began on 26 December 2005 with cutting the side edges of vinyl that have wrapped the mud underneath and four sides. The mud sample experienced quick drainage (Fig. 4b), evaporation, and development of mud cracks. When the mud cracks were fully developed (Fig. 4c), the vertical subsidence stopped after 11mm of subsidence. The mud sample was structurally stabilized and was left to dry continuously until 5 January 2006 (Fig. 4d). Salt particles began to appear on the surface of the mud to cover the entire surface later. After that time, room temperature was raised to accelerate the evaporation to the end of the experiment on 20 January 2006 (Fig. 4e). Gravimetric soil moisture content was 60% right after the drainage and gradually reduced to 30% after two weeks, 15% after four weeks, and then dropped to 5% at the end of the experiment. Finally, a spray test was performed to increase the soil moisture to 50% (Fig. 4f). Care was taken to spray water gradually preserving the surface structure unchanged.



(a) 6 Dec. 2005 (70%) (b) 8 Dec. 2005 (60%)

(c) 20 Dec. 2005 (30%) (d) 5 Jan. 2006 (15%)

(e) 20 Jan. 2006 (5%) (f) 20 Jan. 2006 (50%)

Figure 4. Photos of the PolScat laboratory experiment on drying mud pictured at antenna position: (a) initial flood state, (b) after drainage, (c) crack began at the middle of mud (19ns), vertical subsidence finished after 11mm, surface stabilized, (d) salt appears, (e) fully dried mud, (f) spray test. The values in parentheses are gravimetric soil moisture contents. Microwave penetration into drying mud began from (c) and progressed up to 6mm penetration at (e). The phase information from the spray test (f) confirmed the measured penetration value in reverse manner by uprising of scattering center from the 6mm depth to the surface.

Fig. 5 shows the PolScat measurement of HH-phase that is the same as Radarsat-1 SAR. The center part of the mud sample at 19ns shows total 155° phase decrease from the initial drainage status to the fully dried mud. This phase decrease indicates 12mm range increase from the antenna to the mud's scattering center. It also corresponds to the 17mm vertical shift of the scattering center downwards. Subtracting the observed subsidence of 11mm, the 6mm down of the scattering center was due to microwave penetration into the fully dried mud sample.

After 20 January 2005, we could still observe the continuous decrease of phase even after the mud was structurally stabilized. The phase change from this point to the end of the experiment was measured to be 50° down, which is equivalent to 4mm range increase in the direction of radar line of sight. This corresponds to 6mm down of the scattering center in the vertical direction, which can be misinterpreted as subsidence otherwise.

The final spray test shows the increase of phase up to 50°, suggesting that the phase center has rebounded from 6mm depth to the surface due to the increased soil moisture while the structure is kept unchanged. This confirms the 11mm subsidence and 6mm microwave penetration measured from the PolScat HH-phase change was correct retrospectively

This experiment have shown that the PolScat measurement, with direct subsidence measurement can discriminate the portion of microwave penetration depth out of total phase variation which might be misinterpreted as subsidence in the conventional DInSAR measurement.

III. CONCLUSIONS

From the PolScat laboratory experiment on drying mud, it is found that horizontally polarized C-band microwave can penetrate up to 6mm into a fully dried mud of 5% gravimetric soil moisture content. It was confirmed that a DInSAR measurement of subsidence on a drying mudflat or a bare soil moisture content observation should compensate the effect of microwave penetration, which can be isolated from a laboratory or in situ measurement with PolScat system.

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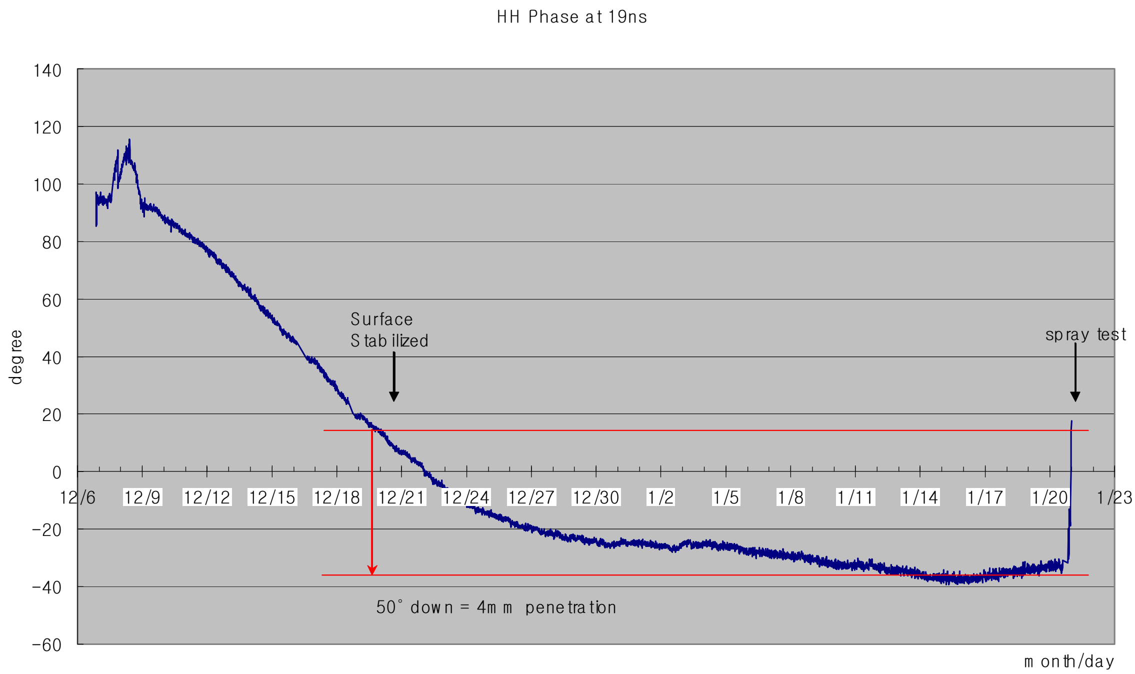

Figure 5. HH phase change at 19ns. The initial 105° phase down is due to 11mm subsidence from contraction of drying mud while the later 50° phase down is due to microwave penetration into a fully dried mud.