Variation of Radar Backscattering Coefficient of Tidal Mudflat Observed by Radarsat-1 SAR and Polarimetric Scatterometer

Heesam Chae[1], Hoonyol Lee[1], Seong-Jun Cho[2] and No-Wook Park[2]
[1] Department of Geophysics, Kangwon National University, Chuncheon, Kangwon-do 200-701, Korea
chae2380@kangwon.ac.kr, hoonyol@kangwon.ac.kr
[2]Korea Institute of Geoscience and Mineral Resources, Daejeon 305-350, Korea.
mac@kigam.re.kr, nwpark@kigam.re.kr

***Abstract*- We have analyzed the variation of radar backscattering coefficient of natural mudflat, when it is above the sea level and subject to structural change and evaporation, by using a set of Radarsat-1 SAR images, tidal height record, evaporation record, and polarimetric scatterometer experiments on drying mud. The 15 Radarsat-1 SAR data, obtained one in 2001 and the others from 2003 to 2004 were all in S5 ascending mode taken at around 18:30pm local time which is an ideal time for evaluating daytime evaporation effect considering 12.42-hour tidal cycle. The *exposure time* of mudflat is calculated by combining the tidal height record and a DEM of mudflat constructed by the waterline extraction method. We then defined the '*evaporation time*' by multiplying the exposure time with the *normalized evaporation index*, which are compared with SAR backscattering coefficient. The result was not a monotonic decrease of backscattering coefficient with the evaporation time but a complex variation of M shaped (increase-decrease-increase-decrease) sequence due to structural and moisture change of drying mud. In the first few hours of exposure, the remnant water pools act as specular reflectors reducing roughness of the surface and the backscattering was very low. As the water pool dries out the backscattering increases due to roughness increase. After the water pools have vanished, the backscattering decreases as evaporation goes on due to the decreasing dielectric constant. Another backscattering jump follows when the mud cracks begin to appear until they fully develop. After that the tidal mudflat is structurally stabilized and the backscattering decreases monotonically. This variation was confirmed by Radarsat-1 SAR images.**

Keywords- radar bcakscattering coefficient, SAR, mudflat, exposure time, normalized evaporationn index, evaporation time, polarimetric scatterometer

I. INTRODUCTION

The tidal flat of South Korea is 28,000 km^2, composed mostly of mud and sand [1]. During the 12.42-hour tidal cycle, the tidal flat are regularly exposed above the sea level undergoing changes of structural and electrical properties by drainage, evaporation, mud crack and bio-turbidity. We have analyzed the variation of radar backscattering coefficient due to change of roughness and dielectric constant of drying mudflat using Radarsat-1 SAR images and polarimetric scatterometer (PolScat) laboratory experiments.

II. ANALYSIS OF SAR IMAGES

The research area is an inter-tidal mudflat near Jebu Island, west coast of South Korea. We used Radarsat-1 SAR images, tidal height record, and evaporation record in order to analyze the radar backscattering coefficient of drying tidal mudflat.

The Radarsat-1 SAR data, obtained one in 2001 and 14 from 2003 to 2004 were all in S5 ascending mode taken at around 18:30pm local time which is an ideal time for observing daytime drying mud surface 12.42-hour tidal cycle. Each SAR image was converted to radar backscattering coefficient. To obtain the region of maximum evaporation time on each image, we have selected 6 regions in upper-tidal mudflat for analysis (Fig. 1).

To analyze the change of radar backscattering coefficient seen on the 15 SAR images, we need a moisture content data of mudflat measured at the time of SAR acquisition to compare with, but no such data exists.

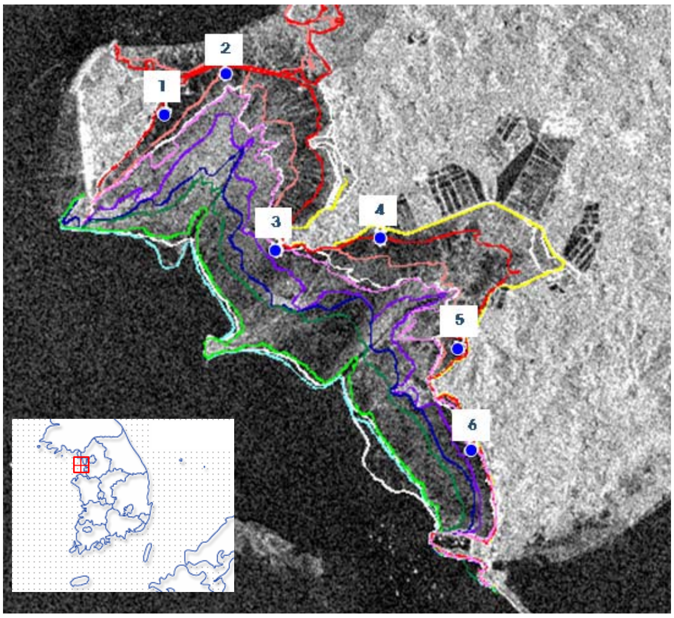

Figure 1. Radarsat-1 SAR image in Jebu island tidal mudflat, region of extracted backscattering coefficient(1-6) and DEM by water-line method.

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Table 1. Radarsat-1 SAR images (ascending S5), tidal height records, evaporation loss records.

No.	Acquisition Date (yyyymmdd)	Tidal Height (cm)	Evaporation Loss (mm)
1	20010703	443	1.2
2	20030506	702.5	1.0
3	20030530	629	4.9
4	20030623	310	1.5
5	20030717	781.5	1.1
6	20030810	451	1.1
7	20030927	908	2.8
8	20031021	301.5	0.9
9	20040218	595.5	2.3
10	20040711	287.5	0.9
11	20040804	828	6.5
12	20040828	507	3.0
13	20040921	583	2.5
14	20041015	875	2.8
15	20041108	310	0.9

Instead, we assumed that the *exposure time* and the amount of 'evaporation' is inversely proportional to soil moisture content.

To calculate the exposure time of mudflat, a DEM and the tidal curve is necessary. DEM was constructed from waterlines of 15 SAR images together with the tidal height record. As there is no tidal station at the research area, we used the data from Pyongtaek tidal station located about 25km southeast of the research area. The difference of the altitude of waterline in each SAR image and the altitude of each sampled location is used to calculate the exposure time of the mudflat from the tidal height curve. We first compared the radar backscattering in terms of the exposure time (Fig. 2). However, there is no particular trend in this comparison. Therefore, we postulated that the exposure time alone can not represent the moisture content of mudflat because of the different weather conditions of SAR image acquisitions.

We also used the daily evaporation loss data measured at Inchon weather station, about 20km north of the research area. The evaporation loss data were normalized from 0 to 1 by dividing the values with 8.5mm, which is the maximum evaporation loss among the ones recorded from the year 2001 to 2004, to give the *normalized evaporation index,* We then defined the *evaporation time*,

$$\text{Evaporation Time} = \text{Exposure Time} \times \text{Normalized Evaporation Index.} \qquad (1)$$

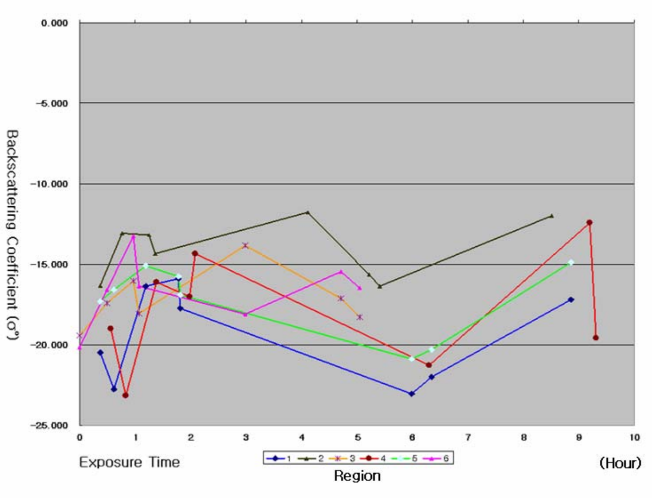


Figure 2. Radar backscattering coefficient with *exposure time* of mudflat.

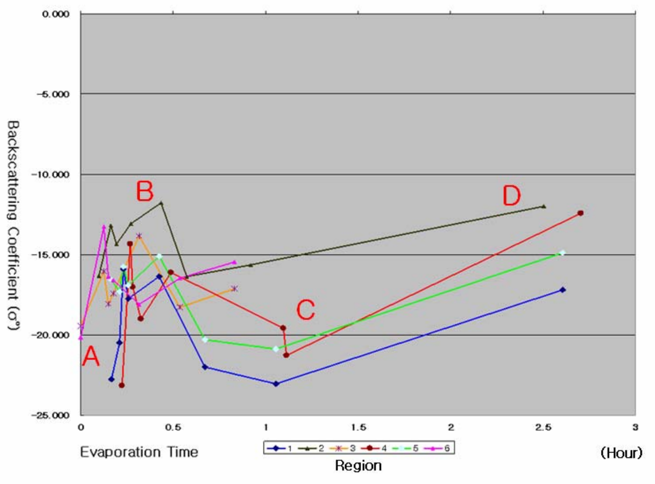


Figure 3. Radar backscattering coefficient with *evaporation time* of mudflat.

This evaporation time considers both the exposure time and the amount of evaporation loss of the mudflat, and is thought to be highly related to the soil moisture content at the time of SAR image acquisition when there exists no directly measured soil moisture data.

Fig. 3 shows the relationship between the radar backscattering coefficient and the evaporation time. Generally, radar backscattering becomes small as the soil moisture content decreases on the drying mud [2]. However, the graph shows a complicated trend rather than a monotonic decrease of the radar backscattering as the evaporation time increases. At the early stage of evaporation time the backscattering increased (A to B), then decreased (B to C), and increased again (C to D).

III. POLSCAT EXPERIMENTS ON DRYING MUD

To interpret the relationship of backscattering and evaporation time of mudflat observed by Radarsat-1 SAR images above, we performed a laboratory experiment on drying mud using a polarimetric scatterometer (PolScat).

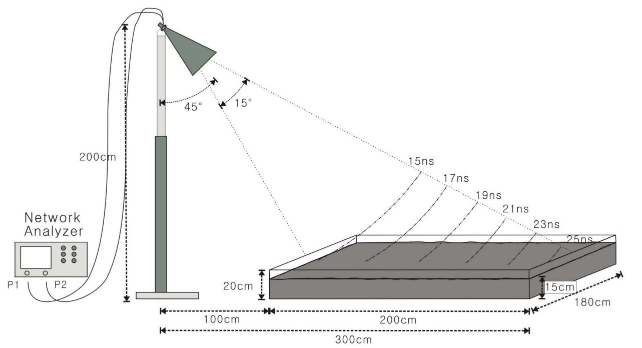


Figure 4. Schematic diagram of laboratory experiment on drying mud using a polarimetric scatterometer.

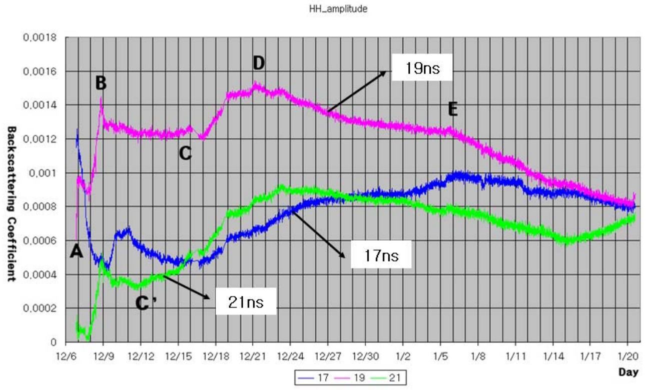
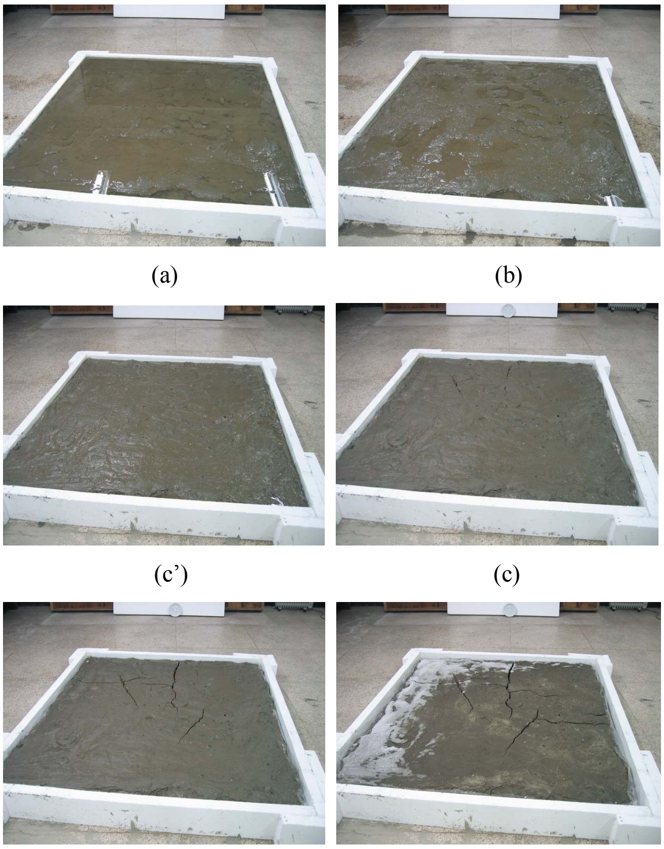


Figure 5. Variation of backscattering coefficient by PolScat.

The PolScat is mainly composed of a vector network analyzer (Agilent 8753ES) and C-band antenna. The antenna is a dual-polarization square horn with center frequency of 5.3GHz and the bandwidth of 600MHz. The range resolution is 25cm and the beam width is 15°.

We have sampled about 1 ton of mud at the study area and put it into a 2m wide, 2m long, 20cm height Styrofoam frame. The look angle of the antenna was set to 45° and the two-way travel time of microwave between the antenna and the mud sample was 15ns at front, 19ns at the center, and 25ns at far range. The mud sample was kept drying for 6 weeks with room temperature about 20°C and the humidity about 30%. The amplitude and phase of HH, HV, VH and VV polarization was measured every 10 minutes, and a photo was taken every hour, all in an automatic way controlled by a computer.

Here we analyze the HH-polarization data which is the same as Radarsat-1 SAR. As the sample dries out, the backscattering did not show a monotonic change because of complicated change of dielectric constant and surface roughness. At initial stage, the surface of mud sample was flooded with water and the backscattering coefficient was very low due to radar total reflection (Fig. 5A, Fig. 6a). As the water was drained out, surface roughness increased and the backscattering increased accordingly (Fig. 5A-B, Fig. 6a-b). Meanwhile, the backscattering decreased for a short time between A and B in Fig. 5. This was a boundary effect of the laboratory experiment in front of the sample where moisture evaporated outside the Styrofoam frame, which will not appear in the natural mudflat. It was confirmed by a rapid decrease of backscattering at 17ns during early stage of the experiment. The backscattering decrease as the mud dried out due to the decrease of dielectric constant (Fig. 5B-C, Fig. 6b-c). At some point, the mud sample began to develop mud cracks resulting in increase of surface roughness and thus backscattering (Fig. 5C, Fig. 6c). The development of mud crack started at the far range first, which can be shown as an earlier rise of backscattering at 21ns than at 19ns (Fig. 5C', Fig. 6c'). The backscattering increased until the mud crack developed fully and the mud surface structure was stabilized (Fig. 5C-D, Fig. 6c-d). As the mud sample was kept drying, the backscattering decrease due to decrease of soil moisture content and dielectric constant (Fig. 5D-E, Fig. 6d-e).



(a) (b)

(c’) (c)

(d) (e)

Figure 6. Photos of the laboratory experiment on drying mud pictured at antenna position: (a) initial flood state, (b) after drainage, (c’) crack development at far range (21ns), (c) cracks at mid range (19ns), (d) fully developed cracks; (e) continuous drying.

To accelerate drying, we increased the room temperature as 28°C and 20% humidity until the mud fully dried out (after Fig. 5E).

The overall change of backscattering have shown an M-shaped variation: the initial increase due to roughness increase from water drainage (A to B), decrease from the dielectric constant decrease due to evaporation (B to C), increase due to mud crack (C to D), and decrease due to continuously drying mud (D to E).

IV. CONCLUSION

The observation of 15 Radarsat-1 SAR images and a PolScat laboratory experiment have shown that the change of the microwave backscattering coefficient on an evaporating tidal mudflat exposed over the sea surface experiences rather complicated behavior. The overall backscattering change was M-shaped (increase-decrease-increase-decrease) due to initial drainage, evaporation, crack development, and continuous further drying. In the SAR analysis, however, we could observe only the initial increase-decrease-increase sequence due to insufficiency of SAR data. It is expected that further accumulation of SAR data would reveal the full scale M-shape on a drying natural mudflat. The result of this study implies that SAR image interpretation on inter-tidal mudflat should be carefully conducted considering the various natural process that might affect the radar backscattering.

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