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RADARSAT SAR Investigations of Lineament and Spring Water in Cheju Island

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RADARSAT SAR 자료를 이용한 제주도 선구조 연구 및 용천 특성 연구

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Abstract

Two RADARSAT SAR images with different modes were acquired by Canadian Space Agency to test the effectiveness of geological lineament extraction and spring water detection over the Cheju Island. Geological lineaments are poorly developed this basalt dominant volcanic island, but more linear features can be extracted when SAR and TM images are simultaneously analyzed than when TM image alone is used. This results mainly owe to the facts that RADARSAT SAR systems are able to provide data with different frequencies, azimuth, and incidence angles. Distribution of spring water along coast is poorly correlated with geological lineaments or drainage pattern, but those in middle range of mountain region are developed along geological lineaments. Detection of spring water using remotely sensed images are turned out to be very difficult to achieve. Radial shaped sea surface temperature anomaly derived from TM thermal band should be the best candidate for spring water, but the resolution is not high enough. We also investigate the normalized radar cross section (or sigma naught) converted from RADARSAT and ERS-1 SAR data but to fail to discriminate the spring water effectively except where relatively large water mass is observed on land side. Speckle noise and irregularity in physical sea surface condition are the serious obstacles for this application.

ERS-1 SAR image acquired in low incidence angle was more useful for geological lineament estimation and water body study than RADARSAT SAR images with high incidence angles. Therefore the selection of

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incidence angle is critical in geological and spring water applications of SAR images, and low incidence angles less than about 30° are recommended to monitor the Cheju volcanic island.

요 약

제주도 지질학적 선구조 및 용천연구를 위한 RADARSAT SAR의 활용 타당성 검토 연구가 Canadain Space Agency의 도움으로 얻어진 2종류 다른 모드를 갖는 SAR 자료를 이용하여 수행되었다. 제주도는 현무암이 우세한 화산섬으로 지질학적 선구조의 발달이 매우 미약하나, 본 연구결과 기존에 Landat TM 만을 이용하여 얻어진 선구조보다 많은 선구조를 추출할 수 있었다. 이는 특히 TM과 다른 관측방향과 입사각을 갖는 RADARSAT SAR 영상자료를 함께 사용함으로서, 보다 다양한 파장과 관측형태를 활용할 수 있는 장점을 극대화 할 수 있는 것으로 사료된다. 본 지역에서 연안에 발달한 용천의 분포와 선구조 혹은 수계망과의 연관은 거의 없는 것으로 사료되나, 중산간 지역에 발달한 일부 용천은 선구조와 연관되어 발달한 것으로 사료된다. SAR 및 광학원격탐사 자료를 이용한 용천의 위치파악을 위한 연구결과는 예상보다 힘든 것으로 나타났다. 이를 위해 열적외선 관측자료를 이용한 연안의 온도분포와 관측된 SAR 자료로부터 정규화된 레이더단면을 이용한 분석이 실시되었다. 해수의 온도는 소규모의 온도 이상분포가 방사상으로 나타나는 경우 가장 용천의 위치와 연관성이 높은 것으로 판단되나 해상도가 충분하지 못하며, SAR의 경우 해상의 상태와 speckle 잡음의 영향으로 육지에 어느 정도 대규모의 저수지가 발달하지 않는 경우를 제외하고는 용천의 위치를 파악하는데는 효과적이지 못한 것으로 나타났다.

본 지역에 얻어지는 SAR 자료의 speckle 및 영상특성은 입사각에 매우 민감하며, 특히 작은 입사각을 갖는 ERS-1의 경우가 비교적 큰 입사각을 갖는 RADARSAT SAR 영상보다 낮은 speckle 잡음비와 구조적 특징을 잘 반영하였다. 따라서 향후 제주도 지역에 대한 RADARSAT SAR 영상 획득을 위해서는 약 30°이하의 낮은 입사각을 갖는 모드를 이용하는 것이 바람직 할 것으로 판단된다.

1. Introduction

1) RADARSAT SAR

Canada's RADARSAT is a civilian Earth observation satellite equipped with C-band HH-polarization synthetic aperture radar (SAR) system. SAR has been proven to be an effective remote sensing instrument because of 1) day/night and weather-independent imaging capabilities; 2) high resolution regardless of antenna altitude; 3) signal data characteristics unique to the microwave region of the EM spectrum. The RADARSAT SAR is the only one civilian SAR system capable of offering a wide range of selectable imaging modes with different swath widths, resolutions, and incidence angles among current satellite-borne SAR systems. This flexibility in the

RADARSAT SAR operations has improved the potential range of SAR applications in Earth sciences.

Although the radar imaging techniques have been dramatically developed in the last decades, the application techniques of SAR are fairly primitive stage because of relatively short history of development compared with optical remote sensing. The application of SAR has been focused on military purpose owing to the ability of night coverage since early 1950's. The first civilian application of SAR was a geological survey over Panama(MacDonald, 1969). Since then, the SAR images have been utilized to extract geological lineaments, for instances Elachi(1980), Harris(1984), Lowman et. al(1987). Harris(1984) showed that more geological lineaments could be detected in the Seasat SAR image than in the Landsat MSS image. Lowman(1987), however, pointed out the radar look-direction bias should be taken into account when one does geological lineament studies using a SAR image. To reduce the radar look-direction bias, Lowman(1987) suggested to use more than two SAR data sets acquired in different look directions. In geological application of the RADARSAT SAR, the selection of incidence angle in addition to look direction is reported to be critical (Singhroy, 1997). Another important characteristic of SAR is that the radar cross section is sensitive to the moisture contents in soil, which encourages the potential applications of SAR data to hydrogeology including water resource management (Martin, 1998), flooding, river discharge (Hockey, 1998), and so on.

In this study, we will focus on two topics: i) the effectiveness of geological lineament studies using RADARSAT SAR images in comparison with ERS-1 SAR and Landsat TM images over the Cheju Island; and ii) the feasibility study of RADARSAT SAR in detection of spring water in the coastal region of the Cheju Island. It is already well known that the SAR is very useful to delineate geological lineaments in the rugged area where the geological lineaments are expressed in topographic relief. However, geological lineament studies in the volcanic area like the Cheju Island are not popular. Therefore, we will investigate the effectiveness of the RADARSAT SAR image to study the geological lineaments in the study area. The boundary of fresh water and sea water mixing process is also reported to be observable in a SAR image at the estuary of a large river system. The mechanism of the detection is based upon the difference in surface roughness of fresh water discharged from a river and the sea water controlled by waves. The target we are focusing here is the boundary between sea water and spring water which is much smaller scale than a river system. Therefore, we will estimate the sigma naught from ERS-1 SAR image (the resolution of 25m) and the fine beam mode RADARSAT SAR image (the resolution of 8m with 3.125m pixel size) which is the best resolution provided by current satellite SAR system. Using the sigma naught obtained from the SAR images, we will discuss the potential and problems for the natural spring detection using SAR in the future.

2) Regional Characteristics

The Cheju Island is a volcanic island formed by a series of more than twenty volcanic eruptions from late Tertiary to early Quaternarly. The most recent volcanic activities were also reported in 1002 A.D. and 1007 A.D. The general shape of the island is elliptic and about three hundred and sixty parasitic cones are developed roughly along the ENE-WSW directional axis of the island. The Cheju Island is composed mainly of olivine basalt with small amount of trachyte, trachyandesite, tuff and pyroclstics, and sediments. Cheju Island has 44% high groundwater recharge ratio because of porous lava-flow with good permeability so that its large-scale stream network is relatively poor. Linear features associated with geological structures in the Cheju Island are poorly developed, although the elongated shape of the island, gravity and magnetic anomaly in the northeastern region suggest the possible faults or fracture zones(Kwon and Lee, 1997). Consequently, the relationship between geologic linear features and groundwater is not clearly defined. Only a few studies using remotely sensed data to evaluate the geological lineaments over the Cheju Island have been carried out, for instance Korea Water Resource Cooperation(1993). This study is the first to use SAR images for geological applications in this area.

Water resource in the Cheju Island largely depends on groundwater developed around coastal area. Groundwater filling effective porosity of rocks or layers is controlled by geological conditions, characteristics of natural resources and yielding conditions. Spring water in the Cheju island developed in volcanic terrain has been regarded as important drinking water resources for a long times. There are 403 spring waters in the Cheju island to yield 1,110,000m^3 per day. Spring water is divided into upper and lower(coastal) according to its location. It is difficult to find out location of spring water using ships owing to mixing of spring and sea water.

In this research, we will focus on applications of remote sensing techniques specifically for the studies of geological lineaments and spring water sites using SAR and optic sensor data. Although few studies using Landsat TM or Landsat MSS have been conducted previously to investigate the geological characteristics over the Cheju Island, SAR data has never been utilized in this region. Since SAR antenna uses microwave instead of visible or infra-red spectra, the SAR data could compensate for the optic data.

2. Methodology and Data

The RADARSAT SAR data sets used in this research were provided by Canadian Space Agency as a part of ADRO program (ADRO #338). Two sets of RADARSAT SAR data were acquired over the study area by one set of standard 5 beam mode and the other of fine 2 beam mode. One ERS-1 SAR data was also acquired in the southwest part of the island. Although the ERS-1 SAR data used in this study was obtained mainly not for the geological analysis but for sea surface wave pattern, it was also found to be useful for this study. The characteristics of the SAR data sets used in this study are summarized as in Table 1. In addition to three SAR data sets, two Landsat TM data were also utilized for comparison. The TM data are mainly used to estimate sea surface water temperature in coastal area.

The approaches we have adopted include: i) geological lineament analysis using SAR and TM data; ii) evaluating sigma naught from SAR data to detect fresh water input in coastal area; and iii) estimating sea surface water temperature from TM data. Details of each method are as follows.

1) Geological Lineament Analysis

Geological lineaments are important to infer the structural features in regional geology, and it also serves as main passageways of groundwater. Geologists identify structures and landforms from variations in topography and textural patterns in remotely sensed images. Drainage pattern is also valuable clue to delineate geological lineaments because drainage system is often developed along structural weak lines. Geological lineaments can effectively be estimated by applying an automatic lineament extraction algorithm, for instance Won et. al(1998a), if relief variations are prominent. The topographic patterns in this volcanic island, however, are smooth lack of distinctive lineaments associated with faults or fracture zones. Drainage system in this island is poorly developed due to high permeability of volcanic rocks. Thus we did estimate lineaments via visual investigation of SAR images rather than automatic lineament extraction approaches. We have also referred to Korea Water Resources Corporation's(1993) results obtained by analyzing a TM image.

Surface roughness is an another important factor governing the radar backscattering. In volcanic area, surface materials and rock types are often identified by their surface roughness characteristics. Therefore, we also take some distinctive features affecting surface roughness including the distribution of parasitic cones, lithologic boundaries, and types of vegetation cover into account when we discriminate geological lineaments.

For geological applications of RADARSAT images, the selection of incidence angle as well as appropriate resolution is critical (Singhroy, 1997). Singhroy(1997) suggested that higher incidence angles ranging from 40 to 60 degrees are suitable in mountainous terrains, while lower incidence angles ranging from 25 to 45 degrees are recommended in flat or prairies. The fine 3 and standard 7 beam mode used in this study were acquired with a central incidence angle of 42.5 and 47.0

Table 1. Summary of SAR data sets used in this study.

Satellite	Acquisition date	Orbit Mode / Look Directon	Band / Polizaton	Incidence Angle(deg.) (beam mode)	No. of looks	Pixel size	Resol-ution
RADARSAT	1996. 8. 15.	ascending/ starboard	C-band/HH	42.5(fine 3)	1	3.125m	8m
	1996. 8. 8.	ascending/ starboard	C-band/HH	47.0(standard 7)	3	8m	25m
ERS-1	1994.10.11.	decending/ starboard	C-band/VV	23.0	4	12.5m	30m

degrees respectively as shown in Table 1. The geomorphology of the Cheju Island is characterized as gentle slope with rare topographic breaks. In this case, lower incidence angles are better off and the data we are using may not be the optimal viewing geometry.

2) Sea Surface Temperature

Sea surface temperature from thermal infra-red observation is already well established and a commonly used technique for water body studies in coastal and open ocean. If the spring water discharging to coastal sea is large enough, the temperature boundary between fresh water and sea water can possibly be discriminated from a remotely sensed image.

In this study, we estimated sea surface temperature from two sets of Landsat TM band 6: one winter scene and the other summer scene. Although the temperature difference between spring water and sea water is not as big as that in discharging system of a power plant, spring water should be discernible if the amount of input is large enough. The Landsat TM data were received and pre-processed by RESTEC, and consequently we applied the conversion equation suggested by RESTEC. The radiance (R) of the thermal band can be estimated by

$$R = \frac{DN}{255}(R_{\max} - R_{\min}) + R_{\min} \quad (1)$$

where $R_{\min} = 0.1534$, $R_{\max} = 1.896$

The estimated radiance in Eq.(1) is then divided by the thermal band width 2.1(μm). Once the radiance is estimated, the absolute temperature (T) is to be obtained by the following Eq.(2)

$$R = 5.1292 \times 10^{-5}\,T^2 - 1.7651 \times 10^{-2}\,T + 1.6023 \quad (2)$$

More accurate results can be achieved when an appropriate atmospheric correction is applied. The thermal band, however, is less sensitive to atmospheric conditions than visible or near infra-red bands. The atmospheric effect to the Landsat TM band 6 data is known to be negligible under favorable weather conditions (Bartolucci et. al, 1988). Since our data were apparently acquired in one of the finest days, we did not conduct atmospheric correction.

The Earth thermal radiation is also detectable in microwave spectrum region, although the signal of microwave temperature is very weak compared with thermal infra red region. Microwave radiometer is recently getting popular for low resolution sea surface temperature observation. The sea surface temperature is theoretically recoverable from SAR data with high resolution. Sigma naught of SAR is correlated with wind speed, friction velocity, wave height and slope. However, air-sea interaction seems more critical factor on radar imaging over ocean surface than sea surface temperature (Kozai, 1998; personal communication). Consequently, it is possible to estimate sea surface temperature from SAR data only if precise information on air temperature and wind speed as well as an accurate wind vector retrieval model are given. RADARSAT Narrow ScanSAR mode may be favorable candidate for the purpose, but a precise model for the mode is yet to be developed and verified. This application was not included in this study, but it should be worth while to try in the future.

3) Normalized Radar Cross Section (σ^0)

Radar backscattering in ocean can be modelled by Bragg's scattering of small-scale surface topography, short gravity and capillary waves, and tilting by long waves or swell effect (Elachi, 1980). Mixing process of fresh water and sea water is sometimes observable in a SAR image due to the difference in surface roughnesses and salinities of the two water body.

Such subtle changes in radar backscattering can possibly be detected by normalized radar cross section (NRCS or sigma naught). The sigma naught defined by the ratio of incidence power to the backscattered power in normal direction to the horizontal surface. One can estimate sigma naught from SAR image if precise antenna-scatterer geometry is known. The relationship between sigma naught and SAR image is generally given by

$$\sigma^0 \propto DN^2 \frac{\sin I}{\sin I_{ref}} \; PowerLoss \qquad (3)$$

where I, I_{ref} are respectively the incidence angle of a target and the reference, and "*PowerLoss*" is the analogue to digital convertor(ADC) power loss. To estimate the incidence angles, auxiliary information on the radius of the Earth and altitude of satellite are also required. We have estimated the sigma naught from RADARSAT and ERS-1 SAR image data through the processing based respectively upon the guidelines of RADARSAT calibration and ERS SAR calibration as summarized in Figure 1. One have to estimate beta naught which is radar brightness in the direction of incidence beam first, and then convert it into sigma naught using radar incidence angle in the image swath. "A2" and "A3" in the flowchart in Figure 1. are a scaling gain value and fixed offset, respectively, and they are recorded in the header file.

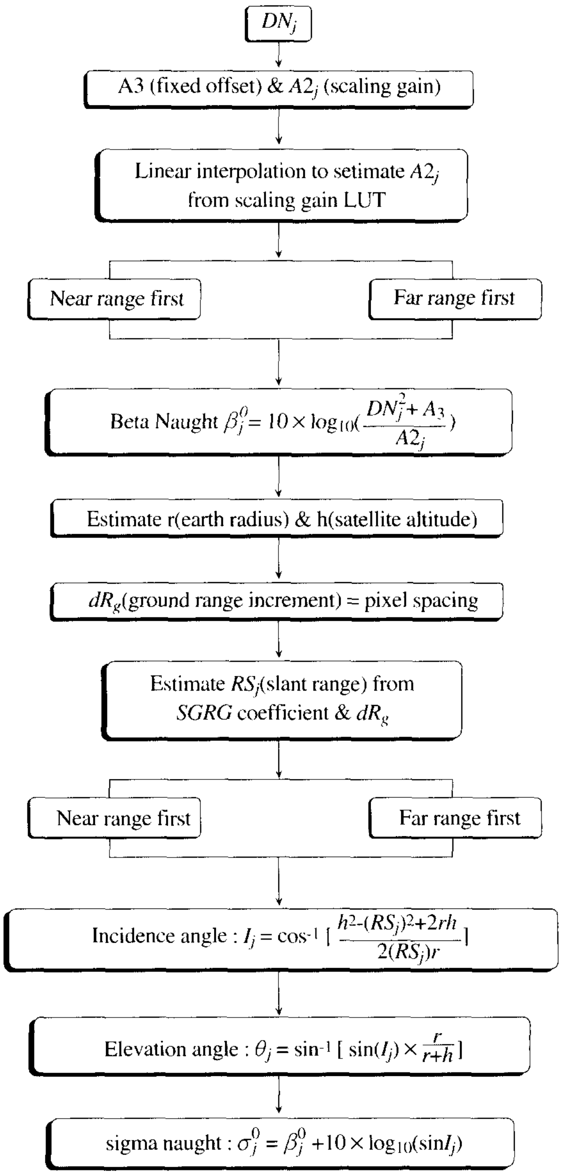

Fig. 1. The block diagram for derivation of sigma naught from RADARSAT SAR image.

The estimate of sigma naught is used to evaluate the coastal water body characteristics around spring water sites. If the discharge of fresh water from land is large enough with respect to radar resolution, discrimination of fresh water input from sea water may be possible in a certain coastal region. The relative soil moisture contents may be another clue to detect spring water sites and also can be evaluated qualitatively from sigma naught.

3. Results and Discussions

1) Geologic Features and Lineaments

The standard beam mode image of RADARSAT SAR is shown in the Figure 2. Although lithologic boundaries in the SAR image are not as clear as in a TM image, linear features and cinder cones are extremely well imaged by RADARSAT SAR. Vegetation cover as well as geomorphologic characteristics is found to be important factor affecting on the radar backscattering in this area. The boundary between low and high radar brightness in northern parts is a combined effect of changes in topographic slope and vegetation cover, and it coincides

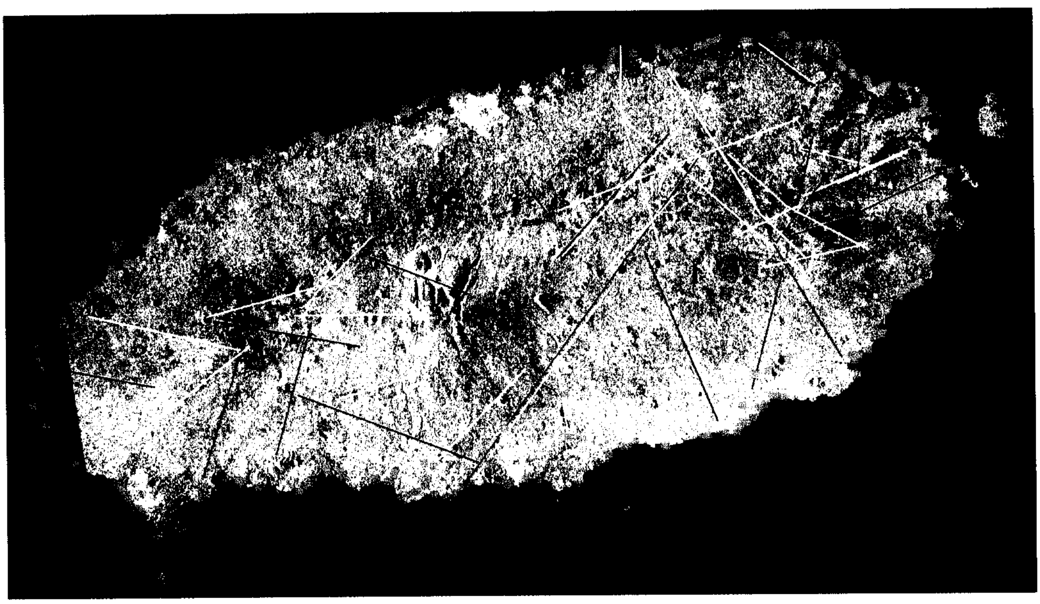

Fig. 2. RADARSAT SAR standard beam 7 image acquired for this study overlaid with the estimated geologic lineaments: the solid lines are the lineament estimated in this study; and the dashed lines from the result of Korea Water Resources Cooperation(1993).

with lithologic boundary. Some typical trachyte or trachyandesite bodies can also be discriminated in the SAR image due to distinctive geomorphological features, for instance Sambangsan trachyte. The speckle noise, however, is serious in this volcanic island than in other sites in the main land. It can be explained by geology, soil, and vegetation: the surface of basaltic flows which is most abundant in this island causes speckle than other rocks; the soil profile is also not fully developed due to relatively young age of the island, and the grain size of soil is irregular; the short shrubs are typical in this area, and consequently backscattering from on top of trees and from surface of soil are randomly mixed. The speckle noise in the RADARSAT fine beam mode image is too serious to discriminate certain geologic features or types of land cover as in Figure 3.

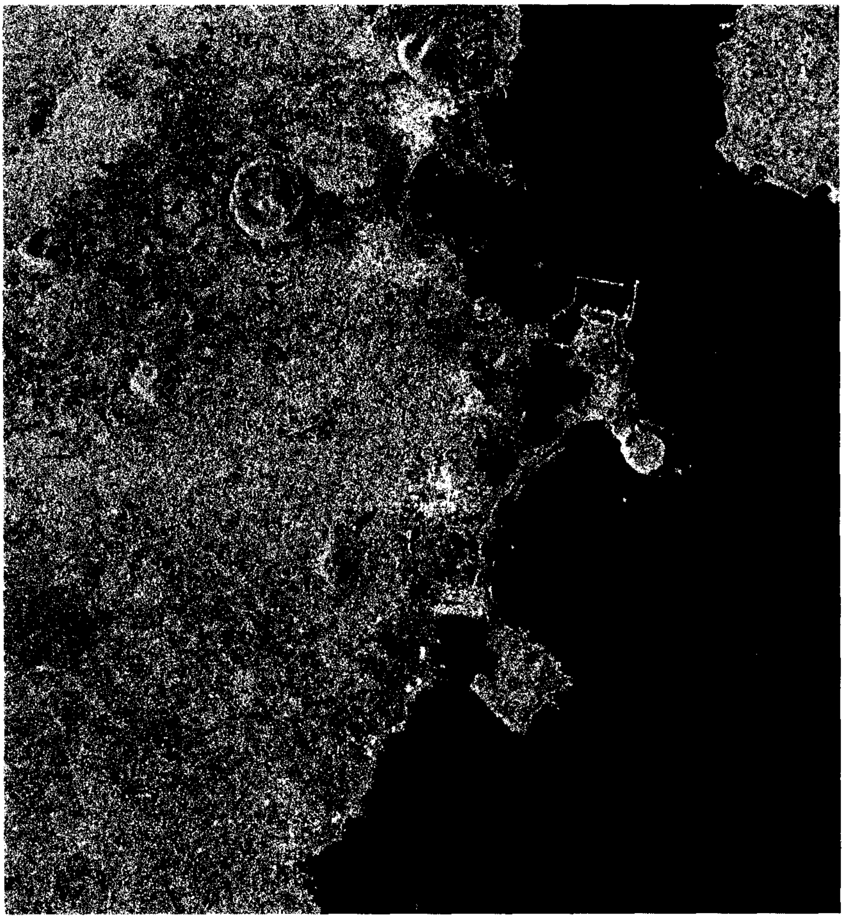

Fig. 3. RADARSAT SAR fine beam 3 image acquired for this study: speckle noise is very serious specifically over relatively flat basaltic layer.

The RADARSAT fine beam mode is generally considered as one of most useful beam mode for investigating features on land surface (Luscombe et. al, 1997). However, we suggest that the RADARSAT standard beam mode is more favorable than the fine beam mode in this region.

The radar backscattering generally depends on target parameters including local slope, surface roughness, and dielectric constant(or moisture content) as well as system parameters such as frequency, polarization, and viewing angles. In relatively flat region such as coastal area in this island, the surface roughness and lithologic components are important factors. To discriminate lithologic boundaries or types of land cover in this coastal region, the radar observation with high local incidence angle may be preferred as Singhroy(1997) pointed out. The high incidence angle in this area, however, causes more speckle noise. This effect is clearly seen in the fine beam mode image as shown in Figure 3. The speckle noise in the fine beam mode gradually increases from the topographic high in central parts of the island to the relatively flat coastal area. The incidence angles of the RADARSAT SAR data used in this study are relatively high with 47° for standard 7 beam mode and 42.5° for fine 3 beam mode as listed in Table 1, while that of ERS-1 is a fixed angle of 23.0°. The linear features and drainage pattern are better detectable in the ERS-1 SAR image than in the RADARSAT SAR images used in this study. In short, we conclude that low incidence angles, for instance Standard 1 or 2 beam mode of RADARSAT SAR, could be more effective to monitor geological features of Cheju Island.

The estimated geological lineaments from RADARSAT SAR, ERS-1 SAR, and Landsat TM images are shown solid lines in Figure 2. The points marked by blue square in Figure 2. are the location of spring water sites. To reduce bias, all possible lineaments were first obtained by two specialists independently. And then we selected only common lineaments in Figure 2. out of two results. The N-S trending drainage system are typically in RADARSAT SAR and TM images as seen in Figure 2 and Figure 4 (a). N20° E-trending drainage systems are also well observed in ERS-1 SAR image as shown in Figure 4 (b). These effects must arise from look-direction bias. Antenna look direction is very important in geologic application of SAR. Linear feature within 20° normal to azimuth is much less distinguishable, while lineament parallel to azimuth is remarkably enhanced (Lowman, 1987). Therefore, at least two looks are recommended in geologic study using SAR. In our case, the ERS-1 SAR image was used as an auxiliary image for lineament study. Two RADARSAT SAR images were acquired by ascending orbit with starboard look direction, while ERS-1 was acquired by descending orbit with starboard look. Therefore the orbit is crossing and the look directions are opposite each other. Unfortunately, the ERS-1 image used here only covers southern parts of the island. Although basalt is impervious, well developed joint and fracture system allows the basaltic layer to have relatively high permeability. Owing to high permeability layers with gentle topographic slope, a coarse parallel drainage pattern is typically developed. The

(a)

(b)

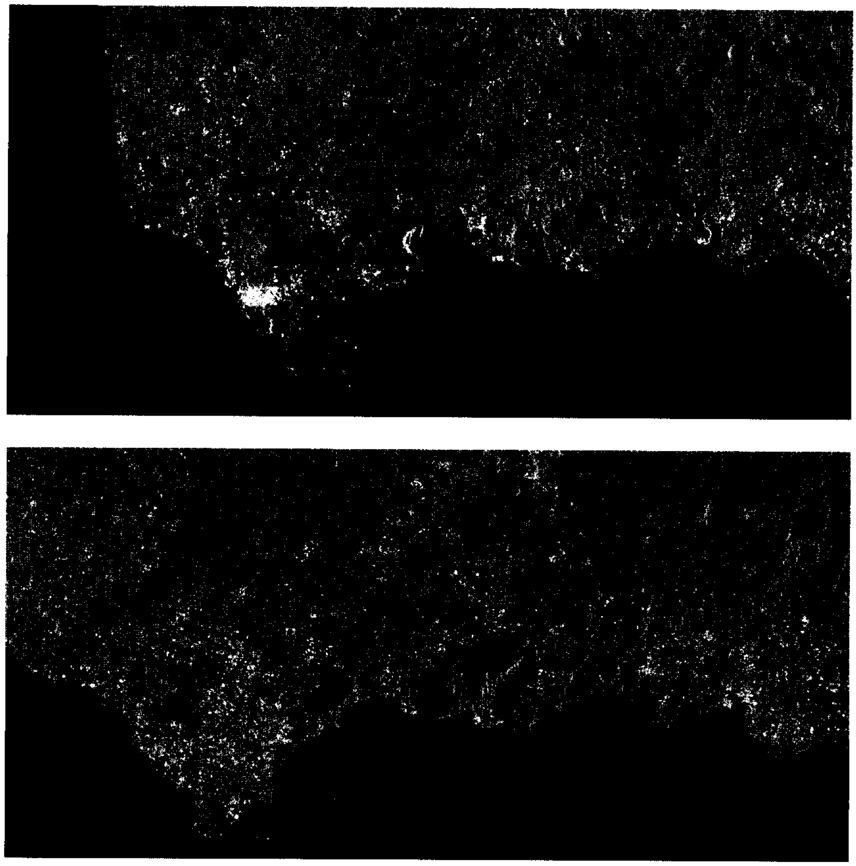

Fig. 4. (a) RADARSAT SAR image and (b) ERS-1 SAR image in the southwest parts of the island: rendition of drainage pattern and trachytic rock bodies in two images are quite different due to opposite look-direction and different incidence angles.

drainage system in the Cheju Island, however, has very low correlation with geologic lineament or spring water site as shown in Figure 2.

Trachyte or trachyandesite composed of more SiO_2 content than basaltic rocks generally forms domal structure in this island (Lee, 1985). These domal structures are well observed in both RADARSAT and ERS-1 SAR images. The topographic and geologic expression of such domal structures and parasitic cones are quite different in two images because opposite look direction and different incidence angles produces different degree of foreshorting and layover effect.

Figure 5. is produced by applying IHS transform to SAR and Landsat TM data. The intensity of TM IHS image is replaced by RADARSAT standard beam mode SAR to obtain the intensity stretched imaged in Figure 5. Through this image merging technique, we can enhance both

Fig. 5. Color composite image obtained by applying a data fusion technique through IHS transform to TM and RADARSAT SAR image.

lithologic and topographic features. For instance, the radial distribution of basaltic lava flow in the eastern region can clearly traceable. The rendition of land cover and topographic expression are also enhanced in the merged image. This merged image was also utilized to estimated geologic lineaments finalized in Figure 2.

Spring water sites are almost evenly distributed along coastal line as shown in Figure 2, and thus any systematic relationship between geologic lineament and spring water site is hardly depicted. However, spring water sites developed in middle to high altitude are closely matched with the estimated lineament (Figure 2). The N-S trending geologic lineament in northeastern part suggested by Kwon and Lee(1997) based upon gravity and magnetic anomaly is also detected in this study. In summary, geologic lineaments in Cheju Island are poorly developed and only few typical lineaments are detected in remotely sensed images. When we estimate geologic lineament using SAR in addition to TM image, we can detect more lineaments. Those estimated geologic lineaments do not show any systematic relationship with spring water sites in coastal area or drainage pattern in overall. However, spring water in the middle range of Halla Mountain is developed along a possible geologic lineament.

2) Sea Surface Temperature

The sea surface temperature estimated from a TM summer scene acquired on August 3, 1988, ranges from 22℃ to 28℃ as shown in Figure 6. This range of the estimated sea surface temperature coincides with the in-situ observation(22℃ to 26℃) at near shore in August of 1987 by Choi et. al(1989). We are specifically interested in regions with low temperature anomalies near shore line. In Figure 6. there exist two low temperature region: one in southwest and the other in northeast area. The most conspicious low temperature anomaly in southwest region with a range of 22℃ to 23℃ in Figure 6. corresponds to the Ilkwa-ri. A weak and elongated anomaly is also observed around Youngsoo-ri in the west part of the island. In the northen coast, a low temperature anomaly are located near to Konae-ri. Some other small scaled low temperature anomalies are also scattered at Samyang-ri, Shinheung-ri, Dongbuk-ri, and Youngdam-ri. The estimated anomalies are generally matched with the results reported by Choi et. al's (1989). In this study, we, however, are focused on pin-pointing scattered small but distinctive anomalies with typically radial distribution.

Due to mixing of various warm and cold currents, the general aspect of water temperature distribution around Cheju Island is complicated (Choi et. al, 1989). Therefore the low temperature

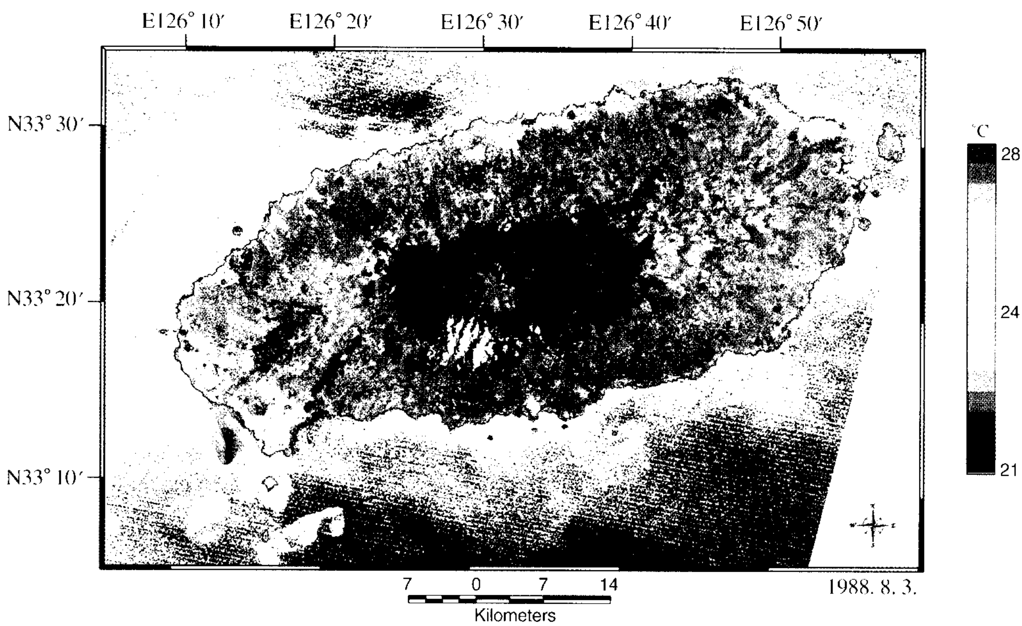

Fig. 6. Sea surface temperature estimated from Landsat TM image.

anomaly, specially large ones, may not always be formed by spring water. However, a number of low temperature anomalies match extremely well with the locations of spring water sites in Figure 2. Specially, some small anomalies with a typical shape of radial distribution near coast line accounts certainly for spring water with every respects.

3) Sigma Naught along Coastal Region

We have estimated sigma naught from RADARSAT SAR standard beam mode image and ERS-1 SAR image over a selected region. We selected the sub-region as in Figure 7. based upon sea surface temperature anomalies in the previous section. Kozai(1998) recently attempted to derive sea surface temperature from RADARSAT ScanSAR data. The sigma naught, however,

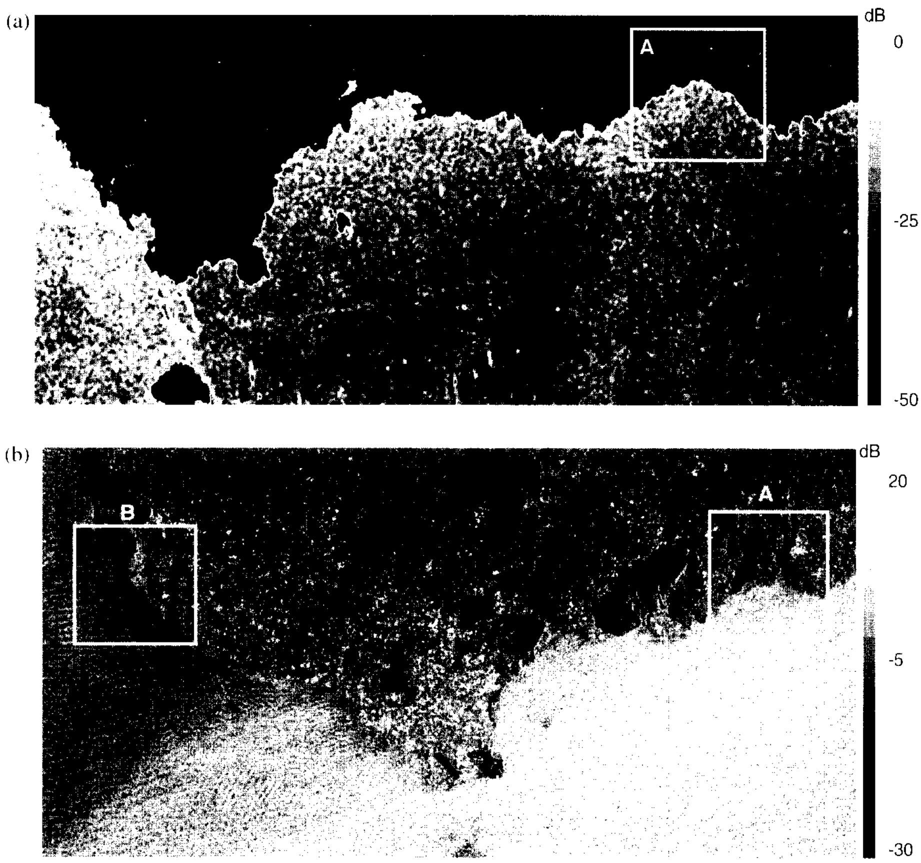

Fig. 7. Sigma naught images of (a) RADARSAT SAR standard beam mode and (b) ERS-1 SAR data.

depends more or less on physical sea surface condition such as wave height and slope, internal waves, wind speed, and friction velocity. The frontal locations where the maximum sea surface temperature, and gradients of salinity and density are reported to coincide with the maximum sigma naught gradient (Kozai, 1998; personal communication). Therefore, physical sea surface condition should be calm to maximize the effect of sea surface temperature. The phenomenon we are seeking for here is the difference in physical condition and temperature of two water bodies: discharged spring water and sea water. The scale of discharged water is very small compared with wave fronts. Thus high resolution is mandatory to be successful. Although we can find out internal waves, the speckle noise in the RADARSAT fine beam mode image acquired for this study as in Figure 3. is too serious to observe small features.

Figure 7 (a) and (b) are the sigma naught images of RADARSAT standard beam mode and ERS-1 SAR, respectively. The sigma naught derived from RADARSAT SAR data in Figure (a) shows high values along coast. The potential boundary of fresh water and sea water could not be defined in this sigma naught image. Only water reservoir on land can be detected as low sigma naught. ERS-1 SAR, principally designed for oceanographic study, seems to be the best among three data sets to observe such delicate changes in water body. The wind speed at the moment of ERS-1 SAR observation was retrieved from SAR image itself to be about 11 m/sec (Won et. al, 1998b). Under such strong wind condition, the sea state was unfortunately very rough. Even in such unfavorable sea surface condition, some unusual features are observed in the area "A" and "B". While features in "B" may be the result of wind front, the low sigma naught in area "A" could possibly be related to the fresh water discharge. Evidence is nevertheless inconclusive because the resolution of the ERS-1 SAR is simply not high enough especially under such rough sea state. RADARSAT fine beam mode should be the best candidate for this application. Speckle noise as shown in Figure 3. is a serious obstacle. Effective speckle reduction without trading-off resolution, for instance Won et. al(1997), will play an important role.

4. Conclusions

RADARSAT SAR images were acquired to evaluate the effectiveness for geological lineament study and spring water detection over the Cheju Island. Utilizing the RADARSAT SAR images with optic data in the analysis, we did successfully detect more geological lineaments than when TM image alone was used. Although the geological lineaments in the Cheju Island are poorly developed, certain linear features in SAR and TM images can be defined as geological lineaments. The estimated geological lineaments, however, are hardly correlated with location of spring water sites or drainage pattern except springs developed middle range of the Halla Mountain. Landsat TM thermal band could be useful to detect location of spring water discharge near coast if the sea surface condition is favorable. We failed to delineate the boundary between fresh water and sea water using estimated sigma naught from SAR images. For this application, high resolution SAR data with much reduced speckle should be required.

ERS-1 SAR image was very useful for geological lineament estimation and water body study using sigma naught. Meanwhile speckle noise is serious in RADARSAT SAR images observed with standard 7 beam mode and fine 3 beam mode over the Cheju Island. Therefore it is apparent that the selection of incidence angle is critical in geological and spring water applications of SAR images, and low incidence angles less than about 30° are recommended to monitor the Cheju volcanic island.

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