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Investigation of Possibility Using PALSAR to Monitor Changes in Rice Paddy Fields

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Abstract

Rice is a staple food in Asia, and production may vary within and among countries or regions. Therefore, monitoring of rice planted areas is important and an unfailing and timely method is needed. Synthetic Aperture Radar (SAR) is expected for paddy fields observation because SAR can observe all weather conditions. In 2006, the JAXA launched the ALOS/PALSAR that is the world's first L-band multi polarimetric satellite based SAR. The purpose of the research is to clarify the problem and effectiveness of ALOS/PALSAR when used to observe rice paddy fields over a large area. The study was carried out in Tsukuba and surrounding areas, Ibaraki Prefecture, Japan. PALSAR data were collected for 11 different periods in 2007 from before transplanting until harvesting all the paddy fields. In this study, ALOS/PALSAR images were compared with ground truth data. As results, in this time, it is difficult to easily distinguish water-filled paddy fields from non-water-filled paddy or other fields based on the differences in backscatter coefficient values in ALOS/PALSAR images. Therefore ALOS/PALSAR data are difficult to use determination of the rice planted area. In addition, the data show that it is difficult to evaluate growth of rice from ALOS/PALSAR backscatter coefficients. At the same time, the data indicate the importance of selecting uniform data sources when performing time series analysis using ALOS/PALSAR data.

1. Introduction

In agricultural areas, changes on the ground surface may be rapid and more dynamic than those in forests. Farm products may be harvested within a few months or less than a year. Therefore, it is important that timely and periodic observations be carried out in agricultural areas. When using optical sensors, because they are influenced by weather, the availability of timely observations may be difficult. On the other hand, Synthetic Aperture Radar (SAR) can observe rainy and cloudy weather, and is capable of producing timely observations of agricultural land. Thus, both periodic and timely observations can be obtained through satellites SAR remote sensing.

Rice is a staple food in Asia, and production may vary within and among countries or regions. Therefore, monitoring of rice planted areas is important and an unfailing and timely method is needed. Satellite based SAR is useful for monitoring rice production because it can provide timely and periodic observations, even during the Asian monsoon season.

Until date, there have been many studies carried out using SAR to monitor rice paddy fields (Kurosu *et al*., 1995; Le Toan *et al*., 1997; Ogawa *et al*., 1998; Okamoto and Kawashima, 1999; Ribbes and Le Toan, 1999; Ishitsuka *et al*., 2001; Shao *et al*., 2001; Li *et al*., 2003; Ishitsuka *et al*, 2003). Most of the research has used C-band SAR, for example the Canadian RADARSAT Earth observation satellite project or the European Space Agency's ERS system. In addition, a small amount of research has been carried out using L-band SAR, provided by aircraft based AIRSAR, Japan's JERS-1, and Pi-SAR systems, as well as NASA's shuttle based SIR system (Miranda et al., 1996; Ferrazzoli *et al*., 1997; Rosenqvist, 1999; Lee *et al*., 2001; Ishitsuka *et al*, 2002, Ishitsuka *et al*, 2004). In 2006, the Japan Aerospace Exploration Agency (JAXA) launched the Advanced Land Observing Satellite (ALOS). ALOS has a Phased Array type L-band Synthetic Aperture Radar (PALSAR) that can observe using multiple polarizations. ALOS/PALSAR is the world's first L-band multipolarimetric satellite based SAR system. Here, I report on the problem and effectiveness of ALOS/PALSAR when used to observe rice paddy fields over a large area.

2. Materials and Method

2. 1. Study Area

The study was carried out in Tsukuba (36° 01' 57" North, 140° 04' 38" East) and surrounding areas, Ibaraki Prefecture, Japan (Fig.1). This region has one of the major mountains of the Kanto region, Mt. Tsukuba, in the north, and the second largest lake in the country, Kasumigaura, in the east. The rivers are running through the area from north to south (such as Kokai River, Sakura River, East and West Yata Rivers). The area has a flat geographical feature called the Tsukuba-Inashiki Plateau, 20-30m above sea level, which is covered with Kanto Loam Layer. Land-use is combined with urban, woods, and fields including paddy fields. The annual average temperature is mild, 13.7 degree Celsius (1995). The annual average rainfall between 1992 and 1996 was 1342.1 mm. (Tsukuba city hall, 2006)

2. 2. Data used

PALSAR data were collected for 11 different periods from before transplanting until harvesting all the paddy fields (Table 1). The first image was taken before paddy field puddling and leveling, a time when paddy fields are not filled with water. In the last 2 images, most of the paddy fields had been harvested. Therefore, there were 8 ALOS/PALSAR images showing conditions when rice plants were present on the paddy fields. Unfortunately, 4 of those 8 images only provide single polarization data. Multipolarization data are available for the remaining 4 images, and moreover, full polarimetric data are only present in one of those four.

The satellite images were geometrically corrected using polynomial regression with ground control points (GCP) chosen from Digital Map 25000 (Geographical Survey Institute, Tsukuba, Japan). The study area was relatively flat; therefore no orthogonal corrections were applied.

σ^0 was calculated using equation (1) (Shimada *et al*., 2007)

$$\sigma^0 = 10 \bullet \log_{10}(DN^2) + CF \quad (1)$$

where DN is a digital number and CF is a calibration factor. In these digital PALSAR images, CF is read from the header file, CF= -83

Digital image processing was carried out using the software IMAGINE (ESRI Corp., Redlands, CA, USA) and TNTmips (MicroImages Inc., Lincoln, NE, USA).

2. 3. Methods

ALOS/PALSAR images were compared with ground truth data. Field surveys were carried out periodically from May to September. Rice height was measured, and paddy field conditions were recorded with a GPS camera.

An initial question was whether ALOS/PALSAR

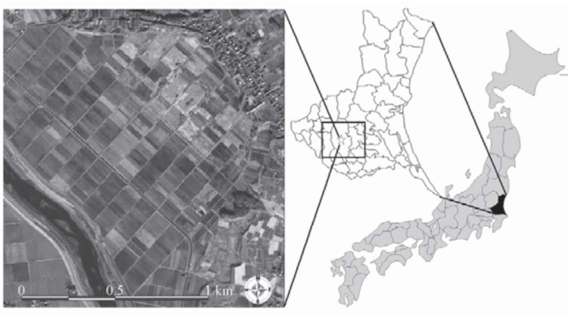

Fig. 1. Study Area
The painted part by black is Ibaraki Prefecture. Rectangle shows coverage of Fig. 3. ☆ located in field survey point. Left image is around field survey area observed by IKONOS on January 17th 2001

Table 1. Collected PALSAR data

	Orbit	Polarization
19-Apr-07	Ascending	Full
11-May-07	Ascending	Single
04-Jun-07	Ascending	Full
26-Jun-07	Ascending	Dual
14-Jul-07	Descending	Single
31-Jul-07	Descending	Single
11-Aug-07	Ascending	Dual
29-Aug-07	Descending	Single
15-Sep-07	Descending	Dual
26-Sep-07	Ascending	Dual
14-Oct-07	Descending	Dual

Full: VV+VH+HV+HH
Dual: HH+HV
Single: HH

could specifically detect only areas filled with water. Most studies of paddy fields using SAR, have incorporated specular reflection on water surfaces to detect water bodies and water-filled paddy fields. Fig. 2 shows an example of the basic principal from Ishitsuka *et al*. (2003). If ALOS/PALSAR is not possible to detect water, it is difficult to extract water-filled paddy fields. Thus, we tested whether ALOS/PALSAR detects water surfaces.

The second part of my investigation was to determine whether ALOS/PALSAR could detect rice growth. If ALOS/PALSAR could effectively detected rice growth, as well as water-filled paddy fields, it would be useful for monitoring rice production over large areas.

3. Results and Discussion

3. 1. Detection of water-filled paddy fields

Fig. 3 shows the ALOS/PALSAR image of the study area taken on May 11th, 2007. Most paddy fields had finished puddling and leveling, and transplanting of rice was underway on that date. Dark areas from the north to the south, in the image, appear like a stripe along the left of the figure, and similar dark areas are seen in the upper-central to right side of the image. These are locations of major paddy fields in this region, and the image suggests that specular reflection of water has been detected from these rice paddy fields. In the image taken on May 11th, 2007, the portions that appear like a thin dark stripe in a bright gray area are "yatsuda" agricultural area along a valley (Fig. 3 upper right).

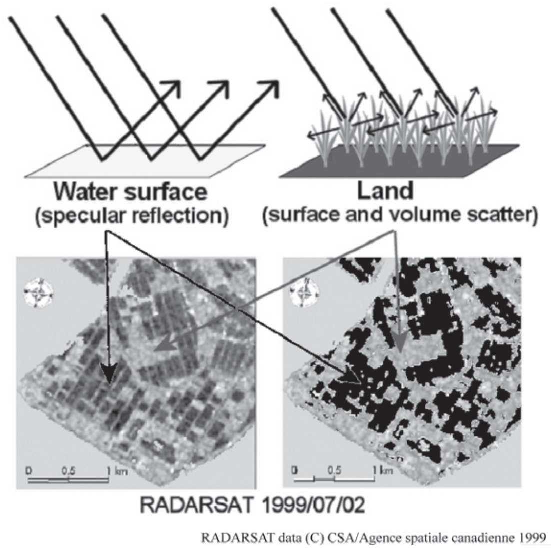

Fig. 2. Basic principal of detecting water-filled paddy fields

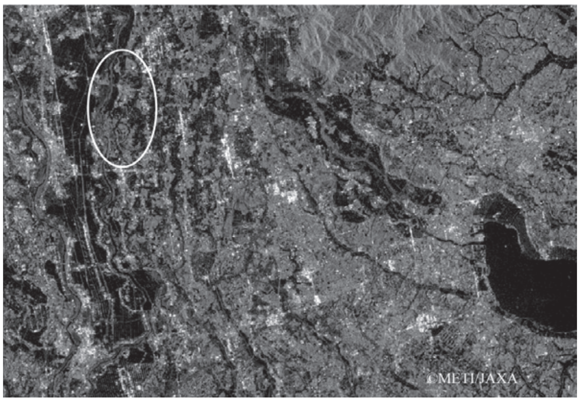

Fig. 3. PALSAR Image (May 11th 2007)

It is known that darkness in SAR images may indicate specular reflection from water surfaces (Iisaka, 1998; Ouchi, 2004). On the other hand, image portions that appear bright white or gray indicate urban or forest areas. However, all parts that appear dark are not rice paddy fields (areas circled in Fig. 3). This region has many turf fields and such waterless fields may appear dark. Thus, it is difficult to distinguish those turf fields from water-filled paddy fields. The reason for this difficulty is that L-band SAR may consider a surface to be smooth even if somewhat rough. This is because of the wavelength of the L-band, which is longer than that of the C-band. In concrete terms, the convexo-concave of turf field surfaces is typically small and is usually accepted as smooth using the Rayleigh criterion, equation (2), which may be used as an indicator of surface roughness.

$$\sigma_h << \lambda/(8\cos\theta) \quad (2)$$

where σ_h is the surface roughness, defined as the root-mean-square height relative to a perfectly smooth surface, λ is the wavelength of the SAR and θ is the angle of incidence.

Therefore turf field roughness is not markedly different from water-filled paddy fields, both may appear dark.

Similar results have been obtained in another area. Ishitsuka and Saito (2007), reported that it was difficult to clearly distinguish paddy fields filled with water, from fields during puddling and leveling operations, or from wheat fields. These difficulties were related to similarities in ALOS/PALSAR backscatter coefficient values for those area types. Therefore, it appears that ALOS/PALSAR has difficulty, specifically distinguishing water-filled paddy fields.

Polarimetric observation is an important character of ALOS/PALSAR. I studied only using single HH polarization until here, and I consider the other polarization images have possibility different from HH polarization. Images taken on April 19th, 2007 and June 4th, 2007 that observed full polarimetric data were compared. Figs. 4 and 5 show examples of enlarged image areas around rice paddy fields in VH, HH, and VV polarization. Images observed on April 19th, 2007 are shown on the left side, whereas those observed on June 4th, 2007 are seen on the right. Only VH polarization shows cross polarization because it is able to consider HV and VH polarization as the same. On April 19th, 2007, most paddy fields were not water-filled; however, there were a few paddy fields that had started water filling or were undergoing puddling and leveling. On June 4th, 2007, all paddy fields had already finished transplanting. Therefore ground surface of the paddy fields had changed from bare to water drastically.

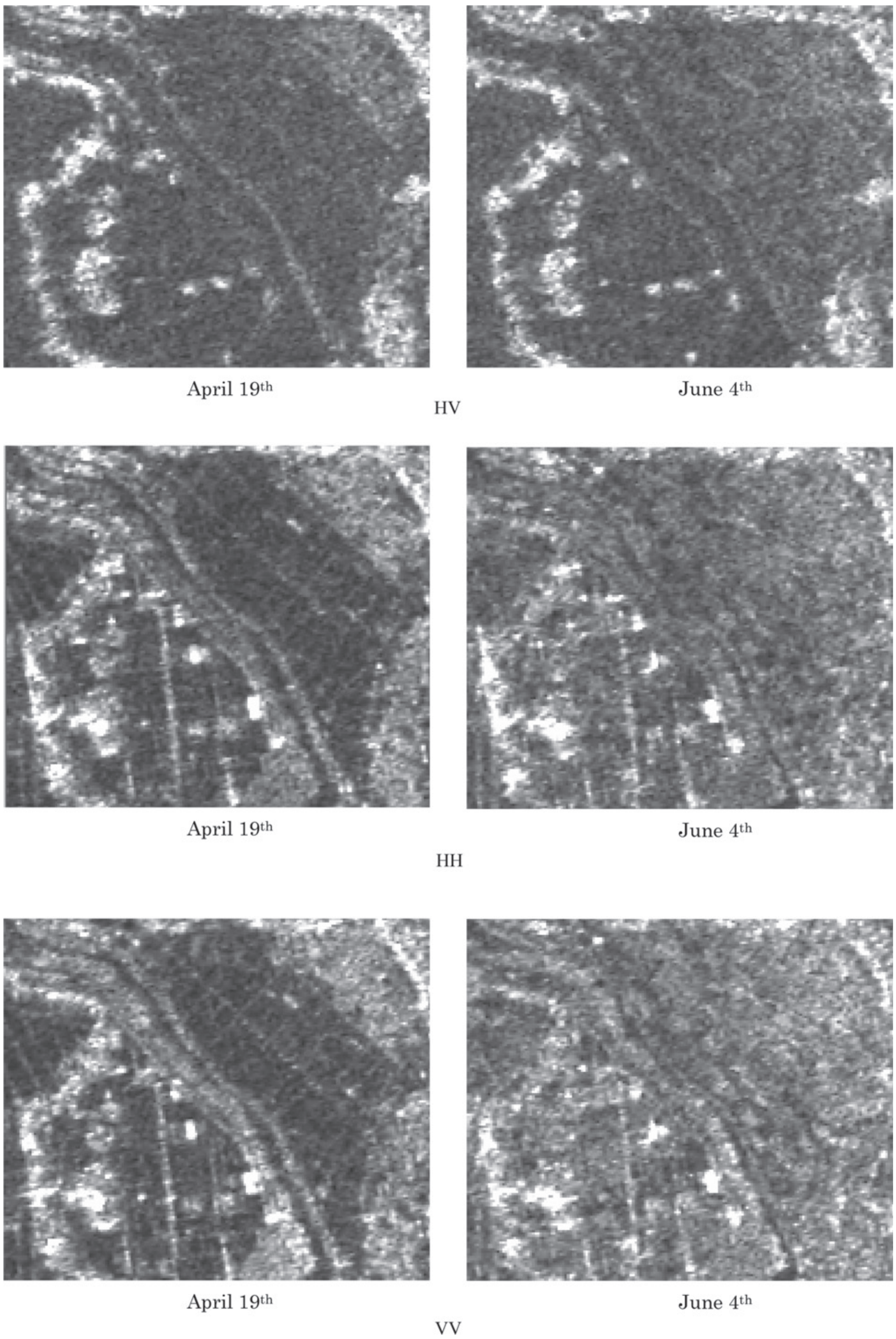

Fig. 4. Comparison of image observed on April19th 2007 with June 4th 2007
-Examples that the water-filled paddy fields can distinguish other fields comparatively-

Fig. 4 shows examples that water-filled paddy fields can be distinguished from other fields comparatively. In the HV images, there was no marked change between two periods. HV is a form of cross polarization that is appropriate for volume scattering (Iisaka, 1998; Ouchi, 2004). The data suggest that there was no substantial change in the volume of the plant body though the change in the surface was dramatic. In HH and VV images, the water-filled paddy fields can be identified because those fields changed to dark. However, some fields were not able to be detected the change because the fields already look dark in the April image. In addition, the change of the backscatter coefficient in VV polarization between two periods was greater than that in HH polarization.

Fig. 5 shows examples that it was difficult to distinguish between water-filled paddy fields and other fields. In HV images, there is hardly a difference in the two

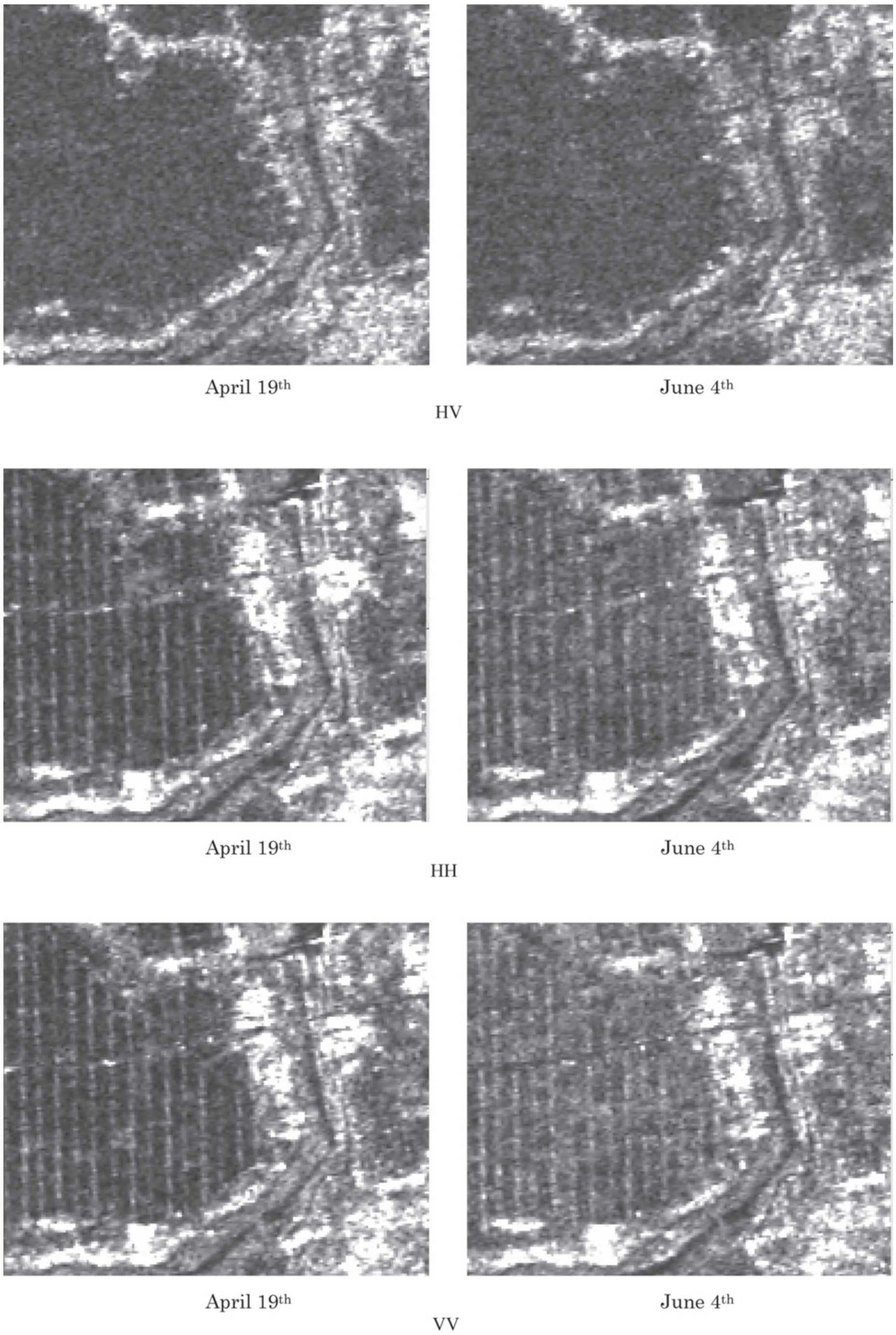

Fig. 5. Comparison of image observed on April19th 2007 with June 4th 2007
-Examples that the water-filled paddy fields can not distinguish other fields clearly-

periods images. In HH and VV images, the paddy fields are seen to change only slightly. However, there were many paddy fields with no or little change between two periods. Also in this comparison, the change in the VV polarization between the two periods was greater than that in the HH polarization. It is considered that there may be a difference of convexo-concave or soil moisture in paddy fields. The data also suggest that VV polarization may be more effective than HH in detecting water-filled paddy fields.

In summary, with conventional methods, ALOS/PALSAR data are difficult to use determination of the rice planted area because it is difficult to ensure accurate distinction of water-filled and non-filled paddy fields.

3. 2. Comparison of rice growth

Here, I compare the growth of rice with the backscatter coefficients values in a temporal series of ALOS/PALSAR images. Fig. 6 shows time series changes in backscatter coefficients (dB) in HH polarization images. These backscatter coefficients values represent averages from several paddy fields; in addition, maximum and minimum values are also presented.

On first glance, the pattern in Fig. 6 appears random and there is no obvious relationship with rice growth. However, in Fig. 6, indicated “A” is the ascending, “D” is descending, it seems to be related to satellite orbit. Therefore, I selected ascending data only and, because they were at a different resolution, excluded the full polarimetric data. Using those data restrictions, Fig. 7 was created. It shows a temporal change of backscatter coefficient in the ascending HH images that appears to be related to the height of rice as measured during ground truthing. The relationship’s initial appearance of randomness decreased and the fluctuations decreased. This indicates the importance of selecting uniform data sources when performing time series analysis using ALOS/PALSAR data.

In the Fig. 7, it seems both values increased, and that suggesting a good relationship between backscatter coefficients and rice growth. However, the backscatter coefficients increase was less than 3dB and the backscatter coefficients variance was larger than 3dB. Thus, it is difficult to evaluate growth of rice from ALOS/PALSAR backscatter coefficients.

When evaluating the biomass of rice from backscatter coefficients, HV polarization was considered suitable because cross polarization reflects volumetric scattering. Fig. 8 shows temporal change in backscatter coefficients only in the ascending data from the same resolution HV images and the ground truth data for rice height. It is difficult to detect relationship between rice growth and backscatter coefficients using HV polarization.

As results, it is difficult to evaluate rice growth

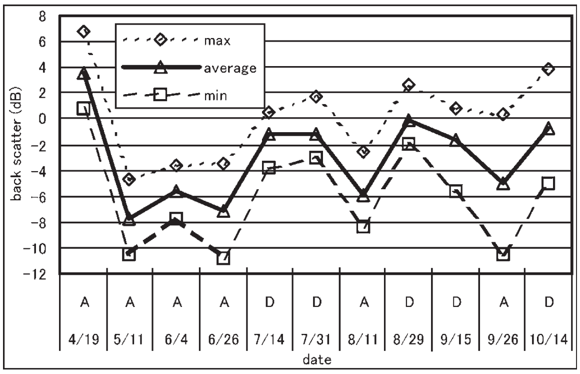

Fig. 6. Time series change of backscatter coefficient

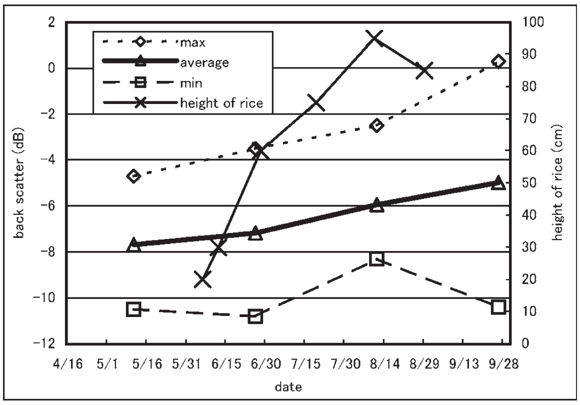

Fig. 7. Time series change of backscatter coefficient only in ascending HH images same spatial resolution and height of rice

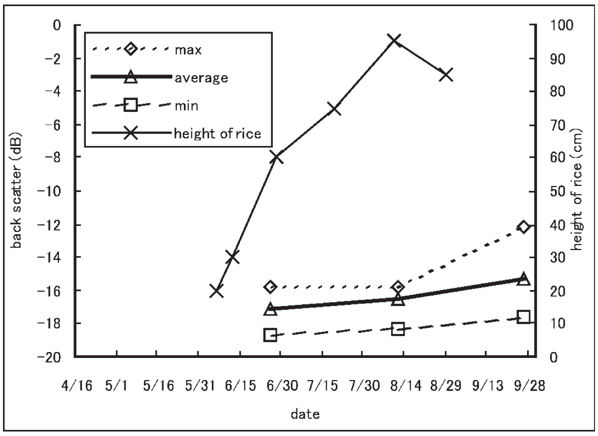

Fig. 8. Time series change of backscatter coefficient only in ascending HV images same spatial resolution and height of rice

from differences in backscatter coefficients values in ALOS/PALSAR images. However, in this study, there were little data to conclude. Continuation of research is needed.

4. Conclusions

There are many studies of rice paddy fields using SAR, and they mostly use C-band SAR, such as RADARSAT. When using L-band SAR, conventional methods cannot be used to directly monitor rice paddy fields because the scattering of paddy fields is different from C-band SAR. In this study, I compared ALOS/PALSAR data with ground truth data to identify problems and determine effectiveness when estimating the planted area of rice paddy fields.

The data indicate that it is difficult to easily distinguish water-filled paddy fields from non-water-filled paddy or other fields based on the differences in backscatter coefficient values in ALOS/PALSAR images. However, I consider that it is possible to distinguish such fields if ALOS/PALSAR images are combined with a SAR image taken at different wavelengths or combined with an optical sensor derived image. In addition, the data set in this time indicates that it is difficult to evaluate growth of rice from ALOS/PALSAR backscatter coefficients, at the same time, the data set indicates the importance of selecting uniform data sources when performing time series analysis using ALOS/PALSAR data.

Unfortunately, there were no full polarimetric mode data available during the 2007 rice-growing period in this region. Typically, vertical polarization microwave scatters well when observing plant bodies with a vertical structure, such as the rice plant. There is possibility that the change of the backscatter coefficient in VV polarization may have been greater than those in this study, if full polarimetric data exist in growing or earring or harvesting period. Further investigation into vertical polarization and full polarimetric data are needed. In addition, research into changes related to microwave incidence angle is needed.

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