様式Ｃ－１９

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研究課題名（和文）　乾燥地と永久凍土環境に対する新しいレーダーリモートセンシング技術の開発
研究課題名（英文）　Development of radar remote sensing techniques for monitoring arid and permafrost environments
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研究成果の概要（和文）：

本研究では、永久凍土と積雪域に対するマイクロ波リモートセンシングデータの新しい利用方法を開発した。従来の研究は 、氷結と氷解時の検出分解能は 25-50km のスケールであった。本研究では、シベリア生態系の氷結氷解時の画像に対し、1km の分解能を提示した。 また，積雪観測への応用として、積雪画像に対する新しい情報融合法をファージ理論と偏波によるターゲット分解技術を用いて、独自の技術を開発した。応用の結果で、L バンド全偏波 SAR は、季節的な積雪に対して十分な情報を提供していることを本研究で報告した。

研究成果の概要（英文）：

In this study, novel techniques on application of microwave remote sensing data for monitoring permafrost ecosystem and for mapping snow-covered area have been developed. Previous studies on monitoring thaw and refreeze states of permafrost environment have a limited spatial scale of 25-50km. In this study, a new technique to detect freeze/thaw states of the Siberian ecosystem in the spatial resolution of 1km was originally developed. In addition, a new method to map seasonal snow-covered area from radar remote sensing image was developed based on the characteristic seasonal changes of polarimetric parameters and a new data fusion method. Experimental results applied to Niigata Prefecture, indicate that the fully polarimetric L-band data can be a useful tool for mapping seasonal snow-covered area.

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１．研究開始当初の背景

Monitoring and mapping of land degradations with in-situ measurements are very difficult, resulting in limited amounts of observational data. Remote sensing techniques provide large spatial coverage through non-intrusive measurements over the Earth's surface. In particular, there is a rapidly increasing interest in the application of SAR (Synthetic Aperture Radar) remote sensing for Earth observation due to its high spatial resolution and all-weather imaging capability.

SAR images terrain in terms of microwave scattering mechanism. Therefore, same thematic target can appear differently in the image, which depends on observation geometry, frequency, polarization, incidence angle, target orientation, and so on. Unlike optical image, an interpretation of radar image is not straightforward. Although certain desired information is contained in the data, it is not easily accessible. Consequently, the capability of microwave radar remote sensing for monitoring environmental changes has not been fully exploited.

The utilization of multi-temporal and fully polarimetric radar measurements can be a unique solution to discover full usability of radar remote sensing for detecting environmental changes of terrain, since it offers full scattering information on the Earth's surface. However, polarimetric SAR remote sensing for cold-land application can be still considered to be in an experimental stage probably because most of the effort has been trying to squeeze more out of single-modal observations of terrain than they are capable of delivering. Consequently, developing smart method for practical application of polarimetric time-series data to monitor anthropogenic degradation has been a challenge of the community.

２．研究の目的

This study aims to develop novel techniques on application of microwave remote sensing data for monitoring and mapping seasonal permafrost and snowpack dynamics. Environmental changes of those areas, resulting from various factors including human activities and climatic variations, have been important issues. Concrete targets to be investigated are: (1) monitoring freeze/thaw cycle of Siberian permafrost ecosystem from ENVISAT ASAR time-series; and (2) mapping seasonal snow-covered area in Niigata from ALOS/PALSAR fully polarimetric mode.

３．研究の方法

(1) Permafrost monitoring

Several studies have reported on applications of active microwave sensors to detect freeze/thaw transitions in permafrost areas. Most of previous studies were carried out based on the C- and Ku-band scatterometer measurements due to their global coverage and high temporal resolution. The final products, such as, the onset of seasonal transition date, from scatterometer measurements generally have 25~50km spatial resolution. SAR remote sensing allows Earth observation with much higher spatial resolution than that of the scatterometer. But there have been few studies on the practical application of SAR data to detect freeze/thaw processes in cold regions.

Due to the high temporal sampling rate of ASAR Global Monitoring (GM) mode, it has a high application potential for analyzing the land surface freeze/thaw process in high latitudes. However, seasonal threshold approach, which is the most generally used in this field, can be hardly applicable to the GM data because of the noisy backscatter and complex seasonal response to different land cover and climate conditions.

In order to use GM time-series for analyzing freeze/thaw states, a least square fitting of piece-wise step function is introduced. The thawing date can be determined by minimizing the sum of squared residuals between measured backscatter time-series and a pre-defined step function. Detailed methodology for obtaining research goal is as following:

- Geocoding and radiometric calibration of GM time-series with sub pixel accuracy.
- Resampling of time-series data to a fixed global grid with an interval of 15 arc seconds.
- Incidence angle normalization to remove the incidence angle dependency.
- Extract normalized time-series of each grid-cell
- Apply a step function to the time-series for timing of the spring transition period.
- Apply a inverse step function for timing of the autumn transition period.

(2) Snow mapping

Most previous studies on snow monitoring by SAR have been carried out based on the use of C-band or higher frequencies due to their higher sensitivity to snow properties. Since this study aims as the capability assessment L-band SAR, such as ALOS/PALSAR for detection of seasonal snow covered areas, a novel approach is required. In this context, the methodology adopted in this study involves discovering polarimetric indicator appropriate to detect seasonal snowpack.

Detailed methodology for obtaining research goal is as following:

- Geocoding and precise co-registration of PALSAR time-series data acquired at snow-free and snow-covered condition.
- Extract polarimetric parameters of the eigenvector-based and model-based target decomposition method.
- Determine optimal parameters for snow cover detection.
- Information fusion of optimal polarimetric parameters using fuzzy set theory
- Mapping snow covered area using defuzzification procedure.

４．研究成果

(1) Permafrost monitoring

The selected study site covers central Yakutsia in eastern Siberia and spans from 61°N to 64°N and from 122°E to 132°E. Icy deposits are located at depths of between 1–3m below the surface and underlie vast area of Central Yakutia and exceed 20–25m in thickness. The GM images covering Yakutsk study site have been used to suitability of developed method for monitoring freeze/thaw cycles over permafrost regions. Complete results and elaborate validations have been reported in peer-reviewed papers and conference proceedings. The research achievement in this study can be summarized as followings:

- A rigorous method of extracting seasonal transition dates of permafrost ecosystem from of GM data sets is presented on the basis of a least square fitting of piecewise function to the backscatter time-series.
- It has been validated against a meteorological data set and a snowmelt timing product of SeaWinds scatterometer, and compared to fully polarimetric SAR data.
- Results for an eastern Siberian permafrost area illustrate that it can be a promising approach in operational monitoring of permafrost ecosystem with 1km spatial resolution (50 times higher than scatterometer measurement).

(1) Snow mapping

The selected study site is Uonuma area in Southern Niigata Prefecture. It is renowned one of the deepest seasonal snowpacks due to winter monsoon blowing from Siberia to the islands of Japan. For the study site in Niigata Prefecture, two polarimetric PALSAR images acquired on Nov. 6, 2007 (autumn, snow-free) and February 6, 2008 (winter, snow-covered), have been used to evaluate applicability of SAR data for monitoring snow-cover areas Complete results and elaborate validations have been reported in peer-reviewed papers and conference proceedings. The research achievement in this study can be summarized as followings:

- Seasonal changes in the polarimetric signal scattered from snow-covered mountainous ecosystem has been originally investigated.
- A snowpack is nearly transparent in co-pol backscatter in which signal scattered from snow-ground interface. Thus, the single polarization measurement provides insufficient information to detect snow.
- Different polarimetric parameters offer better information on the snow properties.
- Particularly, the polarimetric entropy and the volume scattering component provide complimentary information.
- Snow extents can be identified successfully from the information fusion approach based on the fuzzy set theory.

５．主な発表論文等

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６．研究組織

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