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論 文 内 容 要 旨

Snow, as one of the most important parameters of climate change, has been aroused more and more attention in many fields. However, most of snow cover detection results with using the satellite remote sensing images have low accuracy due to the effect of atmosphere, regional terrain and the underlying surface covered by snow. In this study, several main factors of affecting the snow cover detection, such as the atmosphere, the terrain, the underlying surface of snow and cloud, are concerned and considered. The Akita Prefecture and Tohoku Region of Japan as the study area is selected, and the MODIS images from Terra satellite and Aqua satellite are the main study use images data. The main objective of this research is that the snow cover detection accuracy is improved and developing a snow cover detection method which is applicable to the Akita Prefecture, Japan. In the present work, several novel methods on snow cover detection were proposed to improve its accuracy. The work is divided into five chapters, which were described as follows.

In chapter 1, research background, which includes the current climate conditions of world and Japan, the significance of snow observations, observation methods of the snow and previous researches of snow cover detection using the satellite imagery data, is described. Meanwhile, developing snow cover detection methods with high accuracy as the research objectives is also presented. And the construction of this thesis is listed in this chapter.

In chapter 2, the study region and the used data are presented. The study area includes Akita

Prefecture Area and Tohoku Region, and the used data include the MODIS imagery data, Landsat Satellite Operational Land Imager Data, Digital Elevation Model Data, In-situ data (AMeDAS data and RSIS Data). In addition, the initial preprocessing steps, which include Geographic Correction, Study Area Clipping, Atmospheric Correction and Topographic Correction, before the snow cover detection conducted with proposed methods were also described in this chapter.

In chapter 3, a new method for snow cover detection via the combination of NDSI and NDVI based on the atmosphere conditions, the terrain features and the underlying surface covered by snow was proposed to be used for the study area of this work, Akita Prefecture in Japan. The preprocessing, including atmospheric correction with CREFL_SPA, geographic correction with the MRT Swath, study area clipping and topographic correction with a shadowing function method was conducted before the snow cover detection to improve the accuracy of snow pixels detection. The process of the whole snow cover detection is divided into two parts. One is that NDSI was used to detect the snow pixels of the whole area. The other one is that NDVI was used to distinguish the mixed pixels of the snow and forests. Then the threshold value of NDSI was correspondingly lowered to improve the detecting accuracy for snow in forests. The Terra MODIS Level-1 B product data and AMeDAS snow depth records in 13 observation stations across the whole Akita Prefecture during the period of December 2010 to April 2011 were selected. Through the validation of compared to the MOD10_L2 data and NDSI alone results, it has been proved that the accuracy of proposed method for snow cover detection was improved about 11%. Therefore, it is feasible and effective to use the proposed method for the snow cover detection in Akita Prefecture of Japan with MODIS images. This method is proved to be applicable to Akita Prefecture.

In addition, in the present work, GIS forest region data and the NDVI were adopted for the forest area discrimination based on Terra/MODIS data and natural and geographic situation of the Tohoku region. The whole research was conducted in the environment of the Interface Definition Language (IDL). During the forest area discrimination, the GIS forest region data and the NDVI were input and calculated. Then, image comparisons between GIS forest region data and the NDVI forest area discrimination were investigated. The results of snow cover detection without the forest area discrimination and with GIS forest region data and the NDVI for the forest area discrimination were also compared from December 2013 to April 2014. Through validation, the results show that the accuracy of without the forest area discrimination, with GIS forest region data and with the NDVI for the forest area discrimination are 78.18%, 89.35% and 86.23%, respectively. The accuracy with GIS forest region data and with NDVI for the forest area discrimination was increased by 11.17% and 8.05%, respectively. And the accuracy with GIS forest region data is about 3.12% higher than the NDVI discrimination method.

In chapter 4, section 4.2, FLAASH and 6S code model were adopted for the atmospheric correction based on Terra/MODIS data and natural and geographic situation of Akita prefecture. FLAASH model was calculated in the environment of the Interface Definition Language (IDL). The applied 6SV1 is a vector version of the 6S radiative transfer code. It can simulate the reflection of solar radiation, spectral and geometrical conditions. The parameter items and values of FLAASH and 6S code model were input during the atmospheric correction, then image comparisons

between FLAASH and 6S code model atmospheric correction were investigated. The results of snow cover detection without atmospheric correction and with FLAASH and 6S code model for atmospheric correction were also compared from December 2010 to April 2011. Through validation, the results showed that the snow cover detection accuracy was improved by 40% and 46% with FLAASH model and 6S code model for atmospheric correction comparing to without atmospheric correction. Moreover, the accuracy of snow cover detection with 6S code atmospheric correction is higher than 6% compared to the FLAASH model, and it can be confirmed as optimal atmospheric correction method.

In section 4.3, a new snow cover detection method based on visible red and blue channel from MODIS imagery under the cloud-free condition is proposed for Akita Prefecture considering the influence of atmosphere, topographic features, snow-covered underlying surface and the principle of the snow cover detection from MOD10_L2. In this method, the MOD02HKM product is preprocessed by the geographic correction, study area clipping, atmospheric correction and topographic correction. Then, the spectral analysis was conducted. The composited true color images which represent 5 types of typical snow cover distribution situations on clear days and their corresponding 2-dimensional scatter plot density distribution figures in visible red band 1 and blue band 3 are selected as the training images. The final snow cover detection map was extracted by determining the threshold values of the reflectance as greater than 0.458 in band 1 and greater than 0.60 in band 3 through all of situations analysis. And finally, the snow map of Akita Prefecture was obtained. As the validation data, the snow depth records of 31 observation stations across the whole study area were chosen and divided into forest region, the plain region and basin region. Meanwhile, the overall accuracy, over-estimation error and under-estimation error as the validation method were calculated to prove the high accuracy of proposed method. Through the validation, the average accuracy of the proposed method is 26.27% higher than the MOD10_L2 products based on in-situ snow depth data from these 31 observation stations. It can be also proven that the proposed method is feasible and applicative for Akita Prefecture.

In addition, in order to operate the snow cover detection more effectively under the cloud condition, in section 4.4, another new snow cover detection method, which also based on terrain features and the underlying snow-covered surface in Akita Prefecture, Japan, is proposed to conduct the snow cover detection and eliminate the impact of cloud as much as possible. As it is difficult to remove a large area of cloud using information from optical sensors, predominantly sunny days (with cloud cover making up less than 5% of the acquired images) are selected for snow cover detection. The preprocessing steps are the same as the section 4.3. In this method, during the snow cover detection process, mixed pixels of snow and cloud were first extracted from other ground surface features according to a 2-D scatter plot of spectral reflectances in bands 1 and 3. Then, cloud pixels were detected with a 2-D scatter plot of spectral reflectances in the short-wave infrared bands 6 and 7 and removed from snow pixels. Finally, a final snow cover map of Akita Prefecture is obtained. Compared with the MODIS snow products, in-situ snow depth data and previous snow cover detection method, the average accuracy obtained from the proposed method provides an improvement of 11.79% compared to the MOD10A1

product, and 22.05% compared to the NDSI and NDVI combination in Akita Prefecture. Furthermore, the new proposed method is also further validated with the MODIS image and AMeDAS snow depth data from Aomori Prefecture and the Landsat OLI image data from Mt. Chokaizan region. Through the validation, this proposed method is also proven to be a feasible and effective snow cover detection method.

In chapter 5, the conclusion and results of the whole study are described in this chapter. And the proposed methods for snow cover detection are also expected to apply for improving the environment management and agricultural development.

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論文審査結果要旨

本論文は、地球観測衛星テラとアクアの MODIS 画像を対象に積雪の検知方法について検討したものである。従来法である正規化雪指数（NDSI）と NASA の積雪検知プロダクトは、大気補正、地形補正、および積雪に覆われたカテゴリの状況を考慮しておらず、森林や山地のような複雑な状況を有する地域での検知結果の正確性に問題があった。これに対し、論文提出者は大気補正と地形補正などの前処理の効果を明らかにしたうえで、研究地域に適用し、より精度の高い積雪検知方法を三つ提案した。また、提案方法の信頼性を実験的に検証し、従来法、積雪検知プロダクトに比べ、積雪検知精度が向上することを明らかにした。本論文は全五章で構成されている。

第一章は序論であり、研究背景や目的および論文の構成について述べている。第二章では、研究地域や使用した衛星画像、数値標高モデルおよび現場の積雪観測データについて述べたうえで、積雪検知に必要な地理補正、切り出し、大気補正と地形補正などの前処理ステップについて検討した。第三章では、正規化植生指数（NDVI）と NDSI を組み合わせ、カテゴリに応じた検知方法を提案した。また、従来法と積雪検知プロダクトと比較し、提案方法の有効性と信頼性を明らかにしたうえで、アメダス観測所で誤差を生じる原因について検討した。このほか、GIS か NDVI を利用した森林地域分類方法および積雪検知結果への影響にも検討した。第四章では、大気放射伝達モデルをベースにした FLAASH と 6S コード大気補正方法を行い、各モデルに入力したパラメーターと大気補正前後の効果を比較したうえで、この二つ方法が最終的な積雪検知結果に及ぼす影響についても評価した。次に、6S コード大気補正と地形補正などの前処理の効果を明らかにしたうえで、一年間の積雪とカテゴリの季節変化および赤と青波長範囲内での画素分布に基づき、雲のない画像の二次元散布図を利用する検知方法を提案した。さらに、全体精度、誤検知と未検知誤差を導入し提案方法の信頼性を評価した。また、雲のある画像に対し、バンド１と３及びバンド６と７の二次元散布図を利用し、雲を除去したうえで積雪を検知する方法を提案した。日時の異なる研究地域である秋田県、および第三者地域である青森県の MODIS 画像との検証および鳥海山地域の高分解能 Landsat OLI 画像との比較を通じ、提案方法の効果と信頼性を明らかにした。第五章では、本研究で得た結果をまとめ、今後の研究課題を提起している。

以上、本論文は，積雪検知分野において多くの知見と成果を得ており、学術的、工学的価値が高く、その研究成果は理論上及び実用上の観点において衛星リモートセンシングを主とする分野に大いに寄与できるものと考えられる。よって、本論文は博士（工学）の学位論文として合格と認める。