ASTER 衛星画像と既存都市域マップの複合的利用による高精度・高分解能都市域マッピング

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Developing Urban Extent Map of High Accuracy and Resolution by Integrating ASTER satellite Images and Existing Urban Extent Maps

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概要：本研究では，ASTER 衛星画像と既存の都市域マップの複合的な利用で，都市域マップを高精度・高分解化する手法を提案した．提案手法は次の 2 ステップで構成される．1) ASTER/VNIR 衛星画像を教師無し学習に基づいてクラスタリングし，既存都市域マップを重ね合わせることで都市クラスタを識別し抽出する，2) ASTER/VNIR 衛星画像からの抽出結果と既存都市域マップの組み合わせ別にグラウンドトゥルースデータに対する条件付確率を算出する．既存都市域マップとして，空間分解能 1km の MOD12Q1 と GRUMP を用いて，世界の 101 の都市域を対象に試行した．その結果，都市域マップの空間分解能は 15m に向上し，MOD12Q1，GRUMP に比べて，精度が向上した．以上より，本手法は都市域マップの高精度・高分解能化に有用であるといえる．

Keywords: ASTER 衛星画像(ASTER satellite image), 都市域マップ(urban extent map), ベイズ推論(Bayesian inference)

1 Introduction

There will be serious impacts of global climate change at several places over the world in the future. The size, scale, and form of cities and their likely future growth trajectories will be a critical concern (Laumann, 2005).

Several organizations have developed global urban extent map and land cover map for the requirements; however they are not enough detail for analysis on urban scale, because the spatial resolution is 1km. Angel et al. (2005) indicates it is impossible to analyze urban form with the coarse resolution of existing urban extent map.

On the other hand, spatial resolution of ASTER/VNIR, mounted on Terra earth observation satellite, is 15m. Multi-band images taken by ASTER/VNIR are used in many cases of extracting and change detection of urban extent. In addition, ASTER/VNIR has been operated for completing cloud free coverage all over the land since December, 1999. Now, it is expected to be completed. Thus, ASTER/VNIR image is very suitable for urban extent mapping all over the world. Integrating ASTER/VNIR and existing urban extent map will improve accuracy and resolution of global urban extent map.

In this paper, we suggest the method for automation of developing urban extent map of high accuracy and resolution by integrating ASTER satellite Images and existing urban extent maps. We preliminary developed new urban extent map on 101 sites of the world with the method using available dataset.

2 Method

2.1 Method for Developing urban extent map of high accuracy and resolution

Objective of this study is processing of ASTER/VNIR multi spectral images on urban areas all over the world. To achieve processing on huge

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number of urban area, the data processing has to be automatic. Generally, non-supervised clustering is used for automatic processing; however class (urban/non-urban) of the clusters has to be recognized manually.

In this study, existing urban extent maps are used as information for recognition of urban area by overlaying the maps on clustered ASTER/VNIR images. The method is effective for automation because it does not need manual processing.

However, land cover which have similar spectral characteristics to urban area, such as barren or sand, are possible to be clustered into same cluster with urban area. It means there are uncertainties on the result of extracting urban area from ASTER/VNIR.

We focus on Bayesian inference, which is applicable to dealing uncertainties (Lu, 1996). Conditional probability calculated by Bayesian inference indicates likelihood of hypothesis on true value (urban/non-urban) estimated by observation (Skidmore et al., 1996). We suggest 2 steps of procedure for developing new urban extent map as following 2.2.1 and 2.2.2.

2.1.1 Extracting urban area from ASTER/VNIR images

Urban area is extracted from ASTER/VNIR images by clustering pixels and classifying the clusters into urban or non-urban. The clustering is based on non-supervised method, such as ISODATA, for automation.

Recognizing urban/non-urban of clusters is achieved by calculating percentage of "urban" in existing urban extent map against each cluster. To normalize difference in area of urban between ASTER/VNIR scenes, the percentage was divided by percentage of "urban" in a whole image. We call it Urban Pixel Specialized Index (UPSI) and it is defined as formula 1.

$$UPSI_i = \frac{UA_i / CA_i}{UA / A} \qquad (1)$$

where i means subscription for each cluster, $UPSI_i$ means UPSI of cluster i, CA_i means number of pixels in a scene, UA means number of 'urban' pixels in a scene, A means number of pixels in a scene. Each cluster is labeled as urban or non-urban by thresholding on UPSI.

2.1.2 Calculating conditional probability

Conditional probability is calculated for each combination of the result of 2.1.1 and existing urban extent maps with ground truth point dataset which represents whether urban or non-urban at sample point.

Here, we define that class in the result of 2.1.1 is "urban" as condition A, that class in existing urban extent map is "urban" as condition B, and that ground truth is "urban" as condition C. Conditional probability of condition C under condition A and B is calculated as formula 2 by Bayes theorem.

$$P(C|A \cap B) = \frac{P(A \cap B|C) \cdot P(C)}{P(A \cap B)} = \frac{P(A \cap B \cap C)}{P(A \cap B)} = \frac{N(A \cap B \cap C)}{N(A \cap B)} \qquad (2)$$

where $P(X|\, Y \cap Z)$ means probability of X under condition Y and Z, $N(X)$ means number of pixels under condition X.

Conditional probability of condition C is calculated for all combinations of A and B. Urban area is assigned on pixels at which conditional probability is higher than an appropriate threshold.

2.2 Accuracy assessment

User's accuracy (UA) and producer's accuracy (PA) is used for accuracy assessment of the result. UA indicates lowness of inclusion errors. PA indicates lowness of exclusion errors. They are defined as formula 3.

$$UA = \frac{N(U_g \mid U_a)}{N(U_a)} \quad PA = \frac{N(U_a \mid U_g)}{N(U_g)} \qquad (3)$$

where $N(U_g|\, U_a)$ means number of pixels where the ground truth is urban under condition that the result is urban, $N(U_a|\, U_g)$ means number of pixels where the result is urban under condition that ground truth is urban, $N(U_a)$ means number of pixels where the result is urban.

There is reverse relationship between UA and PA due to the definition. Thus the result is evaluated considering both UA and PA.

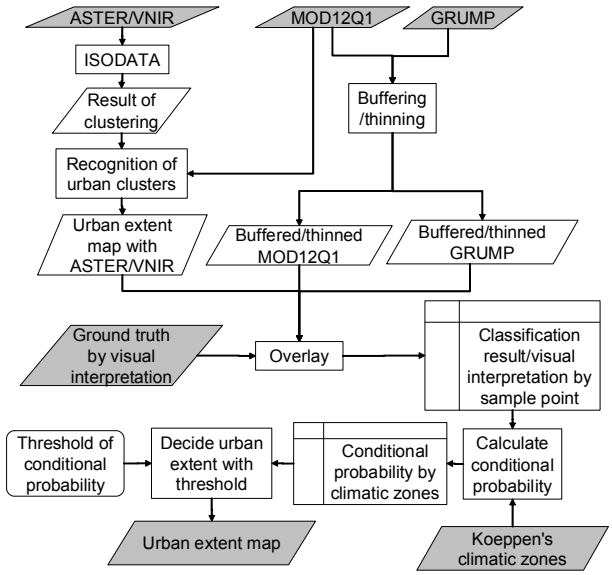

Fig. 1 Flowchart of data processing

3 Data processing

3.1 Material

GRUMP (http://beta.sedac.ciesin.columbia.edu/gpw/) and "urban and built-up area" of MOD12Q1 (http://duckwater.bu.edu/lc/mod12q1.html) are used as existing urban extent map. ASTER Data beta processed by the AIST GEO Grid from ASTER Data is used as input ASTER/VNIR. As ground truth point dataset, about 500 sample points per scene are visually interpreted on ASTER/VNIR image. The half of the ground truth point dataset is used for accuracy assessment; the other is used for calculating conditional probability.

3.2 Extracting urban area from ASTER/VNIR images and buffering/Thinning on existing maps

ISODATA method is applied for non-supervised clustering of ASTER/VNIR images at 101 cities of the world. UPSI is calculated on each cluster as formula 1. Threshold with which UA times PA is the highest is decided as the most appropriate one.

The accuracy of MOD12Q1 and GRUMP will be improved by thinning, because urban area of GRUMP and MOD12Q1 is pointed out to be overestimated (Elvidge et al., 2004; Tatem et al., 2005). The overestimation may not be general. Thus buffering for underestimation is also considered. The most appropriate buffering/thinning distance, with which UA times PA is the highest, is calculated.

3.3 Calculating conditional probability and decision of urban area

Class (urban/non-urban) of urban extent map, which is the result of 2.2 and 2.3, is attached to ground truth point dataset by overlaying them. Conditional probability against ground truth under each combination of urban extent maps is calculated with the table by climatic zone. Urban area is decided by threshold on the conditional probability. UA and PA of several cases are calculated by adjusting the threshold on conditional probability.

4 Result

4.1 Thresholding on UPSI and buffering/thinning on MOD12Q1, GRUMP

101 scenes of ASTER/VNIR images are clustered into 100 clusters and UPSI is calculated for each cluster by overlaying MOD12Q1. The most appropriate threshold, with which UA times PA is the highest, is 1.2.

UA and PA are calculated for buffered/thinned MOD12Q1 and GRUMP in each case of buffering/thinning from 0km to 10km. The most appropriate distance, with which UA times PA is the highest, is no-buffering/thinning for MOD12Q1 and 2km-thinning for GRUMP. The threshold and distance is used for following analysis

4.2 Calculating conditional probability and Accuracy assessment

Conditional probability is calculated by overlaying urban extent map, which is the result of 4.1. UA and PA are calculated in each case of threshold by 0.1 (Figure 2). When threshold of conditional probability is 0.4, UA times PA is the highest. The UA is 56% and the PA is 57%.

5 Discussion

5.1 Misclassification by climatic zone

Figure 2 shows UA and PA in each case of threshold by 0.1. Accuracy of the result is better than MOD12Q and GRUMP in aspect of both UA and PA. This means the result is comprehensively more accurate than existing urban extent maps.

UA and PA by climatic zone show that the

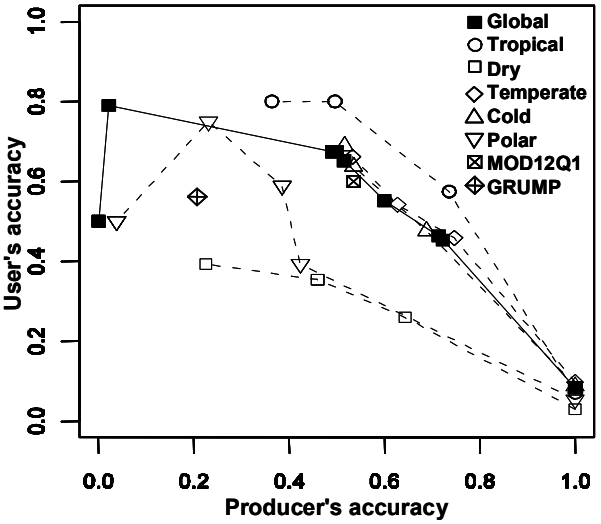

Fig. 2 UA and PA of proposed method by climatic zones and existing urban map

misclassification is more likely in dry zone than in the other climatic zones. Result in dry zone is overestimated than actual urban area, and the boundary is similar to MOD12Q1 and thinned GRUMP. It indicates the overestimation is due to overestimation of existing urban extent map.

Small et al. (2005) shows blooming effect, which is cause of overestimation of GRUMP, depends on size of urban. The size of urban will be different between climatic zones. Thus discrimination of climatic zones in threshold and buffering/thinning will resolve the misclassifications.

5.2 Index based on spatial structure of urban area

Some actual urban areas are missed because the areas area not included in urban extent of MOD12Q1 and thinned GRUMP. It may be due to that extraction of urban extent from ASTER/VNIR images and existing urban extent map is based on feature parameter by pixel. In urban area, spatially high resolution observation detects complex spatial texture. Spatial resolution of ASTER/VNIR is 66 times higher than existing urban extent maps and is enough to detect complex spatial texture of urban from other land cover. Thus feature parameter based on spatial texture of urban area will help to improve accuracy.

6 Conclusion

In this paper, we implemented the method for improving accuracy and resolution of urban extent map by integration of ASTER/VNIR and, as existing urban extent map, MOD12Q1 and GRUMP. Spatial resolution of urban extent map developed with proposed method improves to 15 m. In addition, user's accuracy and producer's accuracy of the map assessed as 54% and 57%, better than existing urban extent maps. The developed map will help to enable to analyze urban form in urban scale globally.

For further study, 1) algorithm for deciding appropriate buffering/thinning distance for each climatic zone will be implemented; 2) feature parameter based on spatial texture will be introduced.

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