

北・中央アジアにおける広域土地被覆変化地域の調査

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研究代表者 建石隆太郎
(千葉大学環境リモートセンシング研究センター)

研究組織

研究代表者：建石隆太郎（千葉大学環境リモートセンシング研究センター教授）

研究分担者：石山隆（千葉大学環境リモートセンシング研究センター助手）

海外共同研究者：ピーター グーニン Peter Gunin

（ロシア科学アカデミー生態進化研究所・研究室長）

海外共同研究者：ニコライ ハーリン Nikolai Kharin

（ロシア科学アカデミー森林生態生産問題センター・主任研究員）

海外共同研究者：ナタリア オガール Natalia Ogar

（カザフスタン植物学研究所・研究部長）

海外共同研究者：エカテリーナ ラチコフスカヤ Ekaterina Rachkovskaya

（カザフスタン植物学研究所・上級研究員）

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研究発表

(1) 学会誌等 (査読つき学術論文)

Ryutaro Tateishi, Land cover mapping of Asia - Problems and solutions of continental/global land cover mapping, Journal of International Society for Tropical Ecology, 43(1), pp.3-8, 2002

R.Tsolmon, R.Tateishi, J. Tetuko S.S, A method to estimate forest biomass and its application to monitor Mongolian Taiga using JERS-1 SAR data, International Journal of Remote Sensing, Vol.23, No.22, pp.4971-4978, November 2002

R.Tsolmon, R. Tateishi and T.Furuya, HUVSGUL LAKE basin forest biomass and its monitoring using JERS-1 SAR Satellite data, Journal of the Mongolian Academy of Sciences, No 2, pp. 60-68 , 2002

Sato, H.P. and R. Tateishi, Proposal for Global land cover guideline legend based on FAO's LCCS, Asian Journal of Geoinformatics, Vol. 3, No.2, pp.35-45, 2002.

Sato, H.P. and R. Tateishi, Definition of the ST-land cover guideline legend derived from the FAO land cover classification system, Asian-Pacific Remote Sensing and GIS Journal, Vol. 15, pp.49-64, December 2002

Tateishi, R. and M.Ebata, Analysis of phenological change patterns using 1982-2000 Advanced Very High Resolution Radiometer (AVHRR) data, Int. J. of Remote Sensing, vol.25, no 12, 2287-2300, 2004

Tateishi, R., Y.Shimazaki, and P.D.Gunin, Spectral and temporal linear mixing model for vegetation classification, Int. J. of Remote Sensing, vol.25, no. 20, pp.4203-4218, 2004

(2) 口頭発表

国際学会発表 -

Jong Geol Park and Ryutaro Tateishi, Land cover change detection using 18 years PAL data by Bhattacharya distance method, Proceedings of the International Symposium on Remote Sensing, pp.14-18, Cheju, Korea, Oct.31-Nov.2, 2001

Ryutaro Tateishi and Hiroshi P. Sato, Proposal of standard classification system for land cover/land use mapping for global/national applications, Proceedings of the International Symposium on Remote Sensing, pp.252-257, Cheju, Korea, Oct.31-Nov.2, 2001

Mitsuhiko Ebata and Ryutaro Tateishi, Phenological stage monitoring in Siberia by using NOAA/AVHRR data, Proceedings of the 22nd Asian Conference on Remote Sensing, pp.412-417, Singapore, November 5-9, 2001

Yasunobu Shimazaki and Ryutaro Tateishi, Land cover mapping using spectral and temporal linear mixing model at Lake Baikal Region, Proceedings of the 22nd Asian Conference on Remote Sensing, pp.843-847, Singapore, November 5-9, 2001

Zhu Lin and Ryutaro Tateishi, Application of linear mixture model to time series AVHRR NDVI data, Proceedings of the 22nd Asian Conference on Remote Sensing, pp.1446-1450, Singapore, November 5-9, 2001

Ryutaro Tateishi, Trend and Challenges of Global Land Use/Land Cover Mapping from Space, International Symposium on LUCC Contribution to Asian Environmental Problems, Tokyo, Japan, Dec.13-14, 2001

Sato, H. and R. Tateishi, Proposal for global standard classification system of land cover/land use, International Symposium on LUCC Contribution to Asian Environmental Problems, Tokyo Japan, December 13-14, 2001

R. Tsolmon, R. Tateishi, T. Javzandulam, J.E. Aban, A method to estimate forest biomass and its application to monitor Mongolian Taiga using AVHRR and VEGETATION, Proceedings of International Geoscience and Remote Sensing Symposium and 24th Canadian Symposium on Remote Sensing 2002, Vol.1, 2002, 24-28 June 2002, Toronto, Canada

R. Tsolmon, Ts. Javzandulam and R. Tateishi, Linear mixing model based on optimization method for Mongolian land cover classification map using Landsat ETM+ satellite data, Proceeding of International Conference on Optimization and Optimal Control ICOOC 2002 UlanBator, Mongolia, 13-17, August, 2002

L. Zhu and R. Tateishi, Linear Mixture Modeling for Quantifying Vegetation Cover Using Time Series NDVI Data, Proceedings of the 23rd Asian Conference on Remote Sensing,

Kathmandu, Nepal, November 25-29, 2002.

Ryutaro Tateishi, H.P.Sato, L.Zhu, Global land cover ground truth database, Proceedings of ISPRS Commission VII Symposium on Resource and Environmental Monitoring, Hyderabad, India, Dec.3-6, 2002

Sato, H.P. and R. Tateishi, Global land cover legend based on FAO' s LCCS, Proceedings of ISPRS Commission VII Symposium on Resource and Environmental Monitoring, Hyderabad, India, Dec.3-6, 2002

R. Tsolmon, R. Tateishi, B. Sambuu, Sh. Tsogtbayar Analyses and trends of forest biomass in higher northern latitudes, the 24th Asian Conference on Remote Sensing, pp. 184-186, November 3-7, 2003, Busan, Korea

R. Tsolmon, R. Tateishi and A. Kondoh, A study on the biomass change of Mongolian forest by using NDVI biomass modeling, the 2nd International Workshop on Terrestrial Change in Mongolia December 2-3, 2003, Yokohama Japan

R. Tsolmon, R. Tateishi and Ts. Enkhzaya, Livestock mapping in Mongolia using satellite and statistical data, the CEReS International Symposium on Remote Sensing, pp. 37-38, December 16-17, 2003 Chiba University, Chiba, Japan

R. Tateishi, Global Land Cover Mapping and Change Monitoring, the CEReS International Symposium on Remote Sensing, pp. 11-14, December 16-17, 2003, Chiba University, Chiba, Japan

Ts. Enkhzaya , R. Tateishi and R. Tsolmon, Satellite data analyses for pasture land use in Mongolia, the 2nd International Workshop on Terrestrial Change in Mongolia December 2-3, 2003, Yokohama Japan

Sato, H.P., Tateishi, R. and Lai, L., Land cover classification in Asia using near and short wave infrared bands of SPOT / VGT data, Paper No. H-3, Proceedings of the International Society for Photogrammetry and Remote Sensing (ISPRS) Working Group VII/6 Workshop, 21-22 October 2003, Kyoto, Japan.

Ryutaro Tateishi, Trend and challenges of global land cover mapping and monitoring, Proc. of the first Int. workshop on land cover study of Mongolia using remote sensing /GIS, 8-10 June 2004, Ulaanbaatar, Mongolia

- 国内学会発表 -

Lin Zhu and Ryutaro Tateishi, Linear mixture modeling approach for estimating vegetation cover using time series SPOT VEGETATION data, Proceedings of the Japan Society of Photogrammetry and Remote Sensing (JSPRS) Annual Meeting, pp.75-78, 4-5 July 2002, Tokyo

R. Tsolmon., R. Tateishi and P.D. Gunin, Mapping of Forest Biomass in Mongolian and Siberian Taiga using AVHRR and VEGETATION data, Proceeding of Japan Society of Photogrammetry and Remote Sensing Symposium, Japan, pp.129-132, 5 July 2002 (Tokyo: JSPRS).

江幡光彦、建石隆太郎、時系列 NOAA/AVHRR PAL データを用いたフェノロジーの全球トレンド解析、日本写真測量学会平成 14 年度年次学術講演会発表論文集、pp.99-104、2002 年 7 月 4-5 日、東京

Renchin Tsolmon, Ryutaro Tateishi, and Peter D. Gunin, Mapping of forest biomass in Mongolian and Siberian taiga using AVHRR and VEGETATION data, Proceedings of the Japan Society of Photogrammetry and Remote Sensing (JSPRS) Annual Meeting, pp. 129-132, 4-5 July 2002, Tokyo

島崎康信、建石隆太郎、時系列リニアミキシングモデルによる画素内比率推定に関する研究 —Spectral and Temporal Linear Mixing Model の提案—、日本写真測量学会平成 14 年度年次学術講演会発表論文集、pp.137-142、2002 年 7 月 4-5 日、東京

佐藤 浩、建石隆太郎、LWCI を用いたアジア地域の土地被覆分類の試み、日本地理学会発表要旨集、No. 62, p.191, 金沢、平成 14 年 9 月 26 - 30 日

佐藤 浩、建石隆太郎、FAO の LCCS によるグローバルな土地被覆ガイドライン凡例の提案、日本地理学会発表要旨集、No. 63, (投稿中)、東京、平成 15 年 3 月 29-31 日

Tsend-Ayush JAVZANDULAM, Ryutaro TATEISHI and Renchin TSOLMON, Methodology for determining soil line and characteristics of vegetation indices、日本写真測量学会平成 15 年度年次学術講演会発表論文集、pp. 213-216, 12-13 June 2003, 東京

建石隆太郎、グローバル土地被覆マッピングの動向と GLI、日本リモートセンシング学会第

35 回学術講演会論文集、pp. 25-26、2003 年 11 月 26-27 日、長岡

Ts. Javzandulam, R. Tateishi and J. Tetuko S.S “A method to retrieve soil moisture in Mongolian arid and semi arid area using L-band Synthetic Aperture Radar Data” Proceedings of the 36th conference of the Remote Sensing Society of Japan. 19-20 May 2004, pp.29-30

(3) 出版物

なし

研究成果による工業所有権の出願・取得状況

なし



Figure 1 (a) wheat and fallow land (50° 32.1' N lat., 106° 22.769' E long.)



Figure 1 (b) pine and steppe (50° 30.382' N lat., 106° 23.106' E long.)

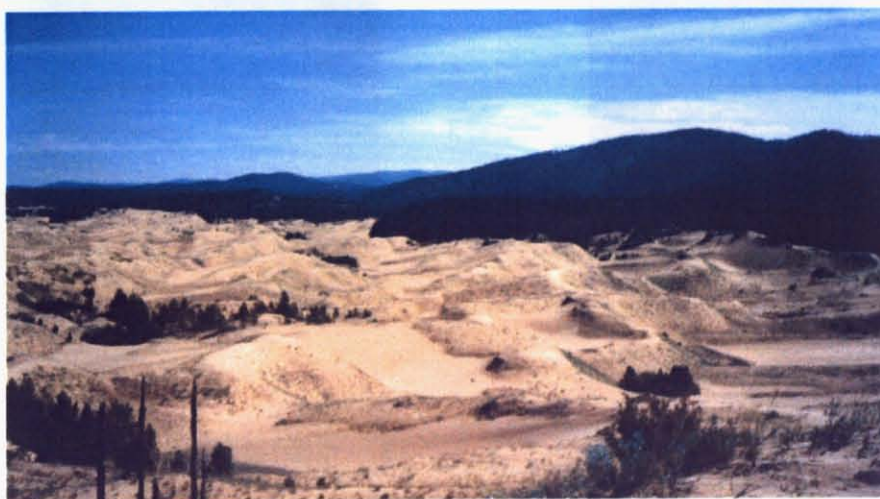


Figure 1 (c) desert sand in Taiga forest (50° 22.763' N lat., 107° 23.905' E long.)

南シベリアにおける現地調査写真（第4章参照）



図 5-4-b GTP10(43.54N,114.25E)



図 5-4-c GTP11(43.53N,115.21E)



図 5-4-d GTP9(43.53N,114.19E)



図 5-4-e GTP6(43.45N,113.08E)



図 5-4-f GTP4(43.43N,112.34E)



図 5-4-g GTP1(43.40N,111.57E)

内モンゴルにおける現地調査写真 乾燥地域 (第 5 章参照)



図5-4-j GTP14(43.30N,116.49E)



図 5-4-k GTP14(43.30N,116.49E)



図 5-4-l GTP15(43.19N,117.03E)



図 5-4-m GTP16(43.38N,120.50E)



図 5-4-n GTP12(43.56N,115.58E)

内モンゴルにおける現地調査写真 草原地域〈第5章参照〉

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第 1 章

要約

第1章 要約

現在、砂漠化、(伐採、火事等による)森林消失、農地開発などの土地被覆変化がグローバルに起きている。このような土地被覆変化は、人間活動あるいは自然環境変化の要因で起こっており、これが逆にまた地域的な気象、水収支、動植物の種、等の自然環境を変動させる大きな要因となったり、また人間活動に直接影響を与える。すなわち、土地被覆変化は環境変動の一つの指標である。言い換えれば、土地被覆は地球環境の研究における重要な入力パラメータの一つである。グローバルあるいは大陸規模の土地被覆情報は衛星データによりある程度観測可能であり、いくつかのグローバルあるいは大陸規模の土地被覆データセットが作成されている。しかし、正確な土地被覆情報すなわちランドトールスが不足していることがすべての研究において指摘されている。

本研究の目的は次の二つである。

- ① シベリア、モンゴル、中国西部、中央アジアを対象地域として、土地被覆の現況および変化を知るために土地被覆ランドトールスデータベースを衛星データ、地図、現地調査により作成する。
- ② 衛星データを利用して上記地域の1981年以降の土地被覆現況および土地被覆変化を調査し地図化する。

本研究の成果は以下のとおりである。

- ① 土地被覆のランドトールスデータベースの構築の先立ち、標準土地被覆分類項目を定義する必要がある。このため、グローバルな地域を対象とする既存の土地被覆分類項目およびその分類のニーズを調査した。これに基づきグローバル土地被覆マッピングのための土地被覆ガイドライン凡例(ST land cover guideline legend)を作成し、これに基づいて土地被覆ランドトールスデータベースを構築した。(詳細は第6章、第7章第1節参照)
- ② 土地被覆ランドトールスの品質評価の方法を確立した。収集した土地被覆ランドトールスデータの品質を検査し、ミスデータを除去する目的で、ランドトールスデータの検査手法を確立した。その方法は土地被覆タイプ毎にランドトールスサイトの年間正規化植生指標(NDVI)のパターンをプロットし、他のサイトと異なるパターンを持つサイトを再確認する方法である。この方法により、既に収集したランドトールスデータの一部の土地被覆分類項目を変更あるいは削除することによりランドトールスデータを改善できる。(詳細は第7章第2節参照)
- ③ グローバル土地被覆マッピングの傾向を分析し、今後の方向性を明らかにした。今後の方向性の一つがランドトールスデータベースの構築と蓄積・更新である。すなわち、ランドトールスデー

タは従来、分類に使用された後はプロジェクトの内部に隠れて公開されることはなかった。マッピング対象がグローバルとなった現在、グラントルースデータは異なるプロジェクト間で共有し、蓄積、改良されていくべきである。（詳細は第2章参照）

- ④ 1982年から2000年にかけてのAVHRRデータを用いて、土地被覆変化の可能性のある地域を抽出した。1982-84年の10-day composite AVHRR NDVIデータの平均と1998-2000年の平均とを比較し、閾値以上の差のある地域を土地被覆変化可能性地域とした。この結果、植生増加の変化地域と植生減少の変化地域とを抽出することができた。（詳細は第3章参照）

- ⑤ 中国東北部の延吉(Yanji)から内モンゴルの二連浩特(Erenhot)までの東西約 1500km を中国科学院植物研究所の研究者と共同で土地被覆現地調査を行った。比較的遠くまで見渡せる土地被覆が一様な地域において、カメラ、GPS によりその土地被覆を記録し、グラントルースデータを作成した。この調査に基づき内モンゴルの土地被覆状態を分析した。また、バイカル湖南においてロシア科学アカデミー生態進化研究所のグループと共同で土地被覆現地調査を行い、土地被覆状態を分析した。（詳細は第4章、第5章参照）

第2章

グローバル・大陸規模の土地被覆 マッピングにおける問題点

2.1 Global land cover mapping and change monitoring

(R. Tateishi, Global Land Cover Mapping and Change Monitoring, the CEReS International Symposium on Remote Sensing, pp. 11-14, December 16-17, 2003, Chiba University, Chiba, Japan)

2.2 Land cover mapping of Asia - problems and solutions of continental/global land cover mapping

(Ryutaro Tateishi, Land cover mapping of Asia - problems and solutions of continental/global land cover mapping Tropical Ecology, 43(1), 3-8, 2002)

2.3 グローバル土地被覆マッピングの動向と GLI

(建石隆太郎、グローバル土地被覆マッピングの動向と GLI、日本リモートセンシング学会第 35 回学術講演会論文集、pp. 25-26、2003 年 11 月 26-27 日、長岡)

2. 1 Global Land Cover Mapping and Change Monitoring

Ryutaro Tateishi
Center for Environmental Remote Sensing, Chiba University
E-mail: tateishi@faculty.chiba-u.jp

Abstract

This paper describes existing global land cover data, and on-going global land cover mapping projects; these projects are initiated by US Geological Survey, European Commission/Joint Research Centre, Boston University, Global Mapping project, and Japan Aerospace Exploration Agency (JAXA). Also, the present trend of global land cover mapping are explained. Furthermore, a study to extract/analyze land cover changed/unchanged areas using global AVHRR NDVI data from 1981 to 2000 is shown.

1. Introduction

Land cover is one of key environmental parameters for global environmental sciences/policies and it is also necessary for land use planning and agricultural area planning. Before the production of global AVHRR data (1992-1993), existing thematic maps were the main information sources for global land cover mapping. However these global land cover map without the use of satellite images had poor quality. After the use of global AVHRR data, global land cover mapping has developed rapidly. In this paper, presently available global land cover data and on-going projects are introduced and their characteristics and trends are explained. Land cover data shows usually land cover information of a specific time (year). Another necessary land cover information is that of changed/unchanged area. These changed/unchanged information can be extracted by time series satellite data. At the last section of this paper, a study to extract changed/unchanged areas using global time series AVHRR NDVI data is explained.

2. Existing global land cover data

The following four global land cover data derived from satellite data are available.

(1) IGBP-DISCover

The first 1-km global land cover data was developed by a U.S. Geological Survey (USGS) and other organizations. Working under the auspices of the IGBP, Loveland et al. (1999, 2000) developed and applied a global land cover characterization methodology using 1992-1993 1-km AVHRR NDVI data. The methodology is based on unsupervised classification with extensive post-classification refinement. The IGBP DISCover classification provides a general picture of global land cover based on a 17-class land cover legend. The accuracy of the IGBP DISCover land cover data was established through an independent IGBP accuracy assessment. Scean (1999) determined that the DISCover overall accuracy was 59-71 percent depending on the specific validation procedures used.

(2) University of Maryland

A group of John Townshend and Ruth DeFries used the same satellite data as IGBP-DISCover to make a global land cover map with the different land cover legend from IGBP-DISCover land cover data. This group focuses now not on categorical classification but on the estimate of area percentage representation of basic land cover types in a pixel.

(3) Boston University

A group of Mark Friedl uses MODIS data for the global 1-km land cover classification with the same legend of 17 classes as the IGBP-DISCover. This group tries to make a global map every six months to detect land cover changes.

(4) GLC2000

The Joint Research Centre of European Commission coordinated the GLOBAL LAND COVER 2000 Project (GLC 2000) in collaboration with a network of partners around the world. The general objective of GLC2000 is to provide for the year 2000 a harmonized land cover database over the whole globe. The year Two Thousand is considered as a reference year for environmental assessment in relation to various activities, in particular the United Nation's Ecosystem-related International Conventions. To achieve this objective GLC 2000 makes use of a dataset of 14 months of pre-processed daily global data acquired by the VEGETATION instrument on board the SPOT 4 satellite. The legend of GLC2000 is defined by FAO's Land Cover Classification System (LCCS).

3. On-going global land cover mapping projects

The following four global land cover mapping projects are going on.

(1) USGS initiative

A new global land cover mapping project using MODIS 500 m data has started. The mapping will be completed within a few years.

(2) EC/JRC initiative

A new global land cover mapping project called "GLOBECOVER" using ENVISAT/MERIS 300 m data has started. The mapping will be completed within a few years.

(3) JAXA initiative

The initially planned global land cover mapping project using GLI 250 m data will not be achieved by the failure of ADEOS II satellite. However a project of land cover mapping for the whole Asia using GLI 250 m data from April to October 2003 continues.

(4) Global Mapping project

As Global Map version 2, a new global land cover map with the resolution of 1 km will be produced by the cooperation with other projects by 2007.

4. Trend of global land cover mapping

The present global land cover mapping projects have the following features and trends.

(1) global mapping of individual land cover classes

Some key land cover classes important for environmental studies such as wetland, paddy, mangrove, and lake are planned to be mapped individually in different projects.

(2) categorial data + percent area cover of basic land cover types

In addition to the categorial classified land cover map, percent area cover of basic land cover types in a pixel is considered to give actual information of the ground surface. Tree, grass, cropland, urban, and bare ground are examples of basic land cover types.

(3) harmonization of land cover legend

Different land cover legends are used in different projects and in different regions. In order to convert one legend to another one, we have a tool to define land cover classes by a common system. The ideal tool for this is Land Cover Classification System (LCCS) developed by FAO.

(4) improvement of resolution

1 km resolution of AVHRR data was improved to 500 m of MODIS, 300 m of MERIS, and 250 m of GLI.

(5) optical sensor + SAR + lidar

In addition to optical sensor data, global SAR data or lidar data may be used for global land cover mapping. SAR data have a potential to derive information of wetland and forest, and lidar data have a potential to derive vegetation height.

(6) development of global land cover ground truth data

Quality of land cover map is mainly dependent of training sample data (ground truth data) used for the classification. However ground truth data are not exchanged and accumulated. Development of global land cover ground truth data by the cooperation of different projects and for the common use will improve the quality of a land cover map.

5. Global land cover change monitoring

Using time-series AVHRR NDVI data, extraction of land cover changed areas was tried in global area and problems of this method were identified.

5.1 Data used

Normalized Difference Vegetation Index (NDVI) of NOAA NASA Pathfinder Land Data Set (PAL data) from 1982 to 2000 were used in this study. In order to remove cloud effects, Temporal Window Operation (TWO) method (Park and Tateishi 1999) was applied to NDVI data. The TWO method is an algorithm to make a seasonally smooth change pattern for temporal variables at least longer than one year. The TWO-processed data were resampled to 4' (approximately 8 km at the equator) grid raster data in the geographic (latitude/longitude) coordinate system.

5.2 Methodology

(1) The averages of 10-day NDVI from 1982 to 1984 were calculated, and similarly from 1998 to 2000 too.

(2) The difference from the averaged NDVI 1982-84 to the averaged NDVI 1998-2000 were calculated for the corresponding 10-day time period.

(3) The sum of the above difference was calculated for thirty-six 10-day (or one year).

(4) The positive value of the above sum is considered as areas of increasing vegetation activity, and negative value is considered as areas of decreasing vegetation activity.

(5) In order to investigate the trend of time series NDVI values, time-series NDVI curves of unchanged areas of different land cover types such as desert, snow, and forest were analyzed.

5.3 Result

By using large positive and negative threshold values, potential of land cover changed areas were extracted.

However, the following noises and distortions cause wrong results as land cover changed areas.

- high or low NDVI noises remaining after preprocessing
- misregistration along seashore lines
- difference of NDVI levels in different NOAA satellites

Examples of time-series NDVI curves of extracted real land cover changed areas are shown in Fig. 1 and Fig. 2.

6. Conclusions

- Four global land cover data are available
- several global land cover mapping projects are going on
- Trends of global land cover mapping were identified
- Time series NDVI data are effective for global land cover change detection. Noises and trend of NDVI must be eliminated.

References

- Chandra Giri, Zhiliang Zhu, Thomas Loveland, 2003, Global and regional land cover characterization and mapping, Proceedings of the CEReS International Symposium on Remote Sensing, paper No.1-1, 16-17 December 2003, Chiba, Japan
- GLC2000
<http://www.gvm.sai.jrc.it/glc2000/defaultGLC2000.htm>
accessed on 29 October 2003
- Global Land Cover Ground Truth (GLCGT) Database Version 1.2
<http://www.cr.chiba-u.jp/database.html>
- Global Mapping project
<http://www1.gsi.go.jp/geowww/globalmap-gsi/globalmap-gsi.html>
- LCCS
http://www.fao.org/SD/2001/EN0101a_en.htm
accessed on 29 October 2003
- Loveland, T.R., Zhu, Zhiliang, Ohlen, D.O., Brown, J.F., Reed, B.C., and Yang, Limin, 1999, An analysis of the IGBP global land-cover characterization process: Photogrammetric Engineering and Remote Sensing, v. 65, no. 9, p. 1,021-1,032.
- Loveland, T.R., Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, Z., Yang, L., Merchant, J.W., 2000. Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data. *International Journal of Remote Sensing* 21(6/7): 1303-1330.
- Park, J.G. and Tateishi, R., 1999, A proposal of the Temporal Window Operation (TWO) method to remove high-frequency noises in AVHRR NDVI time series data, *Journal of the Japan Society of Photogrammetry and Remote Sensing*, 38(5), 36-47.
- Rosenqvist, A., M. Shimada, T. Igarashi, M. Watanabe, T. Tadano and H. Yamamoto, 2003, Support to multi-national environmental conventions and terrestrial carbon cycle sciences by ALOS and ADEOS-II – the Kyoto & Carbon Initiative, Proc. of the Int. Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France, July 21-25, 2003
- Scepan, J., 1999. Thematic Validation of High-Resolution Global Land-Cover Data Sets. *Photogrammetric Engineering and Remote Sensing* 65(9): 1051-1060.

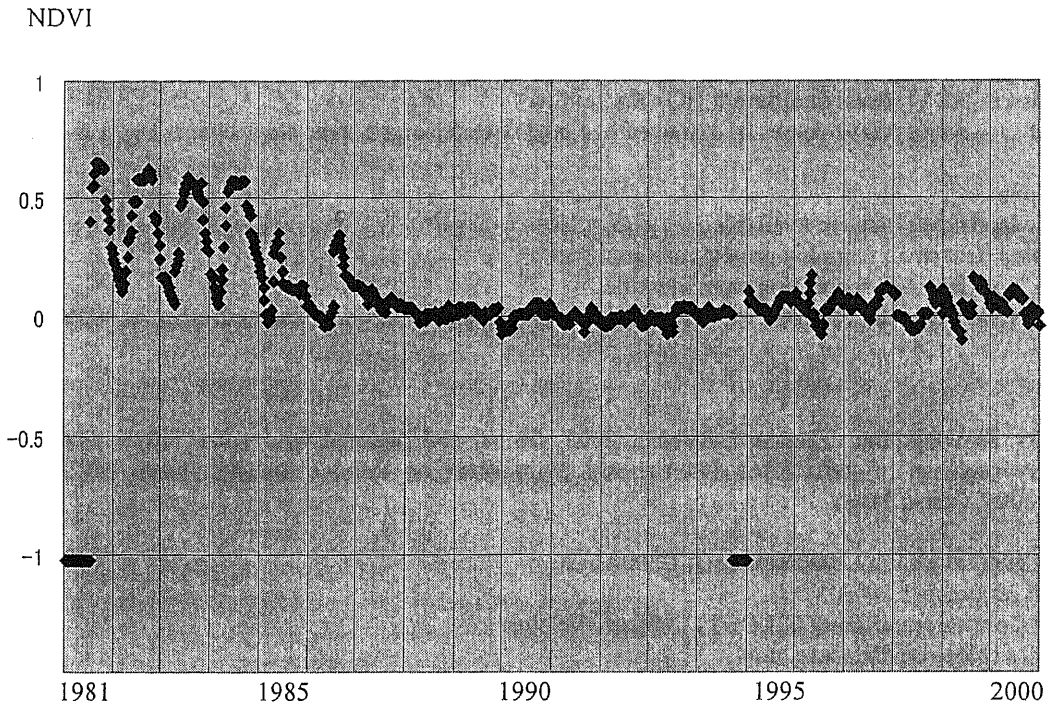


Figure 1 Time-series NDVI curve 1981-2000
Eastern Iran 31° 28'N, 61° 40'E Decease of vegetation

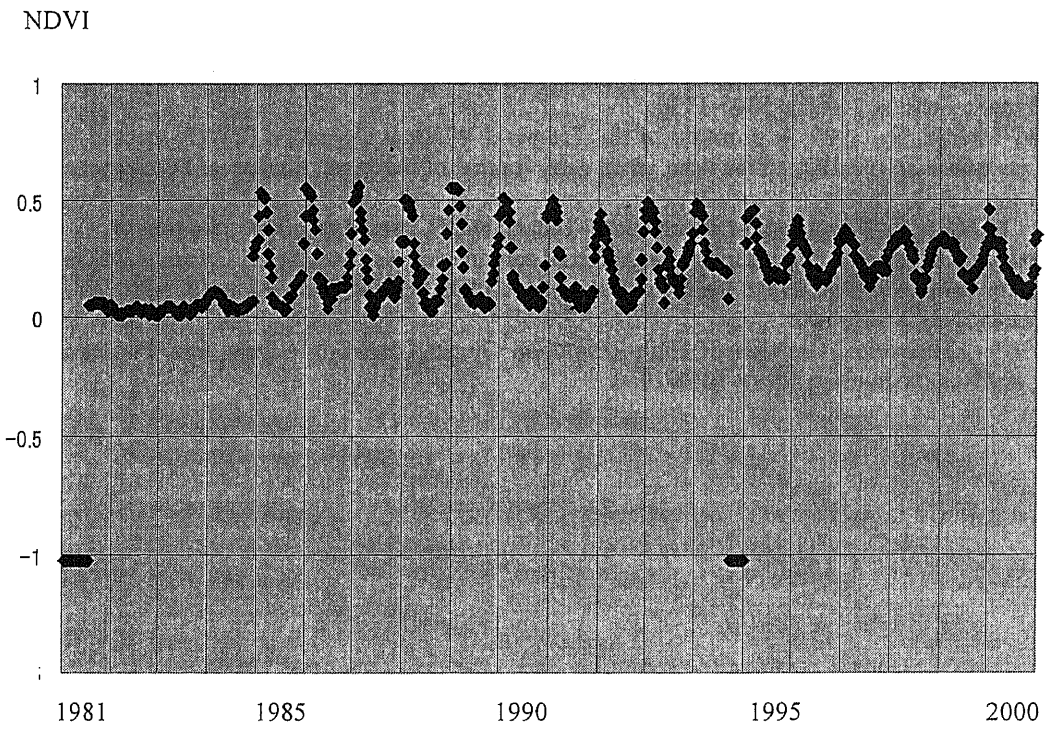


Figure 2 Time-series NDVI curve 1981-2000
Saudi Arabia 19° 52'N, 44° 48'E Irrigation

第3章

時系列 NOAA AVHRR データによる 大陸規模の植生変化の分析

(Tateishi, R. and M.Ebata, Analysis of phenological change patterns using 1982-2000 Advanced Very High Resolution Radiometer (AVHRR) data, Int. J. of Remote Sensing, vol.25, no 12, 2287-2300, 2004)

Analysis of phenological change patterns using 1982–2000 Advanced Very High Resolution Radiometer (AVHRR) data

R. TATEISHI*

Center for Environmental Remote Sensing (CEReS), Chiba University,
1-33 Yayoi-cho Inage-ku Chiba 263-8522, Japan

and M. EBATA

IBM Japan Ltd, 1-14, Nisshin-cho, Kawasaki-ku, Kawasaki-shi,
Kanagawa 210-8550, Japan

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Abstract. Using the National Oceanic & Atmospheric Administration (NOAA) National Aeronautics & Space Administration (NASA) Pathfinder Land dataset (PAL data) from 1982–2000, vegetation phenology (onset, peak and offset) was defined and analysed with climate data. In areas of precipitation-dependent phenology such as Central Africa, it was found that Normalized Difference Vegetation Index (NDVI) is affected approximately 20–40 days after the occurrence of precipitation, depending on land cover types. In areas of temperature-dependent phenology such as Siberia, the relationship of phenology and latitude/elevation was investigated. Using temporal NDVI data of 1982–2000, changes in seasonal NDVI pattern were classified into 11 classes and mapped in the Northern Hemisphere. From this analysis, increasing trends of the annual sum of NDVI were found in Siberia, NE Europe and the northern part of North America where good correspondence with the increasing trend of air temperature was recognized. In contrast, some areas such as the east of the Aral Sea showed a decreasing trend of the annual sum of NDVI. It was found that, in the Northern Hemisphere, the area with increasing trend of the annual sum of NDVI is approximately 12 times larger than the area with the decreasing trend. Also, it was found that areas of increasing/decreasing trend of the annual sum of NDVI correspond roughly to areas with increasing/decreasing trend of air temperature from 1982 to 1995.

1. Introduction

Changes in vegetation activity due to global environmental changes such as global warming are a salient issue in environmental studies. Tucker *et al.* (2001) reported increased vegetation activities in higher northern latitude regions during 1982 and 1999, except during 1991–1992 (Mt Pinatubo eruption in June 1991), from analysis of National Oceanic & Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data. This phenomenon may be caused by an increase in average air temperature of 0.8° in high latitude regions of the Northern Hemisphere from the latter half of the 1970s to the present (Hansen

*Corresponding author; e-mail: tateishi@faculty.chiba-u.jp

et al. 1997). However, the trend of vegetation activities and climate varies geographically and some areas show a cooling trend over the last 20 years.

This study aims to elucidate the changes in vegetation activity globally over 20 years using NOAA/AVHRR data to analyse the relationships between these and climate variables such as precipitation and air temperature. This will clarify geographical distributions of phenological pattern change during 1982–2000 – the main objective of the study. Though some areas have had increasing vegetation activity and other areas have had decreasing vegetation activity during these 20 years, no map has yet been produced to identify their geographical locations.

2. Data sources

Four sources of data were used in this study.

1. *NOAA NASA (National Aeronautics & Space Administration) Pathfinder Land Dataset (PAL data)*. Normalized Difference Vegetation Index (NDVI), channel 4, channel 5 and Solar Zenith Angle data of NOAA AVHRR from 1982–2000 were used. These data are ten-day composite and nominally 8 km resolution data. Land Surface Temperature (LST) data were calculated from channel 4 and channel 5 data using the split window method (Price 1984). In order to remove cloud effects, the Temporal Window Operation (TWO) method (Park and Tateishi 1999) was applied to NDVI and LST data. The TWO method is an algorithm to make a seasonally smooth change pattern for temporal variables at least longer than one year. The TWO-processed data were re-sampled to 4' (approximately 8 km at the Equator) grid raster data in the geographical (latitude/longitude) coordinate system.
2. *Climatic Research Unit (CRU) climate data*. Global 30' grid raster data of air temperature and precipitation were used. These data are available from the Climatic Research Unit (CRU), School of Environmental Sciences, University of East Anglia (New *et al.* 1998; CRU website <http://www.cru.uea.ac.uk/>, accessed May 2003). The data are interpolated data to 30' in latitude/longitude; these are monthly data from 1901 to 1996.
3. *International Geosphere Biosphere Programme (IGBP) Data and Information System (DIS) global land cover data*. These data are 1 km resolution land cover data with 17 classes produced by the activity of the IGBP–DIS group (Loveland and Belward 1997).
4. *Global elevation data*. Global terrain elevation data, ETOPO5 (NOAA-EPA 1992), were used in this study.

3. Satellite-defined vegetation phenology

Three main phenological stages, onset, peak and offset, are defined using ten-day composite NDVI time series data from PAL data. Therefore, these phenological stages are described by the ten-day temporal unit.

In this study, onset time is defined as the time of the greatest NDVI increase using three consecutive ten-day NDVI data. The onset time can be characterized as the greatest leaf expansion or the most grass green-up in the vegetation growing season. On the contrary, the offset time is defined as the time of the greatest NDVI decrease using three consecutive NDVI data. The offset time can be characterized by the most leaf abscission or the most grass brown-off. The peak time is defined as the time of the maximum sum of three consecutive NDVI data in an annual cycle. The 'duration' can be defined as the time length from the onset to the offset.

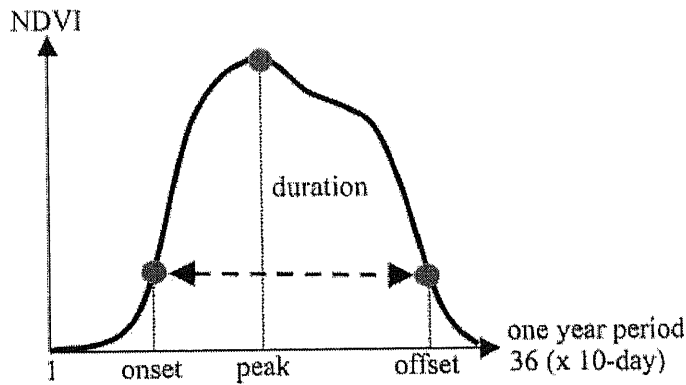


Figure 1. Definition of onset, peak, offset and duration. NDVI, Normalized Difference Vegetation Index.

Therefore, the duration can be considered as the period of 'green vegetation'. Figure 1 shows the concepts of onset, peak, offset and duration.

4. Climatic effects on phenology

4.1. Standard deviation analysis of onset

Since the methodology of this study is based on phenological characteristics described by onset, peak and offset, geographical regions with unclear phenological characteristics, such as tropical forests and desert areas, are excluded from the phenological study. In order to do this, standard deviation analysis was applied to onset data.

First, the temporal average onset image data were derived from NDVI of 1982–2000. Then, the spatial standard deviation was calculated from a 7 × 7 pixel window of the average onset image. The size of 7 pixels (1 pixel = 4 arc-minute) was chosen in order to extract homogeneous areas in terms of phenological characteristics within a 30 arc-minute grid area, which is the size of CRU climatic data. Figure 2 shows

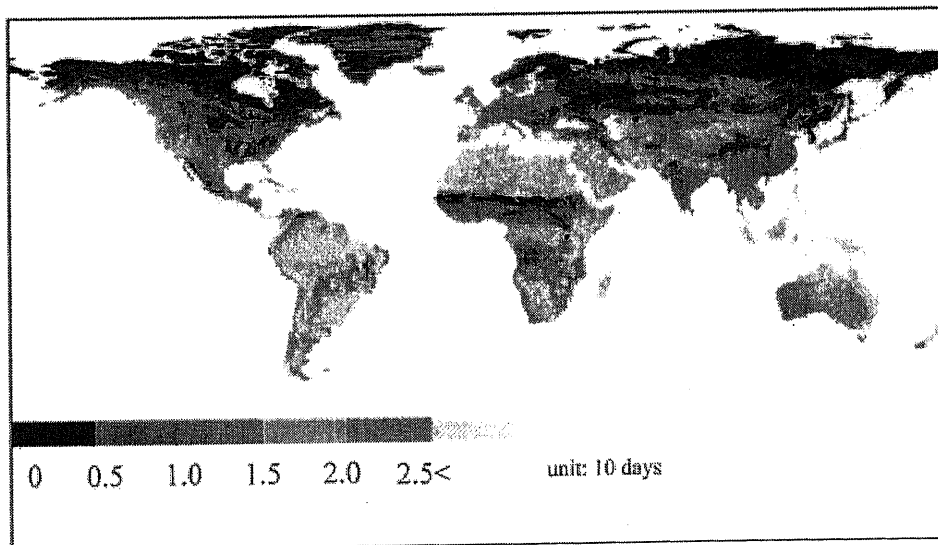


Figure 2. Standard deviation of the onset date.

the standard deviation image of the onset. Regions with a standard deviation greater than 2.5 (unit: ten days) were excluded from the study comparing NDVI-derived phenology with climatic data such as temperature and precipitation and from the study reported in §5 of this paper because these areas have no clear onset and phenology.

4.2. Correlation analysis of NDVI and temperature

In order to clarify the geographical difference of the effect of temperature on vegetation activity, correlation analysis was applied between NDVI and land surface temperature (LST). The correlation coefficient between 36 average ten-day composite NDVI and 36 average ten-day composite LST from 1982 to 2000 was calculated pixel by pixel. Figure 3 shows the global correlation coefficient image. Middle and high latitude regions of the Northern Hemisphere have a positive correlation, implying that temperature positively influences vegetation activity. On the contrary, the east part of South America, a part of Central Africa and the west part of Australia have a negative correlation. Generally, air temperature, precipitation and soil are the three main factors for vegetation growth; the first two have temporal variability. However, NOAA/AVHRR data can provide only land surface temperature (LST). Therefore, the correlation between LST and air temperature were investigated at 12 different land cover types based on IGBP-DIS global land cover data using LST derived from AVHRR and CRU climate data from 1989–1991. At the same time, to analyse the reason for the positive/negative correlation between NDVI and LST, as shown in figure 3, that correlation between NDVI and LST was investigated for 12 different land cover types. Figure 4 shows the relationship between these two types of correlation coefficients – NDVI and LST and LST and air temperature – for monthly data from 1989–1991 at 12 different land cover types. The time period of the analysis was selected to avoid the effect of NOAA satellite change in order to keep the same sensor characteristics. The geographical locations of 12 different land cover types were selected from areas having a homogeneous land cover and clearer phenology. Homogeneous land cover areas were selected by the unit area of at least 30 by 30 arc-minutes, and areas of clearer phenology were extracted using the threshold of 2.5 standard deviations of the onset in 7×7 NDVI pixels. NDVI and LST values used for correlation analysis are an average of 7×7 pixels, which correspond to one air temperature value. From figure 4, it

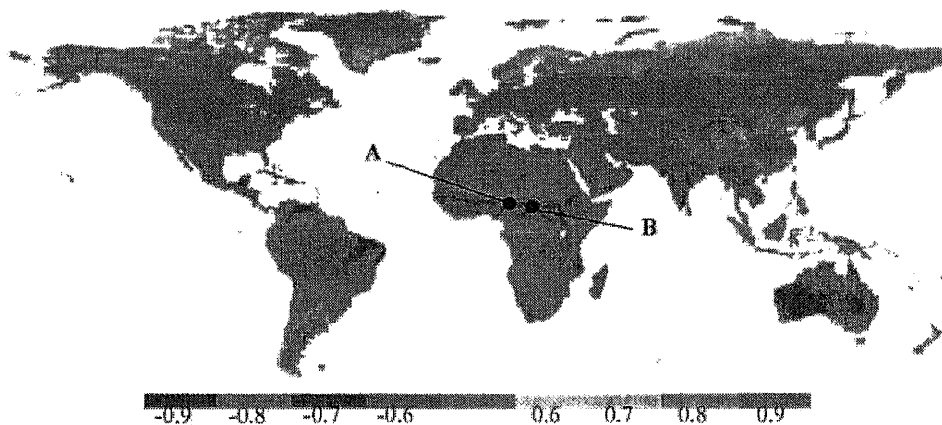


Figure 3. Correlation coefficient between NDVI and LST. A, woody savanna; B, savanna.

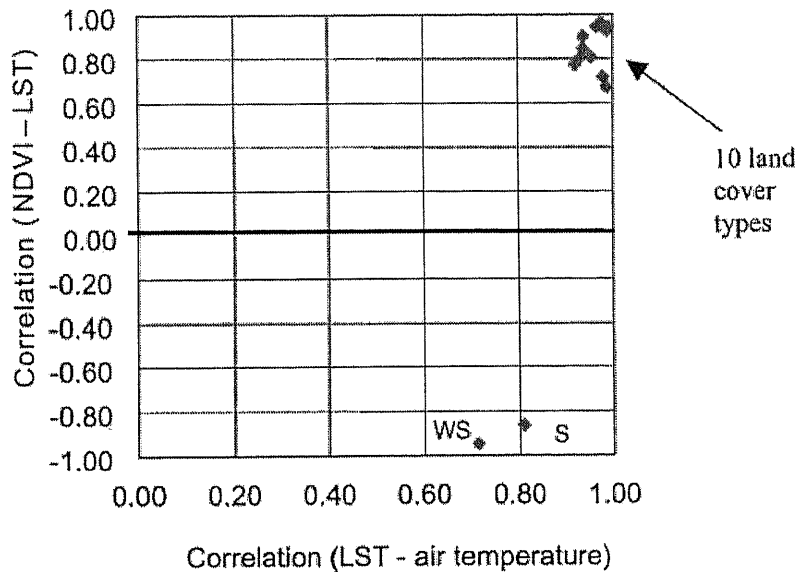


Figure 4. Correlation between NDVI (Normalized Difference Vegetation Index) and LST (land surface temperature) and between LST and air temperature for twelve types of land cover. WS, woody savanna (latitude: 10° N, longitude: 15° E); S, savanna (10° N, 20° E). The ten land cover types (based on the IGBP-DIS land cover dataset) are as follows: evergreen needleleaf forest (53° N, 124° W); deciduous needleleaf forest (55° N, 118° E); deciduous broadleaf forest (42° N, 75° W); mixed forest (52° N, 83° W); grassland (49° N, 57° E); cropland (52° N, 17° E); cropland/natural vegetation mosaic (55° N, 32° E); 'cool' open shrublands (69° N, 157° W); 'cool' closed shrublands (67° N, 135° W); 'cool' barren or sparsely vegetated (70° N, 92° E). 'Cool' means that the area has a minimum LST in the year of lower than 0° C.

can be said that the correlation coefficient between LST and air temperature is higher than 70% in all land cover types, and that only woody savanna and savanna in the examined land cover samples have a negative correlation between NDVI and LST. This negative correlation suggests that precipitation greatly affects vegetation activity in these areas and that precipitation has a negative correlation with LST.

In order to investigate further the effect of temperature and precipitation on vegetation activity, the temporal change of NDVI, air temperature and precipitation of woody savanna and savanna were analysed. Point A in figure 3 is woody savanna located at 10° N latitude, 15° E longitude. Point B is savanna located at 10° N latitude, 20° E longitude. NDVI of points A and B were calculated as the average values of 7×7 NDVI pixels, which is a 28 arc-minute grid, while temperature and precipitation data of these points are 30 arc-minute grid data. Figure 5(a) shows the temporal change of NDVI and air temperature from CRU climate data at point A for the three years of 1989–1991; figure 5(b) shows NDVI and precipitation at point A for the same three years. Figures 5(c) and (d) are similar figures at point B. At both points A and B, air temperatures are over 25° C throughout the year; this is a sufficient temperature condition for vegetation activity of savanna. Sufficient precipitation for vegetation activity, however, comes

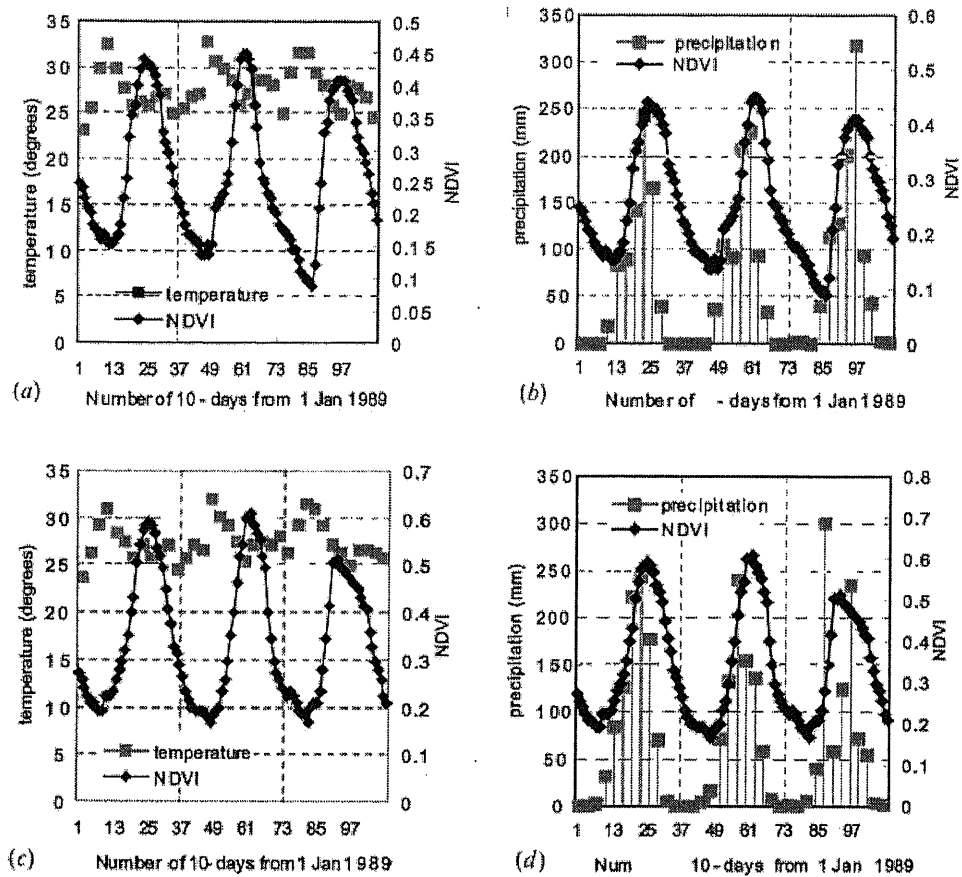


Figure 5. NDVI and (a) air temperature at point A (woody savanna); (b) precipitation at point A; (c) air temperature at point B (savanna); (d) air temperature at point B. See figure 3 for location of points A and B.

only for a limited period in the year. Therefore, precipitation can be considered to be the main factor for vegetation activity in these areas.

The above analysis indicates that there are two types of region as regards the effect of climate on vegetation phenology. One region has a temperature-dependent phenology, which is the positive correlation area in figure 3; the other exhibits a precipitation-dependent phenology, which is the negative correlation area in figure 3. Since air temperature becomes lower in the rainfall period, the precipitation-dependent area shows a negative correlation between NDVI and land surface temperature (LST).

4.3. Precipitation-dependent phenology

In the precipitation-dependent area, the change in NDVI is assumed to be affected by the occurrence of precipitation. In this case, the NDVI change must show some delay following the occurrence of precipitation. In order to confirm the relationship of NDVI change and precipitation change, and to know the time delay of the effect of precipitation on NDVI, the time lag correlation coefficient between

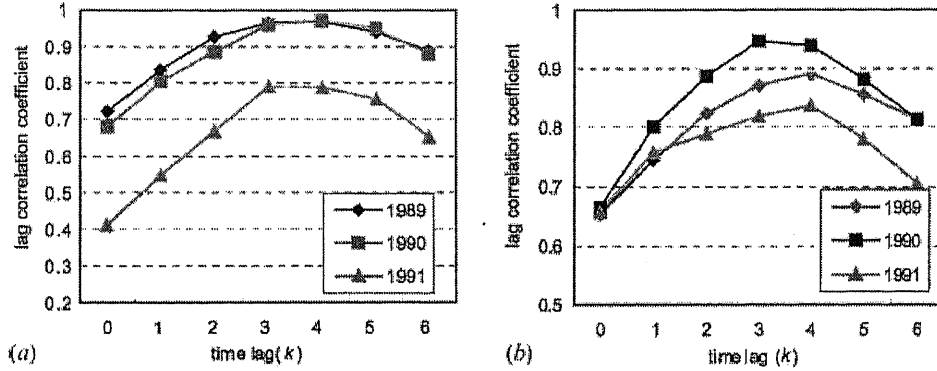


Figure 6. Correlation coefficient $r_{\text{lag}}(k)$ at (a) point A (woody savanna); (b) at point B (savanna). See figure 3 for location of points A and B.

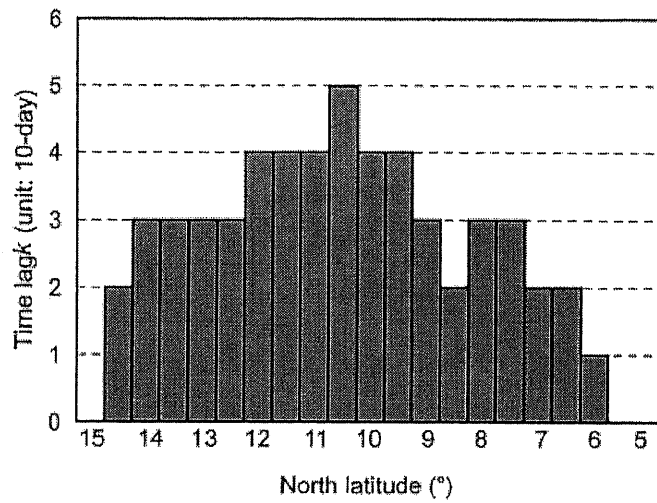
NDVI and precipitation is defined by the following equation:

$$r_{\text{lag}}(k) = \frac{\frac{1}{n-k} \sum_{i=1}^{n-k} (\text{NDVI}_i - \overline{\text{NDVI}})(p_{i+k} - \bar{p})}{\sqrt{\left(\frac{1}{n} \sum_{i=1}^n (\text{NDVI}_i - \overline{\text{NDVI}})^2\right) \left(\frac{1}{n} \sum_{i=1}^n (p_i - \bar{p})^2\right)}} \quad (1)$$

where $r_{\text{lag}}(k)$ is the correlation coefficient between NDVI at time i and precipitation at time $i+k$; NDVI_i is the NDVI at time i ; $\overline{\text{NDVI}}$ is the average of NDVI in a year; p_{i+k} is the precipitation at time $i+k$; \bar{p} is the average precipitation in a year; i is the time scale of a ten-day unit; n is 36 (one-year period); and k is the time lag between NDVI and precipitation.

Figure 6(a) shows the change in correlation coefficient $r_{\text{lag}}(k)$ by time lag k at point A (woody savanna) in Central Africa for the years 1989, 1990 and 1991. Figure 6(b) shows the same change at point B (savanna). Figures 6(a) and (b) indicate that both have high correlation coefficients over about 0.8 at their maximum values and that the maximum occurs at the time lag of 3–4 (30–40 days). This result confirms that NDVI (vegetation activity) is affected by precipitation in these areas, and this effect occurs with a time lag of 3–4 (30–40 days) after the precipitation. The three-year period of 1989–1991 was selected for this analysis to avoid the effects of a change of NOAA satellite. The lower correlation values in 1991 compared with the other two years may be due to the effects of the eruption of Mt Pinatubo in June 1991. However, the work required to find the reasons behind this difference was not undertaken in this study.

For further analysis, the geographical change of time lag k was investigated. Figure 7 shows the time lag k at every 30' from 5° to 15° N latitude along 20° E longitude. The land cover type around 10° N latitude, with a longer time lag of 4 (unit: ten days), is savanna according to the IGBP-DIS land cover data, while the land cover type around 7° N latitude and 13° N latitude, with a shorter time lag of 2–3, is woody savanna. It can be said that the precipitation-dependent area in Central Africa has a time lag from precipitation to NDVI increase of 2–4 (20–40 days); also the length of the time lag is dependent on land cover types.

Figure 7. Time lag k along 20° E longitude.

4.4. Temperature-dependent phenology

As a temperature-dependent area, the phenology of north Eurasia was investigated. The geographical region of 40–80° N latitude (from the middle of the Caspian Sea to the north end of Eurasia) and 20–180° E longitude (from Finland almost to the east end of Eurasia) was extracted for analysis. The average of three phenological stages (onset, peak and offset) for each latitude with the width of 1° from 50° to 75° N latitude was calculated, as shown in figure 8. Proceeding in this manner from low to high latitude,

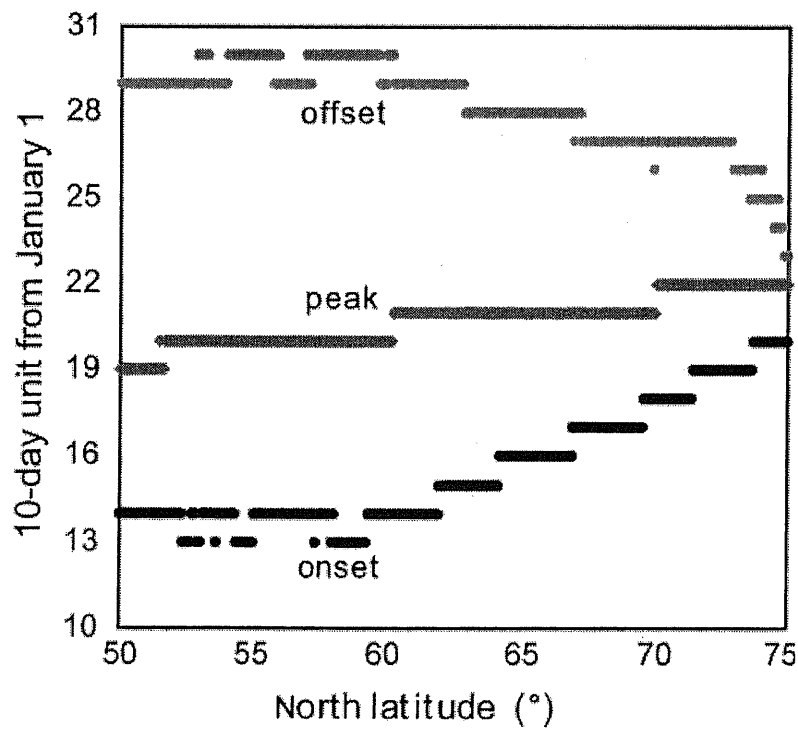


Figure 8. Change of onset, peak and offset by latitude.

onset and peak becomes later, and offset becomes earlier, and duration becomes shorter. This is mainly caused by lower temperatures in higher latitude regions and the subsequent reason of the effect of snow coverage.

To investigate the effects of terrain elevation on the onset, the geographical region of 63–65° N latitude and 55–65° E longitude (Ural Mountains) was selected. The elevation of this area ranges approximately from 0 m to 1200 m. According to IGBP-DIS land cover data, the land cover type below 500 m is 'mixed forest', and that over 500 m is 'cool barren or sparsely vegetated' or 'cool open shrubland'. Figure 9 shows the relationship between onset and elevation. Areas below 500 m show a linear relationship, but no apparent relationship exists in areas over 500 m.

From the above analysis, phenology in temperature-dependent areas is affected by latitude, elevation and vegetation type.

5. Change in phenology during 1982–2000

Tucker *et al.* (2001) reported increased vegetation activity in Siberia over the last 20 years as a result of the effects of global warming. The geographical area, however, was not clearly identified; and there may, in fact, be an opposing trend – decreased vegetation activity – in some other geographical area.

Eleven types of phenological change pattern were identified in this study using the following four phenological parameters:

- **duration:** length from onset to offset; the unit is ten days in this study;
- **time of onset/offset:** onset time or offset time; the unit is ten days in this study;
- **NDVI_{peak}:** maximum NDVI in a year;

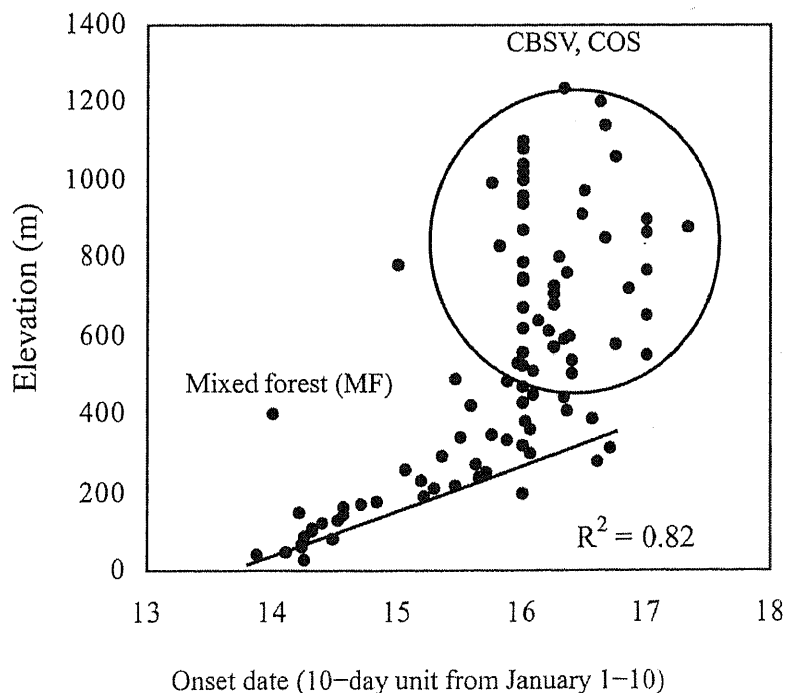


Figure 9. Relationship between onset and elevation. CBSV, 'cool' barren or sparsely vegetated; COS, 'cool' open shrubland. 'Cool' means that the area has a minimum LST in the year of lower than 0°C.

- Σ NDVI: sum of NDVI over the NDVI level at the time of onset during the above 'duration'.

NDVI has a positive linear correlation with the fraction of absorbed photosynthetically active radiation (fAPAR) (Goward and Huemmrich 1992). However, another report said that a linear correlation of NDVI with fAPAR is not always valid (Moreau and Li 1996).

Running and Nemani (1988) reported that NDVI seasonal change patterns coincide with that of net primary production (NPP) estimated by the forest process model. The previous studies indicate that NDVI has a positive correlation with vegetation activity, such as fAPAR and NPP, though the relationship is not always linear. If Σ NDVI is defined as in this study, it can be said that the yearly trend of Σ NDVI shows the trend of increase or decrease in vegetation activity.

The thresholds of increase, decrease and no change for the above four variables are determined as follows. The threshold for duration and time of onset/offset is based on the ten-day unit. The threshold for NDVI_{peak} and Σ NDVI is based on a least-squares regression line from 1982 to 2000. If the regression value at 2000 is within $\pm 3\%$ of the value at 1982, NDVI_{peak} or Σ NDVI is assumed to display no change. If it is more (less) than plus (minus) 3%, the NDVI_{peak} or Σ NDVI is assumed to increase (decrease).

Tucker *et al.* (2001) reported that the change in NDVI value for the Taklimakan desert and Arabian desert from 1982 to 1999 was within 0.002, which is assumed to be the change in AVHRR sensor characteristics over 18 years. The above-mentioned threshold value of 3% is equivalent to an NDVI value of 0.009 when the NDVI level in 1982 is 0.3. This means that the determined threshold value is sufficiently larger than the effect of the change in sensor characteristics.

According to the above threshold, eleven patterns of change during 1982 and 2000 were found (figure 10; table 1). Figure 11 shows the area of each phenological change pattern. The patterns where Σ NDVI exhibits an increasing trend are patterns 7, 9, 10 and 11, regions occupying 15.2% of the whole land area of the Northern Hemisphere. Figure 12(a) shows this geographical distribution, which encompasses wide areas including high latitude regions of Siberia, Europe and North America. The patterns where Σ NDVI exhibits a decreasing trend are patterns 6 and 8, which occupy 1.2% of the total land area of the Northern Hemisphere. Figure 12(b) shows this geographical distribution, encompassing limited areas such as a part of Central Asia. These areas and their geographical distributions depend on threshold values of change and no change. The result, however, indicates that the area of increasing trend in Σ NDVI is approximately 12 times as large as its decreasing counterpart.

Further analysis was done by comparing the trend of Σ NDVI with the trend of air temperature. The annual average of monthly air temperature over 5°C was calculated from CRU climate data, its trend from 1982 to 1995 was derived by regression analysis. Figure 13 shows the geographical distribution of positive and negative trends of this annual average of air temperature.

From figures 12(a) and 13 it could be inferred that some areas show a good correlation of increasing trend in Σ NDVI and increasing trend in air temperature: for example, areas surrounded by dotted lines in figure 13 – Siberia, NE Europe and the northern part of North America. Tropical areas, such as Central America, the Middle East, northern India and SE Asia, have an increasing trend in air temperature but no increasing trend in Σ NDVI, because these regions are covered by tropical vegetation or desert. The NDVI patterns of these cover types are less influenced by slight changes in air temperature.

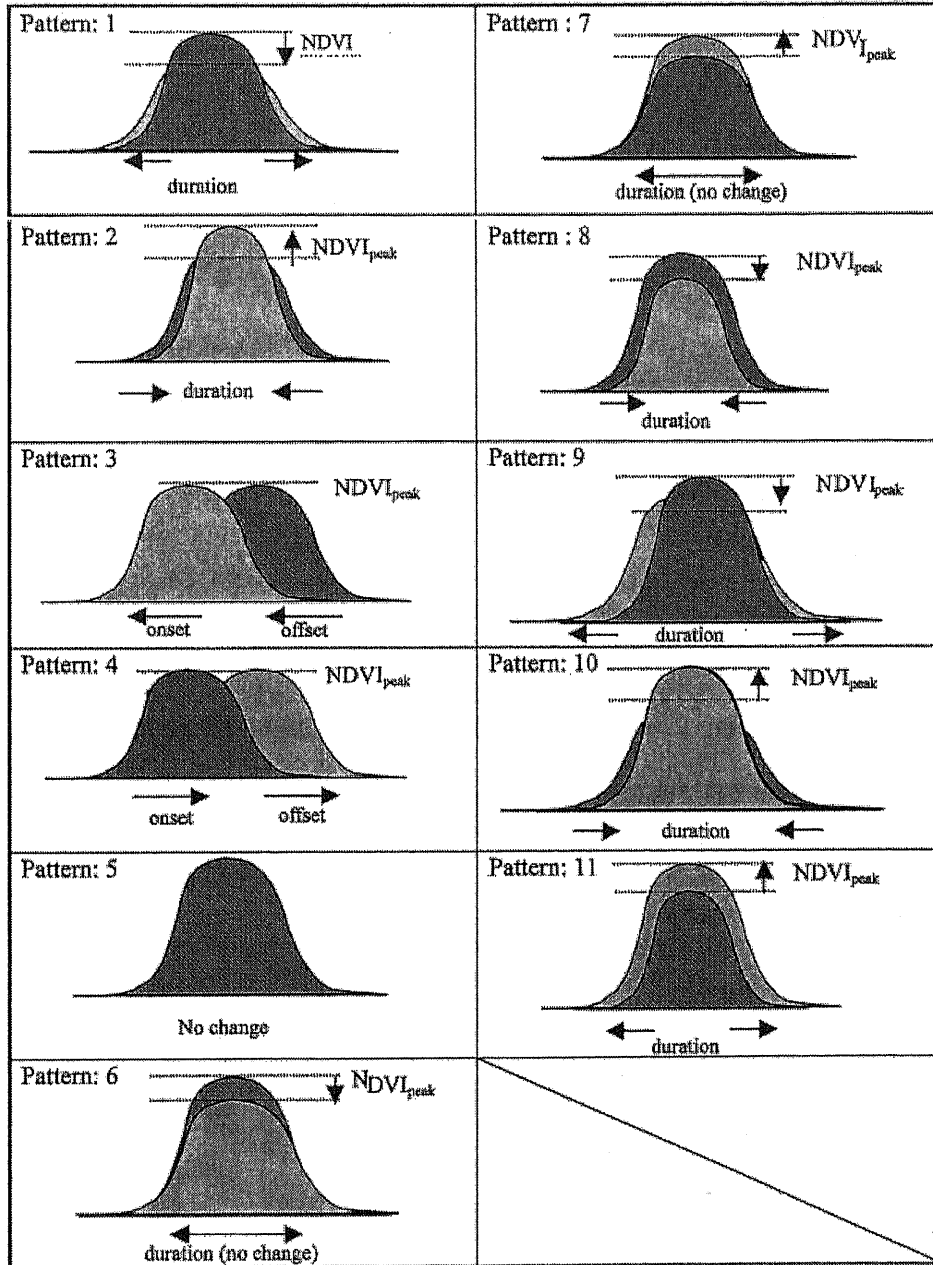


Figure 10. Patterns of phenology change (NDVI, Normalized Difference Vegetation Index; NDVI_{peak}, maximum NDVI in a year).

In contrast, from figures 12(b) and 13, the decreasing trend in ENDVI in Central Asia correlates well with the decreasing trend in air temperature. However, areas such as eastern Asia, the southern part of the USA, and northern Siberia, have a decreasing trend in air temperature, but no decreasing trend in ENDVI. Further analysis is necessary to understand these phenomena.

Table 1. Patterns of phenology change.

	Duration	NDVI _{peak}	Σ NDVI	Timing	Area (km ²)
Pattern 1	+	-	no change		211 648
Pattern 2	-	+	no change		703 872
Pattern 3	0	0	no change	earlier	259 840
Pattern 4	0	0	no change	delay	44 928
Pattern 5	0	0	no change		272 640
Pattern 6	0	-	-		85 120
Pattern 7	0	+	+		673 152
Pattern 8	-	-	-		182 976
Pattern 9	+	-	+		286 912
Pattern 10	-	+	+		934 208
Pattern 11	+	+	+		1 272 128

+, increase; -, decrease. Timing relates to the timing of onset and offset. Area (km²) relates to the coverage of each pattern within the area of less than 2.5 standard deviations of the onset date, which is shown in figure 2, in the Northern Hemisphere.

6. Conclusions

This study analysed plant phenology from 1982–2000 using PAL data and CRU climate data. The results can be summarized as a number of points.

1. Since some areas, such as desert or tropical evergreen forests, have no clear phenology, the area for phenological analysis was selected as that with a less standard deviation of onset date than the threshold of 2.5 (unit: ten days) within 7×7 PAL NDVI pixels, which is approximately the same size as a pixel size of CRU climate data. These areas, such as deciduous forest, can be considered to have relatively clear phenological features.
2. Geographical areas of temperature-dependent phenology and those of

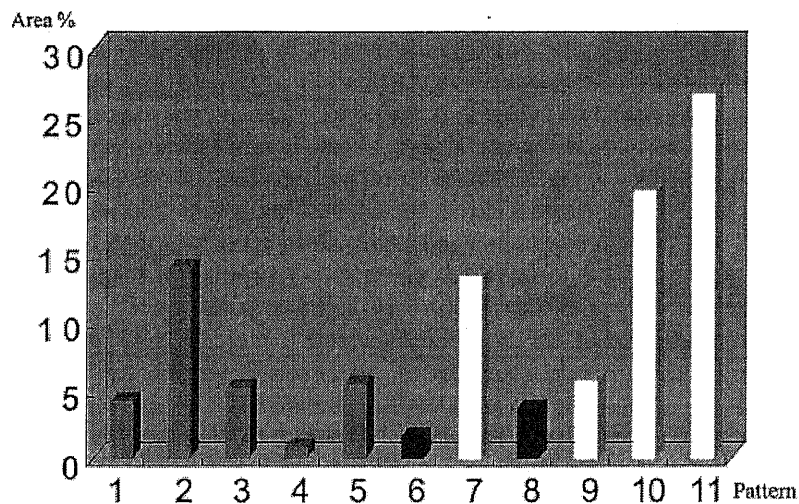


Figure 11. Area of each phenological change pattern. Patterns 7, 9, 10, 11 (white): Σ NDVI increasing trend; patterns 6, 8 (black): Σ NDVI decreasing trend; patterns 1–5 (grey): no change. Vertical axis is the percentage area of each change pattern, where 100% is the study area with less than 2.5 (unit: 10 days) standard deviations of onset date in the Northern Hemisphere.

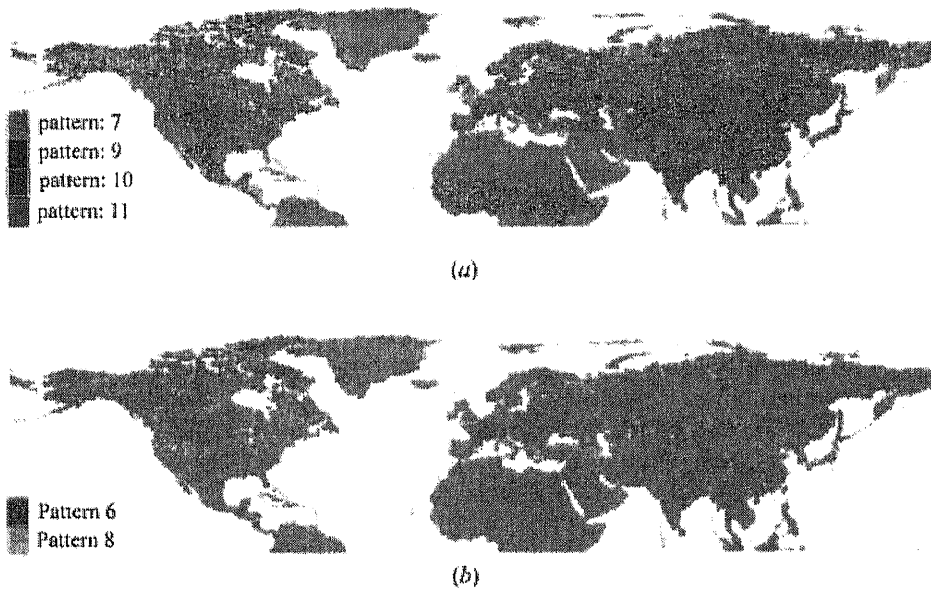


Figure 12. Geographical distribution of (a) Σ NDVI increasing trend; (b) Σ NDVI decreasing trend.

precipitation-dependent phenology were identified by analysis of NDVI seasonal change with land surface temperature, air temperature and precipitation. For example, Siberia exhibits a temperature-dependent phenology, while the Sahel region of Africa has a precipitation-dependent phenology. It was found that, in the Sahel region, vegetation seasonal change (NDVI rise) occurs approximately 20–40 days after the occurrence of precipitation. This time lag depends on land cover type. In regions with temperature-dependent phenology, such as Siberia, phenology depends on latitude and terrain elevation.

3. Based on phenological parameters such as duration, time of onset/offset, NDVI_{peak}, Σ NDVI, 11 patterns of phenological change from 1982–2000 were identified in the study area with less than 2.5 (unit: ten days) standard deviations of onset date in the Northern Hemisphere. Among the 11 patterns, the most dominant one has an increasing trend in duration, NDVI_{peak} and Σ NDVI, and occupies 6.2% of the whole land area of the Northern Hemisphere. The total area of increasing trend in Σ NDVI occupies 15.2% of the whole land area of the

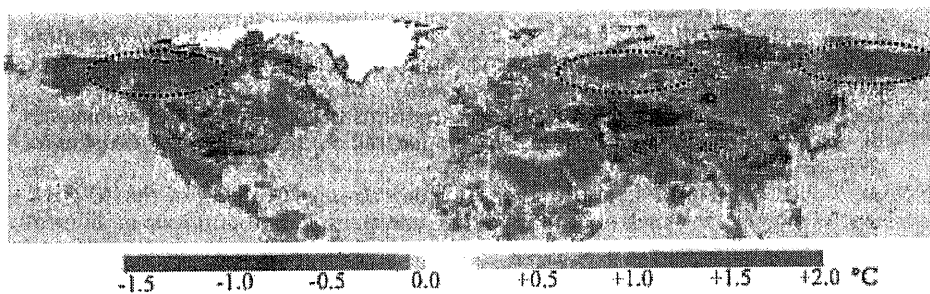


Figure 13. Geographical distribution of the trend of air temperature from 1982–1995 (trend in change of monthly average over 5°C).

Northern Hemisphere. These areas are located over a wide range of geographical regions including Siberia, Europe and many parts of North America. On the other hand, the area of decreasing trend in Σ NDVI occupies only 1.2%. The typical area exhibiting a decreasing trend is a part of Central Asia, more specifically the area between the Aral Sea and Lake Balkash. Areas showing Σ NDVI increasing/decreasing trend depend on threshold values used to assess increasing and decreasing, but it is notable that the increasing trend covers a ca 12 times larger area than that of the decreasing trend.

4. It was found that most areas of the increasing/decreasing trend in Σ NDVI correspond well with the area of increasing/decreasing trend in air temperature from 1982–2000, for example Siberia, NE Europe and the northern part of North America (for an increasing trend) and Central Asia (for a decreasing trend). However, some areas, such as East Asia, the southern part of the USA, and North Siberia have a decreasing trend in air temperature, but no decreasing trend in Σ NDVI. There needs to be further analysis on the relationship between Σ NDVI and air temperature.

Acknowledgments

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References

- GOWARD, S. N., and HUENNRICH, K. F., 1992, Vegetation canopy PAR absorptance and the normalized vegetation index: an assessment using the SAIL model. *Remote Sensing of Environment*, **39**, 119–140.
- HANSEN, J., REUDY, R., GLASCOE, J., and SATO, M., 1997, GISS analysis of surface temperature change. *Journal of Geophysical Research*, **104**, 30997–31022.
- LOVELAND, T. R., and BELWARD, A. S., 1997, The IGBP-DIS global 1km land cover data set, DISCover: first results. *International Journal of Remote Sensing*, **18**, 3289–3295.
- MOREAU, L., and LI, Z., 1996, A new approach for remote sensing of canopy absorbed photosynthetically active radiation. II: Proportion of canopy absorption. *Remote Sensing of Environment*, **55**, 192–204.
- NEW, M., HULME, M., and JONES, P., 1998, *Representing twentieth century space-time climate variability: Development of 1901–1996 monthly grids of terrestrial surface climate* (University of East Anglia: Climatic Research Unit (CRU), School of Environmental Sciences).
- NOAA-EPA, GLOBAL ECOSYSTEMS DATABASE PROJECT, 1992, *Global Ecosystems Database Version 1.0 User's Guide, Documentation, Reprints, and Digital Data*. CD-ROM (Boulder, CO: USDOC/NOAA National Geophysical Data Center).
- NOAA/NASA Pathfinder AVHRR Land Data Set User's Manual Version 3.1, September 1994, pp. 2–11. http://daac.gsfc.nasa.gov/guides/GSFC/guide/avhrr_dataset.gd.html accessed on 24 Dec.2003.
- PARK, J. G., and TATEISHI, R., 1999, A proposal of the Temporal Window Operation (TWO) method to remove high-frequency noises in AVHRR NDVI time series data. *Journal of the Japan Society of Photogrammetry and Remote Sensing*, **38**, 36–47.
- PRICE, J. C., 1984, Land surface temperature measurements from the split-window channels of the NOAA-7 advanced very high resolution radiometer. *Journal of Geophysical Research*, **85**, 7231–7237.
- RUNNING, S. W., and NEMANI, R. R., 1988, Relating seasonal patterns of the AVHRR vegetation index to simulated photosynthesis and transpiration of forests in different climates. *Remote Sensing of Environment*, **24**, 347–367.
- TUCKER, C. J., SLAYBACK, D. A., PINZON, J. E., LOS, S. O., MYNENI, R. B., and TAYLOR, M. G., 2001, Higher northern latitude NDVI and growing season trends from 1982 to 1999. *International Journal of Biometeorology*, **45**, 184–190.

第 4 章

Landsat データと現地調査による バイカル湖南部の土地被覆調査

(Tateishi, R., Y. Shimazaki, and P. D. Gunin, Spectral and temporal linear mixing model for vegetation classification, Int. J. of Remote Sensing, vol. 25, no. 20, pp. 4203-4218, 2004)

第5章

SPOT/VEGETATION データと現地調査による内 モンゴルの土地被覆調査

5-1 対象地域の特徴

研究対象地域は、北緯40度～46度 / 東経 110 度～ 135 度とした。

主に、中国の内モンゴル自治区、及び吉林省である。この地域は西にゴビ砂漠から続く乾燥地帯、中央に大草原、そして東には、街を中心に広がる農地と広葉樹林帯と、バラエティーに富んだ Ground Truth をもつ地区である。また、環境汚染により西の乾燥地帯が年々東方の草原地帯を侵食している地域でもある。一方、東の吉林省は長春・吉林という大都市を中心にした中国でも有数の農業省であるが、近年の人口増加・工業化に伴う土地利用変化が著しい。このような点から経年変化に対する特徴をもっている地域でもある。

本研究では、この地域を大きく3つの地域に分けてそれぞれの地域の特徴を下記に示す。

- ・ **Area1** (40N-46N 110E-116E)
中国とモンゴルの国境（エレンホト）を中心とした地域。乾燥地帯だが、わずかに植物が生えている Desert steppe 地帯である。
年間降水量 約 80mm
- ・ **Area2** (40N-46N 115E-125E)
世界四大草原の一つシリンホトを中心とした草原地帯。
温帯半湿潤気候 年間降水量 約 450mm
- ・ **Area3** (40N-46N 124E-135E)
長春、吉林などの大都市をもつ地域。街を中心に広大な農場が広がっている（米、小麦、トウモロコシ、瓜など）。東部の北朝鮮・ロシア国境付近には落葉広葉樹林帯が広がっている。
温帯性気候 年間降水量 400-1000mm

5-2 現地調査結果と Ground Truth point(GTP)

2001年7月下旬から8月上旬にかけて中国科学院植物研究所のチームと共に現地調査を行った。調査ルートは図3-2aに示したとおりである。北朝鮮との国境の町、図門から出発し、主な街として延吉・安図・敦化・吉林・長春・

通遼・シリンホト、そしてモンゴルとの国境の町（エレンホト）までおよそ 2000km におよぶ道のりである。調査旅行中に行った作業工程をまとめておく。

調査旅行作業工程

- ・ 周りの風景を確認しながら移動（車）する。
- ・ 広範囲に同じ土地被覆の続く地域を見つける。
- ・ 条件の地域を発見したら、GPS を使い緯度経度を記録、そして、東西南北（4 方向）の土地被覆をデジタルカメラに収める。
- ・ 全工程終了した後、緯度経度別のアルバムを作成、Ground Truth とする。

Ground Truth point (GTP)

Ground Truth (以下 GT) とはリモートセンシングデータと観測対象物との対応関係を明らかにするため、地上の実態に関する情報を観測、測定、収集することをいう。そして、Ground Truth を持っている地域の中で、地上の状態が一様なポイントを Ground Truth Point(以下 GTP) と呼ぶ。本研究では 23point の GTP を収集した。

GTP 収集手順

- ・ まず衛星写真を教師なし分類（ISODATA 法）にかけた。（図 3-2b）本研究では Vegetation の NDVI データ（2000 年一年間のデータ）を 40 個のクラスに分類した。
- ・ 上記のデータと現地調査で得た情報を使い、広範囲で一様な土地被覆である地域を見つけ出す。
- ・ そして、そのポイントの中心を 20-30pixel 抽出し、GTP とする。

本研究の GTP の特徴

本研究で抽出した、GTP の特徴を地域別に示す。

Area1 11 個の GTP を抽出した。Point number 1 ~11 である。ここは一面 Desert steppe 地帯で 11 個すべてのポイントを Desert というクラスに位置付けた。

Area2 6個のGTPを抽出した。Point number 12～17である。ここは一面 steppe 地帯で6個すべてのポイントを Steppe というクラスに位置付けた。

Area3 6個のGTPを抽出した。Point number 18～23である。この地域は町・農地・森林などの混成地区であるため、GTPを抽出するのは比較的難しかった。City・Farm・Forestと3つのクラスにおいて2ポイントずつ定めた。

City (point number 18,20) Farm (point number 19,21)

Forest (point number 22,23)

5-3 使用データ

① SPOT/Vegetation

土地被覆分類に使われるデータはさまざまだが、本研究ではフランスの人工衛星 SPOT の Vegetation データを使用した。2000年の1月～12月までの1年間分 10-day composite のデータである。

SPOT-4 : 1997年に打ち上げられたフランスの衛星
太陽同期軌道 高度 : 約822km
傾斜角 : 約99°
回帰日数 : 26日

Vegetation : Spot-4の観測センサ。空間分解能(1.15km) 観測幅(2200km)
波長域 : b0(0.43-0.47 μ m), b2(0.61-0.68 μ m)
b3(0.78-0.89 μ m), MIR(1.58-1.75 μ m)
本研究では、バンドb2とb3から得たNDVIを主に使用した。

② Landsat/TM

Landsat-5 : 1984年に打ち上げられたアメリカの衛星である
太陽同期軌道 高度 : 約705km
傾斜角 : 約98°
回帰日数 : 16日

TM : Landsatの観測センサ。空間分解能(30m) 観測幅(185km)

波長域 : band1(0.45-0.52 μ m), band2(0.52-0.60 μ m)
band3(0.63-0.69 μ m), band4(0.75-0.90 μ m)
band5(1.55-1.75 μ m), band7(2.08-2.35 μ m)
band6(10.40-12.50 μ m 空間分解能 120m)

band7を赤,band4を緑,band2を青にしたカラー画像をNASAのホームページ
<http://zulu.ssc.nasa.gov/mrsid/mrsid.pl>から無料でダウンロードできる。

この画像を使って精度評価を行った。データの撮影時期は地域によって異なり1987~1995年(6~10月)の間の一日のデータである。

③ 中国土地利用図

中国の科学出版社から出版されている、縮尺 1/100 万の土地利用図である。1990年に出版されているため情報はそれ以前のものである。広葉樹林・草地・町・畑などのクラスが示されている。これを TM 画像と共に精度評価用の Ground Truth 情報として用いた。

5-4 処理方法と分類結果

地域別に NDVI の平均値グラフ・処理方法・結果を説明する。そして最後に、それぞれの地域で行った処理結果の合成を行い、対象地域全体の土地被覆分類図を示す。

5-4-1 Areal

この地域には 11point の GTP があり、いずれも Desert のクラスに属する。ポイントの位置は図 5-4-a と表 5-4-a に示す。このポイントの NDVI 平均値を時系列に並べたグラフがグラフ 5-4-a である。同じグラフの縦軸のスケールを変えたものをグラフ 5-4-b に示す。Desert 地区であるため各ポイントは、年間を通して NDVI 値は小さい。このグラフの特徴は 1 月~6 月・10 月~12 月の値は各ポイント大きな違いがなく、同じ波形をとるということである。そして、6 月~10 月ではそれぞれ山形の波形をとるが、ピークの値が違っている。

このピークをとる 9 月の NDVI 値と、それぞれのポイントにおける現地写真と比較した。9 月の NDVI 値が高い順に現地写真を並べる。まず、上位

3つのGTP10,11,9（9月のNDVI値,0.408,0.328,0.304のポイントについてである。写真は図5-4-b,図5-4-c,図5-4-dに示してある。そして図5-4-e・図5-4-fは、グラフ中で固まりになっているNDVI値0.200～0.244付近の写真である。最後に一番小さなNDVI値0.164をとったGTP1の写真である（図5-4-g）。写真とNDVI値を比較すると、NDVI値の大きなポイントの方が緑が多いと相対的に認められる。つまり、この地域において、9月のNDVI値は植生の量に依存するということがいえる。各GTPのグラフのピークが同じ時期になるのは、この地域の植物の種類が少ないためであると考えられる。

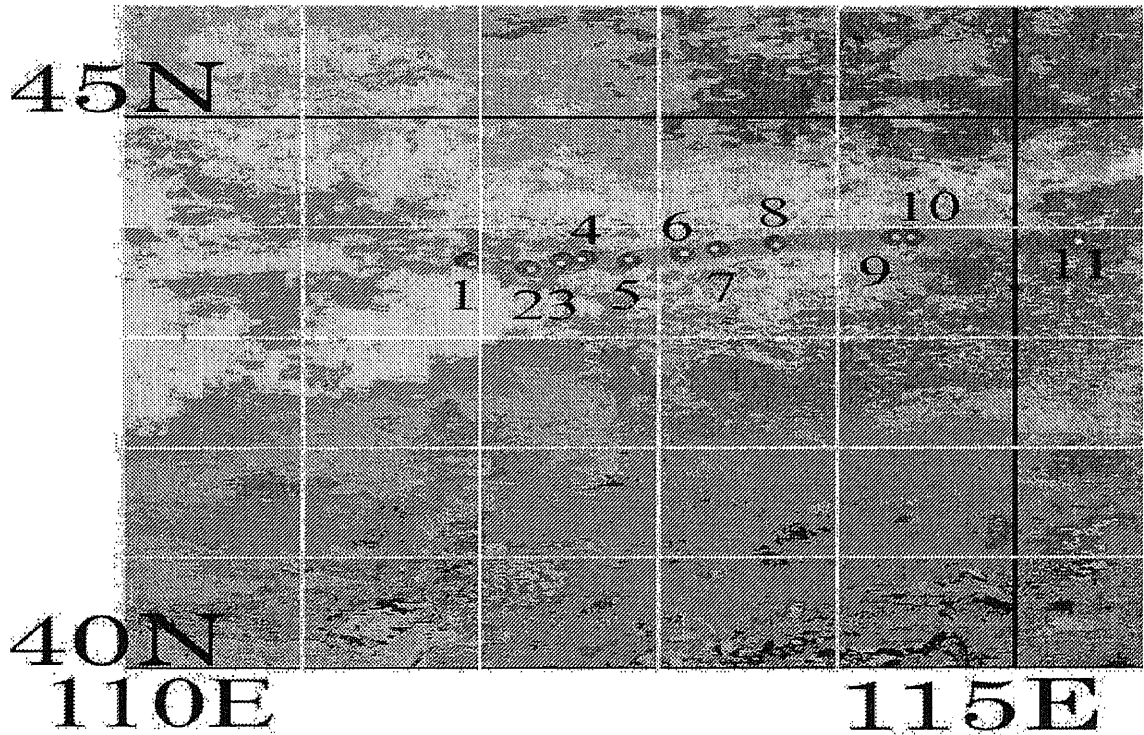
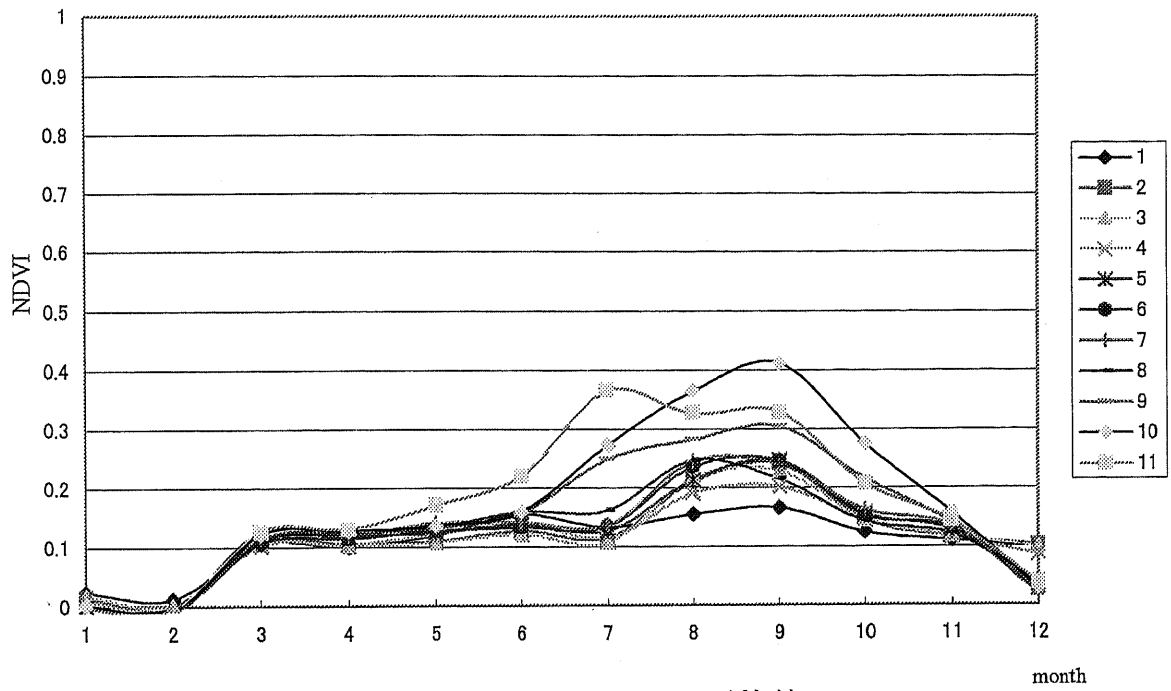


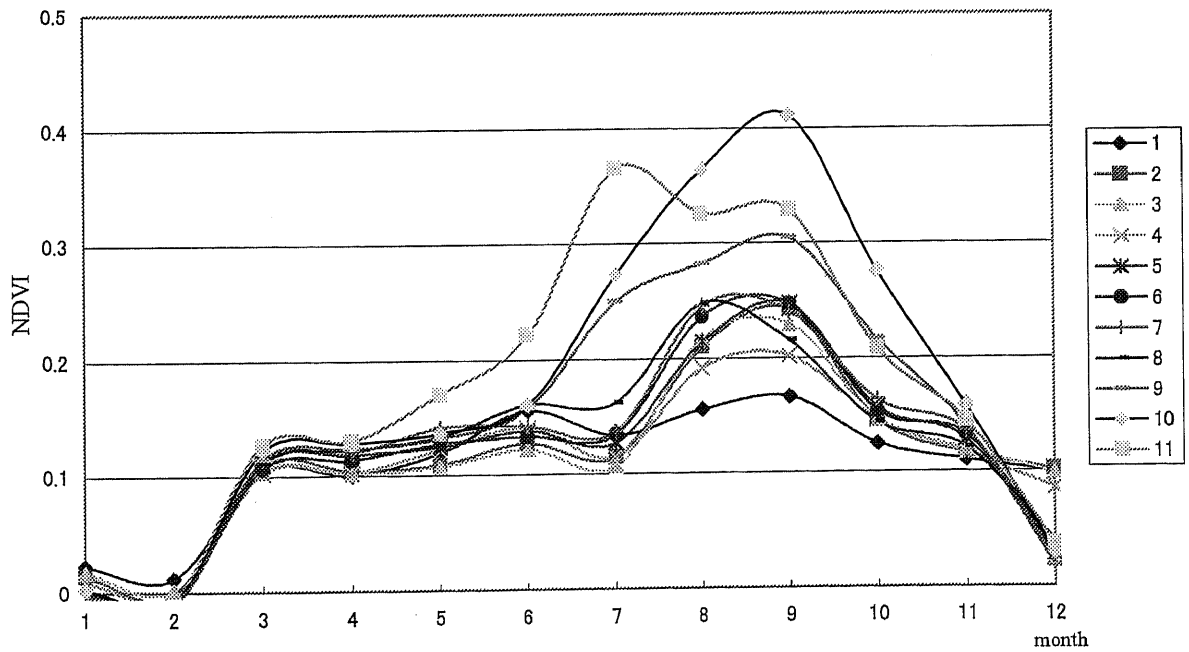
图 5-4-a Areal GTP

GTP number	Latitude (N)	Longitude (E)	class
1	43.40	111.57	Desert
2	43.37	112.17	Desert
3	43.41	112.27	Desert
4	43.43	112.34	Desert
5	43.42	112.50	Desert
6	43.45	113.08	Desert
7	43.47	113.19	Desert
8	43.50	113.41	Desert
9	43.53	114.19	Desert
10	43.54	114.25	Desert
11	43.53	115.21	Desert

表 5-4-a Areal GTP



グラフ 5-4-a NDVI 平均値



グラフ 5-4-b NDVI 平均値 (スケール変換)

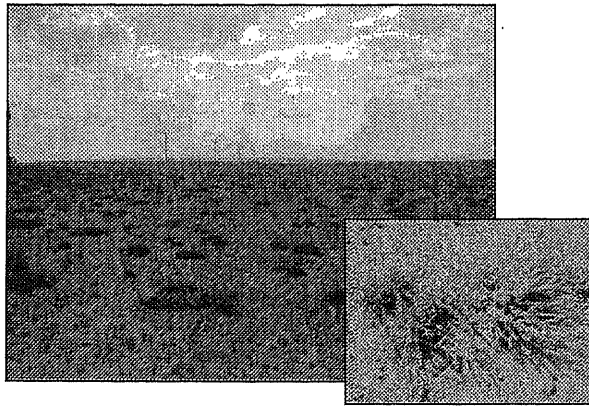


图 5-4-b GTP10(43.54N,114.25E)

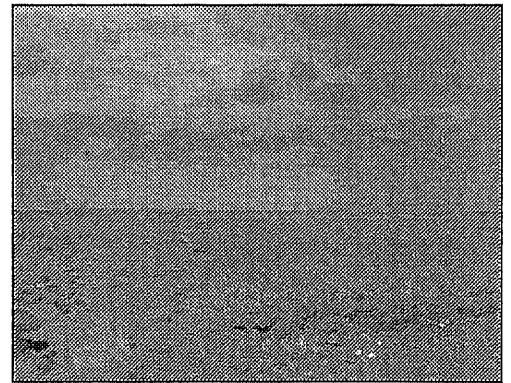


图 5-4-c GTP11(43.53N,115.21E)

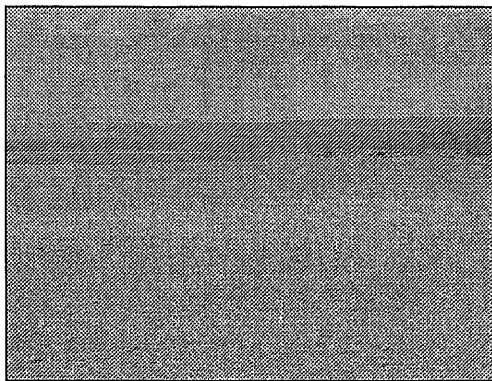


图 5-4-d GTP9(43.53N,114.19E)

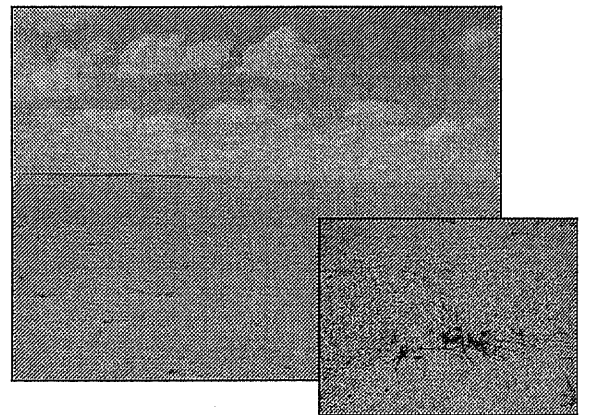


图 5-4-e GTP6(43.45N,113.08E)

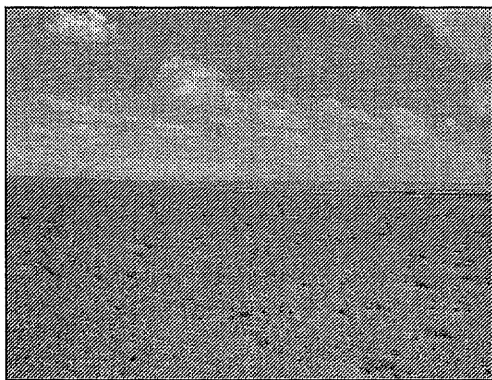


图 5-4-f GTP4(43.43N,112.34E)

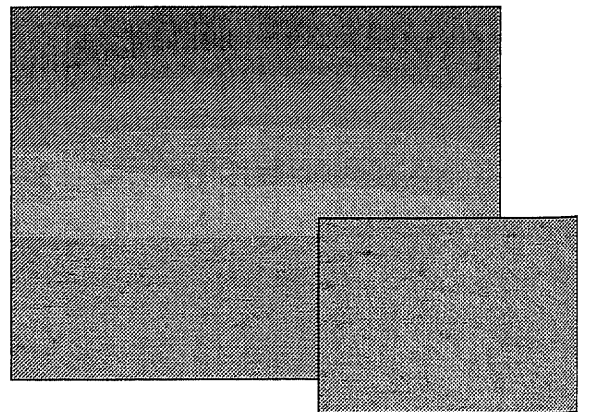


图 5-4-g GTP1(43.40N,111.57E)

5-4-2 Area2

この地域には6pointのGTPがあり、いずれもSteppeのクラスに属する。ポイントの位置は図5-4-iと表5-4-bに示す。このポイントのNDVI平均値を時系列に並べたグラフがグラフ5-4-c(monthly composite), グラフ5-4-d(10-day composite)である。この地域にはさまざまな植生が共存しているため、Desert地帯とは違い、多様な形の波形をとっていると考えられる。しかしながら、6月に大きなピークがありその時期のデータで植生量の違いを推定できると考えた。

Area1と同様にポイントの写真と比較して考えた。この地域は6月～10月にかけて、GTPごとのNDVI値の順番が変わるので、写真と比較するうえで、現地調査を行った8月のNDVI値順に並べ比較した。

最高値のGTP14(図5-4-j, 図5-4-k)、中間のポイントGTP15(図5-4-l)、GTP16(図5-4-m)、最も小さなGTP12(図5-4-n)である。Steppe地帯なので全体に植物が生えているが、拡大した写真を見ると、NDVI値が小さくなるにつれ、単位面積あたりの植物が生えている密度が小さくなってきていることがわかる。これらのことからSteppe地帯においてもNDVI値を使って植生の量を表わすことができると考えた。

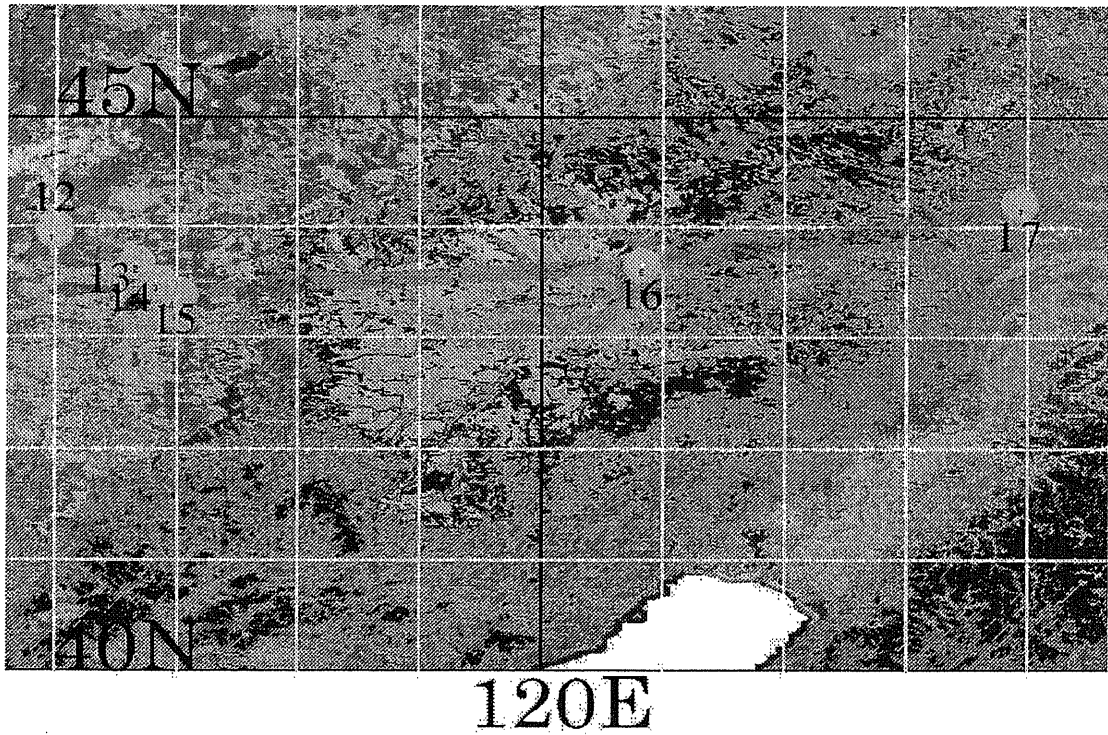
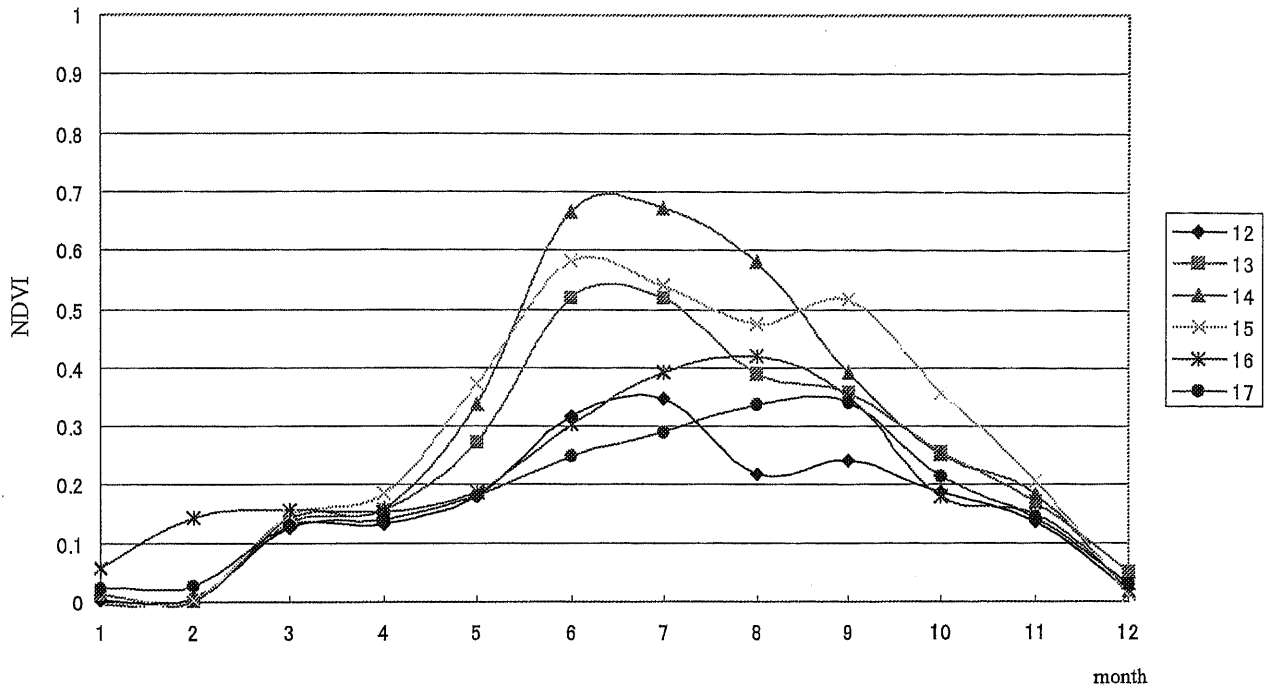


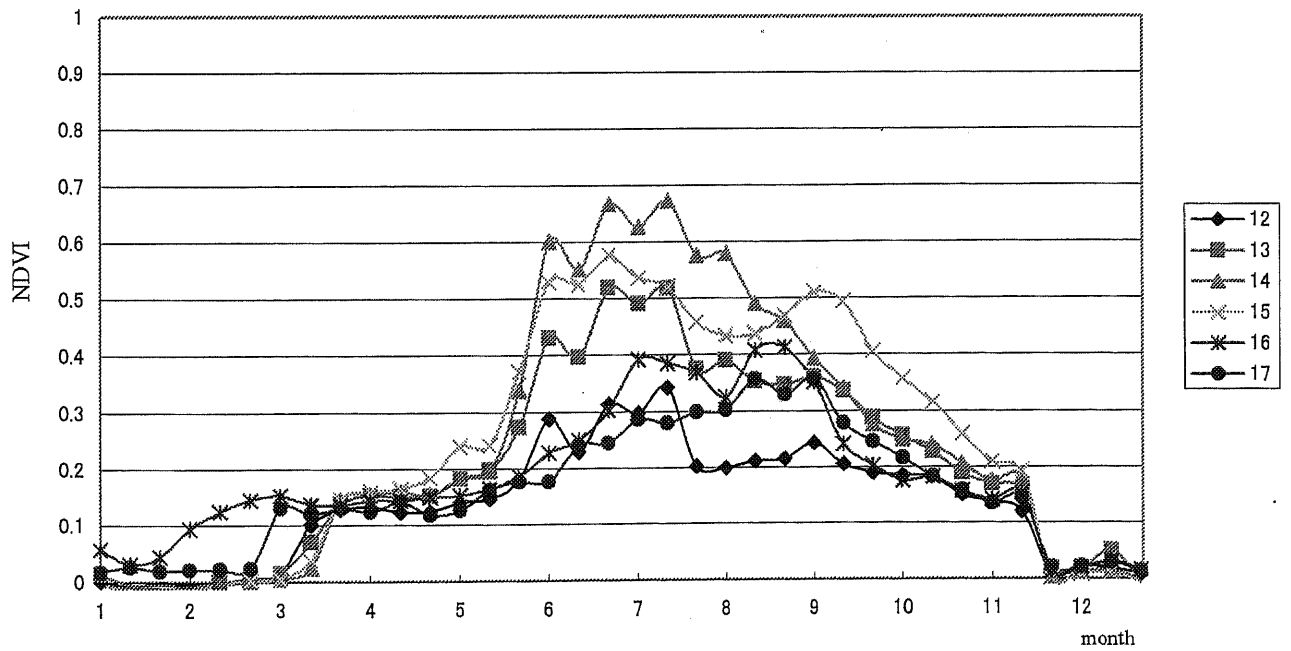
图 5-4-i Area2 GTP

GTP number	latitude	longitude	class
12	43.56	115.58	Steppe
13	43.39	116.40	Steppe
14	43.30	116.49	Steppe
15	43.19	117.03	Steppe
16	43.38	120.50	Steppe
17	44.12	123.56	Steppe

表 5-4-b Area2 GTP



グラフ 5-4-c NDVI 平均値(monthly)



グラフ 5-4-d NDVI 平均値(10day)



图 5-4-j GTP14(43.30N,116.49E)

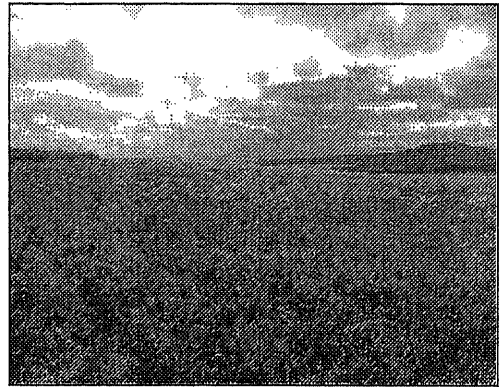


图 5-4-k GTP14(43.30N,116.49E)

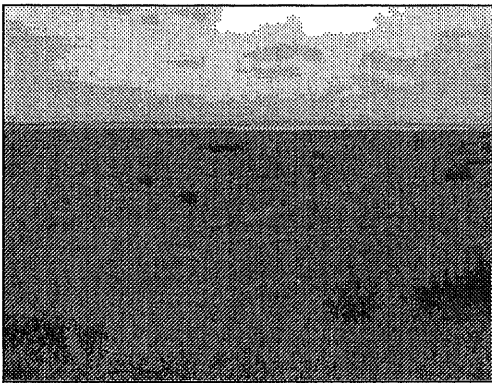


图 5-4-l GTP15(43.19N,117.03E)

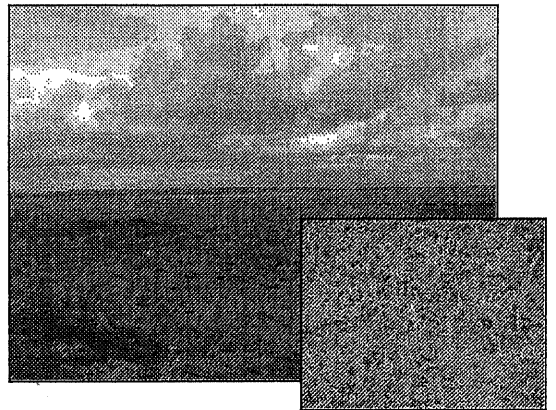


图 5-4-m GTP16(43.38N,120.50E)

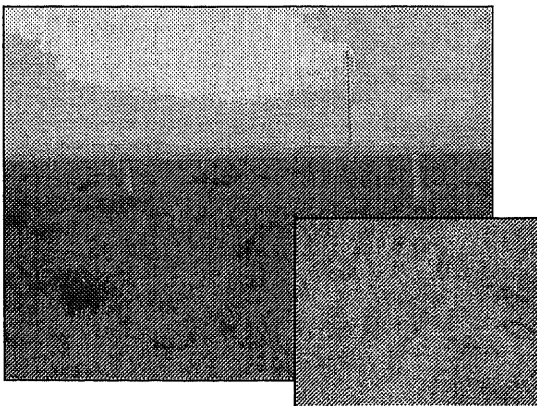


图 5-4-n GTP12(43.56N,115.58E)

5-4-3 Area3

この地域には 6point の GTP があり、City/Farm/Forest それぞれのクラスに 2point ずつある。ポイントの位置は図 5-4-p と表 5-4-c に示す。このポイントの NDVI 平均値を時系列に並べたグラフがグラフ 5-4-e(monthly composite)、グラフ 5-4-f(10day composite) である。グラフより同じクラスの GTP における NDVI 値はほぼ同じ波形をとっていることがわかる。ピークの値が大きいほうから Forest/Farm/City である。この地域は 3 つのクラスが混成する地区である。(図 5-4-q, 図 5-4-r, 図 5-4-s) そこで、前の 2 つの Area とは異なり、それぞれのクラスを抽出する処理を施した。それぞれのクラスとして抽出する条件を次に記す。

Forest : 5月に値が急激に上がるのが特徴。そこで、5月下旬が 0.66 以上、5月上旬が 0.34 以下という条件を設定し、その条件を満たす pixel を Forest とした。

Farm : Forest に比べ 6月～10月にかけてコンパクトな山ができているのが特徴である。Forest と差別化するために 6月上旬と 10月上旬が 0.46 以下、あいだの 8月が 0.7 以上という条件を設定し。その条件を満たす pixel を Farm とした。

City : 年間を通して 0.3 以下というのが条件である。
ただ、この場合 Desert と区別がつかず、西の砂漠の地域も拾ってしまうので、大きな固まりを Desert とみなし削除した。残ったものが City である。

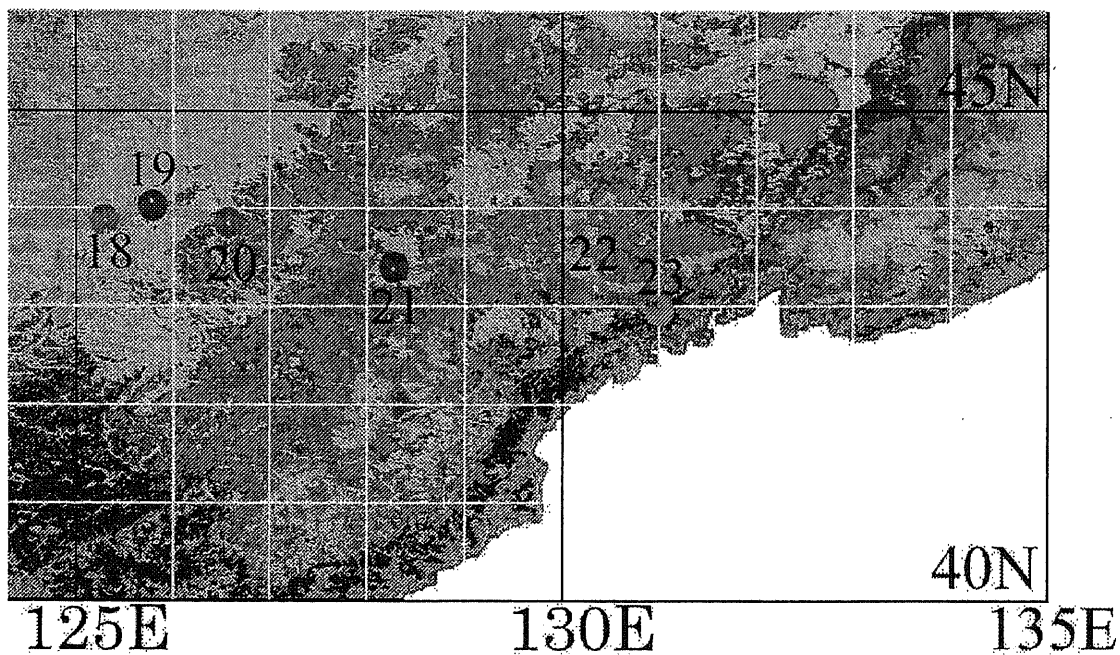


图 5-4-p Area3 GTP

GTPnumber	Latitude(N)	Longitude(E)	class
18	43.53	125.19	City
19	44.04	125.47	Farm
20	43.54	126.35	City
21	43.22	128.16	Farm
22	43.12	130.20	Forest
23	43.03	131.01	Forest

表 5-4-c Area3 GTP

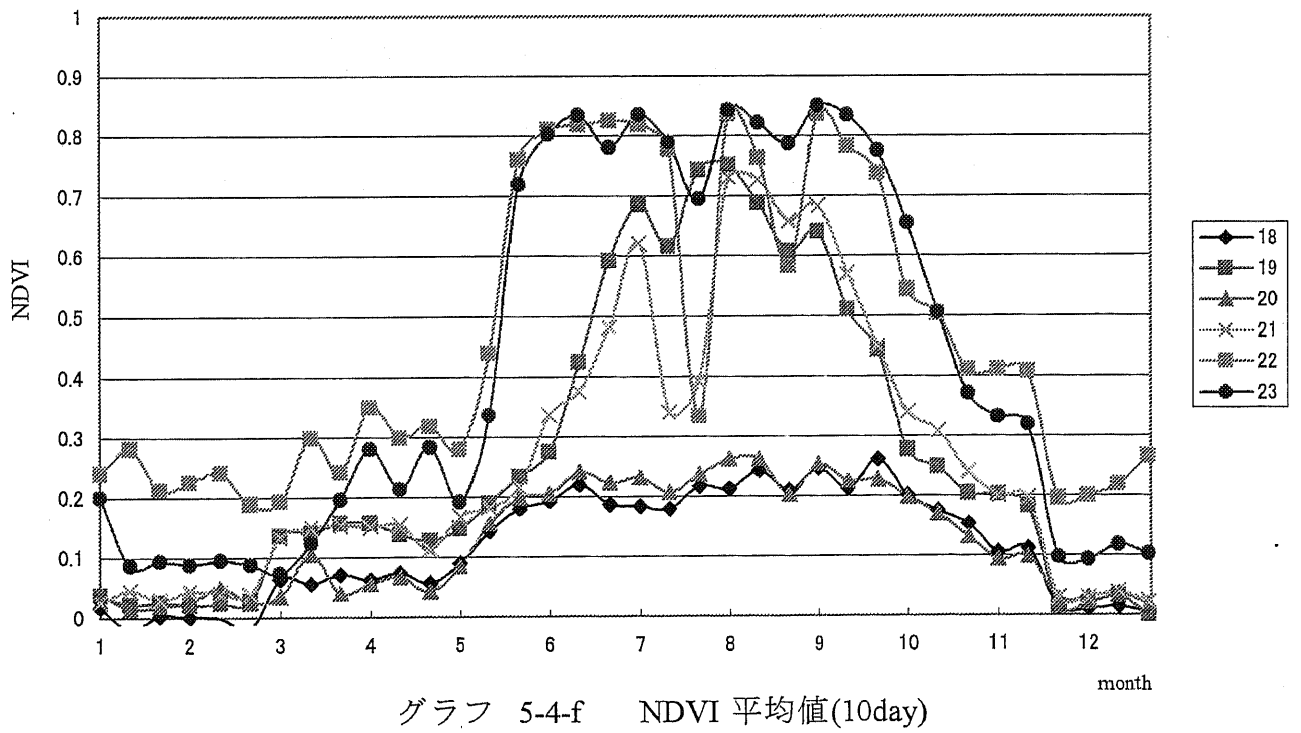
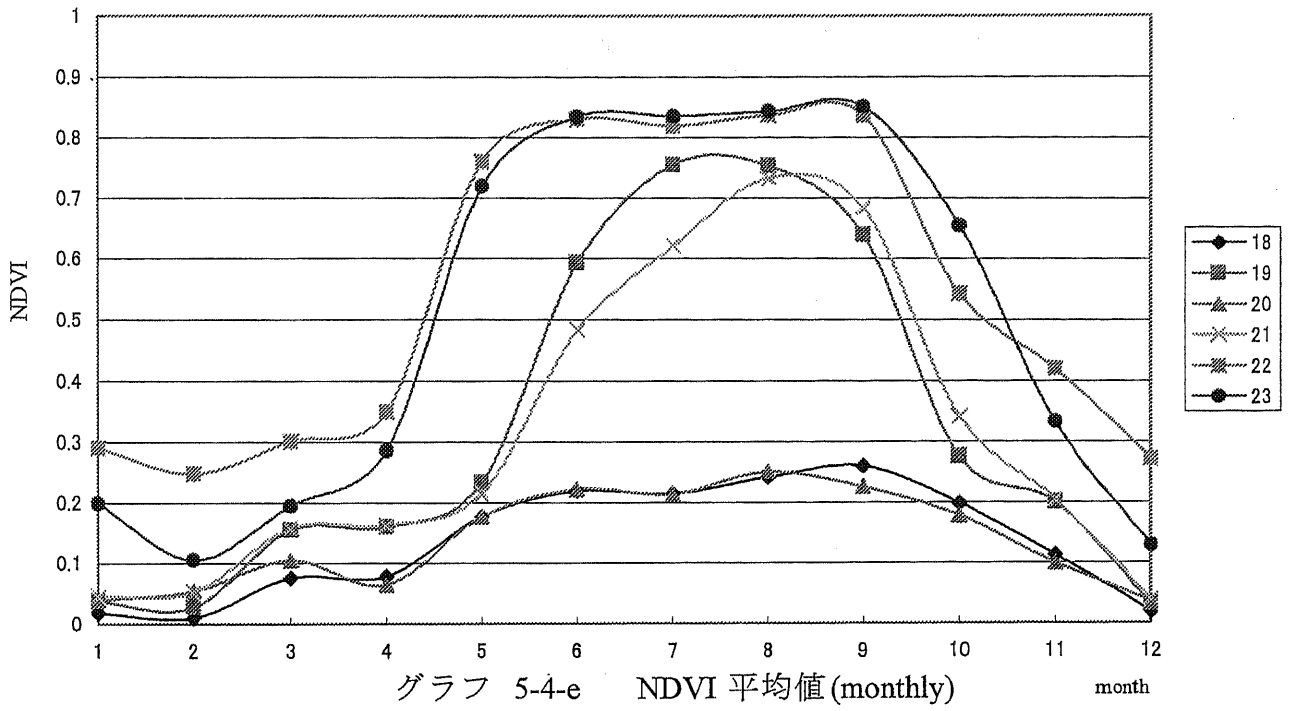




図 5-4-q Forest GTP23(43.03N,131.01E)

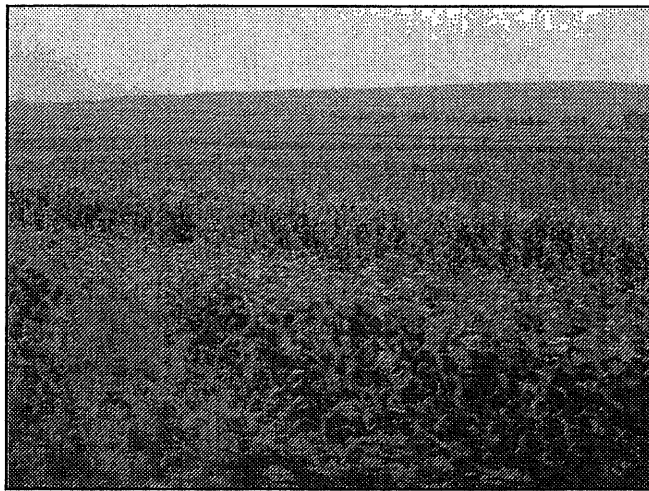


図 5-4-r Farm GTP19(44.04N,125.47E)

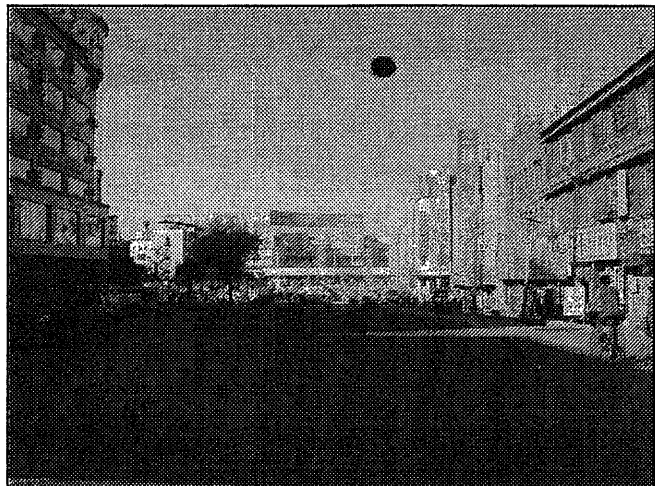


図 5-4-s City (長春) GTP18(43.53N,125.19E)

5-5 まとめ

それぞれの地域で処理した結果画像を合成した。
合成する上で、複数のクラスに属しているpixelがあるので、優先条件をつけた。

1 : Forest/Farm/City

2 : Desert

3 : Steppe

上記の順位で各クラスを色づけしていった。Forest/Farm/Cityに関しては互いに排他的なのでそれぞれそのままのクラスに属する。DesertはCityの部分も抽出しているのでCityが上位の順位になるようにした。SteppeはForestやFarmの条件もみたしているため、両クラスの下位にくるようにした。Desert・Steppe間の優先順位については、どちらにしても大きな違いはないが、よりDesert部を浮き立たせるためDesertを上位にした。

以上の条件で合成したものが、図 5-4-y である。

第6章

グローバル土地被覆マッピングのための 土地被覆分類項目の提案

(Sato, H.P. and R. Tateishi, Proposal for Global land cover guideline legend based on FAO's LCCS, Asian Journal of Geoinformatics, Vol. 3, No.2, pp.35-45, 2002.)

第7章

土地被覆グランドトゥルスデータベース

7.1 Global land cover ground truth database

(Ryutaro Tateishi, H.P.Sato, L.Zhu, Global land cover ground truth database, Proceedings of ISPRS Commission VII Symposium on Resource and Environmental Monitoring, Hyderabad, India, Dec.3-6, 2002)

7.2 土地被覆グランドトゥルスデータベースの構築

7. 1 GLOBAL LAND COVER GROUND TRUTH DATABASE

R. Tateishi^{a*}, H. P. Sato^b, L. Zhu^a

^a Center for Environmental Remote Sensing (CEReS), Chiba University
1-33 Yayoi-cho Inage-ku Chiba 263-8522 Japan - tateishi@ceres.cr.chiba-u.ac.jp

^b Geography and Crustal Dynamics Research Center, Geographical Survey Institute,
Tsukuba 305-0811, Japan - hsato@gsi.go.jp

Commission IV, Working Group WG IV/8

KEY WORDS: Land cover, Ground truth, Global environmental databases

ABSTRACT:

There are many global/continental or large area land cover mapping projects because land cover is one of key parameters in environmental studies. Though ground truth collection is an important and difficult task in land cover mapping, it is usually performed independently in each project without any cooperation between them. This is the background of the development of Global Land Cover Ground Truth (GLCGT) database by the cooperation of many projects and researchers. The developed GLCGT database will be used freely by any researcher. This cooperative and common development of GLCGT database will realize reliable and continuously improved land cover ground truth data. It also eliminates duplicated efforts of ground truth collection among projects.

1. INTRODUCTION

There is no doubt in recognizing the importance of global environmental databases. Many projects are going on to develop global datasets of key environmental variables. However, not only among different variables but even within one variable such as land cover, different projects to develop one global dataset have been independent and each project has problems and difficulty.

Under this background, the ISPRS Working Group IV/6(1996-2000) and its successive Working Group IV/8(2000-2004) have been trying to clarify problems lying in different fields and to find the better directions to solve these problems. More concretely, ISPRS WG IV/6(1996-2000) had a workshop at Hawaii in 1999 aiming to survey existing global datasets/databases and to observe their trend, to identify obstacles in global datasets/databases and their usage, and to find the better solutions to remove these obstacles. The result of this workshop was published as a book on "Global Environmental Databases" in 2000(Tateishi and Hastings, 2000). The successive WG/8(2000-2004) published a book on "Global Environmental Databases Volume 2" for the same purpose as the first one, by including additional global environmental variables and additional cross-cutting issues among different variables(Tateishi and Hastings, 2002).

In these books, it is found that the main obstacles are lack of cooperation among different projects, lack of network, lack of harmonization, and lack of standardization. All these obstacles are related each other. For example, in the field of land cover, different land cover legends are used in different mapping projects to meet different needs of mapping (Sato and Tateishi 2001). Different legends prevent to compare or combine one mapping data with another data. In order to solve this problem, Food and Agriculture Organization(FAO) proposed Land Cover

Classification System (LCCS) which is a hierarchical comprehensive classification system allowing to derive almost any land cover legend (Di Gregorio, 2000). FAO's LCCS is one of good examples of better direction of global land cover data production. Furthermore networking of land cover experts by FAO and UNEP and similar attempt by Joint Research Center (JRC) of European Union are another good example of better direction.

In this paper, authors propose another good example towards better global land cover mapping. It is the development of land cover ground truth database. The collection of ground truth data is the most difficult part of global land cover mapping and its quality affects greatly the mapping result. Nevertheless, the collection of ground truth is usually done independently in each mapping project. The proposal here in this paper is to develop ground truth database for global land cover mapping by the cooperation of many projects and researchers for their common use.

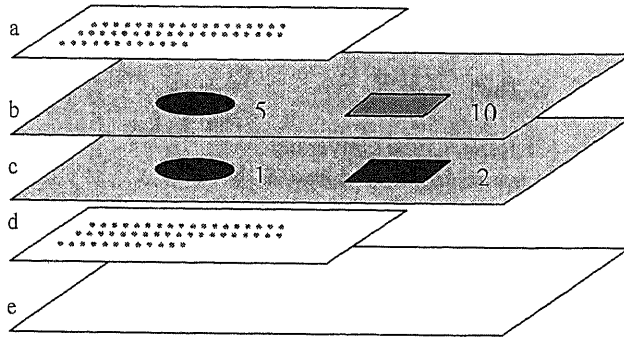
2. PROPOSED GLOBAL LAND COVER GROUND TRUTH(GLCGT) DATABASE

The GLCGT database consists of regional land cover ground truth (RLCGT) data. The geographical size of a RLCGT data is flexible, from a city size to a continental size.

2.1 Regional land cover ground truth (RLCGT) data

The regional land cover ground truth (RLCGT) data consists of metadata, GT land cover code data, GT site code data, and description of GT sites as mandatory datasets, and optional data as shown in Figure 1.

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.



a:	Metadata of RLCGT data Text
b:	Ground truth (GT) land cover code data Raster
c:	Ground truth (GT) site code data Raster
d:	Description of GT sites Text
e:	Optional data Text, raster or any

Figure 1
Architecture of

regional land cover ground truth (RLCGT) database

2.2 Metadata of RLCGT data

Metadata includes the following items.

- 1 RLCGT code (this code is assigned by the coordinator of the RLCGT database project)
- 2 the organization or project which produced a specific RLCGT data
- 3 representative person which produced this RLCGT data (name, affiliation)
- 4 contact person for this RLCGT data (name, affiliation, postal address or fax or email)
- 5 date of the production of this RLCGT data
- 6 latitude of the north edge of this region
latitude of the south edge of this region
longitude of the west edge of the region
longitude of the east edge of the region
- 7 pixel size (by arc second)
- 8 number of pixels (east-west)
number of pixels (north-south)
- 9 definition of land cover code
- 10 definition of the additional land cover code if any (recommended codes are 201-254)
- 11 description of optional data if any
- 12 any other description about this RLCGT data

2.3 Ground truth (GT) land cover code data

The GT land cover code data is a main part of ground truth data. The GT land cover code data is a raster data which cover a rectangular geographical region. The geographical region is defined in the metadata of RLCGT data. The north edge (not a

center) of the north end pixel is recommended to be a multiple of 30 second (example: 60 degree north latitude, 60 degree 35 minute north latitude, or 61 degree 20 minute 30 second north latitude). This is the same in the case of south, west, and east edges. This makes overlay of different RLCGT data with different pixel size easier.

The geodetic coordinate system must be based on ITRF94 + GRS80 which is practically the same as WGS84 for this application. In other words, the used geodetic coordinate system is the same as the one for Global Positioning System (GPS).

The pixel size (or interval) is **30 arc second or less**. It is arbitrarily determined but is recommended to be a factor of 30 such as 15, 10, 6, 5, 3, 2, 1 arc second. It makes the overlay of different RLCGT data with different pixel size easier.

Land cover class must be based on the Land Cover Classification System (LCCS) by Food and Agriculture Organization (FAO) of the United Nations (UN). The GT land cover code (1-254) must be clearly defined and described in the metadata of RLCGT data. Though contributors to input GT data can define any GT land cover code, the use of land cover code of the **ST (Sato-Tateishi) land cover guideline legend** (Sato and Tateishi, 2002) is recommended. The **additional** GT land cover code (201-254), if any, can be defined by contributors for each RLCGT data under the condition that the additional code must be clearly defined in the metadata of RLCGT data.

The background value of GT land cover code data must be 0. A pixel value is recorded in **one byte**.

The ground truth (GT) is recorded as a pixel value of land cover code. A geographical unit of one GT can be any number of pixels and have any shape, but a unit of GT more than 2 x 2 pixels is recommended. This is because one pixel GT may not be reliable due to the misregistration of the reference image used in the work of GT collection. A unit of GT is called a "GT site" here.

2.4 Ground truth (GT) site code data

A unit of GT (or a GT site) has a unique site code (1-254) in the RLCGT data. The GT site code is used to relate a GT site with its description in "Description of GT sites" file. The GT site code data has exactly the same size and format data as the GT land cover code data. A GT site code data cover the same rectangular geographical region as the corresponding GT land cover data. The background value of GT site code data must be 0. A pixel value is recorded in one byte. When a number of GT site exceeds 254, another RLCGT data must be defined.

2.5 Description of GT sites

The description of GT sites is a text description of each unit of GT. The recorded information is as follows.

- site code
- approximate latitude and longitude of the GT site
- land cover code of the GT site
- any description about the land cover of this GT site
- **information source** by which a land cover type of the GT site was recognized

The information source is the most important part of this description because, by this information, the reliability of the ground truth is estimated.

(example)

- site code: 3
- lat/long: N42degree 56minute, E130degree 50minute
- land cover code: 12
- land cover: broadleaf deciduous forest
- information source: field survey, Jul-Aug 2001 (by Tateishi)
FS -Point No. 5
+ Land use map of China 1:1,000,000

published by the Science Press, 1990

or

Landsat TM (24 Feb 2000 and 16 Jan 2000)
+ knowledge (Ekaterina Rachkovskaya)

or

vegetation map of Kazakhstan and Middle Asia,
1:2,500,000, 1995
+ field survey in early 1990 (by Ekaterina
Rachkovskaya)

or

land use map 1:200,000, Geographical Survey
Institute, Japan 1982
+ knowledge (Tateishi)

3. CONCLUSION

This paper describes the concept of global land cover ground truth (GLCGT) database which is proposed to Global Land Cover 2000 (GLC2000) project initiated by Joint Research Centre (JRC), GLI land cover project by NASDA Japan, and Global Mapping project initiated by Geographical Survey Institute (GSI) Japan. The recommended land cover legend for GLCGT database is Sato-Tateishi (ST) land cover guideline legend which is based on the Land Cover Classification System (LCCS) by Food and Agriculture Organization (FAO) of the United Nations.

REFERENCES

Di Gregorio, A. and Jansen, L.J.M., 2000. Land cover classification system (LCCS) Classification concepts and user manual version 1.0, FAO, 179p. Amsterdam, pp. 321-332.

Tateishi, R. and D. Hastinds (Eds.), 2000. *Global environmental databases*. ISPRS WG IV/6 (1996-2000), Geocarto International Centre, 233p.

Tateishi, R. and D. Hastinds (Eds.), 2002. *Global environmental databases Volume 2*. ISPRS WG IV/8 (2000-2004), Geocarto International Centre, 154p.

Sato, H.P. and R. Tateishi, 2001. Global land use, land cover and vegetation classification systems: a review (in Japanese), Report of Geographical Survey Institute, Japan, No.96, pp.69-99 Amsterdam, pp. 321-332.

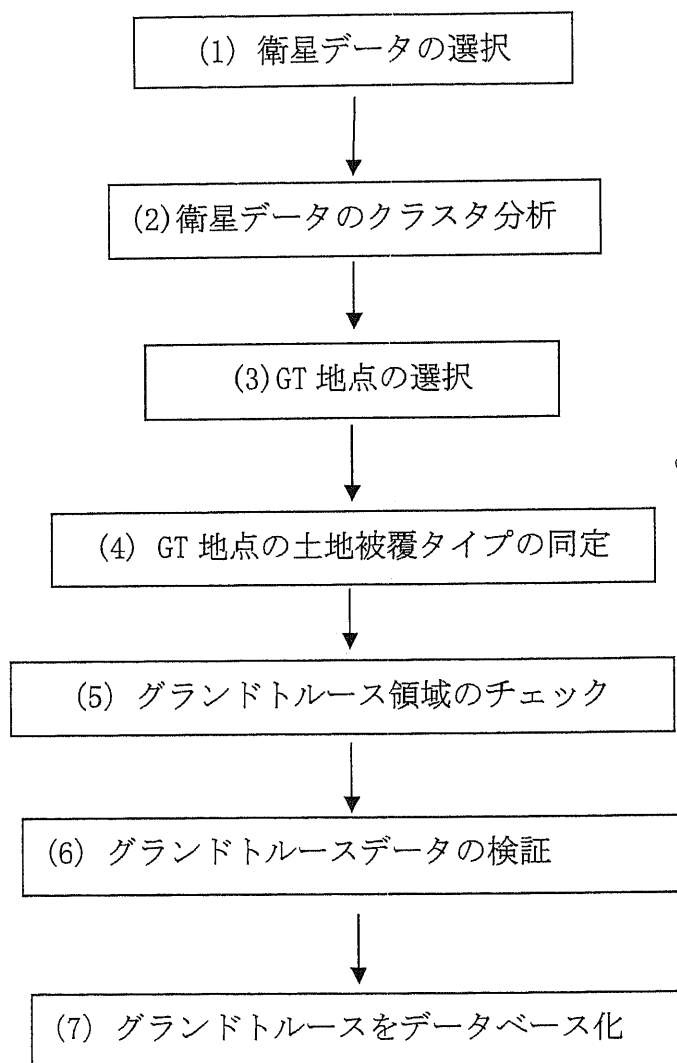
Sato, H.P. and R. Tateishi, 2002. Global land cover legend based on FAO's LCCS, In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Hyderabad, India, Vol. XXXIV-7 (the same proceedings as this paper, in press)

7. 2

第7章 第2節 土地被覆グランドトールースデータベースの構築

第6章で提案したST land cover guideline legendに基づいて収集されたグランドトールース地点数は合計469個で、その中の331個は表2.3に示したR001~R006、138個はR007のインドの地域にそれぞれ分布している。収集したグランドトールースデータのファイルは7つの地域に分けられている。ここで収集したグランドトールースをデータベース化するまでの方法について述べる。

7.2.1 グランドトールースデータを取得する作業の手順



(1) 衛星データの選択

グローバル土地被覆グランドトゥルスデータを収集するための背景画像として、解像度 1 km 程度の低解像度衛星データ (MODIS, VEGETATION, GLI, AVHRR など) がよく用いられる。また、各土地被覆タイプの区別を知るため、グランドトゥルス地点を取る前に、主成分カラー合成画像、月別 NDVI のクラスター分析結果などが用いられる。また、グランドトゥルス地点の土地被覆タイプを確認するため、解像度が数 m から 30m 程度の衛星データも必要になる。Landsat, ASTER などの衛星データがよく用いられる。本研究は、インターネット上で無料で配布されている Landsat の画像を利用した。図 4.1 は検証に用いた 2000 年の SPOT/vegetation 10-day composite 衛星データセットである。

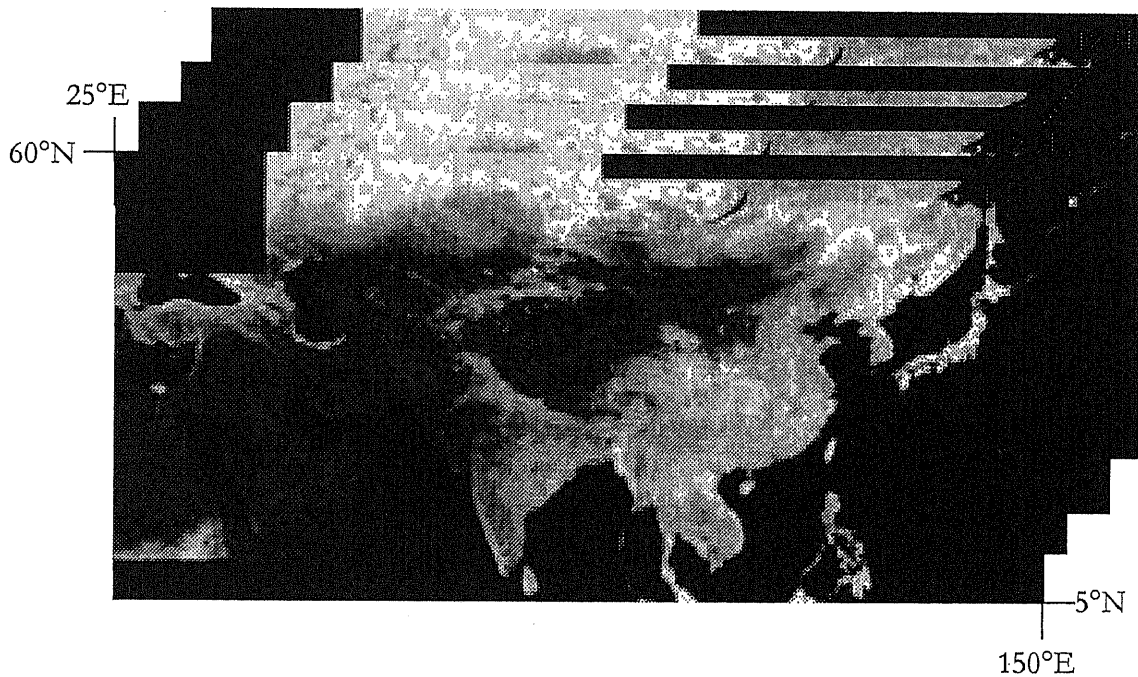


図 4.1 2000 年 SPOT/VEGETATION 衛星データセット

(2) 衛星データのクラスター分析

土地被覆タイプを判読するため、月ごとの NDVI データに対しクラスター分析画像とカラー合成画像の両方を用いた。クラスター数は 40~100 までの程度で、地理的領域が広がるほどクラスター数を増加させる必要がある。図 4.2 はインド地域のグランドトルースを収集する際用いたクラスター画像である。図 4.3 は同地域 10 月のカラー合成画像の例である。

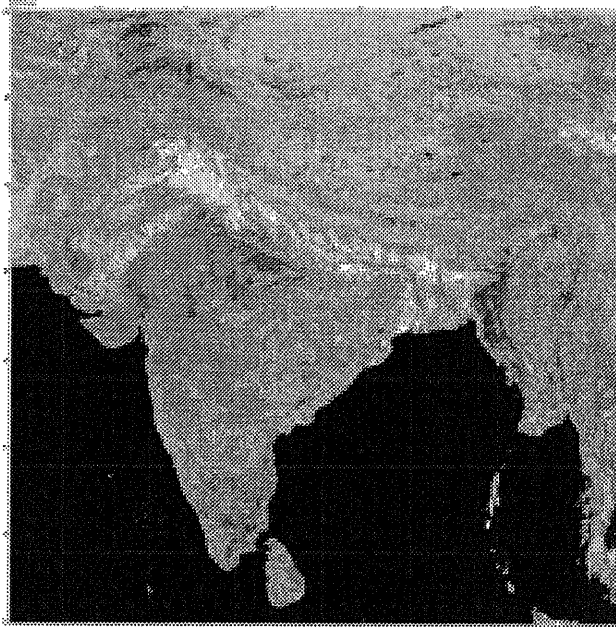


図 4.2 インド地域のクラスター画像

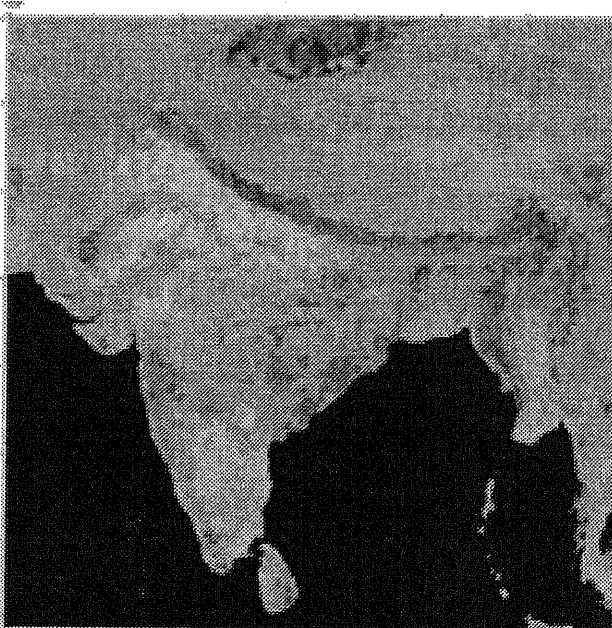


図 4.3 インド地域の NDVI カラー合成画像

(3) グラントルース地点の選択

効率に作業を進行するため、1年間の時系列低解像度衛星データからグラントルース収集領域を切り出す。ここで、グラントルース収集領域は収集する予定のグラントルースデータを地理的に含む長方形領域のことである。一般的には、大陸規模の場合もあるし、一国の国土程度のこともある。一つの分類項目に対し、異なる植物生態区分からグラントルースデータを取る。例えば、農地を亜熱帯地域からも温帯地域からも取る。これは同じ土地被覆タイプでも気候帯が異なれば、植生の活動状態が異なる可能性があるため、それぞれの気候帯に対しグラントルースデータを取る必要がある。

一箇所のグラントルースデータは土地被覆タイプの“均質な”、1 km 解像度で最低3×3画素程度の面積を持つ領域から取る。ここで“均質な”とは、収集するグラントルース閉領域内の各画素が同じ土地被覆タイプであるということを意味する。

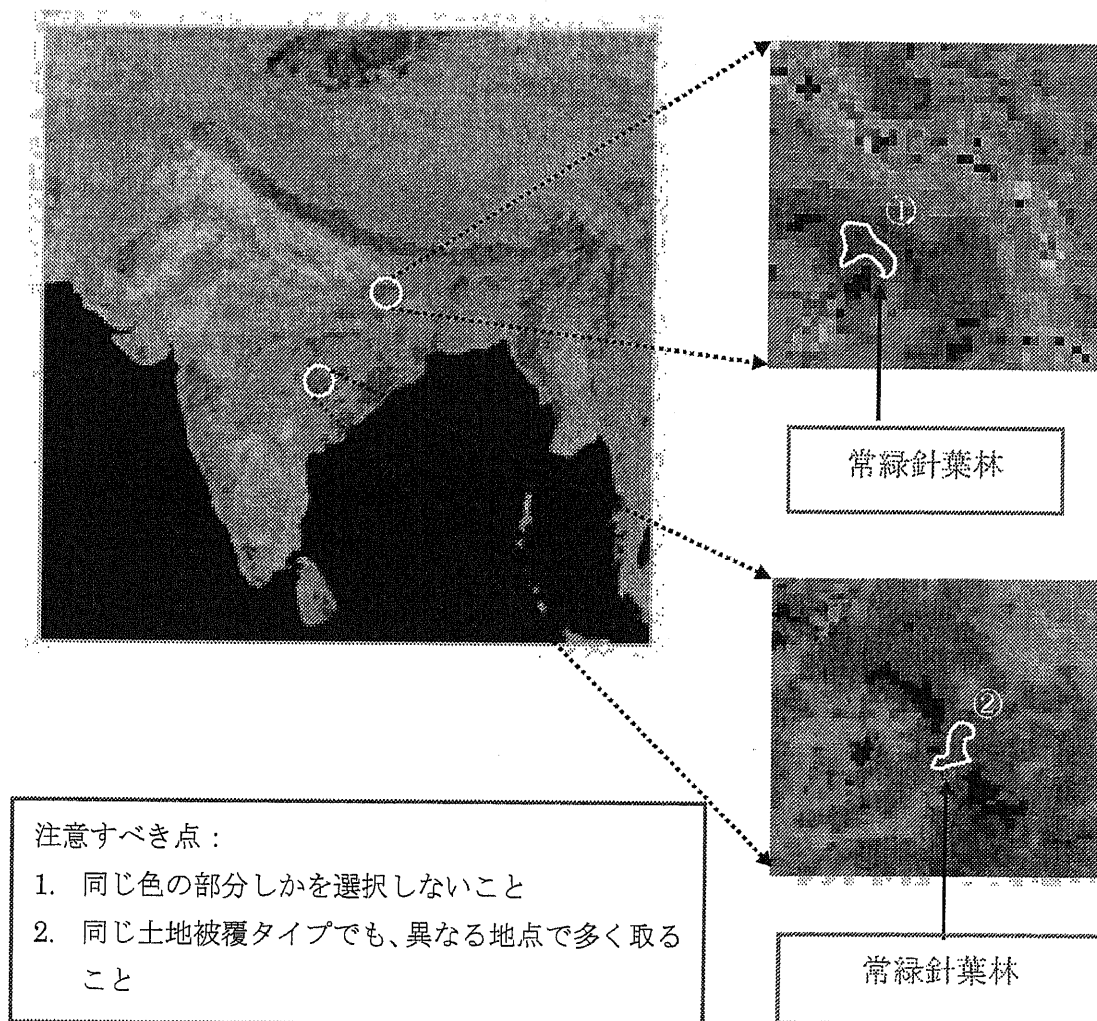


図 4.4 グラントルース地点を選択する要領

(4) グランドトルース地点の土地被覆タイプの同定

グランドトルース地点の土地被覆タイプを同定するために、その地域の土地被覆をよく知っている専門家の知識、または既存の土地被覆図、土地利用図、植生図を利用し、ハードコピーの背景画像上でグランドトルース地点の土地被覆クラスをわかるもののみを同定する。同定する際に、ディスプレイの背景画像上でその地点を選び、そのグランドトルース土地被覆コードとサイト（地点）コードを保存する。グランドトルース土地被覆コードとは土地被覆分類項目に対し事前に与えられたコードである。グランドトルースサイト（地点）コードデータは土地被覆コードデータと同じ地理範囲、画素サイズ、画素数、データ量を持たなければいけない。

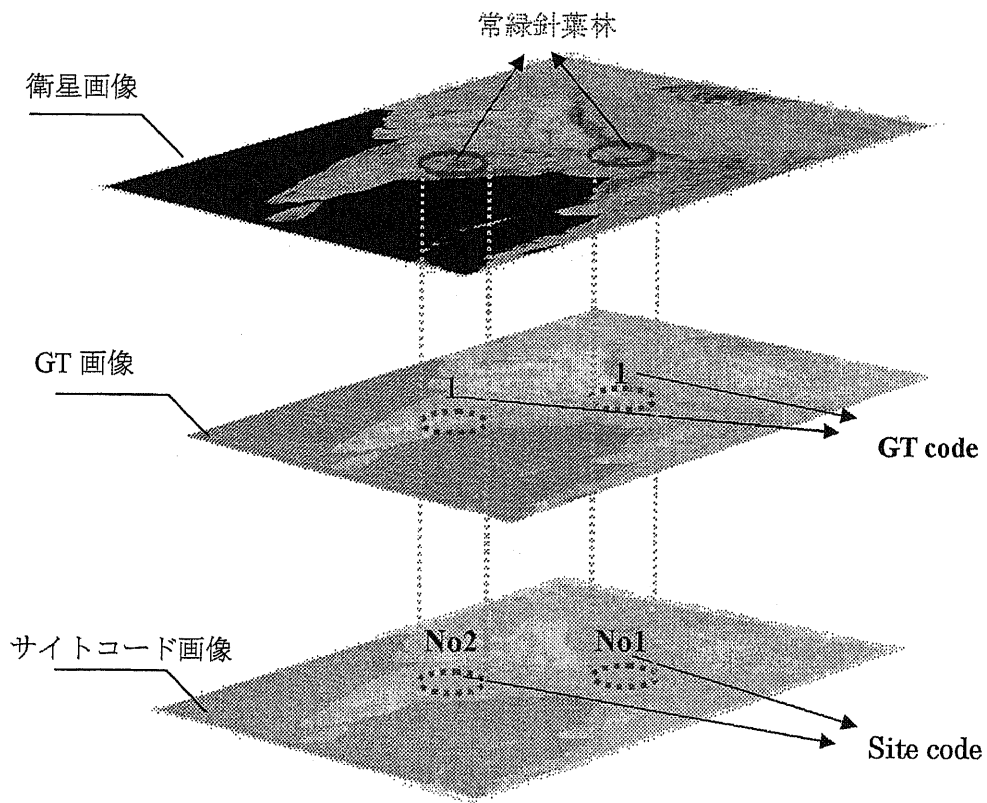


図 4.5 GT 地点の土地被覆タイプの同定方法

(5) グラントルース領域のチェック

複数の作業者が同一地域のグラントルースを収集する場合、同一地域を重複して矛盾したグラントルースを取る場合がある。これをチェックし是正する。例えば、図 4.6 は実際に検出した誤りの例である。コードとコードが重なっているため、その部分の画素値を 0 にする。

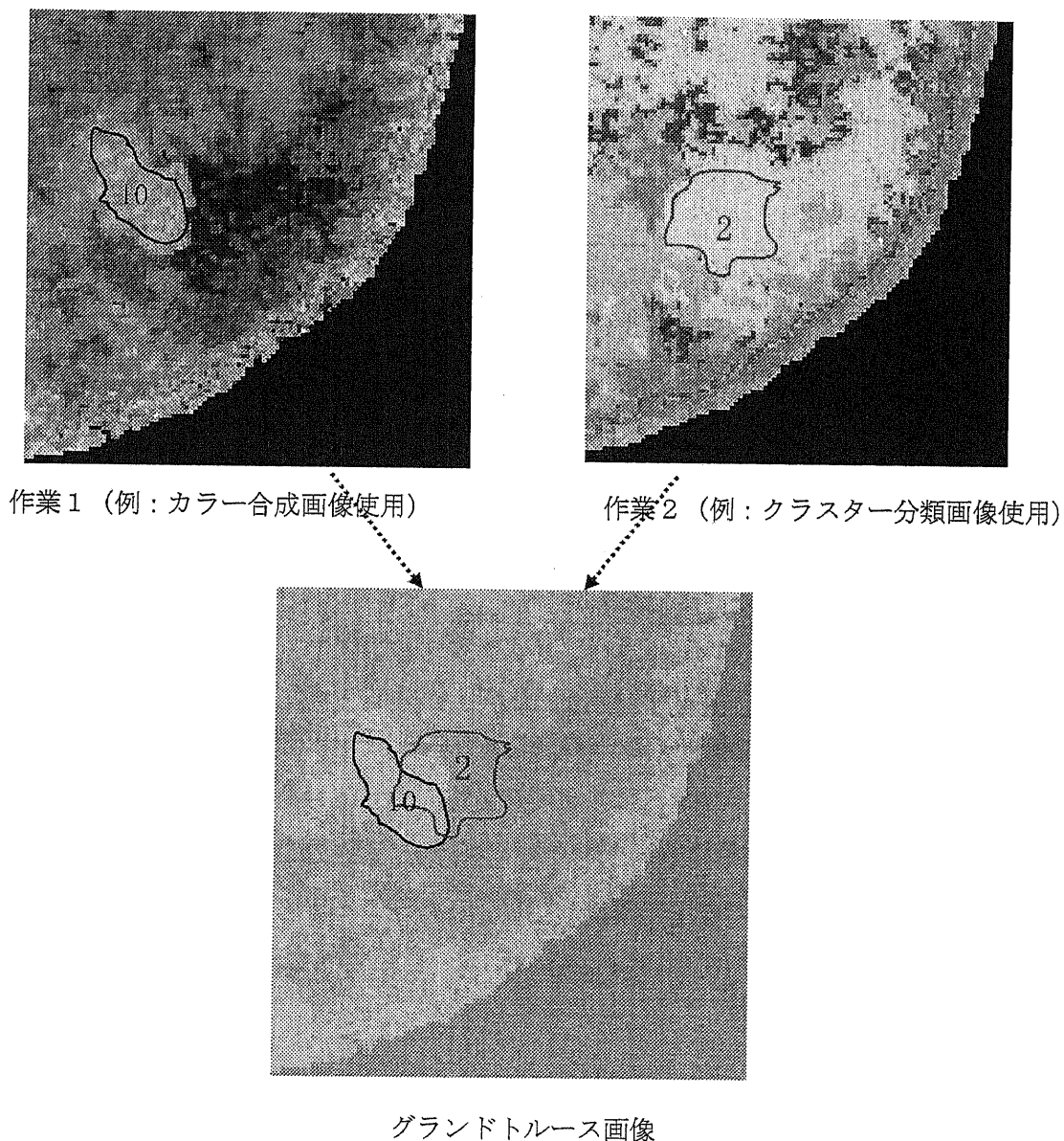


図 4.6 誤ったグラントルースデータの例

7.2.2 グラントルースデータの検証

7.2.2.1 グラントルース検証のフローチャート

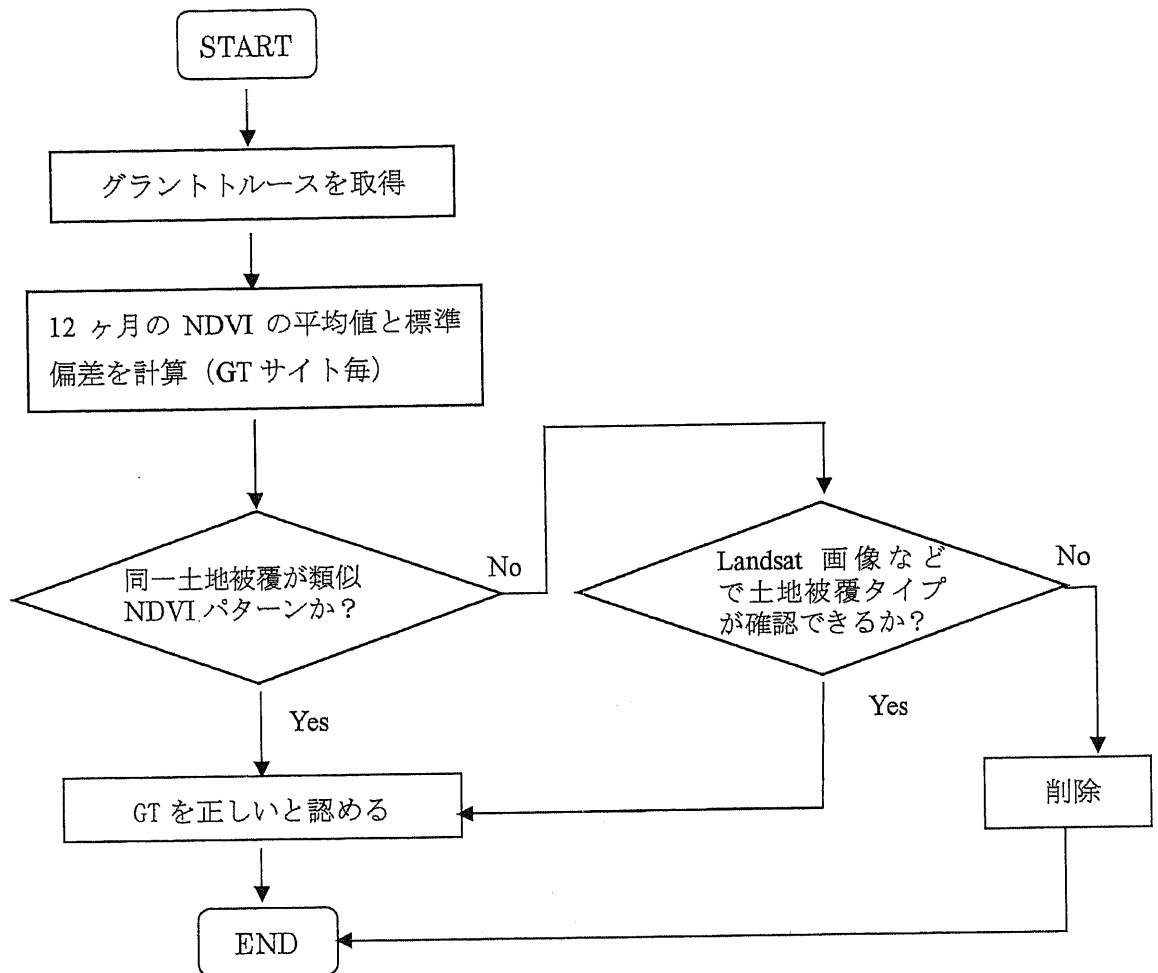


図 5.1 グラントルースデータを検証のフローチャート

7.2.2.2 NDVI 季節変動パターンの検証

(1) 土地被覆変化パターンの検出

土地被覆変化には経年変化(annual change)と季節変化(seasonal change)二つの変化がある。経年変化とは、ゴルフ場の造成や森林伐採などの変化で、一般的には周期性がなく一方向への変化が多い。季節変化とは、落葉性の植物に見られるような一年周期の変化である。画像上では季節変化と経年変化とが混在しているが、対象地物の季節変化の特性をよく知った上、土地被覆タイプの NDVI 季節変化パターンを利用し、土地被覆タイプの分布を明瞭に読み取ることができる。図 5.2 に裸地と農地の NDVI の季節変動パターンを示し、ここから、異なる二つの土地被覆タイプを容易に見分けることが分かった。

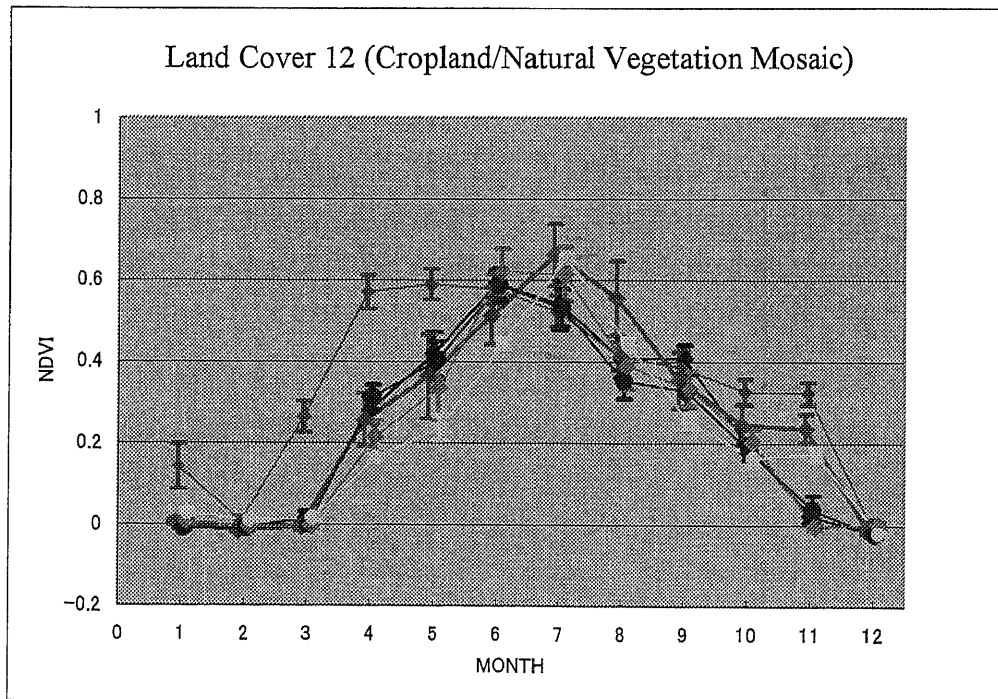
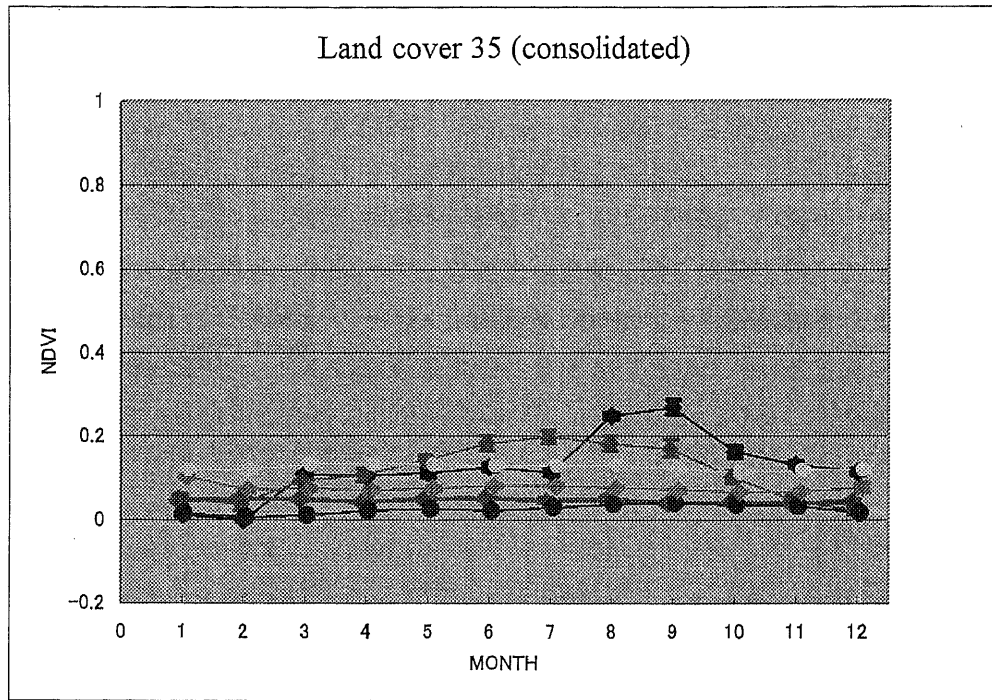


図 5.2 各カテゴリーの NDVI の季節変動パターン

(2) NDVI 季節パターンの解析

本研究では、グラントルースサイト（地点）ごとに monthly NDVI の平均値の変化パターンを抽出し、グラントルースデータを検証する。また、他の土地被覆タイプが混在するかを調べるため、標準偏差値も計算する。

図 5.3 に示すようにグラントルースサイト内の画素の 1 年間の monthly NDVI の各月の NDVI 平均値と標準偏差を求める。

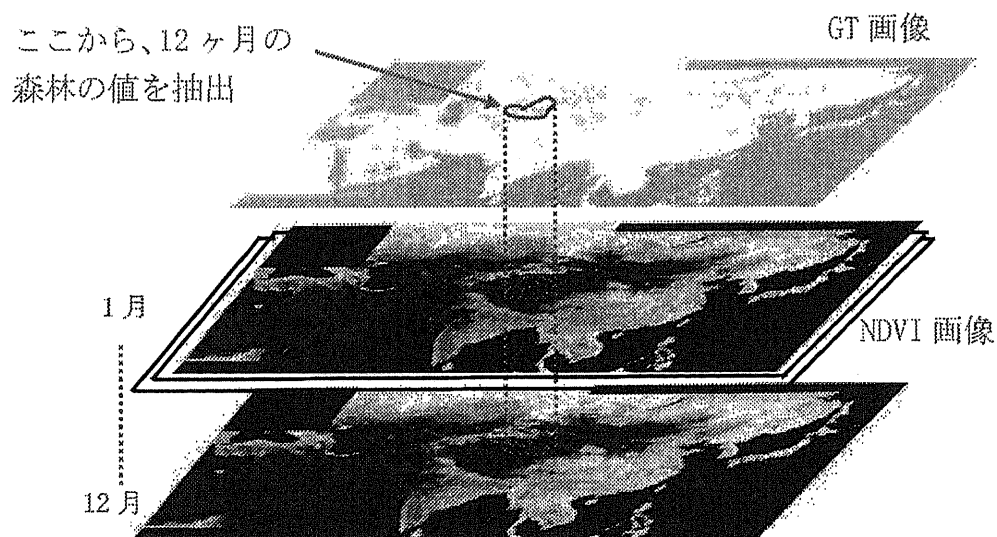


図 5.3 NDVI データを抽出

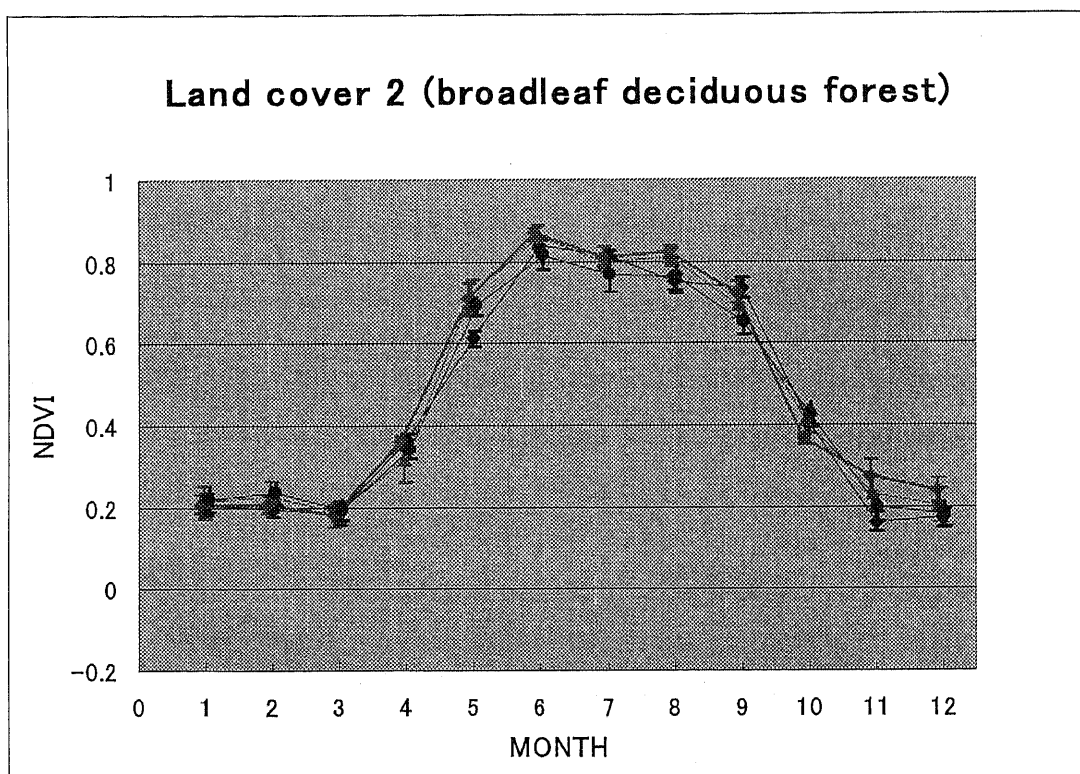


図 5.4 正しい NDVI 変化パターン

図 5.4 に 4 つのグランドトルースサイト（地点）の広葉落葉林の NDVI 季節変動パターンを示す。落葉樹木は春夏期が生長期であり、NDVI の値が高く、秋冬期に葉っぱが落ちるため、NDVI の値が低くなるという特徴がある。グラフから観察すると、4 つの変動パターンは互いに一致する。また、全体の標準偏差が小さいため、他の土地被覆タイプが混在する可能性が低いと考えられる。以上のことにより、4 地点とも正しいグランドトルースデータと判断する。

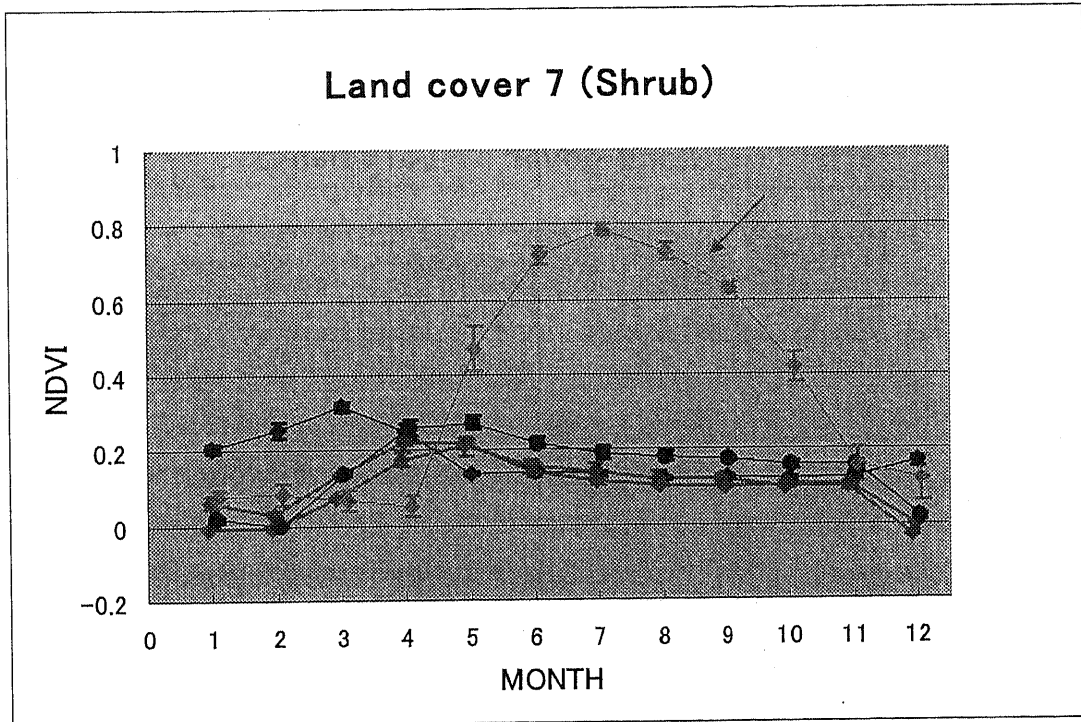


図 5.5 正しくない NDVI 変動パターン

同じ土地被覆項目に対する複数のグラントルース地点の NDVI 季節変動パターンの中、他と大きく異なるパターンがある場合、そのデータは削除される。例えば、図 5.5 にロシア地域の灌木林の変動パターンを示す。矢印に指されている変動パターンが他の 4 つと違いがあり、他の土地被覆タイプだと判定するため、このグラントルースデータは正しくないデータとして削除される。

一方、農地などの場合、例え同じ土地被覆であっても、農作物種類や生長時期などがそれぞれ異なるため、単に NDVI 変動パターンで判定できない場合もある。そのため、問題データの位置を確定し、地図あるいは高解像度の衛星画像などを用いて判定する。判定した結果により、削除するかあるいは変更するかを決める。

例えば、図 5.6 に農耕地のグラントルースデータを示す。青いパターンは中国南京郊外の NDVI 変動状況を示している。標準偏差は小さいが、6月の部分の平均値が他のより非常に低くなっているため、さらに Landsat の写真を用いて、判定した。図 5.7 に示す白い地域がグラントルースを取った地点で、川沿いにたくさんの四方形模様が写っている。地図などの資料を参考し、それを農地のパターンと認定した。ここで6月の NDVI 値が低下した原因が衛星データあるいは雲などに問題がある可能性が高いと判断し、このグラントルースデータを正しいデータとした。

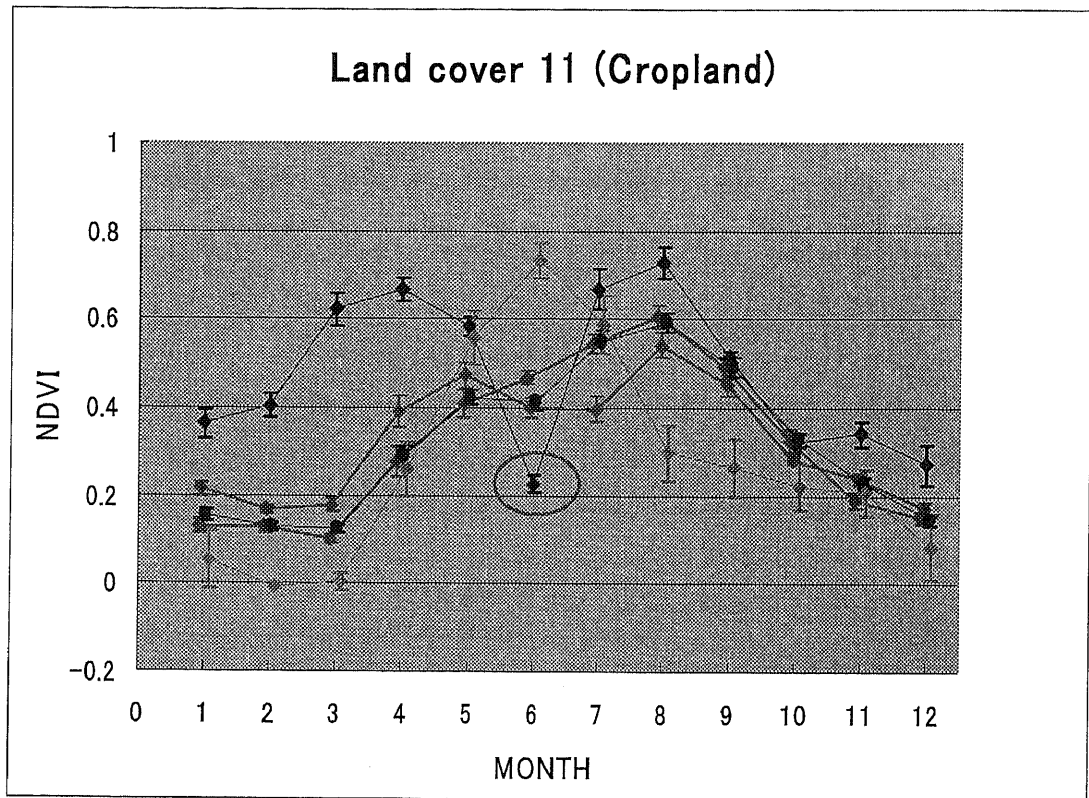


図 5.6 農耕地の NDVI 変動パターン

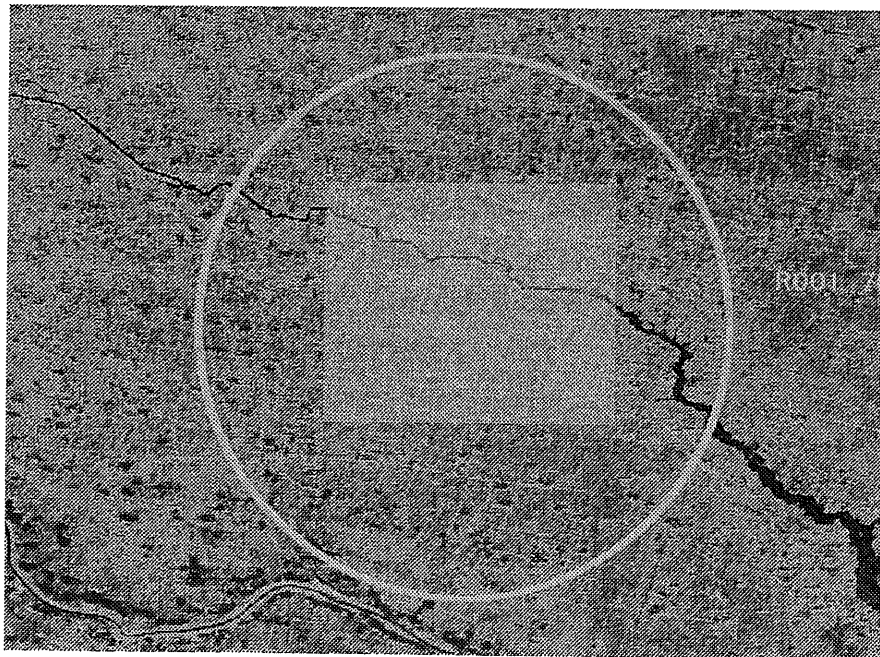


図 5.7 中国南京郊外の LANDSAT_5 TM のイメージ

一方、グラントルースを取る作業の中で、オペレータによるミスもこの NDVI 変動パターン図から検出することができる。

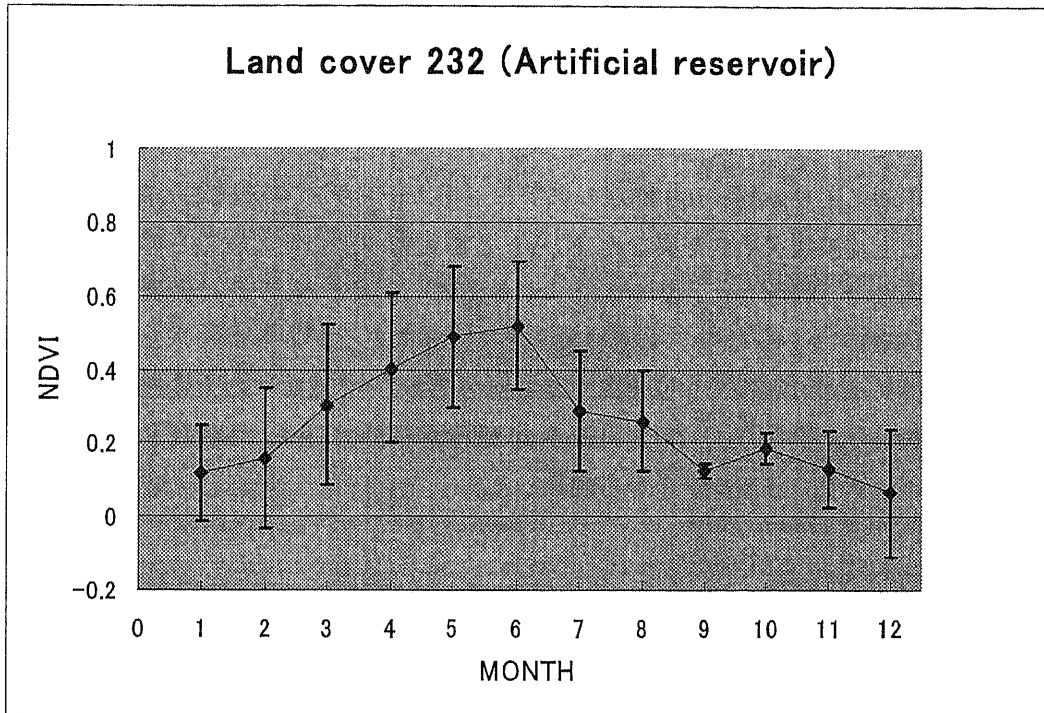


図 5.8 農業灌漑用のダムの NDVI 変動パターン

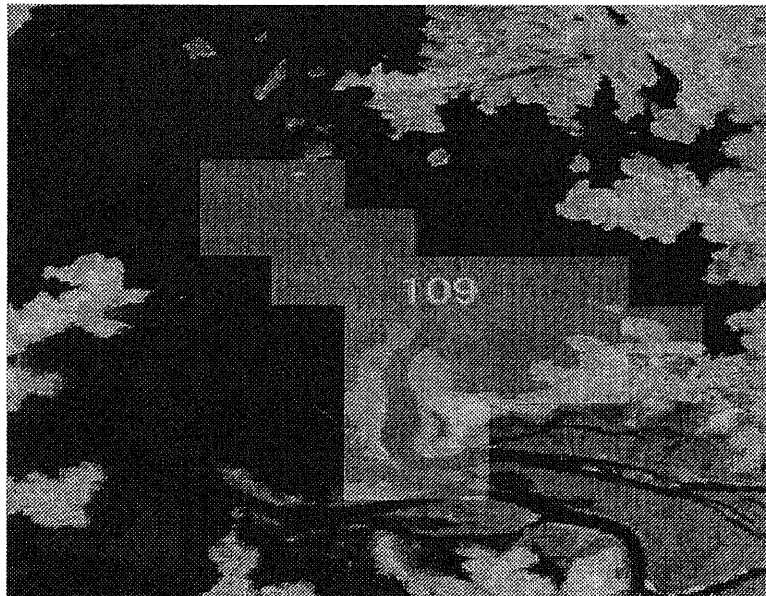


図 5.9 インド南部の Landsat_7 TM のイメージ

図 5.8 にインド南部の農業灌漑用ダムの年間 NDVI 変動パターンを示す。全体的に標準偏差が大きいため、他の土地被覆タイプが混在している可能性が高いと判断できる。

図 5.9 に示す Landsat 画像の中で、白い部分がグラントルースサイトであり、ダムの水域以外の土地被覆タイプも写っている。その原因は、オペレータがそのグラントルース地点を選択する際に、他の土地被覆タイプも入れてしまったことである。そこで、このようなグラントルースデータは純粋なダムデータでないため、削除すると判断した。

以上の手順により、合計 469 地点のグラントルースデータを検証した。その内、図 5.10 に示す同じ土地被覆タイプで異なる NDVI 季節変動パターンを持つものを 19 点抽出し、Landsat 画像で再検討した。表 5.2 に示すように、19 点の内、6 点は変更なしと処理した。NDVI 季節変動パターンは同じ土地被覆タイプの他のグラントルースと異なっても、当該の土地被覆タイプであることが確認できたためである。2 点は他の土地被覆タイプが適当であると判断した。残りの 11 点は、Landsat 画像からだけでは土地被覆タイプが確認できなかったため、グラントルースから削除した。

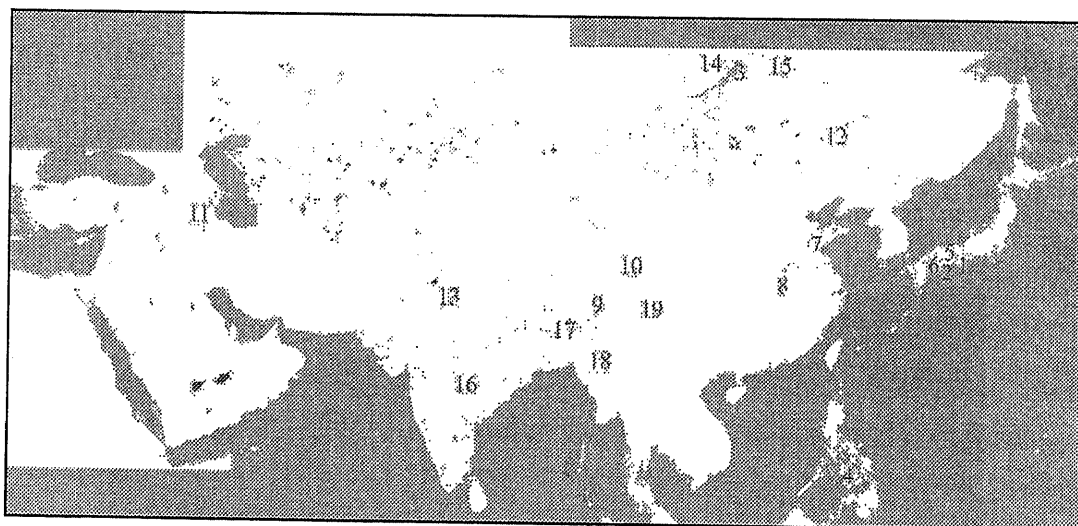


図 5.10 異なる NDVI パターンを持つグラントルース地点

No.	RLCG コード	GT 地点 コード	土地被覆タイプ	対応
1	R001	7	Evergreen Needleleaved forest	変更なし 理由: landsat 画像で確認 (和歌山)
2	R001	8	Evergreen Needleleaved forest	変更なし 理由: Landsat 画像で確認 (九州)
3	R001	34	Bare area	削除 理由: 裸地にもかかわらず 6-10 月の NDVI が高い
4	R001	55	Arableland, coconuts mainly	変更なし 理由: Coconuts は一年中 NDVI が高い
5	R001	59	Broadleaf Deciduous forest	削除 理由: 落葉にもかかわらず 1-4 月の NDVI が高い
6	R001	60	Evergreen Needleleaved forest	変更なし 理由: Landsat 画像で確認 (四国)
7	R001	69	Paddy	変更なし 理由: Landsat 画像で確認 (中国、南京郊外)
8	R001	70	Crop	変更なし 理由: Landsat 画像で確認
9	R001	71	Broadleaf evergreen	削除 理由: 常緑であるのに 7-9 月の NDVI が低い (中国、雲南)
10	R001	73	Exposed rock	削除 理由: 9-11 月に NDVI が高い
11	R002	29	Sparse herbaceous → Crop, two-time	土地被覆タイプを変更 理由: Landsat 画像で検証し、Crop, two-time に変更する
12	R004	70	Closed graminoids	削除 理由: 5-9 月 NDVI が高すぎる
13	R004	124	Savanna → Crop, two-time	土地被覆タイプを変更 理由: Landsat 画像で検証し、Crop, two-time に変更する
14	R006	36	Lichens and mosses	削除 理由: 6-10 月 NDVI が高すぎる
15	R006	38	Mixed Shrubs	削除 理由: 5-10 月 NDVI が高すぎる
16	R007	109	Artificial reservoir	削除 理由: 他の土地被覆が混ざっている
17	R007	181	Broadleaf evergreen forest	削除 理由: 5-6 月 NDVI が高すぎる
18	R007	192	Two time crop, paddy	削除 理由: 5-12 月 NDVI が低すぎる
19	R007	197	Snow	削除 理由: 他の土地被覆が混ざっている

7.2.3 グラントルースデータのデータベース化

完成したグラントルースデータベースはいくつかの地域のグラントルース (RLCGT) データから構成されている。それぞれの地域データに図 3.8 のようにグラントルースファイルを含め、データ作成の時間、使用した資料などの詳細を記述した 4 つのデータファイルで構成される。

RLCGT の構成部分

-metadata of RLCGT data	(text)	dataset name: "meta***.pdf"
-ground truth(GT)land cover code data	(raster data)	dataset name: "lgt***.raw"
-ground truth(GT) site code data	(raster data)	dataset name: "site***.raw"
-description of GT sites	(text)	dataset name: "source***.pdf"

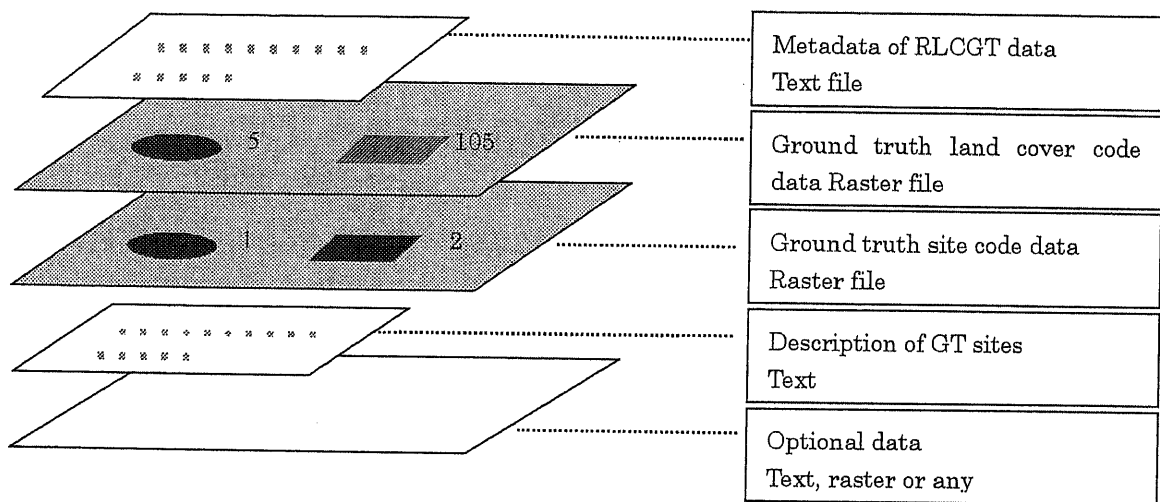


図 3.8 グローバルランドカバーグラントルースデータベースの構造

(1) Metadata of RLCGT Data (meta***.pdf)

1. RLCGT コード (GLCGT データベースのプロジェクトの担当者に指定される。)
2. RLCGT データを作成組織名あるいはプロジェクト名。
3. RLCGT データを作成代表者。
4. RLCGT データの連絡担当者。
5. RLCGT データの作成日付。
6. RLCGT データファイルの四隅の緯度、経度。
7. ピクセルのサイズ (単位: 秒)。
8. ピクセルのナンバー (東~西、北~南)。

9. ランドカバーコードの定義。
10. 追加されたランドカバーコードの定義。
11. 選択データの説明。
12. RLCGT データについて他の関連にある説明。

(2) Ground Truth Land Cover Code Data (lcgt***.raw)

GT データの主な部分で、WGS84 に基づく経度緯度において 30 秒ごとの画素に再配列される。また、異なる解像度のデータの重ね合わせを容易にするため、経度緯度の始まりは 30 秒画素の中心でなく、角となるように再配列を行う。

(3) Ground Truth Site Code Data (site***.raw)

1つの地点の GT データに唯一のサイトコード (1~254) を対応させる。対応したナンバーは “source***.pdf” ファイルに記述されている。また、今後の検証の作業と分類作業を順調に進むため、グランドトルースサイトコードデータのサイズ、形及びフォーマットなどは必ずグランドトルースランドカバーコードデータと一致すると厳密に要求されている。コードの値に範囲については、いままでグランドトルースサイトコードデータが常用色の表示範囲 8 ビットの 255 までに対応しているが、その値を超えた場合、RLCGT データが 16 ビットに変更し、再定義しなければいけない。

(4) Description of GT Sites (source***.pdf)

1つの GT データごとに詳しい説明はテキストファイルの中に書かれている。

- サイトコード
- GT サイトの正確な緯度、経度座標
- グランドトルースサイトのランドカバーコード
- 当該 GT サイトに関連があるすべての説明
- GT サイトデータの情報源

この中で、GT サイトデータの情報源が最も重要な部分である。GT サイトデータの正確さはこの情報源に基づき評価される。サンプルファイルは以下に示す。

```
-site code:          3
-lat/long:          N42degree 56minute,E130degree 50minute
-land cover code:   12
-land cover:        broadleaf deciduous forest
-information source: field survey, Jul-Aug 2001(by Tateishi)
                   FS-point No.5
                   +Land use map of China 1:1,000,000 published by the Science
```

Press, 1990

or

Landsat TM (24 Feb 2000 and 16 Jan 2000)

+knowledge (Ekaterina Rachkovskaya)

or

vegetation map of Kazakhstan and Middle Asia, 1:2,500,000, 1995

+field survey in early 1990 (by Ekaterina Rachkovskaya)

or

land use map 1:200,000, Geographical Survey Institute, Japan 1982

+knowledge (Tateishi)