REDD
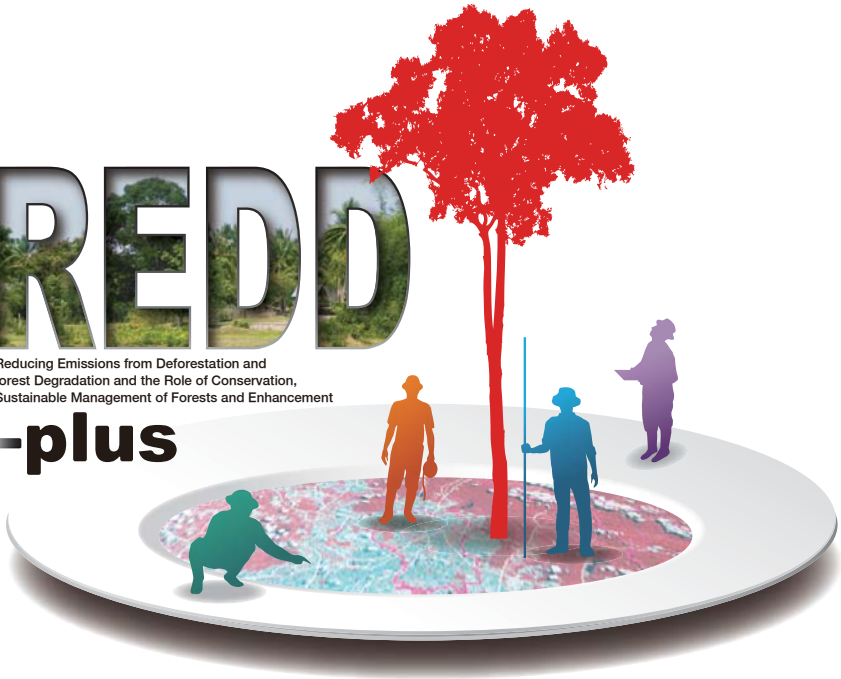
Reducing Emissions from Deforestation and
forest Degradation and the Role of Conservation,
Sustainable Management of Forests and Enhancement

-plus

COOKBOOK
ANNEX

Research Manual Vol. 5

Satellite Image Analysis for Area Estimation Using Remote Sensing

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Research achievement of the 4th mid-term plan 19 (Forest Management Technology-16)

Preface

The basic concept of REDD-plus is to provide economic incentives such as funding or credits to developing countries for REDD activities (reducing emissions from deforestation and forest degradation) and "plus" activities (reducing CO_2 emissions and CO_2 levels in the atmosphere by carbon sequestration). Thus, in order to estimate the changes in the amount of carbon stored in forests, monitoring using scientific approach is essential.

The REDD Research and Development Center, Forestry and Forest Products Research Institute compiled "REDD-plus Cookbook" in 2012; an easy-to-understand technical manual which provide basic knowledge and techniques required for REDD-plus with the main focus on the forest carbon monitoring methods. Knowledge and techniques required for REDD-plus are compiled in units called "Recipe" in this REDD-plus Cookbook. This REDD-plus Cookbook is intended for the policy makers working for the introduction of REDD-plus and the practitioners and experts working on the REDD-plus activities.

As REDD-plus Cookbook focuses on basic knowledge and techniques required for REDD-plus, the experts working on the REDD-plus activities will need further detailed information in the field. Thus, we compiled "REDD-plus Cookbook Annex" to provide the experts with more detailed and practical information in each "Recipe". In this manual, specific measuring methods are explained. Also, this manual is intended to be used as a textbook for building capacity. In order to have a better technological understanding on these topics, it is recommended to read this manual in conjunction with REDD-plus Cookbook.

We hope this manual will contribute to the promotion of REDD-plus in many parts of the world.

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The REDD Research and Development Center
Forestry and Forest Products Research Institute

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1 Outline

1.1 Purpose of REDD-plus Cookbook Annex

The "REDD-plus Cookbook," published by the Forestry and Forest Products Research Institute in 2012, is a technical manual that simply explains the basic knowledge and techniques for REDD+ with a focus on forest carbon monitoring. This satellite image analysis manual explains the analytical method to estimate forest areas using remote sensing technique. Forest areas derived from remote sensing techniques will be used to estimate forest carbon stock, as indicated by the REDD-plus Cookbook.

This manual was prepared for foresters who estimate forest areas using satellite data in practice. We hope that it also provides useful information to students studying forestry and forest ecology, and organizations, such as NGOs, that are interested in REDD+.

1.2 How to use this survey manual

The data analysis methods presented here are standard methods for REDD+. When estimating forest area based on satellite image analysis, results would be different depend on source data, acquisition date, and analysis method. Reliable forest area estimates must select the appropriate data, acquisition period, and analytical method. The accuracy, precision, and bias of maps must be evaluated thoroughly. Therefore, before performing satellite image analysis, it is recommended to read this manual and understand all processes.

Classifications and accuracy assessment of satellite images for area estimates using remote sensing, have different default parameters and operational methods, depending on the software used. It is important to carefully read manuals and tutorials of software before starting an analysis.

1.3 Recipes covered by REDD-plus Cookbook

Recipes covered by REDD-plus Cookbook are shown in [ ]. Please refer to REDD-plus Cookbook.

REDD-plus Cookbook can be downloaded from the sites below.

http://redd.ffpri.affrc.go.jp/pub_db/publications/cookbook/index_en.html

2 What is necessary for satellite image analysis

2.1 Computers

To perform image and GIS analysis, computers with advanced specifications are necessary. For example, ERDAS Imagine is a commonly used image analysis software and recommends a 64-bit CPU that can perform multicore processing and uses memory of 8 GB or more. The software requires 4 GB of disc space. Depending on the mapping project, several TB of space are necessary for storing data, intermediate files, and results, which requires fast disc access. The operating system should be 64-bit (Windows10 Pro 64-bit, etc.). Image analysis software is generally capable of 3D display using OpenGL, etc. Software that can use GPU for operations are available. To maximize these functions, a high-performance graphics card is necessary.

2.2 Display

A large display is necessary for image analysis. Dual display is convenient for comparison of images and analysis while looking at reference images. A high-performance graphics card is necessary for dual display output.

2.3 Internet connection

Landsat images, commonly used for REDD+ projects, are usually downloaded from the United States Geological Survey (USGS) homepage. Each Landsat satellite image is 800-1000 MB, which requires a high-speed internet connection. Recently, Google Earth has been used as reference data for classification. When using Google Earth, a high-speed internet connection is essential. In addition, to access help for analytical methods, software manuals, user community pages, and free tools require an internet connection.

2.4 Software

Image analysis software includes ERDAS Imagine, PCI, ENVI, TNTmips, etc., which are all available for a price. As for open source software, there is GRASS, which is distributed with the GIS software QGIS as a set. Representative GIS software, ArcGIS, has plug-ins, such as Spatial Analyst, and some level of processing is possible. Specialized software such as the object-based classification software, eCognition, are also available for forest cover mapping.

2.5 Programming environment

Recent image analysis software has high-quality GUI, and a programming environment is not essential. However, scripts that download multiple Landsat satellite images at once, or free image analysis tools, such as cloud removal, are available on the internet. To use these tools, programming skills, such as C and Python, are necessary.

3 Acquiring satellite images [*Recipe-T05*]

Various types of data from satellite images are used for forest area estimates. Free online Landsat images are generally used. Because forest area estimates for REDD+ are restricted costs on the monitoring. Here, we present the steps to download Landsat images from the USGS Earth Explorer (https://earthexplorer.usgs.gov/). To use this site, one must register as a user with the USGS. A tutorial with more details on the download steps can be found here: https://earthexplorer.usgs.gov/documents/helptutorial.pdf.
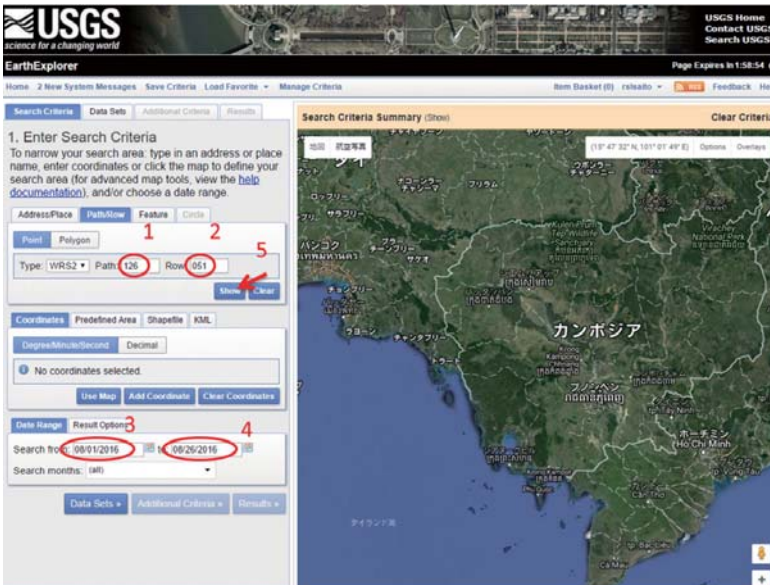

Figure 1. Earth Explorer Search Criteria screen
Earth Explorer, USGS (https://earthexplorer.usgs.gov/)

Landsat image scenes are indicated by a path determined by the orbit, and row determined by the latitude at the center of the scene. First, input the path and row of the observation target (Figure 1).

1: Input the path.
2: Input the row.
3: Input the start date for acquisition of search target images.
4: Input the end data for acquisition of search target images.
5: Click on "Show" to display the observation target site.

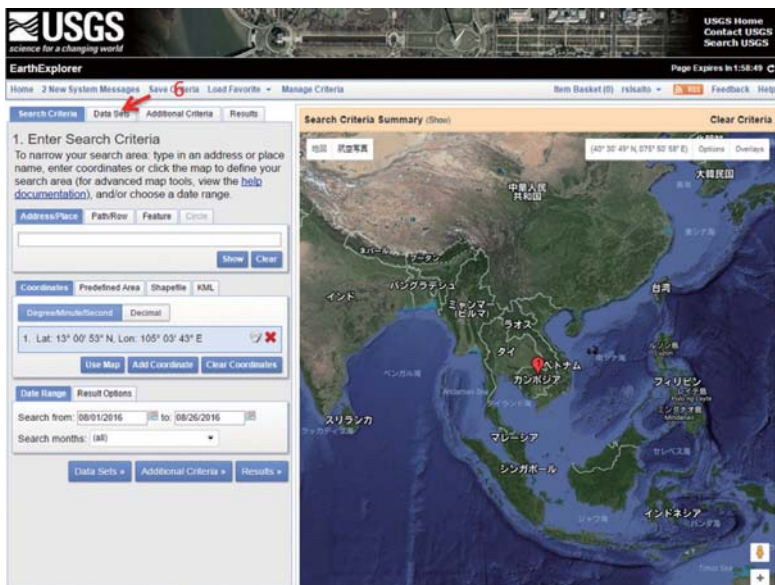Figure 2. Earth Explorer Search Tab for data sets
Earth Explorer, USGS (https://earthexplorer.usgs.gov/)

6: If the path and the row are correct, click on "Data Sets" identified with "6."
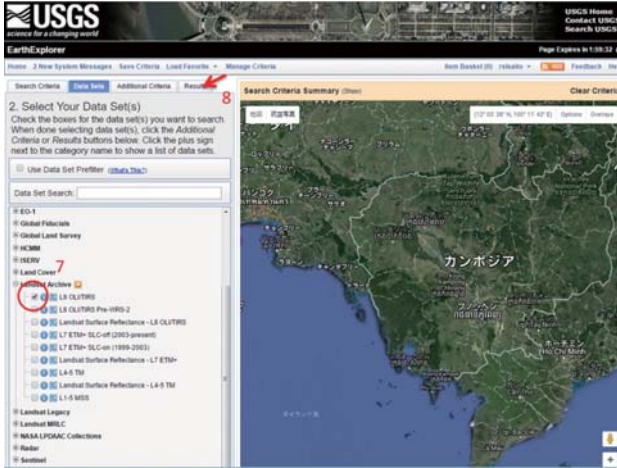
Figure 3. Search Tab for data sets

Earth Explorer, USGS (https://earthexplorer.usgs.gov/)

7: Select L8 OLI/TIR from data sets.

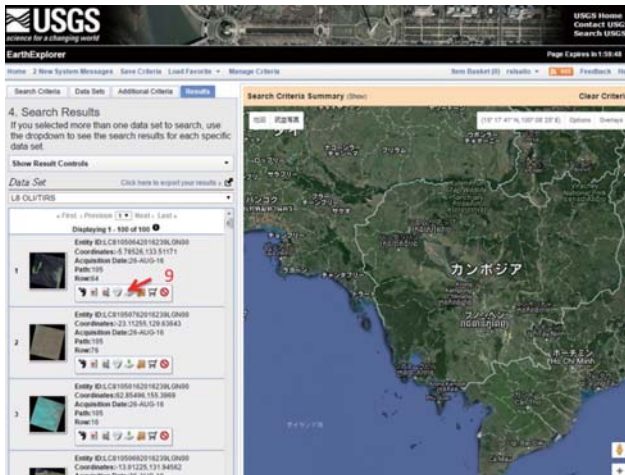8: Click on "Results" (Figure 3).

Figure 4. Search results

Earth Explorer, USGS (https://earthexplorer.usgs.gov/)

Search results are displayed (Figure 4).

9: Click on the download icon of the desired image.
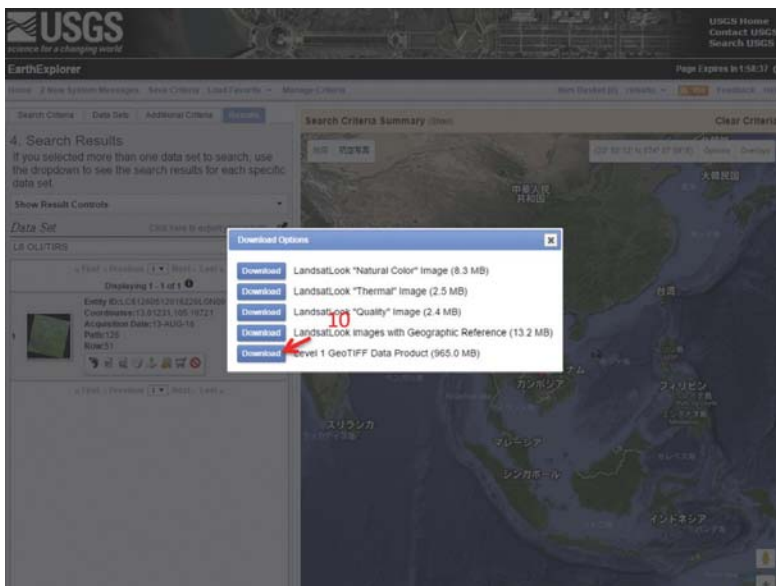
Figure 5. Download options dialog box
Earth Explorer, USGS (https://earthexplorer.usgs.gov/)

Options of the data available for download are displayed (Figure 5). If you click on the download icon for Level1 GeoTIFF Data Product (data size is about 800-1000 MB), a dialog box for the download destination and the file name appears. Choose the folder and set the file name, click on "OK," to start the download.

Higher-order processing products, such as Landsat Surface Reflectance Higher-Level Data Products, are processed only after an order is placed. When the processing is complete, there will be an e-mail notification and the product can be downloaded from a specified site. At this point, there is a Python script ready, and multiple images can be downloaded through batch processing using this script.

4 Consideration of atmospheric correction, cloud removal, and seasonality

Downloaded satellite data stores radiance values acquired by the sensor during satellite orbit. Since these values include, not only reflection from objects, such as forests, but also reflected light and a scattered-light component from aerosol and water vapor in the atmosphere, these impacts must be reduced and converted to reflectance from the ground surface. This process is called atmospheric correction and can be performed easily using the ENVI module FLAASH (Fast Line-of-sight Atmospheric Analysis of Hypercubes) or commercially available software such as ATCOR for Imagine. As for 6S, scripts such as the GRASS module and Py6S (http://www.py6s.rtwilson.com/) are available free of charge. However, to be able to execute this, a programming environment and the skills required to use such an environment are necessary.

For atmospheric correction, the USGS website performs a higher-order process called Landsat Surface Reflectance Higher-Level Data Products, providing data that have already been converted to ground surface reflectance. If you do not own atmospheric correction software or the skills to perform atmospheric correction, using such data may be an option.

4.1 Steps for atmospheric correction

Let us explain atmospheric correction using ATCOR for Imagine 2014 incorporated into ERDAS. First, data downloaded in "2" are read by ERDAS Imagine to perform layer stacking. Then, a parameter file is prepared to convert digital numbers to radiance values, this is called a calibration file. Below, we present the calibration files of the Landsat 8 OLI sensor as an example.

```
7    c0    c1    [mW/cm² sr micron]
1    -6.366048    0.001273
2    -6.518911    0.001304
3    -6.007121    0.001201
4    -5.065543    0.001013
5    -3.099860    0.000620
6    -0.770907    0.000154
7    -0.259837    0.000052
```

The first row in the first column is the band number, second to eighth rows are conversion parameters of each band. The conversion parameter is different for each scene.

During processing, the data acquisition date and time and the latitude-longitude at the center

of the scene become necessary. Thus, this information should be prepared.

DATE_ACQUIRED = 2014-03-10
SCENE_CENTER_TIME = 03:14:00.1527749Z
CENTER LAT: 13.00646
CENTER LON: 106.624715

This data is stored in the file with the extension of "*******.MTL.txt".

Next, we move onto processing with ATCOR.
① Turn on ATCOR2 (ATCOR2 is for flat areas and ATCOR3 is for mountainous areas). Create a new project file.
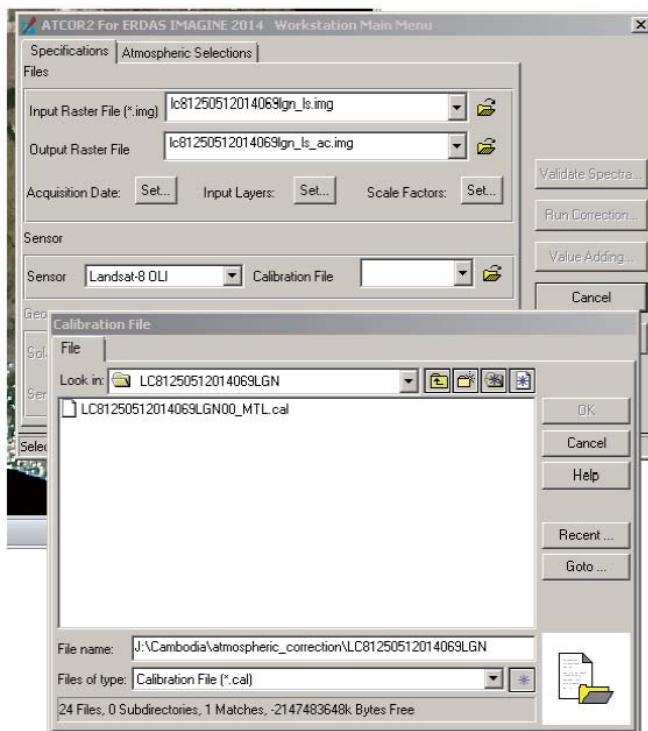② Choose input and output files (Figure 6).

Figure 6. Input and output file menu.

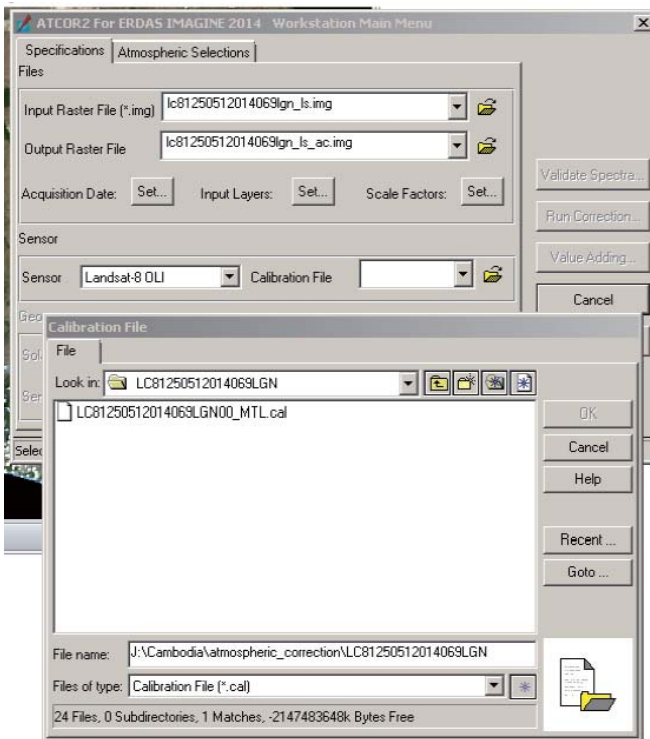③ Select the sensor and choose the calibration file that was prepared earlier (Figure 7).

Figure 7. Calibration file menu.

④ Use the solar position calculator (Figure 8) to calculate the solar zenith and apply. Here, input the date and time of the data acquisition as well as the latitude and longitude at the center of the image in the header file. The calculation result is applied according to the geometry field from the main menu (Figure 9).
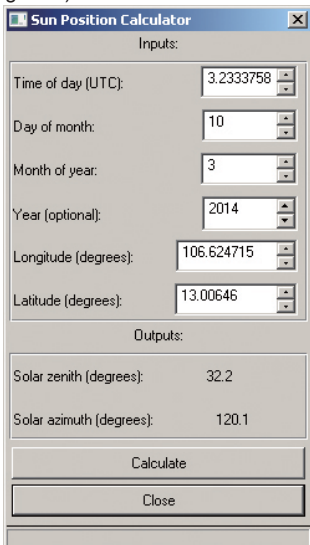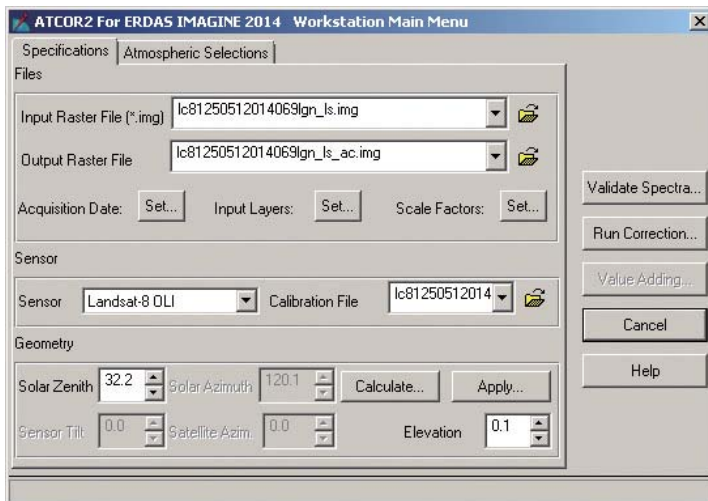

Figure 8. Solar position calculator.

Figure 9. Results of applying the geometry.

⑤ Select the type of aerosol in the atmospheric selections menu (Figure 10) and estimate the visibility. Click on "Run Correction."
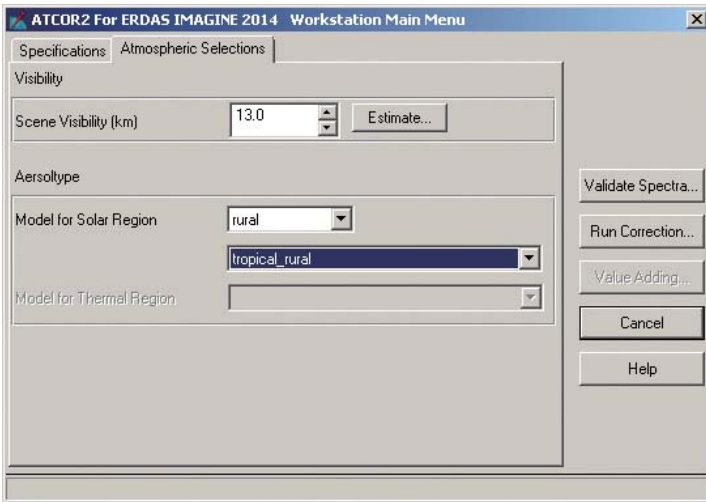

Figure 10. Atmospheric selections menu.

⑥ Click on "Atmospheric Correction" on the atmospheric correction screen (Figure 11) to execute atmospheric correction.
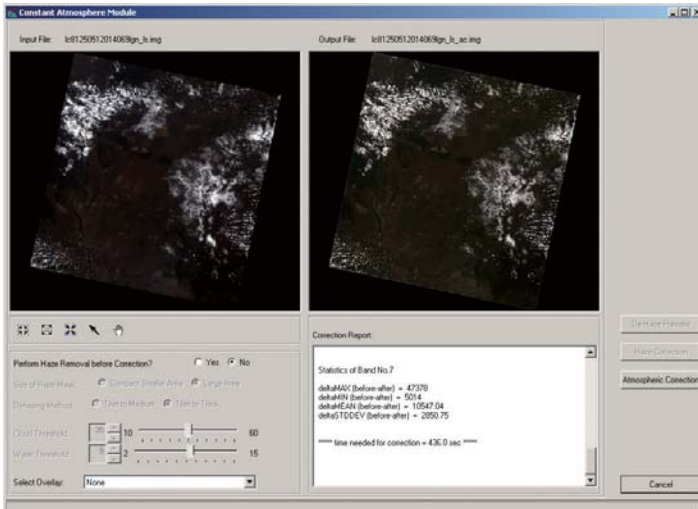

Figure 11. Atmospheric correction screen.

Here, one can obtain the image of reflectance with the atmospheric correction performed.

The present example is ATCOR2 without a digital terrain model (DTM). In this case, radiance due to topography is not corrected. ATCOR corrects radiance due to topography, but as an input value, DTM and topographic feature values calculated from a DTM are necessary. In developing countries SRTM, ASTER GDEM, and ALOS DSM can be used as a DTM. Correction of radiance due to topography could be overcorrected, thus the corrected results must be carefully examined.

ATCOR

ATCOR for IMAGINE is an add-on module for ERDAS IMAGINE.

As a pre-process of difference of extraction or classification, ATCOR for IMAGINE can perform atmospheric correction of satellite data. This product is exclusively supplied by GEOSYSTEMS Germany.

For more details, please see https://www.geosystems.de/en/products/atcor/.

Contact: info@geosystems.de

4.2 Cloud masking [*Recipe-T06*]

Satellite images contain clouds, haze, and their shadows. Satellite image pixels covered by these cannot be used to estimate areas and must be removed. This is called masking. For Landsat image data, a mask to remove clouds, haze, and their shadows can be prepared with free software called Fmask, which can be obtained from the following site.

https://github.com/prs021/fmask

Fmask is executed by copying Fmask.exe (execution) to the folder containing the downloaded Landsat data and then decompressed, via command prompt. Results are outputted to the executed folder with a format that can be opened with the image analysis software ENVI (Figure 12). Pixel values of the resulting image show the following classes.

0 => Clear land area
1 => Transparent water area
2 => Shadow of clouds
3 => Snow
4 => Cloud
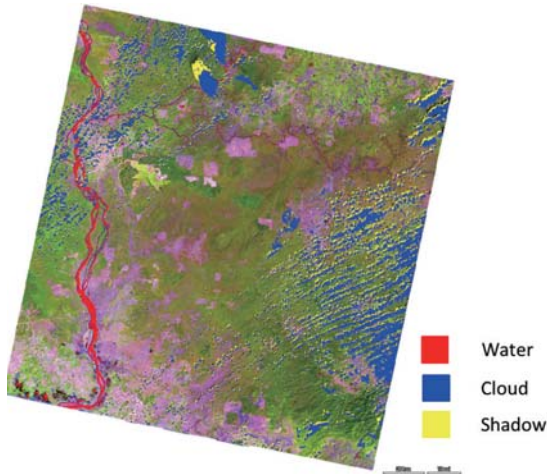255 => Pixel without observed value

Figure 12. Example of extracted water area, clouds, and shadows of clouds.

Since the value of "1" in mask image indicates cloud free areas, masking is performed with the image analysis or GIS softwares.

> **TIPS** There was a period during which TIRS (thermal band) of Landsat 8 was broken. Thus, Fmask has versions with and without TIRS.

4.3 Seasonality [*Recipe-T06*]

Since satellite images are captured routinely as the satellite passes, these images are obtained throughout the year. However, since there are evergreen and deciduous forests, the appearance of the image differs depending on the season. As the solar elevation changes, the positional relationships between the sun, observation target, and the satellite also change, and the radiance input into the sensor also changes. Though atmospheric correction can reduce some of these effects, generally these effects are taken into consideration, the acquisition time is specified, and the satellite data are selected in time series analysis (White 2017). If an image from a period of defoliation is selected, it is easy to differentiate evergreen forests and deciduous forests. But deciduous forests can be easily mistaken with other land uses, such as agricultural lands. On the other hand, if an image from other seasons is selected, it is easy to differentiate forest from non-forest, but it is difficult to differentiate evergreen forests from deciduous forests. Therefore, the season used for analysis must be selected based on the objective of the study, and it is an important option to use data from different seasons for classification.

5 Definition of the class [*Recipe-T07*]

Forest carbon stock in REDD+ is obtained with the product of activity data and emission factors. Forest area estimated via remote sensing, is equivalent to the activity data. Thus, to classify forests, the emission factors must be determined for each classified class. If there is an existing map, class could be set accordingly, but class without an emission factors would be meaningless. Considering the performance of a satellite sensor, it must be examined if there are classes that cannot be classified by the analysis.

6 Ground truth [*Recipe-T08*]

Ground truth refers to data that are considered to be true values used to understand spectral characteristics of each class and to analyze accuracy. Therefore, a representative location for each class is selected, for which ground cover is confirmed on the ground, and forest type, biomass, etc., are surveyed. In a case where a landcover map is being prepared from medium resolution satellite data, if the ground truth is only land cover, it may be substituted by aerial photographs or the interpretation of high-resolution satellite images.

The survey points are randomly or systematically sampled to prevent arbitrary influences affecting the data analysis. For methods of sampling, there is completely random or stratified sampling. As a systematic and completely random sampling, the most common method is to choose all grid points at a certain interval to be the survey points (Figure 13). If funds and labor are limited, stratified sampling, such as selecting a point per land cover, is effective. For forests, limited access often prevents the ability to reach the survey points, causing a bias of a small number of samples from areas with poor access which is a sampling issue.

TIPS If image capture date and ground truth capture date (day of the ground survey or the day aerial photographs were taken) are different, land cover might have changed during that time, which should be noted.

TIPS For more details on ground truth survey methods, please see [*Cookbook Annex Vol. 4*].
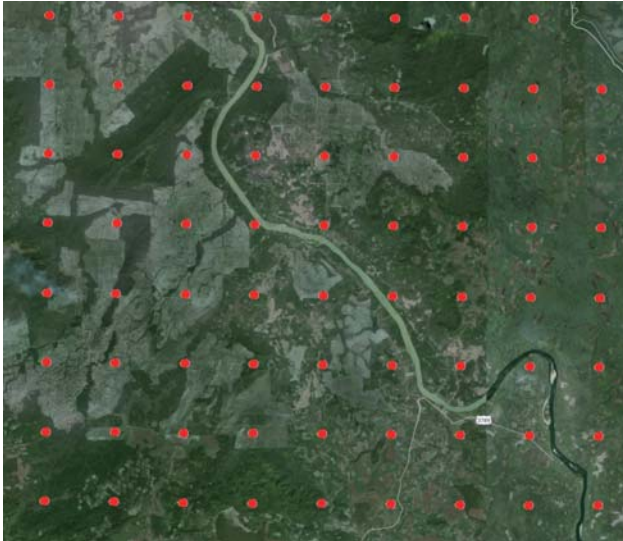
Figure 13. Ground truth points arranged systematically.

7 Classification [*Recipe-T09*]

Presently, in tropical countries, color composite images are prepared from satellite data, such as Landsat. By visually interpreting these images, a land cover map is prepared. However, this method has problems, such as the need for an experienced interpreter, results dependent upon the interpreter, and the requirement of sufficient time. Though Landsat has multiple band data, color composite images only have three bands; thus, the information in the other bands is wasted. On the other hand, classification by a computer obtains land cover classes by using statistical processing of feature values of each band of satellite data, such as reflectance.

For classification there are: the pixel-based classification, where each pixel is a unit, and object-based classification, where each object is a unit. Let us discuss the characteristics of each.

7.1 Pixel-based classification

The pixel-based classification method statistically processes spectral information of each band per pixel and classifies them into similar groups. Specifically, there are methods such as clustering, maximum likelihood, and minimum distance methods which are installed as major functions of remote sensing software. For clustering, which is an unsupervised classification, parameters such as the number of initial clusters and repeats must be set. These default values

should be tried, then parameters should be adjusted until appropriate results are obtained. Classes are assigned to the obtained clusters while referring to the original images, aerial photographs, field survey results, or Google Earth images. With supervised classification, training areas must be selected for the target classes. Training areas require a sufficient number of pixels and must be selected from pure areas. Size and region of the training areas must be selected appropriately while referring to classification results, original images, aerial photographs, field survey results, and Google Earth images. Furthermore, in recent years methods have developed that incorporate neural networks and machine learning, but these methods must be executed with designated statistical software and programming.

TIPS

The initial number of clusters is generally 30 to 50, though the cluster number depends on the number of target classes. If cluster images include agricultural lands and urban areas, a larger number of clusters will focus on these areas, and there will not be many clusters in forested areas. Therefore, in the initial classification, vegetations and non-vegetations (including cloud, shadow, and water) are classified, then the area of vegetations should be classified after creating a vegetation masking image.

7.2 Object-based classification

The object-based classification method statistically processes spectral information for each band per object and classifies the information into similar groups. Objects refer to a set of pixels obtained by dividing regions. Objects have similar characteristics and are generated with spatial grouping. Thus, the results are similar to maps created through visual interpretation. When creating objects, the parameters must be set, e.g., colors and scales. Attention should be paid when setting parameters, especially since the patch size of objects are related to minimum mapping unit (MMU).

In pixel-based classification, pixel values are used. However, in object-based classification spectral attributes are used for classification, such as the mean and standard deviation of pixel values included in objects, spatial attributes, circumference, extensibility (aspect ratio), and texture attributes (e.g., data range, dispersion, and entropy). These attributes are automatically calculated by the software, and for classification the selected attributes are used. If attributes useful for classification are not clear, some software has functions to provide supervision so that effective attributes for classification can be automatically selected.

The object-based classification is often not part of conventional software, instead it is often provided as an extension or as dedicated software.

8 Accuracy assessment [*Recipe-T09*]

A land cover map based on the classification of satellite images is not consistent with the actual land cover, as it contains a certain amount of error. To use such a land cover map, its classification accuracy and bias must be known. Thus, the person preparing the map must assess the accuracy of the classification results and clarify the classification accuracy and biases. To evaluate the classification accuracy, a table of discrimination efficiency is used, from which indices of accuracy are derived, such as the overall accuracy, user accuracy, producer accuracy, and Kappa coefficient. Most software is equipped with an accuracy assessment function as a standard or as a plugin.

Ground truth data used for accuracy assessment needs data that is systematically or randomly acquired, as discussed in Chapter 6.

References

White, J.C., Wulder, M.A., Hermosilla, T., Coops, N.C., Hobart, G.W. (2017). A nationwide annual characterization of 25 years of forest disturbance and recovery for Canada using Landsat time series. Remote Sensing of Environment,194: 303-321