Proceedings for the training on national land cover monitoring using optical satellite data

Bangladesh Forest Department

07 - 11 February 2016

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SilvaCarbon

The Forest Department of Bangladesh leads actions to improve forest management and conservation, adopting forward thinking, innovative approaches in its management of approximately 1.5 million hectares of land across the country.

In 2015, the Forest Department began a process to establish a National Forest Inventory and Satellite Land Monitoring System for improved forest and natural resource management. The process supports national objectives related to climate change mitigation and provides information in support of the UN REDD programme aimed at Reducing Emissions from Deforestation and Forest Degradation (REDD+). The process also addresses domestic information needs and supports national policy processes related to forests and the multitude of interconnected human and environmental systems that forests support.

The activities implemented under the Bangladesh Forest Inventory process are a collaboration between several national and international institutions and stakeholders. National partners from multiple government departments and agencies assist in providing a nationally coordinated approach to land management. International partners, including the United Stated Agency for International Development (USAID), the Food and Agriculture Organization of the United Nations (FAO) and SilvaCarbon are supporting the development of technical and financial resources that will assist in institutionalising the process.

The results will allow the Forest Department to provide regular, updated information about the status of trees and forests for a multitude of purposes including for assessment of role of trees for firewood, medicines, timber, climate change mitigation.

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Disclaimer

Executive Summary

In the context of the project ‘Strengthening National Forest Inventory and Satellite Land Monitoring System in support of REDD+ in Bangladesh’, the aim of the training was to present leading methodologies for a national-scale satellite-based land cover and land use monitoring to national experts in remote sensing and GIS involved in supporting the national forest monitoring system of the Forest Department of Bangladesh.

The objectives were to provide an overview and hands-on exercise on University of Maryland GLAD satellite data processing system, to facilitate knowledge exchange between national and international experts, to contribute to the national forest monitoring system as one component to be integrated with the land use/cover assessment and to present the 2000-2014 forest cover mapping activities.

Nine people (55% male, 45% female) attended the five-day workshop from various organizations including the Bangladesh Forest Department, Bangladesh University of Engineering and Technology (BUET), Bangladesh Society of Geo Informatics (BSGI) and Bangladesh Space Research and Remote Sensing Organization (SPARRSO).

The training was jointly organized by FAO and SilvaCarbon with support from USAID and UNREDD. The event was held at the Forest Department of Bangladesh.

Contents

1. Introduction

In the context of the project 'Strengthening National Forest Inventory and Satellite Land Monitoring System in support of REDD+ in Bangladesh', the national forest monitoring system of the Forest Department aims at providing information about the status of forest and tree in an integrated way with land/use cover mapping activities.

For this, several national institutions are collaborating for the development of a national land use/cover map that integrates the different definitions and legends and the forest/tree cover monitoring system will provide information that are consistent with the other initiatives. In addition, forest land boundaries are being mapped using the cadastral maps and will provide additional information related to the tree and forest tenure.

University of Maryland (UMD) national-scale mapping tool is presented as a leapfrog technology whereby implementing partners can rapidly map national-scale land cover, type and change over a set study interval. Currently, UMD employs Landsat data from 2000 to present as the baseline input data and period of analysis.

In October 2015, a full package with lectures, training on processing chain and equipment was given by UMD to four experts from Resources Information Management System (RIMS) of the Bangladesh Forest Department.

In collaboration between Silvacarbon, UN-REDD and GCP/BGD/058/USAID, this training aimed at strengthening national capacities in forest and tree cover change monitoring.

2. Objectives

The aim of the training were to transfer knowledge on tree and forest cover monitoring to national experts in remote sensing and GIS involved in supporting the national forest monitoring system of the Forest Department and exploring harmonization possibilities with Land Use maps produced at national level.

The specific objectives were:

- to replicate the training undertaken in UMD involving more participants from several institutions;
- to facilitate knowledge exchange between national and international experts;
- to contribute to the national forest monitoring system as one component to be integrated with the land use/cover assessment;
- to present the UMD methodology for 2000-2014 forest cover mapping activities and see the articulation with existing systems;
- to support the 2015 land cover/use map development for the interpretation process.

3. Summary of Sessions

3.1 Introduction session

The workshop was inaugurated by the Forest Department's Chief Conservator of Forest Mr. Yunus Ali. Mr. Ali emphasised the importance of up-to-date forest monitoring methods. Chief Technical Adivser Matieu Henry, provided an overview of the previous activities related to the development of a classification system (based on LCCS) and the importance of integrated land cover monitoring solutions to ensure comparability and transparency.

Following the introductions, a series of presentations were provided by government partners to provide a background on the different land cover initiatives that took place in the past and are currently on going.

Overview of presentations

LAND COVER MAPPING IN BANGLADESH USING SATELLITE DATA IMAGERY (ZAHEER IQBAL)
SPARSSO and FD first produced the land cover map for 2005-2007 under NFA, with manual delineation of imagery. An overview of forest survey using satellite data in Bangladesh encompassed the following landmarks: 1999-2007 (SPOT and LANDSAT), 2008-2012 (QUICKBIRD), and 2012-2015 (WORLDVIEW at subnational level).

Aerial photos have been widely used in the past, in particular to map reserves independently
Other examples using satellite imagery include Coastal afforestation, Tiger surveys, regular patrolling of canals in Sundarbans, spatial monitoring and reporting tool (SMART) for monitoring of tigers and crocodiles populations. Future needs in terms of support and continued provision of imagery were expressed

LAND COVER MAPPING FOR 2015: USE OF SPOT 6 DATA (RASHED JALAL)
A brief presentation of the data acquired by FAO and the methodology envisioned was given. Letter of agreement with CEGIS has been signed to realize the map of the Delta Region under the DECCMA project, the rest of the country will be done by FS RIMS.

GEOPORTAL DEVELOPMENT (LIAM COSTELLO)
A brief presentation on the proposed Geoportal was presented. Geoportals have been established in a number of countries to support forest monitoring objectives. The web based platform acts as a repository for spatial data and allows interactive visualization of field and remote sensing data related to forest and biomass dynamics, management activities and other project management related information. The DRC Geo Portal was presented as an example of the kinds of data that may be presented. In Bangladesh, the process has been initiated and is currently in the process of development. For further information on activities related to the geoportal, contact the project team.

LAND COVER CLASSIFICATION SYSTEMS (RÉMI D'ANNUNZIO)
The approach of LCML/ LCCS as described in detail in FAO (2015)[1] will be applied to all land cover maps previously produced in Bangladesh. To assess the potential benefits of these methods, two case studies were introduced: the harmonization process of two maps created under the LCCS-v3 ISO standard, and the application of LCCS to a woodfuel supply assessment in the context of protracted crisis[2].
A key message of the presentation was that an approach rather than a toolbox is promoted and supported by FAO on these issues.

EXPERIENCE FROM TRAINING AT UNIVERSITY OF MARYLAND IN 2015 (BAKTIAR NUR SIDDIQUI AND TARIQ AZIZ)
The summary of the one-month training given to RIMS expert in Maryland in October 2015 covered the following main questions:
- Collection of training data (Loss, Gain, NF, F) was done during the stay
- Preliminary interpretation of 500 points of validation in the Edge, Core, Buffer around forest categories led to preliminary overall accuracy of 83%, 63% for F-NF.

Accuracy assessment of change needs to be done in Bangladesh and requires more training for RIMS personnel.

OVERVIEW OF THE GLAD ACTIVITIES OF UNIVERSITY OF MARYLAND (PETER POTAPOV)
The Global Land Analysis and Discovery (GLAD) activities developed by UMD include different areas such as:

- Global Forest Change since 2000 with yearly updates
- Monitoring of crops and intact landscapes

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[1] FAO 2015. *Proceedings for the training on national land cover classification systems using LCCS 3. 29 November – 3 December.* Dhaka, Bangladesh.

[2] d'Annunzio, R., Gianvenuti, A., Henry, M., Thulstrup, A., (2015) Manual for assessing woodfuel supply and demand in displacement settings. FAO. Rome.

- Uncertainty analysis
- Use of combined LIDAR and optical data for biomass mapping

Inconsistencies between land cover and land use and comparisons between sampling and wall-to-wall methods were underlined. The recent example of Peru's case study was demonstrated[3] .

Regarding Bangladesh, UMD will procure a yearly update of the Landsat metrics and the purpose of the series of capacity building activities is to ensure that Bangladesh is able to process these metrics to provide updated versions of the Tree Cover and Tree Cover Change product every year, including validation (accuracy assessment) of the layers.

3.2 Technical sessions: GLAD methodology applied to Bangladesh

All presentations given by P. Potapov and A. Hudson during the 3 days of training to the GLAD methodology are in annex, as well as a synthetic document that describes products and methodological steps. The different items were broken down as follows:

Day1: Overview of the GLAD methodology for tree cover and tree cover change mapping.
- Examples of national and global implementation.

Day2: Data processing for Bangladesh
- Demonstration of wall-to-wall national Landsat products
- Structure of the Bangladesh dataset and Landsat time-series metrics
- Informative map representation of Water Dynamics
- Preliminary forest cover and change dynamic mapping results for Bangladesh
- Lectures on image classification and sample-based analysis
- Demonstration of image interpretation, supervised classification, and sample-based assessment

Day3: Hands-on sessions
- Experience of the national products and image data interpretation/visual assessment
- Supervised image classification chain:
    - SPOT image classification
    - National-scale Landsat-based forest classification

Day4: Hands on session on reference data acquisition for map validation

3.3 Integration of the different land cover and land use products

Two separate sessions were dedicated to this item and moderated by Rémi d'Annunzio. The main objective was to obtain a clear vision of what integration will be done between the different land cover, tree cover, tree cover change and other thematic products available in Bangladesh.

The results of that consultation can be summarized in the Figure 1. The main items are:
- Translation of existing LC/LU maps into LCCS legend
- use of field data for finalizing LCCS legend
- cross validation and comparison of translated maps, if possible with a time analysis
- overlay of RIMS (2016) tree cover change with FIGNSP 2011-12 map to breakdown activity data into forest types

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[3] Potapov et al., (2014) National satellite-based humid tropical forest change assessment in Peru in support of REDD+ implementation. ERL 2014. available at doi:10.1088/1748-9326/9/12/124012

- integration of yearly updates of tree cover change (RIMS 2016) into the forest classes of the Land Cover map for 2015
- use of SPOT data into the Landsat metrics classification scheme to obtain % canopy cover at national level.
- use of different sources of free data (Sentinel 2) for further updates of tree cover change mapping

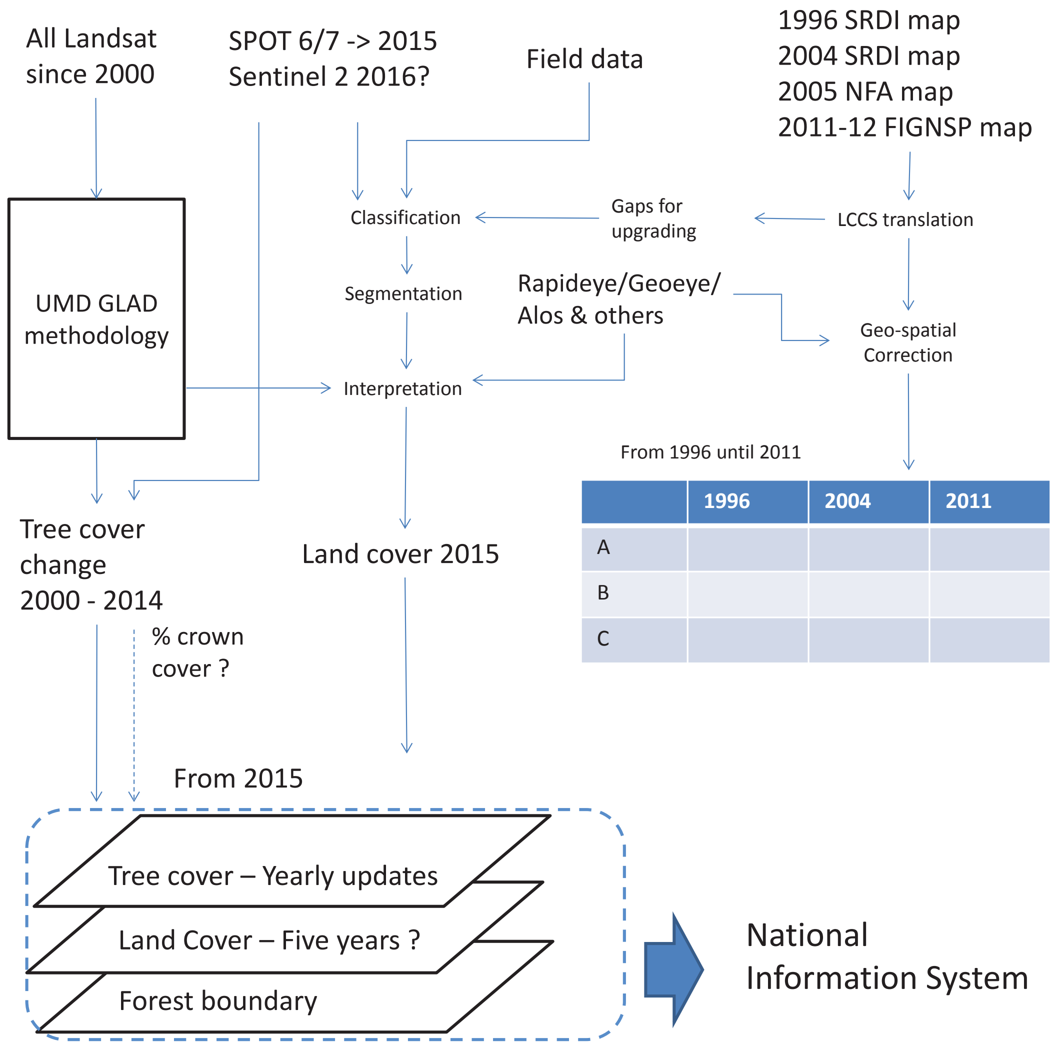

FIGURE 1 INTEGRATION PROCESS OF LAND COVER AND LAND COVER CHANGE PRODUCTS IN BANGLADESH

4. Recommendations for next steps

All the activities related to integration have been shared with the participants of the workshop and scheduled for 2016. The comments are integrated into Table 1.

The recommendations for these activities are :
- FD-RIMS will focus on finalizing the validation dataset for the tree cover change 2000-2014 with the aim of presenting a final report to CCF by May 2016
- the development and finalization of the LCCS-v3 legend is a priority if we want the products to be translated in time for integration (in particular the adapted legend of the FIGNSP product will need to be ready when the RIMS team works on the breakdown of their product by Forest Types)
- the use of SPOT 6 derived Tree NonTree classification as training data for a Landsat based Canopy cover percentage gave very promising results and will be further explored as an area of collaboration between RIMS, UMD and FAO.
- further capacity building will be needed by RIMS to establish a standardized methodology for the creation of a 2015 land cover map. The methodology adopted by CEGIS in the DECCMA project should be followed as closely as possible. FD-RIMS will send a first draft to FAO for comments and support.

- an appropriate combination of hierarchical, semi-automatic and manual assignment of classes should be employed
- the upcoming training with radar data organized by FAO will be a good introduction using SEPAL in that framework

TABLE 1 WORK PLAN OF FUTURE INTEGRATION OF PRODUCTS

Cluster	Task	Who	When	Comments	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
LCCS	Establish LCCS legend	BSGI	15/03/2016	BSGI to provide training to SRDI and RIMS Workshop scheduled March 13/14								
	Translate products into LCCS legend	SRDI BSGI RIMS	15/03/2016	1996 and 2004 SRDI map 2005 NFA map 2011-12 FIGNSP map -->> RIMS								
	Identification of gaps and identification between existing products	BSGI	15/03/2016	Will be done manually								
Land cover mapping	Create forest boundaries	CEGIS DATEX	01/04/2016	Two pilot projects ongoing Whole country to finish by 2017 Mouza map digitization ?								
	Create land cover map 2015	DECCMA [CEGIS BUET] FD RIMS	01/06/2016	Start with the Delta region by CEGIS/BUET Other parts of country by FD-RIMS Field data + VHR for training and/or validation Tree specie determination? Only Sundarban								
Tree cover and tree cover change map	Validation of tree cover and tree cover change map 2000-2014	RIMS	31/03/2016	On going								
	Breakdown tree cover and tree cover change map 2000-2014 into Forest types	RIMS UMD	01/04/2016	Use 2011-2012 FIGNSP map								
	Report of the TC and TC change map 2000-2014	RIMS	30/04/2016									
	Integration of yearly tree cover change map into LC 2015 map	RIMS	15/06/2016	Determine classes of transition from/to forest To the extent that the map is ready								
	Classification of SPOT data into T-NT	RIMS	01/04/2016	Get training data for the whole country Send to UMD								
	Use of T-NT classif. To derive TC% into RIMS change map for year 2014	UMD	01/06/2016	UMD to send data back								
Other	Test use of Sentinel 2 data into classification process	RIMS +?	01/04/2016	Linkage with FAO training on Radar data (Sentinel 1)								

5. List of participants

Sl	Name	Gender	Organisation	Designation	Email
1	Bablu Zzaman	M	Forest Department	Forester	zzaman1978@gmail.com
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5	Md Tariq Aziz	M	Forest Department	Research Officer	tariqaziz9718@gmail.com
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7	Mostafizur Rahman Akand	M	SPARRSO	Senior Engineer	akhand2@yahoo.com
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9	Shammi Haque	F	BUET	Lecturer	haque018821@gmail.com

6. Annex : summary of GLAD methodology for Landsat data processing

Landsat Data

To create multi-temporal metrics, we used the entire Landsat data archive from 2010 to 2014 available at the USGS National Center for Earth Resources Observation and Science (EROS). Landsat data include imagery from L5 TM, L7 ETM+, and L8 OLI/TIRS. We only use data at processing level L1T, terrain-corrected by USGS.

All reflective bands (excluding ETM+ and OLI panchromatic bands) of each Landsat image were converted to Top of Atmosphere (TOA) reflectance and the thermal band (high gain thermal band for ETM+) was converted to brightness temperature (Chander et al., 2009). Spectral reflectance was scaled to the range 1-40,000, temperature recorded in 0.01K (1DN=0.01K).

While all spectral bands were used for quality assessment, only four bands (red, NIR, SWIR1, and SWIR2) were normalized and included in the multi-temporal metrics. Band numbers for TM-ETM+: 3,4,5,7; for OLI: 4,5,6,7

Elevation data

The Shuttle Radar Topography Mission (SRTM) elevation and computed slope layers were added as additional data for classification. The void-filled seamless SRTM data available from the CGIAR-CSI SRTM 90m dataset (http://srtm.csi.cgiar.org) were used. SRTM elevation data were re-projected and resampled to match the Landsat pixel grid.

Image Processing

<u>1. Reprojection</u>

Landsat L1T images were reprojected from local UTM projections to geographic coordinates, with pixel size of 0.00025 degree. The output projection for multi-temporal metrics is: “+proj=longlat +datum=WGS84 +no_defs”.

<u>2. Calibration</u>

The raw image digital numbers (DN) values were converted to top of atmosphere reflectance (for reflective bands) and to brightness temperature (for the thermal band). The conversion minimizes differences in sensor calibration, sun-earth distance and sun elevation and was carried out using the approach described in Chander et al. (2009) with coefficients taken from metadata. First, digital number (DN) data was converted to radiance (L), W/(m^2 sr µm) using the following equation:

$$L = G * DN + B$$

where G (gain) and B (bias) are band-specific rescaling coefficients taken from metadata. Then radiance was converted to reflectance (ρ):

$$\rho = \pi * L * d^2 / (ESUN * \sin\phi)$$

The calibration coefficients include band-specific mean exoatmospheric solar irradiance ESUN, W/(m^2 sr µm), and date-specific constants: astronomical constant d (Earth–Sun distance in astronomical units) and sine of Sun elevation in radian (sinϕ).

3. Quality assessment

For per-pixel quality assessment (QA), a set of cloud, shadow, atmospheric haze, and water detection models was used. The models correspond to a set of classification tree models derived from training data collected throughout the tropical biome. To collect training data, a set of Landsat images were selected in different parts of the tropical forest zone, and each classified to land, water, cloud, haze, and shadow classes. From these images, 10% samples were randomly selected and used to create the generalized classification tree models. Each model was applied per Landsat image, yielding cloud, shadow and water class probability values. Based on these values a QA code was assigned to each pixel reflecting the probability of the pixel to be a land or water cloud-free observation, using the method described in Potapov et al. (2012).

4. Radiometric normalization.

Radiometric normalization was used in our algorithm to reduce reflectance variations between image dates due to atmospheric conditions and surface anisotropy. A MODIS surface reflectance composite aggregated from cloud-free observations over 10 years of data was used as a normalization target. To normalize Landsat imagery, we calculated a mean bias between MODIS surface reflectance and Landsat top of atmosphere reflectance for each spectral band over the land area within normalization mask and used it to adjust Landsat reflectance values. To exclude clouds, cloud shadows, and areas representing rapid land-cover change, only pixels with MODIS-Landsat reflectance difference below 0.05 were included in the normalization mask. To remove the effect of surface anisotropy combined with variations in the viewing and solar geometries the reflectance bias was modeled using scan angle as independent variable:

$$\rho_{norm} = \rho - (A * scan + B)$$

, where A and B are model-derived coefficients relating Landsat scan angle (scan, degrees) with Landsat/MODIS reflectance bias. Radiometric normalization was performed independently for each spectral band and Landsat image.

5. Data output

The output products for each image, subsequently used to generate multi-temporal metrics, include:
a. Normalized spectral reflectance for red, NIR, SWIR1, and SWIR2 bands:
DN= ρ*40,000 (set to DN=1 for ρ<=0)
b. Brightness temperature (10-12 µm):
DN=K*100
c. Quality flag:

1	Clouds – high certainty
2, 11	Snow
3	Haze
4	Shadow – high certainty
5, 7	Water
6	Land
8	Buffer around clouds
9	Shadow - probable
10	Shadow – low certainty

d. In addition to the reflectance bands, two indices were calculated and added to the metric pool: Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI)

NDVI = ((NIR-red)/(NIR+red))*10,000+10,000

NDWI = ((NIR-SWIR1)/(NIR+SWIR1))*10,000+10,000

Multi-Temporal Metrics

The Landsat imagery process resulted in a time-series of cloud- and shadow-free normalized reflectance observations. From this time-series, we derived a suite of multi-temporal metric sets for each 30-m pixel. Multi-temporal metrics are useful transformations of image time-series for both coarse resolution (Reed et al. 1994; DeFries et al. 1995; Hansen et al., 2005) and medium resolution data (Broich et al. 2011; Potapov et al. 2012; Hansen et al., 2013).

To create metrics, all observations were extracted for each of the composite pixel. After analysis of QA flags, the best cloud-free observations were selected as metric data pool. To calculate the multi-temporal metrics, we implemented two main approaches: one based on time-sequential reflectance change, and another based on reflectance ranking. For the first approach, we analyzed the spectral reflectance time-series and corresponding observation dates. For the second approach, we ranked the spectral band reflectance from low to high (each band was processed individually), or ranked observations by the corresponding NDVI, NDWI, and brightness temperature ranks.

Metrics are stored in tiles (1x1 degree side), with 2-pixel overlap. Most of the metrics are stored as 16-bit unsigned GeoTIFF files, except for DEM (16-bit signed) and several technical metrics (not used for image classification). Metric names generated from metric types (see below) and band/index suffix. Band suffixes area: b3 – red, b4 – NIR, b5 – SWIR1, b7 – SWIR2, NDVI – NDVI, NBR – NDWI. Date, count, and other special band names also described below.

<u>1. Start/end point image composites</u>

first*, last*

The first and the last single cloud-free observations were selected as the cloud free observations closest to the end of year 2010 and the end of year 2014. The dates of the selected observations were listed in additional layer.

medfirst*, medlast*, meanfirst*, meanlast*,

The three first/last observations were selected in a similar way. From these three observations, a mean and median have been calculated. The mean/median composites were proved to be less sensitive to noise and could be used for visual analysis and product evaluation. The median composite represent observation indicated by median value of NIR band.

comp_2010*, comp2014*

Circa 2010 and circa 2014 image composites (and observation date used) were constructed from observations corresponding to band 4 median of 5 cloud-free observations closest to July, 15, 2000 and July, 15, 2014. These composites are for visual presentation only, and were not included into classification metric dataset.

***date**

Date metrics provided for first, last, median of 3 first and 3 last observations. Date format is in days since 1/1/1980.

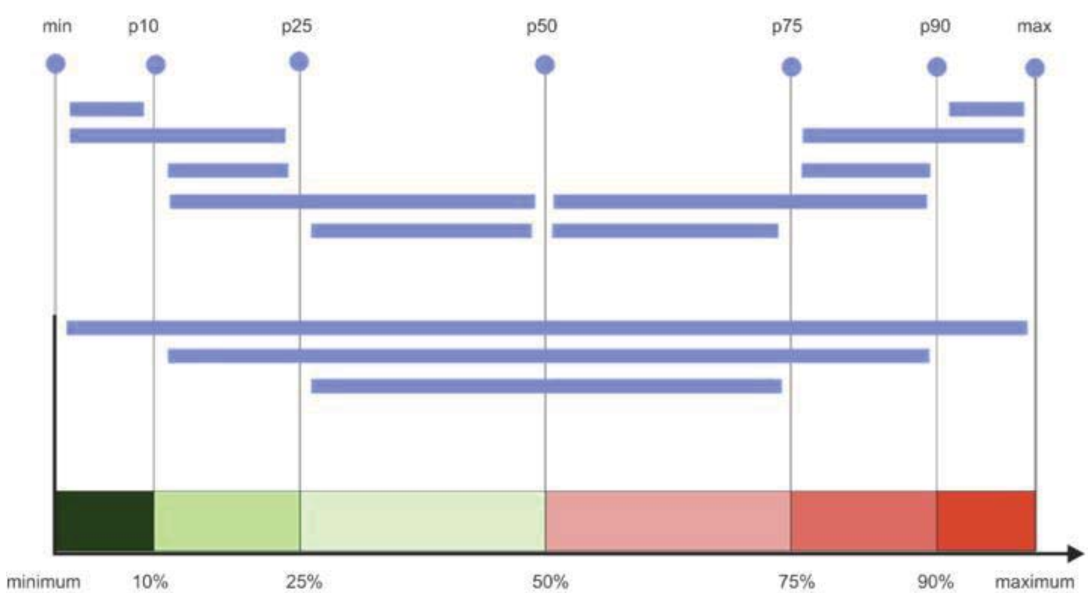
2. Rank-based metrics

prc*

To produce rank-based metrics, band reflectance data from 2010 to 2014 were ranked based on (i) band reflectance value or (ii) corresponding ranks of selected indices (NDVI, NDWI) and brightness temperature. Metrics were created from observations representing selected percentile values (minimum, 10%, 25%, 50%, 75%, and 90% percentiles, maximum). Percentile value listed in metric prefix (e.g. prc50* indicate median observation). If metric was generated by ranking correspondent value (NDVI, NDWI, or temperature), the corresponding band indicated by second suffix (e.g. prc90_b5_NDVI – SWIR1 band value from the observation that represent 90% percentile of NDVI value).

av*

Averages of all data pool observations within selected rank interval. “Symmetrical” averages were produced for all values between selected ranks for intervals centered at the median (minimum-maximum, 10%-90%, 25%-75%). “Asymmetrical” average were produced for intervals on one side of the median (minimum-10%, 10%-25%, 25%-50%, 50%-75%, 75%-90%, 90%-maximum). Similar to percentiles, averages may be produced from simple band reflectance ranks, or from observations ranked by corresponding NDVI, NDWI, or temperature value.



Graphical explanation of a rank-based metric set. Vector represent all data pool (cloud/shadow free) reflectance values ranked by value. Blue circles represent selected percentiles (prc) metrics. Blue lines represent ranges for selected symmetrical (bottom) and asymmetrical (top) average metrics (av*).*

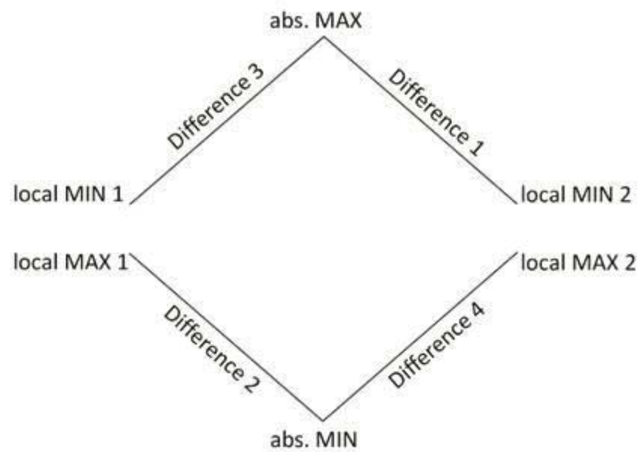
3. Trend analysis metrics

This metric set includes:

a. **reg*, sd***

Slope of linear regression of band reflectance values versus image date, and standard deviation of band reflectance value from 2000 to 2011.

b. **maxgain*, maxloss*, mingain*, minloss*, deltagain*, deltaloss***
Reflectance signal and change corresponding to segments of signal gain and drop, including minimal, maximal and delta values. Segments are defined by absolute minimal and maximal values, independent for each band and index.



Graphical explanation of segment-based metrics. First, absolute min and max values are selected. Then, local minimums and maximums are found within each segment defined by extreme values. The difference show the magnitude of signal change. The largest of difference 3 and 4 represent gain segment, and the largest of differences 1 and 2 represent loss segment. After selecting segment, max, min, and delta values are assigned and recorded as metrics.

4. Annual metrics
y20*
Annual metrics were created for change date allocation, and for other classification post-processing. Each annual metric set include number of observations (_count), percent water and snow detections (_prc*), and selected band/index ranks (minimum, median, maximum).

5. Technical metrics
pf.tif
Processing flag (PF), that shows the quality and dominant land/water cover for each pixel. The PF value interpretation table provided below.

100-109	Clear land
110-119	Land or snow
120-199	Land or intermittent water
200-299	Land/intermittent water with poor observation quality
300-340	Poor observation quality

350	Persistent clouds
400	Permanent water

count*
represent number of cloud-free (data pool) observations: count_observations – all available images (any QA); count_all – all cloud-free observations; count_metric – cloud-free observations between the last cloud-free observation on 2010 and the end of the interval (2014)
qa*
temporal technical metrics

DEM-based and hydrological metrics

The following metrics included to the metric set to assist wetland mapping:
dem
SRTM digital elevation data, in meters
slope, aspect
DEM-derived data, scaled for 16-bit range. Slope in degrees, scaled: DN=slope*500. Aspect in degrees, scaled: DN=aspect*100.
maxcurv, mincurv, planconv, profconv, rmse, mindem*, reldem*
Hydrological metrics. See description below.

Hydrological metric set

Hydrological metrics were created to facilitate wetlands and swamp forest mapping. These metrics represent properties of terrain related to water flaw and accumulation. Metrics were derived from the 3 arc sec (approximately 92 m) spatial resolution Digital Elevation Model (DEM) derived from the NASA Shuttle Radar Topography Mission (SRTM). The derivatives were generated by fitting a quadratic function to the digital elevation model. Quadratic coefficients were generated by an ordinary least squares (OLS) fitting of 9 neighboring DEM pixels. We calculated the root mean square error of the OLS fitting to indicate quality of the fit. Derived metrics presented in the table below.

Filename	Name	Description
dem	Digital elevation model	SRTM-based elevation, meters
rmse	Root Mean Squared Error	Error as the measure the accuracy of the DEM, m
planconv	Plan Convexity	The plan convexity (intersecting with the x,y plane) measures the rate of change of the aspect along the plan
profconv	Profile Convexity	The profile convexity (intersecting with the plane of the z-axis and aspect direction) measures the rate of change of the slope along the profile
aspect	Aspect	Aspect, degree
slope	Slope	Slope, degree and percent
mincurv	Minimum curvature	Curvature is the measure of how much the curve “bends” at a single point.
maxcurv	Maximum curvature	

Additional metrics are describing relative height with respect to variously defined support area/catchment sizes. Six different sets of catchment basins were derived using maximum area

thresholds of 1,000, 2,000, 5,000, 10,000, 15,000, and 20,000 SRTM 90m grid cell. Two sets of metrics were derived for each catchment size:
"**mindem**" - Minimum elevation calculated for each sub-watershed or catchment
"**reldem**" – Relative elevation per basin. Represents the arithmetic difference between the DEM and the minimum elevation.
Only the last metric ("reldem") used for classification.

Methods

We mainly used the Methodology provided by Bwangoy et al, (2009).

The slope, aspect, profile convexity, plan convexity, maximum and minimum curvatures and the Root Squared Mean Error were derived from the digital elevation data using the ENVI software topographical modeling package.

The Sub-watershed catchment, the Minimum Elevation and the Relative Elevation were derived using a combination of ArcHydro and ArcToolbox (Raster Calculator and Zonal Statistics). In order to automate the process and make it standard, a Model Builder has been designed under ArcGIS 10.x. The ArcHydro tools Fill Sinks, Flow Direction, Flow Accumulation, Stream Definition, Stream Segmentation and Catchment Grid Delineation have been successively used to ultimately delineate the sub-watersheds.

"Zonal Statistics" tool was used to calculate the minimum elevation for each sub-watershed while "Raster Calculator" tool to calculate the difference between the DEM and the Minimum Elevation to derive the Relative Elevation.