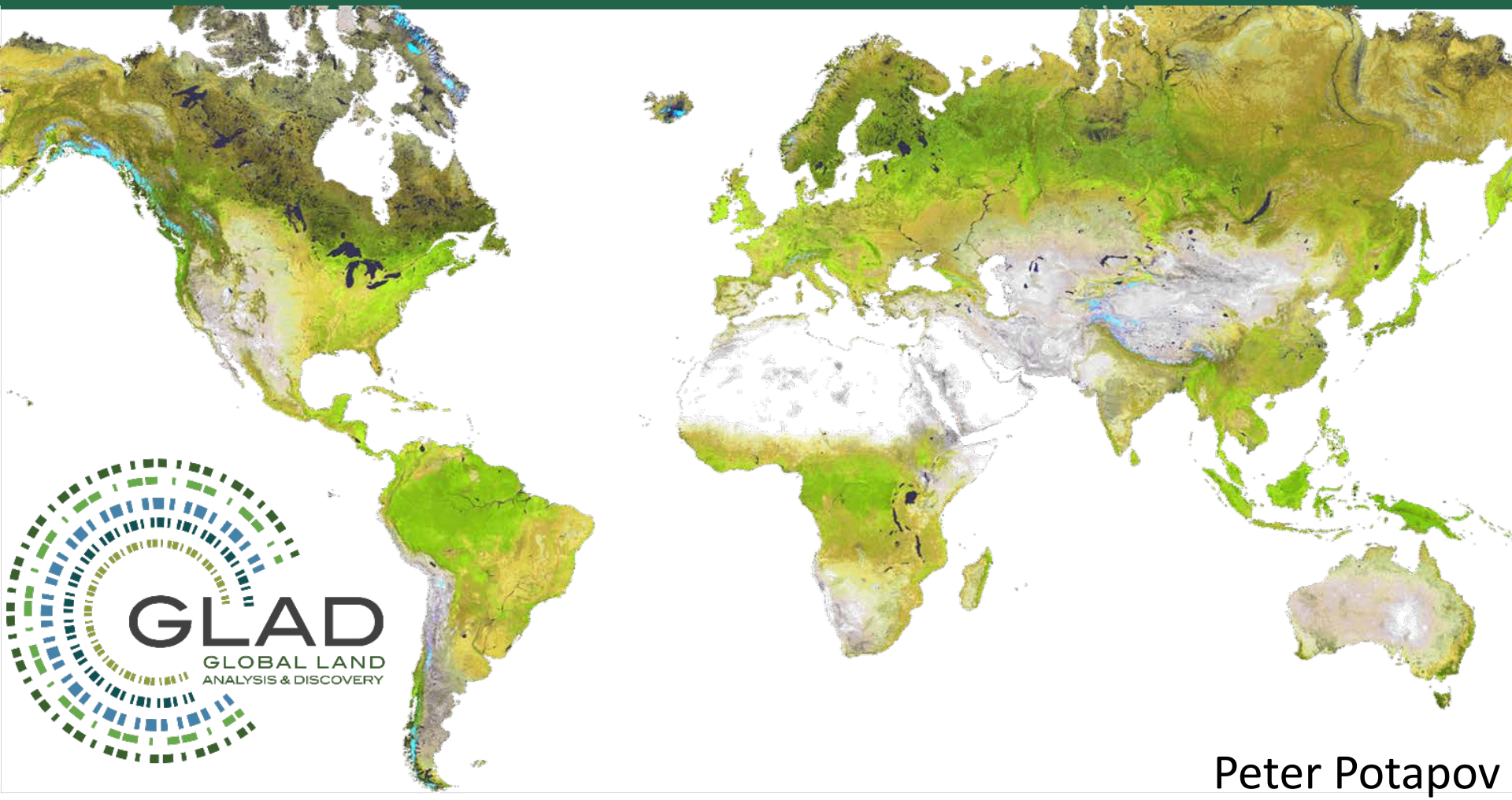
National Tree Canopy Cover and Change Quantification Using Satellite Data Archives



GLAD
GLOBAL LAND
ANALYSIS & DISCOVERY

Peter Potapov

UNIVERSITY OF MARYLAND
Global Land Analysis and Discovery Lab

Why Tree Canopy Cover?

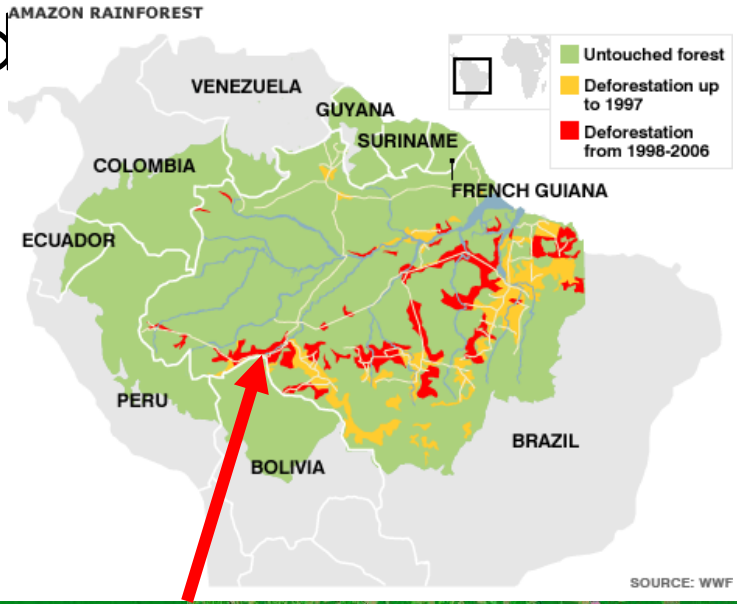
Ecosystem Functions Biodiversity habitat Biogeochemical cycle regulation Hydrological regime regulation Carbon sequestration	Required for biosphere functioning.	Best performed by pristine forest landscapes, or forest wildlands.
Ecosystem Services Provisional Timber and fiber Non-timber products, food Environmental regulation Water supply, flood control Air purification Cultural Recreation Spiritual, cultural amenities	Provide invaluable services and support for human population and national economies.	May be sustained or enhanced by appropriate management or degraded by overexploitation.
Development through conversion Lan-use conversion Intensive timber management	Consequences of the national land planning, economic growth, population increase, and international trade and investment policies.	Should be regulated, limited, and balanced to preserve ecosystem functions and services of the remaining forests.

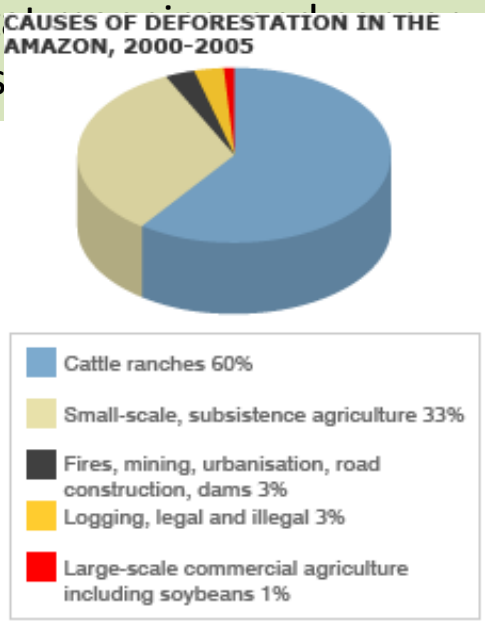
Why Tree Canopy Cover?

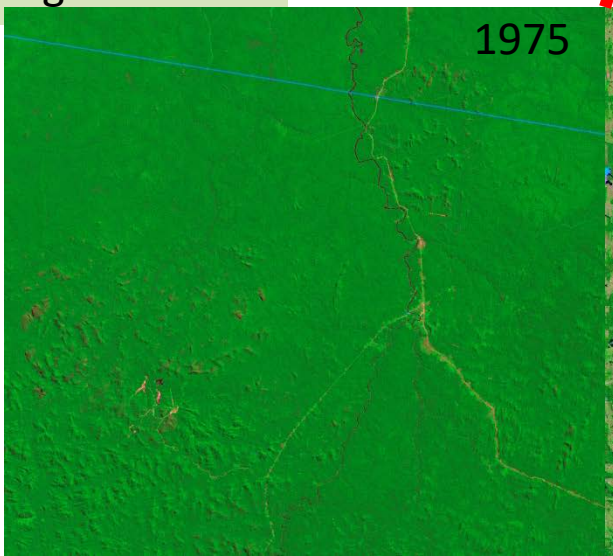
Why do we need timely spatial information on tree cover area and

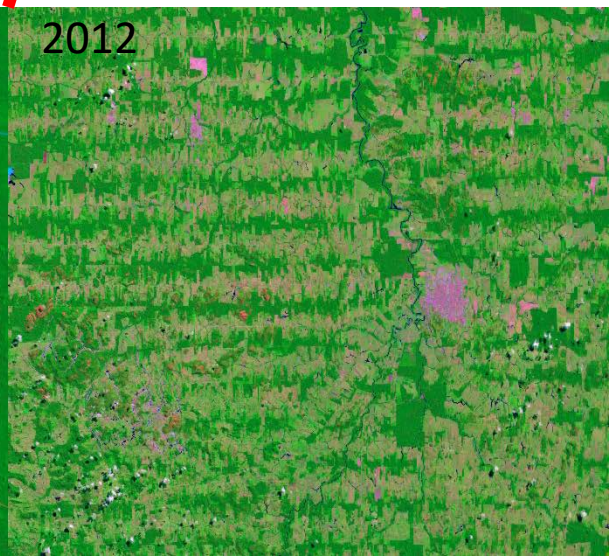
National Forest Inventory and Land Management Policy

- Quantification and monitoring of forest resources.
- Land cadaster and management.
- Assessment of forest ecosystem services, habit ation status.
- Fores nagement.







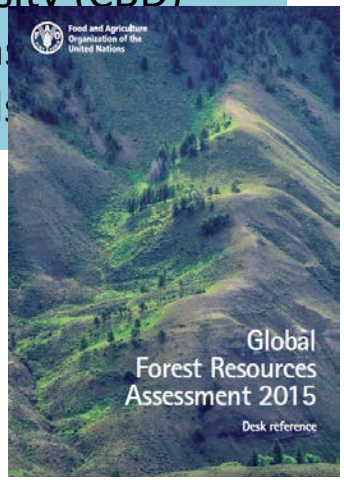


Why Tree Canopy Cover?

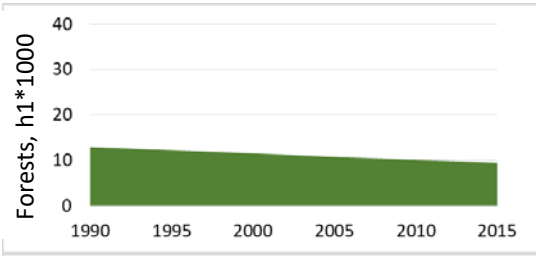
Why do we need timely spa
tree cover area an

National Forest Inventory and Land Management Policy

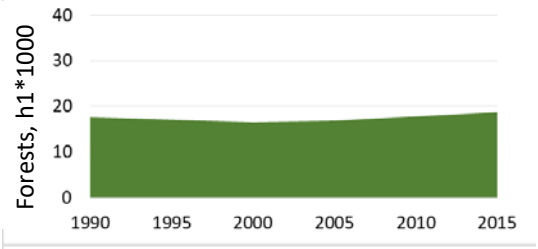
- **International Reporting and Policy Implementation**
  - FAO FRA National reports
  - Reducing Emissions from Deforestation and forest Degradation (REDD)
  - UN Sustainable Development Goals
  - Convention on Biological Diversity (CBD)
  - Ramsar Convention for the cons
    and sustainable use of wetland



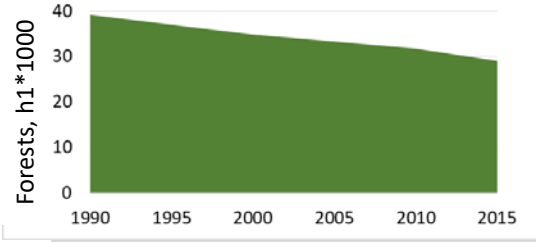
Cambodia



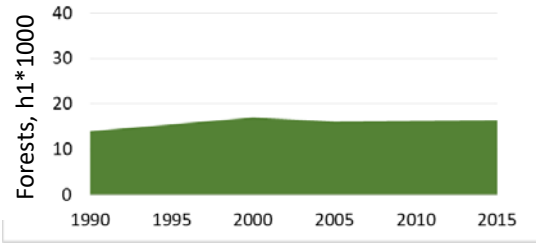
Laos



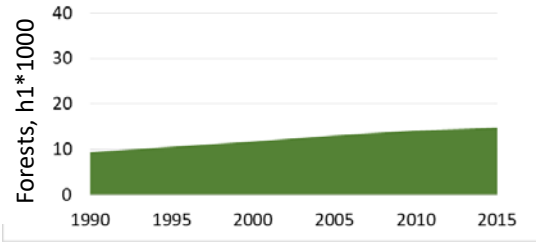
Myanmar



Thailand



Vietnam



Why Tree Canopy Cover?

Why do we need timely spatial information on tree cover area and change?

National Forest Inventory and Land Management Policy

International Reporting and Policy Implementation

UNFCCC GHG Emissions Reporting, NFMS for REDD+ activities

- Measurement of the reference emission and deforestation levels.
- Operational monitoring of forest cover change for emissions reporting.
- Reporting on the effects of the national policy implementation.

United Nations
Framework Convention on Climate Change

Why Tree Canopy Cover?

Tree Cover Area and CO_2 Emissions Reporting

- Basic IPCC equation to calculate carbon emissions from LC change (IPCC, 2006, vol.1, ch.1.2):

$$\boldsymbol{Emissions = Activity\ Data * Emission\ Factor}$$

- Using emission factors specific for forest types may improve the GHG emission accuracy. The equation for multiple forest types (strata) is:

$$\boldsymbol{E = \sum AD_i * EFi} \qquad \boldsymbol{i - stratum - specific\ data}$$

- Remotely sensed data enable mapping and monitoring of forest cover and change over large areas (**Activity Data**) at regular intervals, providing information on where and how changes are taking place at annual or even finer time scales. Long-term satellite data archives are the only datasets available for estimating historical activity data.
- The most promising and robust ways to map aboveground carbon stock across landscapes (**Emission Factor**) rely on the synergistic use of field measurements and remote sensing data.

What is Tree Canopy Cover?

Tree canopy cover definition





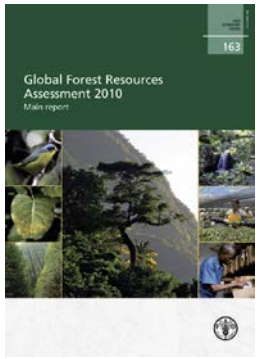


100%

Tree defined as woody vegetation above 5 m tall. All types of woody vegetation are included (natural forests, plantations, orchards, woodlots, agroforestry, bamboo, etc.). *Mangroves and certain other forest types may be defined using lower height threshold.*

Tree canopy cover (TCC) - % summary tree crown projection over the land unit area. Crown projection include in-crown gaps.

What is Tree Canopy Cover?



FAO Forest resource assessment, 2010

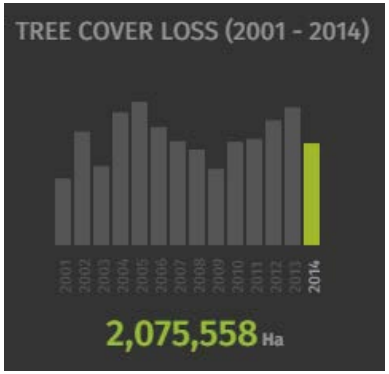
Forest definition: Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds.

Definition inconsistency: forest and tree cover change area in Canada.

Red – areas of "gross forest cover loss", i.e. changes in land-cover from 2000 to 2014.



Remotely sensed data provides information on land-cover, not on land-use!



Forest area change in Canada (FAO)

Forest area (1 000 ha)			
1990	2000	2005	2010
310 134	310 134	310 134	310 134

What is Tree Canopy Cover?

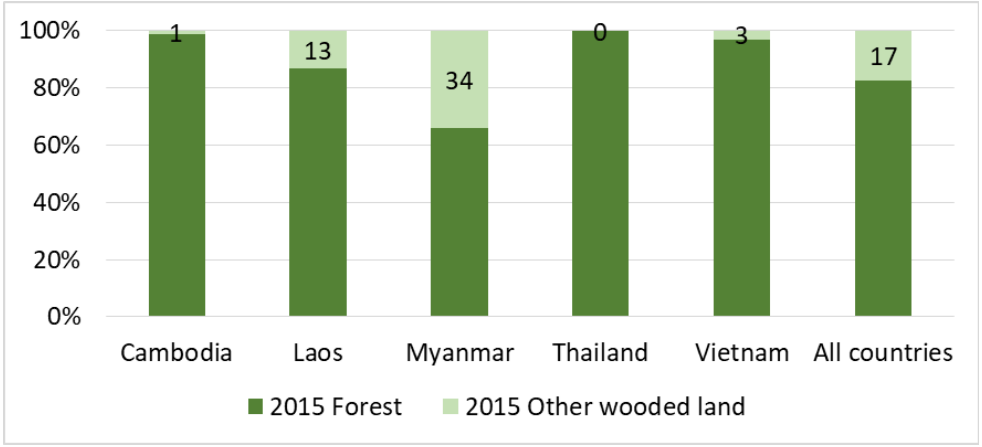
Trees Outside Forests

Trees outside forests plays important role in the national total tree cover.

- TOF make up significant portion of national tree cover area;

  Madagascar: ~50%; Bangladesh: 54%; Nepal: 34%

Percent total wooded land (FAO FRA 2015)



- TOF plays important role in the national economy;

  Bangladesh: TOF supply >70% fuelwood, >80% bamboo; >50% timber.

- In Asian countries LULUCF serves as a major sink of the CO_2 balancing national emissions. To calculate changes (emission or removal) in the "forest and other woody biomass" stocks, the **total** plantation area, forest, and trees outside forest should considered.

Why GLAD?

Objective

Providing timely spatial information on tree cover area and change

Requirements

Monitoring institution:

- Free data. Low-cost, easy to implement data processing and analysis methods.
- Fast data processing to allow timely updates.
- Complete ownership and replicability of results.

National reporting:

- Reporting format and timing is aligned with national forest policies and suitable to quantify their effects.
- Spatial and temporal consistency at national scale.
- Known uncertainty. Accuracy is suitable for MRV.

International reporting:

- Transparency and replicability of methods and data.
- Consistency between countries.
- Known uncertainty estimated using good practices.

Why GLAD?



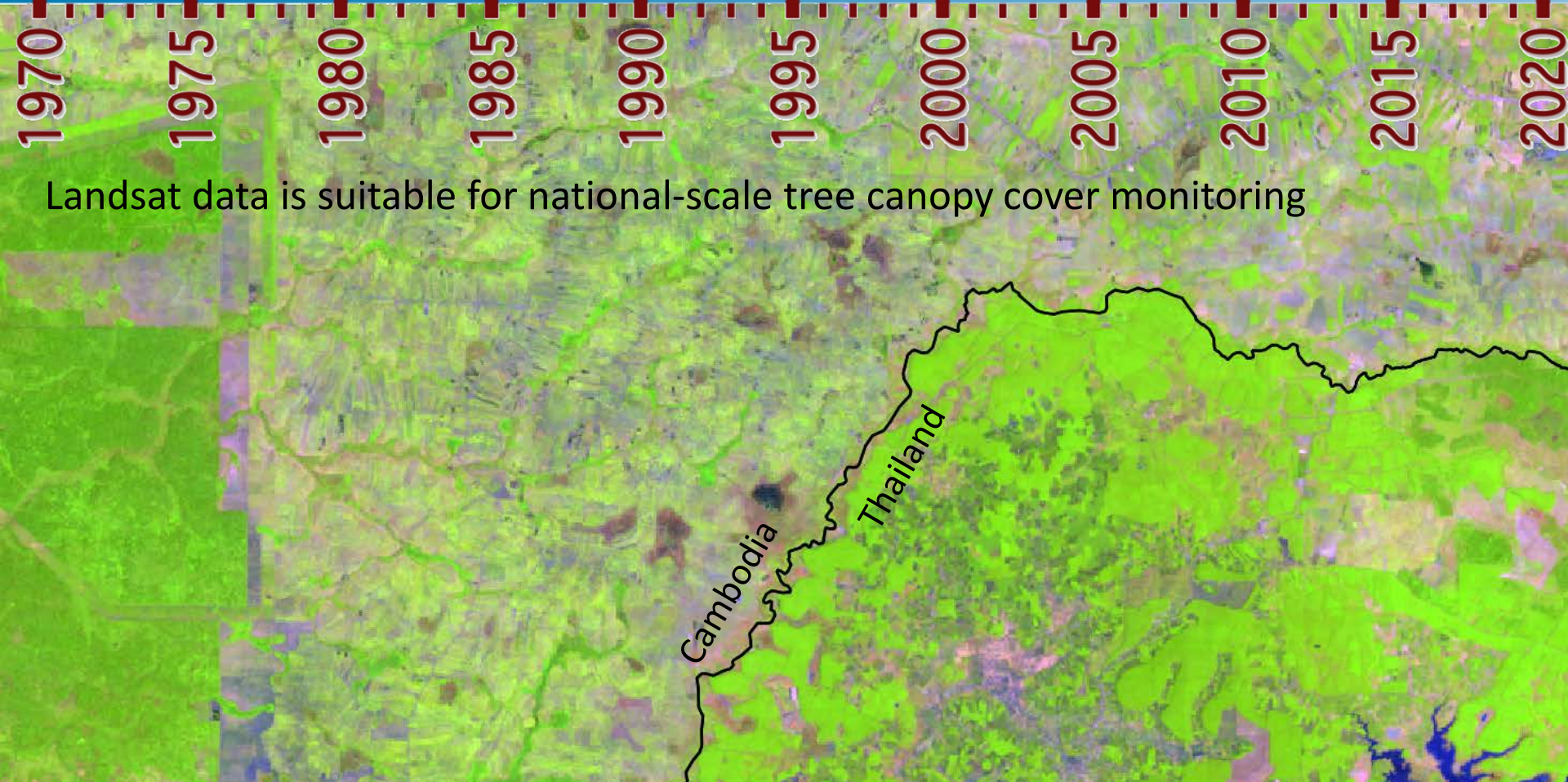
www.glad.umd.edu



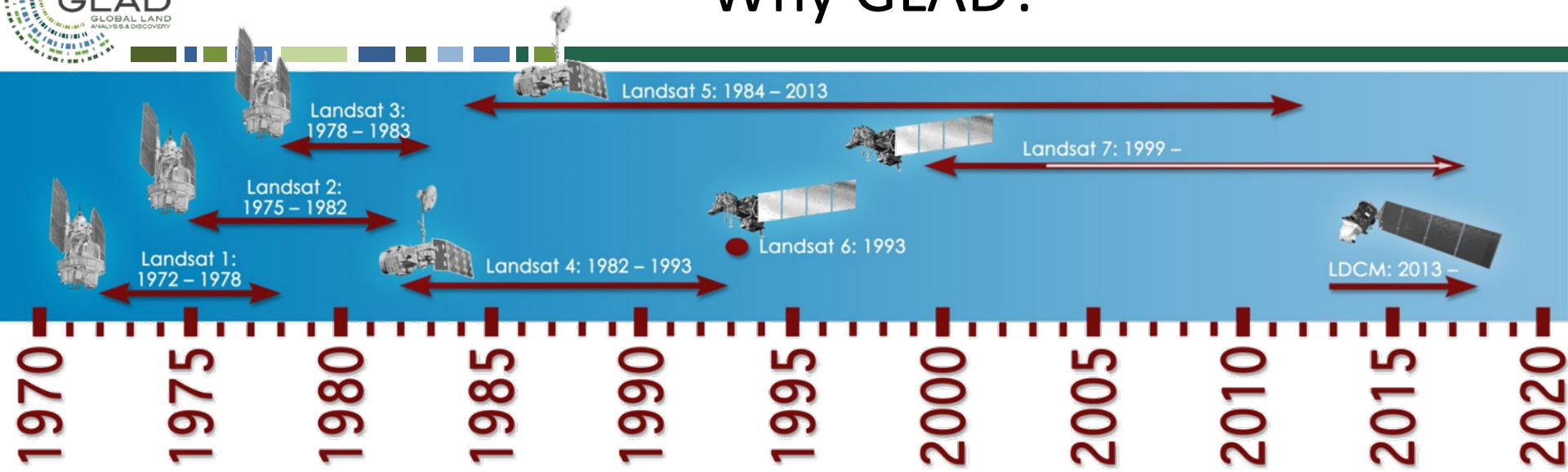
Why GLAD?



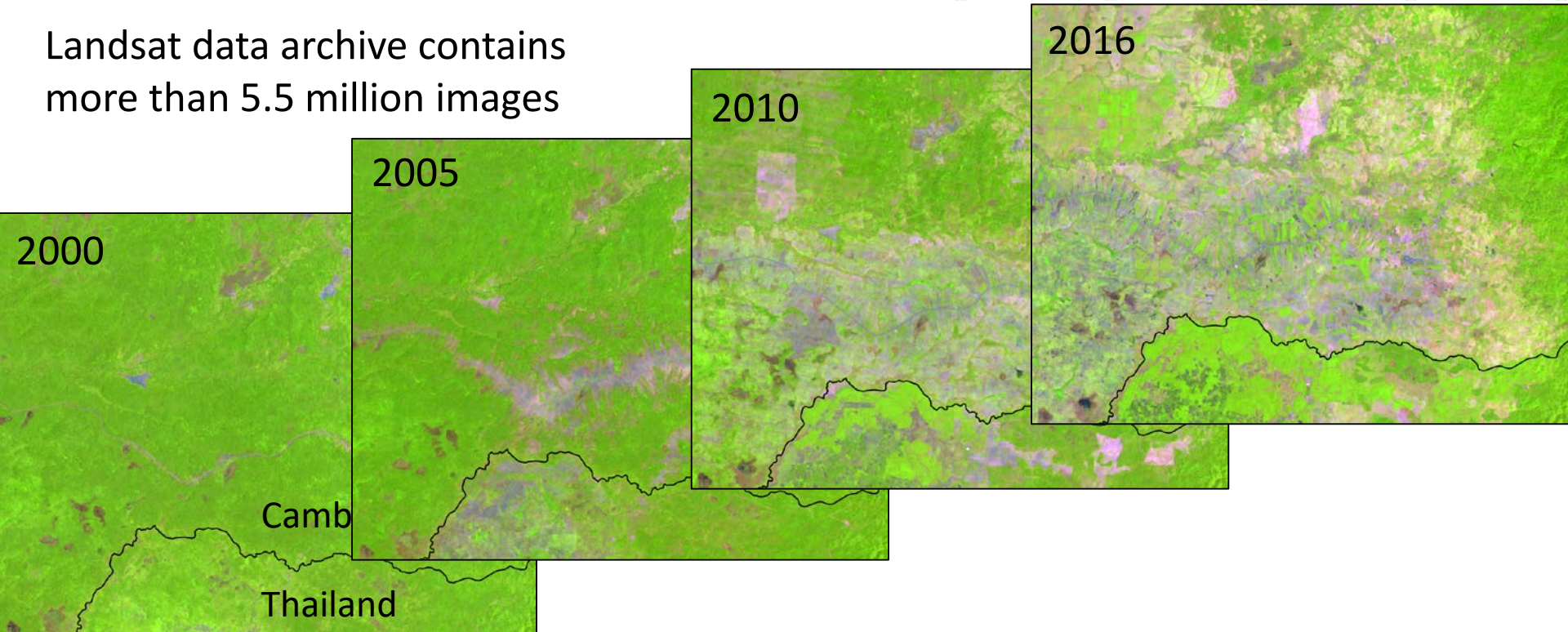
Landsat data is suitable for national-scale tree canopy cover monitoring



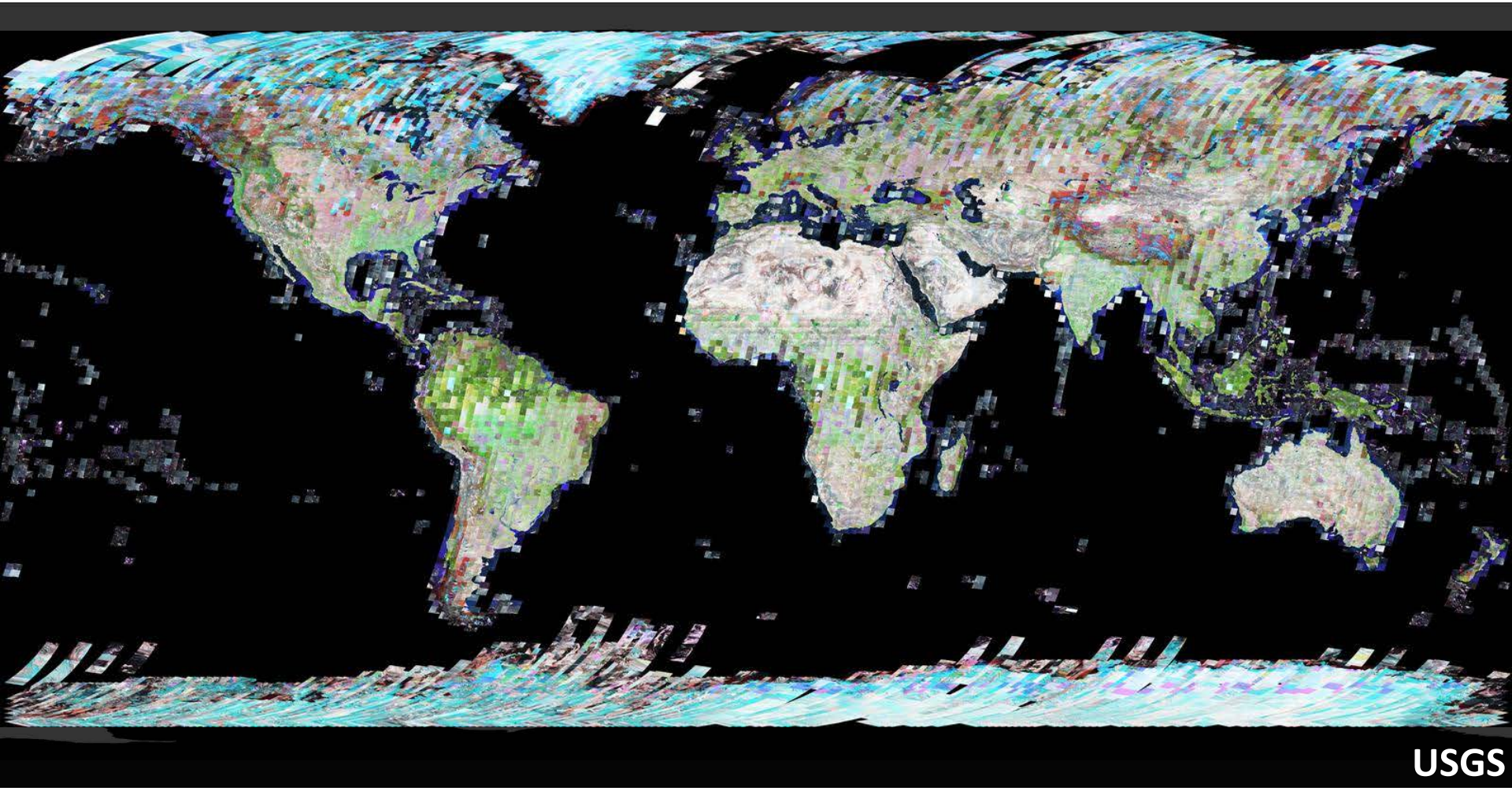
Why GLAD?



Landsat data archive contains more than 5.5 million images

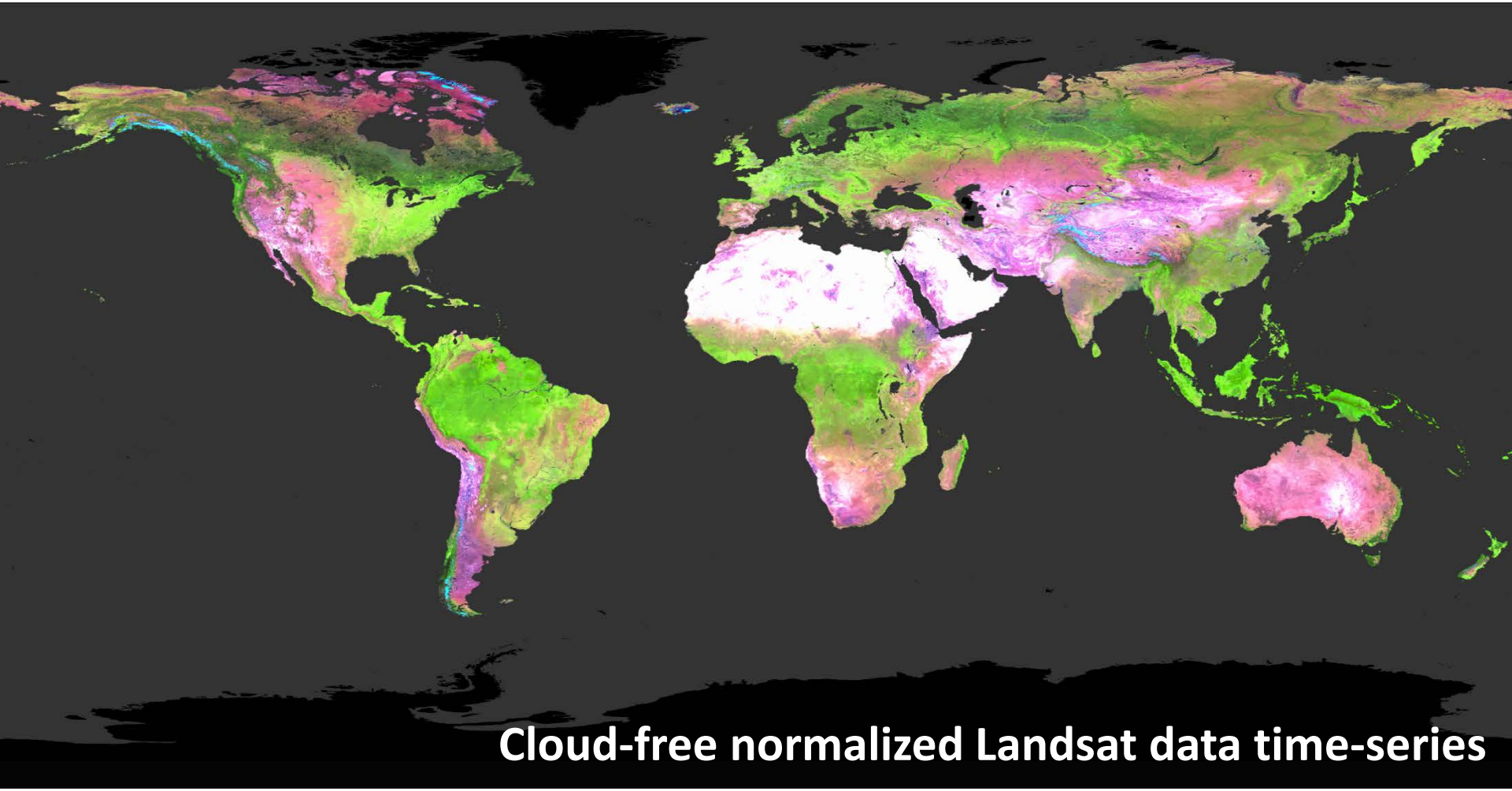


Why GLAD?



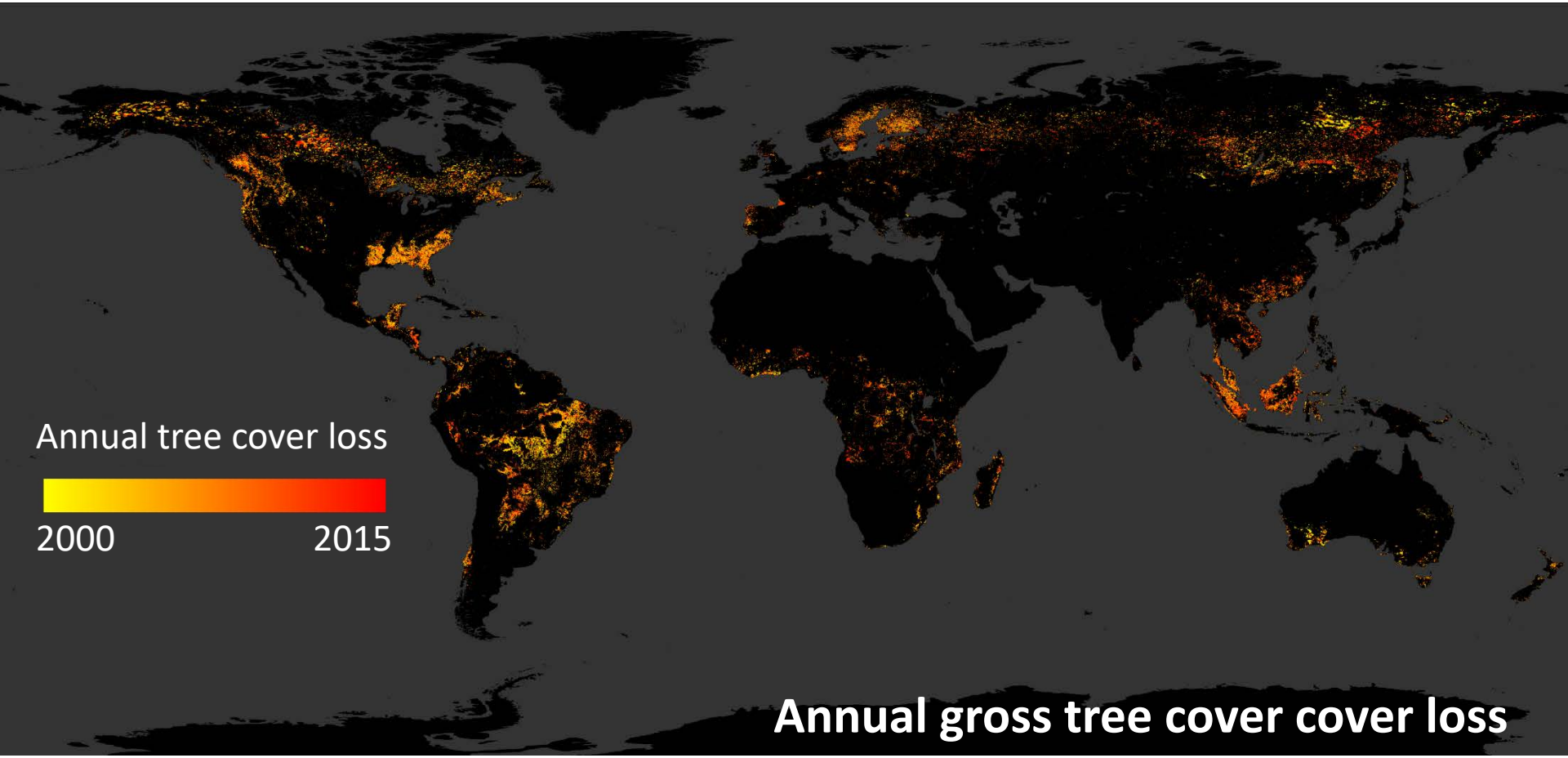
Spatial and temporally consistent Landsat surface reflectance data time-series provides the basis of annual land cover monitoring. Landsat data archive is the only data source that allowing global historical tree cover change monitoring.

Why GLAD?



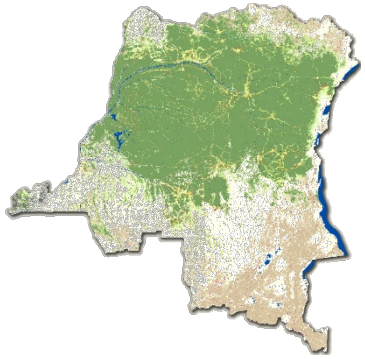
Spatial and temporally consistent Landsat surface reflectance data time-series provides the basis of annual land cover monitoring. Landsat data archive is the only data source that allowing global historical tree cover change monitoring.

Why GLAD?



Global maps of tree cover, it loss and gain, are readily available. The UMD/GLAD maps are produced on a consistent basis and are updated annually. These maps, however, **may have limitations** in the regions with heterogeneous landscape and small-scale tree cover dynamics.

GLAD National Tree Cover Monitoring System

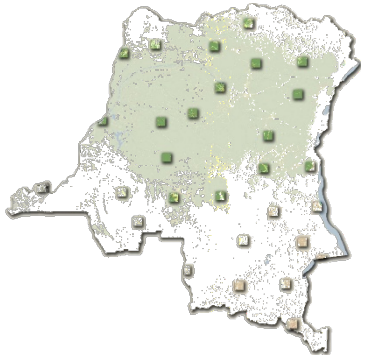


Stage I: National wall-to-wall tree canopy cover and change mapping

Global consistently processed Landsat data (provided by GLAD)

- National wall-to-wall tree canopy cover, height, change maps
- Annual, monthly, or near-real-time monitoring

Stratified sampling design and time-series data



Stage II: Probability sampling and sample-based assessment

Sample reference data

- Sample-based estimates of tree cover area and change.
- Tree cover and change by regions, forest types, or AGB strata.
- Change by year, disturbance type, gross and net change.
- Accuracy of the national wall-to-wall maps.

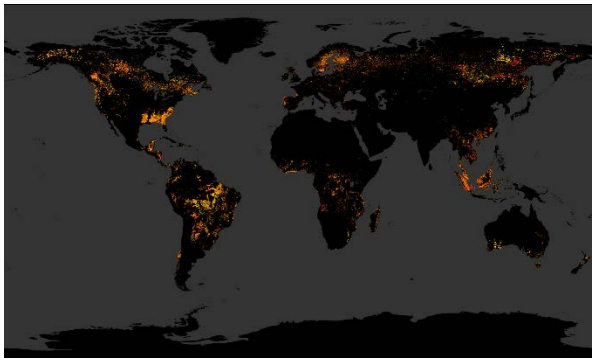
*All estimates with known uncertainty

National and international reporting and spatial information distribution

National state of the forest reporting. National forest atlases and web services.
Support for NFI (plot location, extrapolation of field data).
International reporting (FAO FRA, REDD+, IPCC/UNFCCC).

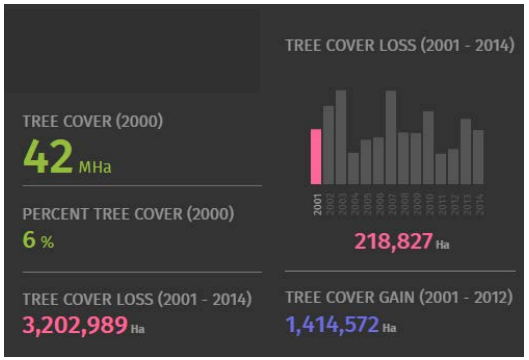
GLAD National Tree Cover Monitoring System

Wrong way



Direct area extraction from the global map





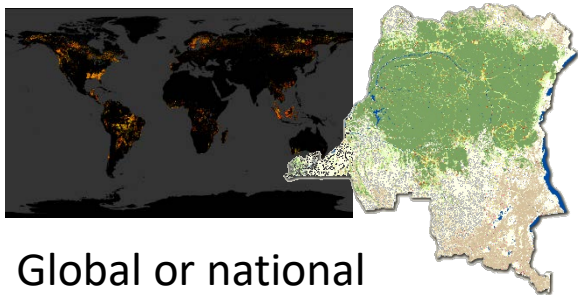
Global forest extent and change products provides spatially consistent, wall-to-wall data…

However:

- All maps derived from remotely sensed data contain errors due to data limitation, classification/change detection algorithm limitation, analyst errors and bias, etc.
- Errors on the global overview maps usually introduce bias in area estimations. Most of the overview maps provide “conservative” estimates of rare classes, i.e. they underestimate forest change.
- The global map errors may be spatially biased (e.g. due to different characterization model sensitivity within different environments). Its quality may not be suitable in a particular region.
- The uncertainty of classification may not be estimated from the map alone.

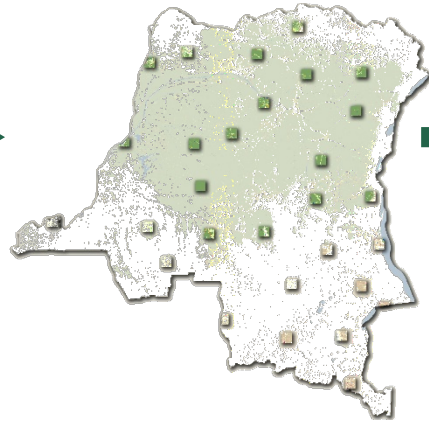
GLAD National Tree Cover Monitoring System

Good practice



Global or national wall-to-wall TC change maps

Statistical sampling



Sample-based:

- Map accuracy
- Area
- Uncertainty

Spatially exhaustive (wall-to-wall) maps

- Provide information on spatial allocation of forest cover and change.
- Allow sampling design/area estimation with improved efficiently and precision.
- Global maps may have limitations and should be substituted with regional/national maps when possible.

Sample-based assessment (reference sample data)

- Provides highest quality determination of the forest cover and change conditions per sample unit
  - Serves as reference data for map **accuracy assessment.**
  - Allows **unbiased area estimation** with known **uncertainty.**

GLAD National Tree Cover Monitoring System

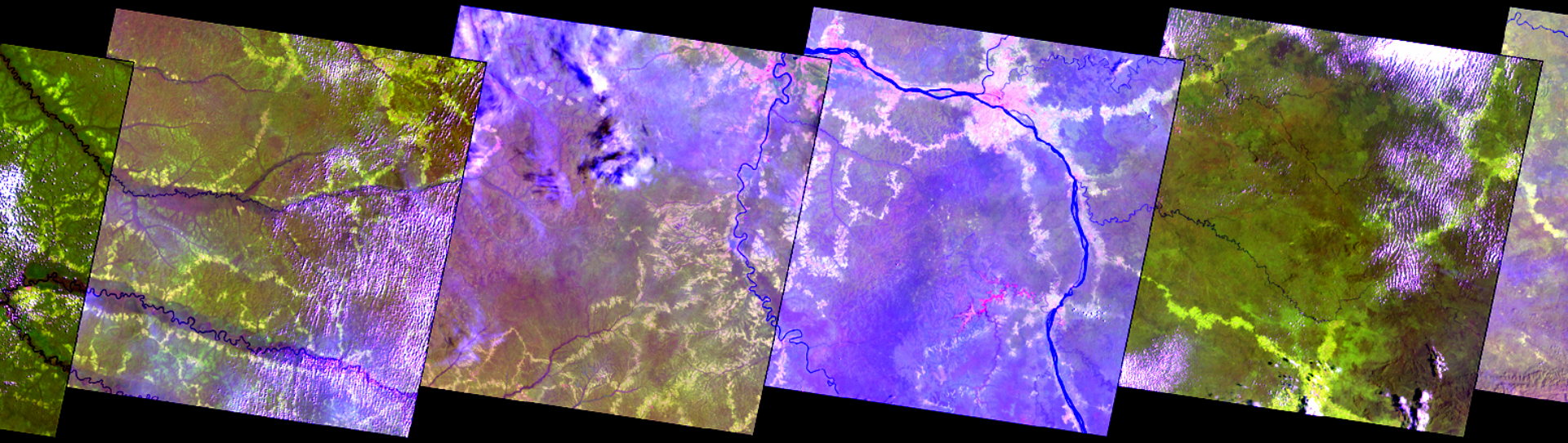
The GLAD system objective is to provide **timely spatially consistent information on national tree cover area and change**.

The GLAD system benefits:

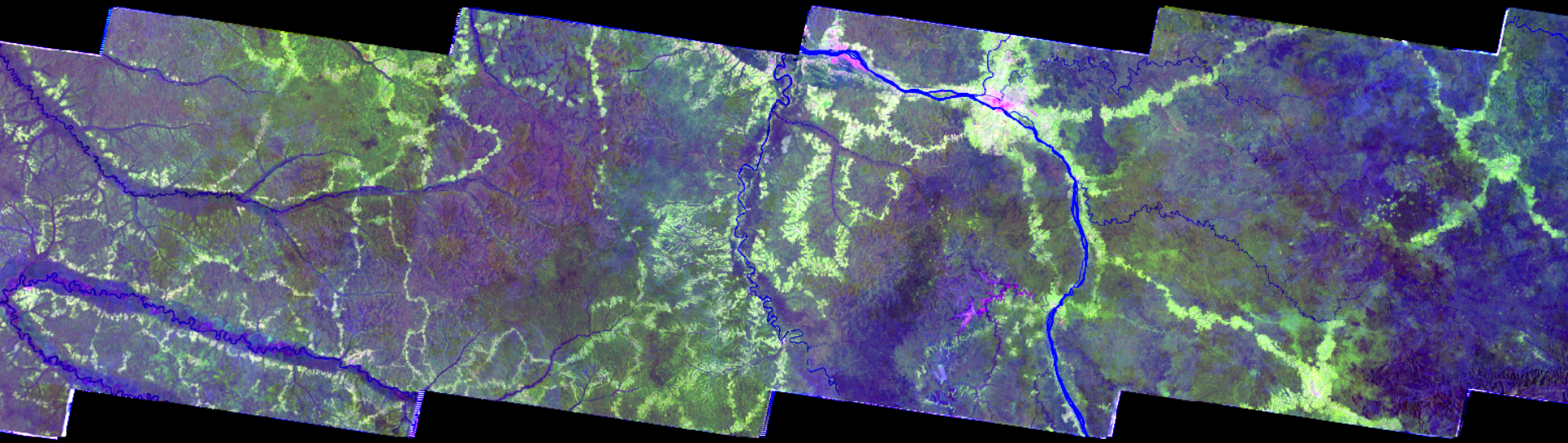
- **Globally spatially and temporally consistent analysis-ready data** based on Landsat (+Sentinel-2) data archive (annually updated, distributed free-of-charge).
- **Efficient data characterization methods and tools** (for mapping and sampling) using purposely developed software.
- **Timely update** of national products (i.e. at annual intervals). Availability of the near-real-time data (weekly forest change alerts product).
- Outputs are suitable for the **national and international reporting.** All estimates includes “good practice” uncertainty estimation.
- In-country data characterization that ensure **complete product ownership** and **replicability**.
- **Harmonization** of input data and products between agencies and regions.

GLAD National Tree Cover Monitoring System

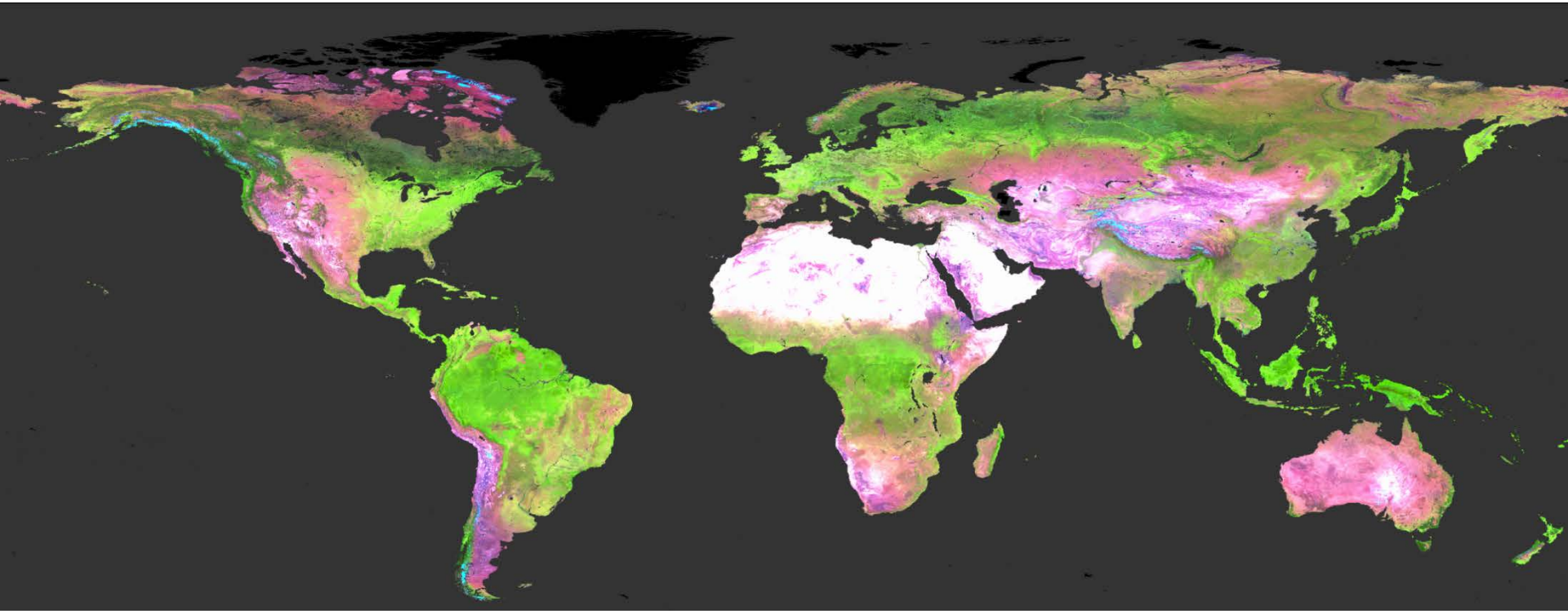
Landsat source L1T data (Collection 1 data)



GLAD Landsat data composites and metrics

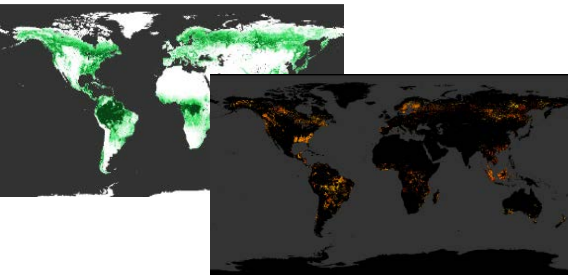


GLAD National Tree Cover Monitoring System



Spatially and temporally consistent inputs for…

Wall-to-wall mapping

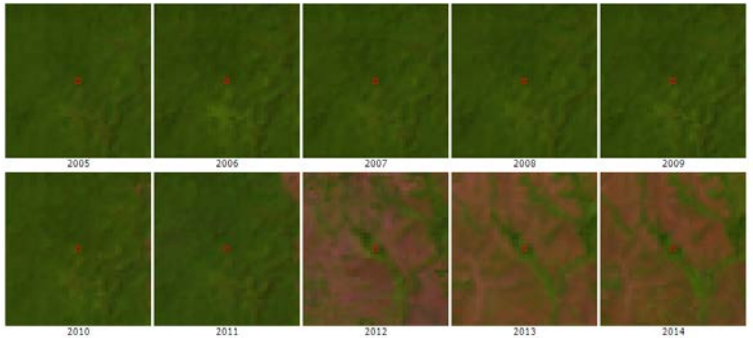


Global LC/LCC mapping



National mapping and change detection

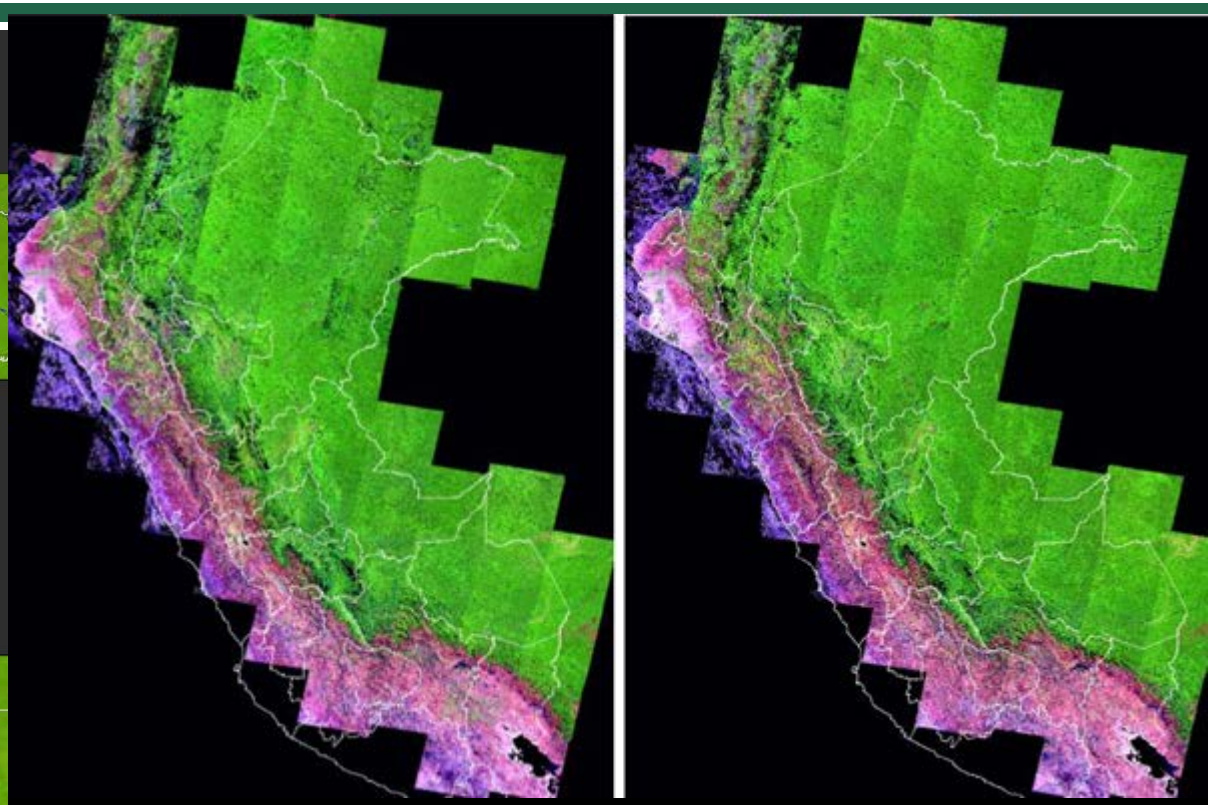
Sample-based analysis



National Forest Monitoring: Peru



GLAD spectrally, spatially, and temporally consistent wall-to-wall national data



CLASlite scene-based national data compilation

Circa 2000 image composite

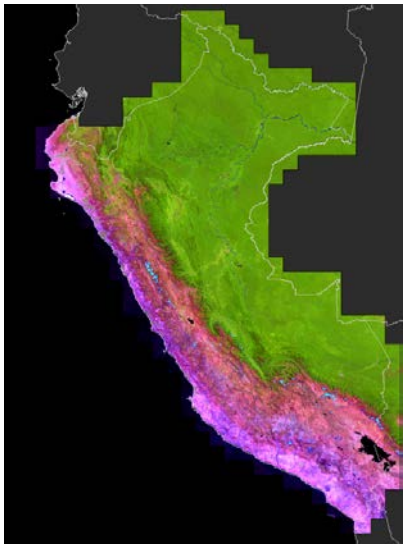
Circa 2011 image composite

National Forest Monitoring: Peru

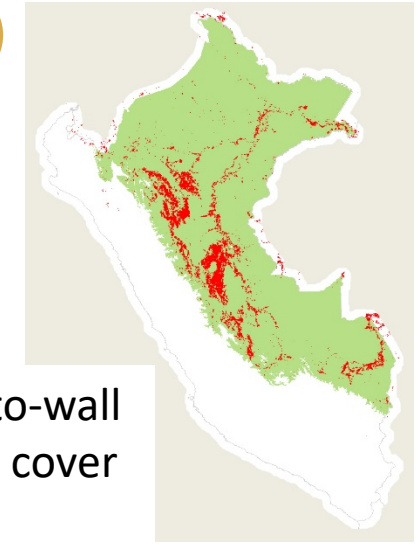
1

GLAD

Landsat data composites and metrics

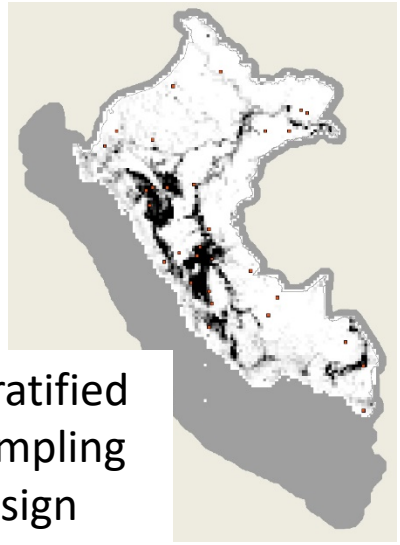


2



Wall-to-wall forest cover loss

3

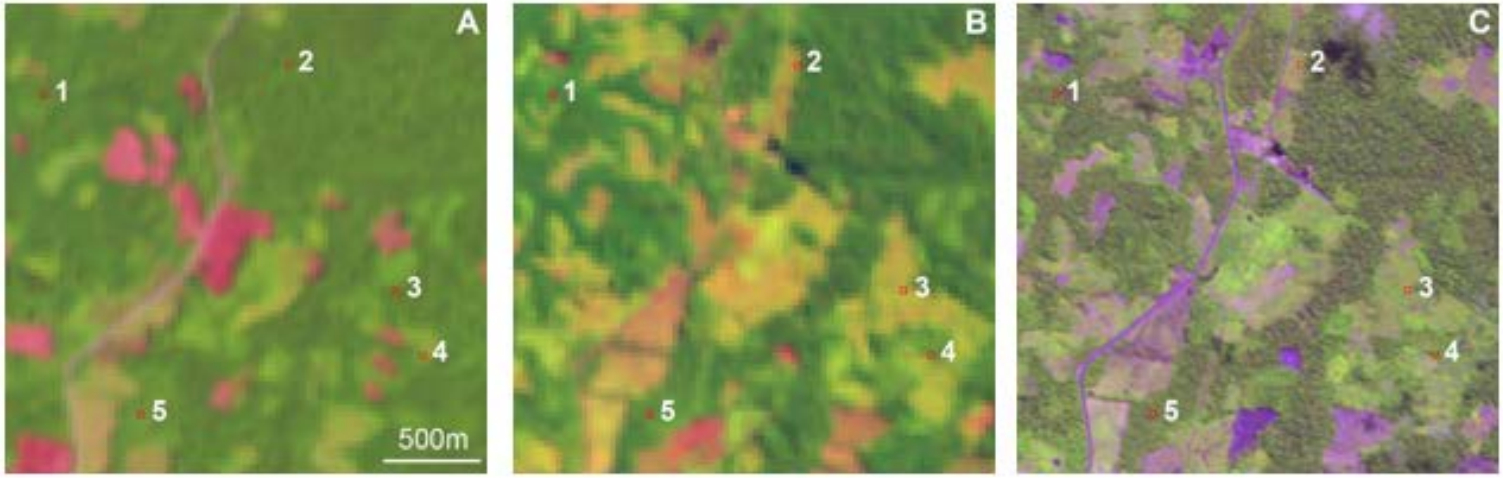


Stratified sampling design

MINAM

4

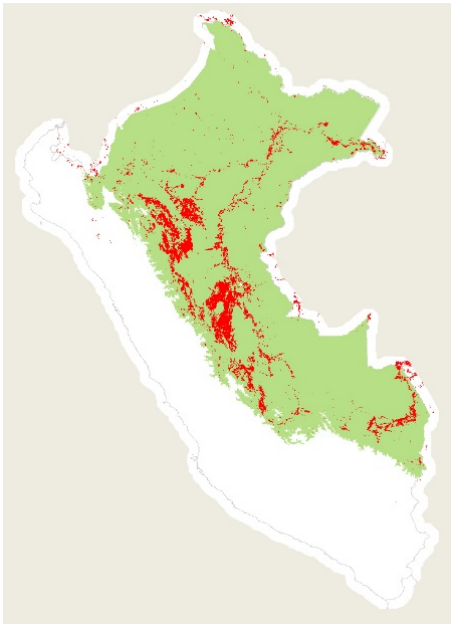
Sample block analysis using Landsat and RapidEye data



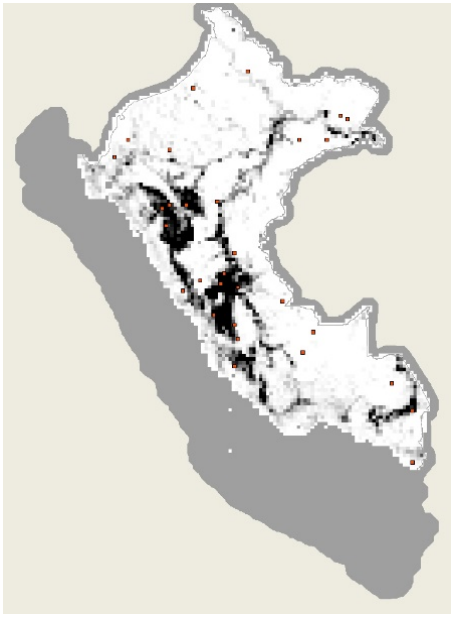
National Forest Monitoring: Peru

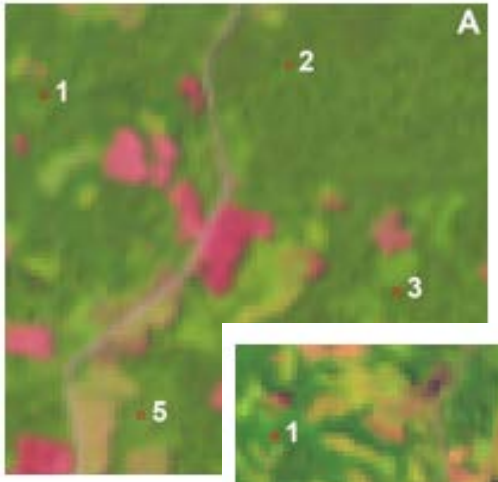
Two-stage cluster sampling design to reduce high spatial resolution data cost

Forest cover loss within primary humid tropical forests, 2000-2011

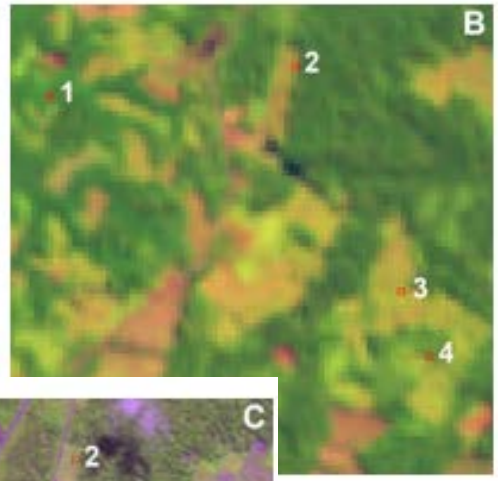


Stratified sampling design (sampling grid of 12x12 km blocks, 30 blocks sampled)

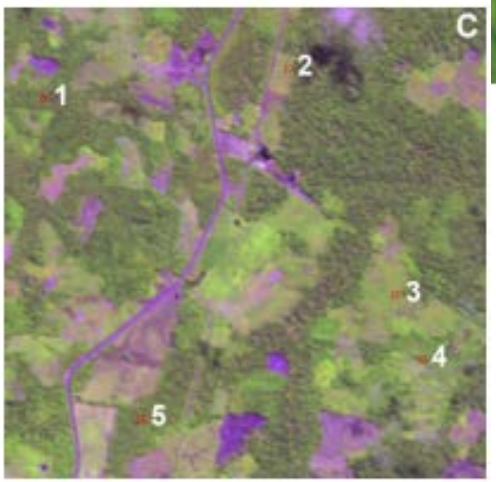




Landsat 2000



Landsat 2011



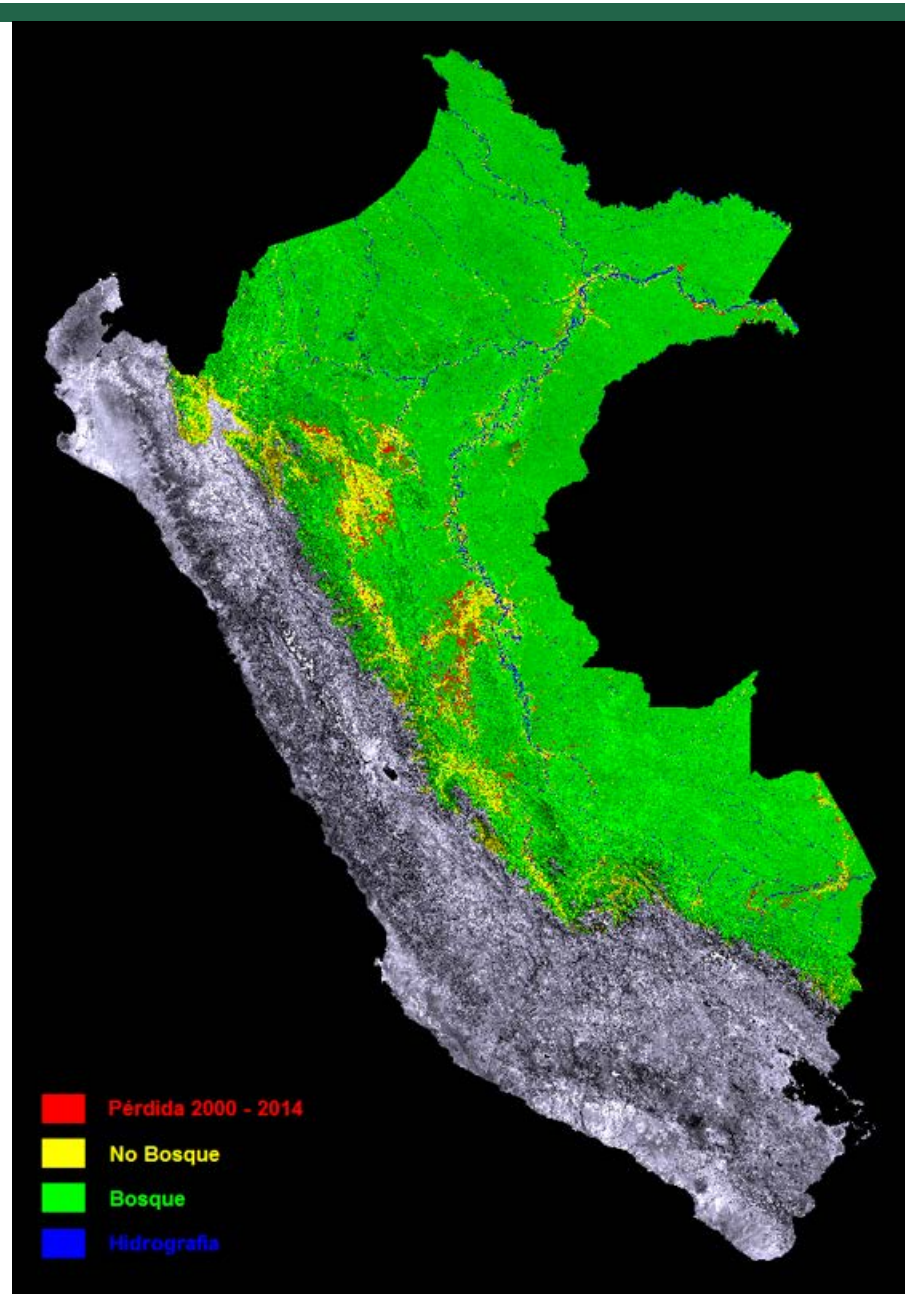
RapidEye 2011

Total number of 12x12 km blocks within humid tropical forests: 5532. Sampled blocks: 30 (0.5%).
Forest loss area estimated with SE of +/- 6.6%.
Mapped loss area is 15% lower than the sample-based area.

National Forest Monitoring: Peru

Forest cover change for Peru by MINAM, baseline 2000-2011, annual update 2013-2016





PERÚ Ministerio del Ambiente | Viceministerio de Desarrollo Estratégico de los Recursos Naturales | Programa Nacional de Conservación de Bosques para la Mitigación del Cambio Climático

NIVEL NACIONAL - BOSQUE HÚMEDO AMAZÓNICO

BOSQUE - NO BOSQUE Y PÉRDIDA DE BOSQUE 2000 - 2014 POR DEPARTAMENTOS

DEPARTAMENTO	NO BOSQUE AL 2000[2]	PÉRDIDA DE BOSQUE[3] 2001 - 2014 (MONITOREO DE LA PÉRDIDA)														HIDROGRAFÍA[1]	BOSQUE AL 2014[4]	
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	TOTAL 2001-2014		
	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	%
TOTAL	5,656,910	83,995	79,832	72,874	93,146	147,624	74,502	106,186	105,704	152,161	136,205	123,563	149,477	150,289	177,571	1,653,129	100.00	1,819,384	69,179,377	100.00

National Forest Monitoring: Peru

National reports

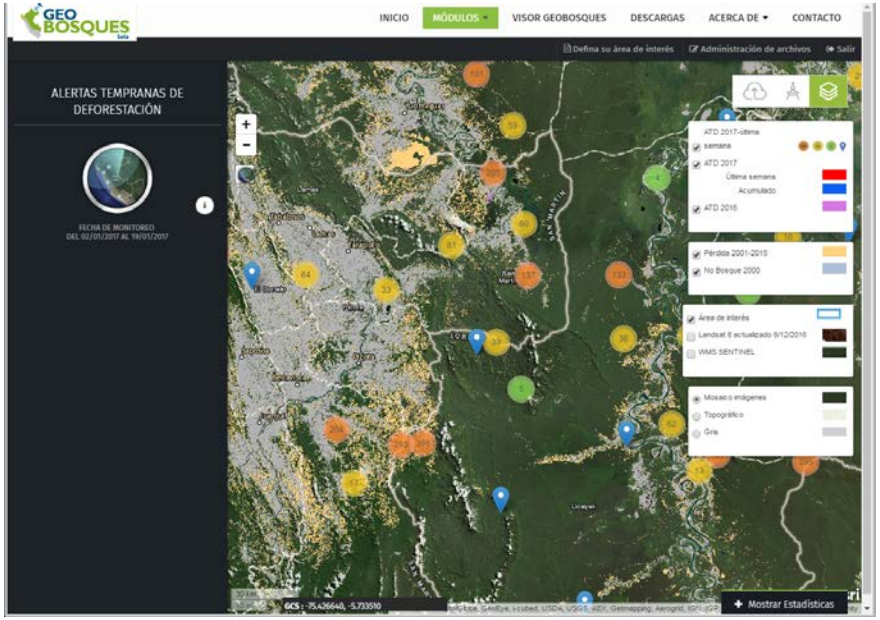




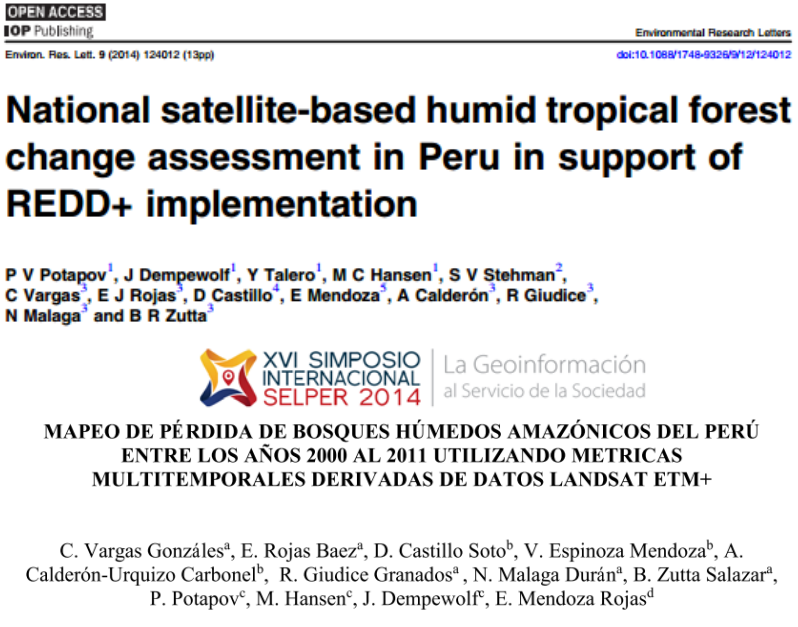
Software use and image analysis training



National forest data portal (include forest alerts)



Joined scientific publications



OPEN ACCESS
IOP Publishing
Environmental Research Letters
Environ. Res. Lett. 9 (2014) 124012 (13pp)
doi:10.1088/1748-9326/9/12/124012

National satellite-based humid tropical forest change assessment in Peru in support of REDD+ implementation

P V Potapov[1], J Dempewolf[1], Y Talero[1], M C Hansen[1], S V Stehman[2], C Vargas[3], E J Rojas[3], D Castillo[4], E Mendoza[5], A Calderón[3], R Giudice[3], N Malaga[3] and B R Zutta[3]

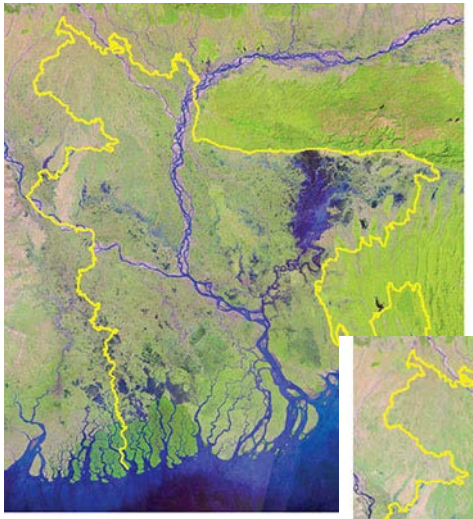
XVI SIMPOSIO INTERNACIONAL SELPER 2014 | La Geoinformación al Servicio de la Sociedad

MAPEO DE PÉRDIDA DE BOSQUES HÚMEDOS AMAZÓNICOS DEL PERÚ ENTRE LOS AÑOS 2000 AL 2011 UTILIZANDO METRICAS MULTITEMPORALES DERIVADAS DE DATOS LANDSAT ETM+

C. Vargas Gonzáles[a], E. Rojas Baez[a], D. Castillo Soto[b], V. Espinoza Mendoza[b], A. Calderón-Urquizo Carbonel[b], R. Giudice Granados[a], N. Malaga Durán[a], B. Zutta Salazar[a], P. Potapov[c], M. Hansen[c], J. Dempewolf[c], E. Mendoza Rojas[d]

National Forest Monitoring: Bangladesh

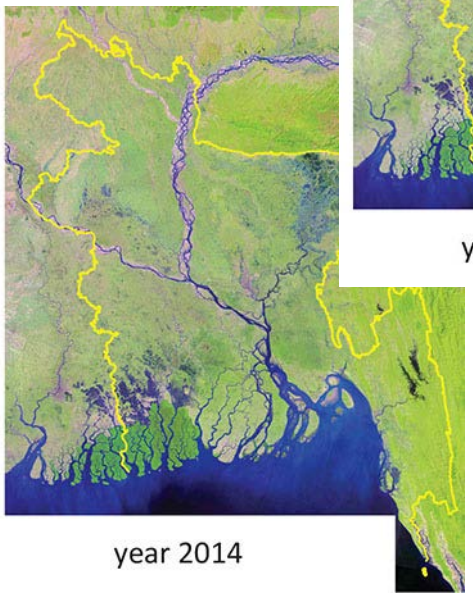
Spatially, and temporally consistent wall-to-wall national data



year 2000



year 2007

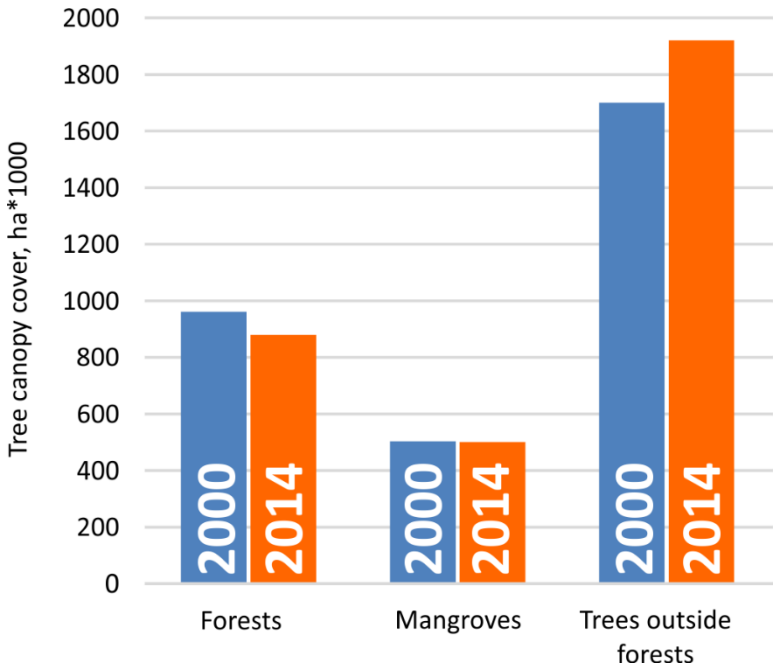


year 2014



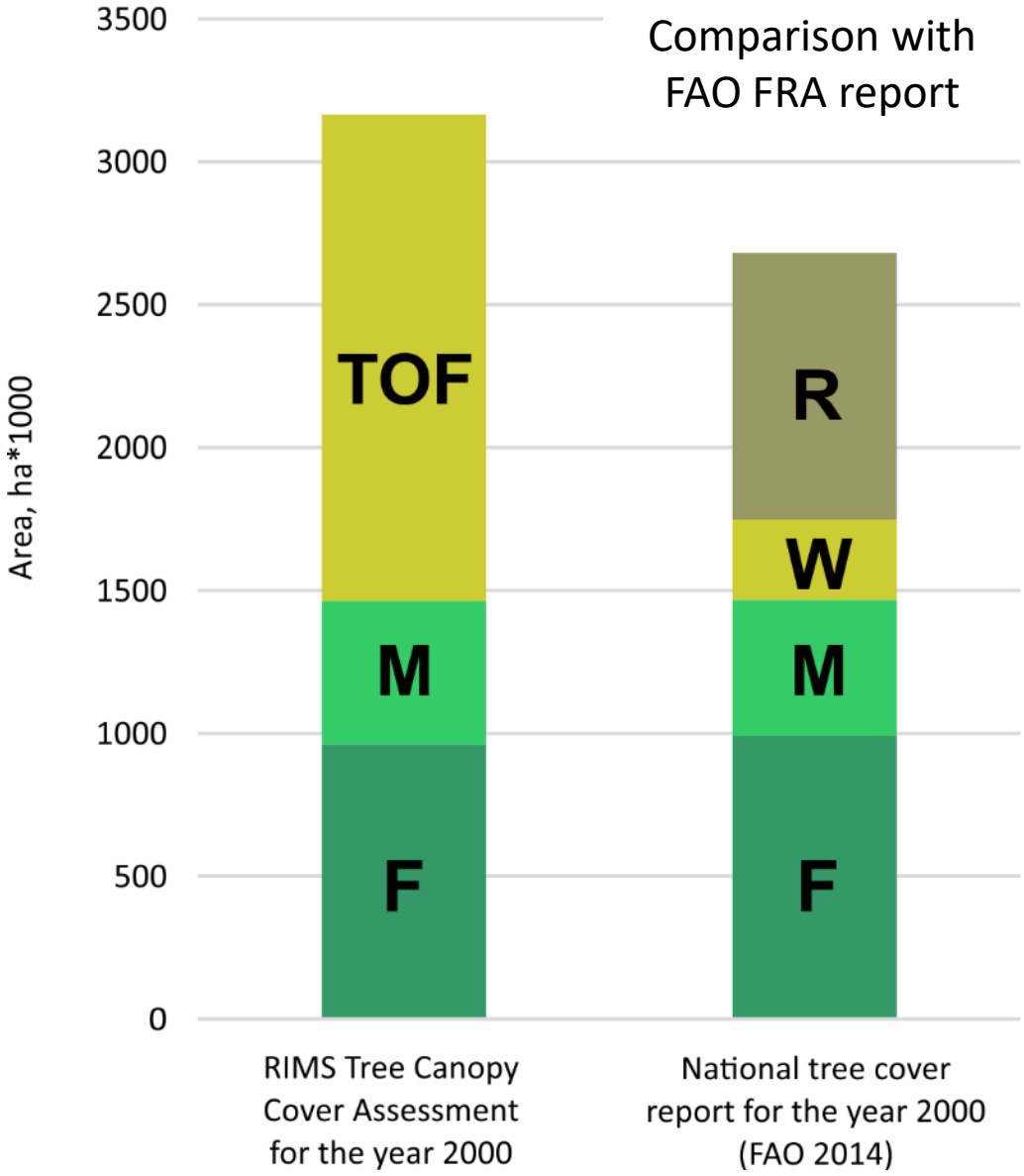
National Forest Monitoring: Bangladesh

National sample-based tree canopy cover and change estimates for Bangladesh



National tree cover dynamics, 2000-2014

Comparison with FAO FRA report



GLAD National Tree Cover Monitoring System

GLAD team

National monitoring team

I. Sample-based TCC area assessment

Year 1

National TC change product

Stratified sampling design and reference data

Sample-based analysis of TC cover and change area for national reporting.

II. National wall-to-wall TC/TCC mapping

Year 2

Automated Landsat data processing

Hardware/software complex for TC monitoring. Training on software use and data analysis

Mapping national TC/TCC. Validation of map accuracy using stratified sample data.

III. Operational annual TC monitoring

Year 3

Source Landsat data processing

Annual image data updates. Technical consultations

Operational update of national TC/TCC maps. Sample-based estimation of TC change area. National reporting and on-line map publication.

GLAD National Tree Cover Monitoring System

Former and on-going national GLAD capacity building projects

Country	Project	Partners/Sponsors
Peru	Operational monitoring of humid tropical forest conversion in support of REDD+ and IPCC GHG reporting, 2000-current.	MINAM, SilvaCarbon
Colombia	Comprehensive land-cover monitoring for IPCC GHG reporting. 2000-ongoing.	IDEAM, SilvaCarbon
Ecuador	Forest cover change quantification 2000-2011.	SilvaCarbon
Mexico	Tree cover extent, structure, and change assessment, 1985-2014	CONABIO
Guatemala	Support of the NFMS for forest monitoring 2000-current.	SilvaCarbon
Democratic Rep. of the Congo	Forest monitoring 2000-current, forest type mapping, habitat modelling.	USAID, OSFAC, JGI
Rep. of the Congo	Forest monitoring 2000-current, forest type mapping.	USAID, CNIAF
Cameroon	Support of the NFMS for forest monitoring 2000-current.	USAID, SilvaCarbon
Vietnam	National tree cover monitoring in support of NFI	FIPI, SilvaCarbon
Bangladesh	Tree canopy cover monitoring 2000-current in support of REDD+ and NFI.	RIMS, SilvaCarbon
Madagascar	Tree canopy cover monitoring 2000-current in support of REDD+	GEF, BNREDD+
Indonesia	Forest cover change quantification 1980-2000, wetlands mapping.	USFS, MoF, LAPAN
Nepal	Tree canopy cover change assessment, 2000-2016	DFRS, ICIMOD, SilvaCarbon