Remote sensing as a tool for monitoring ecosystem services in tropical forests

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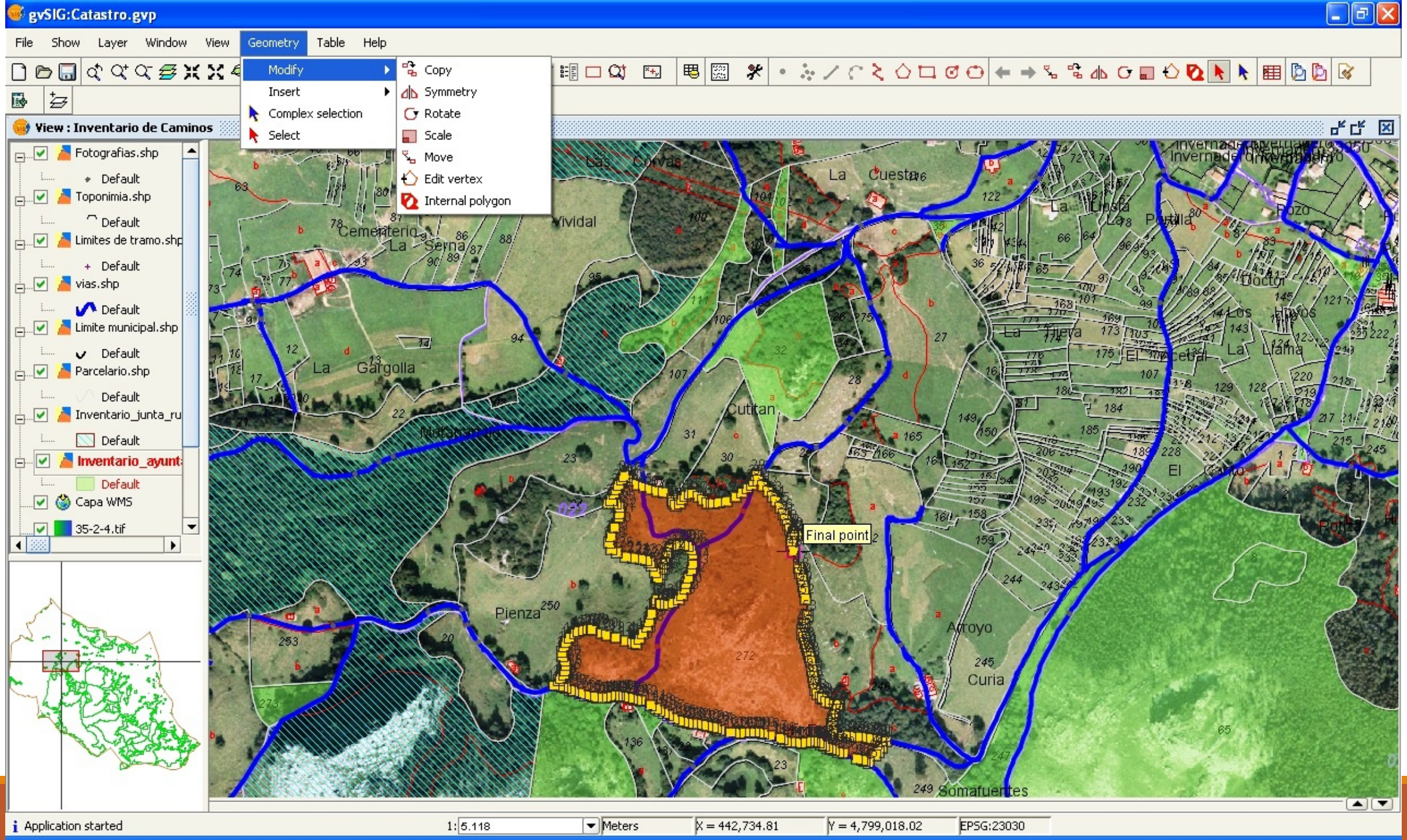
Ecosystem Services

- Ecosystem services are the benefits people obtain from ecosystems.

- These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth.

Ecosystem services	Secondary Indicators
Aesthetic enjoyment	Distance to Scenic site
	Protected areas
Air Quality Regulation	Deposition velocity
	Pollutant concentration
	Tree cover
Biological Control	Pest density
Climate Regulation	Above ground biomass
	Below ground biomass
	Forest biomass
	Land cover
	NPP
	Nutrient flux
	Soil carbon
Erosion prevention	Erodibility
	Land Use
	Slope
	Soil characteristics
	Soil retention
	Vegetation map
Food provision	Climatological parameters
	Crop yield
	Land cover
	Livestock
	NPP

Ecosystem services	Secondary Indicators
Genetic Resources	Land cover
Inspiration for culture, art and design	Land cover
	Land Use
	landscape value
Lifecycle maintenance	Above ground biomass
Lifecycle maintenance Total	
Maintenance of Genetic Diversity	Land cover
Maintenance of soil fertility	Earthworm
	Land cover
	Litter
	Nutrient retention
	Soil characteristics
Medicinal Resources	Land cover
Moderation of extreme events	Annual flood
	Flood plain
	Hazard
Recreation and tourism	Accessibility
	Accommodation
	Cultural heritage
	Fish abundance
	Flower viewing
	Footpaths
	urban green space
	Visitors numbers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File
Show
Layer
Window
View
Geometry
Table
Help
Modify
Insert
Complex selection
Select
Copy
Symmetry
Rotate
Scale
Move
Edit vertex
Internal polygon
View : Inventario de Caminos
Fotografias.shp
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Toponimia.shp
Default
Limites de tramo.shp
Default
vias.shp
Default
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Default
Parcelario.shp
Default
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Default
Inventario_ayunt
Default
Capa WMS
35-2-4.tif
Final point
Application started
1: 5.118
Meters
X = 442,734.81
Y = 4,799,018.02
EPSG:23030

Ecosystem Services

- Preserving ecosystem services means preserving ecosystems through sustainable management, restoration, and decreasing or stopping further loss.

Diario Voces, Peru.

Diario La Hora, Ecuador.

Indicators of Ecosystem health

- Ecosystem extent and fragmentation
- Level of disturbance
- Primary productivity

The Convention on Biological Diversity (2011-2020)

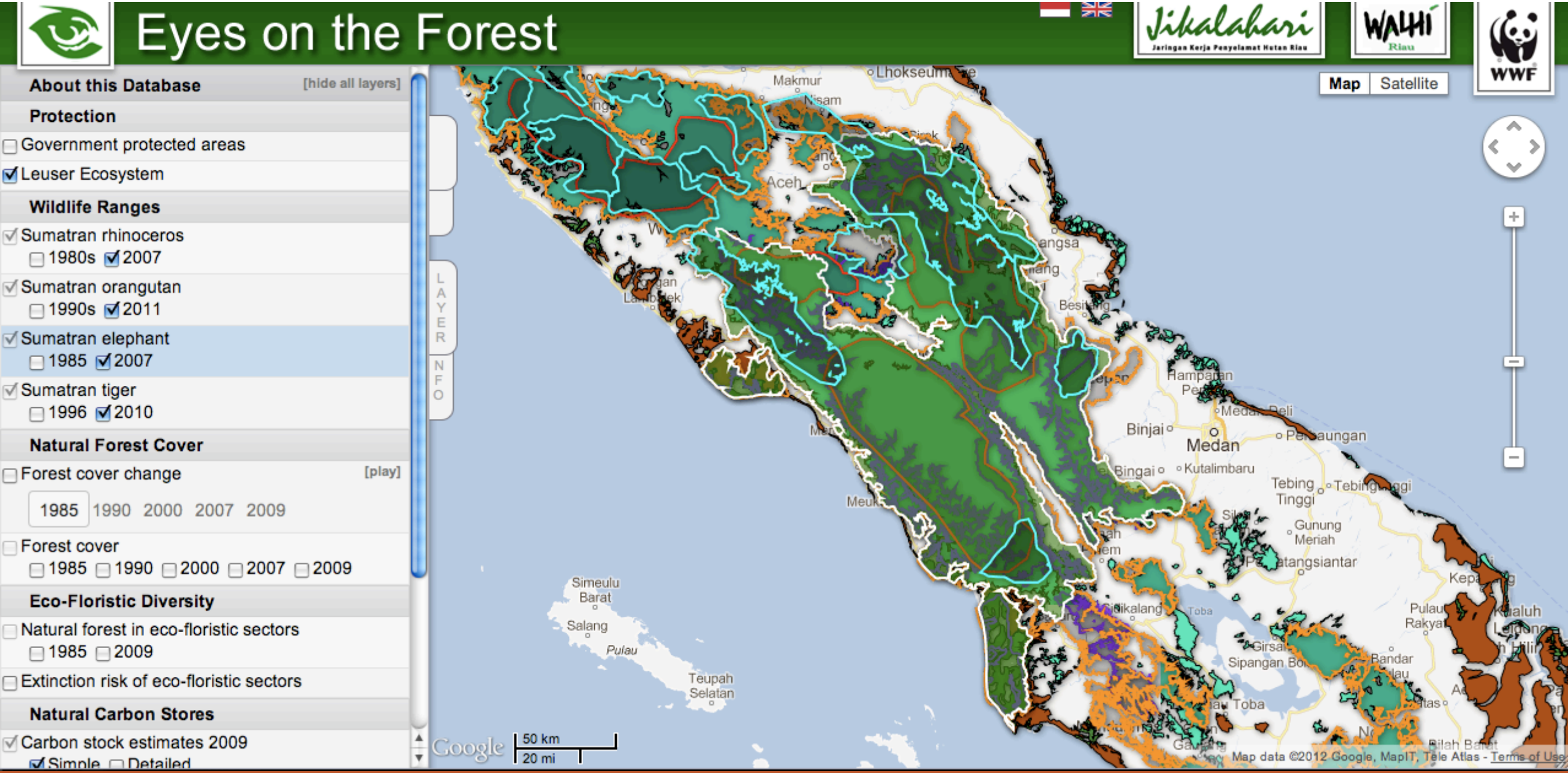
CBD is an Intergovernmental agreement signed in 1992 to promote actions to preserve biological diversity

Strategic Plan Indicators to reduce the direct pressures on biodiversity and promote sustainable use:

1. Trends in extent, condition and vulnerability of ecosystems
2. Trends in fragmentation
3. Trends in proportion of habitat loss, degradation
4. Trends in primary productivity

Bswm.maps.da.gov.ph

Traditionally, maps were manually drawn from image interpretation and field knowledge.


Eyes on the Forest
Jikalahari
Jaringan Kerja Penyelamat Hutan Riau
WALHI
Riau
WWF
About this Database
[hide all layers]
Protection
Government protected areas
Leuser Ecosystem
Wildlife Ranges
Sumatran rhinoceros
1980s 2007
Sumatran orangutan
1990s 2011
Sumatran elephant
1985 2007
Sumatran tiger
1996 2010
Natural Forest Cover
Forest cover change
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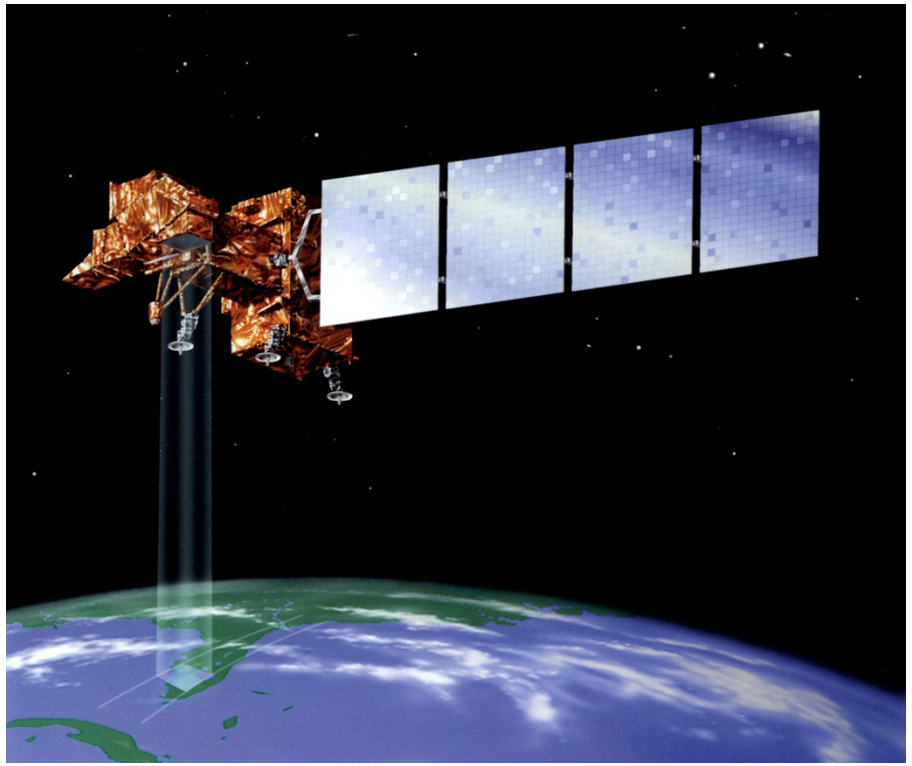
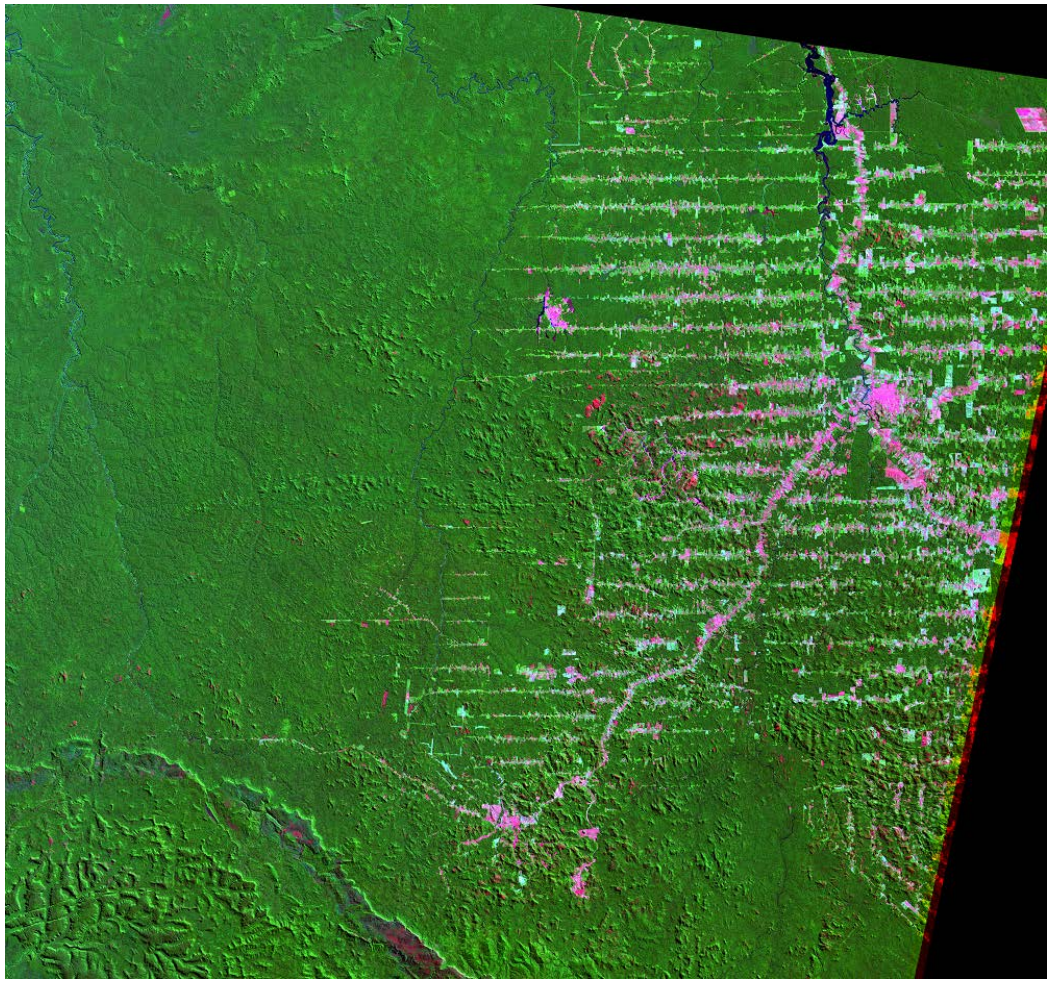
1985 1990 2000 2007 2009
Forest cover
1985 1990 2000 2007 2009
Eco-Floristic Diversity
Natural forest in eco-floristic sectors
1985 2009
Extinction risk of eco-floristic sectors
Natural Carbon Stores
Carbon stock estimates 2009
Simple Detailed
LAYER
INFO
Map
Satellite
Makmur
Lhokseumawe
Aceh
Binjai
Medan
Bingai
Kutalimbaru
Tebing Tinggi
Gunung Meriah
Simeulu Barat
Salang
Pulau
Teupah Selatan
Toba
Google
50 km
20 mi
Map data ©2012 Google, MapIT, Tele Atlas - Terms of Use

Remote Sensing



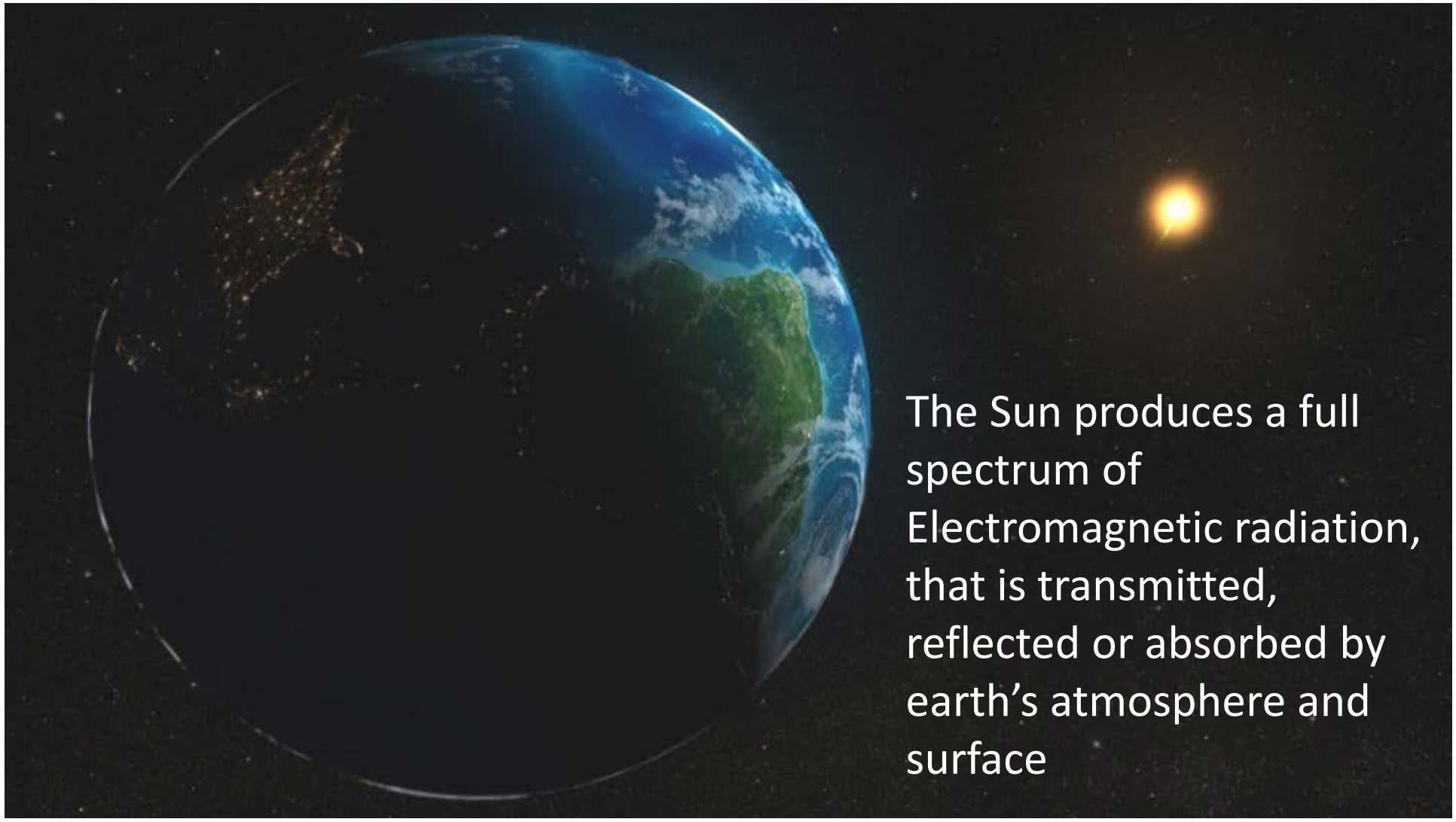
Landsat.gsfc.nasa.gov



USGS.gov

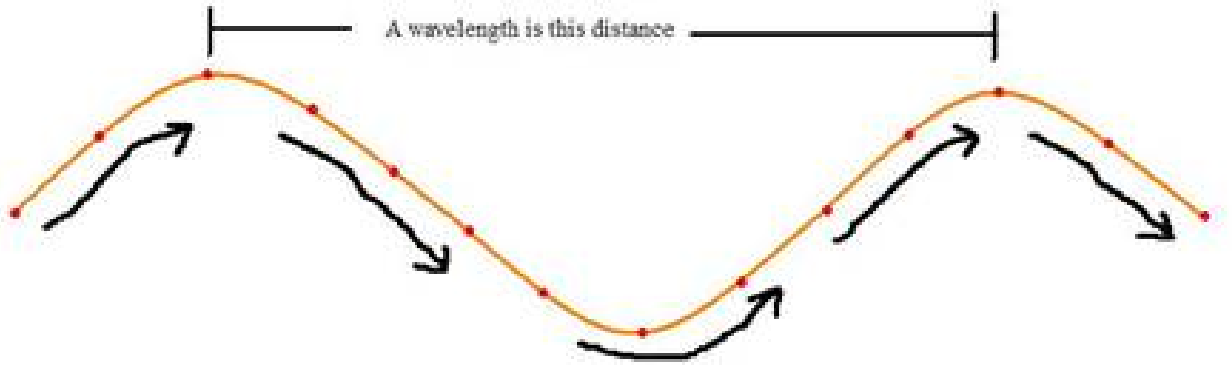
What is remote sensing?

Remote Sensing is the practice of deriving information about the earth's land and water surfaces through the analysis of reflected or emitted electromagnetic radiation from the Earth's surface.


The Sun produces a full spectrum of Electromagnetic radiation, that is transmitted, reflected or absorbed by earth’s atmosphere and surface

Electromagnetic radiation

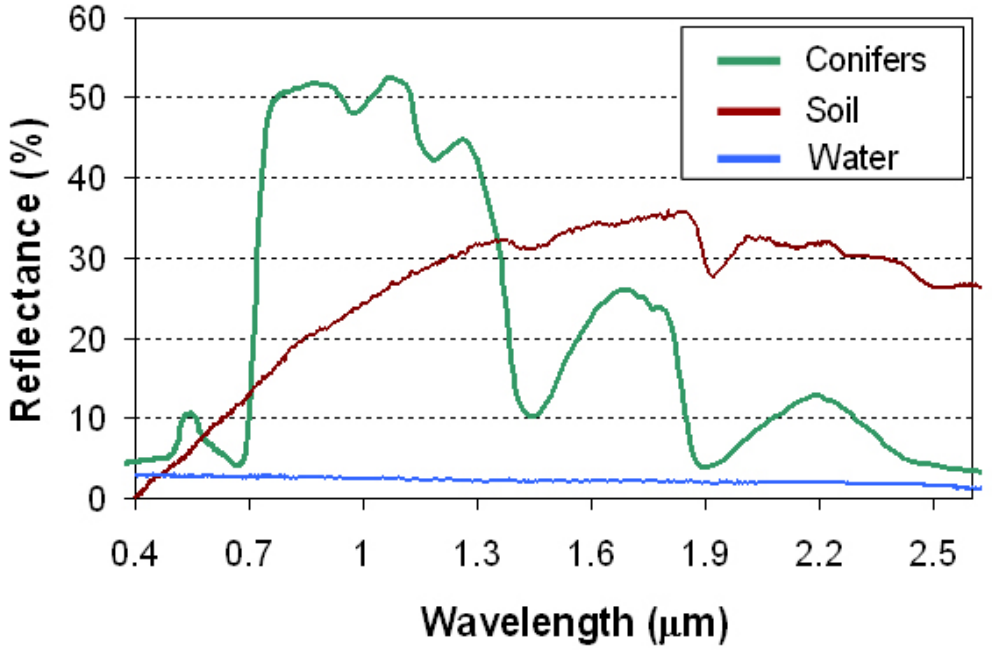
Electromagnetic radiation is the flow of photons (also called light quanta) through space. Measured in watts per steradian per square meter $W \cdot sr^{-1} \cdot m^{-2}$



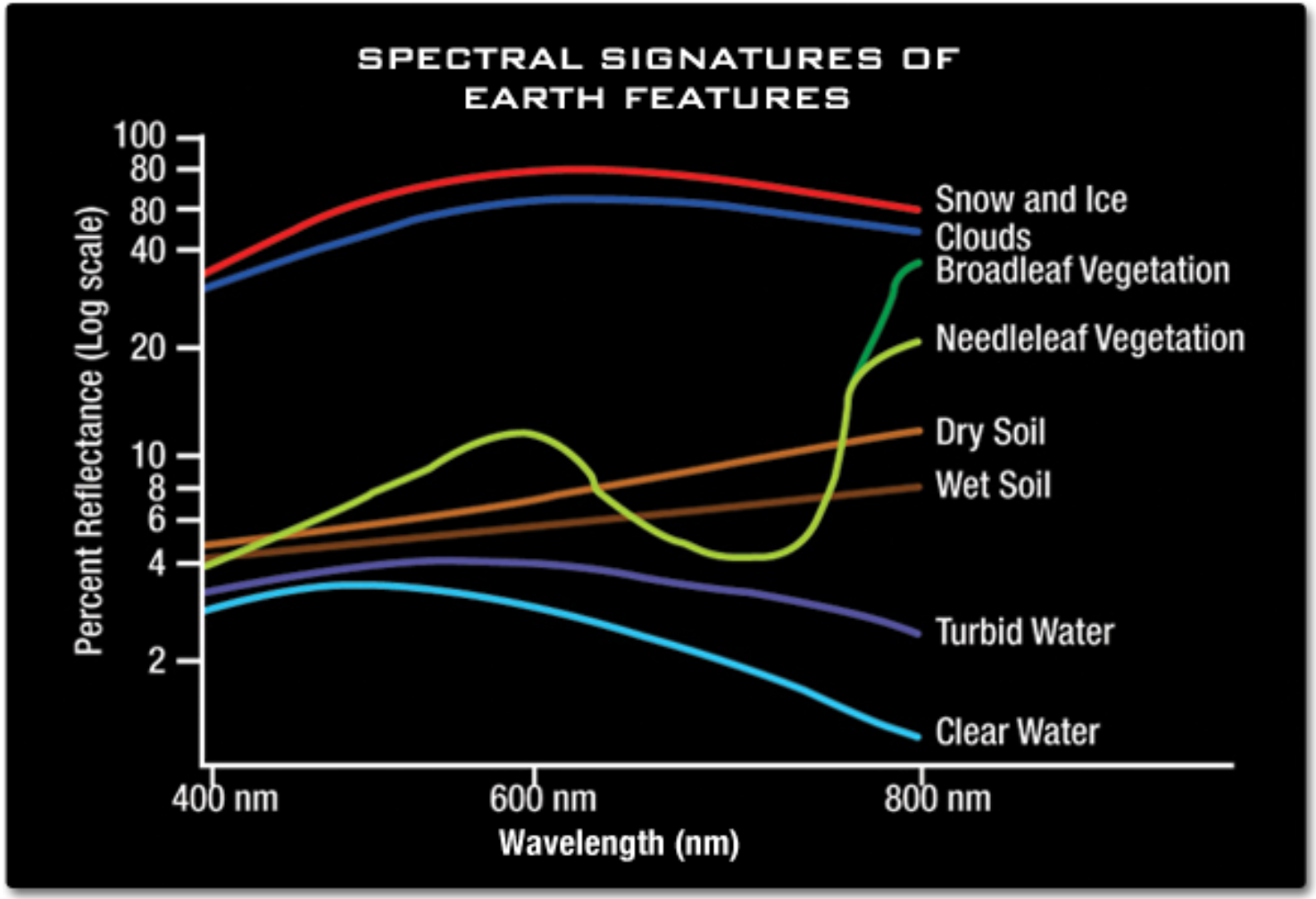
The red dots resemble photons, which travel in waves following the arrows. Photons provide the energy needed for life.

Spectral Differentiation

Refers to the observed spectral differences in the energy reflected or emitted from features of interest. Spectral differences allow us to detect features based on their spectral response.



Spectral Differentiation



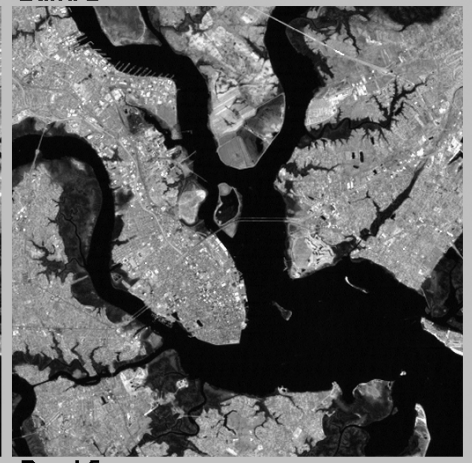
NASA operates thirty (30) optical and radar sensors that are orbiting the earth and collecting hourly, daily, weekly and bi-weekly spectral information for the entire earth’s surface.

Band 1

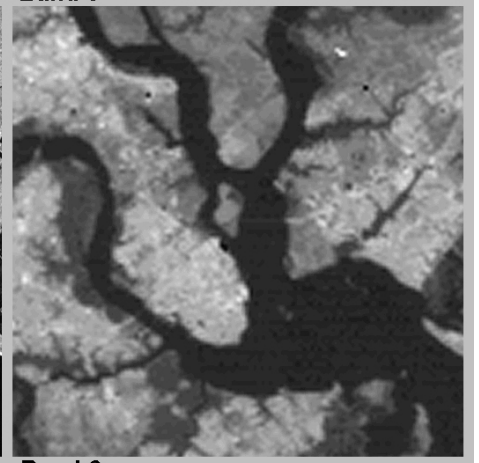
Band 2

Band 3

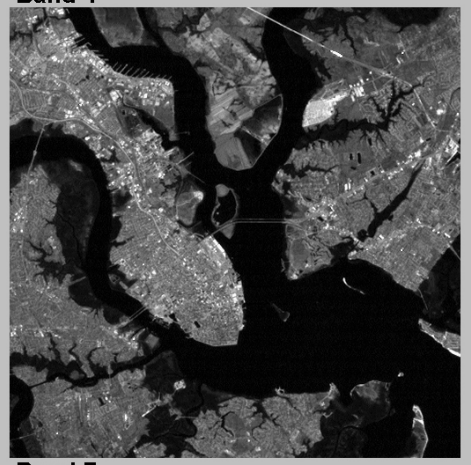
Band 4



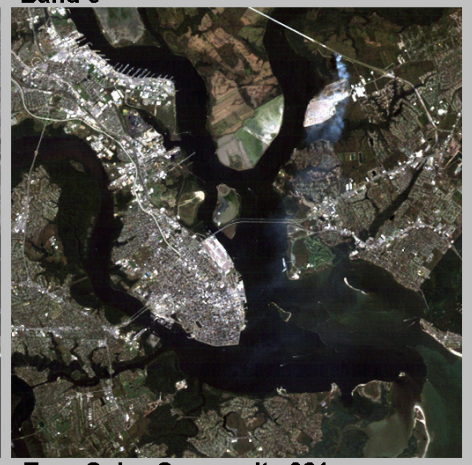
Band 5



Band 6



Band 7

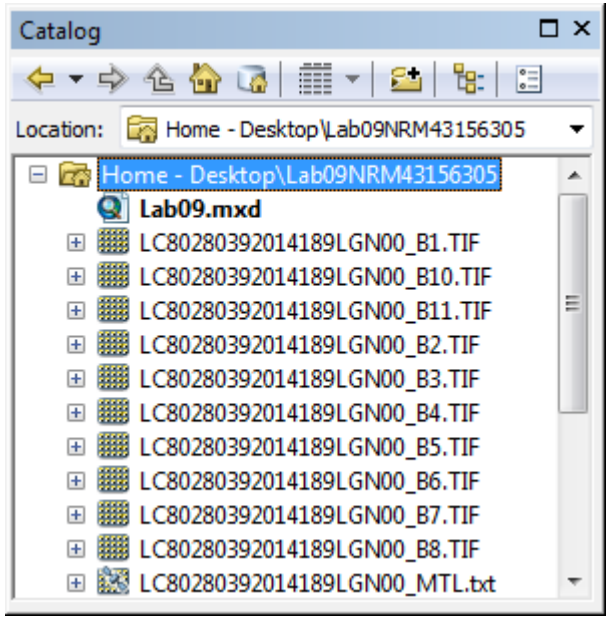


True Color Composite 321

False Color Composite 432

Band	Wavelength (micrometers)	Resolution (meters)
Band 1 – Coastal Aerosol	0.43 – 0.45	30
Band 2 – Blue	0.45 – 0.51	30
Band 3 – Green	0.53 – 0.59	30
Band 4 – Red	0.64 – 0.67	30
Band 5 – Near Infrared (NIR)	0.85 – 0.88	30
Band 6 – SWIR 1	1.57 – 1.65	30
Band 7 – SWIR 2	2.11 – 2.29	30
Band 8 – Panchromatic	0.50 – 0.68	15
Band 9 – Cirrus	1.36 – 1.38	30
Band 10 – Thermal Infrared (TIRS) 1	10.60 – 11.19	100
Band 11 – Thermal Infrared (TIRS) 2	11.50 – 12.51	100

A satellite image from Landsat OLI sensor



Spatial Resolution

Data sources:

NASA/USGS LPDAAC - https://lpdaac.usgs.gov/

NASA/USGS Earth Explorer - http://earthexplorer.usgs.gov/

Agencia Espacial de Brasil - http://www.aeb.gov.br/

Agencia Espacial Argentina - http://www.conae.gov.ar/

ABAE (Venezuela) – http://www.abae.gob.ve

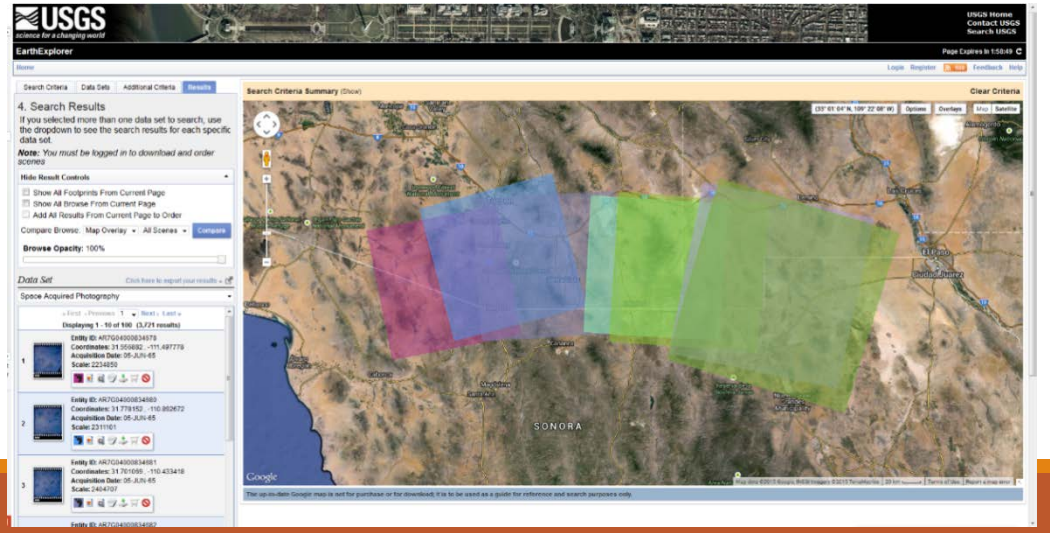
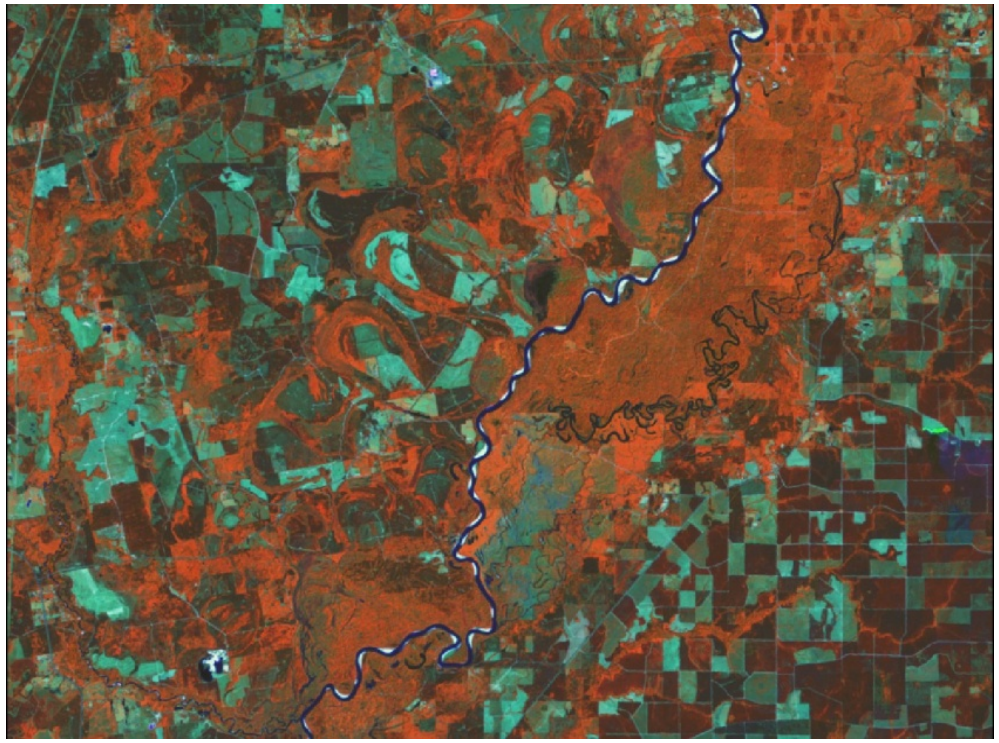


Image Processing techniques

TRUE COLOR COMPOSITE (RGB 321)

Imágenes de falso color

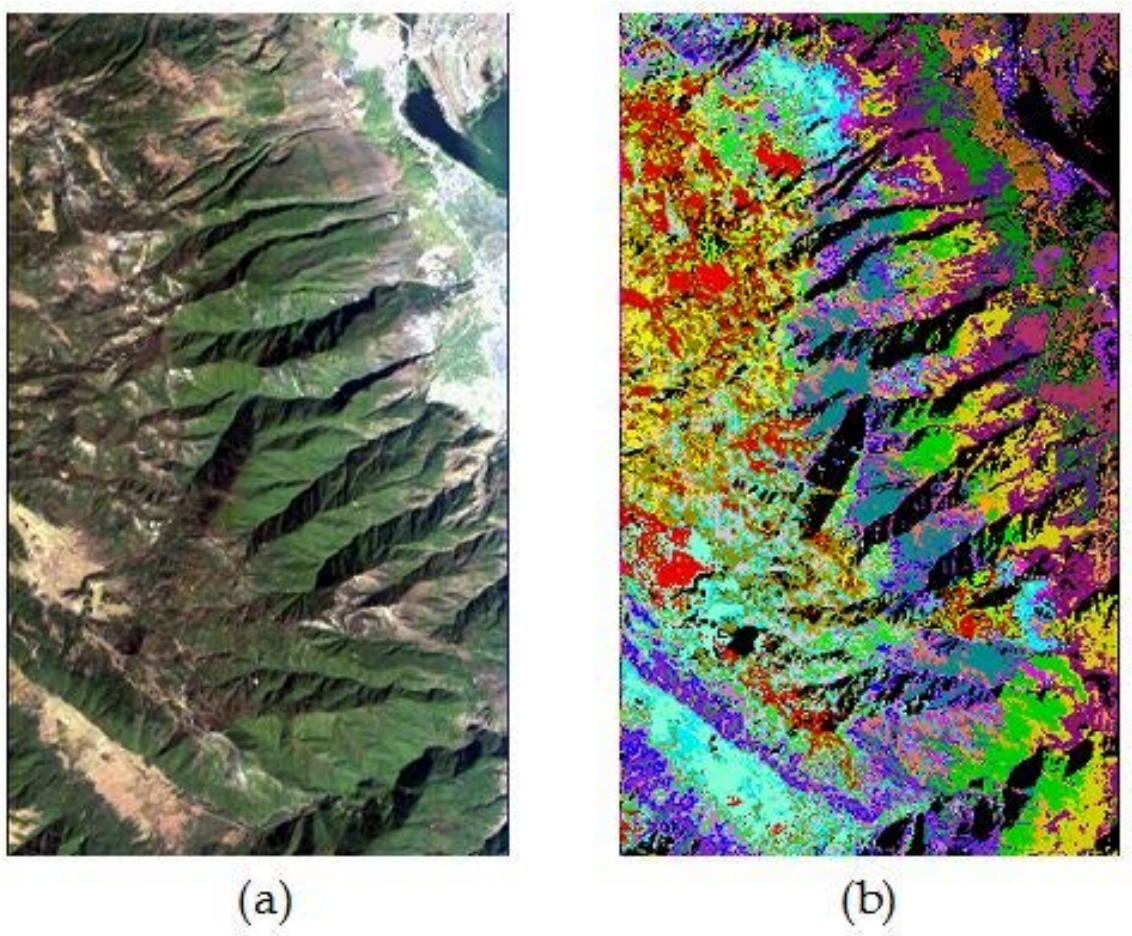


Land cover mapping using satellite images

Land cover mapping through satellite image analysis is a process that takes advantage of the spectral differentiation of land covers and assigns a land cover class to each pixel based on its spectral values.

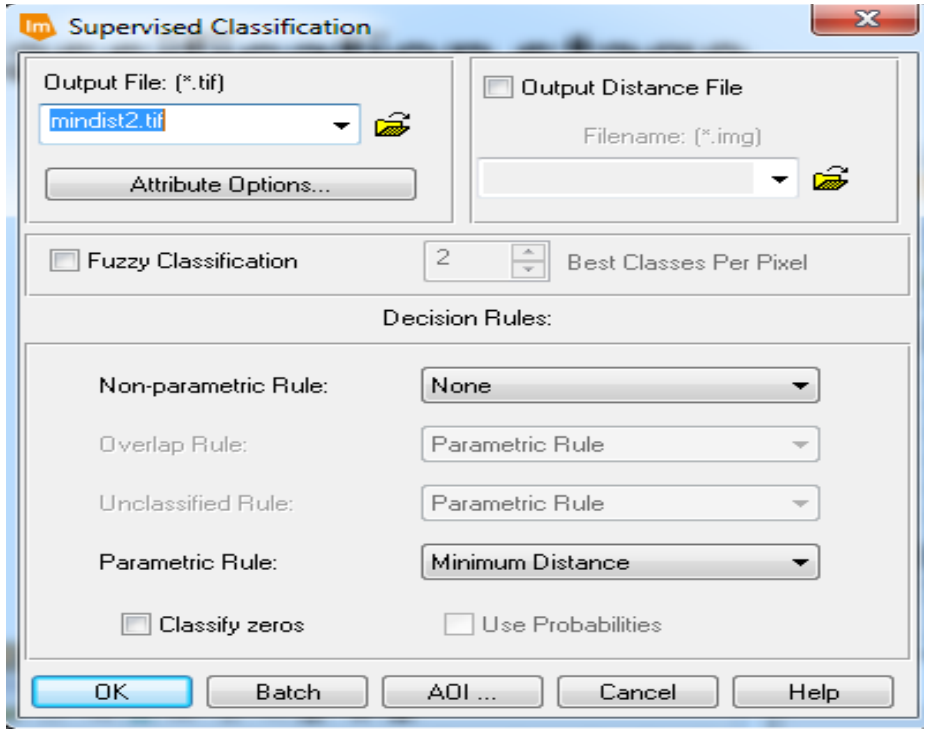
This process is called "**Image Classification**"

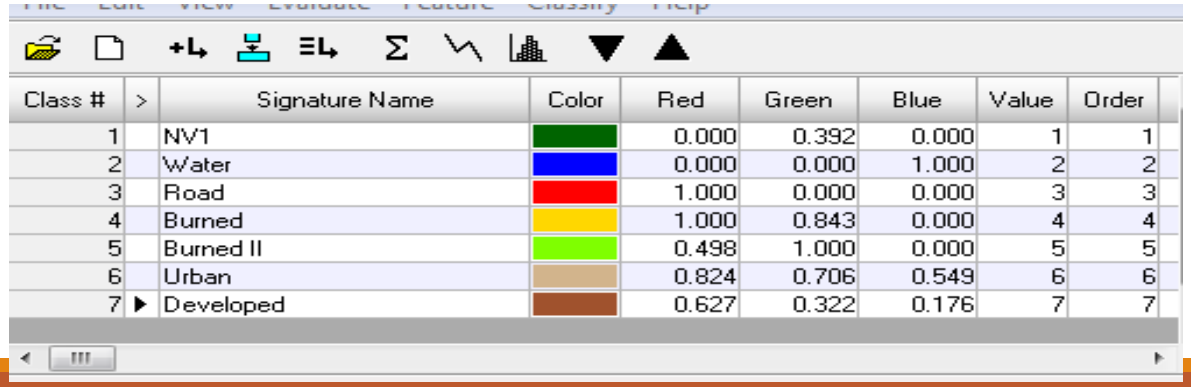
The result is a thematic map (a map divided by classes).



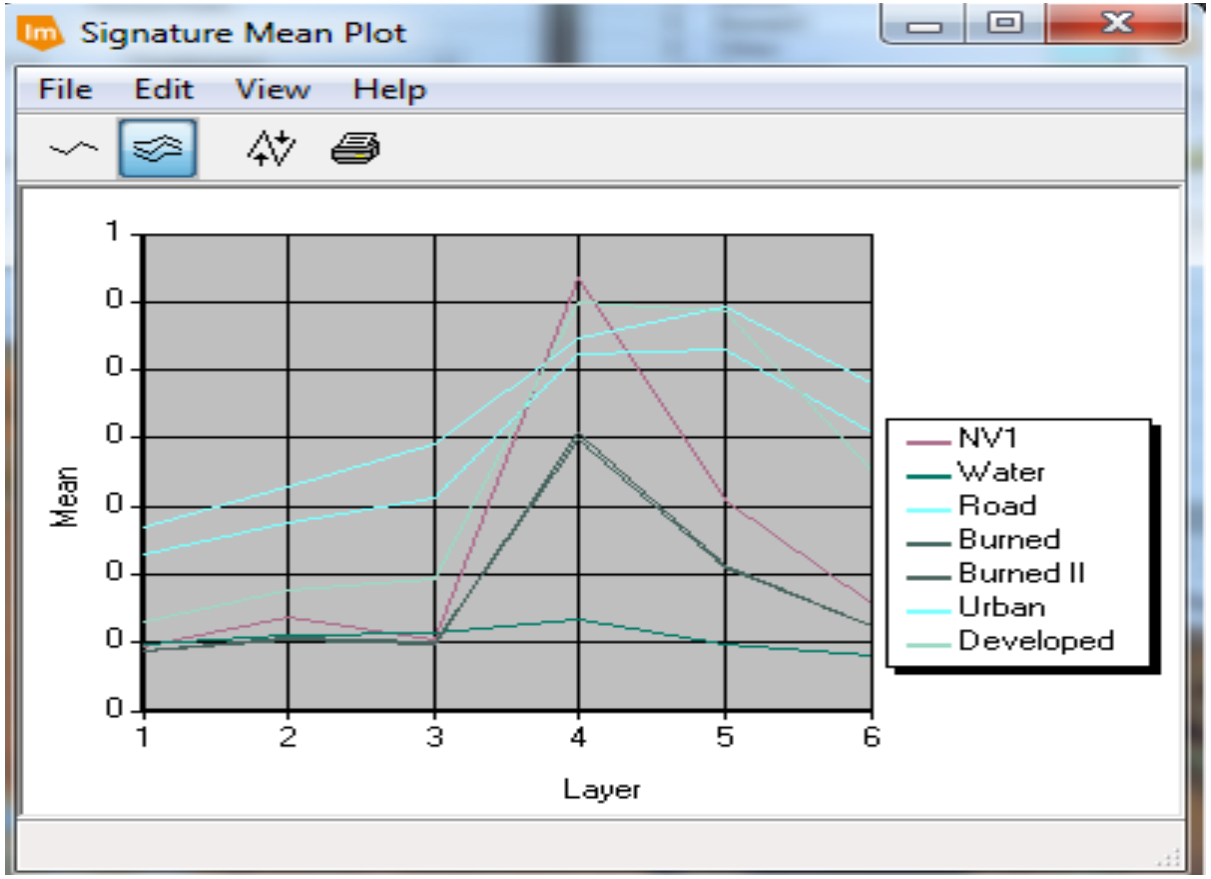
(a) (b)

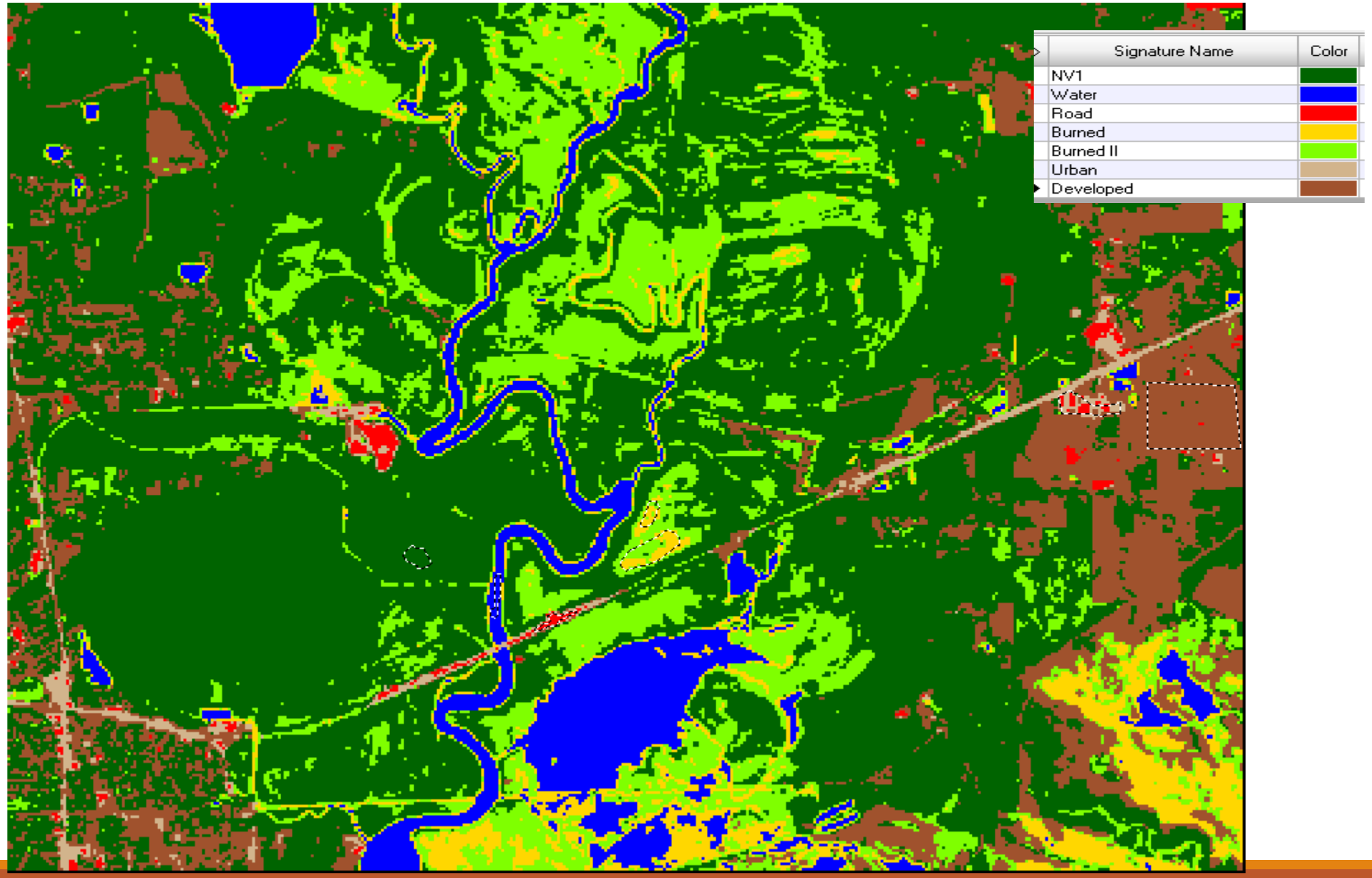
Image Classification





Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order
1		NV1		0.000	0.392	0.000	1	1
2		Water		0.000	0.000	1.000	2	2
3		Road		1.000	0.000	0.000	3	3
4		Burned		1.000	0.843	0.000	4	4
5		Burned II		0.498	1.000	0.000	5	5
6		Urban		0.824	0.706	0.549	6	6
7	▶	Developed		0.627	0.322	0.176	7	7

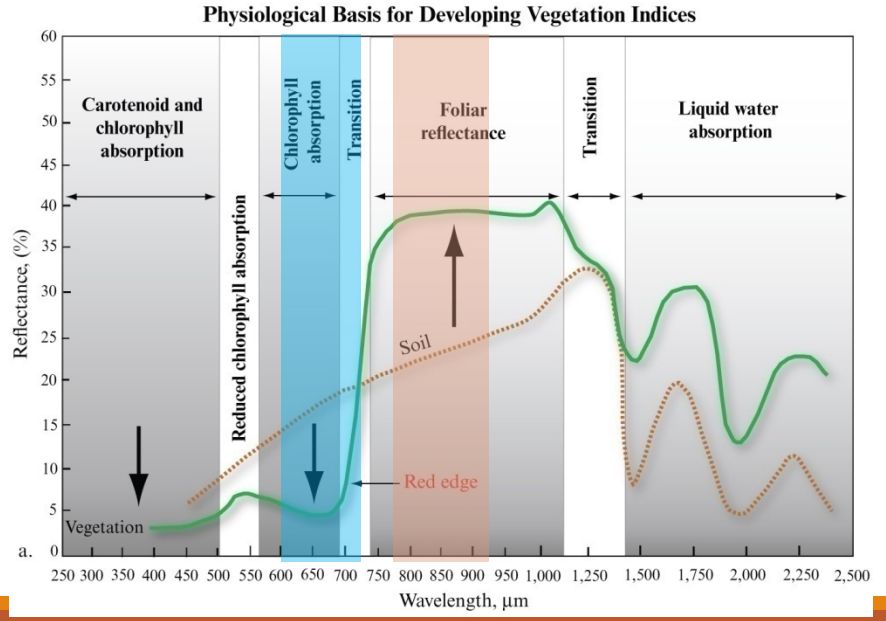



Signature Name
Color
NV1
Water
Road
Burned
Burned II
Urban
Developed

Normalized Difference Vegetation Index- NDVI

•Uses the inverse relationship between red and near-infrared reflectance associated with healthy vegetation. Normalizes index between -1 and +1 values. Healthy vegetation generally falls between values of 0.20 to 0.80

$$NDVI = \frac{NIR-Red}{NIR+Red}$$



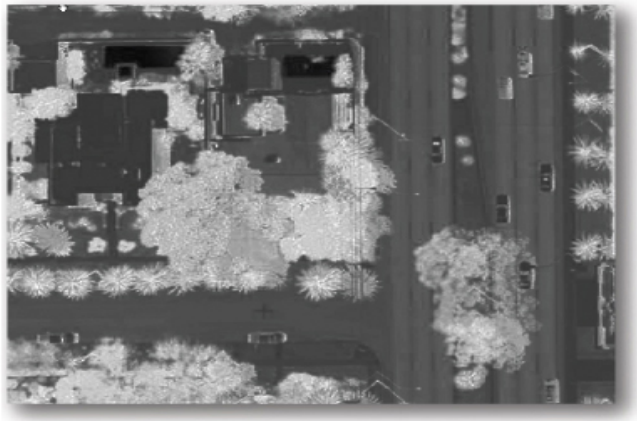
Normalized Difference Vegetation Index (NDVI) Image Extracted from UltraCam® Digital Frame Camera Imagery

a. Color composite (RGB = NIR, red, green).

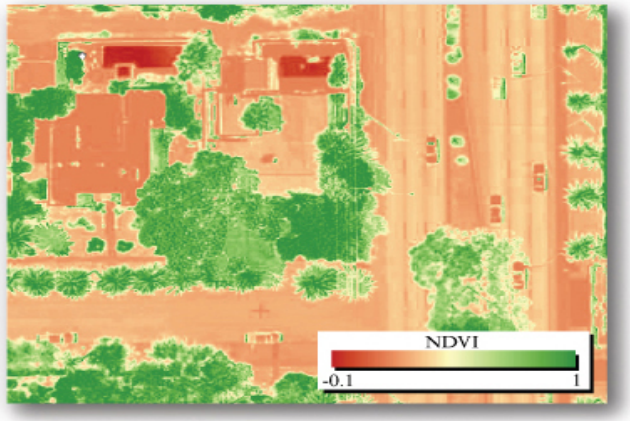
b. Green band.

c. Red band.

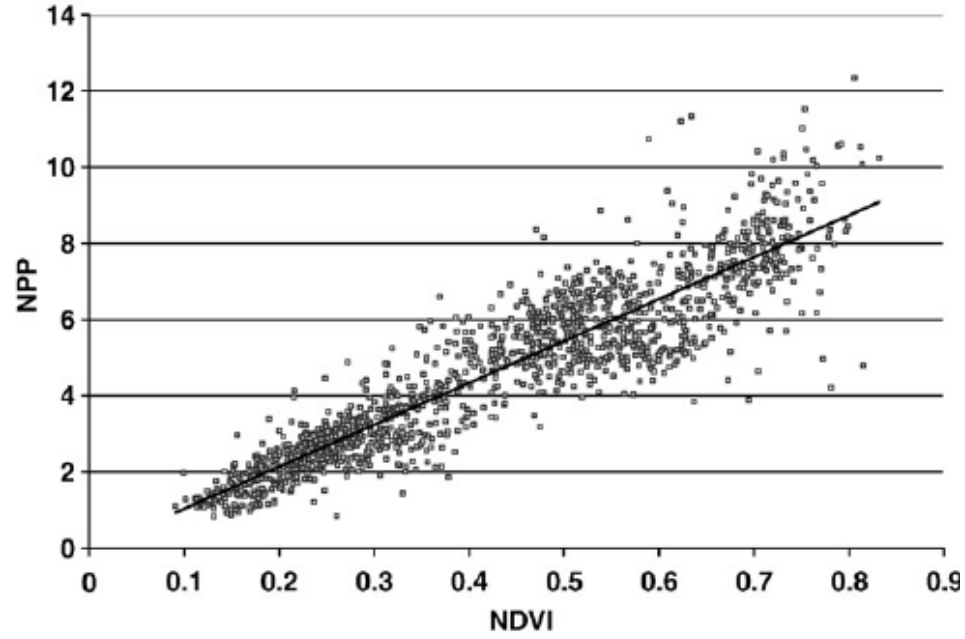
d. Near-infrared band.

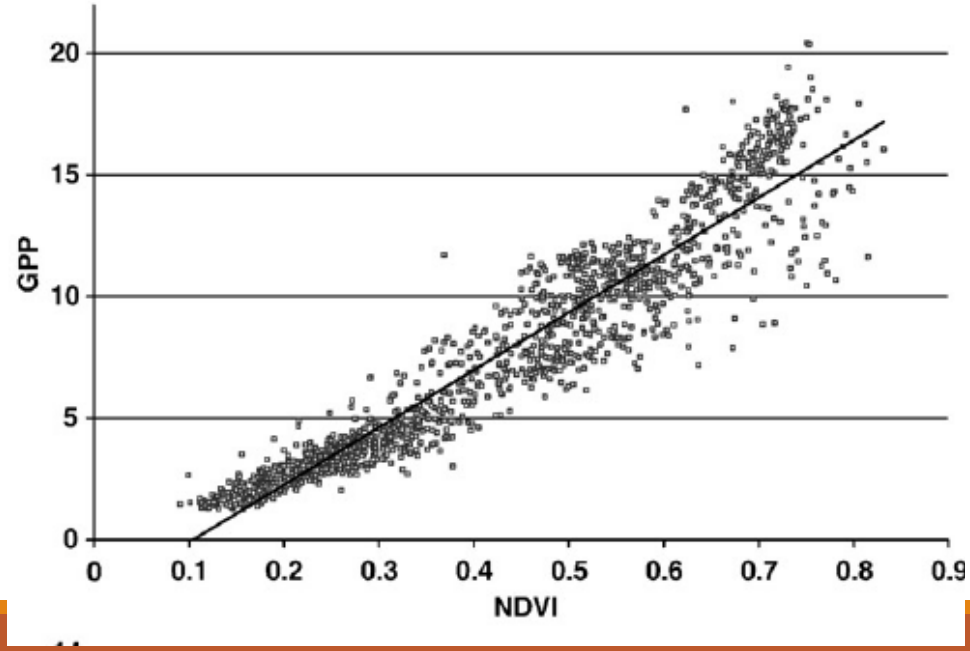


e. NDVI derived from red and near-infrared bands.



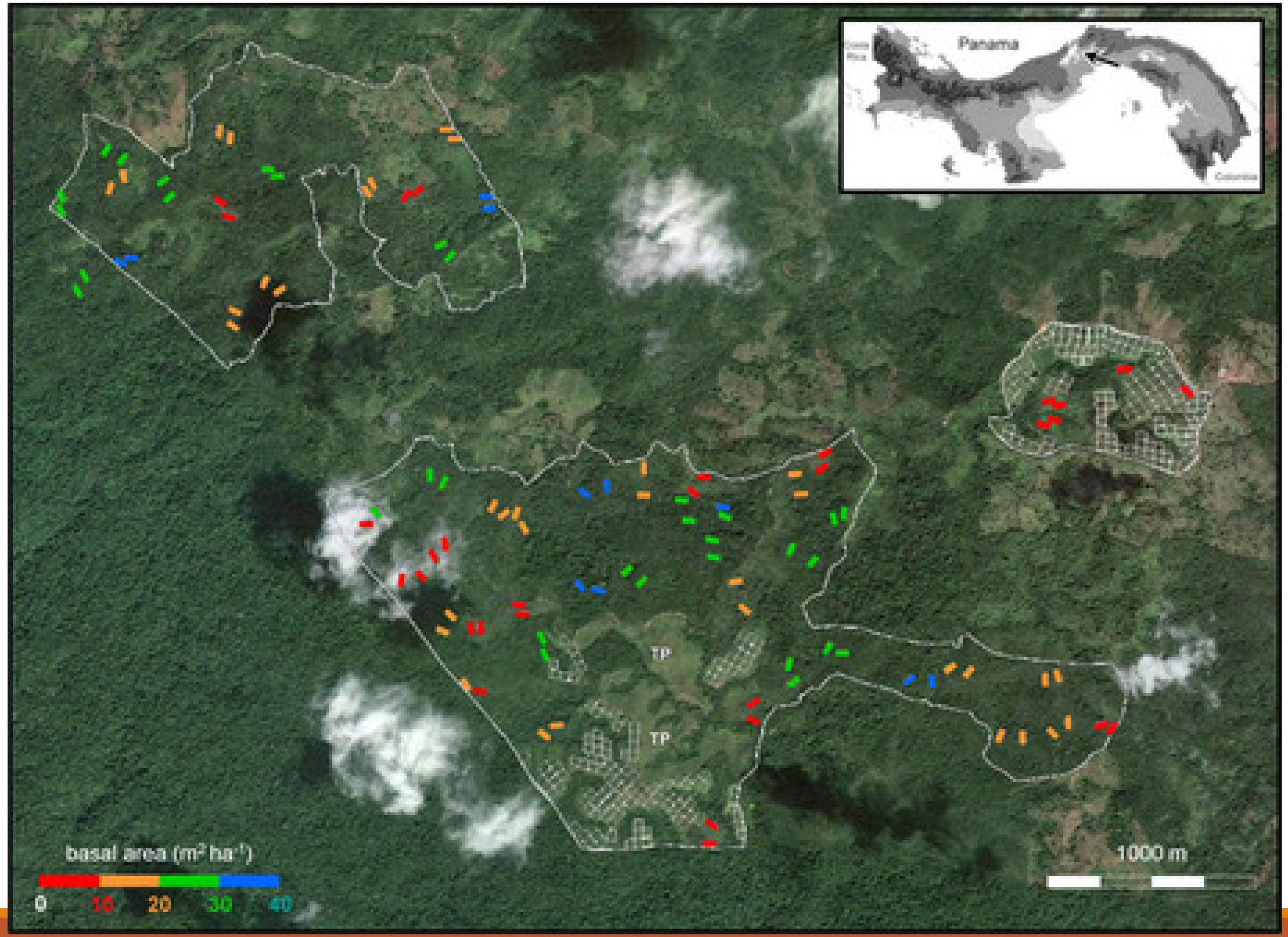
f. Color density-sliced NDVI.

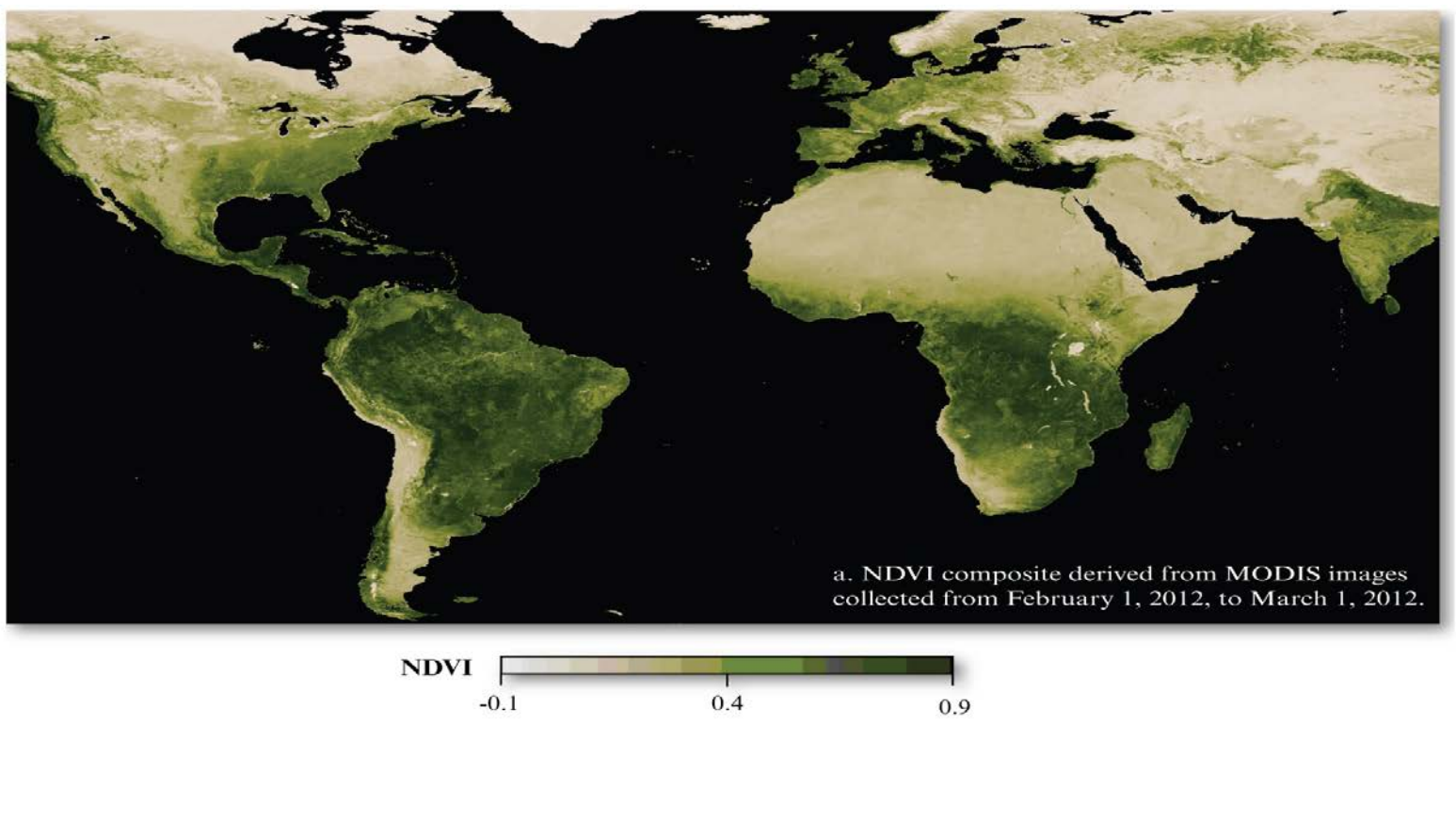

NPP
NDVI
0
2
4
6
8
10
12
14
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


GPP
NDVI
0
5
10
15
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


SH2: Shark River 2
Vegetation Plot
Hydrology Station
Fauna Traps
SETs
Vegetation Plot

Usgs.gov


Panama
TP
TP
basal area (m² ha⁻¹)
0
10
20
30
40
1000 m



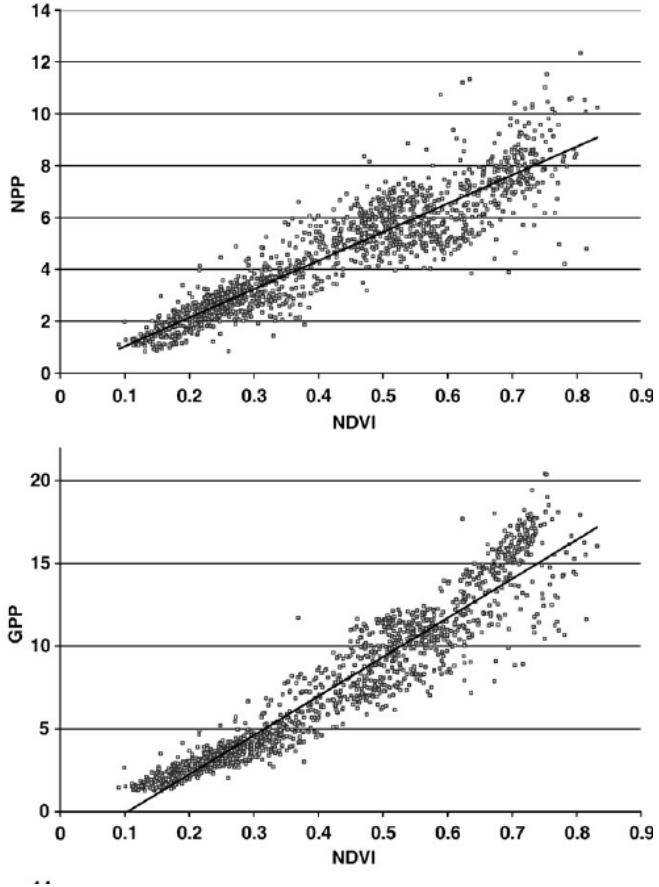


FIGURE 8–43a NDVI composite image derived from MODIS data acquired from February 1, 2012, to March 1, 2012. The darker the green, the higher the NDVI value and the greater the leaf-area-index (LAI) and biomass.

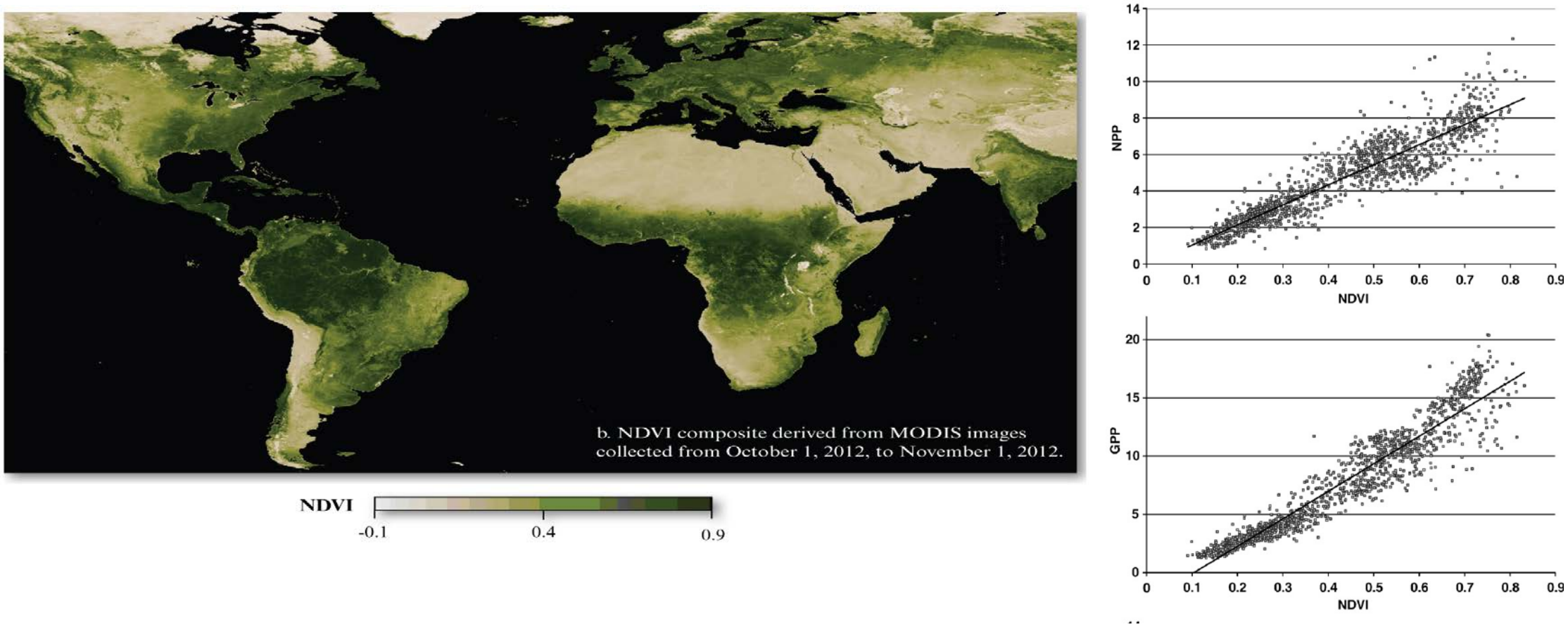
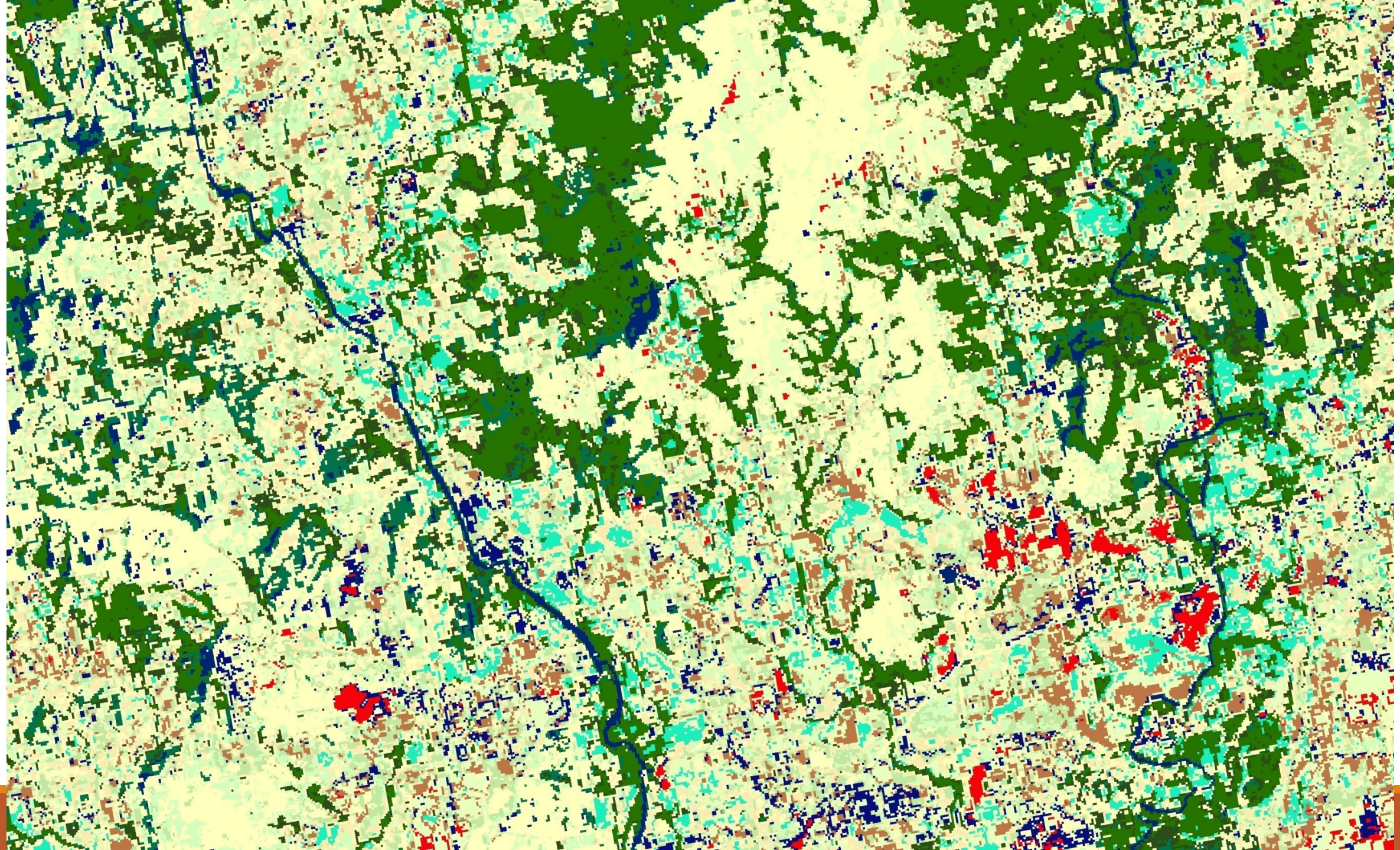
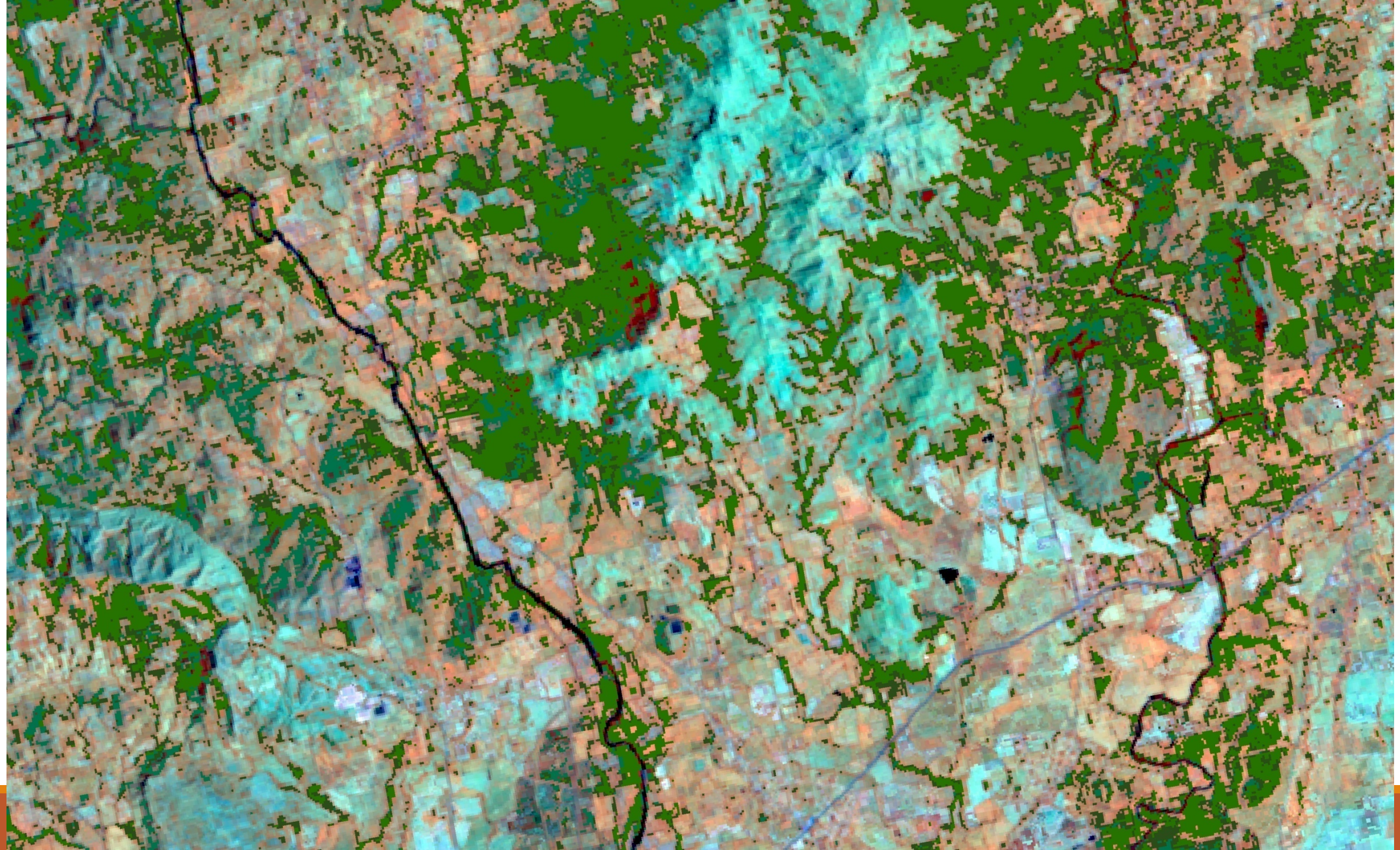
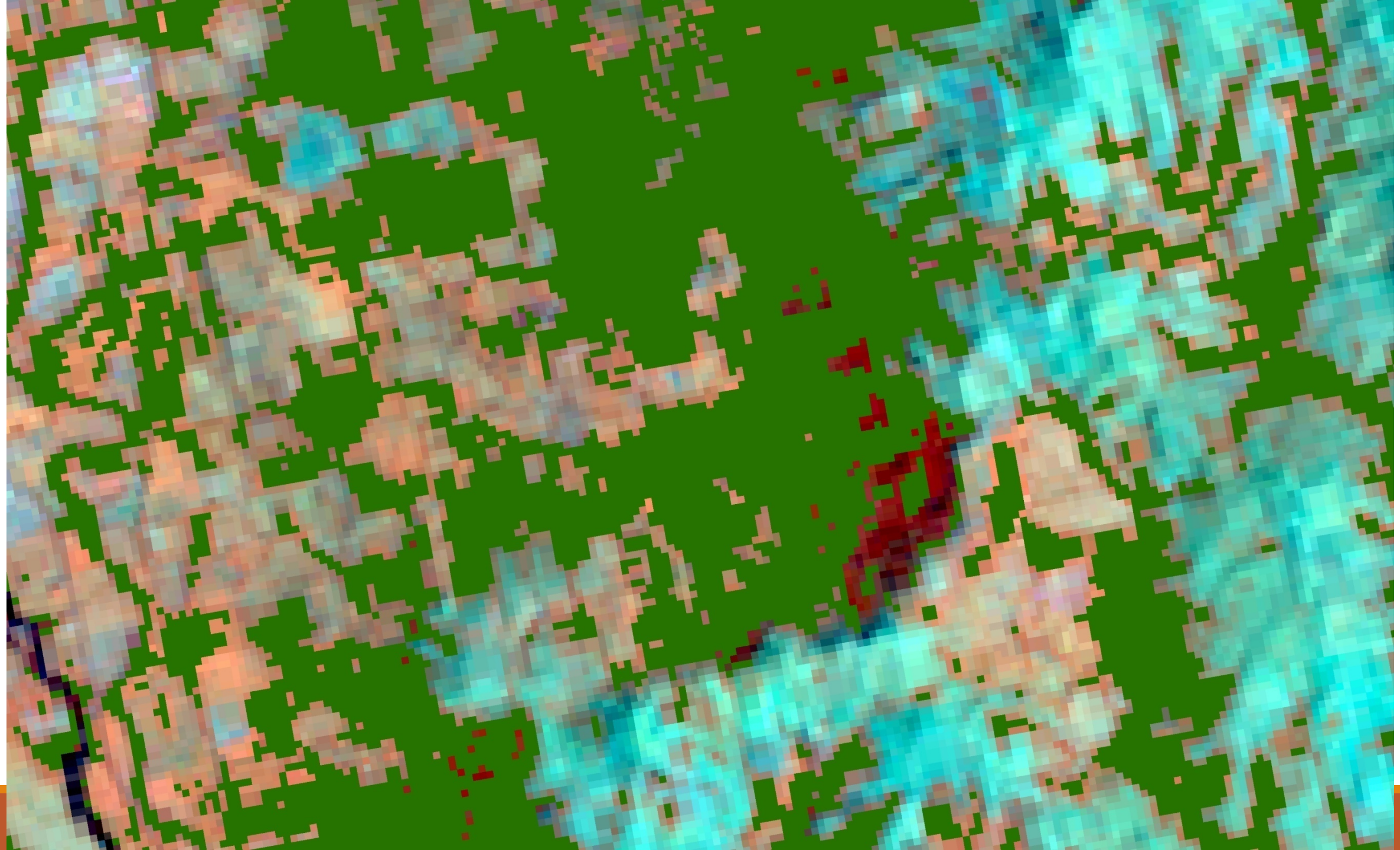


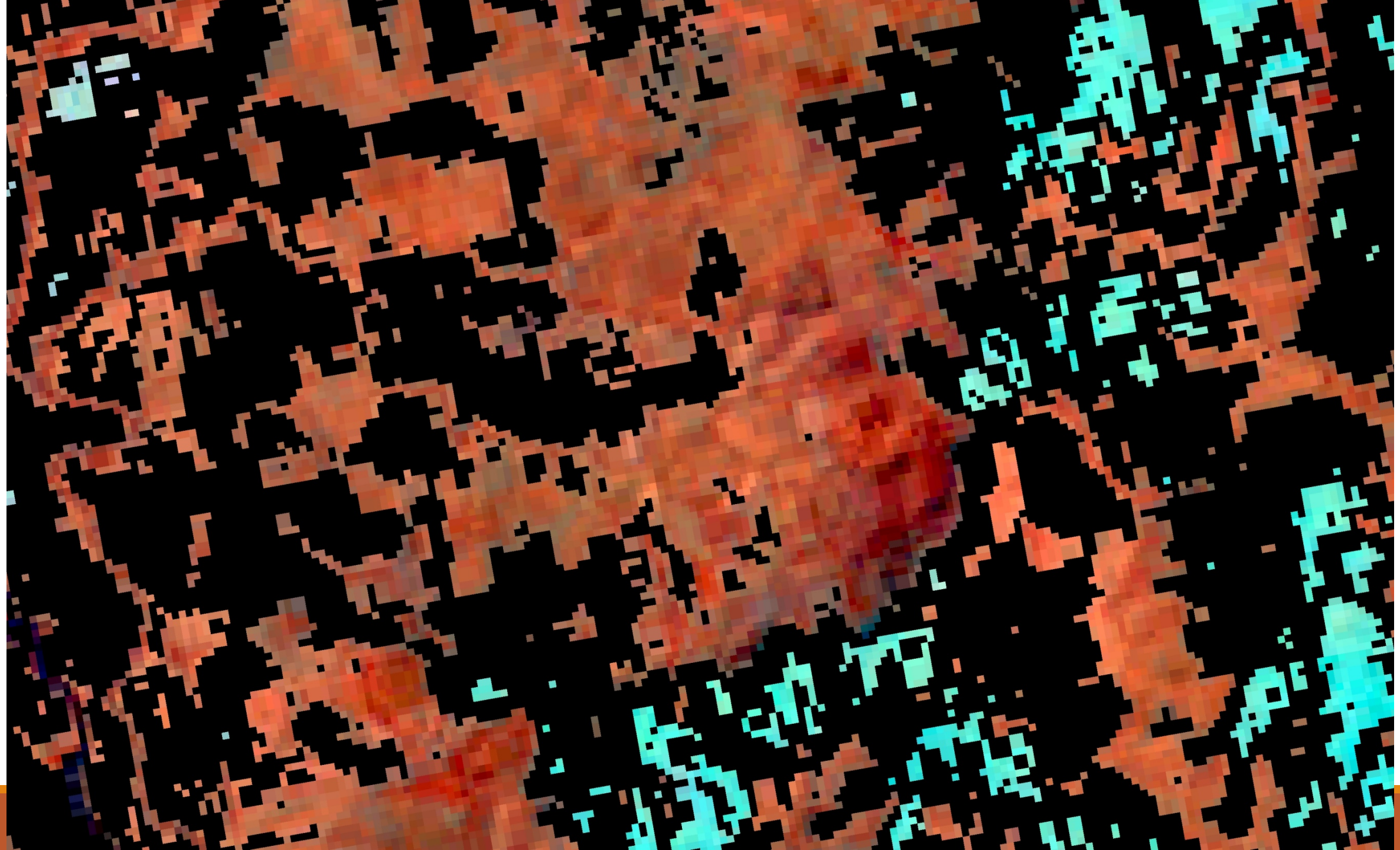
FIGURE 8–43a NDVI composite image derived from MODIS data acquired from February 1, 2012, to March 1, 2012. The darker the green, the higher the NDVI value and the greater the leaf-area-index (LAI) and biomass.

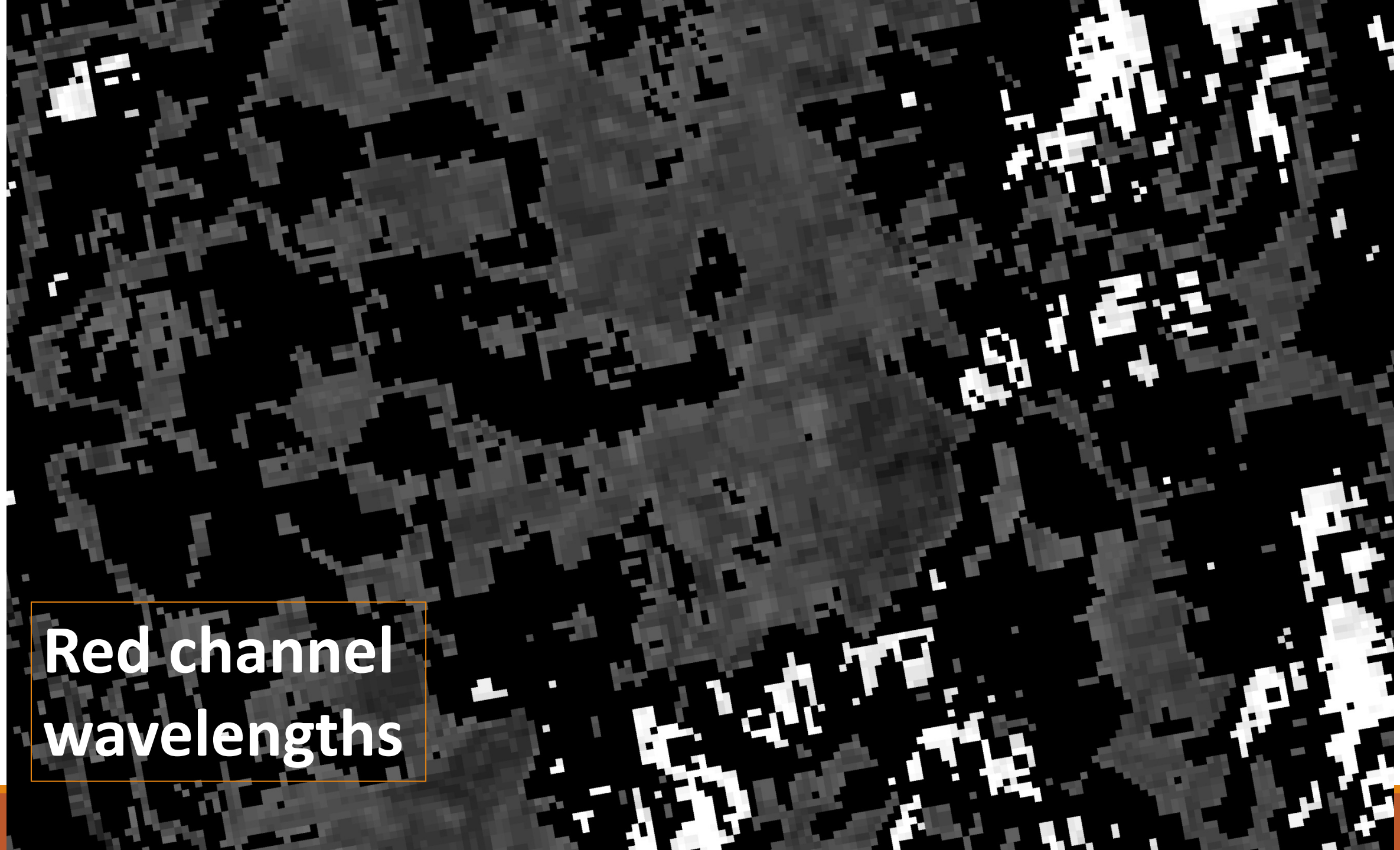
Monitoring Ecosystem health

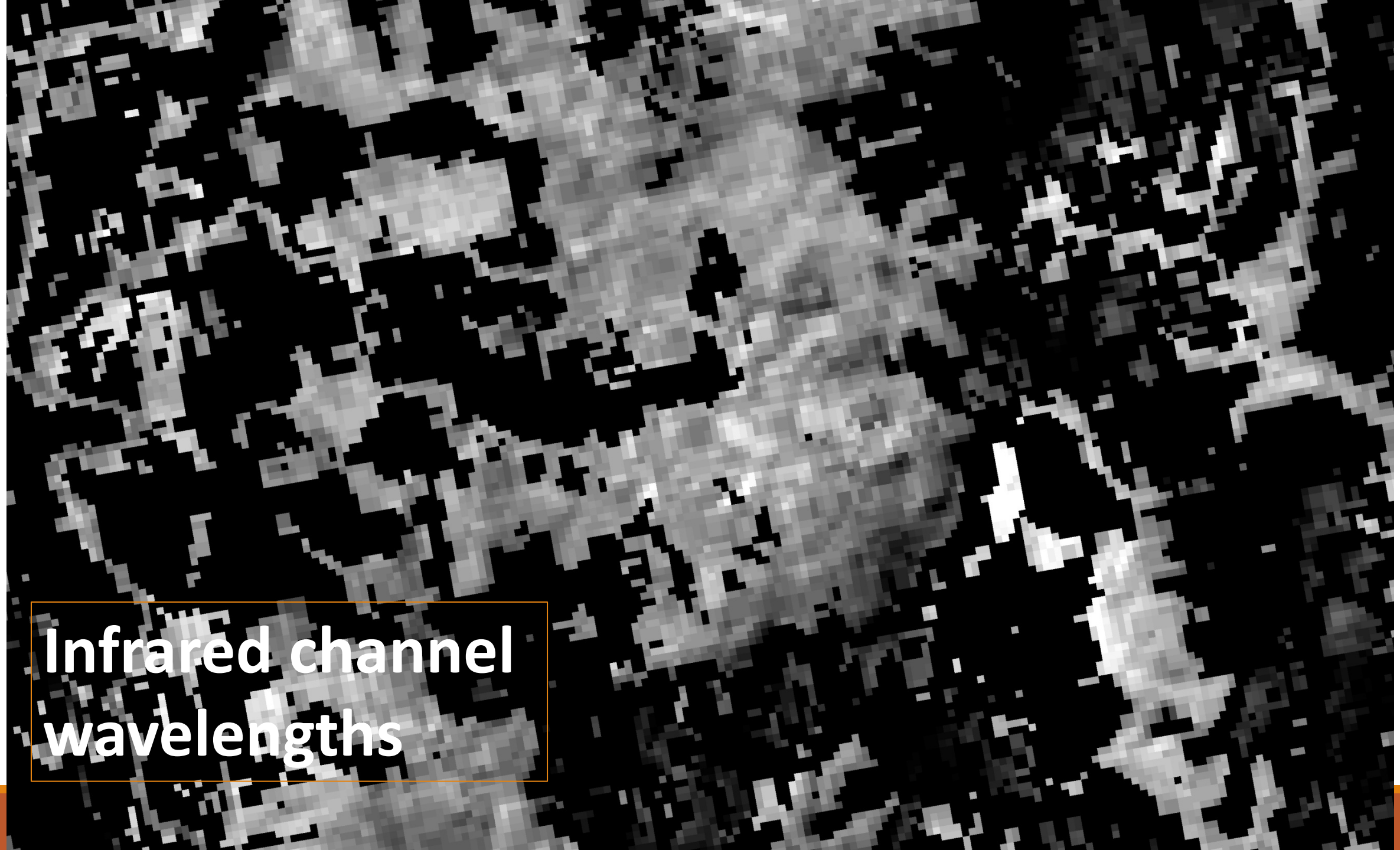




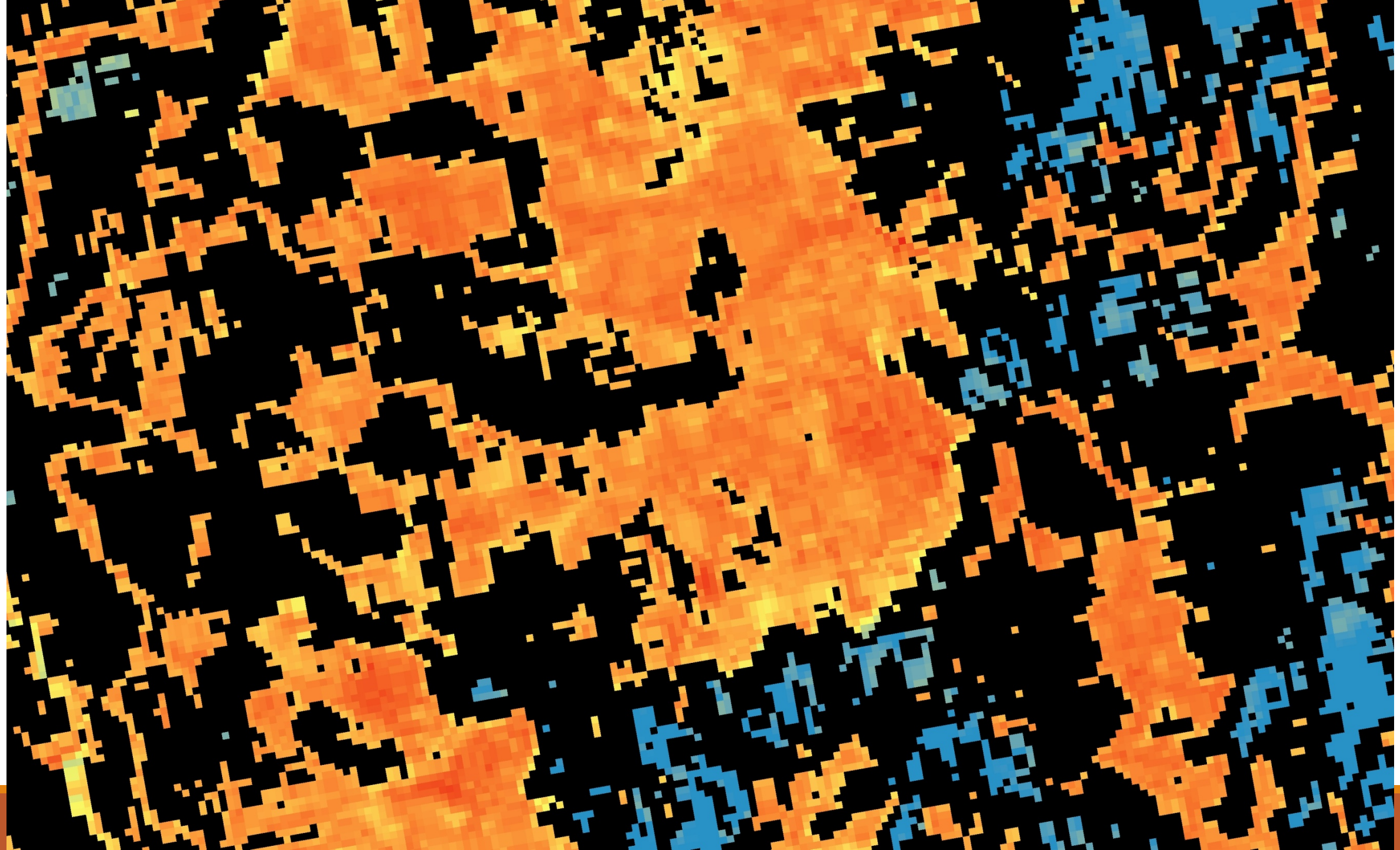




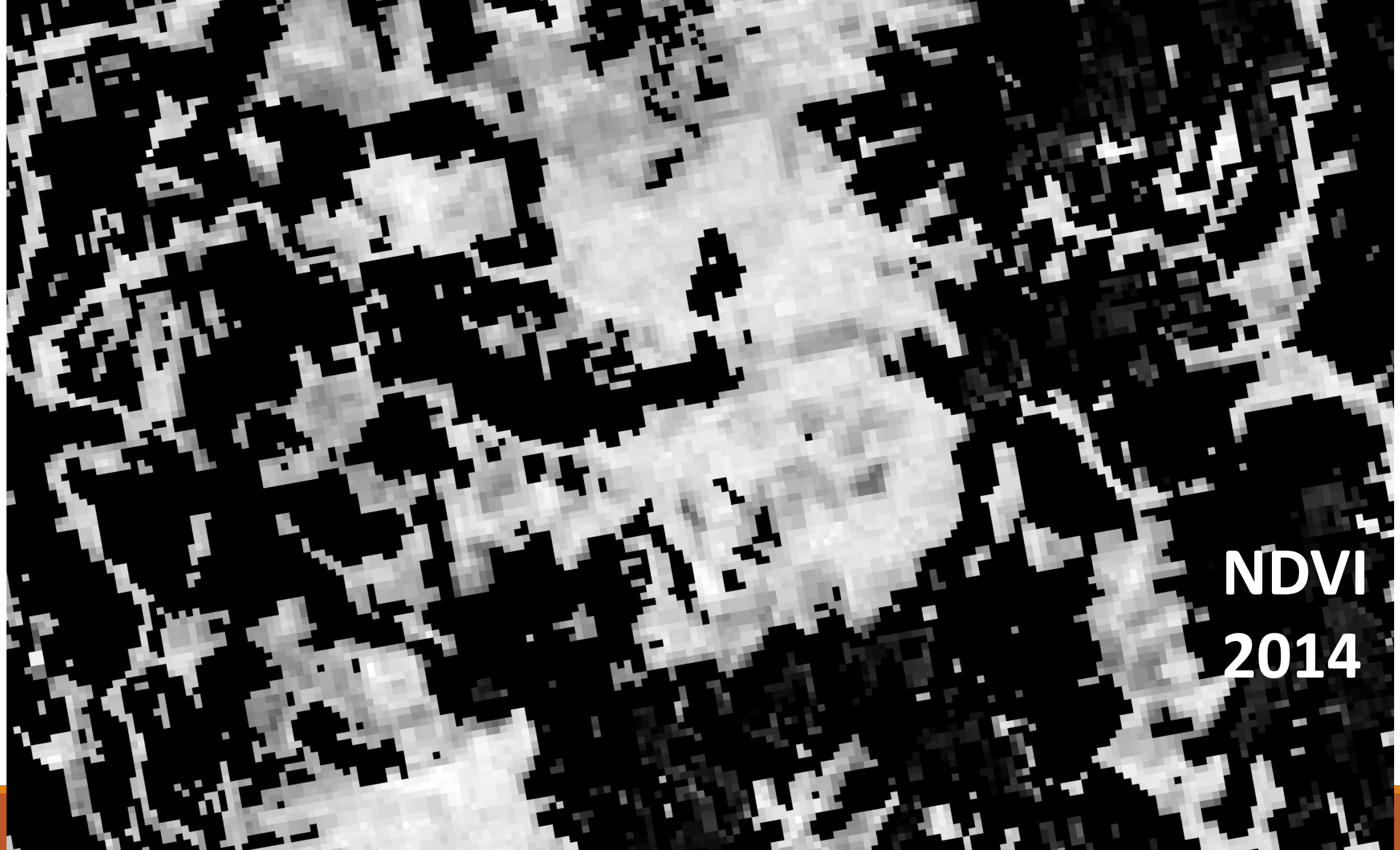

Red channel
wavelengths


Infrared channel
wavelengths


NDVI
2001

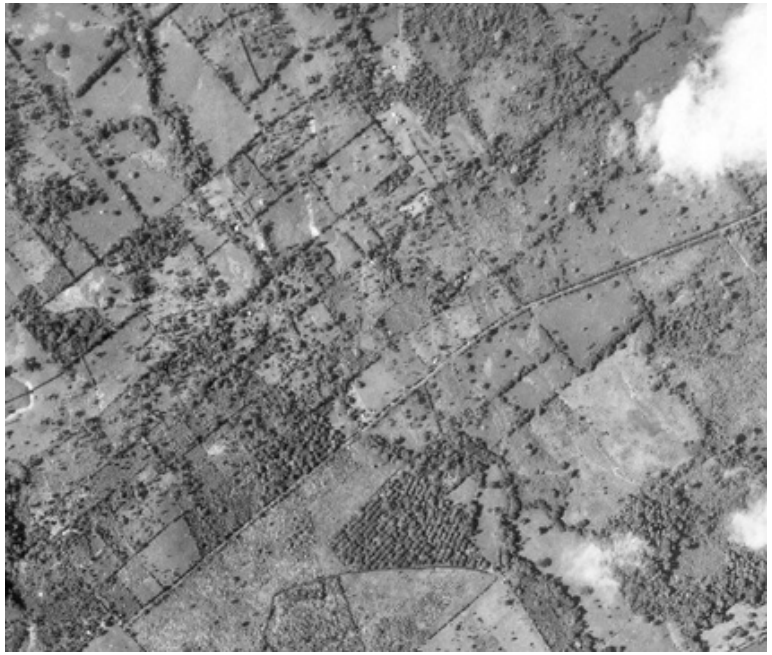



NDVI
2001

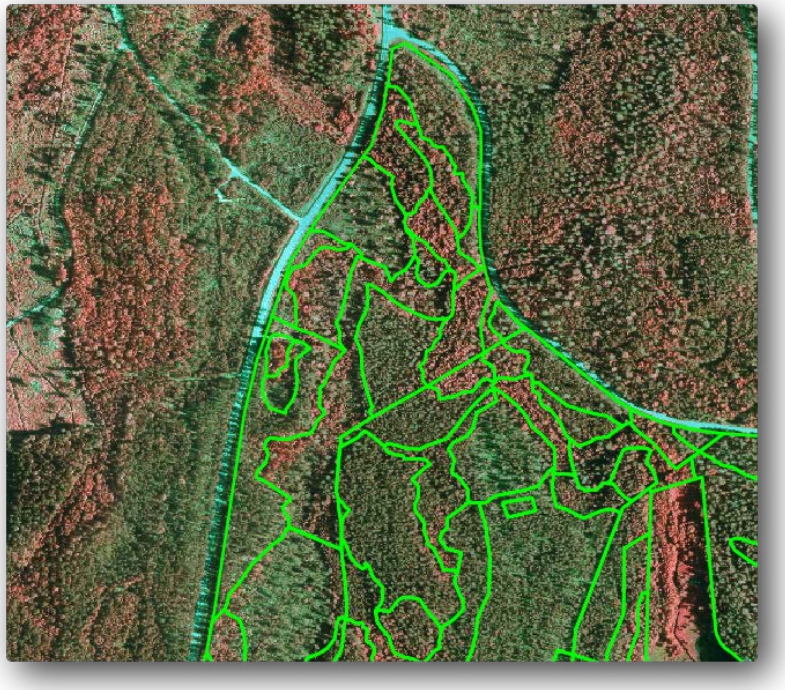

NDVI
2014

Traditional strategies for ecosystem monitoring

- Aerial photo or satellite image interpretation. Performed usually once every decade.



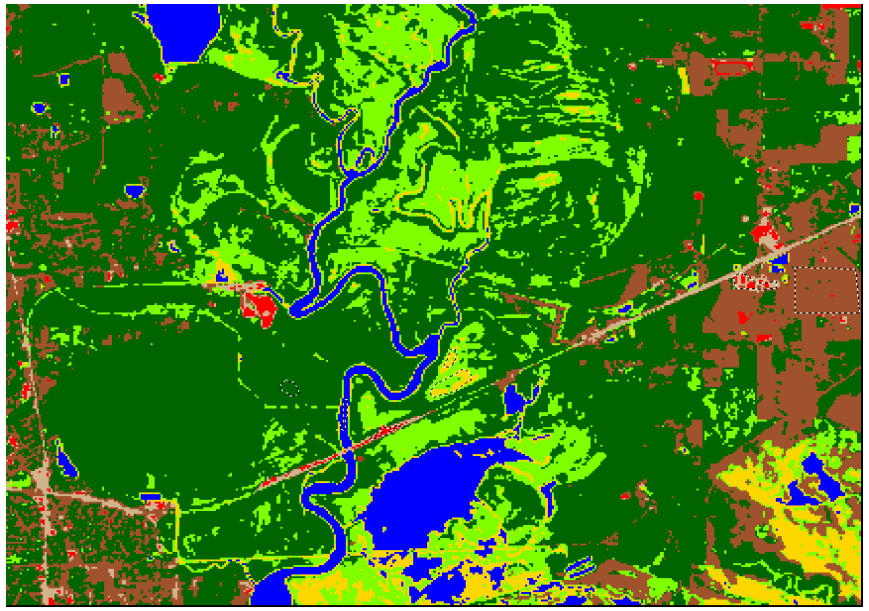
Fao.org



Docs.qgis.org

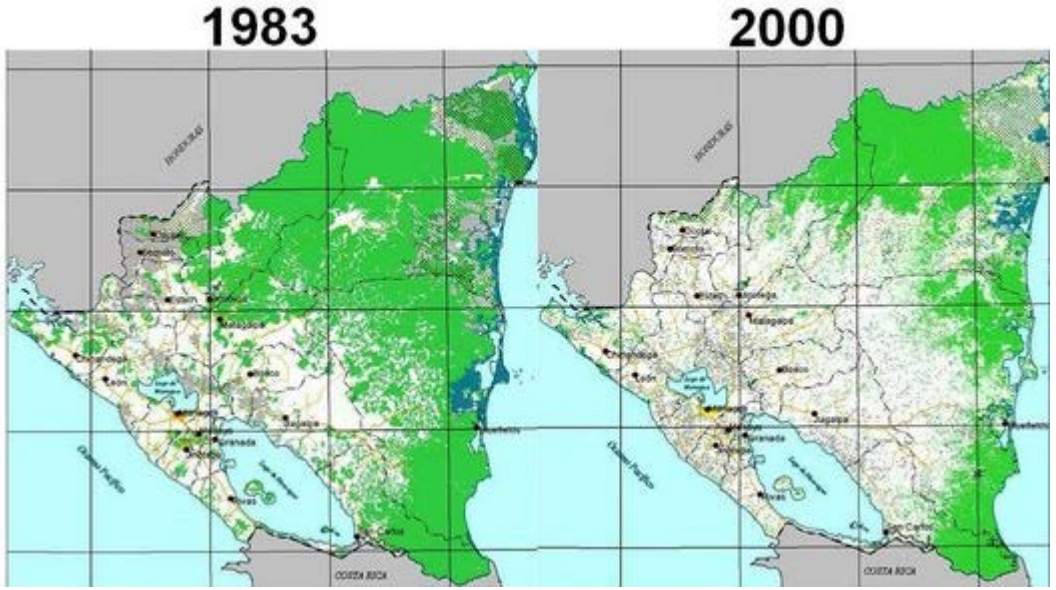
Traditional strategies for ecosystem monitoring

- Automated image classification. Annual, biannual or bidecadal assessments.



Traditional strategies for ecosystem monitoring

- Automated image classification. Annual, biannual or bidecadal assessments.



MARENA

Nicaragua

Landsat Program (NASA)

- Series of Earth Observation satellites with a spatial resolution of 30 m and temporal resolution of 16 days.
- Global data being collected since 1972. The Landsat program is still active.

Landsat:
Change Detection

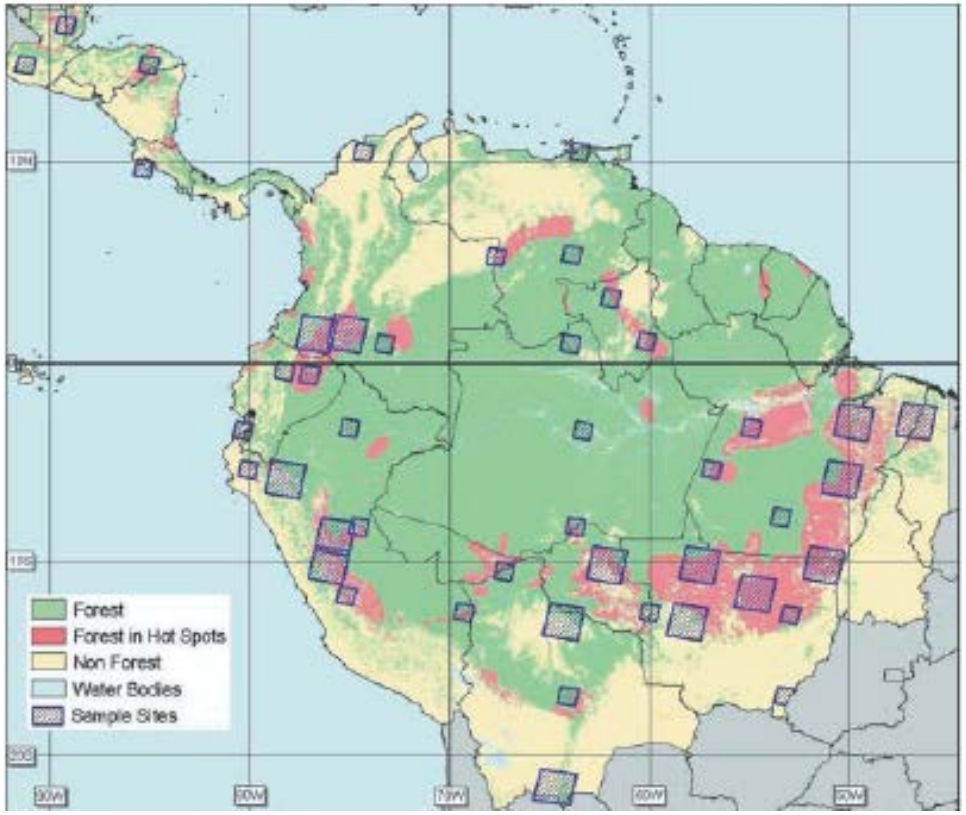
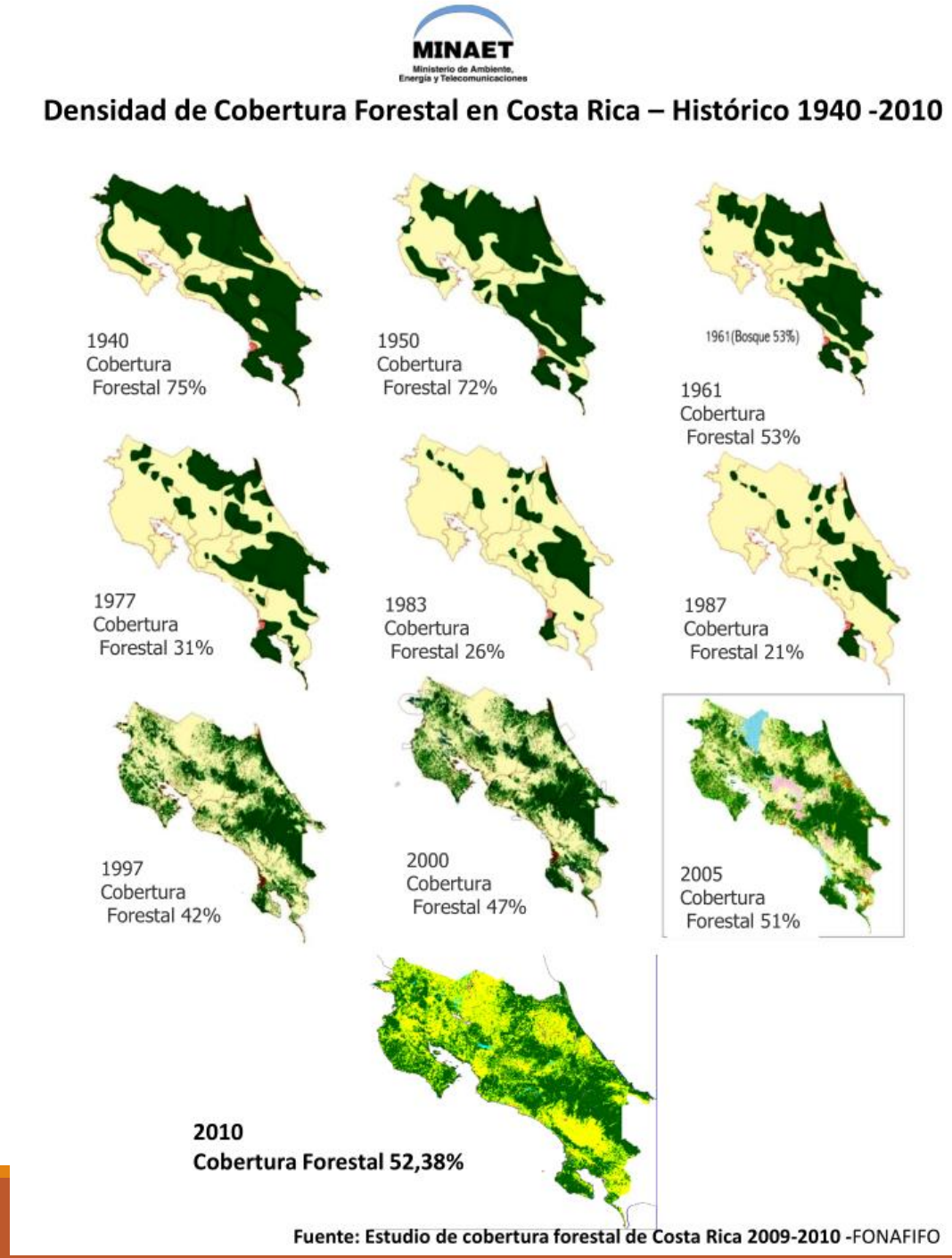


Table 1. Humid tropical forest cover estimates for the years 1990 and 1997 and mean annual change estimates during the 1990–1997 period. All figures are × 10^6 ha. Sample figures were extrapolated linearly to the dates 1 June 1990 and 1 June 1997. Average observation dates were February 1991 and May 1997 for Latin America, February 1989 and March 1996 for Africa, and May 1990 and June 1997 for Southeast Asia. Estimated ranges are at the 95% confidence level.

	Latin America	Africa	Southeast Asia	Global
Total study area	1155	337	446	1937
Forest cover in 1990	669 ± 57	198 ± 13	283 ± 31	1150 ± 54
Forest cover in 1997	653 ± 56	193 ± 13	270 ± 30	1116 ± 53
Annual deforested area	2.5 ± 1.4	0.85 ± 0.30	2.5 ± 0.8	5.8 ± 1.4
Rate	0.38%	0.43%	0.91%	0.52%
Annual regrowth area	0.28 ± 0.22	0.14 ± 0.11	0.53 ± 0.25	1.0 ± 0.32
Rate	0.04%	0.07%	0.19%	0.08%
Annual net cover change	−2.2 ± 1.2	−0.71 ± 0.31	−2.0 ± 0.8	−4.9 ± 1.3
Rate	0.33%	0.36%	0.71%	0.43%
Annual degraded area	0.83 ± 0.67	0.39 ± 0.19	1.1 ± 0.44	2.3 ± 0.71
Rate	0.13%	0.21%	0.42%	0.20%

Achard et al. 2002 Determination of deforestation rates of the world's humid tropical forests. Science, Aug 9, 297 (5583):999-1002.

Landsat:
Change Detection

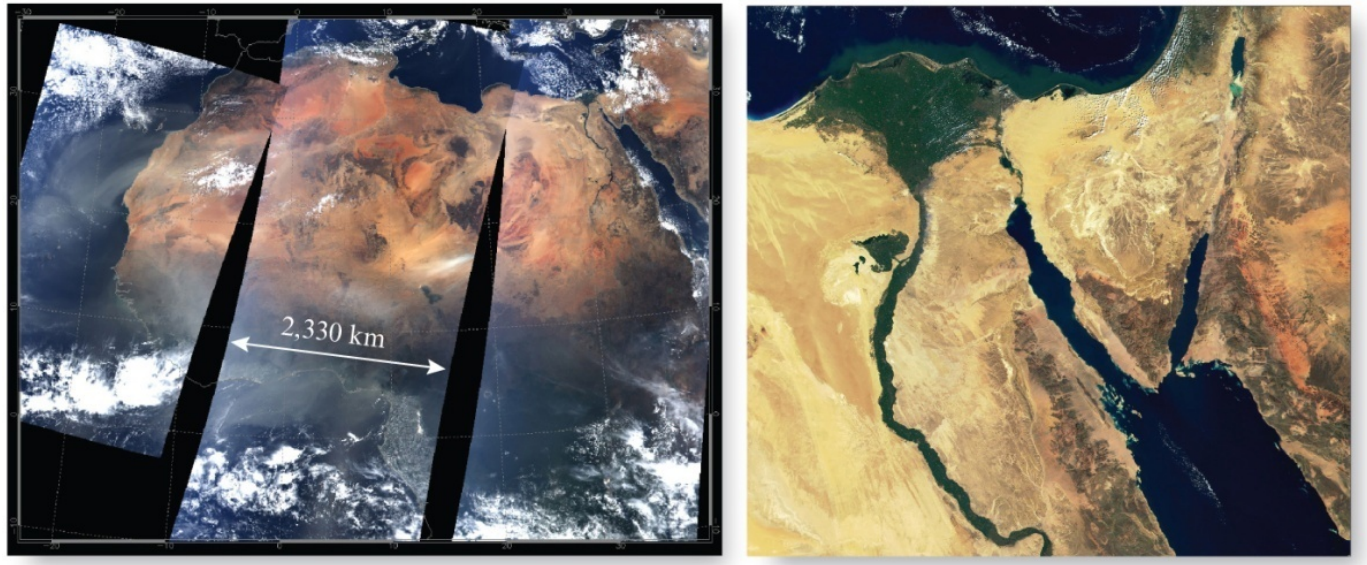


El Programa MODIS (NASA)

Moderate Resolution Imaging Spectrometer (MODIS)

• A bordo de los satélites Terra andAqua (AM/PM); resolución temporal de 1-2 días; 36 bandas

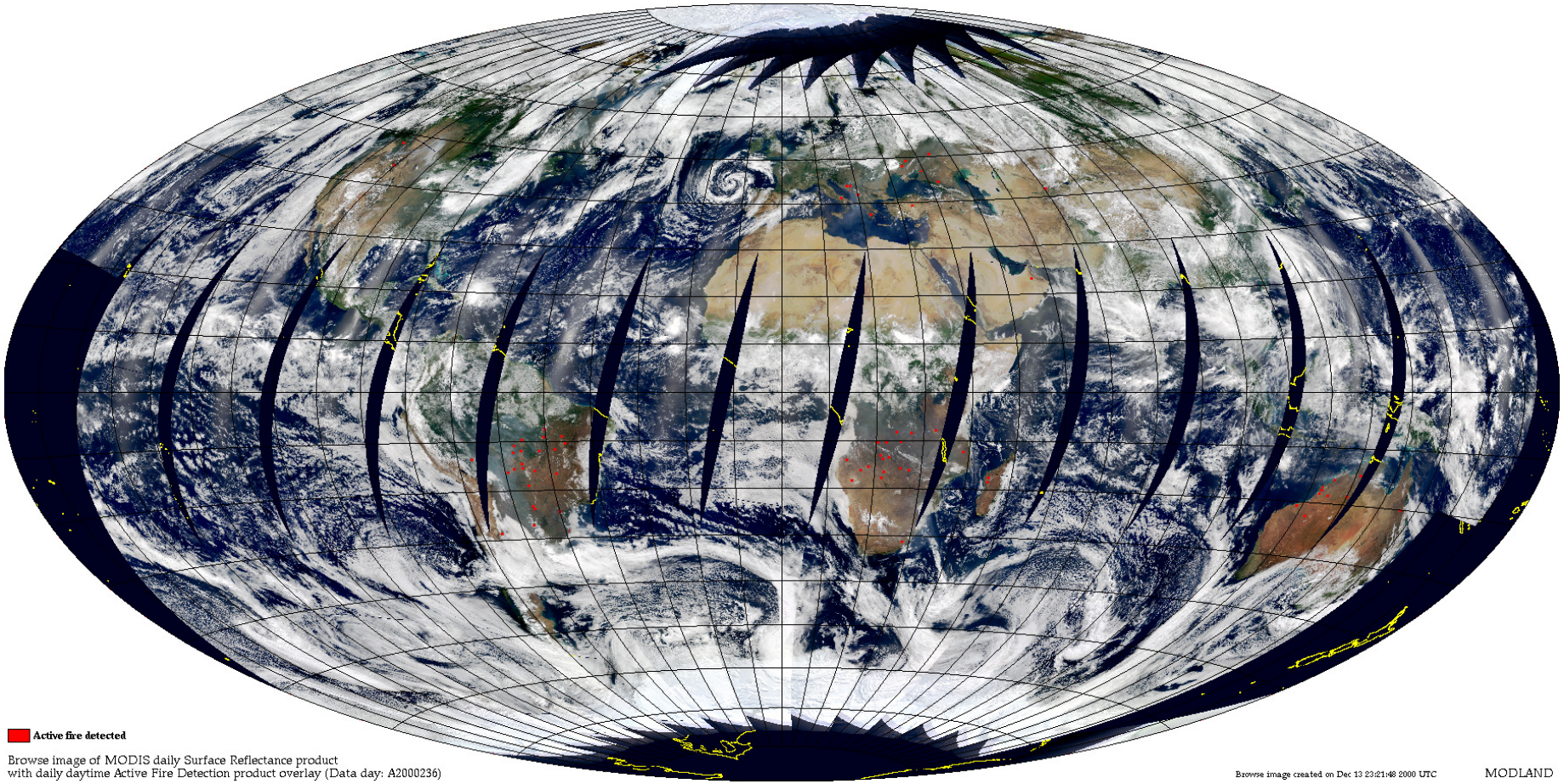
Moderate Resolution Imaging Spectrometer (MODIS) Imagery



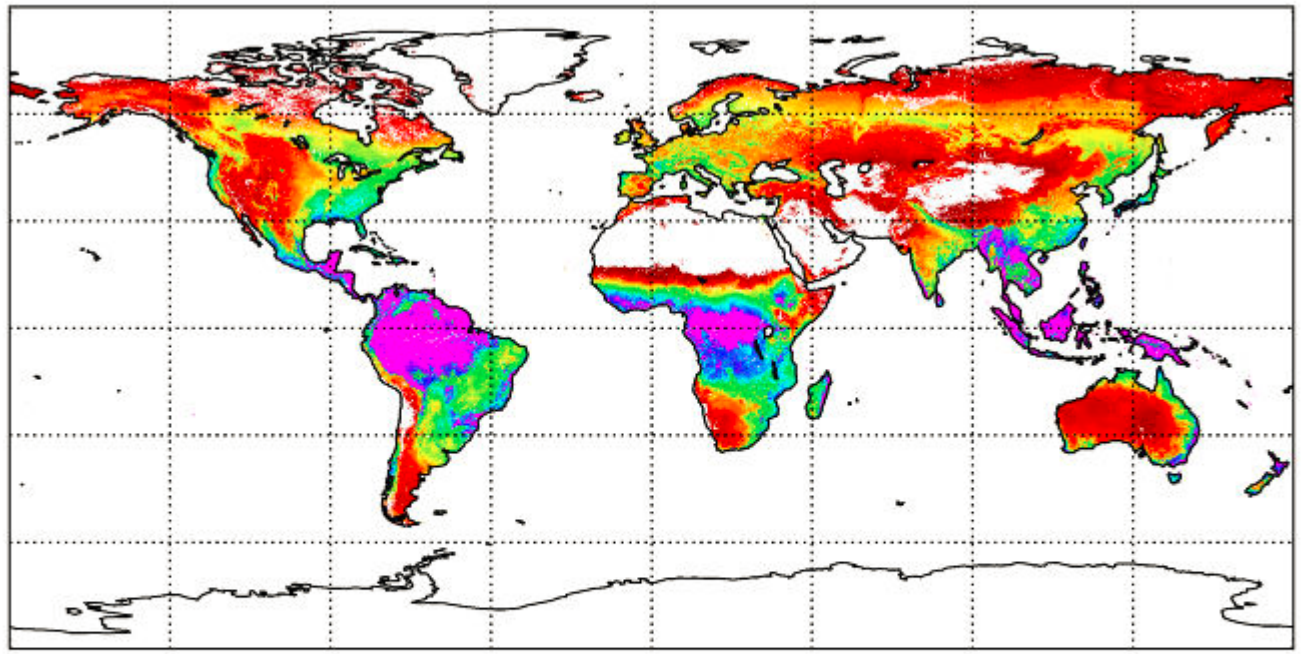
a. Three swaths of MODIS imagery over northern Africa on February 29, 2000.

b. MODIS image of the Nile Delta obtained on February 28, 2000.

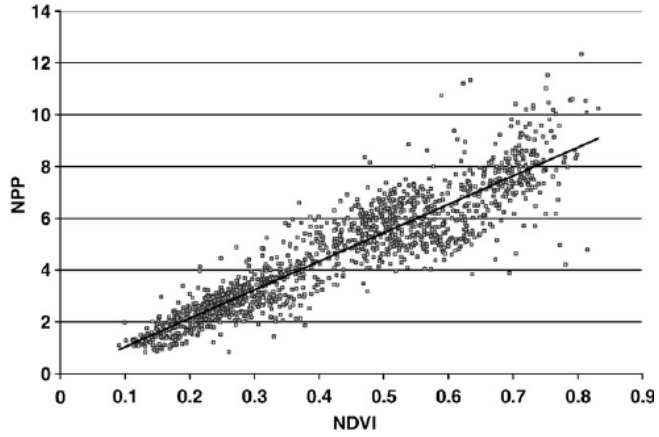
Moderate Resolution Imaging Spectrometer (MODIS)

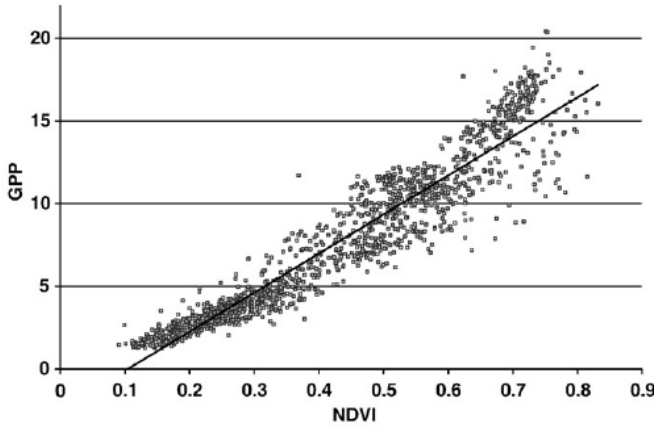


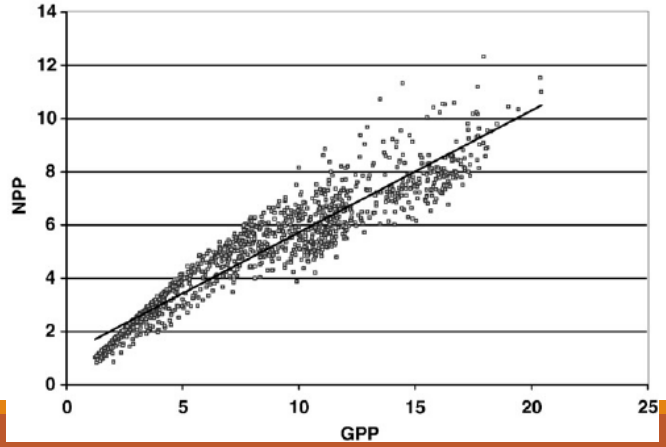
MODIS:
Global and regional assessments



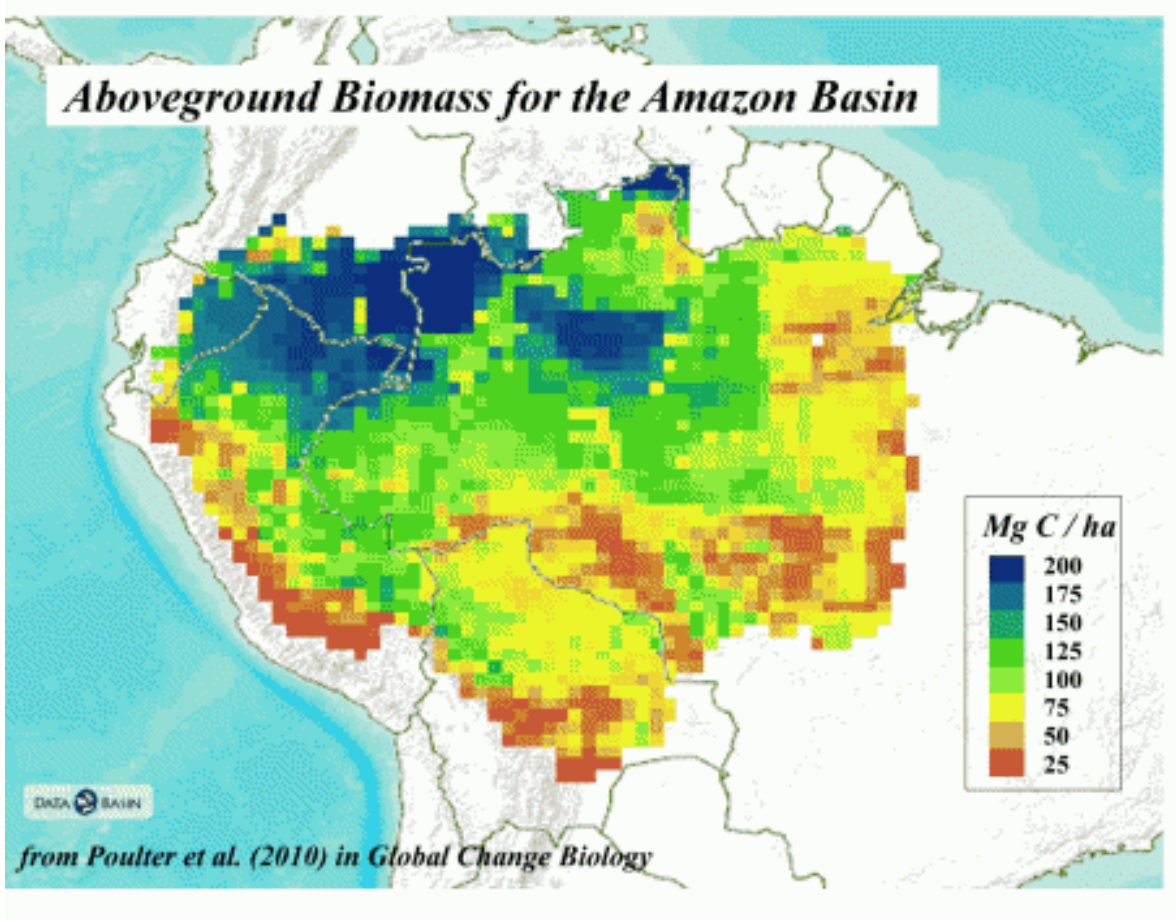
Mean GPP 2000 to 2005







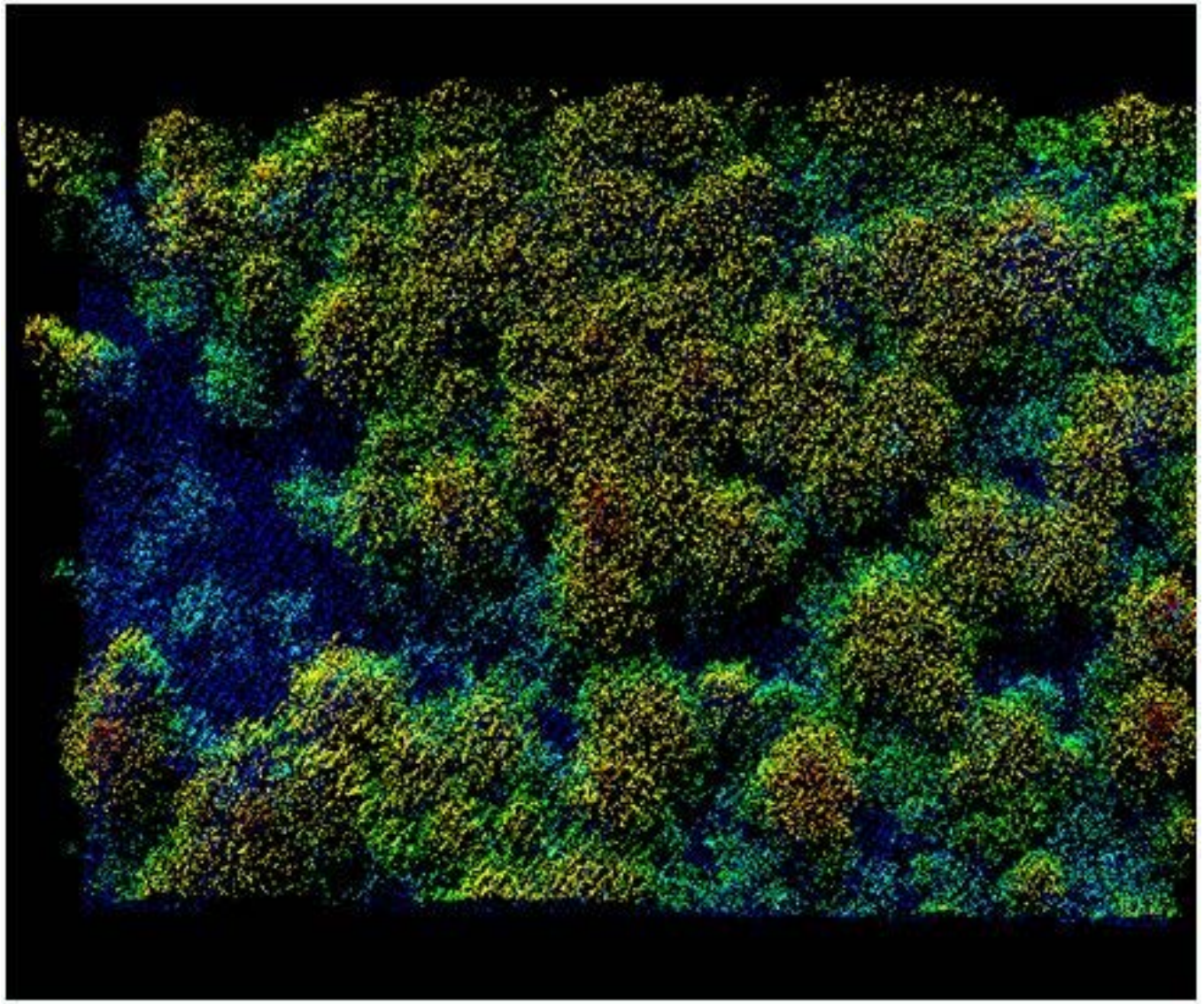
MODIS:
Global and regional assessments



MODIS: Active fire detection

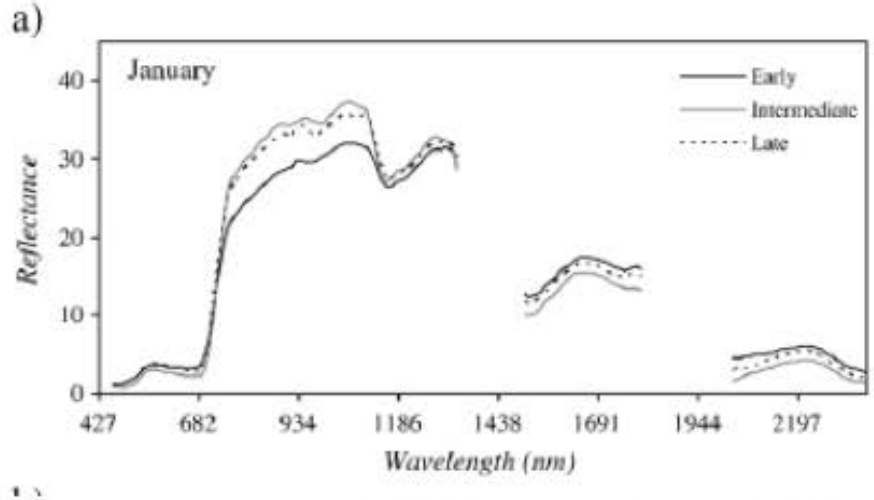
Firecast.conservation.org

Light Detection and Ranging (LiDAR)

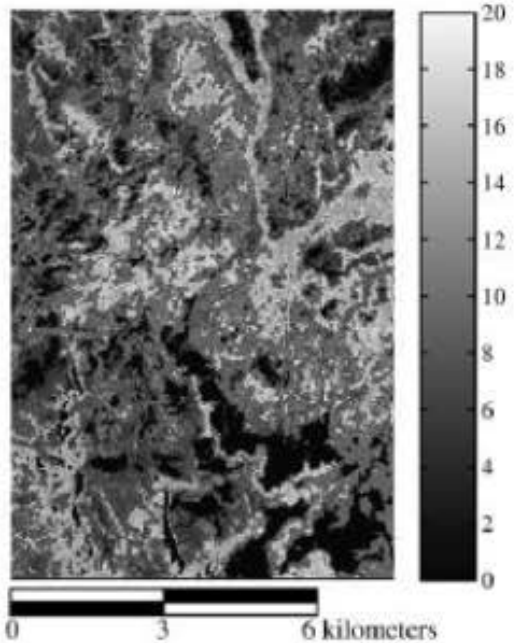


- Structural diversity

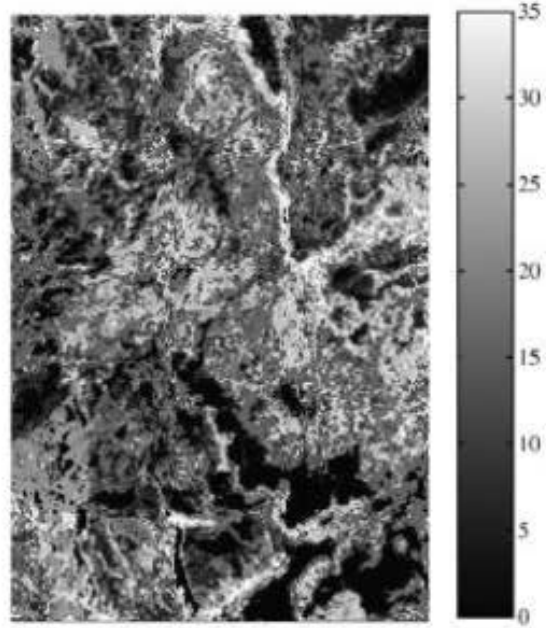
  Kalacska et al. 2007 used Hyperion (Hyperspectral sensor) and field measurements of Forest structure to identify forest regrowth



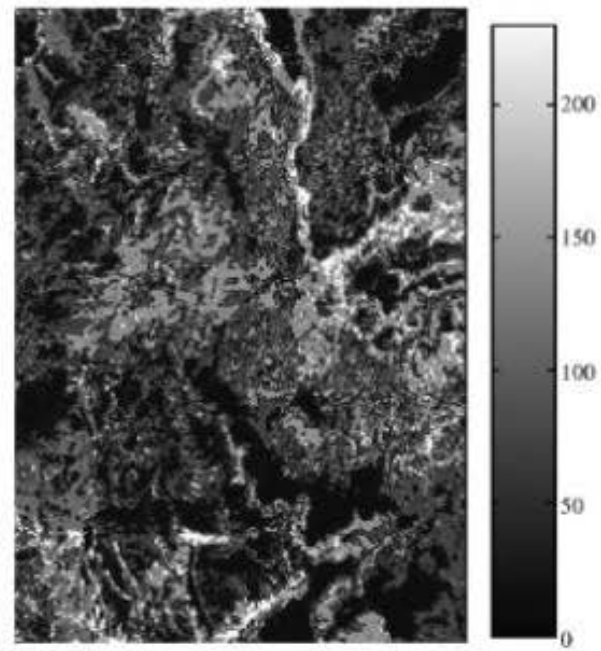
Tree Canopy Height



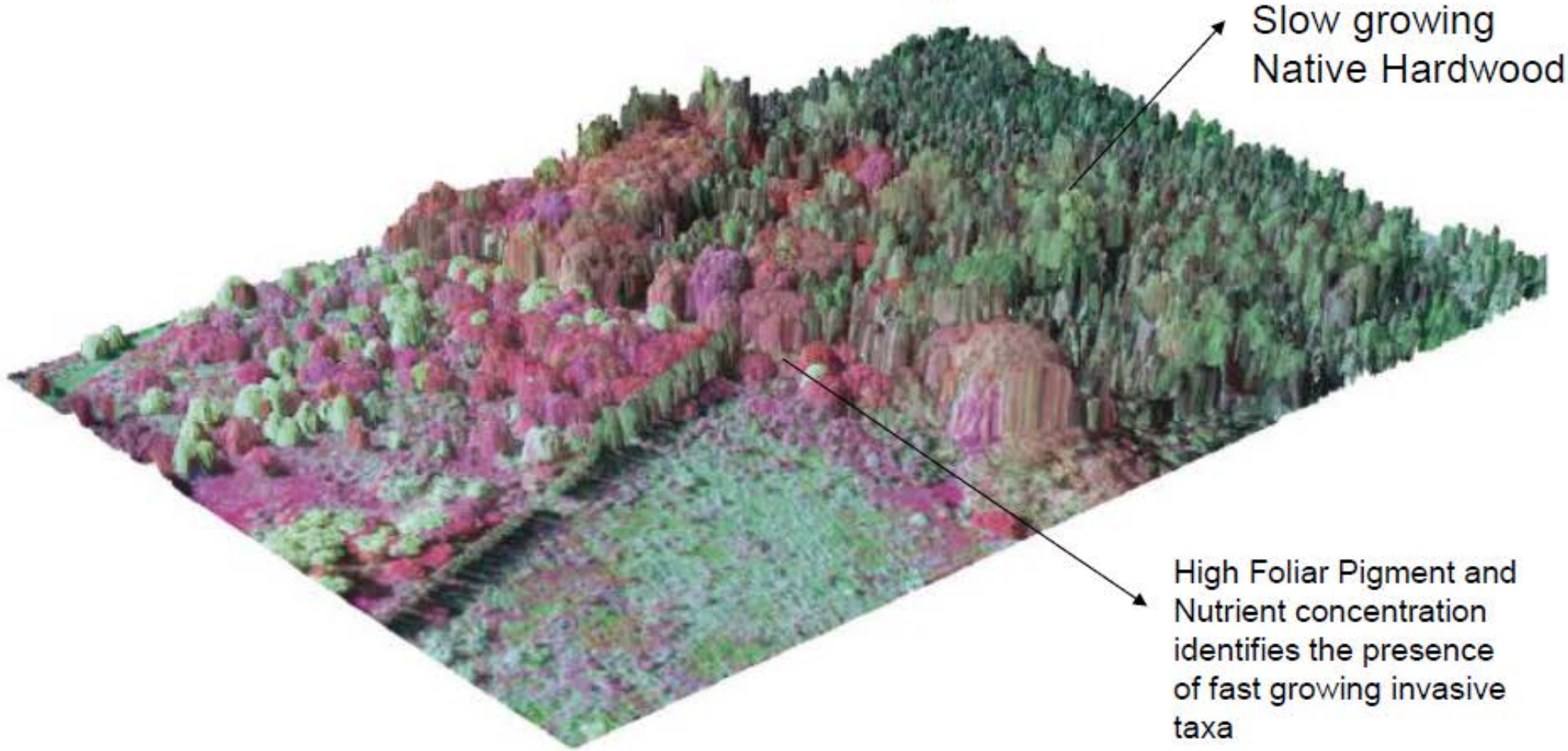
Tree Basal area



Holdridge Complexity Index

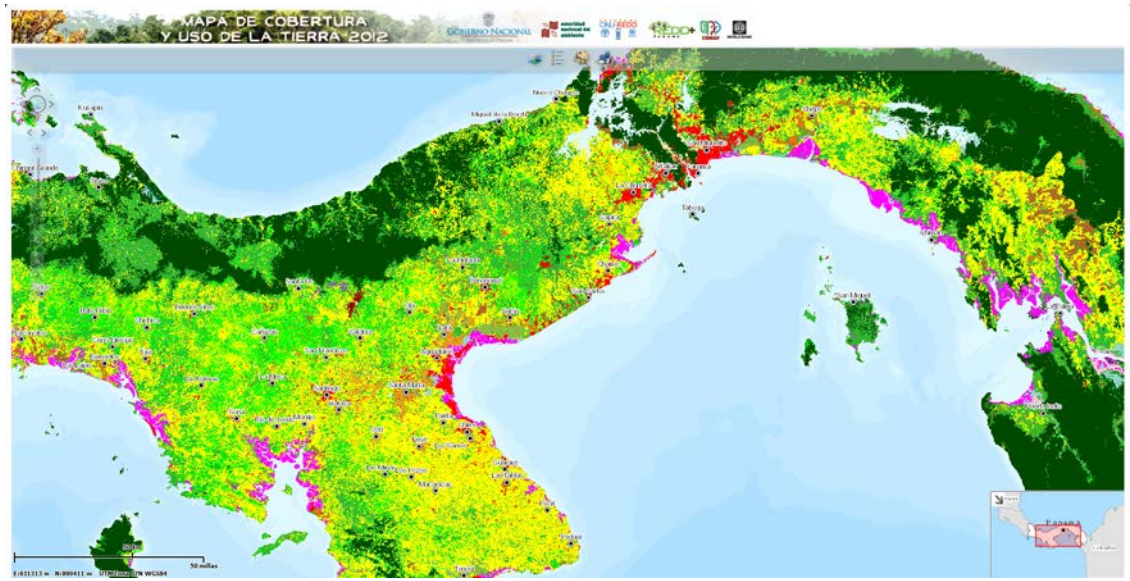


• Functional and biochemical diversity



Canopy height, crown size and Chemical Diversity Map (Townshend, 2008)

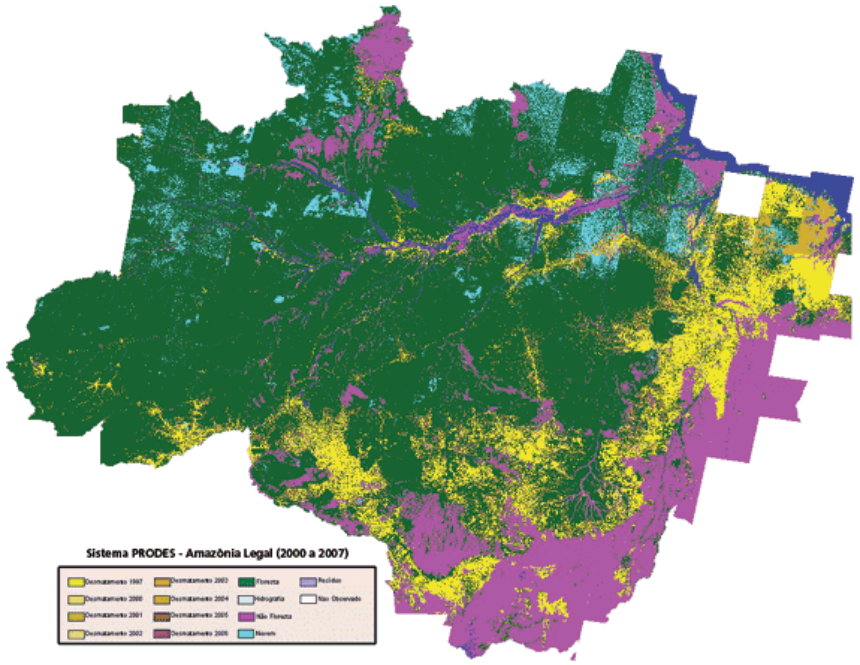
UN-FAO: Land cover national assessments using image classification techniques

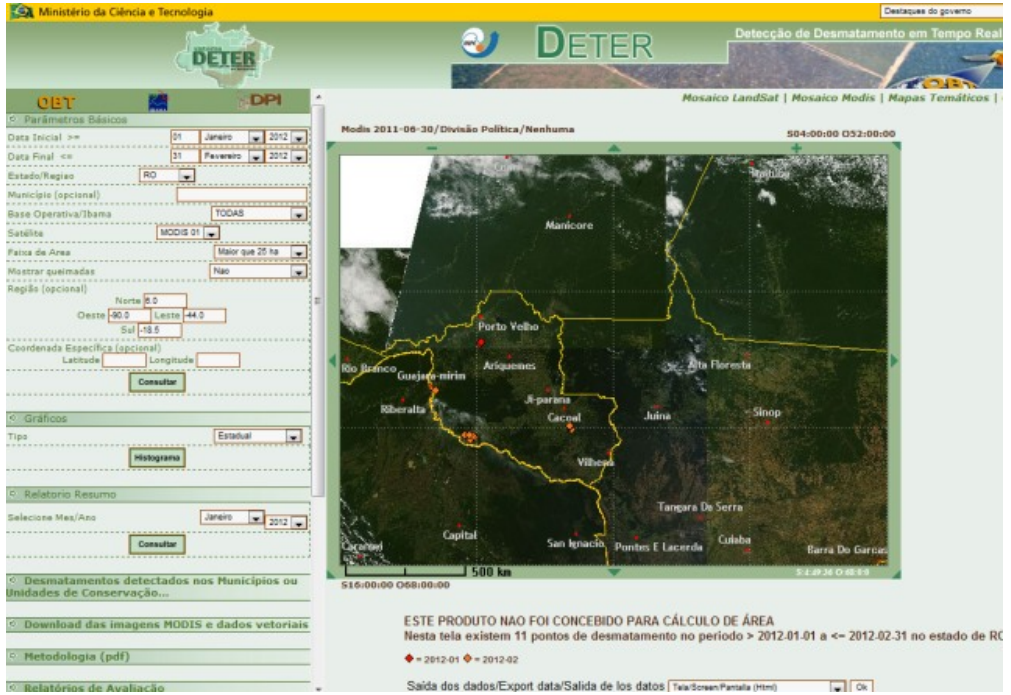


País	Cubierta Forestal Al 2000	Deforestación anual 1990-2000	Tasa anual de deforestación (%) 1990-2000	Tasa anual de deforestación 1980-1990
Argentina	34,648,222	-285,111	-0.8	
Belize	1,347,823	-35,625	-2.3	
Bolivia	53,068,062	-161,075	-0.3	
Brasil	481,599,300	-2,226,400	-0.4	
Chile	15,535,696	-20,307	-0.1	
Colombia	49,601,300	-190,470	-0.4	
Costa Rica	1,968,253	-15,774	-.0.8	
Ecuador	10,556,870	-137,220	-1.2	
El salvador	120,590	-7,251	-4.6	
Guatemala	2,849,722	-53,743	-1.7	
Honduras	5,382,500	-58,970	-1.1	
México	55,205,278	-630,574	-1.1	
Nicaragua	3,277,900	-117,200	-3.0	
Panamá	2,876,333	-51,899	-1.6	
Paraguay	23,370,013	-122,978	-0.5	
Perú	65,215,364	-268,794	-0.4	
Uruguay	1,292,298	50,149	5.0	
Venezuela	49,506,000	-217,539	-0.4	
TOTAL	857,423,524	-4,593,345	0.535*	

PRODES y DETER systems (INPE, Brasil)

The Brazilian Space Agency manages a system for providing annual forest cover change data (PRODES) and a system for the detection of forest disturbances in real time (DETER, every 16 days).

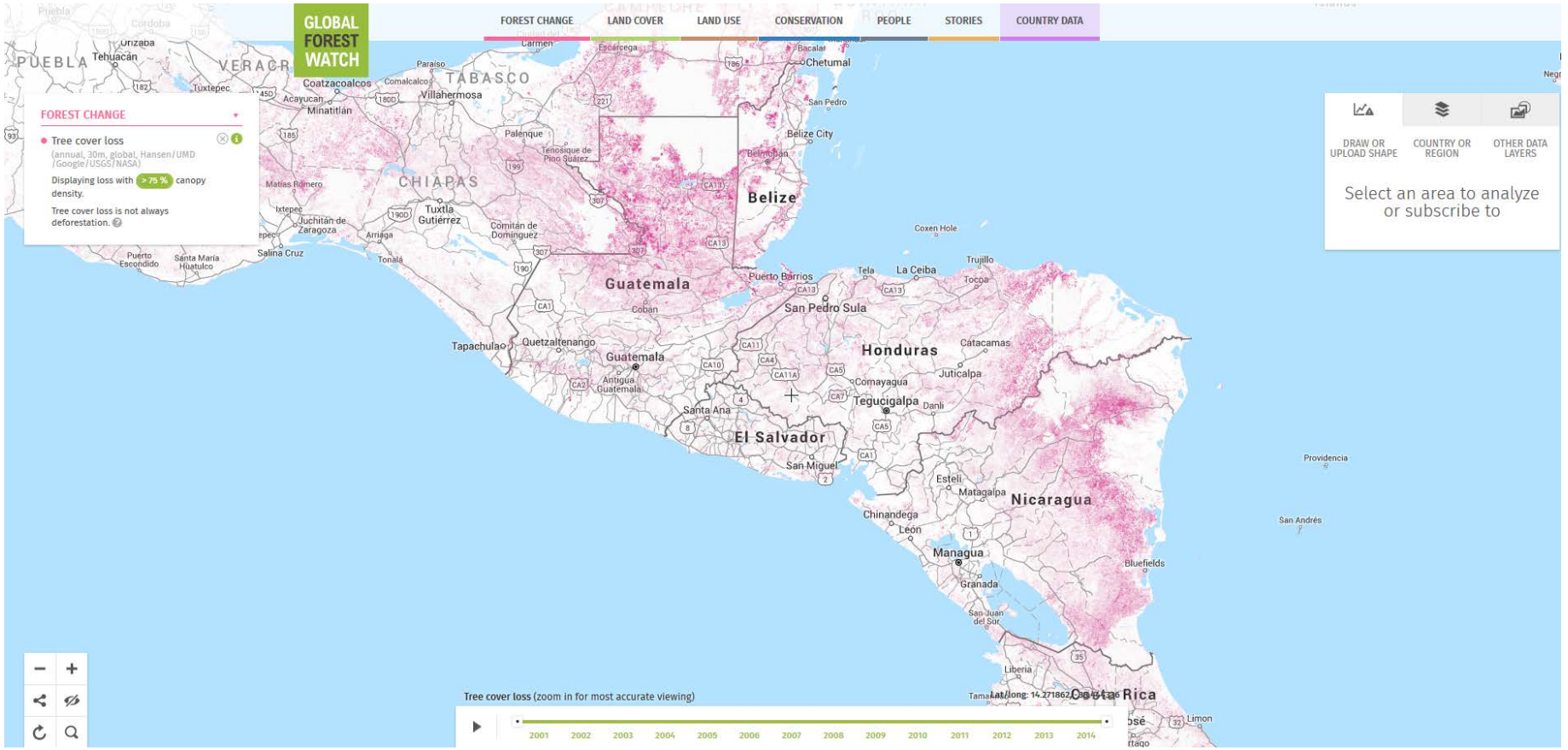




Recent advancement in satellite image acquisition and processing capabilities

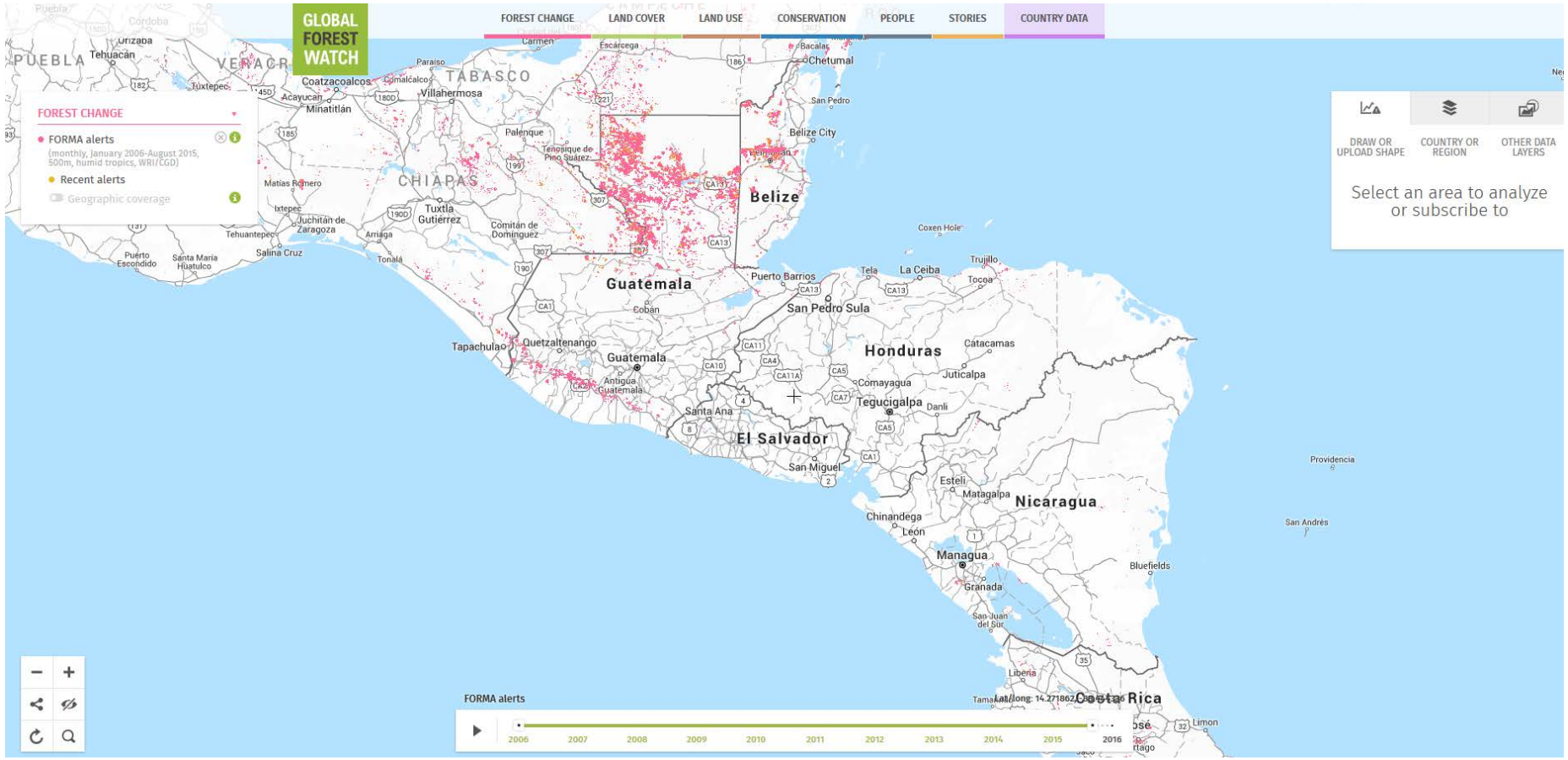
- Global free availability of Landsat and MODIS imagery through NASA/USGS repositories
- Corrected and processed products such as spectral indices, cloud-free products and fire detections.
- Image processing through “cloud computing”: Google Earth Engine.

Global Forest Watch (GFW)



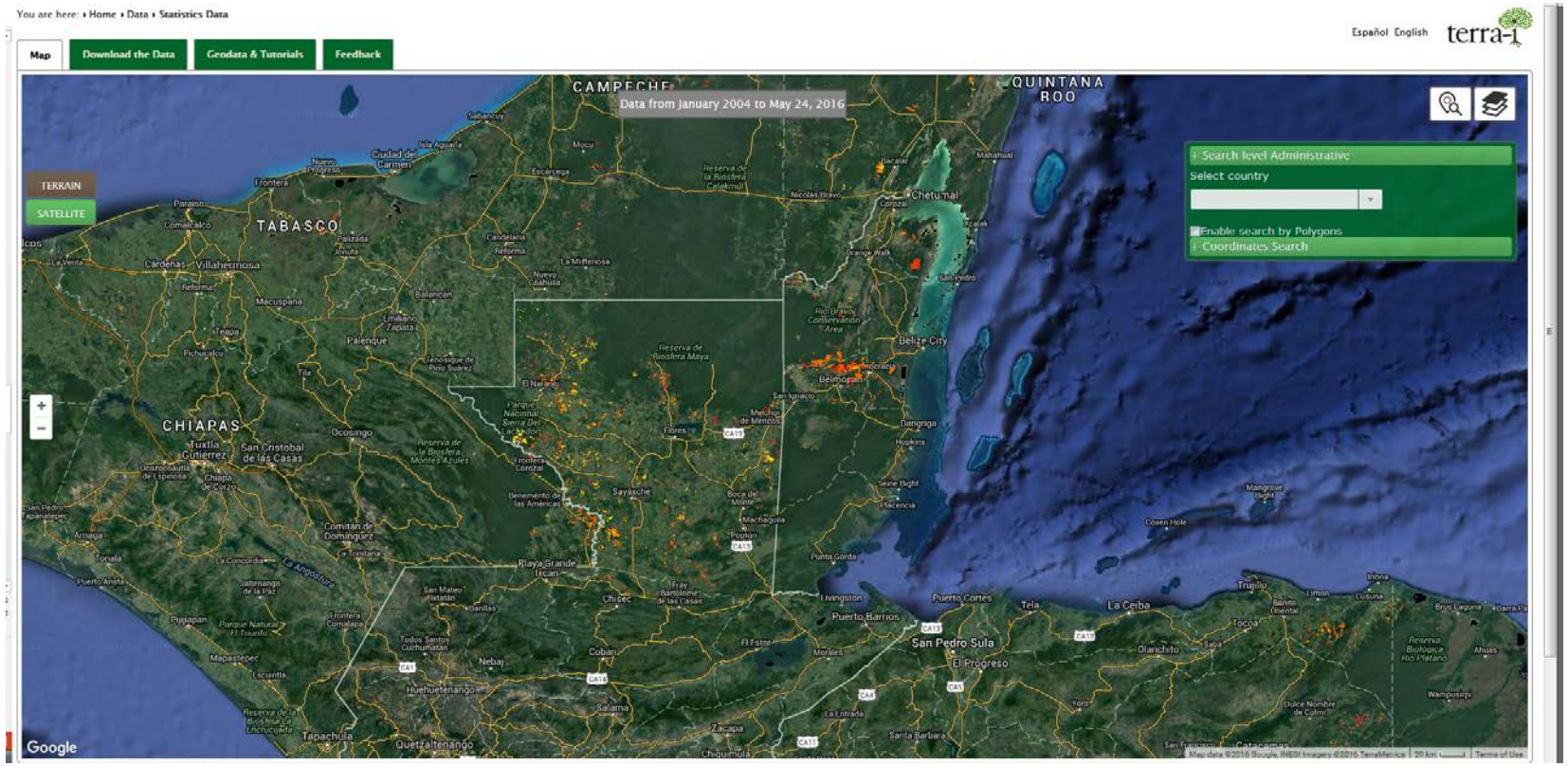
Detects abrupt annual changes in forest primary productivity estimates from Landsat pixel values (30-m pixel resolution)

Global Alert System (FORMA - GFW)



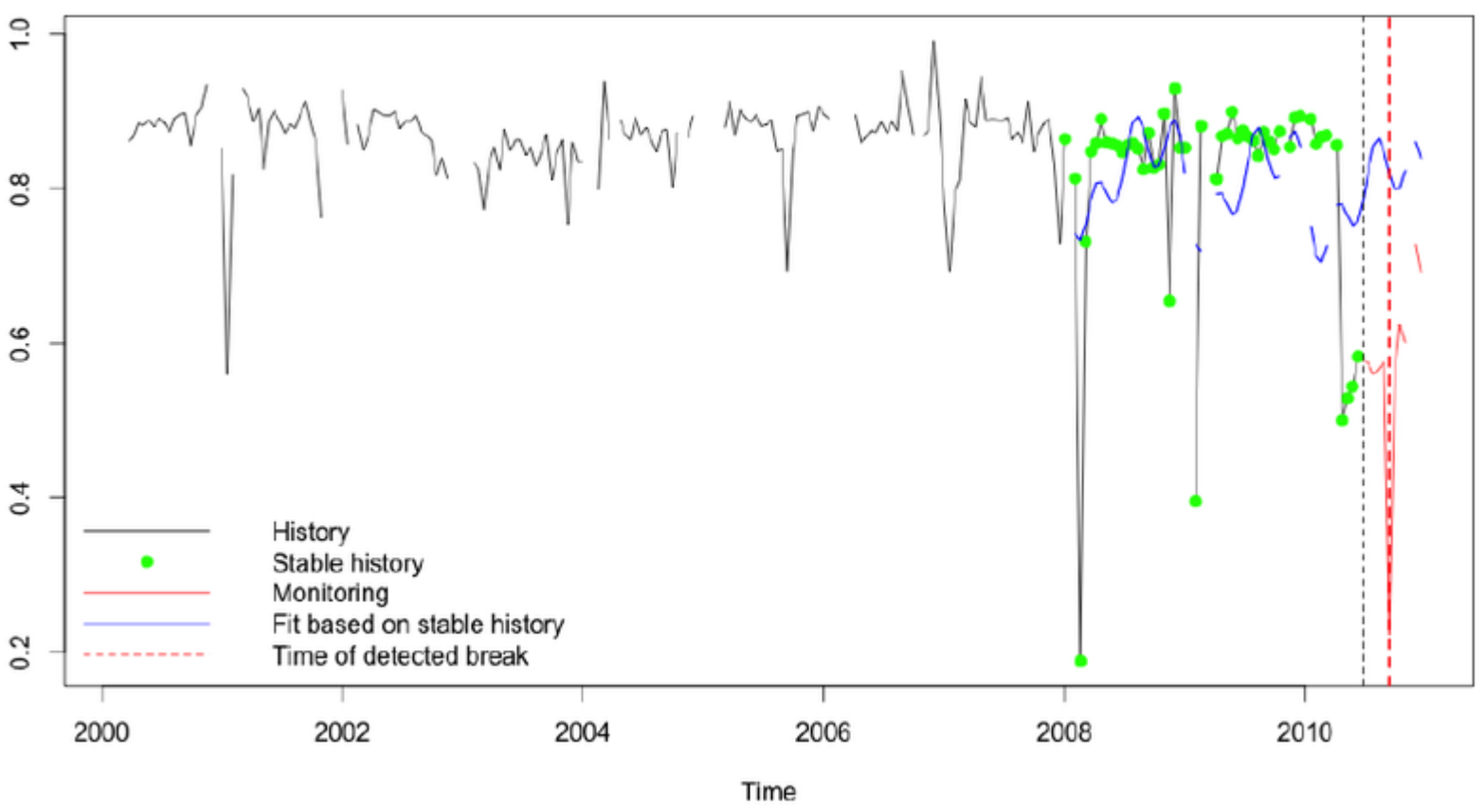
Detects bimonthly changes in MODIS Primary productivity pixel values (500 m resolution, 16-days). Includes fire detections.

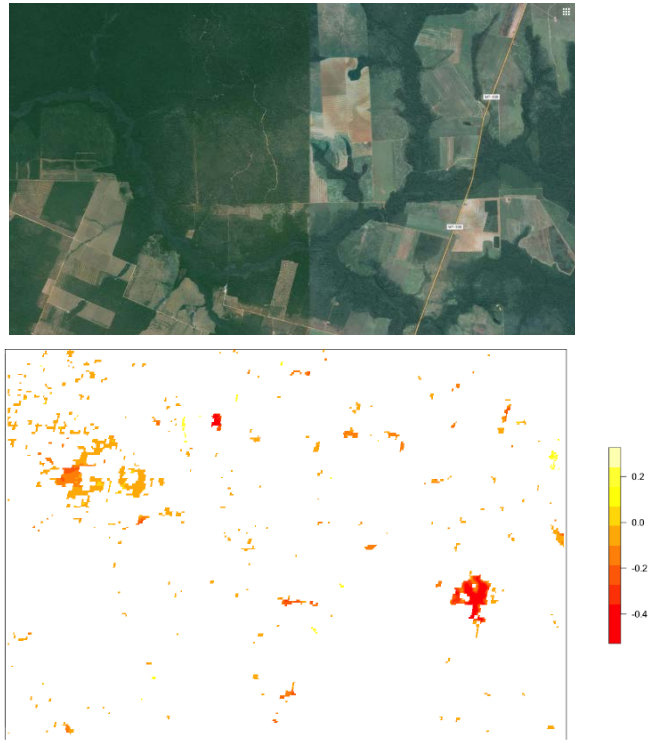
Terra-i



Similar to the FORMA system (MODIS). Detects forest cover changes every 16 days at 250-m pixel resolution.

Monitoring system using R-package BFAST (for Landsat data)





Verbesselt et al. 2012

Establishing a ecosystem observation system using RS

- Technical capabilities in image processing (trained and experienced personnel).

- Well structured organization and well-defined protocols for measuring, reporting and validation of results.

- Computational capabilities (high performance computers, broad bandwidth internet connectivity).

Establishing a ecosystem observation system using RS

- Continuous institutional, political and financial support.
- Ability to adapt and upgrade to new technologies.
- Transparency.

Assessing the capabilities in Latin America

- Assessment in the context of REDD+

- Romjin et al. 2012. *Environmental Science and Policy.*

Paises en desarrollo	**Challenges for the implementation of remote sensing systems**
Belize	High
Ecuador	High
Haiti	High
Honduras	High
Panama	High
Salvador	High
Bolivia	Intermediate
Colombia	Intermediate
Costa Rica	Intermediate
Cuba	Intermediate
Guatemala	Intermediate
Guyana	Intermediate
Nicaragua	Intermediate
Paraguay	Intermediate
Peru	Intermediate
Republica Dominicana	Intermediate
Trinidad y tobago	Intermediate
Venezuela	Intermediate
Argentina	Low
Brazil	Low
Mexico	Low
Uruguay	Low

Capacity building in Latin America

• Foster the development of research on the implementation of near real time ecosystem observation systems in each country.

• Create the institutions, centers or departments dedicated to this task.

• Develop the legal mechanisms to secure long term political and financial support.

• From the start, methods should include connections with local governmental and non-governmental institutions in charge of environmental protection and territorial planning (agricultura, urban environmental and tourism).

Questions?

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TEXAS TECH UNIVERSITY, USA.