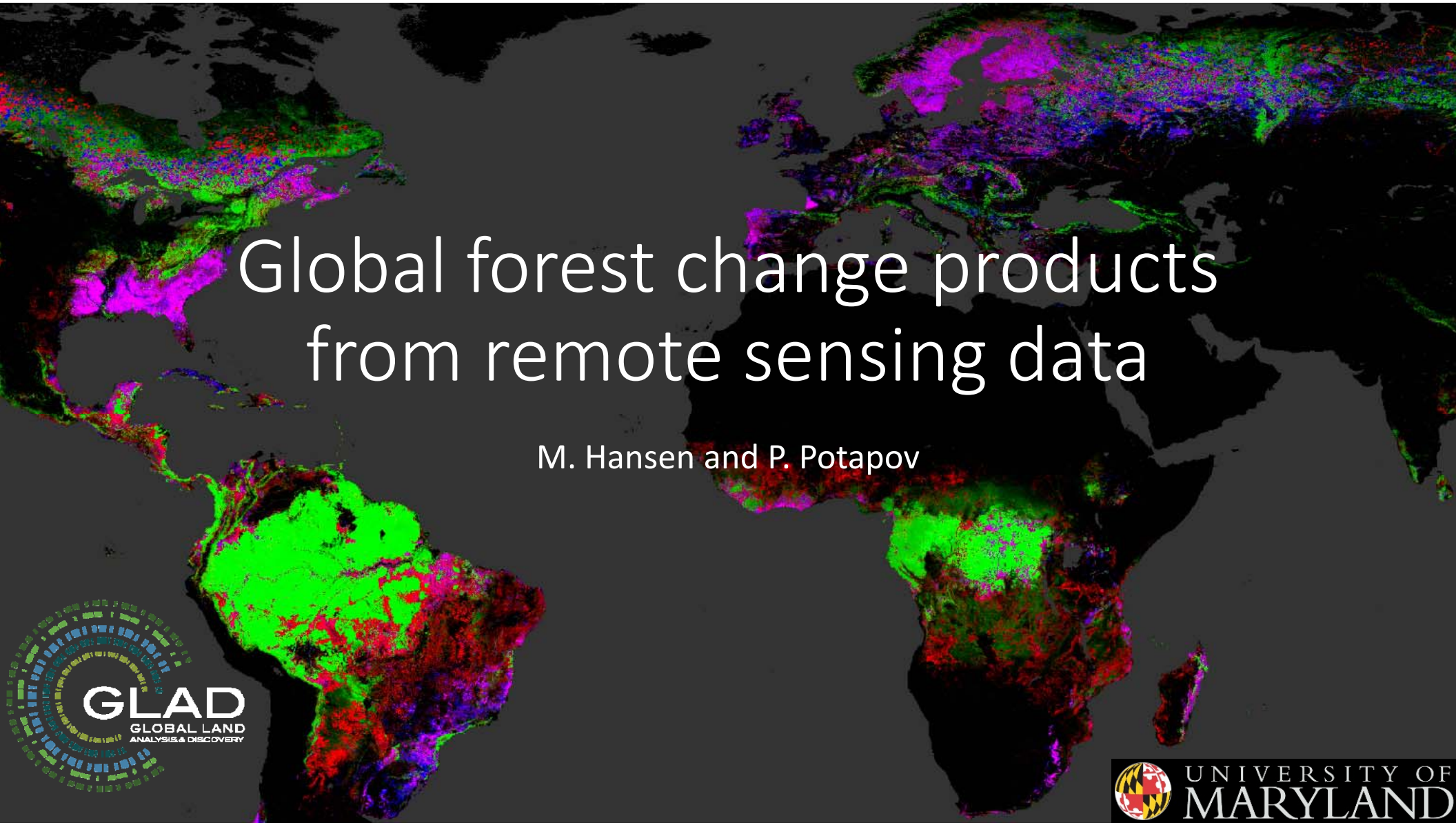


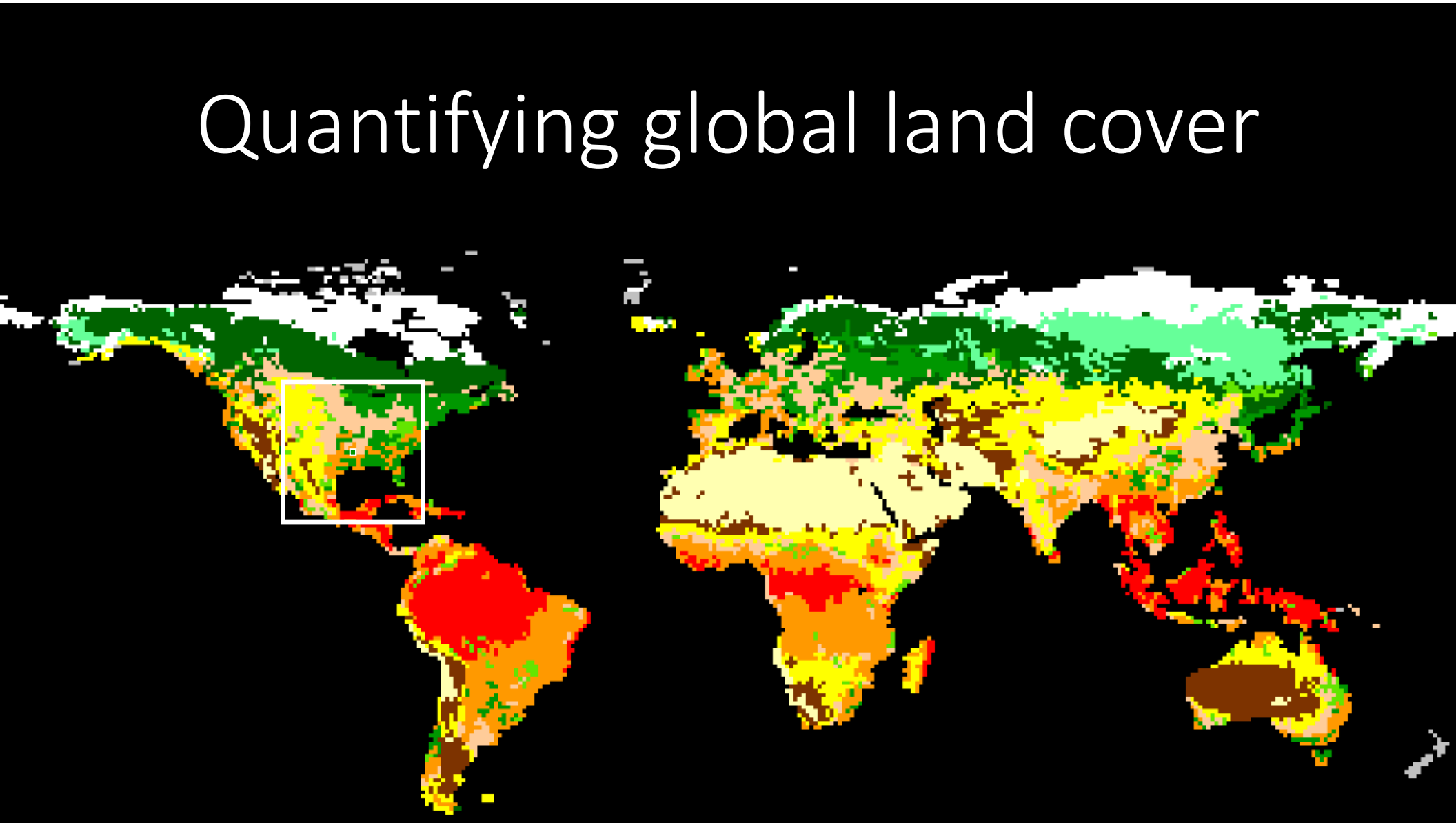
Global forest change products from remote sensing data

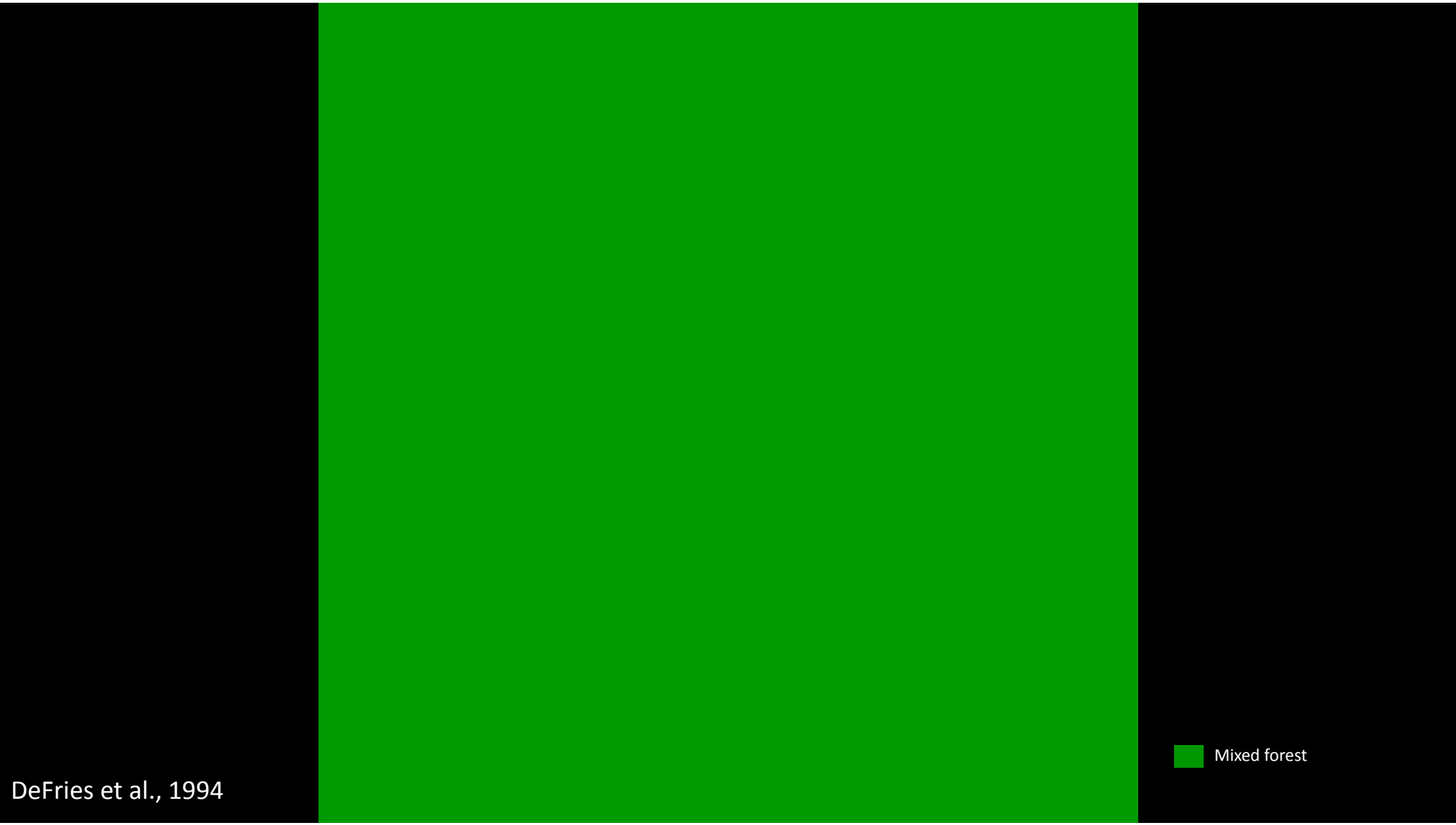
M. Hansen and P. Potapov

GLAD
GLOBAL LAND ANALYSIS & DISCOVERY

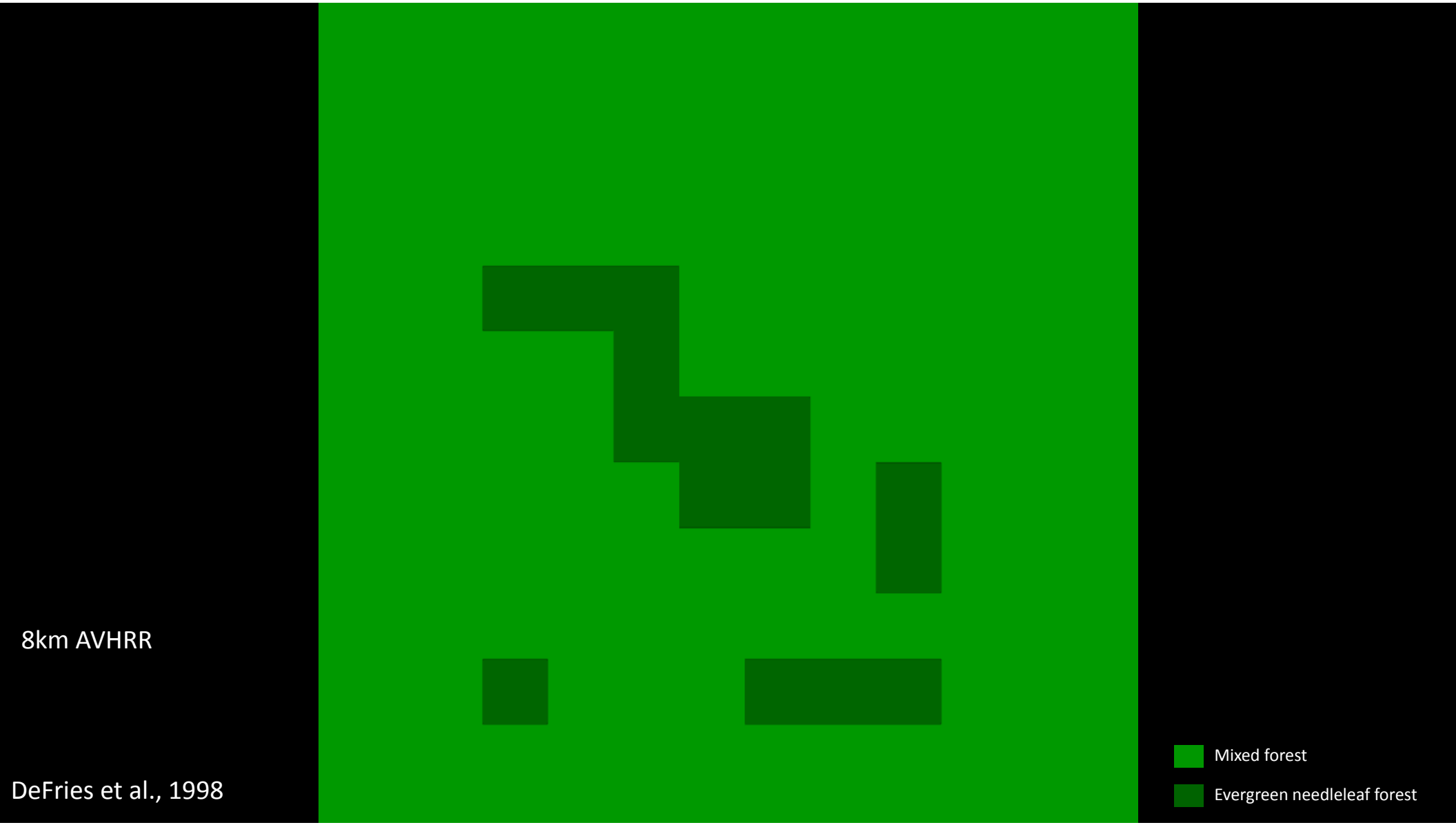
UNIVERSITY OF MARYLAND

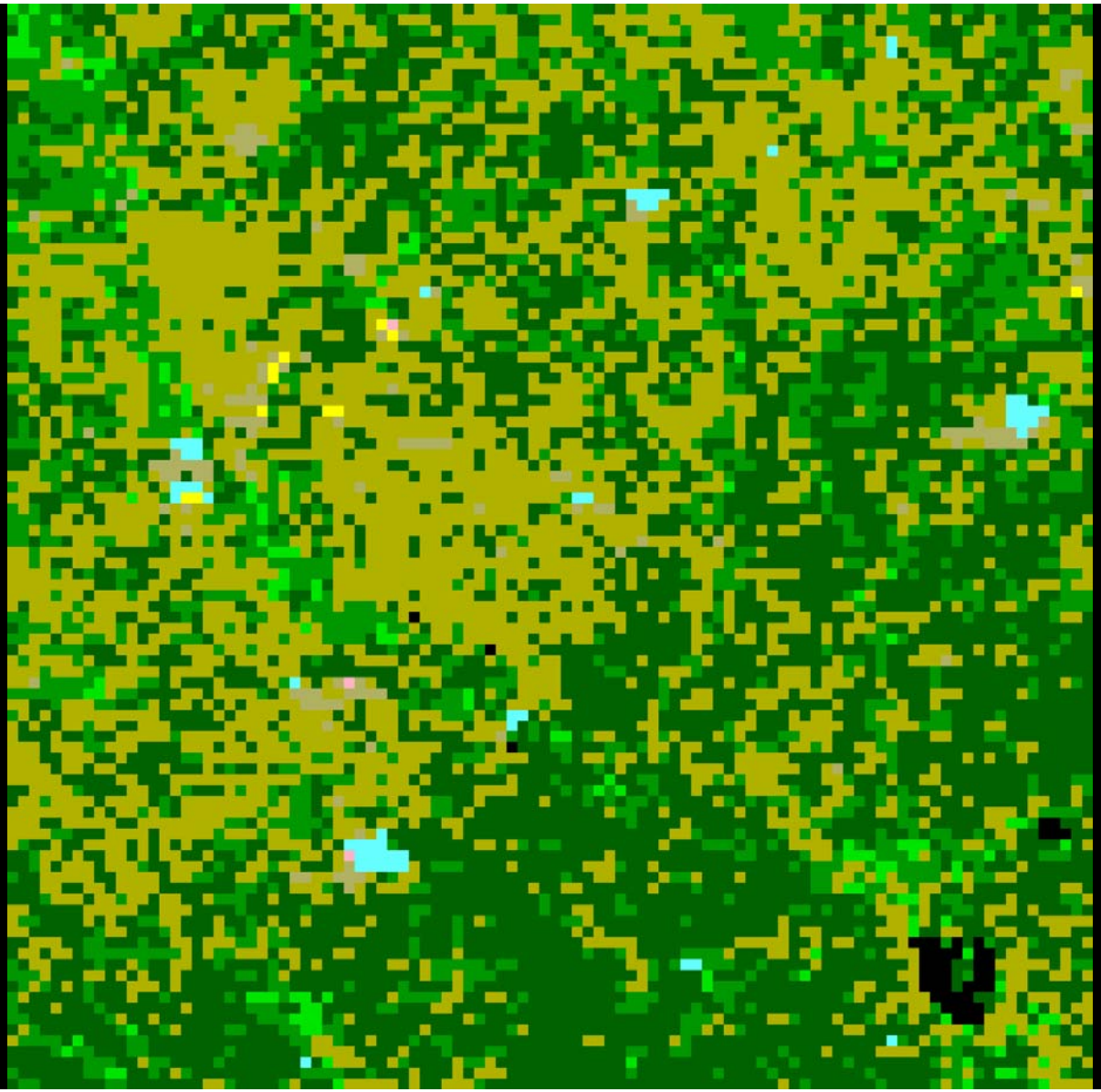
Quantifying global land cover





DeFries et al., 1994


8km AVHRR
DeFries et al., 1998
Mixed forest
Evergreen needleleaf forest

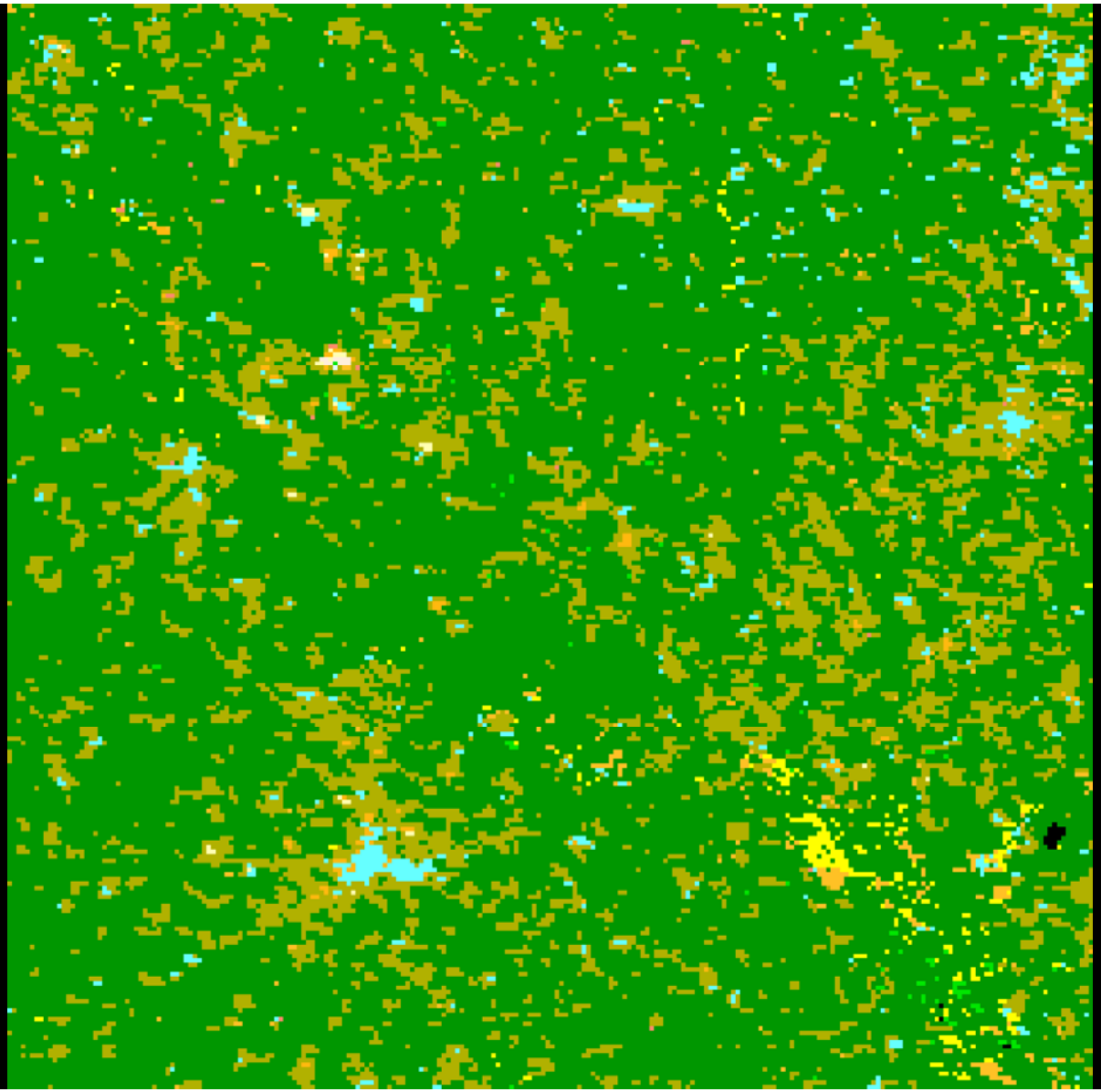


1km AVHRR

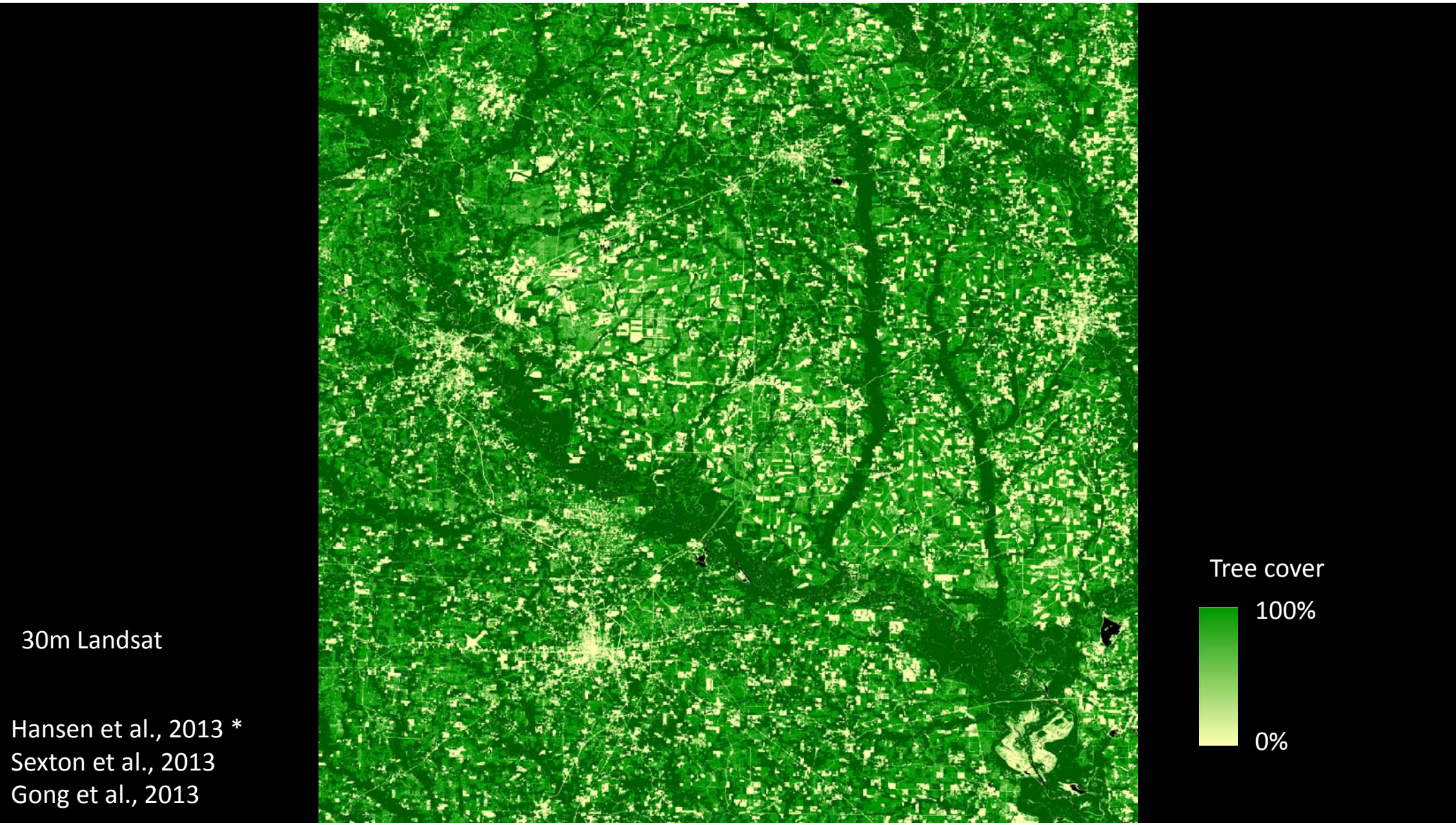
Loveland et al., 2000
Hansen et al., 2000 *
Bartholomé et al., 2005

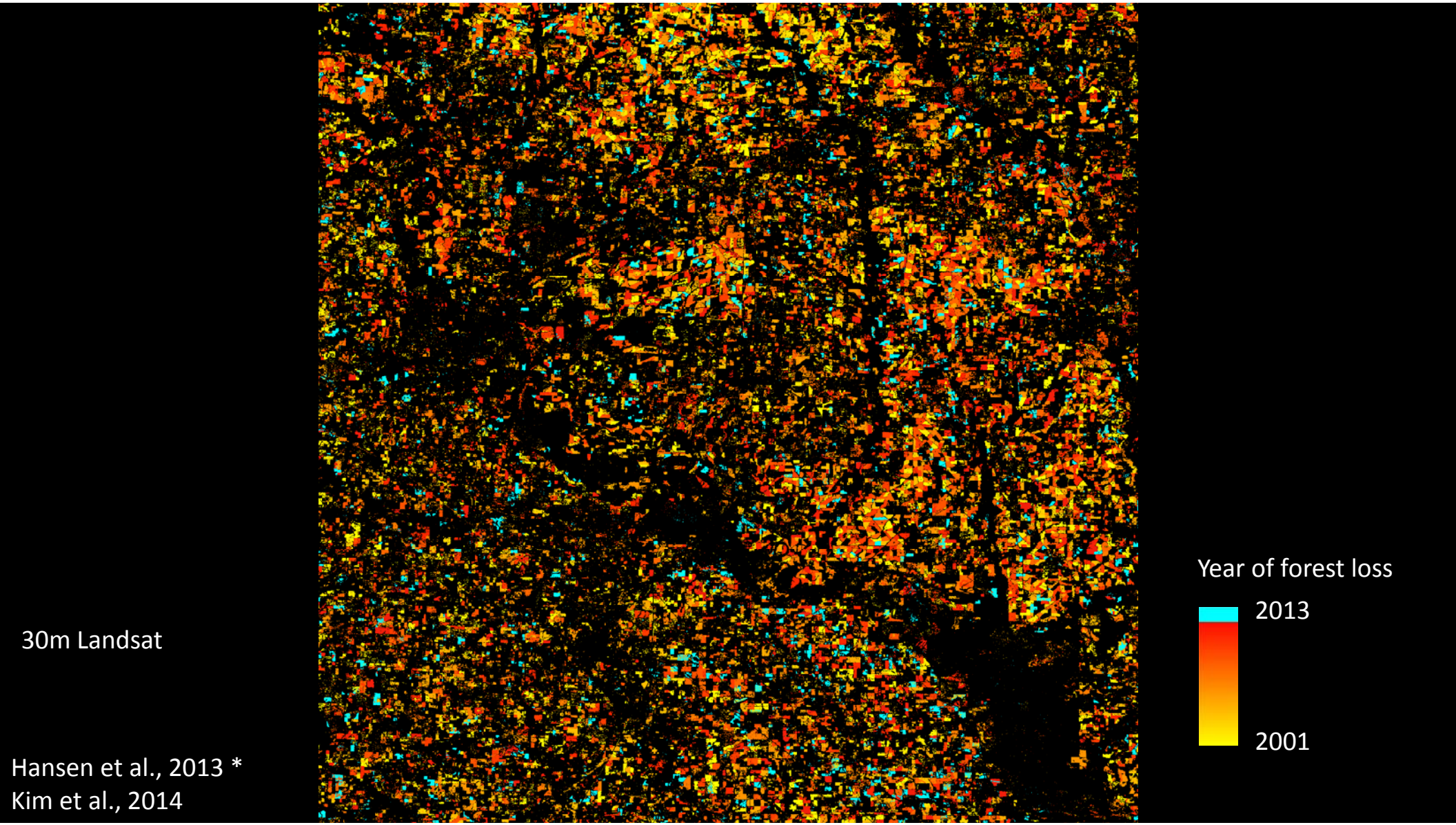
250m MODIS

Friedl et al., 2002 *
Hansen et al., 2002
Arino et al., 2008



Mixed forest
Evergreen needleleaf forest
Deciduous broadleaf forest
Woody savanna
Savannas
Grassland
Cropland
Urban and built-up

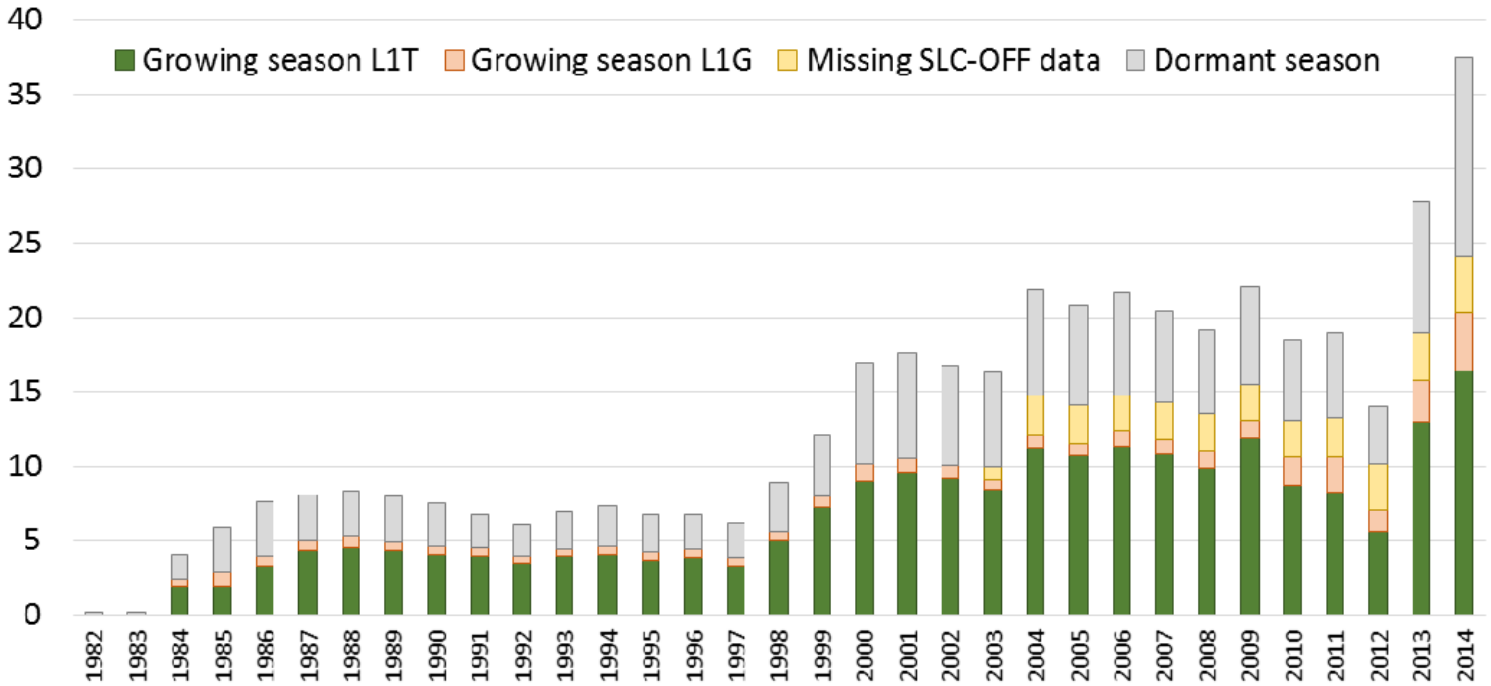

30m Landsat
Hansen et al., 2013 *
Sexton et al., 2013
Gong et al., 2013
Tree cover
100%
0%


30m Landsat
Hansen et al., 2013 *
Kim et al., 2014
Year of forest loss
2013
2001

Data requirements for global land monitoring

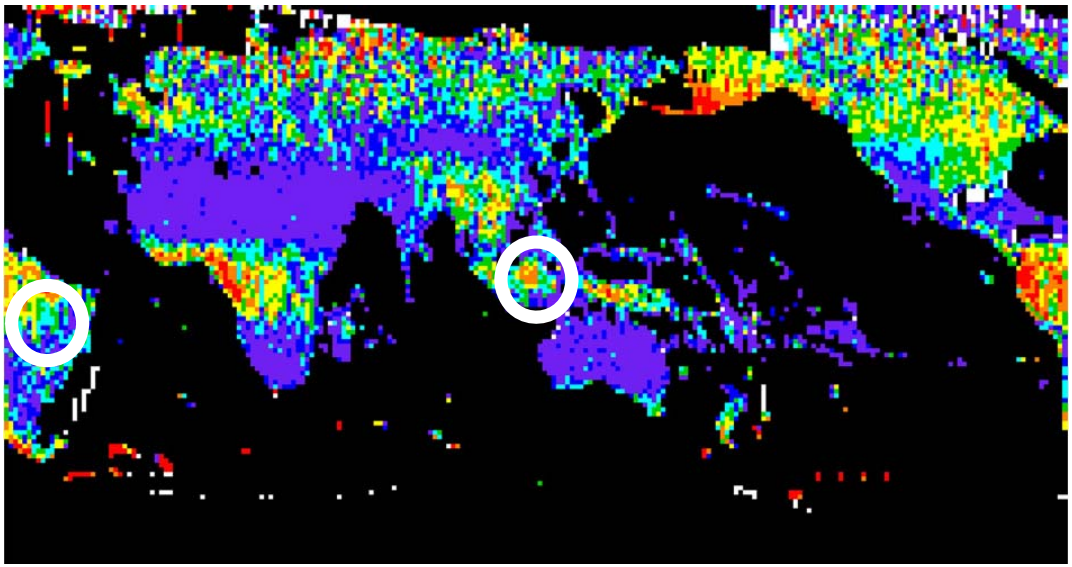
- Systematic global acquisitions
- No/low cost
- Easy access
- Minimal pre-processing required

The Landsat Data Archive



L1T data archive (images per year) during woody vegetation growing season

The Landsat Data Archive

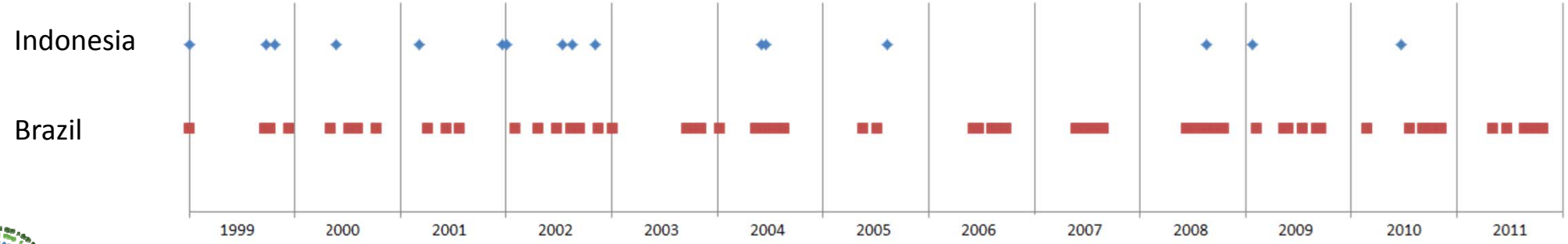


Mean cloud fraction in ETM+ acquisitions for each global land scene in 2002

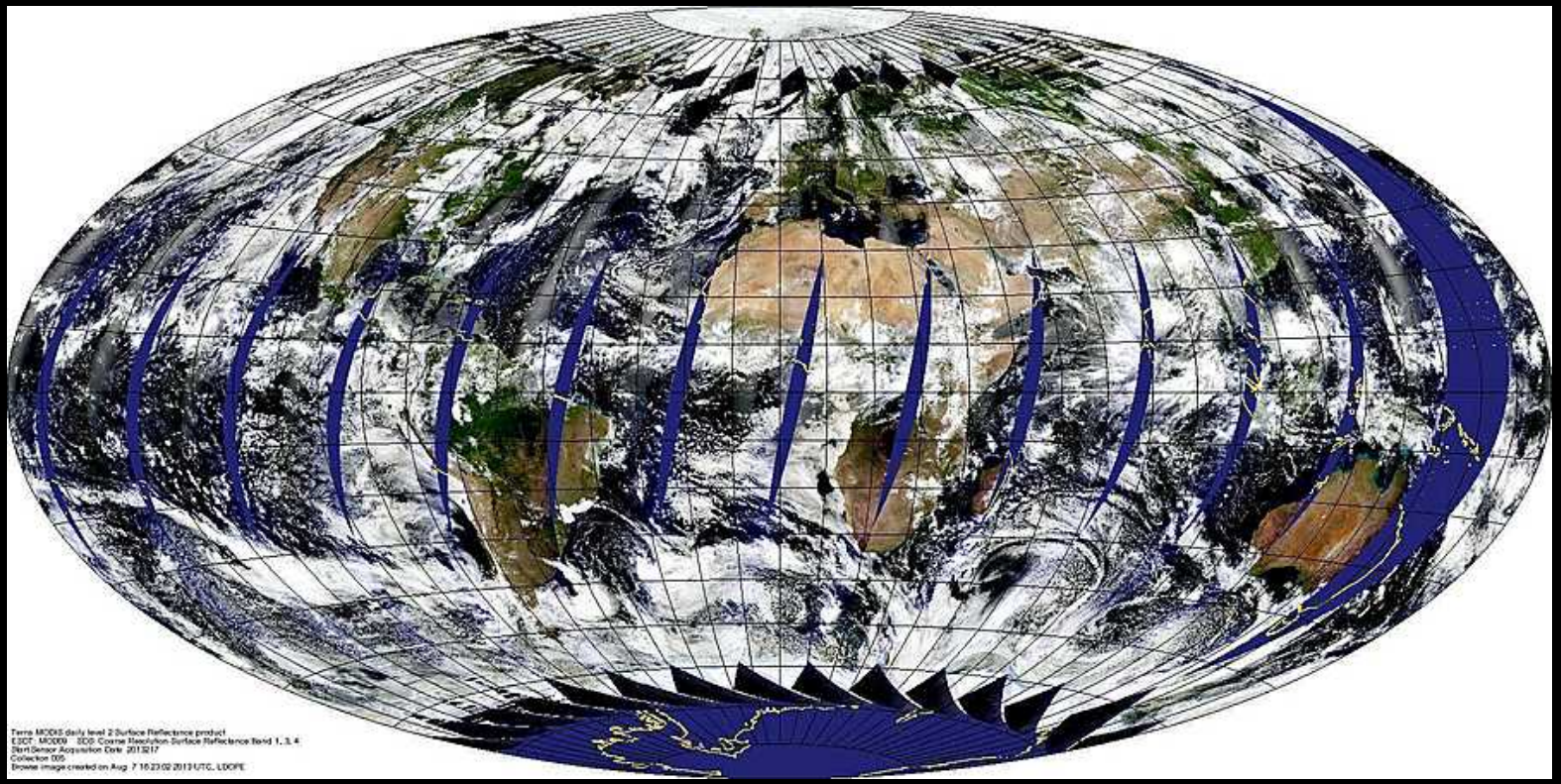
100% 0%

From: *Ju J. & Roy D. (2008)*

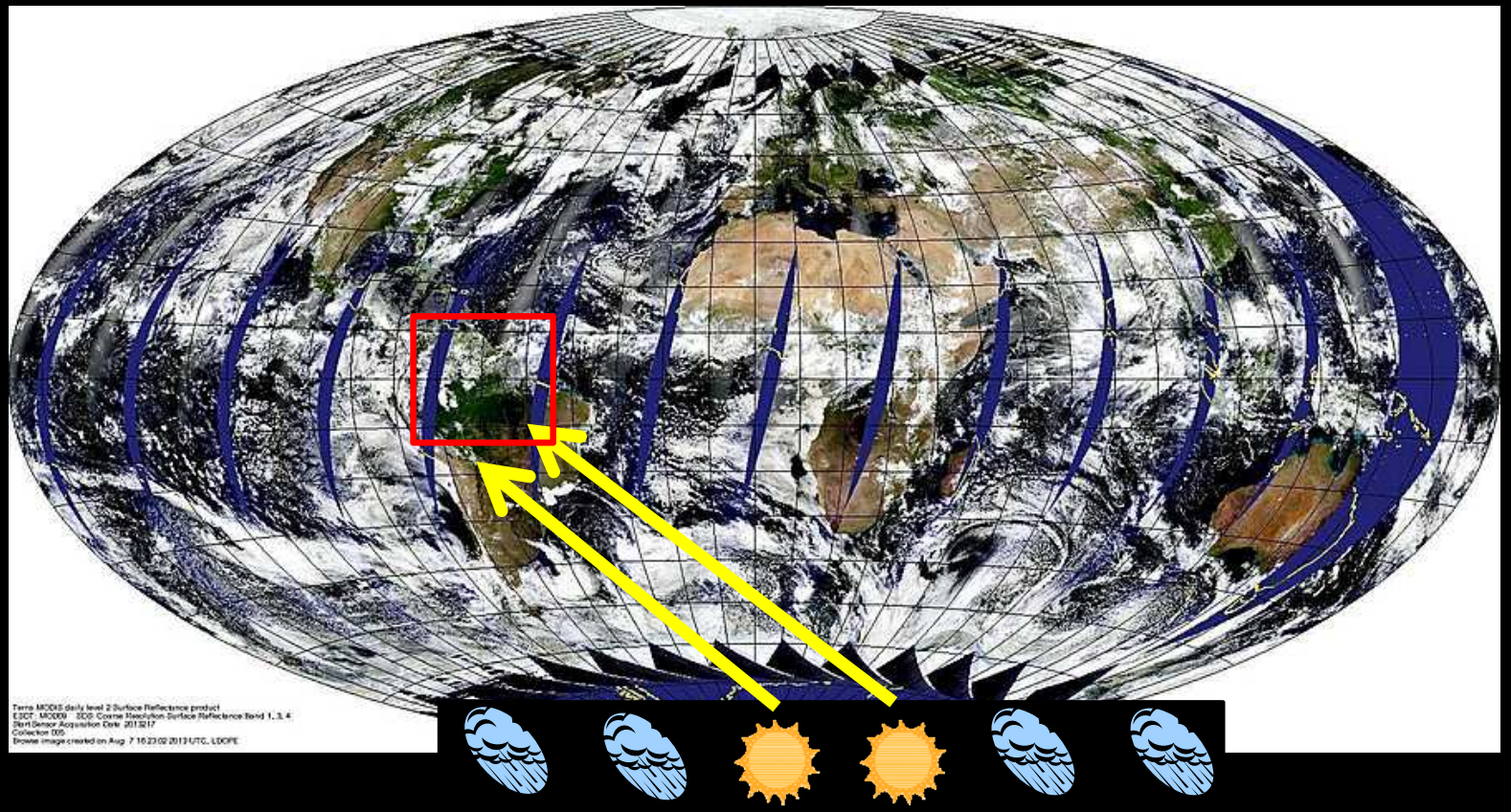
Cloud-free observation frequency for selected 30m pixels in Brazil (P228 R68) and Indonesia (P117 R61)

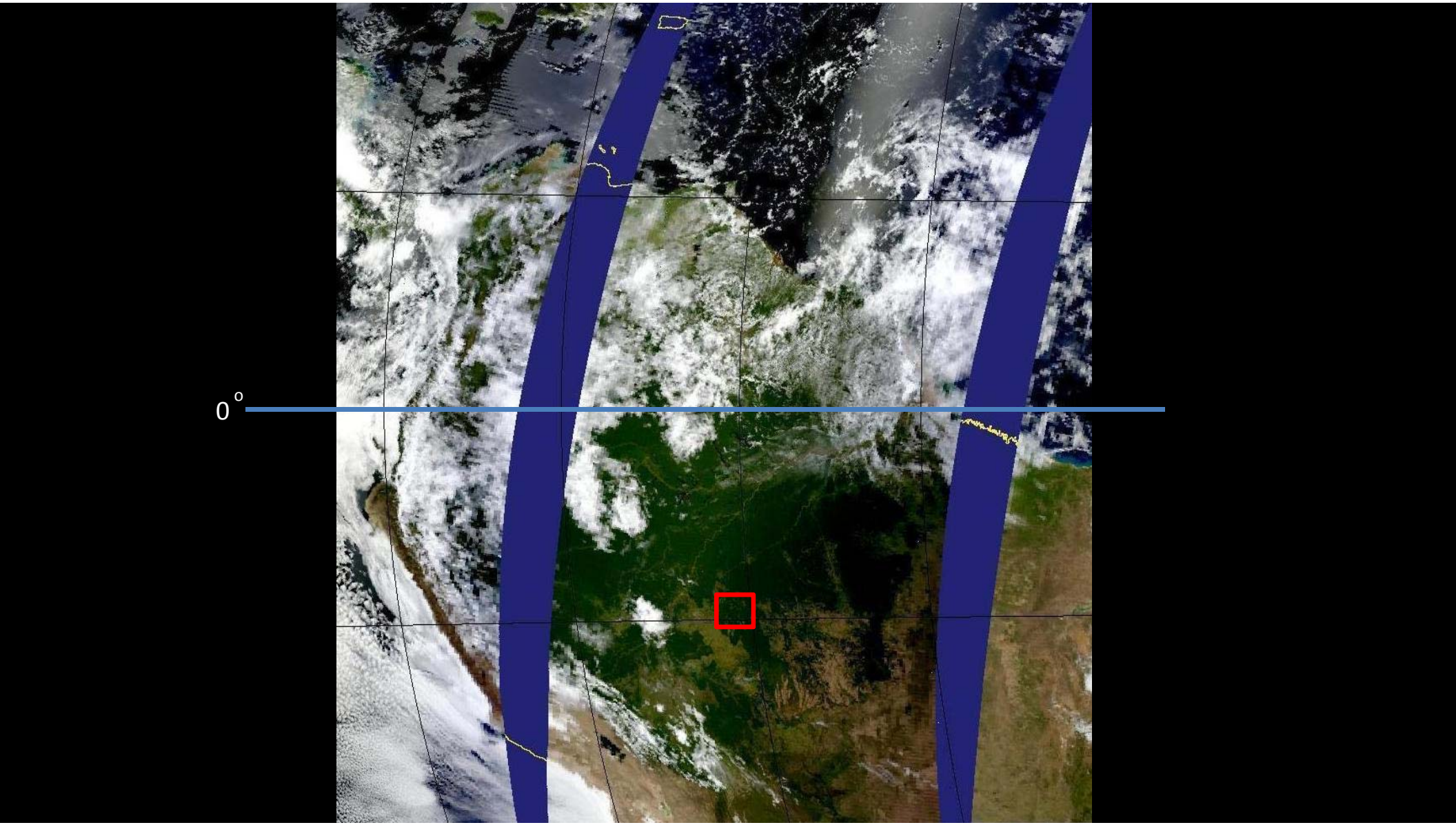


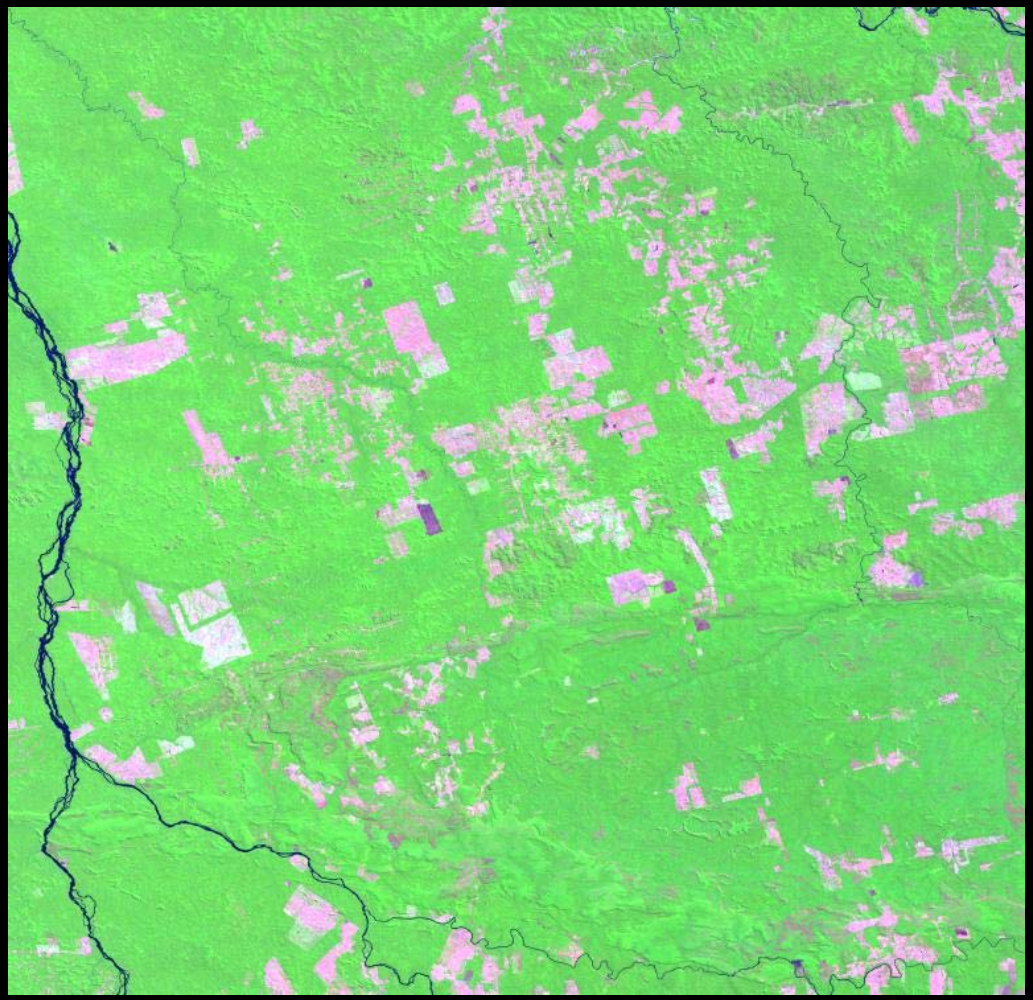
Daily MODIS image for August 5, 2013



Seasonally cloud-free window over the southern Amazon

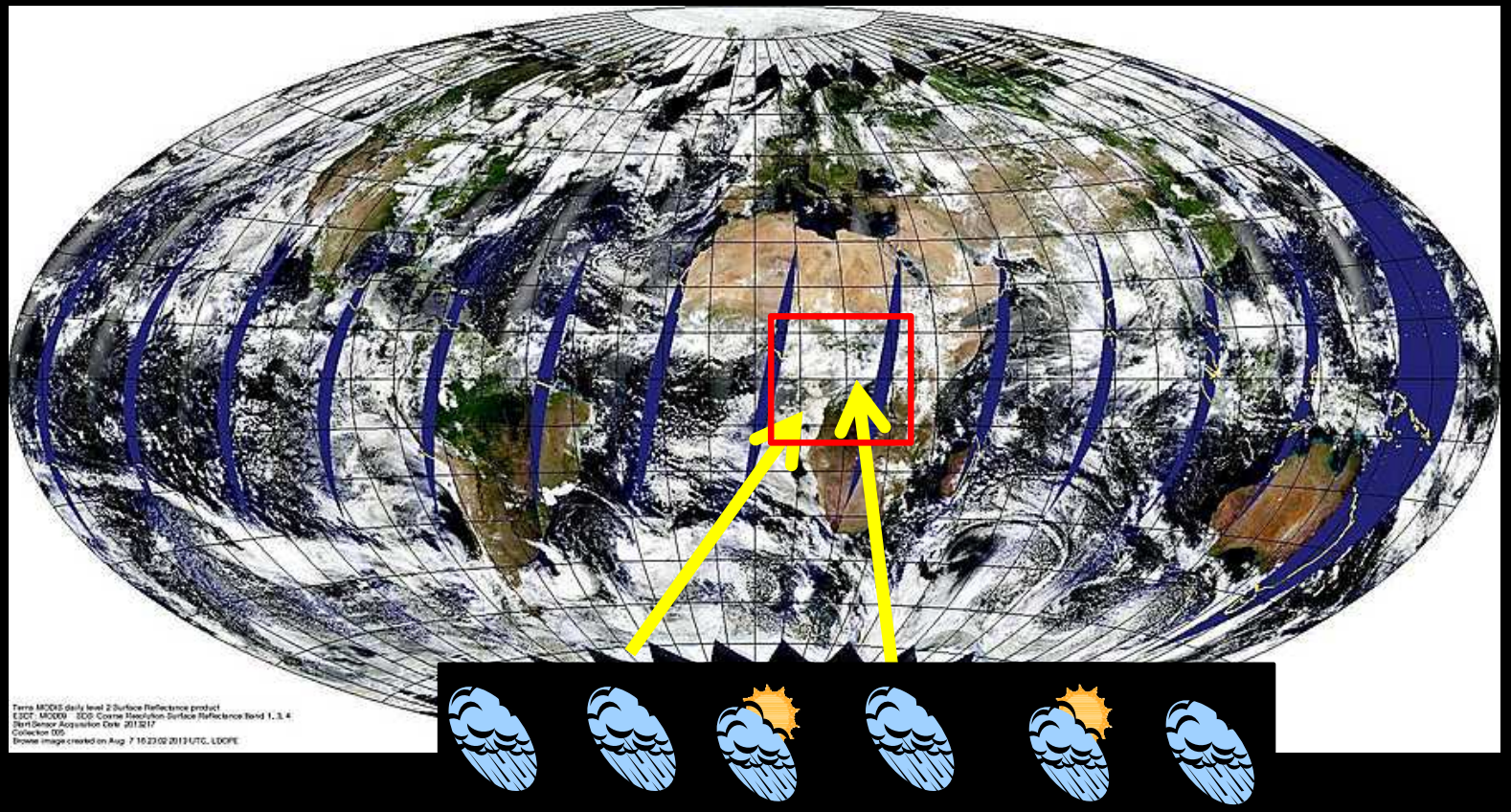


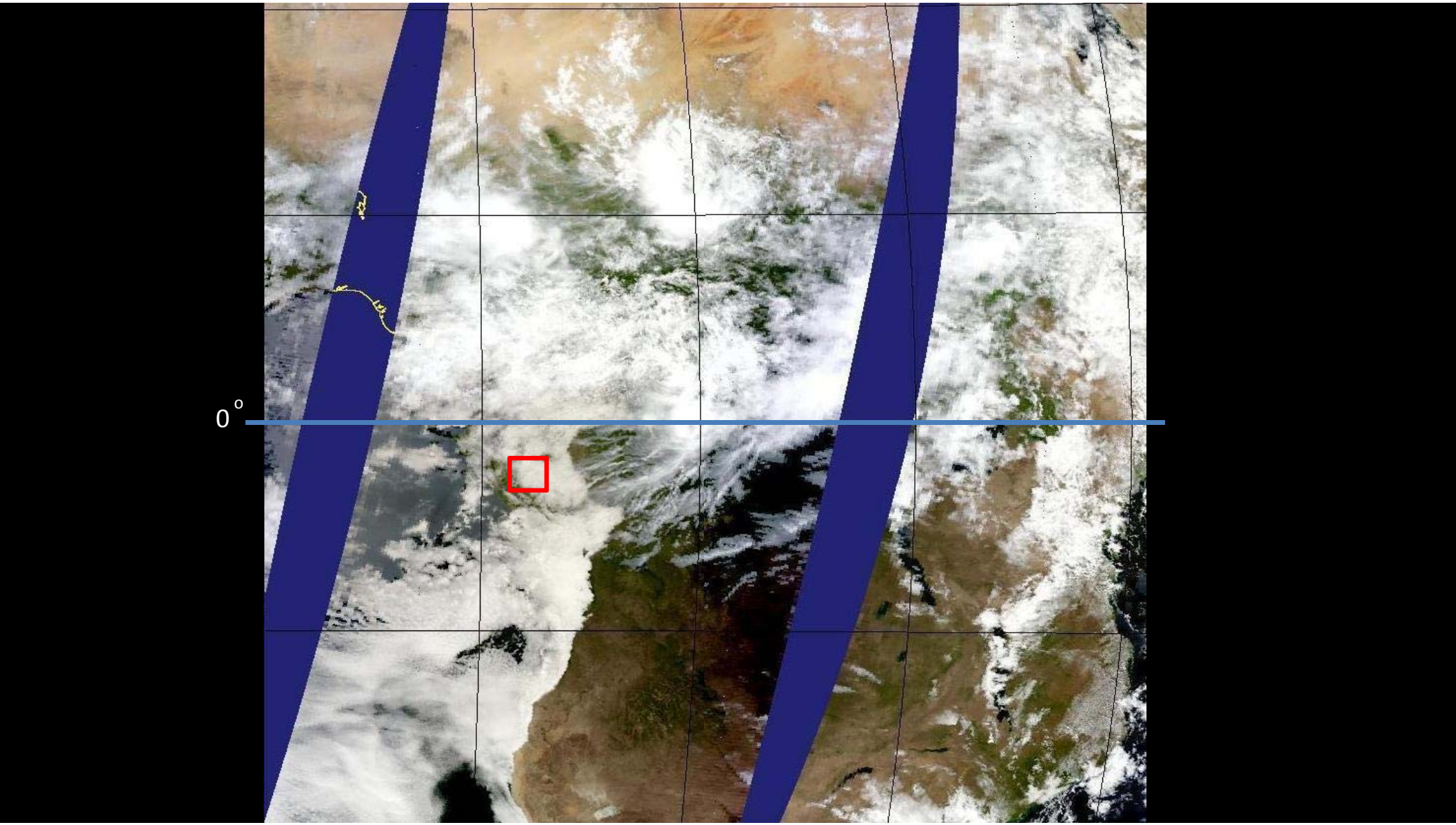

0 °

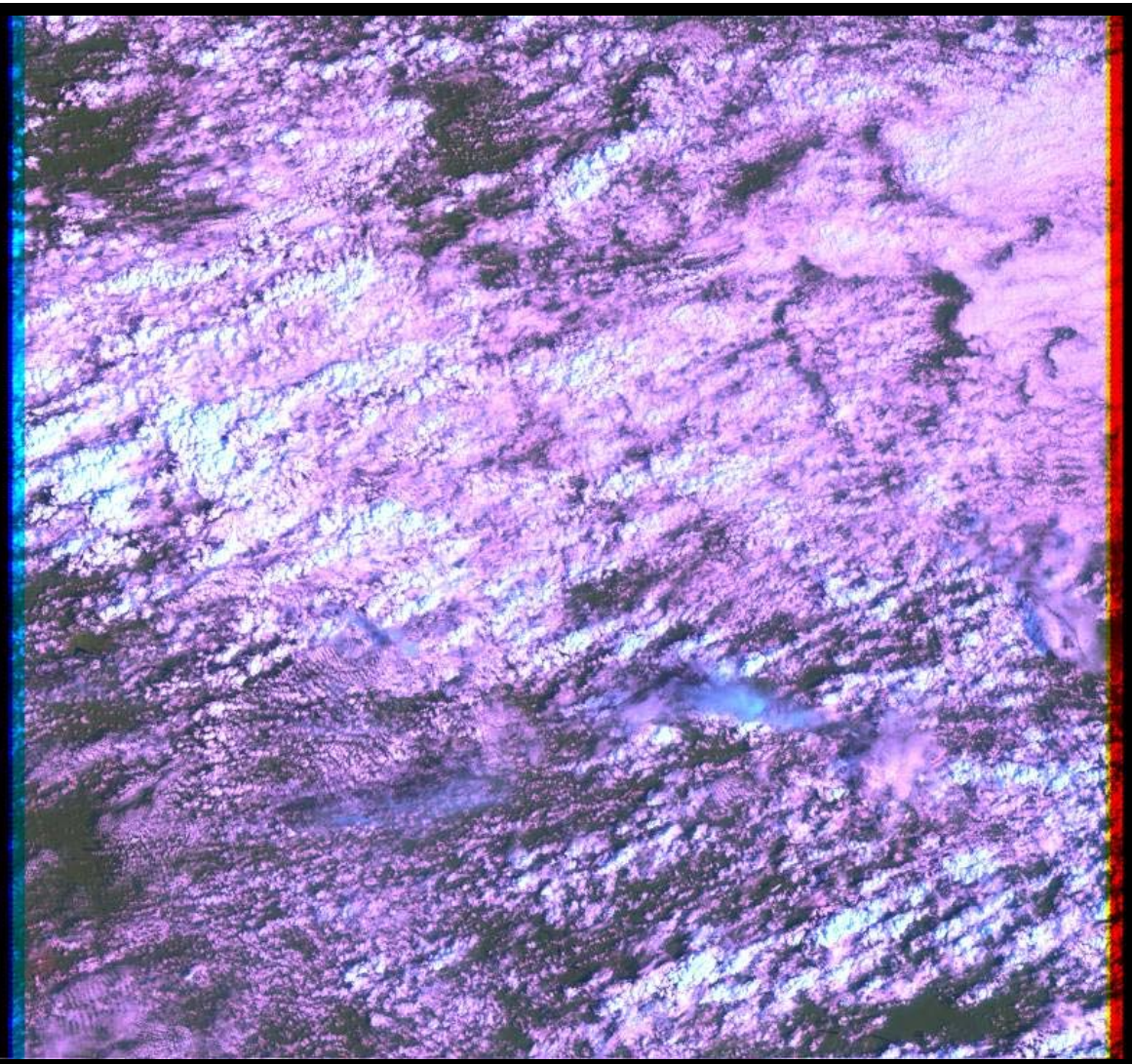


2000 day 208

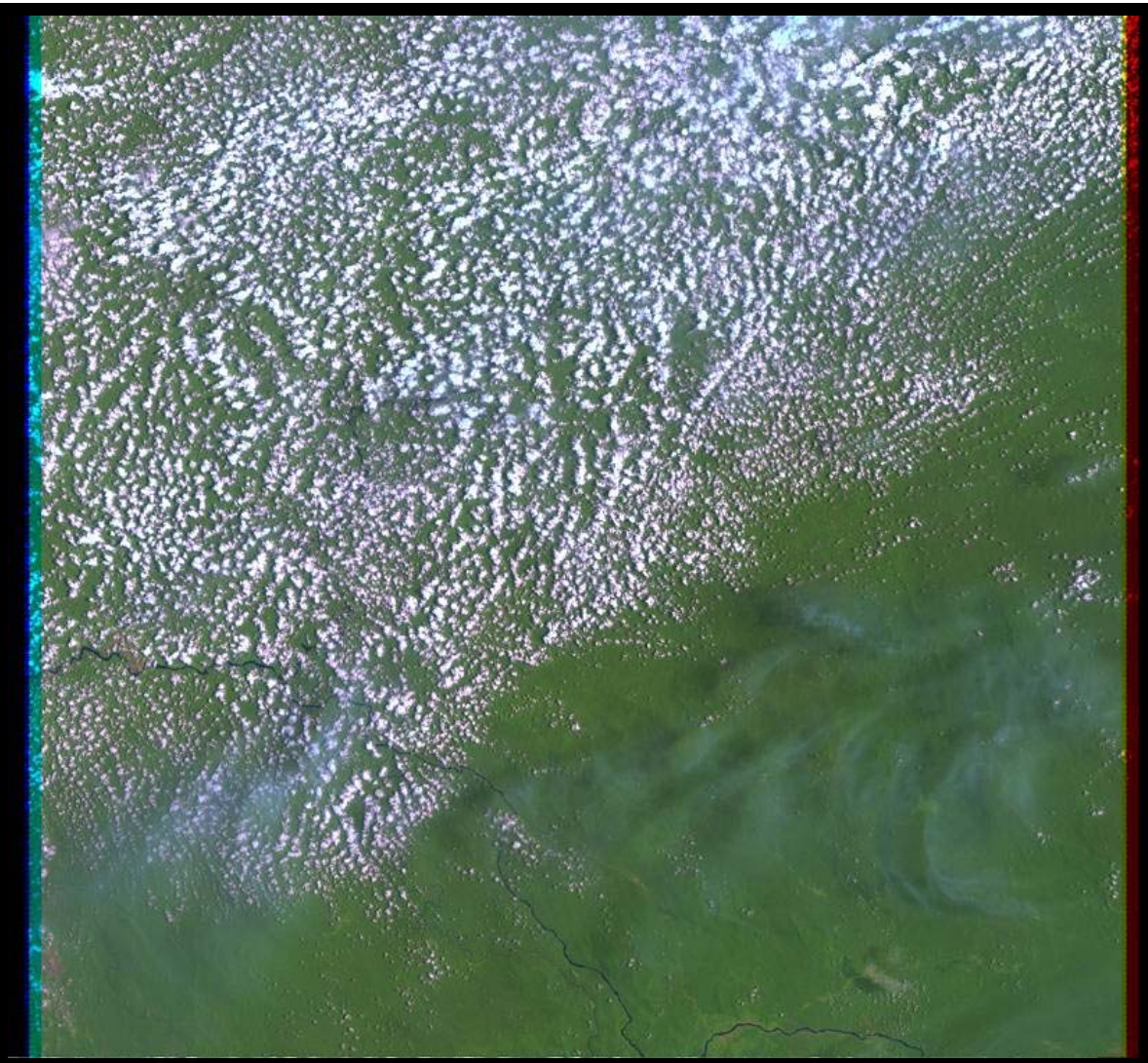
Conversely, Central Africa is persistently cloudy



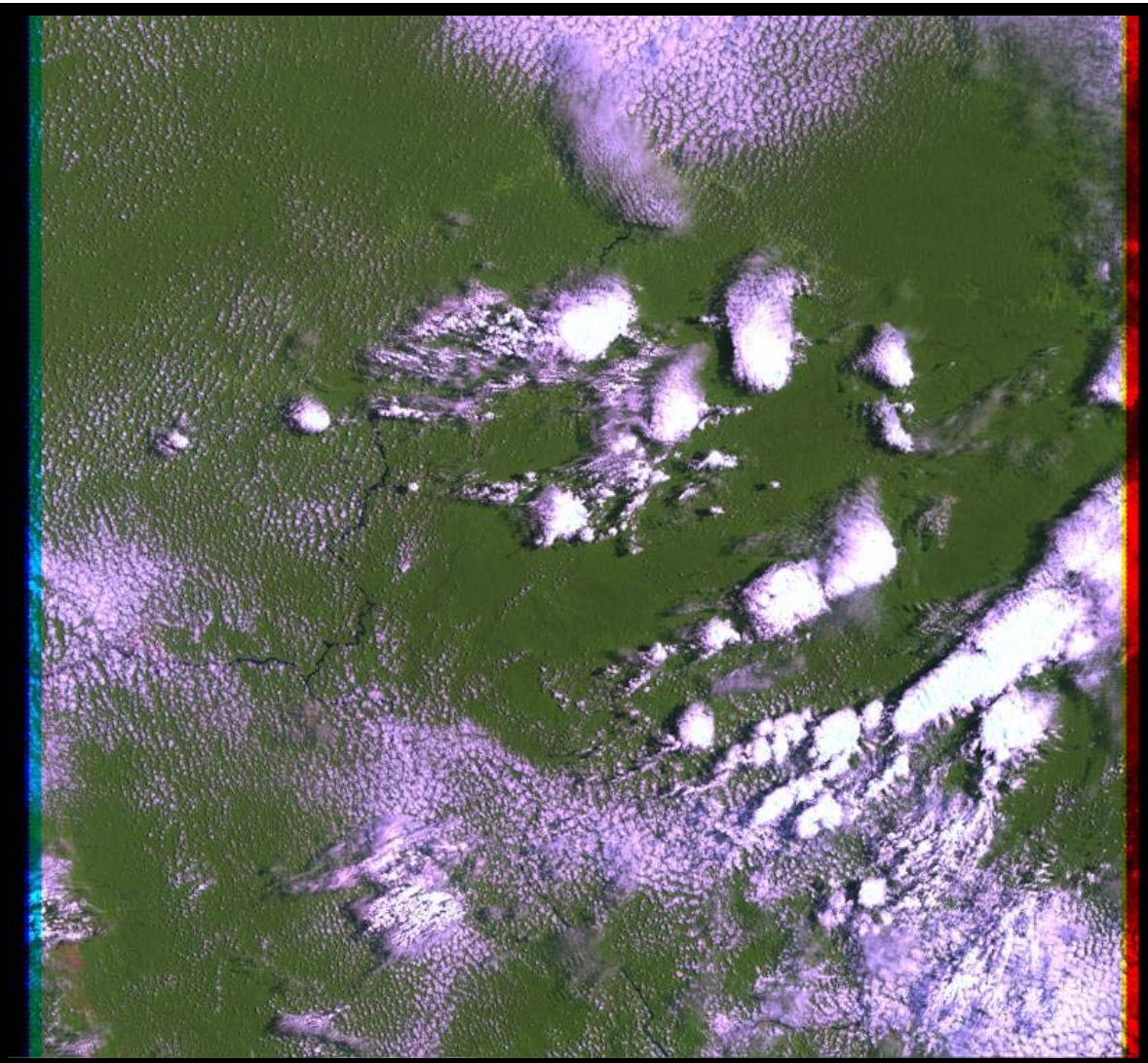

0 °



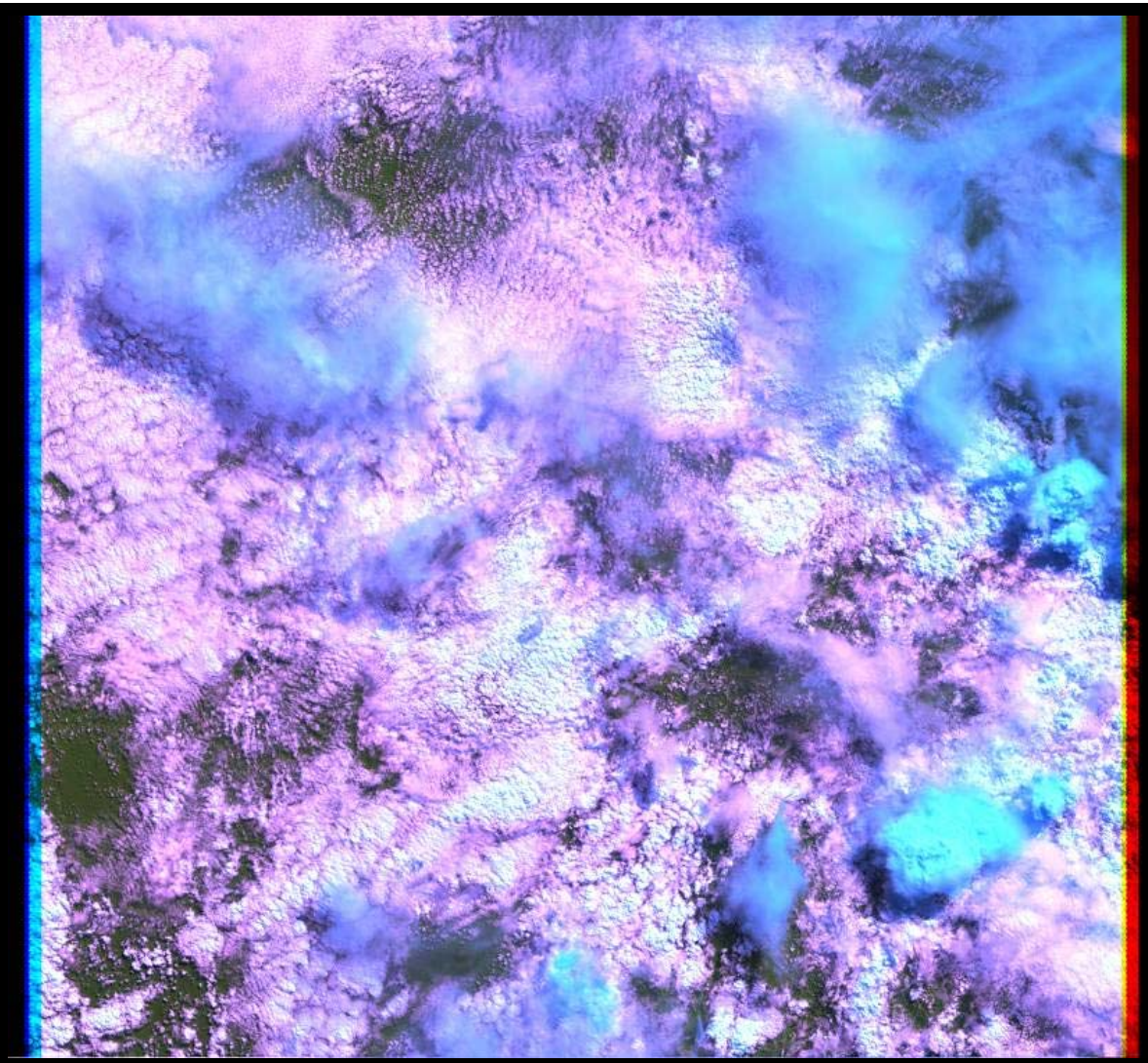
2000 day 36



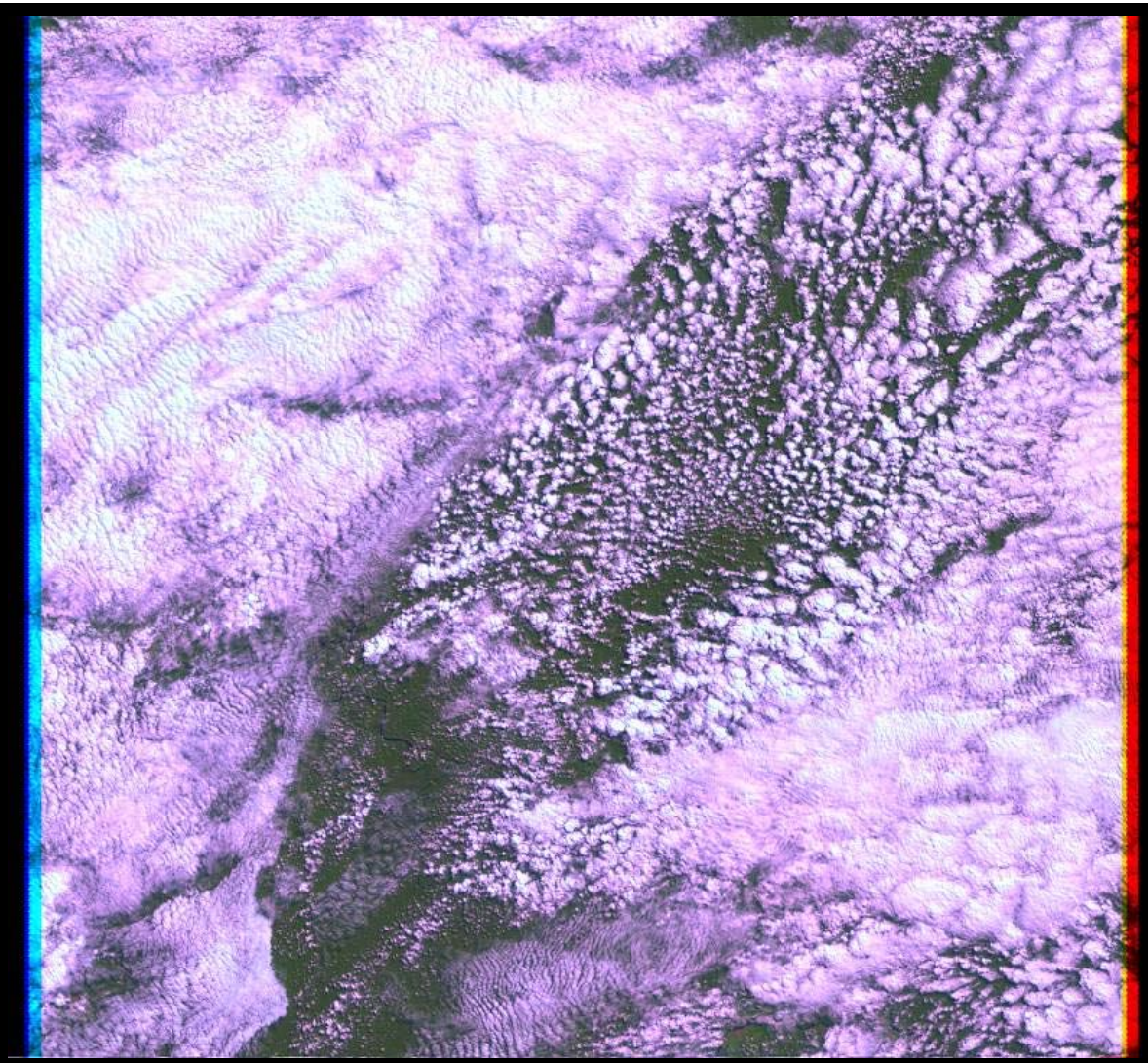
2000 day 68



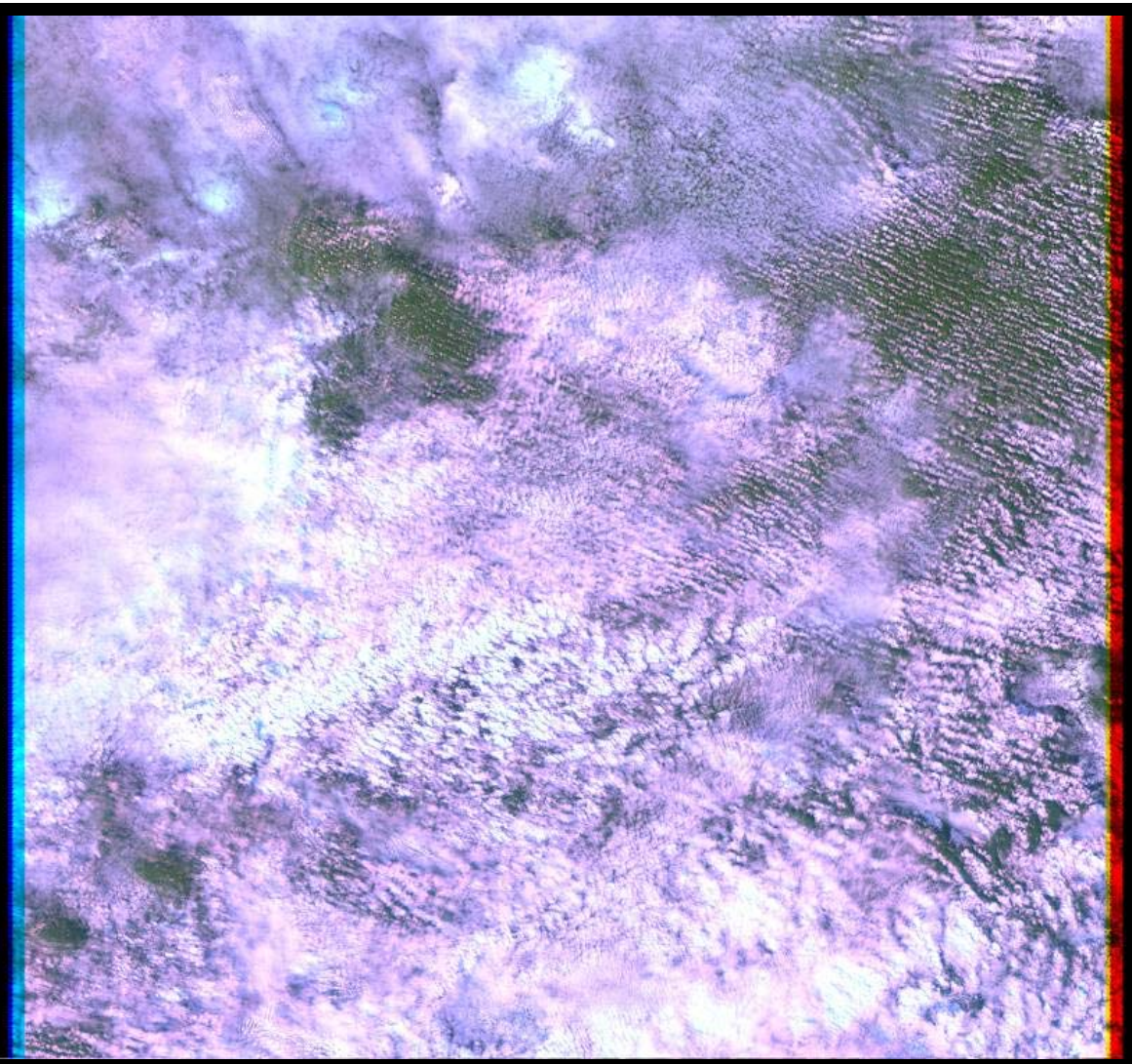
2000 day 84



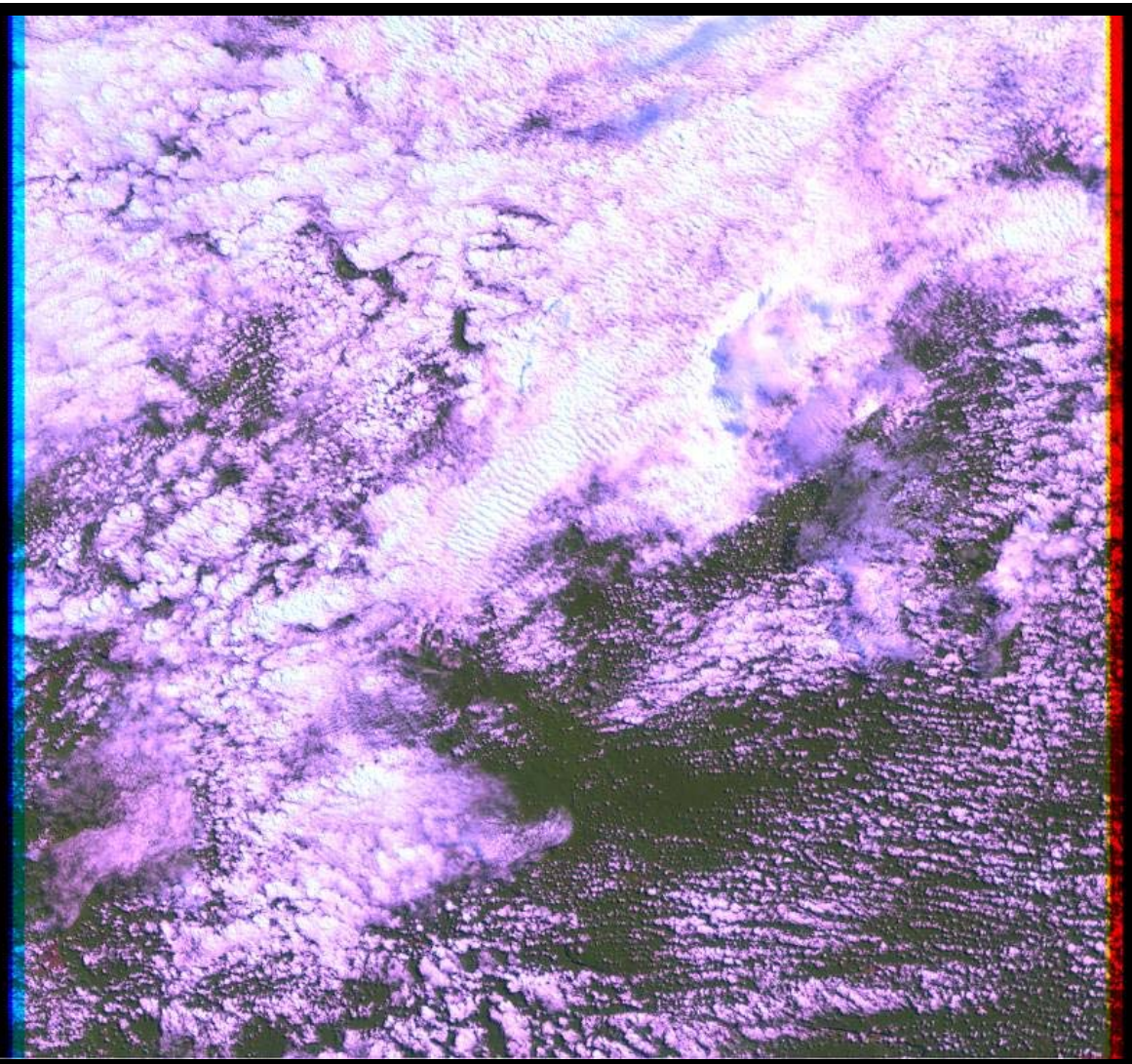
2000 day 180



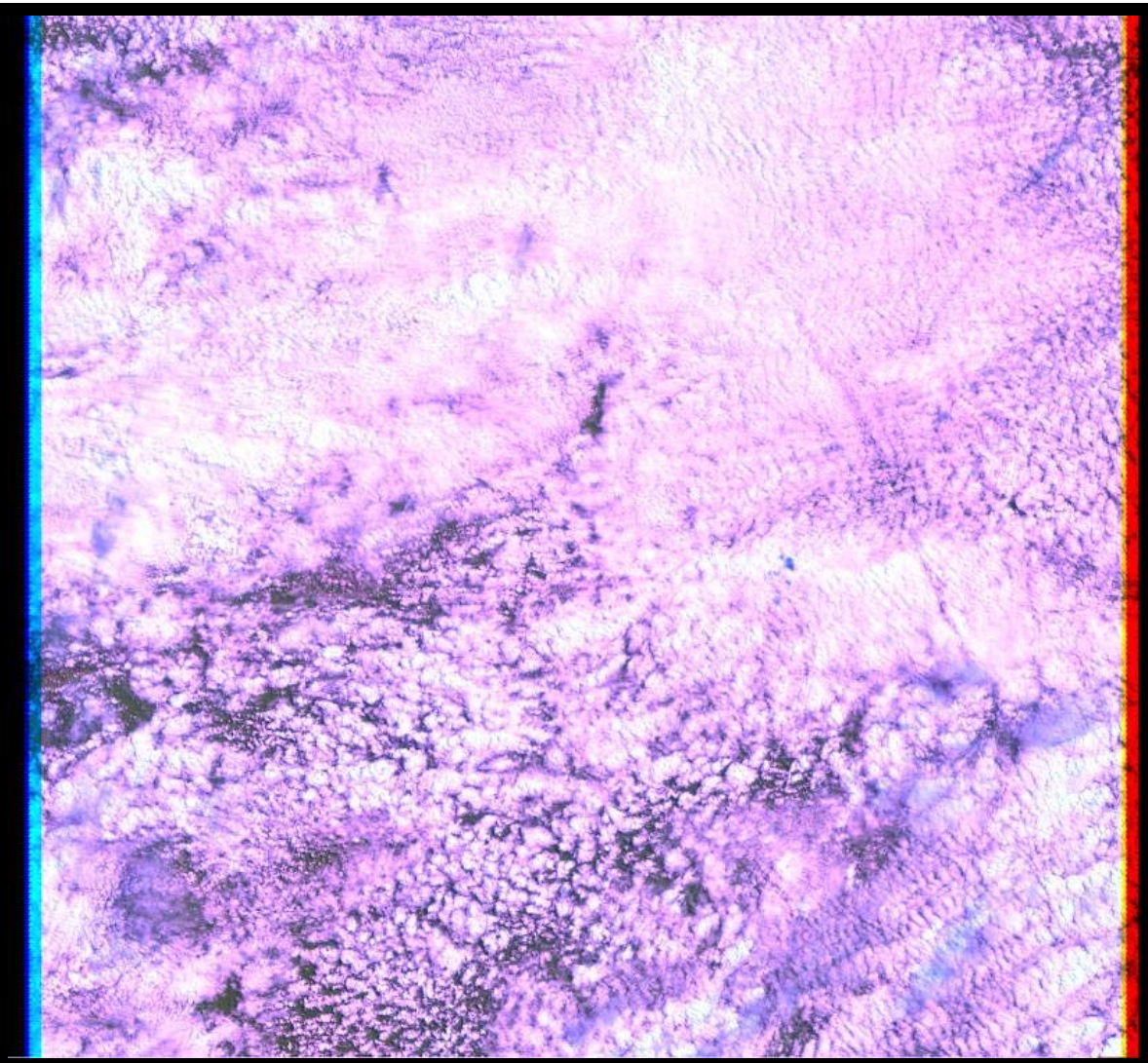
2000 day 196



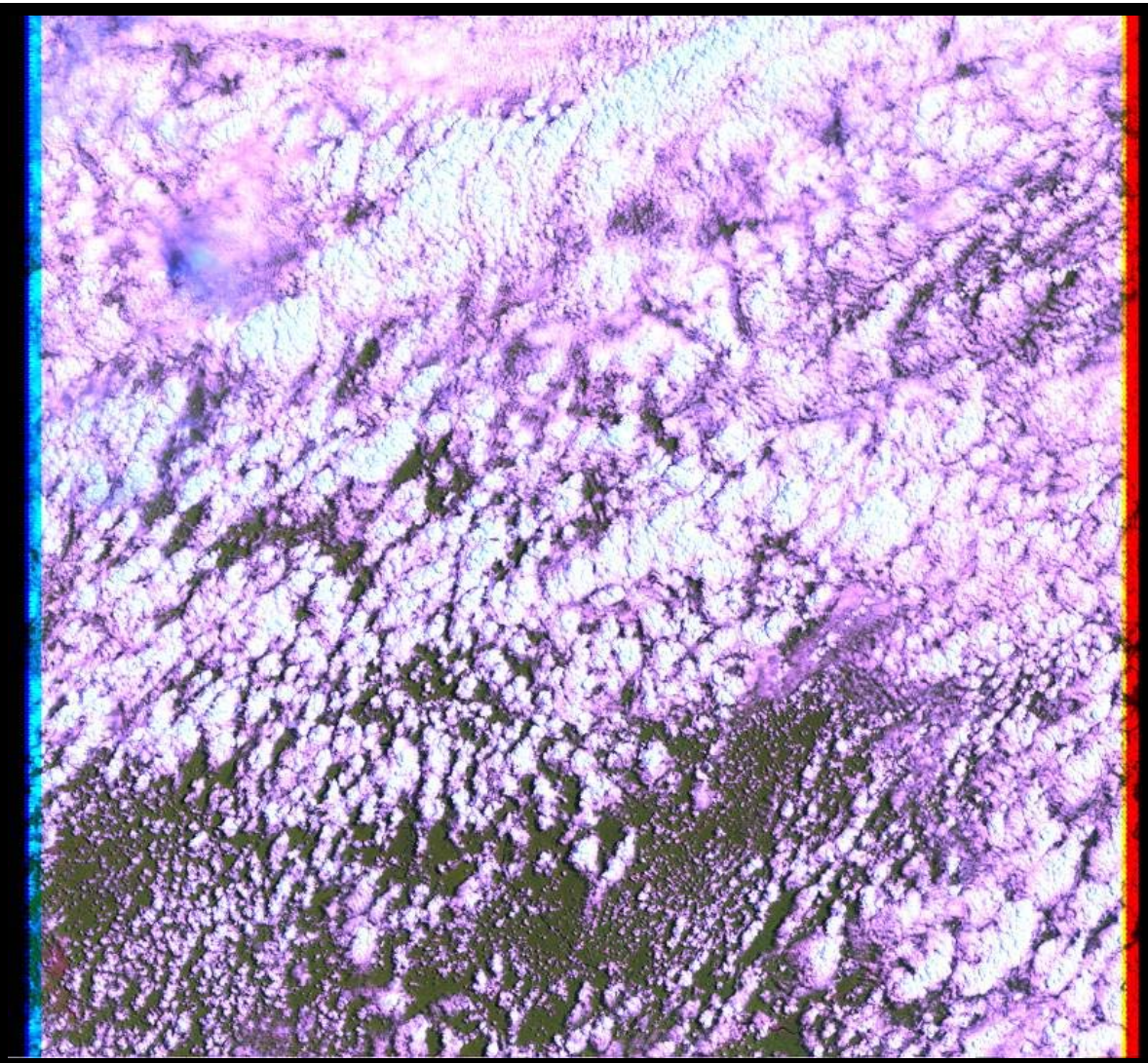
2000 day 212



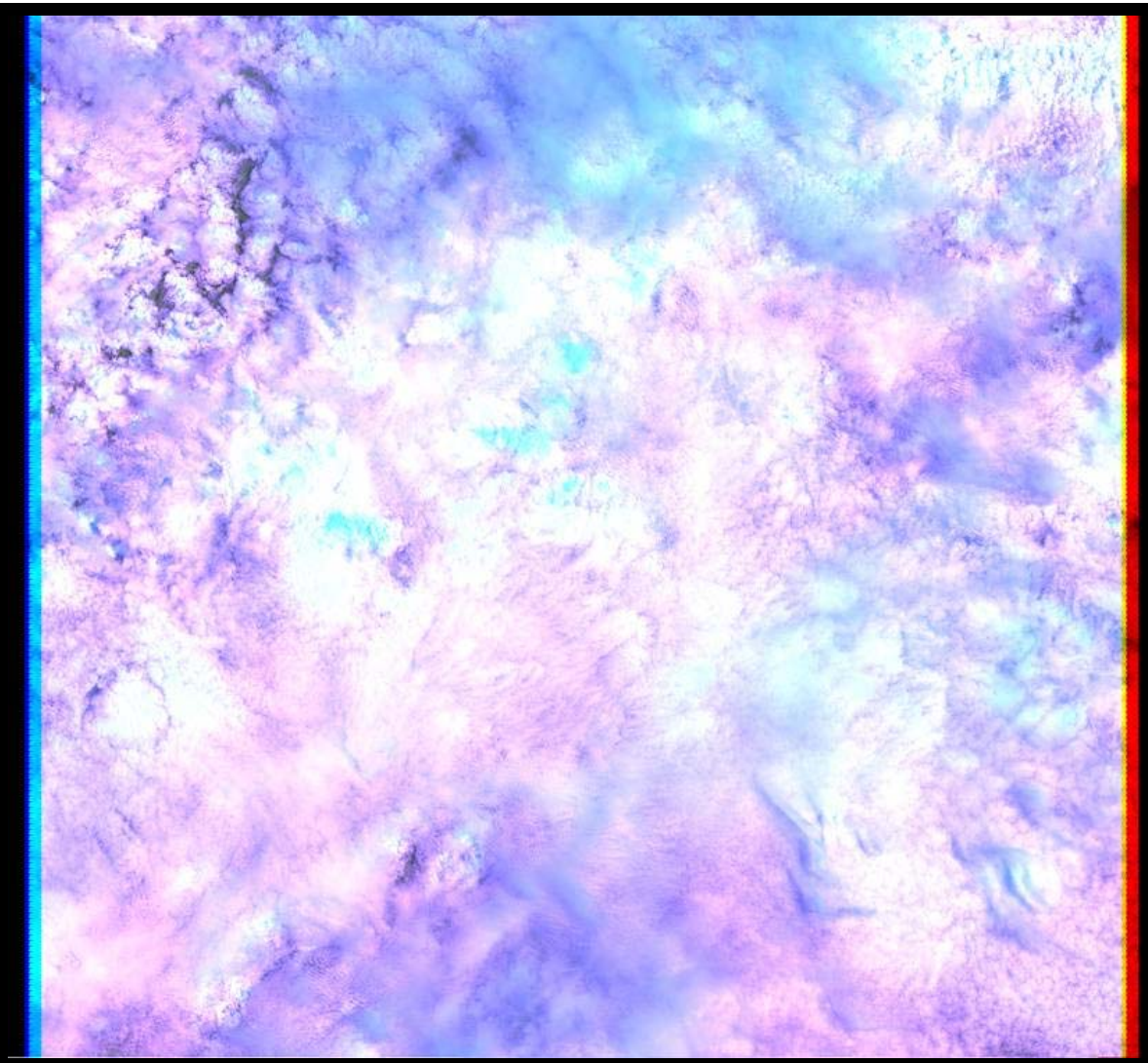
2000 day 228



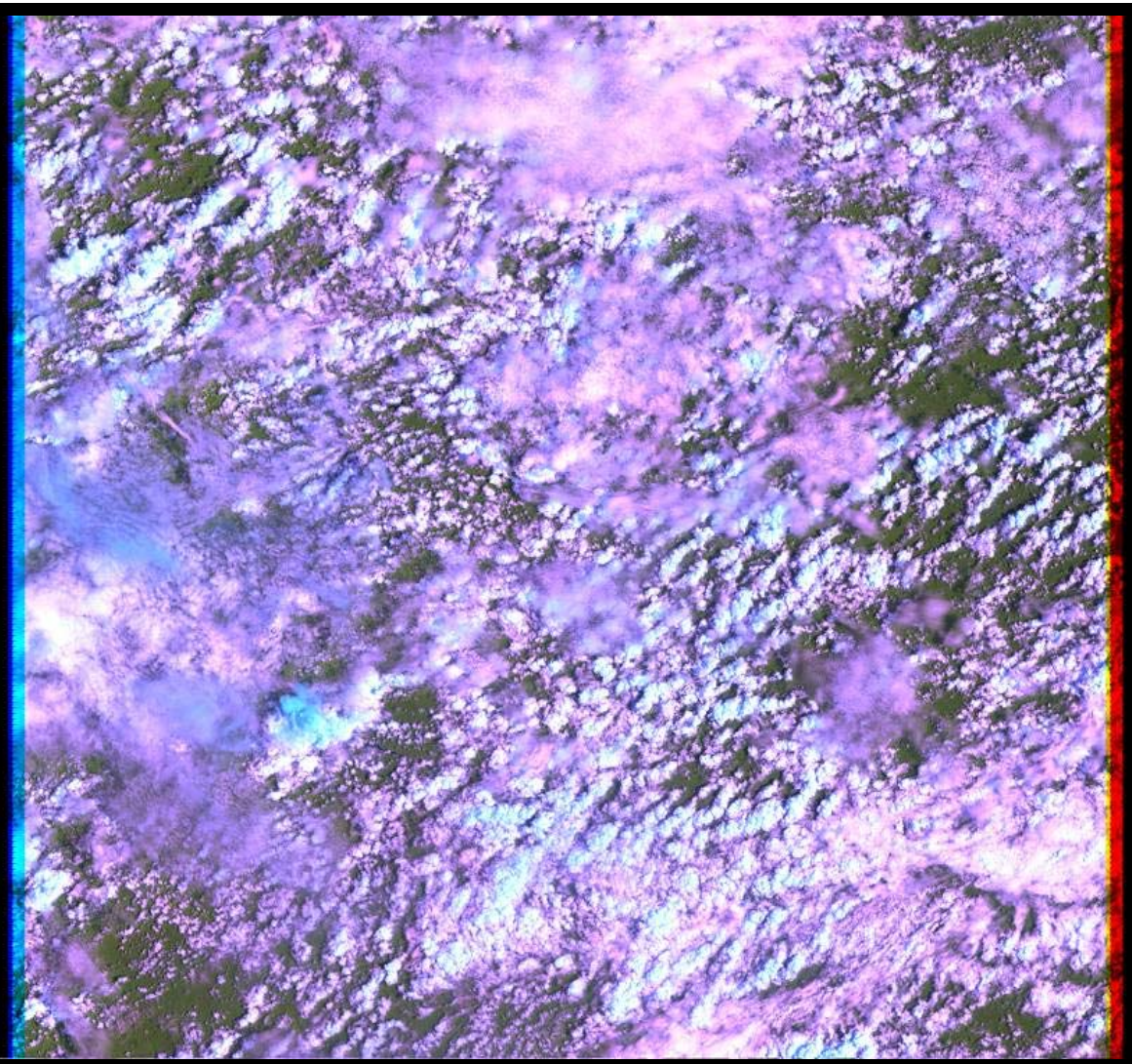
2000 day 244



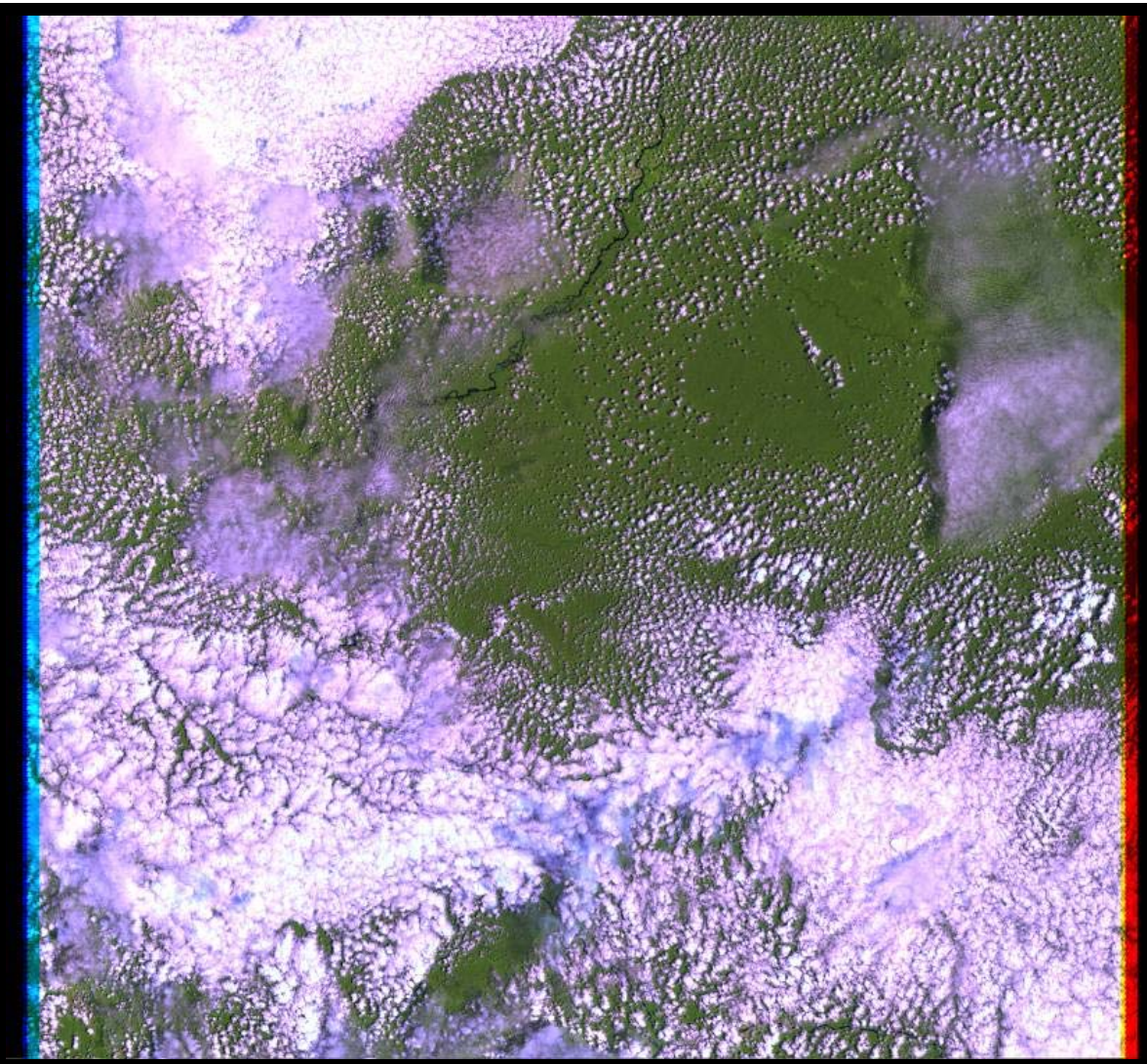
2000 day 260



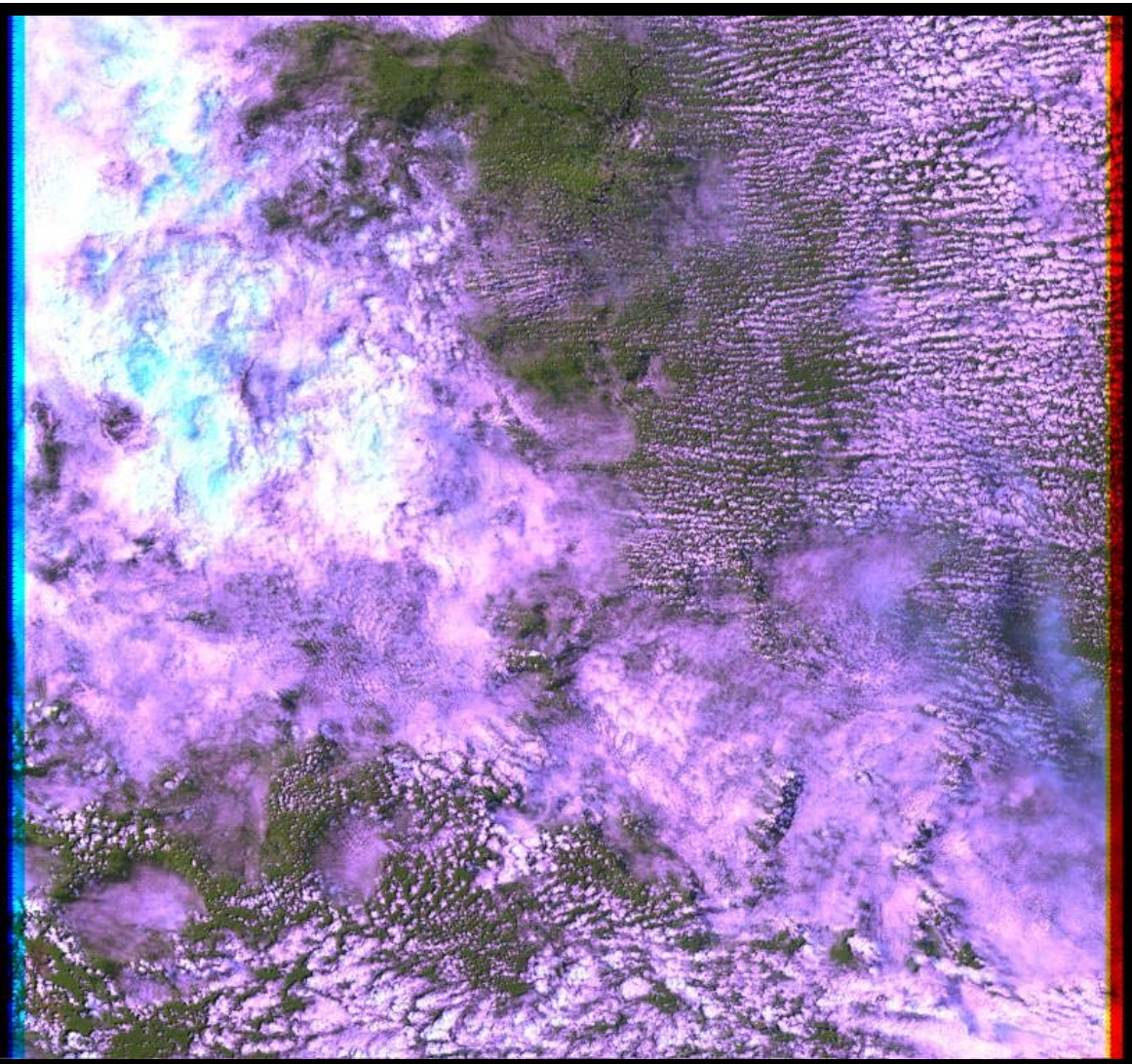
2000 day 276



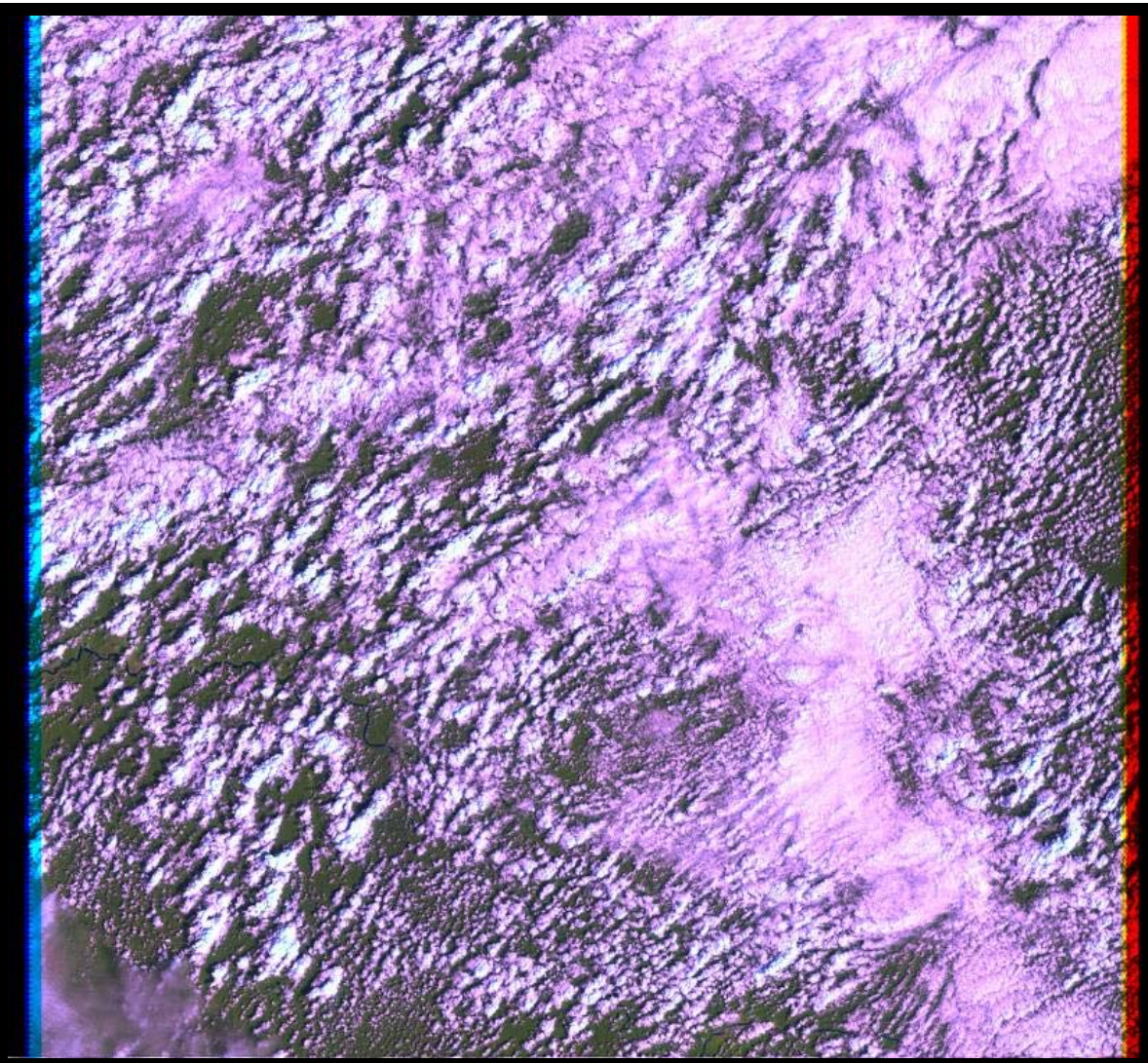
2000 day 292



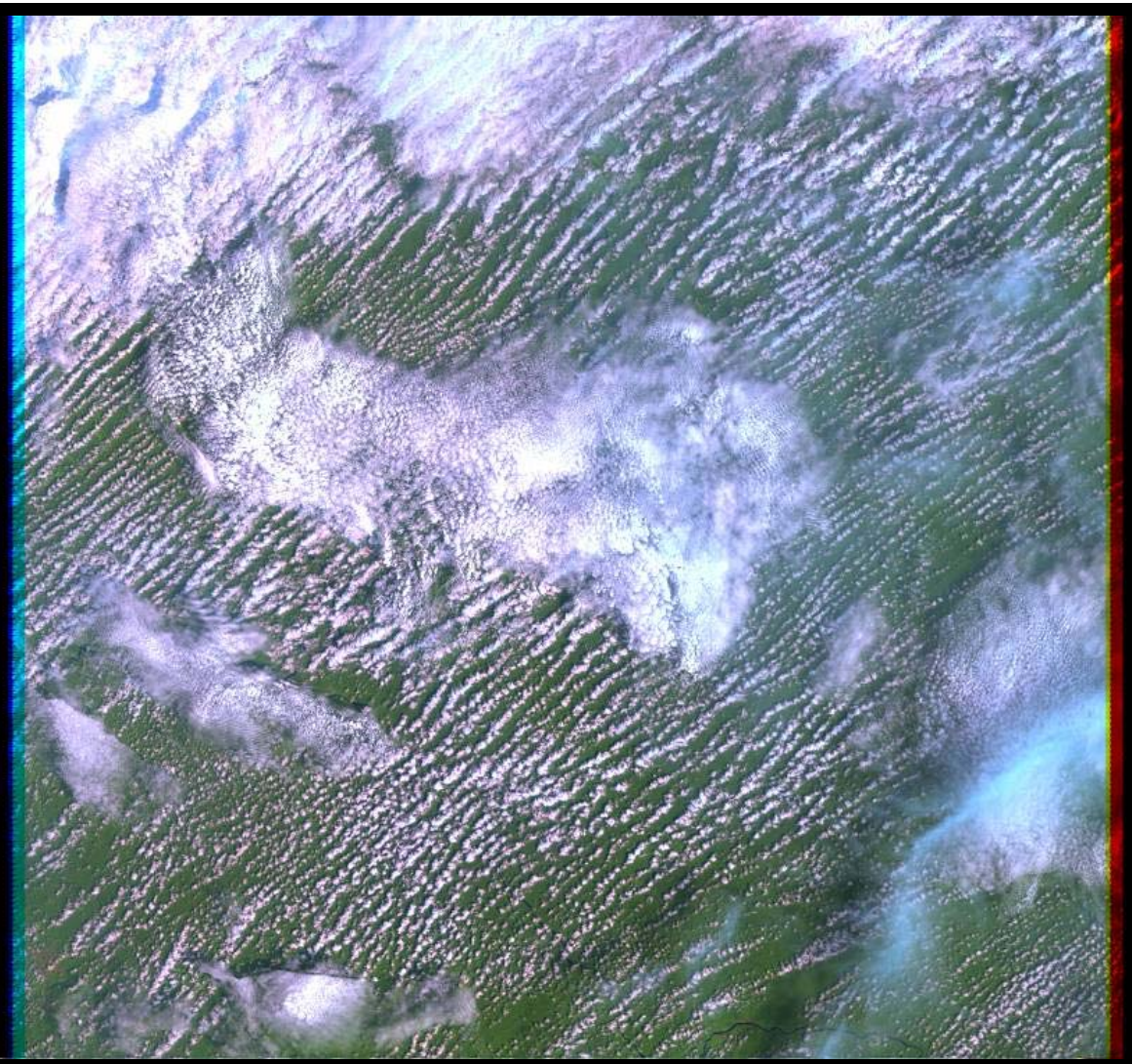
2000 day 308



2000 day 324



2000 day 340



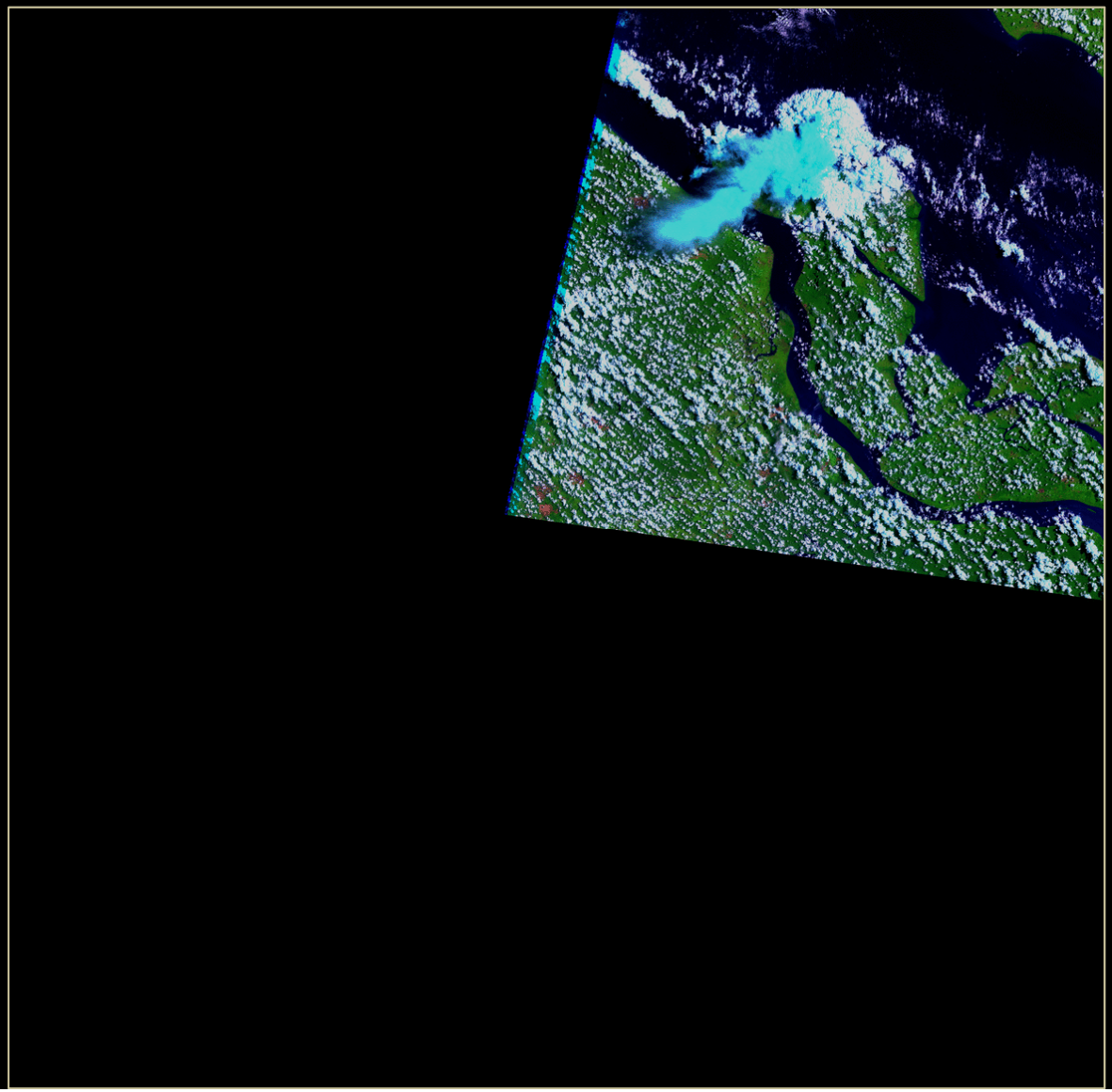
2000 day 356

~2000 image composite

Indonesia

Indonesia, Riau province

Image# : 001 WRS : 126059 Year : 1999 Day : 251

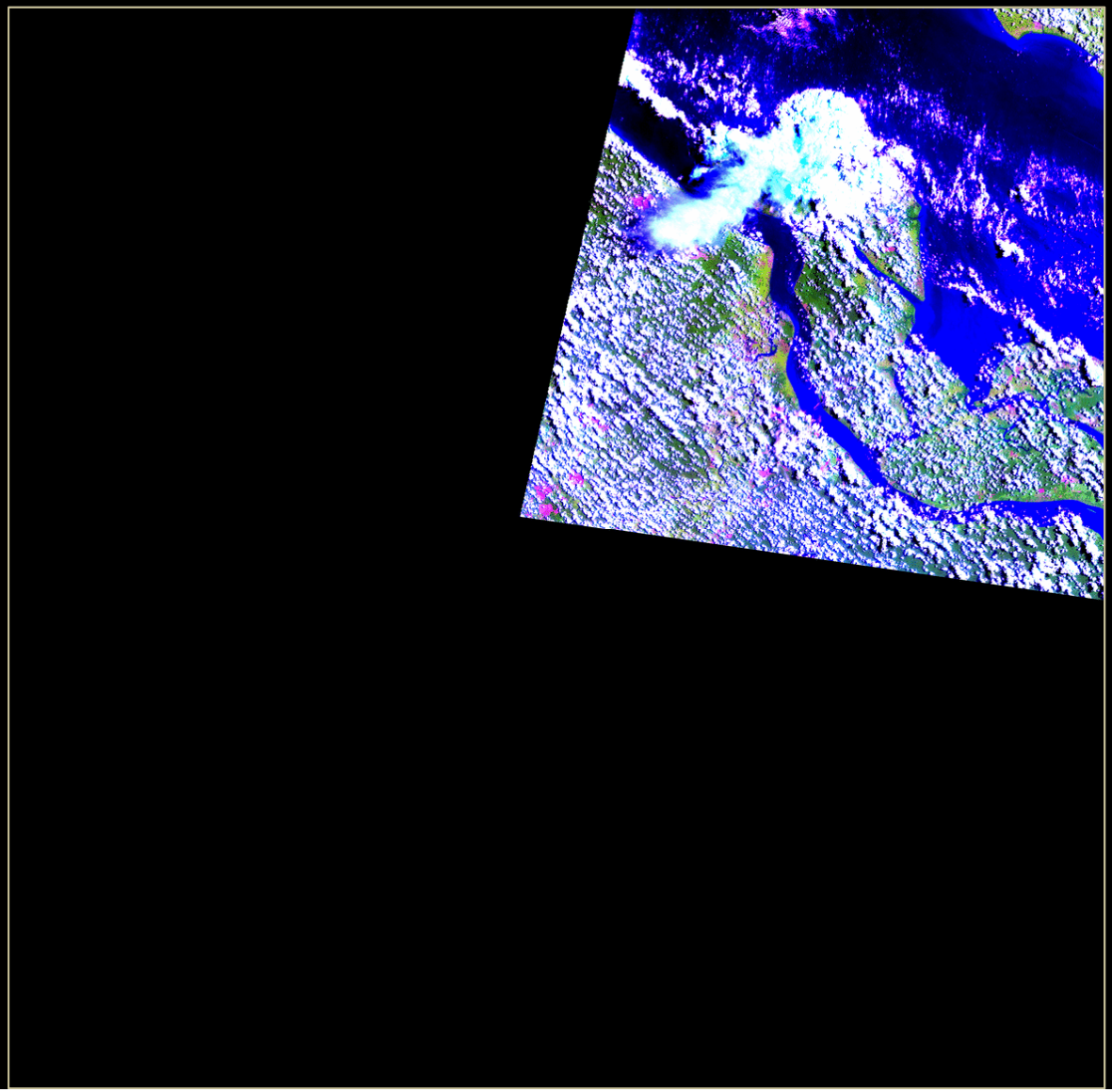


Indonesia, Riau province

Image Process

- Raw Digital Numbers

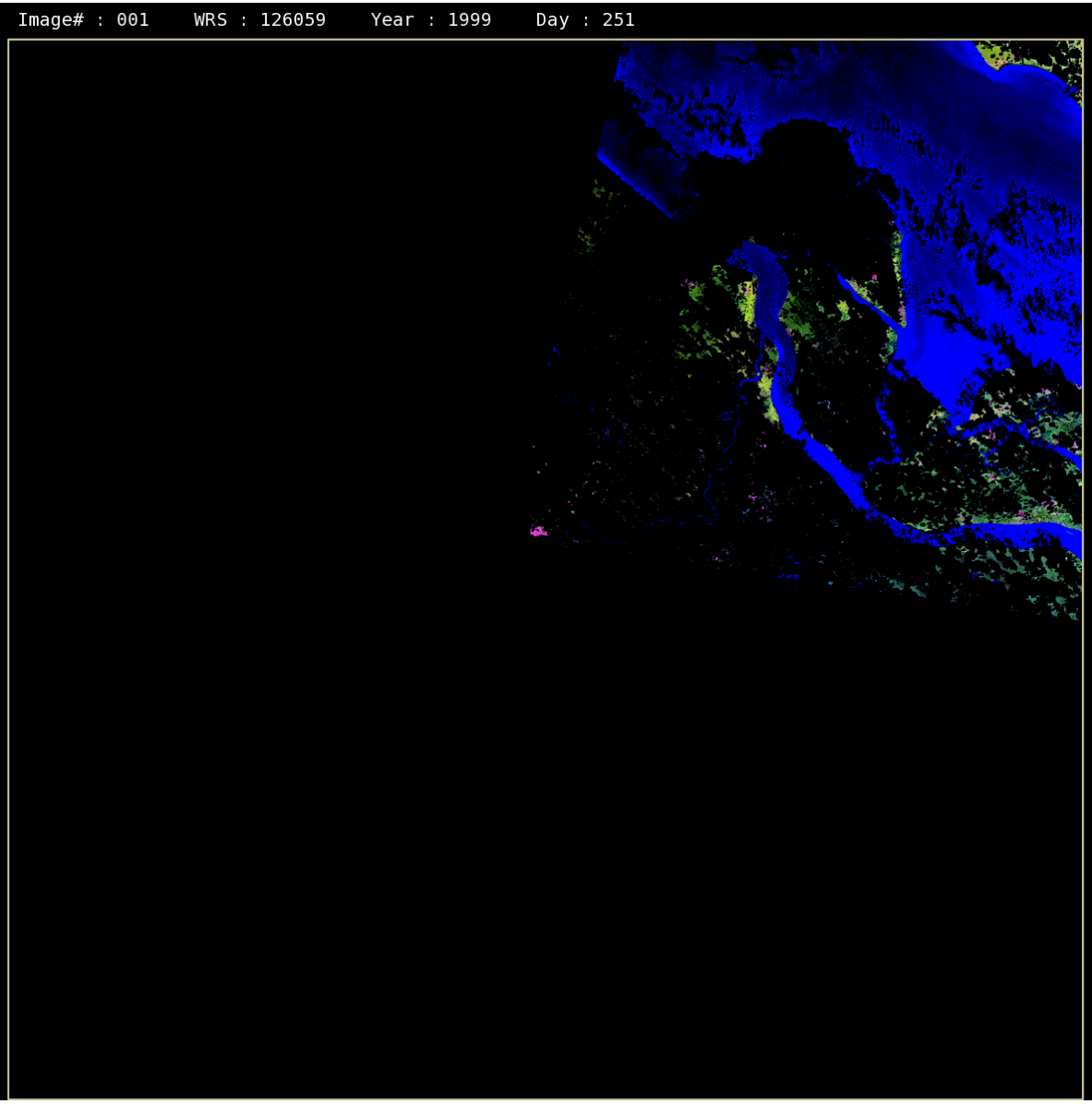
Image# : 001 WRS : 126059 Year : 1999 Day : 251



Indonesia, Riau province

Image Process

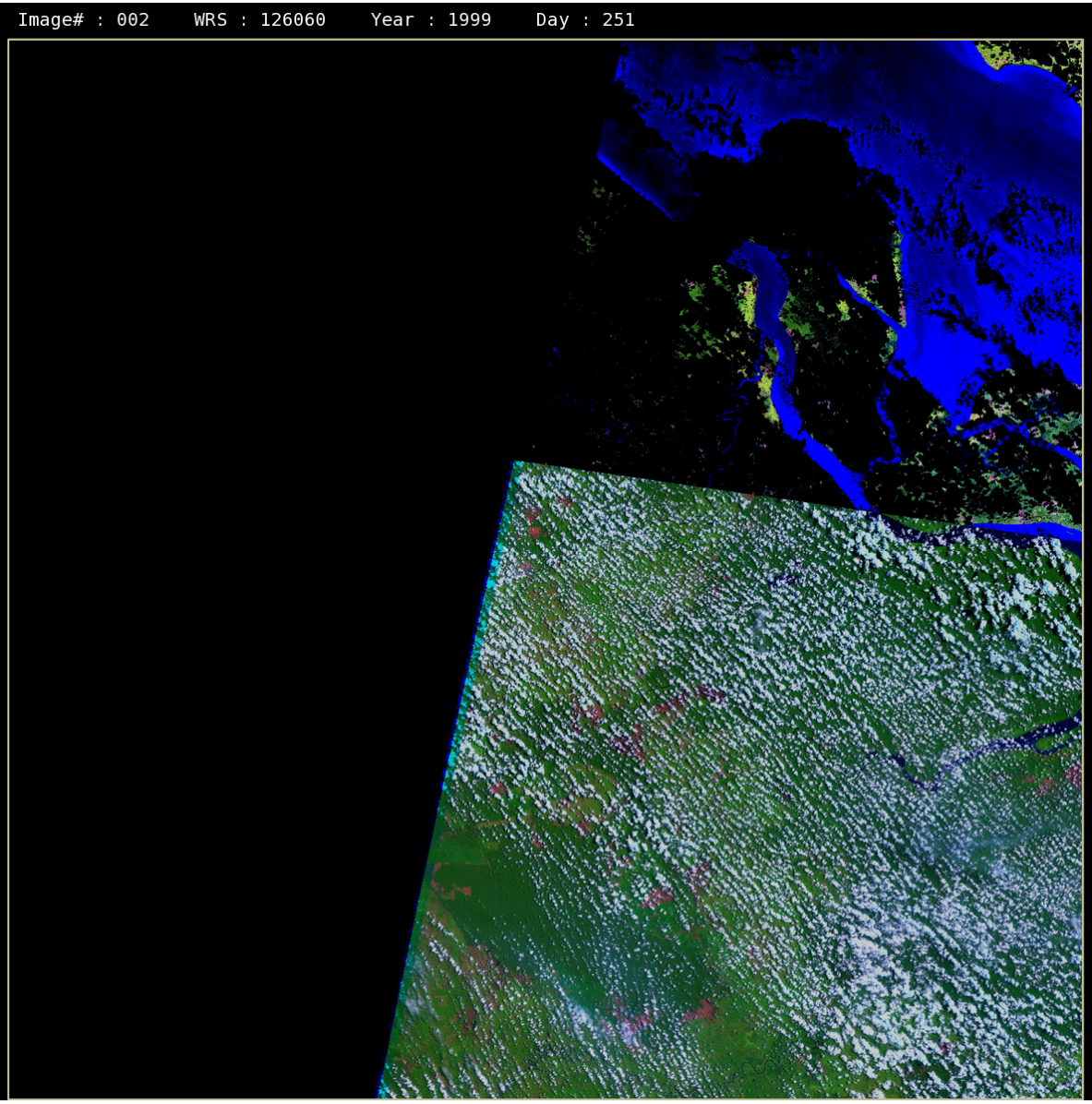
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization



Indonesia, Riau province

Image Process

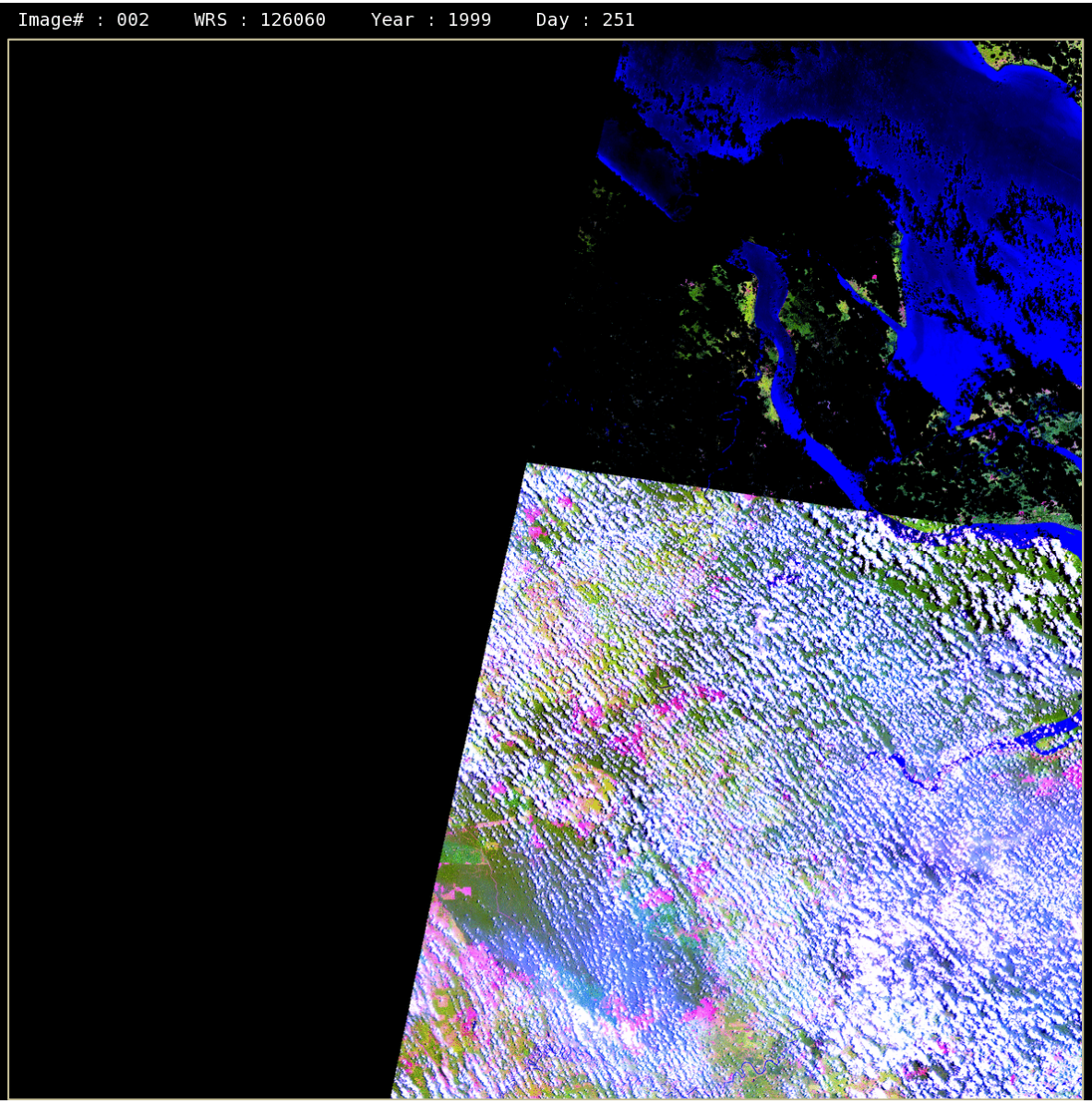
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing



Indonesia, Riau province

Image Process

- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing

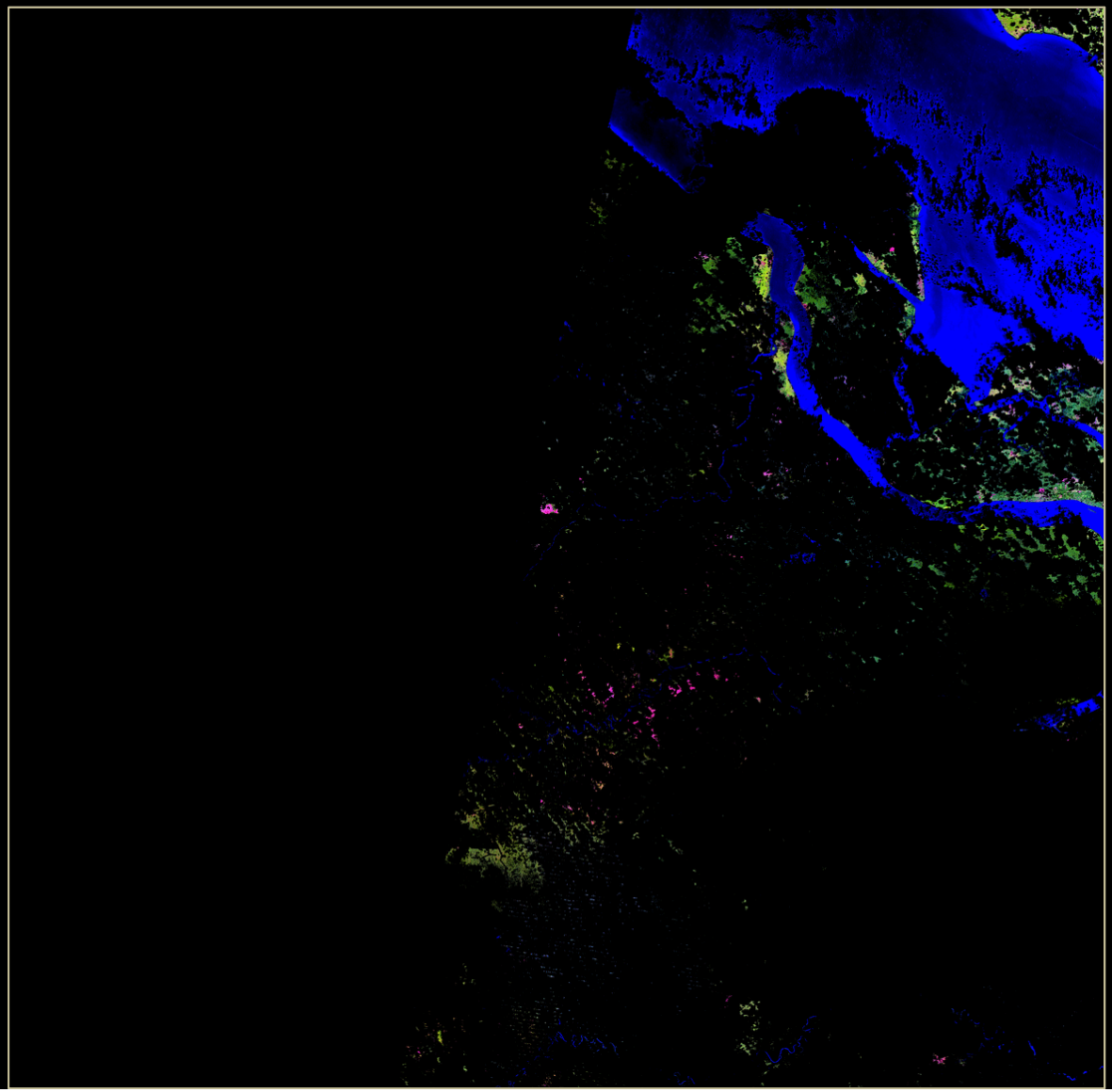


Indonesia, Riau province

Image Process

- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing

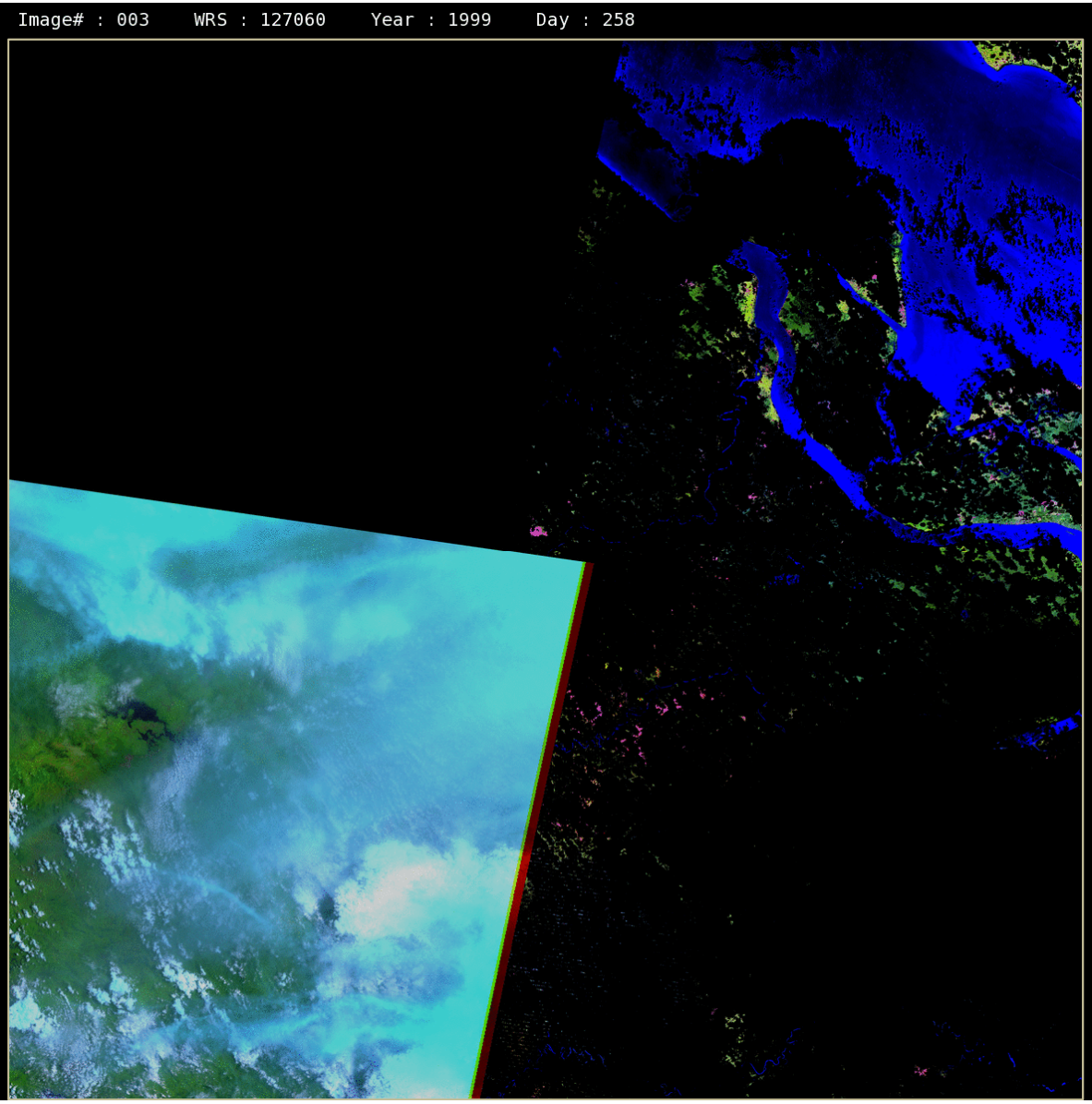
Image# : 002 WRS : 126060 Year : 1999 Day : 251



Indonesia, Riau province

Image Process

- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing

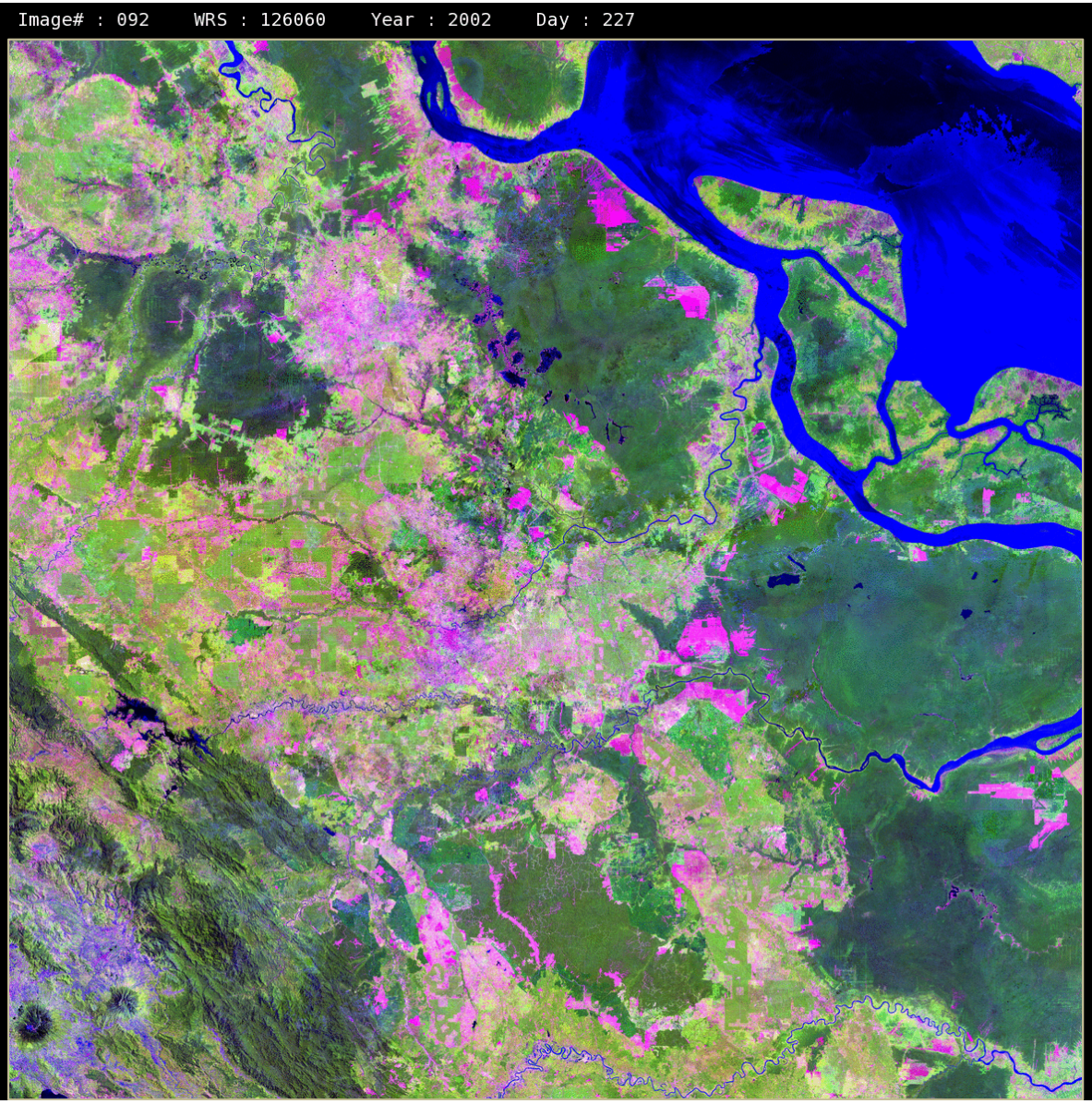


Indonesia, Riau province

Image Process

- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing

Compositing…



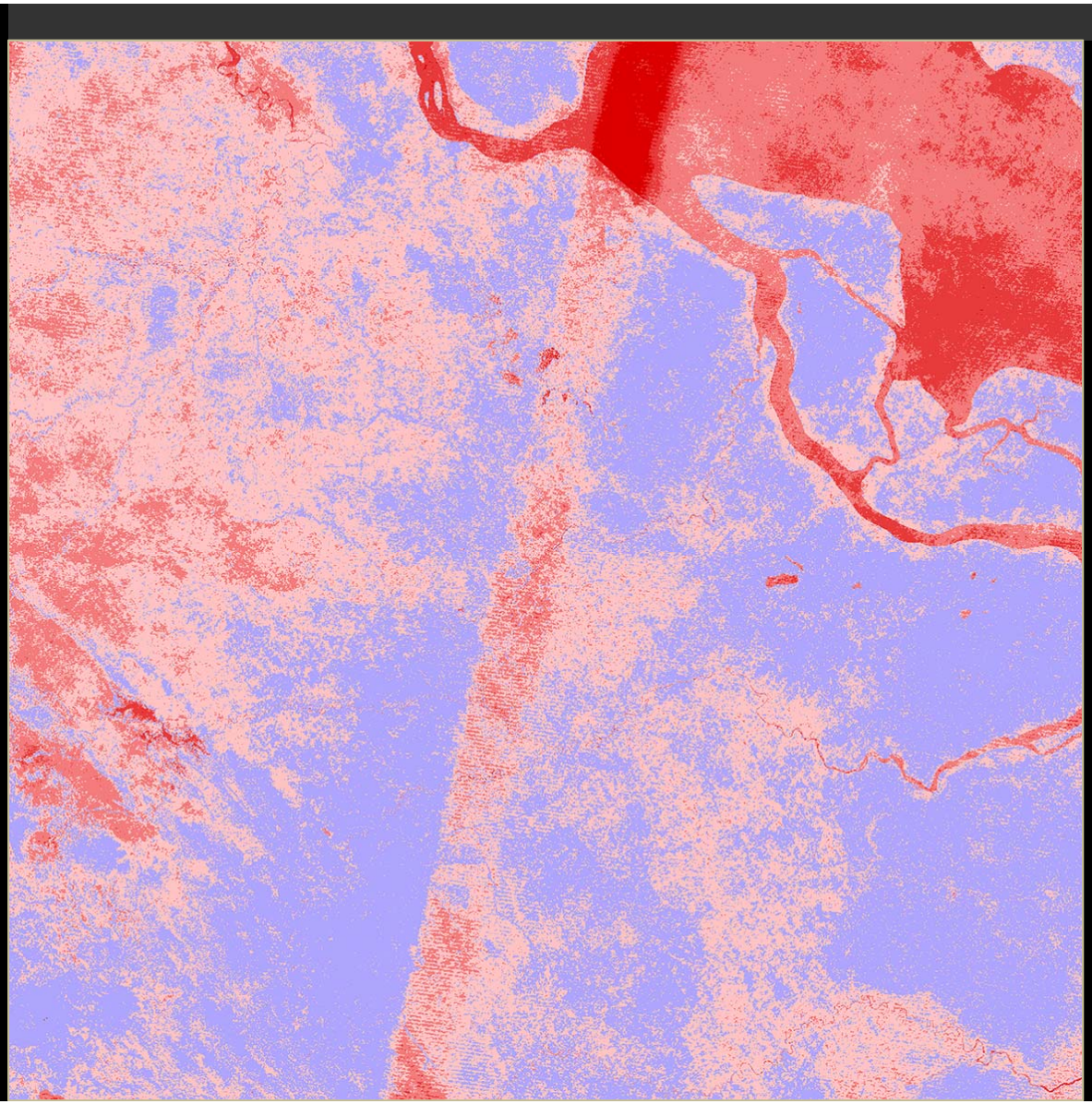
Indonesia, Riau province

Image Process

- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing

Cloud-free mosaic

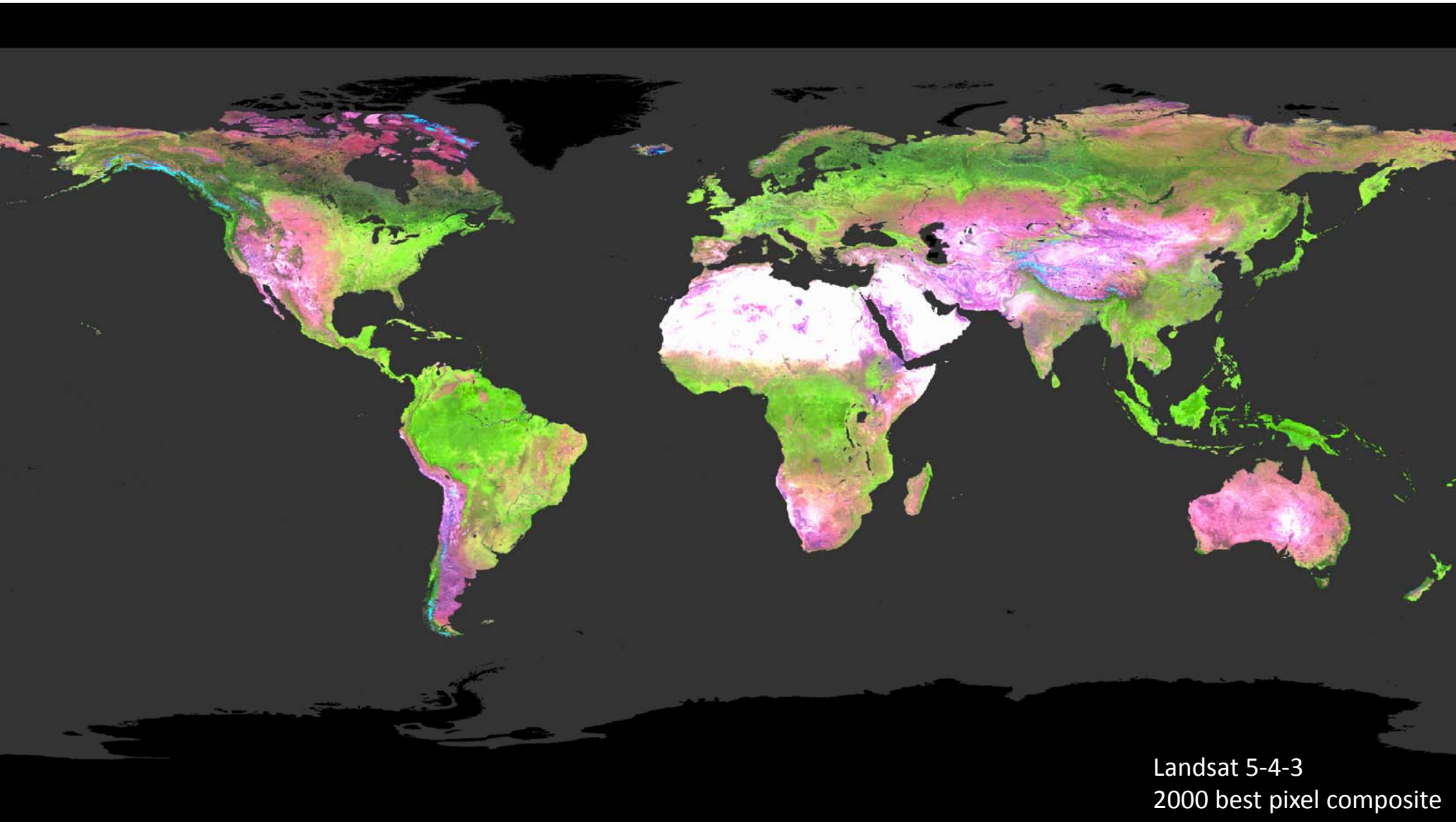
- 92 images total
- more then 20 per path/row
- 3 years of data!

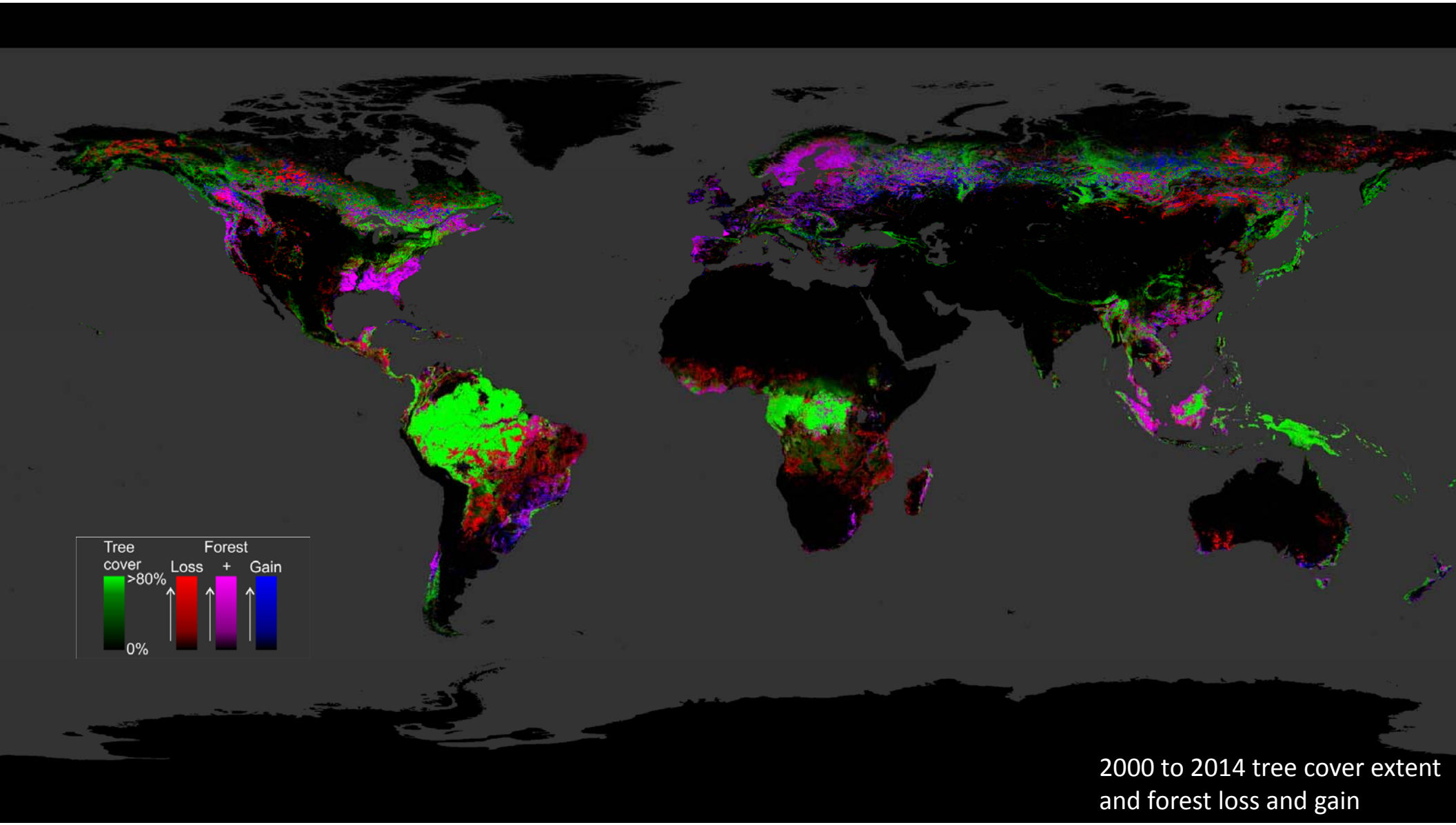


Indonesia, Riau province

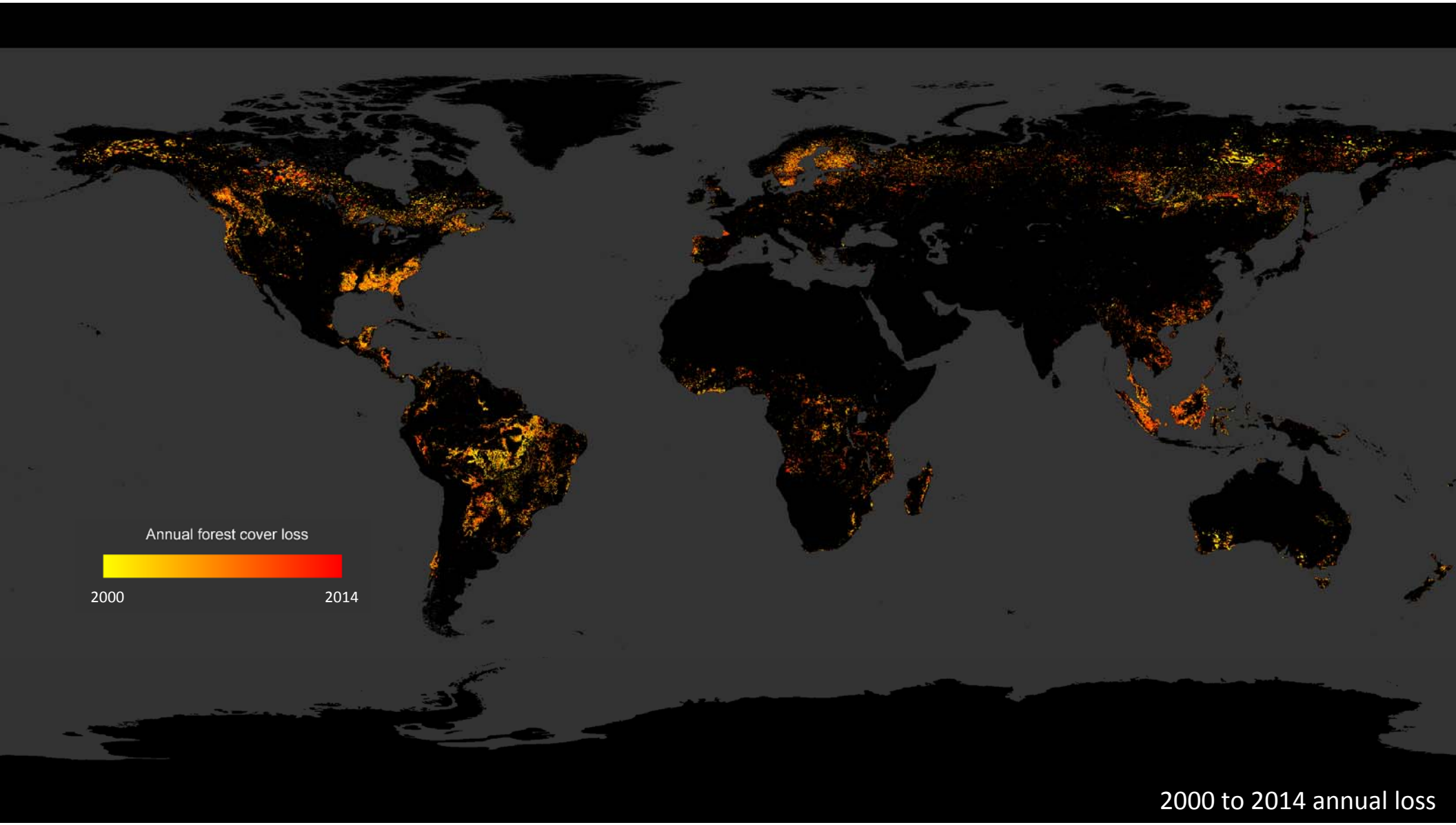
Number of clear-sky observations for 1999-2005 time interval

- 1-7
- 8-13
- 14-20
- 21-30
- 31-56


Landsat 5-4-3
2000 best pixel composite

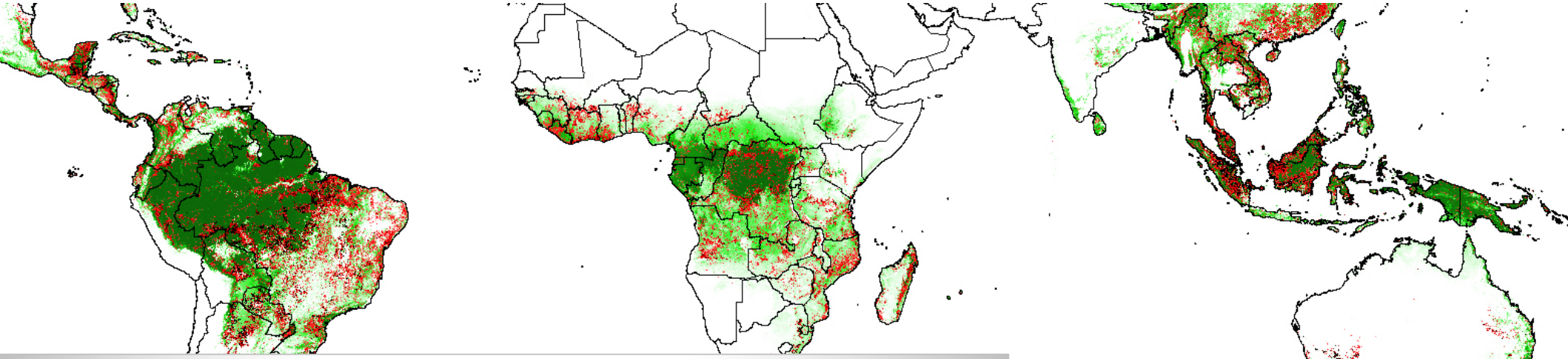


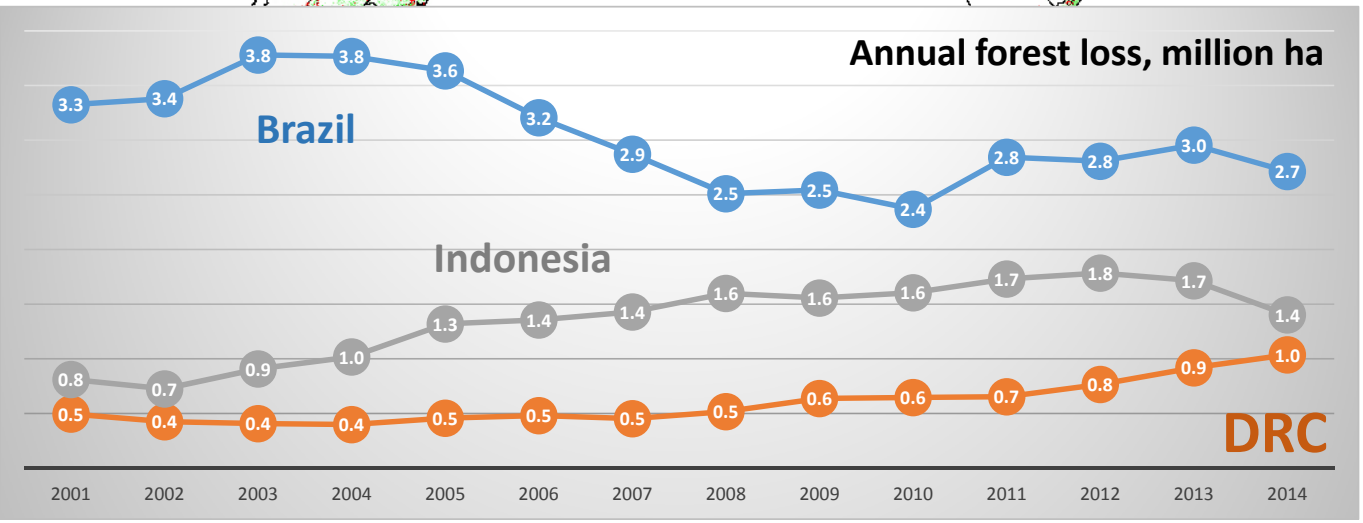
2000 to 2014 tree cover extent and forest loss and gain

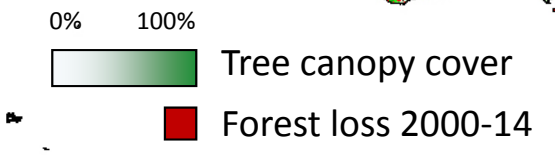

Annual forest cover loss
2000
2014
2000 to 2014 annual loss

Global forest cover change 2000-2014

Gross forest cover loss 2000-2014 within tropical countries

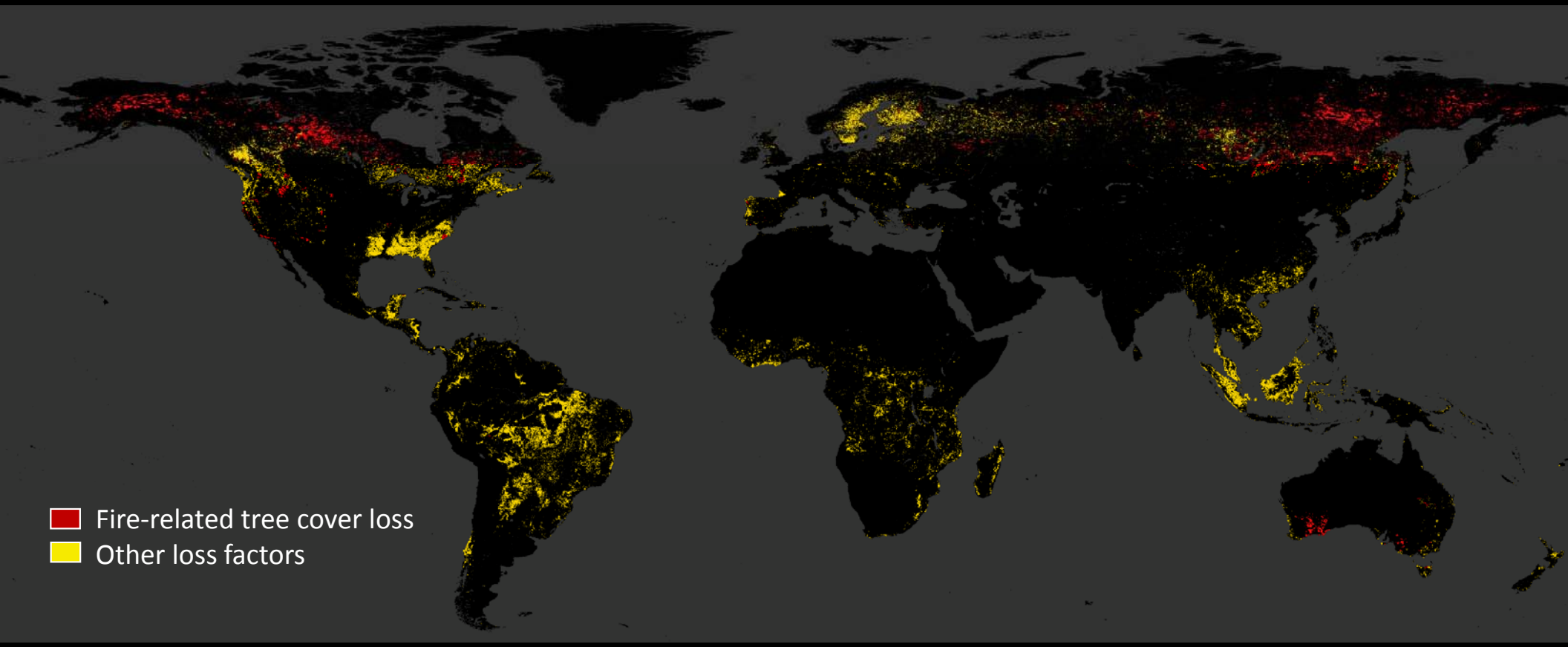




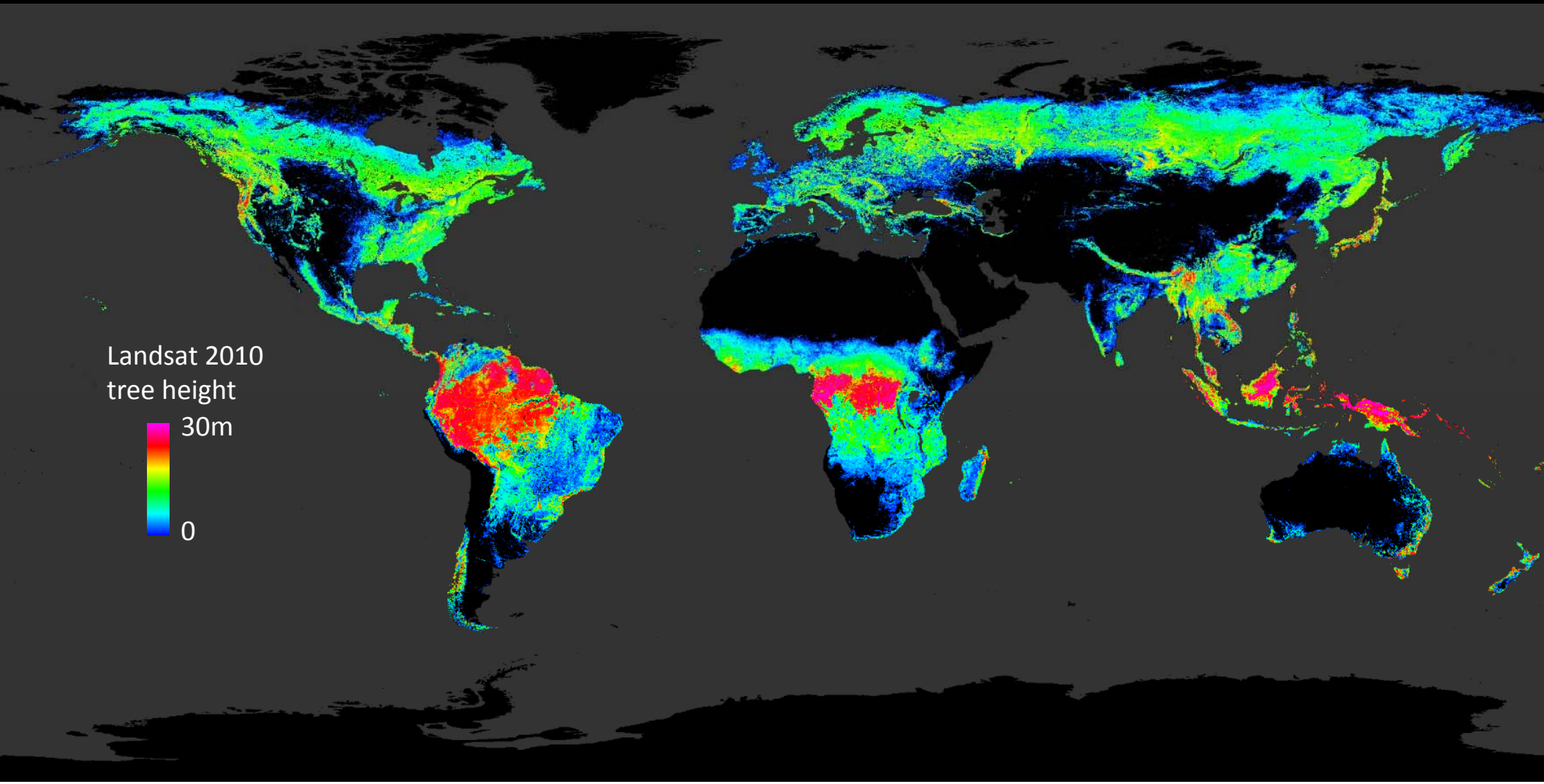


Annual loss shown using 3-years mean filter

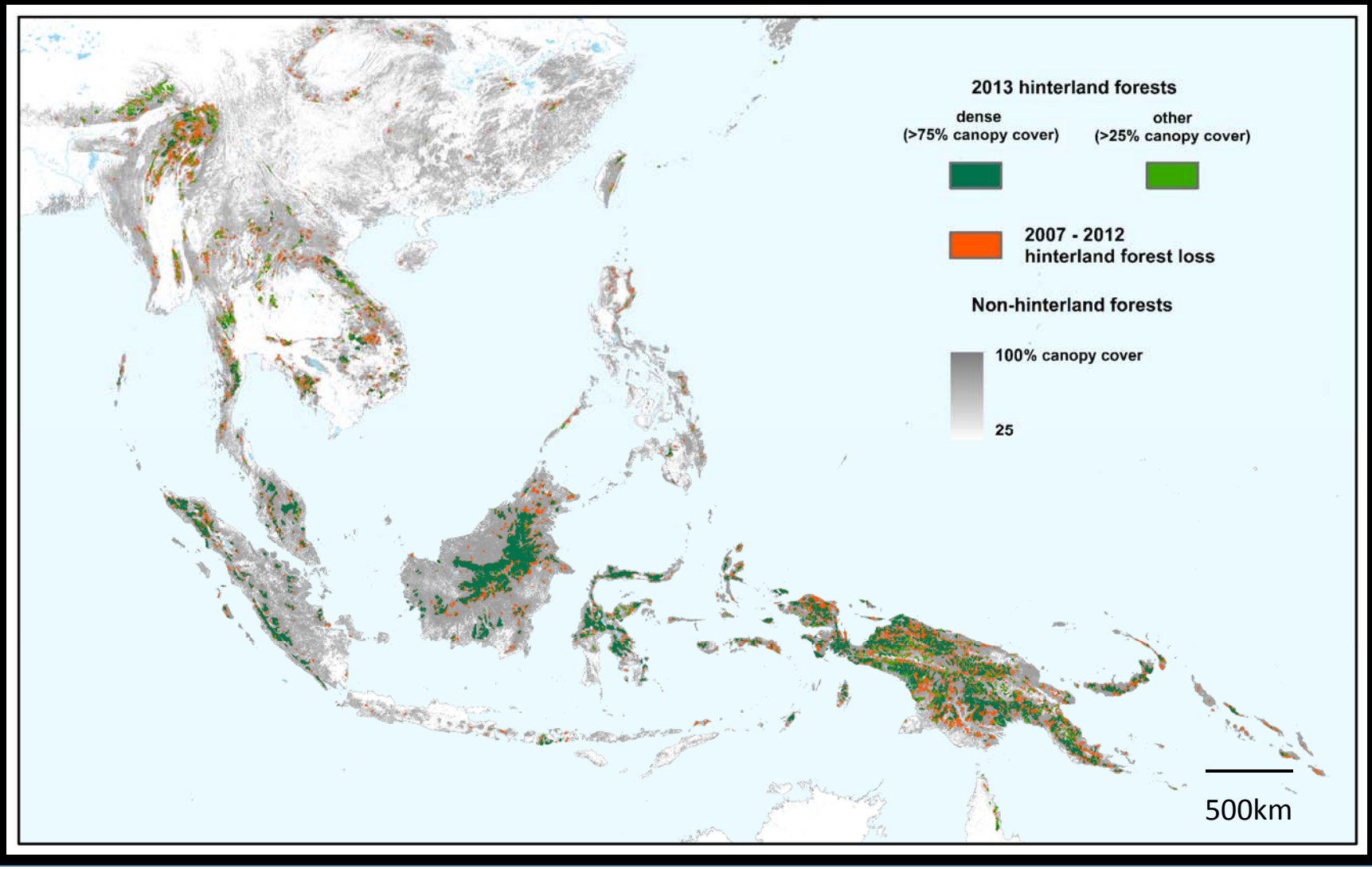
Forest cover change factor attribution, 2000-2012



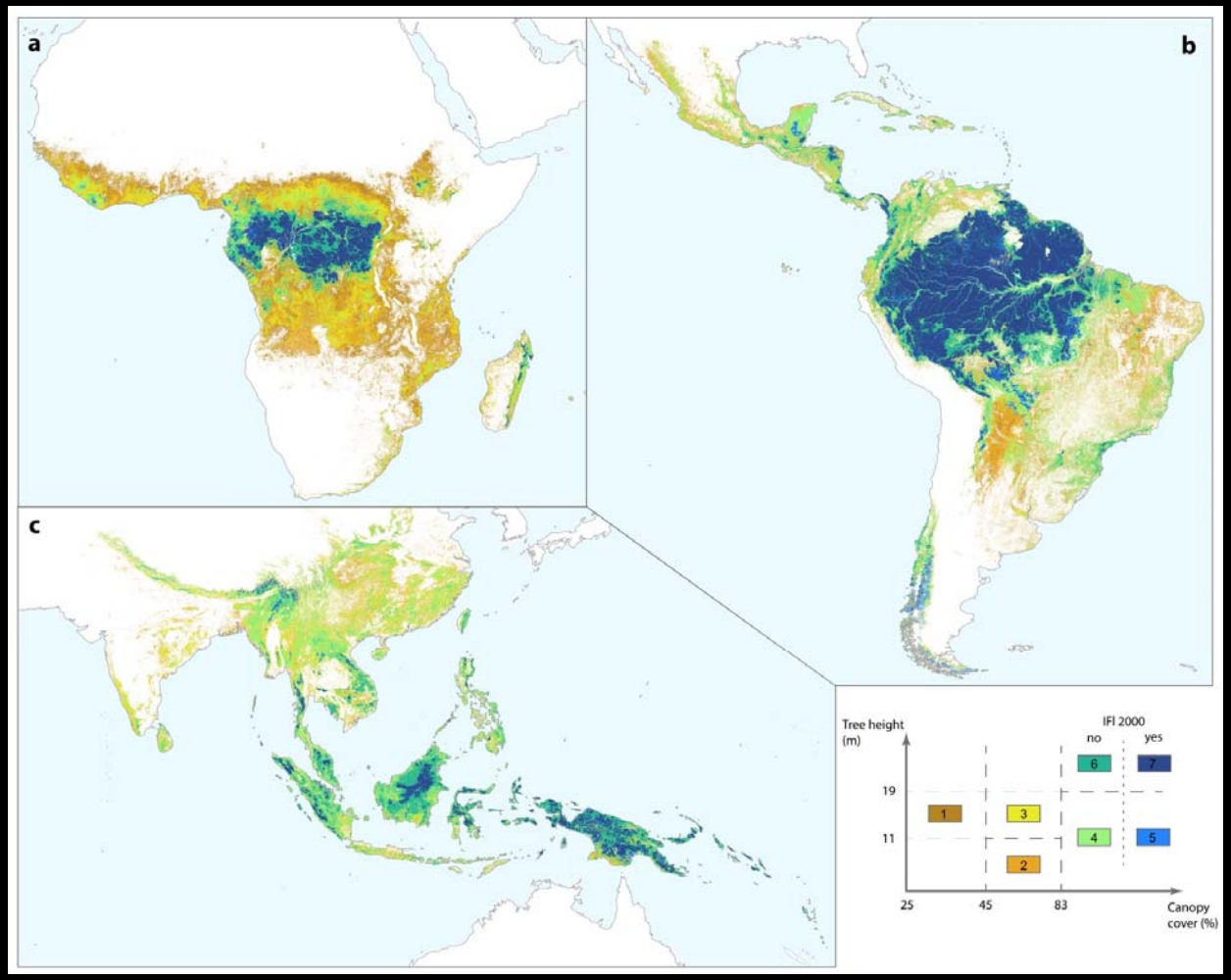
Tree cover height



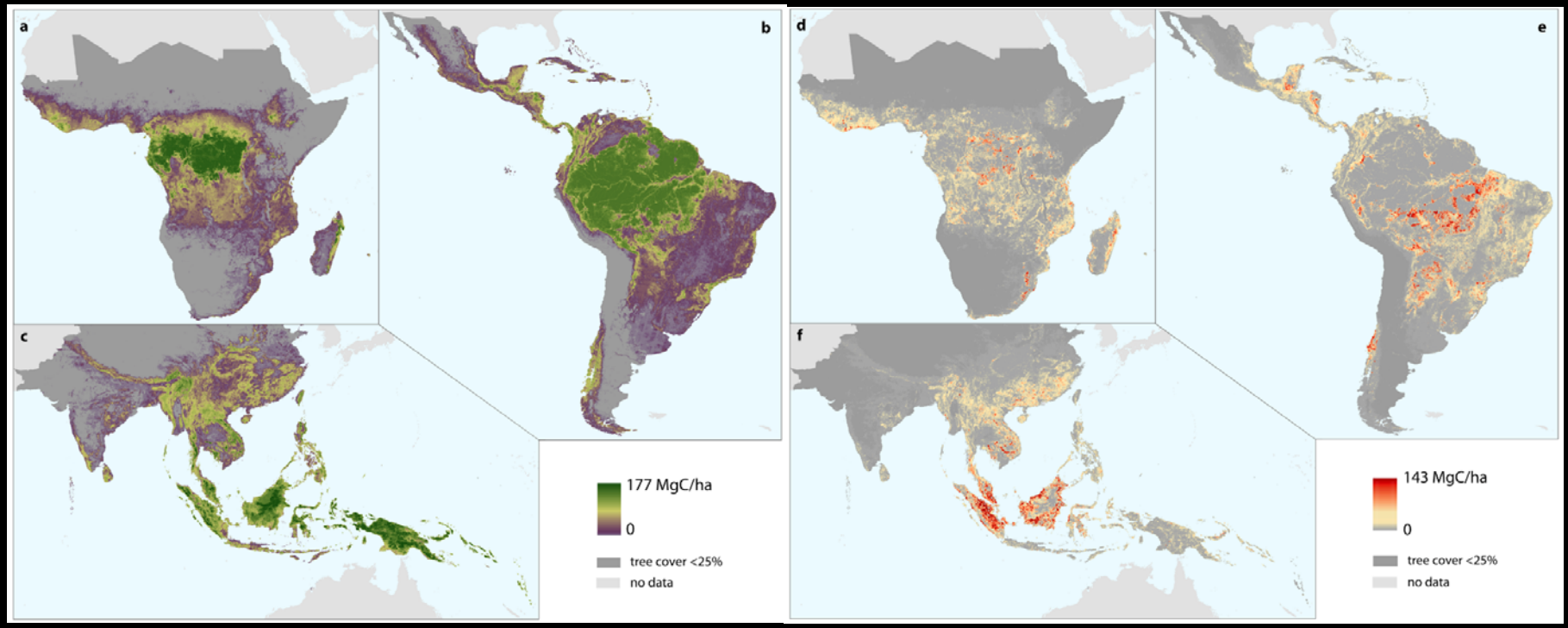
Forest intactness



Pan-tropical stratification of forest cover into carbon stock strata

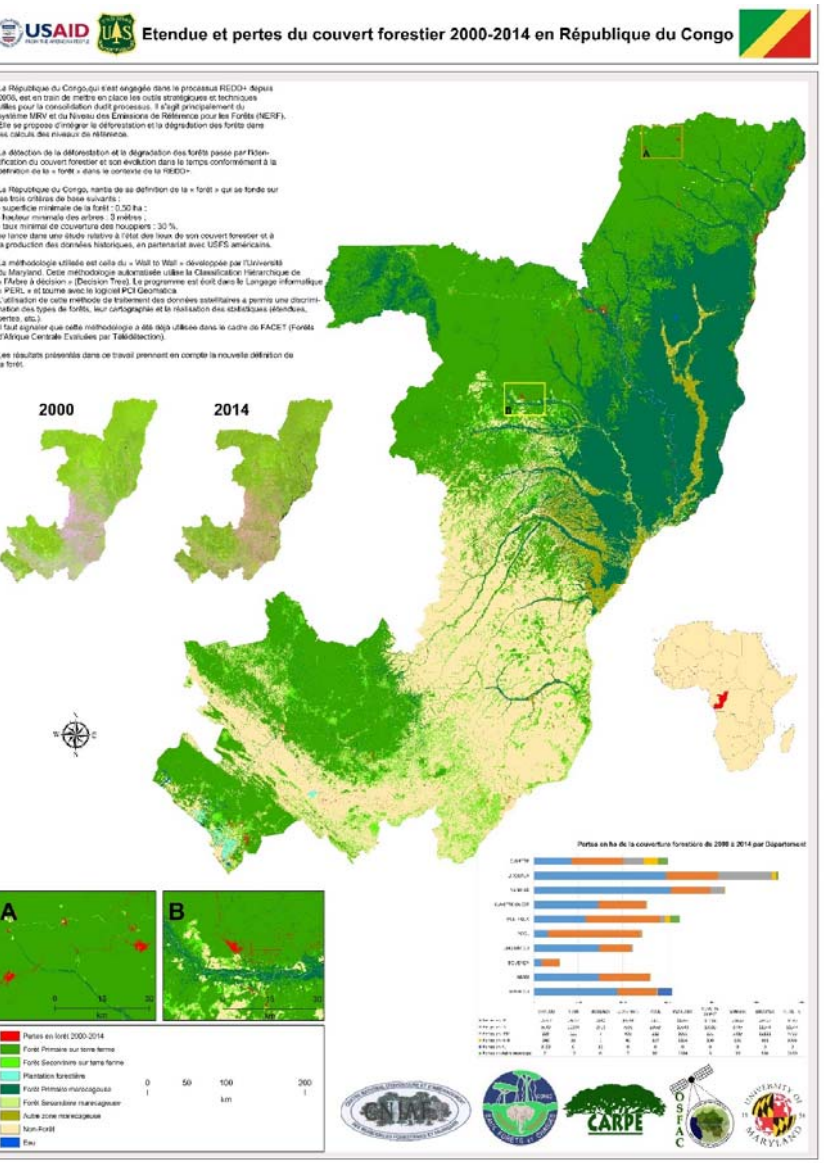


Pan-tropical aboveground carbon stock loss, 2000-2012



Forest strata average aboveground carbon (AGC) density and loss: a-c, year 2000 aboveground carbon (AGC) density; d-f, estimated 2000-2012 AGC loss. Data are aggregated to 5 km for display purposes.

Tyukavina et al., 2015, Aboveground carbon loss in natural and managed tropical forests from 2000 to 2012, *Environmental Research Letters*



Working with national partners through USAID CARPE/SilvaCarbon

- Peru
- Colombia
- Ecuador
- Republic of Congo
- Democratic Republic of the Congo
- Bangladesh
- Indonesia
- Vietnam

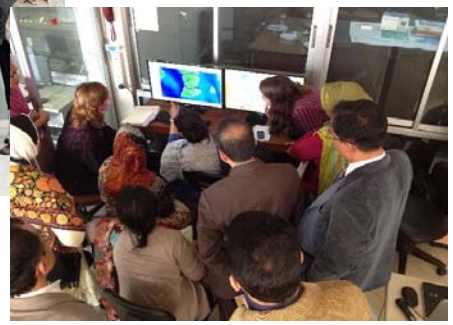
National Implementation of GLAD Forest Monitoring

National forest atlases

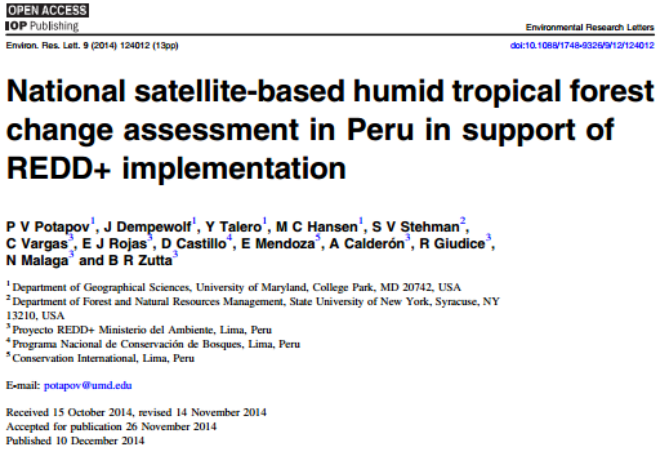
Software use and image analysis training

Peru

Bangladesh



Joined peer-review publications



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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]

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[2] Department of Forest and Natural Resources Management, State University of New York, Syracuse, NY 13210, USA
[3] Proyecto REDD+ Ministerio del Ambiente, Lima, Peru
[4] Programa Nacional de Conservación de Bosques, Lima, Peru
[5] Conservation International, Lima, Peru

E-mail: potapov@umd.edu

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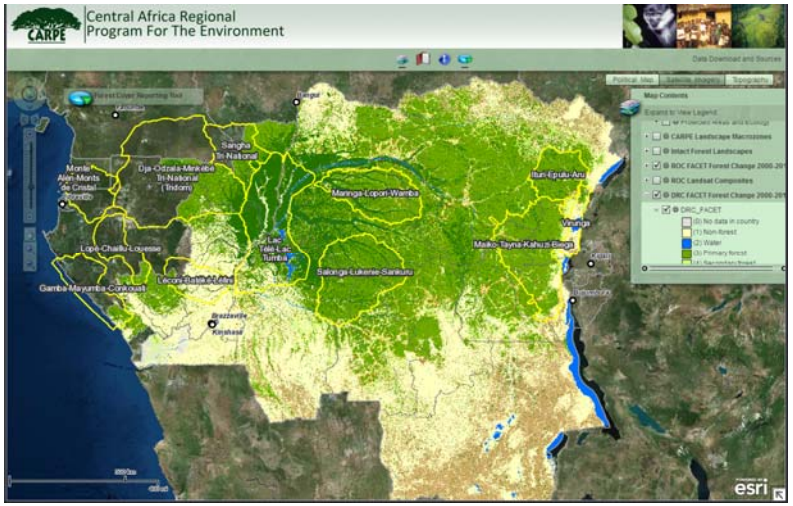
Accepted for publication 26 November 2014
Published 10 December 2014

Regional on-line maps and reports



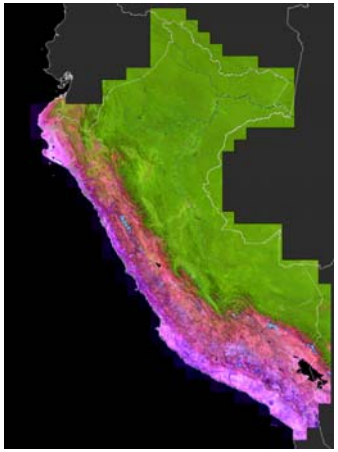
National Implementation of GLAD Forest Monitoring

National scale forest loss mapping and sample-based validation in Peru

1

GLAD

Landsat data composites and metrics



2

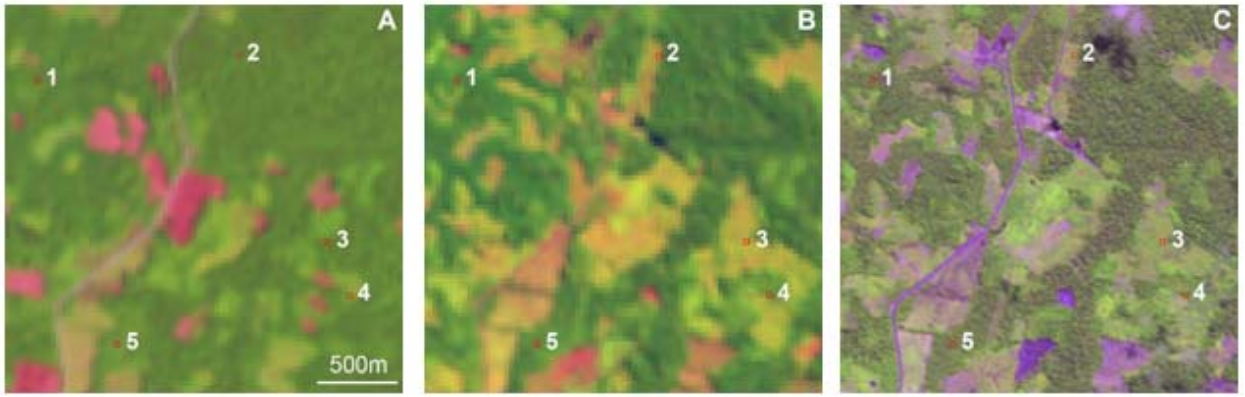
Wall-to-wall forest cover loss

3

Stratified sampling design

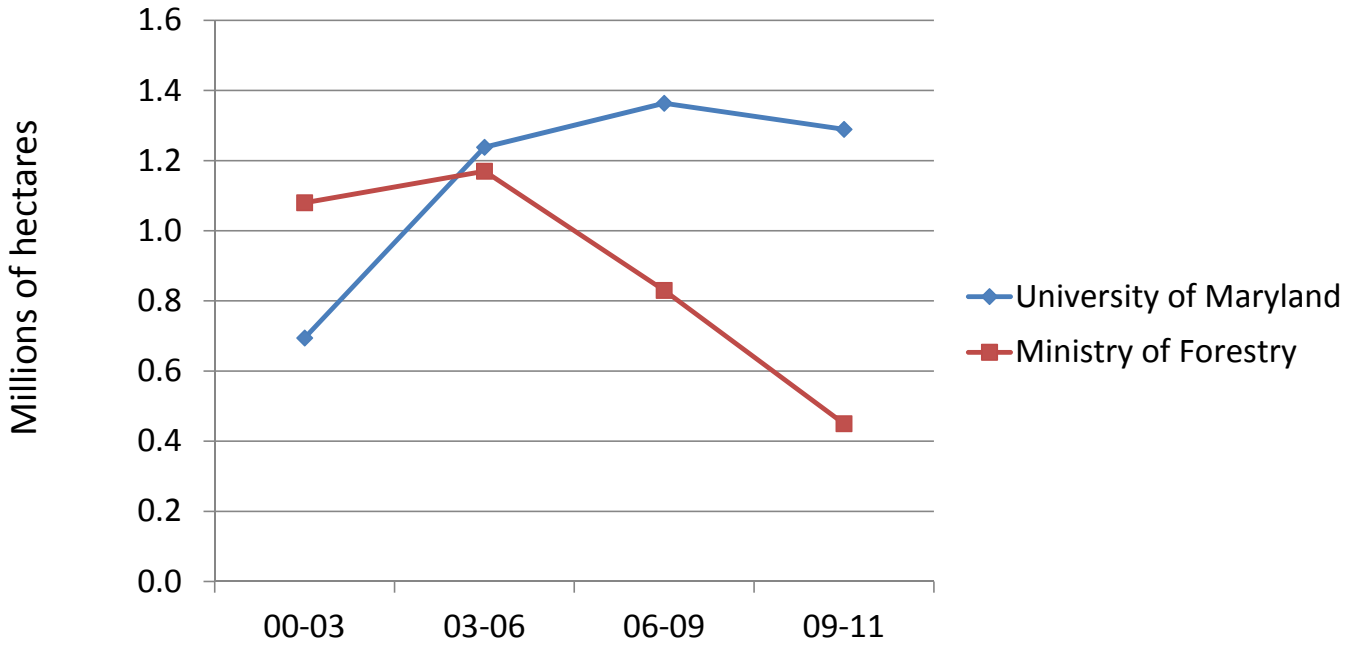
MINAM

4

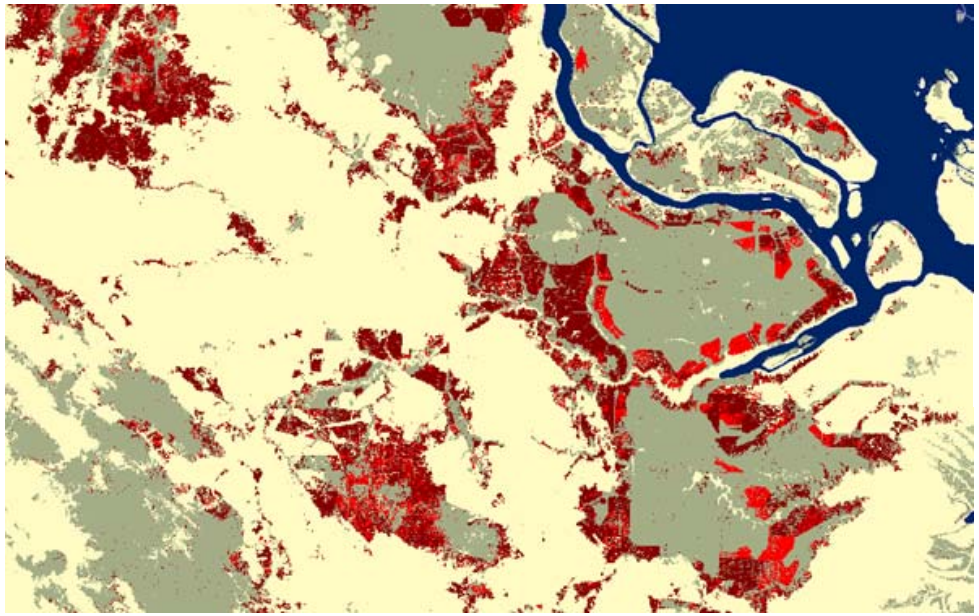


Sample block analysis using Landsat and RapidEye data

Comparison with official data – recent divergence in forest cover loss estimates for Indonesia



The current reported rate of deforestation by the Indonesian government of 0.45Mha/yr incorporates forest regrowth dynamics and plantation forests in estimating a 'net deforestation'.

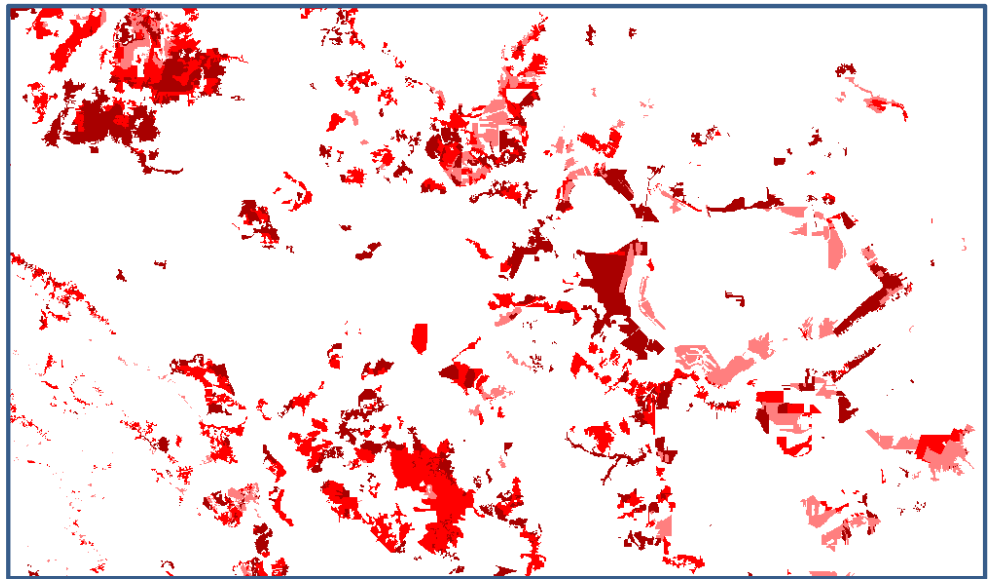


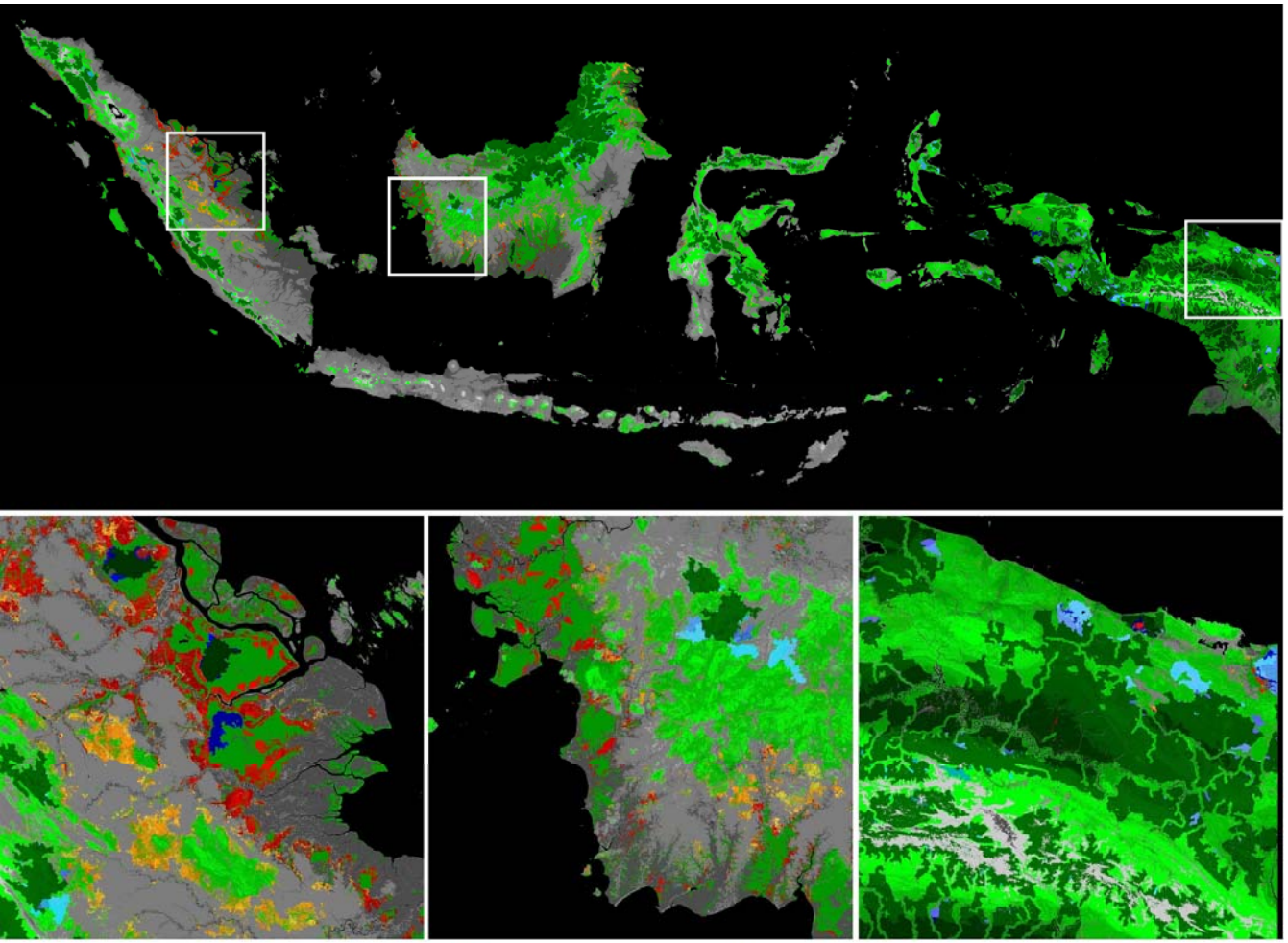
UMd

2001-2010
2011-2012

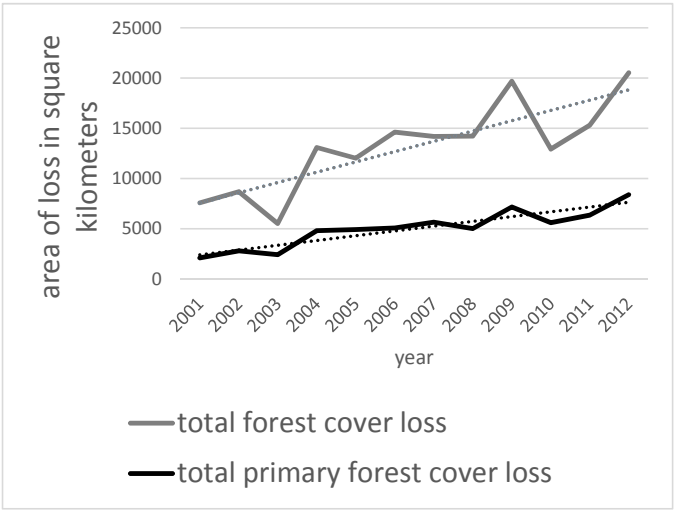
Indonesian Ministry of Forestry

2009-2011
2006-2009
2009-2011





Loss inside and outside of primary forests in Sumatra, Indonesia

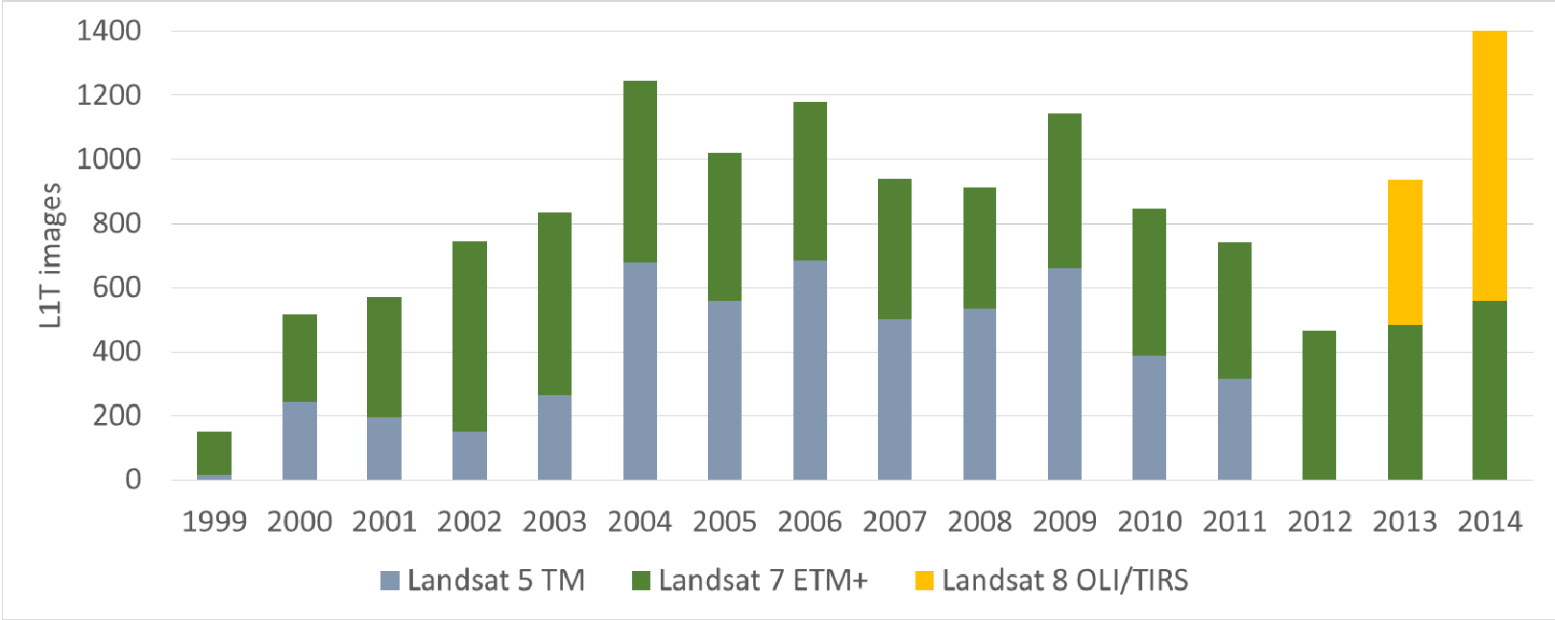


Margono et al., 2014,
Primary forest cover loss in Indonesia, 2000 to 2012,
Nature Climate Change

Step 1. Landsat data processing

Landsat data archive

Vietnam land area, 1999-2014 (L1T data only)



Total number of processed images: 13.644

Excluded images: L1G, poor/incorrect registration, sensor anomalies, nearly complete cloud/haze cover

Step 1. Landsat data processing

I. Image processing

L1T Data archive, 1999-2014 (13.644 images)

Data volume ~ 3 TB

Image QA and reflectance normalization

Processing time @7sec/image ~ 27 hours

Normalized imagery dataset (4 ref + 1 term bands + QA)

Data volume ~ 5 TB

II. 16-day interval composites

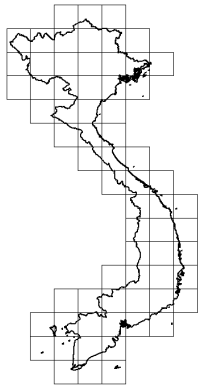
Normalized imagery

Select observation with the best QA

Processing time ~ 24 hours

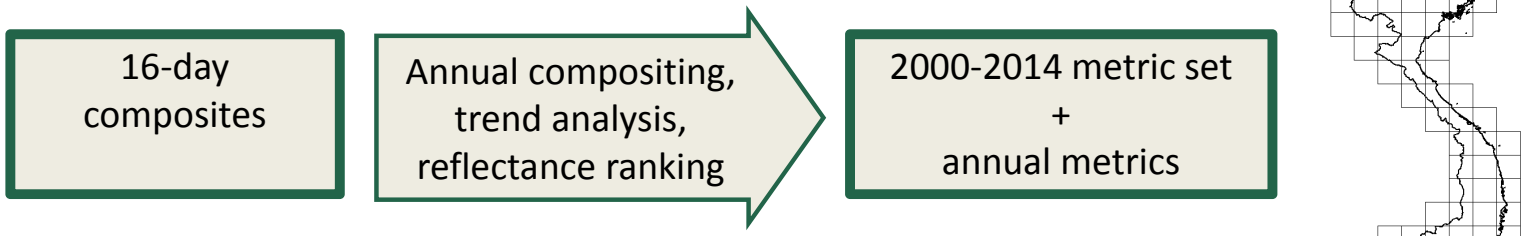
16-day composites as 1x1 degree tiles (368 composites)

Data volume 1.77 TB (67 tiles)



Step 1. Landsat data processing

III. Multi-temporal spectral metrics



Processing time 43 hours

Data volume:
Multi-year: 1.1 TB
Annual: 1.3 TB

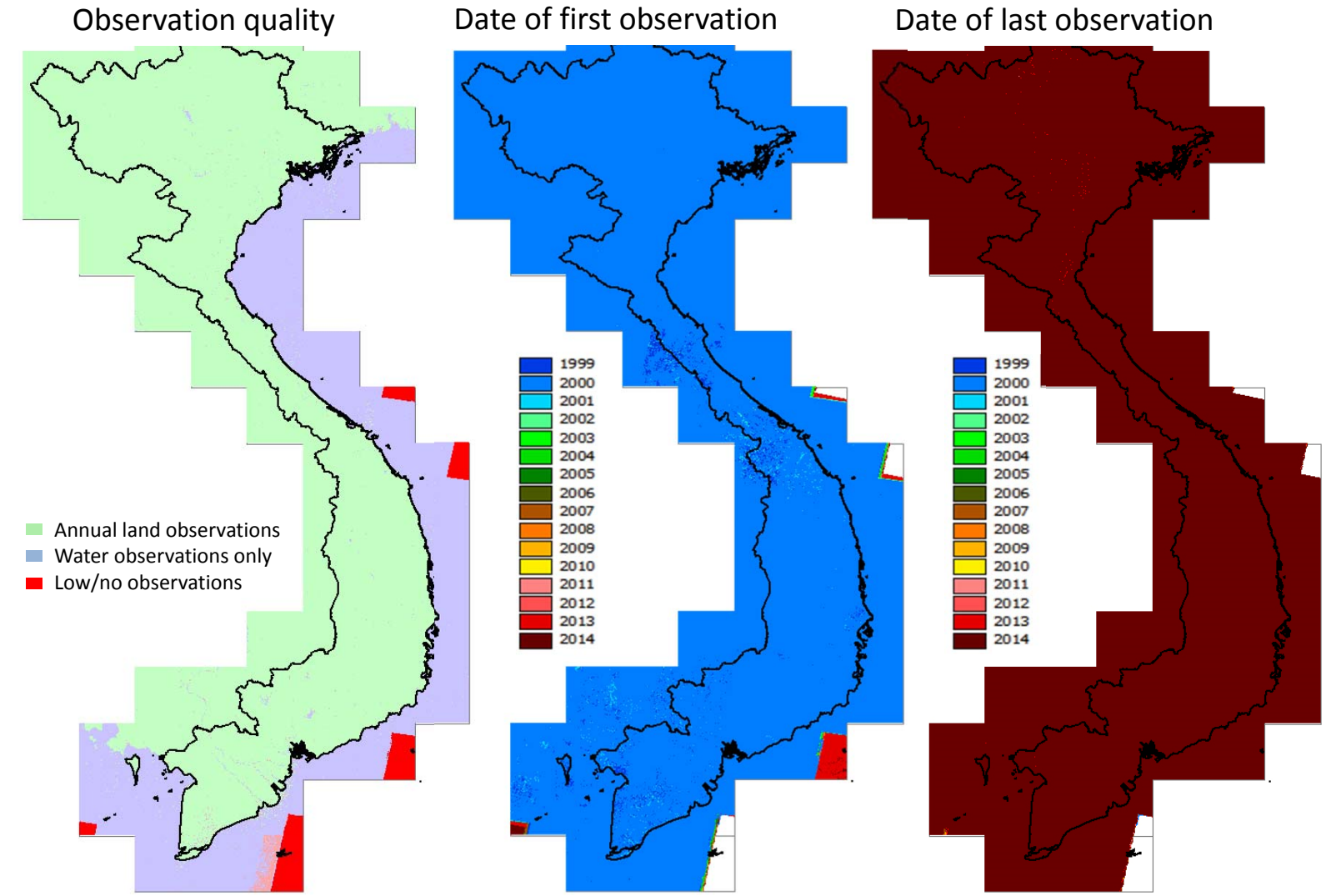
Multi-year metric set (>600 metrics) include:

a. Metadata layers (dates of observation, observation count, QA)
b. Rank-based metrics
c. Trend analysis metrics
d. Composites for specific dates
e. Ancillary data (elevation and topography metrics)

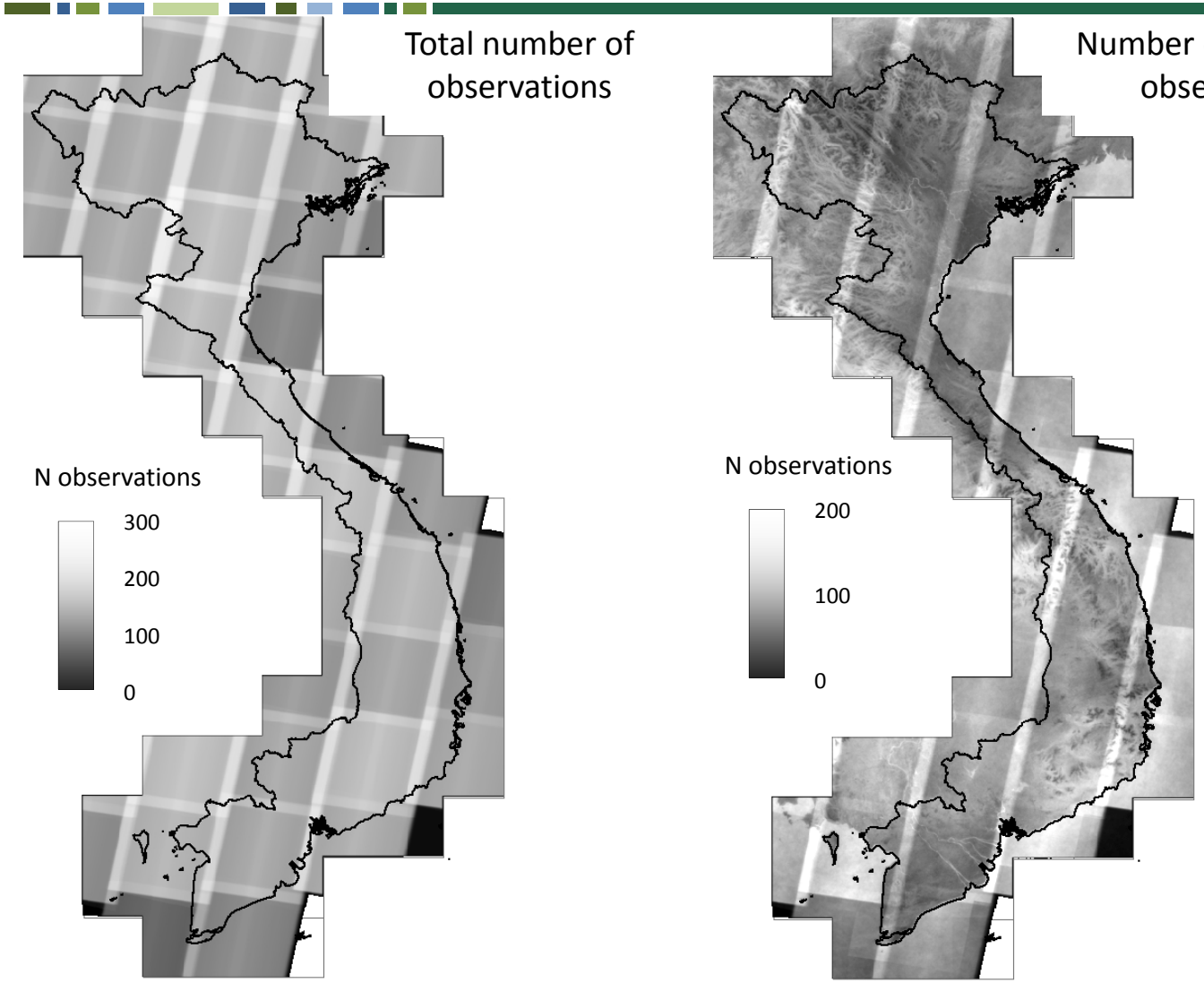
Annual metric set (~40 metric/year):

a. Number of observation
b. Median, Q1 and Q3, min and max reflectance an VI
c. Annual and growing season average reflectance and VI

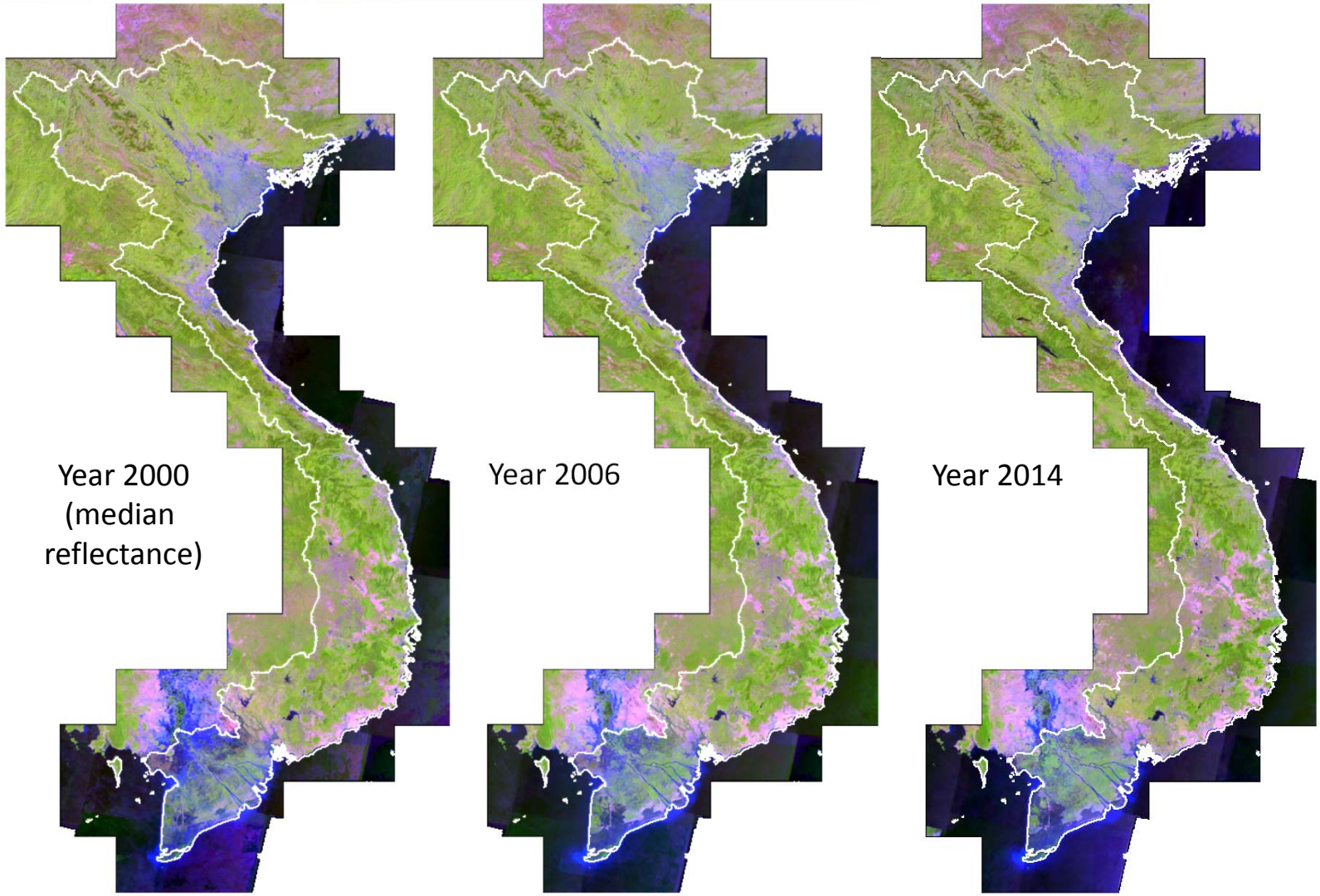
Step 1. Landsat data processing



Step 1. Landsat data processing



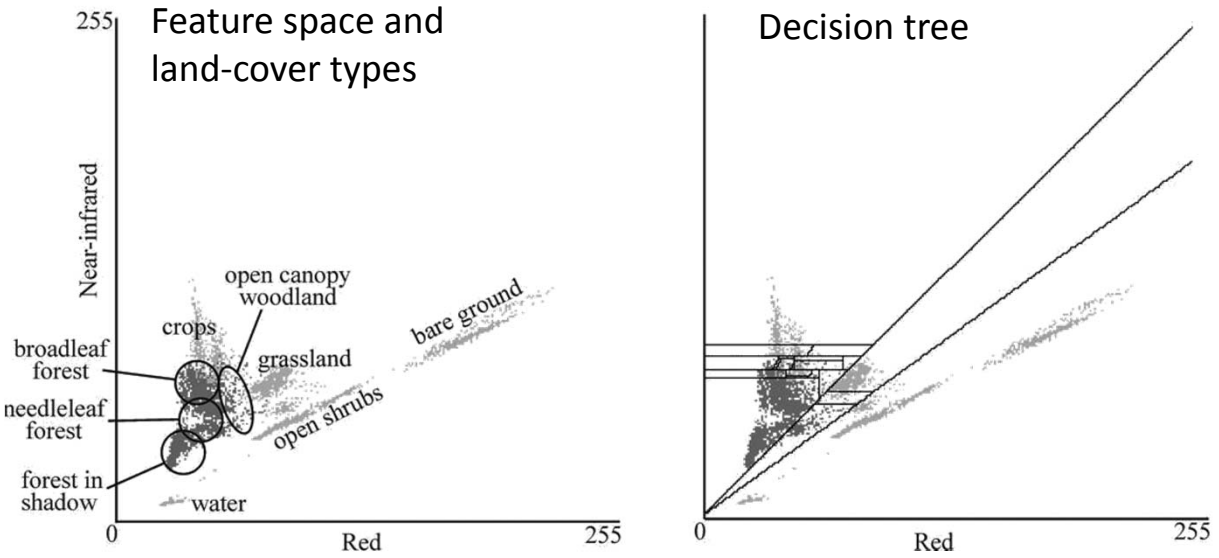
Step 1. Landsat data processing



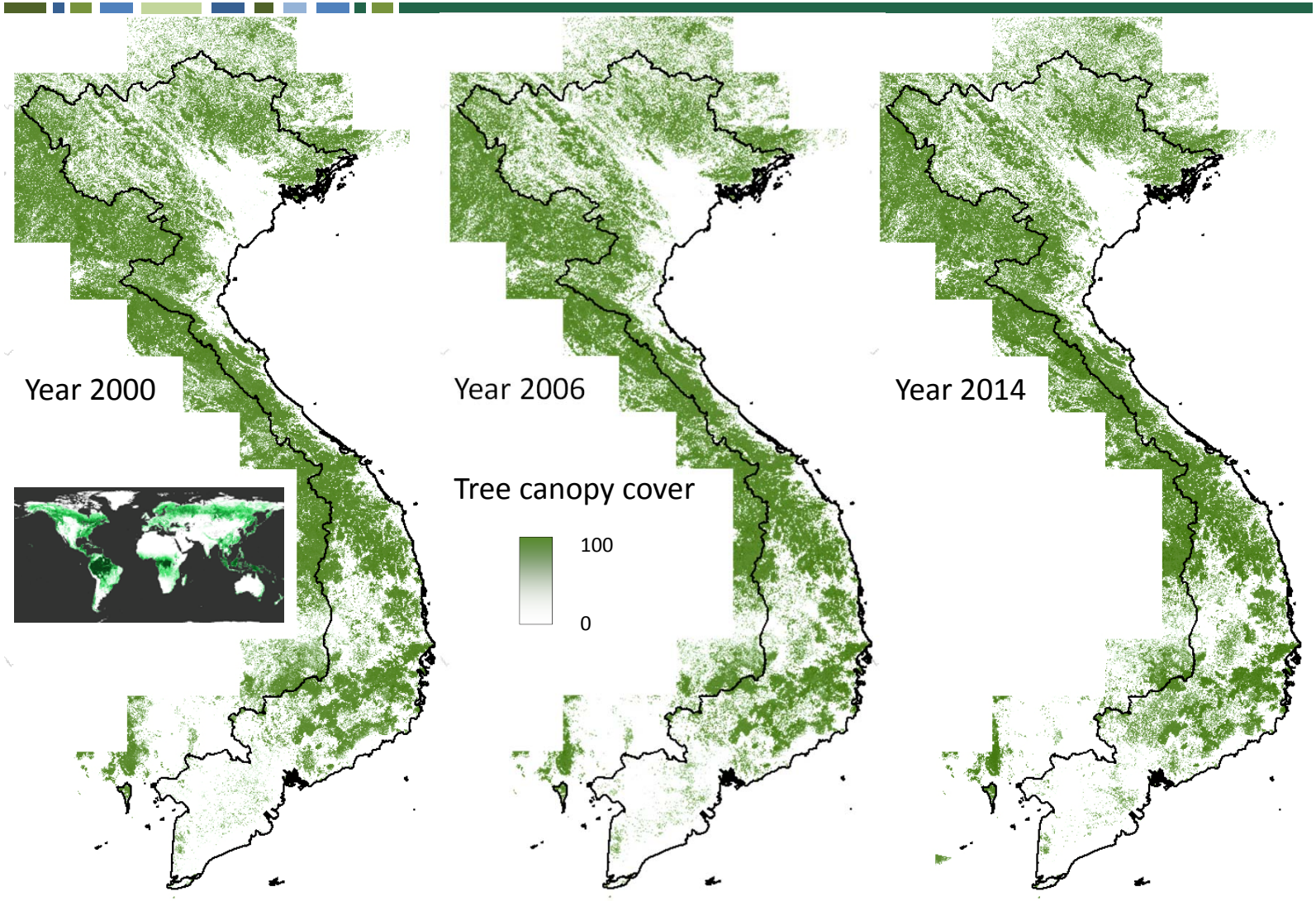
Step 2. Forest cover and change mapping

Classification method – Decision tree

Decision tree ("Classification and regression trees" – CART; Breiman *et al.*, 1984) non-parametric hierarchical classifier that predicts class membership by recursively partitioning a data set into more homogeneous subsets. This splitting procedure is followed until a perfect tree (one in which every pixel is discriminated from pixels of other classes, if possible) is created with all pure terminal nodes or until preset conditions are met for terminating the tree's growth.

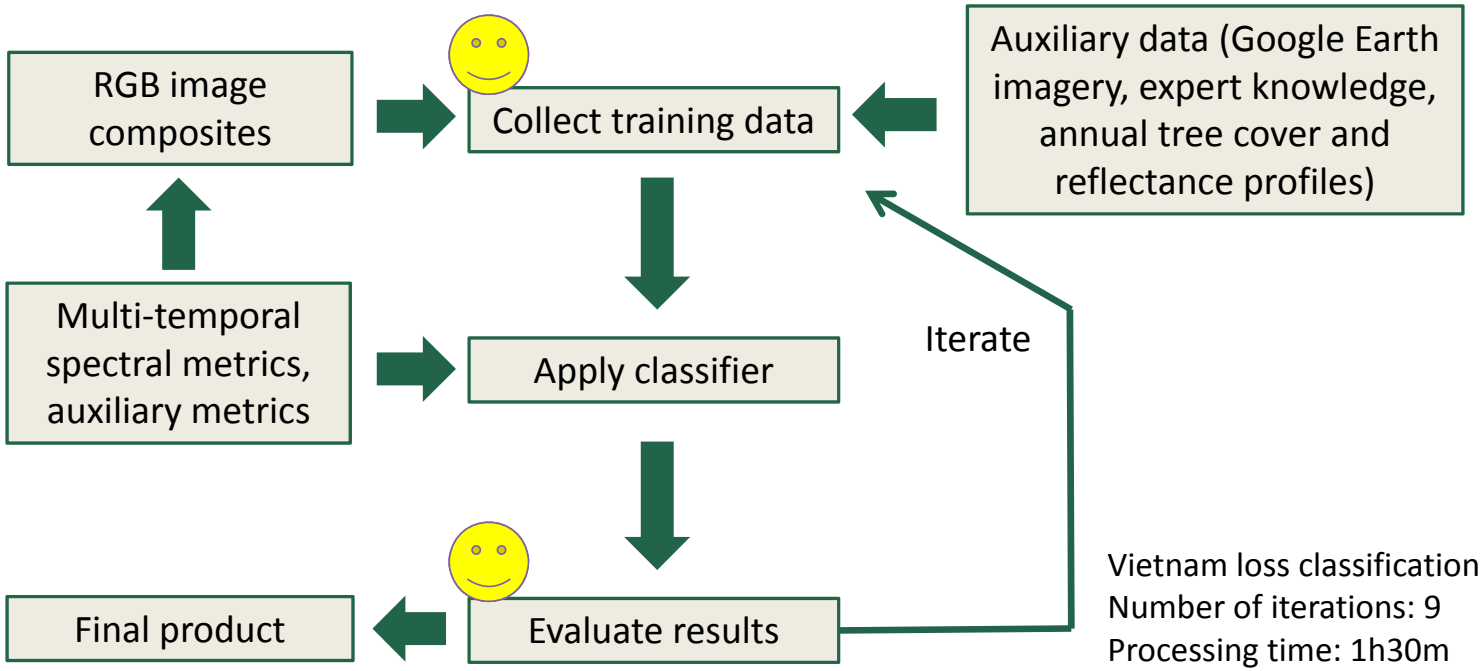


Step 2. Forest cover and change mapping



Step 2. Forest cover and change mapping

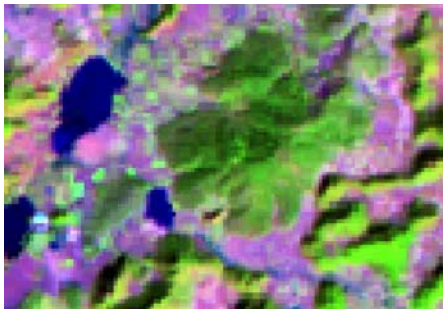
Analyst-driven supervised change classification is based on "**active learning**" method. Active learning focuses on the interaction between the analyst (or some other information source) and the classifier. The model returns to the analyst the classification outcome and helps to highlight the most uncertain areas. After accurate labeling by the analyst, these areas are added to the training set in order to reinforce the model. In this way, the model is optimized on well-chosen difficult examples, maximizing its generalization capabilities.



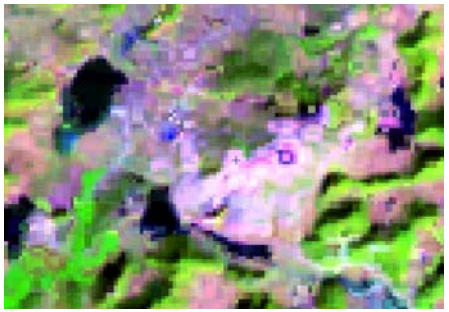
Vietnam loss classification:
Number of iterations: 9
Processing time: 1h30m
(67 cores, 30GB RAM/core)

Step 2. Forest cover and change mapping

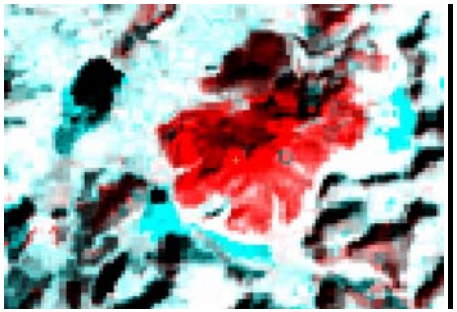
Adding training areas for a decision tree



Year 2000



Year 2014



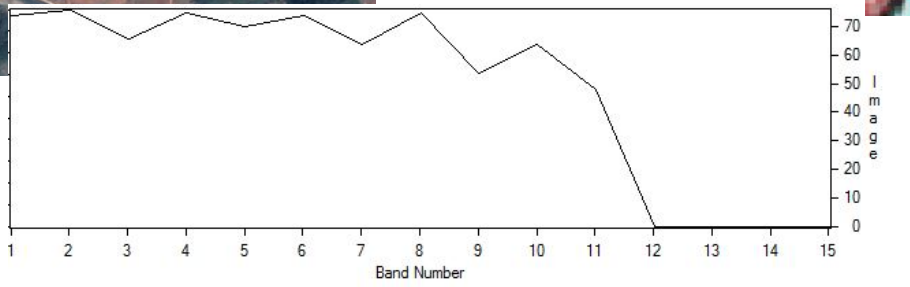
SWIR band 2000/2014

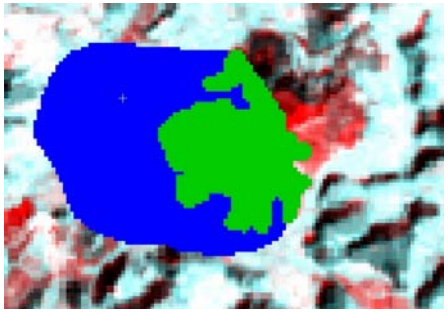
3 km

Google Earth imagery

Auxiliary data

Annual tree canopy cover





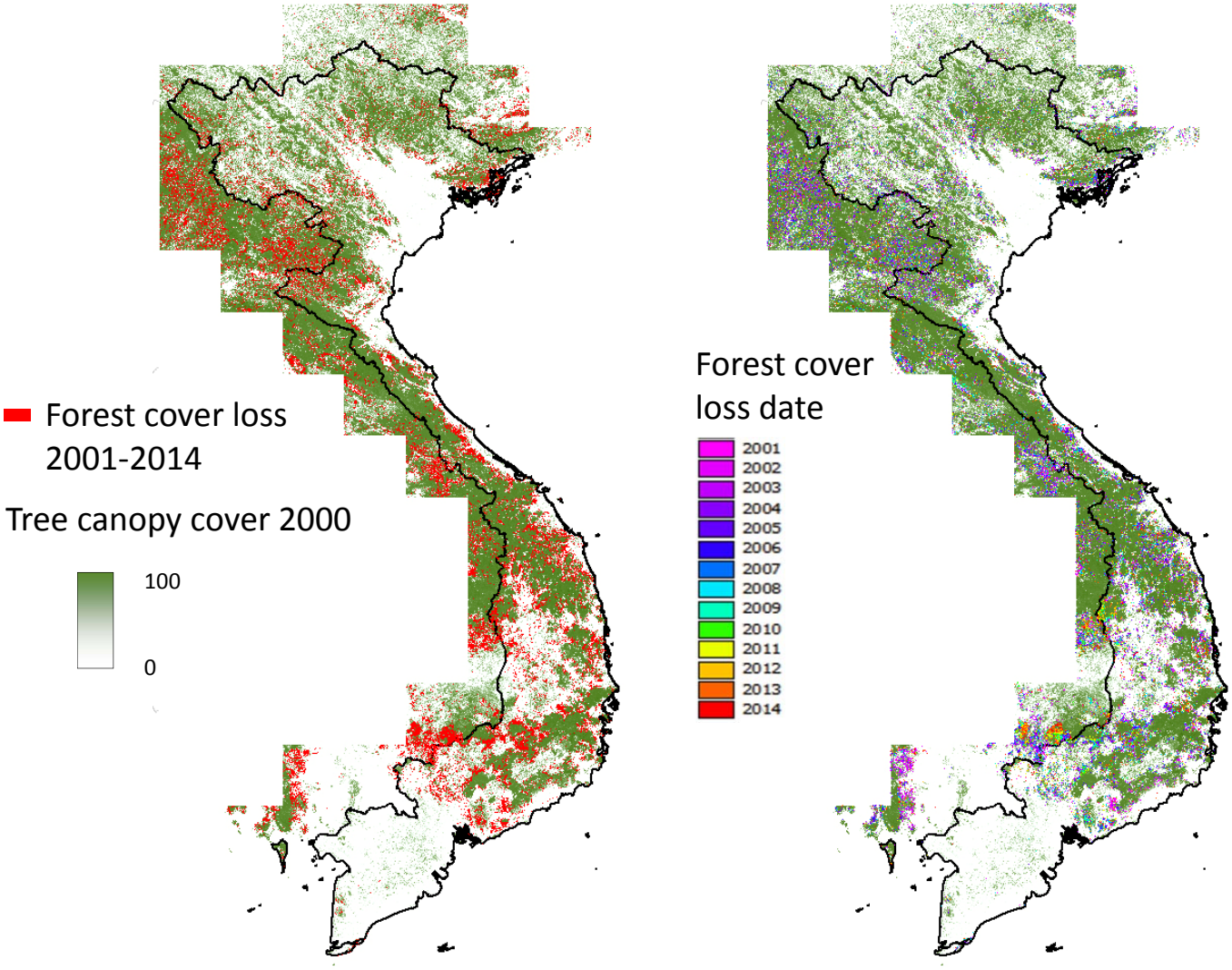
Training areas

Forest loss

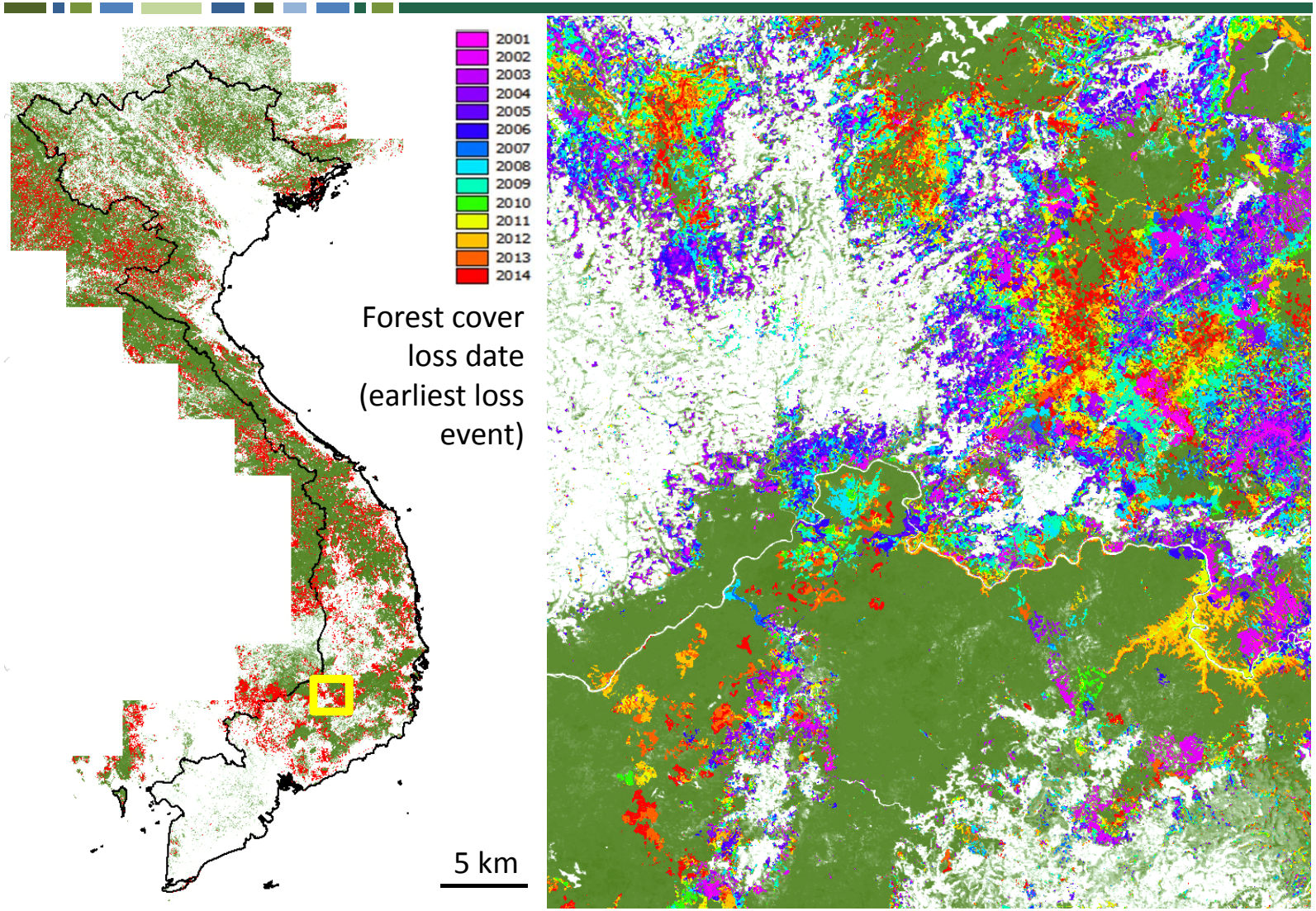
No change

104d18'19.2059"E 23d42'10.8851"N

Step 2. Forest cover and change mapping

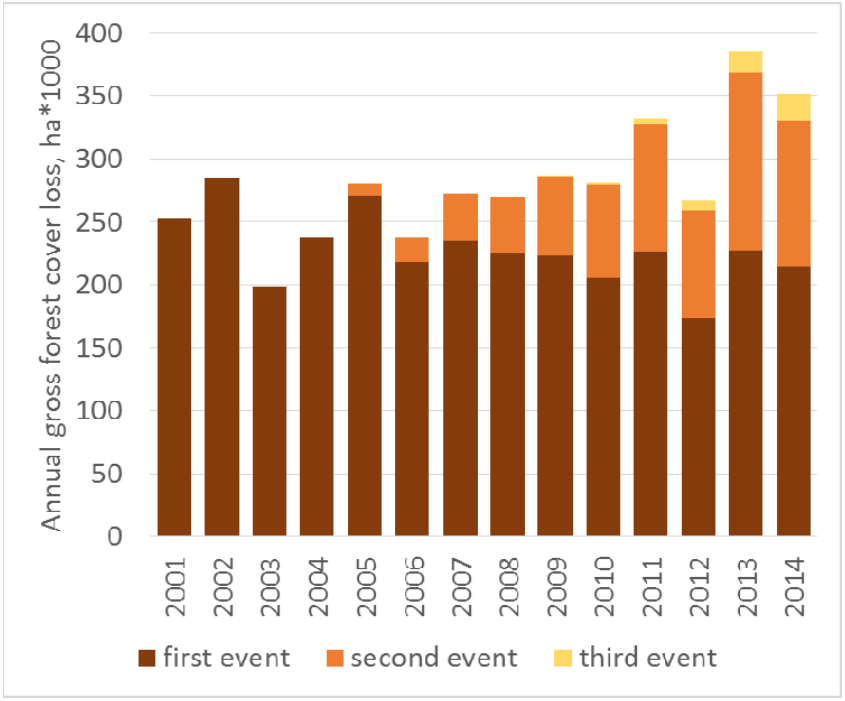


Step 2. Forest cover and change mapping



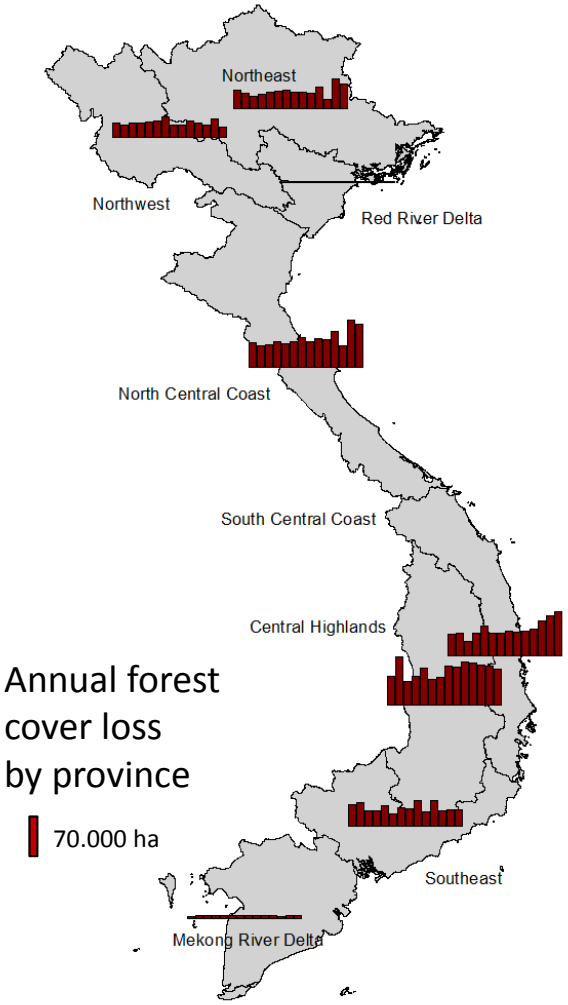
Step 2. Forest cover and change mapping

Total annual gross forest cover loss



Forest loss area experienced second loss event: 21.7%

… third loss event: 1.6%

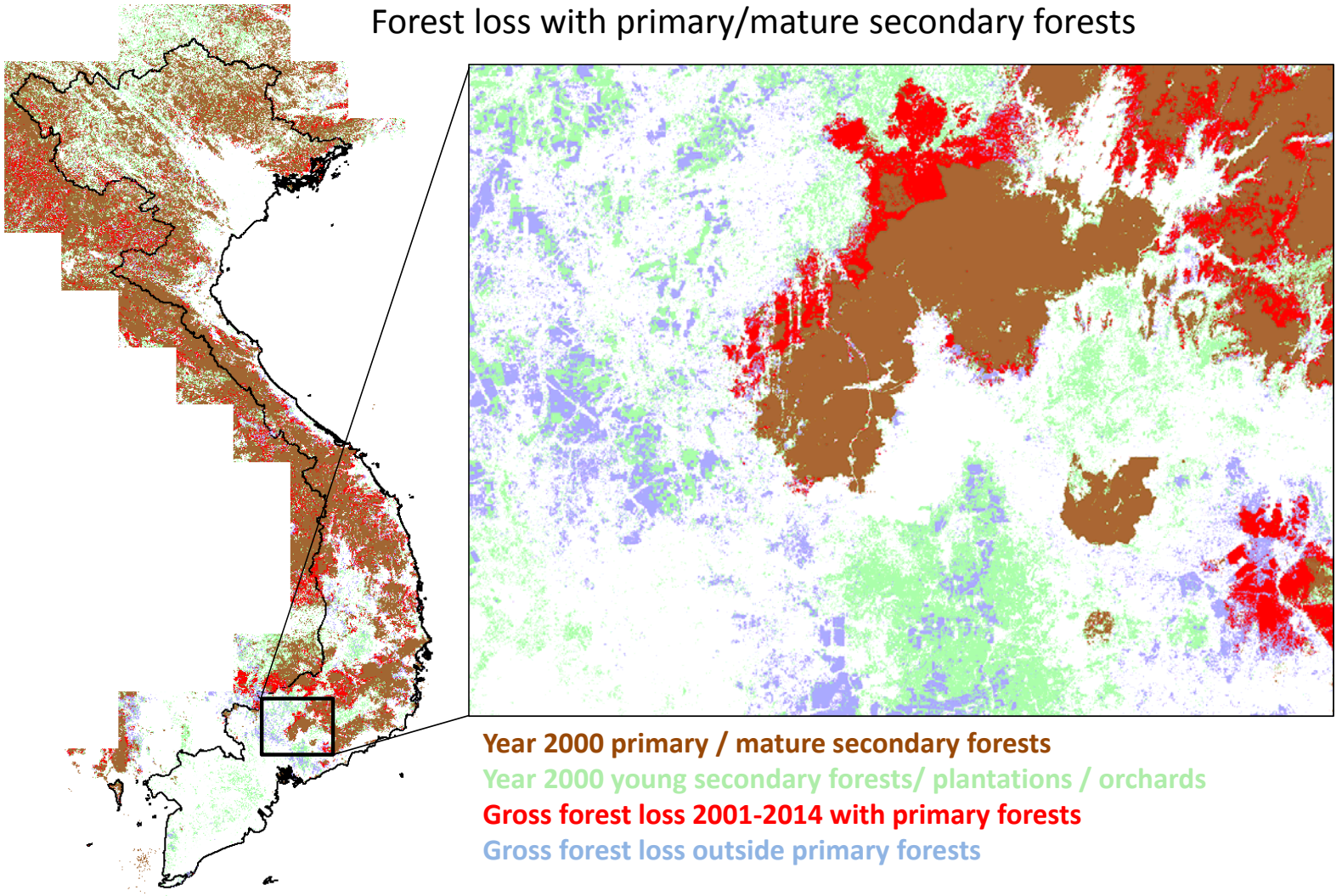


Annual forest cover loss by province

70.000 ha

Step 2. Forest cover and change mapping

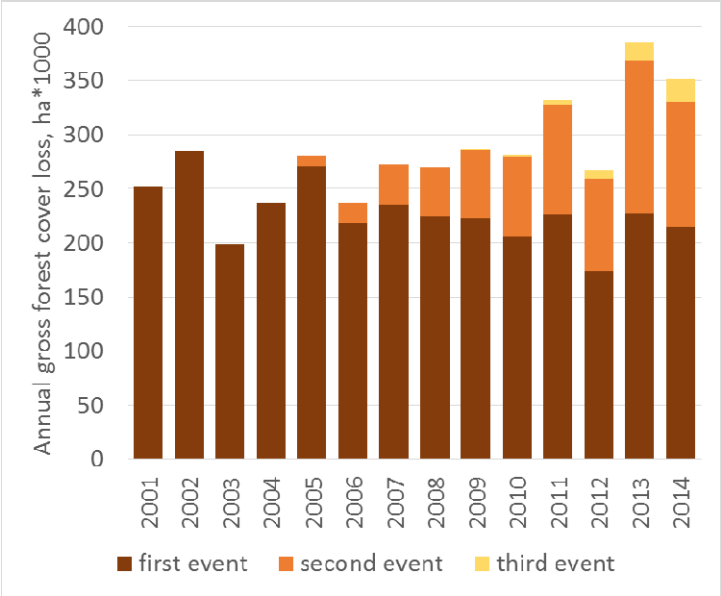
Forest loss with primary/mature secondary forests



Year 2000 primary / mature secondary forests
Year 2000 young secondary forests/ plantations / orchards
Gross forest loss 2001-2014 with primary forests
Gross forest loss outside primary forests

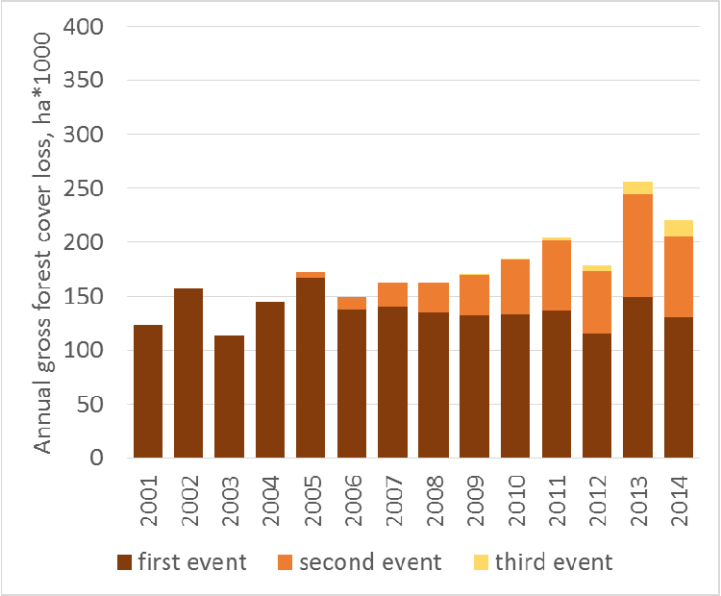
Step 2. Forest cover and change mapping

Total annual gross forest cover loss



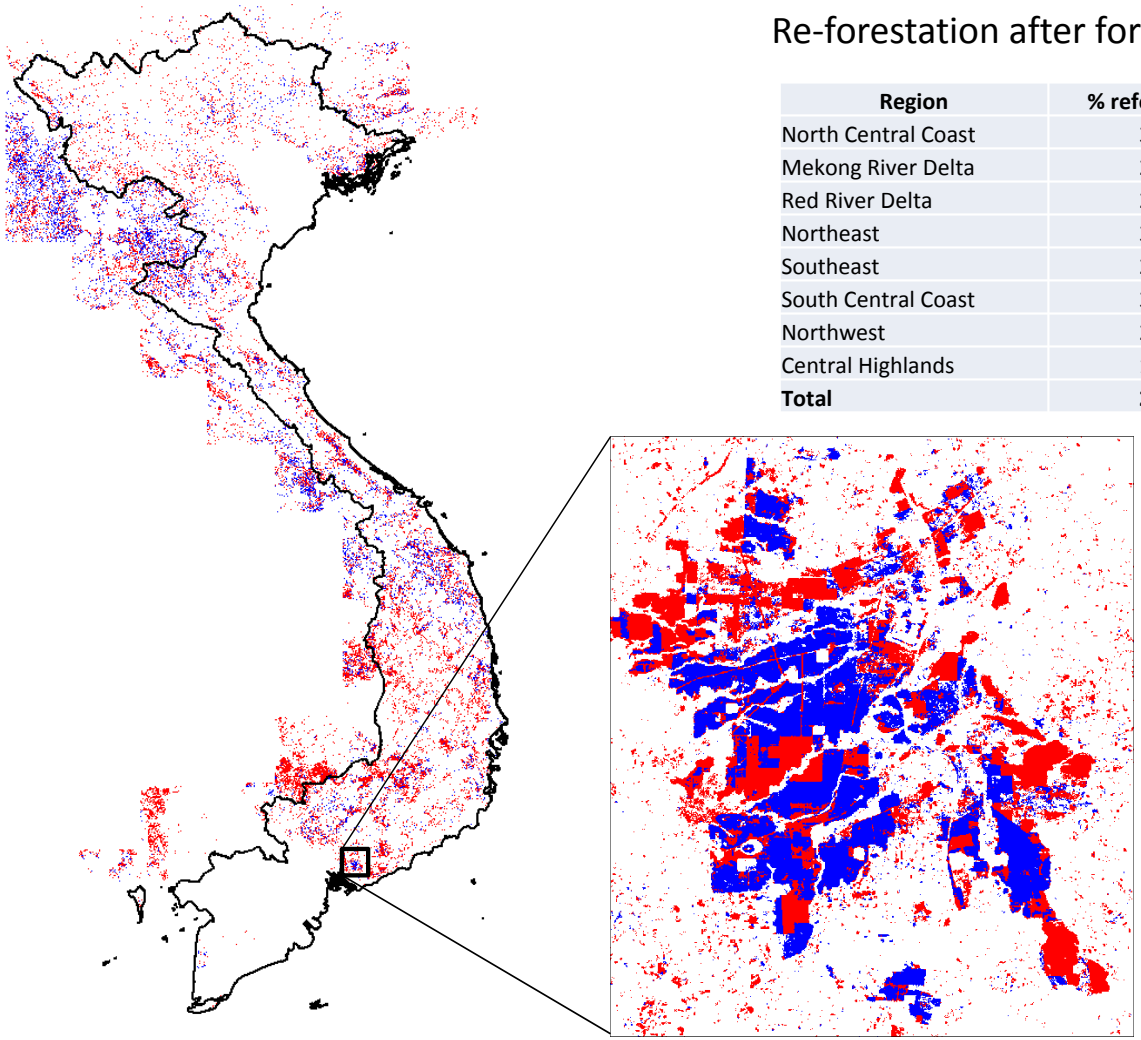
Total gross forest loss 2001-14: 3.2 million ha.

Forest loss with primary and mature secondary forests



Primary forests contribute 60% of total gross forest loss.

Step 2. Forest cover and change mapping



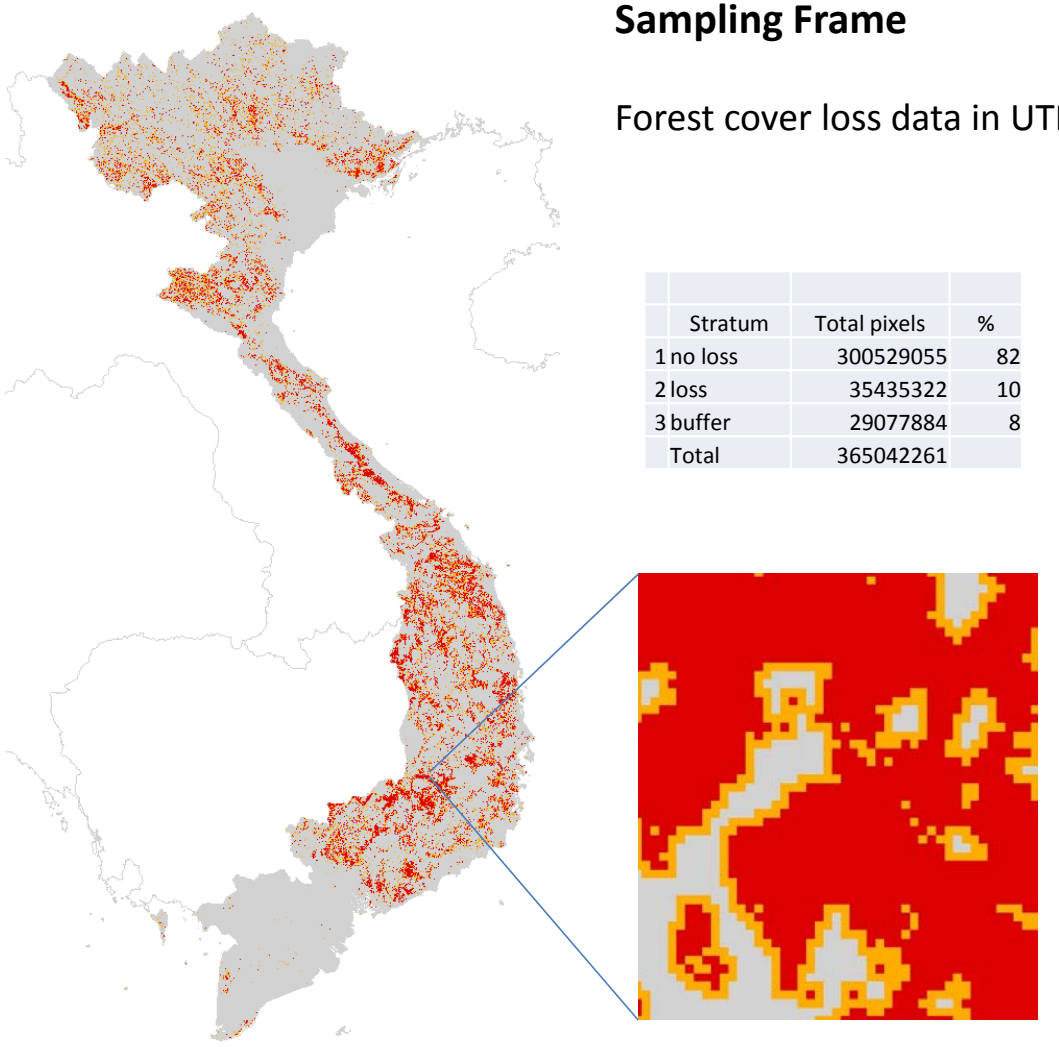
Re-forestation after forest loss

Region	% reforested
North Central Coast	38
Mekong River Delta	28
Red River Delta	27
Northeast	32
Southeast	25
South Central Coast	37
Northwest	25
Central Highlands	16
Total	**28**

Tree cover >=60% established after forest loss event

Other forest loss

Step 3. Validation



Sampling Frame

Forest cover loss data in UTM zone 48 (pixel area 900m^2)

	Stratum	Total pixels	%
1	no loss	300529055	82
2	loss	35435322	10
3	buffer	29077884	8
	Total	365042261	

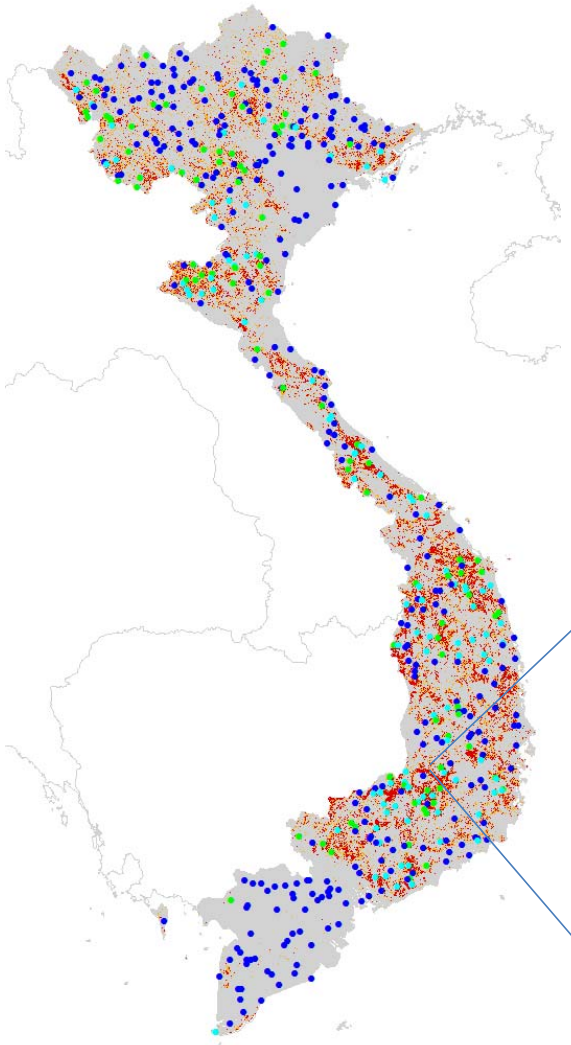
Stratum

1 (no loss)

2 (loss)

3 (buffer around loss)

Step 3. Validation

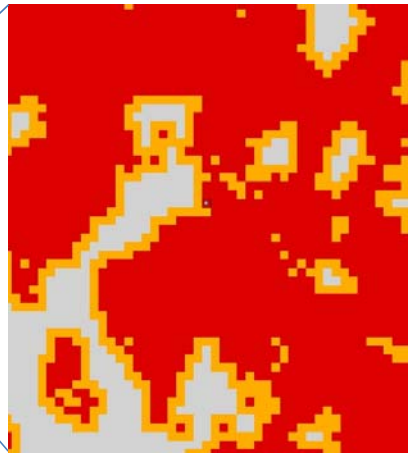


Sampling Frame

Forest cover loss data in UTM zone 48 (pixel area 900m^2)

Sample allocation

				Sample allocation		
	Stratum	Total pixels	%	proportional	equal	selected
1	no loss	300529055	82	412	167	**300**
2	loss	35435322	10	49	167	**100**
3	buffer	29077884	8	40	167	**100**
	Total	365042261		500	500	**500**



Stratum

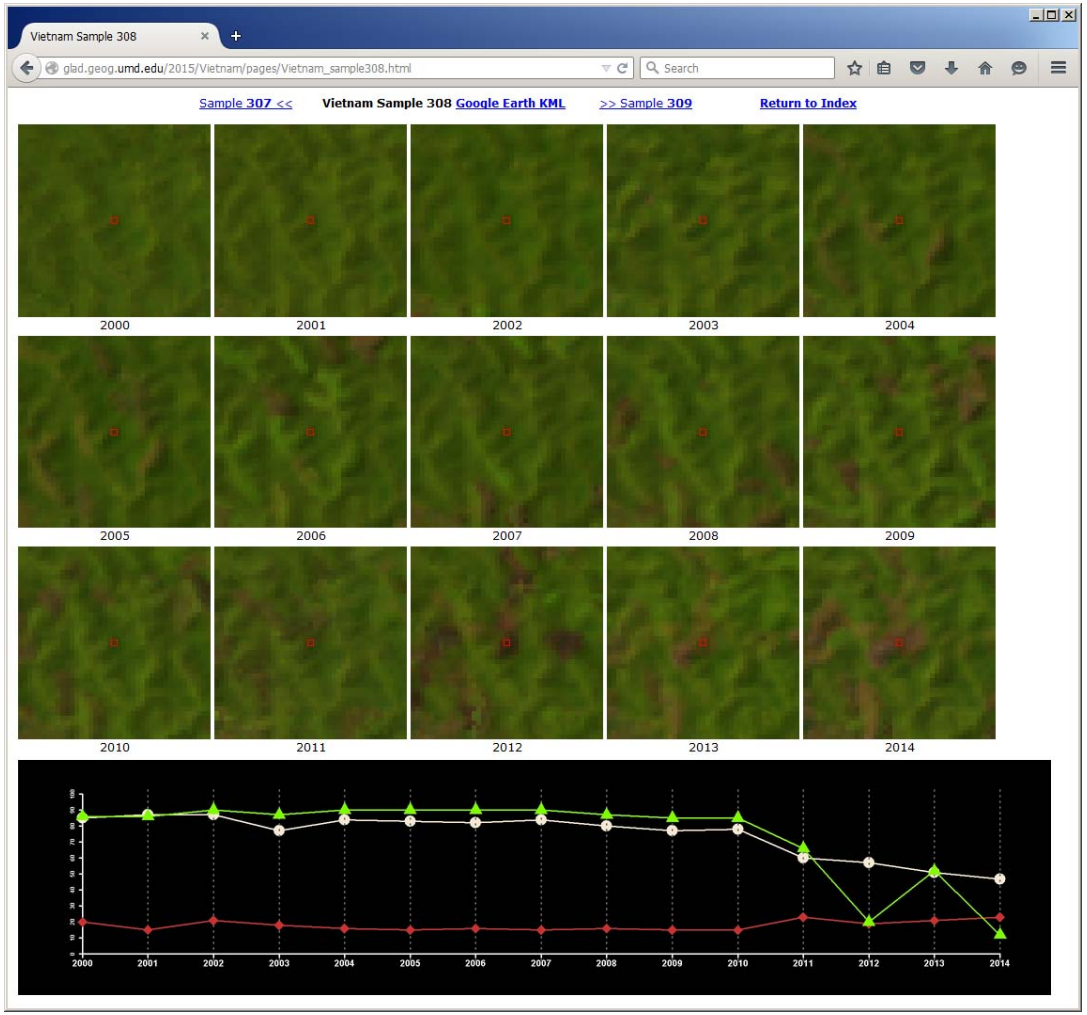
1 (no loss)

2 (loss)

3 (buffer around loss)

Step 3. Validation

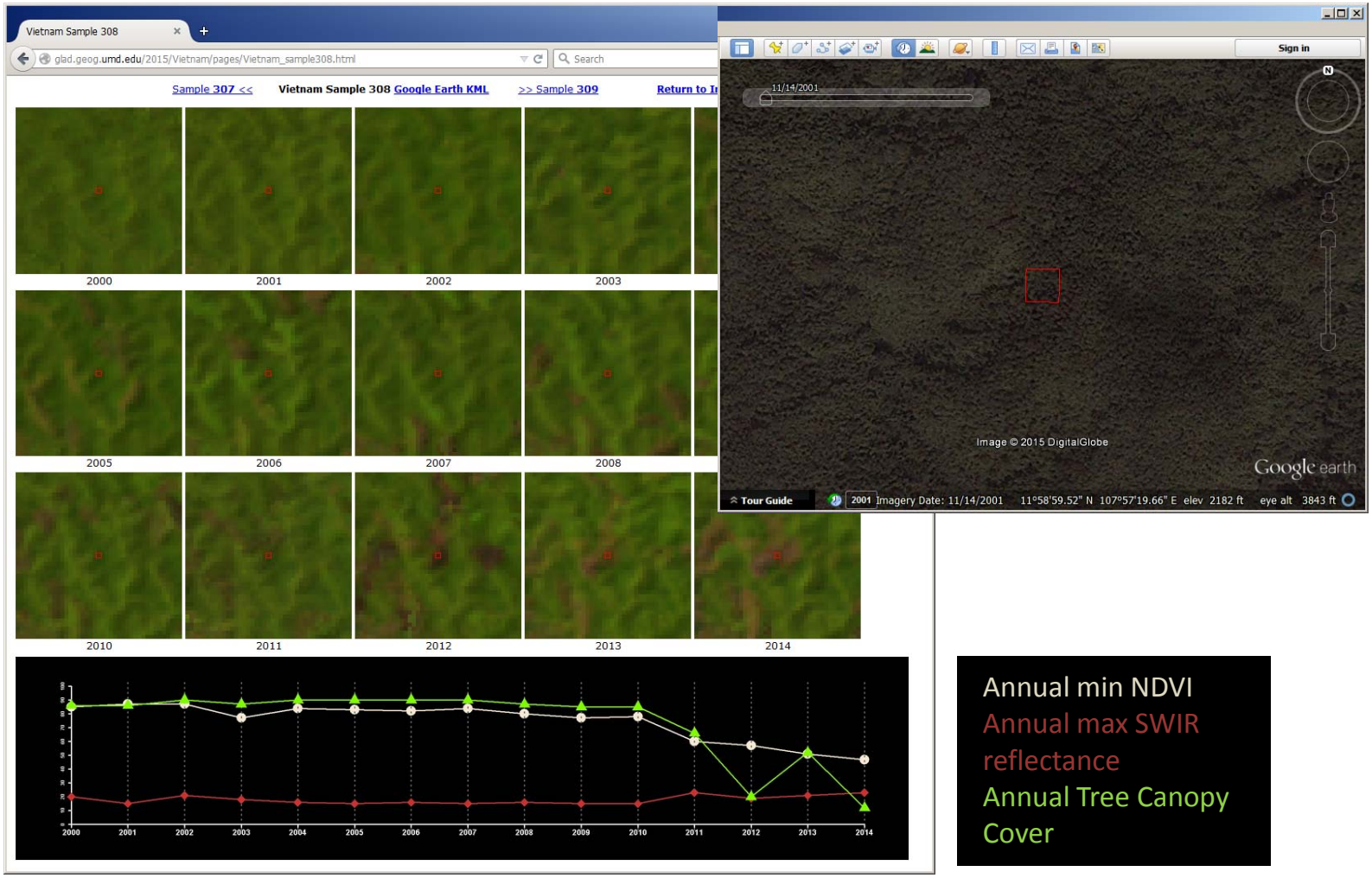
Reference data



Annual min NDVI
Annual max SWIR reflectance
Annual Tree Canopy Cover

Step 3. Validation

Reference data



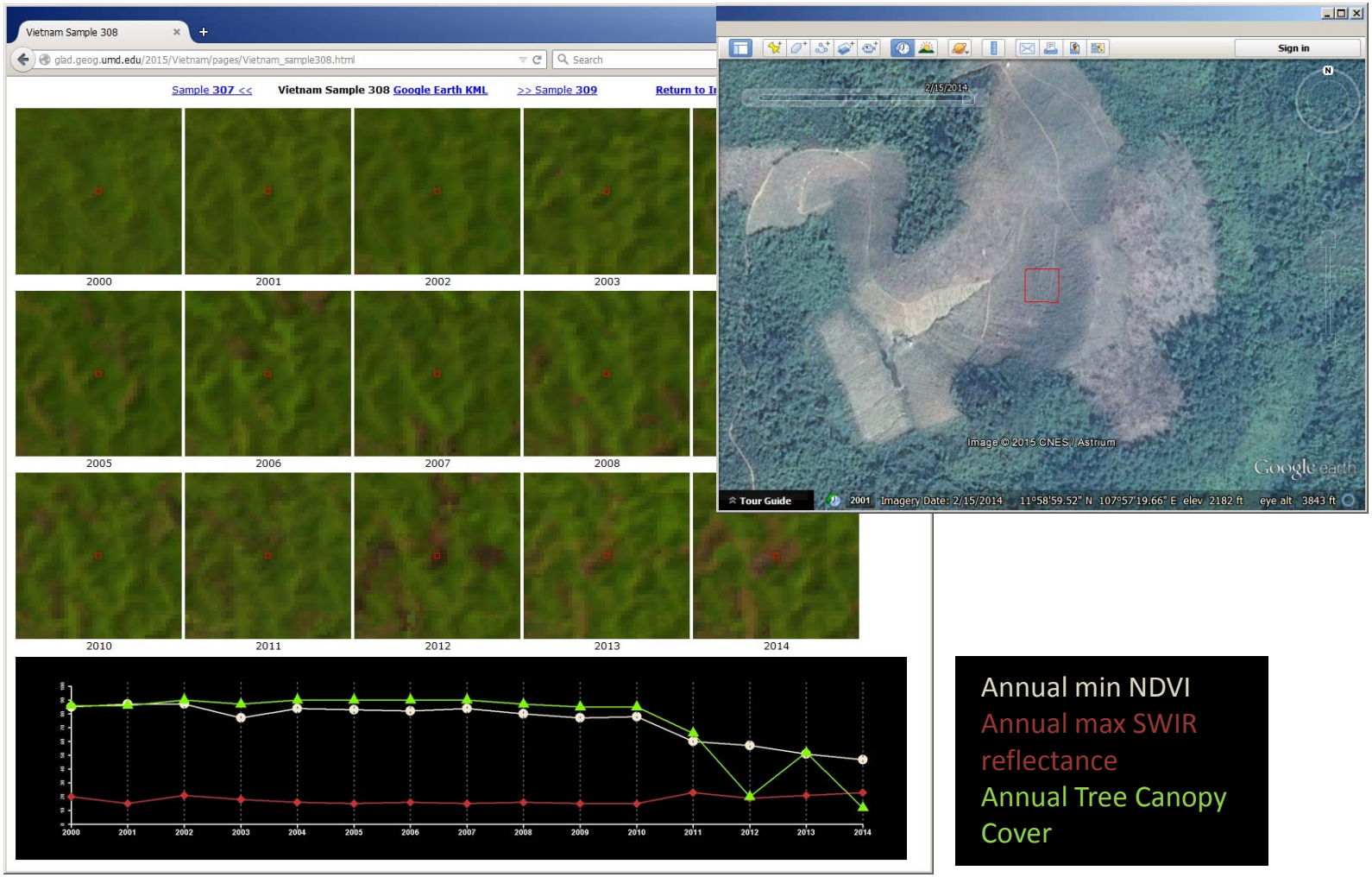
Annual min NDVI

Annual max SWIR reflectance

Annual Tree Canopy Cover

Step 3. Validation

Reference data



Annual min NDVI
Annual max SWIR reflectance
Annual Tree Canopy Cover

Step 3. Validation

Validation results

Source validation results

		loss fraction			
	Stratum	**0**	**0.5**	**1**	
1	**No loss**	294	3	3	300
2	**Loss**	6	0	94	100
3	**Loss buffer**	57	26	17	100

Map accuracy

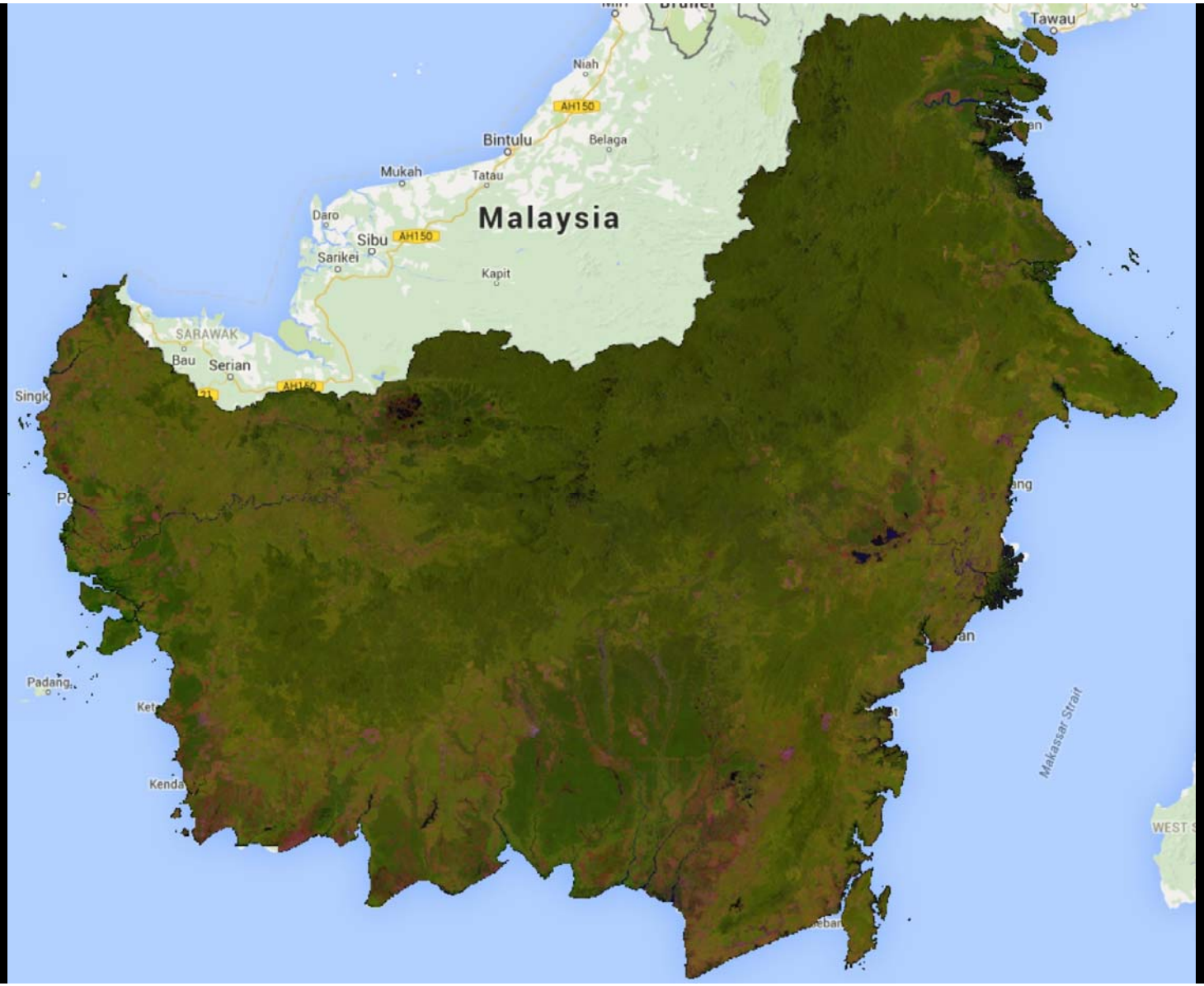
		Forest loss class	
Estimation option	Overall accuracy	User's accuracy	Producer's accuracy
Fractional pixels as no loss	97.24	94	80.73
Including fractional loss	95.79	94	71.57
Without "loss buffer" stratum	98.47	94	91.72

Area of forest loss

Estimation option	Map loss area (ha)	Sample-based area of loss (ha)	95% confidence interval (% loss)
Fractional pixels as no loss	3.189.179	3.713.196	10.53
Including fractional loss		4.188.645	11.12

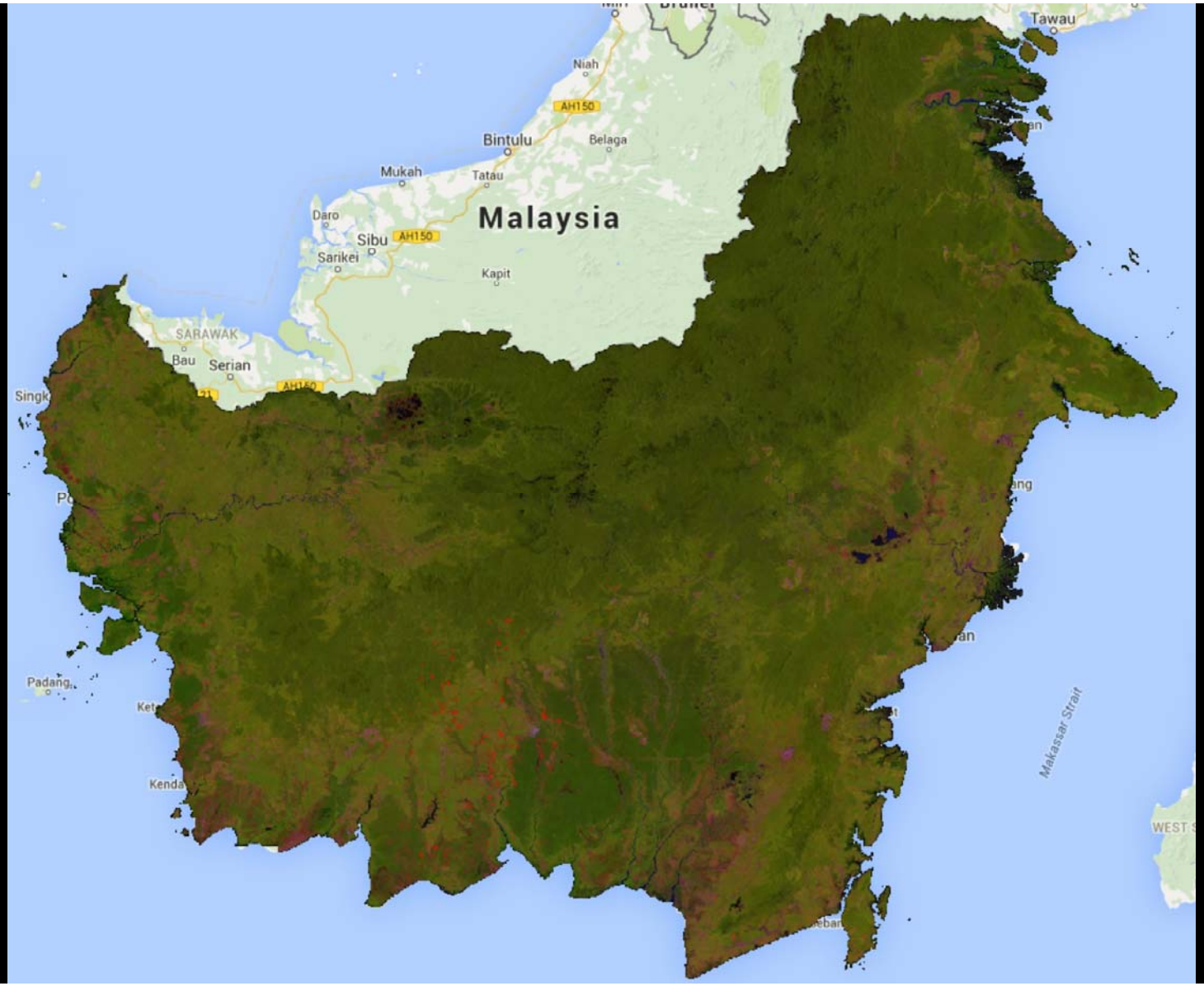
Accuracy estimation based on Olofsson et al. 2013

Weekly forest disturbance alerts



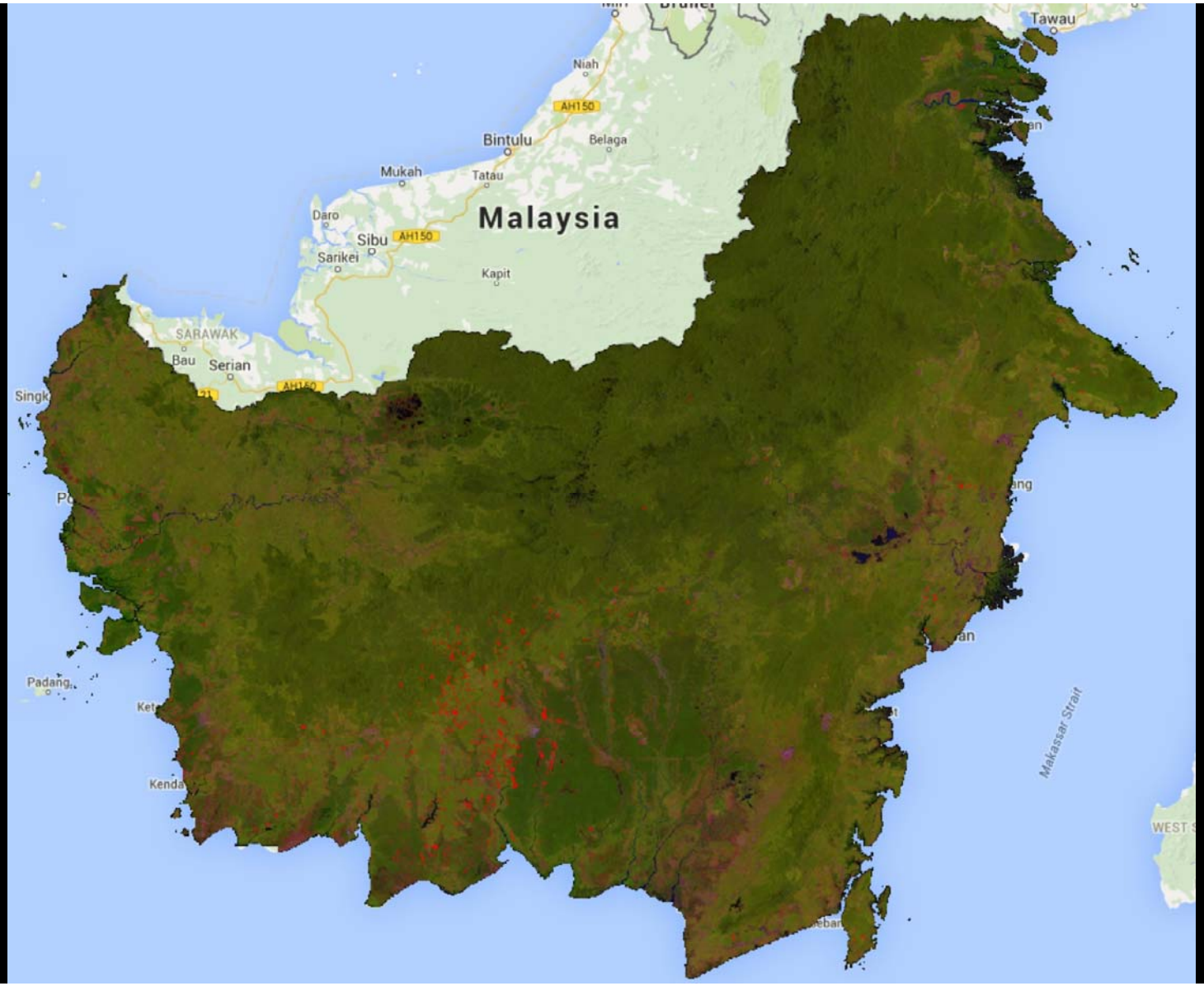
Start 2015

Weekly forest disturbance alerts



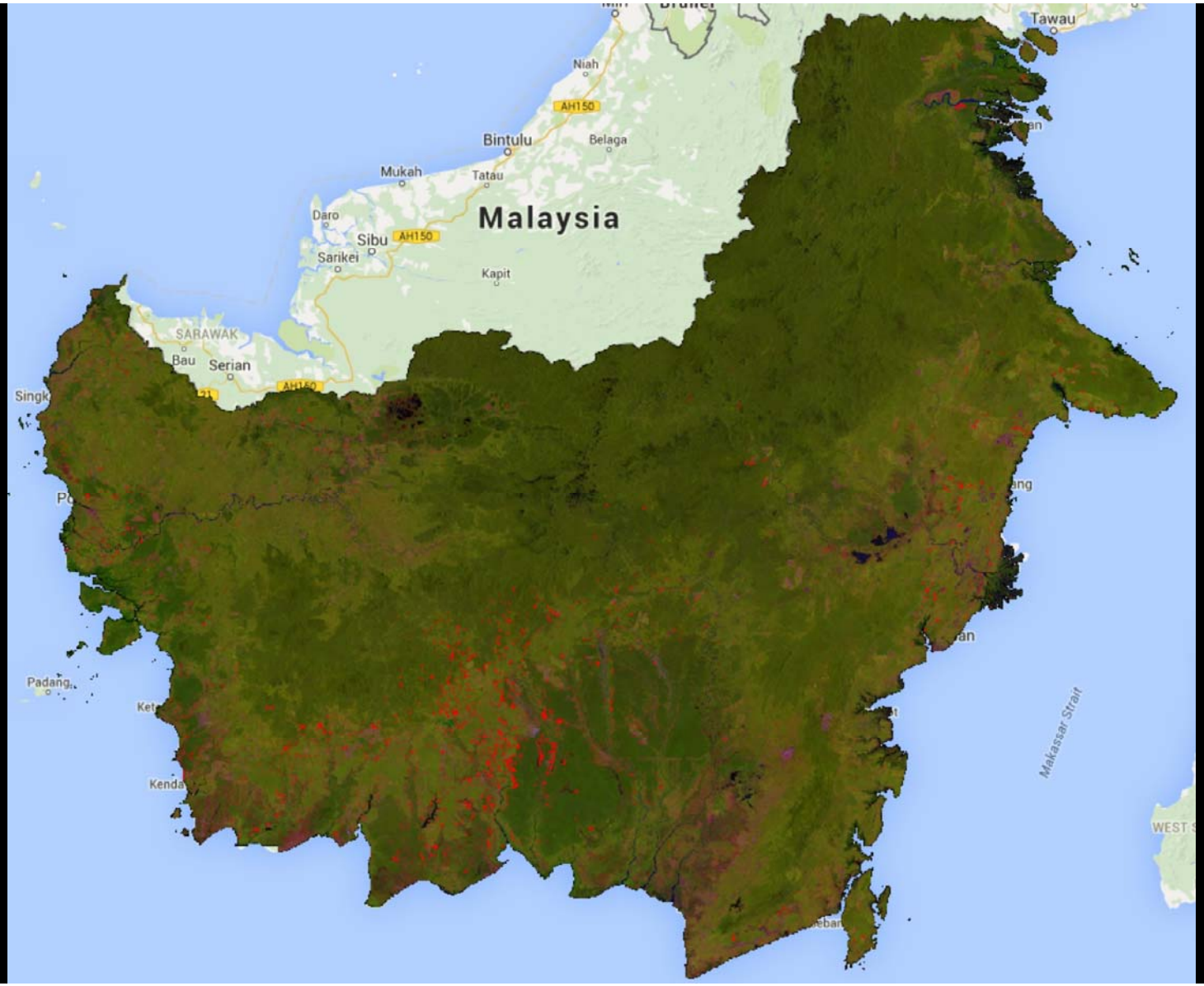
-> Jan. 25

Weekly forest disturbance alerts



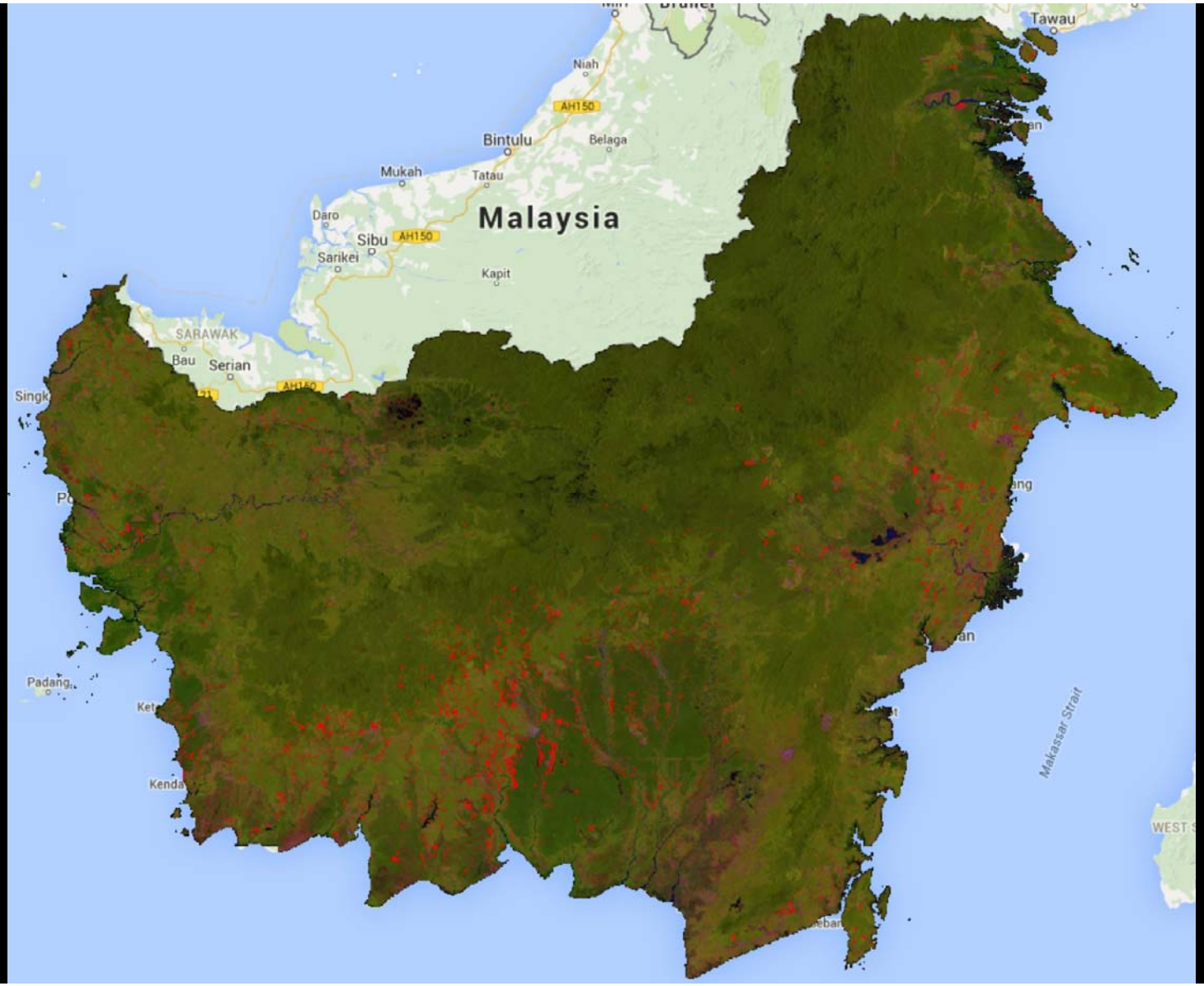
-> Feb. 19

Weekly forest disturbance alerts



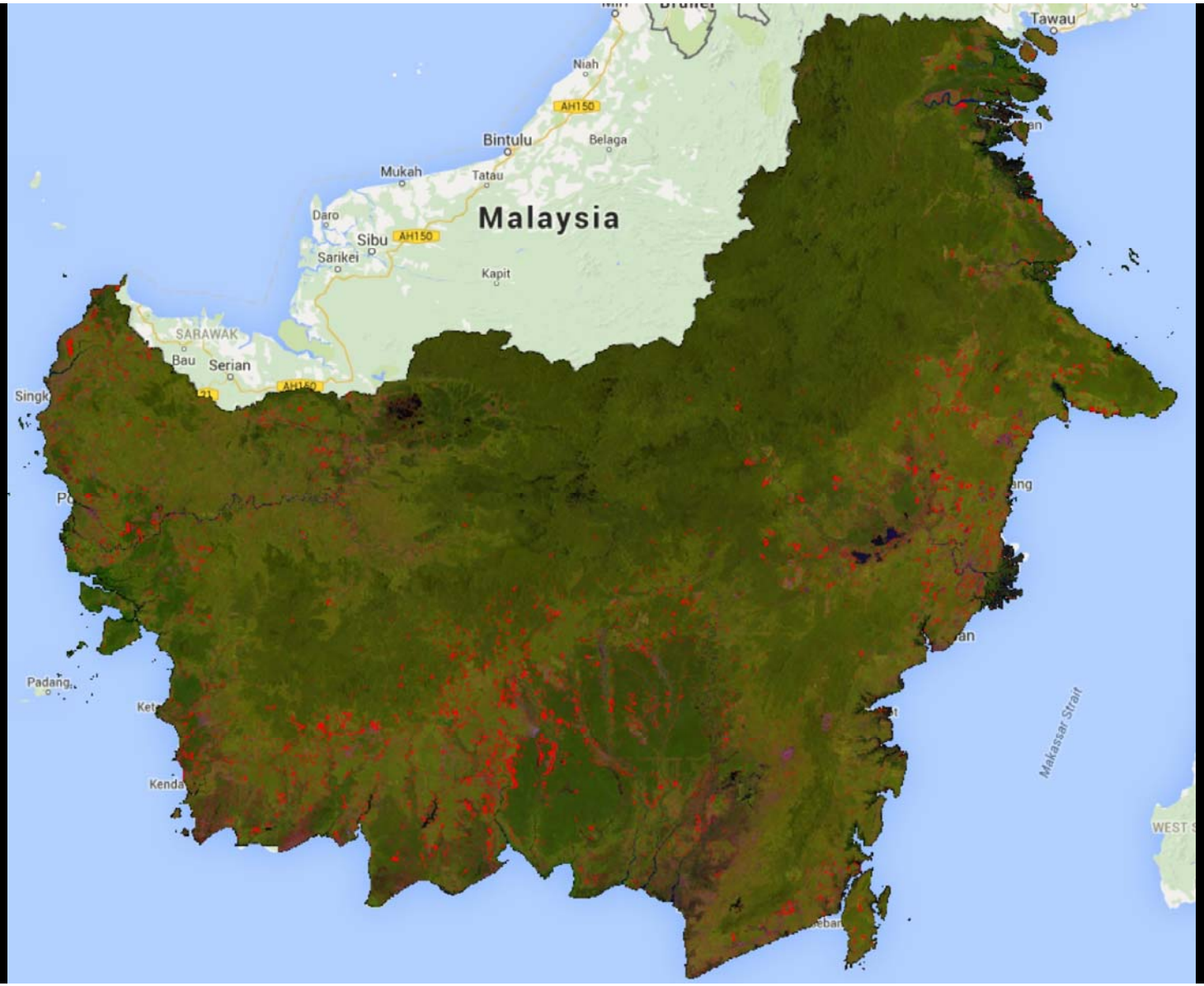
-> Mar. 16

Weekly forest disturbance alerts



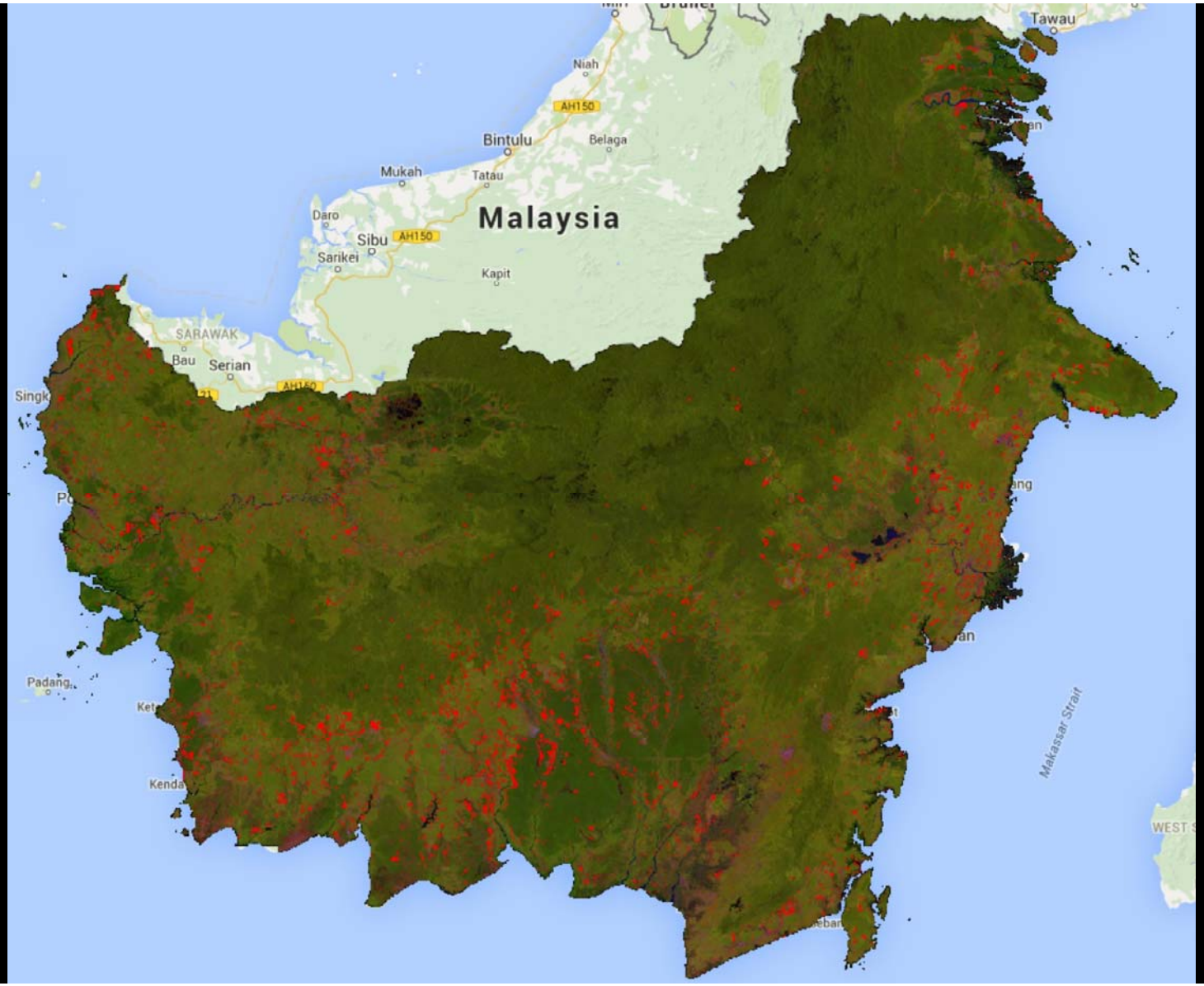
-> Apr. 10

Weekly forest disturbance alerts



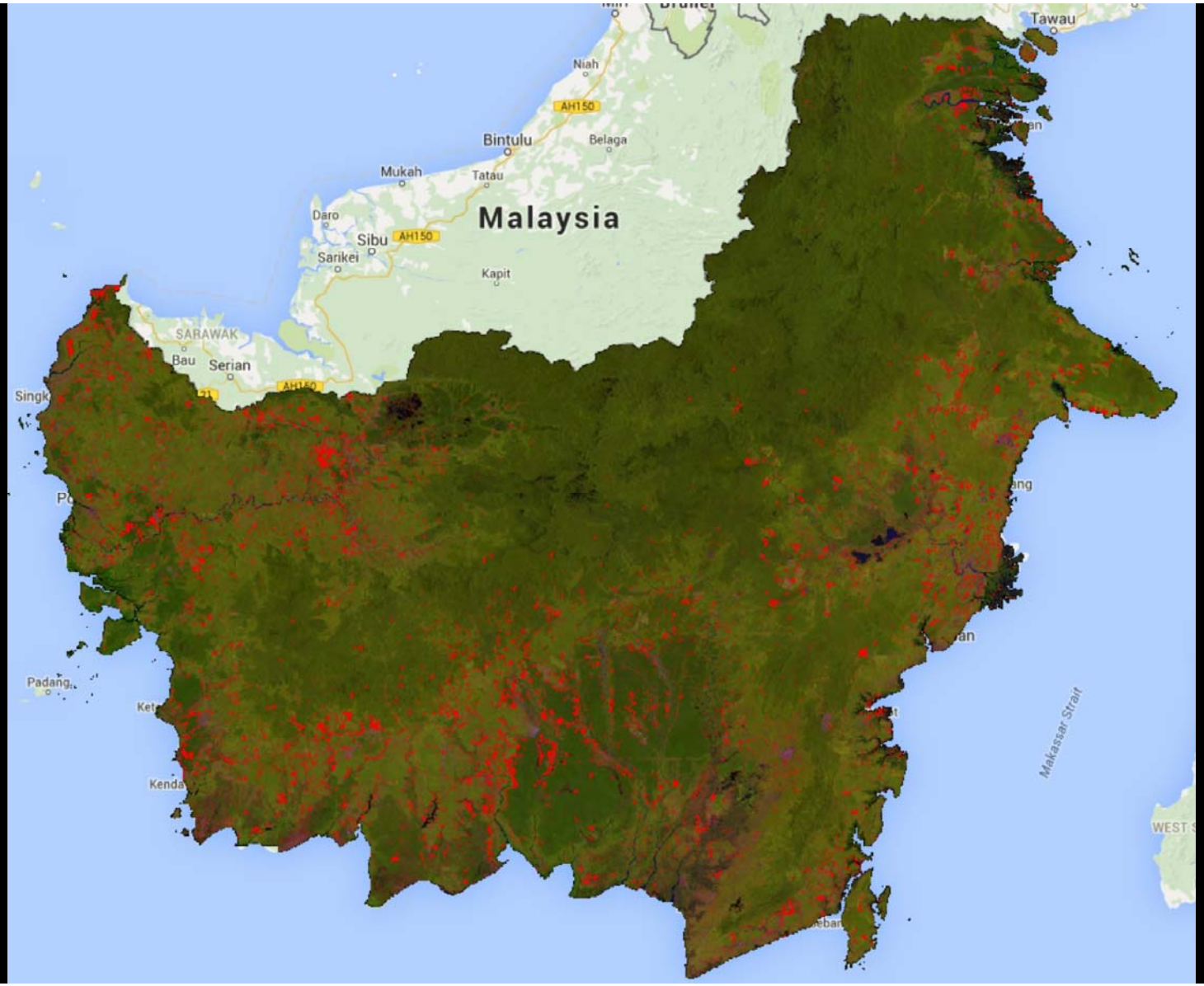
-> May 5

Weekly forest disturbance alerts



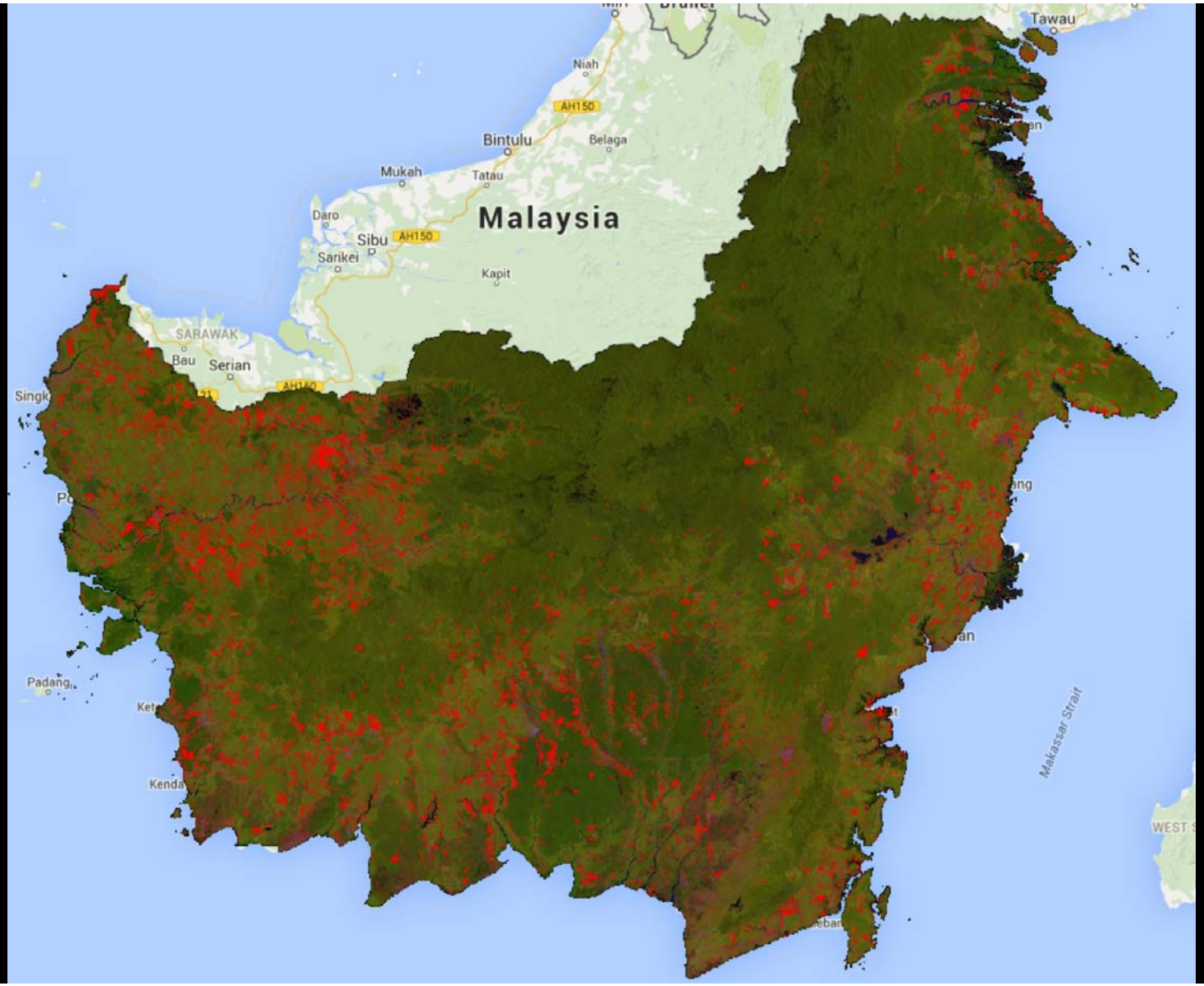
-> May 30

Weekly forest disturbance alerts



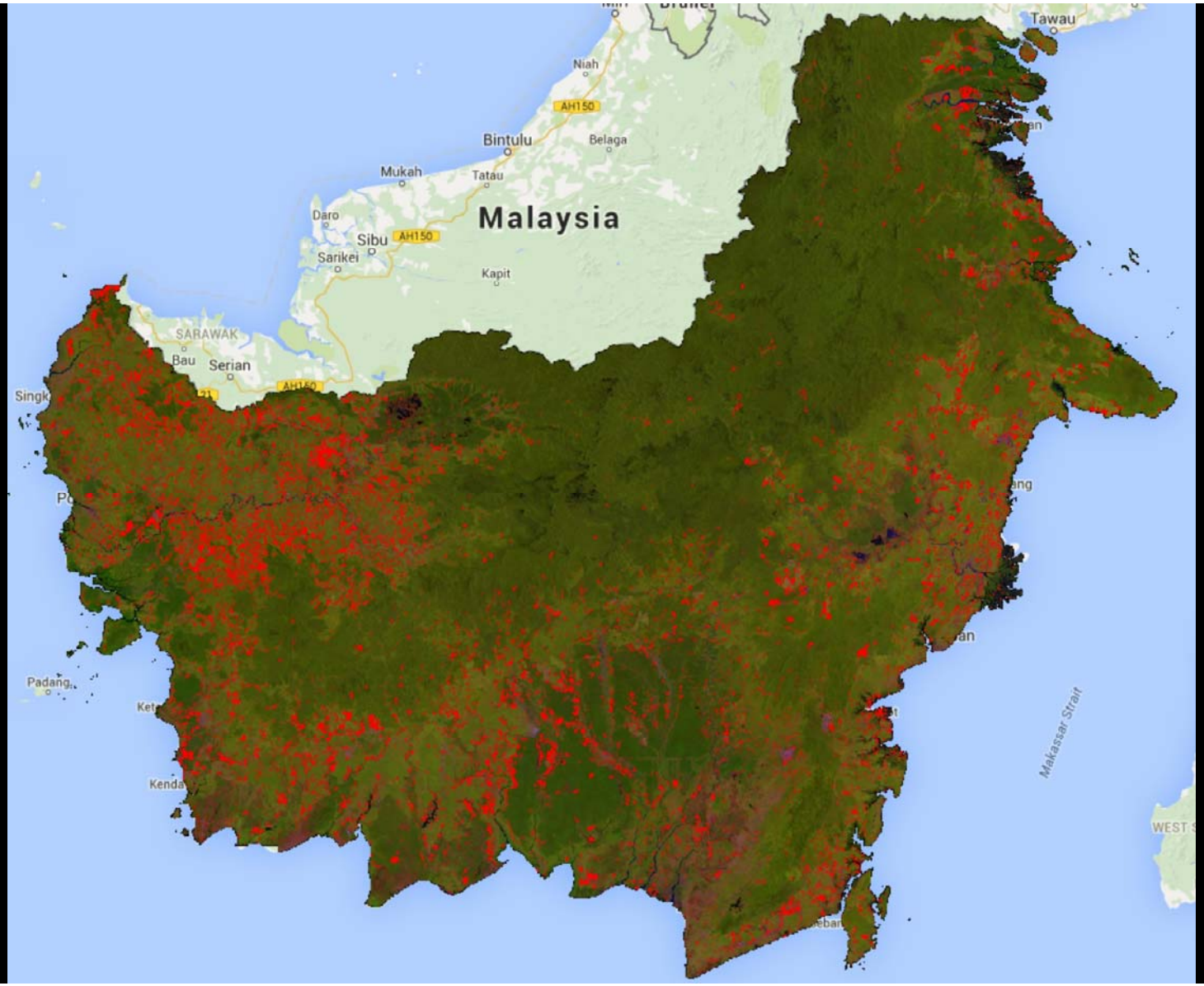
-> Jun. 24

Weekly forest disturbance alerts



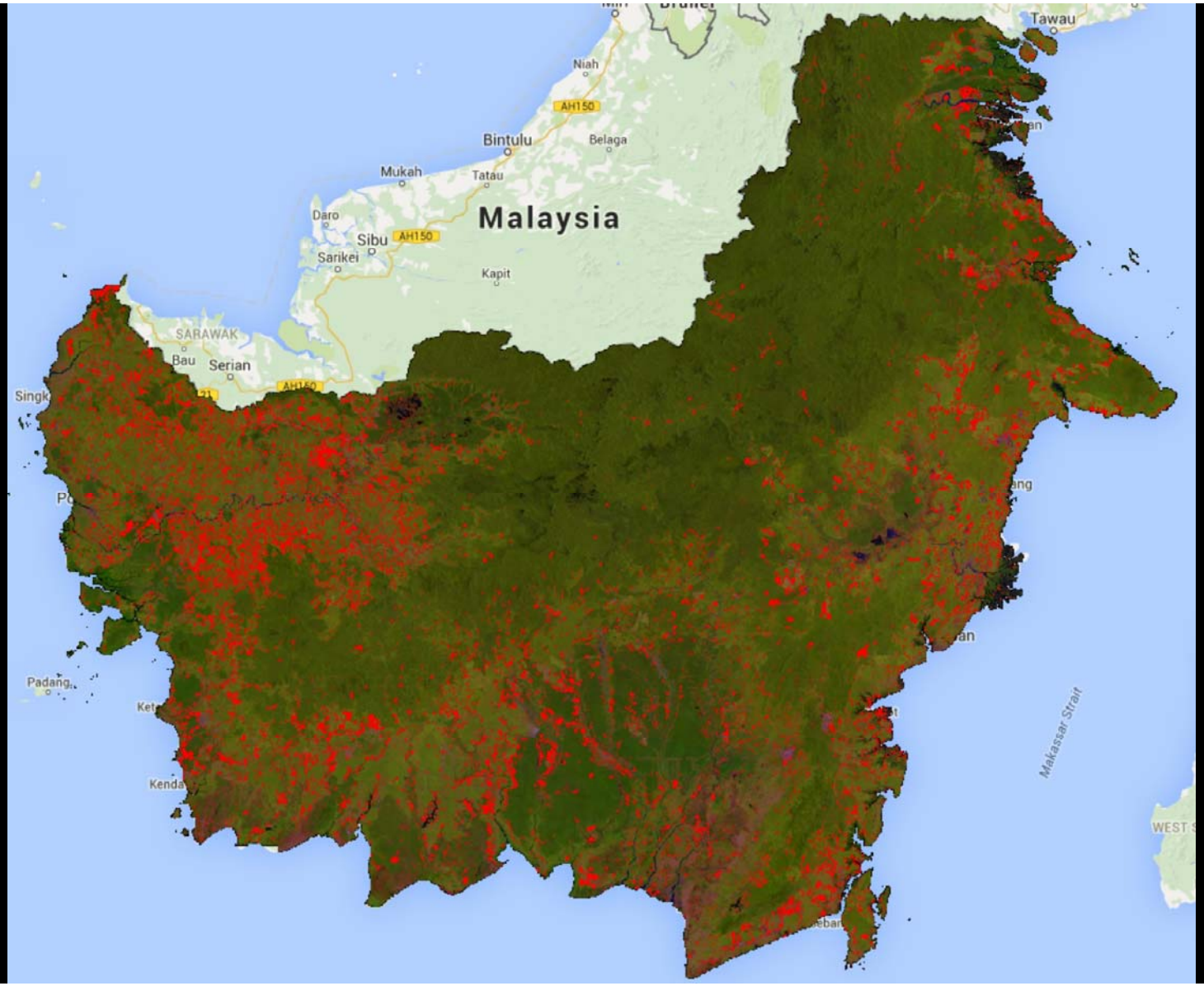
-> Jul. 19

Weekly forest disturbance alerts



-> Aug. 13

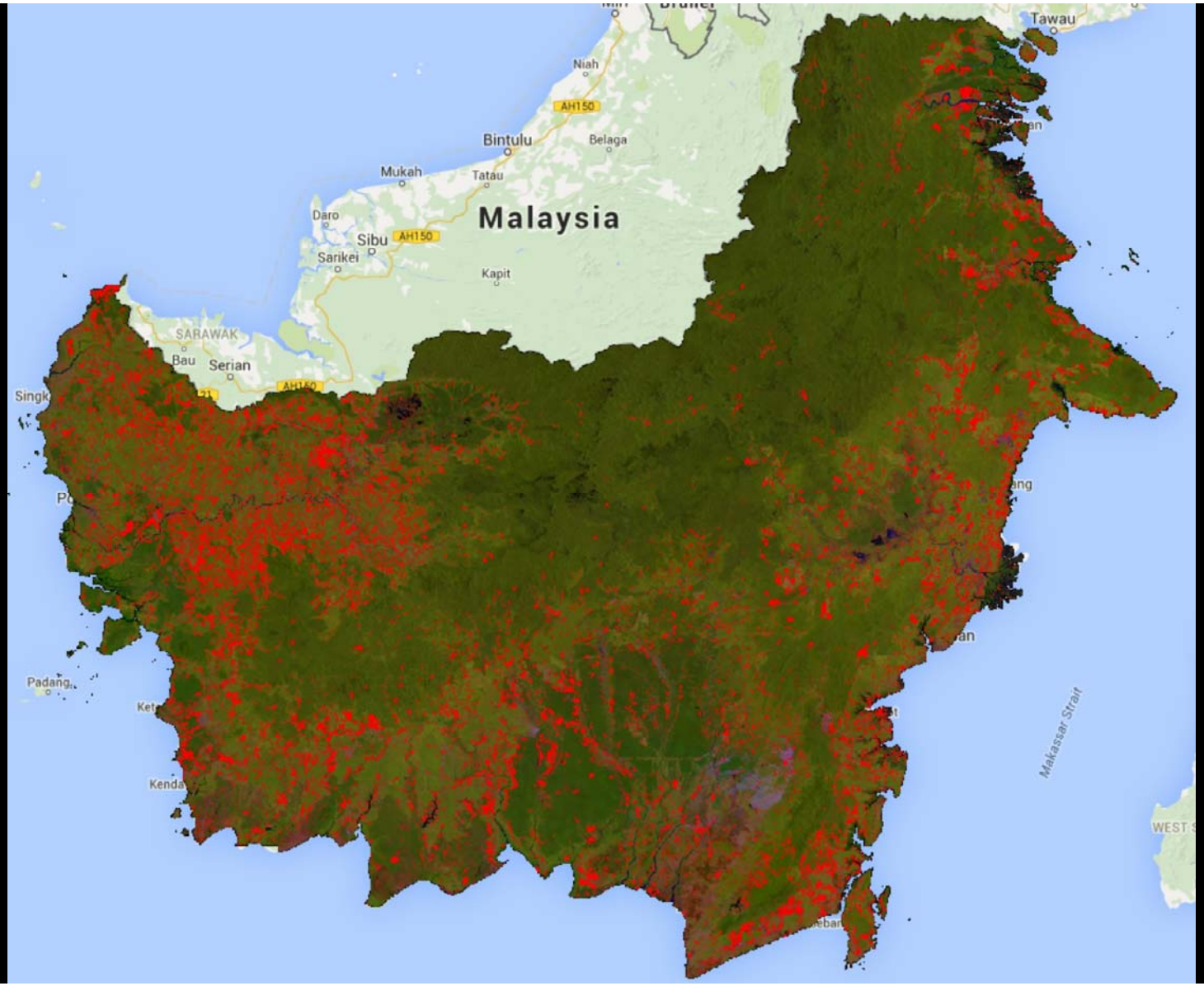
Weekly forest disturbance alerts



150 km

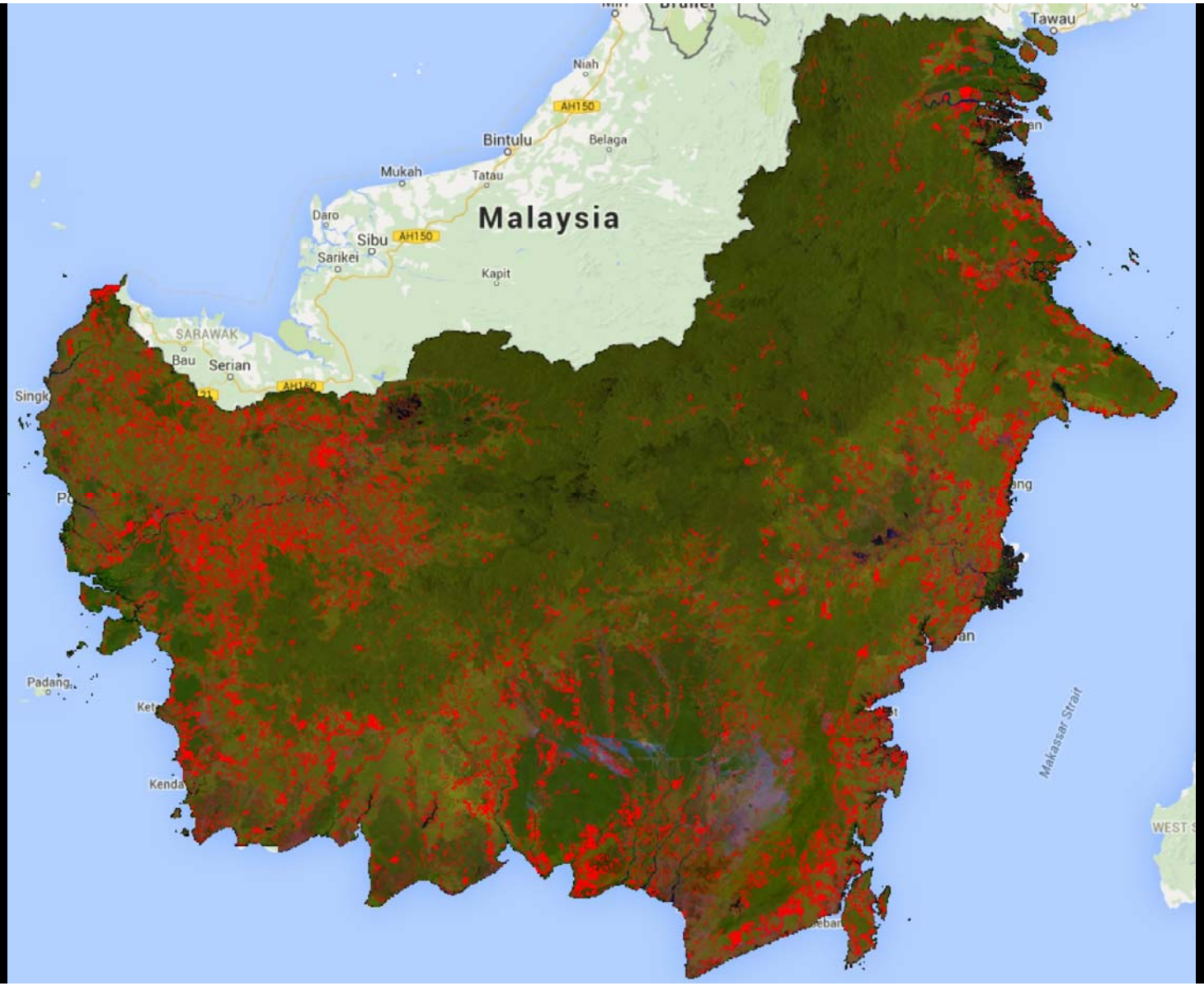
-> Sep. 7

Weekly forest disturbance alerts



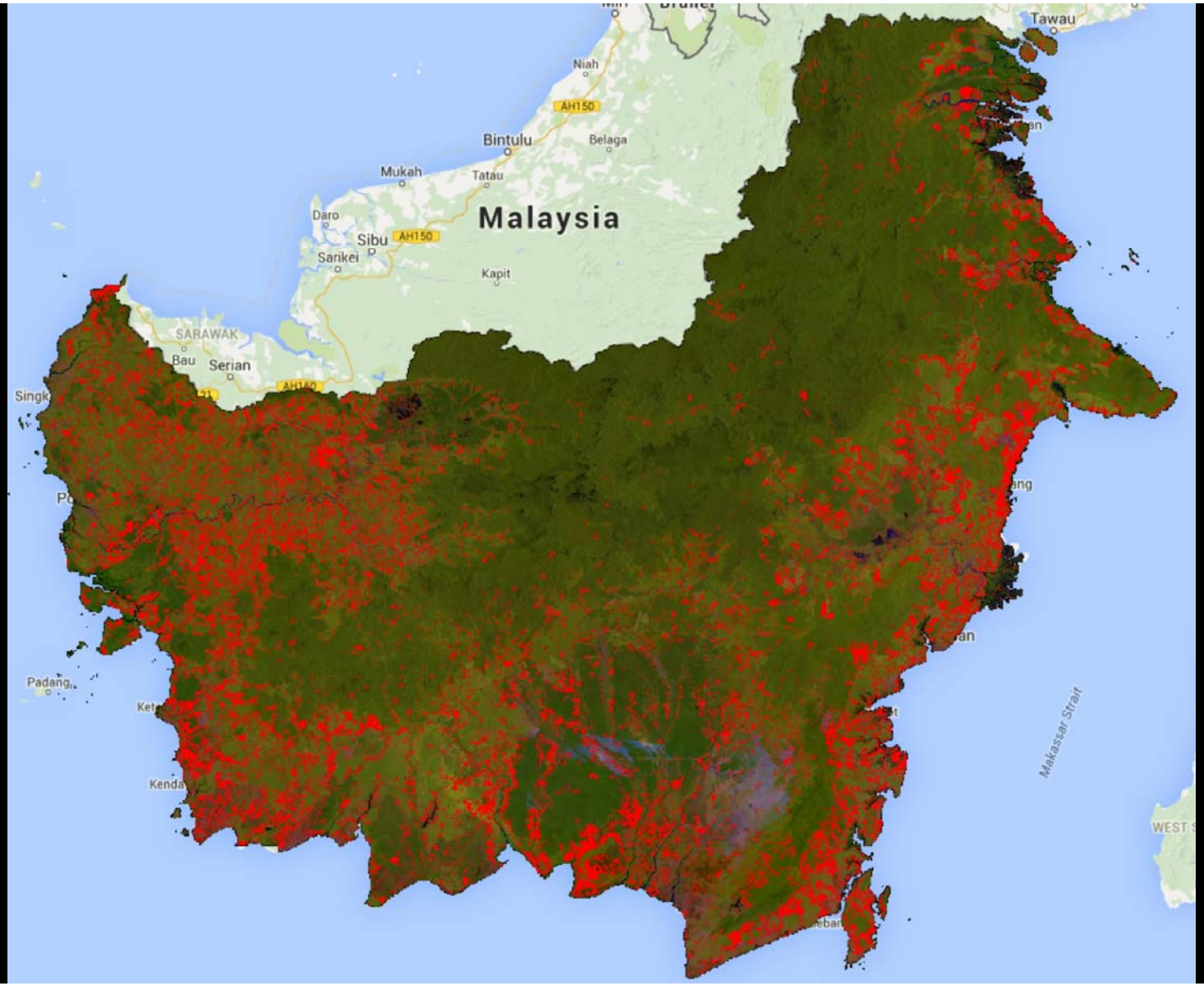
-> Oct. 2

Weekly forest disturbance alerts



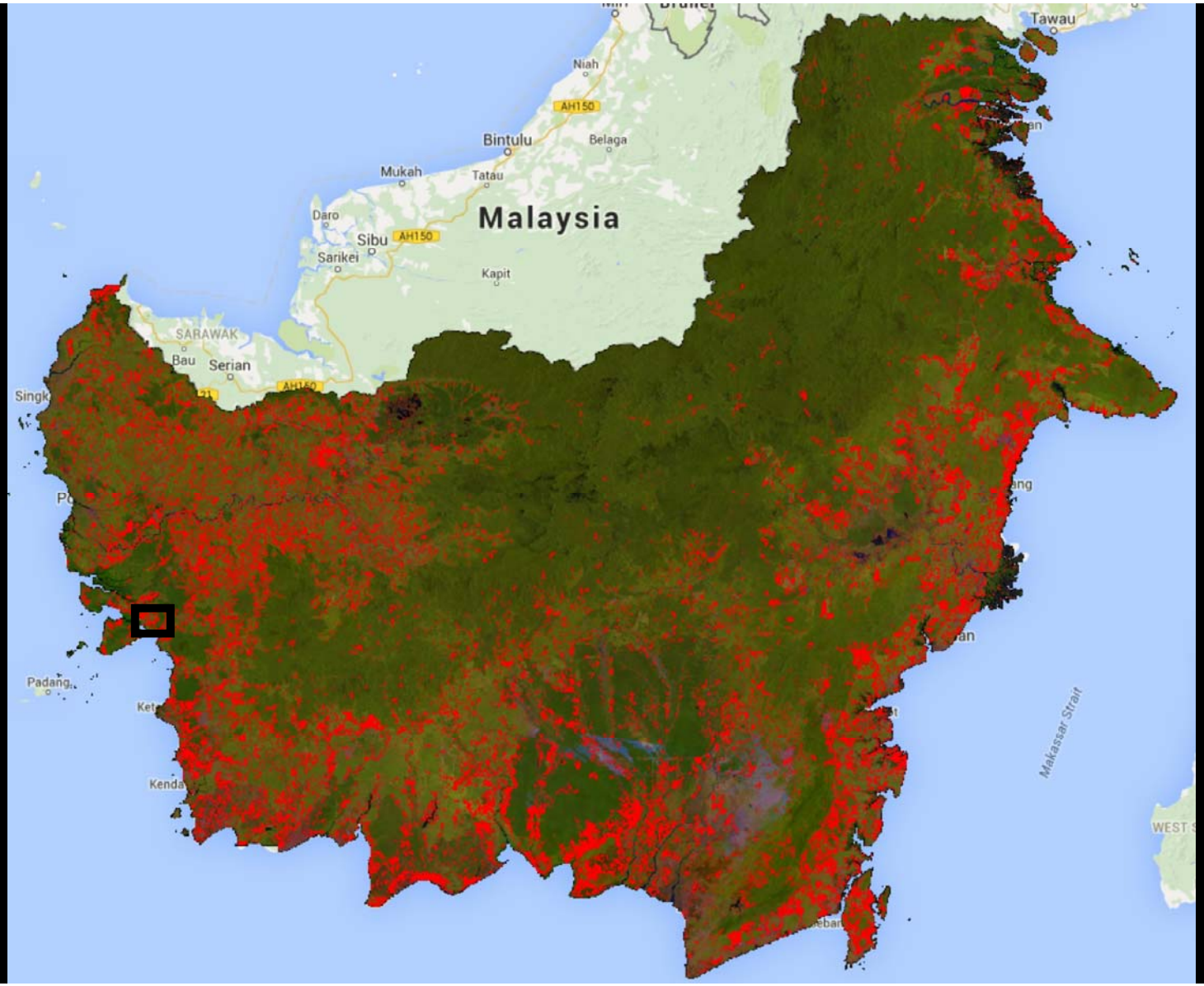
-> Oct. 27

Weekly forest disturbance alerts



-> Nov. 21

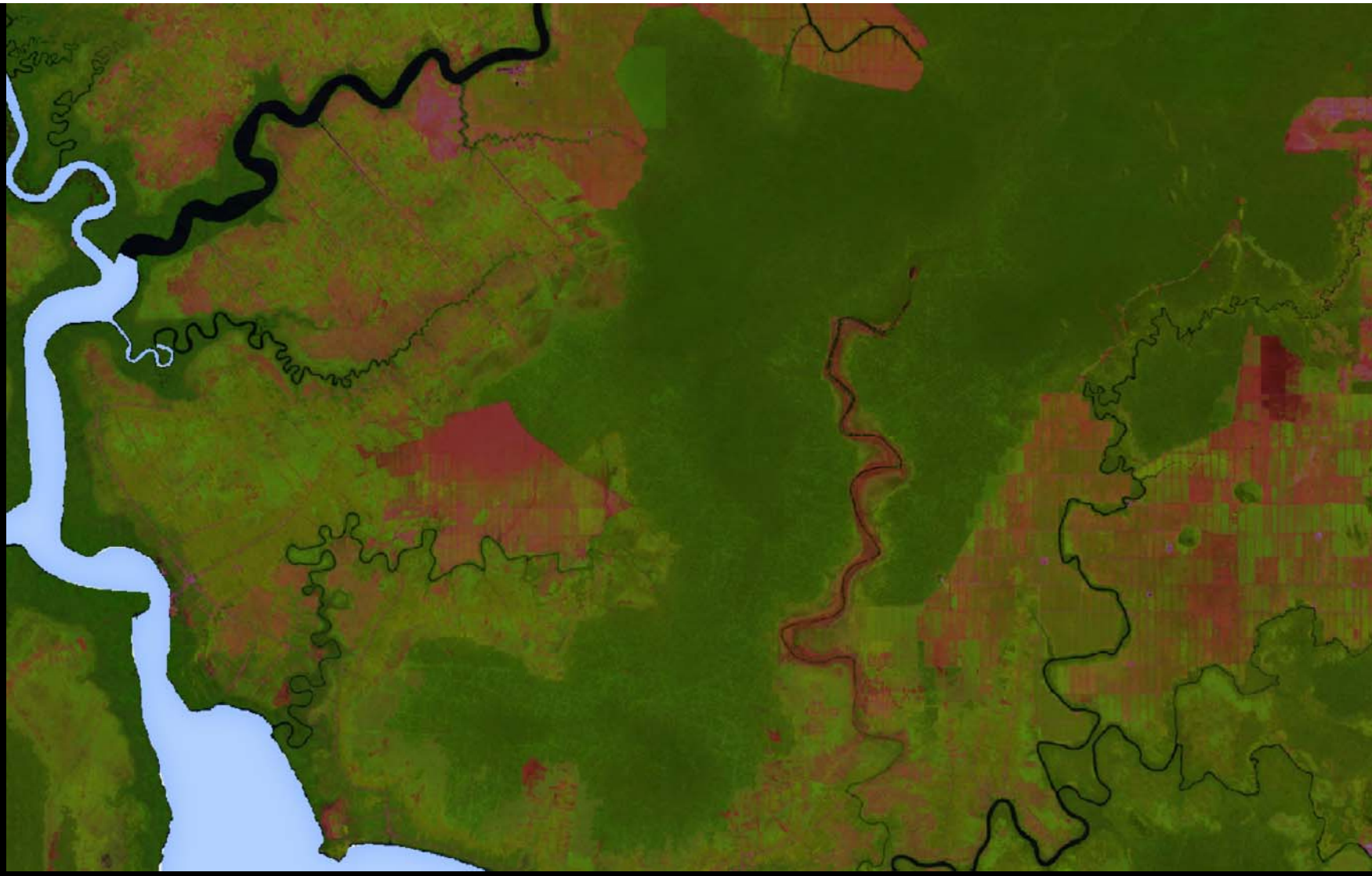
Weekly forest disturbance alerts



-> Dec. 16

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

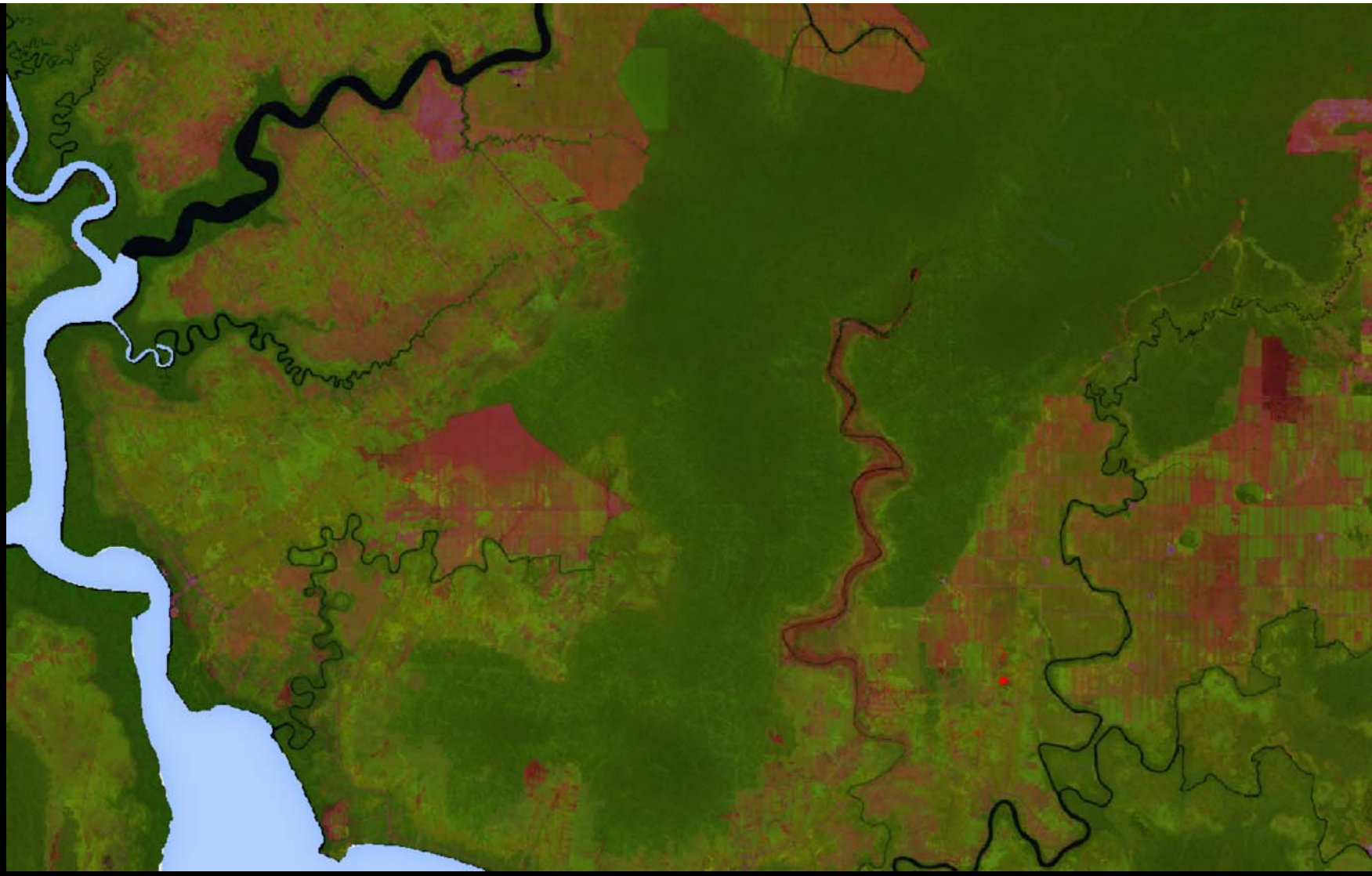


Start 2015

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

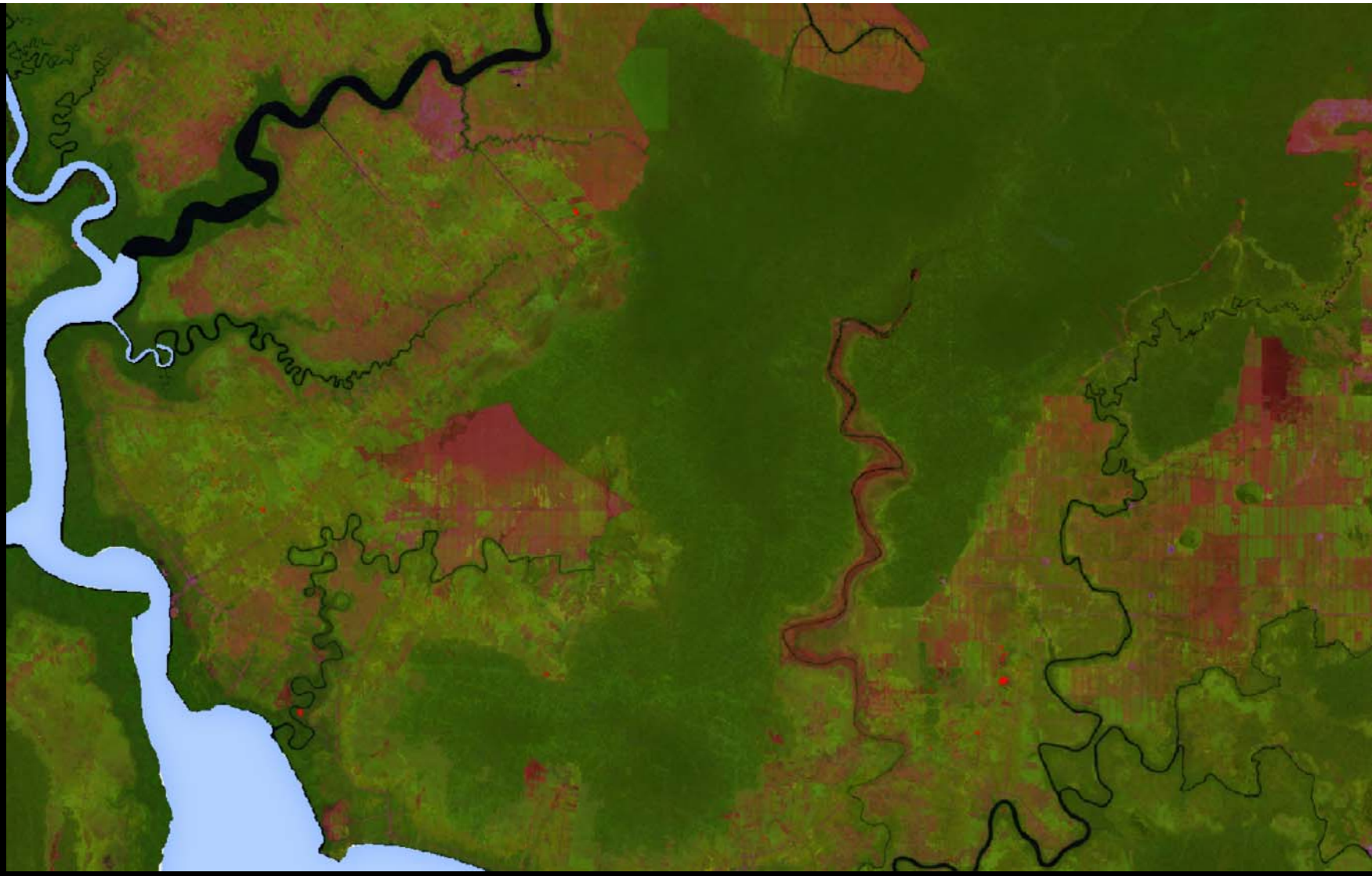


-> Jan. 25

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

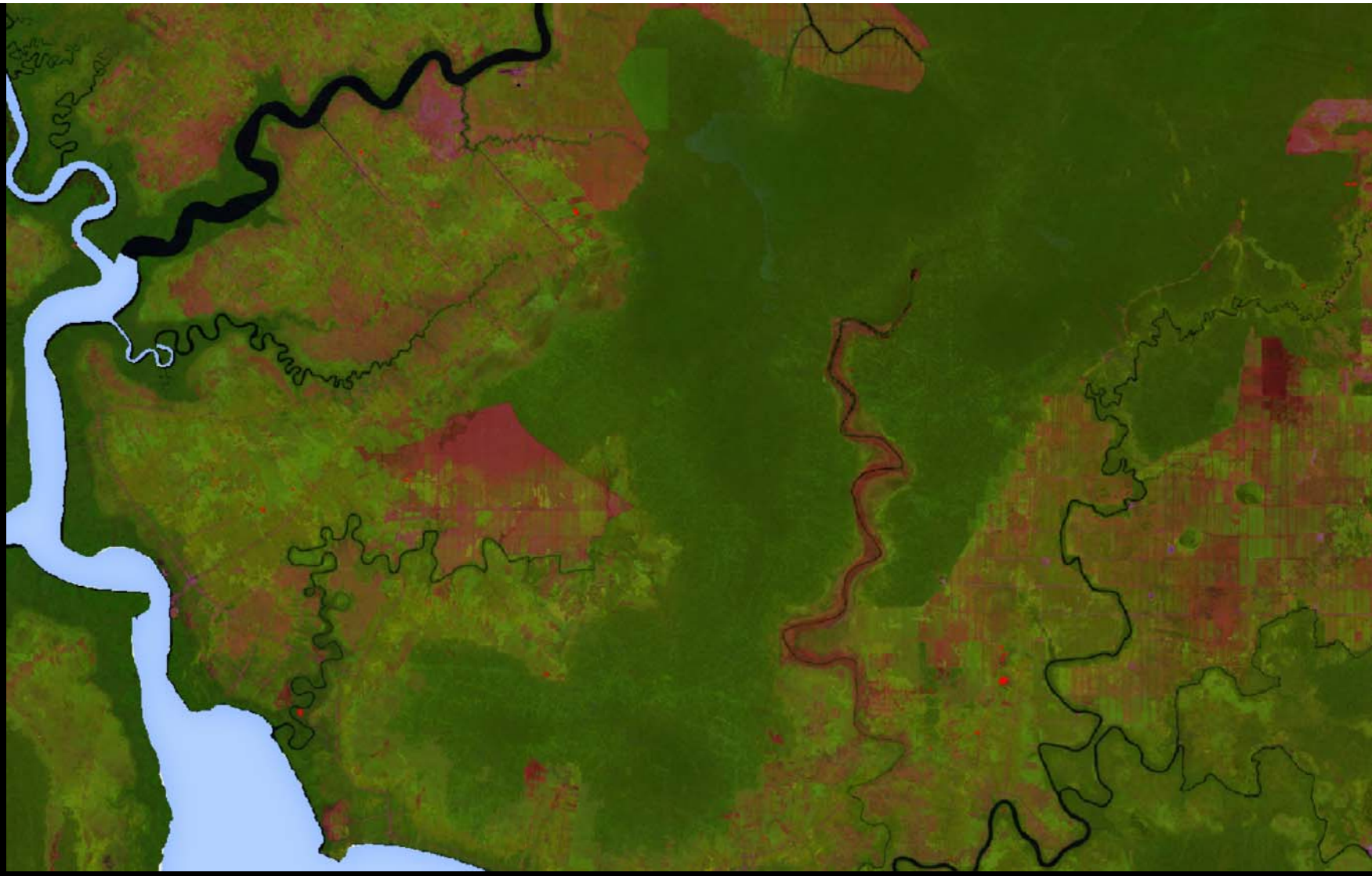


-> Feb. 19

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

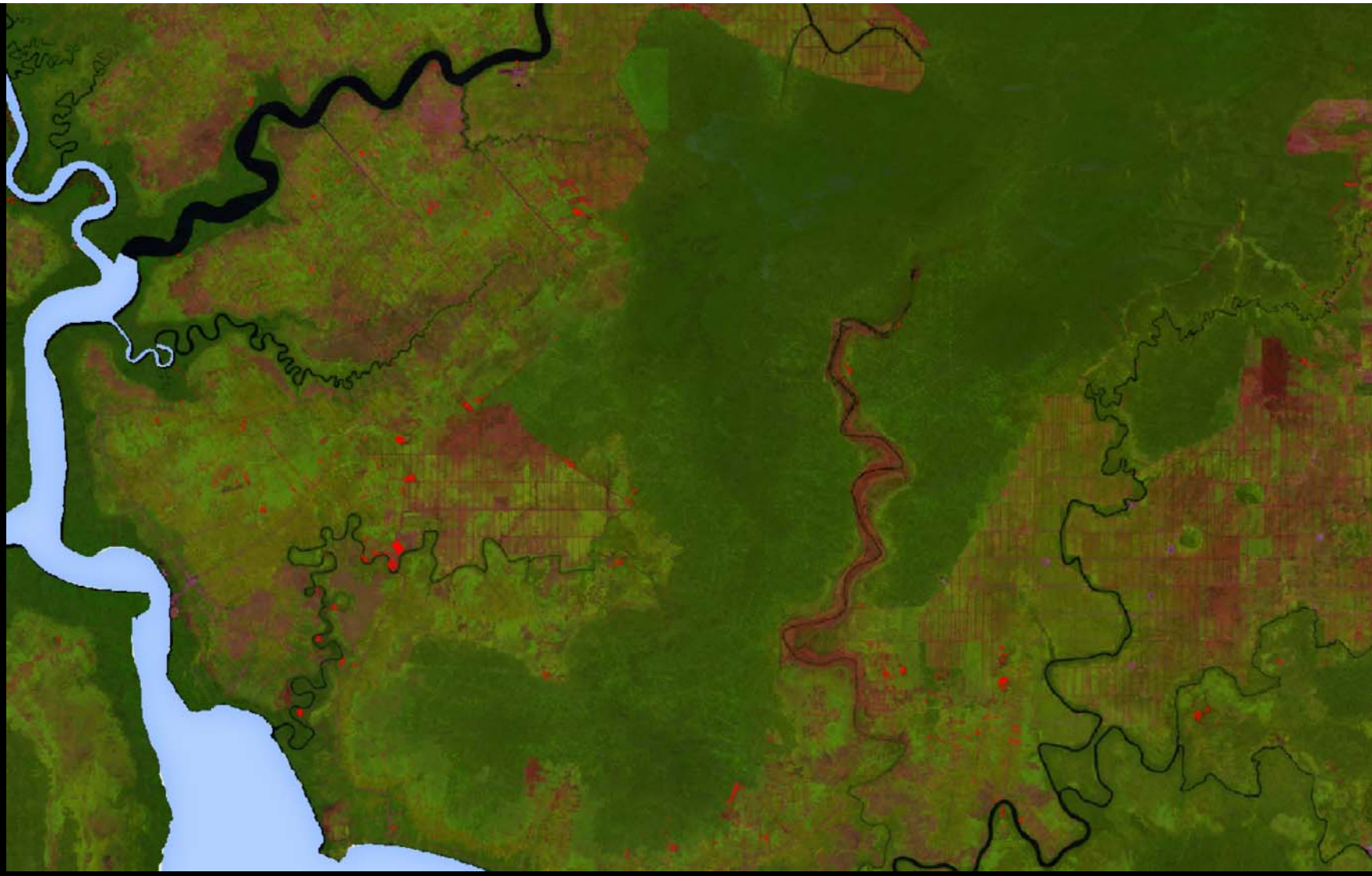


-> Mar. 16

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

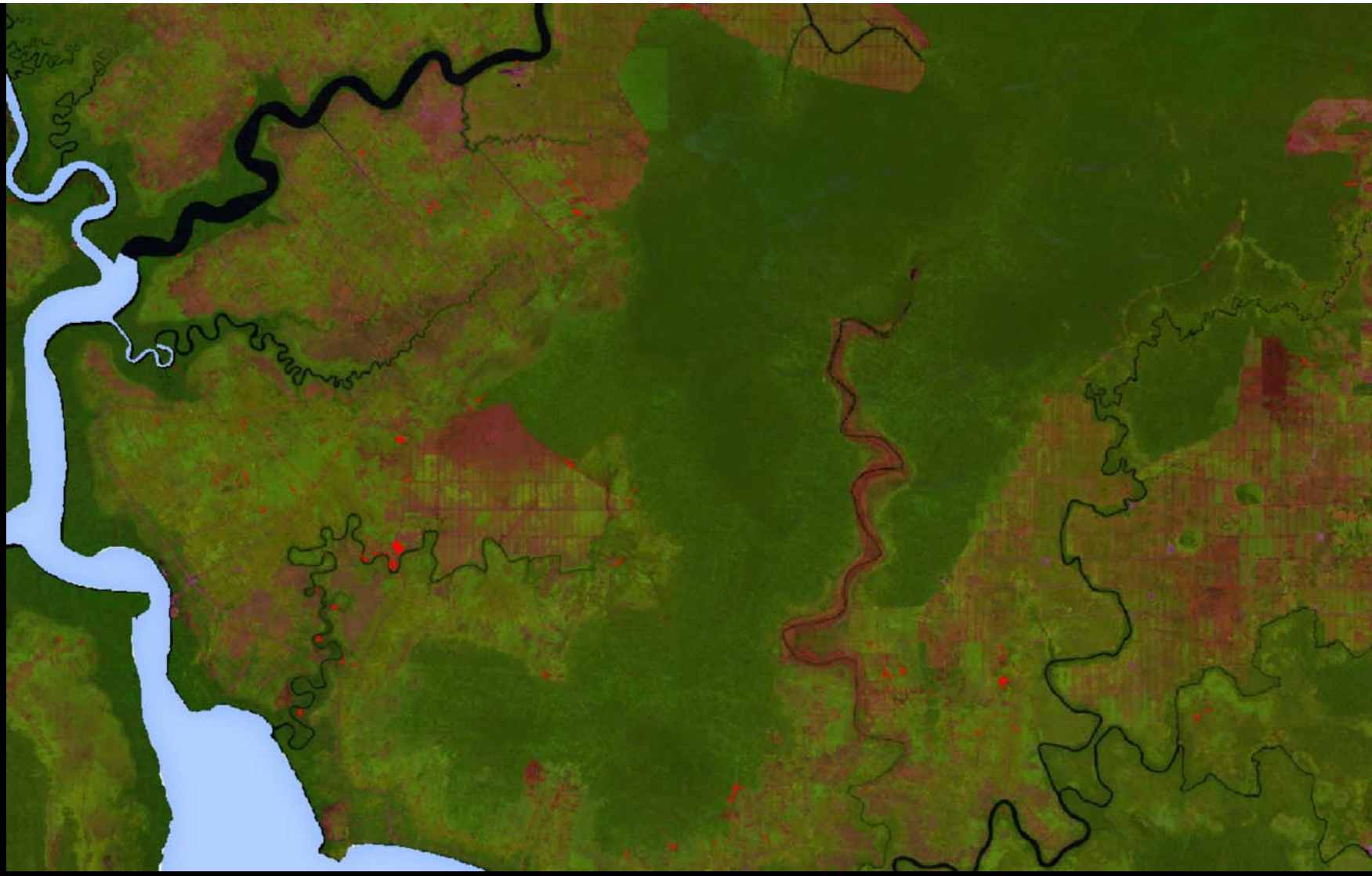


-> Apr. 10

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

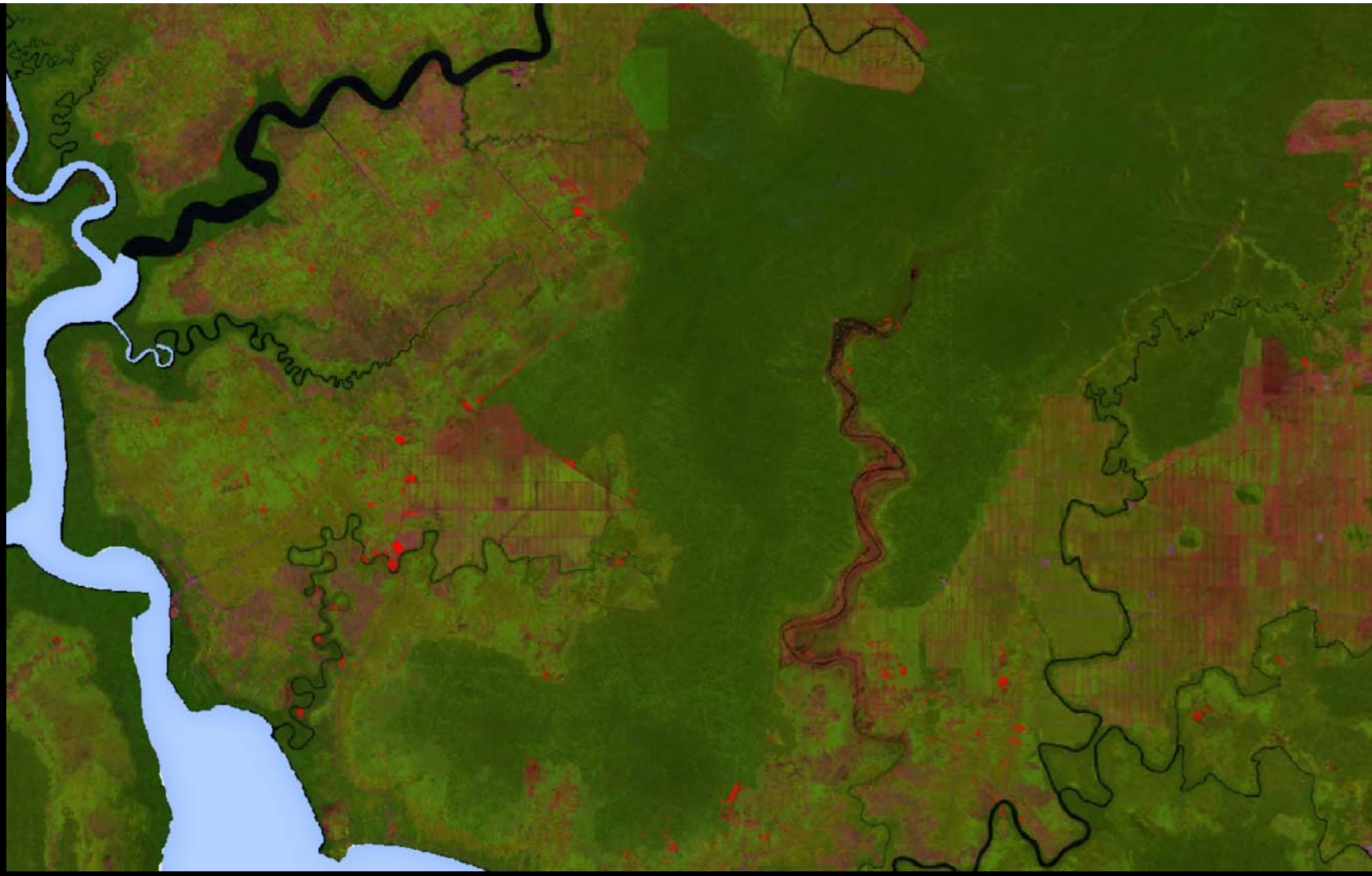


-> May 5

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

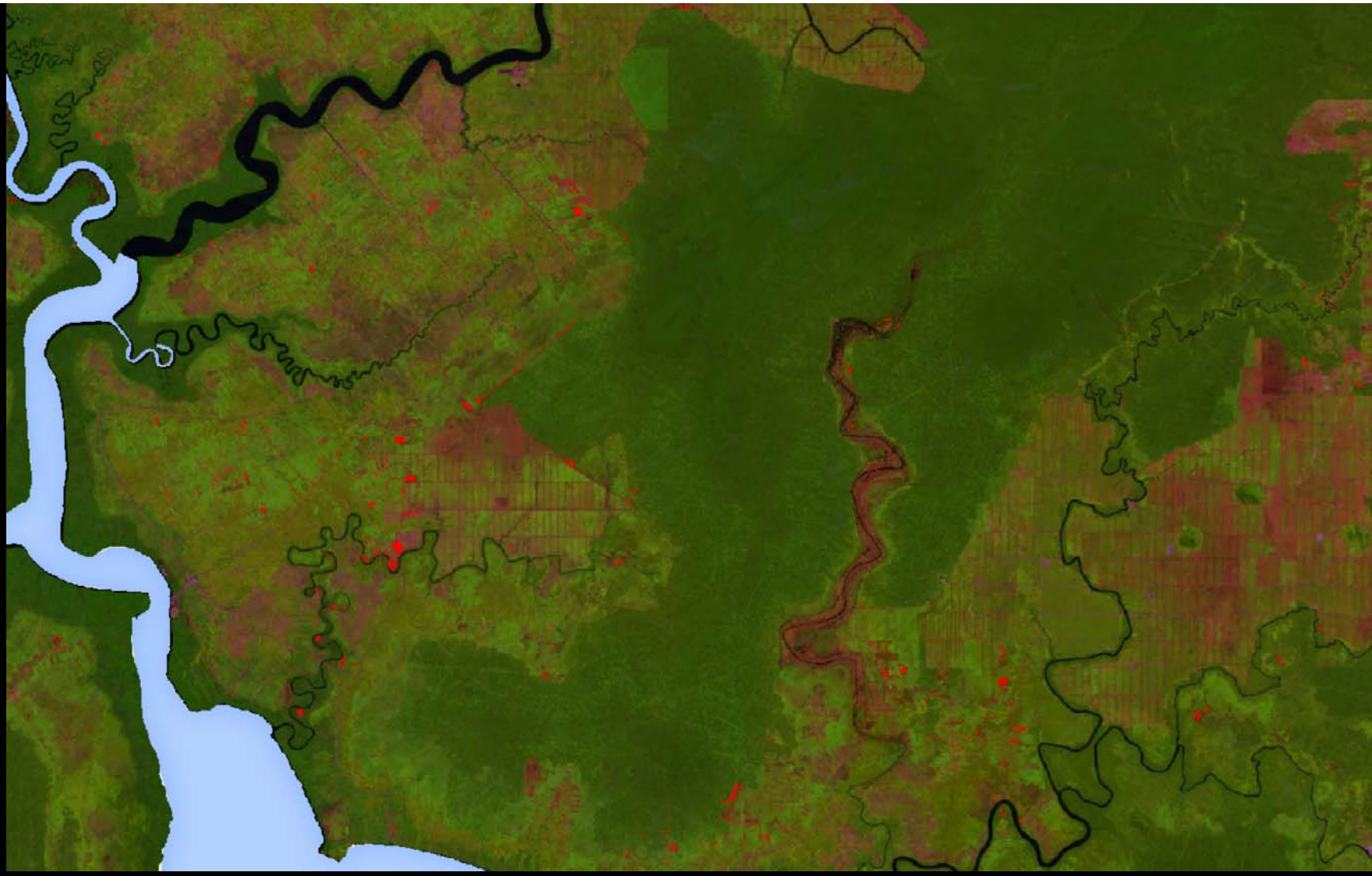


-> May 30

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

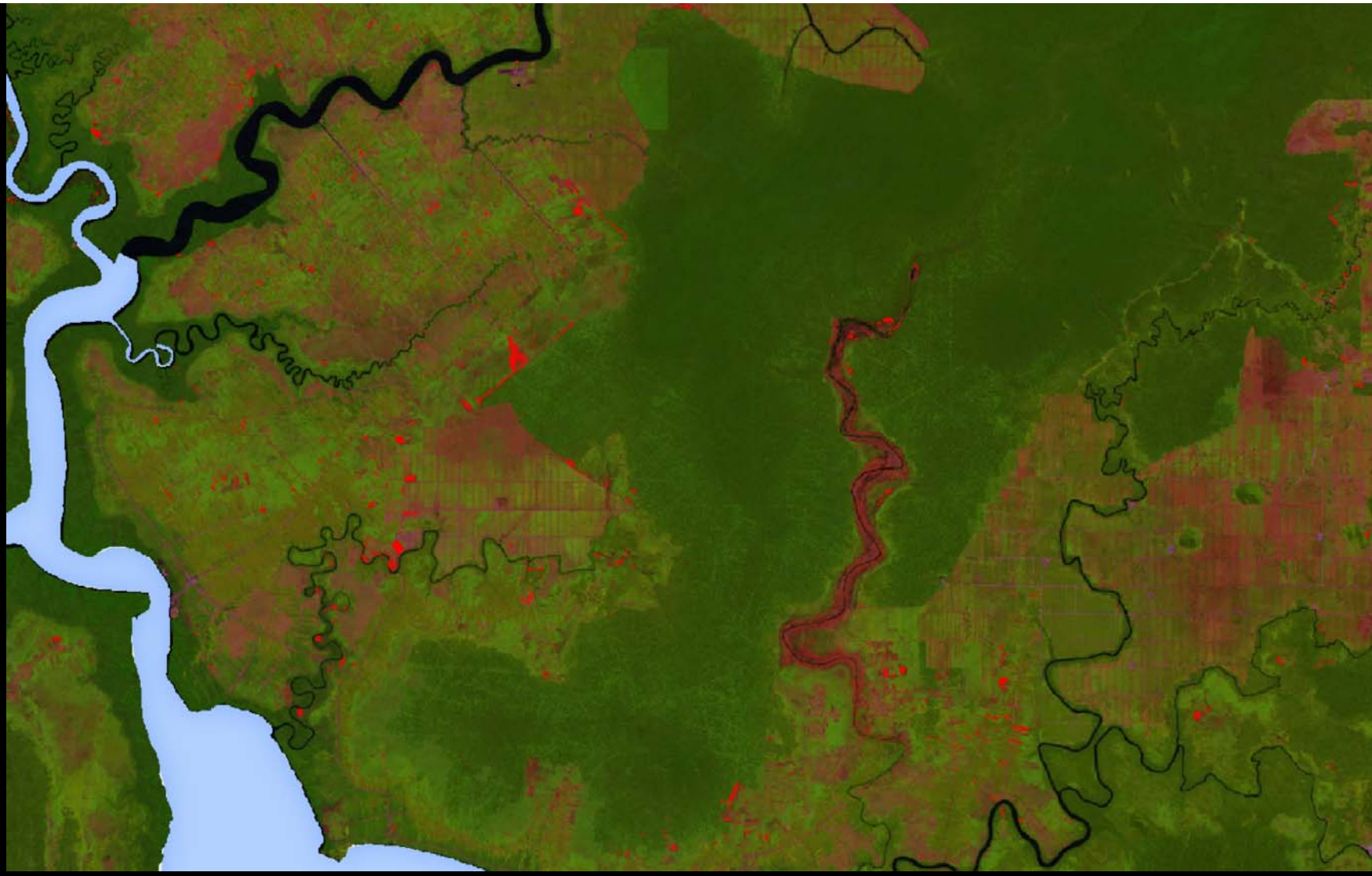


-> Jun. 24

6.5 km

Weekly forest disturbance alerts

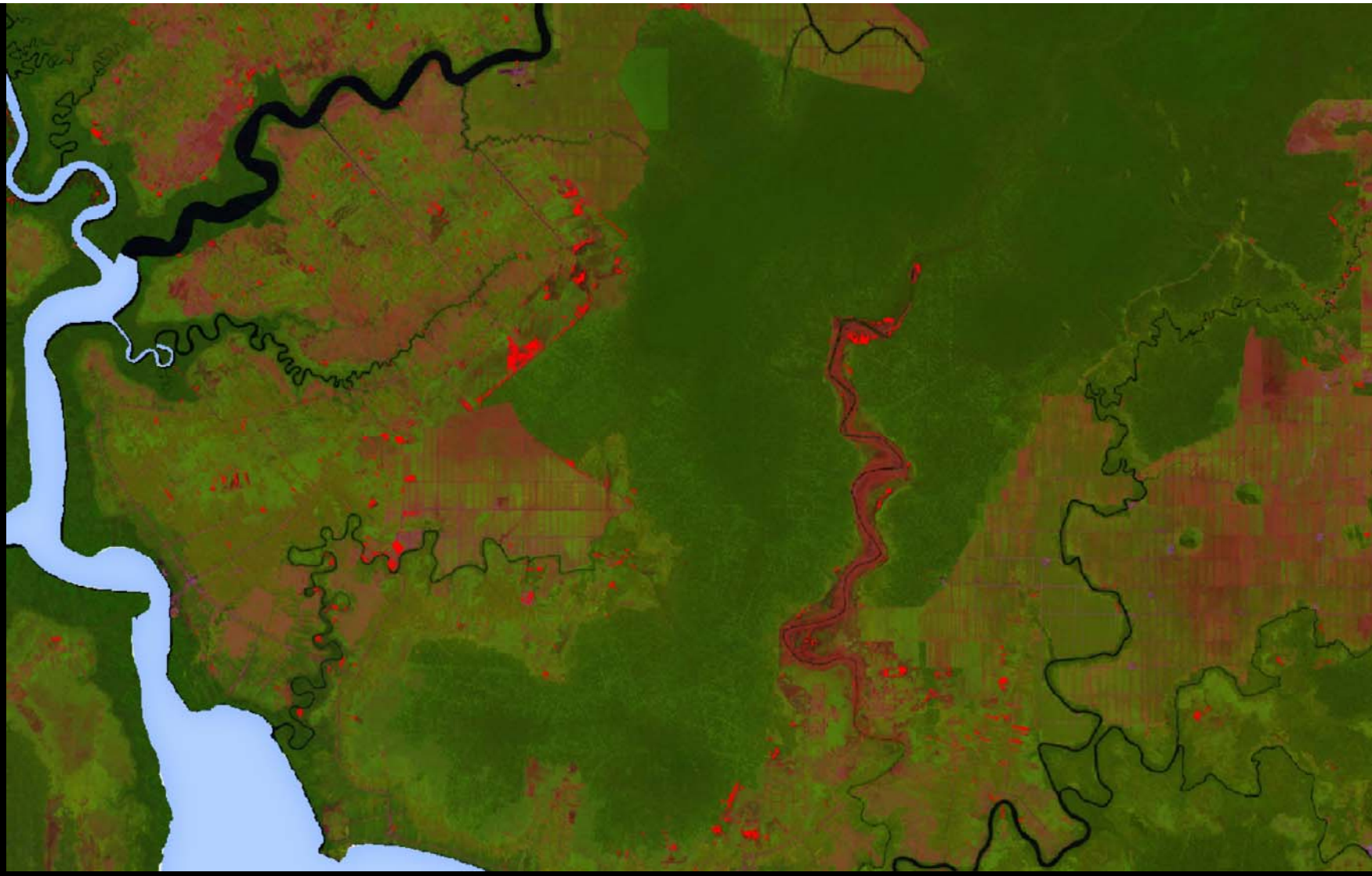
Taman Nasional Gunung Palung Located at center



-> Jul. 19

6.5 km

Weekly forest disturbance alerts

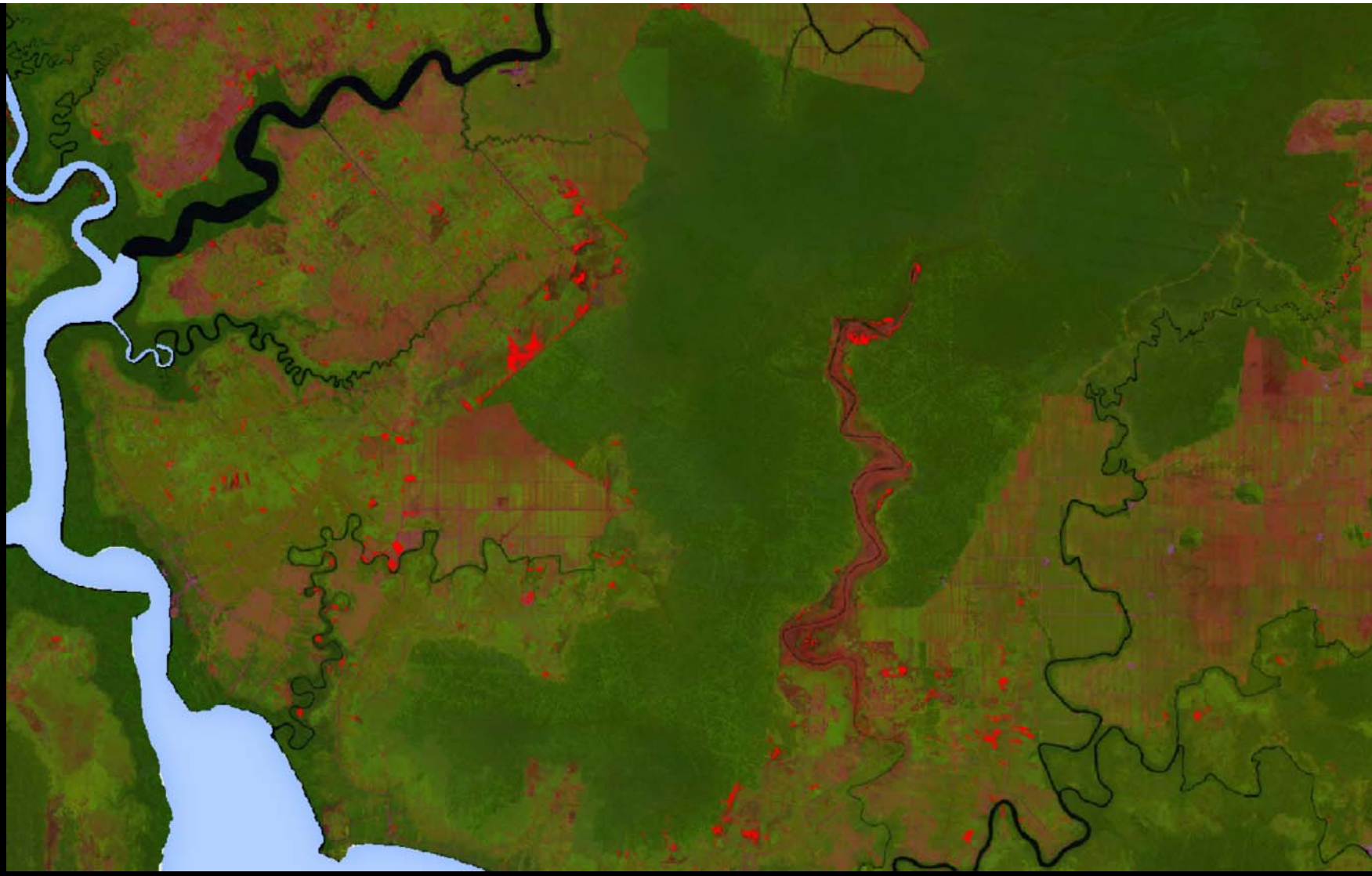


Taman Nasional Gunung Palung Located at center

-> Aug. 13

6.5 km

Weekly forest disturbance alerts

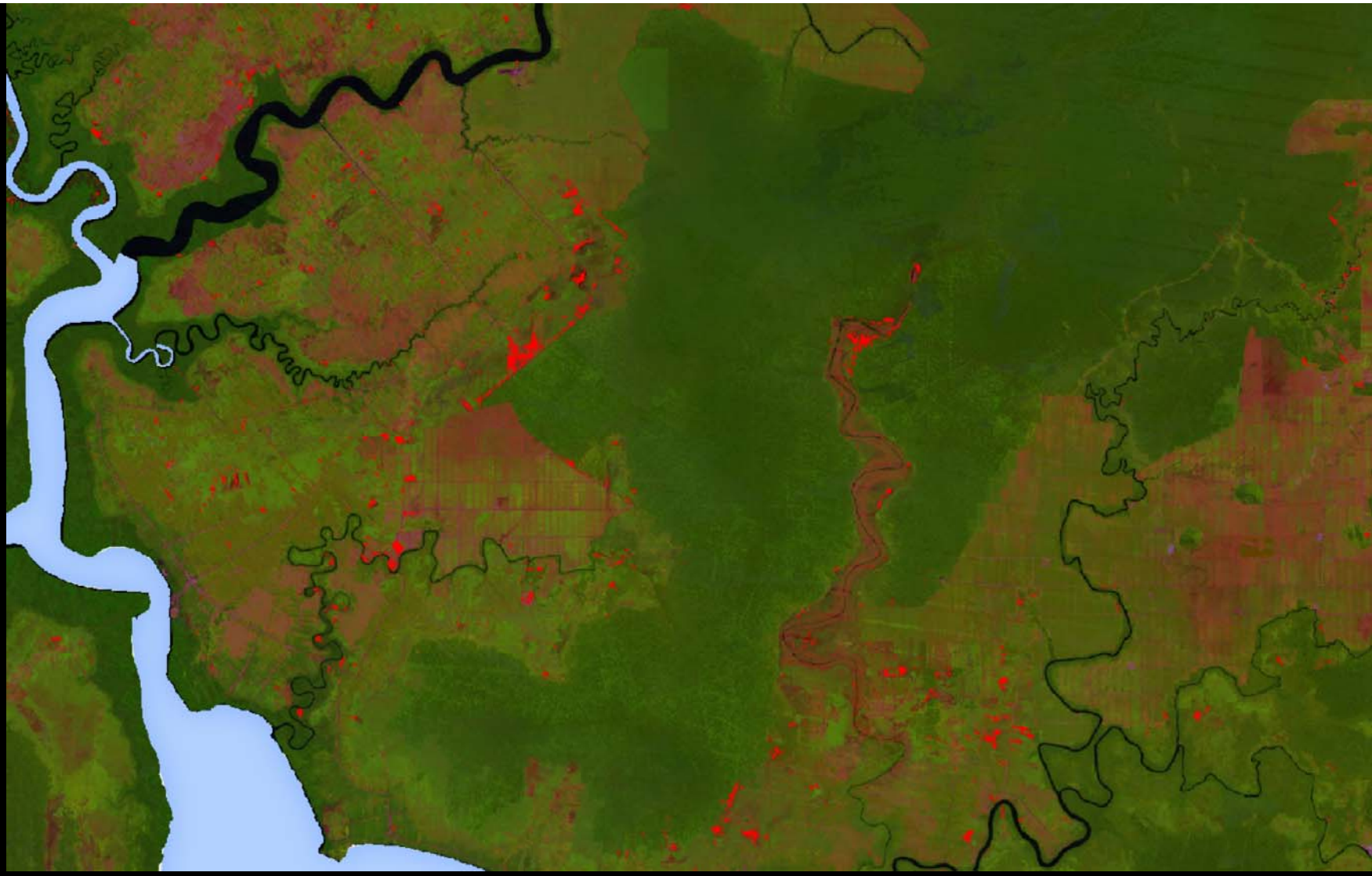


Taman Nasional Gunung Palung Located at center

-> Sep. 7

6.5 km

Weekly forest disturbance alerts



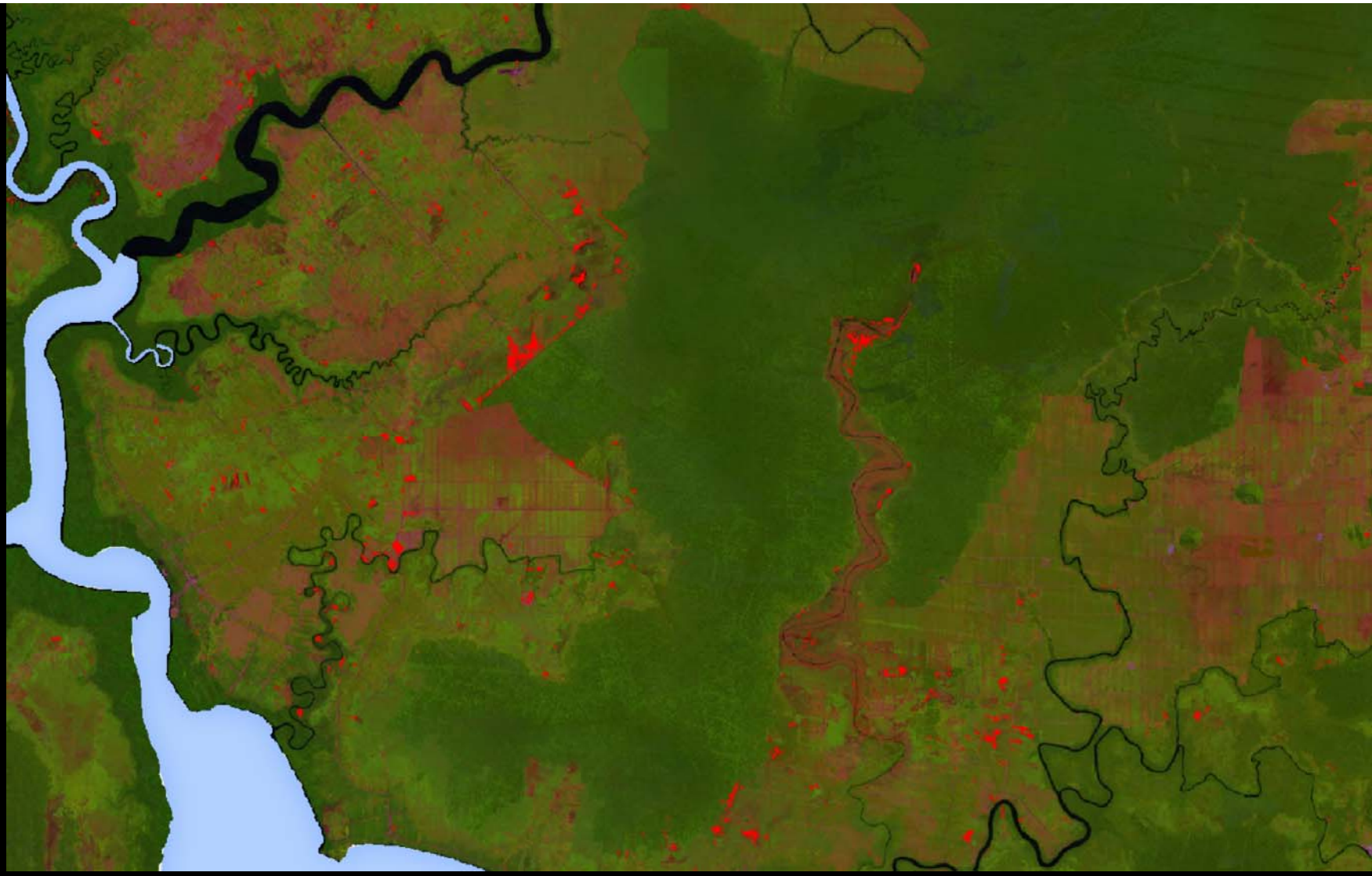
Taman Nasional Gunung Palung Located at center

-> Oct. 2

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

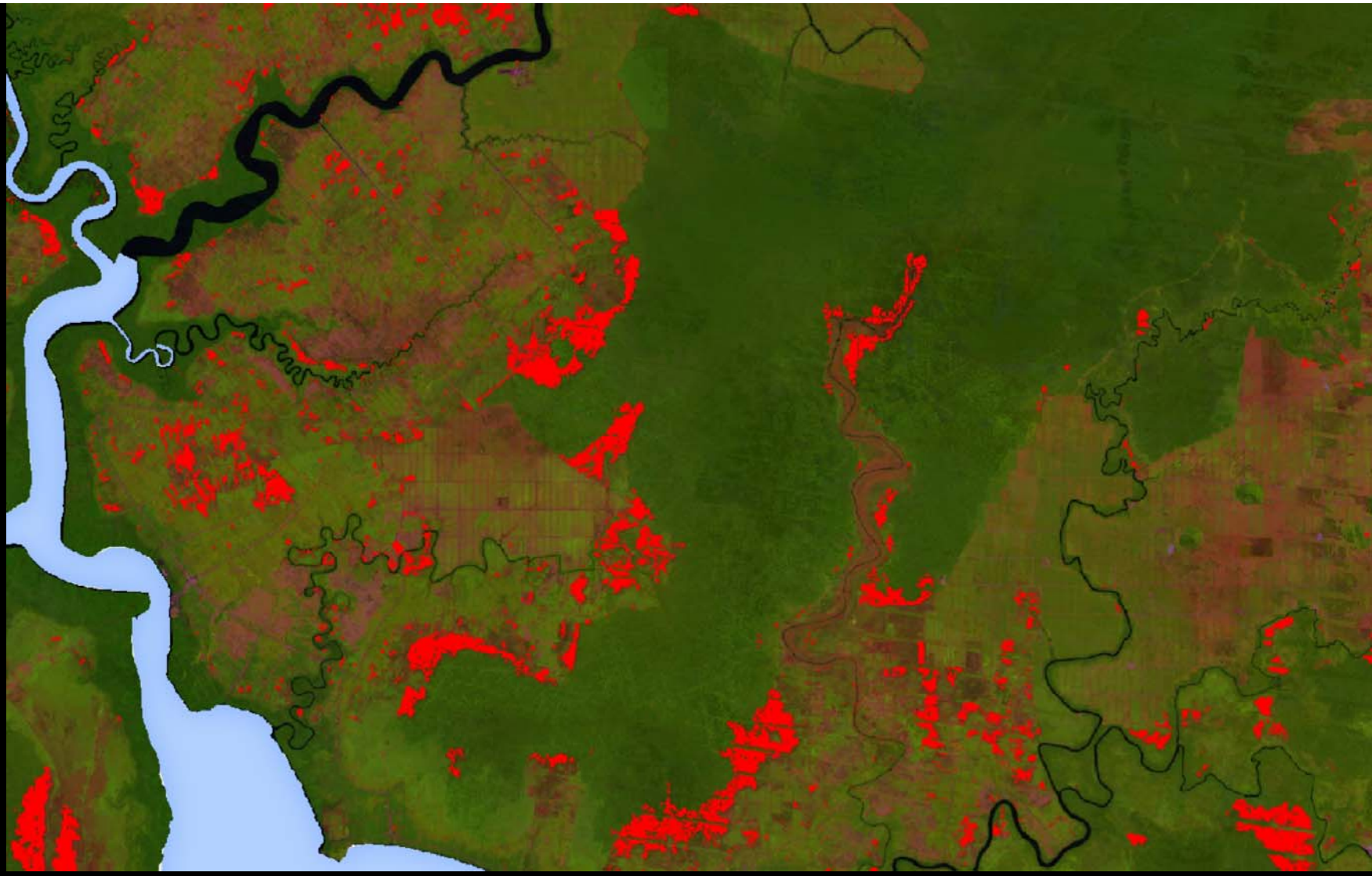


-> Oct. 27

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center

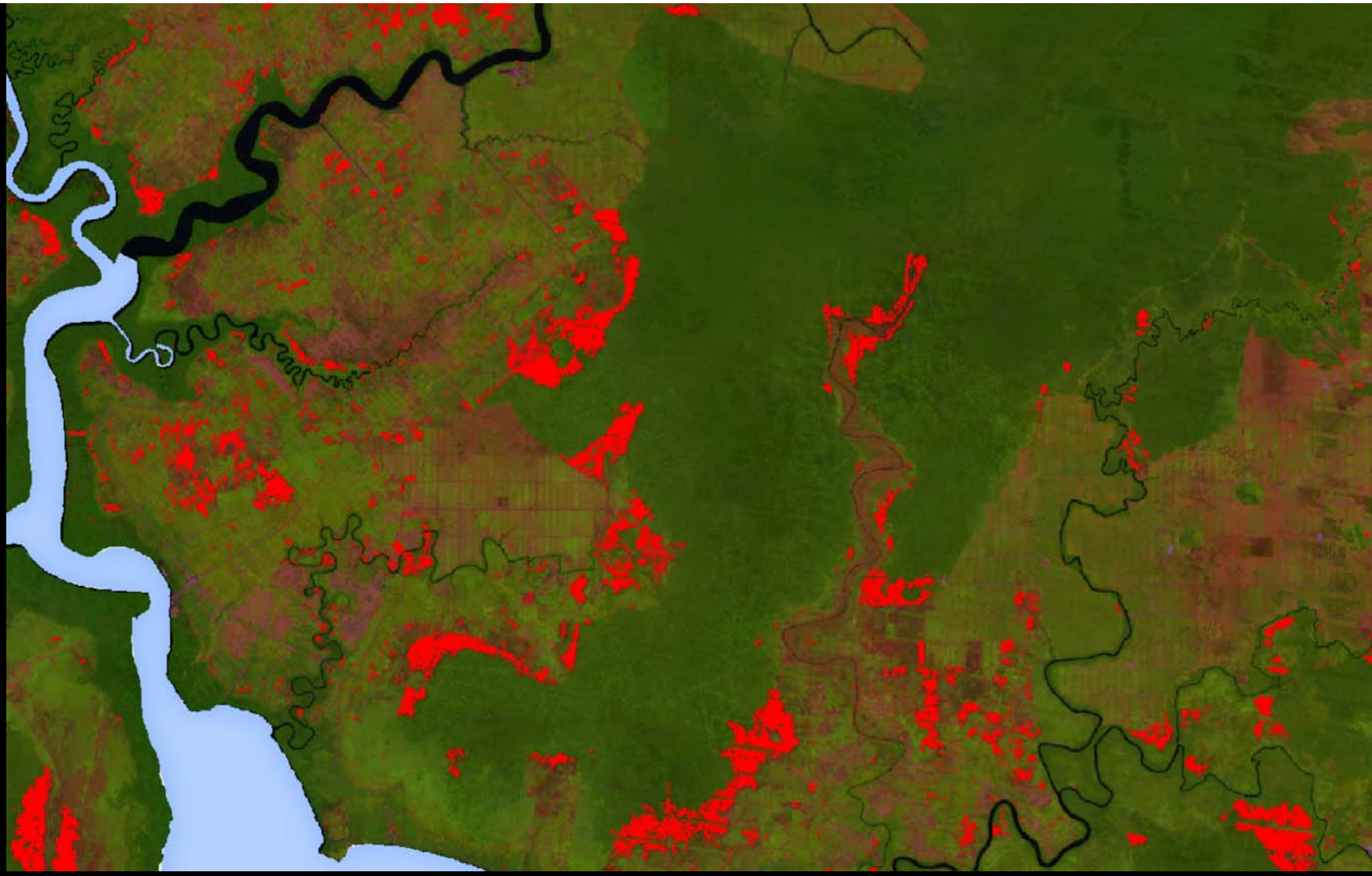


-> Nov. 21

6.5 km

Weekly forest disturbance alerts

Taman Nasional Gunung Palung Located at center



-> Dec. 16

6.5 km

Operational global land monitoring using multi-spectral data