Geographic Information Science Center of Excellence

South Dakota State University

USGS National Center for Earth Resources Observation and Science

Towards Global Land Cover Change Monitoring

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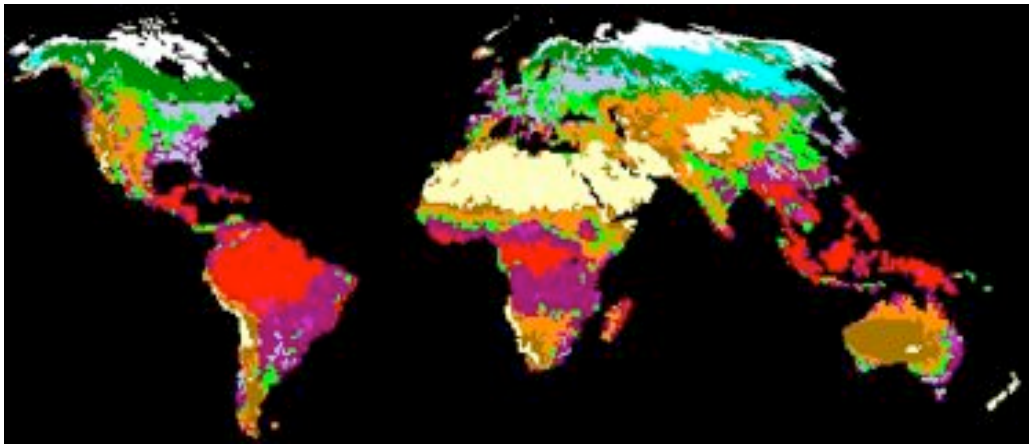
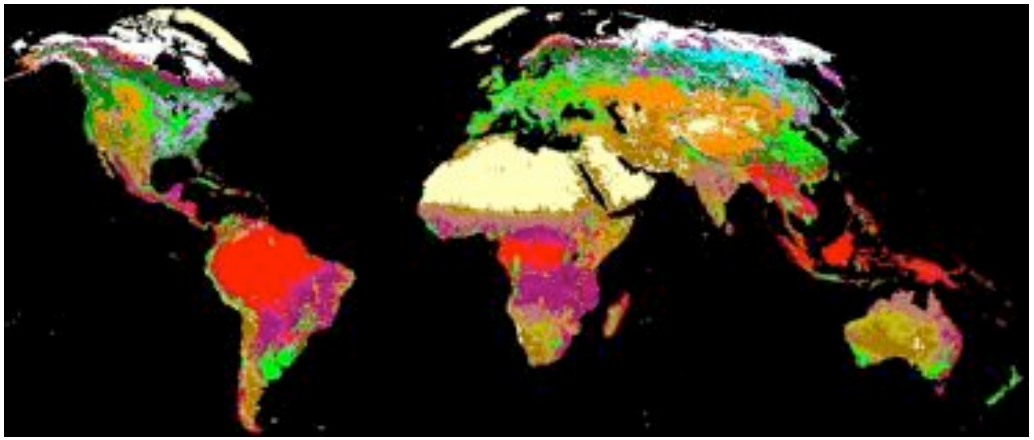
Global land cover classifications through 2000 at UMd

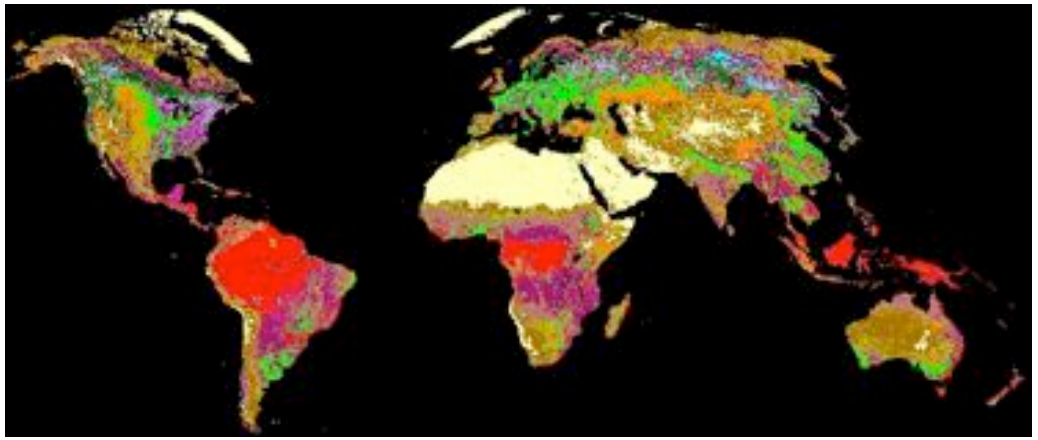
1 degree
1994



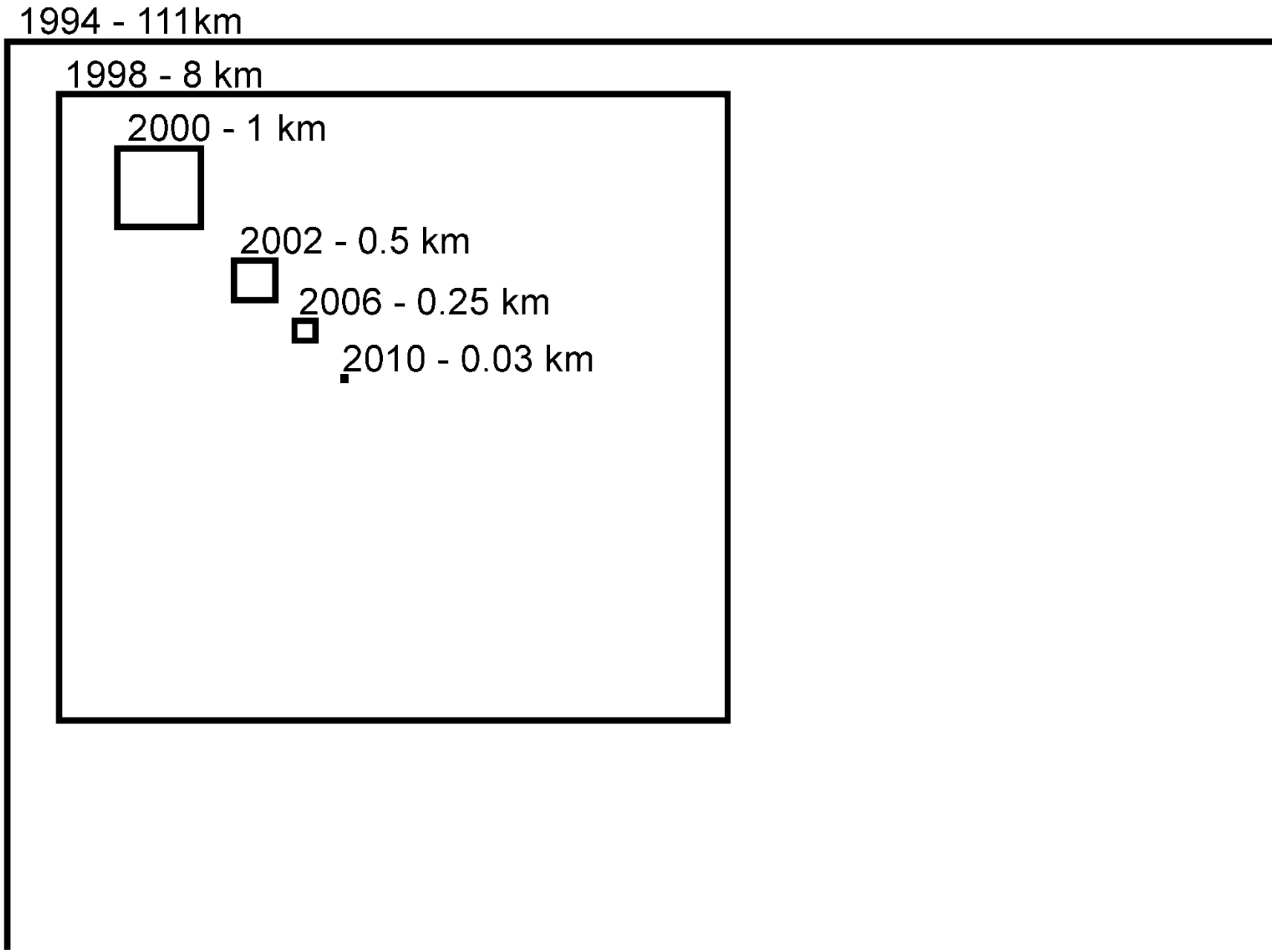
8 km
1998



1 km
2000



Global land cover mapping



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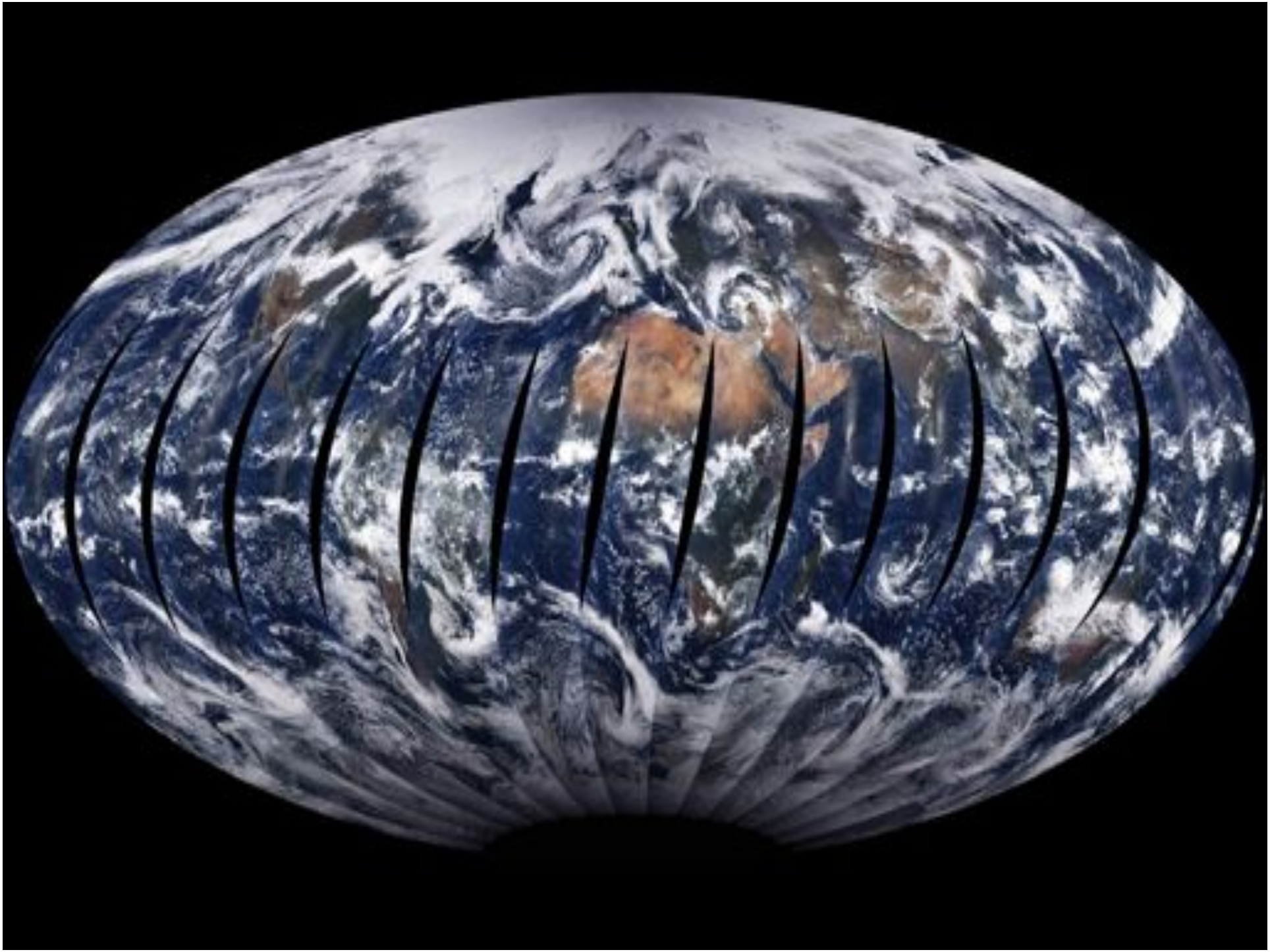
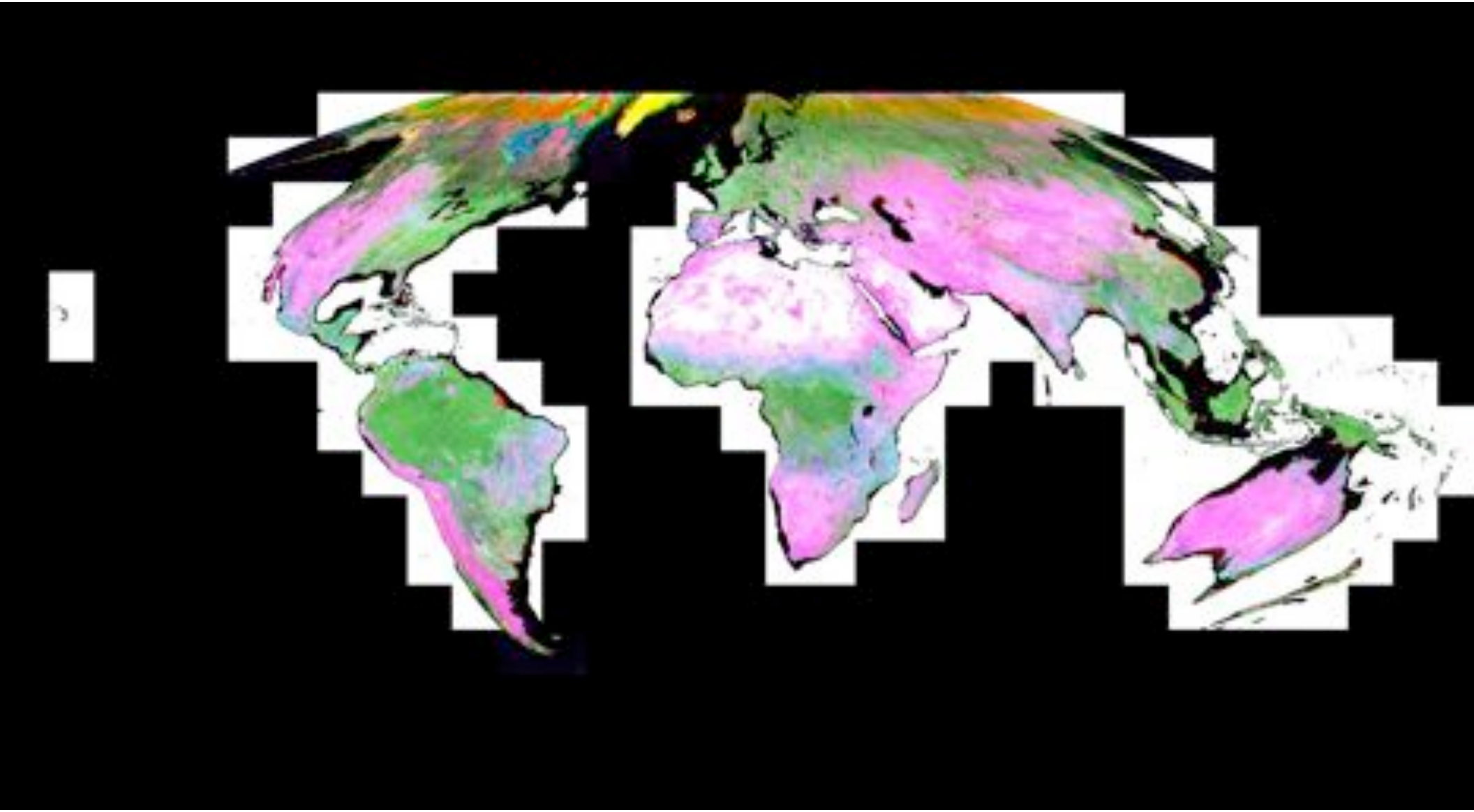
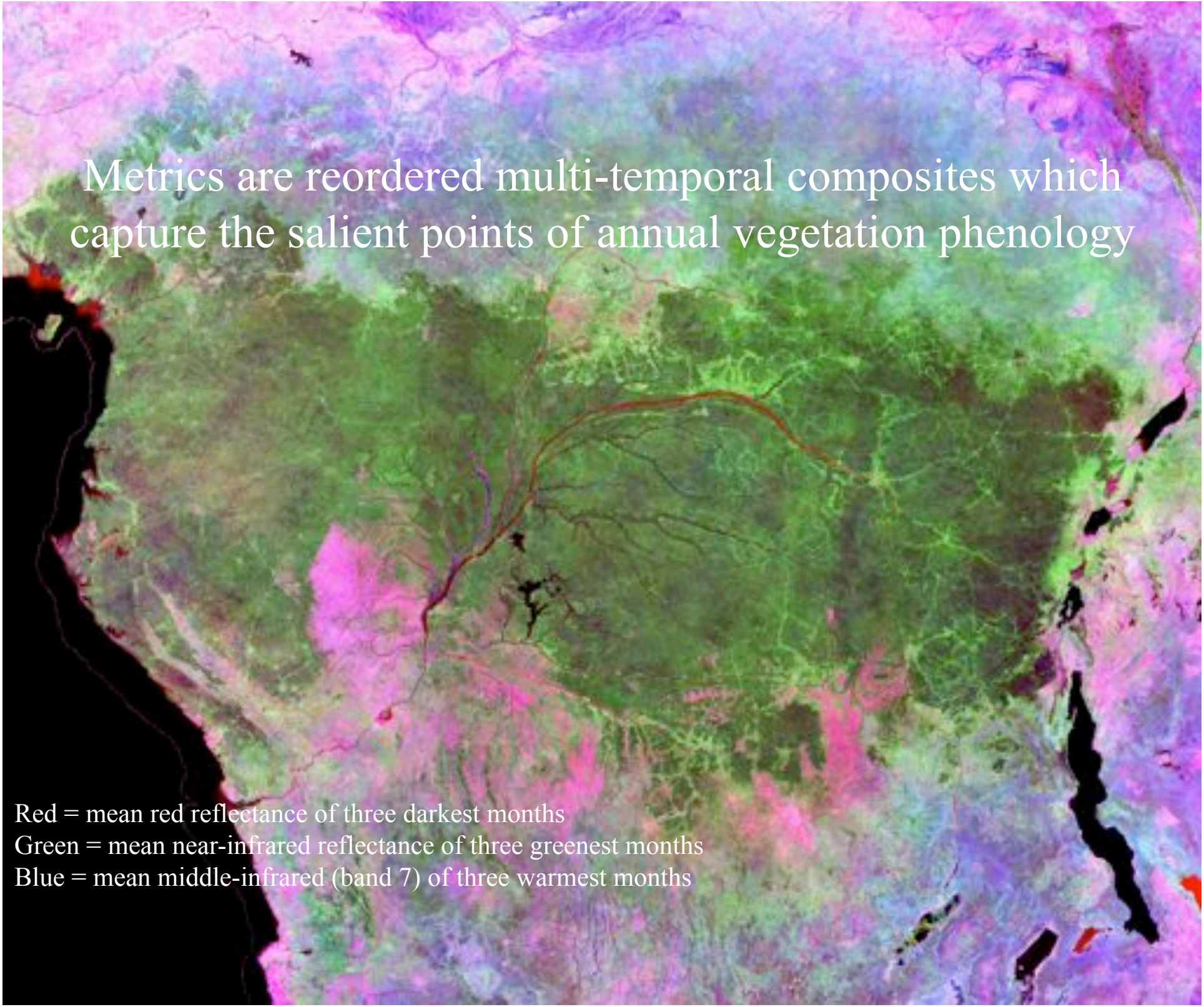
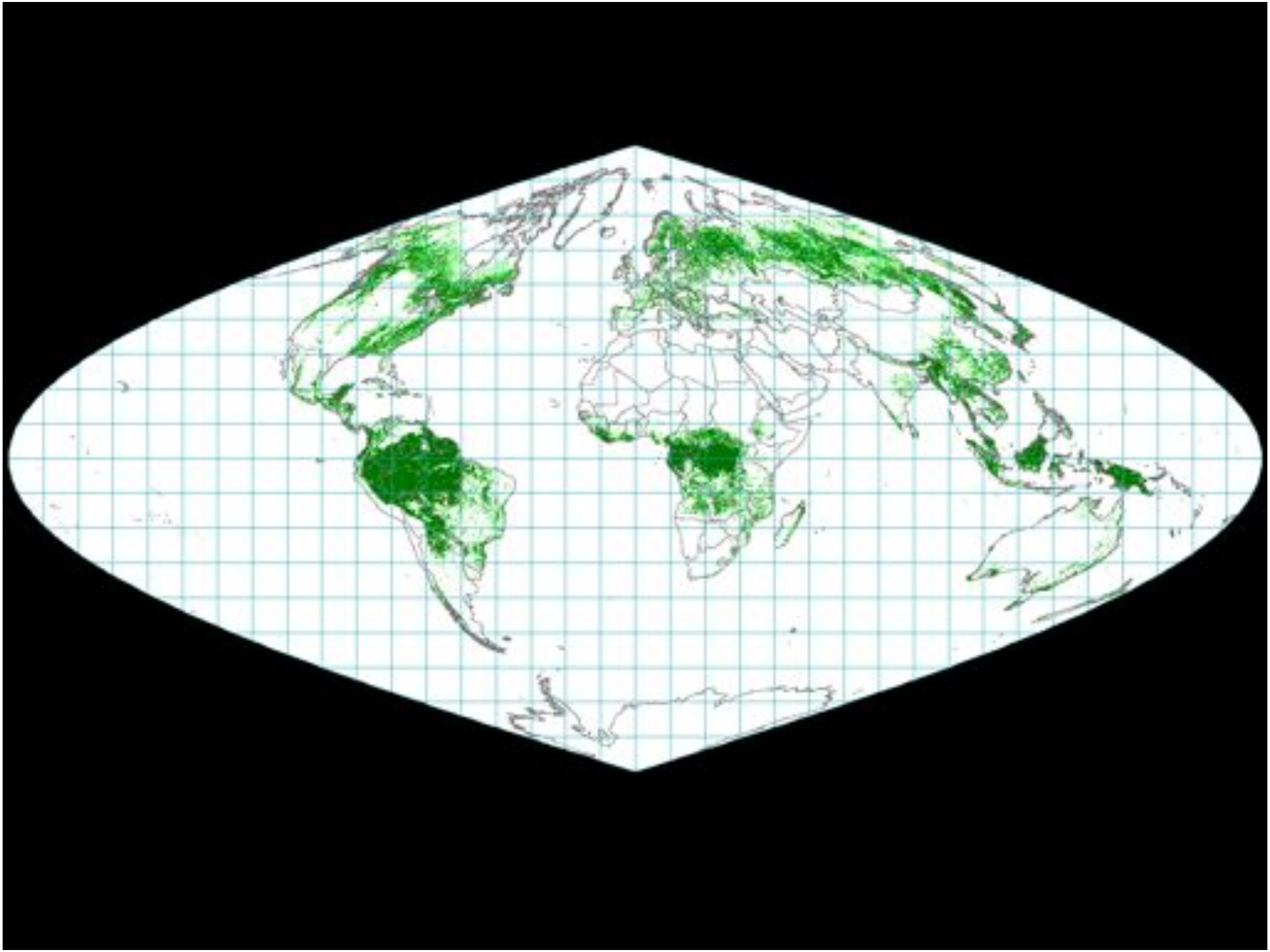


Global MODIS metrics

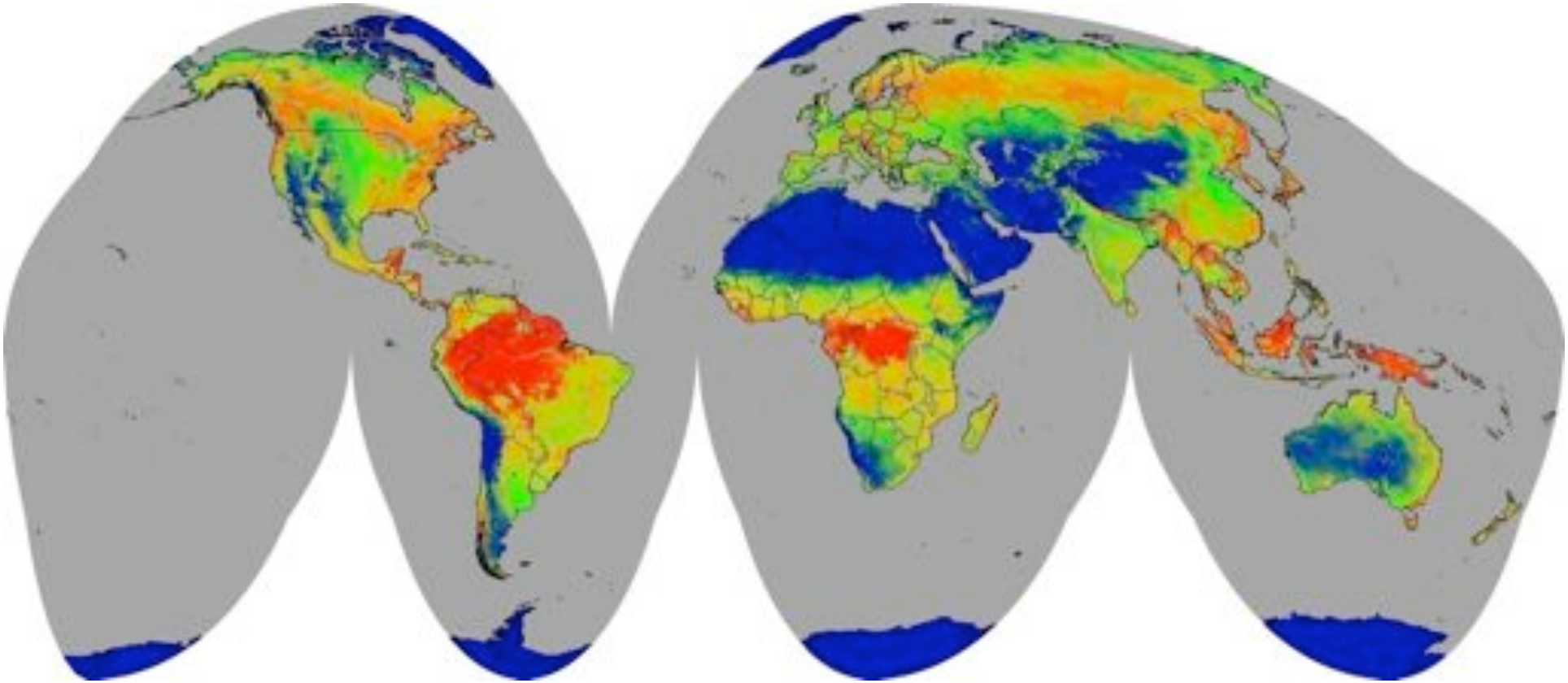


Red = mean red reflectance of three darkest months
Green = mean near-infrared reflectance of three greenest months
Blue = mean middle-infrared (band 7) of three warmest months


Metrics are reordered multi-temporal composites which capture the salient points of annual vegetation phenology
Red = mean red reflectance of three darkest months
Green = mean near-infrared reflectance of three greenest months
Blue = mean middle-infrared (band 7) of three warmest months



MODIS Vegetation Continuous Fields – 2000



Percent cover 0% Bare ground Grass/shrubs/moss Trees 100%

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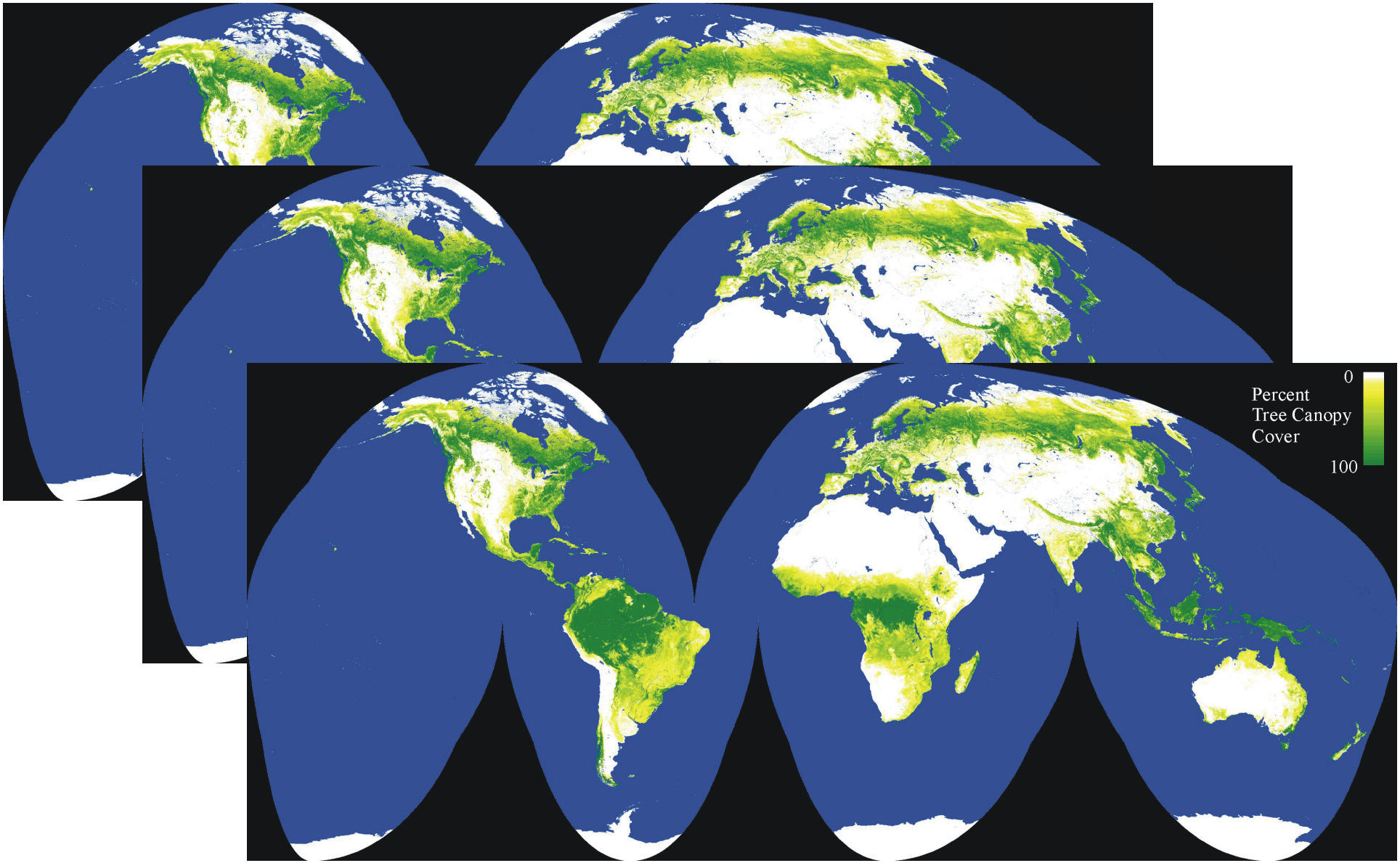
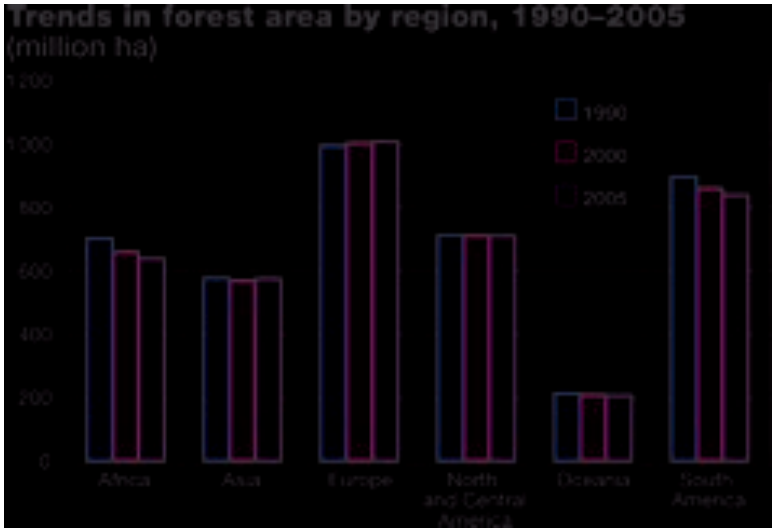
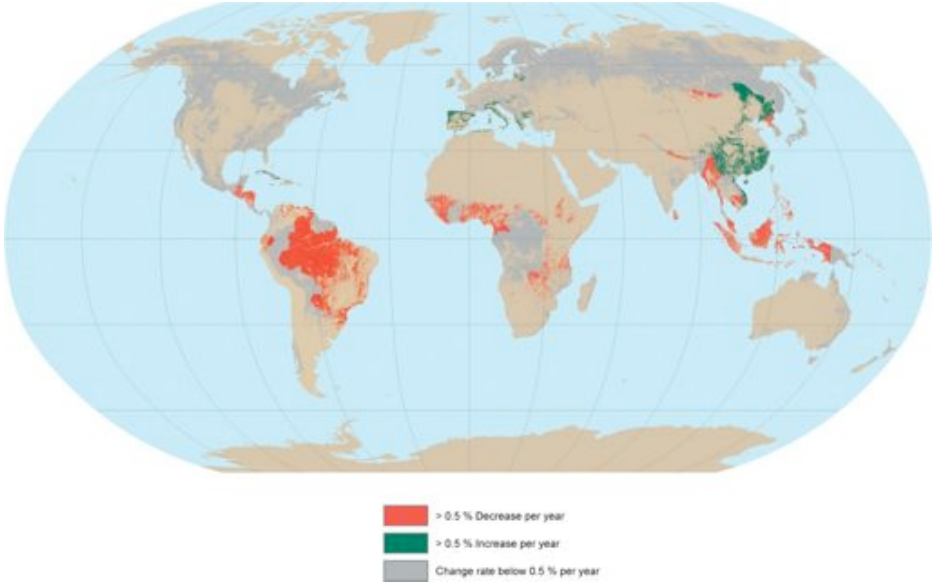
Annual updates of land cover



United Nations Food and Agriculture Organization Forest Resource Assessment Report

- Africa and South America feature largest forest losses
- Overall rate of forest loss continues to decrease





Forest definitions

- IPCC Good Practice Guidance
  - Forest is a minimum area of land of 0.05 – 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 – 30 percent with trees with the potential to reach a minimum height of 2 – 5 meters at maturity *in situ*
- Our current definition
  - .09 hectares (one Landsat pixel) with tree crown cover >= 30 percent for trees >=5 meters in height
  - Optical data cannot reliably quantify sparse and/or short tree cover in the context of monitoring

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Forest monitoring using MODIS and Landsat data sets – first approach

- Employ MODIS to indicate change and develop a stratified sampling frame (low/medium/high) for Landsat-scale analysis
- Acquire and interpret Landsat image pairs per stratum
- Use MODIS change and Landsat change in regression estimator approach to derive final change estimate
- Targeted sampling allows some spatial disaggregation of change

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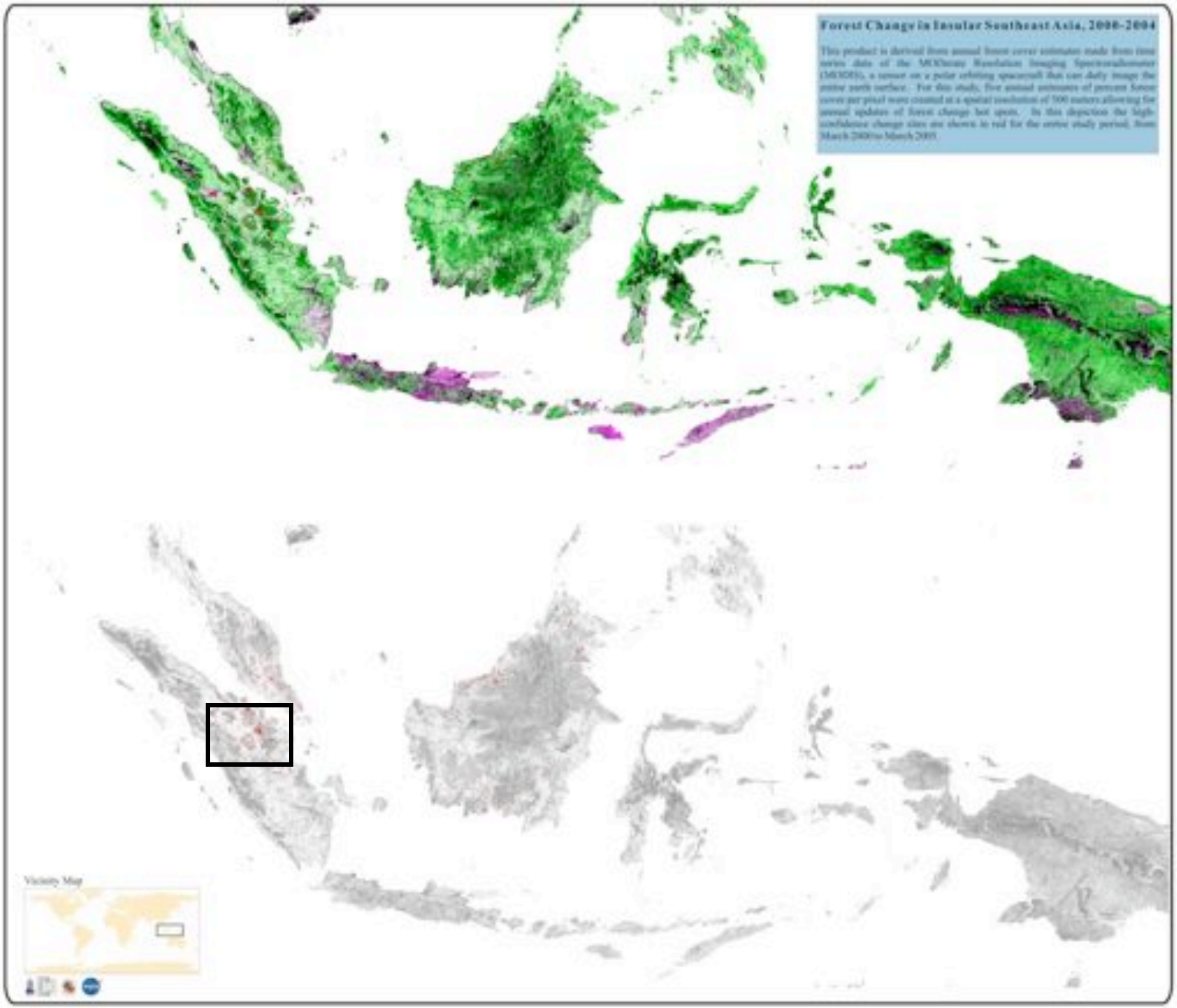

Forest Change in Insular Southeast Asia

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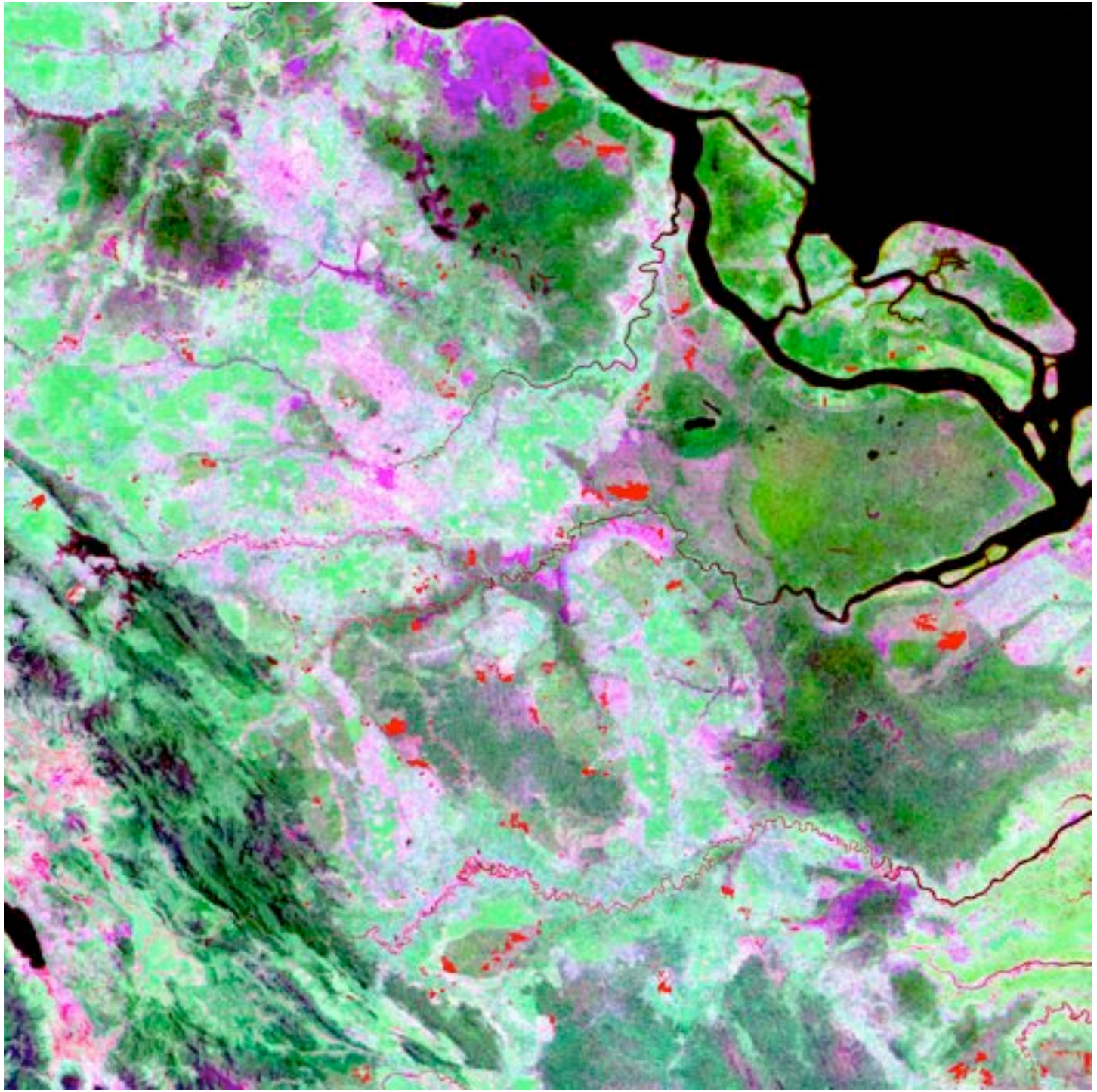
Annual forest cover loss

00-01



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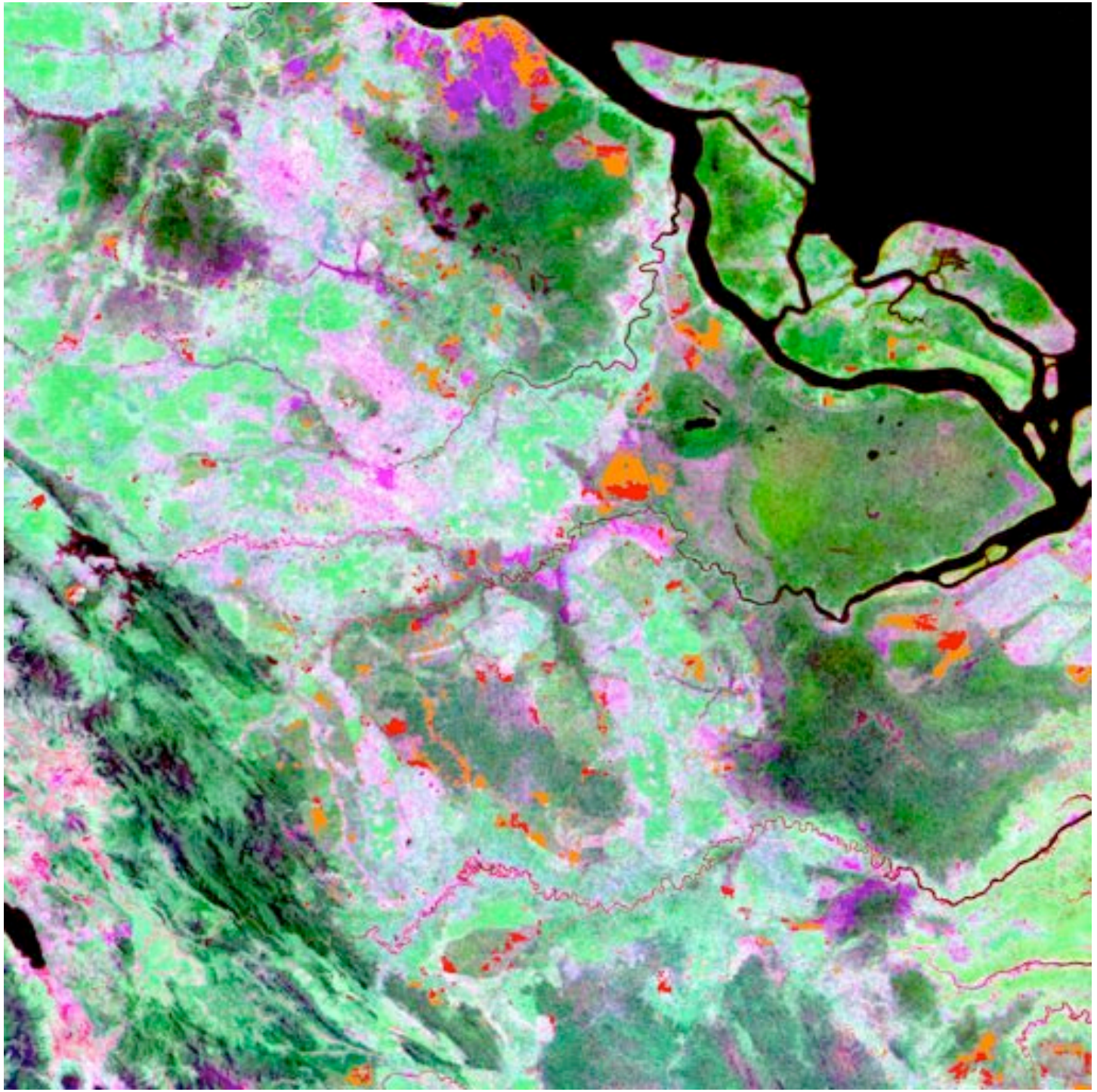
Annual forest cover loss

00-01

01-02



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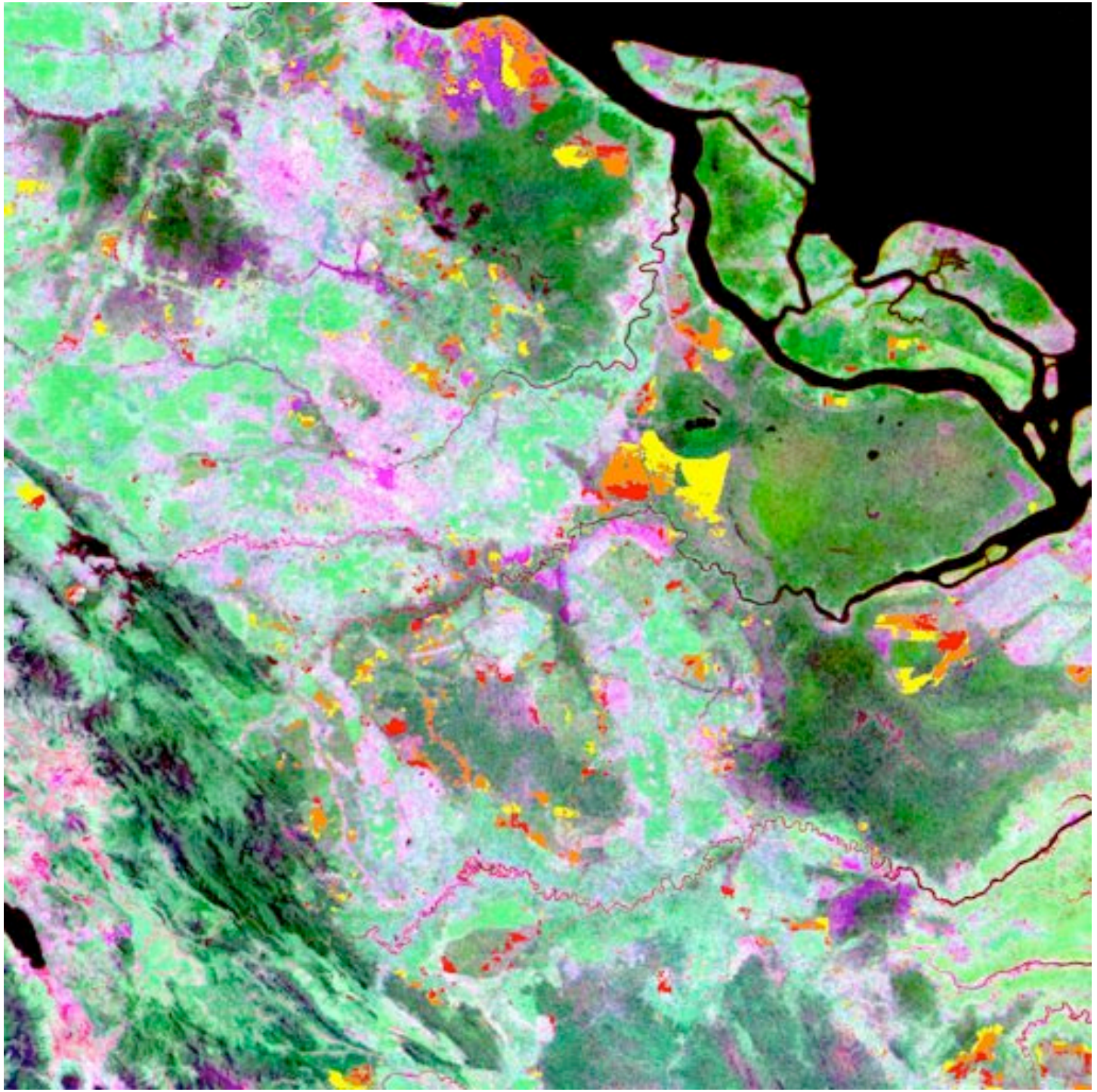
Annual forest cover loss

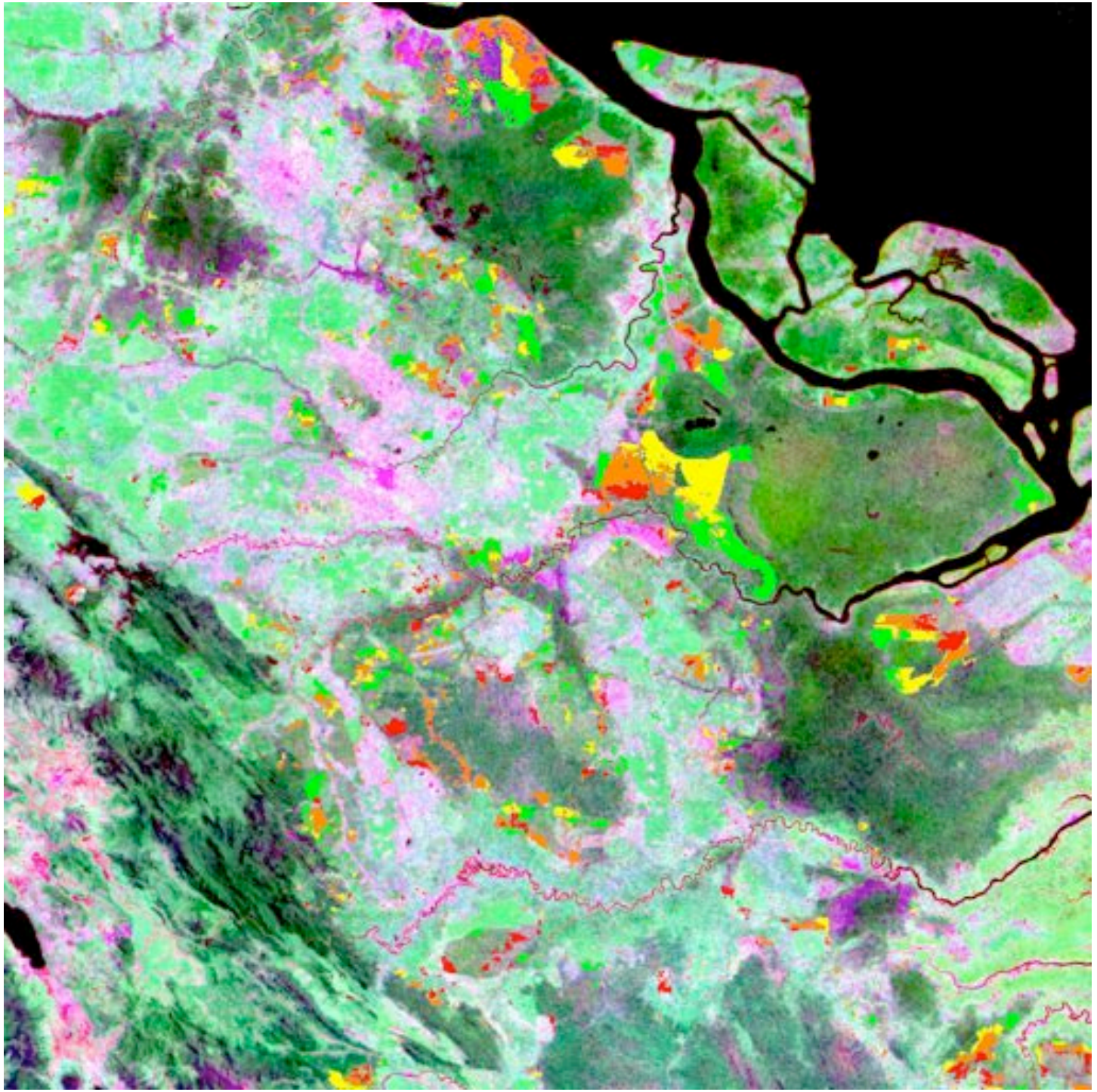
- 00-01
- 01-02
- 02-03



SDSU

Annual forest cover loss

- 00-01
- 01-02
- 02-03
- 03-04



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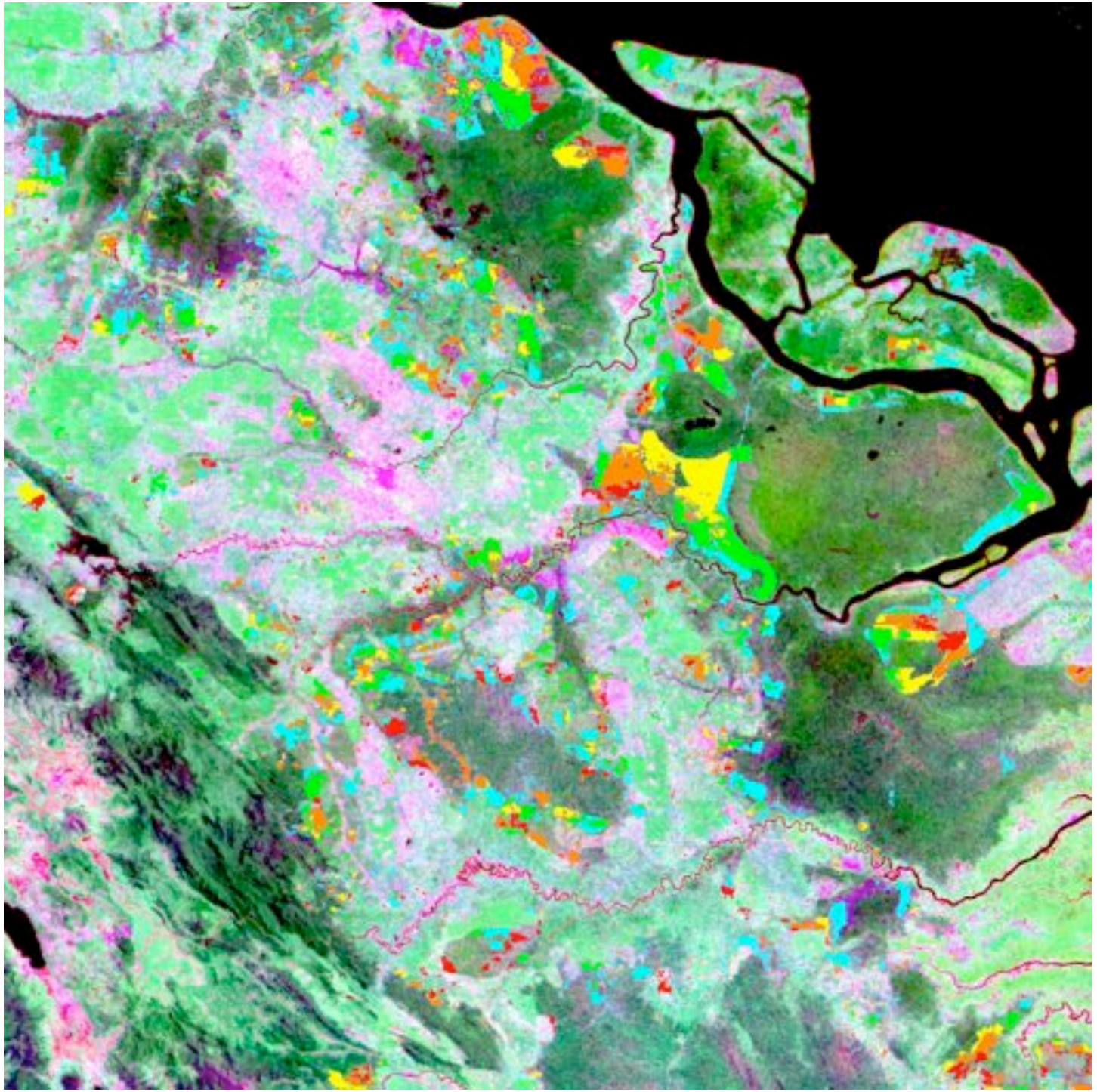
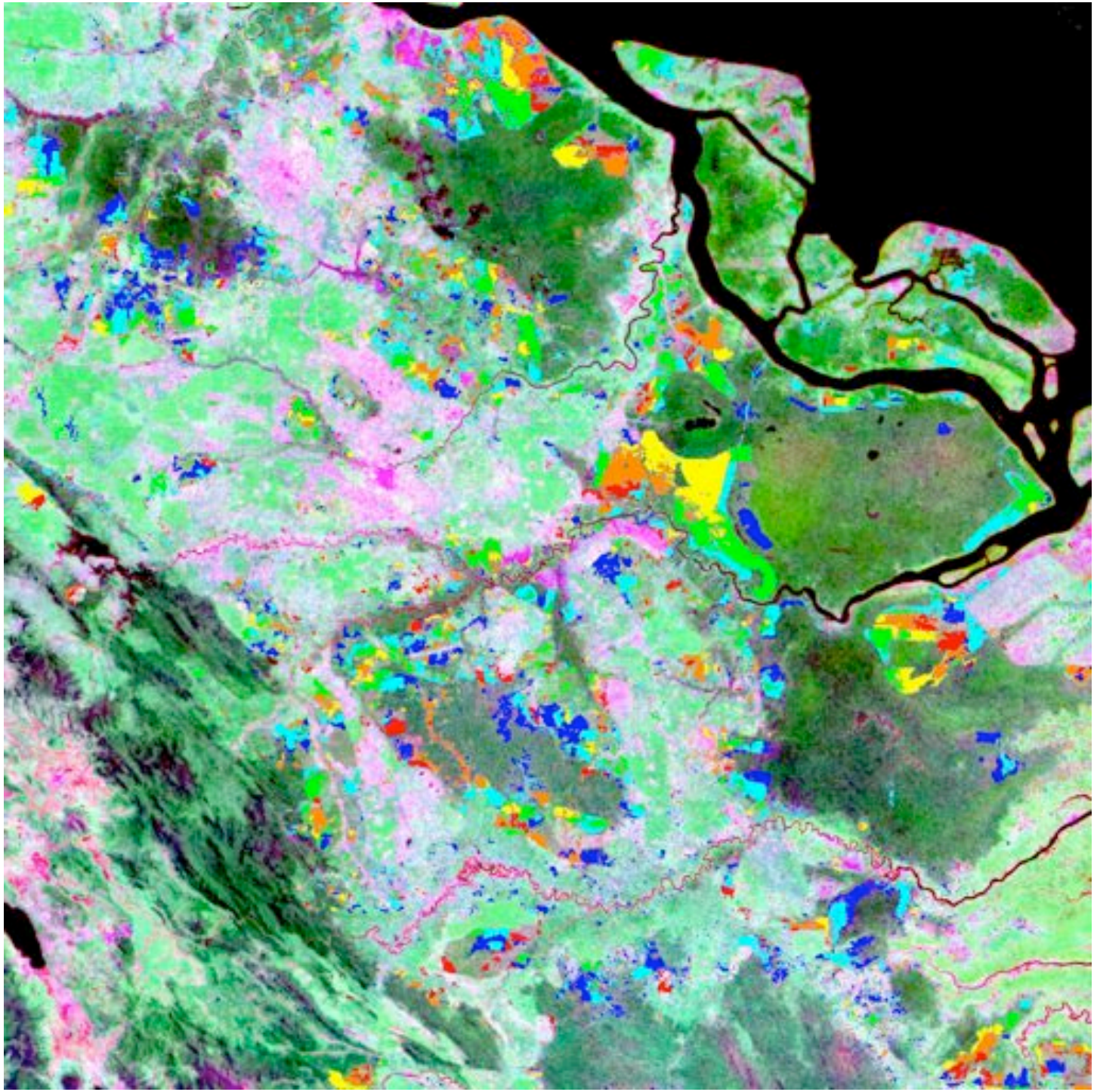
Annual forest cover loss



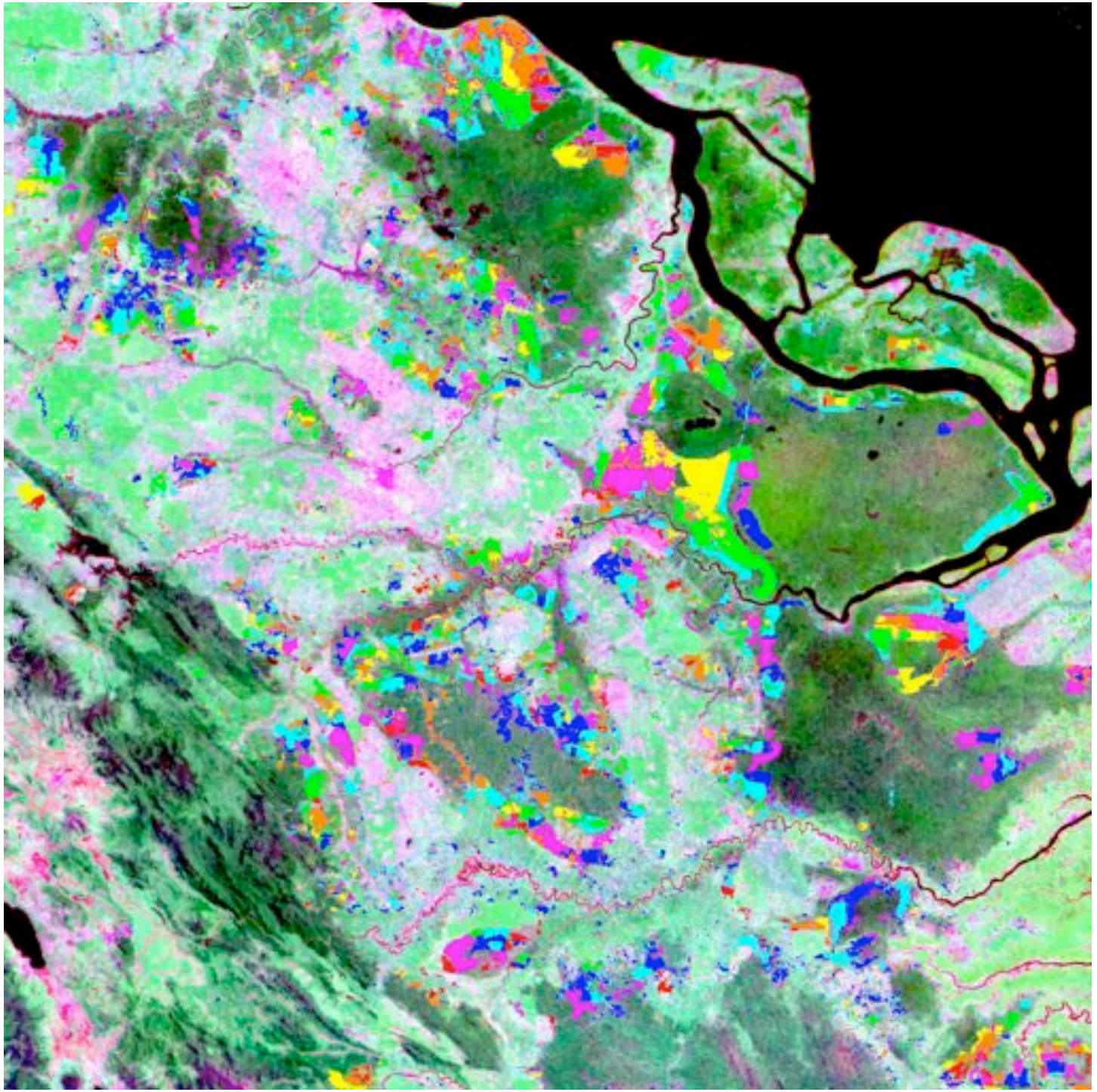
SDSU

Annual forest cover loss



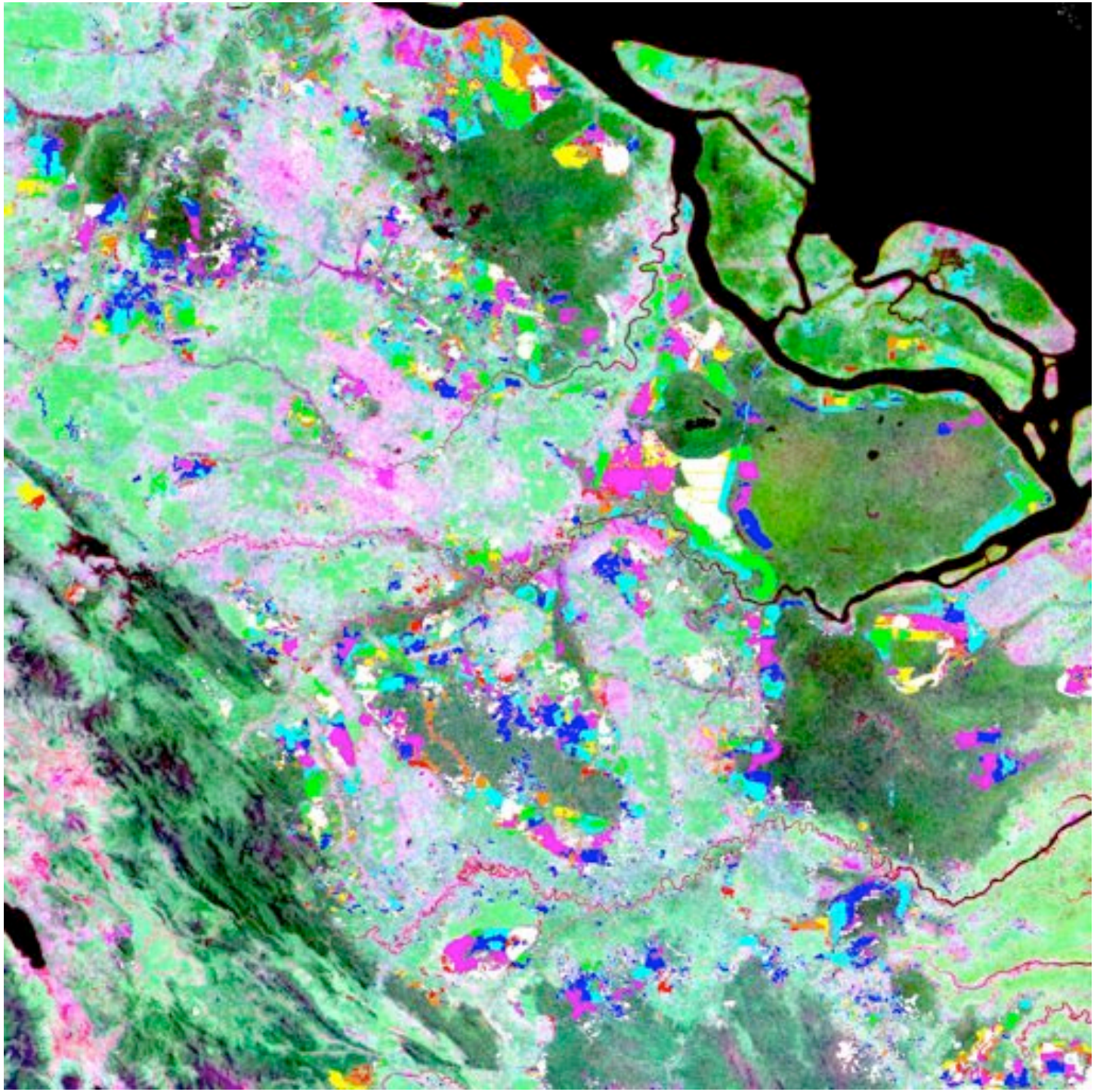
SDSU

Annual forest cover loss

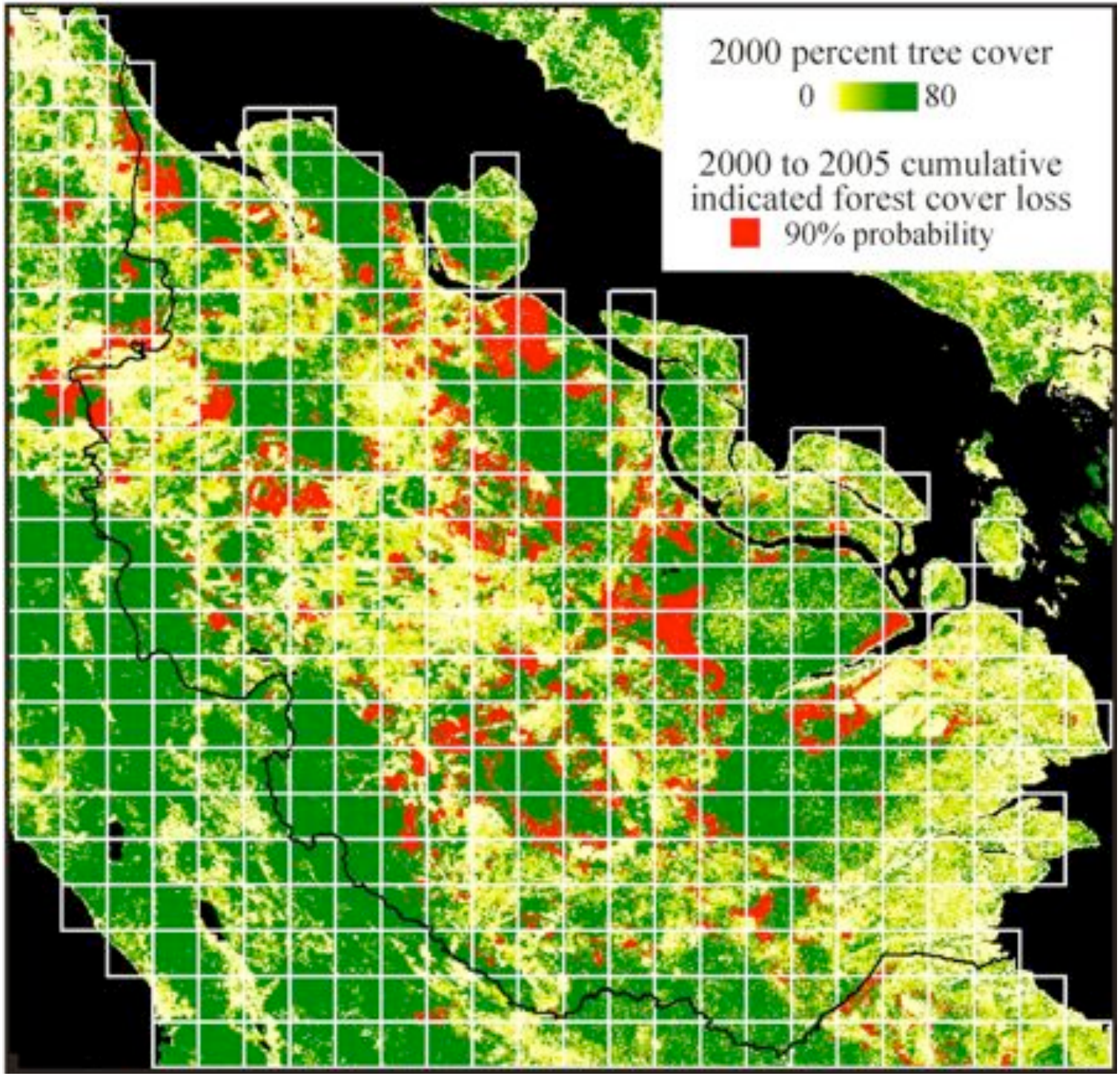


SDSU

Annual forest cover loss



SDSU


2000 percent tree cover
0
80
2000 to 2005 cumulative
indicated forest cover loss
90% probability

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MODIS change indicator map, resampled to 20km by 20km blocks

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Quantifying changes in *rates* of forest clearing – Indonesian example

Using national-scale forest cover loss indicator maps
from AVHRR for 1990 to 2000 and
from MODIS for 2000 to 2005

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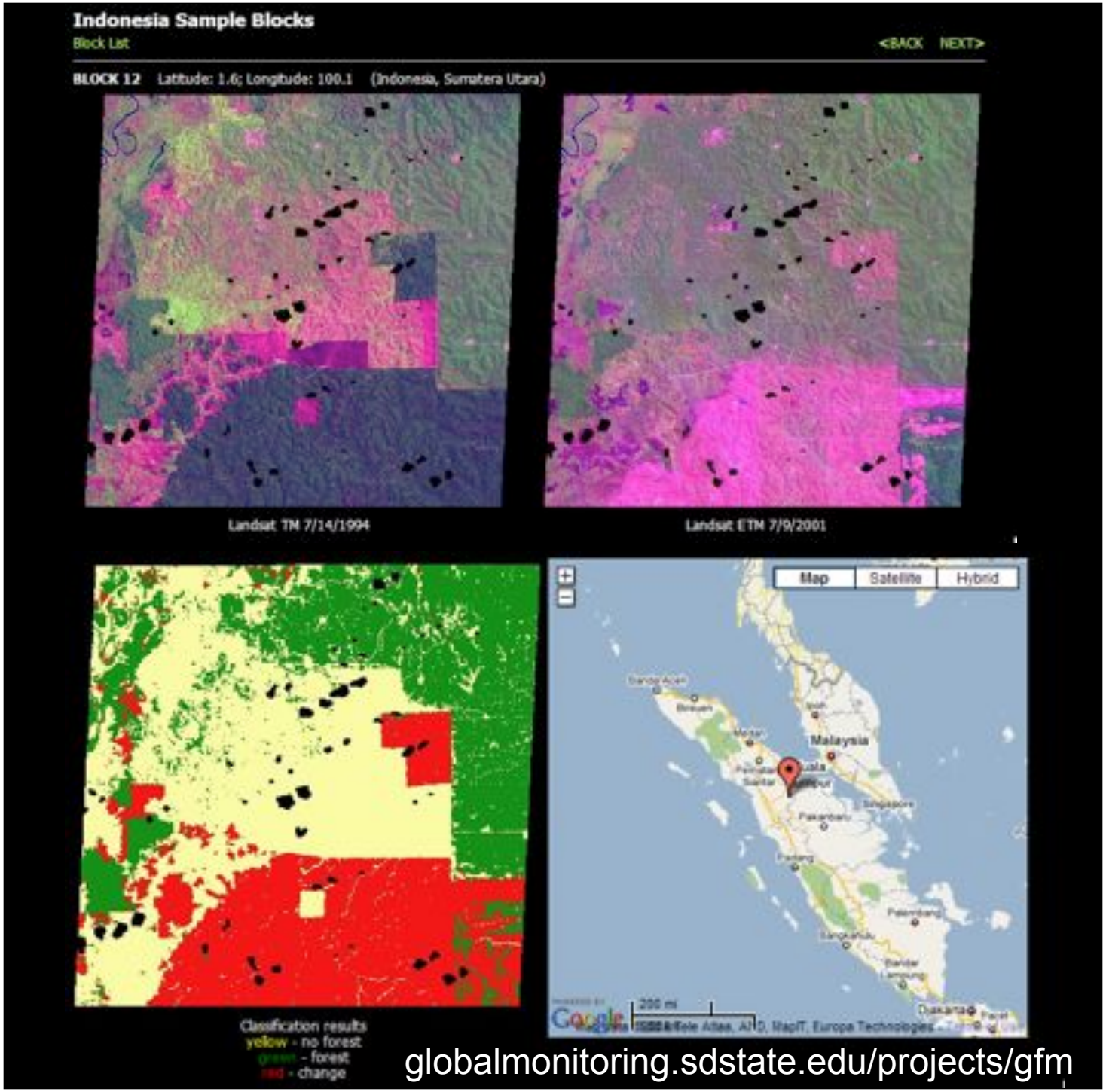
Indonesia Sample Blocks
Block List
<BACK NEXT>
BLOCK 12 Latitude: 1.6; Longitude: 100.1 (Indonesia, Sumatera Utara)
Landsat TM 7/14/1994
Landsat ETM 7/9/2001
Classification results
yellow - no forest
green - forest
red - change
Map
Satellite
Hybrid
Malaysia
200 mi
globalmonitoring.sdstate.edu/projects/gfm

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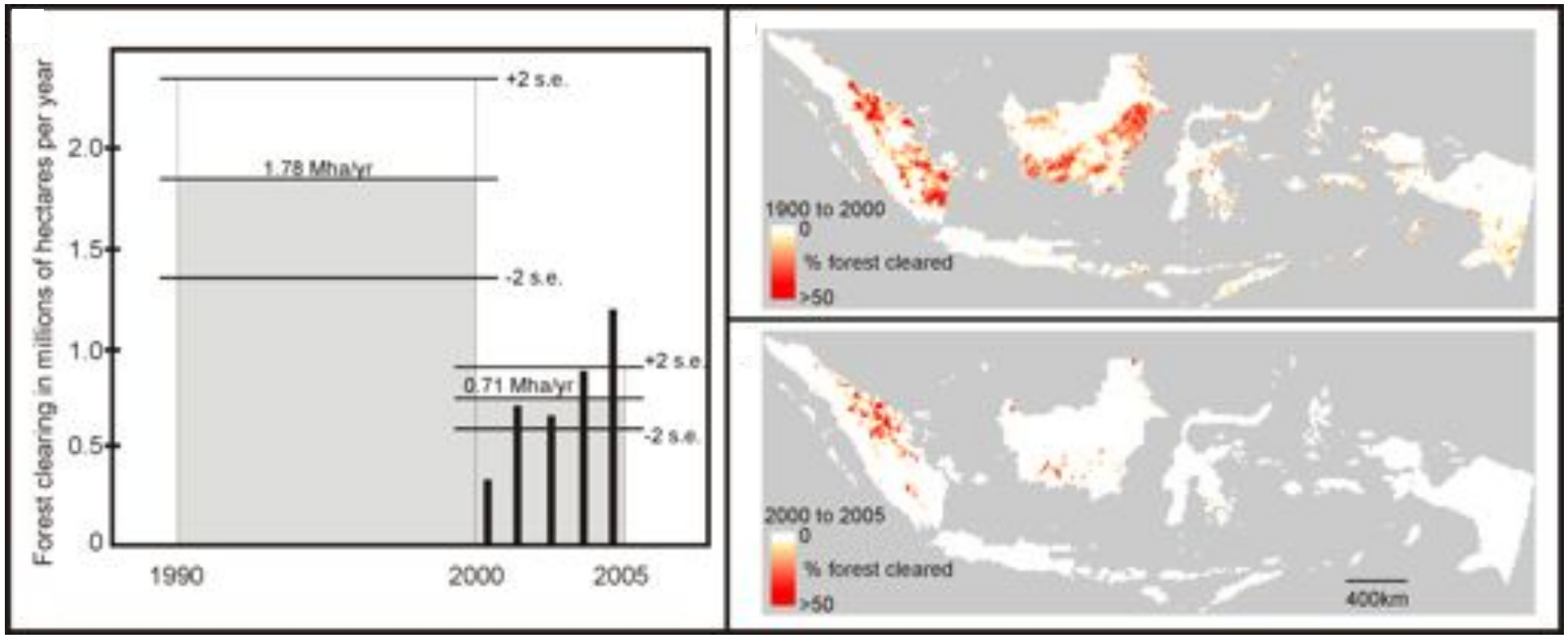
Indonesia forest clearing, 1990 to 2005



- 1990's
  - ENSO fires of 1997-98
  - Oil palm expansion
  - Increasing timber plantations
  - Stable central government and growing economy
- 2000
  - Economic crisis
  - Oil palm policy reform / slowed expansion
  - Less fire and easily accessible lowland forest

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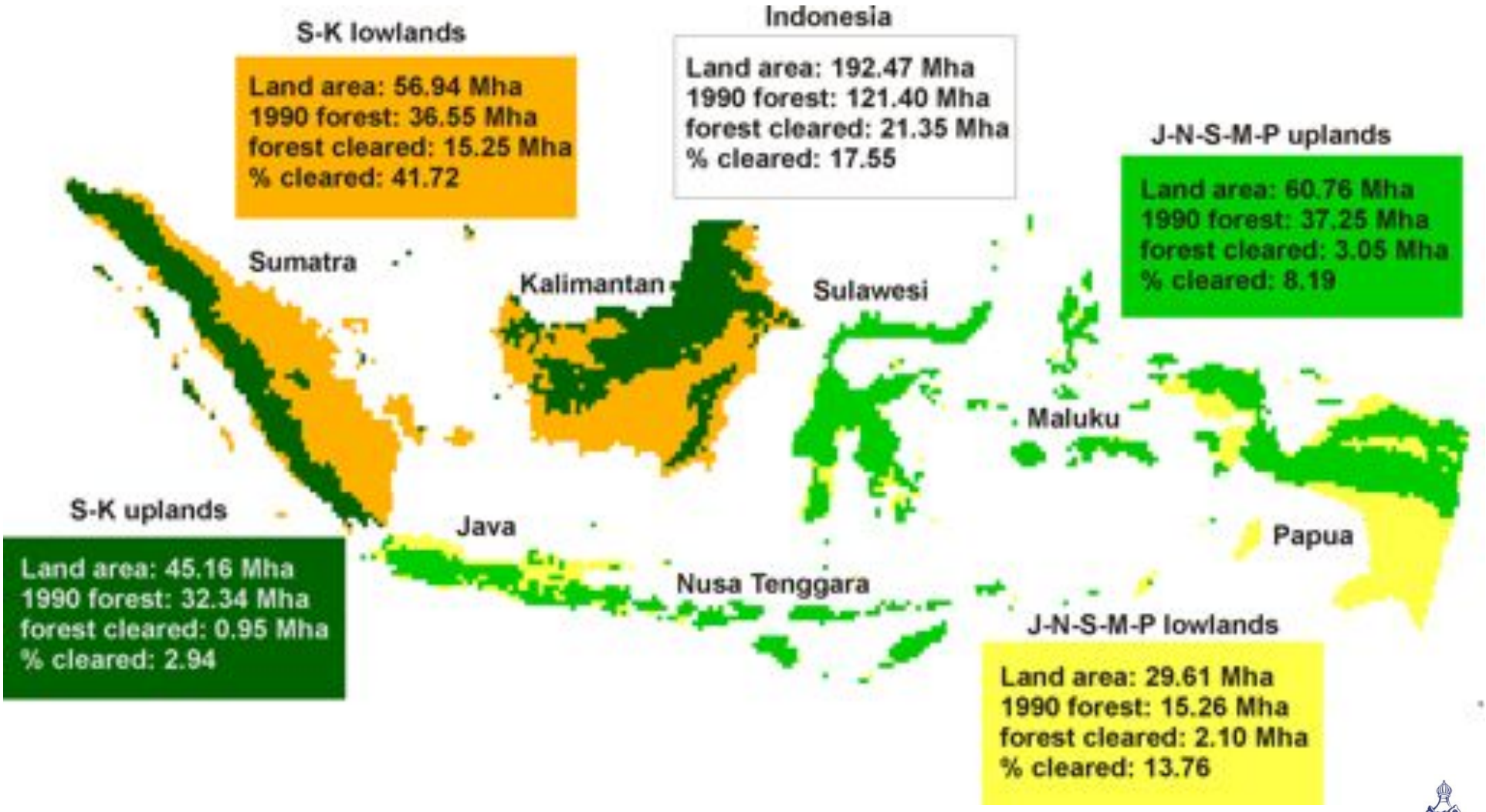
S-K lowlands
Land area: 56.94 Mha
1990 forest: 36.55 Mha
forest cleared: 15.25 Mha
% cleared: 41.72
Indonesia
Land area: 192.47 Mha
1990 forest: 121.40 Mha
forest cleared: 21.35 Mha
% cleared: 17.55
J-N-S-M-P uplands
Land area: 60.76 Mha
1990 forest: 37.25 Mha
forest cleared: 3.05 Mha
% cleared: 8.19
Sumatra
Kalimantan
Sulawesi
Maluku
Papua
Java
Nusa Tenggara
S-K uplands
Land area: 45.16 Mha
1990 forest: 32.34 Mha
forest cleared: 0.95 Mha
% cleared: 2.94
J-N-S-M-P lowlands
Land area: 29.61 Mha
1990 forest: 15.26 Mha
forest cleared: 2.10 Mha
% cleared: 13.76

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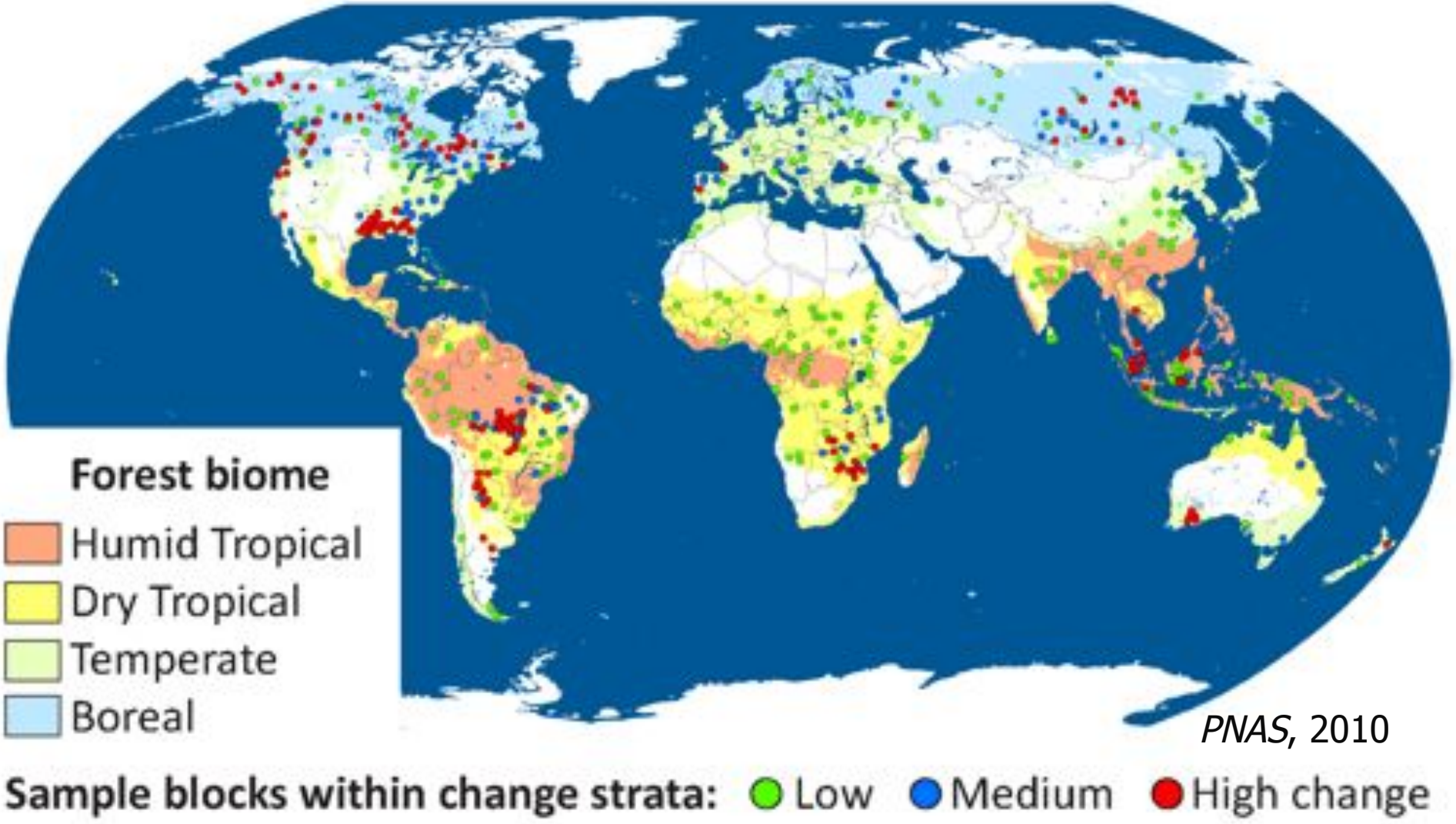
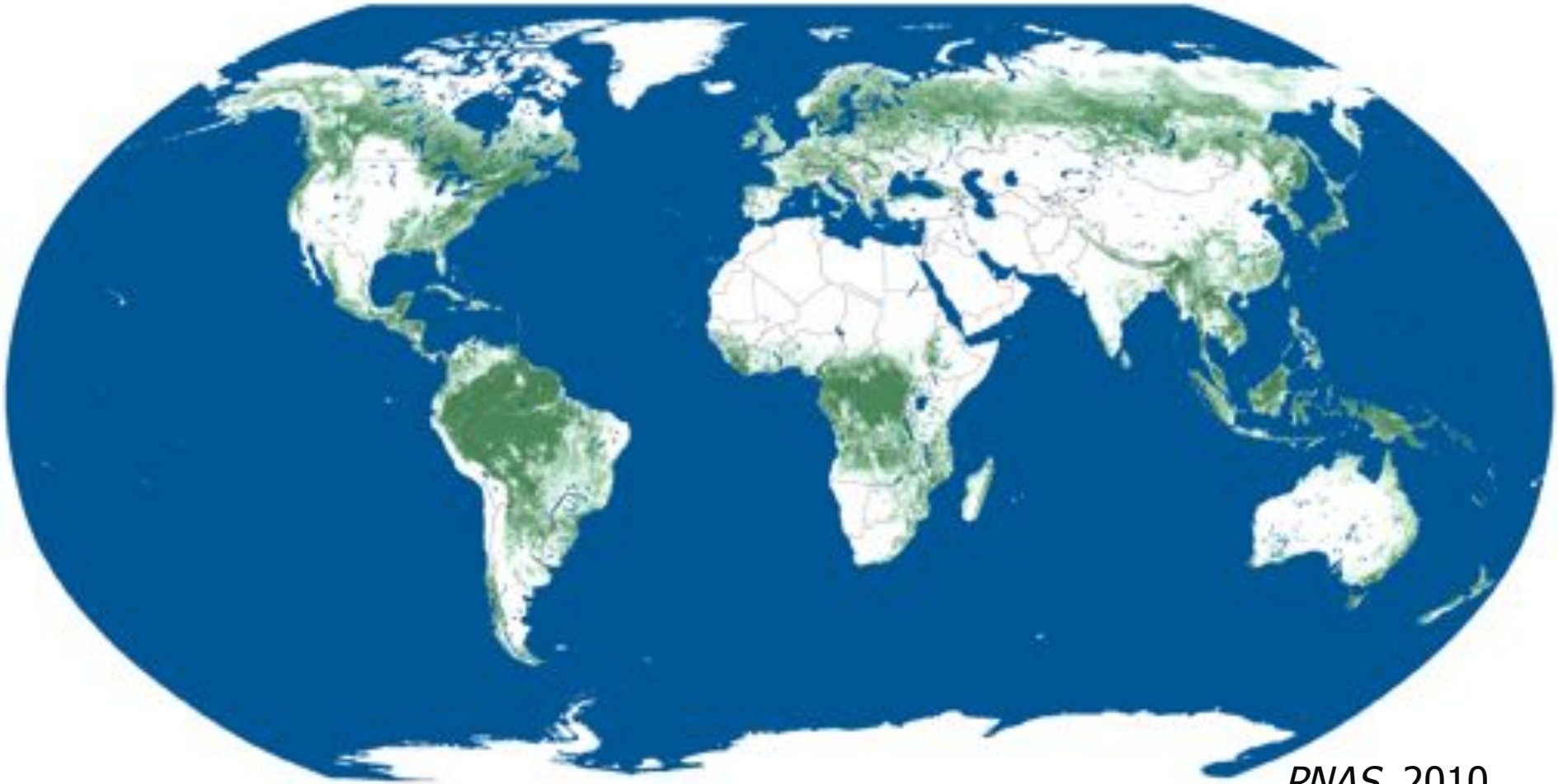
MODIS-stratified Landsat samples



PNAS, 2010

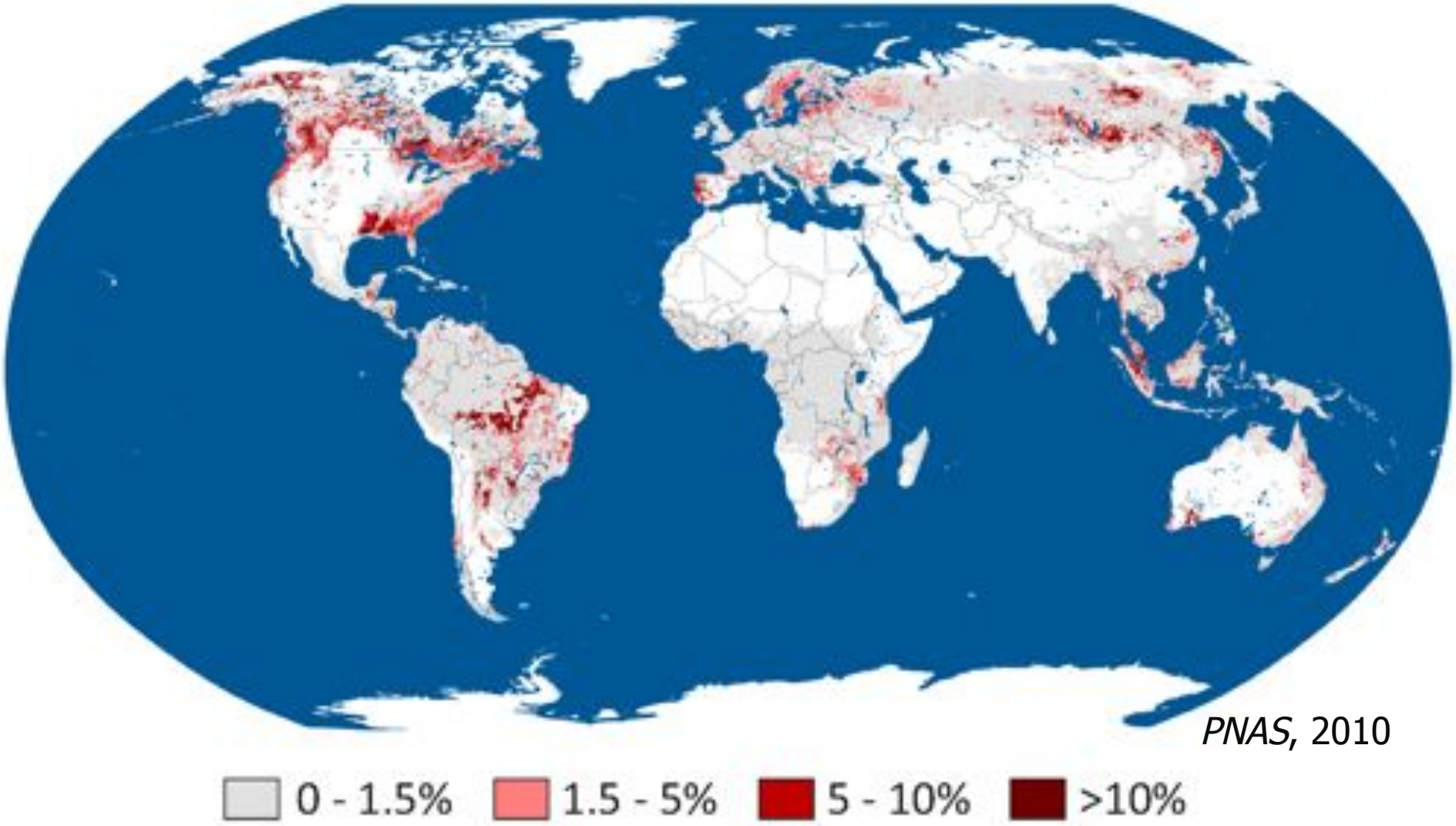
Percent forest cover, 2000



PNAS, 2010

0 - 10% 10 - 25% 25 - 50% 50 - 75% 75 - 100%

Percent gross forest cover loss, 2000 to 2005



PNAS, 2010

2005 United Nations Food and Agriculture Organization Forest Resource Assessment Report

- Africa and South America feature largest forest losses
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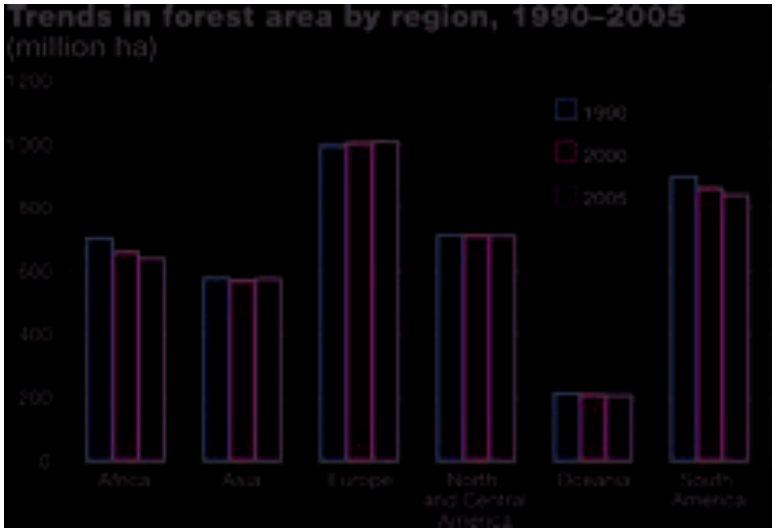
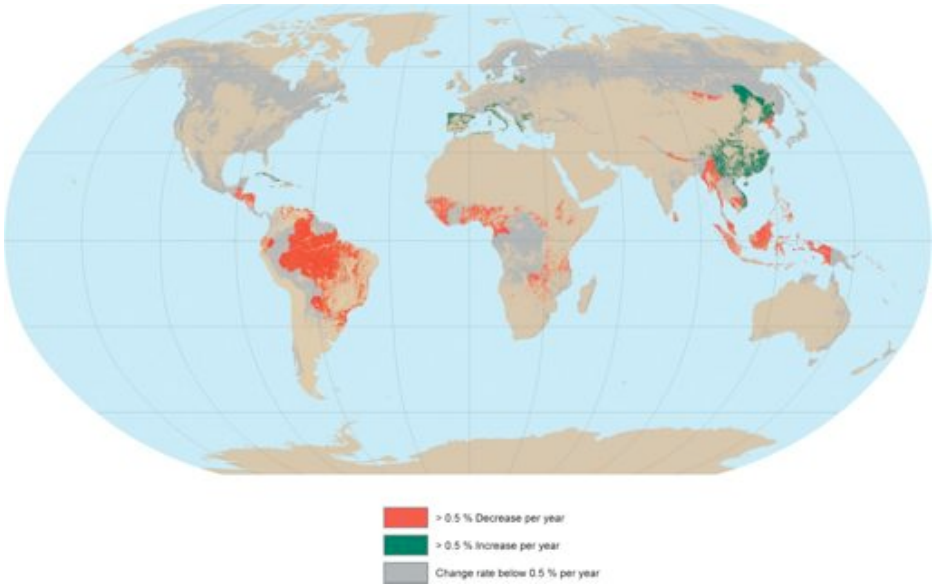
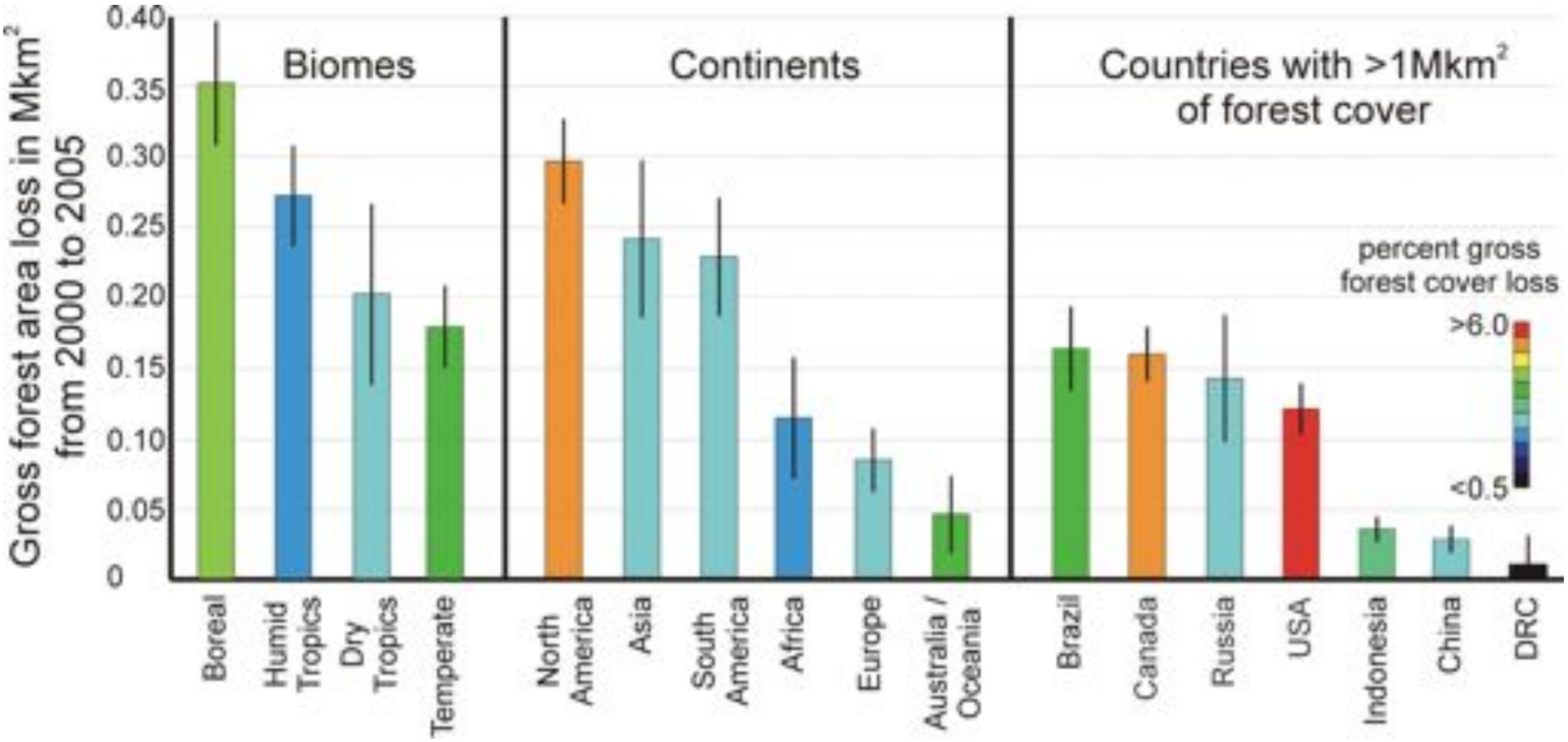
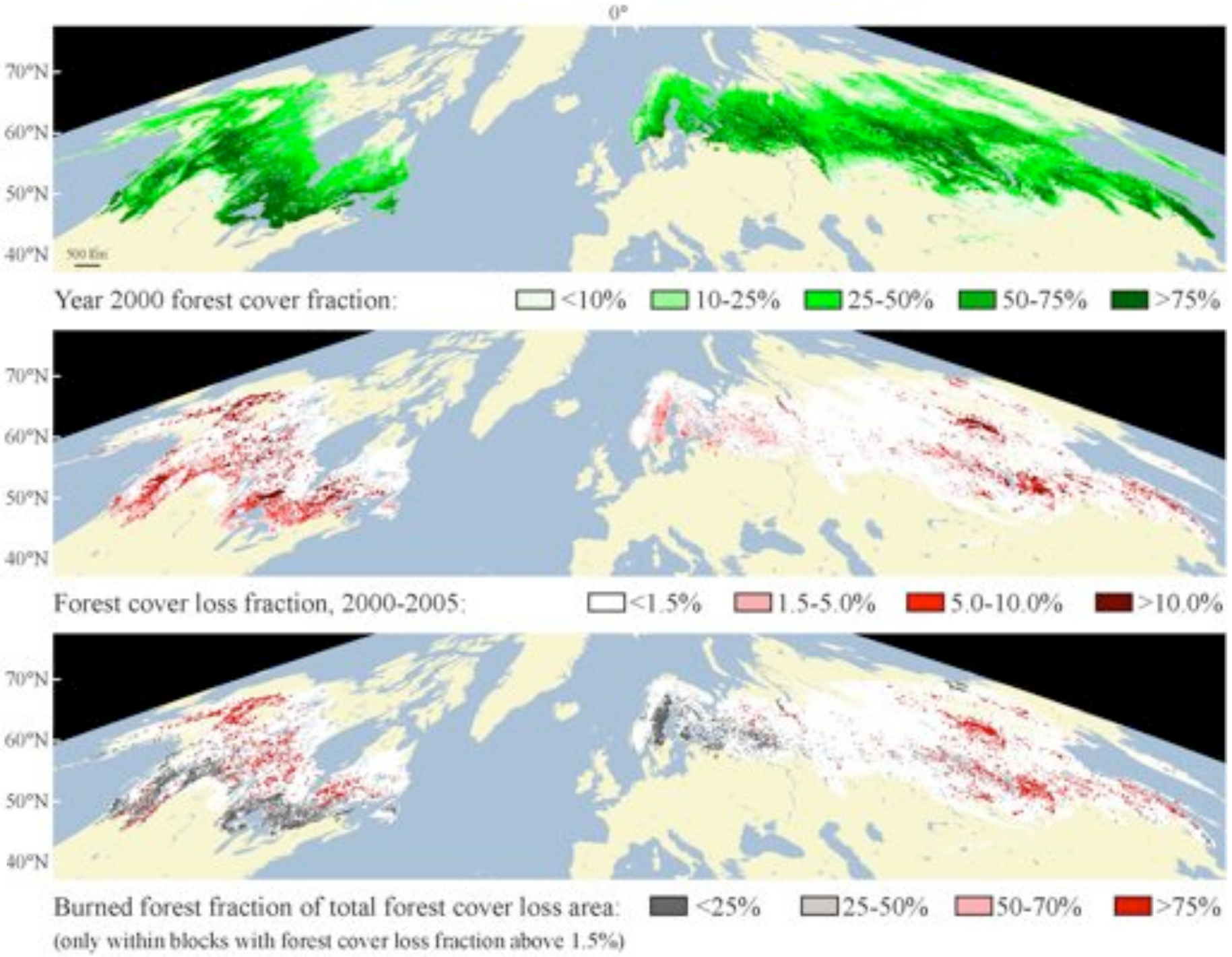




Global gross forest cover loss, 2000 to 2005



PNAS, 2010


0°
70°N
60°N
50°N
40°N
500 Km
Year 2000 forest cover fraction:
<10%
10-25%
25-50%
50-75%
>75%
70°N
60°N
50°N
40°N
Forest cover loss fraction, 2000-2005:
<1.5%
1.5-5.0%
5.0-10.0%
>10.0%
70°N
60°N
50°N
40°N
Burned forest fraction of total forest cover loss area:
<25%
25-50%
50-70%
>75%
(only within blocks with forest cover loss fraction above 1.5%)

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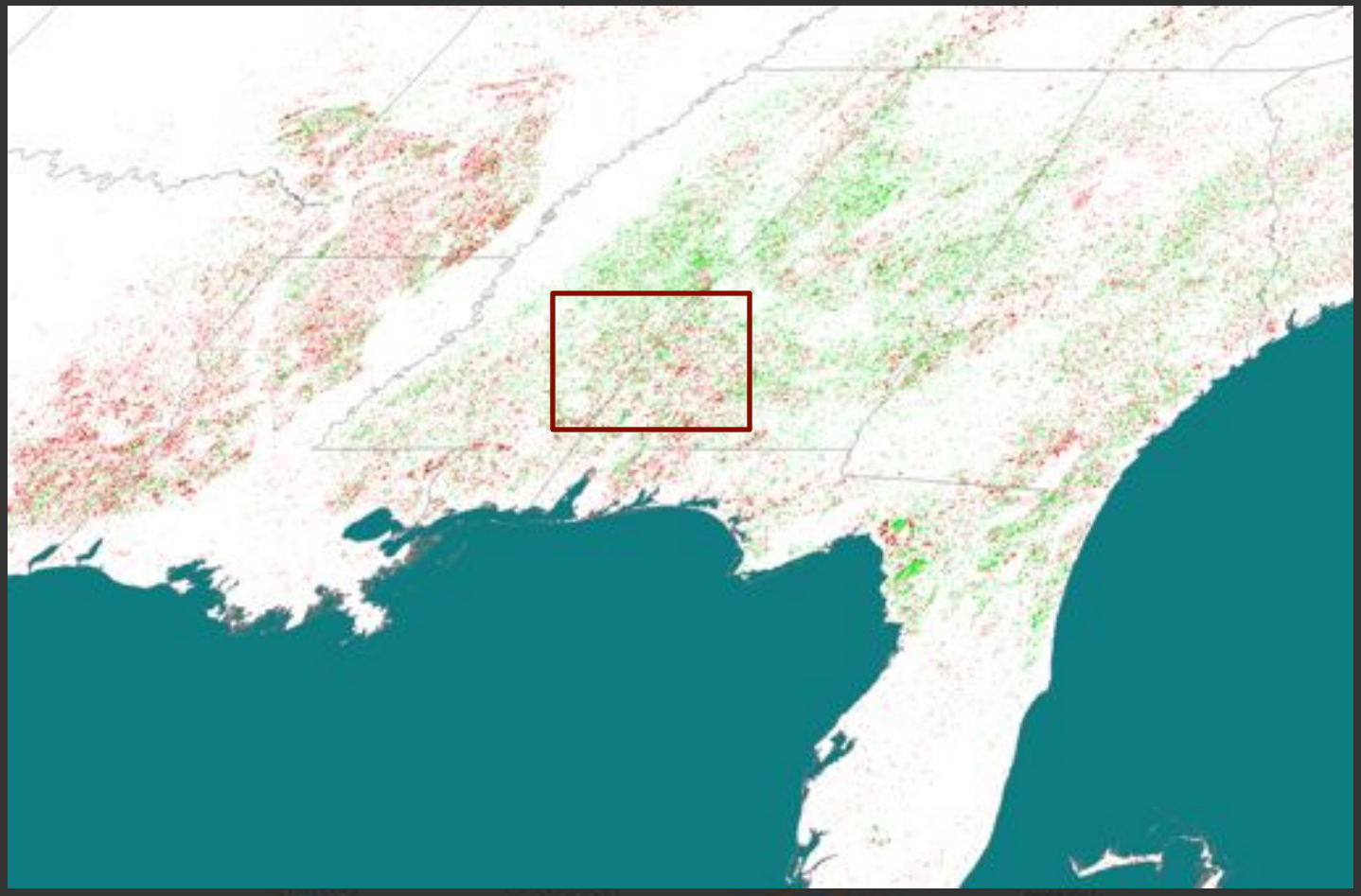
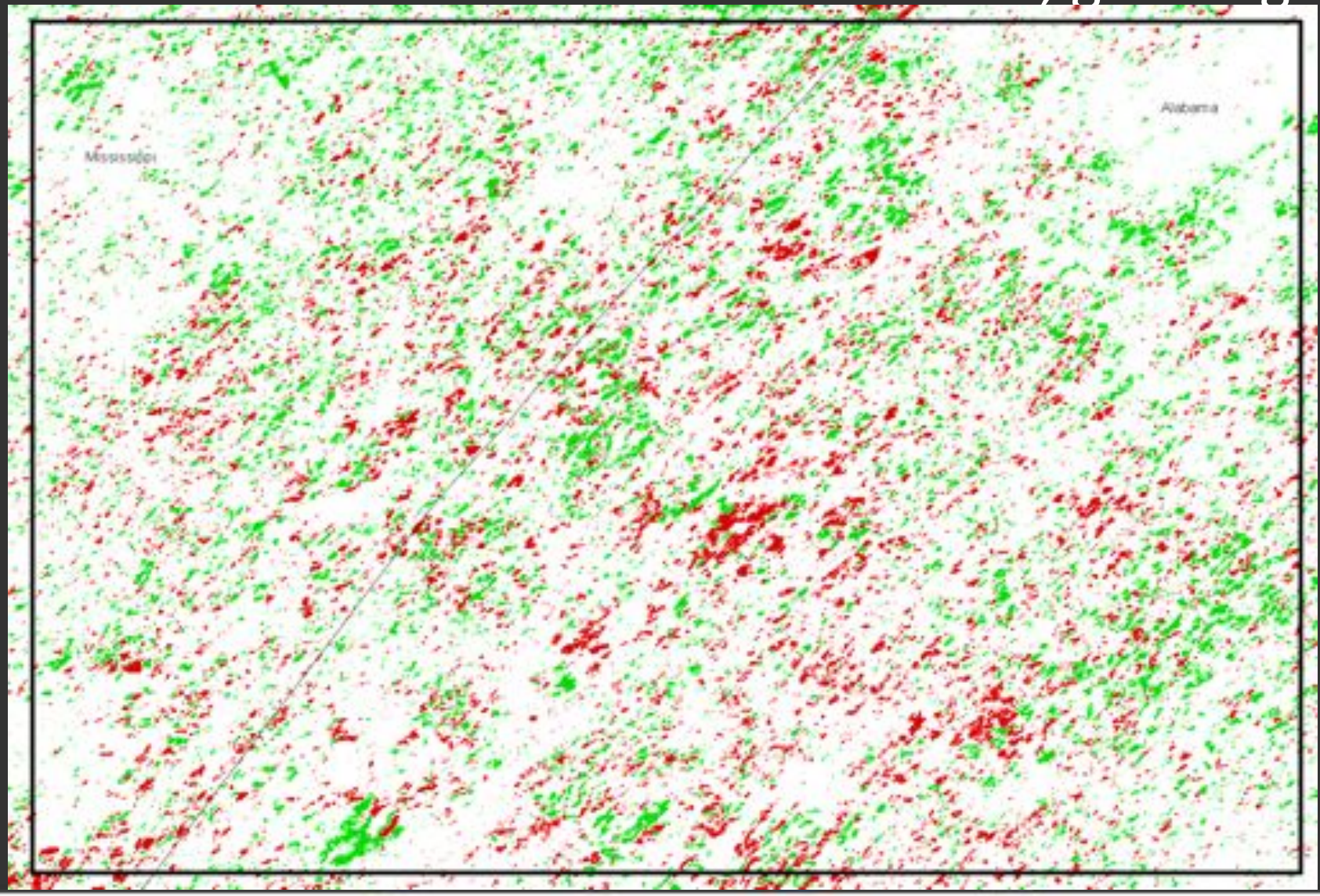
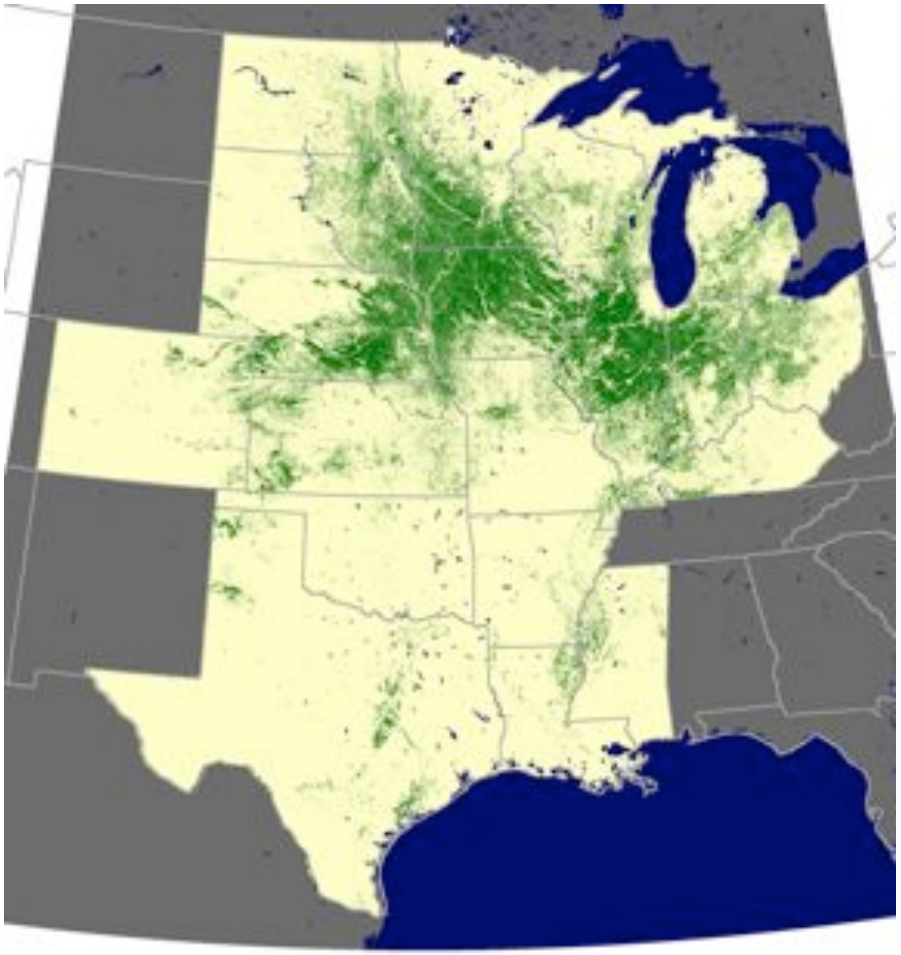
Southeast US 2000-2009 - red=loss, green=gain



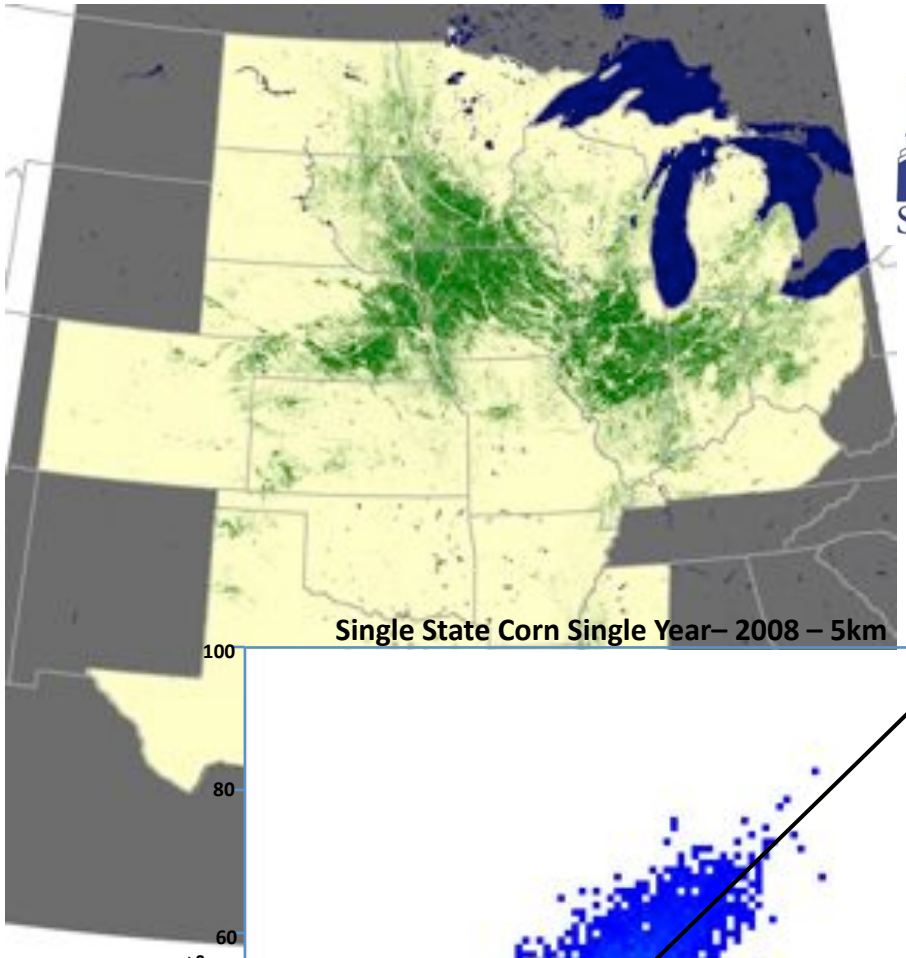
Global Forest Cover Change
www.forestcover.org

Southeast US 2000-2009 - red=loss, green=gain

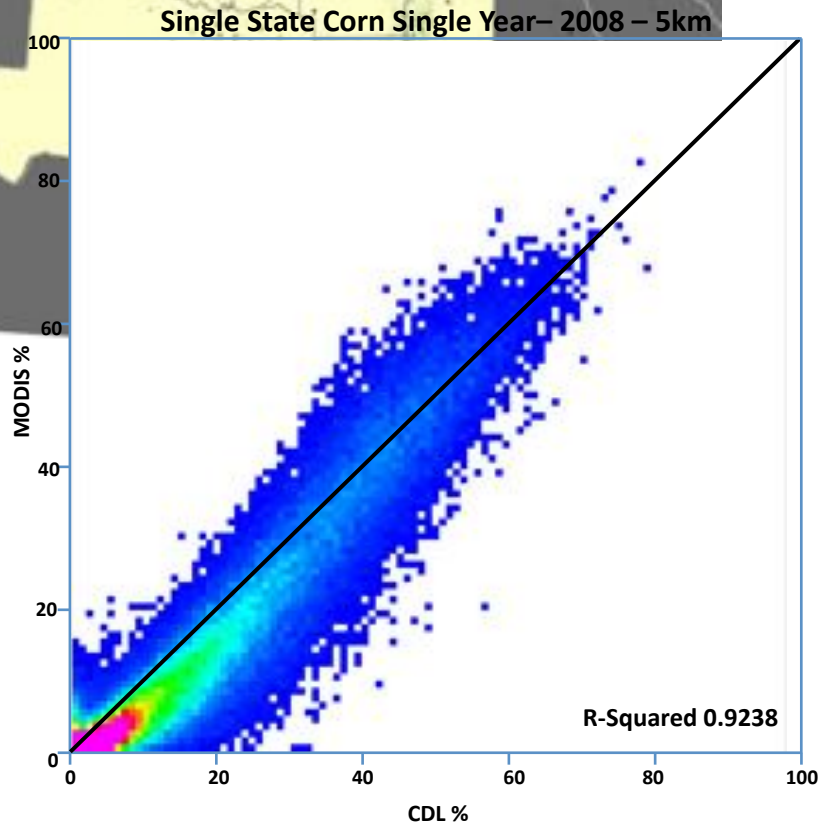




NASS AWiFS CDL 2008 corn

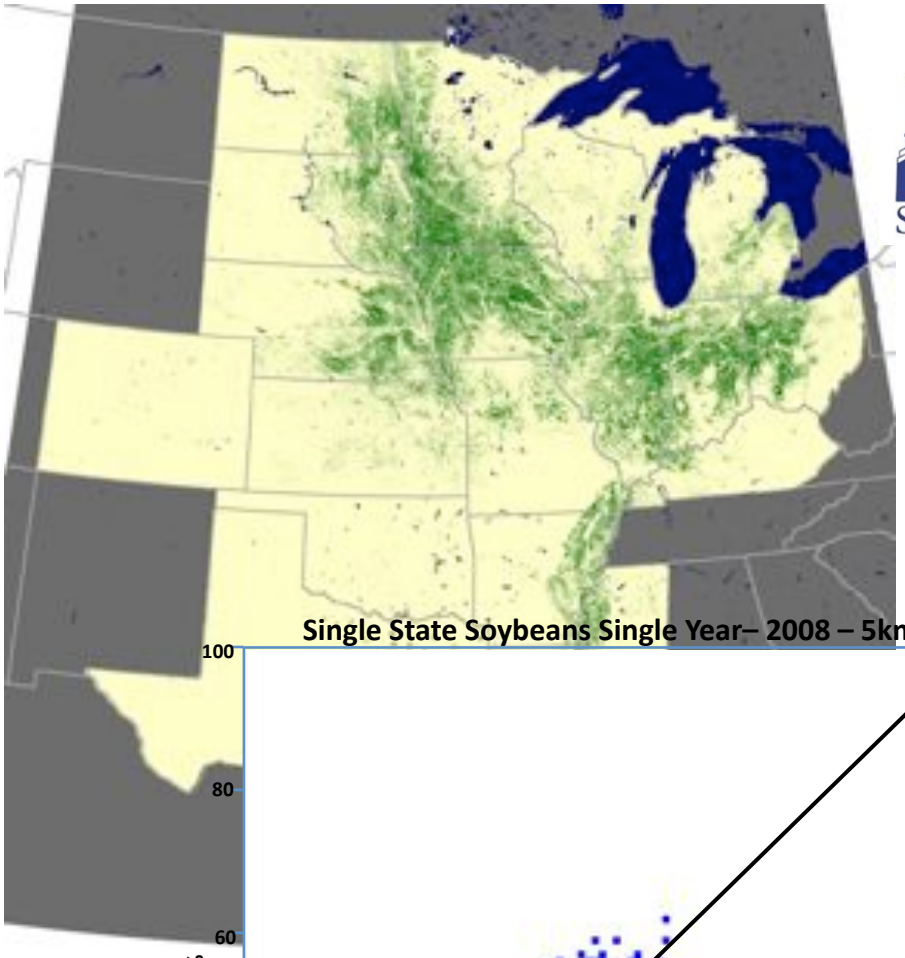


MODIS 2008 corn

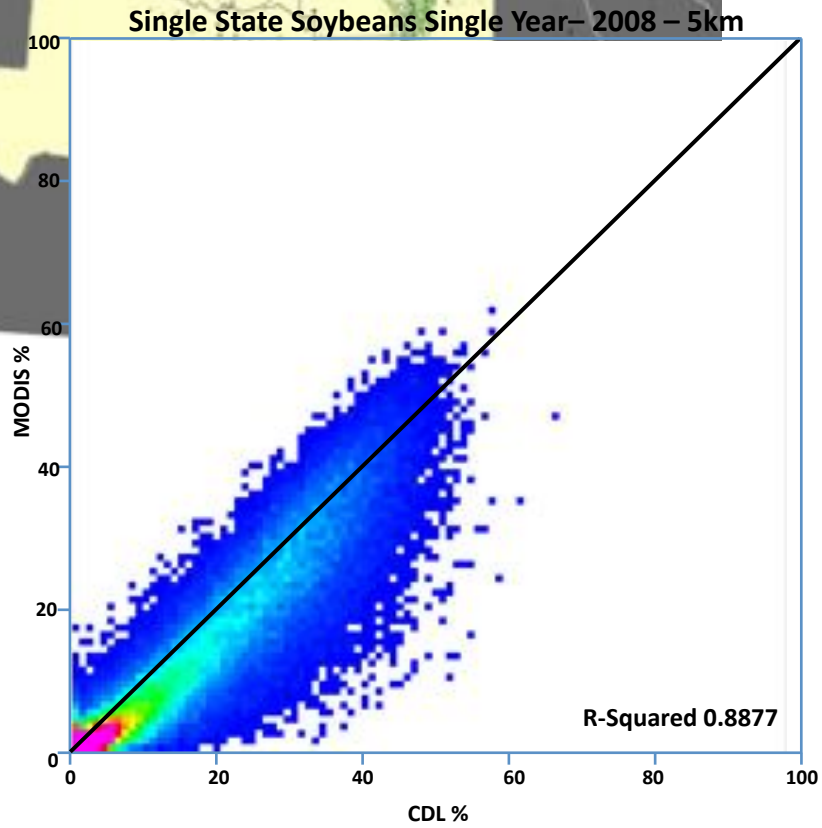


MODIS data for corn indicator mapping – per state model

NASS AWiFS CDL 2008 soy

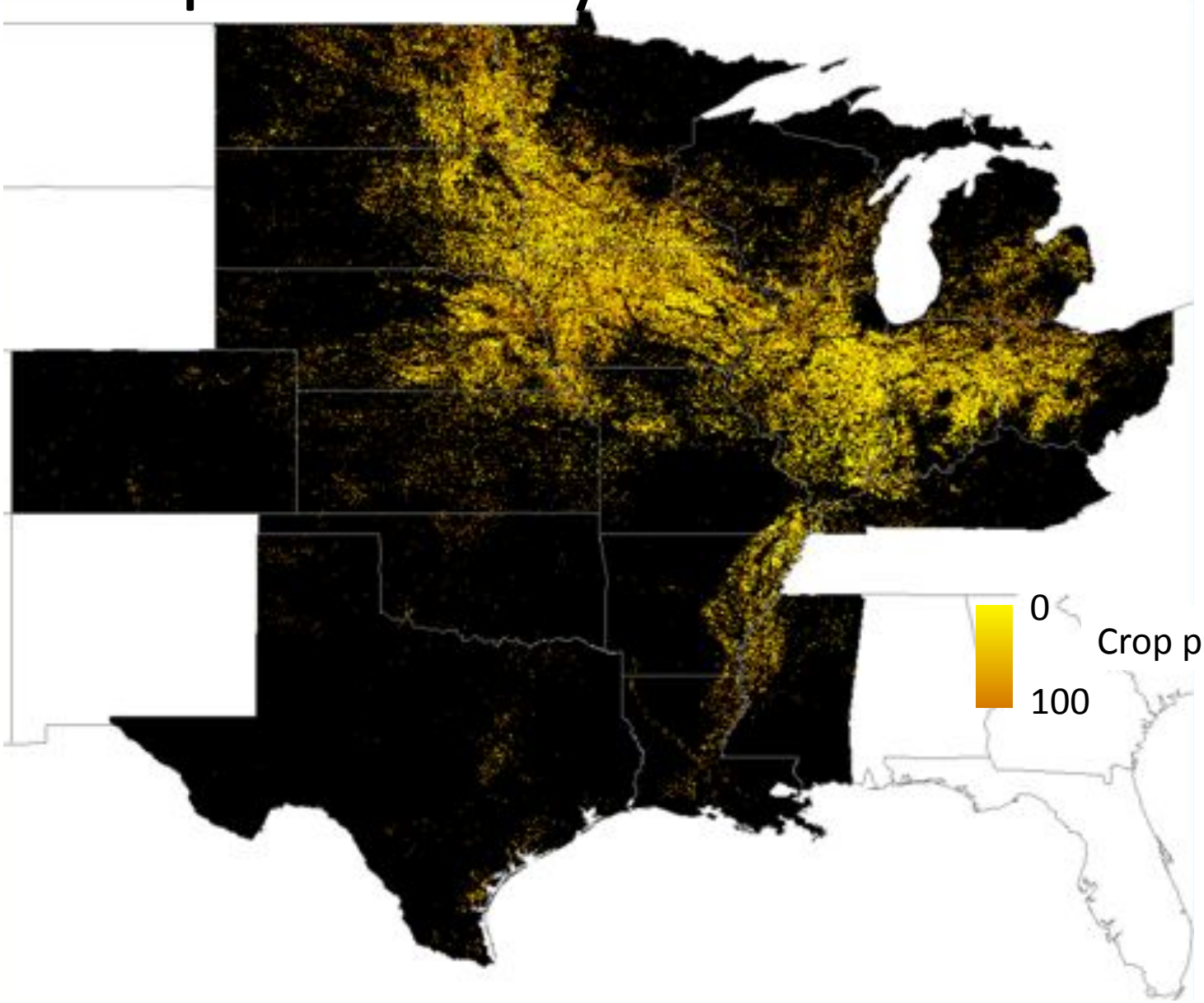


MODIS 2008 soy



MODIS data for soy indicator mapping – per state model

MODIS percent soybean cover 2008



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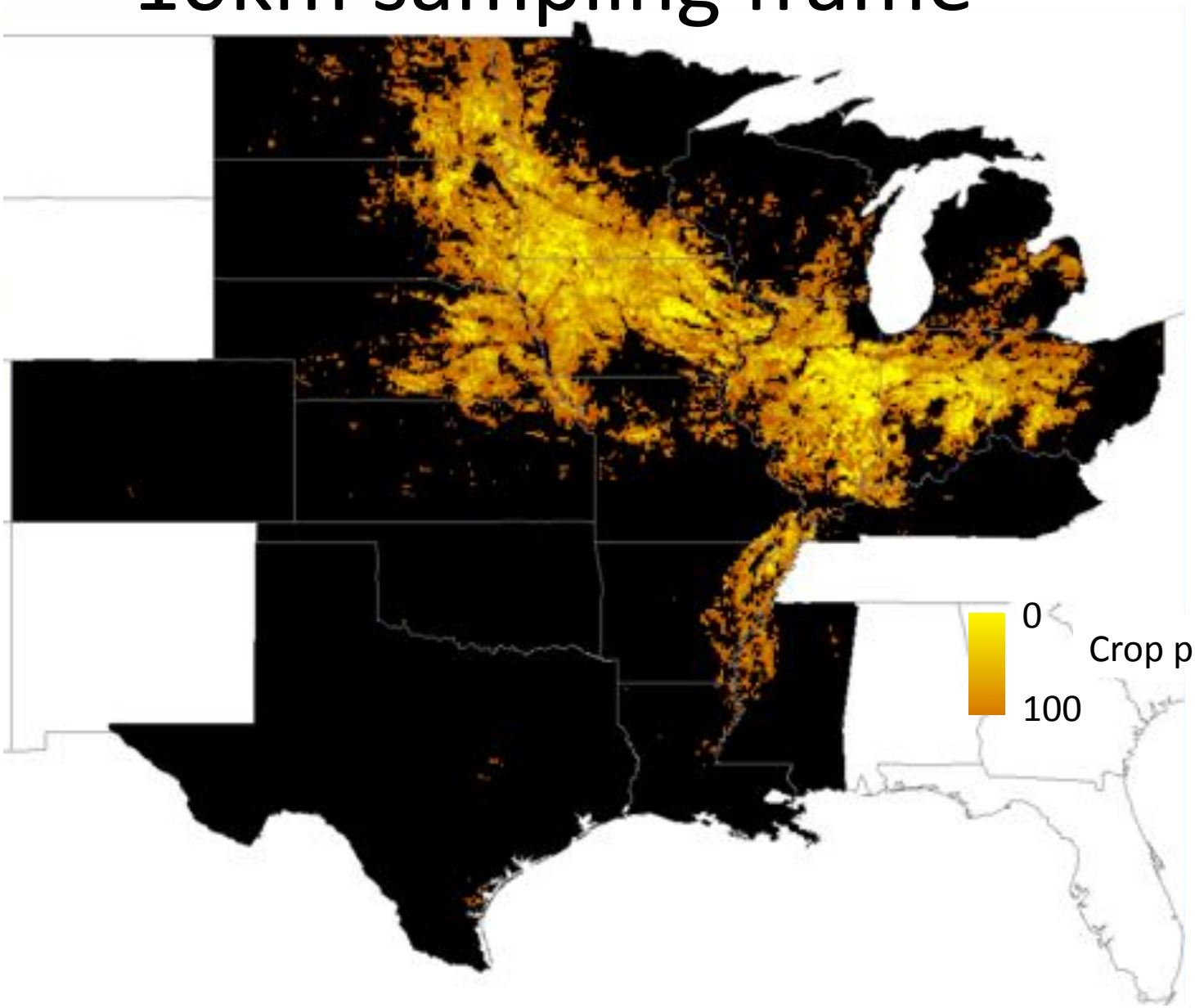
10km sampling frame



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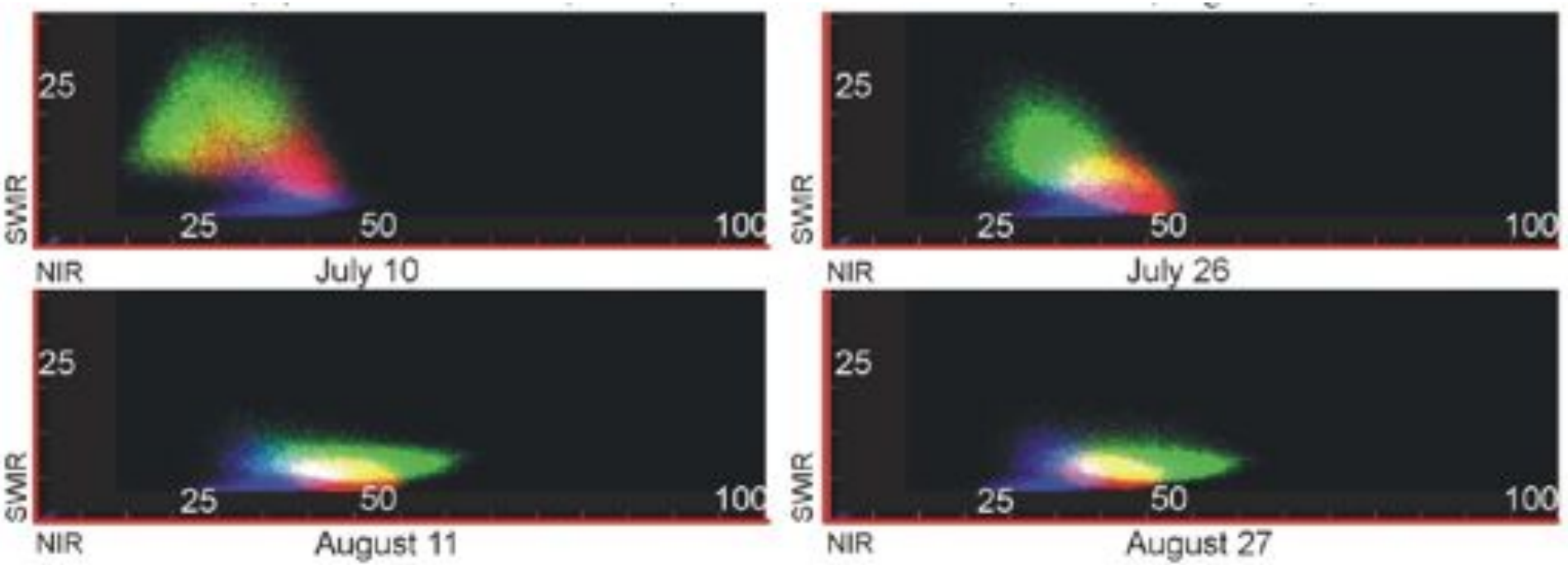
Sampling at peak crop condition and/ or highest separability

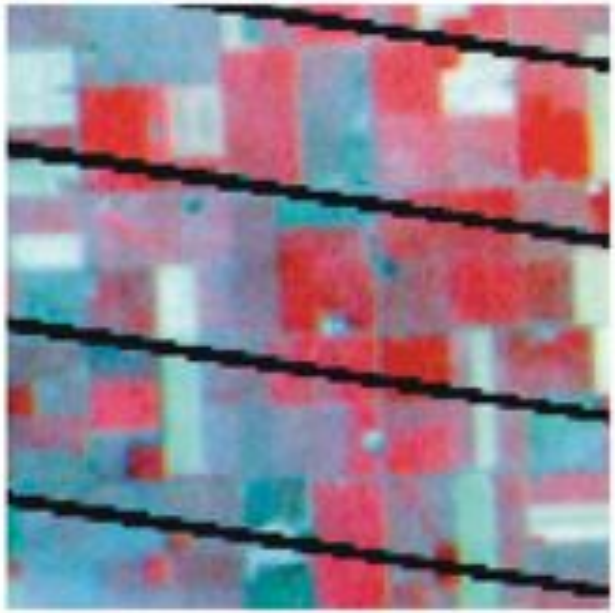


Soybean and corn phenology from MODIS, Minnesota, USA

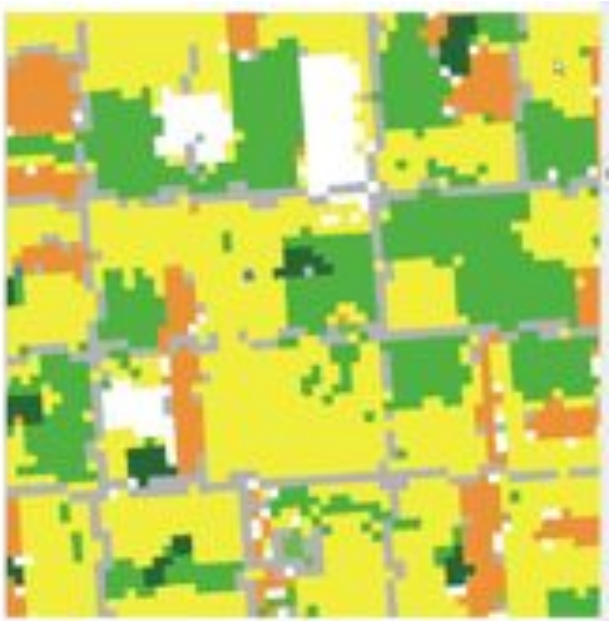
Red = corn > 50%
Green = soy > 50% cover
Blue = other vegetation > 50% cover

Peak cover condition moderate/high spatial resolution samples

RapidEye 5m



Landsat 30m



NASS CDL

yellow is soybeans
light green corn
orange winter wheat

July imagery

RapidEye near Garretson, South Dakota

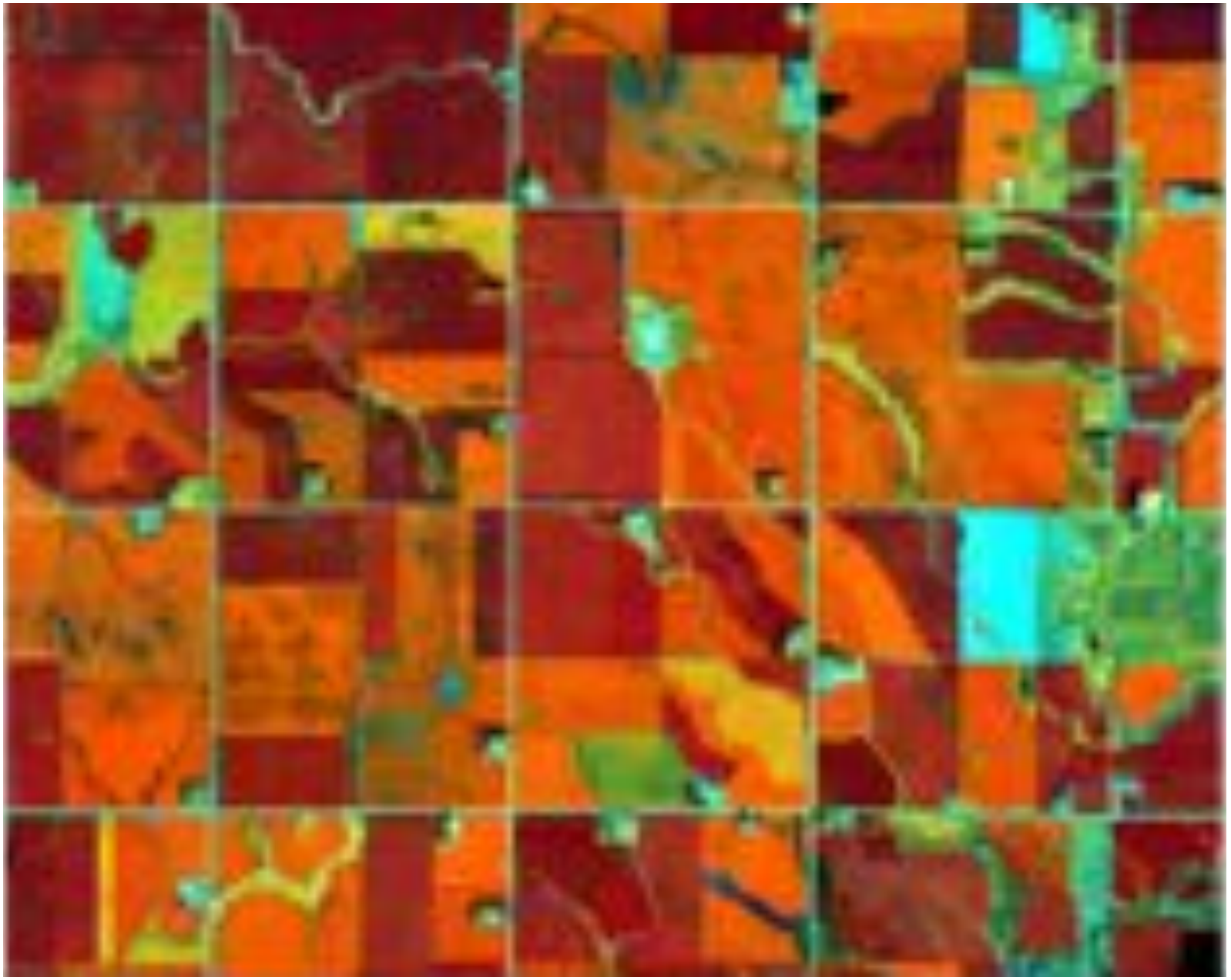


Image Date
08/11/2010

NIR

Red-Edge

Red

Forest monitoring using MODIS and Landsat data sets – 2nd approach

- Use MODIS to radiometrically normalize Landsat imagery for exhaustive mapping at 30m spatial resolution via:
  - 1) Landsat epochal composites
    - Combine best observations over a given interval to create cloud-free image
    - Cloud-free composites require such a long compositing period that change occurs within the composite interval
  - 2) Landsat time-series characterizations
    - Map each good pixel and create time-series of forest cover estimates in metric space
    - No image composite needed
    - Unequal numbers of cover estimates over the regions (scene overlaps, SLC-off gaps)

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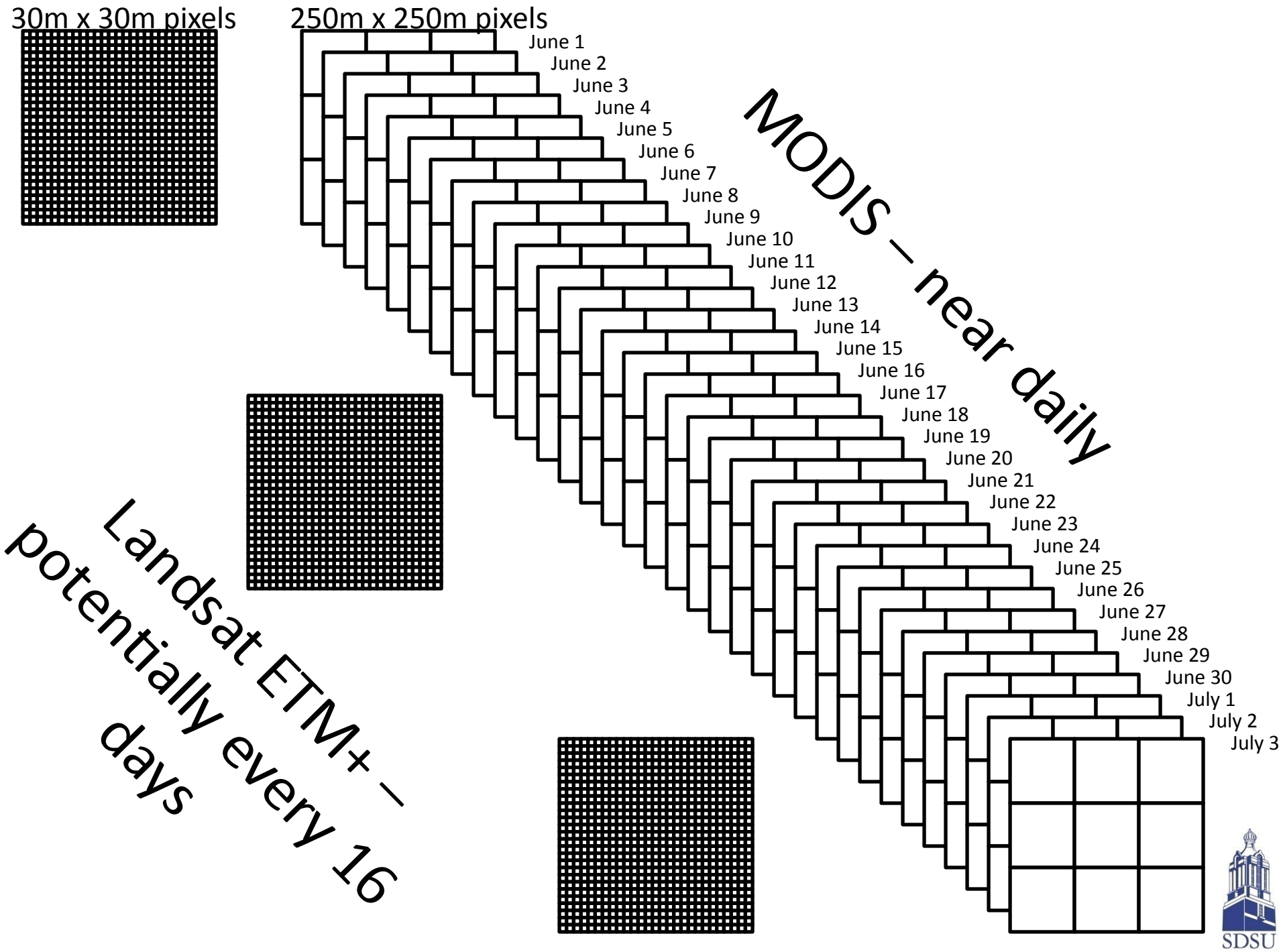
30m x 30m pixels
250m x 250m pixels
June 1
June 2
June 3
June 4
June 5
June 6
June 7
June 8
June 9
June 10
June 11
June 12
June 13
June 14
June 15
June 16
June 17
June 18
June 19
June 20
June 21
June 22
June 23
June 24
June 25
June 26
June 27
June 28
June 29
June 30
July 1
July 2
July 3
MODIS – near daily
Landsat ETM+ – potentially every 16 days
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MODIS processing

Landsat-based training

Classified Landsat scenes

Forest cover

0% 100%

Coniferous forest mask

Coniferous forests

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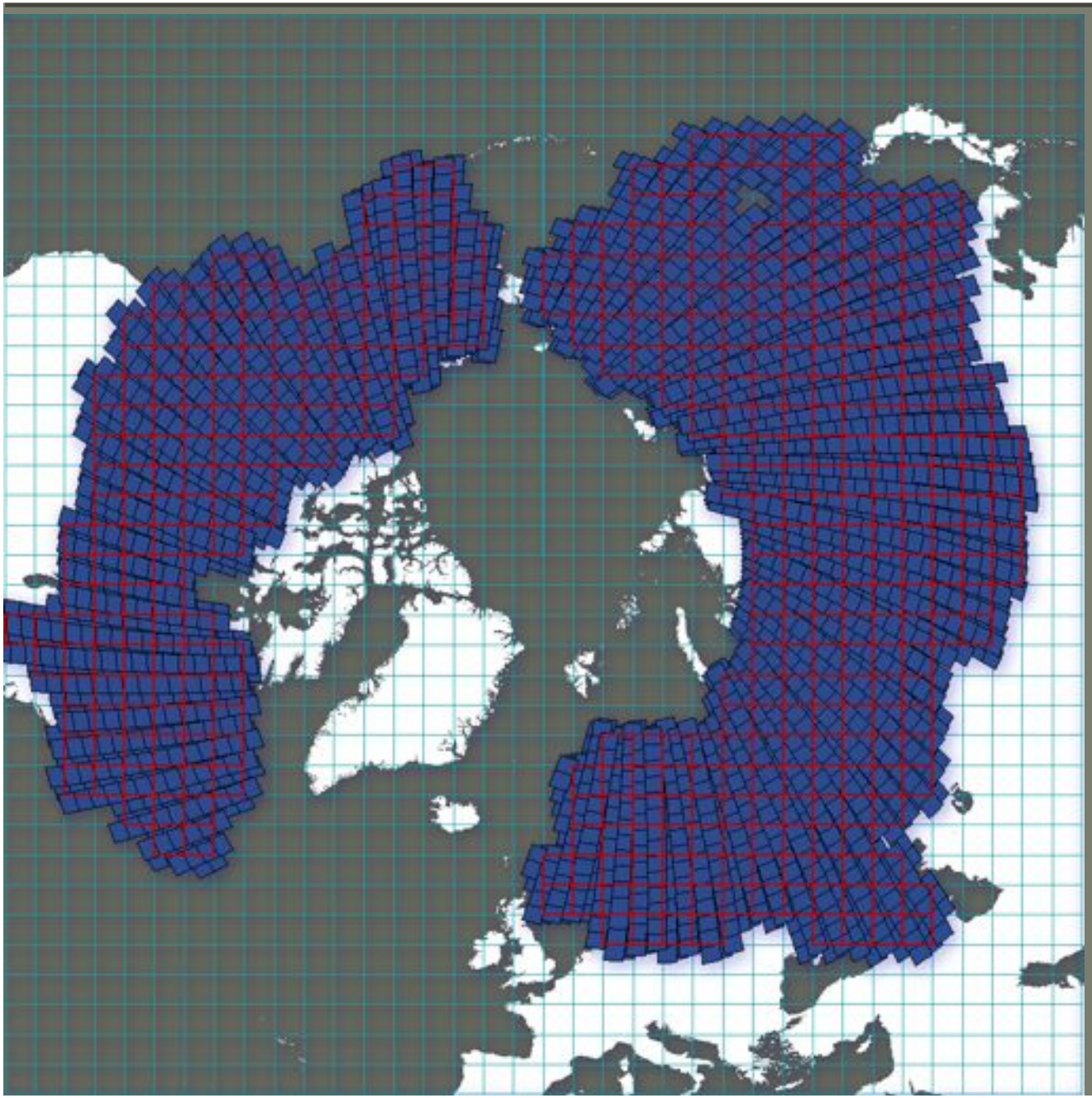
Boreal example

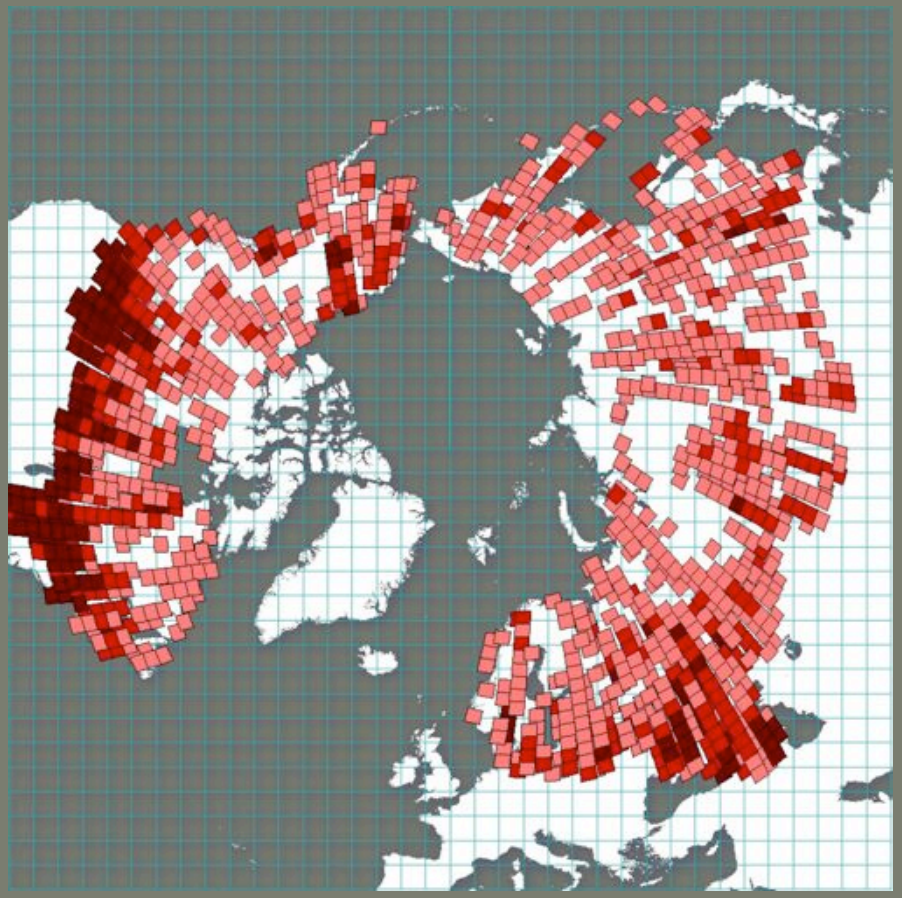


All selected WRS2 path/row (3154)

Image selection

Landsat image selection criteria

- Date
  - Circa 2000 composite



Available Landsat images for year 2000

(within growing season, with cloud cover below 50%)

	Images per path/row	Percent of all path/row
	0	23
	1	38
	2	26
	3	8
	4	3
	5 and more	2

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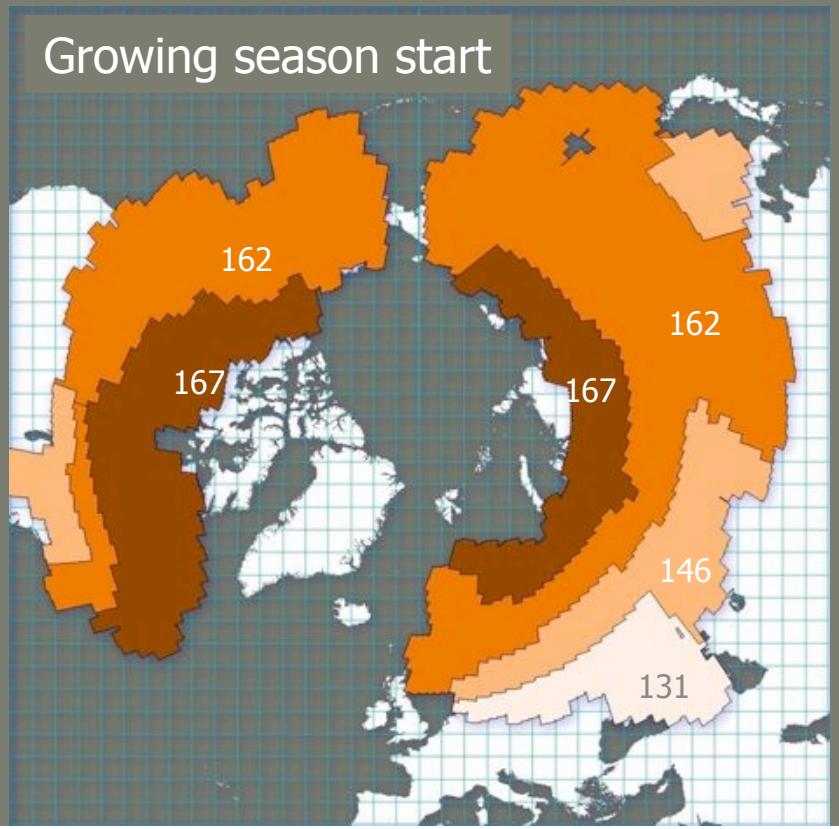
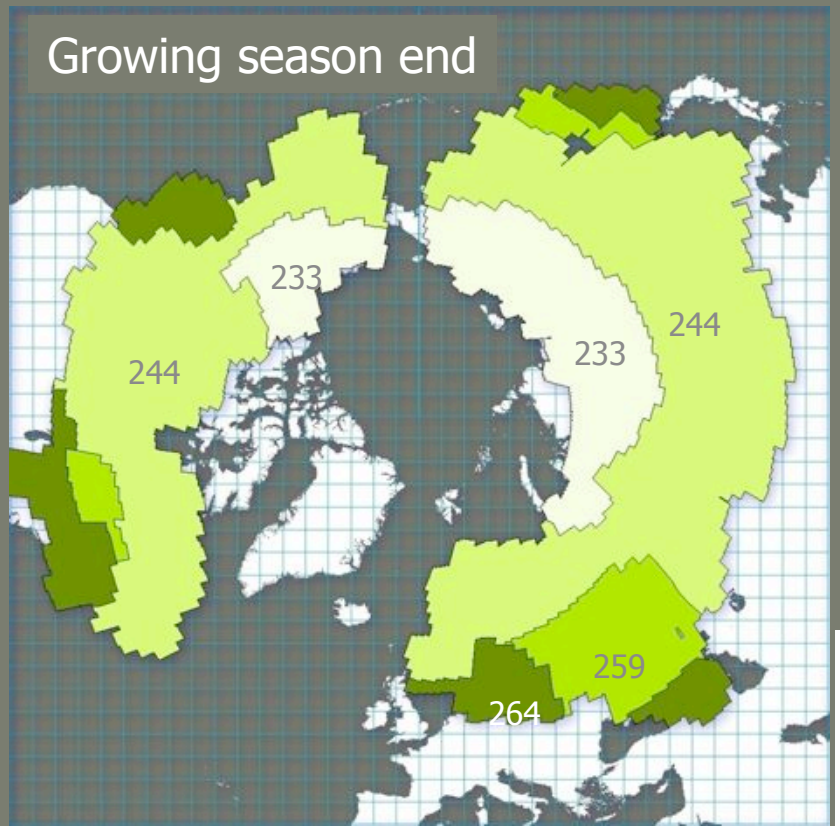
Image selection

Landsat image selection criteria

- Dates
  - Circa 2000 composite: 1999-2002 slc-on data
  - Circa 2005 composite: 2003-2007 slc-off data
  - Within growing season





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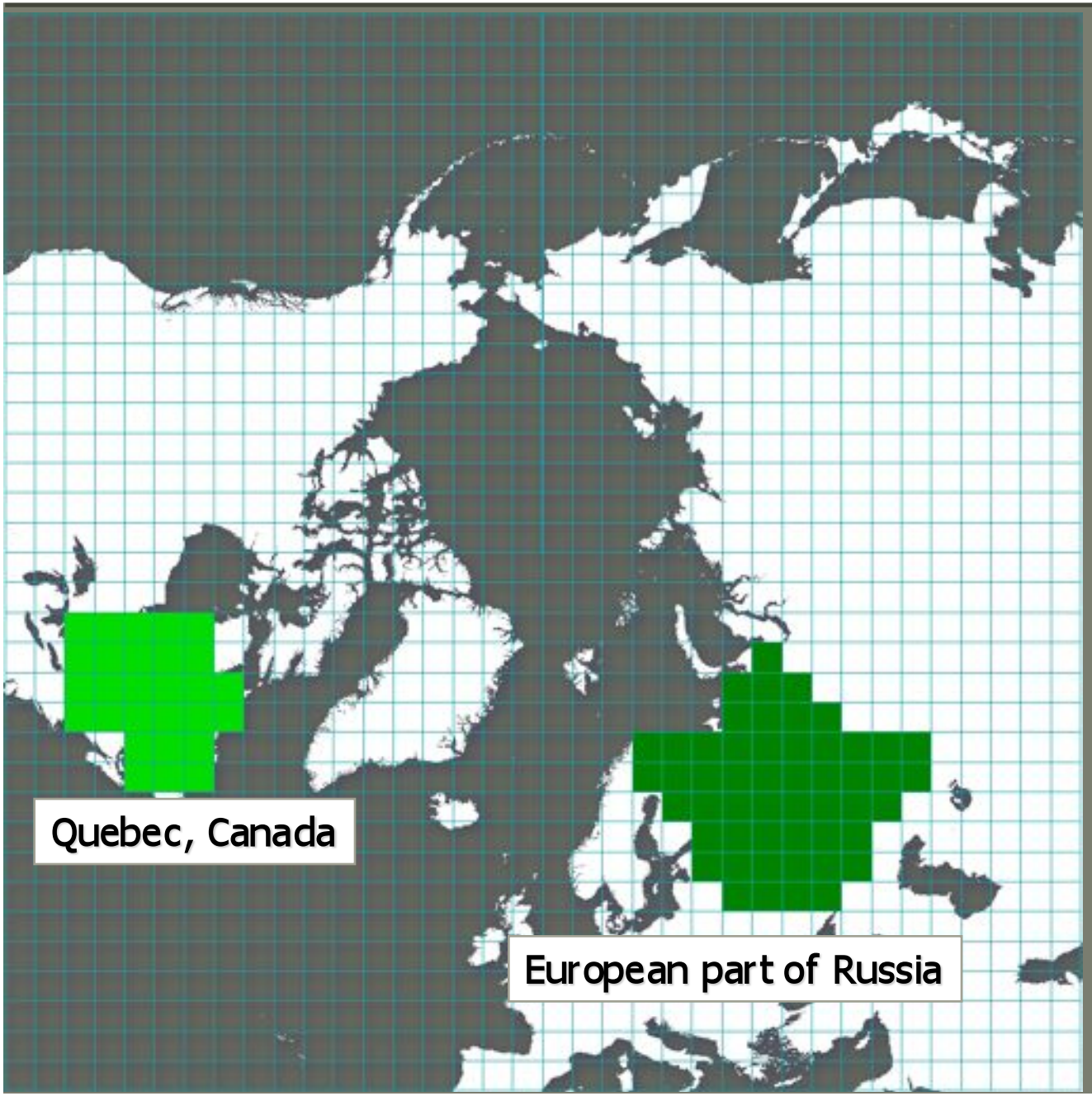
Tiling system



Test areas

1. Quebec, Canada
   28 tiles

2. European part of Russia
   52 tiles

http://kea.sdstate.edu/projects/boreal/index.html

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Image selection

Landsat image selection criteria

- Dates
  - Circa 2000 composite: 1999-2002 slc-on data
  - Circa 2005 composite: 2003-2007 slc-off data
  - Within growing season
- Cloud cover
  - Less then 50% ACCA cloud cover
  - OR, less then 50% cloud cover for any of the scene quarter

Image inputs

	European Russia	Quebec, Canada
1999-2002	**2969**	**1505**
2003-2007	**4623**	**1951**

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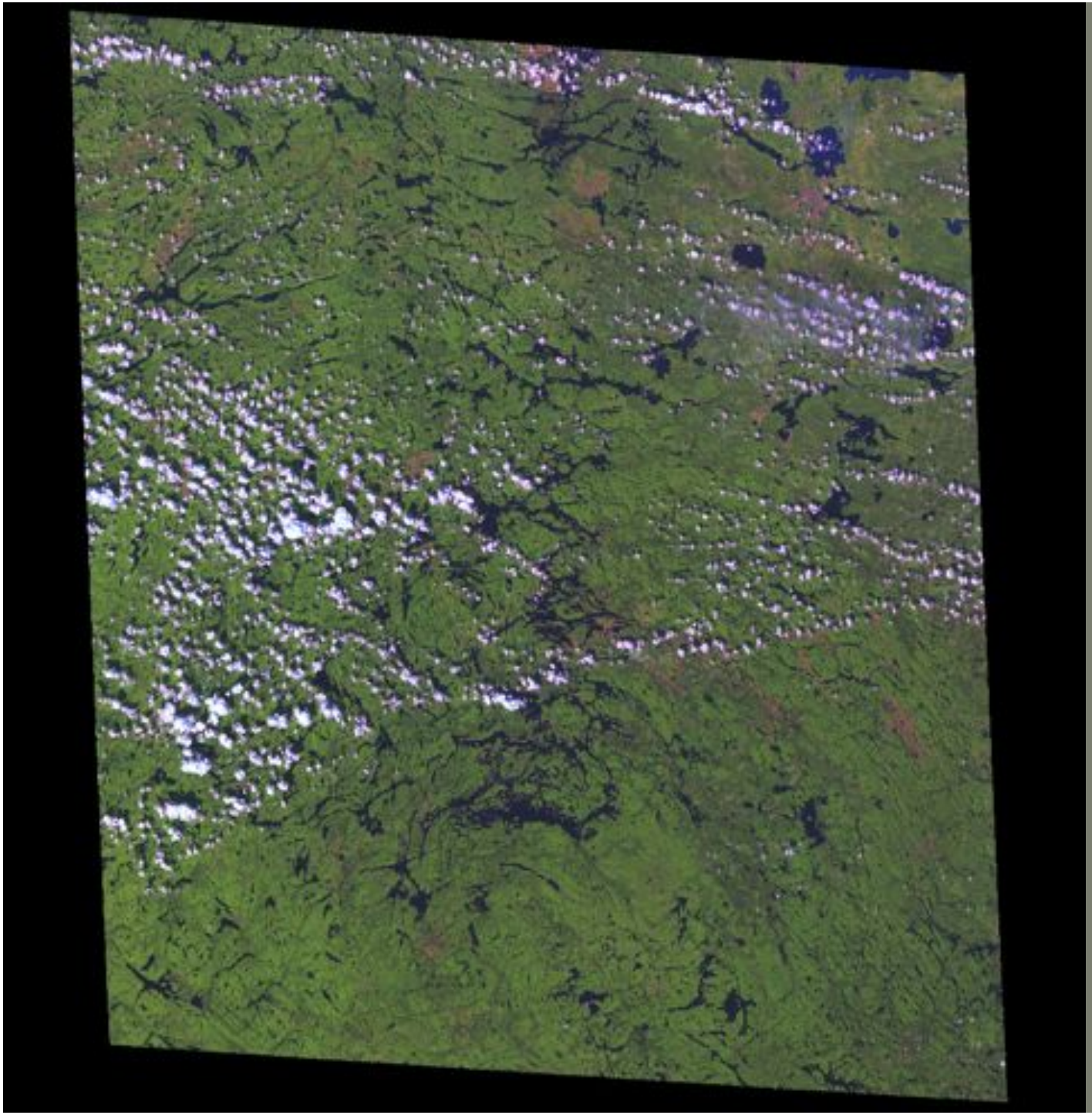

Source imagery

Quebec (P17R27)

1999/08/27
2000/06/26
2000/07/12
2000/08/13
2001/06/13
2001/07/31

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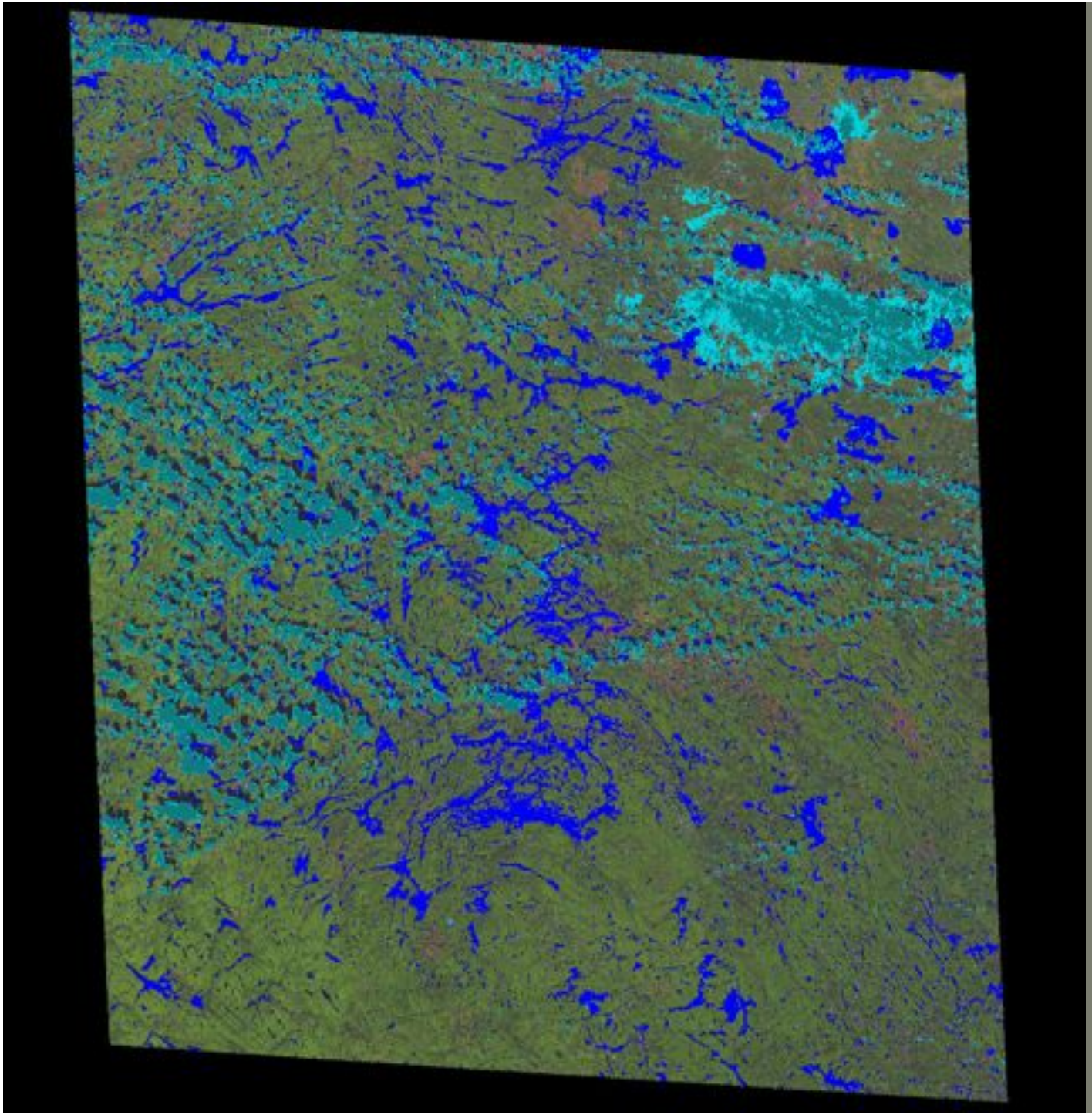

Quality assessment flags

Cloud likelihood

- 50-90%
- >90%

Shadow likelihood

- 50-90%
- >90%

Water likelihood

- >50%

1999/08/27
2000/06/26
2000/07/12
2000/08/13
2001/06/13
2001/07/31

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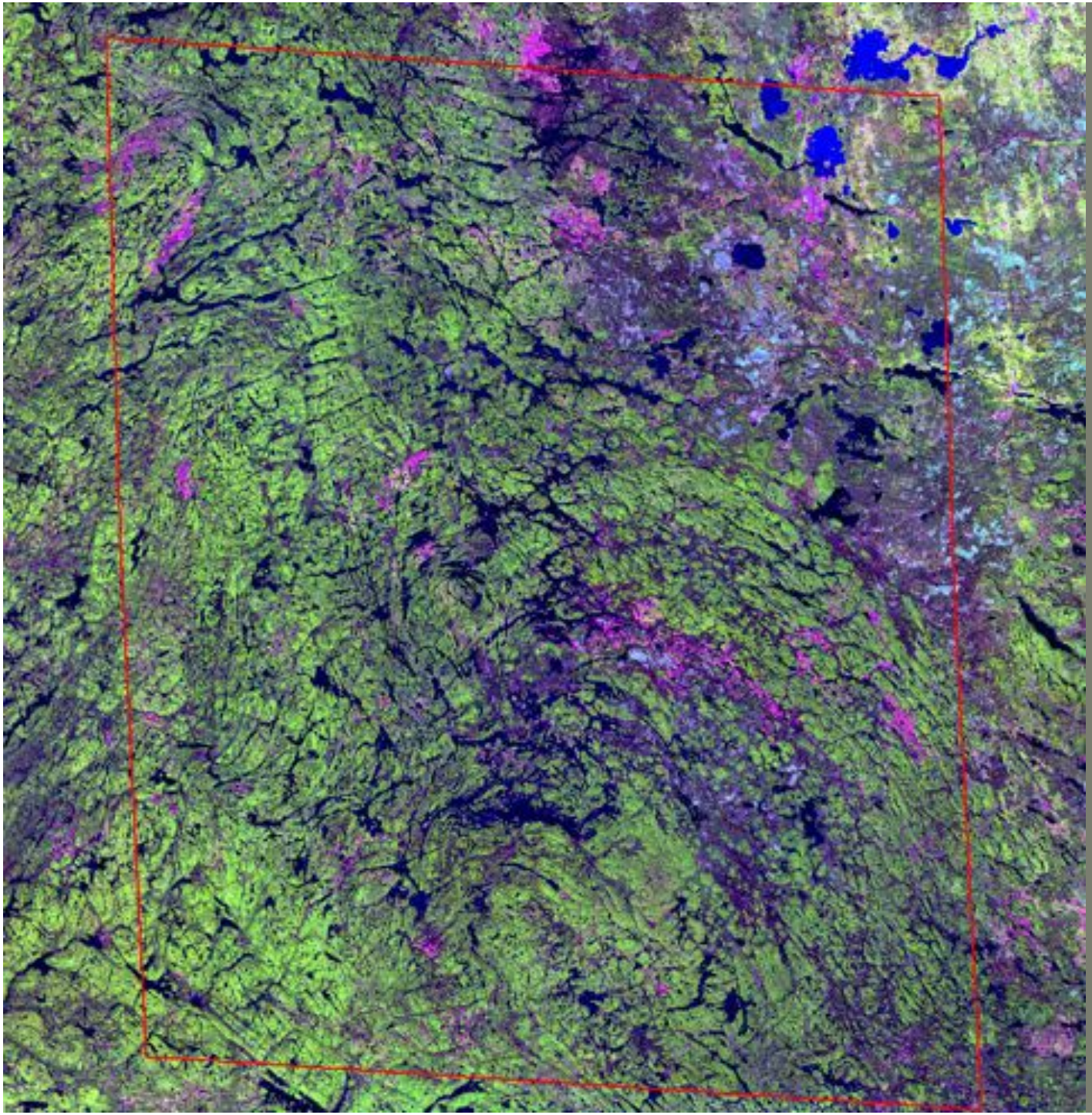

Composite image
for circa year 2000

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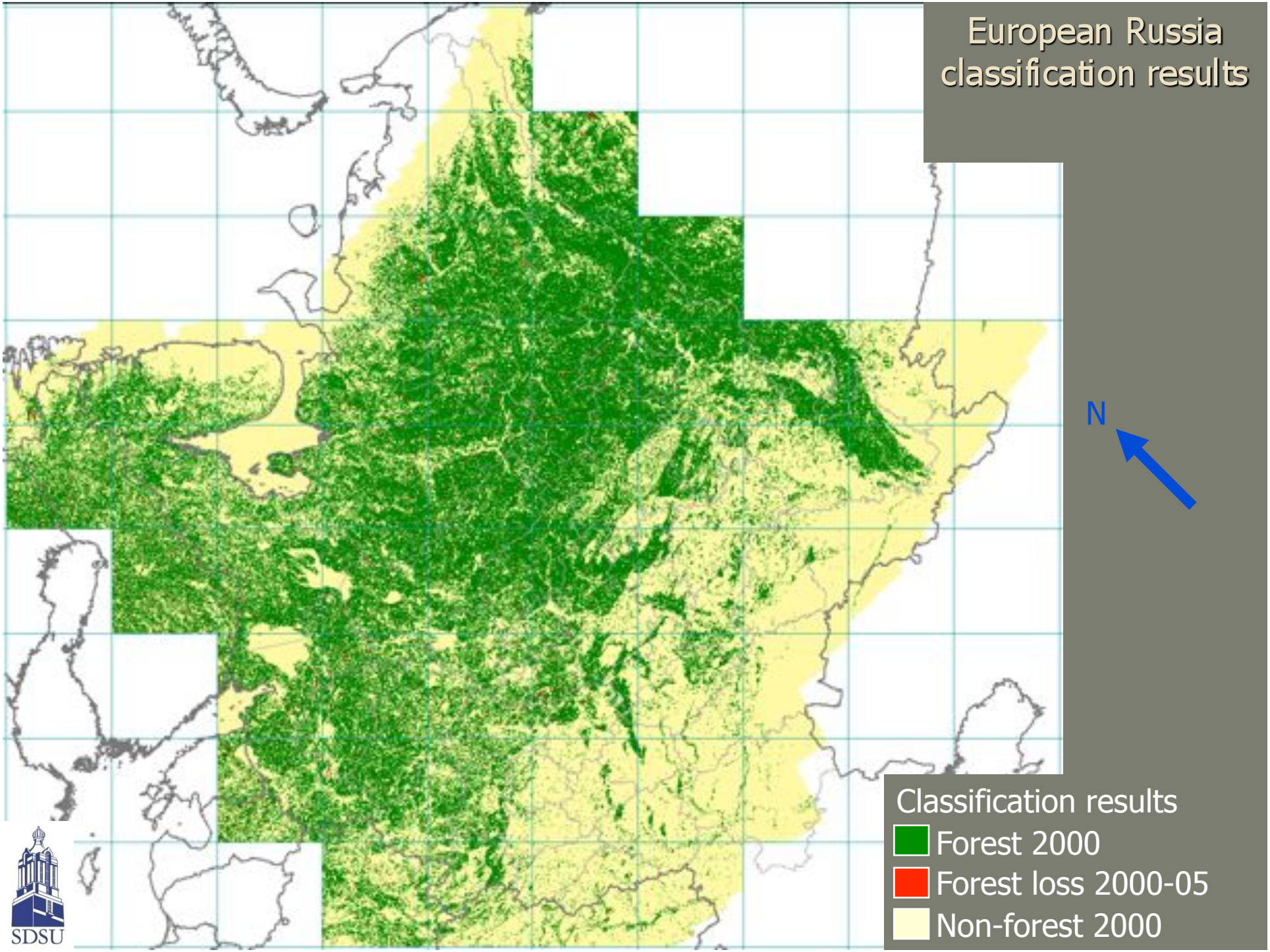
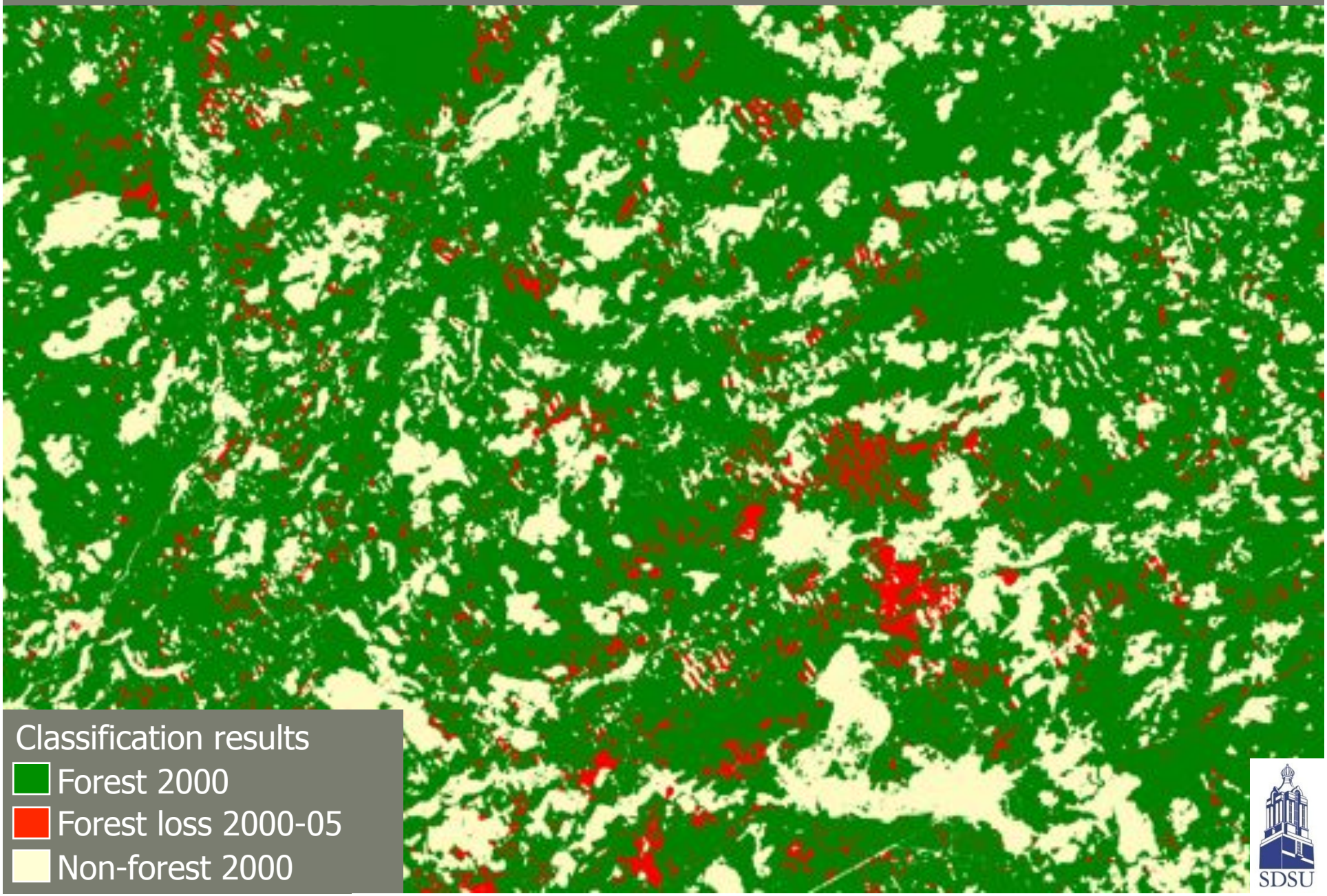

European Russia
classification results
N
Classification results
Forest 2000
Forest loss 2000-05
Non-forest 2000
SDSU

European Russia: Classification examples



European Russia

Selected 42 administrative regions

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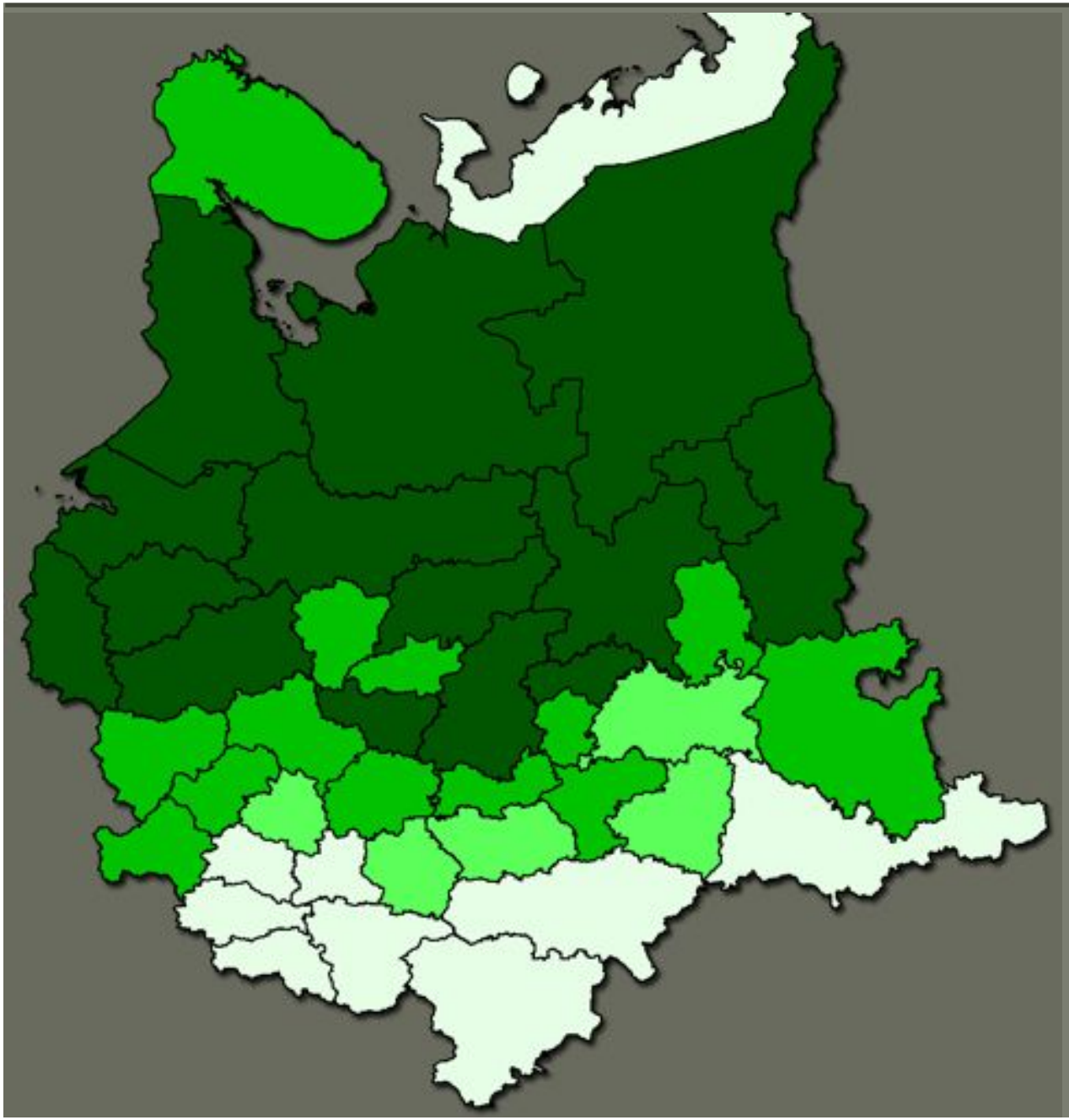
European Russia



Forest cover
(% of regions' area)

- <10%
- 10-25%
- 25-50%
- >50%

Total forest cover:

Landsat derived:
150,228 thousand ha

Russian Forest Service:
148,852 thousand ha

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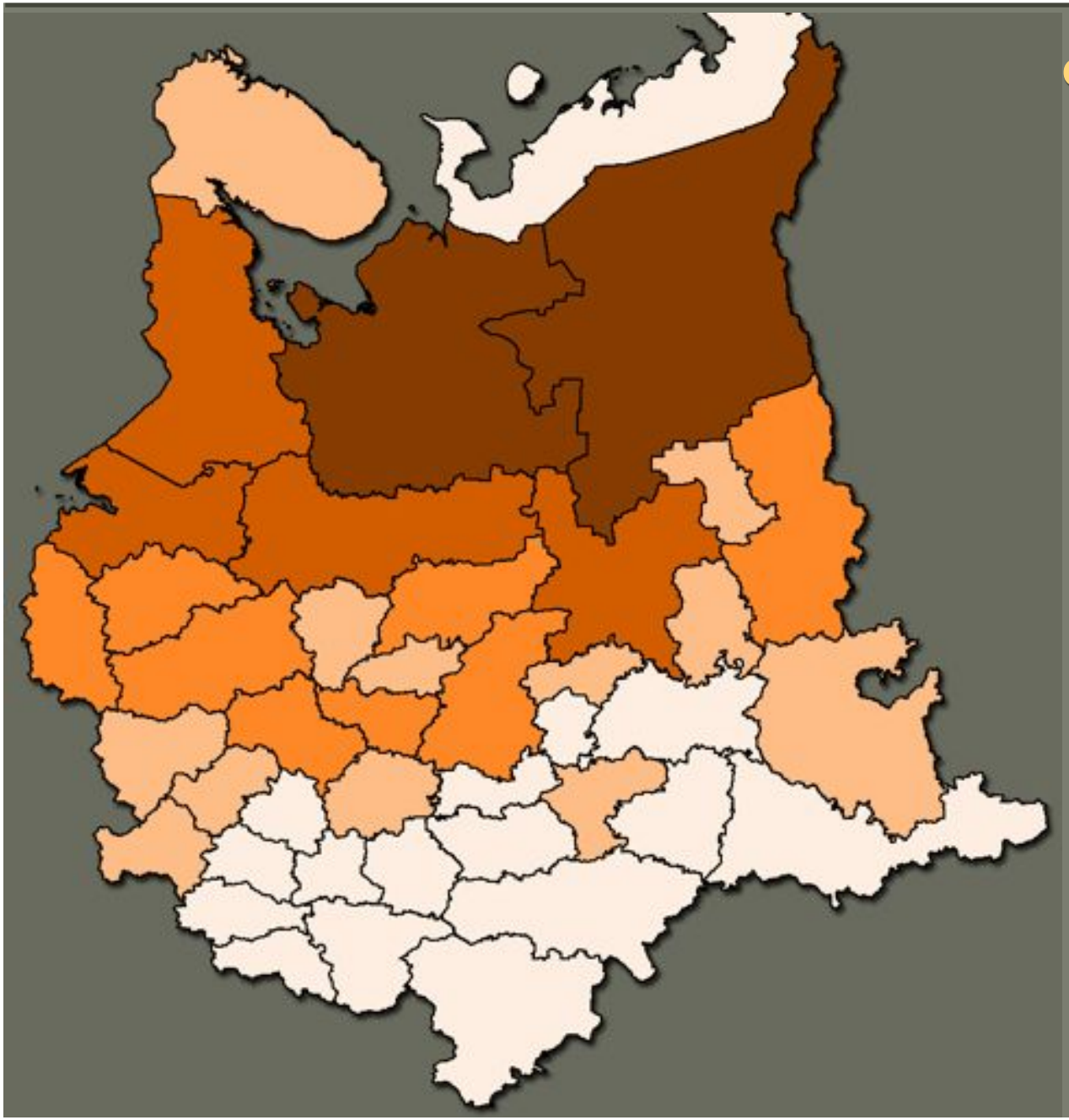
European Russia



Gross forest cover loss (% of total)

- <0.5%
- 0.5-2%
- 2-5%
- 5-10%
- 10-15%

Total gross forest cover loss:

2,210 thousand ha

1.5% of year 2000 forest cover

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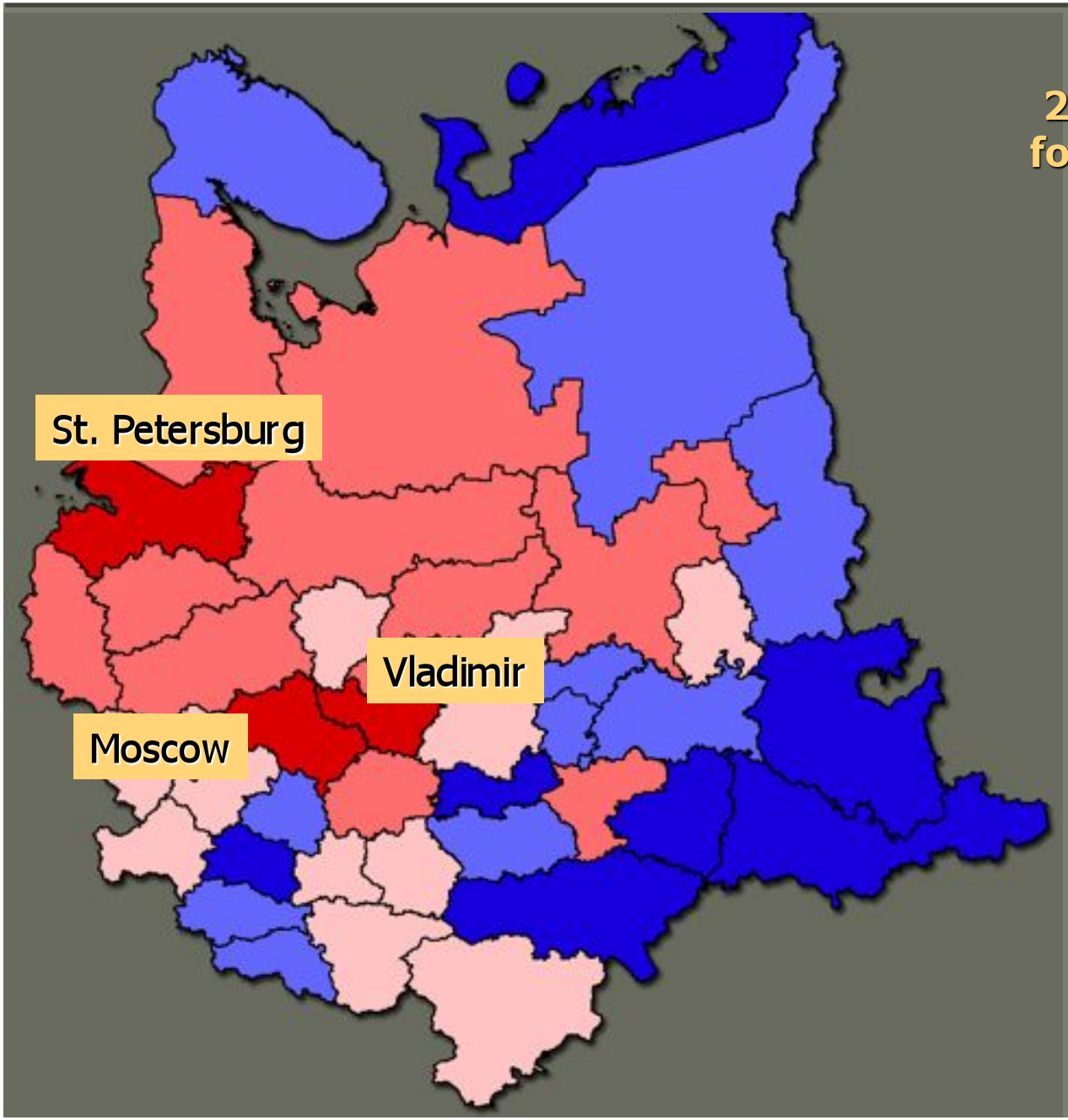
European Russia



Forest cover loss 2000-2005 as percent of forest cover for year 2000

- <0.5%
- 0.5-1%
- 1-1.5%
- 1.5-2.5%
- >2.5%

Regions with the highest forest cover loss:

Vladimir (3.7%)
St. Petersburg (3.5%)
Moscow (3.1%)

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European Russia

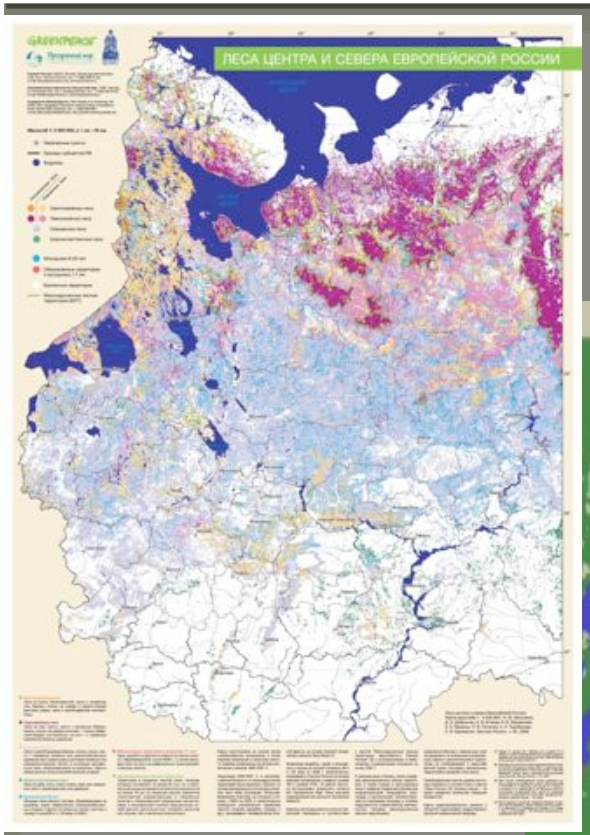
Extensive forest and peat bog fires (fall 2002)

MODIS image 07/30/2002
www.ssec.wisc.edu

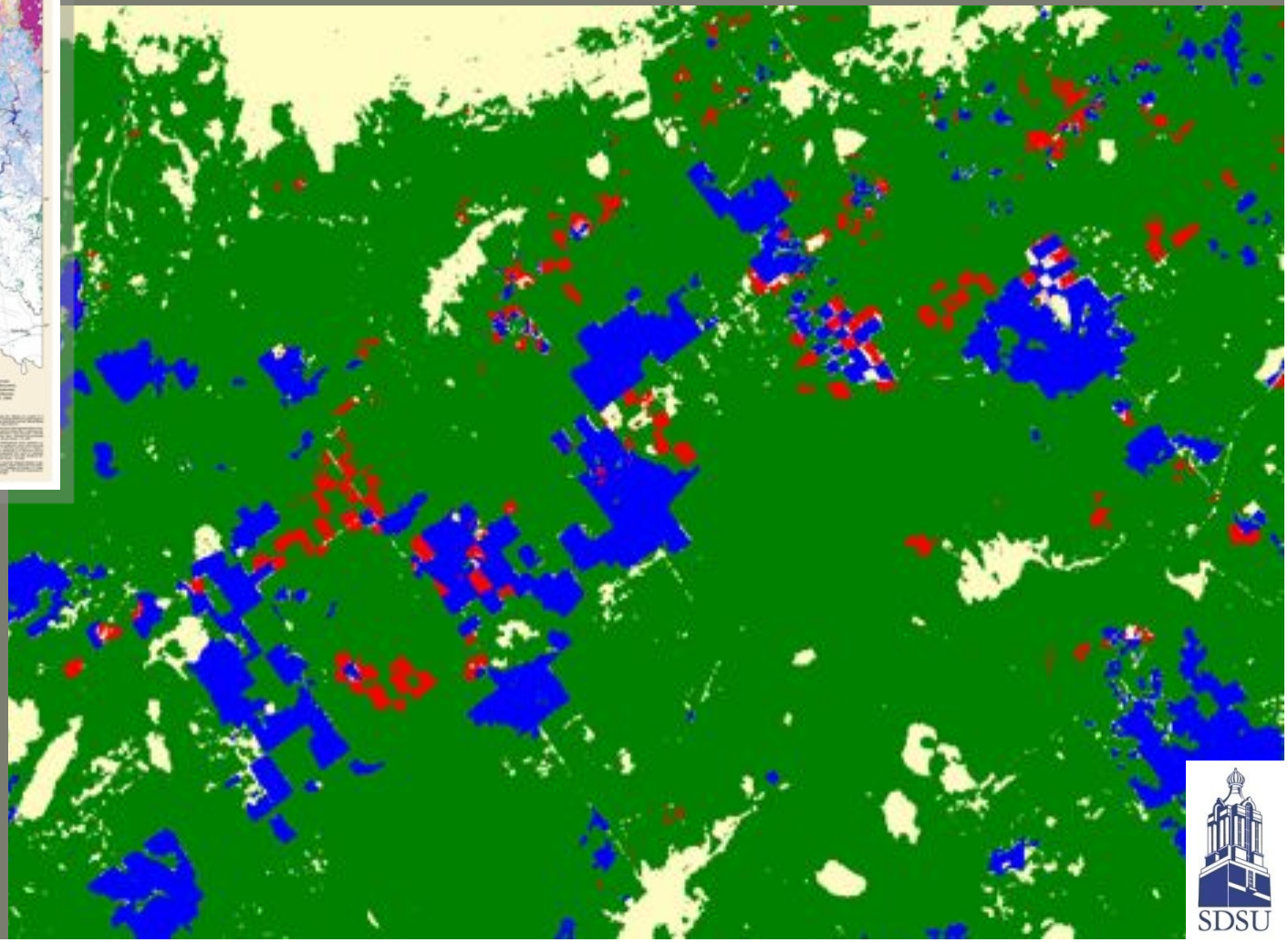
European Russia

Moscow suburbs expansion (partly illegal construction on forest lands)

European Russia



Yaroshenko et al. (2008)
European Russia's Forests (poster map and GIS dataset).
Moscow, Greenpeace.



- Forest 2005
- Gross forest loss 1990-2000
- Gross forest loss 2000-2005

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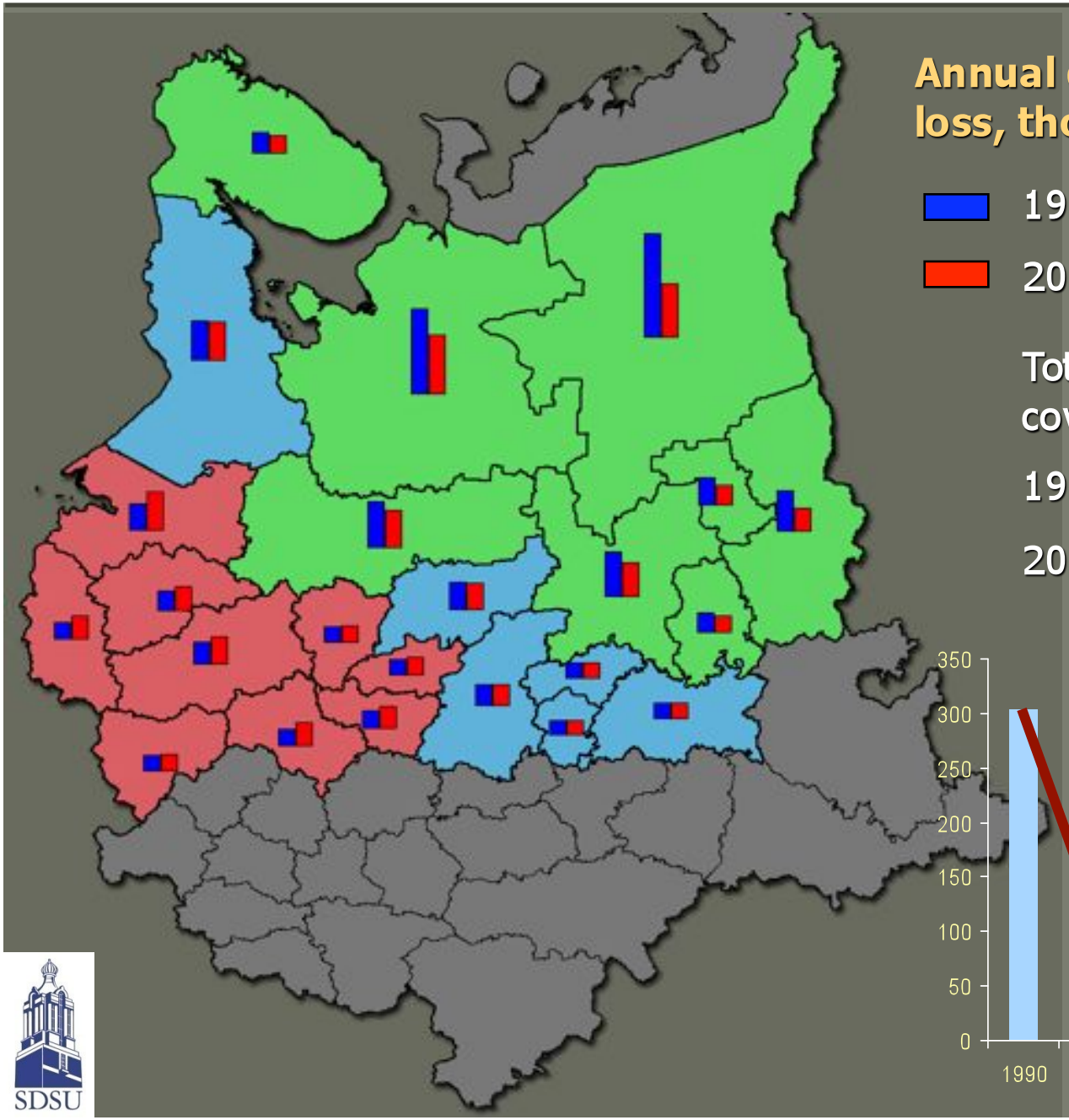
European Russia



Annual gross forest cover loss, thousand ha

1990-2000

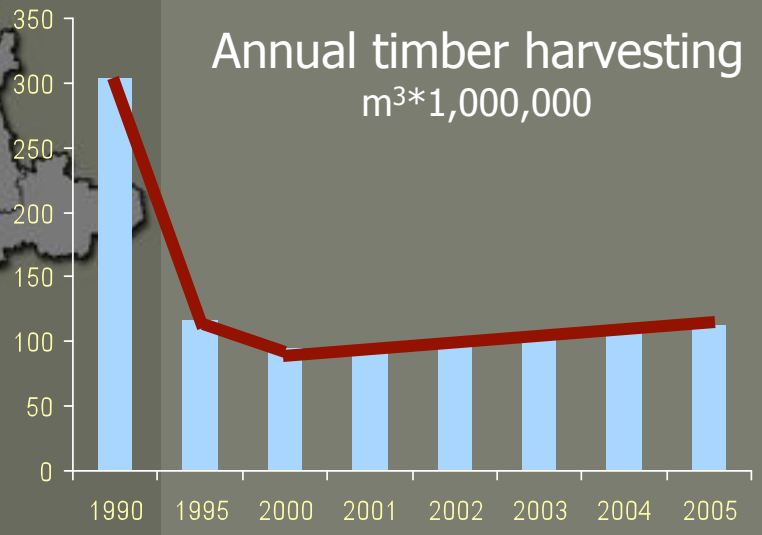
2000-2005

100 ha*1000

Total annual gross forest cover loss:

1990-2000: **530** ha*1000

2000-2005: **406** ha*1000



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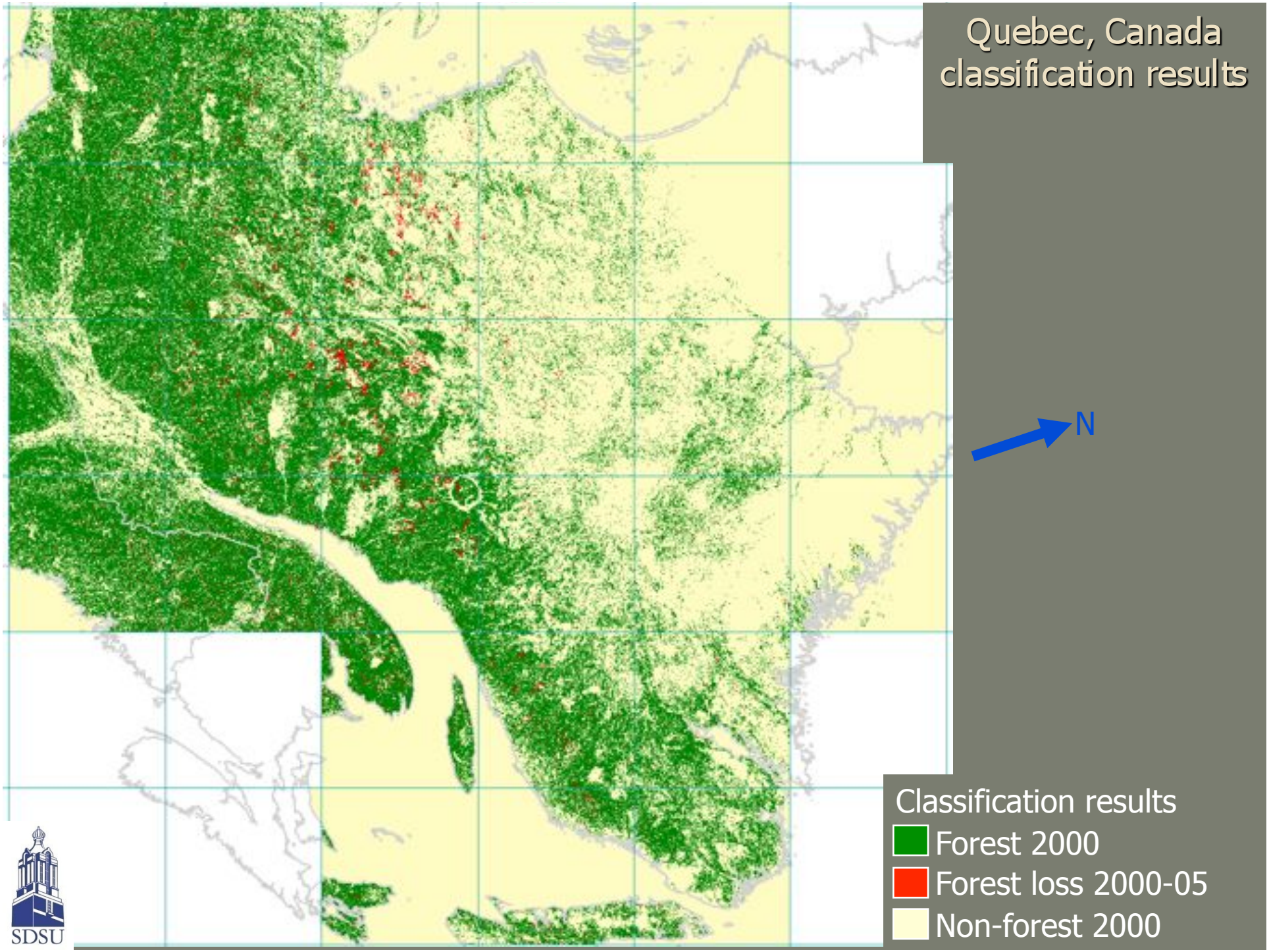
Quebec, Canada classification results



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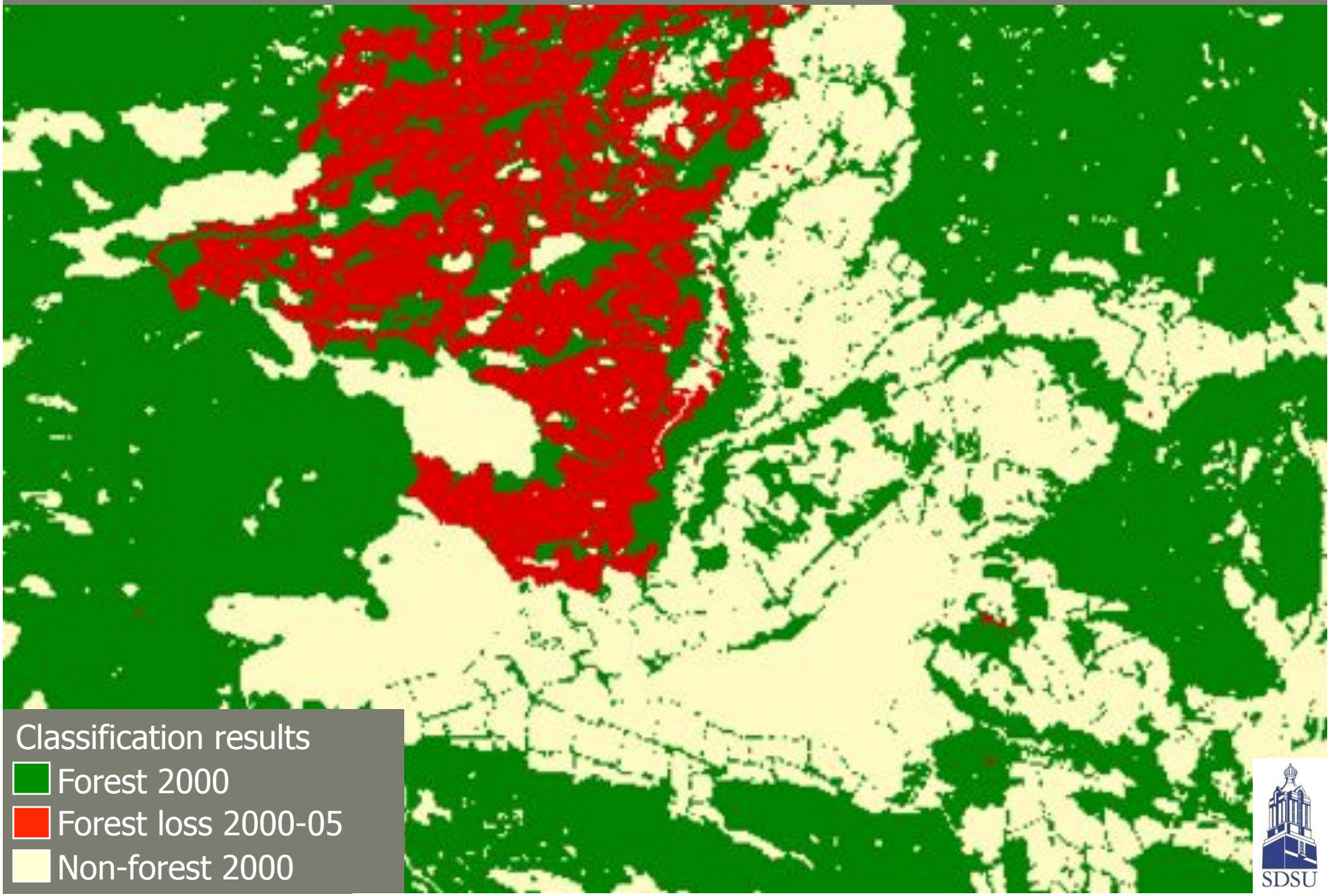
Quebec, Canada: Classification examples



Monitoring at national scales in the tropics – different situations

- Brazil
  - Large-scale change, most of which is located in seasonally cloud-free region, deforestation
- Indonesia
  - Large-scale change, occurring in persistently cloud-affected region, much topography, active forestry
- Democratic Republic of Congo
  - Fine-scale change, occurring in persistently cloud-affected region

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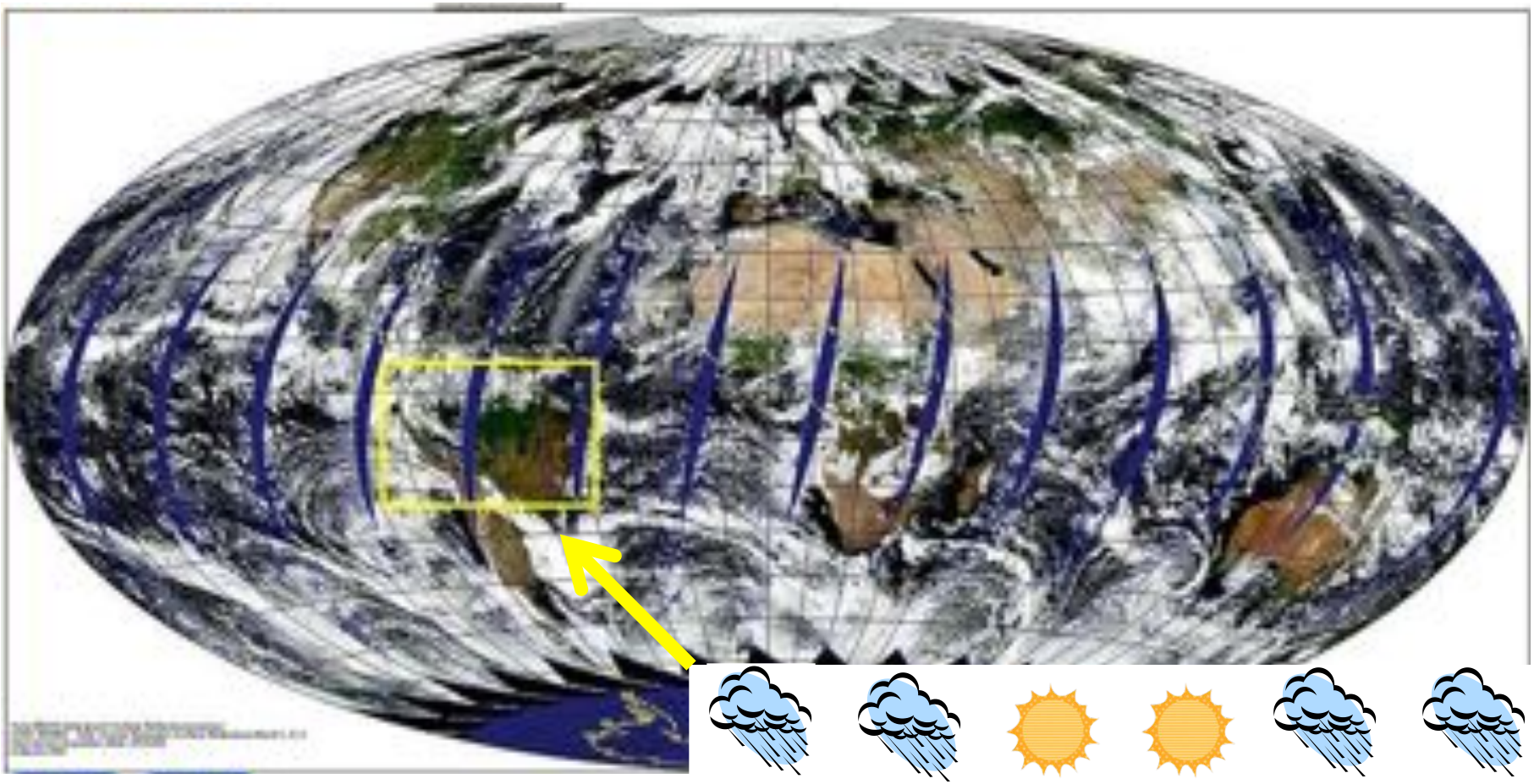
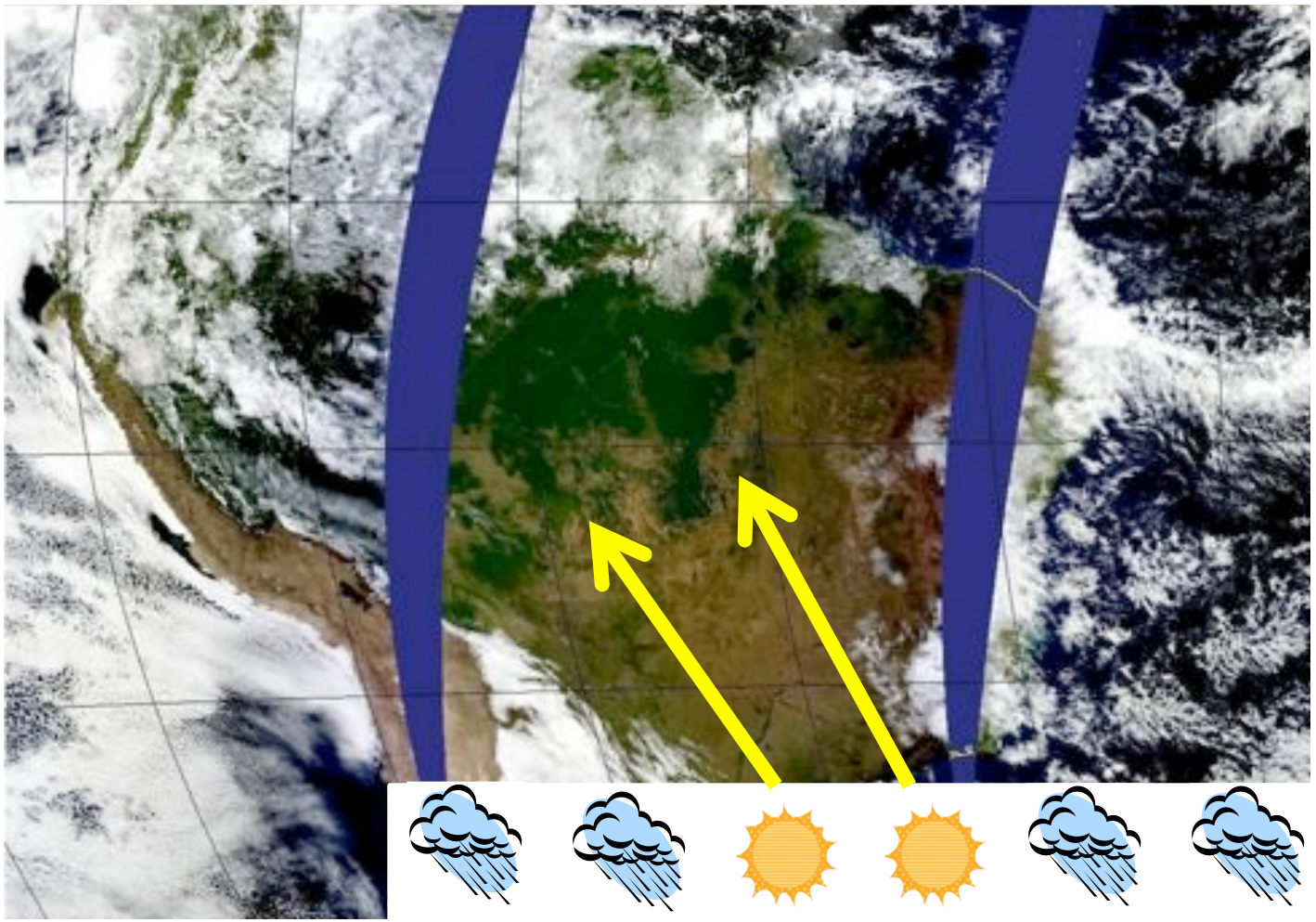
Humid tropical cloud cover

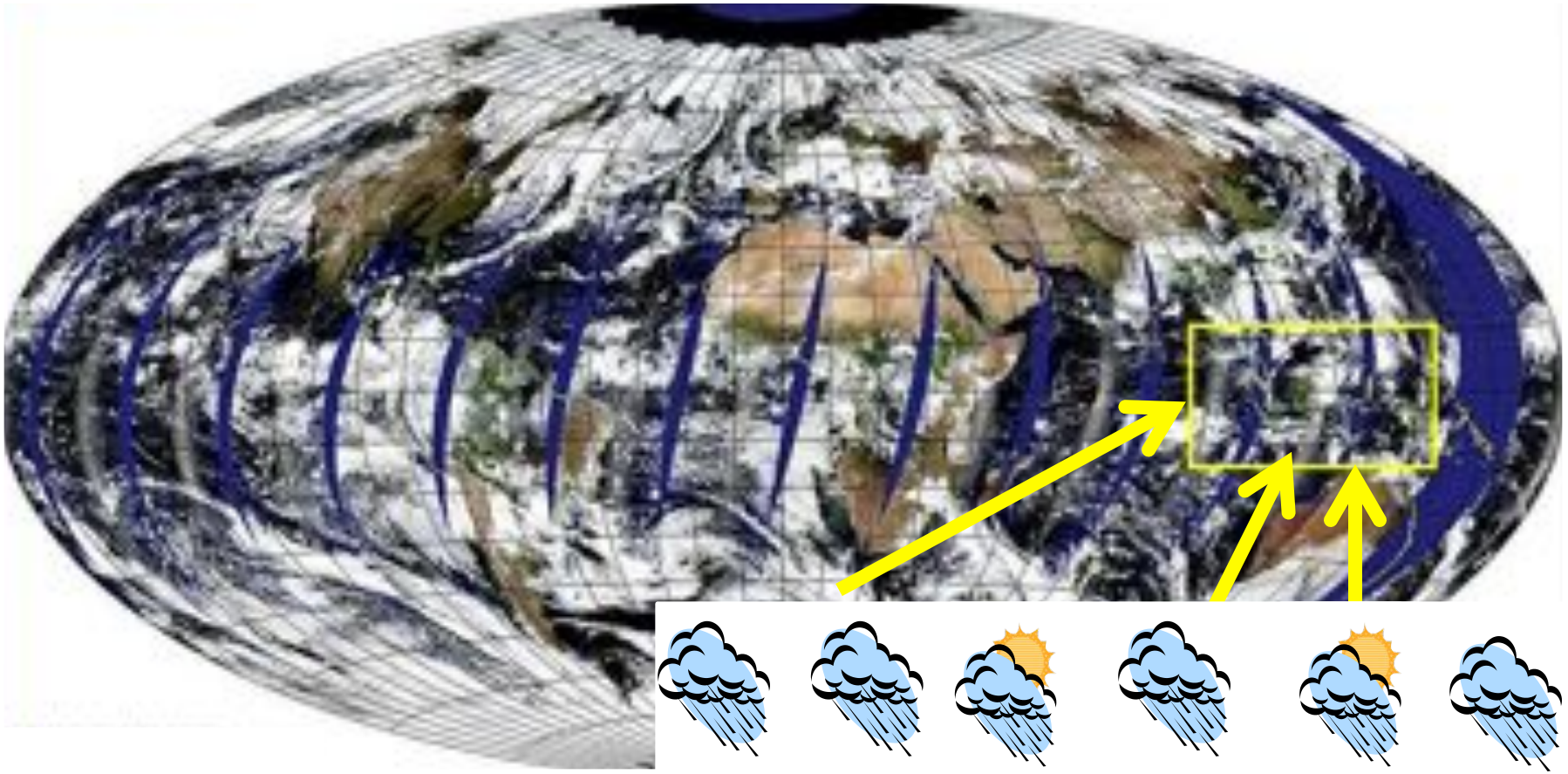
for one day of MODIS data



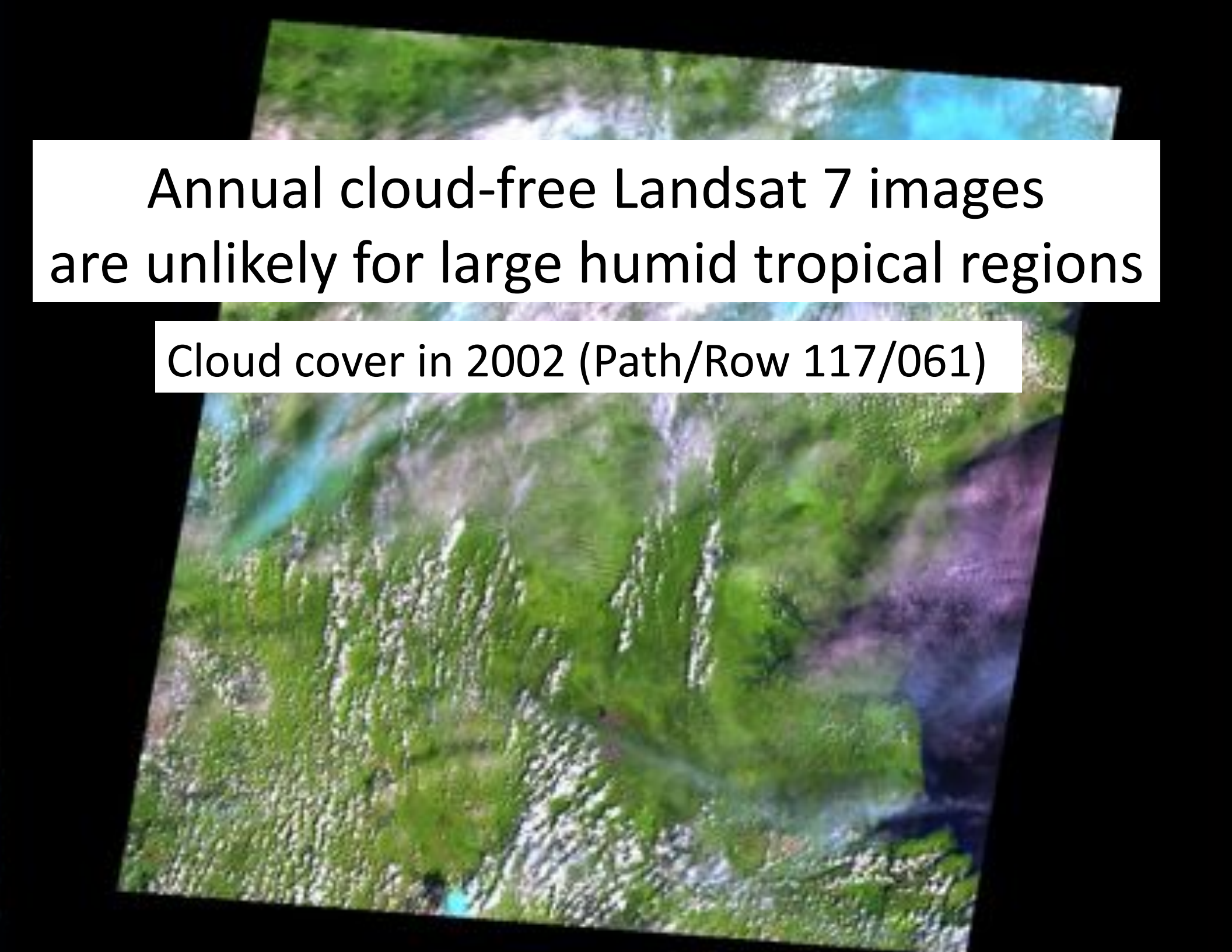
Seasonally cloud-free window over the southern Amazon



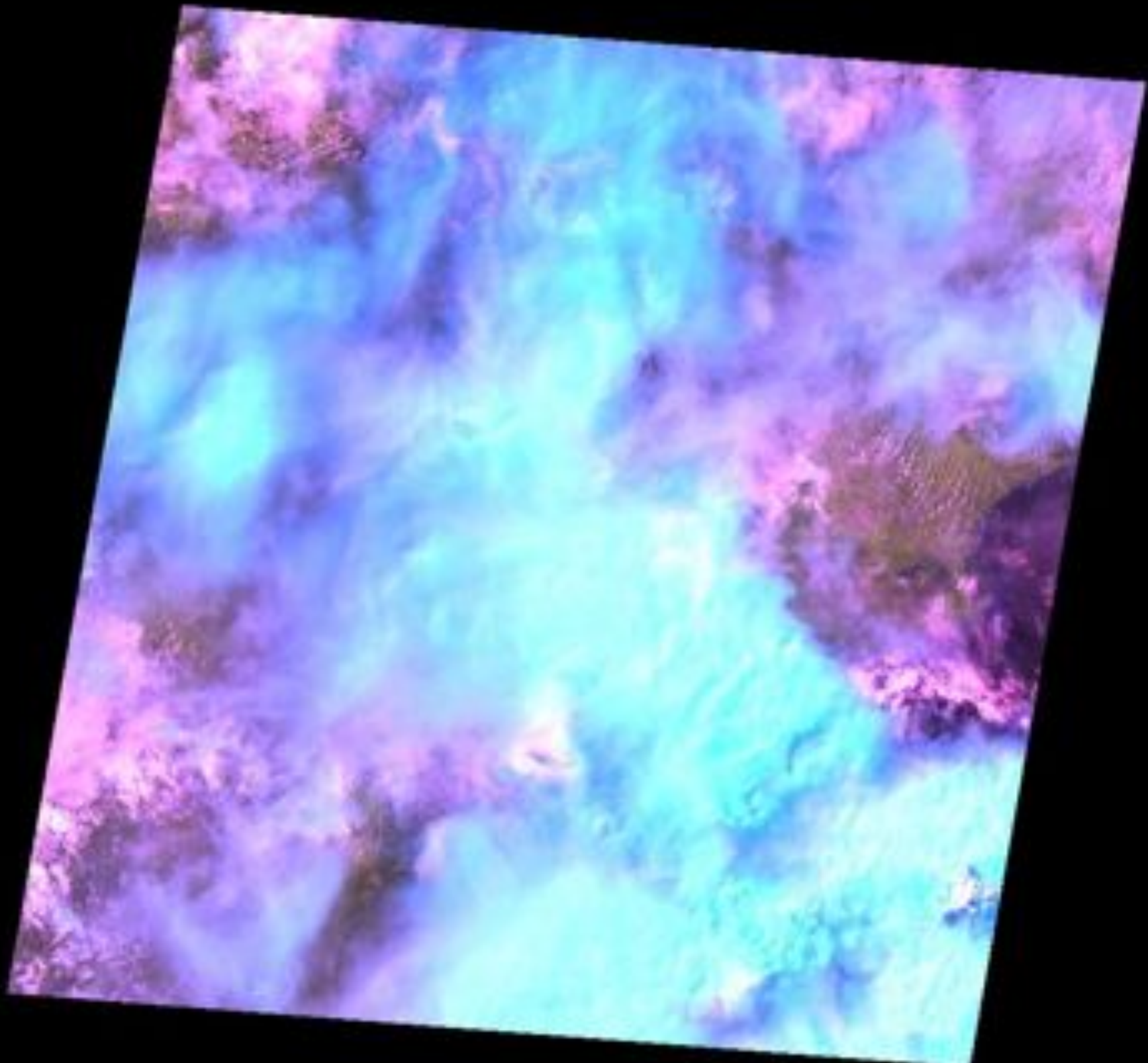
Conversely, Indonesia is persistently cloudy

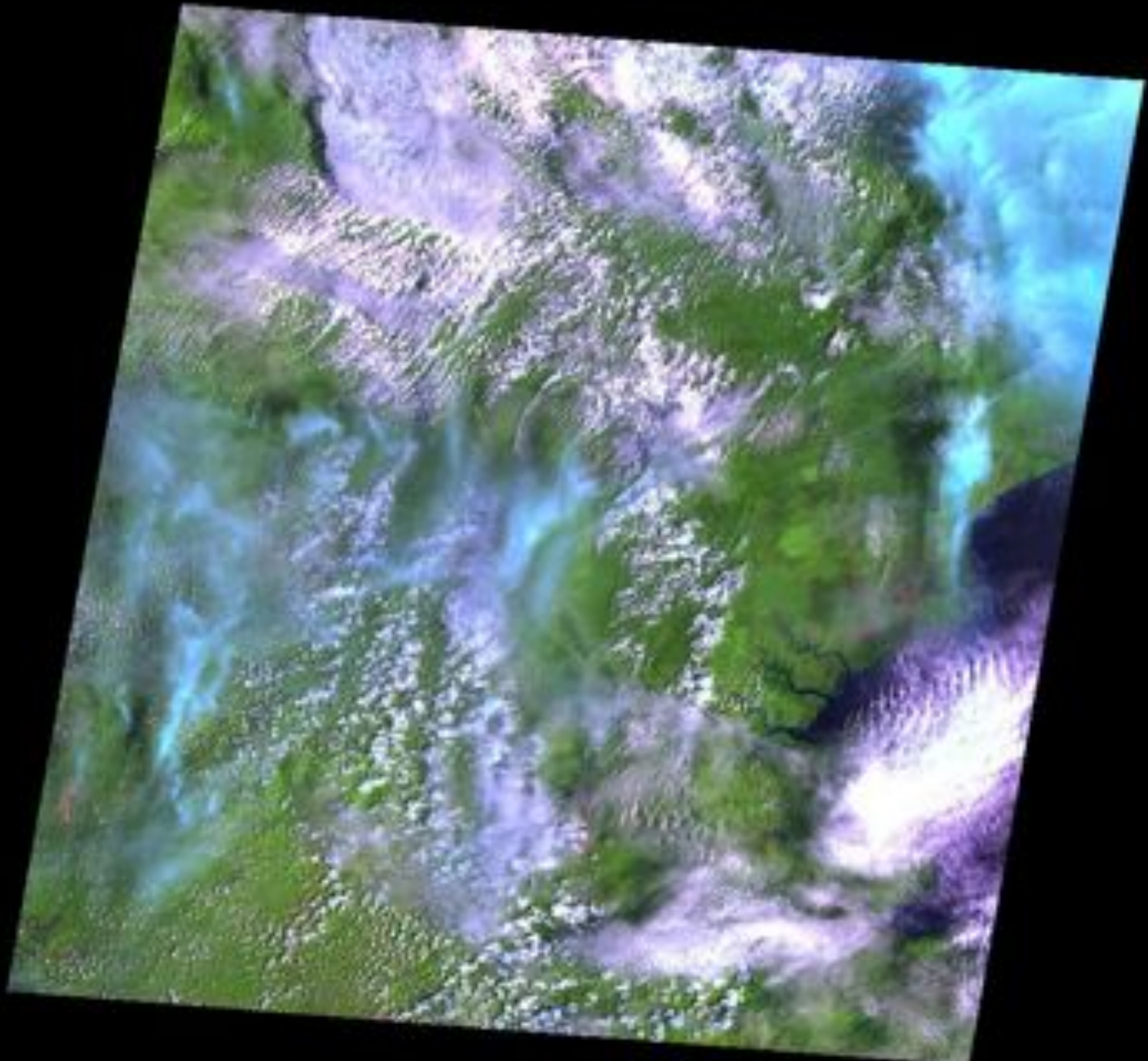


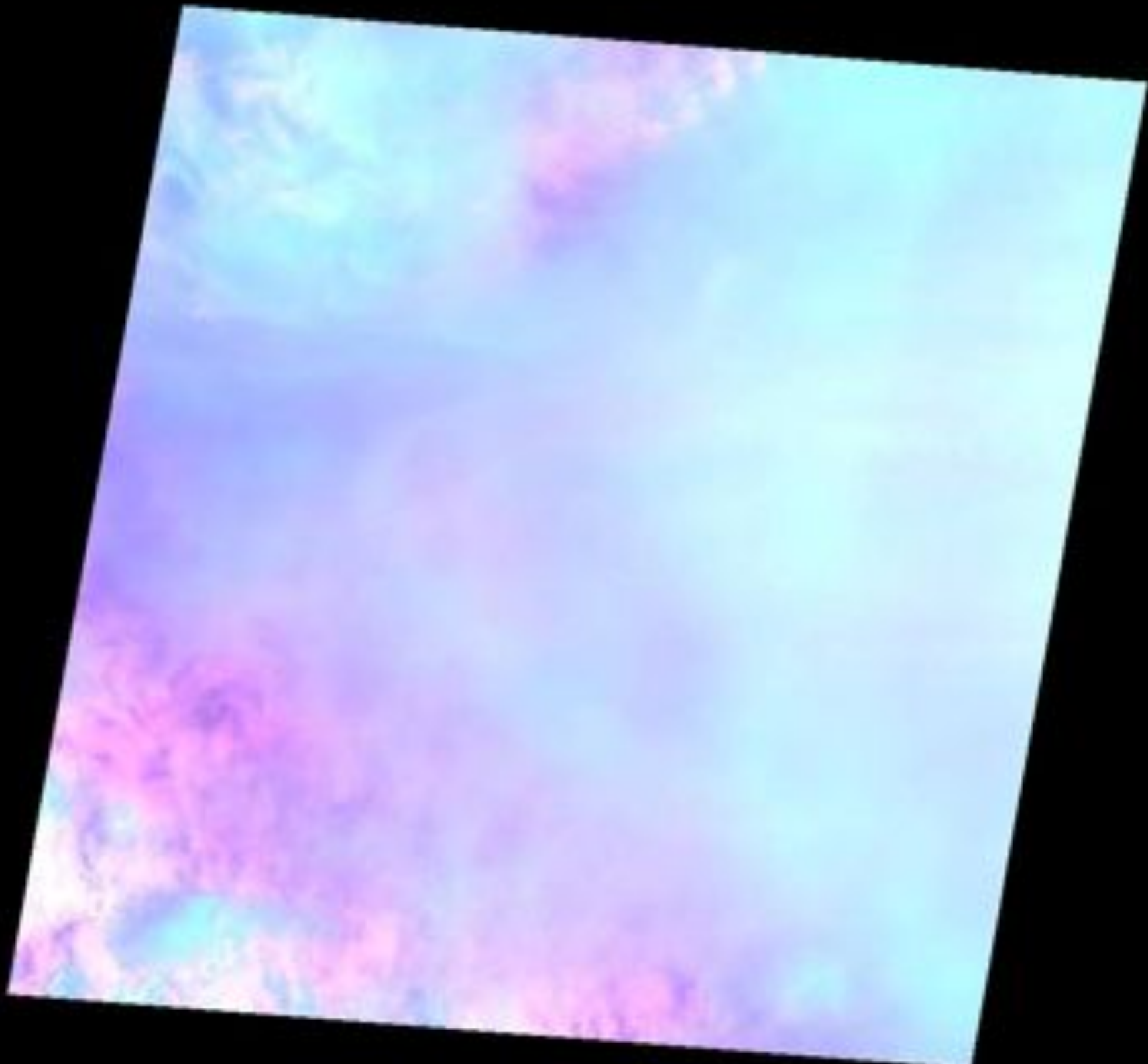
Annual cloud-free Landsat 7 images are unlikely for large humid tropical regions

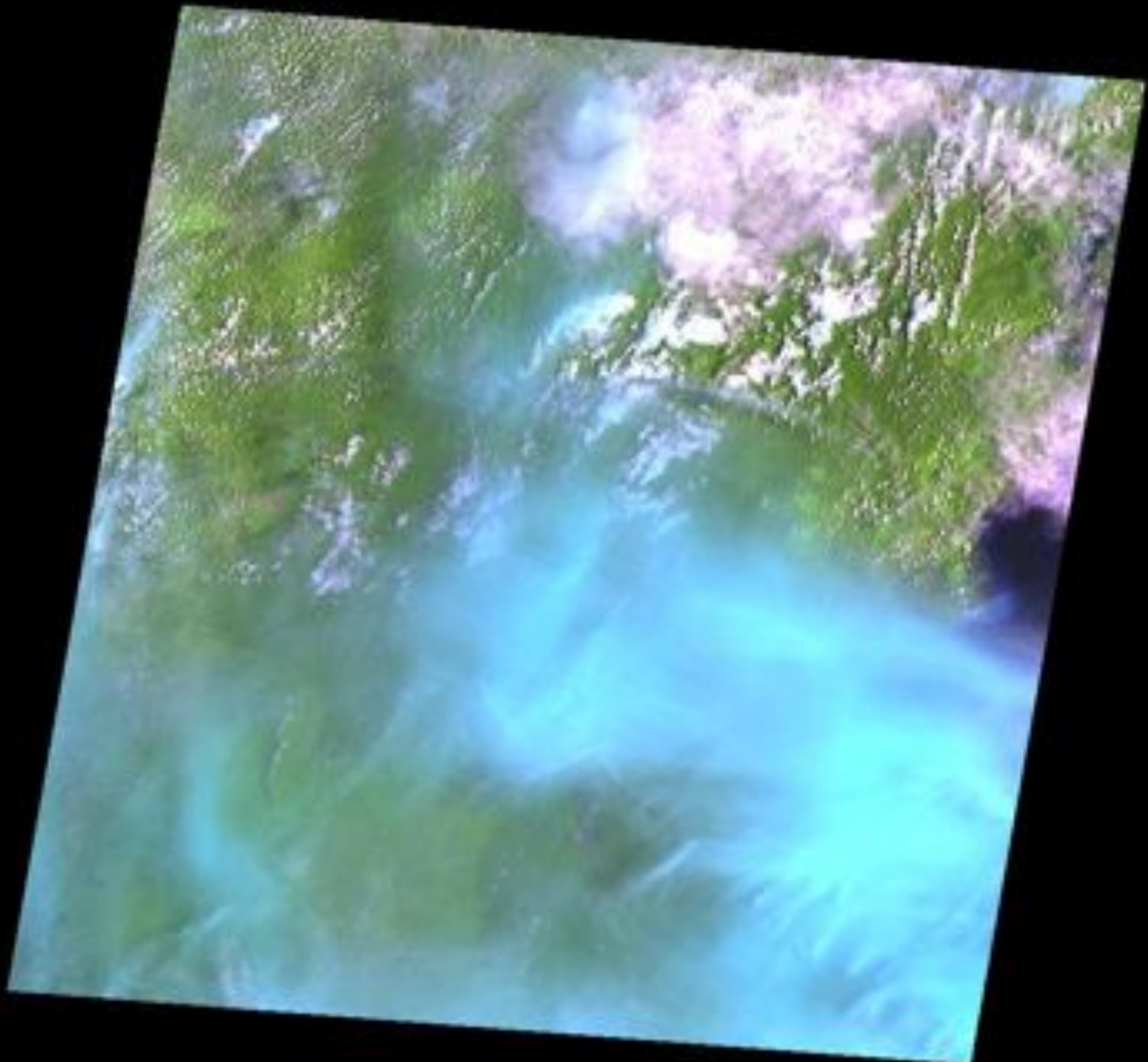


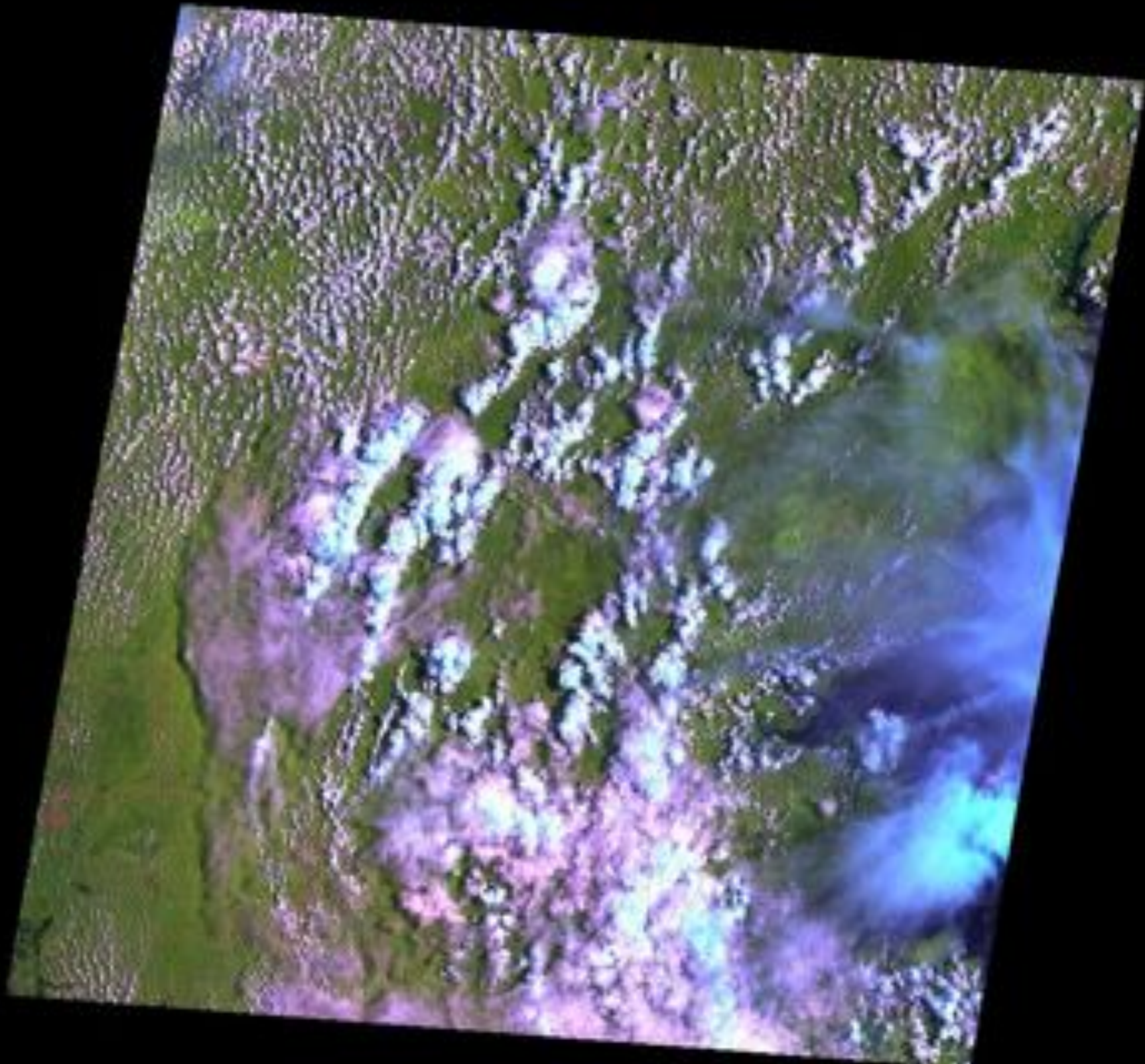
Cloud cover in 2002 (Path/Row 117/061)

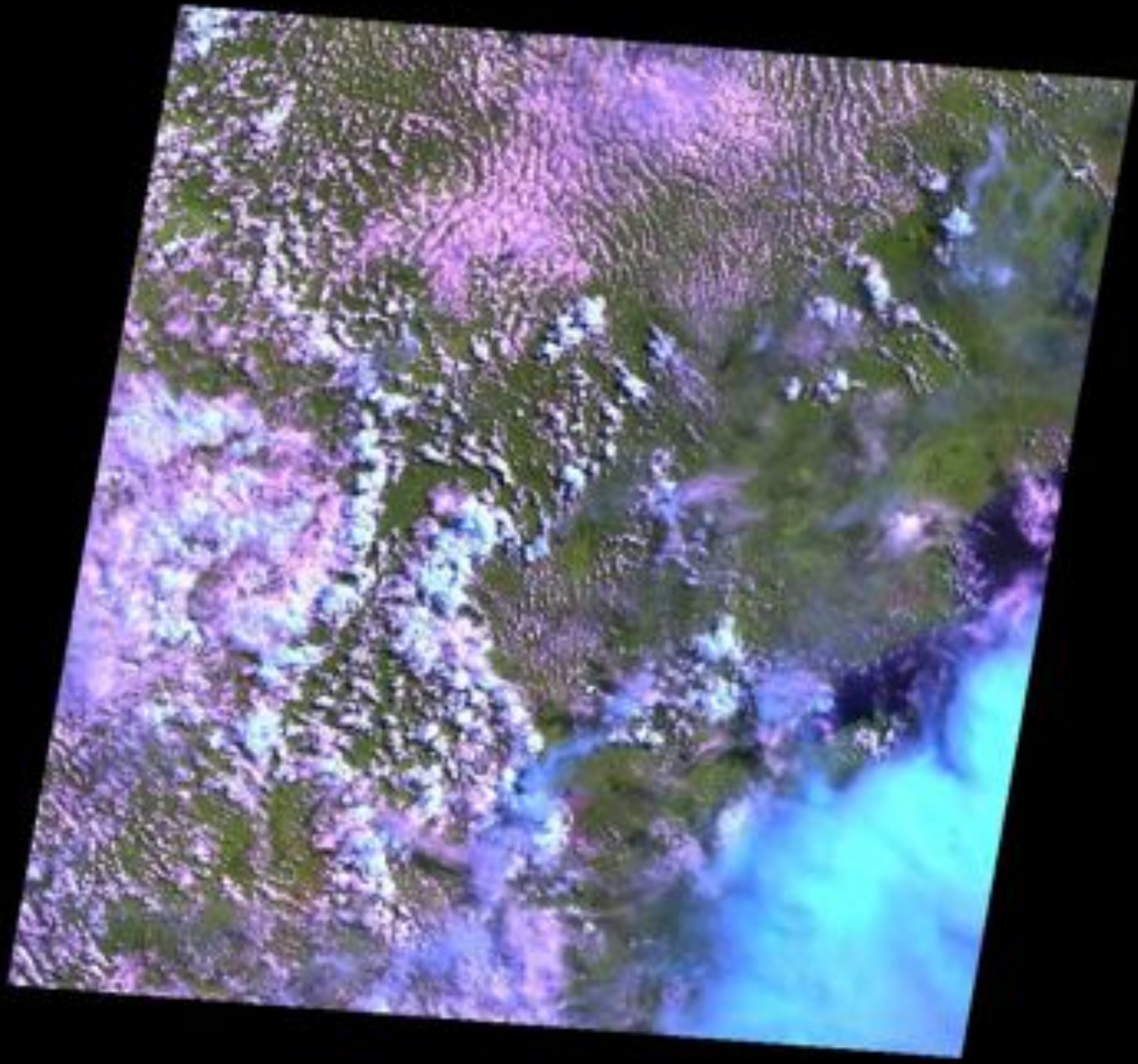


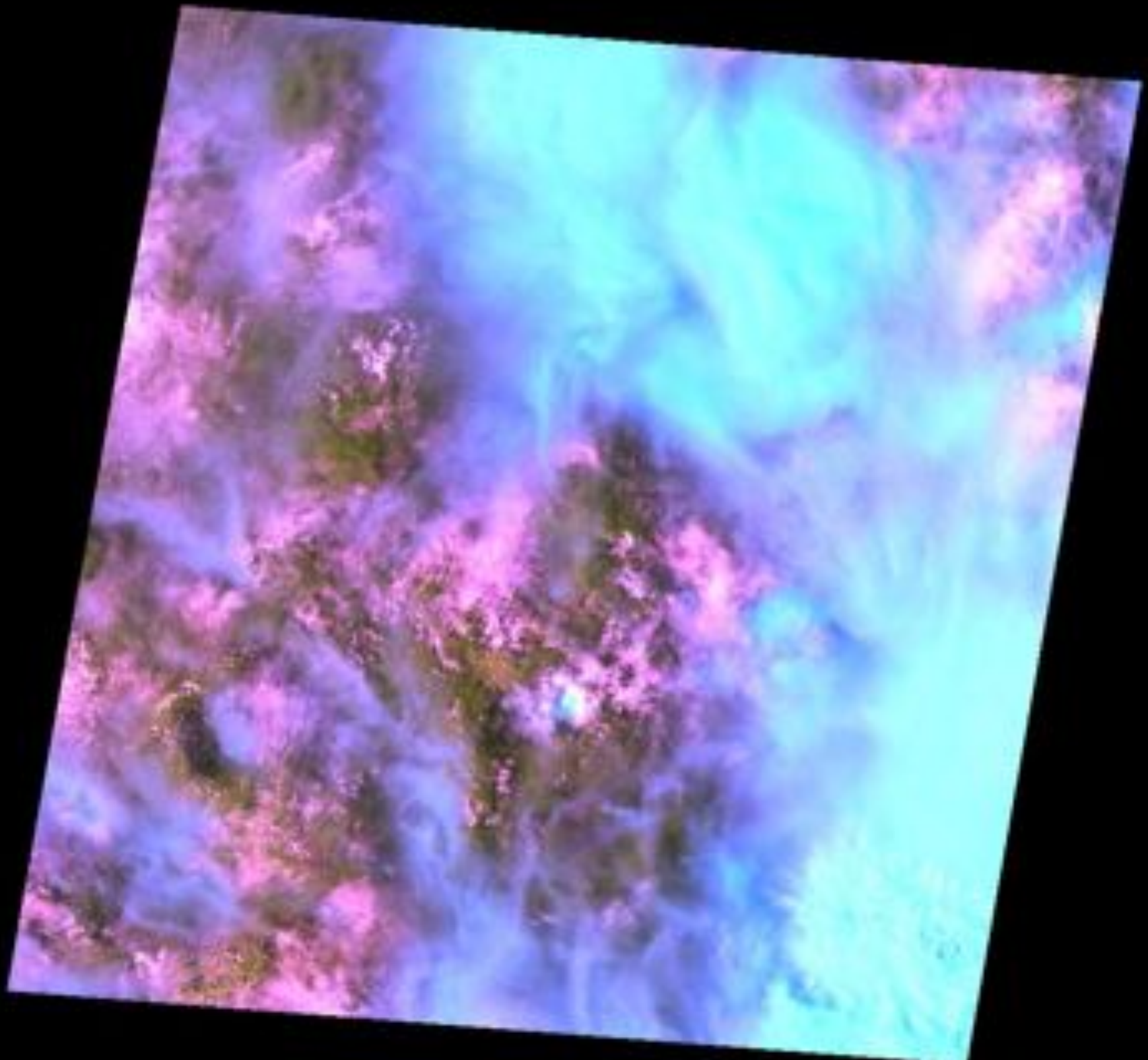


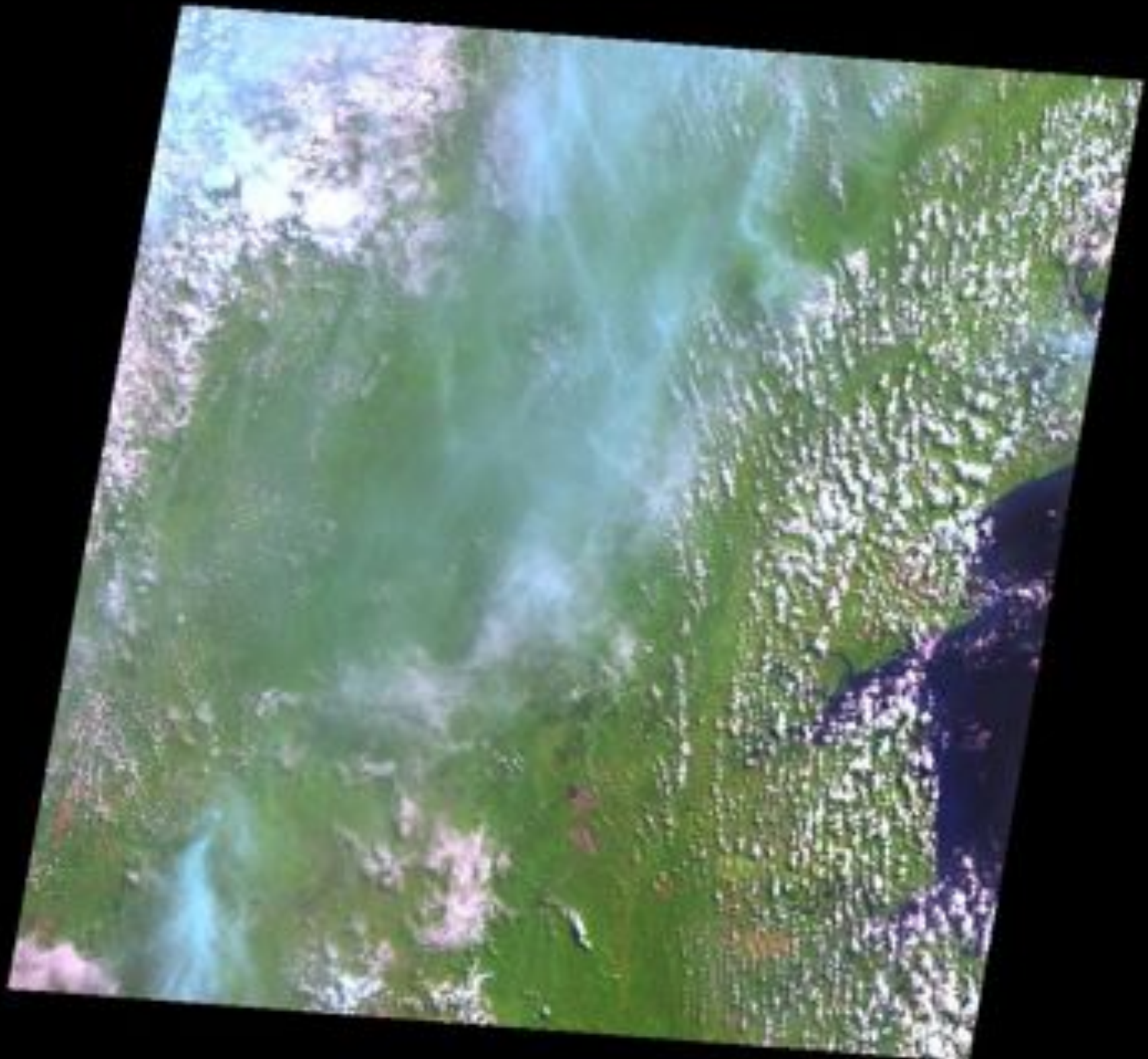


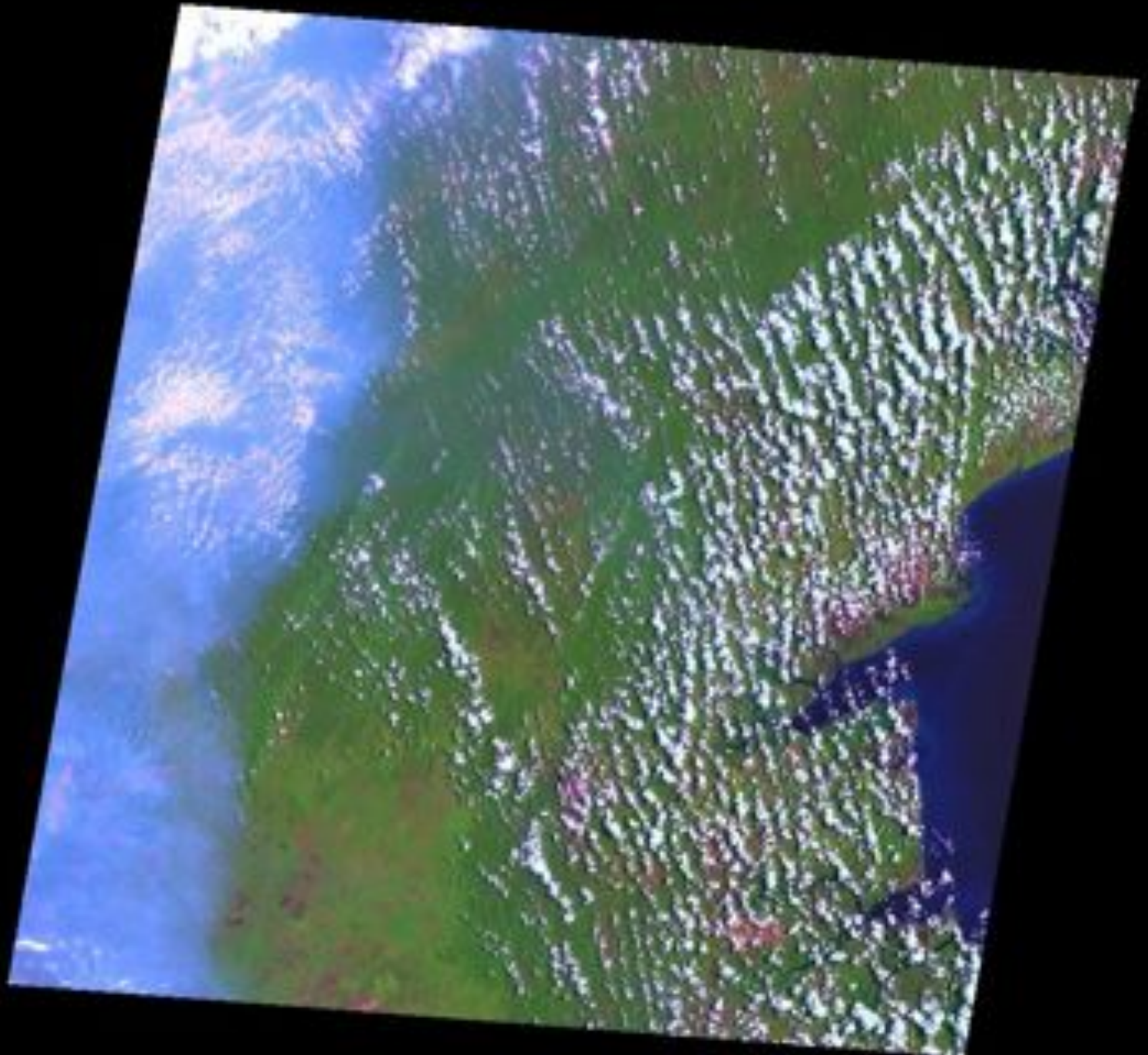


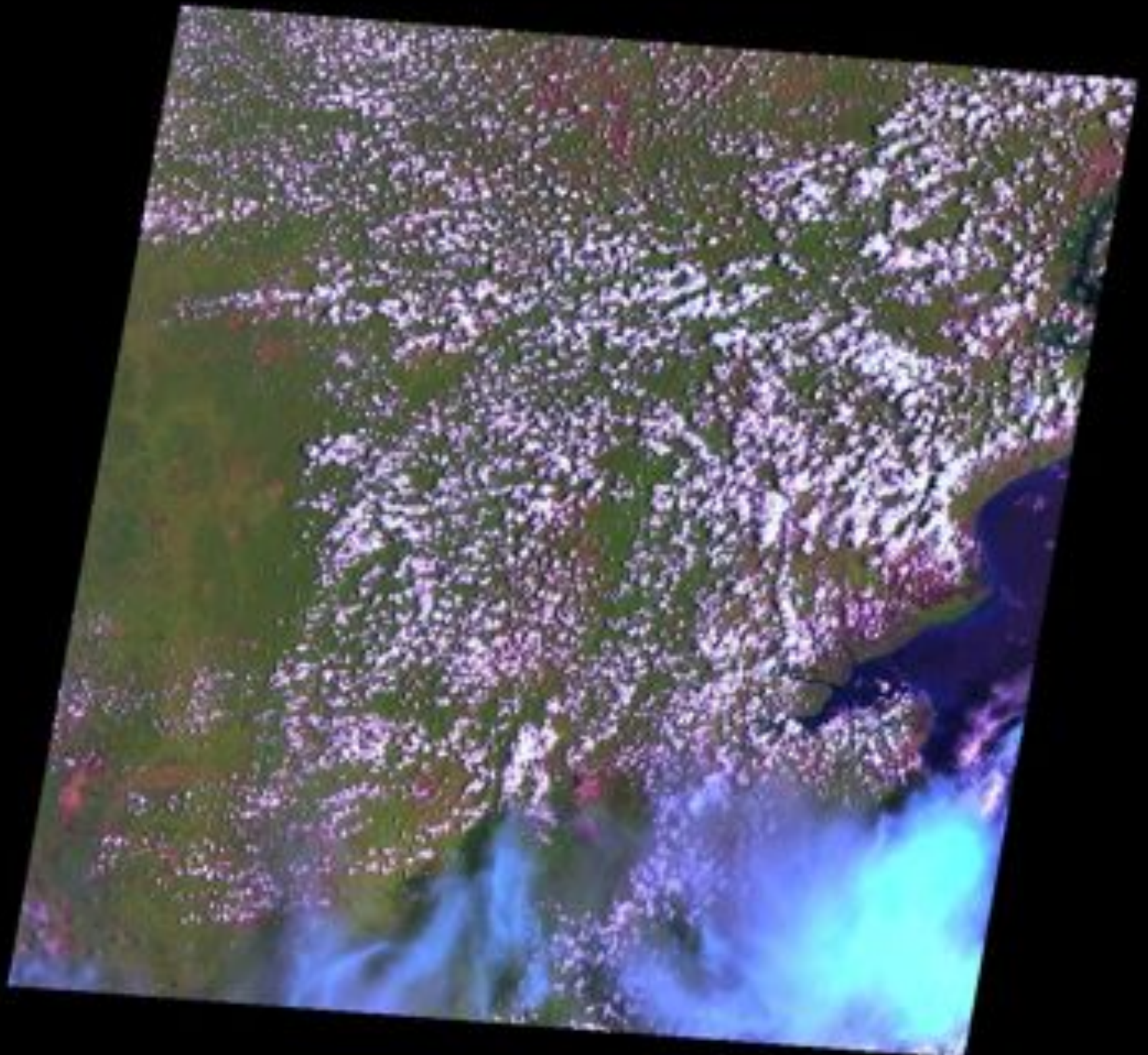


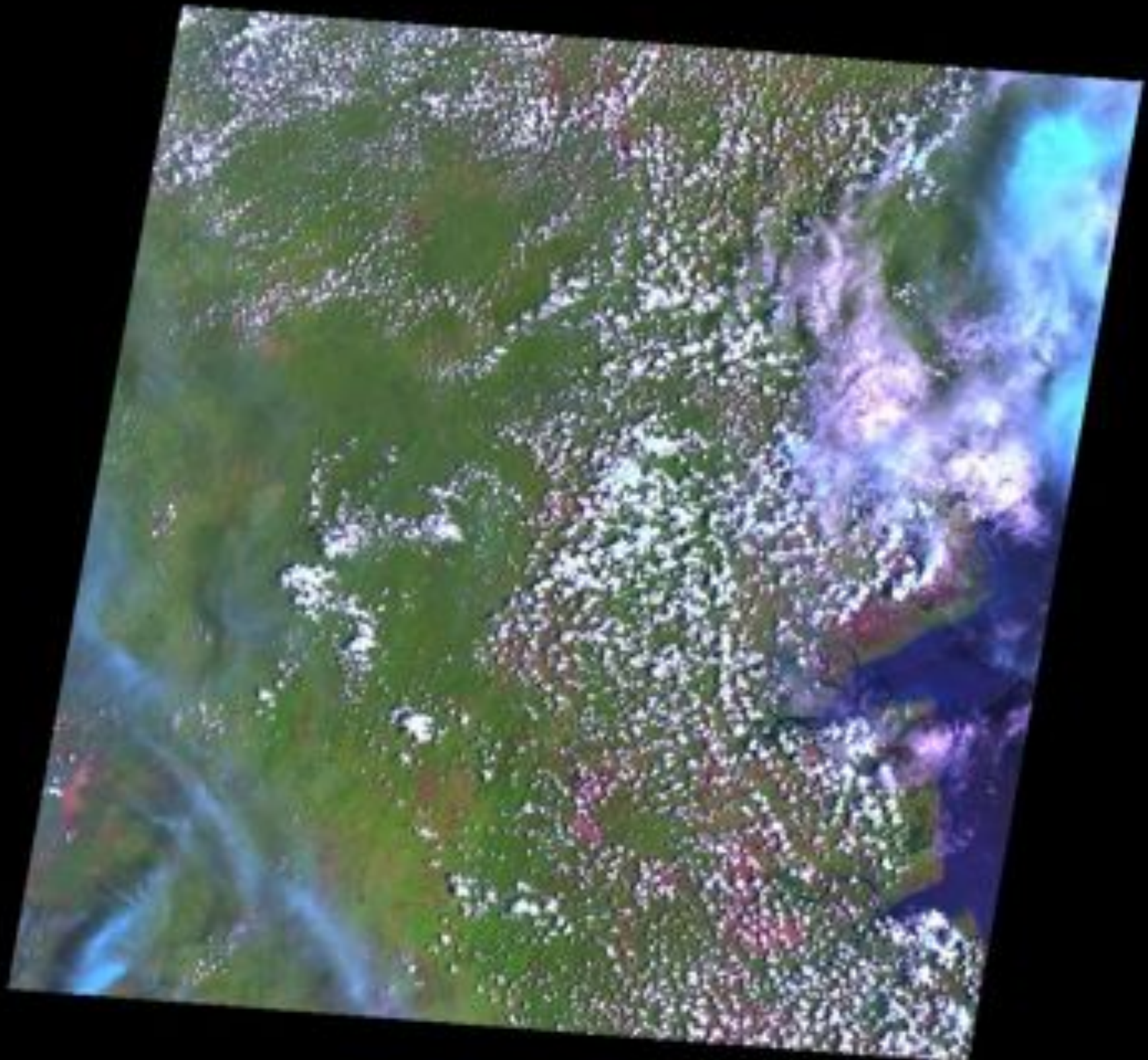


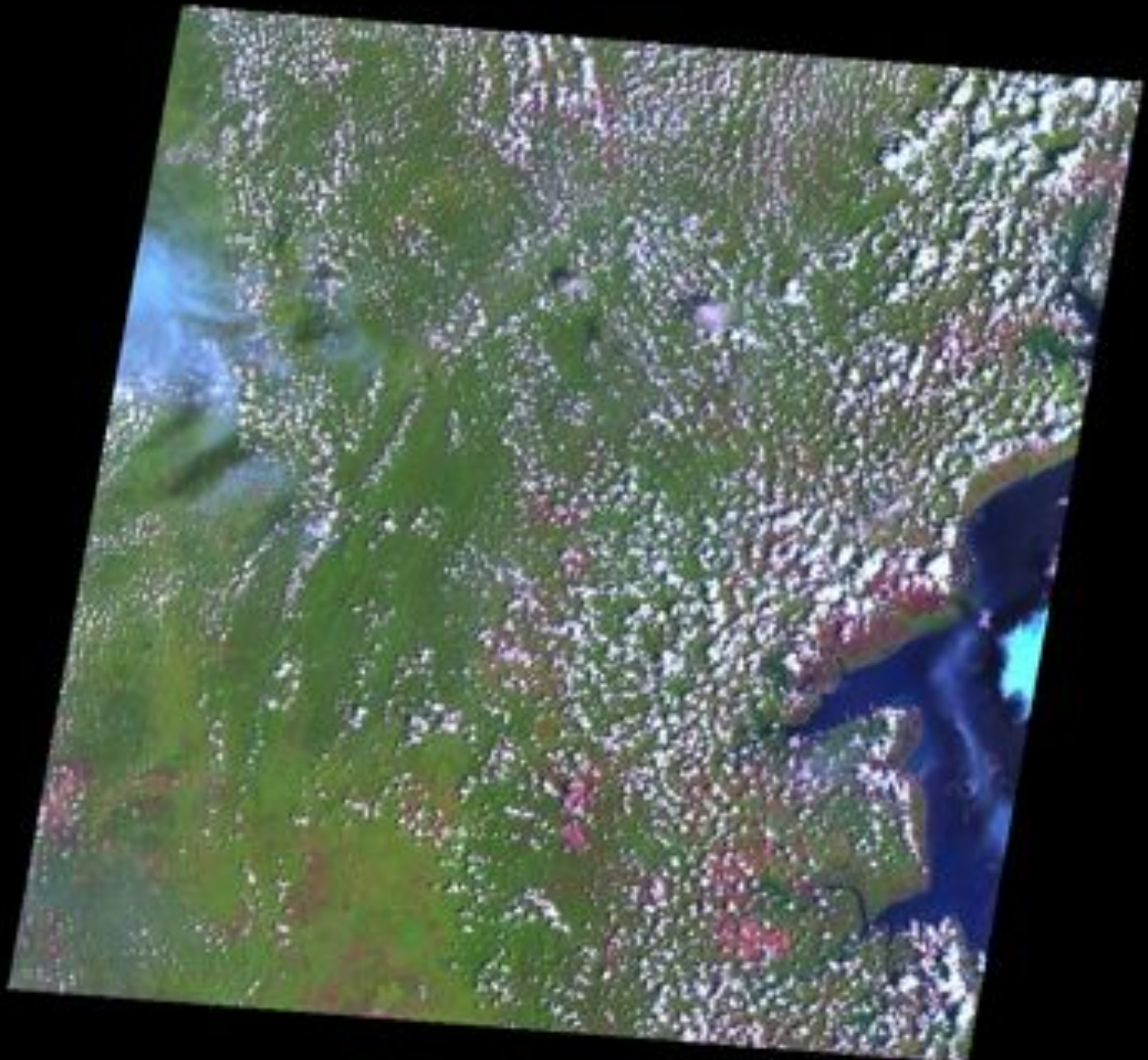


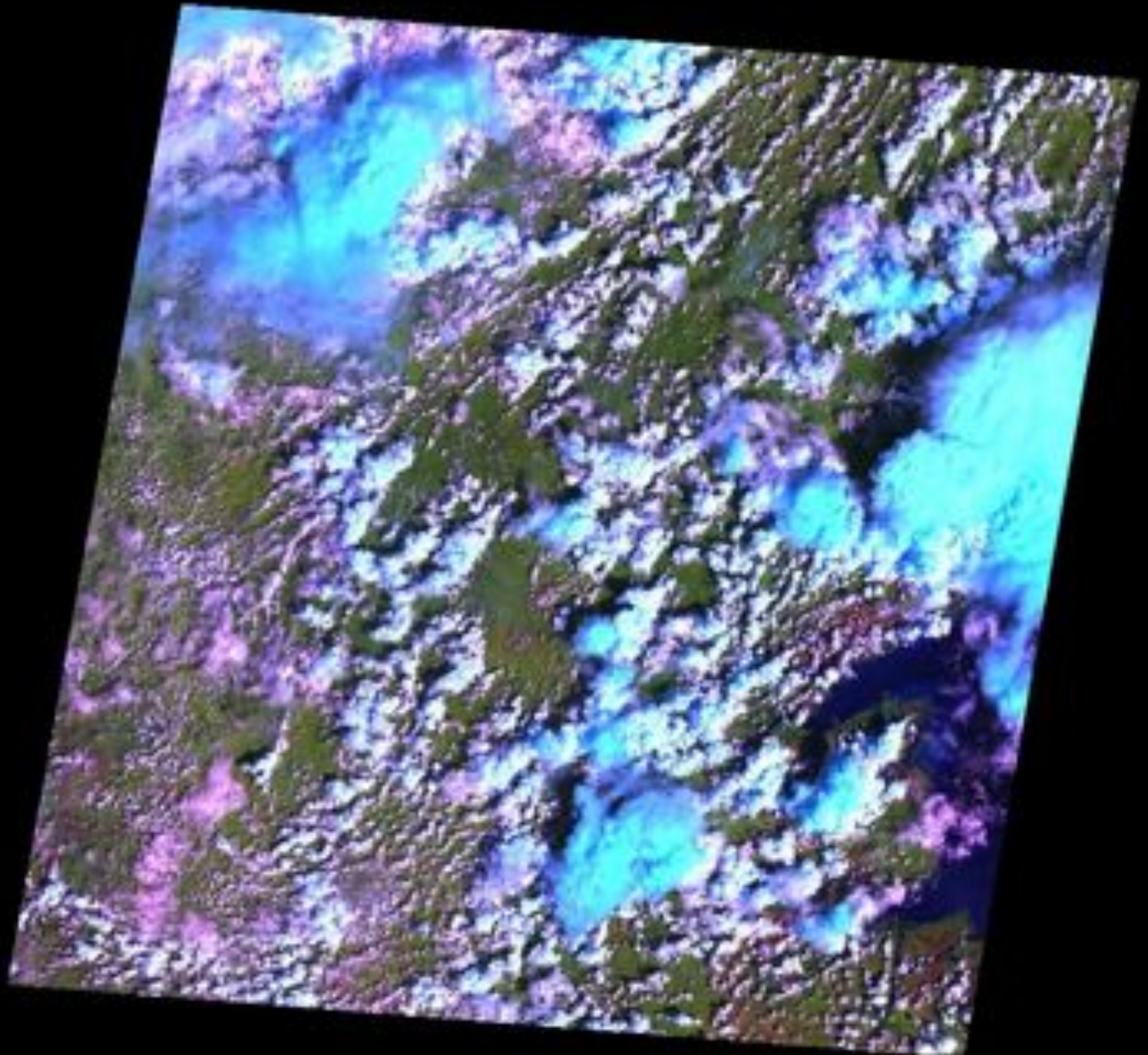


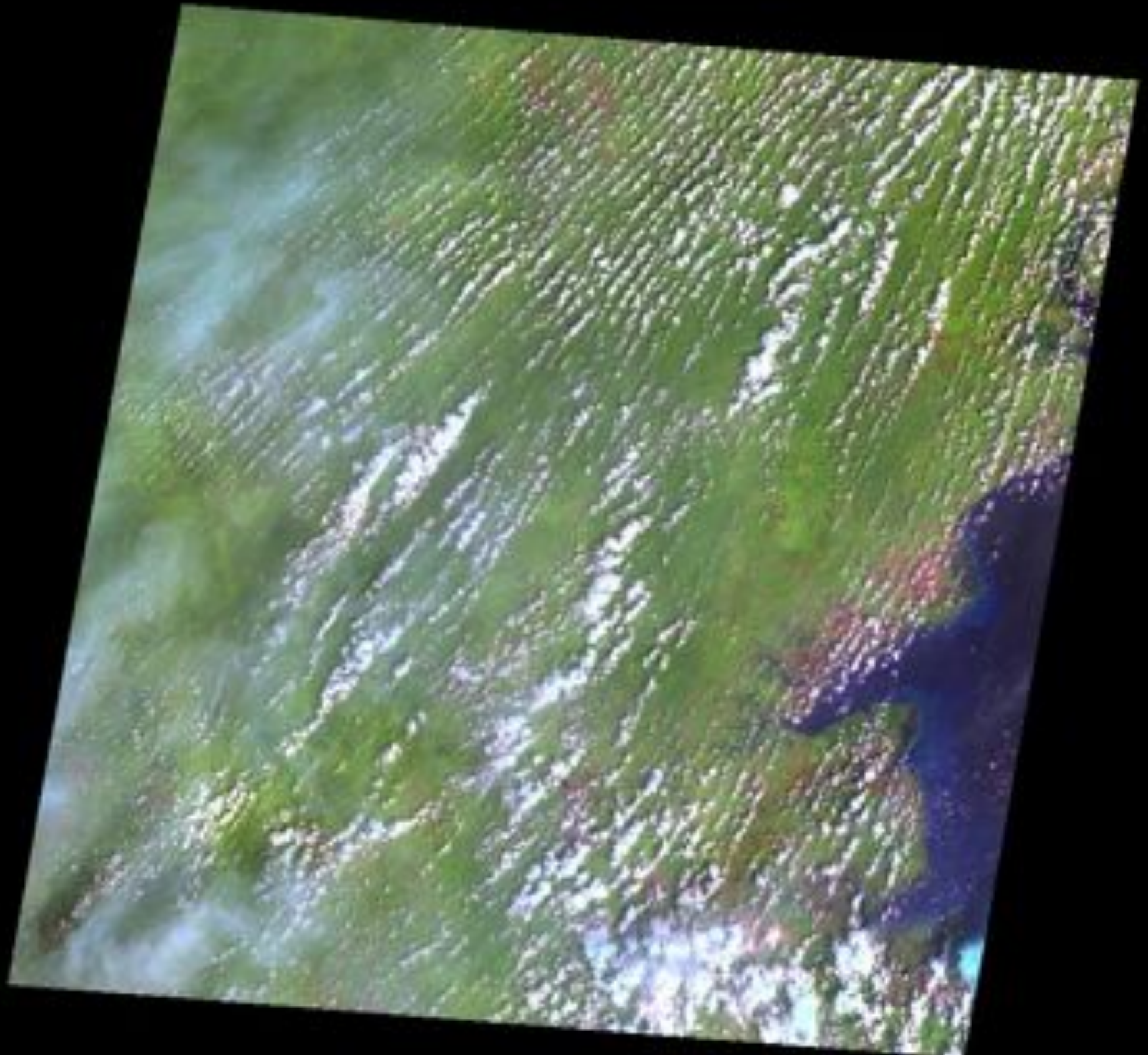


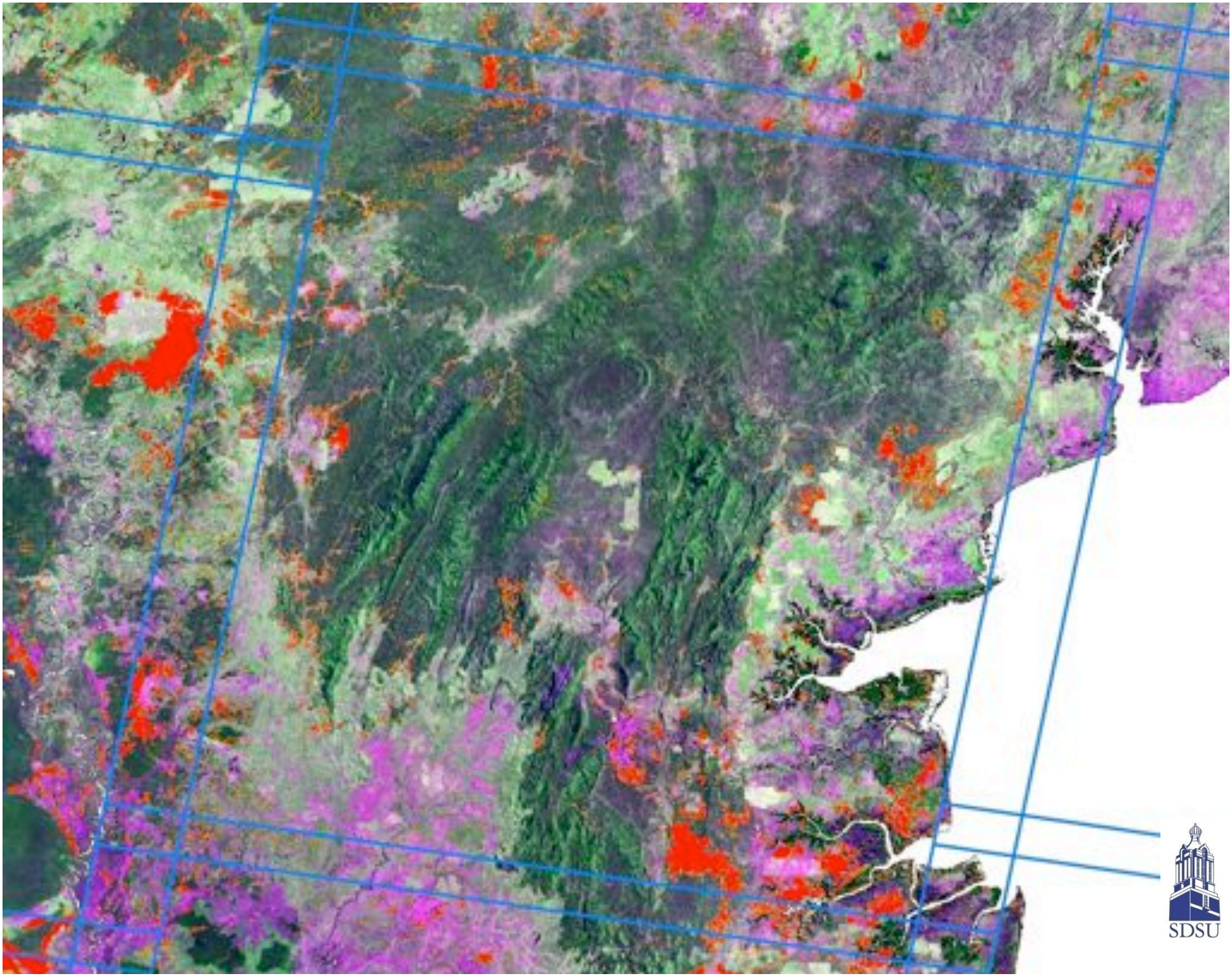








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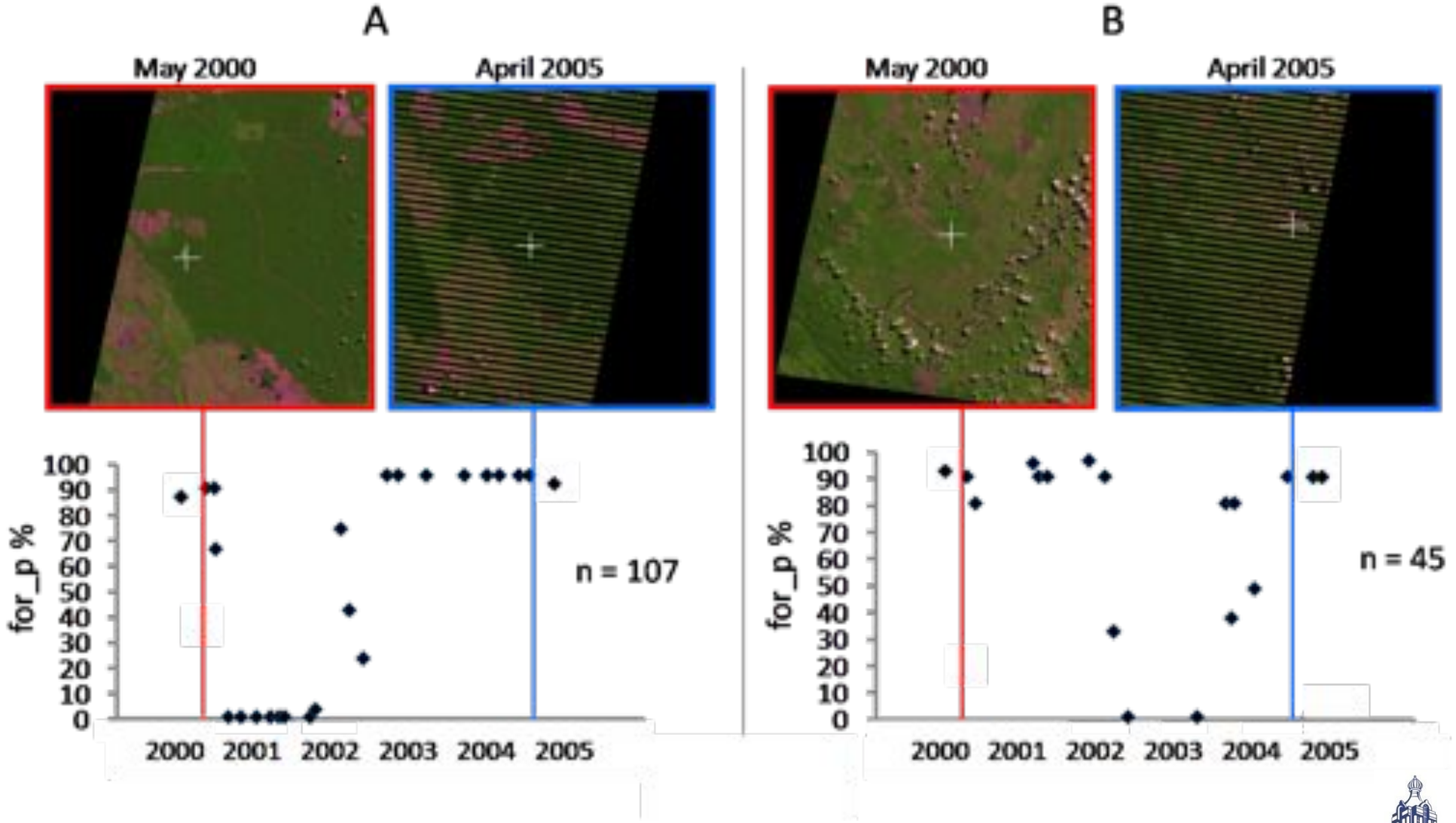
Per pixel time series



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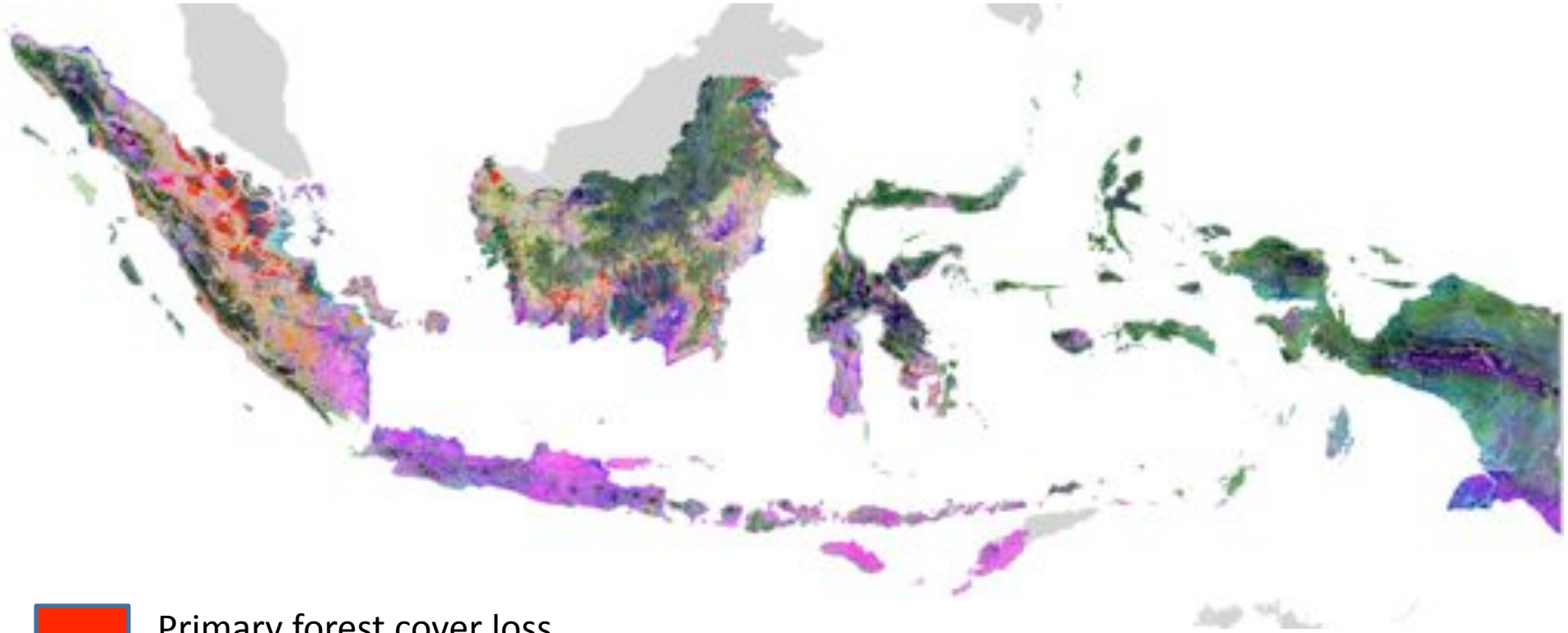
Forest cover loss in Indonesia, 2000 to 2010

15,692 Landsat Enhanced Thematic Mapper Plus images from 1999 to 2010



Primary forest cover loss

Other forest cover loss

Nearly 1 million hectares per year, almost half in primary forests

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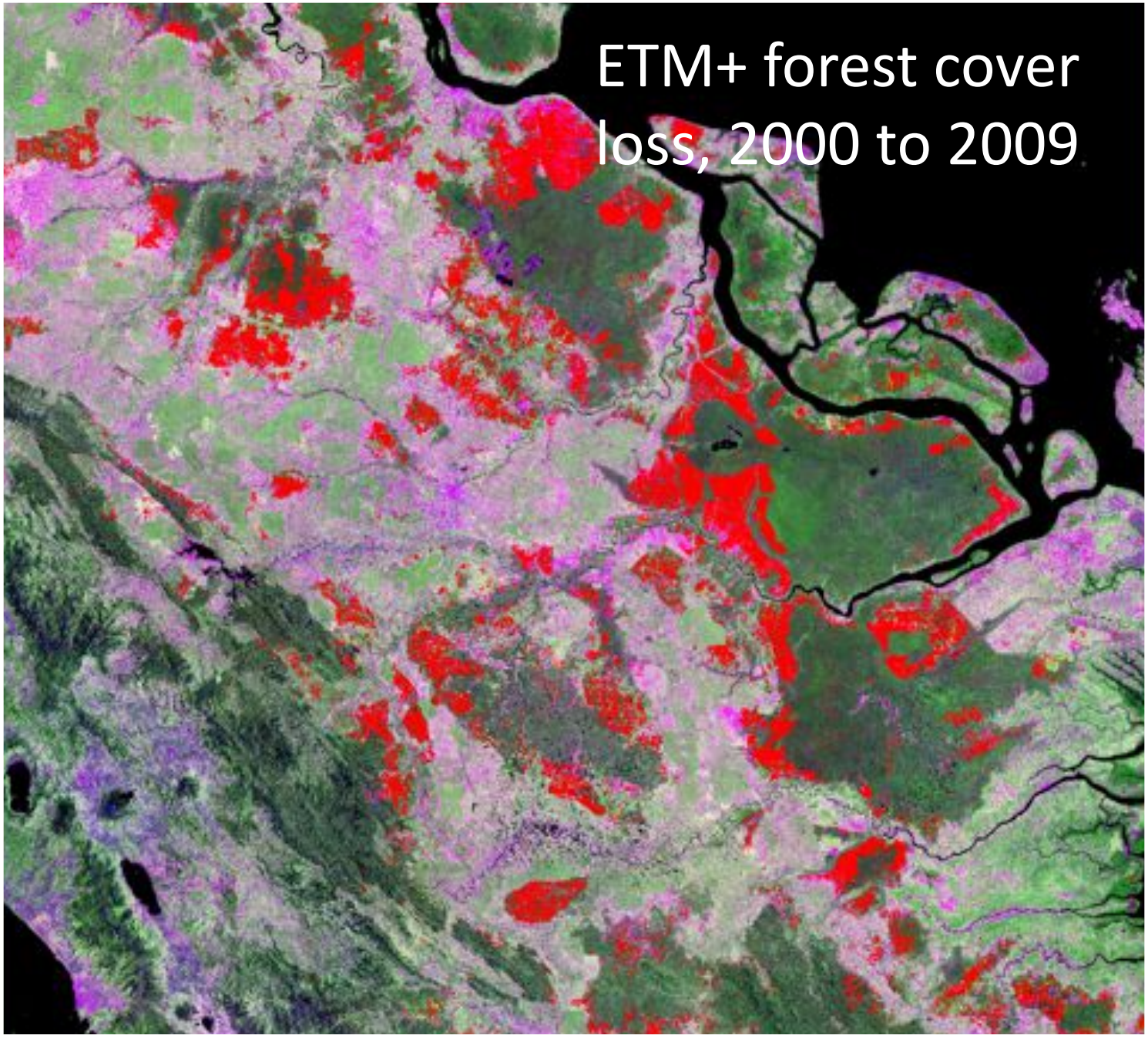
Total forest cover loss

00-08



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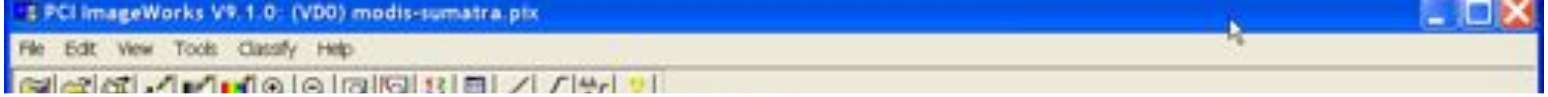
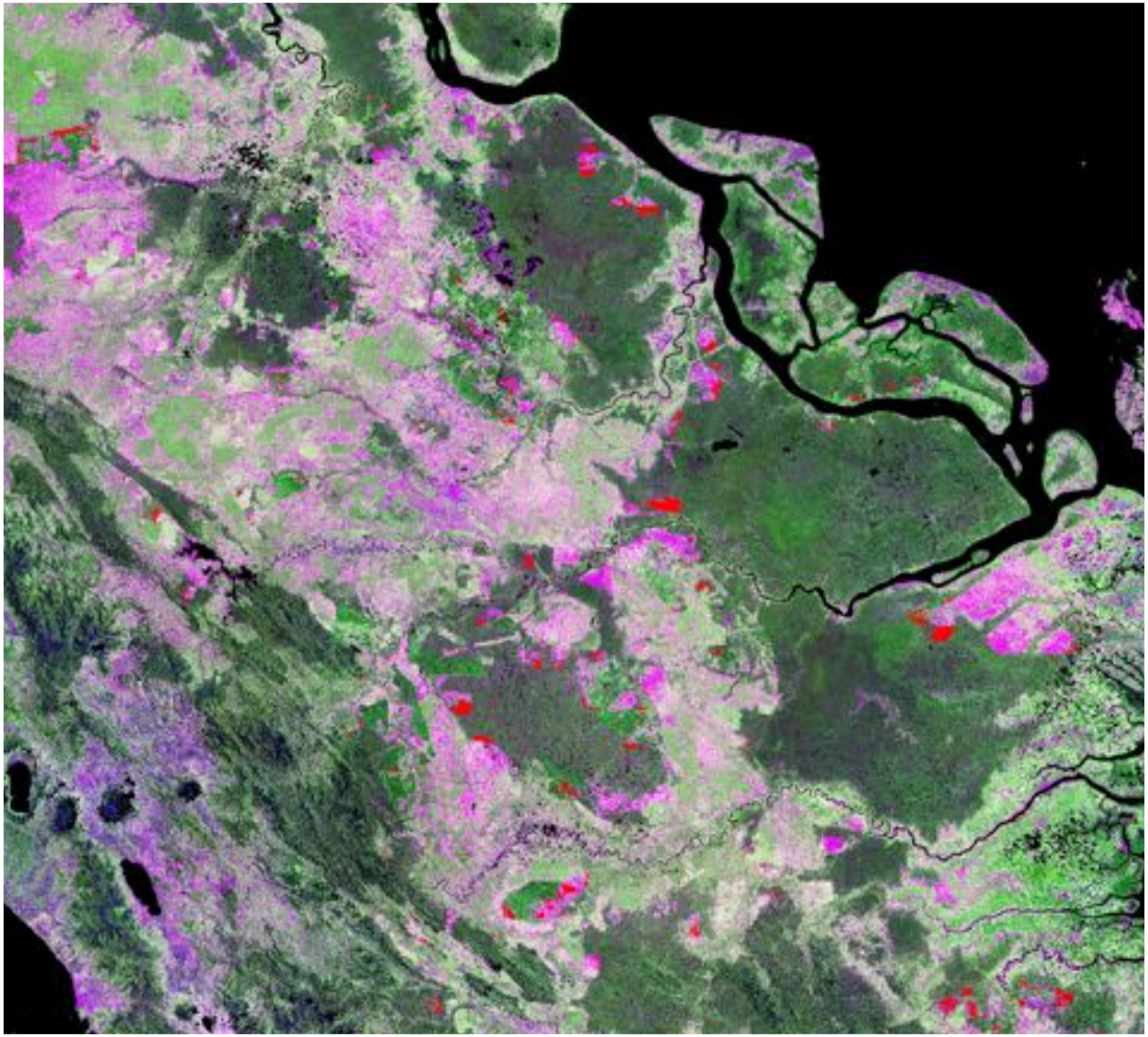


Annual forest cover loss

00-01



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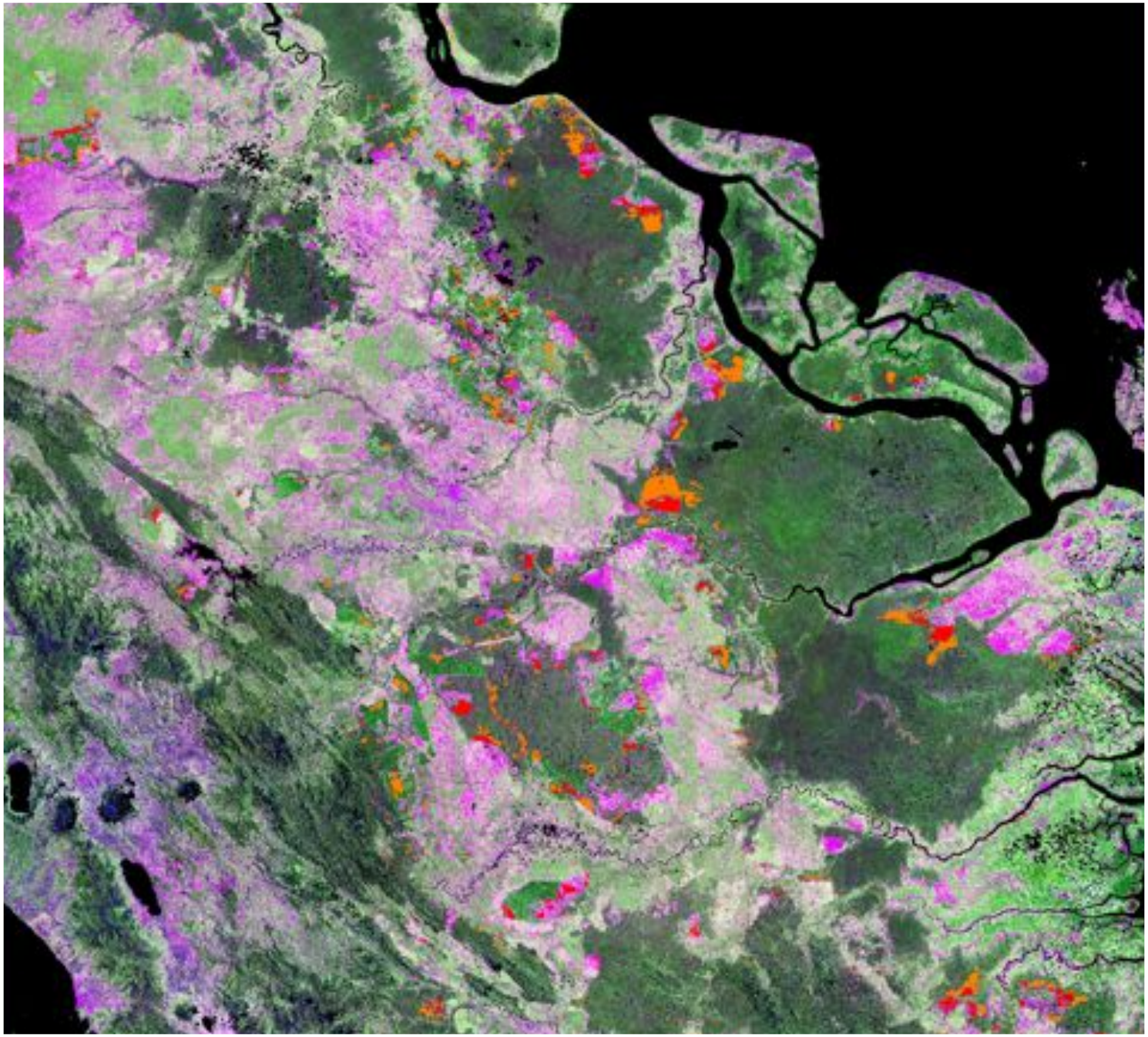
Annual forest cover loss

00-01

01-02



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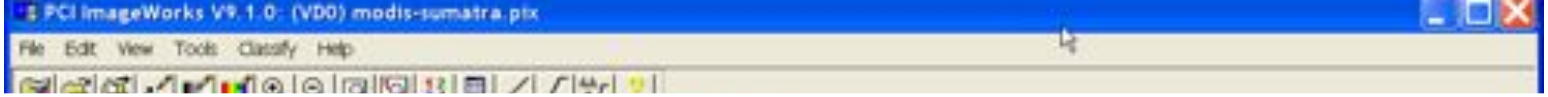
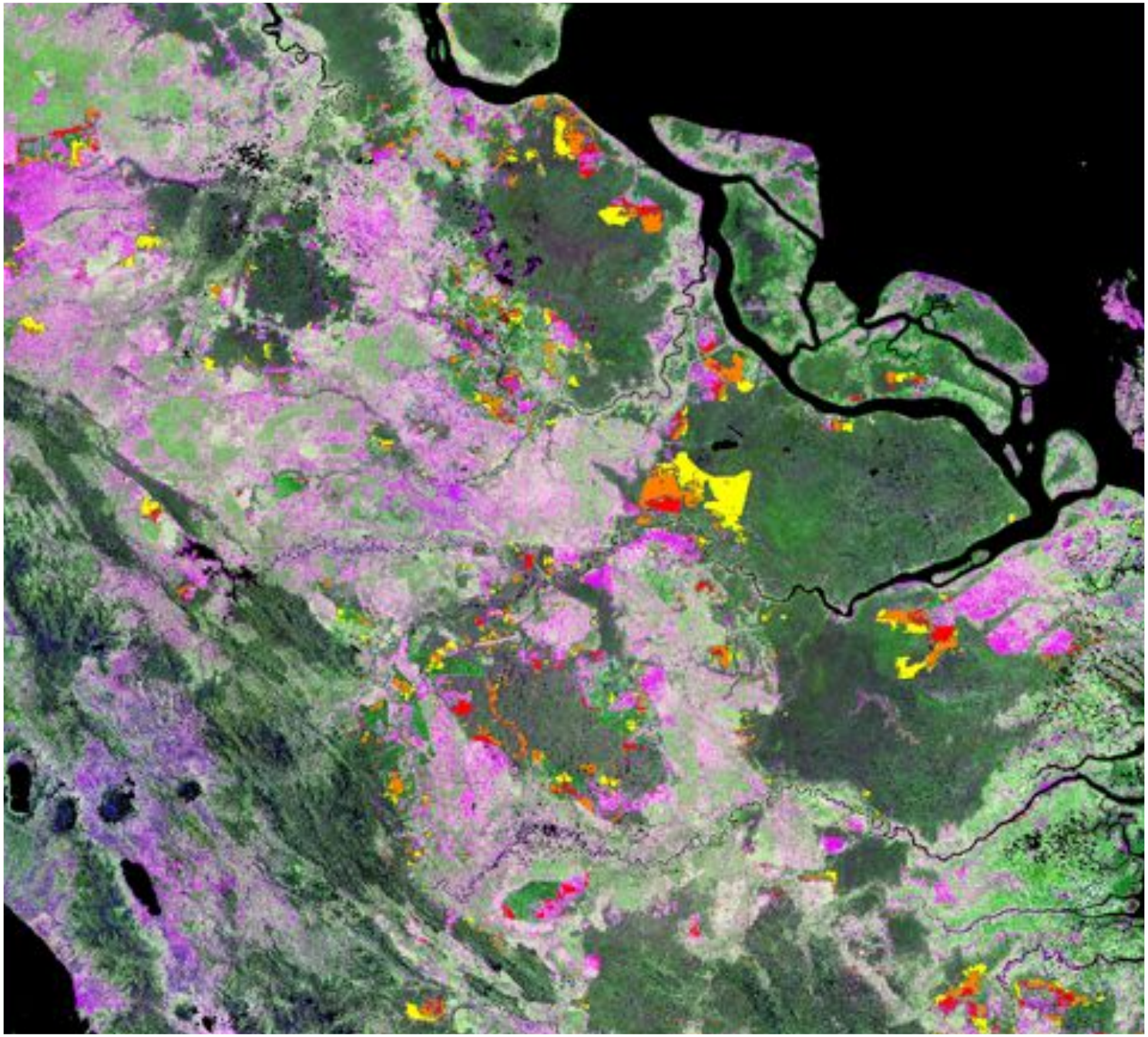


Annual forest cover loss

- 00-01
- 01-02
- 02-03



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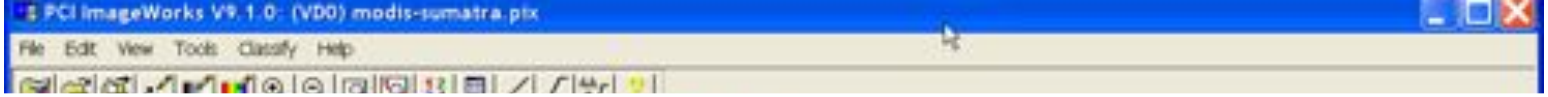
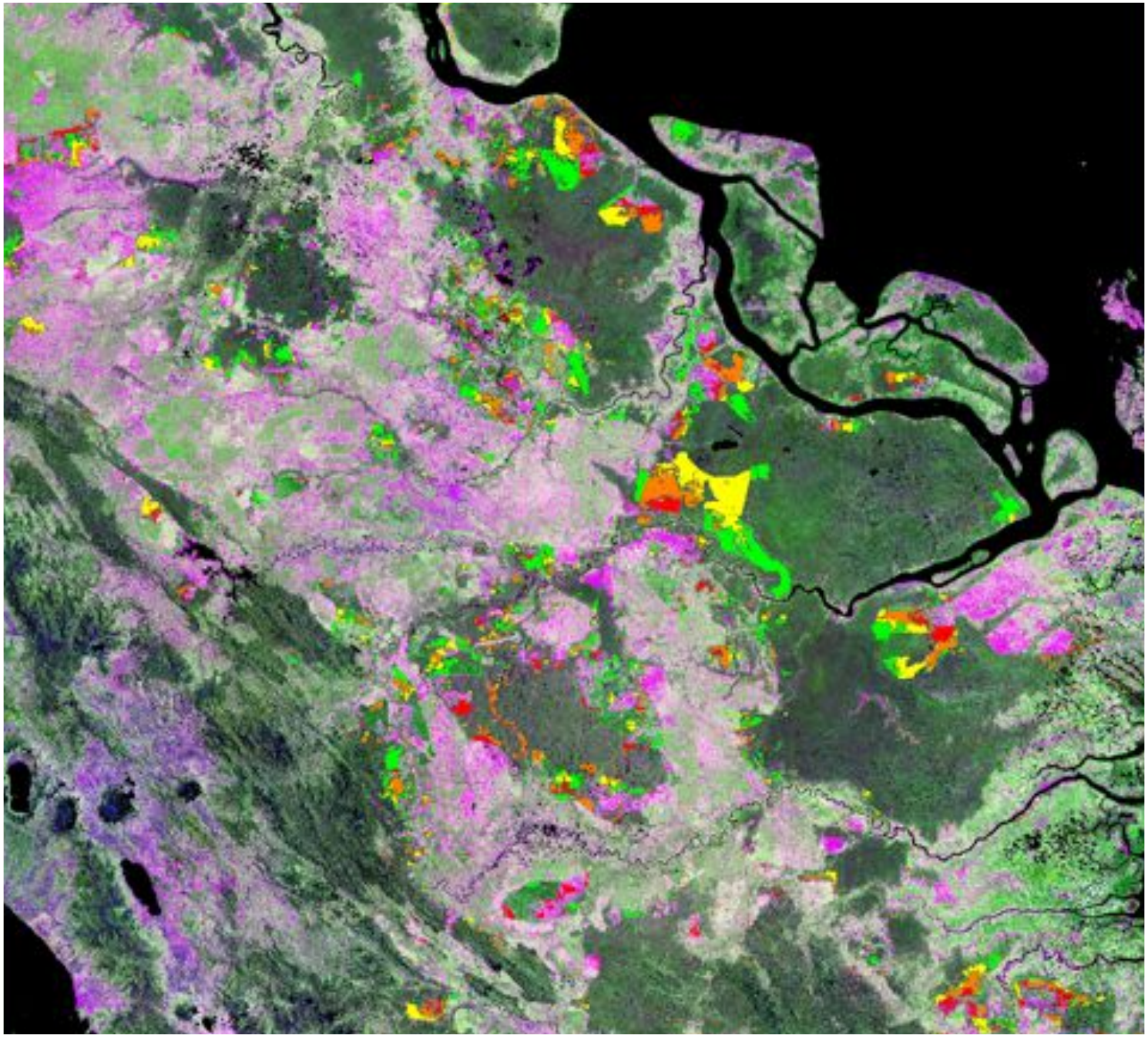


Annual forest cover loss

- 00-01
- 01-02
- 02-03
- 03-04



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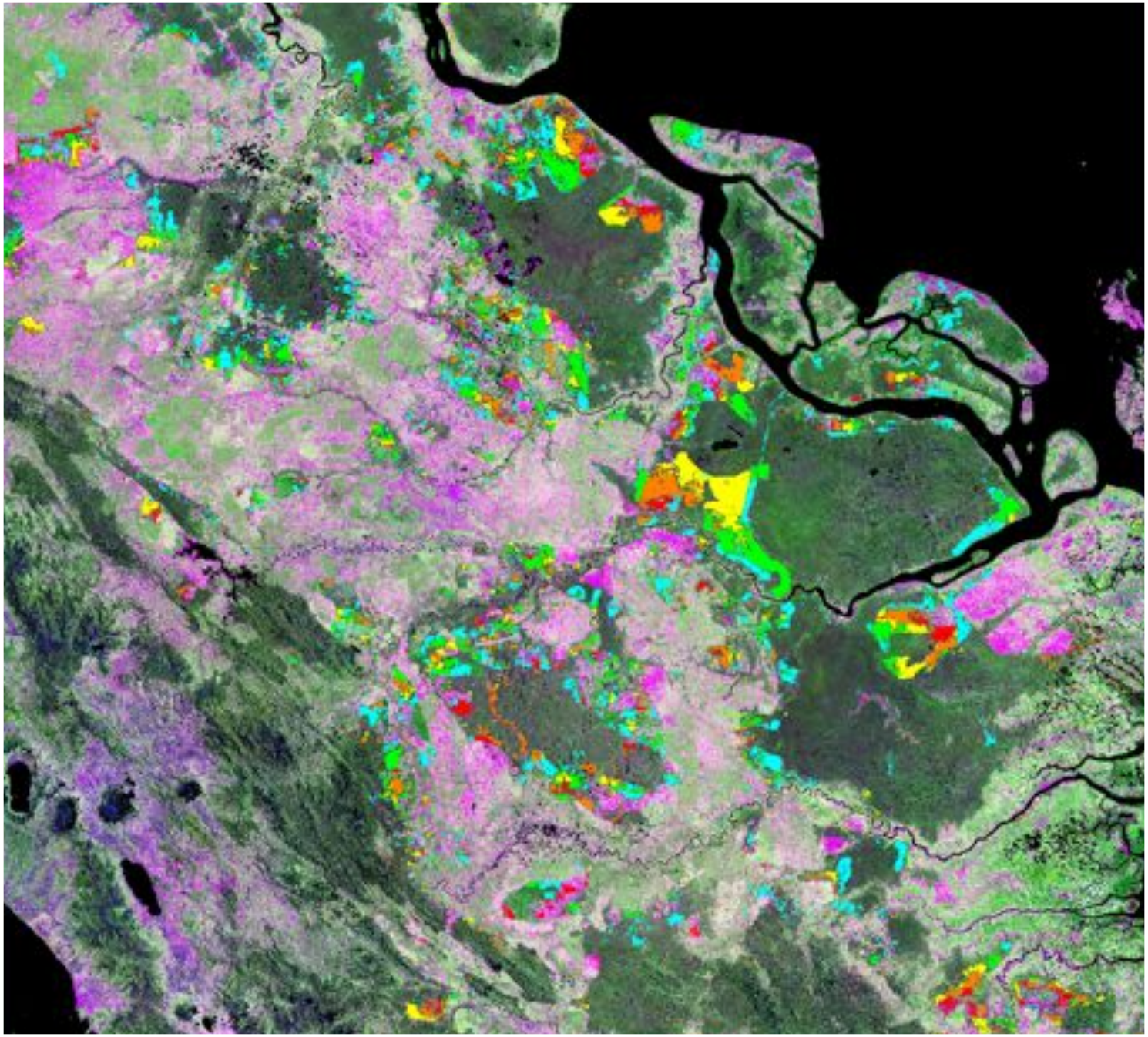
Annual forest cover loss

- 00-01
- 01-02
- 02-03
- 03-04
- 04-05



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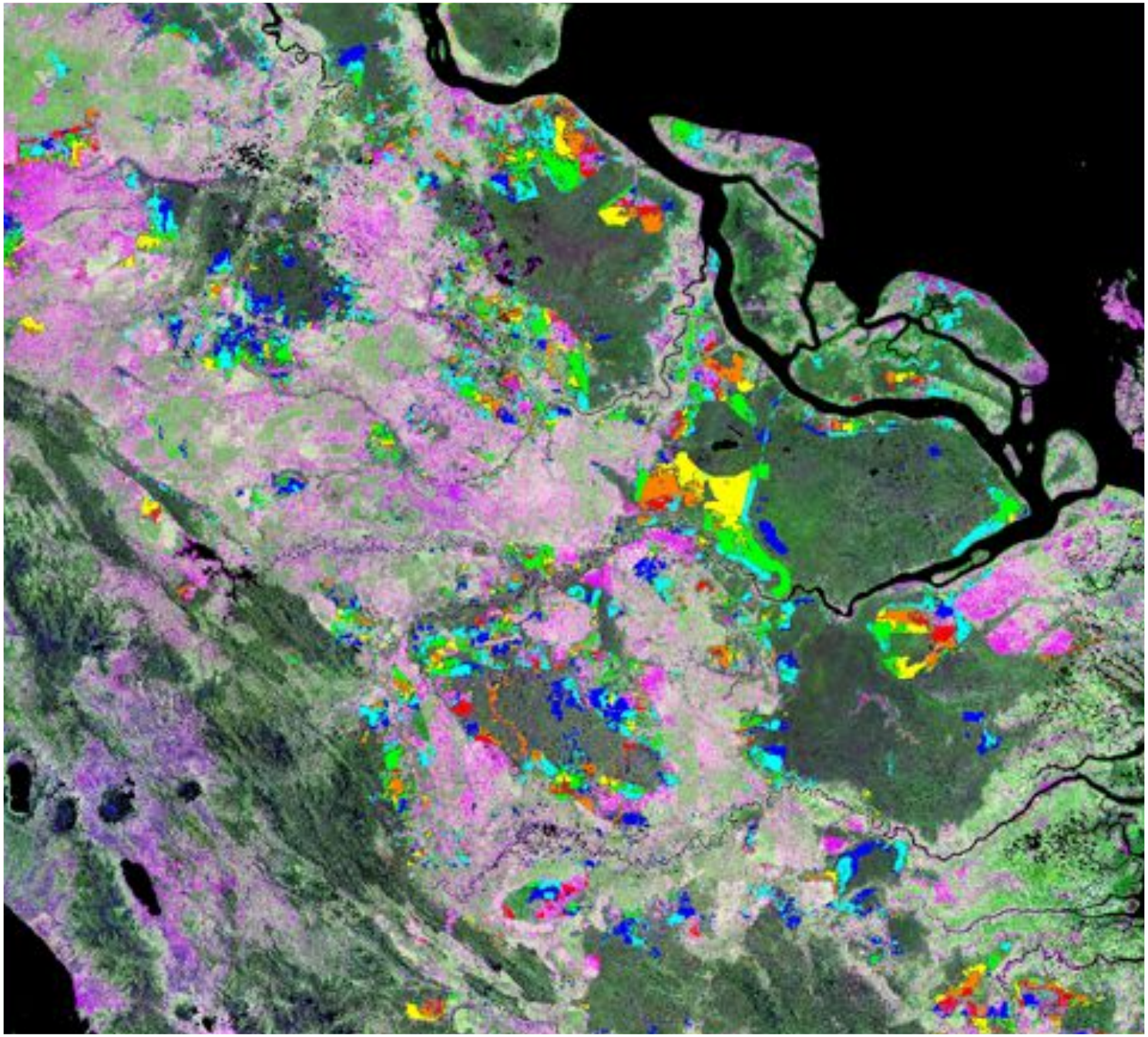
Annual forest cover loss

- 00-01
- 01-02
- 02-03
- 03-04
- 04-05
- 05-06



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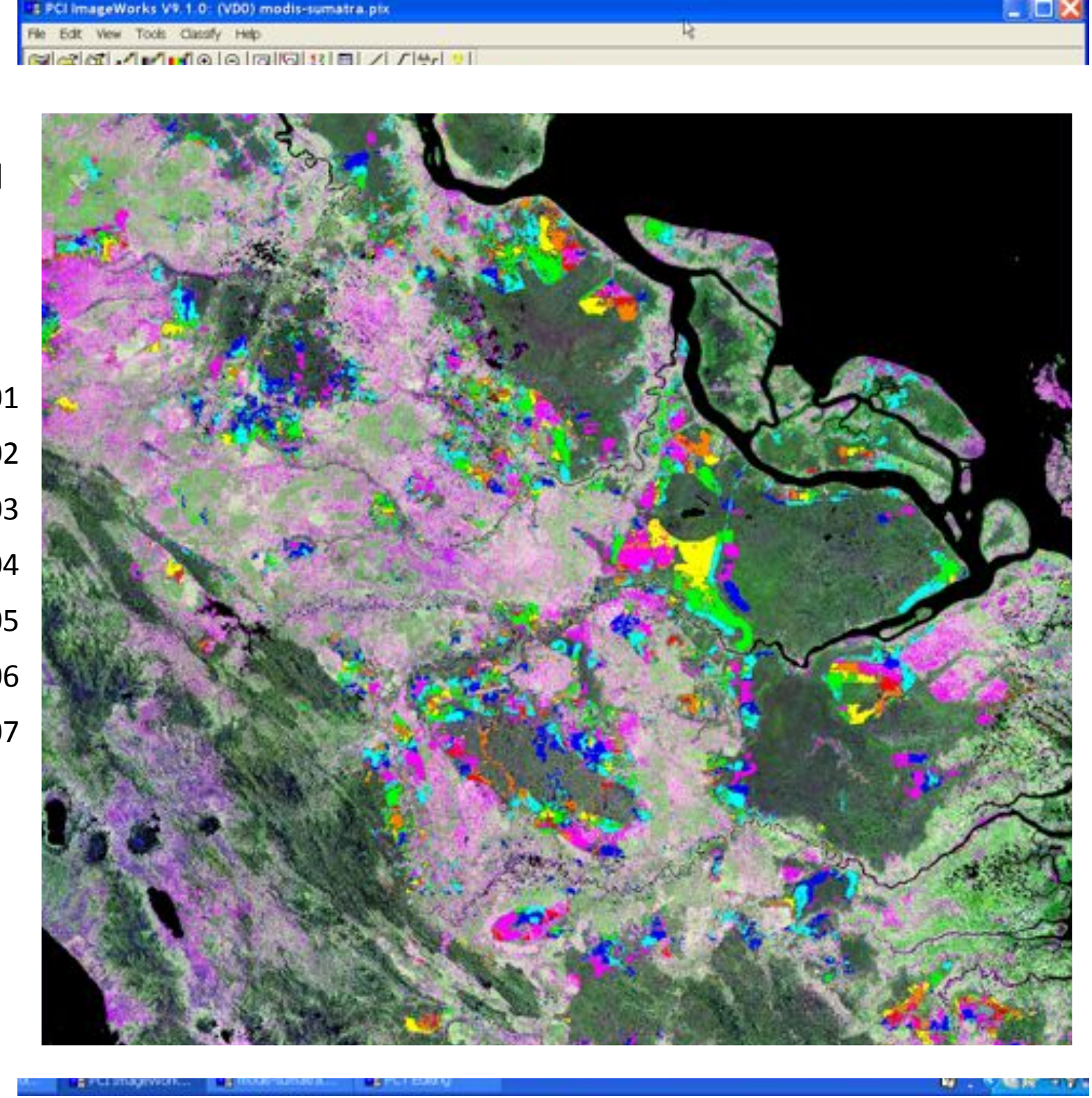
PCI ImageWorks V9.1.0: (VD0) modis-sumatra.pix
File Edit View Tools Classify Help
Annual forest cover loss
00-01
01-02
02-03
03-04
04-05
05-06
06-07

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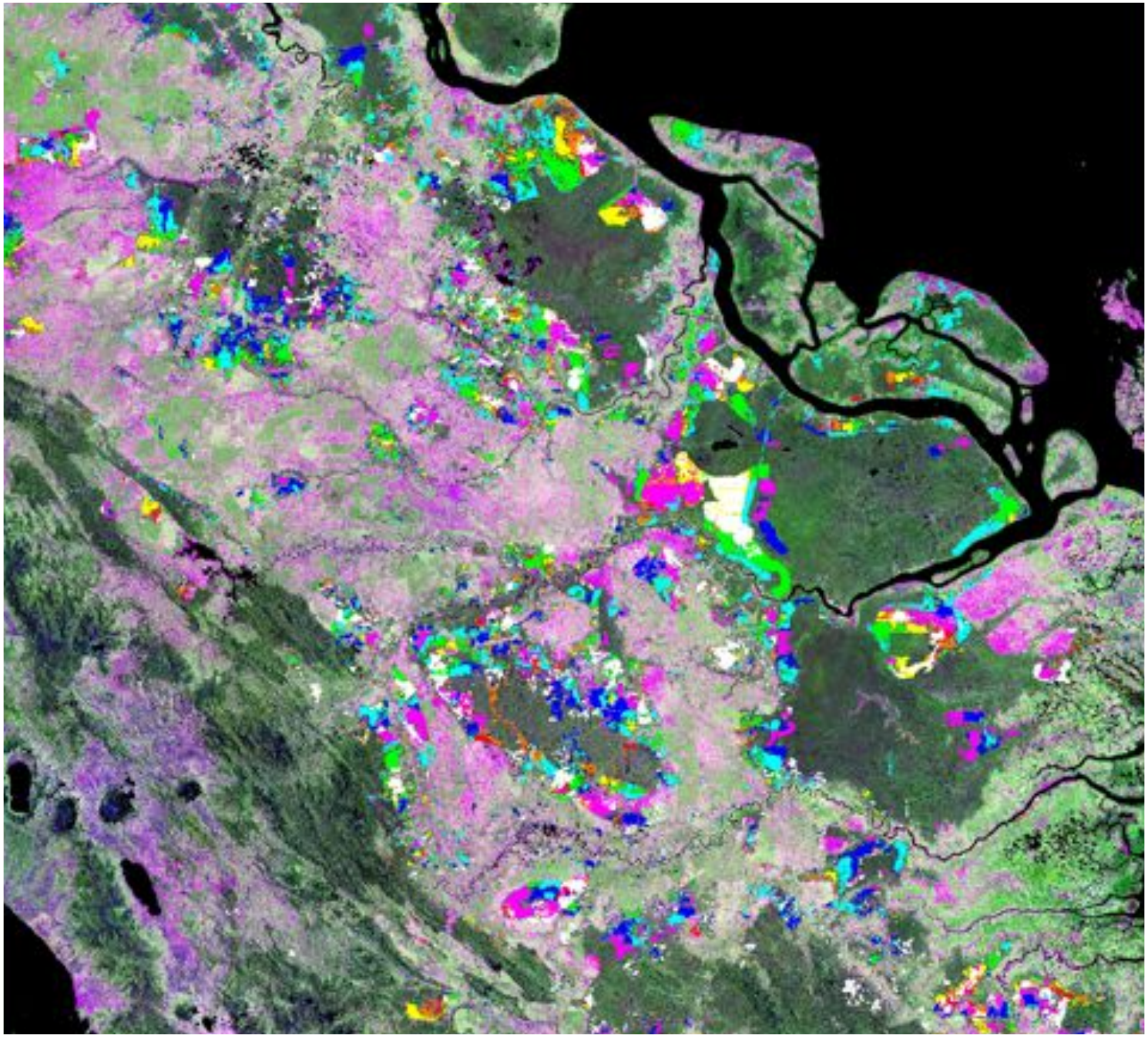
Annual forest cover loss

- 00-01
- 01-02
- 02-03
- 03-04
- 04-05
- 05-06
- 06-07
- 07-08



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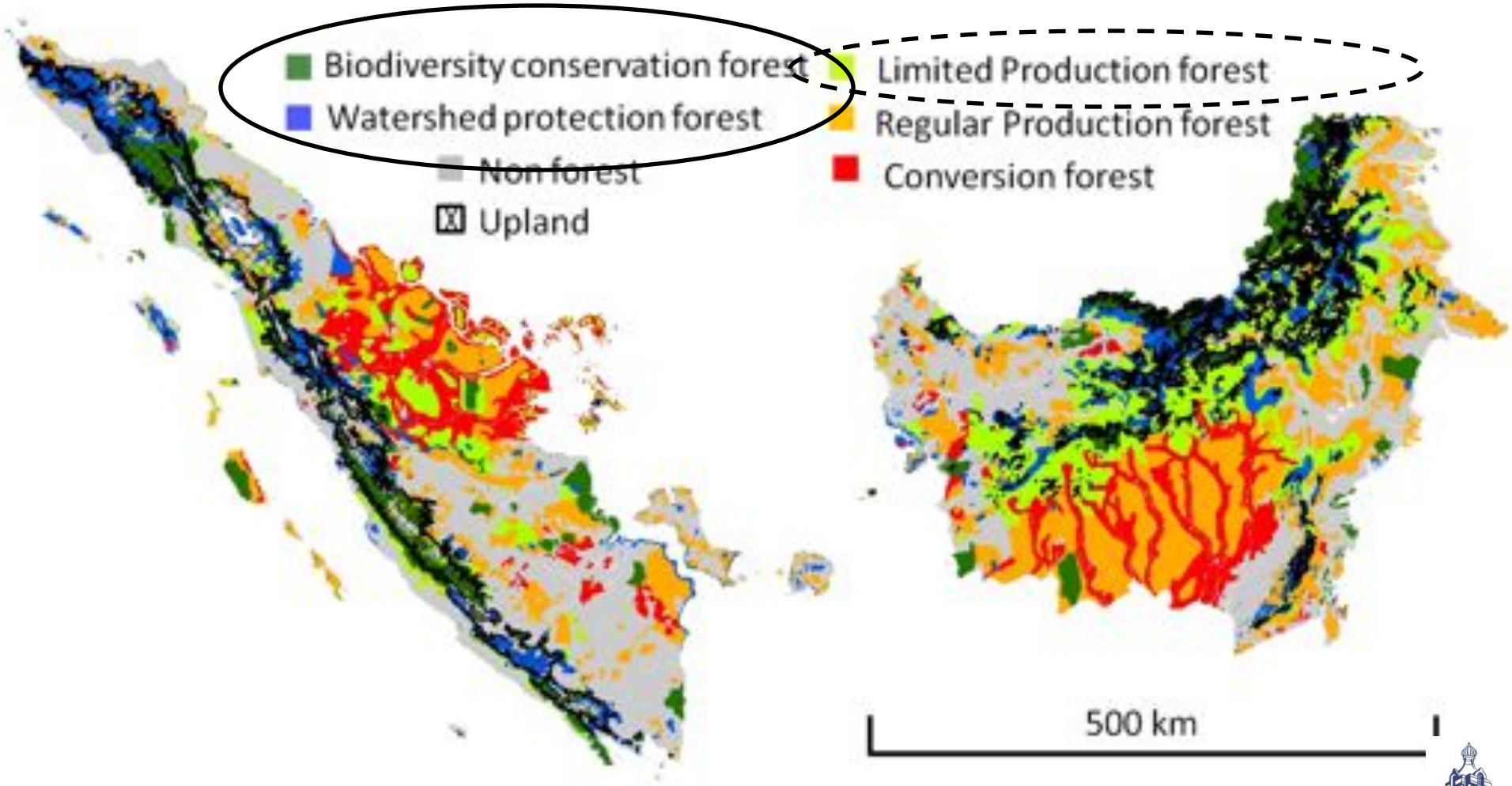
Forest land use zones



Indonesian Ministry of Forestry (2000)

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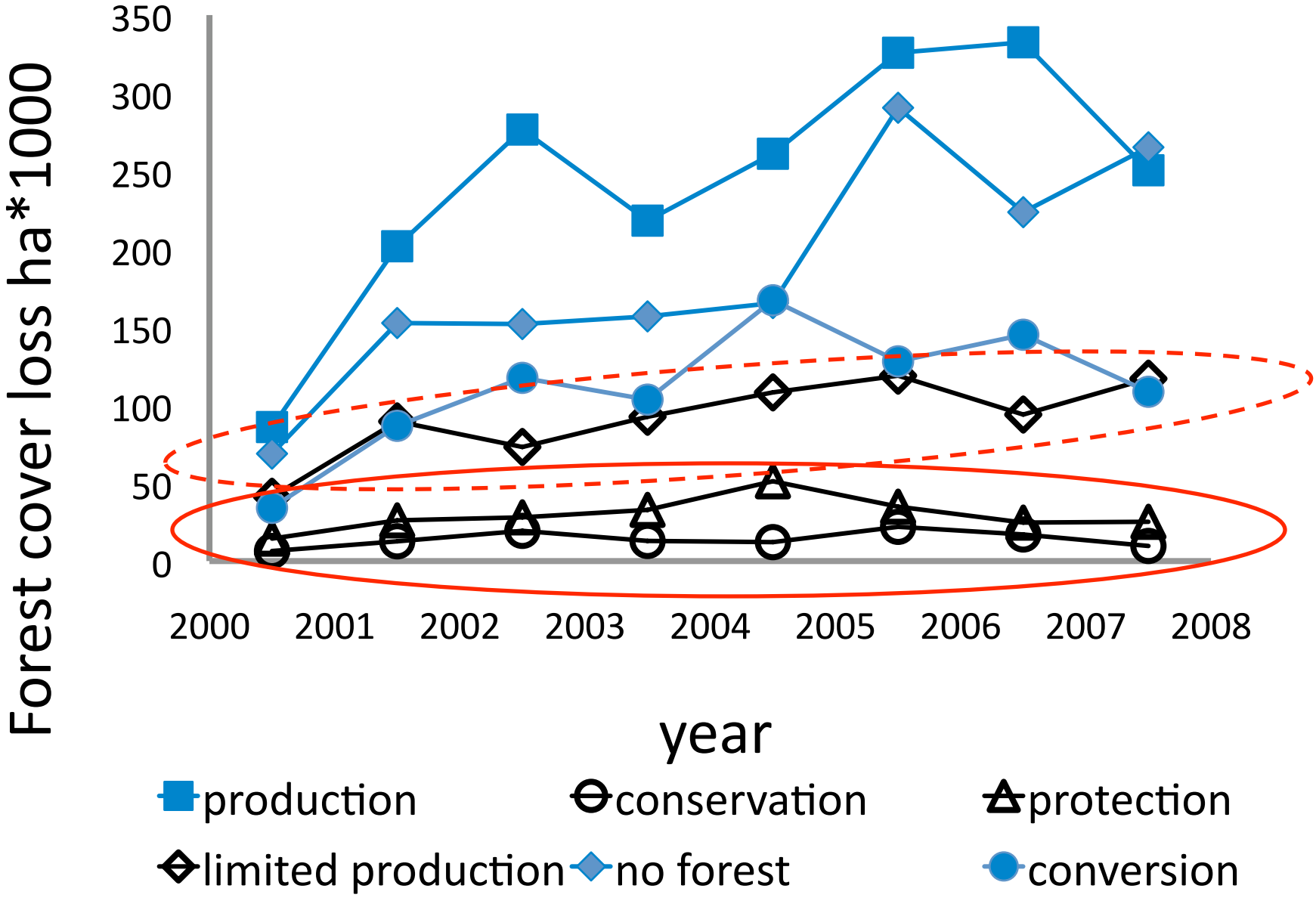
Forest cover loss trends per forest land use zone



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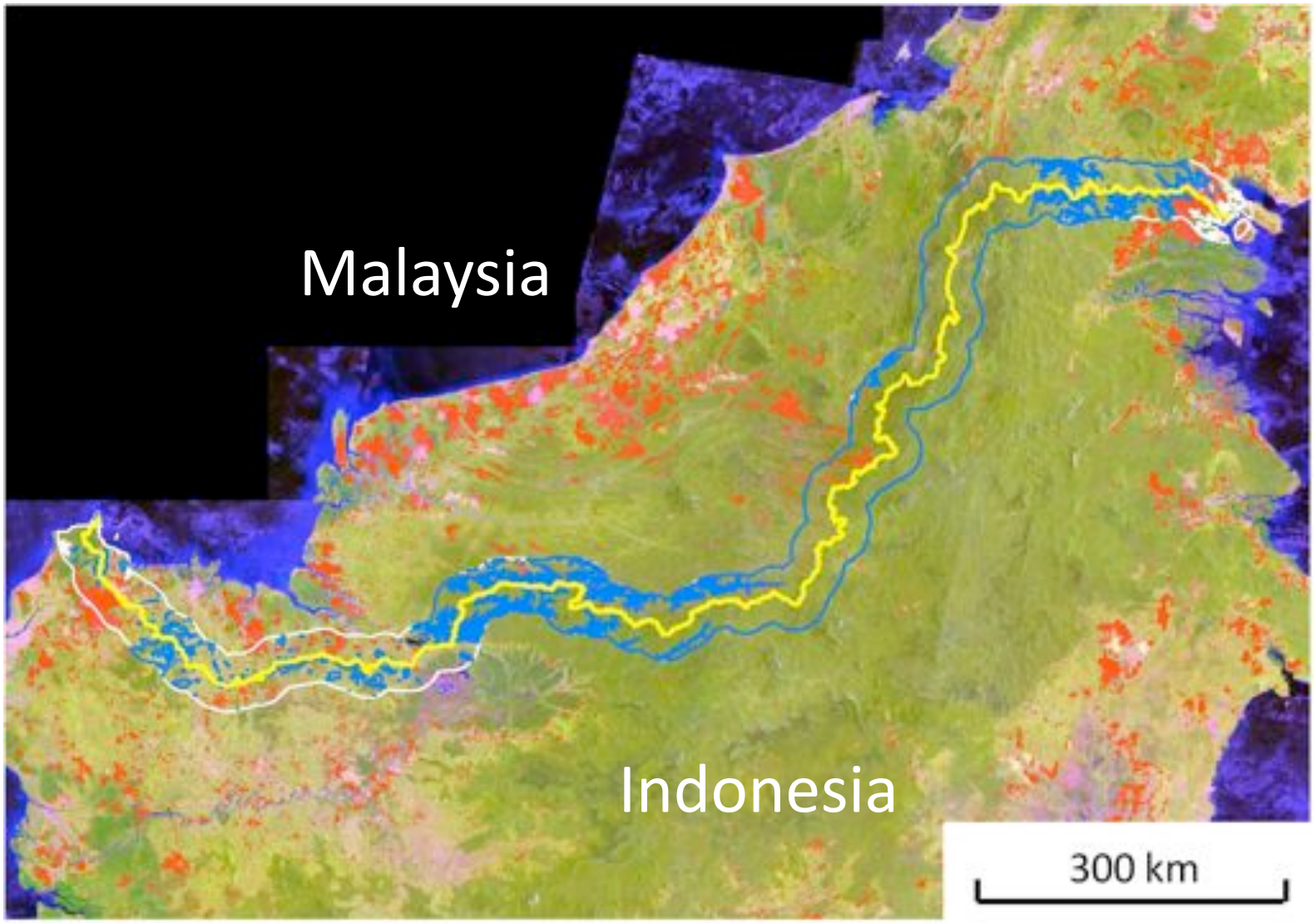
Trans-boundary effects



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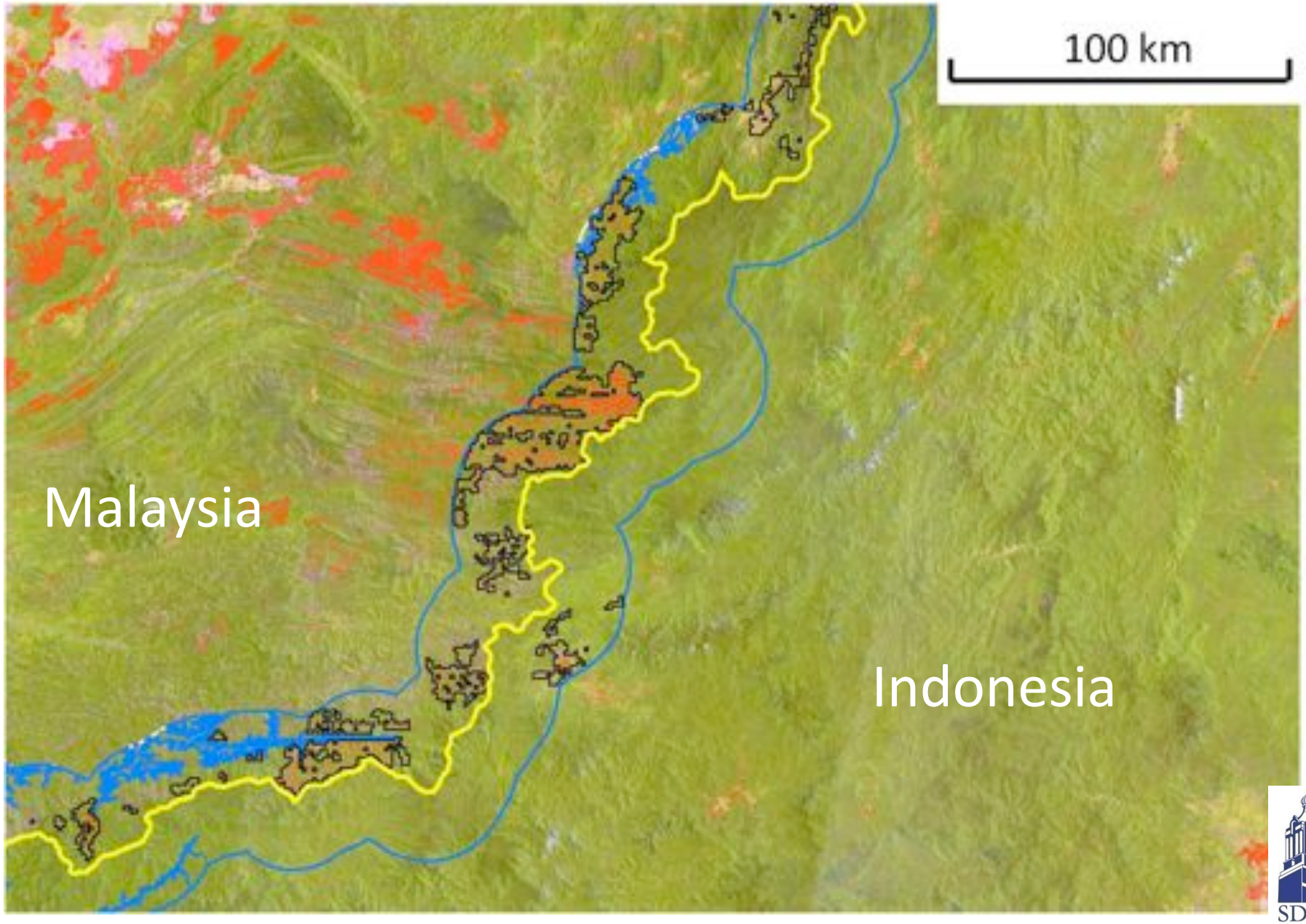
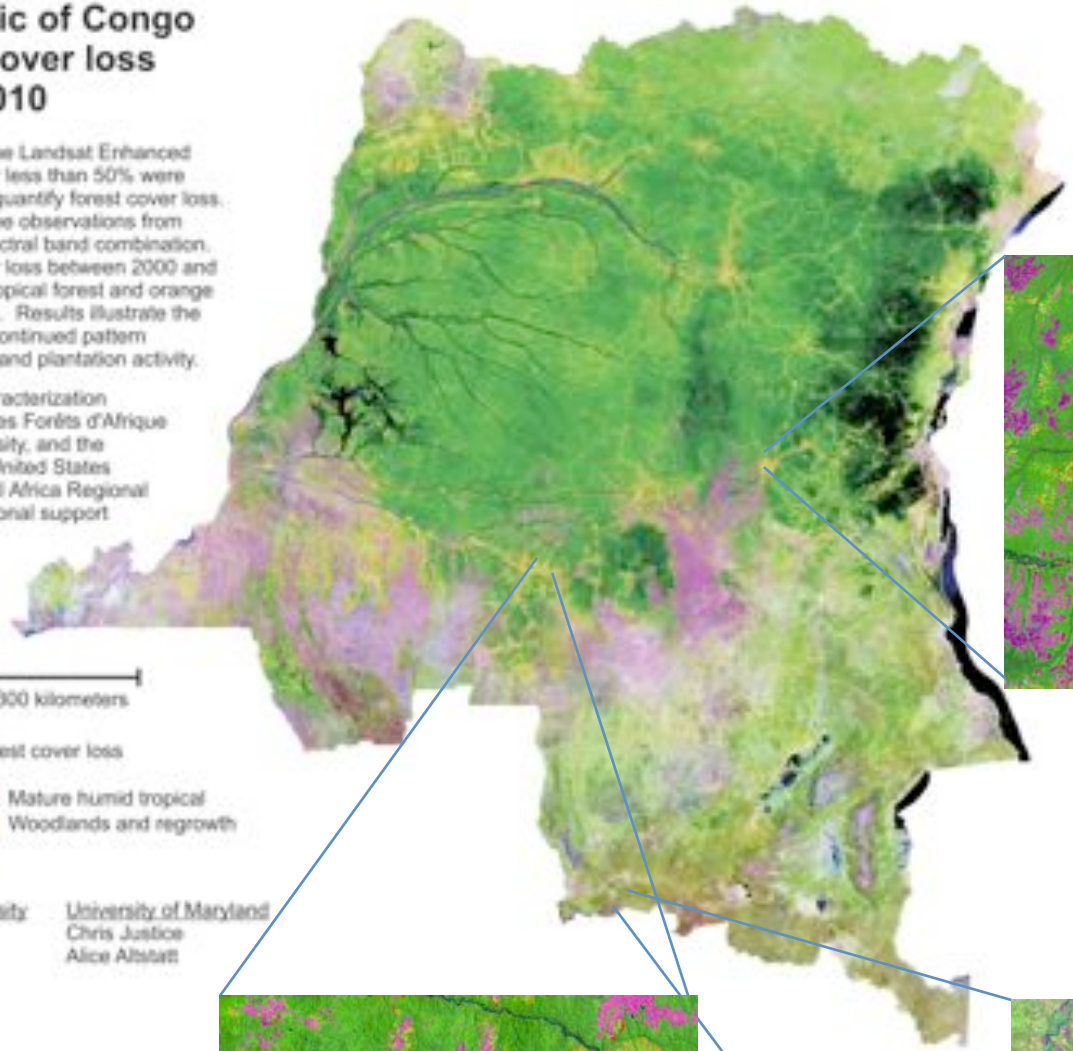
Trans-boundary effects

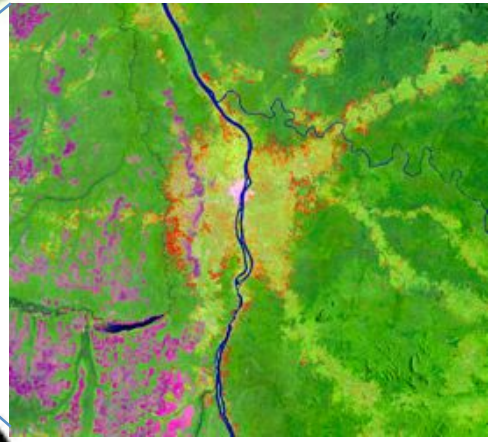


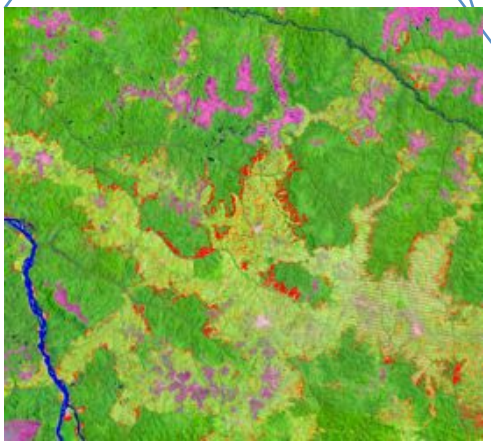
The Democratic Republic of Congo from space - Forest cover loss from 2000 to 2010

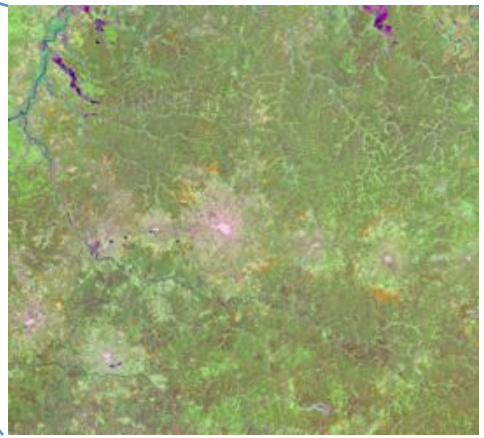
All images from the USGS EROS archive for the Landsat Enhanced Thematic Mapper Plus sensor with cloud cover less than 50% were automatically processed and characterized to quantify forest cover loss. The image composite was made from cloud-free observations from 2005 to 2010 and is displayed with a 5-4-3 spectral band combination. Areas in red and orange represent forest cover loss between 2000 and 2010, where red is clearing of mature humid tropical forest and orange clearing of woodlands and secondary regrowth. Results illustrate the spatial distribution of forest cover loss, with a continued pattern of agricultural clearing, mining, hunting camps and plantation activity.

Application of the Landsat processing and characterization was performed by the Observatoire Satellital des Forêts d'Afrique Centrale (OSFAC), South Dakota State University, and the University of Maryland, and supported by the United States Agency for International Development's Central Africa Regional Program for the Environment (CARPE). Additional support was provided by the United States National Aeronautics and Space Administration and the United States Geological Survey.









300 kilometers

Forest cover loss

- Mature humid tropical
- Woodlands and regrowth

OSFAC
Landing Mane
Patrick Amani
Eddy Bongwele

South Dakota State University
Matthew Hansen
Peter Potapov
Mark Broich
Bernard Adusei

University of Maryland
Chris Justice
Alice Alstatt

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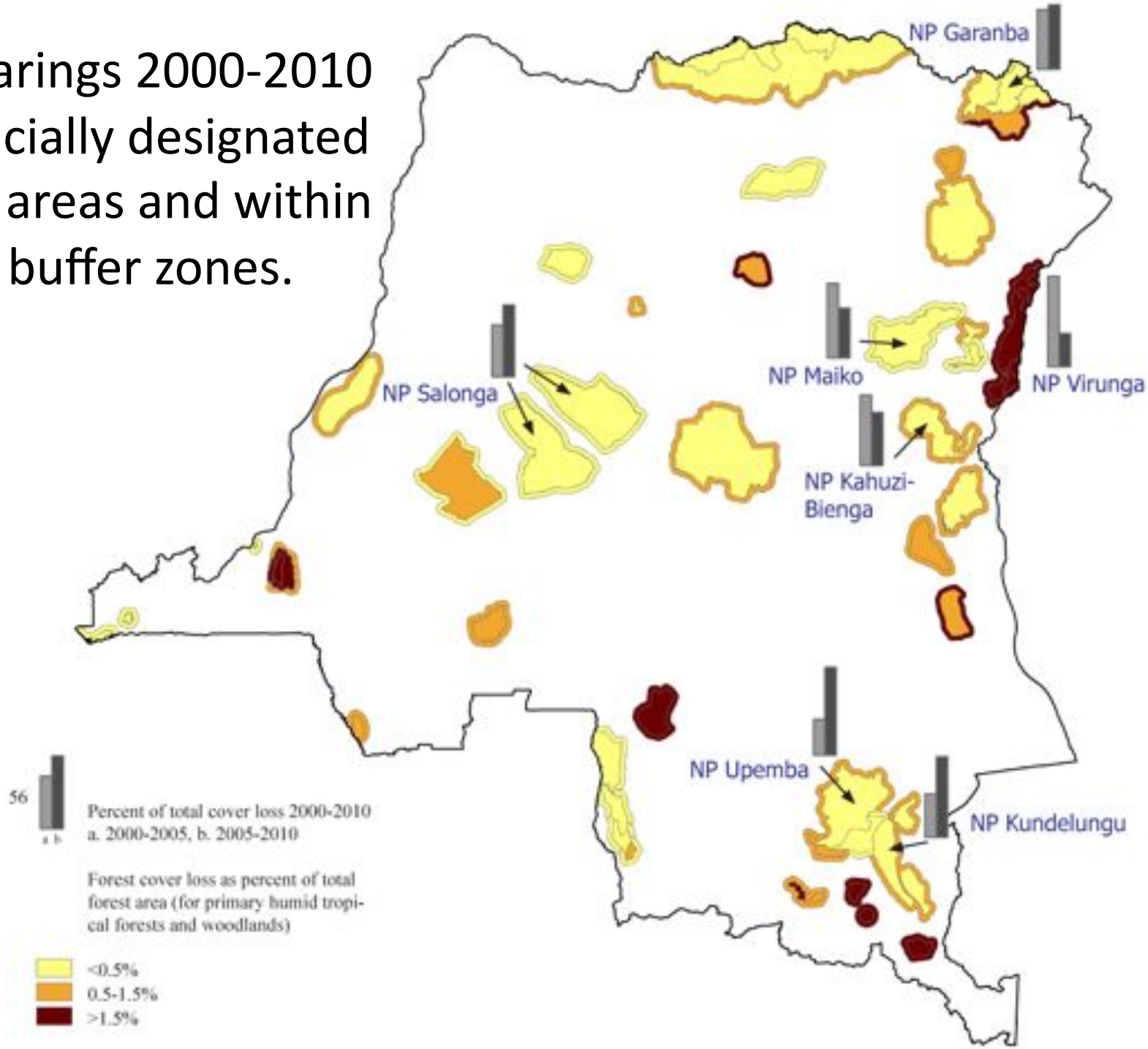
Forest clearings 2000-2010 within officially designated protected areas and within 10-km buffer zones.



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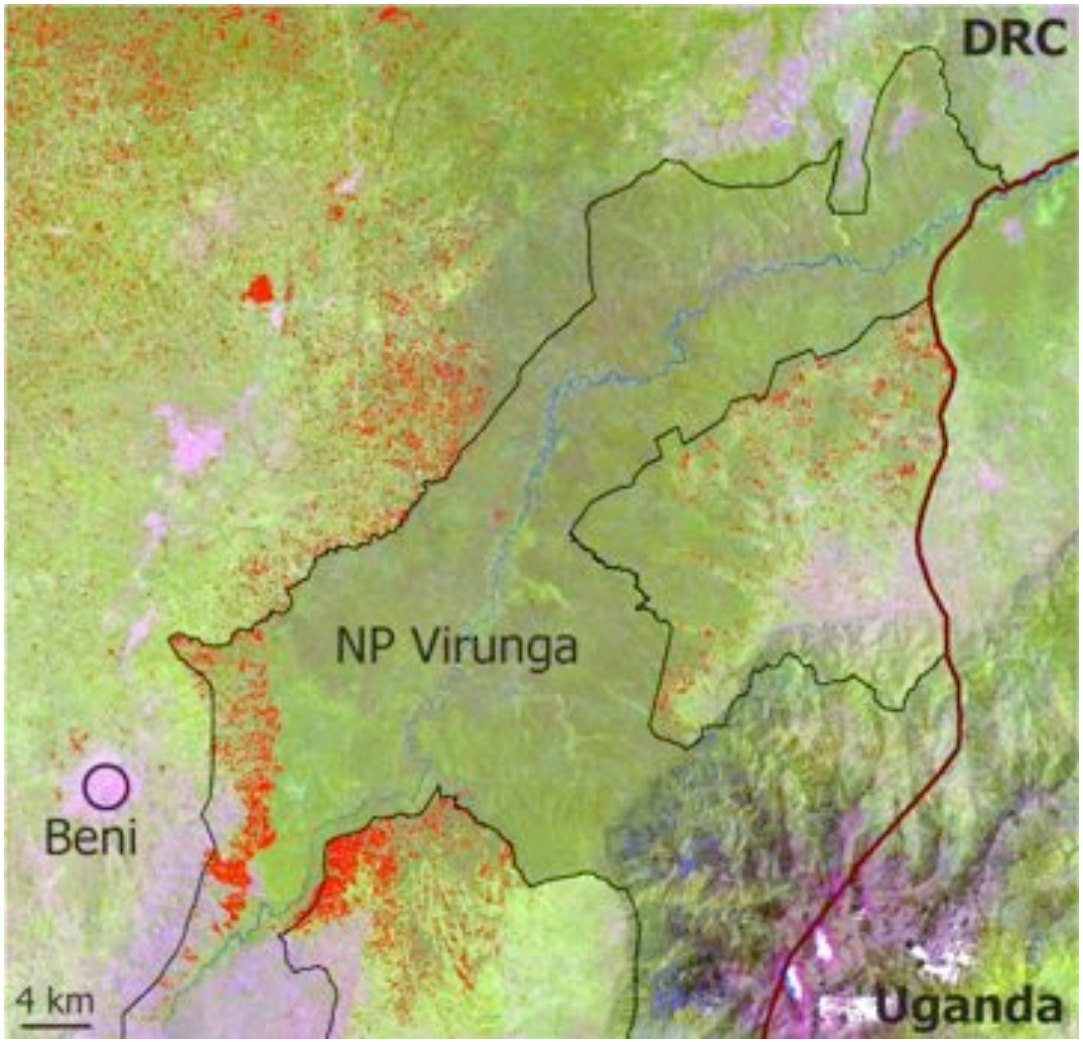
Virunga National Park



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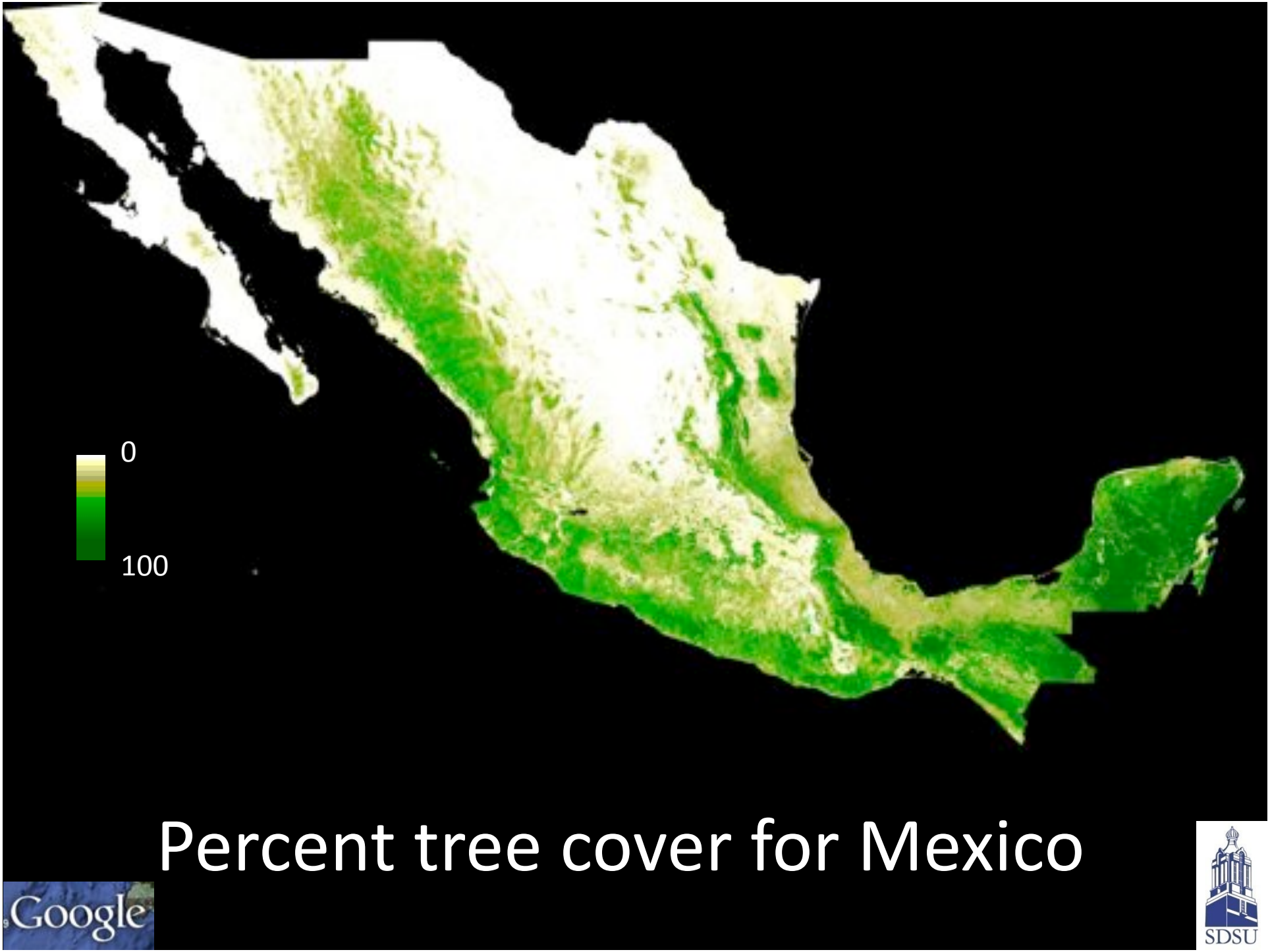
Forêts d'Afrique centrale évaluées par télédétection
FACET

Étendue et perte du couvert forestier en République démocratique du Congo de 2000 à 2010

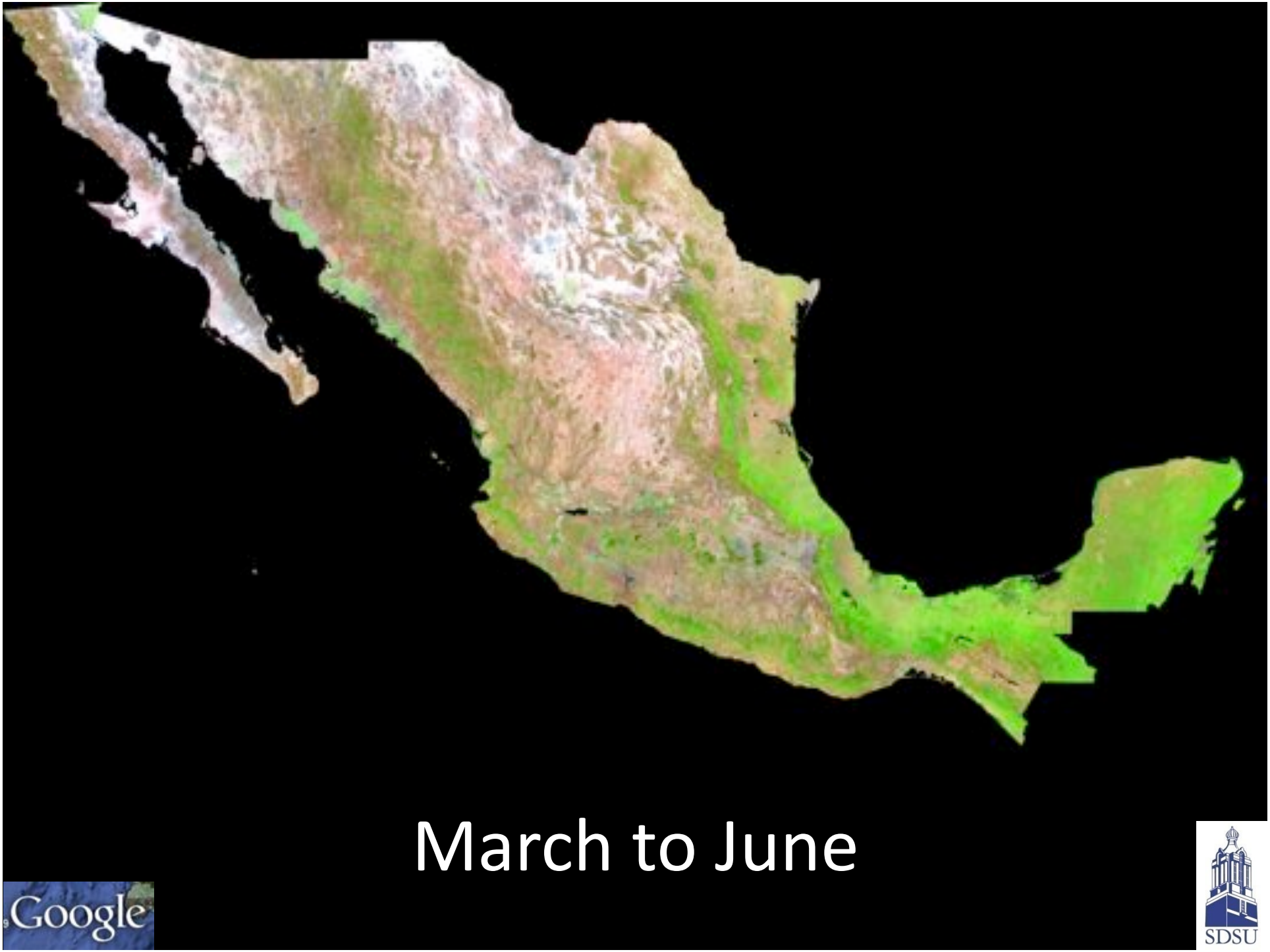
Observatoire satellital des forêts d'Afrique centrale (OSFAC)
Université d'État du Dakota du Sud (SDSU)
Université du Maryland (UMD)

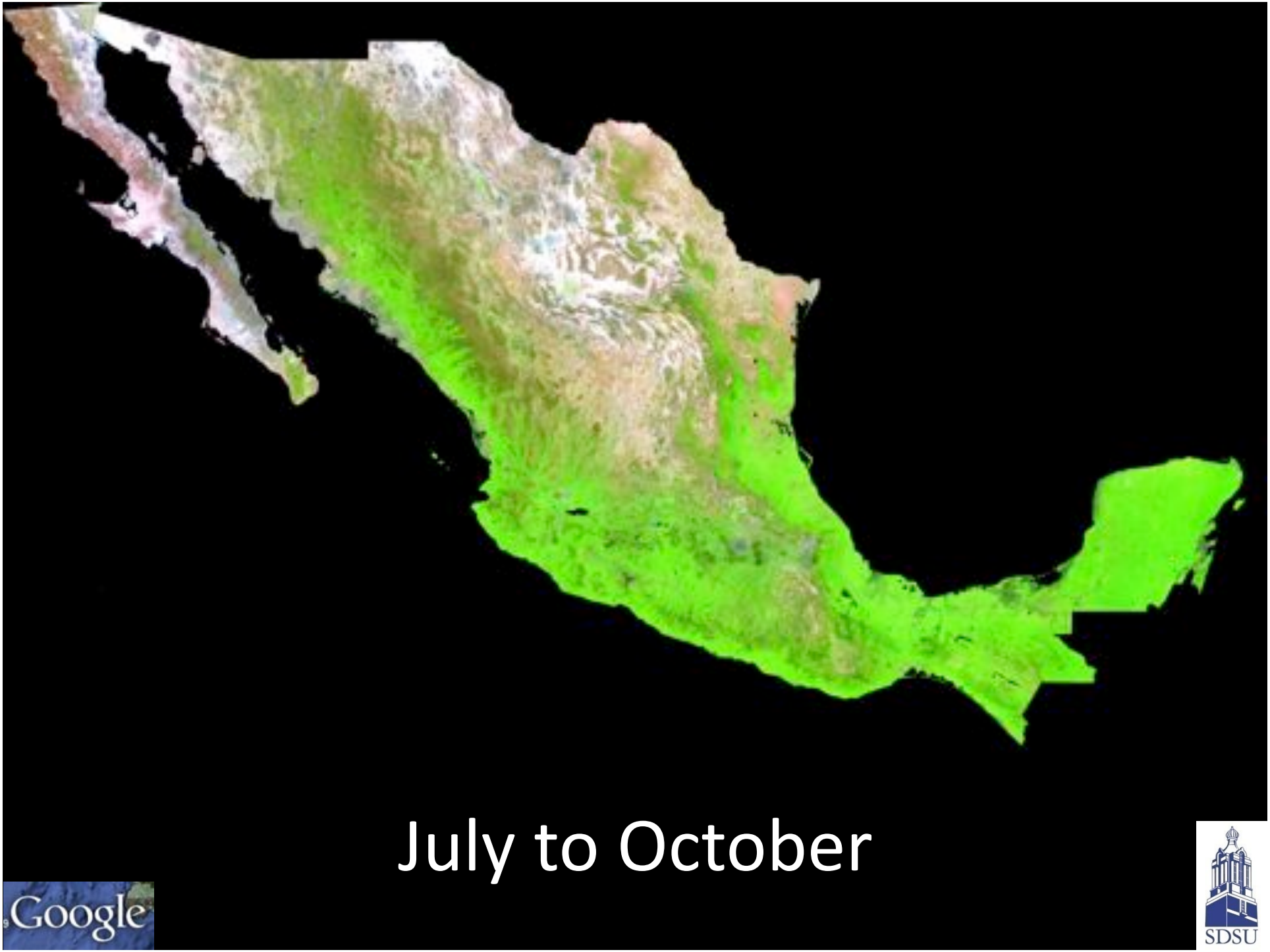
http://osfac.net/facet.html

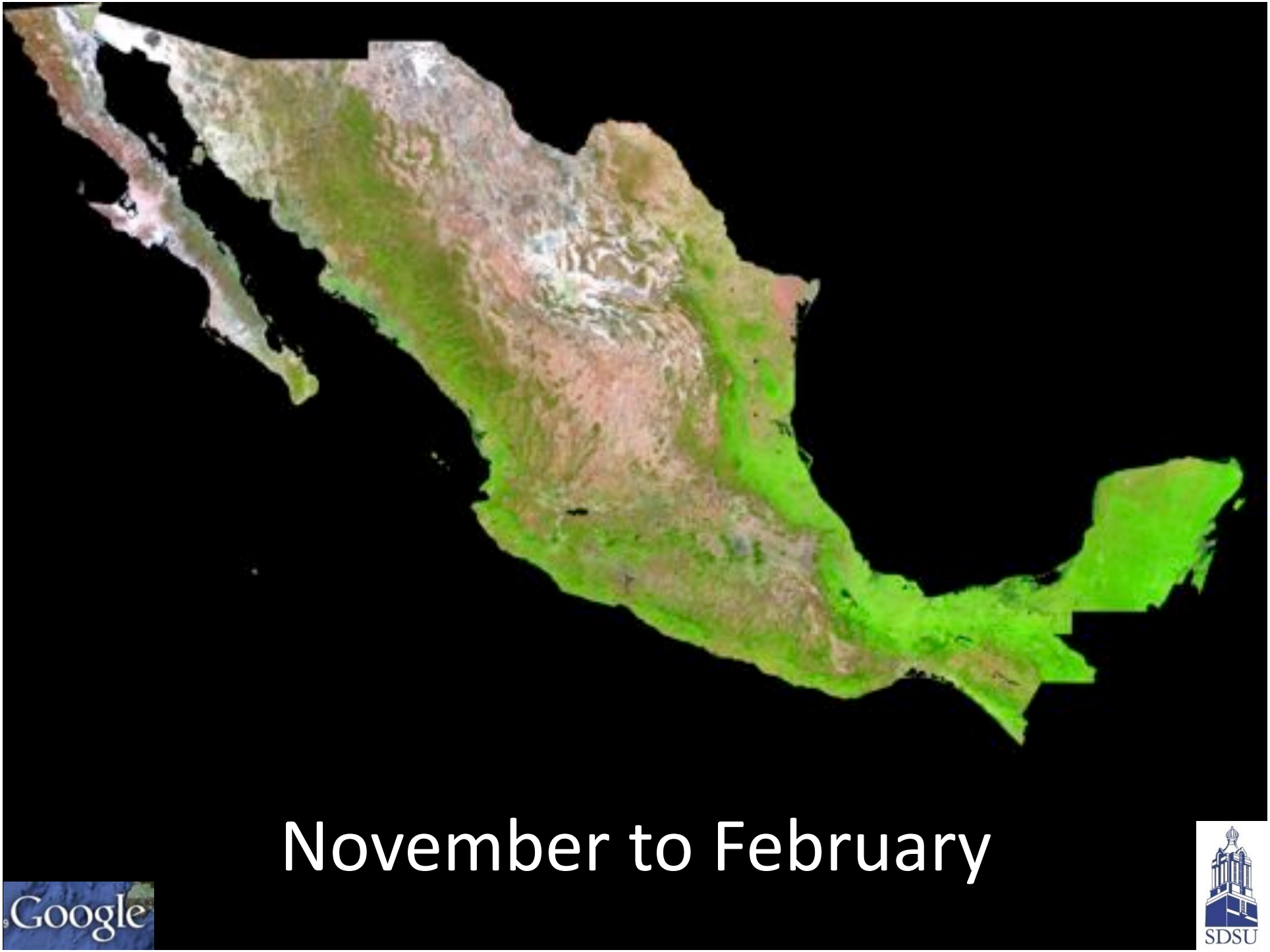
SDSU

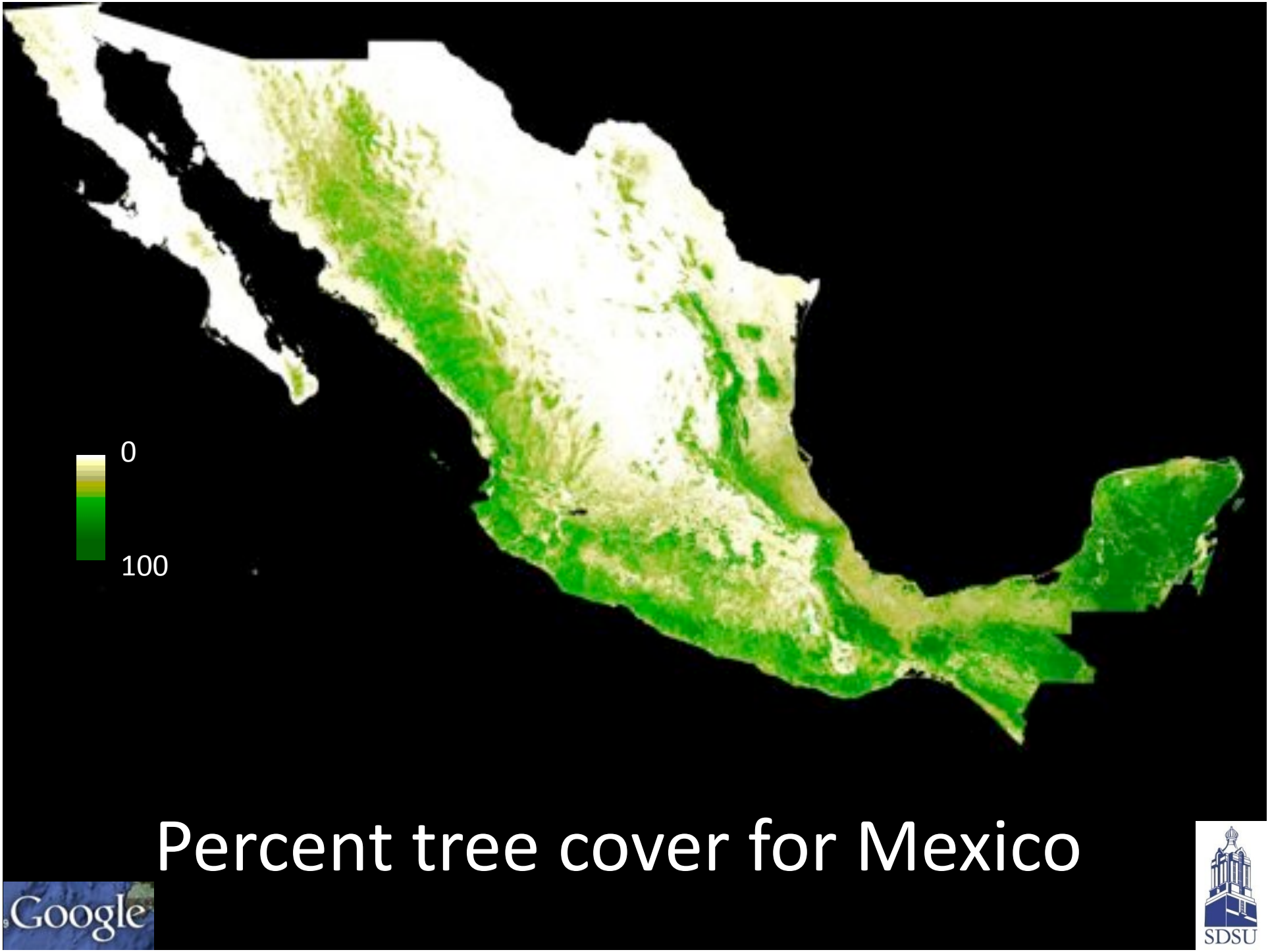


Percent tree cover for Mexico

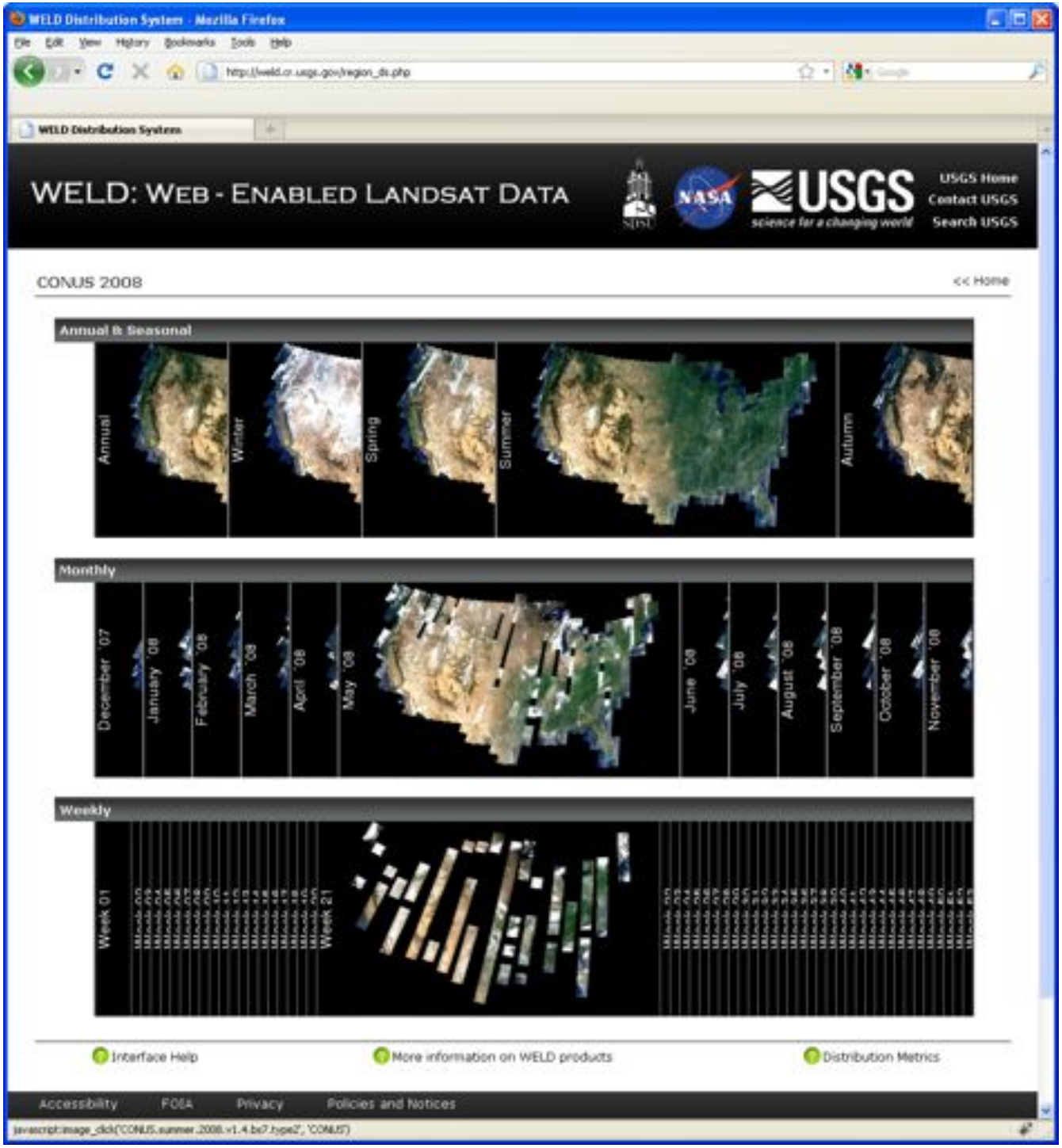

March to June
Google
SDSU


July to October
Google
SDSU


November to February



Percent tree cover for Mexico



David Roy,
SDSU

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WELD Land Cover

- Vegetation Continuous Field approach
  - 30 meter sub-pixel fractional cover estimates
  - Produced annually
    - Maximum percent tree cover
    - Maximum percent vegetation (excluding tree cover)
    - Minimum percent bare ground
    - Minimum surface water extent
    - Minimum snow/ice extent (nested within bare ground)
  - Test products include weekly bare ground, water, snow/ice

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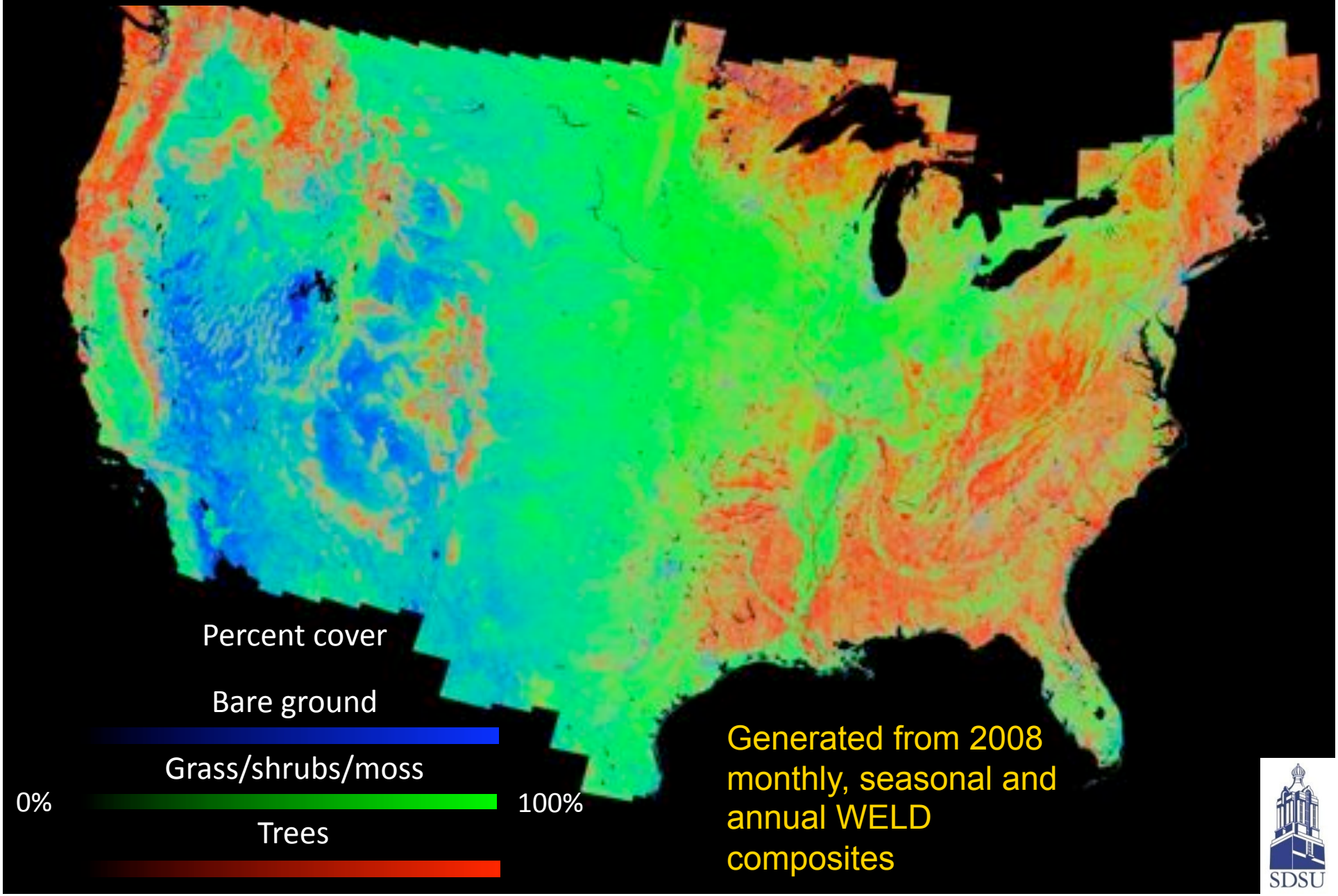
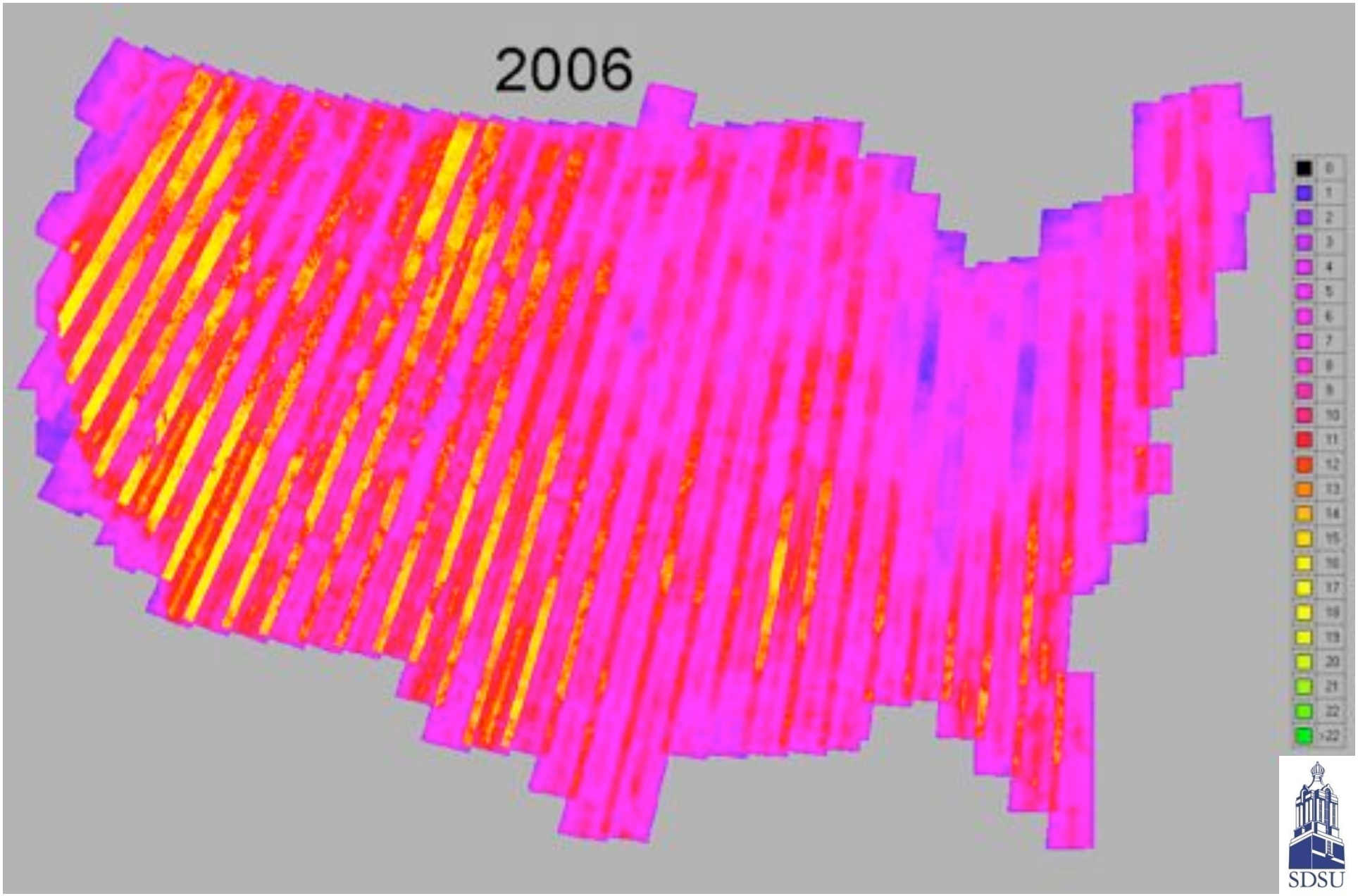
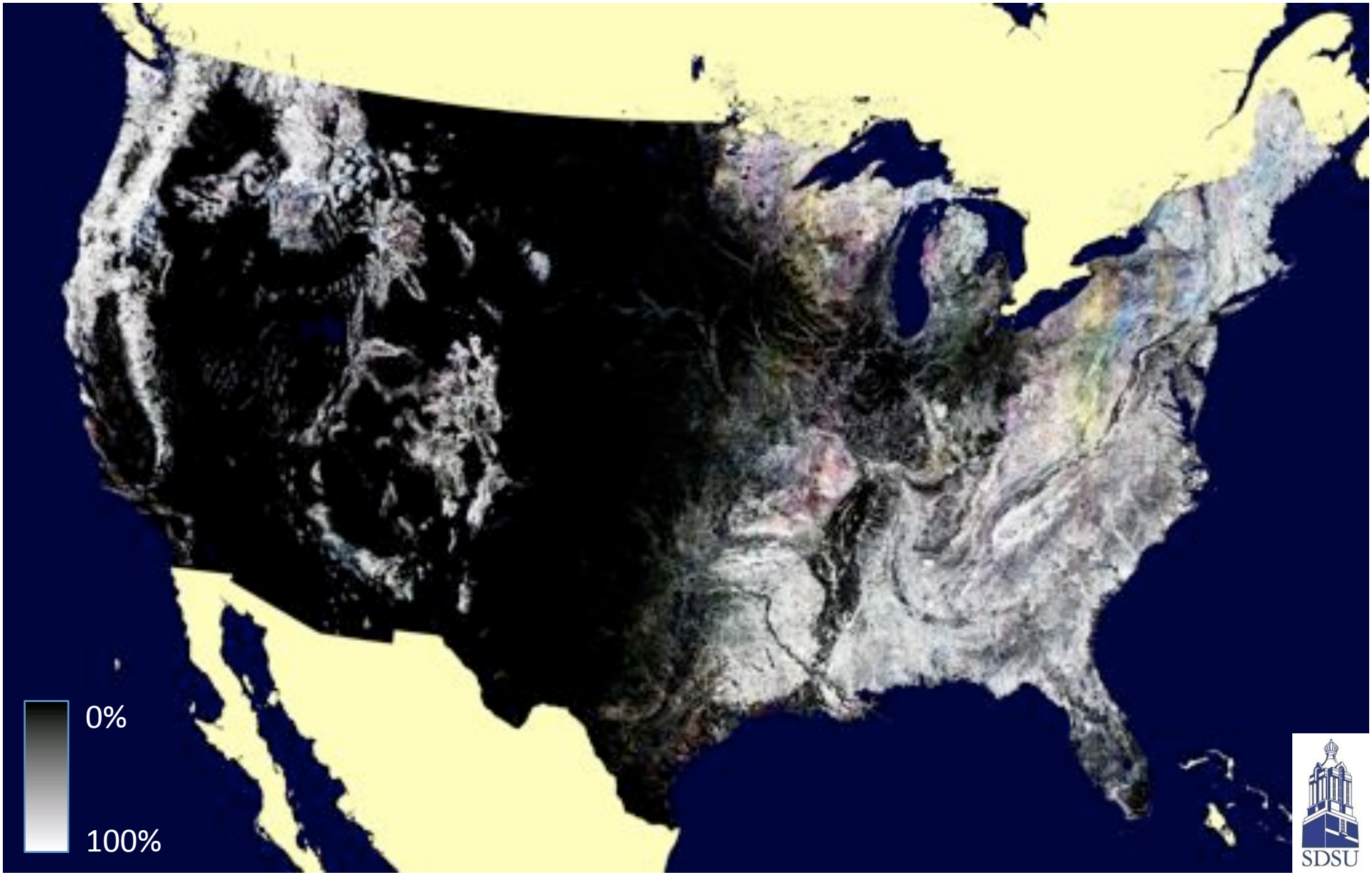
CONUS 30m Vegetation Continuous Fields (%)



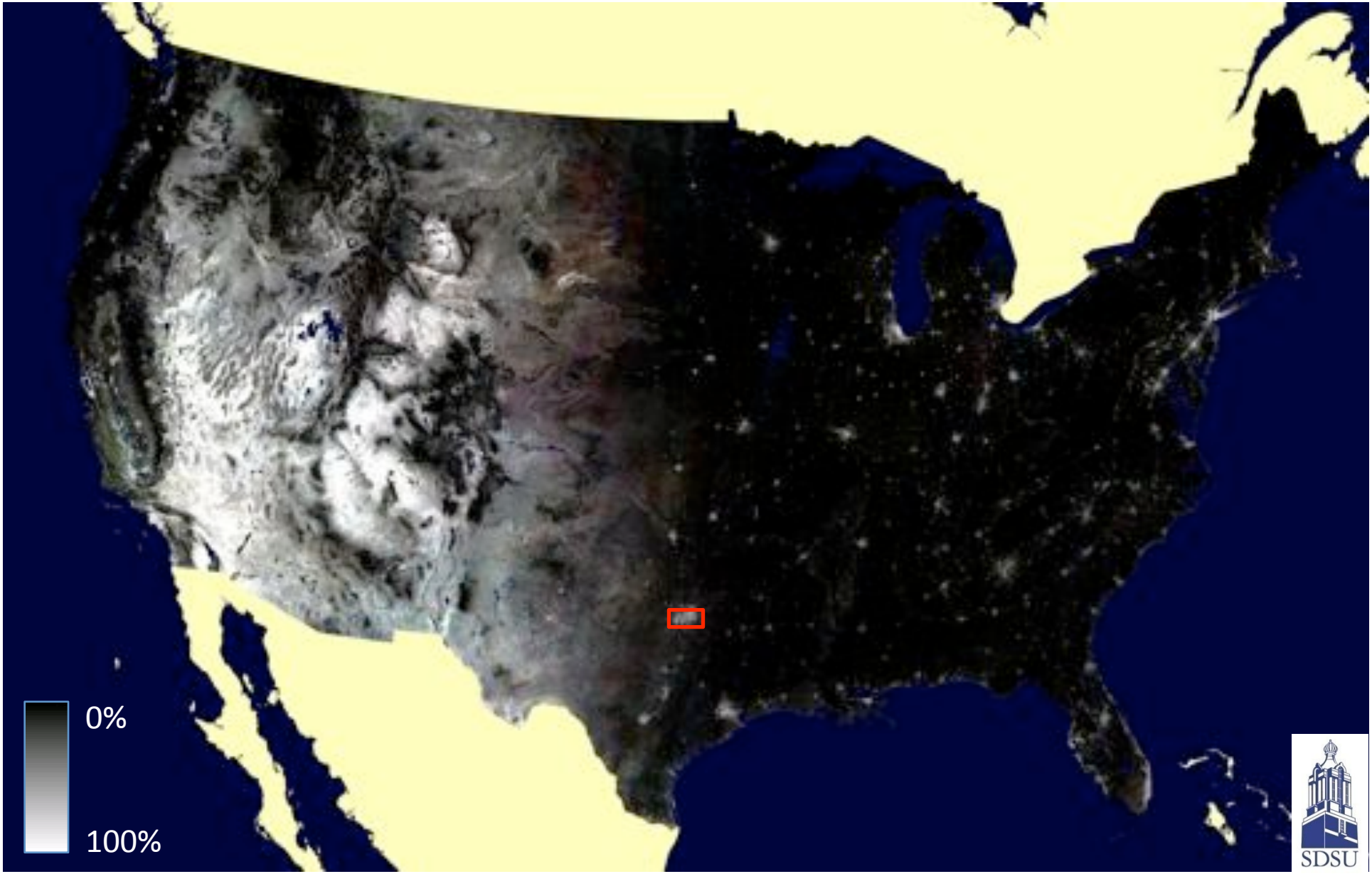
Growing season high quality observation counts



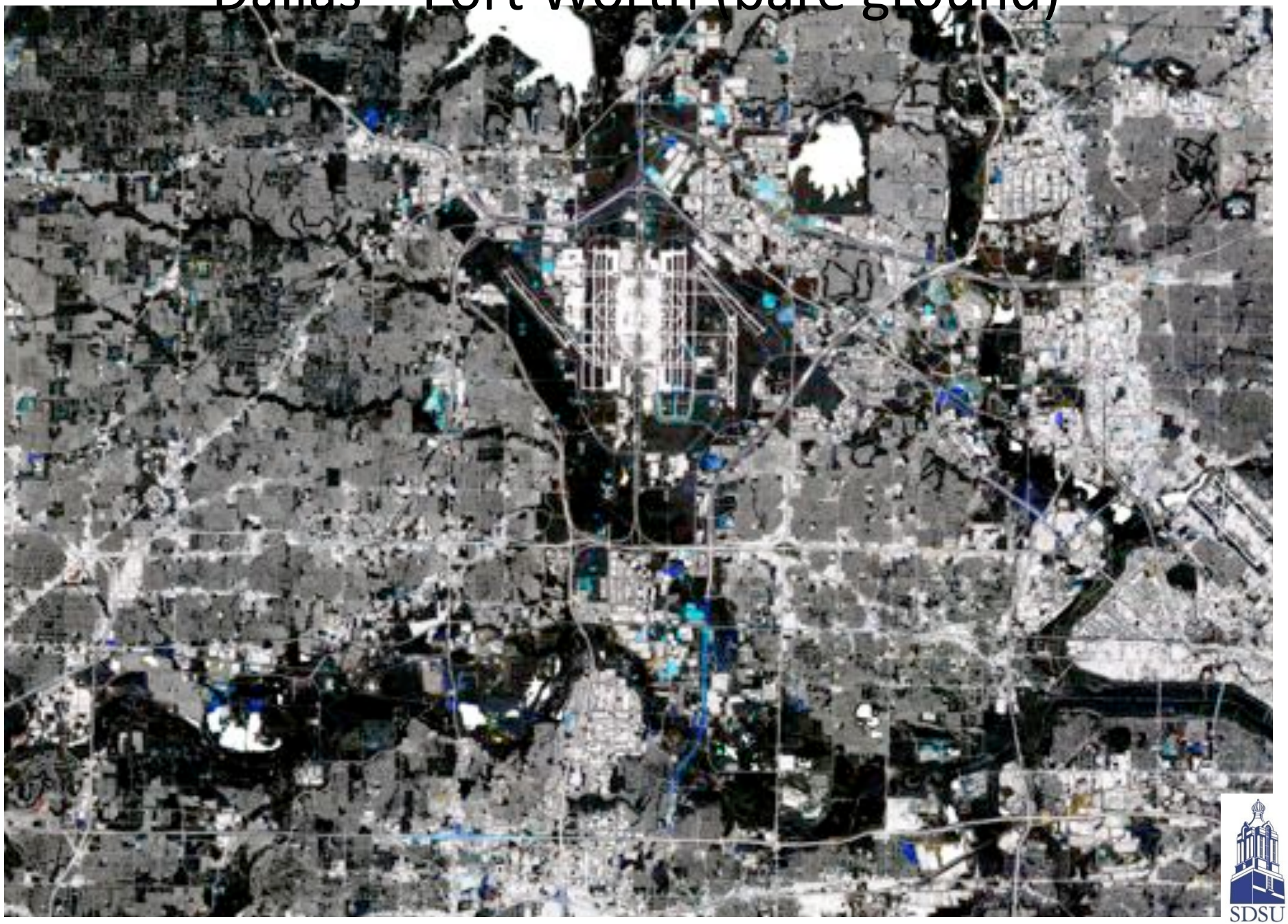
Five years of percent tree cover



Five years of percent bare ground



Dallas – Fort Worth (bare ground)



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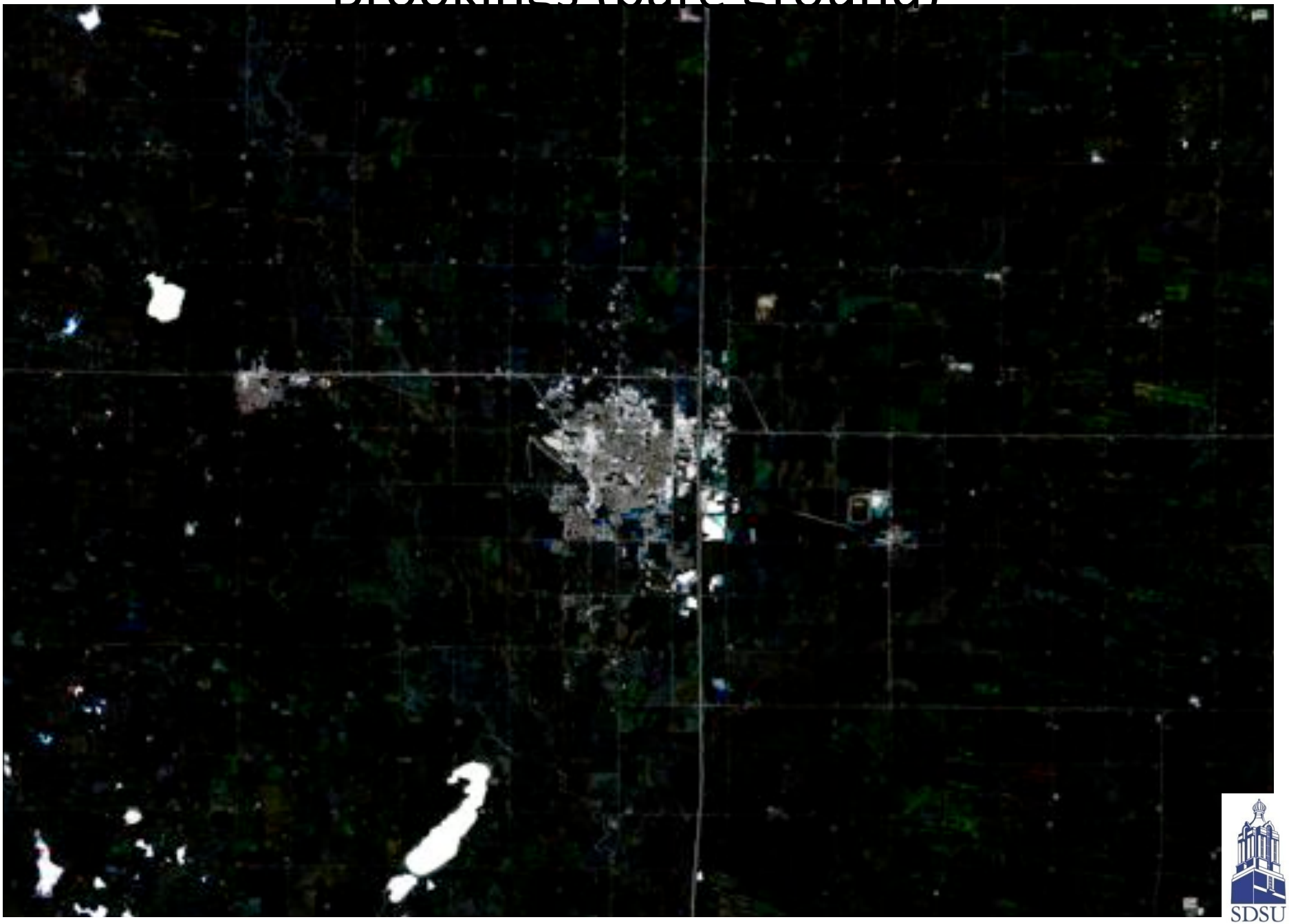
Brookings (bare ground)



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North Carolina coastal plain (tree cover)

Grey-scale = no change, blue/cyan = increase in tree cover, red/yellow = decrease in tree cover

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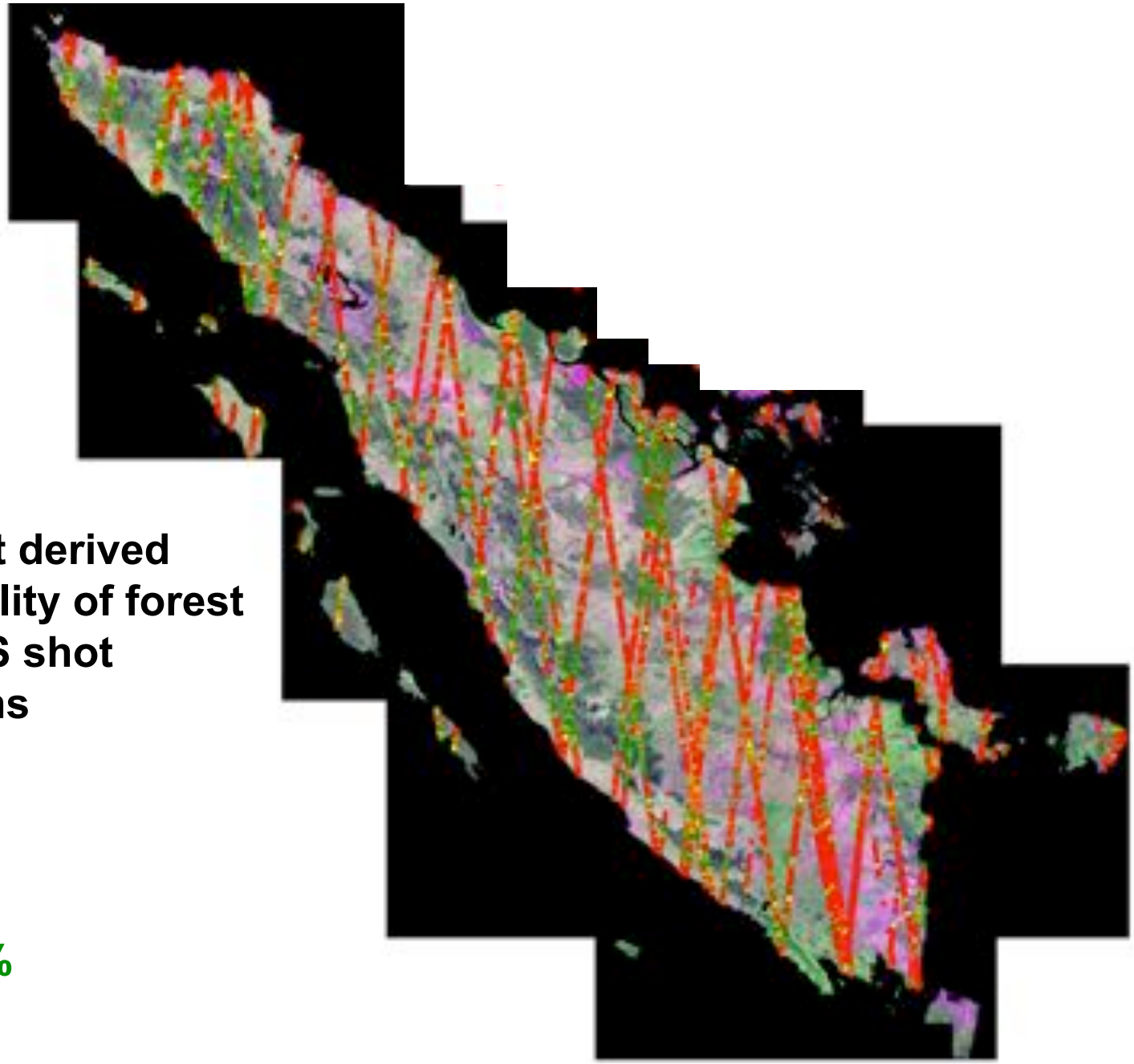
Science of Terra and Aqua

- Integrating MODIS, Landsat and GLAS in characterizing forest extent, structure and change

- MODIS provides consistent time-series inputs and results that enable the radiometric normalization and mass-processing of the Landsat archive, to be calibrated for forest structure characterization using samples of GLAS data

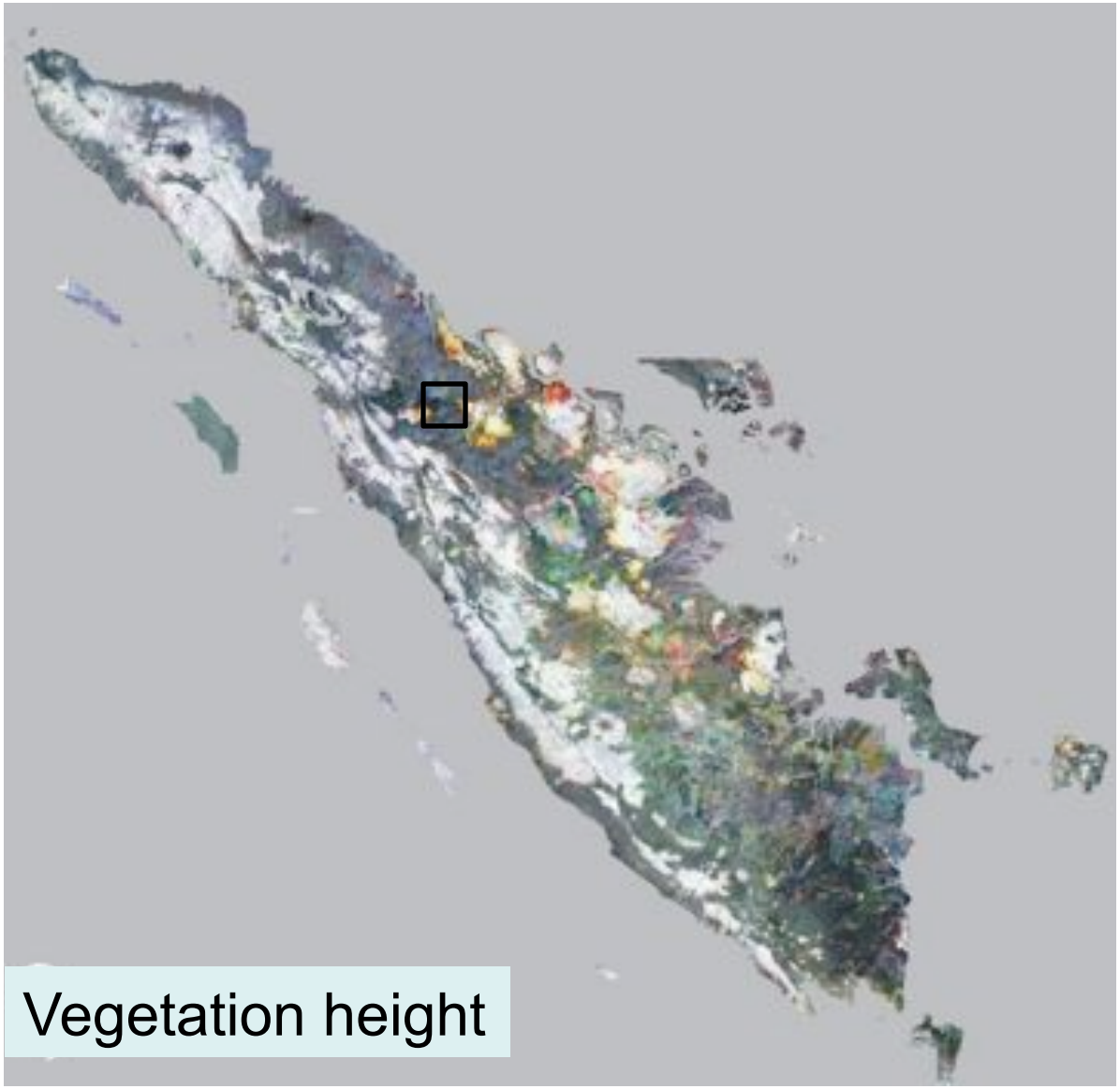
GLAS shots over Sumatra, Indonesia on Landsat 2004-2006 composite 5/4/7



Landsat derived probability of forest at GLAS shot locations

0-25%
26-50%
51-75%
76-100%

GLAS-calibrated Landsat (r=2001,g=2004,b=2007)

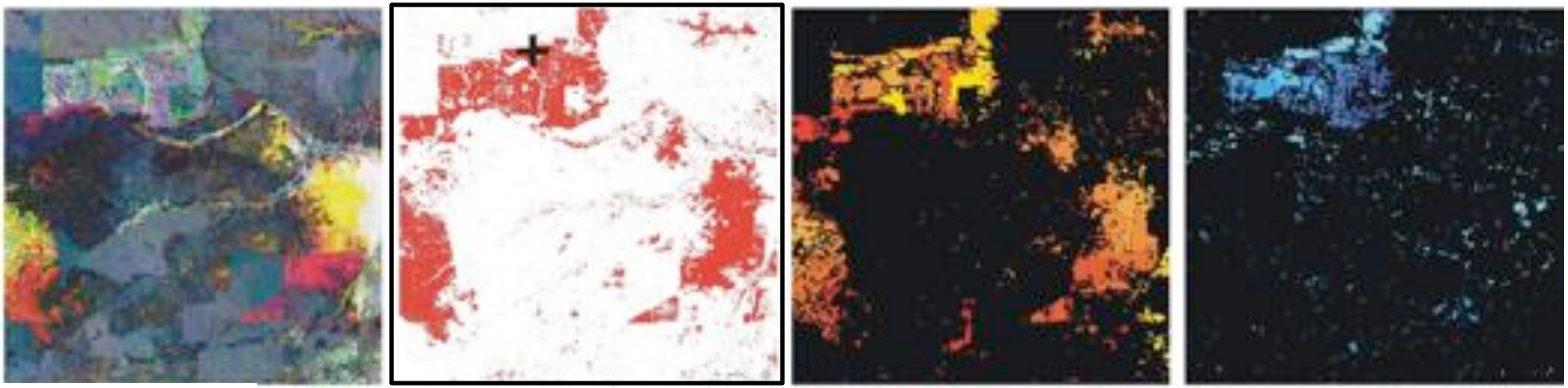


GLAS-calibrated Landsat (r=01,g=04,b=07)

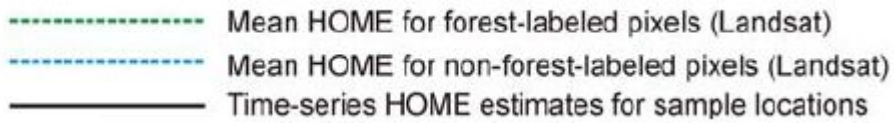
Landsat forest cover loss (00-08)

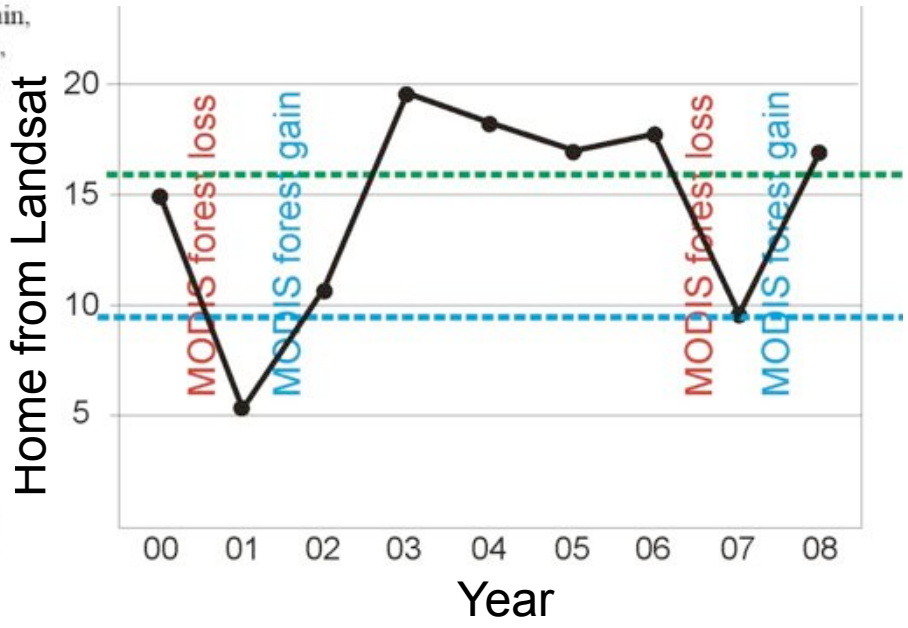
MODIS forest cover loss (00-08)

MODIS forest cover gain (00-08)

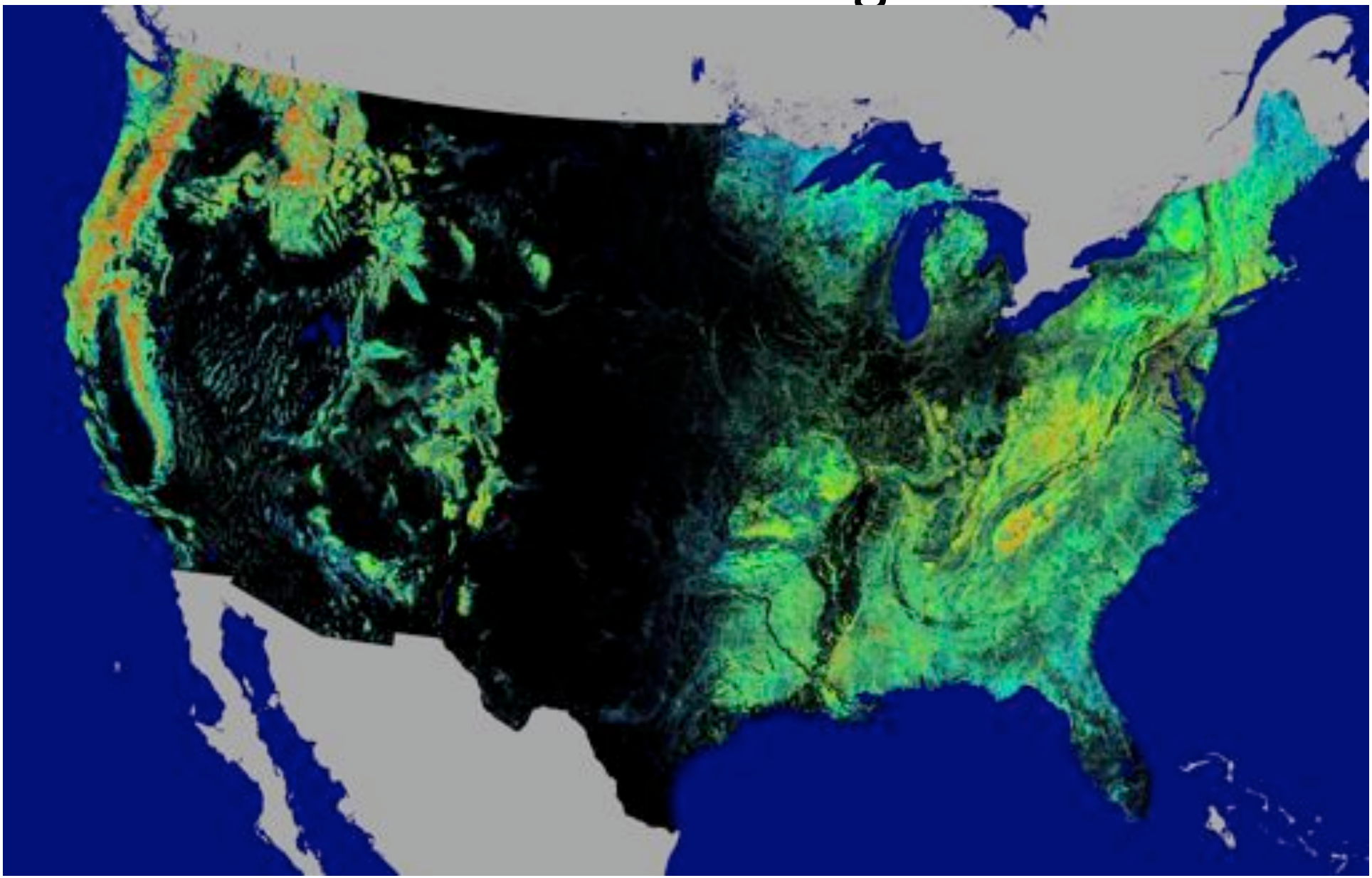


Subsets, 60km x 60km, of change products from Sumatra, Indonesia. Locations (a-f) of these areas are shown in Figure 5 a). Column one is an r-g-b of three year median vegetation height estimates where bright is tall vegetation and dark is short vegetation; column two is our existing Landsat forest clearing estimate in red for 2000 to 2008 (not calibrated using GLAS); columns three and four are MODIS annual forest cover loss and gain, respectively. For forest cover loss, = 00-01, =01-02, = 02-03, = 03-04, = 04-05, = 05-06, = 06-07, = 07-08. For forest cover gain, = 00-01, =01-02, = 02-03, = 03-04, = 04-05, = 05-06, = 06-07, = 07-08.





Tree cover height



Red > 25m, green 10-25m, blue 5-10m, black < 5m

Data requirements for global land cover monitoring

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

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Factors affecting Landsat processing that differ from heritage MODIS methods

- Acquisition strategy
- Observation frequency (scene overlap/SLC-off)
- Observation quality (clouds/haze/shadow)
- Phenology

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Characterizing land cover with MODIS and Landsat

- Methods for generic and automated land cover change monitoring for large areas using Landsat and MODIS are quickly maturing
- Landsat's infrequent and inconsistent acquisition rate makes annual updates of land cover difficult for many parts of the world
- More robust validation protocols and investments are needed, as data products will proliferate with new capabilities
- For developing countries needing to monitor forest cover, the open archive is a boon
  - However, high-performance computing is needed as single image-based methods will not work for many regions
  - How is capacity developed in this context?

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Some references

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- Potapov P., Hansen M. C., Stehman S. V., Loveland T. R., Pittman K., 2008, Combining MODIS and Landsat imagery to estimate and map boreal forest cover loss, *Remote Sensing of Environment,* 112, 3708-3719.

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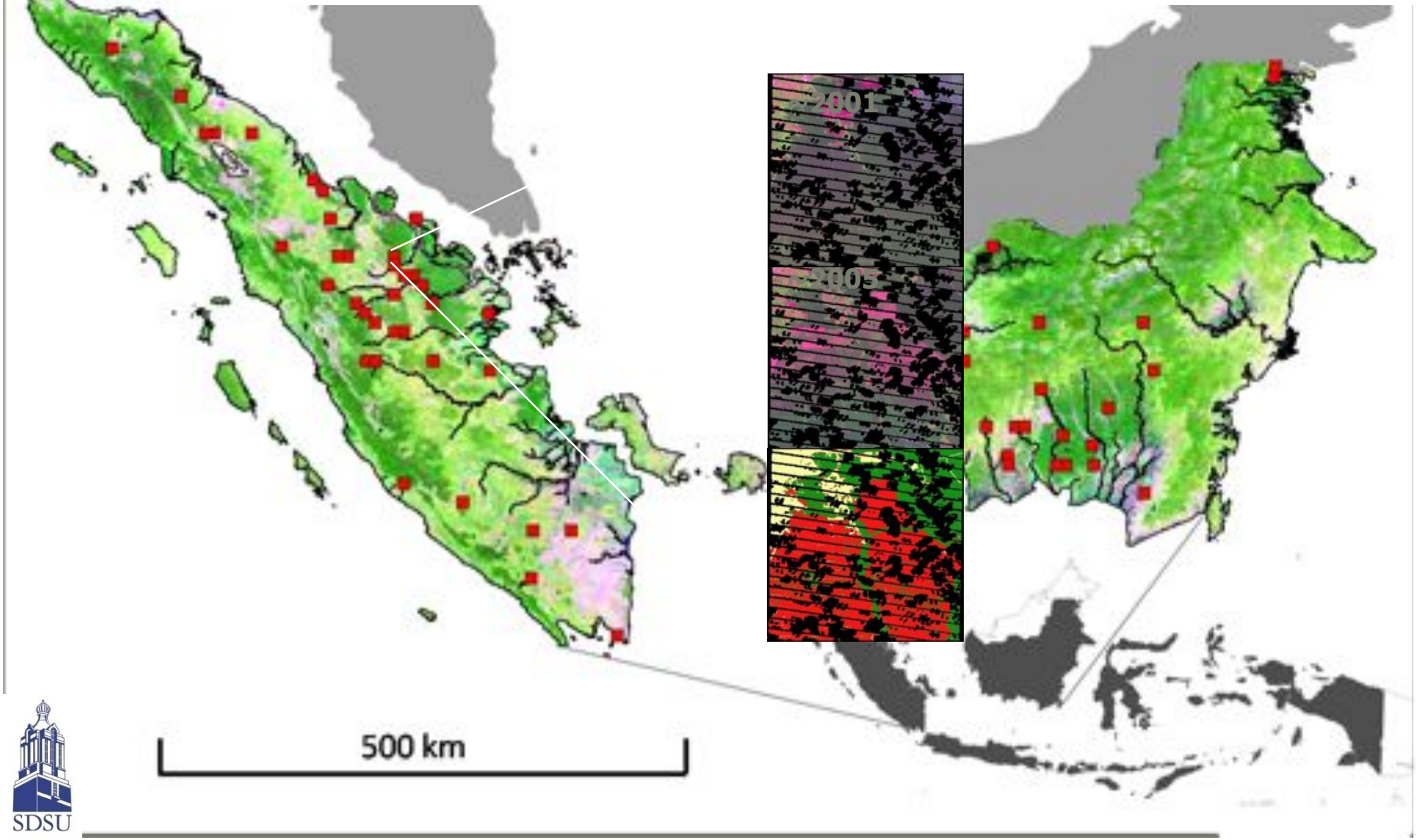
Validation data of forest cover loss 2000-2005

- Expert interpreted sample blocks (n = 64)
- Sample based estimate: 2.95% +/- 0.41



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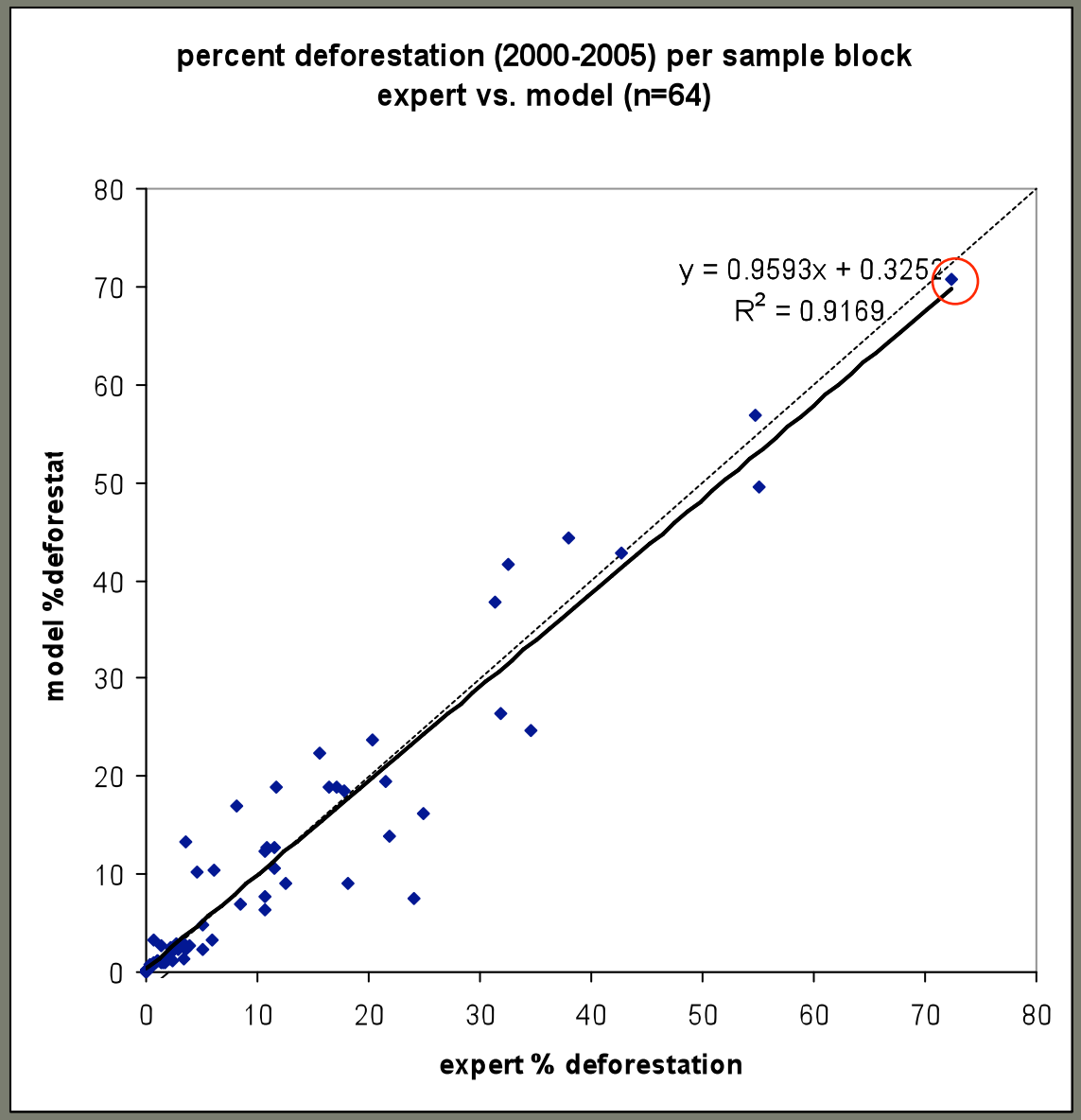
Comparison of model (map) results with expert- interpreted sample blocks II

Model based on full time series analysis per pixel

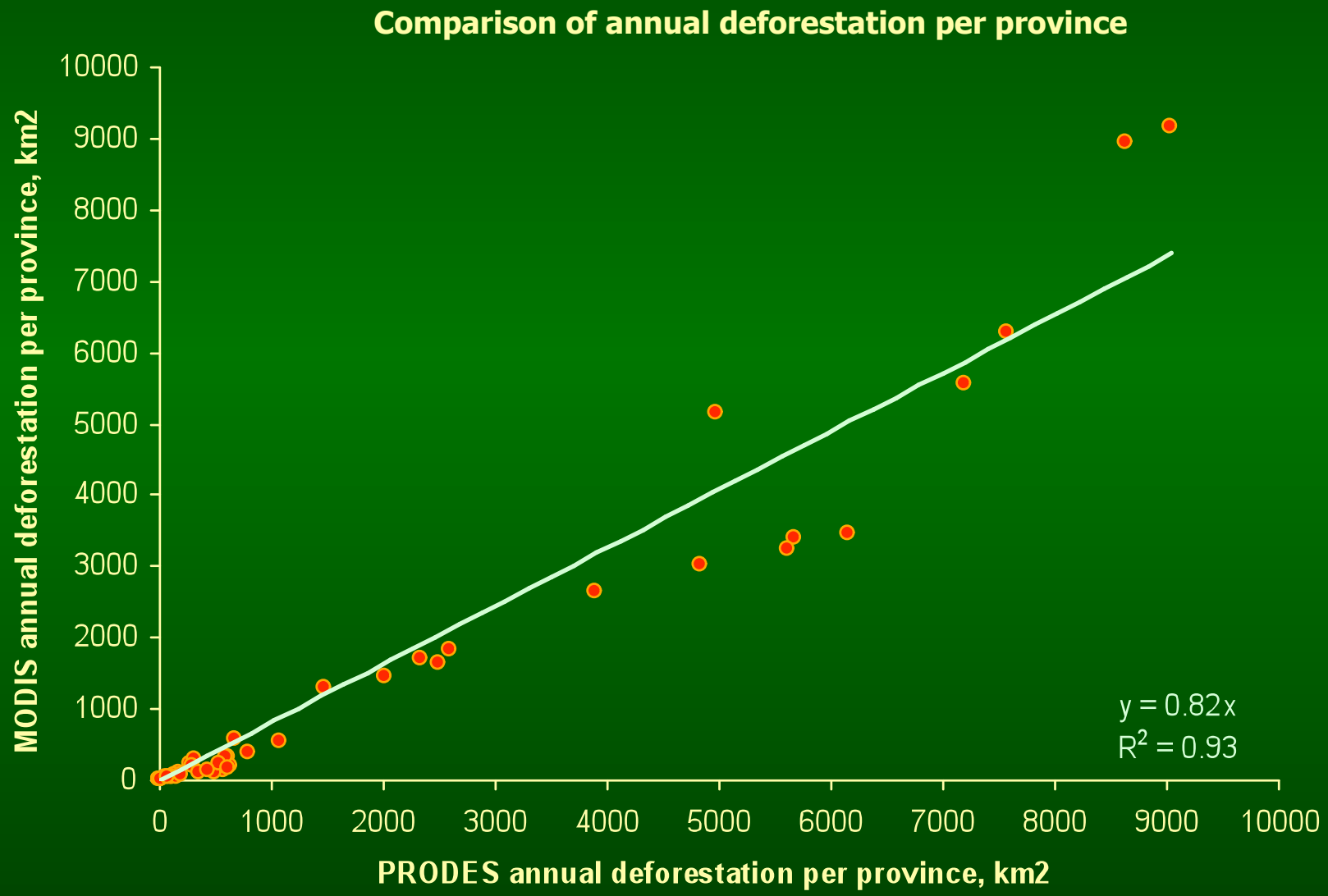


SDSU

Verification

MODIS change analysis verification using independent datasets

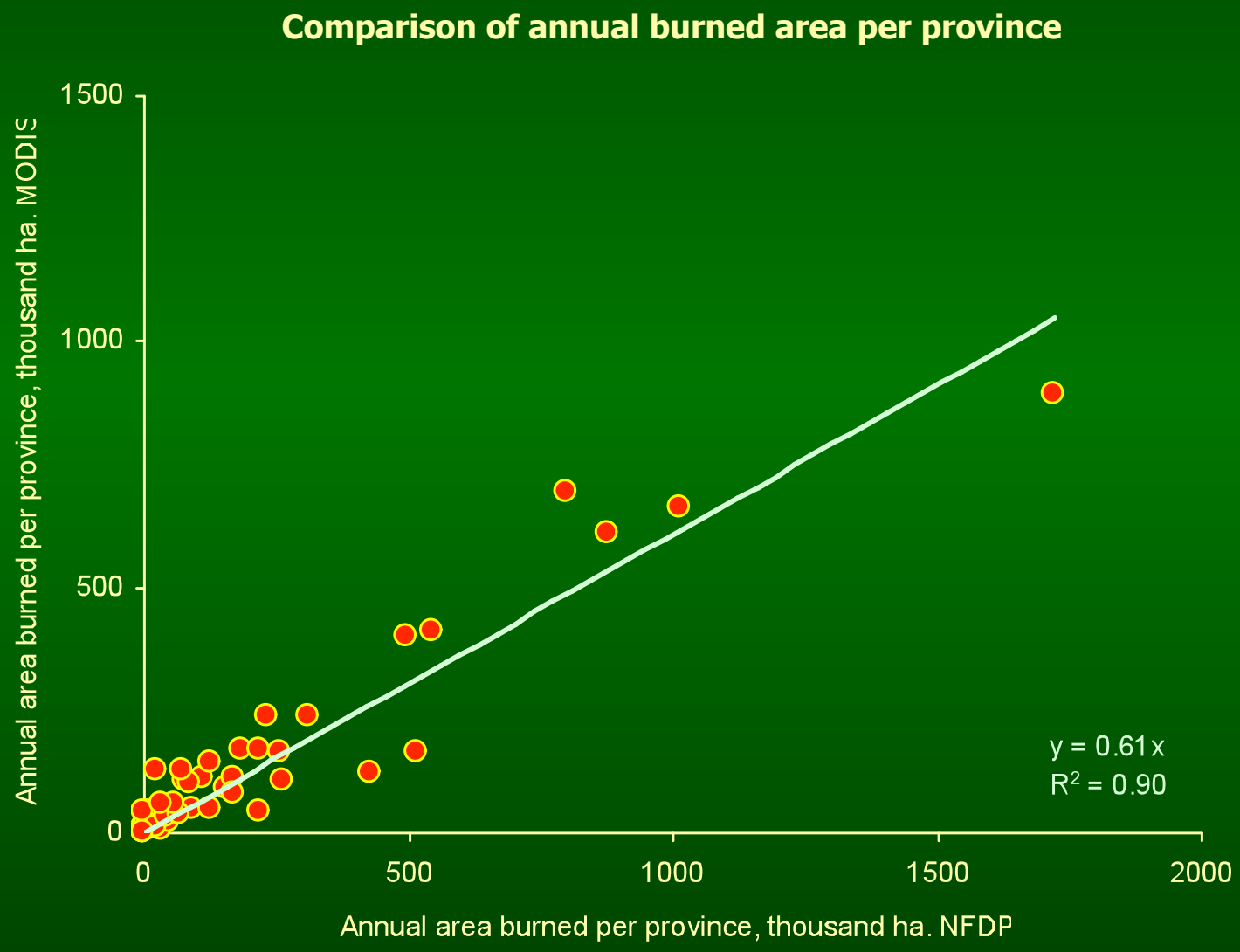
PRODES data for Brazilian Amazon



Verification

MODIS change analysis verification using independent datasets

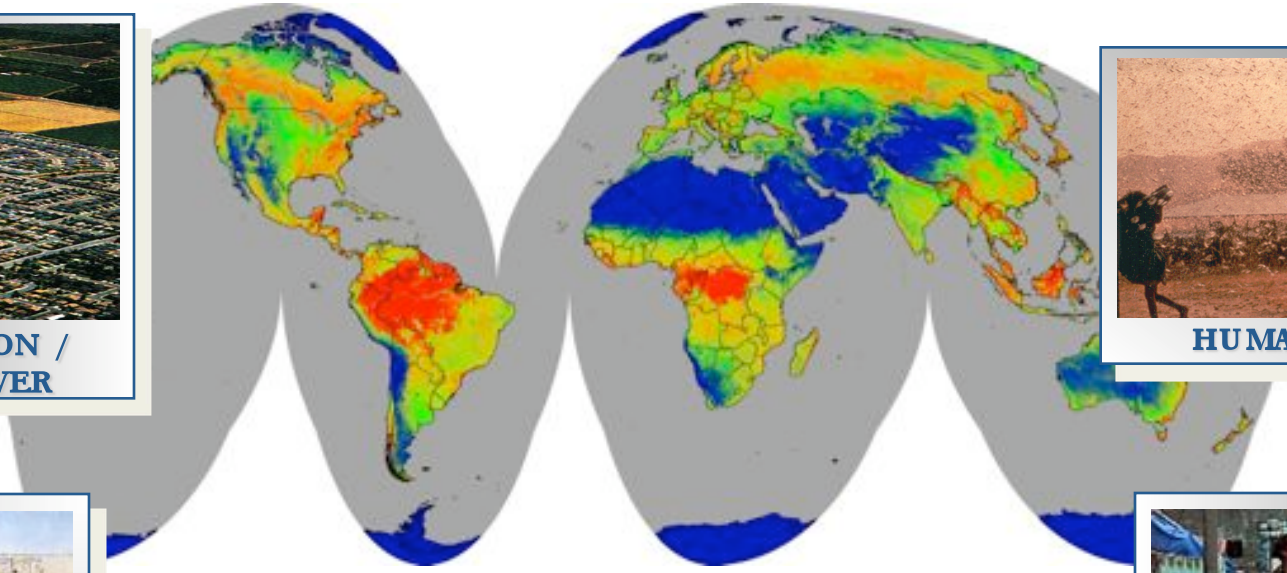
NFDP burned areas data for Canada



Value-added science applications

- **CHALLENGE – DEVELOP GLOBALLY CONSISTENT AND LOCALLY RELEVANT DATA**

POPULATION / LANDCOVER



HUMAN HEALTH

WATER RESOURCES

BIODIVERSITY

AGRICULTURAL / FOREST

NATURAL HAZARD RISK ASSESSMENT