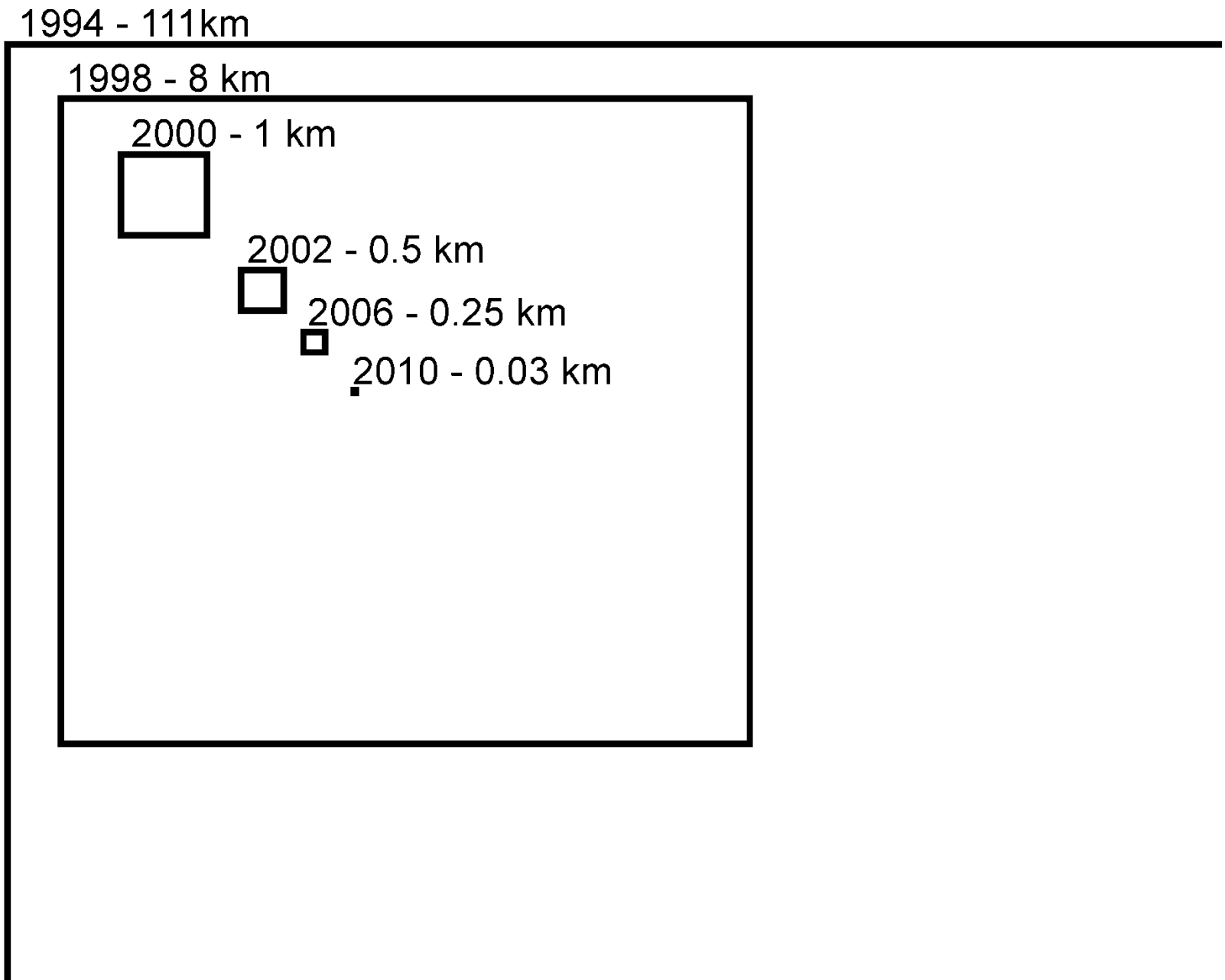
M. Hansen, P. Potapov, M. Broich, S. Stehman, S. Turubanova,
B. Adusei, B. Arunarwati, E. Lindquist and S.Goetz

Producing Composite Imagery and Forest Cover and Change Characterizations

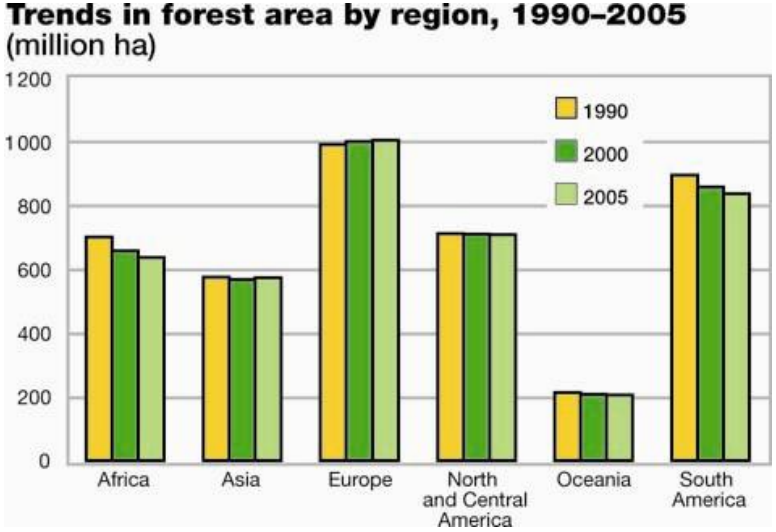
South Dakota State University
Geographic Information Science Center of Excellence

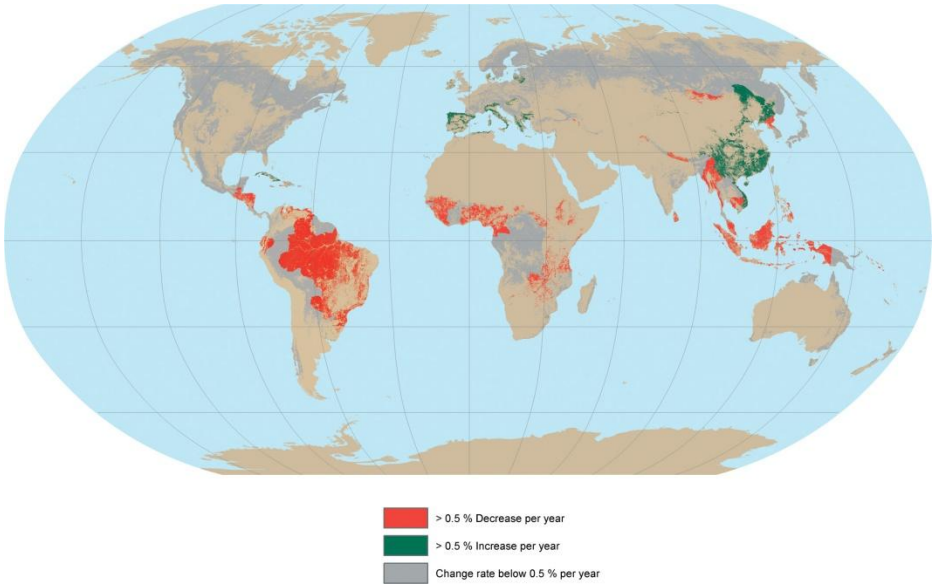


SDSU

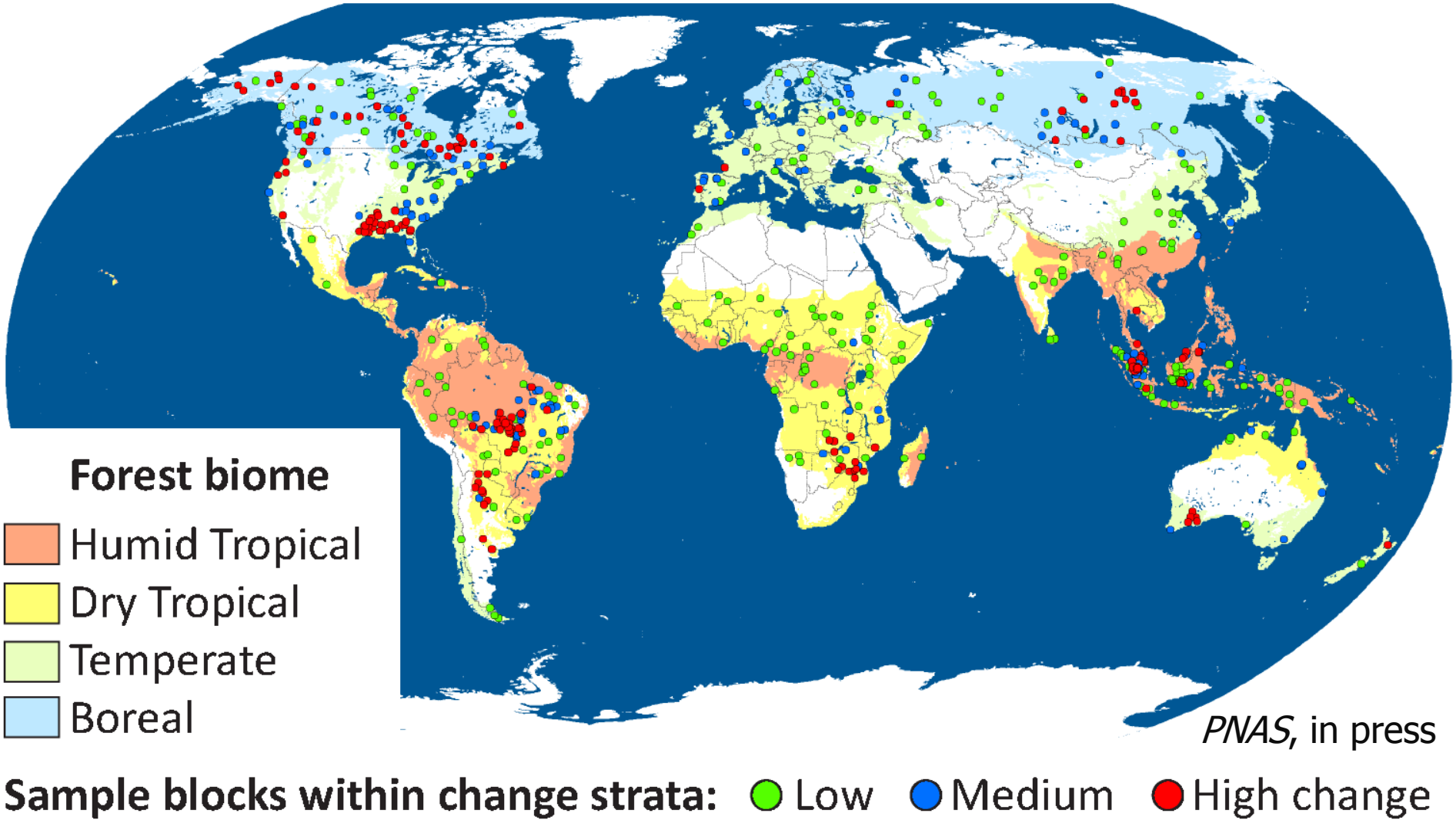
2005 United Nations Food and Agriculture Organization Forest Resource Assessment Report

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

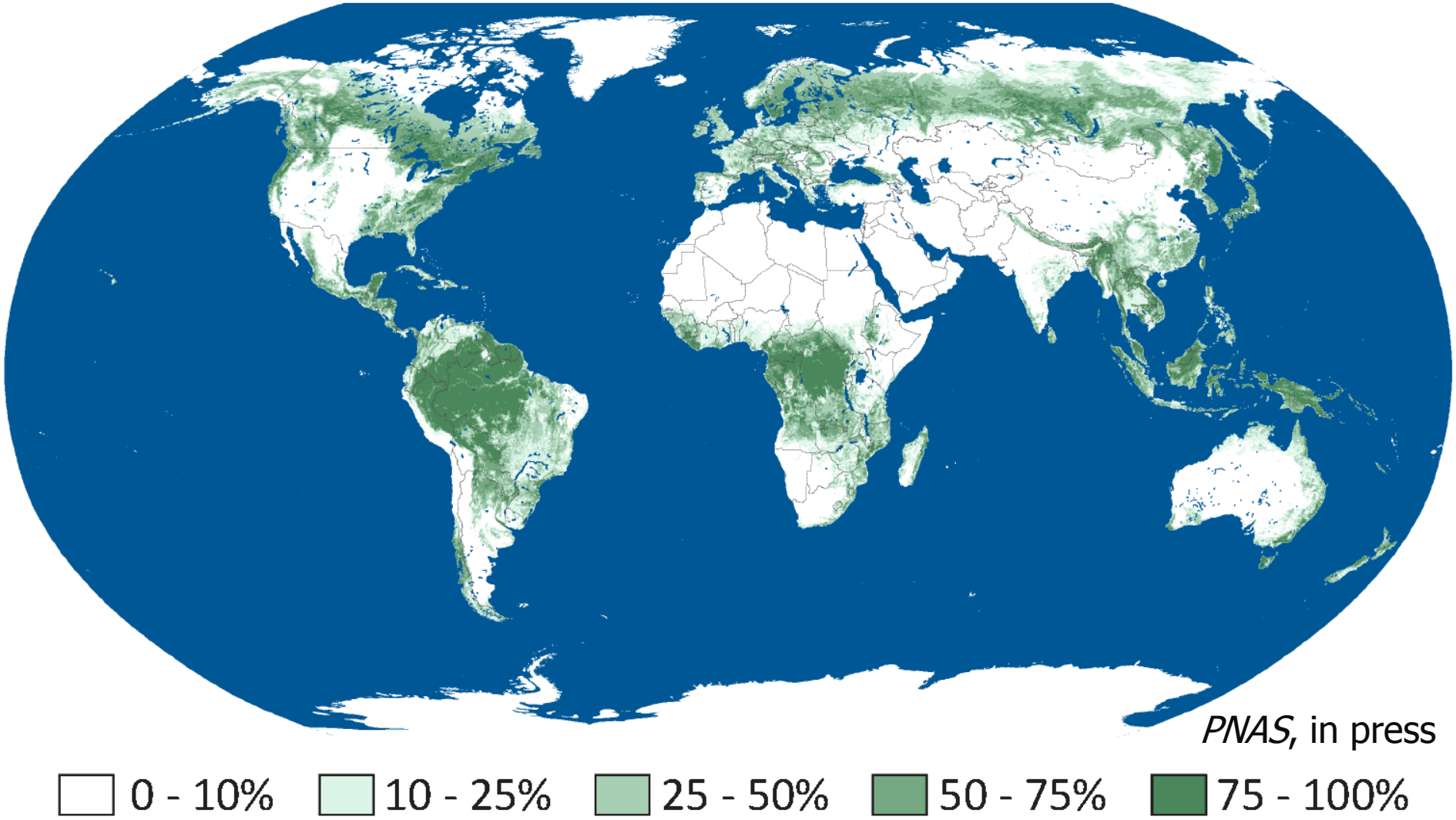




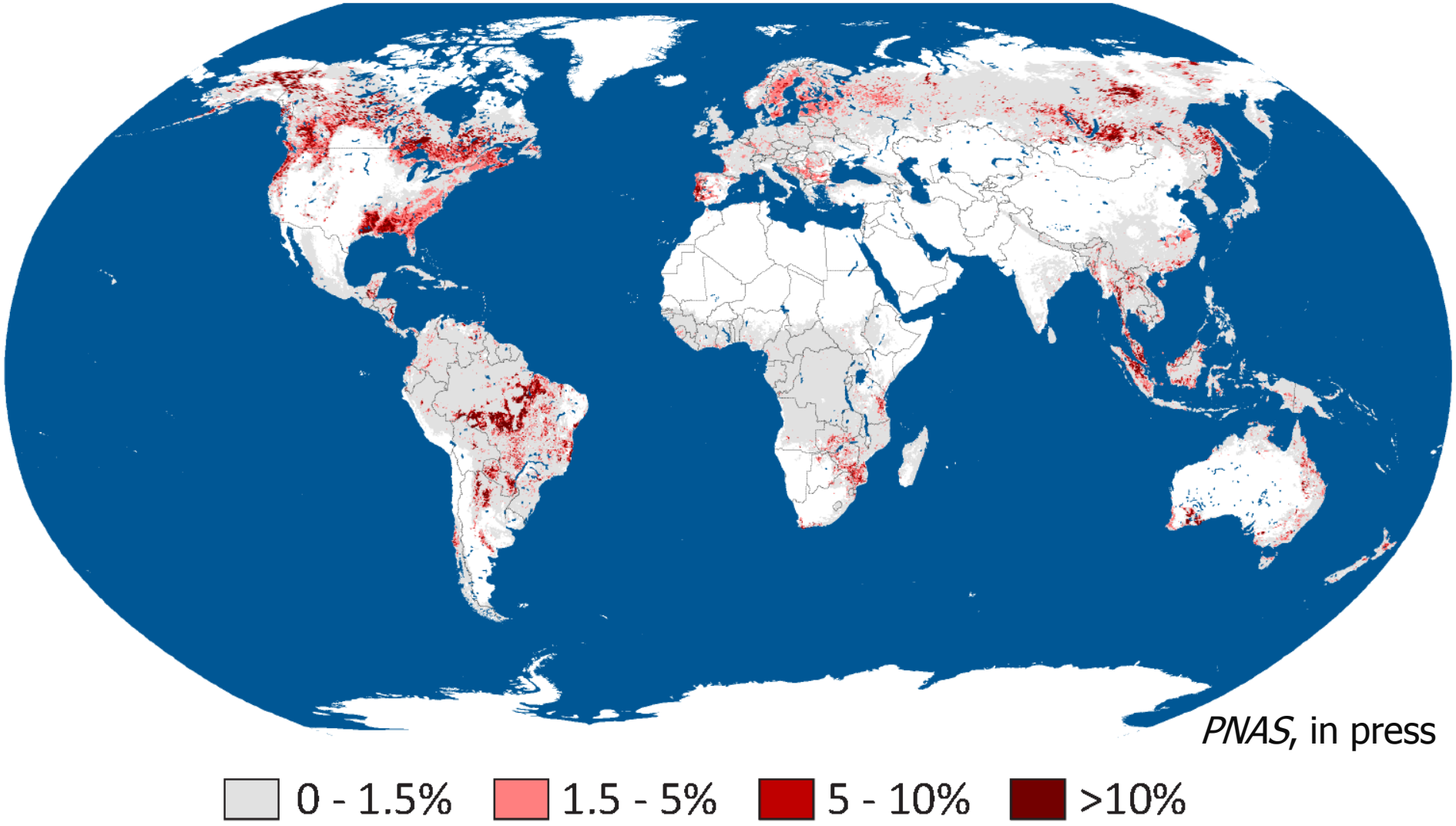
MODIS-stratified Landsat samples



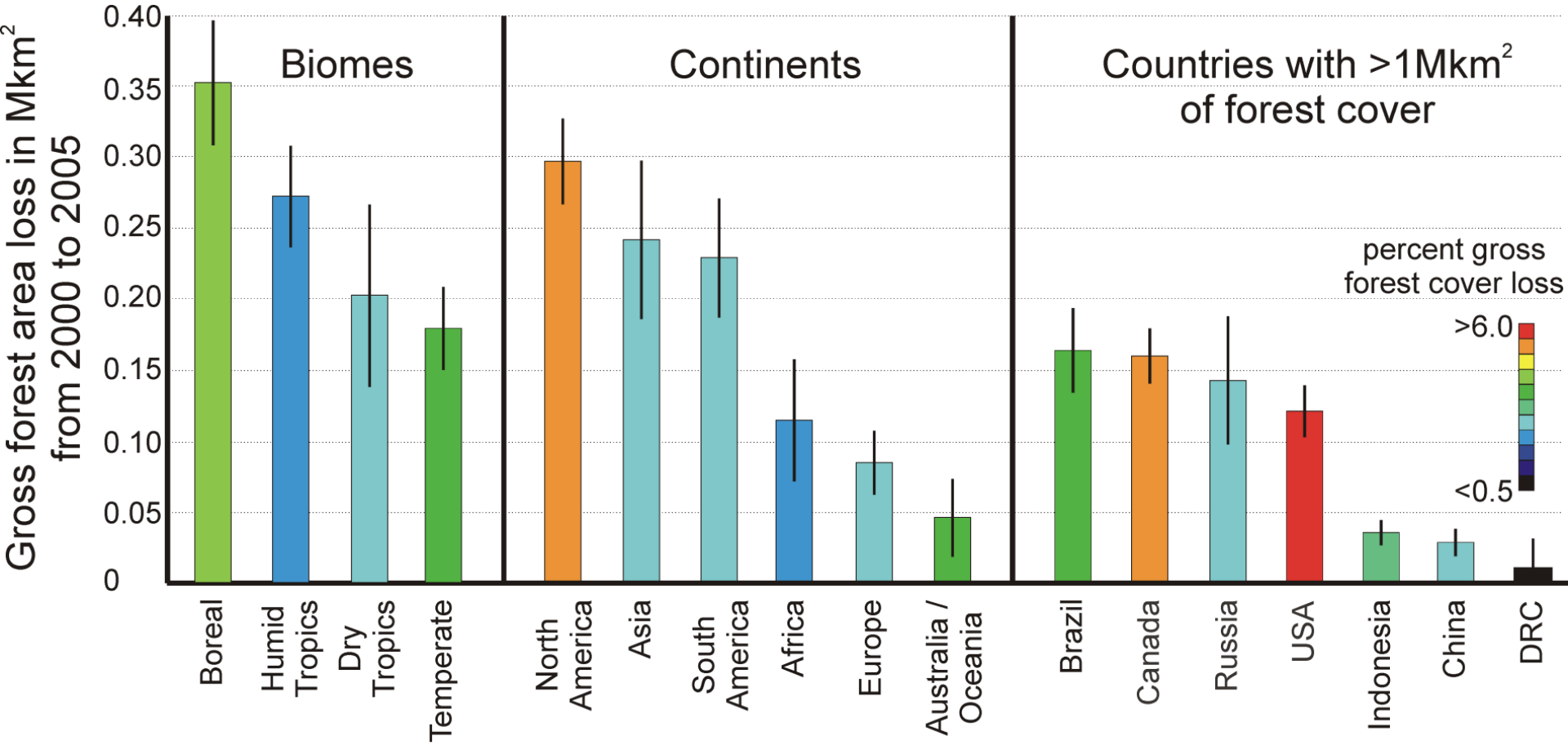
Percent forest cover, 2000



Percent gross forest cover loss, 2000 to 2005



Global gross forest cover loss, 2000 to 2005



PNAS, in press

Data requirements for global forest monitoring

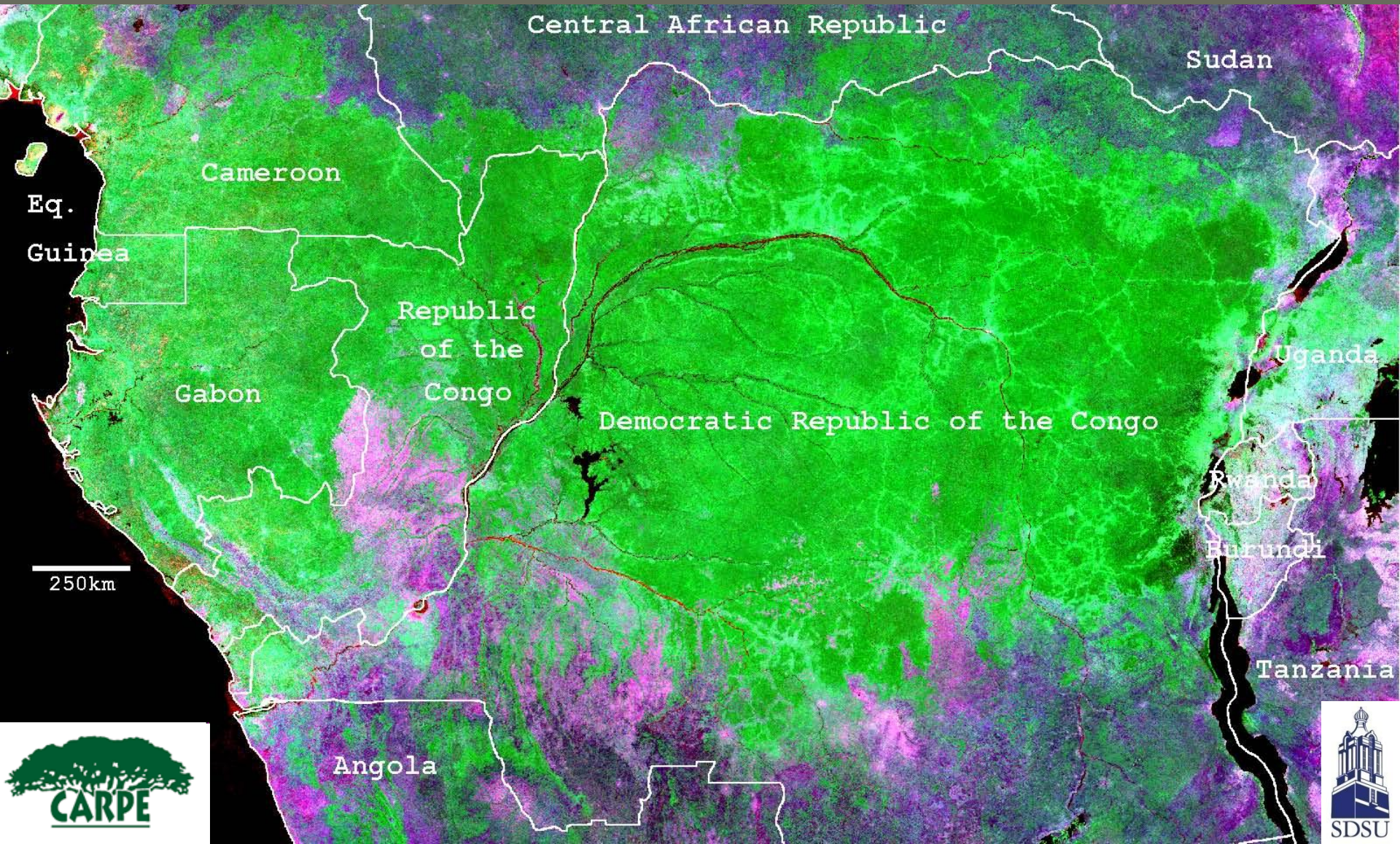
- Systematic global acquisitions
- No/low cost
- Easy access
- Minimal pre-processing required

Monitoring at national scales in the humid tropics – different situations

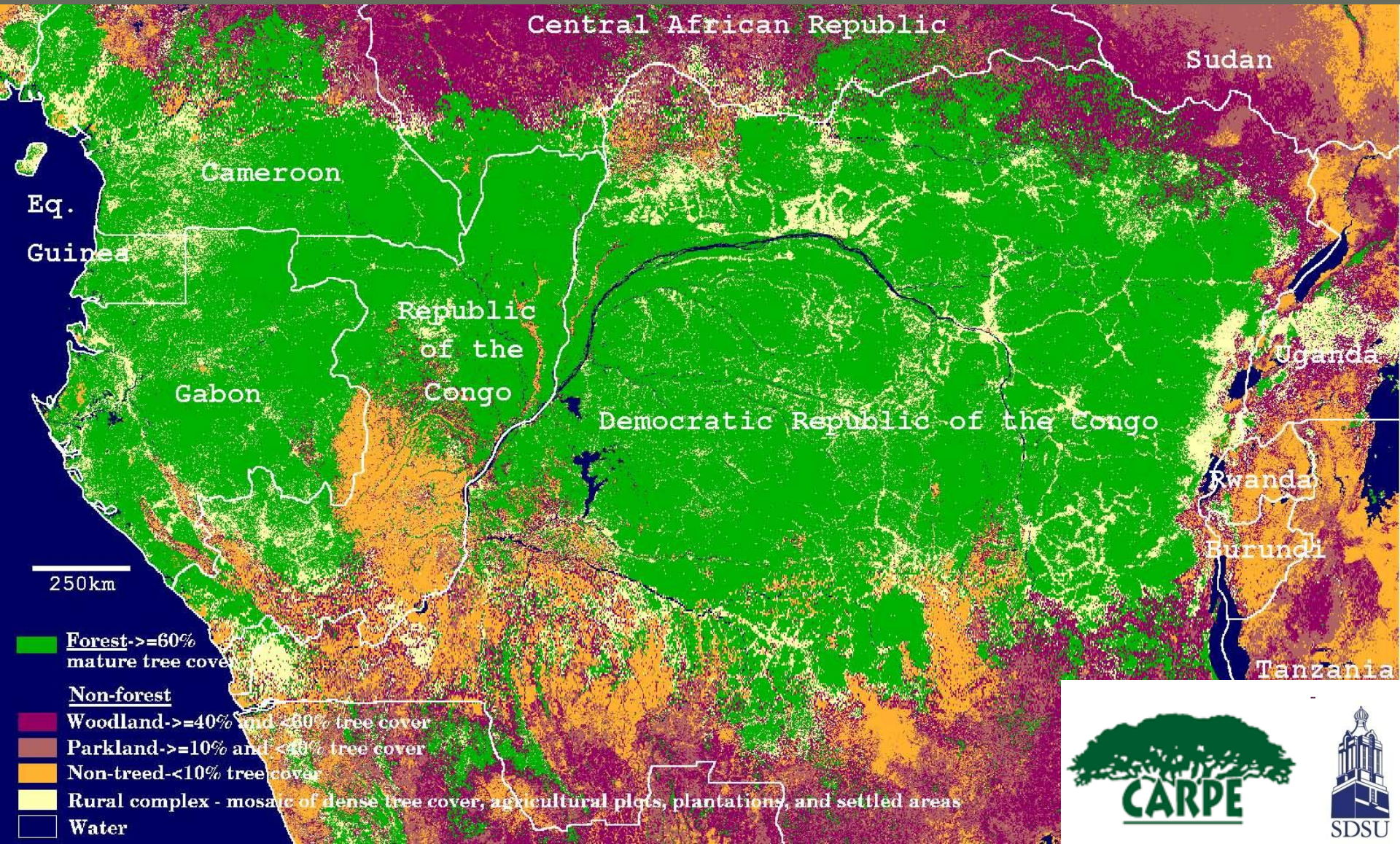
- Brazil
  - Large-scale change, most of which is located in seasonally cloud-free region, deforestation
- Indonesia
  - Large-scale change, occurring in persistently cloud-affected region, much topography, active forestry
- Democratic Republic of Congo
  - Fine-scale change, occurring in persistently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

SDSU

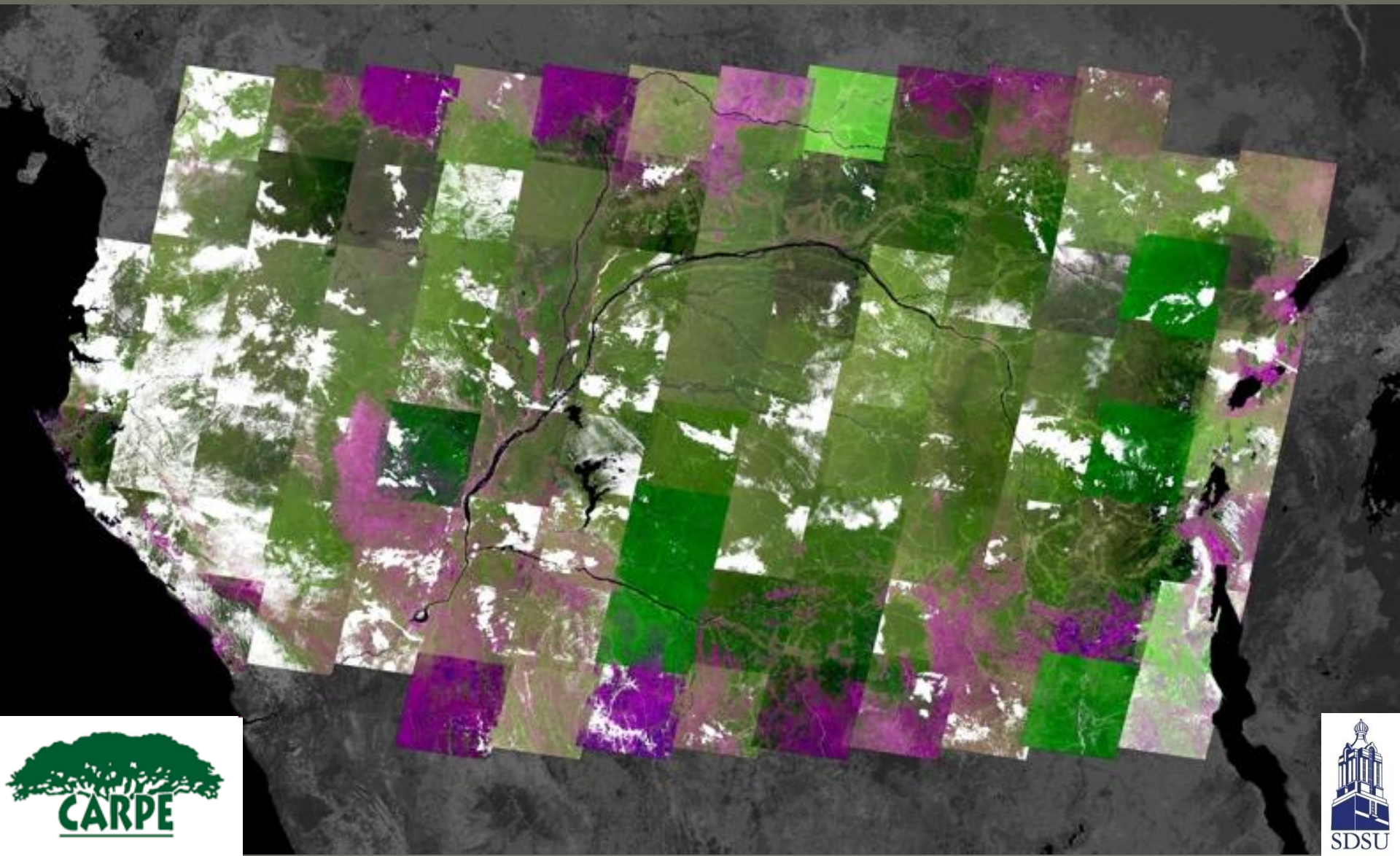
MODIS time integrated metrics



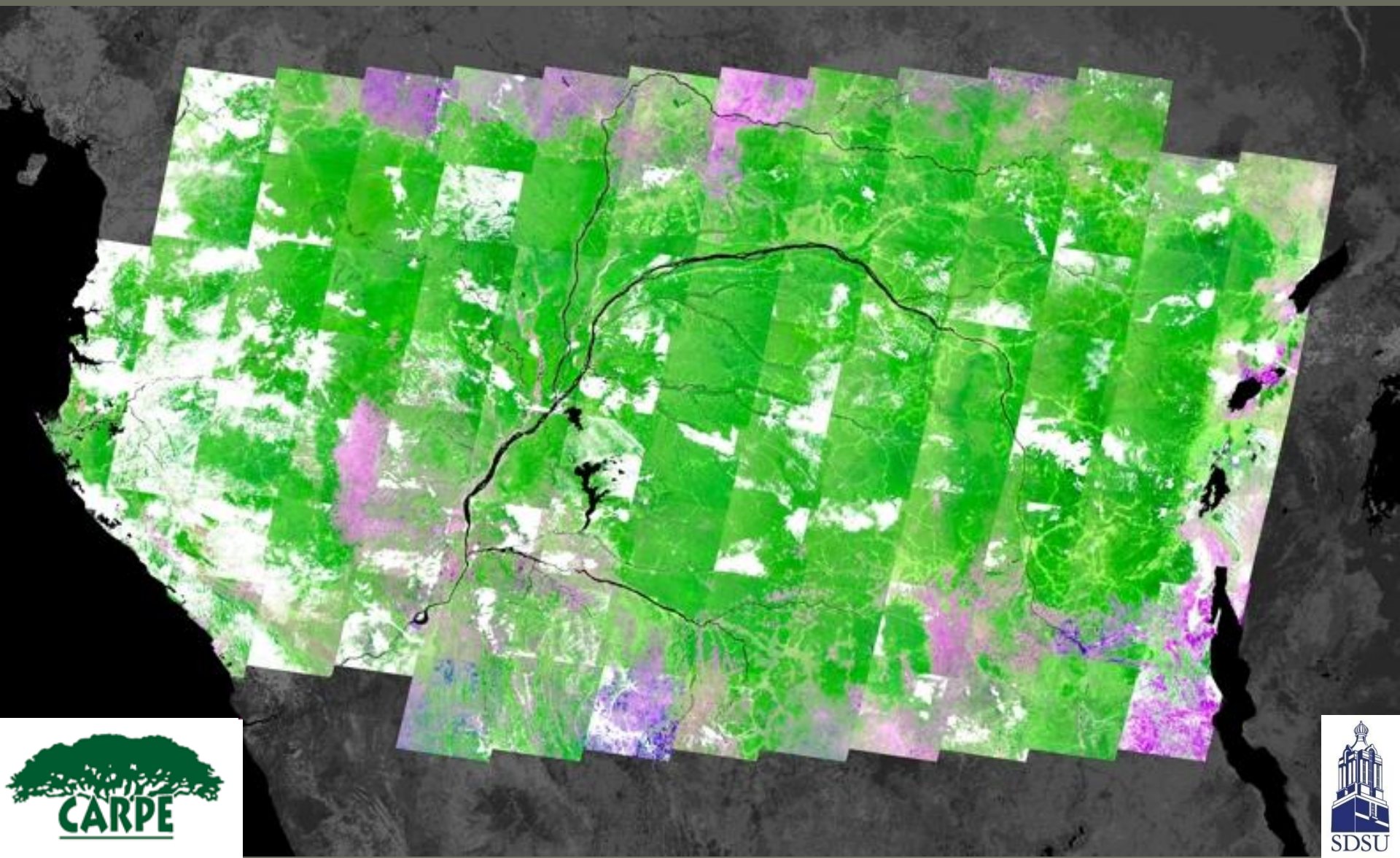
MODIS forest cover maps as inputs for automated mapping at finer scales in Central Africa



2000 Global Land Survey



Bias-adjusted



Anisotropy adjusted

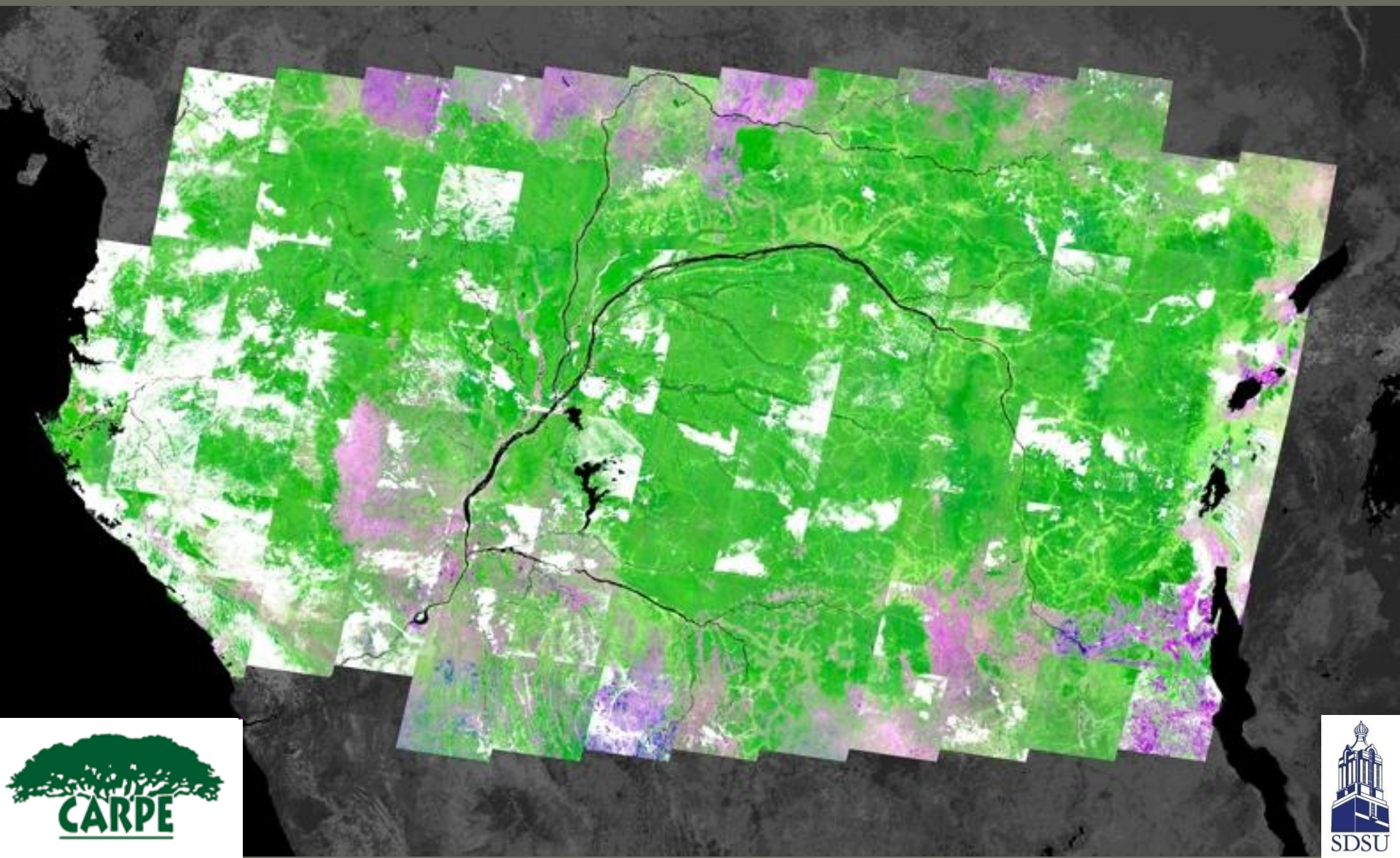
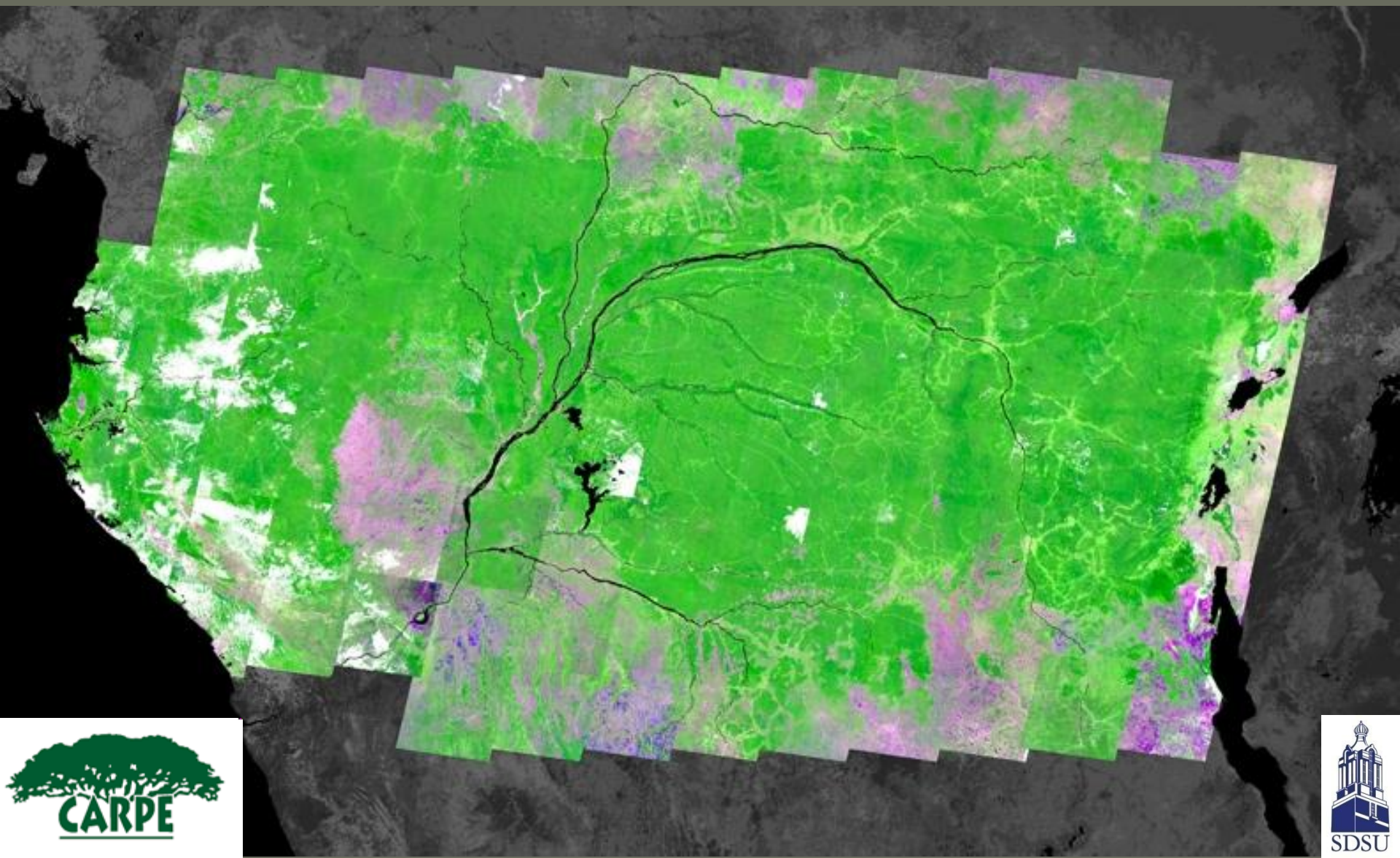
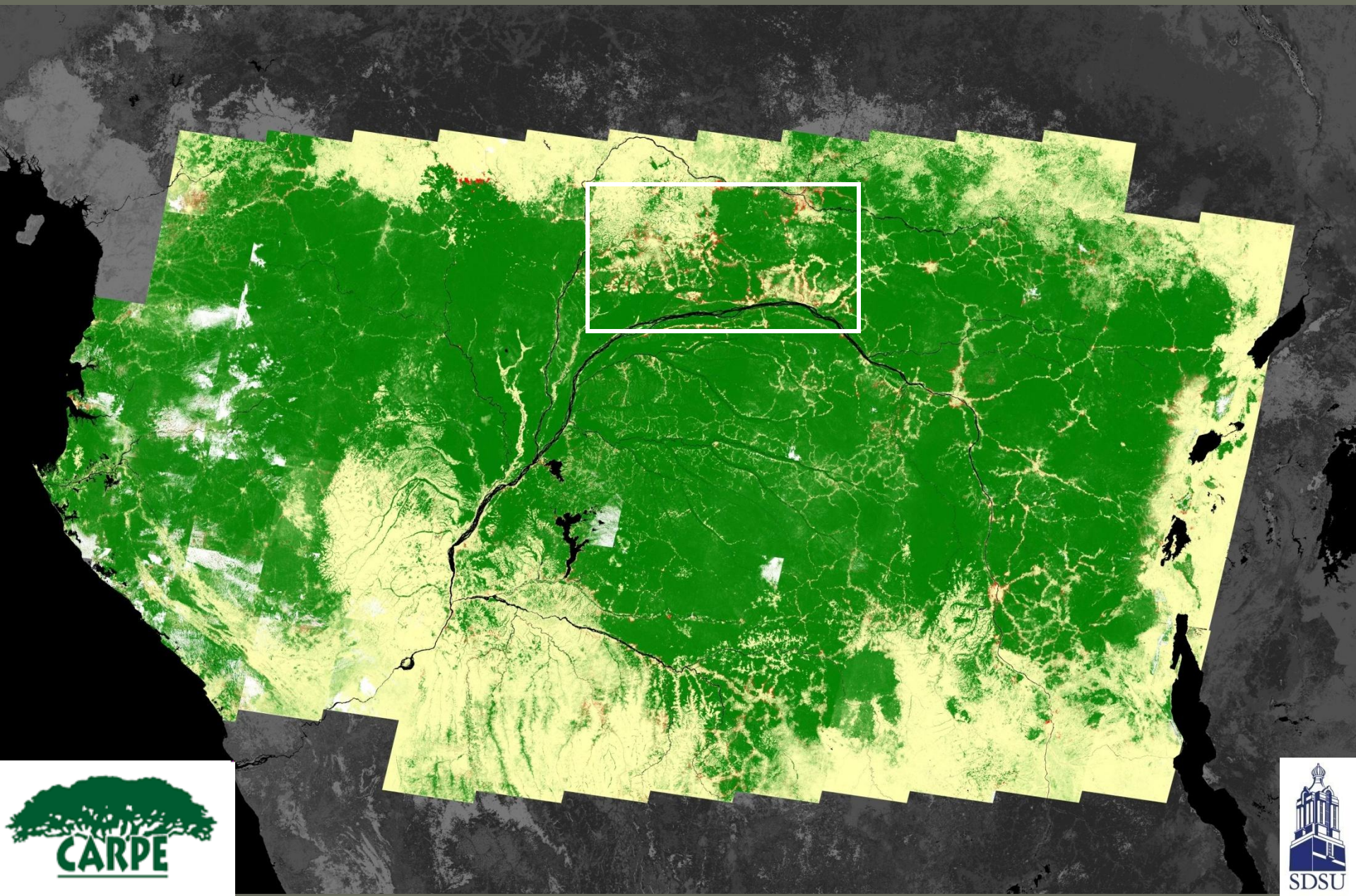


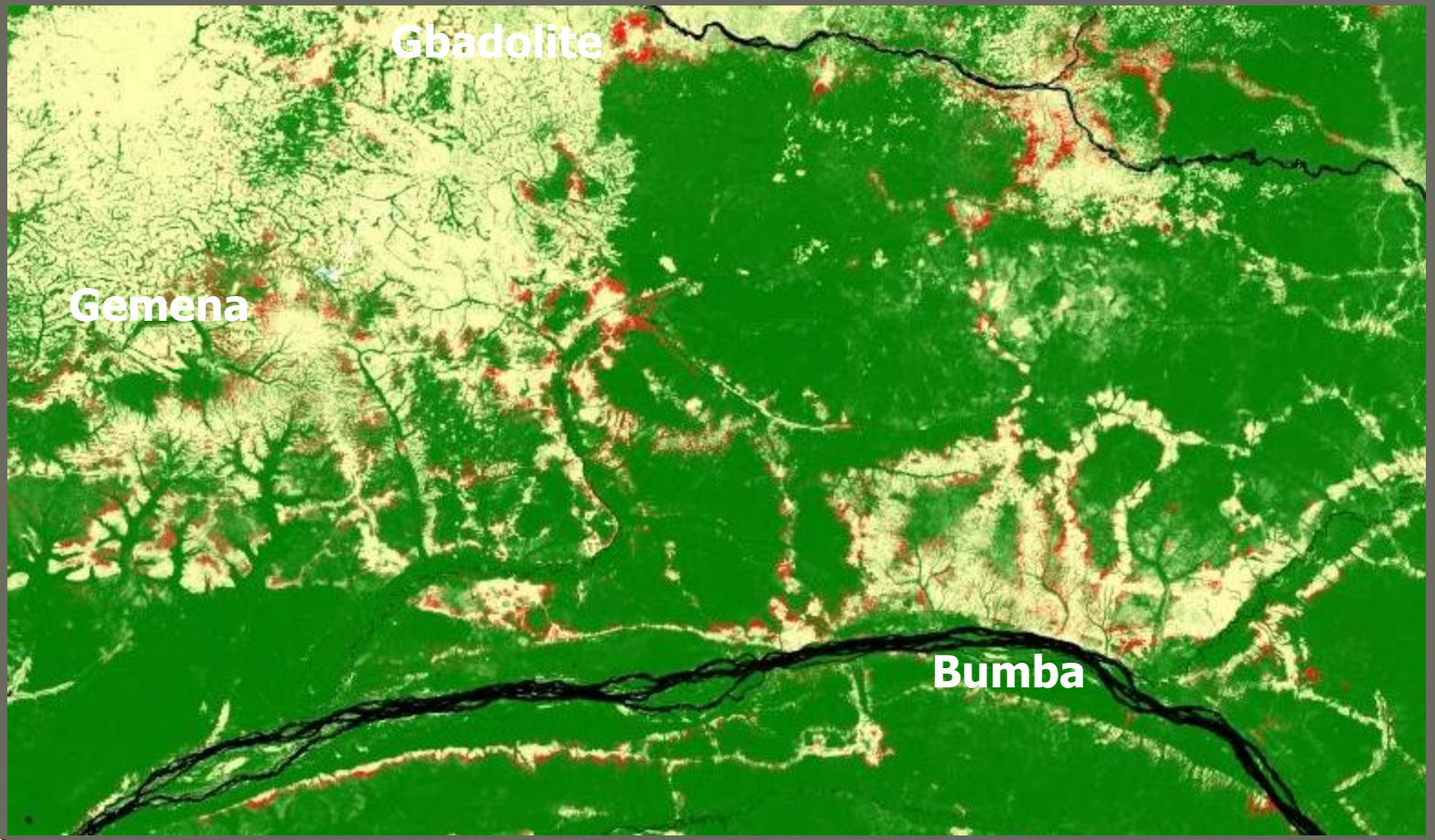
Image composite (3-5 images per path/row) and epoch



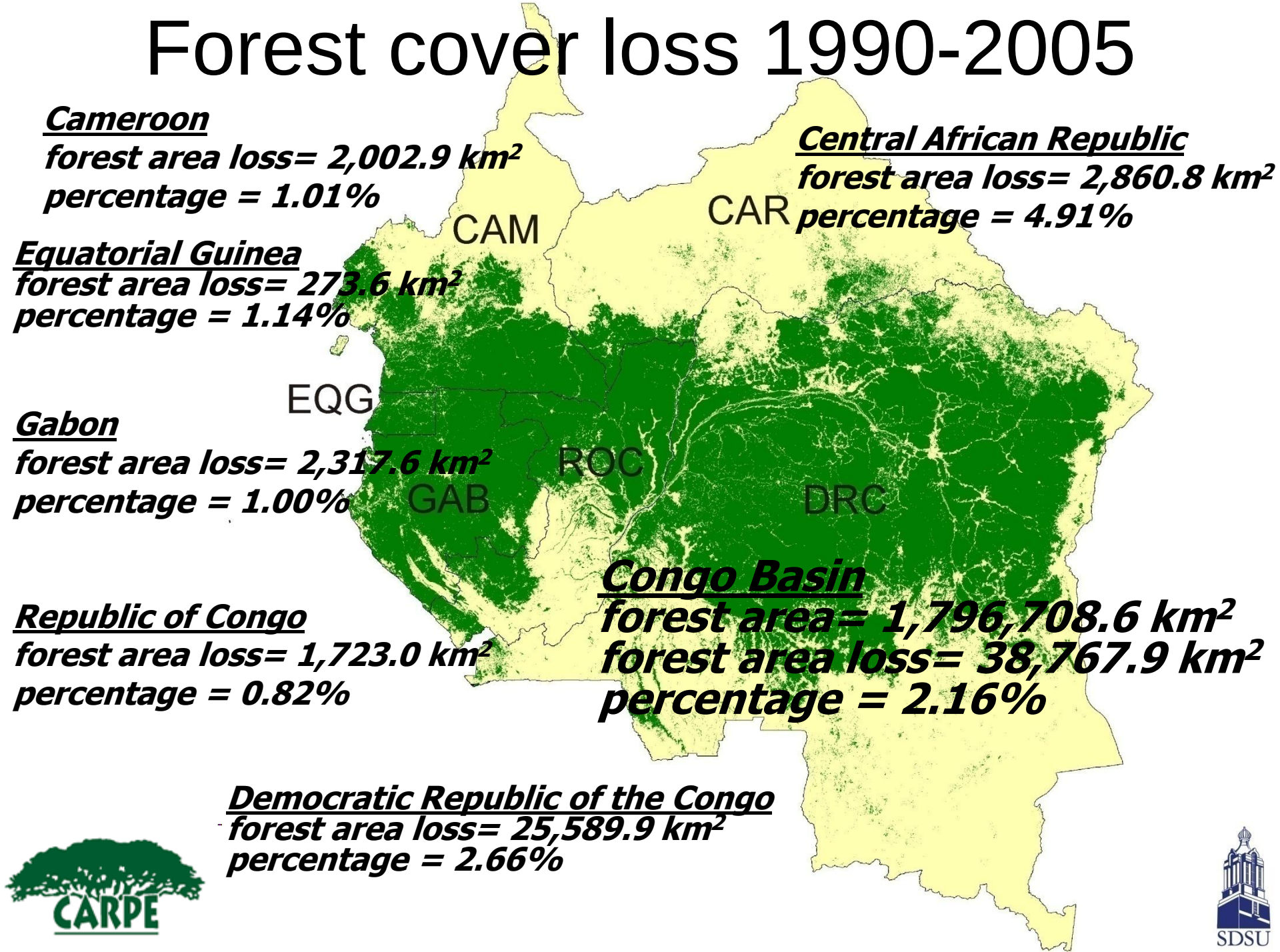
Landsat forest cover and change



Landsat forest cover and change



Forest cover loss 1990-2005



Cameroon
forest area loss= 2,002.9 km²
percentage = 1.01%

Central African Republic
forest area loss= 2,860.8 km²
percentage = 4.91%

Equatorial Guinea
forest area loss= 273.6 km²
percentage = 1.14%

Gabon
forest area loss= 2,317.6 km²
percentage = 1.00%

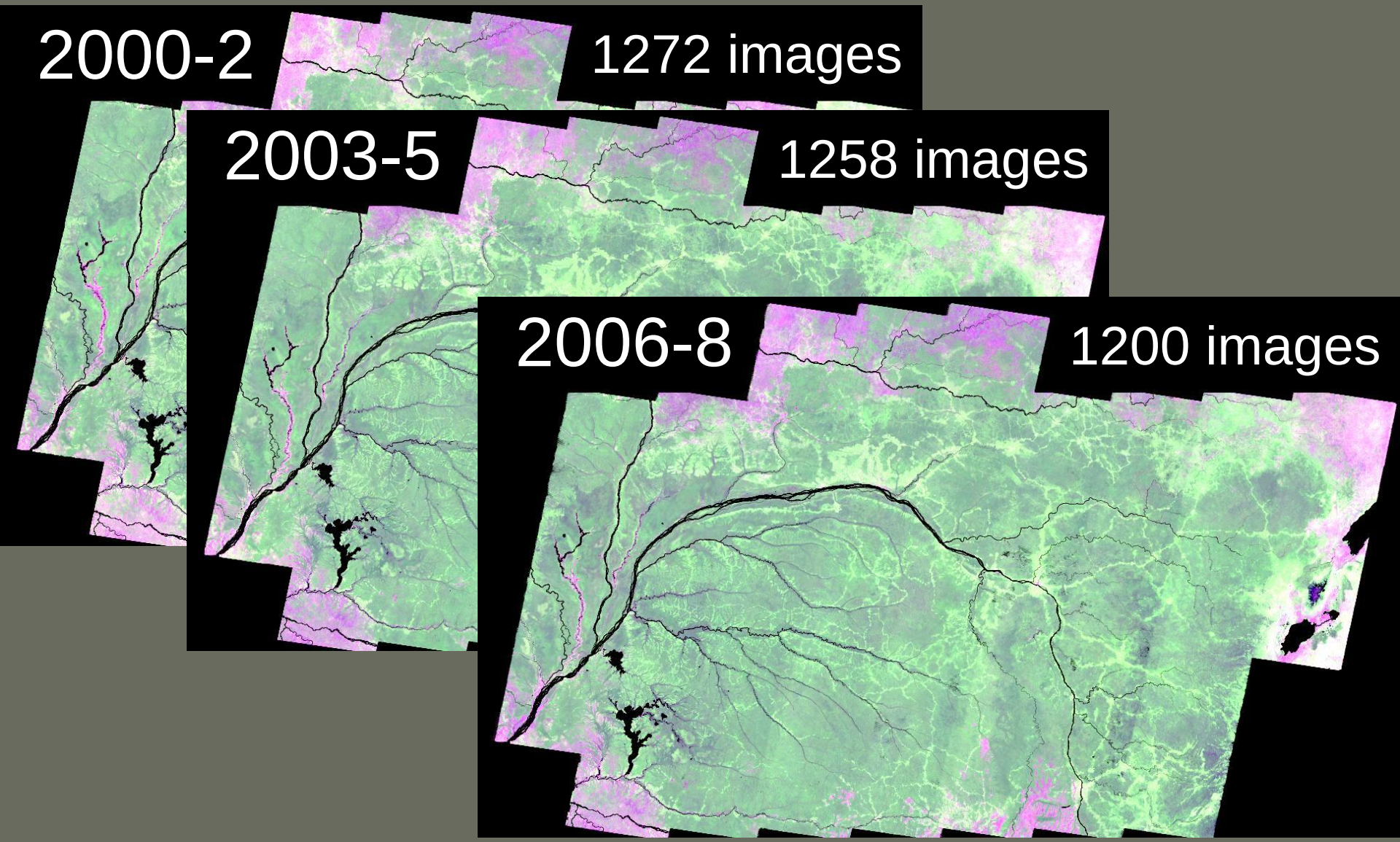
Republic of Congo
forest area loss= 1,723.0 km²
percentage = 0.82%

Congo Basin
forest area= 1,796,708.6 km²
forest area loss= 38,767.9 km²
percentage = 2.16%

Democratic Republic of the Congo
forest area loss= 25,589.9 km²
percentage = 2.66%

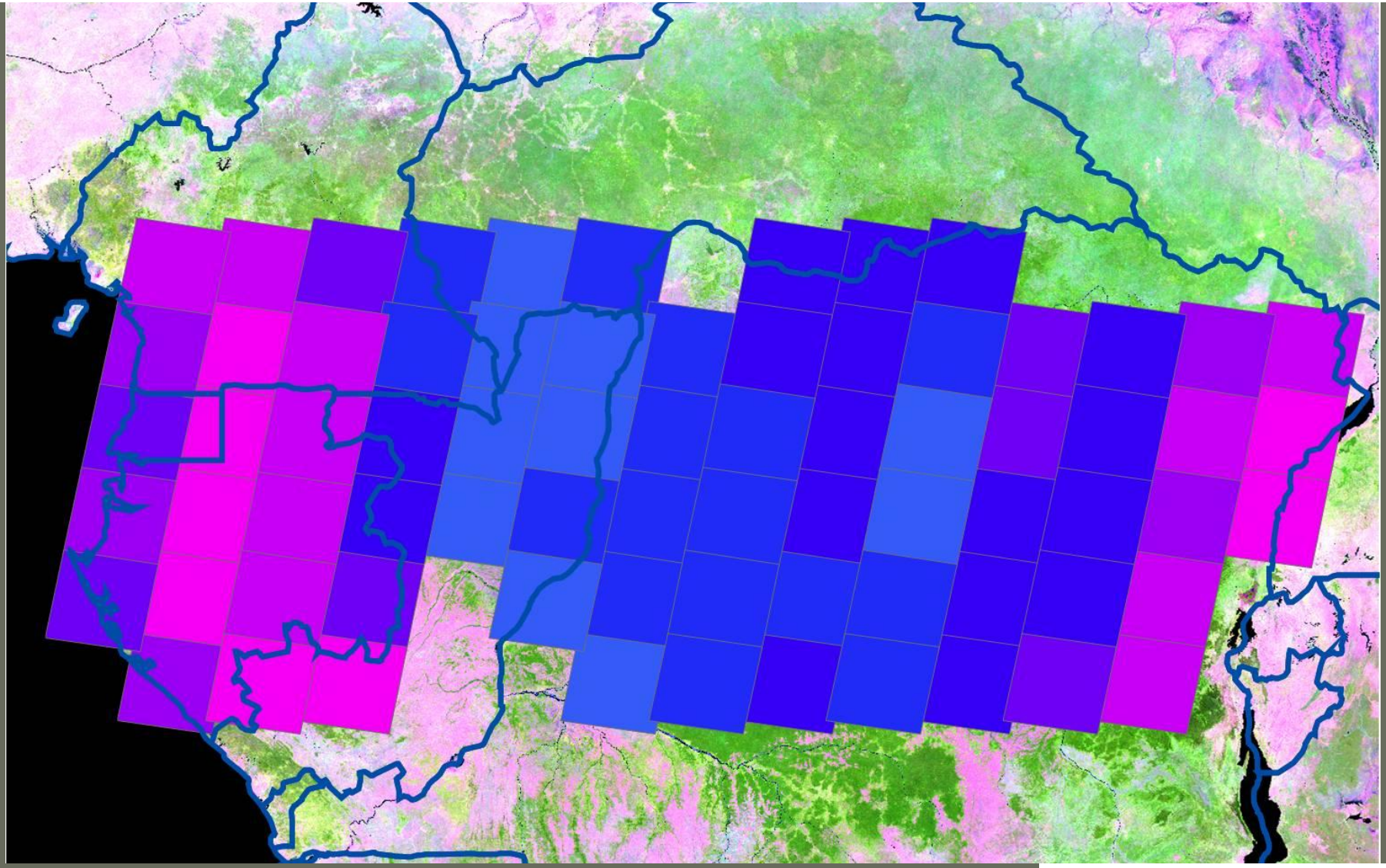
CARPE

SDSU



SDSU

Number of images in the USGS/EROS archive

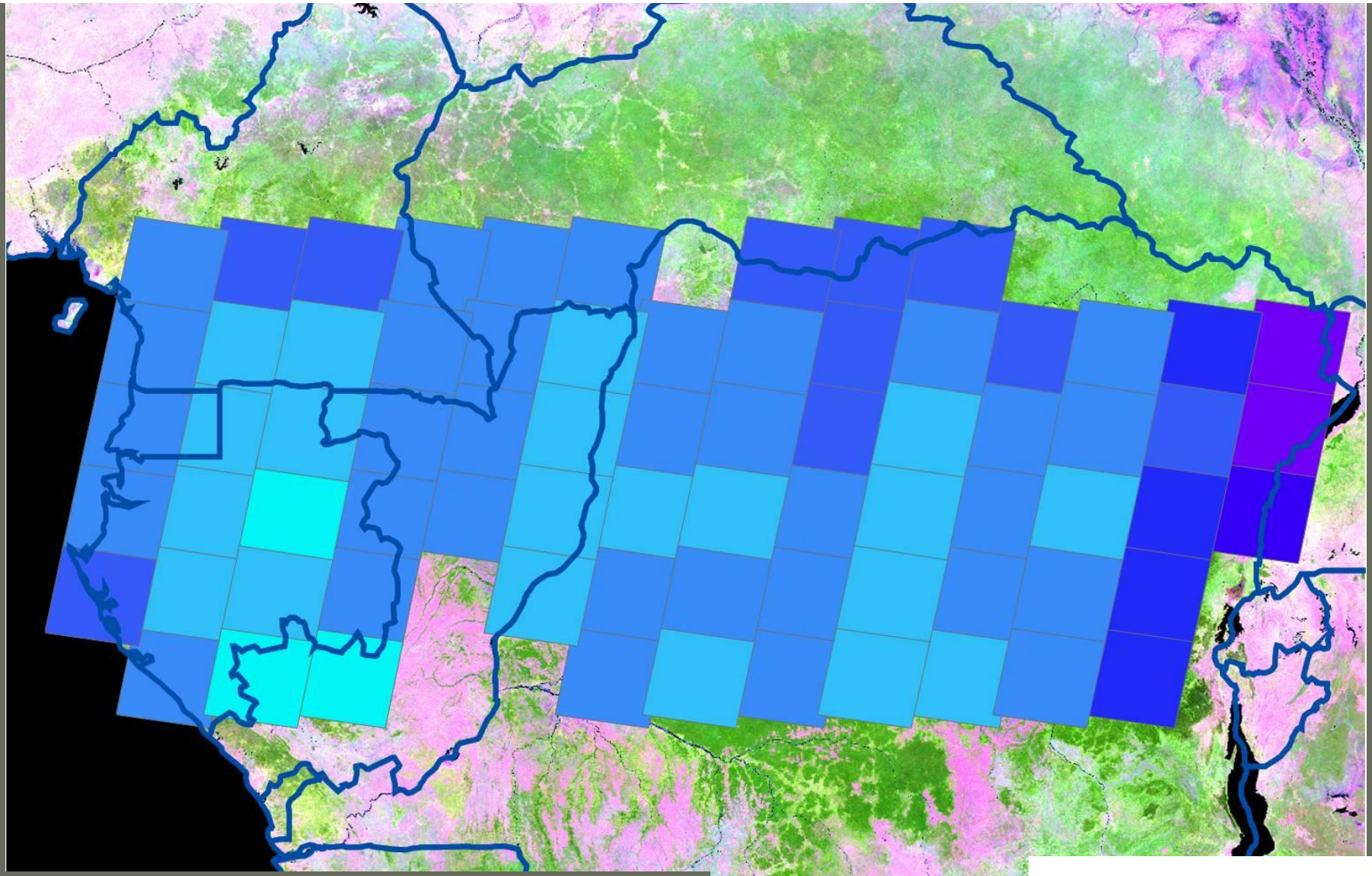


# of images: 10 – 55 – 110

CARPE

SDSU

Number of images with < 50 ACCA cloud cover

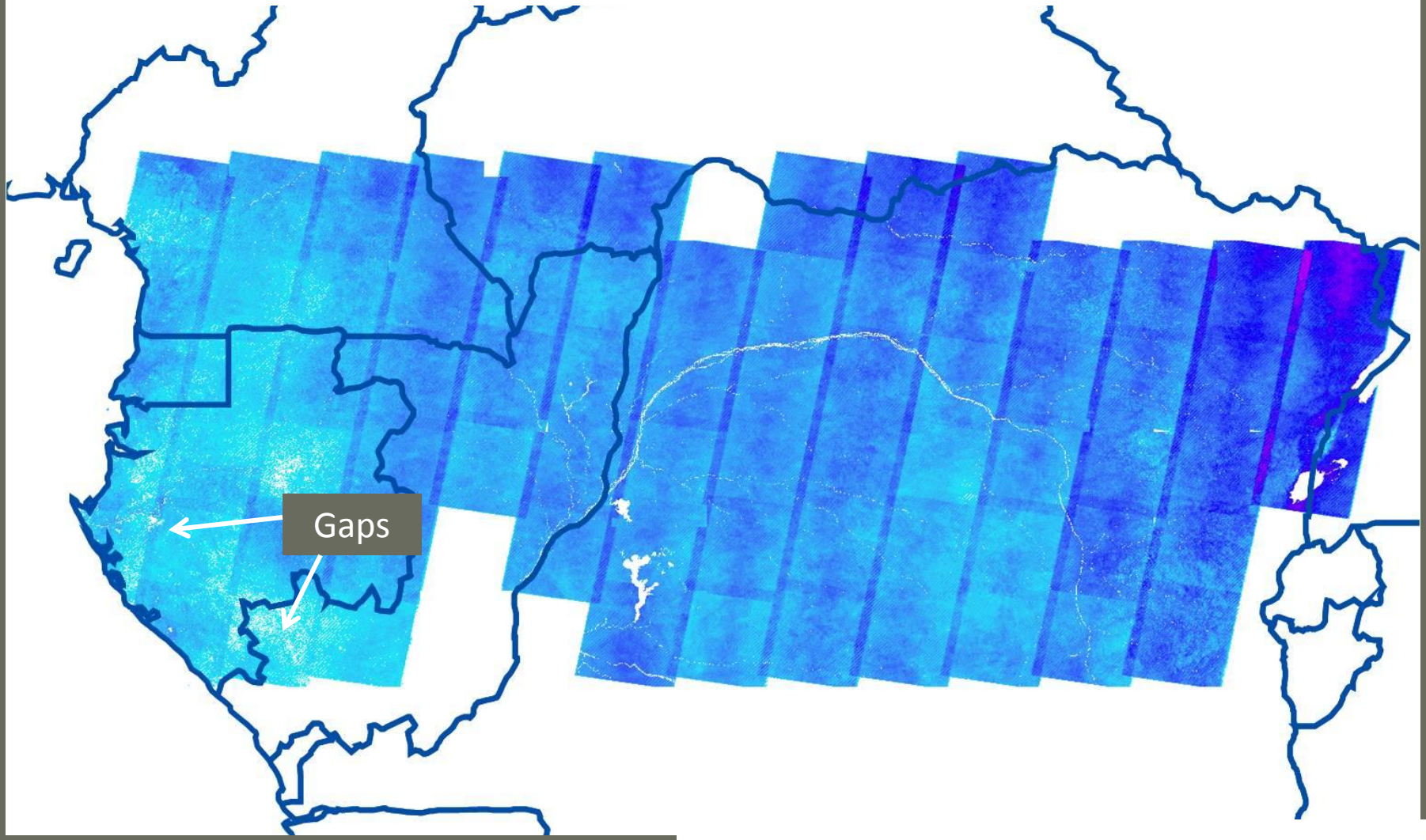


# of images: 10 – 55 – 110

CARPE

SDSU

Number of good observations per pixel for 2003-2005 composite



# of images: 1 – 20 – 40

CARPE

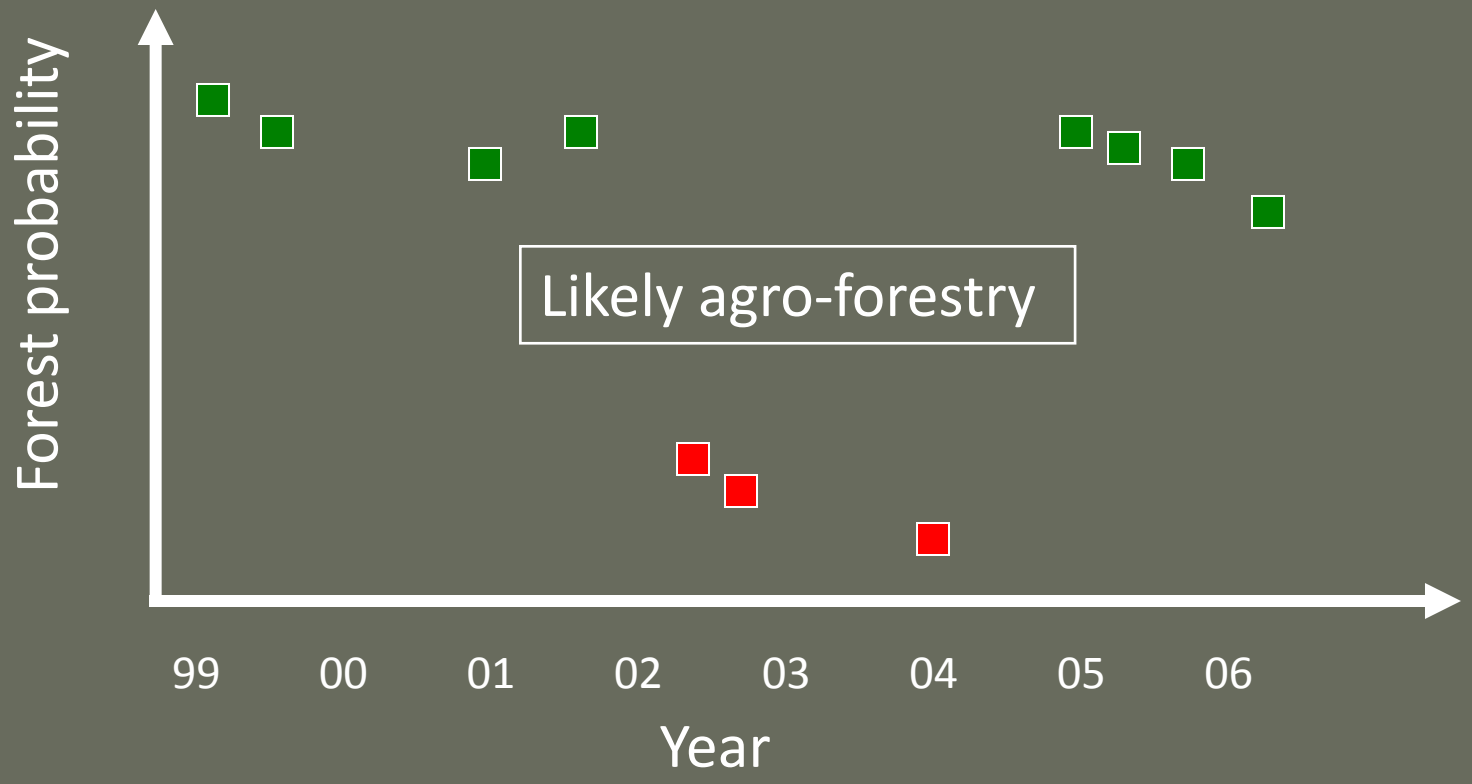
SDSU

Different approaches

- 1) 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) 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)

SDSU

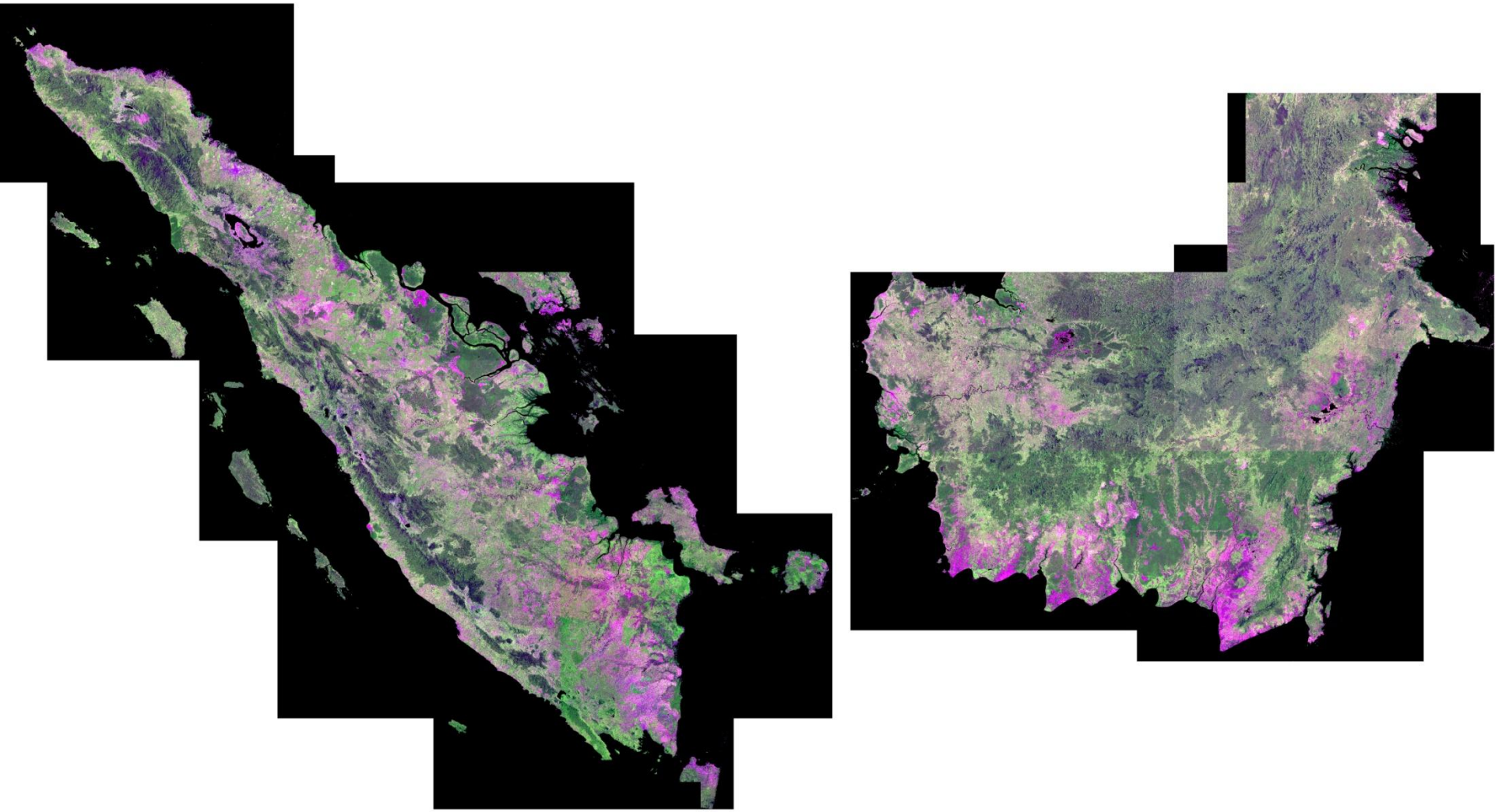
Per –pixel time series analysis using all good observations



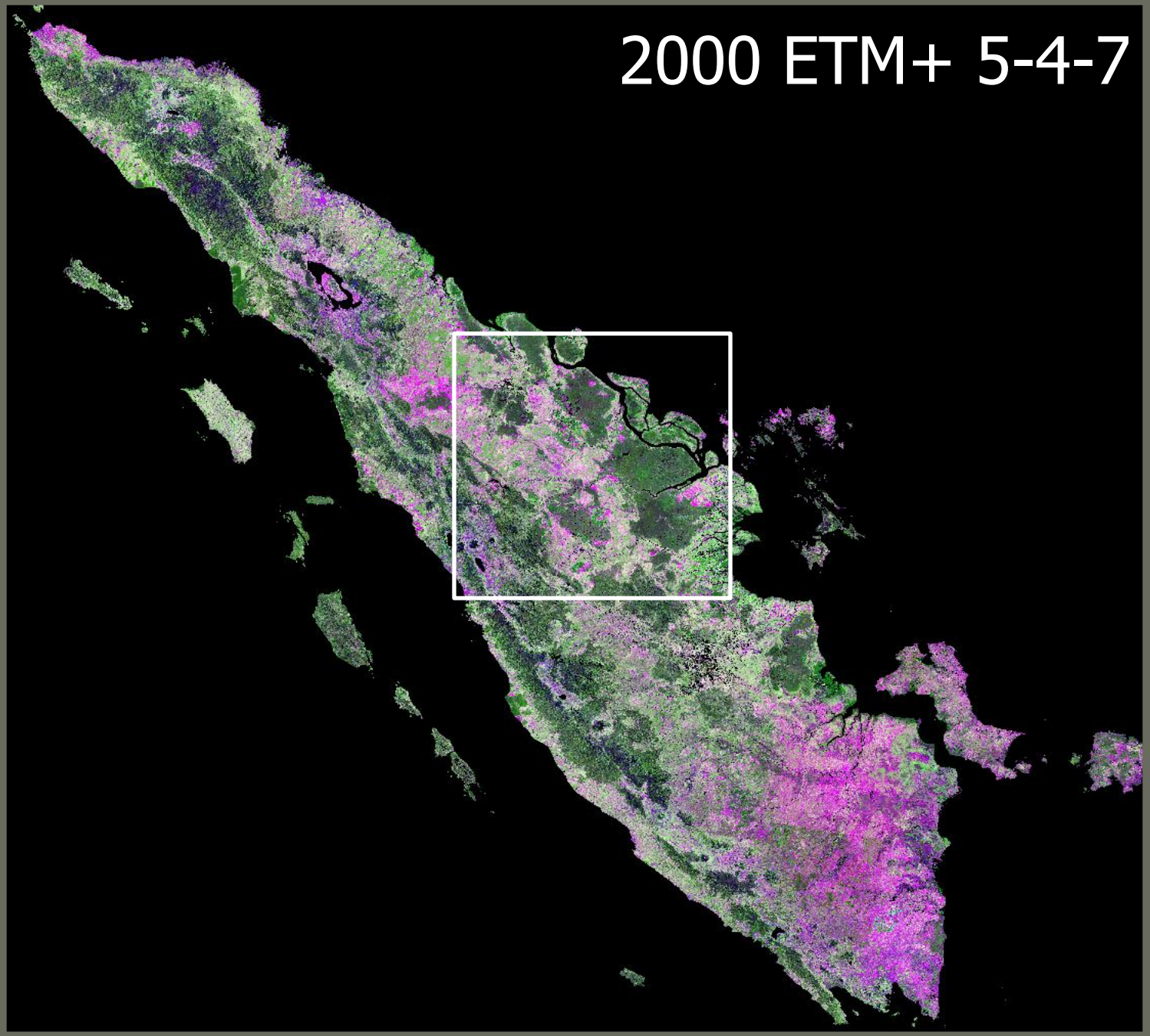
Interpretation: = forest = no-forest

SDSU

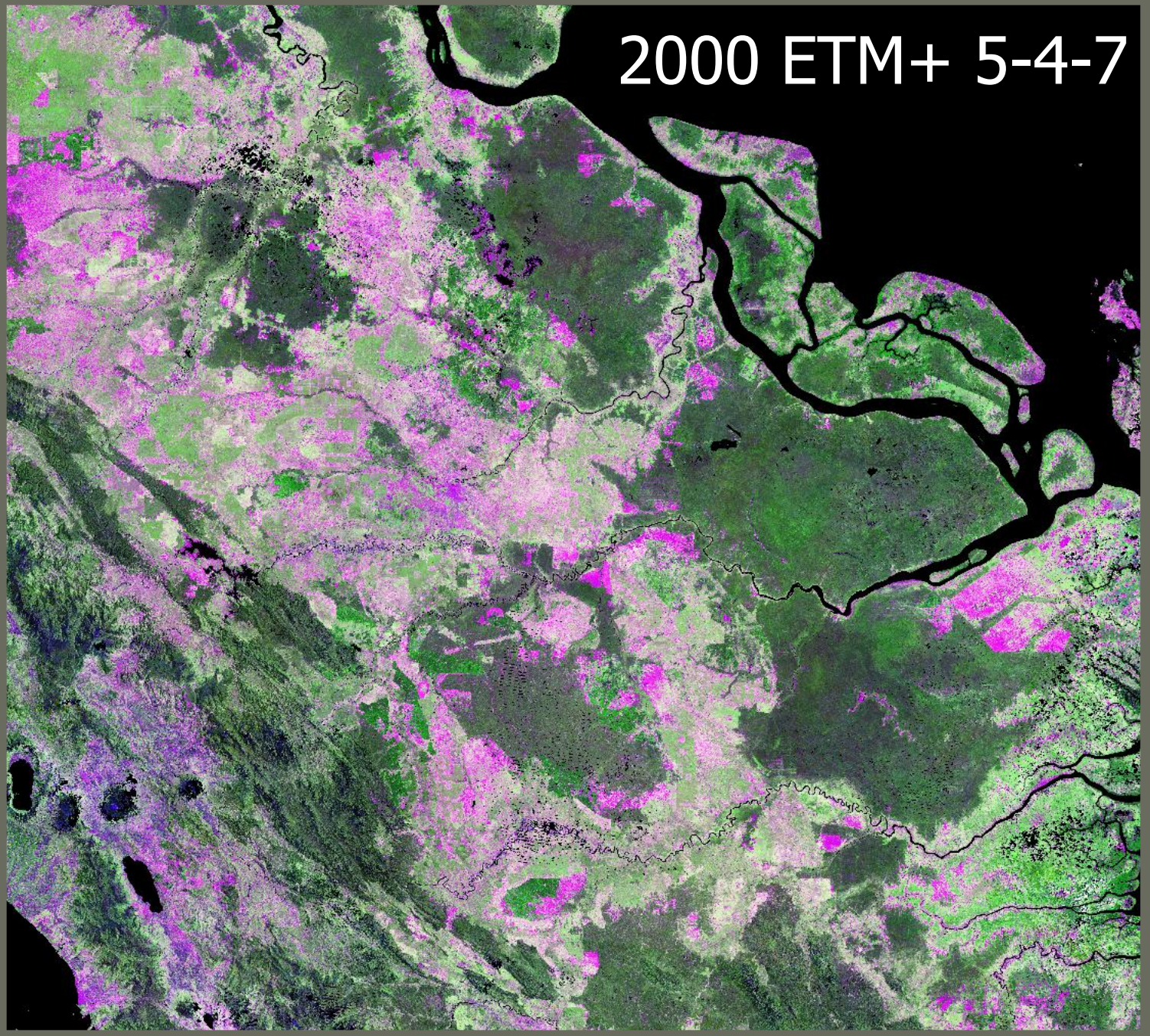
Indonesia, 1999 to 2009



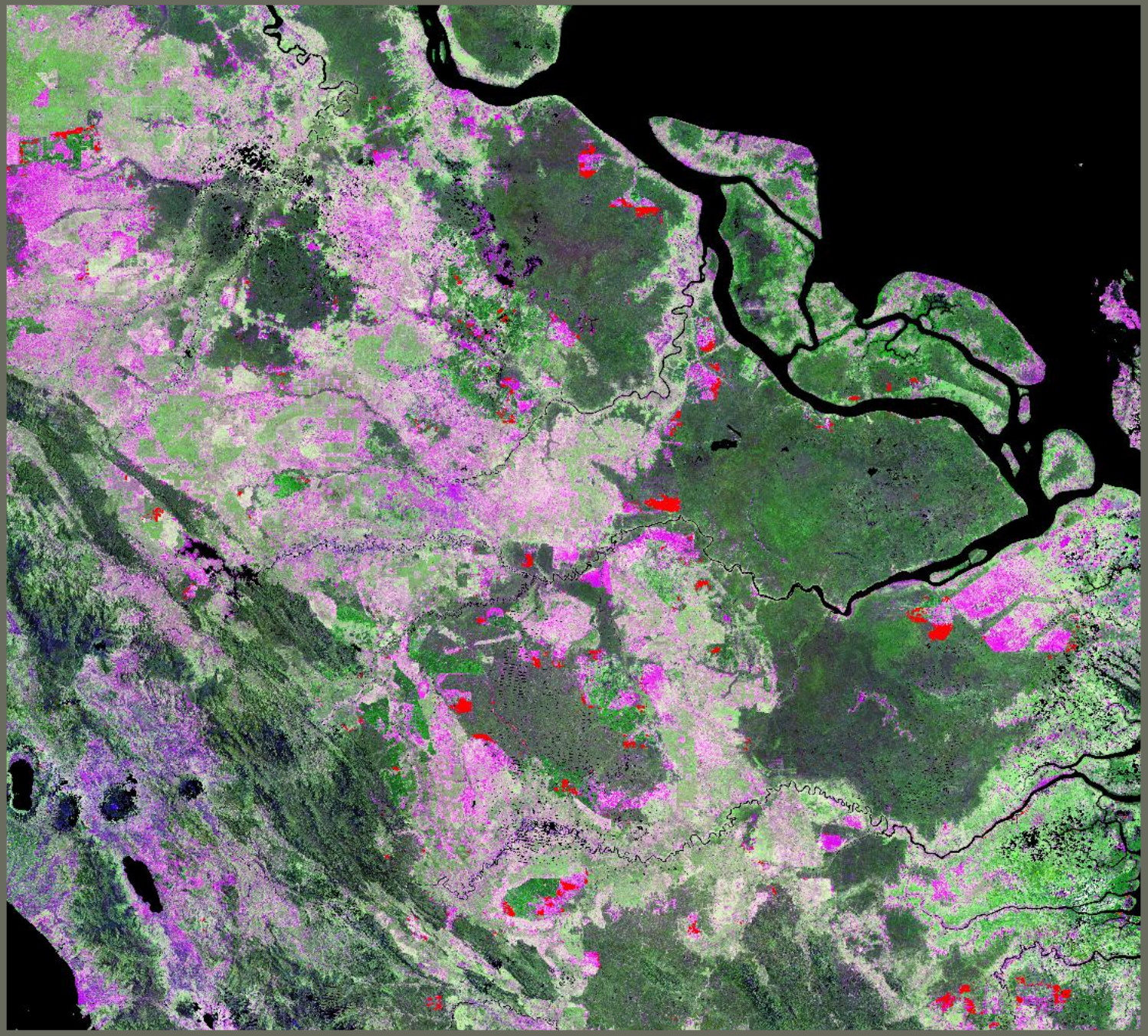
6,189 images



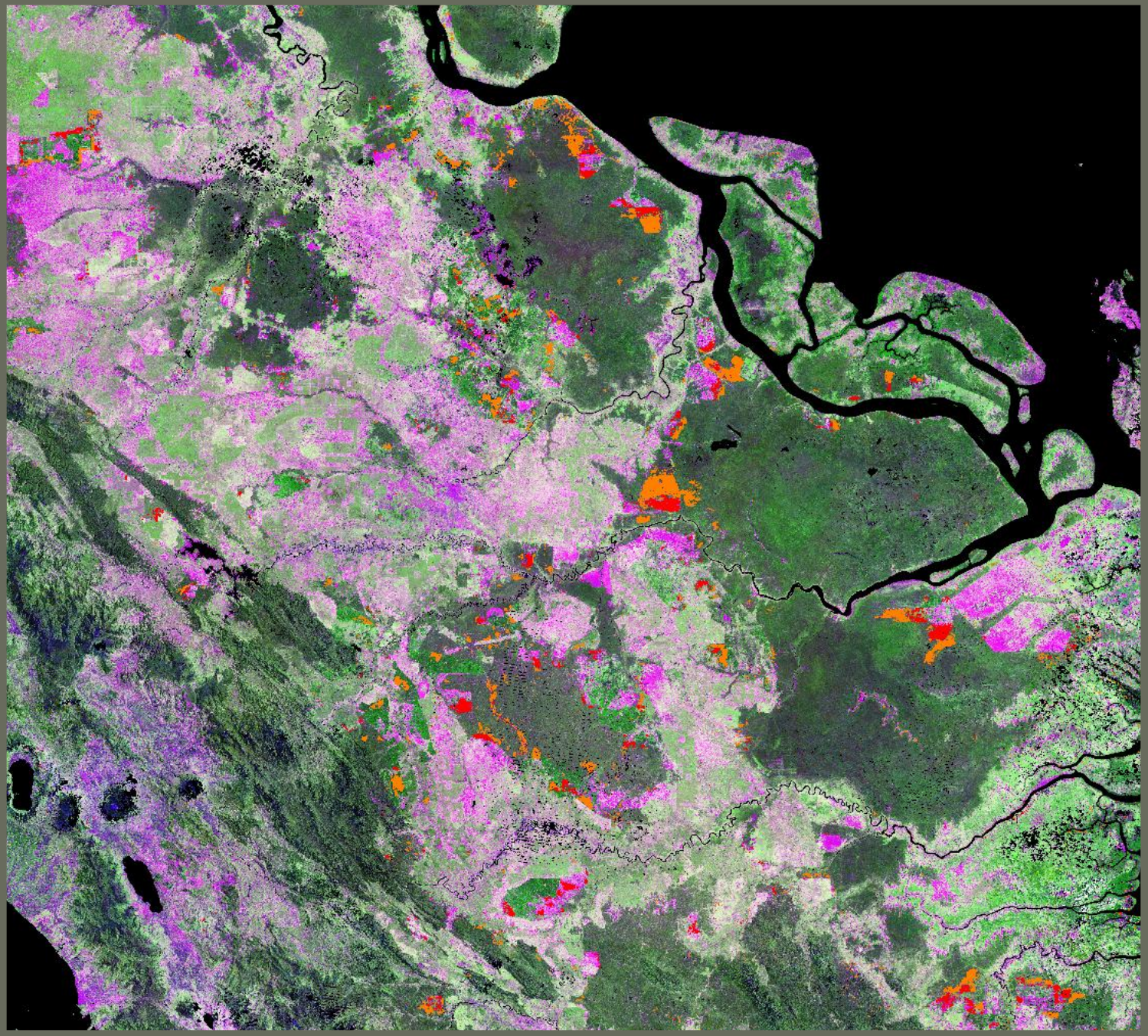
SDSU



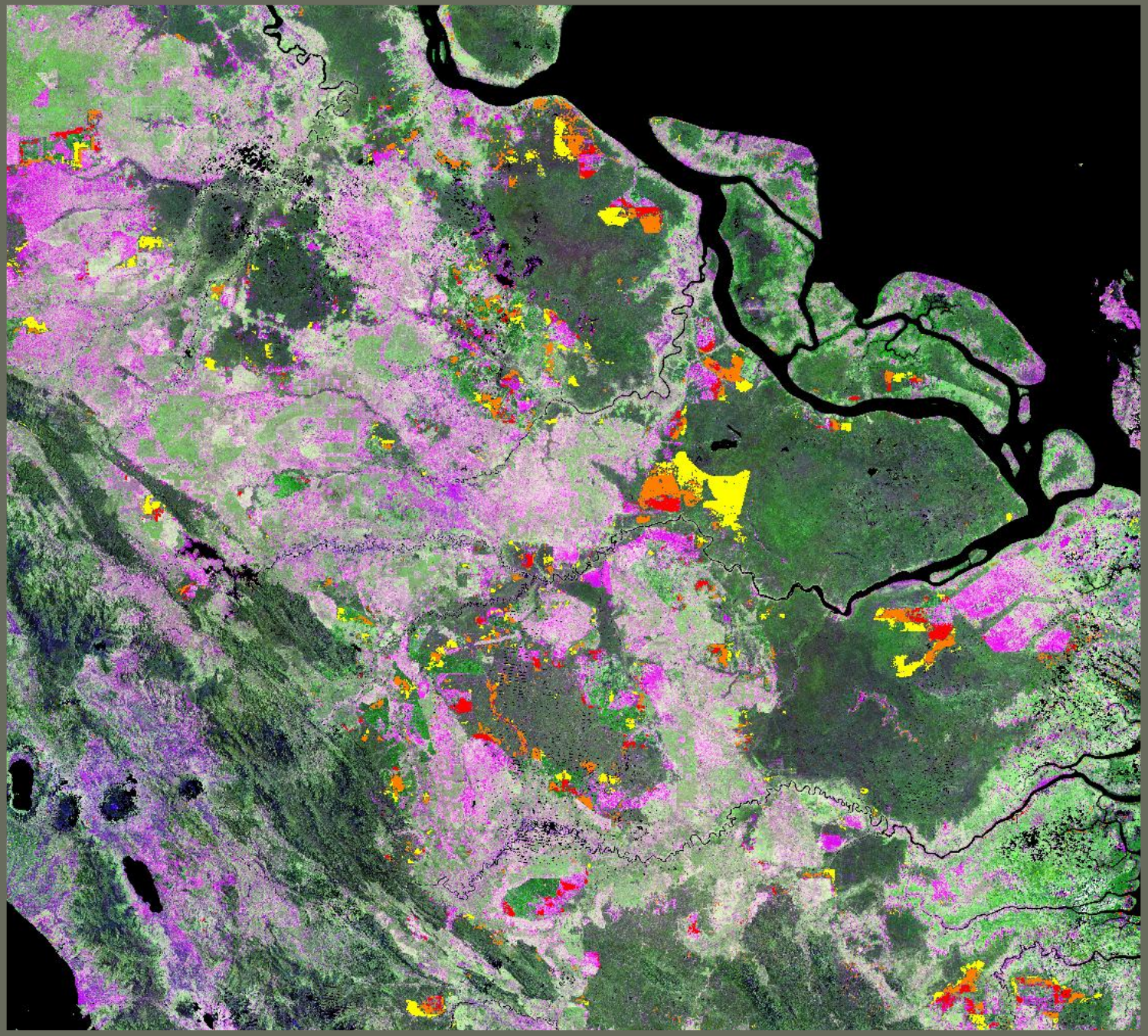
SDSU



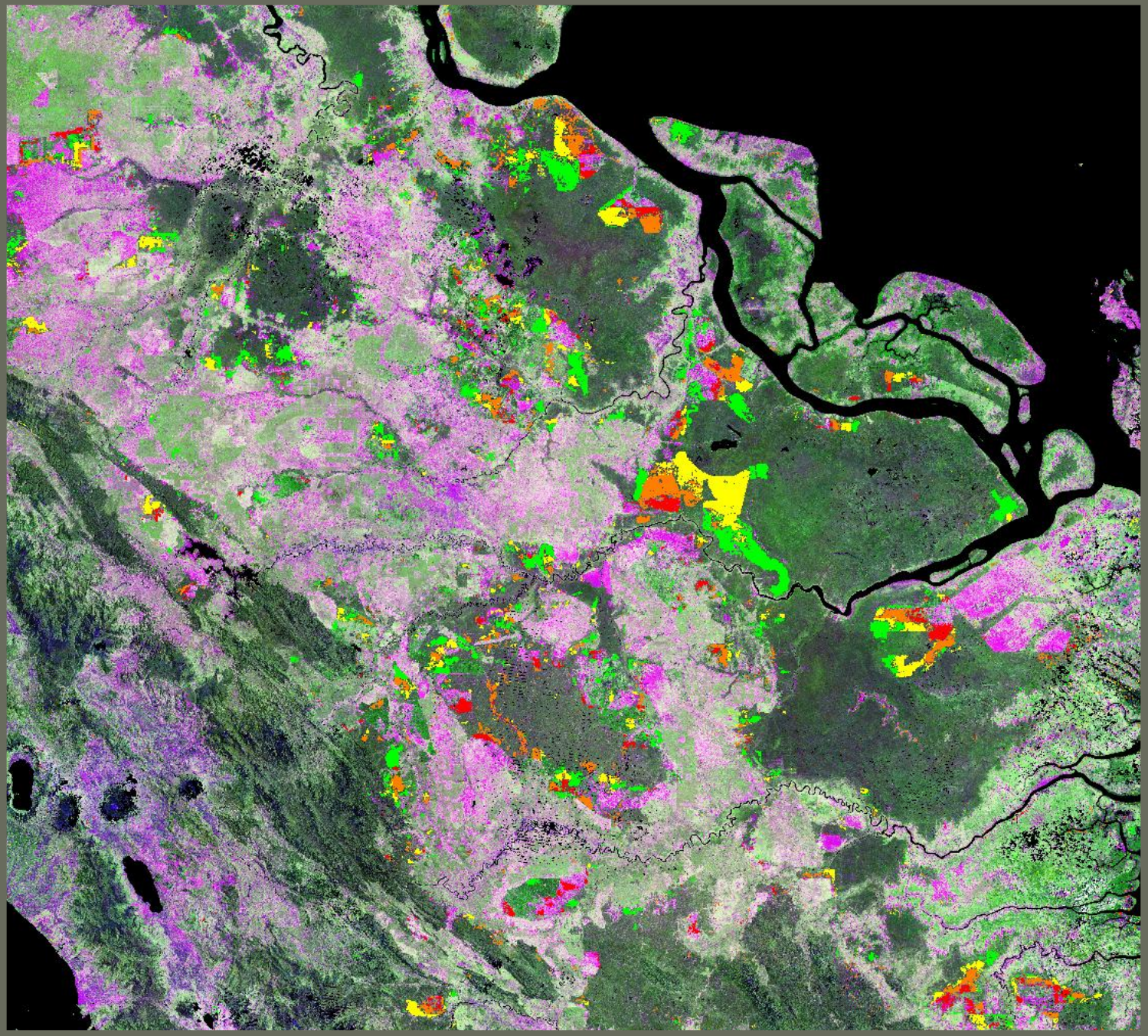
SDSU



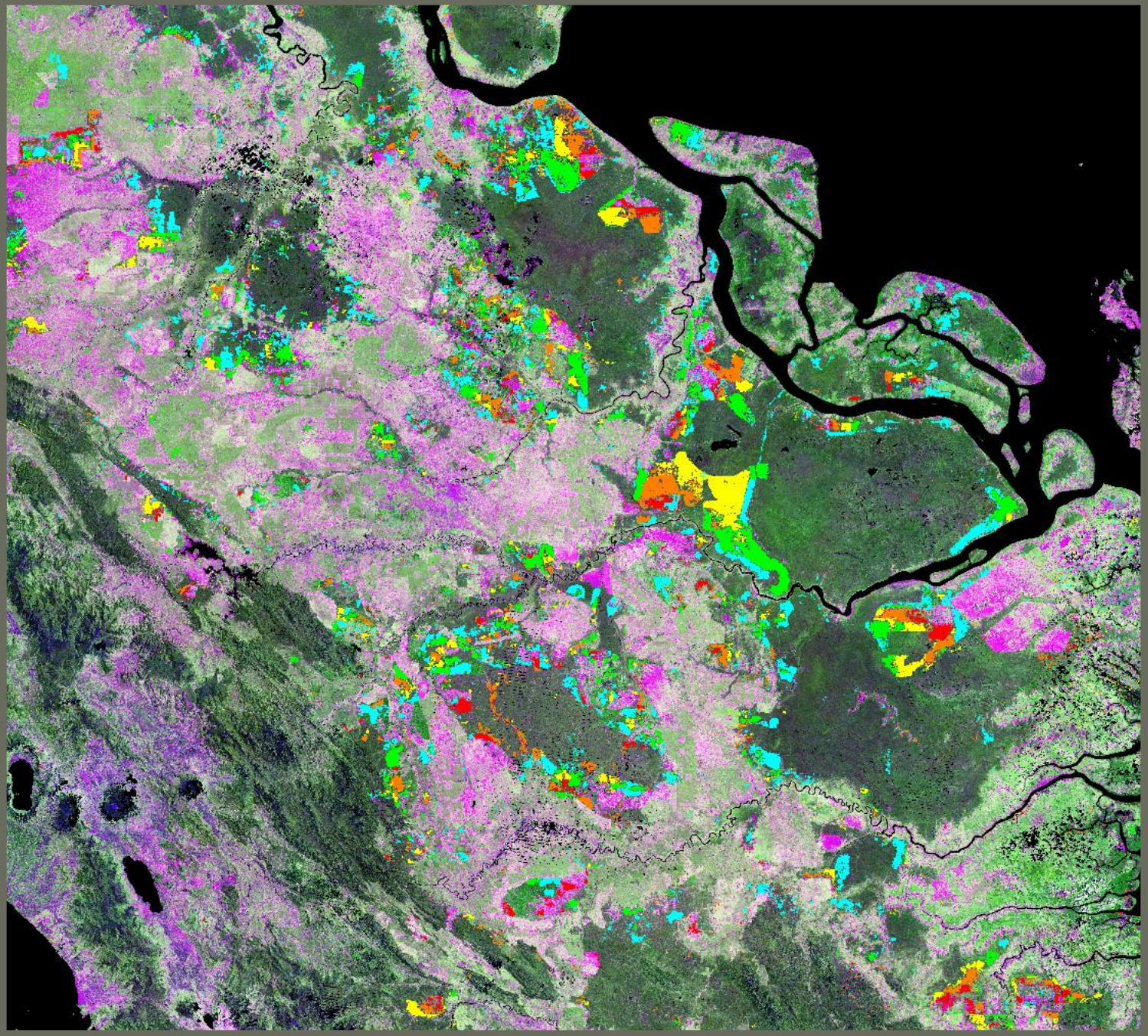
SDSU



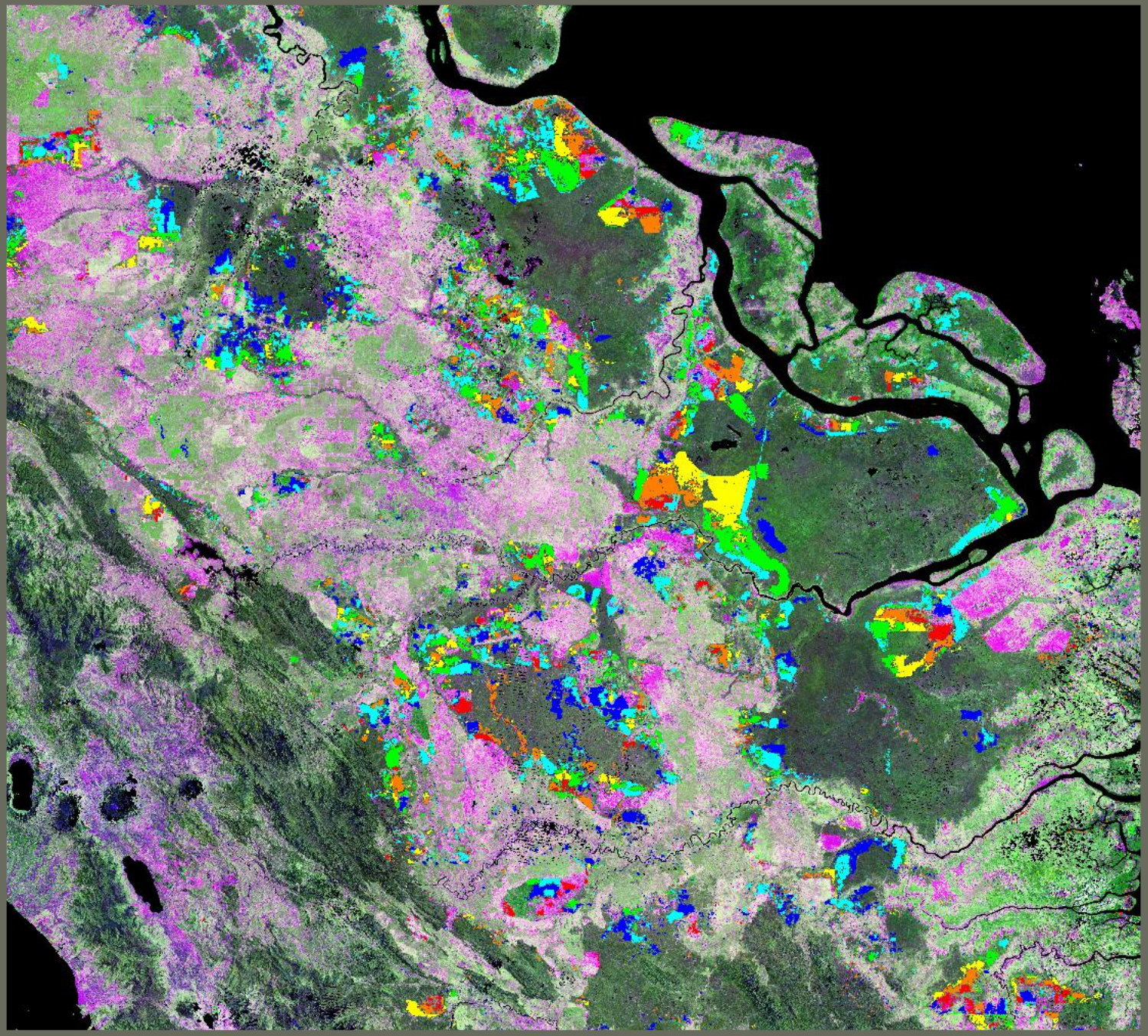
SDSU



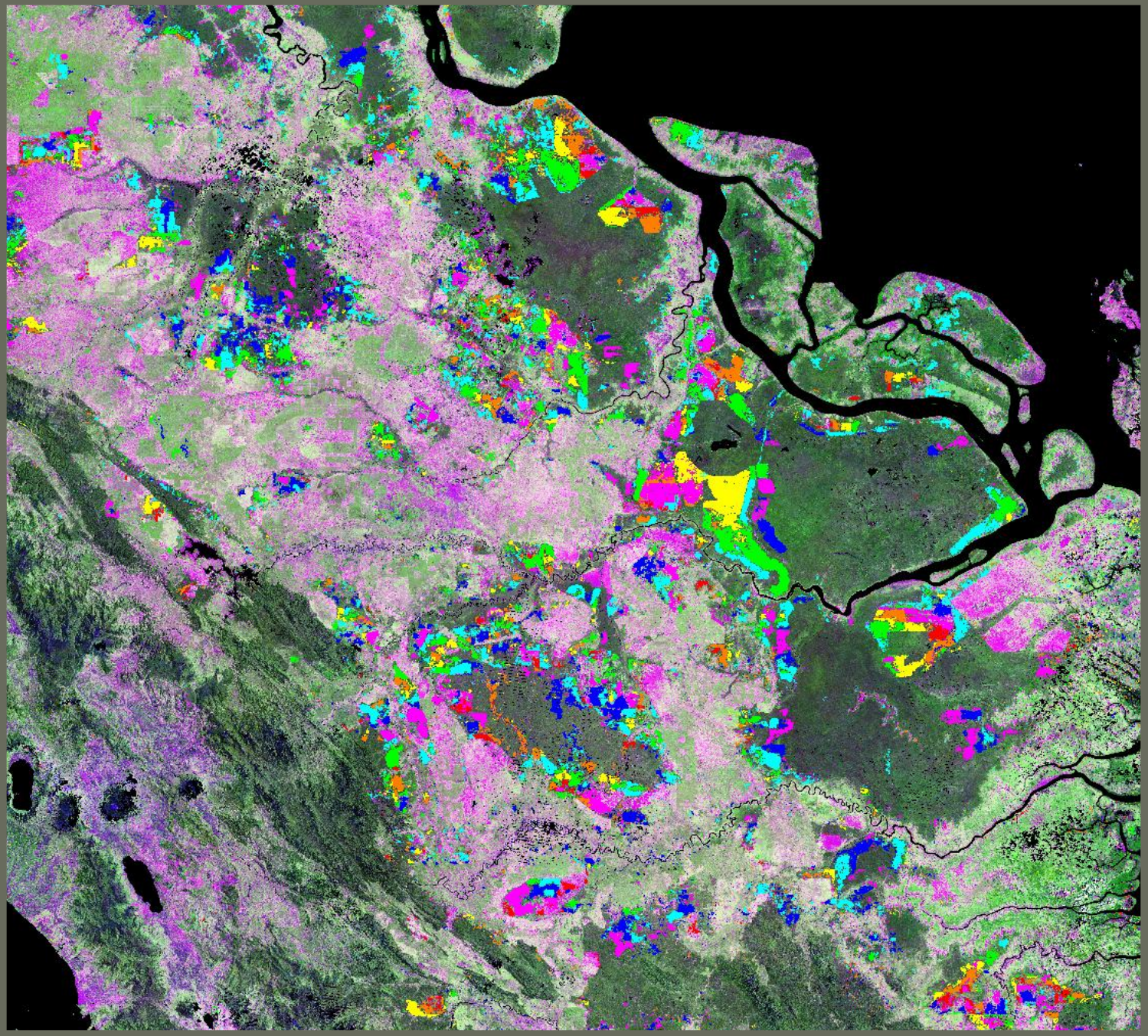
SDSU



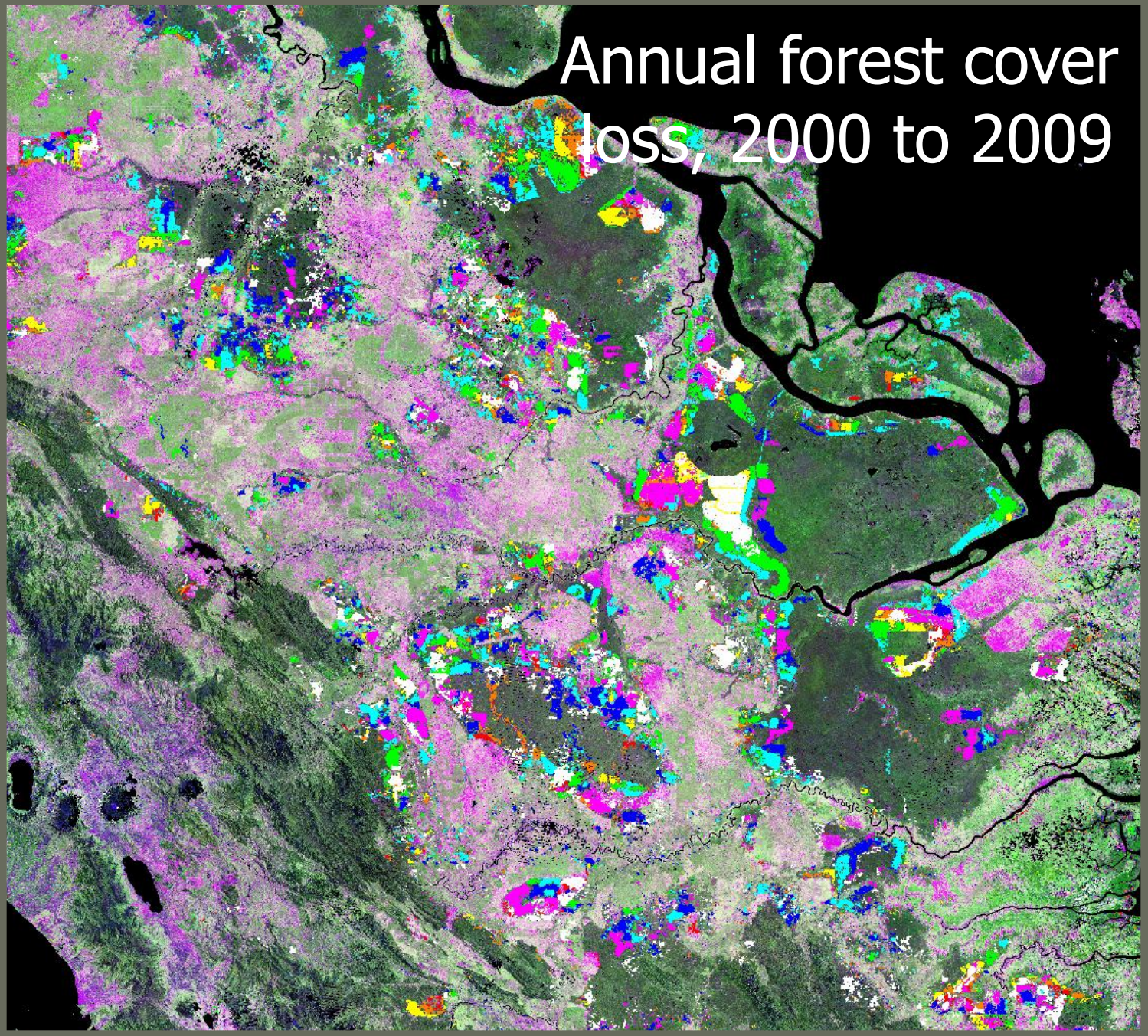
SDSU



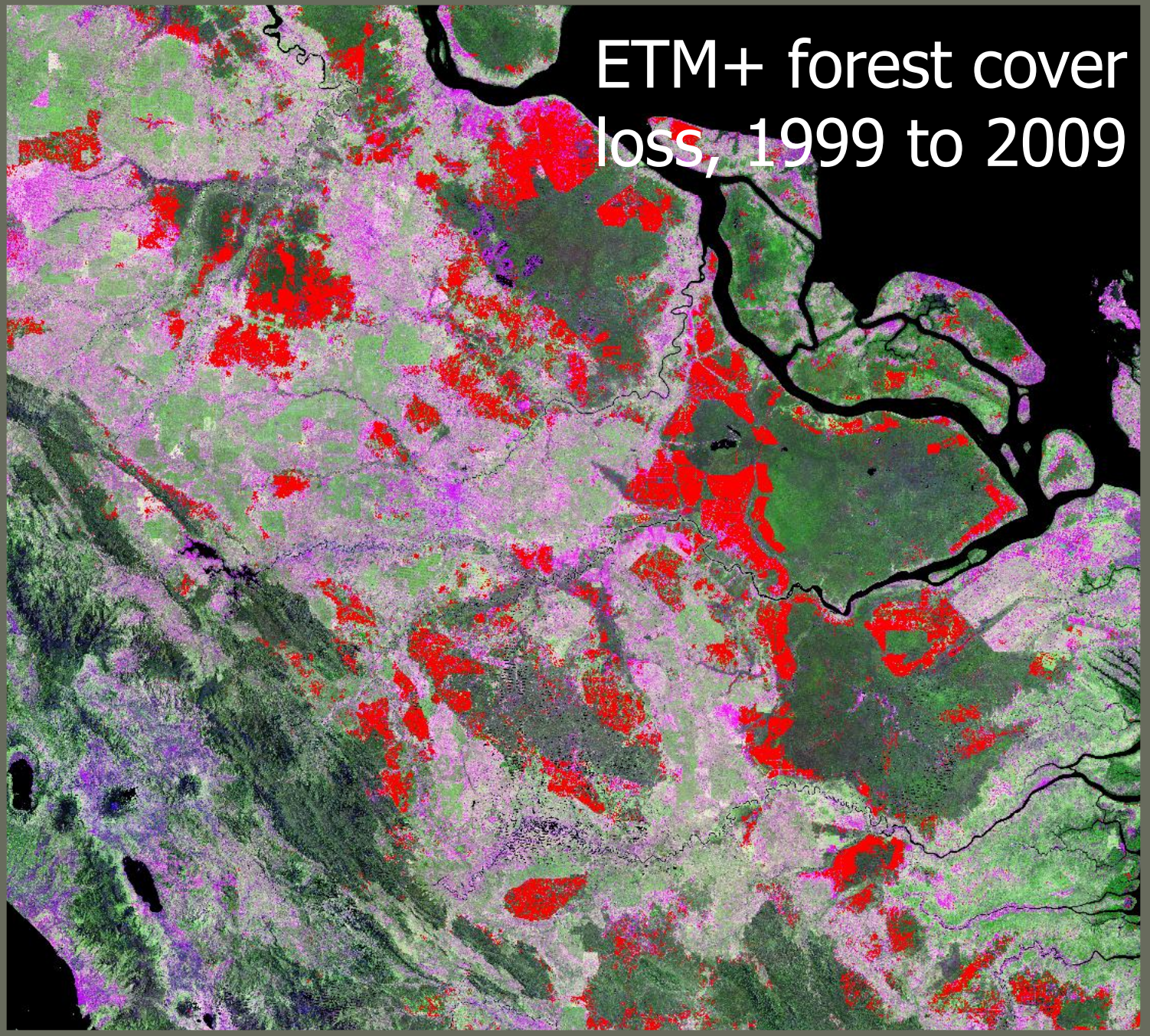
SDSU



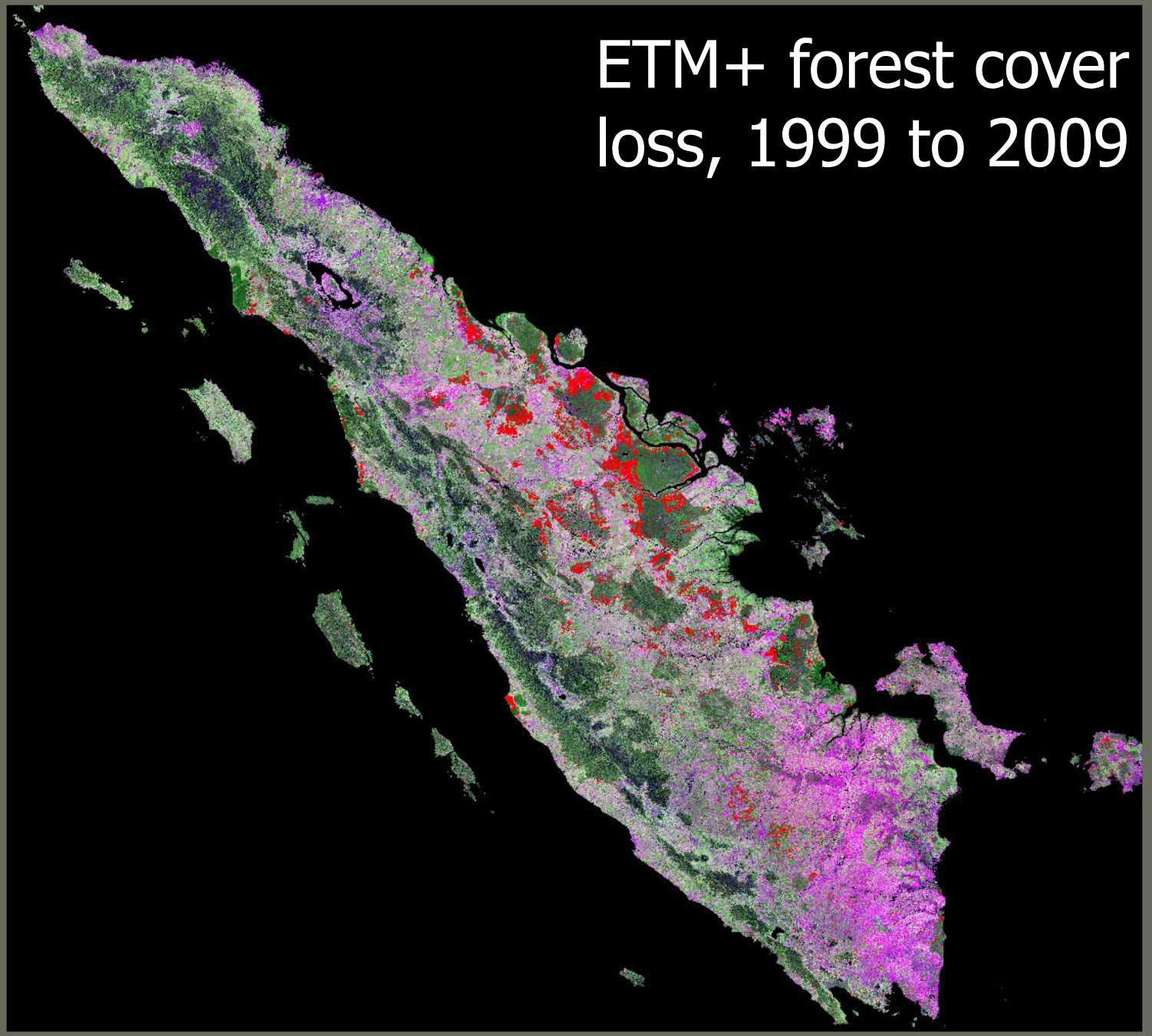
SDSU



SDSU



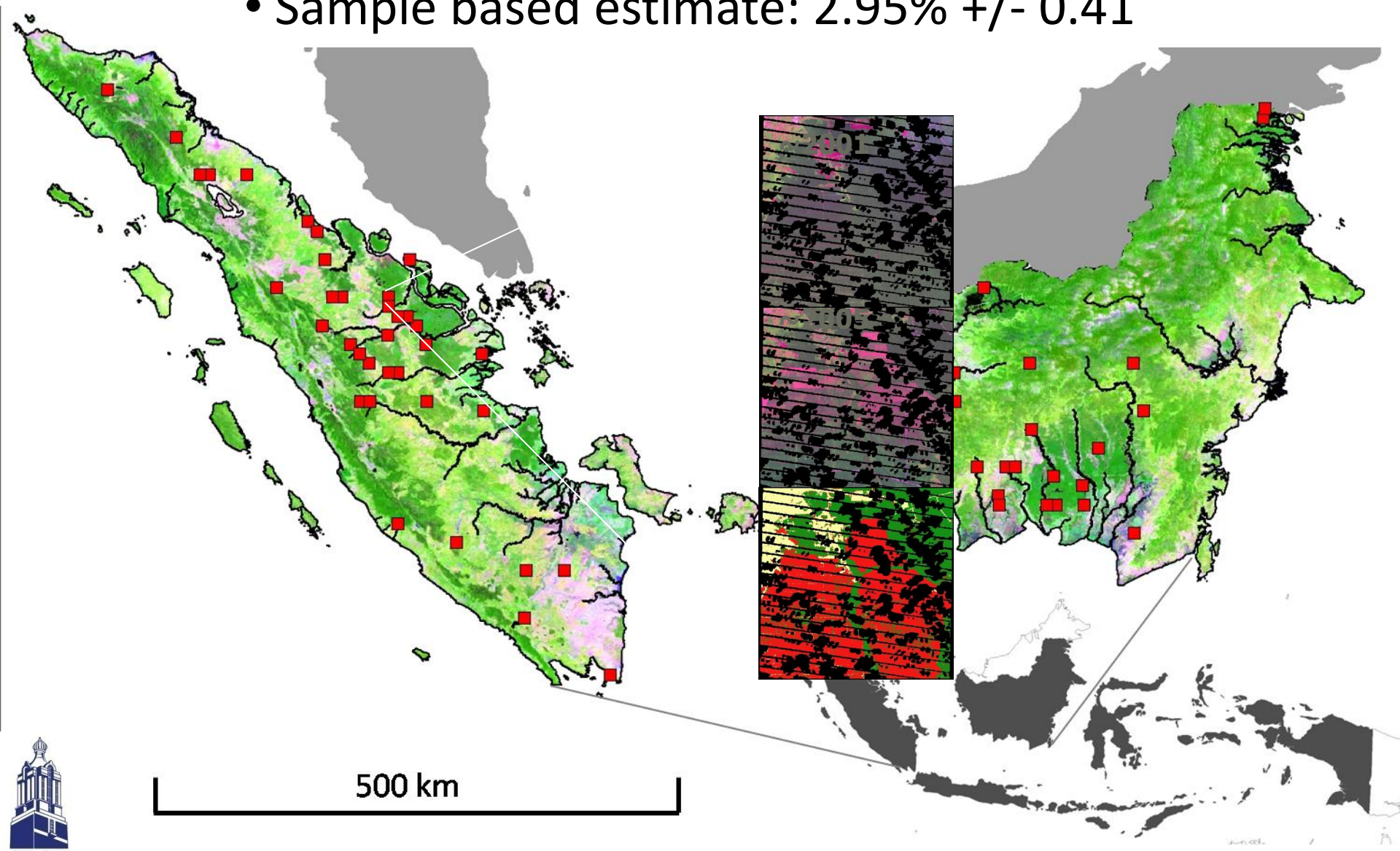
SDSU



SDSU

Validation data of forest cover loss 2000-2005

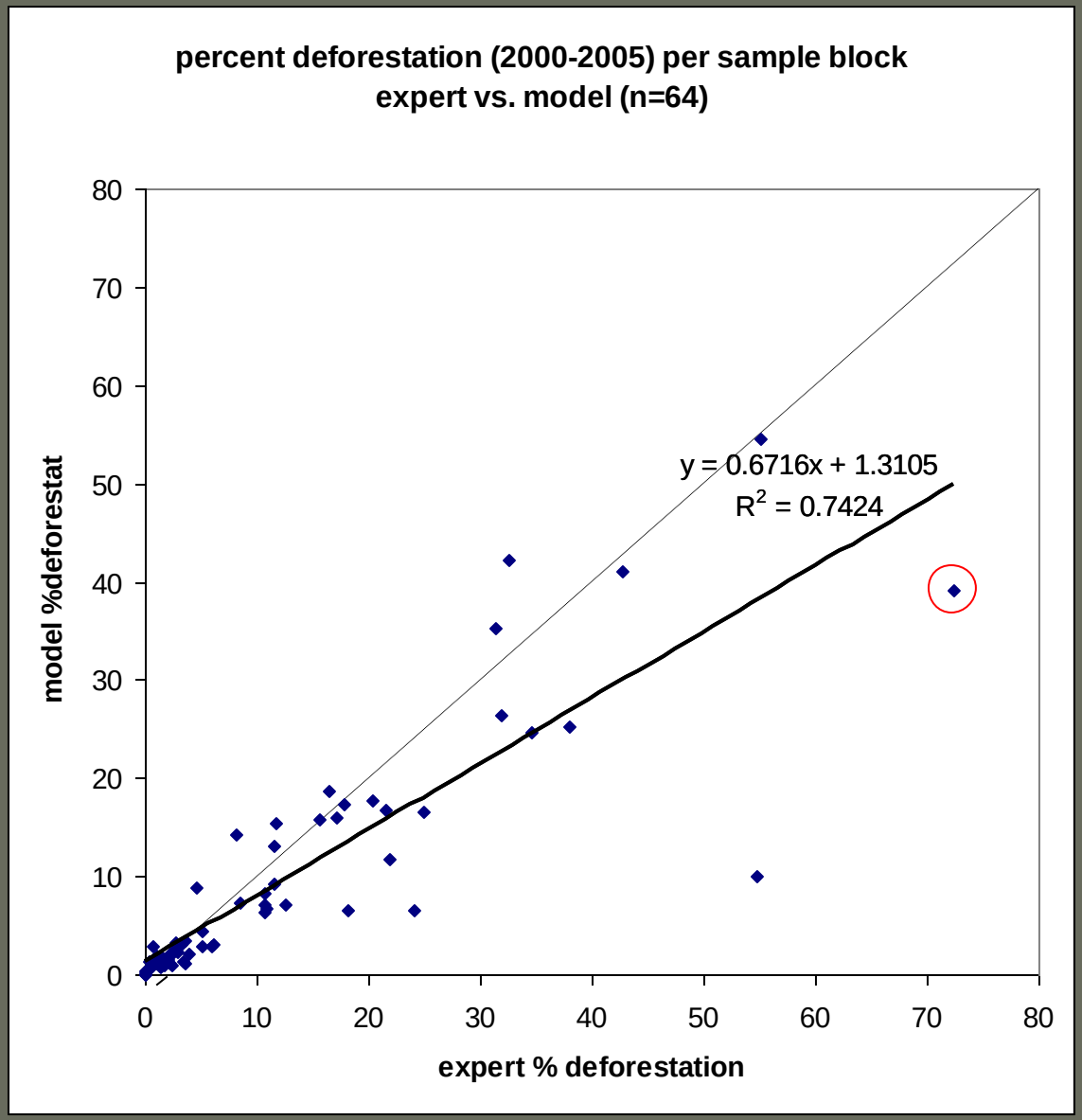
- Expert interpreted sample blocks (n = 64)
- Sample based estimate: 2.95% +/- 0.41



SDSU

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

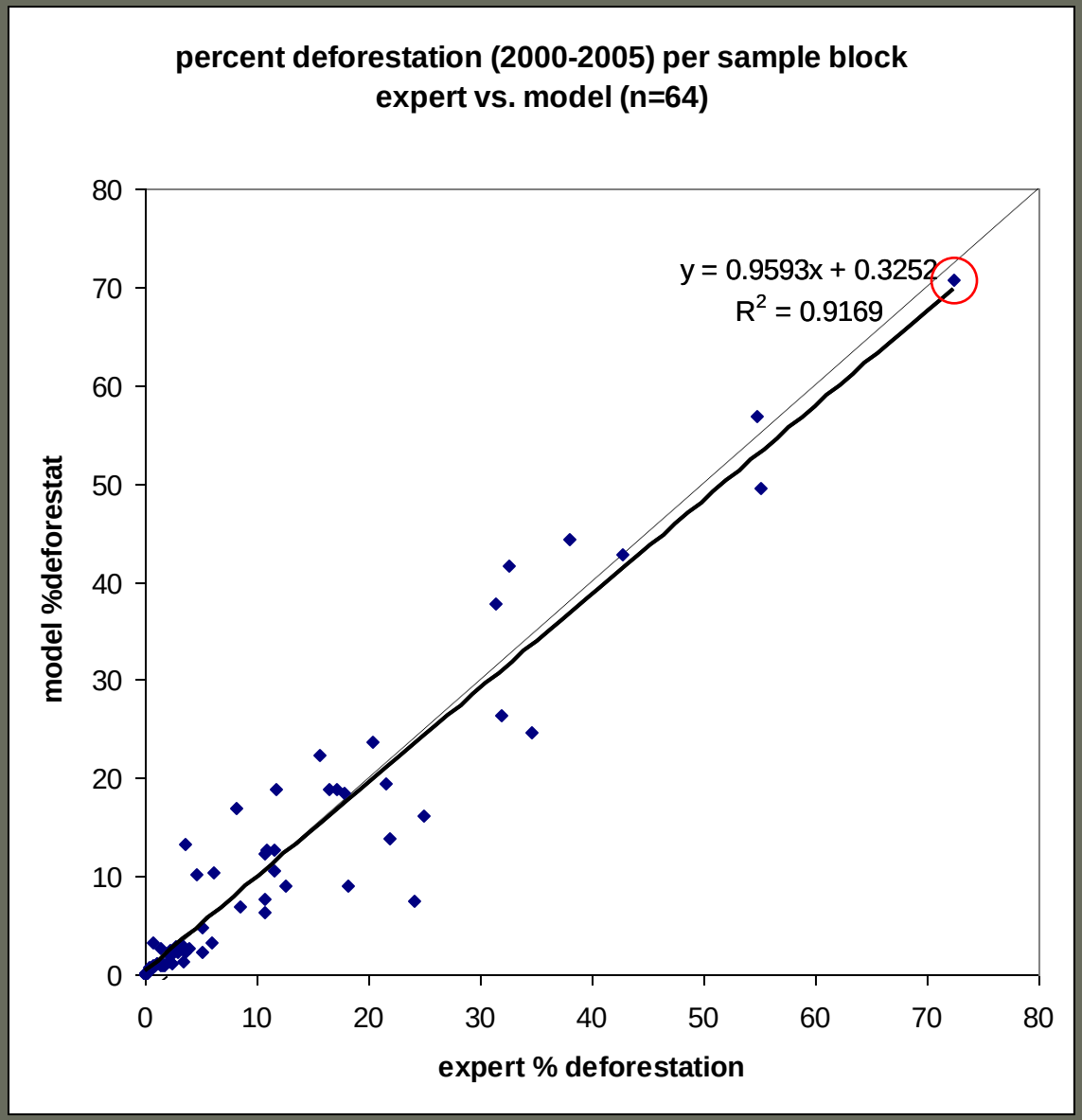
Model based on differencing the time 1 / time 2 characterizations



SDSU

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

Model based on full time series analysis per pixel

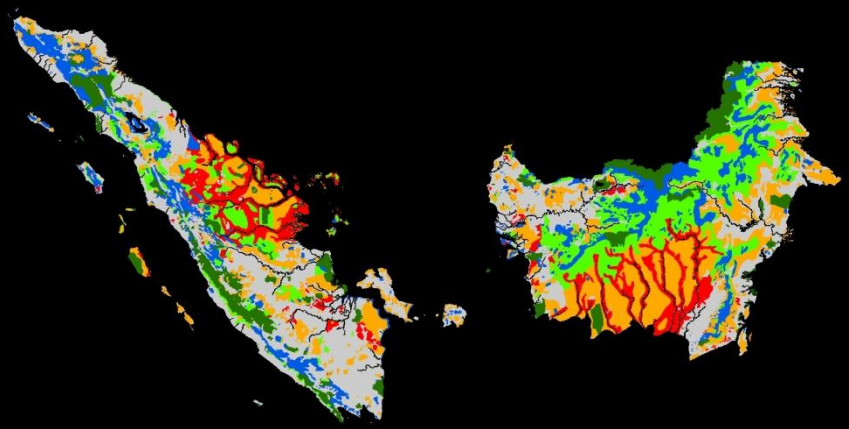


SDSU

Forest cover loss and land use

Percent of mapped deforestation per land use zone

- 69% in zones designated for forest land use
- 52% in zones designated for production or limited production and 17% occurred in conversion zones
- 24% in zones not designated for forest land use
- 2.35% in conservation zones and 5.12% in protected zones => 2,132 km^2 of illegal cutting

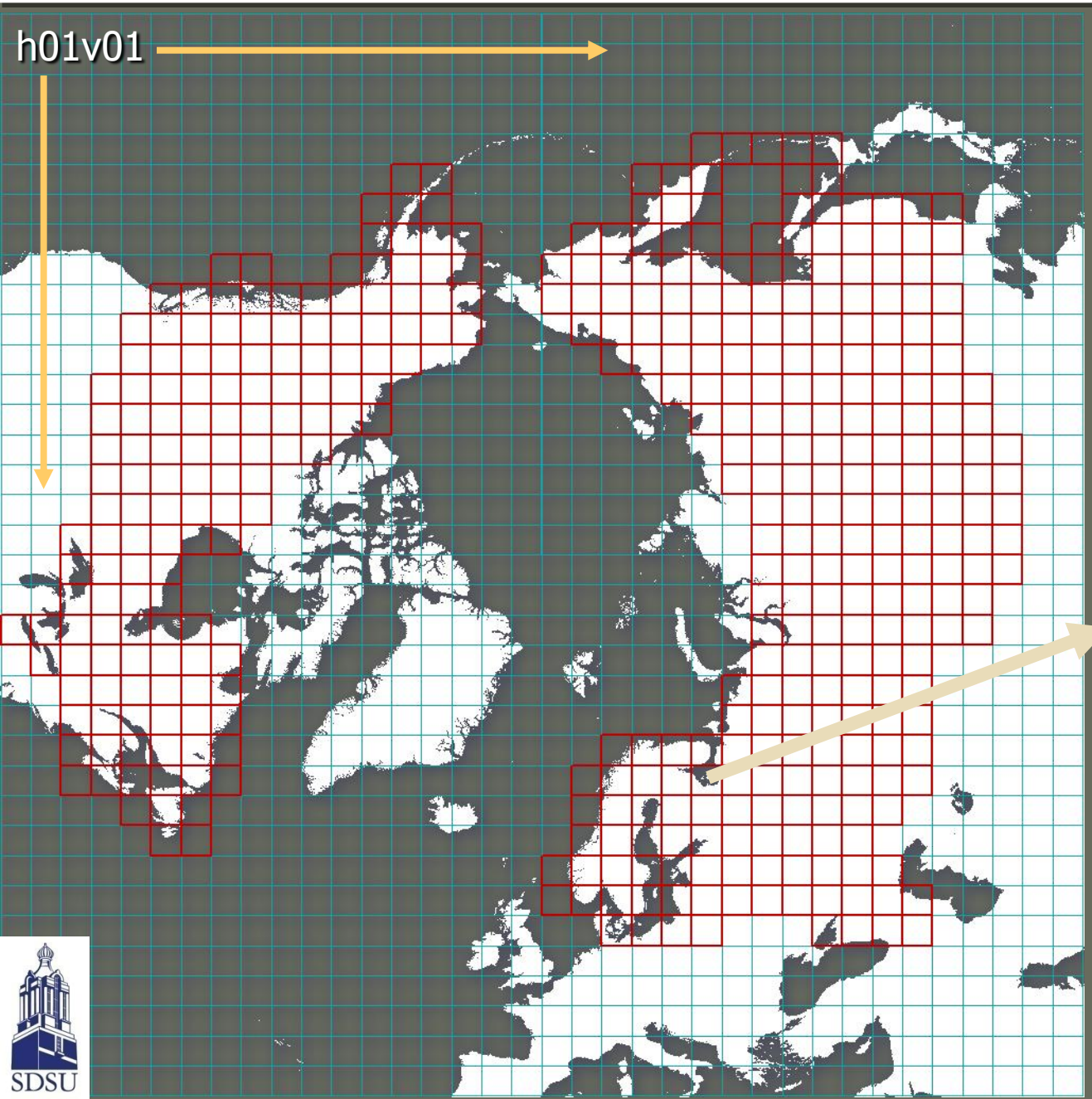


Total mapped forest cover loss 2000-05:
2.86% or 28,546 km^2

Landsat boreal forest cover monitoring

SDSU

Tiling system



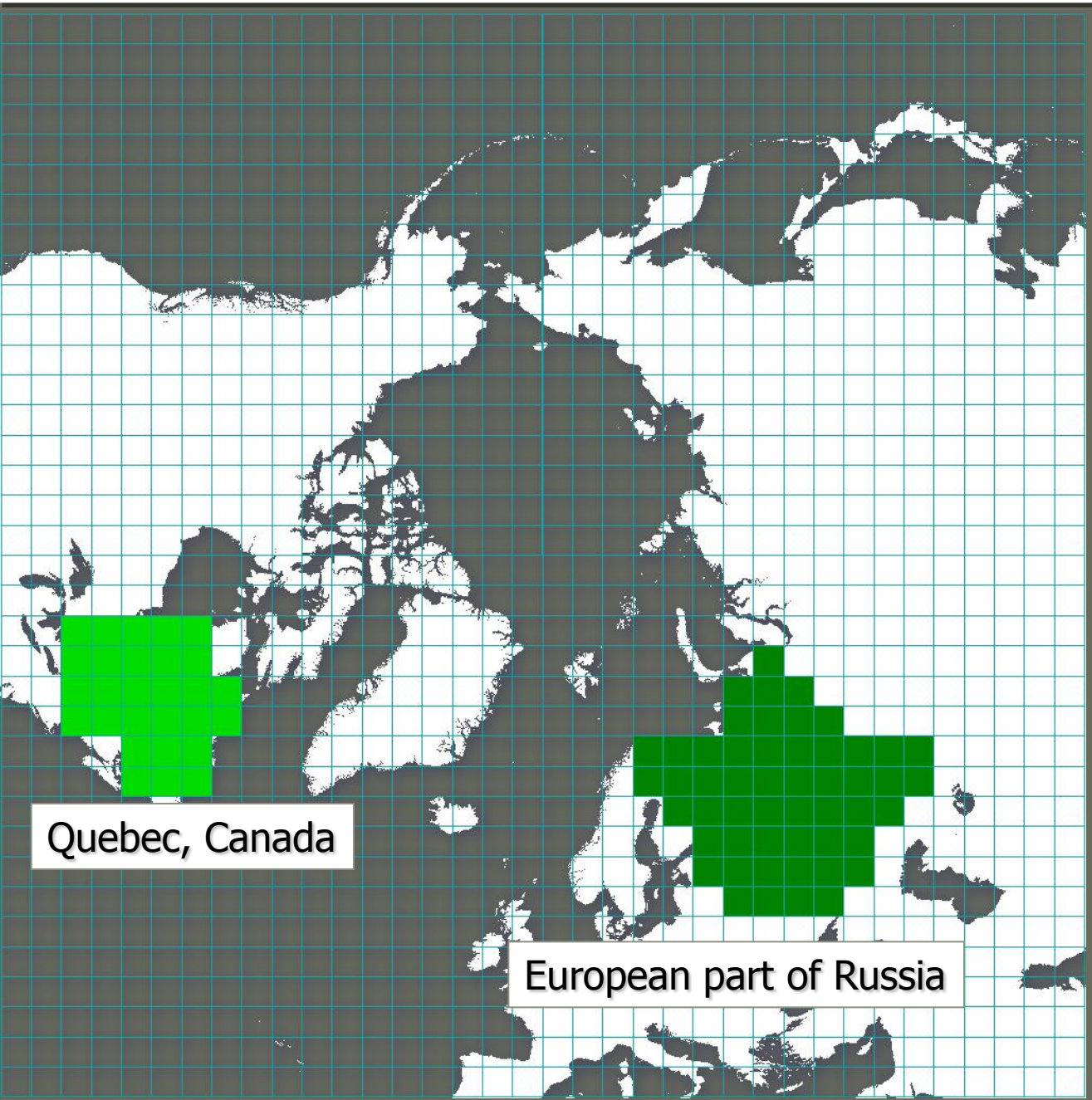
Lambert Azimuthal Equal Area projection centered at the North Pole

300,000 m

5000 pixels at 60m spatial resolution

SDSU

Tiling system



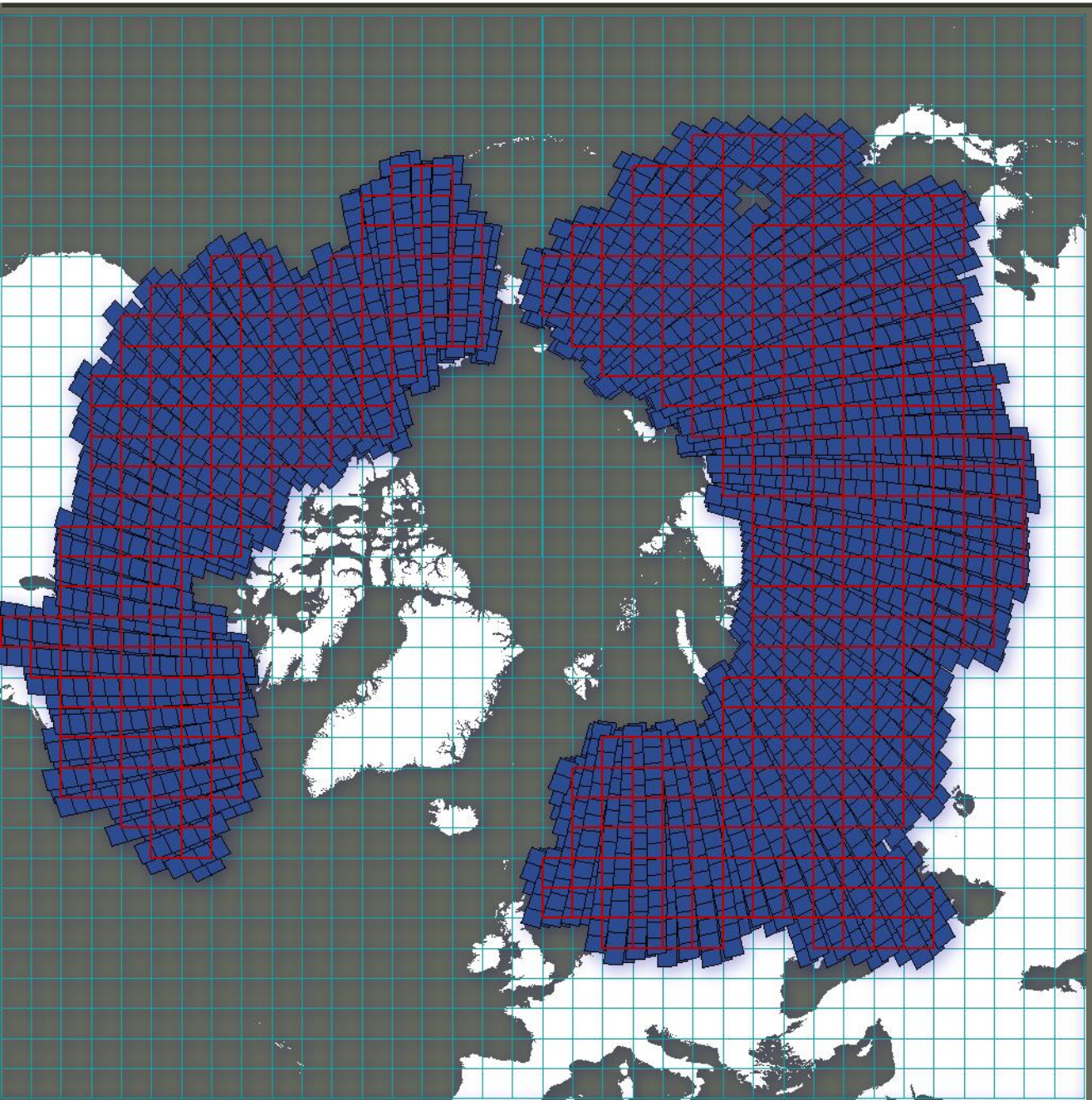
Test areas

1. Quebec, Canada
   28 tiles

2. European part of Russia
   52 tiles

SDSU

Image selection



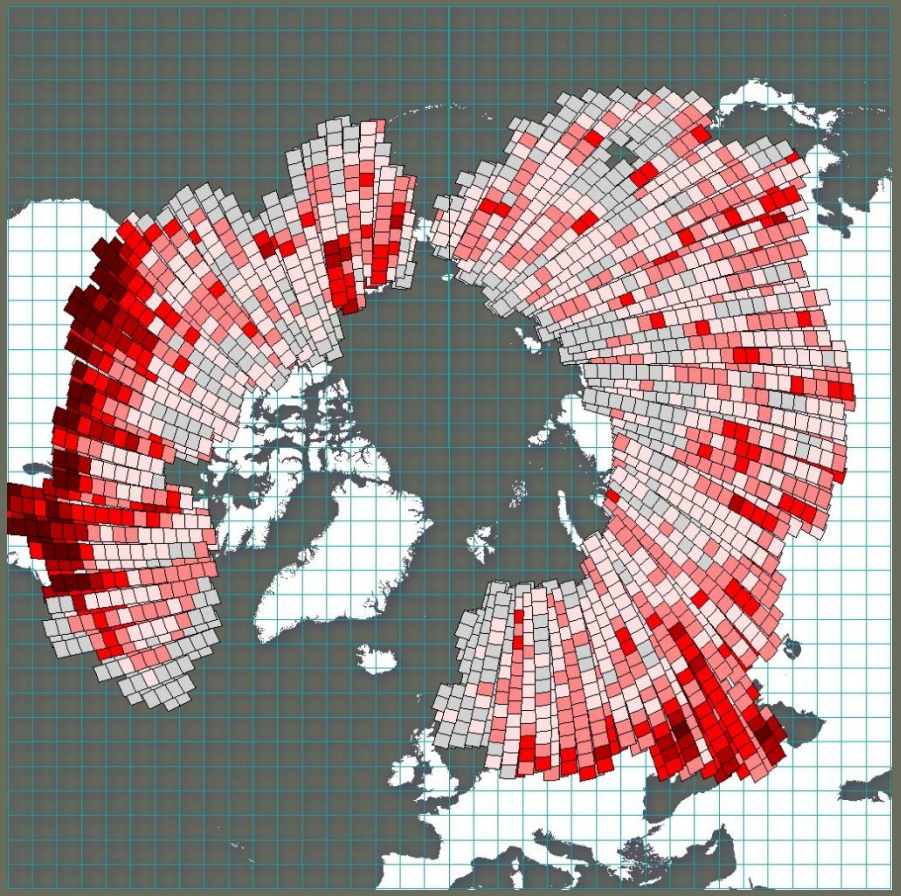
All selected WRS2 path/row (3154)

SDSU

Image selection

Landsat image selection criteria

- Date
  - Circa 2000 composite



Available Landsat images for year 2000

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

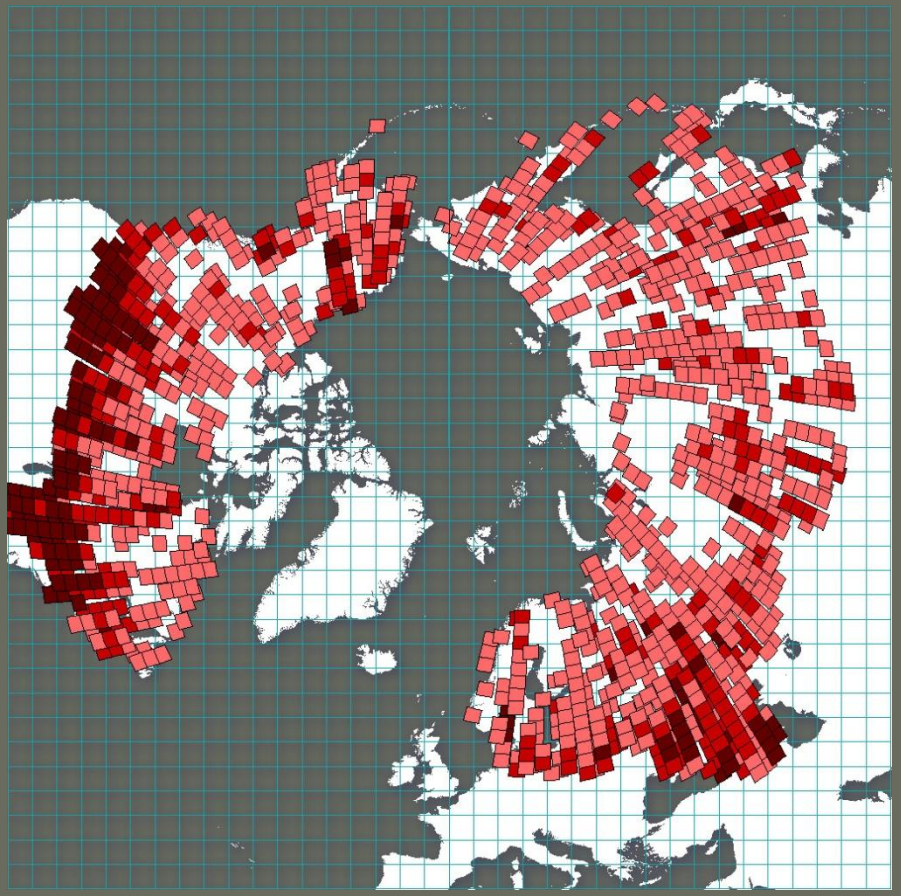
	Images per path/row	Percent of all path/row
	0	23
	1	38
	2	26
	3	8
	4	3
	5 and more	2

SDSU

Image selection

Landsat image selection criteria

- Date
  - Circa 2000 composite



Available Landsat images for year 2000

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

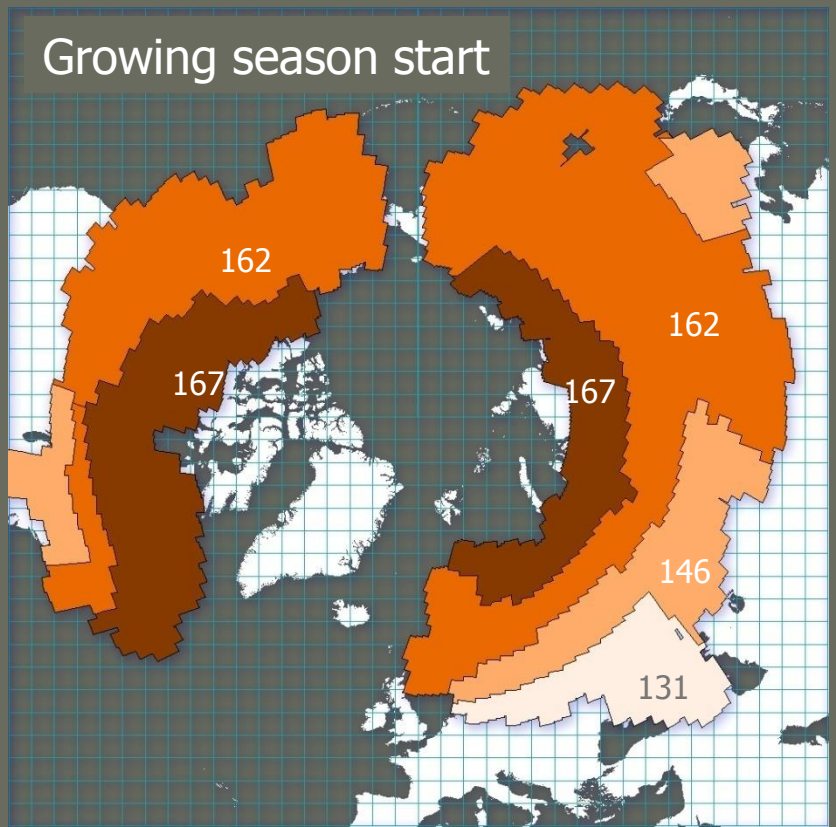
	Images per path/row	Percent of all path/row
	0	23
	1	38
	2	26
	3	8
	4	3
	5 and more	2

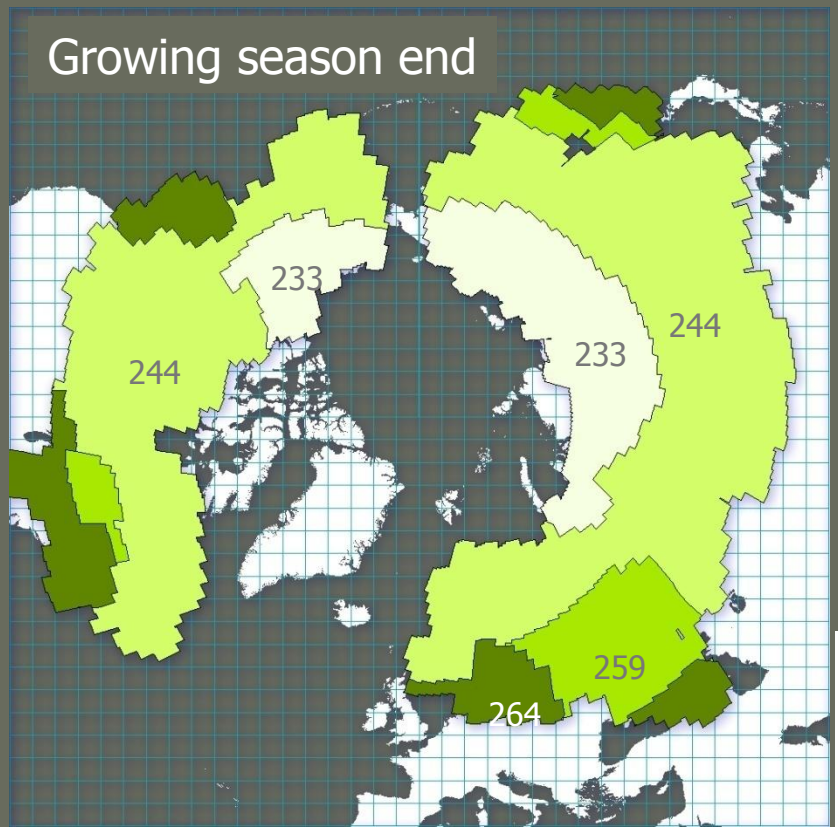
SDSU

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





SDSU

Image selection

Landsat image selection criteria

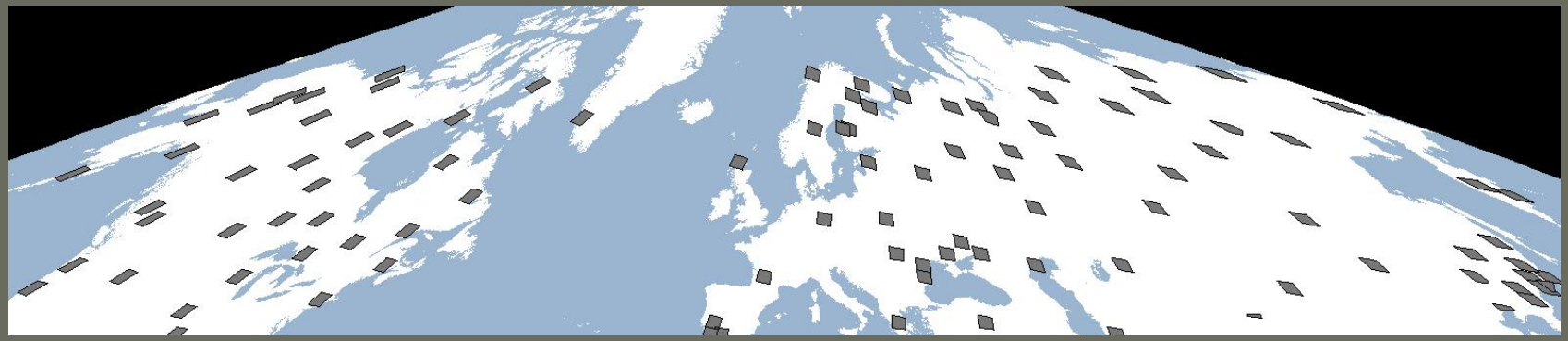
- Dates
  - Circa 2000 composite: 1999-2002 slc-on data
  - Circa 2005 composite: 2003-2007 slc-off data
  - Within growing season
- Cloud cover
  - Less then 50% ACCA cloud cover
  - OR, less then 50% cloud cover for any of the scene quarter

Image inputs

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

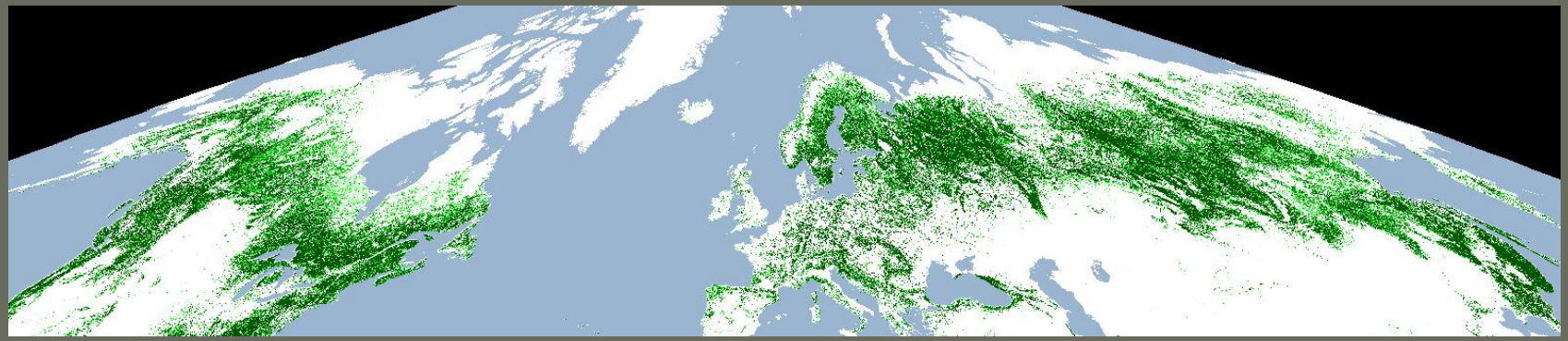
SDSU

MODIS processing



Landsat-based training

Classified Landsat scenes



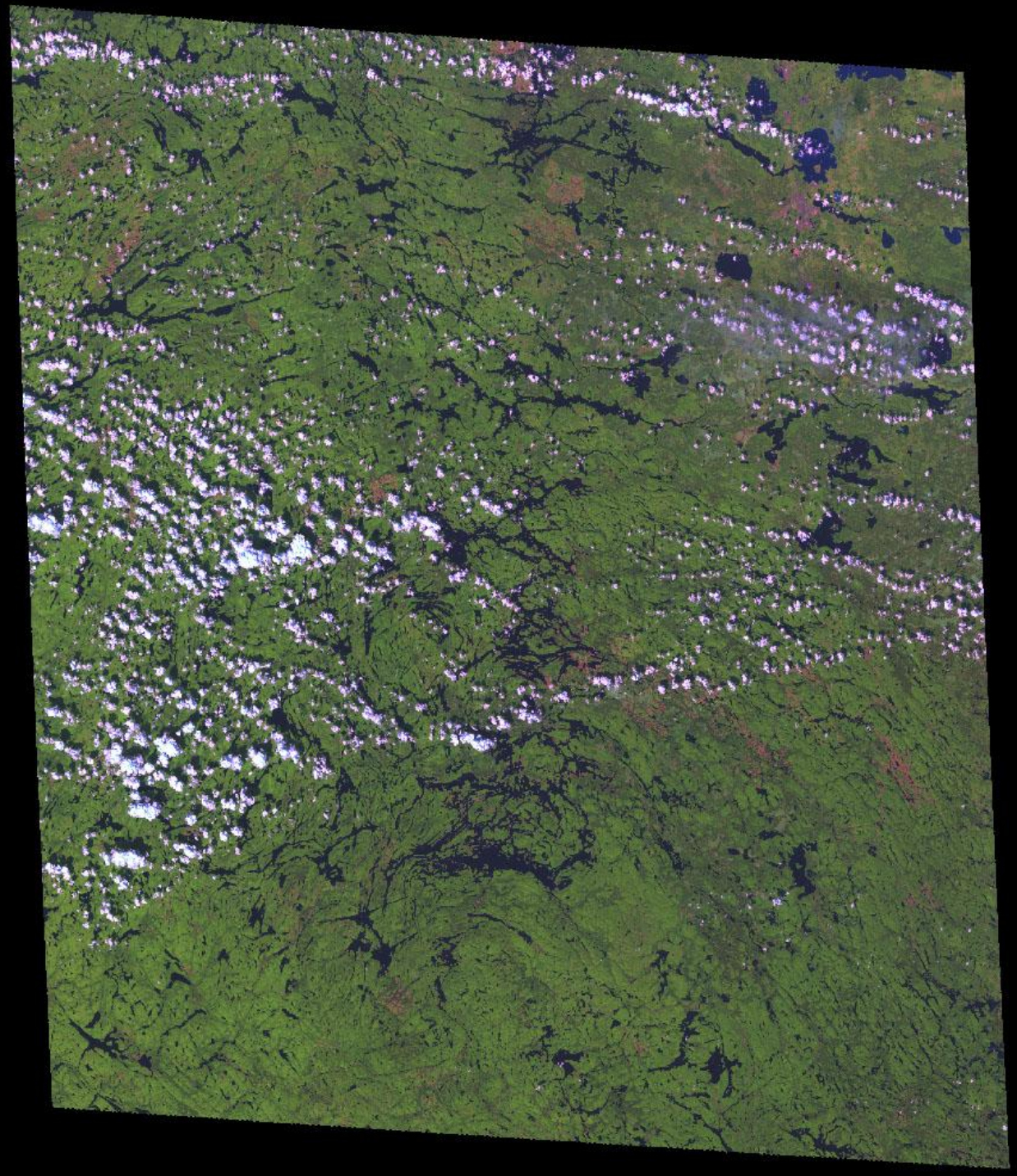
Forest cover

0% 100%

Coniferous forest mask

Coniferous forests

SDSU

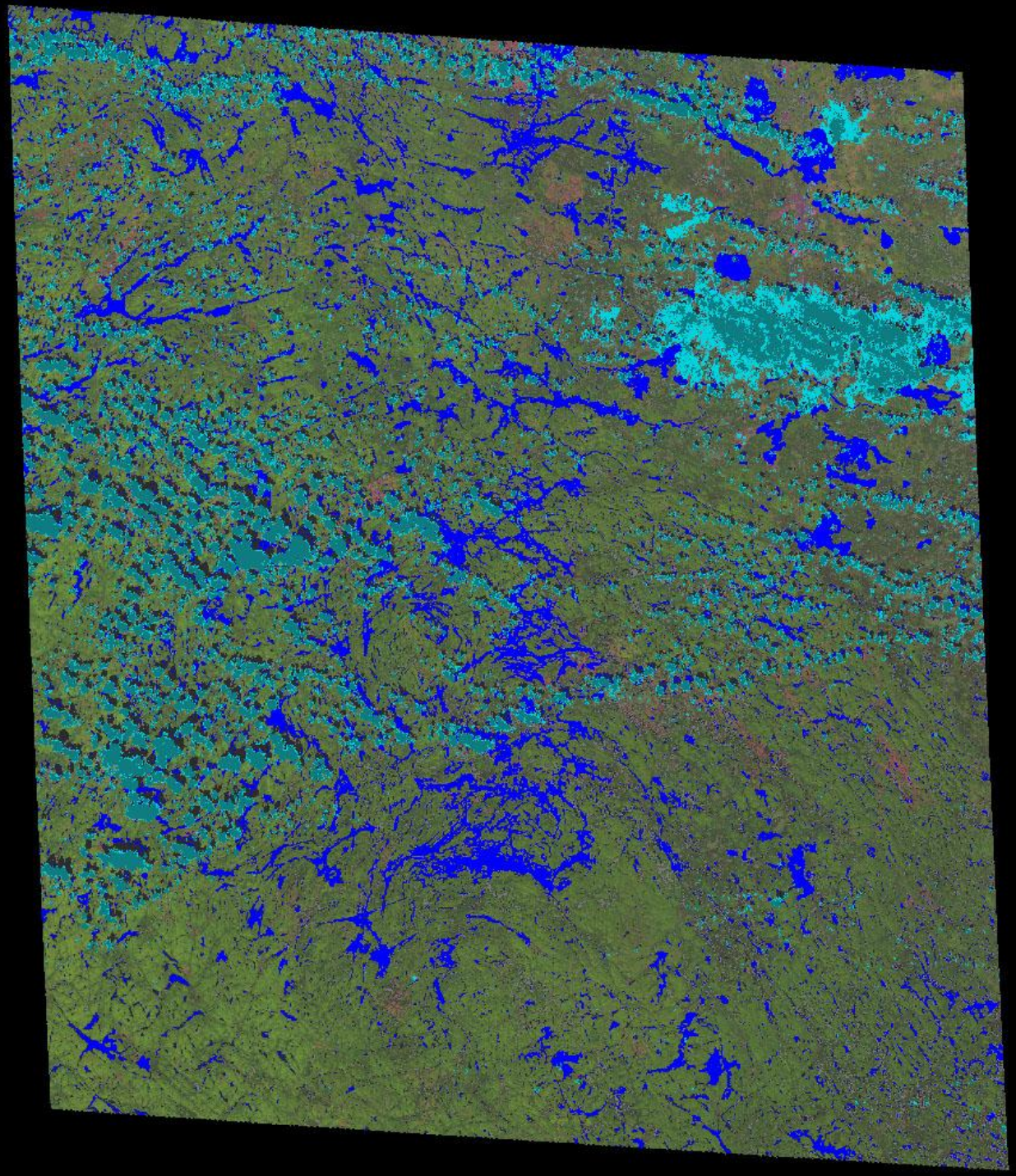


Source imagery

Quebec (P17R27)

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

SDSU



Quality assessment flags

Cloud likelihood

- 50-90%
- >90%

Shadow likelihood

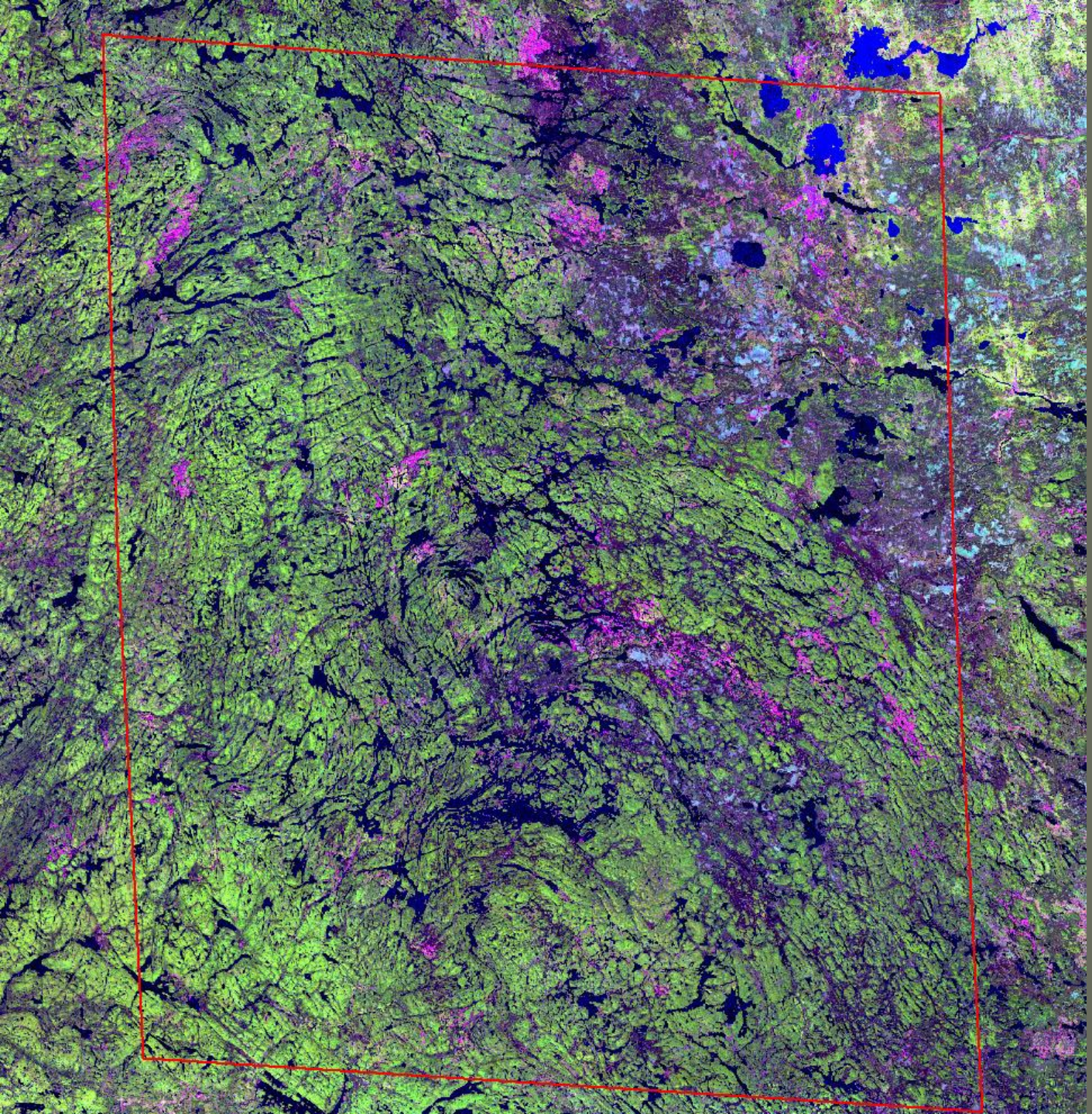
- 50-90%
- >90%

Water likelihood

- >50%

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

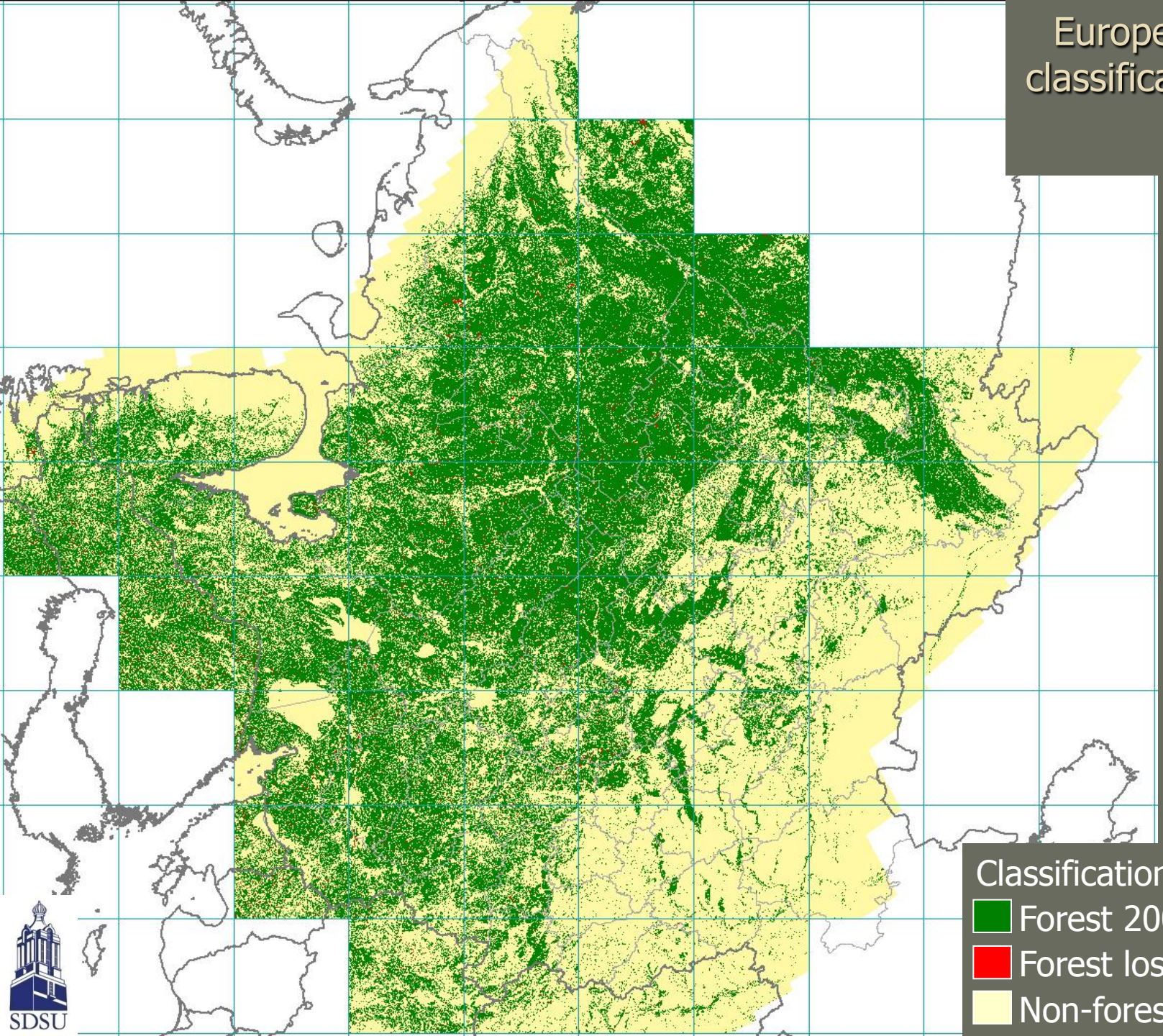
SDSU



Composite image
for circa year 2000

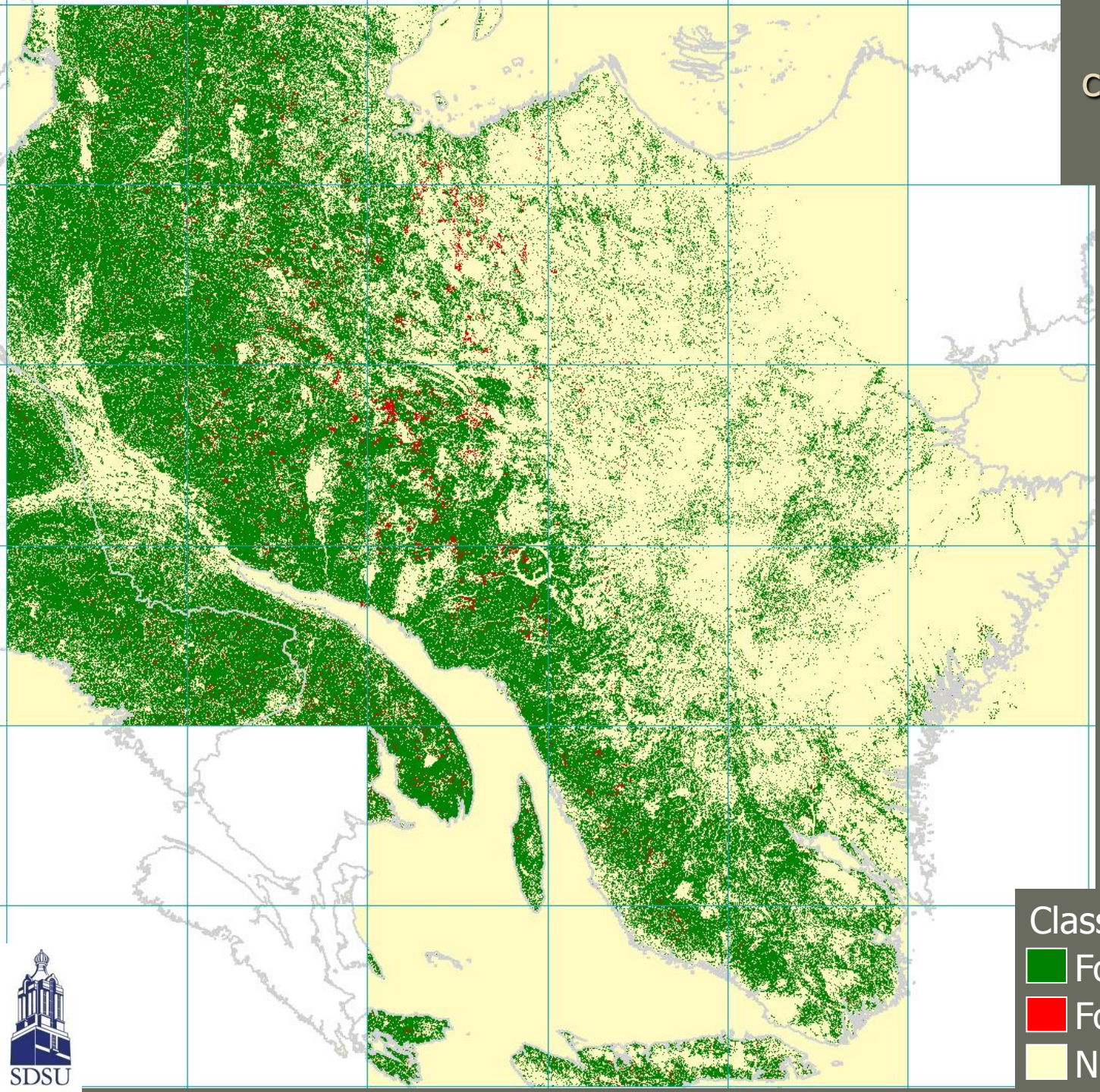
SDSU

European Russia classification results



SDSU

Quebec, Canada classification results



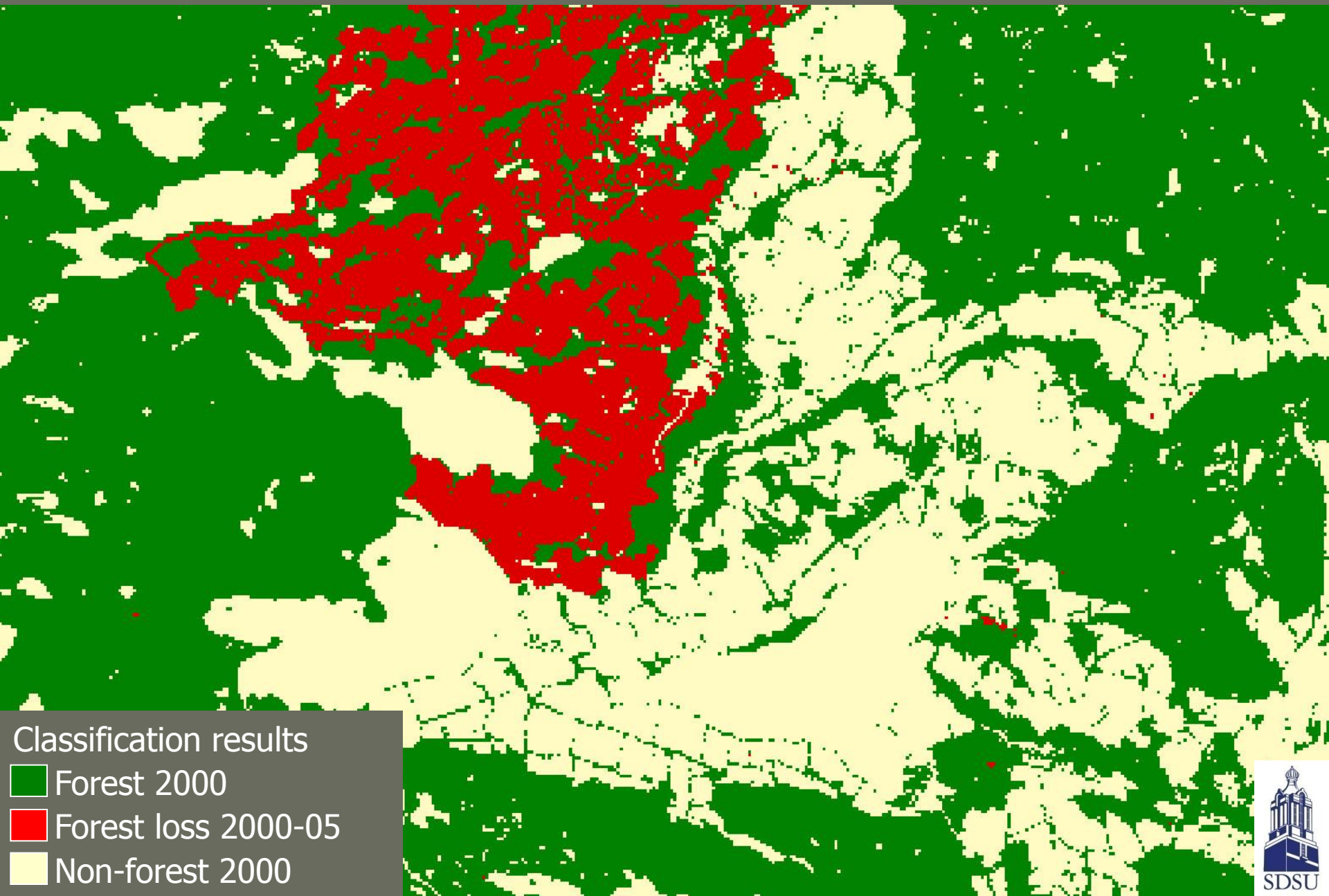
N

Classification results

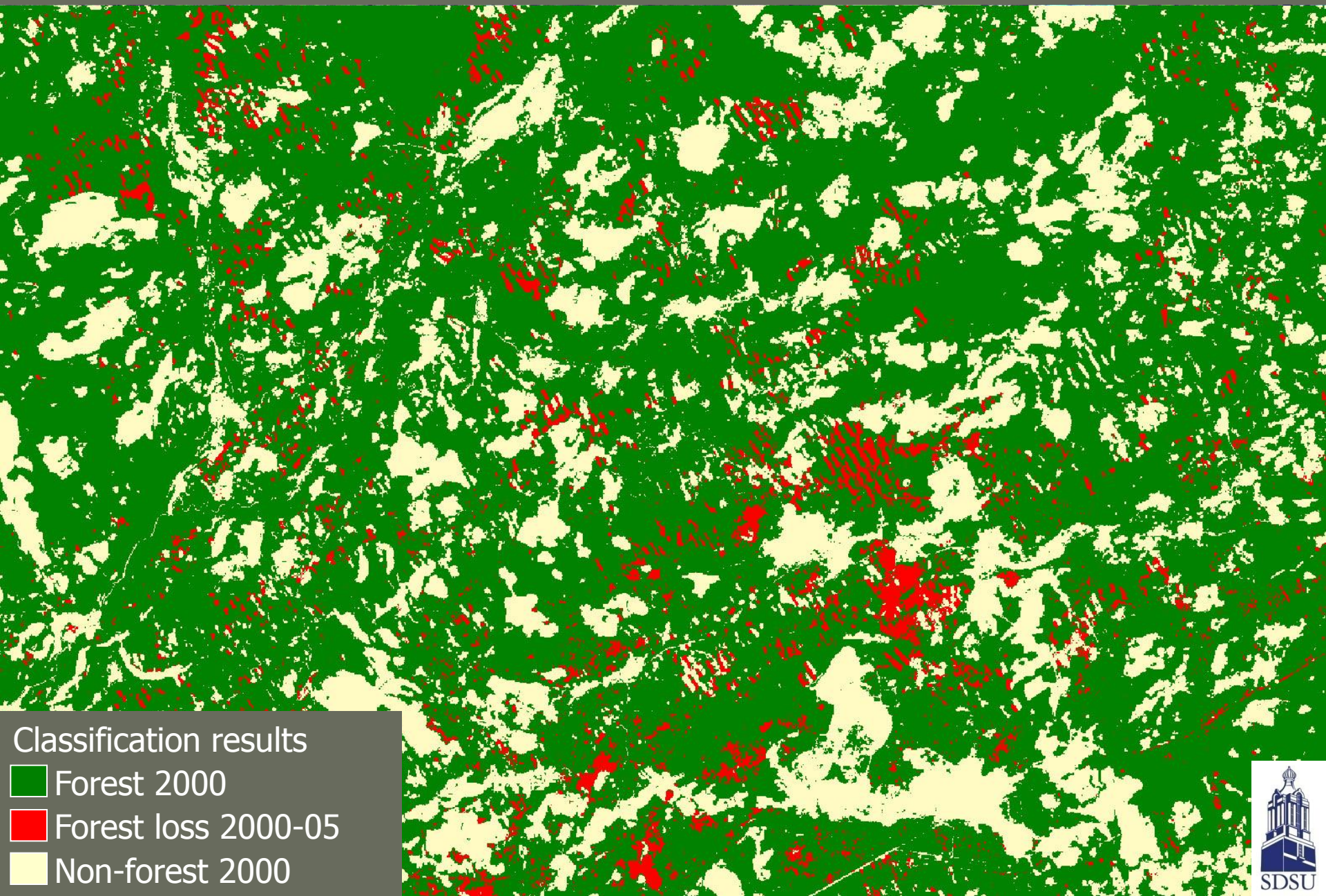
- Forest 2000
- Forest loss 2000-05
- Non-forest 2000

SDSU

Quebec, Canada: Classification examples



European Russia: Classification examples



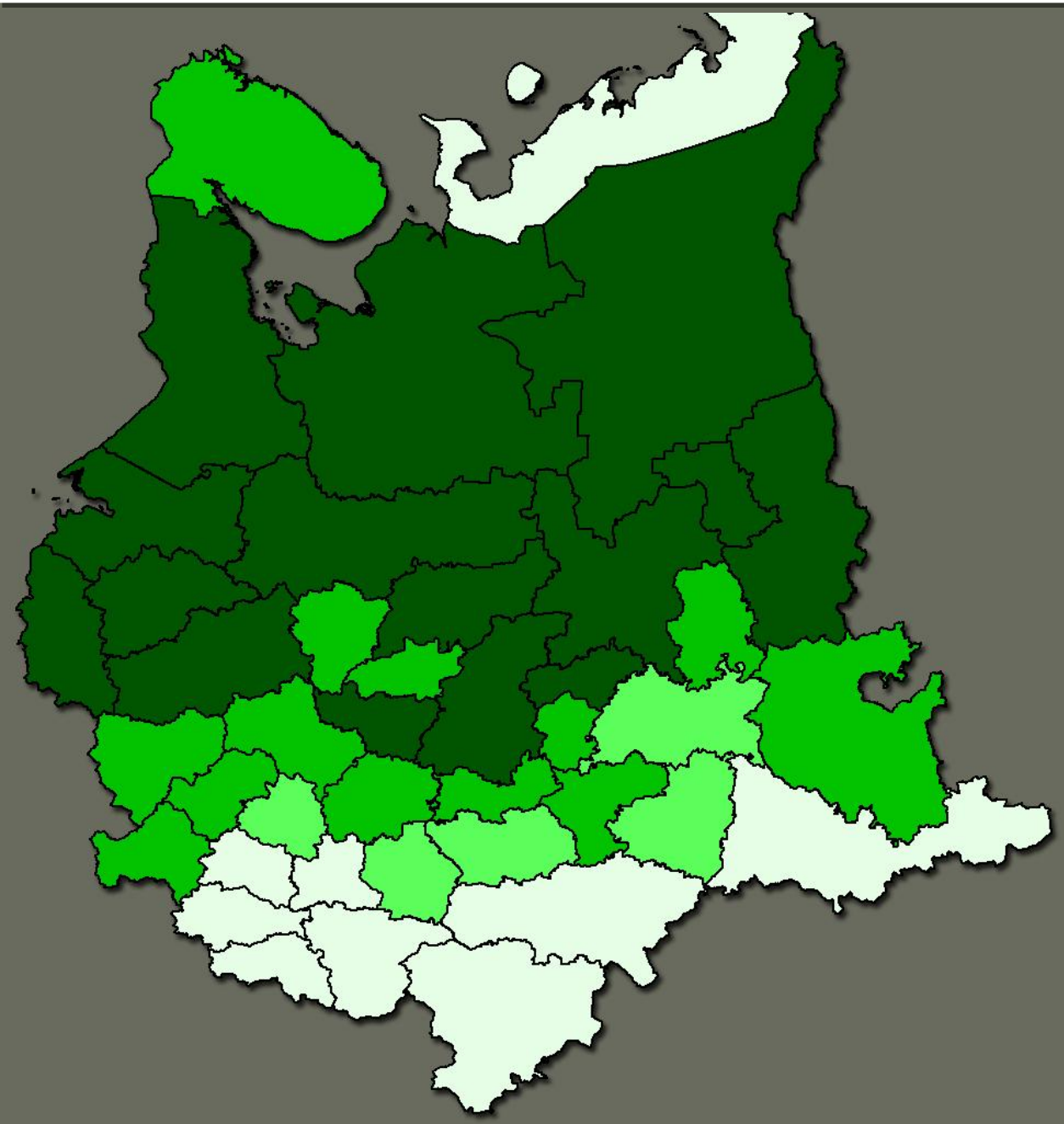
SDSU

European Russia

Selected 42 administrative regions

SDSU

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

SDSU

European Russia

Gross forest cover loss (% of total)

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

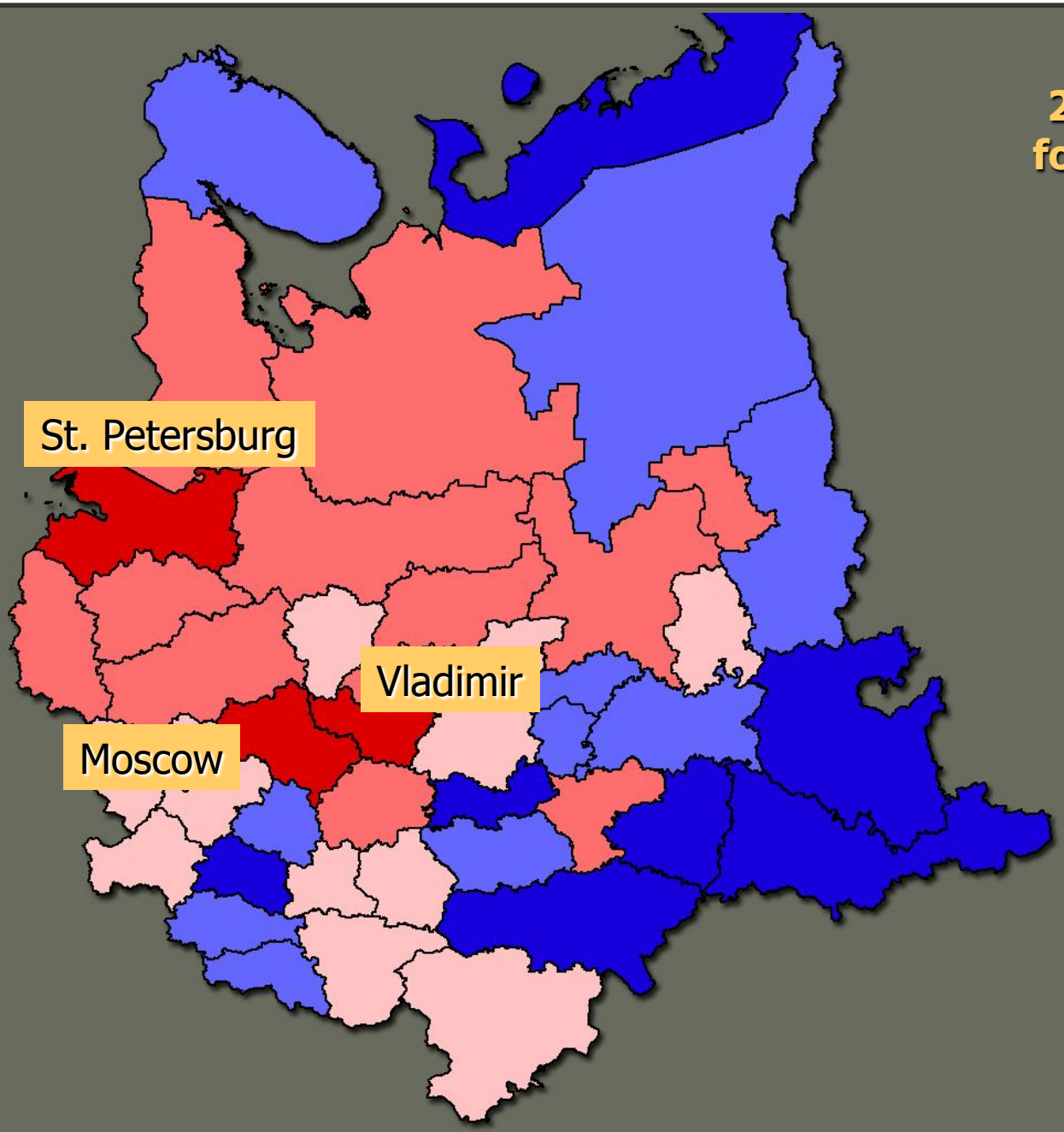
Total gross forest cover loss:

2,210 thousand ha

1.5% of year 2000 forest cover

SDSU

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%)

SDSU

European Russia

The bark beetle outbreak 1999-2000
followed by increased "sanitary" logging

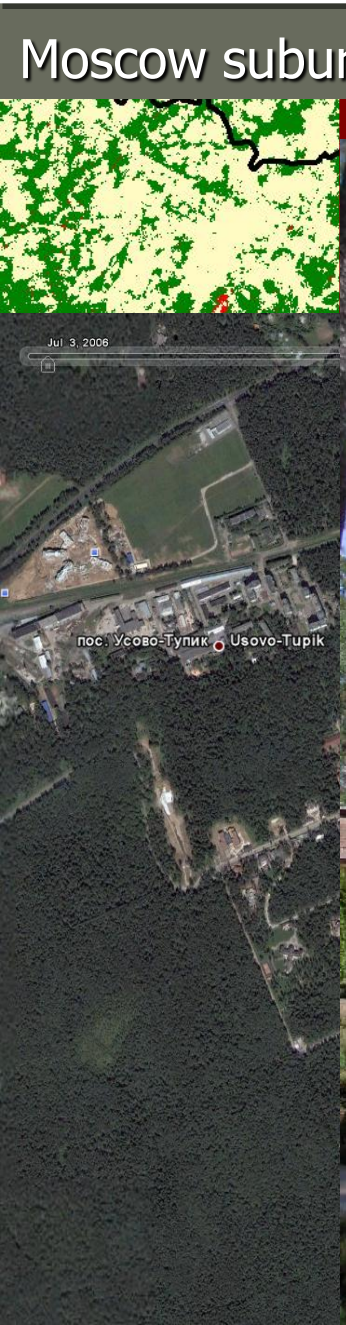
European Russia

Extensive forest and peat bog fires (fall 2002)

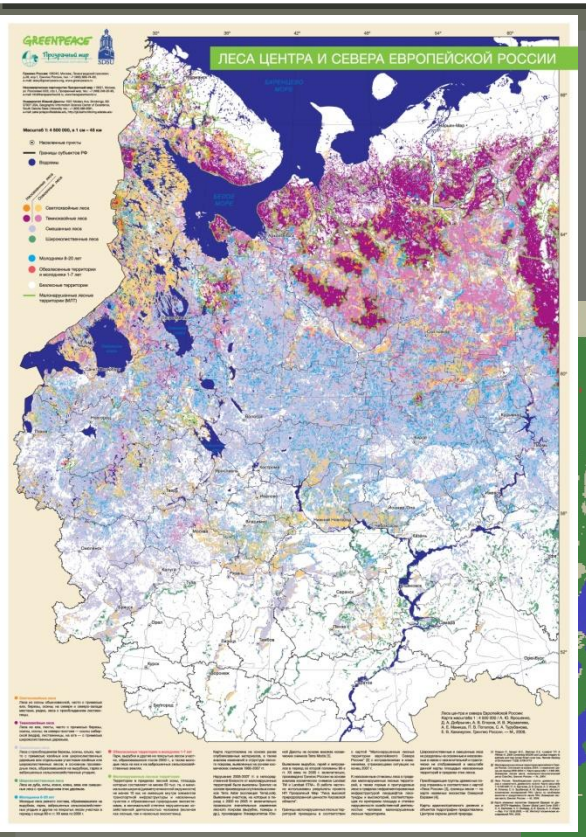
MODIS image 07/30/2002
www.ssec.wisc.edu

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.

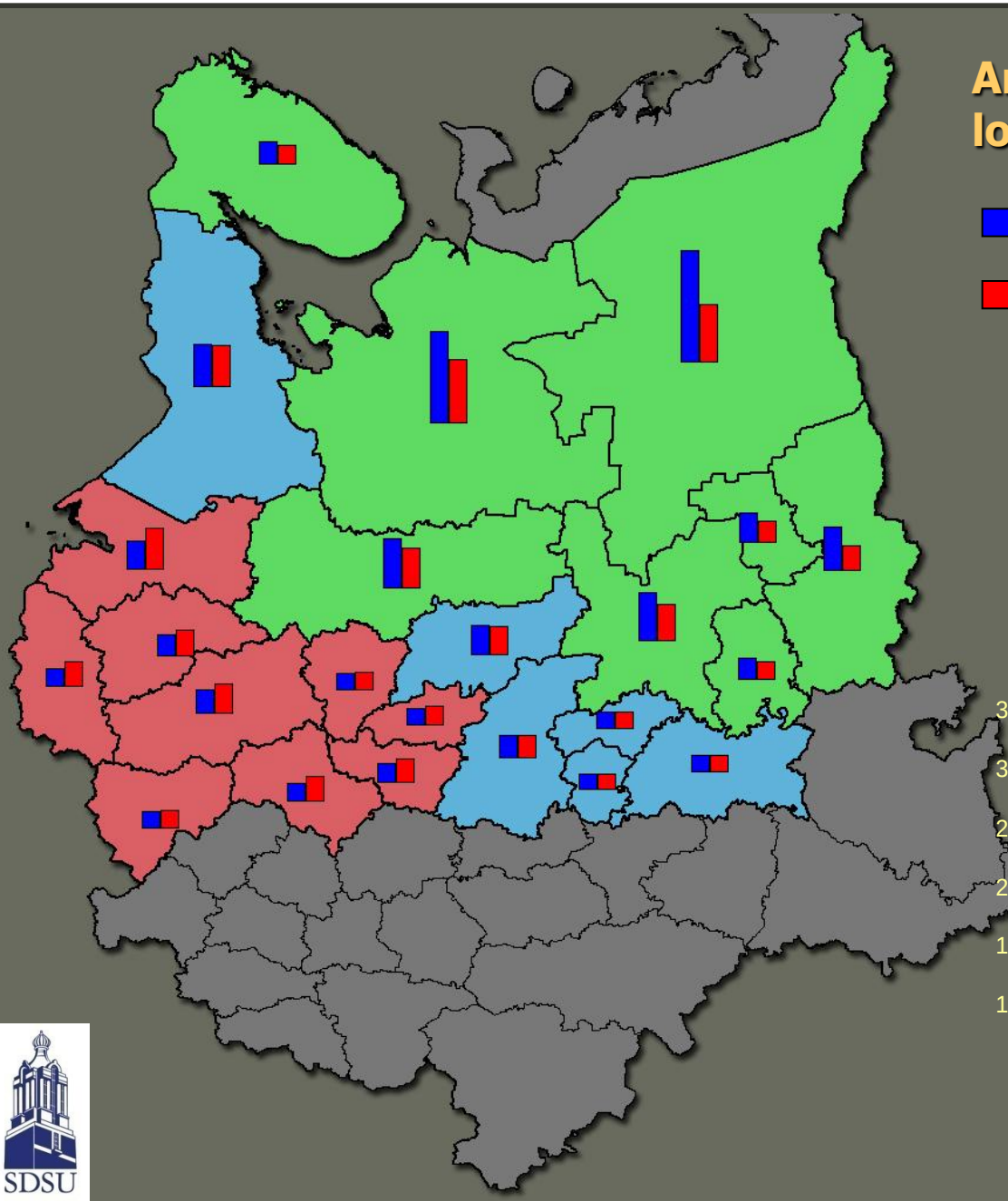
Forest 2005

Gross forest loss 1990-2000

Gross forest loss 2000-2005

SDSU

European Russia



Annual gross forest cover loss, thousand ha

1990-2000

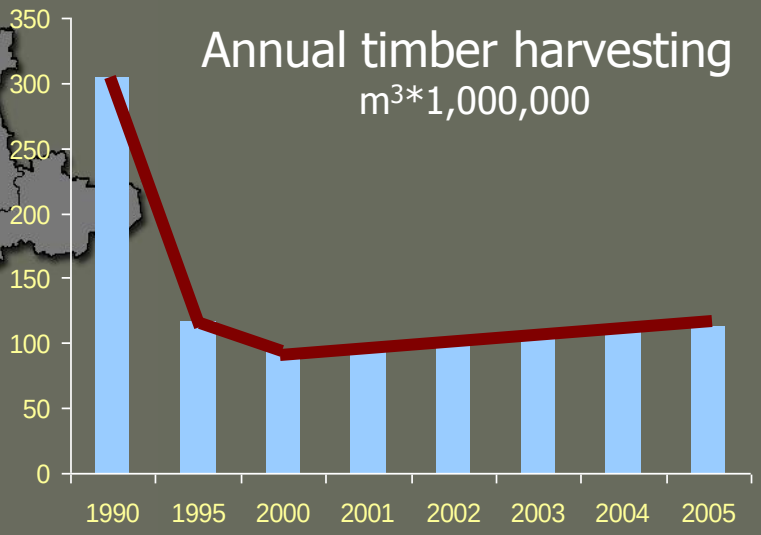
2000-2005

100 ha*1000

Total annual gross forest cover loss:

1990-2000: 530 ha*1000

2000-2005: 406 ha*1000

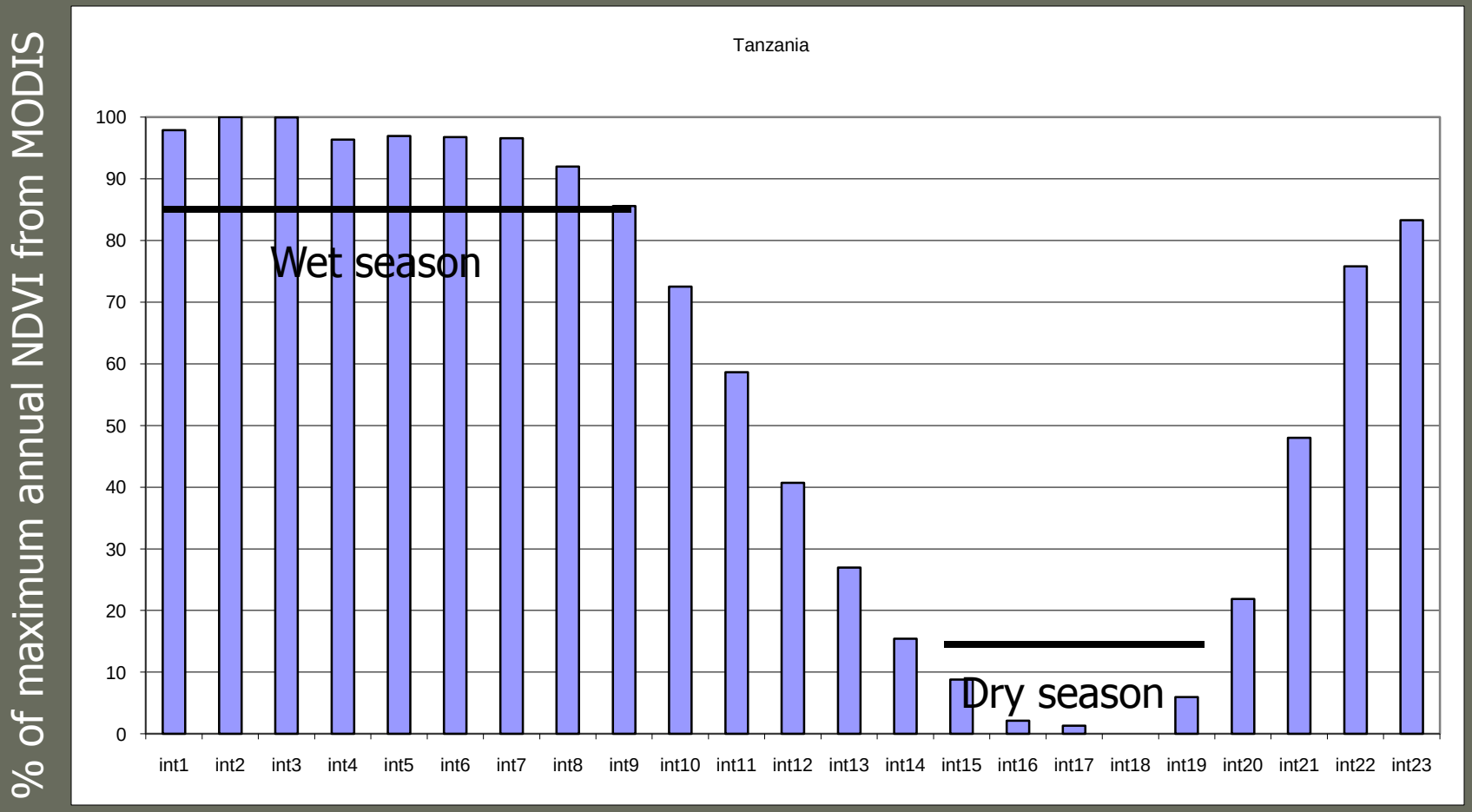


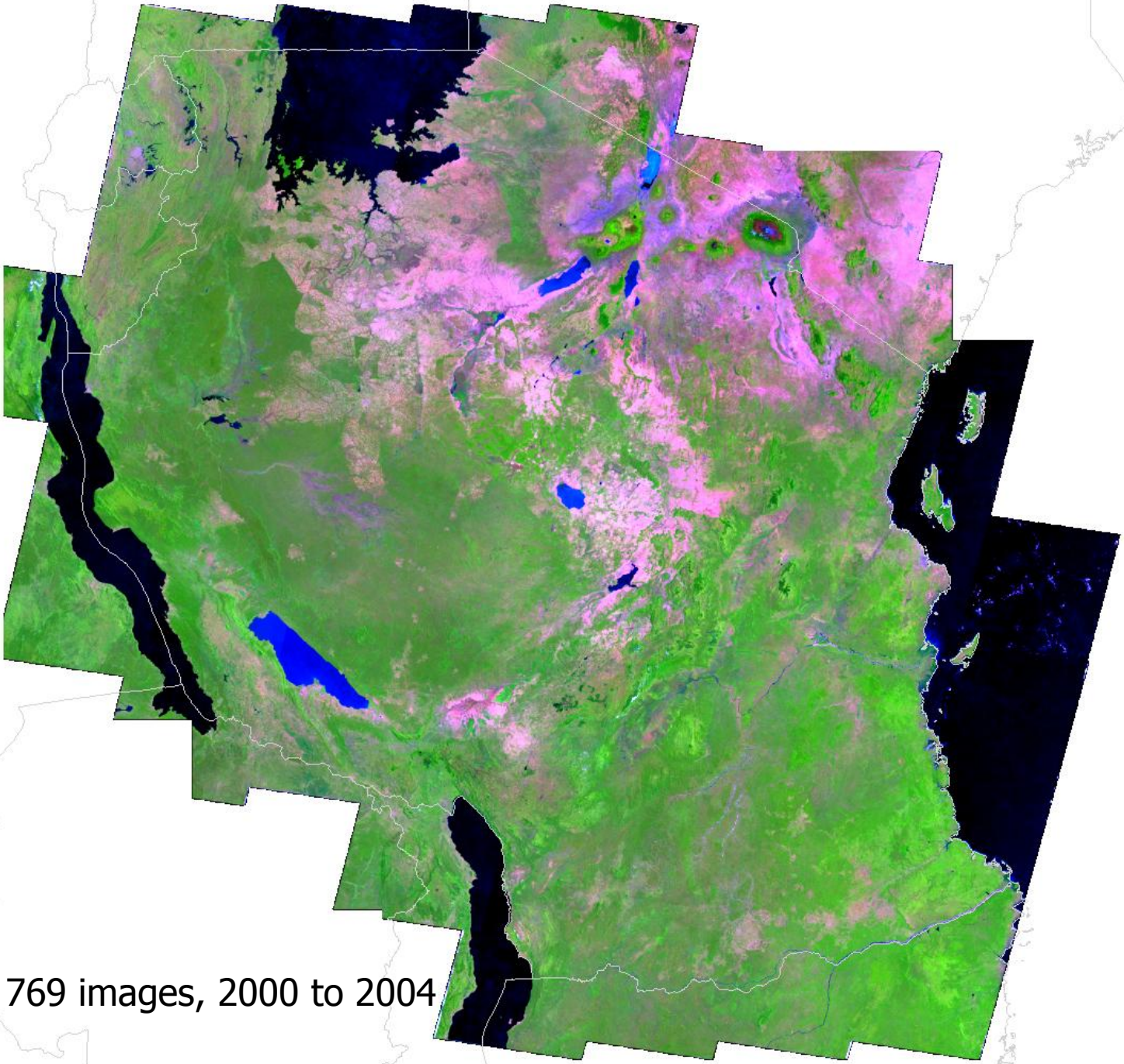
SDSU

Landsat dry tropical forest cover monitoring example

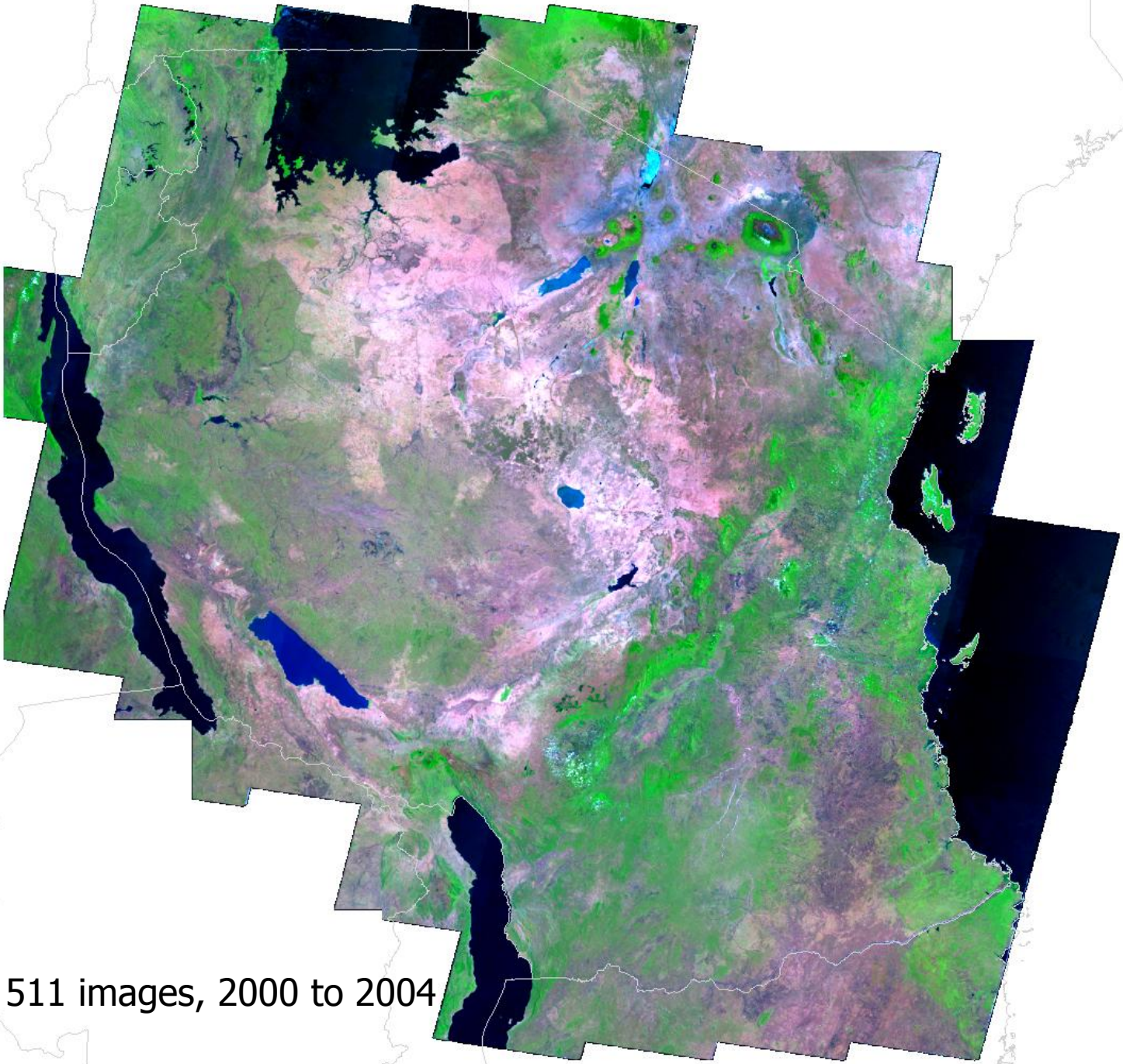
SDSU

Dry tropical biome – Tanzania test case





769 images, 2000 to 2004



511 images, 2000 to 2004

Factors affecting Landsat processing for forest monitoring

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

SDSU

Conclusions

- Our methods for generic and automated forest change monitoring for large areas are quickly maturing
- A goal is to provide consistent results over large areas that retain local relevance
- We rely on 1) systematic global acquisitions and the provision of data at 2) no cost and with 3) easy access
- Current work is aimed at creating a standard approach applicable at the global scale
- Approach validated using existing reference datasets
- Monitoring results are and will be available
  - carpe.umd.edu
  - globalmonitoring.sdstate.edu/projects/boreal
  - Indonesia and Quebec to come…

SDSU