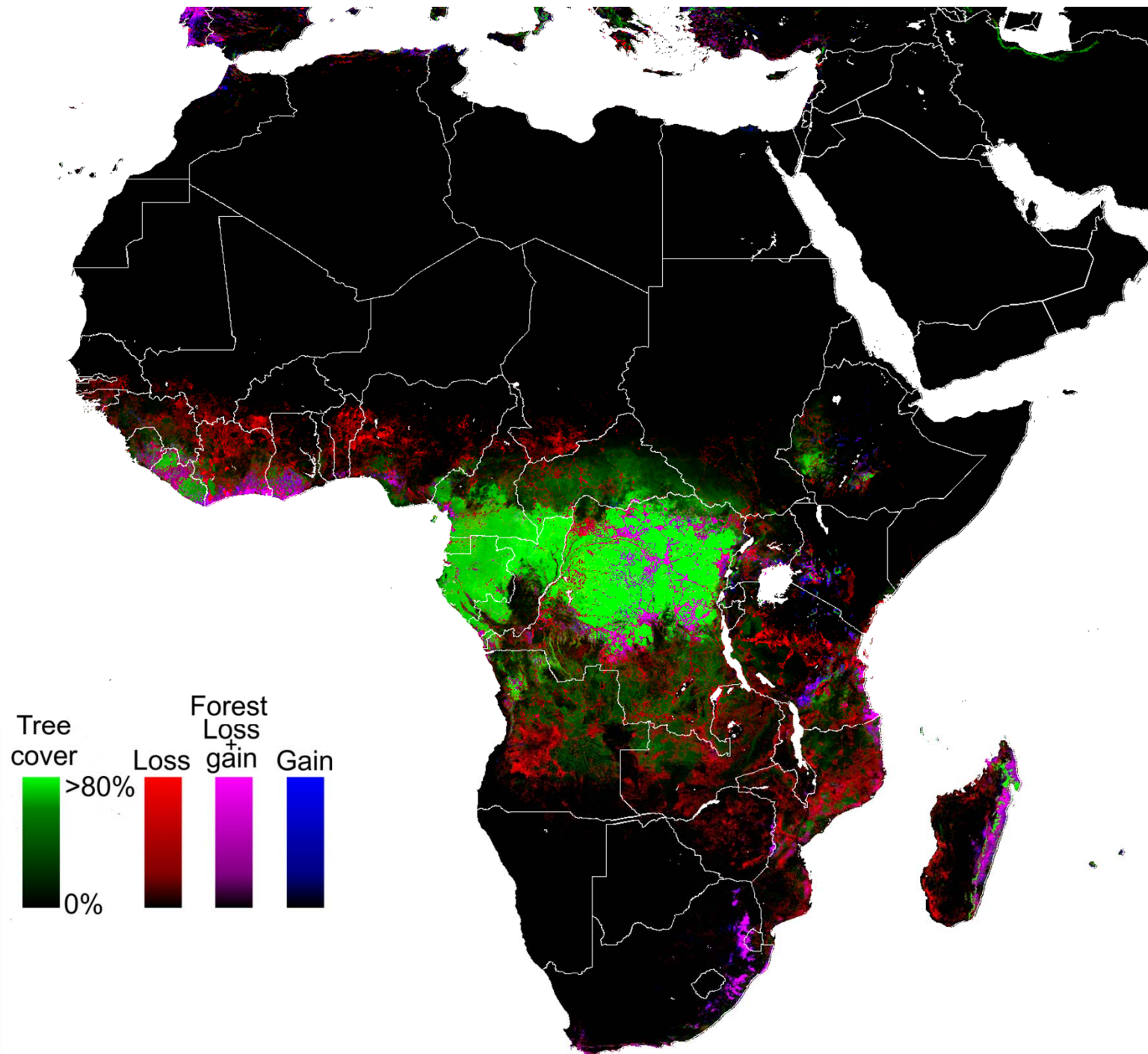


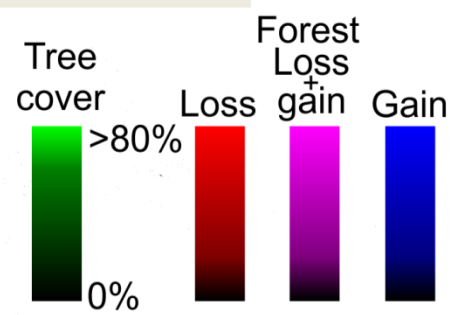
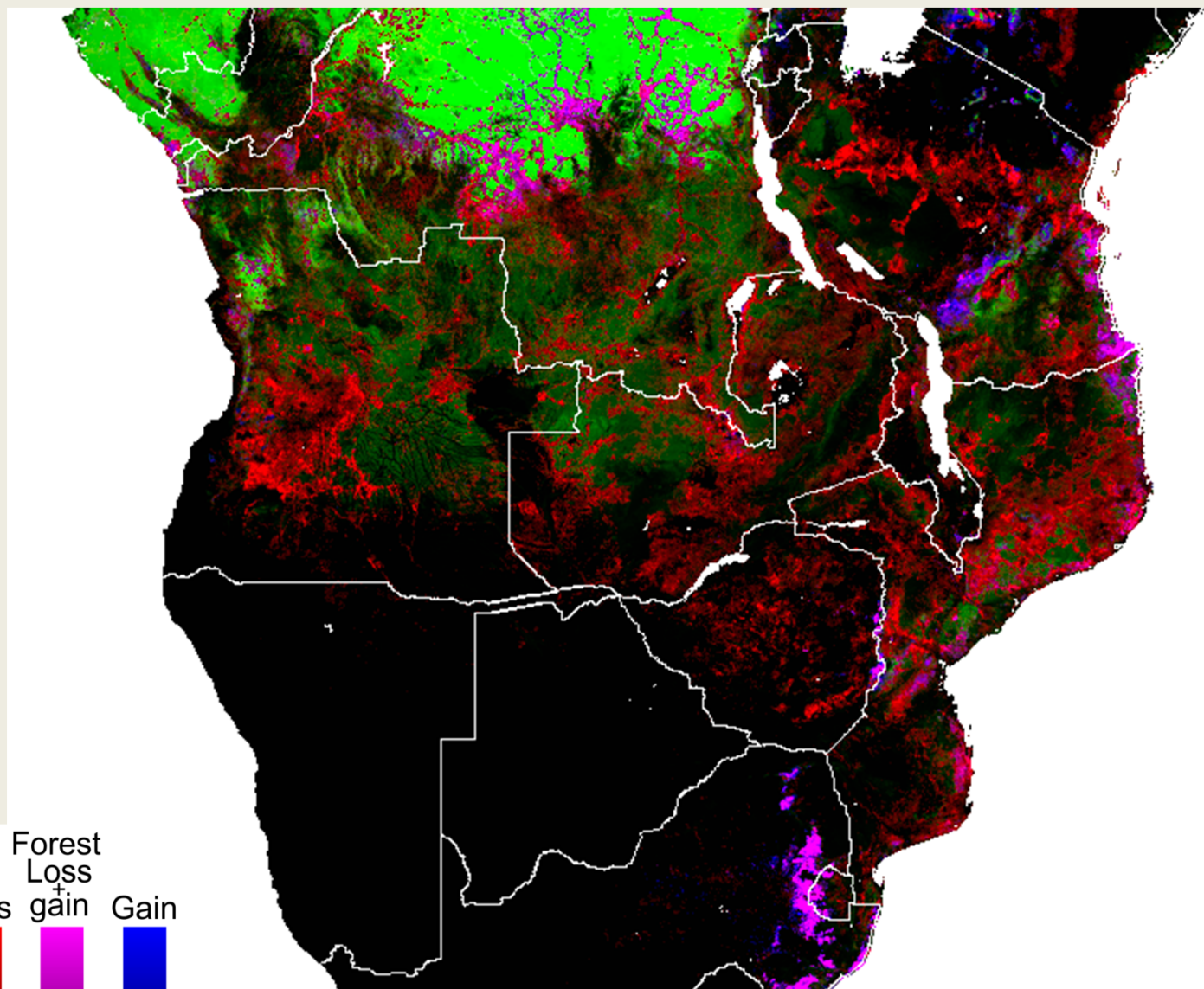
Forest cover monitoring in Africa using Landsat data

M. Hansen, P. Potapov, S. Turubanova, A. Tyukavina
University of Maryland

R. Moore, M. Hancher
Google, Inc.



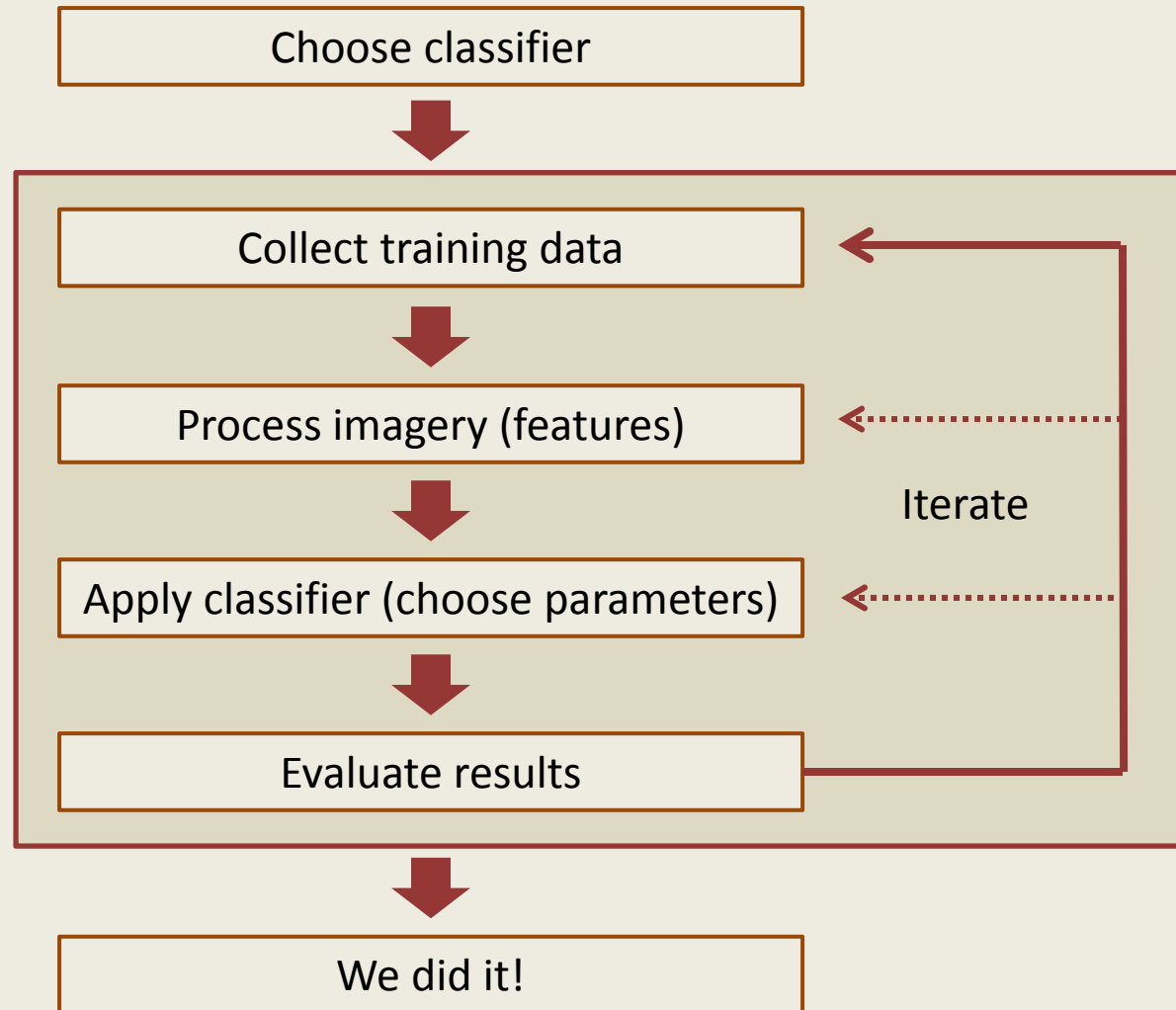




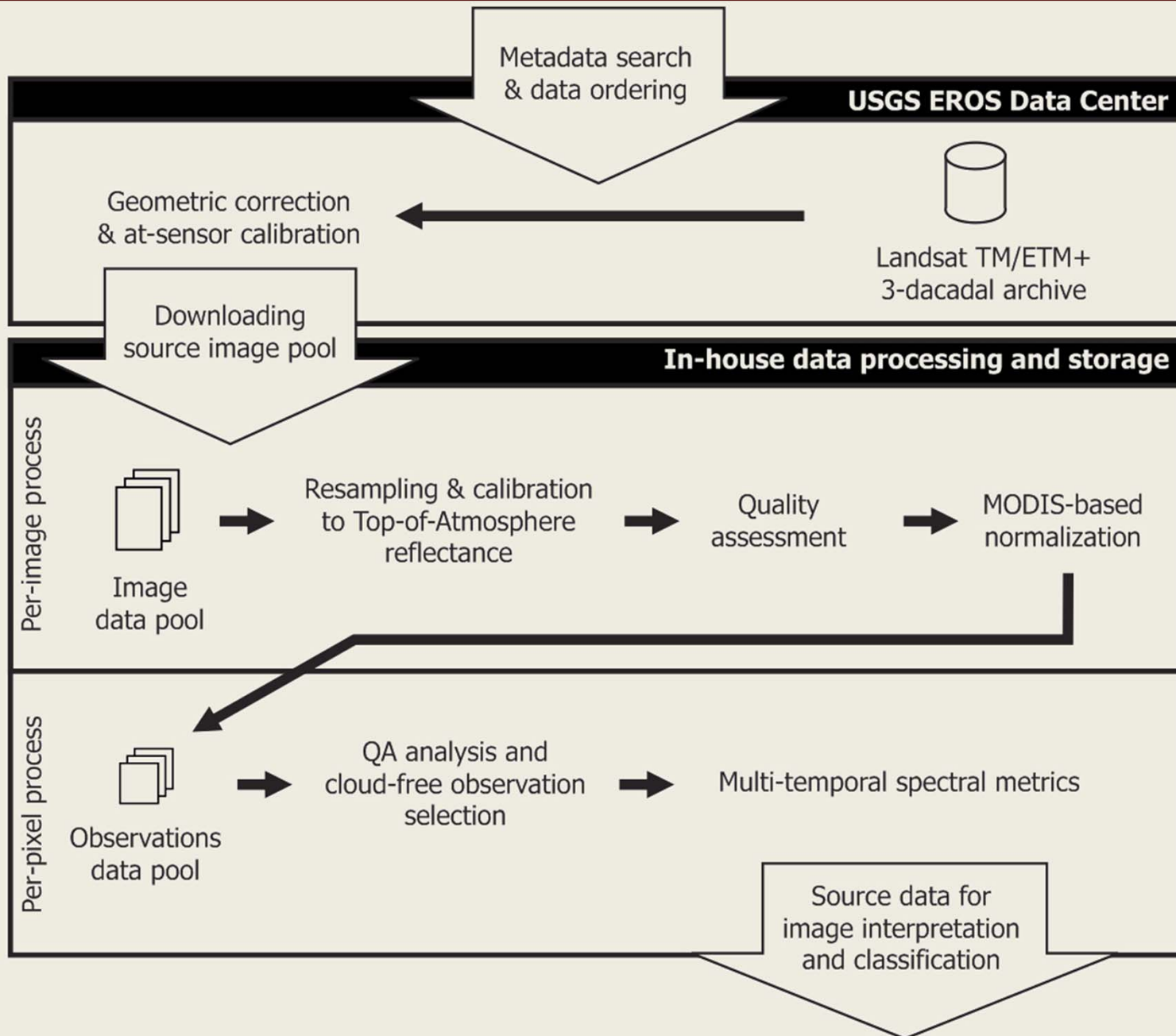
Data requirements for large area land monitoring

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

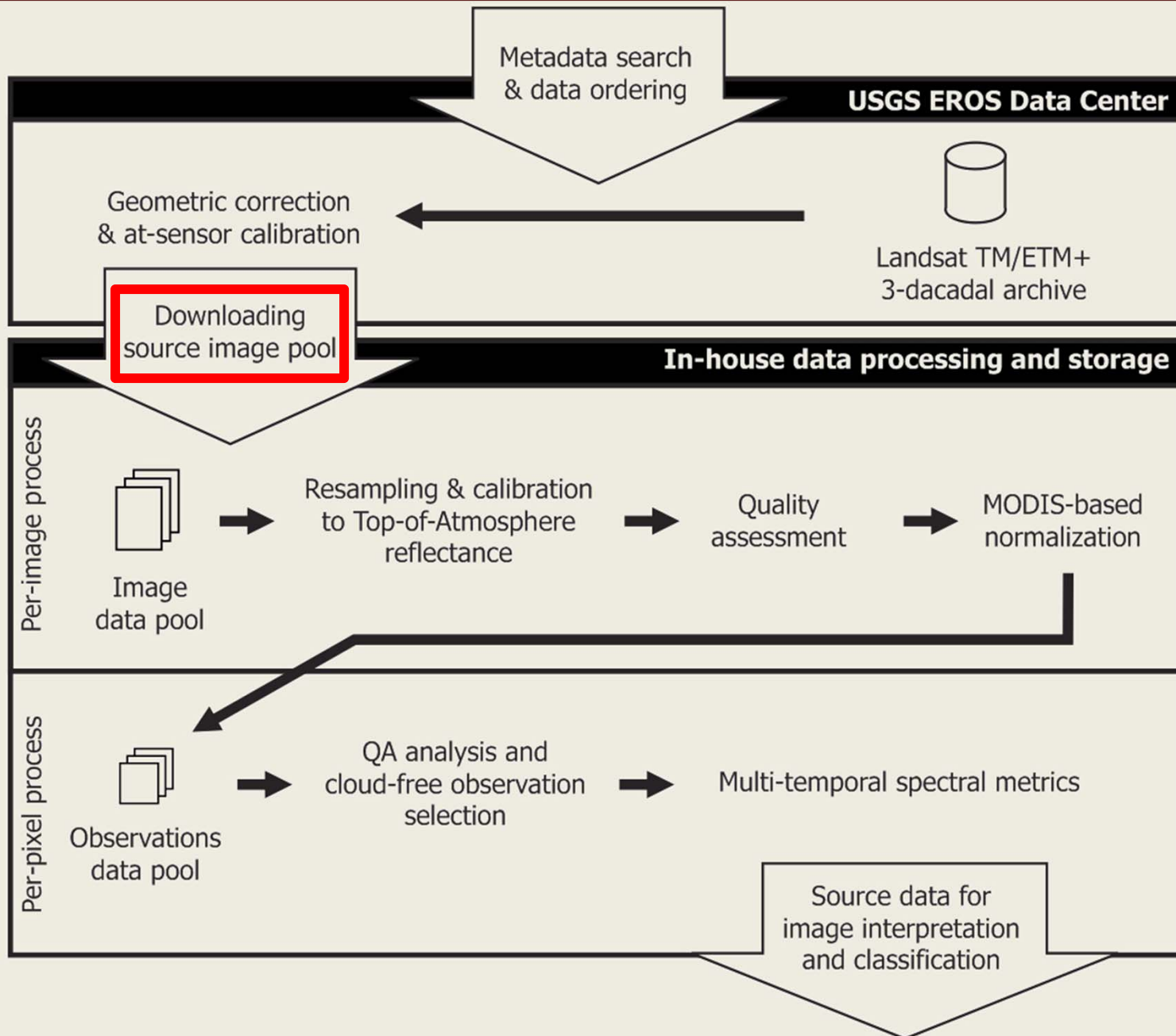
Supervise classification workflow



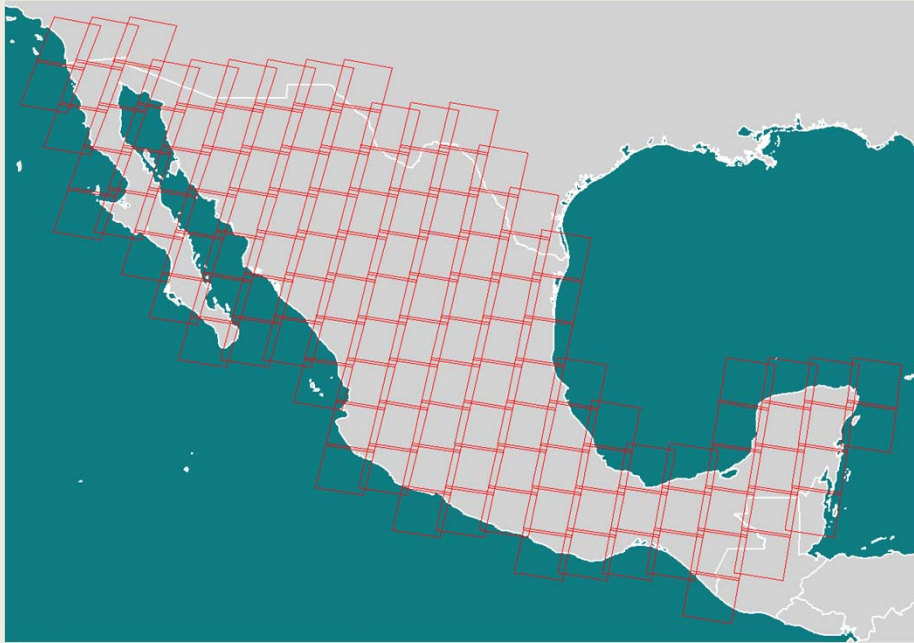
Landsat data processing workflow



Landsat data processing workflow



Landsat data ordering and processing at the USGS EROS



1. Create WRS2 Path/Row catalog for the AOI

2. Search for relatively cloud-free scenes (70-80% max cloud cover) over selected area, time interval, and season

3. Order and Download data using Landsat bulk order interface

4. Check for product level (L1T vs. L1G) and GCP error statistic to filter out images with poor registration.

USGS science for a changing world **NASA**

Landsat Missions

Home About Gallery Products Science Tools Links Contact Us

Landsat Search and Download

Landsat imagery held in the USGS archives can be searched on the following pages:

- **Glovis** <http://glovis.usgs.gov>
- **EarthExplorer** <http://earthexplorer.usgs.gov>

Many scenes are ready for immediate download from the websites listed above; requests can be placed for processing of scenes not downloadable, using these same websites. Once requests are placed and imagery is processed, an email notification is returned with the direct download location. Processing generally takes 1-3 days.

Imagery not found in the USGS archive may have been collected by the USGS International Cooperator (IC) ground stations. Each station is the primary source of distributing data collected at their location. Details on the IC network can be found at http://landsat.usgs.gov/about_ground_stations.php.

Before downloading Landsat data, it is important to understand that a number of files will be included, and how the individual band files work together in image processing software to create a final RGB color image. Please see these pages for more details:

- [Files provided with a Landsat scene](#)
- [Landsat Spectral Band Designations](#)
- [Which Spectral Band to Use](#)

The [Landsat Processing Levels](#) page provides information on parameters, correction levels and systems used during data processing.

Landsat Data Bulk Download - This link will open the USGS Registration Sign In page. After successful sign in, the Bulk Download page will be displayed, with instructions on using this utility.

There are no restrictions on Landsat data downloaded from USGS EROS, and it can be used or redistributed as desired. However, a statement of the data source when citing, copying, or reprinting USGS Landsat data or images is requested. Details can be found on the [EROS Data Citation](#) page.

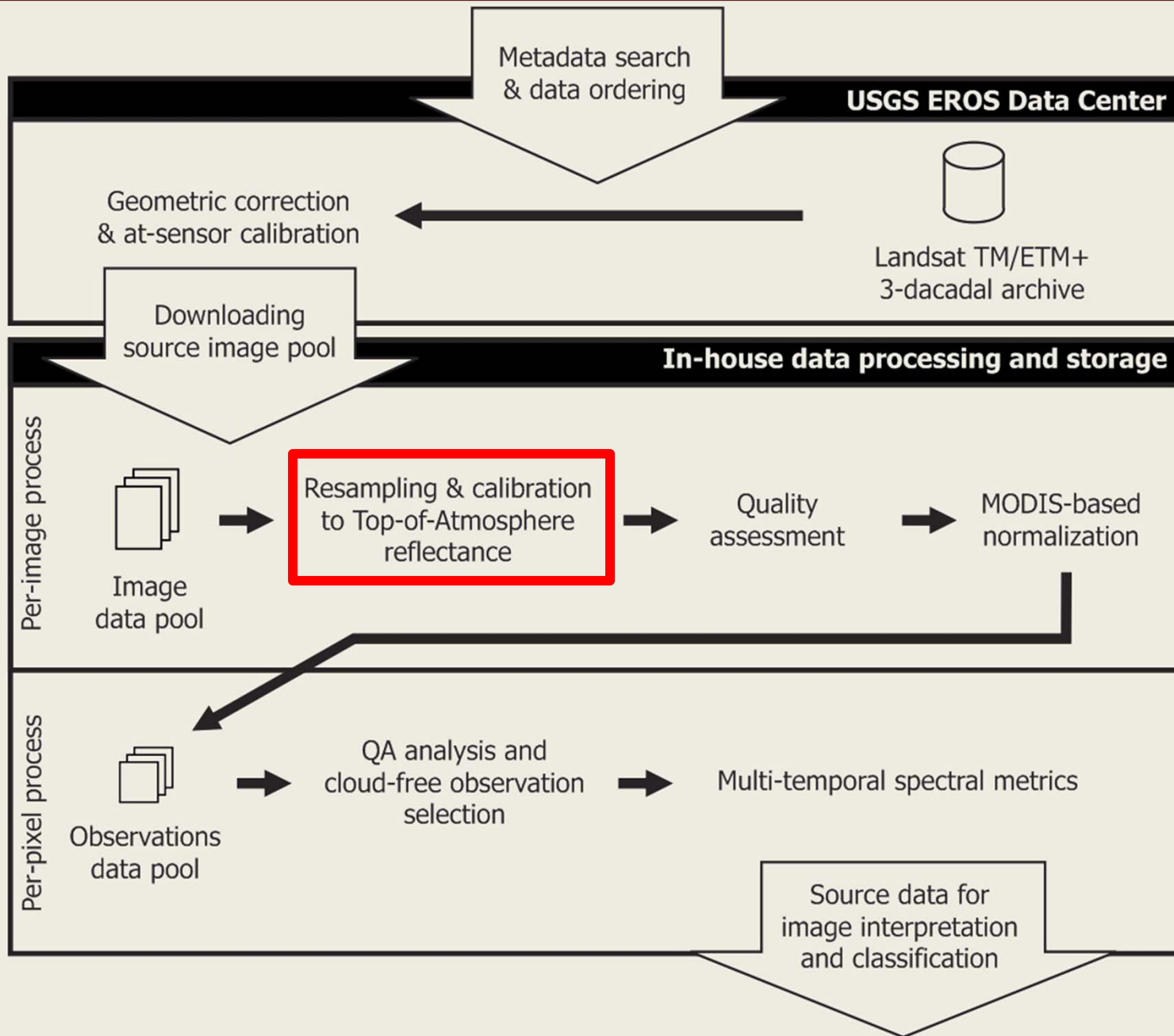
Accessibility FOIA Privacy Policies and Notices

U.S. Department of the Interior | U.S. Geological Survey
URL: <http://landsat.usgs.gov>
Page Contact Information: [Ask Landsat](#)
Page Last Modified: 05/12/11 12:14 pm
[Sitemap](#)

USA.gov TAKE PRIDE IN AMERICA

http://landsat.usgs.gov/Landsat_Search_and_Download.php

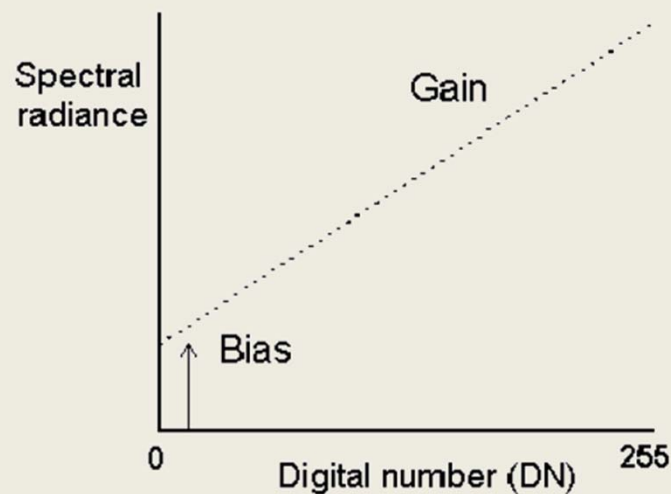
Landsat data processing workflow



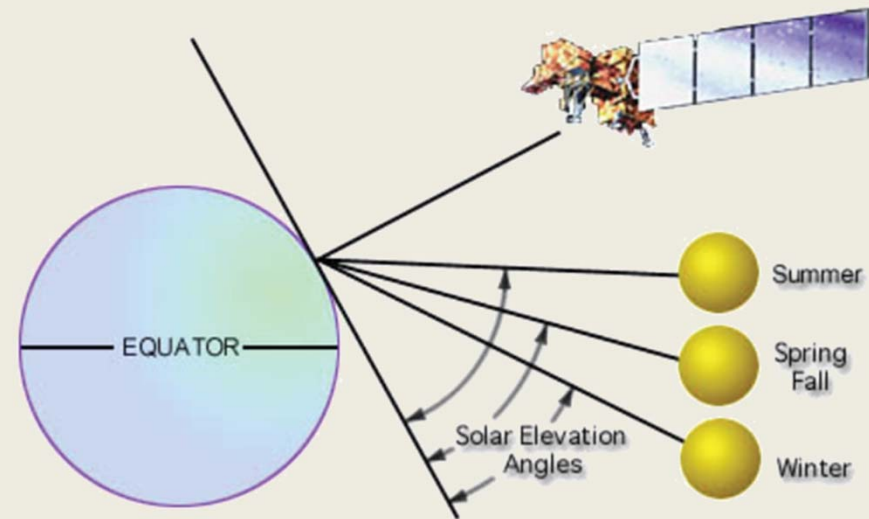
Landsat data calibration

Conversion to TOA reflectance

1. DN -> Radiance



2. Radiance -> TOA Reflectance



$$\rho_{\lambda} = \pi * L_{\lambda} * d^2 / ESUN_{\lambda} * \cos \theta_s$$

$$L_{\lambda} = \text{Bias} + \text{Gain} * \text{Digital Number}$$

Where:

ρ_{λ} = Unitless planetary reflectance

L_{λ} = spectral radiance (from earlier step)

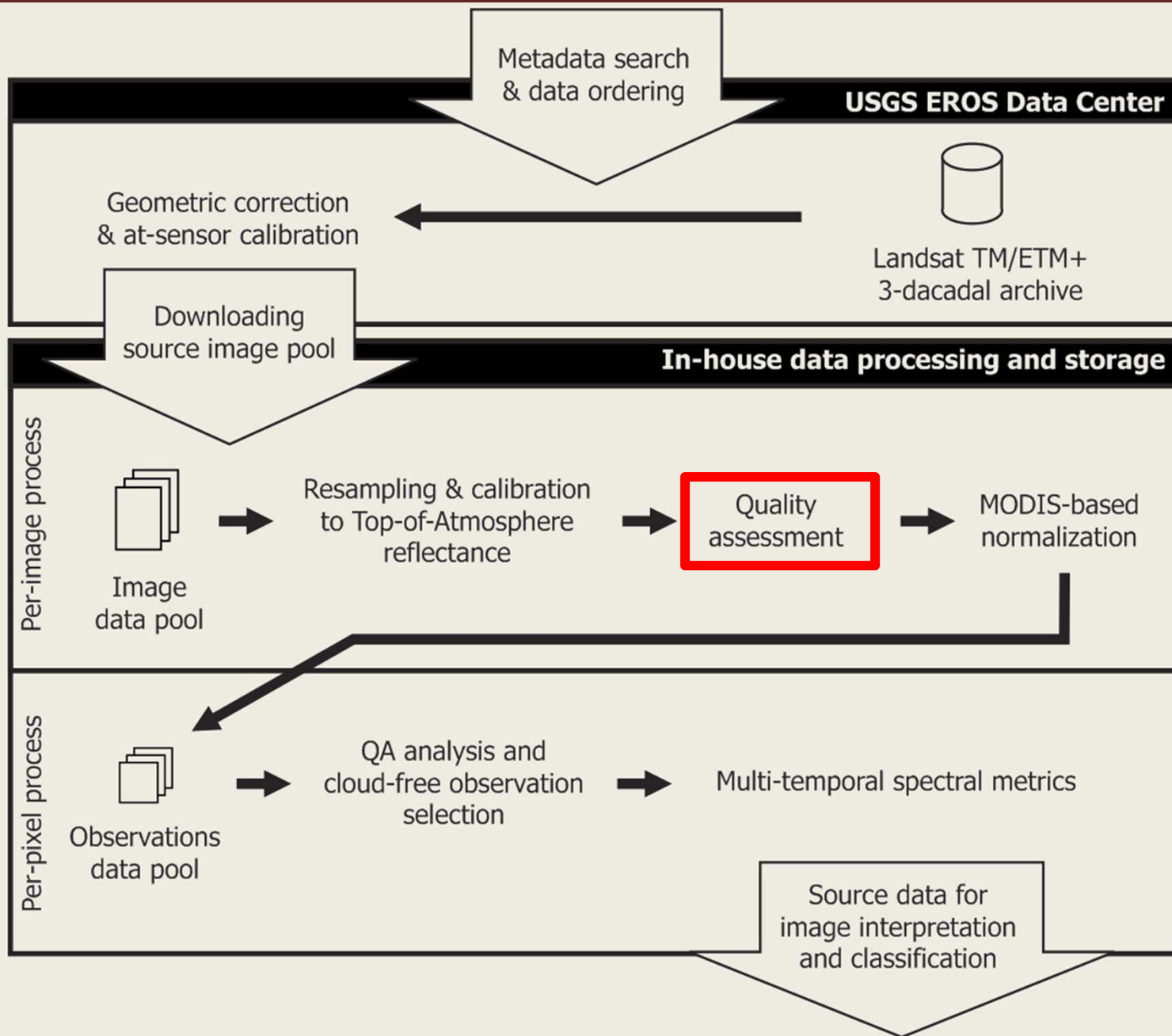
d = Earth-Sun distance in astronomical units

$ESUN_{\lambda}$ = mean solar exoatmospheric irradiances

θ_s = solar zenith angle

Chander et al., 2009

Landsat data processing workflow



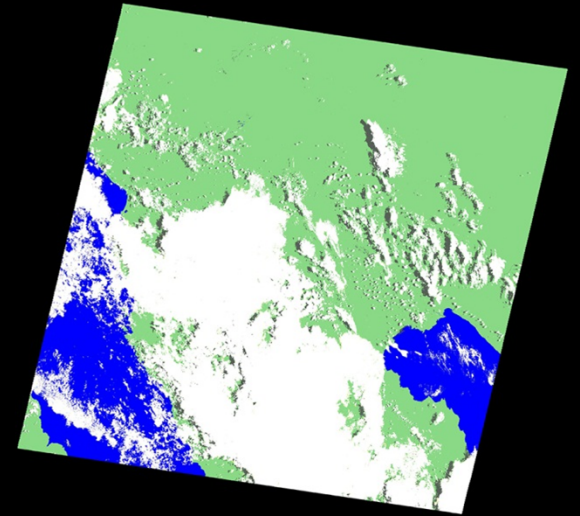
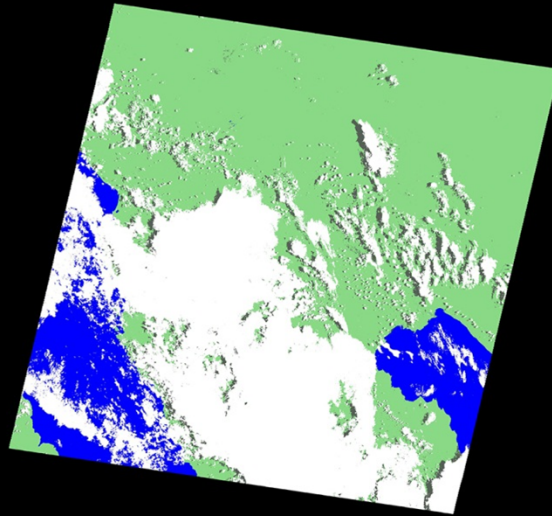
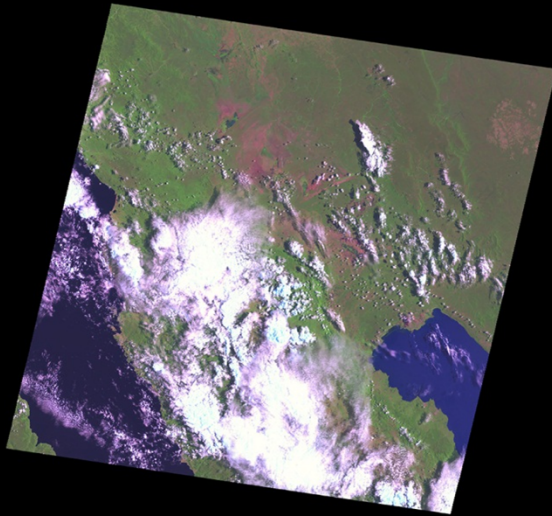
Per-pixel quality assessment

Image data

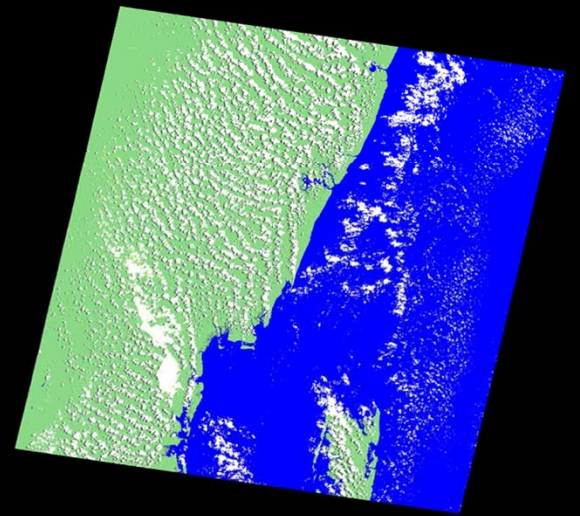
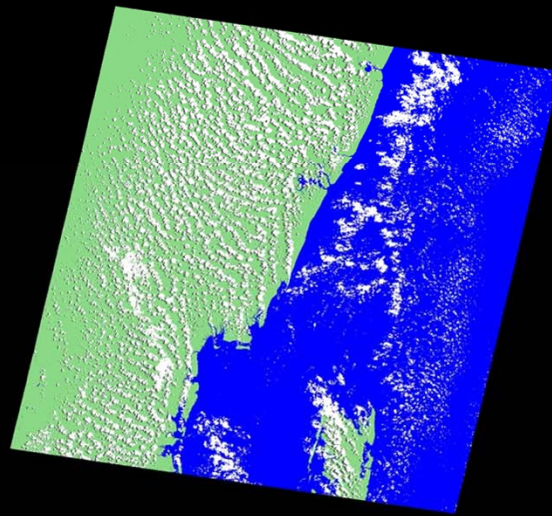
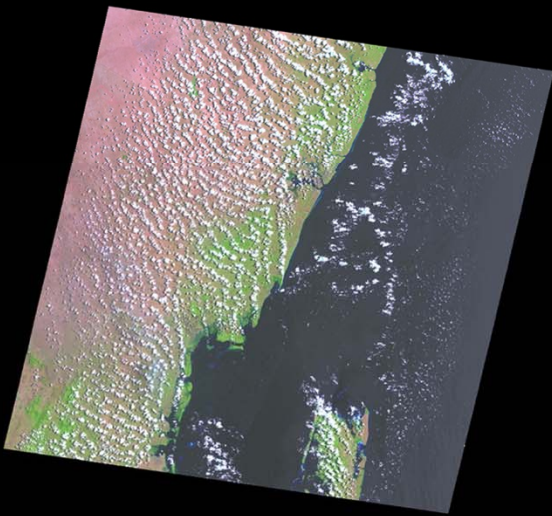
Classification results

Generalized model results

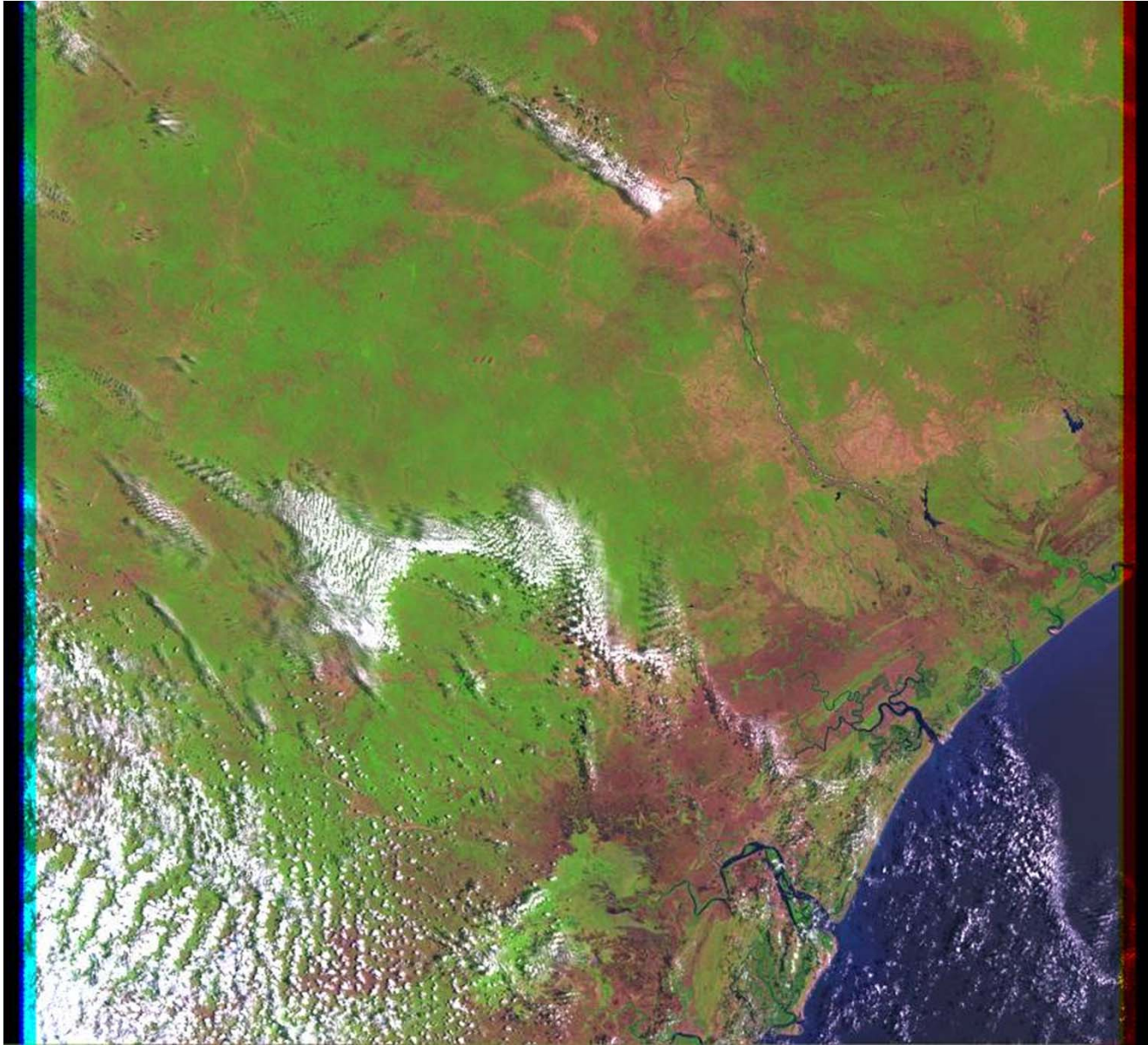
p171r065



p166r063

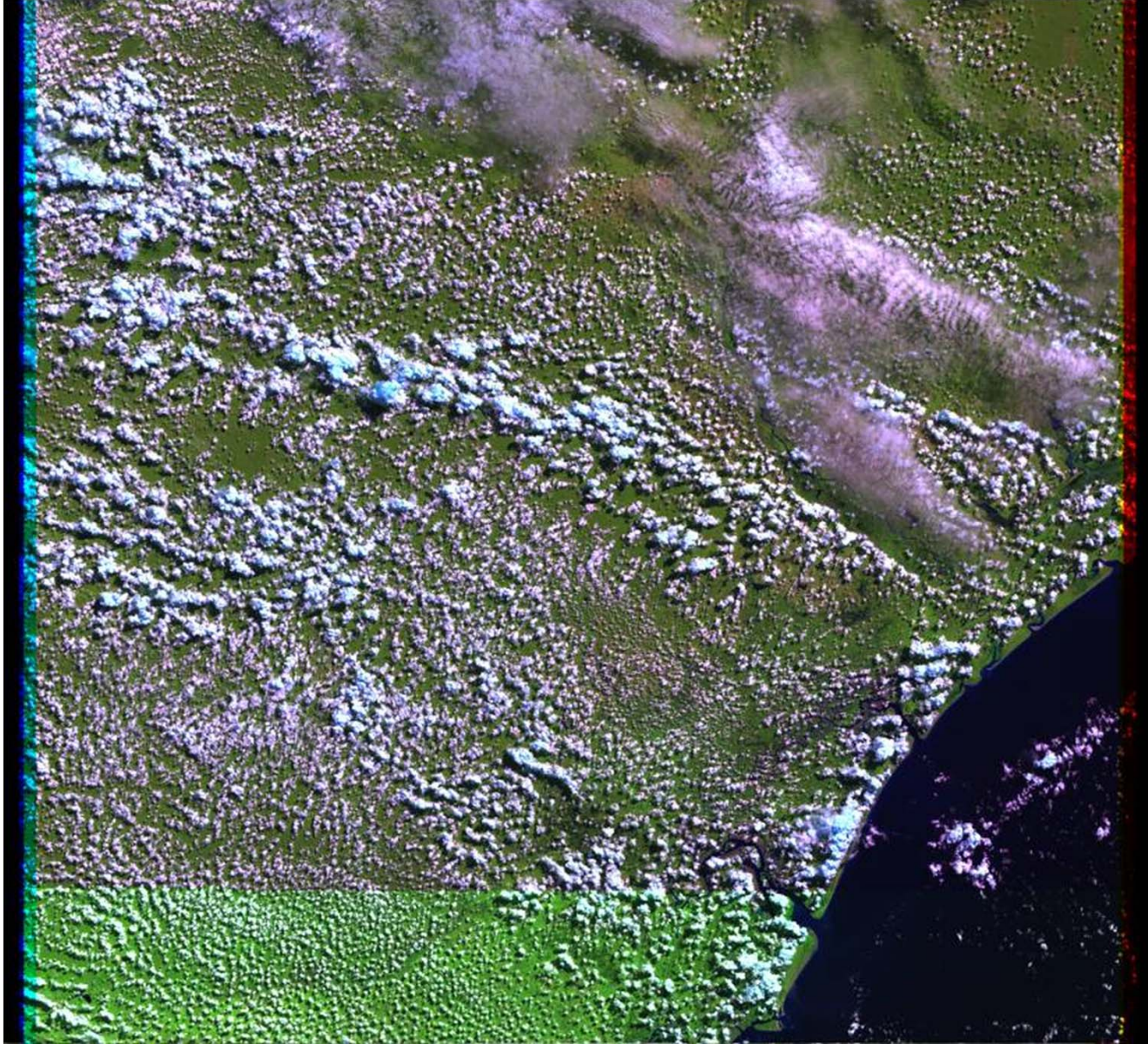


166/072 1999-2000 growing season



Dec. 5, 1999

166/072 1999-2000 growing season



Apr. 12, 2000

166/072 1999-2000 growing season



Apr. 28, 2000

166/072 2000-2001 growing season



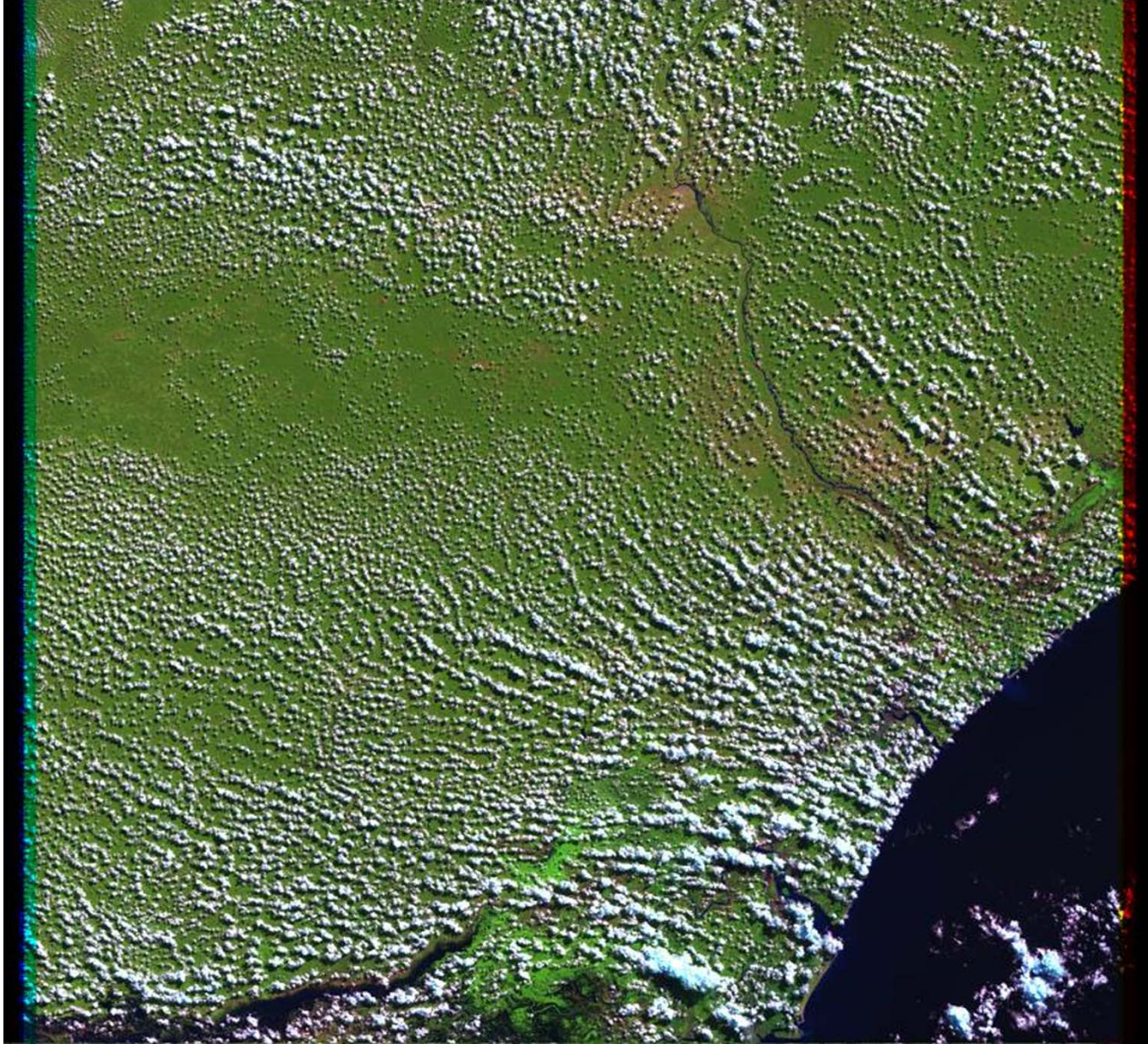
Jan. 8, 2001

166/072 2000-2001 growing season



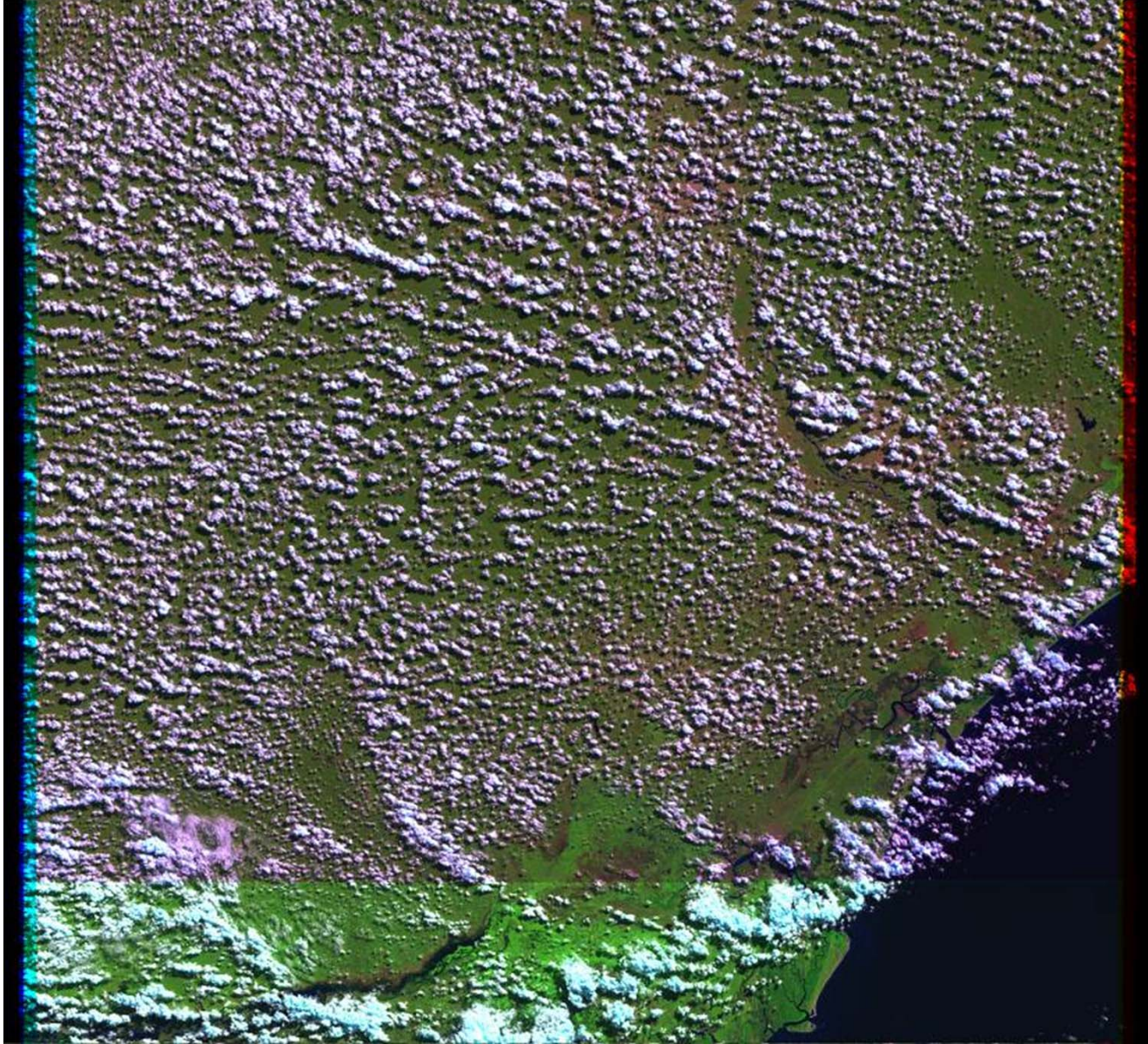
Feb. 26, 2001

166/072 2000-2001 growing season



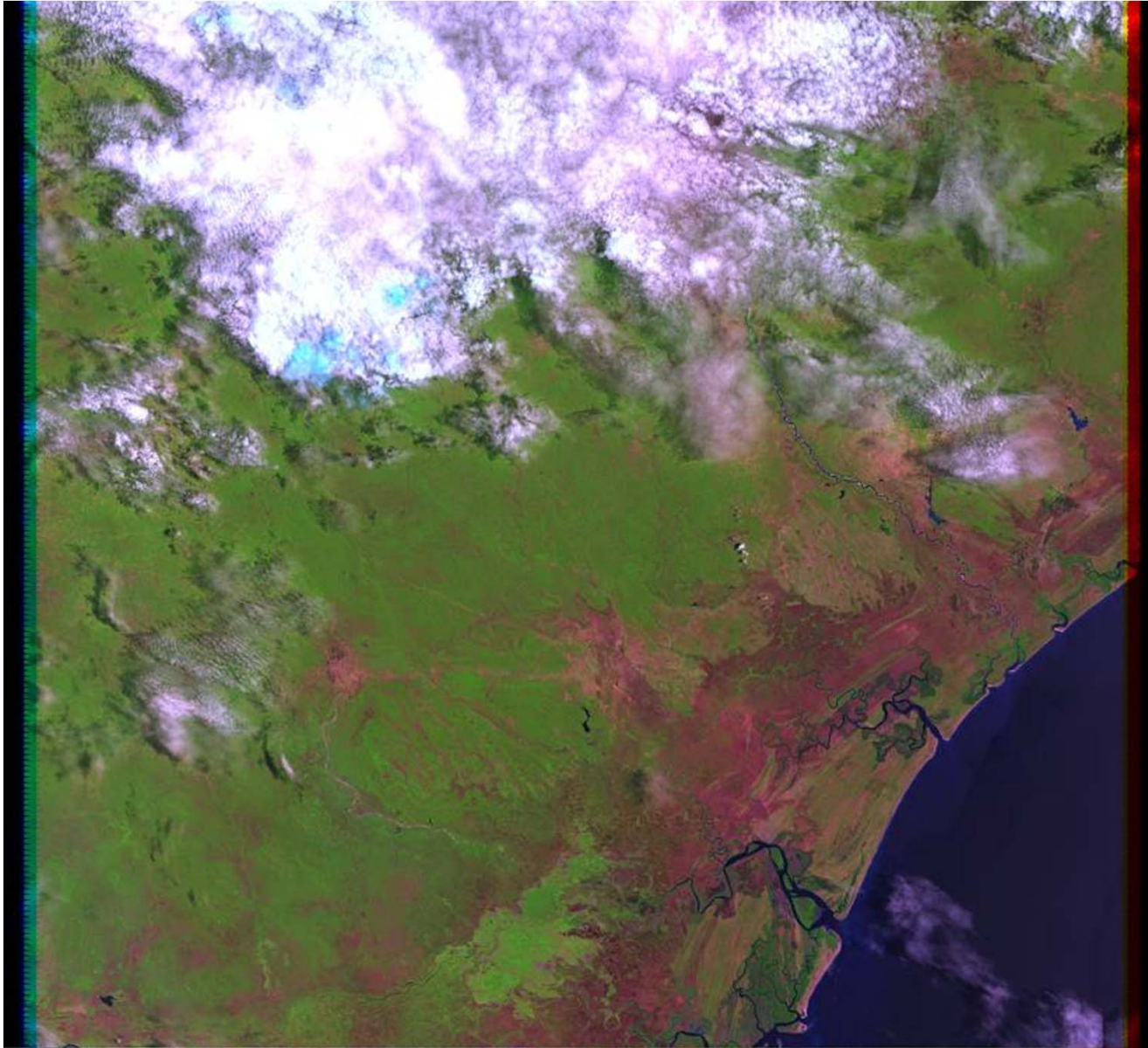
Apr. 14, 2001

166/072 2000-2001 growing season



Apr. 30, 2001

166/072 2001-2002 growing season



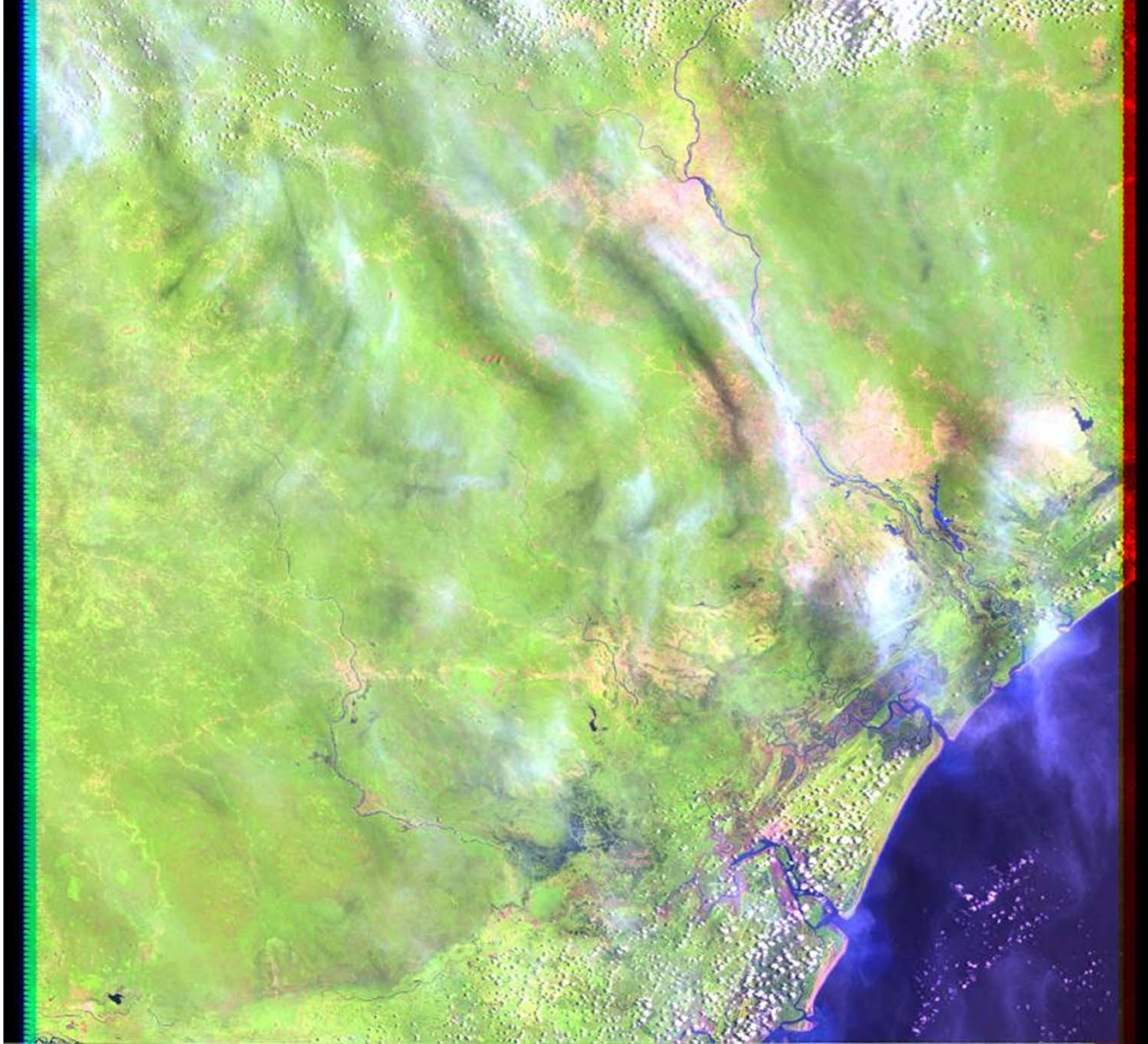
Dec. 26, 2001

166/072 2001-2002 growing season



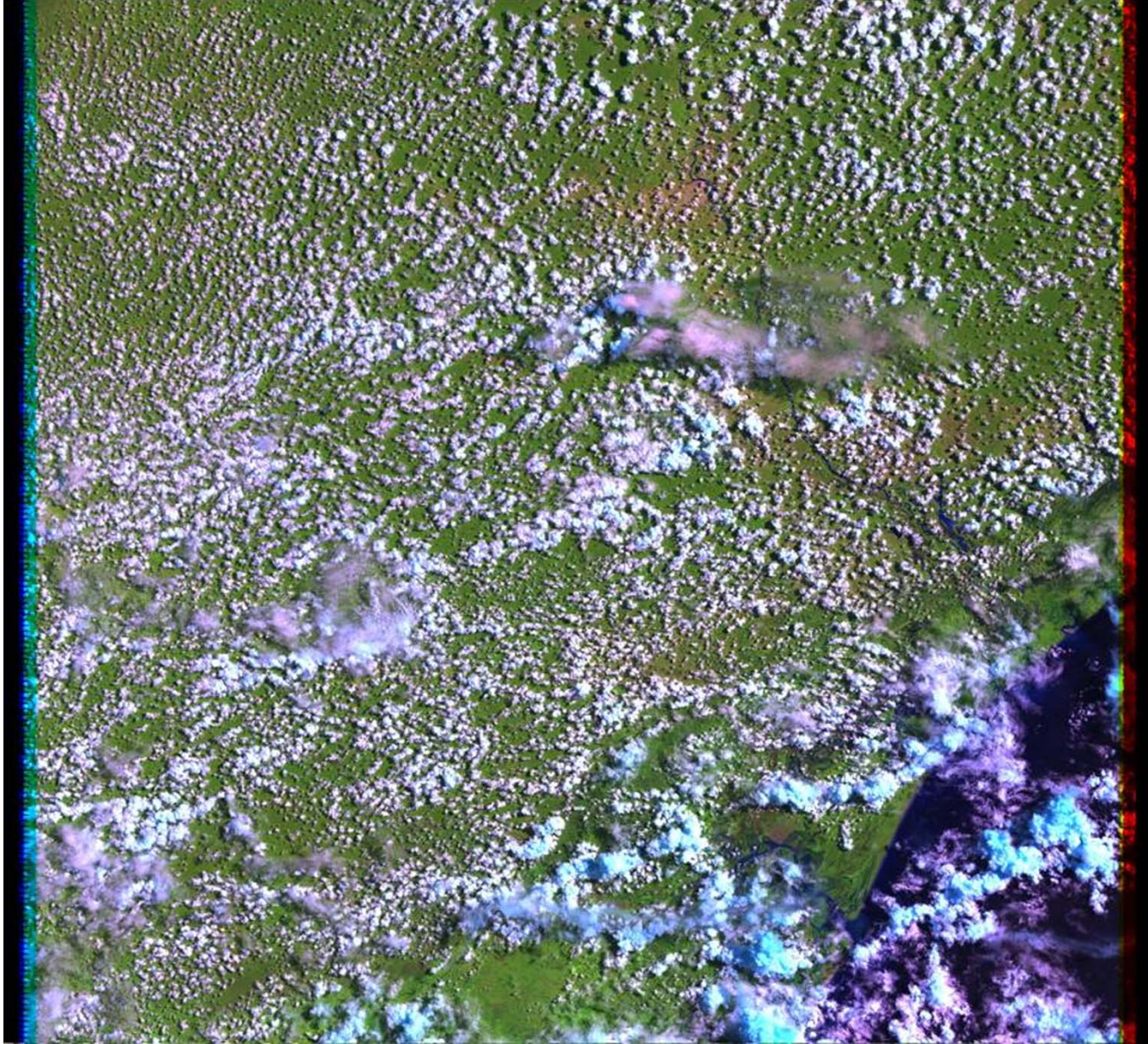
Jan. 11, 2002

166/072 2001-2002 growing season



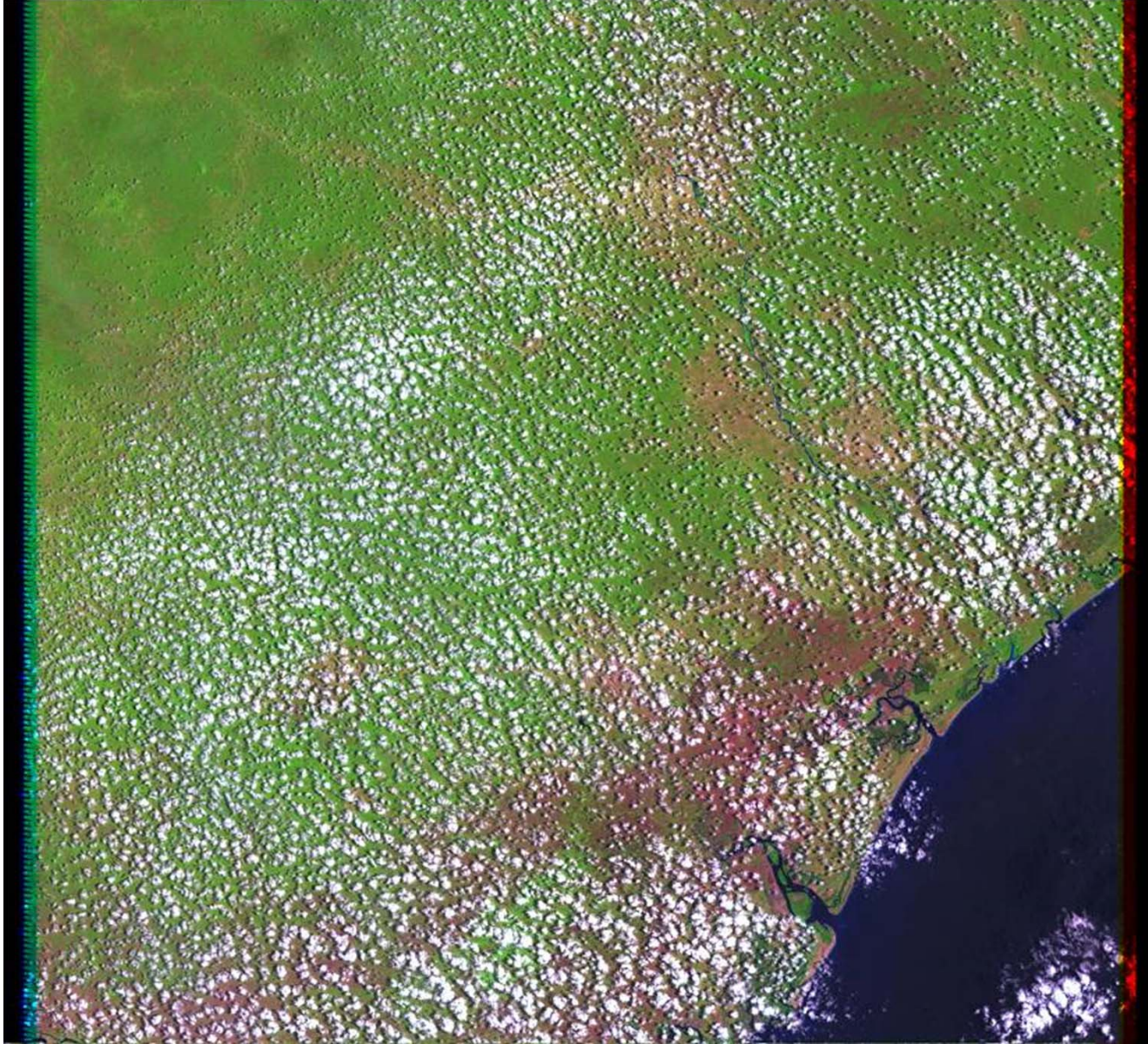
Feb. 13, 2002

166/072 2001-2002 growing season



Feb. 29, 2002

166/072 2002-2003 growing season



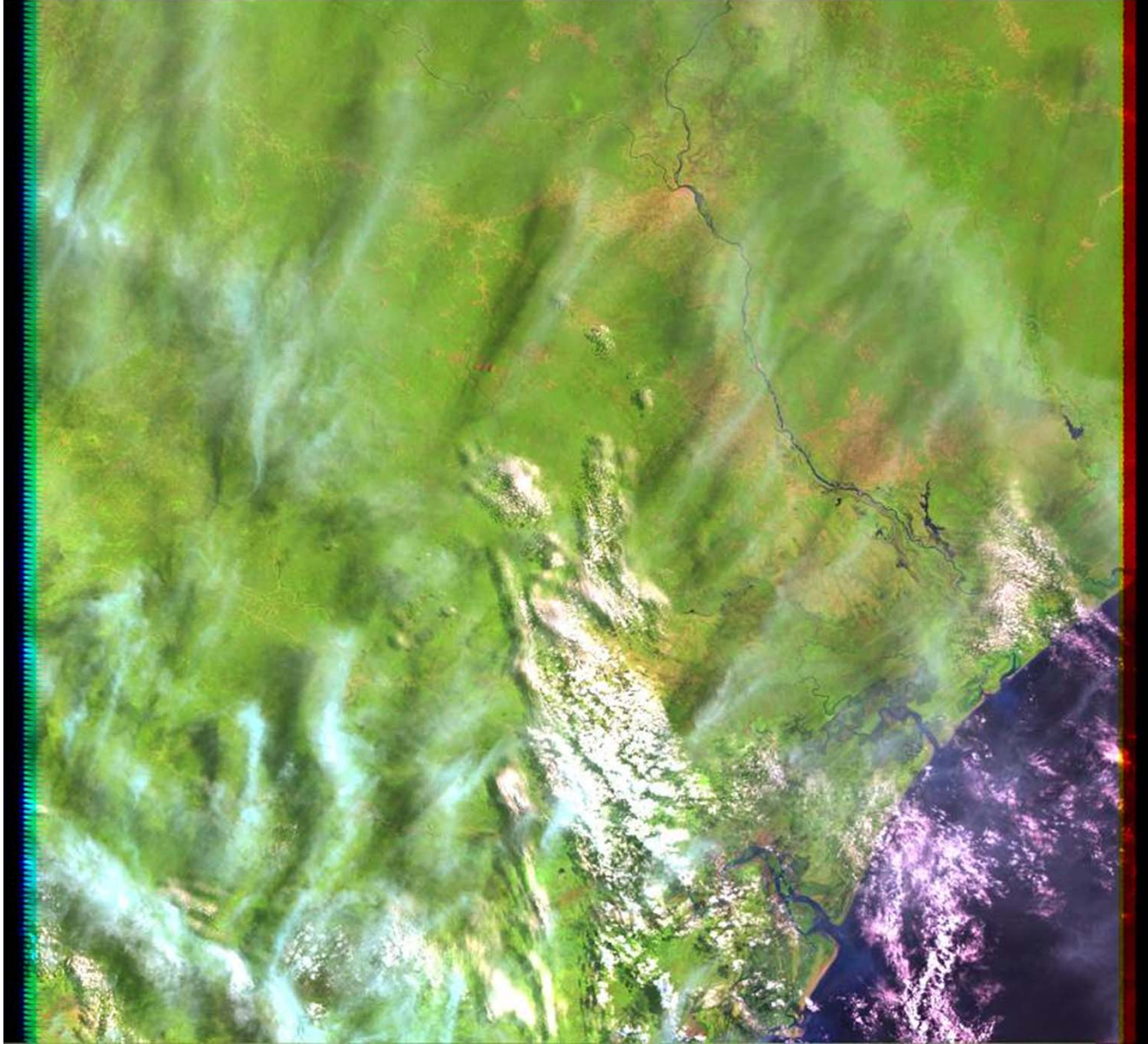
Dec. 26, 2002

166/072 2002-2003 growing season



Jan. 14, 2003

166/072 2002-2003 growing season



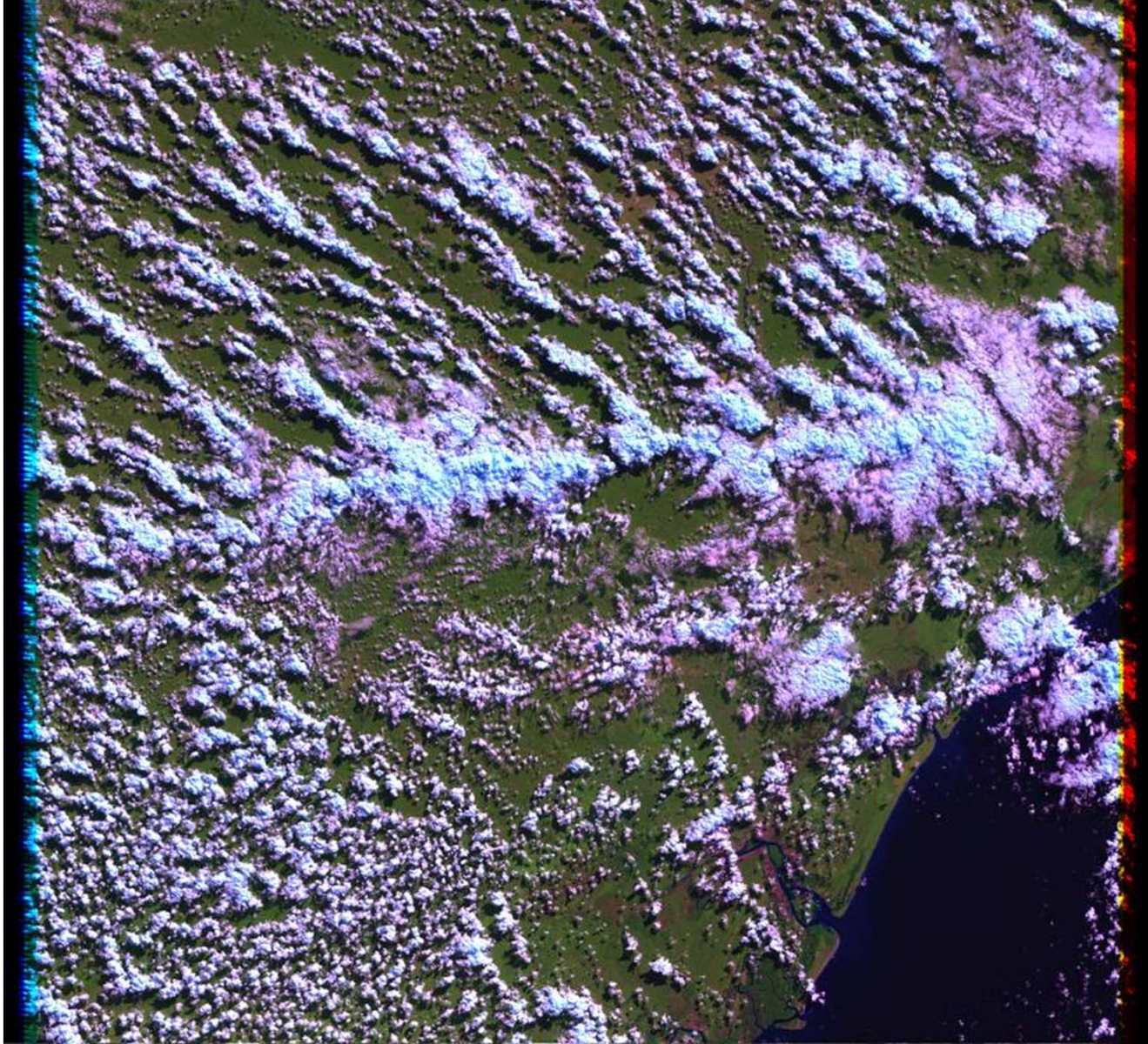
Mar. 3, 2003

166/072 2002-2003 growing season



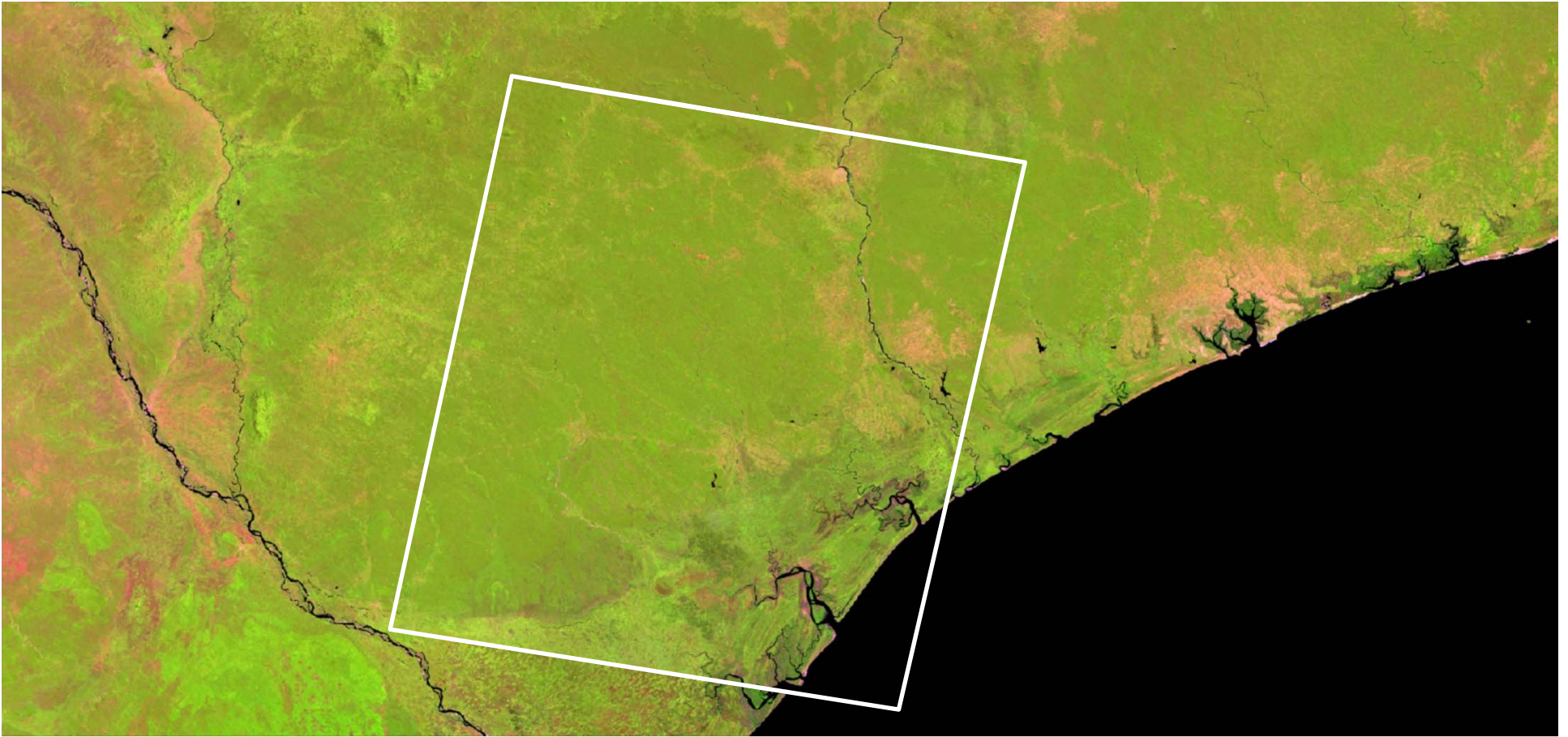
Mar. 19, 2003

166/072 2002-2003 growing season

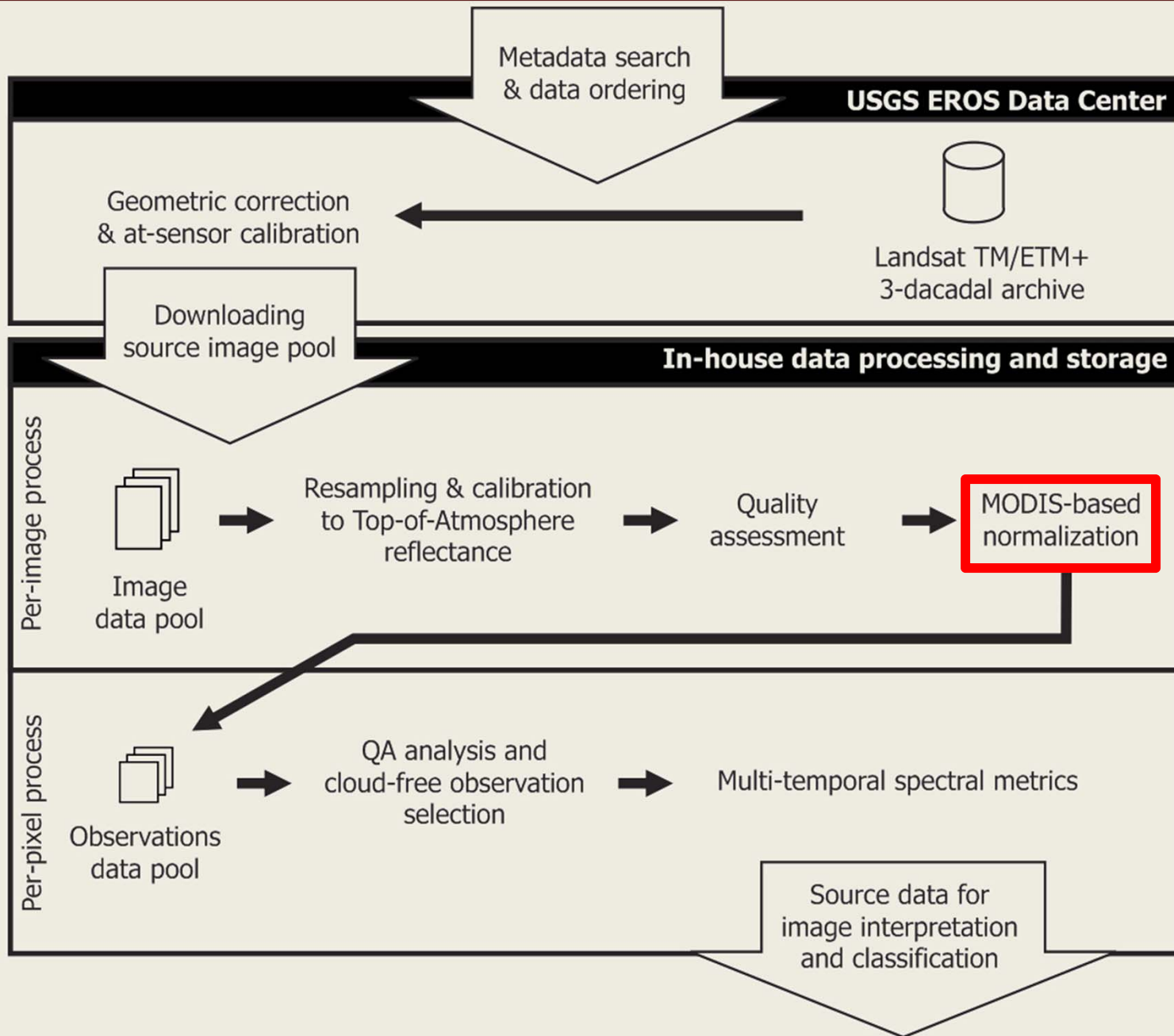


May 6, 2003

2000 5-4-3 composite

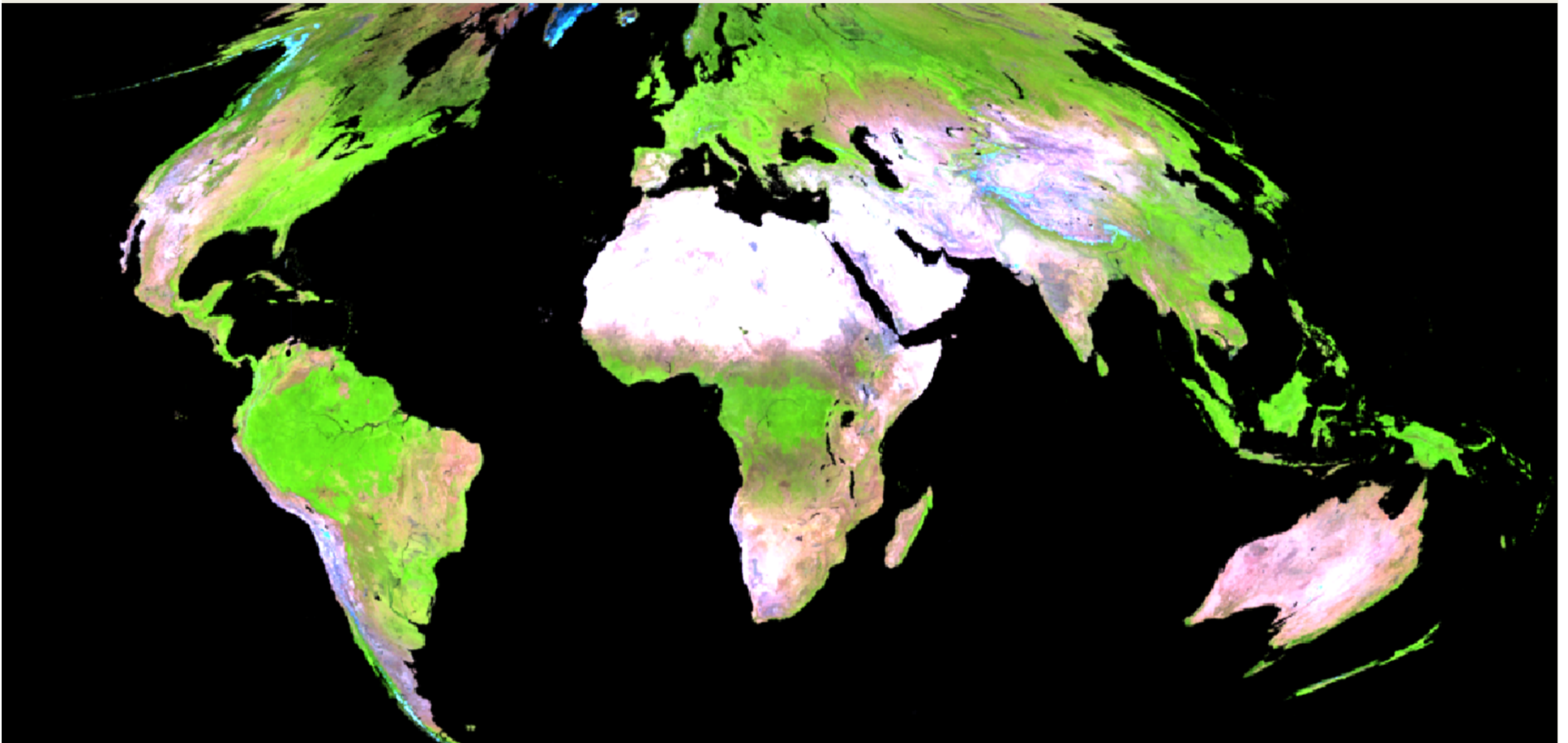


Landsat data processing workflow



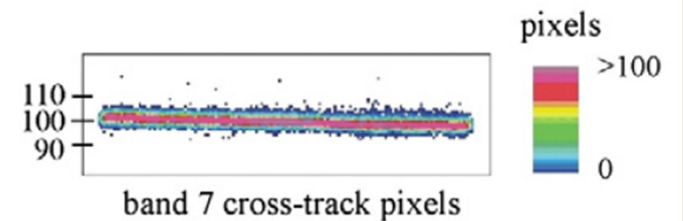
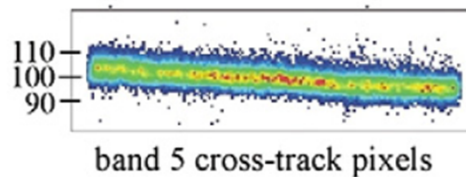
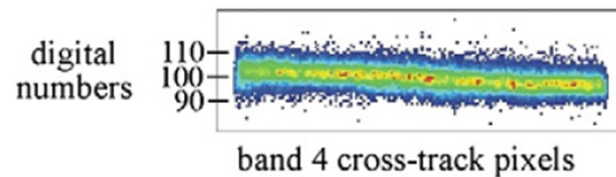
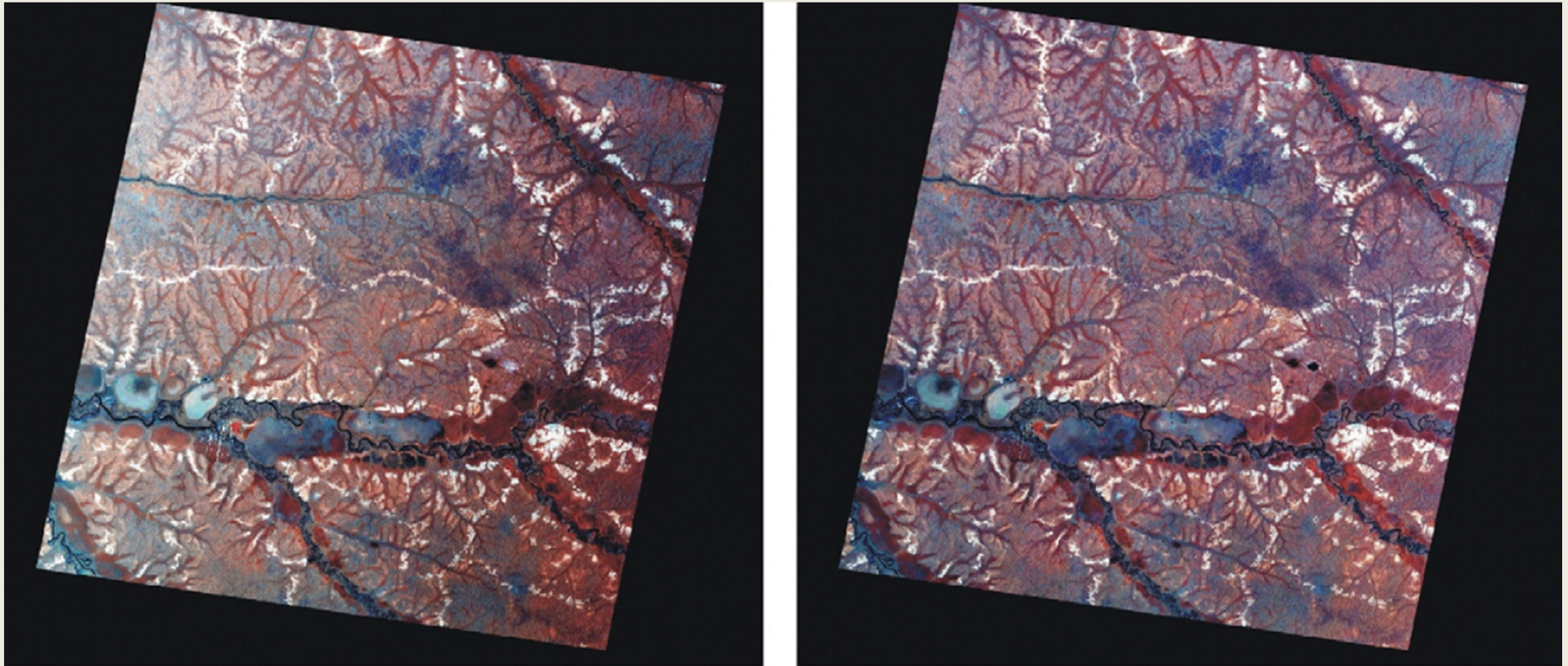
Landsat data normalization

Global MODIS TOC reflectance as normalization target

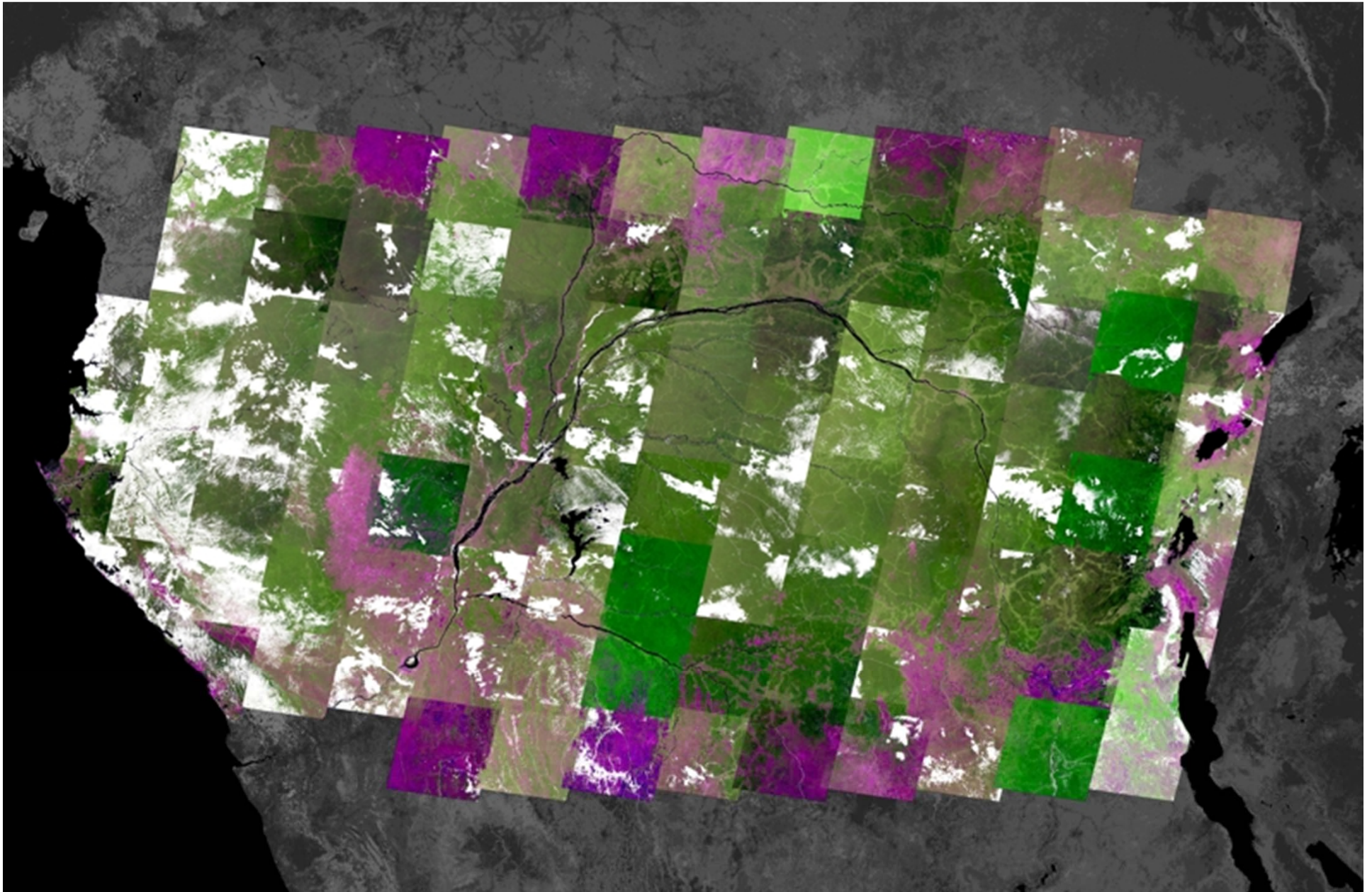


Best cloud-free observations for the peak of vegetation season
over 10 years of data (2000-2009)

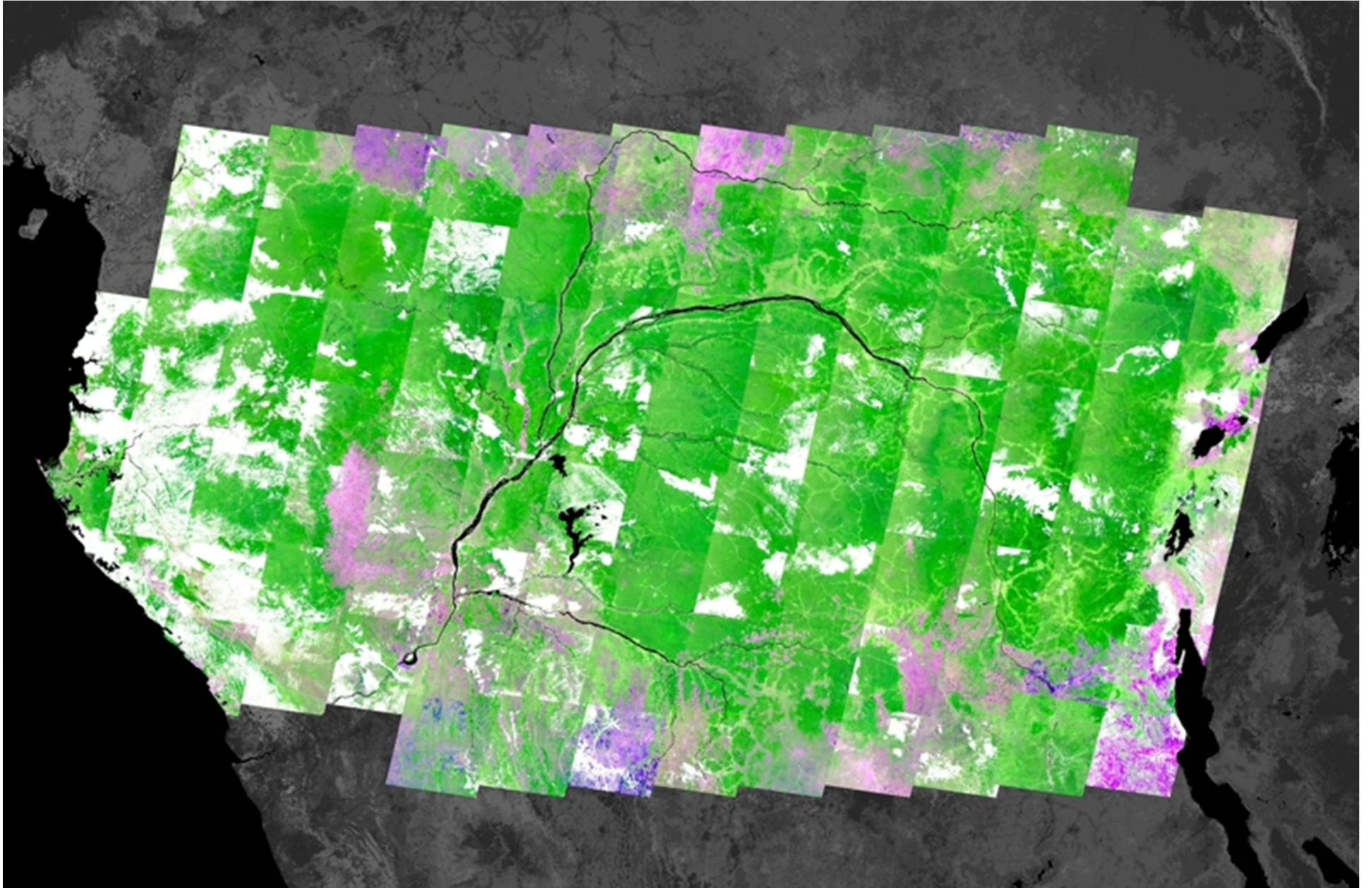
Correct for view geometry effects



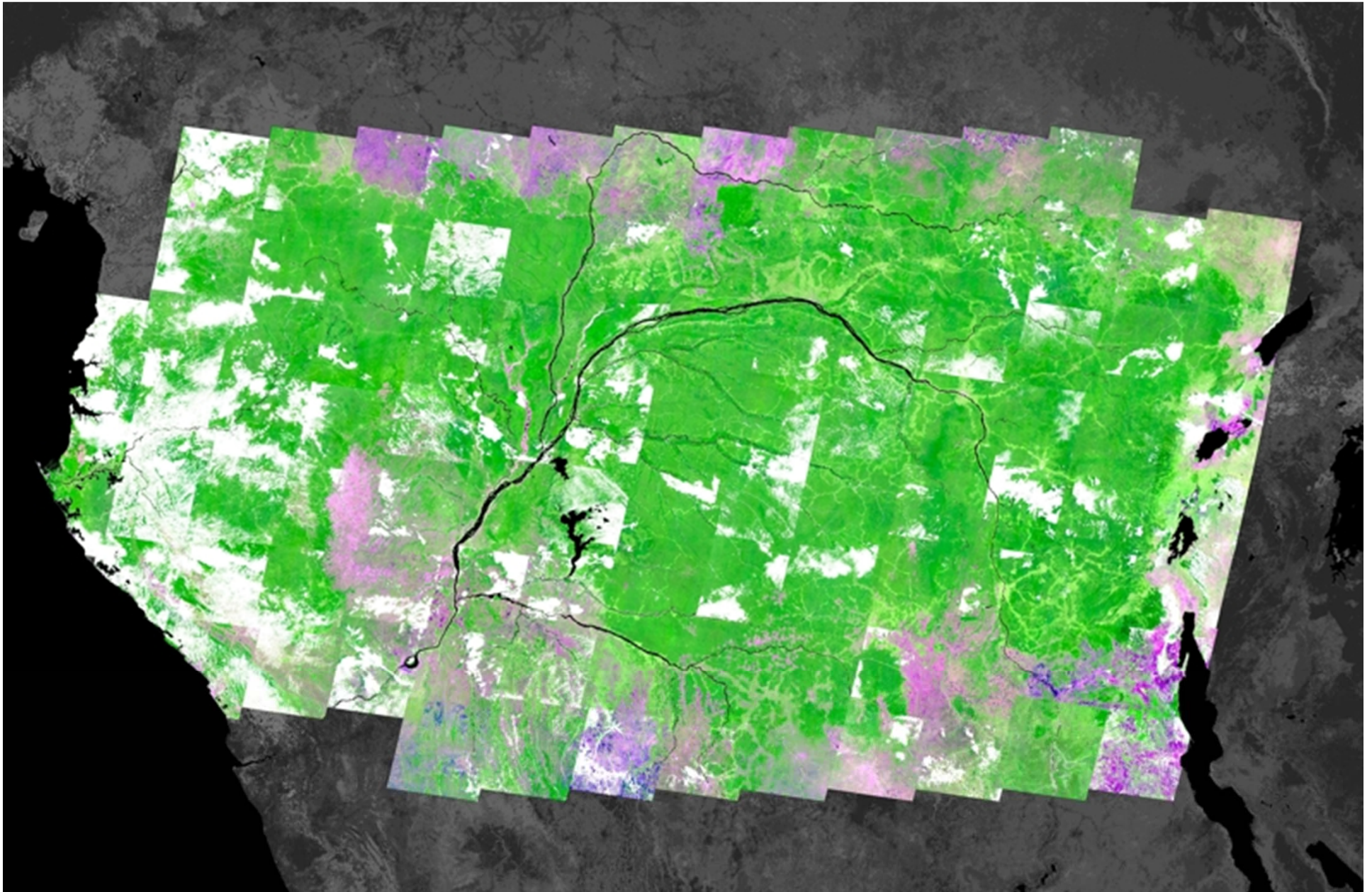
Uncorrected imagery



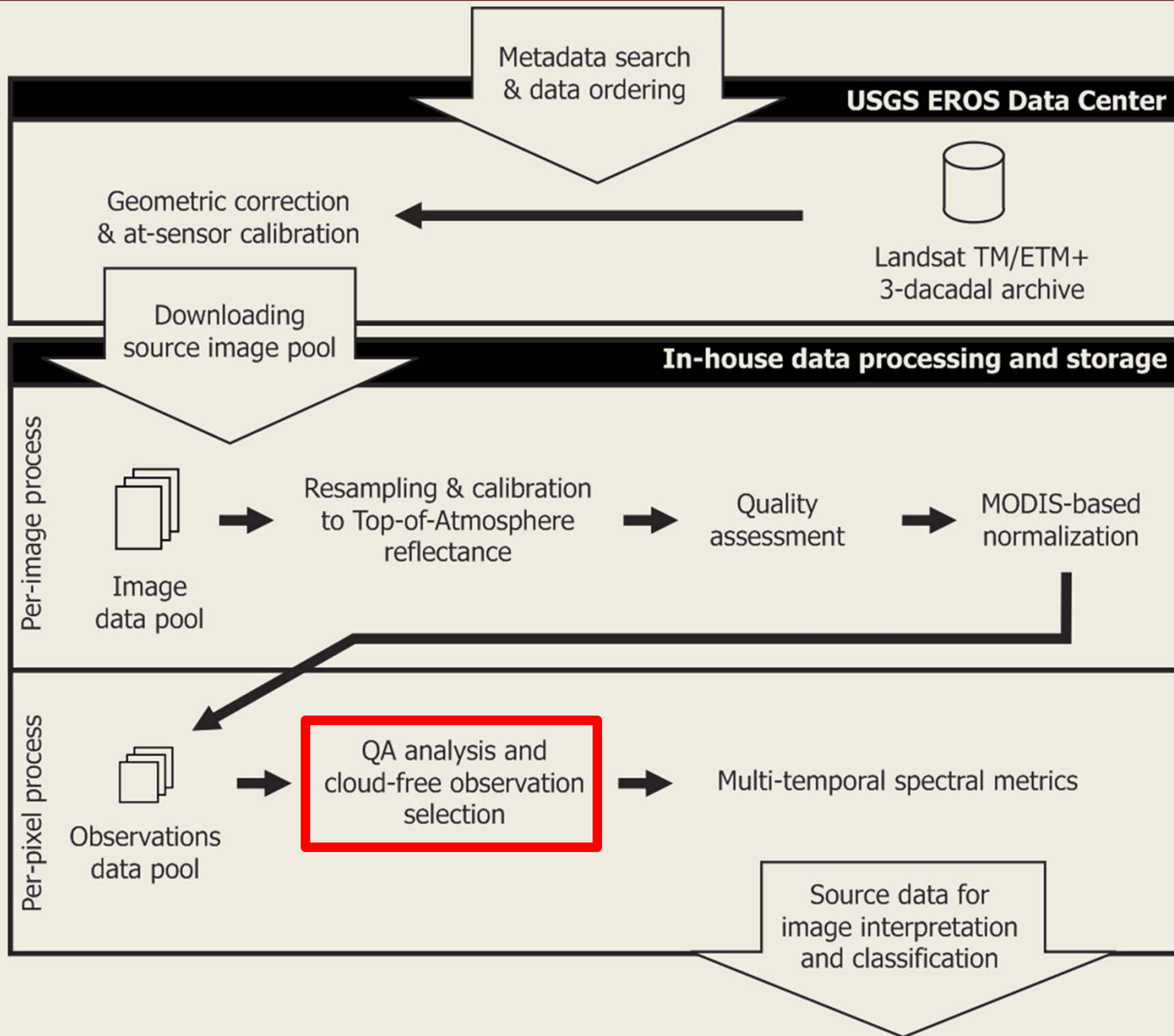
Bias-adjusted TOA



Anisotropy-adjusted

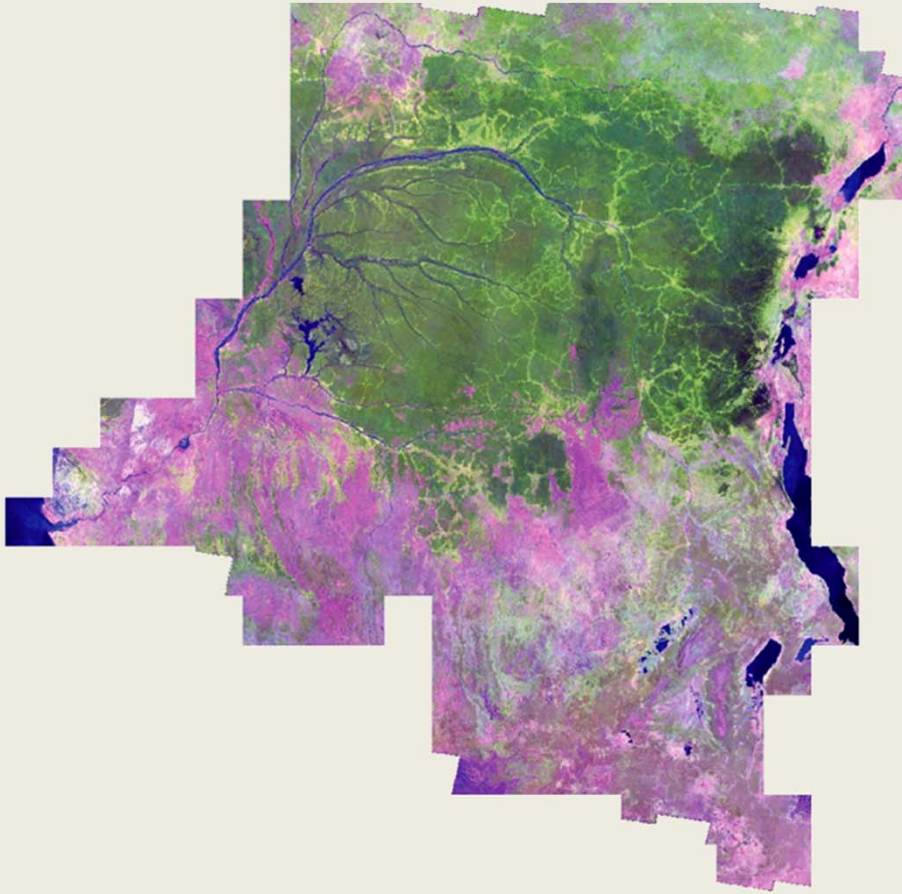


Landsat data processing workflow

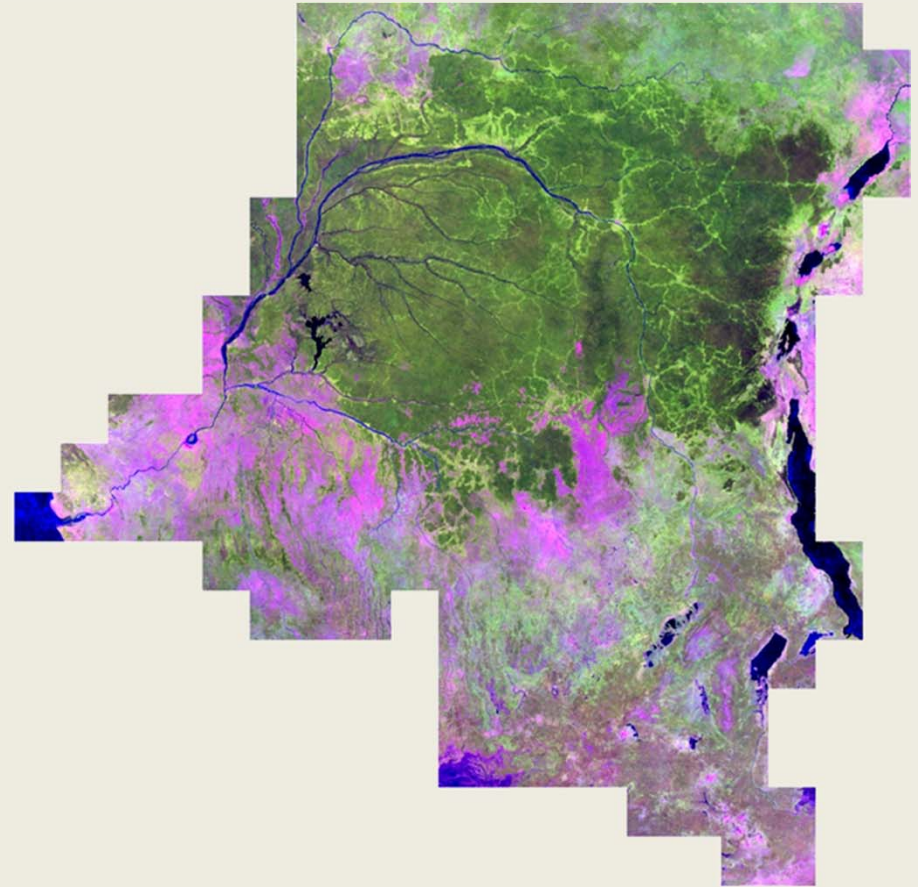


Landsat data normalization

Global MODIS TOC reflectance as normalization target



Landsat normalized reflectance
(median spectral reflectance from
2000-2005 composite)



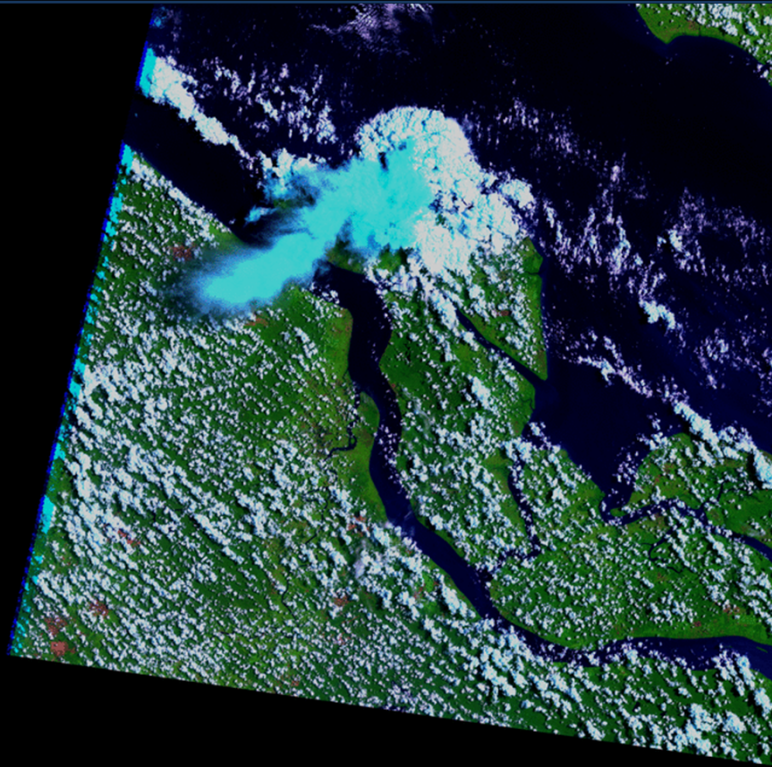
MODIS TOC reflectance
(mean spectral reflectance from
2000-2009 peak greenness composite)

Indonesia





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

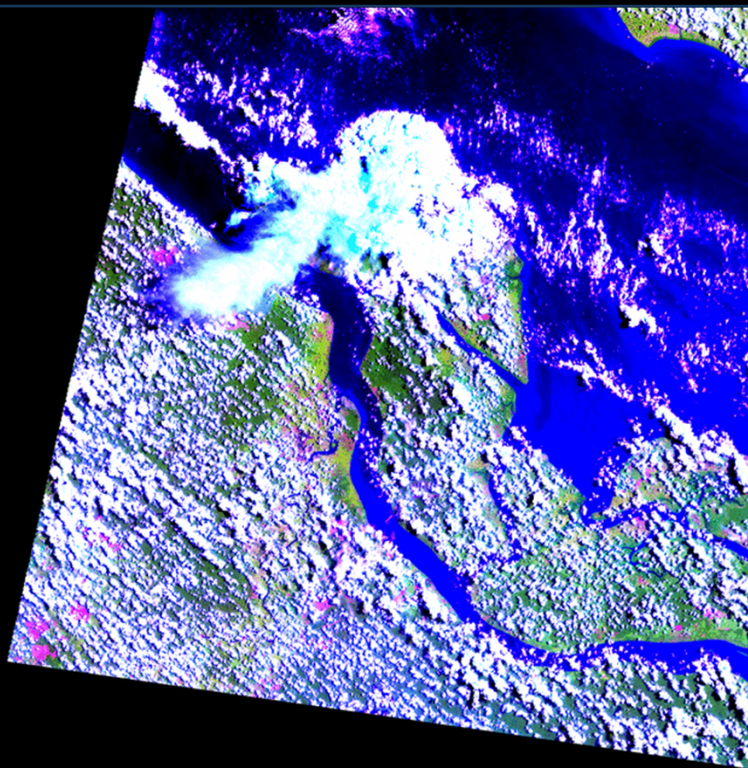


Indonesia, Riau province

Image Process

- Raw Digital Numbers

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

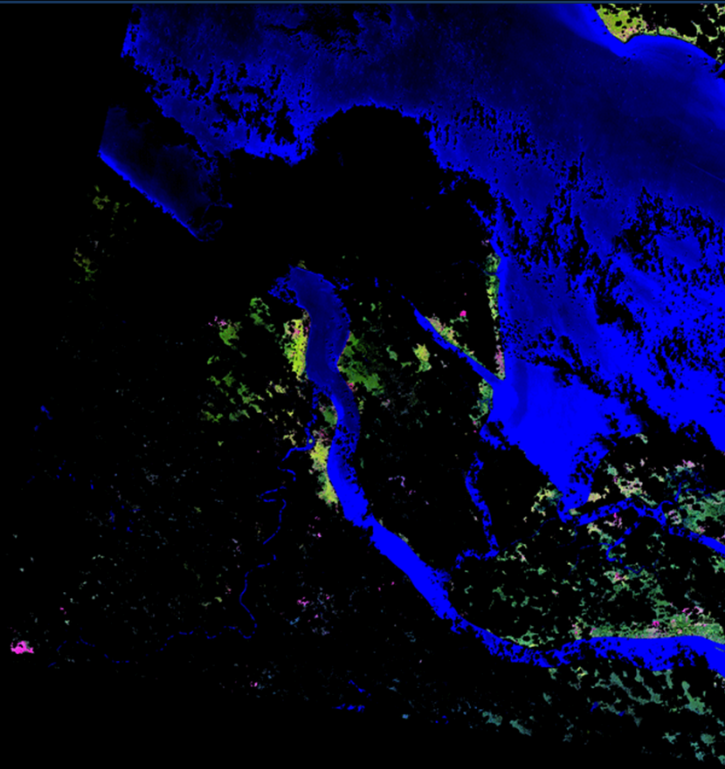


Indonesia, Riau province

Image Process

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

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

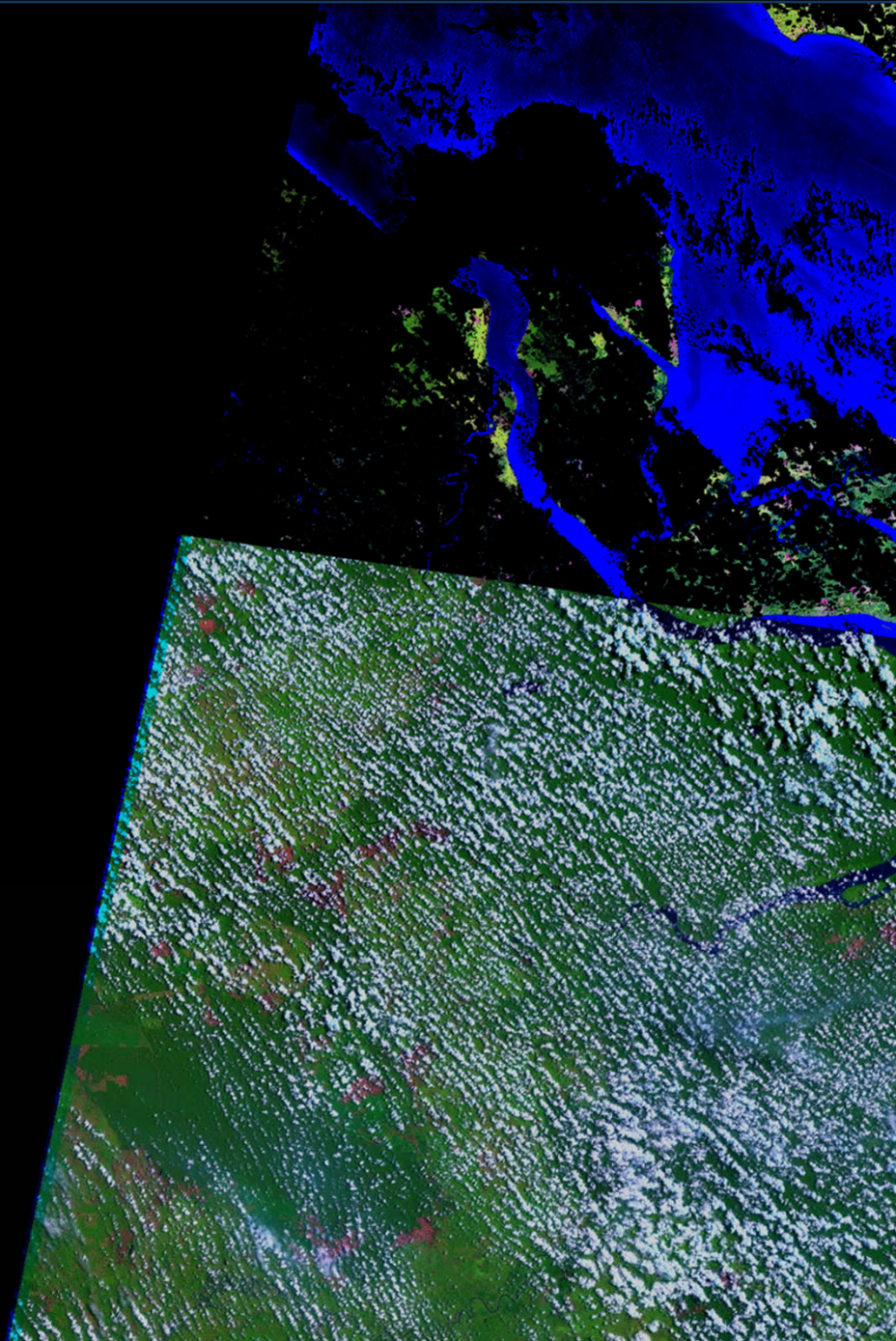


Indonesia, Riau province

Image Process

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

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

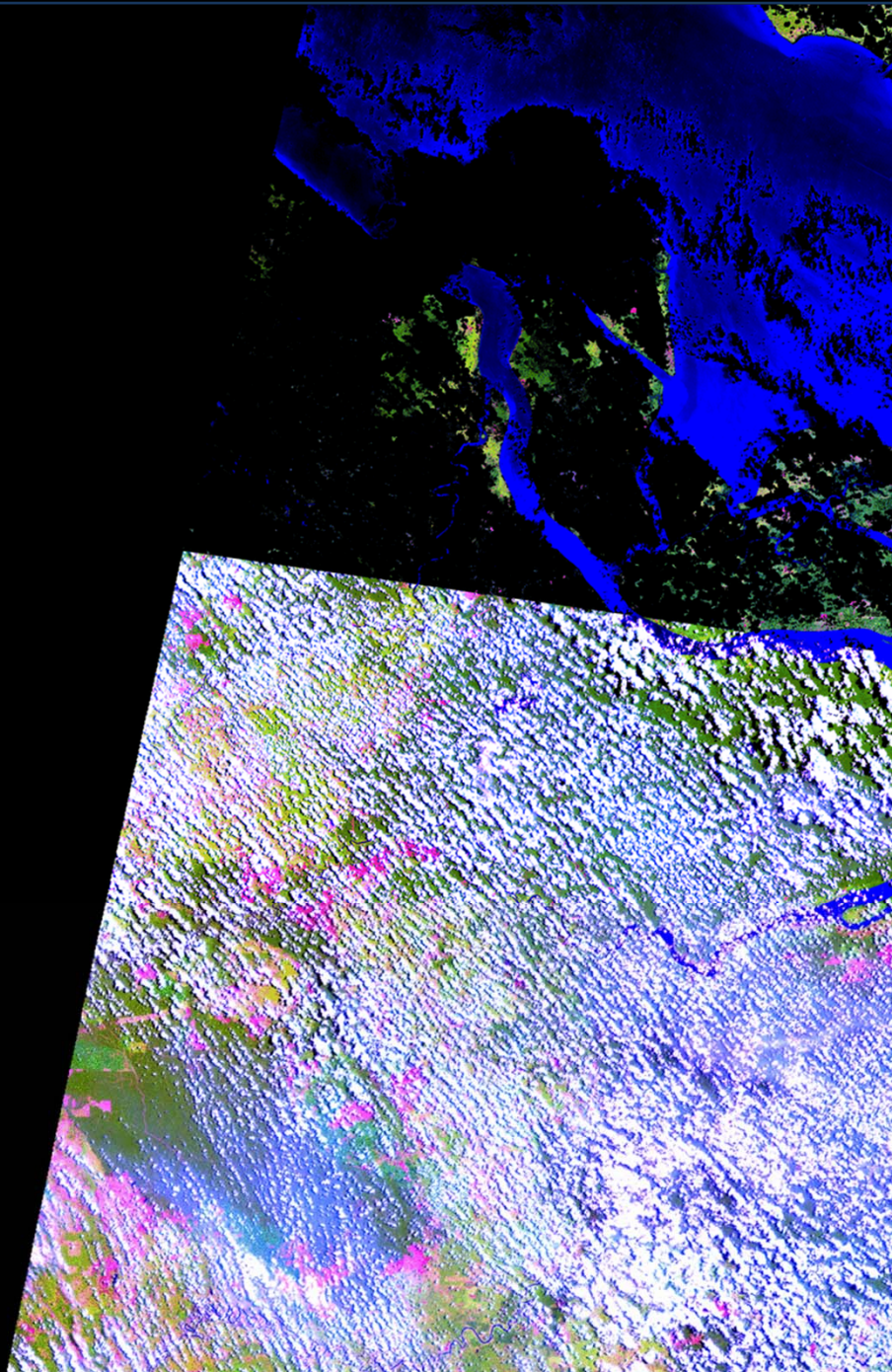


Indonesia, Riau province

Image Process

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

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

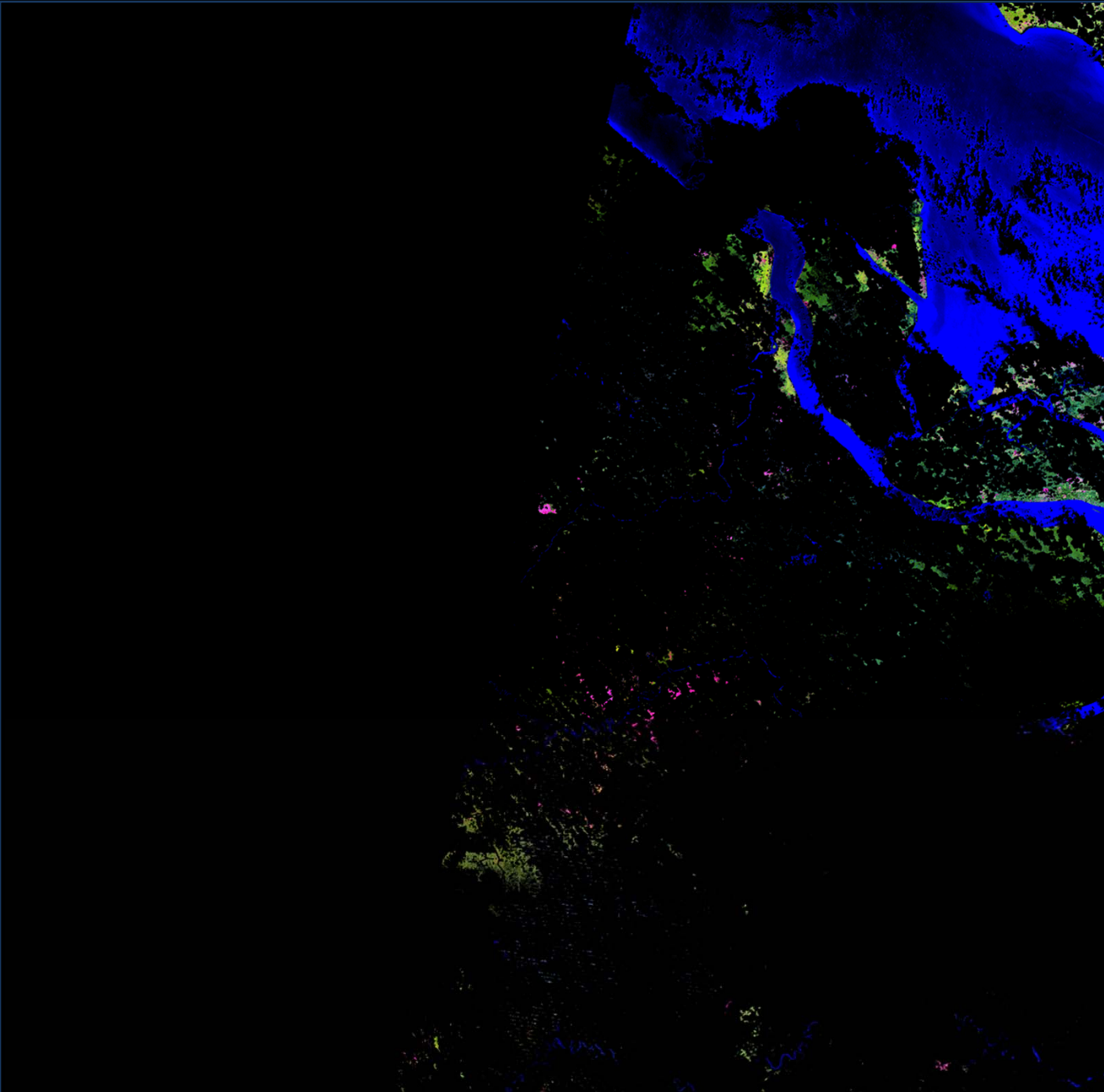


Indonesia, Riau province

Image Process

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

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

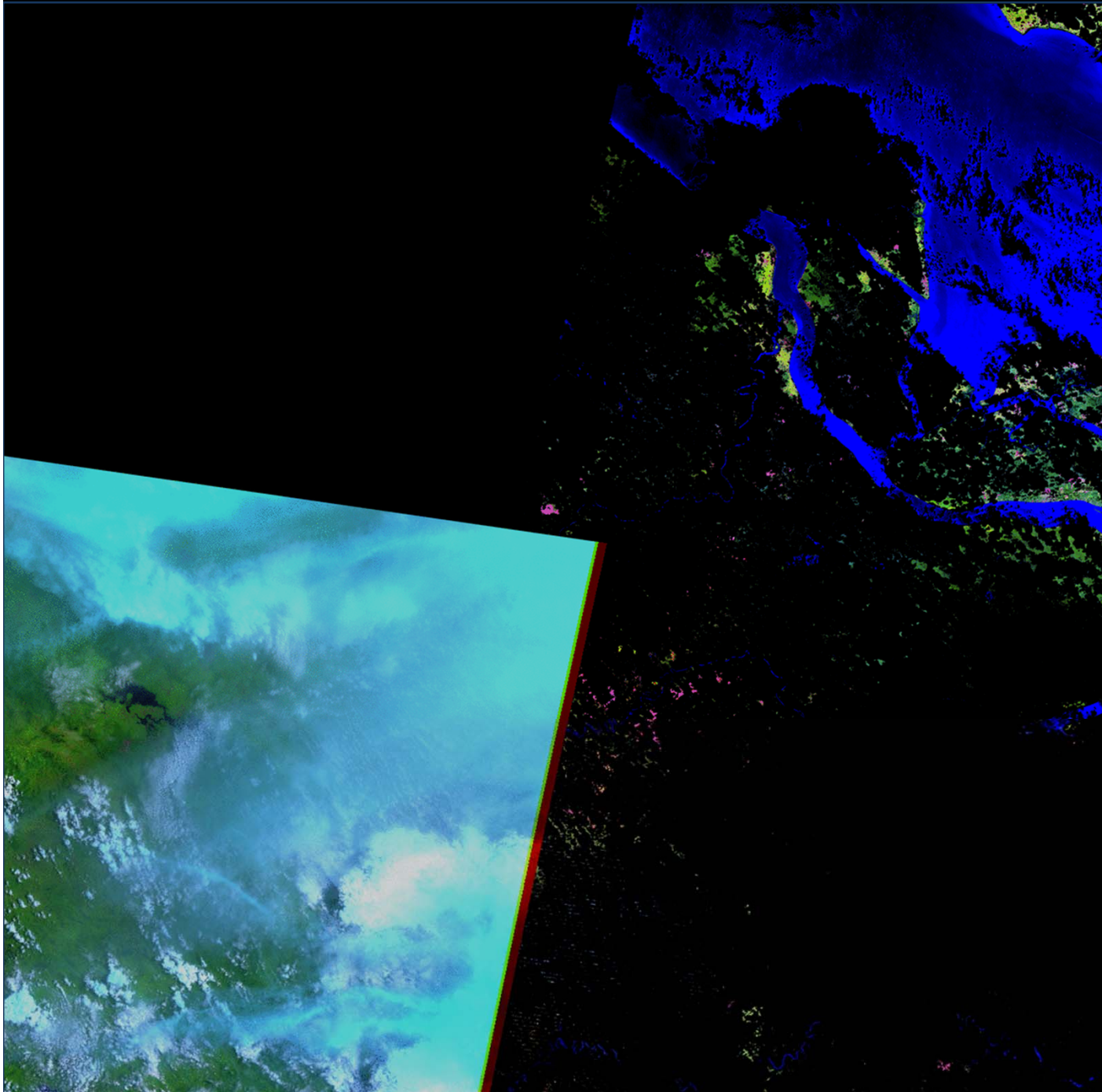


Indonesia, Riau province

Image Process

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

Image# : 003 WRS : 127060 Year : 1999 Day : 258



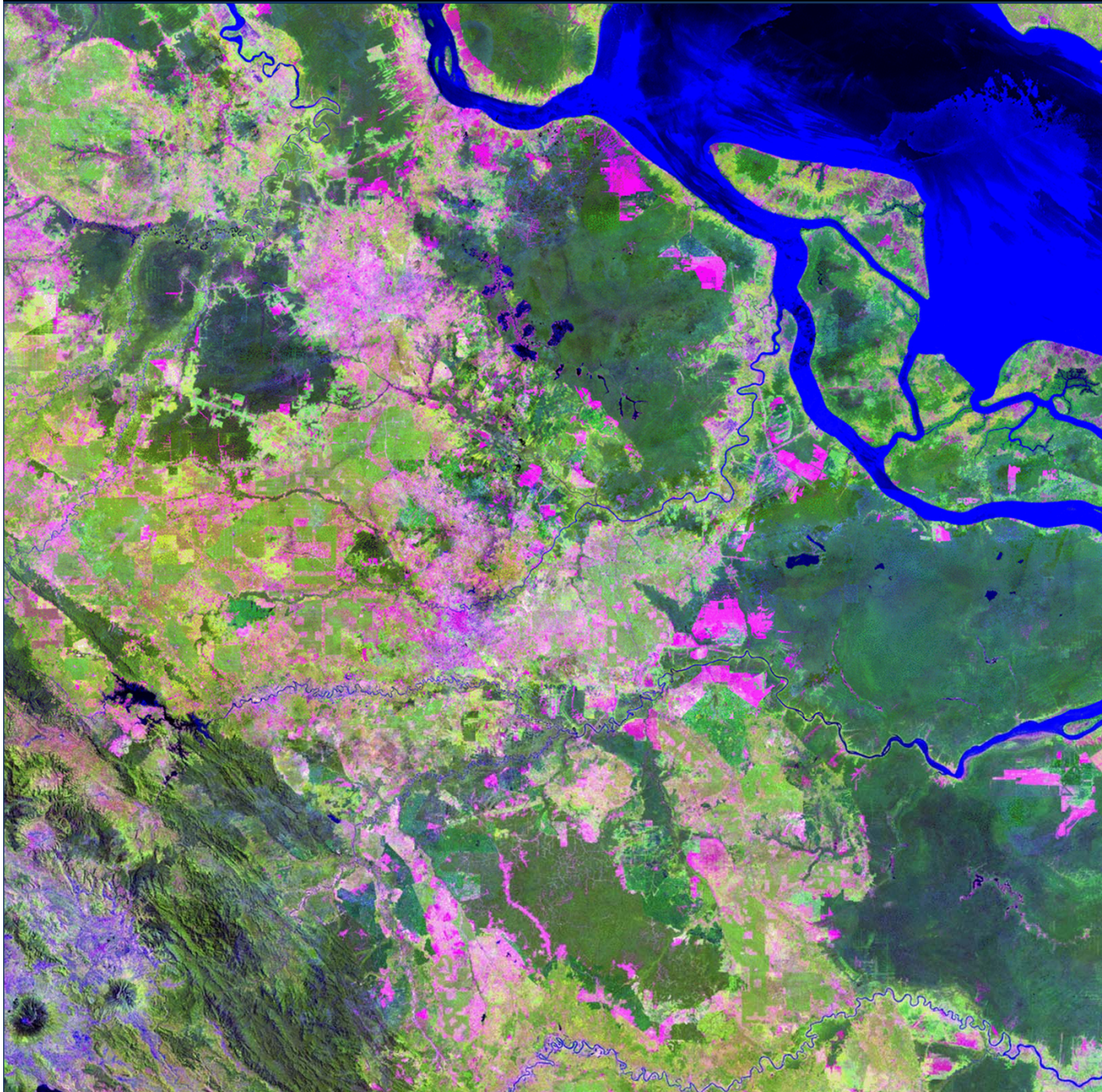
Indonesia, Riau province

Image Process

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

Compositing...

Image# : 092 WRS : 126060 Year : 2002 Day : 227



Indonesia, Riau province

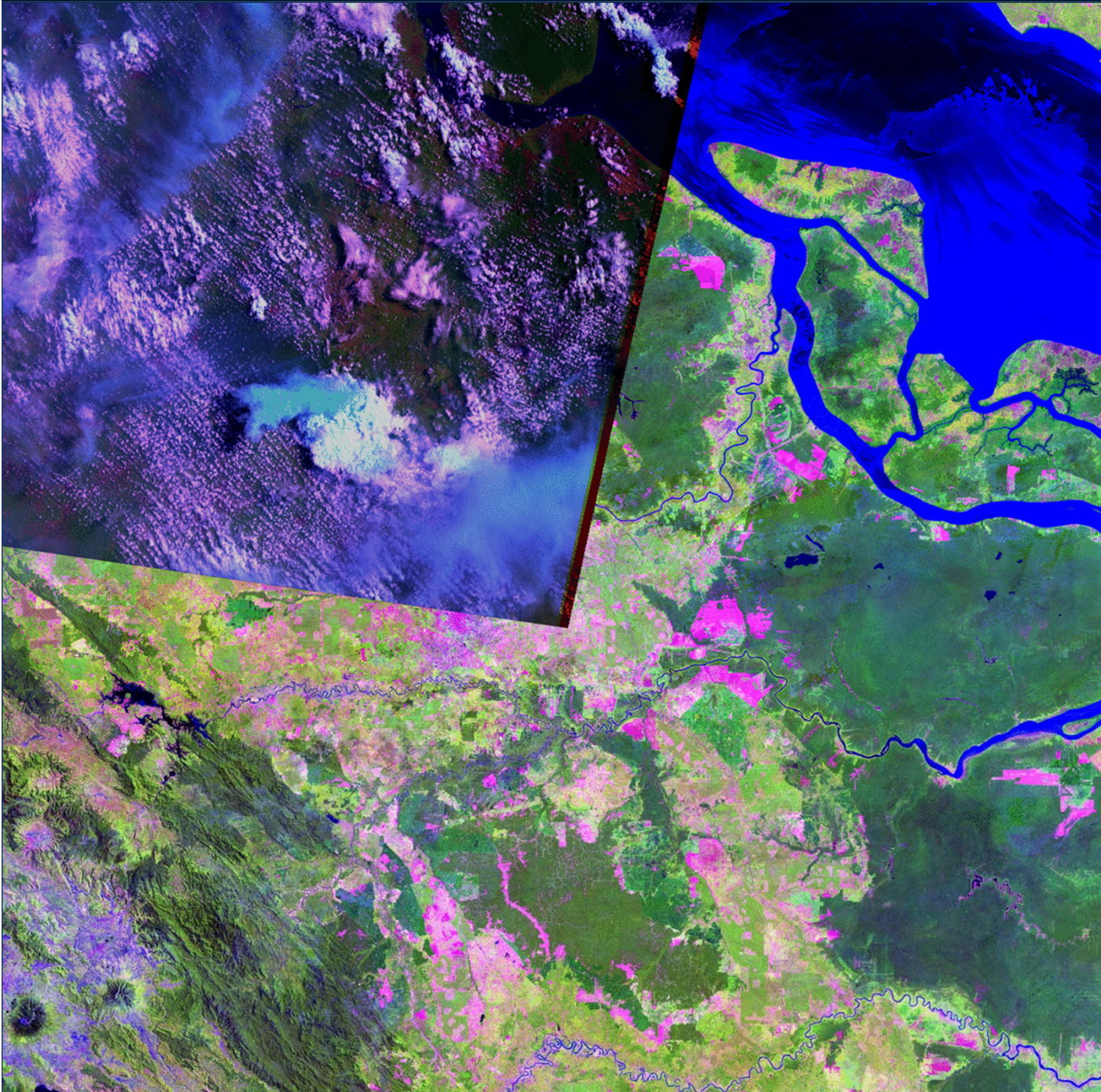
Image Process

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

Cloud-free mosaic

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

Image# : 093 WRS : 127059 Year : 2002 Day : 234



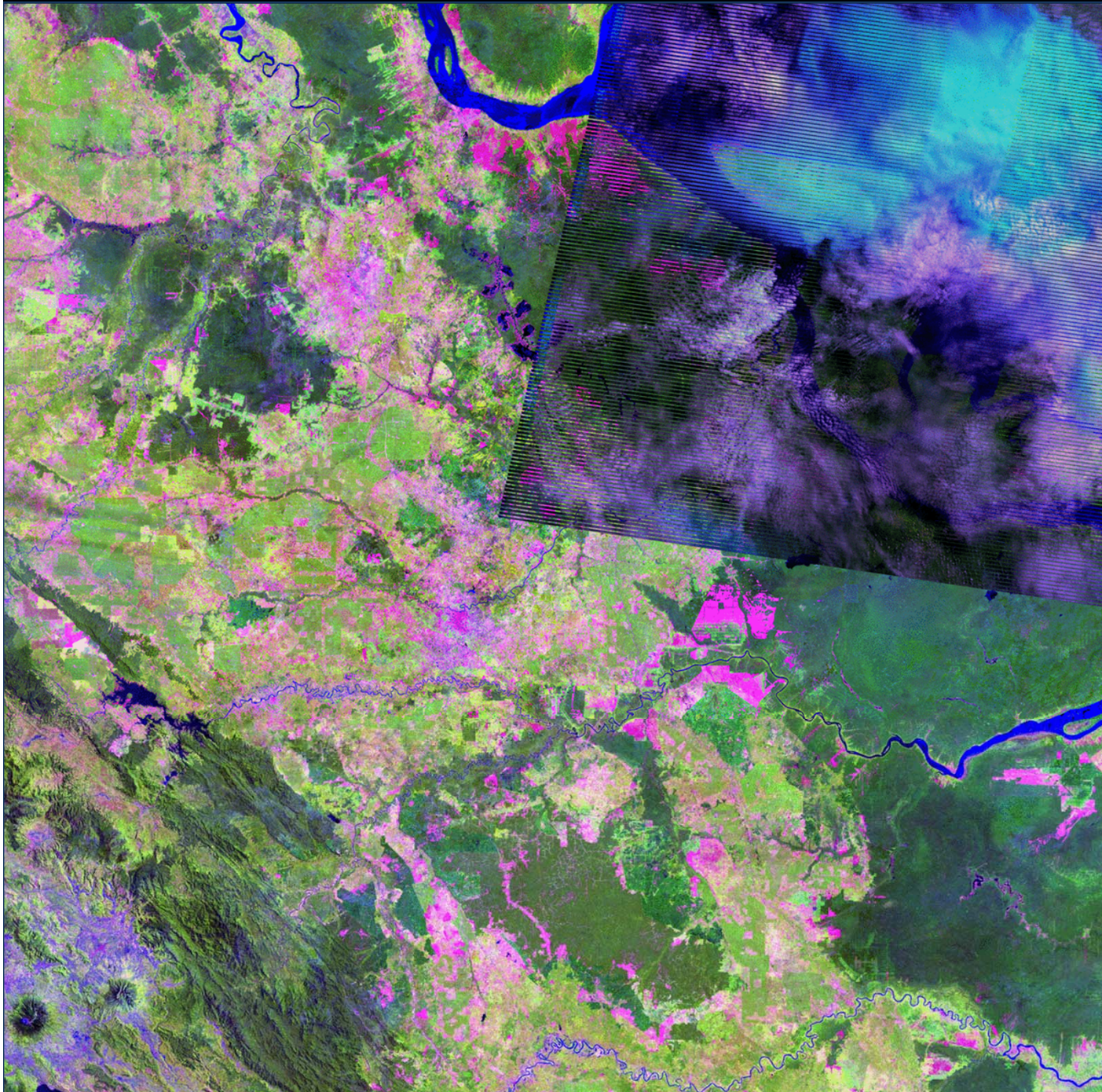
Indonesia, Riau province

Image Process

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

Keep adding data...

Image# : 115 WRS : 126059 Year : 2003 Day : 198



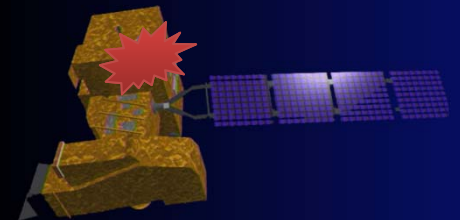
Indonesia, Riau province

Image Process

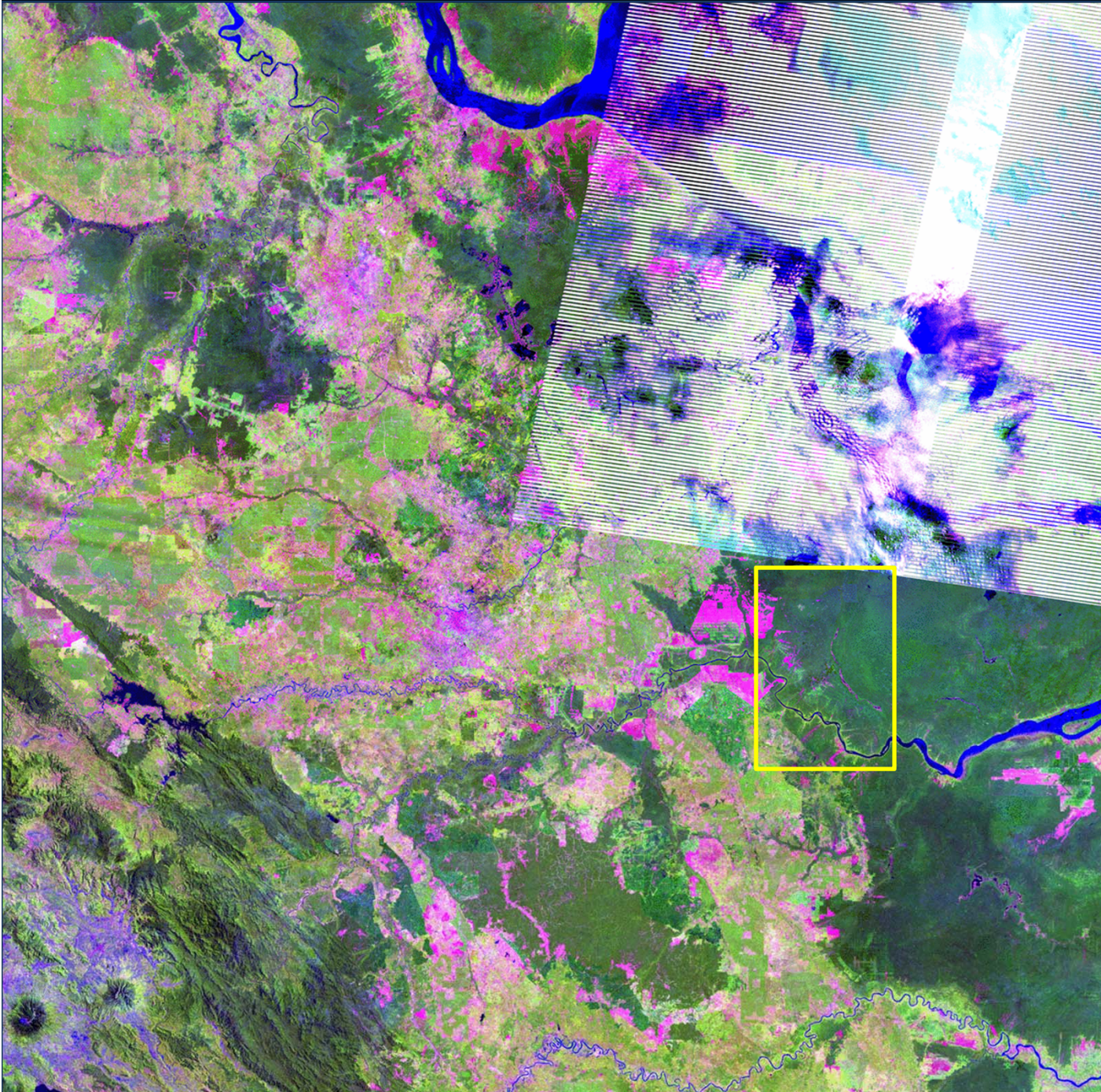
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing

Keep adding data...

Scan Line Corrector
(SLC) failed – May 2003



Image# : 115 WRS : 126059 Year : 2003 Day : 198



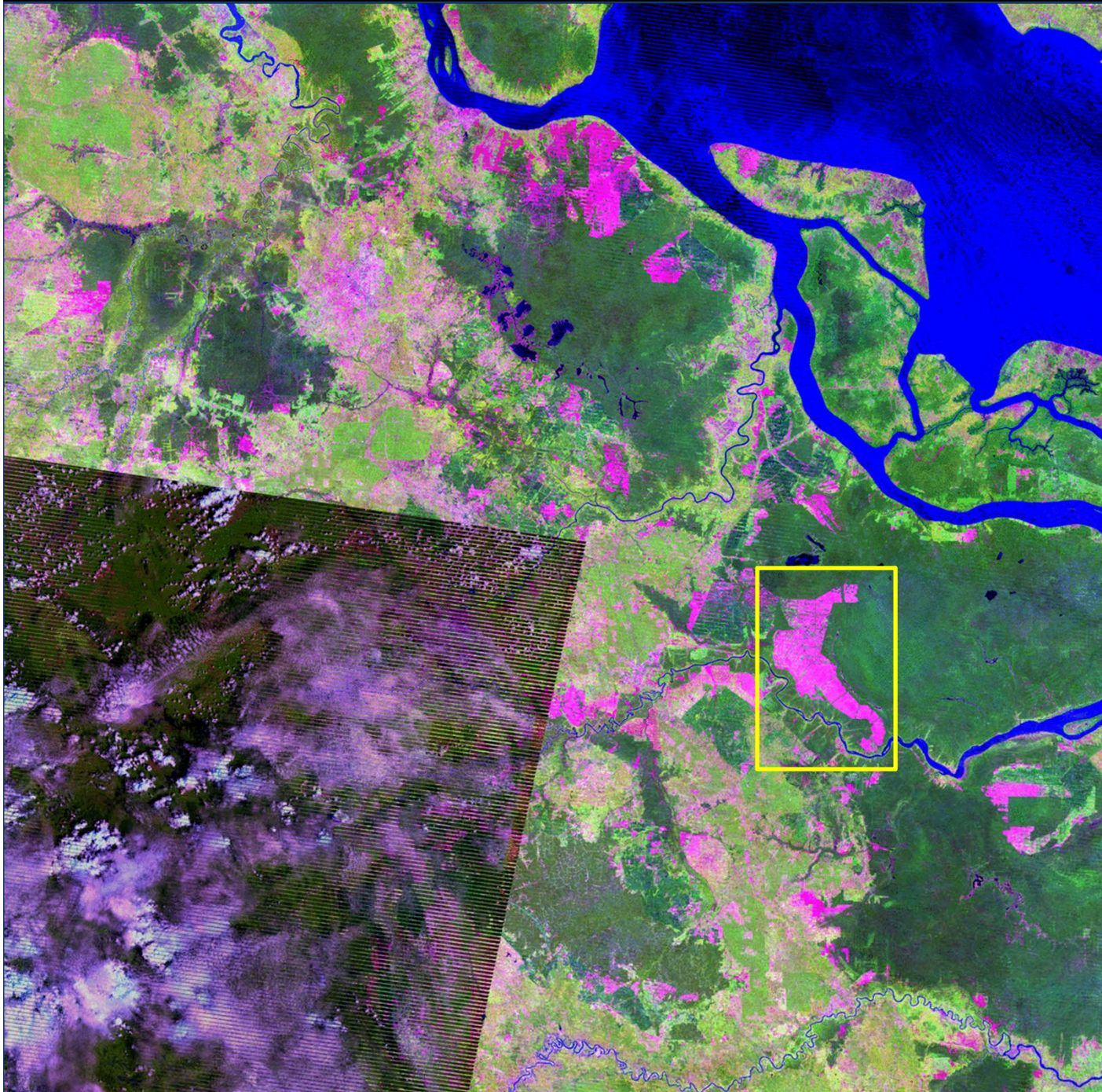
Indonesia, Riau province

Image Process

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

Adding SLC-OFF data...

Image# : 166 WRS : 127060 Year : 2004 Day : 304



Indonesia, Riau province

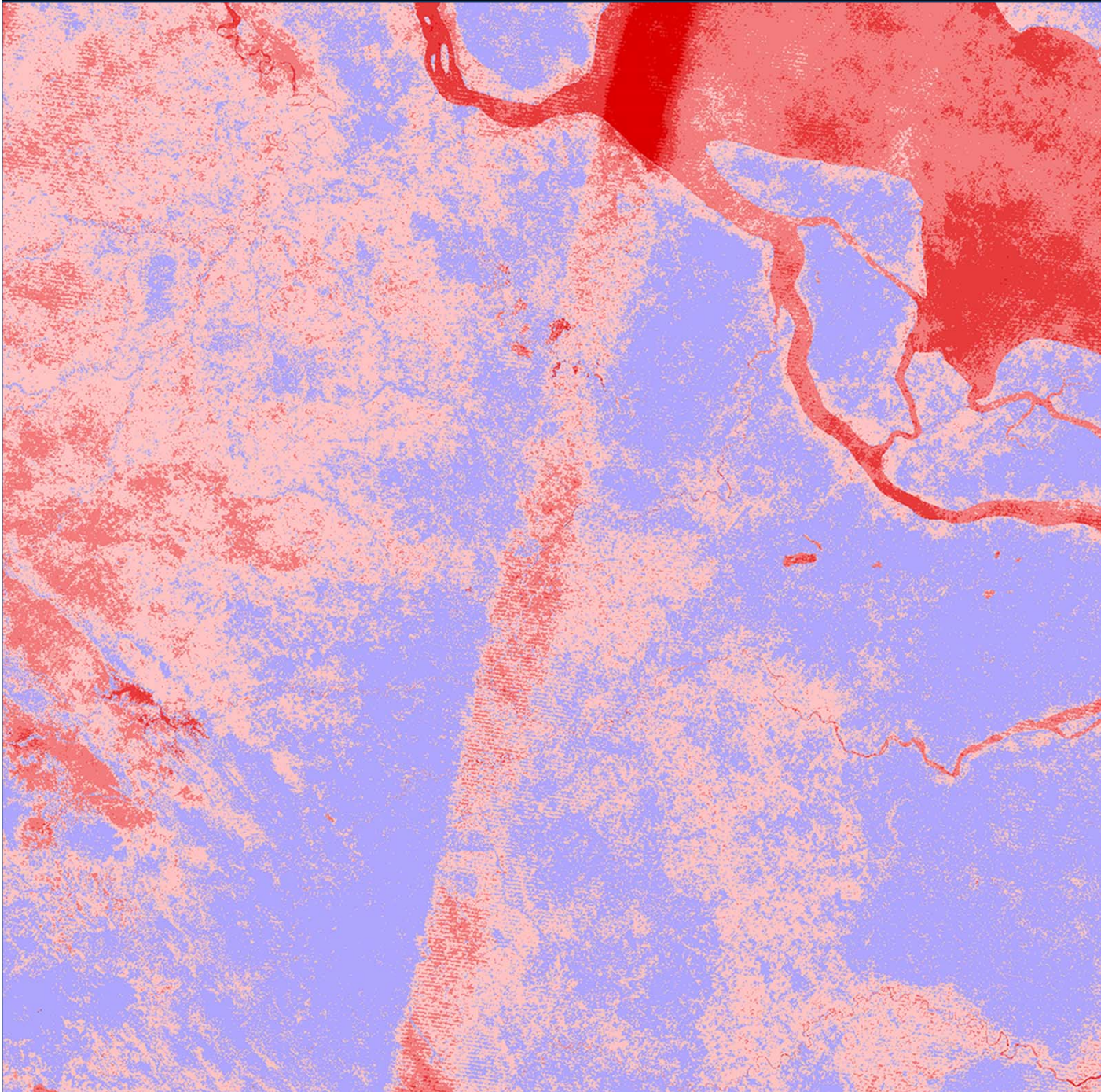
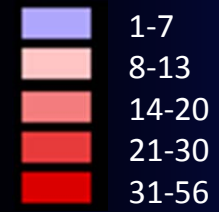
Image Process

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

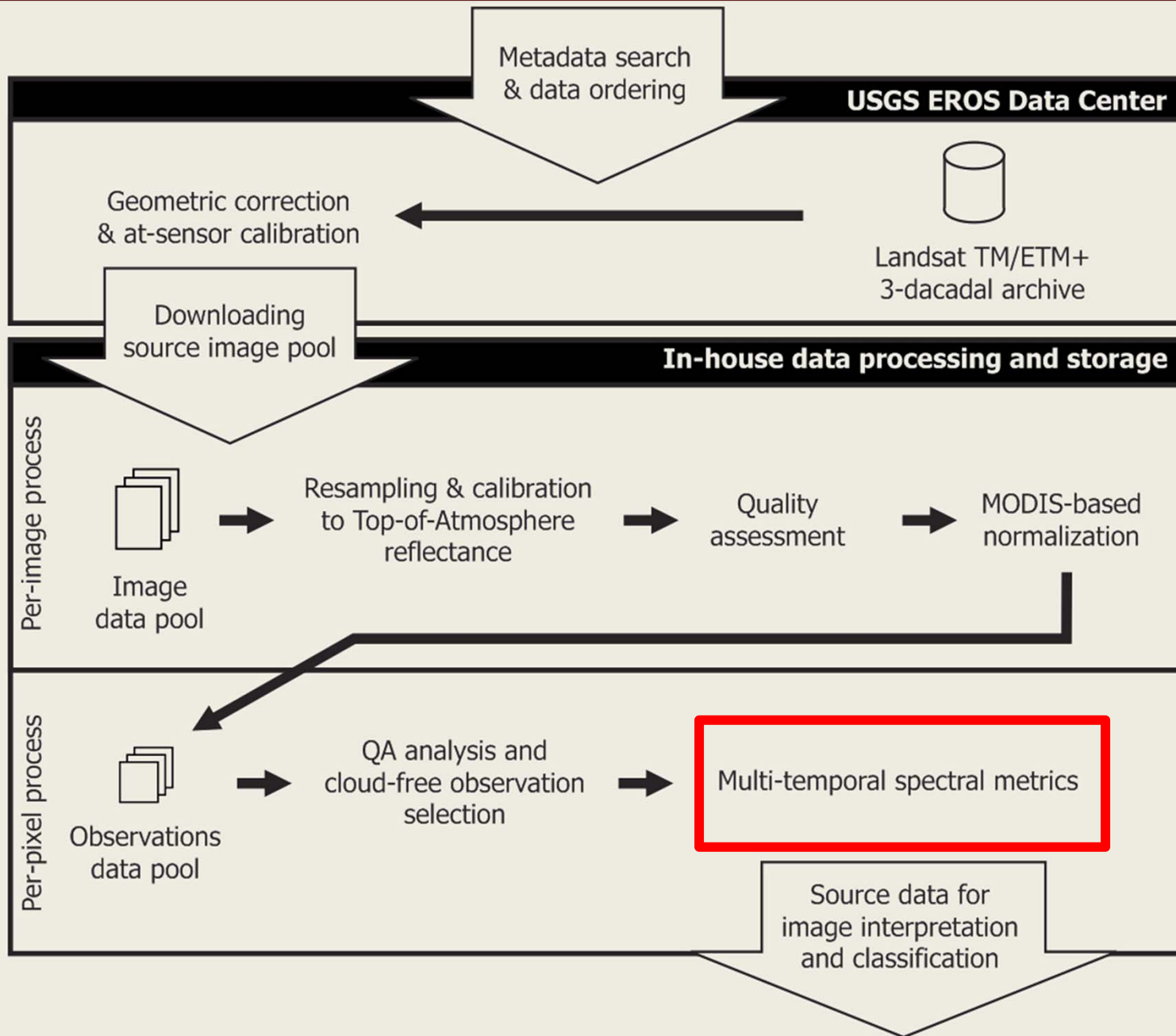
Adding SLC-OFF data...

Indonesia, Riau province

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



Landsat data processing workflow



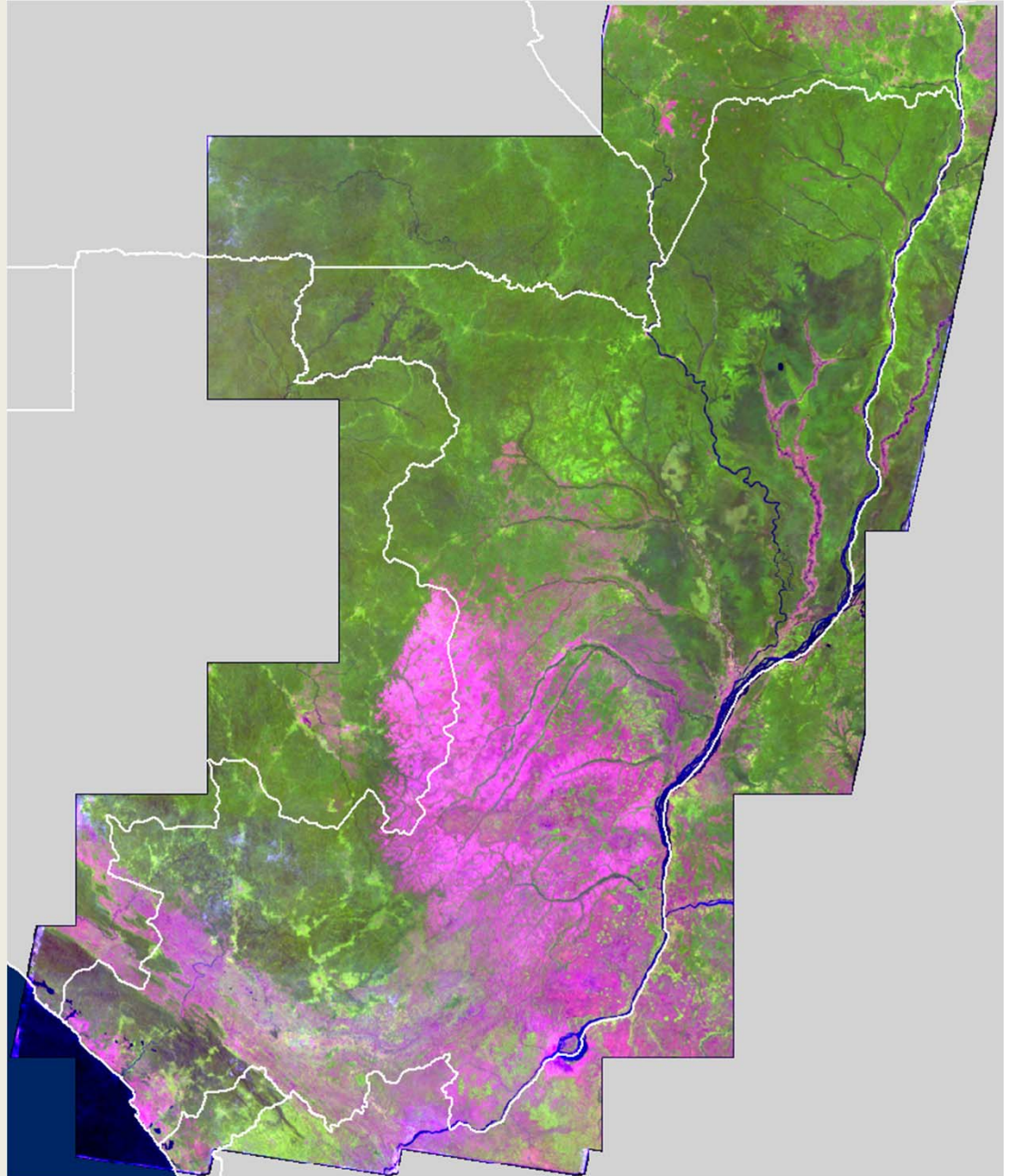
Multi-temporal metrics

Multi-temporal metrics approach

- **Image composite metrics**
 - Time-sequential (start/end date) composites
 - Annual composites for results post-processing
- **Rank-based metrics**
 - Reflectance values distribution within time-series
- **Trend analysis metrics**
 - Change in reflectance between consequent observations
 - Linear regression of reflectance signal versus observation date
 - Reflectance signal and change corresponding to segments of signal gain and drop.

Image composite metrics

Time-sequential
composites



Republic of the Congo
Circa year 2010

Image composite metrics

Image dates for time-sequential image composites

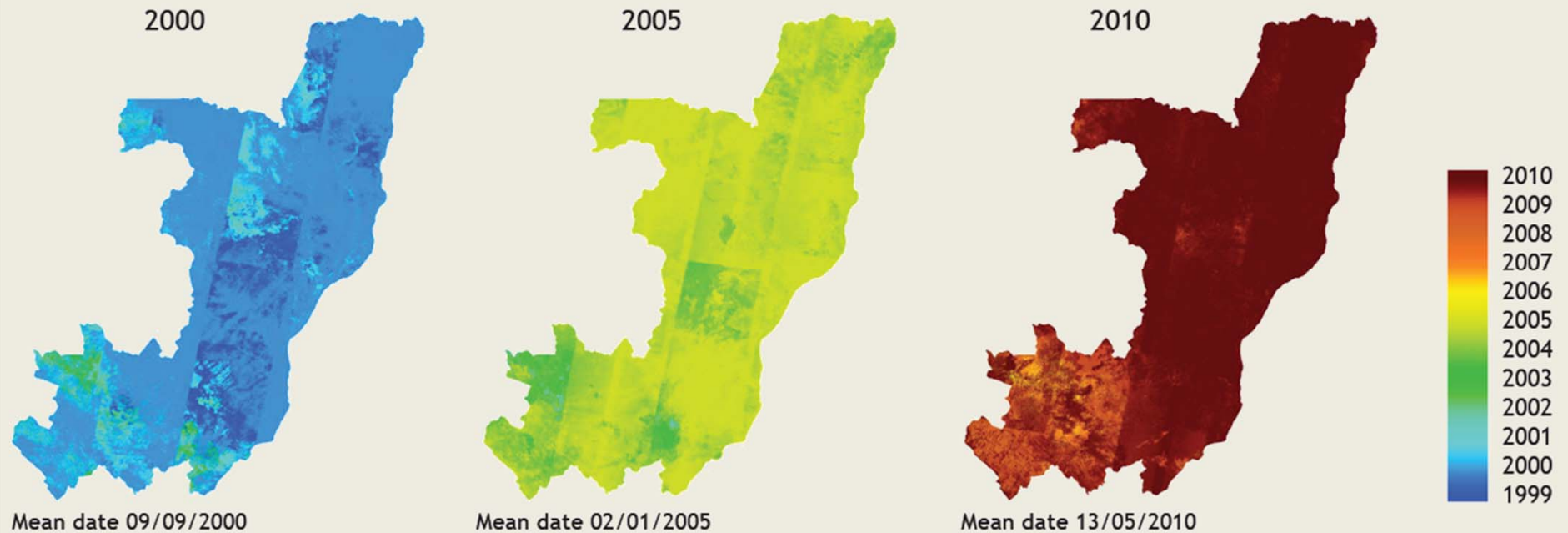


Image composite metrics

Shortcomings of time-sequential composites

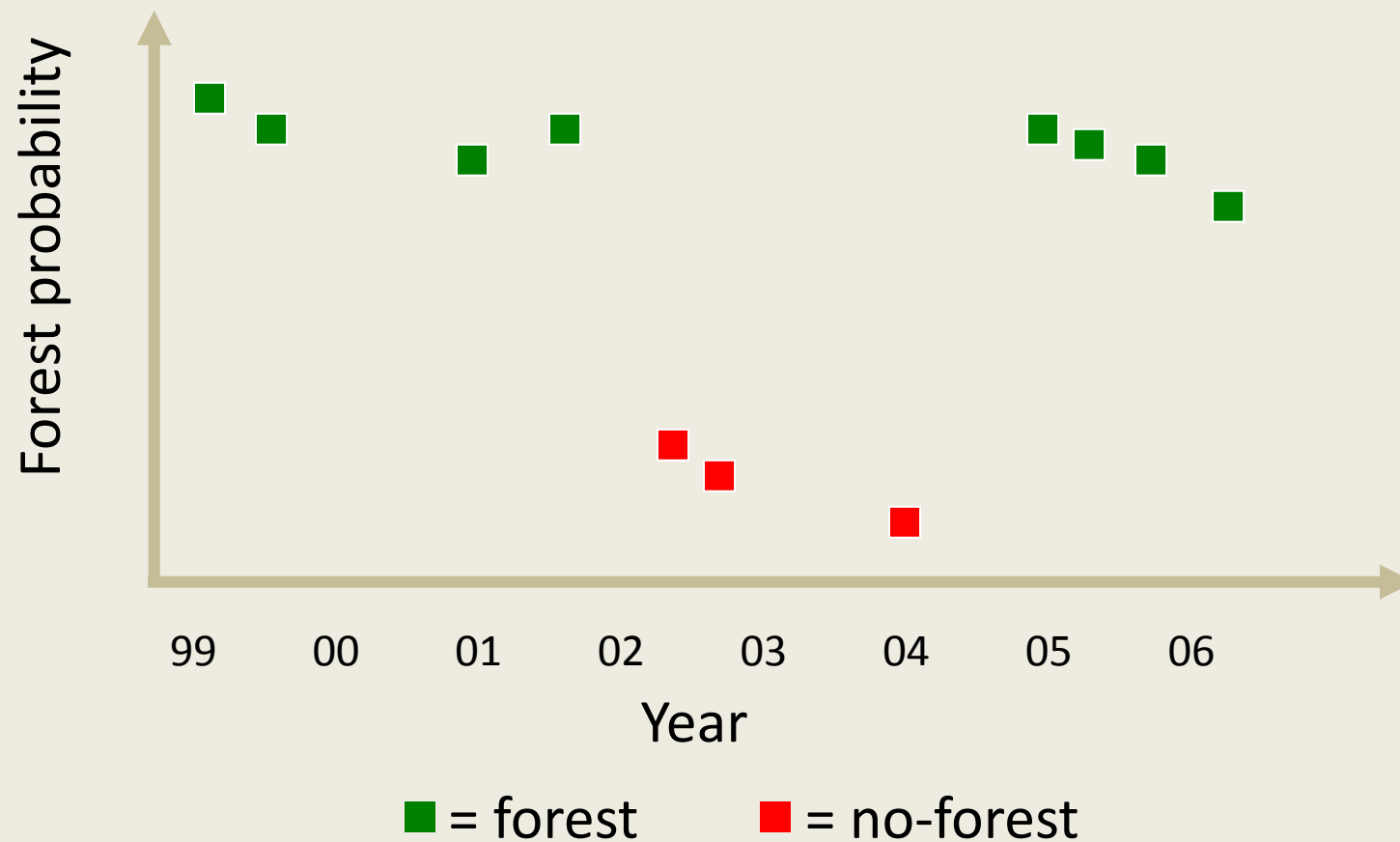


Image composite metrics

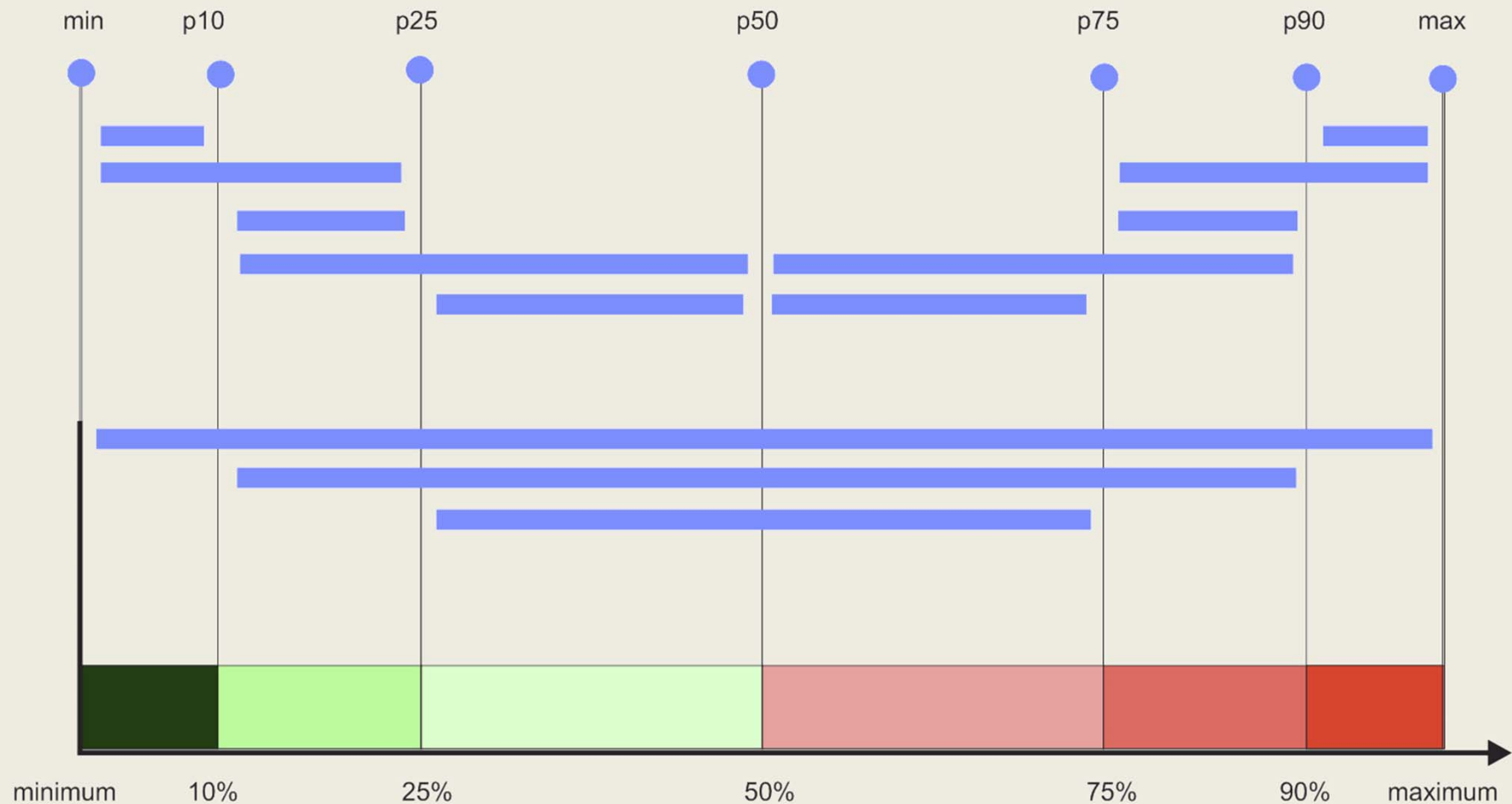
Shortcomings of time-sequential composites



Indonesia: Band 5 difference 2000 – maximum for 2000-2005

Rank-based metrics

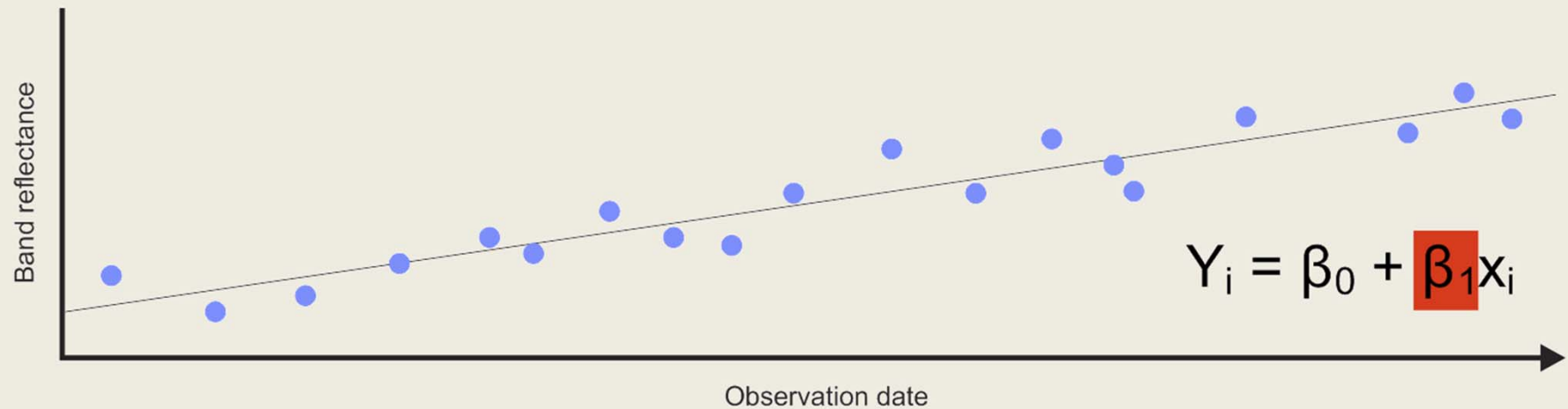
Rank-based metrics types



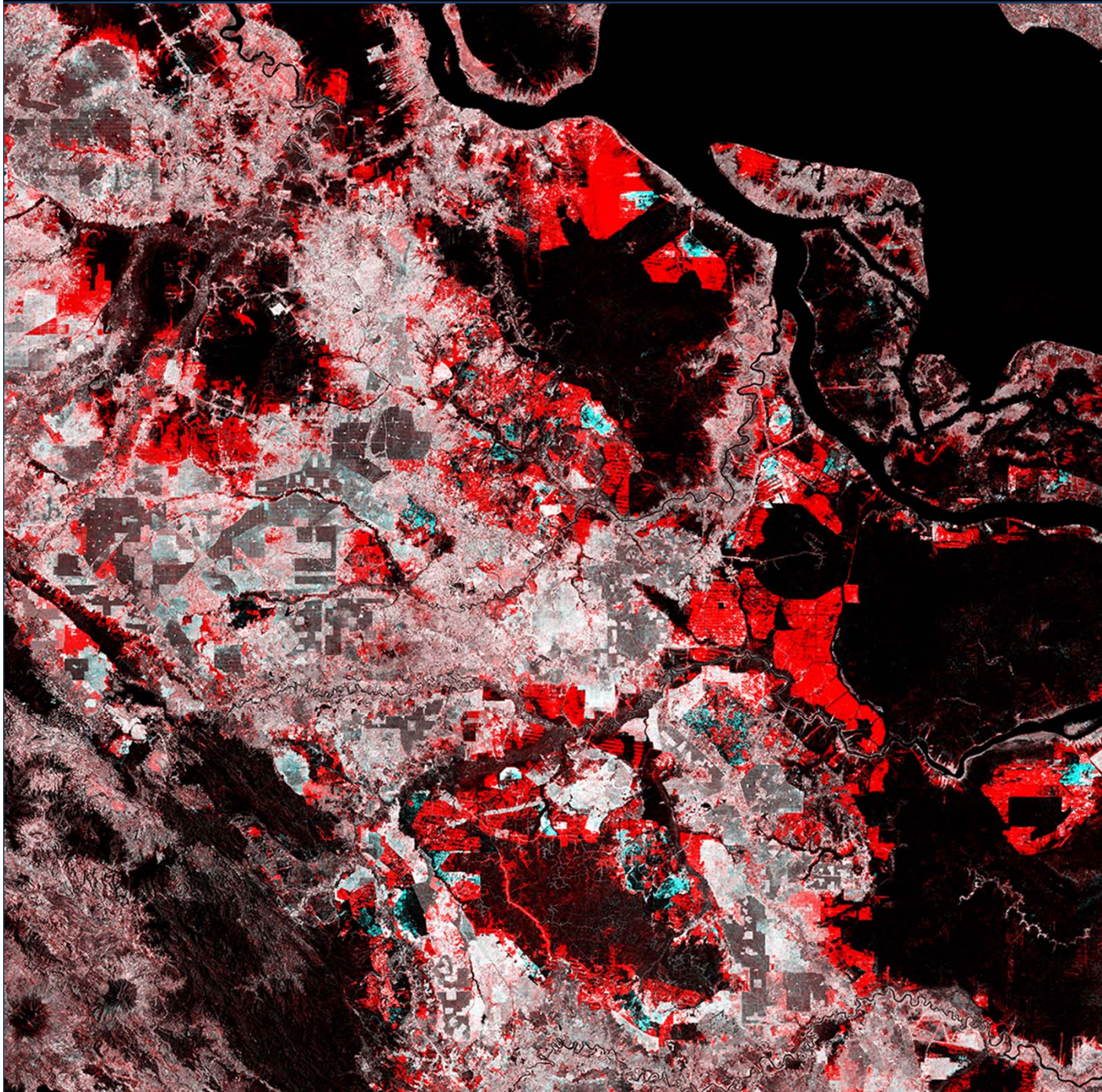
- Ranked by band value (b3, b4, b5, b7, NDVI, NBR)
- Ranked by corresponding band/index value (b3, b4, b5, b7)
 - NDVI, NBR, Brightness temperature

Trend analysis metrics

Linear regression



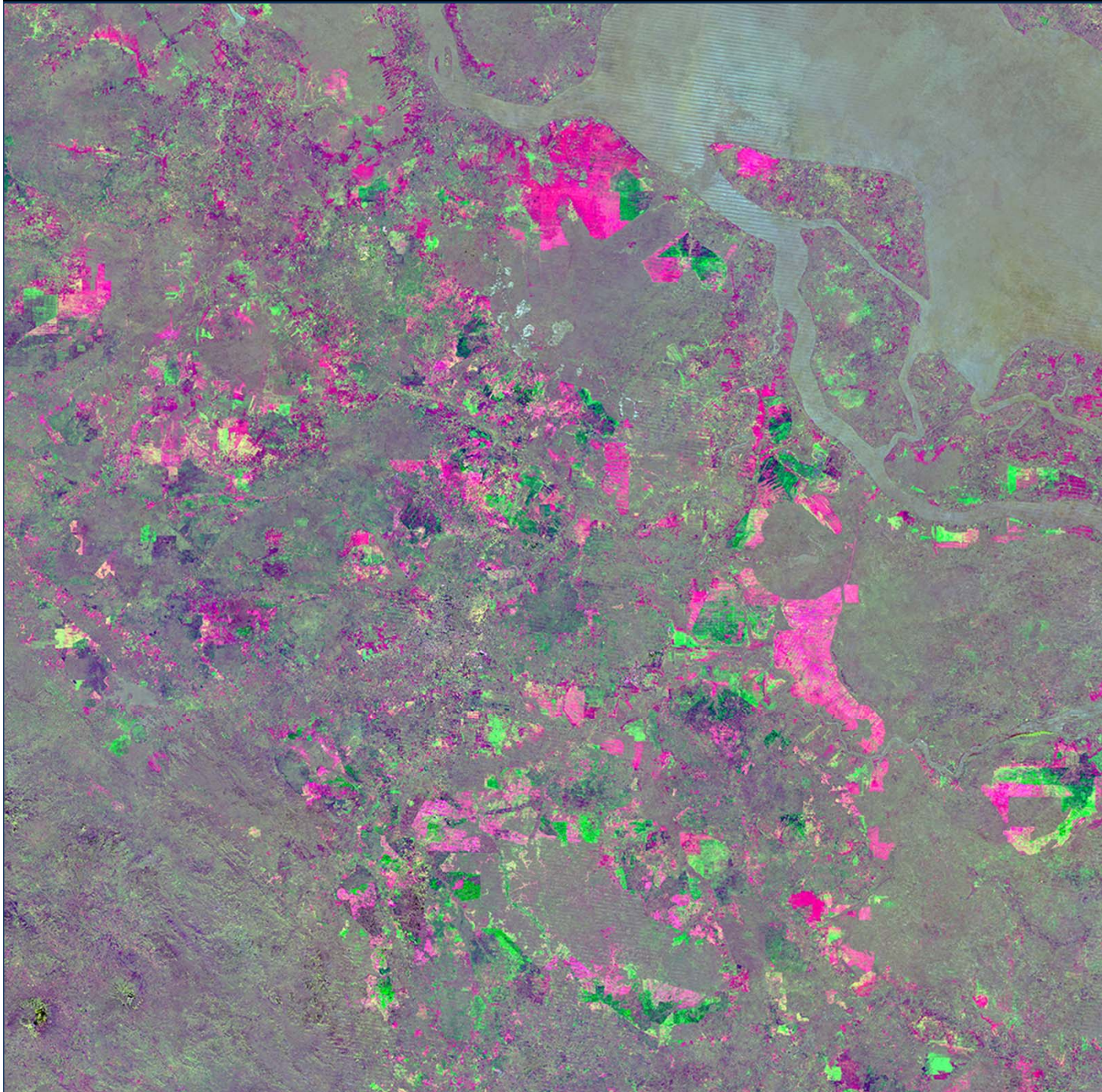
- Slope of linear regression of band reflectance vs. image date
 - Single-date observations
 - Annual median reflectance
- Standard deviation of reflectance value
 - Single-date observations
 - Annual median reflectance



Riau province,
Indonesia

2000-2005 metric
space

- Comparing SWIR band reflectance from Max value composite vs. year 2000 composite
- Using slope of linear regression between reflectance and observation date

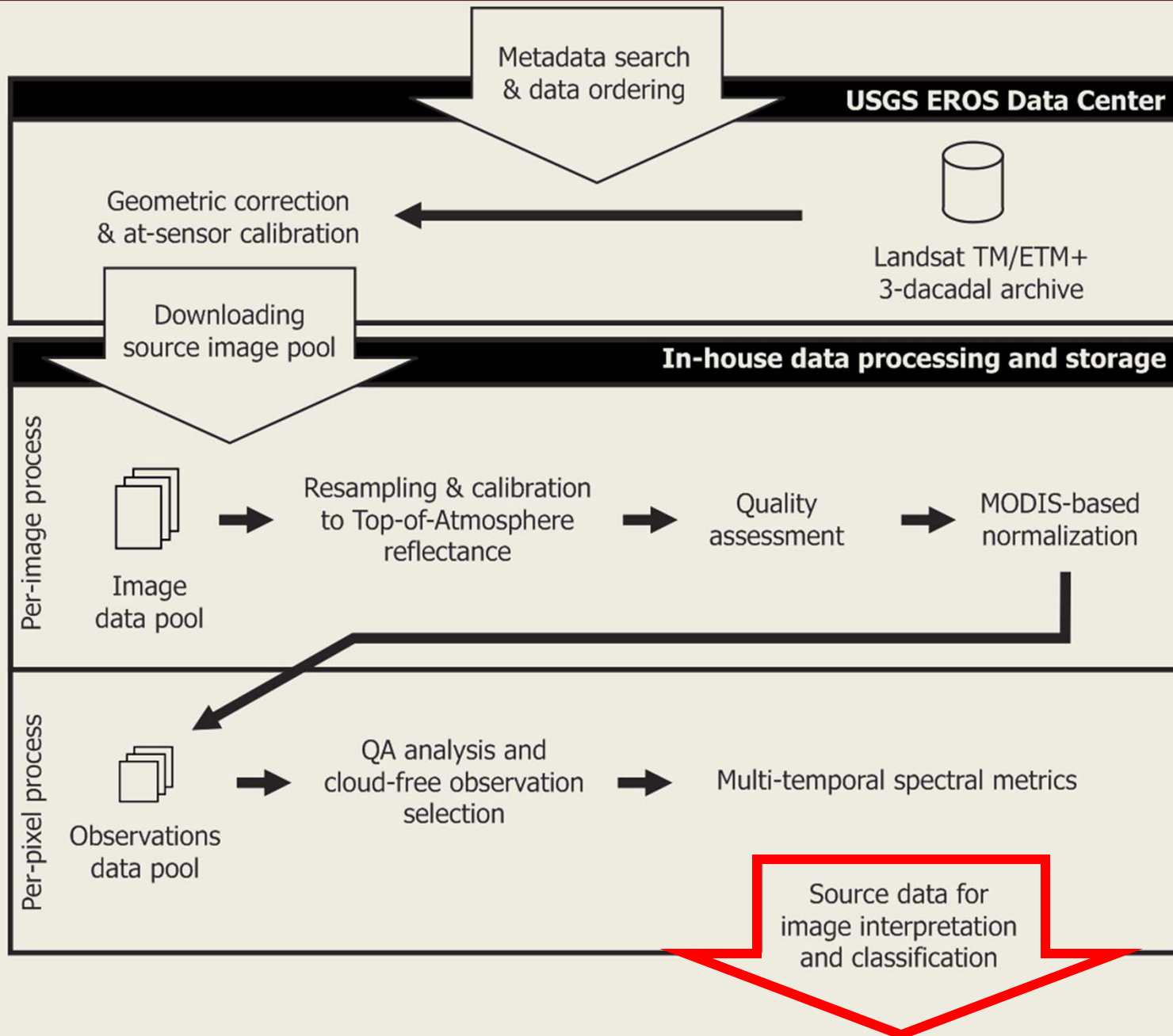


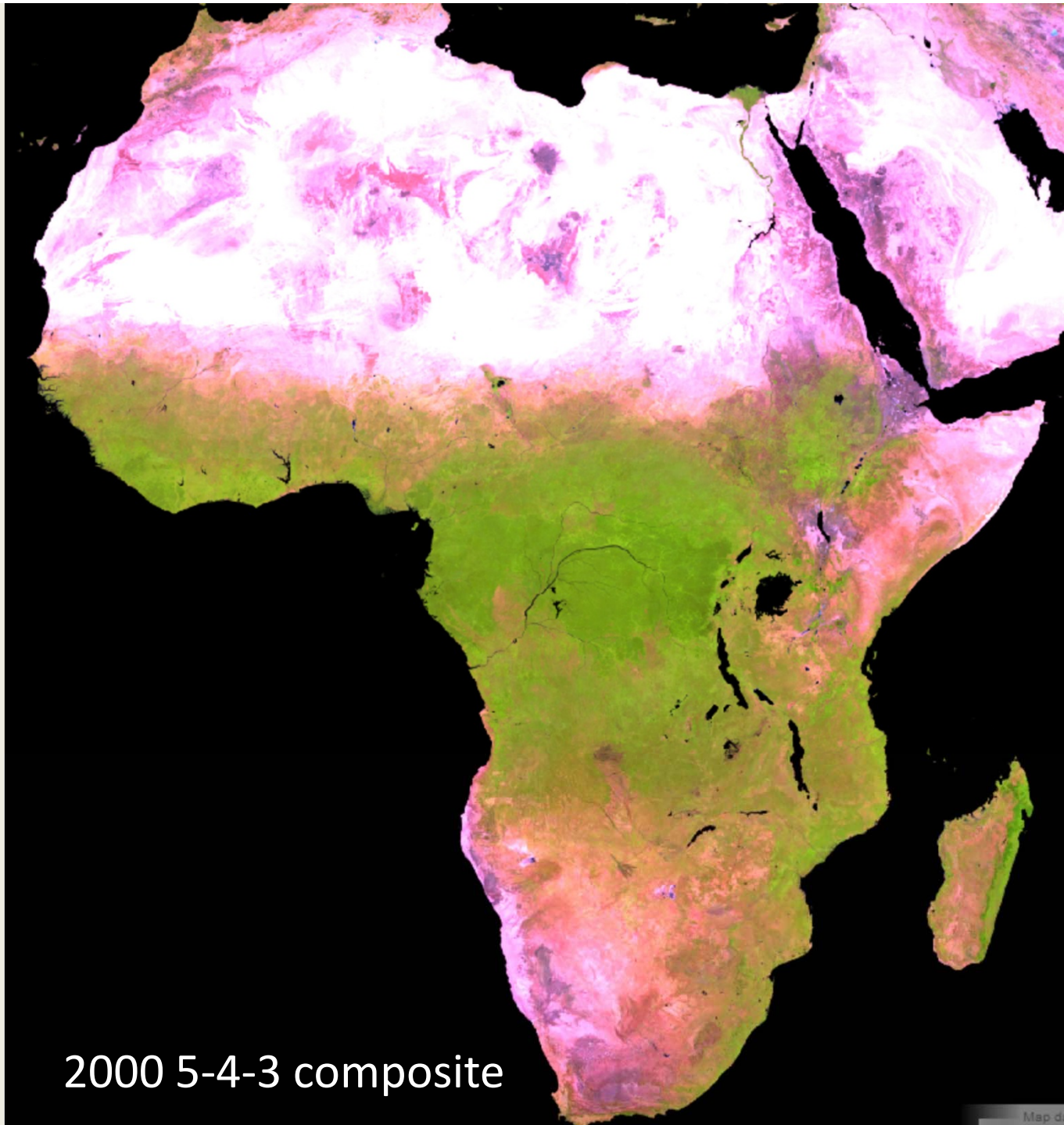
Riau province,
Indonesia

2000-2005 metric
space

- Comparing SWIR band reflectance from Max value composite vs. year 2000 composite
- Using slope of linear regression between reflectance and observation date

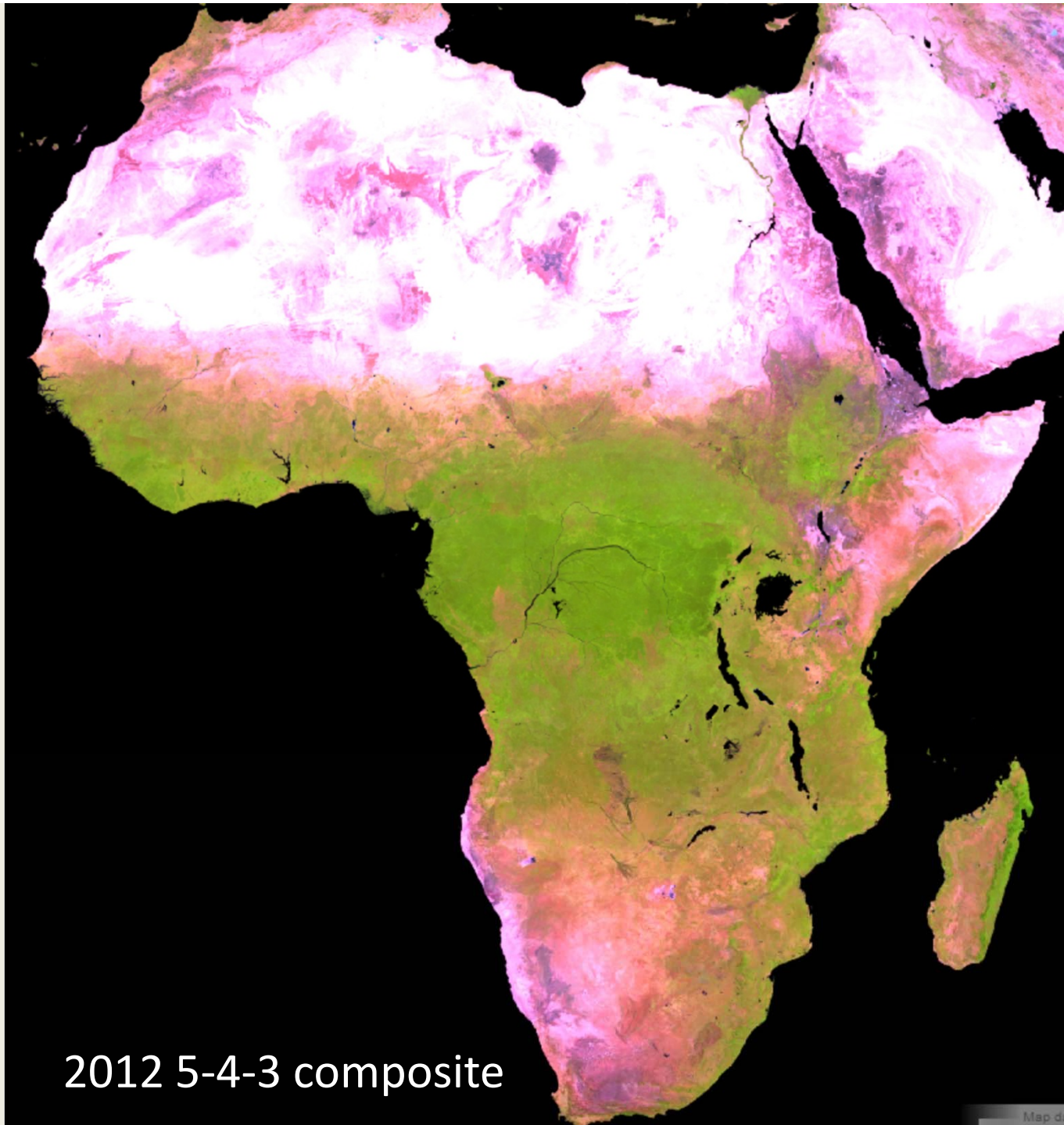
Landsat data processing workflow



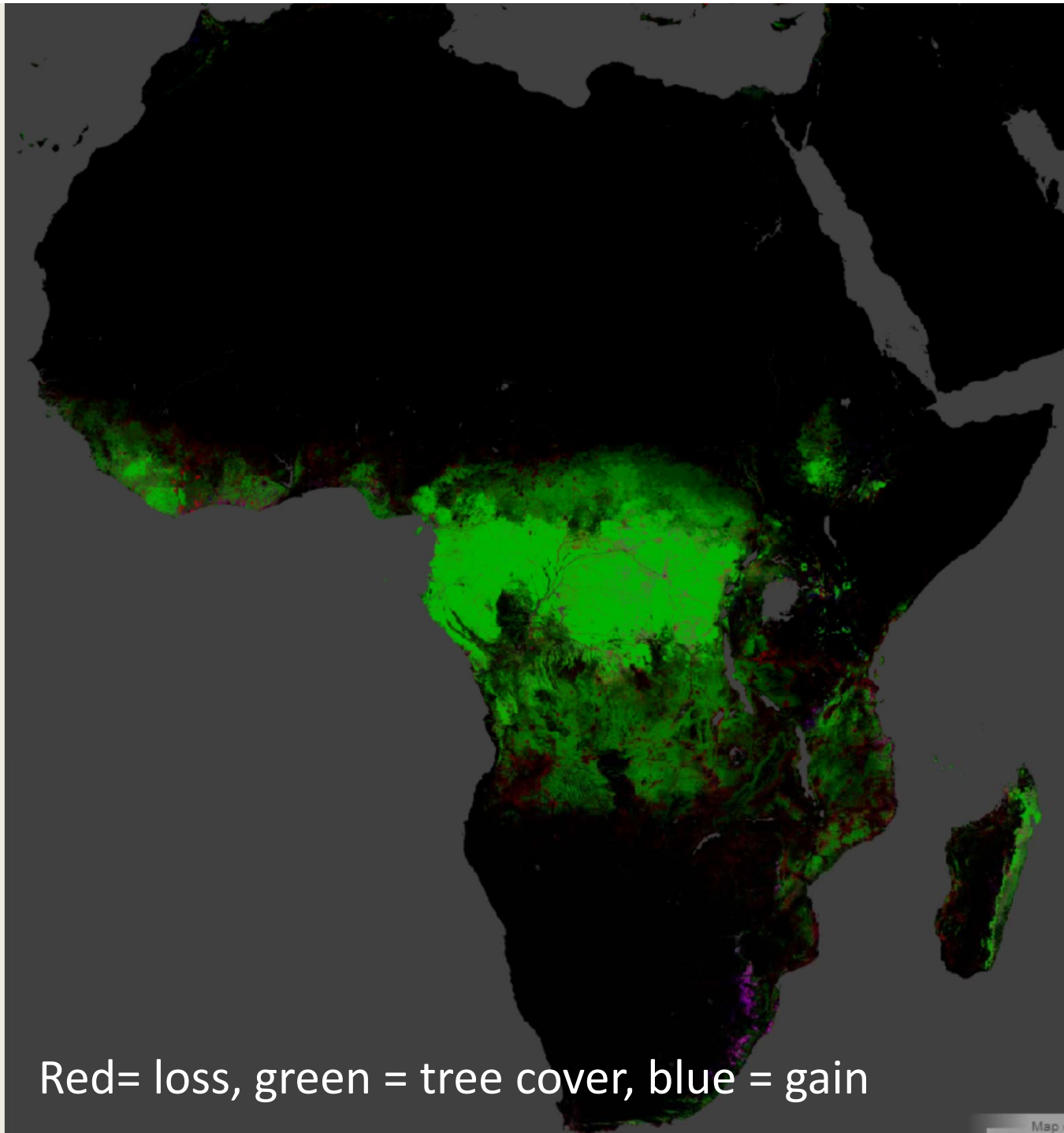


2000 5-4-3 composite

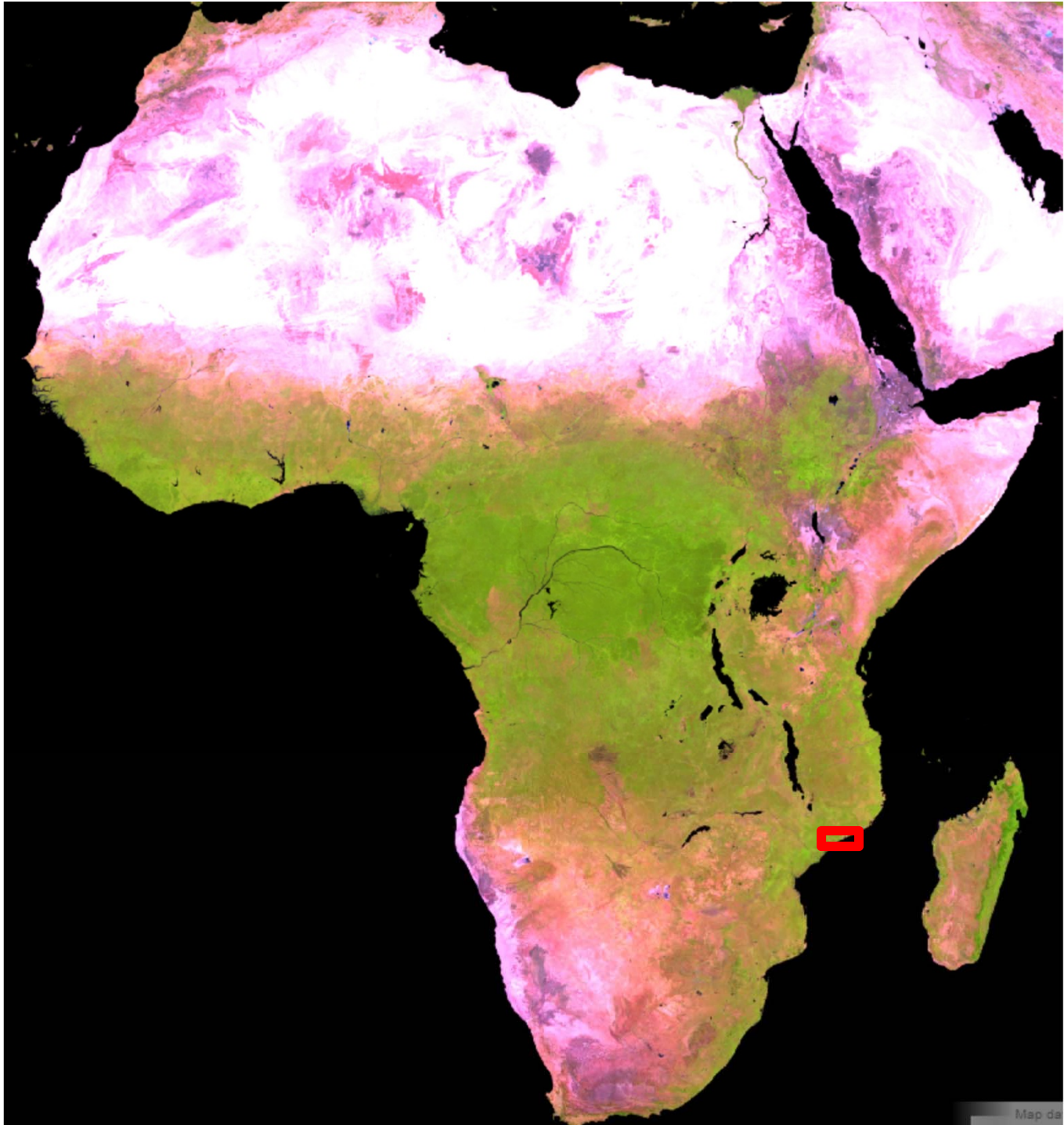
Map d...



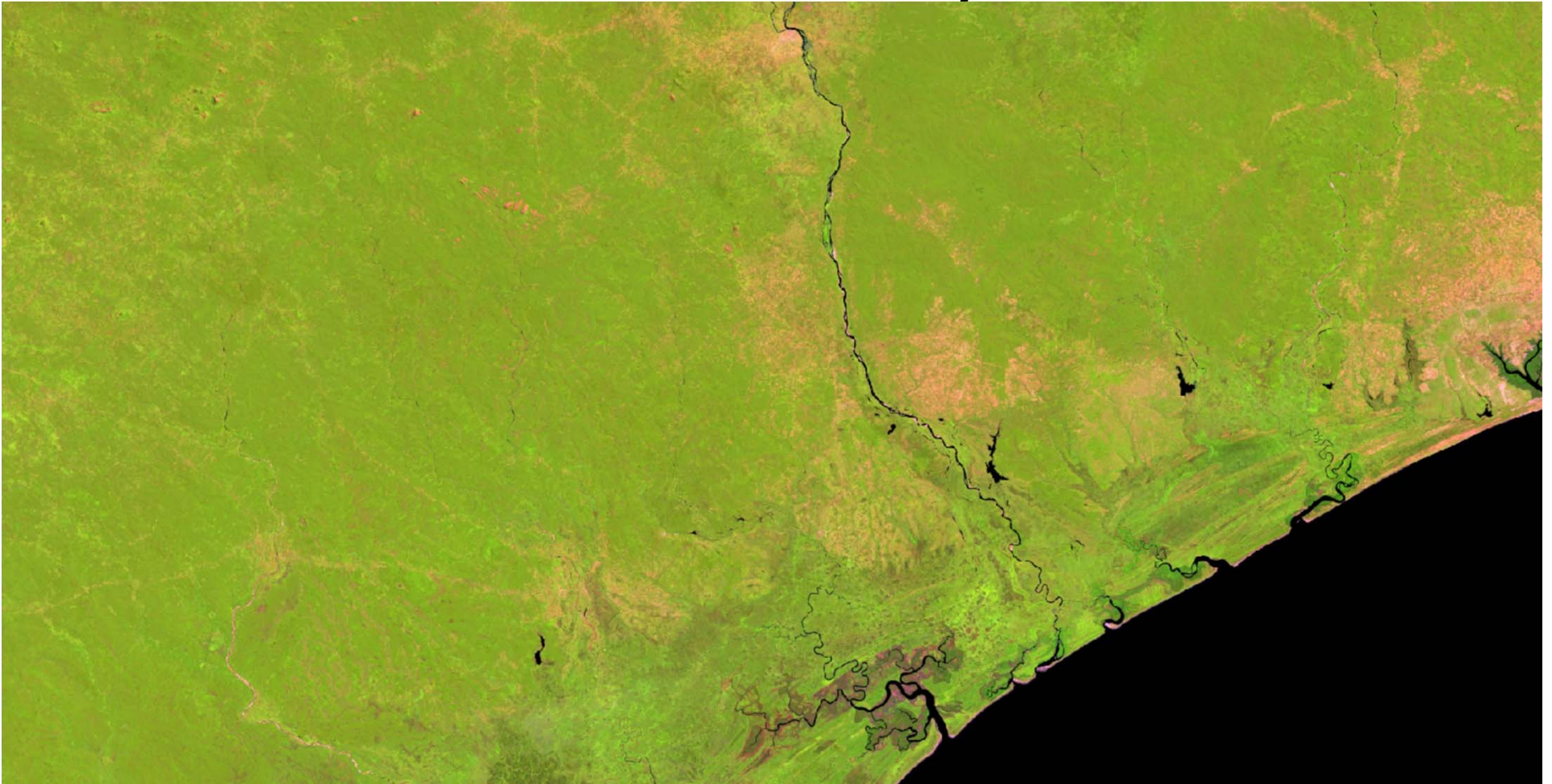
2012 5-4-3 composite



Red= loss, green = tree cover, blue = gain

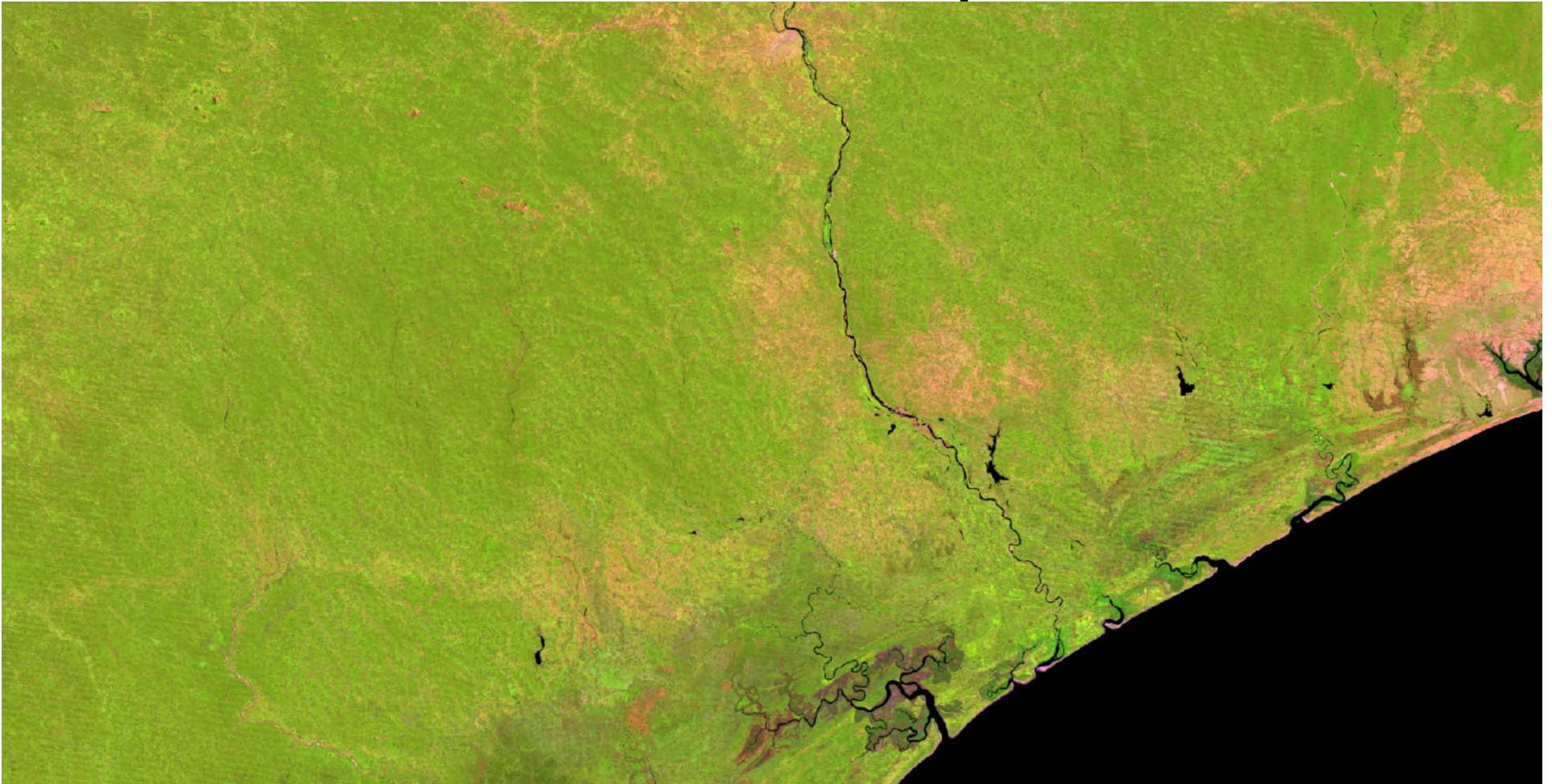


2000 5-4-3 composite



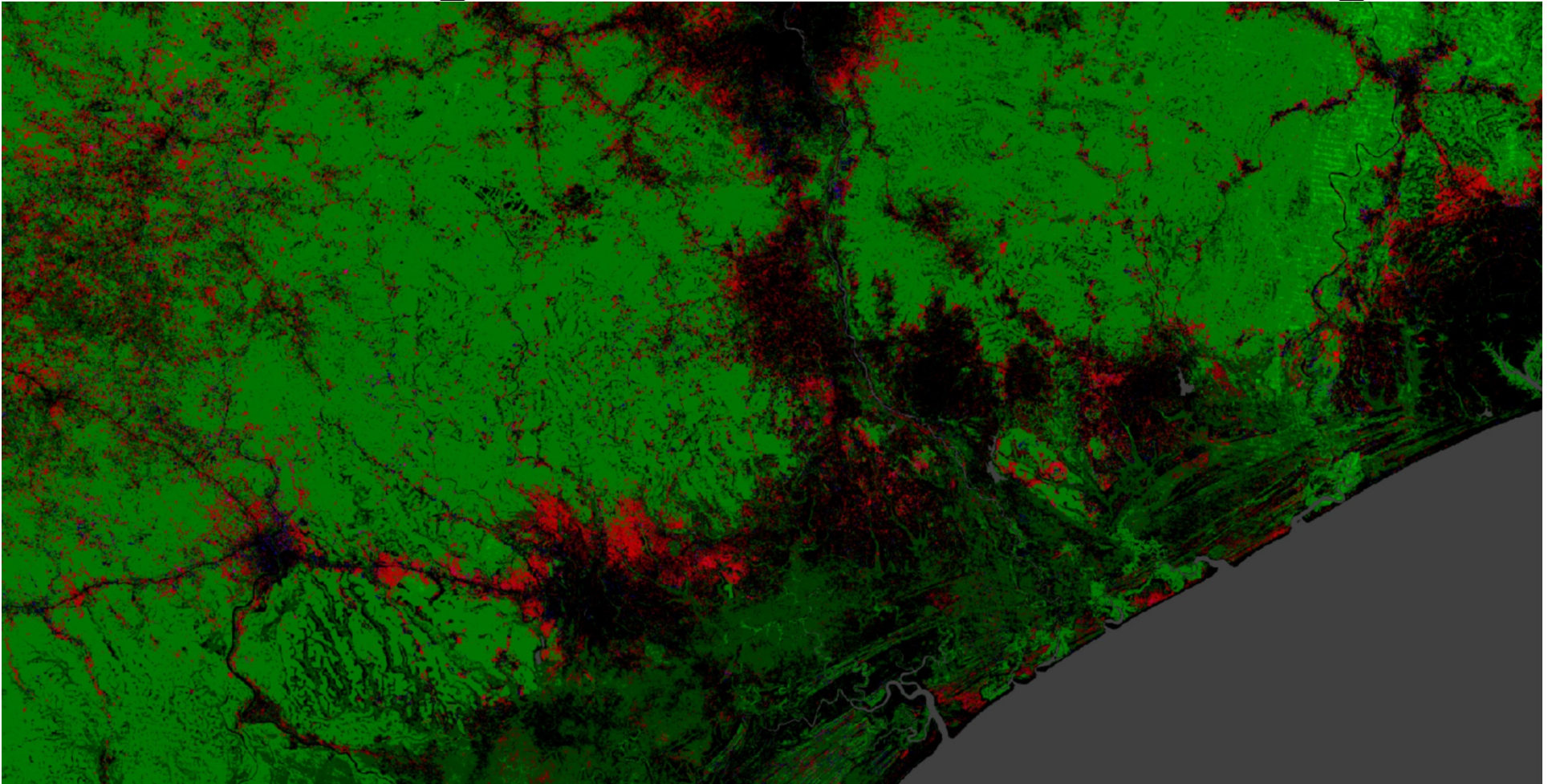
Southern Zambezia

2012 5-4-3 composite



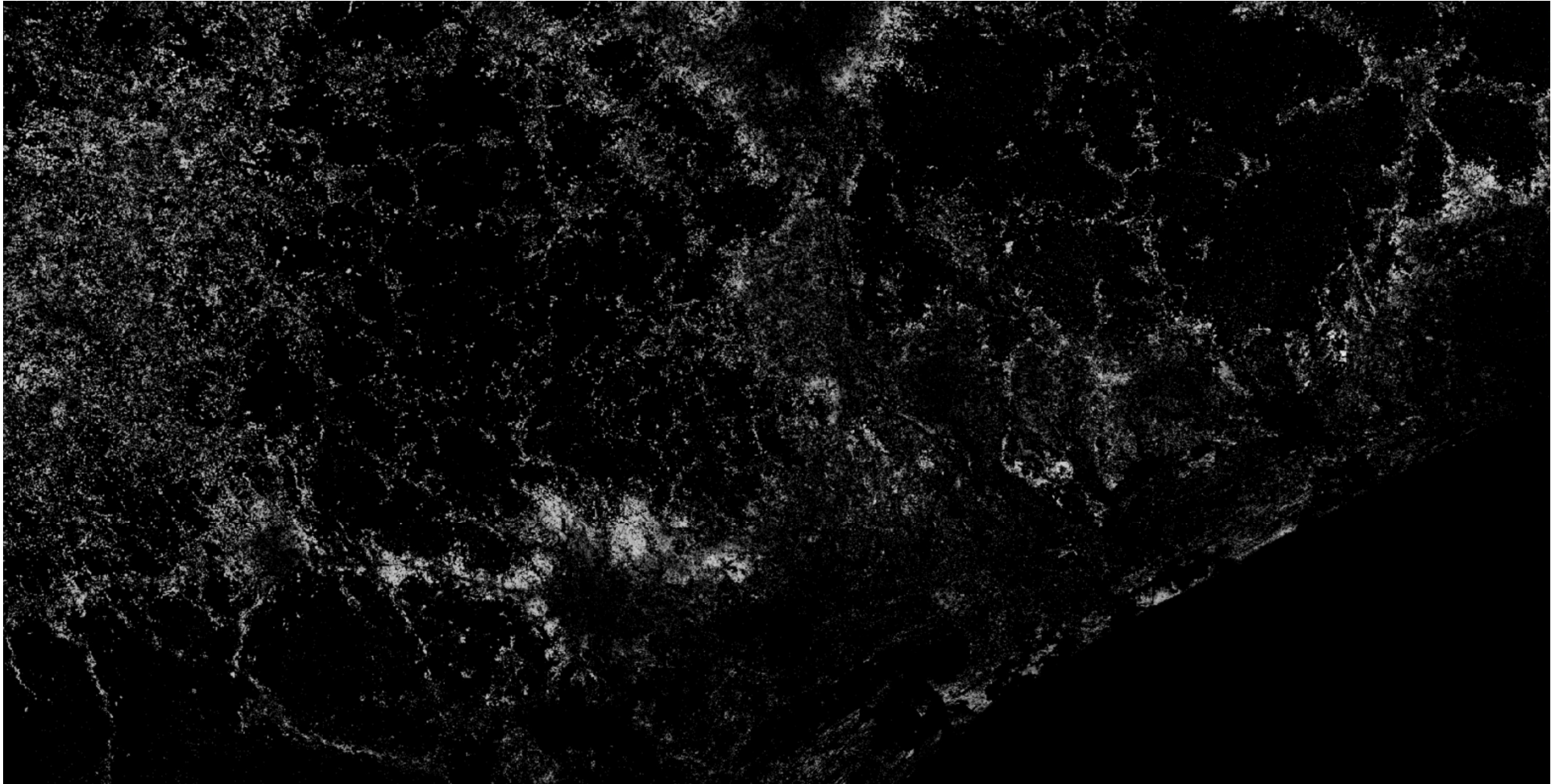
Mashonaland West

Red= loss, green = tree cover, blue = gain



Southern Zambezia

Forest loss

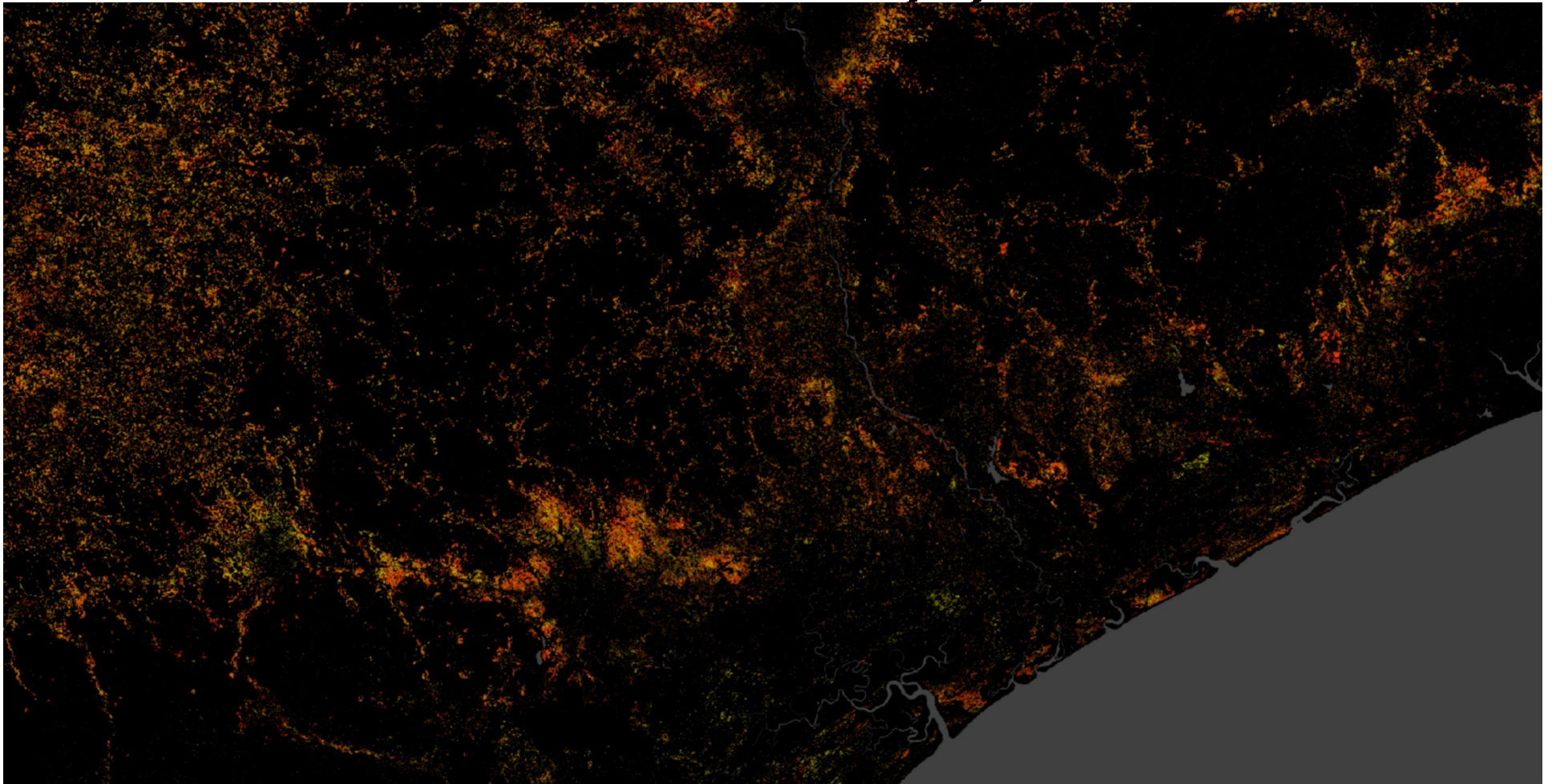


Loss

No loss

Southern Zambezia

Forest loss by year



2000 2005 2012

Southern Zambezia

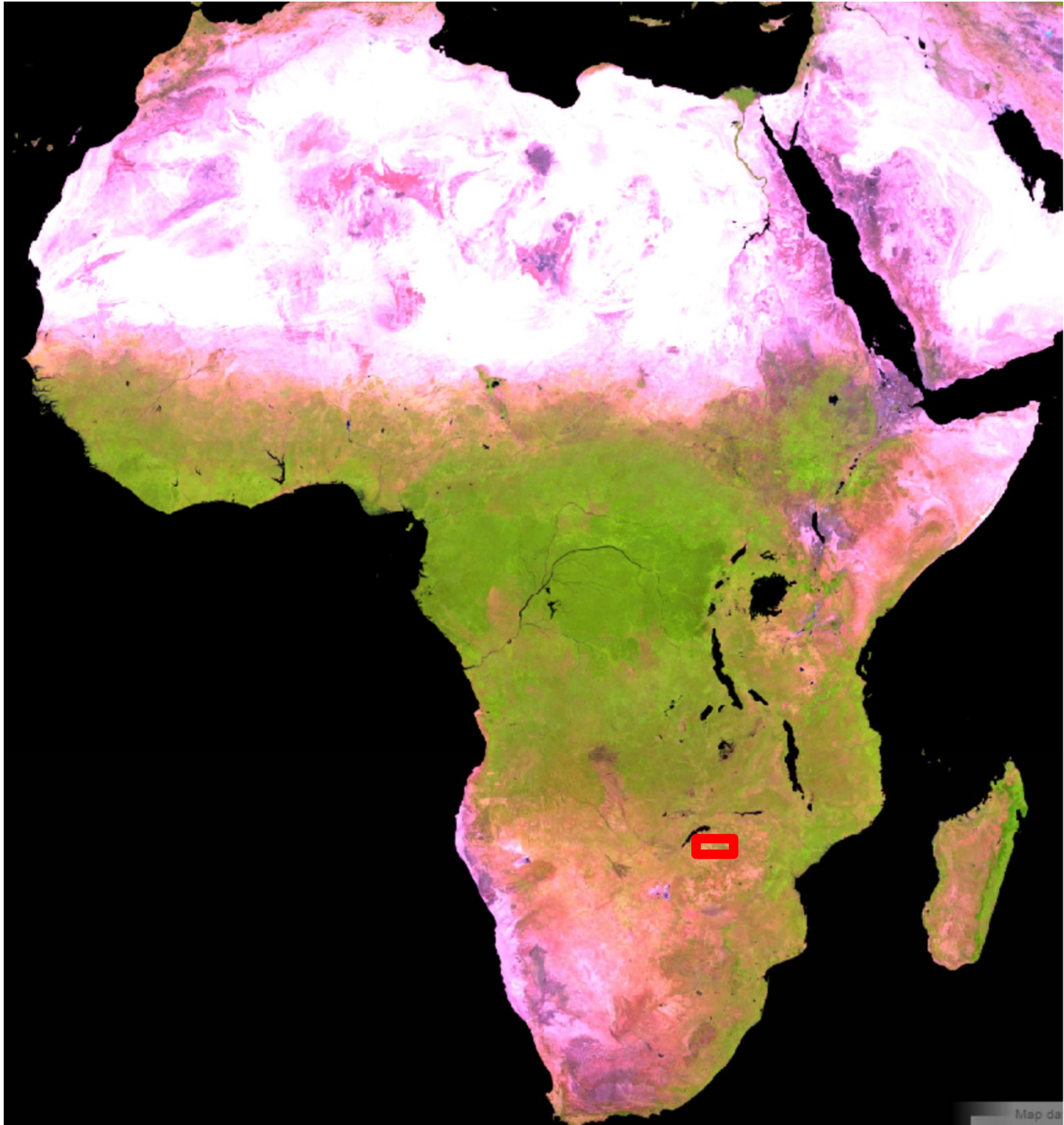
Forest gain



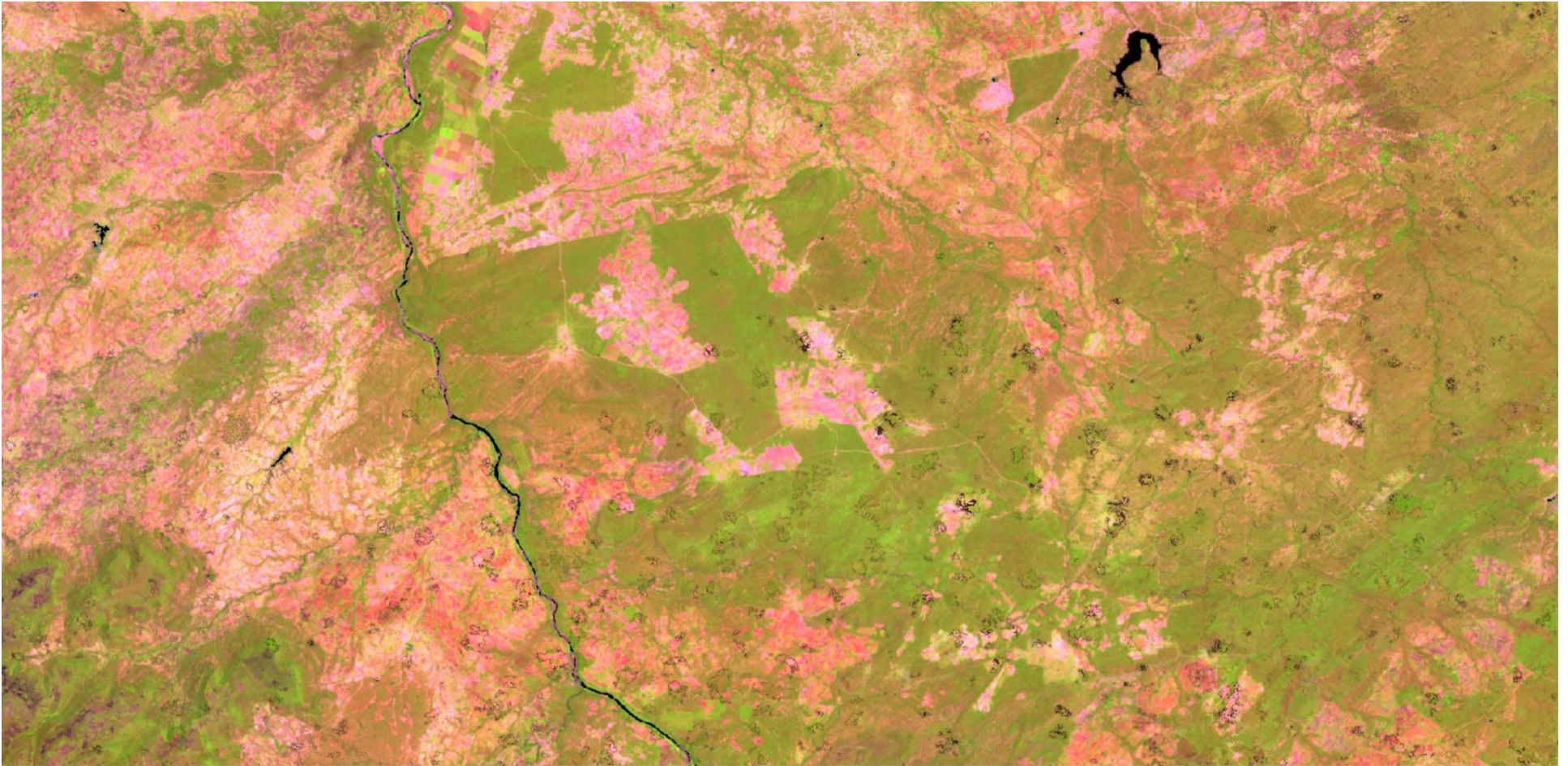
Gain

No gain

Southern Zambezia

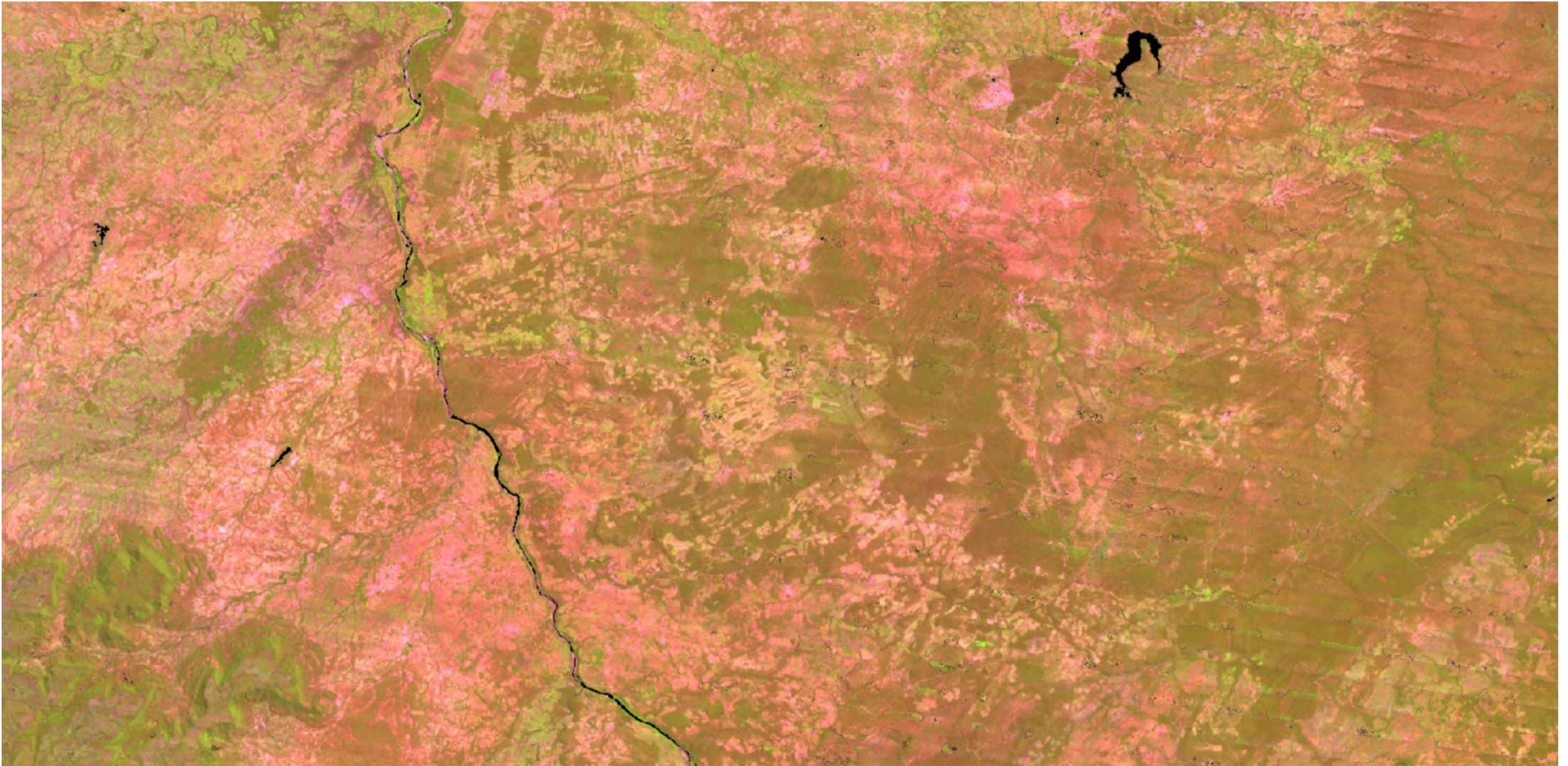


2000 5-4-3 composite



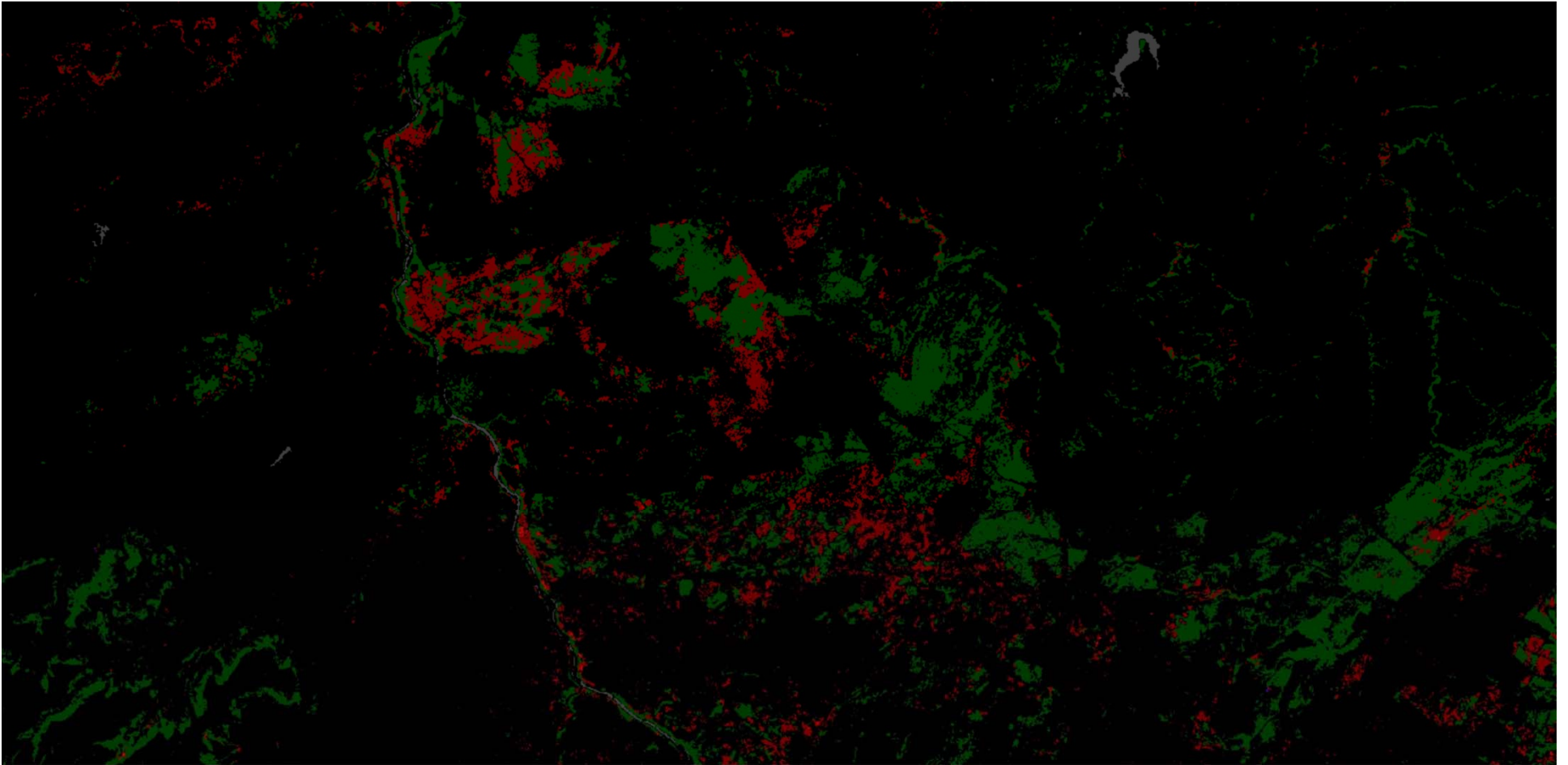
Mashonaland West

2012 5-4-3 composite



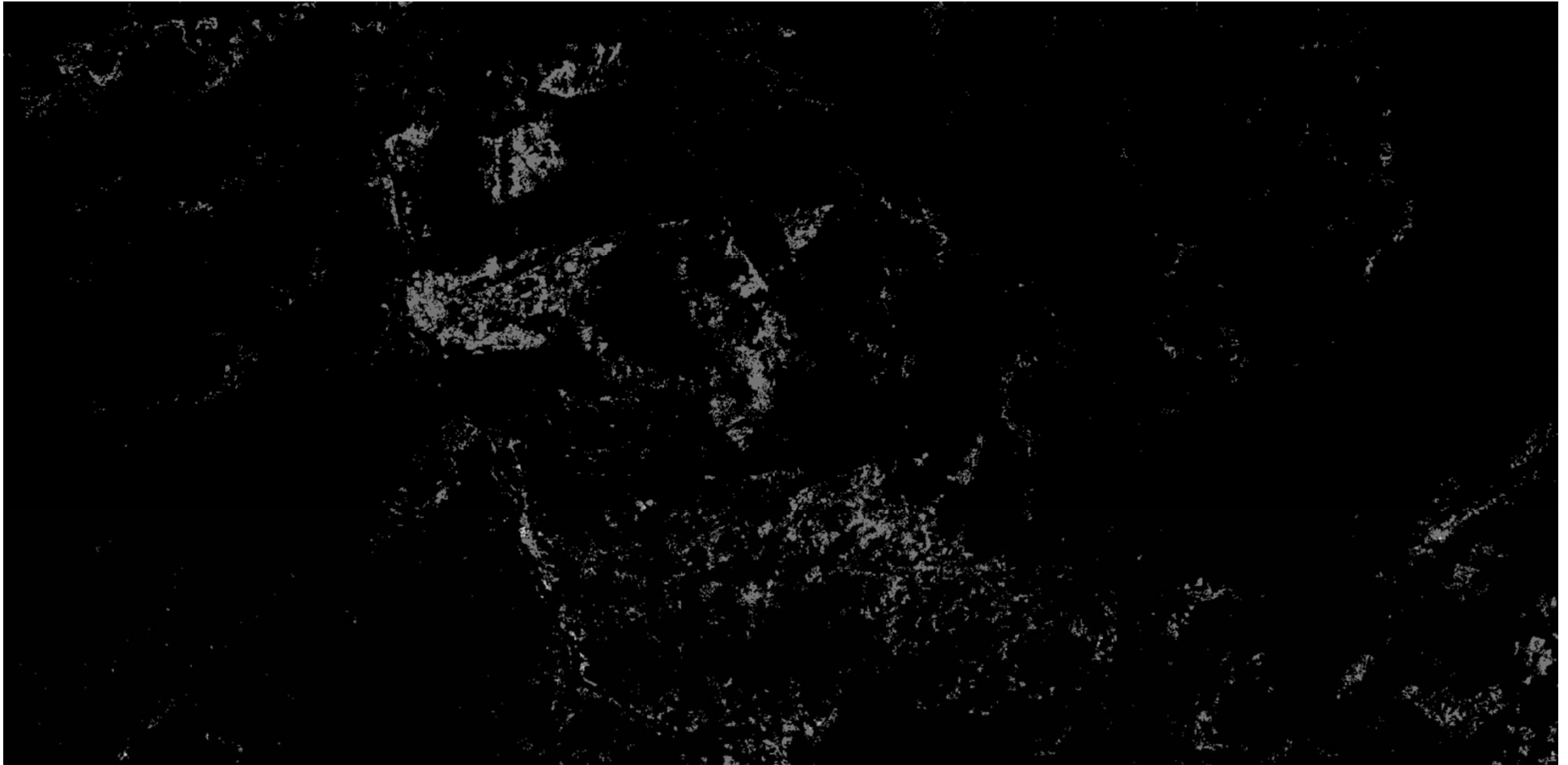
Mashonaland West

Red= loss, green = tree cover, blue = gain



Mashonaland West

Forest loss

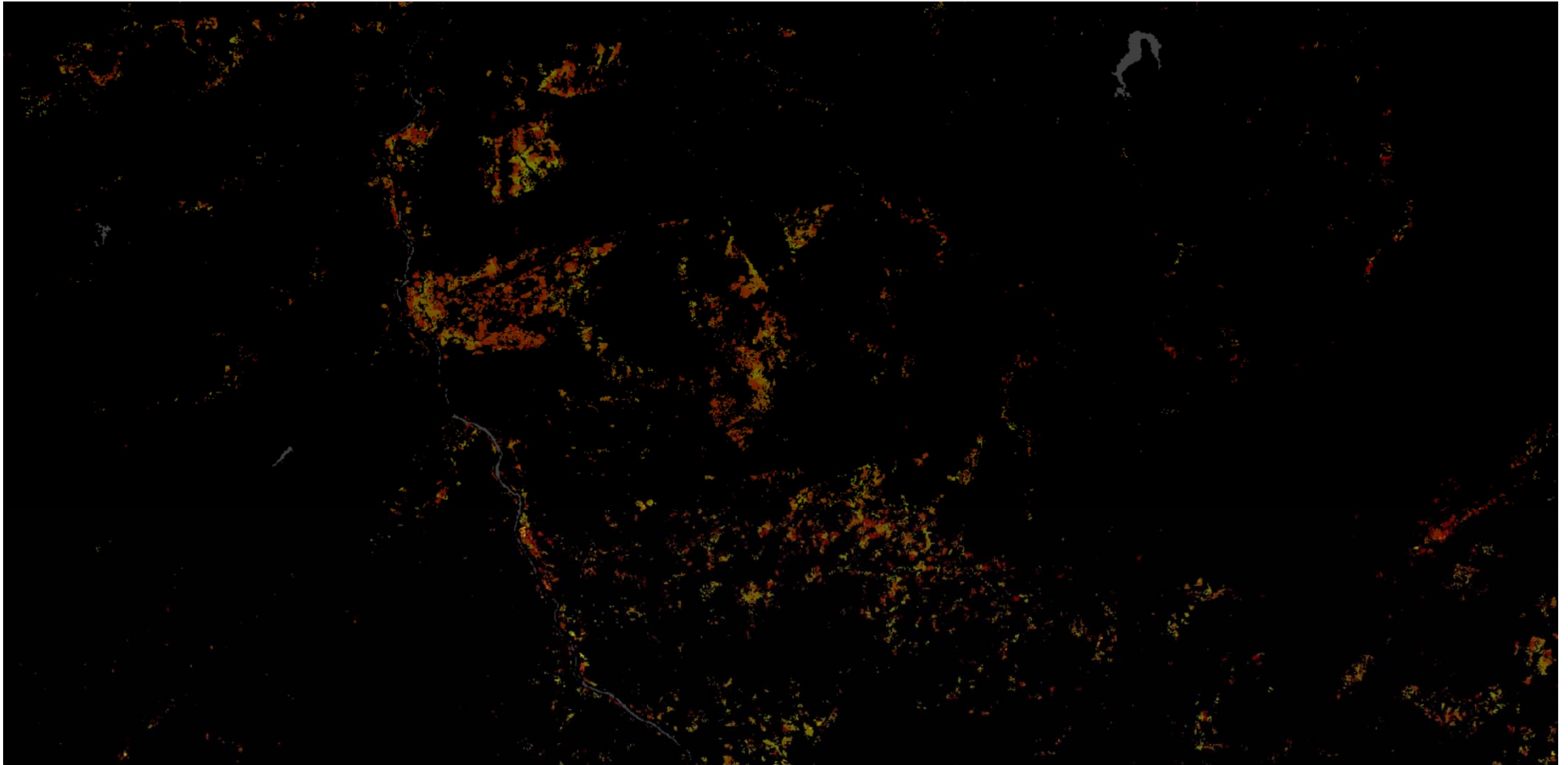


Loss

No loss

Mashonaland West

Forest loss by year



Mashonaland West

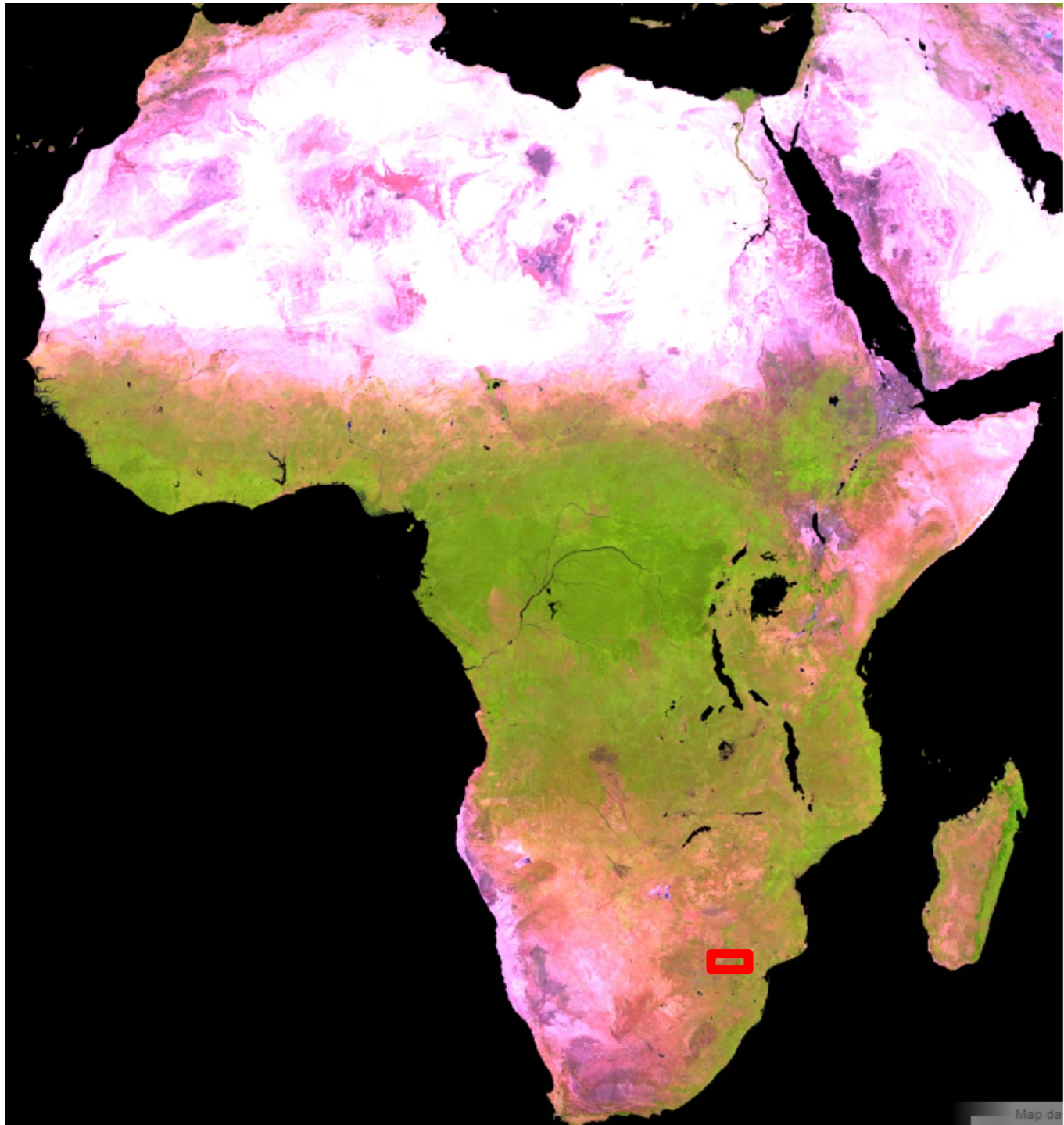
Forest gain



Gain

No gain

Mashonaland West

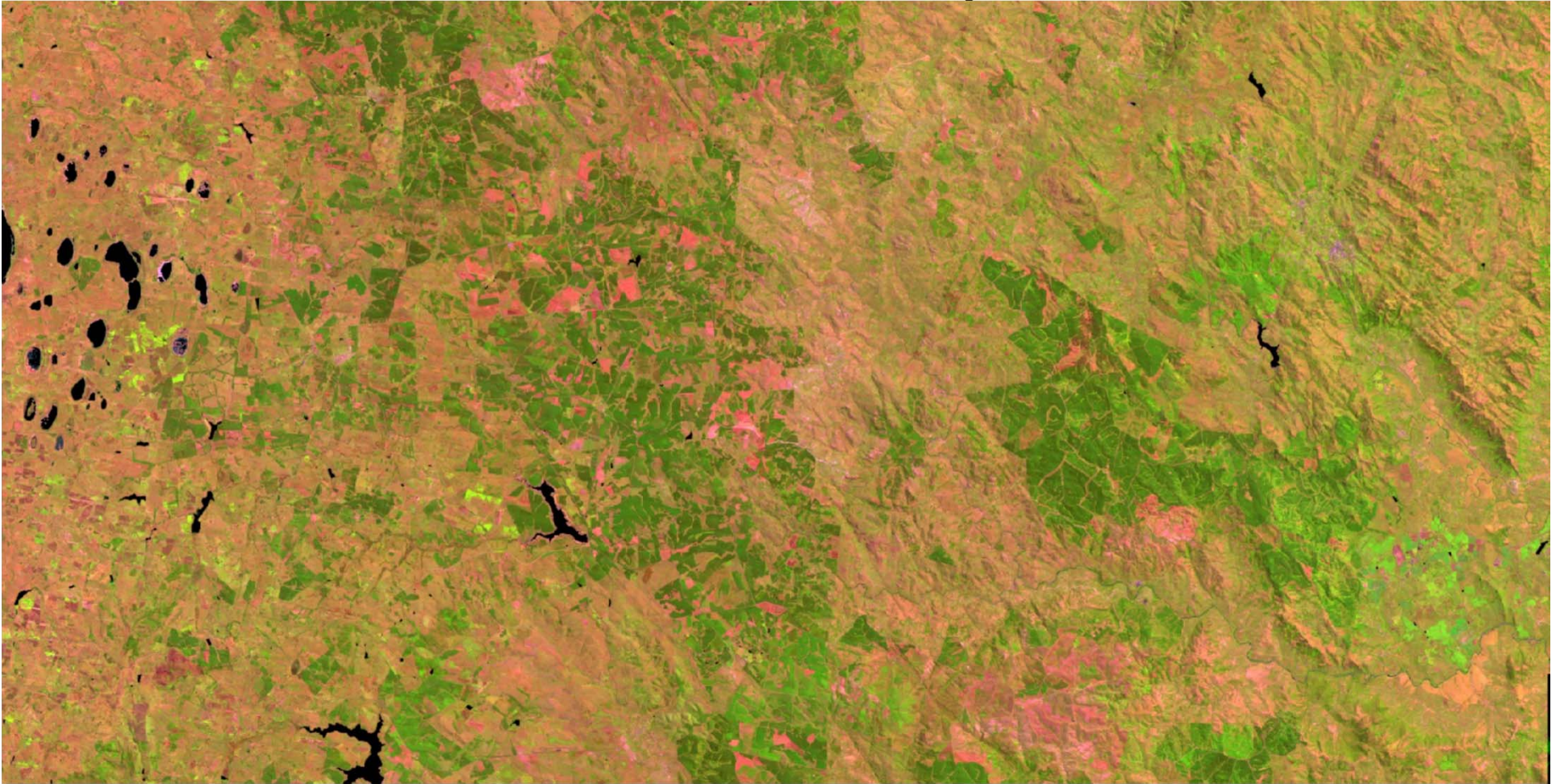


2000 5-4-3 composite



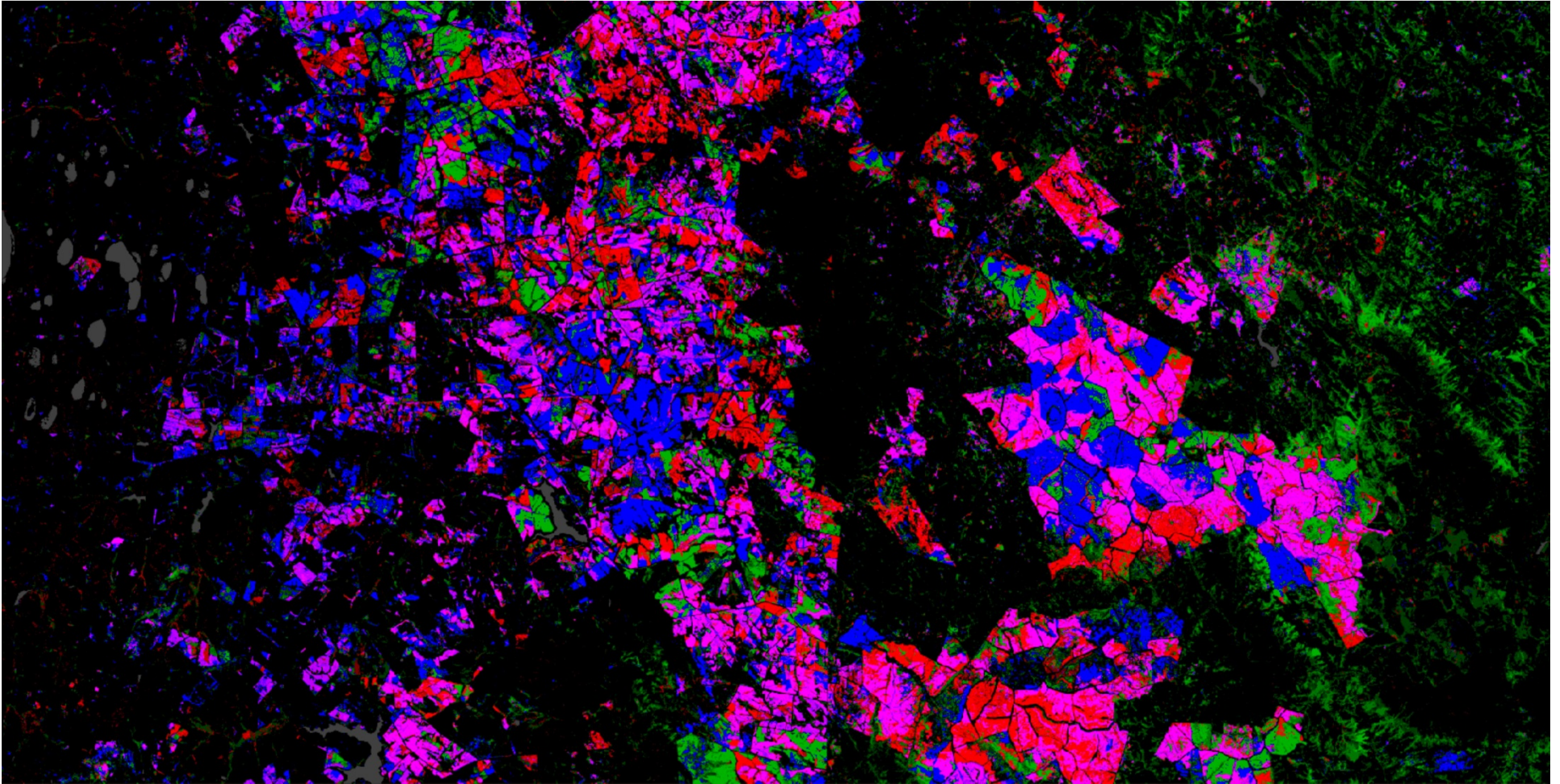
SA/Swaziland border

2012 5-4-3 composite



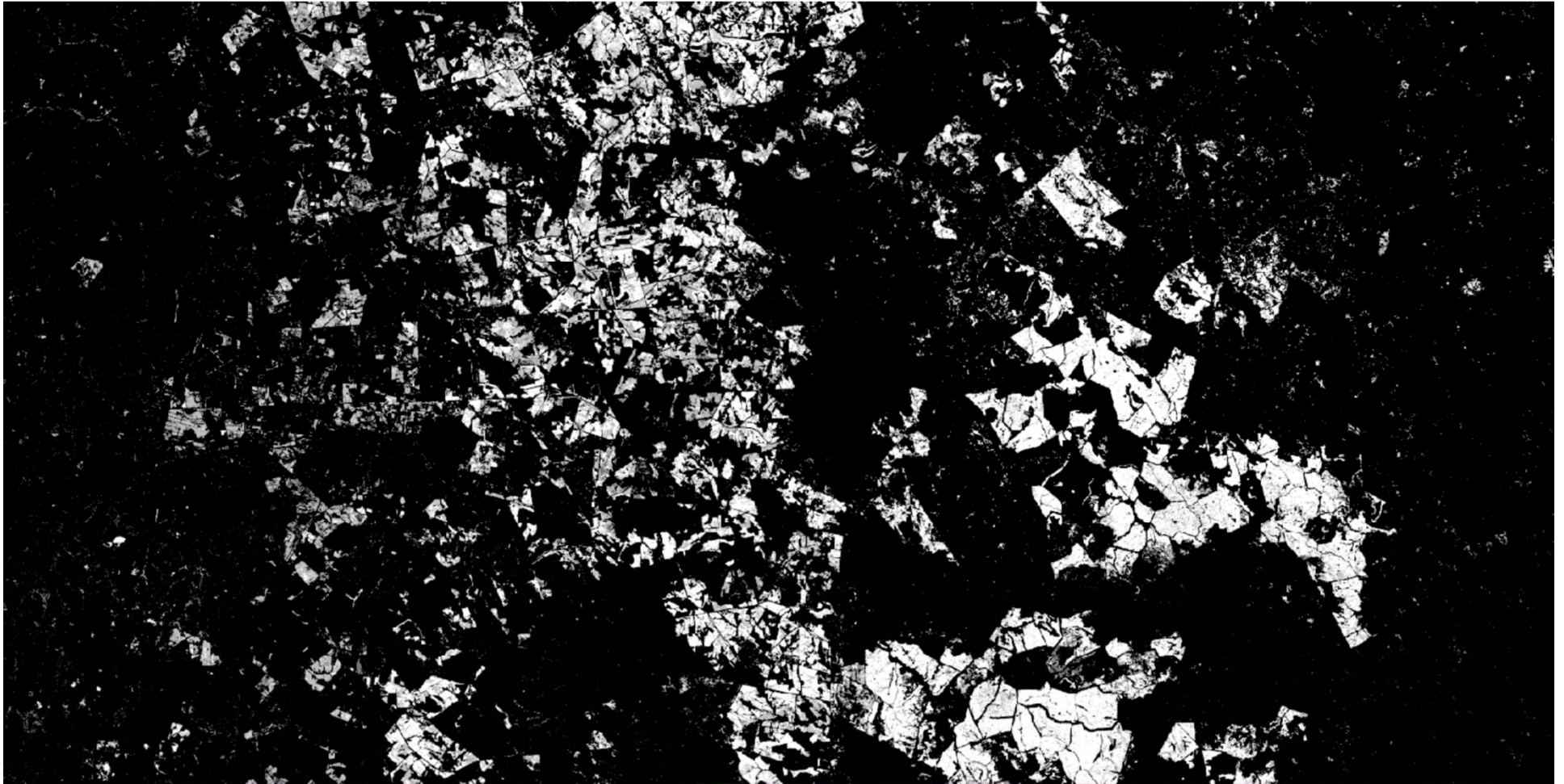
SA/Swaziland border

Red= loss, green = tree cover, blue = gain



SA/Swaziland border

Forest loss

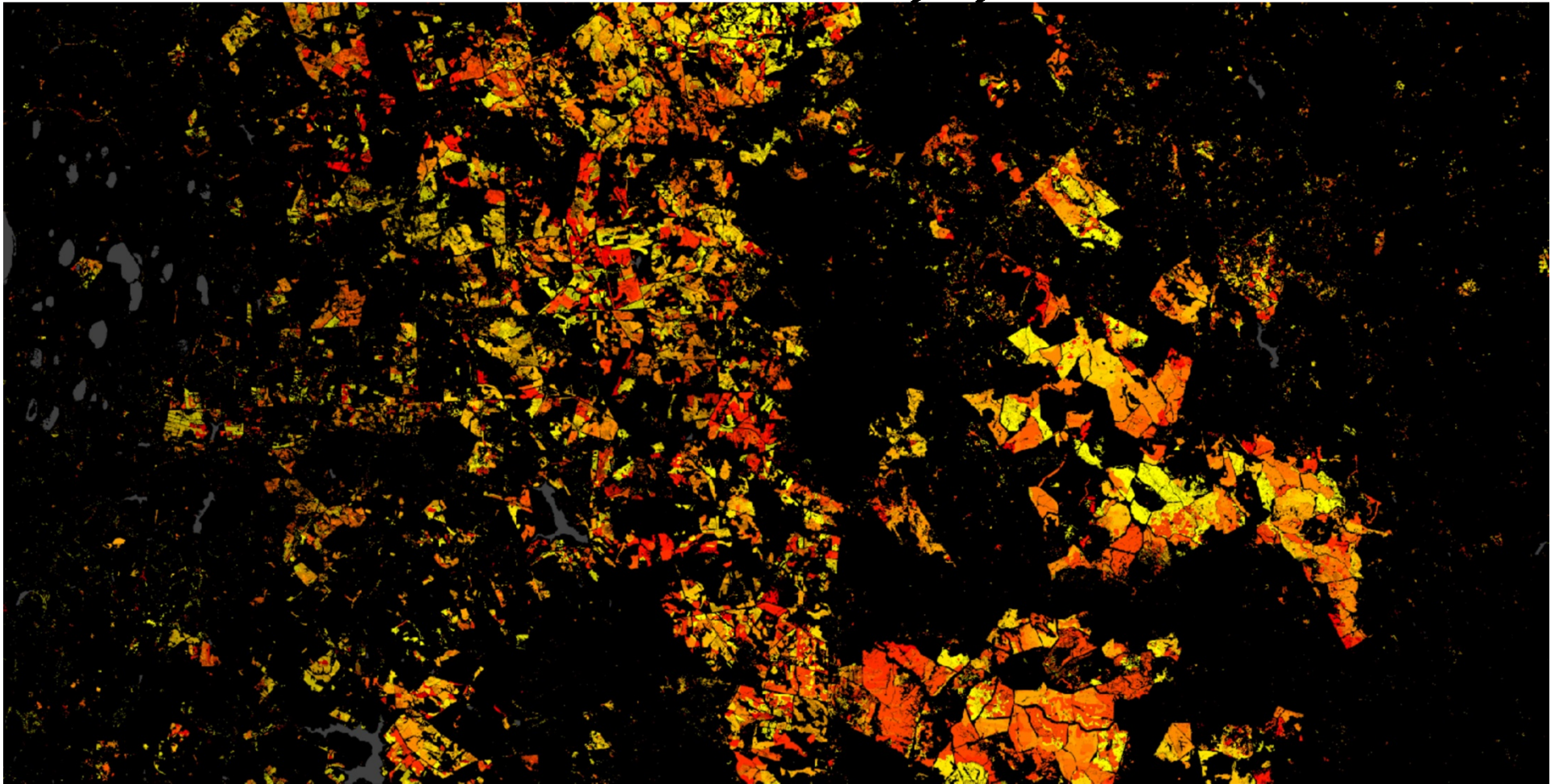


Loss

No loss

SA/Swaziland border

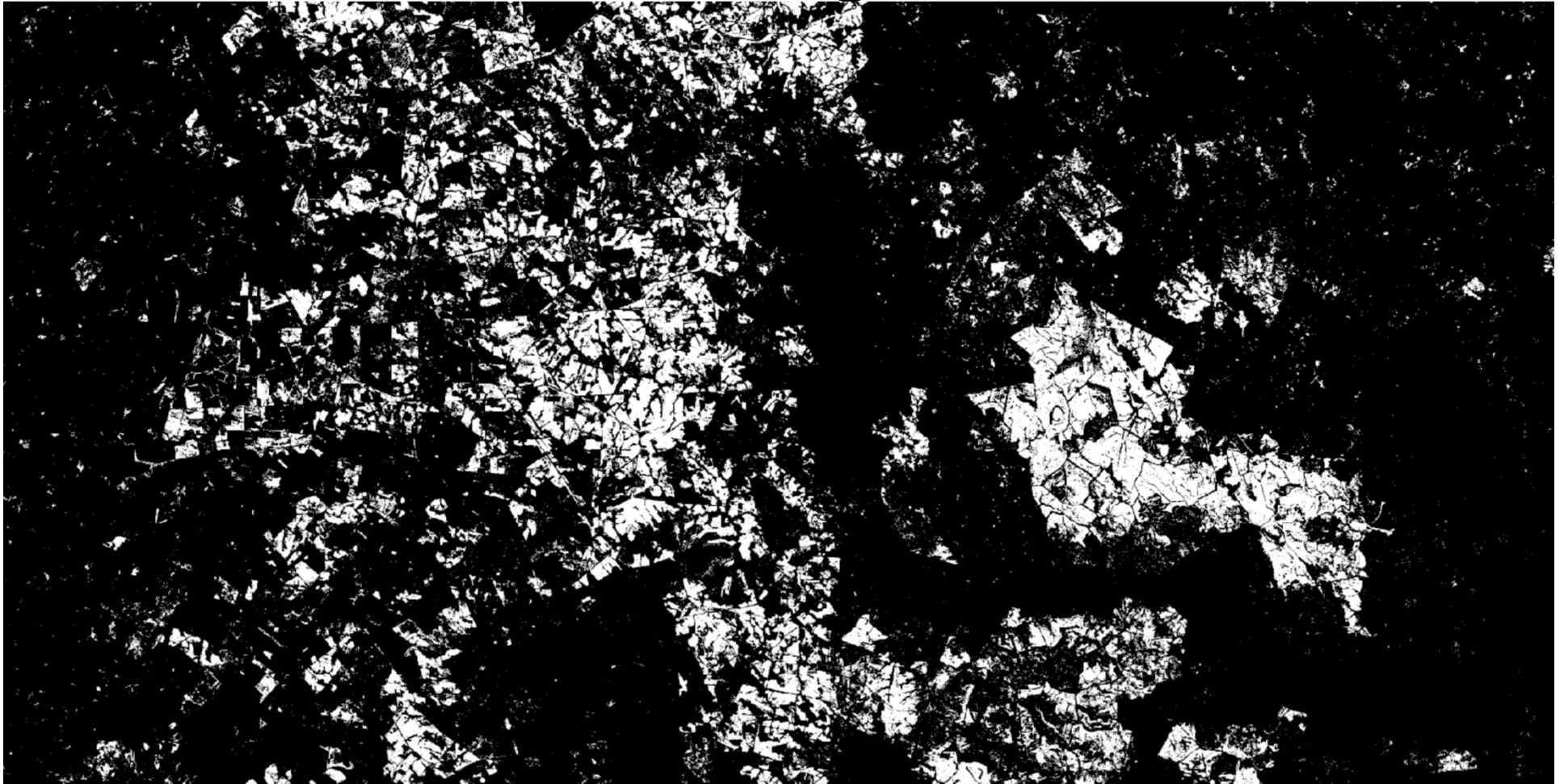
Forest loss by year



2000 2005 2012

SA/Swaziland border

Forest gain

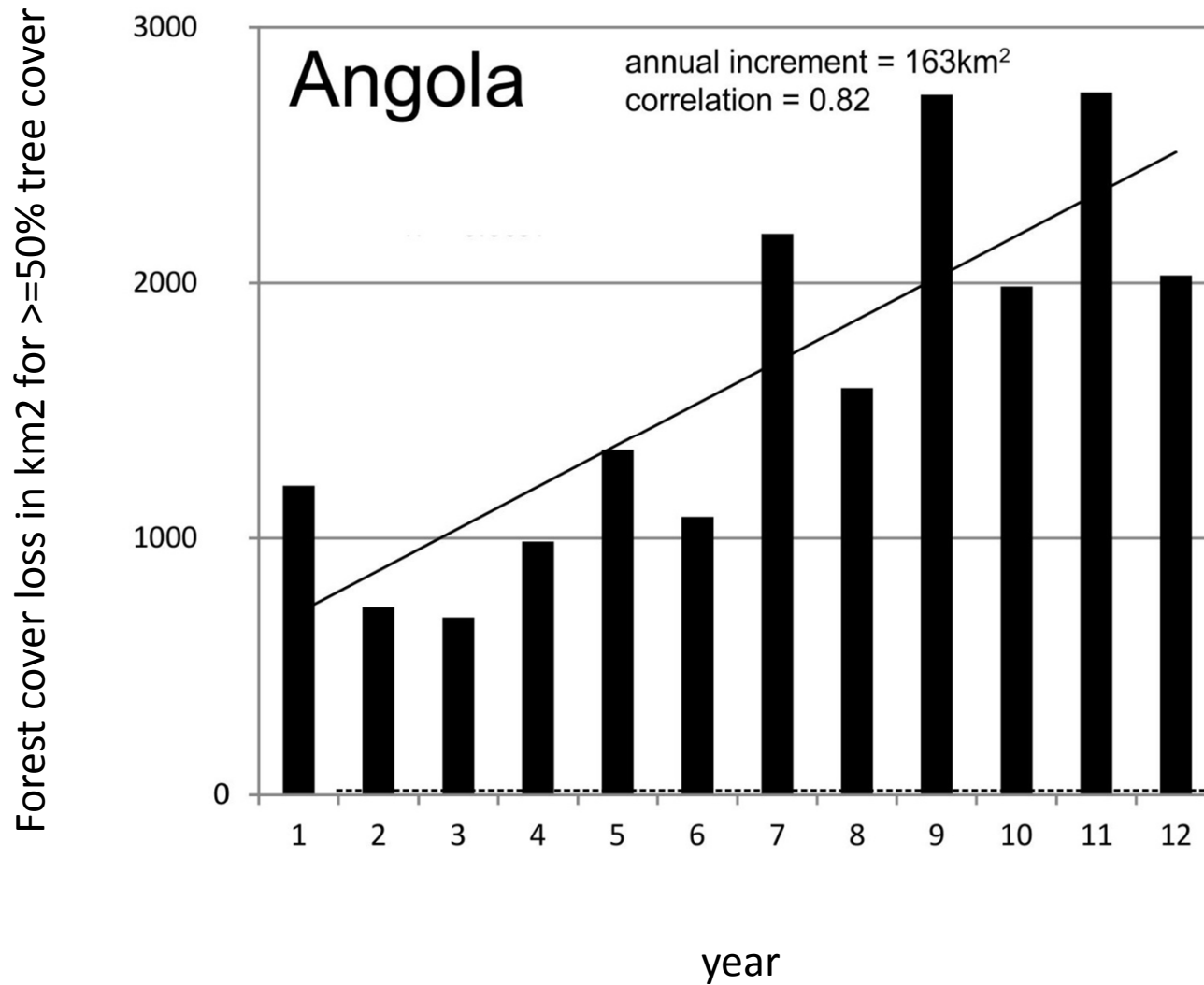


Gain

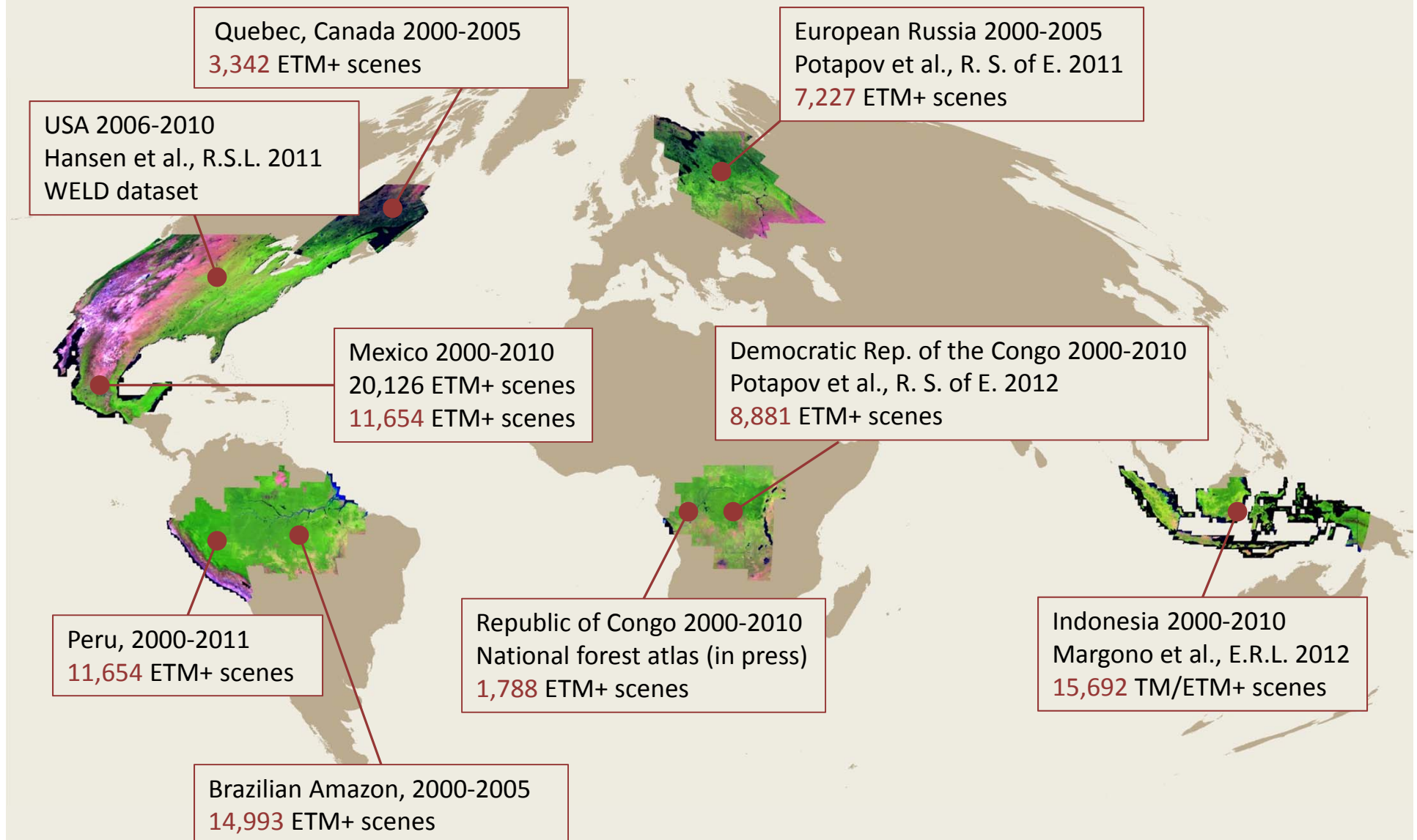
No gain

SA/Swaziland border

Trends in loss



National and regional forest cover change mapping projects



UNIVERSITY OF
MARYLAND

DRC and RoC training led by Patrick Lola Amani of OSFAC and UMd



Summary

- Pre-processing of data sets for user-friendliness is critical
 - With national-scale normalized cloud-free inputs, almost any method of characterization can work
 - Automation of pre-processing enables fast *iteration* of historical record as new understanding and/or methods are realized
- Key to activity data in addition to quality is latency
 - How to produce timely information on national forest dynamics?
 - Methods should be more formally evaluated in this regard – days/weeks for production of national-scale products
- Analyst-driven characterization is key to providing ownership of the mapping process and products
- Validation is critical
 - Not ground lies, not model sensitivity, not using opportunistic sites
 - A probability-based sample of independently-derived estimates of the variable of interest is required
- Landsat acquisition strategy, cost and access model and pre-processing should be emulated by other systems
 - Sharing of methods within this context is very straightforward
- Portability
 - Our method has been implemented globally and at national scales for Indonesia, the USA, European Russia, the DR Congo, the Republic of Congo, Peru and Colombia
- Very high spatial resolution capabilities should be initially used in sampling mode for validation and/or estimation (not for mapping)

