Forest cover monitoring in Africa using Landsat data

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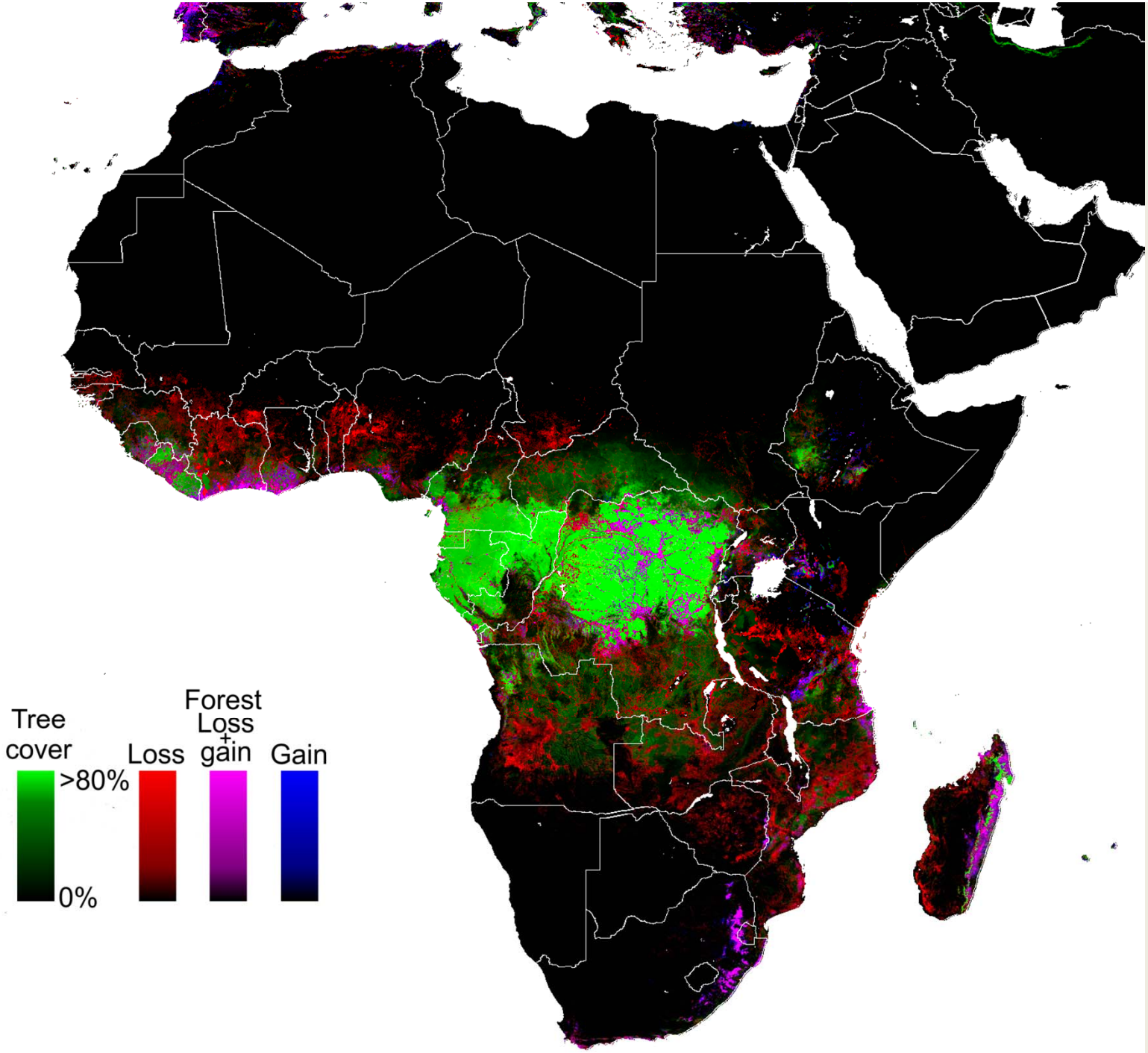
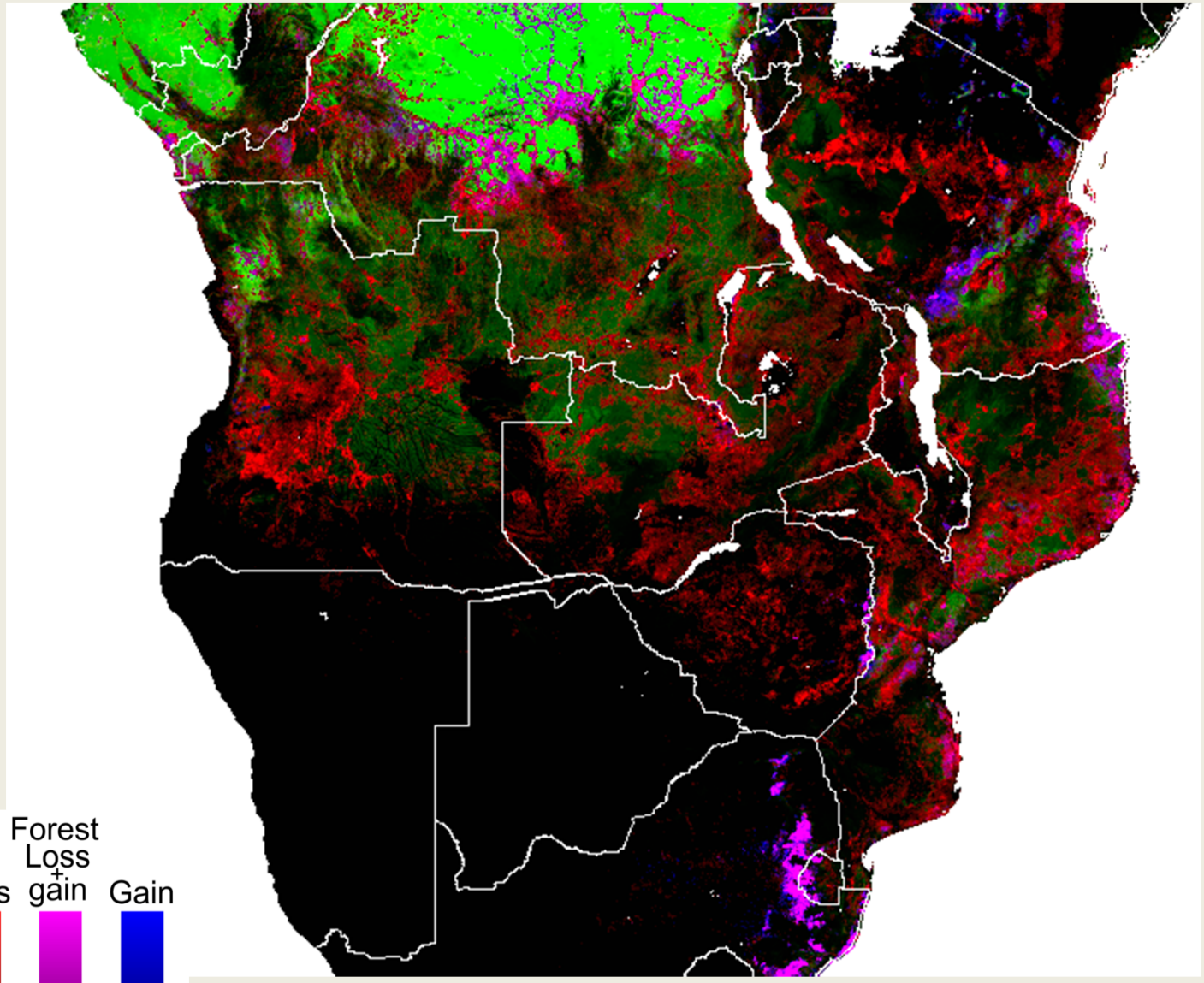
University of Maryland

R. Moore, M. Hancher
Google, Inc.

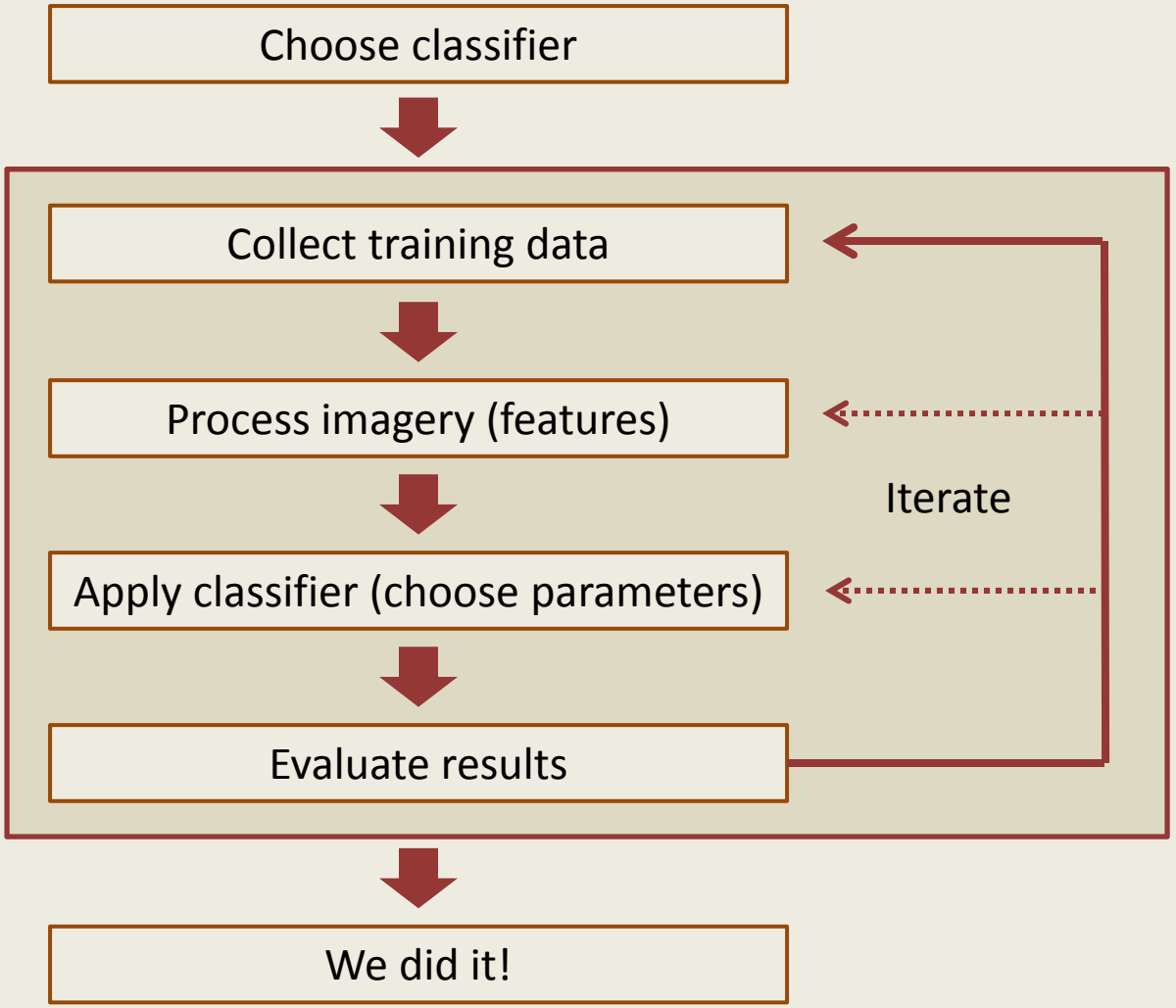

Tree cover
>80%
0%
Loss
Forest Loss + gain
Gain


Tree cover
>80%
0%
Loss
Forest Loss + gain
Gain

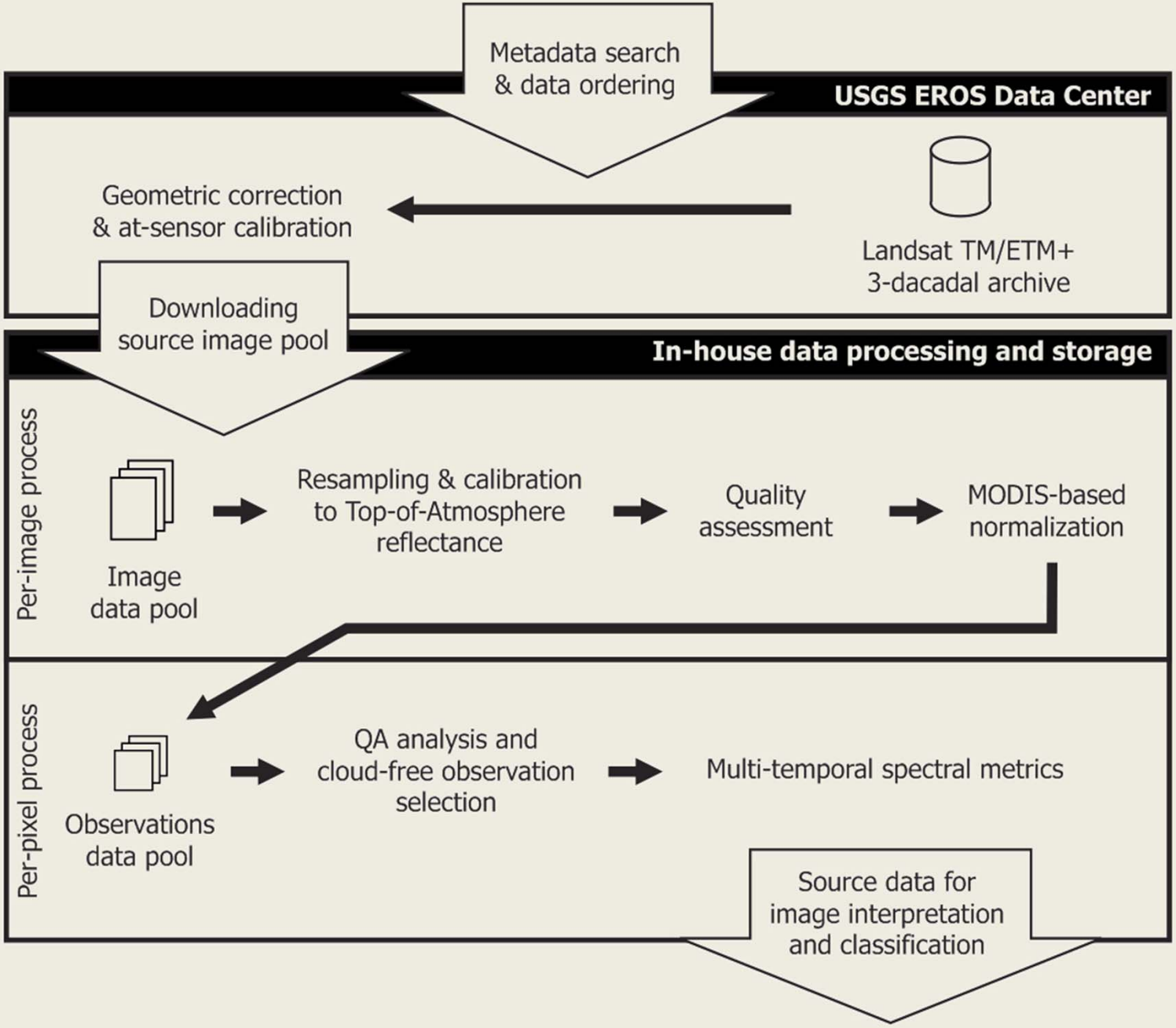
Data requirements for large area land monitoring

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

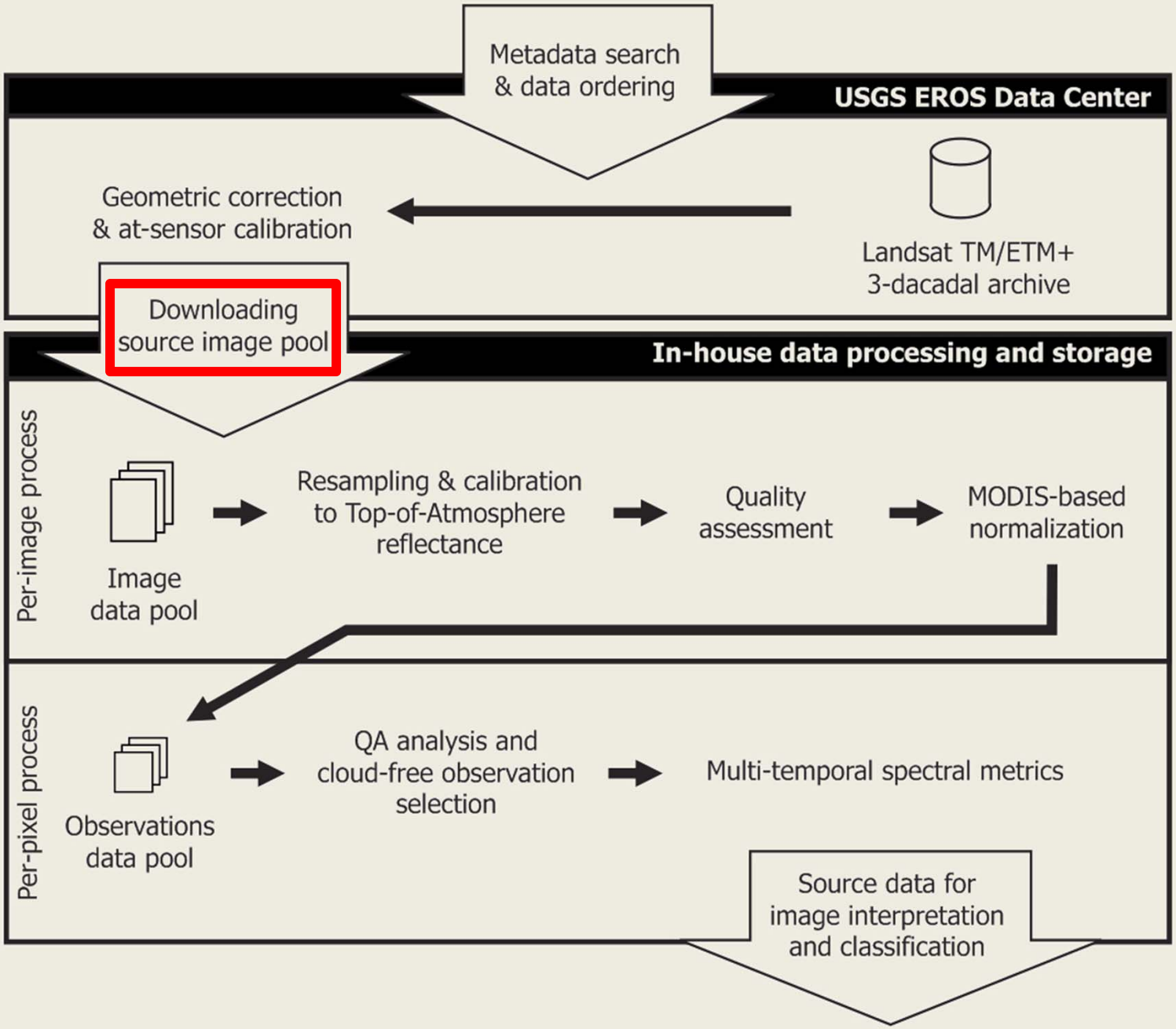
Supervise classification workflow



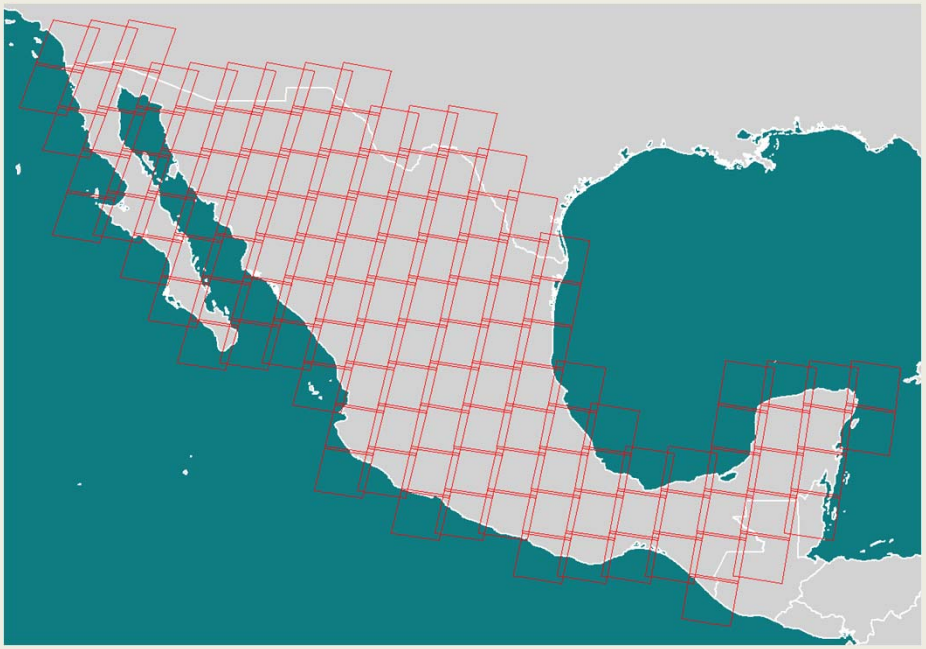
Landsat data processing workflow



Landsat data processing workflow



Landsat data ordering and processing at the USGS EROS

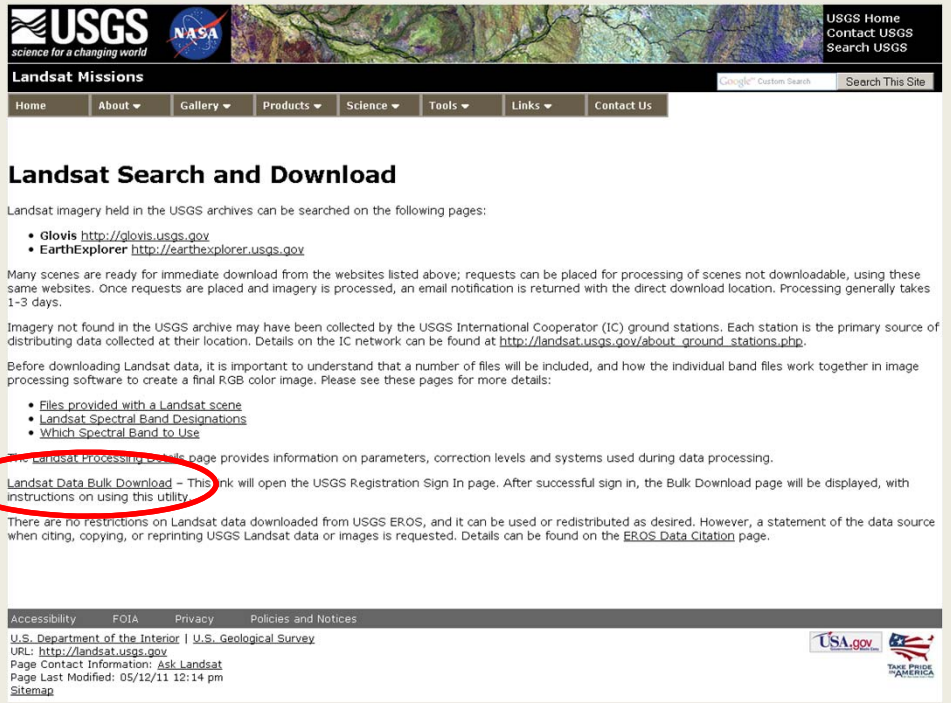


1. Create WRS2 Path/Row catalog for the AOI

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

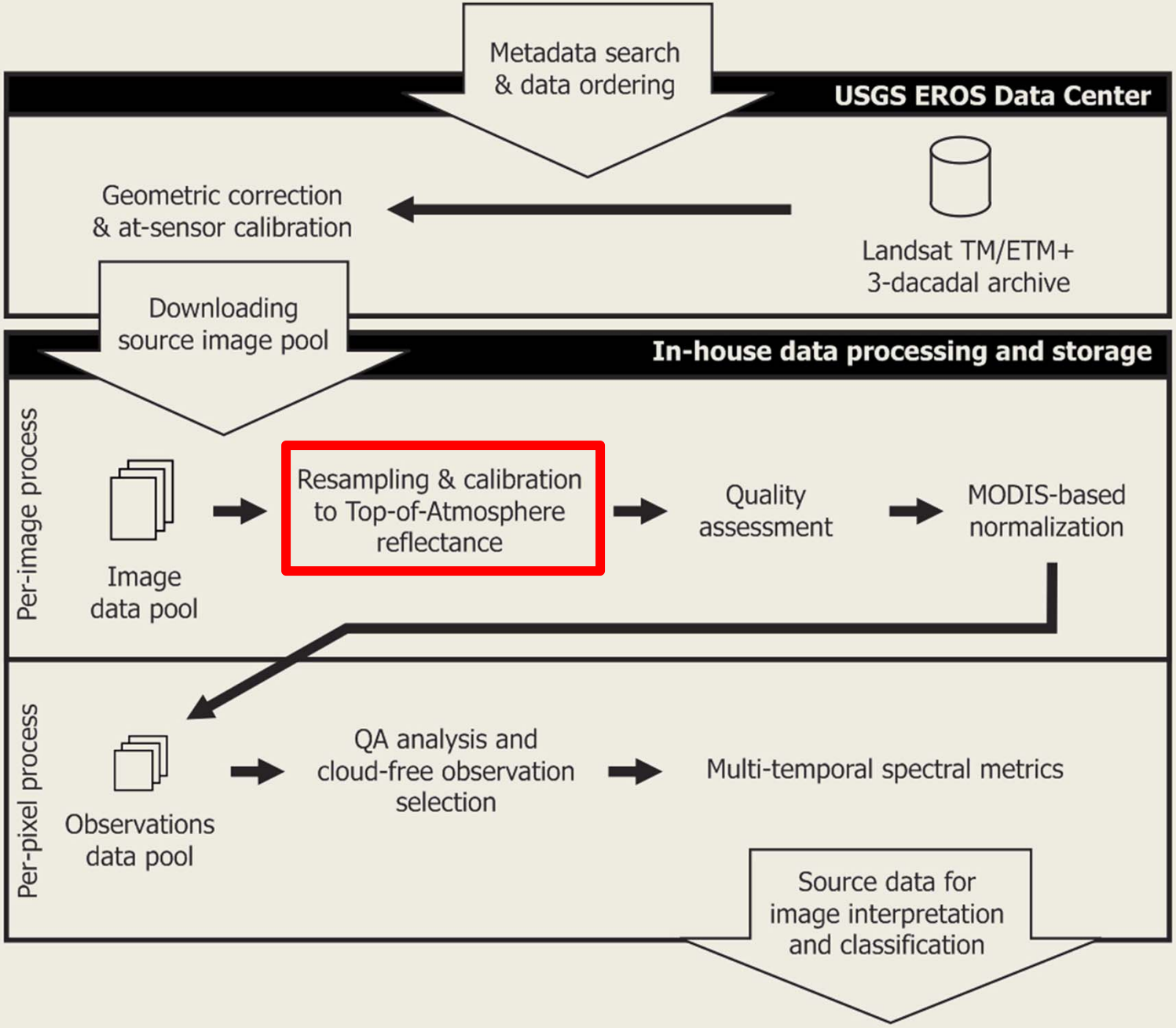
3. Order and Download data using Landsat bulk order interface

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



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

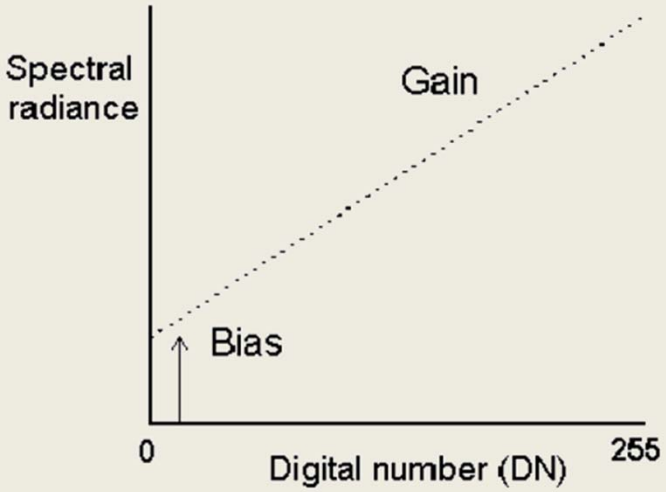
Landsat data processing workflow



Landsat data calibration

Conversion to TOA reflectance

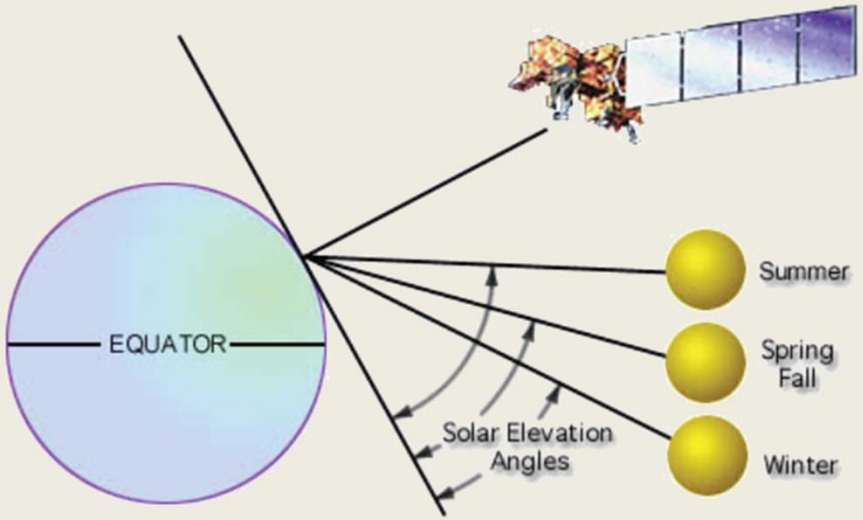
1. DN -> Radiance



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

Chander et al., 2009

2. Radiance -> TOA Reflectance

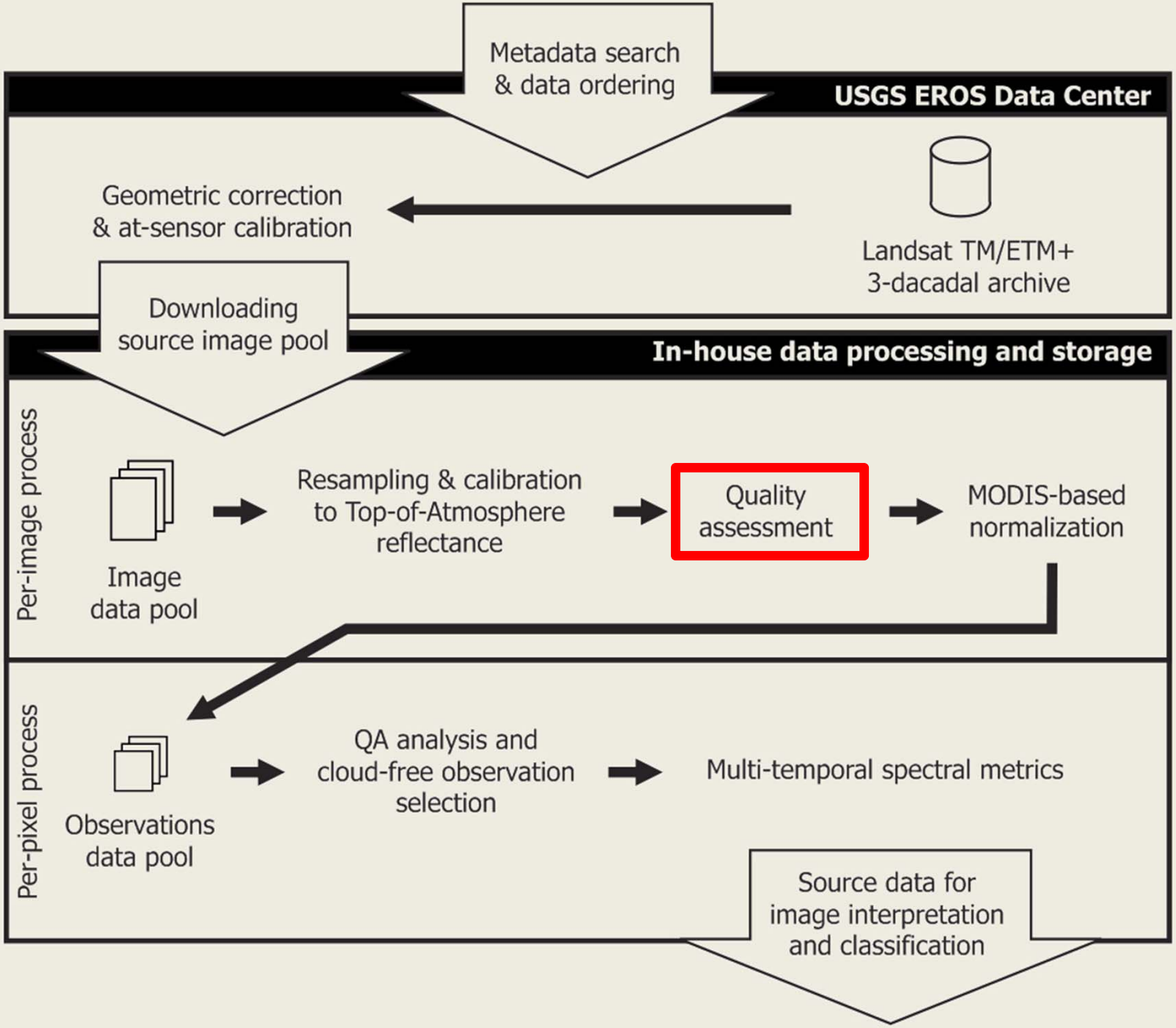


$$\rho_\lambda = \pi * L_\lambda * d^2 / ESUN_\lambda * \cos\theta_s$$

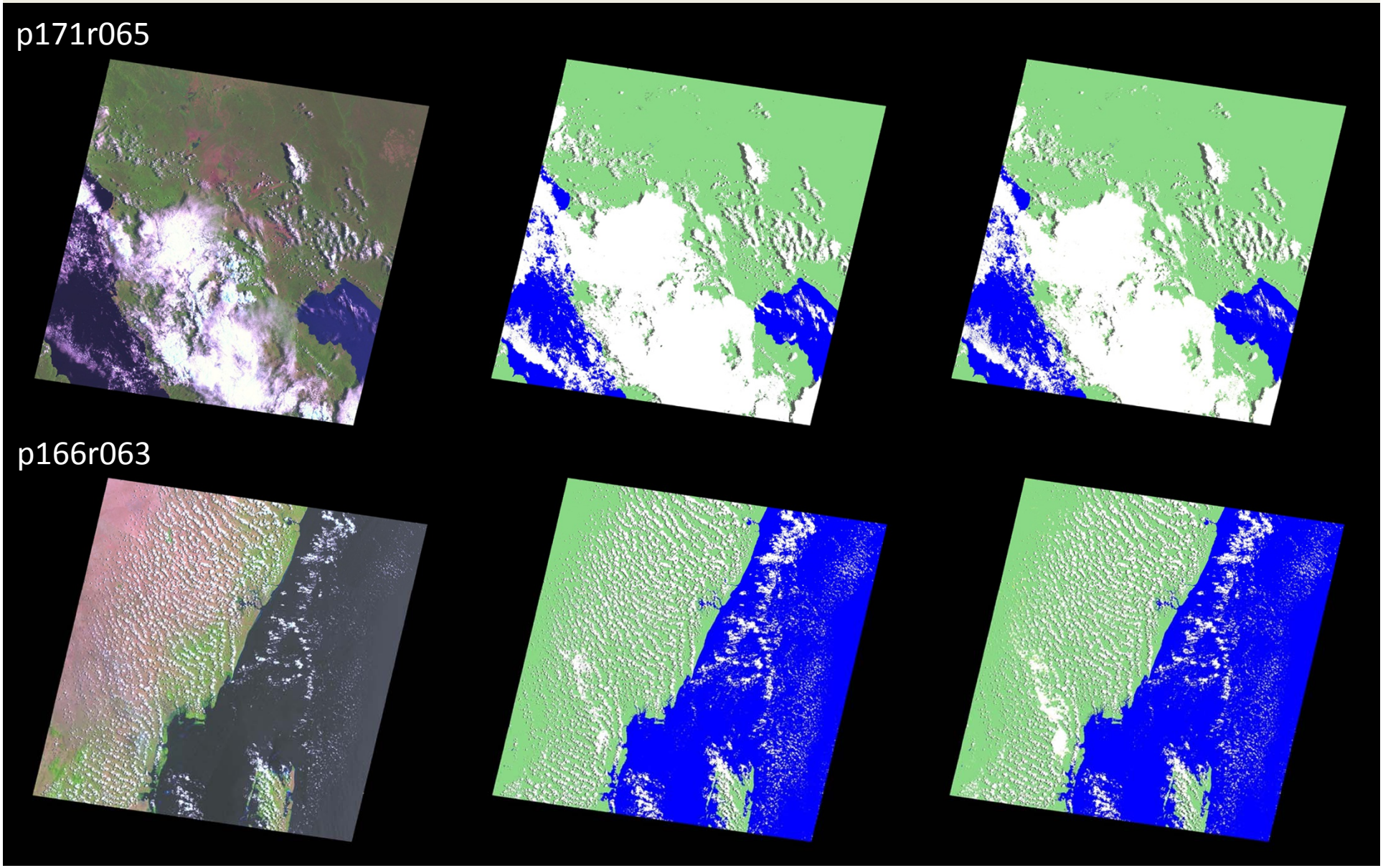
Where:

- ρ_λ = Unitless plantary reflectance
- L_λ= spectral radiance (from earlier step)
- d = Earth-Sun distance in astronmoical units
- $ESUN_\lambda$ = mean solar exoatmospheric irradiances
- θ_s = solar zenith angle

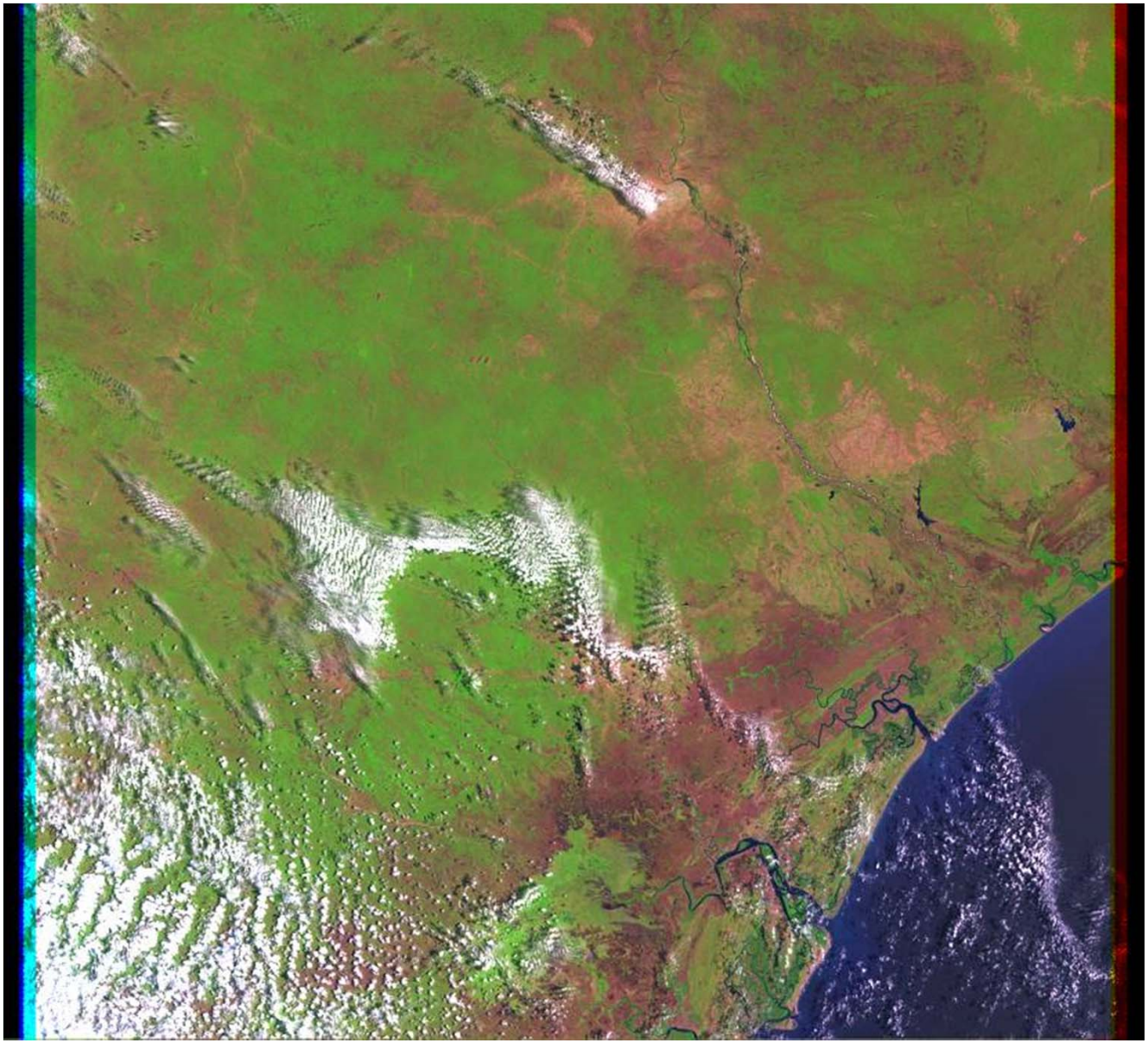
Landsat data processing workflow



Per-pixel quality assessment

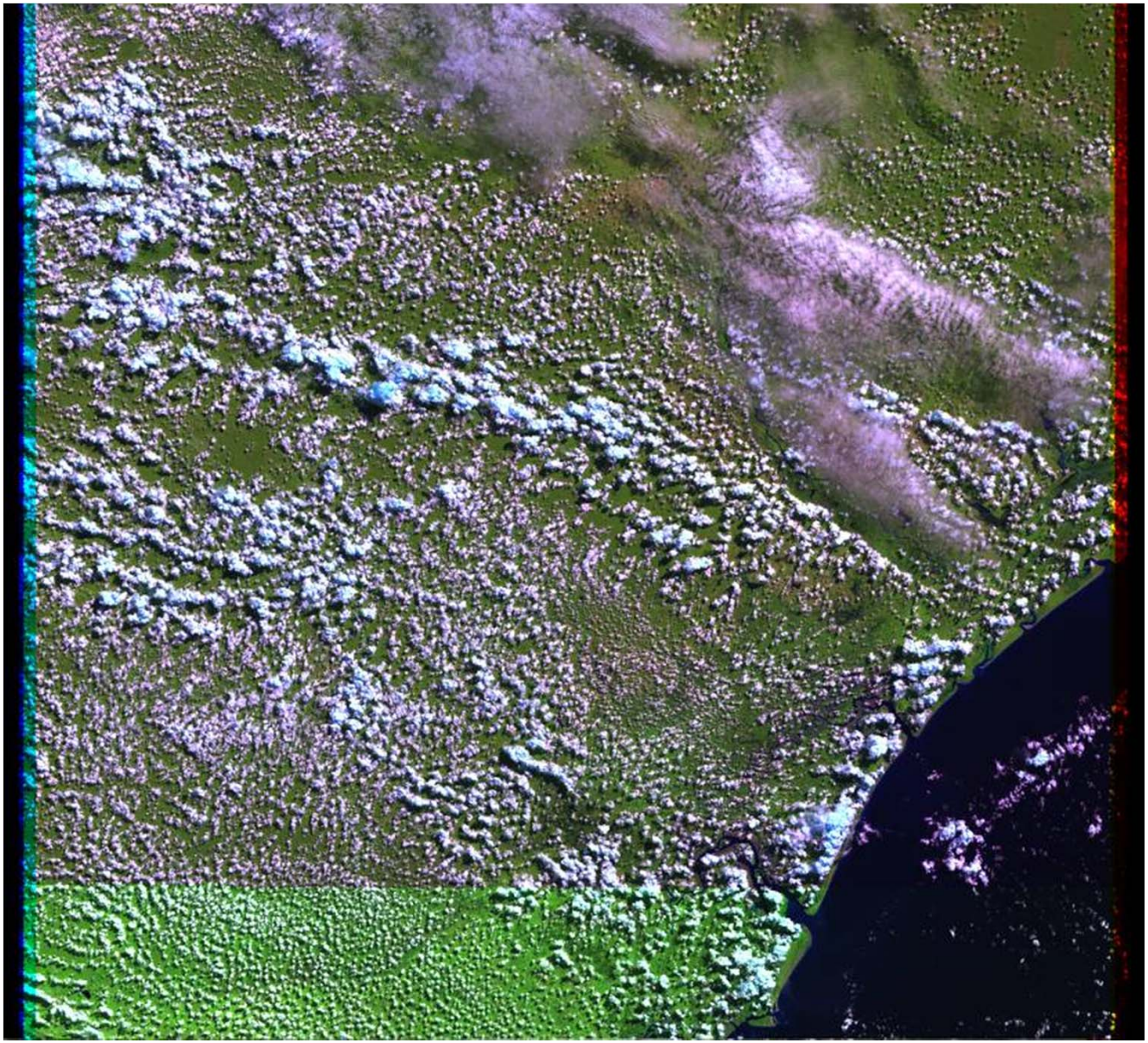


166/072 1999-2000 growing season



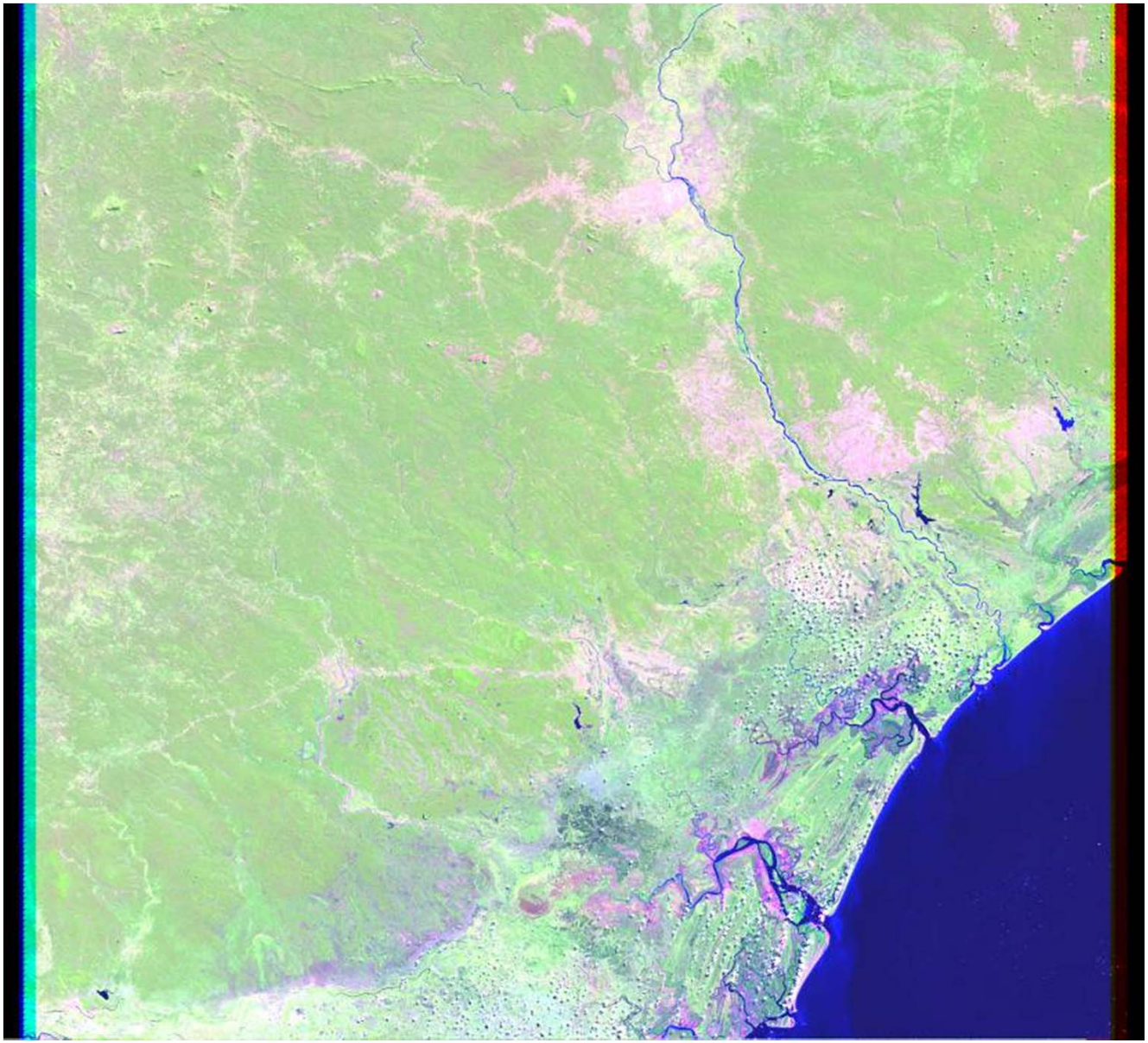
Dec. 5, 1999

166/072 1999-2000 growing season



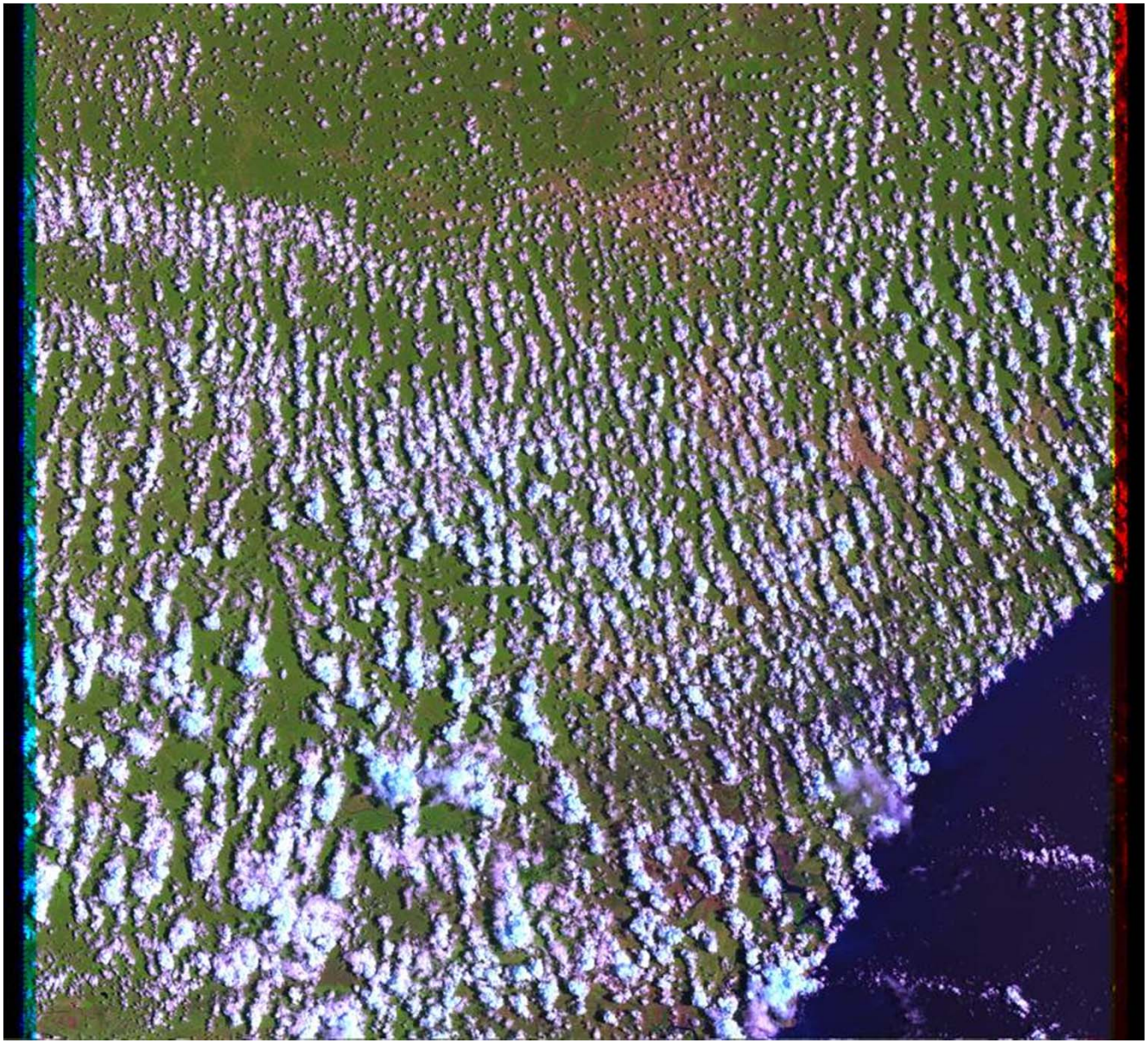
Apr. 12, 2000

166/072 1999-2000 growing season



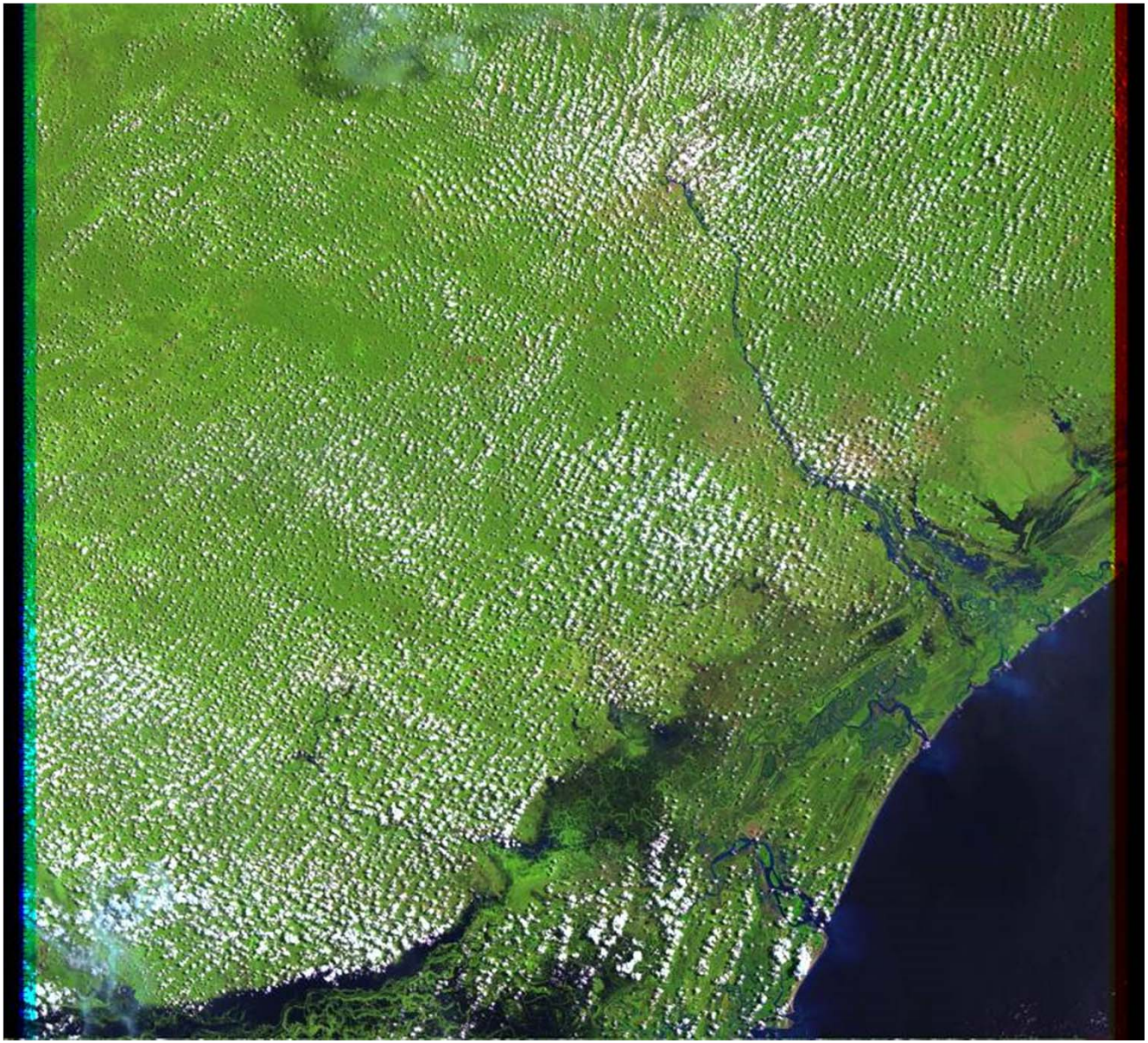
Apr. 28, 2000

166/072 2000-2001 growing season



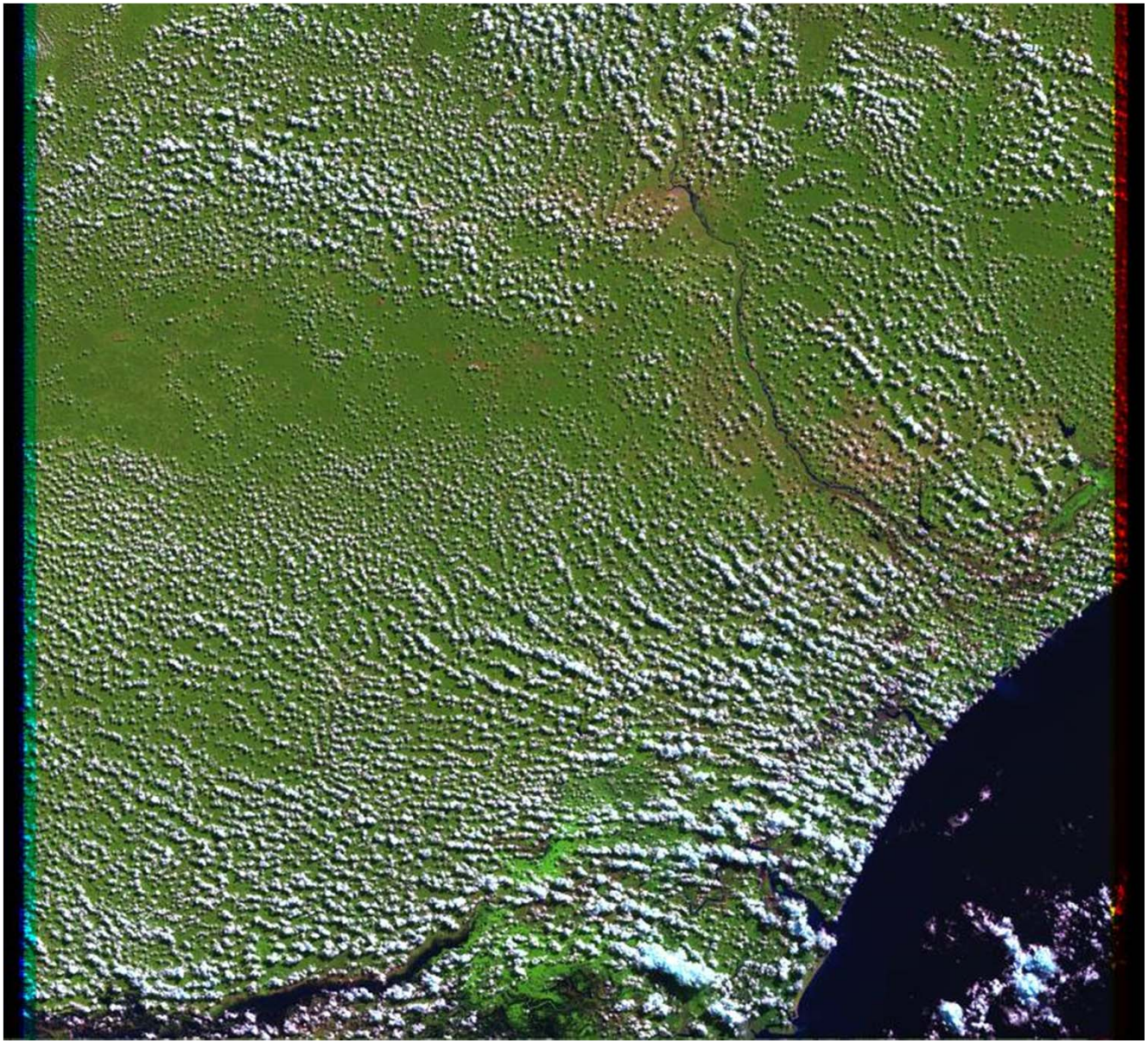
Jan. 8, 2001

166/072 2000-2001 growing season



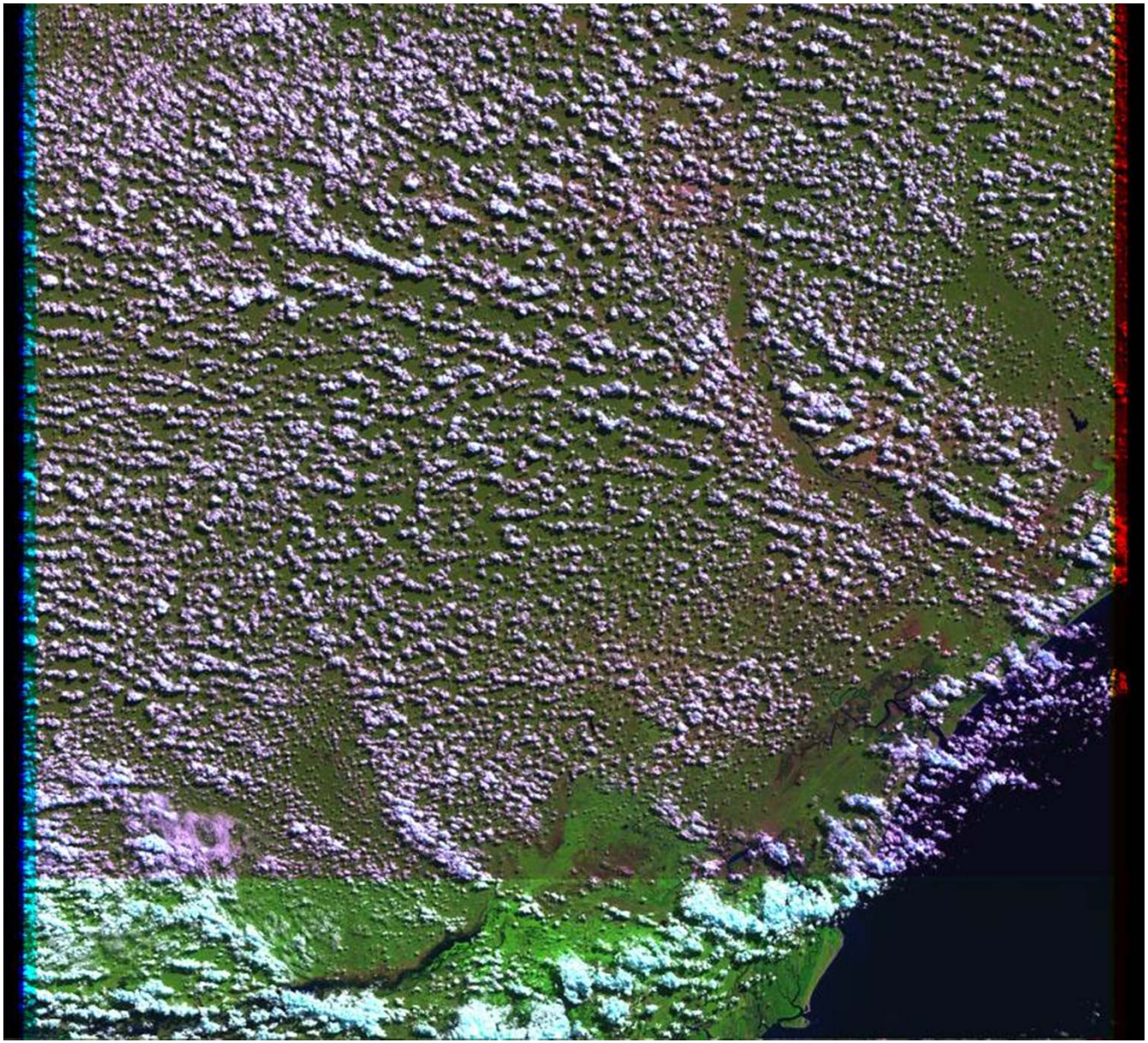
Feb. 26, 2001

166/072 2000-2001 growing season



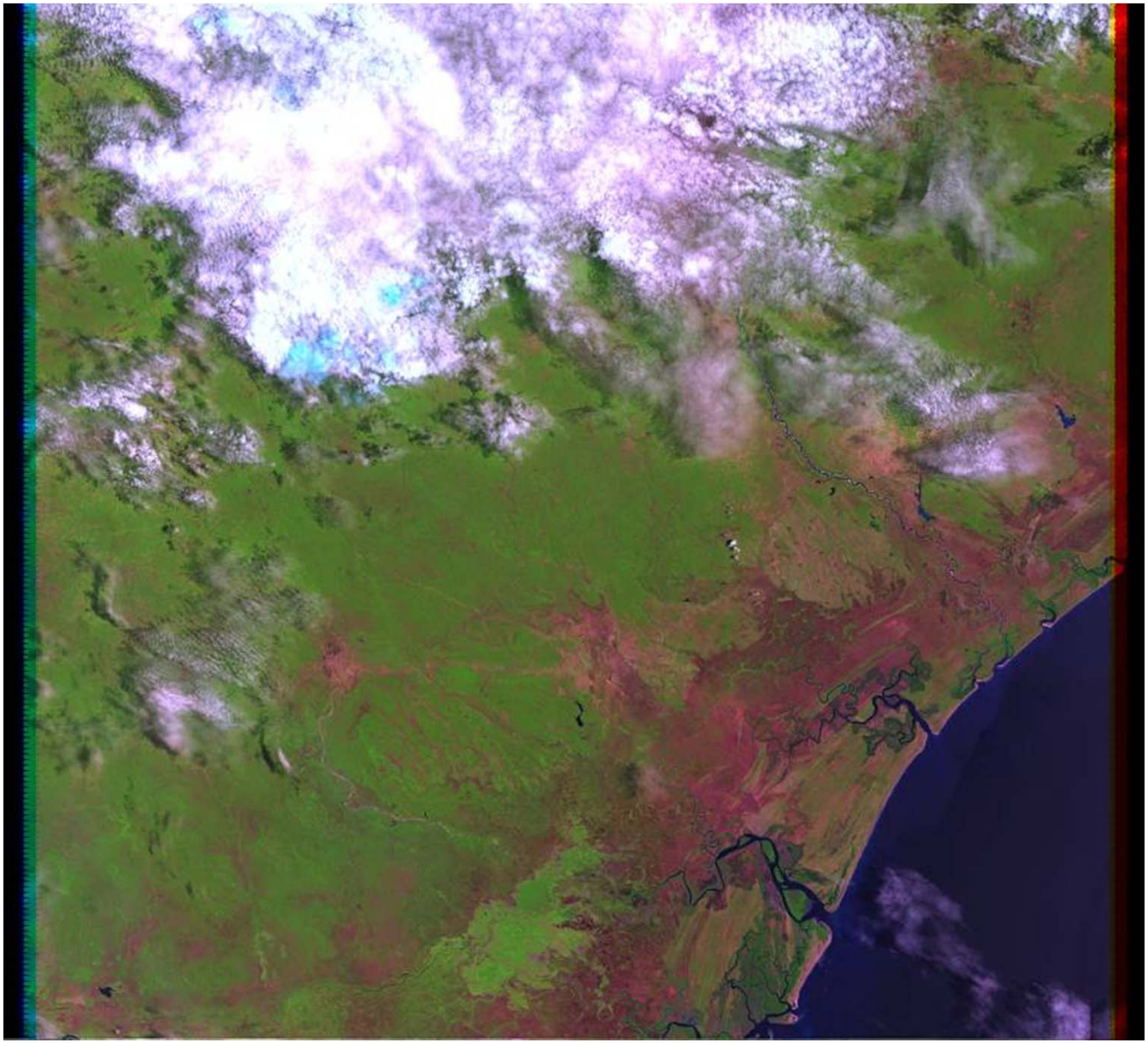
Apr. 14, 2001

166/072 2000-2001 growing season



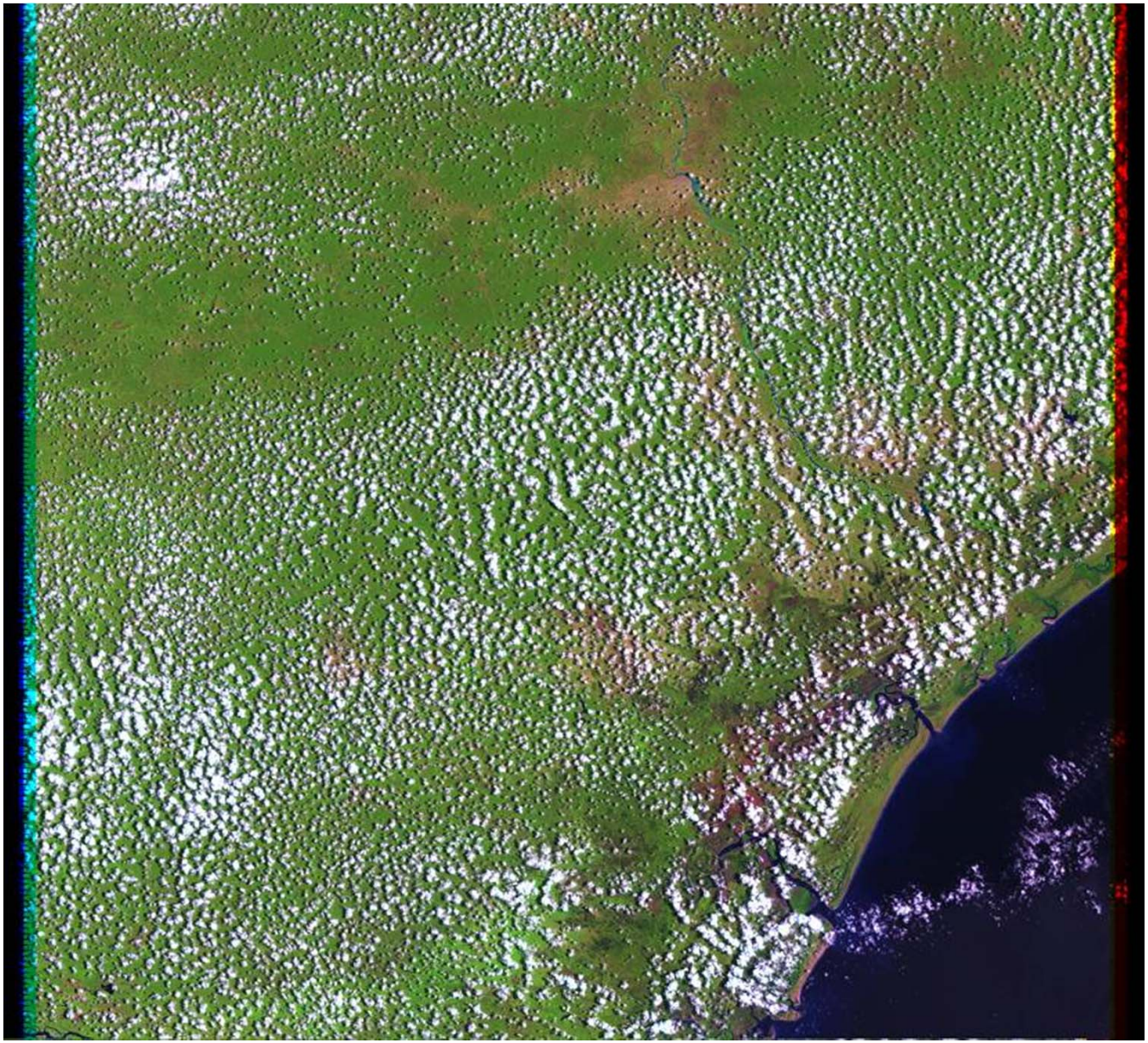
Apr. 30, 2001

166/072 2001-2002 growing season



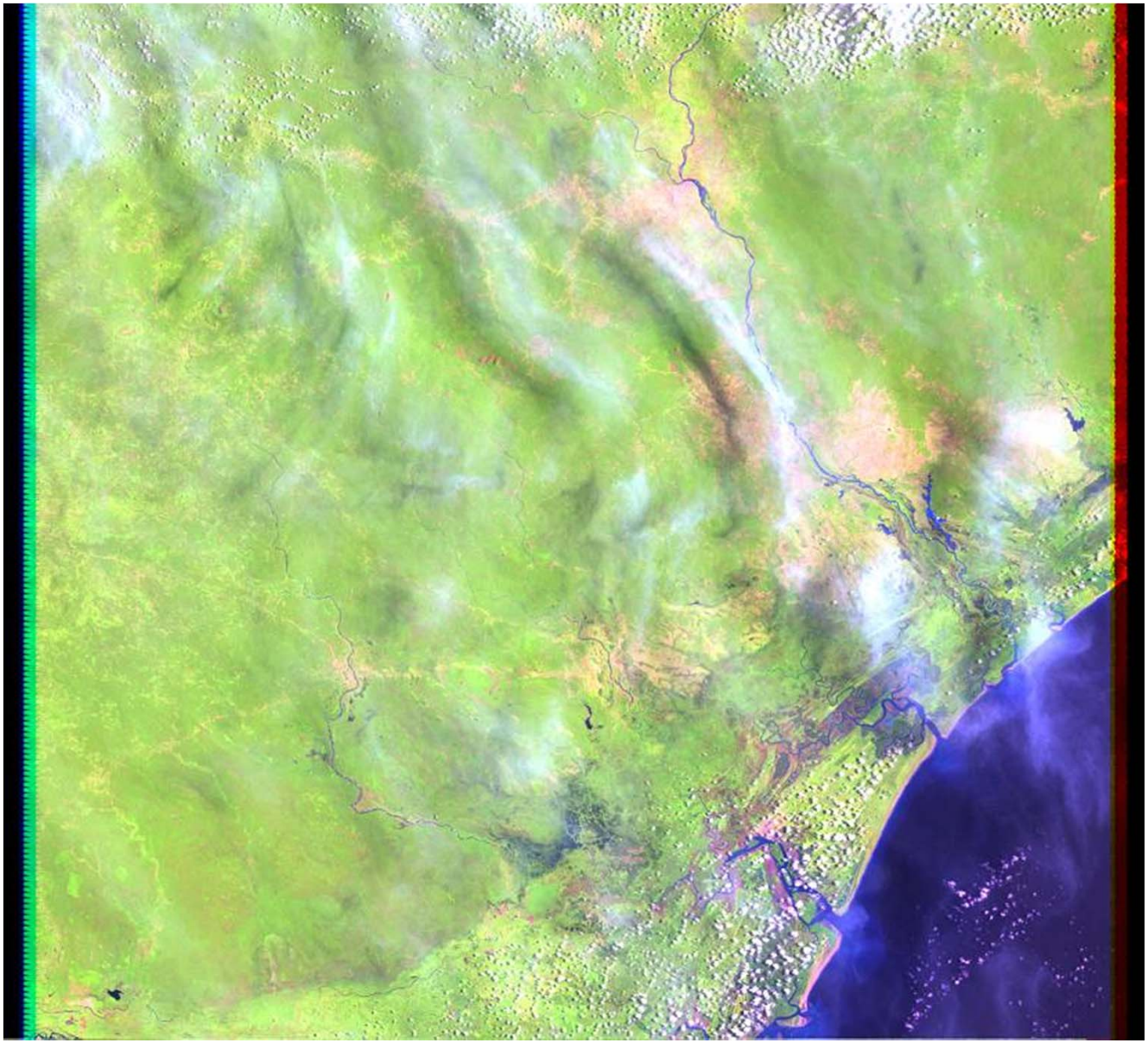
Dec. 26, 2001

166/072 2001-2002 growing season



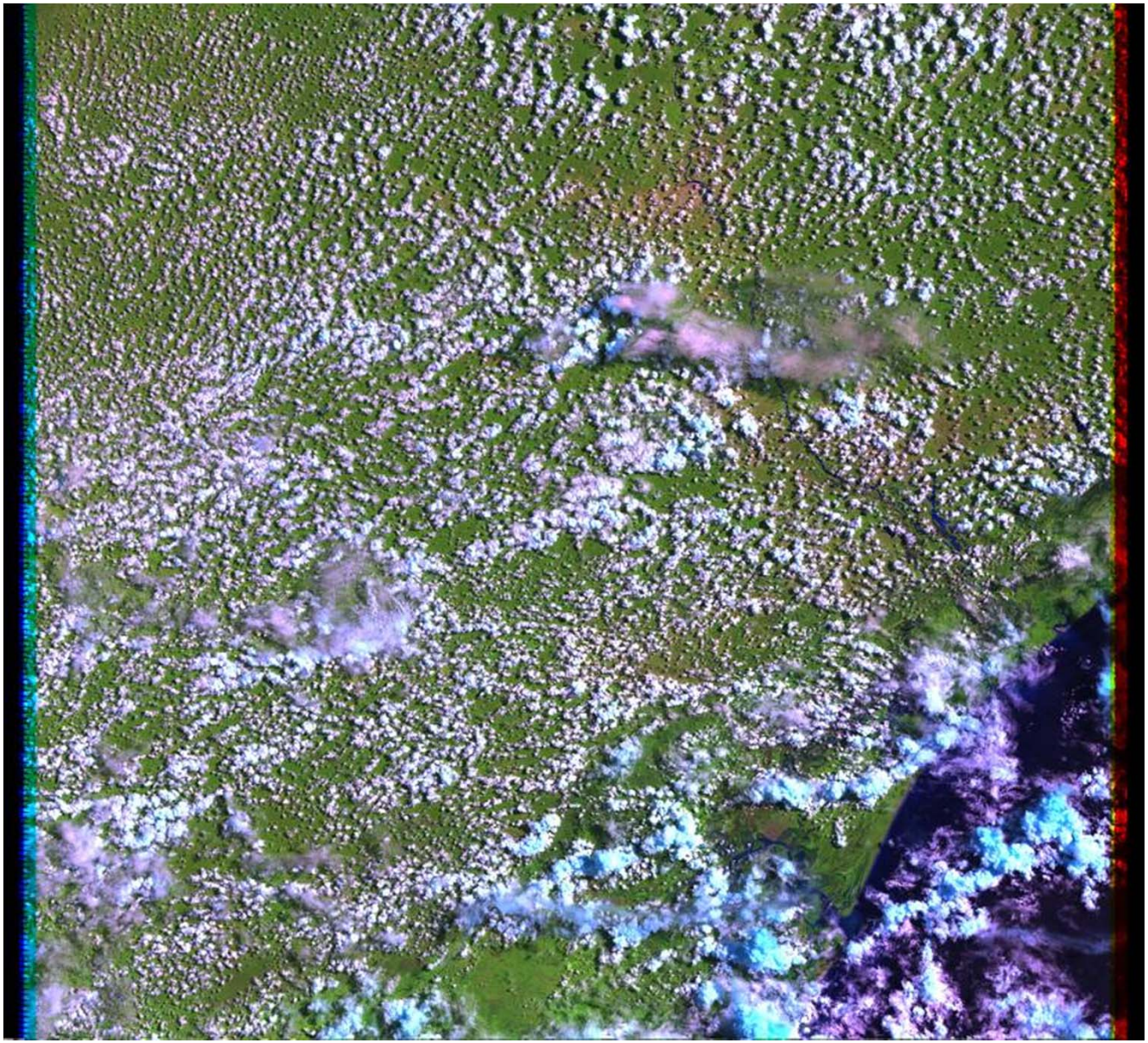
Jan. 11, 2002

166/072 2001-2002 growing season



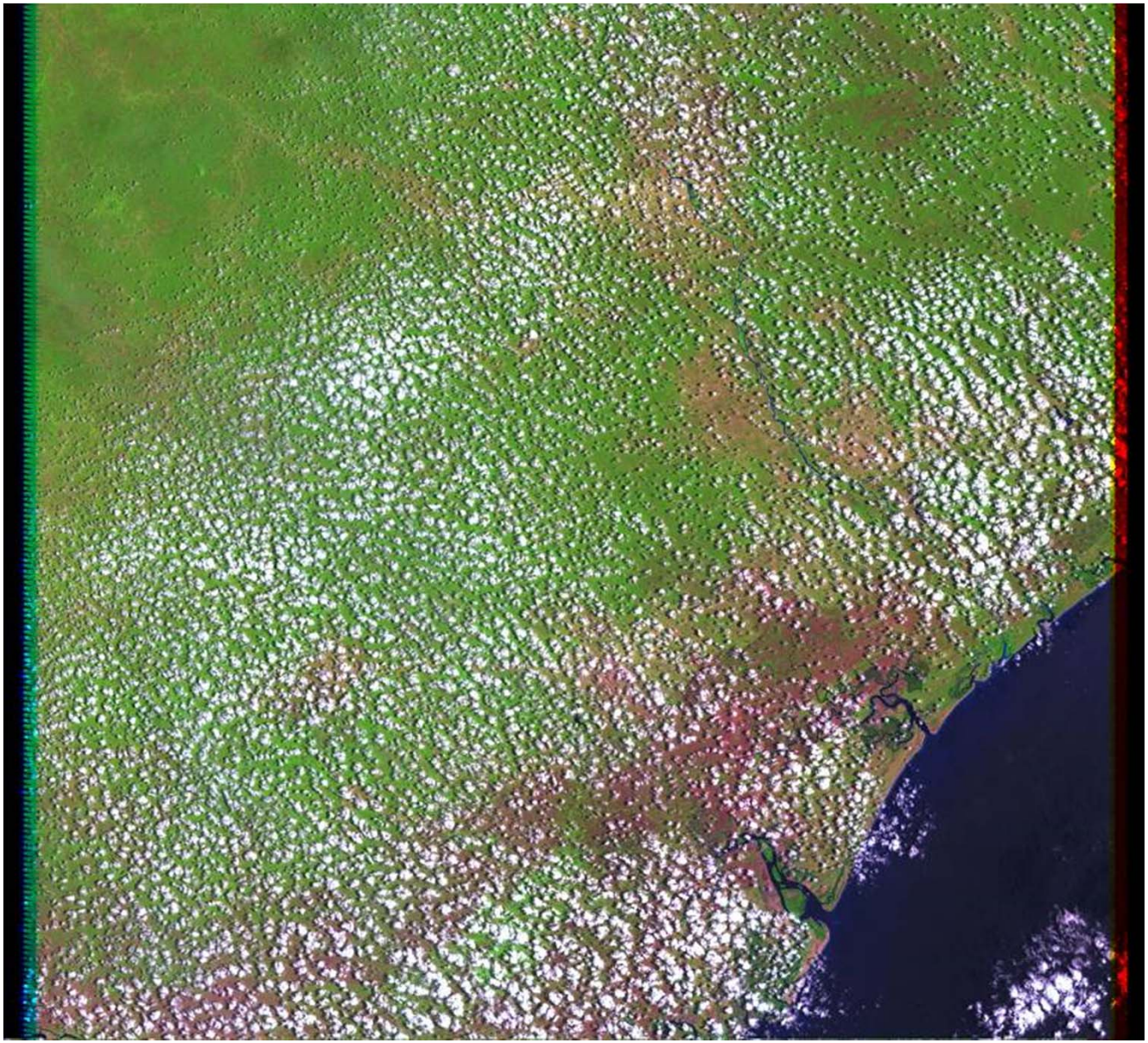
Feb. 13, 2002

166/072 2001-2002 growing season



Feb. 29, 2002

166/072 2002-2003 growing season

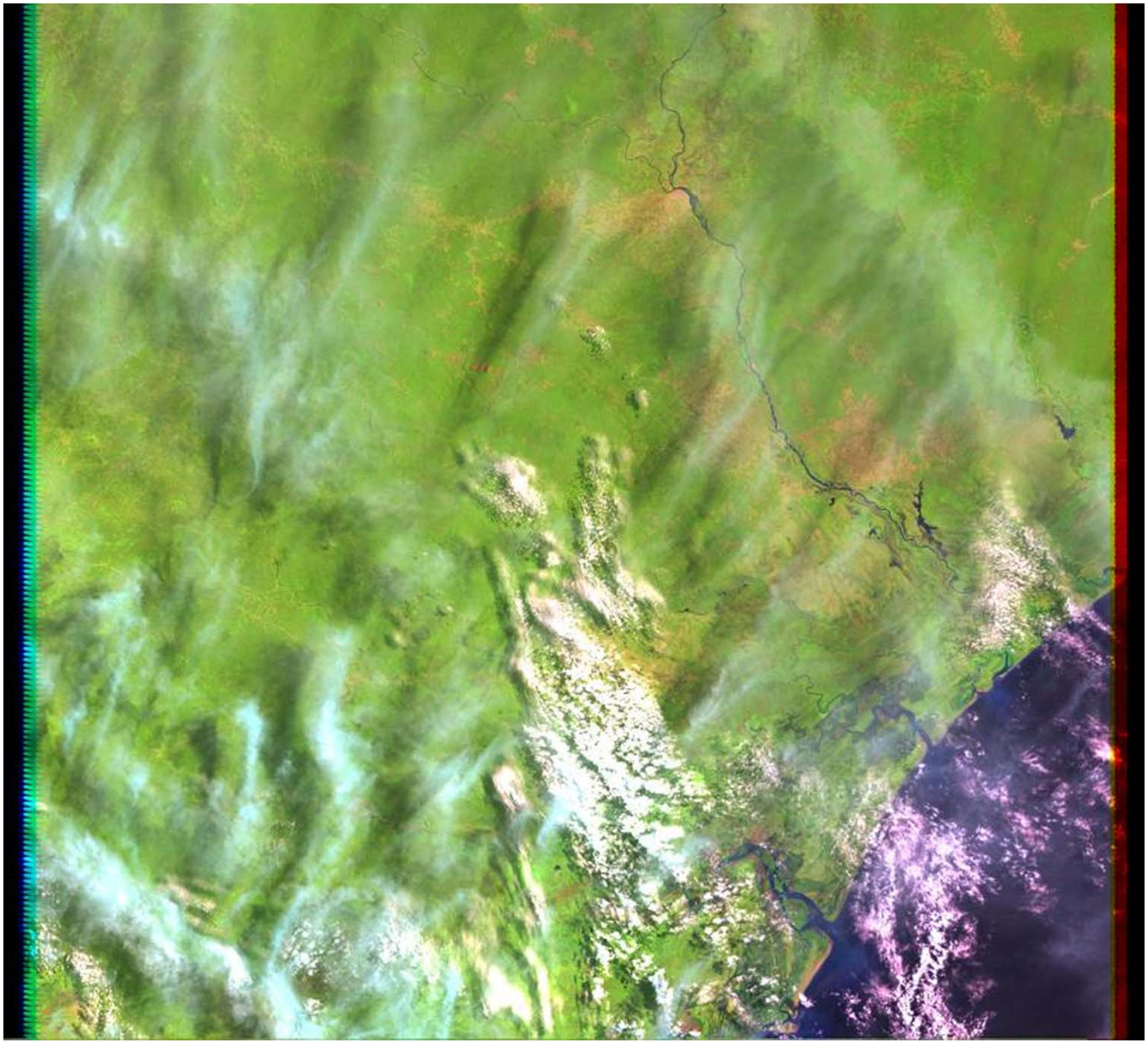


Dec. 26, 2002

166/072 2002-2003 growing season

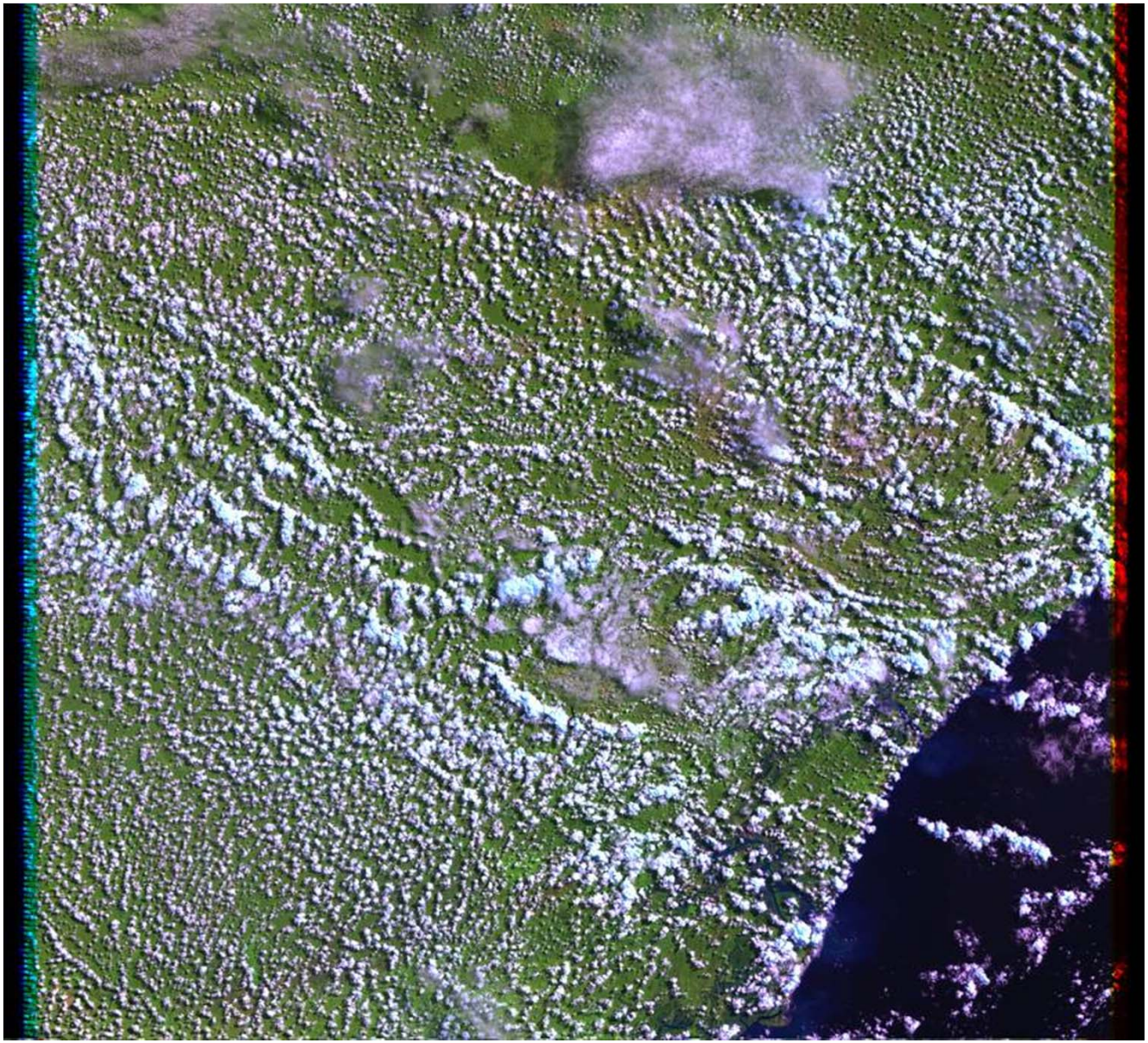
Jan. 14, 2003

166/072 2002-2003 growing season



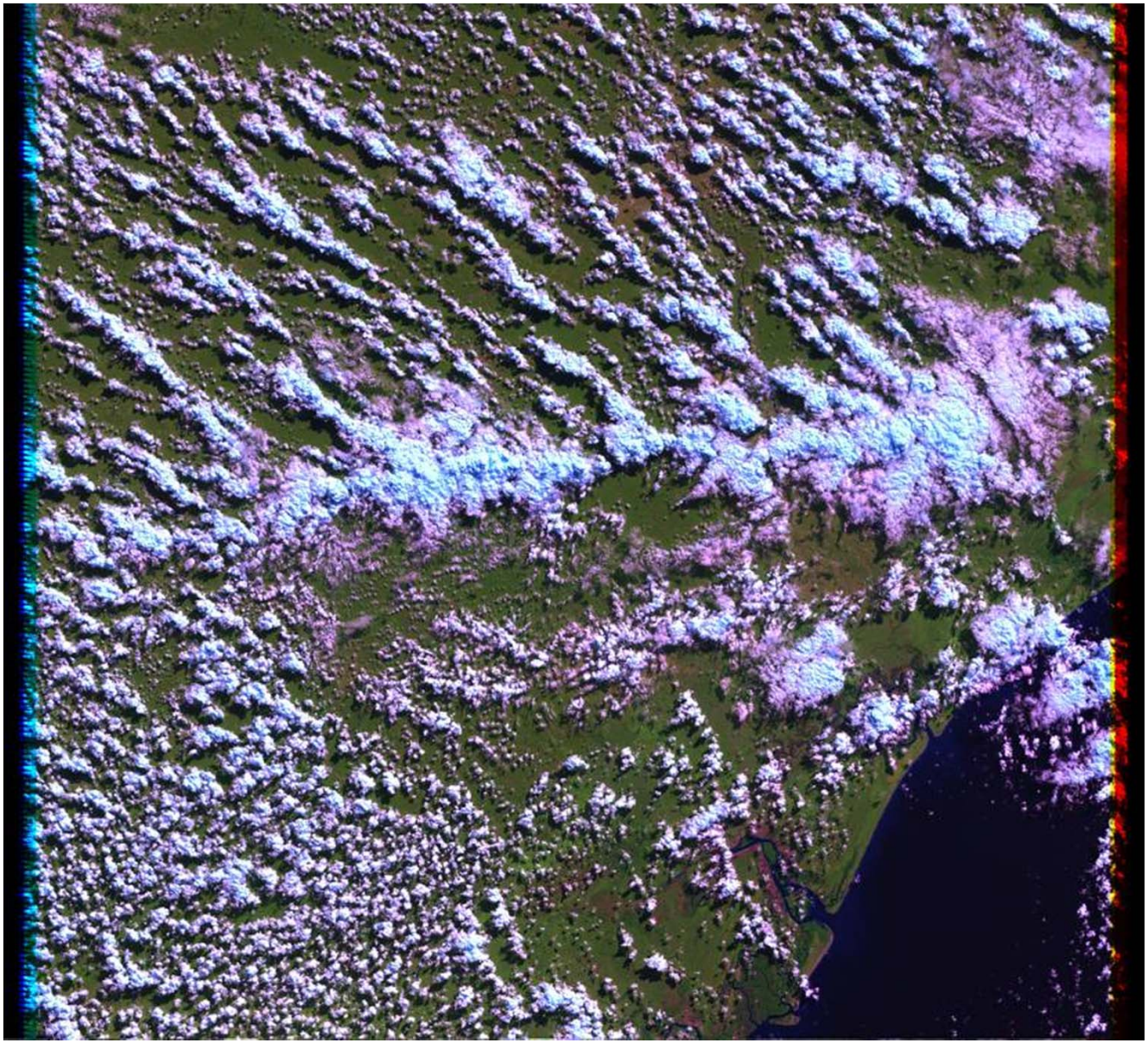
Mar. 3, 2003

166/072 2002-2003 growing season



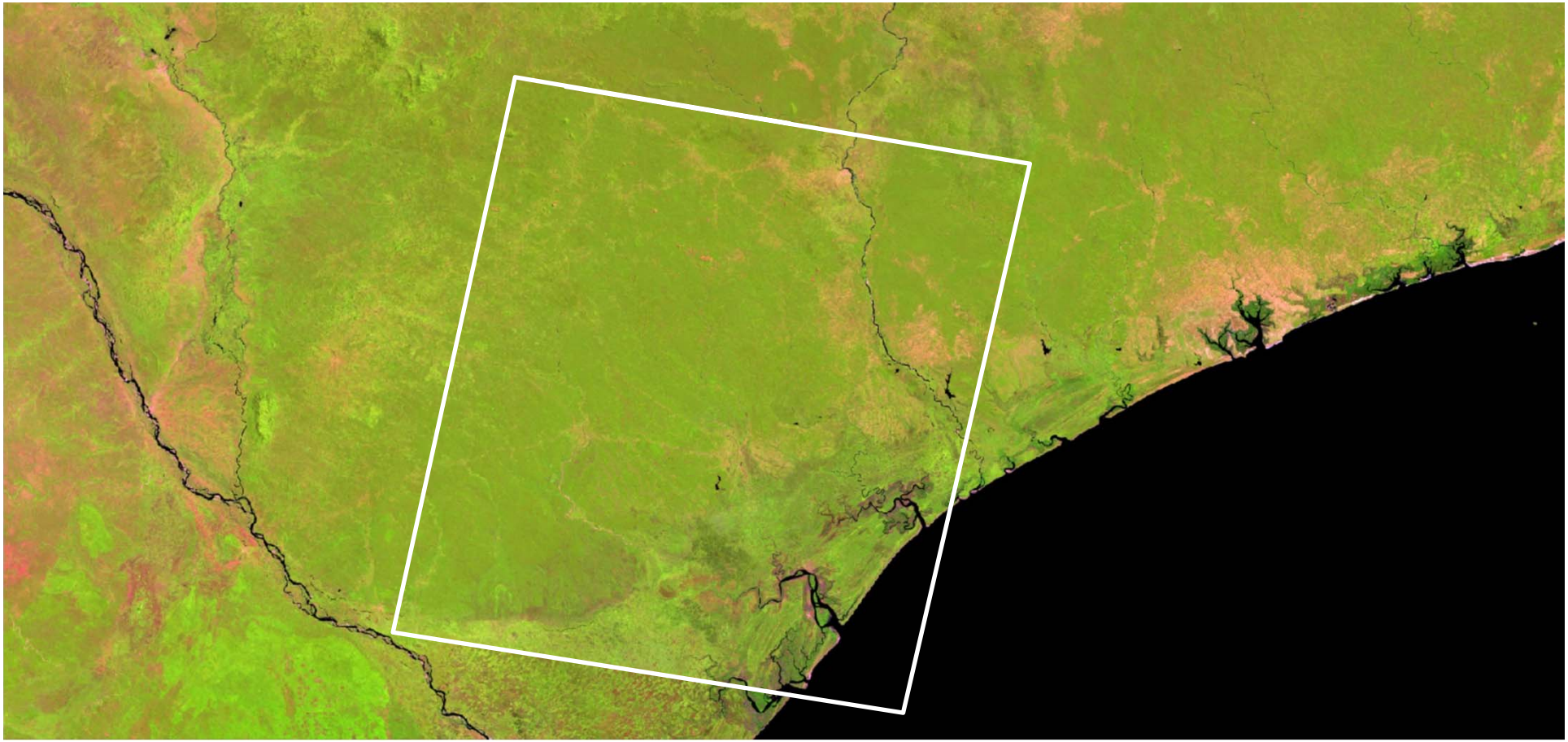
Mar. 19, 2003

166/072 2002-2003 growing season

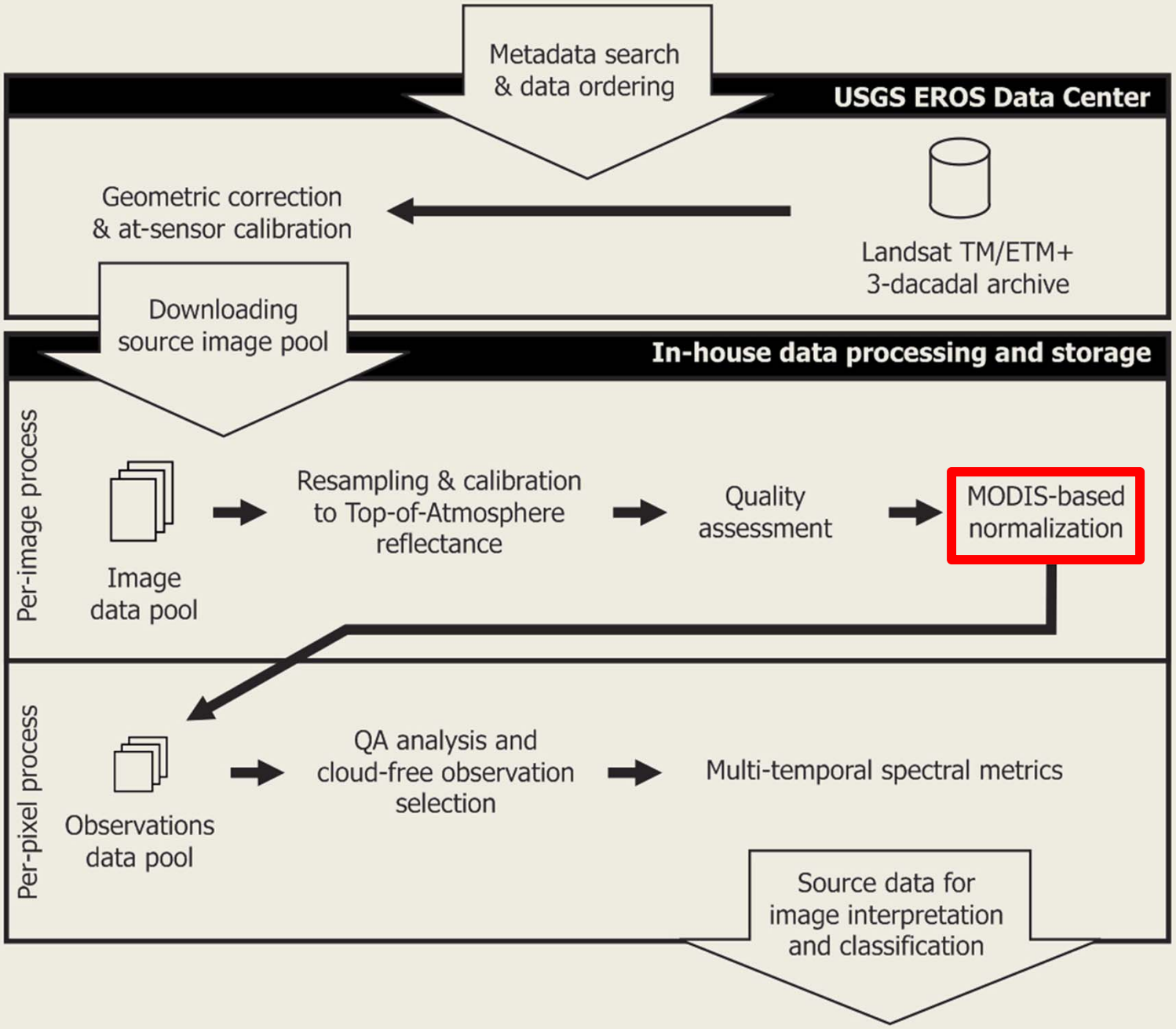


May 6, 2003

2000 5-4-3 composite

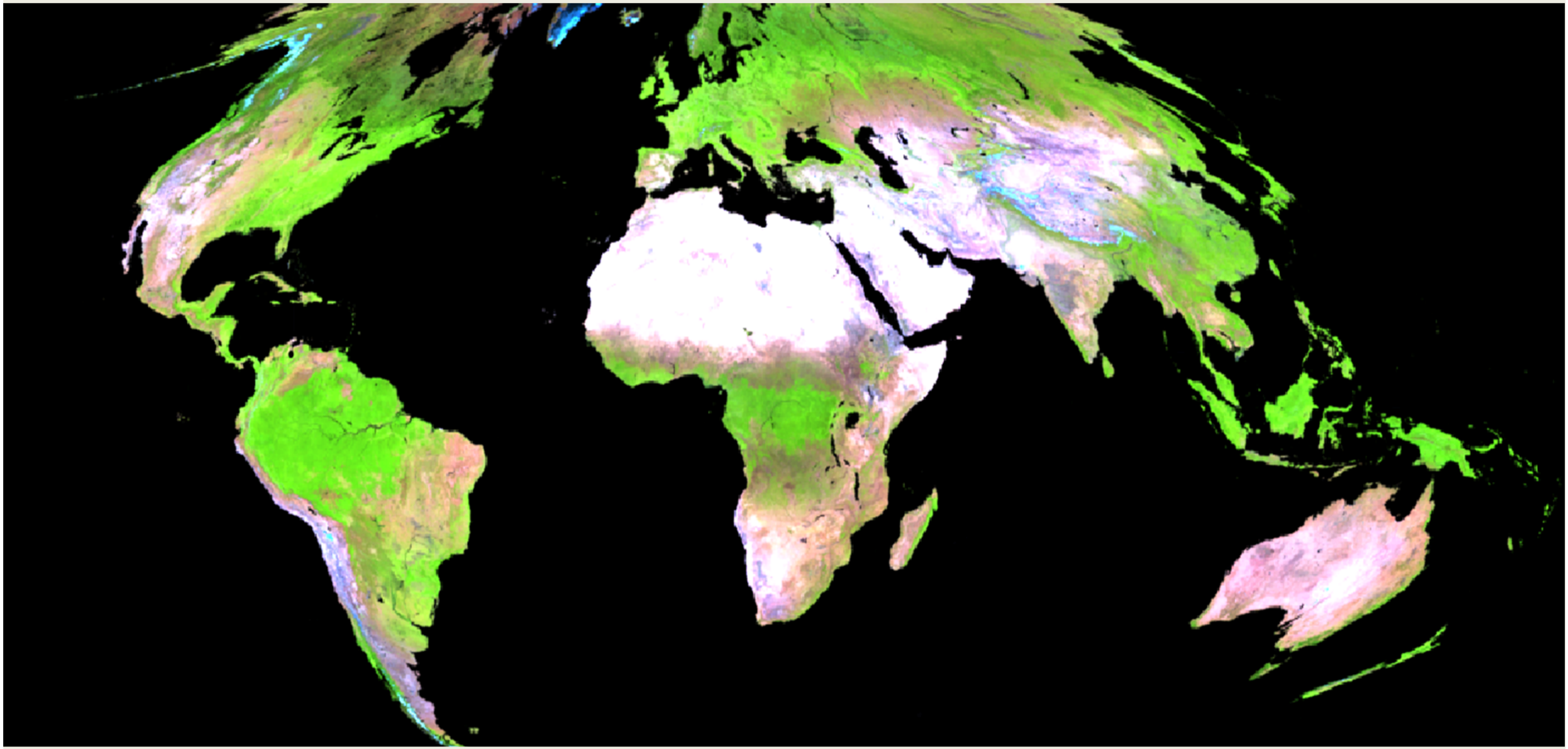


Landsat data processing workflow



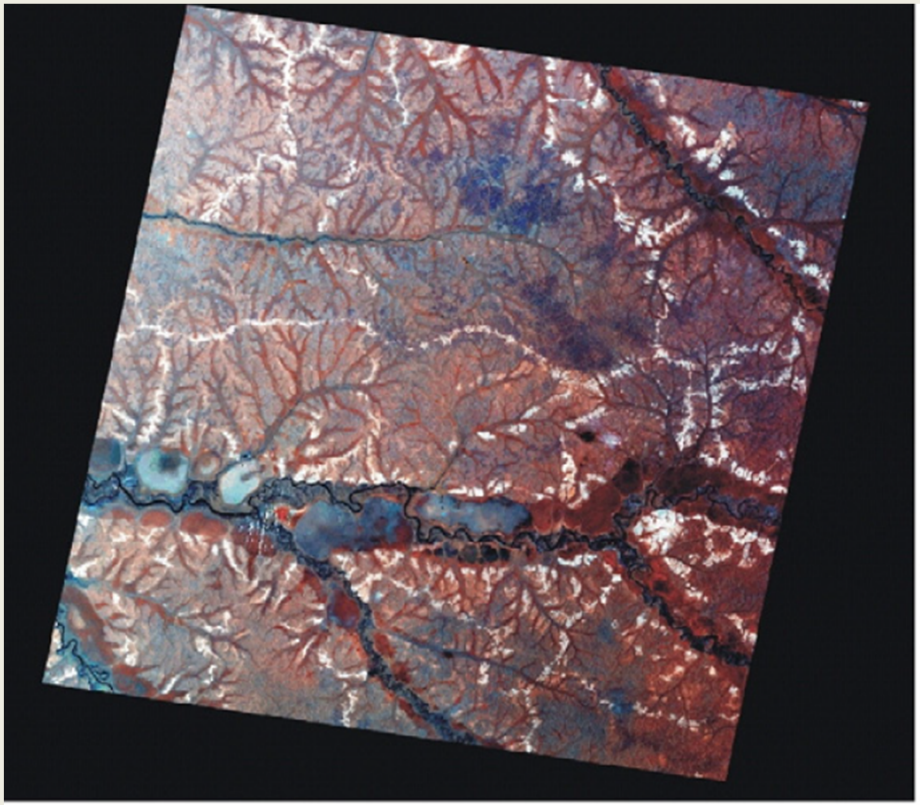
Landsat data normalization

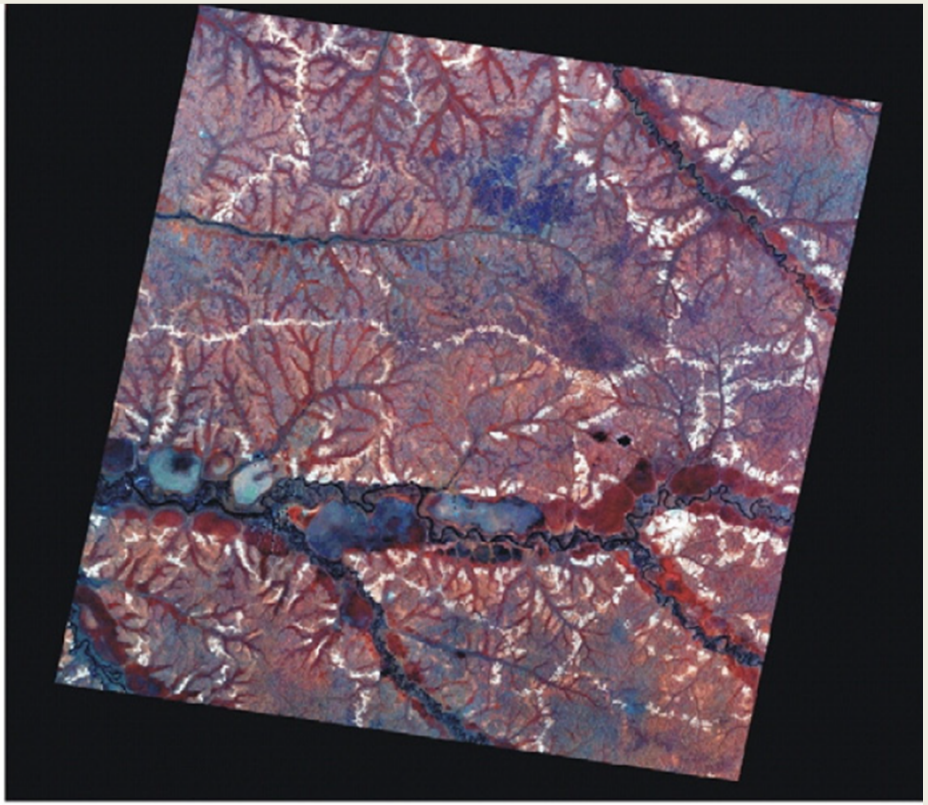
Global MODIS TOC reflectance as normalization target

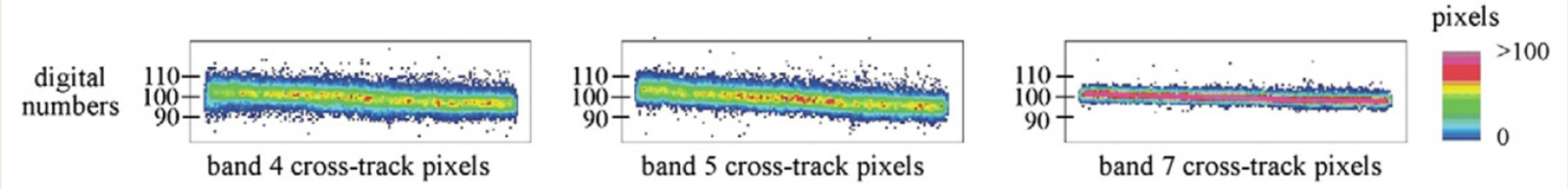


Best cloud-free observations for the peak of vegetation season
over 10 years of data (2000-2009)

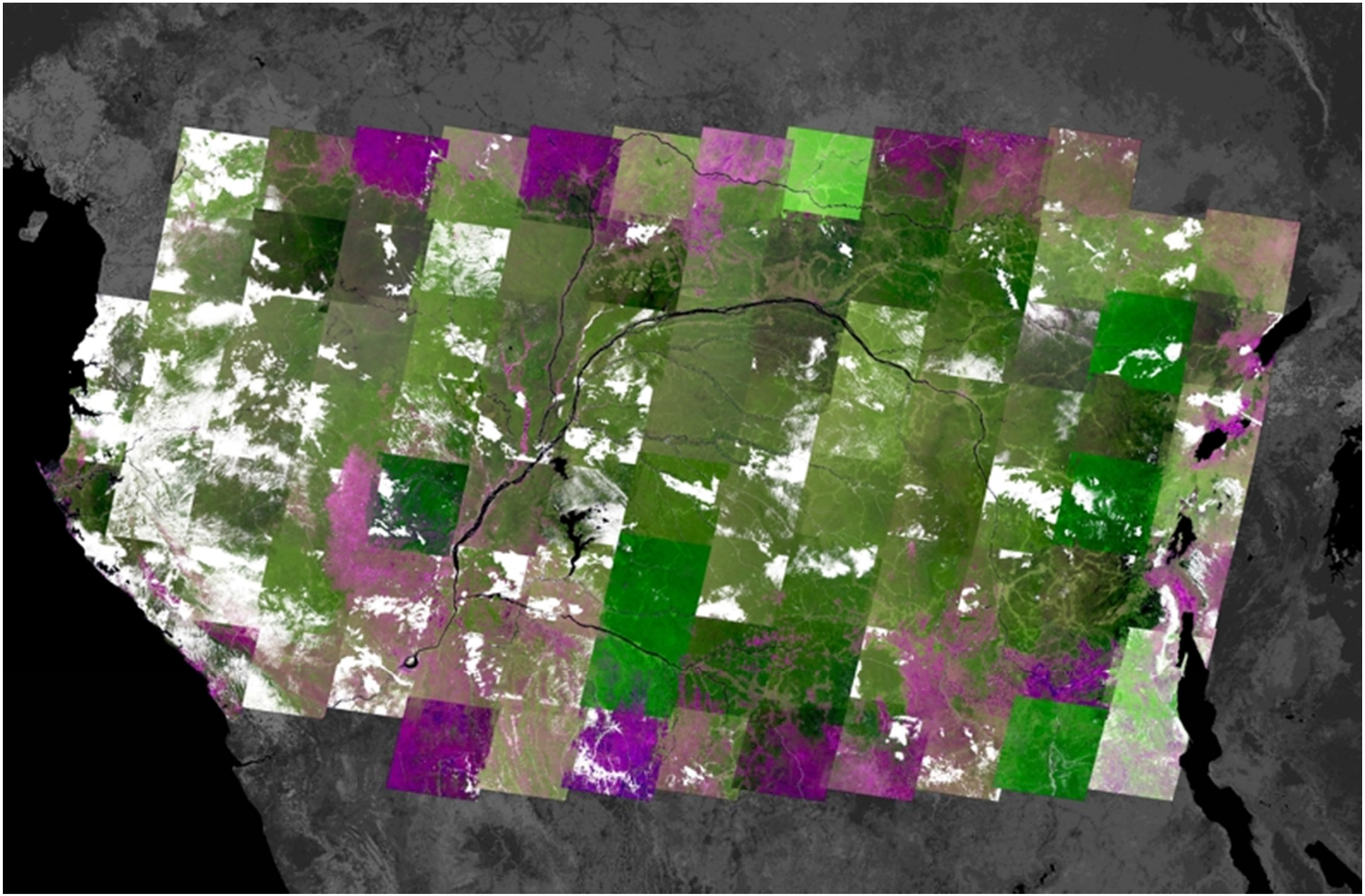
Correct for view geometry effects



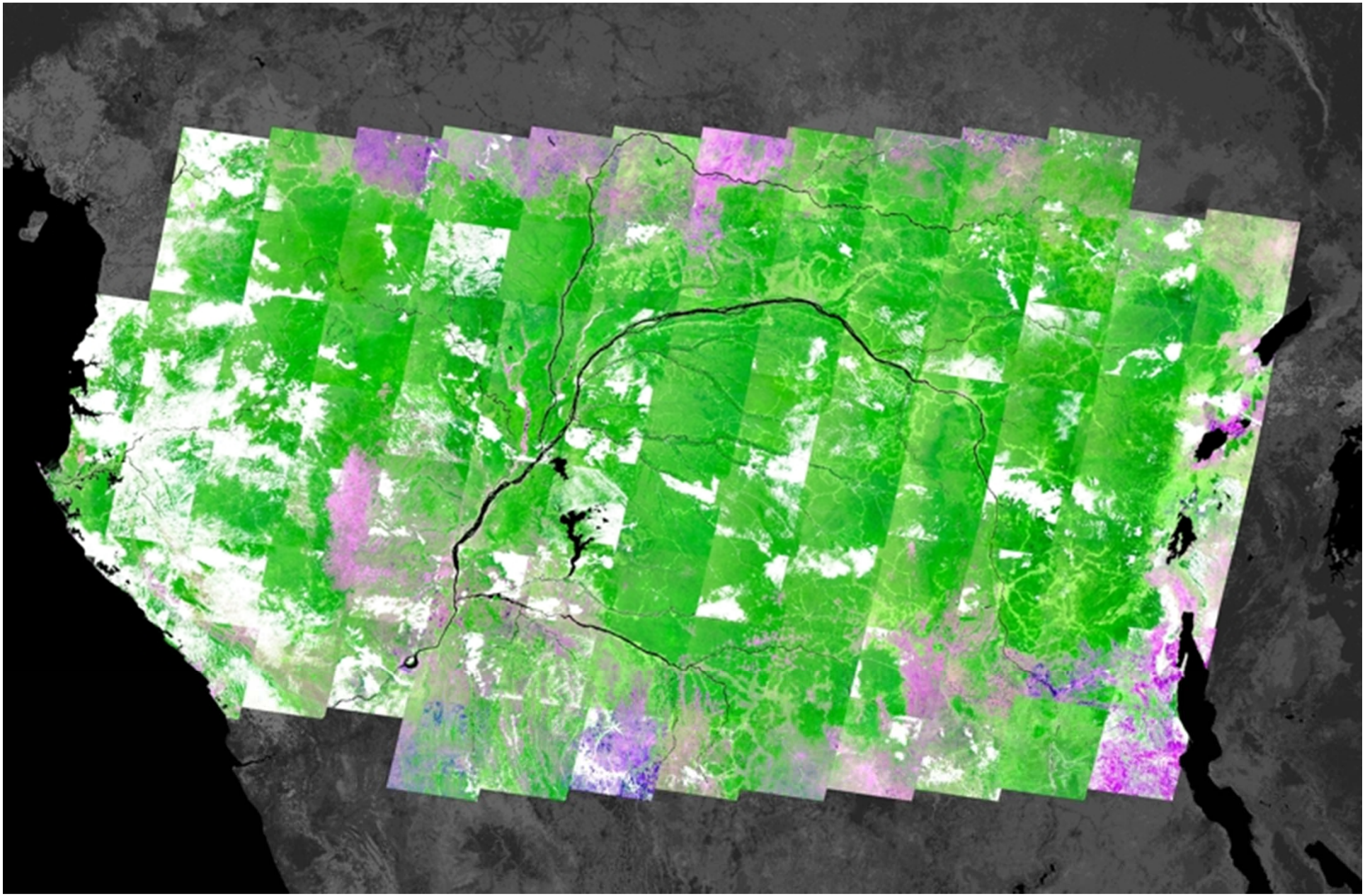




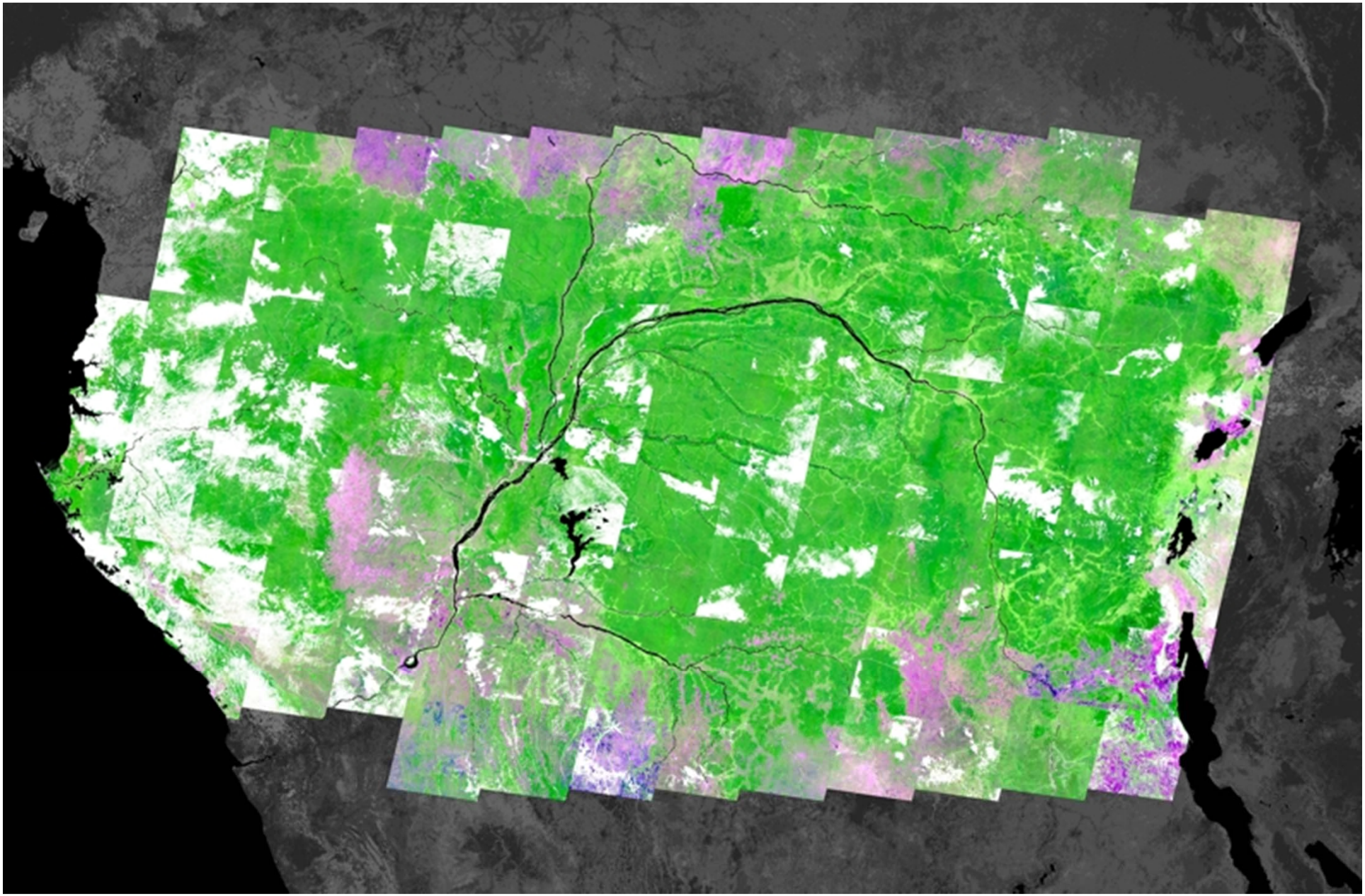
Uncorrected imagery



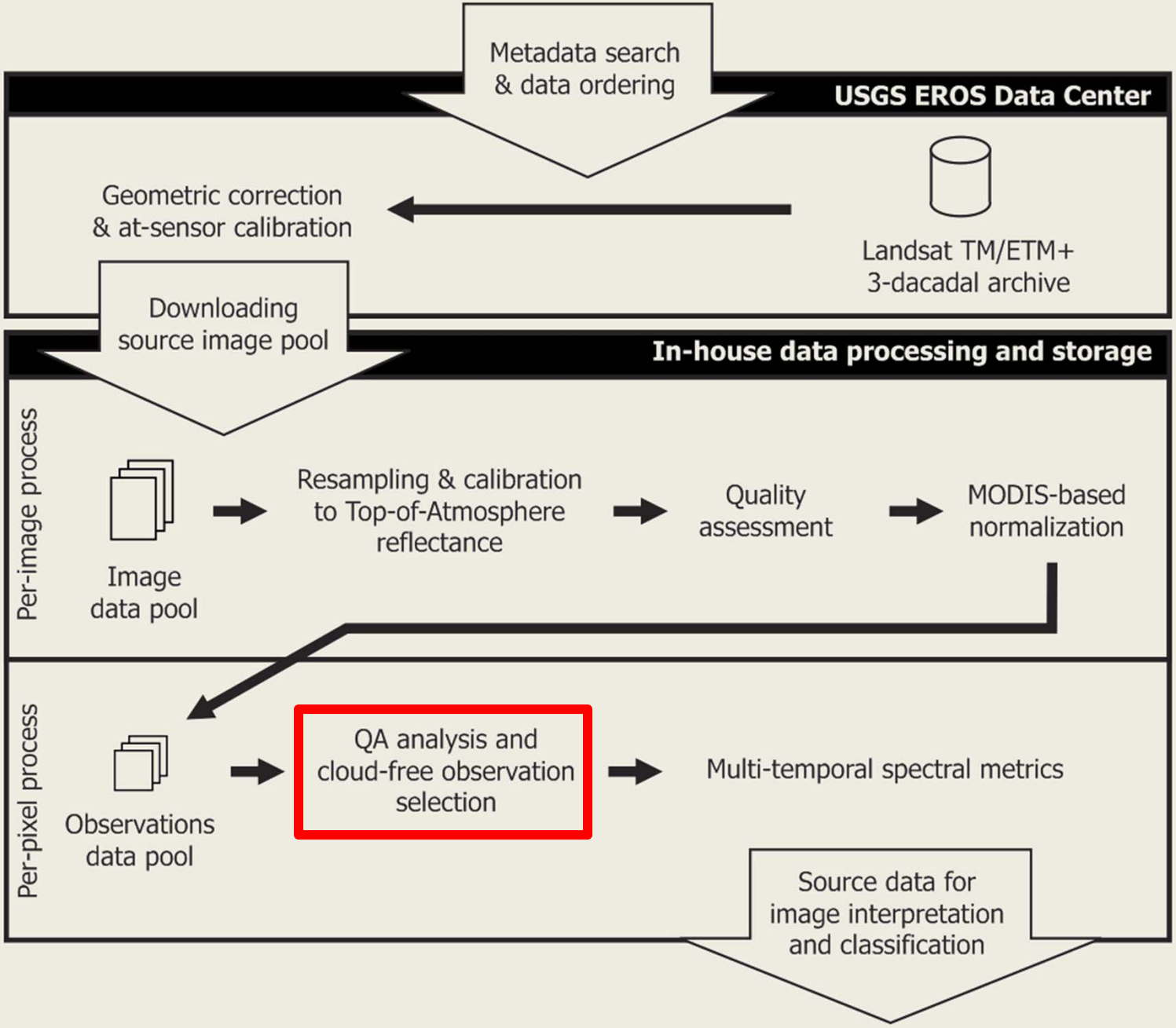
Bias-adjusted TOA



Anisotropy-adjusted



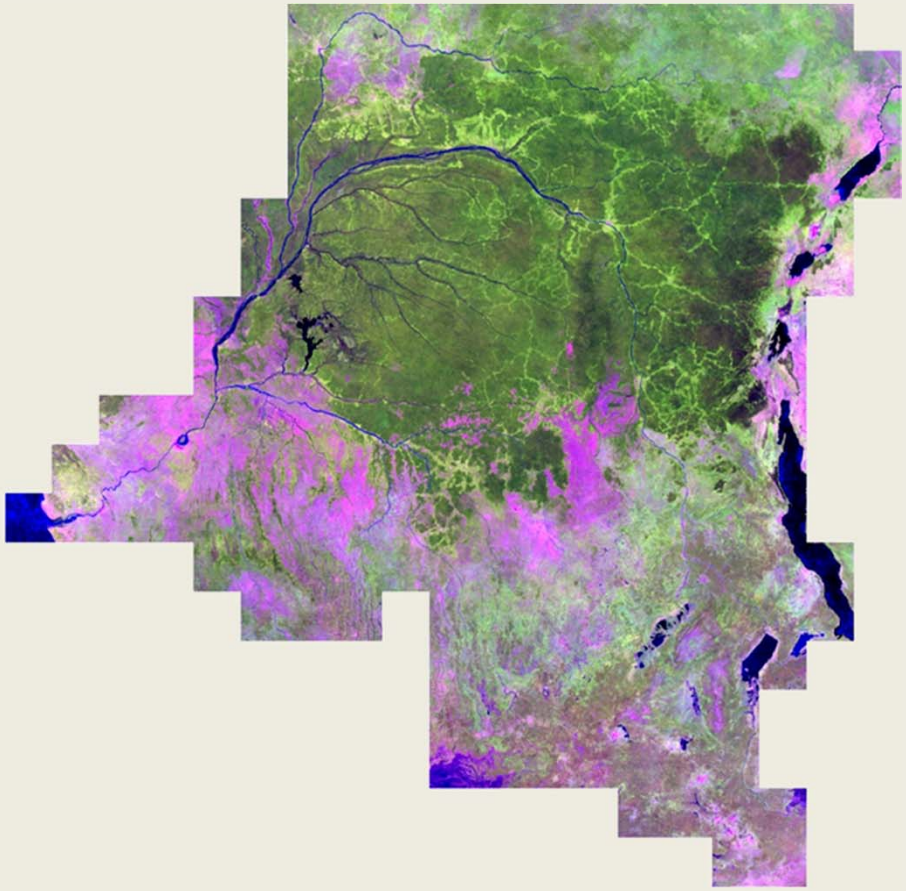
Landsat data processing workflow



Landsat data normalization

Global MODIS TOC reflectance as normalization target

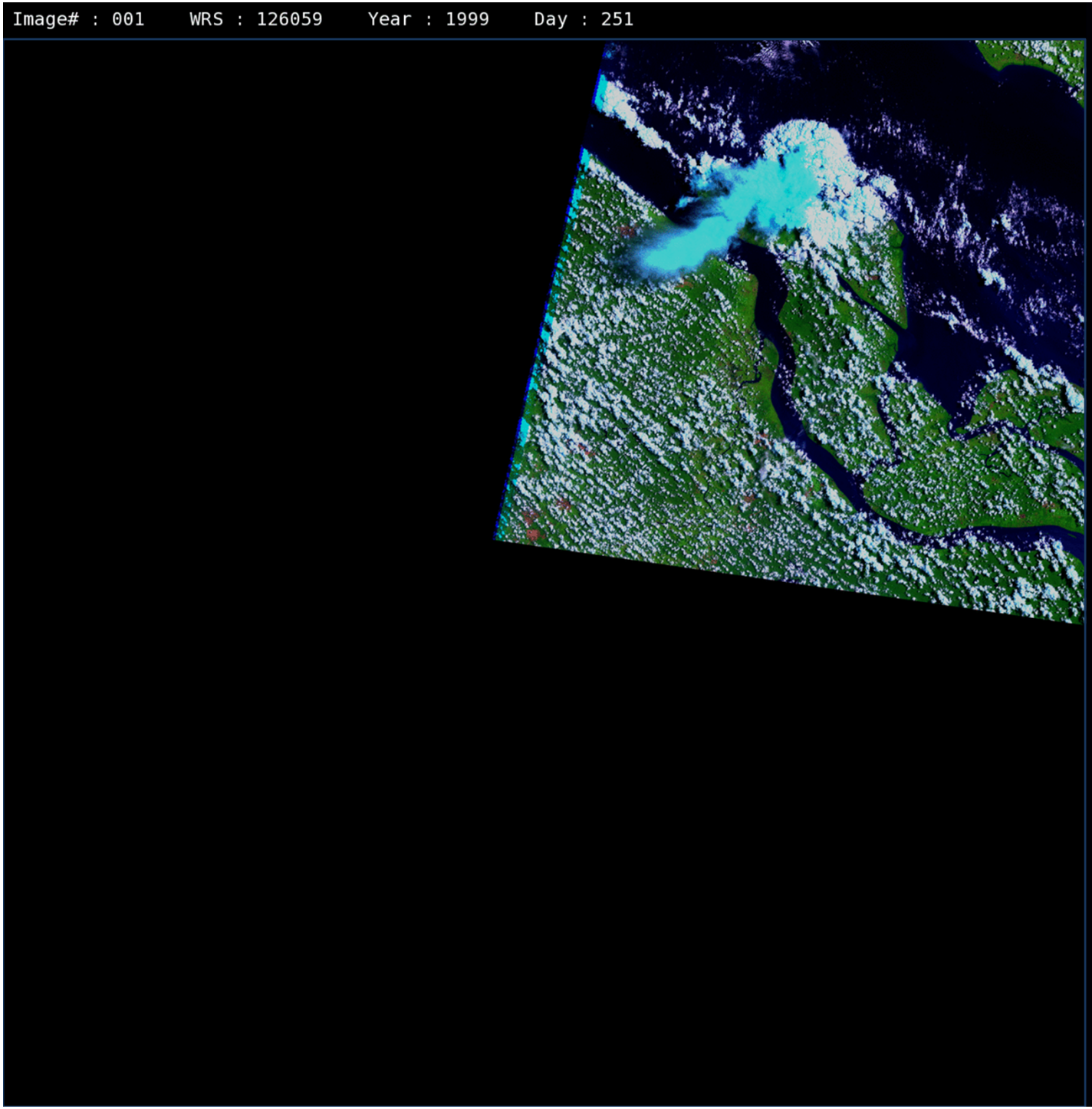
Landsat normalized reflectance
(median spectral reflectance from 2000-2005 composite)



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

Indonesia

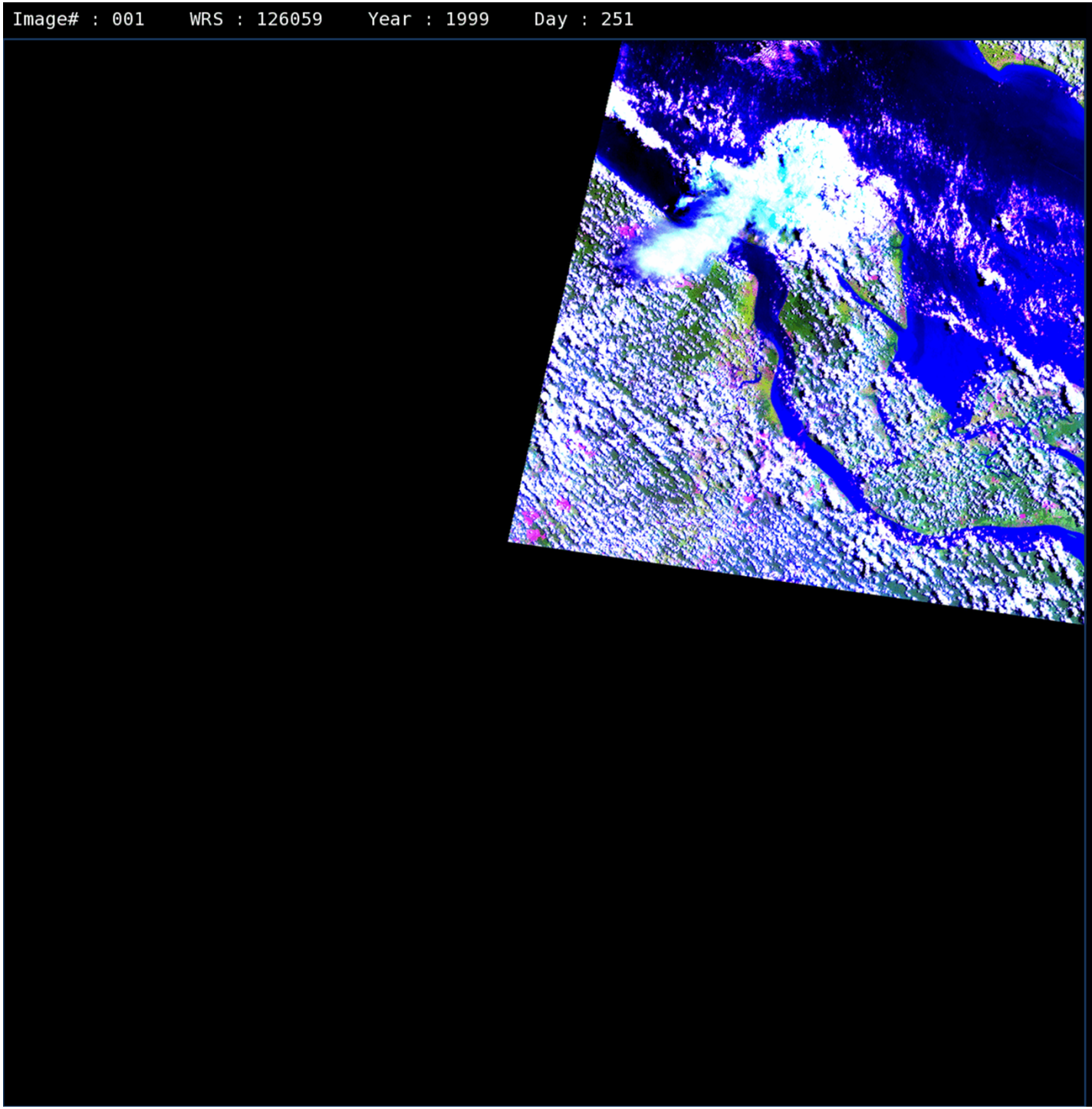
Indonesia, Riau province



Indonesia, Riau province

Image Process

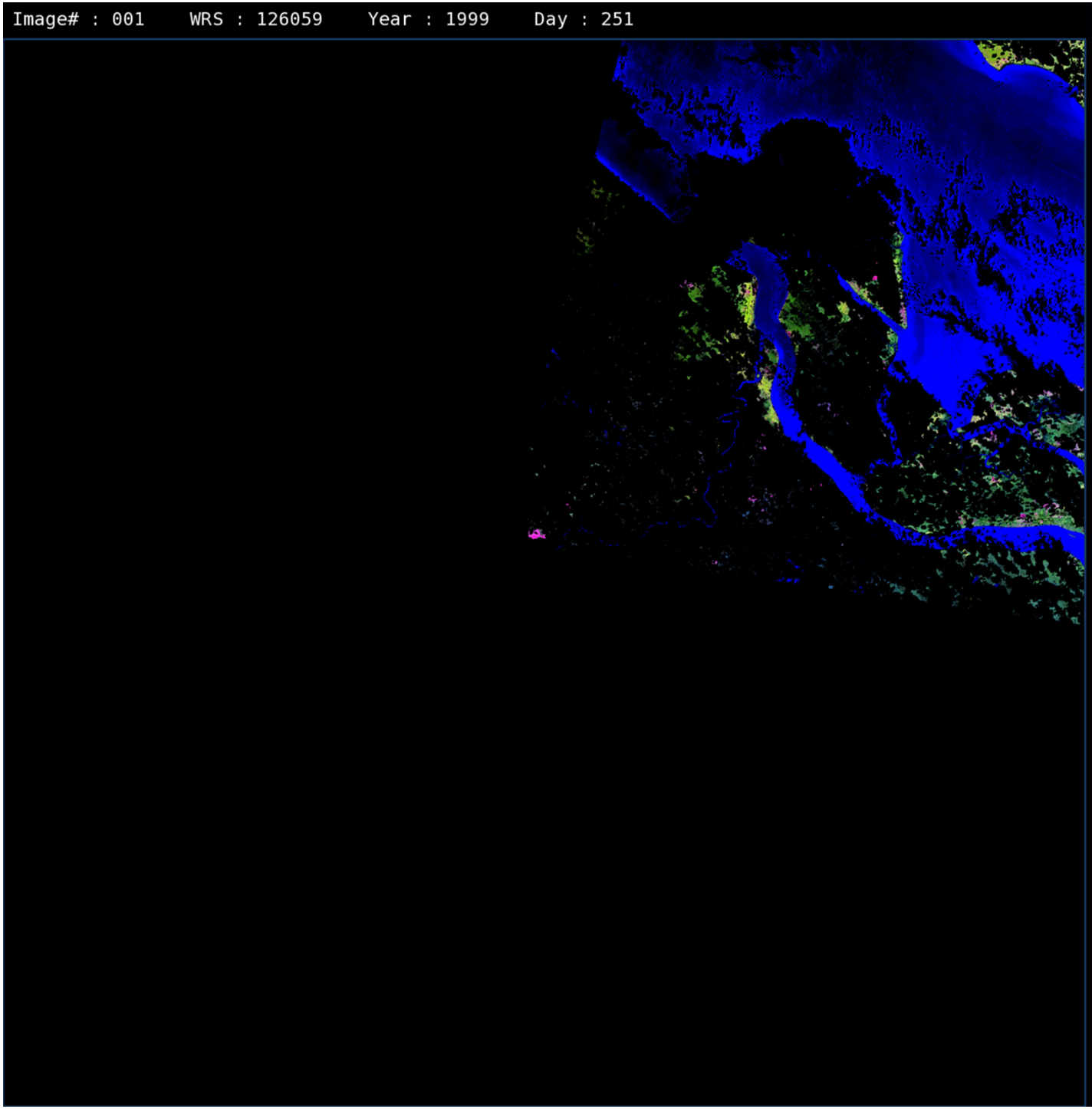
- Raw Digital Numbers



Indonesia, Riau province

Image Process

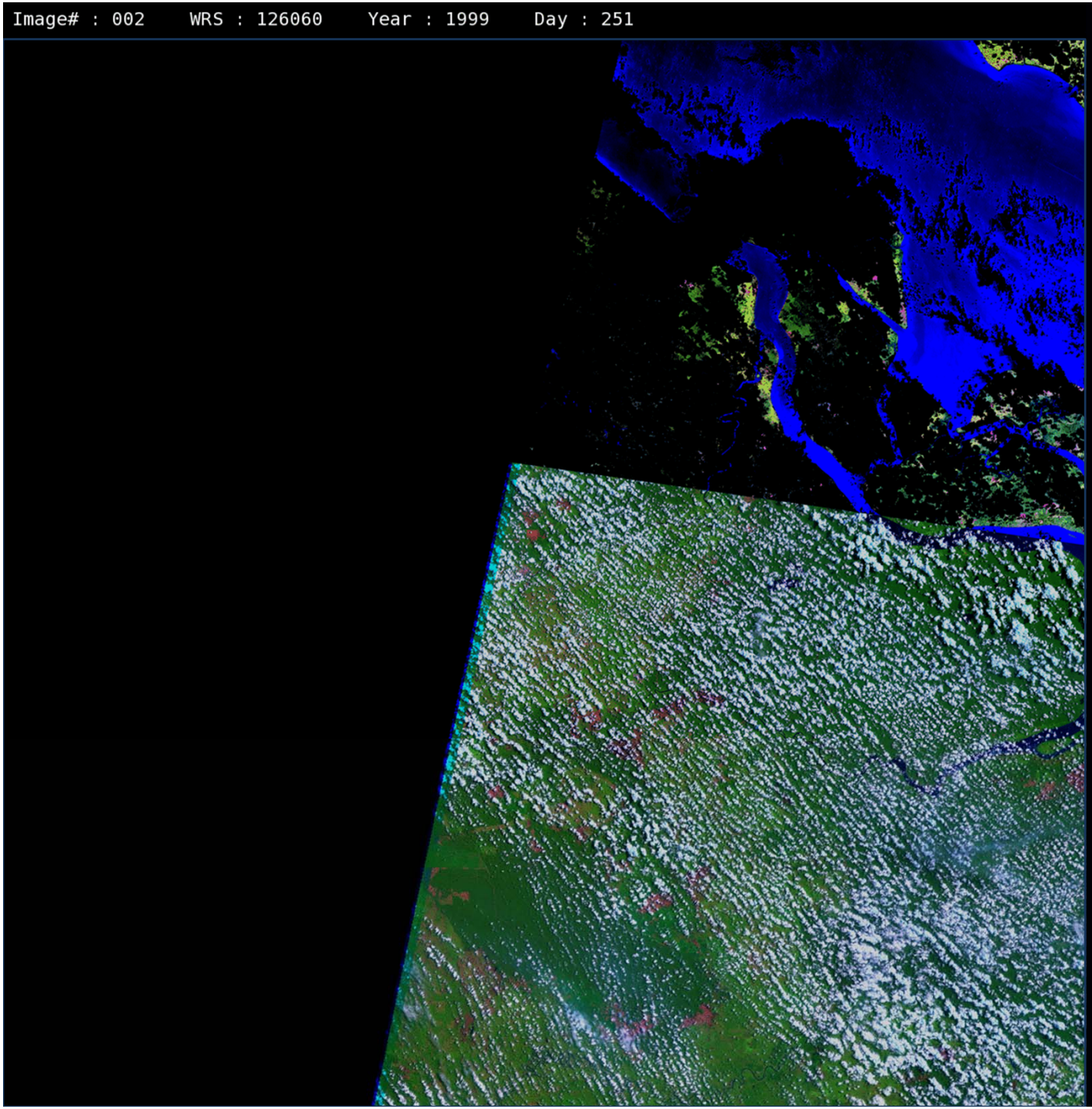
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization



Indonesia, Riau province

Image Process

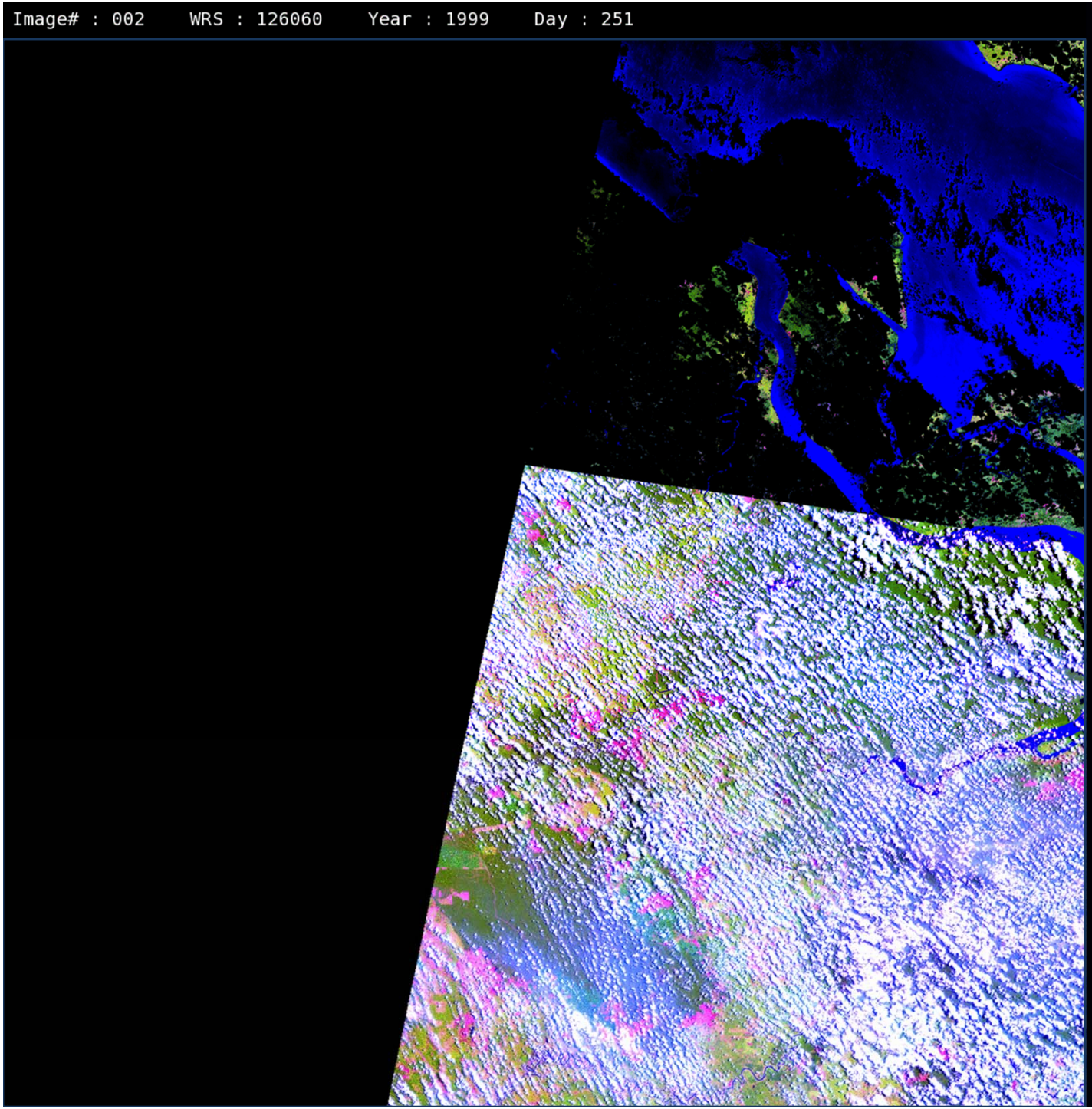
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing



Indonesia, Riau province

Image Process

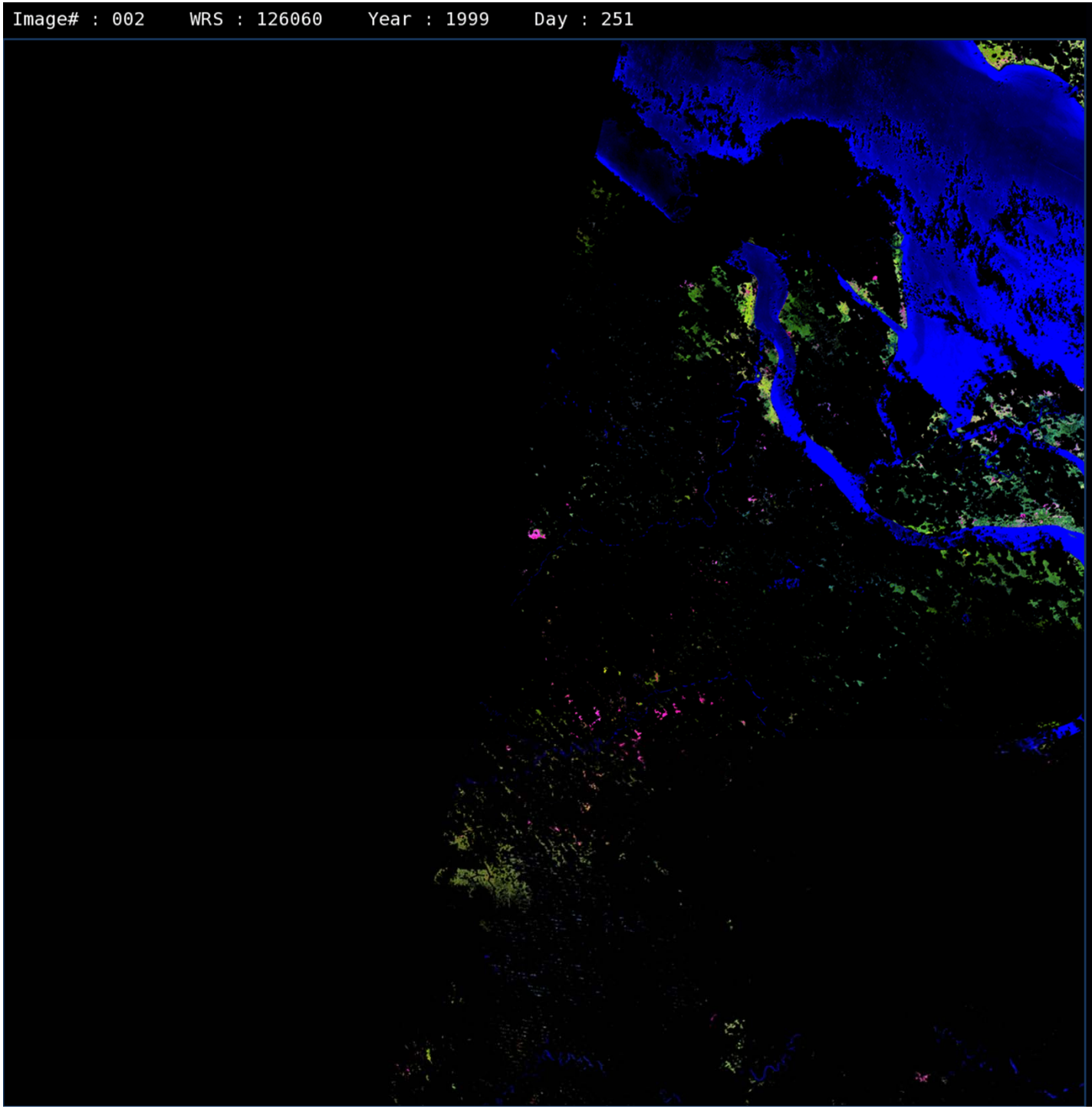
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing



Indonesia, Riau province

Image Process

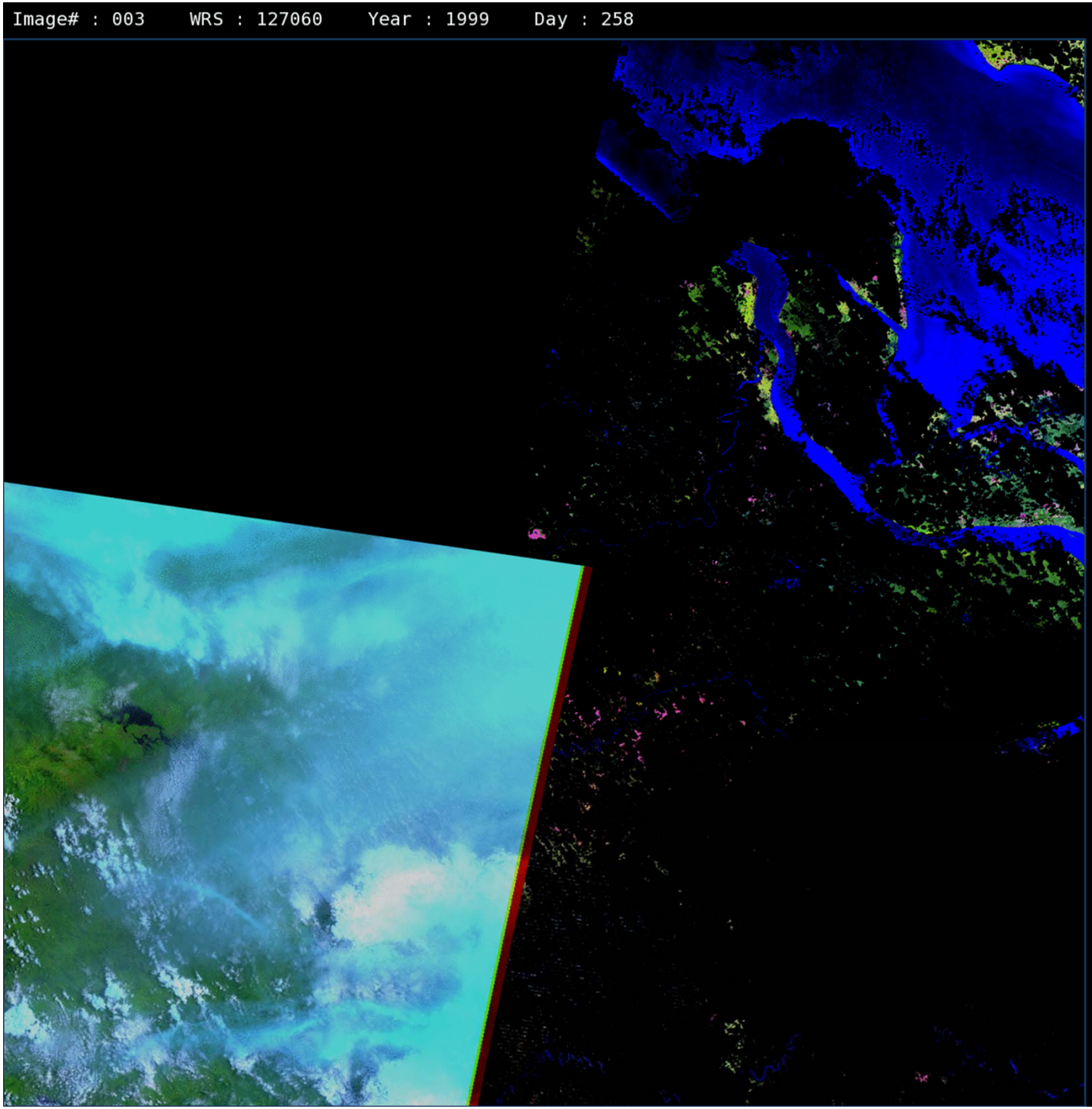
- Raw Digital Numbers
- Top-of-Atmosphere reflectance and Normalization
- Cloud masking and Compositing



Indonesia, Riau province

Image Process

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

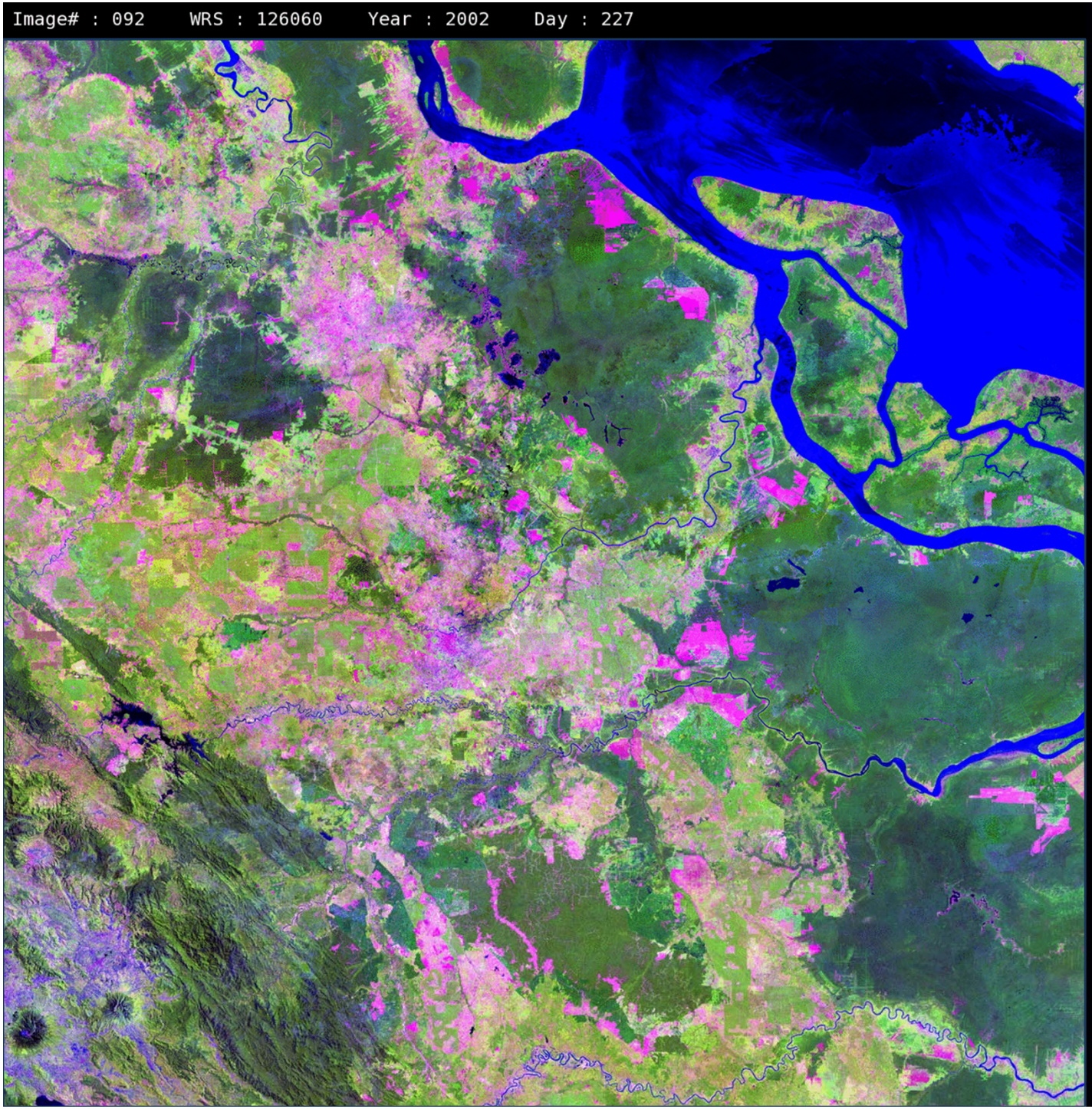


Indonesia, Riau province

Image Process

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

Compositing…



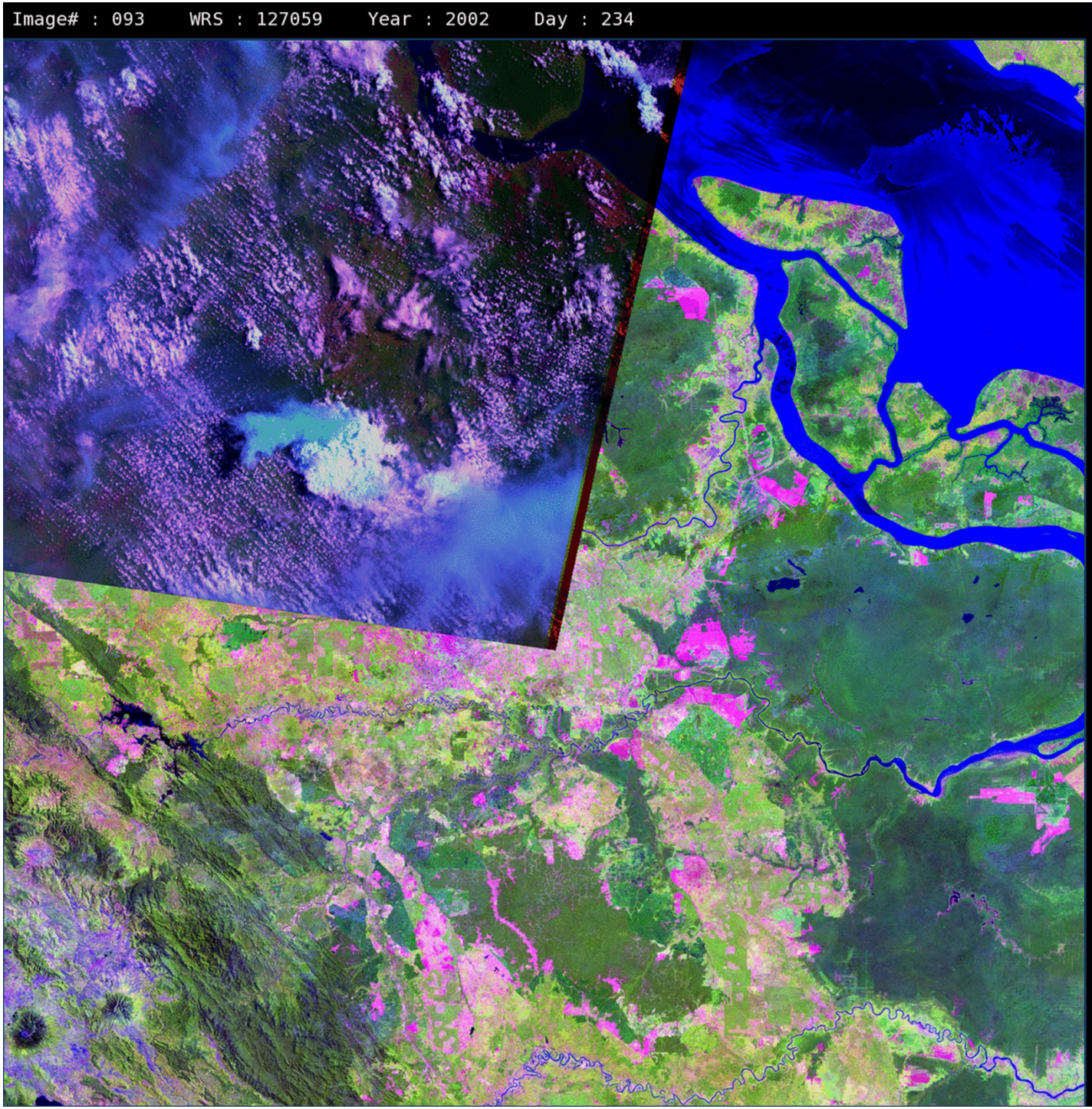
Indonesia, Riau province

Image Process

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

Cloud-free mosaic

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

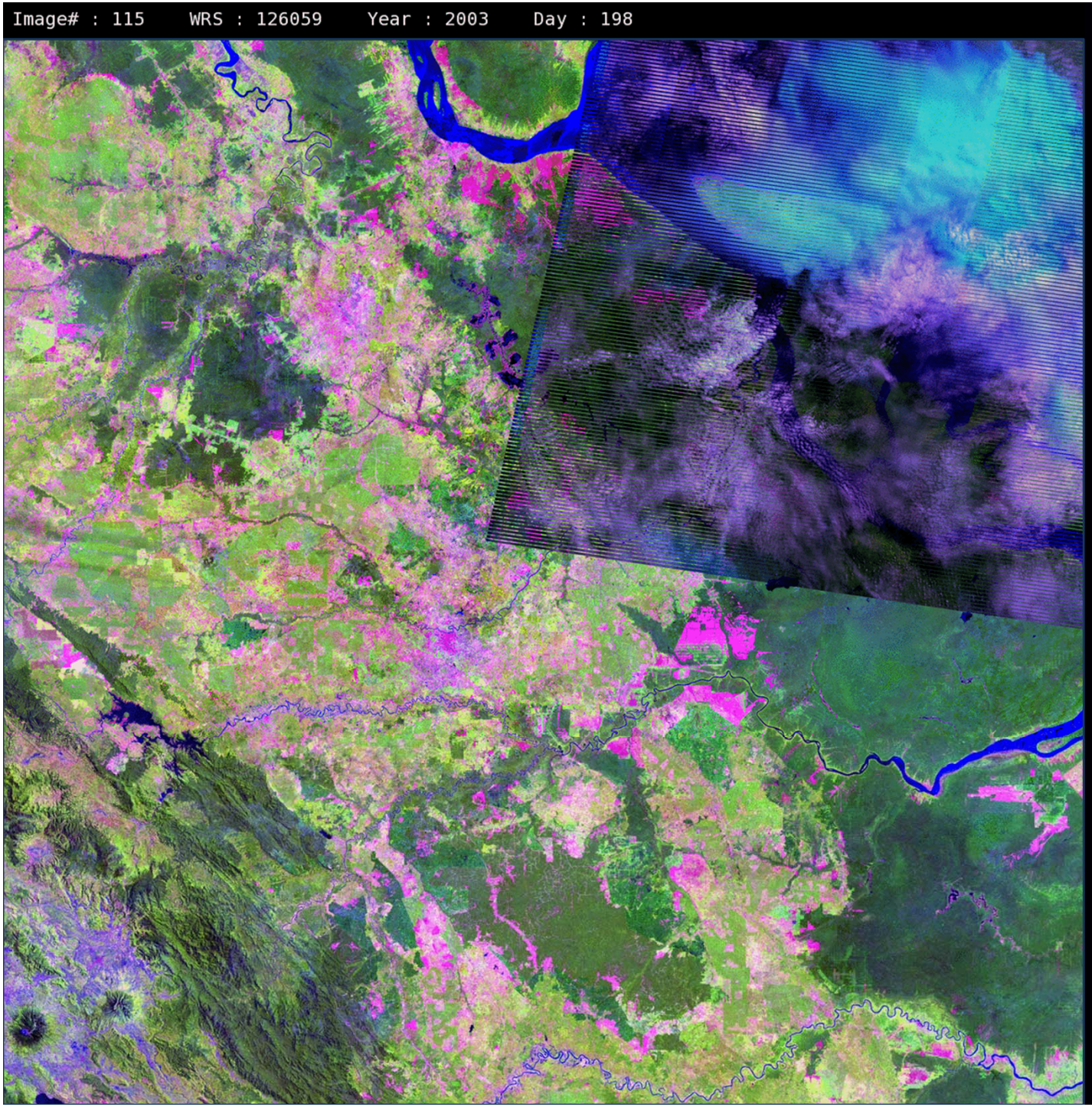


Indonesia, Riau province

Image Process

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

Keep adding data…



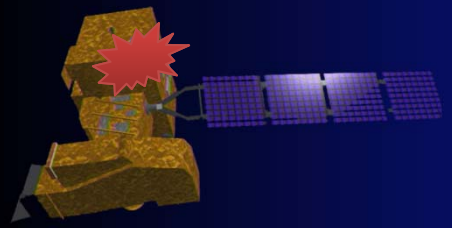
Indonesia, Riau province

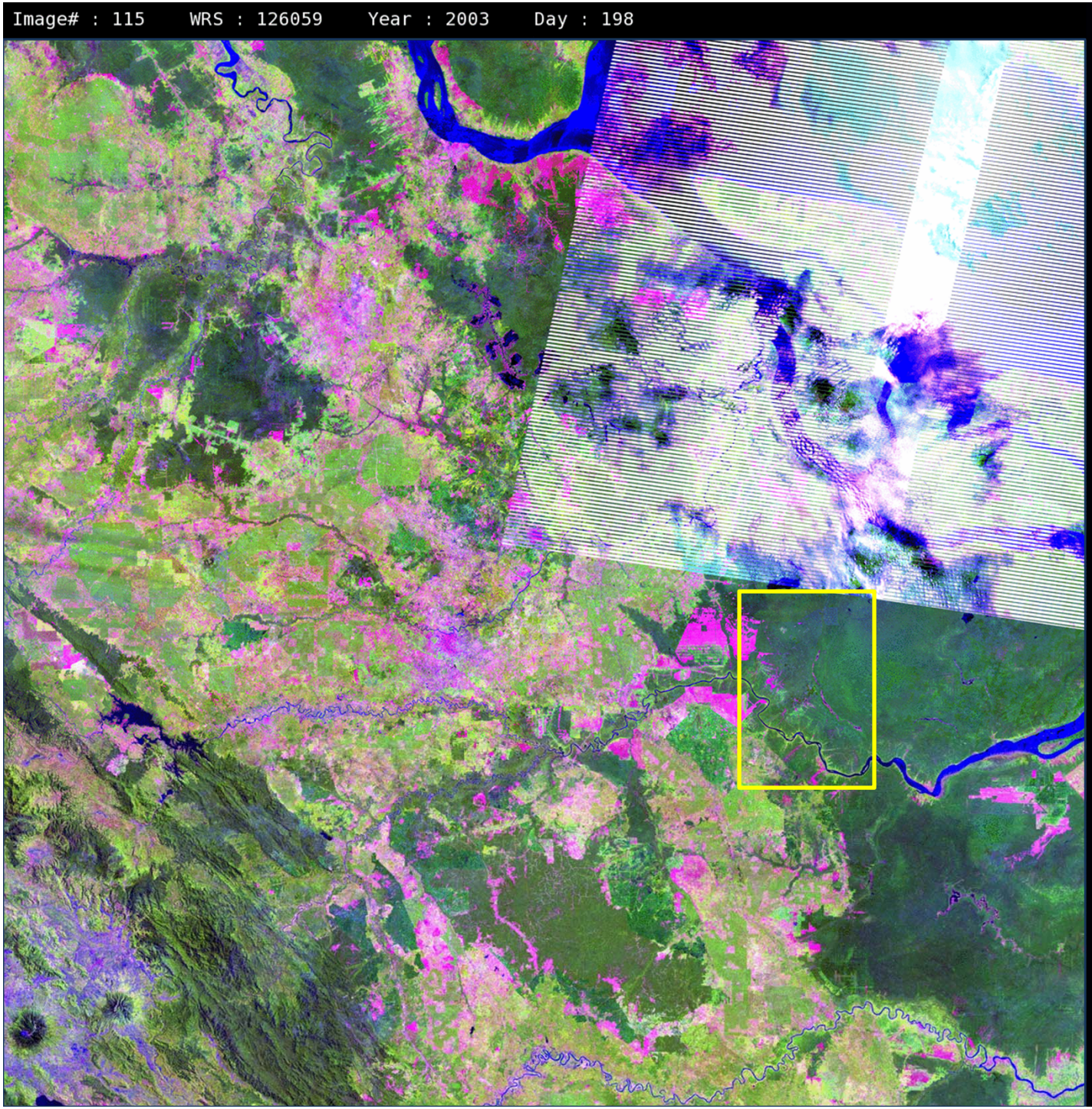
Image Process

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

Keep adding data…

Scan Line Corrector (SLC) failed – May 2003



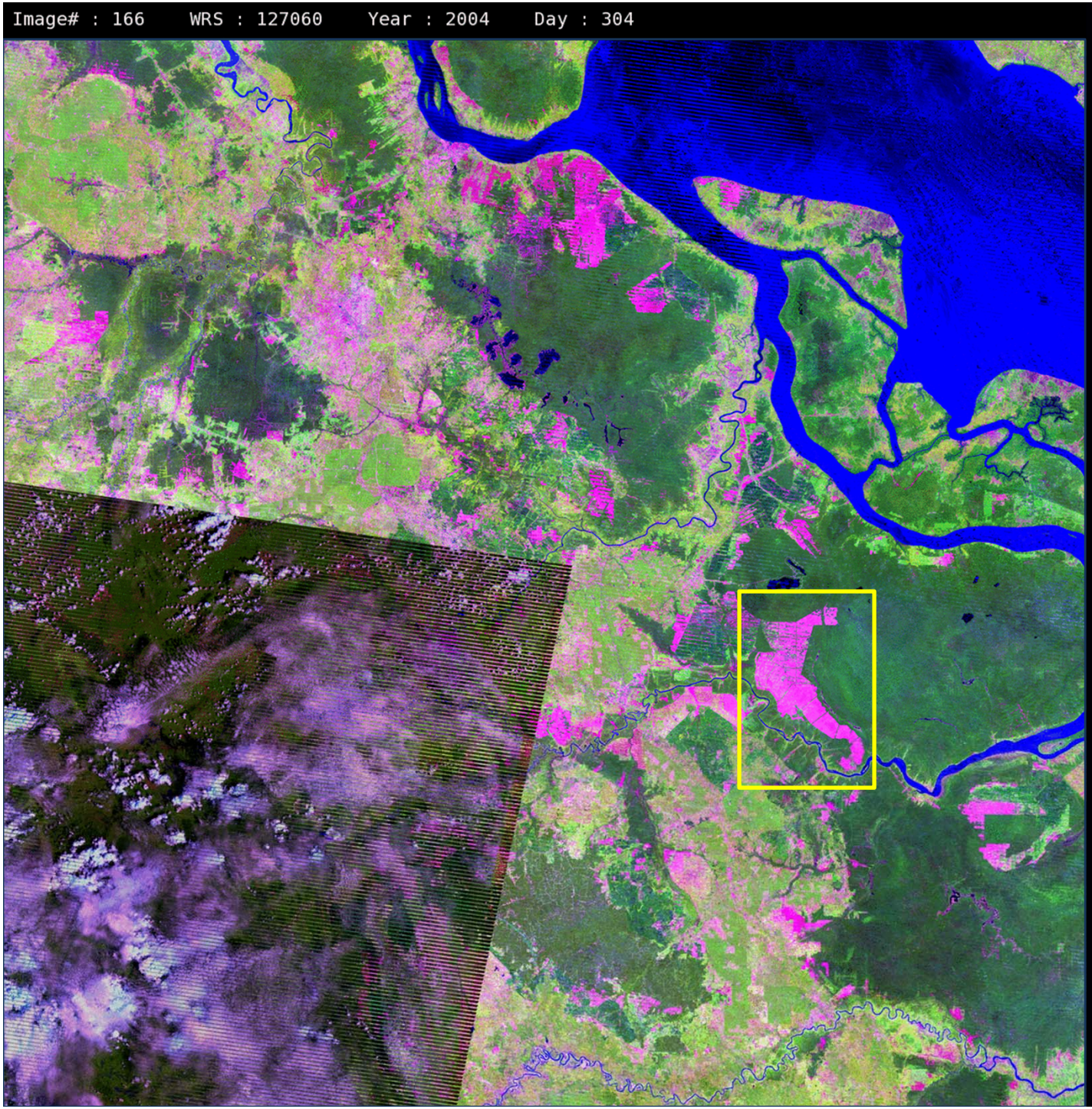


Indonesia, Riau province

Image Process

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

Adding SLC-OFF data…

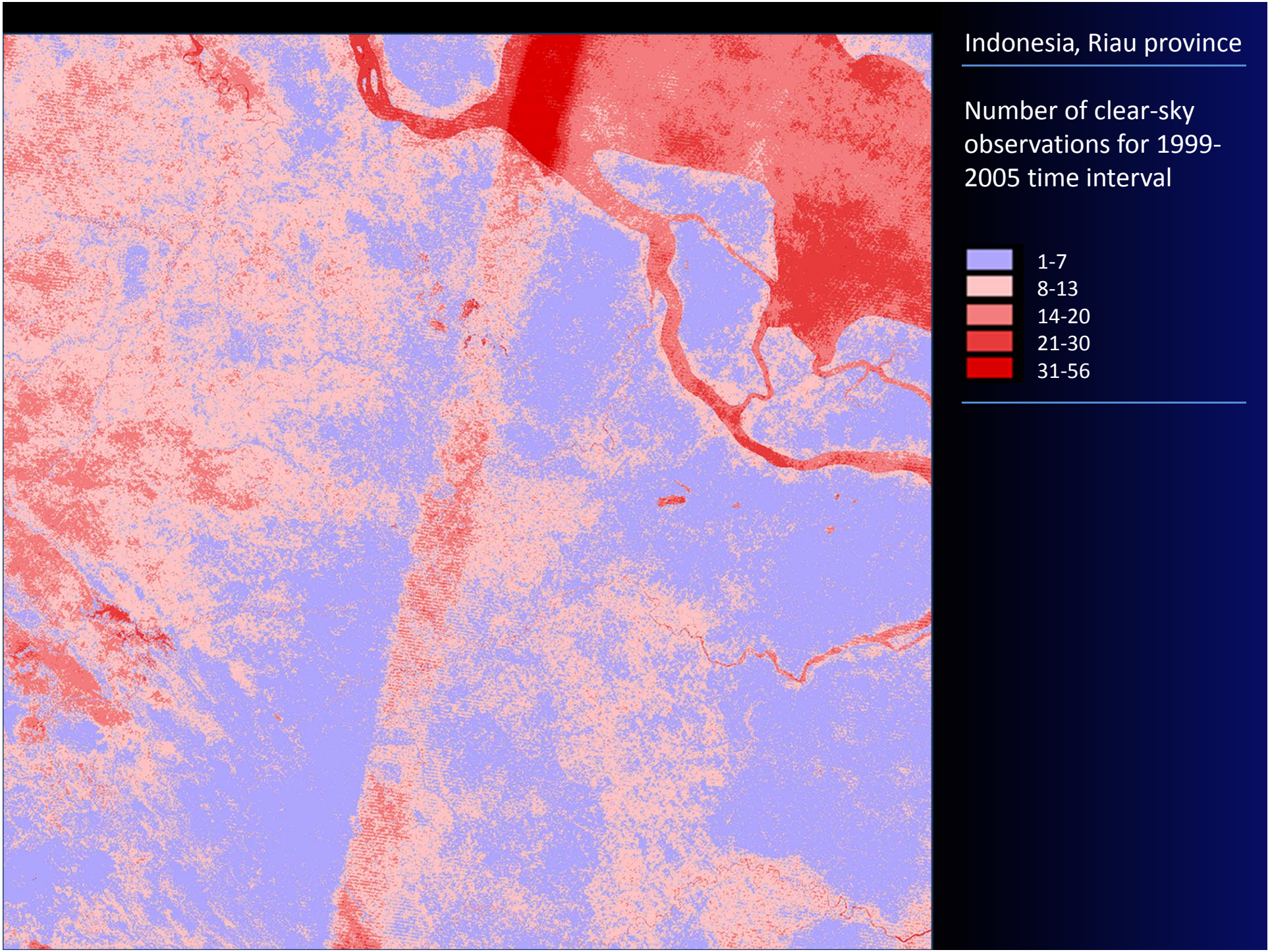


Indonesia, Riau province

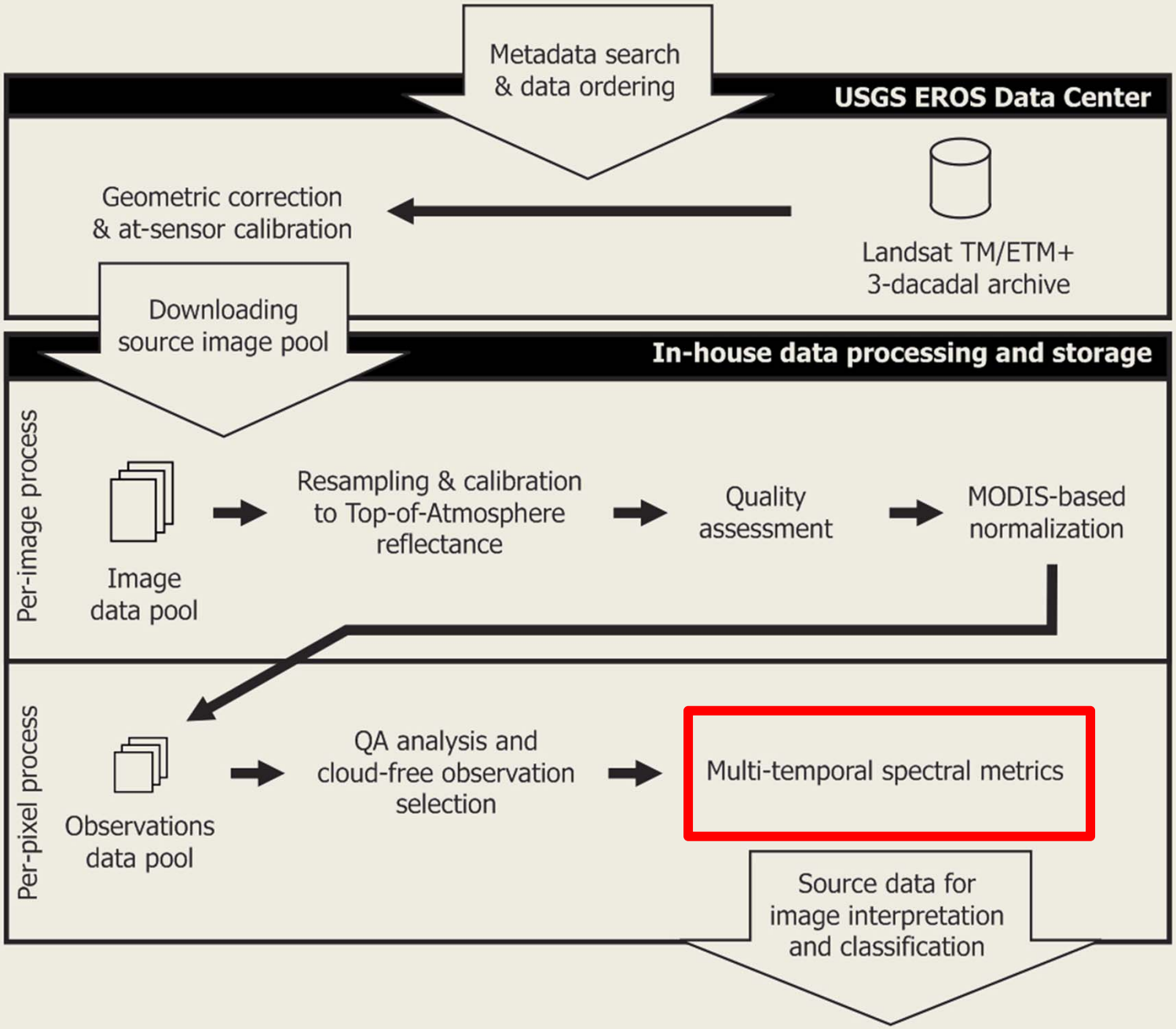
Image Process

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

Landsat data processing workflow

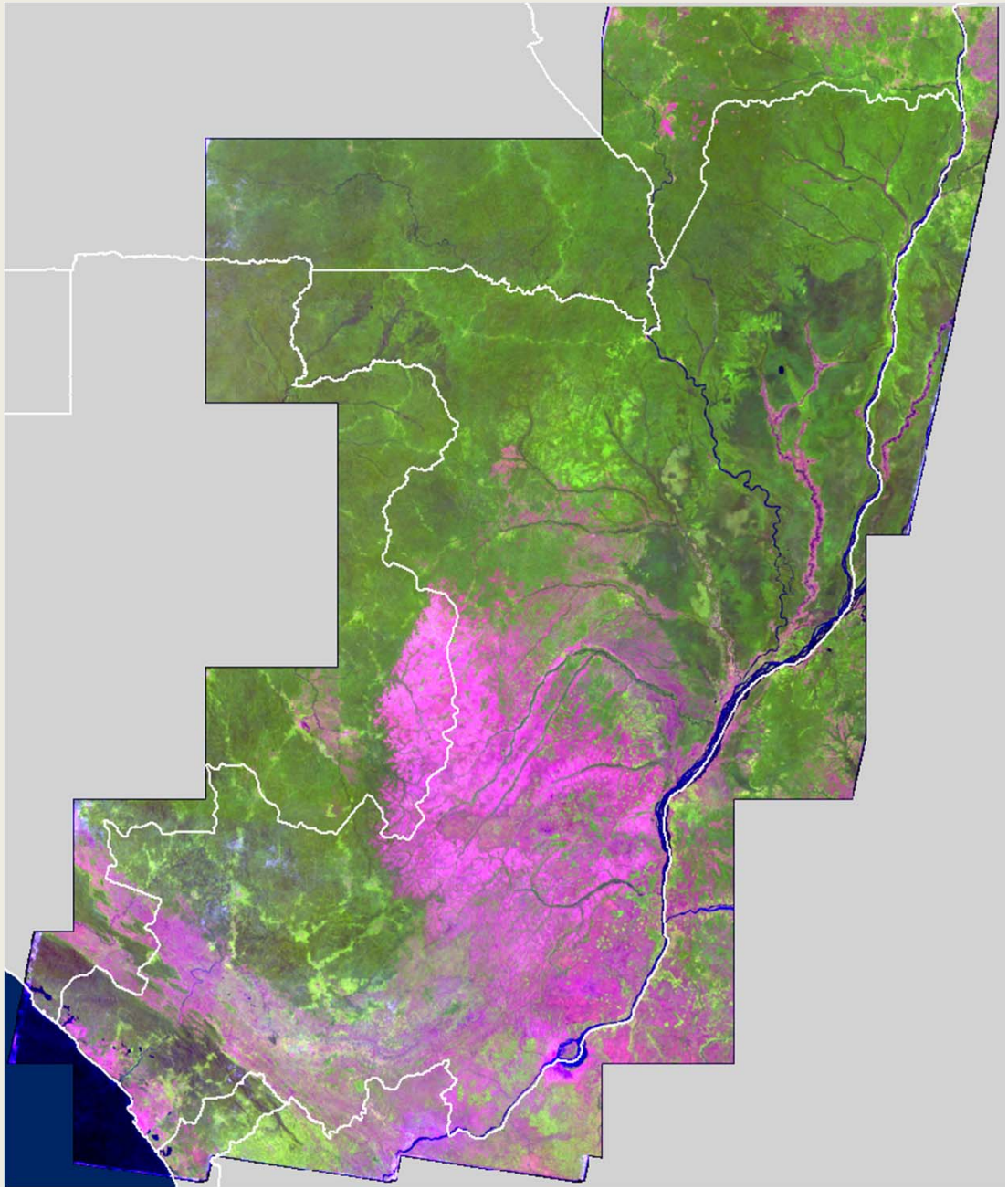


Multi-temporal metrics approach

- 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

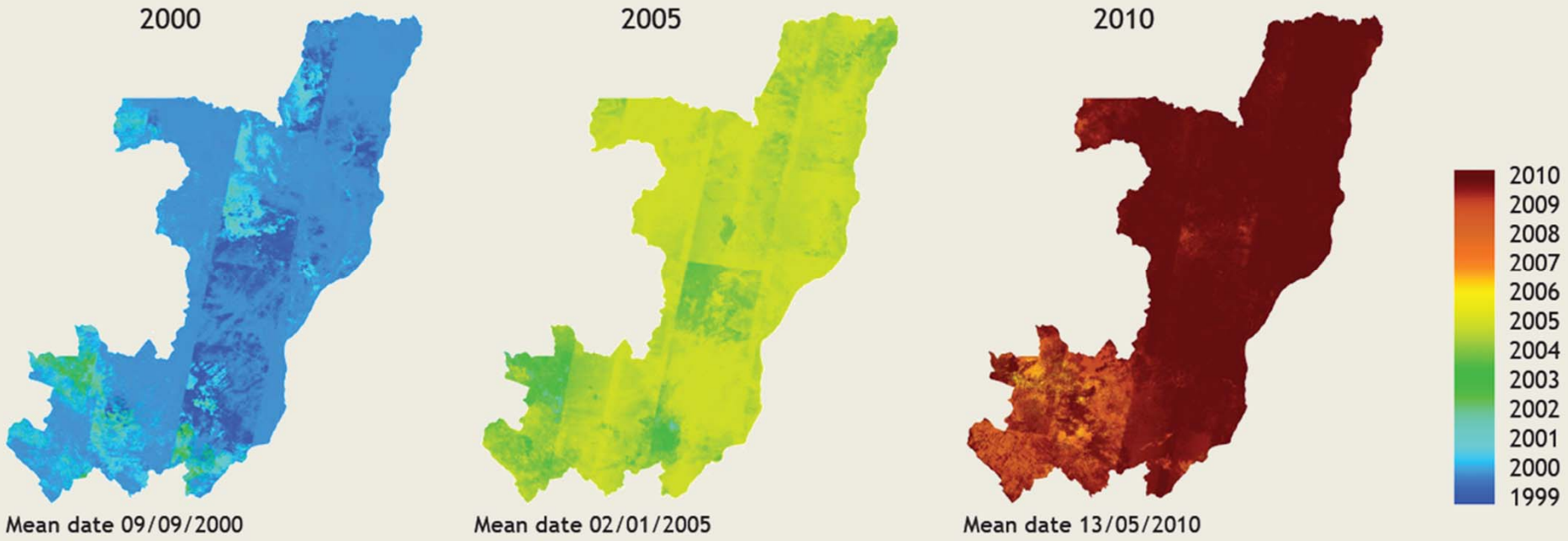


Image composite metrics

Shortcomings of time-sequential composites

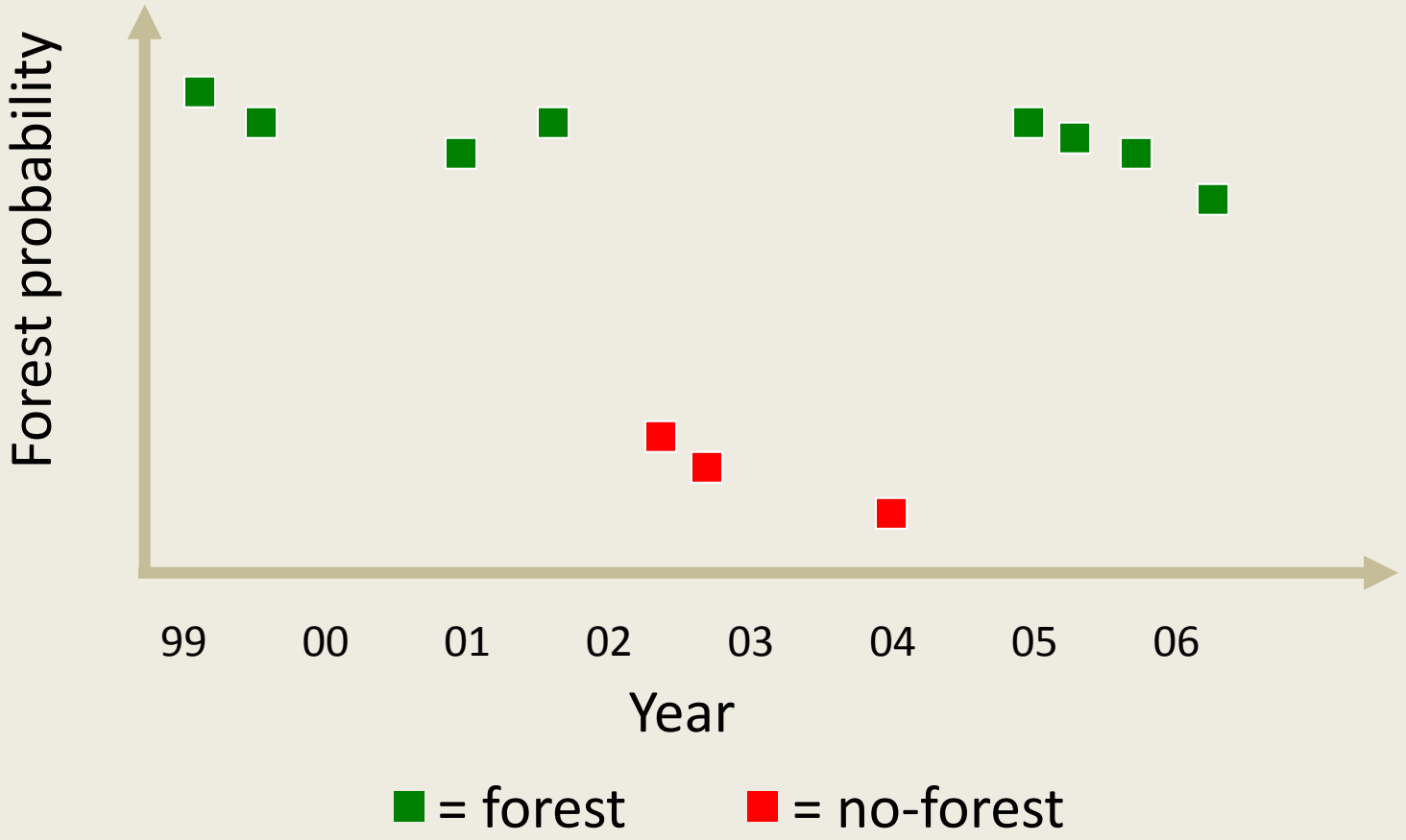
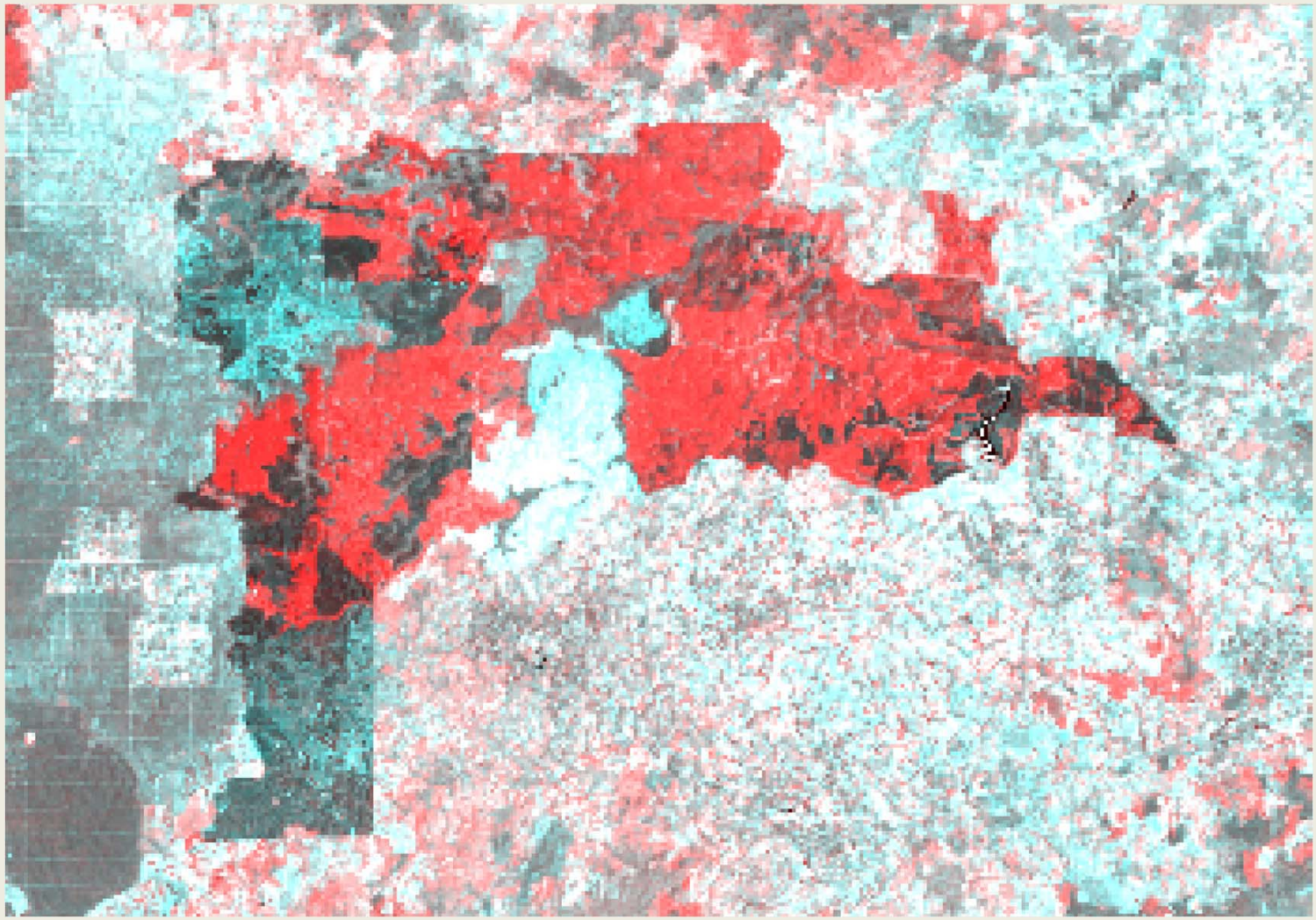


Image composite metrics

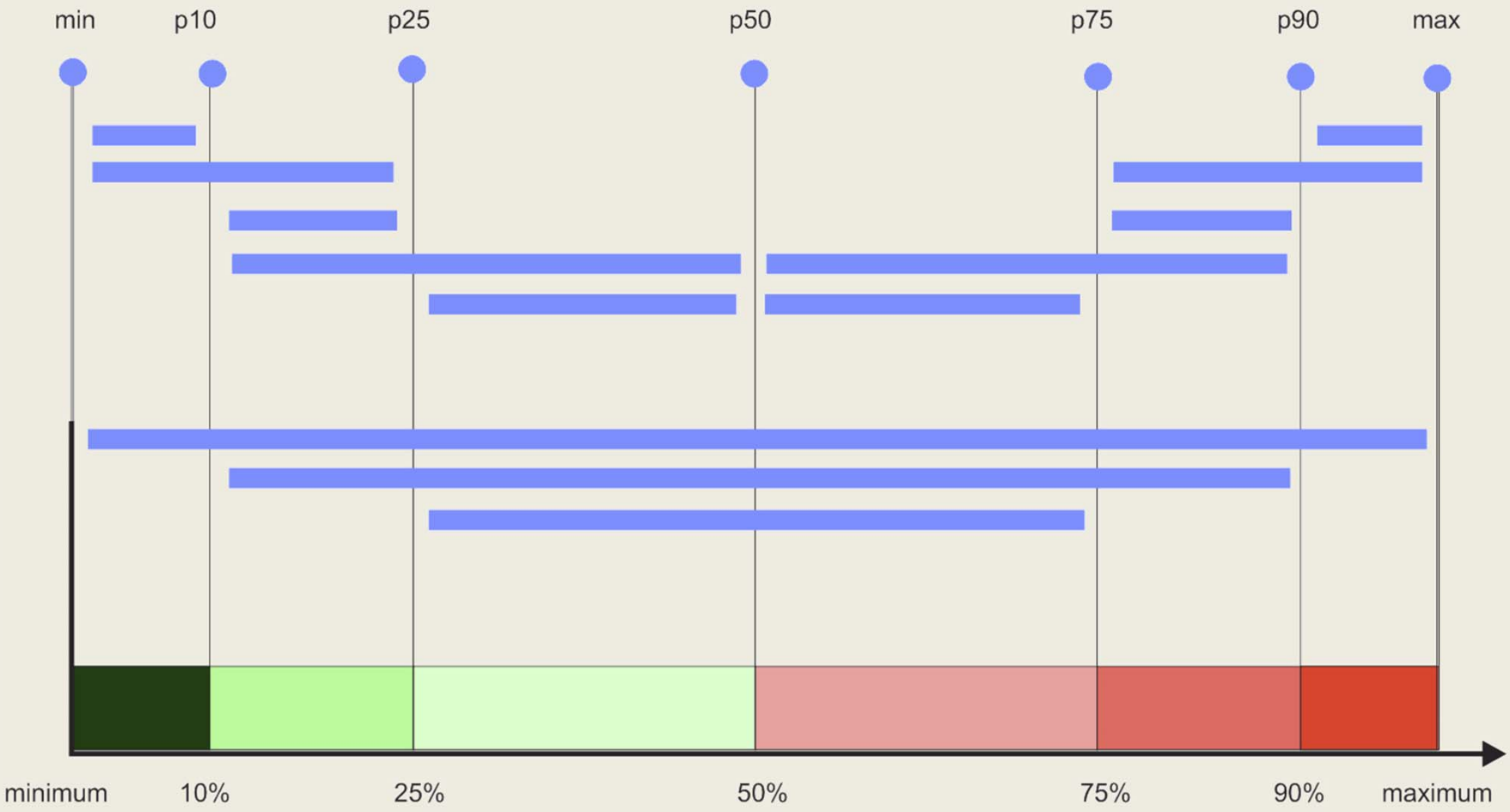
Shortcomings of time-sequential composites



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

Rank-based metrics

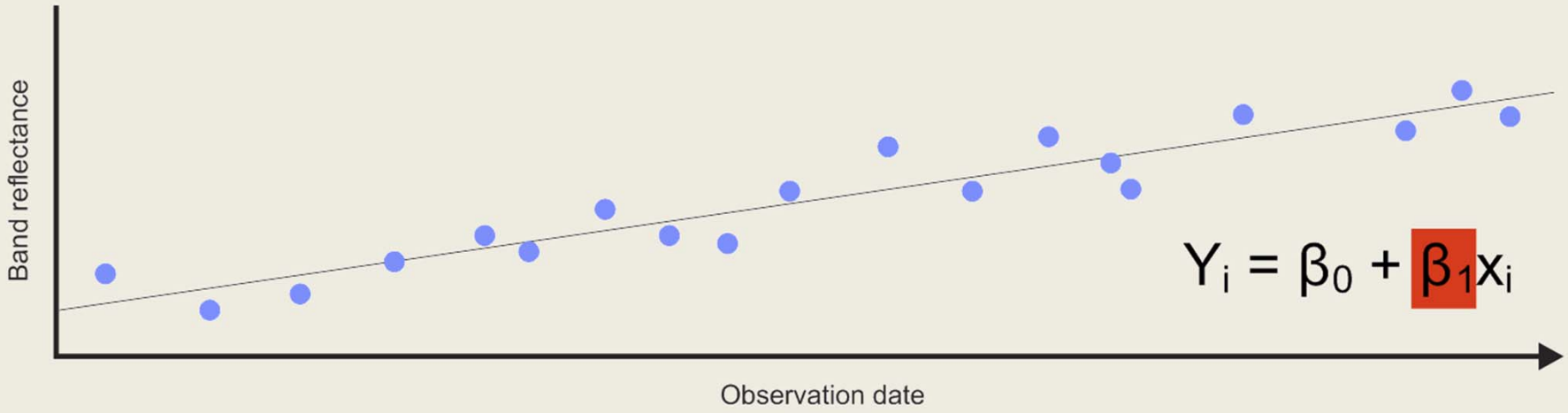
Rank-based metrics types



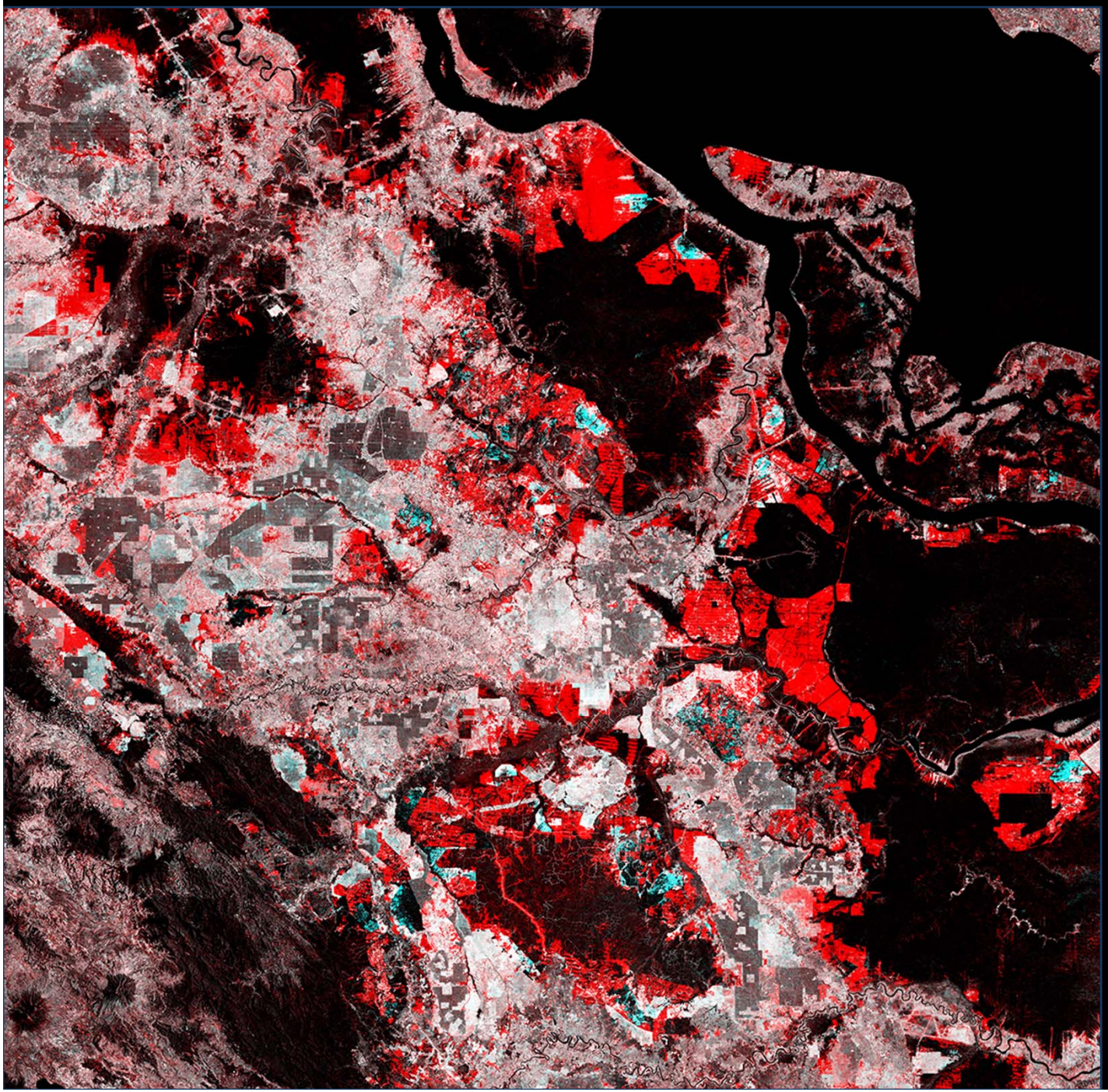
- Ranked by band value (b3, b4, b5, b7, NDVI, NBR)
- Ranked by corresponding band/index value (b3, b4, b5, b7)
  - NDVI, NBR, Brightness temperature

Trend analysis metrics

Linear regression



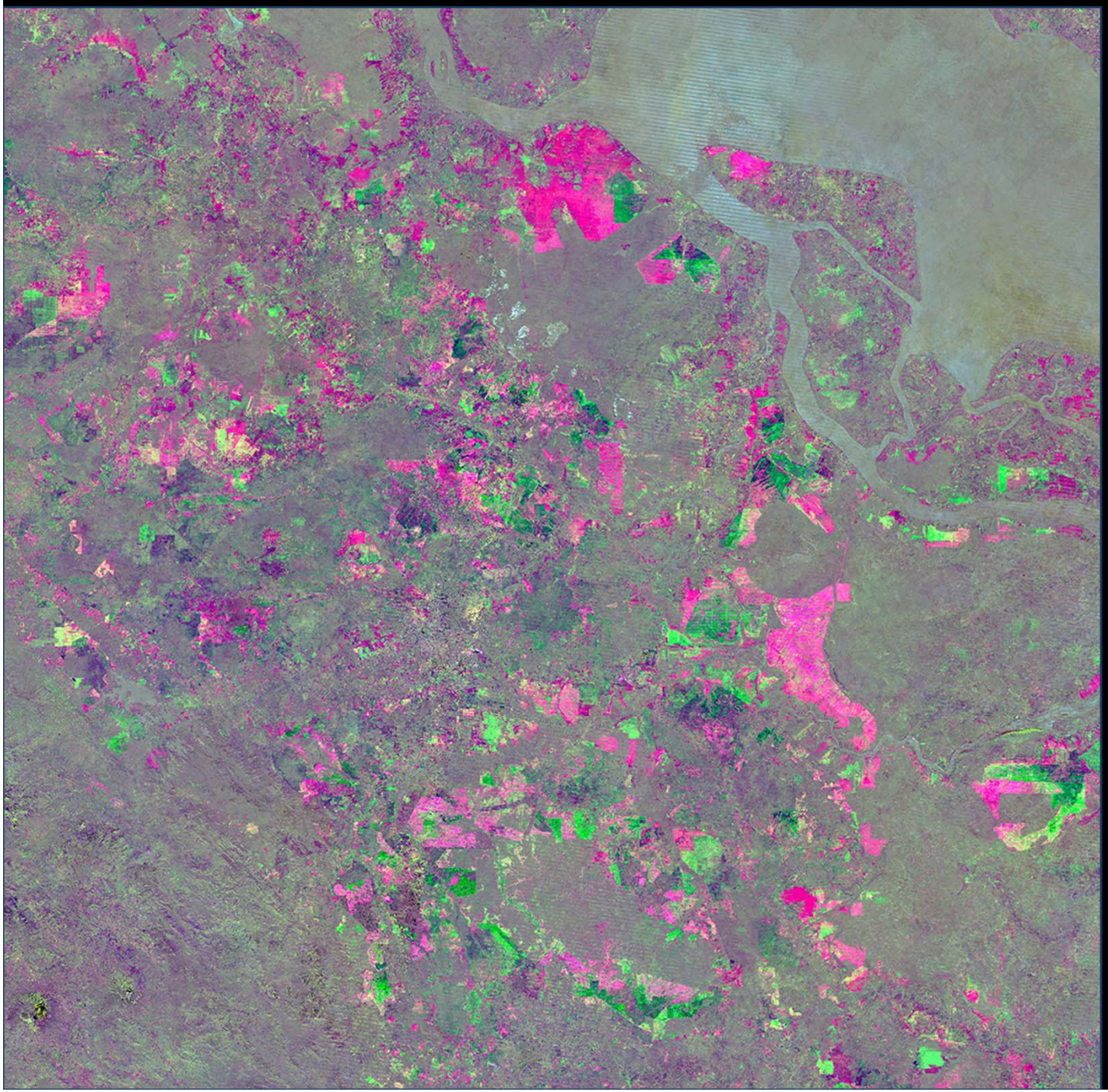
- Slope of linear regression of band reflectance vs. image date
  - Single-date observations
  - Annual median reflectance
- Standard deviation of reflectance value
  - Single-date observations
  - Annual median reflectance



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
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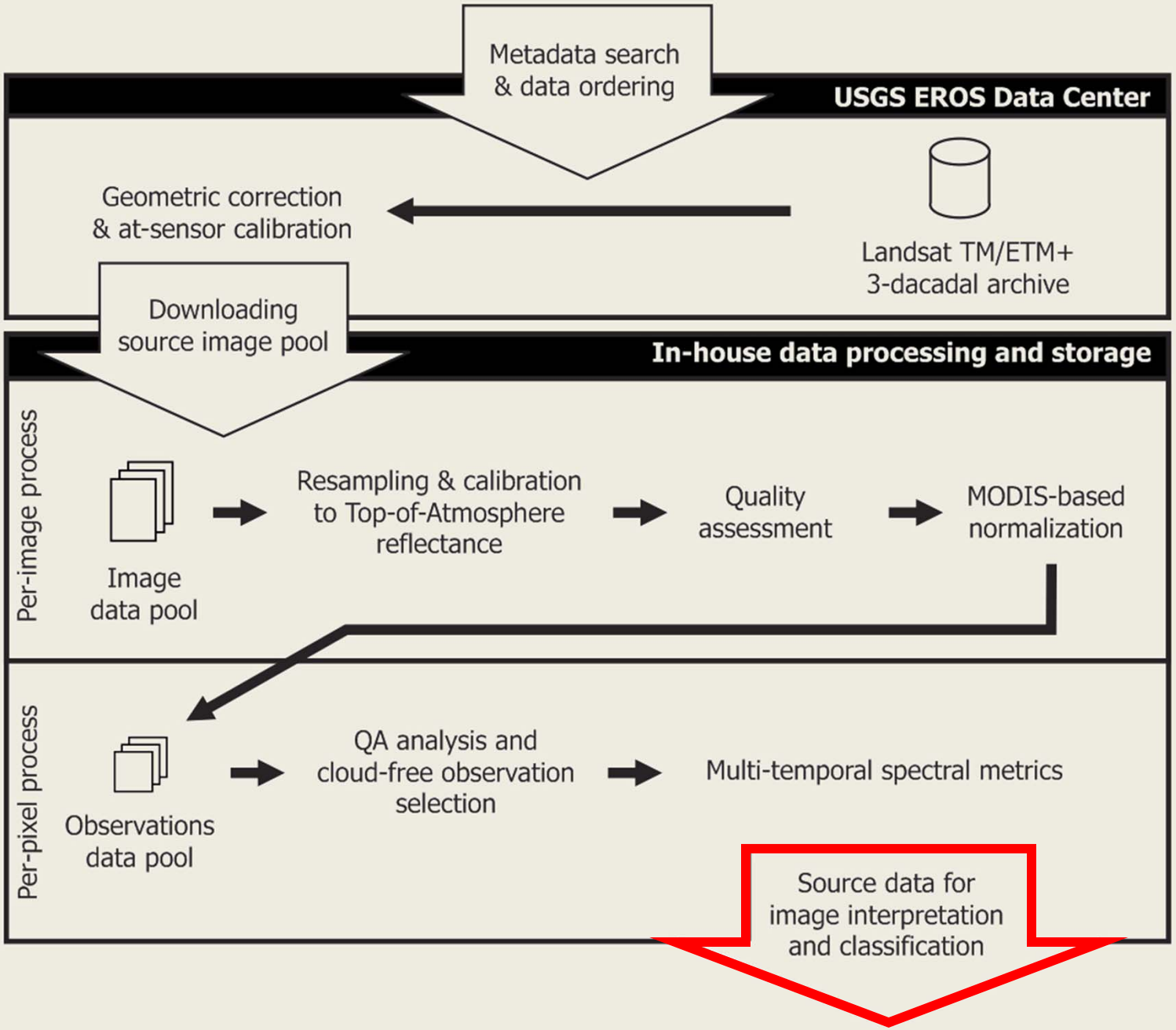
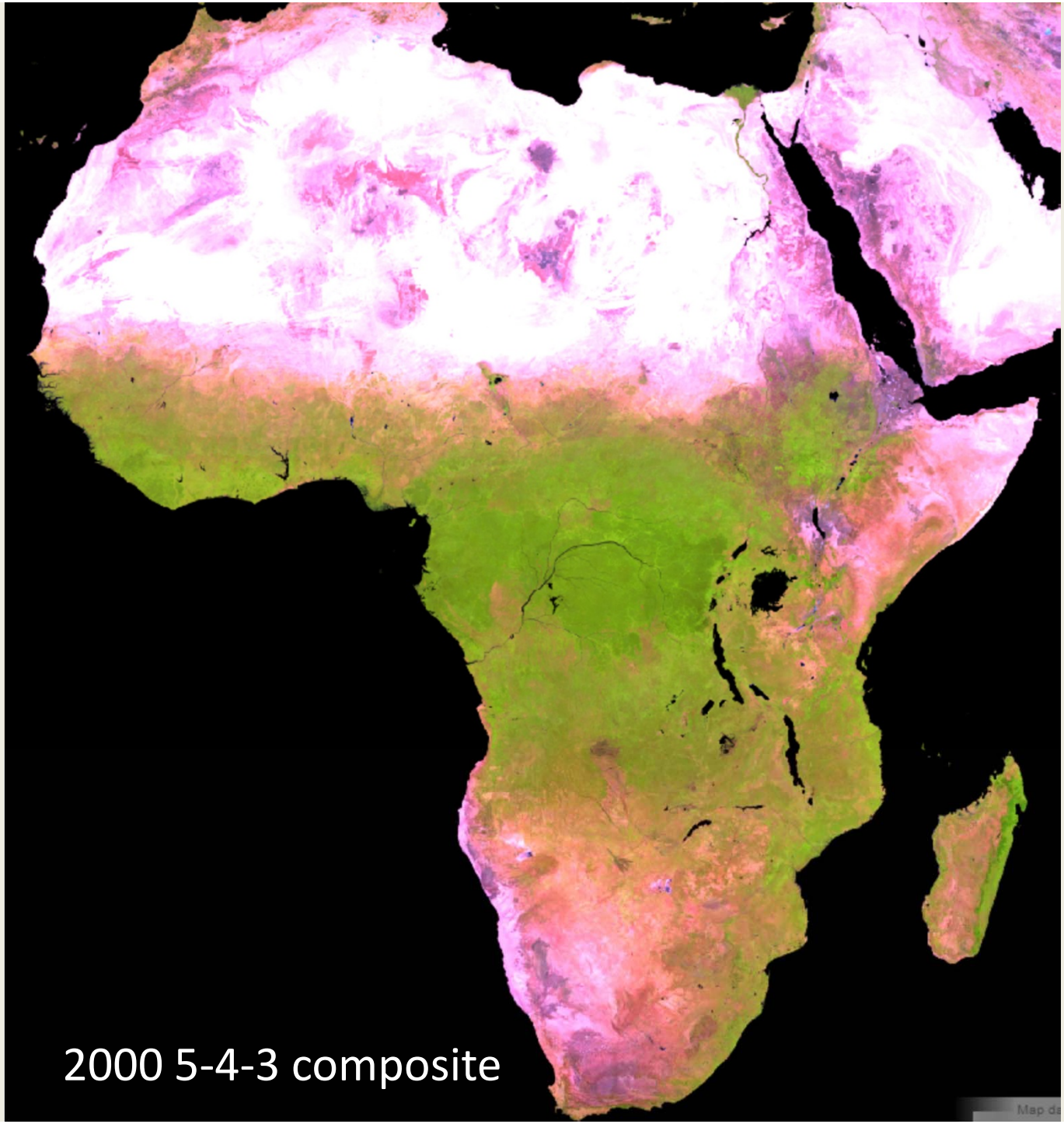
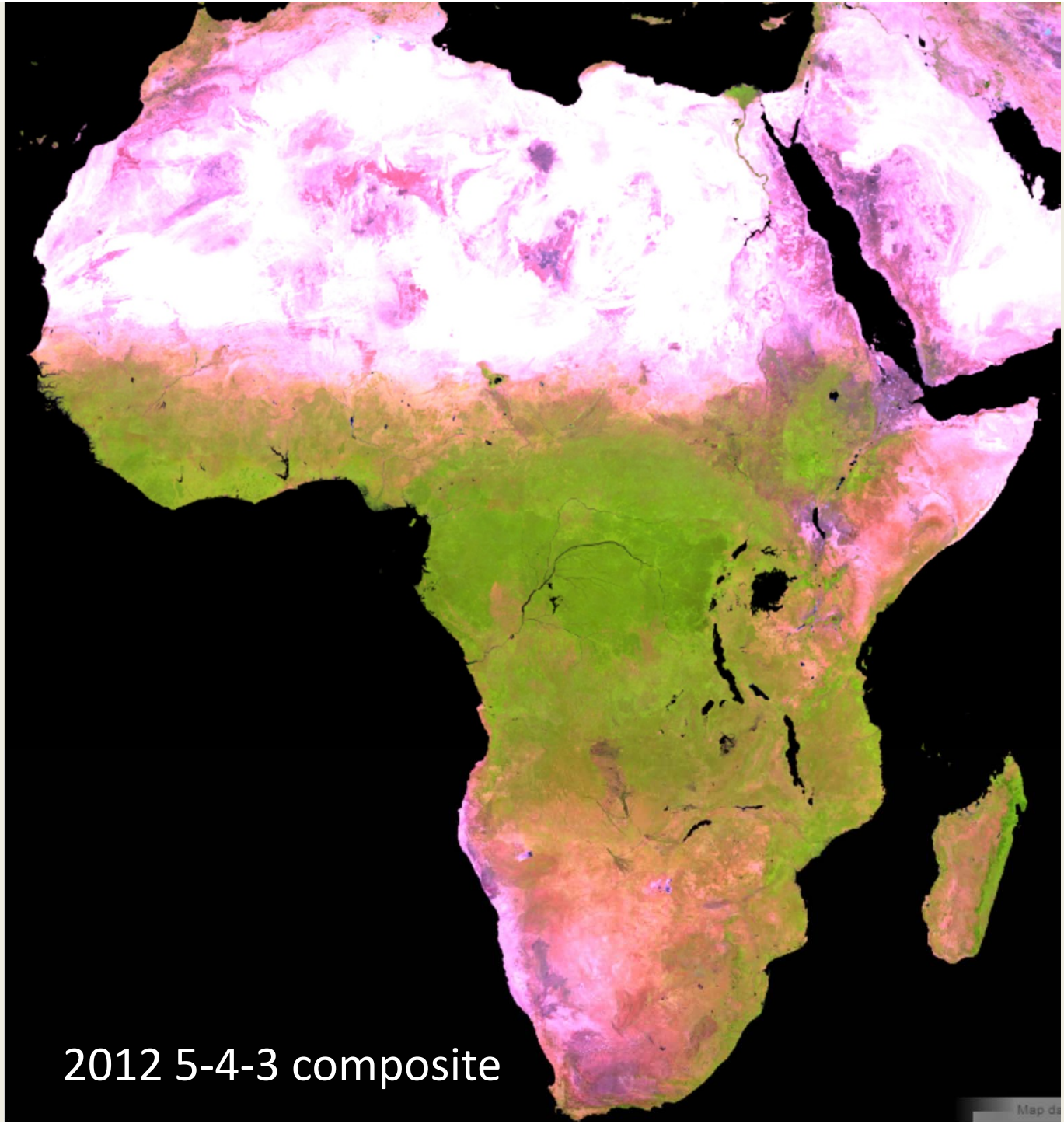
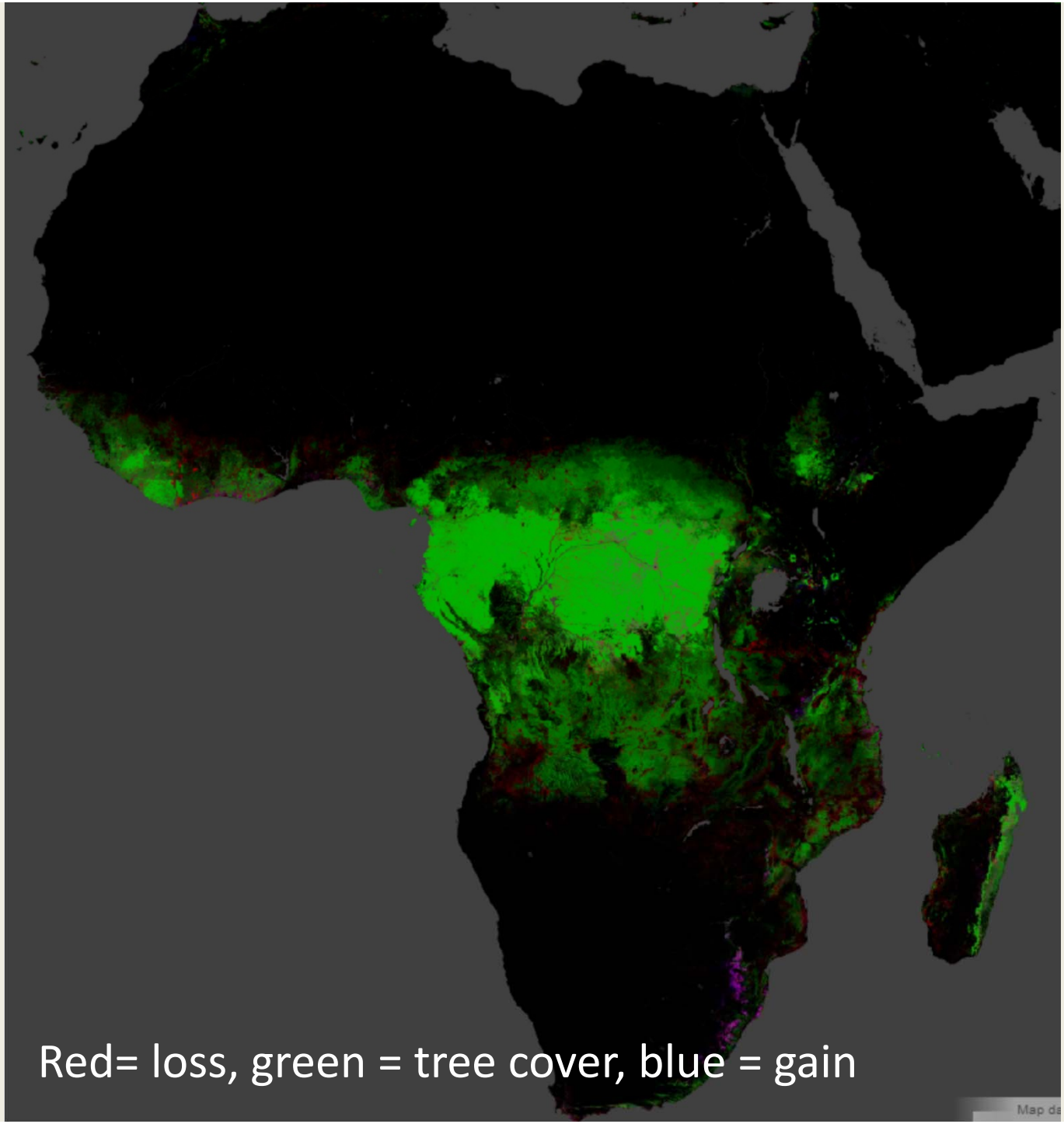
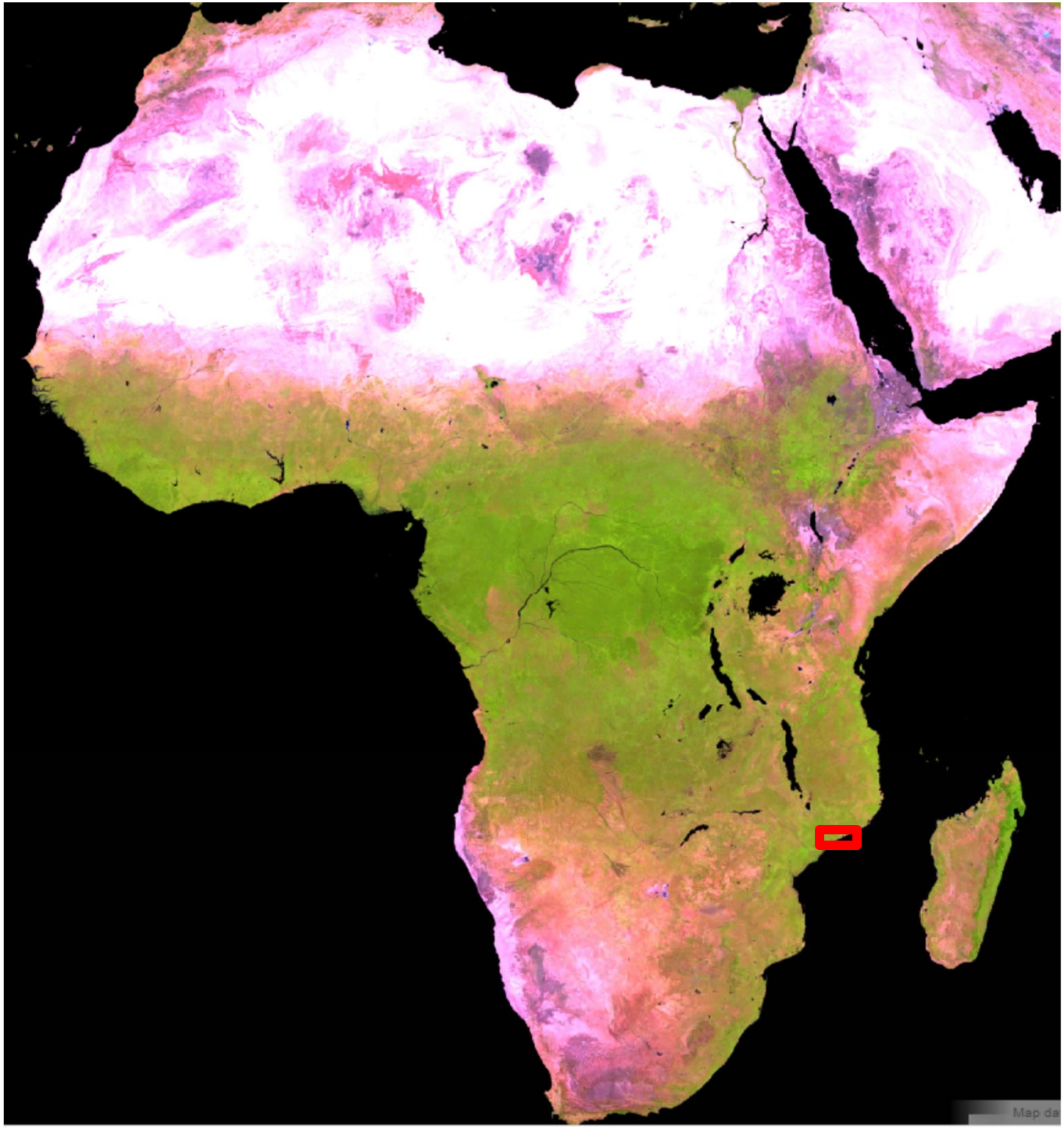
Landsat data processing workflow



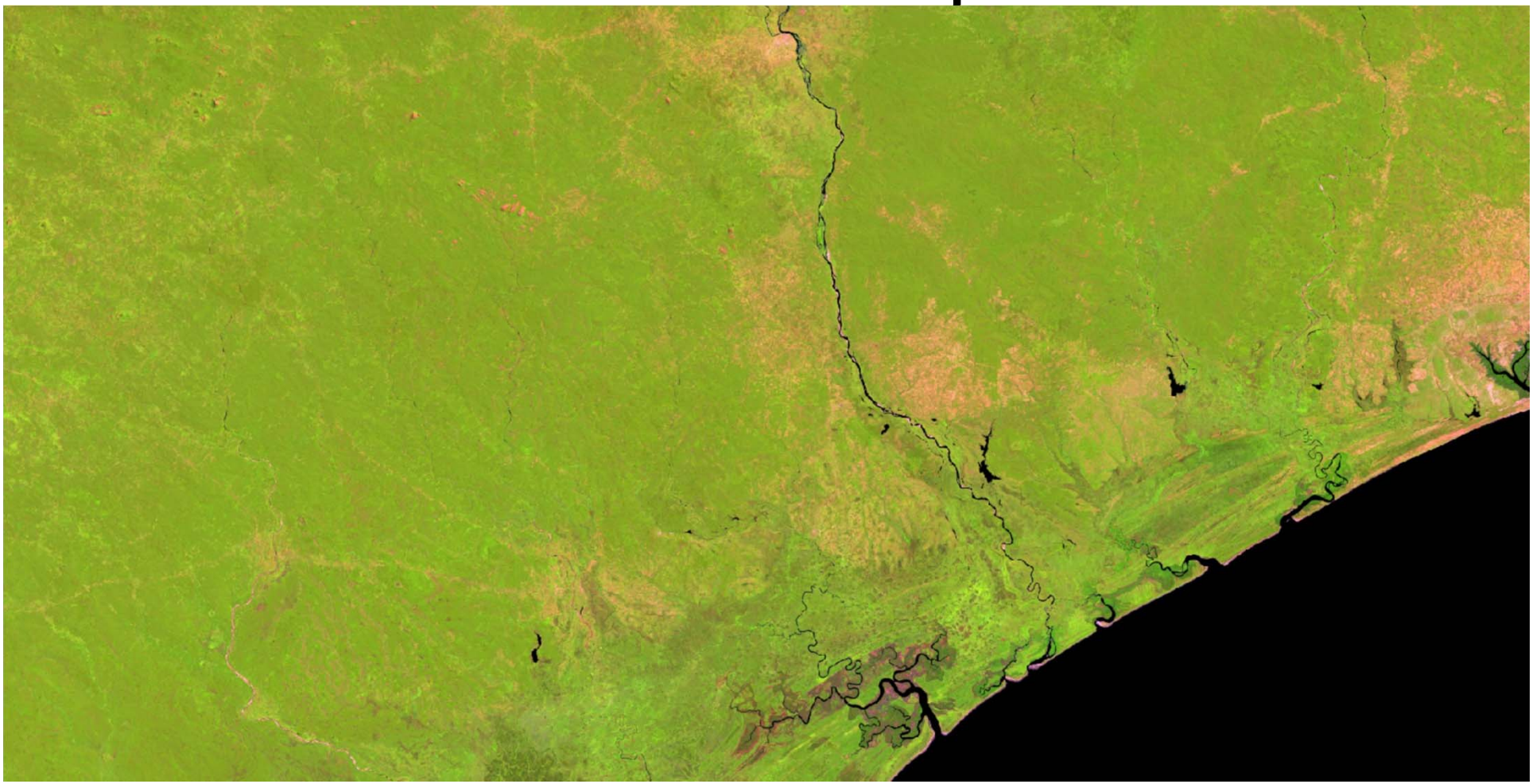

2000 5-4-3 composite


2012 5-4-3 composite


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

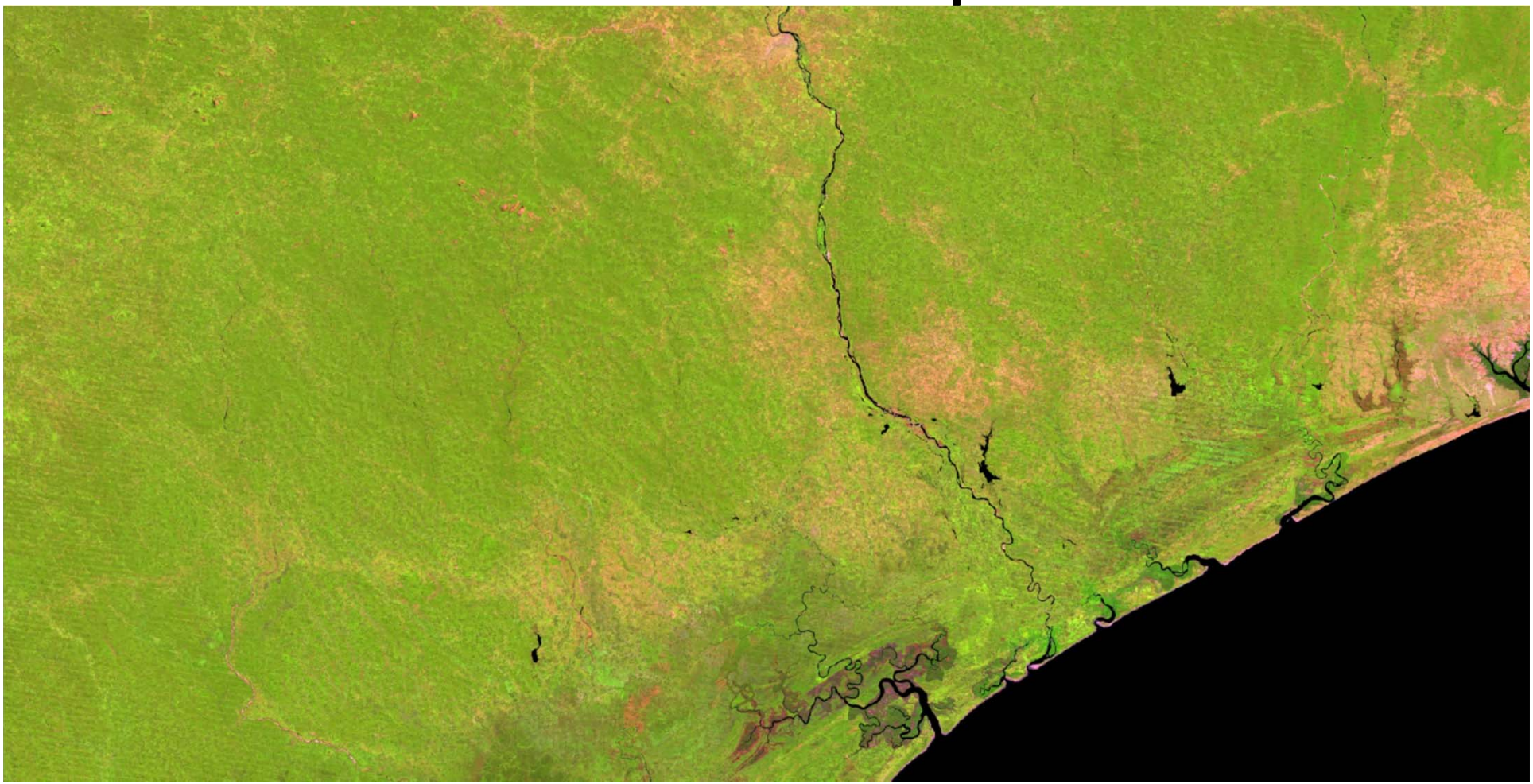


2000 5-4-3 composite



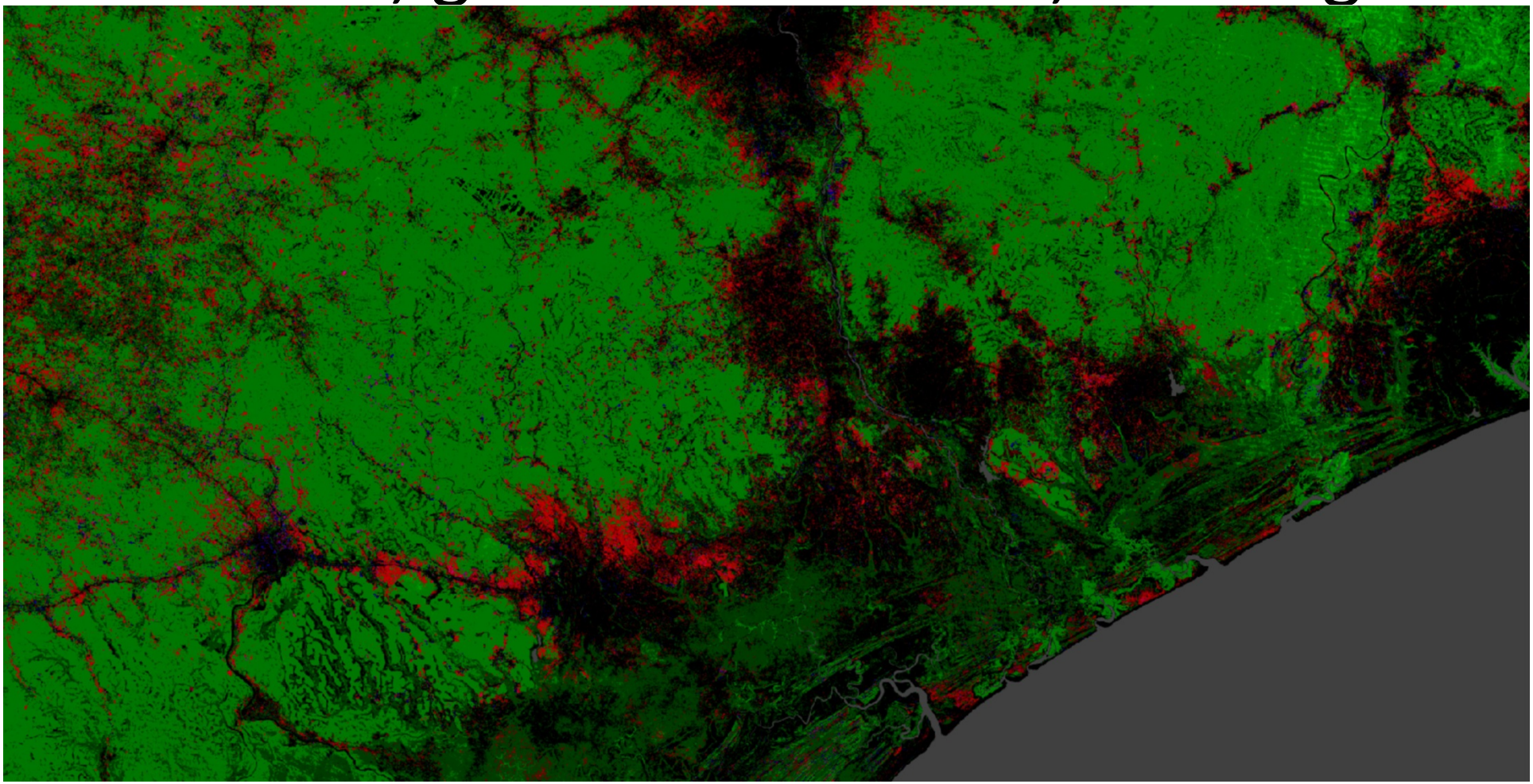
Southern Zambezia

2012 5-4-3 composite



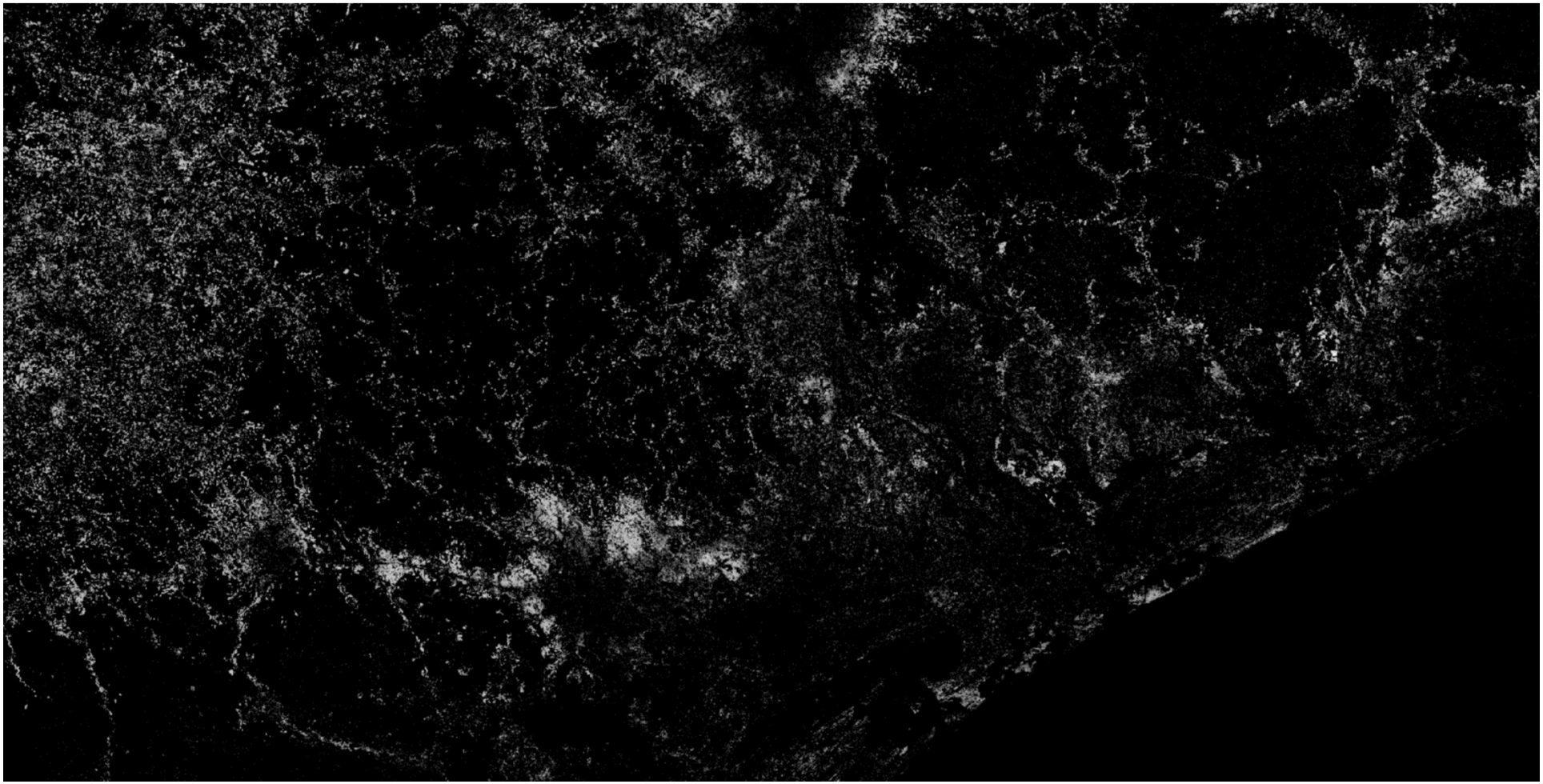
Mashonaland West

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



Southern Zambezia

Forest loss

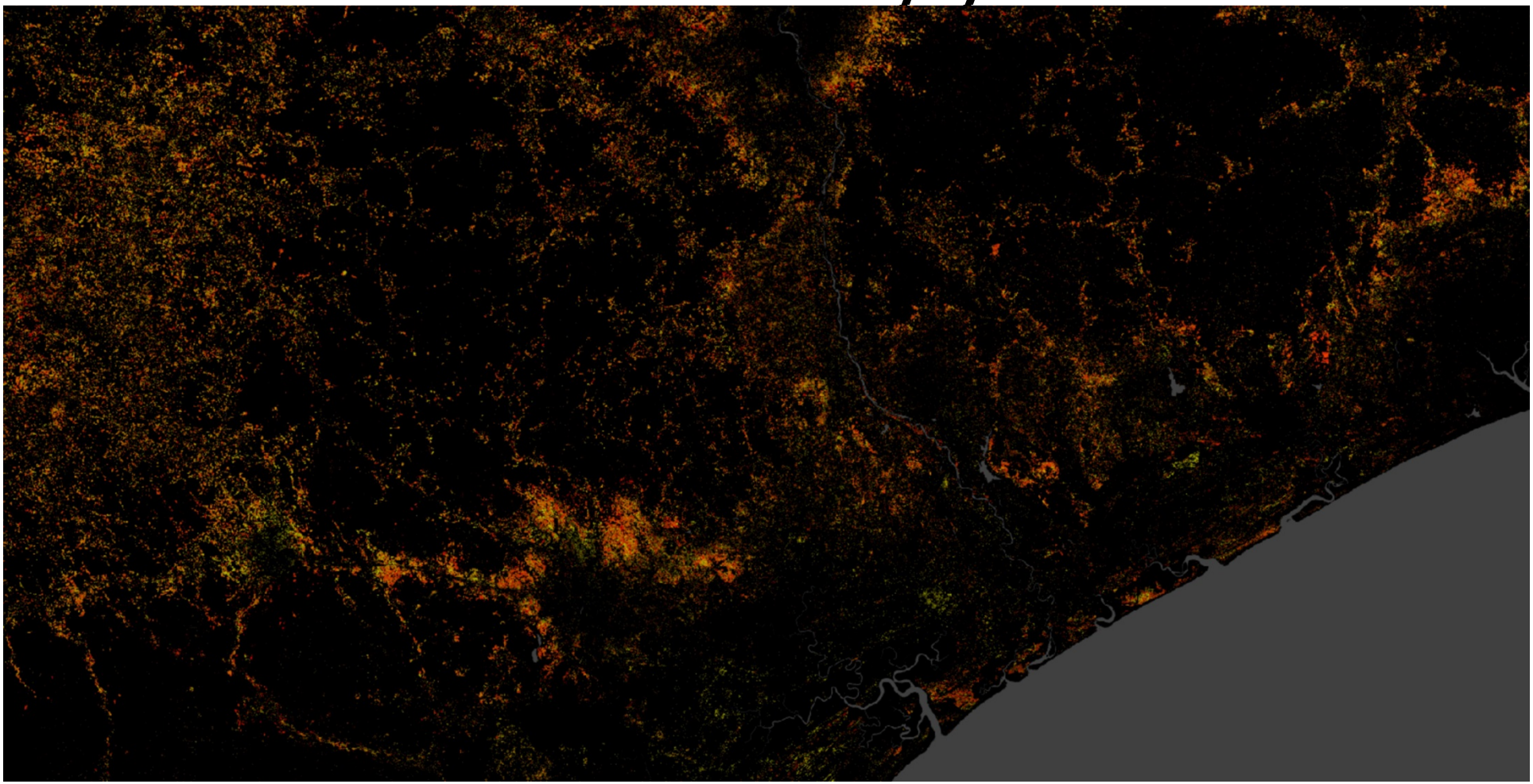


Loss

No loss

Southern Zambezia

Forest loss by year



2000 2005 2012

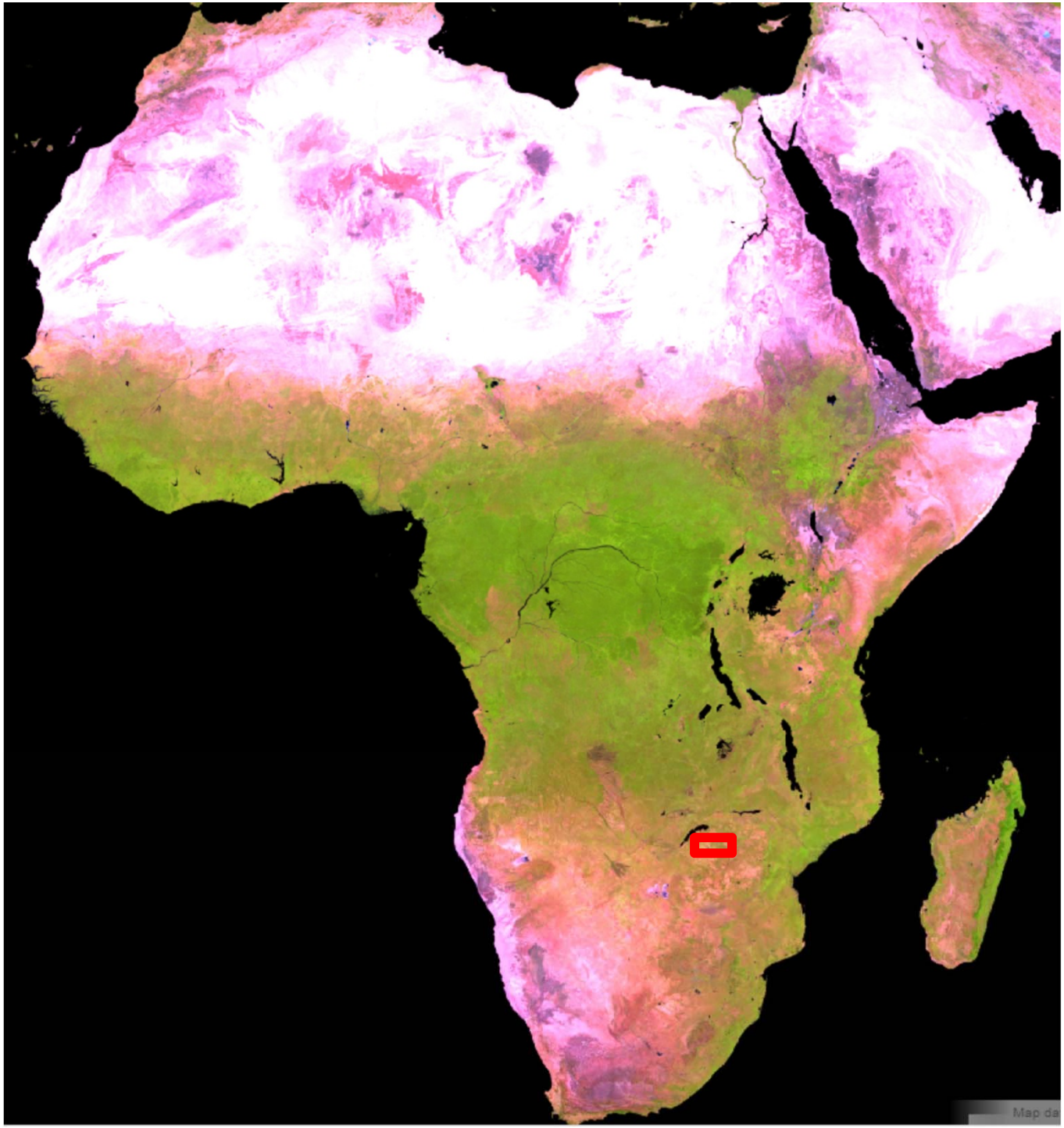
Southern Zambezia

Forest gain

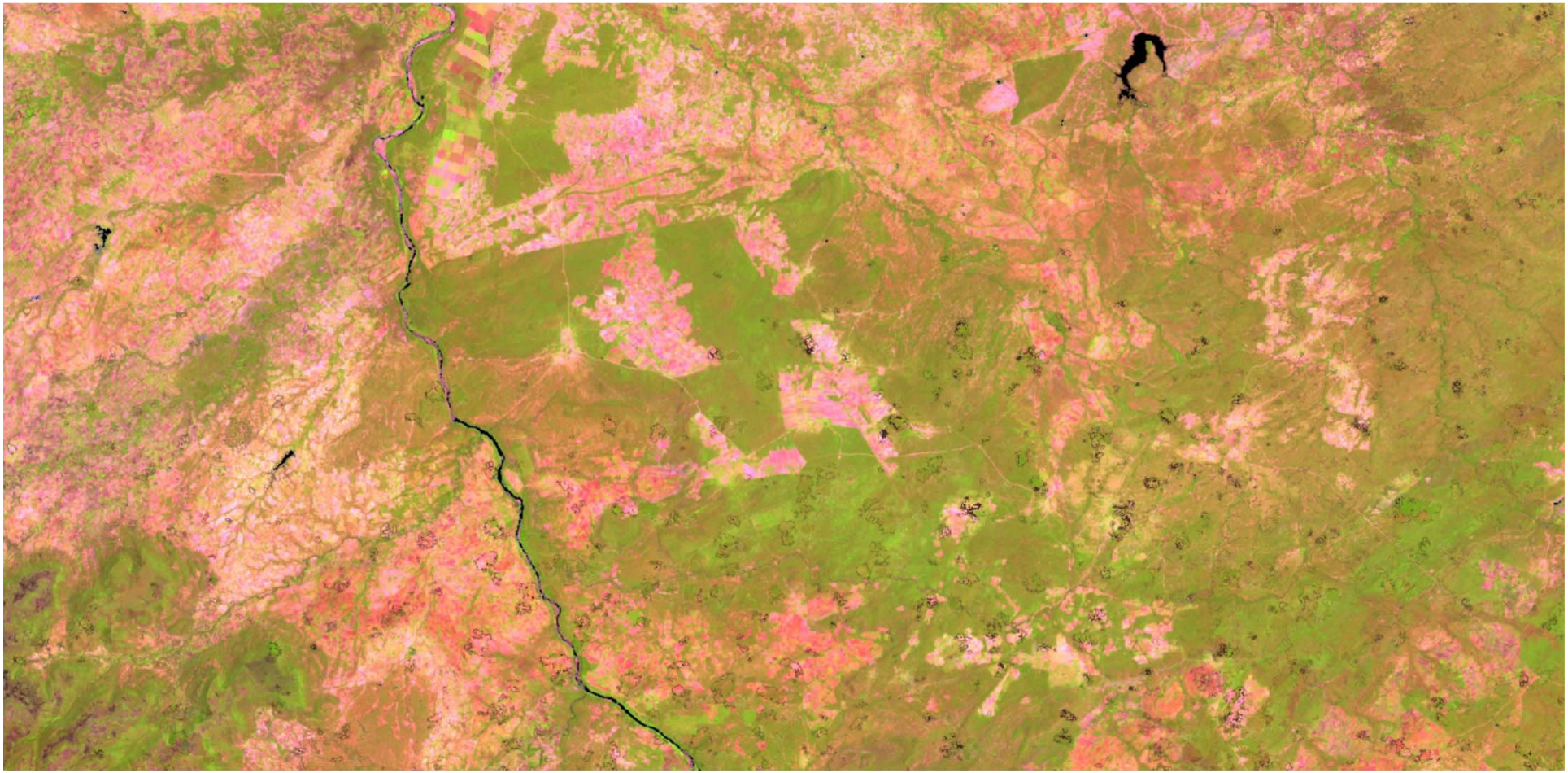
Gain

No gain

Southern Zambezia

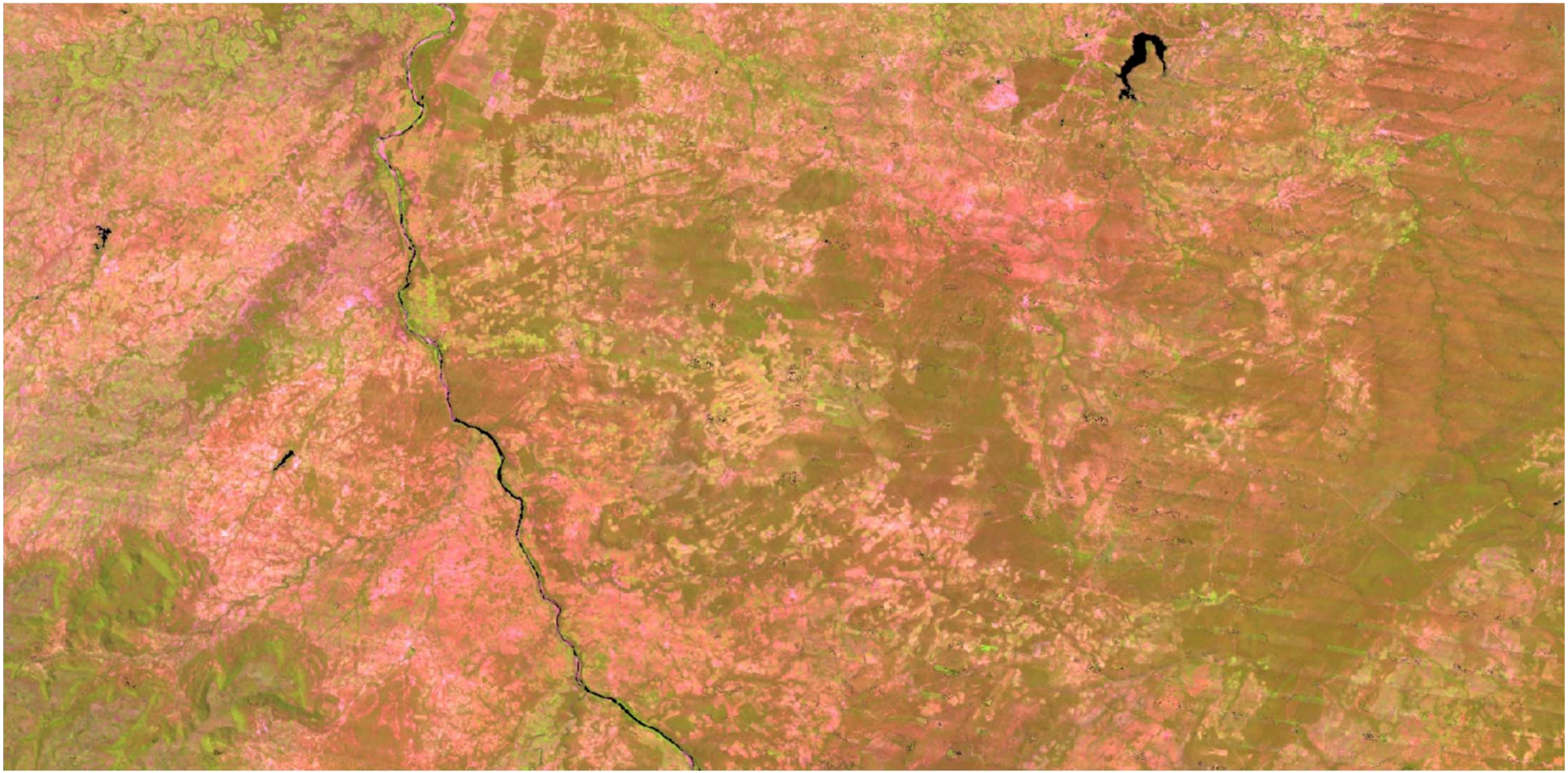


2000 5-4-3 composite



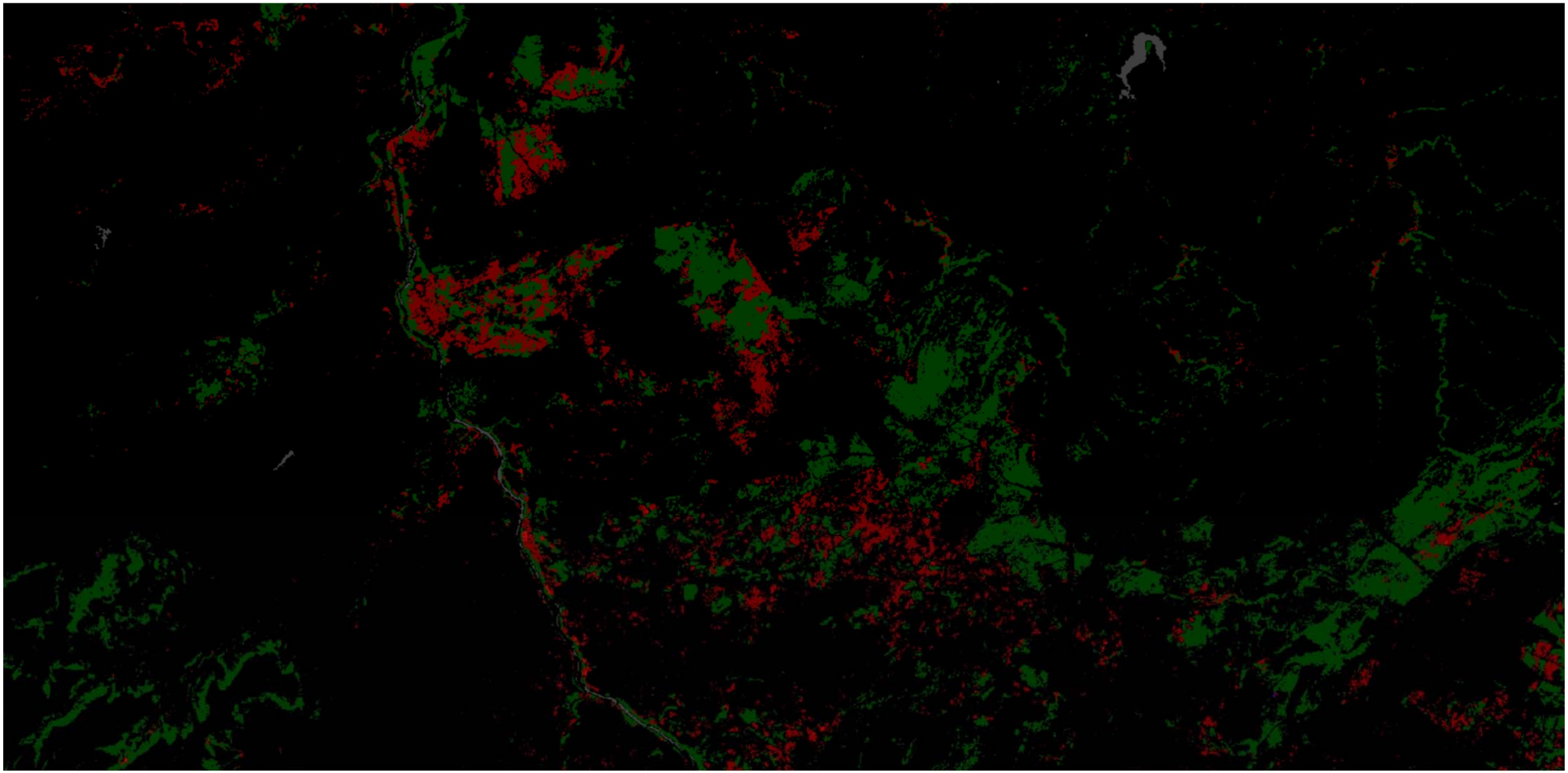
Mashonaland West

2012 5-4-3 composite



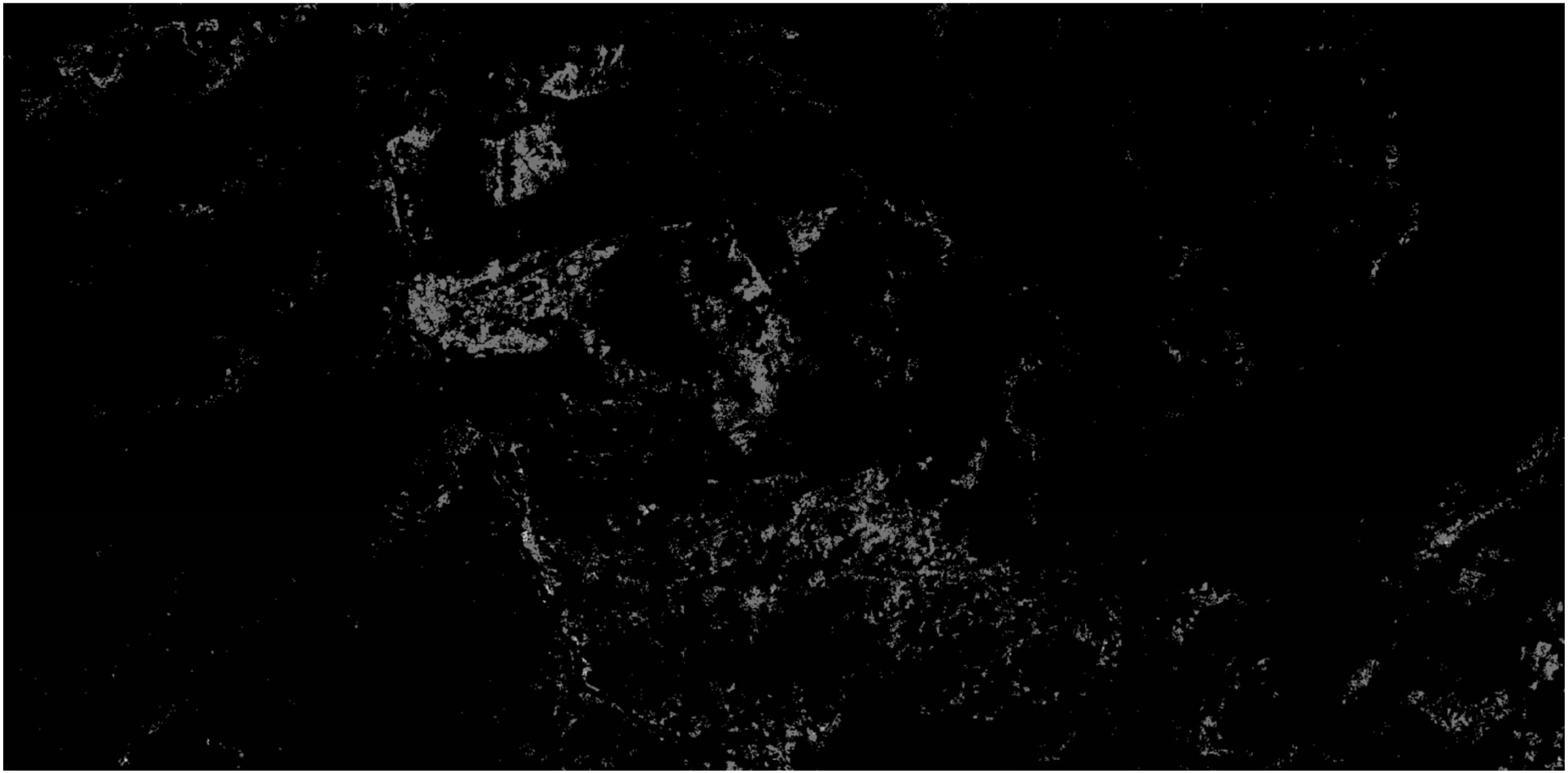
Mashonaland West

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



Mashonaland West

Forest loss

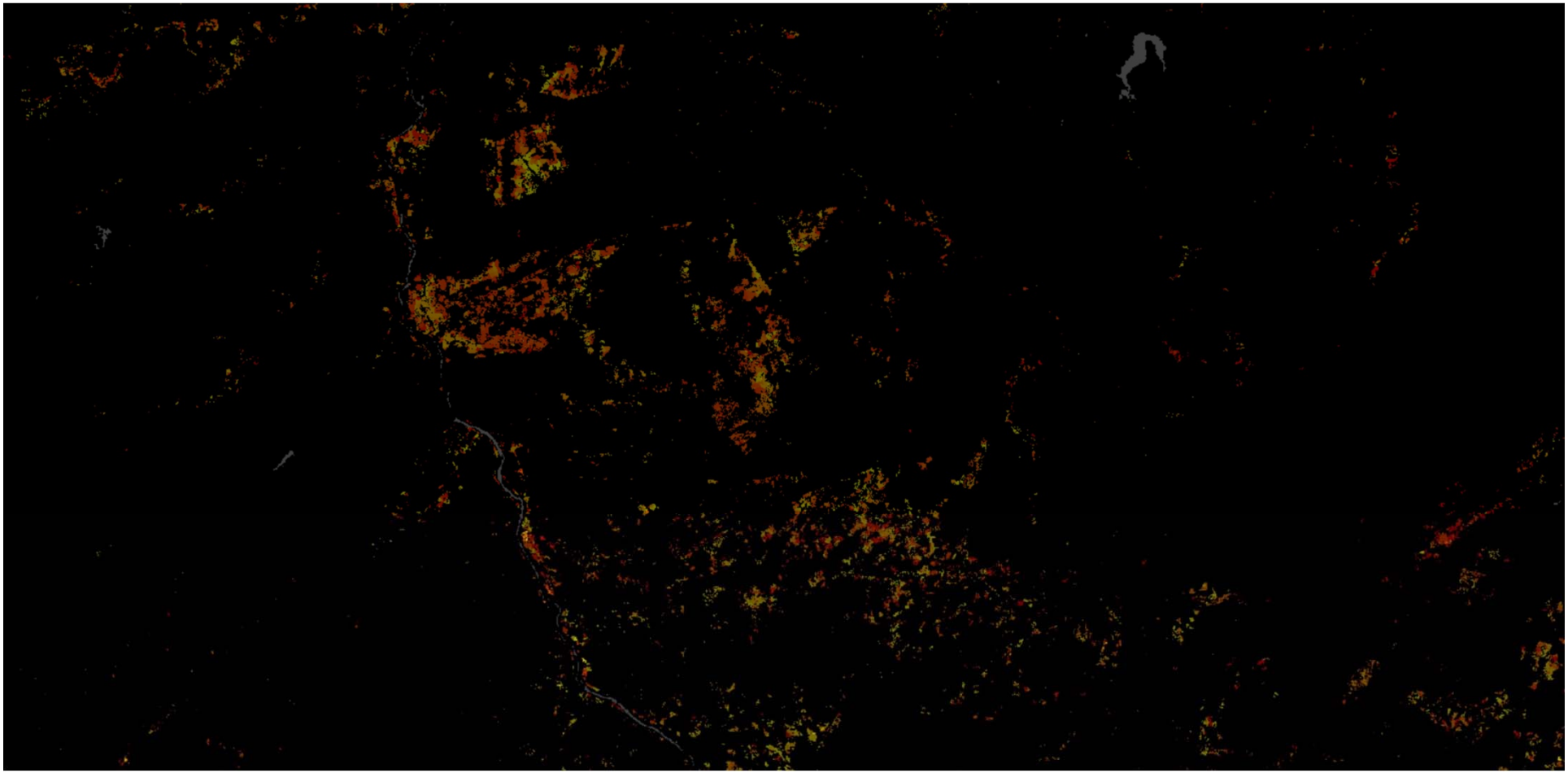


Loss

No loss

Mashonaland West

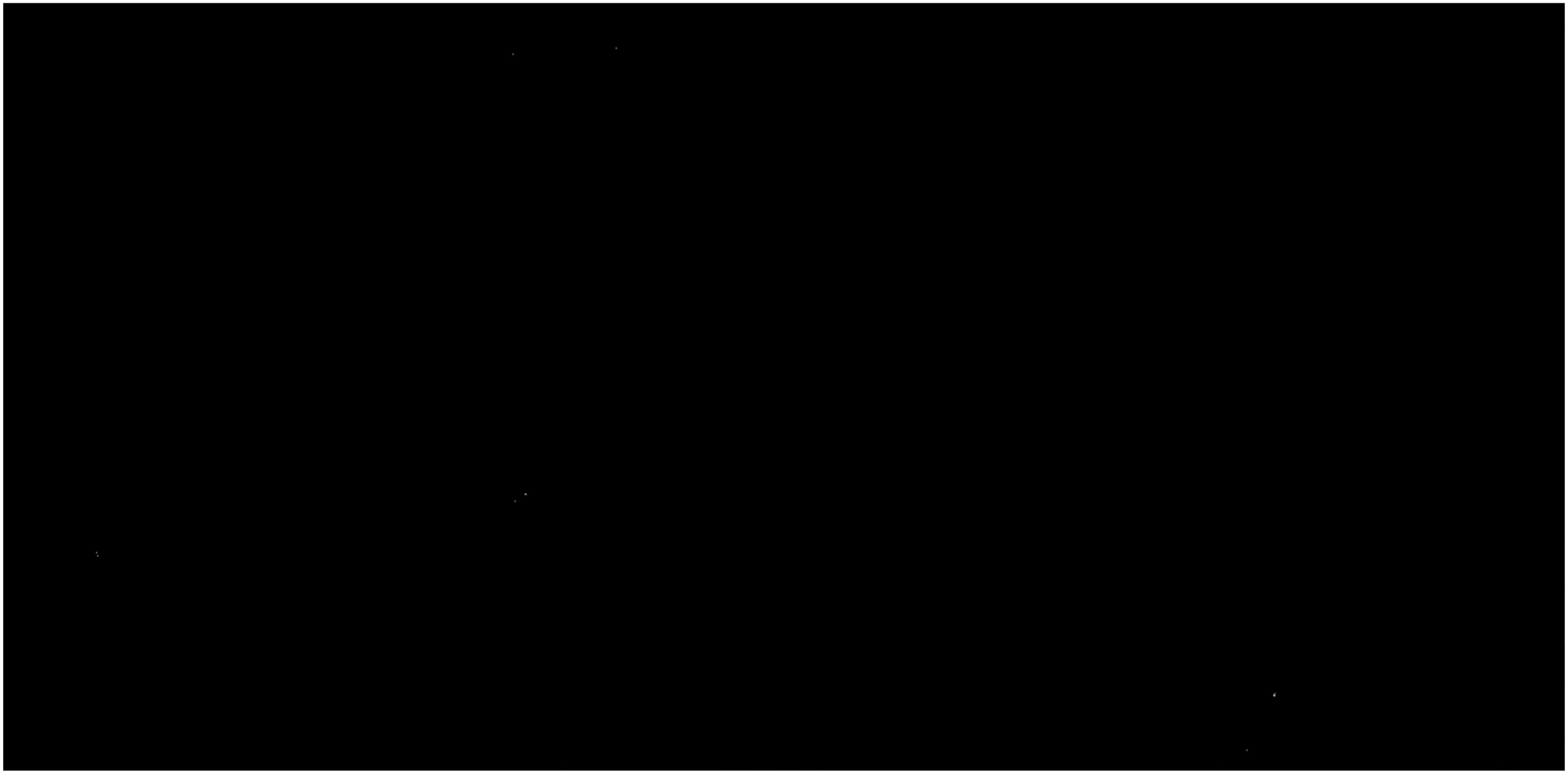
Forest loss by year



2000 2005 2012

Mashonaland West

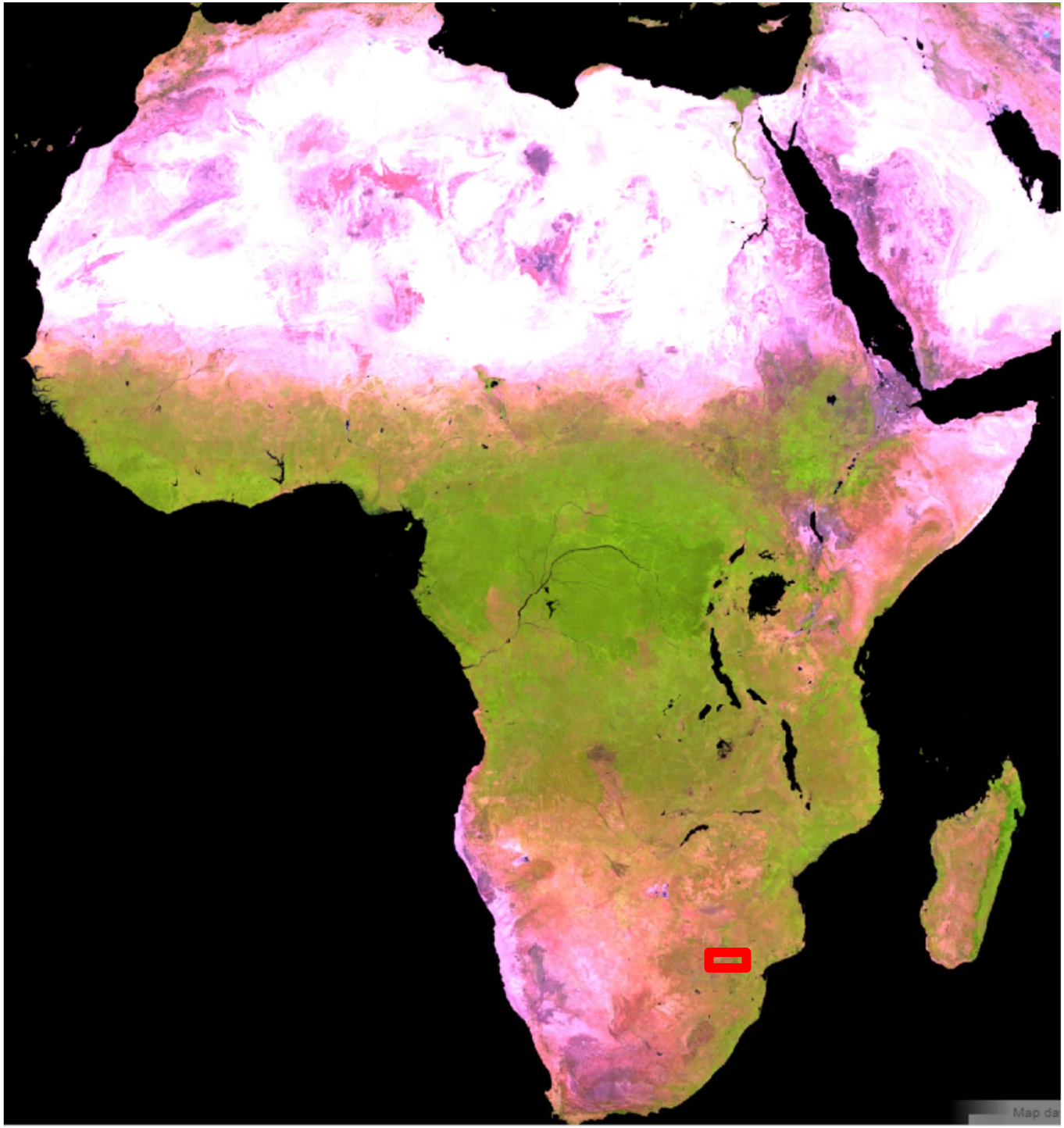
Forest gain



Gain

No gain

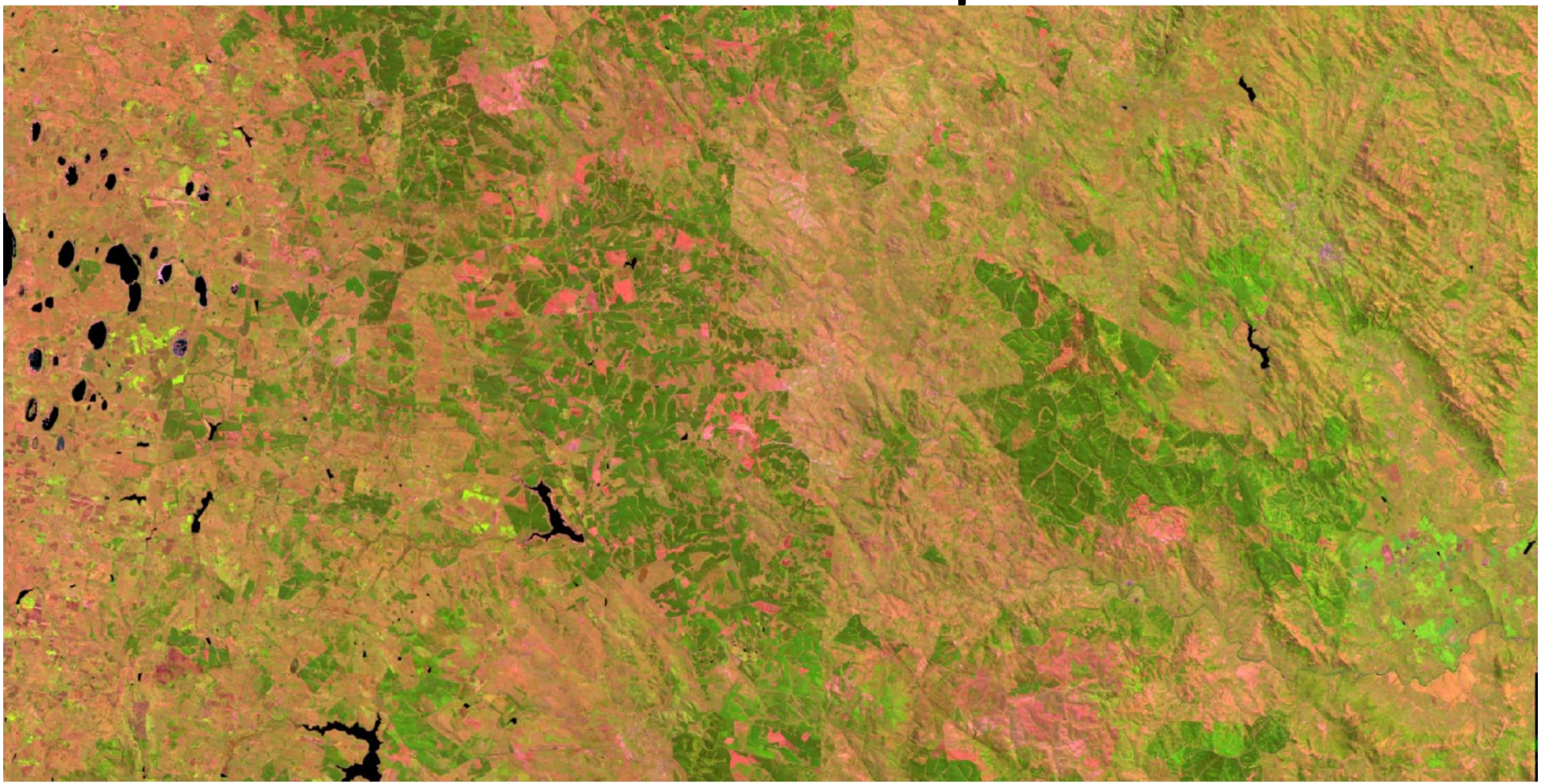
Mashonaland West



2000 5-4-3 composite

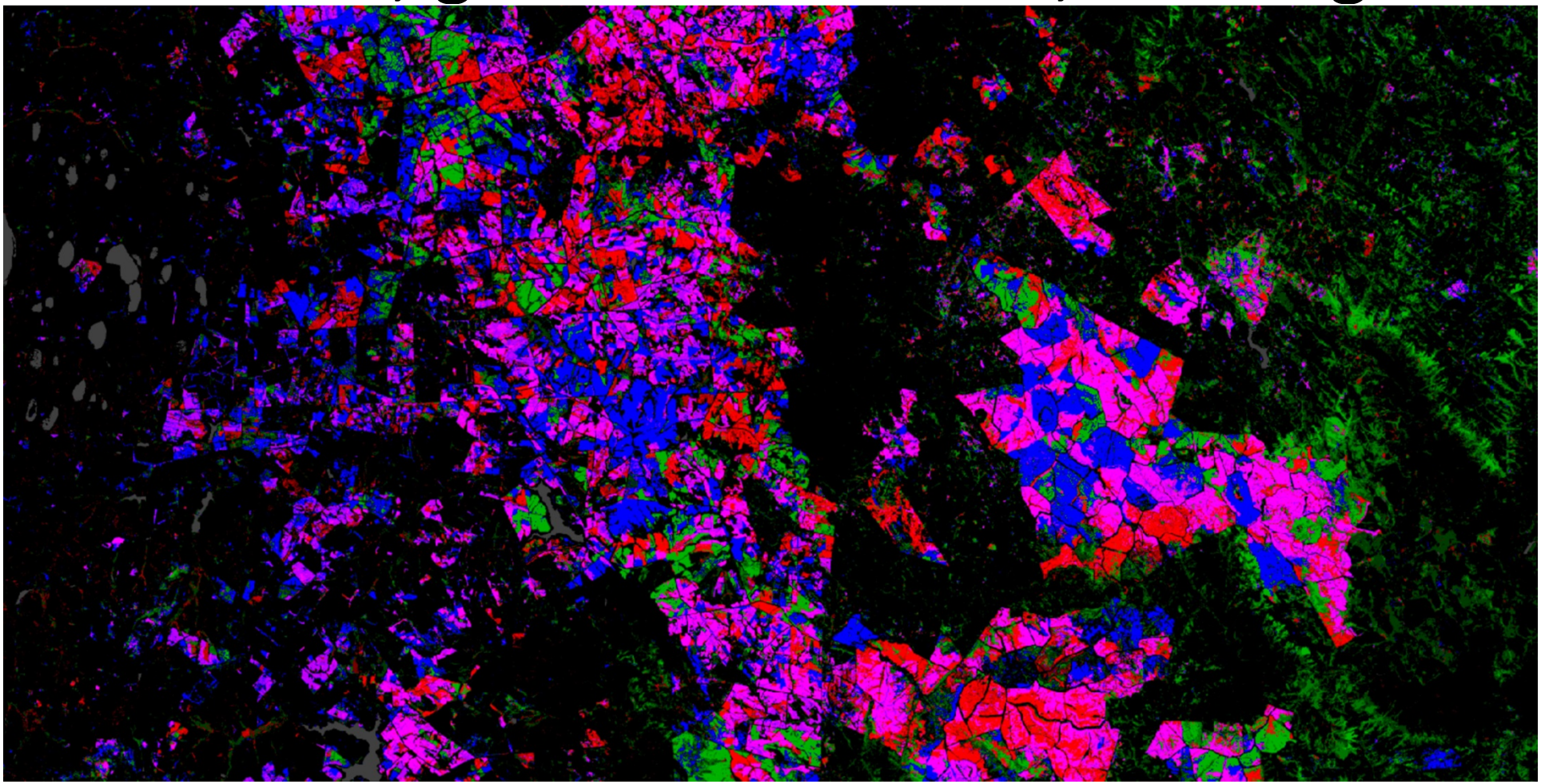
SA/Swaziland border

2012 5-4-3 composite



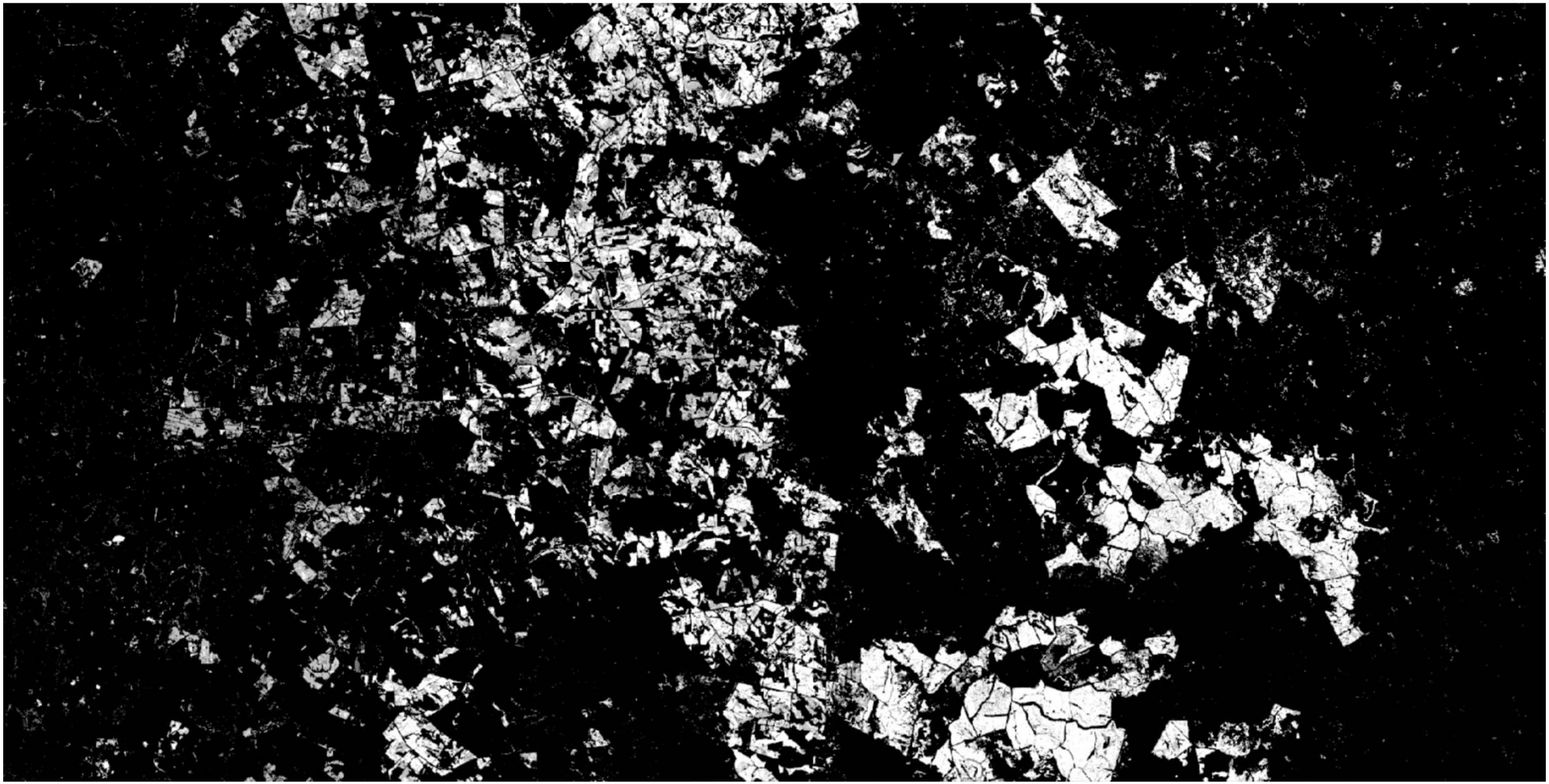
SA/Swaziland border

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



SA/Swaziland border

Forest loss

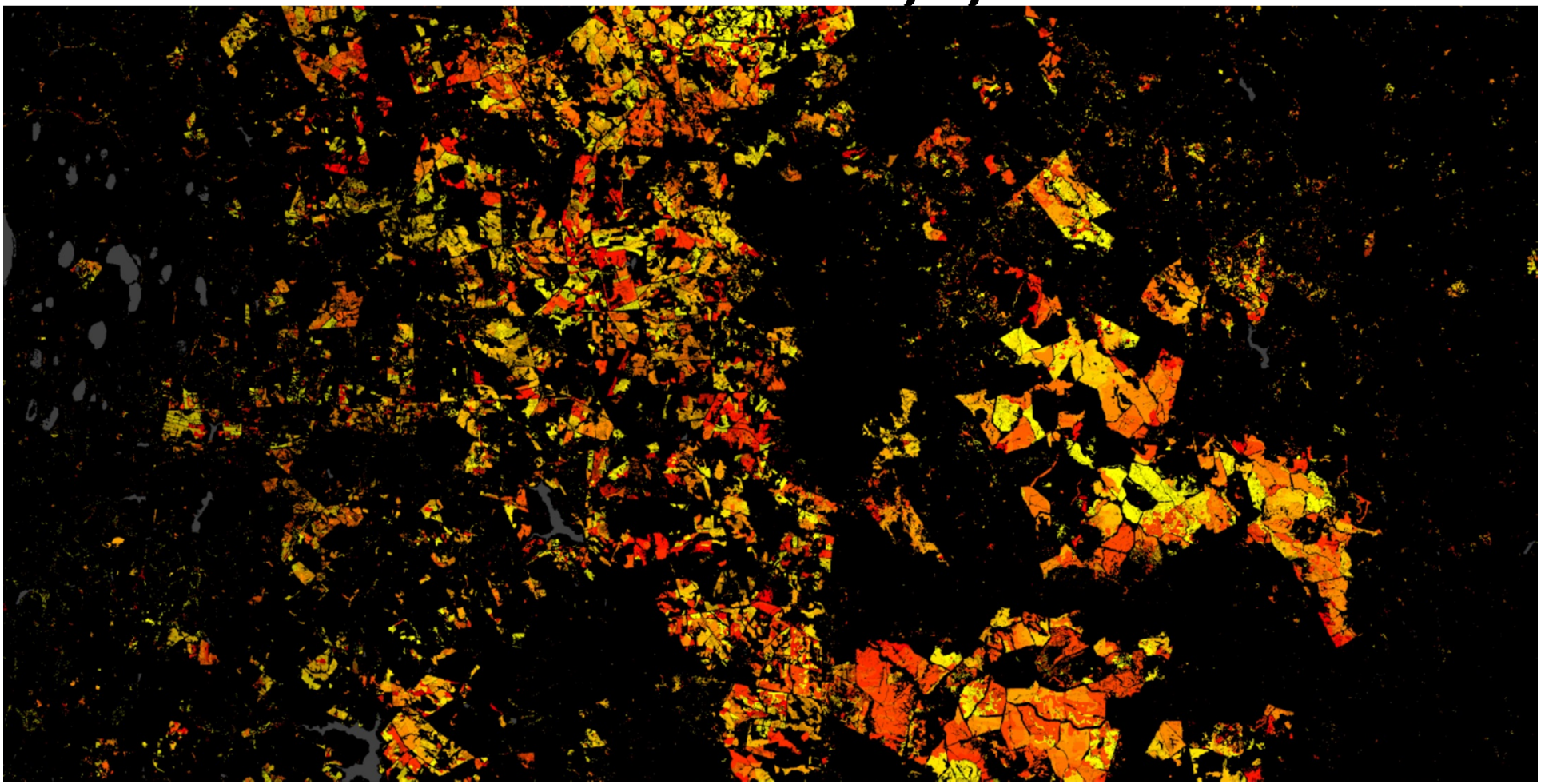


Loss

No loss

SA/Swaziland border

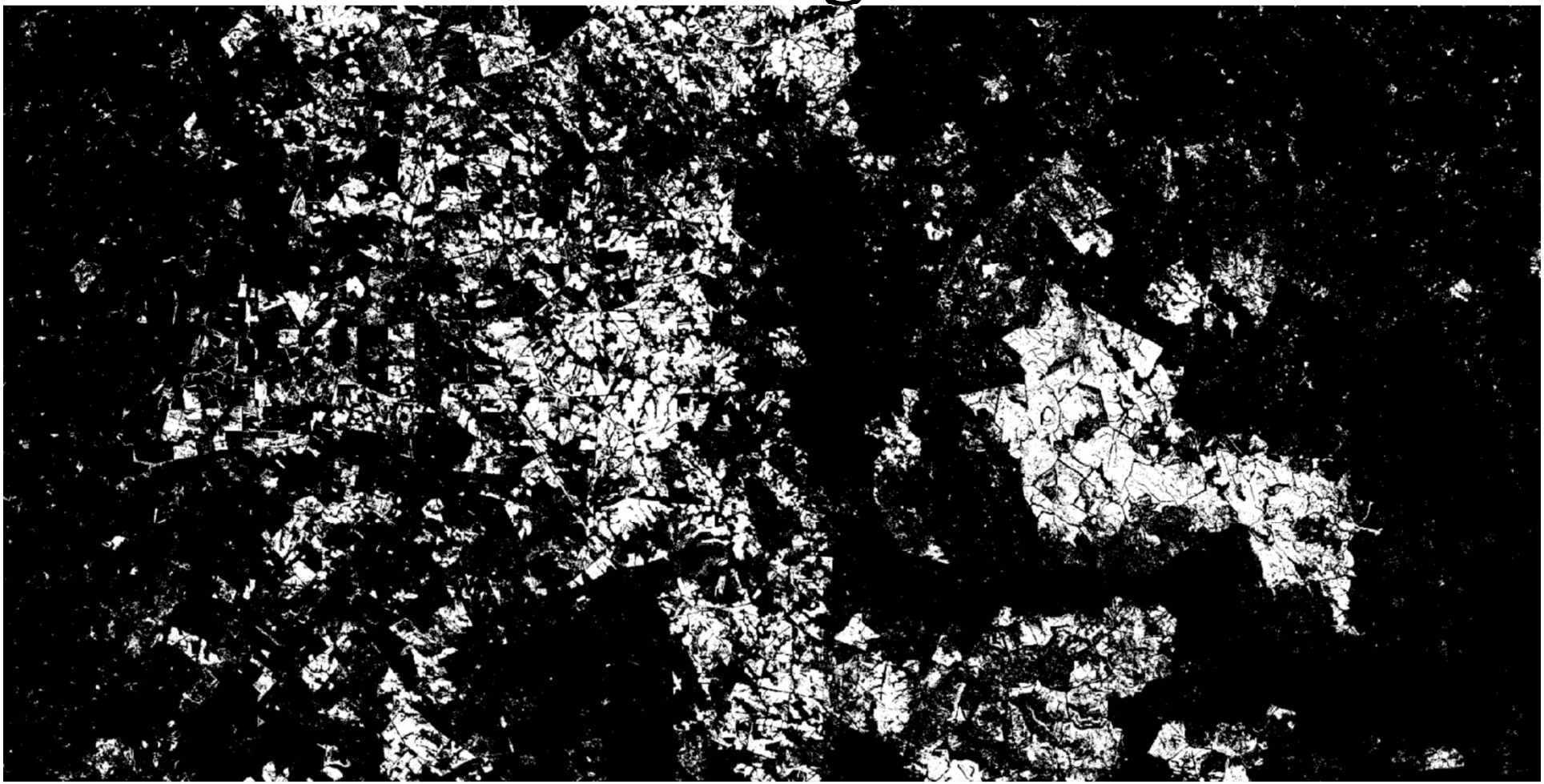
Forest loss by year



2000 2005 2012

SA/Swaziland border

Forest gain

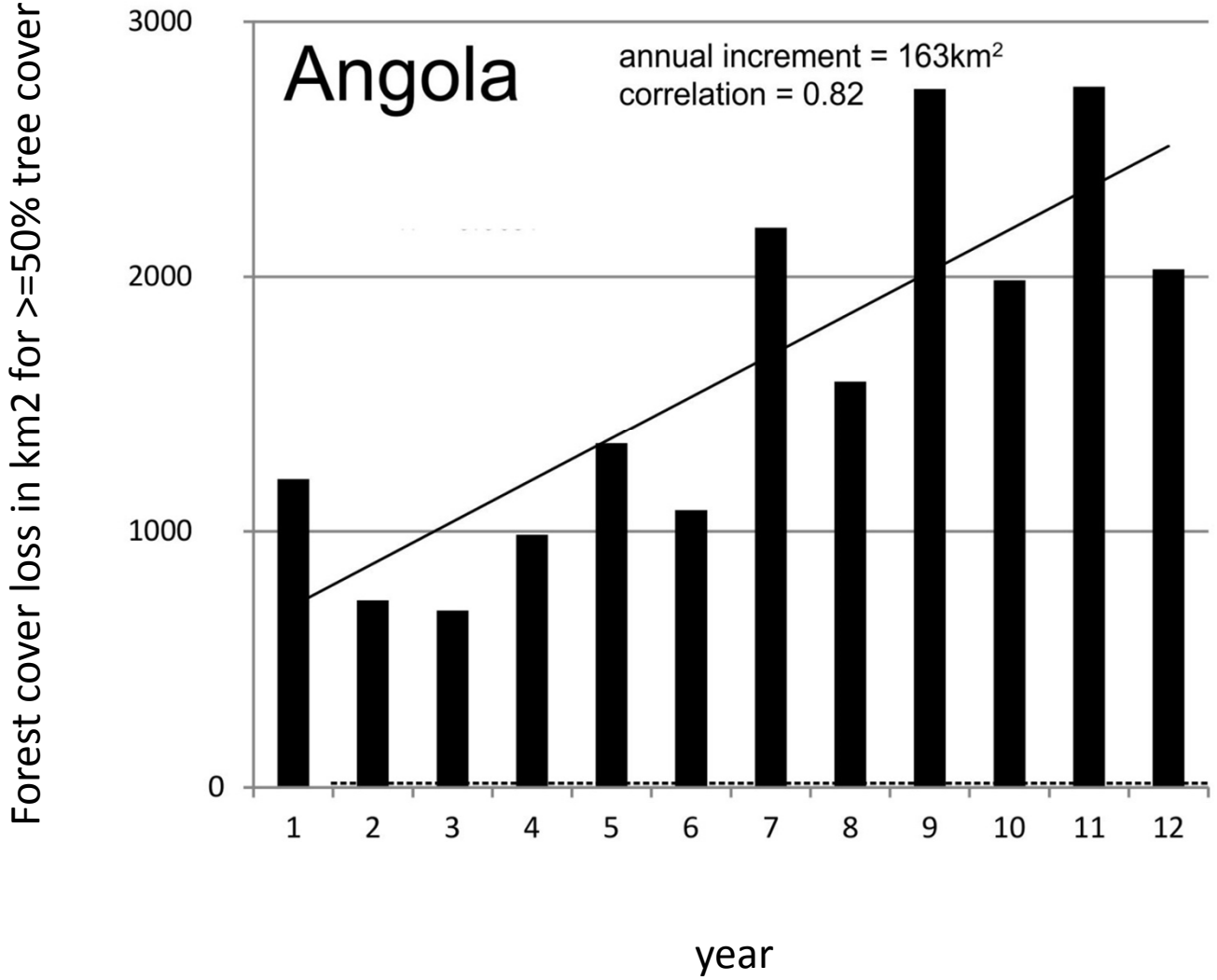


Gain

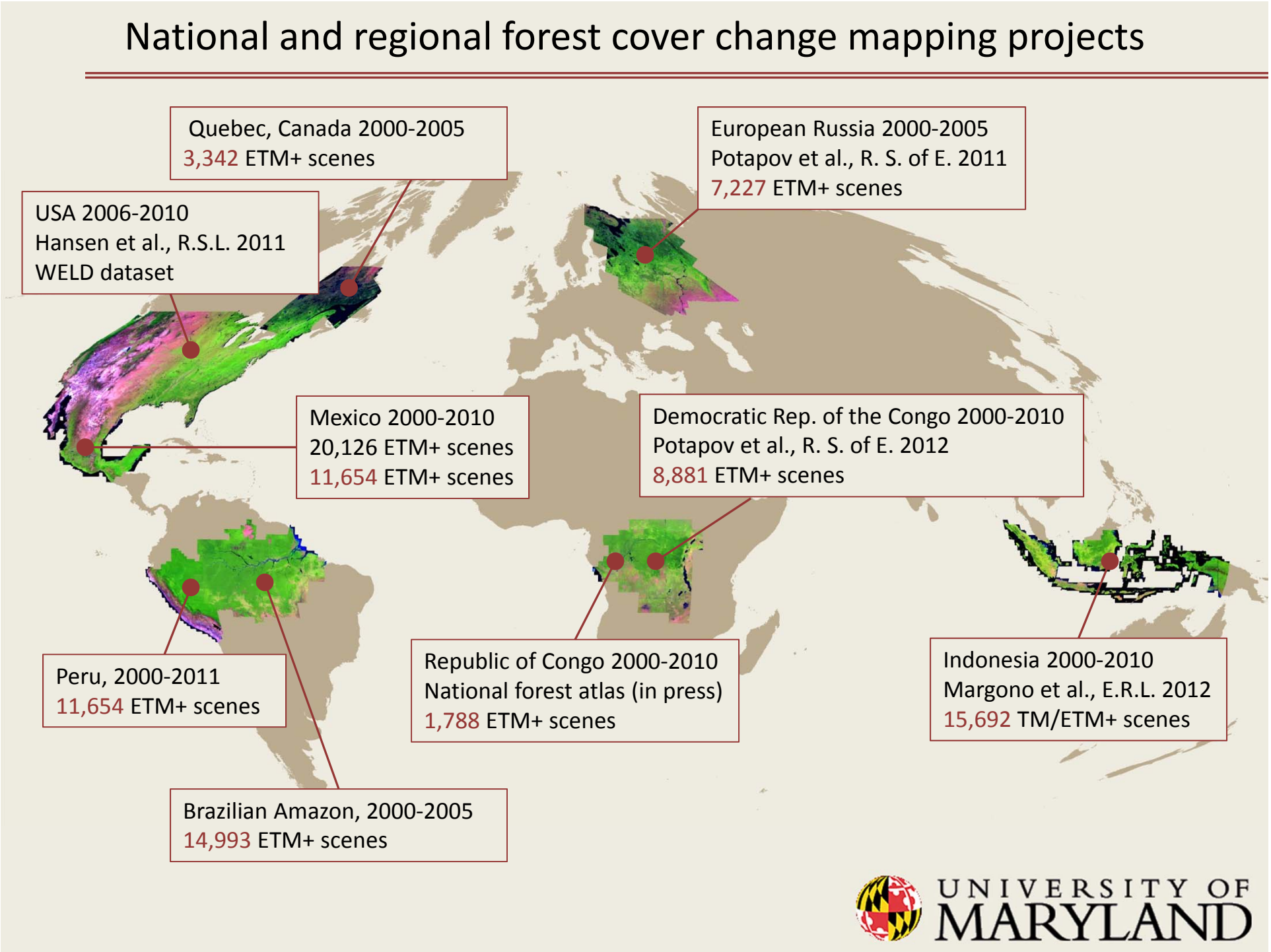
No gain

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 DRCongo, 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)