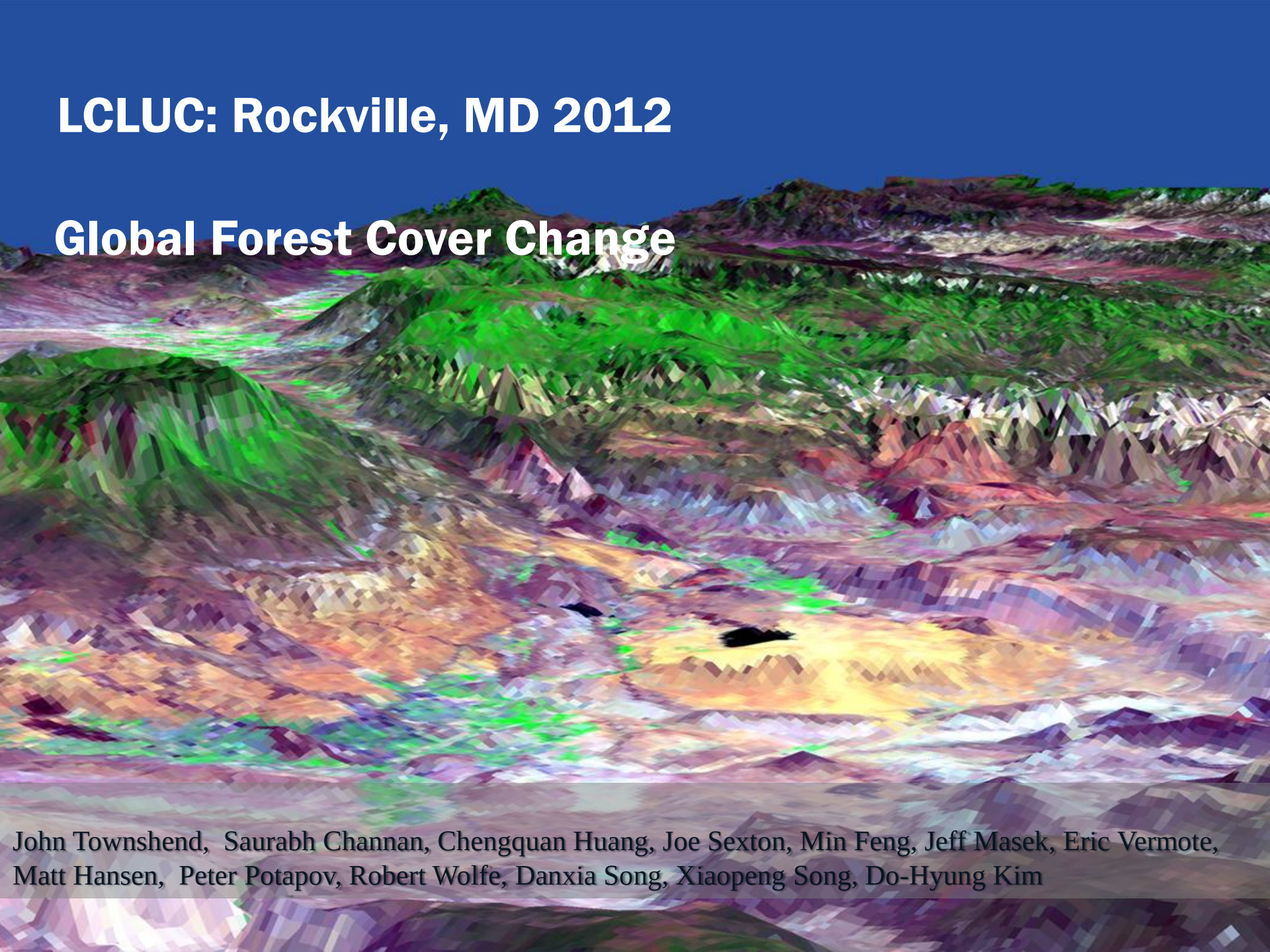
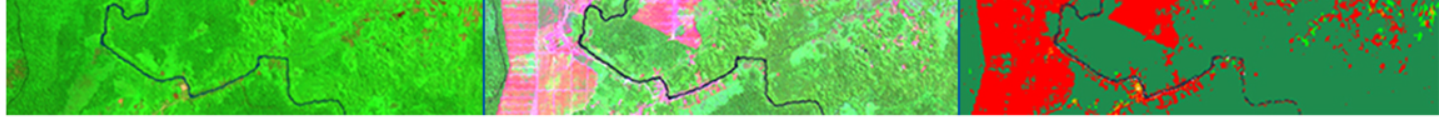
LCLUC: Rockville, MD 2012

Global Forest Cover Change

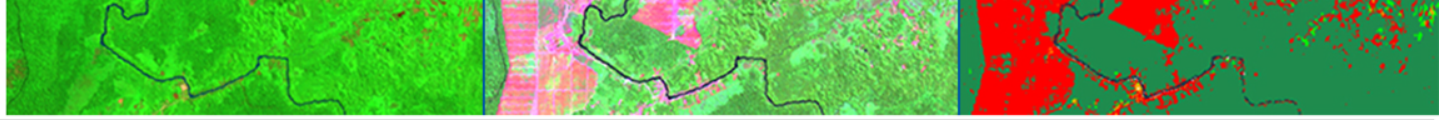


John Townshend, Saurabh Channan, Chengquan Huang, Joe Sexton, Min Feng, Jeff Masek, Eric Vermote, Matt Hansen, Peter Potapov, Robert Wolfe, Danxia Song, Xiaopeng Song, Do-Hyung Kim



Overview

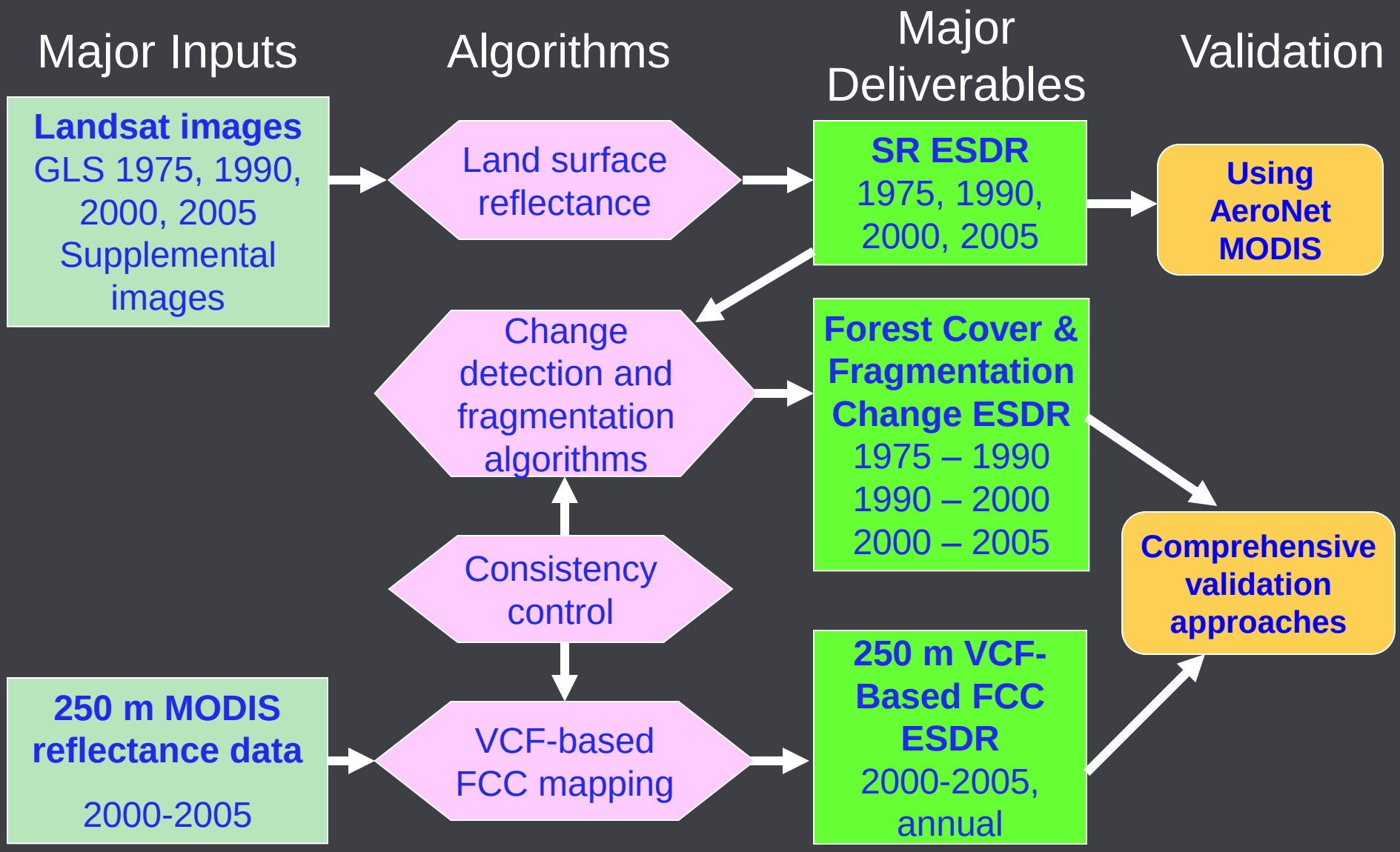
- Goals
- Challenges
- Where we are
- Questions



Project Goals

- Global, fine resolution (<100 m) surface reflectance (SR) ESDR
  - For 1990, 2000 and 2005
- Global, fine resolution (< 100 m) forest cover change (FCC) ESDR
  - For 1990-2000, 2000-2005, and 1975-1990 for southern South America
- Global, 250 m, forest cover change (VCF FCC) ESDR
  - For 2000 to 2005, using vegetation continuous fields

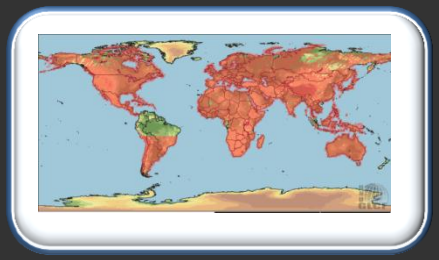
Overall Processing Flow



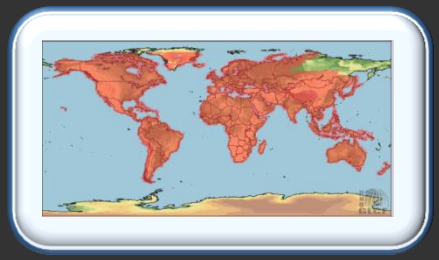
Available Data Collections

Landsat data collections are available:

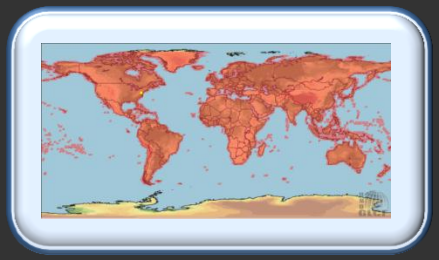
- Global Land Survey (GLS, formerly known as GeoCover)
- In 4 epochs: GLS1975, GLS1990, GLS2000, GLS2005 (2010 coming soon)
- At 30m resolution (1990-2005) and 60m resolution (1975)
- Global coverage of imagery



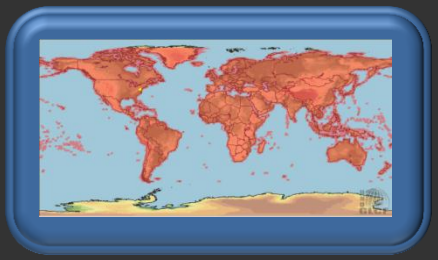
GLS1975



GLS1990



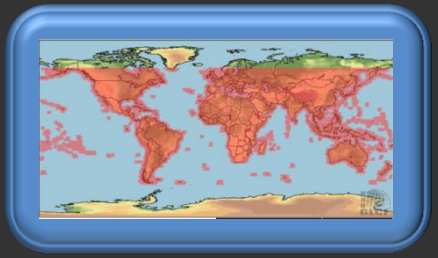
GLS2000



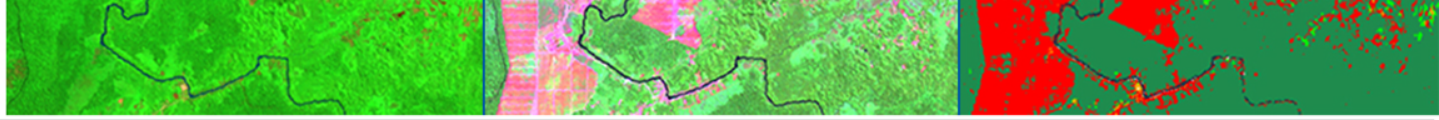
GLS2005

Several collections of elevation imagery available:

- SRTM (90m global)
- ASTER-DEM (30m global)
- locals

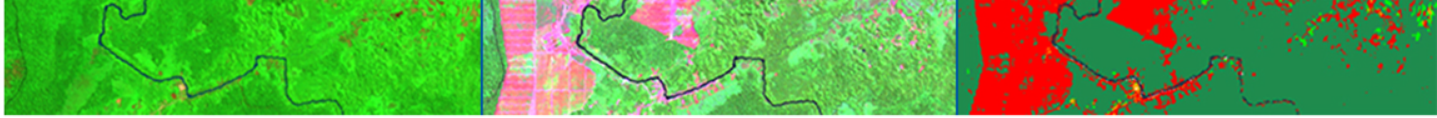


GLSDEM-90m



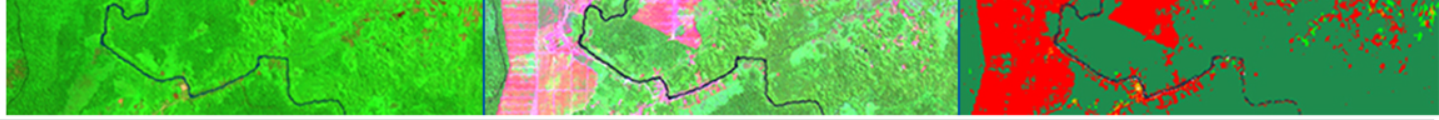
Challenges: Input Data

- GLS 2005:
  - Leaf-off scenes
  - Cloudy
  - SLC-OFF
- GLS 2000
  - Leaf-off scenes
  - Cloud
  - Bad data(now replaced)
- GLS1990
  - Leaf-off scenes
  - >50% missing/incorrect calibration
  - Waiting on USGS repatriation
- GLS1975
  - Entire archive needs to be replaced



Challenges: Input Data

- GLS 2005:
  - Leaf-off scenes
  - Cloudy
  - SLC-OFF
- GLS 2000
  - Leaf-off scenes
  - Cloud
  - Bad data(now replaced)
- GLS 1990
  - Leaf-off scenes
  - >50% missing/incorrect calibration
  - Waiting on USGS repatriation
- GLS1975
  - Entire archive needs to be replaced
  - Very different calibration values from different GRS



Percent land areas (%) not covered by GLS images.

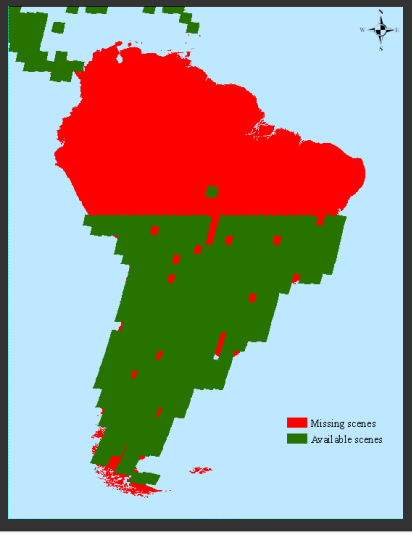
Continent	GLS1975	GLS1990	GLS2000	GLS2005
	%Area	%Area	%Area	%Area
Africa	4.03	0.20	0.00	0.00
Asia	4.98	15.27	0.16	0.60
Australia	1.17	0.00	0.00	0.00
North America	11.06	4.82	0.61	1.82
Oceania	90.14	12.68	0.00	0.00
South America	57.24	3.48	0.00	0.07
Europe	2.88	0.66	0.66	0.72

Noojipady et al.

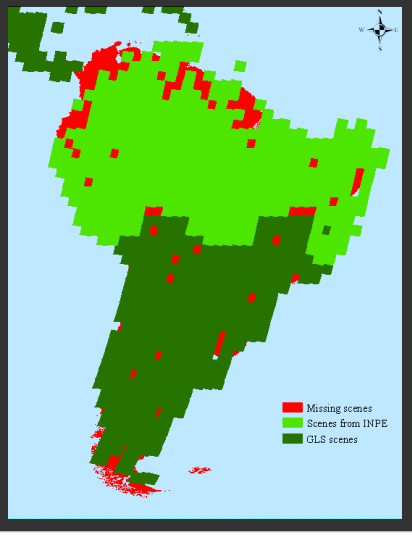
Filling a Major Hole in GLS 1975

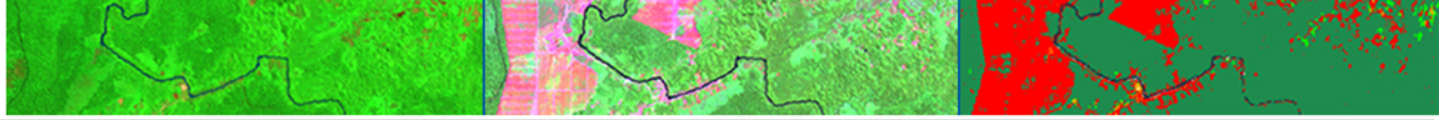
- No GLS 1975 image for the entire northern SA
- Suitable images exist at INPE for most of the gap
  - Have obtained 475 L1G images from INPE
  - Will orthorectify using GLS standards
  - All improvements to GLS will be made available

A major data gap (red) in GLS 1975

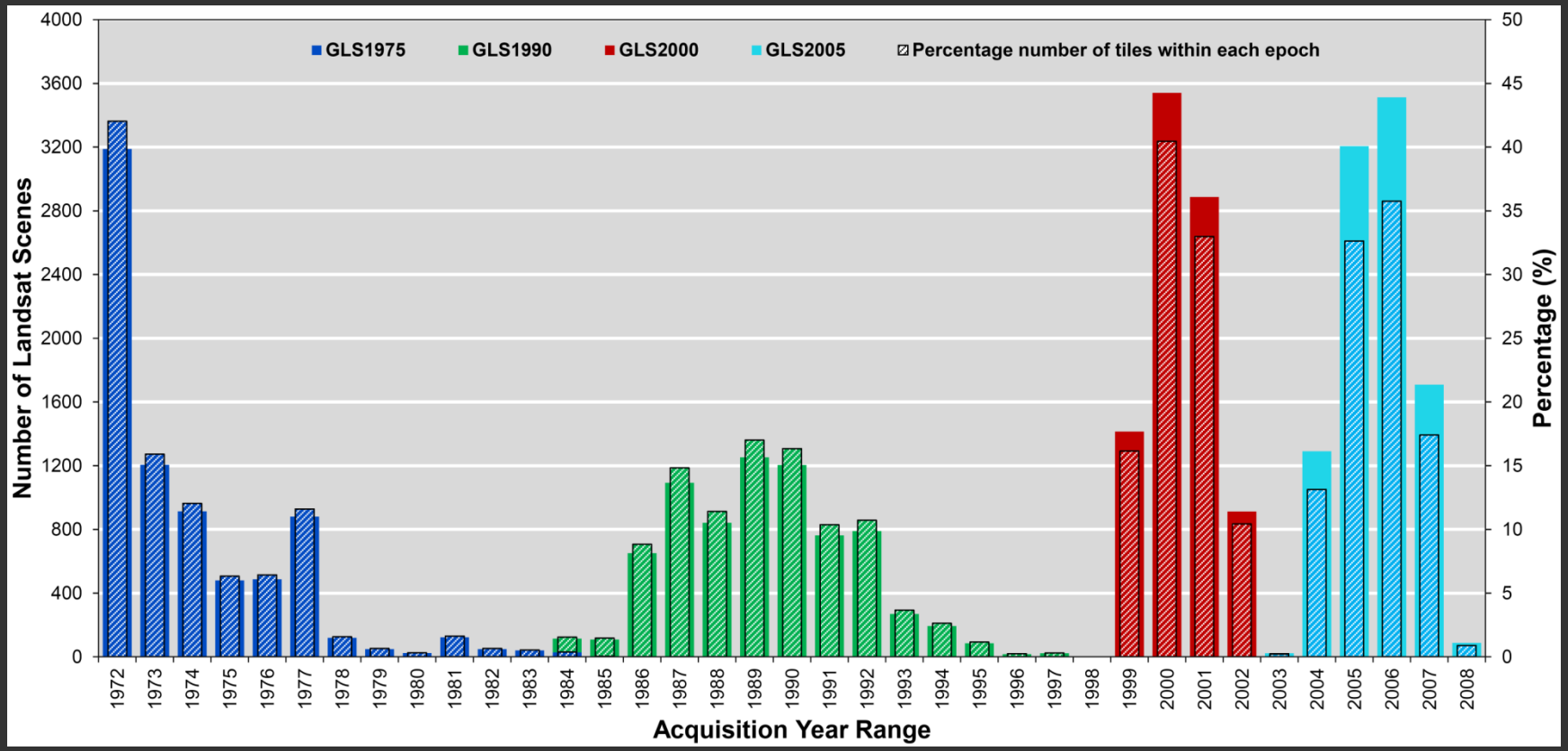


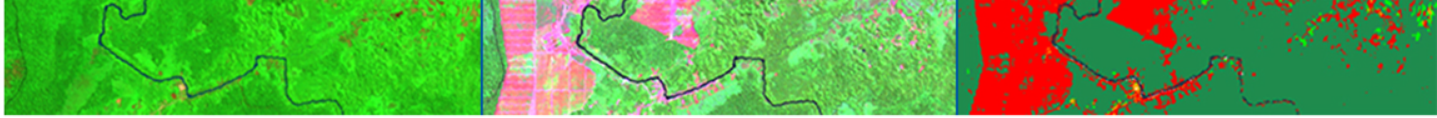
Gap filled using images from INPE (bright green)





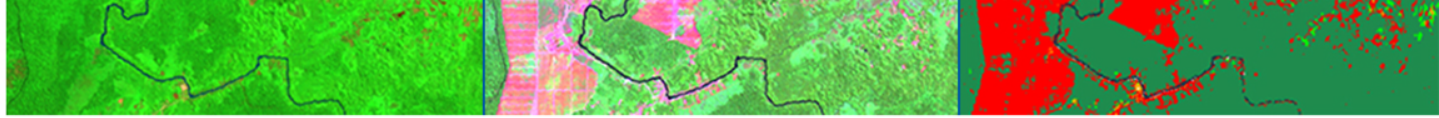
Acquisition year range of the GLS datasets





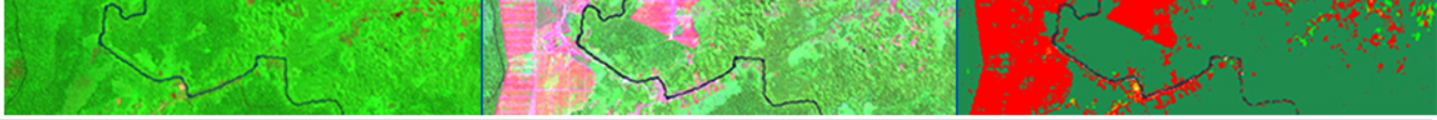
Summary of image-to-image corregistration accuracy of the GLS datasets measured using the GLS 2000 dataset as the reference.

Dataset	Total RMSE (Line)	Total RMSE (Sample)	Total RMSE
GLS-1975	18.2 m	16.95 m	24.88 m
GLS-1990	7.75 m	8.08 m	11.19 m
GLS-2005	4.69 m	5.09 m	5.89 m



Surface Reflectance (SR)

- First Global Surface Reflectance product at Landsat resolution:
  - ✓GLS2005
  - ✓GLS2000
  - ✓GLS1990
- GLS2000 and GLS2005 SR available for download via GLCF @ www.landcover.org since June 2011.



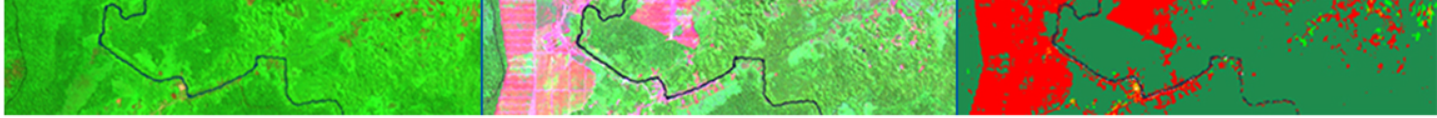
Atmospheric Correction

Based on MODIS/6S radiative transfer approach

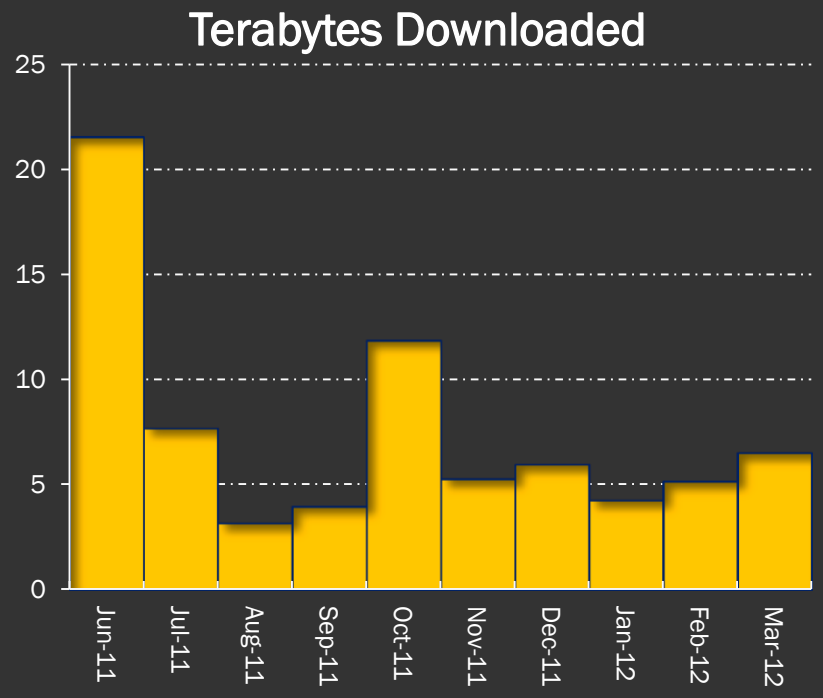
- water vapor from NCEP (2.5deg) re-analysis data
- ozone from TOMS/EP-TOMS/TOVS/OMI
- topography-dependent Rayleigh correction

Aerosol optical thickness estimated from imagery using the Kaufmann et al (1997) "Dense, dark vegetation" approach

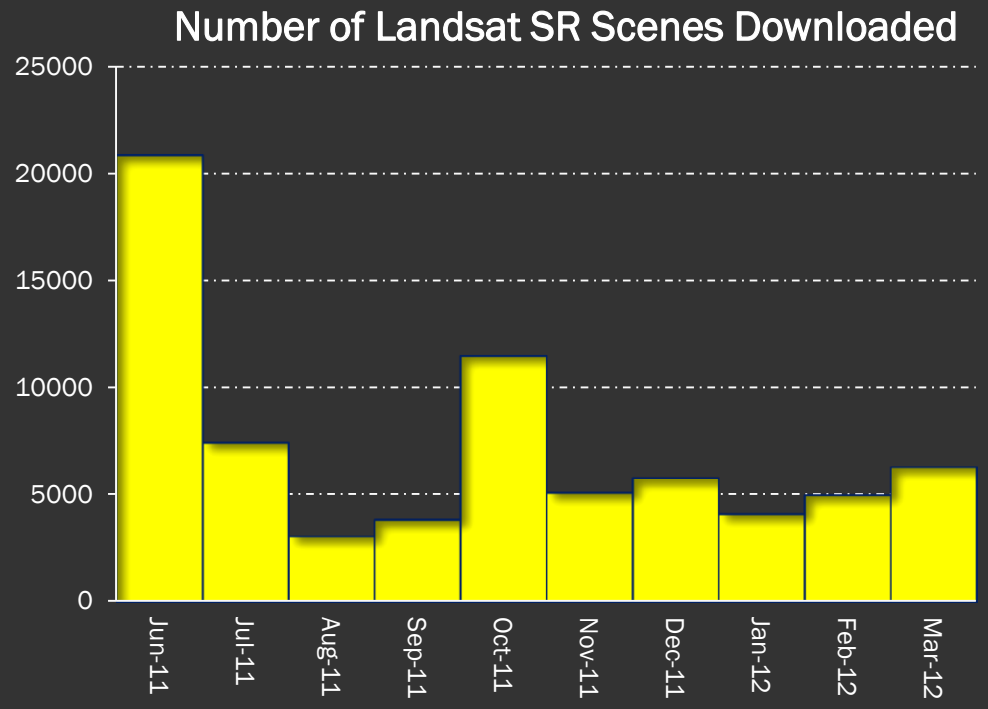
- Average Landsat TOA to 1km resolution; select "valid" targets for AOT
  - *NDVI > 0.3*
  - *2.2 mm TOA < 15%*
  - *screen for cloud, snow/ice, salt playas*
- estimate blue surface reflectance = 0.33*(2.2 μm TOA reflectance)
- difference between TOA_{blue} and SR_{blue} gives AOT_{blue}
- interpolate valid targets across image
- use continental aerosol model to calculate AOT spectrum



Landsat SR Data Distribution

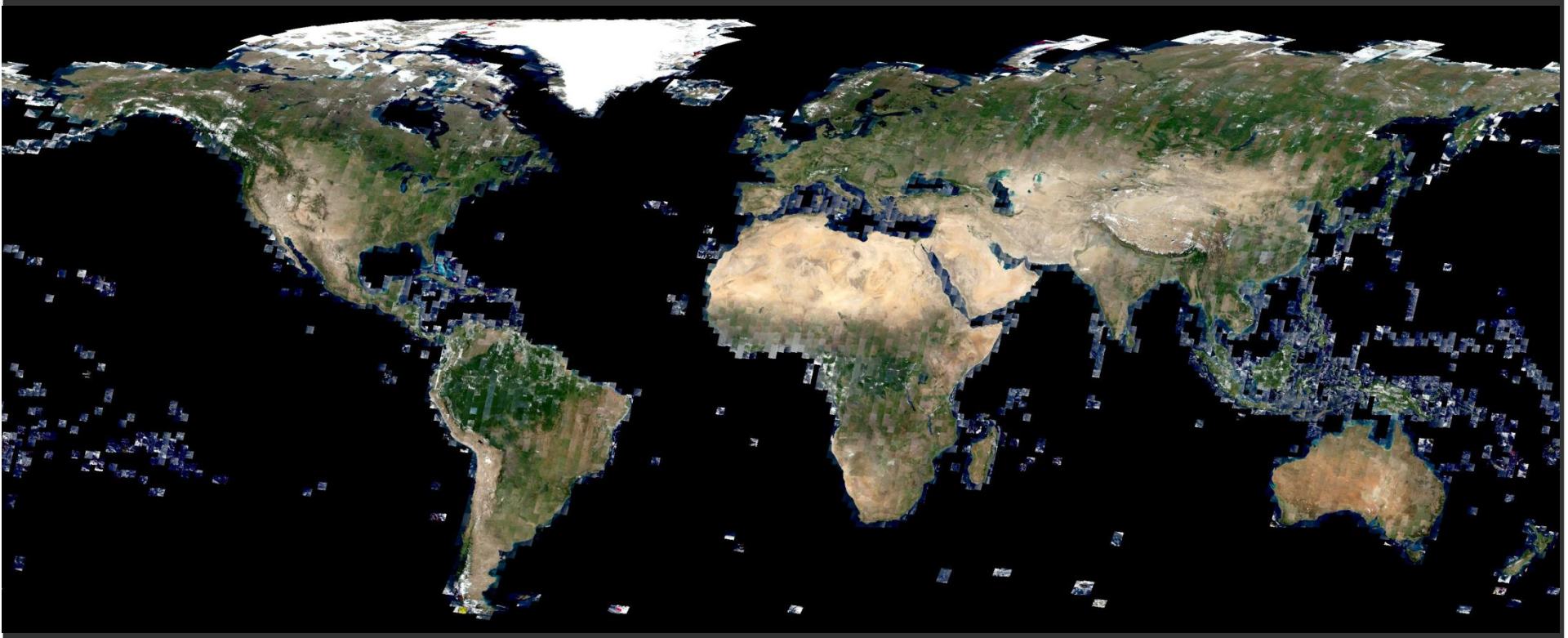


Total of 75.3 terabytes downloaded



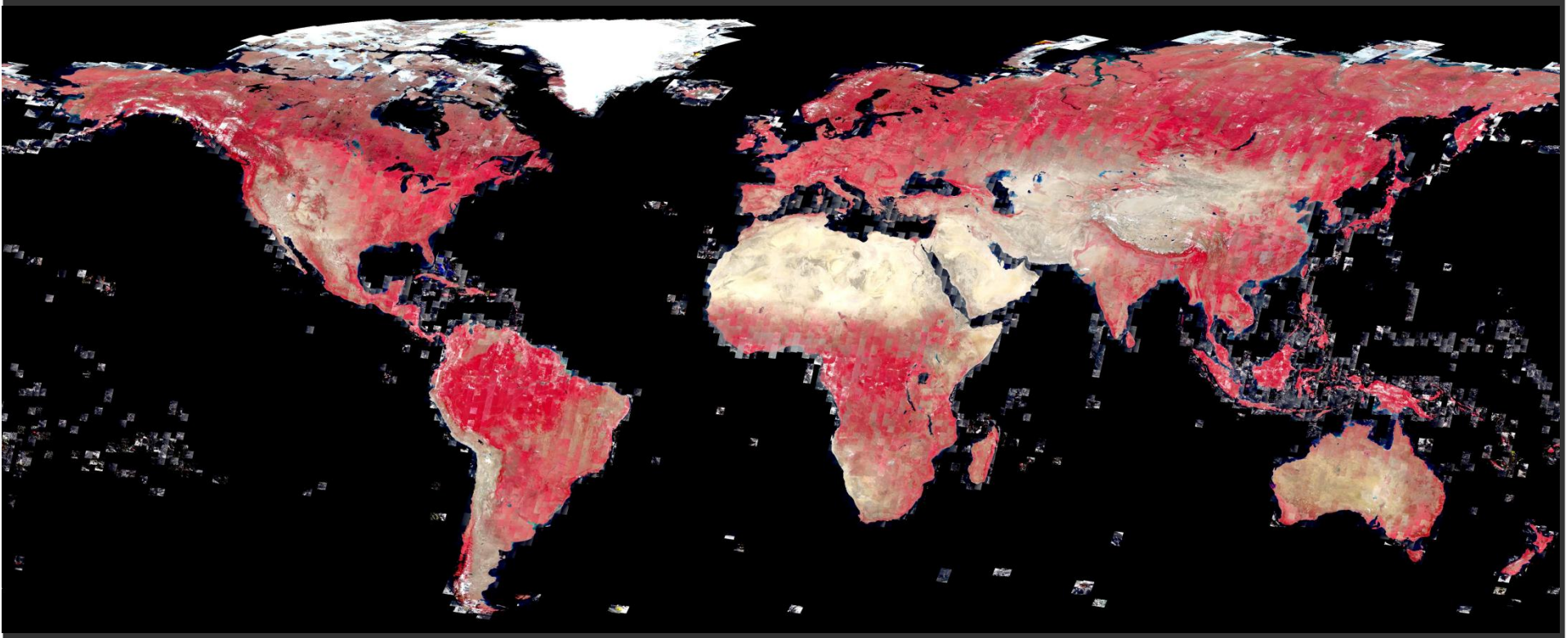
Total of ~73,000 scenes downloaded

Global mosaic of GLS 2000 SR



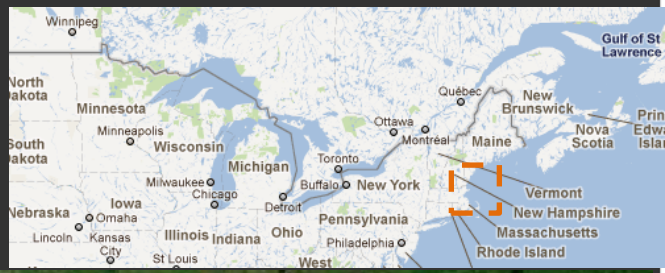
Landsat 3, 2, 1 bands

Global mosaic of GLS 2000 SR



Landsat 4, 3, 2 bands

Global Forest Cover Change
www.forestcover.org



TOA

Cape Cod, USA (72W - 67.5W, 41N - 46N)

SR

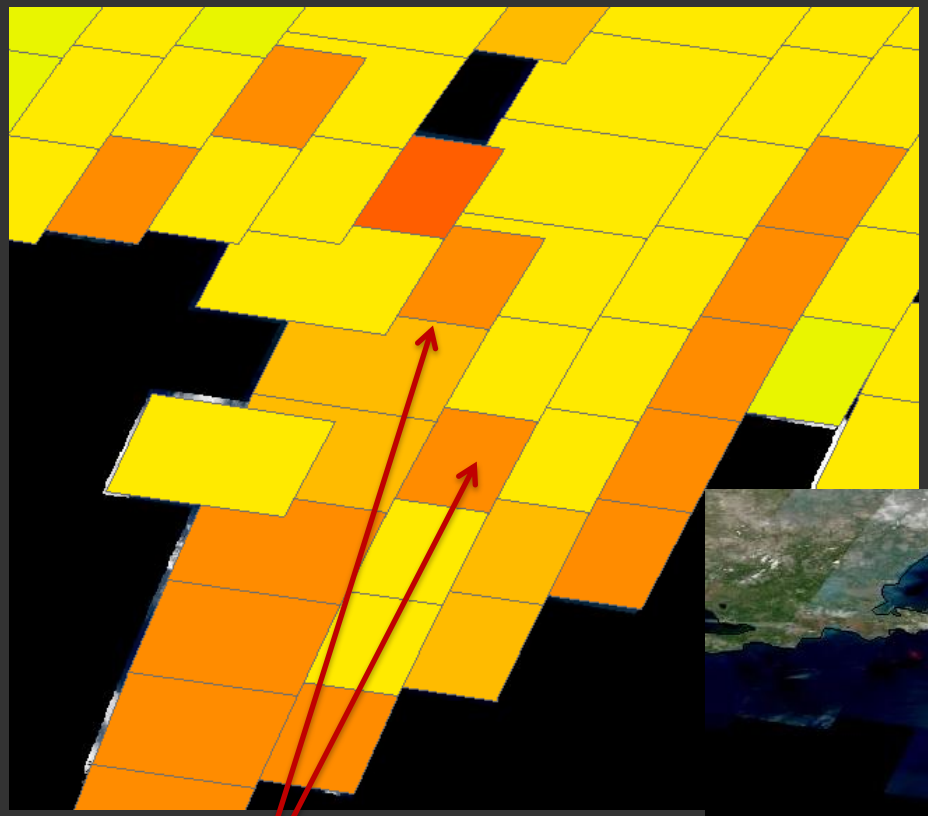
Global Forest Cover Change
www.forestcover.org

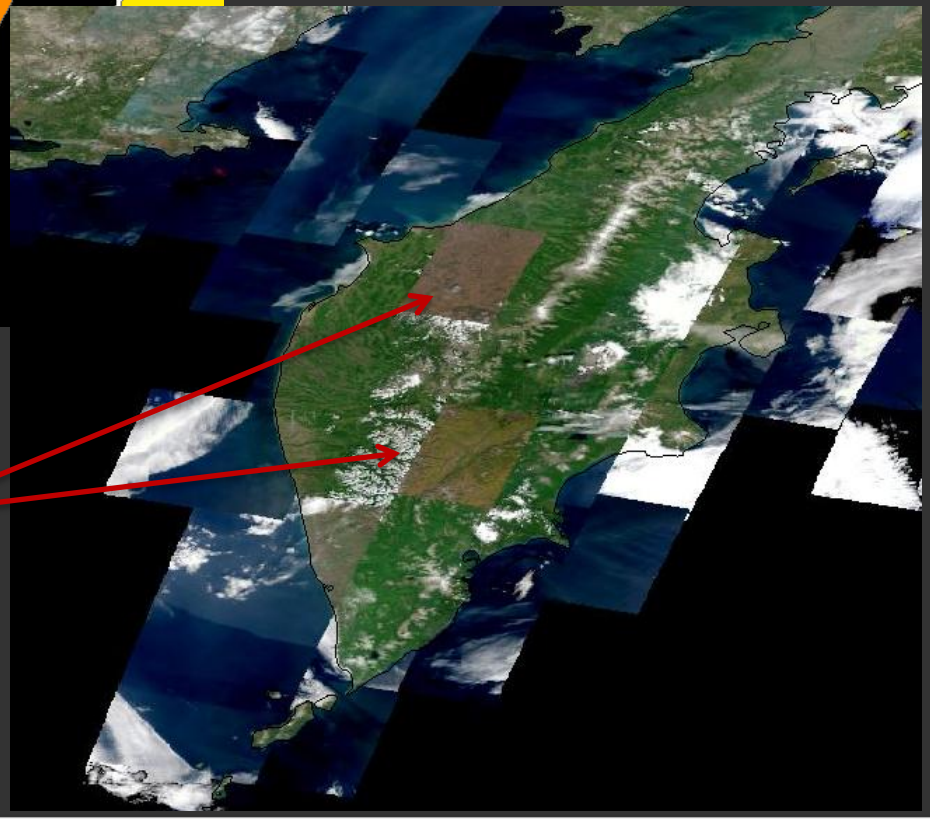
TOA

Ireland, (11W - 5W, 51N – 55.5N)

SR

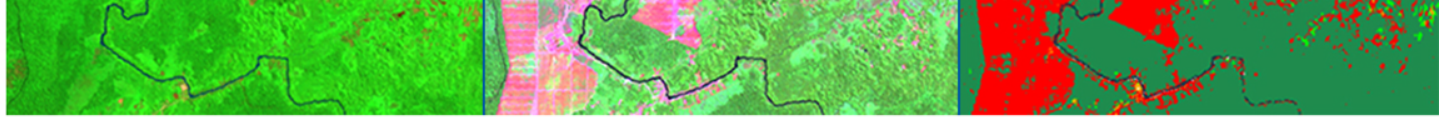
Phenology Differences





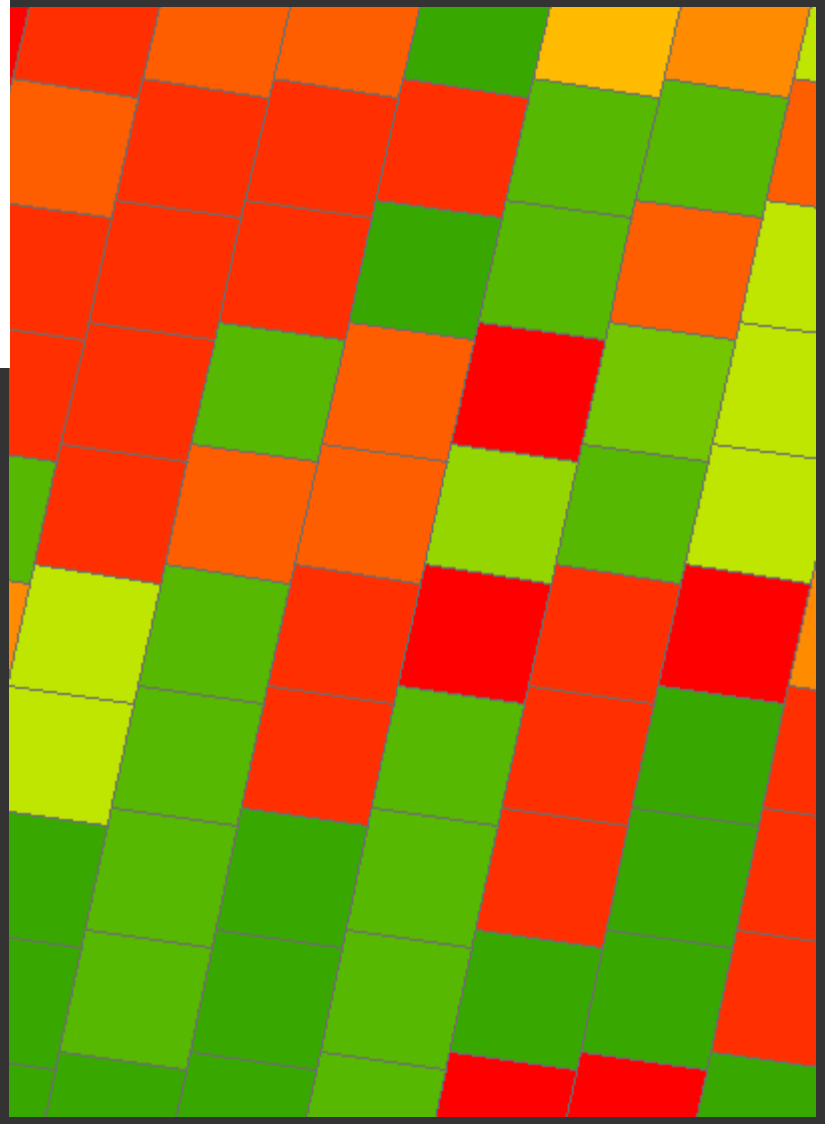
The phenology difference of the GLS images causes visual patch in the global SR mosaic.

Global Forest Cover Change
www.forestcover.org

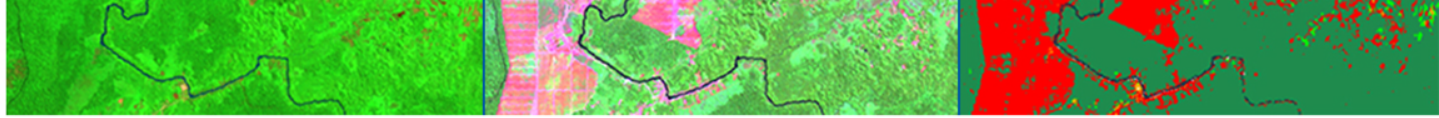


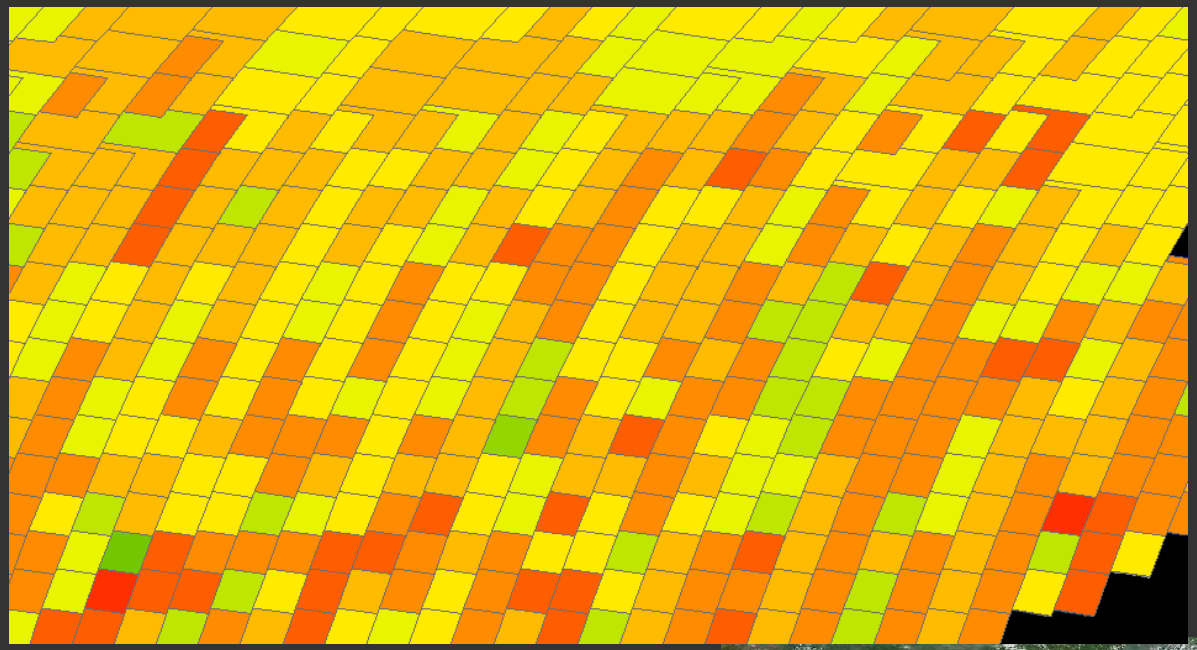
Month

1
2
3
4
5
6
7
8
9
10
11
12

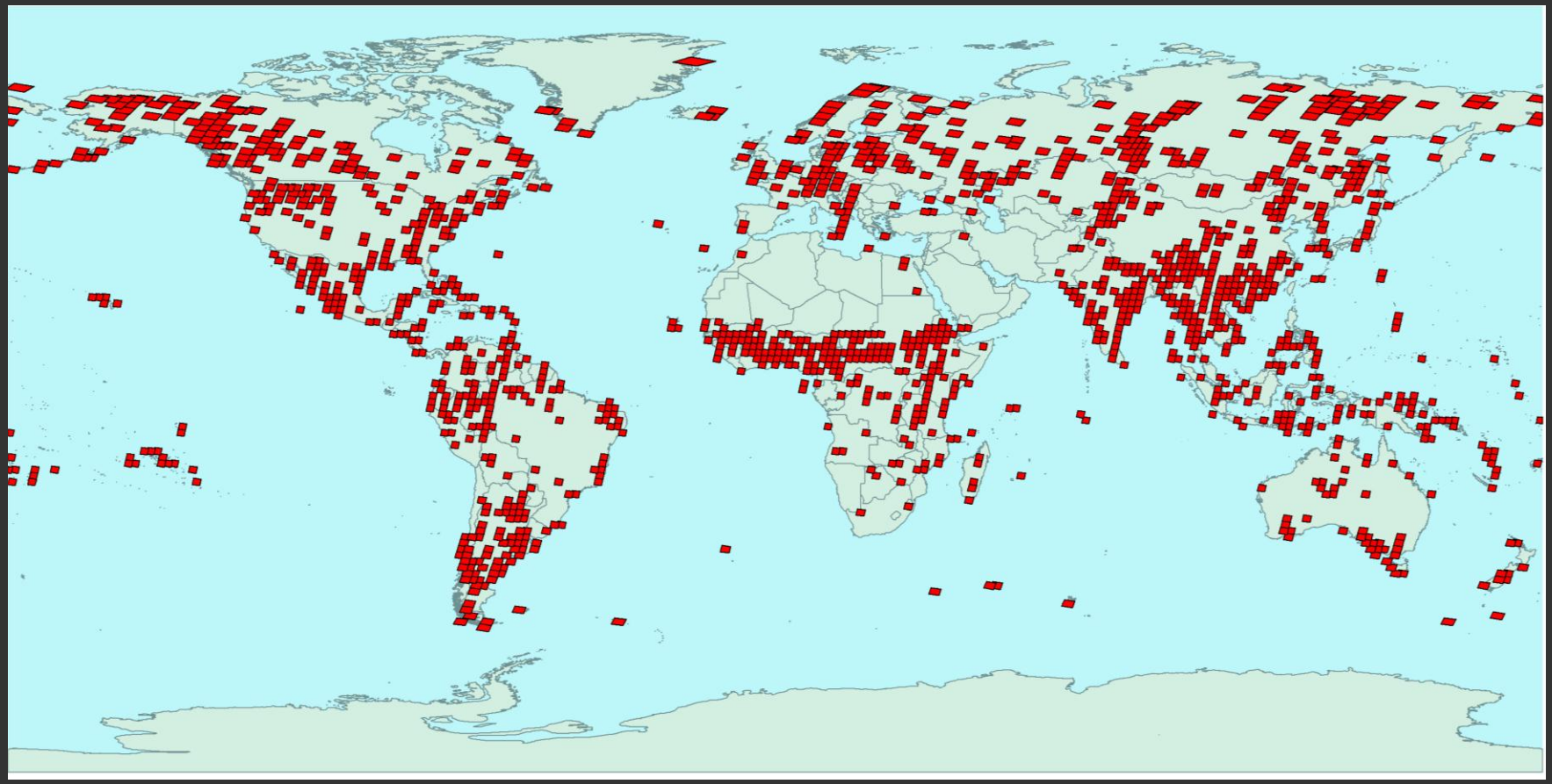


Global Forest Cover Change
www.forestcover.org



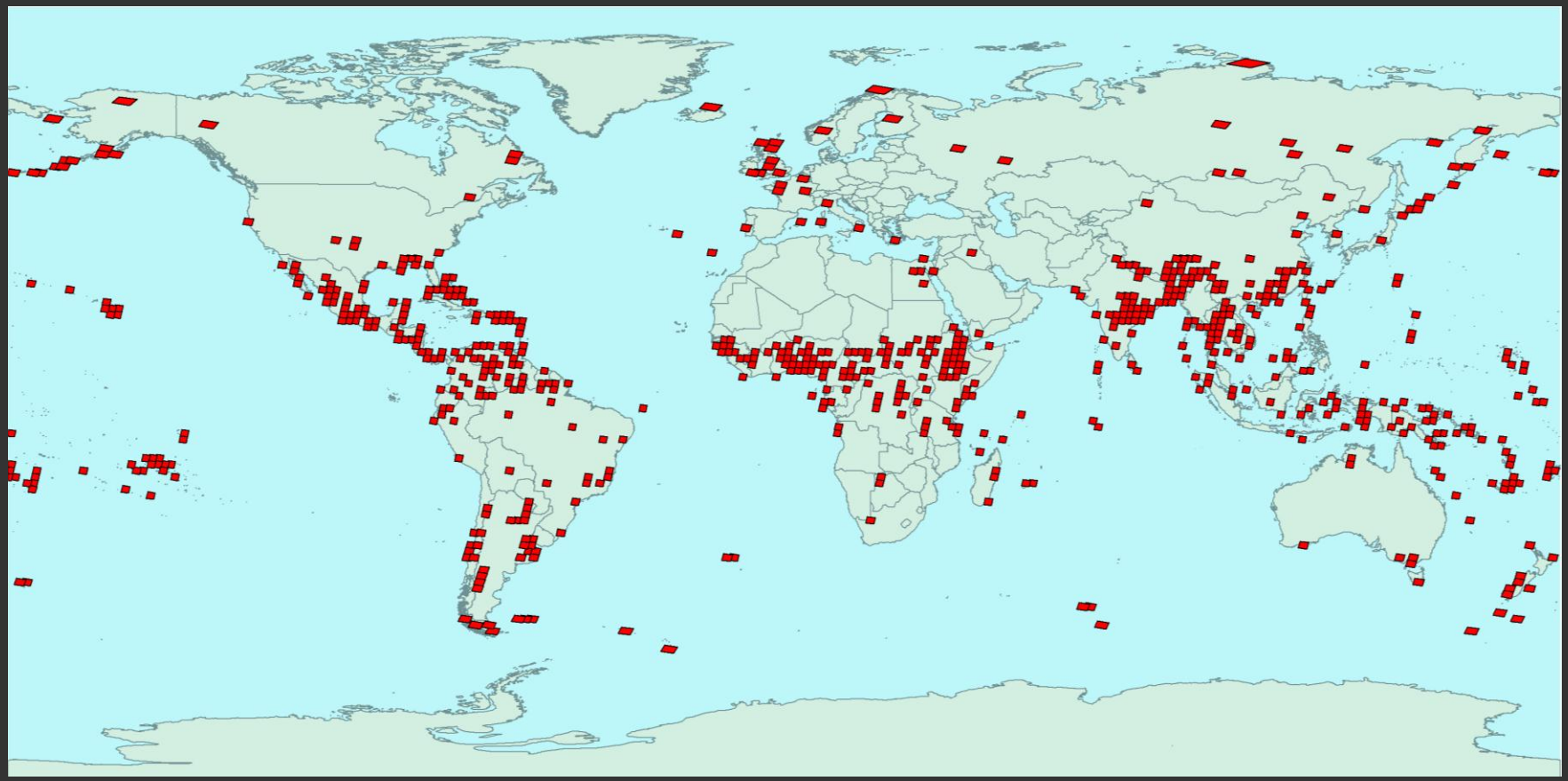


Month



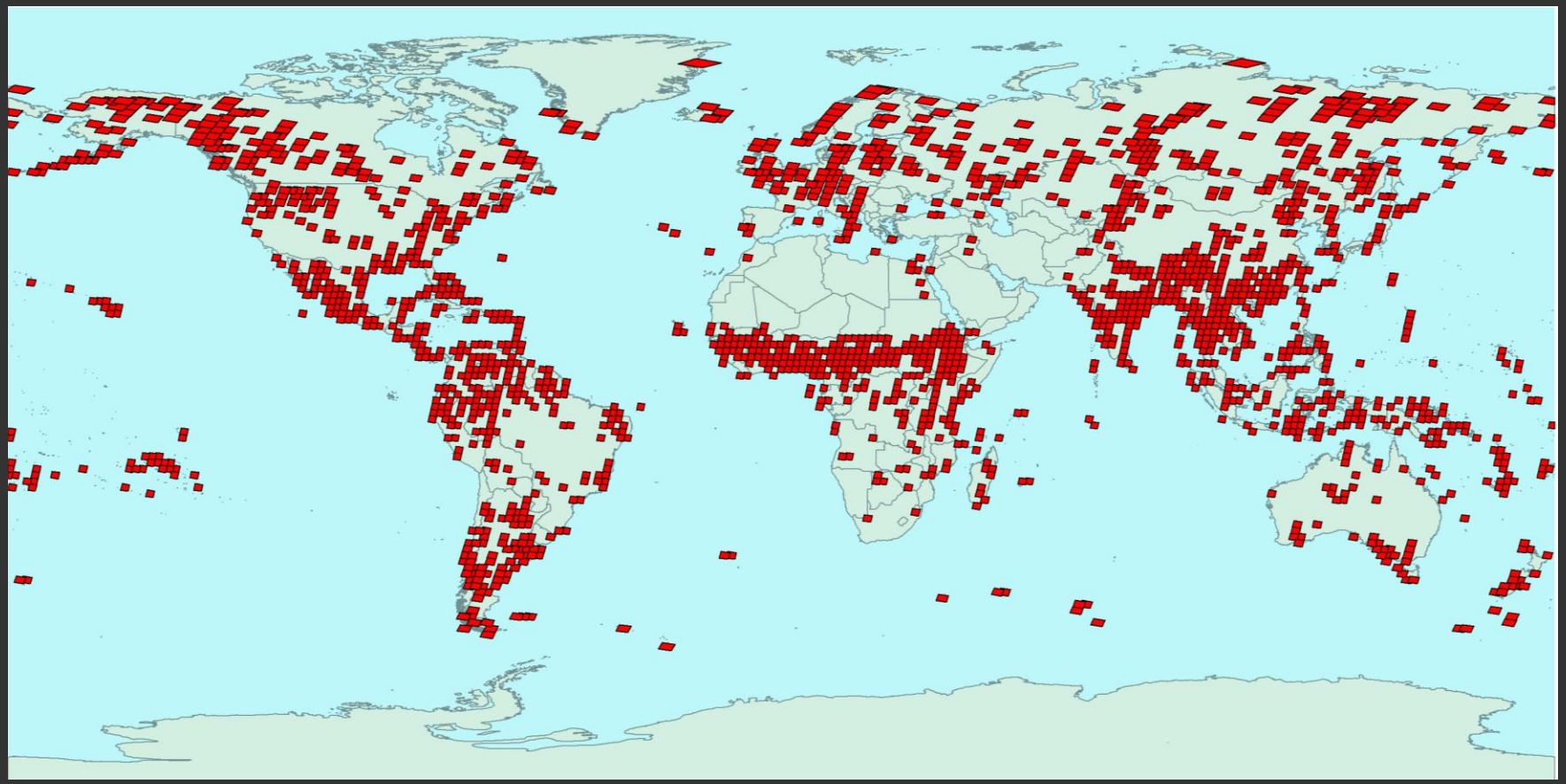
1516 GLS2000 images eligible to be replaced under 70% Rule.

Global Forest Cover Change
www.forestcover.org

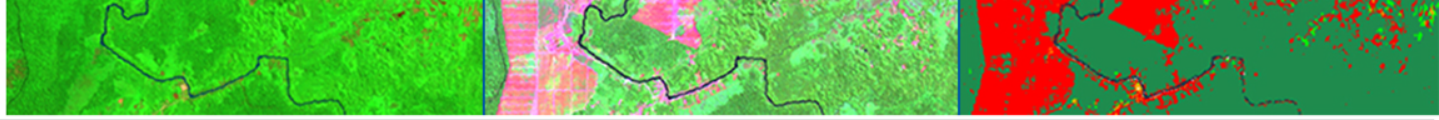


812 GLS2005 images eligible to be replaced under 70% Rule.

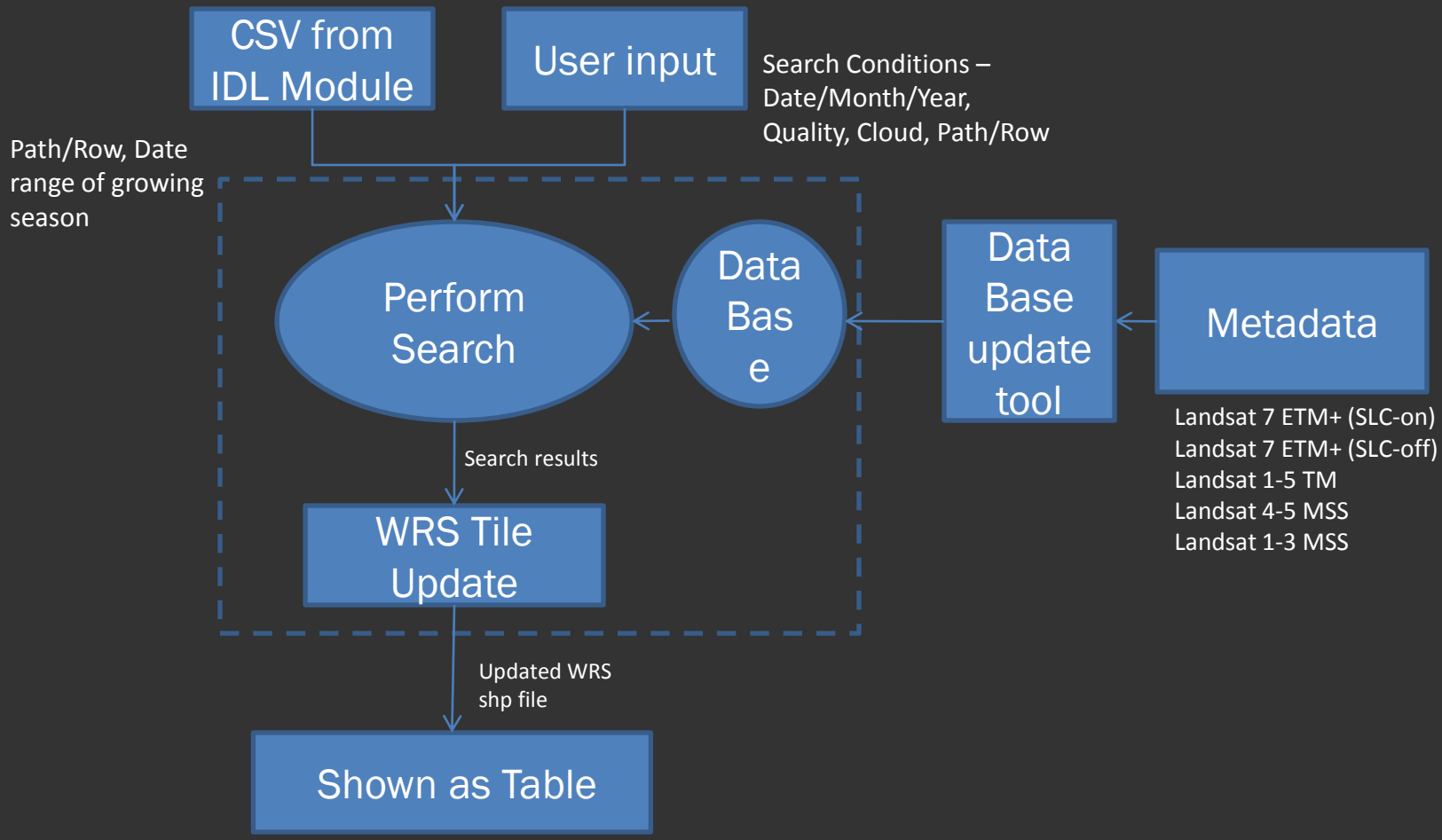
Global Forest Cover Change
www.forestcover.org



GLS2000 *or* GLS2005 images eligible to be replaced under 70% Rule.



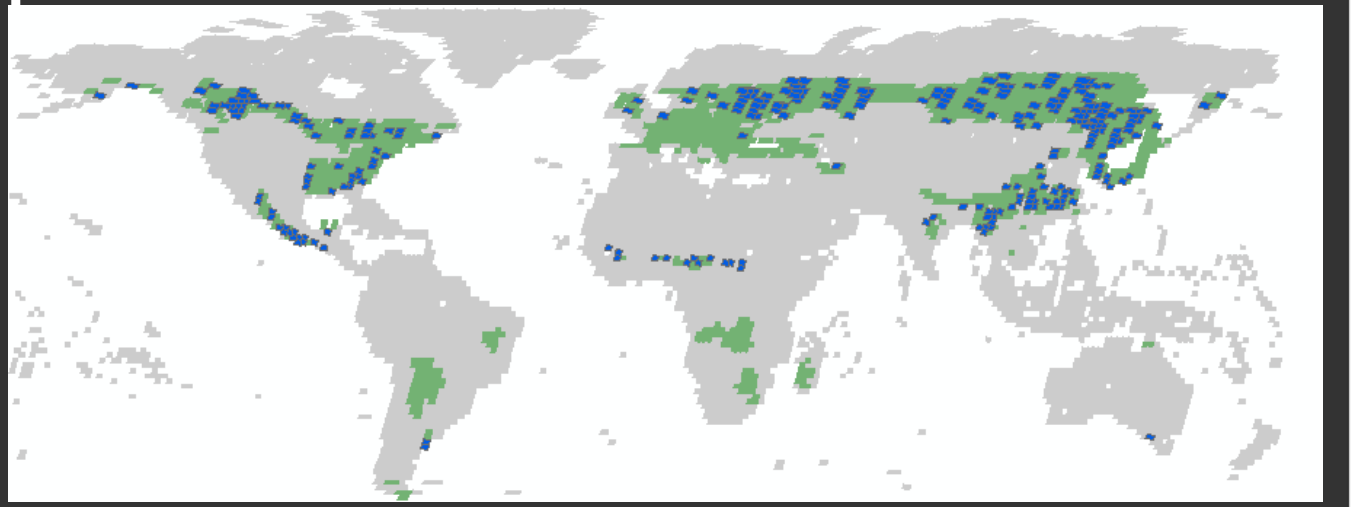
Web app System Diagram



Replacement Scenes

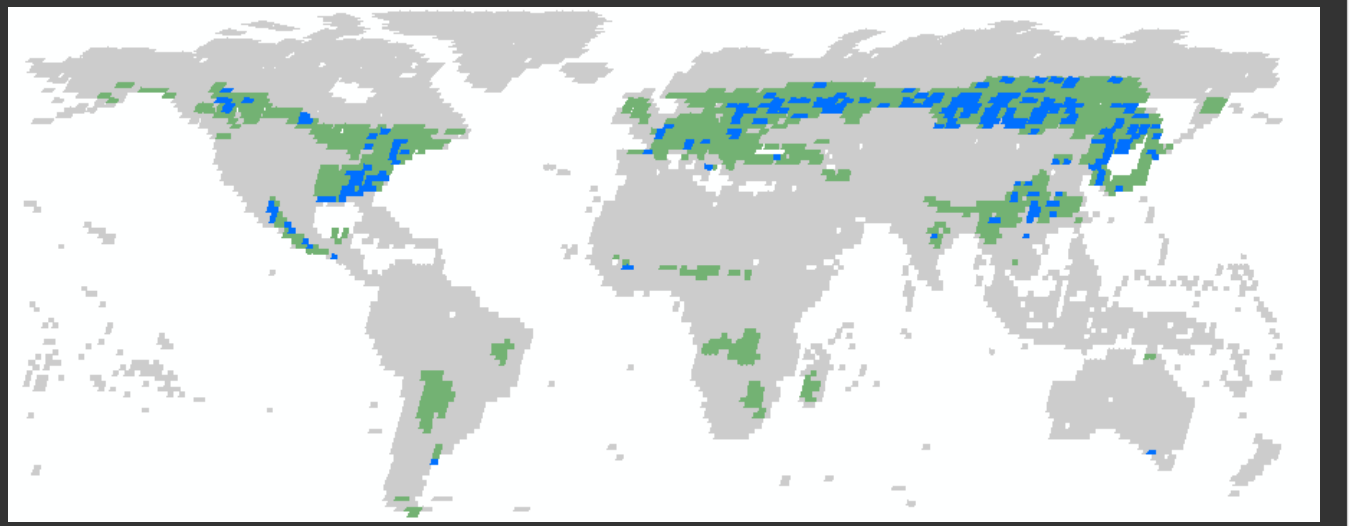
GLS 2000

284 Replacement / 424 scenes need to be replaced



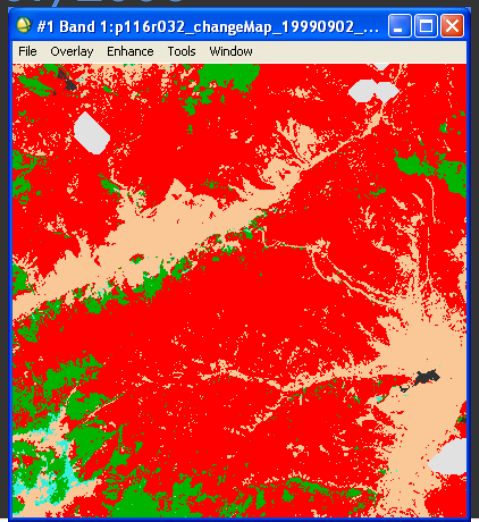
GLS 2005

252 Replacement /435 scenes need to be replaced



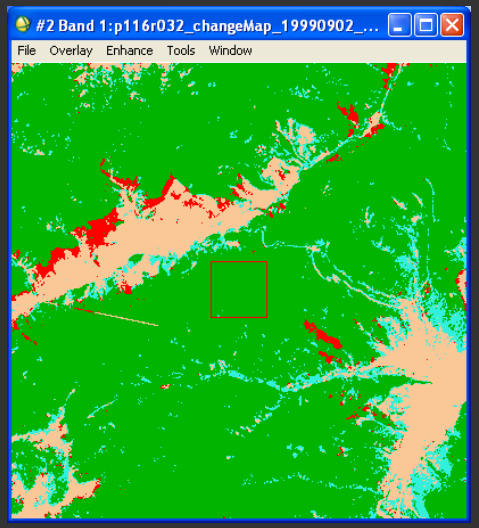
TDA-SVM Result with replaced image

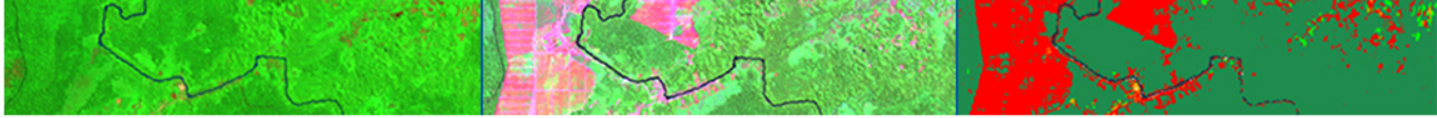
Change map 09/02/1999 – 10/07/2006



- Unclassified
- Forest to Forest
- Forest to Non Forest
- Non Forest to Forest
- Non Forest to Non Forest

Change map 09/02/1999 – 08/28/2006

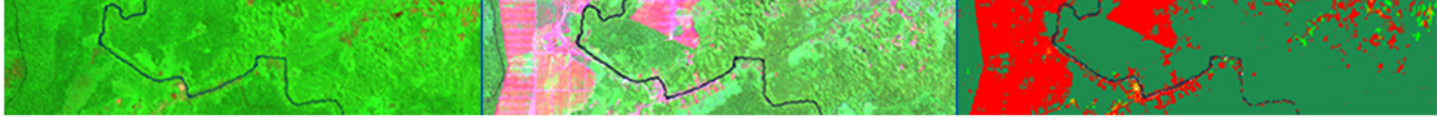




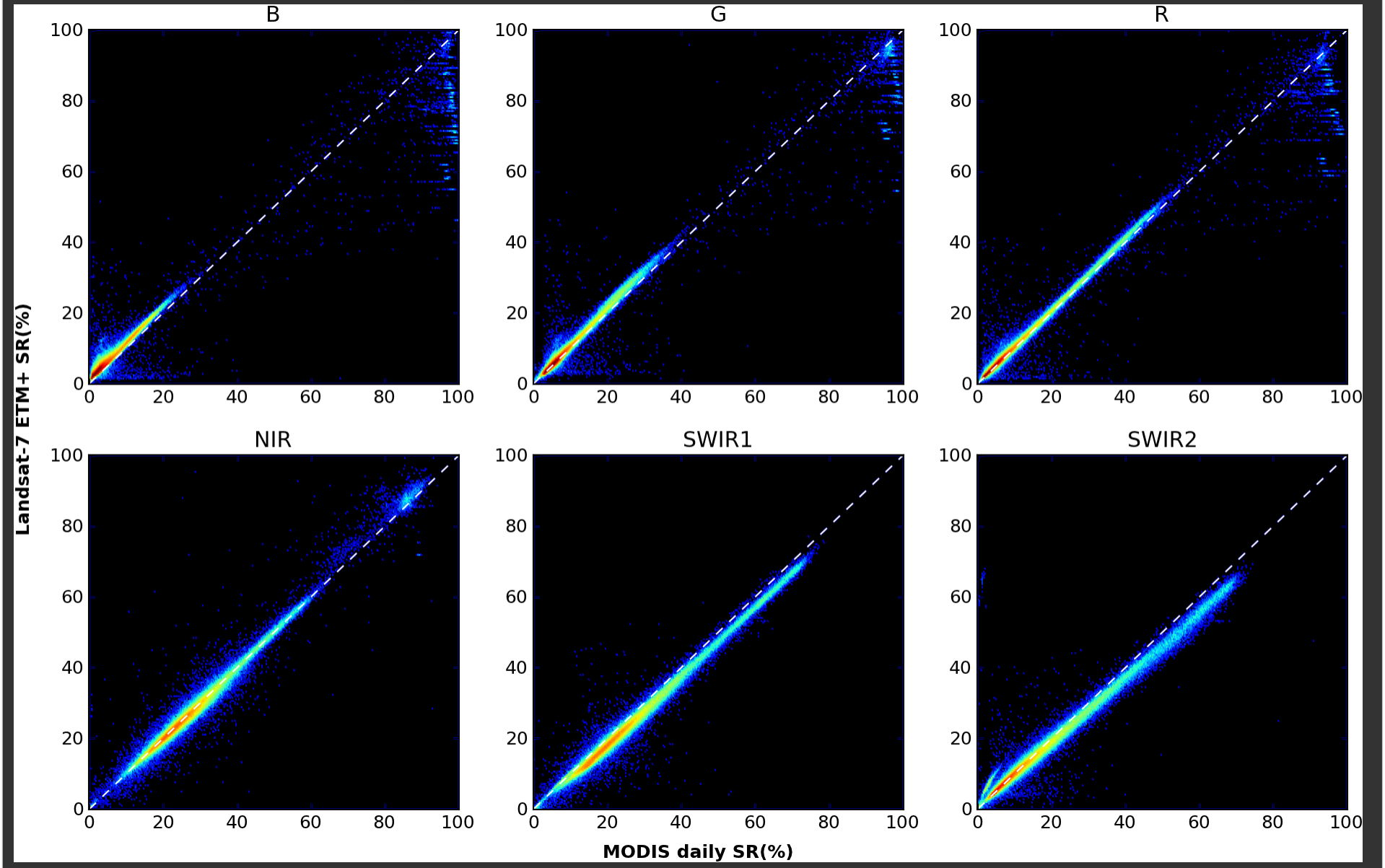
SR: Error estimation

- Compared Landsat SR results with MODIS SR daily and NBAR.
  - Overall sanity check for erroneous output
- Results are mostly consistent with MODIS SR data.

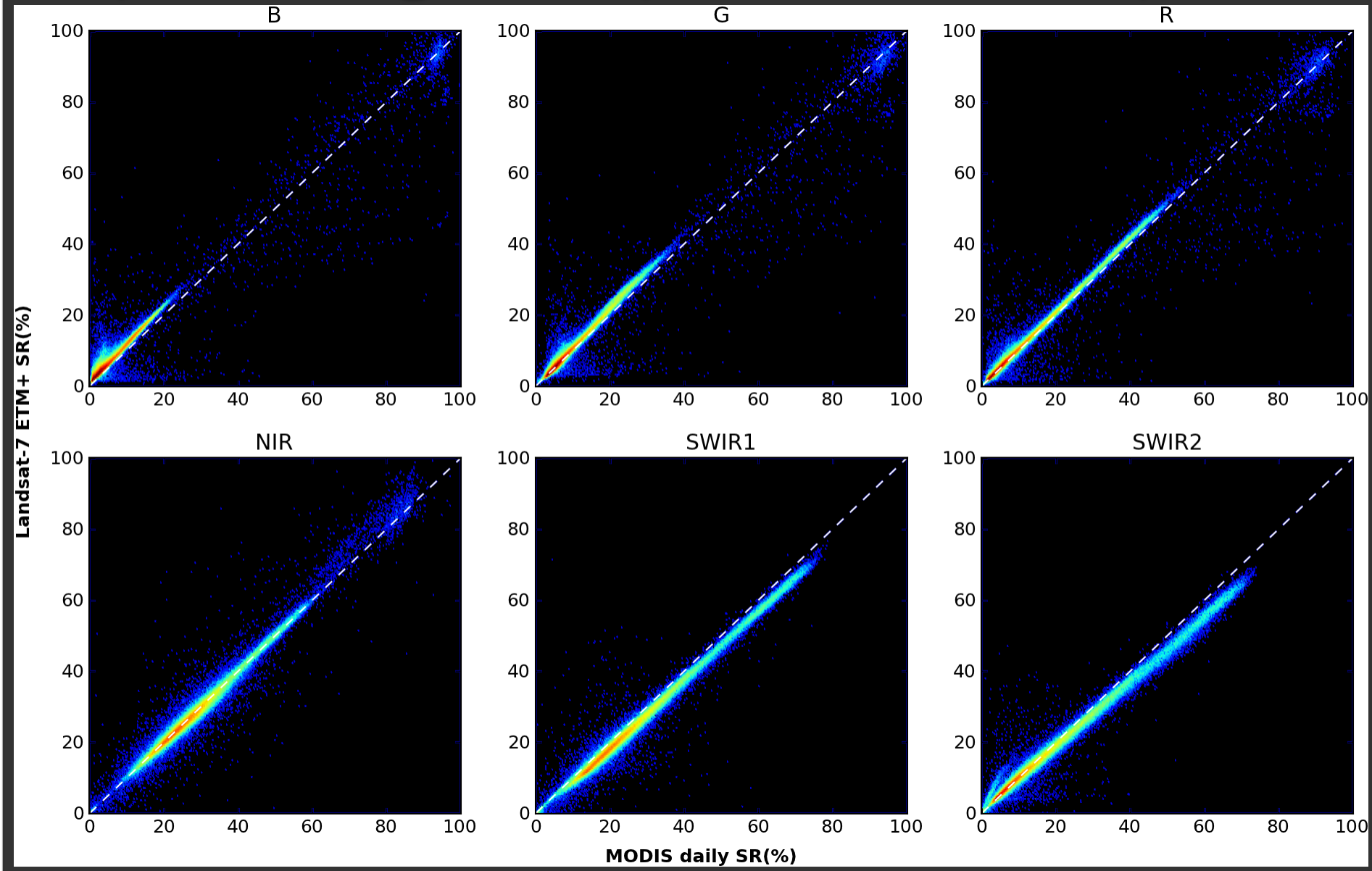
Epoch	Sensor	Band	Num	Slope	Intercept	R^2	RMSD	$RMSD_S$	$RMSD_U$	MBE	$RMSD_R$
2000	ETM+	B	215072	0.630	18.311	0.803	1.950	1.811	0.508	0.928	0.483
		G	215067	1.459	-41.535	0.867	1.148	0.947	0.508	0.251	0.161
		R	215073	1.344	-26.729	0.895	1.110	0.845	0.580	0.115	0.159
		NIR	215057	0.935	2.384	0.908	1.402	0.826	1.032	-0.302	0.075
		SWIR1	215075	0.981	2.512	0.919	2.490	2.235	0.950	-2.169	0.161
		SWIR2	214770	0.973	1.125	0.906	1.740	1.307	0.915	-0.758	0.163
2005	ETM+	B	202237	0.827	-0.184	0.820	1.731	1.604	0.470	1.423	0.477
		G	202838	0.890	0.763	0.879	1.139	0.942	0.511	0.527	0.161
		R	202662	0.910	0.652	0.905	1.015	0.762	0.574	0.459	0.153
		NIR	203112	0.939	1.998	0.916	1.379	0.791	1.038	-0.222	0.072
		SWIR1	203124	0.991	2.163	0.925	2.429	2.176	0.942	-2.117	0.155
		SWIR2	203096	0.999	0.416	0.910	1.688	1.298	0.860	-0.832	0.152
	TM	B	94914	0.650	0.571	0.565	2.058	1.757	0.811	1.022	0.535
		G	95865	0.809	1.394	0.698	1.909	1.525	0.929	0.364	0.304
		R	95782	0.859	0.897	0.766	1.882	1.450	0.976	0.381	0.318
		NIR	95561	0.911	3.599	0.814	3.203	2.369	1.941	-1.207	0.187
		SWIR1	95905	0.858	4.202	0.795	3.187	2.569	1.680	-1.701	0.255
		SWIR2	95904	0.826	1.506	0.808	2.016	1.491	1.175	0.148	0.272



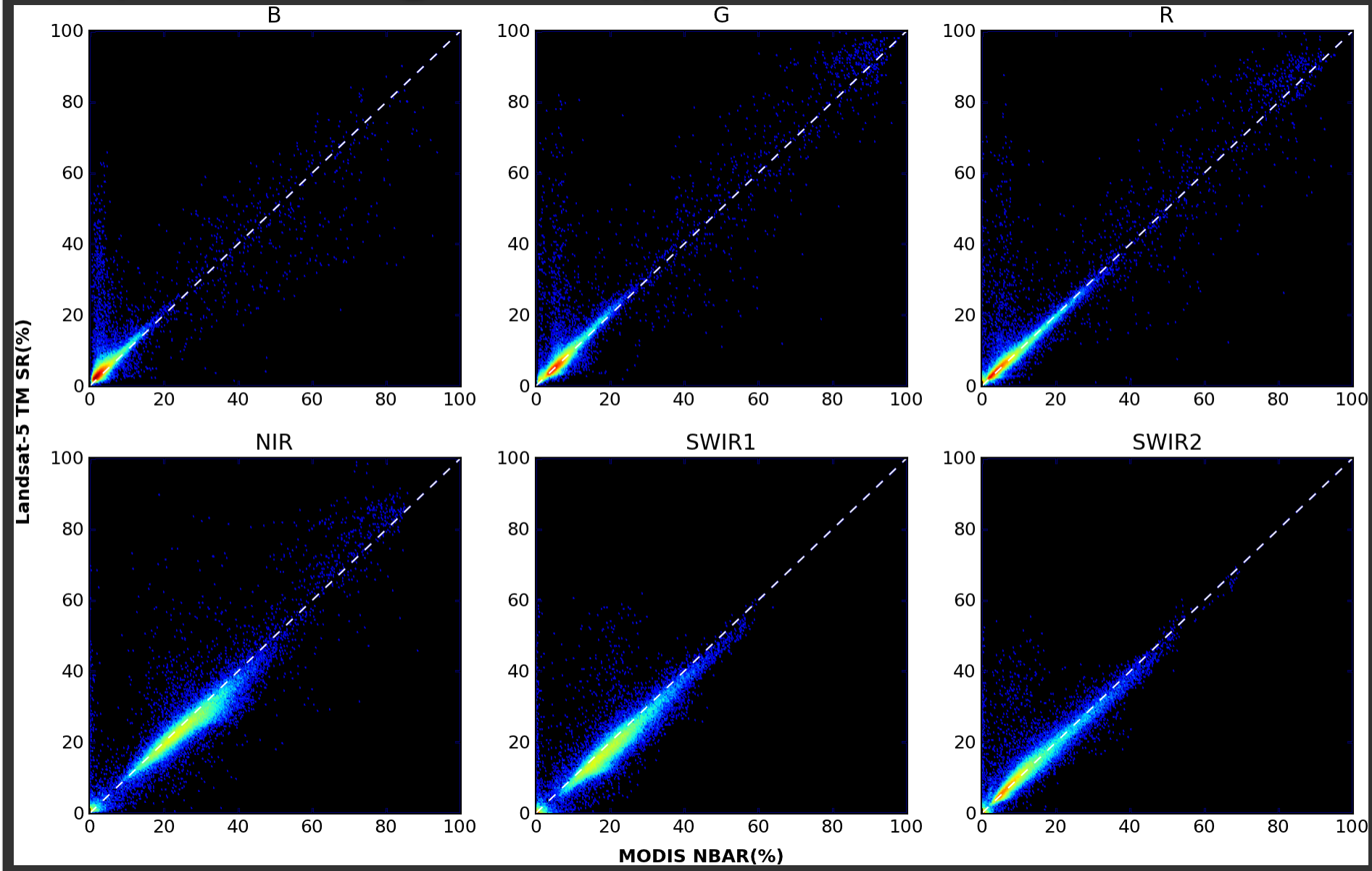
SR processing result (GLS 2000 ETM+)

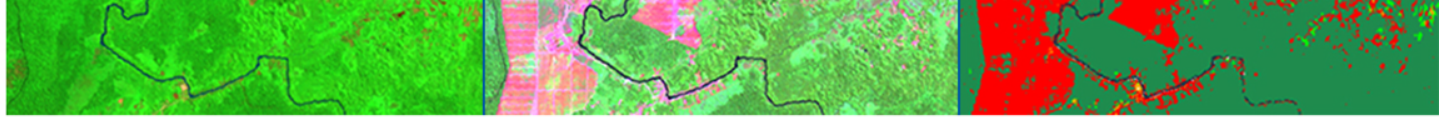


SR processing result (GLS 2005 ETM+)



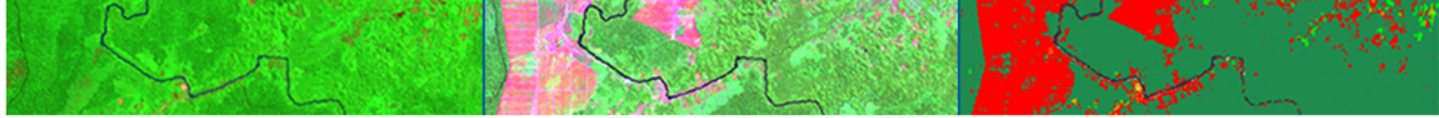
SR processing result (GLS 2005 TM)





SR: Papers

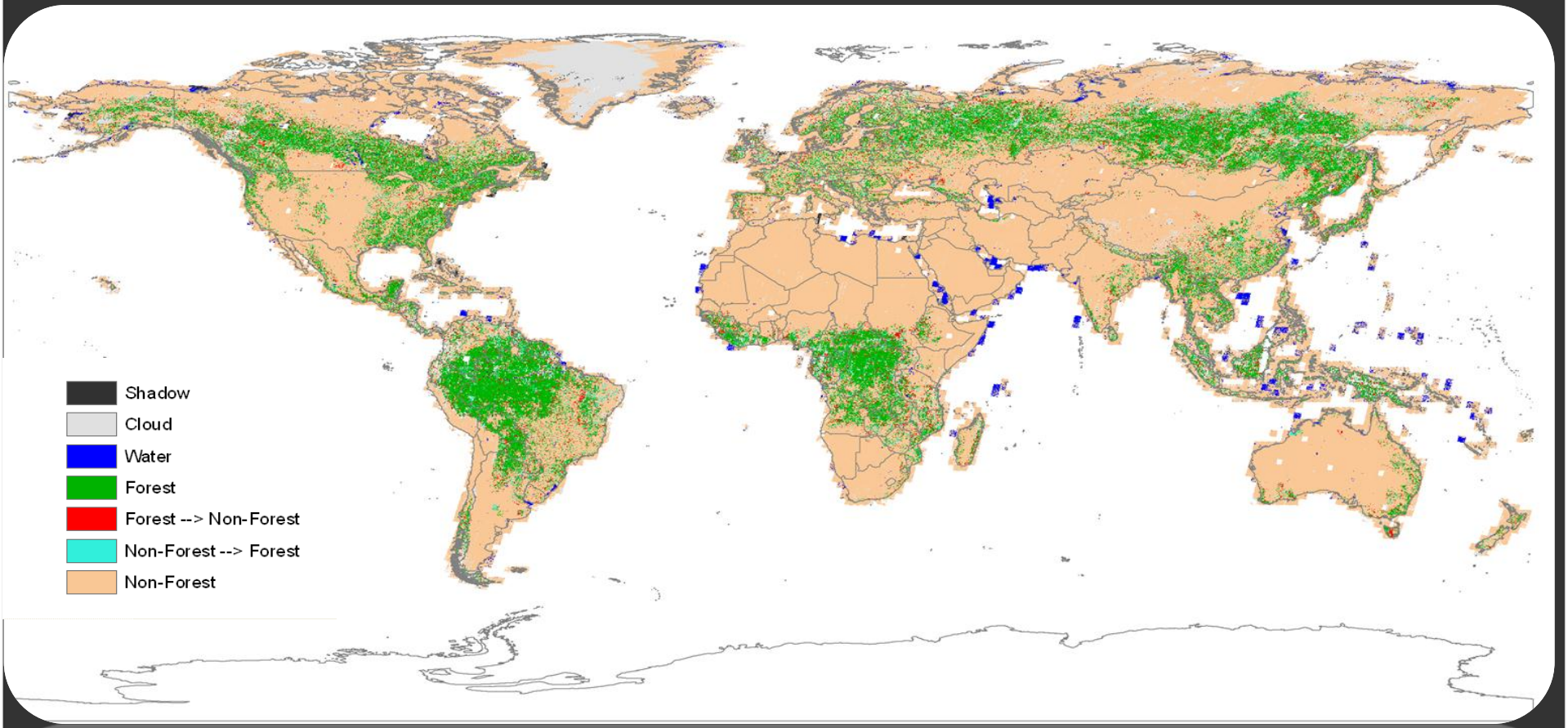
- Feng, M., Huang, C, Channan, S., Vermote, E. F., Masek, J. G., & Townshend, J. R. (2012). Quality assessment of Landsat surface reflectance products using MODIS data. *Computers & Geosciences*, 38 (1): 9-22 . doi:10.1016/j.cageo.2011.04.011
- Feng, M., Sexton, J., Huang, C., Masek, J., Vermote, E., Gao F., Narasimhan, R., Channan, S., Wolfe, R., Townshend, J. (in review). Global, long-term surface reflectance records from Landsat: a comparison of the Global Land Survey and MODIS surface reflectance datasets.



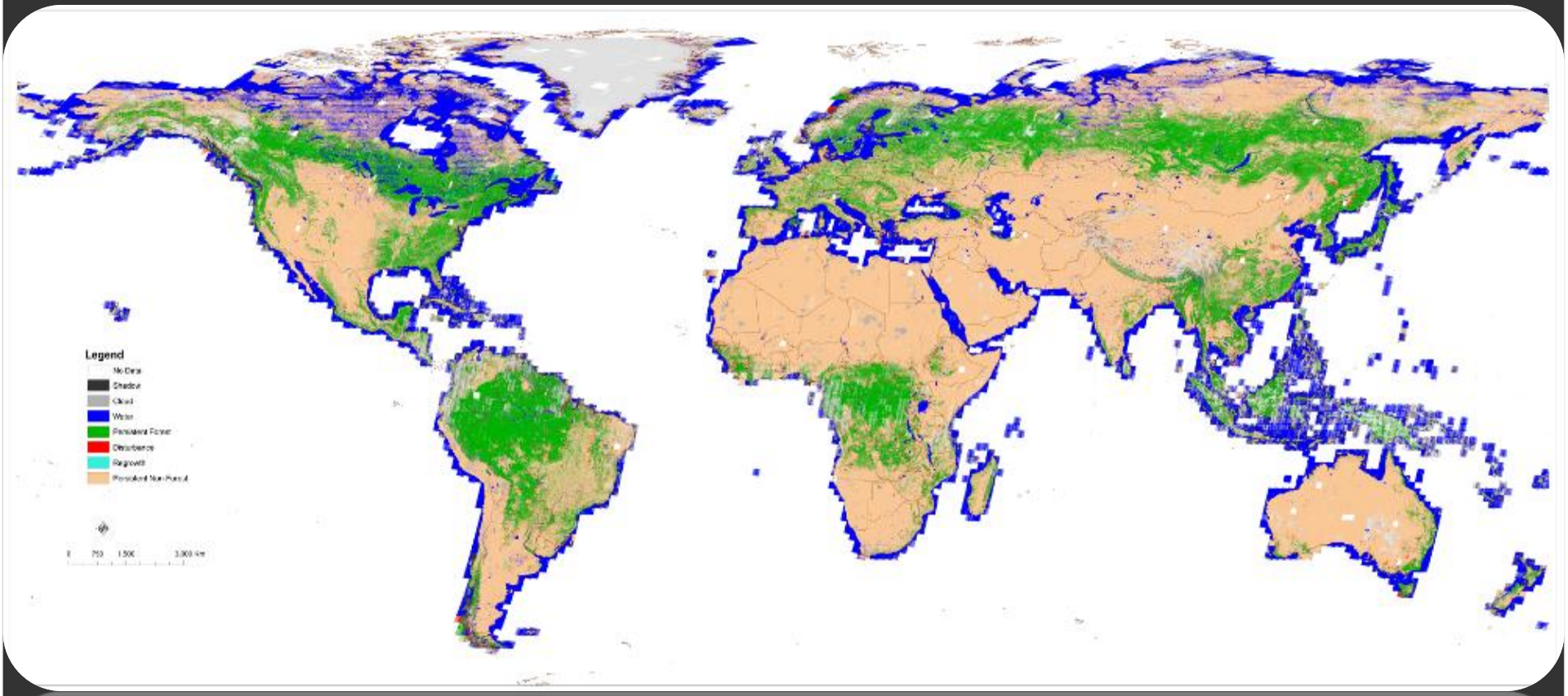
Forest Cover Change (FCC)

- Develop a tri-decadal Global FCC leveraging GLS collection.
  - 2000 – 2005: On going
  - 1990 – 2000: On going. Partially processed, waiting for the rest of USGS repatriation of Landsat for circa 1990
  - 1975 – 1990: Waiting on USGS repatriation of circa 1975 Landsat

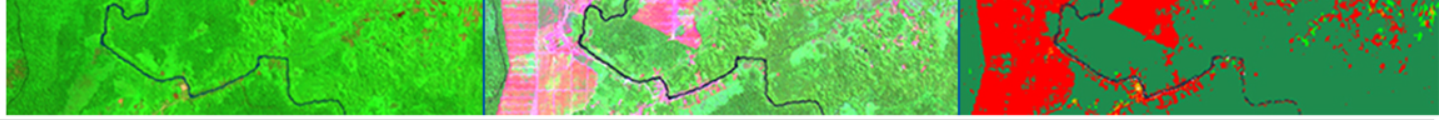
Forest Cover Change 2000-2005 v0.0



Forest Cover Change 2000-2005 v0.2

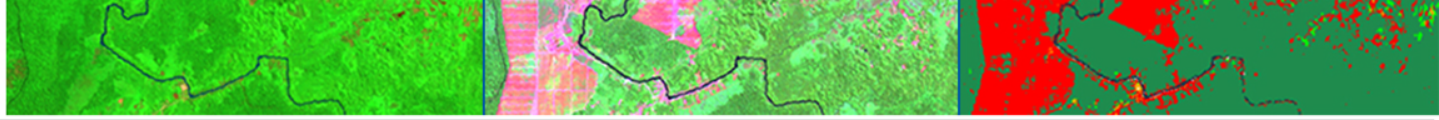


Funding source: NNH06ZDA001N-MEASURES



FCC Challenges

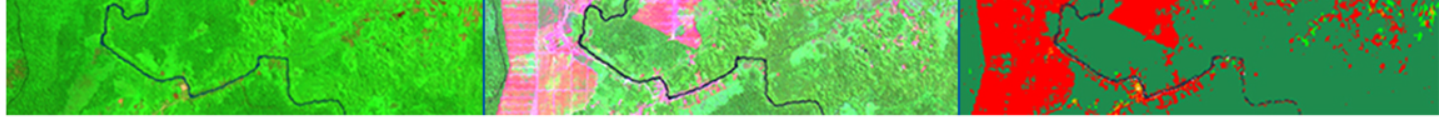
- FCC 2000 – 2005:
  - ✓Phenology
  - ✓Improved cloud, cloud shadow & water detection
  - ✓Terrain Illumination correction
  - ✓Commission errors:
    - ✓Large crop regions
    - ✓Semi arid/spare forests



FCC Challenges: Solutions

- Phenology:
  - Figure out global start and end of peak phenology
  - Harvest Landsat metadata archive to find phenologically optimized scenes

Global Forest Cover Change
www.forestcover.org



For each pathrow

16-day MODIS NDVI

MODIS LC

Overlaid

40 % forest?

Yes

No

40 % evergreen?

No

40 % Decidous?

No

Yes

Yes

Scene NDVI

Forest NDVI

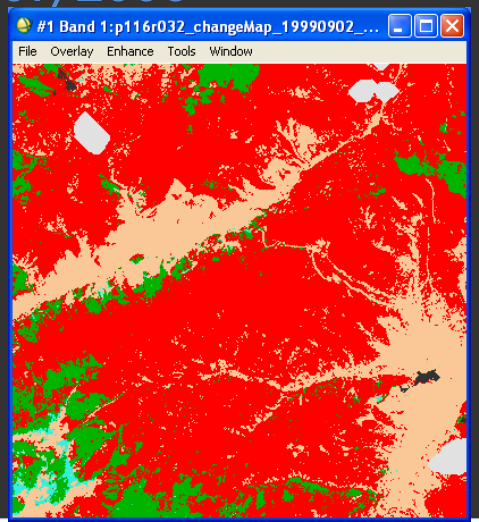
Evergreen NDVI

Deciduous NDVI

Median NDVI for each year

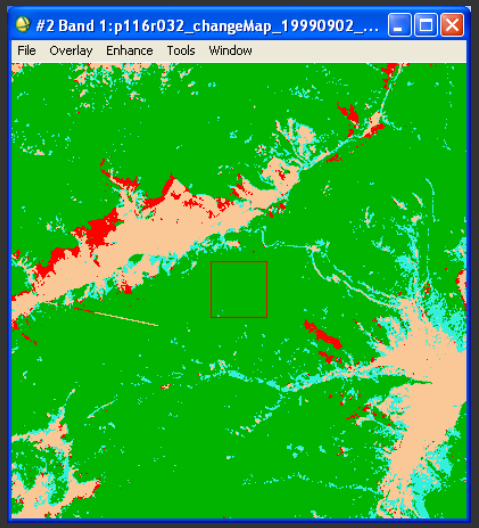
TDA-SVM Result with replaced image

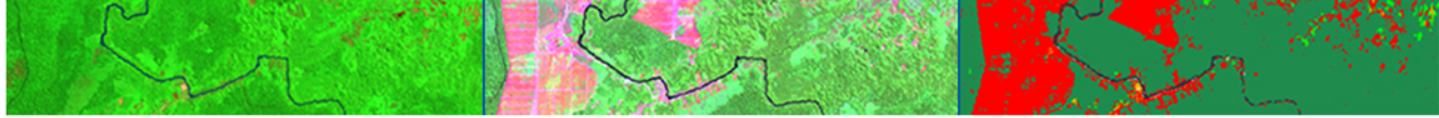
Change map 09/02/1999 – 10/07/2006



- Unclassified
- Forest to Forest
- Forest to Non Forest
- Non Forest to Forest
- Non Forest to Non Forest

Change map 09/02/1999 – 08/28/2006





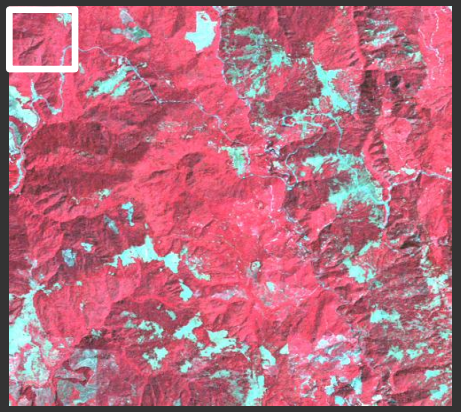
FCC Challenges: Solutions

- Terrain Illumination Correction:
  - Bin Tan, Jeff Masek, et. al.

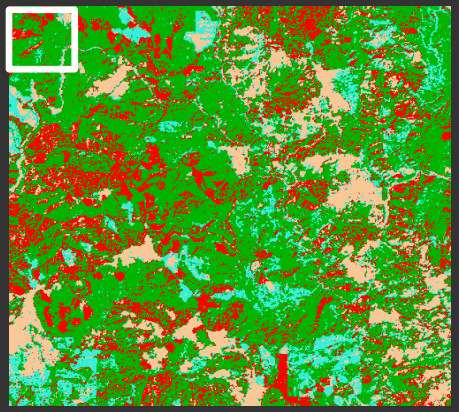
Mapping Forest Changes in Mountain Area

Path 46, Row 32

1989-09-03

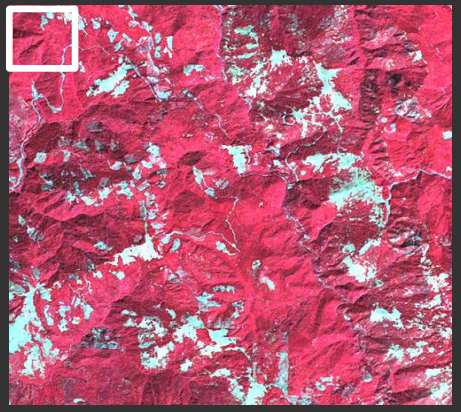


SVM Result



Deforest
Regrowth
Forest
Non Forest

2002-10-01

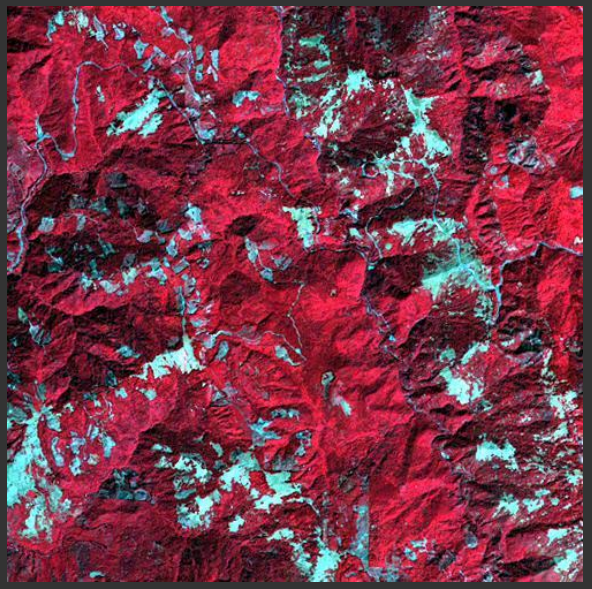


Illumination Condition (IL)

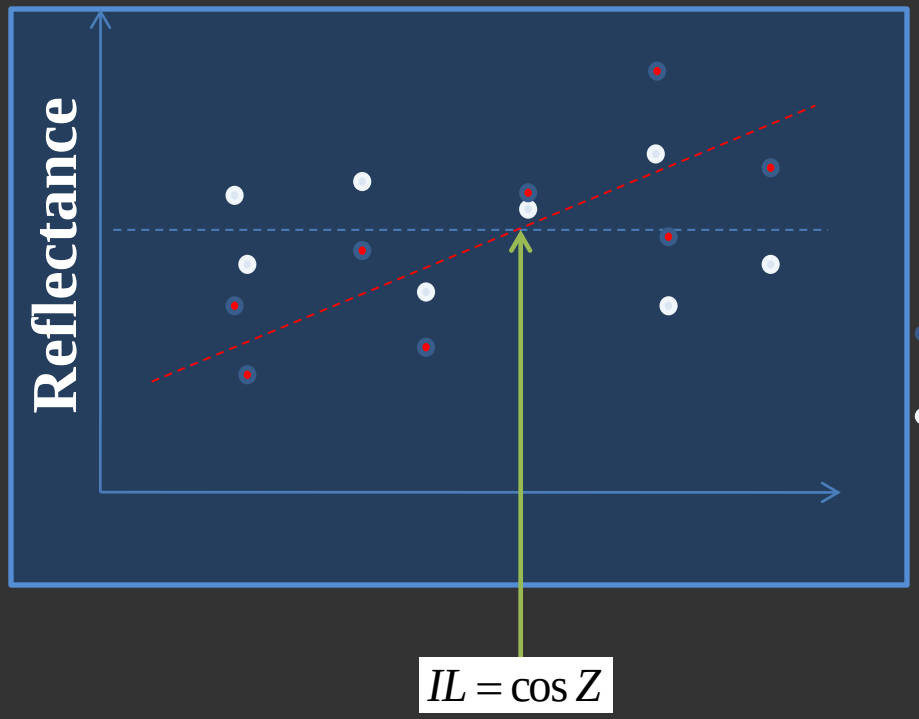
$$IL = \cos Z \bullet \cos S + \sin Z \bullet \sin S \bullet \cos(\phi_z - \phi_S)$$

Z: the solar zenith angle,
Φ_z: the solar azimuth angle,

S: the slope angle,
Φ_s: is the aspect angle of the incline surface.



Rotation Model



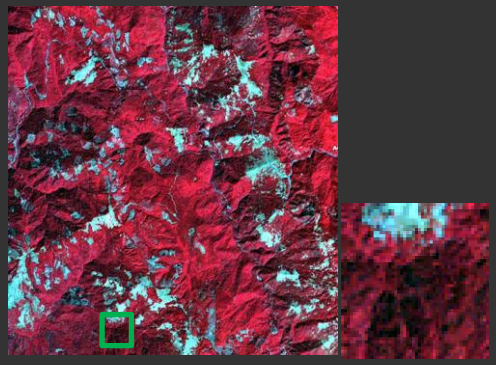
Rotation Model :

$$L_H(\lambda) = L_i(\lambda) - (a * IL + b)$$

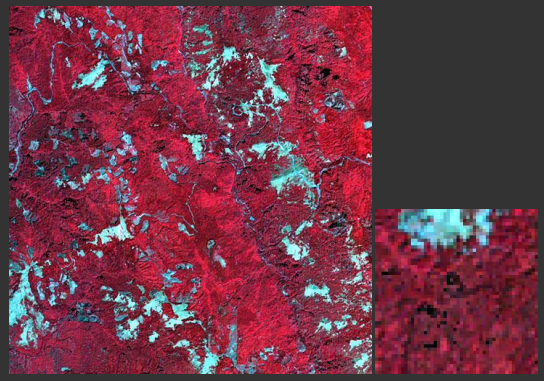
Where a and b s from regression

Corrected Reflectance

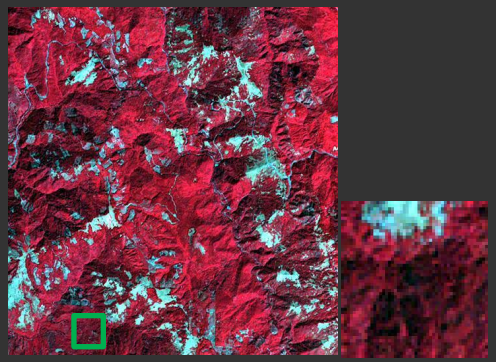
TOA-Original



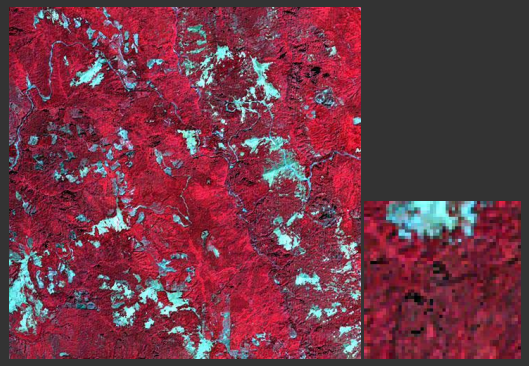
TOA-Corrected



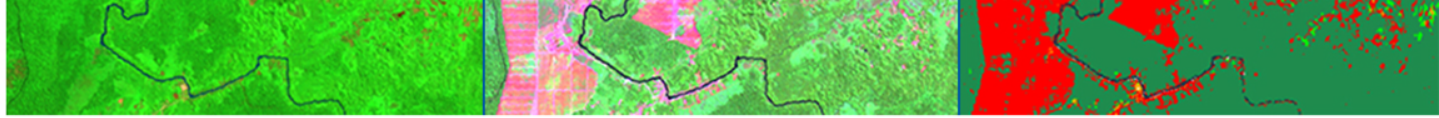
TOC-Original



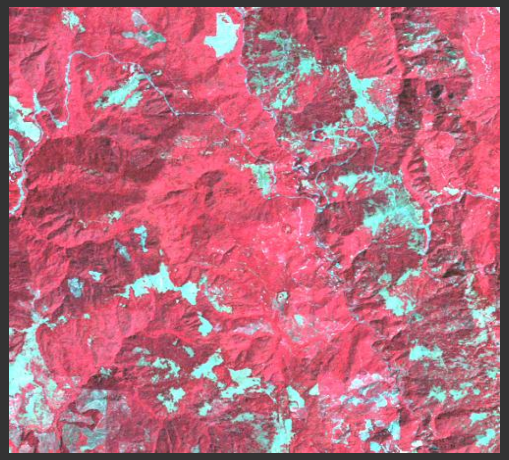
TOC-Corrected



Global Forest Cover Change
www.forestcover.org

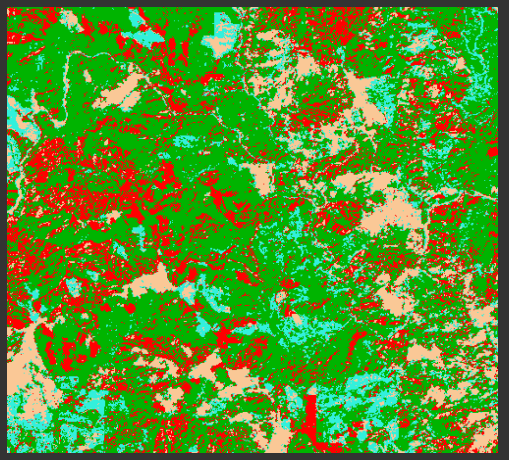


1989-09-03

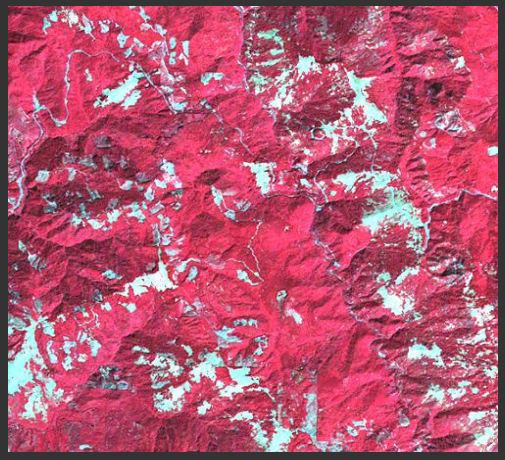


1989-09-03 Corrected

SVM w/o IC

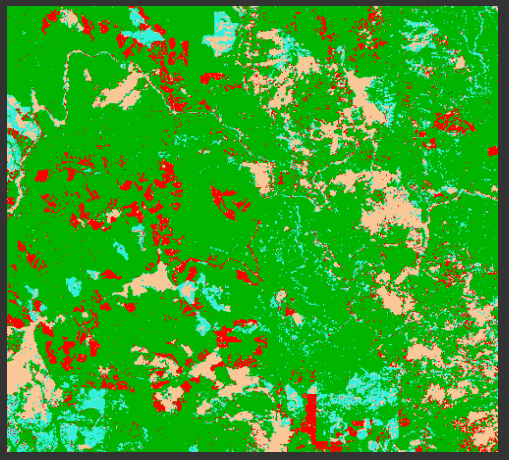


2002-10-01



2002-10-01 Corrected

SVM w IC

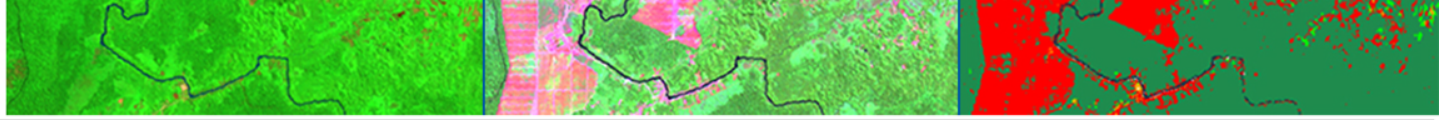


Deforest

Regrowth

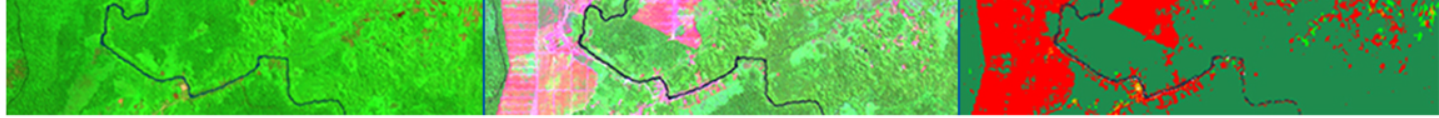
Forest

Non Forest



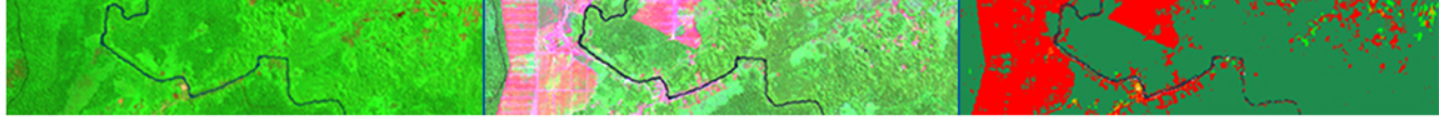
Terrain Illumination: Synopsis

- Works well with GLSDEM at 30m over US
  - 90m DEM globally starts producing artifacts
- Working towards integrating ASTER GDEM globally at 30m



FCC Challenges: Solutions

- Commission errors:
  - Large crop regions
  - Semi arid/spare forests



FCC Challenges: Solutions

Problem

- TDA-SVM can detect most changes, but it has two main problems:
  - Too much false changes in sparse forest and major crop regions
  - Underestimate forest in sparse forest region

Solutions

- Create additional, correct training samples in some false change area, then rerun SVM to map change
  - Use MODIS to identify known false changes
  - Determine whether the false change pixels are forest or not

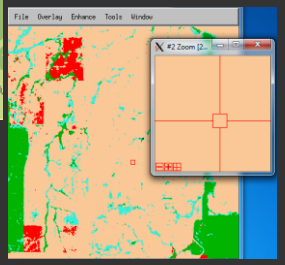
Overall Concept and Assumption

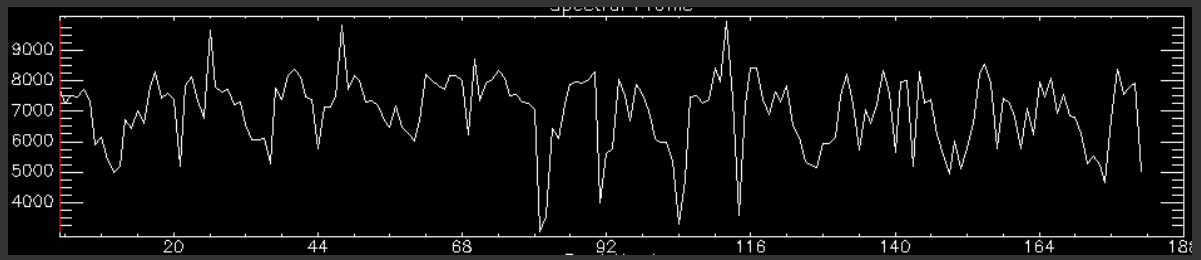
- MODIS NDVI trend by different states follows distinctive patterns

Change map

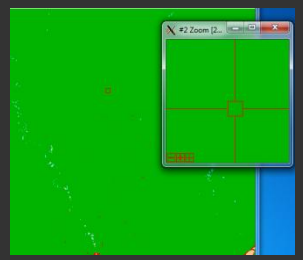
MODIS NDVI

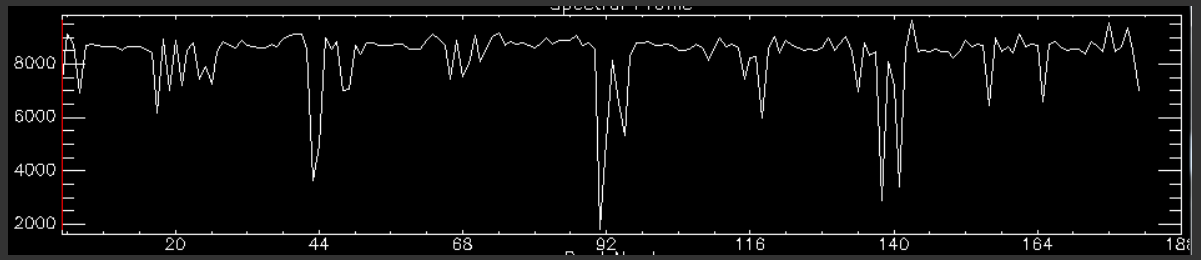
Persistent non-Forest



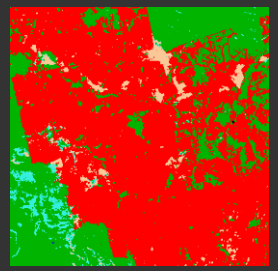


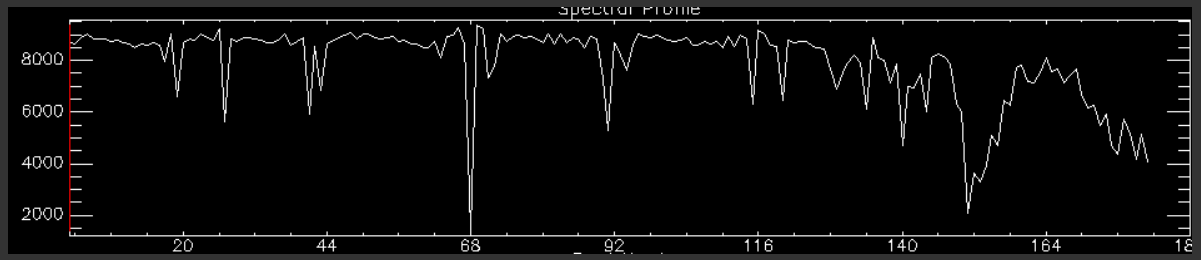
Persistent Forest





Deforestation





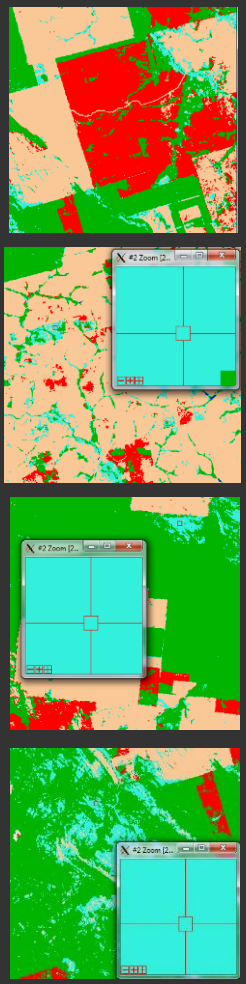
2000 2001 2002 2003 2004 2005 2006 2007

- Detected changes (size > a MODIS pixel) can be validated using MODIS time series data.
- Once change pixels are validated, it can be added to existing training data .

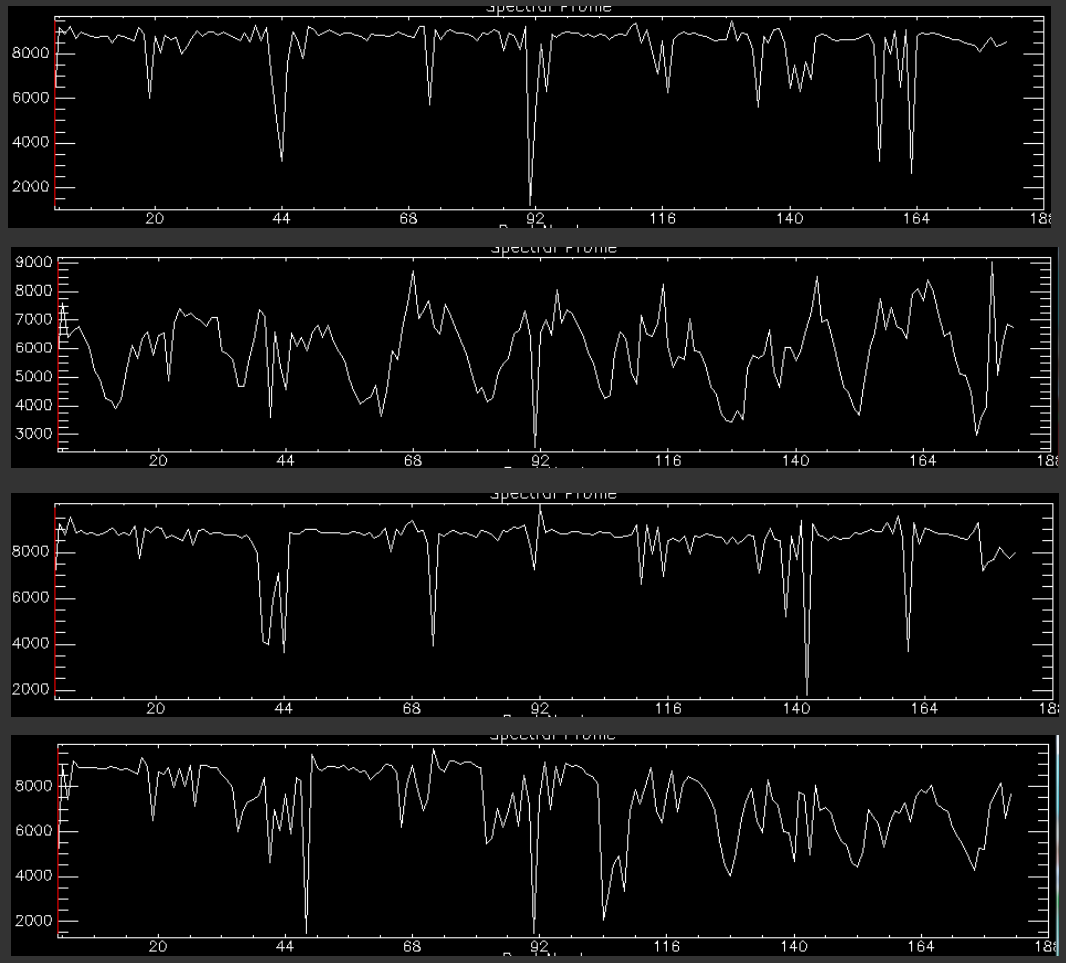
MODIS NDVI for the area miss-identified by TDA

- NDVI trend of Persistent Forest confused as deforestation
- NDVI trend of Persistent Non-Forest confused as regrowth
- NDVI trend of Persistent Forest confused as regrowth
- NDVI trend of deforestation confused as regrowth

Change map



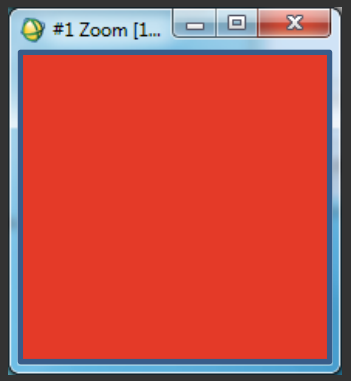
MODIS NDVI



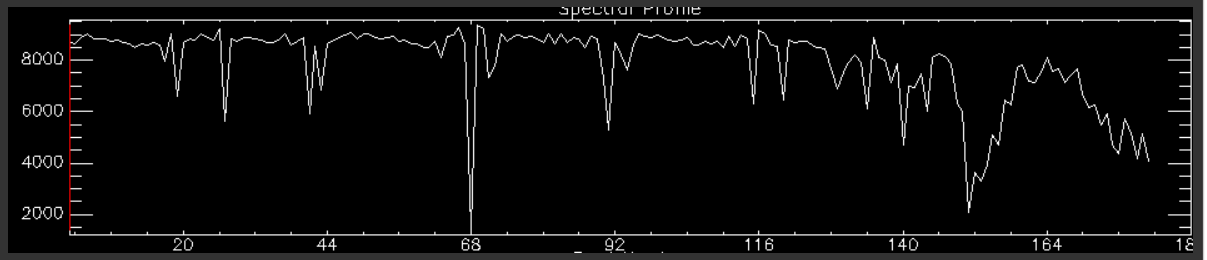
2000 2001 2002 2003 2004 2005 2006 2007

Training Data Update

90% (for example) of pixel is change



Aggregated to 1km



Compared with MODIS NDVI

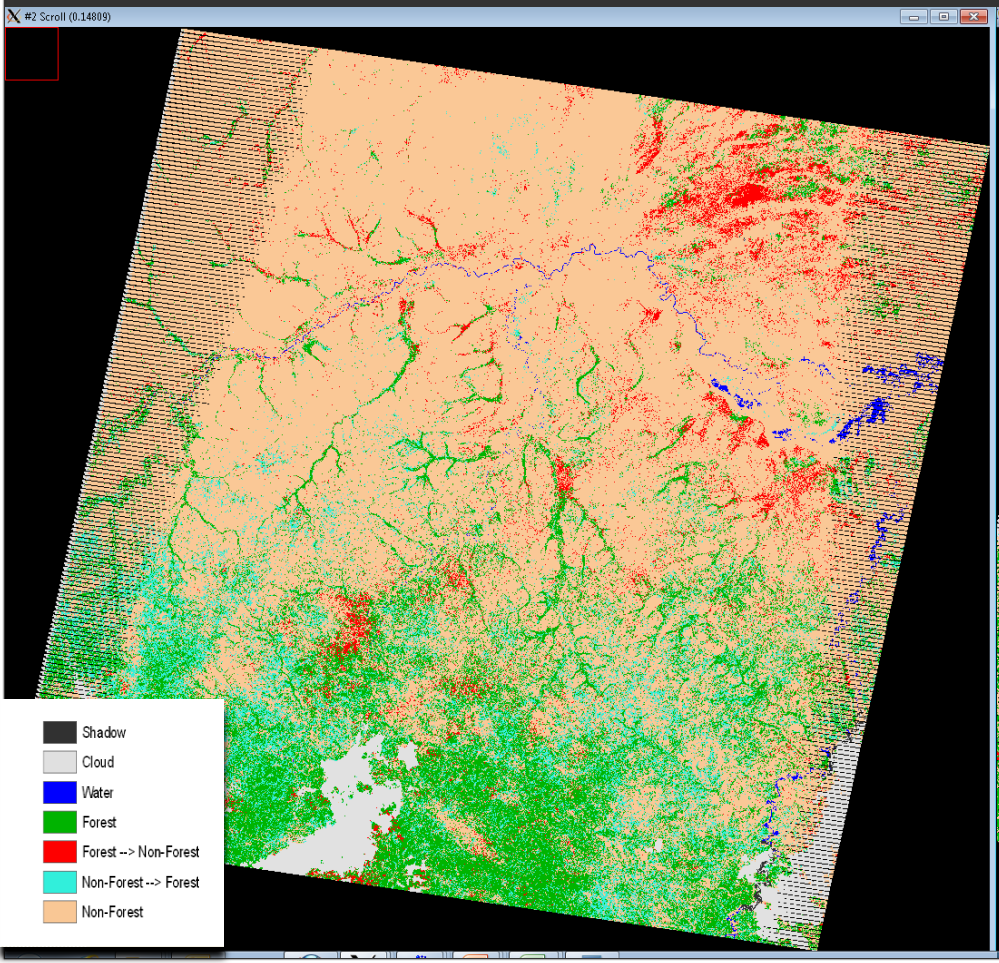
Actual Change?

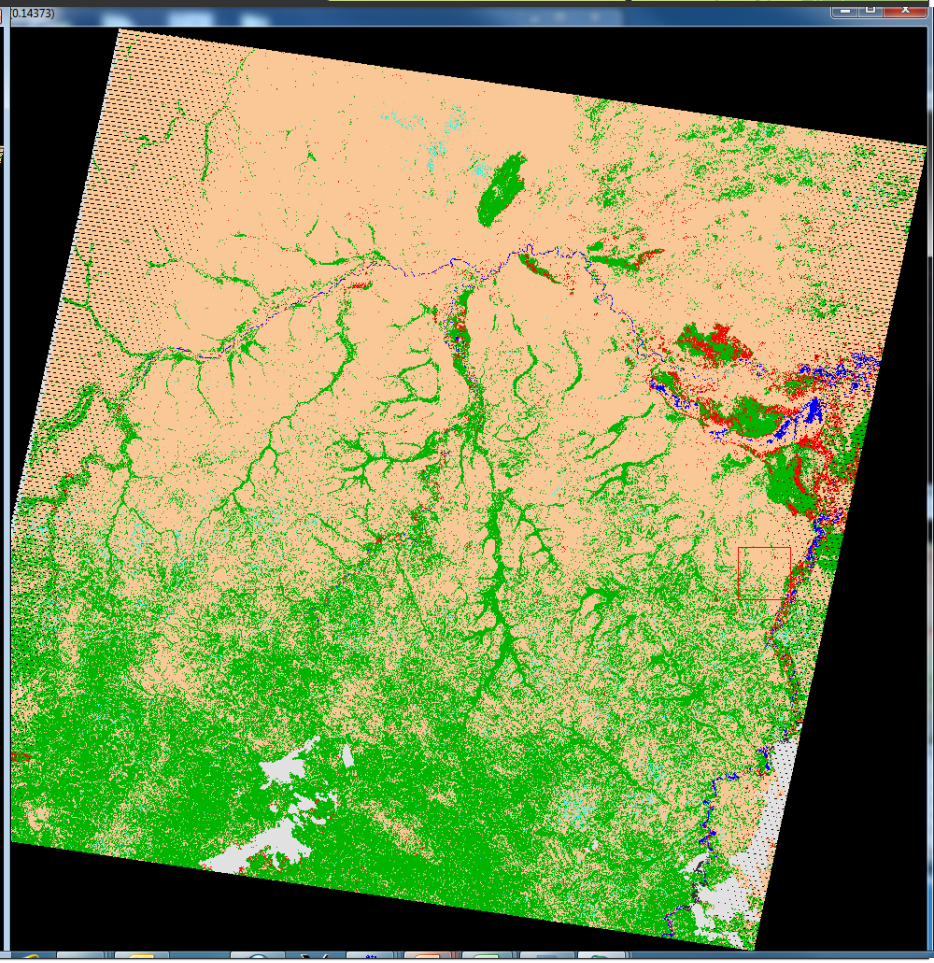
Add Change pixels to Training data.

Global Forest Cover Change
www.forestcover.org

Results

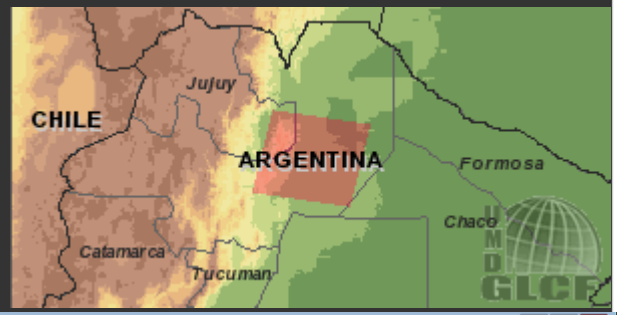
Path 176 Row 54



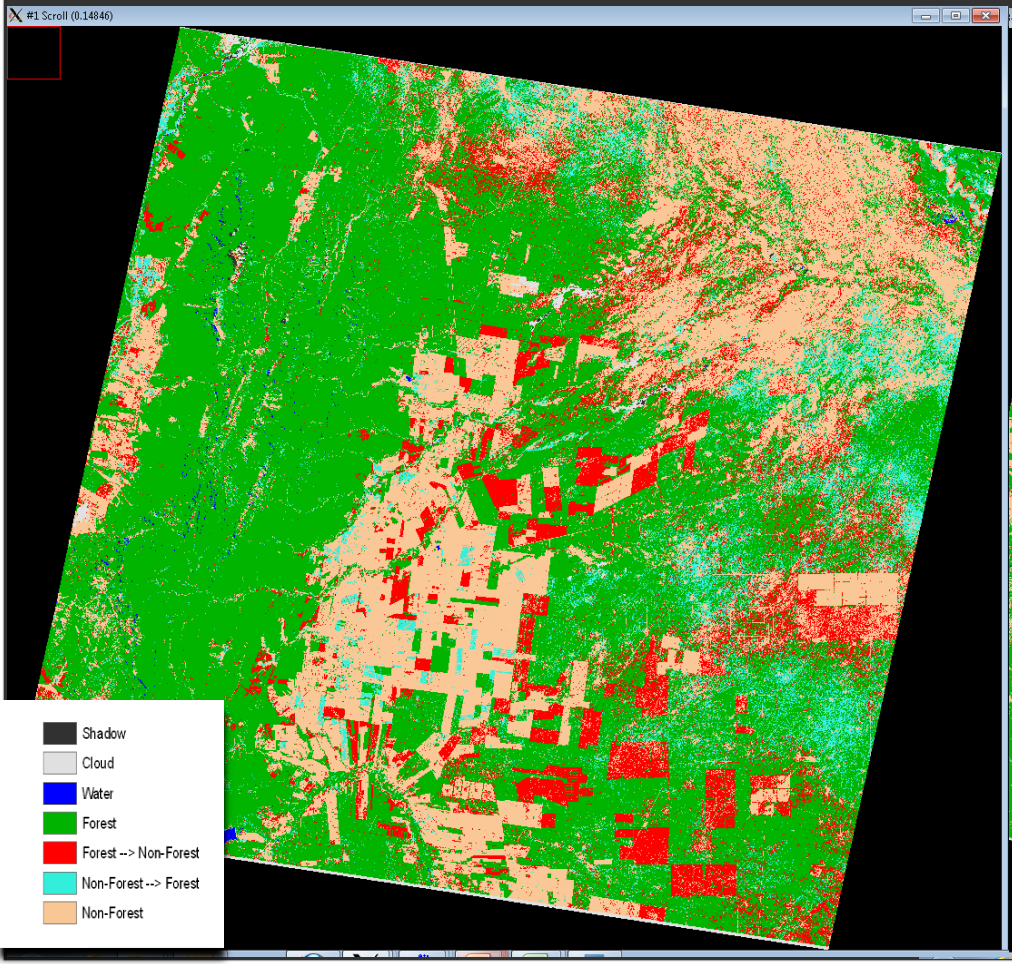


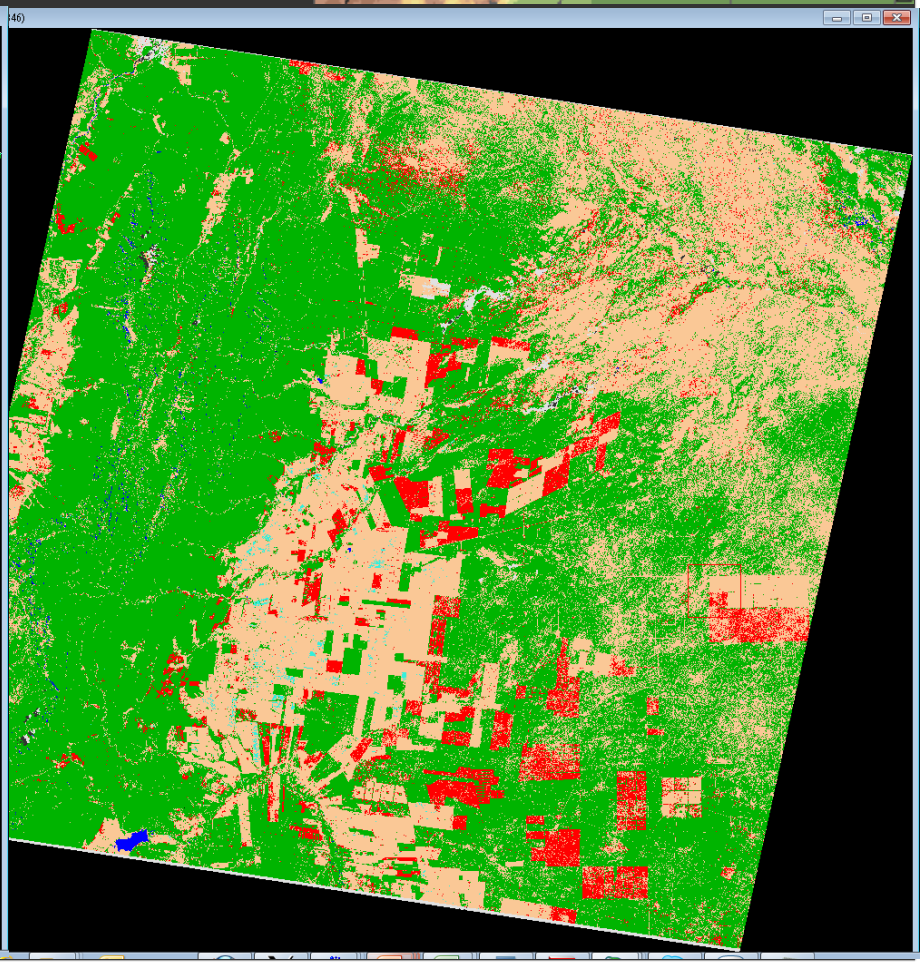
Global Forest Cover Change
www.forestcover.org

Results



Path 230 Row 77

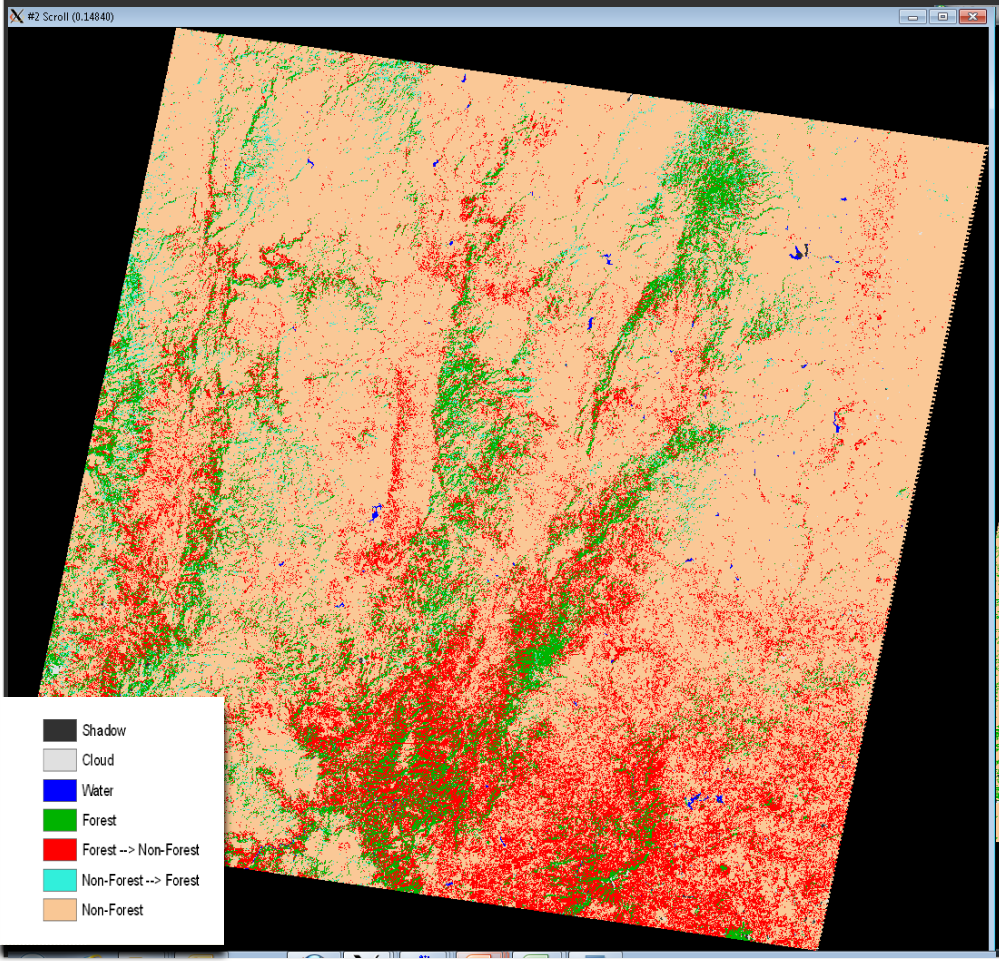


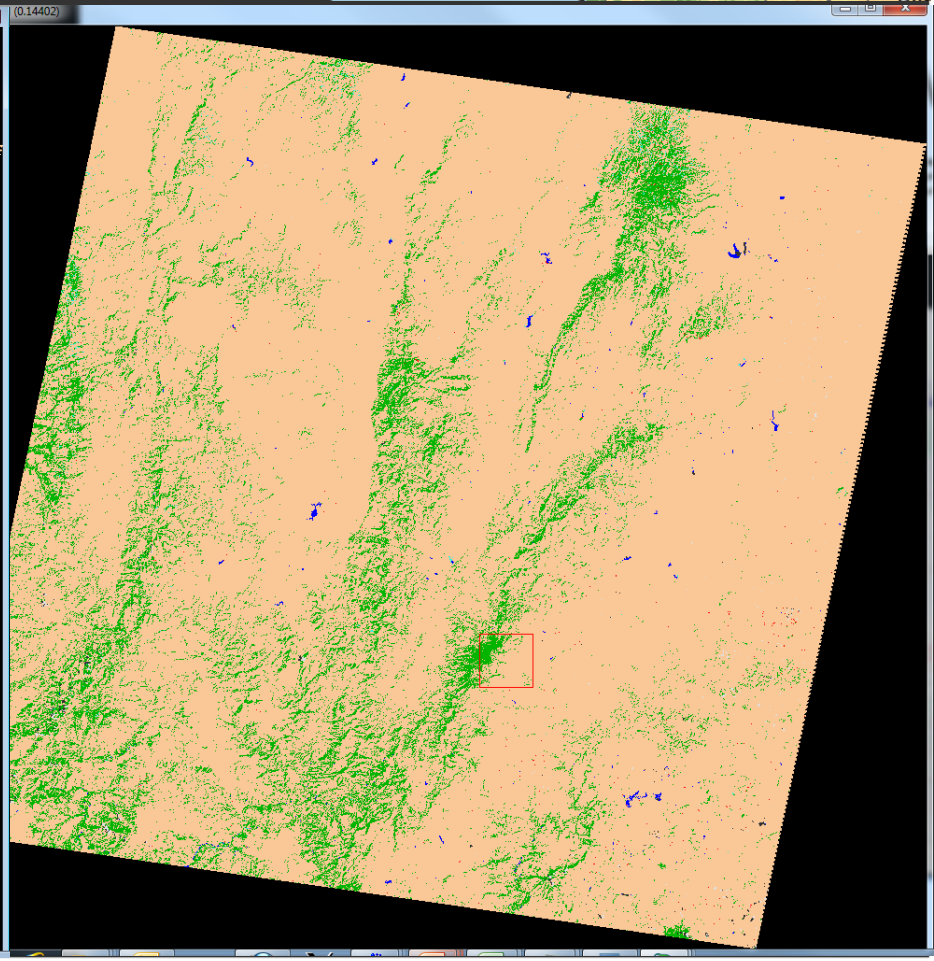


Global Forest Cover Change
www.forestcover.org

Results

Path 29 Row 45

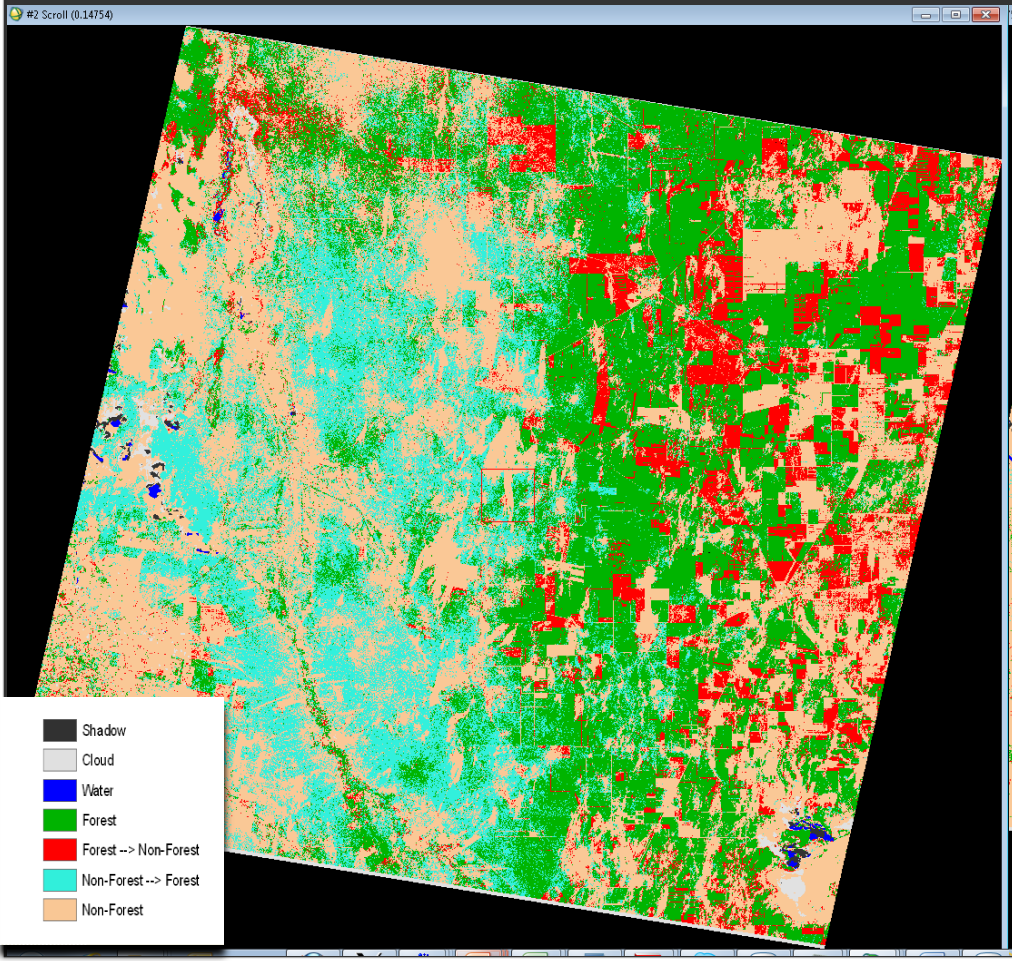


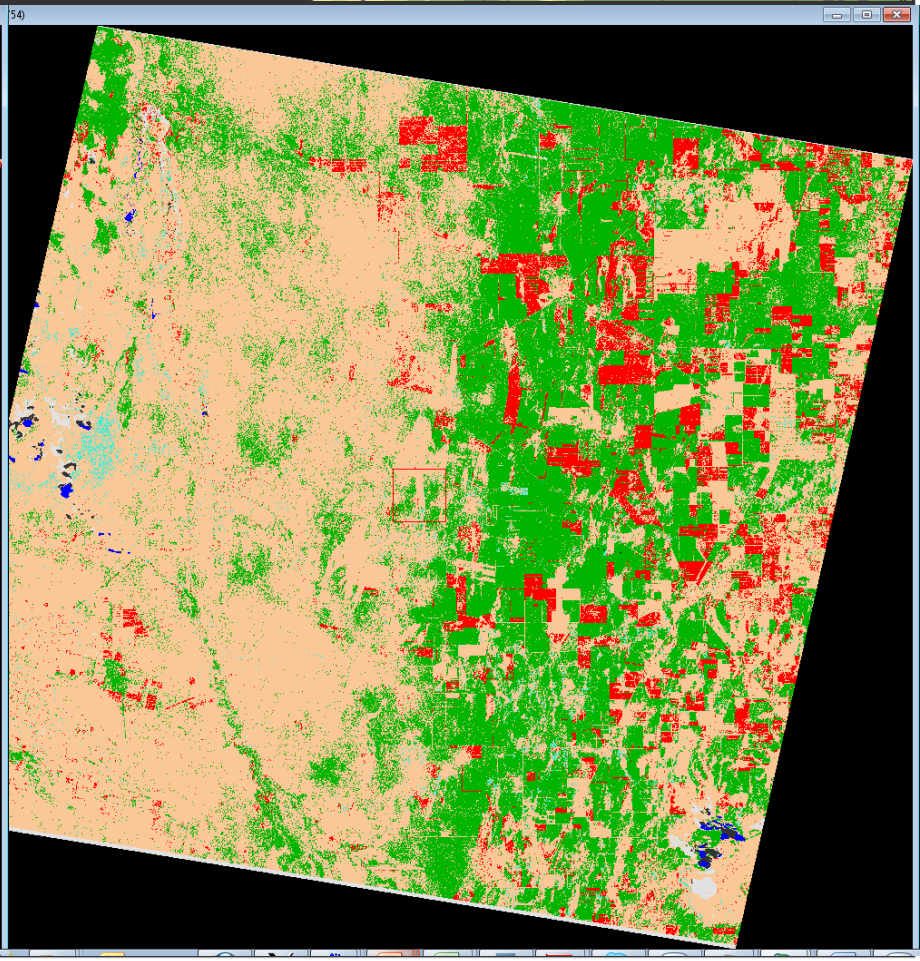


Global Forest Cover Change
www.forestcover.org

Results

Path 229 Row 79

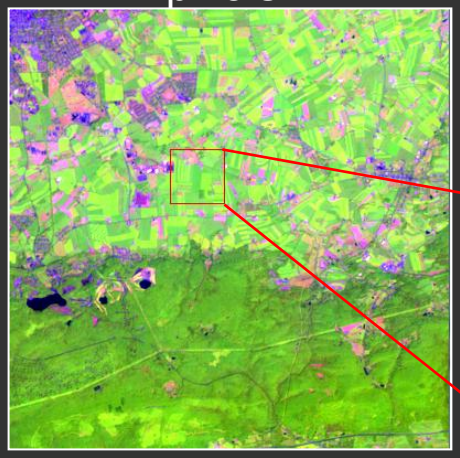


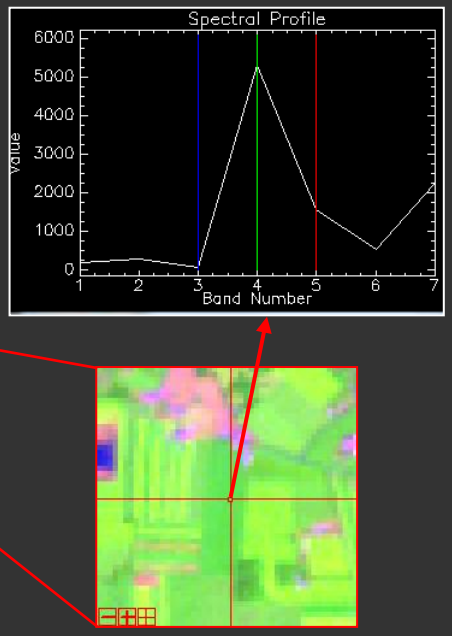


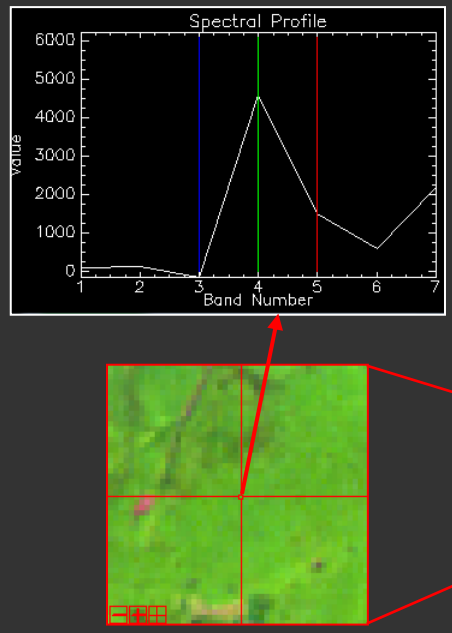
FCC Challenges: Solutions

- Problem:
  - Crop pixels present similar spectral signatures as tree pixels during peak phenological seasons, causing misclassifications in single-date Landsat image as well as false forest changes in two-date images.

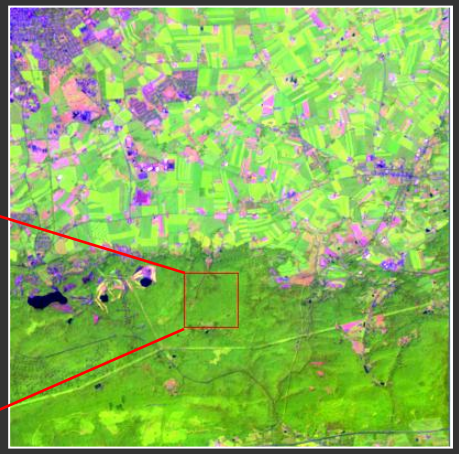
Spectral signatures of crop pixels





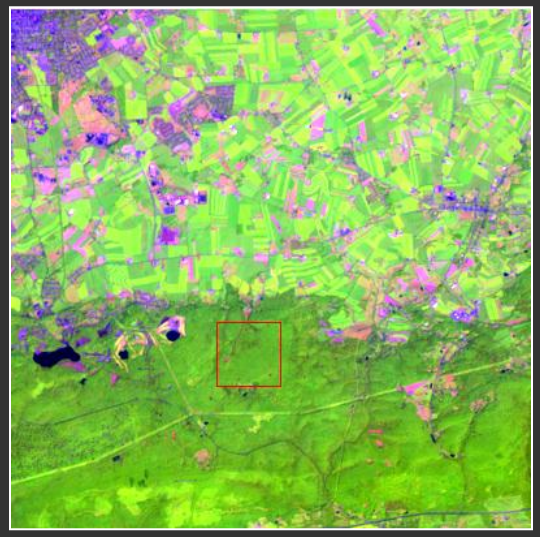


Spectral signatures of tree pixels

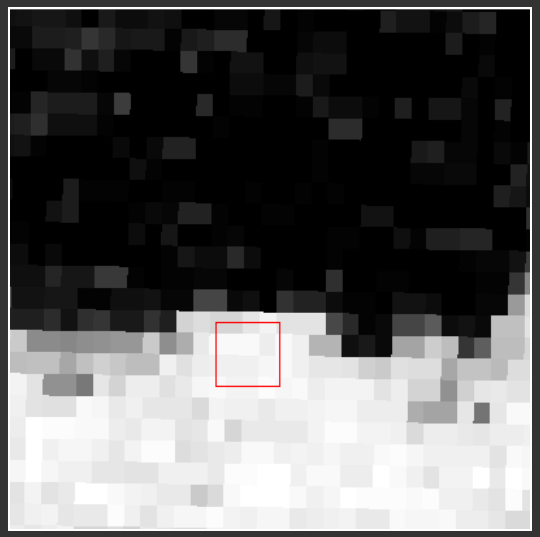


- Solution:
  - Given the variability of crop types and phenology at local to global scales, reliable external land cover information is needed to assist Landsat classification and change detection.
  - Converging Landsat surface reflectance, MODIS VCF and MODIS cropland probability product, automatically select confident tree and crop pixels as training for SVM

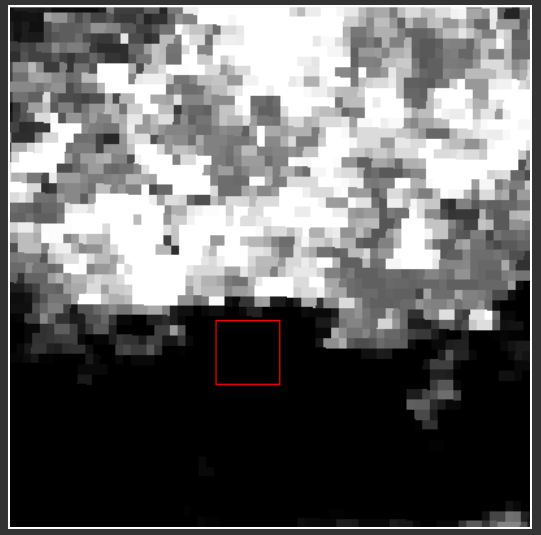
Landsat



MODIS vegetation continuous fields tree cover

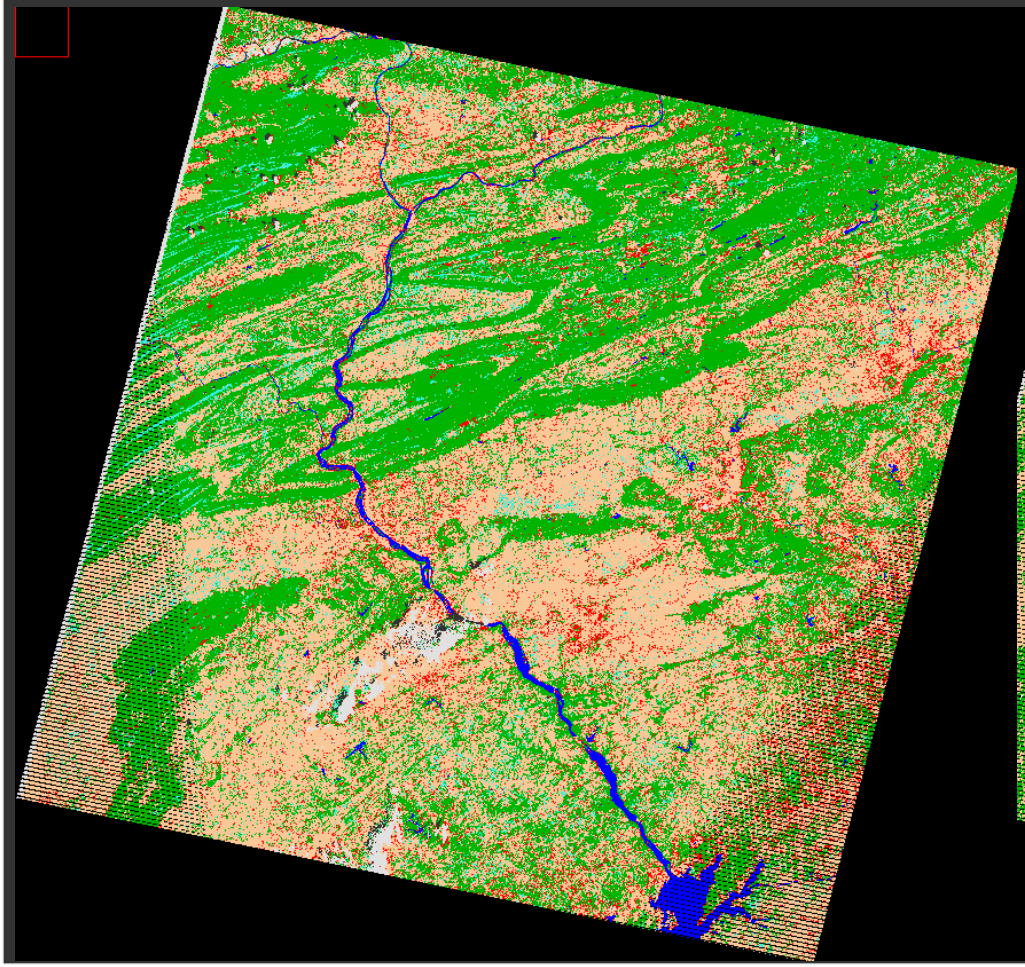


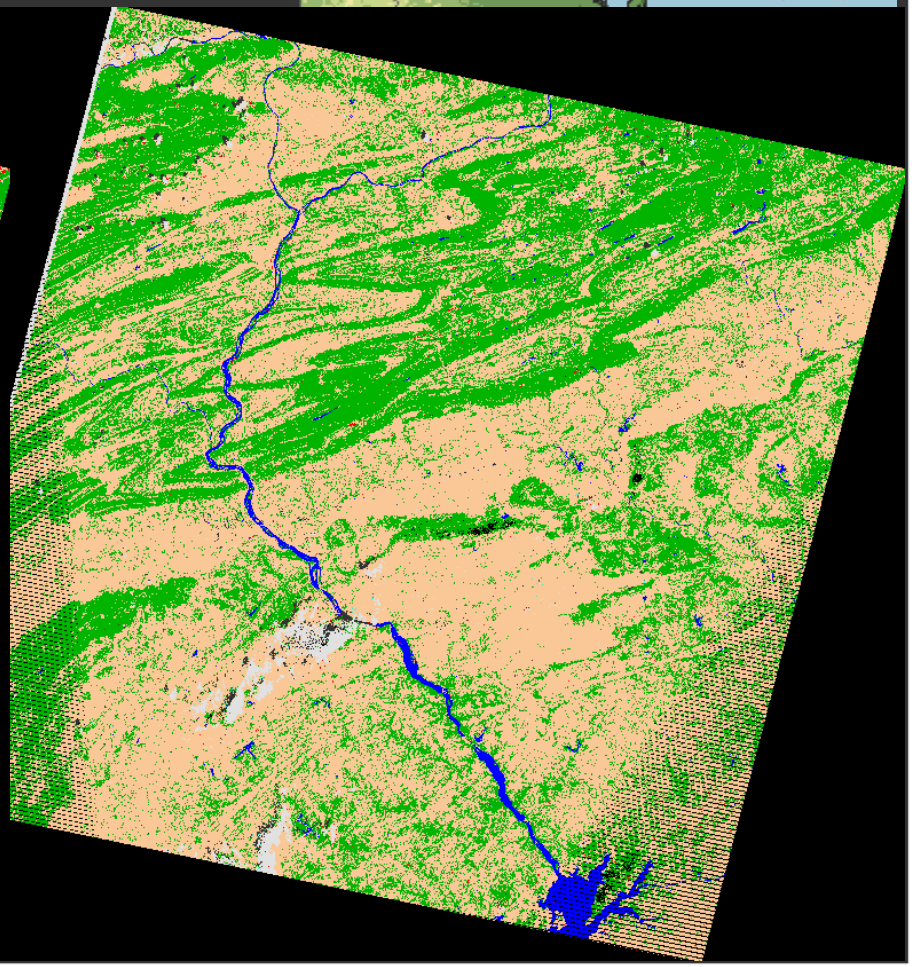
MODIS cropland probability product



Results

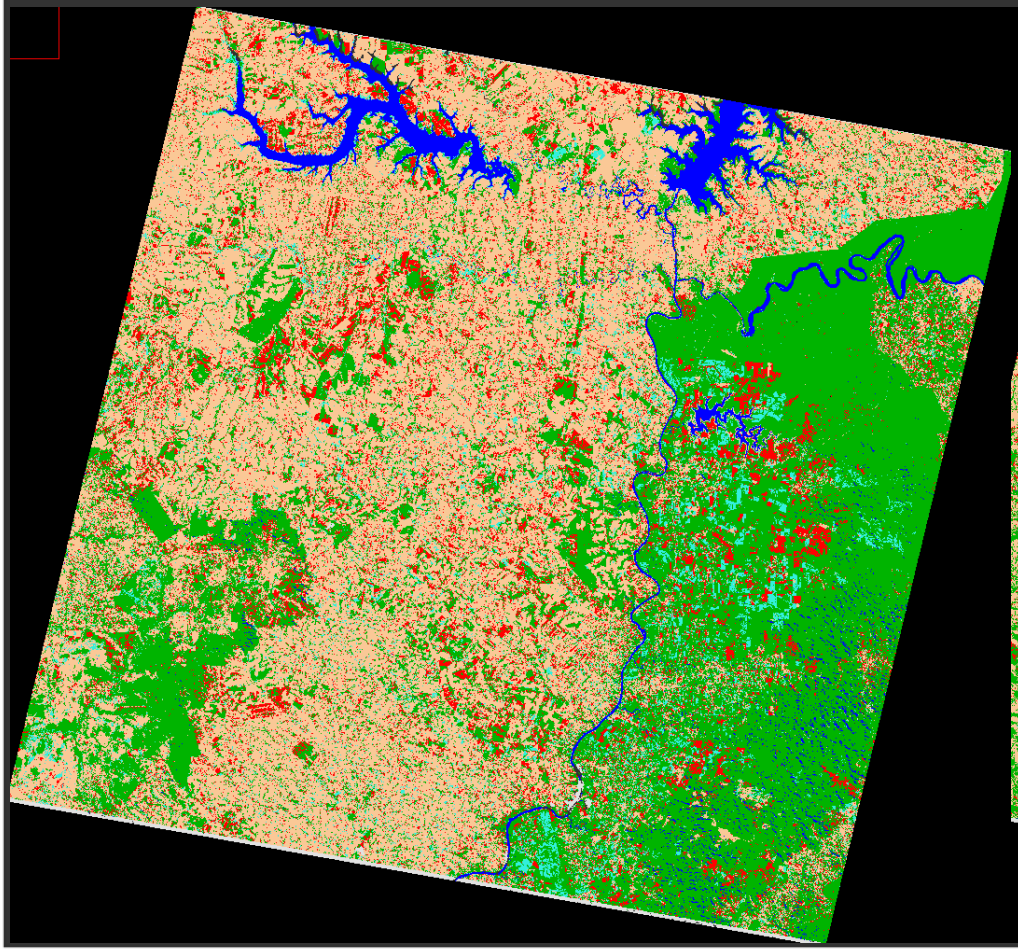
Path 15 Row 32

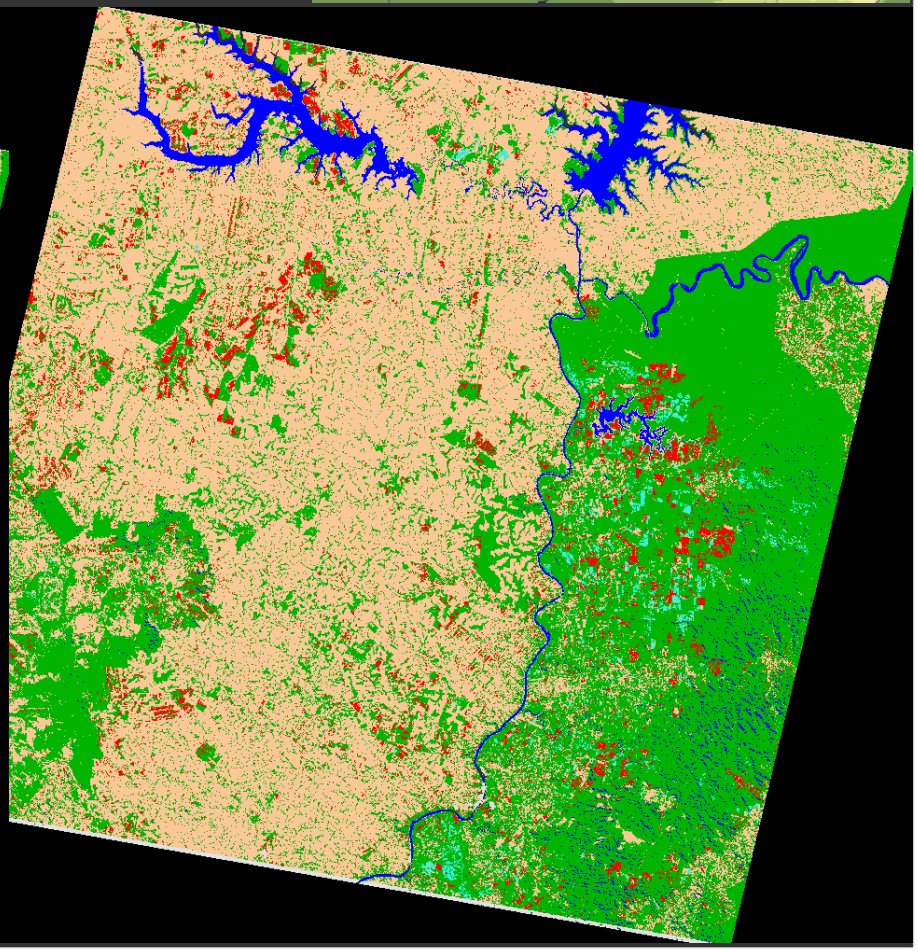




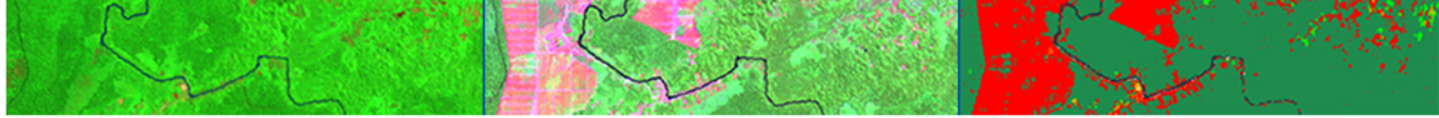
Results

Path 224 Row 78





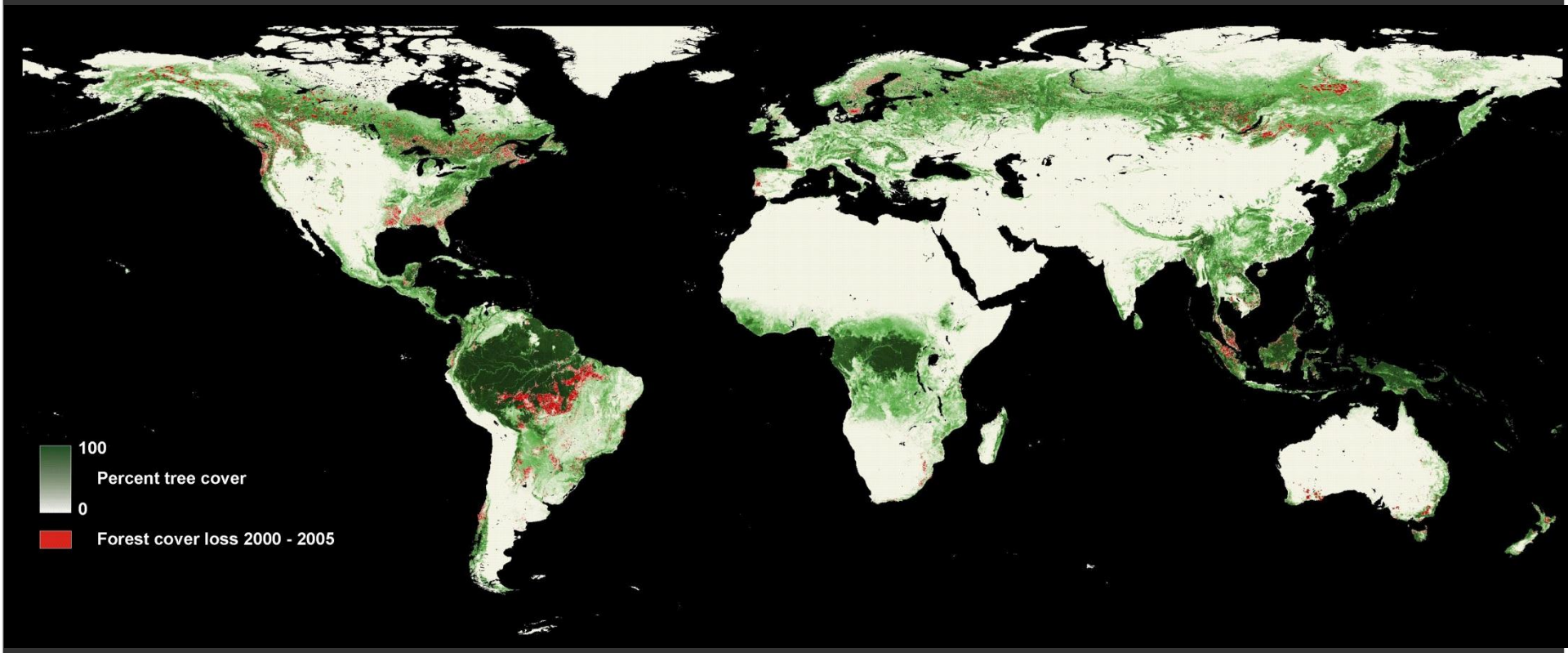
Global Forest Cover Change
www.forestcover.org



MODIS VCF FCC (Matt Hansen)

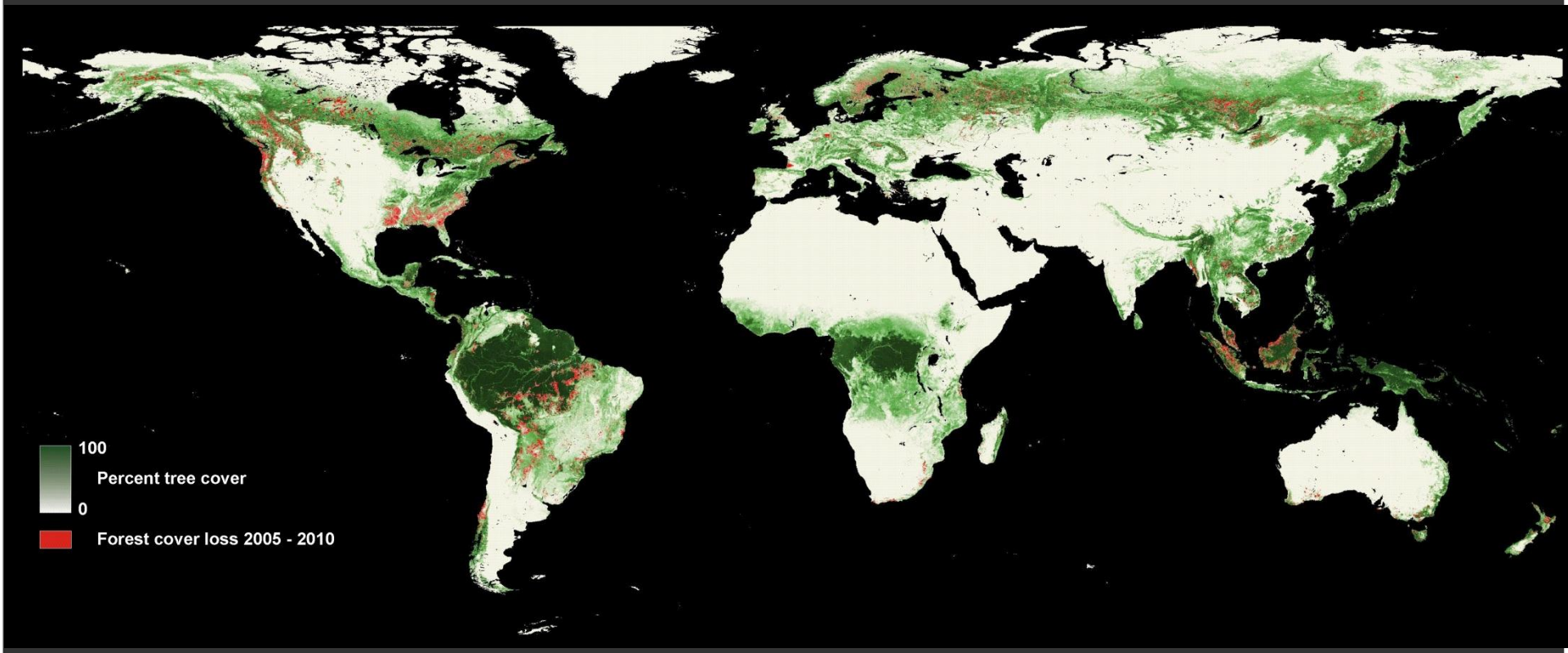
Global Forest Cover Change
www.forestcover.org

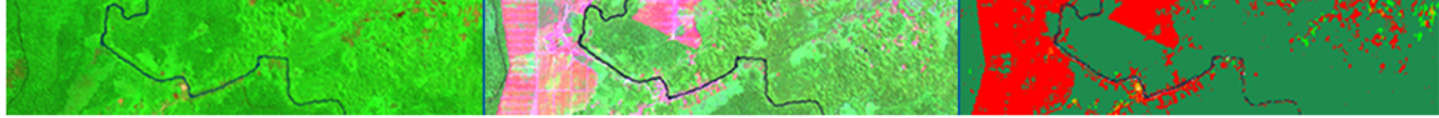
MODIS VCF FCC 2000 - 2005



Global Forest Cover Change
www.forestcover.org

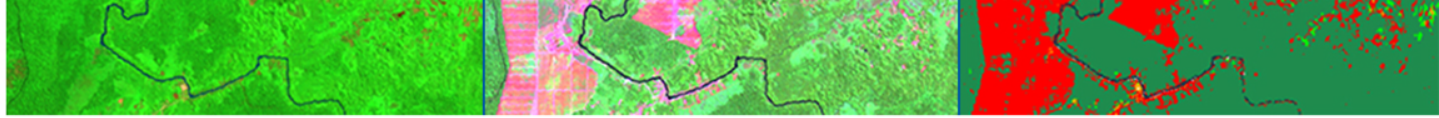
MODIS VCF FCC 2005 - 2010





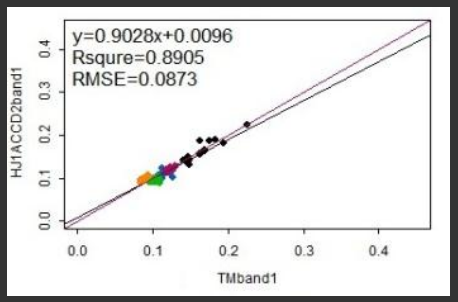
Lessons Learned

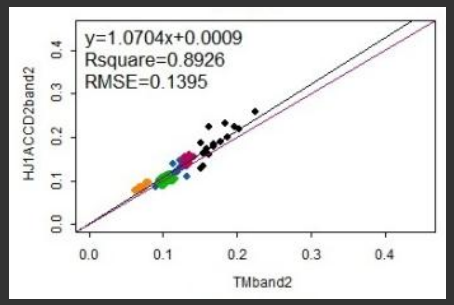
- Mission creep
- Be ready to take on “known and unknown unknowns” issues
  - Calibration issues; issues with data in general
  - Phenological issues
- Multiple iterations of data processing
- Benchmarking
- Scene based solution don’t work, make changes to your algorithm and process globally.
- Data volume
- End-to-end process has been challenging to automate.
- Really should be using multi temporal data within a year to define what is and is not forest.

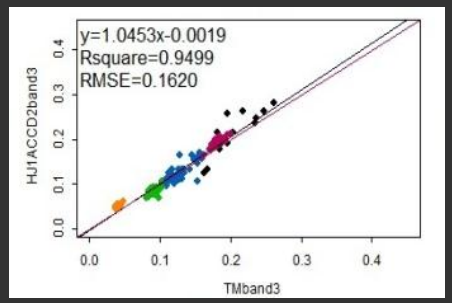


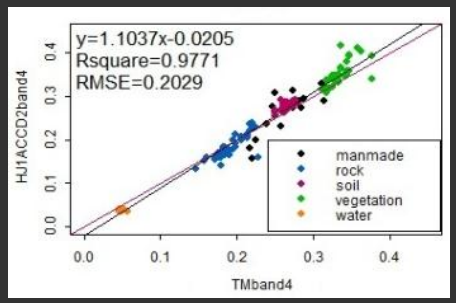
Other data sources e.g. HJ data

2009-06-30

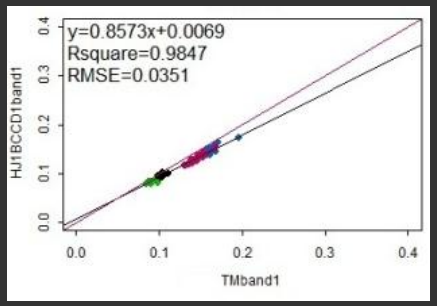


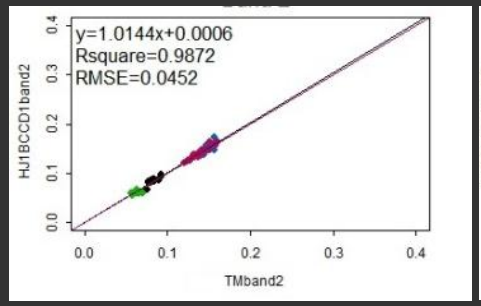


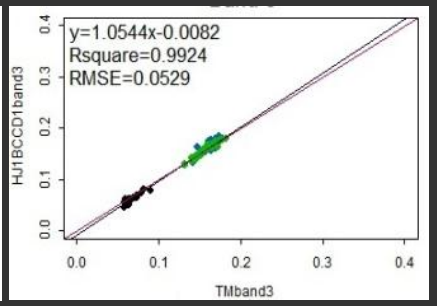


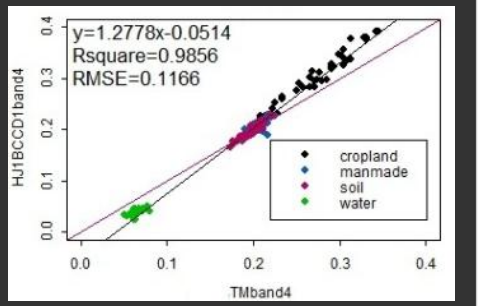


2011-06-08

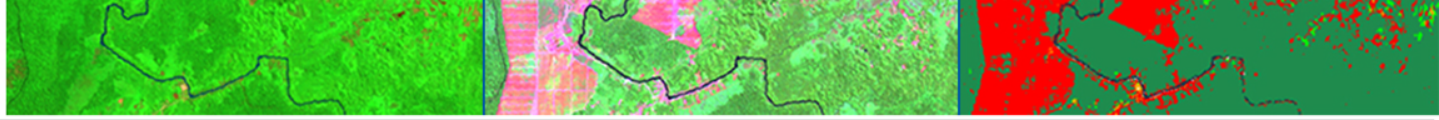








Bo Jiang, Shunlin Liang, John Townshend, Zan Dodson



Questions

Please visit the GLCF at www.landcover.org