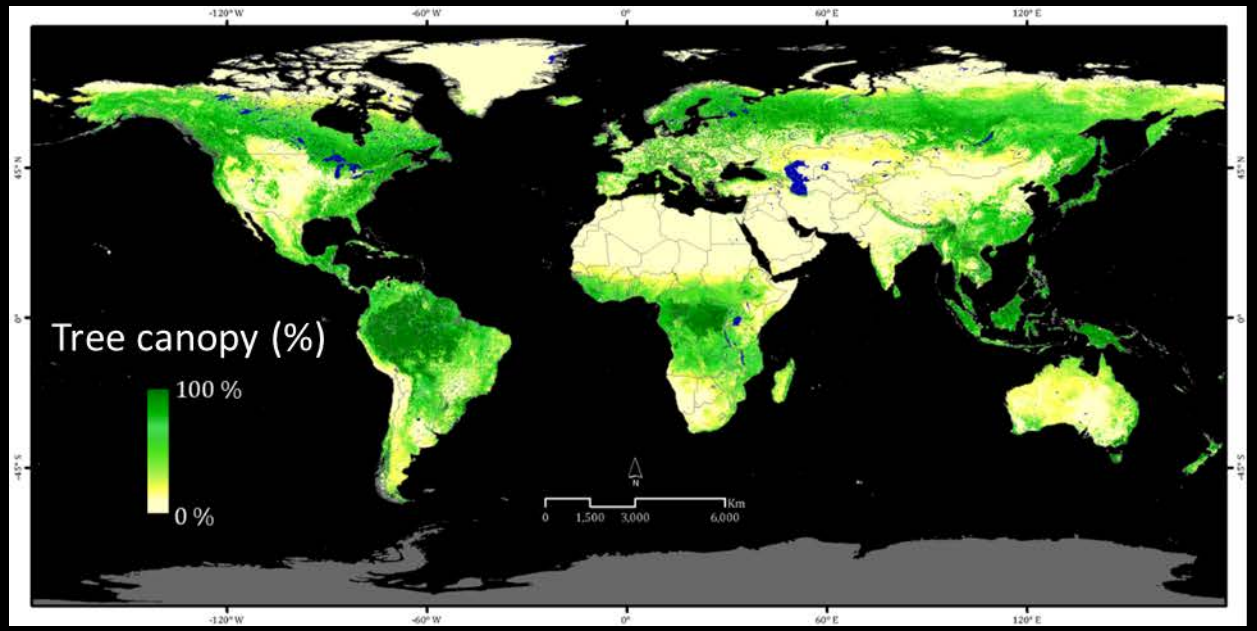
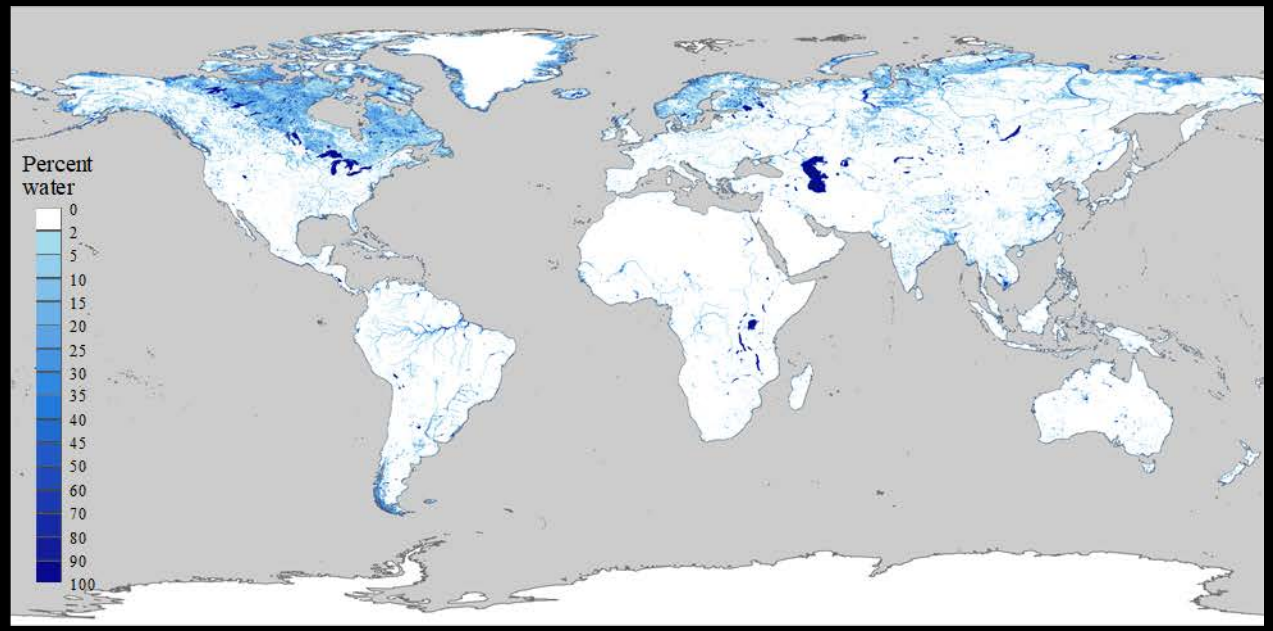

-120° W
-60° W
0°
60° E
120° E
85° N
0°
45° S
Tree canopy (%)
100 %
0 %
N
0
1,500
3,000
6,000
Km


Percent water
0
2
5
10
15
20
25
30
35
40
45
50
60
70
80
90
100

Multi-sensor imaging of tree and water cover time-series at continental to global scales

Joe Sexton
Min Feng, Saurabh Channan, John Townshend (PI)

Global Land Cover Facility
Department of Geographical Sciences, University of Maryland

Contributing partners:
Jon Ranson, Chris Neigh, Paul Montesano (NASA-GSFC)
Peter Leimgruber, Qiongyu Huang, Sumalika Biswas, Melissa Songer (Smithsonian)
Christiane Schmullius (University of Jena)
Nairara Pinto (NASA-JPL)

NASA LCLUC MuSLI Team Meeting
Gaithersburg, MD
April 6, 2018

Objectives: algorithms

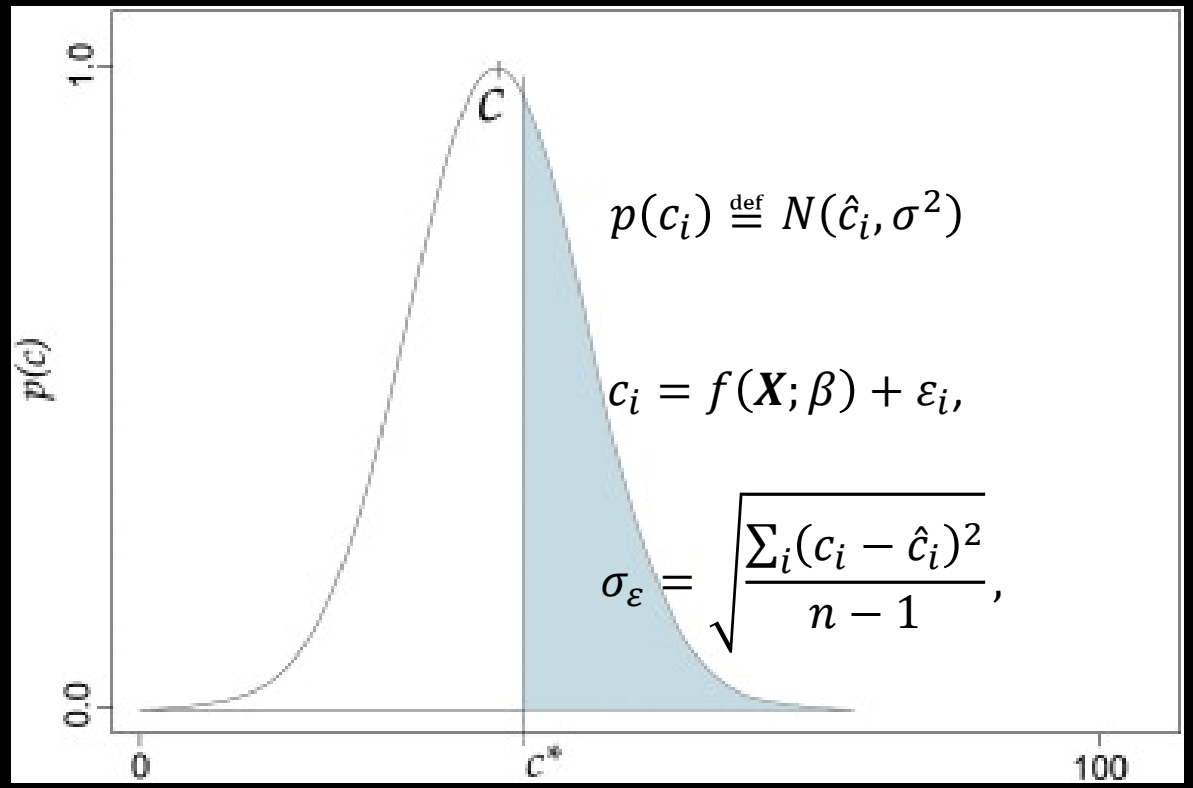
- Multi-sensor (“-agnostic”) estimation of land cover
  - tree-canopy (percent)
  - water (binary)

  - Landsat-5,-7 (Global Land Survey)
  - Sentinel-1, -2

Targets: land-cover datasets

- Percent tree-canopy cover & binary water cover
  - Resolution: annual, 30-m
  - Extent:
    - Global in 2000, 2005, 2010, 2015
    - North and South America from 2010 - 2015

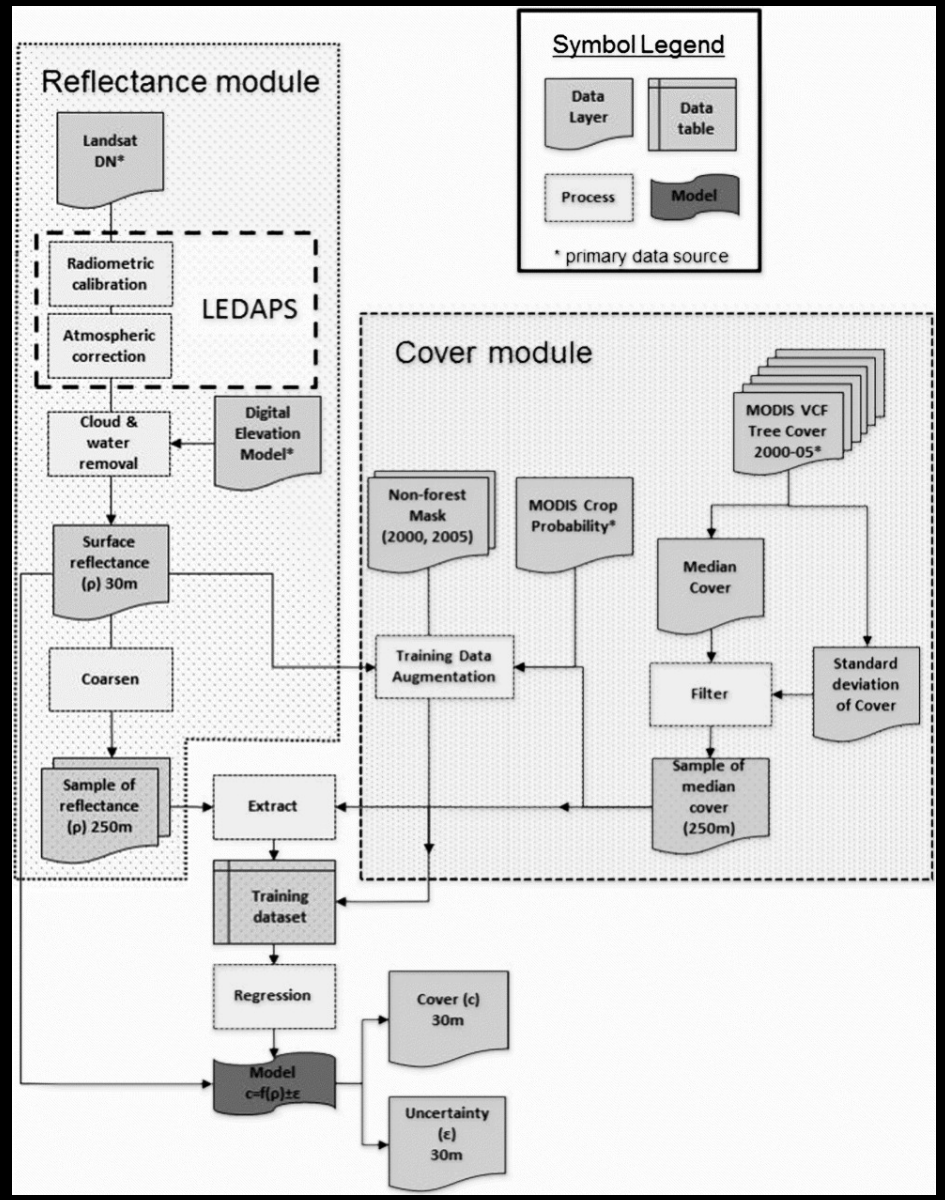
Algorithm - estimation



$$p(c_i) \stackrel{\text{def}}{=} N(\hat{c}_i, \sigma^2)$$

$$c_i = f(\boldsymbol{X}; \beta) + \varepsilon_i,$$

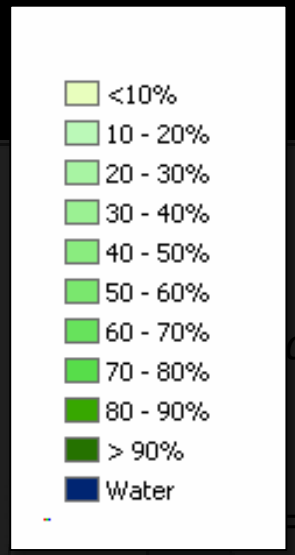
$$\sigma_\varepsilon = \sqrt{\frac{\sum_i (c_i - \hat{c}_i)^2}{n-1}},$$

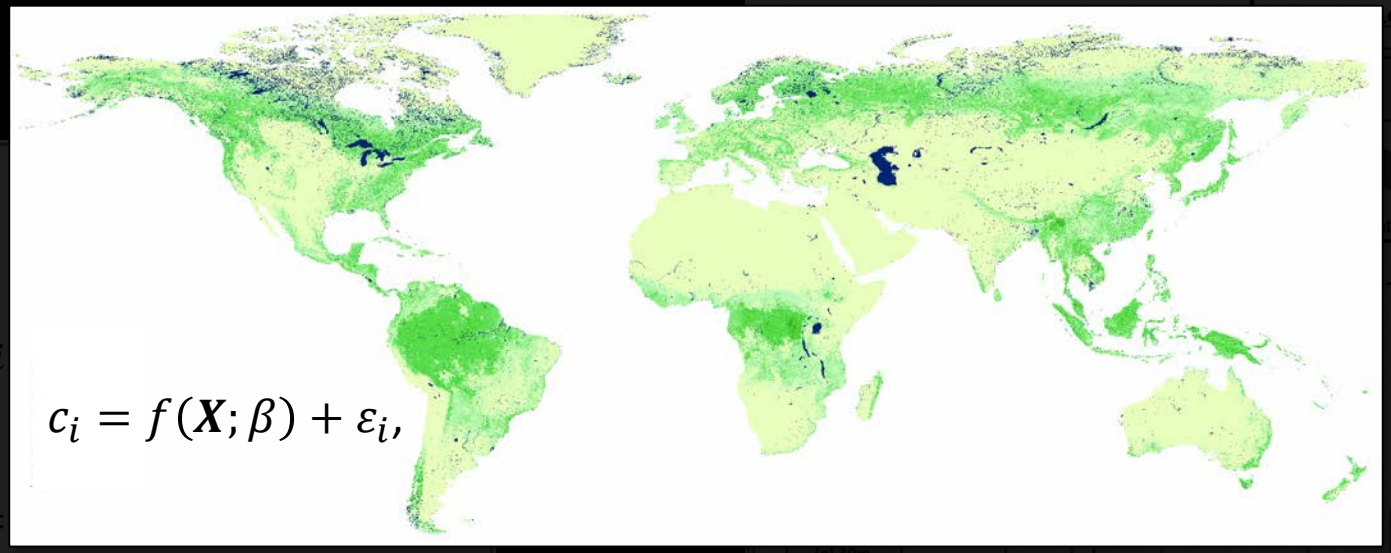


Sexton, JO; X-P Song; M Feng; P Noojipady; A Anand; C Huang; D-H Kim; KM Collins; S Channan; C DiMiceli; JR Townshend; *International Journal of Digital Earth* **2013,** 6, 427-448.

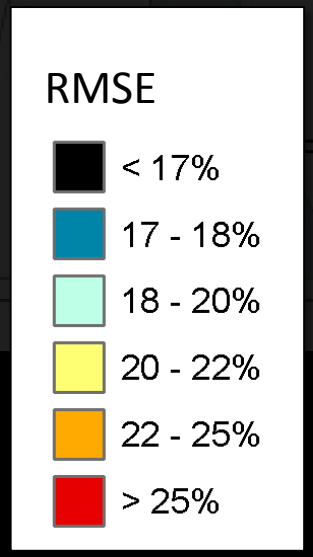
Sexton, J.O., P. Noojipady, A. Anand, X.-P. Song, C. Huang, S.M. McMahon, M. Feng, S. Channan, J.R. Townshend. 2015. *Remote Sensing of Environment* 156: 418-425

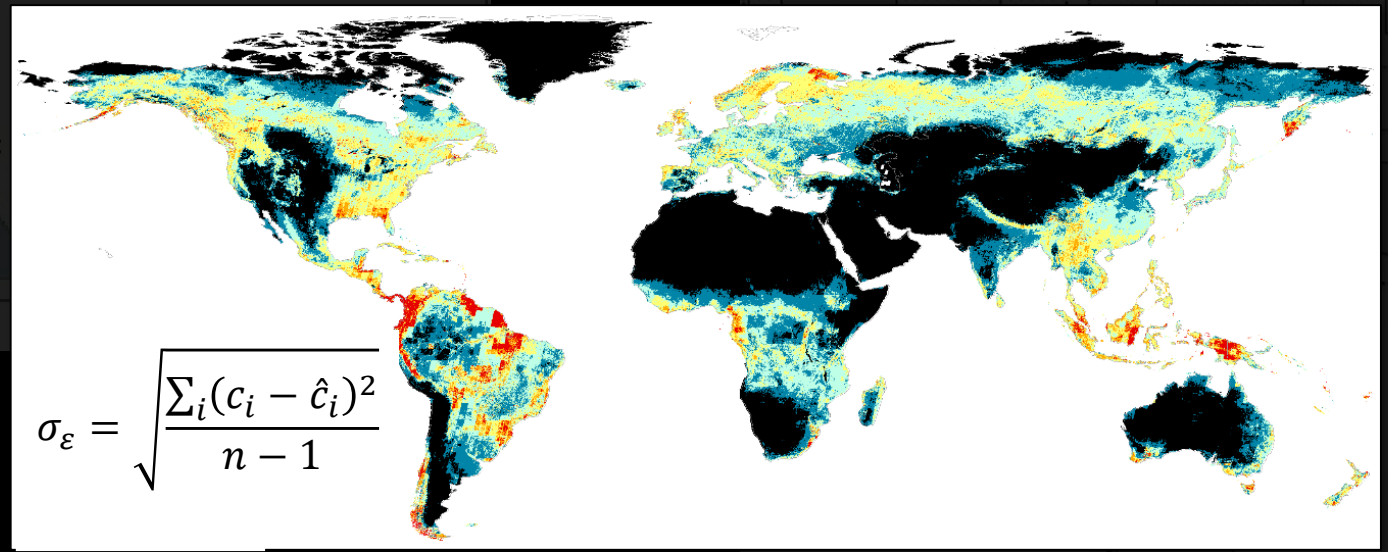
Global, pixel-level estimates of cover and uncertainty.





$$c_i = f(\boldsymbol{X};\beta) + \varepsilon_i,$$





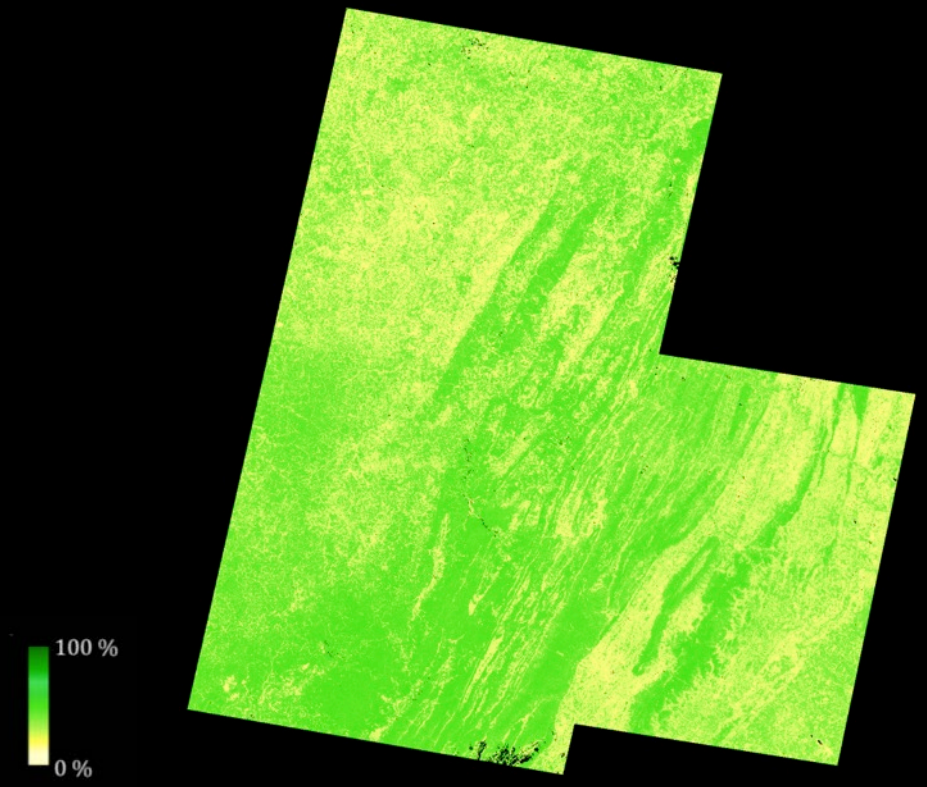
$$\sigma_\varepsilon = \sqrt{\frac{\sum_i (c_i - \hat{c}_i)^2}{n-1}}$$

A model for the distribution of all possible states of tree cover, given the best available imagery.

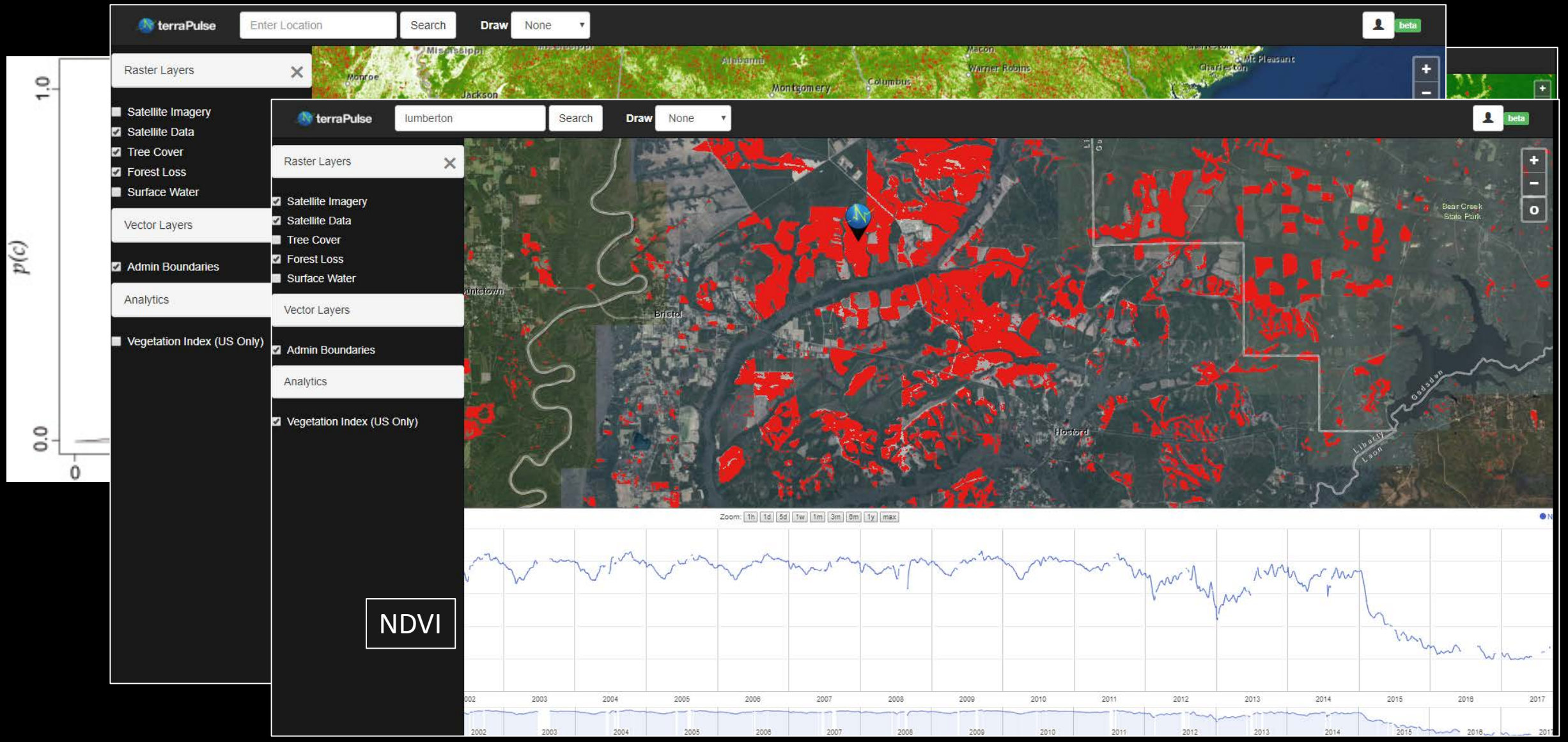
Sexton et al. 2013. *Int. J. Dig. Earth.*

Compositing output estimates

- Based on uncertainty layers
  - Principle of Maximum Likelihood: Take the estimate of cover with the lowest uncertainty
  - Clean cloud, shadow, snow
  - Uncertainty drops with increasing image-density



Forest gain & loss

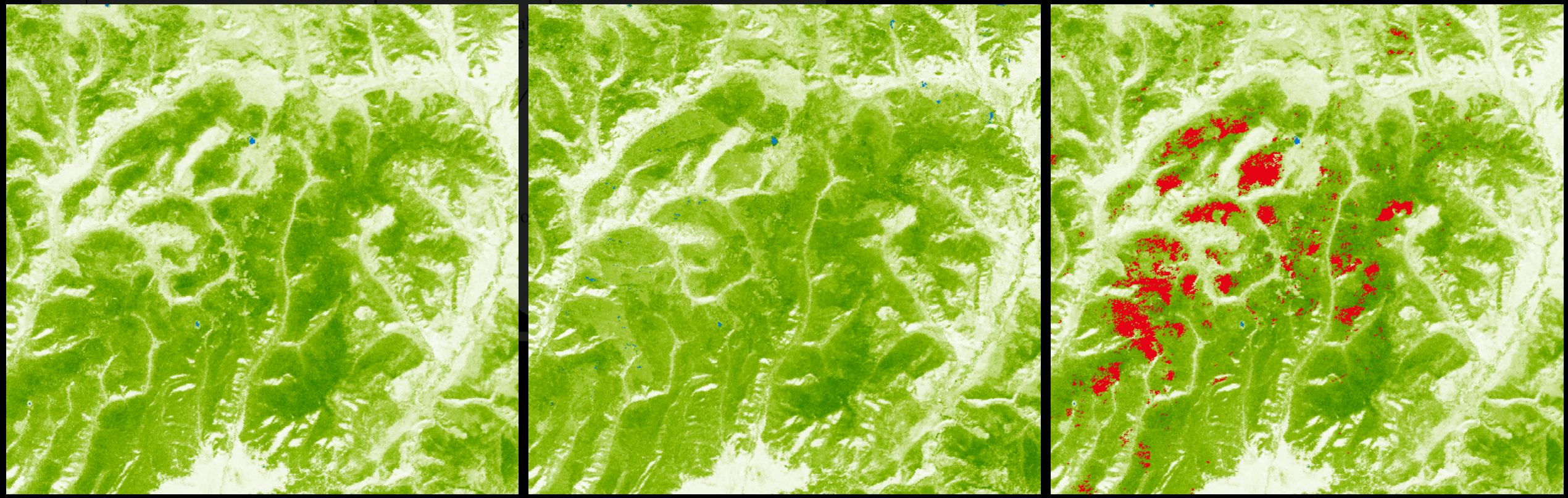


Canopy gain/loss (e.g., degradation)

Tree Cover (2010)

Tree Cover (2012)

Tree Cover Loss (2010-2012)

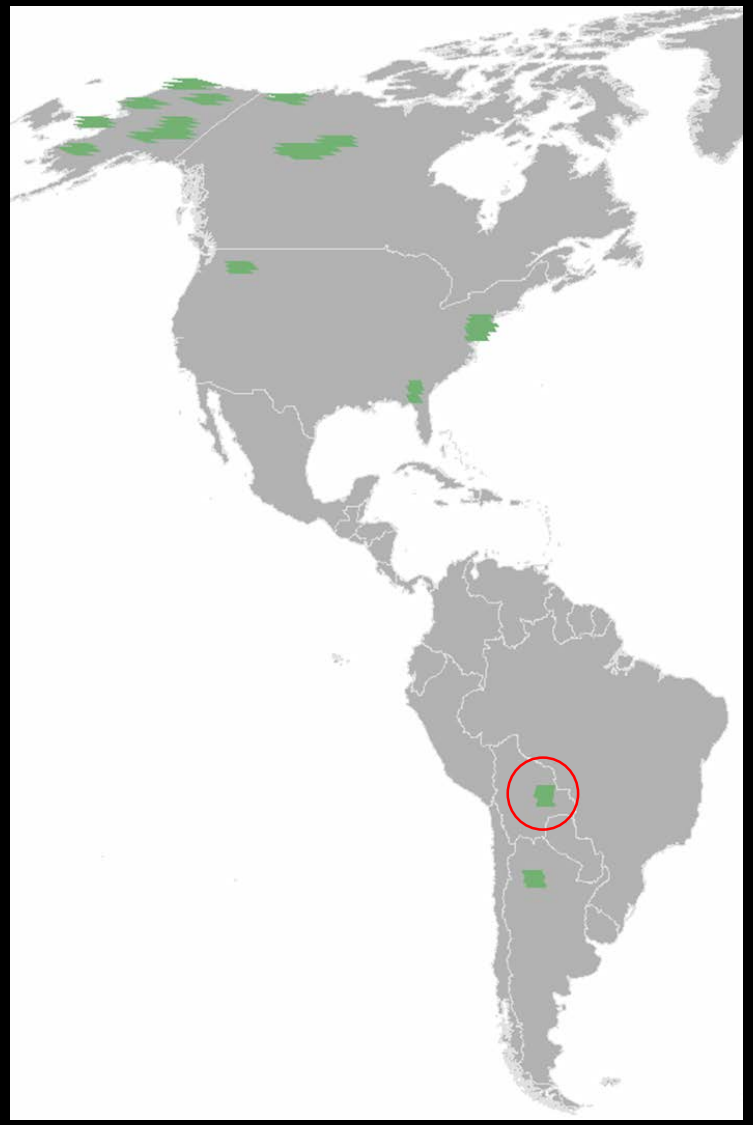


Tree Cover and Loss (Tsaagan-Uur, Mongolia)

Multi-sensor fusion of Landsat and Sentinel-2

- Sample of 5 sites
  - North & South America
  - all forest biomes

- Data
  - Previous: GLS Landsat -5, -7
    - Global Land Survey (GLS)
  - New: HLS S30
    - 9581 Landsat-8
    - 3177 Sentinel-2
    - 12758 total



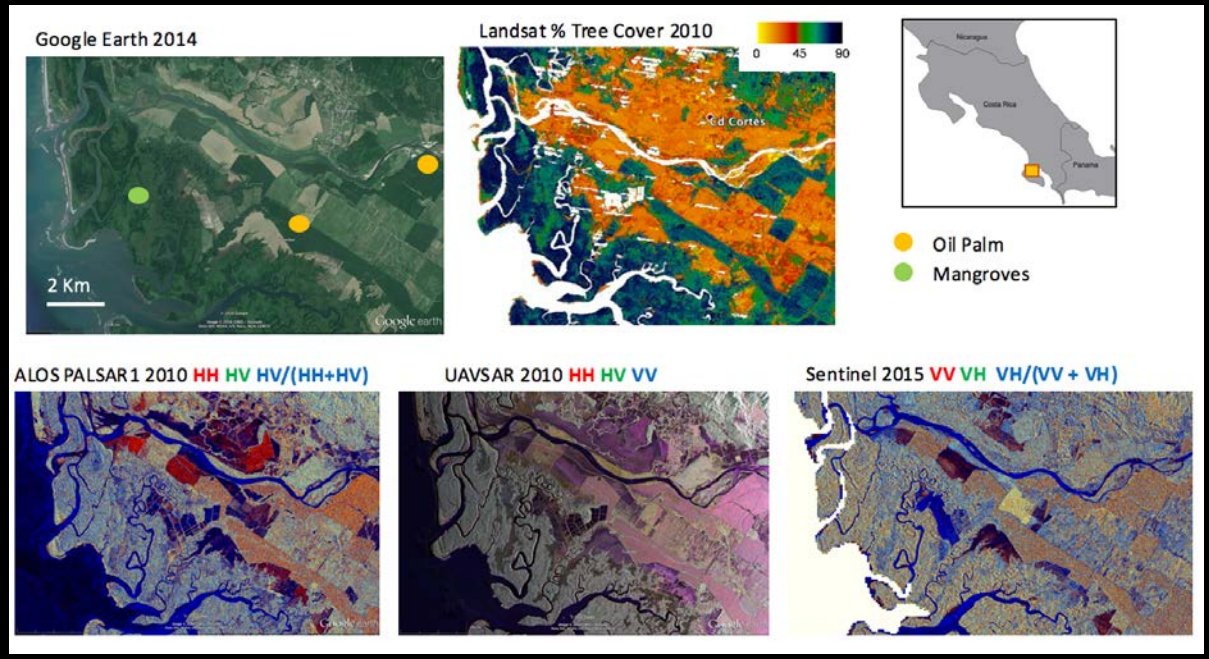
2015 & disturbance-year

Optical-SAR fusion

- Estimate tree canopy cover
- Fill gaps (e.g., clouds) in optical estimates
- Discriminate natural forests from plantations

- Sentinel C-band backscatter & ratios
- UAVSAR L-band entropy

- Solely C-band models unlikely to discriminate forest types—need to incorporate with optical
- Possible L-band only model



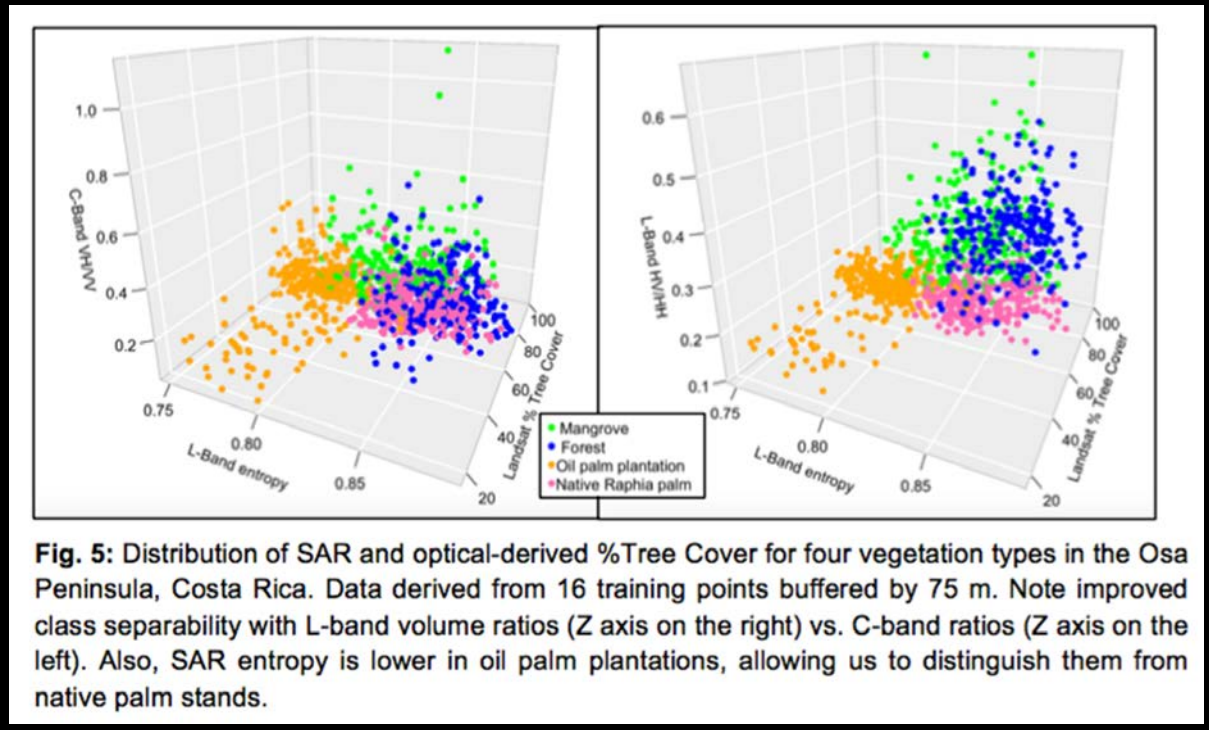


Fig. 5: Distribution of SAR and optical-derived %Tree Cover for four vegetation types in the Osa Peninsula, Costa Rica. Data derived from 16 training points buffered by 75 m. Note improved class separability with L-band volume ratios (Z axis on the right) vs. C-band ratios (Z axis on the left). Also, SAR entropy is lower in oil palm plantations, allowing us to distinguish them from native palm stands.

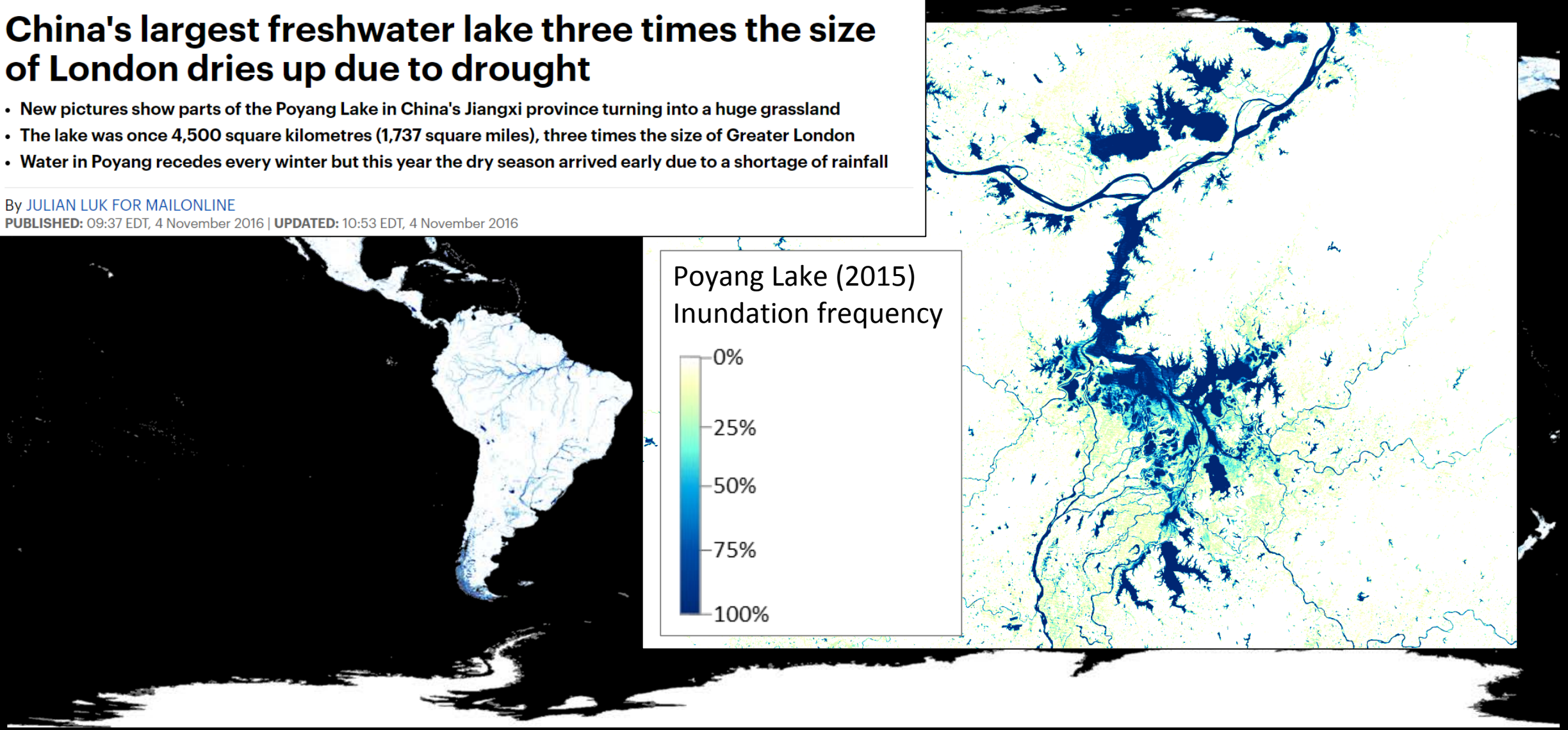
Pinto et al. *in prep*.

From masking water to mapping inundation frequency

China's largest freshwater lake three times the size of London dries up due to drought

- New pictures show parts of the Poyang Lake in China's Jiangxi province turning into a huge grassland
- The lake was once 4,500 square kilometres (1,737 square miles), three times the size of Greater London
- Water in Poyang recedes every winter but this year the dry season arrived early due to a shortage of rainfall

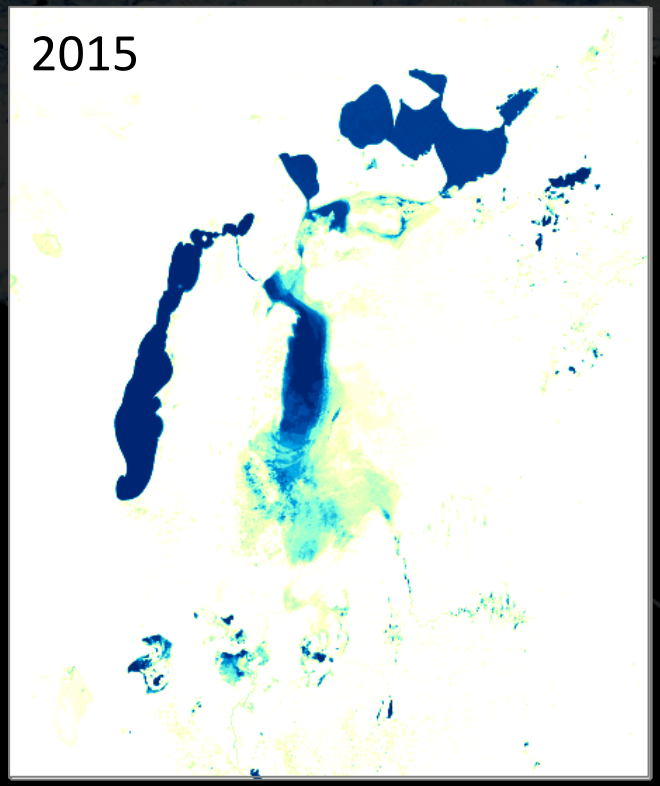
By JULIAN LUK FOR MAILONLINE
PUBLISHED: 09:37 EDT, 4 November 2016 | **UPDATED:** 10:53 EDT, 4 November 2016



From masking water to estimating inundation frequency

Aral Sea's Eastern Basin Is Dry for First Time in 600 Years NATIONAL GEOGRAPHIC

August 25, 2000 August 19, 2014



Calibration & validation

Reference:

- Lidar
- High-res
- *Drone?*

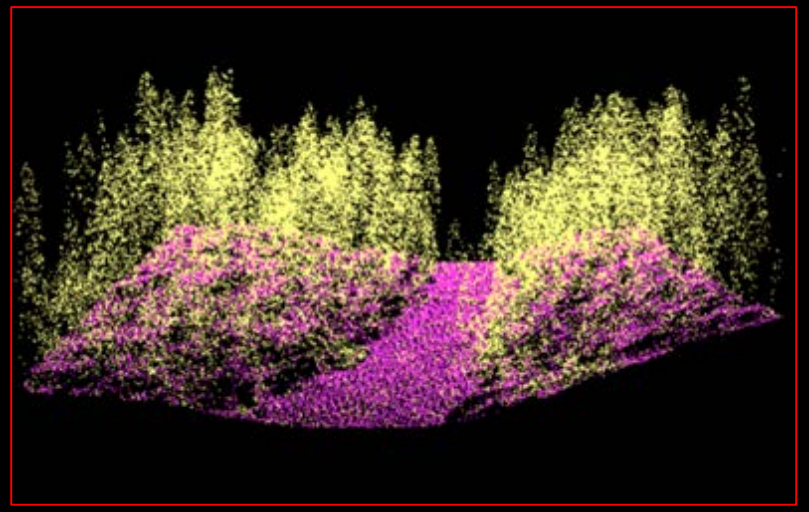
Metrics:

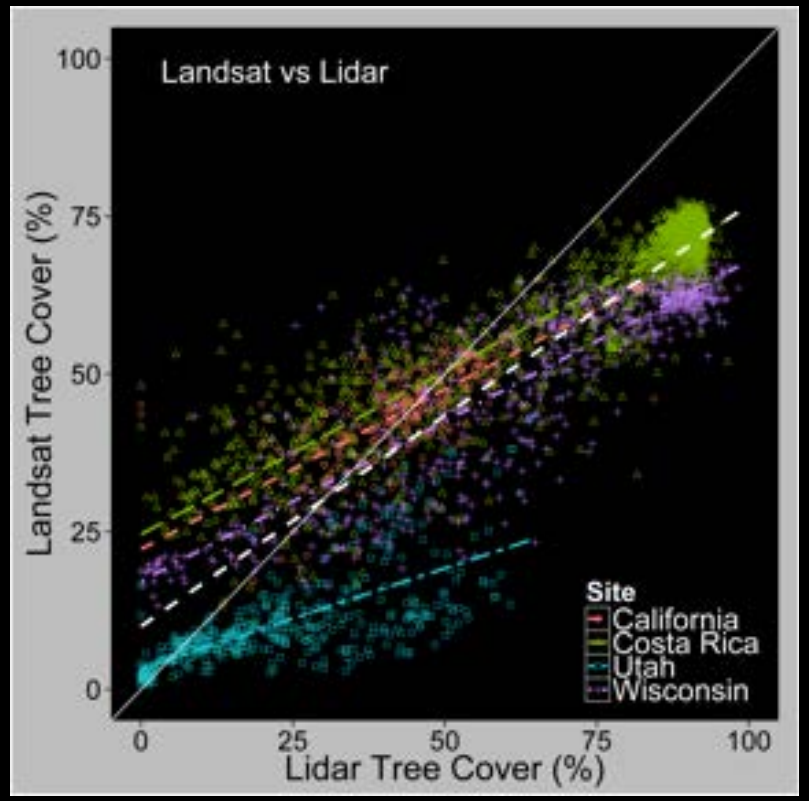
$$RMSE = \frac{\sum_{i=1}^{n} \sqrt{(M_i - R_i)^2}}{n}$$

$$RMSD = \sqrt{RMSD_S{}^2 + RMSD_U{}^2}$$

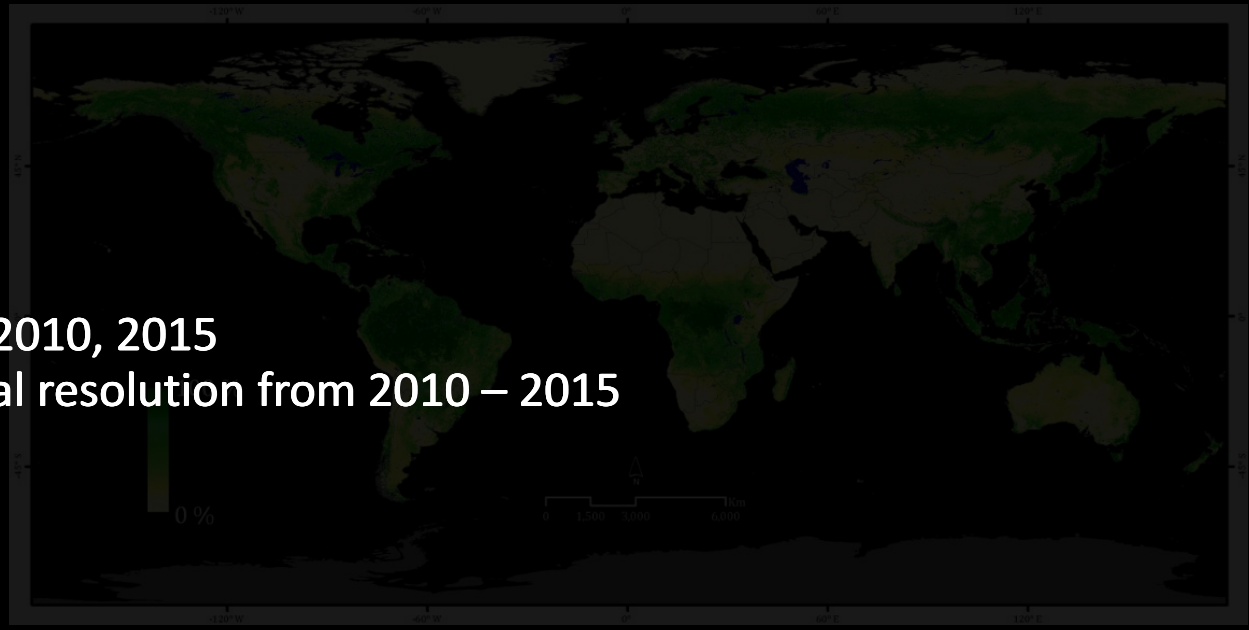
$$RMSE_s = \sqrt{\frac{\sum_{i=1}^{n} (\hat{M}_i - R_i)^2}{n}}$$

$$RMSE_u = \sqrt{\frac{\sum_{i=1}^{n} (M_i - \hat{M}_i)^2}{n}}$$





Progress



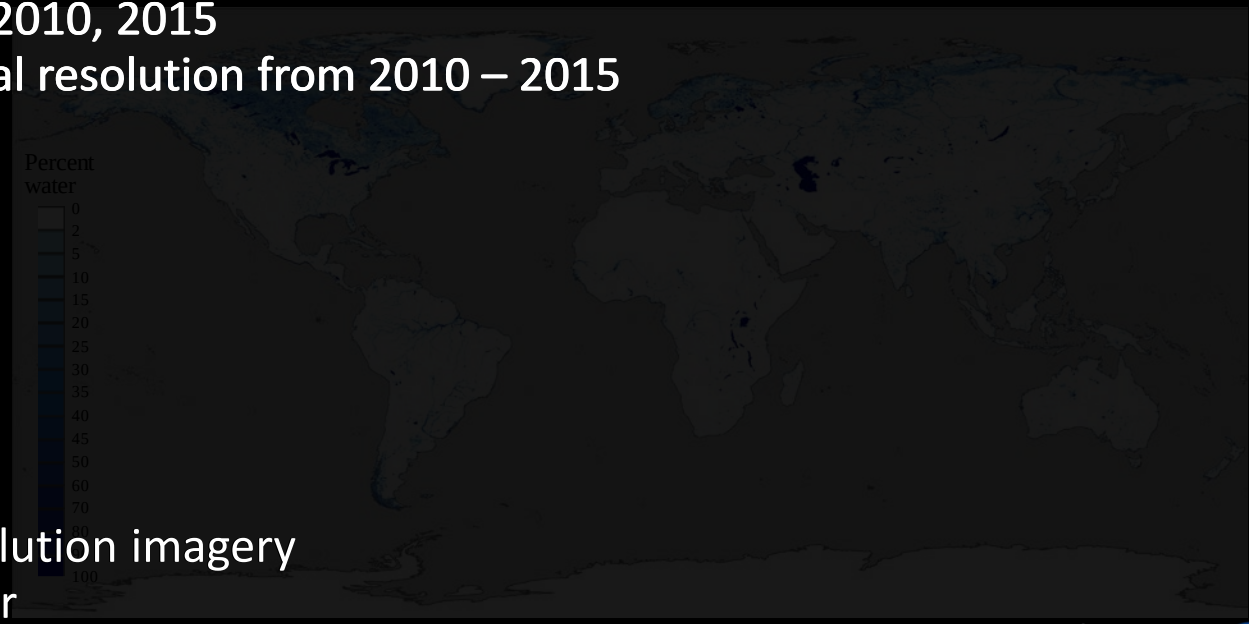
Data:

✓tree-canopy cover (%)

- Globally at 30-m, annual resolution in 2000, 2005, 2010, 2015
- North- and South-America coverage at 30-m, annual resolution from 2010 – 2015
- Per-pixel estimates of uncertainty
- Ecoregional, lidar-based validation

✓ Inundation frequency (p(water))

- Globally at 30-m, annual resolution in 2000, 2005, 2010, 2015
- North- and South-America coverage at 30-m, annual resolution from 2010 – 2015



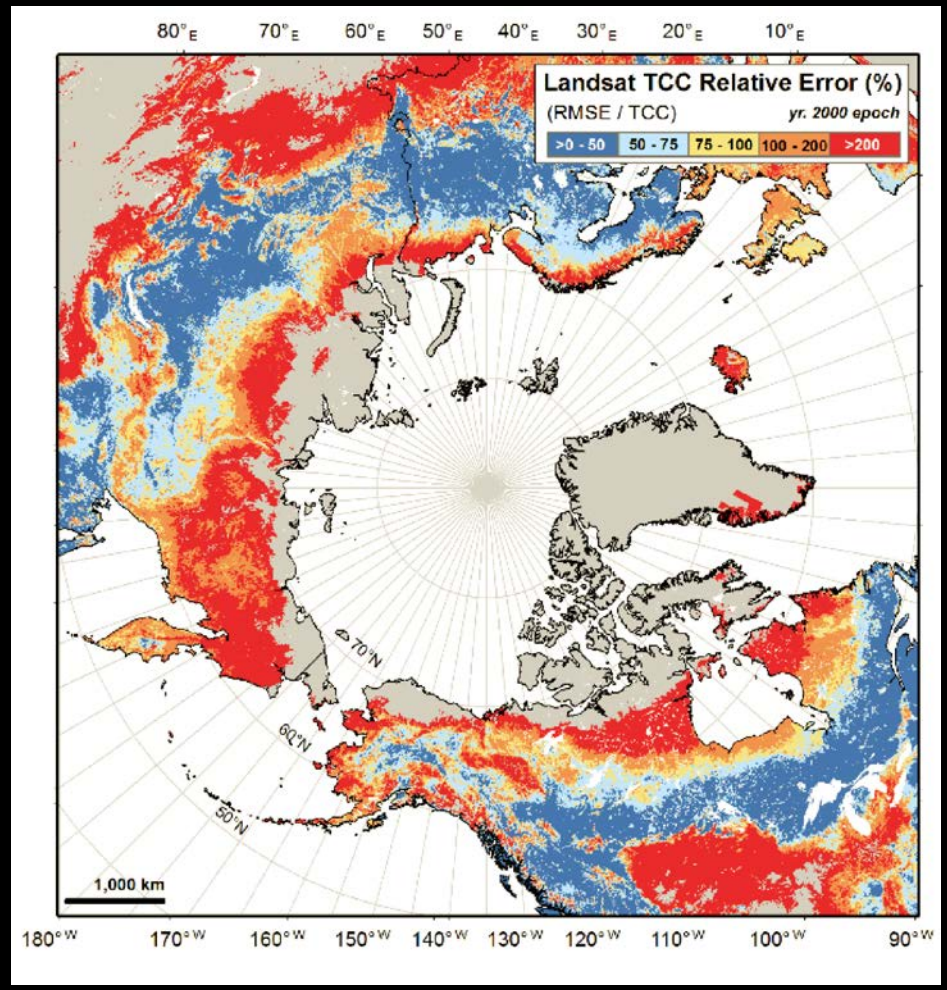
Algorithms:

- Estimation
  - ✓ single-image to “full-stack”
  - ✓ Landsat *or* Sentinel-2, Landsat *and* Sentinel-2
- Validation & calibration
  - ✓ Validation of tree-canopy cover based on high-resolution imagery
  - ✓ Lidar-based (linear) calibration of tree-canopy cover

Application & validation

Mapping the taiga-tundra ecotone

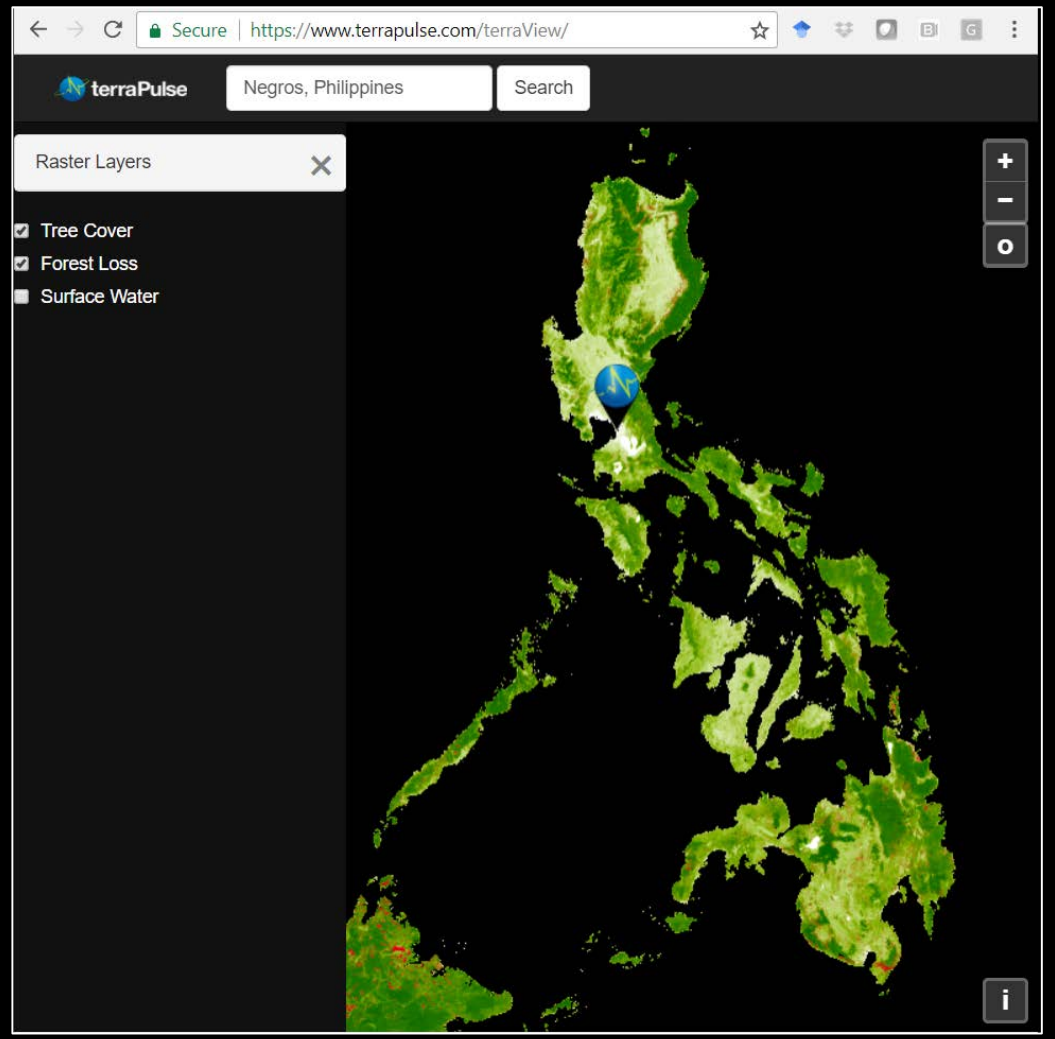
- Motive
  - Global indicator of biosphere response to climate change
- Challenges
  - Ecology
    - Climate: temperature, precipitation
    - Soil: depth, structure
    - Biology: dispersal, competition
  - Remote sensing
    - Short, sparse canopies
    - Snow & water cover
    - Short viewing seasons & shallow illumination angles
- Ecoregional calibration
    - Lidar & high-resolution optical
    - Empirical, linear
- Results
  - Removed saturation at >80% canopy cover
  - Reduced uncertainty (RMSE) by ~ 50%
  - More sensitive to cover of trees defined by > 2 m height



Philippine National Forest Monitoring System

- Sponsor: USAID/USFS
- Objectives
  - Nationally calibrated forest/nonforest dataset
  - Establish forest reference emission level (FREL)
  - Build capacity of national forestry & mapping agencies

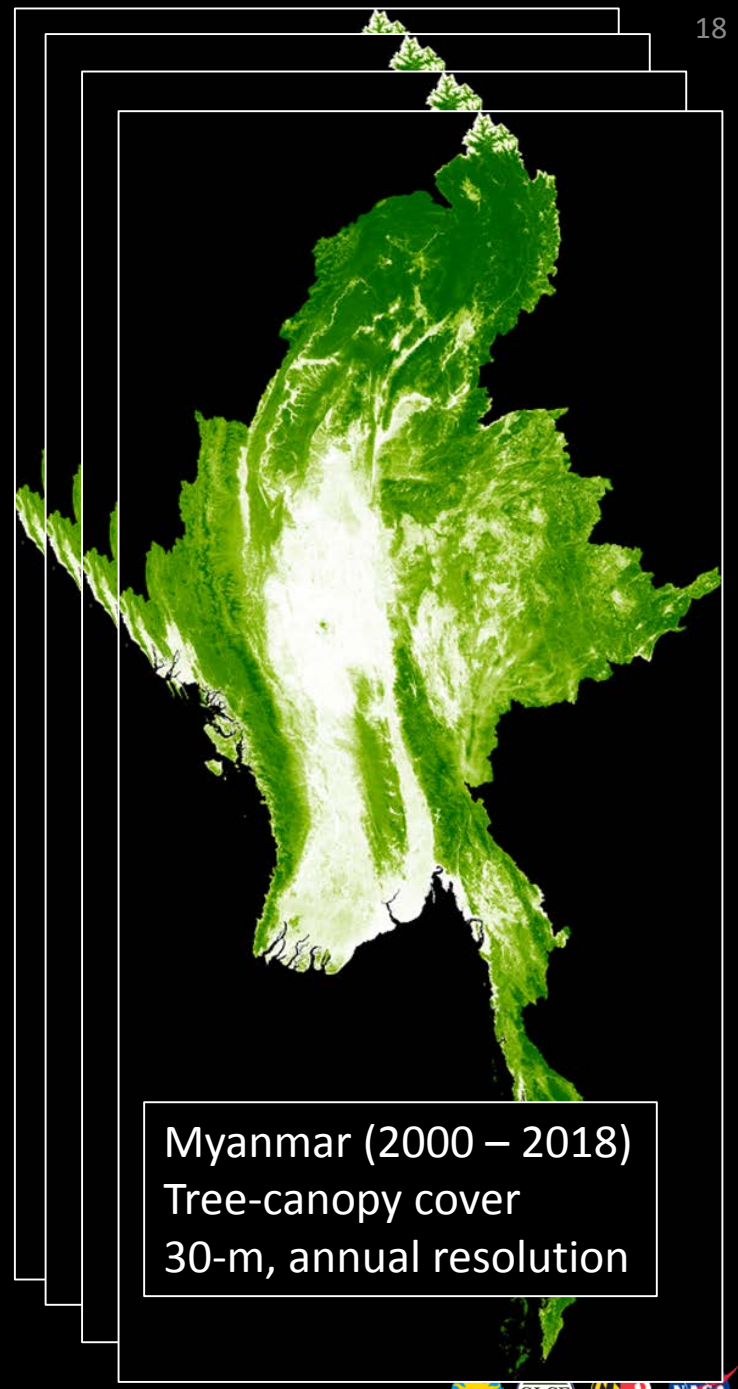
- Partners
  - National
    - Forest Management Bureau
    - NAMRIA
  - International/Implementing
    - B-WISER



Deforestation & conflict in Myanmar

- Coupling of forest clearing & civil conflict?
- Spatially complex dynamics
  - Small patches
  - regional variation in change-rate & -acceleration
- In-country partners
  - Potential for calibration
- Data specs
  - Thematic: Tree-canopy cover, forest loss
  - Spatial: national extent at 30-m resolution
  - Temporal: annual frequency from 2000 – 2018
  - Accuracy: locally calibrated (drone)

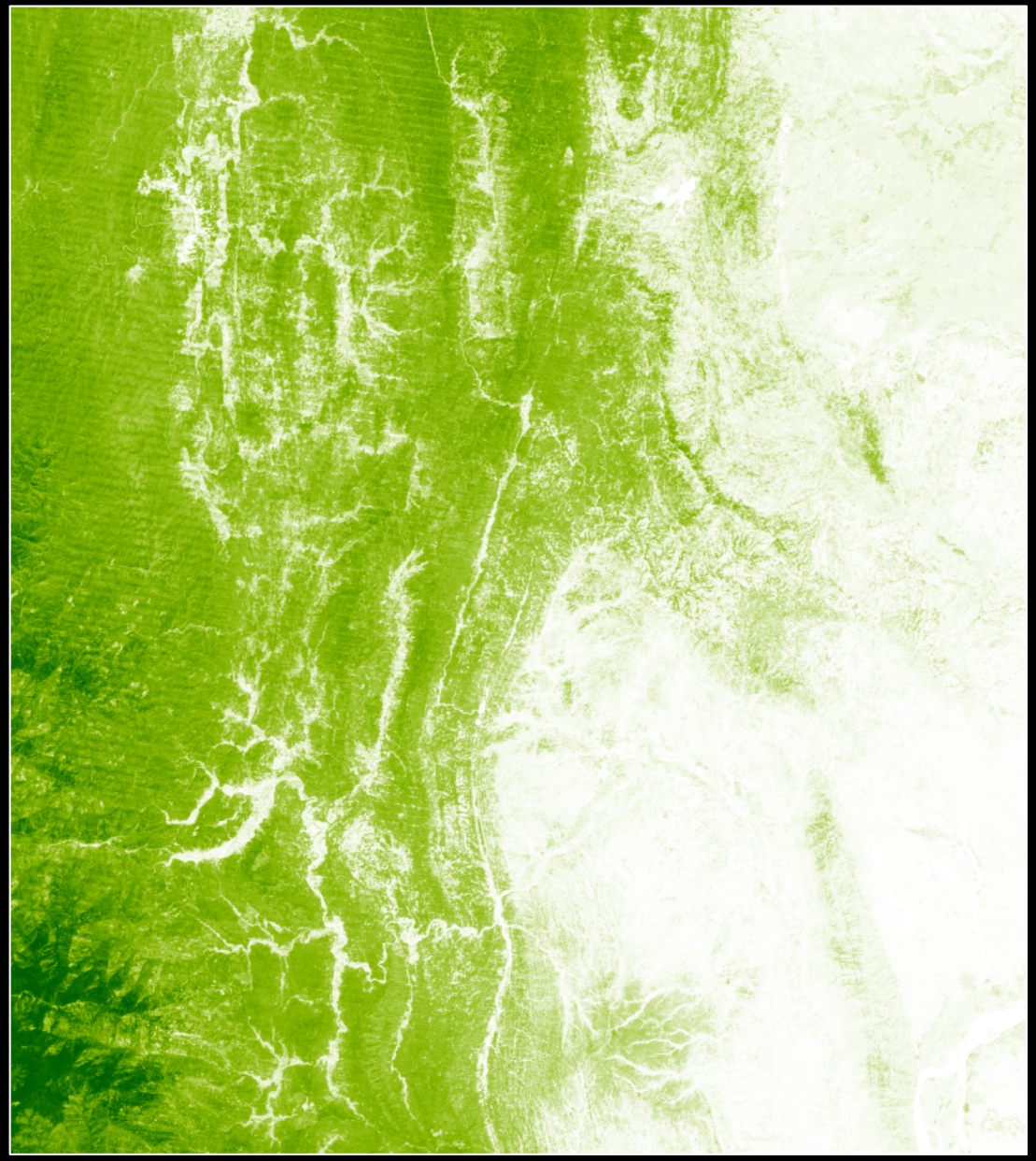
- Progress
  - Tree-canopy cover in 2000, 2005, 2010-2015
- Improvement
  - Filled gaps
  - Increased precision



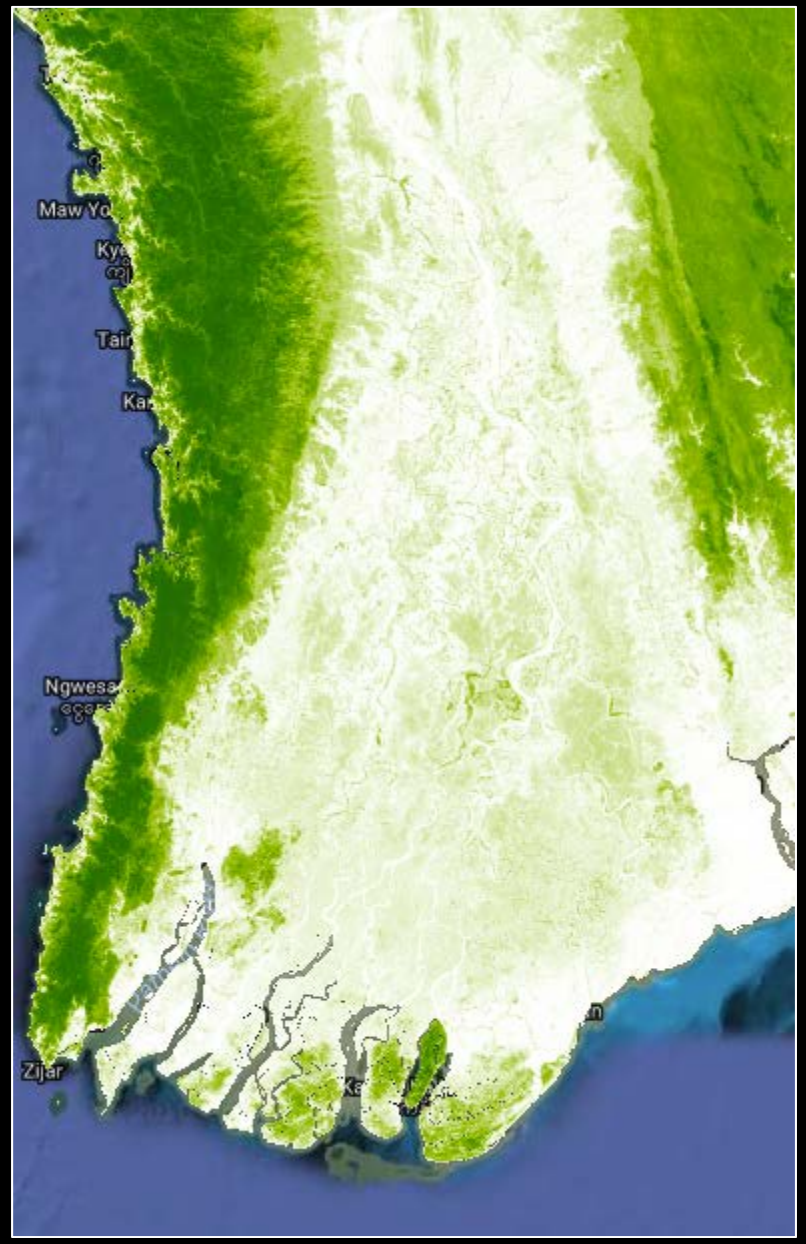
Myanmar (2000 – 2018)
Tree-canopy cover
30-m, annual resolution

Leimgruber et al. (2017 – 2020) NASA Land-Cover & Land-Use Program.

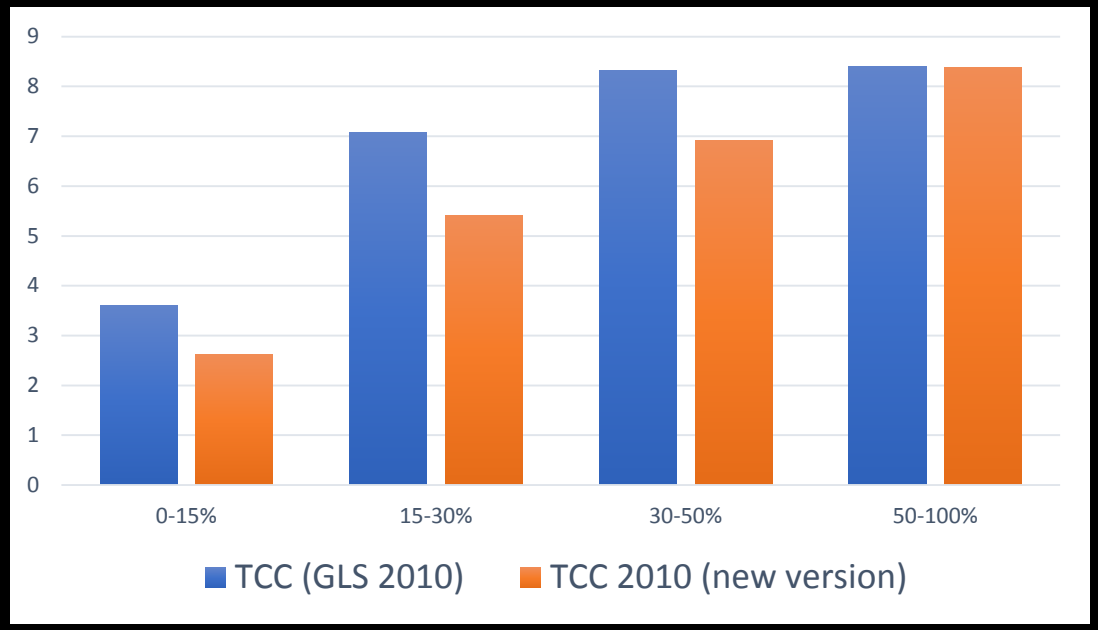
TCC 2015 (Full-stack)

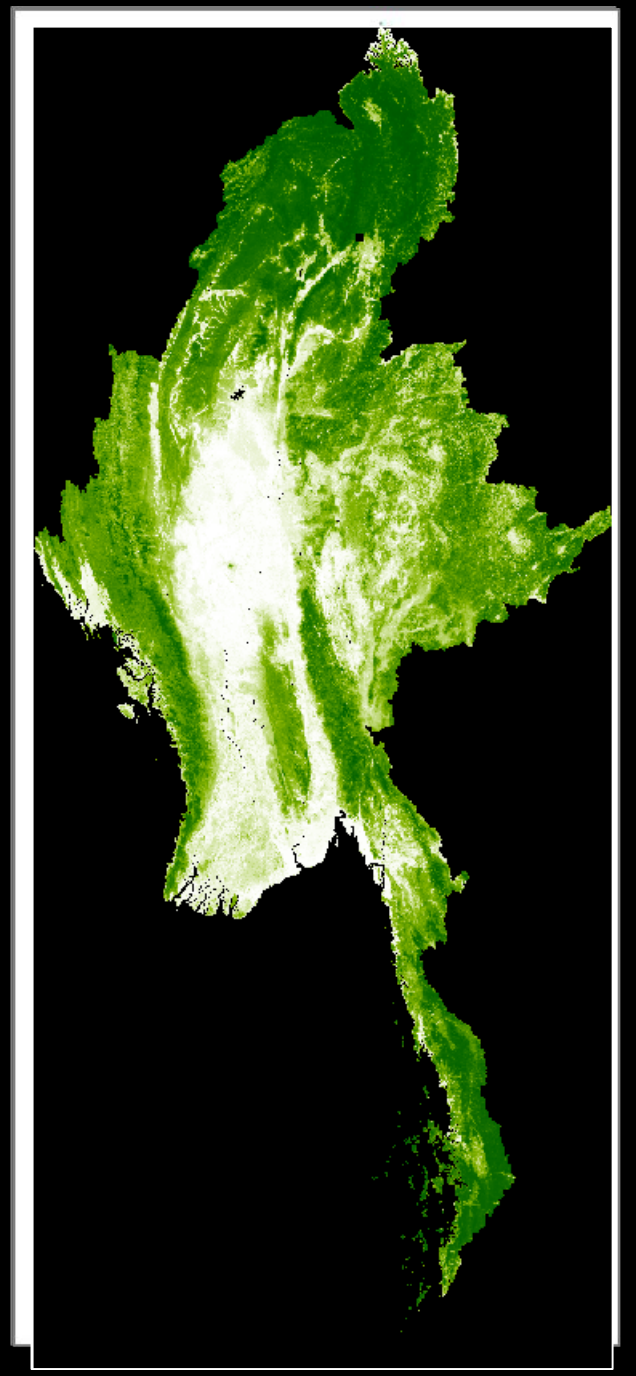


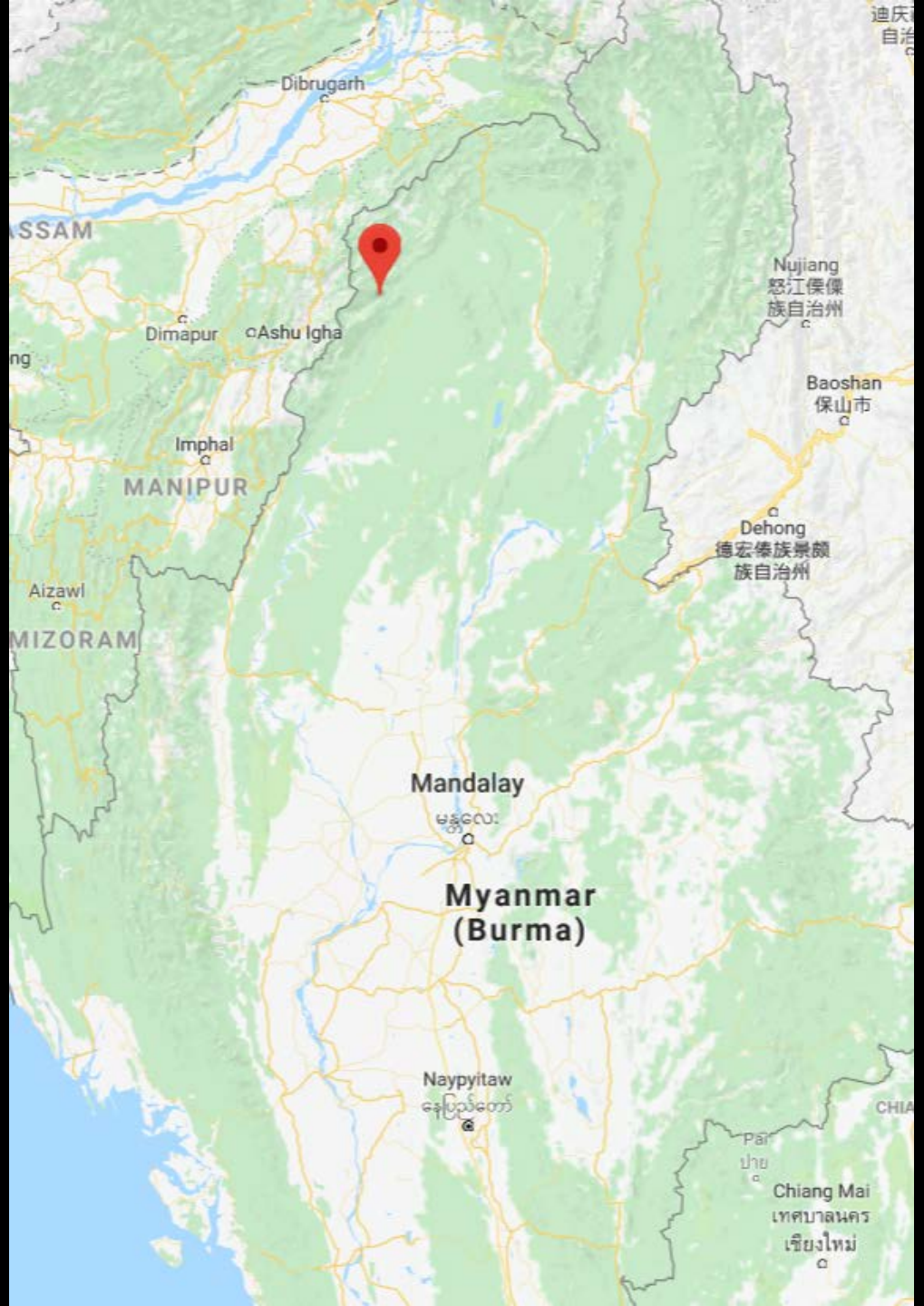
TCC 2015 (Full-stack)

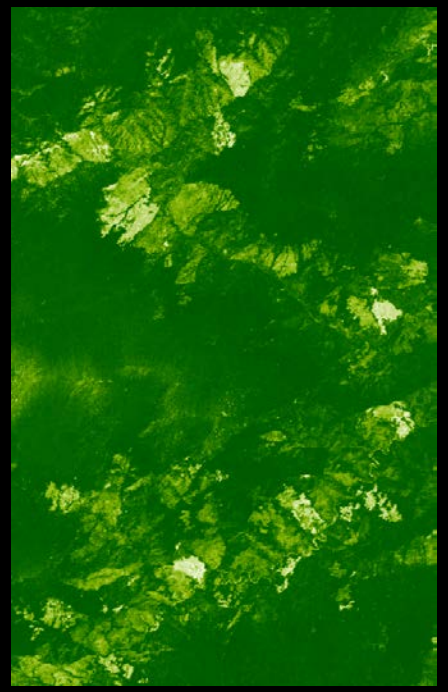


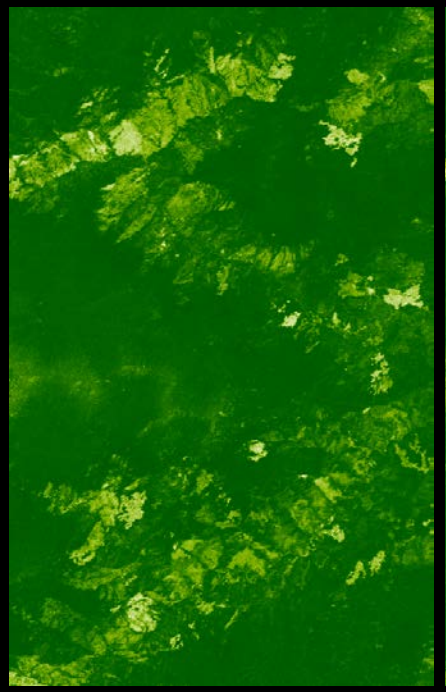
RMSE (% TCC)

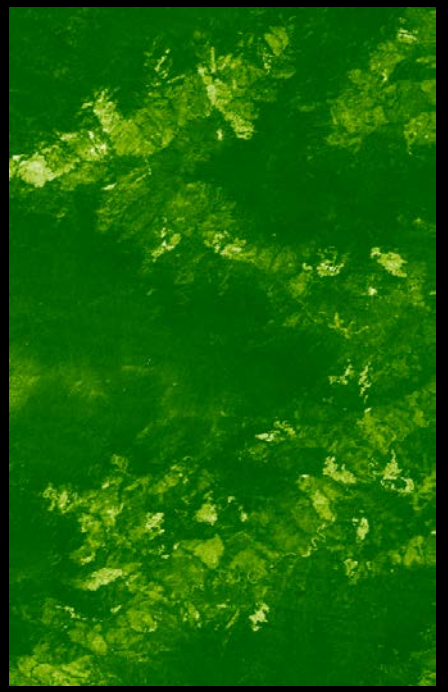

9
8
7
6
5
4
3
2
1
0
0-15%
15-30%
30-50%
50-100%
TCC (GLS 2010)
TCC 2010 (new version)

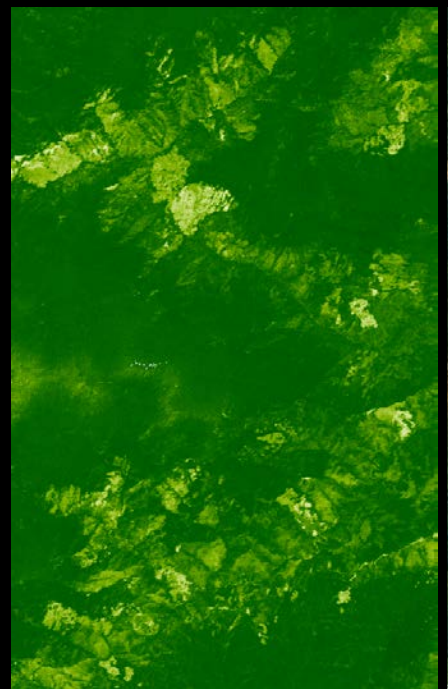


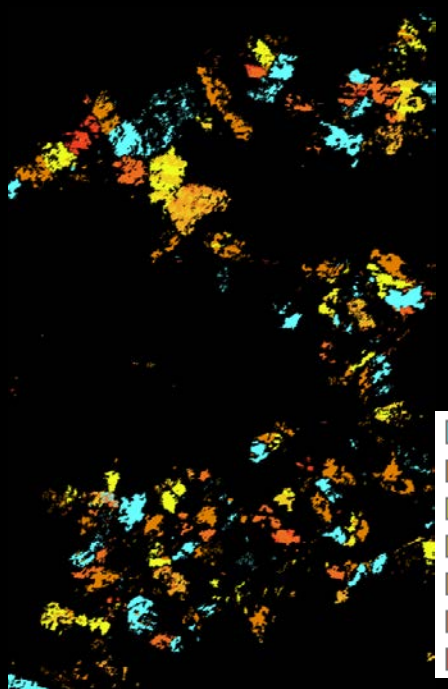

Dibrugarh
ASSAM
Dimapur
Ashu Igha
Nujiang
怒江傈僳
族自治州
Baoshan
保山市
Imphal
MANIPUR
Dehong
德宏傣族景颇
族自治州
Aizawl
MIZORAM
Mandalay
Myanmar
(Burma)
Naypyitaw
Chiang Mai
เชียงใหม่

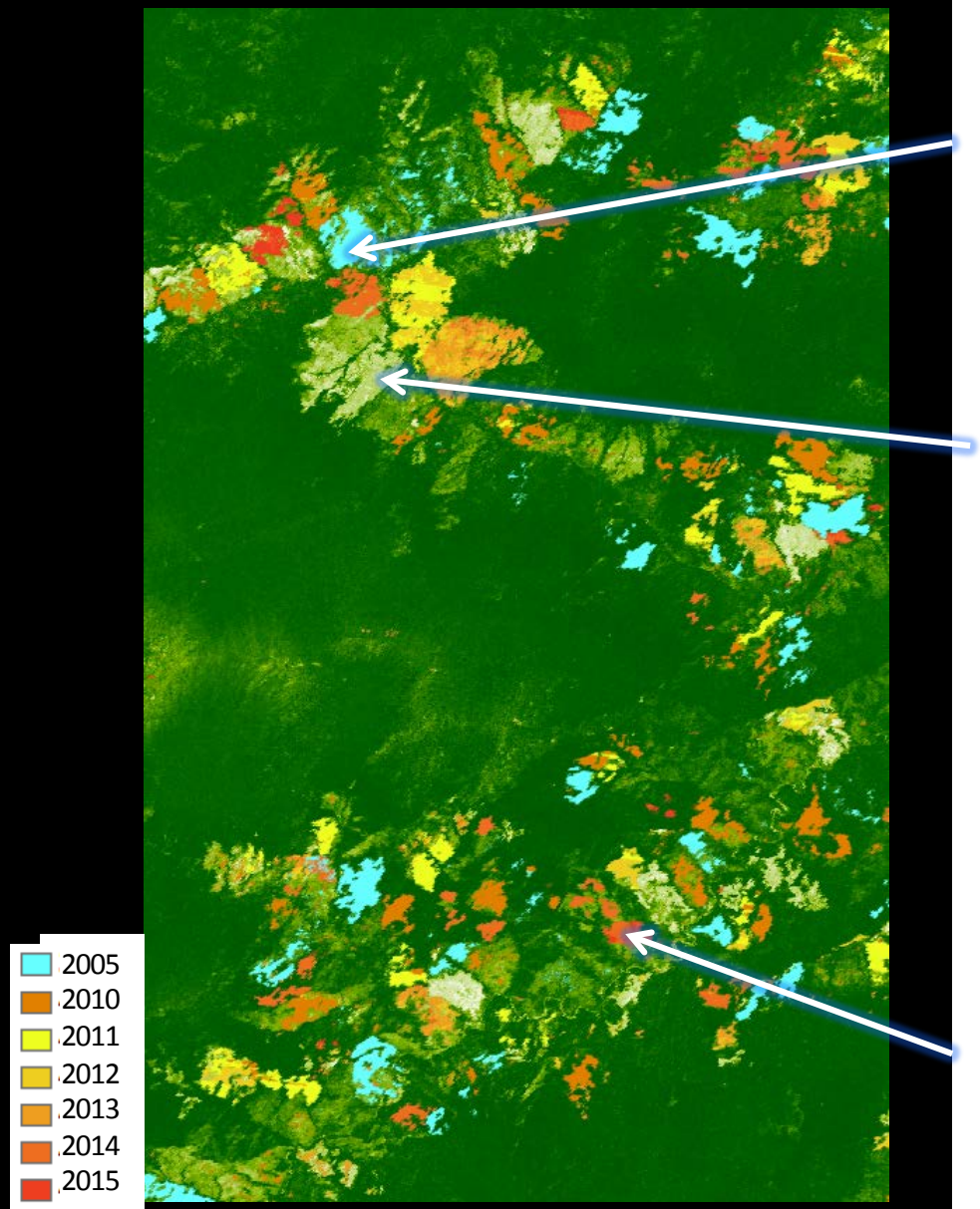









2005
2010
2011
2012
2013
2014
2015


2005
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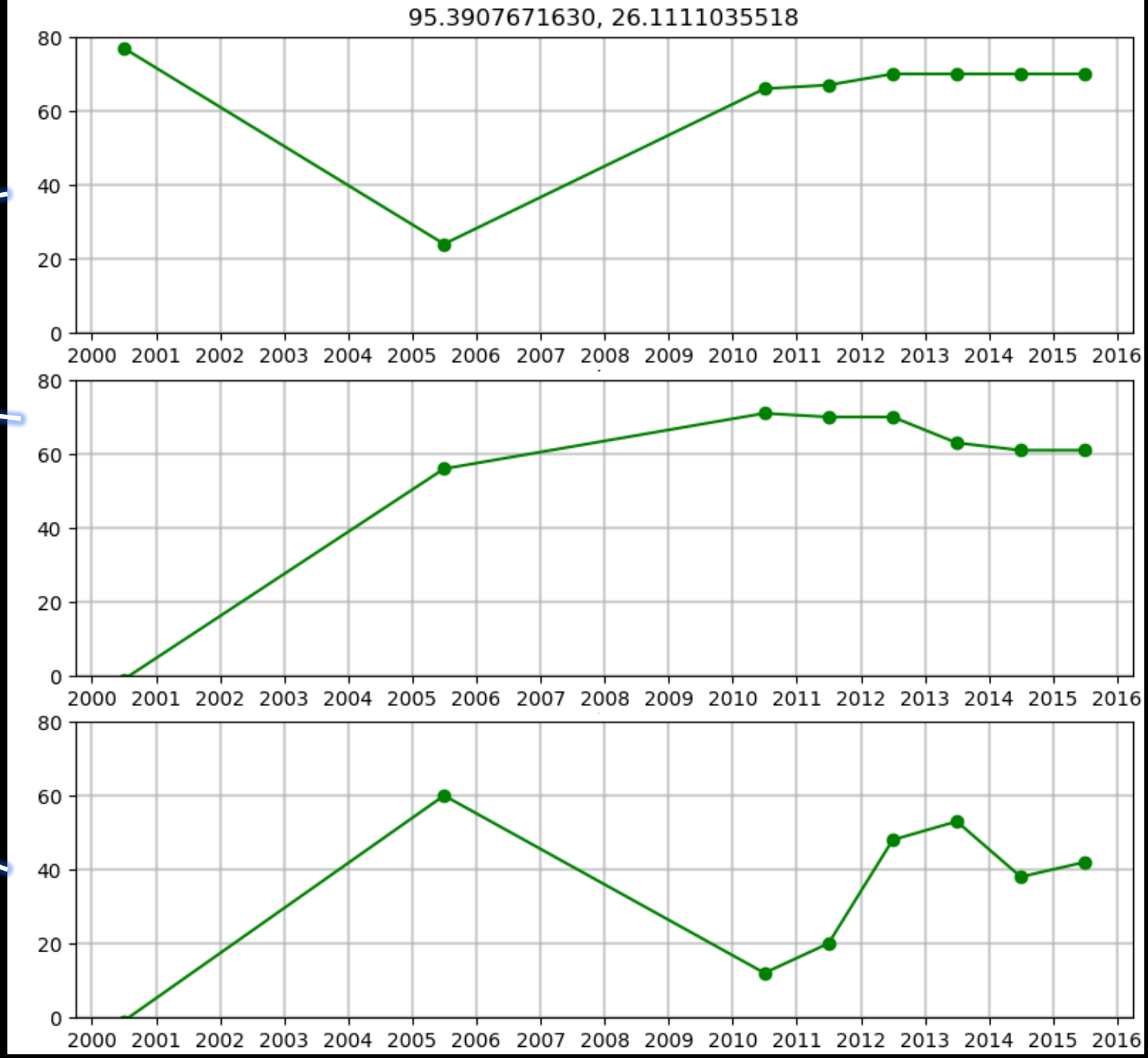
95.3907671630, 26.1111035518
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60
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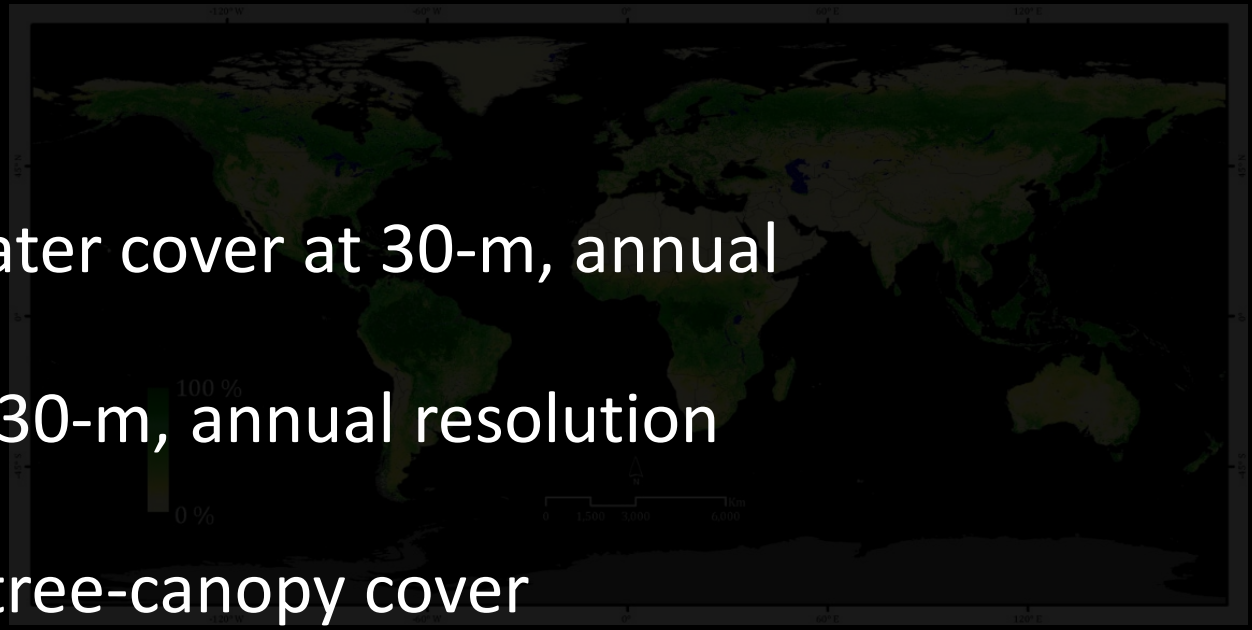
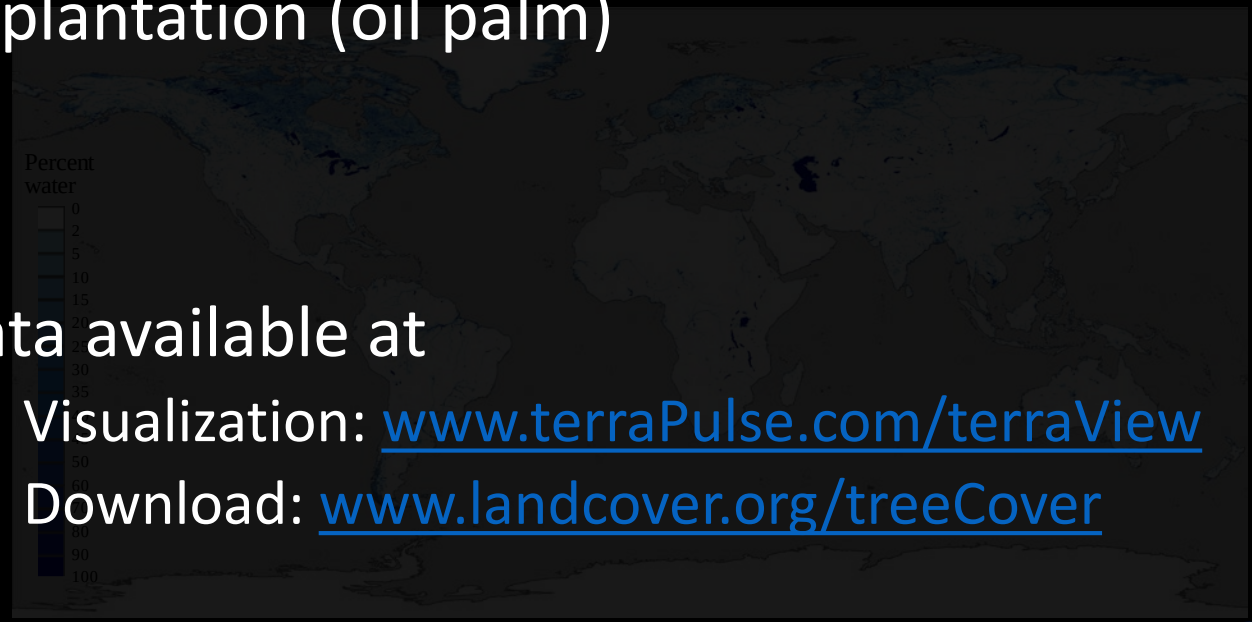
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Milestones & products



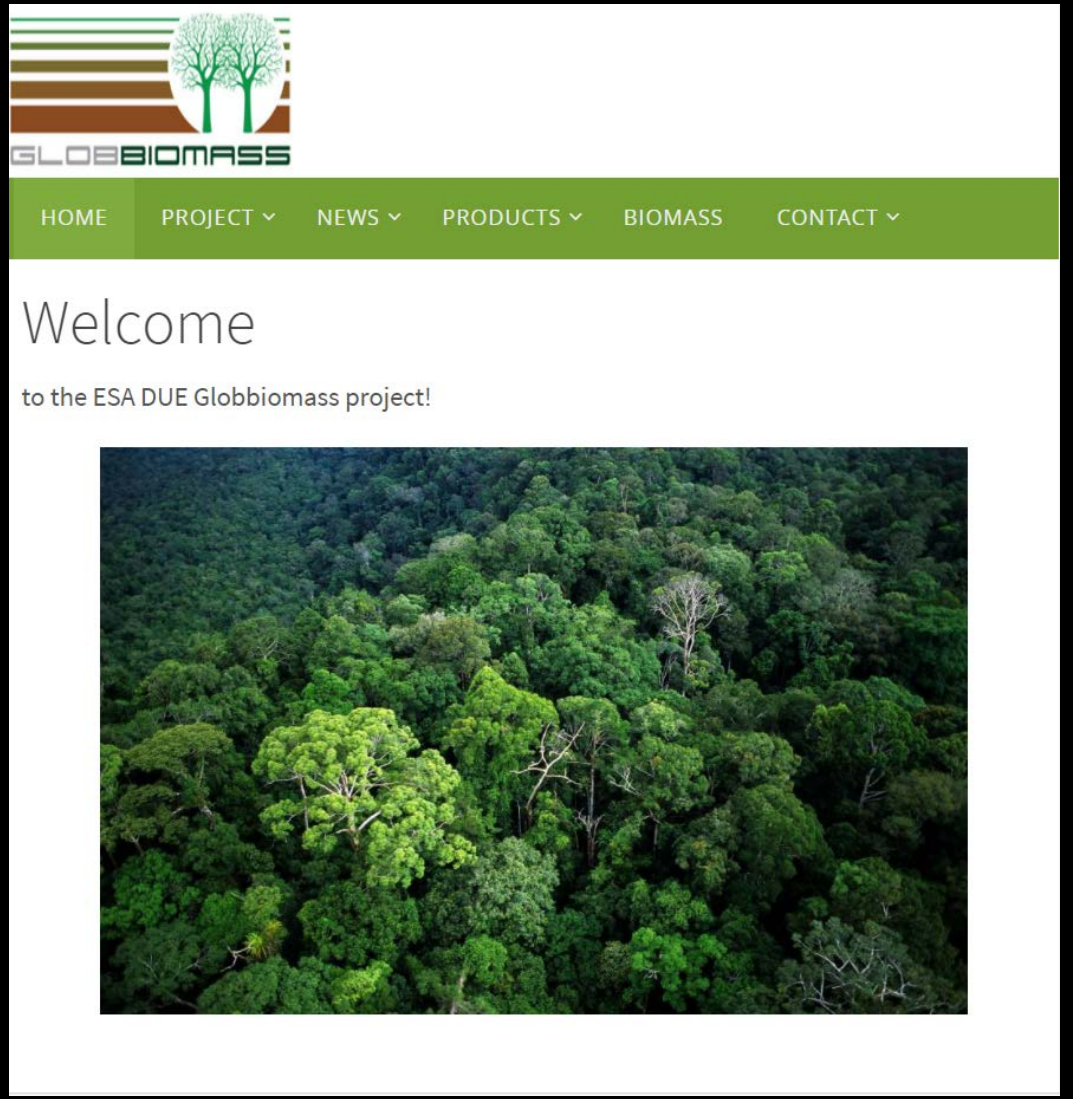
- Global estimates of tree-canopy and water cover at 30-m, annual resolution in 2000, 2005, 2010, 2015
- North- and South-America coverage at 30-m, annual resolution from 2010 – 2015
- Lidar-based calibration & validation of tree-canopy cover
- SAR discrimination of natural forest *vs.* plantation (oil palm)
- Algorithms developed & ready for HLS
  - Estimation
  - Change detection
    - Forest loss & degradation
  - Time-series
    - Disturbance & regrowth history
    - Stand age



- Data available at
  - Visualization: www.terraPulse.com/terraView
  - Download: www.landcover.org/treeCover

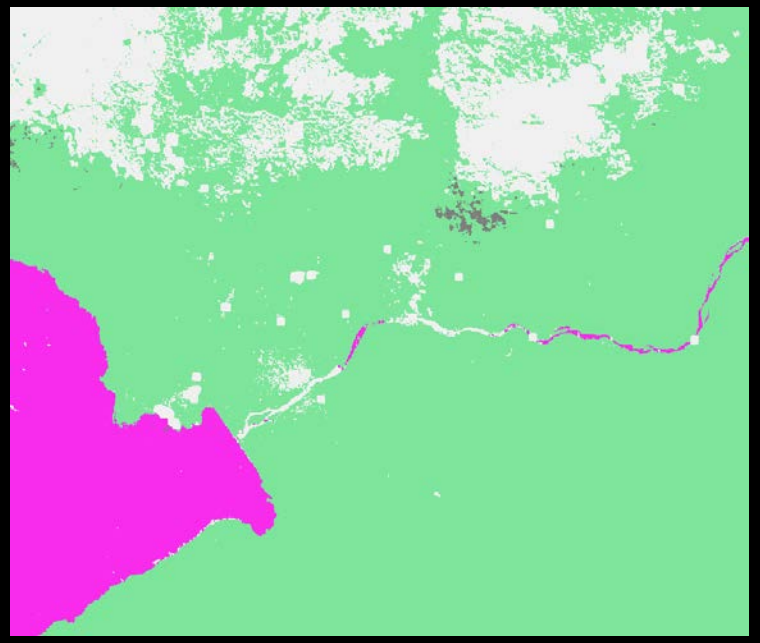
ESA GLOBBIOMASS

- Series of international meetings
- Landsat-based tree-canopy cover distributed to GLOBBIOMASS
- GLOBBIOMASS using tree-canopy cover as a predictor of higher-level products
- GLOBBIOMASS funded for second round



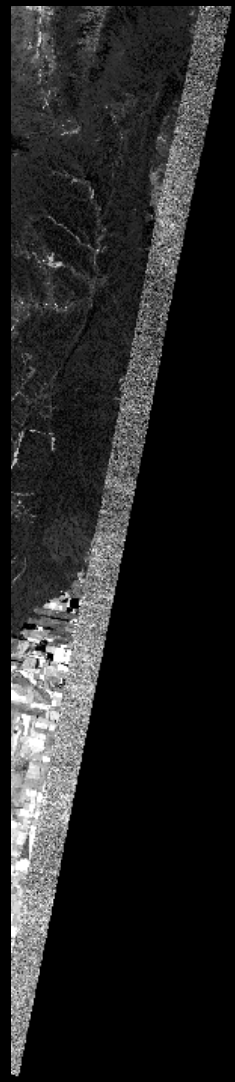
Polar-ICE data stories

- Outreaching Arctic science to elementary schools
- Course modules built for science classes
- Science teachers instructed on ecology & Earth observation



The cloud/shadow masks have significantly improved in version 1.3, but commission and omission errors were found for cloud, shadow, and water

Inconsistent extent in OLI band 9



glcfpro30.umd.edu - PuTTY

```
  SPATIAL_RESOLUTION=30
  TIRS_SSM_MODEL=FINAL
  TIRS_SSM_POSITION_STATUS=ESTIMATED
  ULX=300000
  ULY=7100020
  unit=Celsius
  USGS_SOFTWARE=LPGS_2.6.2
Corner Coordinates:
Upper Left   (  300000.000, 7100020.000) ( 67d 5'11.87"W, 63d58' 9.93"N)
Lower Left   (  300000.000, 7100050.000) ( 67d 5'12.01"W, 63d58'10.90"N)
Upper Right  (  299970.000, 7100020.000) ( 67d 5'14.07"W, 63d58' 9.87"N)
Lower Right  (  299970.000, 7100050.000) ( 67d 5'14.21"W, 63d58'10.84"N)
Center       (  299985.000, 7100035.000) ( 67d 5'13.04"W, 63d58'10.39"N)
ERROR 1: HDF4_EOS:EOS_GRID:/data/glcf-js-14-1/data/hls.gsfc.nasa.gov/data/v1.3/s
ites/TUC/L30/2016/20JLR/HLS.L30.T20JLR.2016353.v1.3.hdf:Grid:band10, band 1: Inv
alid block dimension : -1 * 1
Band 1 Block=0x0 Type=Int16, ColorInterp=Gray
  Description = TIRS1
  NoData Value=-10000
ERROR 1: HDF4_EOS:EOS_GRID:/data/glcf-js-14-1/data/hls.gsfc.nasa.gov/data/v1.3/s
ites/TUC/L30/2016/20JLR/HLS.L30.T20JLR.2016353.v1.3.hdf:Grid:band10, band 1: Inv
alid block dimension : -1 * 1
  Offset: 0,   Scale:0.01
[fengm:glcfpro30] ~>
```

The HDF files of L30 and S30 v1.3 are not compatible with HDF-EOS