

# **Generation of the 10m resolution L-band SAR global mosaic and forest/non-forest map**

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# **Global forest monitoring system using 18 year SAR dataset (JERS-1 SAR ~ ALOS/PALSAR)**

Product: Ortho-rectified and slope corrected high resolution global forestry data (**gamma-naught, classification, (biomass)**)

Resolution: **10m**

Sensor: JERS-1 SAR/ALOS-PALSAR  
Reprocessing all the EORC/JAXA SAR archives

Dates: 1994-1996-1998~2007, 2009

Products:**Horizon1/2 + Mosaic**

Aug. E, 2010

# Amazon Deforest Watch (Santarem) JERS-1 & ALOS

## Acquisition Term

1993/6/26  
~2007/9/13

JERS-1  
• 1993/6/26  
• 1997/5/4  
• 1997/7/31

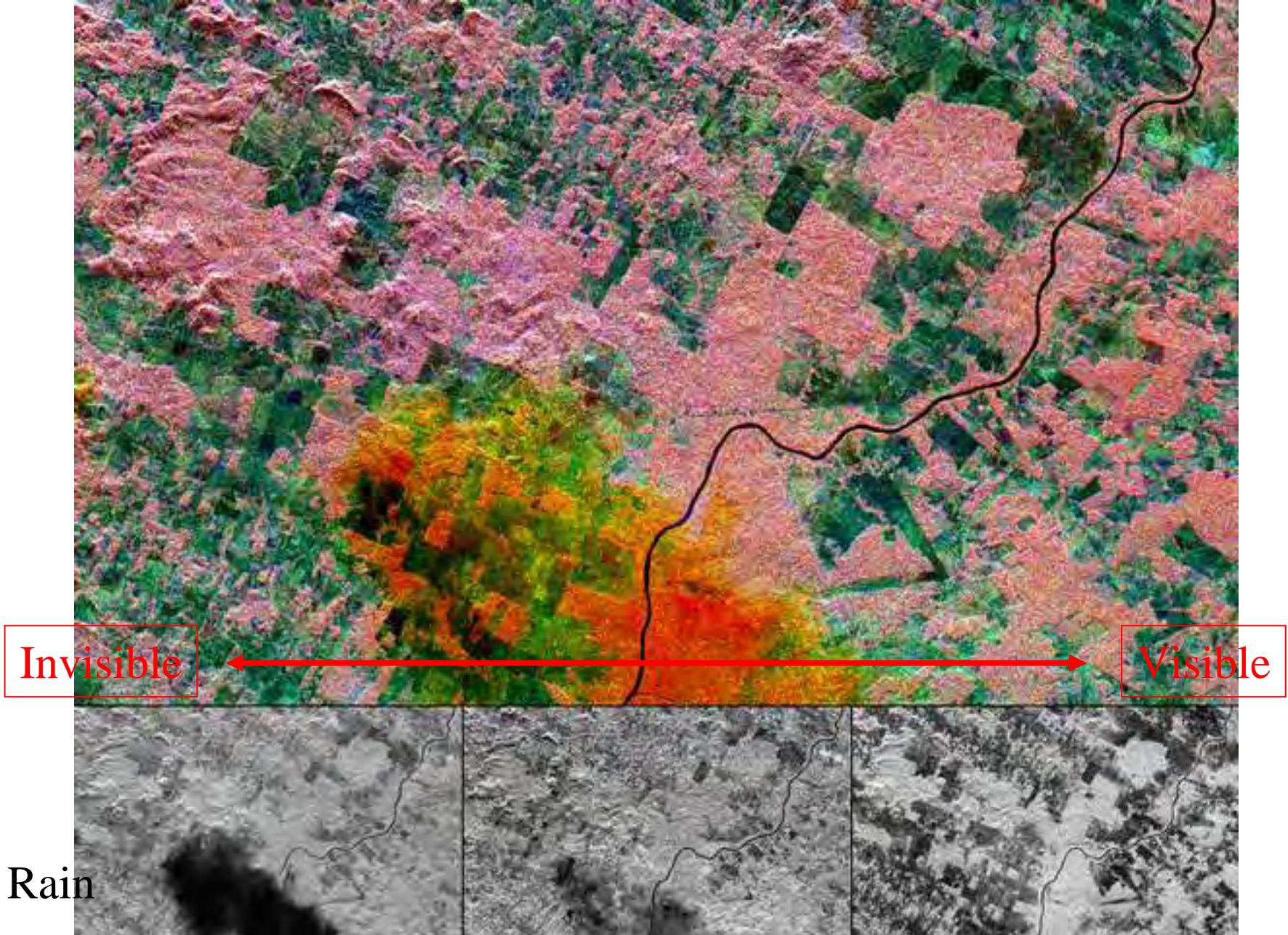
ALOS  
• 2007/6/13  
• 2007/9/13

Lat : S 2° 34'  
Lon : W 54° 45'

2007/9/13

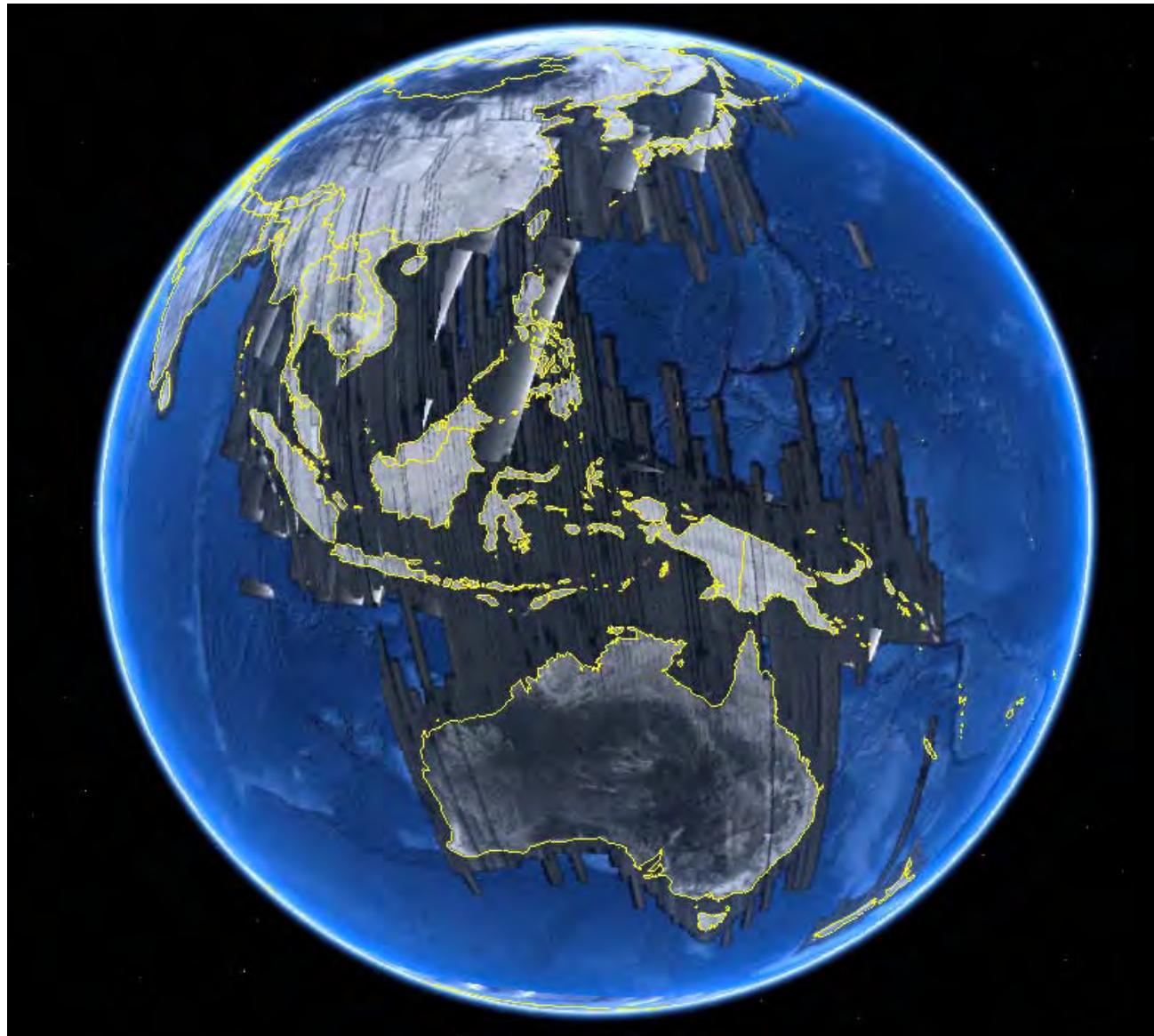


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SAR data of Rondonia (difference in frequency by SIR-C of 1994)

# Global Observation Scenario



High resolution  
wall-to-wall  
observation

PALSAR  
AVNIR-2  
PRISM

Systematic, time-space consistent observations  
46 days acquisition: (I.e., July 28 2009~ Sept. 11, 2009)

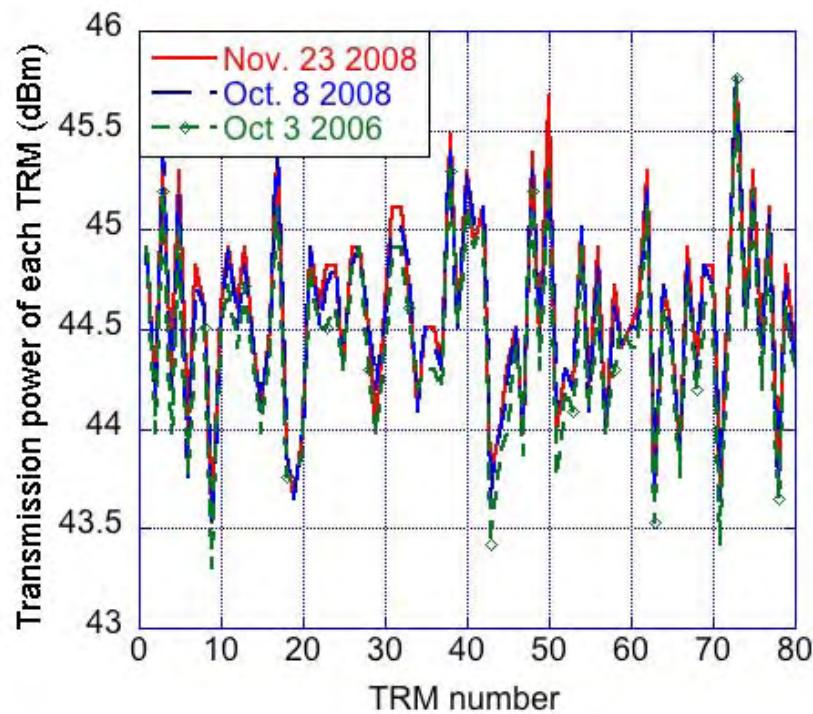
## Key issues for generating the global satellite data

1. Collection of the same season data (Cloud free)
2. Stability and calibration (geo/radio) of the SAR
3. Effective SAR processing (strip processing)
4. Ortho-rectification
5. Radiometric normalization(slope correction)
6. Mosaicking and radiometric normalization
7. Classification (Forest/non-forest, land classification)

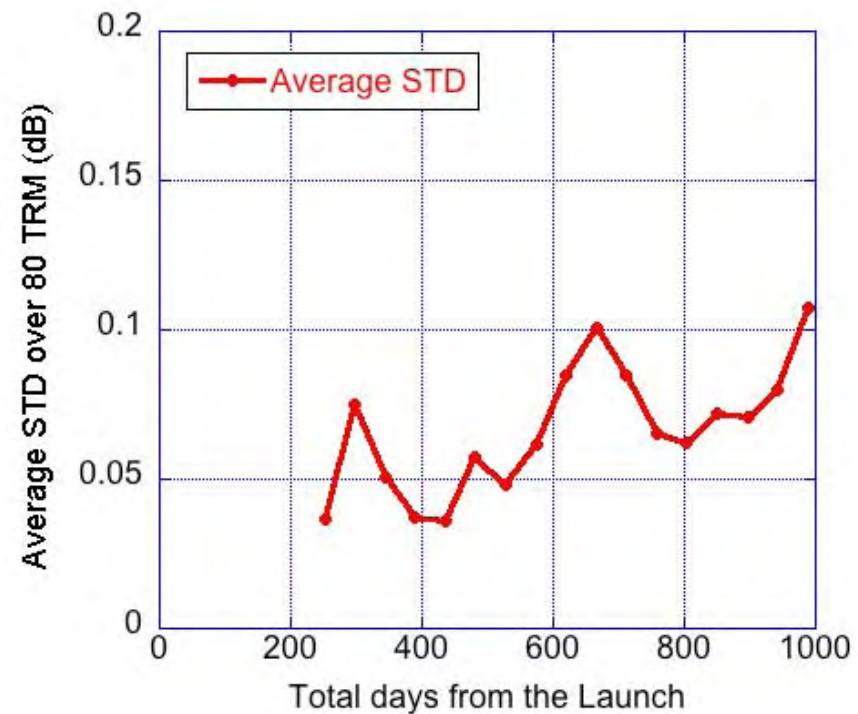
# Key issue for generation of the forest product

- 1 ) Collection of the same season data (SAR's merit)
- 2) Stability and the calibration (geometric and radiometric) of the SAR
- 3) Effective processing of SAR data (requires strip processing)
- 4) Ortho-rectification of the SAR and validation
- 5) Radiometric normalization of the SAR (slope correction)
- 6) Mosaicking processing of the SAR data (integration of the SAR data to the global scale considering the radiometric normalization)
- 7) Classification processing (Forest/non-forest, land classification)

# Transmission power monitor



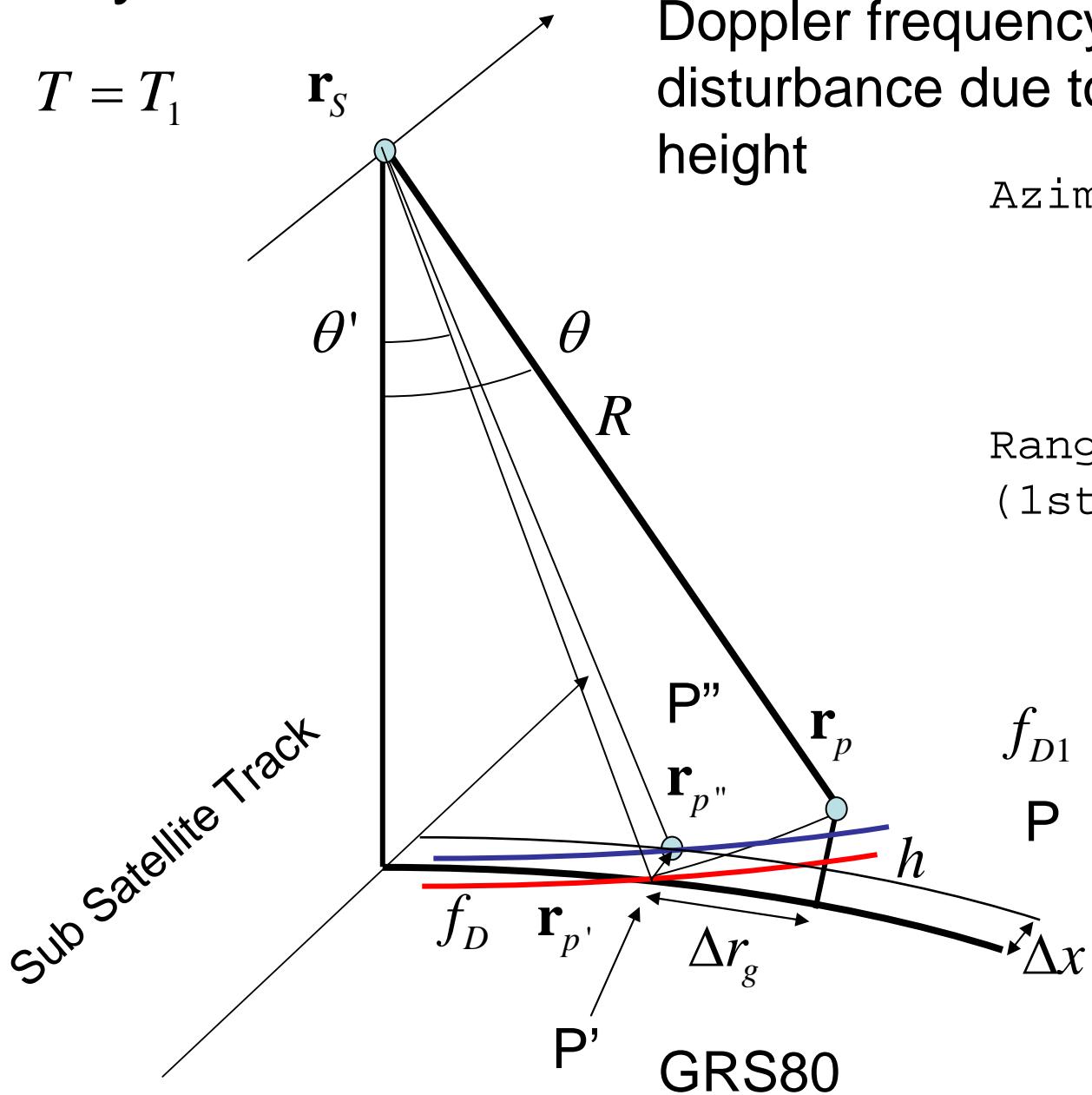
Variation of the Pt  
Over 80 TRM



Std Dev. Of Pt

# Geometry issue

$$T = T_1$$



Doppler frequency disturbance due to the height

Azimuth Shift

$$\Delta x = -\frac{\Delta f_D}{f_{DD}} v_g$$

Range Shift (1st order)

$$\Delta r_g \cong \frac{h}{\tan \theta_{inci}}$$

$$f_{D1}$$

$$\mathbf{P}$$

# Geometric Evaluation Result

Geo error (ortho ) >

Geo error (slant)

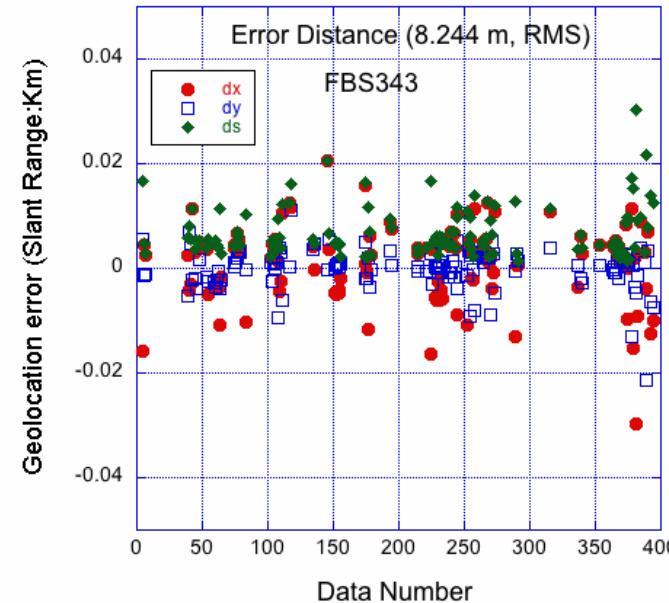
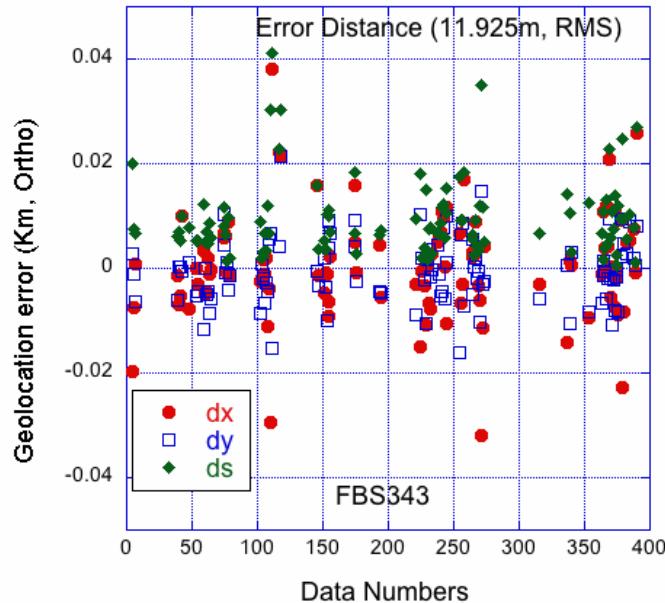


TABLE IV Geolocation Accuracy Measurement for the Ortho-rectification Image and Slant Range Image

Off-nadir Angle ( $^{\circ}$ )	Geolocation Error (ortho: m)	Geolocation Error (Slant: m)
21.5	17.383 (7.211, 21)	13.19 (5.267, 28)
34.3	11.925 (7.266, 104)	8.244 (4.716, 124)
41.5	9.488 (5.127, 50)	7.286 (4.017, 56)
Total Value in RMSE	12.103 (6.718, 175)	8.885 (4.619, 208)

Note: Values in each element are RMSE defined Eq. (28) (standard deviation, number of samples)

G\_err\_ortho ~12.10m (RMSE)

TABLE IV Geolocation Accuracy Measurement for the Ortho-rectification Image and Slant Range Image

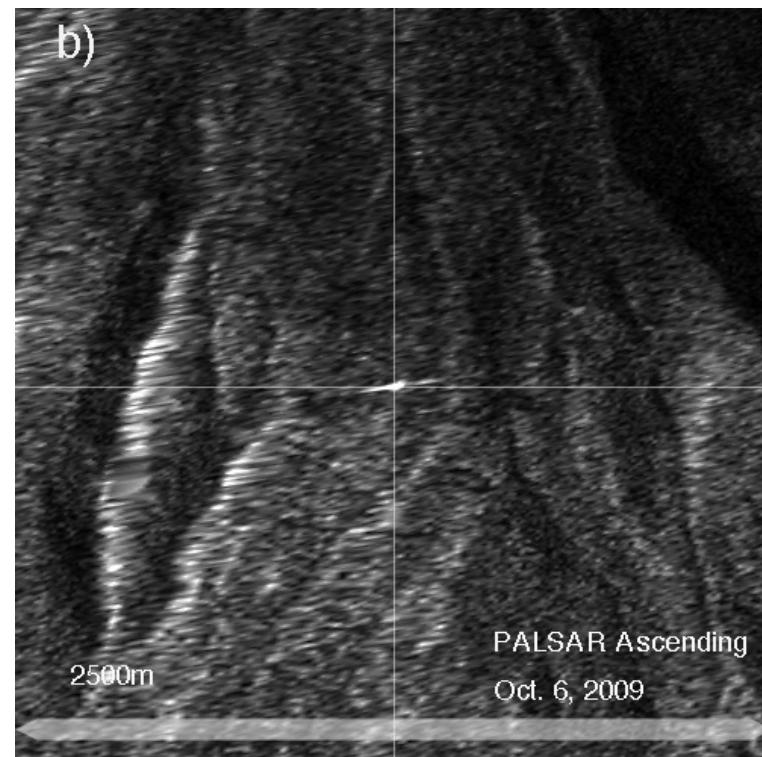
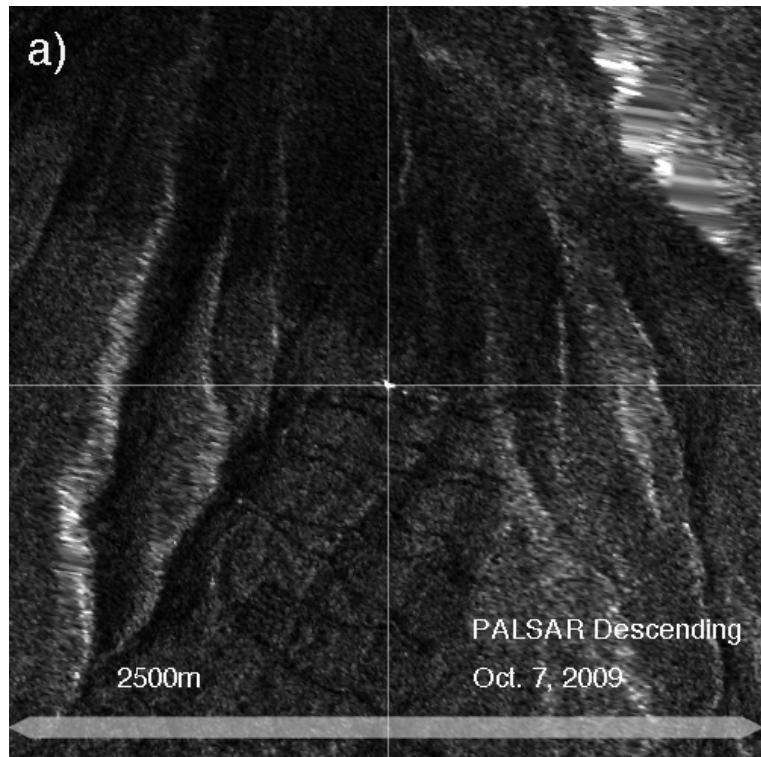
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# Position estimation of the ortho-rectified image

TABLE V Comparison of the Ortho-rectified Geometric Accuracy

No.	Latitude	Longitude	Height (m)	$\Delta x$ (m)	$\Delta y$ (m)	$\Delta s$ (m)
Ascending	N35 20°13.00'	E138 43°57.03'	2410.625	0.253	3.092	3.102
Truth (asc)	N35 20°12.90'	E138 43°57.020	2412.449			
Descending	N35 20°13.090	E138 43°55.900	2410.000	3.040	3.711	4.797
Truth (desc)	N35 20°12.90'	E138 43°55.780	2412.449			



# Slope correction

- Sigma-naught
- Gamma-naught
- Beta-naught

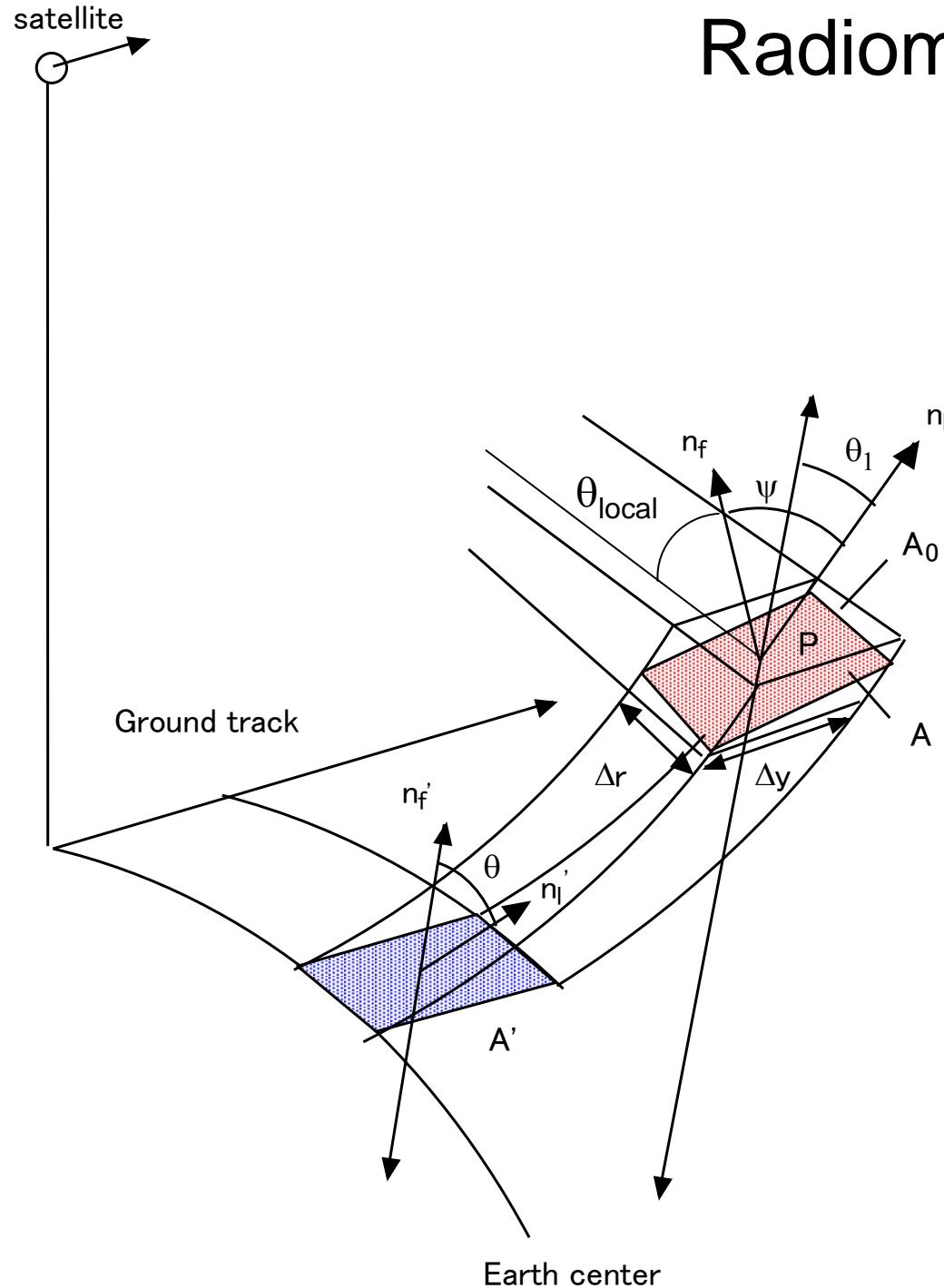
$$\sigma^0 = \lim_{R \rightarrow \infty} \frac{4\pi R^2 \langle E_s E_s^* \rangle}{A \langle E_i E_i^* \rangle}$$

$$= \frac{\sigma}{A}$$

$$\gamma^0 = \frac{\sigma^0}{\cos \theta}$$

$$\beta^0 = \frac{\sigma^0}{\sin \theta}$$

# Radiometry issue



# Radiometry:Slope corrections on $\sigma^0$ and $\gamma^0$

$$\tilde{\sigma}^0 = \sigma^0 \frac{\cos \psi}{\sin \theta} \frac{1}{LIAC}$$

$$\theta_l = \cos^{-1} \left\{ \frac{(\mathbf{r}_s - \mathbf{r}_p) \cdot \mathbf{n}_l}{|\mathbf{r}_s - \mathbf{r}_p|} \right\}$$

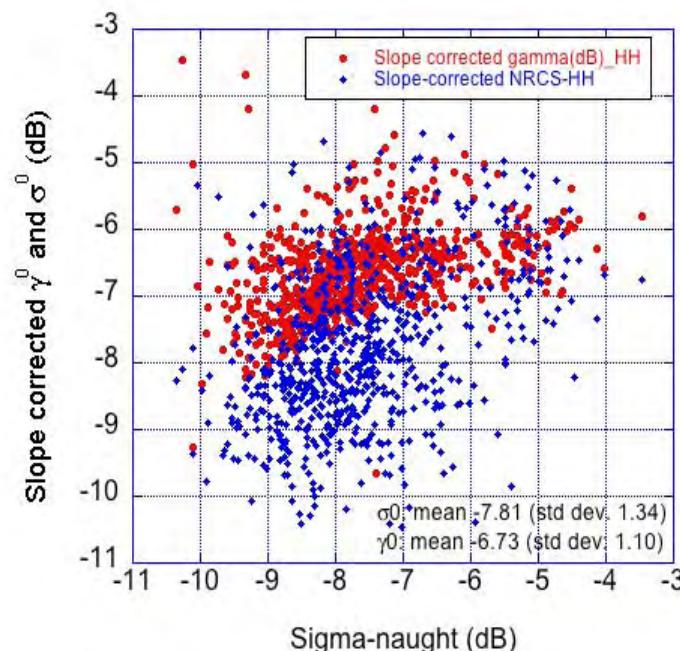
$$\mathbf{n}_l = \frac{1}{\sqrt{h_x^2 + h_y^2 + 1}} \begin{pmatrix} h_x & h_y & 1 \end{pmatrix}^t$$

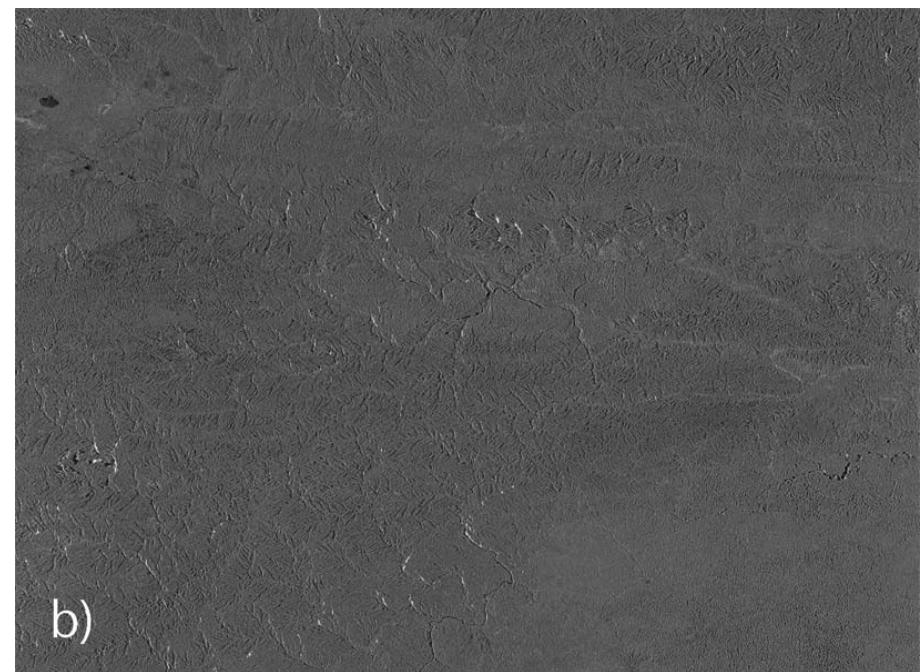
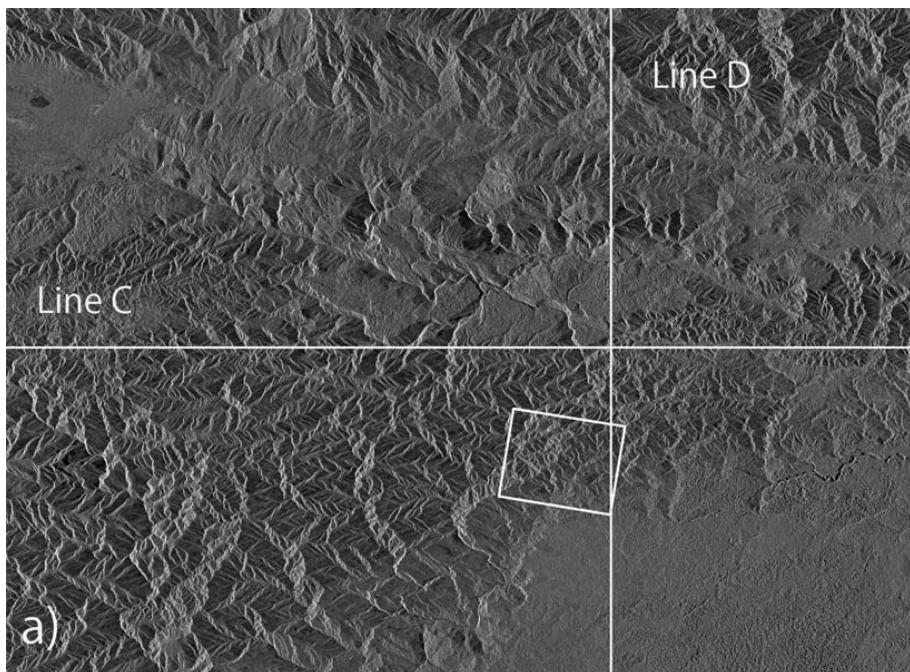
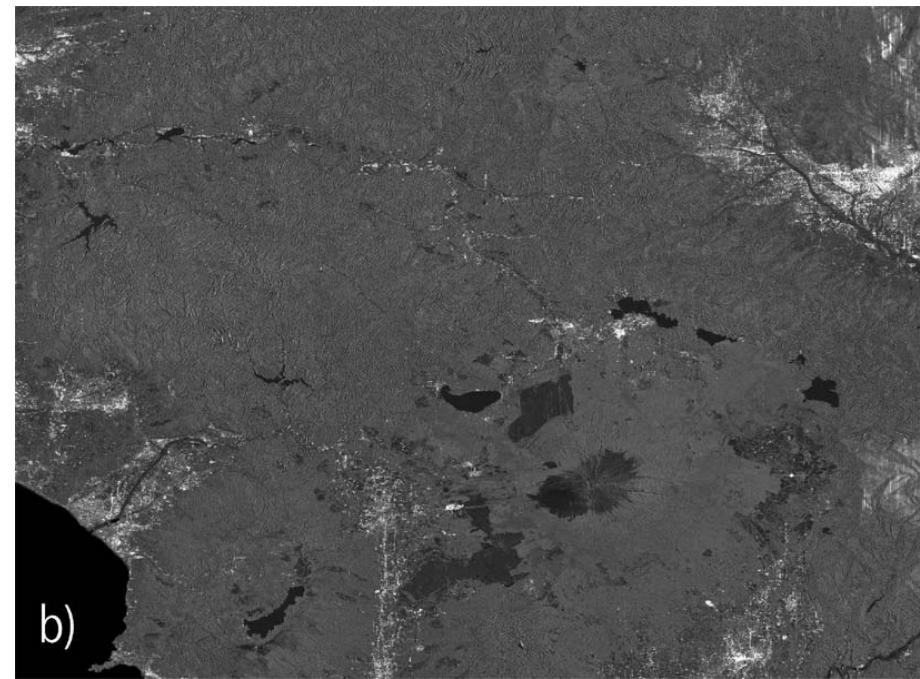
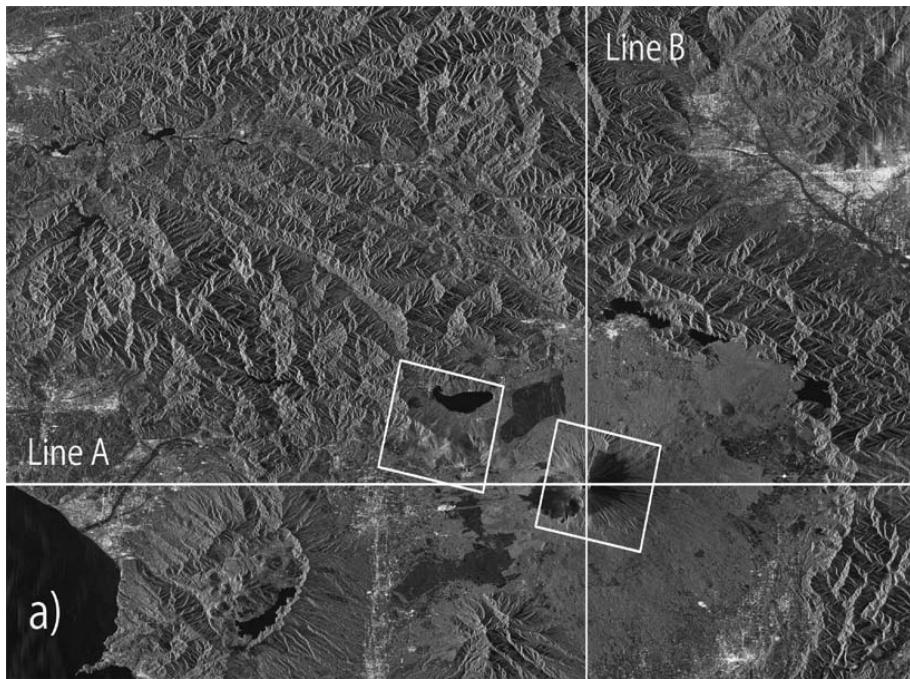
$$\cos \psi = \mathbf{n}_f \cdot \mathbf{n}_l = \frac{\sin \theta_l - \cos \theta_l \cdot h_x}{\sqrt{h_x^2 + h_y^2 + 1}}$$

$$LIAC \sim 10^{d\theta_l}$$

$$\gamma^0 \equiv \frac{\sigma^0}{\cos \theta_{local}} \frac{\cos \psi}{\sin \theta_{inci}}$$

$$\theta_{local} = \cos^{-1} \left\{ \frac{(\mathbf{r}_s - \mathbf{r}_p) \cdot \mathbf{n}_l}{|\mathbf{r}_s - \mathbf{r}_p|} \right\}$$

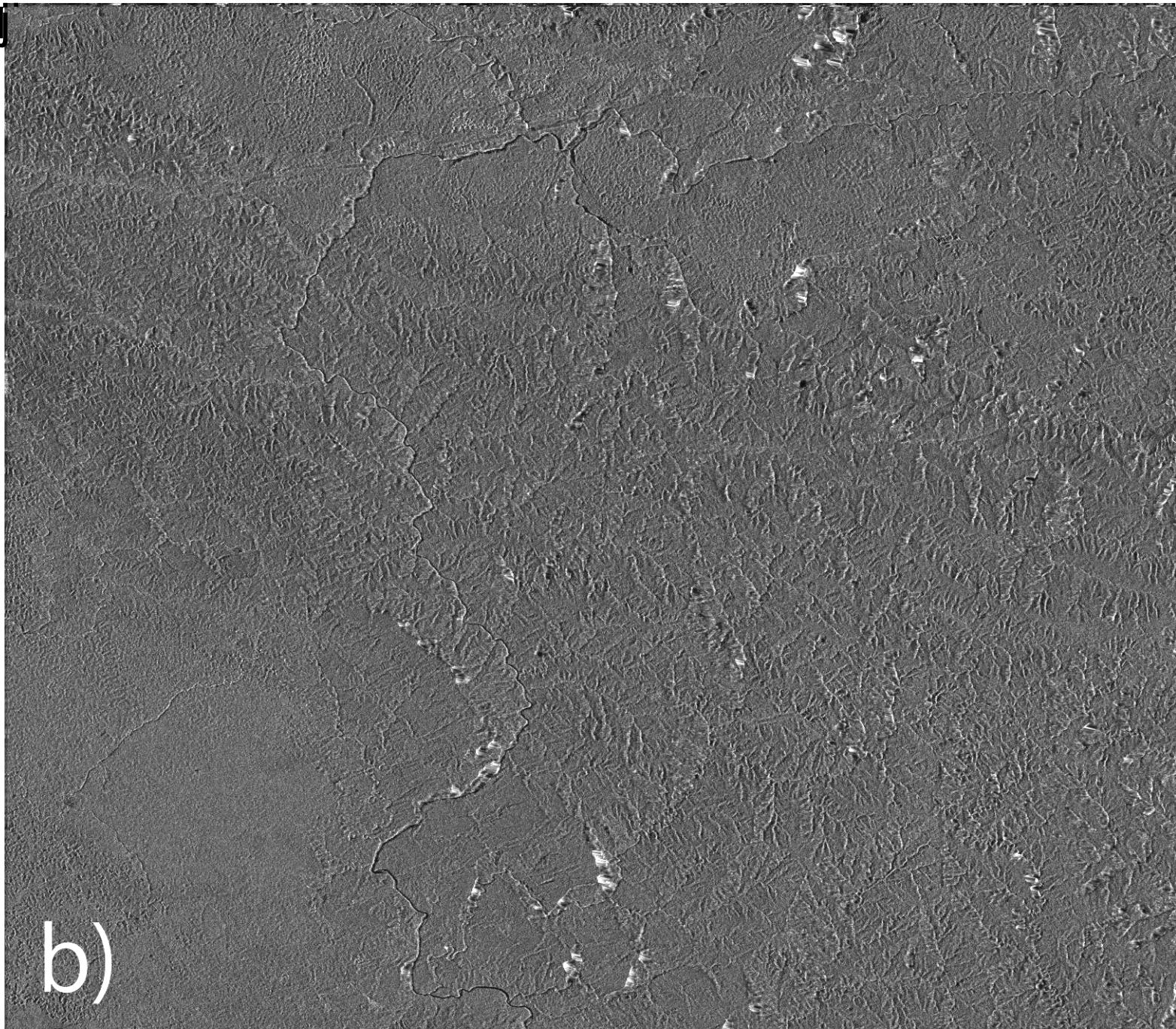


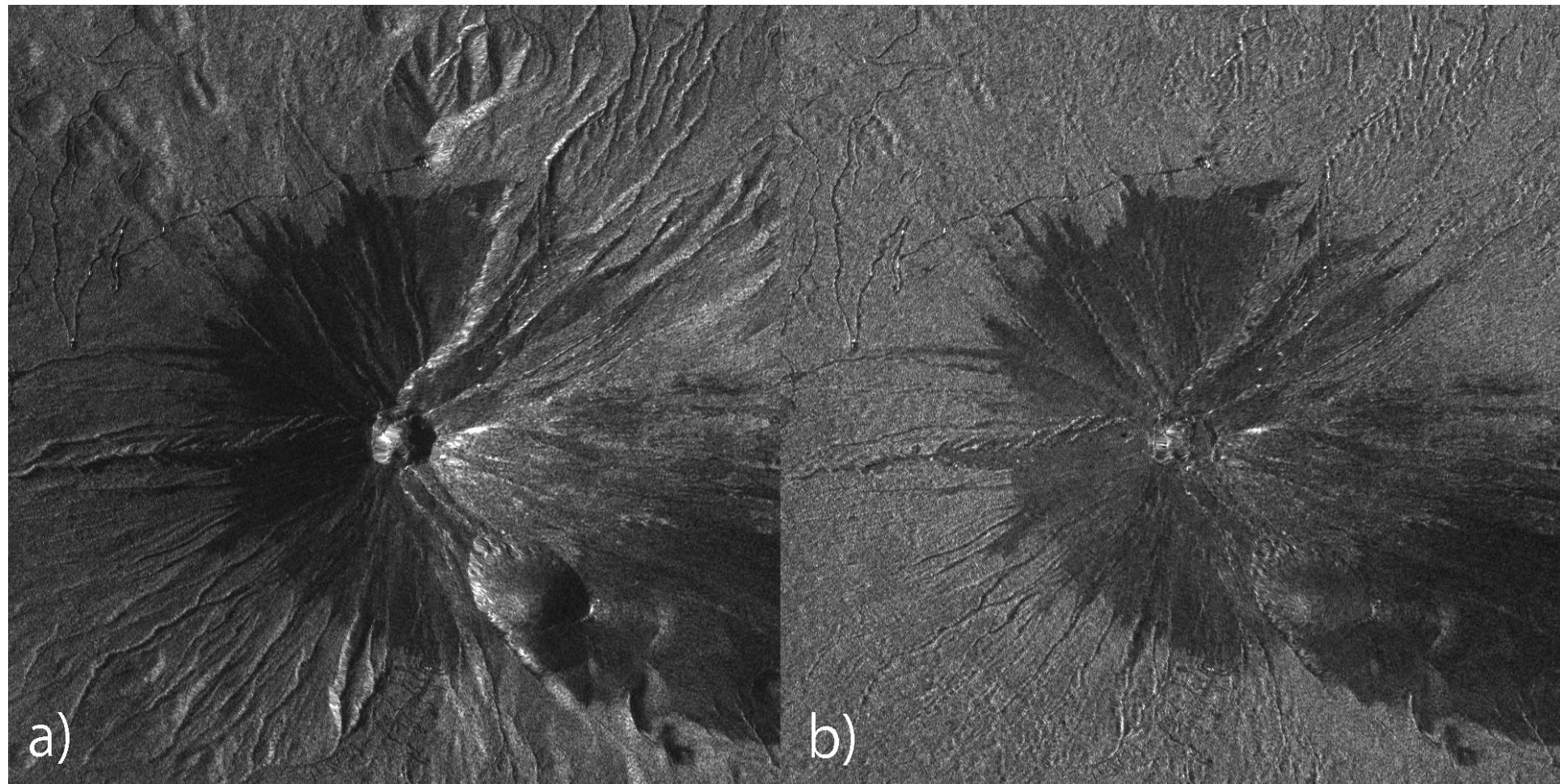


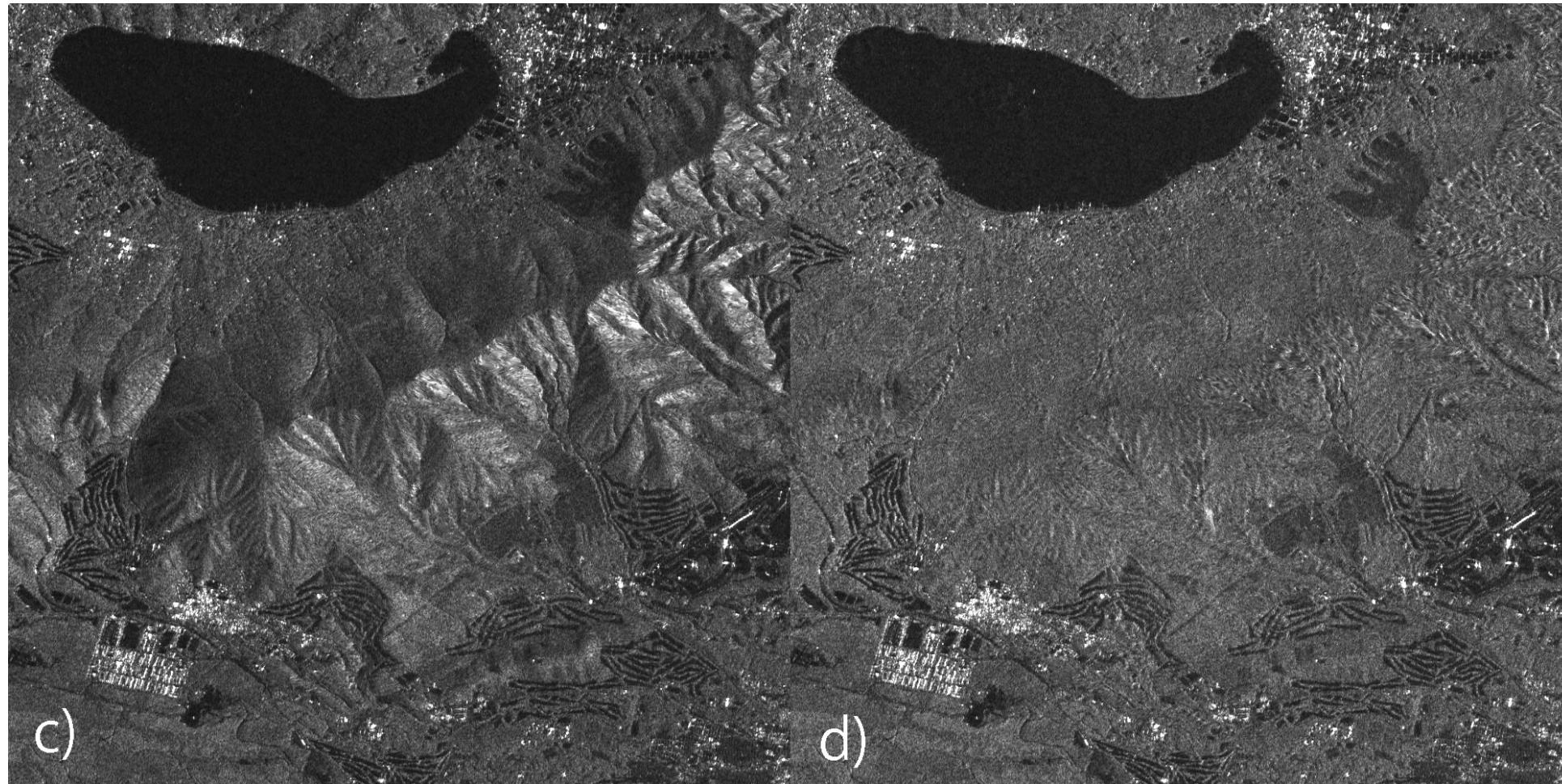
富士山

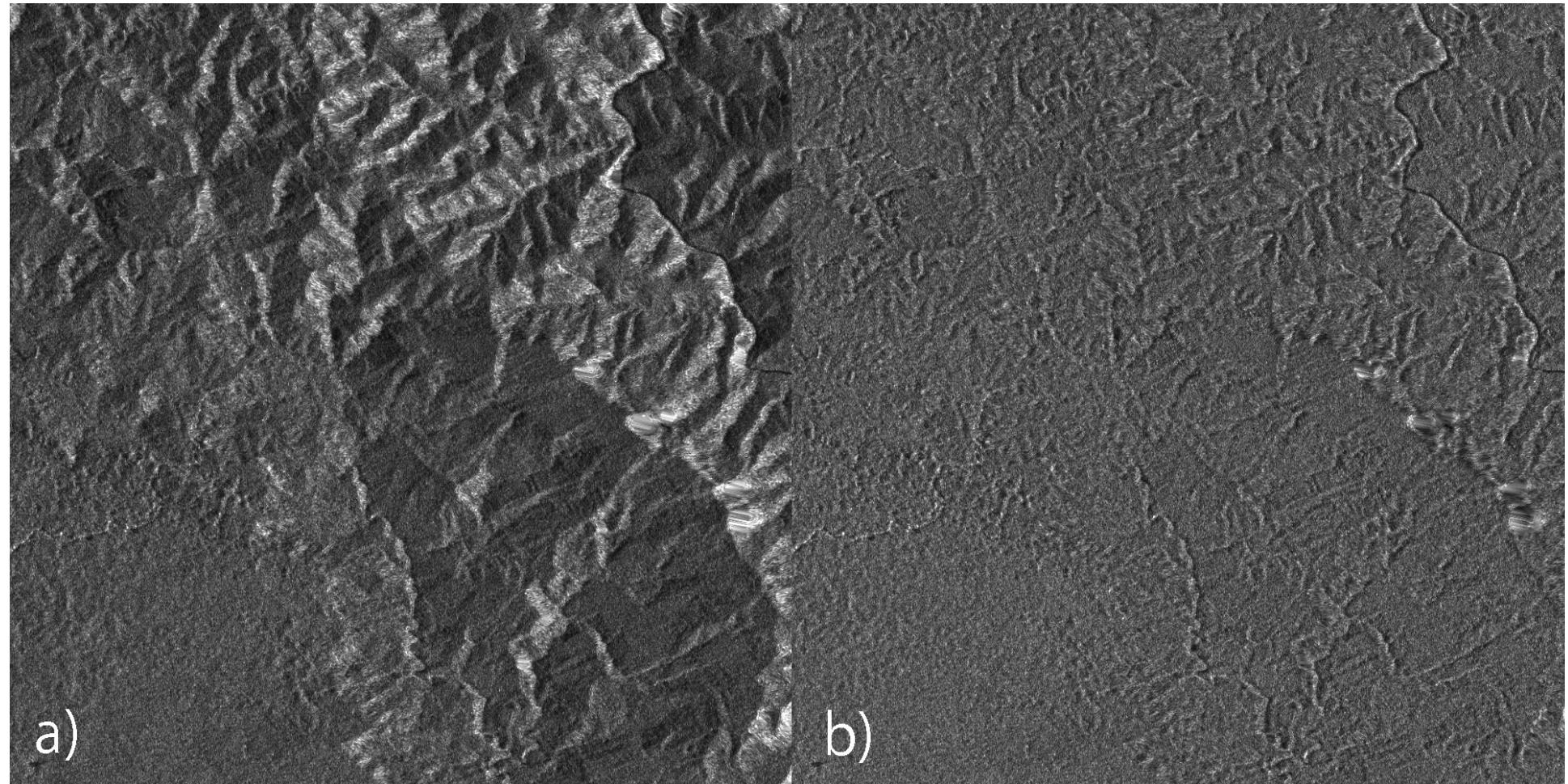
PNG

b)



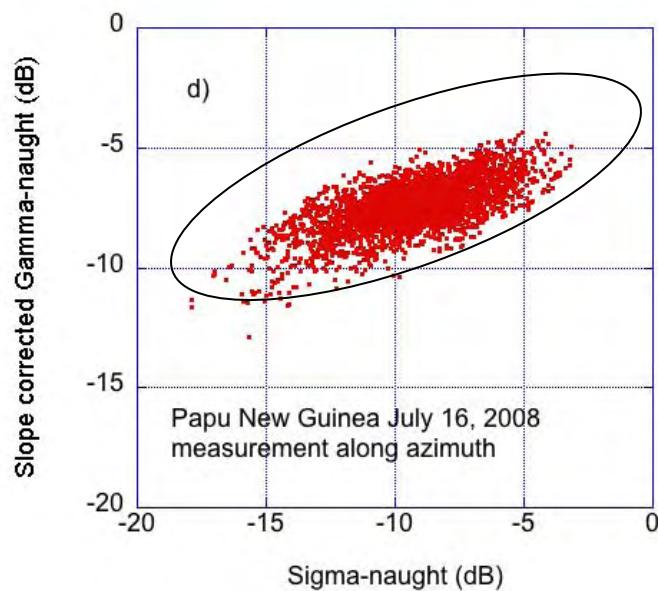
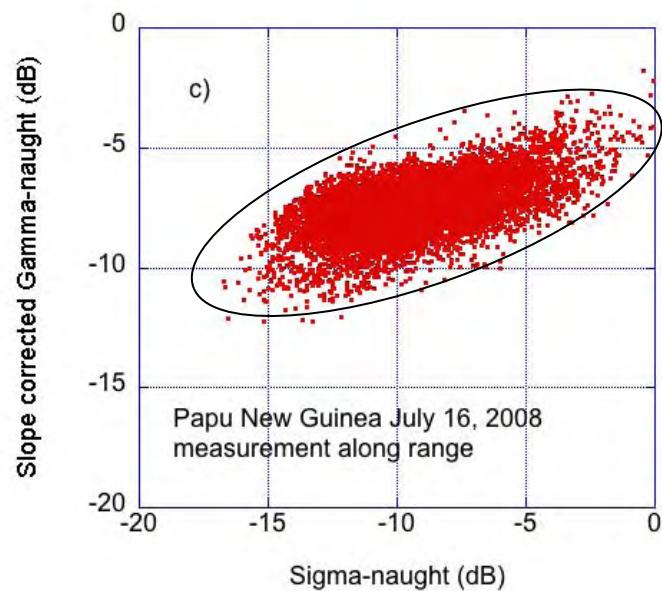
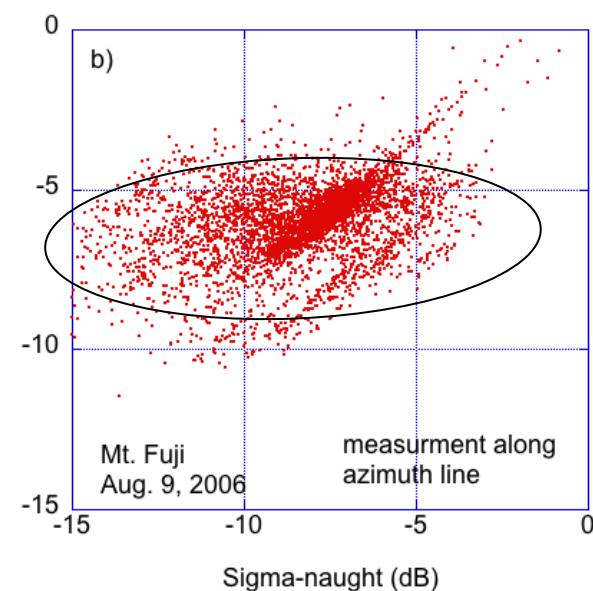
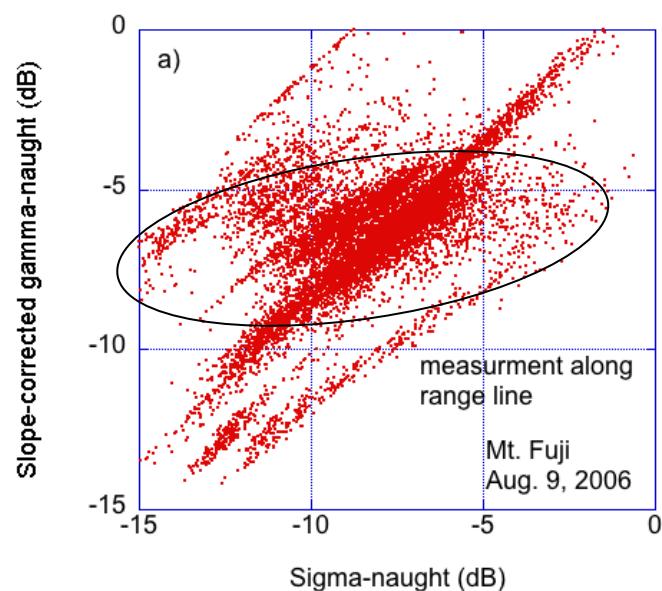






a)

b)



1st stage:Preprocessing:

- Selection of map projection
- Input ortho-rectified, slope corrected  $\gamma^0$
- Determine canvas limits for mosaicking
- Determine flight directions as average of all strips



2nd stage:Mosaicking

- Evaluate geometric accuracy over test areas
- Measure range dependency of  $\gamma^0$  and apply radiometric flattening
- Radiometrically balance neighbouring strips
- Generate georeferenced mosaic.



3rd stage:Geocoding

- Convert to selected map projection

# Mosaicking and SAR Strip Processing

Advantages:

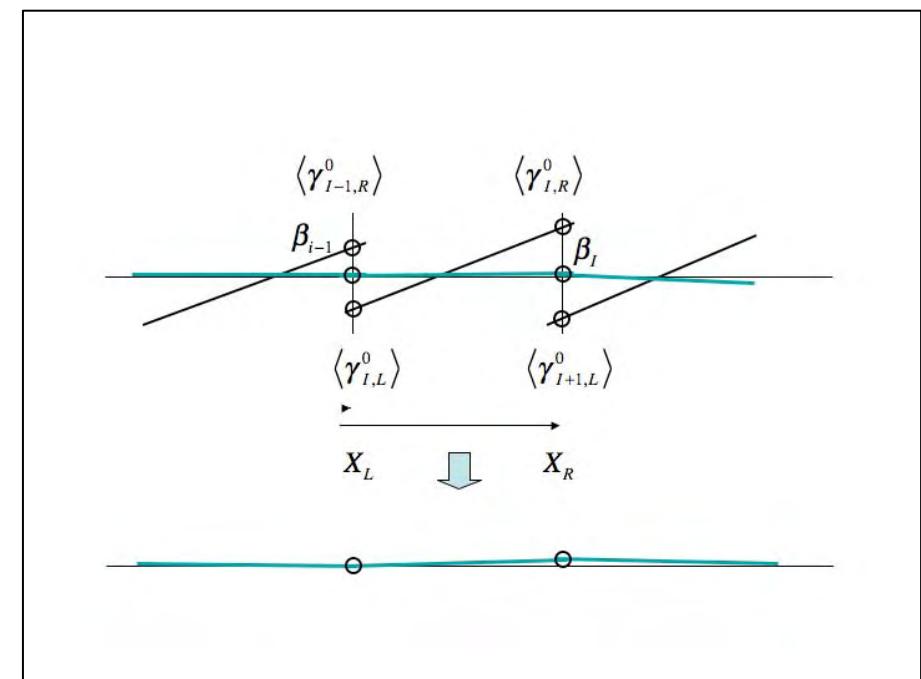
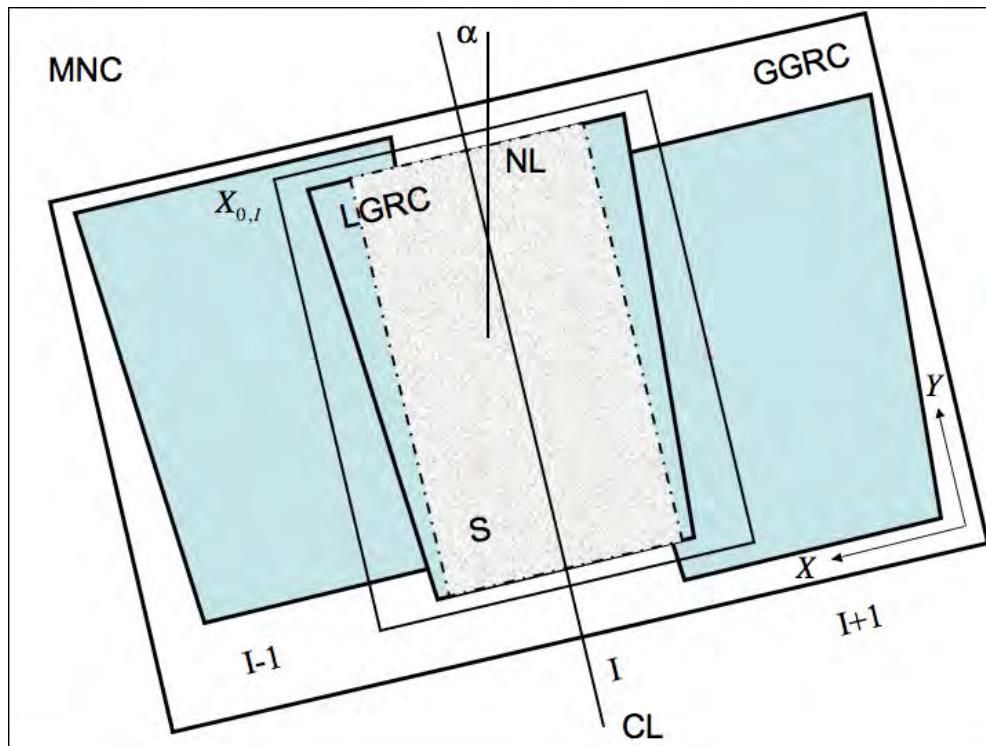
Global researches

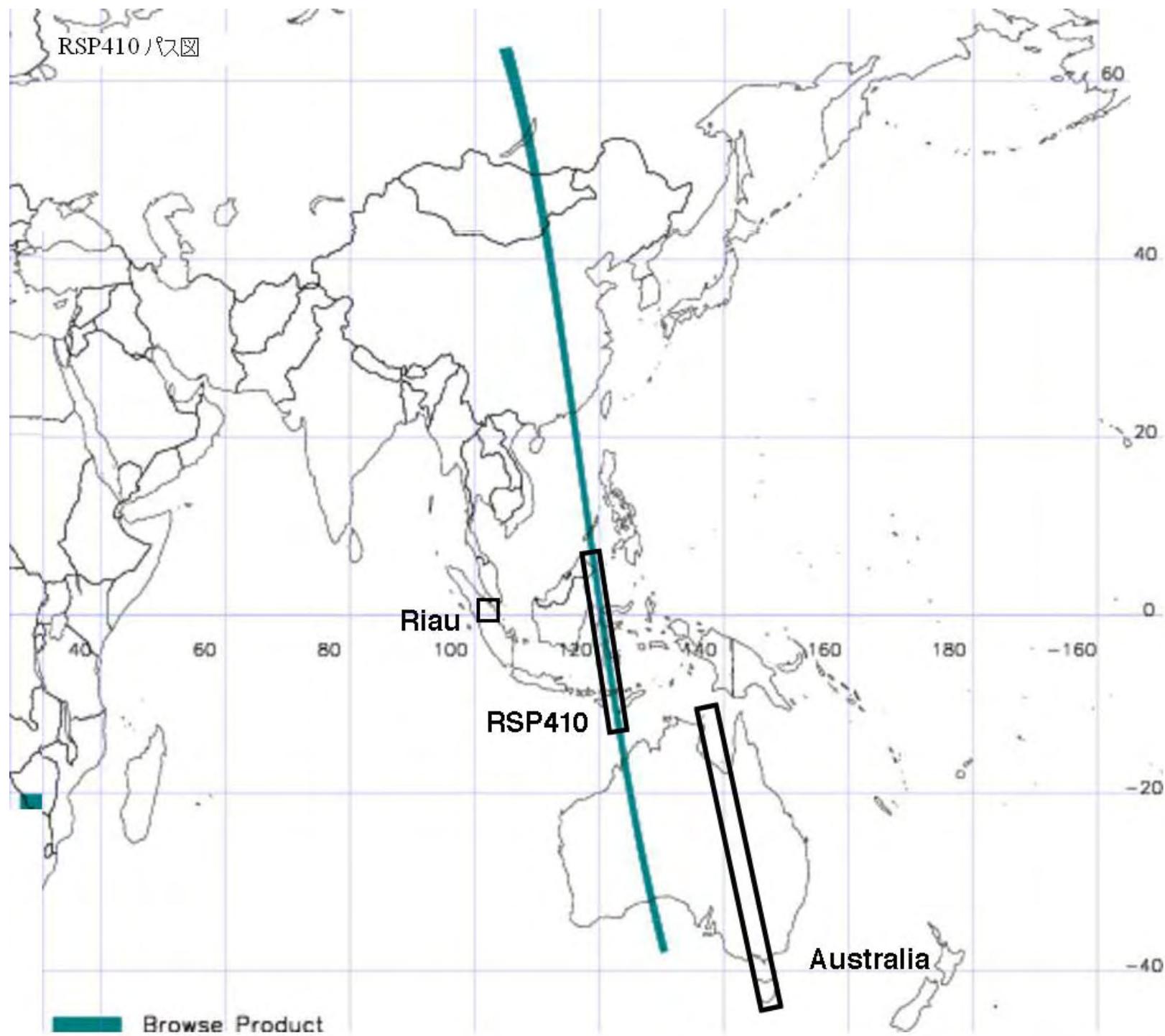
Temporal variation

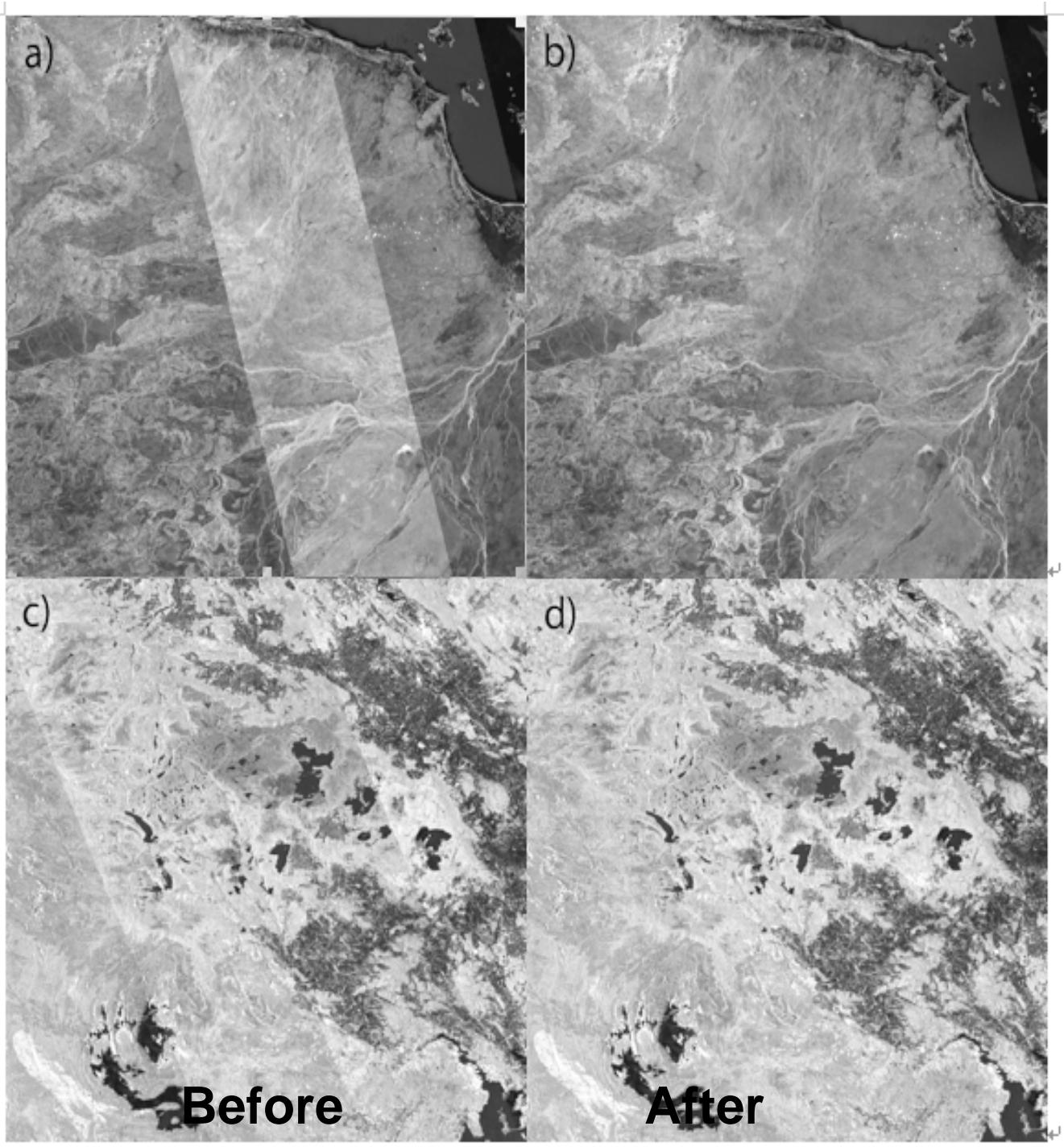
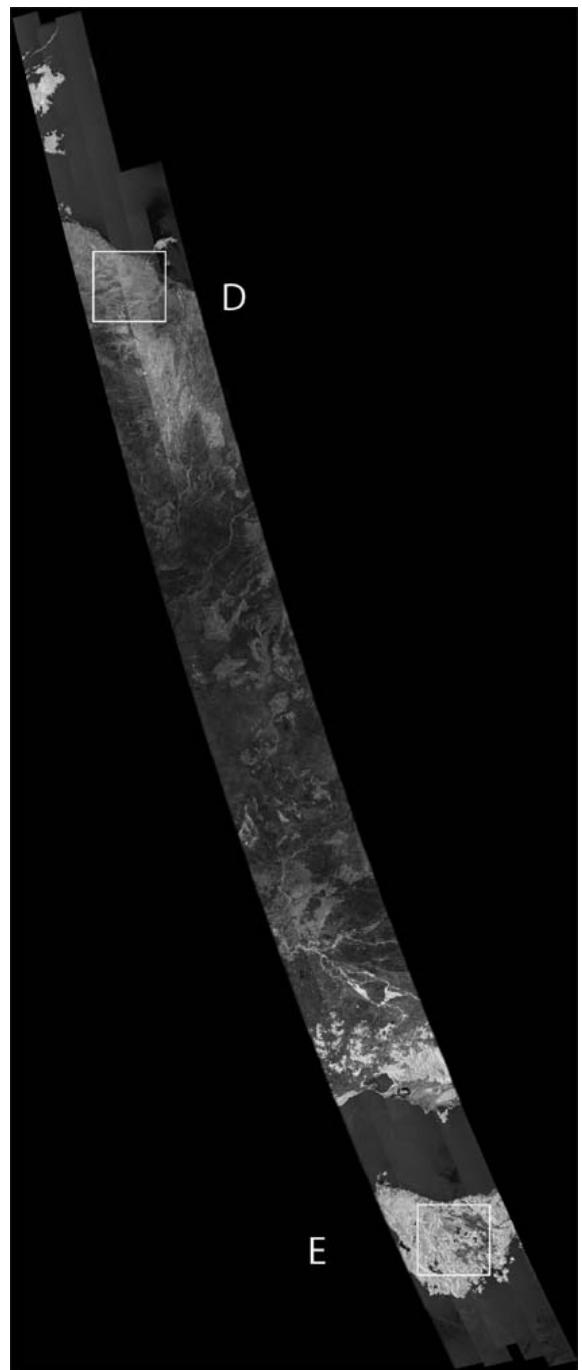
Reduce the number of images : 86400 -> 1000

Requirements

Geometric and radiometric collocations







# Geometric accuracies

Co-registration: 0.261,0.277

Accuracy: 34.14: Landsat-mosaic  
 Accuracy: 11.00:CR-mosaic

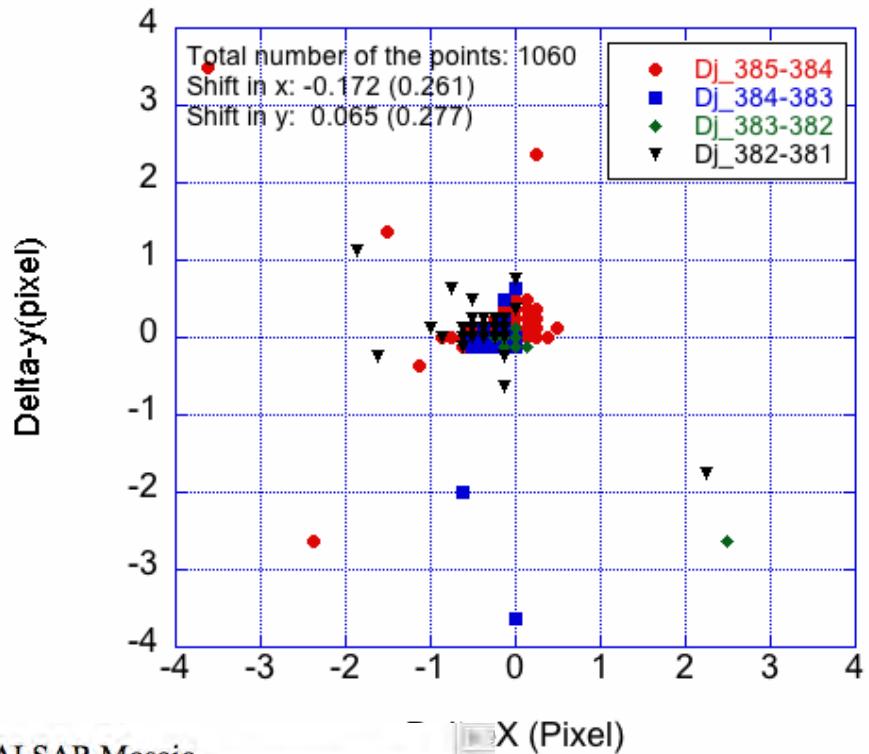
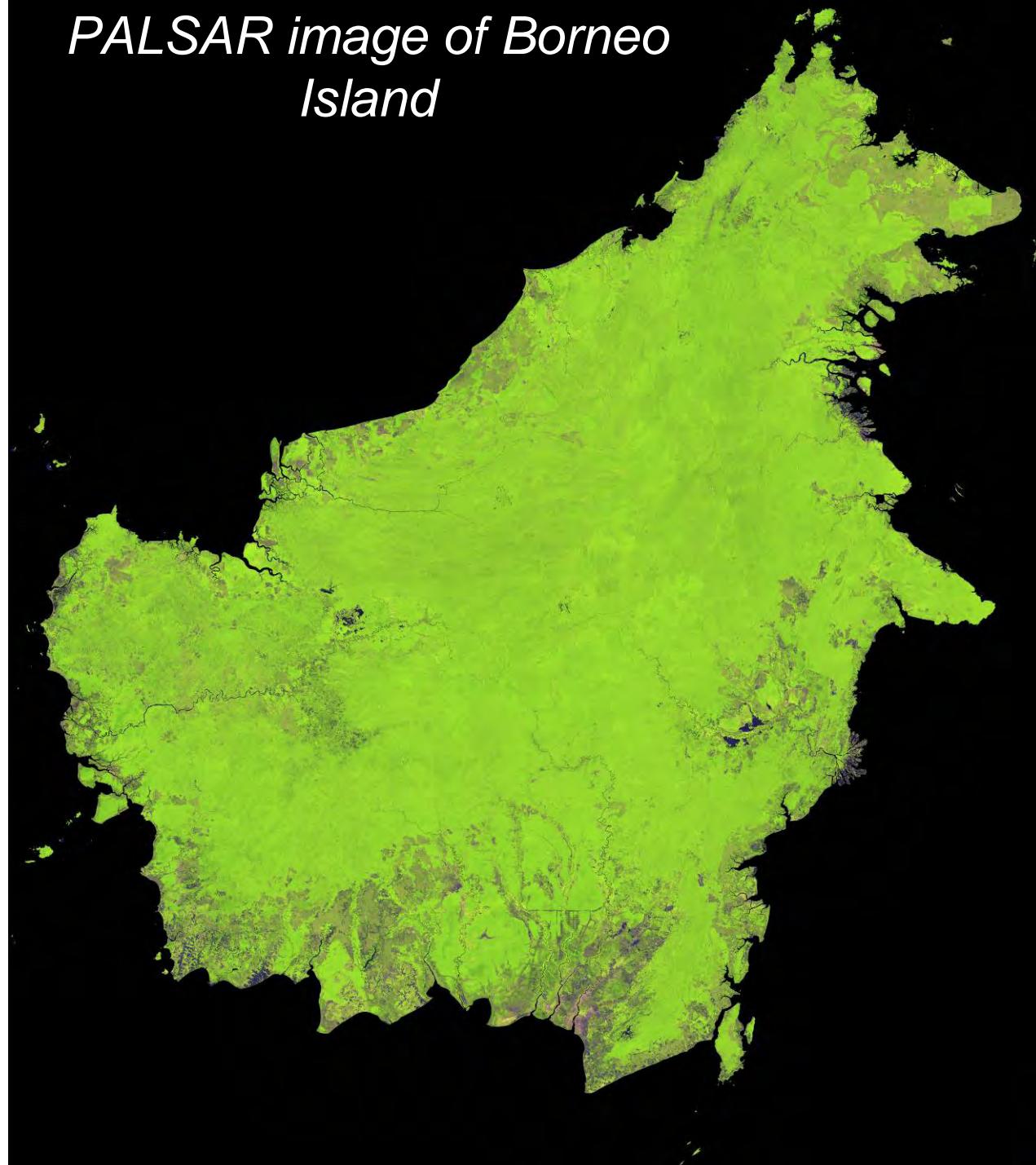


Table IV Summary of Geolocation RMSE of the JAXA PALSAR Mosaic<sup>a</sup>

Area <sup>a</sup>	Northing RMSE (m) <sup>a</sup>	Easting RMSE (m) <sup>a</sup>	Total RMSE (m) <sup>a</sup>	No. of GCPs <sup>a</sup>
Japan (2007) <sup>a</sup>	22.81(-112.9,43.8) <sup>a</sup>	34.20(-114.2,69.9) <sup>a</sup>	41.11(0.0,119.3) <sup>a</sup>	104 <sup>a</sup>
Borneo-Jawa (2007) <sup>a</sup>	23.13(-76.7,71.1) <sup>a</sup>	32.15(-94.5,49.4) <sup>a</sup>	39.61(0.0,98.0) <sup>a</sup>	104 <sup>a</sup>
Sumatra (2007) <sup>a</sup>	27.98(-96.9,65.8) <sup>a</sup>	30.03(-86.3,60.7) <sup>a</sup>	41.05(0.0,129.8) <sup>a</sup>	70 <sup>a</sup>
Philippine (2007) <sup>a</sup>	17.19(-35.67,35.66) <sup>a</sup>	16.86(-26.89,33.23) <sup>a</sup>	24.08(0.48,43.56) <sup>a</sup>	49 <sup>a</sup>
Philippine (2009) <sup>a</sup>	22.83(-54.90,74.90) <sup>a</sup>	29.34(-75.18,39.54) <sup>a</sup>	37.17(0.02,98.39) <sup>a</sup>	101 <sup>a</sup>
Borneo-Jawa (2009) <sup>a</sup>	24.79(-62.75,71.95) <sup>a</sup>	30.23(-79.32,26.33) <sup>a</sup>	39.09(0.0,85.42) <sup>a</sup>	83 <sup>a</sup>
Sumatra (2009) <sup>a</sup>	26.42(-50.9,67.1) <sup>a</sup>	32.99(-131.9,39.7) <sup>a</sup>	42.26(0.0,131.9) <sup>a</sup>	83 <sup>a</sup>
Japan (2009) <sup>a</sup>	26.46(-55.8,52.3) <sup>a</sup>	33.26(-90.0,61.3) <sup>a</sup>	42.50(0.0,99.8) <sup>a</sup>	69 <sup>a</sup>
Indochina (2009) <sup>a</sup>	27.96(-52.5,72.9) <sup>a</sup>	30.60(-92.8,75.5) <sup>a</sup>	41.45(0.0,118.0) <sup>a</sup>	89 <sup>a</sup>
Central Africa (2008) <sup>a</sup>	24.30(-46.7,47.4) <sup>a</sup>	21.16(-48.2,42.3) <sup>a</sup>	32.22(2.9,63.0) <sup>a</sup>	131 <sup>a</sup>
Central Africa (2009) <sup>a</sup>	16.52(-35.17,30.81) <sup>a</sup>	16.20(-39.16,35.88) <sup>a</sup>	23.14(2.73,44.36) <sup>a</sup>	147 <sup>a</sup>
Sulawesi (2007) <sup>a</sup>	17.01(-35.14,31.79) <sup>a</sup>	15.44(-30.68,37.59) <sup>a</sup>	22.98(2.30,43.27) <sup>a</sup>	68 <sup>a</sup>
Sulawesi (2009) <sup>a</sup>	15.38(-33.76,33.74) <sup>a</sup>	16.21(-41.20,34.76) <sup>a</sup>	22.35(0.85,45.16) <sup>a</sup>	67 <sup>a</sup>
Australia (2009) <sup>a</sup>	19.66(-44.41,30.90) <sup>a</sup>	18.91(-41.28,48.26) <sup>a</sup>	27.28(2.35,58.44) <sup>a</sup>	218 <sup>a</sup>
All <sup>a</sup>	22.35 <sup>a</sup>	25.81 <sup>a</sup>	34.14 <sup>a</sup>	1393 <sup>a</sup>

Note: The numbers in brackets represent the minimum and maximum values respectively.<sup>a</sup>

# *PALSAR image of Borneo Island*



*PALSAR mosaic images*

*Observation date: 2009/06/12 ~ 2009/8/19*

*Observation Path: 29*

*Mode: HH, HV*

*Resolution: 10m*

*Processor: SIGMA-SAR*

*Ver. 10022201*

*Slope Correction: On*

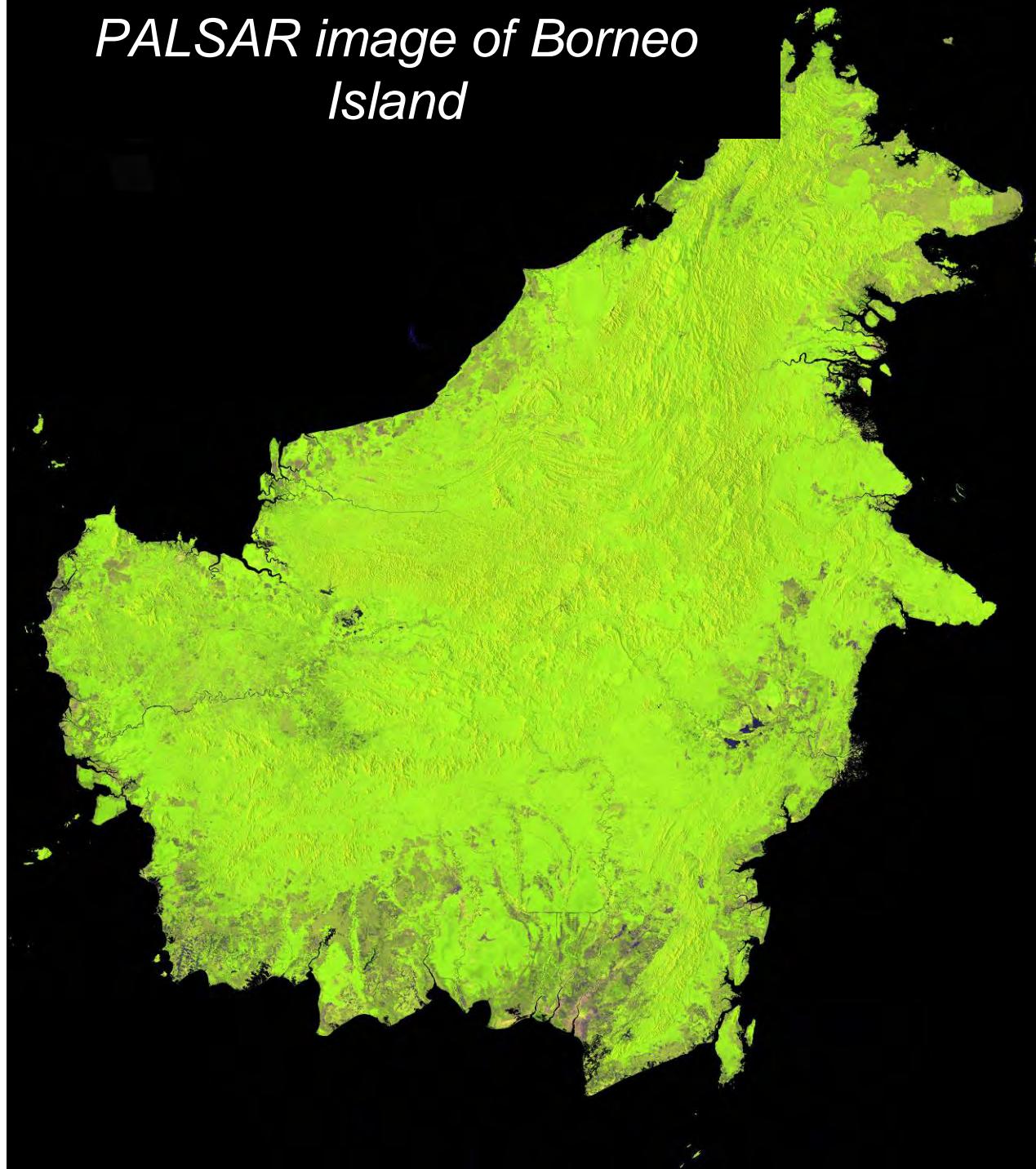
*Spacing: 10m*

*Resampling: Bi-linear*

*DEM: SRTM-3*

*Projection: Geographic Lat/Lon*

# *PALSAR image of Borneo Island*



*PALSAR mosaic images*

*Observation date : 2009/06/12 ~ 2009/8/19*

*Observation Path : 29*

*Mode : HH, HV*

*Resolution : 50m*

*Processor: SIGMA-SAR*

*Ver.09110501*

*Slope Correction: Off*

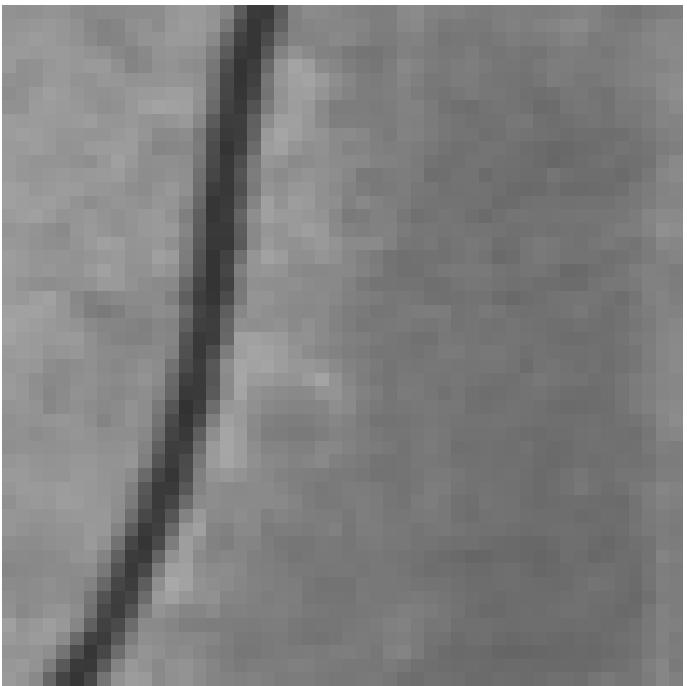
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*Resampling: Bi-linear*

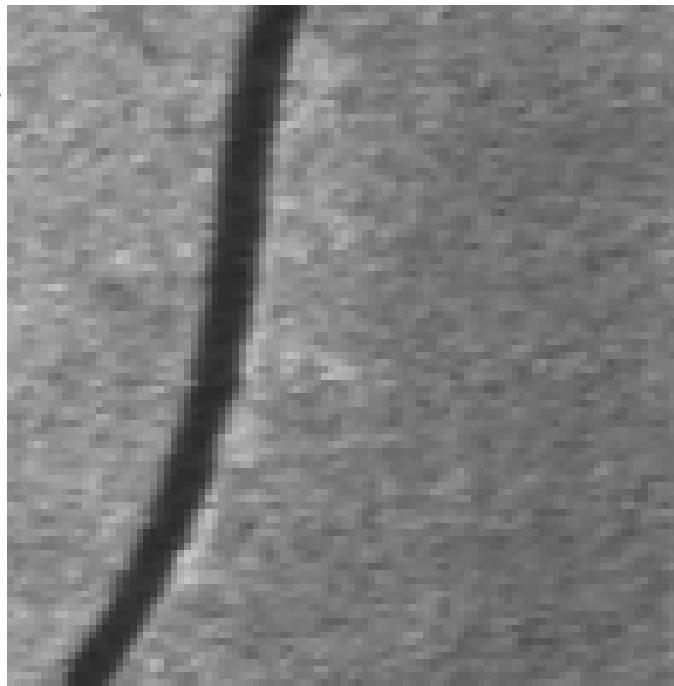
*DEM: SRTM-3*

*Projection: Geographic Lat/Lon*

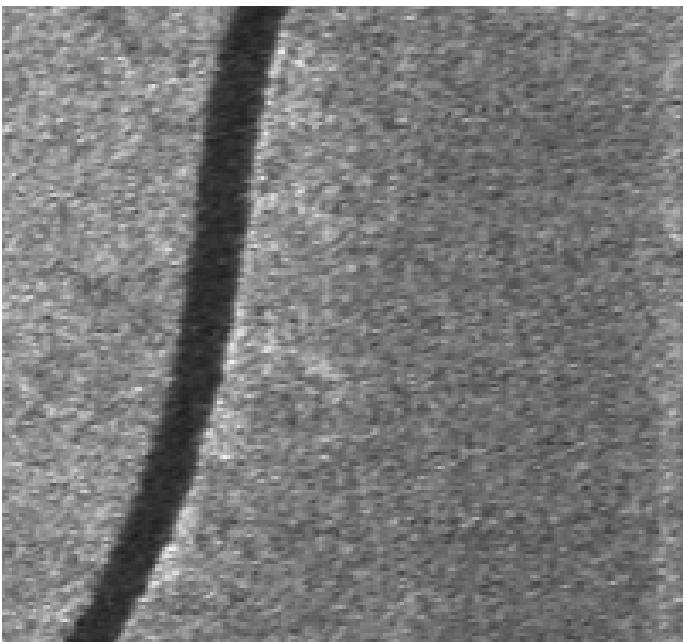
50m  
解像度



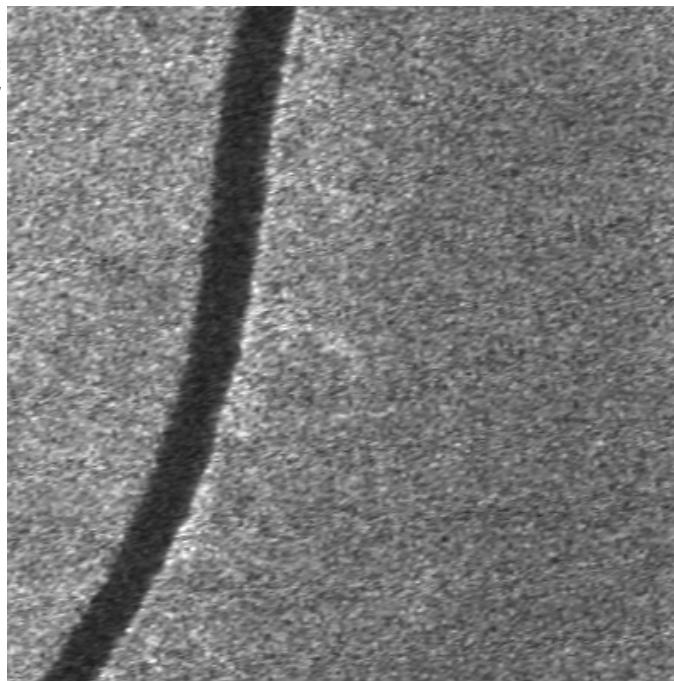
25m  
解像度



12.5m  
解像度



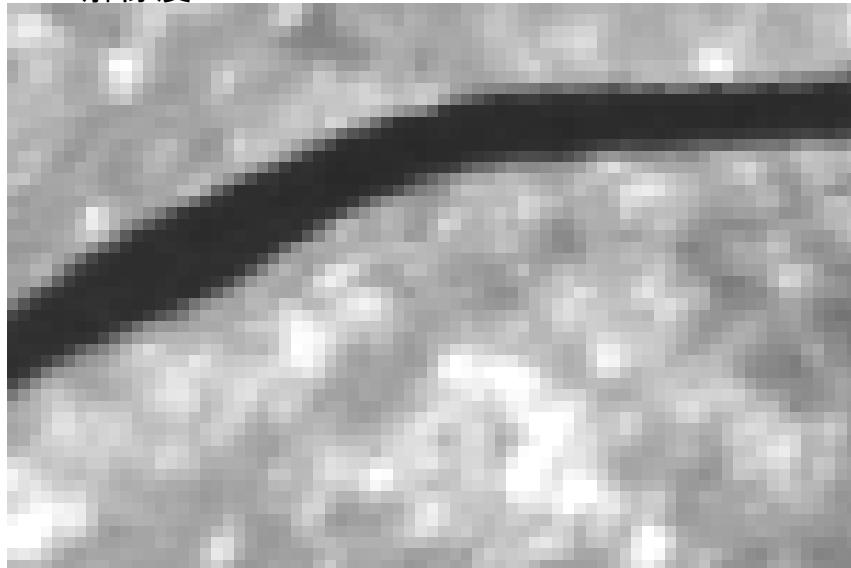
6.25m  
解像度



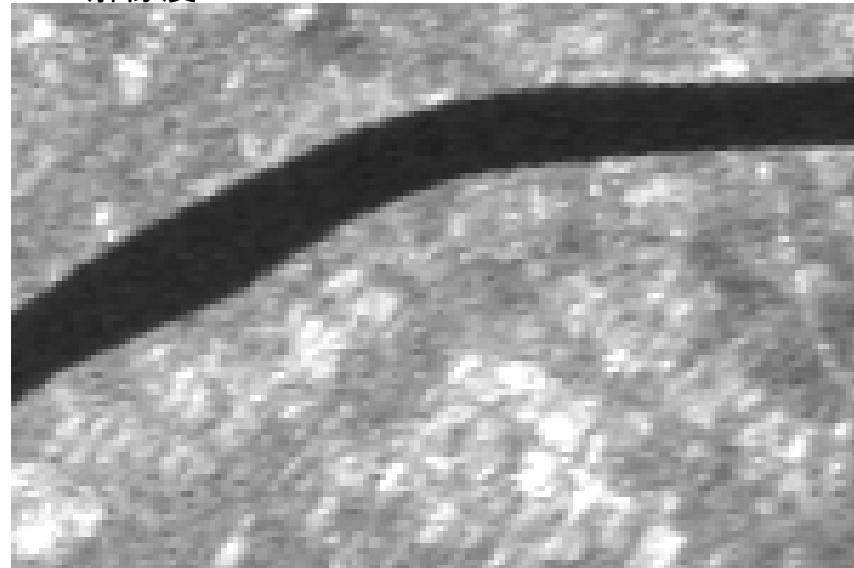
Comparison of resolutions

※画像は2.5km四方

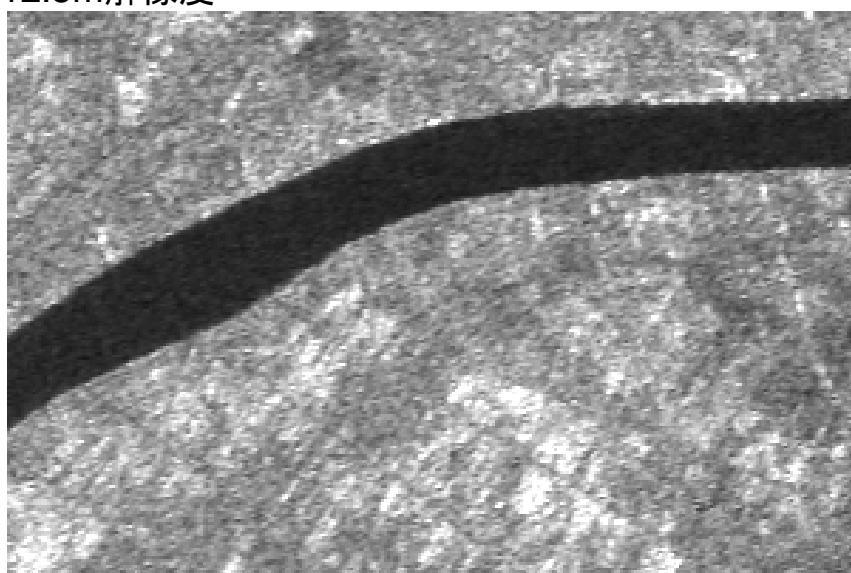
50m解像度



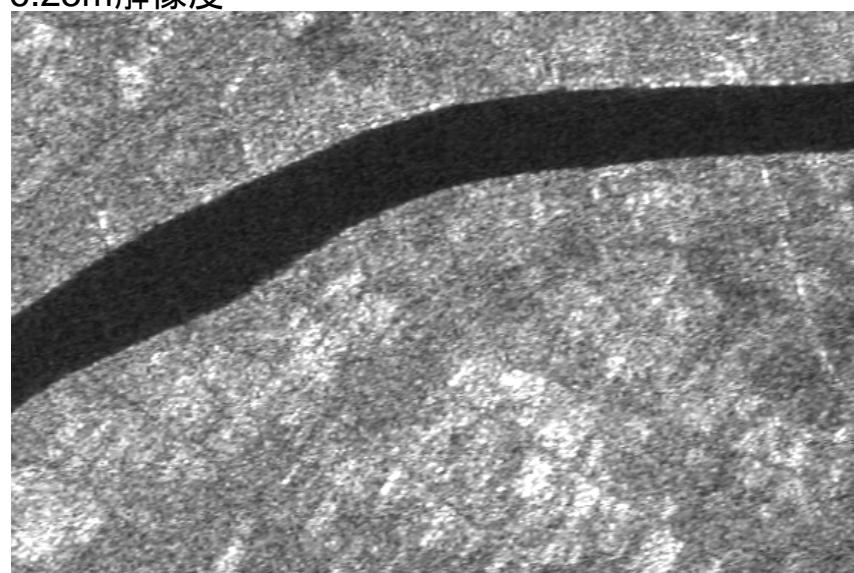
25m解像度



12.5m解像度



6.25m解像度



Comparison of resolutions

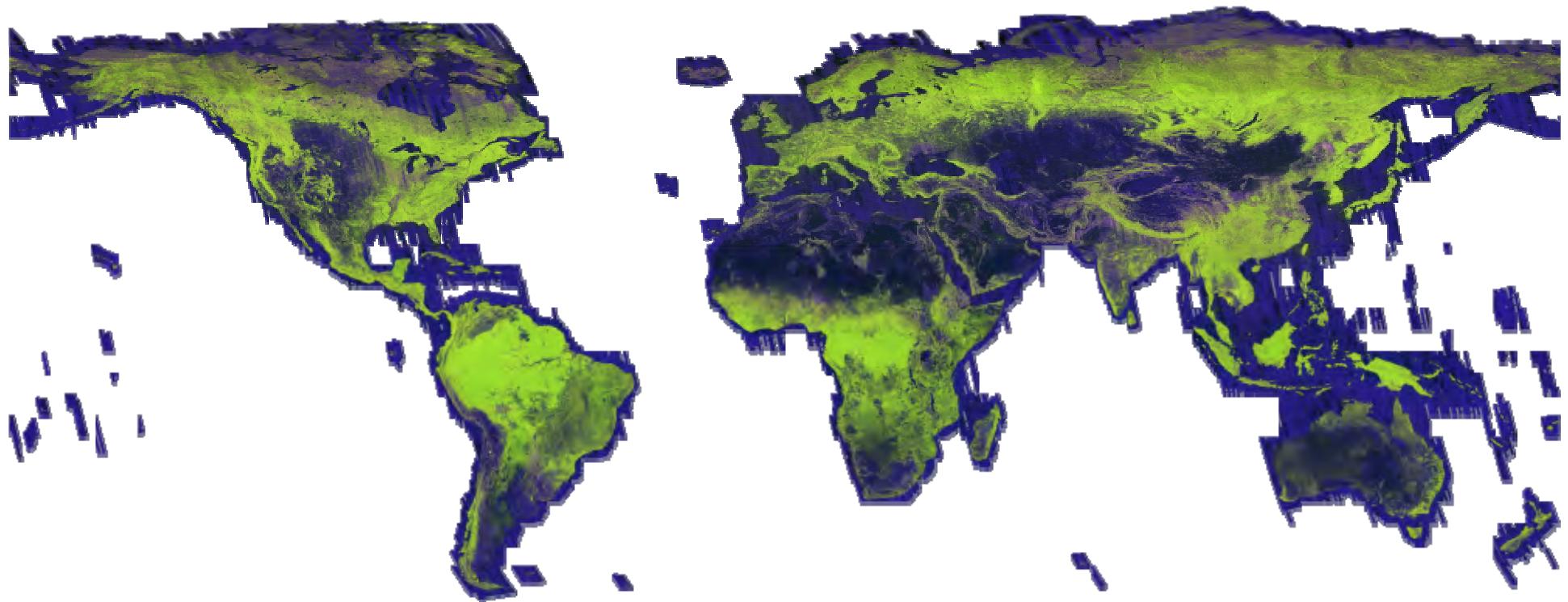
High resolution is necessary

※画像は2.5km × 3.75km四方

## References

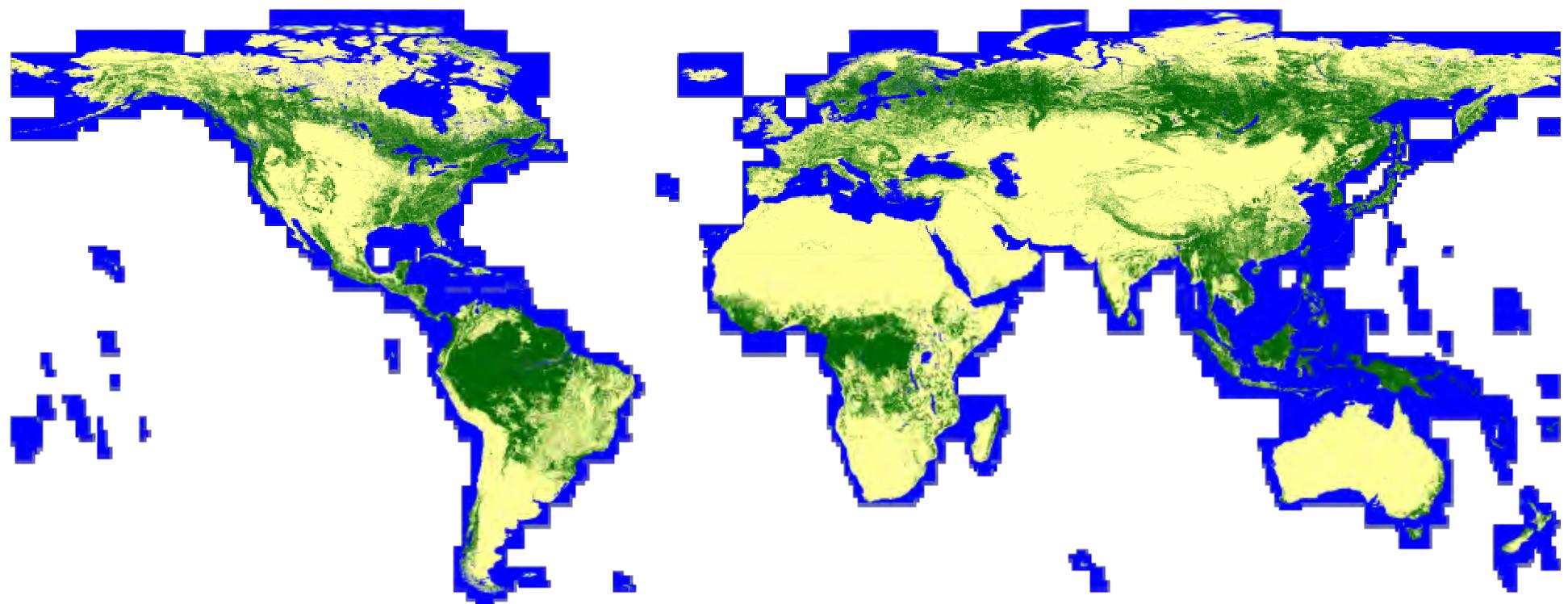
- (1)Shimada M. Ortho-rectification and Slope Correction of SAR Data Using DEM and Its Accuracy Evaluation. *IEEE JSTAR special issue on Kyoto and Carbon Initiative, 2010;3(4): (in press)*.
- (2)Shimada M and Otaki T. Generating Continent-scale High-quality SAR Mosaic Datasets: Application to PALSAR Data for Global Monitoring. *IEEE JSTARS special issue on Kyoto and Carbon Initiative, 2010;3(4):in press*.
- (3)Shimada M, Tadono T and Rosenqvist A. Advanced Land Observing Satellite (ALOS) and Monitoring Global Environmental Change. *Proceedings of the IEEE, 2010;98(5):780-799*.
- (4)Shimada M, Isoguchi O, Tadono T and Isono K. PALSAR Radiometric and Geometric Calibration. *IEEE Trans. GRS,2009; 47(12):3915-3932*.
- (5)Shimada M. Long-term stability of L-band normalized radar cross section of Amazon rainforest using the JERS-1 SAR. *Can. J. Remote Sensing, 2005;31(1):132-137*.
- (6)Shimada M and Isoguchi O. JERS-1 SAR mosaics of Southeast Asia Using calibrated path images. *International Journal of remote sensing, 2002;23(7):1507-1526*.

# PALSAR 10m Global Orthorectified Mosaic 2009



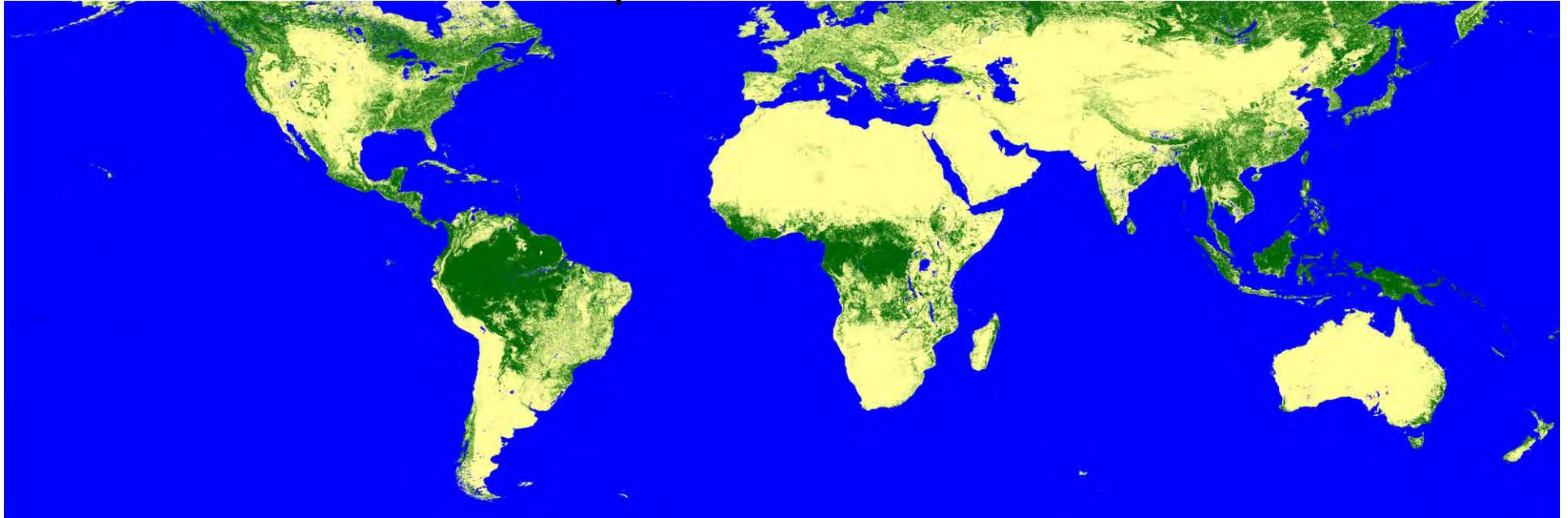
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# PALSAR 10m Global Forest/Non-Forest Map 2009

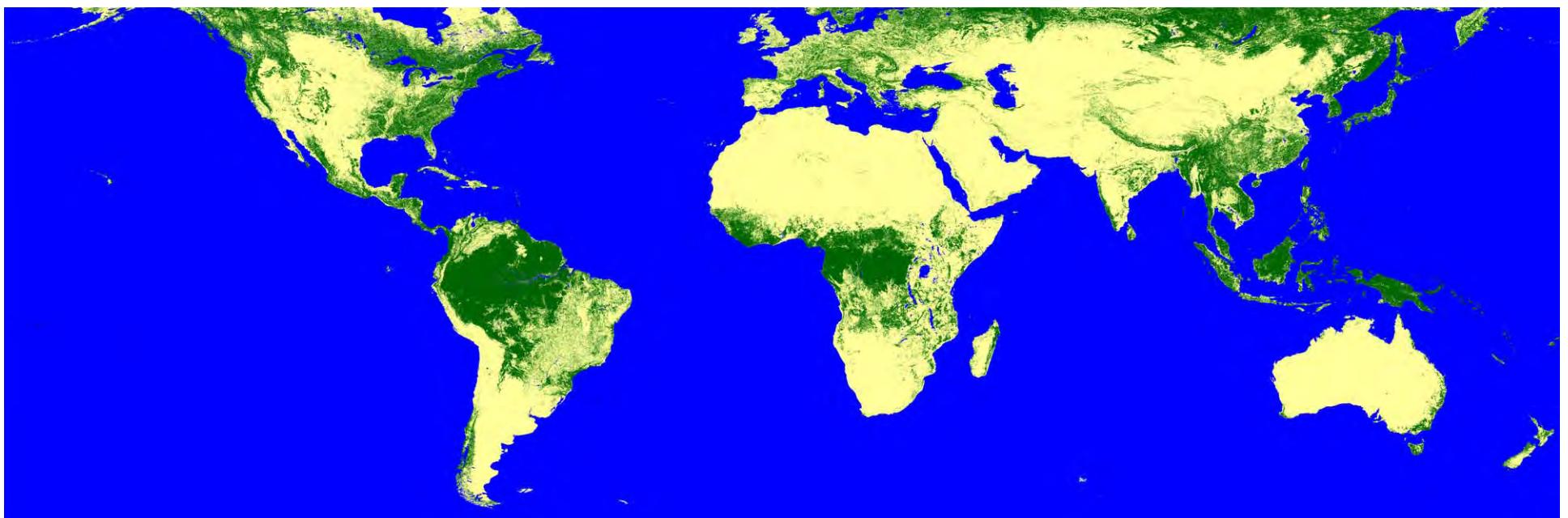


©JAXA,METI analyzed y JAXA

2007 forest/non-forest map

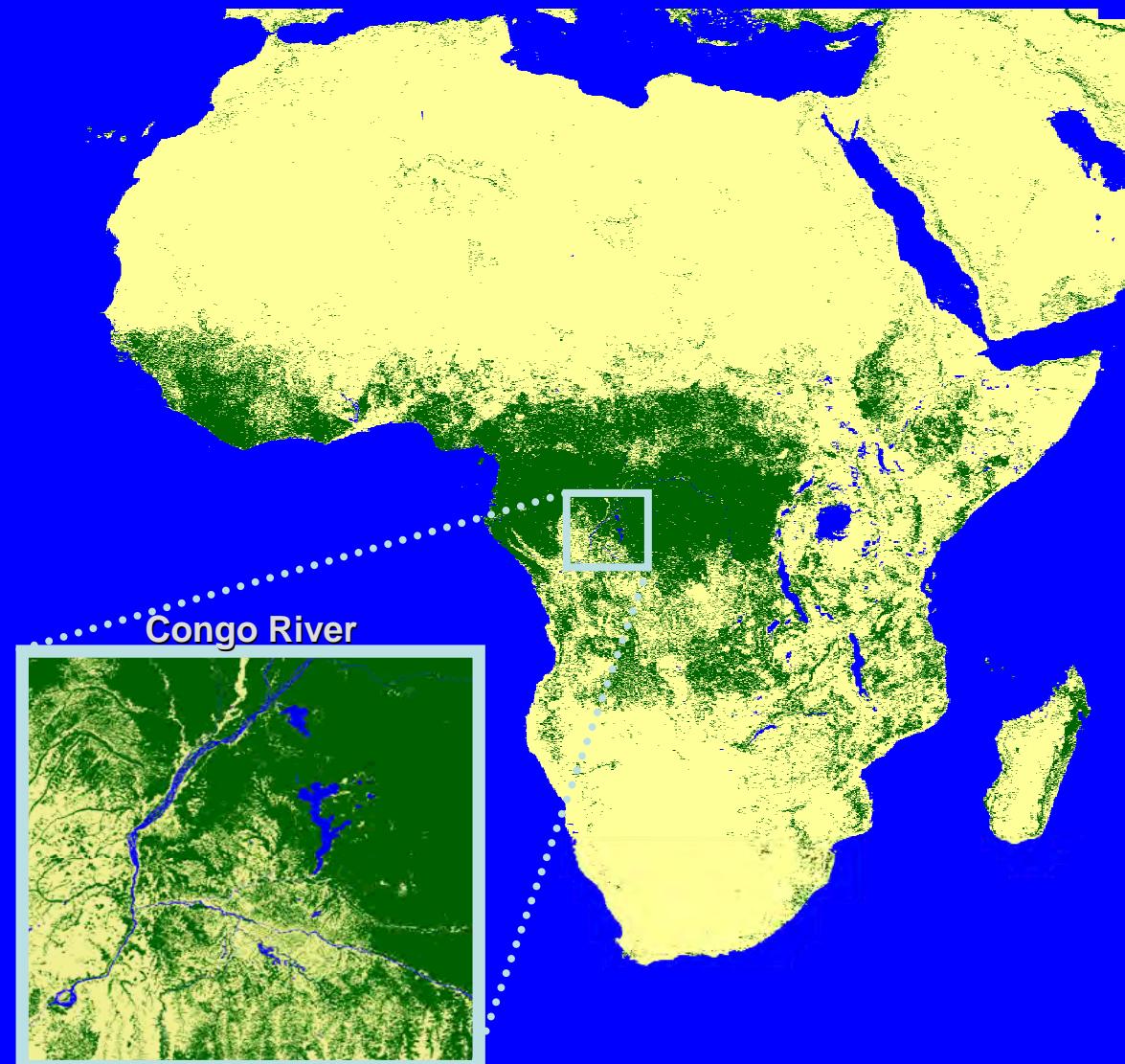


2009 forest/non-forest map



# PALSAR 10m Global Forest Map 2009

## Africa



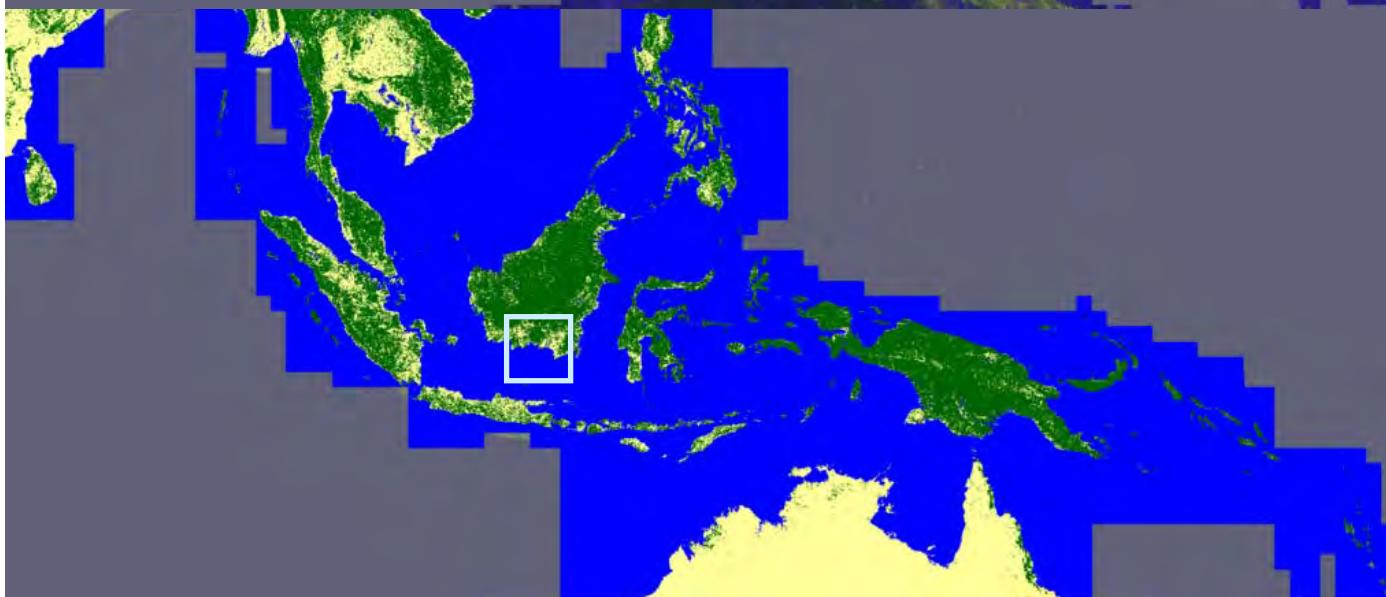
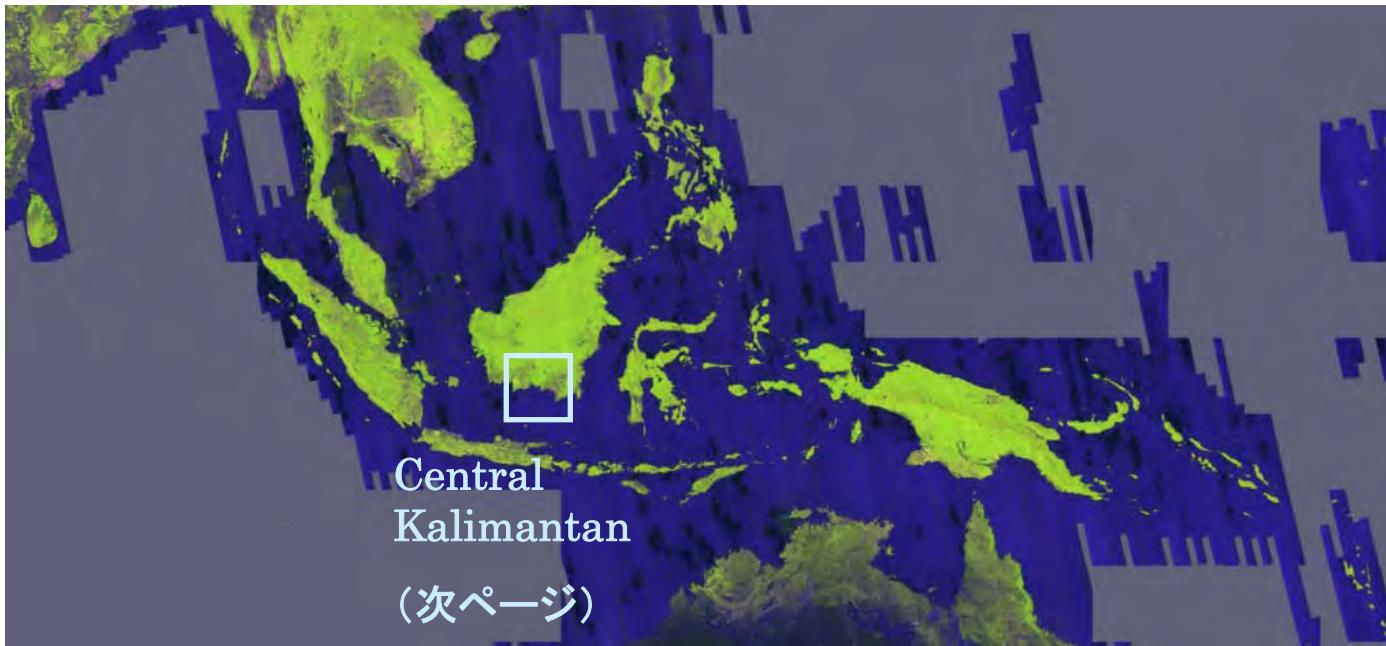
© JAXA, METI analyzed by JAXA

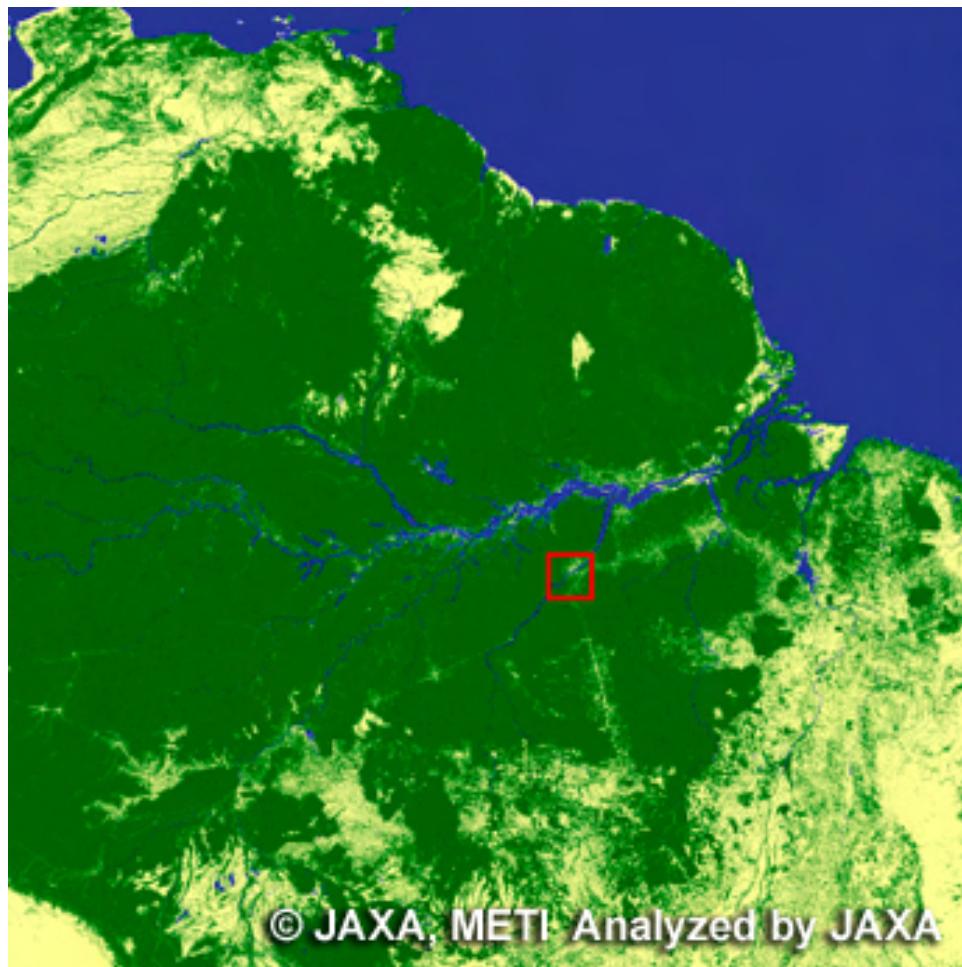
# PALSAR 10m Global Forest/Non-forest Map 2009 South America



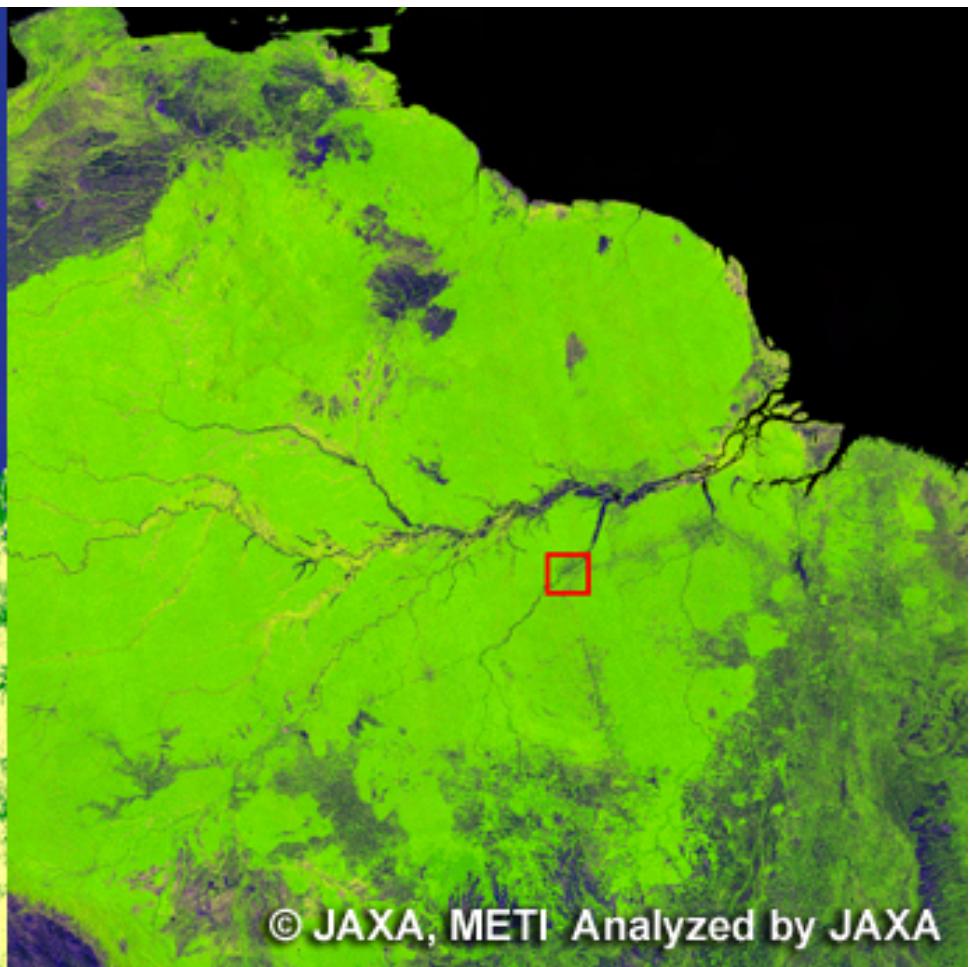
© JAXA, METI analyzed by JAXA

# South East Asia

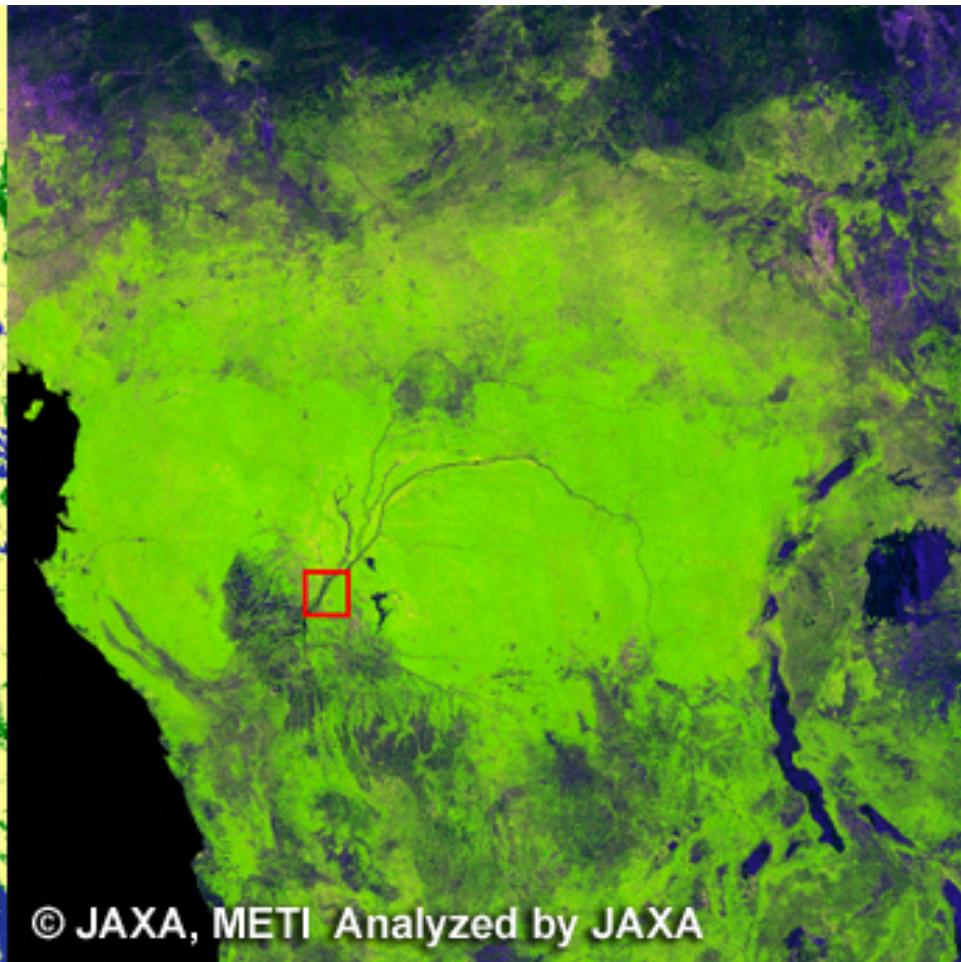
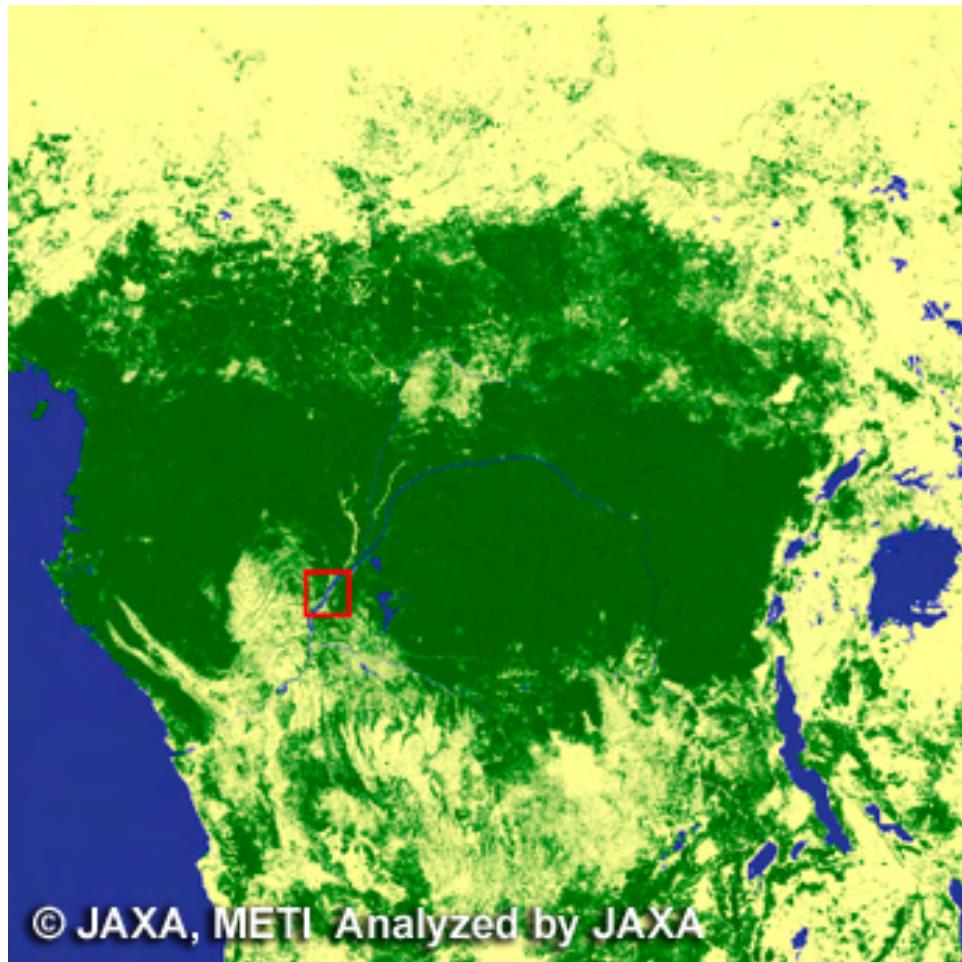


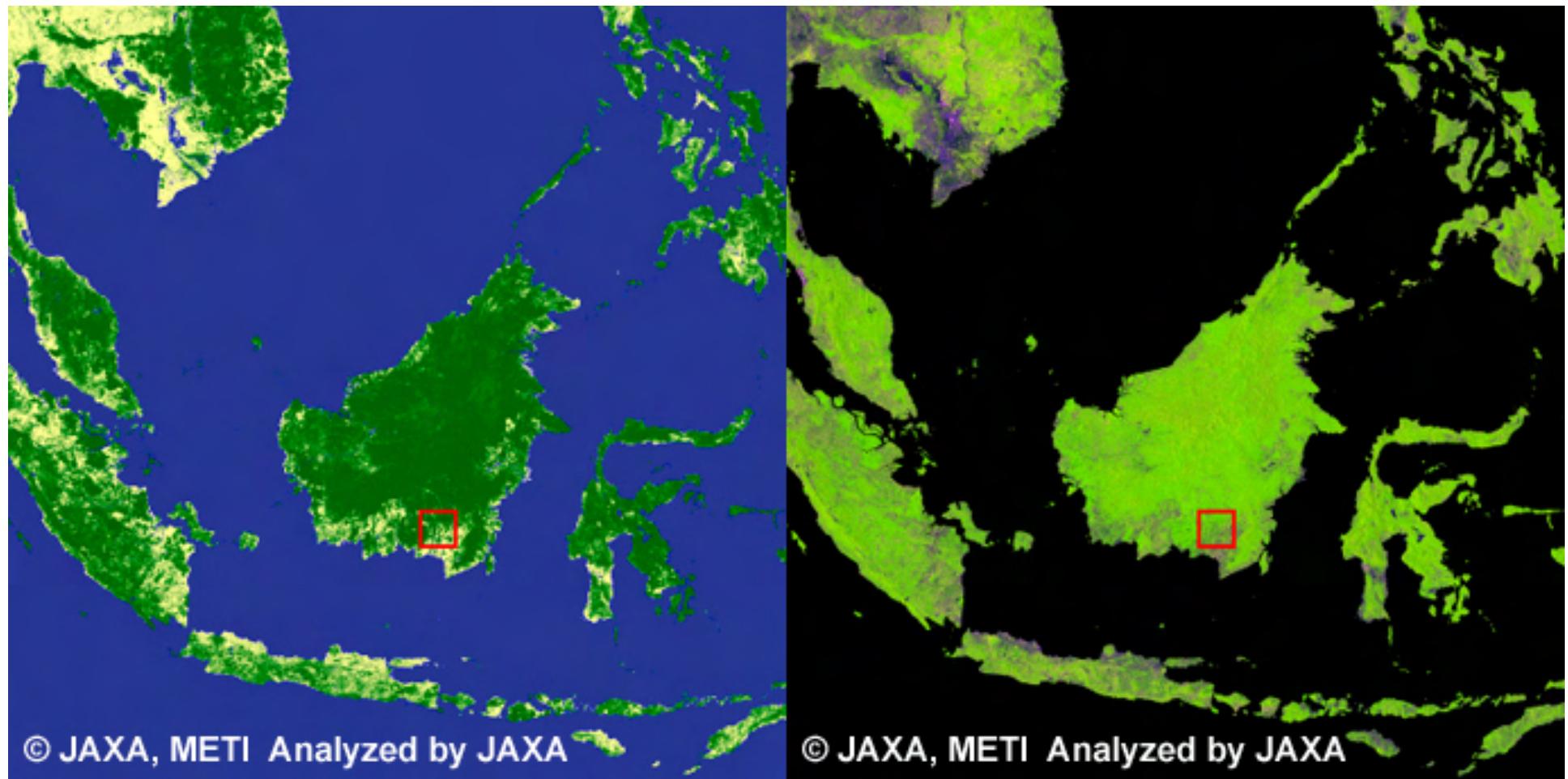


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© JAXA, METI Analyzed by JAXA

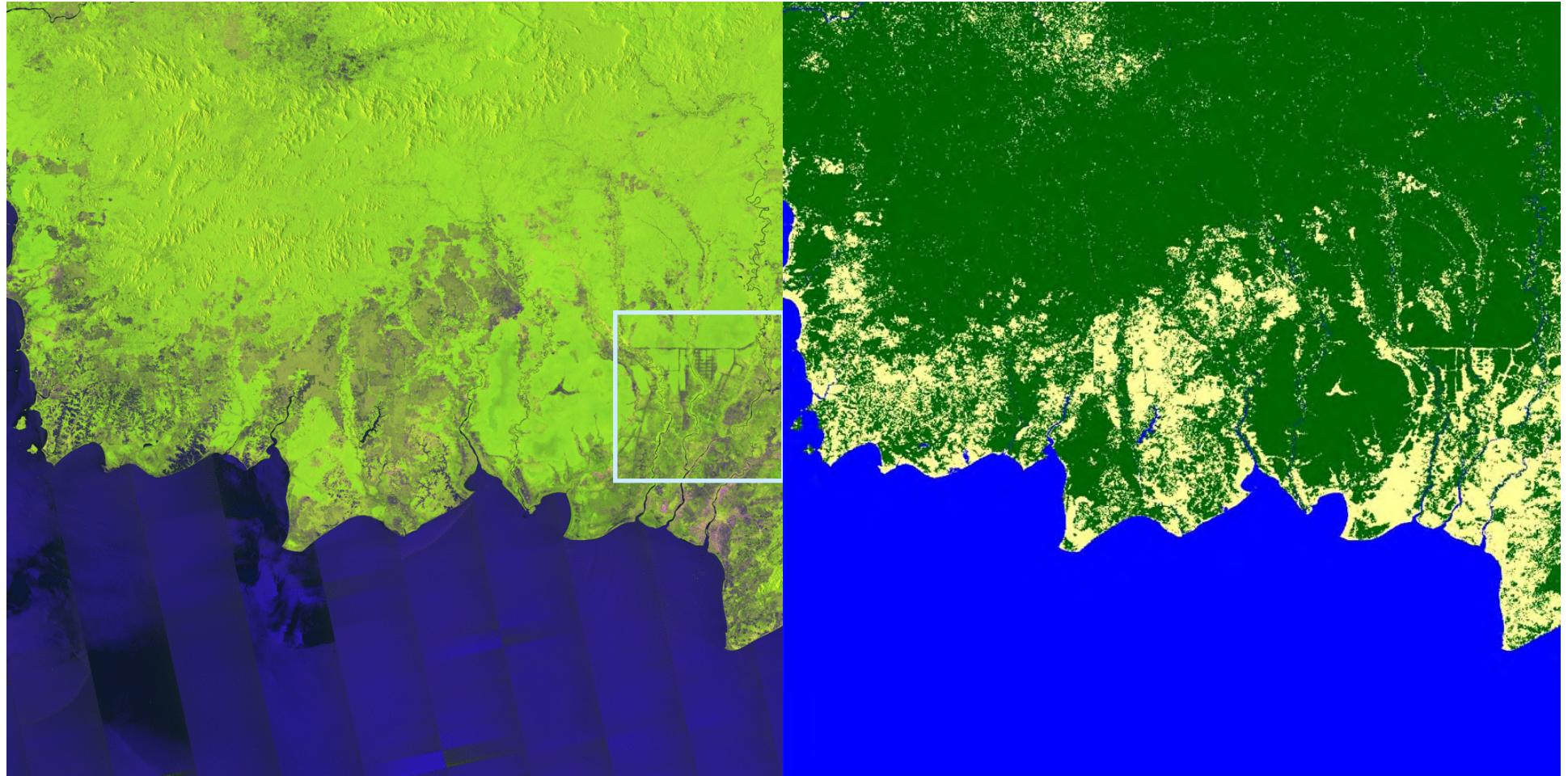




© JAXA, METI Analyzed by JAXA

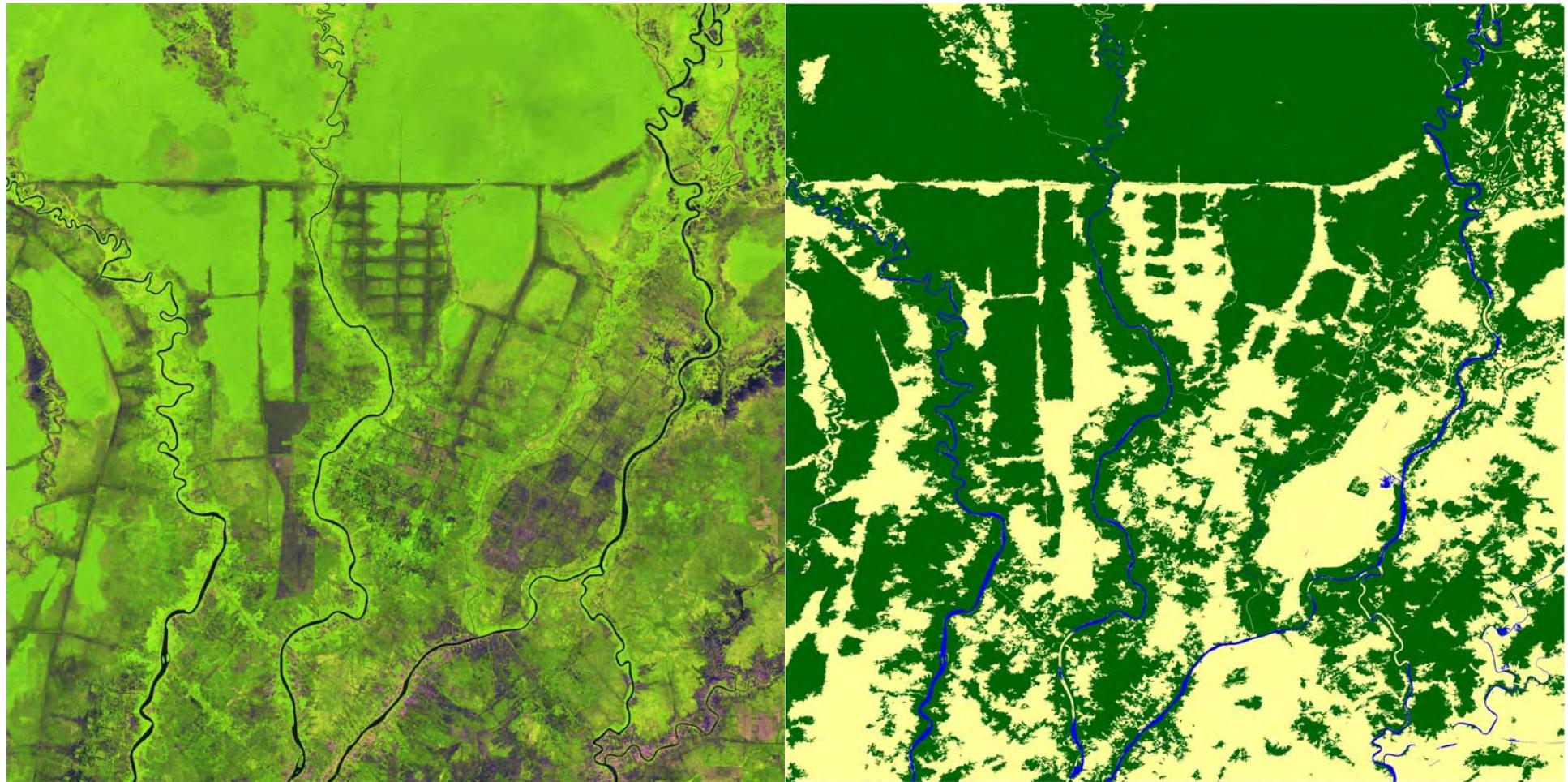
© JAXA, METI Analyzed by JAXA

# Central Kalimantan



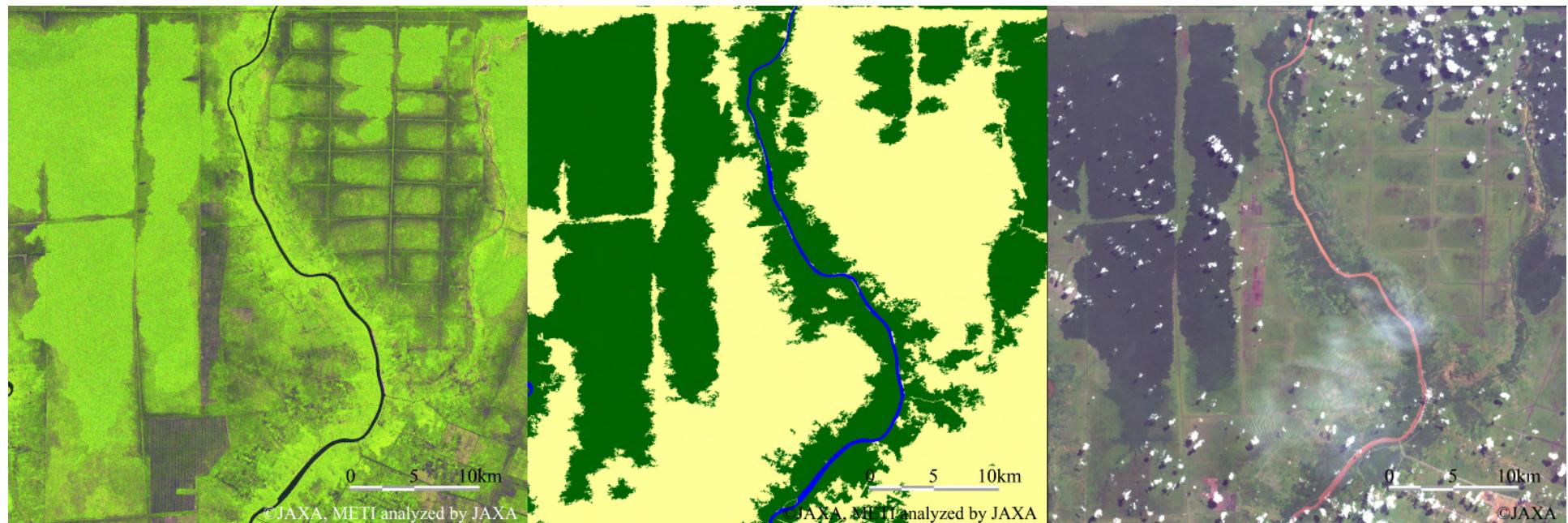
↔  
100km

# Central Kalimantan



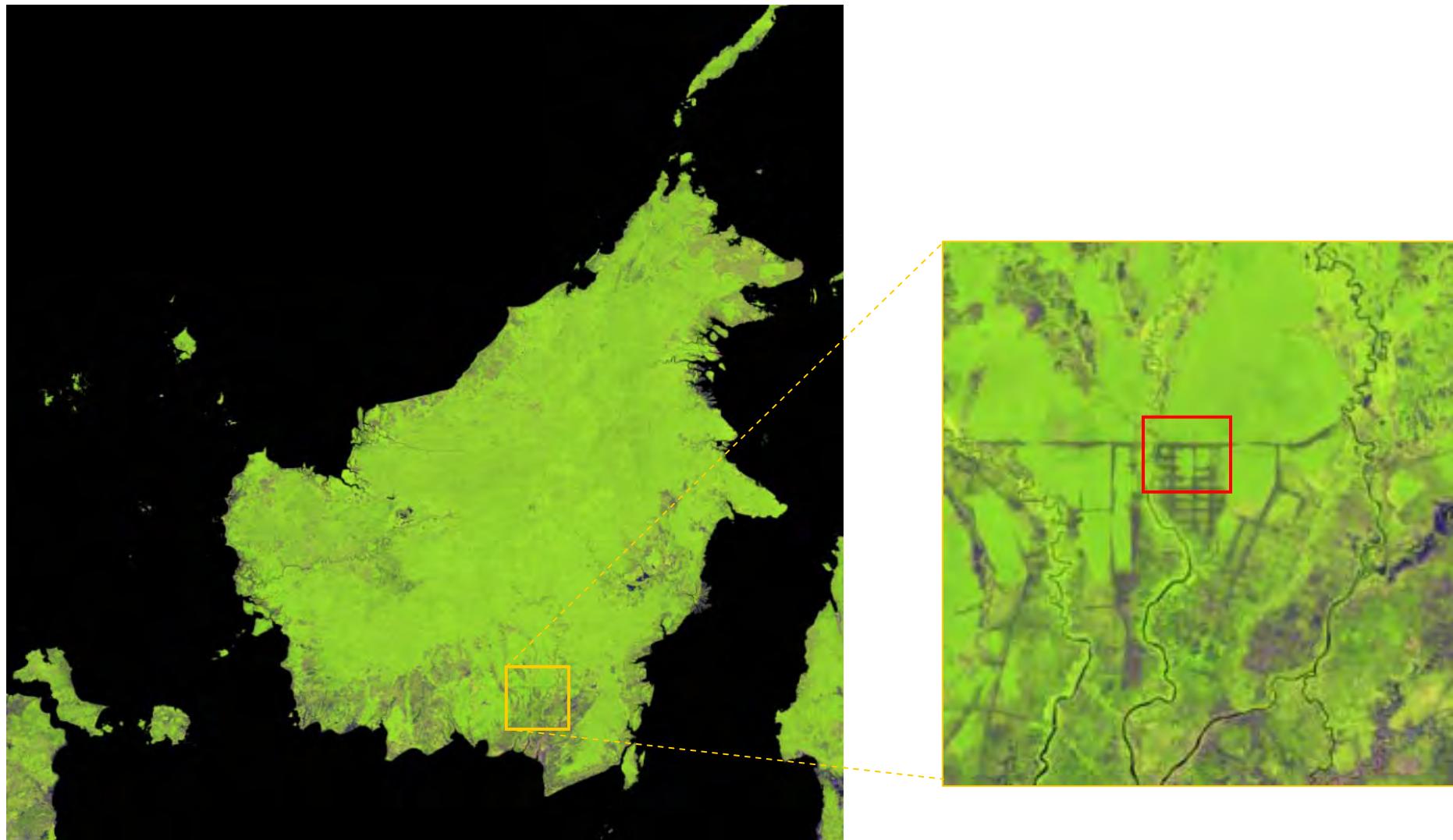
↔  
20km

# Forest/Non-forest classification

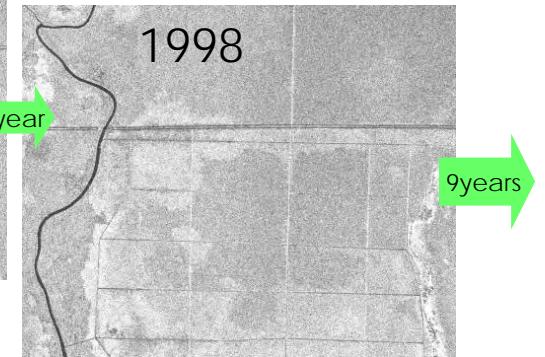
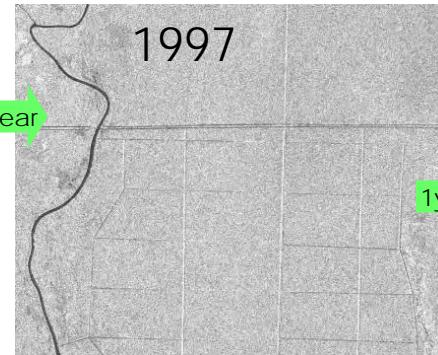
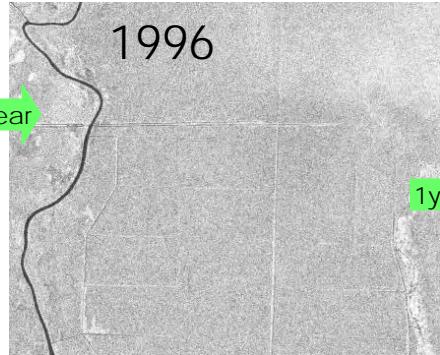
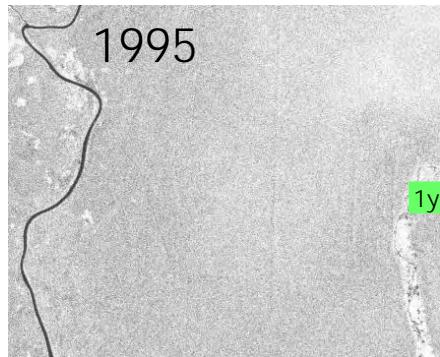


# Deforestation Monitoring in Central Kalimantan

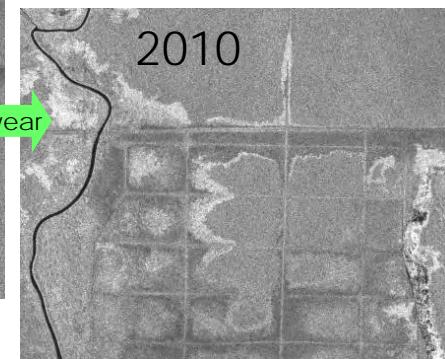
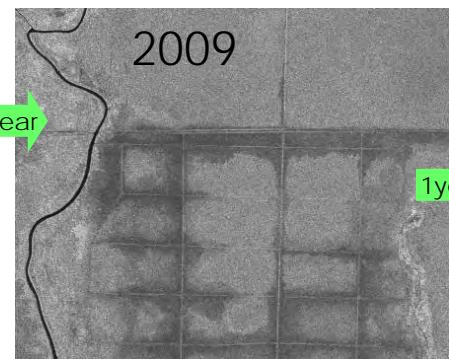
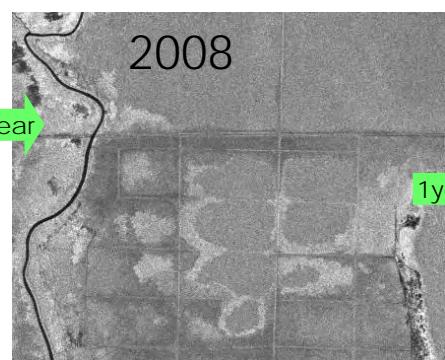
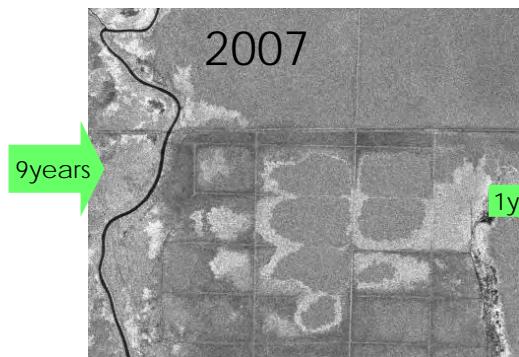
By JERS-1/SAR (1994-1998) and ALOS/PALSAR (2007-2010)



## Descending path



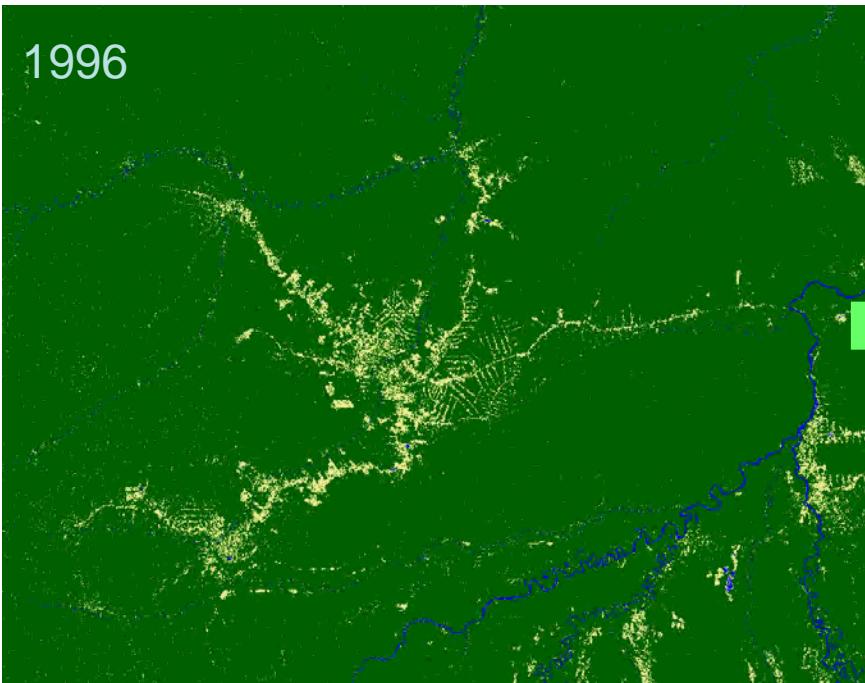
## Ascending path



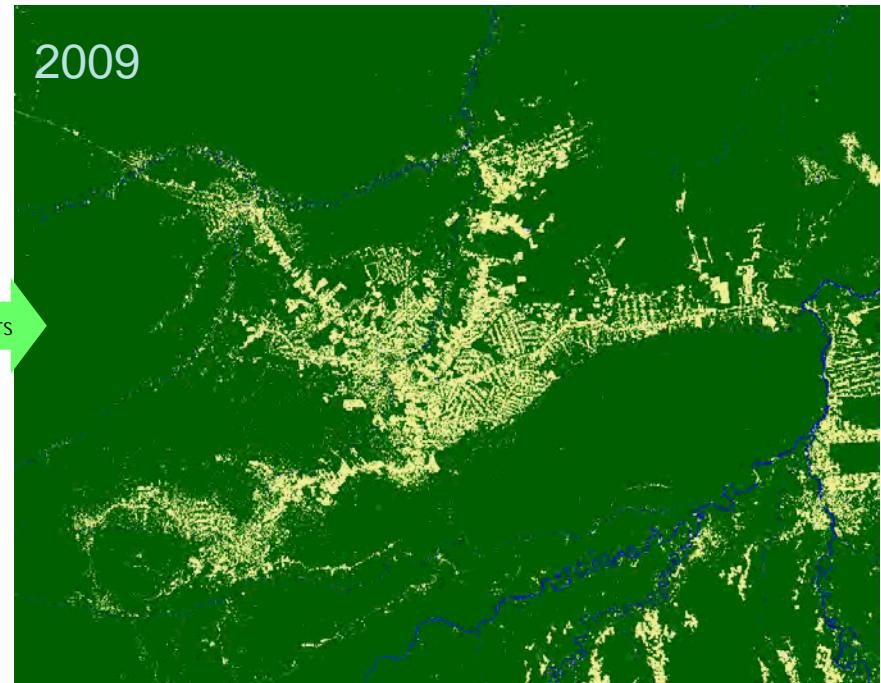
Calibration error?  
Change of soil moisture?

# Deforestation Monitoring in Rio Branco by JERS-1/SAR and ALOS/PALSAR

JERS-1/SAR

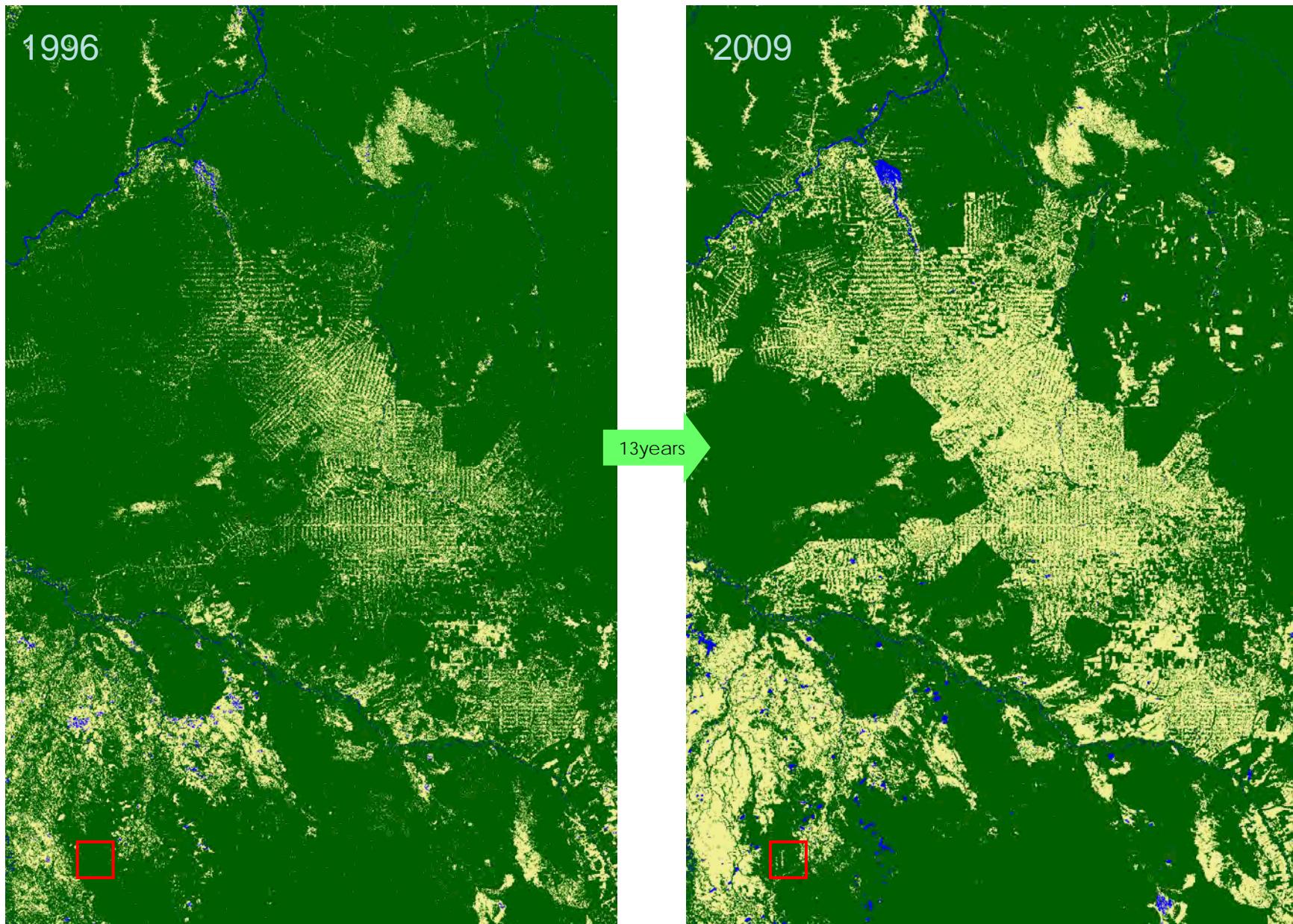


ALOS/PALSAR

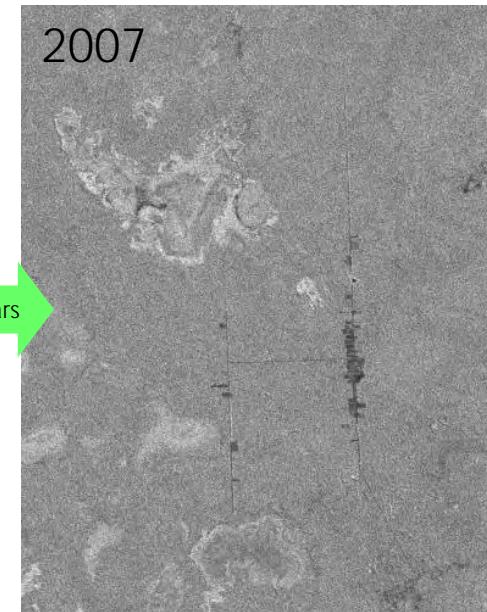
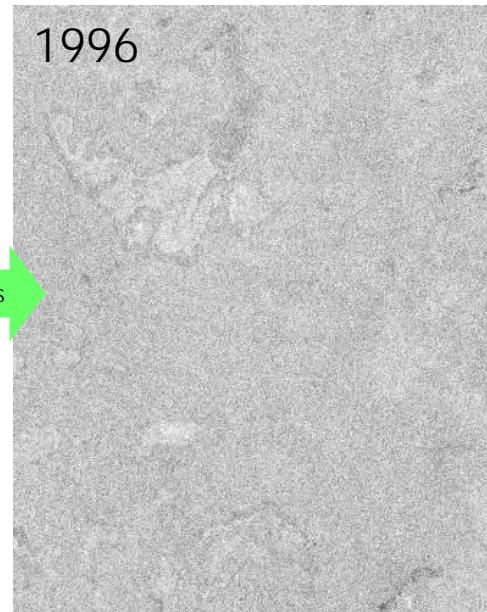
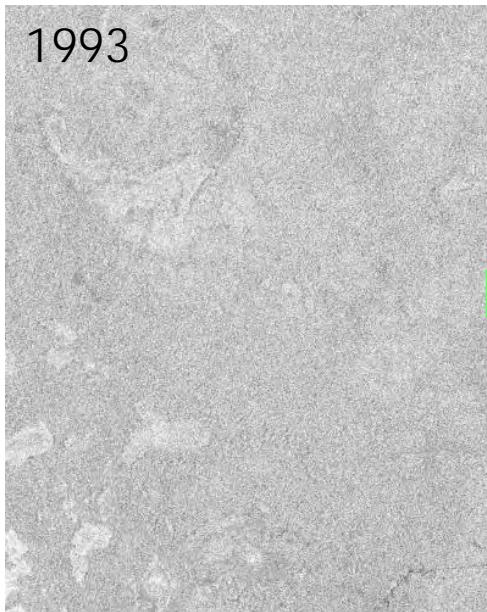


13years

## Deforestation Monitoring in Rondonia by JERS-1/SAR and ALOS/PALSAR



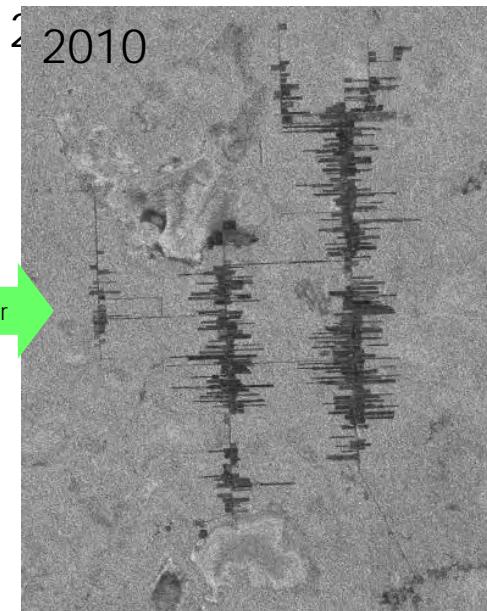
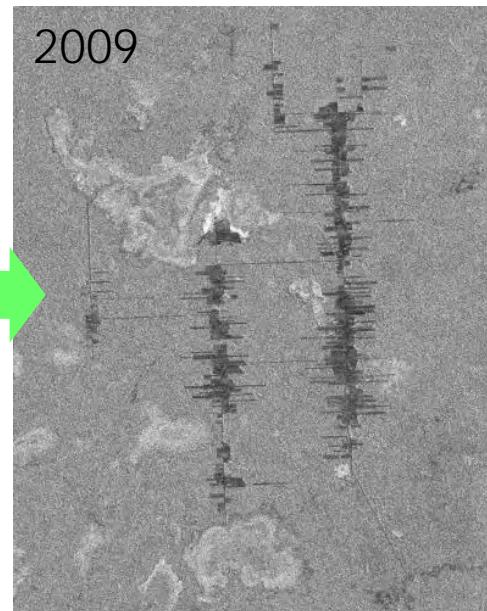
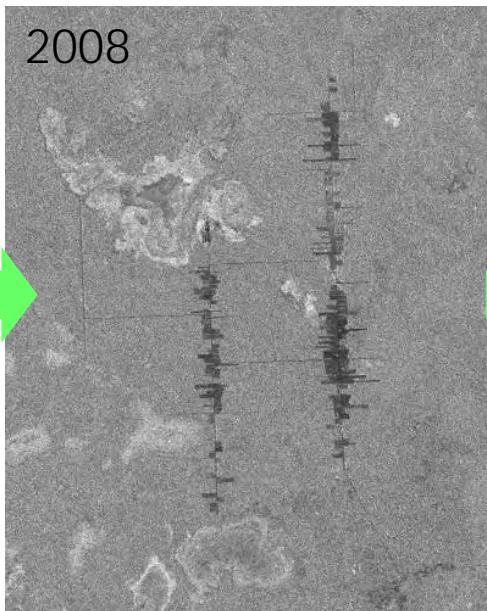
# Bolivia



3years

11years

1year



1year

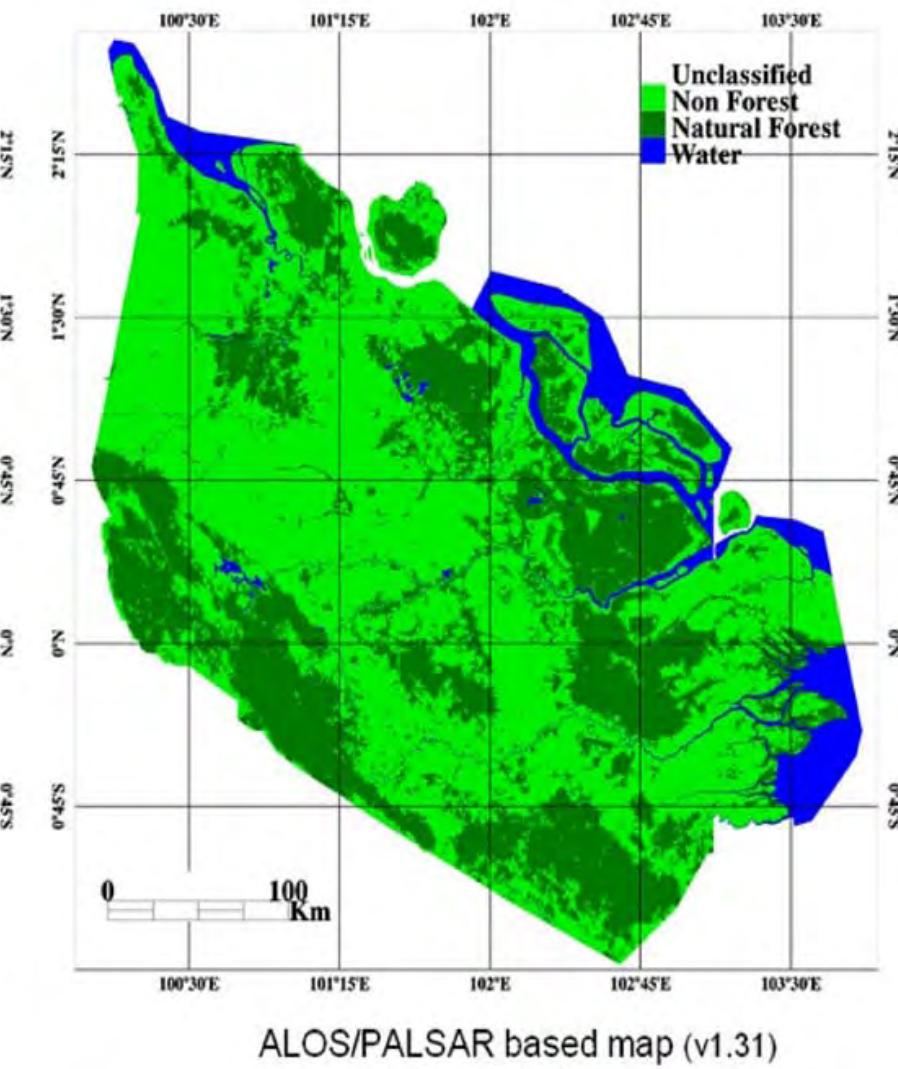
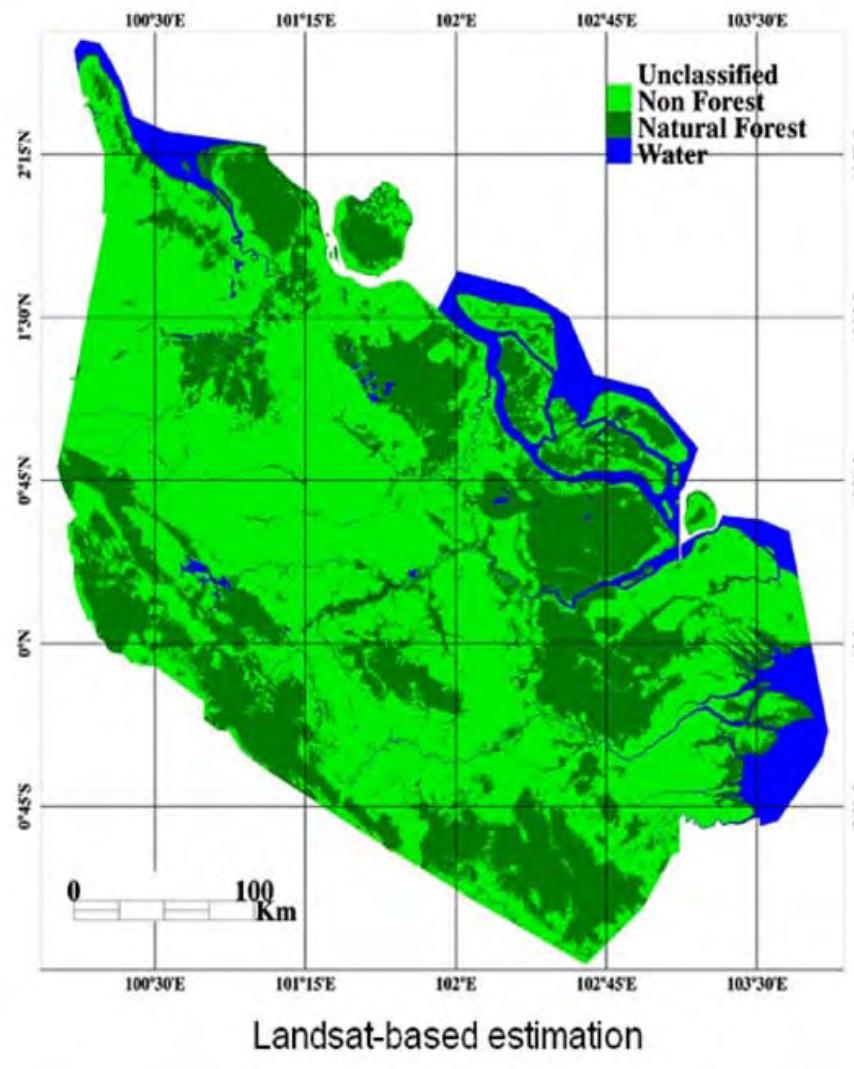
1year

1year

- Forest classification at 50m resolution over Riau province, Indonesia

- Size: 102 178 km<sup>2</sup>  
40.871.201 pix. (86.5 %)

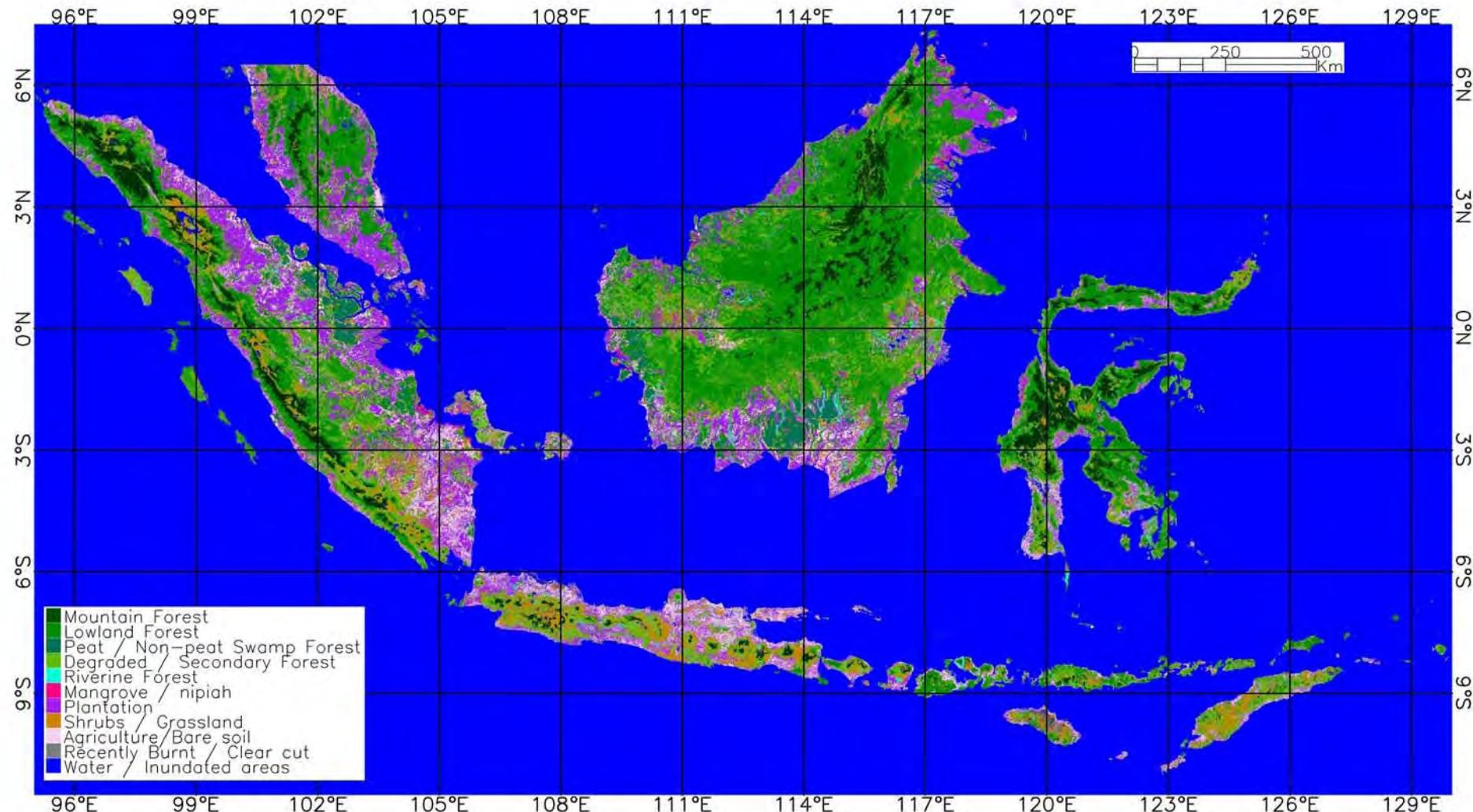
- Accuracy 35.338.102 /



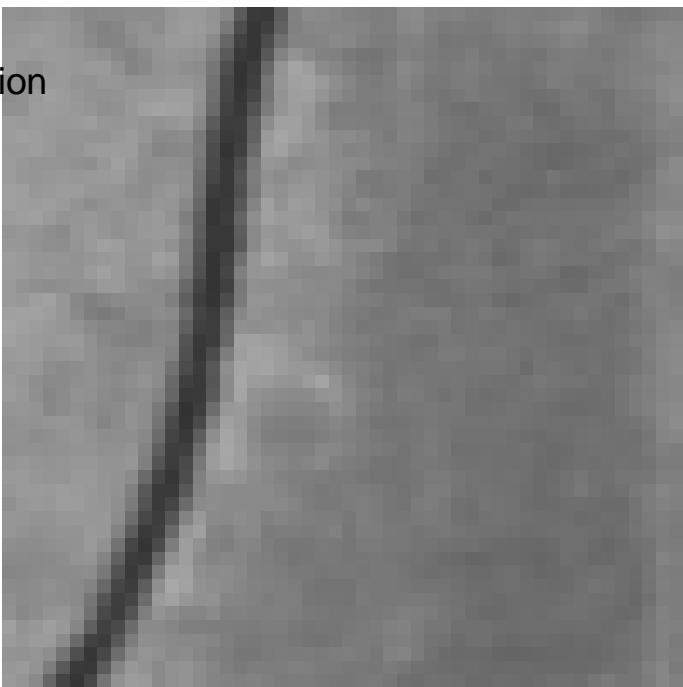
# Forest classification : 83%

Land cover classification at 50m resolution across the entire Borneo

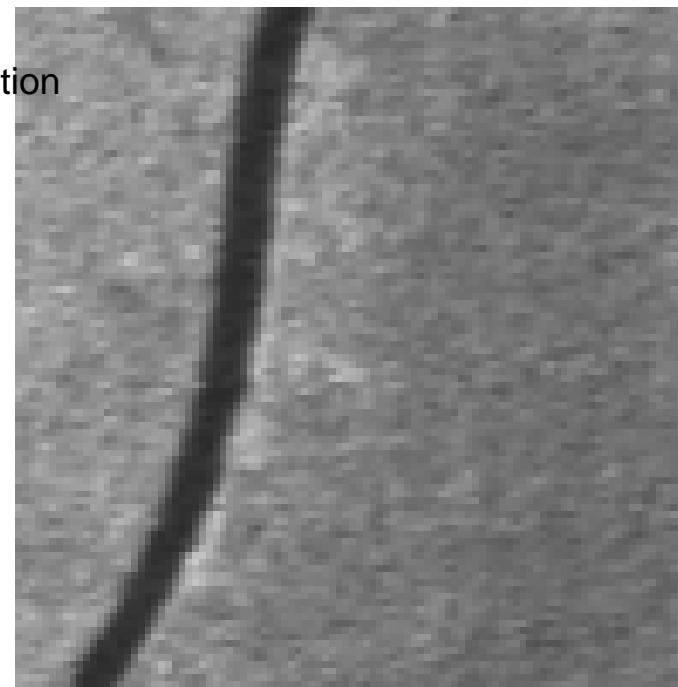
- Based on FBD PALSAR mosaic available on the internet (2007, 2008, and 2009)
- Methodology based on the Support Vector Machines
- 11 classes discriminated



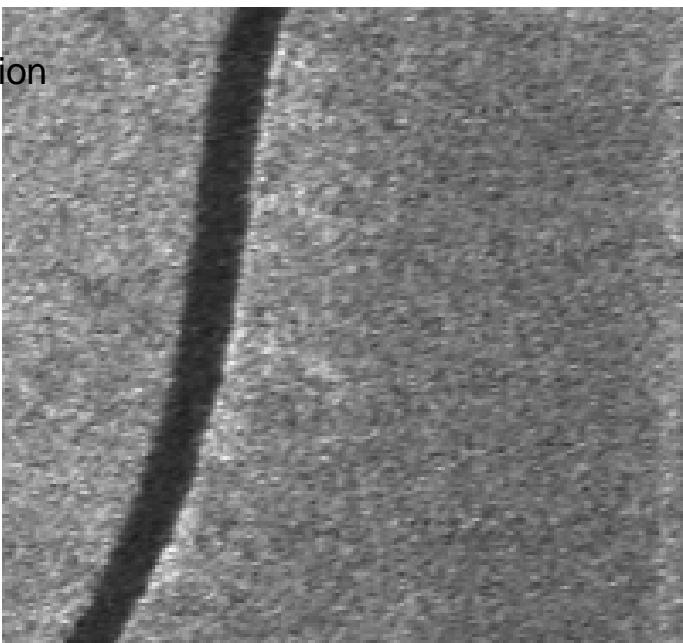
50m  
resolution



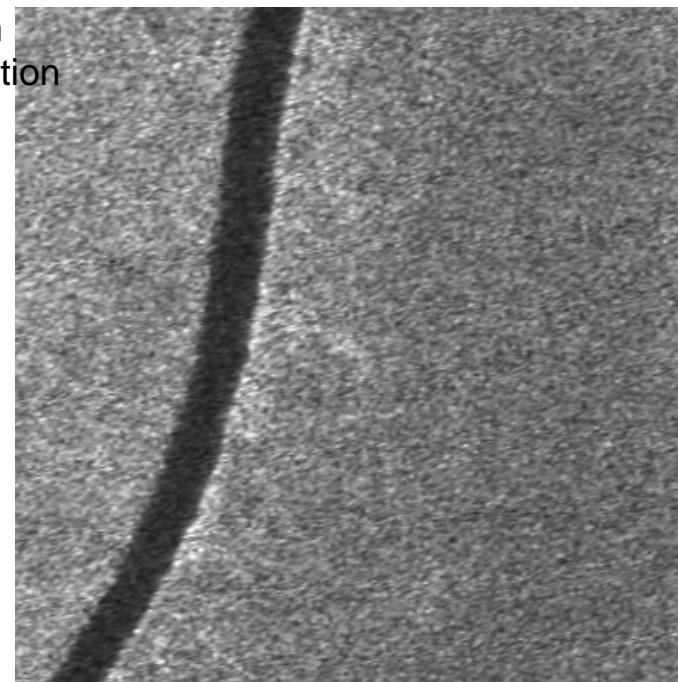
25m  
resolution



12.5m  
resolution

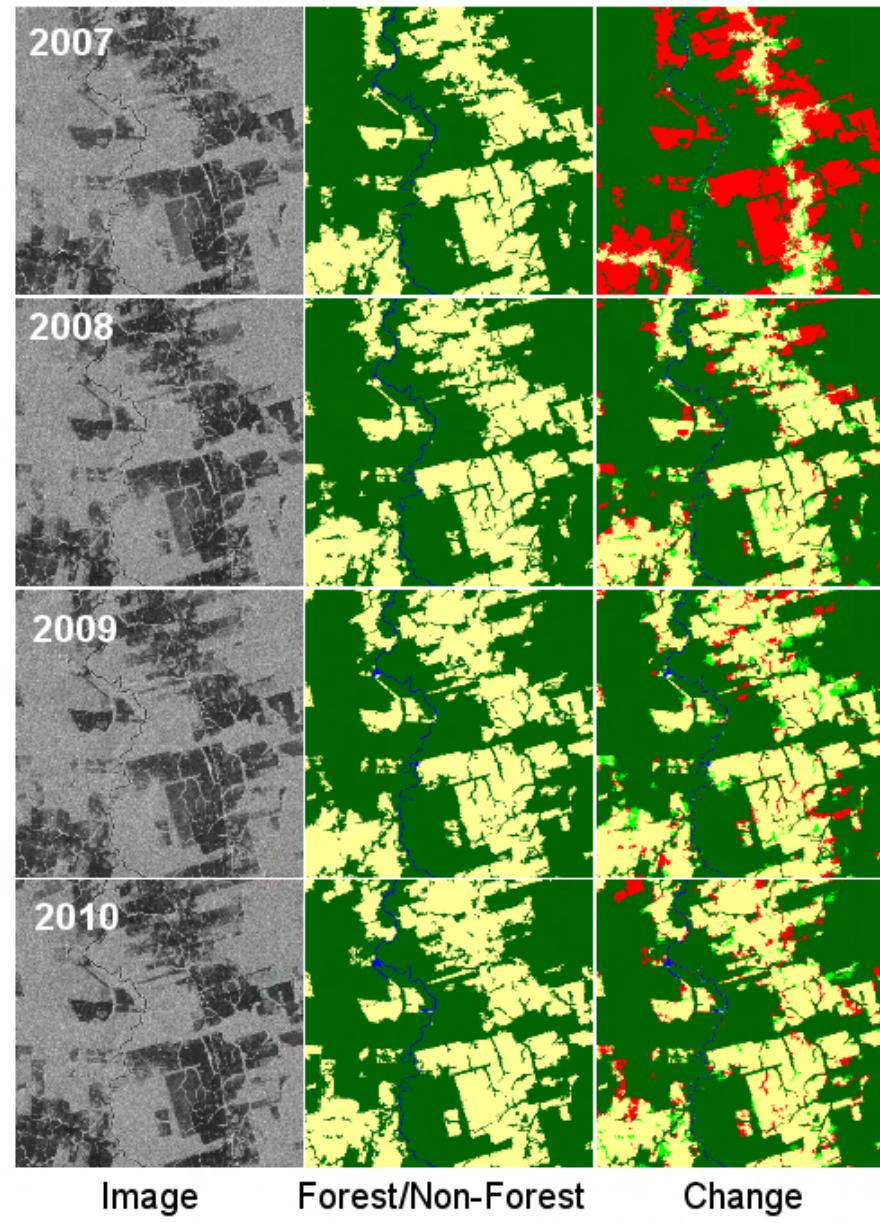
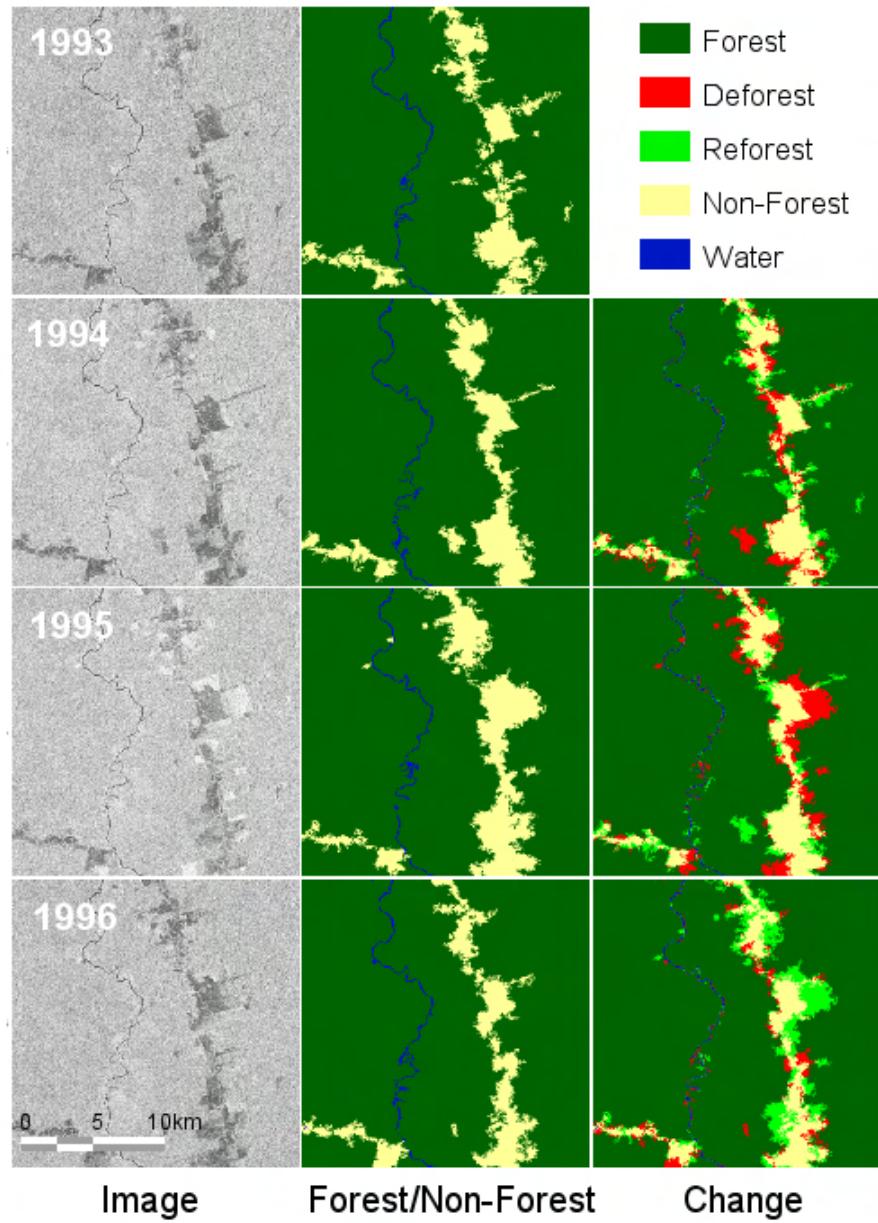


6.25m  
resolution



Comparison of resolutions

※画像は2.5km四方



(C)JAXA, METI analyzed by JAXA

Press release on Oct. 21, 2010.

The Japan Aerospace Exploration Agency (JAXA) has generated the world's first 10-meter resolution images and maps of the global forest and non-forest area distribution (in 2007 and 2009) using the Phased Array type L-band Synthetic Aperture Radar (PALSAR) aboard the Advanced Land Observing Satellite "DAICHI" (ALOS,) and will publish them on our website. We would also like to inform you that we will introduce the image maps at a side event for the 10th Conference of the Parties (COP 10) to the Convention on Biological Diversity and also at the Ministerial Summit for the Group on Earth Observation (GEO) to be held in Beijing in 2010. We will analyze and process past data to understand global-scale forest carbon volume change to compile useful data for control measures to tackle deforestation and forest deterioration. For data distribution, we will conclude an agreement with cooperative organizations.

Season: June 2009~ Sept. 2009

Volume: ~30TB per year

## Future Plan

Product generation : 1995~2007, 2008, 2009, 2010:  
2011: early

Deforestation rate at each country/province  
2011: February

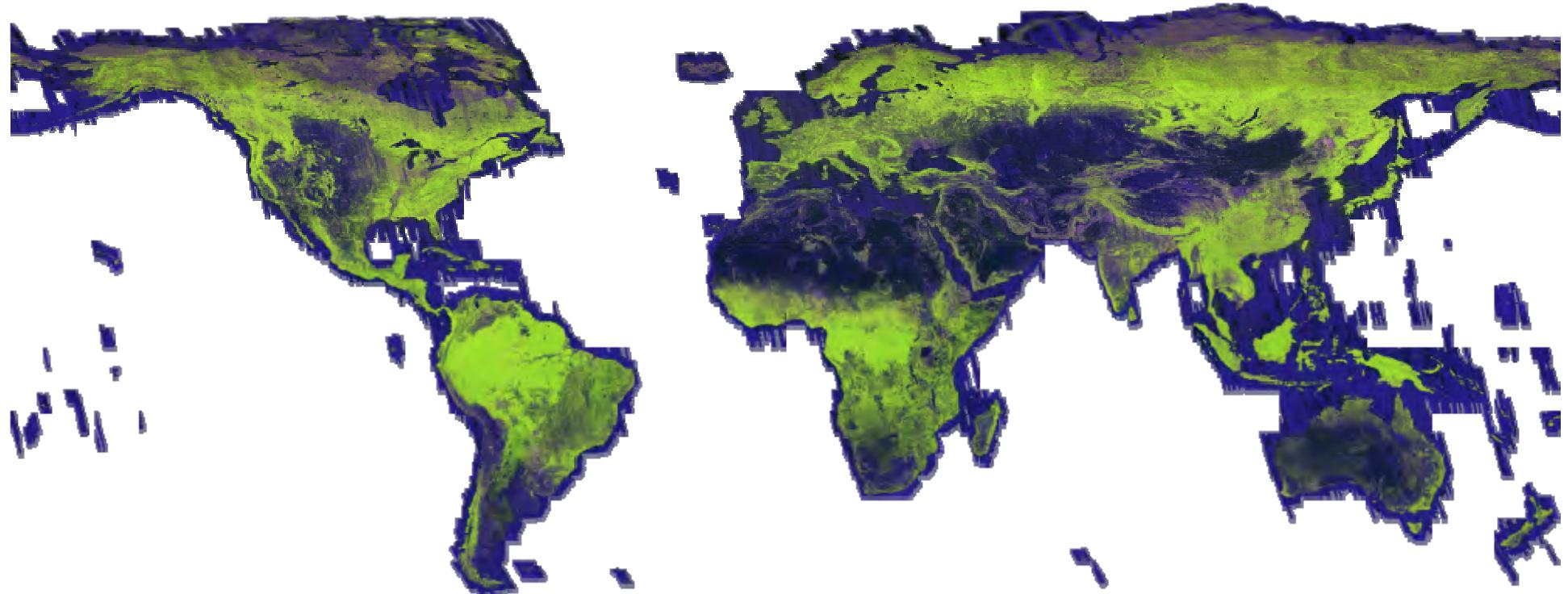
Product validation, accuracy improvement, conversion  
to biomass

Exchange of ground truth data and data

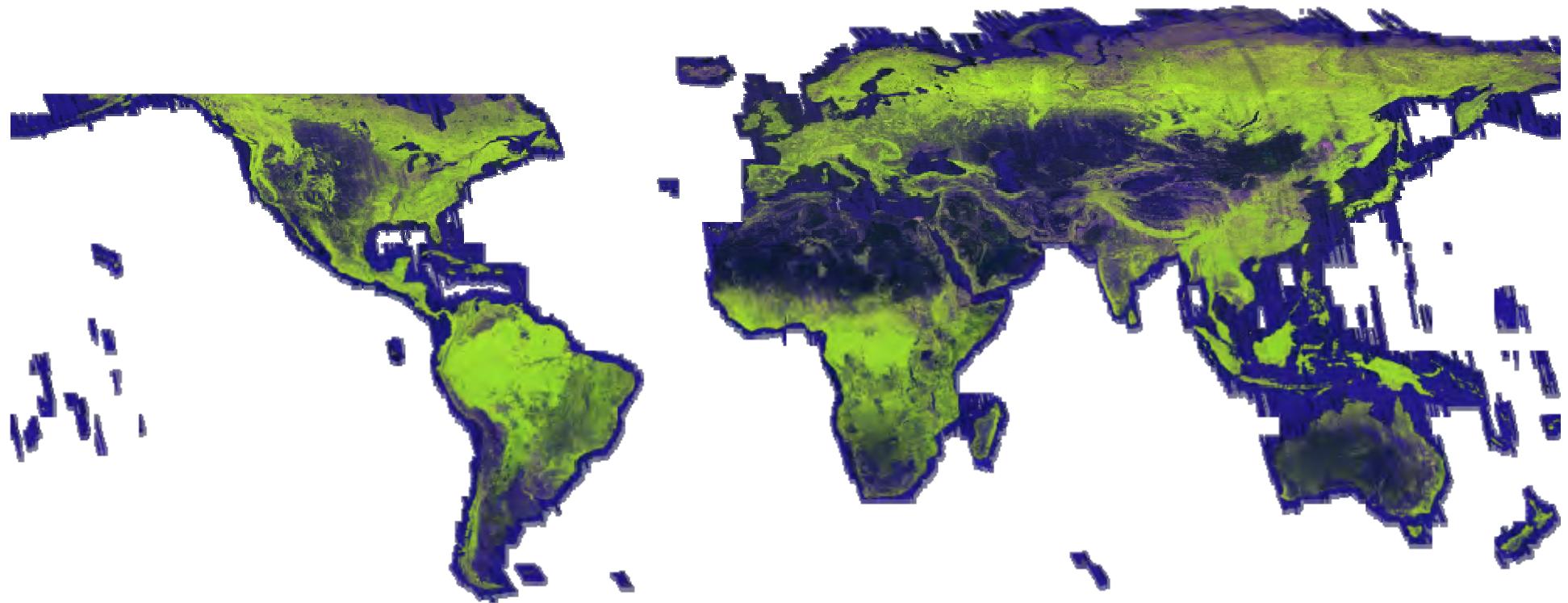
Collaborative agencies: INPE, IBAMA, INDONESIA,  
NGO

# Processing status

# 10m Global Mosaic 2009



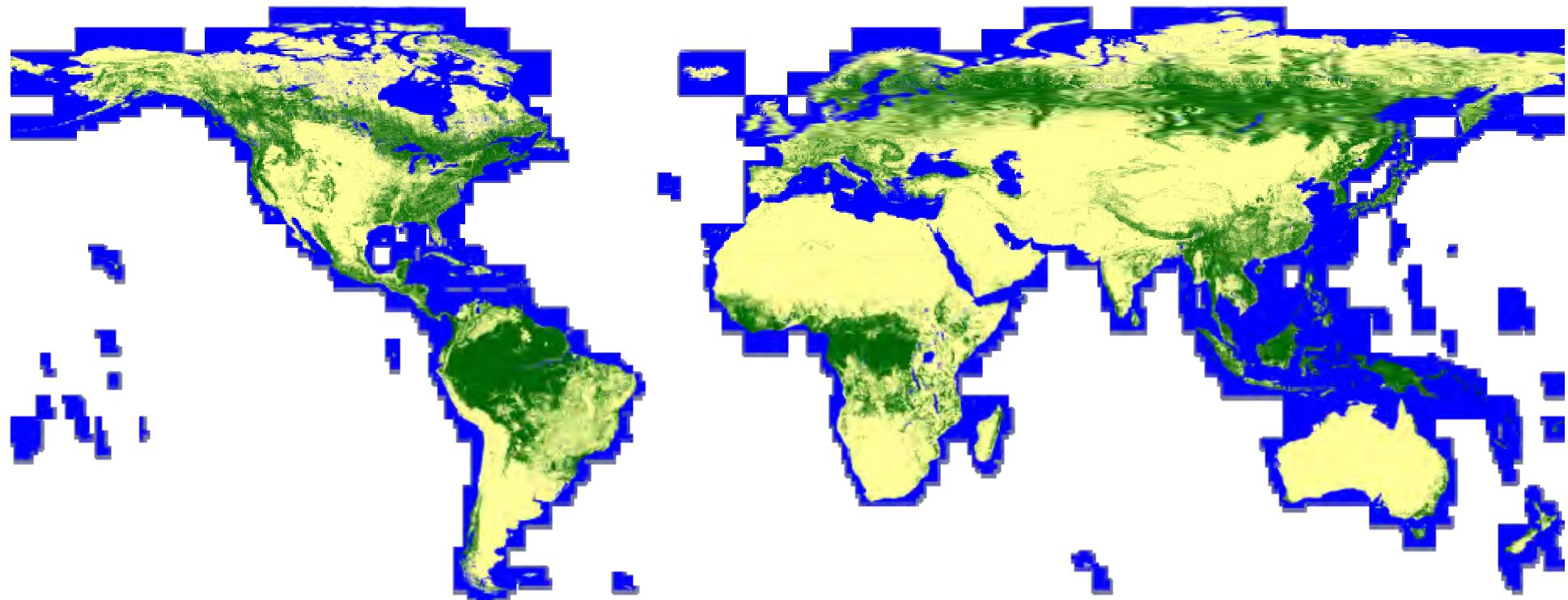
# 10m Global Mosaic 2007



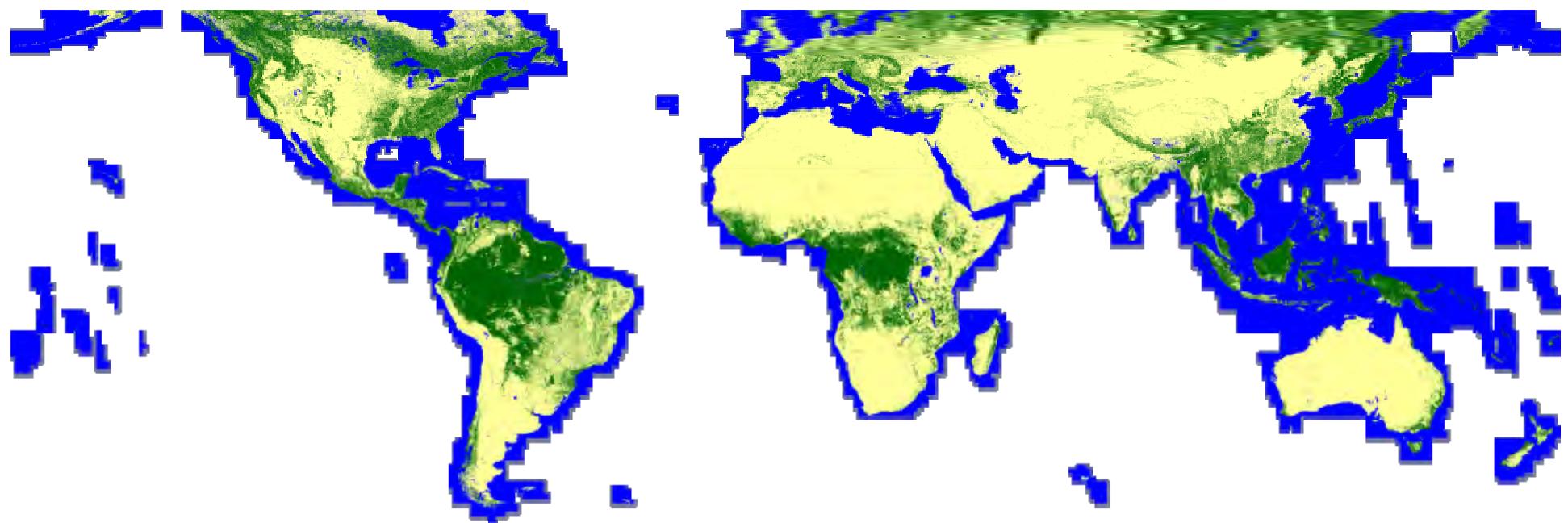
# 10m Global Mosaic 1995



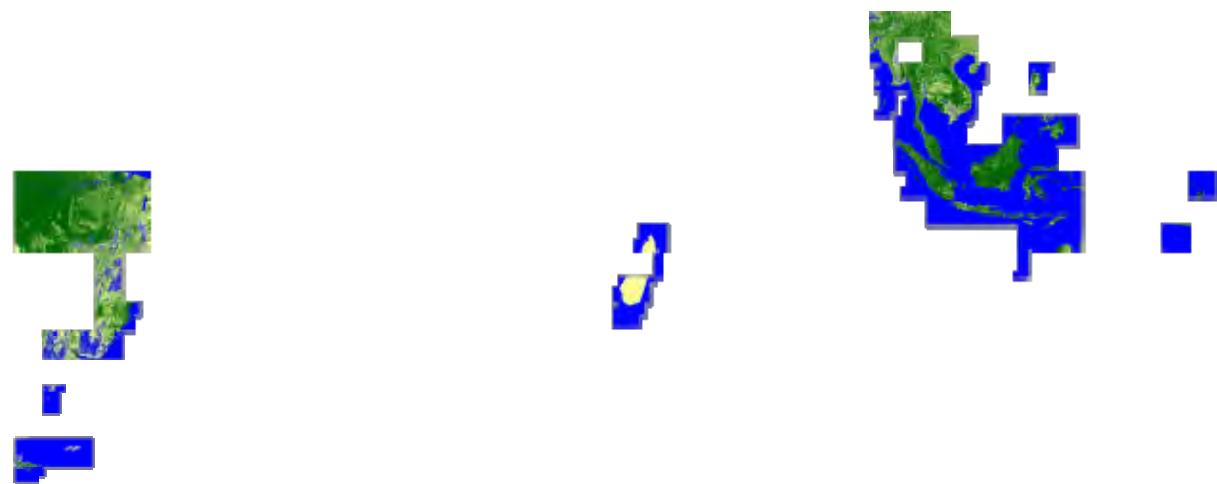
# 10m Forest/Non-Forest Map 2009



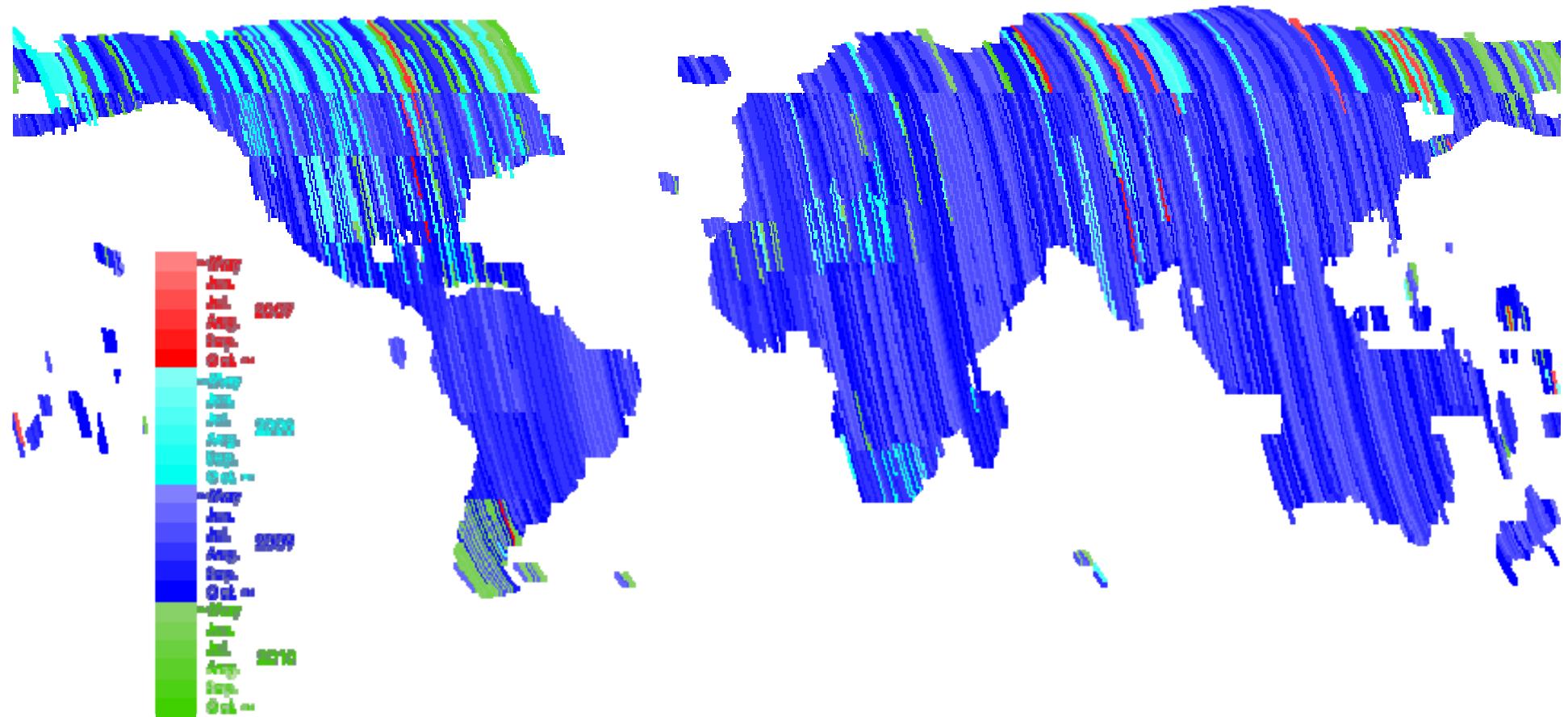
# 10m Forest/Non-Forest Map 2007



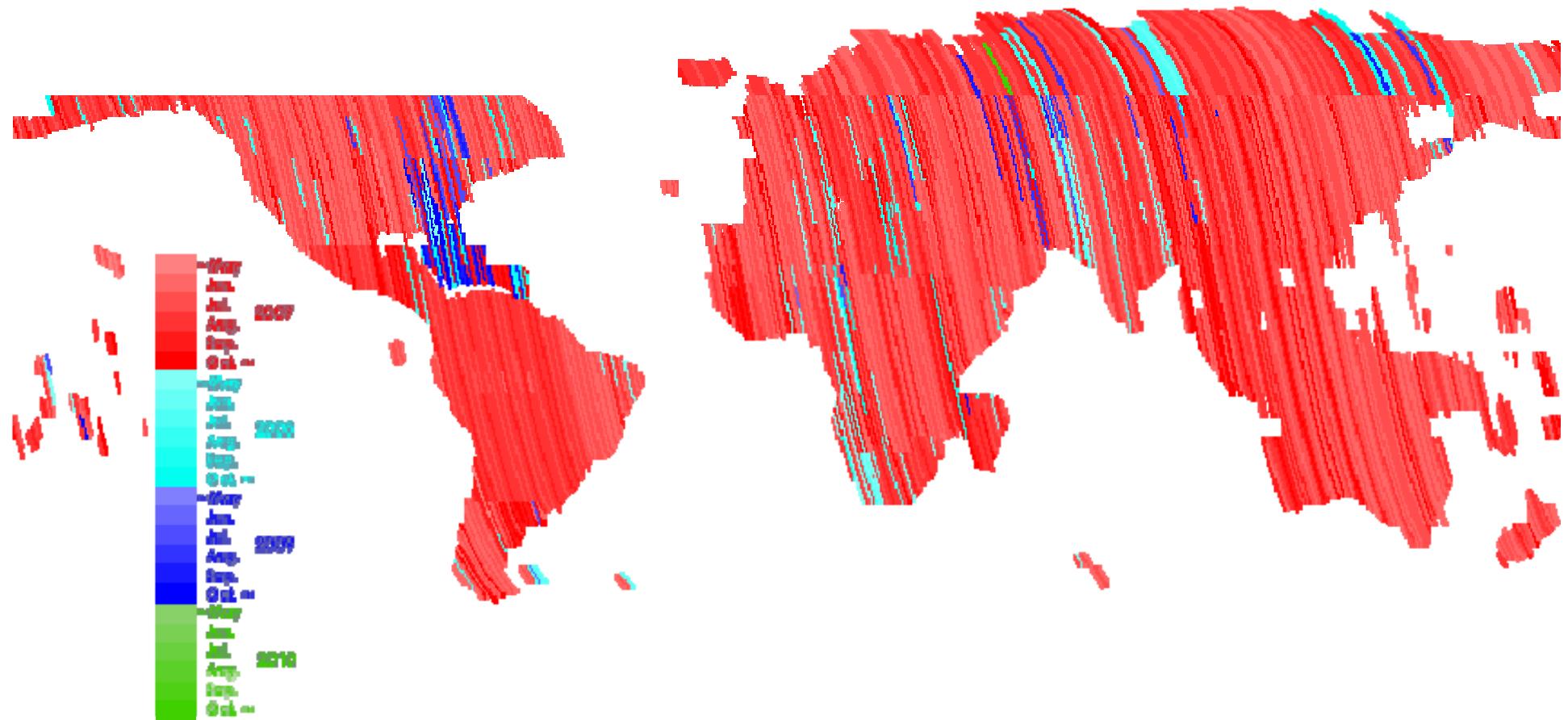
# 10m Forest/Non-Forest Map 1995



Observation Date 2009



Observation Date 2007



## Observation Date 1995

