ALOS

K&C Initiative
An international science collaboration led by JAXA

PALSAR wide-area land cover mapping and consistent annual monitoring methodology

Case studies Borneo and Suriname

Dirk Hoekman
Wageningen University

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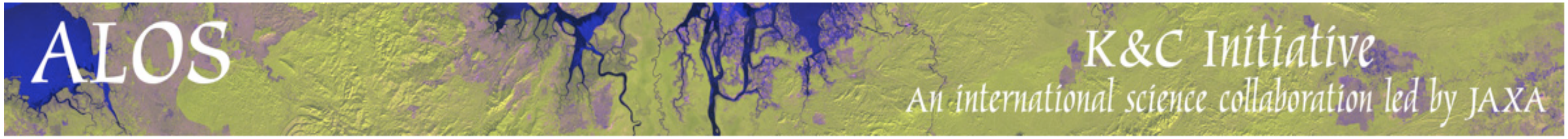
Presentation outline

1. Introduction
2. Summary wide-area map Borneo 2007
3. Wide-area consistent time series
4. Integration of WB data: example Mahakan watershed
5. Legend development – Dedicated field campaigns
6. Extension to other eco-zones: example Suriname
7. Conclusions - Outlook



Introduction

Objective: design and validate <u>operational methodology</u> for wide-area wall-to-wall monitoring using ALOS PALSAR

- Allowing **interoperability** with complementary radar and optical data sources
- Contributing to UNFCCC, Ramsar, CBD, with applications in National Carbon Accounting Systems, MRV systems, REDD-projects
- Prototype areas are Insular SE Asia, Gabon, Colombia and Guianas

- Work partly is NL contribution to GEO Forest Carbon Tracking Task
- Borneo, Sumatra and Guyana are GEO-FCT National Demonstrator sites

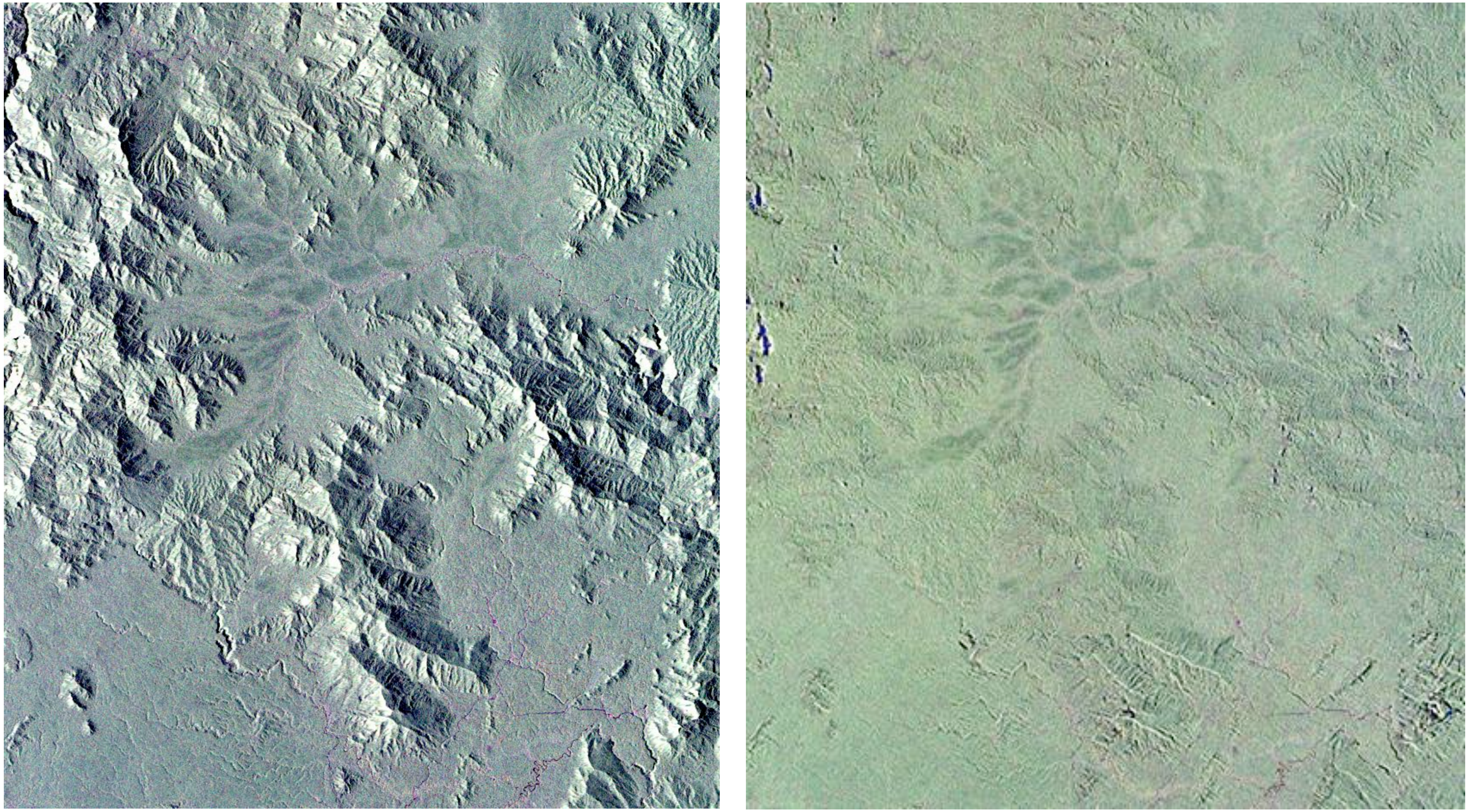
Wide area SAR mapping methodology: input data

Two observations per year (one in dry season and one in wet season)
Two polarisations (FBD: HH+HV, FBS: HH) at 50m spatial resolution

ALOS K&C © JAXA/METI

	FBD			FBS		
RSP	Date	Cycle	Shift	Date	Cycle	Shift
RSP410	20070804	13	+12	20070201	09	+12
RSP411	20070821	13	+29	20070218	09	+29
RSP412	20070723	13	0	20070120	09	0
RSP413	20070809	13	+17	20070206	09	+17
RSP414	20070826	13	+34	20070223	09	+34
RSP415	20070728	13	+5	20070125	09	+5
RSP416	20070814	13	+22	20070211	09	+22
RSP417	20070831	13	+39	20070228	09	+39
RSP418	20070802	13	+10	20070130	09	+10
RSP419	20070704	12	-19	20070216	09	+27
RSP420	20070905	13	+44	20070305	09	+44
RSP421	20070807	13	+15	20070204	09	+15
RSP422	20070824	13	+32	20070221	09	+32
RSP423	20070726	13	+3	20080126	17	+369
RSP424	20070812	13	+20	20070209	09	+20
RSP425	20070829	13	+37	20070226	09	+37
RSP426	20070915	14	+54	20070128	09	+8
RSP427	20070817	13	+25	20070214	09	+25
RSP428	20070903	13	+42	20070303	09	+42
RSP429	20070805	13	+13	20080205	17	+379
RSP430	20070707	12	-16	20080408	18	+442
RSP431	20070608	12	-45	20070121	09	+1

Slope correction/mitigation example



FBS/FBD composite before and after slope correction (same backscatter scale)

Wide area SAR mapping methodology: *LCCS labeling*

Id.	Label	Land cover	Flooding or wetness	Relative biomass level
		Additional brief descriptors		
	FOREST FORMATIONS			
1	Tropical lowland forest, broadleaved evergreen	Moist evergreen rain forests (Trees dominant; Closed canopy cover > 65 %; Height > (3-) 5 m; Below 1000 m elevation)	No flooding	High
20	Tropical mountain forest, broadleaved evergreen	Moist evergreen rain forests (Trees dominant; Closed canopy cover > 65 %; Height > (3-) 5 m; Above 1000 m elevation)	No flooding	High
2	Riverine forest	Moist evergreen rain forests (Trees dominant; Closed canopy cover > 65 %; Height > (3-) 5 m; Below 1000 m elevation)	Flooded more than 4 months per year	High
3	Swamp forest	Freshwater swamp forest (Closed canopy; cover >65%)	Flooded more than 4 months per year	High
4	Mangrove forest	Mangrove forests. Canopy cover is closed to open (>15%). The height is in the range of >30m - 3m. Regularly flooded and saline water.	Tidal flooding	Medium
5	*Nipah* mangrove forest	Closed canopy forest with very high (variable) proportion of trunkless palms (*Nypa fruticans*); cover >65%. Regularly flooded, saline water.	Tidal flooding	Medium
6	Peat swamp (pole) forest	Peat swamp forest; Open canopy cover >40 %. Fresh or brackish water.	Flooded seasonal, less than 4 months per year	High
7ab	Peat swamp (padang) forest	Peat swamp forest; Open canopy cover >10-20 %; Shrubs, cover>11 %; Note: overlap with riverine shrubland. Fresh or brackish water.	Seasonal flooding	Medium
8	Forest mosaics / Fragmented or degraded forests	Secondary, fragmented evergreen forest cover, with shrub and cropland components. Includes forest regrowth.		High
	WOOD AND SHRUBLAND FORMATIONS, GRASSLAND			
9	High shrub	Evergreen shrubland (Shrubs), includes re-growing tree cover, sparse tree cover (Tree coverage ≤ 10-20 %).		High
10	Medium shrub	Evergreen shrubland (Shrubs) and regrowth, grasslands.		Medium-Low
11	Ferns / grass	Closed to open herbaceous vegetation with sparse cover of shrubs. Includes areas dominated by ferns in previously burnt areas.		Low
12	Grasslands	Herbaceous cover, grassland closed – open, includes *alang-alang* dominated grasslands		Low
	CROPLAND			
13	Cropland (upland)	Rain-fed cropland		Low
14	Cropland (irrigated)	Irrigated and temporarily flooded cropland in river plains: rice fields (*sawah)*	Wet	Low
15	Plantations	Mature oil palm plantations (note: rubber and forest plantations are not well detected)		Medium
	OTHER LAND COVER			
16	Tree cover, burnt	The main layer consists of closed to open trees. Recently burnt, dead vegetation with standing tree stems remaining (canopy cover lost). Burn severity unknown.	Seasonal flooding	Low
17	Water bodies			

Wide area SAR mapping methodology: *Map result*

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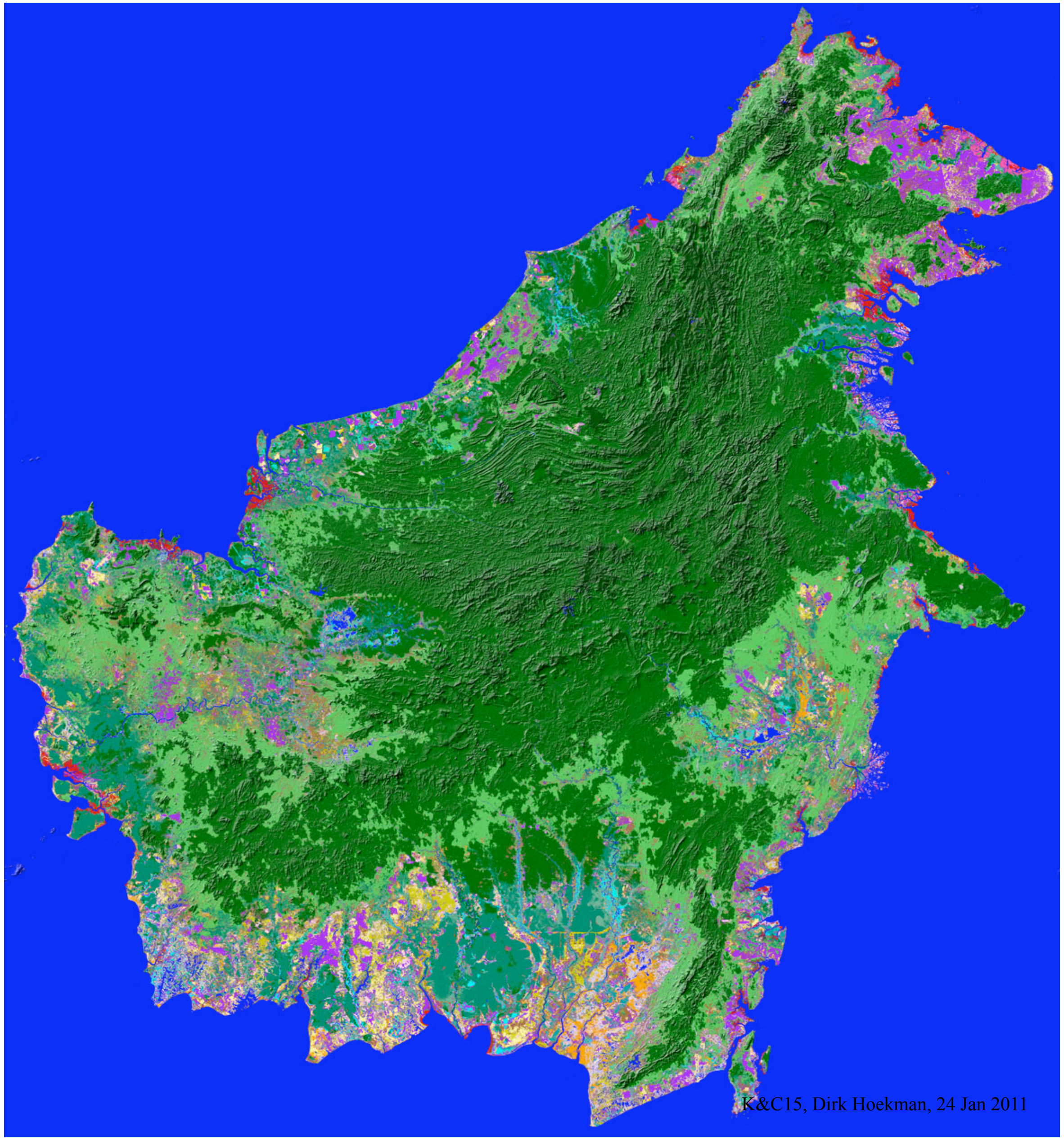
ALOS PALSAR 2007

LULC classification Borneo

(shaded relief version)

- Lowland forest
- Riverine forest
- Swamp forest
- Mangrove forest
- *Nipah* mangrove forest
- Peat swamp forest (pole)
- Peat swamp/riverine shrub
- Forest mosaics/degraded
- High shrub
- Medium shrub
- Ferns / grass
- Grassland
- Cropland (upland)
- Cropland (irrigated)
- Plantations (oil palm)
- Tree cover, burnt
- Water bodies
- Layover /Shadow
- No strip coverage
- Mountain forest



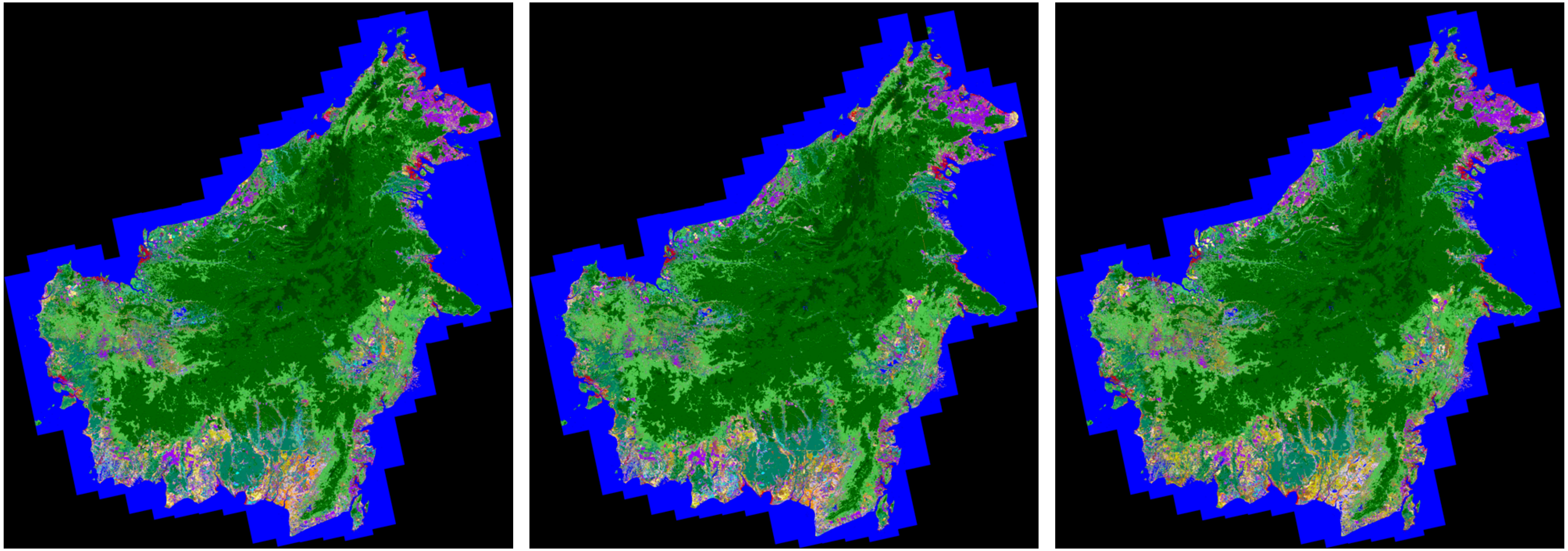
Wide area SAR mapping methodology: *Validation*

Quantitative validation according good practice guidelines of GOFC-GOLD reveals over 85% full agreement with reference data derived from high resolution optical remote sensing and field data and less than 5% disagreement. Remaining cases relate to minor differences along biomass and wetness continua.

The radar based map show classes which cannot be distinguished well with optical data, such as wetland classes and floodplains.

Ref: Hoekman *et al.*, 2010, *IEEE JSTARS*

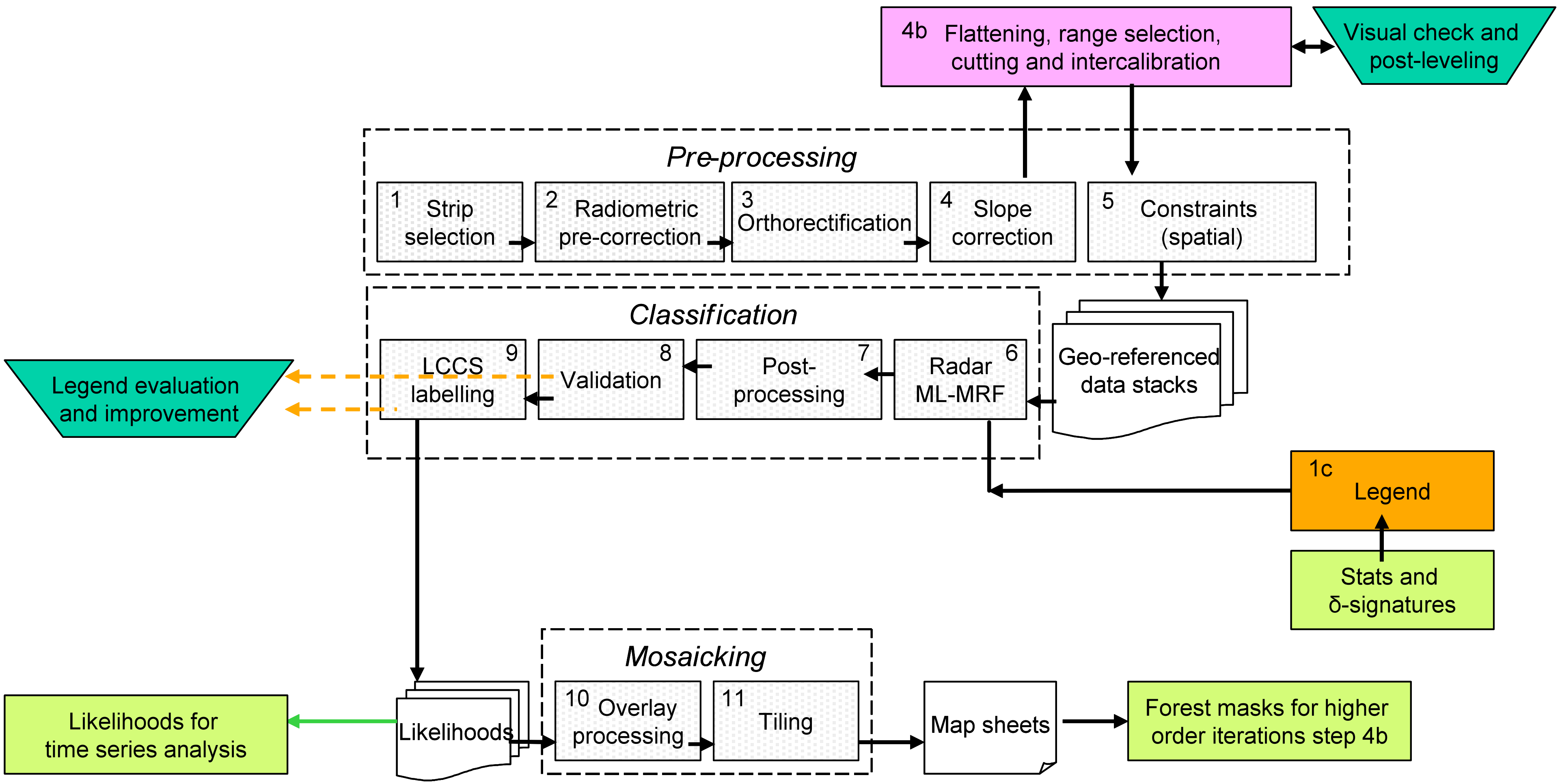
Wide area SAR mapping methodology: *Time series*



2007 2008 2009

Figure 3. After careful calibration and intercalibration of the 2007, 2008 and 2009 data sets and straightforward application of the statistics associated with the legend developed for the Borneo 2007 map, corresponding 50 m resolution maps for the years 2008 and 2009 have been produced. Input PALSAR data courtesy: ALOS K&C © JAXA/METI.

Wide area SAR mapping methodology: *Flow diagram*

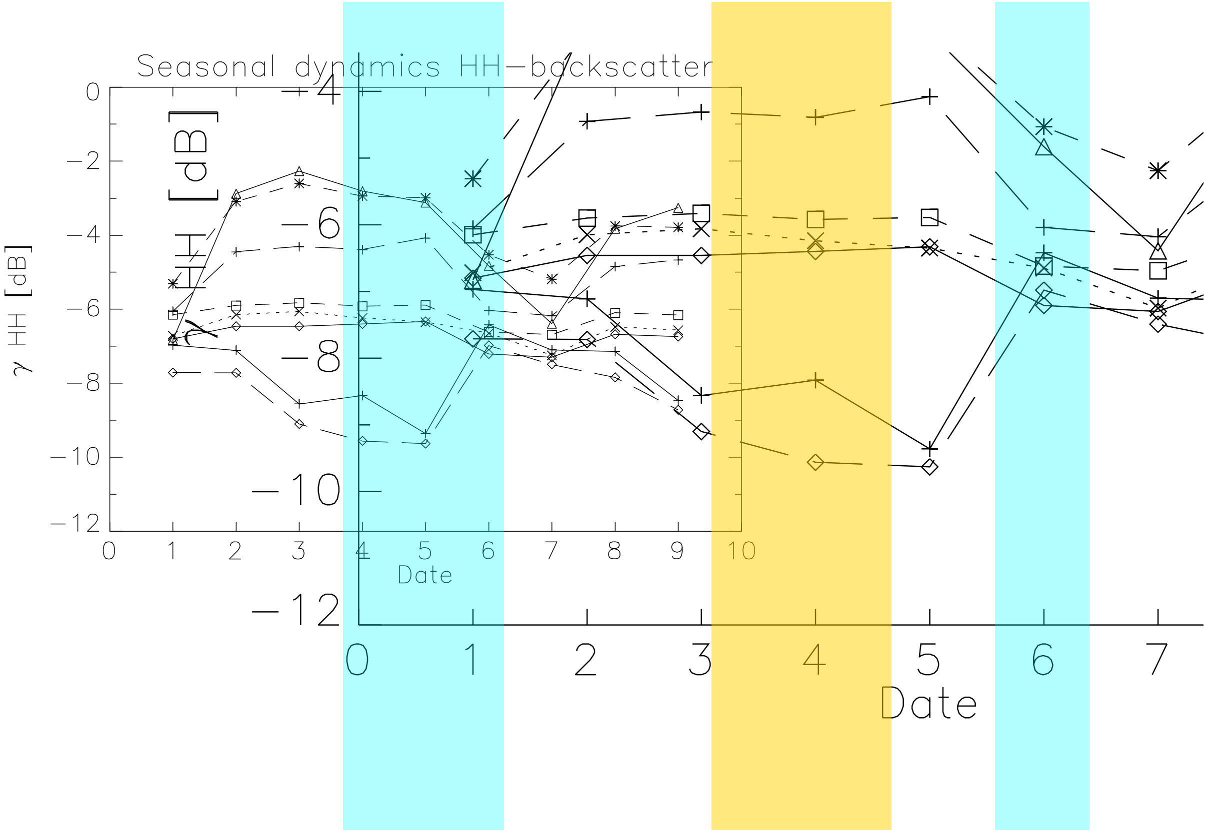


Consistent time series methodology: *Basic steps*

Monitoring land cover change on an annual basis requires consistent year-to-year mapping. To achieve this several techniques are in development. In our approach, to date, these are:

1) Intercalibration of multi-annual mosaics
2) Estimation of differential signatures (to correct for environmental factors)
3) Bayesian temporal analysis (3 components)
4) Deriving constraints from WB temporal analysis (to date large series exist)

Consistent time series methodology: *Background*



[illegible]	[illegible]	[illegible]

Figure 5. Central Kalimantan, PALSAR Wide Beam time series acquired in nine consecutive passes (the dates are shown in the legend; only July 2007 is missing). The three curves in the middle show a relatively small temporal backscatter variation for HH-polarisation for the classes mixed forest, mangrove forest and peat swamp pole forest. The upper three curves show classes with increased backscatter and the lower two curves show classes with decreased backscatter in the dry season. Note that 2006 was a very dry year with prolonged dry season. Consequently on 11 November 2006 (Date 1) the terrain is still very dry, while on 14 November 2007 the terrain is already wet and more inundated (Date 8).

Consistent time series methodology: *Example oil palm*

For most classes the backscatter levels within these observation windows, for example of oil palm plantations, are not entirely stable.

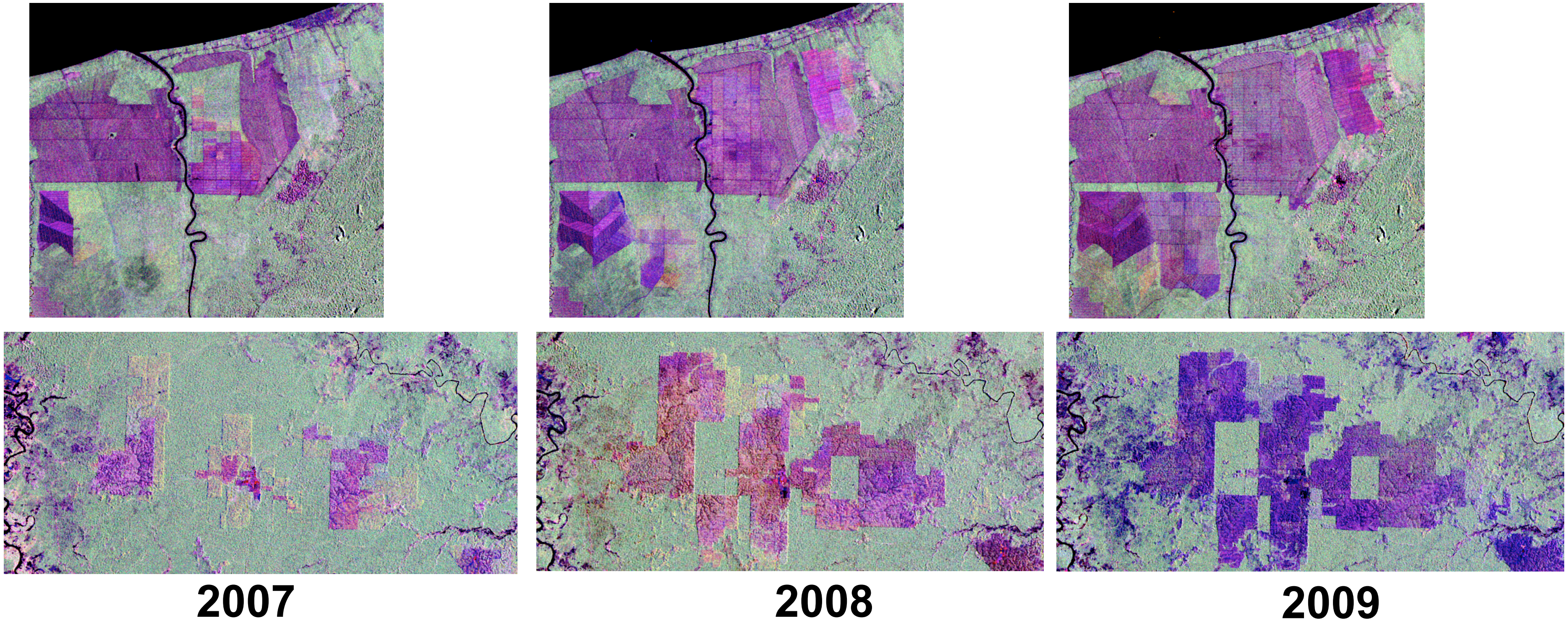


Figure 9. Oil palm development area in Sarawak (top, 25 x 22 km) and in Central Kalimantan (bottom, 36 x 17 km). Colour scheme: FBS-HH, FBD-HH, FBD-HV. Though all data originate from the same strip (RSP 422) the plantations in Sarawak maintain fairly stable backscatter levels, while in Central Kalimantan they seem to vary from year to year. The latter is partly related to the 2009 El Niño drought. Input PALSAR data courtesy: ALOS K&C © JAXA/METI.

Consistent time series methodology: *Model δ-signature*

The statistics of classes are not stable and can change temporarily and locally due to environmental conditions such as drought. This can be described by semi-empirical models:

$S = S_B + S_\delta\,(f_S\,;\,f_E)$

with

- S = (radar) signature (of a class/object)
- S_B = signature of 'average' class structure
- S_δ = differential signature
- f_S = local (within-class) structural variation [*object*]
- f_E = global variation due to environmental factors [*entire scene*]

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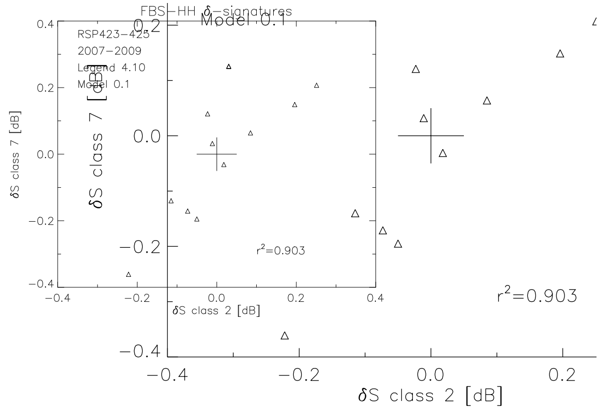
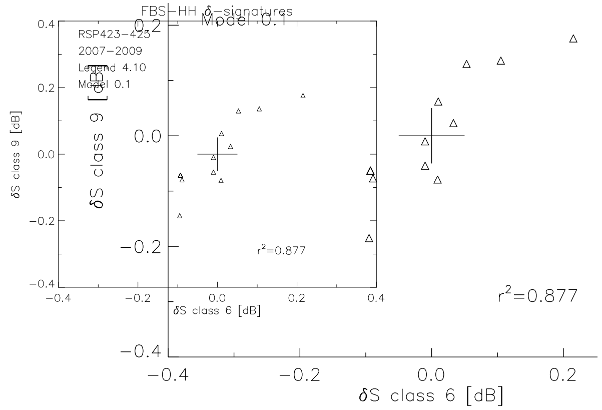
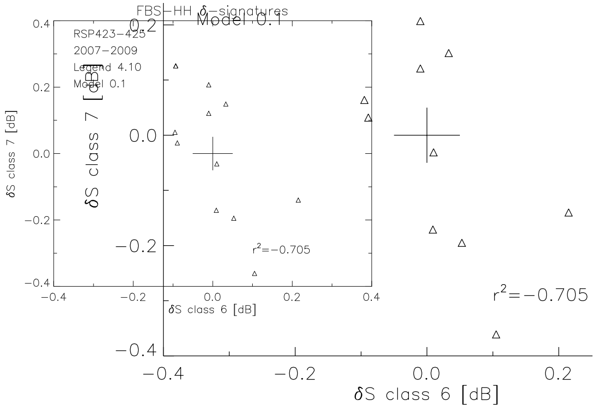
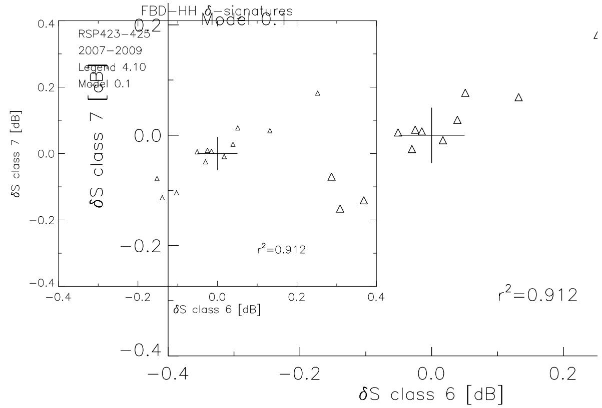








- ➢The δ-signatures of groups of classes are correlated.
- ➢This grouping depends on polarisation and season.

	Group 1		**Group 2**
2	*Riverine Forest*	1	*Forest*
3	Swamp Forest	6	Peat Swamp Pole Forest
7	*Peat Swamp Padang Forest*	8	*Secondary Forest*
16	*Burnt Peat Swamp Forest*	9	High Shrub
		10	Medium Shrub
		11	Ferns / Grass
		12	Alang-Alang
		13	Dryland Agriculture
		14	Wetland Agriculture
		15	Tree Plantation

FBS-HH grouping

Consistent time series methodology: *Between strip variability*

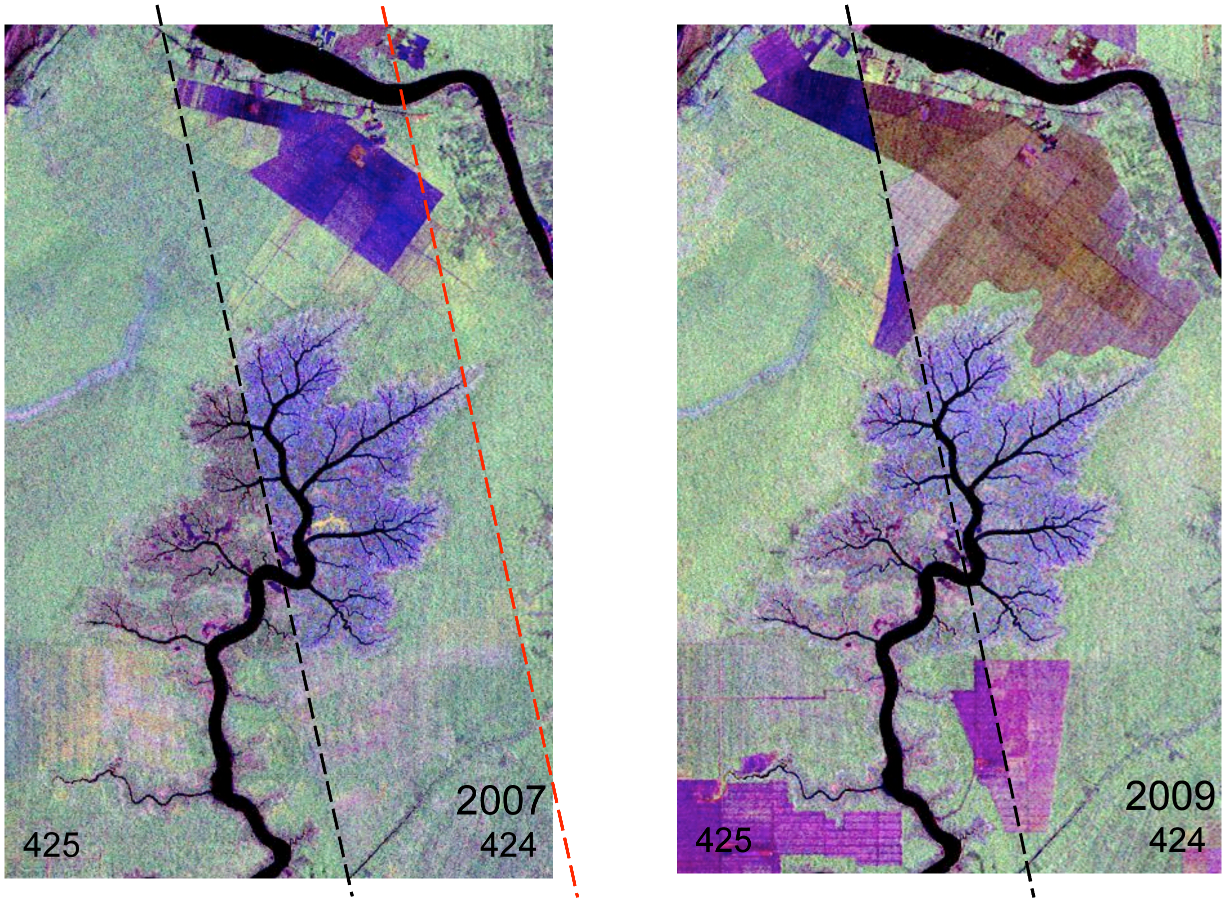


Figure 10ab. A 33km x 52 km section at the border of strips RSP424-425 in Sarawak for the years 2007 (left) and 2008 (right). In 2007 the contrast is noticeable in the mangrove area (centre image) and in 2009 in the young oil palm plantation (top) and older oil palm plantation (bottom). The seam between the RSP424 and RSP425 FBD 2007 strips had to be shifted to the right (red dashed line) because of a slightly different (approx. 10 km more eastwards) coverage.

Table 3. Results of differential signatures modelling *) using the parameter *m* as wetness indicator.

	RSP425	*m*	RSP424	*m*
2007-FBS	26Feb (cycle 9)	0.1	9Feb (cycle 9)	-0.2
2007-FBD	29Aug (cycle 13)	-0.4	12Aug (cycle 13)	-1.2
2009-FBS	3Mar (cycle 25)	+0.3	14Feb (cycle 25)	-0.1
2009-FBD	19Jul (cycle 28)	+1.0	17Aug (cycle 29)	**+3.5**

*) version B2D2-A2.2 420-426

Ref. Hoekman *et al.*, 2010, K&C, phase 2 final report

Consistent time series methodology: *Multi-year classification*

In case the Borneo 2007 map is based on 2007 data exclusively and the Borneo 2008 map is based on 2008 data exclusively, then errors in the 2007 map and errors in the 2008 map, both may result in the erroneous mapping of change.

This huge error propagation may be mitigated by techniques which do not treat 2007 data and 2008 data as being fully independent. An approach with three components is proposed with the following elements which are tentatively referred to as:

(i) probabilistic normalisation,
(ii) land cover change modelling and
(iii) incorporating spatial extent of change.

$$\boldsymbol{P}_{2007 \rightarrow 2008} = \boldsymbol{p}_{2008}\, \boldsymbol{M}\, \boldsymbol{p}_{2007}$$

$$\boldsymbol{M}_{a \rightarrow b} = f(i; ii; iii)$$

Consistent time series methodology: *Flow chart*

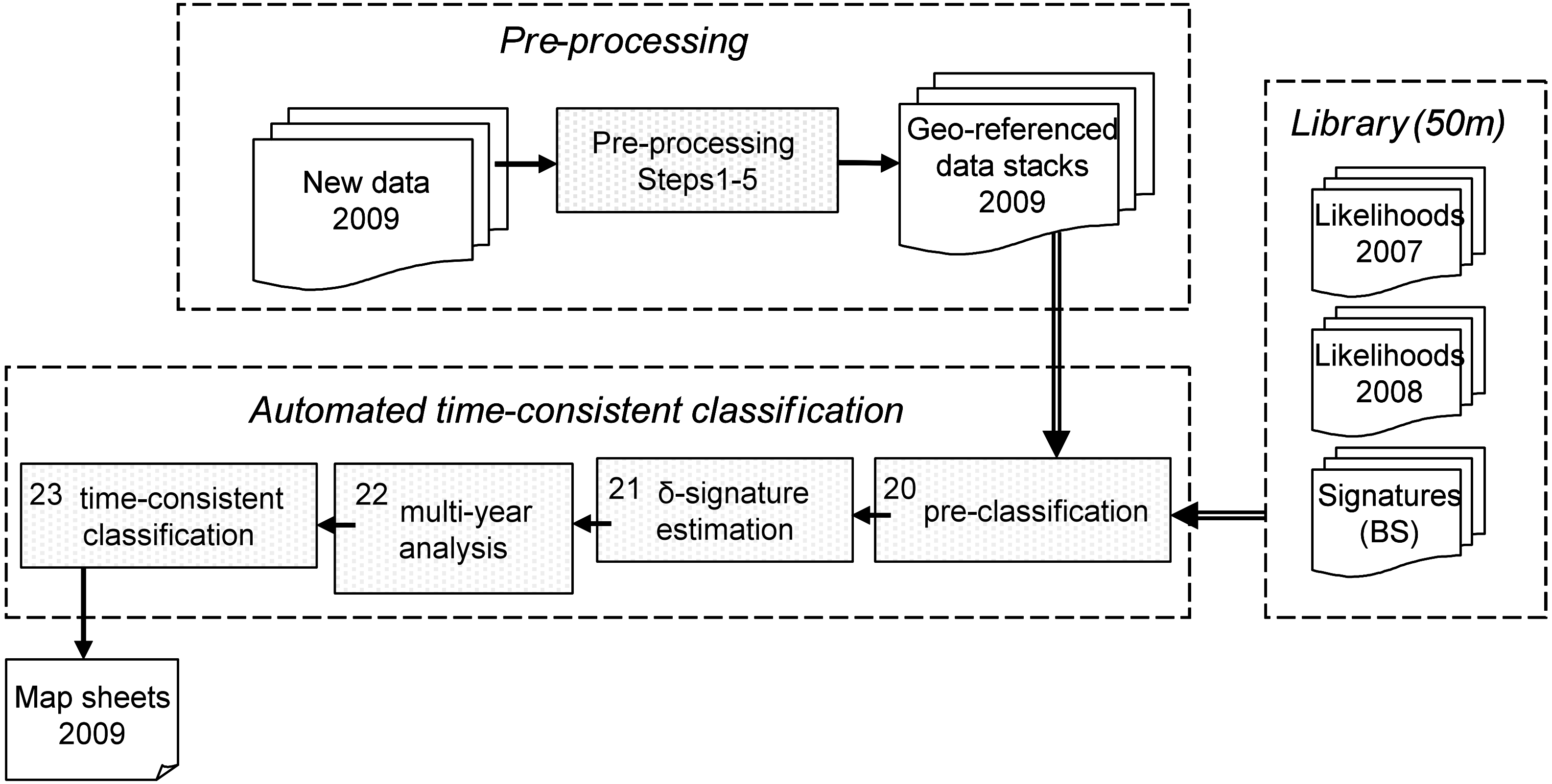
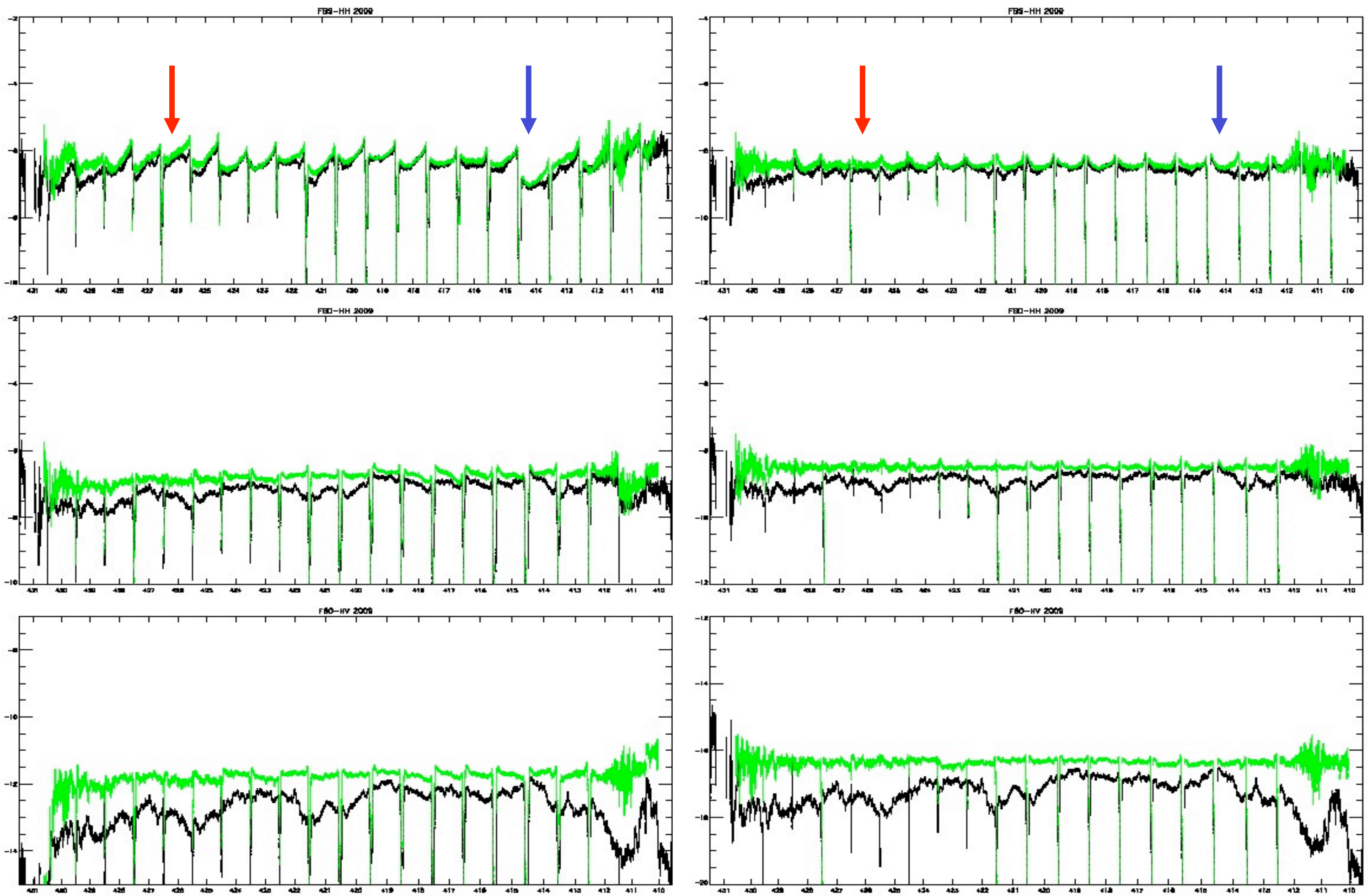


Figure 4. Simplified flow chart showing additional steps for automated time-consistent classification in relation to the steps already shown for single-year wide area mapping in Fig.1.

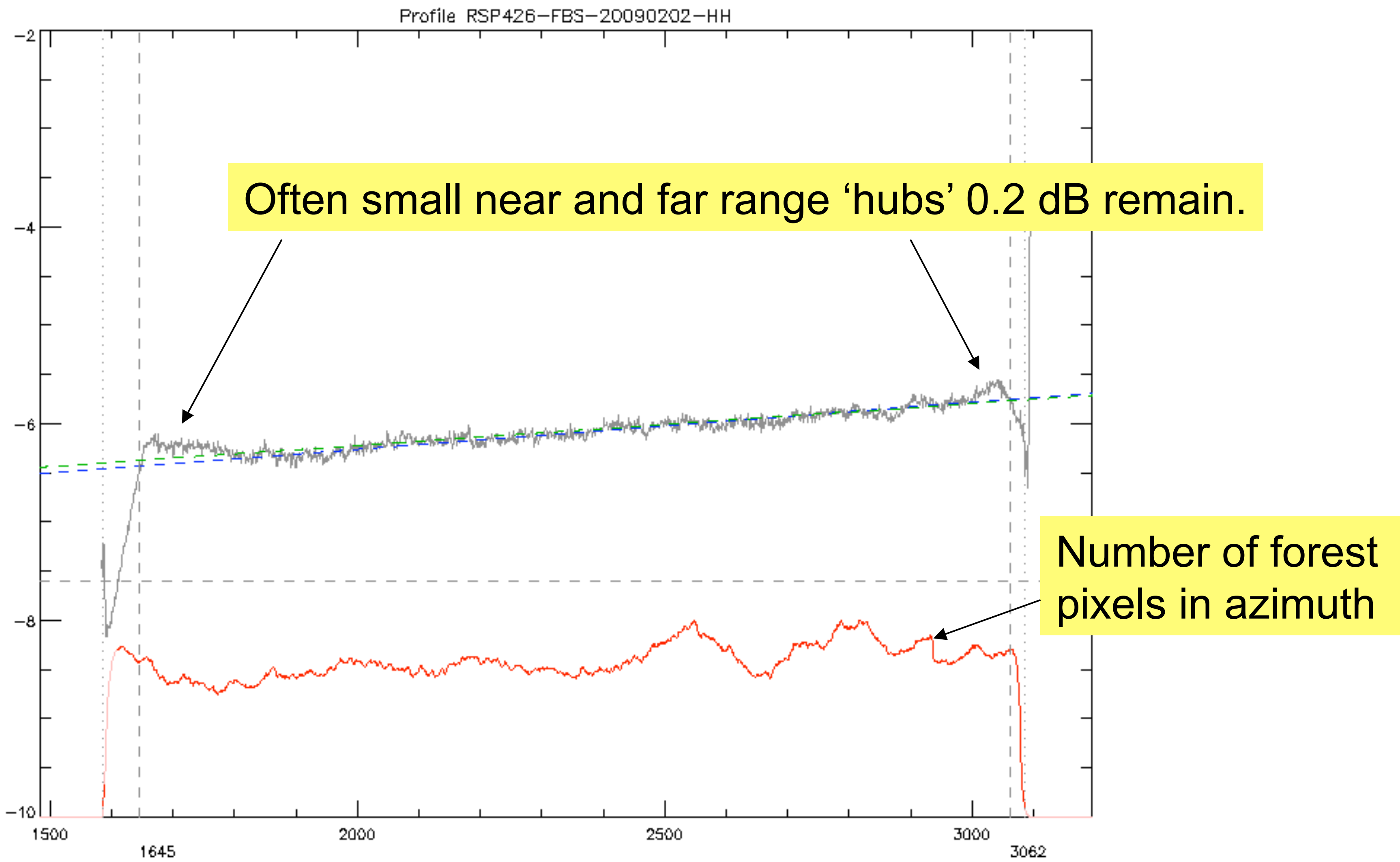
Intercalibration and mosaicking: *Borneo FB strips*

Range profiles before and after automated correction. Average land pixels (black) vs. average forest pixels (green).

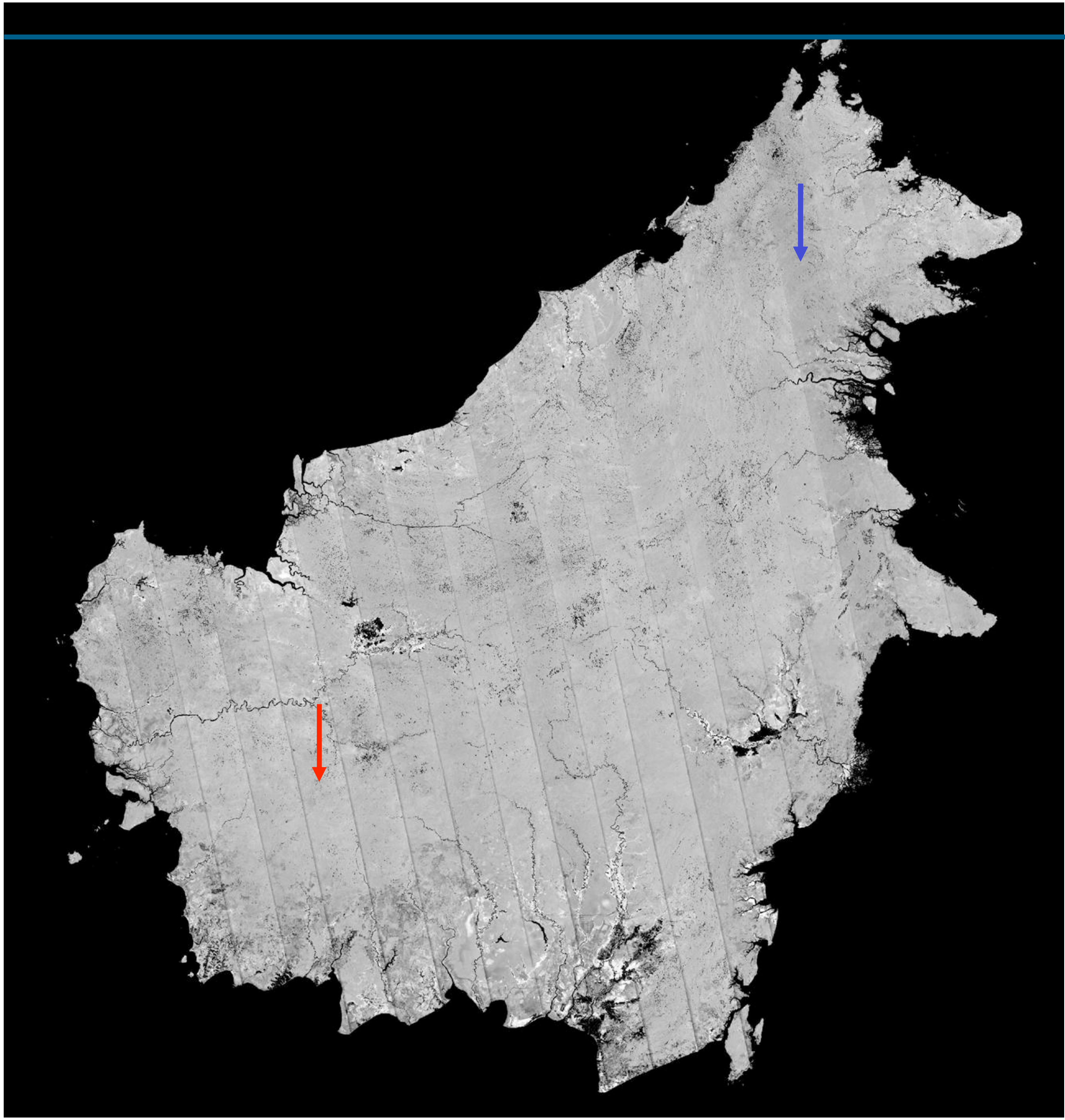


Intercalibration and mosaicking: *Range profile correction*

Automated 1st order polynomial fit and removal of edges



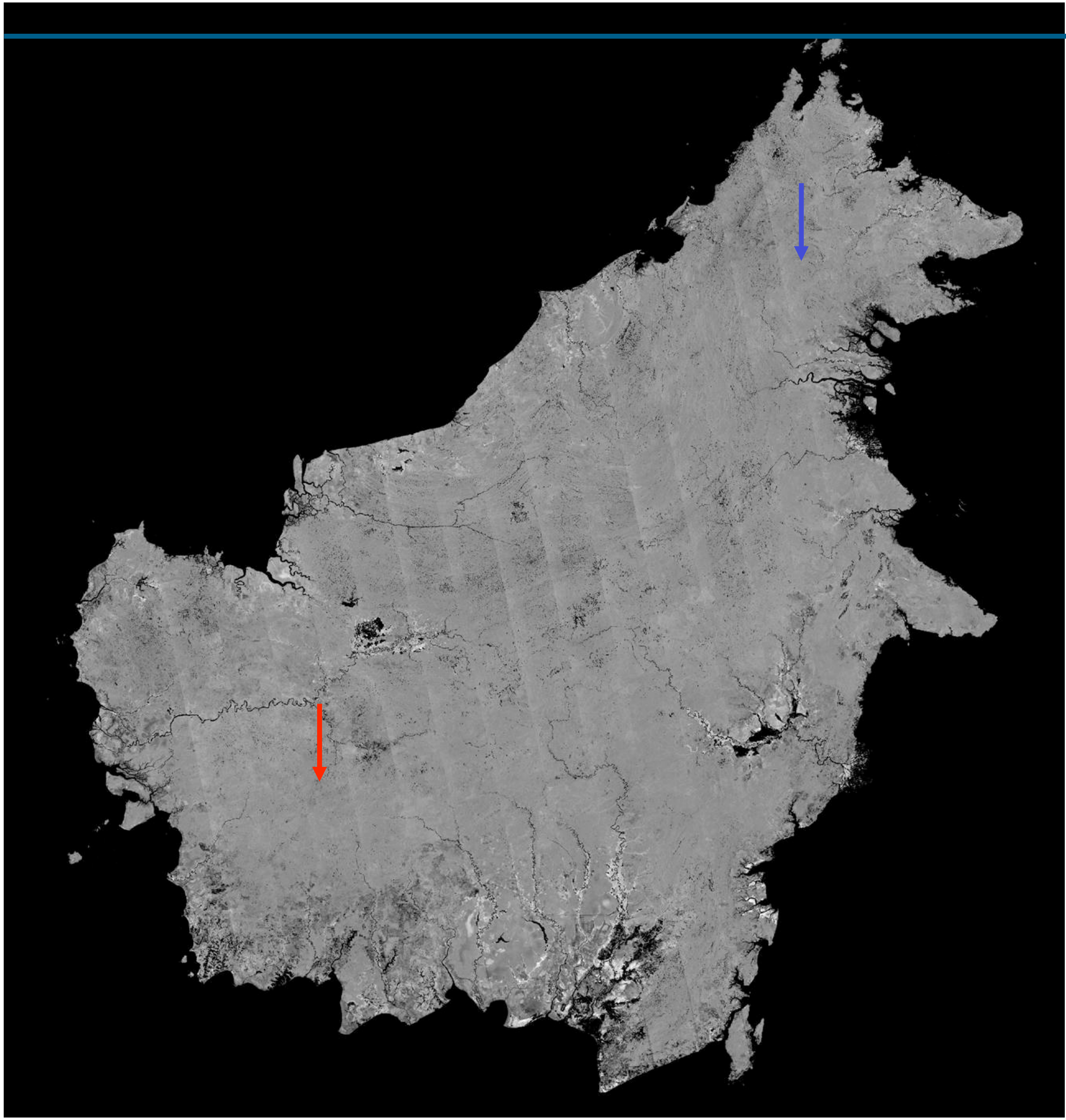
Intercalibration and mosaicking: *Borneo FBS-HH 2009 mosaic*



Mosaic *before* automated correction. Near range is put over far range. Near range anomalies are visible as black striping.

Blue arrow indicates strip with deviating backscatter level.

Intercalibration and mosaicking: *Borneo FBS-HH 2009 mosaic*



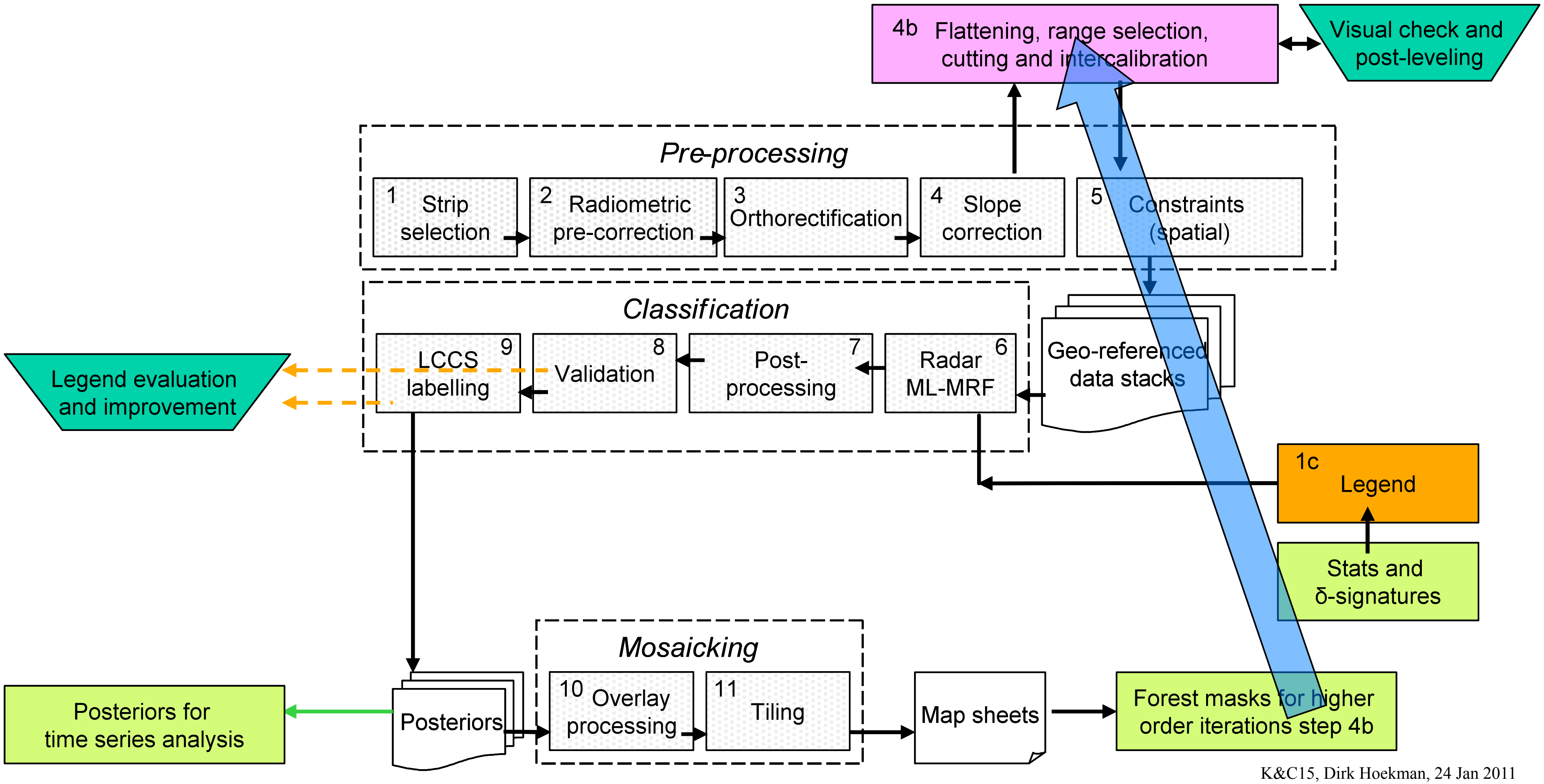
Mosaic *after* automated correction. Near range is put over far range. Near range '*hubs'* (2nd order effects) are visible as light striping.

The amplitude of these 'hubs' are less than .2 dB and can be corrected or removed when overlap is sufficient.

The levels of 2007, 2008 and 2009 are intercalibrated.

Consistent time series methodology: *Flow chart*

New mapping results are used to improve intercalibration of new data, using stable objects



Consistent time series methodology: *Examples*

Example 1: Oil palm plantation development in Sarawak

Example 2: Peat swamp regeneration in Central Kalimantan

Consistent time series methodology: *Ex. plantation development*

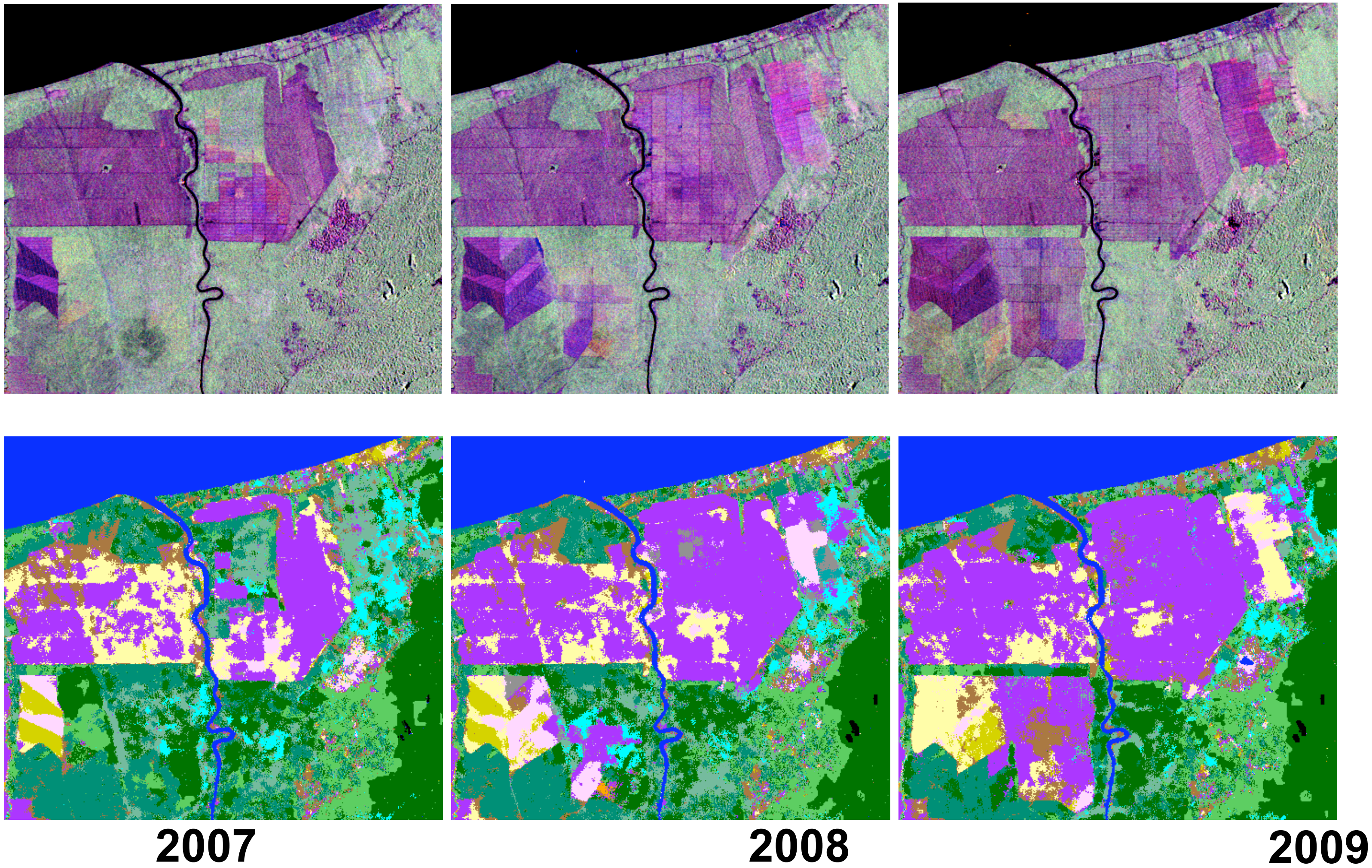
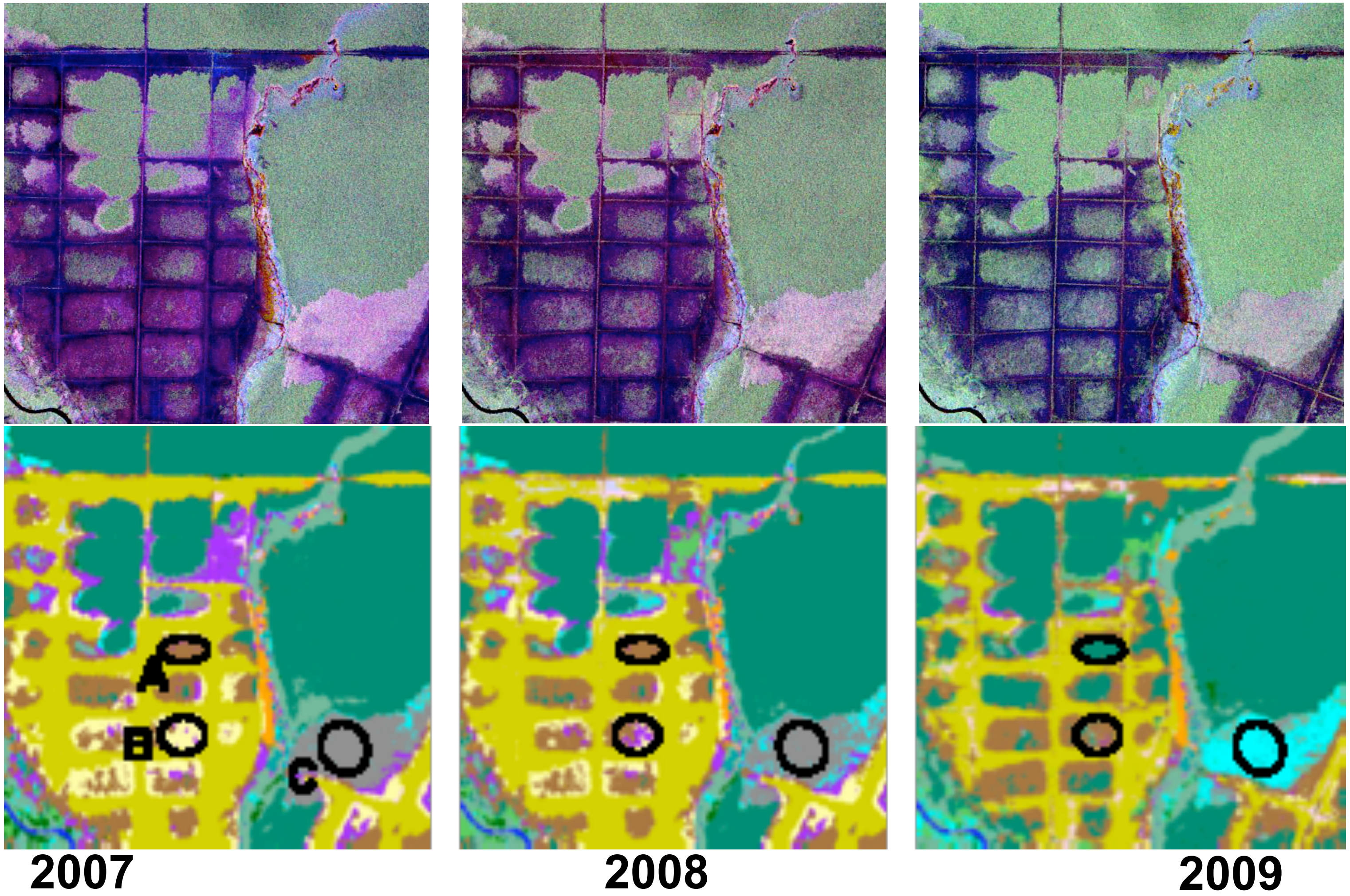
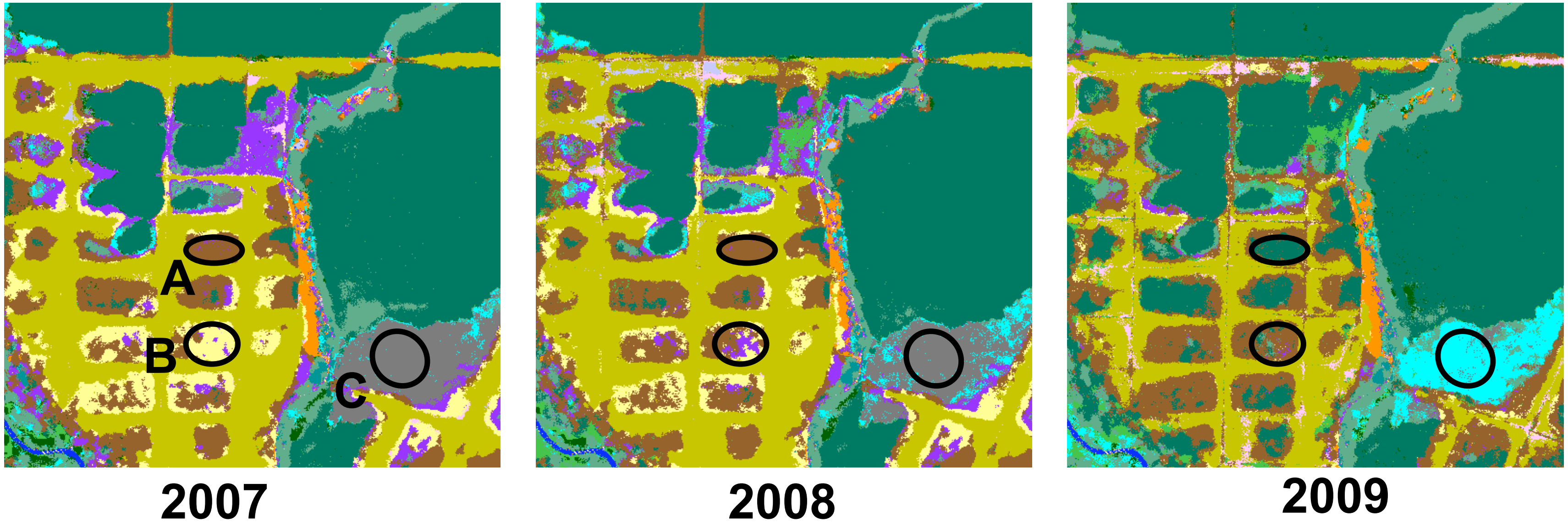


Figure 11. Consistent time-series result (RSP422). ALOS PALSAR is very useful for the detection of changes in forest and land cover. The systematic data acquisition strategy implemented by JAXA allows annual updates of land cover maps over wide areas, such as Borneo island. The purple colour shows the development of oil palm plantations in an approximately 25 km wide area in the state of Sarawak, Malaysia. (Top row) radar data with same colour coding as in all previous figures; (bottom row) maps in colours according the legend shown in Table 2.

Consistent time series methodology: *Example BOR-3*



Consistent time series methodology: *Example BOR-3*

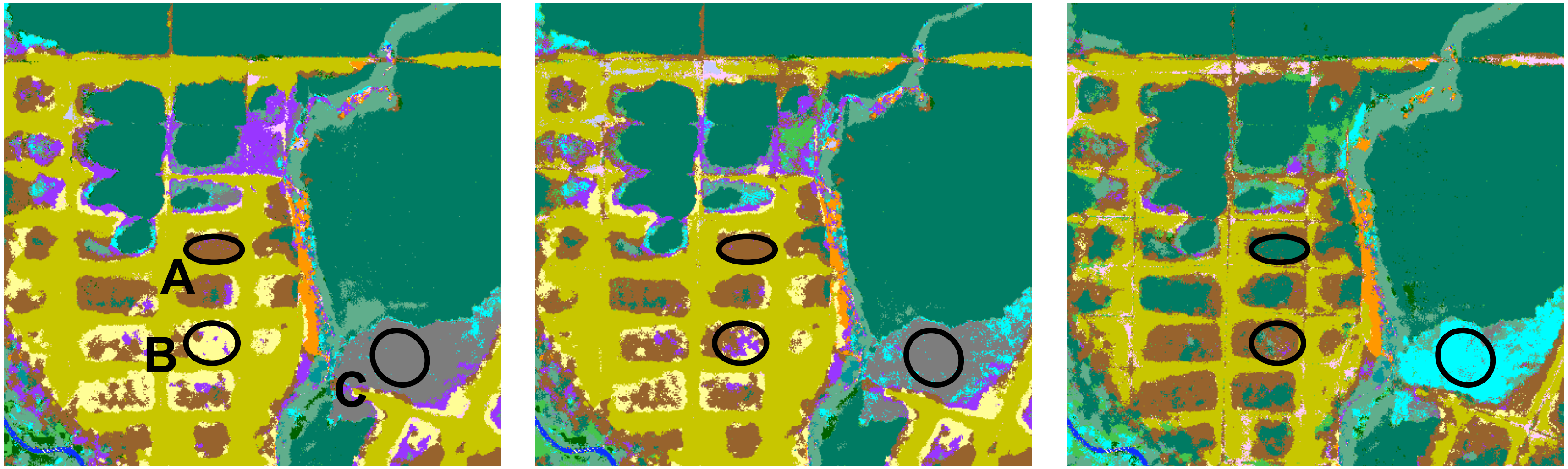


- Peat swamp pole forest
- High shrub
- Ferns / grass
- Grasslands
- Tree cover, burnt
- Riverine forest

Results: GEO FCT validation site BOR-3, RSP 421&422

This area is covered with regenerating peat swamp forest. Two cases of consistent succession stages can be observed. In the left the area of ferns (olive green) reduces; grass (yellow) is replaced by high shrubs (brown) and high shrubs by peat swamp forest (blue green). In the bottom left a (seasonally flooded) area of burnt peat swamp forest (grey) changes into riverine shrubs (cyan).

Consistent time series methodology: *Example BOR-3*



2007 2008 2009

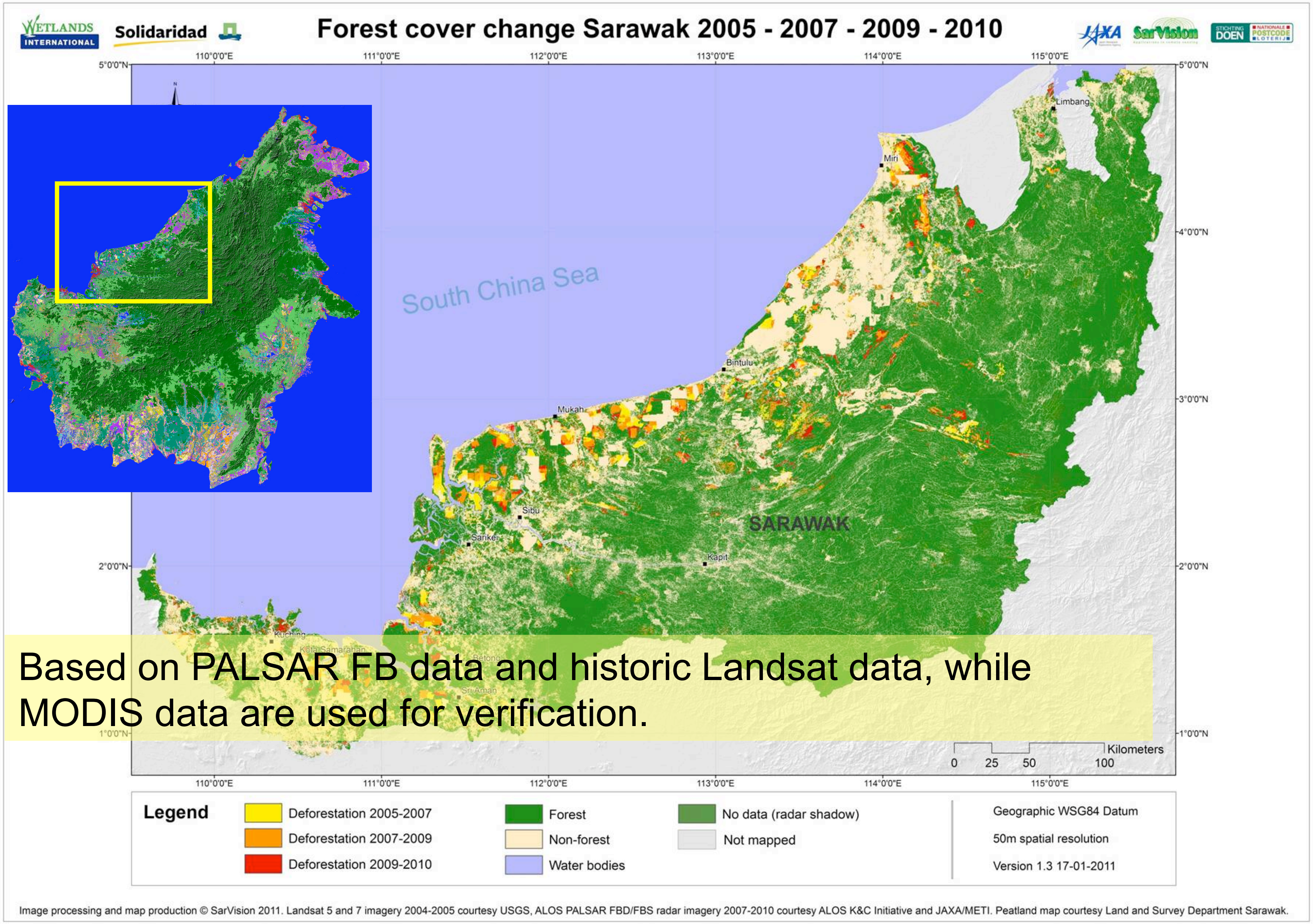
L-HV gamma [dB]

	2007	2008	2009
A	-19.1	-18.7	-17.4
B	-20.5	-19.1	-17.6
C	-16.9	-16.2	-16.1

(1) Land cover type can change even though backscatter does not change and (2) backscatter can change even though land cover type does not change.

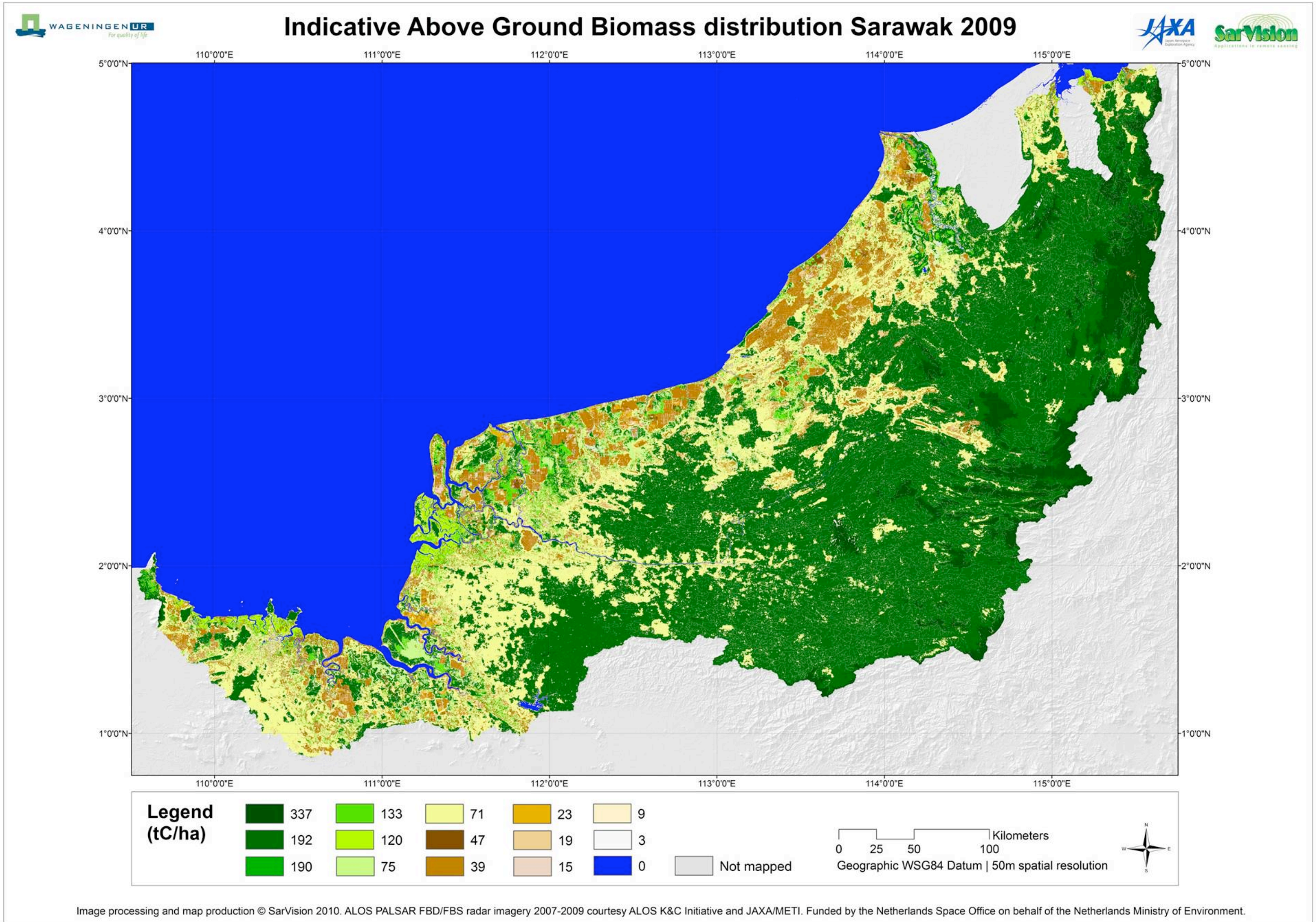
In both cases this can be the correct interpretation which follows from the change in radar signatures due to local and temporal environmental factors

Consistent time series applications: *Forest cover change*



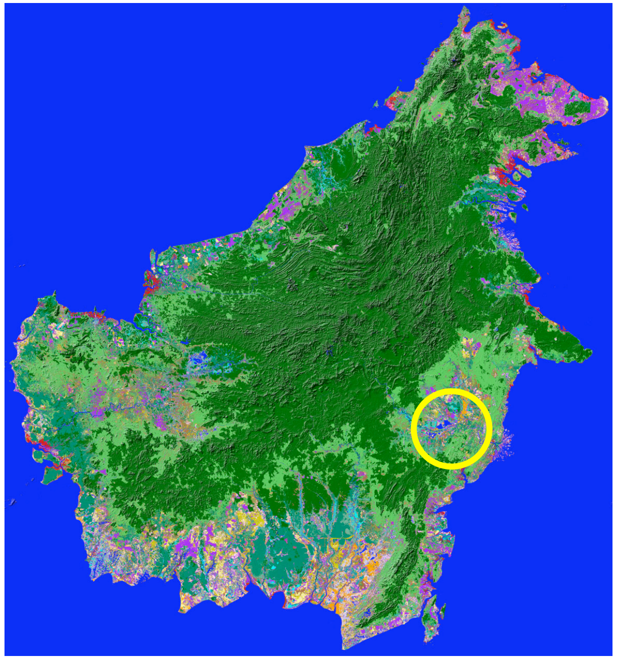
Based on PALSAR FB data and historic Landsat data, while MODIS data are used for verification.

Consistent time series applications: *Biomass monitoring*



Wetlands WB series: *Mahakan watershed, East Kalimantan*

- 20 images (RSP088) available
- Study of hydraulics Mahakan river basin (Hidayat, WU/LIPI)
- Use of PALSAR for flood mapping
- Problem area for FB classification because of irregular flooding regime with short discharge peaks around December and May



Wetlands WB series: *Mahakan watershed, dry conditions*

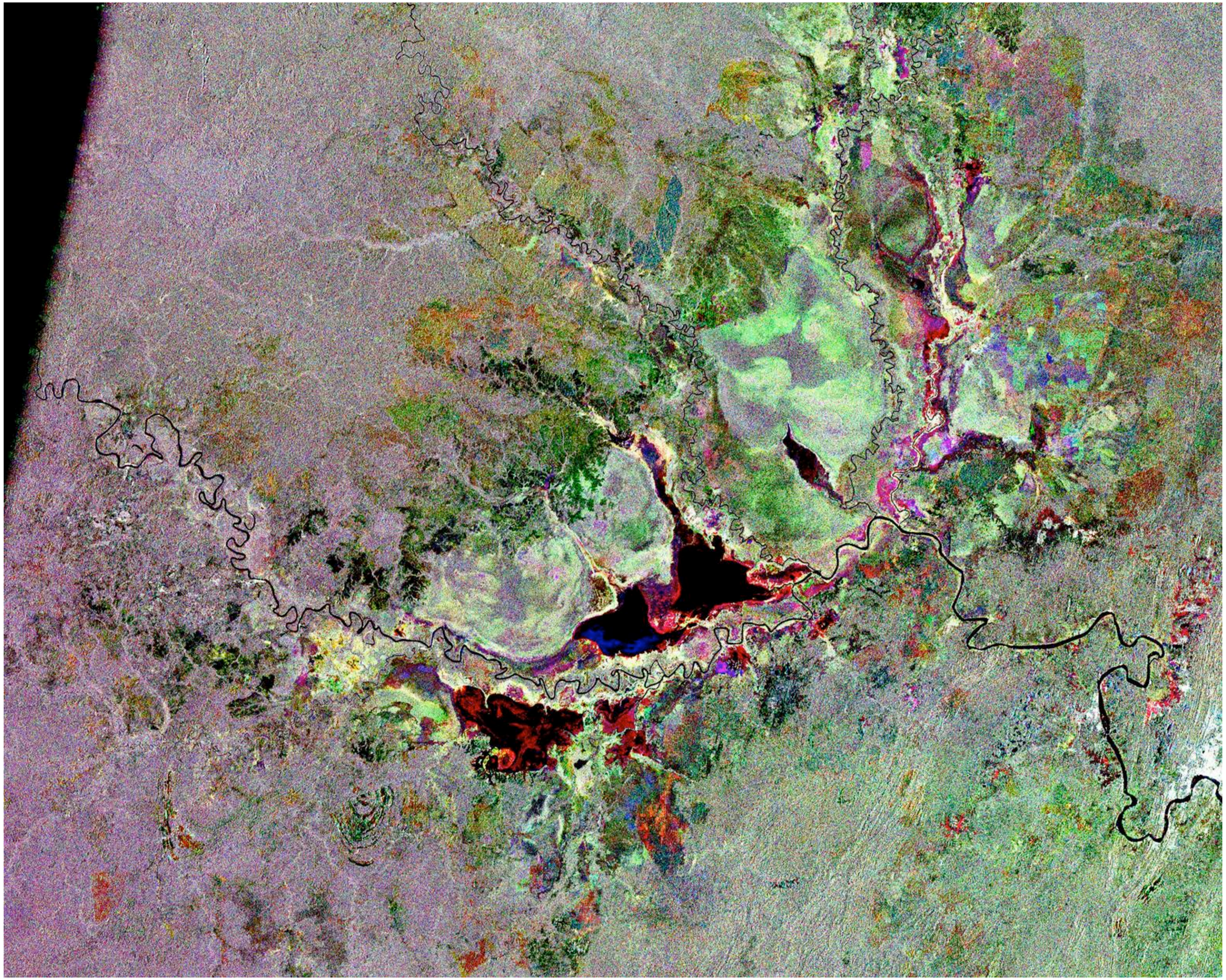


Figure. Mahakan floodplain; 187km x 150km; Dry conditions; WB **20070919** **20090509** **20090924**

Wetlands WB series: *Mahakan watershed, floodplains*

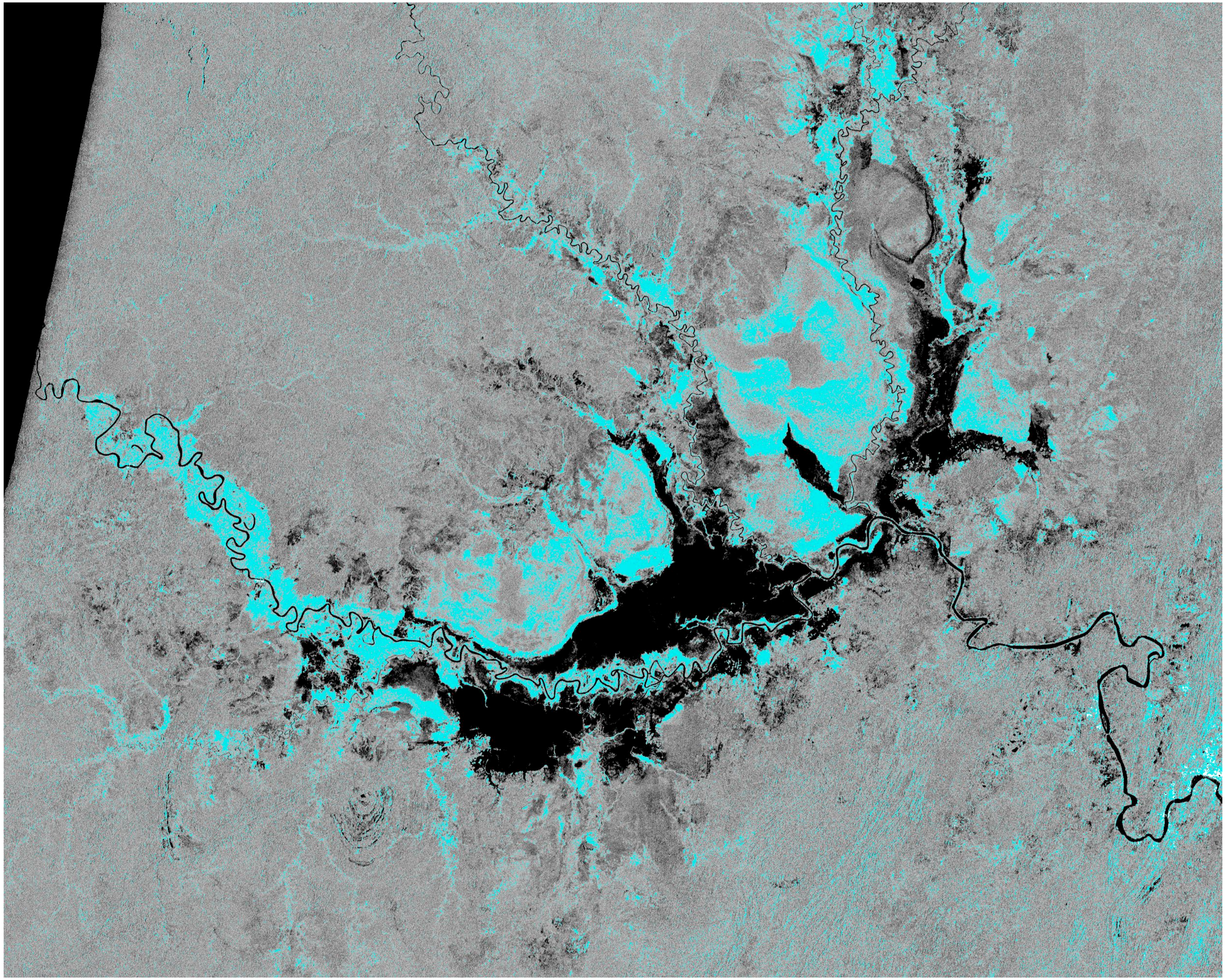
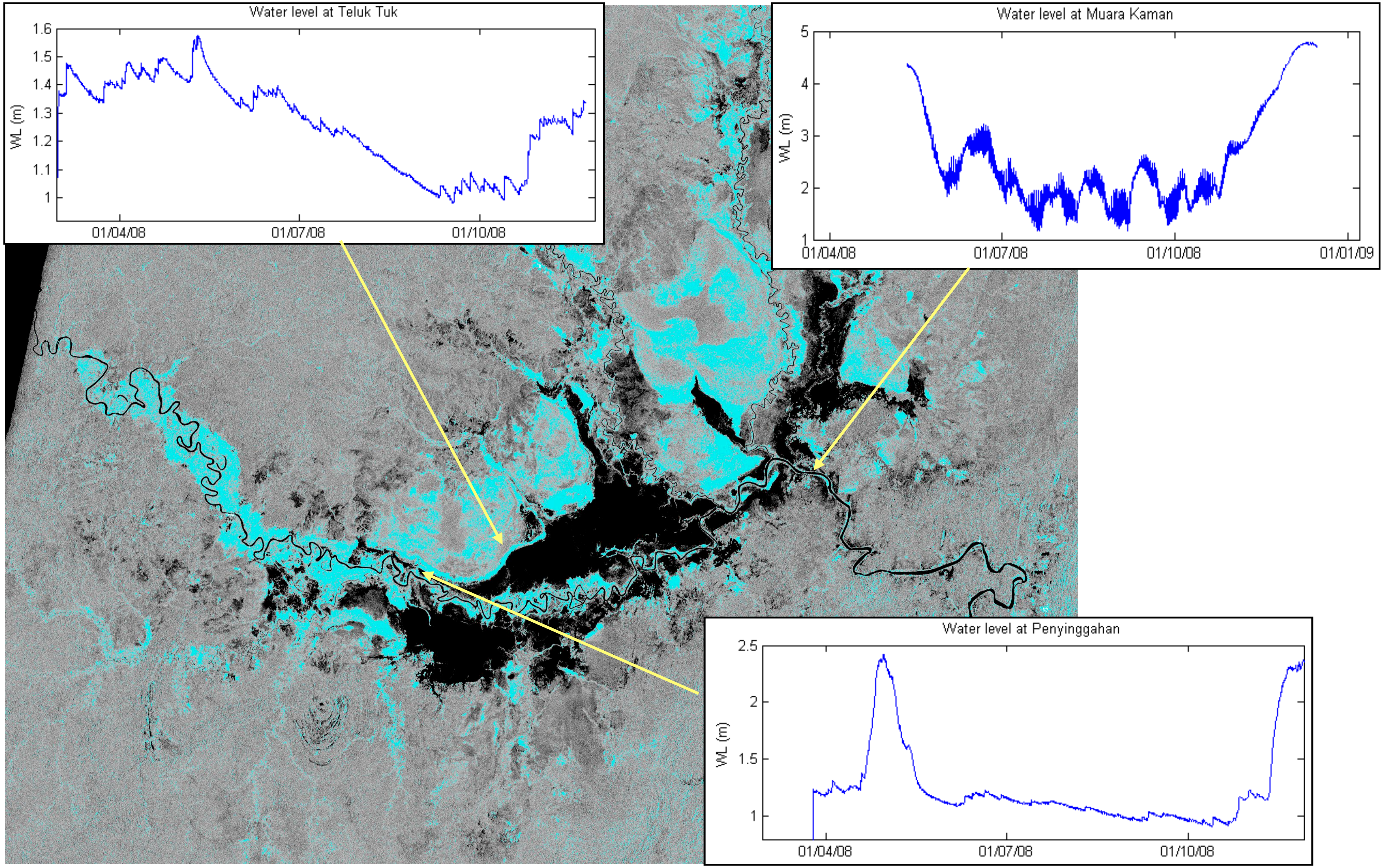
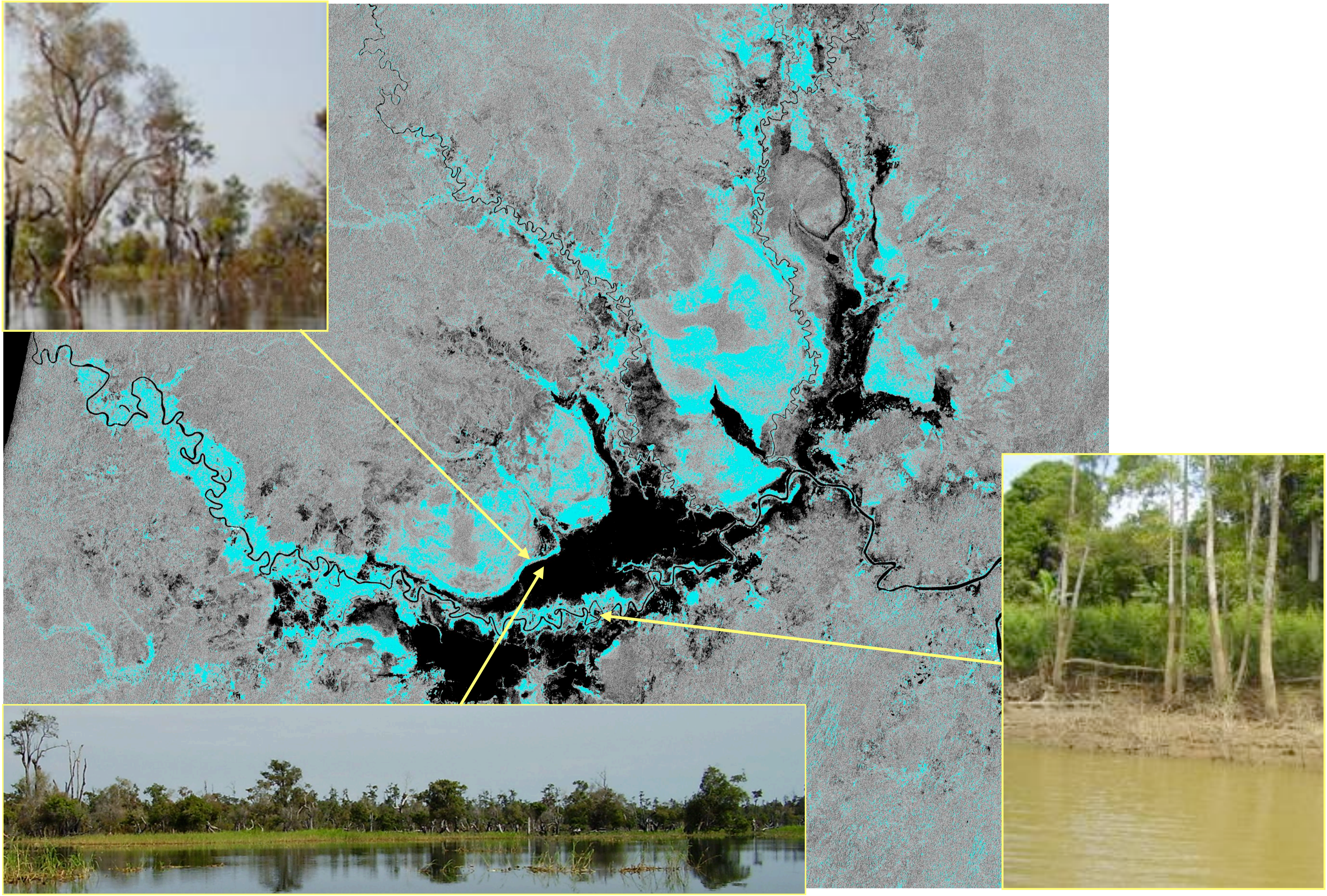


Figure. Mahakan floodplain; 187km x 150km; Wet conditions
WB **20070504 - 20081222 - 20100209**

Wetlands WB series: *Mahakan watershed, water levels*



Wetlands WB series: *Mahakan watershed, vegetation*



Wetlands WB series: *Mahakan watershed, temporal analysis*

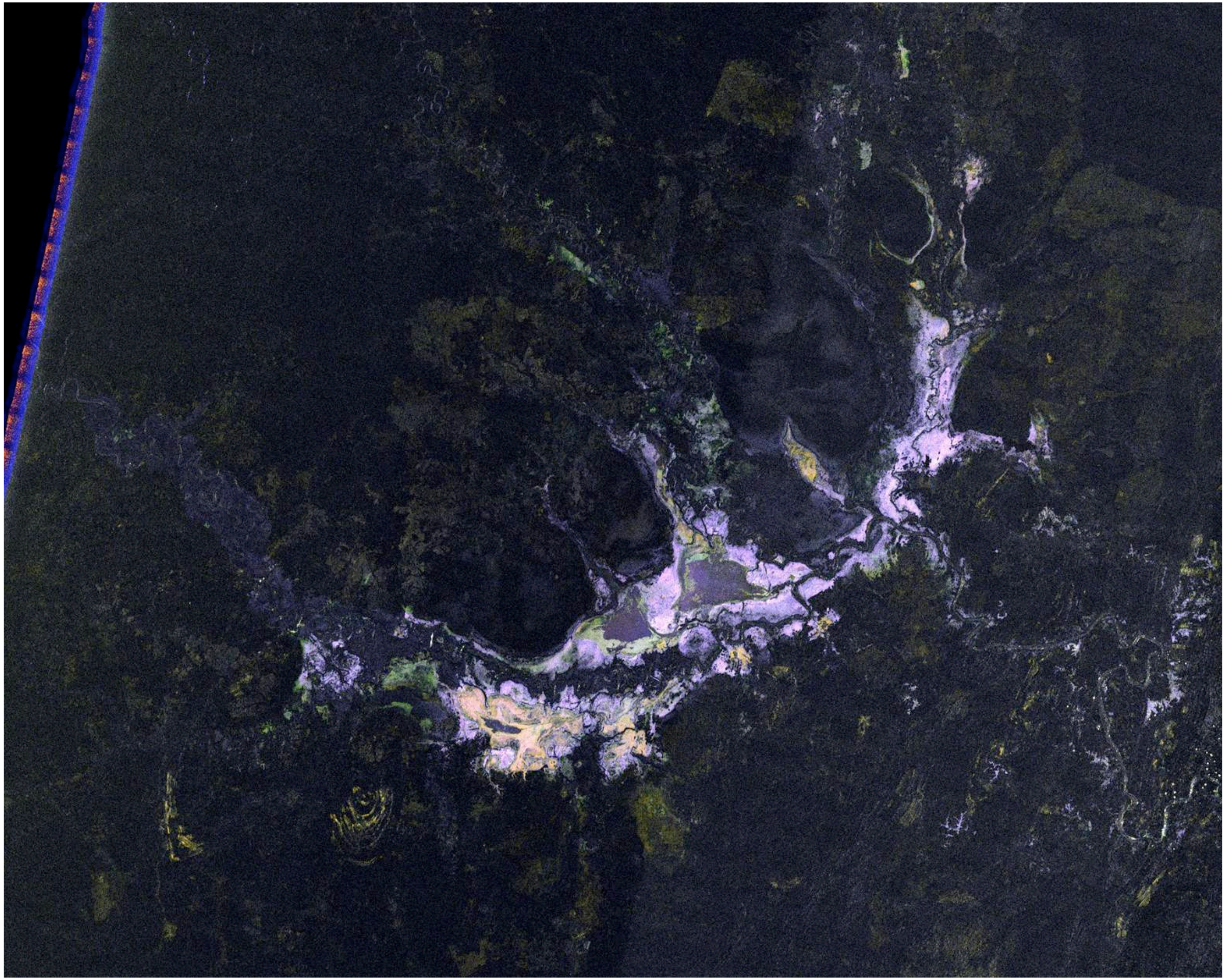
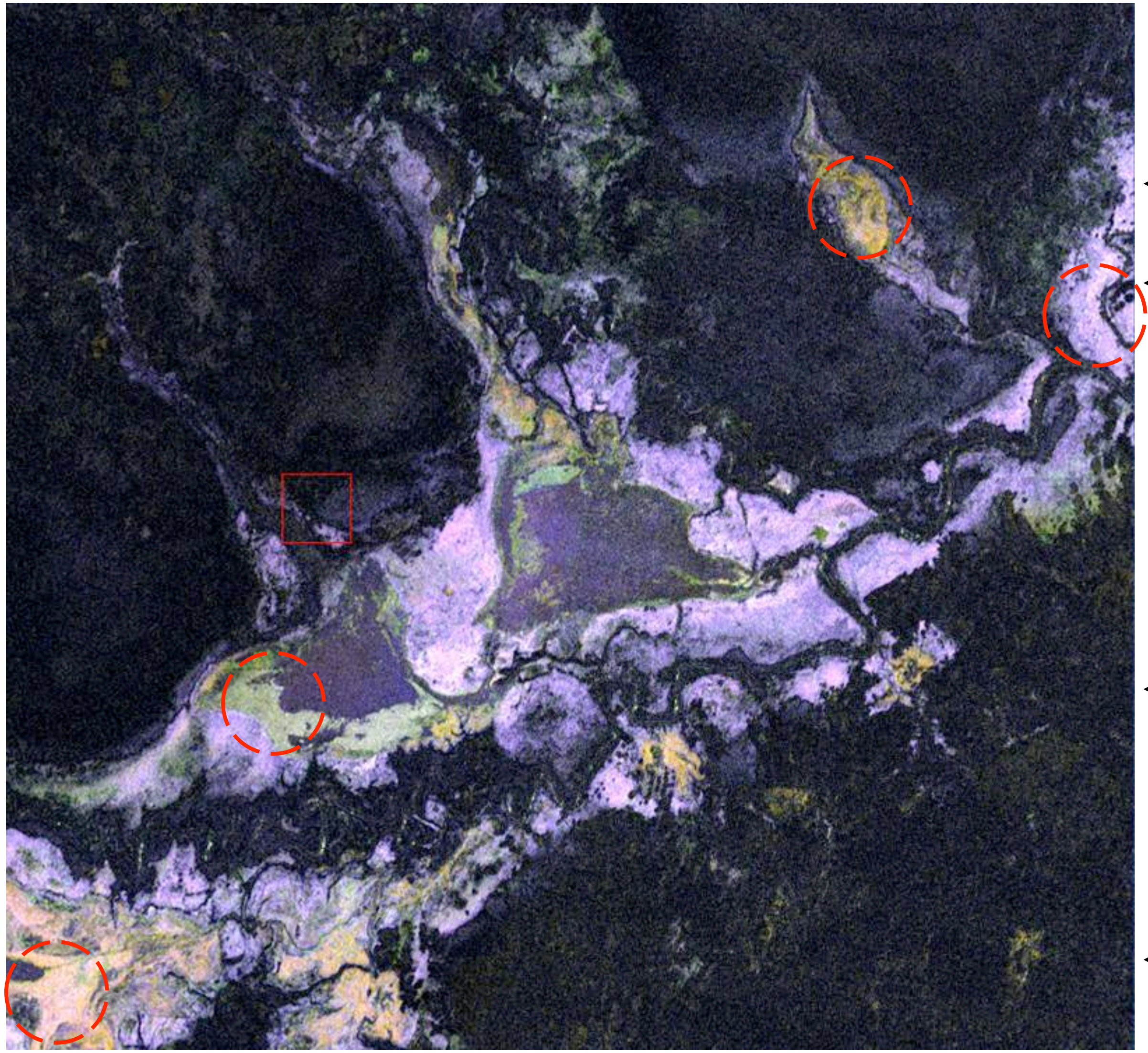


Figure. Mahakan floodplain; 187km x 150km; Irregular features or "Map of what cannot be mapped"; Result of temporal analysis of 20 WB images of period 20070319 until 20100927.

Wetlands WB series: *Mahakan watershed, temporal analysis*

Aquatic vegetation and irregularly inundated land can be mapped with WB, but not with FB



Orange: water hyacinth

Purple: irregularly inundated shrubland

Green: reeds

Yellow: rice growing areas in years when flooding is not too high

Wetlands WB series: *"Calenders"*

Season	J	F	M	A	M	J	J	A	S	O	N	D
2007			n		f			n	n		f	f
2008		n	n		f	n		n	n			f
2009					d				d			
2010		f	n		f	d			d			

Floodplain Mahakan
flooded / non-flooded / dry

Season	J	F	M	A	M	J	J	A	S	O	N	D
2007			n		f			n	n		n	n
2008		n	n		f	n		n	n			f
2009					n				n			
2010		f	n		f	n			n			

Irregularly inundated shrubland
flooded / non-flooded

Season	J	F	M	A	M	J	J	A	S	O	N	D
2007			n		n			n	n		n	n
2008		r	n		n	n		n	n			n
2009					n				r			
2010		n	n		n	n			n			

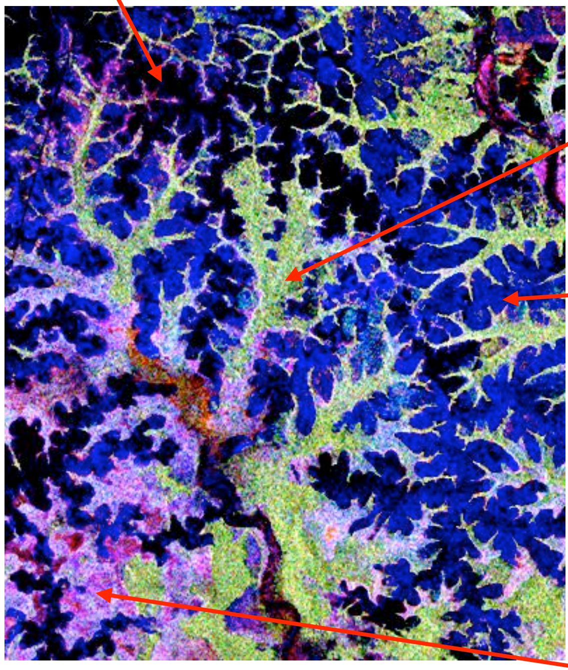
Reeds
reed / non-reed

Fieldwork West Kalimantan. Typical land cover types. Selection of Field photos and appearance on the Palsar detail.

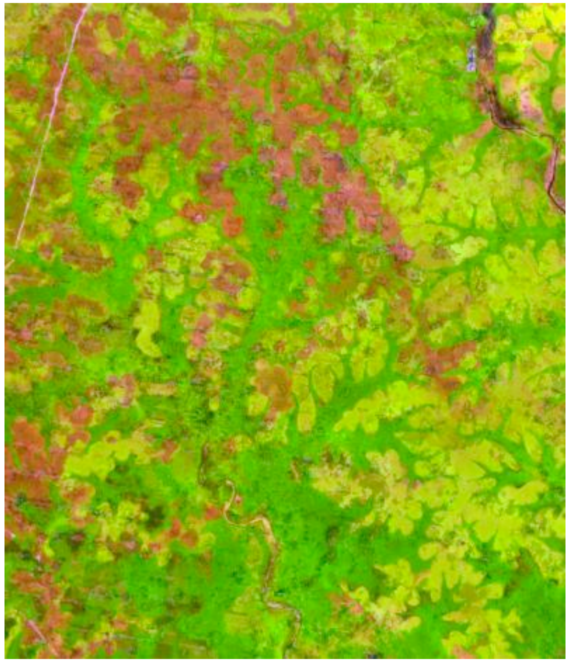
black areas: sand, higher areas,
often covered with low/grassy vegetation

green areas:
lowland with peat swamp forest

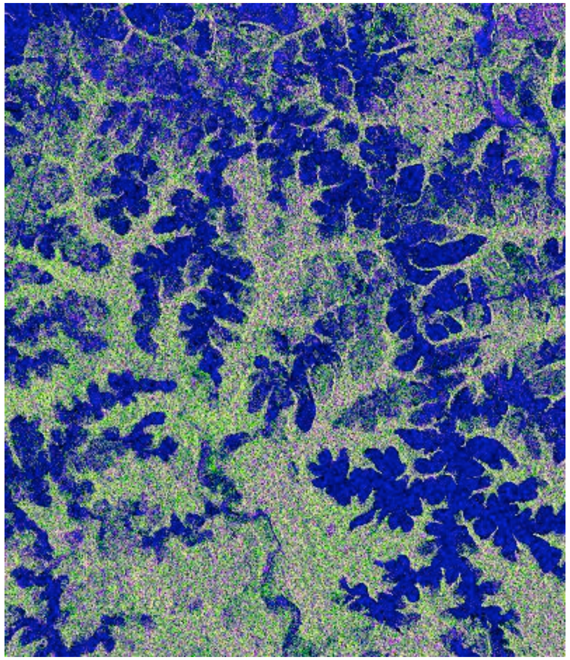
blue areas: ferns/grass



magenta
areas:
shrubland

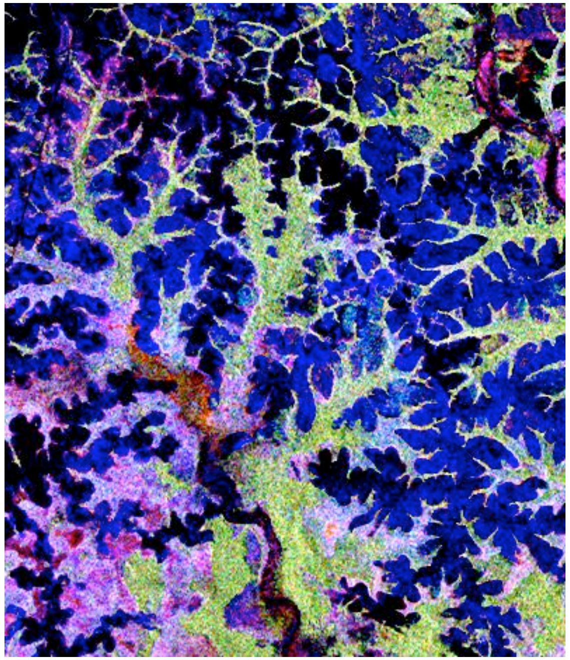


a

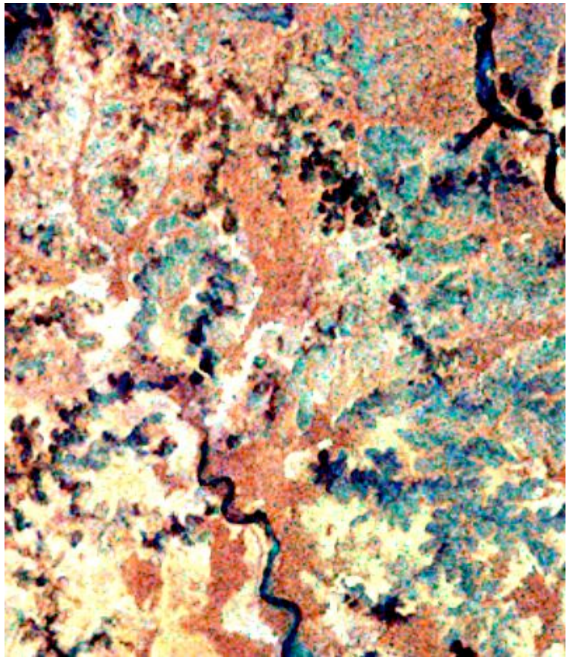


b

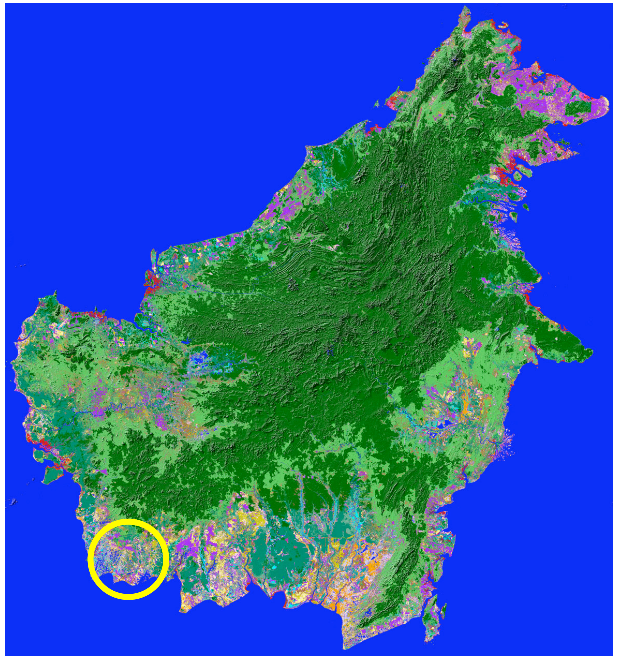
Plate 1. The West-Kalimantan fieldwork area is located in the southern parts of Fine Beam strips RSP427-429. A detail of 20x23 km is shown: a) Landsat 2009 RGB=bands543, b) Radarsat 2009 RGB=VV/HV/VV-HV; c) PALSAR 2009 RGB=FBD-HH/FBD-HV/FBS-HH; d) PALSAR WB1 2007-2010 (24 images) RGB=min/mean/max.



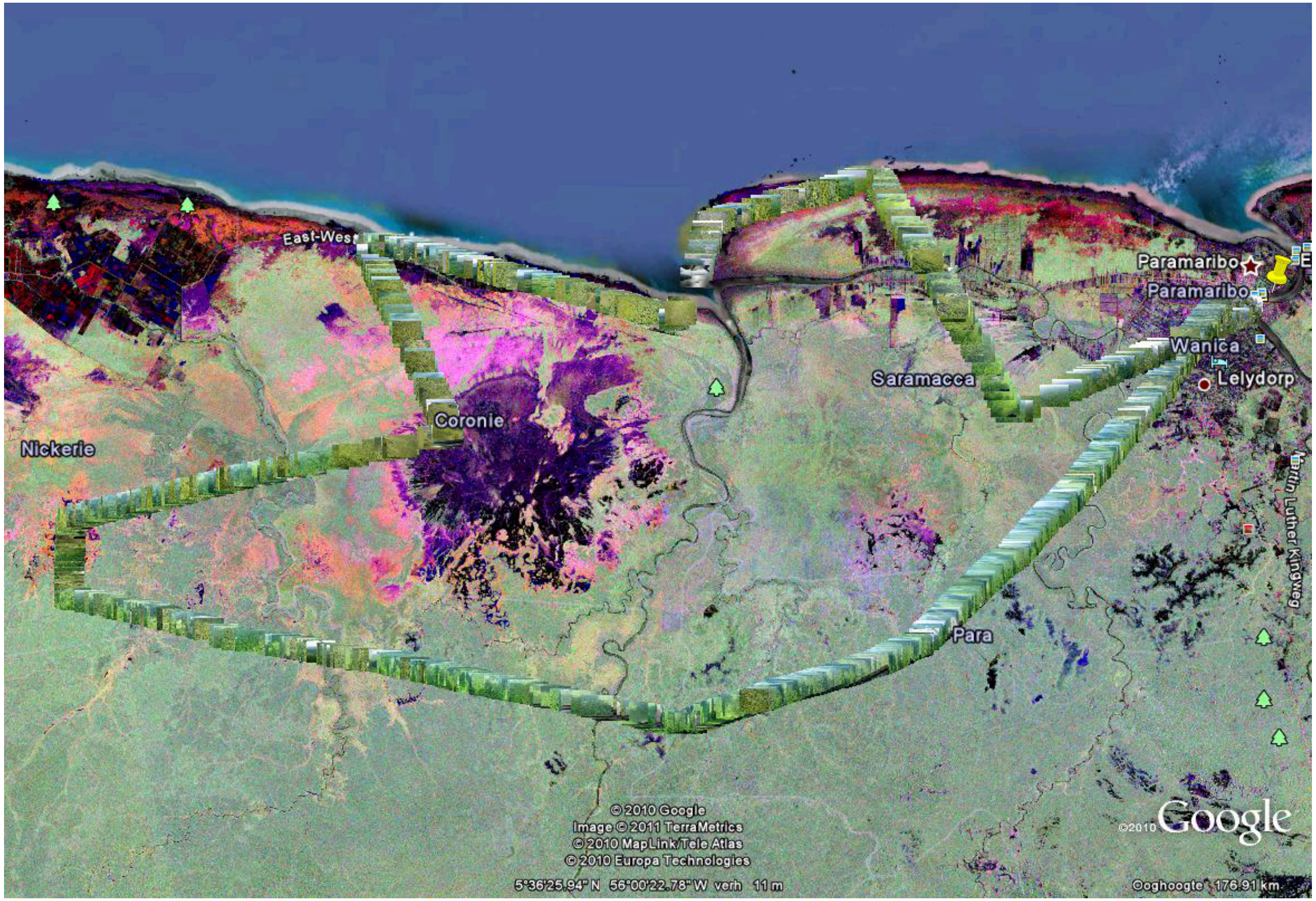
c



d



Suriname FBS-FBD 2010 mosaic of coastal plain and northern forests displayed in Google Earth. First aerial photo survey yielded 1100 photo's.



Wide-area mapping Suriname: *Aerial photo flights*

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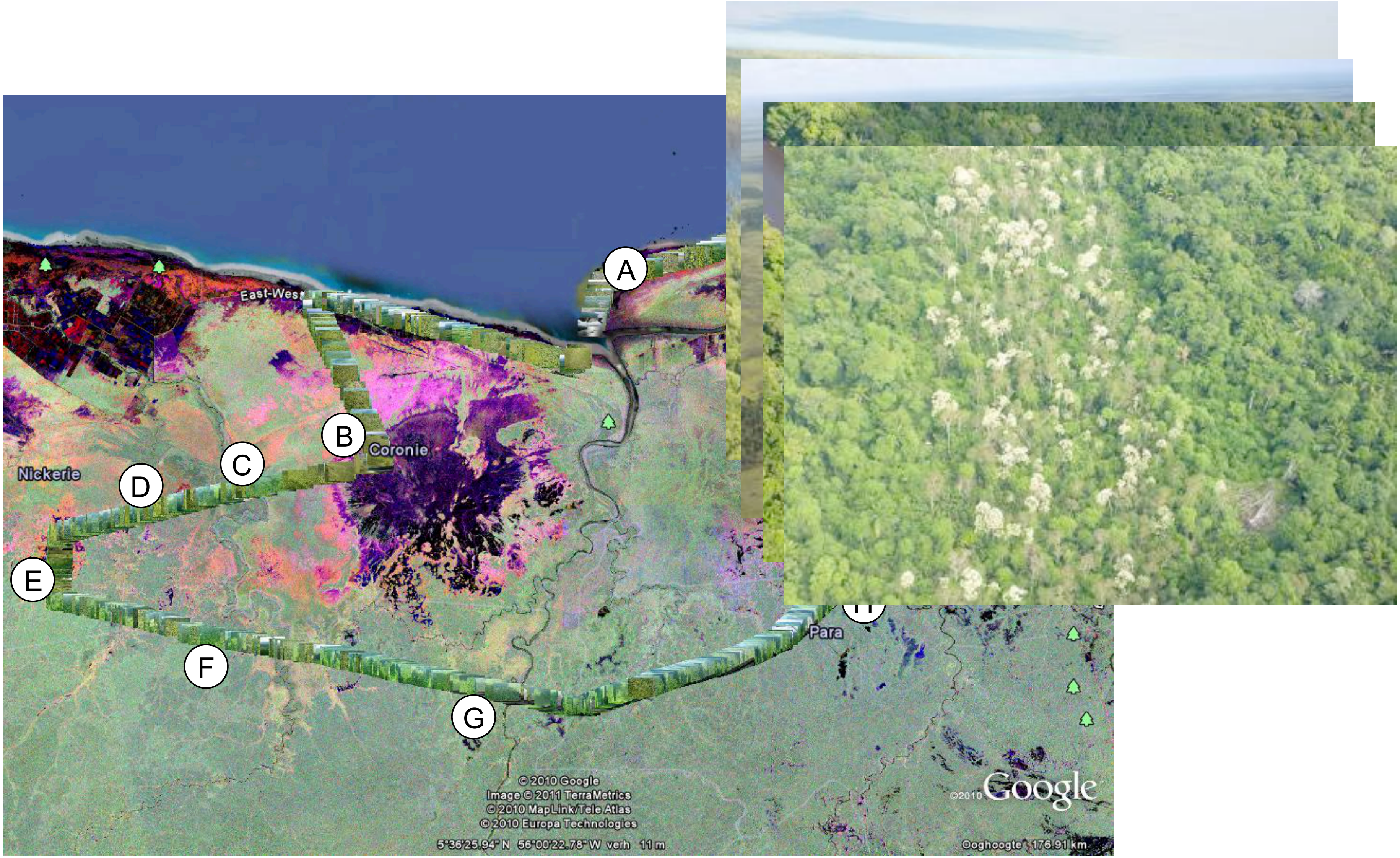
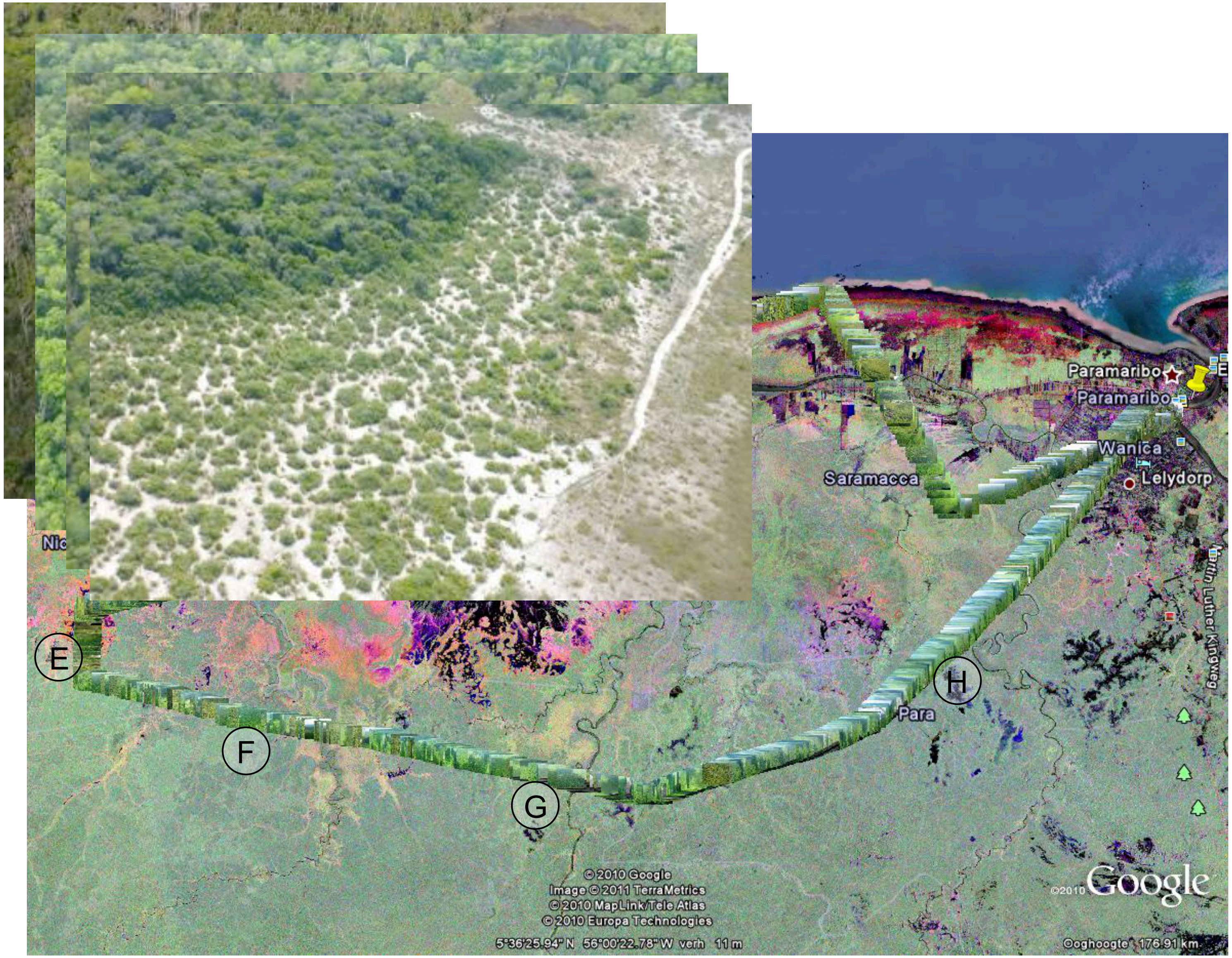
SarVision



Wide-area mapping Suriname: *Aerial photo flights*



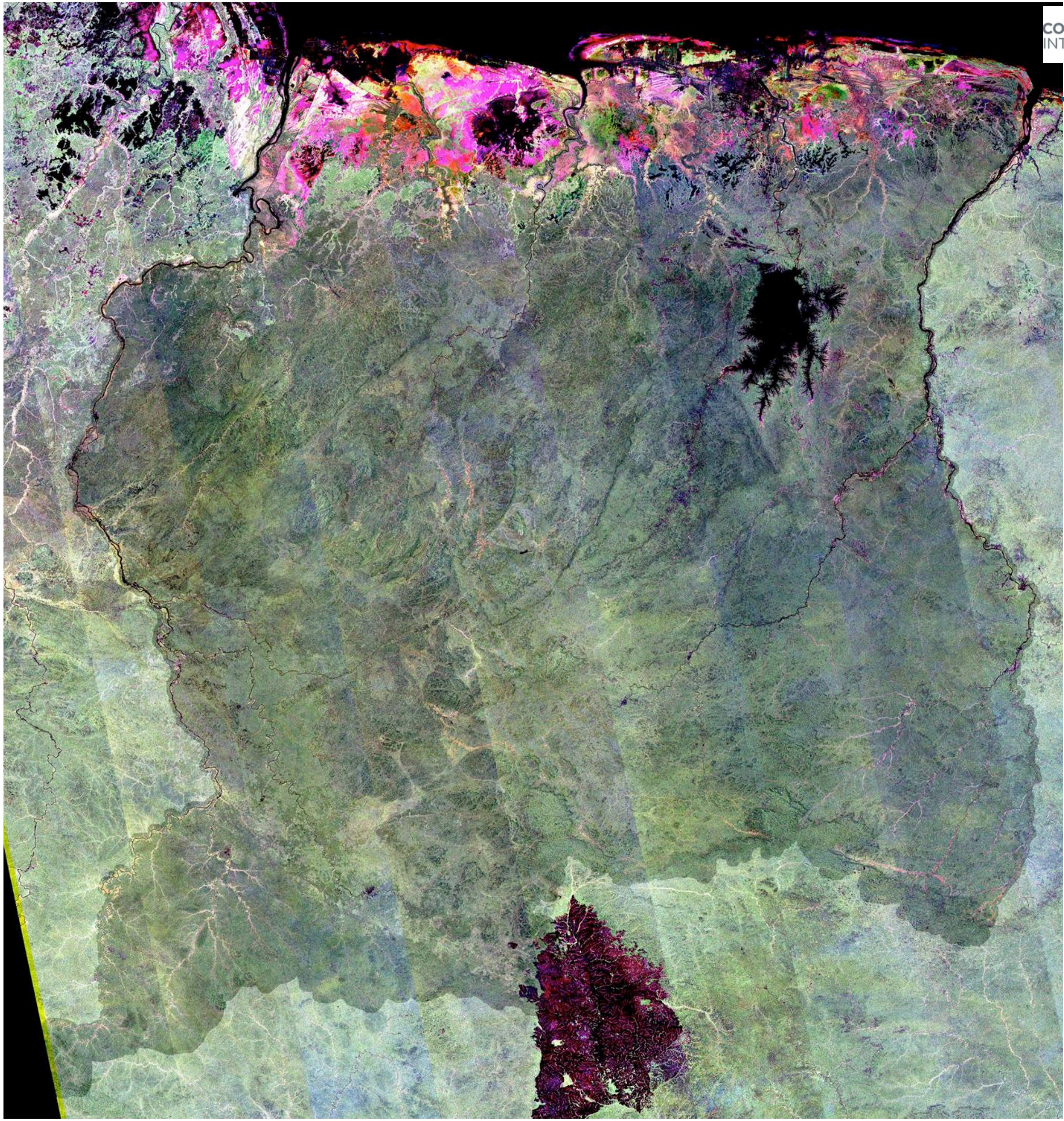
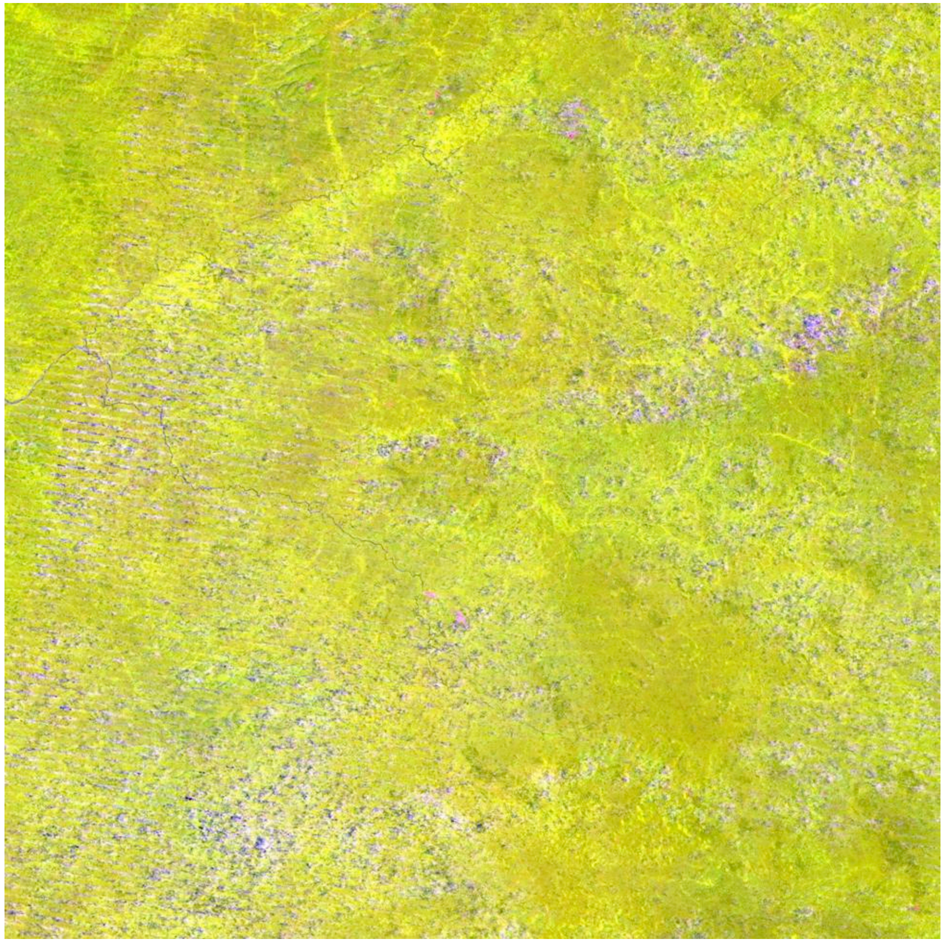


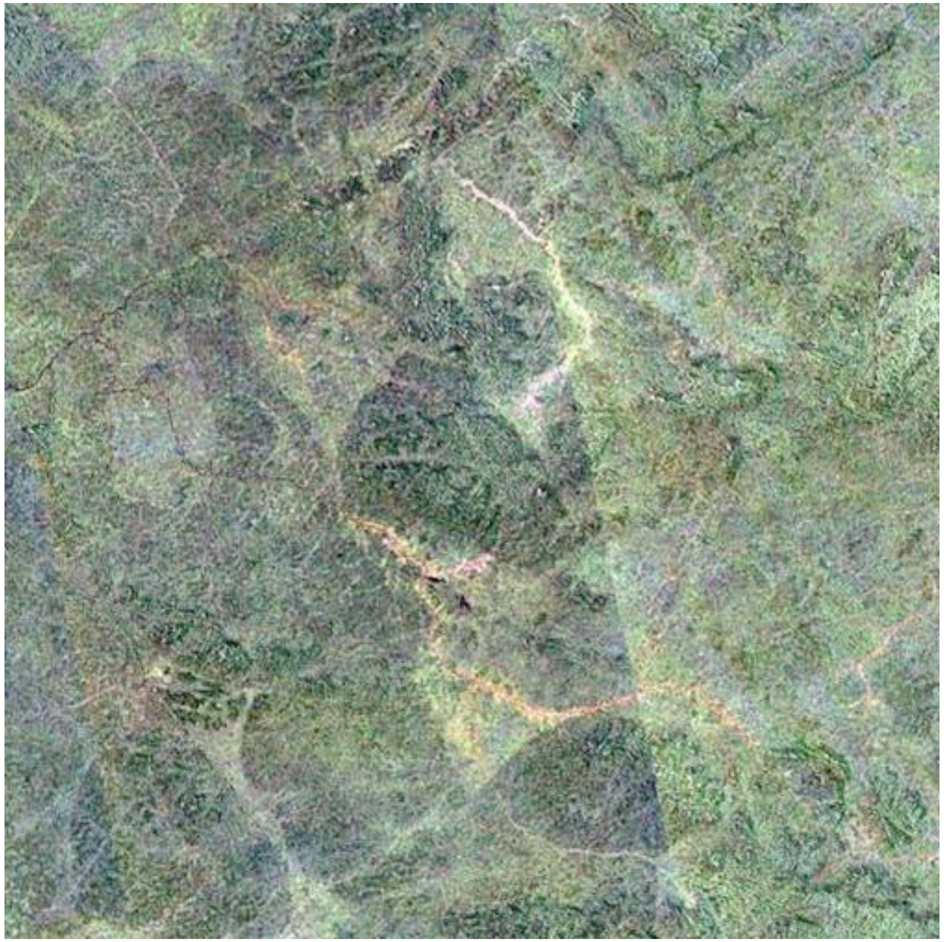
Figure 15. PALSAR FBS-FBD 2009-2010 mosaic of Suriname. The mosaic is stretched to enhance features of the forest in the interior. As compared to Borneo forest biomass levels are substantially lower and, consequently, seasonal variation caused by wetness is more pronounced. The coastal region is characterised by the presence of mangroves, swamps, marshes and savannas. PALSAR data courtesy: ALOS K&C © JAXA/METI.

Wide-area mapping Suriname: *Landsat comparison*

PALSAR 'forest stretch' reveals unique patterns, which differ from patterns in Landsat. PALSAR data may be very useful for biomass stratification.



Landsat 2010 band 543



Palsar 2010 FBDHH-FBDHV-FBS

Detail 100km x 100km

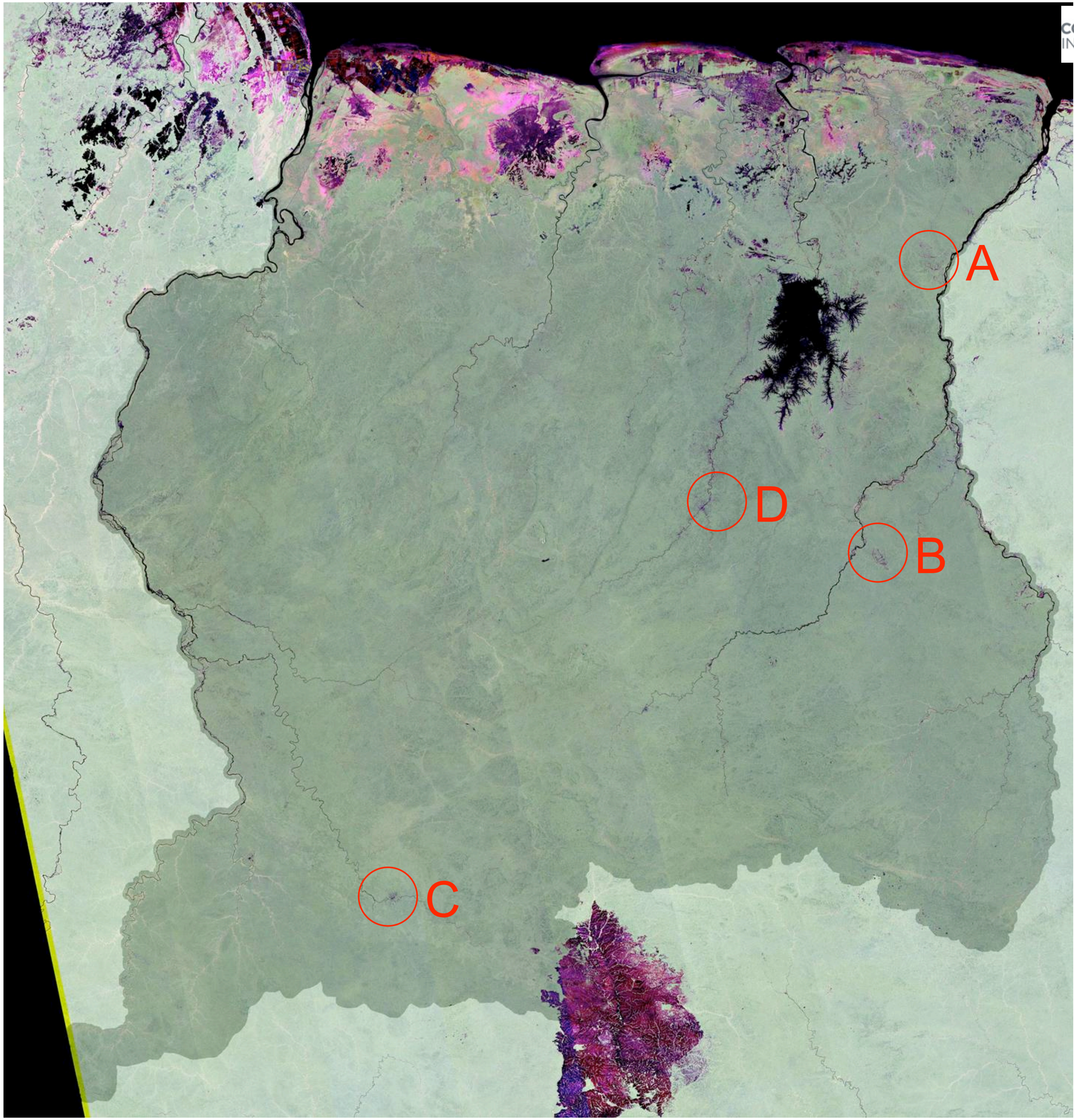
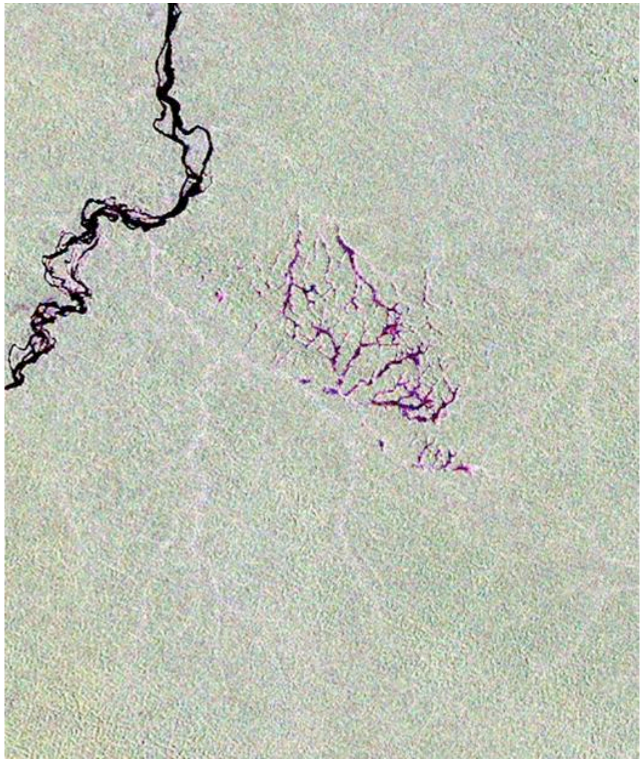


Figure 15b. PALSAR FBS-FBD 2009-2010 mosaic of Suriname. The mosaic is stretched using default values. PALSAR data courtesy: ALOS K&C © JAXA/METI.

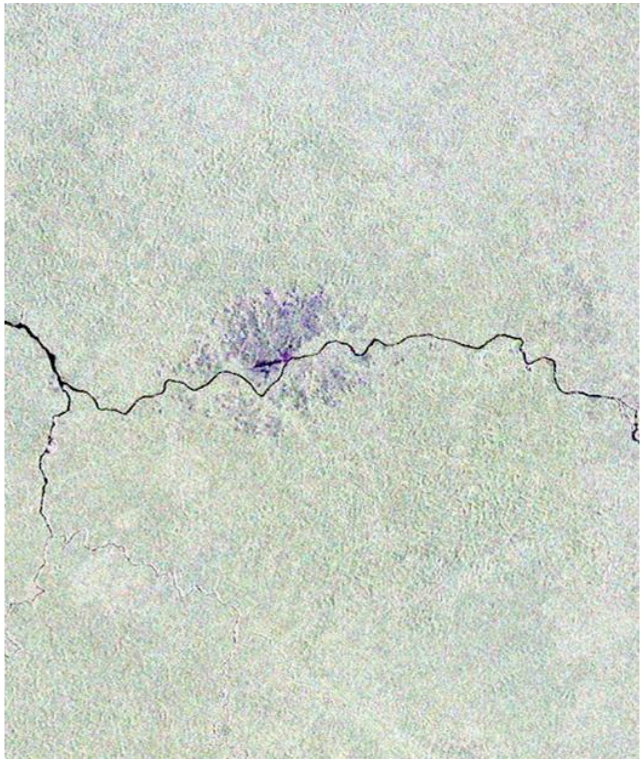
Details 34km x 41km:
A Lange Tabbetje
B Grutterink gebergte
C Kwamalasamutu
D Shifting cultivation along Suriname River

Wide-area mapping Suriname: *Deforestation details*



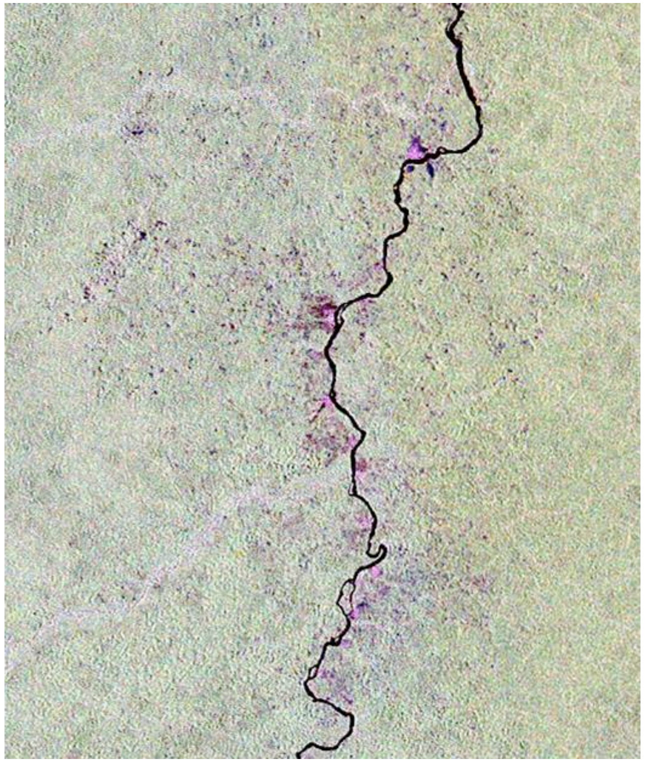
B. Grutterink gebergte (near Granbori)

Mining



C. Kwamalasamutu (west of Sipaliwini savanna)

Indigenous community



D. Shifting cultivation along Suriname River (south of Brokopondo)

Colonization frontier

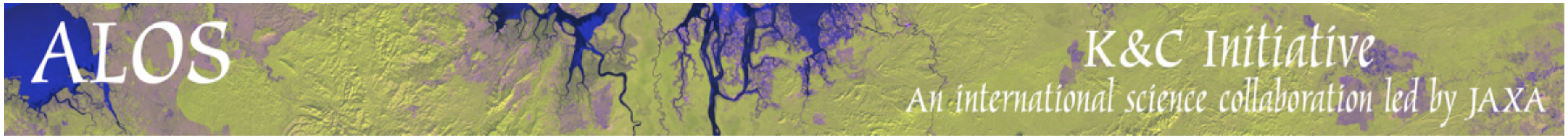
Conclusions

1. Changing environmental conditions may locally affect radar signatures
2. Within a multi-annual (at least 3 years) monitoring environment these conditions can be detected and radar signatures can be adjusted to a certain extent.
3. Several new techniques are under development to make classification more consistent in time.
4. Examples shown for oil palm plantation development, peat swamp restoration/regeneration and wide-area forest cover change are encouraging.
5. Proper pre-processing, including intercalibration and slope corrections, are necessary.
6. Good mapping results improve intercalibration iteratively.
7. The limited resolution of the SRTM DEM poses some problems in hilly terrain.

Conclusions (cont.)

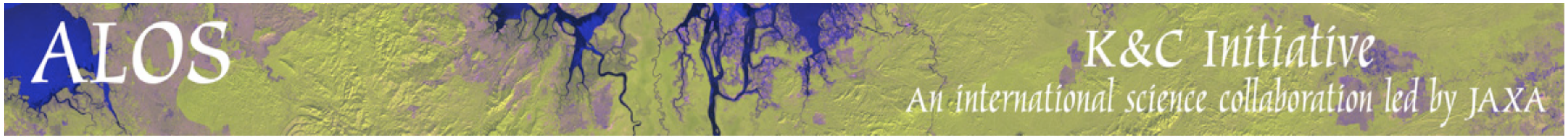
8. WB data should support the classification of multi-annual FB data, notably in areas with irregular flooding regimes. This is now feasible because long time series have been build-up.

9. Approach and legend for Borneo can be applied in Sumatra and Peninsular Malaysia, however major adaptations may be needed for other eco-regions (such as Suriname, Guyana)



Outlook

1. Further development and operationalisation of PALSAR wide-area monitoring approaches.
2. Further integration with WB data.
3. Further development of interoperability between PALSAR and other sensors.
4. More dedicated fieldwork campaigns focussing on the more 'problematic' areas.
5. Expansion to other eco-zones such as the Guianas, Choco, Gabon and New Guinea and development of adjusted or more widely applicable monitoring concepts.
6. Familiarisation and capacity building in GEO-FCT ND countries



Acknowledgement

This work has been undertaken within the framework of the JAXA Kyoto & Carbon Initiative. ALOS PALSAR data have been provided by JAXA EORC

Product Delivery Report for K&C Phase 2

Dirk Hoekman
Wageningen University

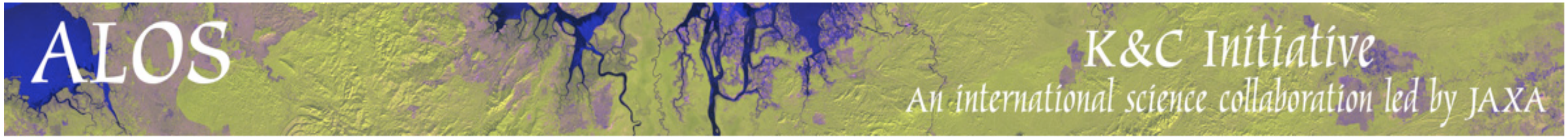
Science Team meeting #15
JAXA TKSC/RESTEC HQ, Tsukuba/Tokyo, January 24-28, 2011

K&C deliverables

Papers and Reports

1. <u>Published</u> (please provide PDF file)

- K&C Phase-1 and Phase 2 reports
- 3 contributions to K&C Booklet
- *Hoekman, 2007, J. Aq. Cons., Vol.17, pp.265-275.*
- *Hoekman and Vissers., 2007, IGARSS symposium*
- *Hoekman et al., 2009, POLinSAR workshop*
- *Hoekman et al., 2009, Borneo map validation report*
- *Hoekman et al., 2010, IEEE JSTARS, Vol.3, pp.605-613*



K&C deliverables

Papers and Reports

2. Submitted/in preparation

- *RSE, 2011/2012, Borneo annual consistent wide area mapping*
- *RSE, 2011/2012, Mahakan wetlands dynamics*

- *Journal, 2011/2012, Suriname land cover*
- *Journal, 2011/2012, Iwokrama, Guyana, Biomass mapping methodology*
- *Journal, 2011/2012, Biomass map Borneo*

K&C deliverables

Data sets and Thematic products (mosaics, classification maps etc.)

1. Completed and Delivered to JAXA

- *Borneo 2007 Land cover*
- *Sarawak 2005-2007-2009-2010 Forest cover change*
- *Sarawak 2009 Indicative AG Biomass*

2. Completed, but not yet delivered (please deliver ASAP)

- *Borneo 2008 Land cover*
- *Borneo 2009 Land cover*
- *Suriname 2010 Land cover map and mosaic 2009-2010*