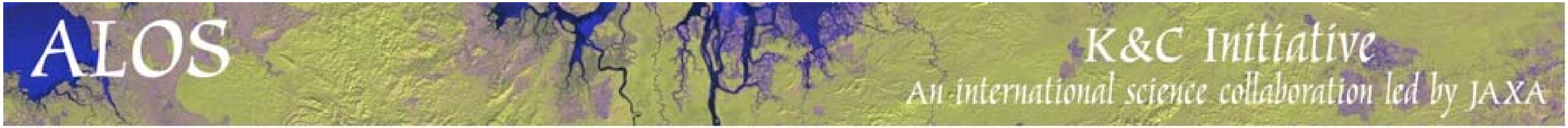

K&C Phase 3

Forest Cover Change and Biomass Mapping

Thuy Le Toan, Stephane Mermoz, Alexandre Bouvet, Ludovic Villard

CESBIO
Toulouse, France

Project Objectives

To demonstrate the feasibility of forest information generated from ALOS-PALSAR to support Carbon Cycle Science and International Conventions (REDD) in 3 projects:

1. Forest cover change and biomass mapping of savanna in **Cameroon**, as a research part of the REDDAF project, also as a contribution to the GEO-FCT, Cameroon being one of the National Demonstrators.
2. Biomass mapping in **African savannas**
3. Forest cover change and biomass mapping in **Vietnam**, where de/af/reforestation have been very active during the last decade. Vietnam is a UNREDD country

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Methodology objectives

1. Modelling of the L-band backscatter of forests→ biomass inversion models
2. Towards a definition of forest cover based on biomass?

Retrieval of forest biomass from L-band backscatter

1. Relationships between the L-band backscatter and Above Ground Biomass (AGB)

   - Electromagnetic modelling:

     Effect of forest type, tree density,seasonality (vegetation and soil moisture)

   - Data analysis

     Relevance *of in situ* AGB data

2. Deriving inversion functions (and validity domain)
3. Developing AGB retrieval methods and uncertainties assessment

Electromagnetic modelling

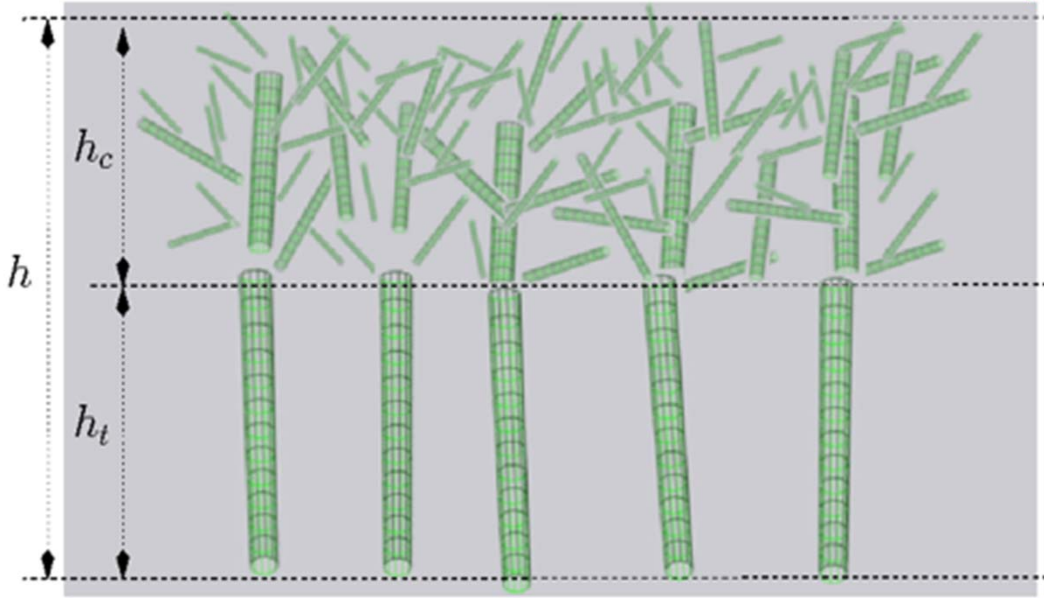
(Multistatic Interferometric & Polarimetric
EM Model for Remote Sensing)

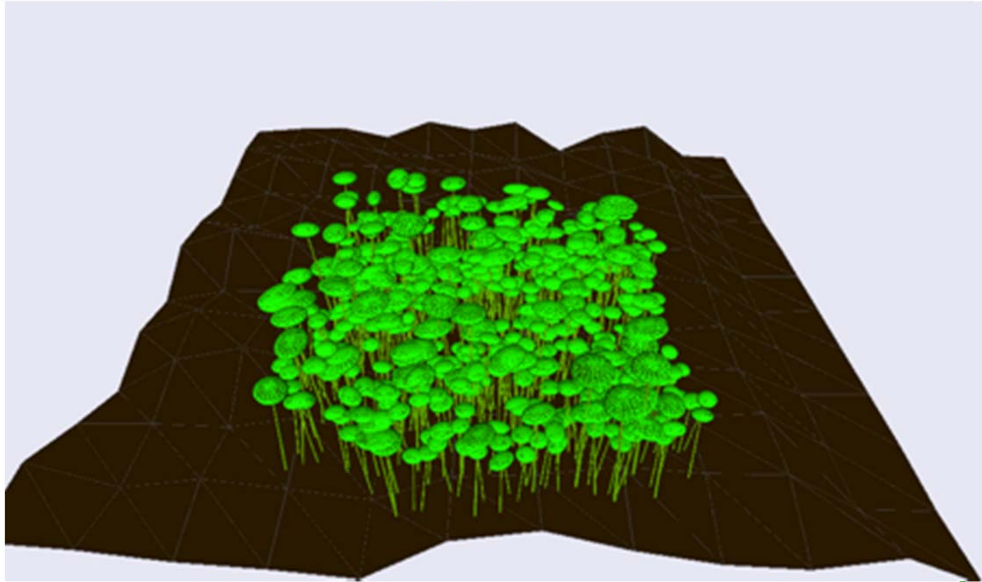
Scene description

Vegetation: Discrete geometrical description based on canonical shapes (cylinders, ellipsoids)

2 possible descriptions
a) based on tree architecture models
b) based on layers

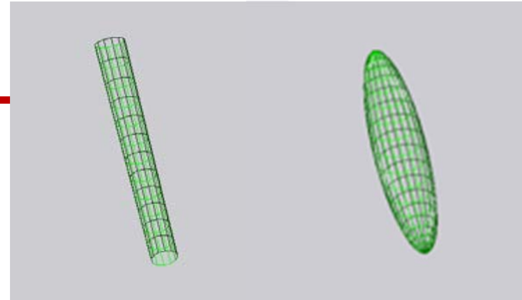
Underlying topography modeled with 3D triangular facets





EM calculations

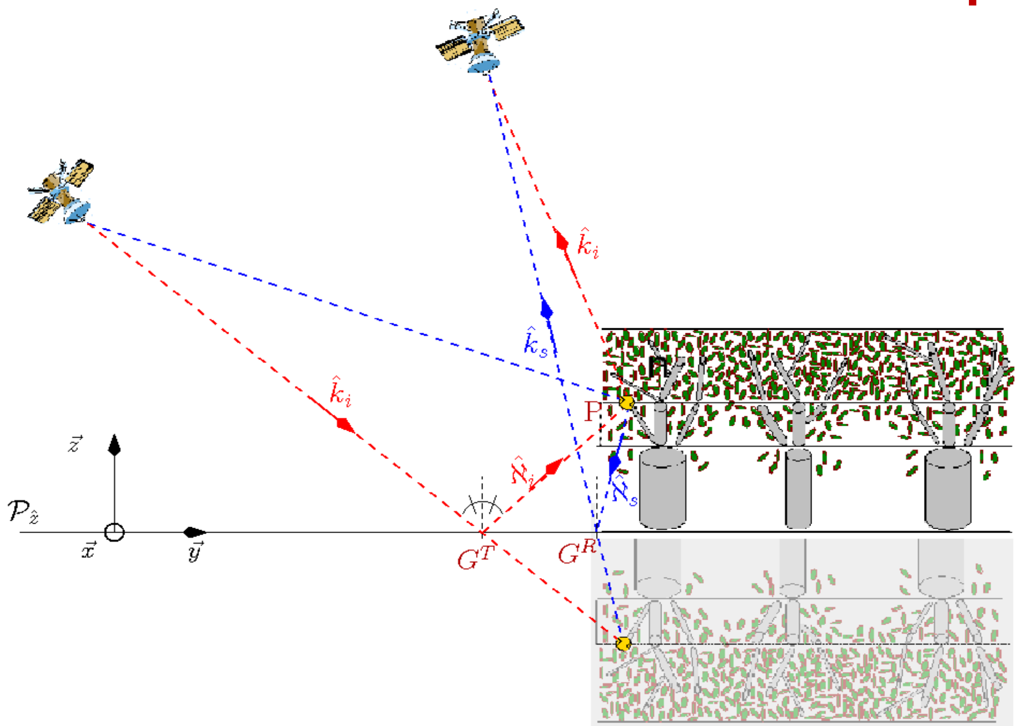
Coherent modeling based on the Distorted Born Wave Approximation and scattering matrices of canonical shapes

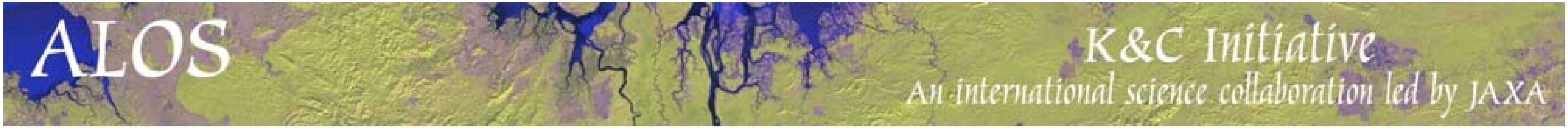


dimensions & dielectric constant

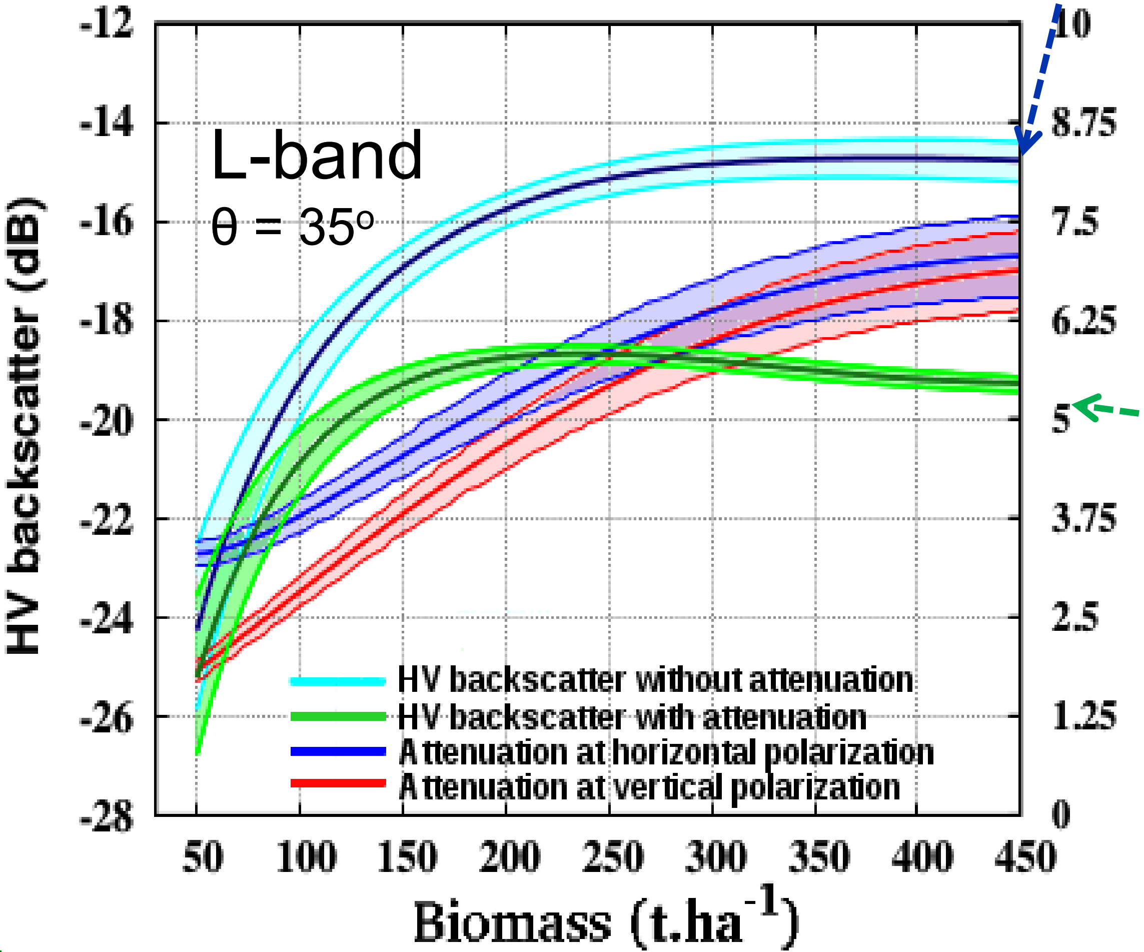
Accounts for several contributions :

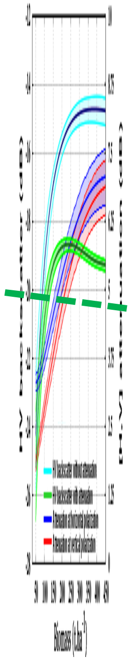
- single scaterring mechanisms from vegetation scatterers and the ground
- multiple scattering mechanisms resulting from coupling effects between vegetation and ground





Open canopy

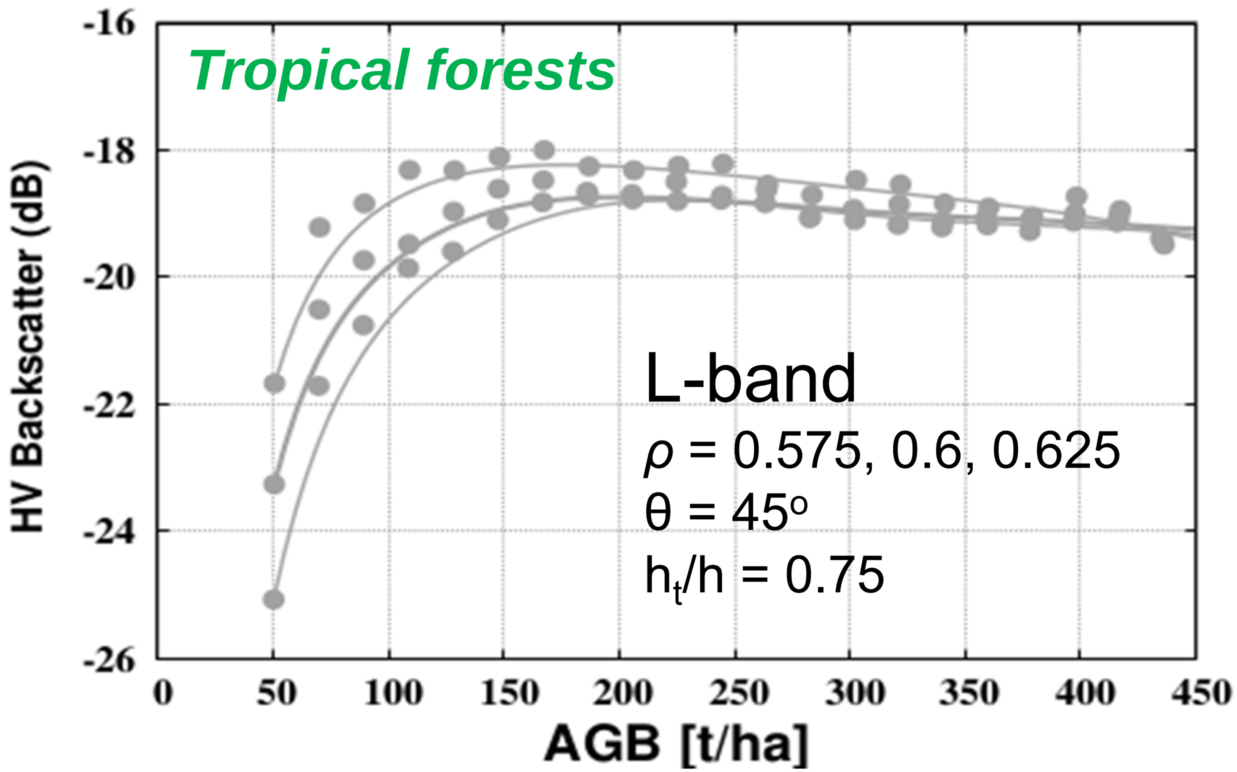




Dense canopy

Simulation of forest characteristics and environment effects

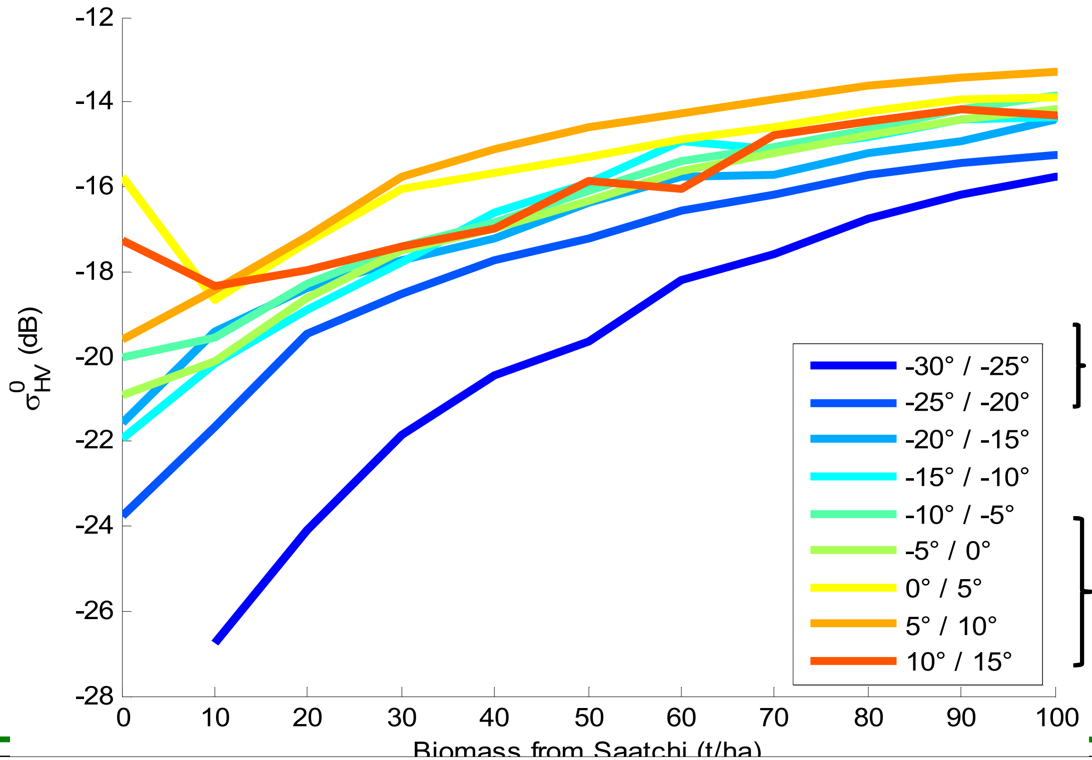
- Forest type (species, age: geometrical and dielectric properties)
- Environment (topography), seasonality (vegetation and soil moisture)
- etc..

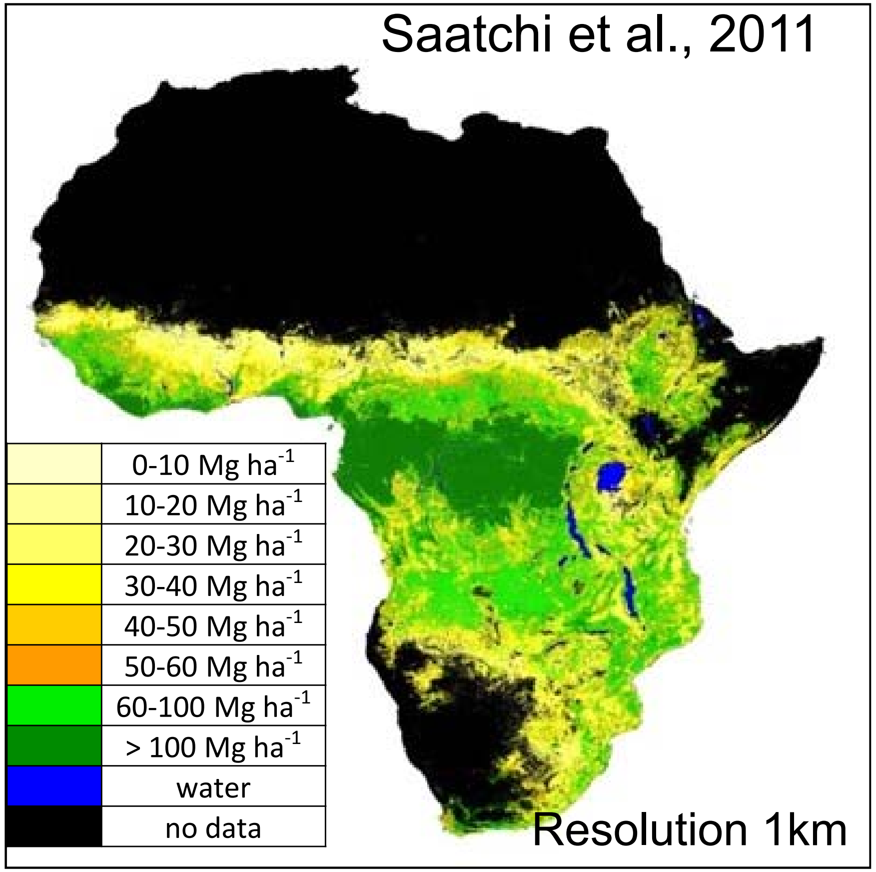


Example of a simulation of The effect of wood density (linked to tree species)

Effect of vegtation and soil moisture

PAISAR backscatter vs biomass by latitude range



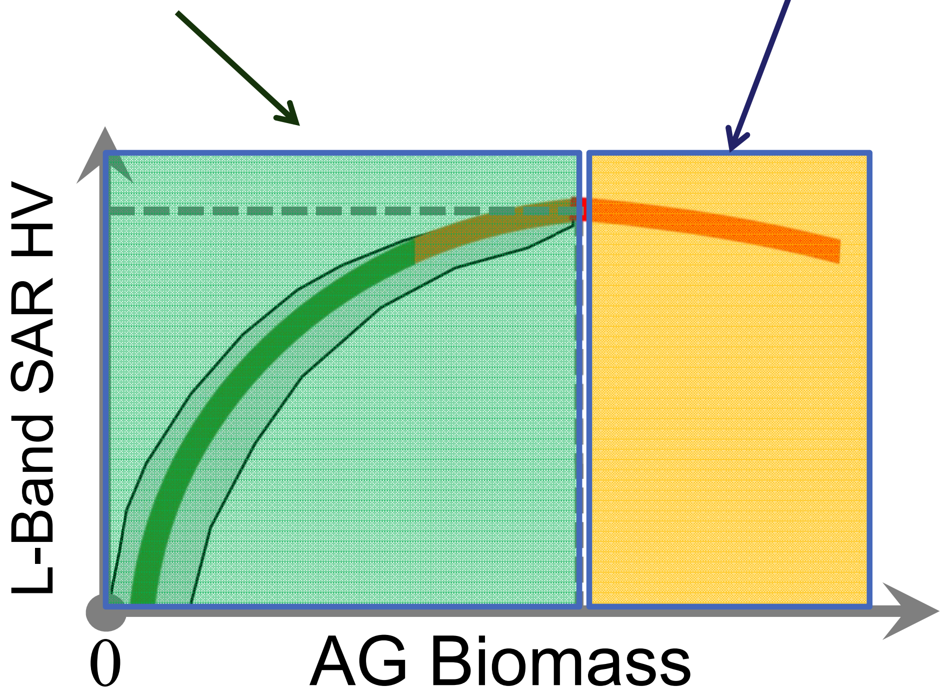


Lower latitudes ⇨ Dry Season
⇨ High dynamic range

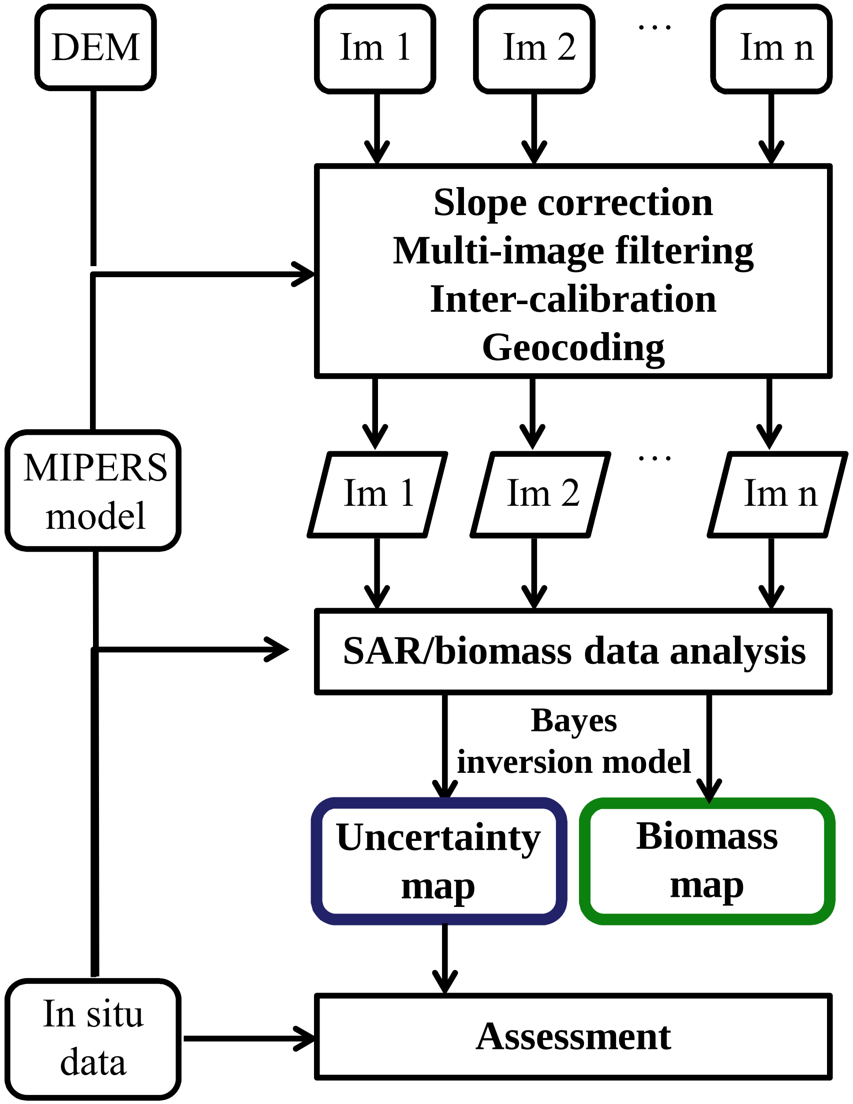
Higher latitudes ⇨ Wet Season
⇨ Low dynamic range

Model for mapping open forest biomass

Model for mapping of dense forest biomass



Biomass mapping method



1. Preprocessing

- Multi-image filtering
- Inter-calibration of image

2. Analysis

3. Inversion method

- Bayes approach

4. Uncertainty assessment

- Error budget and biomass uncertainty map

ALOS

K&C Initiative

An international science collaboration led by JAXA

The Cameroon project

Remote Sensing of Environment 155 (2014) 109–119

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ELSEVIER

Biomass assessment in the Cameroon savanna using ALOS PALSAR data

CrossMark

Stéphane Mermoz [a,*], Thuy Le Toan [a], Ludovic Villard [a], Maxime Réjou-Méchain [b], Joerg Seifert-Granzin [c]

[a] Centre d'Etudes Spatiales de la BIOsphère, UMR CNRS 5126, University of Paul Sabatier, Toulouse, France
[b] Laboratoire Evolution et Diversité Biologique, UMR CNRS 5174, University of Paul Sabatier, Toulouse, France
[c] Mesa-Consult, Konstanz, Germany

LES FORÊTS DU BASSIN DU CONGO

État des Forêts 2013

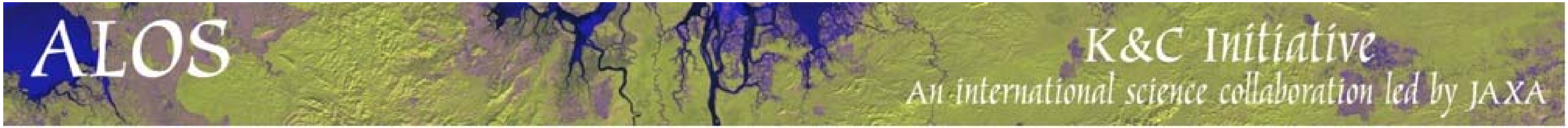
CHAPITRE 1

Évolution du couvert forestier du niveau national au régional et moteurs de changement

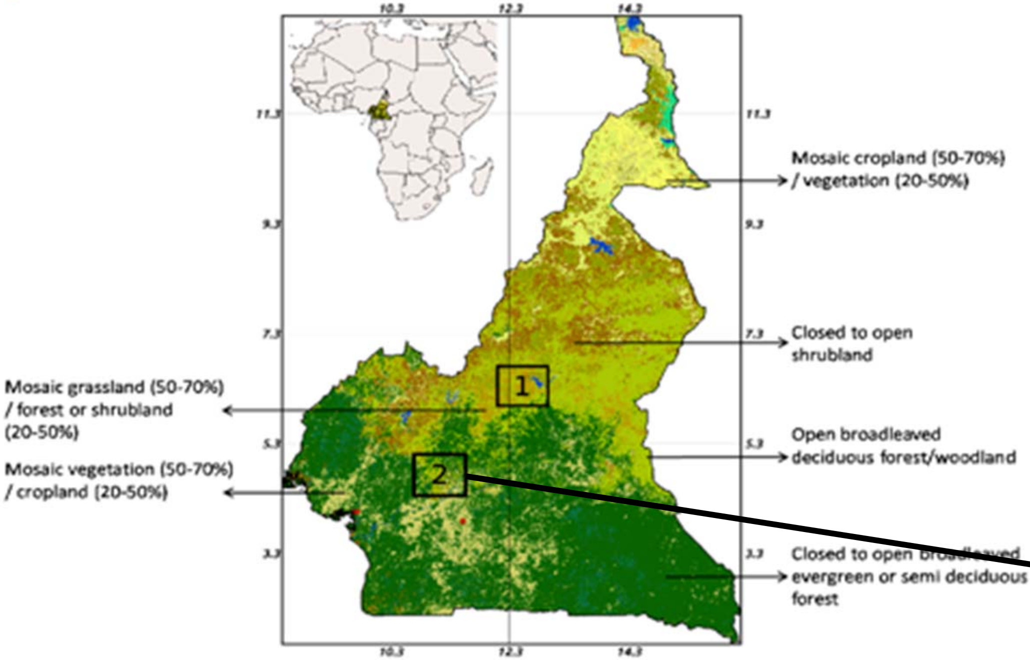
Baudouin Desclée[1], Philippe Mayaux[1], Matthew Hansen[2], Patrick Lola Amani[2], Christophe Sannier[3], Benoit Mertens[4], Thomas Häusler[5], René Ngamabou Siwe[5], Hervé Poilvé[6], Valery Gond[7], Mathieu Rahm[8], Jörg Haarpaintner[9], Jean-Paul Kibambe Lubamba[10]

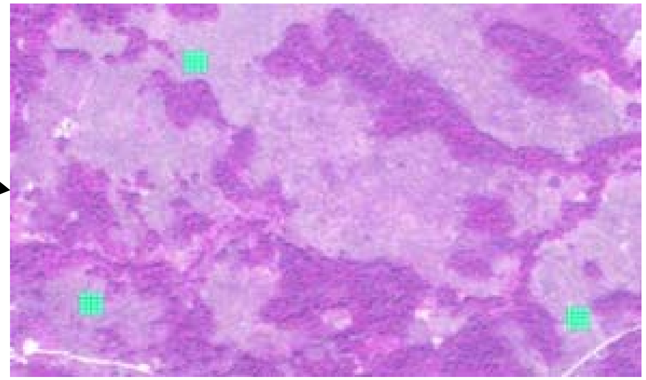
Avec la contribution de : Peter Potapov, Svetlana Turubanova, Alice Altstatt, Louis-Vincent Fichet, Gernot Ramminger, Sharon Gomez, Guillaume Cornu, Lucas Bourbier, Quentin Jungers, Pierre Defourny, Thuy LeToan, Manuela Hirschmugl, Gabriel Jaffrain, Camille Pinet, Cédric Lardeux, Anoumou Kemavo, Philippe Dorelon, Donata Pedrazzani, Fabian Enßle, Joerg Seifert-Granzin, Landing Mane, Ludovic Nkok Banak, Anton Vrieling, Stéphane Mermoz

[1]CCR, [2]University of Maryland, [3]SIRS, [4]IRD, [5]GAF AG, [6]Astrium, [7]CIRAD, [8]Eurosense, [9]Norut, [10]UCL



In situ data collection



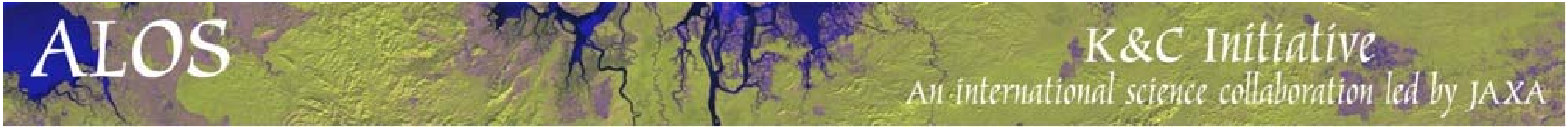


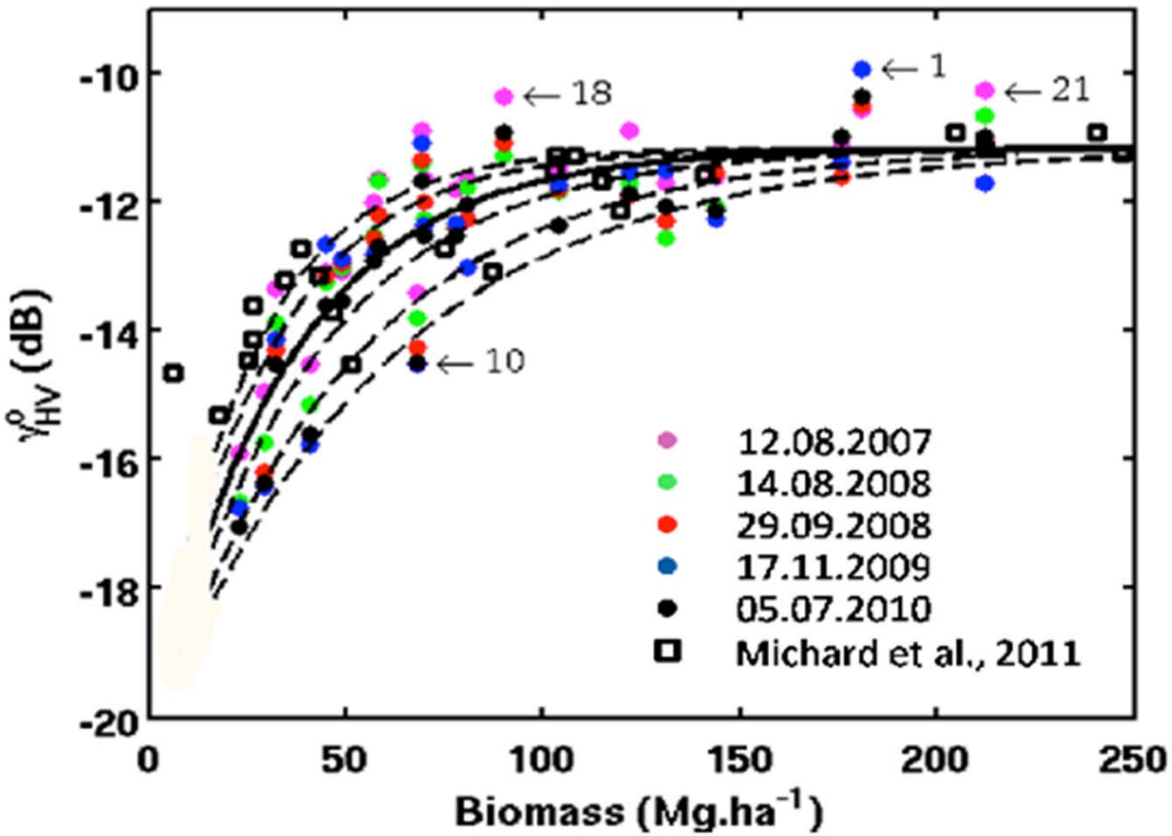
1: Tibati, Adamawa Province: 21 plots available on 3 April 2012

2: Bafia, Central Province: 20 plots available on 17 October 2013

Measures of DBH (Diameter at Breast height), height, identification of species for wood density

→ Estimation of in situ biomass (*Chave et al., 2005*)





$$\gamma^{o}_{HV} = a + b\left(1 - e^{-c.AGB}\right)$$

c varies to account for environmental error sources:

-forest type

-vegetation and soil moisture

-topography

c is 0.025, 0.031, 0.041 and 0.051

Uncertainties assessment

In situ uncertainties:
- Diameter breast height: 2.25%
- Height: 4.47%
- Wood specific gravity: 10%
- Allometric equations: 5%
- Sampling size

Monte Carlo → $\sigma_{AGB,IS,1}$ (from DBH, height, wood specific gravity, allometric equations)

Sampling size → $\sigma_{AGB,IS,2}$

Quadr. sum → $\sigma_{AGB,IS}$ → **Monte Carlo** → $\tilde{\sigma}_{AGB,IS}$

Inverse models with k=1…1000

$$AGB = \frac{1}{c_k} \times \ln\left[1 - \frac{\gamma^{o}_{HV} - a_k}{b_k}\right]$$

SAR backscatter uncertainties:
- Radiometric stability = 0.5 dB
- Speckle noise = 0.4 dB

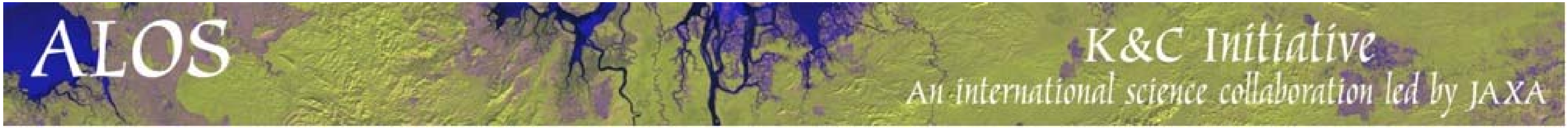
$$p_{AGB,SAR}(B) = J^{\gamma}_{AGB} \cdot p_{\gamma}\left(f^{-1}(B)\right)$$

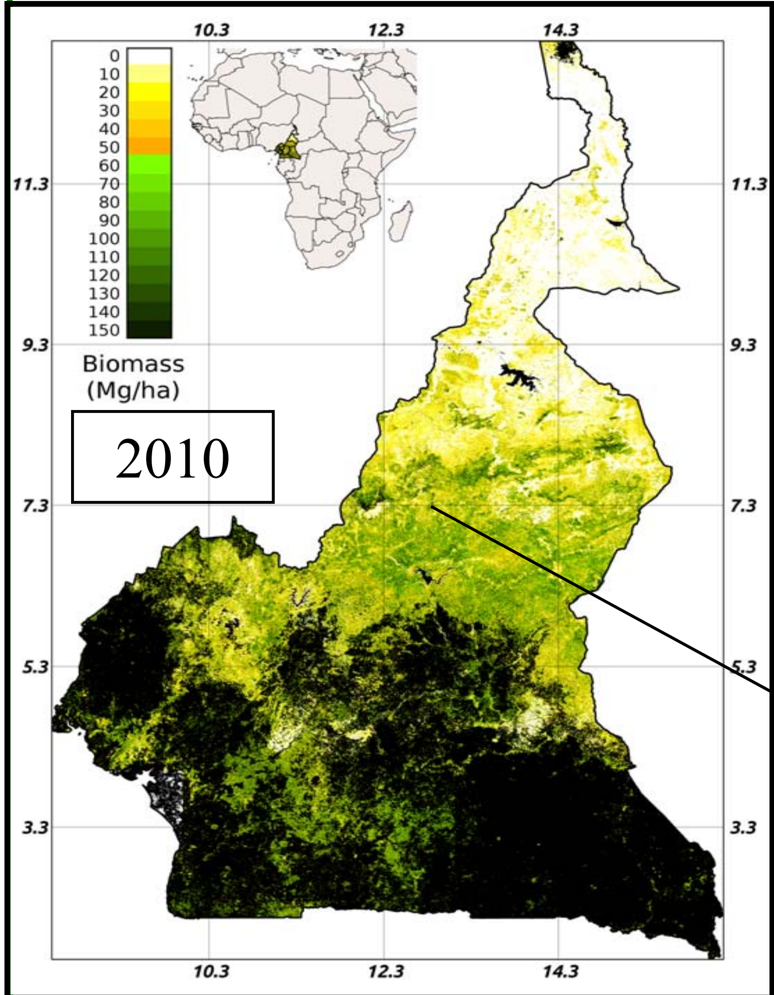
Gaussian fit → $\tilde{\sigma}_{AGB,SAR}$

$\tilde{\sigma}_{AGB,IS}$ and $\tilde{\sigma}_{AGB,SAR}$ → **Quadr. Sum** → $\tilde{\sigma}_{AGB}$

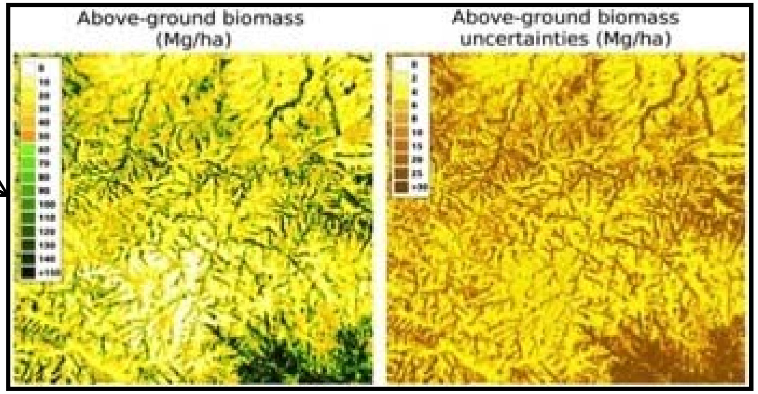
- Systematic controls consisted of remeasuring the DBH and the height of a randomly chosen 5% of trees in each plot
- Error due to sampling size for a A-ha plot: b/sqrt(A) (***Réjou-Méchain et al., 2014***)

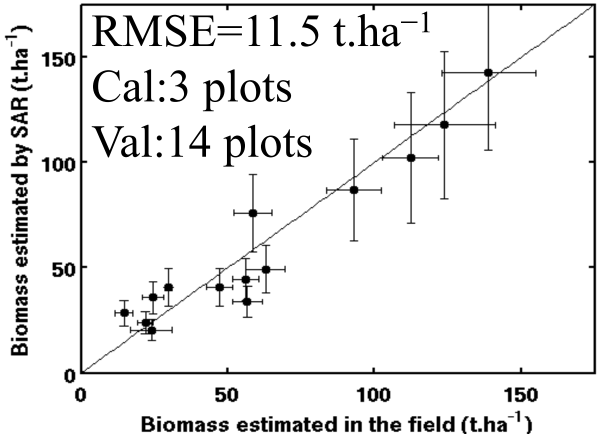
- Radiometric stability: (***Shimada et al., 2010***)
-The standard deviation of the backscatter γ° due to speckle is approximately 0.4 dB when the number of looks is approximately 112 .





	Surface area (ha)	Mean AGB (Mg.ha^{-1})	AGB (Tg)	Carbon (TgC)
Mosaic forest-croplands	1,811,150	89.5	162.9	81.4
Mosaic forest-savanna	5,187,900	75.6	394.2	197.1
Deciduous woodland	10,352,400	53.3	553.6	276.8
Deciduous shrubland – sparse trees	1,949,000	30.7	59.8	29.9
Others	6,622,340	12.6	83.4	41.7
TOTAL	25,922,790	48.2	1253	**626.9**

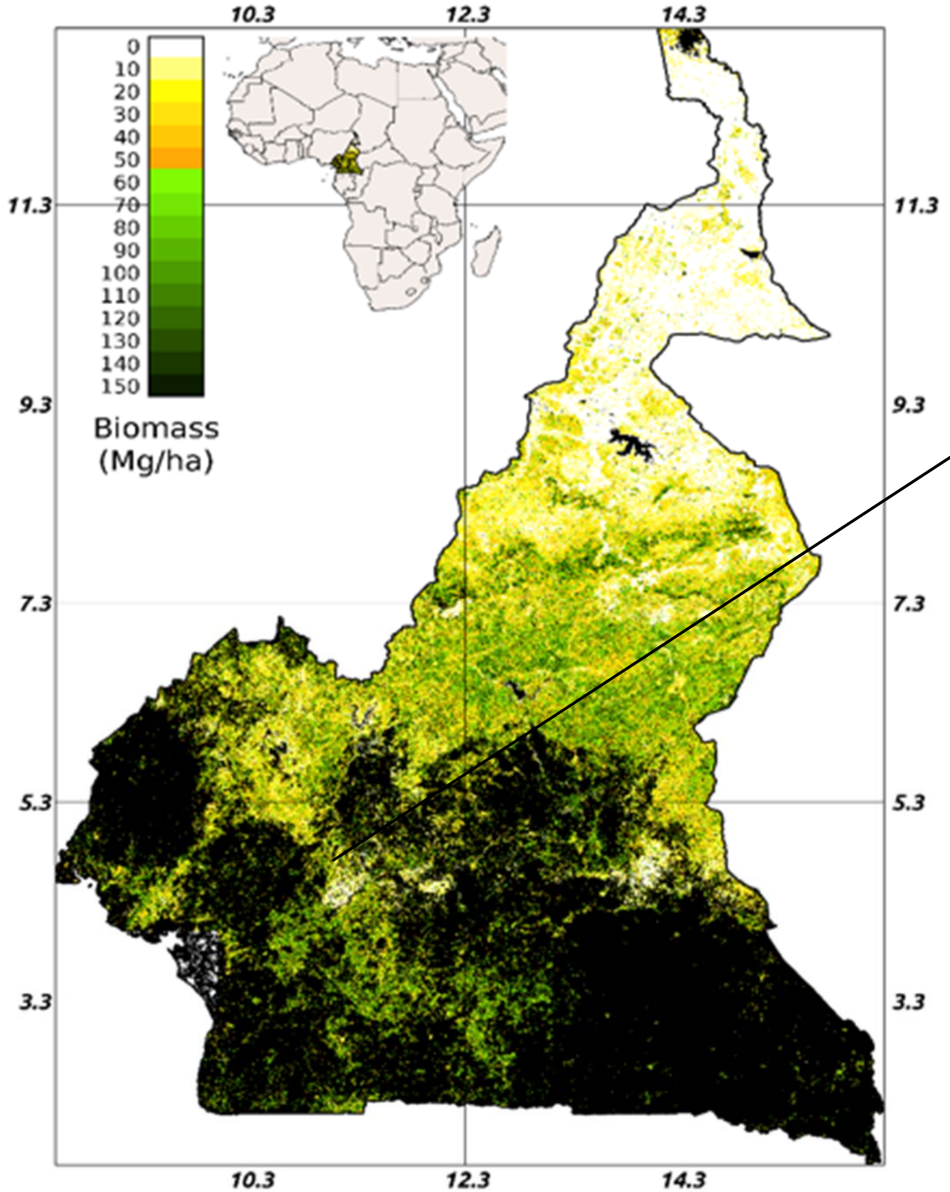


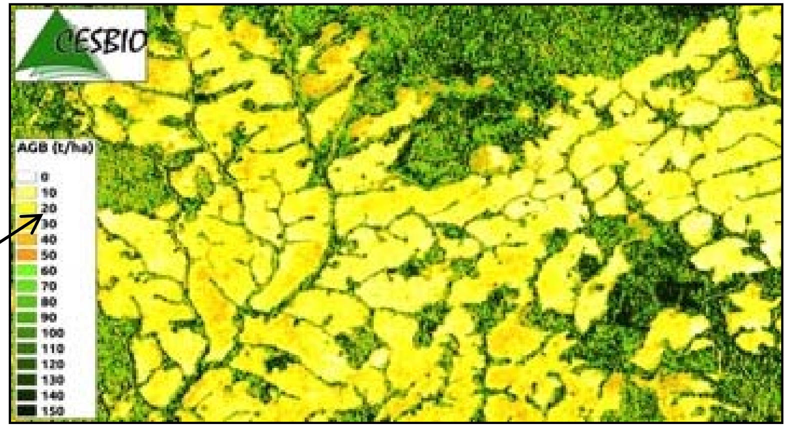


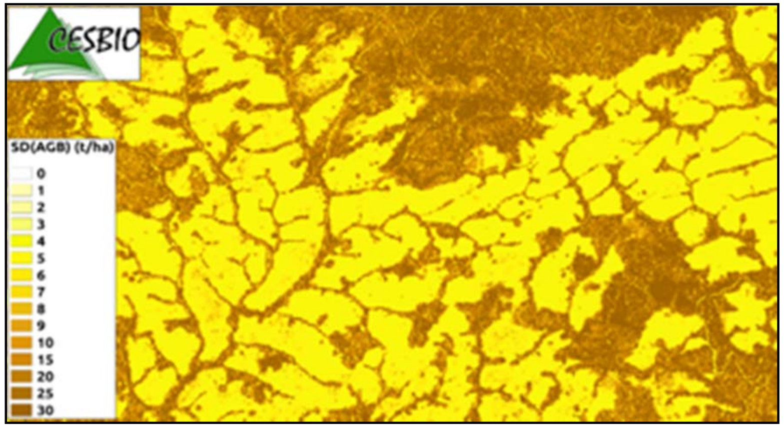
Total aboveground carbon stock:
- This study: 626.9 TgC
- Nasi et al. (2009): 710 TgC

Restriction to the savanna ecosystem, because of the large uncertainties for plots with AGB>150 Mg.ha^{-1}
→ Mask out the dense forest using Globcover 2009 land cover map that presents the highest resolution for dense forest mask (300m).

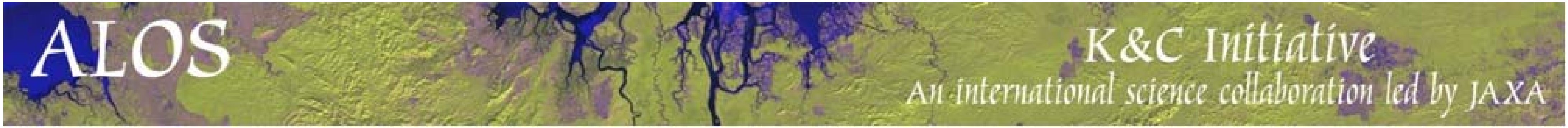
Cameroon Biomass and uncertainties map







Mermoz S., Le Toan T.,Villard, Rejou-Mechain,M., Seifert-Granzin J. ‘Biomass assessment in Cameroon savanna using ALOS PALSAR data’, in review RSE



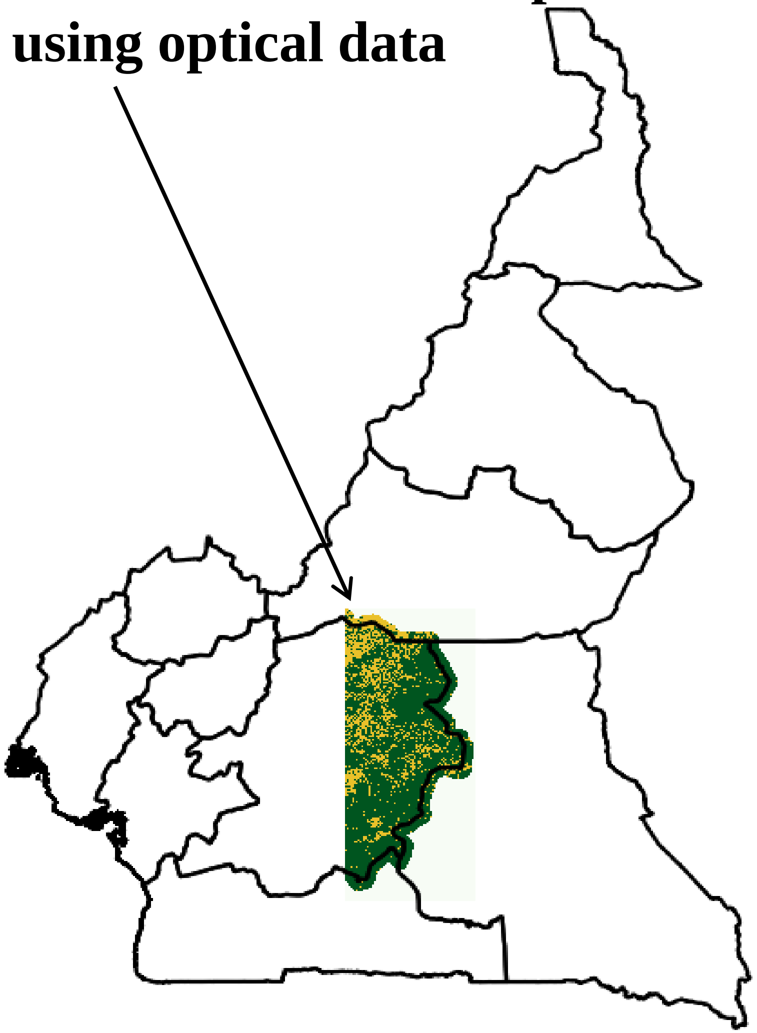
Towards a definition of forest cover based on forest biomass?

COMPARISON OF OPTICAL AND SAR DATA FOR FOREST COVER MAPPING: REDD+ MAY BE HELPED BY SAR DATA

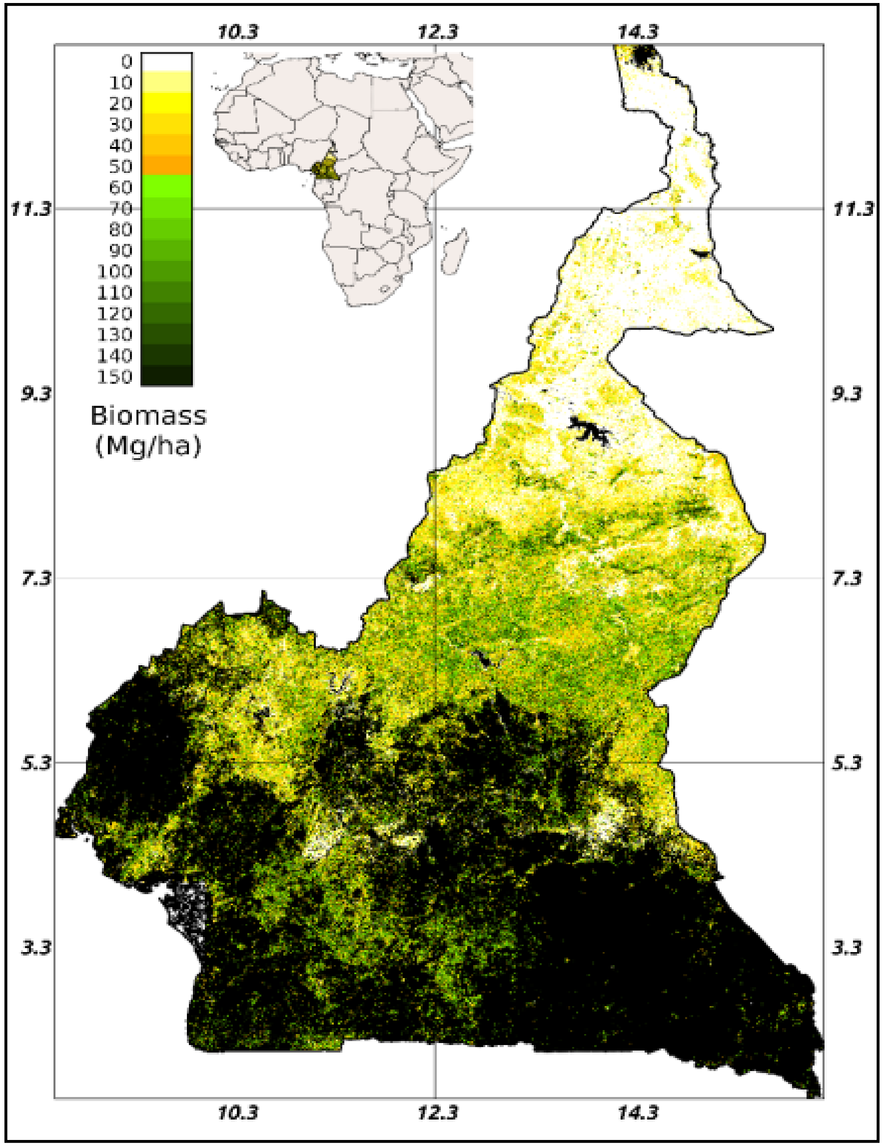
T. Le Toan[1], S. Mermoz[1], L.V. Fichet[2], C. Sannier[2], A. Bouvet[1]

[1]CESBIO, UMR CNRS 5126, Université Paul Sabatier, Toulouse, France
[2]Système d'Information Référence Spatiale (SIRS), Villeneuve d'Ascq, France

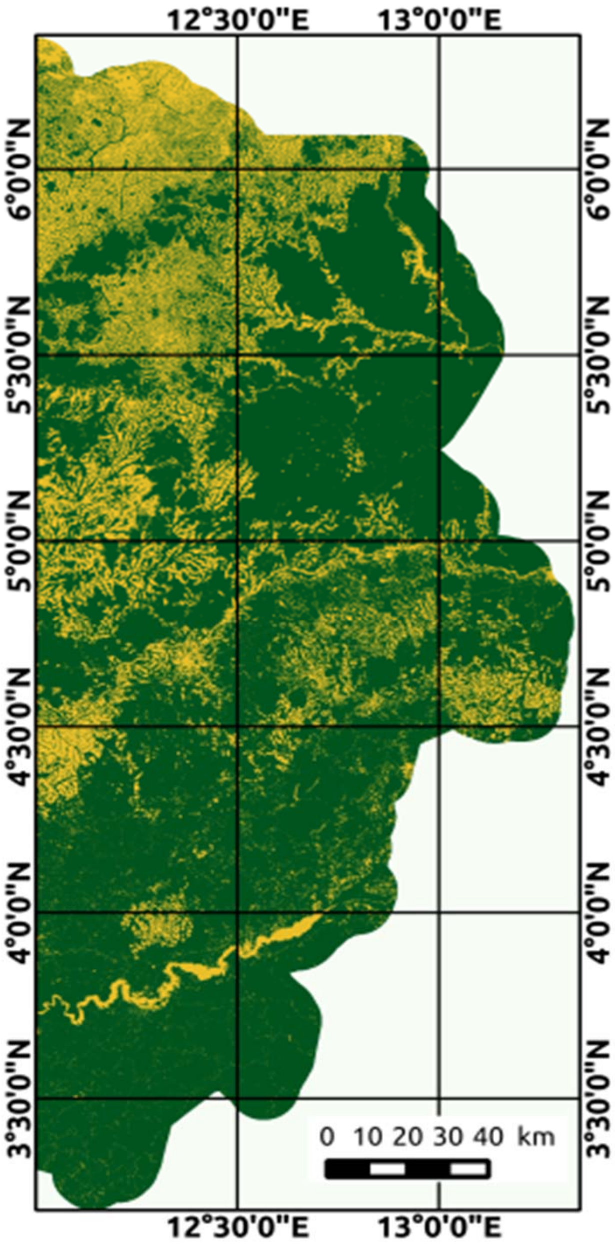
Forest/Non forest map using optical data



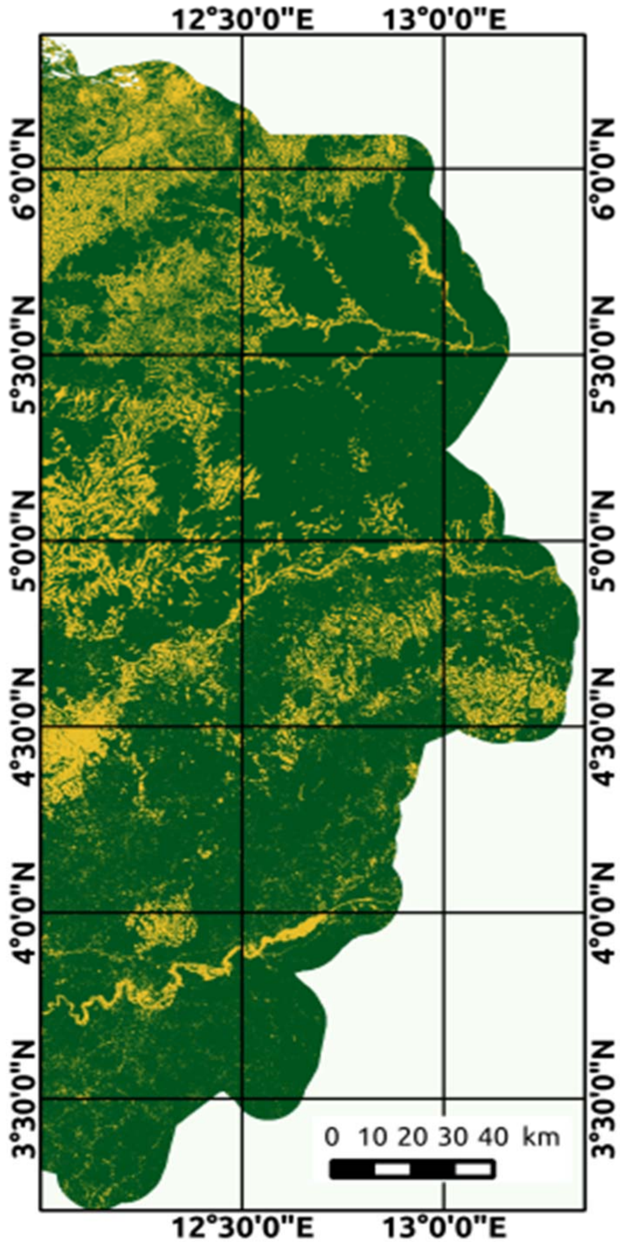
Forest biomass map using ALOS-PALSAR



From optical data



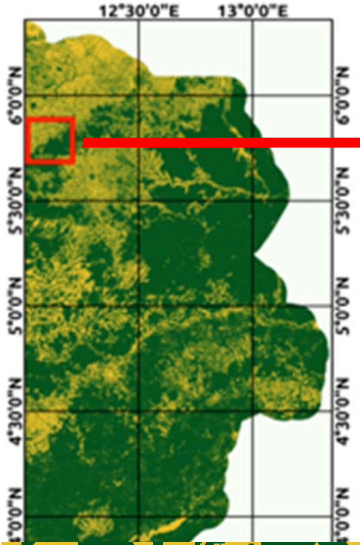
From SAR data

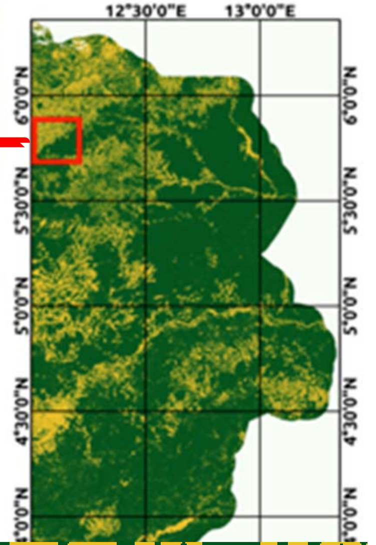


Best results when threshold in biomass = 47.6 t/ha:

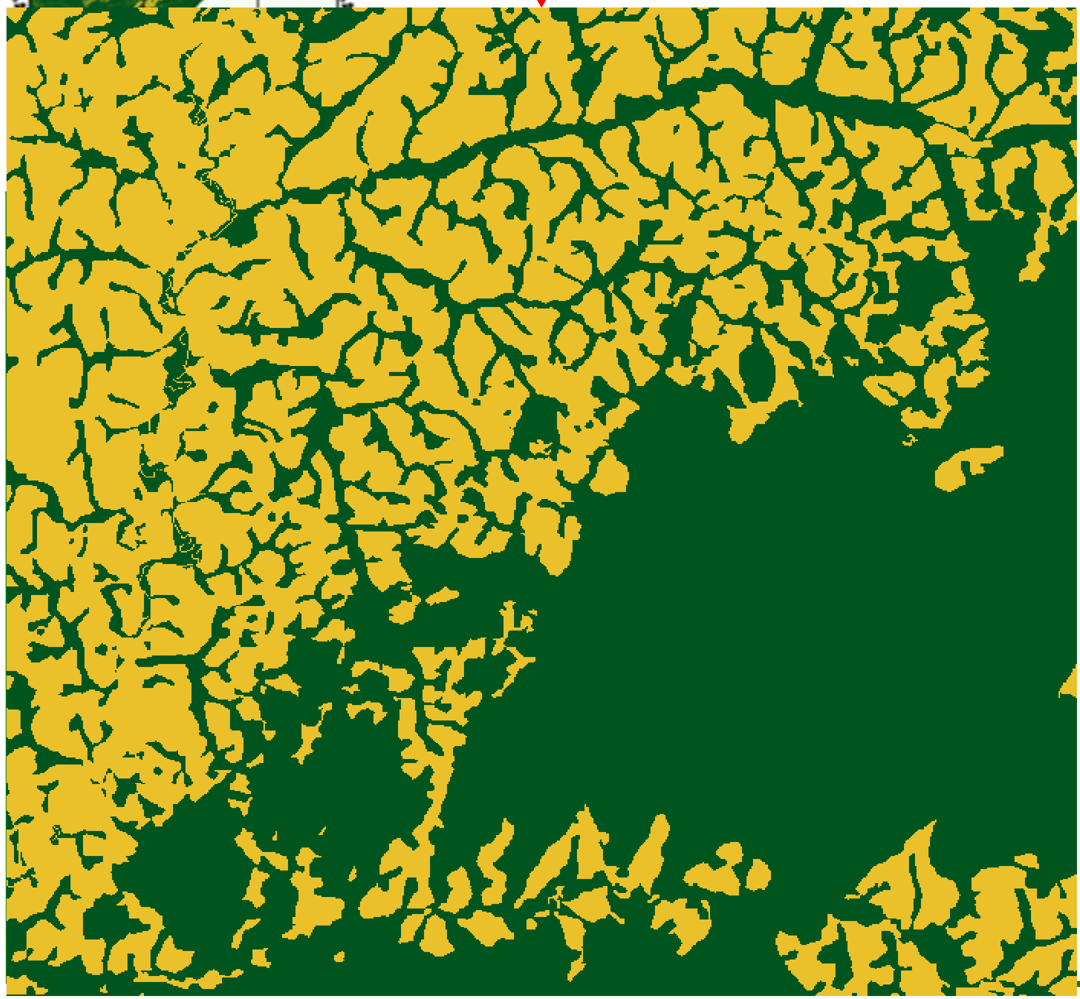
comparison of SAR-based results with reference data:
Mean producer accuracy: 87.4%
Mean user accuracy: 86.1%
Overall accuracy: 89.6%.

The mean value of biomass for 'non forest' class interpreted using optical data is **42.9 t/ha**.

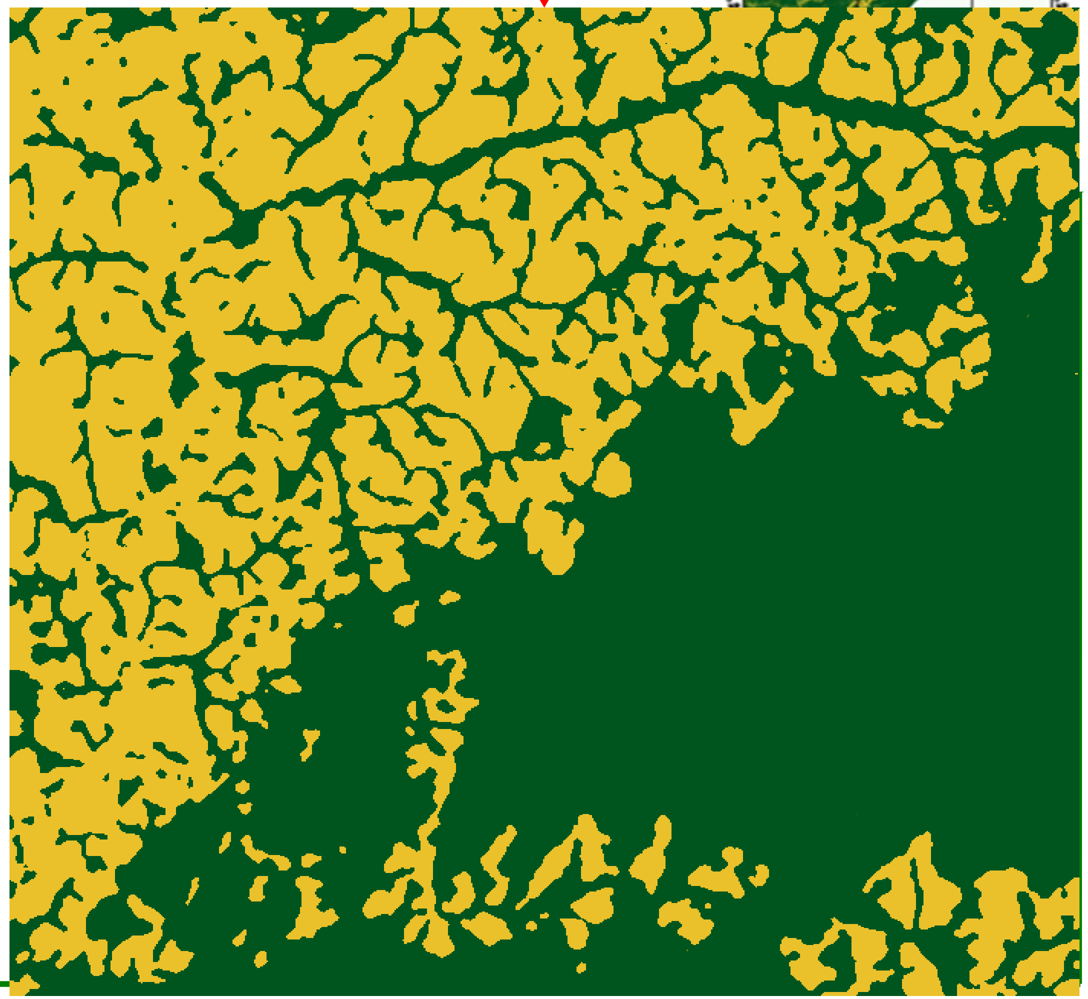




From optical data



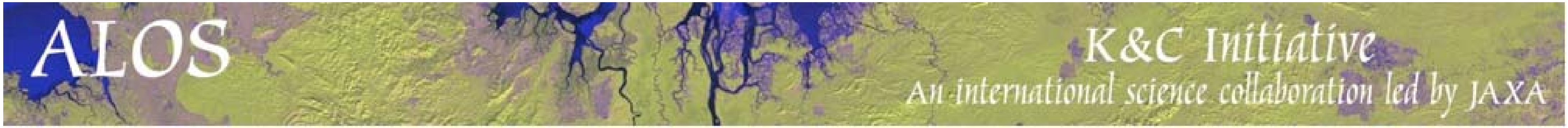
From SAR data



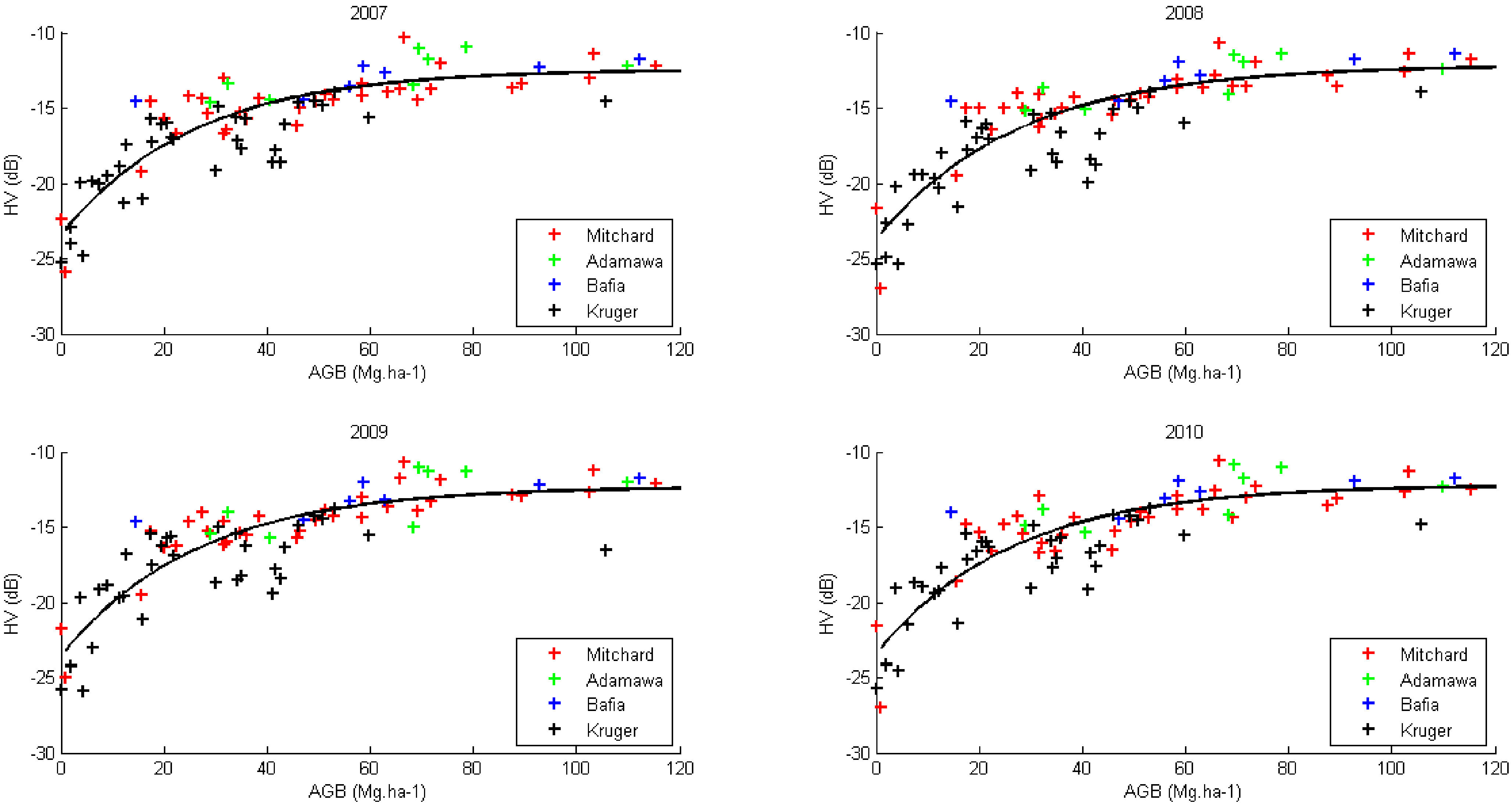
From Cameroon to Africa

A biomass map of African savannas at a spatial resolution of 50 meters using ALOS PALSAR dual-polarization data

Alexandre Bouvet, *Thuy Le Toan, Stéphane Mermoz*
CESBIO, Toulouse, France



Relation backscatter-biomass

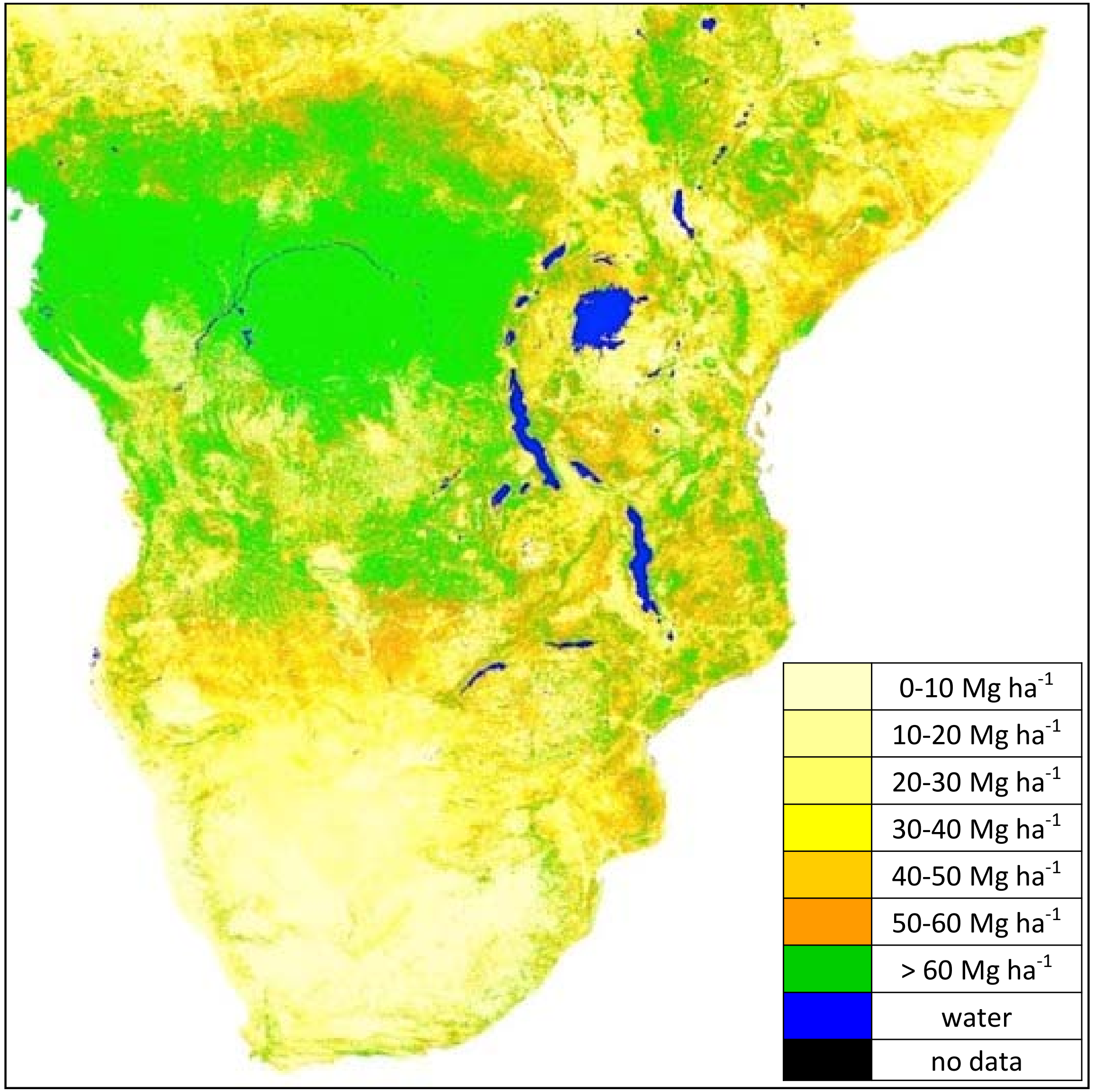


ALOS

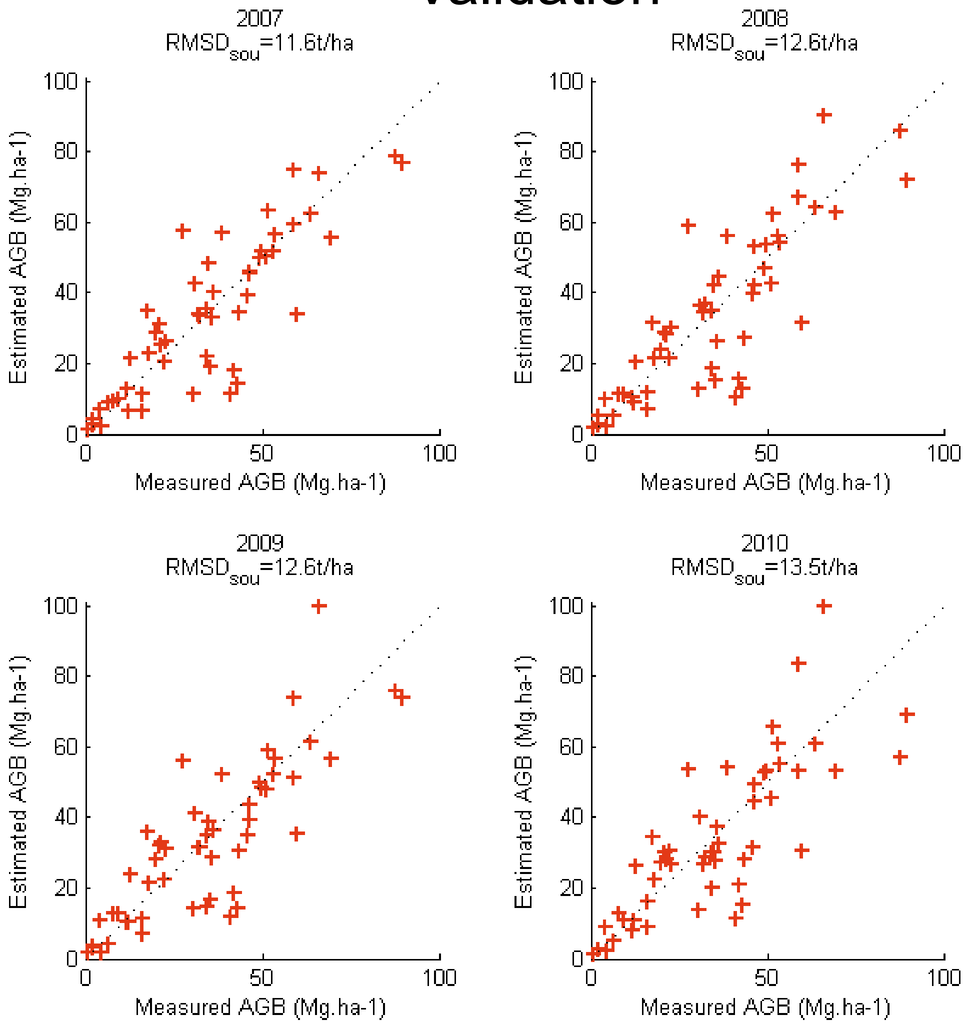
K&C Initiative
An international science collaboration led by JAXA

Biomass map

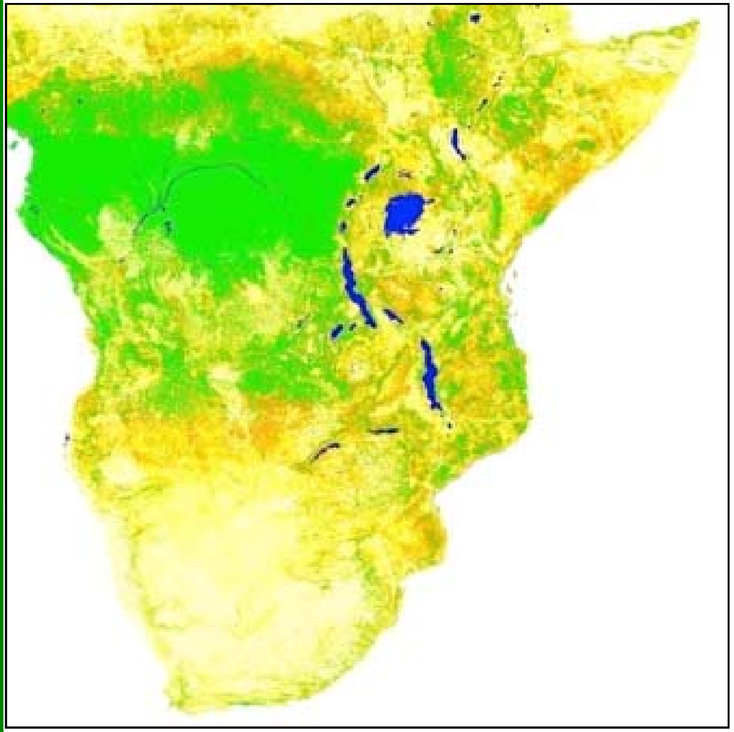
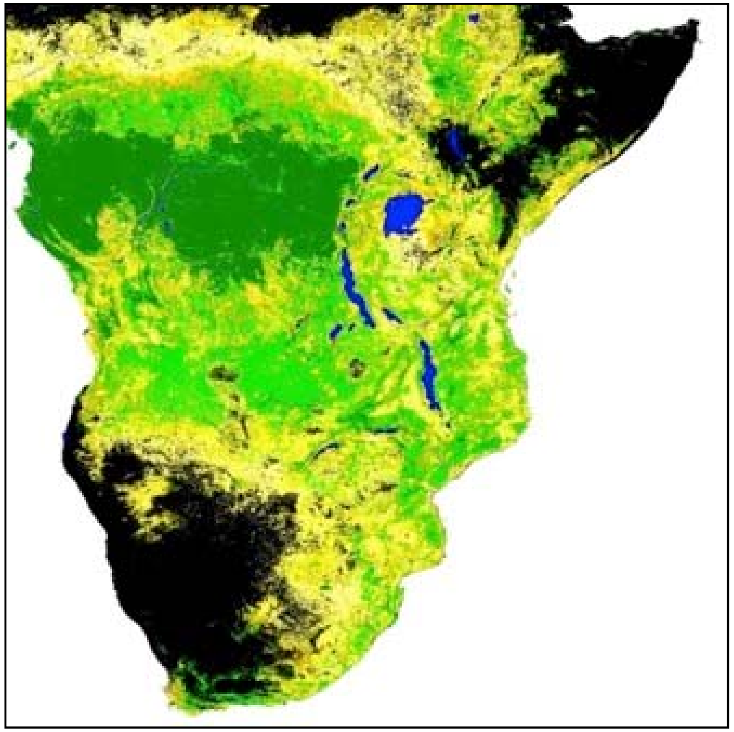
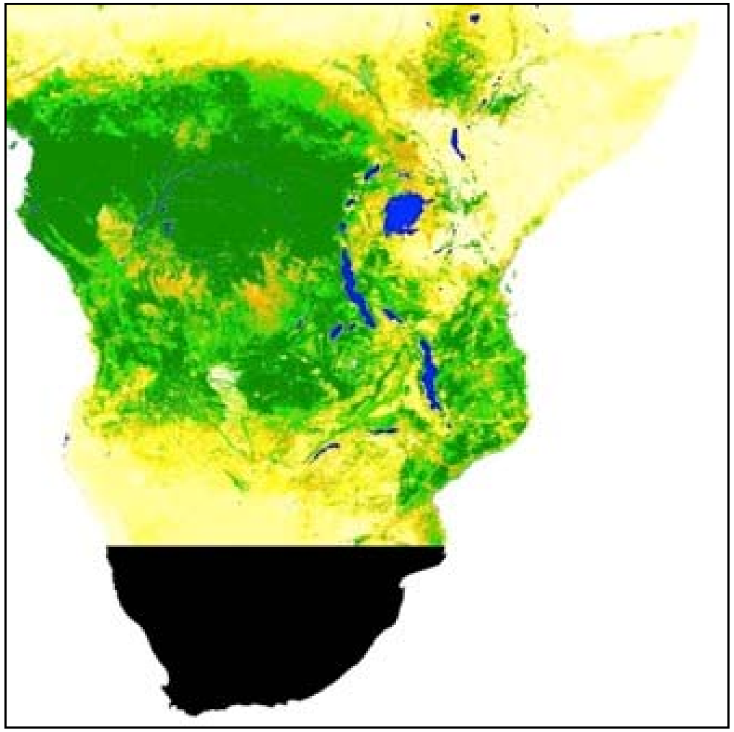
Biomass inversion using the Dry Season regression
Supposed validity domain: Eastern and Austral Africa



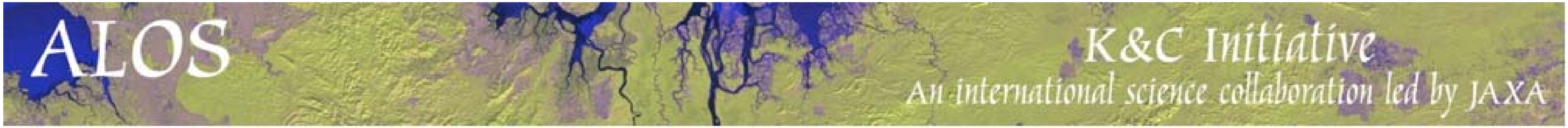
Validation



Comparison with existing maps

This study	Saatchi et al., 2011	Baccini et al., 2012
		

(light yellow)	0-10 Mg ha^{-1}	(orange)	50-60 Mg ha^{-1}
(pale yellow)	10-20 Mg ha^{-1}	(light green)	60-100 Mg ha^{-1}
(yellow)	20-30 Mg ha^{-1}	(dark green)	> 100 Mg ha^{-1}
(bright yellow)	30-40 Mg ha^{-1}	(blue)	water
(light orange)	40-50 Mg ha^{-1}	(black)	no data



Comparison with existing maps

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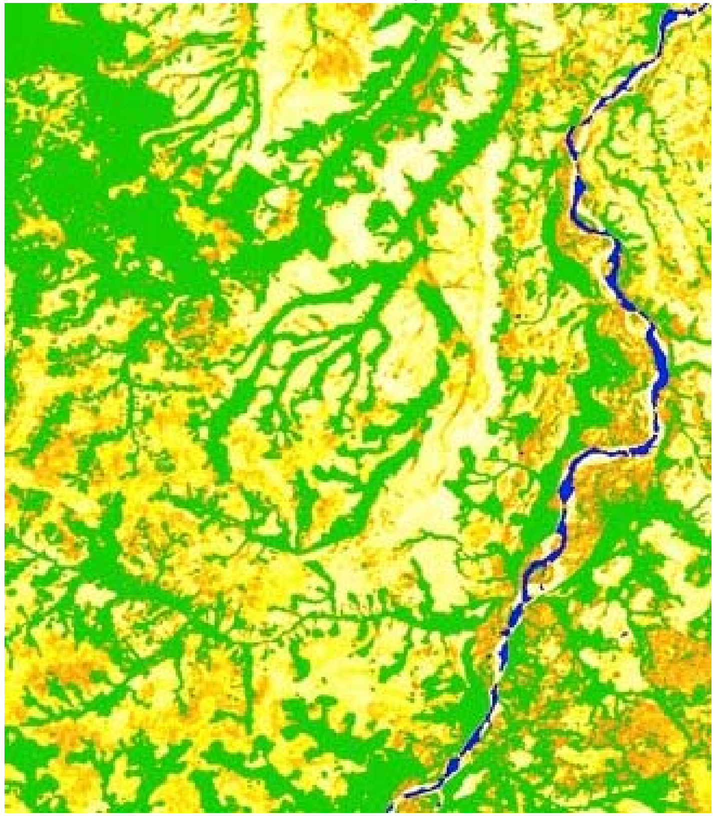
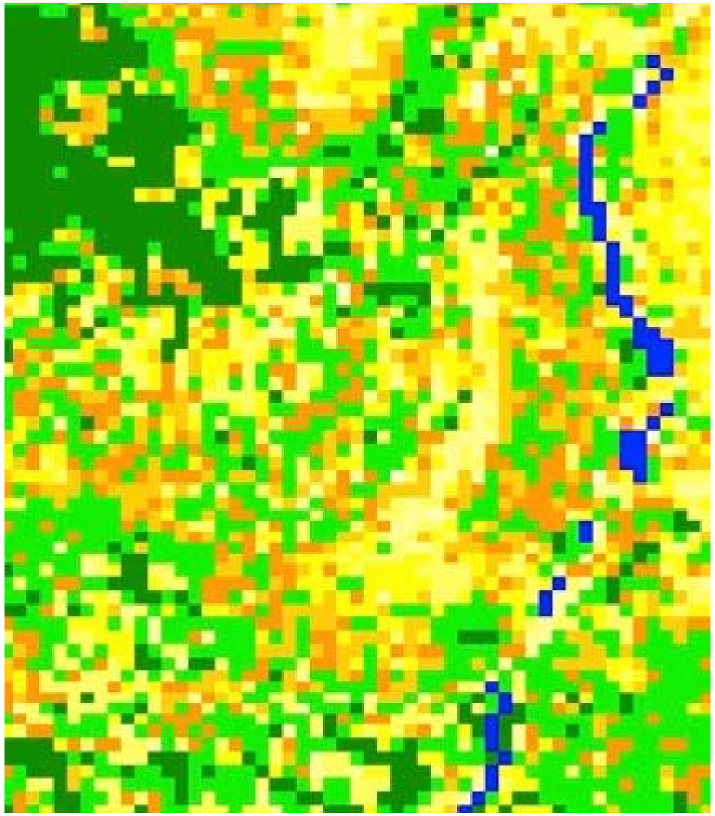
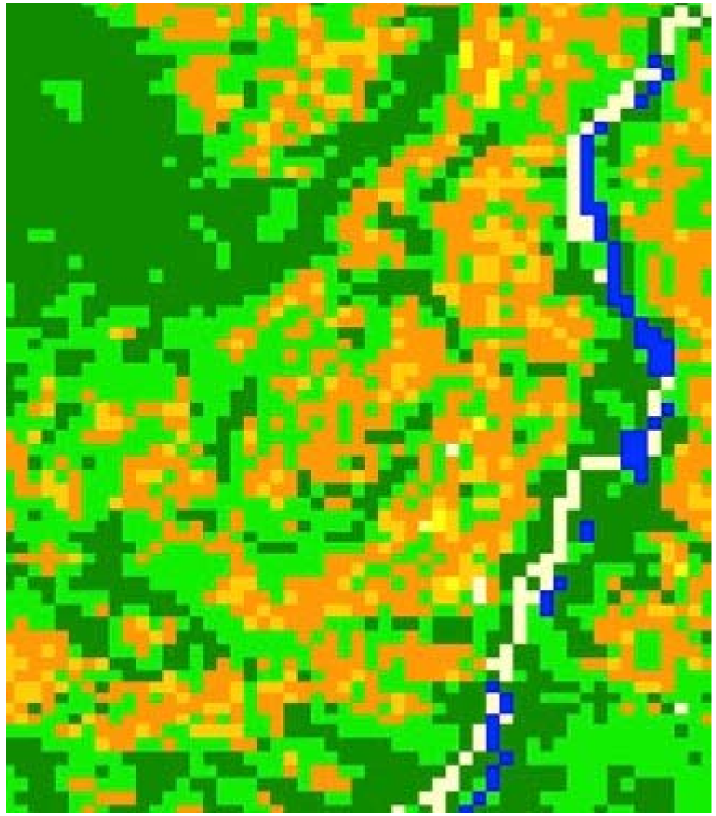


Saatchi et al., 2011



Baccini et al., 2012



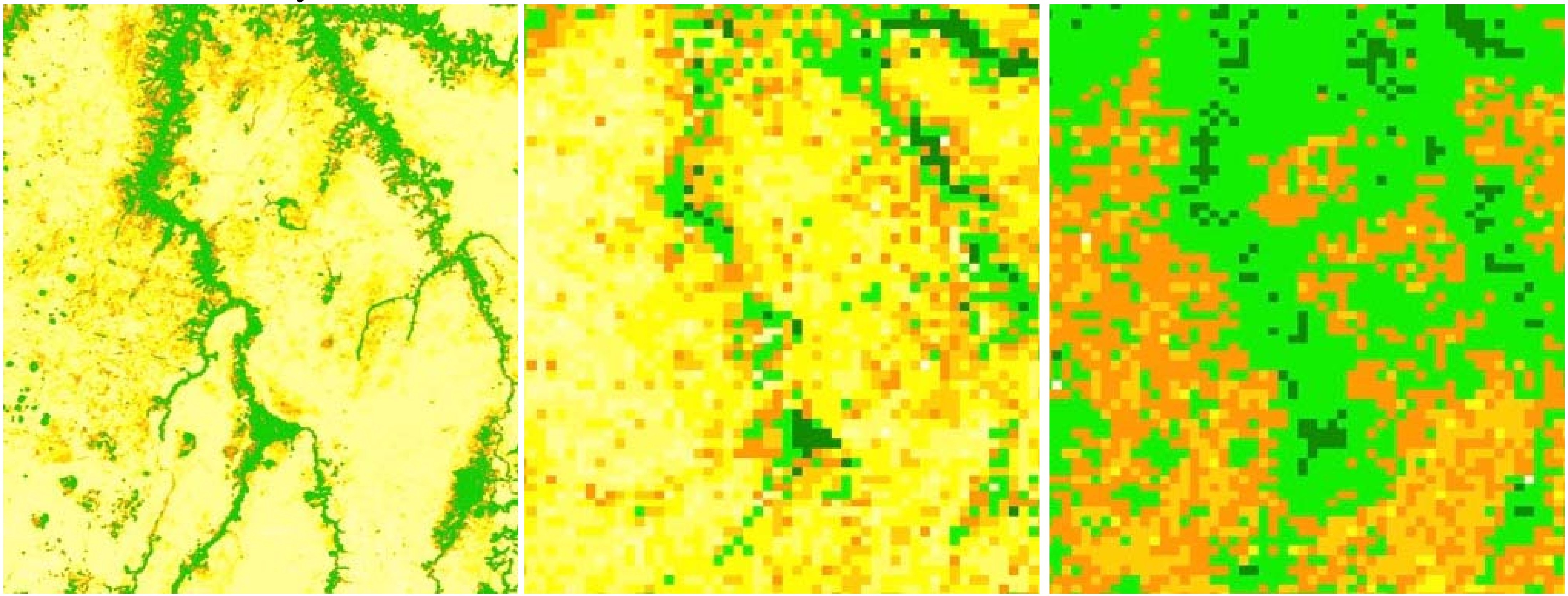
0-10 Mg ha^{-1}	50-60 Mg ha^{-1}
10-20 Mg ha^{-1}	60-100 Mg ha^{-1}
20-30 Mg ha^{-1}	> 100 Mg ha^{-1}
30-40 Mg ha^{-1}	water
40-50 Mg ha^{-1}	no data

Subset from: Latitude: 5° S to 0° N

Longitude: 15° E to 20° E

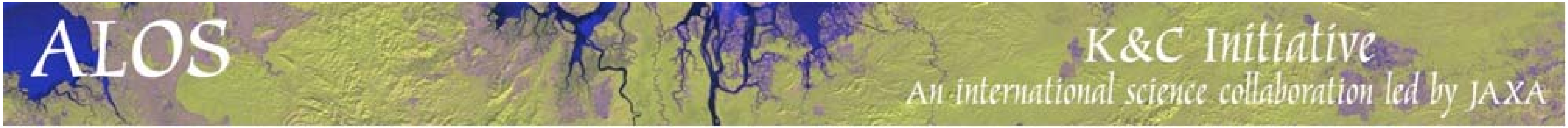
Comparison with existing maps

This study | Saatchi et al., 2011 | Baccini et al., 2012



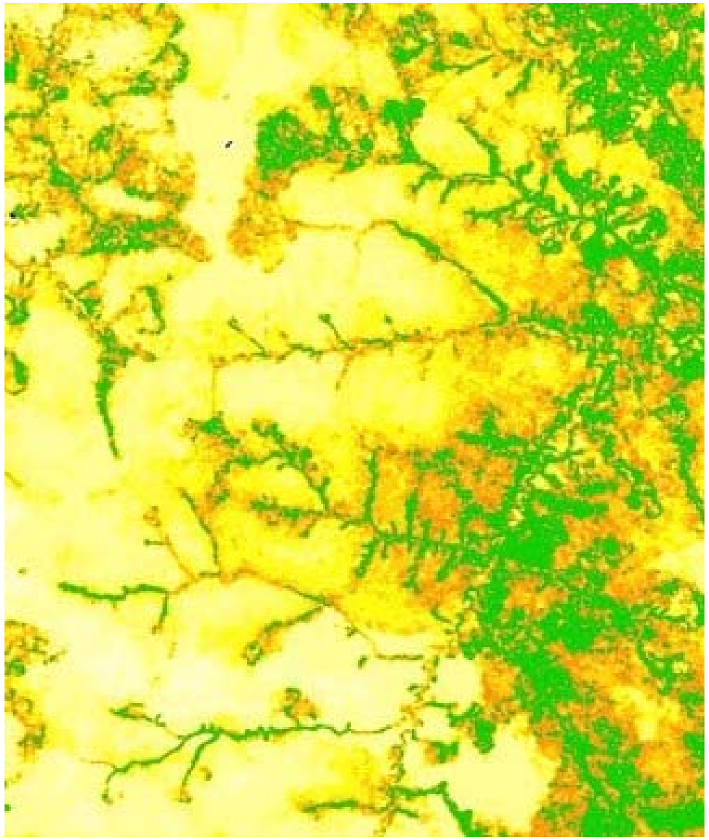
	0-10 Mg ha^{-1}		50-60 Mg ha^{-1}
	10-20 Mg ha^{-1}		60-100 Mg ha^{-1}
	20-30 Mg ha^{-1}		> 100 Mg ha^{-1}
	30-40 Mg ha^{-1}		water
	40-50 Mg ha^{-1}		no data

Subset from: Latitude: 5° S to 0° N
Longitude: 15° E to 20°

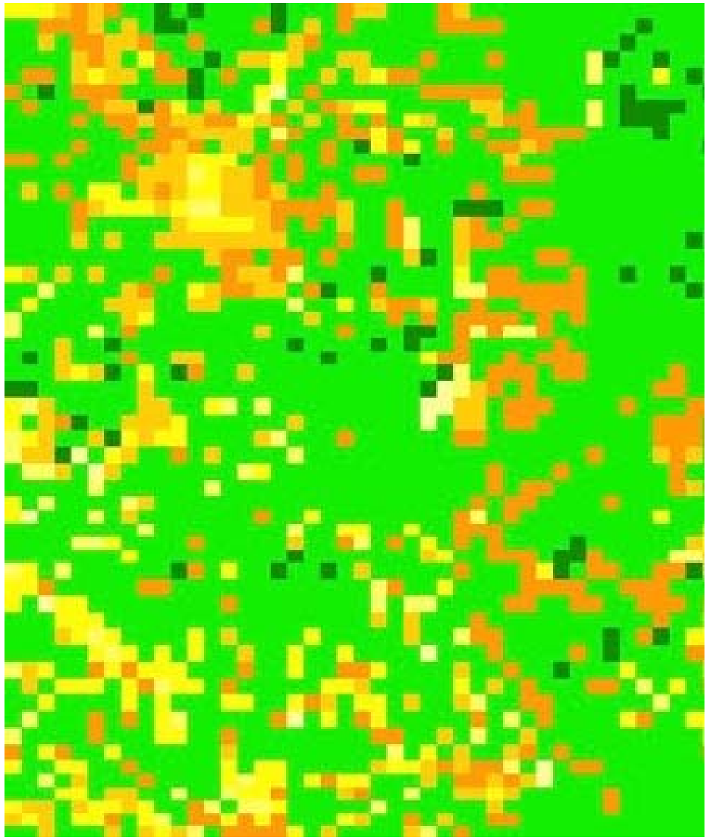


Comparison with existing maps

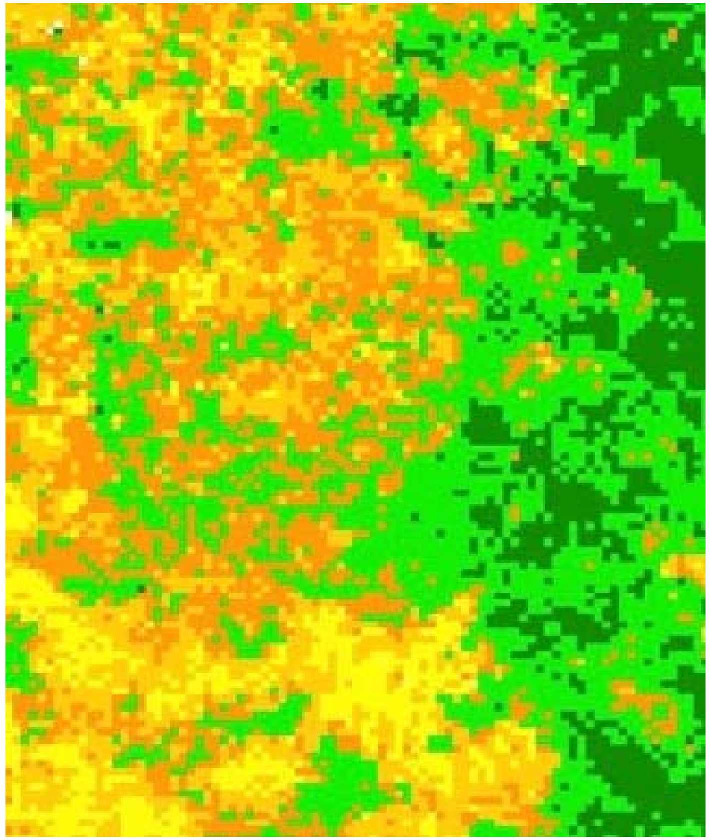
This study



Saatchi et al., 2011



Baccini et al., 2012

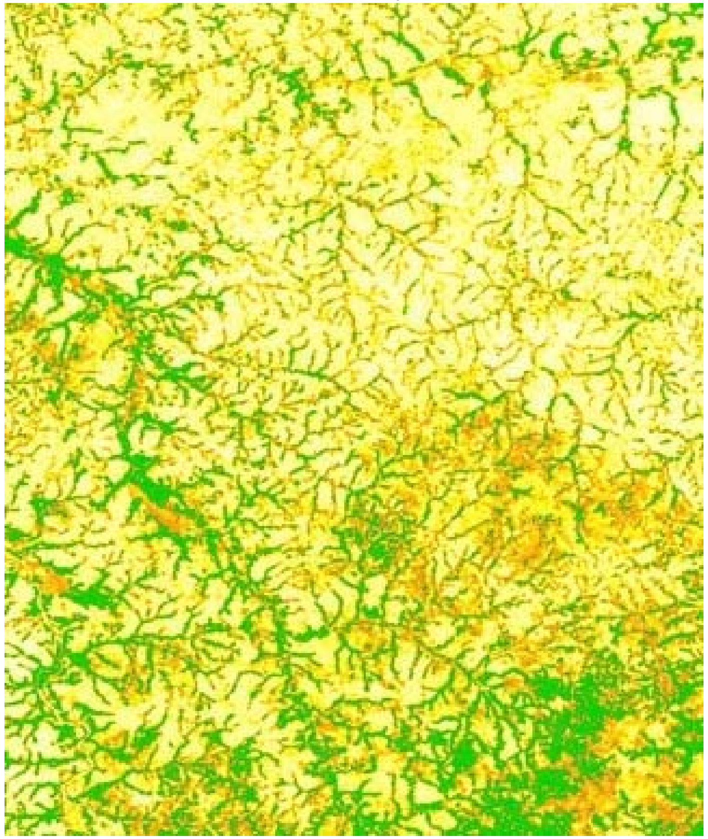


0-10 Mg ha^{-1}	50-60 Mg ha^{-1}
10-20 Mg ha^{-1}	60-100 Mg ha^{-1}
20-30 Mg ha^{-1}	> 100 Mg ha^{-1}
30-40 Mg ha^{-1}	water
40-50 Mg ha^{-1}	no data

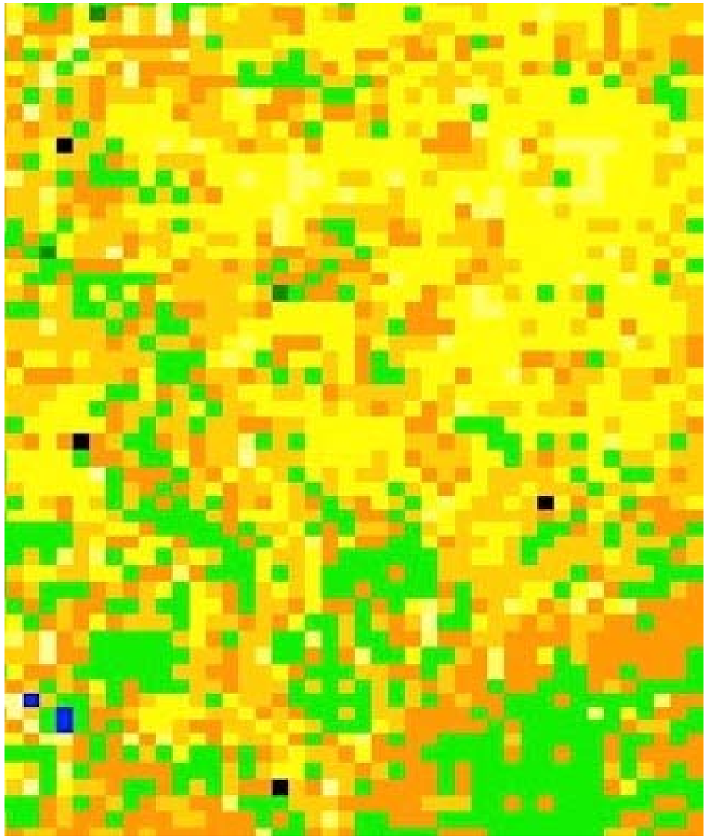
Subset from: Latitude: 10° S to 5° S
Longitude: 20° E to 25° E

Comparison with existing maps

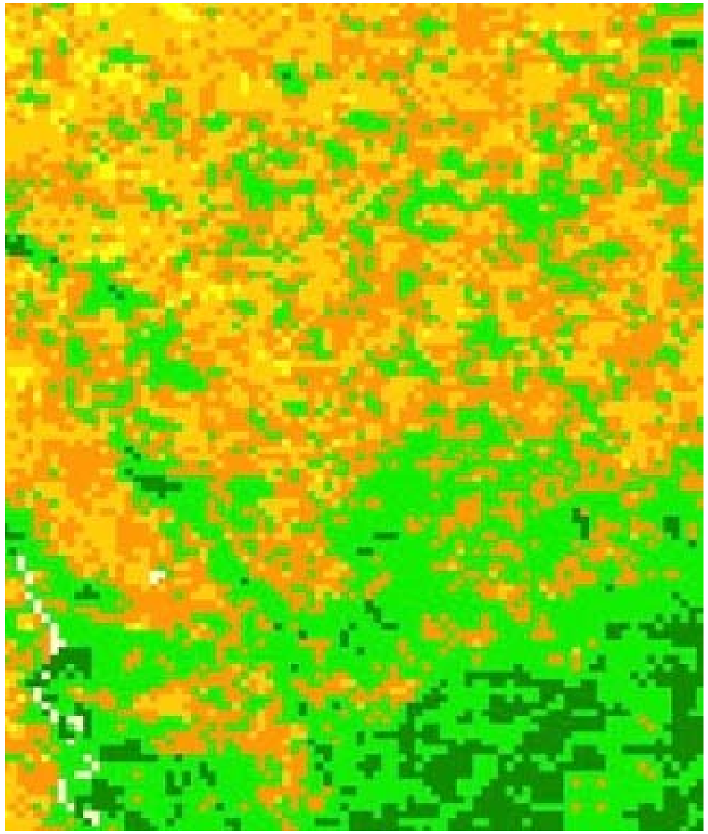
This study



Saatchi et al., 2011



Baccini et al., 2012



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40-50 Mg ha^{-1}	no data

Subset from: Latitude: 10° S to 5° S
Longitude: 20° E to 25° E

Comparison with Lidar map

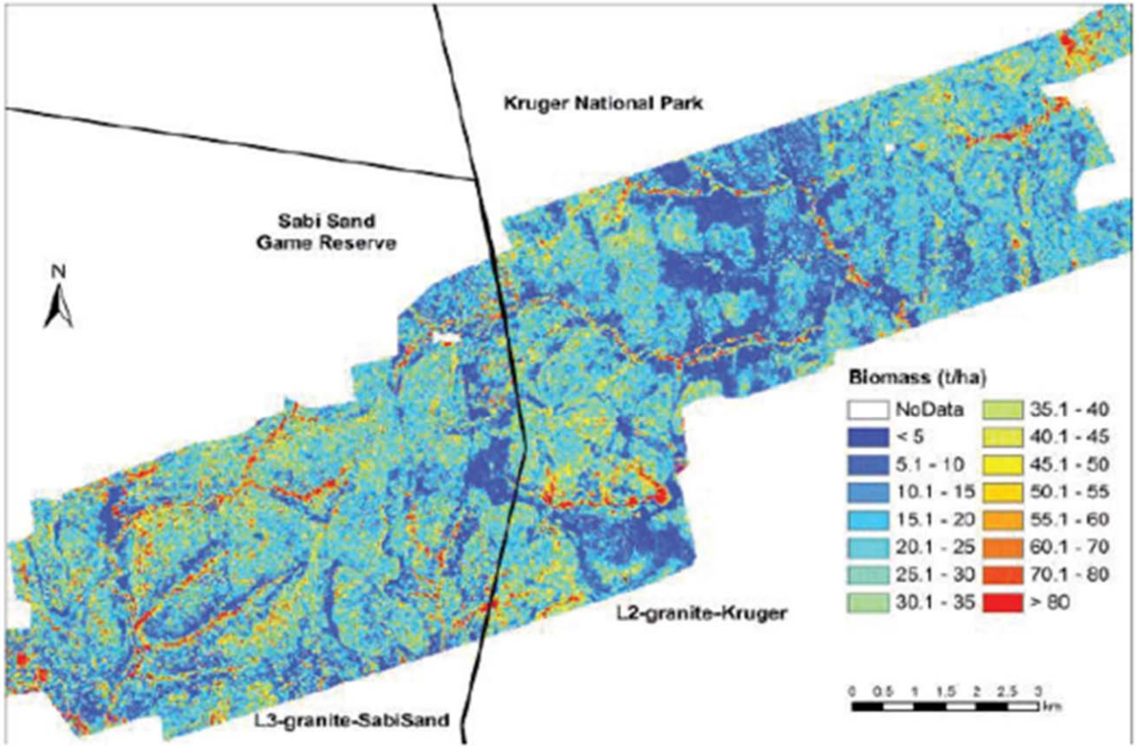
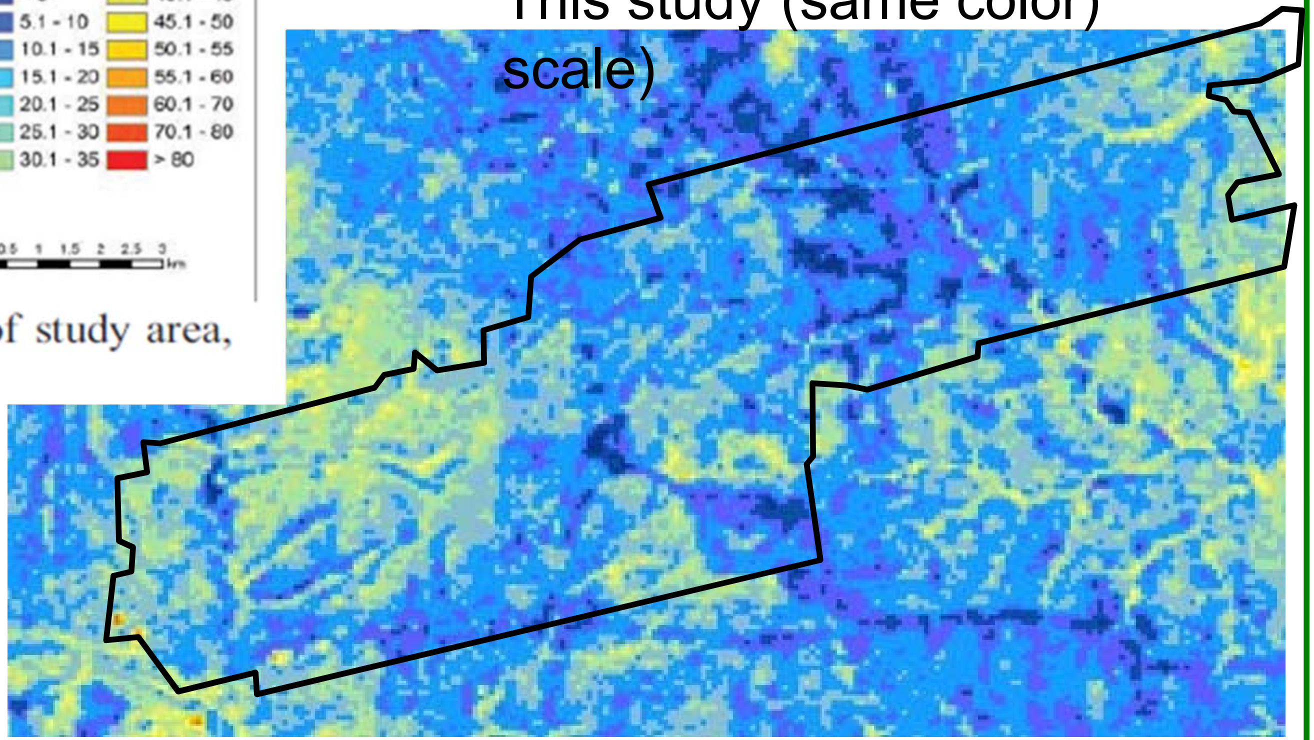


Fig. 1. LiDAR-derived biomass map for part of study area, L2, L3.

Wessels et al. IGARSS 2012

South Africa
24° 44' S /
31° 36'E

This study (same color scale)



And for dense forests ???

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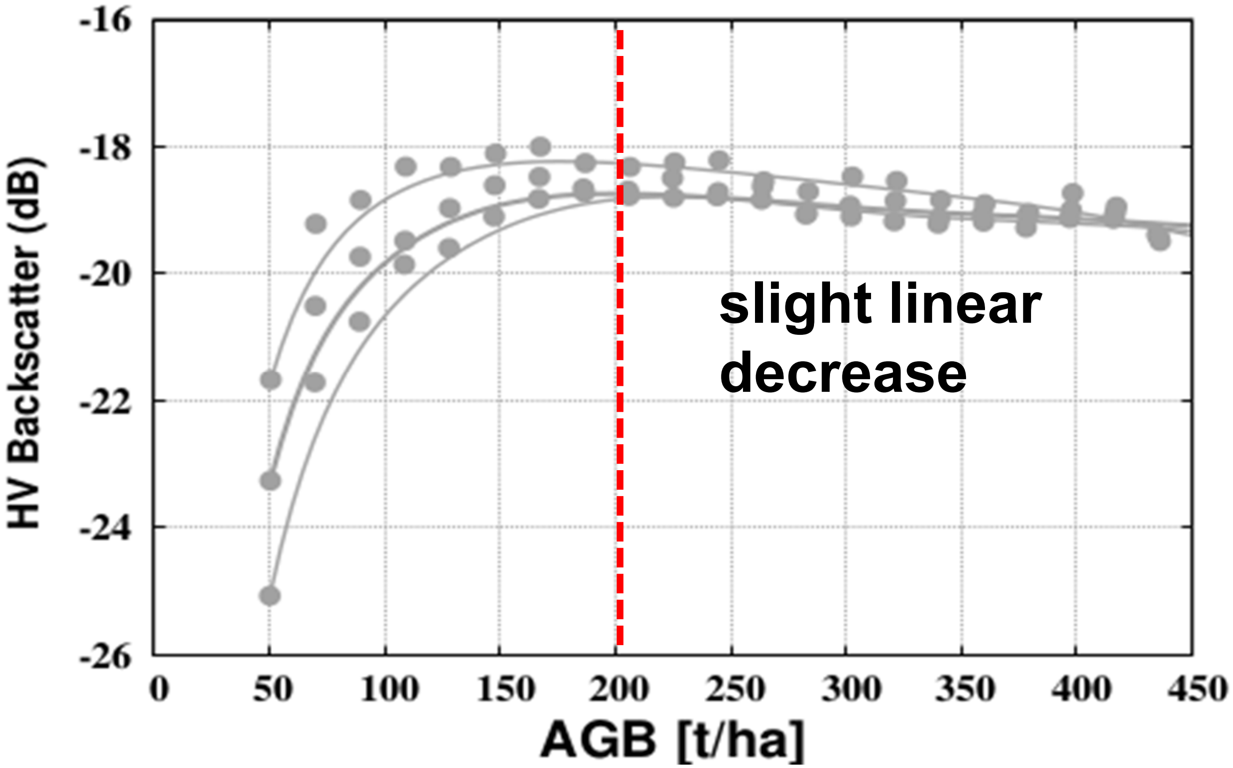
ELSEVIER

Decrease of L-band SAR backscatter with biomass of dense forests

Stéphane Mermoz[a], Maxime Réjou-Méchain[b,c,d], Ludovic Villard[a], Thuy Le Toan[a], Vivien Rossi[d,e], Sylvie Gourlet-Fleury[d]

[a] *Centre d'Études Spatiales de la BIOsphère, UMR CNRS 5126, University of Paul Sabatier, Toulouse, France*
[b] *Laboratoire Évolution et Diversité Biologique, UMR CNRS 5174, University of Paul Sabatier, Toulouse, France*
[c] *Institut de Recherche et Développement, UMR AMAP, F-34000 Montpellier, France*
[d] *Centre International de Recherche Agronomique pour le Développement, UR BSEF, Montpellier, France*
[e] *University of Yaoundé 1, UMI209 UMMISCO, Yaoundé, Cameroon*

Modelling results



L-band

ρ = 0.575, 0.6, 0.625

$\theta = 45^o$

$h_t/h = 0.75$

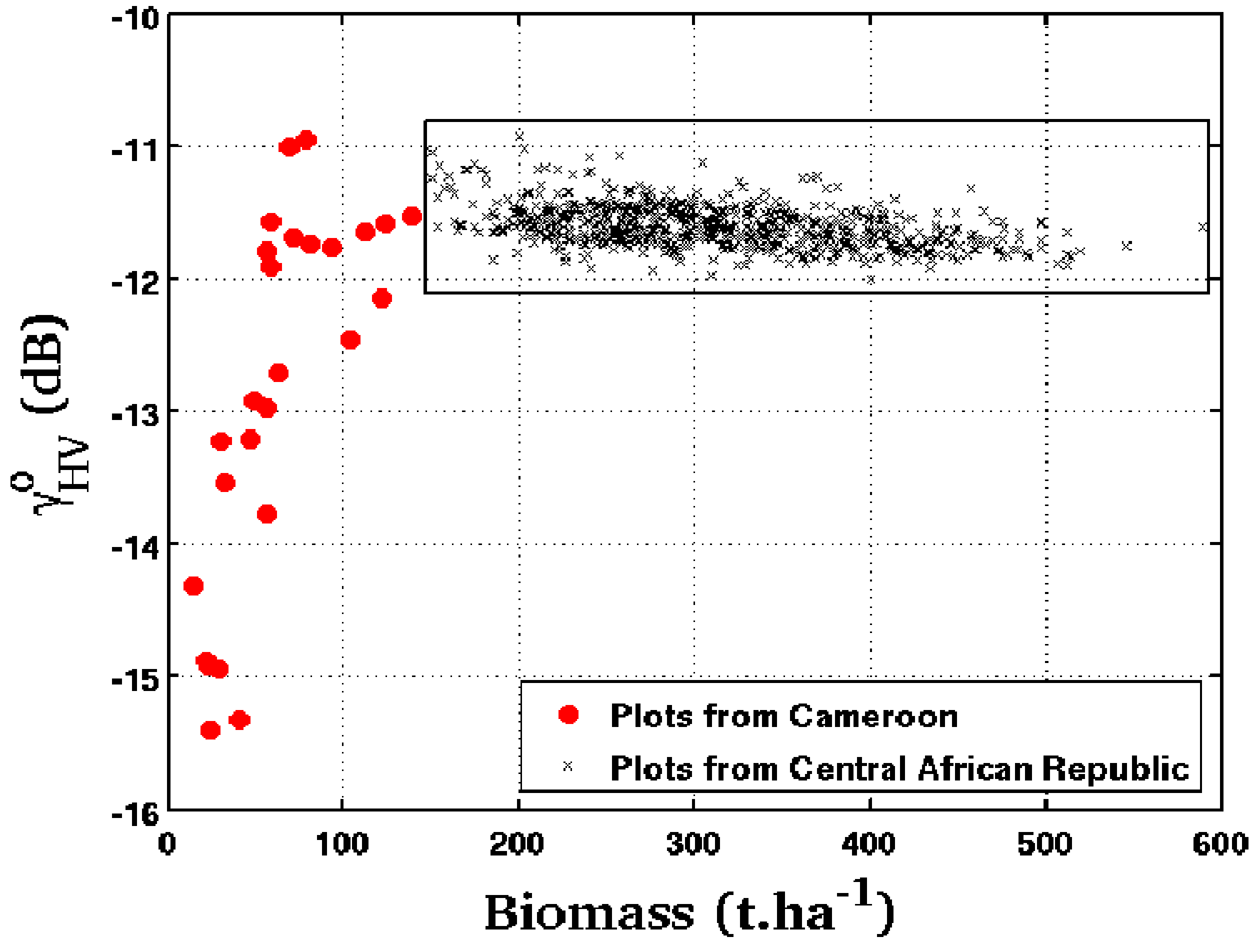
Decrease:

1.7 dB from 220 to 420 $t.ha^{-1}$.

The sum of scattering contributions increases with volume fraction,but is opposed by the extinction coefficient which is also increasing.

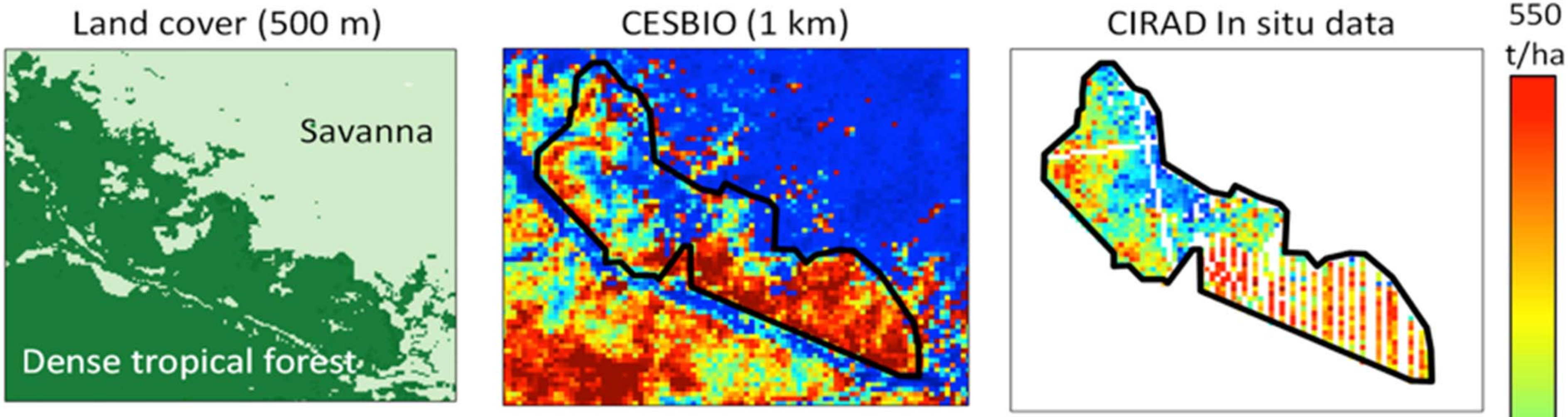
Observations: ALOS PALSAR of dense tropical forest

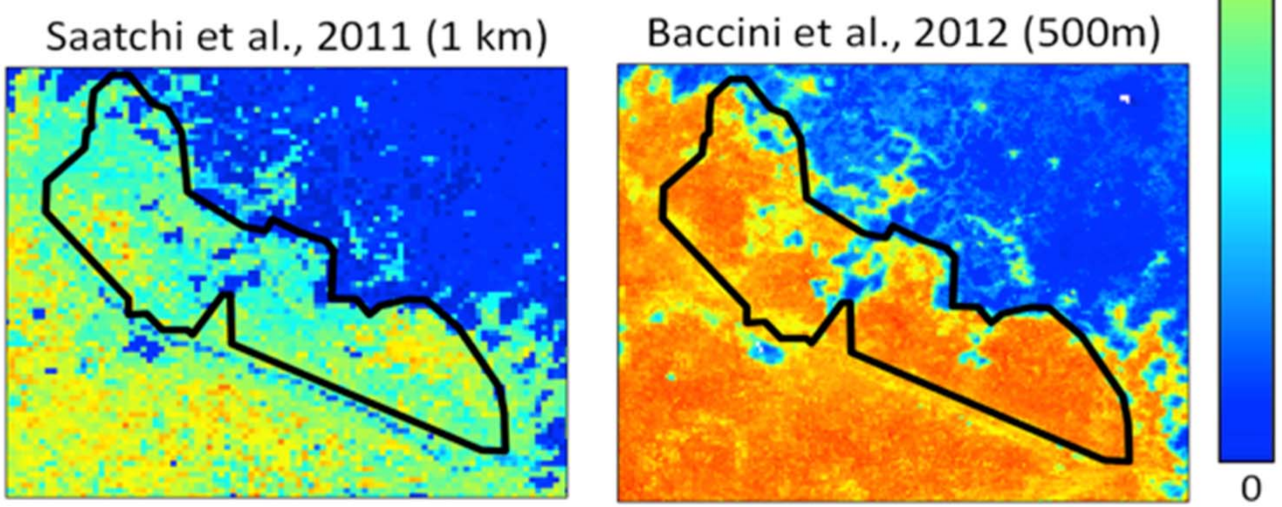
632 plots (1km x 1km)
in-situ AGB: Mean of 312.3 $t.ha^{-1}$, from 150.1 to 545.6 $t.ha^{-1}$.



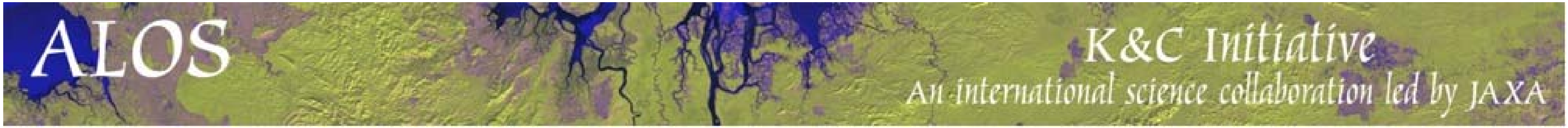
Speckle noise
Sampling error (plot size)
Homogeneity
Terrain slope

New methodology for L-band vegetation mapping





CESBIO method:
RMSE = 35%

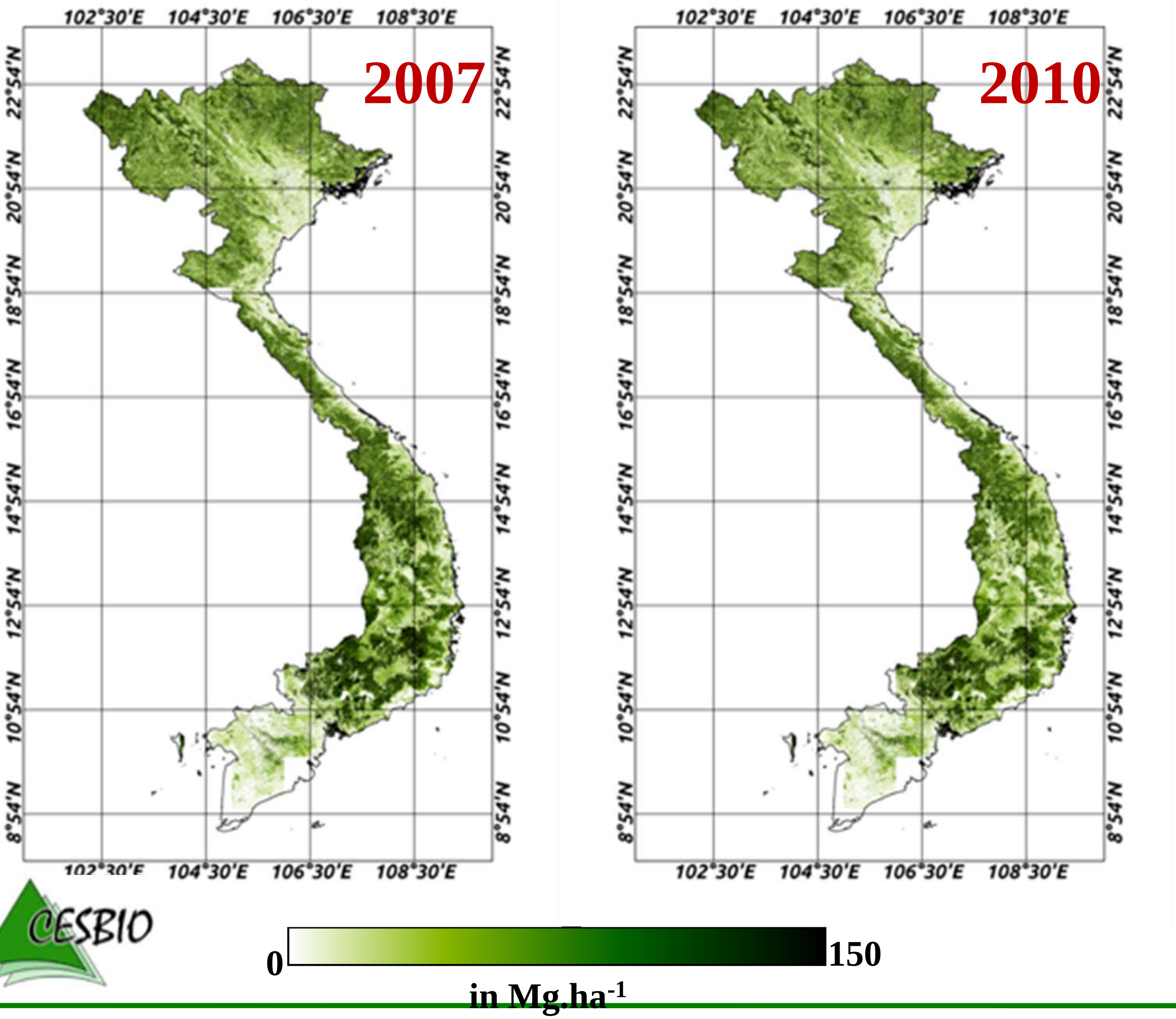


Biến động độ phủ thực vật và rừng

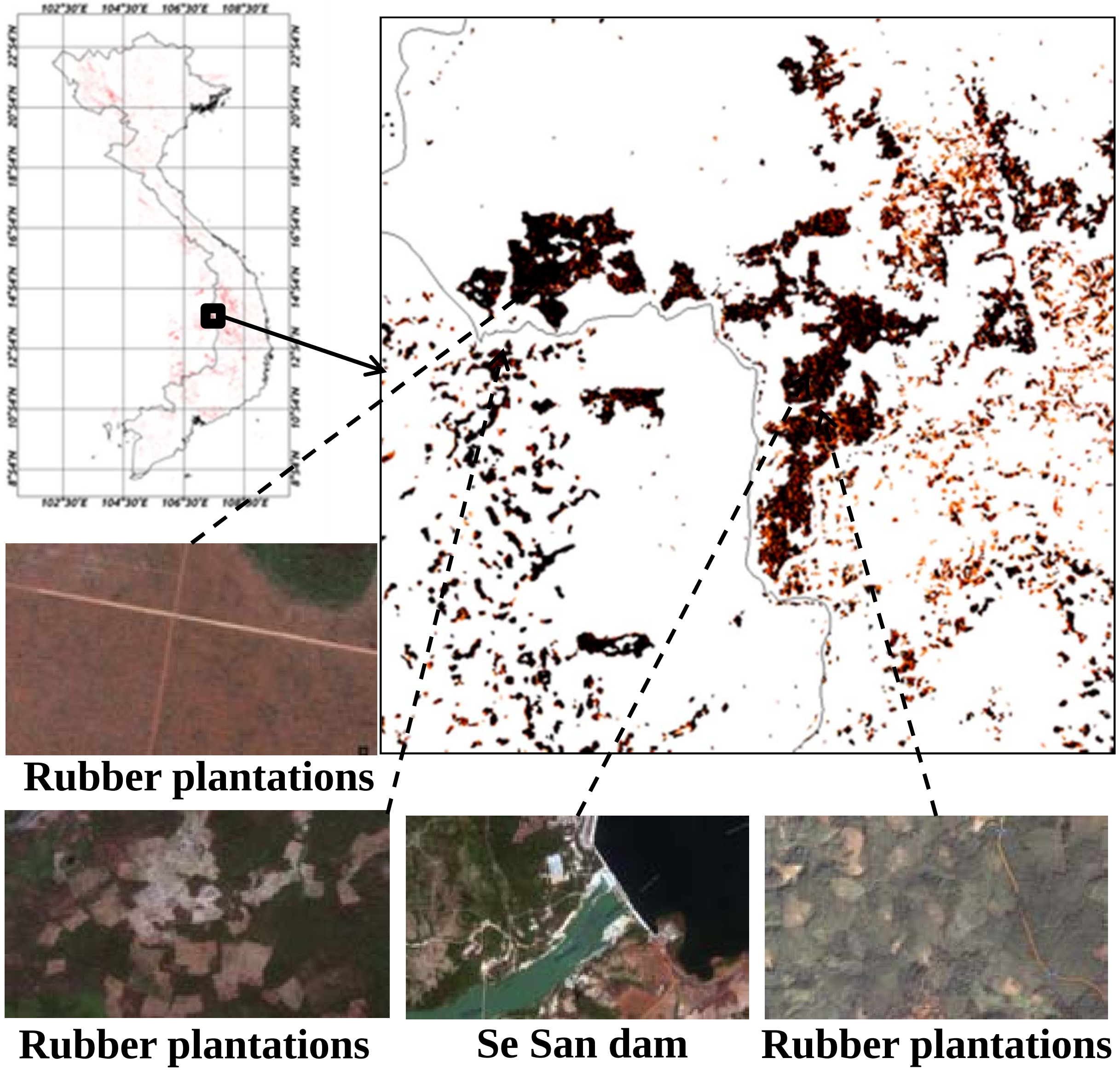
Stephane Mermoz, Thuy Le Toan, CESBIO

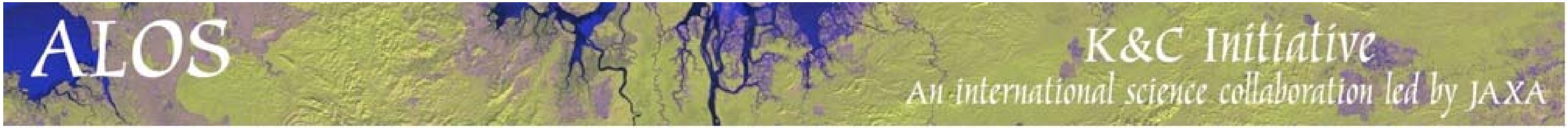
Technical workshop,
Hanoi Vietnam
May 2014

Bản đồ, 50 m, ALOS-PALSAR



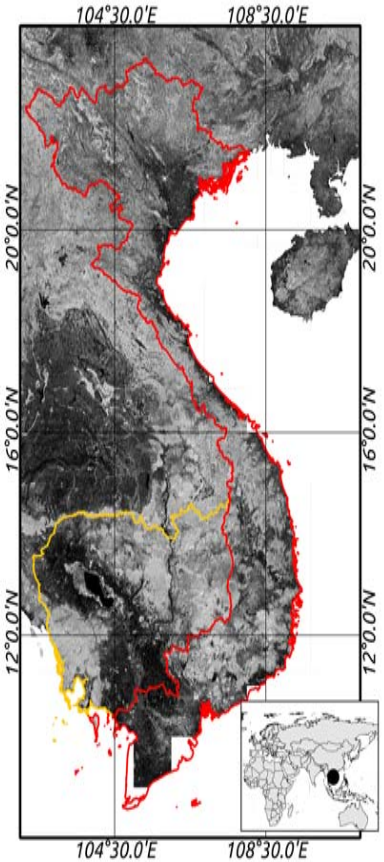
Changes in forest cover 2007-2010

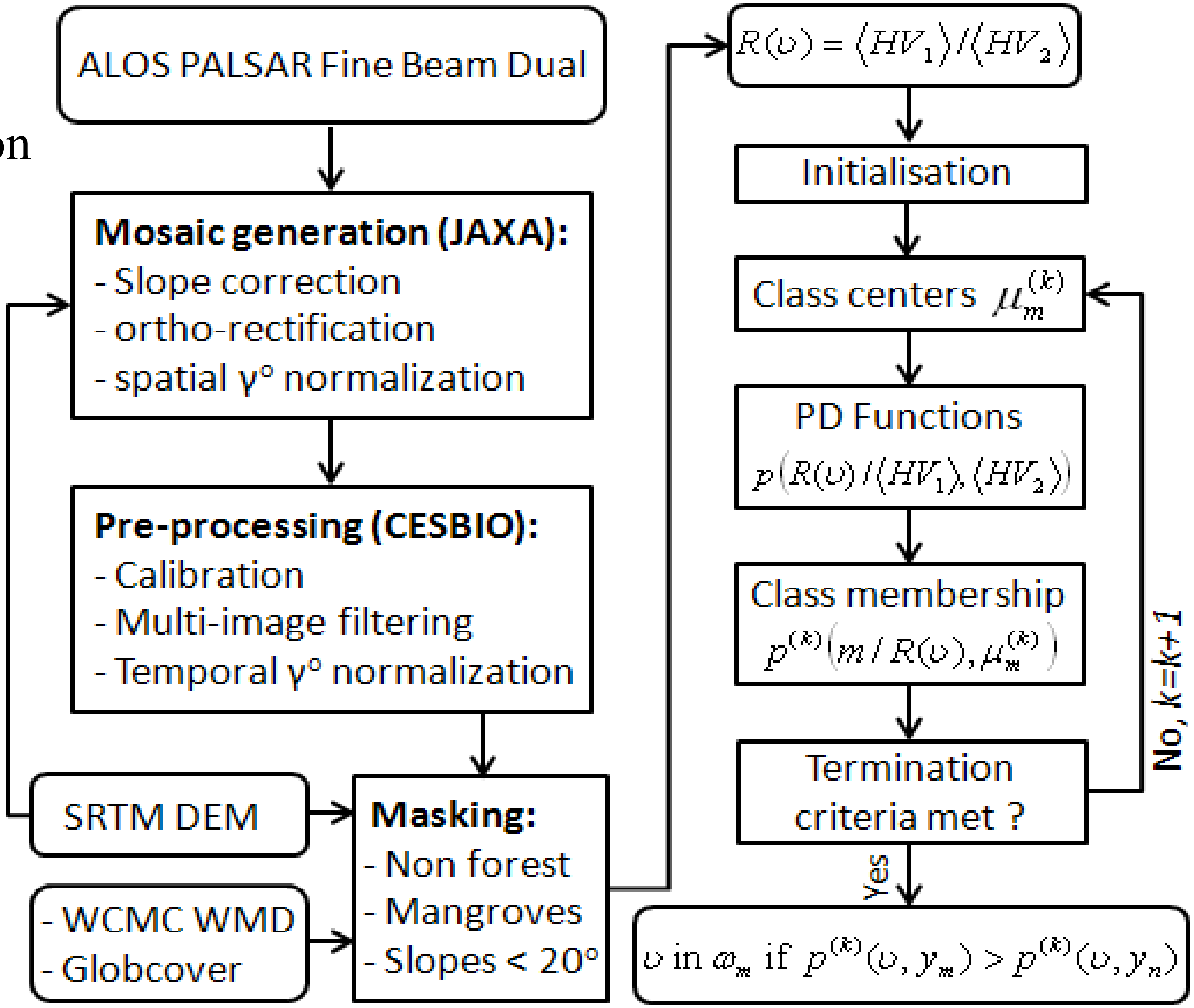




Estimation of forest disturbances and regrowth

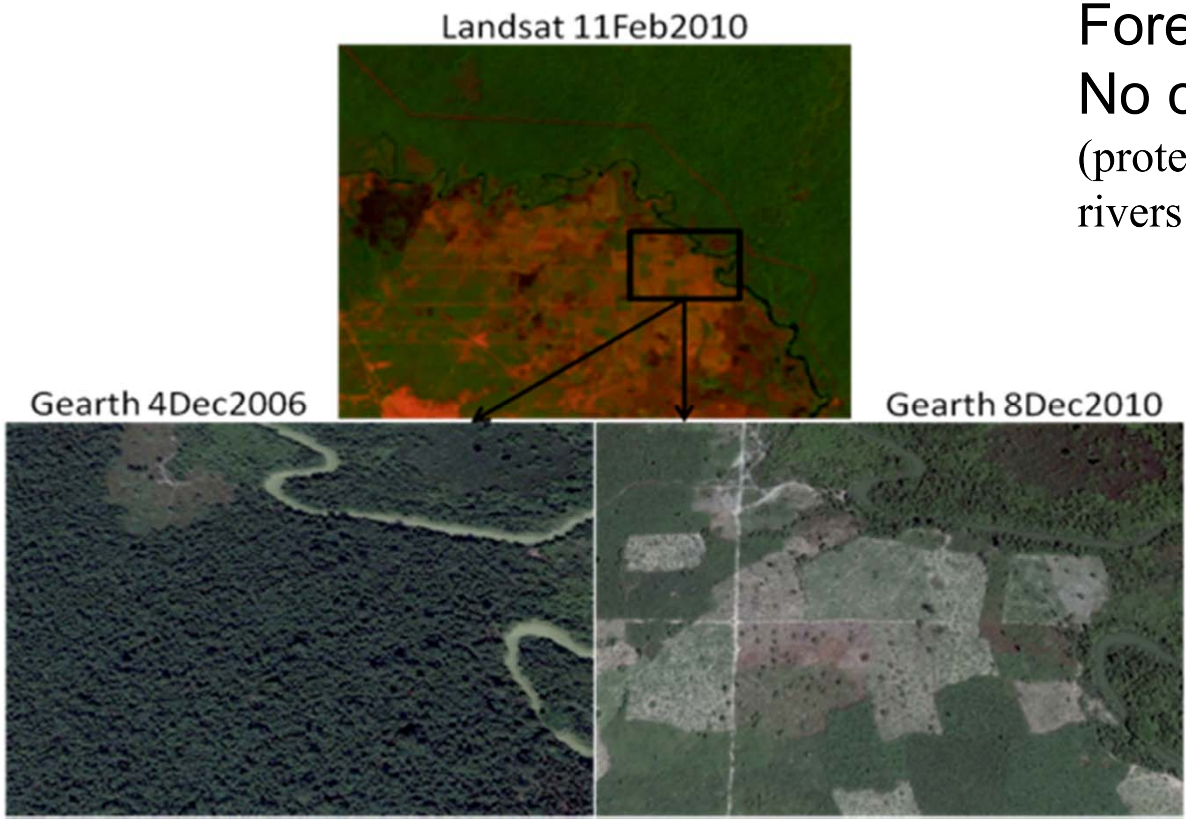
Indicator of changes: HV ratio
Window size: 5x5
Approach: Expectation maximization





Validation mostly based on VHR GoogleEarth
- relatively untapped new source of validation data for remote sensing studies (Knorn et al., 2009; Standart et al., 2011).
- Images captured at a wide variety of dates, mostly cloud free and of a resolution high enough to very easily distinguish forest changes.

In situ plots over 27 Mosaic frames:



Forest disturbances: 386 ha
Forest regrowth: 148 ha
No changes: 451 ha
(protected areas, national parks, plots far from roads, rivers and villages)

Estimation of forest disturbances and regrowth:

OA: 92% (with ponderation factor related to in situ data per class)

	VIETNAM	CAMBODIA	LAO PDR
Disturbances (%)	-1.43	-1.39	-0.98
Carbon loss (MtC)	40.1	32.4	39.7
Regrowth (%)	+1.78	+0.83	+0.70

Deliverables

- ❑ Biomass map of Cameroon savanna 25m available
- ❑ Biomass map of African savanna 50m available by mid 2015
- ❑ Forest disturbances and regrowth in Vietnam, Cambodia and Lao PDR available by mid 2015

In situ data to share

- 41 forest plots in Cameroon of about 1 ha measured in the REDDAF European project.

Deliverables

Papers and reports

Journal papers

Published/ Reviewed

- Mermoz S., Le Toan T., Villard L., Réjou-Méchain M., and Seifert-Granzin J, Biomass assessment in the Cameroon savanna using ALOS PALSAR data, Remote Sensing of Environment, Volume 155, December 2014, Pages 109-119

- Mermoz S., Réjou-Méchain M., Villard L, Le Toan T., and Seifert-Granzin J, Decrease of L-band SAR backscatter with biomass of dense forests, Remote Sensing of Environment, final review

To be submitted

- Mermoz S., Le Toan T. Forest disturbances and regrowth assessement in Southeast Asia using ALOS PALSAR from 2007 to 2010. Remote Sensing of Environment.

- Bouvet A., Mermoz S., Le Toan T, Mitchard E. and Mathieu, R. A biomass map of african savanna. Remote Sensing of Environment.

Books

- Haeusler T., Gomez S., Siwe R., Le Toan T., Mermoz S., Schardt M, and Sannier C.: Reducing Emissions from Deforestation and Degradation in Africa (REDDAF). 7th Research Framework Programme publication ‘Let’s Embrace Space’ EU Publication 2012, Volume 2

- Les forêts du bassin du Congo – État des Forêts 2013. Éds: de Wasseige C., Flynn J., Louppe D., Hiol Hiol F., Mayaux Ph. – 2014. Weyrich. Belgique. 328 p. Dépôt légal : D/2014/8631/30 ISBN : 978-2-87489-298-1

Deliverables

Papers and reports

Conference presentations and papers

•Mermoz S, Le Toan T and Villard L.: Biomass assessment in African savannah forest using multi-temporal ALOS PALSAR Data. EARSeL Workshop on Temporal Analysis of Satellites Images. Mykonos, 23-25 May 2012.

•Mermoz S., Le Toan T., Villard L., and Lasne Y.: Biomass assessment in African forest-savanna using ALOS-PALSAR data. IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Munich, 22-27 July 2012.

•Bouvet A., Le Toan, T. and Mermoz S.: A Biomass Map of African Savannas at a Spatial Resolution of 100 meters using ALOS PALSAR Dual-Polarization Data. European Space Agency Living Planet Symposium, Edinburgh, 9-13 September 2013

•Mermoz S., Le Toan T., Villard L., Réjou-Méchain M., and Seifert-Granzin J.: Savanna Carbon stocks and 2007-2010 change in Cameroon using ALOS PALSAR data. European Space Agency Living Planet Symposium, Edinburgh, 9-13 September 2013. (voir Résumé)

•Le Toan, T., Mermoz, S., Fichet, L. V., Sannier, C., & Bouvet, A. (2014, July). Comparison of optical and SAR data for forest cover mapping: REDD+ may be helped by SAR data. In Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International, pp. 2305-2308

•Fichet, L. V., Sannier, C., Mermoz, S., Pennec, A., & Le Toan, T. (2014, July). Mapping dry forest in Central African Republic using optical and radar data. In Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International (pp. 2336-2339).

•Mermoz, S., Rejou-Mechain, M., Villard, L., Le Toan, T., Rossi, V., & Gourlet-Fleury, S. (2014, July). Biomass of dense forests related to L-band SAR backscatter?. In Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International (pp. 1037-1040).

Thank You !

K&C Phase 4 – Brief project essentials

Forest Cover Change and Biomass Mapping

Thuy Le Toan, Stephane Mermoz, Alexandre Bouvet, Ludovic Villard

CESBIO
Toulouse, France

Project outline and objectives

We propose to build on the experience gained in Phase 3 to:

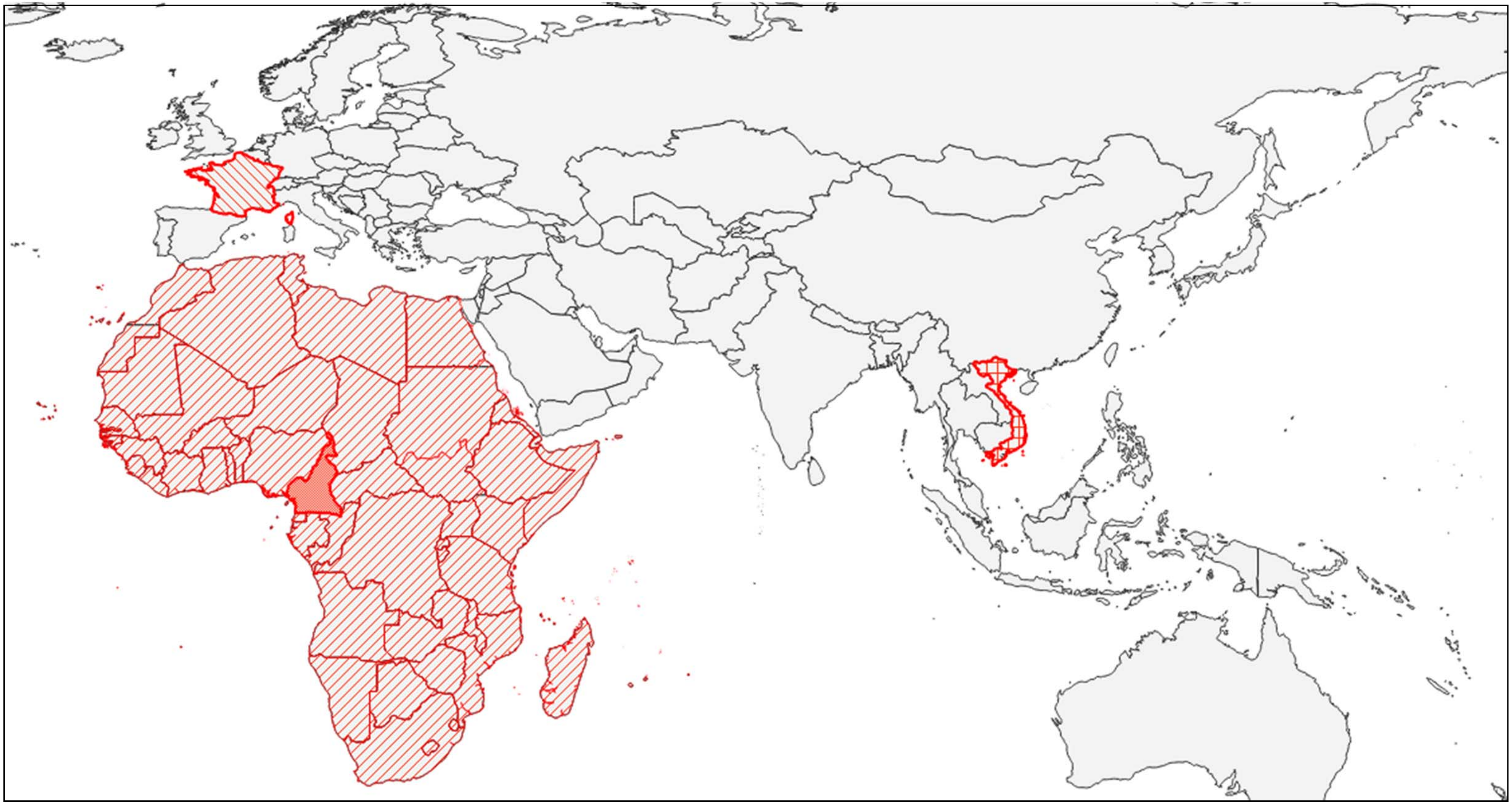
- map biomass and forest cover in Africa/Cameroon savanna, Vietnam and France at 50m and to estimate changes between 1997, 2007, 2010, 2014, 2015 and 2016, 2017.

The main objective is to estimate Carbon stock and changes, to contribute to the Carbon cycle science.

ALOS

K&C Initiative
An international science collaboration led by JAXA

Project outline and objectives



Project milestones

Africa/ Cameroon and Vietnam:

MS1: First results for biomass estimates with ALOS-2 (31.03.2015)

Forest biomass map 1997

MS2: Forest biomass maps 2014-2015 (31.03.2016)

Forest biomass changes 1997-2010-2015

MS3: Forest biomass maps 2016-2017 (31.03.2017)

Forest biomass changes 1997-2010-2015-2017

France

MS1: First results for biomass estimates with ALOS-2 (31.03.2015)

MS2: Forest biomass maps 2014-2015 (31.03.2016)

Forest biomass changes 2010-2015

MS3: Forest biomass maps 2016-2017 (31.03.2017)

Forest biomass changes 2010-2015-2017

Data sharing

Africa

- Reference forest plots for the calibration/validation of the biomass map (coordinates, Above Ground Biomass) belong mostly to research networks (e.g. CTFS, Afritron..) thus accessible to the community.
- Specific ground data collection for low biomass (< 150 tons/ha) during KC Phase 4. Field measurements of biomass can be shared to JAXA after the restriction delay imposed by the research project
- Field photos, forest types and general information (species, range of biomass..) at a number of points

Vietnam

- In addition , ground data collected by University students (e.g. for Master thesis) could be made available.

France

- In addition, forest inventory data (exist but subject to restrictions). Data collected by CESBIO could be shared with JAXA.

Deliverables

Africa/Cameroon and Vietnam

- Forest biomass maps 1997-2010-2015-2017
- Forest biomass changes 1997-2010-2015-2017

France

- Forest biomass maps 2010-2015-2017
- Forest biomass changes 2010-2015-2017