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Continental Surfaces

Fig. 1

Fig. 2

Fig. 3

Global changes include climate change, alterations of the environment due to human activities (land use and cover, urbanization, fossil fuel consumption, etc.) and the associated consequences (erosion, flooding, impact on continental and coastal ecosystems, animal population movements and areas of disease prevalence, etc.). Climate disruptions observed these last few years have confirmed the reality of climate change and aroused a growing public awareness of short-term potential environmental, economic and geopolitical impacts. Besides, the part of anthropic activities and greenhouse gas in drift mechanisms was proven.

Interactions between water and carbon cycles and climate have a crucial role to play. For continental surfaces, the properties of the surface and its plant cover (continental biosphere) strongly impact water, CO_2 and energy exchanges between ground and atmosphere and hydrological cycles (flow, infiltration/evaporation, etc.), with, in turn, retroactive effects on climate. Coasts are also very affected by climate change due to their own biophysical functioning (exchanges with the atmosphere) and their interactions with nearby continental systems.

Climate stakes make it necessary to use operational observation methods to:

(i) quantify ongoing drifts and continuously monitor their impact on surfaces,
(ii) develop, calibrate and validate models that could support projections on the evolution of ecosystems,
(iii) anticipate the effects of mitigation and adaptation methodologies that are considered (sustainable development).

Water management adaptation to climate change is a global emergency

Even if humanity could significantly reduce future greenhouse gas emissions, adverse effects of climate change would still be felt for many decades. Precipitation and hydrological cycles have already begun to change and it will most likely be felt by 2040 or 2050. So we need to take swift actions.

These reasons have led CNES and the scientific community:

(i) to develop, in collaboration with JPL, THIRSTY, a mission with a global cover, combining high spatial resolution and high revisit,
(ii) to continue the important partnership with NASA/JPL for the SWOT mission,
(iii) to keep supporting the BIOMASS mission,
(iv) to support the exploitation of the SMOS mission and provide the next generation of SMOS satellite, SMOS NEXT to address resource management in watersheds,
(v) to continue to prepare the exploitation of data provided by SENTINEL-2 with a strong experiment, SPOT-4-TAKE FIVE.

As for the Continental Surfaces thematic unit at CNES, an infrastructure dedicated to shared space data was created in 2013 within the THEIA unit, with the signing of the convention for the constitution of the unit with nine French institutional organizations, thus answering a recurring request from the scientific community for many years.

THIRSTY

During MISTIGRI's phase A – with the support of TOSCA, priority was given to the consolidation of the mission's objectives and requirements, as well as its framework. Three scientific objectives were identified, focusing on the operation of:

(i) continental biosphere,
(ii) urban areas,
(iii) coastal environments and inland water surfaces.

Spatial resolution, revisit, passing time and required main characteristics of the instrument were then justified. Thanks to this knowledge, cooperation with JPL was established for the THIRSTY mission, with innovative instruments such as cooled detectors. The originality of THIRSTY lies in the combination of high spatial resolution (about 80 m) and a strong revisit capacity (3 days) with global cover. This mission was recommended during CNES Scientific Prospective Seminar in La Rochelle, France.

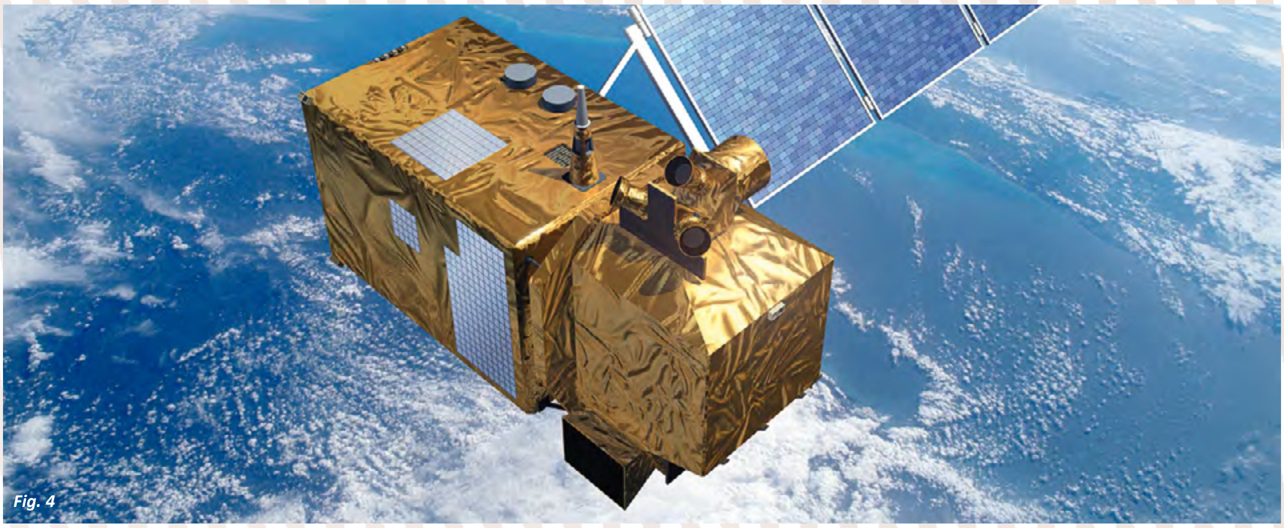

Fig. 4

SMOS (ESA, CNES, CDTI)

SMOS continuously measures soil moisture, water content of vegetation and ocean salinity. Results obtained since 2009 have been outstanding. New applications have been developed, such as monitoring of cyclones and precipitation forecasting. SMOS measures are used to monitor seasonal changes in moisture in the tropics and inland. Good accuracy of measures and their availability in near real-time allowed the development of operational and pre-operational applications. Thanks to this very promising set of results, a new concept was designed to succeed SMOS: the SMOS NEXT instrument, with a ten times finer resolution and a threefold increased sensitivity, will help us develop new coastal application for water resources management and monitoring. This mission was also recommended during CNES Scientific Prospective Seminar.

SWOT

With SWOT, CNES and NASA are using Ka-band interferometry to obtain measurements across a wide swath (120 km) with higher resolution (10 m in high resolution mode). SWOT can map and calculate the height of any mass of water with a surface area greater than 250 x 250 m, no matter what the weather is, for it is not affected by cloud cover. It can also deduce available water quantities at all scales. SWOT will help us calculate the water level of rivers that are more than a 100 m wide and their flow rates. It will also provide accurate maps of flooded land. This data will enable the development and the improvement of applications, such as international and interregional watershed management, flood modeling, clean water management for urban, industrial and agricultural consumption, hydroelectric plant management, measures to help prevent the spread of epidemics and assistance to river navigation. In 2013, milestones were passed towards the implementation of this ambitious mission, with the confirmation that it will carry the nadir altimeter and its transition to phase B at CNES.

BIOMASS

In 2013, the BIOMASS mission was selected by ESA as part of *Earth Explorer* 7. BIOMASS can address fundamental issues about the carbon cycle. Greatest uncertainties are coming from geographical distribution and variations over time of forest biomass, a key-element to estimate carbon stocks and fluxes, especially in areas that are considered critical to the terrestrial carbon budget. This is the case in tropical regions, where deforestation is considered the main source of carbon fluxes due to changes in land use. So far, no space instrument can measure the range of biomass in the tropics (up to 500 tonnes/ha).

CNES support to French teams through TOSCA since 2010 has significantly contributed to the selection of the mission, with the results obtained by the French scientific community, especially through data exploitation of the two campaigns TROPISAR and TROPISCAT on tropical forest in French Guiana. The advanced technics developed by the teams (polarimetry, interferometry and tomography) led to an estimation of biomass up to 500 tonnes/ha. The support of the French scientific community working on BIOMASS, which was recommended during the CNES Scientific Prospective Seminar held in 2014, should keep improving the expertise of the community in the later stages of BIOMASS.

Preparing for SENTINEL-2: SPOT-4-TAKE FIVE

After a proposal from CESBIO and with the support of TOSCA, CNES took advantage of the end of SPOT-4 commercial exploitation to change its orbit and acquire data, with characteristics that are very close to SENTINEL-2's. They were processed and made available to the international community by the MUSCATE center of the THEIA unit. Scientific data processing is ongoing in various laboratories and universities in France, Europe and worldwide.

[Fig. 1 and 3]
SMOS can measure soil moisture, water content of vegetation and ocean salinity with a global cover.
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[Fig. 2]
BIOMASS can estimate carbon stocks and fluxes to provide a better understanding of the carbon cycle on Earth. Here is a picture of the vegetation in Guiana.
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[Fig. 4]
Artist view of SENTINEL-2.
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Continental Surfaces

Seasonal evaporation using instantaneous satellite measurements in the thermal infrared domain

Evolution de l'évaporation saisonnière à partir de mesures instantanées dans l'infrarouge thermique

➔ **Abstract:** *Remote Sensing can assist us in deriving evaporation by estimating the amount of vegetation (VIS/NIR data) and the surface water stress (TIR data). The latter provides an instantaneous estimate at the time of satellite overpass. We used the available energy derived from incoming radiation as well as the typical shape of the diurnal evaporative fraction (the ratio between evaporation and available energy) to extrapolate and interpolate instantaneous estimates to daily and seasonal totals.*

➔ **Résumé :** La télédétection infrarouge thermique permet, en combinaison avec les mesures dans le visible et le proche infrarouge, de fournir des informations sur le stress hydrique de la végétation, et par conséquent d'estimer l'évaporation instantanée au passage du satellite. La fraction d'évaporation (rapport entre l'évaporation et l'énergie disponible) et son évolution caractéristique durant la journée ont permis de reconstituer les variations journalières et saisonnières de l'évaporation.

Evapotranspiration estimates can be derived from remote sensing data and ancillary information, mostly meteorological, through two types of approaches. The first ones estimate a potential evapotranspiration rate from vegetation indices, since the main factor controlling evapotranspiration is the amount of vegetation present on the ground which governs the volume of soil explored by the roots for water extraction. Those methods account for water stress by depleting the maximum rate according to water availability derived from either a surface temperature index or a rough estimate of the water budget. The second type of methods relies on the link between the surface temperature and the latent heat flux through the surface energy budget: water stress triggers a rise in surface temperature above the equilibrium temperature of a well watered surface. Current high resolution satellites (LANDSAT, SPOT…) acquire data in the VIS/NIR domains every few weeks if all platforms are combined. It gives a good overview of the seasonal evolution of the vegetation fraction cover. However, no TIR sensor is available to assess the water cycle at field scale (less than 100 m) at higher time scales. The MISTIGRI space mission proposal and its follow-on THIRSTY (based on HYSPIRI) aim at filling this gap in Earth observation.

Model performance for instantaneous latent heat flux retrieval

Instantaneous evapotranspiration rates and surface water stress levels can be deduced from remotely sensed surface temperature data through the surface energy budget. Surface water stress is defined as the complementary part to the ratio between actual and maximum evapotranspiration rates (e.g., 0 for an unstressed surface, 1 for a non evaporating surface).

Two types of methods can be defined:

(i) contextual methods, where stress levels are scaled within a given image between hot/dry and cool/wet pixels for a particular vegetation cover,
(ii) single-pixel methods which evaluate latent heat as residual of the surface energy balance for one pixel independently from the others.

In order to test the capacity of current algorithms to retrieve instantaneous fluxes, four models, two contextual (S-SEBI, VIT) and two single-pixel (TSEB, SEBS) methods, were applied over one growing season (December-May) for a 4 km by 4 km irrigated agricultural area in semi-arid northern Mexico using input data from ASTER and FORMOSAT-2 [1].

Their performances, both at local and spatial standpoints, were compared to energy balance ground measurements performed at seven locations within the area. They were also compared to simulations of the Soil-Vegetation-Atmosphere Transfer (SVAT) model ICARE forced with local *in situ* data including observed irrigation and rainfall amounts. Water stress levels were not always satisfactorily retrieved by most models, but TSEB as well as S-SEBI, although slightly biased, showed good performances (Fig. 1).

A drop in model performances was observed in all cases when vegetation was senescent, mostly due to a poor partitioning between the soil/plant components of the latent heat flux and the available energy. Corrections based on VIS/NIR data were proposed to cope with this problem. As expected, contextual methods performed well when contrasted soil moisture and vegetation conditions were encountered in the same image (especially in spring and early summer) while they tended to exaggerate the spread in water status in more homogeneous conditions (especially in winter). The best performing surface

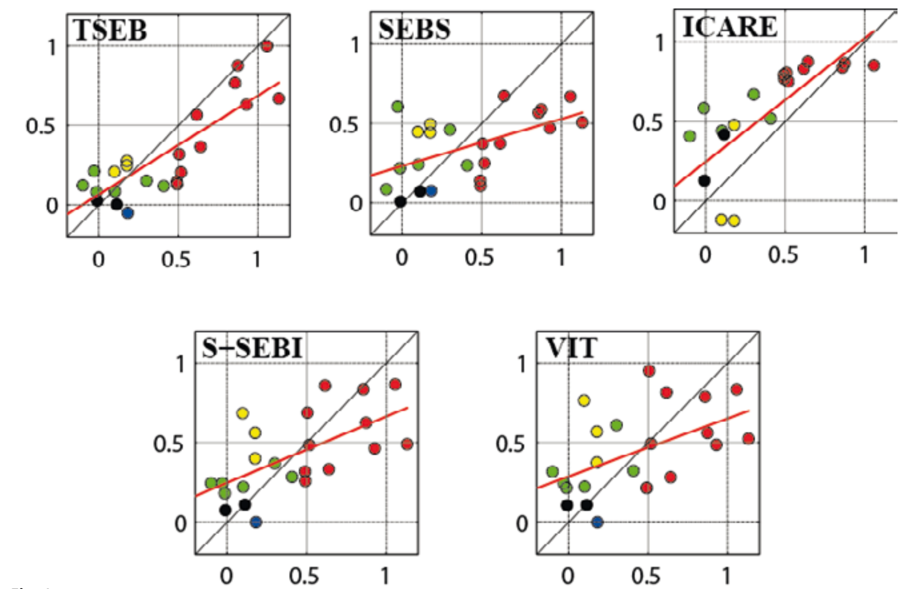

Fig. 1

energy balance models run with available remotely sensed products proved to be nearly as accurate as ICARE forced with *in situ* data.

Reconstruction of daily and seasonal evapotranspiration from instantaneous estimates

Energy balance models provide an instantaneous estimate at the time of satellite overpass for clear days. In order to compute daily evapotranspiration, an extrapolation algorithm is first needed. Deriving seasonal evapotranspiration then requires an interpolation method between clear days to be applied in a second step. We used the evaporative fraction EF (the ratio between evaporation and available energy) to scale evapotranspiration at both scales. Self preservation of EF during the day was assumed to build the daily total from the instantaneous estimate at midday (constant EF). EF was linearly interpolated between two successive images to reconstruct seasonal evapotranspiration. Interpolation and extrapolation performances were tested against measurements of latent heat from 11 datasets in Southern France and Morocco. Interpolation algorithms tended to underestimate evapotranspiration due to the energy limiting conditions that prevail during cloudy days. Taking into account the diurnal variations of EF (variable EF) according to an empirical relationship derived from a previous study (Fig. 2) improved the performance of the extrapolation algorithm and therefore the retrieval of the seasonal evapotranspiration for all but one datasets.

Site	Daily EF	RMSE (mm.day^{-1})	Water lost through ET on clear sky days, (reconstructed/ observed) (mm)	Error in %
Auradé (2006)	Constant	0.45	194.1 / 251.2	22.7
	Variable	0.33	242.1 / 251.2	3.6
Auradé (2007)	Constant	0.60	143.6 / 188.0	23.8
	Variable	0.36	188.6 /188.0	0.0
Lamasquère (2006)	Constant	0.54	221.0 / 279.7	21.0
	Variable	0.54	285.5 / 279.7	-2.1
Lamasquère (2007)	Constant	0.43	182.3 / 194.3	6.1
	Variable	0.74	225.4 / 194.3	-16.3
Avignon (2004)	Constant	0.90	204.8 / 243.1	15.8
	Variable	0.83	217.1 / 243.1	10.7
Avignon (2005)	Constant	0.75	94.5 / 117.5	19.5
	Variable	0.63	103.7 / 117.5	11.7
Avignon (2007)	Constant	0.54	160.0 / 179.2	10.7
	Variable	0.47	174.3 / 179.2	2.7
Marrakech (2004)	Constant	0.26	117.8 / 126.74	7.0
	Variable	0.27	120.4 / 126.74	5.0

Fig. 2

[Fig. 1]
Scatter plots of surface water stress (0: unstressed, 1: fully stressed) at each station for TSEB, SEBS, S-SEBI, VIT and ICARE. Values calculated for seven ASTER over-pass dates and seven flux stations.
Color code: red: LAI < 0.4; yellow: 0.4 ≤ LAI < 0.8; green: 0.8 ≤ LAI < 1.2; navy-blue: 1.2 ≤ LAI < 2.0; black: LAI ≥ 2.0.
© After [1]

[Fig. 2]
RMSE and cumulative seasonal evapotranspiration for clear sky days simulated with constant or variable diurnal evaporative fraction (EF) value.
© After [2]

REFERENCES

[1] Chirouze, J. *et al.* (2014), Intercomparison of four remote-sensing-based energy balance methods to retrieve surface evapotranspiration and water stress of irrigated fields in semi-arid climate, *Hydrology and Earth System Sciences*, **18**(1), 1165-1188.

[2] Delogu, E., *et al.* (2012), reconstruction of temporal variations of evapotranspiration using instantaneous estimates at the time of satellite overpass, *Hydrology and Earth System Sciences*, **16**(8), 2995-3010.

Laboratory contribution

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Continental Surfaces

The BIOMASS mission retrieval algorithms over tropical forests

Algorithmes d'extraction sur les forêts tropicales dans le cadre de la mission Biomass

➔ **Abstract:** *The BIOMASS mission is designed to map the full range of the world's above-ground forest biomass, for global carbon flux calculations. This objective is achieved with a P-band SAR. During the mission preparation phase, the important question to be addressed was the retrieval algorithms in dense tropical forests, which have a major role in global carbon storage and carbon loss through deforestation. This paper will summarize the advanced methods developed for tropical forest biomass retrieval.*

➔ **Résumé :** La mission Biomass est conçue pour mesurer la biomasse des forêts à l'échelle globale, pour les estimations de flux de carbone terrestre. Cet objectif est à atteindre avec un SAR en bande P. Durant les phases préparatoires, la question à traiter était l'extraction de la biomasse des forêts tropicales denses, dont le rôle est primordial dans le stockage et la perte de carbone par déforestation. Ce papier décrit les méthodes avancées développées pour extraire l'information de la forêt tropicale.

In response to the urgent need for greatly improved mapping of global biomass, the BIOMASS mission was selected by the European Space Agency as the 7th *Earth Explorer* mission in 2013. The mission will carry a polarimetric P-Band SAR, capable of providing three types of measurements: polarimetric intensity (PolSAR), polarimetric interferometry (Pol-InSAR) and SAR Tomography (TomoSAR) (Fig.1), to be used for the retrieval of forest biomass.

In terms of carbon cycle, the most critical forest regions of the Earth are in the tropical belt, where knowledge on biomass information is poor and biomass information is the most needed. However, estimating biomass of tropical rain forests characterized by high biomass density (up to 500 $t.ha^{-1}$ or greater), and complex layering structure, remained a challenging task.

During the preparatory phase of BIOMASS activities, the algorithms to be employed for Above Ground Biomass (AGB) retrieval have been developed, using data collected over boreal and tropical forests.

These algorithms can be divided into two main classes [1].

(i) AGB estimation from polarimetric intensities (PolSAR): these algorithms combine statistical and physical concepts to develop regressions between AGB and intensity measurements in all polarizations. The algorithms performed well for temperate and boreal forests for which the AGB is less than about 300 $t.ha^{-1}$. Beyond 300 $t.ha^{-1}$, the sensitivity of the backscattered intensity to AGB decreases drastically, and is often obscured by various noise sources, the most important being the topographic effects. Therefore retrieval of AGB of dense tropical forest with AGB up to 500 $t.ha^{-1}$ requires particular attention on the topographic correction. The method developed in [2] has two aspects: changes in effective scattering area induced by slope and correction accounting for changes in polarization orientation and change in relative contributions of volume scattering and double bounce scattering.

(ii) AGB estimation from Pol-InSAR: the techniques allow us to estimate forest height by combining two PolSAR measurements from slightly different orbits. Forest height estimates are then converted into AGB using allometric equations. The information about forest height is expected to be useful at high biomass values, as it helps mitigate intensity saturation phenomena. However, the retrieval accuracy depends on different factors, among them the relevance of the allometric equation to be used and the interferometric coherence between different acquisitions, resulting in a possible source of error for forest height estimates.

The two approaches (PolSAR and Pol-InSAR) are then combined using a Bayesian approach to yield a final AGB estimate. The combined approach is expected to be able to generate AGB maps to about or within the desired 20% for boreal and tropical forests. To achieve this performance, however, AGB estimation algorithms need to be accurately tuned, so as to take into account disturbing factors affecting radar measurements. A network of *in situ* forest plots is currently under investigation to serve in the Cal-Val Strategy.

Another key role in the Cal-Val will be played by SAR tomography (TomoSAR). During an initial phase where system's orbit will be adjusted to gather multiple acquisitions over the same sites, characterized by small baselines and a repeat pass time of the order of a few days, thus allowing a reconstruction of the forest vertical structure. Both forest height and terrain topography can be accurately estimated based on tomogra-

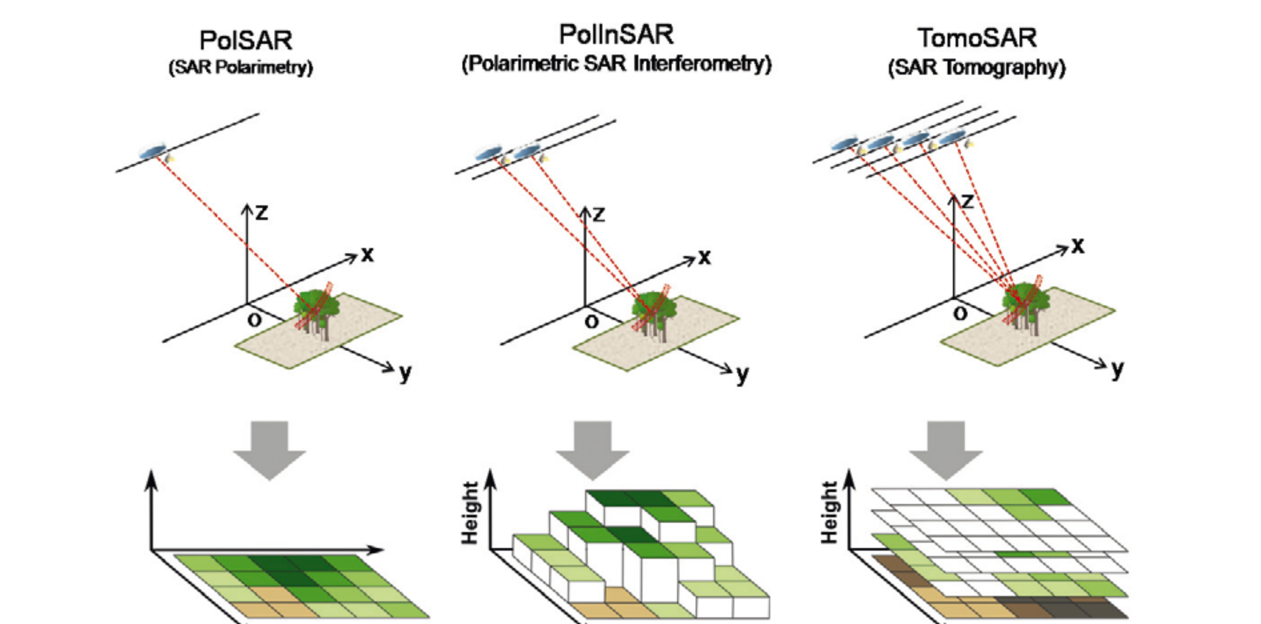

Fig. 1

phic data. This phase, hereafter referred to as the tomographic phase, was planned to cover 10-15% of the world's forest biomass, and is expected to provide useful insights for improving forest height and AGB retrieval during the rest of mission lifetime.

Physically, TomoSAR presents a solution to reduce the ground effects by having access to layers inside the forest canopy where the backscatter from vegetation-ground interactions is not significant. Assessment of TomoSAR for the retrieval of AGB has been performed using data acquired by the ONERA P-band airborne SAR over French Guiana in 2009, during the ESA-CNES TropiSAR campaign. *In situ* data have been provided by the Guyafor group in French Guiana.

As expected, it was found that the backscatter intensity from the bottom layer is very weakly correlated to AGB, whereas the backscatter intensity from a layer at about 30 m above the ground yields the best correlation and sensitivity to AGB in all polarizations, for AGB values ranging from 250 to 450 $t.ha^{-1}$. An interpretation of this result is also provided, based on a forest growth model simulation which indicates that the AGB of the 30 m layer is strongly correlated to the total AGB.

Following this study, the application of TomoSAR in another test site (Nouragues in French Guiana) and the relevance of tomographic technique in P-band spaceborne mission have been successfully assessed.

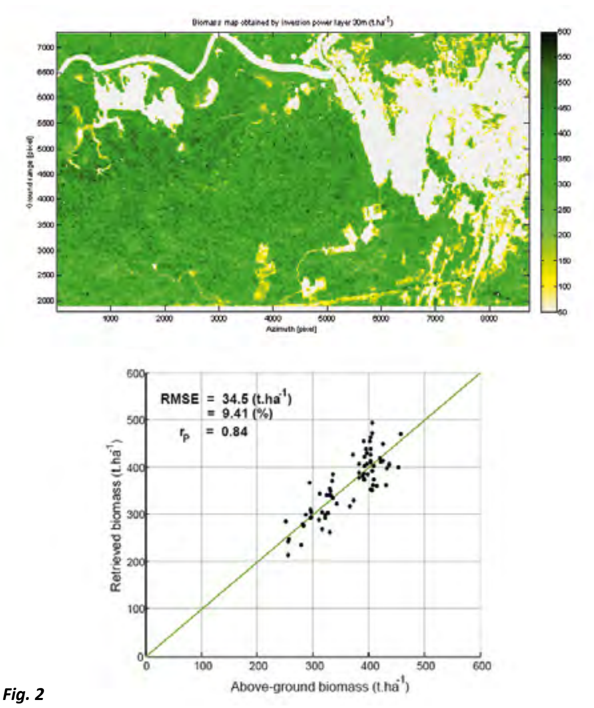

Fig. 2

[Fig. 1]
The three SAR acquisition and measurement methods which will be available from the BIOMASS mission: PolSAR, Pol-InSAR and TomoSAR.
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[Fig. 2]
Map of forest Above Ground Biomass (AGB) in the region of Paracou, in French Guiana, with 50 m resolution. The map is obtained using SAR Tomography result derived from P-band SAT data acquired during the ESA-CNES TropiSAR campaign.
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REFERENCES

[1] Le Toan, T., Quegan, S., Davidson, M.W.J., Balzter, H., Paillou, P., Papathanassiou, K., Plummer, S., Rocca, F., Saatchi, S., Shugart, H. and Ulander, L. (2011), The Biomass mission: mapping global forest biomass to better understand the terrestrial carbon cycle, *RSE*, **15**, Issue 11.

[2] Villard, L. and Le Toan, T. (2014), Relating P-band SAR intensity to biomass for Tropical Dense forests, *JSTARS*, final review.

[3] Ho Tong M. D., Le Toan, T., Rocca, F., Tebaldini, S., d'Alessandro, M. M., Villard, L. (2014), Relating P-band SAR tomography to Tropical forest biomass, *IEEE Geoscience and Remote Sensing*, **52**, NO2, pp 967-979.