INDREX II – INDONESIAN AIRBORNE RADAR EXPERIMENT CAMPAIGN OVER TROPICAL FOREST IN L- AND P-BAND

[1] Irena Hajnsek, Florian Kugler, Kostas Papathanassiou, Rolf Scheiber, Ralf Horn, Alberto Moreira
[2] Dirk Hoekman,
[3] Malcolm Davidson, Evert Attema

[1] Microwaves and Radar Institute
Department: SAR-Technology
German Aerospace Center e.V. (DLR)
PO Box 1116, Wessling,
Germany
e-mail irena.hajnsek@dlr.de

[2] Borneo Orangutan Survival Foundation (BOS)
& Wageningen University (WUR)
Department of Environmental Sciences, Nieuwe Kanaal 11,
6709 PA Wageningen,
The Netherlands

[3] European Space Agency/Agence Spatiale Européenne
Mission Experts Division
Postbus 299,
2200 AG, Noordwijk,
The Netherlands

Abstract

Tropical forests are the most complex, heterogeneous, undiscovered and remote forest ecosystems and represent therefore a big challenge for remote sensing. SAR systems operating at low frequencies seems to be one of the potential remote sensing techniques allowing estimation of vertical structure and surface ground information in such ecosystems. However, a suitable radar data base over tropical forest that allows the assessment of the performance of SAR techniques is today missing. In order to support the closing of this gap the European Space Agency (ESA) has conducted within the framework of its Earth Observation Envelope Programme an airborne radar campaign. The objective of the experiment is to build up a radar data base that will allow the investigation and validation of bio-/geo-physical parameter estimation techniques from polarimetric SAR interferometry (Pol-InSAR) data at L- and P-band and to provide first order data evaluation. The scientific feedback from the evaluation of the acquired data will allow ESA to draw conclusions about the optimal SAR sensor configuration for biomass retrieval and monitoring in tropical areas. In a first line this campaign should be able to provide answers about the feasibility of L- and/or P-band SAR to estimate forest height; about the relation between forest height and forest biomass and about the feasibility of using empirical relations to relate radar backscatter to forest biomass. For this, repeat pass polarimetric SAR interferometry at L- and P-band has been flown over several test sites in Indonesia with the Experimental Synthetic Aperture Radar (E-SAR) of the German Aerospace Centre (DLR) supplemented by extensive ground measurements performed for a wide range of forest types in the frame of the INDREX-II experiment in November 2004. In this paper the general framework of the INDREX-II campaign will be outlined and preliminary results are presented and discussed.

1 INTRODUCTION

The objective of INDREX-II (*Ind*onesian Airborne *R*adar *E*xperiment) is to build up a data base for the investigation and validation of bio-/geo-physical parameters obtained from polarimetric SAR interferometry (Pol-InSAR) at L- and P-band acquired over tropical forests and to secure with this data set feedback to the European Space Agency regarding the optimal SAR sensor configuration and algorithms for biomass retrieval and monitoring in tropical areas.

Over a wide variety of forest types (Boreal, Mediterranean and Temperate) Pol-InSAR data have been already acquired with L-band and investigations with regards to bio/geo-physical forest parameter retrieval are ongoing. The combination of long wavelengths and polarimetric SAR interferometry seems to be an unbeatable technique for quantitative parameter estimation over forest areas. The big unknown forest type in terms of data availability and parameter estimation feasibility is tropical and subtropical forest. Tropical forests are the most complex structured and heterogeneous forest types and SAR systems seem to be the only mapping instruments, which could provide from space on a high resolution basis vertical structure and ground surface information.

In a first line this campaign should be able to provide first order answers to the following questions in a short time:

- Is it possible to estimate forest height at L- and/or P-band over tropical forest by means of the Pol-InSAR technique?
- Is there a relation of forest height and forest biomass over tropical forest?
- Is there an empirical relation between the radar backscatter and the forest biomass using L- and/or P-band?

In order to answer these questions repeat pass Pol-InSAR in L- and P-band have been collected. Additionally, for the support single pass X-band for the digital elevation model generation and dual polarimetric C-band data has been

acquired. In advance and parallel to the flight campaign an extensive ground measurement campaign organised by the Borneo Orang-utan Survival Foundation (BOS) and the University of Wageningen (WUR) is performed estimating forest height and forest biomass in different test areas. In Figure 1 a matrix for the INDREX-II campaign is drafted presenting the SAR observations, the reviewed methodology and the ground measurements as well as the SAR estimated parameters. For the forest biomass retrieval two methods have been chosen, one empirical relation linking the ground measured forest biomass to the radar backscatter and using a classification procedure [1] to support the regional separation of different forest biomass classes and one Pol-InSAR model based approach using the 'Random Volume over Ground model' [2] to estimate directly forest height and through allometric relation forest biomass [3] in tropical forest.

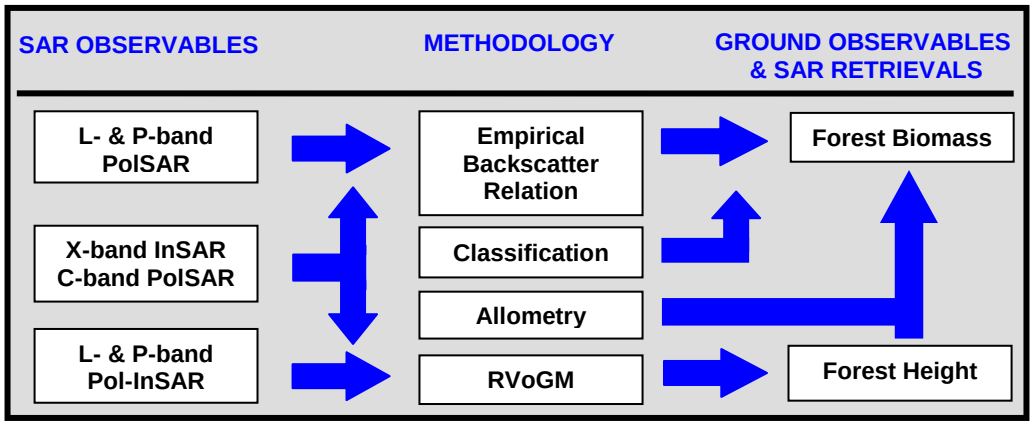

Fig. 1: INDREX-II Objective Matrix with intended SAR Observables, chosen methodology, taking ground measurements and estimating/validating the SAR retrievals (PolSAR: Polarimetric SAR, InSAR: Interferometric SAR, Pol-InSAR: Polarimetric SAR Interferometry, RVoGM: Random Volume over Ground Model).

The initiative to this project originated from the recommendation of the POLinSAR 2003 workshop held from the European Space Agency (ESA) in Frascati. From the participating scientist a gap in the knowledge and performance of polarimetric and interferometric SAR in tropical forest has been identified and a recommendation has been given for an airborne SAR experiment. Shortly after, an invitation of tender has been announced in the framework of the Earth Observation Envelope Programme from ESA/ESTEC under the umbrella of the Mission Expert Division in The Netherlands.

The project has been executed at the Indonesian region Kalimantan, where since 1993 long-term ongoing research is performed and where already good contacts were established during the first Indonesian Airborne Radar Experiment between ESA and the Indonesian Ministry of Forest. The second Indonesian Radar Experiment (INDREX-II) is a follow up campaign of INDREX, which has been already successfully carried out in 1996 with the company Dornier (now EADS Dornier). The objective of INDREX was to generate a digital elevation model over a non-accessible region in order to map the current stage of the environment. Within INDREX-I numerous remote sensing data could be collected and are available in a data base.

In a long term, for example in a frame of other studies, the data set collected within the frame of INDREX-II can be used for a wide range of forest studies, from field ecologists to global ecological modelling. On the one side hopefully open scientific questions will be answered, new ideas in terms of algorithm development will be expressed, and on the other side probably new questions will be rised.

2 LOCATION AND DESCRIPTION OF THE TEST SITES

Two main test areas have been selected. The first area is the Mawas conservation area located in the province Central Kalimantan in the vicinity of its capital city Palankaraya. The second area is located in the Province East Kalimantan in the vicinity of the province's largest city Balikpapan. These two areas comprise all the main broad forest types: lowland Dipterocarp forest, peat swamp forest and mangrove, as well as a variety of the common types of plantations such as oil palm and rubber. Overall 8 test sites have been selected, two located in the Mawas area and six in the Balikpapan area.

2.1 General description of the Mawas area

Southern Borneo is largely flat, gradually sloping towards the sea and is dissected by large parallel rivers running from north to south. As a result of the low altitude extensive coastal swamps have developed during the last 10,000 years, creating massive peat domes, and elevating the land above the present sea level. The Mawas conservation area comprises several large (ombrogenous) peat domes covered by tropical peat swamp forest types. Typically these range very gradually from a relatively tall (30 m) and dense forest type at the edges towards small (15 m or lower) and open forest types at the centre of a dome. Along the large rivers mixed swamp forests (some are topogenous) and floodplain forests are found. The southern and eastern parts are disturbed by excessive drainage (through canals) and peat and forest fires. Efforts are conducted by BOS and Wetlands International to restore the area. Two test sites have been identified for the flight campaign: a disturbed and undisturbed peat forest area with different scientific objectives (Fig. 3).

Fig.2: Location of the test sites at Kalimantan (Mawas, Sungai Wain, Meratus, Samboja Lestari) and the two main airports (Balikpapan, Palangkaraya)

2.2 General description of the Balikpapan area

The Balikpapan area was originally covered by lowland Dipterocarp forest and some mangrove forest. These forest types are typical for SE Asia, however, disappear at alarming rates. During the last decades the acreage of the lowland forest in the Balikpapan area decreased strongly due to intensive selective logging, illegal logging, conversion to plantations and the vast ENSO (El Niño) induced forest fires of 1982 and 1998. Some large pockets of pristine lowland Dipterocarp forest remain in the Sungai Wain reserve (10,000 ha) and the Gunung Meratus reserve (over 100,000 ha). Both areas are protected by BOS, which uses them as orang-utan reintroduction sites. Large mangrove areas adjacent to the Sungai Wain reserve are still largely intact. Because of the relatively good accessibility, large variety of typical tropical land cover types, and the excellent logistic support - first by the *Tropenbos* Foundation, later continued by BOS - a lot of remote sensing related research has been conducted in this area. In 1996 the ESA-MOFEC INDREX campaign was conducted with the Dornier high-resolution (1.5 m) InSAR. In 2000 NASA's second 'Pacific Rim' campaign (PacRim 2) was executed here, yielding AirSAR data in TopSAR and PolSAR mode. In this area six test sites has been identified for the flight campaign, Samboja Lestari, Sungai Wain Reserve, Balikpapan Bay Mangrove area, Penjam Oil Palm Plantation, Penajam Rubber Plantation, Gunung Meratus Reserve (Fig 3).

Test Site	Forest Type	Topography	Forest height [m]	Forest Biomass [t/ha]	Scientific Objectives	Characteristics
Mawas (disturbed/ undisturbed)	Peat forest	Flat	10-30	20-250	Forest biomass; Forest gap; Hydrological status; Illegal logging	Periodically flooded
Samboja Lestari	Plantations	hilly	variable max.: 15	up to 150	Low forest biomass	high diversity
Sungai Wain	Dipterocarp	hilly	10 – 50	100-400	Forest height; Forest biomass;	Dense natural tropical forest
Balikpapan Bay Mangrove	Mangrove	Flat	10-20	50-150	Forest height; Forest biomass;	L-band: High tide P-band:Low tide
Oil Palm Plantation	Plantation	undulating	9-11	60	Forest height; Forest biomass;	Structured feature
Rubber Tree Plantation	Plantation	undulating	15 – 20	80	Forest height; Forest biomass	Structured features
Meratus	Dipterocarp	hilly	10 – 50	100-400	Forest height; Forest biomass; Illegal Logging	Dense natural tropical forest

Fig.3: Characteristics of the test sites at Kalimantan chosen for INDREX-II

2 INDREX-II CAMPAIGN

The whole INDREX-II campaign, including the mission execution, data processing and first analysis is expected to last for 14 month plus 4 a month work preparation phase. The flight campaign has been executed during 3 weeks end of November until beginning of December 2004. In the following the main observables in terms of ground and flight measurements will be presented.

2.1 GROUND MEASUREMENTS

Apart form already collected ground measurements within other remote sensing or environmental protection projects a new ground parameter collection plan for INDREX-II has been developed. The planned collection strategy and the ground measurements has been adjusted to answer the main scientific questions posed in INDREX-II and to validate the objectives which will be estimated using remote sensing techniques.

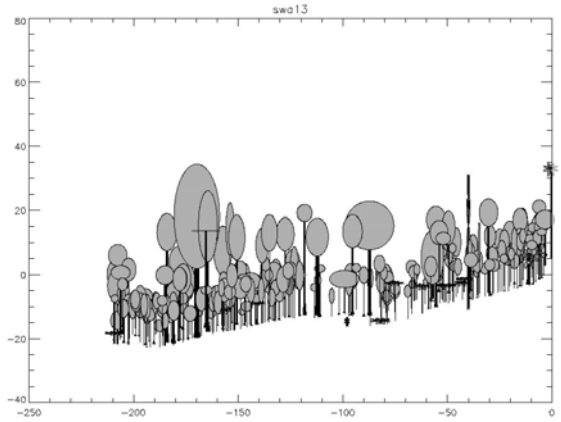

Fig. 4. Example of forest transect structural drawing in the Sungai Wain test site.

- A large 15.4 ha forest block transect was established in the Sungai Wain Dipterocarp forest, 540 m in length and 286 m wide. Within this block 26 sub-blocks (in total 2.1 ha) are being measured for each canopy tree with a diameter at breast height (dbh) ≥ 10 cm. The following data will be provided: species, location, dbh, total tree height, height to first branch, and terrain height. Structural drawing will be made (see Fig. 4). Biomass levels will be derived through allometric equations. This activity started in September and is expected to be completed in March 2005. In sub-sub-blocks smaller vegetation (10 cm > dbh ≥ 1 cm) is sampled.
- Eight transects in the Mawas peat swamp forests have been established in November along the walking bridge, each 100 m in length and 10 m wide (Fig. 5). Within these transects similar observations are being made. The work is expected to be completed in January 2005.
- Meteorological data (rainfall, temperature; 3 gauges) and hydrological data (water levels; 15 gauges) for the Mawas area (mainly along the walking bridge) will be collected at stations equipped with data loggers which make measurements at one hour intervals. The last 5 stations were placed in November. Data of all stations will be downloaded in March 2005. Such data are of particular importance for the Mawas area because of seasonal flooding. To be able to estimate the flooding percentage at the time of over-flight at each point 40 m transects of soil roughness have been measured.
- For the rubber and oil palm plantations height, height to first branch, age, density and biomass data were collected in November. Similar data were collected in December in the Samboja Lestari area for plantations of Teak and Gamelina, for secondary forest plots and for alang-alang grass areas.


Fig 5. Mawas peat swamp forest

- Attempts to make digital geo-coded airborne video and/or photo coverage of all sites (except Meratus) are still ongoing. Incomplete coverages of Samboja Lestari have been obtained in September and December. Adverse weather conditions may cause delays until the end of the wet season in March 2005.

2.2 FLIGHT CAMPAIGN

The flight measurements campaign for INDREX-II has been executed with the DLR's experimental airborne SAR system (E-SAR) from the 15.11.04 until 06.12.04. The radar system has been separately transported via cargo to the island Kalimantan while the DLR's Do228 aircraft was flying to Balikpapan without any equipment. In Balikpapan, the main project base, the radar equipment has been mounted into the aircraft and the system has been tested.

For each test site the modes of Fig. 6 have been flown, except of the Meratus test site, where the C-band mode has been excluded. The repeat pass baselines at L- and P-band have been chosen correspondingly to the expected volume height on ground. For C-band only two passes have been chosen to acquire the full set of available polarisations without interferometric observables. A digital elevation model (DEM) will be calculated from single pass interferometry using X-band. Additionally at X-band one polarisation amplitude image has been acquired in VV.

Mode	Frequency	Flight pass	Polarisation
Pol-InSAR	L-band	3-4 passes	quad pol.
Pol-InSAR	P-band	3-4 passes	quad pol.
InSAR	X-band	1 pass	single pol. (vv)
PolSAR	C-band	2 passes	dual pol. (hh & hv, vv & vh)

Fig. 6 E-SAR flight modes for each test site (except Meratus: without C-band)

Overall 120 flight hours have been flown in the frame of INDREX-II campaign, including ferry, test and calibration and measurement flights. For the measurement flights over the test sits 31 hours have been flown and 10 hours have been used for calibration flights before, during and after the measurements campaign (Fig. 7). The flight has been performed in the beginning of the tropical raining season accompanied with strong winds and thunder storms. Therefore, the measurements flights have been performed in a very flexible way either in the morning or in the afternoon. Concerning the flight configuration the E-SAR system has started with the smallest strip (Samboja Lestari) in order to get used of the tropical flight conditions. Then the longest straight strip covering four test sites (Sungai Wain, Balikpapan Bay Mangrove, Oil and Rubber Plantation), has been acquired. After this a ferry flight to the Mawas area has been done in order to perform the two flights over the peat forest sites. Finally, back in the Balikpapan area the Meratus sites have been flown.

Test Site	Flight Strip (azimuth) [km]	Mission Duration [h]
Mawas	78	10
Sungai Wain Mangrove Oil and Rubber tree plantation	55	12
Samboja Lestari	12	4
Meratus	30	4.5
Total	**175**	**30.5**

Fig. 7 Flight hours for the different test sites

3 EXPERIMENTAL DATA

Already during the flight measurement campaign in Indonesia data processing has been done in order to check the radar data quality for polarimetric as well as for repeat pass interferometric observations. Because of difficult weather conditions one repeat pass flight has been repeated after the flight track investigation. Thus, due to restricting the flights to optimum non-turbulent weather conditions, for most of the flights the nominal tracks could be kept within +/- 2m horizontal and vertical deviations. Even small baselines of 5m could be kept pretty well.

Overall 127 flight tracks have been flown within the 22 days flight measurement campaign corresponding to (were calibration flight tracks 27 of them at the beginning, in between and at the end of the campaign) 200 GByte disc stored raw data. The covered area is about 525 km². The duration of the processing time is expected to take 6 months to complete all the test sites. The estimated data amount of processed radar geometry images (RGI, slant range, multilook and SLC) and geocoded terrain corrected images (GTC) is about 1 Terabyte.

For data processing, long strips are divided into 2-5 overlapping segments in azimuth corresponding to 6 to 10 km length and 3.5 km width. The geocoding is performed onto a 2m grid, WGS-84, UTM projection, zone 50M. Terrain correction is performed using DEMs computed form the X-band single-pass interferometry. All frequencies except of P-band, are delivered with a local incidence range of 25 to 50 degrees, the P-band slant range images will be delivered with a local incidence angle of 18 to 50 degrees.

In order to ensure best radiometric and polarimetric calibration of the data, three calibration flights were conducted. First evaluations of these calibration data confirmed the E-SAR system stability throughout the campaign. The relative deviations measured on the corner reflectors at the Balikpapan Airfield (permanently installed for the duration of the campaign) are within +/- 1 dB. First investigations of range profiles in L- and P-band over homogeneous forest areas confirmed this figure.

4 FIRST ANALYSIS

Different processing steps are needed to be performed for data analysis and are expected to be started after delivery of the processed data in approximately 4 to 6 months. Four evaluation steps are intended to be performed: 1. For an exemplary test site interferometric coherences and phases for different polarisations will be generated. At this step, further quality checks of the data set and a first polarimetric/interferometric analysis will be performed. 2. The ‘random volume over ground model (RVoGM)’ [2] will be applied on a exemplary data set for the estimation of forest height. 3.

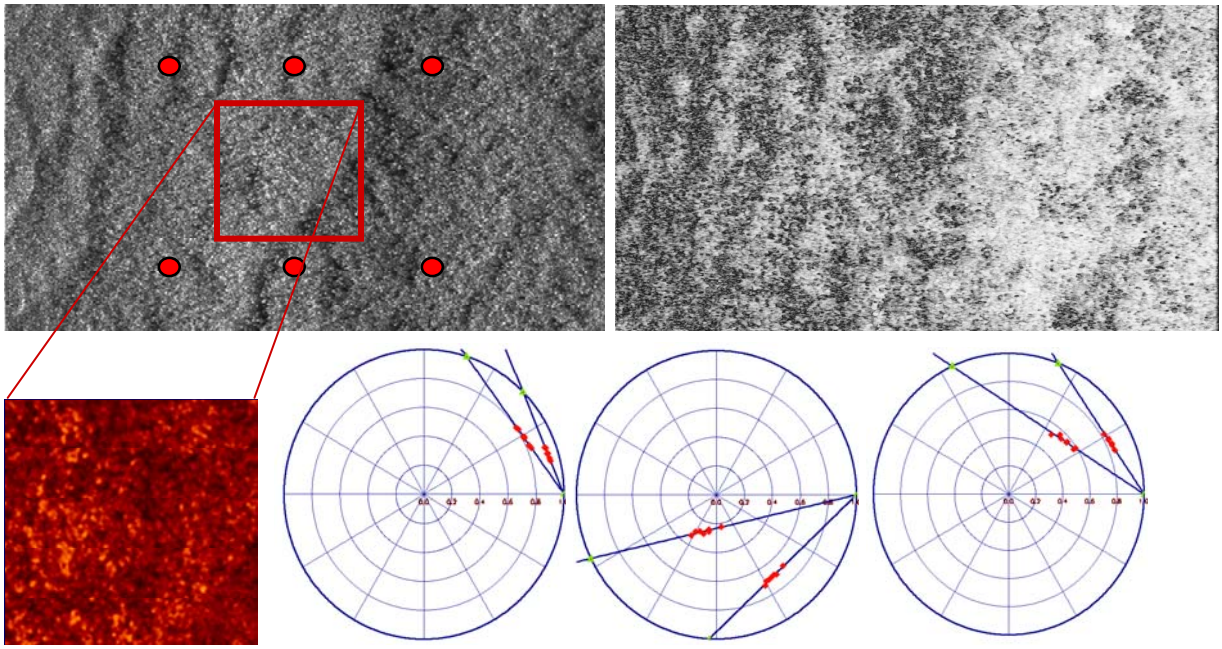

Fig. 8 Test site Sungai Wain northern part at L-band (hh pol.) intensity upper left; interferometric coherence (hh pol.) at upper right; lower left tropical forest height (low heights: dark red, high heights: light red) (mean height 25-30 m; max height 58 m); and lower right interferometric coherence at different polarisation plotted into three complex unit circle for two baselines.

Comparison of the forest heights obtained from SAR against the ground measurements will be performed. 4. Unsupervised ISODATA classification will be applied and investigated over the forest areas. In Fig. 8 the first and second step of an already processed dataset from the northern part of the Sungai Wain test site are presented. Sungai Wain is characterised by very dense natural tropical forest with forest height up to 60 m and dense vegetation on the ground. From this first investigation following results are obtained:

1. For six test regions (fig. 8 upper left) the plotted interferometric coherences at different polarisations lie on a line (fig. 8 lower right) for both baselines, as predicted by the RVoG model.
2. Further, the polarisation diversity spread along the line indicates that L-band penetrates through the volume layer to the ground. The polarisation diversity in the interferometric coherences is due to the ground response.
3. Finaly, using the RVoGM an inversion over a small forest area is performed and forest heights with mean values of 25-30 m (maximum height of 58 m) are obtained. These heights are in agreement with measured forest heights on ground.

5 SUMARY

Although, INDREX-II has been carried out under extreme tropical weather conditions, beginning of the raining season, after the first data processing and quality check it can be stated that the data quality is good. The highest priority has been given and effort has been made for an accurate and stable data acquisition. Data processing and ground measurements collection are still ongoing. The campaign execution can be stated as successfully, as no critical technical problems occurred and all data have been successfully recorded. This is confirmed also by the first obtained results, answering at the same time the first scientific question, that L-band is able to penetrate dense tropical forest and to be able to deliver tropical forest heights using the RVoG model.

6 REFERENCES

[1] Hoekman, D., A New Polarimetric Classification Approach Evaluated For Agricultural Crops, *POLINSAR 2003 Workshop*, ESA-ESRIN, January 2003

[2] Cloude, S. R., Papathanassiou, K. P.: Three-stage inversion process for polarimetric SAR interferometry. *IEE Proceedings - Radar Sonar and Navigation*, 150, 3, (2003), S. 125-134,

[3] Mette, T., Papathanassiou, P., Hajnsek, I., Pretzsch, H., Biber, P. (2004). Applying a common allometric equation to convert forest height from Pol-InSAR data to forest biomass. *Proc. IGARSS04,* 20.-24. Sept. 2004, Anchorage.