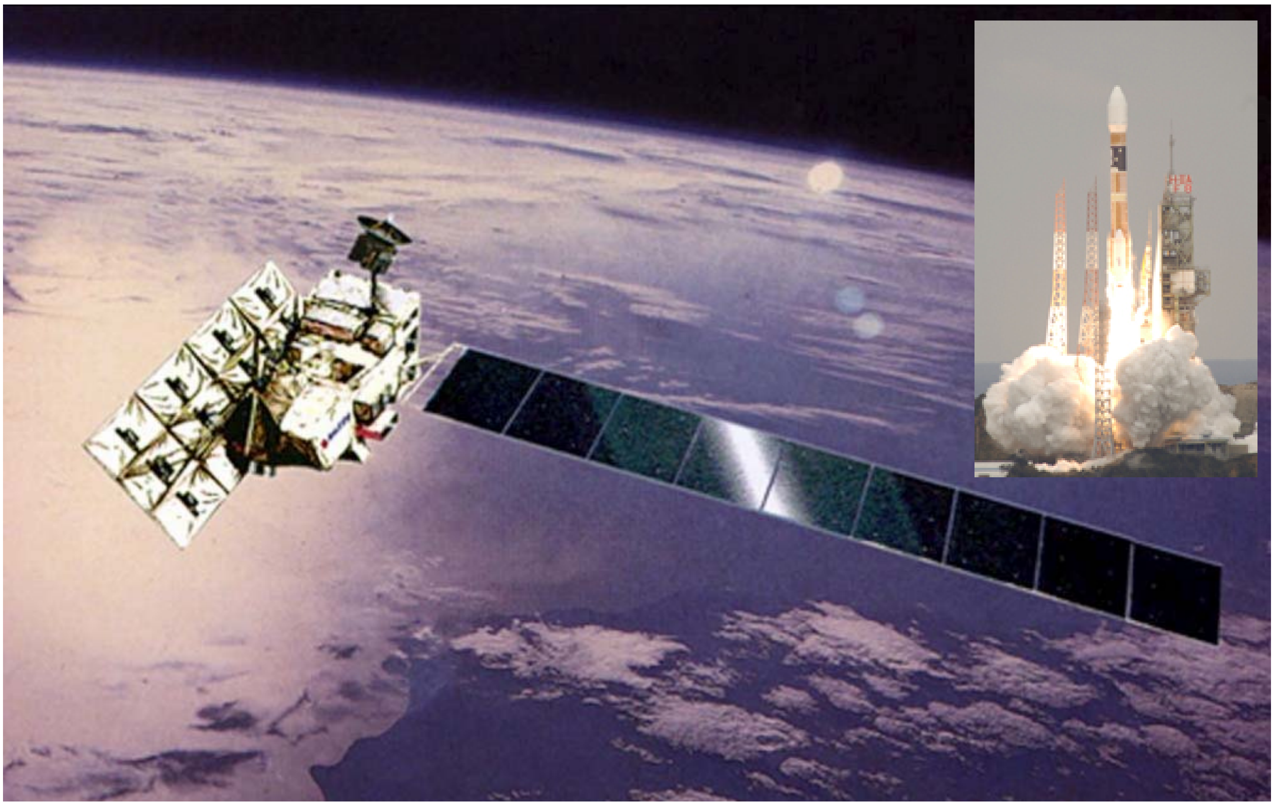
The ALOS Kyoto & Carbon Initiative

Science Plan (v.3.1)



March, 2008

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FOREWORD

This document constitutes the second post-launch revision of the Science Plan for the ALOS Kyoto & Carbon (K&C) Initiative, initiated in 2000 by the Earth Observation Research and Applications Centre (EORC) of the Japan Aerospace Exploration Agency (JAXA) – formerly known as NASDA.

The Initiative is set out to support explicit and implicit data and information needs raised by international environmental Conventions, Carbon Cycle Science and Conservation of the environment - referred to hereafter as the CCCs. The Initiative is led and coordinated by EORC JAXA, and supported by an international Science Team, and focuses primarily on defining and optimising provision of data products and validated thematic information derived from in-situ and satellite sensor data, focusing particularly on that acquired by the Phased Array L-band Synthetic Aperture Radar (PALSAR) on-board the Advanced Land Observing Satellite (ALOS).

The objective of the ALOS K&C Initiative is to define, develop and validate thematic products derived primarily from ALOS PALSAR data that can be used to meet the specific information requirements relating to the CCCs. A key component of this work has been the development of a systematic data acquisition strategy for ALSO PALSAR that fits within the constraints imposed by the orbital and technical capabilities of the spacecraft and also ensures that adequate data will be collected to allow the required thematic output products to be developed on a timely basis.

The K&C Initiative is based on the three coordinated themes relating to global biomes; Forests, Wetlands, Deserts and Semi-Arid Regions, and a fourth theme dealing with the generation of regional ALOS PALSAR mosaics. A key word for the Initiative is regional-scale applications and product development, with data requirements in the order of hundreds or thousands of PALSAR scenes for each prototype area. Each theme has identified key products that can be generated from the PALSAR data including land cover (forest mapping), forest change mapping and forest biomass and structure (Forests), global wetlands inventory and change (Wetlands), freshwater resources and desertification (Deserts). Each of these products are generated using a combination of PALSAR, in situ and ancillary datasets.

The K&C Initiative builds on the experience from the Global Rain Forest and Boreal Forest Mapping (GRFM/GBFM) projects, in which 100 m spatial resolution mosaics of the entire tropical and boreal zones of Earth using data acquired by the Japanese Earth Resources Satellite (JERS-1) L-band HH SAR were generated. The GRFM/GBFM projects confirm the utility of L-band SAR data for mapping and monitoring forest and wetland areas and the benefits of providing spatially and temporally consistent mosaics for regional-scale monitoring and surveillance. The requirements beyond pure sets of satellite image data and the importance of validated thematic information have also been highlighted.

This Science Plan partly outlines the project activities planned prior to the launch of the ALOS space craft (January 24, 2006), and partly with recent updates from certain Science Team members. The Theme Chapters of this plan (chapters 2.2-2.5) have been authored by the K&C Theme Coordinators and the K&C Science Team, with final edit by JAXA EORC.

Ispra, March, 2008

Ake Rosenqvist, Project Manager
ALOS K&C Initiative

1 TECHNICAL BACKGROUND

1.1 The Advanced Land Observing Satellite (ALOS)

1.1.1 Platform characteristics

The Advanced Land Observing Satellite (ALOS) was successfully launched from JAXA's Tanegashima Space Center in southern Japan on January 24, 2006, with the H-IIA launch vehicle No.8. ALOS was placed in a sun-synchronous orbit at 691 km, with a 46-day recurrence cycle. With its 4000 kg, it is the largest satellite developed in Japan.

An enhanced successor of the Japan Earth Resources Satellite 1 (JERS-1), ALOS carries three remote sensing instruments: the along-track 2.5 metre resolution **Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM)**, the 10-metre resolution **Advanced Visible and Near-Infrared Radiometer type 2 (AVNIR-2)** and of relevance here, the polarimetric **Phased Array L-band Synthetic Aperture Radar (PALSAR).**

Table 1.1.A ALOS characteristics

Item	Characteristics
Launch	January 24, 2006
Orbit	Sun synchronous, Sub recurrent
Equator pass time	~10.30 (desc.); ~22.30 (asc.)
Altitude	691.65 km
Inclination	98.16 deg.
Recurrence cycle	46 days $14+{}^{27}/_{46}$ rev./day; 671 rev./cycle
Orbital control	Less than +/- 500 m
GPS orbital position accuracy	0.78 (off-line)
Star Tracker attitude determination accuracy	0.0002 deg (off-line) (~2.5 m on the ground)
Attitude stability Att. determ. accuracy	0.00094 deg/5 sec 0.00006 deg (off-line)
High-speed Solid State Recorder (HSSR)	Capacity: 96 Gbytes Data rate (max): 360 Mbps (recording) 240 Mbps (playback)
Data transmission: Ka-band antenna X-band antenna	 240 Mbps (via DRTS) 120 Mbps (direct down-link)
Solar Array Paddle	3 m x 22 m, 9 segments
Generated power	> 7 kW at EOL
Total weight at launch	4001 kg

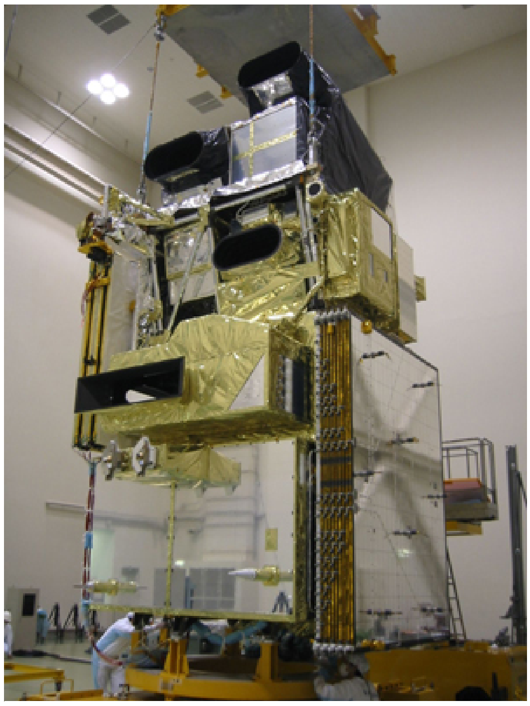

Figure 1.1.1 ALOS Prototype Flight Model, nadir facing the camera.

The main communications link for data downlink and housekeeping communications is the Ka-band Data Relay Communications (DRC) antenna, which provides a 240 Mbps transmission speed. Mounted on the top of the satellite body to accommodate inter-orbit communication with the geostationary Data Relay Test Satellite, the DRC antenna cannot be used for direct communications with the ground. Communications for tracking and control with local ground stations are therefore performed using an X-band antenna, which is mounted at the nadir side of the satellite body.

For orbital determination, a dual-frequency carrier-phase tracking-type GPS receiver provides 1-metre off-line position accuracy. ALOS also features a high precision 3-telescope Star Tracker (STT), which monitors the positions of distant stars to determine the precise attitude of the spacecraft. The STT is mounted on the top of the satellite body for an un-obscured view into space, and provides 0.0002 degrees (off-line) accuracy in attitude, corresponding to a 2.5 metre nadir pointing uncertainty on ground. The attitude movement (angular velocity) of the ALOS platform is stabilized within 0.0002 degrees per 5 seconds. The internal clock on ALOS is synchronized within the accuracy of 404 ns (3 sigma) to the GPS absolute time, yield an 1 μs order absolute time accuracy.

1.1.2 Data storage and downlink

For temporary on-board data storage, ALOS is equipped with a 96 Gbyte High-speed Solid State Recorder (HSSR). The HSSR is to serve all three instruments, and allows the recording of two simultaneous (120+240 Mbps) bit streams, and subsequently, playback of a single bit stream at either 120 or 240 Mbps.

JAXA's Hatoyama Earth Observation Center (EOC), north of Tokyo, constitutes the main ground station for data downlink from ALOS. The main part of the acquired data are transmitted via JAXA's Data Relay Test Satellite (DRTS), which was launched into a geostationary orbit over the Indian Ocean (E90°) in September 2002. Communicating at K_a-band with both ALOS and EOC, the DRTS provides a downlink capacity of 240 Mbps, and it is utilised for both real-time acquisitions and for playback of all data recorded onto the HSSR (Fig. 1.1.2).

Direct transmission from ALOS to local ground stationswithin the ALOS Data Node network is possible at X-band (Fig. 1.1.3). Due to the lower, (120-140 Mbps), transmission speed however, this option is only planned for selected observations in low data rate acquisition modes (AVNIR-2 and PALSAR ScanSAR).

Figure 1.1.2 Transmission from ALOS to EOC (real-time acquisitions and HSSR playback) via the Data Relay Test Satellite (DRTS).

Figure 1.1.3 Direct (real-time) downlink from ALOS to regional ground stations within the ALOS Data Node network.

As the launch of a second DRTS, originally planned to cover the western hemisphere (W90°), has been postponed indefinitely, data over regions outside of the present DRTS coverage have to be recorded onto the HSSR and down-linked when ALOS subsequently comes into the DRTS view. Figures 1.1.4 and 1.1.5 illustrate the present DRTS coverage for ALOS ascending and descending passes, respectively. The transmission unavailability at E 90° - visible in the figures as "holes" in the coverage - is a result of the technical design of the DRC antenna on ALOS, which limits pointing in zenith direction.

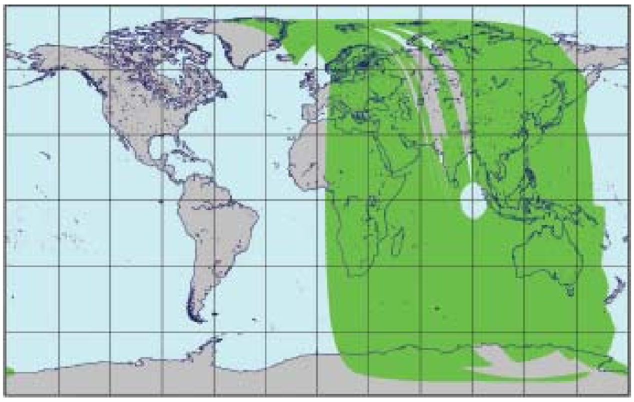

Figure 1.1.4 DRTS coverage (ALOS ascending passes)

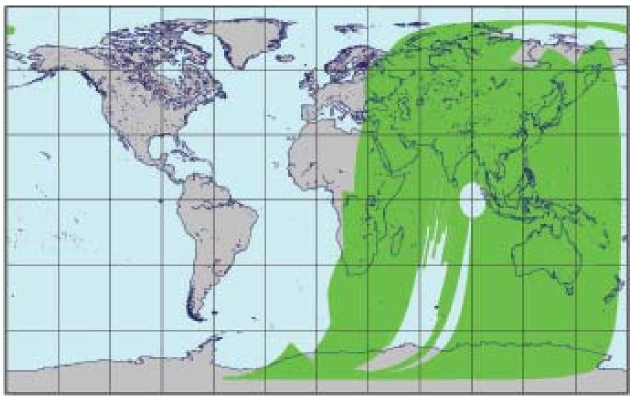

Figure 1.1.5 DRTS coverage (ALOS descending passes)

1.2 The Phased Array L-band Synthetic Aperture Radar (PALSAR)

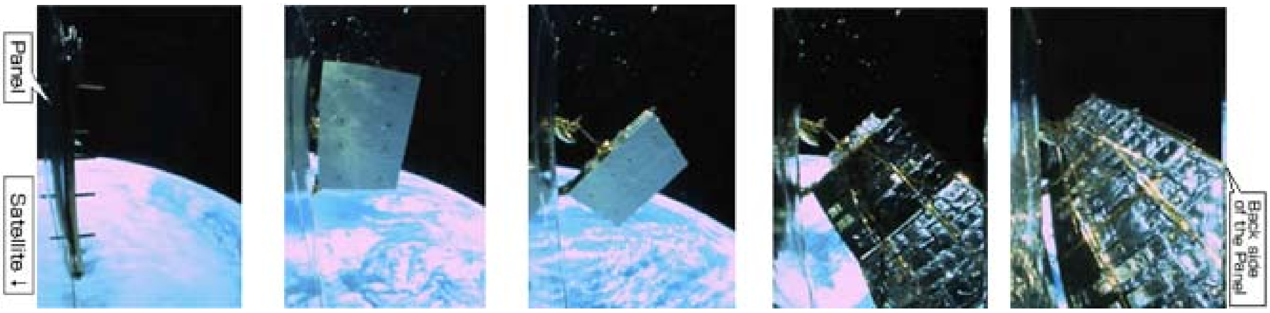

Figure 1.2.1 Deployment of the PALSAR antenna (Jan. 26, 2006).

The Phased Array L-band Synthetic Aperture Radar (PALSAR) is an enhanced version of the Synthetic Aperture Radar on JERS-1 (L-band; HH-polarisation; 35°off-nadir angle) Like its predecessor, PALSAR is a joint collaboration between JAXA and the Ministry of Economy, Trade and Industry (METI), and it had been developed jointly by JAXA and METI's Japan Resources Observation Systems Organization (JAROS).

PALSAR is a fully polarimetric instrument, operating at L-band with 1270 MHz (23.6 cm) centre frequency, and 28 MHz, alternatively 14 MHz, bandwidth. The antenna consists of 80 transmit/receive (T/R) modules on four panel segments, with a total size of 3.1 by 8.9 m. Deployment is performed in three steps; rotation of the folded panel stack 90° from the satellite body, off-nadir tilt of the stack, and subsequently unfolding of the four panels. In order to be better equipped to deal with potential difficulties during instrument deployment, such as were encountered for the JERS-1 SAR (1992), ALOS was furnished with a Deployment Monitoring System, consisting of five cameras for real-time observation of the deployments of the PALSAR antenna, the solar paddle and the DRC antenna. Fig. 1.2.1 shows an image sequence captured from the actual in-space deployment of the PALSAR antenna.

PALSAR features four main modes of operations (Fig. 1.2.2):

- Fine resolution beam mode
- Polarimetric mode
- ScanSAR mode
- Direct transmission mode

The Fine resolution Beam (FB) mode, features 18 beam selections between 9.9° and 50.8° off-nadir angle, each with 4 alternative polarisations: single polarisation HH or VV, and dual polarisation HH+HV or VV+VH. The bandwidth is 28 MHz in single polarisation and 14 MHz in the dual polarisation mode. The data recording rate in FB mode is 240 Mbps, thus requiring data downlink via the DRTS.

Out of the 72 alternative FB modes available, two have been selected for operational use: [HH pol.; 34.3° off-nadir] and [HH+HV pol.; 34.3° off-nadir]. These modes yield 70 km swath width and 10x10 and 10x20 m ground resolution in HH and HH+HV polarisation, respectively. The 34.3° off-nadir angle corresponds to an incidence angle range of 36.6° and 40.9° from near- to far range. PALSAR is operated in near zero-Doppler yaw steering mode to improve processing efficiency and geometric accuracy.

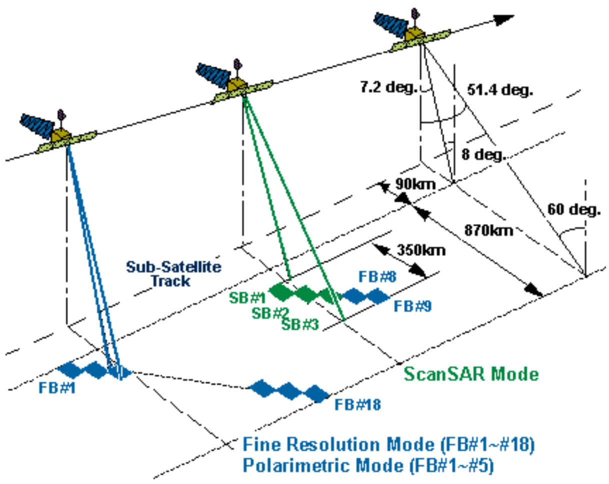

Figure 1.2.2 PALSAR observation characteristics

The Polarimetric mode provides the full quad-pol (HH+HV+VH+VV) scattering matrix with 12 alternative off-nadir angles between 9.7° and 26.2°. The default off-nadir angle for polarimetric acquisitions is 21.5° (22.8°–25.2° incidence range), resulting in 30 km swath width and 30x10 m ground resolution.

The wide-swath ScanSAR mode is available at single polarisation (HH or VV) and can be operated with 3, 4 or 5 sub-beams transmitted in either short (14 MHz bandwidth) or long bursts (28 MHz). Out of the 12 ScanSAR modes available, the short-burst, HH polarisation, 5-beam mode has been selected for operations. It features a 360 km swath width with an incidence angle range varying from 18.0° to 43.0° (the off-nadir angles for each of the 5 beams are 20.1°, 26.1°, 30.6°, 34.1° and 36.5°).

In case of a DRTS contingency, in which the data relay satellite becomes unavailable, PALSAR will be operated in Direct Transmission (DT) mode wherein data downlink to local ground stations will be carried out via the 120 Mbps X-band communications antenna. The DT mode accommodates only real-time, single polarization FB observations with reduced spatial resolution, and short burst ScanSAR.

The characteristics of the PALSAR instrument are given below in Tables 1.2.A and 1.2.B, with the corresponding values for JERS-1 SAR given for comparison. Notable is the 2 kW transmission peak power, which brings about improved radiometric performance in comparison with that of JERS-1, which exhibited limited sensitivity to low backscatter targets (NES-0 ~ -18 dB) due to its reduced (25%) transmission power (325 W).

Table 1.2.A PALSAR and JERS-1 SAR characteristics

Item	ALOS PALSAR	JERS-1 SAR
Centre frequency	1270 MHz / 23.6 cm	1275 MHz / 23.5 cm
Chirp band width	28 MHz (single polarisation) 14 MHz (dual, quad-pol., ScanSAR)	15 MHz
Transmission peak power	2 kW	325 W ($^1/_4$ of nominal 1.3 kW)
Pulse Repetition Frequency	1500 – 2500 Hz (discrete stepping)	1505-1606 Hz (discrete stepping)
Image modes	**Fine resolution beam (FB) mode:** ▪ Single polarization (HH or VV) ▪ Dual pol. (HH+HV or VV+VH) **Polarimetric mode:** ▪ Quad-pol. (HH+HV+VH+VV) **ScanSAR mode:** ▪ Single polarization (HH or VV) ▪ No. sub-beams: 3, 4 or 5 ▪ Short burst (14 MHz) or long burst (28 MHz) **Direct Transmission (DT) mode:** ▪ FB single pol (degraded) ▪ ScanSAR short burst	Single polarization (HH)
Bit quantisation	5 bits	3 bits
Off-nadir angle	Variable: 9.9° – 50.8° (inc. angle range: 7.9° - 60.0°) ScanSAR: 20.1°-36.5° (inc.range 18.0°-43.0°)	Fixed: 35° (inc. angle range: 36°- 42°)
Look direction	Right	Right
Yaw steering	Yes	No
Swath width	70 km (single/dual pol.@34.3°) 30 km (quad-pol.@21.5°) 360 km (ScanSAR 5-beam)	75 km
Ground resolution Rg (1 look) x Az (2 looks)	~ 10 m x 10 m (single pol.@ 34.3°) ~ 20 m x 10 m (dual pol.@ 34.3°) ~ 30 x 10 m (quad-pol.@21.5°) ~ 71-157m (4 look) x 100m (2 look) (ScanSAR 5-beam)	18 m x 18 m
Data rates	240 Mbps (single/dual/quad-pol) 120 or 240 Mbps (ScanSAR)	60 Mbps

Table 1.2.B Radiometric performance for ALOS PALSAR and JERS-1 SAR

	ALOS PALSAR	**PALSAR** Pre-launch spec.	**JERS-1 SAR**
Noise Equivalent σ^0	< -23 dB [FBS HH] < -34 dB [FBD HV] < -23 dB [POL HH and VV] < -28 dB [POL HV and VH] Not yet measured [ScanSAR]	< -21 dB	~ -18 dB
Absolute accuracy	< 0.64 dB (1 σ)	< 1.5 dB	< 0.95 dB
SNR	8.7 dB [FBS] 7.0 dB [FBD] 8.5 [POL] 9.5 dB [ScanSAR]	Not specified	Not measured
HH-HV Cross-talk	<-30 dB	- 25 dB	N/A
VV/HH Gain ratio	0.023 dB (1 σ)	< 0.2 dB	N/A
VV/HH phase difference	0.104° (1 σ)	< 5°	N/A
Geolocation (without GCP)	9.3 m (σ:5m) [FBS, FBD, POL] < 100 m [ScanSAR]	< 100 m < 100 m	< 400 m

1.3

1.4 Orbital characteristics

ALOS features a sun-synchronous orbit at 691 km, with a local equator pass time at about 10:30 and 22.30, for descending and ascending passes respectively. With a 46-day repeat cycle and $14^{27}/_{46}$ revolutions per day, ALOS requires 671 passes to complete a full global coverage.

For ALOS standard image products, JAXA uses a Ground Reference System (GRS) grid to define the (PATH, ROW) location of individual scenes units on the ground. In principle, the GRS is a virtual coordinate system superimposed on the globe, and it has the advantage of providing a common ground-based reference for all three instruments, independent of observation modes and viewing geometry. The disadvantage is that the GRS grid corresponds poorly with the location of the true satellite ground tracks, particularly at higher latitudes, and becomes awkward to use beyond individual scenes.

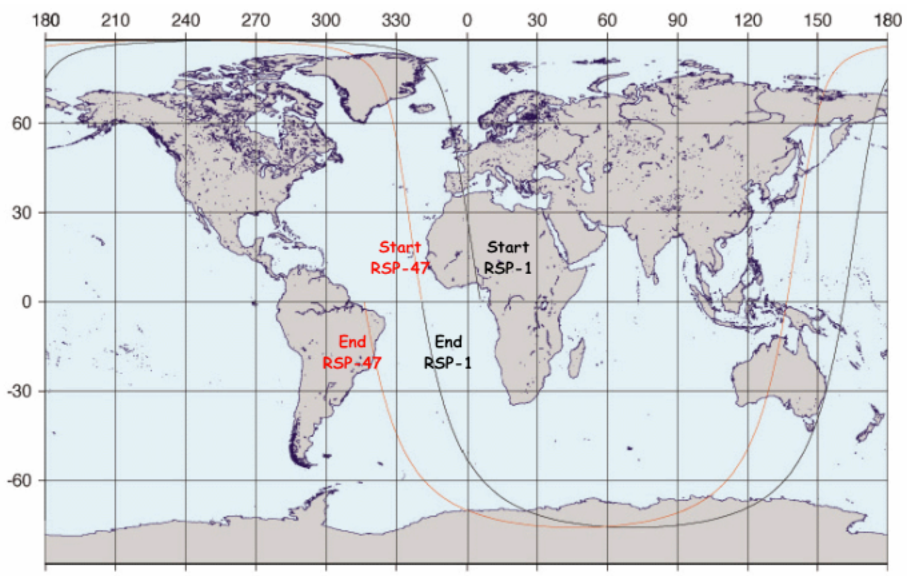

Figure 1.4.1 RSP pass definition concept. RSP pass numbers begin and end at ascending crossing of the Equator.

Within the framework of the Kyoto & Carbon Initiative, extensive strips of data constitute the standard image format and, because of the issues raised above, an orbit-based Reference System for Planning (RSP) is utilised to allow unambiguous path definition. Based on the location of the actual footprints of the image swaths, the RSP system uniquely identifies each of the ALOS passes, which are numbered sequentially westwards from 1 to 671. RSP pass number 1 is defined as the pass where the satellite nadir ground track intersects the Equator at 0° longitude. Each RSP pass covers a full 360° revolution, its start- and end-point being the Equator in ascending (evening) direction, As the RSP passes are numbered sequentially, rather than in chronological order, the RSP number for a given pass is incremented with a factor 46 as it passes northwards over the Equator (Fig. 1.3.1).

In contrast to the GRS system, the RSP pass definition varies between ascending and descending passes, and with the instrument's off-nadir viewing angle. Unique RSP maps therefore have to be employed for each of the specific observation modes used. Within the K&C Initiative, two sets of RSP maps are used: one for PALSAR ascending passes with an instrument off-nadir angle of 43.4°, the other for PALSAR descending passes in wide-swath ScanSAR mode. The former case is illustrated in Figure 1.3.2 which represents an RSP pass map over South-East Asia (ascending passes, 34.3° off-nadir angle). The RSP lines (even – purple; odd – red) indicate the swath centres. As the map shows the ascending case, the increments in the numbering is apparent as the passes cross the equator. (e.g. pass 401 becomes 447). In the case where an ascending image acquisition initiated in the southern hemisphere extends over the Equator, the whole image segment acquired retains the RSP number assigned at the start point.

Figure 1.3.2 also shows the relative temporal order with which adjacent passes are acquired, with the day of acquisition (relative to RSP pass 401) indicated in black. A full 46-day cycle is shown Whilst the JERS-1 orbit was adjusted so that neighbouring passes were acquired on consecutive days, hence resulting in a consistent one-day time difference between adjacent swaths, the ALOS orbit yields an inhomogeneous temporal structure of 17 and 29 days' time difference (i.e. 17-17-29-17-17-29-…etc.) between swaths.

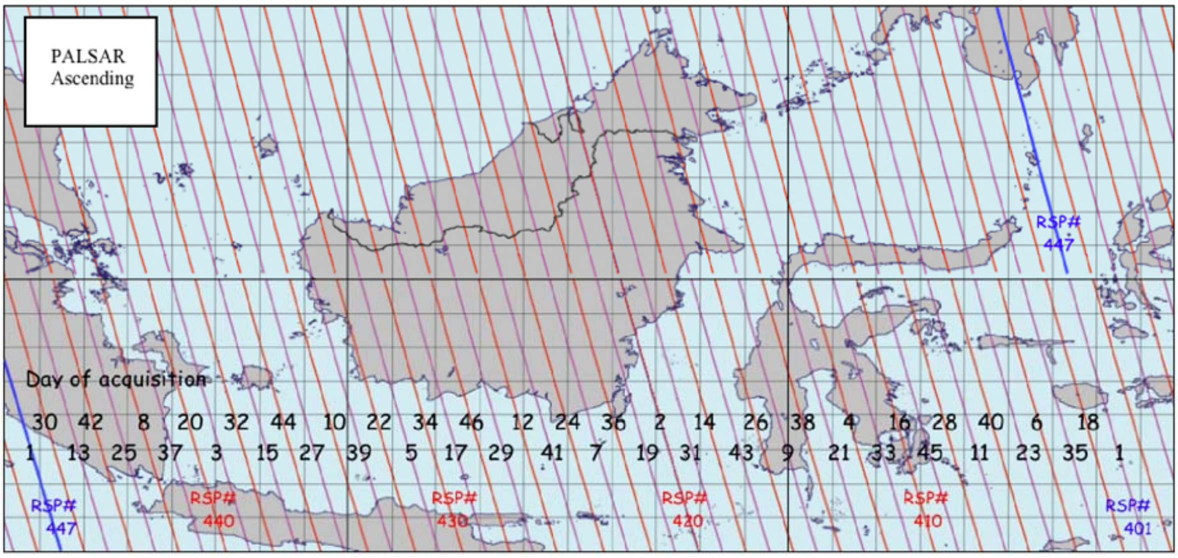

Figure 1.4.2 RSP pass map [ascending passes]. Numbers in black indicate the relative day of acquisition during a given 46-day repeat cycle (Note: path numbers depend on off-nadir angle and are here are given for illustration only).

To reduce data amounts and to minimise competition for data storage and down link with the optical sensors, which only can be operated during descending passes, PALSAR observations during descending passes are limited to the wide-swath, low data rate ScanSAR mode; reduced by two thirds such that only one out of every three passes are acquired. Yet, the 360 km ScanSAR swath width still yields 51% swath overlap at the equator, and in addition, provides a slightly improved temporal pass composition. Groups of 9 neighbouring passes are acquired with 5 days' relative time difference, followed by a 41-day jump, and then another 9 passes with 5 days' time difference, etc. (i.e. 5-5-5-5-5-5-5-5-5-41-5-5-5-…etc.). Figure 1.3.3 shows an RSP pass map for the descending case with the ScanSAR viewing geometry. Note that no change in RSP numbering occurs with the crossing of the equator during descending passes.

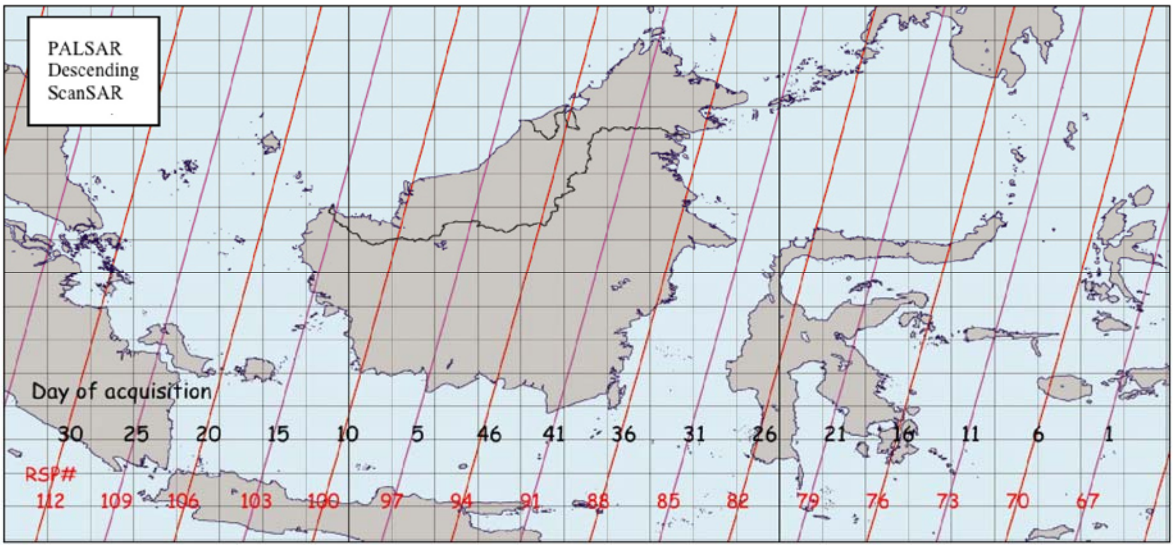

Figure 1.4.3 RSP pass map [descending; ScanSAR]. During standard operations in ScanSAR mode, data volumes are reduced by 2/3 by decreasing acquisitions to 1 out of every 3 ScanSAR passes.

1.5 PALSAR acquisition characteristics

1.5.1 Segment calibration

During PALSAR acquisitions, the observation segments are extended at the start and end to assure proper coverage of the target area. In yaw-steering mode, which is standard for ALOS operations, the length of this observation buffer is 2 x 24 seconds (else 2 x 16 s.). Calibration procedures also need to be performed for each individual acquisition segment, with 28 seconds required for pre-calibration and 10 seconds for post-calibration, and in contrast to the observation buffers, no useful image data are acquired during calibration.

With a blank interval required between two consecutive observation segments of at least 35 seconds, counting from the end of the post-calibration of one segment to the start of the pre-calibration of the next, the effective minimum time space between two image acquisitions (excluding the buffer data) thus becomes 73 seconds or 490 km on the ground.

Figure 1.4.1 (top) illustrates the case of PALSAR acquisitions over two target areas in succession. In the event that the areas are programmed for acquisition with different observation modes (e.g., off-nadir angles or polarisations), complete calibration procedures have to be performed for both individual observation segments. It follows that if two target areas are located closer to each other than the required 73 seconds, or taking also the end buffer observation of the first segment into consideration (i.e., 97 sec. which equates to ~650 km), full or partial data loss of the second segment will occur. If on the other hand the two areas are to be acquired with the same observation mode, the two segments can be merged into one extended continuous observation without loss of data (Fig. 1.4.1, bottom), hence by-passing this severe system limitation entirely.

Pre-cal. *28 sec.*	Start obs *24 sec.*	Observation 1 (Mode X)	End obs *24 sec.*	Post-cal. *10 s.*	Min. interval *35 sec.*	Pre-cal. *28 sec.*	Start obs *24 sec.*	Observation 2 (Mode Y)	End obs *24 sec.*	Post-cal. *10 s.*

Pre-cal. *28 sec.*	Start obs *24 sec.*	Observation (Mode X)	End obs *24 sec.*	Post-cal. *10 s.*

Figure 1.5.1 (Top) Acquisition of two consecutive segments with different observation modes induces a mandatory 73 second interval during which no image data can be acquired. (Bottom) Acquisition of the same areas in a single observation mode allows merging of the segments and extended continuous observations.

1.5.2 Default observation modes

To limit the detrimental effect of mode changes described above, and to assure spatio-temporal homogeneity over regional scales – PALSAR features an observation plan in which operations have been confined to a very limited number of operational modes. Out of the 132 original mode options technically available for PALSAR, only four have been identified as the main default modes (Table 1.4.A).

Table 4 shows the general characteristics of the default modes. The selection was made in consultation with the ALOS K&C Science Advisory Panel (cnf. Annex I) and it represents a compromise taking scientific criteria, user requests, programmatic aspects and satellite operational constraints into consideration.

Table 1.5.A PALSAR default observation modes

Polarization	Off-nadir angle	Incidence range	Swath width	Resolution (4 looks)	Pass designation	Coverage
HH	34.3°	36.6°~40.9°	70 km	10 m	Ascending	Global
HH+HV	34.3°	36.6°~40.9°	70 km	20 m	Ascending	Global
HH+HV+VH+VV	21.5°	22.8°~25.2°	30 km	~30 m	Ascending	Regional
ScanSAR (HH)	5-beam	18.0°~43.0°	361 km	~100 m	Descending	Regional/Global

1.5.3 Temporal stratification of observations

To reduce programming conflicts further, acquisitions are planned in units of whole (46-day) repeat cycles, during which only one of the available default modes is selected. Observations are also divided into descending (~10:30) and ascending (~22:30) passes, with PALSAR operations first and foremost planned for the latter to avoid conflicts with the optical sensors. As PRISM and AVNIR-2 are confined to daytime operations, they are assigned a higher observation priority than PALSAR, which, in descending mode, principally is limited to low data rate (120 Mbps) ScanSAR observations.

2 *THE KYOTO & CARBON INITIATIVE*

2.1 Project outline

2.1.1 Conventions, Carbon and Conservation

The Kyoto & Carbon (K&C) Initiative was initiated by JAXA (then NASDA) Earth Observation Research and Applications Center (EORC) in 2000, and is based on the conviction that Earth Observation technology has the potential to play a more significant role than it does today, in supporting certain environmental conventions, carbon cycle science and natural conservation, with information that cannot be obtained in a feasible manner by any other means. It is recognised that close integration with *in situ* information and analytical models is fundamental in this context.

The Initiative was established under the guidance of an international expert group – the K&C Science Advisory Panel – instituted to help assure scientific relevance in the project design and alignment with conventions and other relevant international efforts. The panel consists of scientists active in the fields of conservation, carbon modelling and biophysical parameter retrieval, SAR experts, and representatives from GOFC, GTOS/TCO, FAO, space agencies, universities and public research institutions (see Annex I).

Conventions, Carbon and Conservation, referred to hereafter as the three C's (CCC) constitute the thematic drivers behind the K&C Initiative, and relate to some of the major public, political and scientific concerns world-wide. Relevant to the establishment of the K&C Initiative is the particular aptness of ALOS PALSAR to support the type of regional-scale information needs posed by the CCC; in particular, given the L-band SAR sensitivity to vegetation structure and inundation, together with the microwave cloud-penetrating capacity to ensure global observations.

2.1.2 Project objectives

The K&C Initiative aims to support the CCC through the provision of (1) systematic global observations and consistent data archives, and (2) derived and verified thematic products.

2.1.2.1 Systematic observations and consistent data archives

As CCC typically concern cross-border phenomena, either human-induced or natural, which affect the environment over large regions, the availability of spatially and temporally coherent, fine resolution information over extensive areas becomes imperative, making "regional-scale" a key word for the K&C Initiative.

Whilst the provision of global systematic observations is one of the *potential* strengths of Earth Observation technology, fine spatial resolution remote sensing data are generally not acquired homogeneously over large areas, but instead are more often collected with local focus over sites that have been specifically requested by commercial or scientific users. Such acquisition schemes result in inconsistent and fragmented data archives that are inadequate for any application that requires extrapolation of locally developed methods and results to a regional or global scale context.

While this is the very case for CCC, the fundamental need for systematic data observations is acknowledged in Article 10(d) of the Kyoto Protocol, which states that countries shall "*co-operate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, [and] the adverse impacts of climate change...*". Requirements along the same lines are voiced by the terrestrial carbon cycle science community (IGOS-P, Carbon Theme Team) who state that "*The challenges [to a terrestrial carbon observation strategy] are to ensure that important existing observations continue and key new observations are initiated [and] to identify activities and agencies willing to contribute to establishing global carbon observations…*" [2].

The K&C Initiative should be seen as a response to this call, and acknowledging the critical need for consistent, global data JAXA has set aside a significant share of the ALOS PALSAR acquisition capacity for this purpose, and established an unprecedented, global Data Observation Strategy in support of the K&C, outlined below in detail in section 3.

2.1.2.2 Derived products

Among the main data products required by CCC are maps of forest cover and associated structure (for biodiversity assessment) and biomass (for carbon assessment); seasonal inundation (for watershed management planning) and coastal land cover maps (coastal protection) and subsurface drainage features (for water exploration and conservation). A key component of the K&C Initiative is to provide such products by applying well-researched and consistent techniques across regions, thereby supporting activities relating to CCC.

2.1.3 Project structure

Building on the experiences and decentralised project structure developed for the JERS-1 SAR Global Forest Mapping project (Rosenqvist et al. 2002, Rosenqvist et al. 2004), also the K&C Initiative is organised as an international collaborative effort. The Initiative is led by JAXA EORC, which is responsible for the overall management, implementation of the ALOS systematic acquisition strategy, as well as processing and distribution of all ALOS data, while product development is undertaken jointly by JAXA EORC and the international science team that involves universities and research organisations from 13 countries. Assisting JAXA to optimise project support on issues relating to the UNFCCC, the Ramsar Wetlands Covention and terrestrial carbon science are four advisors with direct professional connections to the treaties and/or the carbon cycle science community (GTOS/TCO).

Thematically, the Initiative is structured around three main thematic areas (Forest, Wetlands and Desert & Water) that each relate uniquely to one or more of the CCC drivers of the project, and a data-oriented (Mosaic Products) theme to support the three former with image data products (Fig. 2.1.1).

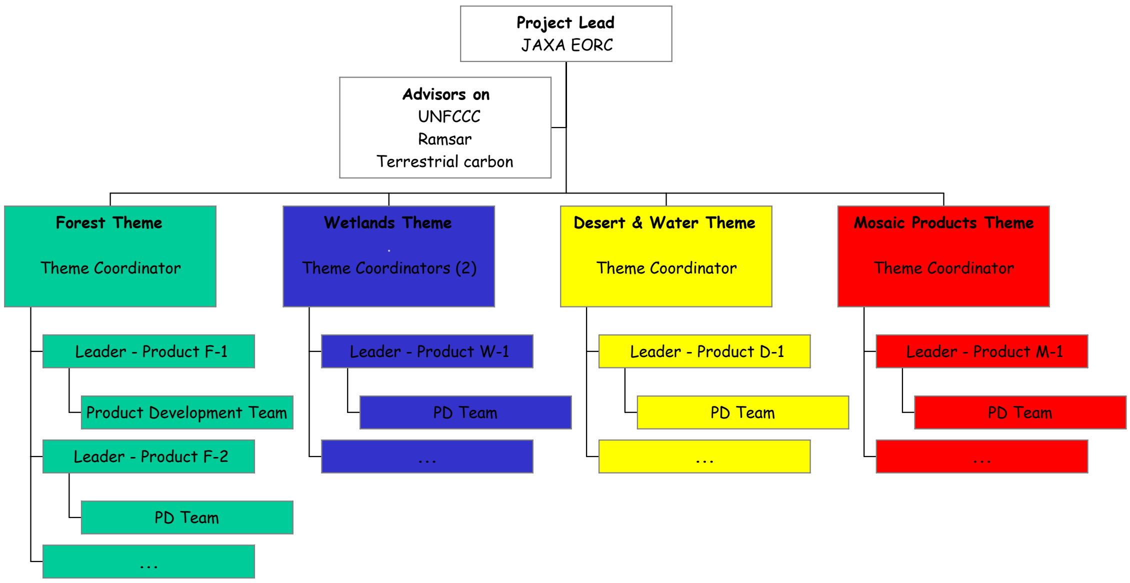

Figure 2.1.1 K&C project organisation and the four themes addressing CCC.

The Forest Theme is focused to support the UNFCCC Kyoto Protocol and the part of the carbon research community concerned with CO_2 fluxes from terrestrial sinks and sources. Key areas considered include land cover (forest) mapping, forest change mapping and biomass and structure.

The Wetlands Theme aims to serve information needs posed by the Ramsar Wetlands Convention and the Convention on Biological Diversity, as well as the significance of wetlands as sources of tropospheric carbon. Key areas considered include regional wetland inventories, seasonal inundation monitoring and specific inventories of mangroves and peat swamp forests.

The Desert & Water Theme addresses issues relevant to water supply and land degradation in arid and semi-arid areas. Key areas considered include freshwater supply and desertification.

The Mosaic Products Theme is a semi-independent unit within the Initiative, which in terms of member composition and scope largely constitute a global-scale extension of the JERS-1 SAR Global Forest Mapping project. The principal objective of this theme is the generation of continental-scale PALSAR mosaics, to be used both as intermediate input data to the three thematic themes, as well as stand-alone image products to be made available to the public.

Each of the four themes is led by a Theme Coordinator, who oversees and coordinates theme-specific scientific activities and liaises with the Product Leaders to support the product development phase. The Theme Coordinators are also the authors of the theme chapters of this science plan, which follow below.

2.1.4 Implementation

Implementation of the K&C Initiative is undertaken in a number of steps:

Implementation of the PALSAR observation strategy
PALSAR acquisitions in support to the K&C Initiative (see section 3) began in October, 2006, immediately following the completion of the commissioning and calibration/validation phases of ALOS. PALSAR data are transferred from JAXA EOC in Hatoyama to JAXA EORC on-line (new since fautumn 2007) for processing and delivery to the K&C Science Team by high-speed FTP (ASPERA).

Local-scale methodology development.
This work is carried out by the Product Leaders and their Product Development (PD) teams, typically using a small number of PALSAR scenes over study site(s) that are representative for the biome(s) of interest, with ample in situ data available for verification.

Regional-scale prototype demonstration.
This step constitutes the essence of the K&C Initiative during the first 3 years, and which covered within this science plan. Applying the methods and algorithms developed in the previous step, "derived products" over extensive regions – described in the theme descriptions that follow below – are generated by the PD teams. All products will be made available to the public and to specific target users.

Review.
In the spring of 2009 – 3 years after the ALOS launch - JAXA performs a review of all K&C projects and the products developed, with respect to scientific significance, accuracy levels achieved, actual relevance to CCC etc., in relation to the amounts of PALSA data provided.

Global-scale extrapolation.
Projects which are deemed successful and with a potential for application over different or larger regions are selected by JAXA for extension for another 2-year period.

2.2 The Forest Theme

Theme Coordinator:

Richard Lucas, University of Wales Aberystwyth, United Kingdom

Product Development Team:

Gianfranco De Grandi, JRC-IES/GVM, E.U.
Dirk Hoekman, Borneo Orangutan Survival Foundation, Indonesia
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Thuy Le Toan, CESBIO, France
Dalton Valeriano, INPE, Brazil

2.2.1 Introduction

Since the 1800s, the world's forests have been depleted significantly and largely as a result of industrialization and agricultural expansion. In many regions, including temperate Europe, and the United States, large tracts of forest were cleared several centuries ago. Much of the deforestation in the past 50 years, however, has occurred in the tropical, subtropical and boreal regions where extensive areas of relatively pristine forest were remaining (Mayaux *et al*., 1998). Between 1990 and 1995, and despite increased awareness of the extent and non-sustainable nature of clearance, the global forest area decreased by 56.3 million ha, with the 8.8 million ha increase in developed countries offset by the 65.1 million ha loss in developing countries (FAO, 1999). In 2000, the FAO Forest Resources Assessment 2000 Project reported that the world's forests covered 3.9 billion ha (or 29.6 %) of the land surface, a reduction of over 50% from the original extent. A significant area has also been fragmented (e.g., Skole and Tucker, 1993), or exists as a secondary formation (Brown and Lugo, 1990; Lucas *et al.,* 2000) and the condition of many forests has been reduced by human impacts, including human-induced fires and atmospheric pollution (Macelloni *et al*., 2001). Such losses are likely to be exacerbated in future years with changes in climate (e.g., through increases in forest fires and storm damage; Siegert and Hoffman, 2000).

The loss and degradation of forests worldwide has significant implications for mankind. These forests contain significant quantities of biomass with the greatest amount (> 200 Mg ha^{-1}) found in the tropics but also in temperate and boreal regions (average of ~ 90 Mg ha^{-1}; Houghton, 2004). The burning of this biomass and removal or felling of timber has contributed to the additional burden of CO_2 in the atmosphere (379 ppm in 2004) and the associated changes in climate. Clearance, degradation and fragmentation of forests have also resulted in significant losses of biodiversity and resources (e.g., pharmaceuticals, natural food products) of social and economic importance (Laurance, 2000; Fairfax and Fensham, 2000; Saatchi *et al*., 2001).

Increased awareness of these impacts has led to action in both the national and international arena, with a number of international conventions (Rosenqvist *et al*., 2003; Grace, 2004), including the UN Framework Convention on Climate Change (UNFCCC), its Kyoto Protocol and the Convention on Biological Diversity (CBD) contributing to the preservation, enhancement and long-term sustainability of global forest diversity and carbon stocks There is now a greater requirement for accountability in relation to the fate of the World's forests and, as a result, the replanting of native or introduced species has been promoted in recent years (FAO, 1999). Large areas of forest are also regenerating naturally (Lucas *et al*., 2000) and it these forests that are playing a key role in the recovery of the carbon and species diversity lost previously through anthropogenic disturbance.

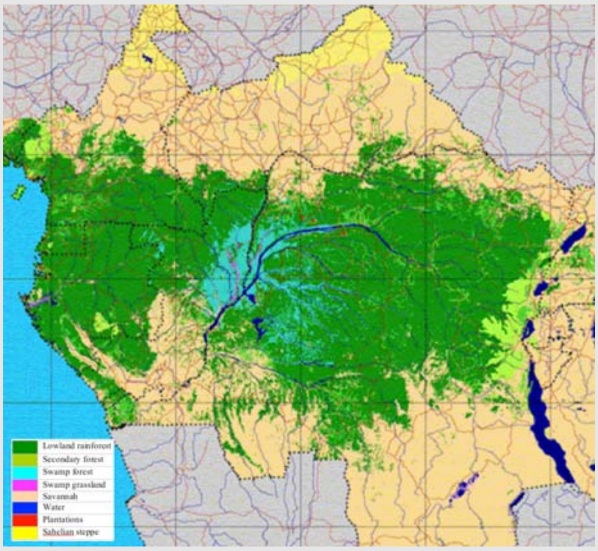
2.2.2 Problem statement

Despite increased awareness of the depletion of the world's forests, deforestation and degradation has continued unabated in many regions. For this reason, there is a need to continue the mapping of forests on a regular basis and to quantitatively assess the changes in extent, condition (in terms of structure, biomass, and species composition) and functioning so that processes and drivers of change can be better understood and quantified. For reporting to international agreements also, there is a requirement to retrieve specific data relating to the carbon budgets and biological diversity associated with these forests. Although considerable advances have been made in these areas in recent years, significant obstacles still remain in terms of collecting and collating relevant and timely data.

Product Box F-1 – Land Cover and Land Cover Change Mapping

K&C product(s): Vegetation map, showing swamp and lowland forests

Intended use: A vegetation new map of the Central Congo basin based on ALOS PALSAR data will allow validation of the previous estimates and temporal analysis on some landscape features to be performed. The PALSAR mapping will be extended to the forest-woodland transition zones bordering the Congo basin to the North and South. These transition zones are less studied than the humid forests but are nevertheless important in connection with sustainable development because the majority of the population resides in these areas. PALSAR images will be used to delineate the agricultural domain and map woodlands and shrublands (with different levels of tree cover). Reforestation in these areas is an important issue that qualifies this product for supporting the Kyoto protocol requirements.
Prototype areas: The Congo river basin and the Sahel region
Input data: ALOS PALSAR Path Images, 50 m resolution



Using the Africa JERS-1 L-band SAR mosaic generated within the GRFM project, and combining C-band ESA ERS-1 data and SPOT VEGETATION optical data, a revised map of vegetation cover was obtained for the Congo Basin at a spatial resolution of 200 m. Important ecosystems for the atmosphere-biosphere exchange processes, such as the swamp forests in the Central Congo basin, were mapped for the first time with high spatial accuracy. Furthermore, the position and extent of the entire river network in the Congo basin was documented in digital form at far higher precision than what available in the past by means of conventional cartography.

Product Developer:
Frank De Grandi Joint Research Centre, E.U.

Clearance of forests, through felling and/or burning, is continuing to add to the levels of CO_2 in the atmosphere but the overall amount and relative contribution from different regions remains uncertain largely because of difficulties in quantifying the biomass losses associated with the pre-cleared forests. The remaining forests are, by contrast, soaking up carbon either in response to increasing CO_2 in the atmosphere (Grace *et al*., 1995) or because large areas are regenerating following clearance (Lucas *et al*., 2000) or thickening because of changing land management practices (Barrett *et al*., 2001; Burrows *et al*., 2002). In many countries, deliberate replanting of forests is also occurring. In these latter cases, spatial and temporal estimates of the magnitude of the associated uptake of CO_2 are equally difficult to obtain. An approach to estimation is to undertake routine and regular mapping of the extent of different forest types at varying stages of regeneration (including mature and senescent) and their associated biomass and biomass increment or losses. However, this represents a significant challenge and one that has remained unfulfilled at a global level.

Estimates of the number of species on Earth range from 3 to 30 million, with tropical forests supporting between 50 and 90 % of the total. Within the next 30 years, as much as 20-25 % of species will have become extinct. The loss of species has been and will continue to be greater in centres of endemism (Saatchi *et al*., 2001) and rare species are likely to disappear whilst those more adaptable to secondary environments (e.g., regrowth forests) tend to thrive. The losses of biodiversity associated with forest depletion but also recovery within regrowing forests have also proved difficult to quantify even though many forest values (e.g., location, biomass, type, structural complexity and growth stage) are linked closely with levels of floral and faunal diversity. Associating diversity with mapped forest attributes has been considered but few attempts at global forest biodiversity assessment have been undertaken, particularly in conjunction with remote sensing data and data products. The losses of biodiversity associated with deforestation and degradation and also the gains associated with regeneration have also not been adequately considered, partly because of the lack of quantitative information and provision of appropriate relational measures. Given the unprecedented loss of species, efforts at identifying the key areas of biological diversity by integrating remote sensing data should be prioritized but approaches to achieving this aim are still embryonic.

Product Box F-2 – Boreal Land Cover Classification and Land Cover Change

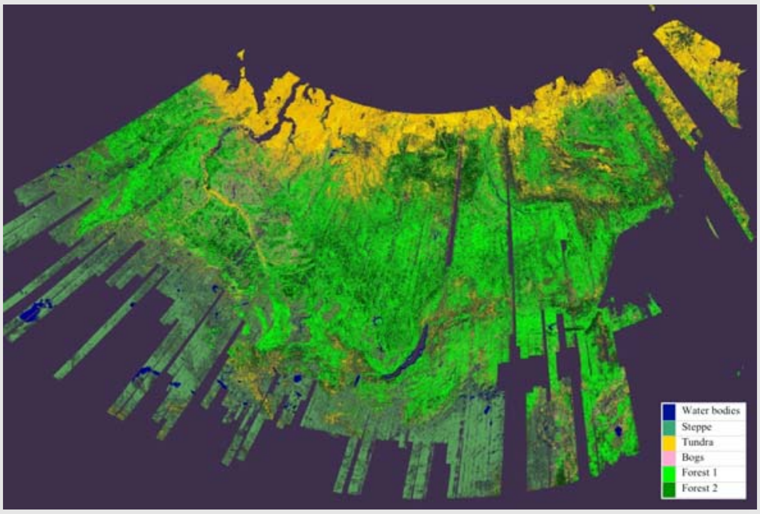
K&C product(s): (LCM6/FCM5)

- Methods for integration of Forest and Land Cover Change theme to improve and update existing land cover products in the boreal zone will be developed.
- Thematic classification for Siberian Taiga based upon dual polarisation dual polarisation PALSAR data, with 2006 being the intended base year.

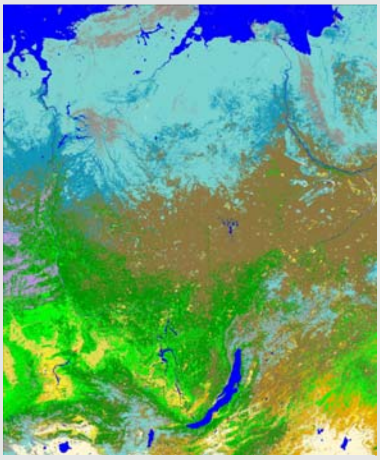
Intended use: Improved land cover maps and land cover change maps to be provided to the carbon community. Land cover mapping has been undertaken previously at 900 m resolution using the Siberia GBFM mosaic (JERS-1 backscatter, 1997-98 acquisitions), a texture measure mosaic obtained by computing the normalized variance of backscatter in a block window of 9x9 pixels and the Siberia Global Land Cover 2000 (GLC2000) map. Preliminary validation using MERIS data has suggested that such a product refines and enhances the mapping accuracy achieved by the optical data alone, especially for some thematic classes, such as bogs and water bodies. Classification of PALSAR mosaic data acquired in 2006 will be extended to the entire Siberian taiga at finer spatial resolution than the JERS-1 SAR mosaics and this is expected to augment our knowledge of this ecosystem in an unprecedented way. The 2006 continental scale snapshot will lay the ground for quantifying changes in land cover and bio-physical parameter estimates derived from the mid-90's JERS-1 data.

Prototype areas: Siberia

Input data: ALOS PALSAR image mosaics, 50 m resolution



Map of major vegetation types within the Siberian taiga generated using the Siberia GBFM JERS-1 SAR mosaic and the Siberia Global Land Cover 20000 map.



Land cover classification of Central Siberia using MODIS data (courtesy of UWS, SIBERIA-II Project).

Product Developers:

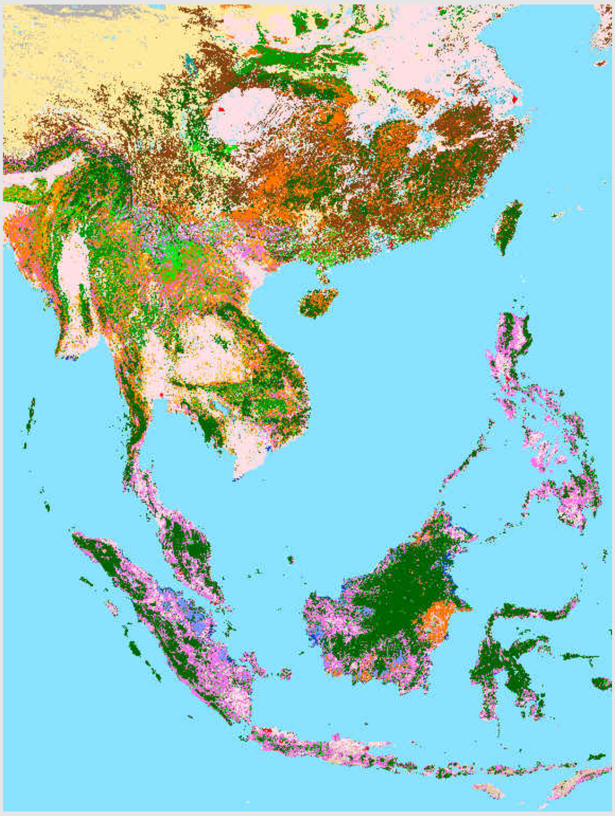
Gianfranco De Grandi	Joint Research Centre, E.U.
Christiane Schmullius	Friedrich-Schiller University Jena, Germany

With the requirement for national reporting under international conventions such as the UNFCCC, the Kyoto Protocol and the CBD, the provision of information on forest extent and cover change and the associated impacts on carbon budgets and biodiversity is now critical and, in some cases, legally binding. Although guidelines are presented for such reporting, countries are still relying on different sources of data and methods for mapping and using varying definitions of forest and forest classes. Methods of estimating biomass and biomass increment are variable and also typically rely on differing sources of data of variable quality. In essence, consistency and accuracy in the approaches are often lacking because of the reliance on a range of data sources and mapping methods. The problem is particularly acute in less developed countries where resources are lacking.

2.2.3 Carbon, Conservation and Conventions

The K&C Initiative focuses on the provision of remote sensing datasets that are appropriate for addressing the key issues relating to carbon cycle science and conservation of biological diversity, thereby supporting the data requirements of international conventions and providing valuable information to other users (e.g., policy makers, land holders and ecologists).

Product Box F-3 – Land Cover Mapping



1 km resolution GLC 2000 map of SE-Asia (Bartholomé et al., 2005)

K&C product(s): (LCM3) Maps of regional land cover at 250 m spatial resolution, using available ADEOS II Global Land Imager (GLI-250) data with particularly emphasis on South East Asia.

Prototype areas: South-East Asia

Intended use: The 250 m resolution land cover maps will contribute to global and regional land cover products and used for environmental resource assessment and as a baseline against which to assess change. The multi-temporal 250 m spatial resolution (including short wave infrared channels) of the available GLI data for South-East Asia will be particularly useful for refining maps of the extent of seasonal forests.

Input data: ADEOS-II Global Imager (250 m) data

Product Developer:

Ryutaro Tateishi Chiba University, Japan

2.2.3.1 Carbon

The K&C Initiative focuses on both carbon pools and also changes associated with activities such as deforestation, reforestation, afforestation and natural regeneration.

Forest carbon pools

Globally, a significant proportion of terrestrial carbon is retained in the biomass of forests, with the majority allocated to the above ground components, although this varies by environment. The spatial variation in biomass is, however, highly variable depending upon location, soils, topographic position and climate. In many regions also, the biomass contained within many forests has been reduced by deforestation and degradation (Houghton, 2004), both natural (e.g., fires, drought) and anthropogenic (e.g., logging, shifting cultivation or wood gathering). For these reasons, the assignment of generalized biomass estimates to mapped areas of forests is now unacceptable given the large variation that exists. Estimates of biomass that consider the spatial heterogeneity of forests are therefore essential, as are methods for generating routine updates of biomass maps. However, few options currently exist to facilitate estimation at a regional or global level, which is attributable in part to the difficulty in obtaining large area coverage over comparable and appropriate time frames by remote sensing instruments with sensitivity to biomass. Methods for reliable and consistent retrieval of biomass are also lacking. Many are based on empirical relationships with forest inventory data and errors associated with sampling, measurement and conversion lead to large uncertainties (Rosenqvist *et al*., 2003). This was highlighted by Houghton *et al*. (2000), whereby several regional estimates of forest biomass in the Amazon were shown to vary substantially.

As forests consistently exhibit higher backscatter at L-band compared to non-forested surfaces (Saatchi *et al*., 1997; Luckman *et al*., 1997; Yanasse *et al.* 1997), the ALOS PALSAR is well suited for mapping forest extent (and hence the location of large carbon pools) across large areas, especially given the provision of regional mosaics over short time periods. Differentiation of forest types (e.g., swamp forests) with varying biomass through either spatial or temporal variations in L-band backscatter, coherence or texture measures has also been proven (de Grandi *et al*., 2000). Although the biomass of many of the World's forests exceeds the level of saturation (~50-100 Mg ha^{-1}) typically observed (Le Toan *et al*., 1992; Dobson *et al*., 1992; Rignot *et al*., 1994; Imhoff 1995; Luckman *et al*., 1997; Le Toan *et al*., 2004), the combination of backscatter and textural measures (Saatchi *et al*,. 2003), height (Neeff *et al*., 2005) or coherence data (Tansey *et al*., 2004) has shown promise for retrieval in higher biomass forests. In the case of forests that are secondary or occurring in less productive environments, successful biomass retrieval using PALSAR dual polarization L-band backscatter (Lucas *et al*., 2005a) or coherence data (Eriksson *et al*., 2003), either singularly or in combination with other (e.g., optical) datasets, is anticipated.

Changes in carbon stocks

The relative magnitude and timing of carbon losses and gains associated with changes in forest extent and state can be monitored by mapping and comparing the extent of forest over time and the associated change in biomass. In general, clear-cuts within forests are relatively easy to detect, but the removal or dieback of individual trees or clusters is rarely identifiable, even at relatively fine spatial resolution, Processes such as selective logging or shifting cultivation are therefore difficult to monitor. Although deforestation statistics have been reported routinely (e.g., INPE, 2004), the extent of regenerating forests has proved to be less straightforward to map. Most approaches have used optical remote sensing data (Lucas *et al*., 2002), but the differentiation of different stages is problematic as the spectral reflectance of regenerating forests rapidly becomes similar to that of the mature forest and varies depending upon the relative dominance of species during the early succession and the changing structure of the forest over time. As optical sensors also only observe in two dimensions, the three-dimensional structure can only be inferred.

A particular advantage of the ALOS PALSAR is that cloud-free observations are provided over large areas and similar time-periods, allowing observation of deforestation activities and regeneration. The significantly reduced L-band backscatter for non-forested areas allows discrimination from forested areas, which tend also to support a consistently higher backscatter over time (Lucas *et al.,* 2005a). Subsequent regeneration (and also reclearance of regenerating forests) can also be identified by a change in L-band backscatter from one date to the next. Temporal L-band coherence data have shown promise for detecting change (e.g., Eriksson *et al*., 2003). In mapping the extent of woody regrowth and thickening within forests, the integration of L-band and C-band SAR or measures of foliage or canopy cover have also proved useful (Lucas *et al*., 2005b).

The ALOS PALSAR is expected to facilitate estimation of changes in biomass associated with forest regeneration through temporal comparison of SAR backscatter or coherence data up to the levels of saturation. Relating such changes to fluxes of carbon is difficult given uncertainties in the processes of decomposition and regeneration and the rates of change (Houghton, 2004). For example, Schulze *et al*. (1999) suggest that several decades may pass before the Net Primary Productivity (NPP) of regenerating forests on cleared land in Siberia exceeds heterotrophic respiration, largely because of the decomposition of dead biomass. Amiro *et al*. (2003) and Law *et al*. (2001) suggested that several decades may pass before burned or clear-felled forests in Canada and the US may become a net carbon sink. Nevertheless, by integrating models and observations of carbon dynamics with forest cover or change information generated using PALSAR data (either singularly or in combination with other remote sensing data), improved estimates of carbon flux may be obtained (Kurz and Apps, 1999; Le Toan *et al.,* 2004). ALOS PALSAR data can also be used to understand biomass dynamics across the landscape. For example, lower JERS-1 SAR backscatter from Amazonian forests regenerating on more intensively used lands suggested a reduced capacity to recover biomass (Prates, 2005). At high latitudes and altitudes, a number of biogeochemical processes are limited by environmental conditions such as freezing of fluids in vegetation or the near surface soil layer. L-band SAR data are anticipated to provide information on the moisture status of vegetation and the near surface layer and to define the onset and duration frost-free periods.

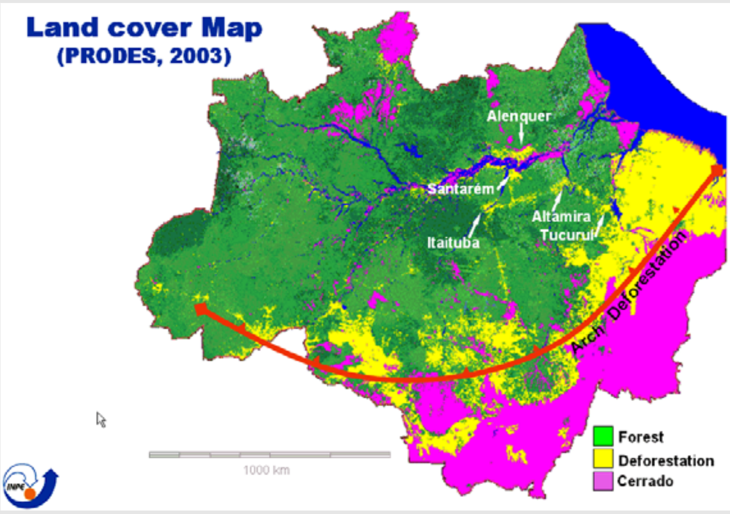
2.2.3.2 Conservation

Evaluating the biodiversity of forests globally has previously been based on surveys of flora and fauna, established links with ecosystem distributions and environmental variables or mapped distributions of each. Remote sensing data products (e.g., forest cover maps) have been used to assess the distribution of biodiversity, but few attempts have been made to correlate diversity or abundance of species with remote sensing data. However, there is increasing recognition of the relationships between diversity and remote sensing-derived estimates of, for example, forest biomass and structure, landscape elements and patterns, productivity and phenology (Saatchi *et al*., 2001).

The PALSAR data will therefore provide opportunities for reporting the biodiversity values of forests, particularly as SAR textural and backscatter/coherence measures are known to relate to forest structure (Saatchi *et al*., 2001) and biomass (Luckman *et al*., 1997). By reporting actual or potential changes (e.g., deforestation) within or in proximity to sensitive areas or those of high biomass and structural diversity, early warnings of adverse change can be given. Furthermore, quantitative estimates of the extent of forest fragmentation and connections (e.g., through corridors of primary or regenerating forests) can be provided. Temporal variations in PALSAR data are expected to provide information on the changing state of forests, including those that are periodically inundated (Rosenqvist *et al*., 2002) or vulnerable to an altered environment (e.g., drainage of peat swamps), and assessments of damage to forests (e.g., through fires).

Product Box F-4 – Deforestation Monitoring

K&C product(s): (FCM2) Yearly updates of forest cover and forest cover change through integration of ALOS PALSAR data with the PRODES products. The use of ALOS data will assist the mapping of deforestation activities where cloud cover is persistent and assist characterisation of the processes of deforestation and regeneration.
Intended use: Monitoring impacts of anthropogenic activities (deforestation, reforestation, afforestation, secondary re-growth cycles, fire damage). Applications include the control of illegal logging. The so called DETER project conducted by INPE in 2004 aims to provide an alert system to detect incipient deforestation in a quasi-real time frame. Although the main data used will be MODIS and WIFF imagery from the China-Brazil Earth Resources Satellite (CBERS), ALOS PALSAR data will form a key component, providing fine spatial information about changes in land cover on an annual basis.
Prototype areas: The Brazilian Amazon
Input data: ALOS PALSAR Path Images, 50 m resolution



Deforestation and forest age-class maps of the Brazilian Legal Amazon generated through the PRODES project using Landsat ETM+. ALOS PALSAR will be used to refine these maps with information about annual changes, particularly in areas of persistent cloud cover, and thus provide a better insight into the dynamics of deforestation.

Product Developer:
Raimundo Almeida Filho National Institute of Space Research (INPE), Brazil.

2.2.3.3 *Multi-national Conventions*

The UNFCCC and the Kyoto Protocol
The 1992 UNFCCC was aimed at stabilizing atmospheric levels of CO_2 to prevent dangerous anthropogenic interference with the climate system and over a timeframe that would allow ecosystems to adapt, food production to be safeguarded and sustainable economic development to be pursued. A key component of the UNFCCC was that the 140 signatory countries agreed to produce a National Greenhouse Gas Inventory (NGGI) to establish national emissions and assess progress in their reduction.

One of the greatest uncertainties in many NGGIs has been the magnitude of carbon sources and sinks associated with the land use, land use change and forestry (LULUCF) sector and, in particular, the extent of vegetation clearance and regeneration and the associated changes in carbon stocks (Barrett *et al*., 2001). The ALOS PALSAR will provide new data that can contribute to the mapping and monitoring of forest cover change, thereby supporting the NGGI process. The ALOS PALSAR is also anticipated to provide better estimates of biomass losses and gains associated with the clearance and growth of regenerating forests because of L-band sensitivity to woody biomass up to ~ 50-100 Mg ha^{-1} and incremental biomass change within this range (Imhoff , 1995; Le Toan *et al*., 2004; Lucas *et al.,* 2005a). Better assessments of the spatial variability of biomass are also anticipated to benefit countries that currently rely on aspatial and generalised estimates of biomass.

Despite the UNFCCC, atmospheric levels of CO_2 have continued to rise, with an acceleration observed in recent years (Grace, 2005). For this reason, the convention was strengthened in 1997 through the Kyoto Protocol. This agreement obliges Annex I Parties to collectively reduce their overall emissions to at least 5 % below 1990 levels by 2008-2012 (the first commitment period). Particular emphasis has been given to afforestation, reforestation and deforestation activities (ARD[1]) and several Articles are indirectly concerned with the identification and spatial quantification of areas of change, including those resulting from fire or revegetation (Henry *et al*., 2002; Rosenqvist *et al.,* 2003). A component of the Kyoto Protocol is the Clean Development Mechanism (CDM) which allows investment into projects in non-Annex I countries, including those associated with afforestation and reforestation activities. In these cases, the monitoring of these processes is essential. The Kyoto Protocol came into force in February 2005, following ratification by Russia in 2004.

The ALOS PALSAR is well suited to the detection of ARD activities given the sensitivity of L-band SAR backscatter to changes in forest cover and associated biomass. The sensor will also provide data that can support a surveillance system to document past and future land use history. Repeat observations with extensive global coverage will be especially required for monitoring of CDM projects, including start dates and geographic and spatial distributions (Rosenqvist *et al*., 2003). The ALOS PALSAR also has the potential to provide consistent coverage at continental scales and over short timeframes as systematic acquisition strategies are being implemented. This potential has already been demonstrated for both the tropical and boreal zones (Rosenqvist *et al*,. 2000; Schmullius *et al*., 2001). Observations are planned over the same time periods between years and random observations have been discouraged. The ALOS PALSAR will also provide repetitive, regional scale monitoring over longer time periods (Rosenqvist *et al*., 2003) and to achieve this, a federated approach with common goals and thematic definitions is being pursued under the framework of the Global Observations of Forest Cover (GOFC) projects (Ahern *et al*., 1998). The requirement for integrating these data with those from other radar (e.g., RADARSAT, ENVISAT Advanced SAR) and optical sensors (e.g., Landsat and SPOT VGT) has also been recognized and promoted through various initiatives, including the K&C Initiative.

2.2.4 Community requirements

Maps of land cover, forest change and biomass and biomass change contribute significantly to a wide and diverse range of activities conducted by national and international communities in the arenas of science, policy, conservation and resource management. Such mapping is required on the global scale for understanding global ecosystem functioning, and as input to Global Circulation Models (GCMs) and Biogeochemical Cycle Models (BCMs). At a regional to national level, mapping is required largely to support obligations to international agreements, such as the UNFCCC and the Kyoto Protocol, but also activities and organisations that promote the sustainable development, management and conservation of forests including the UN Forum on Forests (UNFF) and Food and Agricultural Organisation (FAO), the Intergovernmental Panel on Forests (IPF), the International Tropical Timber Organisation (ITTO) and the Committee on Forestry (COFO). Such information is used at the local scale for assessing forest harvesting cycles, the changing extent of ARD activities, and changes in timber stocks.

2.2.4.1 Land cover

Land cover maps at scales from global to local are required by a wide range of users, including policy makers, environmental convention secretariats and both national governmental and non-governmental organisations. At a global level, maps of land cover have been generated previously using a variety of optical datasets, including AVHRR (De Fries and Townshend, 1994; Hansen et al., 2000), MODIS (Friedl et al., 2002) and SPOT VEGETATION (Bartholomé et al., 2005). By integrating spaceborne SAR data, significant improvements to the mapping of land covers, particularly forests associated with seasonal inundation, has been achieved in several continents (De Grandi et al., 1999; Rosenqvist et al., 2000; Saatchi et al., 2000;

[1] Afforestation is the direct human-induced conversion of land that has not been forested for a period of at least 50 years, while reforestation implies conversion of land that once was forested, but that had been converted to non-forested land. For the first commitment period, reforestation activities are limited to reforestation occurring on those lands that did not contain forest on 31 December 1989. Deforestation is simply defined as the direct human-induced conversion of “forest” to “non-forest”. (UNFCCC, 2001).

Wagner et al., 2003). Regional to continental-scale mosaics generated using ALOS PALSAR data are expected to lead to refinements of land cover maps at various scales and add value to those generated previously.

Drivers	CARBON CYCLE Carbon losses associated with deforestation and gains with regeneration, reforestation and afforestation, thickening and enhanced CO_2 uptake	CONSERVATION Diversity losses associated with deforestation and recovery with forest restoration	CONVENTIONS Forest, forest change and biomass/structural mapping required for UNFCCC, Kyoto Protocol and CBD.
Information Needs	Forest biomass (carbon) pools Biomass change associated with deforestation and forest restoration (e.g., natural regeneration). Land use impacts on capacity of forests to recover diversity.	Forest type (e.g., swamp forests) distributions Forest biomass and structure (cover and height) and link with measures of diversity. Monitoring systems for hotspots of biodiversity. Information on forest degradation.	Forest Change (Deforestation, Reforestation and Afforestation). Carbon fluxes associated with forest losses and gains. Impacts of forest change on biodiversity.
K&C Forest Theme Products	Land Cover Maps Maps for selected tropical, subtropical and boreal regions	Forest Change MappingI: Maps of change associated with afforestation, Deforestation, reforestation, forest management, and natural regeneration	Forest Biomass & Structure Maps of, biomass change and structure (e.g., height)

Figure 2.2.1: Community information needs and Forest Theme products.

2.2.4.2 *Forest change*

Forest change maps are required by many countries to assess and combat deforestation and degradation of forests, to promote the regeneration and planting of forests and to support their rehabilitation, restoration and conservation. In countries such as Brazil and Australia, regional forest change maps have been produced on a regular basis since before the 1990s (e.g., INPE, 1998; SLATS, 2003). Increasingly, other countries are using remotely sensed data for assessing forest change, particularly where resources are limited. The ALOS PALSAR is anticipated to provide data that can be used to provide new maps of forest cover for the mid 2000s and repeat datasets for assessing change. Opportunities also exist for comparison with historical maps generated using JERS-1 SAR data.

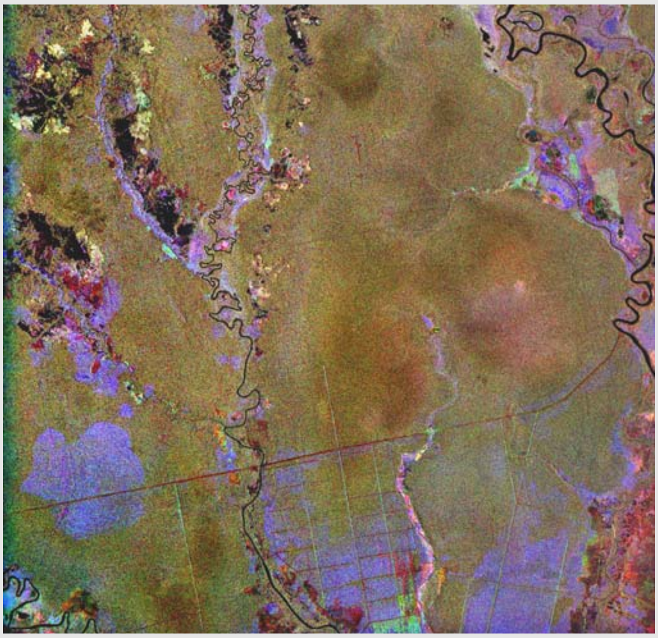
Product Box F-5 – Tropical Forest Change Monitoring

K&C product(s): (FCM1) Maps of change in tropical forest cover.

Intended use: These maps will contribute to global and regional land cover products and used for assessment of resources (e.g., carbon stocks) and as a baseline against which to assess change. The multi-temporal 250 m spatial resolution (including short wave infrared channels) of the available GLI data for South-East Asia will be particularly useful for refining maps of the extent of seasonal forests.

Prototype areas: Indonesia (Sumatra, Kalimantan, Irian Jaya) and Papua New Guinea

Input data: Multi-temporal PALSAR data, 50 m resolution



Deforestation in Central Kalimantan caused by excess peat swamp forest drainage is indicated by the three large blue areas intersected by canals in the bottom part of the image. Smaller blue areas along rivers relate to fire scars and shifting cultivation in secondary forest. JERS-1 SAR multi-temporal composite image (Red 940725; Green 970724; Blue 980716)

Indonesia has a large tropical rain forest area and possesses many unique ecosystems. However, deforestation rates are very high and this is partly the result of a lack of reliable maps and failing law enforcement. The continuous availability of up-to-date data, in a transparent way, will strongly support nature and environmental protection. Very recently developed medium resolution national monitoring systems based on SPOT VGT, MODIS and AVHRR will be integrated and extended with K&C PALSAR data. The higher resolution (50 m instead of 250 m for MODIS), the all-weather capability and several unique observation capabilities of L-band radar, such as forest flooding observation and secondary re-growth biomass estimation (in the low biomass range), are expected to bring near real-time tropical forest monitoring a step closer.

Product Developer:

Dirk Hoekman	Wageningen University, The Netherlands / Borneo Orangutan Salvation Foundation, Indonesia

2.2.4.3 *Biomass and biomass change*

Maps of forests biomass and biomass change are required by many countries for quantifying carbon stocks and changes, particularly those induced by ARD activities. The ALOS PALSAR can contribute to such assessments by providing maps of forest cover and temporal datasets for quantifying rates of regrowth and carbon stocks within low biomass forests. These data can also support existing initiatives, such as the Australian National Carbon Accounting System (NCAS; Jones *et al.*, 2004), which uses a combination of land cover maps as well as productivity models to estimate carbon fluxes associated with forest clearing and planting.

2.2.5 The role of ALOS PALSAR

The ALOS PALSAR is seen as a major vehicle for supporting carbon cycle science and international conventions aimed at reducing greenhouse gas emissions and conserving global biodiversity. Specifically, data from this sensor are expected to become integral components of a forest mapping and monitoring strategy. In contrast to the majority of global observing systems to date, ALOS PALSAR will be the first to provide multi-temporal wall-to-wall coverage at several L-band polarizations and the availability of JERS-1 SAR data from the mid 1990s will greatly enhance the capacity to map the extent of forest types and quantify changes therein (e.g., through forest ingrowth). The sensitivity of L-band SAR to changes in forest cover (e.g., deforestation and regeneration) and also forest biomass, particularly within regenerating forests, will also allow better estimates of the associated losses and gains of carbon. The provision of interferometric data will furthermore provide opportunities for retrieving forest height (and hence structure); information that can be used to improve estimates of biomass. Further benefits of using ALOS PALSAR for forest cover assessment are outlined in Table 2.2.A.

Table 2.2.A General benefits of using ALOS PALSAR data

Extensive areas covered by relatively fine spatial resolution mosaic products allowing consistent regional mapping of forest attributes.
Spatially continuous coverage of entire regions of interest, thereby facilitating wall-to-wall mapping.
Observations independent of cloud cover, haze and smoke rendering the data particularly valuable in regions chronically affected by cloud
Temporal stationarity assured at appropriate levels
Provision of temporal datasets for detection of changes in land cover and vegetation biomass and structure.
Better opportunities for interrogating the three-dimensional structure of vegetation through provision of dual polarisation data.
Geometric consistency allowing rapid comparison of the backscatter coefficient data on a regional basis.
Repeat observations at similar times of the year thereby reducing variability in the backscatter associated with changing environmental conditions and allowing detection of processes such as regrowth and vegetation thickening.
Provision of data comparable with the preceding JERS-1 SAR, thereby facilitating decadal assessment of forest cover change.
Provision of L-band data with sensitivity to biomass and structure

2.2.6 Building on the experience of the JERS-1 SAR

The Global Rain Forest Mapping (GRFM) project (Rosenqvist et al., 2000; De Grandi et al., 2000) provided dual season wall-to-wall JERS-1 SAR coverage for 1996 of the tropical regions between the latitudes of 10oN and 10oS and extending from 14°W and 42°E (January-March) and 8°E – 36°E (October-November). The spatial continuity and relatively high (100 m) spatial resolution of the resulting mosaics have allowed unique information on the characteristics of Central African and South American rainforests to be extracted (Mayaux et al., 2000; De Grandi et al., 2000), including the extent of swamp forests and inundated vegetation and areas of deforestation. The integration of data from other sensors (e.g., ERS-1/2 SAR and SPOT VEGETATION) data has greatly assisted these classifications. Mosaics also exist for South-East Asia and are being generated for Australia. The Global Boreal Forest Mapping (GBFM) project has also resulted in the generation of wall-to-wall mosaics of the boreal regions which have been utilized for mapping of ecosytems and habitats.

ALOS PALSAR mosaics will allow better interrogation of the forested landscape by providing data that are of dual polarization and acquired at a similar incidence angle as the JERS-1 SAR. Decadal changes in the extent and condition of forests can also be observed and quantified, through comparison with the JERS-1 SAR data, and the provision of up to two mosaics per year of the lifetime of the satellite is anticipated to lead to significant advances in global forest cover change assessment.

2.2.7 Components of the Forest Theme

To maximise the opportunities arising from the PALSAR data, a series of sub-components with associated products relating to land cover and forestry has been identified within the Science Plan. This Plan is based on sound scientific investigation undertaken by leading researchers working across a range of disciplines and focusing on a significant proportion of the World's forest biomes. These components relate to the generation of land cover maps (LCM), forest change maps (FCM) and Forest Biomass and Structural Maps (FBS).

2.2.7.1 Land cover maps (LCM)

For global mapping, a number of products have been generated previously from remote sensing data. Within the LCM theme, the integration of data from the ALOS PALSAR and also the ADEOS II Global Land Imager (GLI) data for enhanced land cover mapping will be addressed. The resulting maps will support carbon cycle science and conservation of biodiversity as well as assisting responses to international conventions. The benefits of using ALOS PALSAR data for land cover mapping are outlined in Table 2.2.B and the prototype data products anticipated are described in Product Boxes F-1 to F-3.

Table 2.2.B Specific benefits of ALOS PALSAR for Land Cover Mapping

Fine spatial resolution (100 m) allowing geometric features (e.g., logged areas, burn scars or forest fragments) to be resolved where coarser (e.g., > 1 km) spatial resolution data fail.
Provision of better information on the three-dimensional structure of vegetation and increased discrimination of land cover classes through the combination of L-band polarisations Stability in backscatter between dates allowing better detection of forest cover and discrimination from non-forested areas.
Unique sensitivity of L-band to the surface properties of some land cover classes (e.g., forests and forested wetlands) Opportunities for deriving textural and temporal measures that can be used for better mapping of forest types and non-forest.
Better detection of seasonally or permanently inundated forests (e.g., peat swamp forests, Amazonian igapó and varzea) due to exaggerated double bounce interactions between vegetation and the underlying surface.

2.2.7.2 Forest change mapping

Using multi-temporal ALOS PALSAR data and historical JERS-1 SAR data, maps showing areas of ARD as well as natural regeneration and forest management will be generated for biomes ranging from semi-arid woodlands to boreal forests. These maps will support the monitoring of the global forest resource and assist in the identification of hotspots of change. Routine monitoring of the extent of forests worldwide will be conducted to better quantify loses and gains in carbon and infer impacts on biodiversity. Worldwide, considerable effort has already been invested into operational monitoring of deforestation using Earth Observation techniques (e.g., the National Institute for Space Research (INPE's) PRODES), although generally using optical sensors. Within the K&C Initiative, the utility of multi-annual ALOS PALSAR time series for operational forest change monitoring at national and international levels will be assessed and integration into existing projects will be a key component. The benefits of using PALSAR for forest change mapping are outlined in Table 2.2.C and examples of data products are listed in Product Boxes F-4 to F-10.

Table 2.2.C Benefits of ALOS PALSAR for Forest Change Mapping

Reduced dependence upon optical sensors for operational monitoring of ARD activities because of all-weather and night time viewing capability
Better detection of forest fires through monitoring of changes in backscatter and/or coherence.
Better detection of changes in woody biomass due to dual polarisation L-band SAR sensitivity to biomass up to the level of saturation.
Regular provision of SAR data for fast and spatially complete updates of deforestation, thereby assisting law enforcement and monitoring of ARD activities in some regions.
The provision of an independent product for identifying forest and forest change that can supplement or complement the information generated using data from optical sensors.

2.2.7.3 Forest Biomass and Structure (FBS)

The quantification and mapping of forest biomass is critical for quantifying losses and gains of carbon associated with ARD activities, natural regeneration and forest management (Henry et al., 2002). Structural information (including forest height) is also a useful indicator of forest condition and habitat diversity and is therefore relevant for the assessment of biodiversity values.

Within the K&C Initiative, it is recognized the L-band SAR data are limited for quantifying biomass in forests that support a biomass < 50-100 Mg ha^{-1}, due largely to problems of signal saturation (Tansey *et al.*, 2004; Le Toan *et al.*, 2004). Such low biomass forests represent less than 37 % of the global resource (Imhoff, 1995) and the biomass of those in more productive biomes is unlikely to be quantified without prior research effort. However, many of the forests of interest in carbon accounting and for international conventions are typically those that are subject to change and include those that are regenerating and of low biomass. Data from the ALOS PALSAR will therefore represent an important contribution to mapping in low biomass areas, particularly given the sensitivity of L-band HV to biomass (Lucas *et al*., 2005a). As a research and development topic, the K&C Initiative also aims to investigate and compare a range of techniques for biomass retrieval from the ALOS PALSAR, either singularly or in combination with other sensors, with a view to recommending and applying the optimal techniques to forests in the tropics, subtropics, temperate and boreal regions. Benefits of the ALOS PALSAR for biomass and structural mapping are given in Table 2.2.D and examples of the potential role of data are given in Product Boxes 2.11 to 2.13.

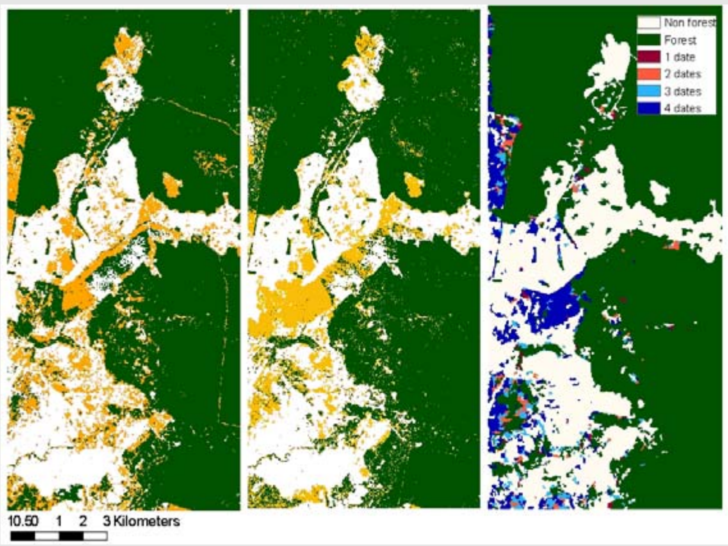
Product Box F-6 – Forest Structural Mapping

K&C product(s): (LCM4/FCM3) Data from both the JERS-1 SAR and ALOS PALSAR will be used to map the extent of forest structural types, including woody regrowth, across Queensland and the northern Territory, Australia and to assess relative decadal changes in the extent of forest structural types

Intended use: Support for quantifying carbon uptake and release associated with woody regrowth but also woody thickening and vegetation clearance. SAR data will be used in conjunction with Landsat sensor-derived Foliage Projected Cover (FPC) data at a regional level to facilitate improved mapping of forest structural types based on relative differences between the amount of leaf and wood material of differing sizes. Comparison of AIRSAR and JERS-1 L-band SAR with FPC data for 2000 and 1995 respectively has demonstrated capacity for mapping extensive stands of Brigalow (Acacia harpophylla) dominated regrowth in Queensland. These same approaches will be adopted at a regional level following validation and refinement of the mapping approach at selected sites across northern Australia.

Prototype areas: Queensland and the Northern Territory, Australia.

Input data: ALOS PALSAR Path Images, 50 m resolution



(Far left) Classification of woody regrowth (orange), forest (green) and non-forest (white) based on time-series comparison ofLandsat-derived land cover datasets.

(Centre) Comparative classification of woody regrowth (orange), forest (green) and non-forest (white) using AIRSAR L-band HH SAR and Landsat-ETM+ derived FPC

(Right) Areas of regrowth mapped using JERS-1 SAR L-band HH data acquired during 1994-1995 and Lansdat TM-derived FPC.

Product Developer:

Richard Lucas University of Wales, Aberystwyth, U.K.

Table 2.2.D Benefits of ALOS PALSAR for Biomass and Structural Mapping

Demonstrated potential for retrieving biomass from polarimetric and multi-incidence L-band SAR data for a range of forest environments (Le Toan *et al*., 1992; Dobson *et al*., 1992; Ranson *et al*., 1994, Imhoff, 1995; Luckman *et al*., 1997; Le Toan *et al*., 2004; Lucas *et al*., 2005a).
Particular sensitivity to biomass in the range 0 – 50 Mg ha^{-1}, thereby allowing the biomass of most regrowth forests to be quantified. Sensitivity to higher levels has been reported (Austin *et al*., 2002).
Capacity for retrieval of component (e.g., branch and trunk) biomass due to differential interaction of HH and HV polarisations with these structures (Saatchi and Moghaddam, 2000; Lucas *et al.,* 2004).
Sensitivity of SAR coherence to biomass, particularly in stable conditions (e.g., winter in boreal forest regions; Eriksson *et al*., 2003), although changes in wet snow cover during the melting period may drastically decrease coherence (Engdahl *et al*., 2004).

2.2.8 K&C Prototype Products

The development of products relating to land cover mapping (LCM), forest change mapping (FCM) and forest biomass and structure (FBS) encompasses the tropical, subtropical, temperate and boreal forest biomes. We will concurrently investigate techniques for classification across this range, identify those that are optimal and address consistency of definitions for mapped classes (e.g., land cover, biomass and forest change).

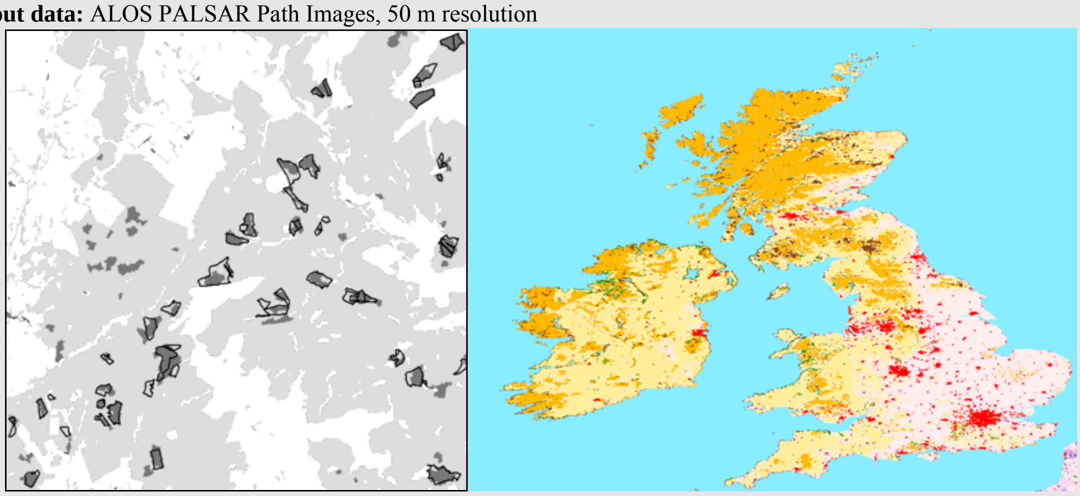
Product Box F-7 – Temperate Forest Extent and Management

K&C product(s): (LCM5/FCM4) Datasets derived from JERS-1 SAR and ALOS PALSAR will be used to map temperate forests and logging activities, and to examine decadal changes in forest cover.

Intended use: Support for traditional methods of forest management and monitoring; contribution to Kyoto monitoring of deforestation. Afforestation and reforestation should be demonstrable by combining the JERS and PALSAR datasets. Temperate forest development is not fast enough to be quantitatively measured with only a few years of radar data.

Prototype areas: England, Scotland and Wales.

Input data: ALOS PALSAR Path Images, 50 m resolution



(Left) Forest extent and clear-cuts detected by JERS in Kielder Forest, UK. Light grey: forest; dark grey: detected clear-cuts; white: non-forest.

(Right) Polygons denoting clear-cuts recorded in the UK Forestry Commission GIS (from Thiel et al. 2005).

Product Developer:

Shaun Quegan NERC Centre for Terrestrial Carbon Dynamics, University of Sheffield, U.K.

2.2.8.1 Tropical forests

A key component of the K&C Initiative is to provide timely information on the extent of forests and forest change within the tropical belt (Figure 2.2.2). The datasets provided will also be used to refine estimates of forest biomass below 50 Mg ha-1 (e.g., those in regeneration). The research will necessarily focus on well-known sites where methods for mapping forests, detecting land cover change and quantifying biomass and biomass change will be advanced.

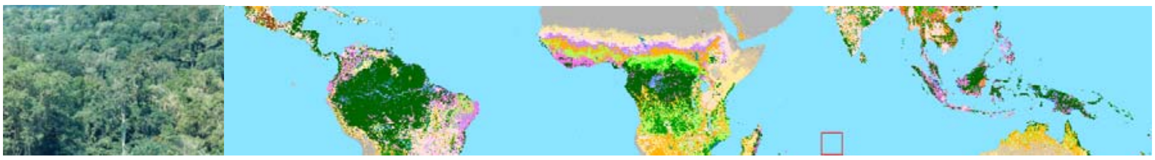


Figure 2.2.2. Tropical forests in Brazil (left) and the tropical forest belt (dark green; right)

For the Brazilian Amazon (Box 2.9), most deforestation has occurred along the border of the forest in the Arc of Deforestation but is now expanding into new areas such as Itaituba and Santarem. From the 1970s to the late 1990s, deforestation was attributed largely to the expansion of beef production and shifting cultivation, but from 1991 to 2001, the area under soybean expanded by 3.6 % per year increasing to 13.8 % from 2001. Selective logging has also become more prevalent. ALOS PALSAR will therefore be integrated with INPE's PRODES land cover change datasets to identify different types of forest (e.g., bamboo, stages of regeneration), areas of forest loss (including that associated with selective logging) and the extent of forest regeneration on abandoned agricultural land and along pipelines (e.g., the Urucu-Coari-Manaus Pipeline).

For insular South-East Asia, including Indonesia (Product Box F-5, F-8), ALOS PALSAR data will be used in conjunction with optical sensor data in a monitoring framework aimed at sustainable development and conservation of tropical forests and associated biodiversity. A key component of this research will be to evaluate the impacts of drainage on the peat swamps of Indonesia and the associated loss of carbon (Hoekman, 2003).

Product Box F-8 – Land Cover and Land Cover Change Mapping

K&C product(s): (LCM2/FCM1) Yearly updates of forest cover (and basic land cover types) and forest cover change (i.e. change histories) derived from PALSAR and optical imagery time series. The use of PALSAR will result in improved spatial and thematic detail and higher accuracy.

Intended use: Monitoring impacts of anthropogenic activities (deforestation, reforestation, afforestation, secondary re-growth cycles, fire damage, swamp forest drainage). Applications are diverse and include land use planning (e.g. suitable locations for oil palm plantations), forest management, nature conservation, law enforcement (illegal logging), providing transparency, fire prevention and carbon offset trading.

Prototype areas: Indonesia

Input data: ALOS PALSAR Path Images, 50 m resolution

Forest change in the province Jambi, Sumatra, Indonesia over the period 1999-2002. Shades of green (4 classes): forest and degraded forest; Shades of red (2 classes): forest loss; Shades of yellow (2 classes): secondary re-growth; White: non-forest. This product was generated by the existing prototype monitoring system and solely based on SPOT-VGT time series. Integration with K&C PALSAR time series is expected to result into more spatial detail and higher accuracy.

Product Developer:

Dirk Hoekman — Wageningen University, The Netherlands/ Borneo Orangutan Salvation Foundation, Indonesia

Table 2.2.E Major topics addressed for the tropical regions

Subtheme	Products	Prototype areas	Purpose
LCM1	Forest type classification	The Congo Basin	Conservation, Biodiversity
LCM2	Forest type classification	Insular SE Asia	Conservation, Biodiversity
LCM3	Land Cover classification	Regional SE Asia	Conservation, Biodiversity
FCM1	Annual extent of forest loss	Insular SE Asia	Carbon
FCM2	Annual extent of primary forest loss	Brazilian Amazonia	Carbon

Table 2.2.F K&C forest activities in the tropical region

Group	Leaders	Research Sites
LCM1	EC Joint Research Centre (JRC)	The Congo Basin
LCM2	Borneo Orangutan Survival Foundation (BOS)	Indonesia
LCM3	Chiba University	South-East Asia
FCM1	Borneo Orangutan Survival Foundation (BOS)	Indonesia
FCM2	Brazilian National Institute for Space Research (INPE)	Brazilian Amazonia

2.2.8.2 Open forests and woodlands of the tropics and subtropics.

In many sub-equatorial regions, extensive areas of open forests and woodlands exist, with the cerrado of South America, the savanna woodlands of Africa and the Eucalypt/Acacia-dominated forests of Australia being prime examples (Figure. 2.2.3).

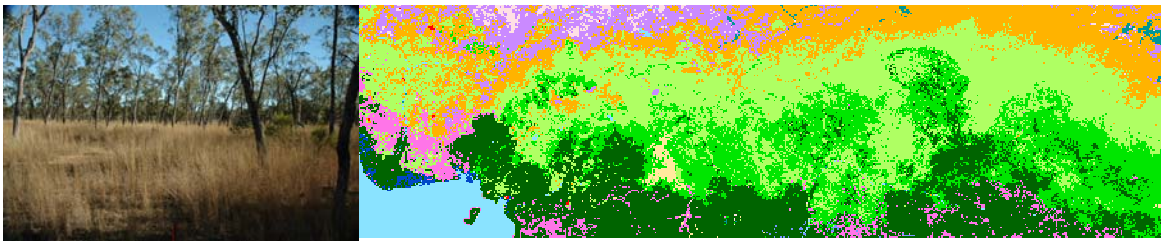


Figure 2.2.3: Eucalypt woodlands in Australia (left) and the distribution of savanna woodlands (pale green) in the Sahelian region of Africa (GLC 2000; Bartholomé et al., 2005)

These forests have received comparatively small attention compared to the tropical forests but they are being deforested at equivalent rates. In Australia, for example, the extensive clearing of vegetation in the late 1990s contributed over 20% of national emissions. Woody thickening, which is attributable to changing land management practices, is also occurring throughout this biome and the associated net uptake of carbon for the Australian continent was suggested to balance the losses resulting from recent clearing activity (Burrows et al., 2002). The biomass of most of these forests is generally below 80-100 Mg ha-1 (Lucas et al., 2005a) and hence below the normally observed saturation levels of L-band SAR (Le Toan et al., 2004). In Queensland and the Northern Territory, Australia, PALSAR will be used, in conjunction with optical sensor data, to refine maps of forest structural types, including woody regrowth (Lucas et al., 2005b) and estimates of woody biomass, and to establish changes in biomass over the sensor lifetime (Table 2.2.G). For the K&C Initiative, efforts will also focus on mapping the extent of woody regrowth and also woody thickening using a combination of Landsat-derived FPC and L-band SAR data. In the transition zones of the Congo Basin, ALOS PALSAR data will be used to provide revised maps of the forest cover and savannas.

Table 2.2.G Major topics addressed for the tropical and subtropical regions

Subtheme	**Products**	**Prototype areas**	**Purpose**
LCM3	Land cover map, savanna transition	Congo Basin	Conservation, Biodiversity
LCM4	Map of forest structural types and change	Northern Australia	Carbon

Table 2.2.H K&C forest activities in the tropical and subtropical regions

Group	**Leaders**	**Research Sites**
LCM3	EC Joint Research Centre (JRC)	Transition zones, Congo Basin
FCM3	Institute of Geography and Earth Sciences (IGES) The University of Wales, Aberystwyth	Central Queensland and vegetation transects in the Northern Territories, Australia

2.2.8.3 Temperate forests

Much of the world's temperate forests are distributed in the northern hemisphere although large areas are found also in Australia and South America (Figure 2.2.4). Many of these forests are intensively managed and a significant proportion falls under the ARD categories defined by the Kyoto Protocol.

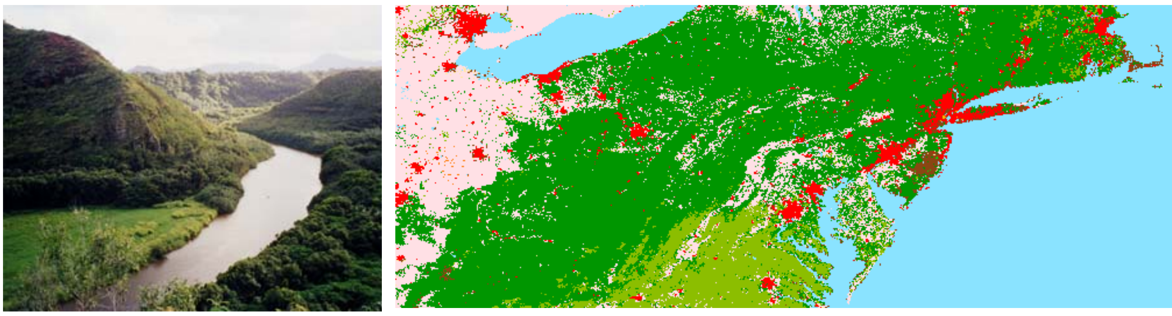


Figure 2.2.4 Temperate forests (left) and b) their distribution in north-east USA (green; right).

For selected temperate forests regions, ALOS PALSAR data will be used to identify and map changes in forest cover, particularly those resulting from forest management, and areas of ARD, as defined by the Kyoto Protocol. Most of the studies (Table 2.2.J) will focus on forests where management is largely through cycles of clear felling and planting and which cover several hectares in area. The identification of selectively logged areas will not be addressed because of the limitations of spatial resolution, although it is recognized that time-series of SAR backscatter coefficient or coherence data may be used to detect such activity (Quegan et al., 2001; Quegan and Yu, 2002). Distinctions will be made between usual cuttings, which are part of a rotation of a forest stand (e.g. commercial forestry), and those that represent an actual change in land use as only the latter is regarded as deforestation in Kyoto Reporting. The mapping of deforestation will also be undertaken within existing sampling frameworks where appropriate and time-series datasets will be vital.

Table 2.2.J Major topics addressed for the temperate regions

Subtheme	Products		
LCM4	Annual extent of forest loss	United Kingdom	Conservation, Biodiversity
LCM5	Biomass	France	Carbon

Table 2.2.K K&C forest activities in the tropical region

Group	Leaders	Research Sites
LCM4	University of Sheffield (SCCD)	Kielder Forest, U.K.
FCM2	Centre d'Etude Spatiales de la Biosphére (CESBIO)	Les Landes. France

2.2.8.4 Boreal forests

2.2.8.4.1 Siberia

The boreal forests (or taiga) are the most extensive of the terrestrial biomes and are located in the northern hemisphere, largely between 50° and 60°, with approximately 60-70% occurring in Siberia, whilst the remainder occurs in northern Europe and North America (Figure 2.2.4)

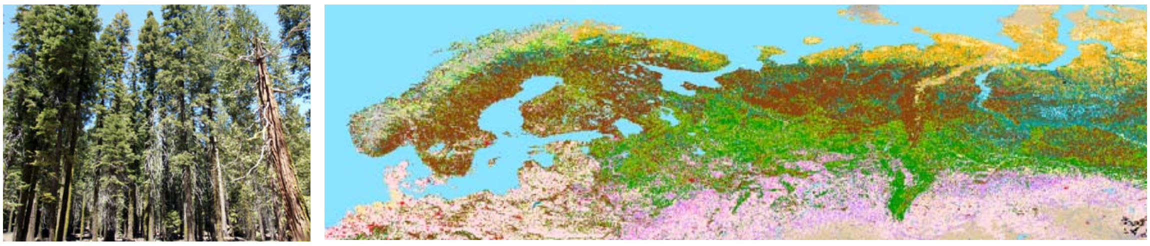


Figure 2.2.4 Coniferous forests of the boreal region (left) and the boreal forest zone (right).

Table 2.2.L Major topics addressed for the boreal regions

Subtheme	Products	Prototype areas	Purpose
LCM6	Land Cover Classification	Siberia	Conservation
FCM5	Land Cover Change	Siberia	Carbon, Conventions
FCM6	Disturbance maps	Siberia	Carbon, Conventions
FCM7	Forest Change maps	Sweden	Carbon, Conventions
BSM1	Statistical estimates of biomass	Sweden	Carbon, Conventions
BSM2	Forest biomass map	Siberia	Carbon, Conventions
BSM3	Pol_InSAR forest height maps	Globally	Carbon
BSM4	Forest biomass retrieval	Globally	Carbon

Data from ALOS PALSAR will be integrated into a number of existing projects, including SIBERIA II, to improve the mapping of land (including forest) cover. A key component will be the use of SAR coherence data for mapping biomass as previous studies using the JERS-1 SAR pairs acquired during frozen conditions have shown that the growing stock volume can be quantified, although saturation occurs at between 100 and 130 m2 ha (~ 50-65 Mg ha-1; Eriksson et al., 2003). As part of the ALOS acquisition plan, PALSAR data will be acquired over at least one full 44-day repeat cycle during the winter months and, in combination with data from ENVISAT C-band data and optical sensors, estimates of biomass and biomass change will be quantified for large areas of Siberia and North America.

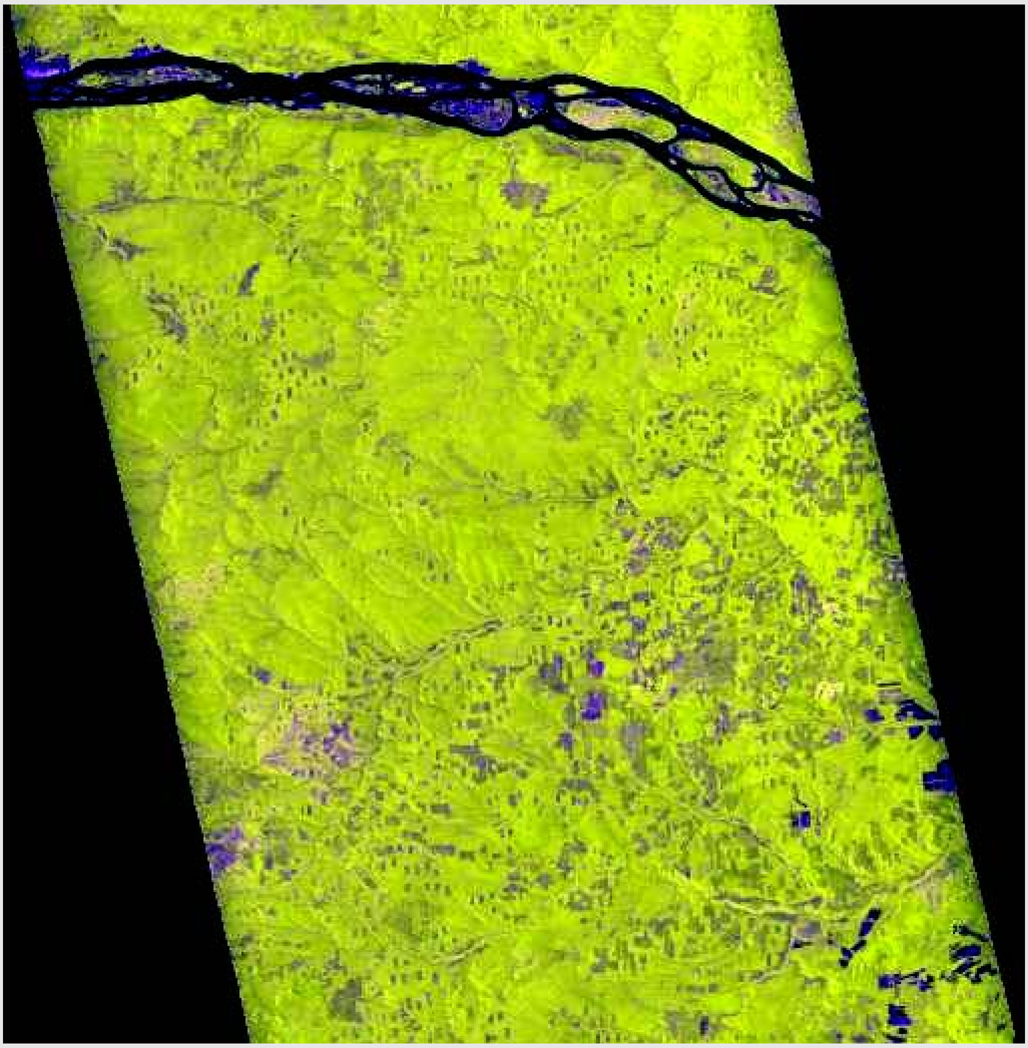
Product Box F-9 – Boreal Disturbance Mapping

K&C product: (FCM6) Maps of boreal forest disturbances

Intended use: High resolution maps of forest disturbances derived from ALOS PALSAR singe- and dual-polarization data will assist local forest authorities for forest cover changes monitoring and carbon balance computation. The maps will also be used for land cover and land cover change assessments both within the K&C Initiative and in other activities within the global change research community. The maps will also be integrated with land cover maps to improve regional products.

Prototype areas: Central Siberia (SIBERIA-II project area: N50°-65°; E80°-120°).

Input data: ALOS PALSAR strip data in Fine Beam mode (FBD, FBS), 50 m resolution



Forest areas heavily exploited for timber production in the Ust-Ilimsk region, Central Siberia, as seen by ALOS PALSAR K&C strip data. The picture is a false colour composite combining PALSAR backscatter in HH-polarization, in HV polarization and the HH/HV polarization ratio respectively in the red, green and blue channel. The dual-polarization data was acquired on 19 August 2007. Rectangular features in grey tones correspond to clear-cut areas, forests appear in green, the Angara river crossing the image along the East-West direction is clearly visible in the upper part of the image.

Product Developer:

Christiane Schmullius Friedrich-Schiller University Jena, Germany

Table 2.2.M K&C forest activities in the boreal regions

Group	Leaders	Research Sites
LCM6	Freidrich-Schiller University	Selected sites in Siberia
FCM5	Friedrich-Schiller University	Selected sites in Siberia
FCM6	Friedrich-Schiller University, CESBIO	Selected sites in Siberia
FCM7	SLU	Sweden
BSM1	SLU	Sweden
BSM2	CESBIO	Selected sites in Siberia
BSM3	JPL, HUT, MPI, U. Mass.	60 global test sites.
BSM4	CESBIO	Global

2.2.8.4.2 Northern Europe

Detection of changes in boreal forest cover and statistical estimates of deforestation and above ground biomass

Today optical satellite data are used operationally for detection of clear-felled areas by forest authorities in Europe. One of these authorities is the Swedish Forest Agency, which collect nationwide coverage of SPOT satellite images every year used for control of cutting permits. Using optical SPOT satellite data, results show that almost all clear-felled areas could be correctly classified by performing change detection. A limitation in using optical satellite data is, however, that the quality of the images largely depends on the weather conditions and the solar illumination. In contrast to optical satellite data, synthetic aperture radar (SAR) offers the possibility to acquire images independent of cloud cover and sunlight. A large number of SAR images can then be acquired throughout a year offering the potential for improved monitoring. Hence, a particular benefit using SAR is the provision of images in areas where the cloud cover is frequent or persistent. The objectives of the present project are to quantify the ability to detect and map forest changes and to evaluate forest variable estimation in boreal forests using ALOS PALSAR data together with field data from three established local study areas and two larger prototype areas in Sweden. The forestry applications include detection and mapping of clear-felled areas and estimation of above ground forest stem volume (biomass). The objectives will be achieved by developing methodology and algorithms and by performing a scientific evaluation for each of the applications. The methodology developed for detection and mapping of clear-felled areas will be carried out at the local study areas Remningstorp and Brattåker to be applied in a second stage at the prototype areas, which will be the counties of Västra Götaland and Västerbotten (see Figure 1). For forest stem volume estimation, the accuracy assessment will be carried out at the local study areas. To date, detection of clear-felled areas and estimation of forest stem volume has been performed at the local study area Remningstorp using PALSAR data. The preparations to perform similar studies at the local study area of Brattåker have started as well as the mosaicking of PALSAR data over the two prototype areas. In addition, meteorological data are planned to be obtained from meteorological monitoring stations in the vicinity of the local study areas (run by the Swedish Meteorological and Hydrological Institute).

Local study and prototype areas

The local study areas used in the project are well characterized and distributed from the south to the north of Sweden to cover different forest types. The differences in weather conditions, topography and forest properties are important to show that the methods developed are robust for operational use. Remningstorp is located in the south of Sweden (58°30' N, 13°40' E). The estate covers about 1,200 ha of forest land. Prevailing tree species are Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birch (*Betula* spp.). The topography is fairly flat with a ground elevation between 120 m and 145 m above sea level. The Brattåker study area is located in the north of Sweden (64º14' N, 19º40' E) and is a forest research area managed by a Swedish forest company, with about 6,000 ha of mainly coniferous forests. The prevailing tree species are Norway spruce and Scots pine, but some deciduous tree species, such as birch (*Betula pubescens*), is also present. The ground elevation varies from 160 m to 400 m above sea level. The Vidsel study area is located in northern Sweden (66º24' N, 19º18' E). The study area is within a nature reserve and is therefore not affected by silvicultural activities such as clear-fellings and thinnings. The dominant tree species is Scots pine and the forest land has low production in comparison to the other two local study areas. The ground elevation varies from about 400 m to 800 m above sea level. The prototype area Västra Götaland is 2.5 million ha and contains 1.3 million ha of forest land. The dominating tree species are Norway spruce (53%), Scots pine (27%) and birch (12%). Västerbotten is the second largest county in Sweden and measures 5.5 million ha. In the 3.2 million ha of forest land, the main tree species are Scots pine (45%), Norway spruce (37%) and birch (14%).

Product Box F-10 – Detection of changes in boreal forest cover and statistical estimates of deforestation and above ground biomass

K&C product(s): (FCM7/BSM1) Multi-temporal ALOS PALSAR images will be used to generate maps of forest cover and forest cover change for Sweden. From these data, a statistical framework for assessing the extent of clear-felled and deforested areas as well as providing estimates of above ground biomass and associated levels of accuracy will be generated.

Intended use: Annual detection and delineation of clear-fellings in Sweden by the Swedish Forest Agency. A particular benefit will be the provision of observations where cloud cover is persistent. The deforestation maps will be used to support Sweden's reporting to the Kyoto Protocol.

Prototype areas: The counties of Västra Götaland and Västerbotten, Sweden.

Input data: ALOS PALSAR Path Images, 50 m resolution

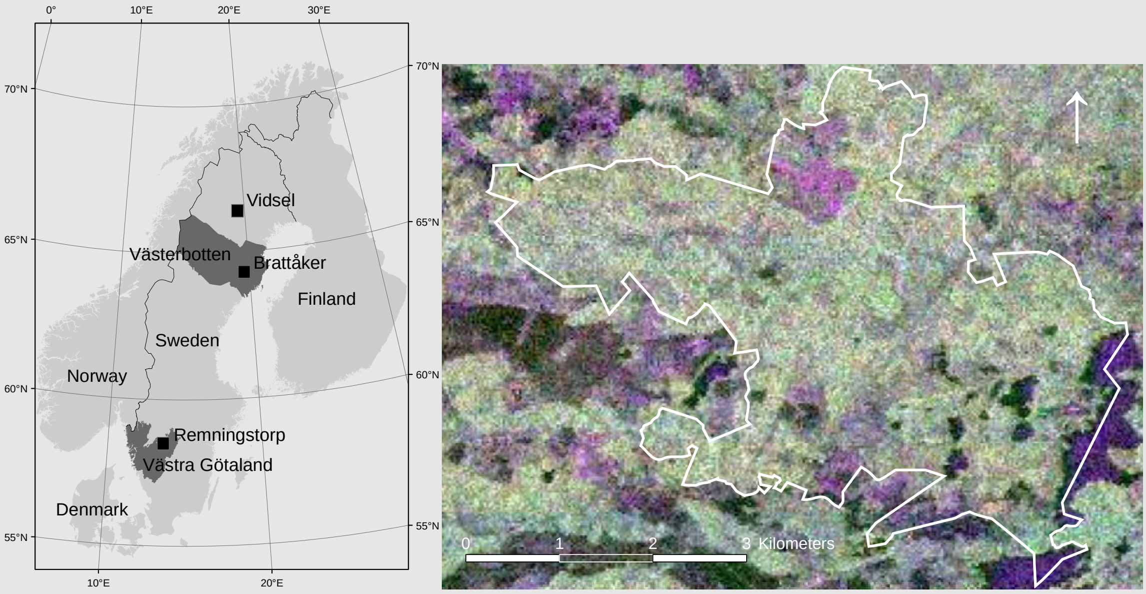


Figure 1. Local study areas used for methodology development shown as black squares and the planned prototype areas for clear-cut mapping shown in dark grey (left image). A color composite image from ALOS PALSAR PLR 21.5° with HH- (red), HV- (green), and VV-polarization (blue) (right image). The image was acquired on 2006-12-04 and is displayed with a pixel spacing of 25 m (© JAXA/METI 2006). The boundary of the Remningstorp test site is shown in white.

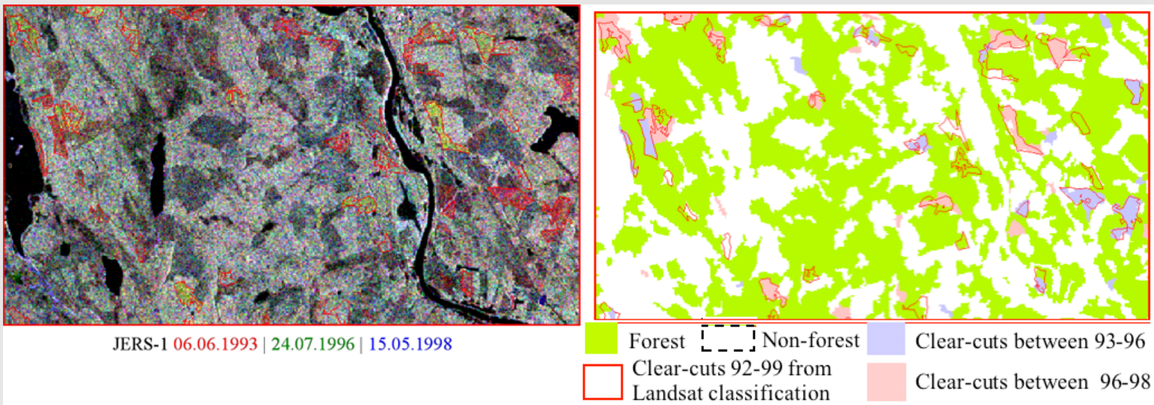


Figure 2. Clear-cut mapping in Sweden using multi-temporal JERS-1 SAR data (from ESA study "Demonstration of L-band capabilities using JERS data", ESTEC Contract 18311/04/NL/CB).

Product Developer:

Johan Fransson	Swedish University of Agricultural Sciences, Sweden
Mattias Magnusson	Swedish University of Agricultural Sciences, Sweden
Leif Eriksson	Chalmers University of Technology, Sweden
Klas Folkesson	Chalmers University of Technology, Sweden
Lars Ulander	Chalmers University of Technology, Sweden
Maurizio Santoro	GAMMA Remote Sensing AG, Switzerland

Collaborators:

Anders Persson	Swedish Forest Agency, Sweden

Detection of clear-felled areas

A controlled experiment has been performed to investigate the ability to detect clear-felled areas using PALSAR FBS data acquired before and after change in forest cover. The experiment consisted of eight mature Norway spruce dominated areas (subject to final harvesting), each with a size of about 1.5 ha, located at the local study area of Remningstorp. Four of the areas were clear-felled and the remaining areas were left untreated for reference. In total, seven images acquired between 2006-06-08 and 2007-02-15 were used in the analysis. The preliminary results clearly show that the clear-felled areas could be separated from the reference areas. The drop in backscattering coefficient between the reference and the clear-felled areas was found to be on average 2.1 dB, when comparing images acquired during the winter season. Here, the analysis was based on three images, where two images were acquired when temperatures were below zero and another one under unfrozen conditions. By excluding the image acquired at unfrozen conditions the difference changed from 2.1 dB to 2.7 dB. The latter result indicates that better separation could be obtained by only using images acquired at frozen winter conditions. In a previous study at Remningstorp, JERS-1 data have been used for change detection, where promising results were reported for clear-cut mapping (see Figure 2). Compared to the SAR on JERS-1, PALSAR has a phased array antenna that allows electronic steering of the off-nadir angle. Moreover, PALSAR has the capacity of simultaneously acquiring multi-polarization and polarimetric data that should further improve the possibilities for accurate detection of clear-felled areas. Differences in the orbit type between summer and winter prevented the creation of a similar difference image for the PALSAR FBS data. In conclusion, the preliminary results support that ALOS PALSAR data can potentially be used for large-scale mapping of changes in forest cover.

Forest stem volume estimation

For forest stem volume estimation ALOS PALSAR images acquired at 18 different dates and in three different modes have been analyzed and evaluated at the local study area of Remningstorp. In total, seven FBS images (the same images as were used for detection of clear-felled areas), four FBD images (with HH- and HV-polarization) acquired between 2007-06-16 and 2007-08-18 and seven PLR images (with HH-, HV-, VH- and VV-polarization) acquired between 2006-05-20 and 2006-12-04 were used in the analysis. Altogether, 56 forest stands with stem volume in the range of 45-650 m^3 ha^{-1} (average 325 m^3 ha^{-1}) were included in the investigation. In the analysis, the total number of stands was divided into two datasets, one for establishing the relation between the backscattering coefficient and stem volume (retrieved from field data) using non-linear regression analysis. The developed model was then inverted and applied on the other dataset in order to evaluate the accuracy of stem volume estimation. The two datasets were created by dividing the total number of stands into two datasets by sorting according to ascending stem volume and assigning every second stand to each dataset. The estimation accuracy of stem volume at stand level was calculated in terms of root mean square error (RMSE). For the best case investigated, an RMSE of 30% (corresponding to 97 m^3 ha^{-1}) was obtained for one of the single polarization images (FBS) acquired in the winter season (2007-01-29). In this case no saturation was observed for high stem volumes. The corresponding RMSEs for the dual (FBD) and quad (PLR) polarization images were between 62% and 81%. Here, the large variation in RMSE could probably be related to differences in season and weather conditions. The better results for single polarization might be explained by particularly favorable weather conditions at image acquisition. Further investigations need to be done in order to verify the cause.

Possible extension

The present project focuses on the development and evaluation of methods for large-scale mapping of changes through detection of clear-felled areas in boreal forests. If this project is successful for the prototype areas Västra Götaland and Västerbotten, the goal is to use the developed methodology for the whole of Sweden.

2.2.8.5 SAR interferometry and interferometric polarimetry for forest height retrieval

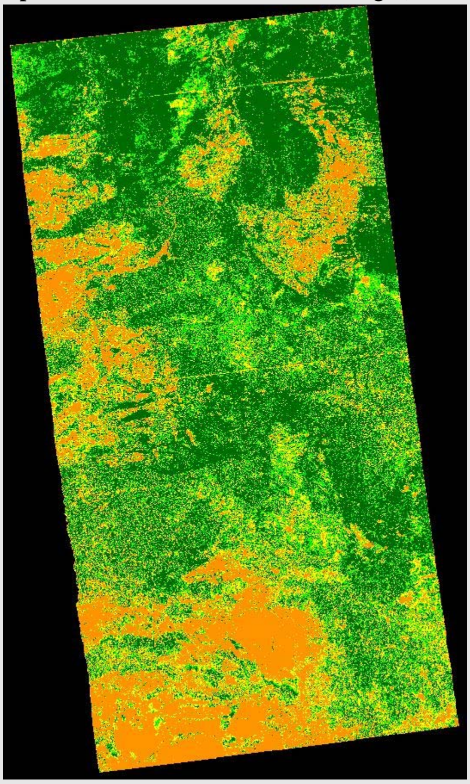
The structure of vegetation is a key ecosystem parameter for biomass stock successions and growth dynamics. Forest height, along with diameter at breast height (dbh), basal area and tree species, is one of the key parameters in forestry for estimating attributes such as biomass and structural diversity. It plays an essential role in dynamic forest development modelling and forest inventory and becomes very important in a remote sensing context as it allows the development of unsaturated biomass estimation schemes from SAR data. Being a standard parameter in forest inventories, tree height is hard to be measured on the ground with typical estimation errors on the order of 10%, yet increasing with forest height and density. Forest height mapping with conventional techniques is very circumstantial and becomes impossible in not accessible remote areas – so that remote sensing becomes the only affordable solution.

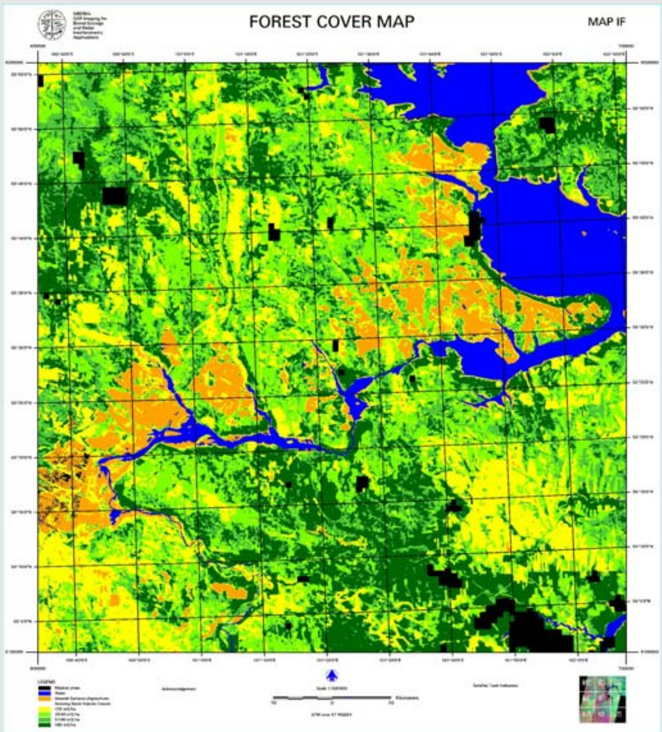
Polarimetric Synthetic Aperture Radar (SAR) Interferometry (Pol-InSAR) is a recently developed radar remote sensing technique, based on the coherent combination of radar polarimetry (Pol-SAR) and SAR interferometry (InSAR) which is substantially more sensitive to structural parameters of volume scatterers (e.g. forest) than conventional interferometry or polarimetry alone. This sensitivity is essential for the development of model-based quantitative parameter estimation methodologies.

Product Box F-11 – Boreal Forest Cover and Biomass

K&C product(s): (LCM6/BSM2) Regional forest and forest biomass classes

Intended use: Assessment of carbon budgets in boreal forests (carbon sources and sinks related to post-disturbance forests), in conjunction with in situ and climatic data and ecological modelling.
Prototype areas: Central Siberia (SIBERIA-II project area: N50°-78°; E80°-120°).
Input data: ALOS PALSAR Path Images, 50 m resolution, multi-temporal ScanSAR





(Left) Regional forest and biomass map of central Siberia derived from multitemporal ENVISAT ASAR WideSwath data.The example shows strip map(400 km x 900 km) including broad classes (water,bogs-agriculture, open forest and forest biomass classes of 10-30, 30-50 and >50 t /ha. ALOS PALSAR present a unique opportunity to have consistent mosaic of forest and forest biomass over boreal forests (Eurasia, America) which play a key role in the carbon budget as regards the effects of climate change. (Right) Forest and forest biomass map at 50 m resolution using 1997-1998 ERS interferometry and JERS data. (Siberia-I project).

Product Developer:

Thuy Le Toan CESBIO, France

In the last years, quantitative model based estimation of forest parameters has been demonstrated from airborne repeat pass fully polarimetric interferometry, indicating the potential of this new technology to estimate forest parameters. The estimation approach is based on the inversion of a two layer Random-Volume-over-Ground scattering model that relates physical forest parameters to the interferometric observables at different polarisations. Using the interferometric coherence and phase information at three different (optimal) polarisations it is possible to estimate forest height, average forest extinction, and underlying topography without the need of any a priori information.

According to the results published in the literature forest height estimation can be performed from single-baseline fully polarimetric SAR data with an accuracy of about 20% widely independent from terrain conditions. In addition, the integration of tree height (estimated using InSAR) and SAR backscatter may further improve the performance with respect to vegetation biomass estimation while other studies (e.g., Treuhaft, 1996 & 2002) have shown the benefits of integrating data from optical sensors.

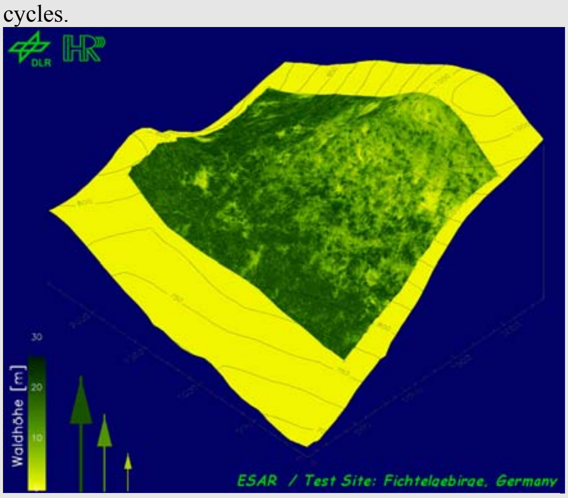
Product Box F-12 – Pol-InSAR and InSAR Forest Height Retrieval

K&C product(s): (BSM3) Forest Height maps (R/D activity)

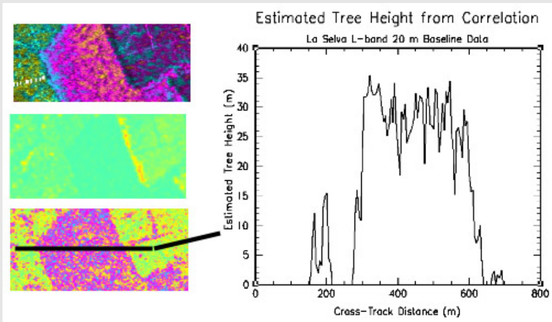
Intended use: To demonstrate the use of Pol-InSAR from ALOS for retrieval of canopy height from a wide range of forest structural types, ranging from tropical rainforest to low open woodlands. Such information will be used for forest inventory but also for better quantifying the above ground biomass of vegetation. Tree height can be retrieved using the complex coherence of interferometric measurements. Contributing sources to the observed coherence are temporal, geometric, thermal and volumetric sources of decorrelation. The calibrated estimate of the combined volumetric and temporal decorrelation (achieved after removal of geometric and thermal sources of decorrelation) is the fundamental observable for height retrieval but also for the development of land cover classification algorithms in much the same way as calibrated backscatter. As part of the K&C Initiative ALOS PALSAR InSAR component, the calibrated correlation data product will be provided over the quad-pol and dual-pol interferometry intensive studs across a range of forest environments and countries.

Prototype areas: 60 study sites worldwide (see Table 2.2.P-Q).

Input data: Repeat-pass Polarimetric ALOS PALSAR data (SLC), acquired during consecutive (46-days) satellite cycles.



Forest height map derived from Pol-InSAR data inversion superimposed to ground topography terrain mode. Test site Fichtelgebirge, Germany. (Courtesy of DLR).



DEM and interferometric coherence maps (left) using two baselines (1.2 and 20 m) for estimating vegetation height. The calibrated volumetric correlation for a 20m baseline (right) is used for estimating the vegetation height

Product Developers:

Alberto Moreira	German Aerospace Center, Germany
Paul Siqueira	University of Massachusetts, USA
Collaborators:	
Shane Claude	National Board of Forestry, Sweden
Reiner Zimmermann	University of Bonn, Germany
Richard Lucas	University of Wales Aberystwyth, U.K.
Martti Hallikainen	Helsinki University of Technology, Finland

Table 2.2.N InSAR tropical and subtropical study sites

Belize	Belize	**Malaysia**	Sabah
Brazil	Caixuana	**Peru**	Alto Mayo
	Manaus		Cocha Cashu
	Tapajos		Rio_Manu
	Carajas	**Tanzania**	Kilimanjiaro-Machame
	Mata Atlantica		Kilimanjiaro-Lerongo
	Jau		South Pare Mts.-Shengen
Indonesia	Samboja Lestari	**Australia**	Cape Tribulation
	Sungai Wain		Kakadu NP
	Mawas		Injune, Queensland

ALOS PALSAR will be the first satellite sensor to provide Pol-InSAR data at L-band worldwide. Using repeat-pass fully polarimetric interferometric SAR data acquired by the ALOS PALSAR sensor - during its early CAL-VAL phase – model based estimation of forest height will be performed (Cloude and Papathanassiou, 1998; Papathanassiou and Cloude, 2001; Cloude and Papathanassiou, 2003). Towards higher estimation accuracy, the observation vector is planned to be extended including dual-pol single-baseline data sets acquired on the latter ALOS PALSAR operation phase. The model-based approach using Pol-InSAR will be investigated for a diversity of forest types of varying homogeneity and supporting a range of biomass levels (Tables 2.2.N-P-Q). The InSAR product developers are listed in Table 2.2.R.

The height estimates will correspond to upper canopy height as for example given by the "Forest Height Hundert (H100)" parameter, defined as the average height of the 100 tallest trees per hectare. However, the diversity of forest ecosystems makes the definition of a standard forest height difficult. It will be finally part of the validation process to provide the definition of the estimated height in a forest ecological context for the different forest types worldwide.

In addition to the forest height measures derived using the aforementioned Pol-InSAR algorithm, there remains too the opportunity and need to provide the intermediate data product of interferometric correlation, calibrated to remove geometric and thermal noise effects. The remaining contributions to the calibrated correlation are the volumetric and temporal sources of decorrelation, which can in turn be used for further algorithm development for estimating vegetation height and land cover classification. These data products will be provided for the regions specified in Tables 2.2.N-P-Q.

Table 2.2.P InSAR temperate study sites

Australia	Victoria Broken-Ovens	**USA**	U. Michigan Biol. Stat
	SE Queensland	**Germany**	Bayerischer Wald
	Hunter		Oberpfaffenhofen
	Blue Mountains		Leinefelde
	Bateman's Bay		Wetzstein
	Tumbarumba		Schneeberg
New Zealand	Kaingaroa	**Spain**	Corridor
	Turangi	**UK**	Glen Affric
	Balmoral	**Japan**	Naeba
	Craigieburn		

Table 2.2.Q InSAR boreal study sites

Alaska	Alectra-CPCW	**Finland**	Helsinki
	Alectra-BCEF	**Russia**	Zotino –East
Canada	Boreas-North		Zotino West
	Boreas-South		Tver

Table 2.2.R Product developers for the InSAR.

Group	**Leaders**	**Collaborators**
Pol-InSAR Forest Height	German Aerospace Center (DLR)	Jet Propulsion Laboratory (JPL) University of Adelaide (UoA) Helsinki Institute of Technology (HUT) University of Massachusetts (Umass) The University of Wales (UoW) Max-Planck Institute (MPI)
InSAR Calibrated Coherence Maps	University of Massachusetts (Umass)	Jet Propulsion Laboratory (JPL) German Aerospace Center (DLR)

2.2.9 Coordination Activity for biomass and structure

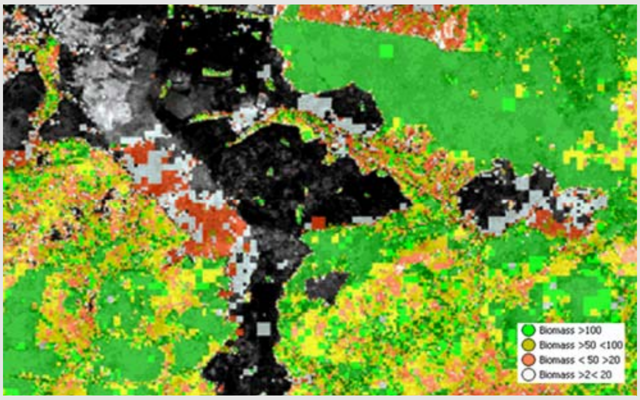
Using ALOS PALSAR data, a number of approaches to the mapping of biomass and structure (e.g., empirical relationships with backscatter or coherence or links with Pol-InSAR-derived height maps) will be considered. Under the K&C Initiative, a coordination activity has been proposed whereby results from all of the Prototype areas are evaluated collectively such that the optimal method for retrieving biomass as well as other structural attributes will be determined, either for global or selected biomes (e.g., the boreal forests). Through this activity, significant advances in regional to global mapping of vegetation biomass are anticipated.

Product Box F-13 – Algorithms for Above-Ground Biomass Retrieval

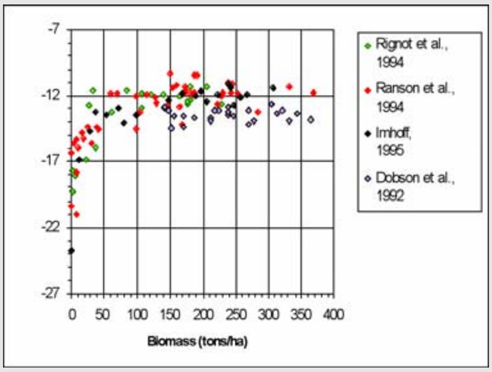
K&C product(s): (BSM4)

- Algorithms for biomass mapping using dual pol and multitemporal PALSAR fine beam data.
- Algorithms using repeat pass interferometry in Northern latitudes
- Algorithms for regional forest mapping with PALSAR ScanSAR.
- Synthesis of the algorithms
- Biomass maps at representative study regions.

Intended use: For forests worldwide, a relatively consistent relationship exists between above ground biomass and L-band cross polarisation backscatter over boreal (Rignot *et al*, 1994), tropical (Imhoff, 1995, Luckman *et al*., 1997) and temperate forests (Le Toan *et al*., 1992, Dobson *et al*., 1992, Ranson *et al*.,1994). The data dispersion observed is attributable mainly to system calibration, the large incidence angle range inherent in airborne systems and also variations in forest structure. Sensitivity to biomass is observed up to about 50 Mg ha^{-1}, with a dynamic range of about 5-6 dB. (Le Toan *et al*., 2004). Other approaches to retrieving and mapping biomass have also been developed, including the use of coherence and interferometric height data. This K&C activity involved comparison of various techniques for the retrieval of biomass, for a range of biomes, and determination of the optimal approach.
The resulting maps will be used for of the assessment of carbon budgets in forests (carbon sources and sinks, in particular related to post-disturbance forests), in conjunction with in situ and climatic data and ecological modelling.
Prototype areas: Individual sites in Siberia, Sweden, Finland (boreal forest), UK (temperate forest), Vietnam, Brazil (tropical forest), Australia (subtrropic) will be used to develop PALSAR processing algorithms based on full resolution PALSAR data.
Input data: Multi-temporal dual-polarisation PALSAR data.



Forest biomass map generated for open forest and woodlands in Queensland, Australia, through epirical relationships established with AIRSAR L-band HV data.



Empirical relationships established between L-band SAR backscatter and biomass for a range of forest types (Le Toan et al., 2004).

Product Developers:

Thuy Le Toan (lead)	CESBIO, France
Collaborators:	
Shaun Quegan	University of Sheffield, U.K.
Christiane Schmullius	Friedrich-Schiller University Jena, Germany
Richard Lucas	University of Wales Aberystwyth, U.K.
Martti Hallikainen	Helsinki University of Technology, Finland

2.2.10 Technical issues

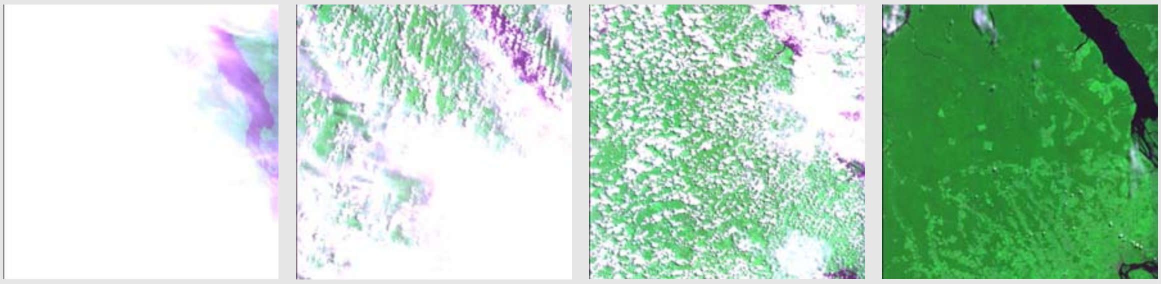
Although ALOS PALSAR is expected to provide a wide range of information relating to land cover, forest change and biomass/structure, a number of limitations are acknowledged. Although an advantage of SAR data for detecting land cover change is that data takes can be timed accurately due to their all-weather capability, thereby optimizing conditions for detecting changes in land cover, ground conditions (e.g.

moisture in the soil and on vegetation following rainfall; Lucas et al., 2004) can impact on the SAR response and repetitive data acquisitions therefore need to be planned (e.g., for a specific month or season) such that seasonal bias in the time series is avoided (Rosenqvist et al. 2003).

Product Box F-14 – Law Enforcement Deforestation Assessment

K&C product(s): Indicative documents of new deforestation areas for a fast response by the Brazilian Government law enforcement. The Palsar ALOS data will assist the identification of very recent deforestation activities and also where the cloud cover is a limiting factor for the use of optical remote sensing as a resource to support field activities.
Intended use: The ScanSAR images will be used to detect changes in the original forest in order to provide alerts to law enforcement activities. For each new change, the polygon area will be used to generate a deforestation detection individualized document. This will be used to complement the DETER system produced by INPE and used by IBAMA. The polygons indicated by ScanSAR data will be checked after, when the clouds are not affecting the optical imagery from the China-Brazil Earth Resources Satellite (CBERS).
Prototype areas: The Brazilian Amazon and the Brazilian Atlantic Forest
Input data: ScanSAR trip mode 100m resolution and ALOS PALSAR Path Images 50 m resolution

CBERS 2 – Path165 and Row 103



17/01/2006 10/03/2006 05/04/2006 22/06/2006

LANDSAT 19/08/2005 RADAR R99B 07/04/2006 CBERS 22/06/2006

A individualized deforestation detection on the Brazilian Legal Amazonian is time limited by the cloud cover presence when only optical sensors are used. The above images show the time when the optical images (Landsat or CBERS) can be used to detect new deforestation polygons and how the SAR images (L band airborne SAR image acquired by SIPAM R99 aircraft) can reduce the time detection after the occurrence of deforestation.

Product Developer:

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Dr. Flavio Jorge Ponzoni	National Institute of Space Research – INPE, Brazil.
Dr. Guilherme H. B. de Miranda	Federal Police Department - DPF, Brazil.
Francisco Artur C. Gonçalves	Federal Police Department - DPF, Brazil.

Active fires are not possible to detect with microwave systems as the smoke plumes are invisible to the radar. Burn scars however, may be detected in cases where the fire has caused substantial change to the structure of the forest (Antikidis et al. 1997) and can be detected from SAR for several years after the burn. In many forested areas, observations by optical sensors are limited by the presence of clouds and haze. All weather and night time viewing therefore represent particular advantages of the ALOS PALSAR.

Although providing considerable potential for mapping land cover change and biomass, PALSAR is limited by spatial resolution, the provision of data in only two polarizations and observations at incidence angles that may not be optimal. The spatial resolution of the mosaics proposed for many regions is considered limited for the observation of biomass in fragmented habitats or where heterogeneity is inherent. The saturation of the L-band backscatter at relatively low levels of biomass is also expected to be a limitation in the mapping of higher biomass forests such as those across Amazonia but may be more appropriate for savanna woodlands such as the cerrado in South America and the open forests and woodlands of Southern Africa and Australia.

2.2.11 Acknowledgements

This chapter was authored Richard Lucas, with input from Ake Rosenqvist.

2.3 The Wetlands Theme

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2.3.1 Introduction

Wetlands are important environments due to their unique role in the transformation of biogeochemical material and as wildlife habitats for innumerous species. The organic carbon productivity of these environments is the largest on earth, on average 1300 g of dry weight m^{-2} yr^{-1}. The association of both the high productivity and the physical-chemical characteristics of wetland ecosystems favours the production and flux of high rates of methane, a "greenhouse" gas, to the atmosphere. Wetlands contribute approximately 33% of the total methane annually emitted to the atmosphere. The action of humans in transforming these ecosystems into agriculture fields and other uses is likely contributing to the carbon imbalance in the atmosphere (Schlesinger, 1997). Given the global importance of wetland ecosystems, it is surprising that at the present not even the global extent of wetlands is well known (Matthews et al., 2000, Melack et al., 2000). Estimates of global distribution of wetlands vary from 5.3×10^{12} m^2 (Matthews and Fung, 1987) to 8.6×10^{12} m^2 (6% of the land surface of the world), of which 56% are in tropical and subtropical regions (Mitsch and Gosselink, 1993). These numbers are based on crude estimates worldwide.

Wetlands encompass systems ranging from inundated forests, swamps, lakes, points, rivers, saltmarshes and mangroves. They play a key role in ecosystem dynamics and environmental flows and are fundamental to the livelihoods and economies of populations. However, in almost all regions, significant damage has been inflicted on wetlands to the extent that many have been totally destroyed whilst other exist in a condition that is far from pristine. Many of the threats to wetlands result from population increases and the associated pollution, irrigation and land reclamation, salinisation, diversion of flows and clearance of wetland vegetation for agriculture and aquaculture, loss of biodiversity, encroaching urbanisation, weed invasion and climate change. These pressures have as a consequence (i) environmental changes such as decrease in wetland area, loss of habitat and diversity, interruption of fauna migration, increase in erosion processes, decrease in biomass and nutrient export, and (ii) cultural changes such as loss of jobs and fishery, among others. As the term "wetlands" covers a wide range of systems, the threats to these are equally diverse and often difficult to quantify particularly given the inherent variability in diurnal, seasonal and interannual water inundation.

The loss of wetlands is of major concern for a number of key reasons. Firstly, wetlands contain and cycle a significant amount of carbon and play a key role in the global carbon cycle, not least because of the large turnover of methane within these systems. Indeed, it is estimated that natural wetland sources emit about 20% of the methane entering the atmosphere each year (Fung *et al.* 1991) and they are responsible for a significant proportion (>1 %) of biogeochemical fluxes between the land surface, the atmosphere, and hydrologic systems (Sahagian & Melack 1998). They also play a particularly important role in processing methane and carbon dioxide, as well as in sequestering carbon. The loss of vegetation from wetlands (e.g., mangroves and flooded forests) therefore also leads to releases of carbon to the atmosphere. Wetlands are also extremely diverse in terms of their fauna and flora and are an integral component of many coastal but also inland ecosystems. They also function as breeding grounds for many species of vertebrates and invertebrates that play a key role in food chains but also in the economics of many communities. Wetlands also contribute significantly to the protection of coastal areas from erosion and storm damage.

2.3.2 Problem statement

The increasing recognition of the importance of wetland ecosystems to both the economic and environmental health of human communities has stimulated renewed interest in mapping the distribution of wetlands around the world (Darras et al. 1999, Finlayson et al. 1999). However, the broad definition of what constitutes a wetland and disagreements on definition have led to a wide range of mapping techniques and inconsistencies in their application. Indeed, one of the major handicaps facing wetland inventory is the lack of a universally understood classification system to describe wetland environments (Finlayson and van der Valk, 1995). As a result, estimates of wetland extent vary widely. The establishment of globally acceptable definitions of wetlands and wetland types is therefore fundamental if appropriate mapping techniques are to be implemented. Furthermore, the provision of a spatially consistent data source to which the mapping techniques can be applied is also fundamental. Remote sensing does provide such a dataset but even so, standardising procedures for mapping regionally, let alone globally, remains a significant challenge.

Remote sensing data have, for some time, provided opportunities for identifying, describing and mapping the distribution of wetlands at a range of scales from local to global and certainly recent advances in remote sensing instruments and spatial analysis techniques have only increased their potential (Phinn et al. 1999; Sahagian and Melack, 1996). However, few studies have been undertaken with the explicit aim of presenting the spatial distribution of wetlands on a global or even continental scale. Further, the methods by which wetland environments are identified or classified from existing global datasets vary considerably (Sahagian and Melack 1996, Darras et al. 1999) and the results of mapping are often inconsistent. For example, Lowry & Finlayson (2004) analysed ten different datasets representing wetland distribution across northern Australian and found considerable differences in the areal estimates of wetland extent. Mapping has proved difficult in many areas because of the lack of temporally and spatially consistent datasets and also because many areas are inaccessible, remote or temporally dynamic. The accuracy of many approaches has also rarely been tested (Sahagian and Melack, 1996) with many assessments relating to the specific environments or objectives and an overall indication of the areal extent of all wetlands types in these areas is often not provided.

The variable nature of wetlands is such that their role in biogeochemical cycles is poorly understood in many regions. For example, large uncertainties exist in the estimates of methane production and this reflects in part the lack of accurate estimates of total wetland area and of characteristics such as the redox state that regulate emission rates. Since methane is a greenhouse gas with 4-35 times the global warming potential of carbon dioxide (Houghton et al. 1992), improved knowledge of wetland extent and properties remain a high priority because of the suggested impacts of changing climate on methane emissions (Potter, 1997; Richey et al. 2002) and the contribution of outgassing (e.g., from rivers and wetlands in the humid tropics) to carbon emissions (Richey et al. 2002). Remote sensing observations might therefore play a key role in refining assessments of emissions, particularly given the frequency of acquisition and wide area of coverage.

2.3.3 Carbon, Conservation and Conventions

The Wetlands Theme of the K&C Initiative focuses on the provision of remote sensing datasets that can be used to assist the global mapping and monitoring of wetlands and identifying and quantifying the threats to which these are exposed. Specifically, it aims to develop a suite of products which may be used to improve the understanding of carbon cycle science, assist the implementation of conservation and management strategies and support national and international obligations to multi-national conventions.

2.3.3.1 Carbon

In terms of carbon cycles, the boreal wetlands, tropical peat swamps, paddy rice and mangroves are of particular relevance. Specifically, boreal wetlands and tropical peat swamps contain significant amount of carbon which may be released as a result of climate change and anthropogenic activities (e.g., deforestation and disturbance) (e.g. Weller et al. 1993; Shaver et al. 1990; Chapin et al. 1995). Significant amounts of methane are released through rice cultivation practices. Clearance of mangroves in recent years has also led to a loss of carbon which is significant (but poorly recognised) as these forests often contain more carbon per unit area than tropical forests.

The most basic requirement for modelling regional to global methane or carbon dioxide emissions from wetlands is a digital wetlands map with appropriate scale and classification scheme. While several global wetlands datasets exist (e.g., Matthews & Fung ,1987; Lehner & Döll, 2004) these datasets possess a number of limitations, reflecting the methods / processes used to generate these datasets. Specifically, these have been compiled from a variety of map sources generated using a range of methods and to varying degrees of accuracy. Many of these sources use class names (e.g., swamp, fen and bog) that may overlap or vary in meaning and seasonal and permanent wetlands may not be distinguished. For these reasons, such classification schemes cannot usually be directly incorporated into physical models. Working groups of the IGBP (Sahagian & Melack 1998) and the European Commission (European Commission, 1996) have addressed this concern and concluded that there is a need to characterize wetlands in terms of their functional characteristics rather than based on traditional regional terminology or on criteria such as phytosociology.

Once mapped, there is a need to understand the fluxes of gases from wetlands. Key to the K&C Initiative is that the functioning of wetlands cannot be considered separately from their hydrodynamics (Mitsch, 0000). Specifically, methane production within anoxic soil layers is controlled by water table depth (are you sure about this? The Jaú study showed that the CH4 emissions were more closely related to the water flow, or turbulence, than the depth) which changes depending upon the type of wetland and also factors such as the level of seasonal inundation of river floodplains (to depths of more than 10 m), changes in groundwater level resulting from runoff or direct precipitation, thawing of surface and soils water or lowering of water levels due to evapotranspiration or diversion for irrigation. Some of these processes can be observed and measured directly from satellite sensors whilst others can be modelled using a combination of remote sensing, field and climatic data. The timing of satellite sensor acquisitions must, however, consider the frequency and periods associated with flooding, groundwater dynamics and freeze-thaw cycles for particular regions and wetland types. Information on the Net Primary Production (NPP) of wetlands is also required for carbon modelling, particularly as this provides the organic matter necessary for anaerobic degradation and methane production.

Small lakes are also more significant in accumulating carbon than larger lakes (Pajunen, 2000). Carbon accumulation in lakes can therefore be estimated on the basis of size although other factors are related to ecosystem setting control carbon in lakes including topography, hydrology, geology and temperature. However, these interactions are not well understood.

2.3.3.2 Conservation

Wetland ecosystems fulfil a vital role in maintaining the ecological and economic health of many regions. As well as providing a wealth of resources or services, including products used for fuel, construction, fishing, paper, medicines, textiles and leather, and food items, these ecosystems also influence ground water recharge, retain nutrients and sediment and stabilise shorelines (Saenger, 1994; Blasco et al., 1996; Finlayson & D'Cruz 2005). Mangrove ecosystems, for example, are an integrated component of the coastal environment in that they are important contributors to primary production (Bandaranayake, 1994), act as nursery sites for many commercial fish and crustacean species (O'Grady et al. 1996) and are a seasonal base for many migratory species (Finlayson & D'Cruz 2005). The Sumatra tsunami disaster in December 2004 furthermore made evident the importance of mangroves as protective buffers to reduce the impacts from natural hazards. From a conservation perspective, wetland habitats contain many of the world's most endangered species of fauna and flora, many of which are unique, or endemic to specific wetland habitats.

Long-term preservation and sustainable use of these resources is therefore critical for the economic and social well being of current and future generations. Key requirements include the establishment of regional and temporal datasets of wetland extent and condition which incorporate an understanding of the inundation dynamics of an area and spatially quantifiable measures of both anthropogenic and natural pressures and threats to wetland communities.

2.3.3.3 Multi-national Conventions

In an effort to slow the deterioration and loss of wetlands, a number of international agreements have been established. Central to these is the Ramsar Convention. Signed in 1971 in Ramsar, Iran, this Convention became an intergovernmental treaty which provided the framework for national action and international co-operation on wetlands and the use of their resources. The mission of the Convention is the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world (Ramsar COP8, 2002). The Ramsar Convention relies on voluntary actions by the signatory parties - thereby making it less controversial than the Kyoto Protocol - and it aims to halt and reverse the global trends of wetland degradation and destruction through the dissemination of information, involvement of local communities and establishment of sustainable management plans. There are presently 141 Contracting Parties to the Convention, with 1387 wetland sites (totalling 122.7 million hectares) designated for inclusion in the Ramsar List of Wetlands of International Importance. The Convention on Biological Diversity (CBD) was also initiated as a result of the United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro in1992, and now has some 175 signatory parties. The CBD has multiple objectives which relate to conserving biodiversity, and ensuring the sustainable and equitable use of the components of biodiversity. These are addressed in collaborative initiatives with other institutions and conventions, which target specific environments such as the Ramsar convention on wetlands.

The Ramsar Convention
Ramsar Contracting Parties have been encouraged to undertake better and more efficient wetland inventory, establish and maintain national inventories (http://www.ramsar.org/key_res_vii.20e.htm) and identify all sites that meet Ramsar selection criteria (http://www.ramsar.org/key_criteria.htm). Such information may be used to support national programs and reporting requirements for other international treaties, such as the CBD, and those relating to migratory species, world heritage and climate change. At the same time, regional strategies, such as the Asia-Pacific migratory waterbird conservation strategy (http://ngo.asiapac.net/wetlands/ mwbird.htm) are dependent on inventory information for planning and prioritizing management and monitoring actions.

To assist Contracting Parties undertake their inventory activities, the 8th Conference of Contracting Parties (“CoP8”) of the Ramsar Convention in Spain (2002) adopted a resolution outlining a framework for wetland inventory (http://www.ramsar.org/key_res_viii_06_e.htm). This framework was intended to address inadequacies in wetland inventory that had been identified in several international fora (Finlayson & Davidson, 2001; Finlayson et al. 1999, 2001).

As an official International Organisation Partner of the Convention, Wetlands International acts as a specialist advisor and provider of data on wetland inventory and also manages (under contract) the Convention’s Ramsar Sites Database. Increasingly, Wetlands International has recognised the importance of remote sensing technology in this context, particularly as adequate access to up-to-date spatial and temporal information about wetlands and their catchment basins is seen as a fundamental component in the development of wetland management plans for conservation and sustainable utilisation. While not explicitly addressed by the Ramsar Convention, the contribution of both natural and anthropogenic wetlands (e.g. rice paddies) to the burden of atmospheric methane is widely recognised and provides further evidence of a link between wetland dynamics and carbon fluxes. As the emissions from wetlands are poorly quantified over regional to global scales, improved understanding of wetland inundation dynamics is of high priority in the climate change context.

The CBD and its relevance to wetlands
Major issues identified by the CBD include conserving the richness of inland water biodiversity and reducing the risks many species face, ensuring that the goods and services they deliver will be maintained. A significant concern is that inland water ecosystems (wetlands) experience greater changes or modifications induced by anthropogenic activity than marine or terrestrial systems, and consequently are amongst the most threatened ecosystem types of all. Potential threats to these ecosystems and their associated biological resources include habitat loss and degradation, physical alteration, water withdrawal, overexploitation, pollution and the introduction of invasive alien species. Some 41 % of the world’s population lives in river basins under water stress, whilst more than 20 % of the world’s 10,000 freshwater fish species have become extinct, threatened or endangered in recent decades. A significant issue identified by the CBD was finding an effective way to communicate and illustrate the extent, health and character of different ecosystems. At the same time, the adoption by the international community of the far-reaching goal of significantly reducing the rate of biodiversity loss by the year 2010, clearly underlined the need for effective and well coordinated monitoring mechanisms, complemented by innovative assessment tools to facilitate the generation of consistent and comprehensive evaluation of progress towards the achievement of this target. The type of information required to address these issues include baseline information on the temporal and spatial characteristics of threatened wetland habitats; understanding the composition, extent and health of a wetland community; identifying areas of greatest change; and identification of potential threats / pressures to the environment

2.3.4 Community requirements

The requirement for wetland information range from the reporting requirements of signatory members of international conventions such as the Ramsar convention, to the requirements of government and non-government organisations involved in the conservation of wetlands and study of the carbon cycle. The key requirements of these organisations, and the products that will be developed to address these issues are summarised in Figure 2.3.1.

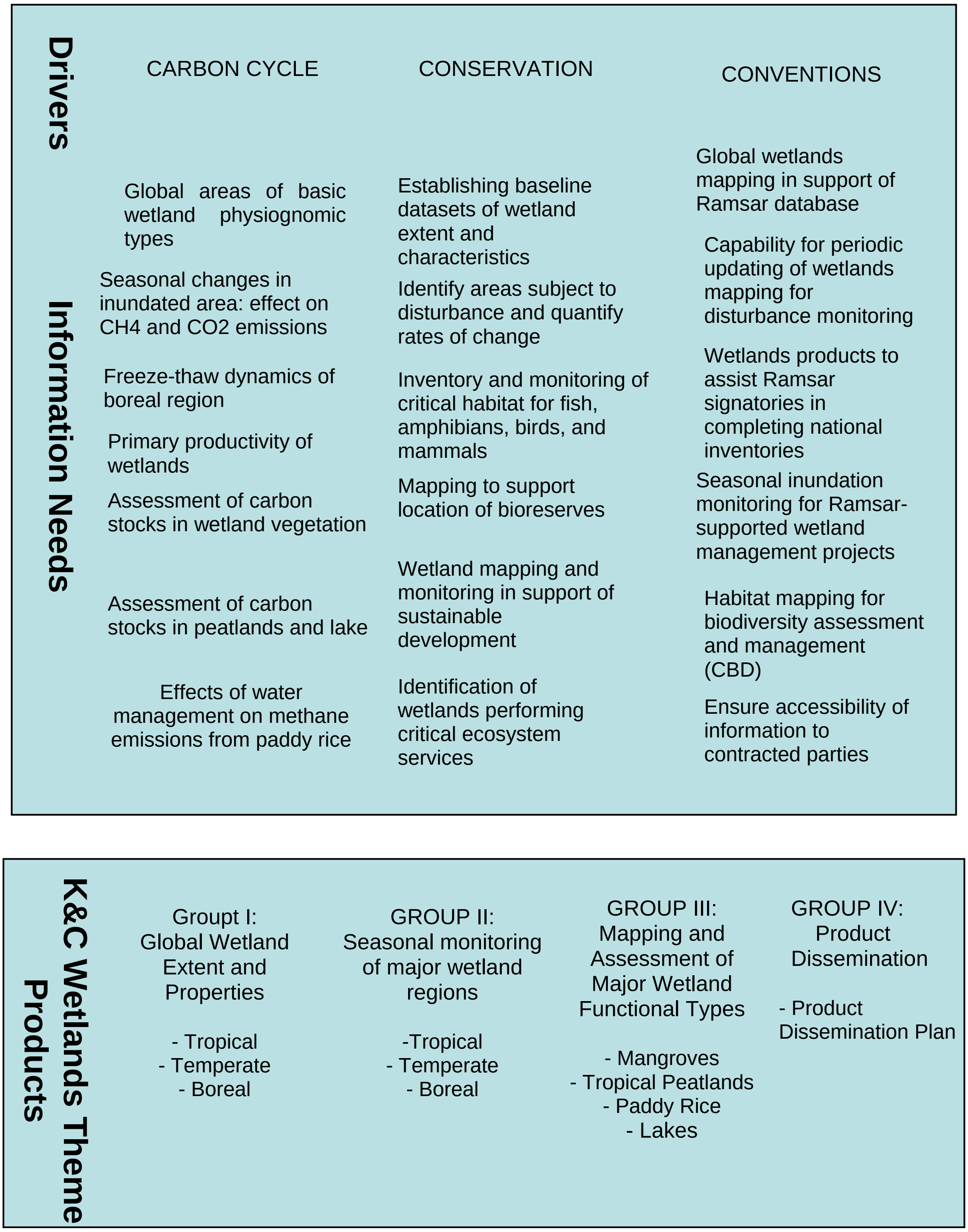


Figure 2.3.1: Community information needs and Wetland Theme products.

2.3.4.1 *Wetland extent*

As the locations and extents of wetlands in the world, are not all recorded, the identification and delineation of wetland areas, and incorporation of this information into the Ramsar Global Wetlands Data Base, maintained by Wetlands International, is a important contribution area of the K&C.

2.3.4.2 *Mapping of seasonal inundation*

Mapping of spatio-temporal characteristics of inundation phenomena in global wetlands is not only an issue for CH_4 modelling, but also from an environmental aspect as seasonal information about hydrological dynamics is at present generally not available and would be highly valued to support the development of sustainable wetland management plans (Rosenqvist et al. 2003). Scales of interest range from semi-continental (e.g. Amazon /Congo river basins), regional (e.g. the Pantanal) to local (Ramsar-designated sites).

2.3.4.3 Detection and spatial quantification of disturbances

The ability to identify and monitor both human-induced and natural disturbances is vitally important to both Ramsar-designated and other wetlands. Specifically, the ability to detect and monitor change in biomass and area of specific wetland habitats, such as peat swamp forests, or mangroves is a key reporting requirement for signatories to international conventions such as the CBD, and to wetland managers generally.

2.3.4.4 Habitat mapping

A key concern of the CBD is the identification and protection of habitats which are at risk from anthropogenic and natural pressures. For example, mangrove habitats are experiencing increasing pressures from both natural and anthropogenic sources, despite comparatively little being known about them. The extent of both direct anthropogenic disturbance and also the influence of climate change on mangroves across the tropics and subtropics have proved difficult to quantify due to the lack of regional and temporal baseline datasets of mangroves extent and condition against which to assess change.

2.3.5 Significance of the ALOS PALSAR

2.3.5.1 Radar remote sensing of wetlands

Over the past few decades, numerous studies have established the theoretical basis and practical application of mapping wetland extent, vegetation structure, and inundation status using active microwave SAR systems (reviews in Hess et al. 1990, Costa et al. 2002, Costa, 2004). All SAR instruments share the advantages of day-night operability (as active sensors), cloud penetration, and the ability to calibrate without performing atmospheric corrections. The longer L-band (~23.5 cm) SAR wavelength, and to a certain extent also C-band (~5.5 cm), have the ability to penetrate vegetation canopies to various degrees depending on vegetation density and height, dielectric constant (primarily a function of water content), and SAR incidence angle. Variations in backscattering allow discrimination among non-vegetated areas (very low to low returns), herbaceous vegetation (low to moderate returns), and forest (moderate to high returns), and to some degree among different forest structures and regrowth stages. Where water is present beneath a forest canopy, enhanced returns caused by specular "double bounce" scattering between water surface and tree trunks makes it possible to distinguish between flooded and non-flooded forest.

Research using the dual-frequency SIR-C instrument (Hess et al. 1995) and various airborne SAR systems showed that 1) combinations of C-, L-, and P-bands, which are sensitive to differently sized canopy elements, are optimal for distinguishing among various types of vegetation types and structures; 2) HH-polarized mode is optimal for detecting sub-canopy flooding; 3) L-band, HV-polarized mode minimizes errors in classifying wind-roughened open water, and aids in forest structure discrimination; 4) L-HH detects sub-canopy flooding beneath nearly all types of wetland forests, while C-HH does not penetrate denser wetland forests (Costa, 2004); 5) although accuracy of vegetation classification is reduced using a single frequency, (only C, only L) (Costa et al. 1998)the disadvantages are largely obviated by using a suitable time series in which temporal changes in flooding and vegetation phenology allow discrimination between classes.

In summary, L-band SAR systems are the single best option for fine spatial -resolution remote sensing of wetland extent and characteristics over large regions because they operate regardless of cloud cover, can distinguish basic vegetation structure, and provide superior canopy penetration and water surface discrimination relative to C-band. A dual-polarisation L-band system such as ALOS PALSAR will furthermore provide improved accuracy in discriminating between rough water surfaces and bare ground, and improved mapping of vegetation structural characteristics.

The capabilities of L-band SAR for wetlands mapping were clearly demonstrated by several Global Rain Forest Mapping studies, in which JERS-1 100 m mosaics and higher-resolution time series were used to map inundation periodicity for the Jaú River basin in Brazil (Rosenqvist *et al.* 2002), floodplain habitats of the central (Hess *et al.* 2003) and lower (Costa, 2004) Amazon basin and wetland extent for the lowland Amazon. The digital maps produced in these studies were combined with modeling and with other datasets to estimate methane emissions from wetlands for the Jaú basin (Rosenqvist *et al.* 2002), for the central Amazon, and for the entire lowland Amazon (Melack *et al.* 2004), as well as to estimate carbon dioxide outgassing from Amazonian rivers (Richey *et al.* 2000). Studies such as these were made possible by the GRFM project's systematic observation strategy, which allowed many high-resolution acquisitions to be mosaicked into a temporally consistent dataset.

2.3.5.2 The role of PALSAR for wetlands mapping and monitoring

As shown in Table 2.3.A L-band SAR capabilities (based on JERS-1 L-HH studies) are good to very good for wetland delineation, inundation mapping, and discrimination between woody and non-woody vegetation. Discrimination among wetland forest types would be poor to fair using a single ALOS coverage, but fair to good using multiple dates, since forest types are correlated with inundation periodicity. For estimation of biomass of herbaceous or woody wetland stands, ALOS capabilities would be poor to fair unless combined with complementary C-band sensors such as Radarsat or Envisat. Costa et al. (2002) demonstrated this approach for estimating above-water biomass of aquatic macrophytes at an Amazon floodplain site, finding that an index derived from combining JERS-1 and Radarsat data improved the correlation with field-measured biomass and plant height, and increased the saturation point for biomass. The combination of JERS-1 with ERS-1/2 data was found to be valuable for mapping woody and herbaceous wetland vegetation in central Africa (Mayaux et al. 2002) and in coastal Gabon (Simard et al. 2002).

Table 2.3.A Strengths & weaknesses of JERS-1 LHH-band SAR for wetlands applications

Mapping task	With single-date JERS-1	With multi-date JERS-1	With complementary data
Wetland delineation	good	very good	Excellent with SRTM
Inundation mapping	very good	very good	Excellent with river stage data
Woody vs. non-woody	good	very good	Excellent with CHH or optical
Wetland forest types	poor to fair	fair to good	Very good with CHH or optical
Aquatic macrophyte biomass	poor	fair	Good with CHH or CVV
Wetland forest biomass	poor	fair	
Suspended sediments (white water vs. black water)	no capability	no capability	-

PALSAR data acquired in 100 m resolution ScanSAR mode, with 46-days' repetition during a period of one full year, as outlined in the PALSAR Observation Strategy will be required to characterise the variations associated with forest inundation and rice cultivation. The PALSAR Observation Strategy plan for repetitive annual global fine resolution observations at 20 metres resolution will be utilised for identification and spatial assessment of changes, complemented with optical data when feasible. As the attributes that characterise wetlands differ widely, the usefulness of PALSAR and optical data has to be evaluated on a case-by-case basis. Also the 100 metre JERS-1 SAR continental-scale mosaics generated within the Global Forest Mapping project will be used to support the inventory. For these reasons, the theme proposes the use of a) JERS-1 SAR data from the mid 1990s and b) ALOS PALSAR data from the mid 2000s in conjunction with optical sensor data for characterising and regionally mapping tropical and subtropical mangroves over two time periods (1990s and mid 2000s) and subsequently comparing and quantifying changes in their extent and condition.

2.3.6 Building on the experiences of JERS-1 SAR

Evident from the discussion above, JERS-1 SAR constitutes a pathfinder mission for wetlands applications development using spaceborne Synthetic Aperture Radar. In particular, the Global Rain Forest and Boreal Forest Mapping (GRFM/GBFM) projects demonstrated not only the unique capacity of L-band SAR data as such (sensitivity to vegetation structure and below-canopy inundation) to support wetlands applications, but also the fundamental importance of acquiring data in a systematic manner, over regional scales with maintained spatial and temporal consistency, and with adequate temporal repetition frequency. Although systematic, regional-scale acquisitions only were implemented for some selected regions and during a limited period of the JERS-1 mission, the data sets collected within the GRFM/GBFM framework constitute the main legacy of JERS-1, which has resulted in the establishment of the global-scale, mission-long observation plan implemented for ALOS .

It should thus be acknowledged that the applications planned for ALOS PALSAR within the K&C Initiative - described below in the sections to follow - to a great extent build on the experiences gained from the JERS-1 SAR mission in general, and within the GRFM and GBFM projects in particular.

2.3.7 Components of the Wetlands Theme

As identified in the preceding sections, carbon cycle, conservation, and multi-national conventions have a range of information requirements relating to wetland inventory, mapping and monitoring. To address these issues and requirements, four key components of the wetlands theme have been identified, through which product development will be undertaken using ALOS PALSAR data (alone, or in conjunction with complementary datasets (Table 2.3.B).

The first component of the wetlands theme (global wetland extent and properties) aims to produce high-resolution (50 m) mapping products aimed at providing the first accurate global inventory of wetlands. The second component of the wetland theme focuses on the seasonality of wetland habitats, both flooding extent and freeze-thaw state, primarily through the development of regional products based on 100 m ScanSAR mosaics. The third component also focuses on products that are regional in scope, such as wetlands that have particular significance in terms of carbon cycle studies, conservation, and/or multinational conventions. Finally, the fourth component of the theme, a program for the dissemination of the products, is designed to maximize the dissemination and use of the wetlands theme products by scientists, managers, and agencies.

Table 2.3.B – Components and Products of the Wetlands theme

Component	Product
I. Global wetland extent and properties	1. Tropical wetland extent and properties
	2. Boreal wetland extent and properties
II. Seasonal monitoring of major wetland regions	3. Seasonal monitoring of major tropical/sub-tropical wetlands
	4. Wetland extent, flood inundation patterns and vegetation change in the Greater Mekong River Basin
	5. Seasonal dynamics of the Pantanal ecosystem
	6. Seasonal monitoring of major boreal wetlands
III. Mapping and monitoring of key wetland types	7. Global mangrove extent and properties
	8. Tropical peat lands extent and properties
	9. Pan-Asian mapping and monitoring of rice paddies
	10. Global lakes census
IV. Product dissemination	11. Wetlands product dissemination plan

2.3.8 K&C Prototype Products

2.3.8.1 Global wetland extent and properties

Tropical wetland extent and properties

It is estimated that wetlands emit about 20% of the methane entering the atmosphere each year, but large uncertainties exist owing to lack of accurate estimates of total wetland area. Since the global warming potential of methane as a greenhouse gas is 4-35 times that of carbon dioxide, improved knowledge of wetland extent and properties are a high priority in order to understand the global methane budget and to predict how changes in climate could alter net emissions of methane. Further, wetland ecosystems in tropical regions of the world are experiencing increasing pressures and disturbances, including clearance and conversion, rising sea levels, extreme climate events, and sediment deposition. These degrade ecosystem services provided by these ecosystem such as erosion control, fisheries conservation, and wildlife habitat. However, many tropical regions lack regional baseline information on the temporal extent, distribution and character of wetlands which could be used to conserve and protect wetlands.

Boreal wetland extent and properties

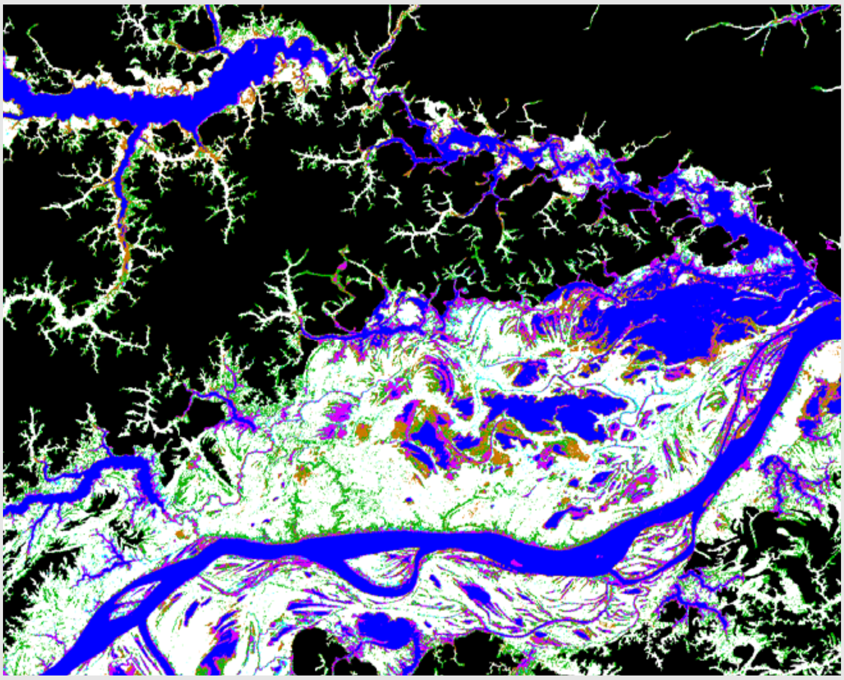
High latitude wetlands are important methane source areas, while upland forests in the taiga are important methane-consuming sinks. Vegetation biomass stocks and their changes are one of the major indicators of carbon sequestration and/or release. Regional-scale, accurate quantification of vegetation biomass, and wetland type and extent at resolution scales of 1 km or better is key in improving estimates of the carbon budget. Spatially explicit biomass estimates also enable verifiability and transparency in resulting improvements to the carbon budget.

Product Box W-1 – Tropical wetland extent and properties

K&C product(s): Maps of wetland extent.

Intended use: To document, monitor, and understand the regional biodiversity, habitats, vegetation and ecological dynamics of the wetland in South America.

Prototype areas: The Amazon, Orinoco, and Paraná basins, northern Australia.
Input data: PALSAR dual-polarisation path images, 50 m resolution.



Classified high-water JERS-1 mosaic for the Cabaliana floodplain along the Solimões river, Amazonas, Brazil. Classes are open water (blue), flooded forest (white), flooded herbaceous (floating meadows; magenta), flooded woodland (tan), non-flooded forest (green), and non-wetland (black). and (S) shrubland.

Product Developers:

Laura Hess	University of California, Santa Barbara
Maycira Costa	University of Victoria, Canada
Tony Milne	University of New South Wales

2.3.8.2 Seasonal monitoring of major wetland regions

Seasonal monitoring of tropical / sub-tropical wetlands

Seasonally inundated river floodplains provide important habitat for aquatic flora and fauna, and play a key role in sustaining regional fish production (Junk 1997; Forsberg et al. 1993). They furthermore represent, as mentioned above, globally significant sources of trace gases essential to climate regulation (Devol et al. 1988). Seasonal flooding plays a key role in this context and the annual inundation pulse has been identified as a dominant environmental factor in the Amazon basin, affecting both aquatic biota on the floodplain (Junk 1997) as well as the emissions of CO_2 (Richey et al. 2002) and CH_4 (Rosenqvist et al. 2002). The characteristics of the flood pulse, in terms of timing, duration and spatial extent, varies spatially on the floodplain as a function of fluctuations in river stage height and topography.

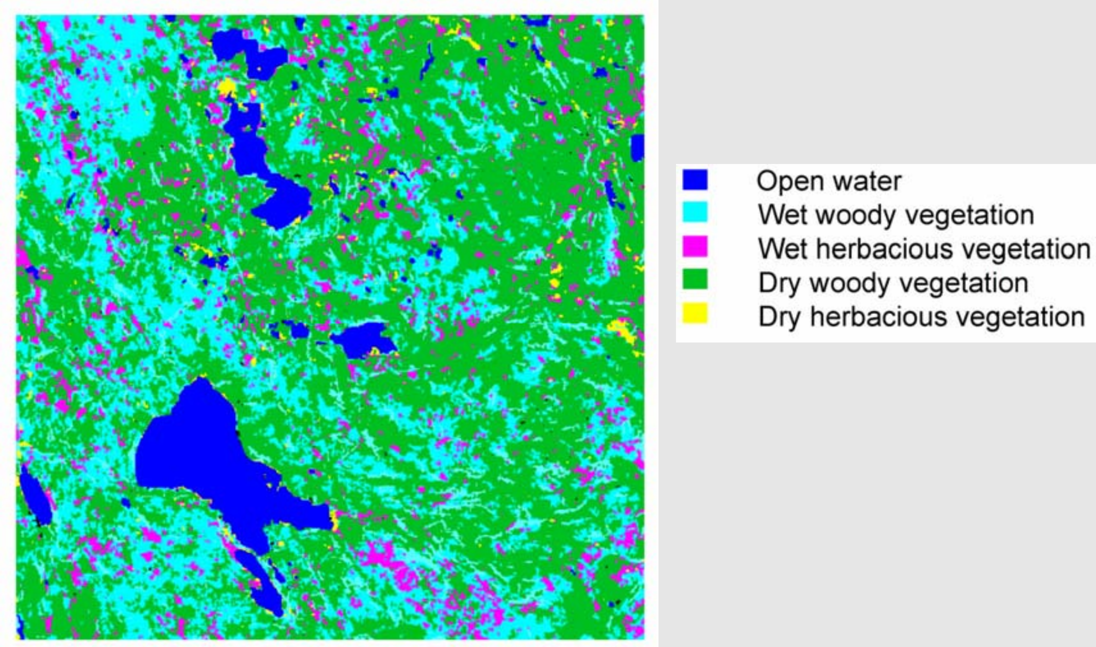
Information about the timing and duration of flooding in any river basin is generally limited to point measurements obtained through gauge stations along the major rivers, while information about the spatial extent of flooding and its variations over time are unavailable due to the lack of suitable measurement techniques. While optical remote sensing sensors can be used to delineate the thematic extent of the floodplain forest through the different spectral characteristics of the floodplain and terra firme vegetation, they can not be used to map the instantaneous extent of inundation, since flooding mainly occurs beneath the canopy layer. Such information can only be obtained with L-band SAR systems, which thanks to its long microwave wavelength possess the unique capability to reveal spatial information about the distribution of below-canopy flooding. In this context, repetitive observations during the flood cycle are required to adequately characterise the highly variable temporal and spatial flooding patterns.

Product Box W-2 – Boreal wetland extent and properties

K&C product(s): Maps delineating open water in the boreal landscape; maps delineating boreal wetland vegetation..

Intended use: To document, monitor, and understand the extent of boreal wetlands.

Prototype areas: Alaska.
Input data: PALSAR dual-polarisation path images, 50 m resolution.



Classification of the BOREAS Southern Study Areas, Saskatchewan, Canada, using JERS-1 SAR mosaic assembled as part of the Global Boreal Forest Mapping project. Multi-season JERS data were combined with ERS SAR in an object-oriented classification approach.

Product Developer:

Kyle McDonald	NASA JPL, USA

Collaborators:

John Kimball	University of Montana, USA

Within the framework of the GRFM project, JERS-1 SAR blanket coverages were acquired twice over the Amazon and Congo river basins, corresponding to their approximate high and low water levels. While these dual-season data sets provided unprecedented views of the flooding characteristics in these river basins, it also became evident that only two acquisitions were insufficient to fully characterise the great local and regional variability that typify such large river systems.

Within the K&C Initiative, PALSAR observations in ScanSAR mode will be undertaken over a large number of selected river basins of global significance – including the Amazon, Orinocco, Paraguay, Paraná, Yukon, Macenzie, Congo, Niger, Zambesi, Okavango, Darling, Mekong, Irrawaddy, Yangze, Yellow river, Ob, Lena and Yenisey – on a 46-day repeat basis 8-9 times during 1-year time windows, to enable flood duration mapping of unprecedented extents and details. The timing of the acquisition windows vary between the areas, as they have been individually adapted to fully capture the local inundation seasonality.

Wetland extent, inundation patterns and vegetation change in the Greater Mekong River Basin

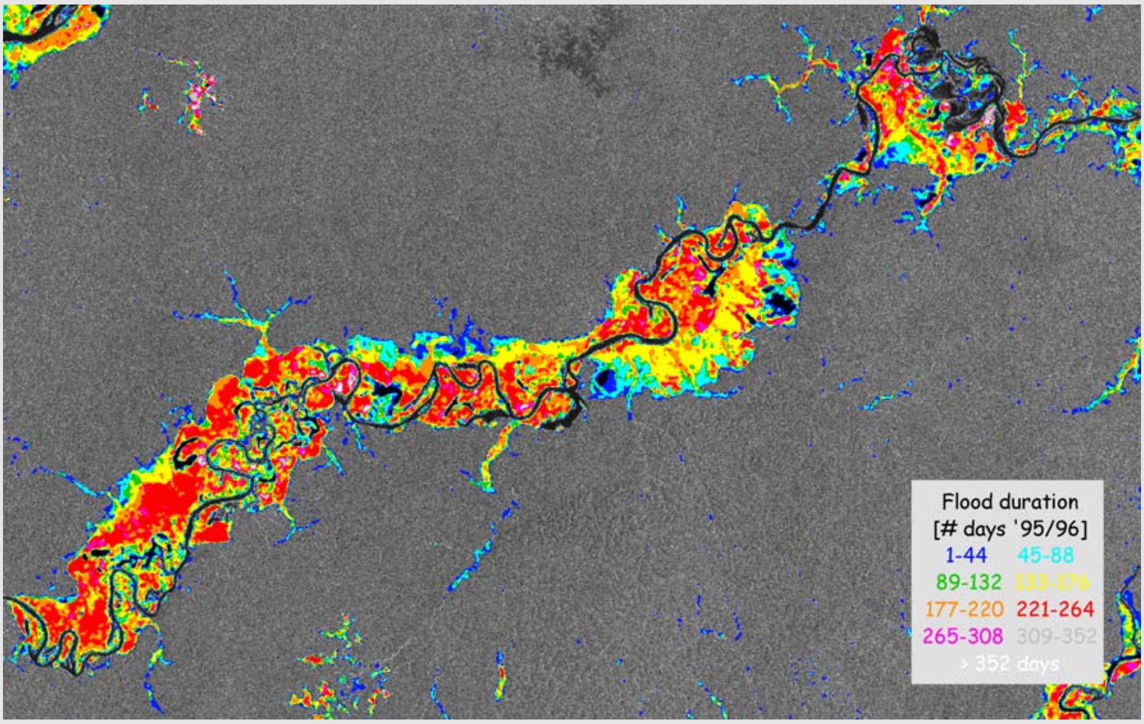
The need for adequate monitoring and management of environmental resources in order to meet the food, water and energy needs of the population of the Greater Mekong Basin as well as to minimise the deleterious impacts of economic development on the environment are major challenges facing all member governments (Thailand, Lao PDR, Cambodia and Vietnam) who are signatories to the "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin" signed in 1995, and for international agencies working to promote sustainable development, utilisation, management and conservation of water related resources in the Mekong River including UNDP,UNEP, Mekong River Commission (MRC) and the RAMSAR Convention on Wetlands.

Product Box W-3 – Seasonal monitoring of tropical/sub-tropical wetlands

K&C product: Maps of inundation duration and extent.

Intended use: Input to regional-scale CH4 emission models, support to environmental impact assessments and development of wetland management plans.

Prototype areas: The Amazon basin, the Congo river basin, the Okavango delta.
Input data: 1-year time-series of PALSAR ScanSAR path images, 70 m resolution.



Flood duration map showing a section of the Jaú river in the central Amazon basin, derived from a 1-year time series of JERS-1 SAR data - 8 observations acquired on a 44-day interval during a full annual flooding cycle.

Product Developers:

Ake Rosenqvist	JAXA EORC
Laura Hess	University California, Santa Barbara
Frank De Grandi	Joint Research Centre

Sustainable development refers to the adoption of practices in relation to the use of environmental resources that allow for an improved standard of living to be achieved but which at the same time do not impair the capacity of the environment to provide for and support the needs of future generations. A sustainable practice is one which is sensitive to ecological constraints and which seeks to minimize any undesirable effects of exploitation and use which might impact negatively on long-term resource viability. However, sustainable development cannot be divorced from issues of equity, welfare, lifestyle and the expectation of an improved standard of living for the population inhabiting a region. Nor can the implementation of sustainable development practices be separated from the economic and political structures that exist within and between countries.

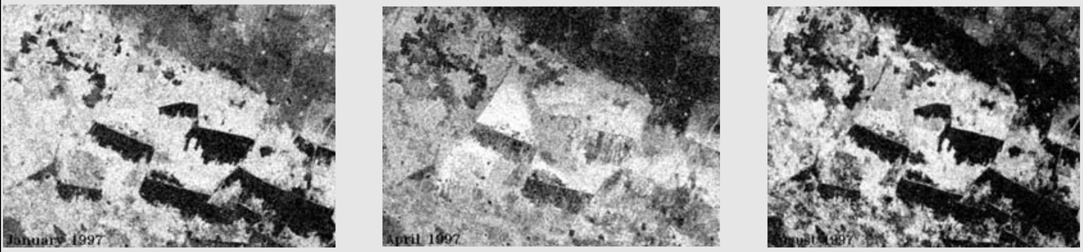
Within the Greater Mekong Region there are significant pressures on the natural environment resulting from its high economic value which unless checked will lead to even more serious environmental degradation than currently exists and which together threaten the natural productivity and long-term sustainability of the unique aquatic and wetland environments found within its borders. These include: wetland forest decline as a result of clearing, firewood harvesting and charcoal production; invasion of exotic species including water hyacinth, mimosa and the golden apple snail; water pollution from siltation and agrochemical runoff; overfishing and loss of species reduced bird, reptile and mammal population though hunting increased population, and eco-tourism.

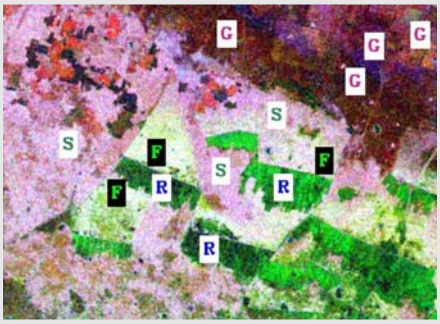
Product Box W-4 – Wetland extent, inundation patterns and vegetation change in the Greater Mekong River Basin

K&C product(s):
Maps of wetland distribution.
Flood mapping system to show flood extent and seasonal water recession patterns
Maps of spatial changes in land cover including that of critical wetlands, natural forests, agricultural land, and human settlements

Intended use: Determining the spatial pattern of vegetation classes in freshwater wetlands and the associated sequence of floodplain draining and drying that accompanies flood events is an important first step in assessing the hydrologic, geomorphic and ecological processes operating in flooded ecosystems. It is also a necessary pre-requisite to the formulation of management plans relating to the sustainable use, conservation and rehabilitation of such environments. PALSAR derived data products from this study will then be integrated with SRTM and other topographic data to produce flood height maps for use in identifying flood prone areas and for predicting the magnitude of flood inundation events for selected study sites within the Mekong Basin. These products will also be used to investigate and understand the flood dynamics and hydrologic exchange mechanisms within the Mekong River network, adjacent floodplains and wetlands.

Prototype areas: The Greater Mekong basin
Input data: Time-series of PALSAR ScanSAR path images. Archived JERS-1 SAR data.





Composite change image (left) derived from the January, April and August (1997) JERS-1 images (above). The changing level of irrigation water stored up-slope under scrubland vegetation (F) leading to higher backscatter is clearly evident in all images. Other landcover types are (B) bare ground (G), rice fields (R) and (S) shrubland.

Product Developers:

Tony Milne	Horizon Geoscience Sydney, Australia

Collaborators:

Ian Tapley	Horizon Geoscience Perth, Australia
Hans Guttman	Mekong River Commission

The Mekong is a system and an integrated and holistic approach is needed to water management issues across the basin. Equally important, however, is the need for individual catchment planning and management based on local knowledge and participation. The countries involved together with international agencies are currently working towards the preparation of policies and the implementation and strategies that seek to promote sustainability and that minimize the negative impacts of economic development on the natural environment of the Greater Mekong Region.

PALSAR L-band data is well suited to detecting water below vegetation cover. At this wavelength water beneath a canopy can cause "double bounce" reflections where instead of the signal undergoing attenuation and loss, reflections between the various trunk and branch components and the underlying water surface cause strong multi-path returns in the direction of the antenna. These enhanced returns permit the detection of water beneath the canopy and provide the basis for mapping wetland types as well as monitoring flood extent and changing water levels. (Pope, 1996; Kasischke et al., 1997; and Milne et al., 2001).

In this project, PALSAR imagery will be used in conjunction with SRTM data to develop baseline datasets showing the extent of flooding in the Mekong River Basin against which subsequent seasonal changes in the extent and duration of flooding can be mapped and assessed.
Understanding the complex hydrologic regimes that occur season to season in the Lower Mekong Basin and providing information for assessing wetland forest status, disturbance and clearing are important first steps to implementing and managing a sustainable resource base for the region.

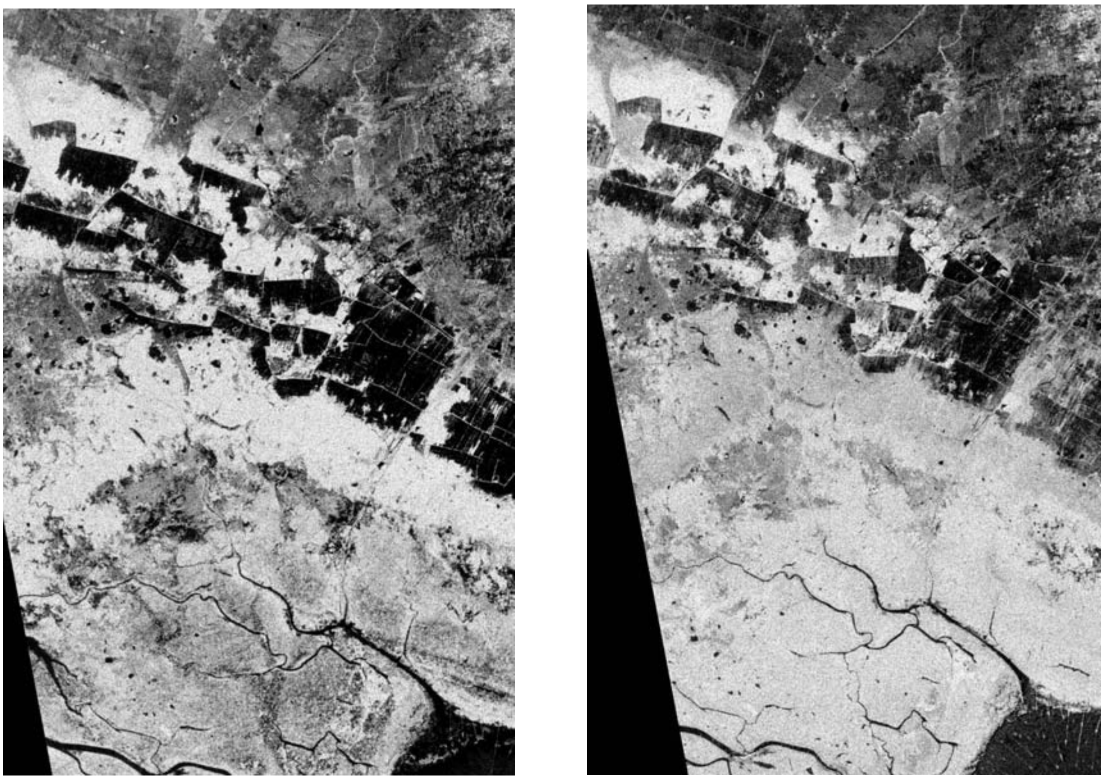


Figure 2.3.2: PALSAR Fine Beam mode images acquired 28th December 2006 and 12 February 2007 showing the visual impact of changing water levels . The darker tones on the December images show open water and saturated forest and shrub-marsh surfaces. In the February image the water level has fallen below the canopy in many places resulting in a higher radar backscatter response. The impact of the higher radiometric and spatial resolution of PALSAR can be seen when compared with JERS images of the same area in the box above.

Seasonal dynamics of the Pantanal ecosystem

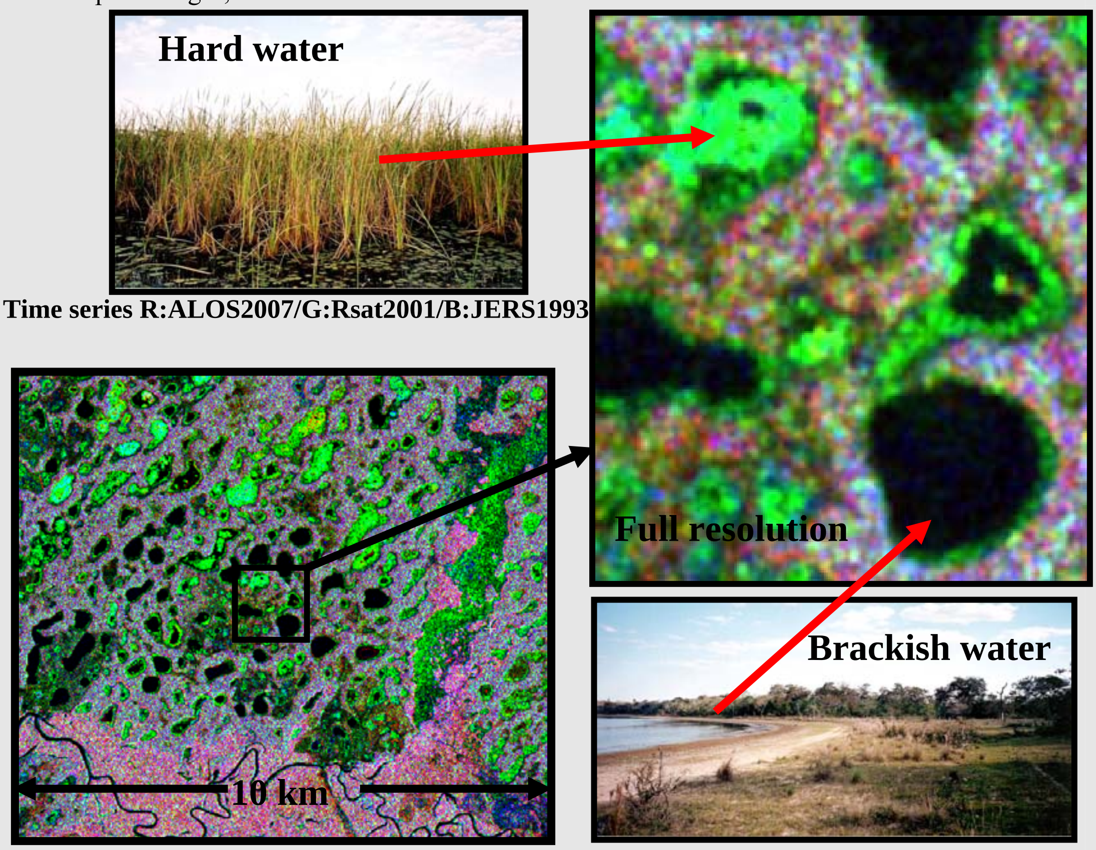
This component aims to increase our understanding of the ecological dynamics required to sustain the Pantanal ecosystem to help reduce the negative impacts of any future developments. Very little is currently known about Pantanal ecology.

The Pantanal, the largest tropical wetland in the world, is roughly located in the center of South America, between Brazil, Bolivia, and Paraguay. In many ways, it is a unique landscape characterized by salt and freshwater lakes, abundant aquatic vegetation, and open and dense savanna (Pott, 2000, 1989; Abdon *et al.,* 1998; Cost and Telmer, 2006; 2007). It is fed by the upper Paraguay River and its tributaries and these promote a strong annual flood. The degree of flooding and its duration and amplitude vary both yearly and spatially. The complicated flood dynamics makes the delimitation of the total area of the Pantanal extremely difficult (Por, 1995). Estimates suggest that the Brazilian Pantanal occupies an area that ranges from 138,000 km^2 during maximum flood (Silva and Abdon, 1998) to 11,000 km^2 during the dry season (Hamilton *et al.,* 1996), a difference of approximately 90%. The entire watershed of the Pantanal occupies an area of approximately 362,000 km^2.

Within the Pantanal, the occurrence of different habitats such as river corridors, gallery forests, perennial wetlands, and lakes (fresh and brackish lakes), seasonally flooded grass lands, and terrestrial forest is related to the dynamics of the flood cycle and its spatial variations. During the rising and maximum water stand, the dominant habitats are the large areas of floating and rooted aquatic vegetation, open water, and flooded forest. The flooded forest is mostly comprised of shrub-like trees and tall, densely foliated riparian trees (Silva and Abdon 1998). The aquatic vegetation is dominantly floating and rooted species that grow quickly during the maximum flood and die during the dry period. The very productive aquatic vegetation is important as both a source of food and in controlling the structure of the food web for the abundant primary consumers such as fish and capybara – the world's largest rodents (Heckman, 1998). This is the foundation for the many other species of plants and animals – salviniaceaes, cyperaceaes, iguanas, tortoises, crocodiles, primates, and multitudes of fish, birds, and insects. However, it is the delicate interplay between the dynamic distribution of vegetation, the high biological productivity of the aquatic plants, the climate, and the hydrological cycle, that nourishes and sustains the incredible diversity of plants and animals. Unfortunately this interplay is poorly understood and is threatened by human development.

Product Box W-5 – Seasonal dynamics of the Pantanal ecosystem

K&C product: Maps of the extent and seasonal patterns of inundation, lakes, aquatic vegetation, forest, savanna, and arid zones of the Pantanal wetlands.
Intended use: To document, monitor, and understand the regional biodiversity, habitats, and fundamental biogeochemical processes (the ecological dynamics) of the Pantanal wetlands in order to determine its conservation requirements.
Prototype areas: Brazilian Pantanal
Input data: Time-series of PALSAR ScanSAR path images, 50 m resolution; seasonal PALSAR dual polarization path images, 50 m resolution.



Identification of lakes and their aquatic vegetation type using a time series of ALOS, JERS-1 and RADARSAT SAR imagery of the Nhêcolandia region of the Brazilian Pantanal.

Product Developers:

Maycira Costa	University of Victoria, Canada
Kevin Telmer	University of Victoria, Canada
Terri Evans	University of Victoria, Canada

A series of human initiatives such as modification of the natural hydrological cycles of rivers, mining, agriculture, and chemical industry, construction initiatives (hydroelectric dams, dikes, Hydrovia, GASBOL – Bolivia-Brazil Gas pipeline), clearing of land and extensive burning, and commerce of wild animals are threatening this wetland ecosystem in an irreversible manner. Some of the resultant effects are loss of habitat and biodiversity, water pollution (mostly mining byproducts and agrochemicals), and erosion and sedimentation of waterways (Gottgens et al. 1998). Developments are already occurring and some will almost certainly continue but ignorance of the dynamics required to sustain the ecosystem makes them very risky and their consequences unpredictable. For example, the five governments of the La Plata basin, Brazil, Bolivia, Paraguay, Argentina, and Uruguay, have jointly developed plans to deepen the Paraguay River, canalize many meanders, and regulate inflows along its course from Cáceres, Brazil, to Porto de Nueva Palmira, Uruguay – an astounding 3400 km, the called Hydrovia (Paraguay-Parana Waterway Project). This project was designed aiming the cheaper transport of soy beans, oil, corn, cotton, manganese, and iron ore, at the expenses of one of the largest environmental disasters ever planned, the canalization and regulation of the Pantanal major rivers. This project as it was initially idealized was waned (recently it has been re-evaluated); however, various smaller hydrological initiatives remain of interest, which are accurate described by Gottens et al., 1998 as the “tyranny of small decisions”.

The state of this initiative is currently unclear, however, the Brazilian government has planned the construction of a series of small projects that when treated individually are considered too small-scale to warrant impact assessments, but that together represent potentially large scale change for the Pantanal (Gottgens 1998). The suspected consequences of these projects have been voiced by many critics – loss of wetlands, changes in water quality, reduction in the diversity of flora and fauna, and negative impacts on the livelihoods of local and indigenous people in the region (summarized by Gottgens, 2000). It is our hope to add to this debate and that a better understanding of the dynamics required to sustain the Pantanal ecosystem – the objective of this activity – will be incorporated into future developments in the region.

Radar imagery are exceptional for studying tropical wetlands because of their all weather functionality and their independence from the sun as an illumination source. Moreover, the microwave radiation interacts differently with distinct habitats of the wetland allowing accurate mapping of the spatial and temporal changes of ground cover (Costa and Telmer, 2006; Costa 2004; Costa et al., 2002; Novo et al, 2001; Ribbes and Le Toan, 1999; Costa et al., 1998; Le Toan et al., 1997; Hess et al., 1995). This is because the Pantanal’s wetlands have distinct characteristics in terms of vegetation type, timing of flooding, etc., and therefore produce distinct signals when interacting with microwave radiation. Costa et al. (2002; 2005) have demonstrated the power of this method for mapping wetlands and estimating biomass in the Amazon. We intend to apply this approach to the Pantanal using PALSAR data. Fine resolution data at dual polarization will be used for thematic characterization and time series of lower resolution ScanSAR will be used to map variations in vegetation and monthly inundation extent during the year. The thematic maps produced will show the seasonal variability of the different ecosystems of the Pantanal. Further, Costa and Telmer (2006) have demonstrated the potential of radar (JERS-1 and Radarsat) for lakes mapping of the Pantanal, through a relationship between emergent aquatic plant assemblages of the Pantanal lakes and total dissolved solids (TDS). As part of the Wetlands theme activities, a map of fresh and brackish lakes of the entire Pantanal (Brazil, Paraguay, and Bolivia) will be generated in order to understand the geochemical evolution of these lakes, seasonality, and correlated their use by the local fauna, and multi-temporal maps of the spatial distribution of habitats such as open water, aquatic vegetation, forest (and flooded), savanna (and flooded), and dry areas of the Pantanal will be generated using ALOS/PALSAR, JERS-1 SAR, CBERS, and SRTM data. These maps will greatly improve our understanding of the dynamics of the Pantanal ecosystem and ultimately support a much more informed approach to human developments in the region.

Mapping inland wetlands in southern and eastern Africa

Inland wetlands occur extensively across sub-Saharan Africa. These ecosystems typically play a vital role in supporting rural populations and their sustainable management is thus critical. In order to prevent depletion of the resources and ecosystem services provided by the wetlands, a balance is required between ecological and socio-economic factors. The sustainable management of wetlands requires information describing these ecosystems at multiple spatial and temporal scales. However, many southern and eastern African countries lack regional baseline information on the temporal extent, distribution and characteristics of wetlands. This information is needed to assist managers in making decisions about future land uses in wetlands that are intensively used for agriculture and fisheries, and which are an important natural resource for local communities. PALSAR fine beam data will be used to document and characterise specific wetland sites within the region, which have been identified due to their vulnerability to both climatic variability and agricultural activities.

Mapping spatial patterns of inundation in the Nile and Zambezi basins

Throughout the White Nile and the Zambezi basin, floodplains and wetlands are extensive. These ecosystems depend on flooding. They also make critical contributions to the livelihoods of many people. Many hydrological interventions (i.e. dams and irrigation schemes) either already exist within these basins, or are being planned to increase economic benefits and food security. However, these interventions will not be without consequences and both the costs and benefits need to be carefully evaluated. One likely consequence of increased flow regulation is reduced downstream flooding. Annual time series of PALSAR data are an invaluable dataset for identifying seasonal patterns of inundation, and will be used to determine flooding patterns and to map the temporal dynamics of inundation across selected regions of the White Nile and the Zambezi.

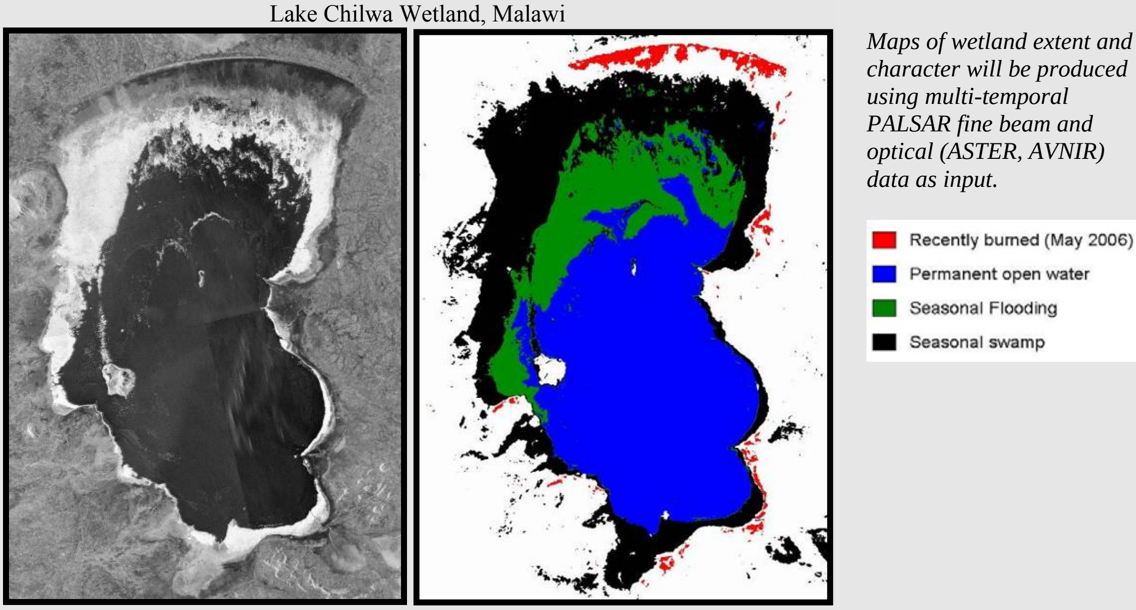
Product Box W-6 – Inland wetlands in Africa: extent and properties

K&C product(s): Maps of wetland extent and vegetation characteristics

Intended use: To a) document and characterise regional habitats, biodiversity and ecological dynamics of inland wetlands in southern and eastern Africa, b) provide baseline data for input to site specific management plans.

Prototype areas: Eastern and southern Africa
Input data: Annual time series of ScanSAR path images, 70m resolution, PALSAR dual-polarisation images, 12.5 m resolution.

Lake Chilwa Wetland, Malawi



PALSAR FBS (May 2006) Broad wetland classes

Maps of wetland extent and character will be produced using multi-temporal PALSAR fine beam and optical (ASTER, AVNIR) data as input.

Product Developers:

Lisa-Maria Rebelo — International Water Management Institute
Max Finlayson — Institute for Land, Water and Society, Charles Sturt University, Albury

2.3.9 Mapping and monitoring of key wetland types

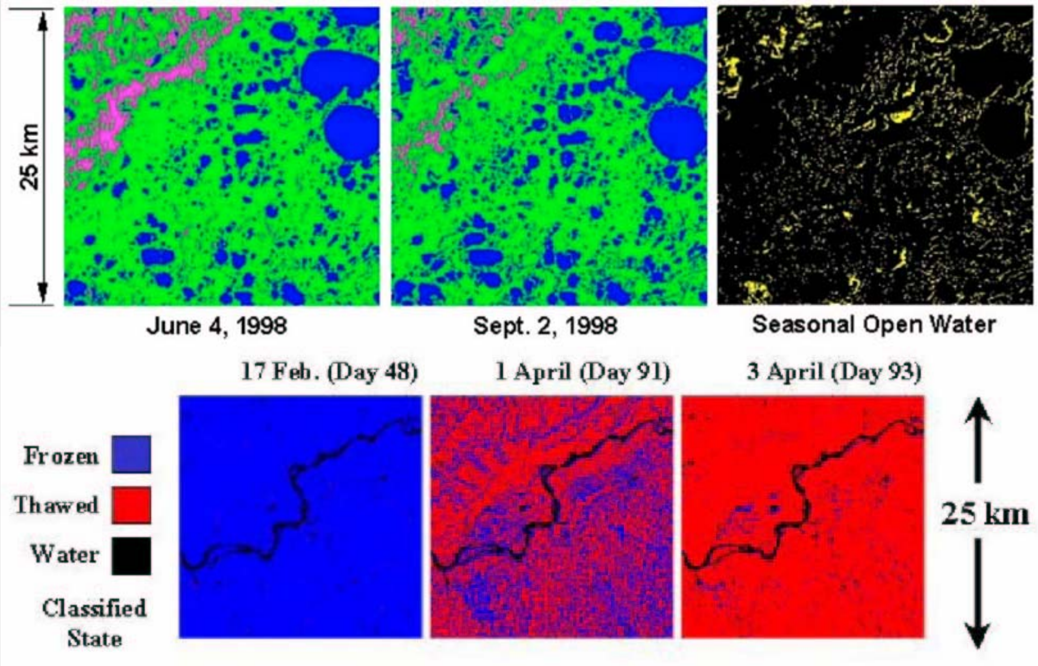
The high temporal resolution ALOS provides the means to map and monitor specific wetland types – such as rice padi, peat swamp, and mangrove forests – which are of particular interest to wetland managers, conservationists and carbon cycle scientists. In addition to mapping possible contributions of greenhouse gases (for example, through monitoring the rice farming practices and rate of clearing in wetland areas), the products may also be used to identify the extent of wetlands at different times of the year, and the threats or pressures impacting on them

Product Box W-7 – Seasonal monitoring of freeze-thaw state and boreal wetlands

K&C product(s): Multi-temporal maps over prototype areas delineating seasonal changes in boreal wetland open water and inundation.

Prototype areas: Alaska, extended BOREAS, Finland, Central Siberian Transect.

Input data: Time-series of PALSAR ScanSAR path images, 70 m resolution.



Seasonal change in open water monitored with the JERS-1 SAR for a regions within Alaska's Yukon delta national wildlife refuge (top). Springtime thaw monitored in the Tanana river floodplain, Alaska (bottom).

Product Developers:

Kyle McDonald	NASA JPL, USA
Martti Hallikainen	Helsinki University of Technology, Finland

Collaborators:

Reiner Zimmermann	University of Bonn, Germany
John Kimball	University of Montana, USA

2.3.9.1 Global mangrove extent and properties

Mangroves are a floristically diverse assemblage of salt-tolerant plants, widespread throughout the tropics and subtropics, and also extending to more temperate zones in both the northern and southern hemispheres (32° N and 38° S respectively; Figure 1). They are most extensive in the tropics, where more than 10 million ha occur, although their combined area represents less than 3 % of the World's tropical forest (Spalding et al., 1997). Mangroves are an important component of coastal ecosystems and are recognized as important contributors to primary production and nutrient cycling in estuarine systems (Bandaranayake, 1994), as providing nursery grounds for many commercial fish and crustacean species (O'Grady et al., 1996) and as a seasonal base for a variety of migratory species. As mangroves occur at the land-sea interface, they also create shoreline buffer zones that protect the coast from erosion and flooding and contribute to groundwater recharge, nutrient and sediment retention and shoreline stabilisation (Blasco et al., 1994; Saenger, 1994; Richards, 1996).

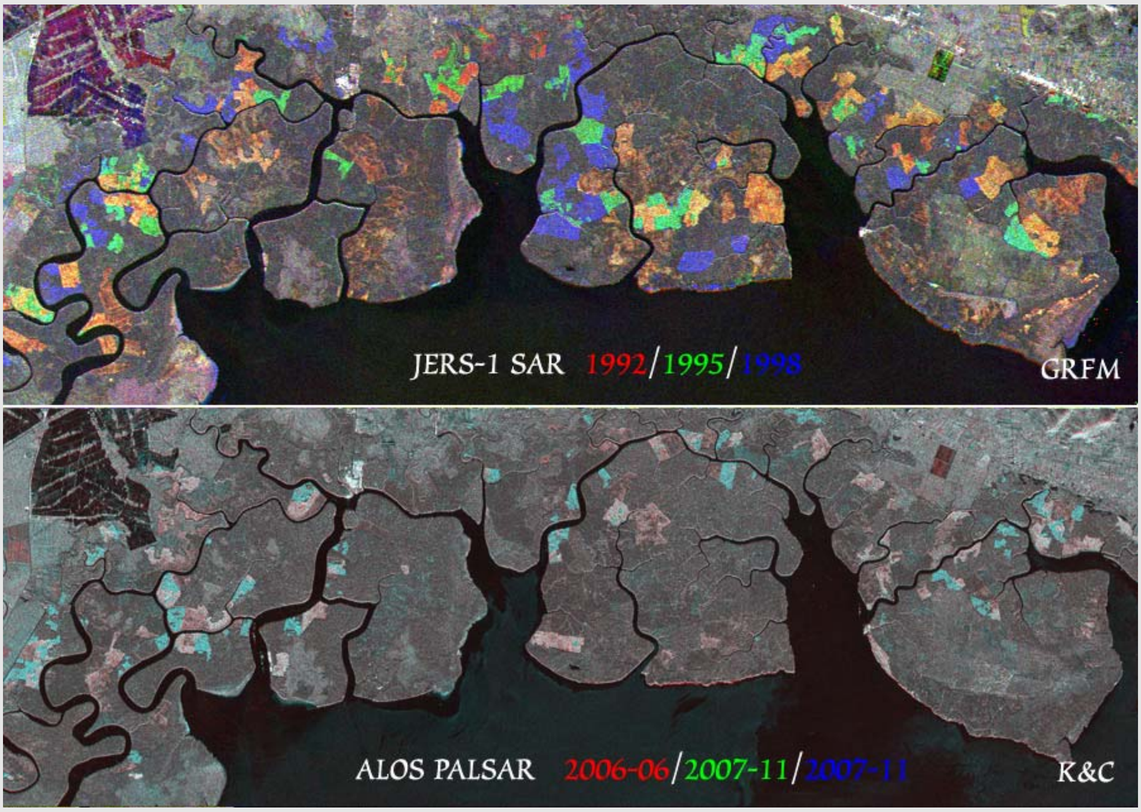
Despite their importance, mangrove ecosystems are threatened by human disturbance (clearing and conversion to other land uses). The FAO in 2003, estimated that, by the end of 2000, only 15 million ha of mangroves were remaining; a decline of ~ 4.8 million ha from 1980. Although deforestation of mangroves is ongoing and remains an issue, the rate appears to have slowed from 1.7% (1980-1990) to 1% (1990-2000) per year. Mangroves are also a dynamic ecosystem and rapidly respond to changes in the coastal environment, including those induced by climate change (e.g., increased storm surges) and sea level rise.

Product Box W-8 – Mangrove extent and properties

K&C product(s): Datasets derived from JERS-1 SAR and ALOS PALSAR will be used to map the changing extent of mangrove communities subject to both natural and anthropogenic change.

Intended use: Monitoring impacts of anthropogenic disturbance of mangroves and natural processes of change (cyclones, tsunami damage, sea level rise and changing sediment patterns).

Prototype areas: Northern Australia, Indonesia, Belize, French Guyana, Brazil, West Africa.
Input data: Annual time-series of PALSAR path images, 50 m resolution.



Conversion of coastal mangroves for firewood and aquaculture in Perak, Malaysia, as observed using a multi-annual time series of JERS-1 SAR and ALOS PALSAR.

Product Developers:

Richard Lucas	University of Wales, Aberystwyth, UK

Collaborators:

Catherine Ticehurst	CSIRO Land and Water, Australia.
Anthea Mitchell/Tony Milne	University of New South Wales, Australia
Kirrilly Pfitzner, John Lowry	ERISS, Darwin, Australia
Dirk Hoekman	University of Wageningen, the Netherlands
Christophe Proisy	IRD, French Guyana
Fernando Miranda	Petrobrás, Brazil
Ake Rosenqvist	Joint Research Centre, EU
Ian Woodhouse	University of Edinburgh, UK

Although global maps of mangroves have been produced (e.g., the IUCN World Mangrove Atlas; Spalding et al., 1977), these represent a static view of the ecosystem and quantitative and spatial estimates of the changing extent of mangroves are not available. For this reason, the K&C Initiative aims to provide and compare regional maps of mangrove extent for selected regions worldwide, with particular focus on northern Australia (Queensland and the Northern Territory), Indonesia, French Guyana, Belize, Brazil and the west coast of Africa. These regions have been selected as they encompass a wide range of natural and anthropogenic disturbance regimes. Furthermore, a wide range of airborne SAR and other data are available for many sites which can be used to support the interpretation of the SAR data. Where appropriate, the potential of ALOS and JERS-1 SAR data to characterise mangroves in terms of floristics, structure and biomass will be assessed in conjunction with data acquired by both optical sensors and the Shuttle Radar Topographic Mission (SRTM).

Table 2.3.C Benefits of using ALOS PALSAR data for mangrove assessment

Retrieval of biomass from polarimetric SAR has already been demonstrated for mangrove forest (Imhoff, 1995; Held et al., 2003; Mougin et al., 1999).
L band SAR is sensitive to biomass up to around 100 Mg ha-1, and can be used to identify and determine the biomass of young/regrowth stands.
SAR backscatter models indicate that L-band HH is sensitive to branch biomass with scattering dominated by interactions between canopy and ground for stands with biomass below saturation.
L-band VV is sensitive to trunk biomass up to the level of saturation.
L-band HV shows increasing sensitivity to leaf and branch biomass with volume scattering dominating in mature forest.
The broad extent of mangroves can be mapped at the resolution of ALOS.
Discrimination of growth stage and zonation will be evident using ALOS through differences in L-band backscatter magnitude as a result of changing scattering mechanisms (volume, interactions).

L-band SAR data from both the JERS-1 SAR and ALOS PALSAR are well suited for discriminating and mapping mangroves for reasons outlined in Table 2.3.C. Even so, a number of issues will need to be considered. Specifically, saturation of the radar response occurs at relatively low (< 100 Mg ha-1) levels of biomass but attenuation (i.e., the progressive reduction in amplitude of the signal) also occurs above certain levels of biomass which can lead to reductions in backscatter and confusion with other land covers. The ability to map mangroves also depends upon the nature of the bounding surface (i.e., whether soil or tall forest) and tidal inundation often leads to elevated backscatter at the longer wavelengths, particularly in forests with a more open canopy and those at a pioneer stage.

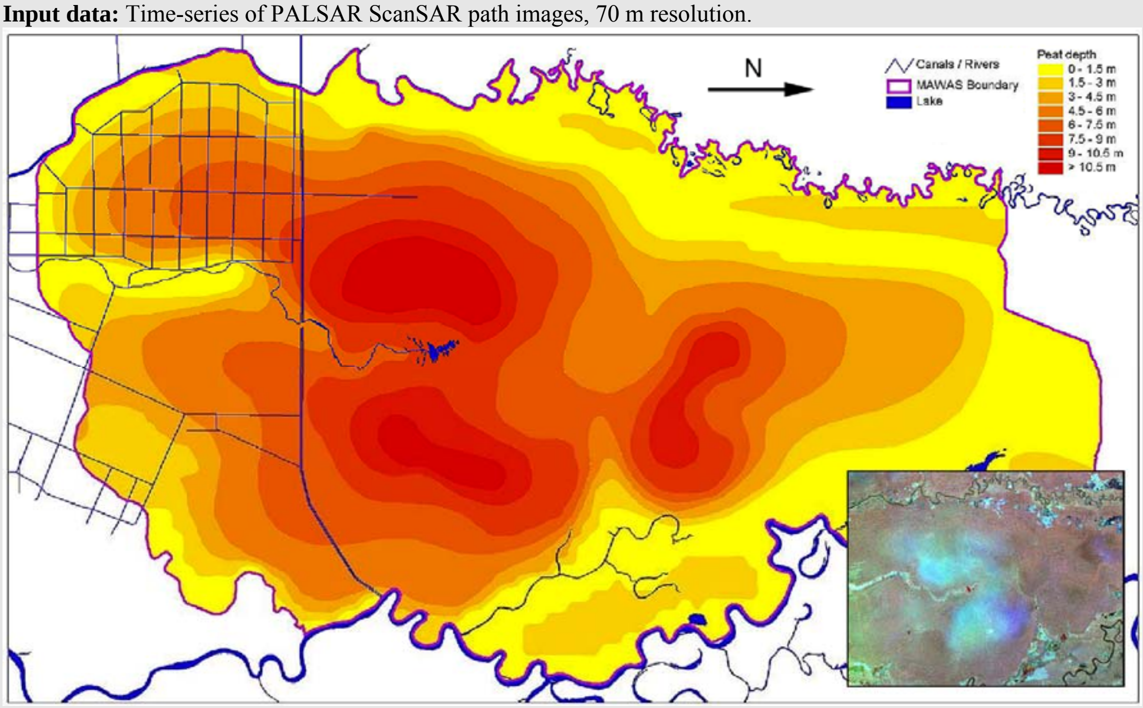
Product Box W-9 – Tropical Peat Swamp Forests

K&C product(s): Maps of tropical peat swamp forests in Borneo, Sumatra and New Guinea, derived from a complete annual cycle of 8 consecutive PALSAR ScanSAR observations, showing location, vegetation type, inundation characteristics, degree of disturbance and estimated peat depth.

Intended use: Peat swamp forest management, protection, risk assessment (assessment of excessive drainage conditions), hydrological modelling, restoration, more accurate and updated assessment of carbon stocks.

Prototype area: Indonesia (Sumatra, Kalimantan, Irian Jaya)

Input data: Time-series of PALSAR ScanSAR path images, 70 m resolution.



Large figure: Peat depth map derived from flooding dynamics, visible on JERS-1 time series, and peat depth sampling. In this 300,000 ha section of Mawas, Central Kalimantan, peat depth varies from 2-15 m.
Inserted figure: JERS-1 Multi-temporal composite of a peat dome, Mawas, Central Kalimantan; (Red 940907; Green 950712; Blue 960104)

Product Developer

Dirk Hoekman, BOSF, Indonesia / Wageningen University, NL

2.3.9.2 Tropical peat swamp forests and properties

Thick deposits of peat underneath peat swamp forests are among the world's largest reservoirs of carbon. Although they occupy only about 0.3% of the global land surface, they could contain as much as 20% of the global soil carbon stock. More than half of this area is located in Indonesia (MacDicken 2002, Rieley & Setiadi, 1997). Peat systems appear fragile and sensitive to hydrological disturbance. Drainage through canalisation has frequently severely disrupted water table level dynamics, causing the peat layers to dry out and trees to collapse over large areas. Besides resulting in CO2 emissions due to oxidisation this process makes them particularly vulnerable to fire, especially during 'El-Niño' years. In addition to their significance to the carbon cycle, peat swamps are particularly significant to the conservation and maintenance of species diversity. For example, of the 57 mammal and 237 bird species recorded in peat swamp forests to date, 51% and 27% respectively are listed as globally threatened species (Sebastien 2002). The relationship between spatial and temporal dynamics of peat swamp forest hydrology, carbon content and forest health needs further study. Such understanding would not only support the conservation of peat swamp forest, but also the rehabilitation of degraded peat areas, which may significantly reduce carbon emission and fire risk.

Temporal dynamics in flooding intensity can be related to the hydrology of ombrogeneous peat swamp forests and, indirectly, to peat depth. The blue areas visible in the multi-temporal JERS-1 SAR image inserted in Product Box W-8 (Mawas, Indonesia) are flooded parts of the relatively flat tops of a complex of two peat domes, with a river originating from a central depression (red spot). In the lower left corner a blue arch shows the relative flat and wet fringe of a dry peat dome.

In the humid tropical regions optical remote sensing systems largely fail because of persistent cloud cover. Conversely, spaceborne radar observation is not hindered by adverse atmospheric conditions (such as clouds, smoke and haze) and can be made frequently and repetitively, including during the wet season. Moreover, radar signals are sensitive to forest structure and biomass level (Hoekman et al 2000, 2002; LeToan 2002 . This offers unique opportunities for applications such as peat swamp forest health and fire susceptibility monitoring as well as fast illegal logging response monitoring. The advantages of ALOS PALSAR for mapping and monitoring peat swamps are summarised in Table 2.3.D.

Table 2.3.D Benefits of using ALOS PALSAR for mapping and monitoring peat swamp environments

All weather observation capability
High temporal capture – good for monitoring disturbance
Assessment of hydrological cycles
Ability to monitor biomass, and forest structure (and thus health / condition of wetlands)
Ability to assess susceptibility to forest fires

2.3.9.3 Pan-Asian mapping and monitoring of rice paddies

Demand for rice in Asia is projected to increase by 70% over the next 30 years (IRRI 2002; Hossain 1997). At the same time, population increase and intensification of economic development will lead to significant land use conversion (e.g., Seto 2000). Paddy rice cropland distributions and management intensity (fertilizer use, cultivars, water management, multi-cropping) will have to change over the coming decades. As water resources become scarcer (Vorosmarty et al. 2000), rapidly expanding urban areas will compete with agriculture for available water. In Asia, agriculture currently accounts for 86% of total annual water withdrawal (IRRI, 2002). Urban demand for water will generally have greater financial and political resources than agricultural demand for water, and for some regions water availability to agriculture may decline significantly over the next few decades. Rising water costs will force all agriculture to improve its water-use efficiency. As this occurs, the practice of midseason draining of rice paddies, which requires less water than continual flooding, is likely to increase throughout many parts of Asia.

Rice Paddy and Carbon Dynaimics – Methane emissions from rice paddies are estimated to 50-100 Tg CH4/yr (Prather & Ehhalt, 2001), or 10-20% of total global emissions. Nitrous oxide emissions from rice paddies have not been quantified; total agricultural soil N2O emissions are roughly 4 Tg N/yr, about half the anthropogenic source and about one-fourth of the total global source (Prather & Ehhalt, 2001). Paddy N2O fluxes are generally low (Abao et al. 2000; Cai et al. 1999).

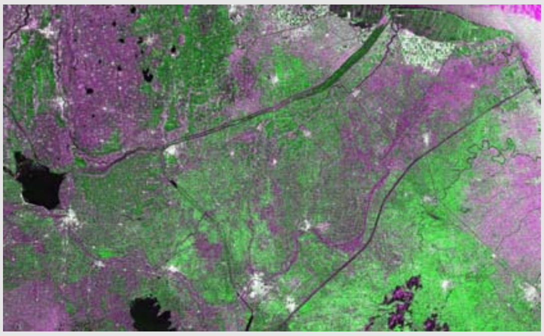
Product Box W-10 – Regional irrigated paddy monitoring

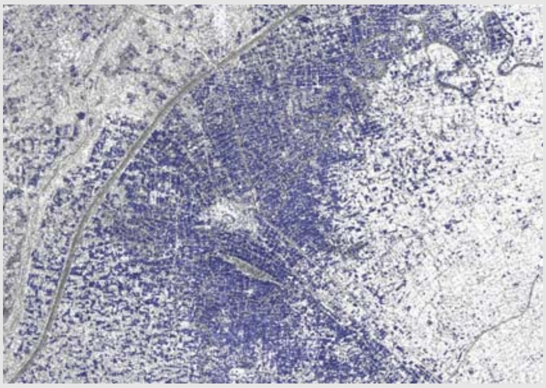
K&C products:

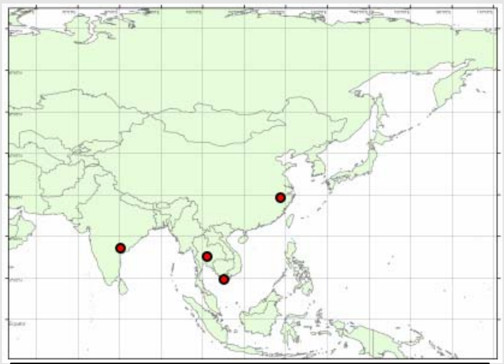
- Algorithms for regional mapping and monitoring of rice production with PALSAR Scansar.
- Regional map of irrigated paddy field (single crop and multiple crop per year) derived from multi-temporal PALSAR Scansar data.
- Algorithms for mapping rice paddy inundation dynamics with multi-temporal PALSAR Scansar data.
- Maps of inundation periods will be developed using multi-temporal PALSAR Scansar data.

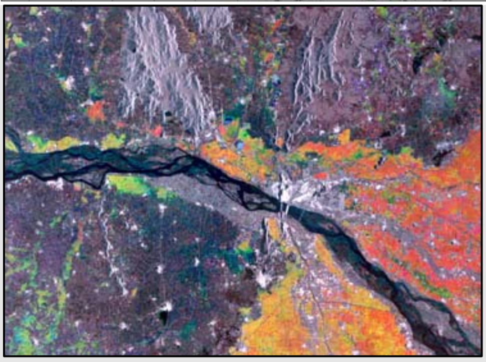
Intended use: Assessment of regional rice production and methane emission in conjunction with in situ, climatic data and ecological modeling.

Prototype areas: China, India, Mainland South-East Asia, and Luzon Philippines.
Local sites in India, China, Thailand and Vietnam (top right figure) will be used to develop PALSAR processing algorithms based on full resolution PALSAR data.
Input data: 1-year time-series of PALSAR ScanSAR path images, 70 m resolution.









Mapping of regional irrigated paddy fields in the Jiangsu province, China, as examplified by the results using multi-temporal ENVISAT ASAR WideSwath data (top left). The paddy field map (bottom left) is based on the temporal change of the SAR backscatter.

Location of algorithm development sites in India, Thailand, Vietnam and China (top right). Multi-temporal JERS data for mapping rice paddy extent and cropping cycles (bottom right) in Vijayawada, India. Map of early (red areas) and late (orange) Kharif rice.

Product Developers:

William Salas	Applied GeoSolutions, USA
Thuy Le Toan	CESBIO, France

Collaborators:

Changsheng Li	University of New Hampshire, USA

Changes in Water Management – Over the past two decades, an alternative water management approach for wetland rice agriculture has gradually been adopted in at least some of the major rice producing countries in Asia (China and India). Midseason drainage, tends to increase rice yield by increasing N-mineralization in the soil and by increasing root development in the rice plants (Wassmann et al. 2000; Lu et al. 2000). For China, estimates indicate that in 1980 only about 10% of paddies were drained in mid-growing season, while now the fraction of fields drained may be closer to 80% (Shen et al. 1998; Ministry of Water Resources and Utilization of China 1996). While the primary motivation for this draining has been to increase yields, a significant consequence has been to reduce methane emissions. Field studies have shown that midseason draining reduces total crop-season methane emissions by 10 to 80% (Wassmann et al. 2000; Cai et al. 1999; Yagi et al. 1996).

Biogeochemical models of trace gas fluxes from rice fields are reliant upon estimates of the area of paddy rice cropland and cropping practices. While many countries provide official county-scale agricultural census data, these data are not ideal for modeling trace gas fluxes and carbon cycle science. In addition, the soil biogeochemical processes that control C and N cycling and trace gas emissions are highly variable in space and time and are a function of soil, climate and cropping practices. Census data do provide sufficient detail on location of rice paddies or timing of cropping cycles. Satellite remote sensing data is an alternative that can be used to improve rice cropland area estimates (Xiao et al., 2002) and provide sufficient spatial and temporal details needed for improved estimation of the impact of rice paddy agriculture on trace gas emissions and carbon cycle science.

SAR mapping of Rice. There are several factors that make SAR data a logical choice for paddy rice analysis. First, radar backscatter has been found to be strongly correlated to several key growth parameters of the rice plant, including height, age, and biomass at both C-band (Kurosu et al., 1995; Le Toan et al., 1997; Ribbes and Le Toan, 1999; Inoue et al., 2002) and L-band (Rosenqvist, 1999). The backscatter of rice fields increases quickly during the vegetative stage of the rice crop and then reaches a saturation level, however the timing of the saturation is also affected by the physical properties of the SAR sensor. Second, the use of multi-temporal SAR data has proven to be effective in the mapping of paddy rice areas. Backscatter can increase by over 10 dB from the beginning of the growth cycle (flooded fields) to the saturation level and because of this large backscatter variation, well-timed image acquisitions (beginning and end of the crop cycle) should be able to operationally identify paddy fields since other land covers do not experience such variation. Rice paddies have been mapped from multi-temporal SAR data using backscatter change thresholds in Indonesia (Ribbes and Le Toan, 1999), Malaysia (Rosenqvist, 1999) and Vietnam (Liew et al., 1998), and from land cover classifications in Japan (Kurosu et al., 1997) and India (Chakraborty et al., 1997). Third, SAR data is independent of cloud conditions. This is very important in tropical and sub-tropical areas where much of the world's rice is grown and the availability of optical satellite data is severely restrained by cloud cover. Compared to C-band data, in which wind or rain may cause backscatter noise on flooded fields, L-band SAR provides a better tool for identification of the characteristic early stages of the cultivation cycles, as the longer wavelength makes it insensitive to such wind- and rain effects, with a low backscatter well contrasted with the backscatter of other land use types. (Rosenqvist, 1999). Time series of PALSAR data acquired through-out the rice growing cycle will be used to map the extent of rice cultivation, and the variation in timing and number of crop cycles in different regions. These systematic regional acquisitions will provide a unique opportunity for regional rice mapping in support of carbon cycle science and agricultural sustainability applications. With operational and regional scale monitoring in mind, this activity within the ALOS K&C Initiative aims to a single methodology to create regional maps of rice paddy extent for selected regions in Asia.

2.3.9.4 Global lakes census

Carbon accumulated in lake sediments has been recognised as an important component of the global carbon cycle and a significant sink for atmospheric CO2 but has been remarkably poorly studied compared to other carbon sinks of similar magnitude such as C storage in soils, peat, terrestrial biomass, or the oceans. Mullolland and Elwood (1982) were perhaps the first to recognise the importance of C storage in lakes with their estimate that globally, lakes accumulate 0.02 Pg C yr-1. Others have since modified this estimate. For example, Dean and Gorham (1998), largely using only lakes in Minnesota and the eastern United States, estimated that lakes globally accumulate as much as 42 Tg of organic C per year. Pajunen (2000) report the initial findings of a very detailed survey of lake sedimentary C for lakes in Finland and conclude that lake sediments constitute the third largest carbon store in Finland after peatlands and forest soils despite covering only 10% of the land mass. Finally, Einsele et al. (2001) claim that 70 Tg of organic and inorganic carbon are buried each year in lakes, representing 25% of the atmospheric carbon estimated to be buried in the oceans annually – 250 Tg (Schlünz and Schneider, 2000).

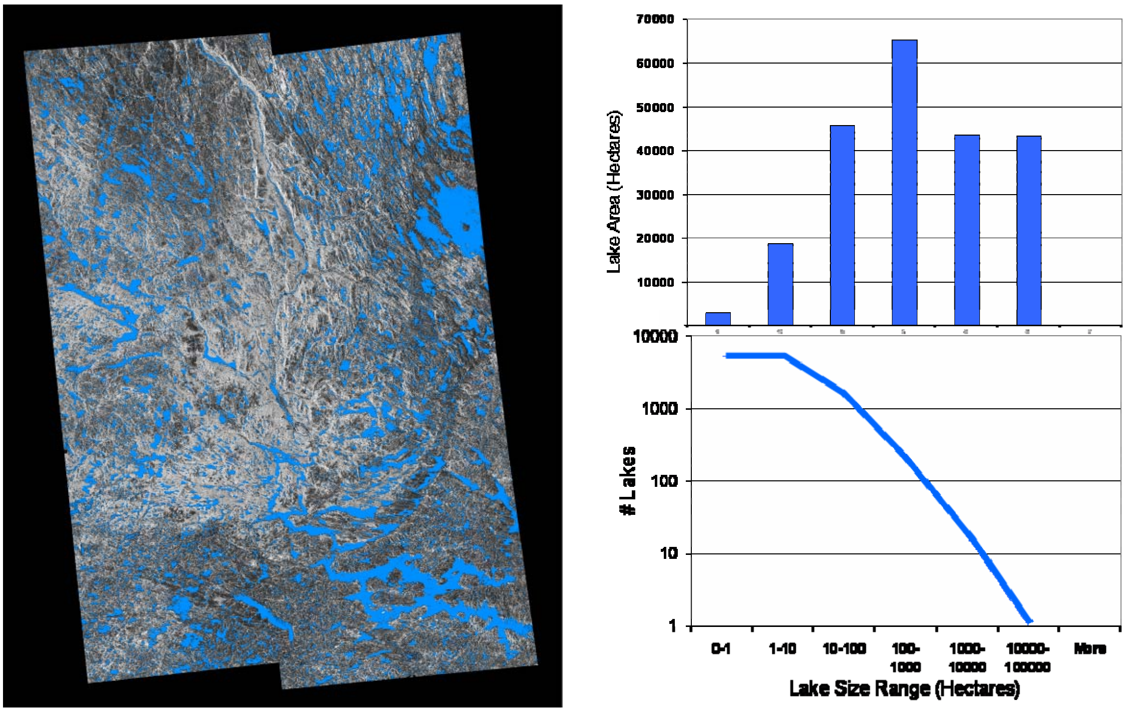
These studies represent important progress but understanding and quantifying C accumulation in lakes remains relatively poorly constrained. Particularly lacking are: (i) estimates of the variation of carbon accumulation in lakes from different geomorphological terrains and climates (tropical and temperate), and (ii) good estimates of the number and size distribution of lakes for these different geomorphologic terrains and climates. This latter point is particularly important because C accumulation rates vary with lake size (Pajunen, 2000) with the smallest lakes accumulating C the fastest.

Product Box W-10 – Global lakes census prototype

K&C product(s): Maps of lakes derived from ALOS PALSAR will be used to determine lake size distribution and its controls by region and globally.

Intended use: Baseline database for (a) determining carbon accumulation rates in lakes by region and globally, and (b) for determining changes to the world's lakes through time induced by shifts in climate or by human development.

Prototype areas: Canada, Brazilian Pantanal, Zambezi River Basin
Input data: PALSAR dual-polarisation path images, 50 m resolution.



Classification of lakes using 12.5 m resolution PALSAR FBS SAR images from the North West Territories, Canada. Graphs show lake polygon count and area across 6 lake size ranges.

Product Developers:

Kevin Telmer	University of Victoria, Canada
Maycira Costa	University of Victoria, Canada
Jamie MacGregor	University of Victoria, Canada
Daniel Stapper	University of Victoria, Canada

To address these shortcomings we will utilize the all weather and vegetation penetrating capabilities of L-band SAR to produce a Global Lake Census prototype that illustrates (using maps) and quantifies lake size and spatial distribution – initially for Canada, the Pantanal and the Zambezi basin, but in a longer perspective for the globe. Several other lake censuses have been completed in the last 50 years, with the most recent completed by Meybeck (1995). Using rainfall/runoff relationships for the globe, he extrapolated existing lake survey's and registers to a global scale. A comprehensive global lake survey from a singular data source and methodology has never been produced. The PALSAR sensor on ALOS now makes such a comprehensive survey possible.

Because of its L-band wavelength, ALOS PALSAR is particularly well adapted for this task. L-band penetrates clouds and vegetation and is less sensitive to water surface roughness than shorter wavelength SAR. These qualities will allow ALOS to very easily differentiate water from land. Because L-band penetrates vegetation, ALOS will even correctly identify small lakes covered with aquatic vegetation (these are strong C accumulators). And due to its all-weather and night/day capabilities, ALOS can collect relatively time contiguous data for large regions. Together, these qualities will robustly facilitate automatic mapping of the world's permanent lakes and reservoirs.

Canada, South America's Pantanal, and southern Africa have been chosen as prototype areas because they contain a wide variety of lake sizes and types whose spatial distribution varies depending on ecosystem characteristics. They represent temperate and tropical climates and they also represent areas that are relatively well studied (boreal) and poorly studied (Pantanal, Southern Africa).

2.3.9.5 *Detection and monitoring Small-Scale Gold Mining*

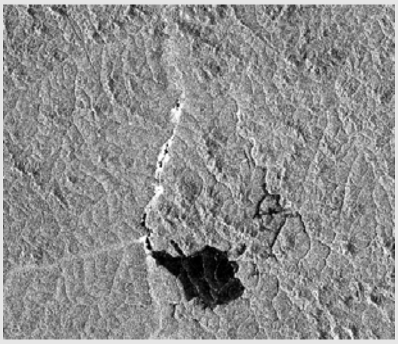
As the international price of gold has continued to climb over the past decade, so has the spread of small-scale gold mining (ASM). This is causing widespread habitats loss and landscape degradation and the common use of mercury is releasing alarming amounts of the poisonous element. Mercury in ASM is directly poisoning local people, contaminating down-stream fisheries, and through long range atmospheric transport, contaminating fisheries globally. ASM is now the single largest direct use source of mercury to the environment globally. The issue has become so serious that the United Nations Environment Program (UNEP) has identified mercury as one of the world's top priority air pollutants and has targeted ASM as a key priority for intervention activities. Unfortunately, much of this modern gold rush occurs in remote areas and in the heavily cloud covered tropics and so the current data on the issue is grossly lacking: information that governments and international organizations need in order to prioritize resources.

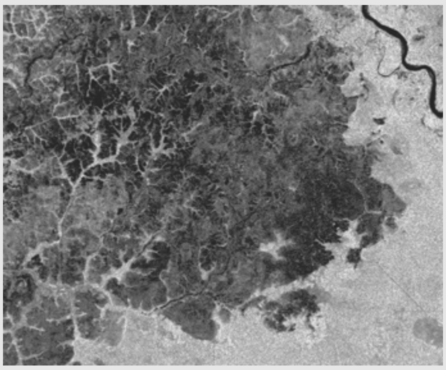
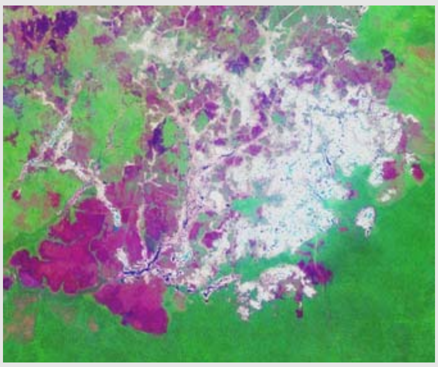
Product Box W-12 – Repeat-Pass Interferometric SAR for detecting and monitoring Small-Scale Gold Mining in the Tropics

K&C product(s): PALSAR fine beam products, including multi and full-polarization acquisitions, taken on separate passes - one to several months apart, will be used to investigate their usefulness for monitoring the activity of small-scale gold miners.

Intended use: To produce 'change detection' images using two or more PALSAR images over areas of both suspected and known-to-be-active ASM sites in Indonesia and Brazil. The differences in the backscatter in the images will be used to detect changes that can be associated with mining activities caused by current mining operations. This has the potential to produce near real time data on the whereabouts and magnitude of ASM operations that can directly feed intervention efforts such as those of the UNIDO's Global Mercury Project.

Prototype areas: Central Kalimantan, Indonesia and the Tapajos Basin, Para, Brazil

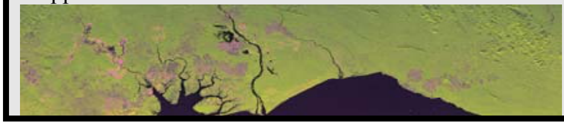


(Top figures) JERS-1 image and aerial photo of gold mining in the Tapajos, Brazil (Bottom); JERS-1 and Landsat 7-ETM images of Galangan, an active mining region (exposed sands) in Kalimantan, Indonesia.

Product Developers:

Kevin Telmer	University of Victoria, Canada
Daniel Stapper	University of Victoria, Canada



2.3.10 Product dissemination

The development of a dissemination program for PALSAR data, is of particular significance to the Ramsar Convention as it represents a means by which the signatory partners can complete inventory activities, and fulfil their obligations to the convention. Specifically, the ability of ALOS to produce high spatial and temporal resolution products, which can be used to delineate and monitor the extent and condition of wetlands in a range of environments at different times of the year would provide extra impetus to the collection of wetland inventory information which could be used to assist with the management and protection of wetland environments. Similarly, the dissemination of the product will enhance the ability of signatory parties to manage and conserve their wetland areas. The identification, compilation and distribution of procedures, and datasets derived from PALSAR and GLI products to produce enhanced wetland information in turn has the potential to further enhance the existing wetland inventory framework.

Liaison and consultation with the Ramsar Convention will occur through the Scientific and Technical Review Panel (STRP) of the Convention. Participation in and liaison with the Wetland Inventory, Assessment & Monitoring Specialist Group (WIAMSG), established by Wetlands International, will ensure continued links with that organization.

Product Box W-13: Product dissemination program

K&C product(s):

- Assessment of status, needs, requirements of Ramsar contracting parties for wetland inventory within the target area(s).
- Recommendations for K&C products for use by contracting parties for specific scenarios/requirements.
- Recommendations for means for applying / supplying said products to contracting parties.
- Recommendations for training and/or other steps required for application of data to meet inventory requirements.
- Provision of image processing training to selected areas and contracted parties, in conjunction with Wageningen University.
- Analysis and preparation of PALSAR datasets for wetland inventory and monitoring
- Establishment of data ‘clearing house’ by Wetlands International.

Intended use: Establishment and updating of inventory information; monitoring of impacts of anthropogenic activities (deforestation/land clearing) and natural processes (cyclones, climate change, tsunami) on wetlands

Prototype areas: South-east Asia (supporting Asian Wetland Inventory & post-tsunami projects of WI); northern Australia; to be extended to other wetland project areas, such as e.g. the Pantanal, the Amazon basin and China at a later date.

Developers: Doug Taylor, Wetlands International, The Netherlands
John Lowry, eriss, Australia
Max Finlayson, IWMI, Sri Lanka
Dirk Hoekman, Wageningen University, The Netherlands
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Support from wetland theme members as required

2.3.11 Acknowledgements

This chapter was authored by Laura Hess, John Lowry, & Richard Lucas with input from members of the Wetland Theme, Ake Rosenqvist and Max Finlayson (International Water Management Institute, Sri Lanka).

2.4 The Desert & Water Theme

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Product Development Tram:
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Francesco Holecz, Paolo Pasquali, Sarmap, Switzerland (Product Leader)

2.4.1 Introduction

The world's population will increase at least by 50% over the next 50 years, leading to increasing resources needs, particularly renewable water and agricultural lands. Water resources and desertification are related problems since water is required to develop new areas for agriculture. The water and desertification crisis is especially crucial in Saharan and sub-Saharan Africa, where less than 50% of inhabitants have access to safe water supplies. The international community has long recognized that water resources and desertification are major economic, social and environmental problem of concern to many countries in all regions of the world.

In 1992, United Nations delivered recommendations for sustainable development: agenda 21 chapter 18 concerns the protection of the quality and supply of freshwater resources. Freshwater resources are an indispensable part of all terrestrial ecosystems. The freshwater environment is characterized by the hydrological cycle, including floods and droughts, which in some regions have become more extreme and dramatic in their consequences since water is needed in all aspects of life. The general objective of UN recommendations is to make certain that adequate supplies of water of good quality are maintained for the entire population of our planet, while preserving the hydrological, biological and chemical functions of ecosystems. The widespread scarcity, gradual destruction and aggravated pollution of freshwater resources in many world regions, along with the progressive encroachment of incompatible activities, demand integrated water resources planning and management. Such integration must cover all types of interrelated freshwater bodies, including both surface water and groundwater, and should consider water quantity and quality aspects. Water resources assessment, including the identification of potential sources of freshwater supply, comprises the continuing determination of sources, extent, dependability and quality of water resources and of the human activities that affect those resources. Such assessment constitutes the practical basis for their sustainable management and a prerequisite for evaluation of the possibilities for their development. There is, however, growing concern that at a time when more precise and reliable information is needed about water resources, hydrologic services and related bodies are less able than before to provide this information, especially information on groundwater and water quality. At the same time, the advancing technology for data capture (cf. Earth observation) and management is increasingly difficult to access for developing countries. Establishment of national databases is then vital to water resources assessment and to mitigation of the effects of floods, droughts, pollution and desertification.

In 1977, the United Nations Conference on Desertification (UNCOD) adopted a Plan of Action to Combat Desertification (PACD). Unfortunately, despite this and other efforts, the United Nations Environment Programme (UNEP) concluded in 1991 that the problem of land degradation in arid, semi-arid and dry sub-humid areas had intensified. Desertification occurs when an ecosystem experiences a diminution or loss of productivity. This process can have a natural and an anthropic component, which may reinforce each other, creating a synergetic effect. The degree of desertification risk is directly related to certain natural conditions such as climate, topography, natural vegetation, soil, and hydrology, as well as to the intensity and type of anthropic activity in the area. Desertification is among the most serious problems of the planet. This trend indicates the increasing need to consider desertification processes in integrated development planning studies, for locating, assessing, and monitoring deterioration of natural conditions in given areas. Information about these conditions can be obtained from direct measurements or inferred from indicators (i.e. keys to the recognition of a desertification process). Being a continuous process, desertification cannot be mapped and monitored by occasional inspections. Spaceborne Earth Observation is the only reliable system to collect systematic qualitative and quantitative information at frequent rates on the variations of geo- and biophysical parameters over large areas. However, as desertification is a complex process, influenced also by climatic and human-induced factors, its understanding and mapping requires a methodology based on E.O. products integrated with ancillary data such as socio-economic and meteorological data, where the ultimate goal is the generation of vulnerability maps to be provided to decision makers for prevention purposes.

2.4.2 Problem statement

The access to freshwater resources is a crucial point for future generations, in particular in arid regions such as North Africa. Some studies foresee that more than two billion people will suffer from water scarcity in 2025, in particular in the Sahara (cf. Figure 2.4.1) and Arabia.

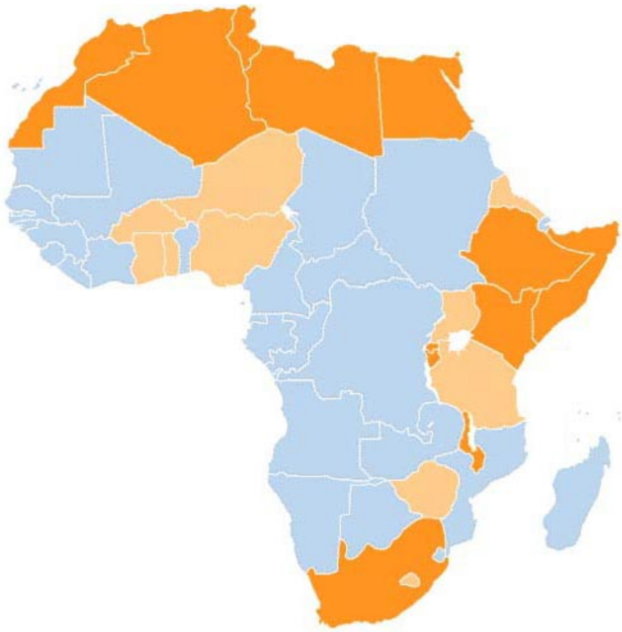

Figure 2.4.1 Estimated water stress in Africa in 2025. Orange corresponds to water scarcity (less than 1000m^3/person/year), and light orange corresponds to water stress (1000 to 1700m^3/person/year).

Currently, typical water prospecting schemes start from existing geological maps, in order to define further fieldwork exploration (geophysical prospecting, drilling). Several pilot projects have shown the usefulness of Earth observation data to help generating structural maps that can then be used for water resources prospecting. Most of these studies considered spaceborne optical data (LANDSAT, SPOT) to map surface structures (e.g. faults) in regions where a geological map is not available. A strong limitation of this process is the fact that most of relevant geological features in arid regions are hidden under a thin layer of sandy sediments. In particular, the eastern part of Sahara (Libya, western Egypt, northern Sudan and Chad) presents hyperarid climatic conditions (less than 1 mm rainfall per year) with large flat areas covered with a few meters of sand. Subsurface geology (bedrock of volcanic rocks, limestone and sandstone) is generally invisible for classical optical remote sensing instruments. As was demonstrated by the Shuttle Imaging Radar (SIR) missions however, radar signals can penetrate the superficial sand layer and reveal unknown paleo-hydrological and tectonic structures, with L-band signal allowing unique access to subsurface information down to a depth of several meters.

Desertification and land degradation is among the most serious problems of the Sahel region in Africa but also concerns several regions in central Asia. Remote sensing data provide valuable tools for evaluating areas subject to desertification and can be used for the purpose of locating, assessing, and monitoring deterioration of natural conditions in a given area:

- Location involves the identification of areas that are currently undergoing desertification and areas expected to be exposed to the forces that can lead to deterioration;
- Assessment involves the identification and quantification of vegetative cover types, soils, land forms, and land-use change patterns. Vulnerability to change, rate of change, and direction of change in desertification patterns can be studied through this assessment;
- Monitoring is accomplished by detecting and measuring changes in landscape characteristics over a period of time. Comparisons are made between present conditions and previously observed conditions for the purpose of recording the reduction in biological productivity.

As desertification is a continuous process, one or some sporadic images have no value and long baseline over large areas must be available (so called structural vulnerability). The structural approach is expressed through tendencies, highlighted by the analysis of historical and new data, which characterize the evolution of environmental biophysical characteristics, and socio-economic properties of population and production systems. Another aspect is related to short time variations (episodic events) observed around the structural trends (so called conjunctural vulnerability). These variations can be induced by climatic events as droughts, which could affect environmental biophysical properties or politic/socio-economic events (migrations, conflicts, etc.) and can affect temporarily the populations/livestock coping capacity. Earth observation data may in this case be used assuming that continuous data acquisitions over a given time frame is available.

2.4.3 Carbon, Conventions and Conservation

The Desert & Water Theme addresses primarily information requirements raised by international conventions, which in turn are closely linked to environmental conservation issues and long-term sustainable development and management.

Protection of the quality and supply of freshwater is a priority of the United Nations: this topic was stressed during the second and third World Water Forums (The Hague 2000 and Kyoto 2003), during the 2001 International Freshwater Conference in Bonn as well as during the 2002 Earth Summit in Johannesburg: "No water, no future". Several actions were proposed during the Johannesburg Summit, in particular to halve the proportion of people unable to reach safe water resources by 2015 and increase water productivity in agriculture to enable food security. UNESCO also set up a "Water interactions systems at risk social challenges" for 2002 – 2007 to support African countries in better managing their water resources.

Within the context of land degradation and desertification, the question of how to tackle this complex issue was a major concern addressed at the 1992 UN Conference on Environment and Development (UNCED), in Rio de Janeiro. UNCED supported a new, integrated approach to the problem, emphasizing action to promote sustainable development at the community level. Ten years later however, at the World Summit on Sustainable Development in Johannesburg, it was recognized that Earth observation technologies have to be urgently promoted and widely used in order to guarantee reliable information – which today are not available – on environmental impacts, land cover and land cover changes ranging from global to local scale.

2.4.4 The relevance of ALOS

SIR-C data have shown that L-band can penetrate dry sandy covers down to a couple of meter, deeper than C-band. L-band is also less sensitive than C-band to the surface roughness that can mask subsurface information. While the very incomplete geographical coverage of the SIR missions do not allow any regional scale mapping, a complete L-band radar coverage of East Sahara nevertheless exists, acquired by the Japanese Earth Resources Satellite (JERS-1) that was operated by NASDA from 1992 to 1998. As a demonstrator, the Saharasar project was initiated in 2002 as a collaboration between the Astronomical Observatory of Bordeaux – AOB – and JAXA: a regional-scale, 50 m resolution radar mosaic over East Sahara (Egypt, northern Sudan, eastern Libya, northern Chad), extracted from more than 1600 JERS-1 L-band SAR scenes, was assembled. This data set provides unprecedented information about unknown subsurface structures (tectonic features, paleo-rivers and lakes, faults) and will allow geologists to substantially revise existing geological maps of the region and then better manage water resource prospecting (cf. Box 1). In the era of the Advanced Land Observation Satellite due for launch in 2005 and in the framework of the JAXA's K&C Initiative, we shall focus on the production of an improved second generation radar mosaic covering the entire Sahara and Arabian peninsula, generated from dual-polarized (HH+HV) data from the L-band PALSAR instrument. The higher resolution expected from PALSAR together with polarimetric capabilities will allow to generate a definitive map of shallow subsurface features that will constitute the basis for new geological maps. In particular; HV/HH ratio will be used to stress regions where subsurface or volume scattering occurs. This unique information will be used as a more relevant start point to define future prospecting plans, and thus provide a better support to water resource detection and management in Sahara and Arabia.

For mapping and monitoring of land degradation and desertification, systematic observations over vast areas and long time periods are required – preferably over a decadal scale in order to catch the generally slow progress related to structural vulnerability, as mentioned above. The observation strategy implemented for ALOS has been designed to provide such repetitive, regional-scale, observations with an increased repetition frequency over semi-arid areas in Africa and central Asia. Given the relatively short time span of a single satellite mission however, the activities planned within the K&C Initiative will focus on mapping of conjunctural vulnerability (i.e. short-term land degradation resulting from e.g. agriculture and/or livestock management), which can be identified using a seasonal time series of data. The combination of ALOS AVNIR-2 and PALSAR data will allow an accurate mapping of surface characteristic changes in time. It is worth noting that it is essential to acquire the Earth observation data on a regular basis during the cropping and pasture seasons. ALOS PALSAR is here of particular interest due to the L-band frequency, which in comparison with shorter wavelength band SAR systems, provides a higher degree of interferometric stability over long time intervals. L-band coherence has to date has not been considered within the desertification issue, but the parameter is expected to be very suitable for tracking soil cover change, as it is sensitive to microscopic object properties and allows the detection of spatial and temporal variations at micro scale.

2.4.5 Components of the Desert & Water Theme

The Desert & Water Theme comprises two major components: freshwater resources, which focuses on the mapping of subsurface geological structures in hyper arid areas for improved identification of aquifers, and desertification, which concerns the mapping and monitoring of land degradation in semi-arid areas.

2.4.5.1 Freshwater resources

Building on the experiences from JERS-1 SAR

The K&C activities related to freshwater resources builds on the experiences of the (JERS-1 SAR) SaharaSAR project (Paillou et al. 2003 & 2004), which was established to evaluate the potential of regional-scale L-band SAR mosaics for providing a new "geological face" of the Eastern Sahara and to assess how radar remote sensing can be used to help revise existing geological maps of the Sahara region, thereby providing better support for water prospecting.

The SaharaSAR assessment was performed in three stages. The first stage involved the selection of a small number of JERS-1 SAR and VNIR scenes for five well-known sites where subsurface structures had already been observed by the SIR-C SAR (Bir Safsaf, Dakhla and Siwa in Egypt, the "crater" in Chad and the Keraf contact in Sudan). By comparing the JERS-1 SAR and SIR-C SAR data, evidence was obtained to demonstrate that the JERS-1 SAR data were of sufficient quality to detect subsurface structures (Fig. 2.4.2), although the reduced power of the JERS-1 SAR (325 W) was considered a partial limitation to the usefulness of the data. Furthermore, the temporal stability of the JERS-1 SAR data allowed the generation of high quality mosaic images with various acquisition dates.

As a second stage, some 250 JERS-1 SAR scenes covering southern Egypt and northern Sudan were used to build a preliminary mosaic to demonstrate the potential of L-band SAR for detecting subsurface features over regional scales. A 250 m resolution visible counterpart of the mosaic, comprised of Landsat 7 Enhanced Thematic Mapper (ETM+) geocoded quick-look images, was used for comparison (Fig. 2.4.3). Analysis of the mosaic demonstrated the capacity of JERS-1 SAR to reveal unknown subsurface structures, leading amongst others to the discovery of a previously unknown double impact crater in Libya (Paillou et al. 2003), shown in Fig. 2.4.4. A field visit confirmed the existence of the crater – 12 km in diameter (Fig. 2.4.5).

Figure 2.4.2 Comparison between L-band radar data of JERS-1 and SIR-C. Visible image JERS-1/VNIR of Bir Safsaf region (left), corresponding JERS-1/SAR image (center), and corresponding SIR-C image (right).

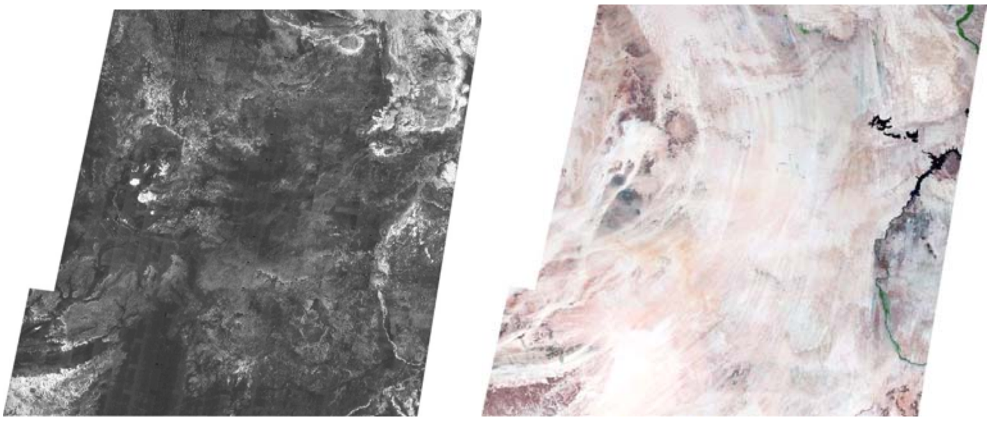

Figure 2.4.3 The 260-scene JERS-1 mosaic (left) and its visible LANDSAT 7-ETM+ counterpart (right), covering the area N20°-25°/E25°-30°, or 1200 by 1200 km.

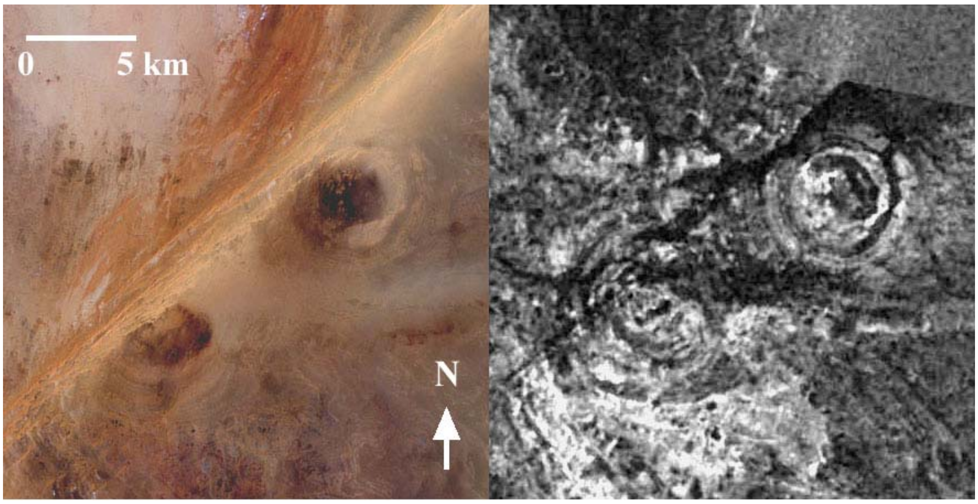

Figure 2.4.4 Landsat 7 ETM+ image of a double circular impact crater (left), and the corresponding JERS-1 L-band image (right) at a resolution of 50 m. Circular structures are better seen in the SAR image.

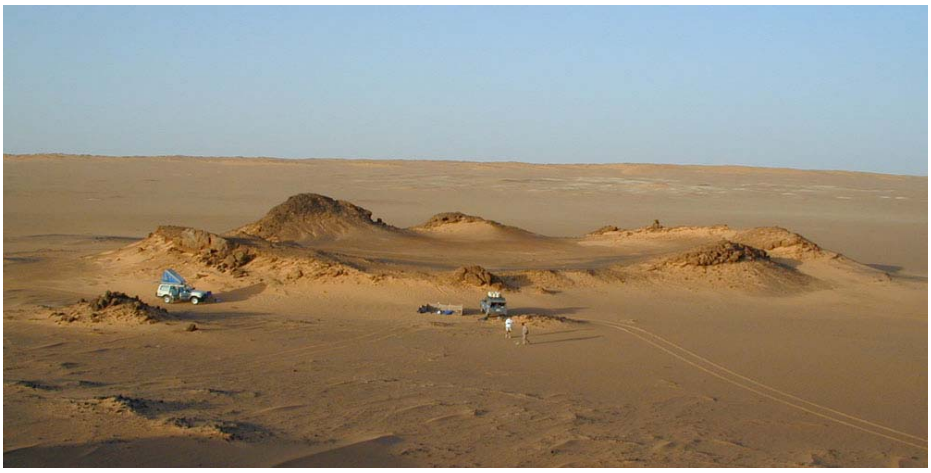

Figure 2.4.5 Landscape as seen from the center of the NE crater, facing to the north-east (horizon corresponds to the inner ridge of the crater).

In the last stage, JERS-1 SAR data were assembled to build a regional-scale radar mosaic over the eastern Sahara (Egypt, northern Sudan, eastern Libya and northern Chad – N8°-33°/E8°-35°). Rather than individual scenes as used in the previous steps, extensive path images (see Mosaic Products 2.5.4), typically some 2500 km in length, were utilised, as an exercise for the forthcoming processing and mosaicking tasks with

PALSAR. Some 60 path images, corresponding to about 2500 scenes, were used. The 100 m spatial resolution JERS-1 SAR mosaic and the Landsat-7 ETM+ 250 m spatial resolution counterpart are presented in Fig. 2.4.6.

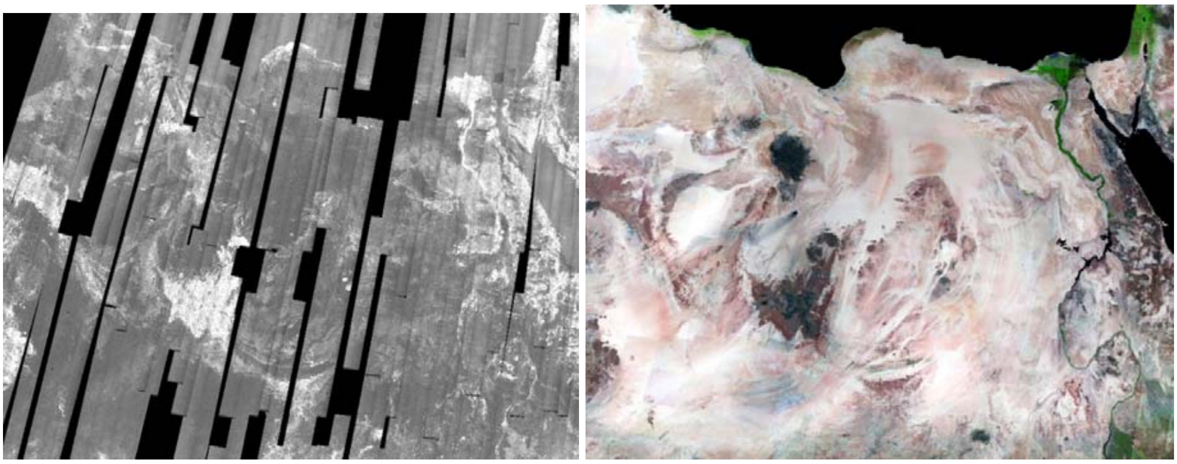

Figure 2.4.6 The 2500 scene JERS-1 mosaic (a – left) and its Landsat ETM; counterpart (b – right). The images cover the area 8°-33°N and 8°-35°E.

This unique dataset provided unprecedented information about unknown subsurface structures (tectonic features, paleo-rivers and lakes, faults and impact craters), allowing geologists to substantially revise existing geological maps of the region. The generation of subsurface structure maps (see Box 1) will assist the definition and organisation of future water prospecting in arid areas. The JERS-1 SAR mosaic has also allowed the discovery of a very large crater field (Paillou et al. 2004, Paillou et al. 2005, Paillou et al. 2006, Heggy et al. 2005 & 2006), which is located in the southwest of Egypt and covers an area of greater than 40000 km^2. More than 1300 craters are contained and the discoveries have been confirmed subsequently by fieldwork.

Table 2.4.B Benefits of using ALOS PALSAR for sub-surface geological mapping

1	L-band SAR signals penetrate dry sand covers several meters - considerably deeper than shorter wavelength (C-band) sensors. PALSAR provides even deeper penetration than JERS-1 SAR due to higher transmission power.
2	L-band SAR is less sensitive than C-band to surface roughness, which can mask subsurface information.
3	The finer spatial resolution from PALSAR together with polarimetric (HH+HV) capabilities and low Neσ0 value will allow generation of a detailed map of shallow subsurface features that will constitute the basis for new geological maps. The HV/HH ratio, in particular, will be used to identify regions where subsurface or volume scattering occurs.
4	The PALSAR systematic observations and mosaic products will allow subsurface geology to be mapped across extensive regions.

K&C activities

While the SaharaSAR project has proved the concept for subsurface geology mapping with L-band SAR, the mosaics generated nevertheless highlight a number of shortcomings of JERS-1 in this context. Notably, the JERS-1 SAR data coverage over northern Africa is not spatially complete, as the gaps in Fig. 2.4.6 illustrate. The low transmitting power of the JERS-1 SAR (reduced from 1.3 kW to 325 W following antenna deployment problems early on in the JERS-1 mission) furthermore impacts interpretability, as the resulting 6 dB increase of the noise floor (ESN ~ -18 dB) yields reduced penetration depth. ALOS PALSAR on the other hand, will through the systematic observation strategy provide spatially consistent coverage over all land areas, and feature a 2 kW transmission power with sensitivity down to about –27 dB, allowing penetration deeper down into ancient river channels. PALSAR also provides an additional (cross-polarisation) channel and improved spatial resolution. Comparison between the JERS-1 SAR and PALSAR data clearly shows the superior capacity of the PALSAR sensor to map subsurface features. Due to its improved $NE\sigma_0$ and finer resolution, PALSAR allows in particular a better detection of fine paleo-hydrological networks, such as the one shown in Fig. 2.4.7.

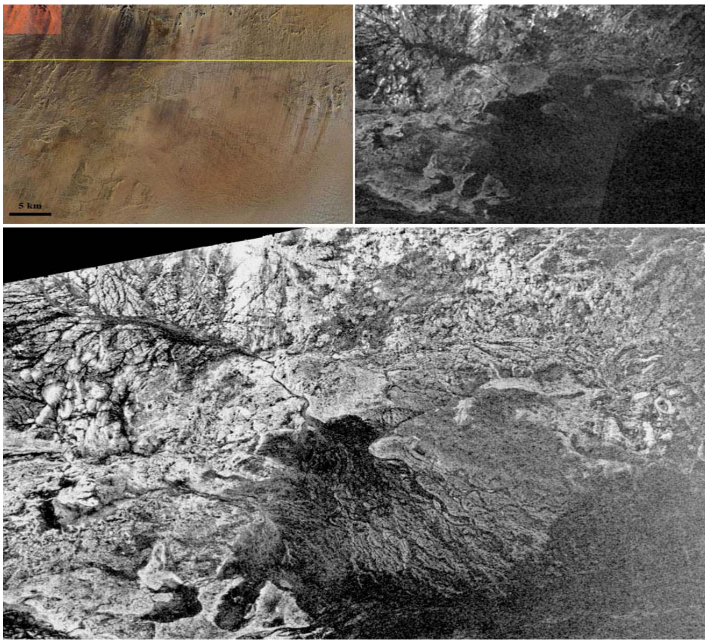

Figure 2.4.7 Landsat (top left), JERS-1 (top right) and PALSAR image (bottom) of a region located around 21°55'N, 26°36'E. PALSAR much better reveals paleodrainage channels in the lower part of the scene.

Within the framework of the K&C Initiative, generation of improved second generation radar mosaics covering the entire Sahara and Arabian peninsula will be conducted, generated from PALSAR dual-polarized (HH+HV) data at 50 m resolution (for further information about PALSAR mosaic assembly, see the Mosaic Theme chapter below). The higher resolution expected from PALSAR, together with polarimetric capabilities, will allow a definitive map of shallow subsurface features to be generated which will constitute the basis for new geological maps. Multi-temporal mosaics, generated using data acquired during (northern hemisphere) summer and winter, will be used in an effort to detect seasonal water table changes in the vicinity of sand dunes and oases. The salinity content of water might in particular produce a very specific signal in L-band data (Lasne et al. 2005 & 2007, Freeman et al. 2007). The HV/HH ratio will be used to locate regions where subsurface or volume scattering occurs.

First PALSAR acquisitions over North Africa and Arabia took place during June and July 2007 (ascending cycles 12 and 13). We produced a new high-quality radar mosaic over eastern Sahara, using more than 200 PALSAR strips (cf. Fig. 2.4.8). First analysis of PALSAR data shows excellent data quality, allowing a very good detection of subsurface structures (Paillou et al. 2007 & 2008). We also implemented a WMS (Web Map Server) at OAB in order to access the PALSAR mosaic through Google Earth, and perform comparative analysis with optical (Landsat) data (see Fig. 2.4.9). New PALSAR acquisitions over Sahara and Arabia are planned during June and July 2008 (cycles 20 and 21): these data will be used to complete missing strips and detect possible soil moisture changes.

The PALSAR mosaic over North Africa and Arabia will constitute a unique tool for the scientific community to study the paleo-environment and paleoclimate of North Africa. It will help build more complete geological maps, as a support to future water prospecting in arid and semi-arid regions. The Gobi desert, southern Africa and central Australia are identified as potential second phase prototype areas.

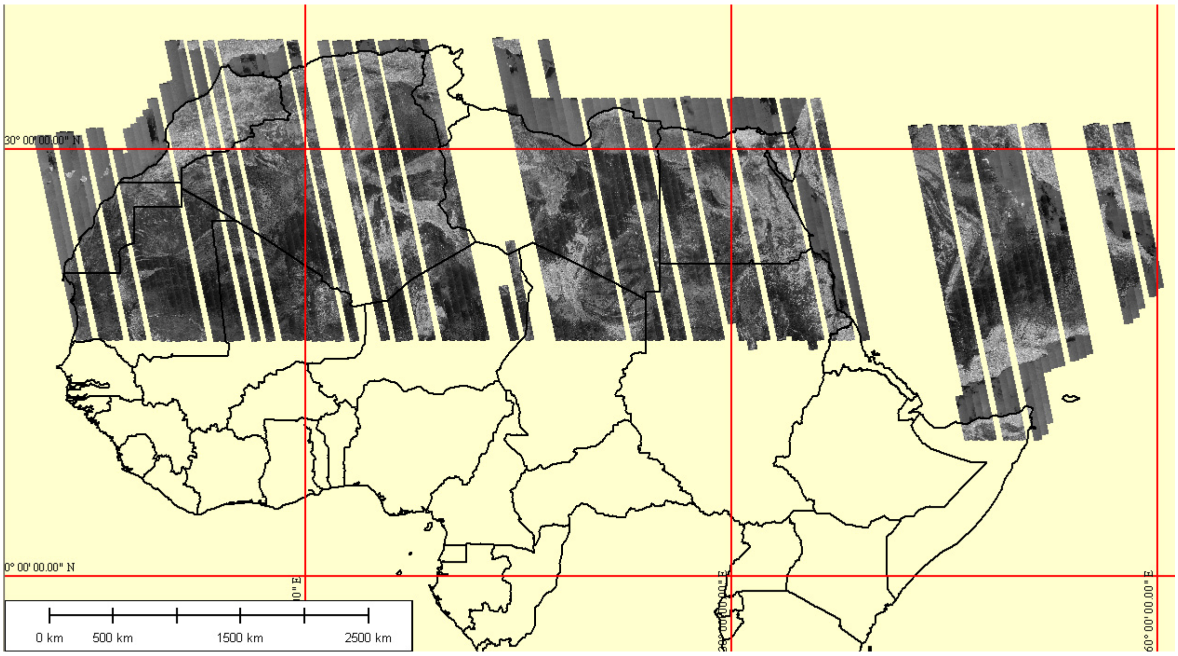

Figure 2.4.8 PALSAR mosaic over North Africa and Arabia assembled from data acquisitions of cycles 12 and 13.

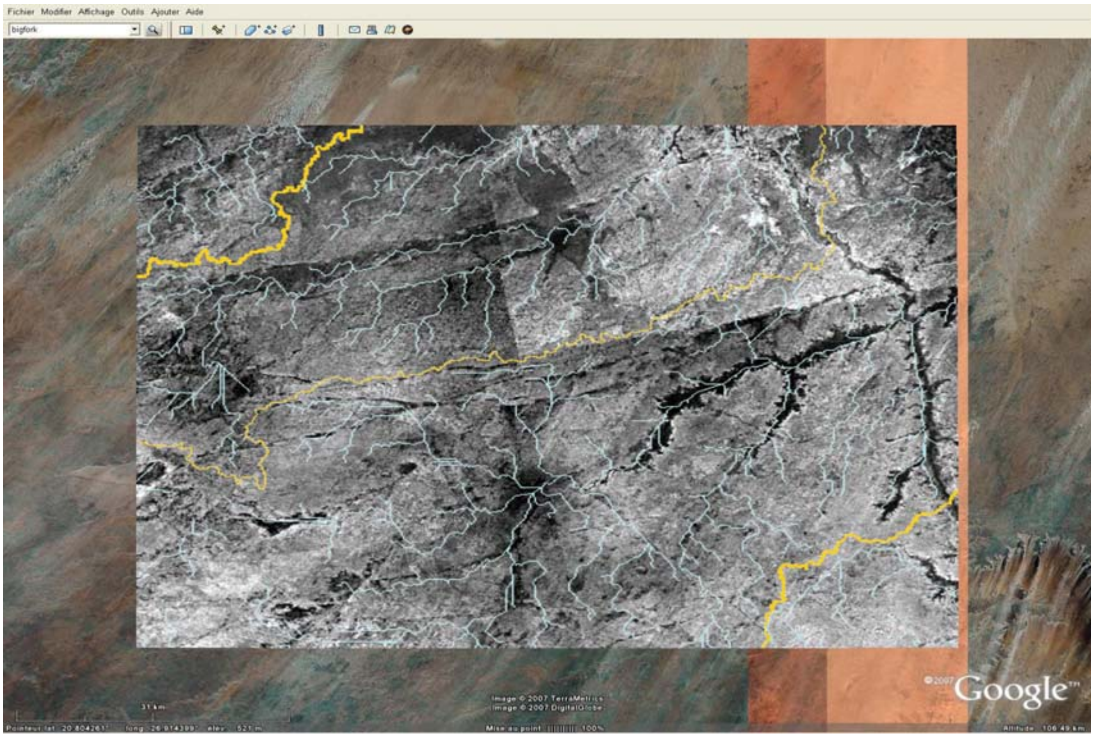

Figure 2.4.9 PALSAR data display in Google Earth using the Web Map Server located at OAB.

Product Box D-1 – Subsurface geology
K&C product(s): Regional maps of subsurface geological structures
Regional maps of sub-surface changes (indicating seasonal moisture variations).

Intended use: As basis for new geological maps over regional scales with significantly improved information about geological and hydrological features. To be used for location of below-ground water reservoirs , as well as input to paleo-climatological studies.
Prototype areas: The Sahara desert, the Arabian peninsula.
Input data: Multi-temporal (18 months) PALSAR mosaics at 50 m resolution.

Landsat ETM+ (left) and JERS-1 SAR (centre) imagery of southern Egypt, revealing an ancient river network below the surface sand layer. The image to the right illustrates a map with subsurface structures interpreted from SAR data, superimposed over the SAR image.

Product Developer:

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Collaborators:

Tom Farr	NASA JPL, USA
Ake Rosenqvist	JRC, Italy

2.4.5.2 Land degradation and desertification

Building on the experience from JERS-1 SAR

While JERS-1 L-band SAR has been used extensively in the context of forestry, wetlands and subsurface geology mapping in the past, the use of L-band SAR, and in particular L-band interferometric coherence, for mapping and monitoring of desertification and land degradation is a virtually new application area.

Theory holds that L-band SAR coherence should prove advantageous in comparison with interferometric coherence derived from shorter wavelength SAR systems, in particular in being less sensitive to temporal noise, and hence remaining stable over longer temporal baselines. Long-term stability over periods as long as three years has also been confirmed with JERS-1 SAR data.

In order to confirm the utility of ALOS PALSAR coherence for desertification mapping, this component of the K&C Initiative will initially focus on demonstration of the technology over four local prototype areas, three in Africa (Senegal, Malawi and Botswana) and one in central Asia (Mongolia).

As described below, PALSAR data will be used in combination with several other data sources, including optical sensors, Envisat ASAR C-band and socio-economic data.

Vulnerability mapping

Land degradation and desertification are complex processes, whose severity, extents and causes vary both spatially and temporally. Requirements for relevant information in consequence vary as well, and a modular approach – where Earth observation products can be generated at different spatial and temporal resolutions – needs to be applied. The products foreseen within this component of the K&C Initiative are obtained in two steps:

- Earth observation products based on a multi-sensor, -resolution and -temporal approach;
- Integration of Earth observation products with socio-economic data to produce vulnerability maps.

The use of different sensors, as shown in Figure 2.4.6, implies the combination of different spatial resolutions and spectral characteristics. Therefore, it raises the problem to obtain scaleable products, which are independent from their spatial resolutions, but also that take advantage of the specific capabilities of the different sensors. For this reason an approach will be applied where generic, scale-independent products (such as Vegetation Index) are obtained from systems having different spatial and temporal resolutions and which can be compared with each other. Specific products (such as Digital Elevation Models) which are sensor related are designed to be applied to well defined areas to assess and monitor specific issues.

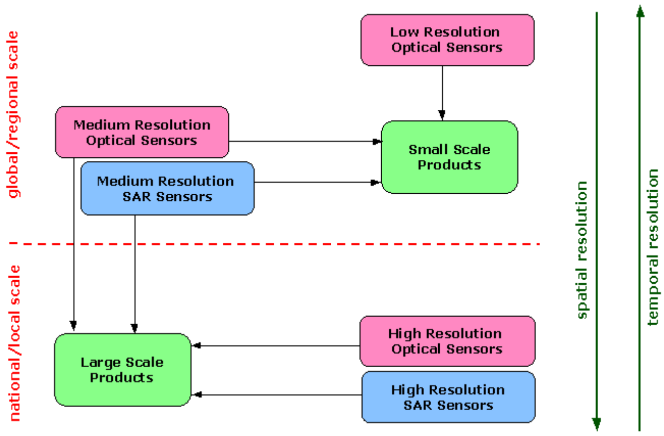


Figure 2.4.6 Scalability and Earth Observation data integration

In order to integrate regional and national/local information, a multi-scale approach is considered:
Small scale monitoring
- Vegetation Index
- Land Cover Map (crop area, surface water, vegetation, bare soil)

Large scale mapping
- Vegetation Index
- Land Cover Map (crop area and types, surface water, different types of vegetation, bare soil)
- Additional Products (detailed information on crop area and vegetation types)

Such an approach allows continuous and long-term monitoring of vegetation vs. dry land status (land degradation/recovery monitoring) at regional scales (small scale monitoring), as well as estimation at local scale (large scale mapping) of the status of land vulnerability by combining specific Earth observation products with socio-economic data. The link between small scale and large scale Earth observation products is guaranteed by the generation of generic products.

Generic product definition
- Land Cover Map (LCM): description of land cover type.
- Vegetation Cover Index (VCI): an area based indicator which quantitatively describe the status of vegetation and assess the dimension of the vegetated area. This indicator ranges from zero (vegetation) to one (bare soil).
- Vegetation Cover Change Index (VCCI): a pixel based indicator which quantitatively describe the changes of vegetation over the time. This indicator, based on the difference between two VCI data, range from -1 (total degradation) to 1 (total recovery). Value zero corresponds to no changes.

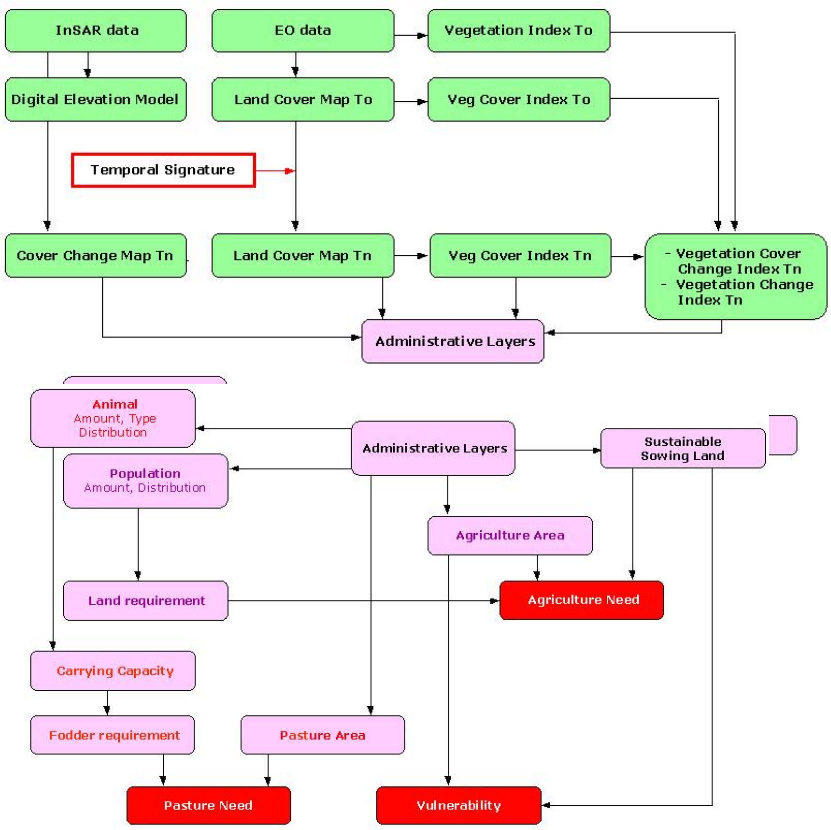
Specific product definition
- Digital Elevation Model (DEM)
- Vulnerability (V), Agriculture Need (AN), Pasture Need (PN): area based indicators, usually at administrative unit (for instance village, district, province), which quantitatively and qualitatively represents the vulnerability of land deterioration considering the land cover type, dimension and human and/or animal pressure.
- Cover Change Index (CCI): a pixel based indicator, which qualitatively describes the cover changes over the time and quantitatively assesses the dimension of the area. The rationing between Cover Change

Maps enables to determine land recovery (infinite) or degradation (zero). One corresponds to no changes.

Figure 2.4.7 illustrates the desertification product generation flow. Note the differentiation between:

- The remote sensing part – highlighted in green – represented by: SAR Interferometry (InSAR) processing for the generation of Digital Elevation Models, Land Cover/Change Maps and the Earth observation data – SAR and multi-spectral – analysis for the generation of Land Cover, Vegetation Cover Index, Vegetation Index, Vegetation Change Cover Index and Vegetation Change Index.
- The multi-disciplinary part – highlighted in light violet and red – characterized by the integration of Earth Observation data with socio-economic data. Note that the computation of vulnerability is based on the type of pressure that a given region is subject to and therefore specific models are required. For instance, in Mongolia land degradation is strongly related to the animal pressure and thereby a specific relationship between available pasture and amount/type of animals must be applied. In Senegal, on the other hand, land degradation is an outcome of population pressure and therefore the agricultural extent/type must be related to the human density.

Taking advantage of the systematic observation strategy implemented for PALSAR, repeat-pass SAR interferometry will be used to combine backscattering coefficient information (σ^o), backscattering coefficient difference between two acquisitions ($\Delta\sigma^o$), and coherence data (interferometric correlation). The merging of backscattering coefficient with coherence allows, for instance improved discrimination between land cover types. In this context, it should be noted that the backscattering coefficient is sensitive to macroscopic object properties and to long-term scatter changes. In most cases, thematic information contents increase with increasing acquisition interval. Coherence is sensitive to microscopic object properties and to short-term scatter changes. In most cases, thematic information contents decreases with increasing acquisition interval, mainly due to phenological or man-made changes of the object or weather conditions. Since the selected sites are located in dry areas, high coherence information even over long-term is expected.



Figur 2.4.7 Desertification product generation flow

Over long time periods, in areas where the temporal interferometric decorrelation is limited, InSAR can be used to extract information on the surface state. Dry zones fulfil this requirement, allowing cover changes to be monitored. Other works confirmed these assertions, reporting for instance that, in the Sahelian area, the predominantly bare desert surface forms an extremely stable landscape, which retains high coherence over several years (sarmap *et al.,* 2003),. The contrast between correlated features and decorrelated signatures permits, therefore, immediate detection and delineation of unstable features. An evident example is the mapping of mobile sand, dune distributions over the desert, and erosion processes.

Cover Change mapping

The capacity to remotely detect and identify land cover types and their temporal and spatial changes is a major issue in arid and semi-arid regions. Thanks to their high temporal repetition, low resolution optical instruments have in the last three decades provided a huge amount of information on the Earth's cover, mainly through various vegetation indices.

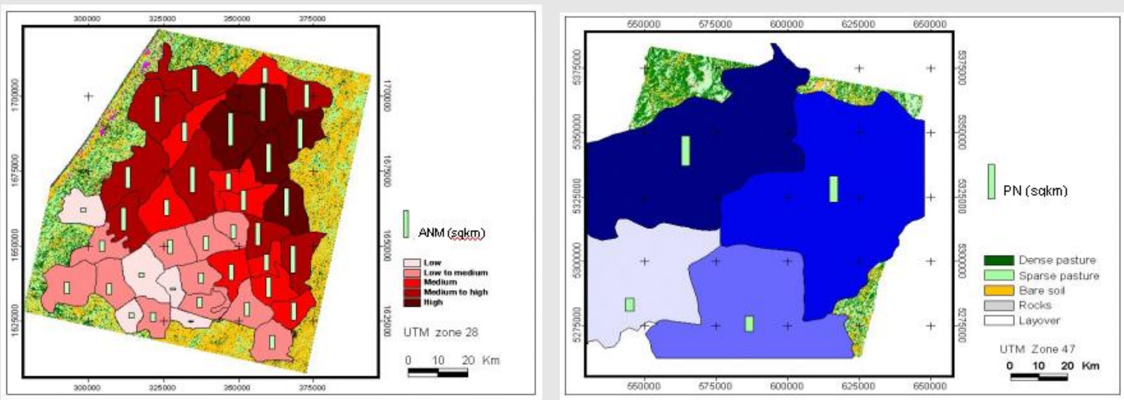
An alternative parameter, which to date has not been considered within the desertification issue, is interferometric coherence. The main particularity of this parameter is that it is sensitive to microscopic object properties and therefore it permits the detection of spatial and temporal variations at micro scale (Stebler *et al.,* 1996). Furthermore, coherence is from a theoretical point of view a polarised statistical estimator that is characterised by a variance that increases with the decrease of the true coherence value. It is therefore more difficult to obtain a robust estimate of low coherence values than for higher ones. The use of L-band PALSAR data is in this context of particular interest, as L-band sensors are characterised by a deeper penetration than their C-band counterparts, thus making the SAR signal less dependant on the first layer in the vegetated areas (forests, grassland), and providing higher values of interferometric coherence even over long time intervals.

Product Box D-2 – Desertification/land degradation

K&C products: Maps of desertification vulnerability
Land Cover maps
Land Cover Change Index
Crop type and acreage
Pasture extent
Digital Elevation Models

Intended use: For early warning purposes at local, national and regional levels.

Prototype areas: Senegal, Malawi, Botswana and Mongolia.
Input data: PALSAR SLC data, multi-temporal time-series acquired during the crop season



Maps of agricultural pressure in Senegal (left) and livestock pressure in Mongolia (right). The products were derived from ERS C-band SAR data within the framework of the ESA TESEO project (Sarmap et al., 2003).

Product Developers:

Francesco Holecz, Paolo Pasquali — Sarmap, Switzerland

In the land degradation context, constant high coherence values or a general increase of the coherence over years would indicate no vegetation (and therefore highlighting the aridity) or a continuous degradation of the soil, while a low coherence or a general decrease would correspond to vegetative areas, a soil recovery or continuous soil changes. Since short-term – monthly and/or seasonal – but also long-term variations of the surface cover are relevant within the desertification issue, the SAR data should preferably be acquired at each repeat-pass over long periods, i.e. years. The basic idea for the generation of this index is to calculate the coherence of image pairs acquired at each repeat-pass, allowing in this way, to identify short-term – i.e. monthly and seasonal – land cover changes. As qualitatively and quantitatively illustrated in Figure 2.4.8 and 2.4.9, repeating the coherence calculation at each repeat-pass over years, long- and short-term spatial and temporal variations (signatures), which are object dependent, can be easily recognised.

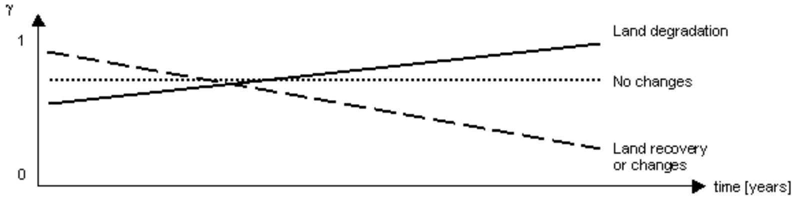


Figure 2.4.8 Qualitative illustration of the land degradation index – long term signature.

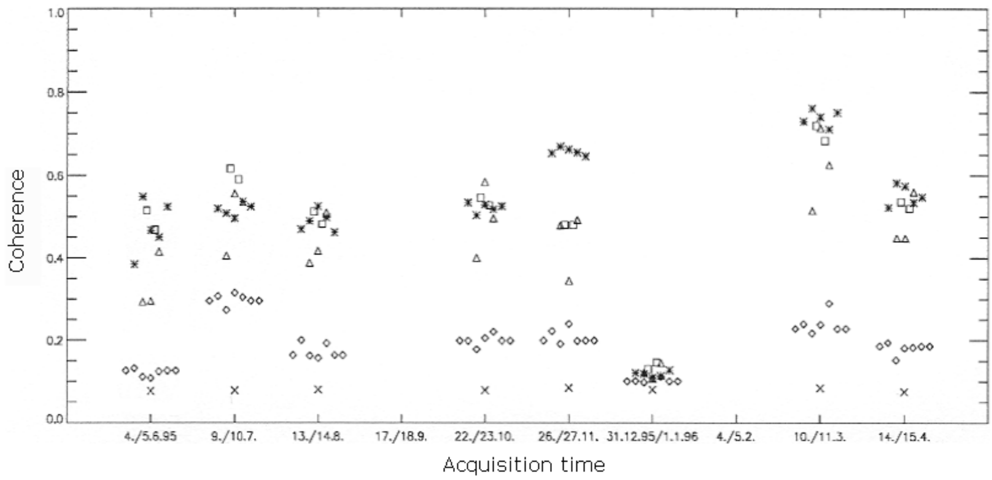


Figure 2.4.9 Inter-annual variations of the coherence derived from ERS acquisitions in the area of Berne, Switzerland – short-term signature (star = agriculture, diamond = forest, triangle = meadow, square = urban area, cross = water).

Two examples of false-colour composite images for a location in Mongolia obtained from L-band JERS-1 images are shown in Figure 2.4.10 for a 3-month (a - left) and 3-year (b - right) time interval respectively. Notable is how the average coherence value is not lower in the three-year case, but actually even higher than in the three-months case. The capability provided by the L-band frequency of generating long time-interval coherence maps (Fig. 2.4.10b) allows to concentrate the analysis on long-term land cover changes rather than on short-term variations of the SAR signal itself over same cover types (Fig. 2.4.10a). This is feasible also for other classes of vegetation (e.g. forest, grassland) that, over long time intervals, would provide too low coherence values in C-band, and therefore would prove difficult or impossible to discriminate using low-penetration systems.

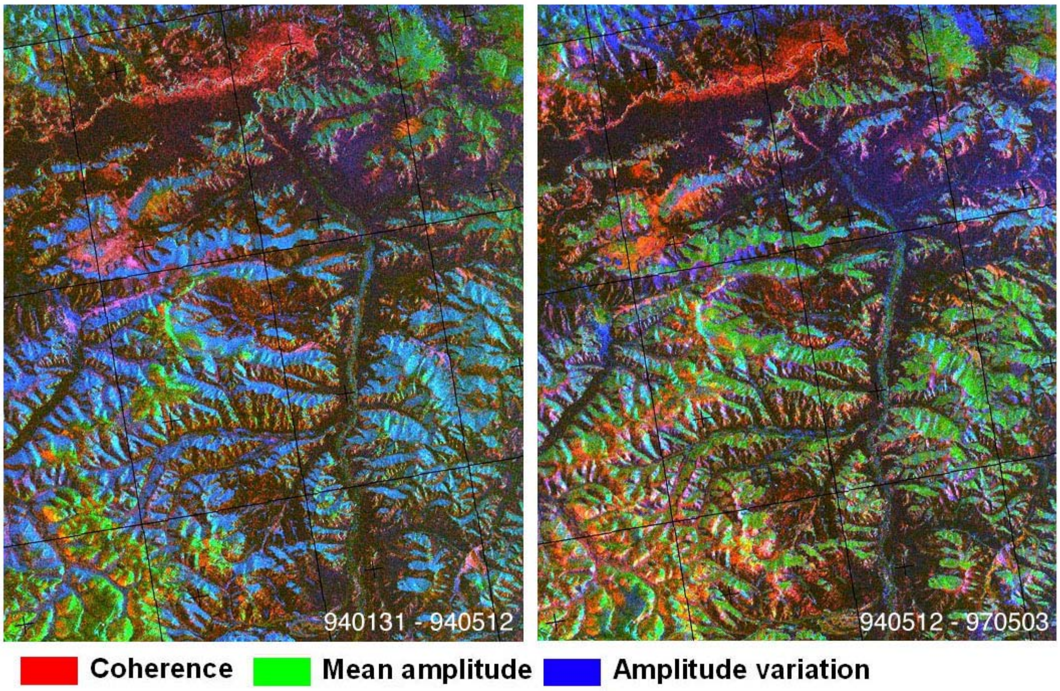


Figure 2.4.10 JERS-1 SAR false-colour composites illustrating changes in L-band backscatter and coherence for a location in Mongolia over (a – left) a 3-month period and (b – right) a 3-year period, respectively. Red channel: coherence. Green: average amplitude. Blue: amplitude variation

Land degradation processes and their corresponding locations can best be detected if land cover changes (in terms of amplitude and coherence) are compared over several years, and during approximately same month, in order to assure similar phenological conditions. From the 3-year image composite in Fig. 2.4.10b (May 94-May 97), the following information can be derived:

- Red areas: Areas with high coherence, indicating no identifiable land cover changes over the 3 year period, and hence: no land degradation is observed. The high coherence values furthermore reveal that these areas are covered by abiotic surfaces, such as rocks and bare soil.
- Green areas: Areas characterised as highly vegetated areas (such as forest), which remain unchanged over the 3-year period. The high backscattering values demonstrate strong radar reflectivity which remains stable over the time.
- Blue areas: Land cover changes have occurred in the cyan (weak) and blue (strong) areas. In these cases, the interferometric correlation is essentially zero and relevant intensity changes could be identified. Such areas (except water) are prone to land degradation.

Hence, interferometric correlation combined with backscatter intensity variations provide useful information to monitor land degradation phenomena. In contrast to backscatter, significant object variations are characterised by low coherence values. In this case, the information provided by the backscattering coefficients allows the determination of land cover differences within incoherent areas.

Figure 2.4.11 represents the relationship between coherence and backscatter variations. It can be seen that incoherent changes correspond to large backscattering changes, highlighting the potentiality and feasibility of the utilisation of SAR time series for crop area determination. A key issue is how multi-temporal Earth observation data should be classified assuming that a reference classification at time T_0 and its corresponding SAR data are available. The need for an automatic or at least semi-automatic method for data classification is essential. In this context, it is worth noting that SAR systems are appropriate because unsupervised processing is possible, provided of course, that data are collected with an adequate repetition frequency and timing.

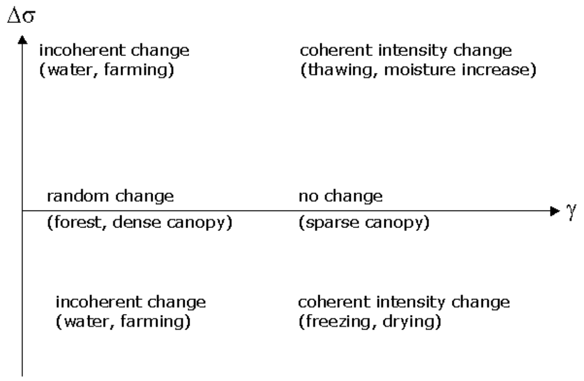


Figure 2.4.11 Relationship between interferometric correlation ( ) and backscatter intensity change ( ) for different types of change.

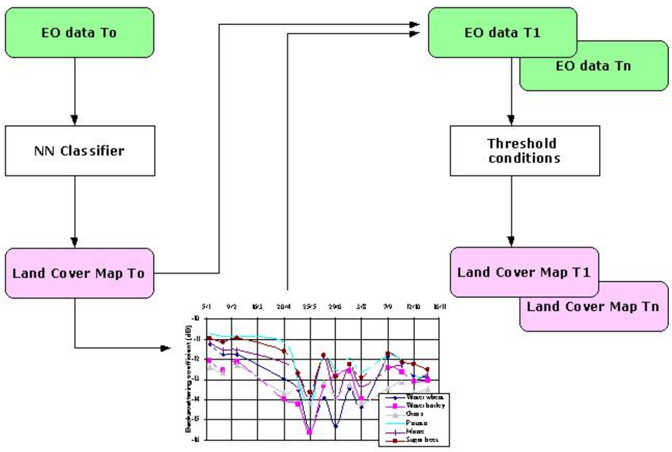


Figure 2.4.12 Multi-temporal classification approach. The diagram shows average backscatter profiles over crop fields.

Fig. 2.4.12. illustrates the implementation of the unsupervised multi-temporal classification, as foreseen within the K&C Initiative. Note that while the focus will be on the determination of major crop types and crop acreage, other features such as water bodies and loss/recovery of vegetation will be also retrieved. As mentioned earlier, integration of ALOS PALSAR data with other data sources such as Envisat ASAR, multi-spectral instruments and ancillary data will enable to generate improved products.

2.4.6 Acknowledgements

This chapter was authored by Philippe Paillou, with significant contributions from Francesco Holecz and Paolo Pasquali (Desertification), and modifications by Ake Rosenqvist and Richard Lucas.

2.5 The Mosaic Product Theme

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2.5.1 Introduction

2.5.1.1 Scope of the Mosaic Product Theme

While the ALOS K&C Initiative seeks to derive regional to continental scale scientific products by implementing a systematic observation strategy of global dimensions for ALOS (Rosenqvist et al., 2004), the Mosaic Product Theme can be considered an integral component of the observation strategy, in which a considerable share of the extensive PALSAR data amounts acquired are used to produce spatially and temporally consistent image mosaics over all land areas on the globe. The mosaic products aim to allow up-scaling from small and localized experimental scientific studies to an operational and regional/continental context in support to the multi-scale information needs relevant to international conventions, carbon cycle science and environmental conservation.

The Mosaic Product Theme differs from the Forest, Wetlands and Desert & Water Themes in that it is not set out to produce *derived thematic products*, but rather a set of *data products*, which are to be provided both as intermediate products to be used by the K&C Science Team in the generation of ALOS K&C Prototype Products, as well as stand-alone data sets which will be made available free of charge in public domain to support public users and research investigations beyond the direct scope of the K&C Initiative.

2.5.1.2 Building on the experiences from JERS-1 SAR

One of the main motivations of the mosaic theme lies in the historical context of the Global Rain Forest and Boreal Forest Mapping (GRFM/GBFM) project in which JERS-1 SAR imagery from the Earth's tropical and boreal zones were calibrated and subsequently mosaicked for further use by scientific users world-wide (Rosenqvist *et al.,* 2000 and 2004). The mosaic theme therefore can be considered as descended from the GRFM/GBFM project, building upon the lessons learned and algorithms developed therein. A major such experience is how extensive and homogeneous image mosaics facilitate multi-scale analysis over regional to semi-continental scales, and thus the development of new applications which earlier have not been feasible using fine resolution remote sensing data.

Figure 1 illustrates a typical GRFM mosaic product: a regional-scale multi-temporal mosaic composite over the entire Amazon River basin, generated from JERS-1 SAR data acquired during the high water (red channel) and low water (green) seasons season, clearly showing the dynamics of the extensive flooding of the Amazon basin. It should be noted that no other sensor than a long-wavelength SAR – acquired consistently within a short time window – has the capacity to provide this kind of synoptic information.

Mosaic generation is however not a straight-forward task, both with regard to the handling of large amounts of data and to geometric precision in the assembly of the data. The Mosaic Product Theme builds on the mosaic technology developed (by JAXA EORC, the Jet Propulsion Laboratory and the E.C. Joint Research Centre) within the GRFM/GBFM framework. A major challenge here is to improve the throughput from data acquisition to the final mosaic product from the order of years to the order of months.

Another issue which became apparent during the GRFM/GBFM project is the necessity for high radiometric calibration accuracy of the mosaic products – both within scenes and between passes. In order to allow analysis of the mosaics as if they were single-, not composite-, images, a radiometric stability across the mosaic of a few tenths of a dB is often required.

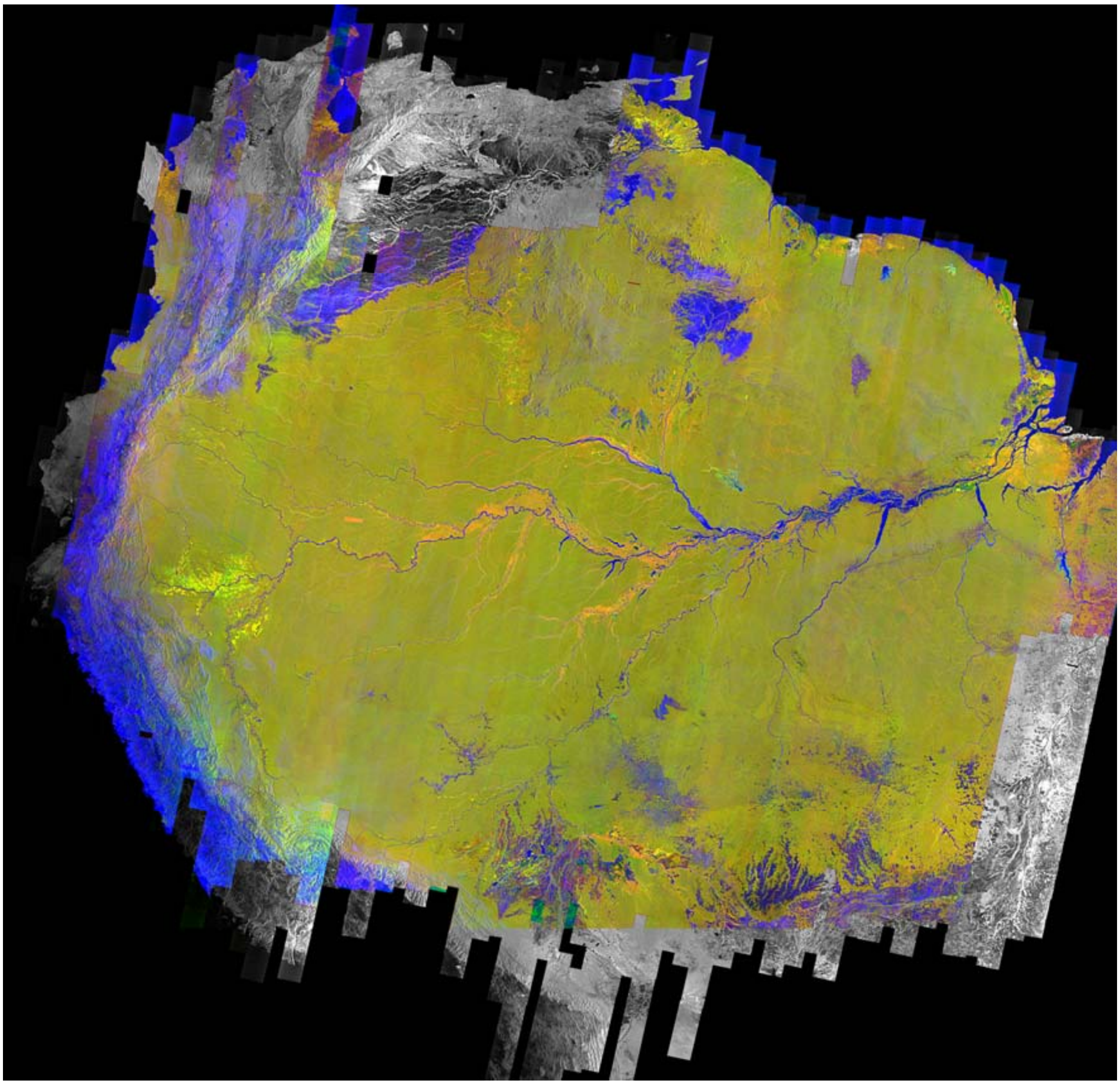


Figure 2.5.1. Continental-scale, dual-season mosaic of the Amazon basin, composed from over 2000 JERS-1 SAR scenes. The high water (June-July, 1996) and low water (Oct. 1995) mosaics are shown in the red and green channels, respectively. The radar texture (blue) is added to enhance topography and features not apparent in the backscatter data.

Within the K&C Initiative, geometric and radiometric calibration will continue to be issues of prime importance. Since the start of the GRFM/GBFM project in 1995 however, there have been several technology enhancements that will make mosaic generation from PALSAR less complicated: path image processing (used for the SE-Asia, Siberia and Europe mosaics, but not for Africa, North- and South America), enhanced computer performance and reduced hardware costs, fast on-line data transfer, improved position accuracy expected for ALOS (poor JERS-1 geolocation accuracy induced major difficulties in the GRFM mosaicking process), and the availability of a near-global high resolution DEM (SRTM) for ortho-rectification and calibration. The fact that all K&C mosaicking partners will be using the same input data products (path images), processed by the same processor (EORC SIGMA-SAR) will also help streamline the process.

2.5.1.3 The significance of ALOS

In the context of this theme, the main significance of ALOS is the implementation of the systematic observation strategy, which will enable the compilation of spatially and temporally consistent image mosaics at fine spatial resolution over any arbitrary region on Earth, on a repetitive basis. While a single full global PALSAR mosaic coverage is planned to be generated within the K&C Initiative within the first three years of the ALOS mission, it should be noted that all data acquired within the observation strategy features – several global coverages per year – are archived for future use.

2.5.1.4 The role of the Mosaic Product Theme

The mosaic product generated within the Theme play an important role within K&C Initiative:

- **Multi-scale analysis:** The K&C Initiative is regional to global in scope and is designed to encourage science investigations on a continental scale. The fine resolution mosaic products enable investigations over extensive regions, at any spatial resolution from fine (50 m) to coarse.
- **Centralised mosaicking:** Continental-scale analysis requires the use of thousands of scenes, and if multi-seasonal or inter-annual data sets are required, the task of building derived products requires a substantial effort towards data management. The Mosaics Product Theme aims to support each of the Forest-, Wetlands, and Desert & Water themes - which all have similar data requirements - by reducing the data processing loads, eliminate duplicate mosaic generation and ensuring the use of similar and consistent intermediate input data.
- **Simplified analysis:** For analysis of large regions extending over a single satellite scene, performing accurate area calculations constitutes a difficulty due to the overlap between adjacent scenes, which arises from the observation geometry and the swath width dependence on the mode of acquisition. An efficient way to simplify area calculations is to remove the overlap between scenes through mosaicking.
- **Data volumes:** The data volume of the mosaic products will be smaller and easier to distribute and manage than multiple standard image products for the same regional coverage.

2.5.2 Components of the Mosaic Product Theme

The Mosaic Product Theme comprises the generation of three types of PALSAR mosaics:
- Fine resolution mosaics
- ScanSAR mosaics
- Browse image mosaics

In addition, the theme also includes the generation of path images – continuous images corresponding to the satellite swaths – which constitute the basic input data for all mosaic products. For K&C activities involving SAR interferometry, standard product PALSAR Single Look Complex data will be provided from JAXA's Earth Observation Center in Hatoyama.

Table 2.5.A K&C PALSAR mosaic and path product characteristics

	Nominal pixel spacing	Number of looks
Path images		
Fine Resolution Slant Range (HH)	52x35 m	64
Fine Resolution Slant Range (HH+HV)	52x70 m	64
Fine Resolution Ground Range/Ortho corrected (HH)	50x50 m	64
Fine Resolution Ground Range/Ortho corrected (HH+HV)	50x50 m	64
ScanSAR Slant Range (HH)	40x70 m	12~20
ScanSAR Ground Range/Ortho corrected (HH)	70x70 m	12~20
Fine Resolution Mosaics		
HH	50x50 m	64
HH/HV	50x50 m	64
ScanSAR mosaics	100x100 m	12~20
Browse image mosaics	500 m / 2 km	12~20

2.5.2.1 Path images

Path images constitute the basic input data for all products to be generated within the K&C Initiative, both within the Mosaic Product theme, as well as within the Forest, Wetlands and Desert & Water themes. The path images are extended image swaths, 70 km in width, which correspond to the data segments acquired by the PALSAR sensor – in whole or parts thereof. Path images may extend to several thousands of km in length. They are intermediate products whose distribution will be limited to the K&C Science Team.

Generated by JAXA EORC using the SIGMA-SAR strip-map processor, the path images are available in slant range, ground range or as ortho-corrected products, in which case the best regional DEM available is used. Within the K&C Initiative, the path images feature a nominal pixel spacing of 50 metres, resampled from the full resolution data by block averaging to yield some 64 independent number looks per pixel. Path images are generated for both the co- and cross-polarised channels when acquired in dual polarisation mode.

The ScanSAR path image products have the same characteristics as the fine resolution products, but with 350 km swath width, 70 m pixel spacing and 12~20 looks (12, 20, 16, 20 and 20 looks for ScanSAR beams 1, 2, 3, 4 and 5, respectively). Depending on the radiometric calibration quality that can be achieved for the ScanSAR data, ScanSAR path images may either be produced for each of the five individual beams, or if the radiometric quality is deemed satisfactory, as combined 5-beam products.

Browse path images will be produced for all PALSAR data acquired by ALOS, generated continuously in an automated manner as the raw SAR data arrive at EORC from JAXA's Hatoyama Earth Observation Center (EOC). Using the SIGMA-SAR processor, the browse imagery are generated through a ScanSAR-type of processing, yielding a 16 look, 70 m pixel spacing for fine resolution data, and 16 look, 192-320 m pixel spacing for PALSAR data acquired in ScanSAR mode.

Product Box M-1 – Path Images

K&C products: PALSAR Path Images

Intended use: To provide original source imagery for investigators to study calibration and incidence angle effects prior to mosaicking. The ScanSAR and fine resolution image mosaics will be composed of these image products.
Prototype areas: All PALSAR data acquired within the K&C Initiative
Input data: PALSAR raw signal data (Fine Beam Single-pol HH, Fine Beam Dual-pol HH+HV, ScanSAR 5-beam HH).

ALOS PALSAR Path Image processed by EORC. This particular path image over Cameroon (RSP 614, acquired August 22, 2007) is a part of a 3000 km data segment (~70 km wide), corresponding to ~ 12 standard JERS-1 images. North is to the left, and SAR illumination direction from bottom to top in the image. (ascending observation, right looking)). All PALSAR path images are generated from full resolution data (10 m for single [HH] polarisation, 20 m for dual [HH+HV] pol.), filtered to 50 m pixel spacing, multi-look (see Table 2.5.A).
Product Developers:
Masanobu Shimada JAXA EORC

Table 2.5.B Benefits of ALOS PALSAR path images

1.	Original source imagery for more in-depth analysis of calibration and incidence angle effects
2.	Rapid processing, available to K&C Science Team within one satellite cycle after acquisition
3.	No re-sampling of imagery beyond what is necessary for SAR processing and initial projection
4.	Input to Fine Resolution and ScanSAR image mosaics

2.5.2.2 Fine resolution mosaics

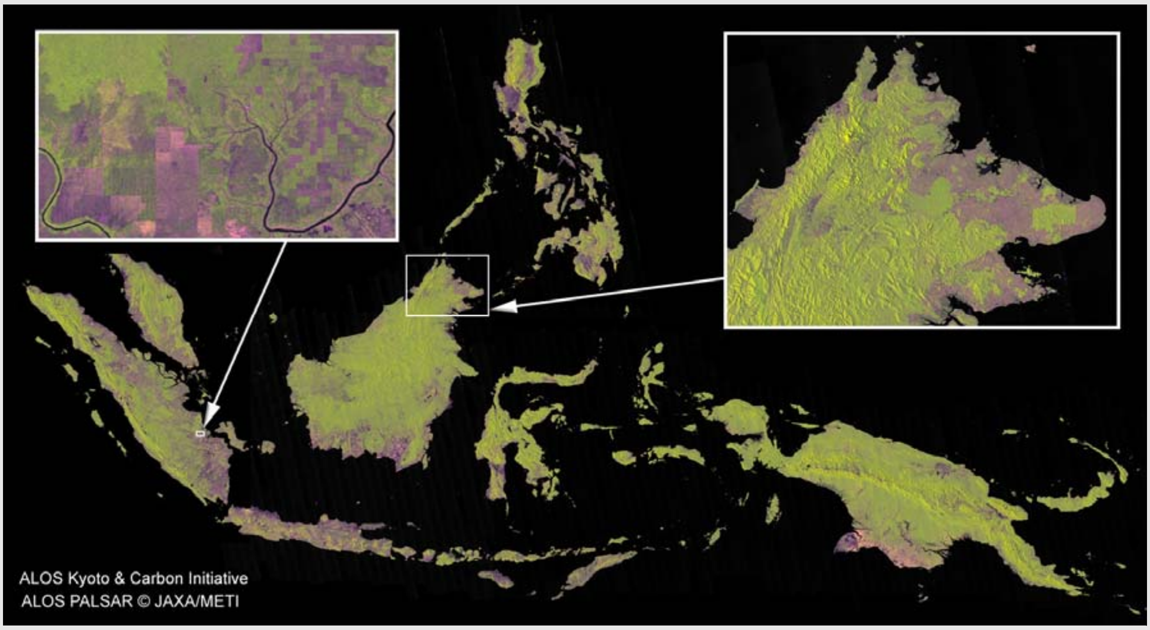
The fine resolution mosaics will be generated from slant range path images, as described above. To take advantage of the polarimetric capacities of PALSAR, the fine resolution mosaics will primarily be generated from PALSAR data acquired in dual-polarisation (HH+HV) mode at 34.3° off-nadir angle. During the first three years of the ALOS mission, at least one full dual-polarisation wall-to-wall coverage is planned over each of the continents. Mosaics at single polarisation (HH, 34.3°) will in addition be generated over regions selected for multi-seasonal studies. In accordance with the systematic observation strategy implemented for PALSAR (see 3.2 below), global dual-polarisation acquisitions will take place on an annual basis between May and September, while single-polarisation observations over the same areas are scheduled during the December-February time window. In order to minimise temporal variations within each of the continental mosaics products, data acquired within a given single 46-day cycle will primarily be used. Data gaps that inevitably will occur will be filled in with data acquired during the previous – alt. the next – satellite cycle.

All fine resolution mosaics will have an output pixel spacing of 50 metres, which for a global data set represents an unprecedented fine resolution. The multi-scale characteristics of the fine resolution mosaics are illustrated in Box M-2. Digital Elevation Models will be used for geometric ortho-rectification, as well as for radiometric calibration (van Zyl *et al.,* 1993) of the mosaics, which will be provided in a standard projection (default: geographical coordinates) and format (GeoTIFF),

Product Box M-2 – Fine Resolution Image Mosaics

K&C products: Fine Resolution Mosaics

Intended use: To provide spatially and temporally consistent, continental-scale imagery to the K&C Science Team and to external science communities, to facilitate synoptic, multi-scale analysis over extensive regions.
Prototype areas: All land areas except Greenland and Antarctica
Input data: PALSAR path images (Fine Beam, HH+HV and HH).



ALOS PALSAR Dual-polarisation mosaic over insular Southeast Asia. (R:HH, G:HV, B:HH/HV), acquired July-Sept, 2007. Mosaic pixel spacing 50 m.

Product Developers:

Masanobu Shimada	JAXA EORC, Japan
Bruce Chapman	NASA Jet Propulsion Laboratory, USA
Granfranco De Grandi	Joint Research Centre, E.U.
Philippe Paillou	University of Bordeaux-1, France

The mosaicking procedures build on the algorithms developed within the GRFM/GBFM project by JAXA EORC (Shimada and Isoguchi, 2002), JPL (Siqueira *et al.,* 2000) and the JRC (De Grandi *et al.,* 2000). The same organisations share the mosaicking tasks within the K&C Initiative, and in addition the University of Bordeaux-1, who will collaborate closely with the JRC. Regional division of the mosaicking work as follows:

- Asia (excl. Siberia) and Oceania – JAXA EORC
- Siberia and Europe – JRC
- Africa – U. Bordeaux-1
- North and South America - JPL

2.5.2.3 ScanSAR mosaics

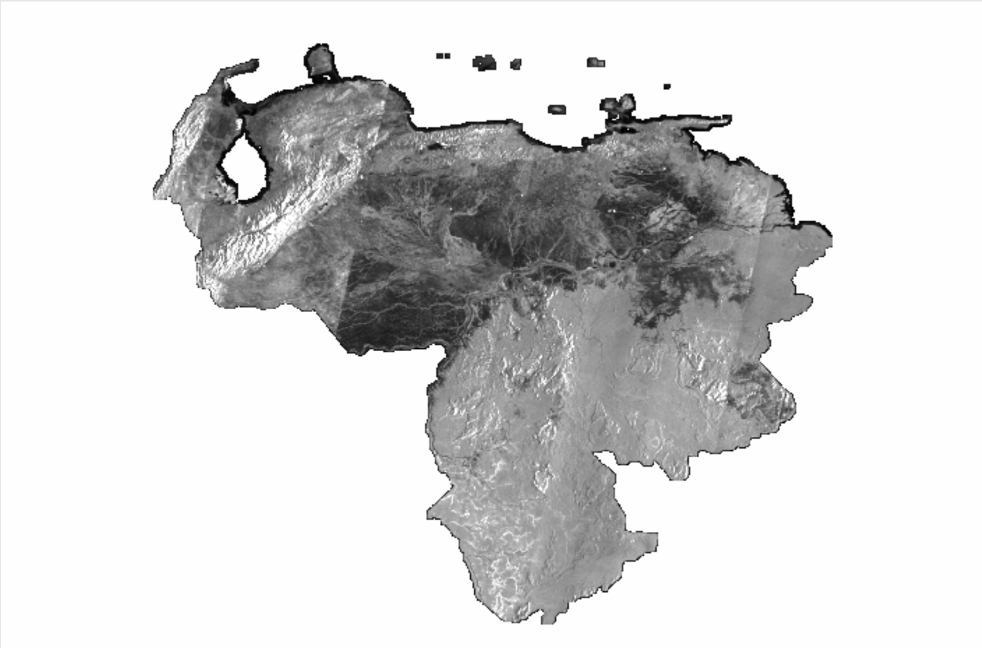
Multi-temporal ScanSAR mosaics constitute the main products to be used within the Wetlands Theme for monitoring of regional-scale seasonal phenomena, such wetland inundation, crop growth and freeze/thaw, taking advantage of the systematic observation strategy implemented for ScanSAR (see 3.2.2. below), in which data over a number of key wetland regions – the K&C Wetland super sites – are acquired during consecutive 46-day cycles during the flooding and cropping seasons.

Product Box M-3 – ScanSAR Image Mosaics

K&C products: Multi-temporal PALSAR ScanSAR mosaics

Intended use: To provide continental scale imagery for investigators to study seasonal changes over large regions. The ScanSAR mosaics are a prime input to the Wetlands Theme, and will be used for generation of extensive, quantitative, seasonal science products.

Prototype areas: All K&C wetland super sites requested by the K&C Science Team
Input data: PALSAR ScanSAR Path Images



PALSAR ScanSAR mosaic over Venezuela, illustrating the wide ScanSAR swath width. (360 km).

Product Developers:

Masanobu Shimada	JAXA EORC, Japan
Bruce Chapman	NASA Jet Propulsion Laboratory, USA
Granfranco De Grandi	Joint Research Centre, E.U.

The ScanSAR image mosaics will be generated from ScanSAR slant range path images, provided in the same standard projection and format as the fine resolution mosaics, but with a pixel spacing of 70 m x 70 m. As mentioned in section 1.3 above, only every 3rd ScanSAR pass will be acquired due to the extensive overlap between the 350 km wide ScanSAR swaths, yielding a 5-day time difference between neighbouring passes. The ScanSAR data are acquired in 5-beam mode with a 350 km swath width, with a single (HH) polarisation.

During the first three years of the K&C Initiative, multi-temporal ScanSAR mosaics are planned to be generated over the Amazon- and Congo river basins, the Pantanal wetlands, the Okavango delta, Indonesia (Sumatra, Kalimantan, Irian Jaya), Papua New Guinea, North Australia, and in the temperate and boreal zones, over the Ob-, and Yenisey river basins, Alaska, Finland and wetlands in south-eastern USA. For each of these super sites, a series of 8-9 mosaics will be produced.

2.5.2.4 Browse image mosaics

Browse image mosaics will be generated for all PALSAR data acquired, using the EORC browse path images as input. Continental mosaics – divided into Asia, Oceania, North- and South America, Europe and Africa – will be compiled in an operational manner once every 46-day cycle. Each mosaic will consist of all data acquired within the 46-day orbit cycle, with separate mosaics generated for data acquired in the ascending (fine beam) and descending (ScanSAR) modes, respectively.

No geolocation or calibration of the imagery will be performed as the browse image mosaics are not intended for further quantitative scientific analysis, but to facilitate rapid assessment of the acquisition strategy results. Observation gaps and poor quality data will be maintained in the browse mosaics.

The browse image mosaics will be produced in geographic coordinates, at 500 m and 2 km pixel spacing. Once the process has become operational, the products will be made available on the EORC and K&C web sites for viewing and downloading within 46-days of the acquisition of the last image strip of the cycle.

Product Box M-4 – Browse Mosaics

K&C products: PALSAR browse image mosaics

Intended use: For assessment of the acquisition success rate and location of data gaps, and for rapid assessment of significant and widespread change in land cover.
Prototype areas: All PALSAR data acquired
Input data: PALSAR raw signal data

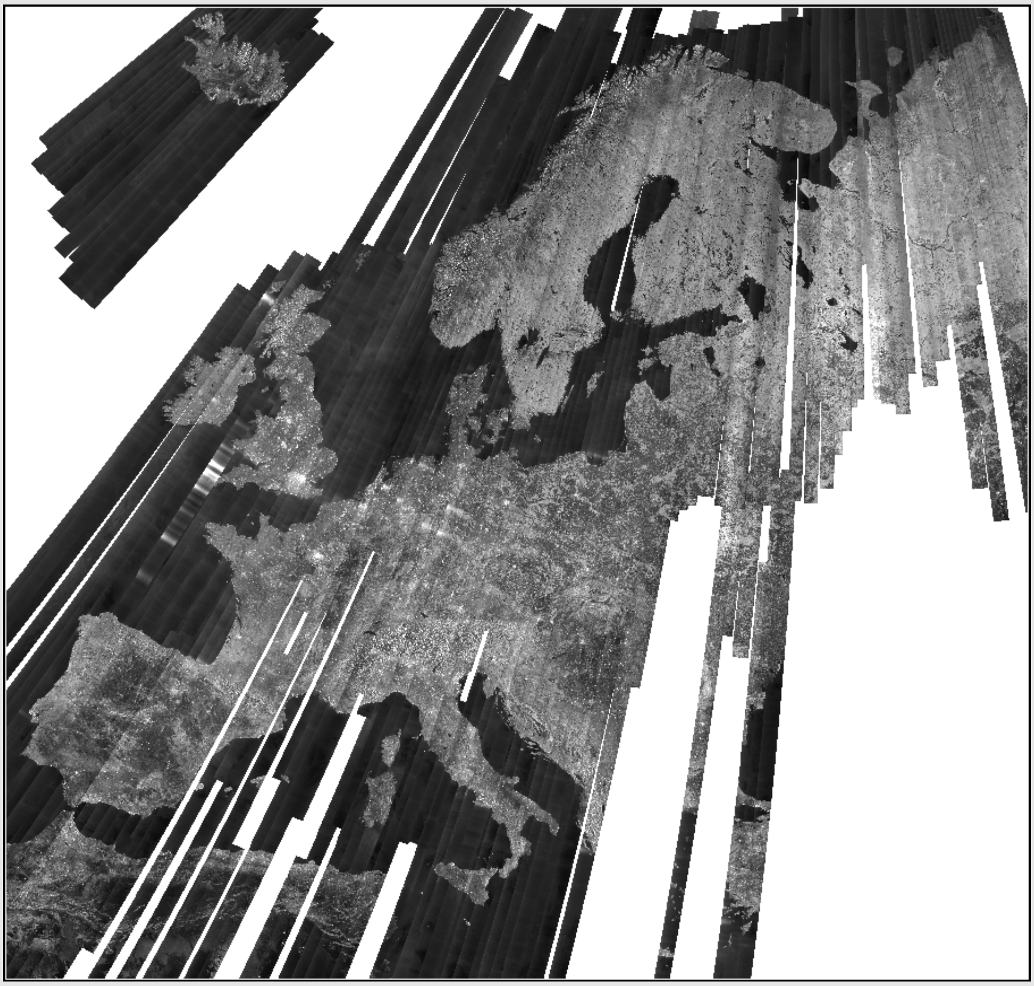


Illustration of the appearance of a low resolution browse image mosaic. Automatic generation of a 46-day cycles basis. No radiometric or geometric corrections applied, data gaps preserved.
Product Developers:
Masanobu Shimada JAXA EORC

2.5.3 Output products

The mosaics generated within the Mosaic Product Theme will feed directly into the generation of the K&C Prototype Products of the Forest-, Wetlands- and Desert & Water themes. The products will be made available to general users tentatively 6 months after initial distribution to the K&C Science Team.

Table 2.5.B Incorporation of mosaic products into the K&C science themes.

	Path images	Fine Resolution	ScanSAR mosaics	Browse mosaics
Forest Theme				
Forest height	Yes	Yes	No	No
Land Cover Mapping	Yes	Yes	Yes	No

Forest Change Mapping	Yes	Yes	No	No
Biomass	Yes	Yes	No	No
Wetland Theme				
Wetland functional type	Yes	Yes	Yes	No
Seasonal inundation monitoring of major wetlands	No	No	Yes	No
Wetland extent	No	Yes	Yes	No
Freeze/thaw products (boreal)	No	Yes	Yes	No
Desert and Water Theme				
Desertification	No	Yes	No	No
Subsurface structure	No	Yes	No	No
HH/HV	No	Yes	No	No

2.5.4 Calibration issues

2.5.4.1 Path images calibration issues

The path image calibration will be based on the standard ALOS calibration parameters developed during the ALOS calibration and validation phase during the first 6 months of 2006. The fine resolution path images will be corrected for topographic effects by: 1) compensation for terrain slope on the effective area of the scattering target, and 2) a refined estimate of the effect of the antenna pattern on each pixel within the swath. There is little experience with calibration of the cross polarized data (HV) from a space borne platforms. The Depending on the calibration accuracy that can be achieved, ScanSAR path images may either be produced as separate files for each of the 5 beam swaths, or as combined 5-beam products.

2.5.4.2 Fine Resolution Mosaics Calibration issues

Through the GRFM project, there is a great deal of experience in accurate calibration of L-band SAR data (Chapman *et al.,* 2002; Shimada, 2005, De Grandi *et al.,* 2000). There are two main issues in the construction of calibrated fine resolution image mosaics: 1) absolute calibration of each image, and 2) relative calibration of each image.

Since the calibration accuracy required for a 'seamless' mosaic (approximately 0.2 dB) is a much higher standard than the ALOS PALSAR absolute calibration requirement (approximately 1 dB), additional calibration may be required. This can be undertaken by comparing overlap regions between adjacent images, and assuming that the brightness has not been modified by changing environmental conditions, and that the difference in incidence angle between the near and far range does not result in a substantially different scattering law regime within the overlap region.

Likewise, the ALOS PALSAR calibration requirement for relative calibration (the largest uncertainty is the correction for the antenna pattern) may not be sufficient to make a seamless image mosaic, and additional correction of the calibration in the range direction may be required, depending on the accuracy of the measured antenna pattern, and the orientation knowledge of the spacecraft.

2.5.4.3 ScanSAR calibration issues

Past experience has shown that calibration of ScanSAR imagery has been difficult to successfully accomplish, especially when the ScanSAR imagery is to be assembled into a seamless mosaic. RADARSAT, a C-band SAR which can operate in a ScanSAR mode, has a long operational track record and comprises the best source to examine for possible calibration issues for ALOS.

RADARSAT exhibited two well-known calibration issues for ScanSAR data: scalloping, and periodic along track amplitude variations whose periodicity depends upon the period of the bursts along track (Martyn et al., 1999). The cause of these errors in calibration is incorrect radiometric compensation for the azimuth antenna pattern and the fact that RADARSAT does not steer to zero Doppler, respectively.

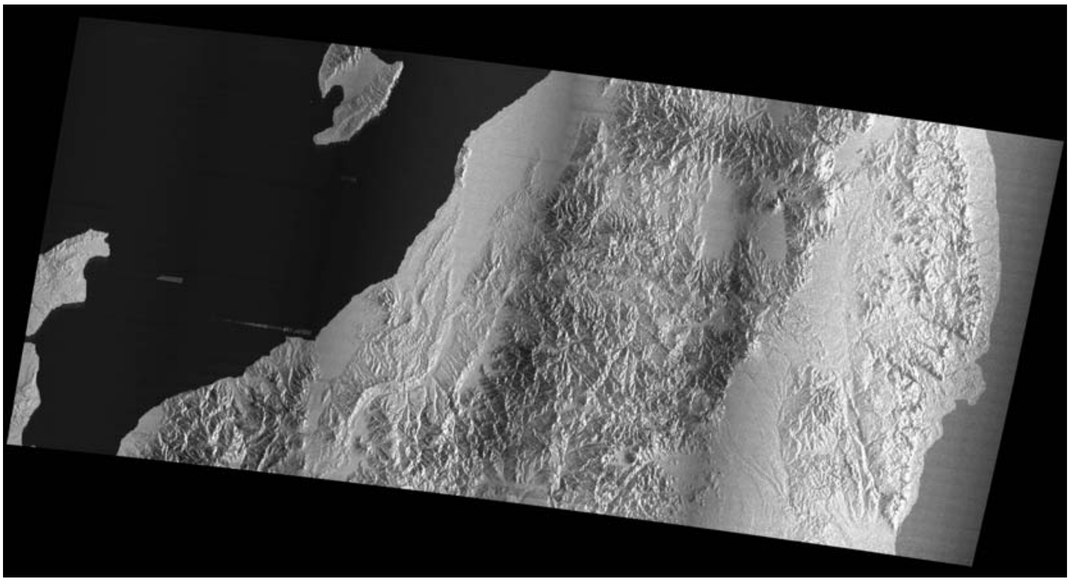


Figure 2.5.2 Uncalibrated ScanSAR image processed by the EORC SIGMA-SAR processor

In addition, within the sub-swath overlap regions, the boundaries between beams are sometimes visible. This is due to the incorrect radiometric compensation for the range antenna pattern, owing to inaccurate knowledge of the roll angle of the spacecraft (e.g. the center Doppler frequency was not known accurately enough).

Calibration of RADARSAT data at the Alaska Satellite Facility (ASF) was initially 'tuned' to high latitude data takes, and it became apparent that the same calibration parameters did not perform as well at the Equator, highlighting the need to base PALSAR calibration on data from a range of different geographical locations.

For ALOS, the L-band bursts will have more pulses due to the larger azimuth beam and the Doppler estimation can therefore be expected to be more robust. In addition, the roll angle estimation will be better than what was possible with RADARSAT. Hence, we expect the PALSAR calibration will be of good quality if the roll angle is well known and properly compensated, if the Doppler centre frequency is well known and properly compensated, and if the antenna pattern in the range and azimuth directions will be well characterised. The calibration of the ScanSAR data versus the calibration of four adjacent fine resolution mode images will probably be comparable. It may be necessary, however, to attempt to improve the calibration to make more seamless mosaics.

2.5.4.4 Browse Mosaic Calibration issues

The browse image mosaics will not be calibrated, and no verification of geometric position will be performed. This product is not intended for quantitative scientific analysis.

2.5.5 Implementation issues:

The projection and format of the image mosaics will be set for each product generated through this theme. It is very likely that a different projection will be required for high and low latitude image mosaics. The format of the data will be one that is easily used, and ingestible by standard GIS packages. The likely format will be GeoTIFF, and the likely projection will be Geographic Coordinates (between latitudes +60 to –60 degrees) or Albers Equal Area (North of 60 degrees latitude).

2.5.6 Acknowledgements

This chapter was authored by Bruce Chapman and Ake Rosenqvist.

3 THE PALSAR SYSTEMATIC OBSERVATION STRATEGY

3.1 Background

3.1.1 Justification

From the previous chapters, the fundamental needs for coherent multi-scale information over large areas have been made evident time and again. The issues addressed within each of the themes almost exclusively relate to wide-area phenomena which stretch across country borders, thereby highlighting the necessity for consistent and repetitive data sets at local, regional and global scales, to assess the instantaneous status and perpetual changes of the environment.

As outlined in Rosenqvist, Milne and Zimmermann (2003), such consistent data do not exist to-date over more than a handful local-regional sites on the Earth, as fine-resolution satellite missions traditionally have prioritised more local-scale interests. Spurred by the establishment of the Kyoto & Carbon Initiative, and the prospect of being able to make a real contribution to issues of public and scientific concern, JAXA has taken has taken the decision to set aside a significant share of the ALOS acquisition capacity for this purpose, to establish an unprecedented, global Data Observation Strategy for ALOS.

It should be noted that the observation strategy is designed not only to support the objectives of the Kyoto & Carbon Initiative in particular, but its broader goals is to contribute to the establishment of a long-term, global archive in which a consistent time series of Earth Observation data can be found for any arbitrary point or region on the Earth. Specific observation plans have furthermore been developed for all three sensors on ALOS, although only the plans relating to the PALSAR instrument are described here.

3.1.2 Characteristics of the observation strategy

The observation strategy aims to satisfy the following requirements for systematic data collection, as defined in Rosenqvist, Milne and Zimmermann (2003):

- **Spatial consistency:** Undertaking continuous wall-to-wall acquisitions over extensive regions.
- **Temporal consistency:** Maintaining temporal homogeneity over regional scales, by carrying out acquisitions during limited time windows.
- **Revisit frequency:** Repetitive regional acquisitions, one or more times per year, to accommodate adequate monitoring of bio- or geophysical changes.
- **Timing:** Acquisitions performed during the same time period(s) every year to minimize temporal bias in the time series acquired.
- **Sensor consistency:** Selection of a limited number of operational default modes to maximize data homogeneity and minimize user conflicts.
- **Long-term continuity:** Systematic observations throughout the mission life.

To assure spatially and temporally homogeneous data collection over regional scales, ALOS observations are spatially planned in units of geographical regions, and Figure 3.1.2 shows the 80+ adjacent, non-overlapping polygons used. With acquisitions planned in 46-day cycle time units, the observation strategy is structured as a set of two-dimensional matrices (one each for PRISM and AVNIR-2, and two (ascending/descending) for PALSAR) with geographical regions in one dimension, and 46-day time units in the other.
Figure 3.1.3 illustrates the concept for PALSAR for the first 3 years of operations (cycles 7-30). The filled polygons represent geographical regions scheduled for observation, with the colour indicating the default sensor mode during the cycle in question (yellow: HH@34.3°; blue: HH+HV@34.3°; orange: polarimetric@21.5°).

To achieve recurrent observations with consistent timing, the PALSAR descending plan is planned in groups of 8 (46-day) unit cycles that will be repeated on an annual (368 days) basis during the mission life. The PALSAR ascending plan, which accommodates the largest number and variety of observation requests, comprises 16 cycles, which are repeated on a 2-year basis.

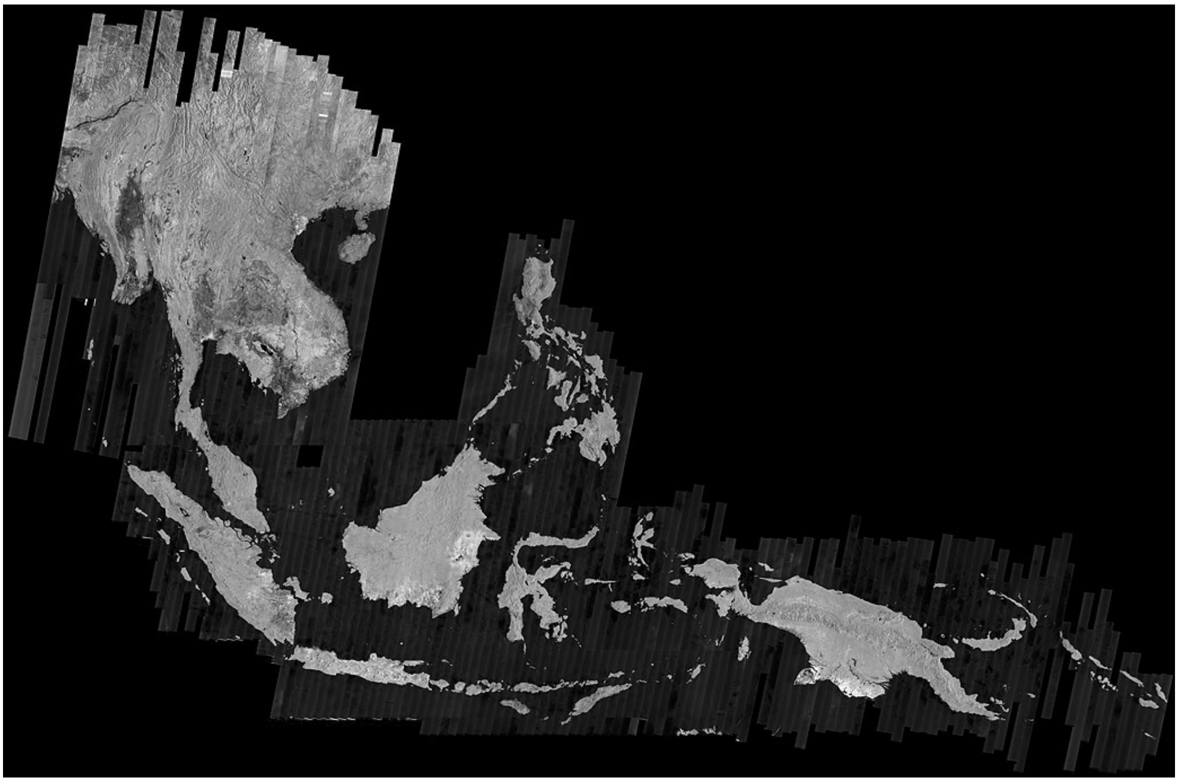


Figure 3.1.1 Extending over ~1/5 of the Earth's circumference, this synoptic JERS-1 view over South-East Asia illustrates the concept of systematic data acquisitions.

3.2 Observation support to the K&C Initiative

3.2.1 The Forest Theme

Support the Forest Theme data requirements is provided chiefly through the PALSAR ascending mode plan, which comprises repetitive, global-scale observations with a constant off-nadir angle of 34.3°. In a trade-off between the interests of user groups focused on vegetation monitoring (i.e. the K&C Forest Theme science team) and crustal deformation (non-K&C user groups), observations in both single polarisation (HH) and dual polarisation (HH+HV) modes are planned. To maintain mode-consistency in the multi-annual time series to be acquired, single-pol observations are scheduled during the (northern hemisphere) winter, and dual-pol observations around the summer months.

The minimum requirement for any of the 80 regions (Figure 3.1.) is to perform at least one single-pol and one dual-pol acquisition annually, and in addition, two dual-pol acquisitions during consecutive 46-days cycles (to enable interferometric applications) on a bi-annual basis. Most areas are however to be acquired significantly more often than this, typically 3-5 times per year. In general, regions in the eastern hemisphere (Asia, Australia, eastern Europe and Africa) within the coverage of the DRTS satellite (Figure 1-3a) are acquired most frequently, while the western hemisphere (the Americas, western Europe and Africa) is restrained by the recording and down-link capacity of the on-board data recorder (HSSR).

To support research relating to polarimetric interferometry (Pol-InSAR), such as the tree height estimation topic within the Forest Theme, Pol-InSAR observation campaigns are planned once every two years, during which selected regions are acquired in full polarimetric mode (21.5°) during two consecutive cycles.

The 2-year repetitive pattern of the ascending plan is apparent in the observation matrix (Fig. 3.1.3) where single-pol acquisitions are displayed in yellow colour, dual-pol in blue and polarimetric in orange.

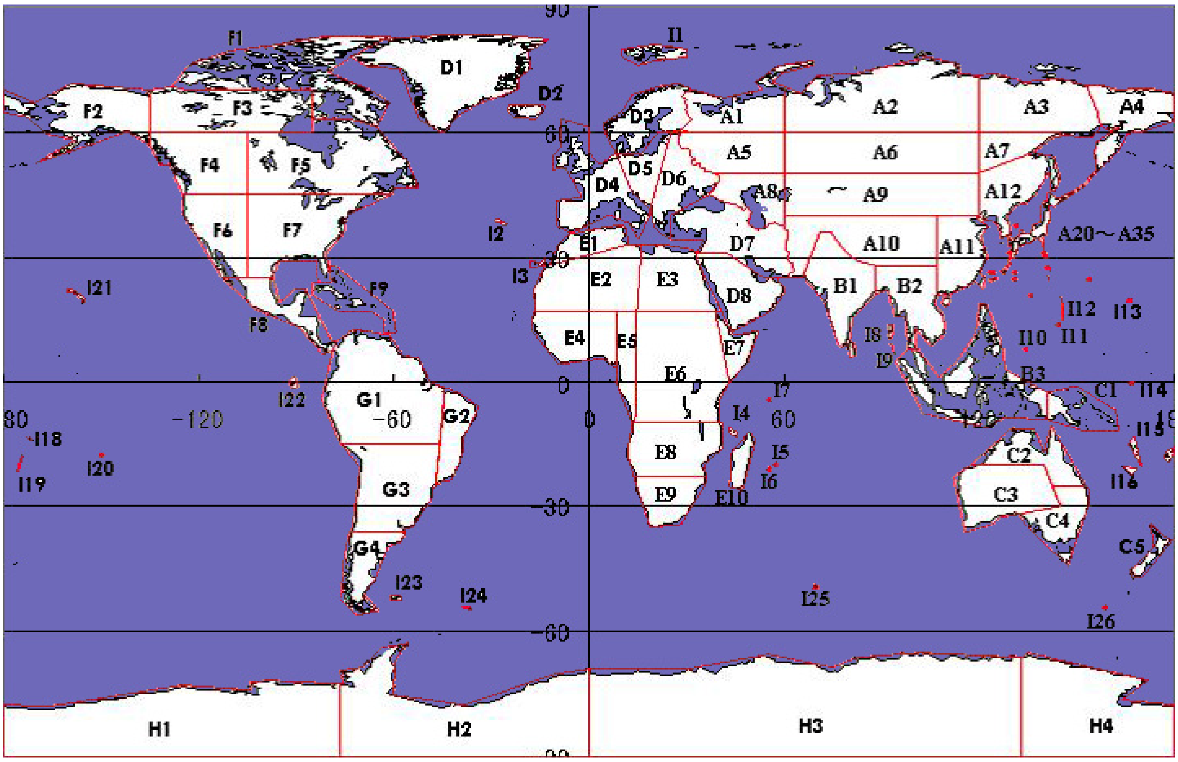


Figure 3.1.2 Geographical division used for ALOS observation planning.

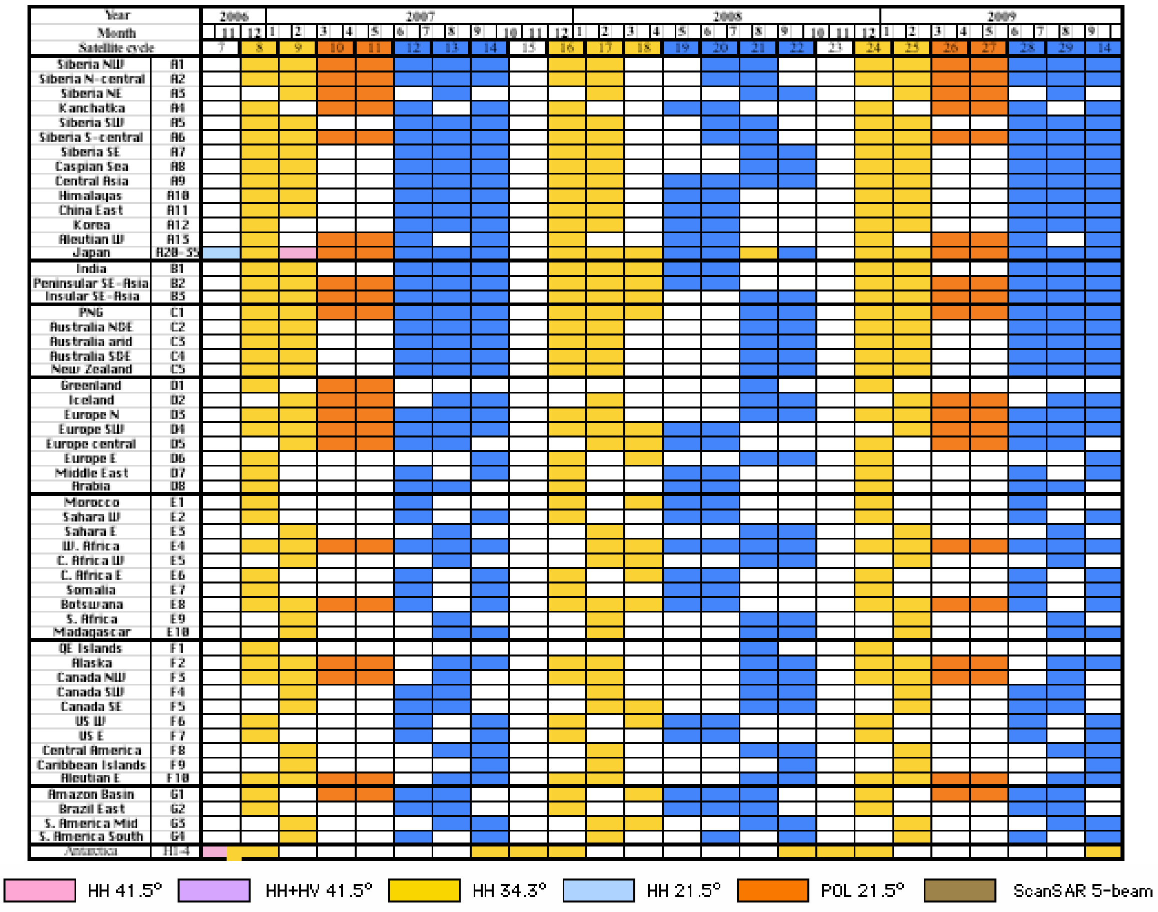


Figure 3.1.3 Space-time matrix used for acquisition planning.

3.2.2 The Wetlands Theme

The Wetlands Theme will also benefit from the ascending observation plan above, in particular on topics relating to the detection of natural and human-induced disturbances and other long-term changes. This includes topics such as inter-annual monitoring of mangroves and peat swamps, where fine resolution information over several years is required.

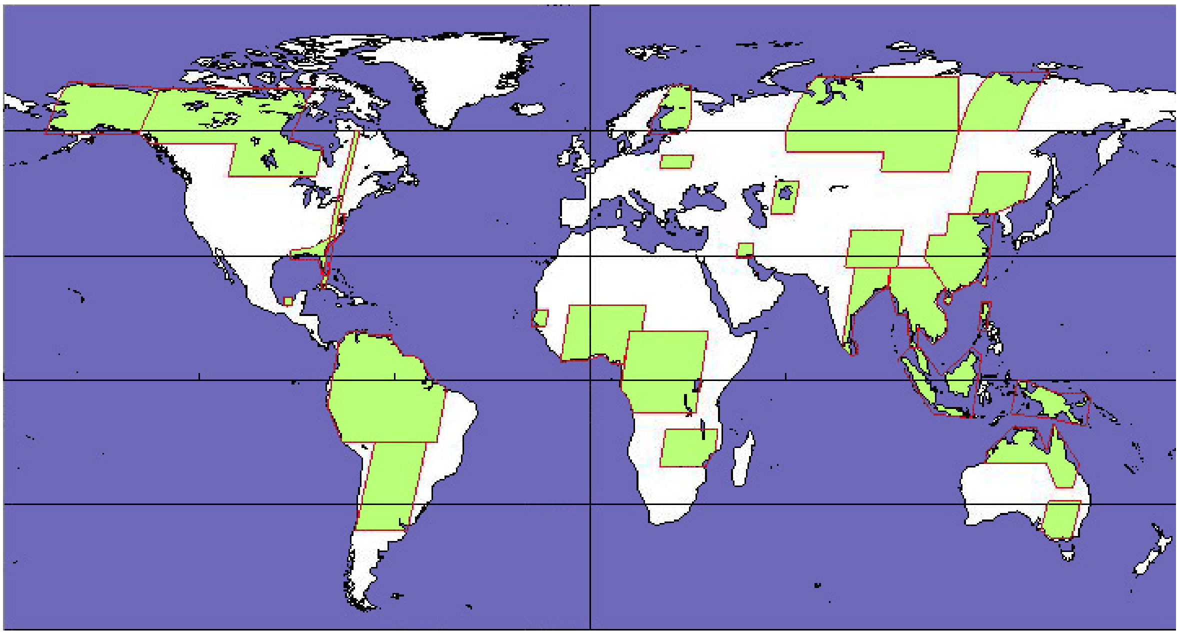


Figure 3.2.1 Wetland regions scheduled for intensive ScanSAR monitoring (ALOS descending passes).

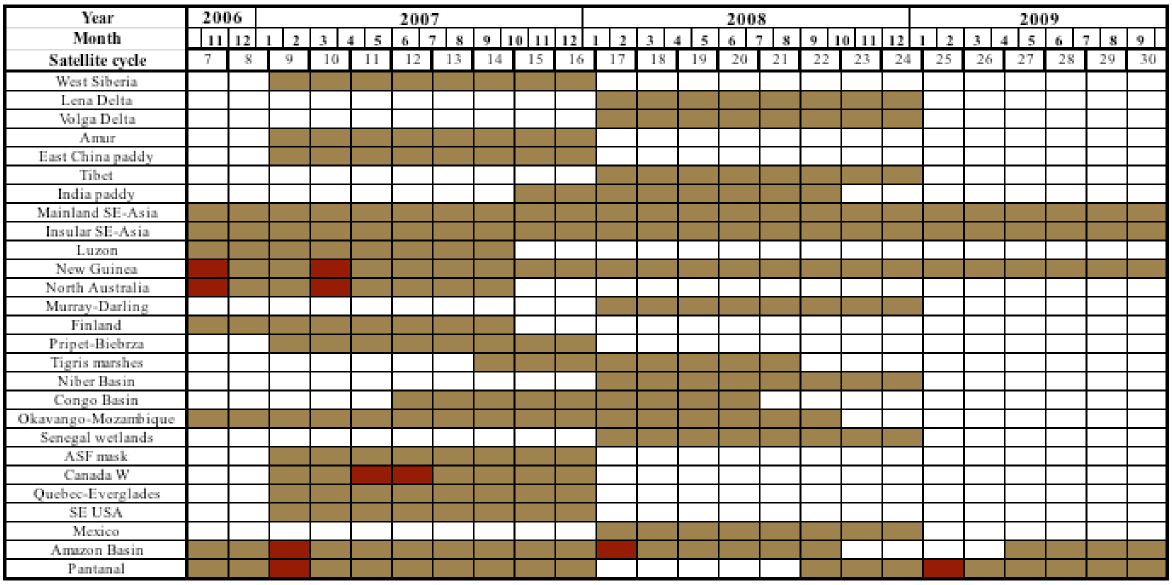


Figure 3.2.2 Space-time matrix for ScanSAR (descending) observations of wetlands (brown – short burst; red – long burst). Intensive 46-day monitoring.

Dedicated support to the Wetlands Theme will however be provided through ScanSAR observations in descending mode (to avoid conflicts with the ascending plan), on studies relating to seasonality, such as freeze-thaw characterisation, rice paddy mapping and monitoring of inundation extents and dynamics. To this end, ScanSAR observations will be undertaken over 27 selected wetland environments of global significance, shown in Figure 3.2.1. To adequately capture the continuous changes that occur throughout the year, ScanSAR observations will be performed every 46-days during typically 8-9 consecutive satellite cycles (12-13 months), in some areas over two years.

In the case of the inundation study areas, the observations are scheduled to encapsulate a full flood cycle, from one dry season to the next. In the freeze-thaw areas, the plans are from winter to winter, while observations over rice paddy areas should encompass the crop cycles from planting to harvest. Figure 3.2.2 shows the wetlands observation plan in matrix form. Annex IV provides the same information as map plots.

3.2.3 The Desert & Water Theme

The Desert & Water Theme data requirements are covered within the PALSAR ascending schedule described above, where all land areas, including all arid and semi-arid regions, will be acquired on a bi-annual basis.

For the sub-surface geology mapping in the Sahara and Arabian deserts (polygon numbers E1-3 and D8 in Figure 3.1.2), where single coverages principally are sufficient, data for analysis will obtained during the first months of operational acquisitions.

For regions selected for mapping soil vulnerability and desertification – western and southern Africa, Central Asia (parts of polygons A9, E4 and E8), where multi-temporal InSAR techniques are required, the original observation plan has been complemented with additional data takes during the relevant vegetation seasons.

3.3 Observation strategy updates

The observation strategy is a plan which is based on pre-launch simulations using JAXA's Mission Management Operations (MMO) System. The observation plan will be assessed during the course of the mission, to optimise performance based on actual observation statistics.

The latest version of the Systematic Observation Strategy for ALOS is available on-line at http://www.eorc.jaxa.jp/ALOS/obs/overview.htm .

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5 LIST OF ACRONYMS

ARD - Afforestation, Reforestation and Deforestation
CEOS - Committee on Earth Observation Systems
FAO - United Nations Food and Agriculture Organization
GEF - Global Environment Facility
GBFM - Global Boreal Forest Mapping project
GOFC/GOLD - Global Observations of Forest Cover/Land Cover Dynamics
GRFM - Global Rain Forest Mapping project
GRS – Ground Reference System of Planning (ground based pass system for ALOS)
GTOS/TCO – Global Terrestrial Observation System/Terrestrial Carbon Observations team
IGBP - International Geosphere Biosphere Programme
IGOS-P - Integrated Global Observation Strategy Partnership
IHDP - International Human Dimensions of Global Change
IIASA - International Institute for Applied Systems Analysis
IPCC - Intergovernmental Panel on Climate Change
ISPRS - International Society for Photogrammetry and Remote Sensing
IUFRO - International Union of Forest Research Organizations
LIDAR - Laser Infrared Detection And Ranging
RSP – Reference System of Planning (orbit based pass system for ALOS)
SAR - Synthetic Aperture Radar
UNFCCC - United Nations Framework Convention on Climate Change
VCL - Vegetation Canopy LIDAR
WCRP - World Climate Research Programme