THE GLOBAL RAIN FOREST MAPPING PROJECT BY JERS-1 SAR

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ABSTRACT:

The **Global Rain Forest Mapping project by JERS-1 SAR (GRFM)** is an effort by NASDA, in cooperation with, among others; the Earth Remote Sensing Data Analysis Center of Japan (ERSDAC), the National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL), the Alaska SAR Facility (ASF), the Joint Research Centre of the E.C. (JRC), the National Institute for Space Research of Brazil (INPE), the National Institute for Amazonian Research of Brazil (INPA) and the University of California Santa Barbara (UCSB) to acquire contiguous SAR data sets of the major rain forest areas on the Earth by the L-band SAR on JERS-1. The areas that have been, or are to be, covered within the project are the entire Amazon Basin, from the Atlantic to the Pacific, central and west Africa, from the eastern coast of Kenya to Sierra Leone in the west, and South-East Asia, including Papua New Guinea. The GRFM project covers a total area of about 40 million km^2, corresponding to some 10,000 scenes, or 1.2 Terra byte of data that is to be processed.
The output of the GRFM project will be regional SAR image mosaics at 100 meter resolutions, semi-continental mosaics at 400 meter resolutions and coarse classifications over certain areas. Mosaics and classifications will be available to the scientific community for non-commercial purposes on CD-ROMs. 100 meter resolution non-mosaicked images will be made available on the Internet.

1. INTRODUCTION

1.1 Background

It is well known that our forests exert strong influence on us and our environment at all levels - local, regional, continental and global. The forests provide food, pharmaceutics, timber and other important raw materials to us and can keep on doing that on a long term, if only managed in a sustainable way. The tropical forests are for several reasons of particular interest. They are fragile ecosystems with extensive biodiversity and they still cover substantial areas of the Earth. The rate at which the global forests are cleared is however very high, although it is difficult to assess the exact extent and impact of this. For environmental conservation, modelling of greenhouse gases or perhaps mapping of animal habitats we need to be able to accurately assess the current status of the forests, but as changes occur very quickly, the need for up to date information is often difficult to satisfy, in particular on a regional or global scale. The only viable means to accomplish this task is indeed by using space borne remote sensing techniques, in the tropical region preferably Synthetic Aperture Radar in order to penetrate the persistent cloud cover.

1.2 The JERS-1 satellite

For monitoring of the tropical belt, the Japanese Earth Resources Satellite 1 (JERS-1) is perhaps the most suitable satellite for the task, given the long wave micro wave band and the on-board Mission Data Recorder. JERS-1 was launched by NASDA and MITI (the Ministry of International Trade and Industry) in February 1992. The satellite carries an L-band Synthetic Aperture Radar (23.5cm/1.275 GHz) with HH polarization and a look angle of 35°. It orbits in a sun-synchronous polar orbit with a recurrence cycle of 44 days, acquiring data at adjacent swaths on consecutive days. The standard scene size is 75 by 75 km with a nominal ground resolution of 18 by 18 meters for the SAR. The satellite, which also carries optical sensors (not utilized within this project), was designed specifically for land applications rather than monitoring of sea and ice, and is currently the only operational L-band SAR satellite in orbit.

1.3 The Global Rain Forest Mapping project

The Global Rain Forest Mapping project (GRFM) was prompted by the recognition of the need for an up-to-date data set of continental coverage over the tropical belt, together with a timely temporal operational availability of the JERS-1 satellite. The major aim of the GRFM project is to create a consistent data set, both in a temporal and spatial sense, covering the entire equatorial belt by using the L-band SAR of the JERS-1 satellite. The project also aims at providing data for studies at local to global scales within the GRFM Science Projects.

The GRFM project is led by NASDA, but relies on extensive cooperation with a number of organizations whose contributions will be described in detail below.

2. SOUTH AMERICA

2.1 Annual flooding patterns of the Amazon river

It is of great scientific interest to monitor the annual flooding patterns of the Amazon river and its tributaries. The water level of the rivers may change with as much as 10 meters between the low water mark and the peak of flood and given the relatively modest topography in the basin, this results in extensive flooding of large areas. The annual flooding have direct or indirect implications on such diverse issues as algae production in the river food chain, spatial distribution of flora and fauna or natural release of green house gases (methane).

In contrast to optical sensors and short wave length SAR, L-band SAR has proved efficient in detecting standing water beneath the forest canopy. The longer wave length signals penetrate the canopy, have a corner reflector type reflection on the trunks and the water surface and return to the satellite with little loss. This results in a brighter backscatter than for non-flooded forest where the exposed rough ground cause a more lossy diffuse scatter. Given this important property of the satellite and the scientific interest in flooded environments, it was decided to map the Amazon basin not only one time, but twice - once during the low water and once during high water.

2.2 Coverage and data acquisition schedule

The data acquisitions over South America cover the northwestern part of the continent, latitude South 14° - North 12° and longitude West 50° - 80°. This covers the entire catchment basin of the Amazon river, including the Brazilian states of Amazonas, Pará, Roriama, Acre, Rondônia and parts of Mato Grosso. Included are also French Guiana, Surinam, Guyana, Venezuela, Colombia and parts of Peru and Bolivia. This amounts to a total area of about 8 million km^2, or more than 2000 scenes. These figures refer to one full coverage - multi-temporal mapping at low and high flood consequently double the figures to 16 million km^2, or almost 4500 scenes.

The low water coverage of the entire area was performed in one sweep from late September to early December, 1995, aiming to coincide with the annual low peak of the river. Incidentally, the lowest water level recorded in the Amazon in decades occurred in October 1995, very timely indeed.

The high water coverage is planned for early May to late July, 1996. With some more luck, we might hit another stage record...

2.3 Ground truth verification

Ground truth measurements in the field were performed simultaneously with the satellite acquisitions. The activities included both videography and photography from a small aeroplane along a number of pre-determined flight lines as well as ground based measurements at

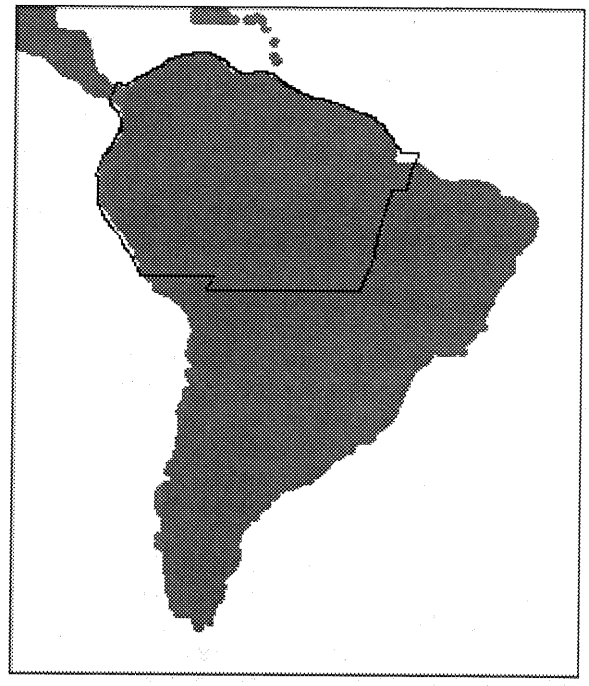

Figure 1. GRFM coverage over South America

areas or transects of specific interest. During the low water coverage, the efforts were concentrated to areas within 1-2 days of reach from the town of Manaus in the central part of Amazonas (Anavilhanas, Balbina, Cabaliana, Mamiruá, Marchantaria, Rio Madeira, Rio Jaú, Xiborena). During the high water acquisitions, these areas will be complemented by field work in and around Rondônia and Rio Tapajos.

The field activities were performed by NASDA, the National Institute for Space Research of Brazil - INPE, the National Institute for Amazonian Research of Brazil - INPA (partially sponsored by NASA), Petrobrás/CENPES, University of California Santa Barbara - UCSB (sponsored by NASA) and the Jet Propulsion Laboratory - JPL (sponsored by NASA).

2.4 Data processing

2.4.1 Raw data processing: The data recorded onto the satellite Mission Data Recorder were down-linked either at NASDA Earth Observation Center in Hatoyama, north of Tokyo, or at the Alaska SAR Facility (ASF) in Fairbanks, Alaska. Financed by NASA, raw data processing of all 4500 scenes will be performed by ASF. The low water season batch will be processed during the spring and summer of 1996 with the high water batch following on after that. The output data will be standard ASF high resolution scenes, i.e. ground range, amplitude, 8 bits scenes at 12.5 meter pixel size.

2.4.2 Generation of low resolution data: The high resolution scenes will be handed over to the Jet Propulsion Laboratory in Pasadena, California for post processing (sponsored by NASA). This step includes downsampling of each of the large 12.5 meter scenes to low resolution scenes at 100 meter pixels. Downsampling

is performed in order to eliminate speckle noise and to make the data more feasible to handle. It is performed by block averaging of the full resolution data within a moving 8 by 8 pixel window as follows:

$$DN_{100m} = Sqrt(\Sigma(DN_{12.5m})^2/n). \quad [1]$$

Where n is the number of pixels in the window. The radar texture, σ_T^2 , is computed in the same step as

$$\sigma_T^2 = [n(\sigma_{100m}/\mu_{100m})^2-1]/(n-1)(1+1/SNR)^2 \quad [2]$$

where: μ_{100m} and σ_{100m} are the mean and standard deviation of the pixel values within the window, n is the number of pixels within the window (64) and SNR is the signal to noise ratio in the window. This results in a texture image of the same size and coverage as the 100 meter low resolution scene computed in the same step.

2.4.3 Land cover classification: Next follows a classification effort on the low resolution scenes by using a modified Maximum-Likelihood classification algorithm developed by JPL (Freeman *et al.*, 1995). The algorithm utilizes the 100 meter resolution scenes and texture scenes as input. Training areas are selected from scenes where ground truth measurements were performed during acquisition. The output will be a coarse land cover classification with the following tentative classes:
1) Forest (e.g. primary forests, tree plantations and secondary stands more than a few years of age)
2) Non-forest (e.g. clear cut areas, pastures, savannah and other areas with low vegetation)
3) Flooded vegetation (e.g. flooded forests, flooded grass, mangrove)
4] Urban areas
5] Open water
6] Unclassified

It is clear that a classification effort of this magnitude of several thousands of scenes will be a generalization of reality and certainly contain errors, but in order to minimize large errors, random verification of the results will be made by JPL, UCSB and NASDA.

2.4.4 Generation of 100 meter regional mosaics: The 100 meter low resolution images generated by JPL are then sent to NASDA Earth Observation Research Center in downtown Tokyo for mosaicking. Software for automatic mosaicking of JERS-1 data is currently under development and expected to be in operation around August 1996. The software utilizes orbital information obtained from the SAR leader file to compute the approximate position for the scene in the mosaic, followed by automatic matching on overlapping areas of neighboring scenes for fine adjustment. Given as an input parameter, the program can generate mosaics in any preferred projection.

Although the size of each image is small, less than 1 Mb, making one large 100 meter mosaic canvas covering the whole Amazon basin and surroundings would not be feasible. The mosaics will therefore be generated in regions, each mosaic covering an area of approximately 5° by 5°, or some 80 - 100 scenes. This will result in an estimated number of 30-35 regional mosaics per season.

2.4.5 Generation of 400 m semi-continental mosaics: 400 meter resolution mosaics will be generated by JPL by using the 100 meter resolution regional mosaics above as input. The 100 meter mosaics will be downsampled by block averaging to 400 meter pixel size regional mosaics. These will then be mosaicked together to form one large semi-continental scale canvas per season, giving a unique overview of some 8 million km2, including its inherent seasonal characteristics.

3. CENTRAL AND WEST AFRICA

3.1 Dual season study and comparison with ERS-1 data

Given the importance of large flooded environments on all from local to global scales, it is naturally of interest to investigate the seasonal patterns of the second largest tropical river basin on the Earth, the one of the Congo river. In contrast to the relatively homogeneous changes between dry and rainy season in the Amazon basin however, the seasonal patterns of the Congo river basin are more diverse. There is an invisible but distinct border along the Equator which divides the climate into an independent southern and northern hemisphere. The Congo river intersects the Equator twice so one part of the basin may experience dry season while the other may be in the middle of the rainy season. For monitoring of seasonal characteristics in the region, it is thus not possible to adjust the satellite acquisitions so easily to hit the dry and rainy seasons, respectively, as was the case in Amazonas. The problem is yet less complicated than it appears since what the JERS-1 L-band SAR is sensitive to, and what we are interested in, is the temporal and spatial distribution of flooding rather than the rain that is causing it. Although perhaps less pronounced, the Congo river also undergoes an annual cycle of high and low water which we need to consider when choosing the time periods for data takes.

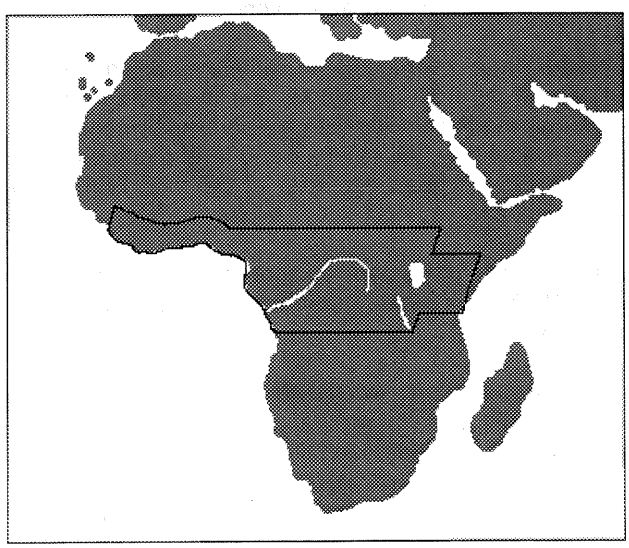

Figure 2. GRFM coverage over central and western Africa

Of great interest in central Africa is also a possible comparison with an available ERS-1 mosaic covering the Congo basin. The data were acquired during the summer of 1994 by using a transportable ground receiving station located in Gabon at the time and the mosaic was generated by the Joint Research Centre of the E.C. within the framework of the TREES project (Tropical Ecosystem Environment Observations by Satellite). It covers the major part of an area between South 6° - North 10° and East 8°-28° (some 400 ERS-1 scenes) and provides a first opportunity to compare data from C- and L-band SAR at such a large scale.

3.2 Coverage and data acquisition schedule

The JERS-1 data acquisitions over central and western Africa can be divided into three main areas: eastern Africa between South 6° - North 5° / East 35°-40°; central Africa/Congo basin between South 8° - North 8° / East 10°-40°; and a 600 km wide strip along the coast of western Africa, approx. North 4°-10° / West 14°-East 10°. This covers a continuous stretch from the Indian Ocean coast of Kenya and Tanzania in the east to Sierra Leone on the Atlantic coast on the west, amounting to about 8 million km^2, or some 2000 scenes. Data acquisitions over this entire strip were accomplished in one uninterrupted effort between early January and early April, 1996, coinciding with the overall low water mark of the Congo river. As the JERS-1 satellite acquires data at adjacent swaths with one day intervals (going from east to west), this results in a temporally very homogeneous data set.

The study of the temporal and spatial extent of flooded environments applies to the Congo basin only (South 8° - North 8° / East 10°-40°), thus excluding the eastern and western parts during the second data take. The acquisitions are planned to concur with the peak of high water in the Congo river in October and November, 1996, adding another 5 million km^2 and some 1200 scenes to the low water figures above.

3.3 Data processing

3.3.1 Raw data processing: The major part of the data acquired during the low water period in early 1996 were down-linked at NASDA Earth Observation Center, where the raw data processing will be performed. NASDA has during the spring of 1996 up-graded its SAR processor to remove radiometric noise which was present in the earlier version of the processor. This included removal of a vertical striping noise and intensity differences between near and far range. The output data is standard NASDA high resolution scenes, i.e. ground range, amplitude, 16 bits, 12.5 meter pixels.

3.3.2 Generation of low resolution data and image mosaics: The high resolution scenes will be shipped to JRC (Institute for Remote Sensing Applications) in Ispra, Italy, for further processing, that is, downsampling to low resolution scenes at 100 meter pixel size and generation of texture images. JRC will also generate 100 meter mosaics by utilizing mosaicking software developed at JRC within the TREES project. Also here will the 100 meter mosaics be generated in a number of more facile regional mosaics. 400 meter semi-continental mosaics will be generated by either JRC or NASDA.

3.3.3 Land cover classification: In cooperation with JRC, and sponsored by NASA, the Jet Propulsion Laboratory are considering a classification effort over certain areas of Africa by utilizing the same classification algorithm as is being used at JPL for the Amazonian data. Although no simultaneous field measurements were made during the satellite acquisitions, some ground truth data can be obtained from local scientists in the area.

4. SOUTH-EAST ASIA AND PAPUA NEW GUINEA

4.1 Mapping of a large distributed target

South-East Asia and Papua New Guinea (referred to below as SEA & PNG) comprises a significantly different environment than in both South America and Central Africa. The region consists of a large number of islands which more often than not are rugged with topographic features and this brings about a new challenge to our mapping project. In an operational point of view, the well distributed archipelago results in that the data takes will have to be divided in to a number of smaller sub regions rather than acquiring the data in one large sweep. The region is currently projected to be acquired one time, yielding a total number of some 3000 scenes. Acquisitions are primarily planned by utilizing the on-board tape recorder, with the two ground receiving stations in Bangkok, Thailand, and Pare pare, Indonesia, as back-up.

Although certain parts of SEA & PNG during the years have been monitored and mapped quite extensively, others, such as e.g Papua New Guinea/Irian Jaya and the inner parts of Borneo/Kalimantan, still remain virtually unknown. This project will thus provide a unique opportunity to get an up-to-date radar "snap shot" over these areas, adding objective data to speculations on controversial issues such as e.g. deforestation. Acquisitions over well documented areas in turn, such as e.g. parts of Thailand and the Philippines, will result in a large scale homogeneous data set which may help to increase the over all understanding and usefulness of SAR data in general.

4.2 Coverage and data acquisition schedule

The data acquisitions over the SEA & PNG region have been tentatively scheduled as follows:

Papua New Guinea/Irian Jaya: March - April 1996
Malay Peninsular and Sumatra: August 1996
Borneo/Kalimantan, Java and Sulawesi: Sept.- Oct. 1996
The Philippines: December, 1996
Burma, Thailand, Cambodia , Laos and Vietnam:
January - February, 1997.

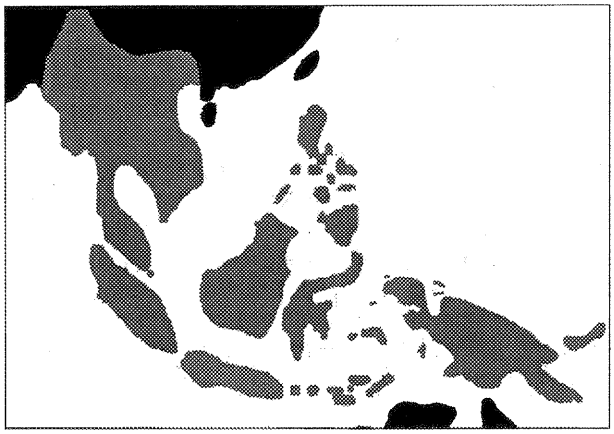

Figure 3. South-East Asia and Papua New Guinea. GRFM acquisitions cover grey areas.

4.3 Data processing

4.3.1 Raw data processing: The raw data processing of all the data will be performed at NASDA Earth Observation Center, using the up-graded version of the SAR processor, generating ground range, amplitude, 16 bits, 12.5 meter pixel standard NASDA scenes.

4.3.2 Generation of low resolution data and image mosaics: The high resolution scenes will be handed over to NASDA Earth Observation Research Center for downsampling to low resolution scenes at 100 meter pixel size and generation of texture images. NASDA EORC will also be responsible for the generation of the 100 meter and 400 meter mosaics, utilizing the newly developed software for automatic mosaicking described above (see 2.4.4). No classification efforts are planned for the SEA & PNG region.

Generation of low resolution images and mosaics covering Papua New Guinea/Irian Jaya will be made by the Earth Remote Sensing Data Analysis Center of Japan (ERSDAC).

5 ON-LINE BROWSER AND GRFM PROJECT OUTPUT DATA SETS

All the 100 meter resolution non-mosaicked scenes generated within the project will be made available on the Internet for on-line browsing and down loading *for non-commercial purposes only*. The data are planned to be stored in GIF format on following web servers:

NASDA EORC (http://www.eorc.nasda.go.jp/eorc/)
JPL (http://southport.jpl.nasa.gov/)
JRC (http://wwwmtv.jrc.it/)
Swedish Space Corporation (http://www.ssc.se/)

Note that the above addresses are tentative and may be subject to change. GRFM home pages at INPE and others are under consideration.

A dedicated CD-ROM for each continent featuring the 400 meter semi-continental mosaics, classification results (if any) and a number of 100 meter regional mosaics over sites of specific interest will be made for wide distribution to non-commercial users world wide. A more limited number of CD-ROMs for each continent containing the remaining regional mosaics will be made available to scientists and researchers working actively in the area. Under consideration is also an educational CD-ROM aimed at high schools and universities with restricted computer resources and limited knowledge of SAR, featuring 100 meter and 400 meter data in file sizes of maximum 1 Mb (to fit on a floppy disc) and educational documentation.

6 GRFM SCIENCE PROJECTS

In parallel with the over all efforts to acquire the continuous continental scale JERS-1 SAR coverage, run what are called the GRFM Science Projects. These projects are generally supported by extensive ground verification efforts and aim both at conducting intensive studies at all from local to global scales. The science projects are independently managed by researchers and scientists from a large number of organizations and universities world wide and they are linked to GRFM and NASDA via research agreements.

Large scale (global, regional, continental) studies aim at studying (e.g.):
* the current deforestation status on a continental level,
* temporal and spatial distribution of annual flooding
* natural release of green house gases from flooded environments,
* refinement of global carbon budget models

Small scale (local) intensive studies (e.g.):
* Mapping of the presence and intensity of deforestation
* Relating physical parameters (e.g. forest biomass) to radar backscatter
* Mapping of animal habitats (e.g. fish, turtles)
* Estimation of river algae production
* Human encroachment around protected areas.

The GRFM Science Projects, which often are interleaved within the over all GRFM mission objectives, include scientists from, among others, NASDA, RESTEC, ERSDAC (Japan), INPE, INPA (Brazil), NRCT (Thailand), Lapan (Indonesia), NASA/JPL (USA), JRC (E.C.), BNSC (U.K.), CNES, CESBIO (France), RAS (Russia), SSC (Sweden), WCS (Congo/USA) and the universities of Michigan, California Santa Barbara, New Hampshire, Southampton and Chalmers Gothenburg.

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