地理学报(英文版) 2002年第12卷第1期

The global rainforest mapping project JERS-1: a paradigm of international collaboration for monitoring land cover change

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The Global Rainforest Mapping (GRFM) project was initiated in 1995 and, through a dedicated data acquisition policy by the National Space Development Agency of Japan (NASDA), data acquisitions could be completed within a 1.5-year period, resulting in a spatially and temporally homogeneous coverage to contain the entire Amazon Basin from the Atlantic to the Pacific; Central America up to the Yucatan Peninsular in Mexico; equatorial Africa from Madagascar and Kenya in the east to Sierra Leone in the west; and Southeast Asia, including Papua New Guinea. To some extent, GRFM project is an international endeavor led by NASDA, with the goal of producing spatially and temporally contiguous Synthetic Aperture Radar (SAR) data sets over the tropical belt on the Earth by use of the JERS-1 L-band SAR, through the generation of semi-continental, 100m resolution, image mosaics. The GRFM project relies on extensive collaboration with the National Aeronautics and Space Administration (NASA), the Joint Research Center of the European Commission (JRC) and the Japanese Ministry of International Trade and Industry (MITI) for data acquisition, processing, validation and product generation. A science program is underway in parallel with product generation. This involves the agencies mentioned above, as well as a large number of international organizations, universities and individuals to perform field activities and data analysis at different levels.

The global rainforest mapping project JERS-1: a paradigm of international collaboration for monitoring land cover change DENG Xiang-zheng, ZHAN Jin-yan, LIU Ji-yuan, ZHUANG Da-fang (Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China) 1 Introduction The Global Forest Mapping Program (GFMP) is an international collaborative effort led by the Earth Observation Research Center (EORC) of the National Space Development Agency of Japan (NASDA) in cooperation with, among others, NASA?s Jet Propulsion Laboratory (JPL), the Space Applications Institute of the Joint Research Center of the European Commission (JRC/SAI), NASA?s Alaska SAR Facility (ASF), European Space Agency (ESA), German Aerospace Center (DLR), Swedish National Space Board (SNSB), Canadian Center for Remote Sensing (CCRS), NASDA?s Earth Observation Center (EOC), the University of California, Santa Barbara (UCSB), the Brazilian National Institute for Space Research (INPE) and the National Institute for Research of the Amazon (INPA). Its objective is to acquire geographically and temporally contiguous Synthetic Aperture Radar (SAR) data sets of the Earth?s major forest systems by using the Japanese Earth Resources Satellite (JERS-1). The two projects associated with this initiative are the Global Rainforest Mapping Project (GRFM) and the Global Boreal Forest Mapping Project (GBFM). The GRFM has been in operation since 1995 whereas the GBFM has been an official NASDA project since the beginning of Japan?s 1998 fiscal year. About thirty international research teams are currently associated with the GRFM with a similar number of international research teams expected for inclusion in the GBFM. The JERS-1 Synthetic Aperture Radar (SAR) is an L-band (23cm wavelength) imaging radar onboard an Earth orbiting spacecraft built, launched, and operated by the Japanese National Space Development Agency (NASDA), the Japanese Ministry of International Trade and Industry (MITI), and the Remote Sensing Technology Center of Japan (RESTEC). This radar has a full-resolution of about 20 meters. Launched in 1992, the spacecraft is in a polar orbit and can image most of the Earth?s land surface. It has a tape recorder, so it can record data from anywhere, and download the data to receiving stations on the ground. The SAR antenna is pointing off at about 35 degrees to the side. The noise equivalent sigma0 is about -18 dB. The full-resolution data is about 4 looks. The swath of the data processed by the Alaska SAR Facility is about 75 km x 100 km. The confluence of policy- and science-driven needs for land cover information, improved data availability from new sensors and improved computing resources and data analysis tools has created the opportunity for major advancements in deriving global and regional land cover products over the next decade (Defries et al., 2000). International efforts such as the GRFM provide new opportunities for the research conducted in the 1990s to contribute to the adequate monitoring of global rainforest. Table 1 Sensors currently operating or planned for identifying global and regional land cover and land cover change (Defries et al., 2000) A lot of new sensors have recently been launched or will be launched in the near future (Table 1). These sensors, many of them designed specifically for identifying land cover and land cover change, will provide greatly improved observations in terms of spatial and spectral resolutions and atmospheric, radiometric and geometric correction (Defries et al., 2000). For example, a number of new and improved products for global rainforest will be derived from the GRFM JERS-1 launched in 1992. 2 Three geographical regions of GFMP This project is divided into three geographical regions: South and Central America, Central and Western Africa, and South-East Asia and Northern Australia. Each region was observed at least once during a ?single season? between September 1995 and January 1997 (Rosenqvist et al., 2000). 2.1 South and Central America The GRFM coverage over South and Central America extends over the area at 14oS to 12oN and 50o-80oW. The entire Amazon Basin, from the Atlantic to the Pacific, was acquired in a single sweep during the generally low flood time of the Amazon River in September-December, 1995 (Figure 1). This portion of the data set comprises some 1500 scenes and covers an area of about 8 million km2. The same area, including the northern part of South America and Central America, was covered again in May to August 1996, during a high flood period of the Amazon River. A second acquisition, featuring the corresponding high-water peak, was performed during the period May to August 1996. This second coverage also includes the Pantanal wetlands, the northwestern part of the South American continent and Central America. The two coverages together amount to some 5000 scenes (Rosenqvist et al., 2000). 2.2 Africa The Africa GRFM acquisition, comprising some 3950 scenes, features east, central and west Africa. SAR data over Central and Western Africa, from the eastern coast of Kenya to Liberia and Guinea in the west were acquired in January-March 1996 (see Figure 2a, 2b, 2c and 2d) (Rosenqvist et al., 2000). The area covered lies between 9oN and 9oS, extending approximately 6000km along the equator and amounts to about 2000 NASDA processed scenes or 8 million km2. The Congo River Basin, about 3.5 million km2, was also covered during October?November, 1996 (the high water season of the river). Madagascar was acquired in January 1997. 2.3 Southeast Asia Acquisition planning over South-East Asia was complicated by several factors, primarily by the fact that the region consists of a large number of islands distributed over extensive sea areas. The regions was divided into a number of sub-areas including the major islands of New Guinea, Borneo/Kalimantan, the Philippine Islands, Java, Sulawesi, Sumatra, the Indochina Peninsula and, in addition, northern Australia, were covered in late 1996 and early 1997. This area covers approximately 4000 NASDA processed scenes (Rosenqvist et al., 2000). 3 The collaboration in data acquisition and processing 3.1 Data acquisition scheduling Figure 2 GRFM coverage over equatorial Africa The data acquisitions were scheduled with the particular intention of obtaining, as far as possible, temporally homogeneous data coverage over extensive areas. Radiometric differences between adjacent swathes could be minimized by taking advantage of the fact that two adjacent JERS-1 swaths were acquired with only one-day time difference. So, a side effect of the sequential extensive areas, which should be kept in mind when analyzing data over extensive areas, is a distinct temporal gradient (one day/60 km) which runs in an east-to-west direction (Rosenqvist et al., 2000). Data acquisition scheduling was performed by NASDA and all acquired data were recorded onto the satellite Mission Data Recorder and subsequently downlinked either at the NASDA EARTH Observation Center (EOC) or at the NASA´s Alaska SAR Facility (ASF). 3.2 Raw data processing The raw data processing proves to be the most time consuming part of the GRFM project, which has been performed at NASDA and at the ASF for each of their respective areas (Table 2). All data are processed to full resolution (18-m ground resolution at three looks) ground range amplitude products, corresponding to the 16-bit ?Level 2.1? product from the NASDA (Rosenqvist et al., 2000; Shimada, 1996) and the 8-bit ASF high-resolution standard product from the ASF (Bicknell, 1992). The choice to perform full-resolution processing (and subsequent filtering to lower resolution), rather than significantly faster low-resolution quick-look processing, was motivated by the scientific need for the highest achievable radiometric quality of the final mosaic. 3.3 The generation of low-resolution data The generation of low-resolution data in the GRFM processing chain entails down sampling of the full-resolution scenes from 12.5 m pixel spacing to low-resolution frame lets of 100 m pixel size. In order to maintain the highest possible radiometric resolution, down sampling is performed by either wavelet decomposition (Africa) or by block averaging in power domains within an 8 pixel x 8 pixel windows (Rosenqvist et al., 2000). The radar texture, calculated as the coefficient of variation within the same windows, is computed in the same step. This results in one amplitude image and one texture image, both co-registered and with a geometry corresponding to the original full-resolution scenes. Table 2 Distribution and collaboration in data acquisition and processing of GRFM project 3.4 Generation of regional mosaics The im age mosaicking procedures developed and utilized at NASDA, JPL and the JRC vary on several points, but the basic concepts can be illustrated by the JRC procedure (Rauste, 1999) now described. Using the 100-m frame lets together with their orbital header information as input, image mosaicking is performed by means of block adjustment. Relative scene displacements, calculated by image correlation in the overlapping areas between scenes (both in azimuth and range directions), are used as observations in the adjustment procedure. Ground control points for absolute geolocation, derived from e.g. existing maps (with varying quality) and the World Vector Shoreline data set, are added as additional observations with higher weight (Rosenqvist et al., 2000). As a first step, only the transformation parameters are calculated, and the result is scanned for gross errors or other outliners, which need to be corrected before the actual mosaic is assembled. The steps of parameter calculation and geometric verification are repeated until acceptable geo-metric accuracy has been achieved. In order to assure relative co-registration between mosaics acquired at different seasons (both the Amazon basin and the Congo basin were acquired at two seasons), block adjustment is performed for all scenes covering the region simultaneously. For the case of Africa (excluding Madagascar which is treated separately), this involves some 3,600 scenes, resulting in a normal equation matrix larger than 10,000 lines by 10,000 columns, Still, the calculation can be performed within a few hours. Once the transformation parameters have been calculated, the geometry is fixed and the actual mosaic generation can either be completed in one single step, or it can be performed in sub-regions and assembled at a later stage. From a computational point of view the latter is more feasible, as simultaneous mosaicking of 3,600 scenes currently requires some 20 hours of computation time. The characteristics of the JRC output are 100 m nominal ground resolution, amplitude and texture mosaics in Mercator projection with 240-m root mean square error (RMSE) absolute geolocation accuracy and 56 m (RMSE) relatively internal accuracy. The procedure employed at JPL for the Amazon and Central America corresponds largely to JRC flow described above. The major difference is that least-squares block adjustment is applied to data form one season only and the second coverage is rectified scene-by-scene to the first ?master? mosaic. The characteristics of the JPL output are 100 m nominal ground resolution, amplitude and texture mosaics on a latitude/longitude grid. The final versions of the South American mosaics have not yet been generated and appraisal of the geometric accuracy hence remains. The mosaicking algorithm currently applied by NASDA differs from the JRC and JPL procedures in that orbital information is used to compute the approximate position for the scene in the mosaic, followed by image correlation in the overlapping areas of neighboring scenes for fine adjustment. An improved version of the algorithm is foreseen for Southeast Asian mosaic generation. 3.5 Validation and calibration Validation of the image radiometry (and geometry) and additional calibration are performed on the 100-m resolution frame lets (Rosenqvist et al., 2000). Although the data processed by the ASF have proven to have comparably stable radiometry, a standardized antenna patterns correction, derived form analysis of a large number of scenes over uniform rainforest regions, is employed by JPL. Additional calibration of deviating frame lets is only occasionally required. The data processed by NASDA EOC on the other hand, display significant antenna pattern variations and random gain deviations that, for the African data, encouraged the JRC to implement a supervised calibration procedure where corrections are applied to all scenes (Rauste, 1999). The radiometric quality of the new NASDA EORC processor, which will be used for all Southeast Asian data, remains to be verified. 4 Great impacts on monitoring regional land cover from GRFM project 4.1 Meeting the requirement of ecosystem-wide monitoring The adequate monitoring of Earth ecosystems is a prerequisite to the sustainable management of renewable resources (Gianfrano De Grandi et al., 2000). Tropical and boreal forests are a case in point because they represent important pools of economical, biological, and ecological resources. These ecosystems are furthermore threatened by the rapid increase worldwide, in the demand for new agricultural land and for new products. Another important aspect related to these ecosystems is their role in the exchange processes between the atmosphere and the geo-, biosphere, and in particular for the carbon cycle and for fluxes of green house gases (GHGs) such as carbon dioxide and methane. In turn, this issue is linked to global climate change, a problem of major concern for all mankind on spacecraft Earth, and hence of great political and scientific relevance. An important requirement in the case of ecosystem-wide monitoring is the combination of timeliness, completeness, and spatial resolution of the observations (Gianfrano De Grandi et al., 2000). The GRFM project is a possible answer to this requirement, based on the recognition that the JERS-1 L-band spaceborne SAR characteristics are ideally suited for mapping and monitoring the vegetation distribution of an entire ecosystem at continental scale, at several spatial resolutions, ant with no weather or time of day constraints. 4.2 Laying the foundation for the relative scientific programs A scientific program is underway within the context of the GRFM project with the aim of exploiting the use of JERS-1 SAR data and the GRFM products in the tropical region. These so-called GRFM Science Projects are independently managed by researchers and scientists from a large number of organizations and universities worldwide (Rosenqvist et al., 2000). The activities include studies of secondary growth and deforestation pa tterns, mapping of the spatial and temporal distribution of annual flooding in the Amazon and Conga river basins (Freeman et al., 1996), estimations of regional emissions of trace gases from the floodplain environments (Rosenqvist et al., 1998), forest classifications in Amazon and Central Africa (De Grandi et al., 1998; Sique et al., 1997), regional-scale vegetation studies (Hess et al., 1998) and others. Field measurements were performed simultaneously with the GRFM acquisitions in several parts of the Amazon during both satellite overpasses, the activities included both videograpahy and photography from a small aeroplane along a number of pre-determined flight lines as well as ground-based measurements in areas or transects of specific interest. Field measurements were also performed in connection with the GRFM acquisitions over northern Australia, which coincided with an airborne SAR campaign (AIRSAR Pacific Rim deployment). The AIRSAR campaign include flights over several transects and subsequent ground measurements (Rosenqvist et al., 2000). 5 Discussion and perspectives The combination of continuous coverage, short acquisition time, and high resolution is a unique asset of the GRFM approach (Gianfrano De Grandi et al., 2000). Experience gained so far lets us confidently say that data sets such as the GRFM ones will bring forth entirely new paradigms for the remote sensing of wide area terrestrial phenomena and will add enormously to our knowledge of the tropical and other poorly documented earth ecosystems. However the benefit comes at the cost of number of technical hurdles (Gianfrano De Grandi et al., 2000). First the end-to-end process from the satellite down link to the generation of several layers of lower resolution products entails a staggering data volume, and a high processing complexity Gianfrano De Grandi et al., 2000). Experience in handling large data volumes was certainly not lacking among the major GRFM processing nodes. For instance, a wide area radar mosaic of Central Africa using the ESA ERS-1 SAR data had already been generated at JRC (De Grandi et al., 1999). Still, the GRFM project introduced one more shift in complexity, due to the geographically distributed processing, and the layers of low-resolution products (multi-temporal, multi-resolution). To give a flavor, the GRFM Africa mosaic consists of some 3900 SAR scenes which is tantamount to 312Gb of high resolution ground range data, and 4.8 Gb for one 100 m baseline product, without accounting for all the intermediate and special purpose lower resolution products. This level of data volume already poses some problems even for simple operations like data ingestion if the available off-the-shelf computer technology in the high-end Unix servers and workstation class is used. Second, since the coverage is not obtained in one snapshot, perturbation of the imaging system nominal values (e.g., the satellite attitude) affect the images that compose the mosaic according to their position differently (e.g., radiometric and geometric distortions). There effects must be taken in due account and corrected for. Moreover, the problem of parameters estimation is exacerbated by the date volume issue, because most manual techniques, like tie-pointing, must be ruled out (Gianfrano De Grandi et al., 2000). Third, even a self-consistent measure of a physical parameter still requires a comparison with independent estimates to be validated. Validation of the image characteristics and, as a second step, of the thematic information that can be eventually extracted (e.g., a vegetation map), is in our opinion one of the central issues in the generation and exploitation of wide area high resolution remote sensing data sets Gianfrano De Grandi et al., 2000). The validation of a measurement that is spatially dependent and extends over a wide area requires a reference set of known and suitable accuracy and must be dense enough to assure the correct sampling of the signal to validate. The problem is compounded by the fact adhoc ground experiments are nowadays difficult to set up in areas of the world like Central Africa, which are plagued by social and political turmoil. Historical data sets are in this case the only source for benchmarks. This entire peculiar question needed to be taken into account in the GRFM development process and constituted the rationale for the development of suitable processing techniques and tools in future. With all the GRFM acquisitions completed and the JERS-1 satellite still functional, in 1996 NASDA decided to proceed with a new global forest mapping venture with a focus on the boreal forest belt in Siberia, Canada, Alaska and northern Europe, thus establishing the Global Boreal Forest Mapping (GBFM) project. This project is divided into three geographical regions: Alaska and Canadian North America, Northern Europe including the U.K. and Iceland, and all of Siberia. Each region was observed at least once during a ?single season? between September 1995 and January 1997. The objectives of the GBFM project are similar to those of the GRFM, i.e., continental-scale mosaic generation and an active science program. It is anticipated that both GRFM and GBFM acquisitions will be repeated in a 10-year time frame within the framework of the NASDA Global Forest Mapping Program, by use of the polarimetric L-band SAR instrument on-board the Advanced Land Observation Satellite, scheduled for launch by NASDA in 2002. References

关键词： Global Rainforest Mapping; low-resolution data; regional mosaic; Global Boreal Forest Mapping