PAPER 2

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COMPILATION OF A BI-TEMPORAL JERS SAR MOSAIC OVER THE AFRICAN RAIN FOREST BELT IN THE GRFM PROJECT

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ABSTRACT

The Global Rain Forest Mapping project GRFM is an international collaborative effort promoted by the National Space Development Agency of Japan NASDA. Main goal of the project is to produce a wall to wall map of the entire tropical rain forest using the L-band SAR on board the JERS-1 spacecraft. Within the GRFM project the European Commission Joint Research Centre acts as main processing node for the assemblage and validation of the radar mosaics related to the African continent. In this paper we give an overview of the techniques used for the compilation of these wide area radar mosaics, with emphasis on the scene geo-referencing. A global optimization technique is used based on a least squares estimation of the scene geometry parameters given observations which comprise intra-scenes correlation measures, ground control points and nominal scene position derived by orbital parameters and the range-doppler equation. Two acquisitions at different dates are simultaneously included in the estimation process, thus assuring optimal co-registration between dates. A similar technique is used for radiometric calibration of the mosaic. Validation of the multi-temporal radar map's geometry with respect to existing cartographic data - a key issue in view of certain thematic applications - is also discussed. A RMSE (Residual Mean Squared Error) of 56 m was obtained when using tie-points between scenes only. This error characterizes the mosaic internal consistency for scenes down-sampled to a pixel spacing of 100 m. A RMSE of 240 m was obtained when using ground control points (GCP) derived from digital cartographic data. This figure characterizes the absolute geo-location accuracy of the GRFM Africa mosaics.

INTRODUCTION

The Global Rain Forest Mapping project (GRFM) [1][2] Africa data sets consists of two blanket coverages of the Central Africa tropical region $10°S - 10°N$ $8°E - 36°W$,acquired during January-March and October -November 1996. A one date continuous coverage of an area in West Africa between $14°E - 8°W$ and the island of Madagascar are also included. The overall data set comprises approximately 4000 scenes acquired by the NASDA JERS-1 L-band synthetic aperture radar (SAR). The SAR raw data were correlated into ground range detected images by the NASDA EORC centre in Japan; processing at the JRC entailed a multi-resolution (from 100 m to 1.6 Km) decomposition using wavelets into radiometry and texture maps, and the generation of wide area mosaics with good radiometric and geometric accuracy. This challenging job required the set up of suitable techniques and processing chains, a full description of which is given in [3]. Given the scope of this short communication, we will focus here on the geo-referencing aspects of the mosaicking procedure.

MULTI TEMPORAL BLOCK ADJUSTMENT

Internal geometric consistency and between dates co-registration of the mosaics for the multi-temporal analysis require that the location accuracy of individual scenes is better than the pixel dimension (100 m). The standard deviation of the scene geo-location data was estimated to be several hundreds of meters. Discontinuities of up to 600 m were detected in early mosaicking experiments without geometric corrections. Methods for revising the geo-location data had therefore to be applied in the mosaic compilation.

A global optimization technique was developed based on a linear least squares estimation (LLS) [4] of the scene geometry parameters given observations which comprise intra-scenes correlation measures, ground control points and nominal scene position derived by orbital parameters and the range-doppler equation.

The two acquisitions at different dates are simultaneously included in the estimation process, thus assuring optimal co-registration between dates.

The scene geometry model used in the LLS includes two translations and a rotation in a Northing Easting (Mercator) coordinate system with origin at the scene centre. This model relies on the - confirmed - assumptions that there is no internal deformation in the JERS products. For observations based on tie-points between scenes this model gives for instance:

$$V_{N^p} = N_1^p - N_2^p = N_1^c + dN_1^c - \left(N_2^c + dN_2^c \right) + y_1 \cos(\alpha_1) \qquad (1)$$
$$-y_2 \cos(\alpha_2) - x_1 \sin(\alpha_1) + x_2 \sin(\alpha_2)$$

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where N^P is the Northing of point P; x, y are the image coordinates; N^C is the Northing of the scene centre; dN^C is the translation in Northing of the scene. A similar equation applies for the Easting direction. The observation equations are linearized for small α.

Tie point measurement is based on image correlation performed at 100 m pixel spacing between adjacent scenes belonging to the same date mosaic, or between scenes at two different dates. For scenes acquired along the same orbit the correlation peak is well defined even without high-contrast features; even homogeneous areas can be correlated successfully because the same speckle pattern is present in both scenes. The points within one date and between strips require always the presence of a high-contrast feature that remains stable during the interval between the SAR acquisitions of the adjacent strips. The same applies to the points between dates, but here the overlap area to search for candidate features is larger because the scenes (same node or path-row position) cover the same area.

To increase the probability of a high correlation maximum, a simple interest operator was implemented. A small area around the centre point of a correlation block is searched for candidate templates. The template that produces the highest value of the interest operator is then selected to be used in the correlation.

The structure of the LLS normal equations coefficient matrix **N** is block diagonal, with bandwidth:

$$w = (2s_{path} + 1) \cdot n_{dates} \cdot n_{par} \quad (2)$$

where s_{path} is the maximum number of scenes in a single path (fast row index), n_{dates} is the number of dates (SAR coverages), and n_{par} is the number of parameters in the geometric model.

A conjugate gradient method can be used efficiently for the solution of linear systems with a block diagonal coefficient matrix. In the implementation of the multi-temporal block adjustment applied to the JERS SAR data the elements of the N matrix within the bandwidth are taken into account when computing the conjugate gradient iterations.

VALIDATION

In order to validate the geo-referencing accuracy, a sequence of block adjustments using different sources for the observations in the LSS were performed, and the relative residual mean square errors (RMSE) measured. The hierarchy of tests included: 1) observations based only on tie-points (see previous section); 2) additional observations based on ground control points (GCP) located on the coast lines; 3) additional observations based on GCP located inland in the Central Africa continent.

All three adjustments included 3624 scenes and 62006 tie-points.

Digital data from the World Vector Shoreline data base was used for the GCPs along coastlines. The World Vector Shoreline data covers fairly well West Africa, the Western coastal zone of Africa down to Angola, and the part of the Tanzanian-Kenyan coast that is included in one of the mosaics. Digital topographic maps scale 1:200000 in the Central African Republic and the Republic of Congo (Congo/Kinshasa) were used in test case 2. The maps were produced by IGN/France mainly in the 1950s. The maps were scanned and digitized by I-Mage Consult, Namure, Belgium within the framework of the Regional Environmental Information Management Project on Central Africa (REIMP-CA), initiated under the PRGIE program of the Worldbank.

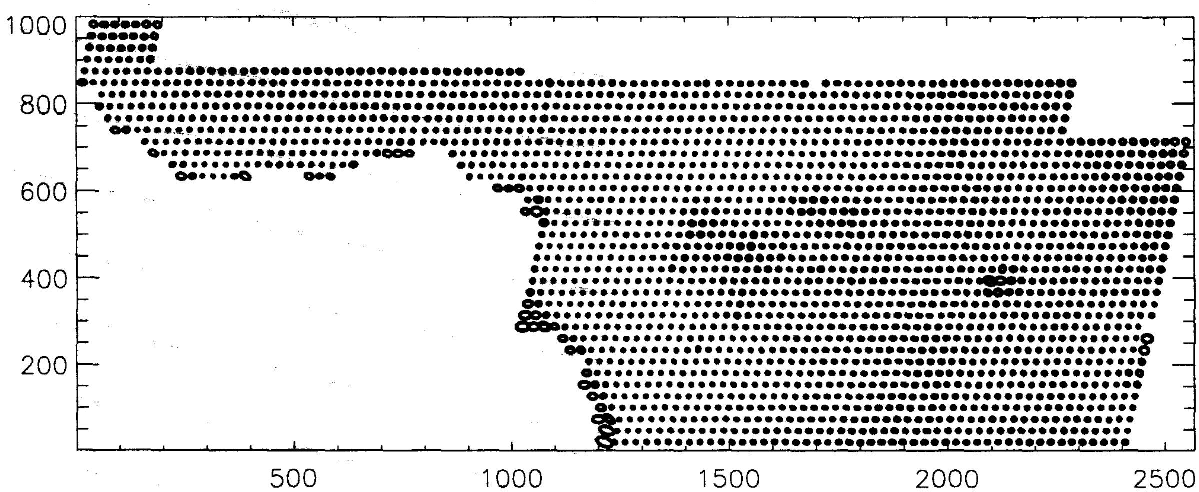

Fig. 1 - Error ellipsis of the scene centres in the whole Central Africa 100 m mosaic after the multi-temporal adjustment using GCPs.

TABLE 1. Residual mean square error statistic (in meters) in the block adjustment of the Central Africa GRFM mosaic

Test case	*Tiepoint N*	*Tiepoint E*	*Centre N*	*Centre E*	*GCP N*	*GCP E*	*Mean dN*	*Mean dE*
1	33.2	34.8	477.5	751.7	503.0	1021.4	26.6	-289.7
2	35.5	40.8	532.0	736.2	193.7	201.6	18.6	-69.3
3	40.1	39.7	543.3	758.0	173.2	166.3	24.3	-46.8

Results of the validation process are reported in Table 1. The columns *Centre N, Centre E* are scene translations in Northing and Easting. The column *Mean dN*, *Mean dE* give the average relative translations between the two dates mosaics. The GCP RMSE in case 1 indicates the mean squared error computed when the 248 coastline GCPs are not considered in the LLS estimator; they are only used to check the error.

As to case 2, the inclusion of GCPs in the LLS degrades the tie-points RMSE by a few metres. On the other hand, it greatly reduces the discrepancy between the mosaic and external control data (from 500 m to less than 200 m in Northing and from 1000 m to less than 200 m in Easting). In case 3 about 50 GCPs located in the Central African Republic and the Republic of Congo were added to the observations, but the RMSE statistics is not change significantly.From this fact we can infer that these GCPs are compatible with the coast line GCPs at the scale of the mosaic pixel size (100 m).

Another interesting way of characterizing the error budget in the scene geometry revision is to plot the local mean and variance of the LLS estimator in Northing and Easting (associating to each scene centre an error ellipse). An example for the whole Central Africa mosaic after the block adjustment using GCPs is shown in Fig. 1. In this case, the semi-major axis of the error ellipse varies between 6 and 55 m with a median at 11 m. The semi-minor axis varies between 6 and 3 m with a median at 10 m. Larger error ellipses correspond to scenes where the number of tie points is reduced because of lack of inter-scene correlation.

CONCLUSIONS

Registration in the sub-pixel range between two dates GRFM Africa mosaics with a sampling interval of 100 m was achieved using the multi-temporal block adjustment described in this paper. A figure of the internal geometric consistency and the between dates registration accuracy is given by a RMSE of 40 m for the tie points.

Adding ground control point data (derived from the World Vector Shoreline data set) shifted the mosaic on the average by a distance between 0.5 and 1 km with respect to the geo-location data from scene headers. Adding more ground control points defined in the central part of the African continent shifted the mosaic only by order of 100 m. Therefore we are confident that the absolute geo-location accuracy is within a couple of hundred metres throughout the whole mosaic that extends from the Western coast of Africa in Sierra Leone to the Eastern coast in Kenya and Tanzania.

A rigorous multi-temporal least squares block adjustment was applied to a semi-continental SAR mosaic consisting of over 3600 scenes and extending over a distance of more than 6000 km. In this respect, the GRFM Africa data set probably represents a milestone in wide area radar mapping of the earth ecosystems.

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