TESTS ON DETERMINING DIGITAL ELEVATION MODELS FROM ERS TANDEM DATA

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ABSTRACT:

The ERS Tandem Mission from August 1995 to May 1996 provided a large resource of data that can be used for a number of applications in the geosciences, based on the principle of interferometry, referred to in this paper as InSAR. InSAR techniques can provide a new and efficient method of deriving DEMs with little manual input. This paper describes research on the determination of digital elevation models (DEMs) by interferometry using the Tandem Mission data, and tests on the quality of the derived elevations for upgrading the digital elevation databases of Australia. Test sites were chosen so that they represent typical areas in Australia, including hilly areas, rivers, cities and towns, in which good details are available for the choice of ground control and check points. Generation of elevations involved the computation of coherence between master and slave images, determination of interferograms, reference of the DEM to the terrain surface either in terms of ground control points (GCPs) derived from reference maps of the area, or using the satellite ephemeris data, generation of the DEMs, and the analysis of their quality. Estimated accuracies of the DEM were determined by comparing the computed DEMs with existing maps and known DEMs of the area.

1. OBJECTIVES OF PROJECT

In April 1995 the European Space Agency (ESA) launched its second Earth observation satellite, ERS2, which like the first satellite, ERS1, includes a C-band Synthetic Aperture Radar (SAR) remote sensing imaging system. The 35 day orbits of the two satellites were programmed for the Tandem Mission, so that ERS2 followed approximately 30 minutes behind ERS1 in the same orbital plane, and hence there was a 1-day interval between the time when ERS1 and ERS2 looked at the same area on the Earth. The ERS Tandem Mission commenced on the August 16, 1995 and while operating until May1996, it provided a large resource of data that can be used for a number of applications in geosciences, based on the principle of interferometry, referred to in this report as InSAR. Pairs of ERS1/2 satellite data acquired in the Tandem Mission are suitable for DEM generation over almost all of the global land surface, including Antarctica. The main objective of the Tandem Mission, therefore, was to ensure acquisition of a unique and valuable set of SAR data that could be used for InSAR purposes.

The aims of this research project were to test the suitability of the method of InSAR, using the ERS1/2 Tandem Mission data, for achieving greater efficiencies in upgrading the digital elevation model (DEM) data in Australia. In addition, the objectives were to develop practical methods of using InSAR techniques on the Tandem Mission data in a production environment. The research was undertaken in cooperation with Geoscience Australia (abbreviated to GA), formerly AUSLIG, and funded by the Australian Research Council's SPIRT Program. Improved DEM data should lead to substantial benefits to the wide variety of users in Australia who require digital elevation data. It should also impact on a much larger group in the community who benefit from the application of this data in achieving better environmental analysis, such as microclimate studies, river drainage delineation, and coastline identification.

1.1 Principles of InSAR

Consider two radar antennas, which simultaneously view the same region from two positions A_1 and A_2 respectively, where the distance between two antennas is referred to as the 'baseline', B. The range distance between A_1 and an illuminated point on the ground is r, while $r+\delta$ is the distance between A_2 and the same point. In this example, the radar wave is transmitted from antenna A_1, and after interaction with the terrain, the backscattered return is recorded by both antennas A_1 and A_2. These signals are then processed to complex SAR images, and phases measured in each image are differenced on a pixel by pixel basis. The phase differences between the two returns signals are sensitive to viewing geometry, baseline orientation and the height of the illuminated point with respect to reference surface. They can be modelled from the corresponding distance δ in terms of wavelength of the emitted signal, which expressed in radians, is:

$$\varphi = \frac{2\pi\delta}{\lambda} \qquad (1)$$

The phase φ in equation (1) is the fractional phase (value 0-2π radians). This leads to an ambiguity in determining the range, which must be solved by so-called 'phase unwrapping' techniques. Hence the phase information can be converted to an image, an interferogram, displaying variations in height, provided the viewing geometry is known to sufficient accuracy.

For repeat pass interferometry SAR, as in the case with the satellite based Tandem Mission, since on each pass the antenna acts as both transmitter and receiver, the total path difference for each observation to an illuminated point on the ground is twice what would be expected in a single pass imaging geometry with two physical antennas. Therefore, the equation for repeat pass geometry is:

$$\varphi = \frac{4\pi\delta}{\lambda} \qquad (2)$$

This study is based on equation (2) for the ERS1/2 Tandem Mission data, together with the necessary equations for phase unwrapping and computations of elevations, using commercial software packages as described below. The steps required to generate elevations by interferometry involve the computation of coherence between master and slave images, determination of interferograms describing the differences in phases in the image pairs, unwrapping of the phase differences, including resolving the ambiguities in the phase differences to determine elevations, and reference of the DEM to the terrain surface either in terms of ground control points (GCPs) derived from reference maps of the area, or using the satellite ephemeris data.

1.2 The Factors affecting the performance of ERS1 and ERS2 interferometry

1.2.1 Tandem Phase Coherence

The ability to derive elevations by InSAR techniques is dependent on the quality of the correlation between the two images of the same area on the terrain surface, which enables the determination of the coherence and hence the phase differences of the signals received by the two antennas. The ideal configuration of the antennas is to acquire both images simultaneously (single pass), as is done for aircraft InSAR, and on the NASA SRTM (Shuttle Radar Topographic Mission). In the latter case, the two antennas were separated by a 60m extendable arm on the Shuttle. The coherence of the Tandem Mission configuration is a great improvement on the 35-day repeat cycle of the individual satellites, which would render InSAR techniques impossible, but it is not an ideal situation for data acquisition. Therefore it could be expected that on occasions the coherence would not be satisfactory for DEM determination. An evaluation of the coherence showed that it varied greatly in the test images, because of its strong dependence on terrain conditions. Coherence in this project was as high as 85%, but it averaged approximately 50% for most test areas.

1.2.2 Temporal Decorrelation

Temporal decorrelation is caused by physical changes in the characteristics of the terrain surface between successive data takes, which results in errors in the phase differences of the signals and hence errors in the computed elevations. Temporal decorrelation may lead to poor or no correlation between the two images and hence gaps in the DEM. In this project, both problems occurred in some test images.

1.2.3 Atmospheric Artefacts

It is known that differences in atmospheric conditions between the two radar data takes can result in variations in elevations, since the travel time for the microwave radiation will be affected by the density of the atmosphere. Differences in travel time will result in errors in phase differences (several wavelengths are possible) and hence errors in the computed elevations of tens of metres. Variations in atmospheric conditions can only be roughly determined from meteorological reports at the time of the data takes and hence no corrections are possible. The most common method used by researchers for overcoming the errors introduced by atmospheric conditions is to determine elevations from the average of multiple image pairs of the same region. It is for this reason that several images of the same area have been tested in this project.

2. Description of Experiments

2.1 Processing software

Two software packages were available at UNSW: Atlantis EarthView InSAR processor supplied by PCI in Canada, and PulSAR InSAR processor supplied by Phoenix Systems, UK.

The characteristics of Atlantis InSAR processor include:

1) It accepts pairs of ERS1 and ERS2 tandem, ERS repeat, JERS1, and RADARSAT single look complex (SLC) images (Level 1 data) and produces elevations, elevation changes, surface changes, surface motions, and other measurements of the ground surface by using SAR interferometry.
2) It requires the location of ground control points (GCPs) in the image and maps of the region for positioning the DEM on the terrain surface
3) Optimal Horizontal Resolution for ERS1/2 is 20m, and for RADARSAT Fine Mode, 10m, and Georeferencing Accuracy is typically better than 20m.

The characteristics of PulSAR InSAR processor are:

1) It is a professional package designed for processing ERS1/2 image from raw data input
2) It uses the satellite ephemeris in the data header file for positioning the DEM on the terrain surface. Hence, no GCPs are required.
3) It uses an initial approximate DEM of the area to assist in the phase unwrapping. The computed DEM is therefore based on the coordinate system of the initial DEM.
4) Precise satellite ephemeris data supplied by ESA can be used to improve the positioning of the DEM

2.2 Selection of scenes for experiments

The test scenes were selected to satisfy certain conditions:

1) The test areas should be representative of those for which the data would be used operationally. Areas where InSAR should prove most suitable are in undulating terrain where there are no significant forested areas, which may cause temporal decorrelation and hence errors in the computed elevations, or gaps in the DEM (‘no-data’). Hence, in order to obtain a true estimate of the elevation accuracies from InSAR, areas were selected in rural regions in south eastern Australia. The areas included some mountains, rivers, and large and small townships.

2) The data should have appropriate parameters for the computation of DEMs. The primary parameters to be satisfied are the period between data takes, which is implicitly one day, and the base length, which should be less than about 300m to ensure good coherence between the images.

3) There should be multiple scenes of the same area to test the effects of errors in the elevations, primarily due to atmospheric effects.

4) GCPs from maps of suitable scale should be available in the area. The majority of images selected were covered by 1:25,000 maps (positional accuracy of GCPs of 8m and elevation accuracy of 3m).

5) Availability of adequate reference data. While maps were available for testing the quality of the DEMs, both in terms of the residuals at the GCPs after the computation of the DEM, as well as identifiable check points on the computed DEM, this is an extremely time consuming process. Hence, it was preferred to use the GA 9” DEM, with a reported accuracy of about 10m, for testing the quality of the computed DEMs. In all cases in these tests, the accuracy of elevations are quoted as the RMS of the differences between the elevations computed by interferometric SAR and the elevations derived from either identifiable GCPs or check points on topographic maps of the area, or the existing GA 9” DEM. The comparison of two DEMs has been carried out using Arc/Info software, which interpolates one DEM onto the other.

3. ACCURACY OF COMPUTED DEMS FROM ERS1/2 TANDEM DATA

3.1 Atlantis Software

Five image pairs were tested using Atlantis software. For full scenes of 40km by 110 km, the RMS accuracy of the derived elevations varied from 9m to 35m, while for quarter-images, the RMS errors were typically of the order of 10m. The lower accuracy for the full scenes is most likely due to the polynomial used to transform the DEM to the terrain surface in Atlantis software. The quality of GCPs plays an important role in Atlantis InSAR processing. Their location is time consuming and in many cases they are difficult to locate in appropriate locations, especially in treed and mountainous areas. Estimates of the accuracies of the elevations derived by Atlantis, compared with existing DEMs varied between 17m and 57m for full scenes and 15m and 59m for quarter-scenes. This test should be more representative of the accuracy of the quality of the DEMs derived by Atlantis, since it is based on elevations over the whole scene, rather than a small number of GCPs.

3.2 PulSAR Software

Nine image pairs of ERS1/2 Tandem raw data were processed by PulSAR software of areas in Victoria and NSW. The following image pairs numbers (as used in Table 1) fully or partially overlap were Nos. 6, 7 and 8; Nos. 9 and 11; No. 12 and No. 13. In this software, two phase unwrappers were available and used, the so-called ‘Default’ developed by the authors of the software and ‘MCFU’, developed by ESA. The accuracies for only the MCFU unwrapper have been shown in Table 1. The accuracies of the elevations in each test case, compared with the known 9” DEM are between 10m and 20m. The average RMS, excluding the results of image pair 6, was 13m, compared with the results from the Default unwrapper of 16m. The reason for the poor result for image pair no. 6 for both unwrappers is not known.

As well as computing the accuracies of individual images, mean elevations were computed for the following overlapping image pairs: 6, 7 & 8, 7 & 8, 9 & 11 and 12 & 13, as shown in Table 1. The means of elevations derived from more than one image pair are superior to the results obtained from individual image pairs, averaging 9m for MCFU and 14m for the default unwrapper. Overall, averaging the elevations of overlapping pairs will result in improved elevations. Indeed, it can be concluded that accuracies of the order of 10m are generally possible by averaging the elevations obtained from two or more overlapping image pairs. These results are similar to the accuracies achieved in Europe (Muller et al 2000), (Kosmann et al 2001).

Image Pair	**Test Cases**	**Max/Min Values**	**Elev. RMS error (m)**	**Mean (m)**
3	23293/3620 NSW Dec 29/30 95	150/-100	8	0
5	23043/3370 Victoria Dec 11/12	187/-282	11	-2
6	22792/3119 Victoria Nov 24/25 95	299/-299	71	0
7	22542/2869 (Victoria) Nov 6/7 1995	295/-298	26	+2
8	23064/3391 Victoria Dec 13/14 95	198/-199	22	0
Mean 7-8	23064/3391 Victoria	175/-221	14	0
Mean 6&7&8		130/-176	15	2
9	22649/2976 Victoria Nov 14/15 95	72/-89	7	2
10	23465/3792 Victoria Jan 10/11 1996	57/-274	10	-2
11	22921/3248 (Victoria) Dec 3/4 1995	285/-275	10	-2
Mean 9&11		18/-32	5	-1
12	25068/5395 Victoria May01/02 1996	297/-298	20	-2
13	22835/3162 Victoria Nov 27/28 1995	252/-227	17	-2
Mean 12&13		155/-104	8	0

Table 1 Comparison of results of full scene tests using PulSAR with MCFU phase unwrapper with the 9" DEM

4. CONCLUSIONS

1) Extensive tests have been carried out using ERS1/2 Tandem Mission radar data for the determination of elevations by interferometric methods, using PulSAR and Atlantis softwares.

2) PulSAR software is superior to Atlantis, primarily because of the achievable accuracies, and the avoidance of the use of ground control points. While the accuracies of elevations from PulSAR vary in places, it is believed that this is primarily due to the problems in obtaining coherence in treed or mountainous areas. Accuracies, measured as RMS differences between the computed DEM and the 9" DEM, of about 10m are achievable with the InSAR technique, based on the average of elevations determined from at least two image pairs. Individual pairs of images will result in accuracies of the

order of 15m, but on some occasions poorer accuracies will result. Marginally better results were obtained by the MCFU phase unwrapper, compared with the Default unwrapper.

3) Altantis software resulted in significantly lower accuracy elevations, of the order of 30m for a full scene, and 10-15m for sub-scenes. However, the need to use GCPs reduced the accuracy of the elevations and slowed down the process very significantly. For many parts of Australia, a sufficient number of accurate GCPs would not be available from existing maps.

5. References

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