SRTM C-Band Topographic Data: Quality Assessments and Calibration Activities

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INTRODUCTION

In February 2000 the Shuttle Radar Topography Mission (SRTM) mapped the topography of the world's landmasses between ±60° using radar interferometry* [1]. SRTM is a joint mission of the US National Aeronautics and Space Administration (NASA) and the German Space Agency (DLR), in partnership with the US National Imagery and Mapping Agency (NIMA). The radar instrument, designed for global coverage, is a two-aperture C-band interferometer, comprising a modified SIR-C C-band system and an added receive antenna mounted at the end of a 60 m deployable boom. Full coverage of the Earth was possible in the 10 day mission by operating the radar in two two-beam ScanSAR modes, one with vertical polarization, and the other with horizontal polarization, as illustrated in Fig. 1. The four beams together covered about a 225 km ground swath. An additional X-band interferometer was also flown on the shuttle, with a narrower swath. For a comparison of X-band and C-band performance, see [2].

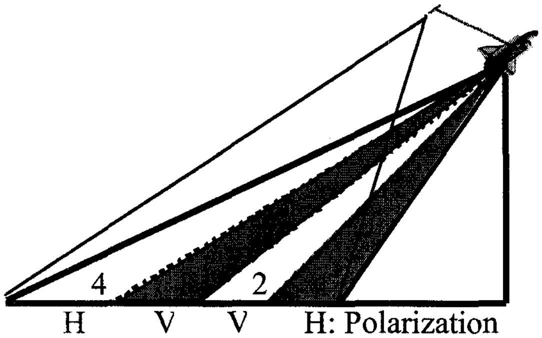

Figure 1. The SRTM C-band radar collects data in two subswaths simultaneously using horizontal (H) and vertical polarization (V). The four ScanSAR subswaths are numbered 1-4 starting from nadir as shown above. Subswath 1 has a near-range incidence angle of about 30°. Subswath 4 has a far-range incidence angle of about 60°. The shuttle altitude is about 230 km.

One of the key components of the interferometer was the Attitude and Orbit Determination Avionics (AODA), comprising a suite of instruments to measure the shuttle position and attitude and the boom tip location relative to the shuttle. Absolute position information was determined from two GPS receivers located on the deployed radar antenna structure. Attitude information was derived from a combination of star tracker and IRU measurements. The boom tip location was determined with an optical target tracker, which measured the angles to several targets located on the tip structure, and an electronic ranging device used to measure the distance to the boom tip.

NASA-funded investigators are examining the quality of the data in detail, however as part of the processing algorithm development team, we have had the opportunity to examine the quality of the data as the algorithms are tuned during the development of the production system. The purpose of this paper is to present the first look at the characteristics of the C-band SRTM topographic data.

ALGORITHMIC APPROACH

The algorithms for processing raw topography data are described in detail elsewhere [3,4]. Briefly, the processing flow is as follows. For a given continent, all data takes that are relevant to that continent are processed from beginning to end. Each of the four subswaths of each data take is processed independently. Processing of the subswaths is accomplished with a specially designed ScanSAR interferometric processor [4] that ingests raw ScanSAR bursts, telemetry and processed motion data, and produces geocoded strips of data in roughly 1000 km segments. The geocoding is done in a coordinate system aligned with the shuttle flight direction for data storage efficiency. Had the AODA data been perfect and the radar parameters perfectly stable over the mission, these segments would be absolutely geolocated, and the final stage of processing would simply combine the strips into latitude-longitude oriented gridded cells.

The AODA data however are not perfect, and the radar phase between the two receive channels can drift, so each strip has a time variable interferometric baseline and phase error that must be estimated and removed before combining the data in a mosaic. The relative three-dimensional offset of one segment relative to another segment from another data take is estimated by automated matching, generating a set of tie-points binding the

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[*] This paper was written at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

continental elements together. In addition nearly all of the 700 datatakes begin and end over ocean, so an absolute reference exists for all data. Some few thousand ground control points are also available, though these are not radar identifiable. These control data are then used in a least square solution to determine time variable baseline and phase corrections over each 1000 km segment of the data takes. These estimates are checked for consistency and quality then are used to adjust each segment before mosaicking.

ACCURACY ASSESSMENTS

In tuning the AODA solutions and the radar algorithms, we have had the opportunity to process large amounts of ocean data as a reference surface and terrain data for quality assessments. This can be characterized in terms of the statistical noise on the data and the long-term trends in the geometric solution. At the time of writing, we are still finalizing the AODA solution, so estimates of accuracy presented here are still preliminary, particularly for systematic trends.

Figures 2 and 3 shows some profiles of the ocean data collected for calibration and stability assessment purposes. These profiles represent the height of the ocean above the geoid as it comes out of the topographic processor. These curves should be flat, but each has a trend of several tens of meters over 8000 km of ocean. This of course is a very small drift in height, less than one millidegree in surface slope. With the mosaicking adjustment scheme described above, these slopes should be easily estimated and removed. The long term variability after removing trends is due to motion errors, and has an RMS below 4 m, within the SRTM net error budget.

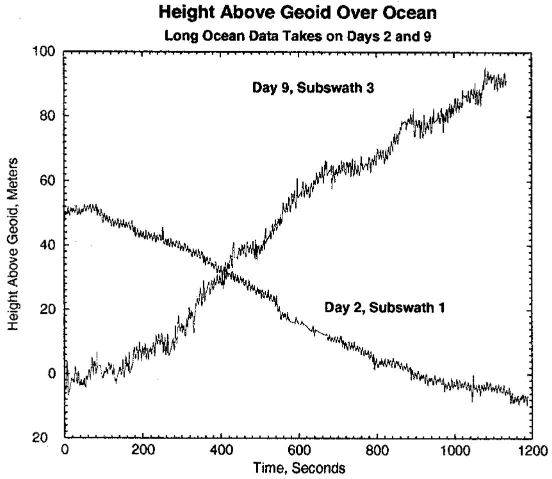

Figure 2: Profiles of ocean height above the geoid as observed at the output of the topographic processor. Curves should be flat. Slope represents uncertainty in AODA solution or radar phase stability. Note time span corresponds to over 8000 km along track.

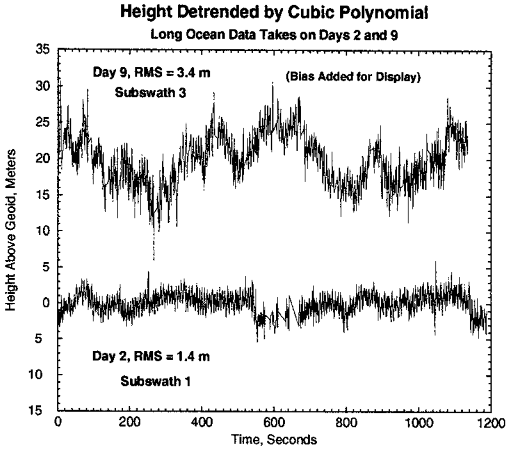

Figure 3. Trends removed from curves in Fig. 2 show the residual height noise expected after mosaicking adjustment. Note increase in height wander from beam 1 to beam 3 indicates small motion solution inaccuracies. The 3.4 m RMS noise in beam 3 is well within the SRTM error budget.

NIMA requested some preliminary data over sites of their interest to get a feel for the data quality. We have produced six fully mosaicked cells for NIMA with the final processing algorithms. NIMA supplied some ground control to level the data at a time when continental adjustment was not possible. Figure 4 shows a profile through a data set where the terrain is very flat, and the variability is an indication of the expected statistical noise in the data.

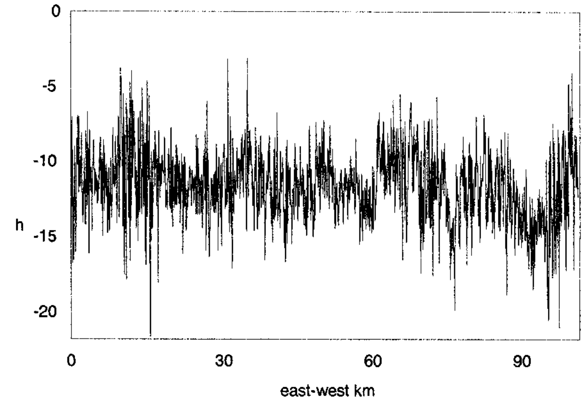

Figure 4: Profile of height over a very flat region of varying radar brightness. Height is above the geoid. Noise across the profile is representative of expected errors in a fully mosaicked SRTM product posted at about 30 m. The RMS height error is on the order of 3 m, well within the SRTM error budget for statistical noise.

CALIBRATION ACTIVITIES

Calibration of the interferometer is underway. Corner reflector arrays in California and Australia are used to determine the radar absolute and differential delays for radar imagery. They are also used along with ocean data to characterize the stability of the AODA solution as compared to the radar phase stability. To some extent the interferometric phase error cannot be distinguished from baseline roll errors, so the calibration here is primarily to find an average value and variance of these quantities. In addition to the long ocean datatakes described above, there were 30 short ocean datatakes designed to characterize the baseline.

SRTM was originally designed without any radiometric calibration requirement because imagery was not a deliverable product, but after the flight of SRTM, NIMA opted to receive image mosaics. Two global mosaics will be produced: one for data acquired on ascending orbits, and another for data on descending orbits. Radiometric corrections have been added to the algorithms, and fine-tuning is underway. Figure 5 shows some profiles of radiometrically corrected data in the Amazon, where the forest canopy is expected to produce angle-independent backscatter. Two data takes are shown from completely different times, and the radiometric level is the same in both, indicating good radiometric stability.

CONCLUSIONS

SRTM was a challenging mission to develop and execute yet the mission operations were quite successful in acquiring 97% of the planned data. The processing of the data to meet accuracy requirements is also quite challenging due to noise in the metrology and radar data. Nonetheless, preliminary processing of substantial quantities of data from around the world suggest that the mission achieved its accuracy goals, and that the production system will succeed in producing the world's first globally consistent, fine resolution, accurate, digital topographic map.

ACKNOWLEDGMENTS

The authors would like to thank the AODA team for diligence in providing accurate motion data required for processing and the Ground Data Processing System Team for generating and formatting the signal data used in this paper.

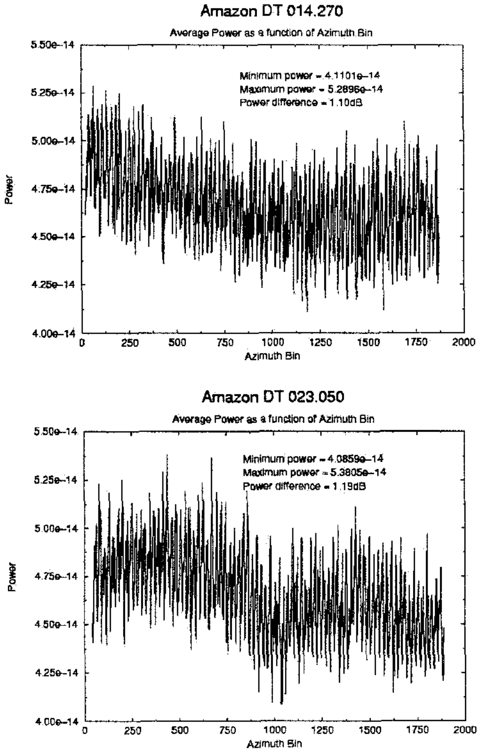

Figure 5: Profiles of radar brightness along track in the Amazon from two different days. Variation is less about 1 dB peak to peak, and stable from one day to the next. The relatively regular oscillations are due to uncompensated burst scalloping effects, but at the sub-dB level. Profiles are preliminary. Range variations are at the 2 dB level with beam-to-beam discontinuities clearly present for beam 2. This is also preliminary and being investigated. Expectation is to have better than 1 dB relative and 3 dB absolute calibration everywhere.

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