High-accuracy, Low-cost SAR Data Correction

Geometric Correction of ASAR Data without Ground Control Points

by Philip Cheng

This article examines the geometric correction accuracy of ENVISAT ASAR data without the use of ground control points. High accuracy results would be of significant interest to users of Synthetic Aperture Radar (SAR) data, because the creation of accurate orthorectified ASAR images would then be possible using only an accurate Digital Elevation Model (DEM), without dependence upon regionally-available ground control points. The article also explores the applicability of the globally-available Shuttle Radar Topography Mission (SRTM) elevation models for correcting ASAR data.

Since the launch of the first *European Remote Sensing* satellite (ERS-1) in 1991, SAR, which can penetrate cloud cover and deliver perfect images even at night, has become a valuable remote sensing tool for both military and civilian users. Military SAR applications include intelligence gathering, battlefield reconnaissance and weapons guidance. Civilian applications include topographic mapping, geology and mining, oil spill monitoring, sea ice monitoring, oceanography, agricultural classification and assessment, land use monitoring, hydrology, interferometry, and planetary or celestial investigations.

ENVISAT

Launched in March 2002, the European Space Agency's Environmental Satellite (ENVISAT) is the largest Earth Observation spacecraft ever built. It carries ten sophisticated optical and radar instruments to provide continuous observation and monitoring of the Earth's land, atmosphere, oceans and ice caps. Its largest single instrument is the Advanced Synthetic Aperture Radar (ASAR), operated at C-band (5.331 GHz), and can be regarded as an advanced version of the SAR instruments on board the ERS-1 and ERS-2 satellites. Its beam elevation steerage allows the selection of different swaths (IS1 to IS7) at different incidence angles (15° to 45°), providing a swath coverage over 400 km wide using ScanSAR techniques. In alternating polarization mode, transmit and receive polarization can be selected allowing scenes to be imaged simultaneously in two polarizations.

In the image mode, ASAR operates in one of seven predetermined swaths (100 km swath width) with either vertically or horizontally polarized radiation; the same polarization is used for transmit and receive (i.e., HH or VV). The ground resolution is about 30m, sampled at pixel separation of 12.5m. In the alternating polarization mode (in one of seven possible swaths), two images in two polarization modes (HH & VV, or HH & HV, or VV & VH) are acquired. The ground resolution is about 30m, sampled at 12.5m spacing. When operating in the ScanSAR mode, a wide swath of > 400km can be achieved, at a ground resolution of about 150m, sampled at 75m pixel spacing.

ENVISAT carries the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) microwave tracking system. The DORIS microwave tracking system and laser retro-reflector can measure the exact geolocation of all ASAR products to within 4.5cm (1.8 inches) and its orbital speed to an accuracy of 0.4mm (1/60th of an inch) per second. This is most important for calibration of radar altimeter measurements. However, the data can also be used for monitoring glaciers, landslides or volcanoes, and to improve modeling of the Earth's gravity field and the ionosphere.

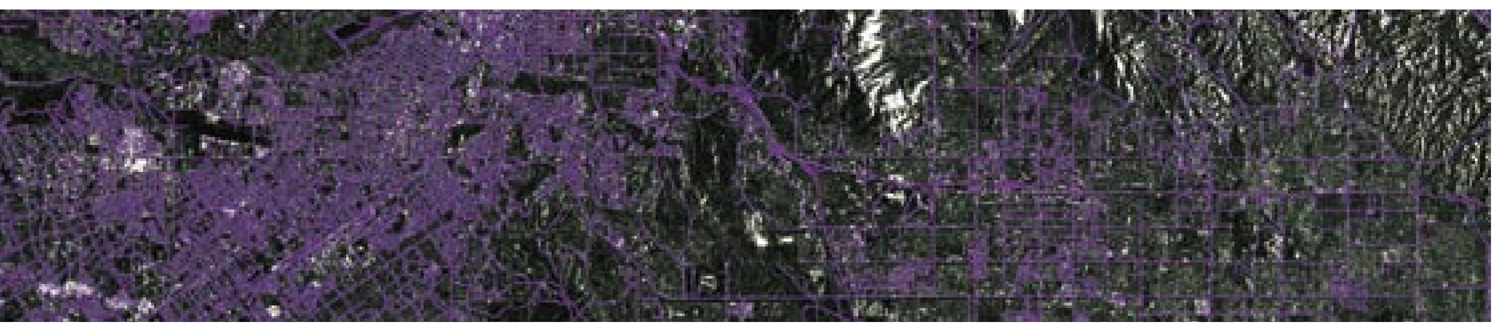
Geometric Correction of ASAR Data

For most SAR applications, it is required to perform a geometric correction (or orthorectification) of the data to a map projection. The correction process requires the use of a rigorous geometric model, ground control points (GCPs), and a digital elevation model (DEM). The collection of GCPs presents a significant problem for SAR geometric correction. First, an existing source of GCPs may not be available. It is often prohibitively expensive to collect new points, especially for areas inaccessible by road. Second, unlike optical satellites, it can be very difficult to identify GCPs on the SAR image, a problem exacerbated in mountainous areas due to foreshortening and layover effects. These problems have limited the geometric correction accuracy of SAR data in the past.

Unique among radar satellites, ENVISAT's DORIS system has provided very accurate orbital information about the satellite. This information could potentially be used to orthorectify the ASAR data accurately to any map projection without the need for GCPs. In this article, different ASAR data will be used to explore the geometric correction accuracy without GCPs.

ASAR Image Products and Correction Software

ASAR data comes in three products with different processing levels: level 0, level 1B and level 2. For testing, the level 1B precision images were chosen because they have the minimum of geometric correction pre-applied to the data. Five different ASAR 1B datasets were obtained from the ESA. The first dataset is an



ASAR_IMP_1P (ASAR Image Mode Precision Image) ascending IS7 product acquired in November, 2002. The other four datasets are the ASAR_APP_1P (ASAR Alternating Polarization Precision Image) descending products acquired in November, 2003. Two were acquired with IS2 swath and two were acquired with IS4 swath. All datasets were acquired over the Orange County area of California, USA. The area has an elevation range of 0 to 3500 meters.

The ASAR IMP data are multi-look, ground range, digital images generated from Level 0 SAR (narrow swath) image mode data (in either HH or VV polarization), using up-to-date (at time of processing) auxiliary parameters, and corrected for antenna elevation gain, range spreading loss and external characterization data. This product is suitable for users seeking to perform applications-oriented analysis. It is also intended for multi-temporal imaging (in either HH or VV polarization) and for deriving backscatter coefficients.

The ASAR APP data are multi-look, ground range, digital images generated on request from Level 0 SAR (narrow swath) alternating polarization mode data, using a technique that allows half the looks of an image to be acquired in horizontal polarization and the other half in vertical polarization. The images are processed to 30m resolution (with the exception of IS1). The product contains two images corresponding to one of the three polarization combination sub-modes (HH & VV, HH & HV, VV & VH).

Both ASAR IMP and APP products have engineering corrections and relative calibration applied to compensate for well-understood sources of system variability. Absolute calibration parameters, when available (depending on external calibration activities), shall be provided in the product annotations.

PCI V10 OrthoEngine software was used for the testing. The software supports rigorous model correction for a variety of optical and SAR satellites. OrthoEngine's ASAR/RADARSAT Specific Radar Model was used in all tests, allowing the computation of the geometric model with or without GCPs.

Test Results

To test the accuracy of a geometric correction without GCPs, independent check points (ICPs) were collected from USGS 1:24000 scale maps for each image (see Table 1). The IMP image and the first two APP images have root mean square (RMS) errors within one pixel resolution (30m). The IMP image's RMS errors are higher than those in the APP images, likely because the IMP data was acquired soon after the satellite launch with an early version of the processor, and therefore likely included less accurate orbit state vectors. The current IMP data should have the same accuracy as the APP data.

More problematic are the third and fourth APP images. Both show a large RMS error, particularly in the Y direction. It was initially thought that the ASAR orbital data had a consistency problem. After sending the data back to the ESA for further investigation, the ESA reported that the problem was caused by an error in handling the timing of APP mode data in the processor. The error only occurred in APP products. As a result, a product quality disclaimer was then posted on the ESA web site (http://earth.esa.int/pcs/envisat/asar/disclaimer). The problem is corrected for APP products generated with ESA PF-ASAR version 4.02 or higher.

A corrected dataset was created by the new processor for scene APP 3, and was retested for geometric correction accuracy (see Table 2). The accuracy was much improved with the corrected product, again showing RMS errors within one resolution.

SRTM Digital Elevation Models

Though these tests prove that ASAR data can be orthorectified accurately without GCPs, the process still requires an accurate DEM. Accurate elevation data were not always readily available for the

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whole world. This problem was recently solved by the Shuttle Radar Topography Mission (SRTM), an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The program's key technology was a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. It obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. The NASA-NGA agreement on data distribution calls for 3 arc-sec (~90 m) resolution data to be released to the public for areas outside the United States. Within the USA, full resolution 1 arc-sec (~30 m) data have been released.

It would be relevant to test the geometric correction accuracy of ASAR data using SRTM DEMs with no GCPs. If the accuracy were acceptable, then users could simply orthorectify ASAR data using SRTM DEM data for any region on Earth. To perform this test, the elevation value of each ICP was replaced (using interpolation) with the elevation value obtained from the SRTM 3 arc-sec DEM. The 3 arc-sec DEM was chosen for its availability across most of the world.

Table 3 shows a summary of the geometric correction results using ICPs with elevations extracted from SRTM DEM data. In most cases, the RMS errors are slightly higher than the results shown in Table 1 and 2. However, all RMS errors remain within one resolution of the dataset. Therefore, for users with accuracy requirements within one resolution (RMS), SRTM 3 arc-sec DEM data proves to be sufficient for the orthorectification of ASAR data.

Figure 1 and 2 show the examples of an orthorectified ASAR image overlaid with USGS 1:100000 scale vector in an urban area and a mountainous area, respectively.

Table 1. Geometric correction accuracy results of four different ASAR datasets using ICPs only.

Product	Number of ICPs	RMS Error (m) X	Y	Maximum Error (m) X	Y
IMP	10	23.6	25.2	33.3	30.8
APP 1	20	10.6	14.1	20.1	22.9
APP 2	15	9.4	9.1	14.2	16.8
APP 3	14	15.7	105.4	37.5	121.9
APP 4	10	31.9	104.1	66.8	116.8

Table 2. Geometric correction accuracy results of one ASAR APP dataset using ICPs only, after processing correction applied by the ESA.

Product	Number of ICPs	RMS Error (m) X	Y	Maximum Error (m) X	Y
APP 3	14	12.1	10.5	22.0	18.2

Table 3. Geometric correction accuracy results of four different ASAR datasets using ICPs only, with elevation values obtained from SRTM DEM data.

Product	Number of ICPs	RMS Error (m) X	Y	Maximum Error (m) X	Y
IMP	10	25.4	25.2	37.1	30.8
APP 1	20	10.6	14.1	18.8	22.9
APP 2	15	11.0	9.1	23.8	16.8
APP 3	14	11.6	10.7	25.8	18.2

Figure 1. Orthorectified ASAR image of an urban area overlaid with 1:100000 scale vector.

Figure 2. Orthorectified ASAR image of a mountainous area overlaid with 1:100000 scale vector.

Summary

These tests prove that even without the use of ground control points, it is possible to correct ASAR level 1B data with high accuracy. The test results show RMS errors consistently within one resolution (30m) of the data. The fact that GCPs are not required for ASAR geometric correction translates to very significant cost and time savings for the user. Moreover, it was proven that ASAR data can be corrected to a high accuracy never before possible with other SAR satellites. If an accurate DEM is not readily available, the user can utilize globally-available SRTM 3 arc-sec DEM data to orthorectify ASAR imagery. In this case, results again show RMS errors within one resolution.

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