ACCURACY OF DEMS FROM REMOTELY SENSED RADAR IMAGES

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ABSTRACT

Satellite-based stereo radar imagery and interferometric radar imaging for both spaceborne and aircraft platforms have increased the availability and quality of radar-derived digital elevation models. Particularly in areas of perennial cloud cover or when a DEM is needed quickly with minimal reliance on ground control, radar is an appropriate source for a fully automatically produced DEM.

Examples for interferometric technologies concern single pass interferometry from IFSARE or dual pass methods with ERS-1/ERS-2 or RADARSAT-1 imagery. An example for stereo-based technologies concerns RADARSAT. Our paper addresses the wide area, rapid-fire DEMs from RADARSAT's 50 m ScanSAR images, all the way down to the detail of an experimental airborne high resolution SAR at a pixel size of 0.5 m capable of mapping individual buildings and their heights.

We outline some critical factors in the applications of these technologies and report about our experiences and results with the accuracies that can be achieved from a variety of such images. These range from fully operational DEM technologies using various types of RADARSAT data and commercial IFSARE images, to the more experimental methods applied to map individual buildings from very high resolution radar images.

We also use these results to comment on the value of future satellite radar projects such as the Shuttle Radar Topography Mission (1999), augmented by an extra antenna to support interferometry and aiming at developing a 30 m resolution DEM of the entire landmass within a latitude band of +/- 60 degrees, and the plans for a commercial LightSAR-project sponsored by NASA that is expected in a polar orbit from 2001 on.

1. INTRODUCTION

1.1 Topography from SAR

A single pass of a SAR provides range, backscatter, and phase information for each pixel of the processed image. The range provides no precise topographic information because the pixel could have originated from any surface feature on the *range/Doppler* circle for that pixel (Figure 1a). There are two direct methods of finding the elevation angle and thus the precise 3D location of features within SAR data sets. These two distinct methods are known as stereo and interferometry. Stereo SAR DEM extraction also known as *radargrammetry* (Leberl 90) relies on a <u>pixel</u> parallax; whereas interferometric SAR (IFSAR) DEM extraction utilizes a <u>wavelength</u> parallax.

Stereo SAR techniques (Figure 1b) derive topography from the angular differences between repeat observations in a method conceptually similar to that used in classic photogrammetry. The elevation of a terrain element is produced from the matching of homologous image pixels in a stereo pair. Elevations are rigorously computed from the intersection of range/Doppler circles associated with these matching image pixels. Larger separation angles provide more stable solutions yet more challenging matching. Local errors stem primarily from image matching while systematic errors are commonly due to platform position measurements. Image patches may be difficult to match if they contain highly dissimilar or indistinct features. Matching failures can produce gaps in stereo DEMs.

For IFSAR, the phase coherence of the radar allows one derive 3D position from the phase difference of observations (Figure 1c). This phase difference specifies an elevation angle on a pixel's range/Doppler circle thereby determining it's position. Phase difference maps or interferograms contain ambiguities modulo the SAR wavelength which can be resolved by a number of critical steps involving systematic flattening with ground control and local phase unwrapping (Ghiglia 1998). Baseline trade-offs exist here too between small separations with unstable solutions and larger separations with lower reliability due to reduced coherence. IFSAR is an extremely precise technique, yet it can produce erroneous results due to errors in phase unwrapping, interferogram flattening, as well as atmospheric effects. A lack of coherence between the interfered signals caused by temporal change, volume scattering or low signal strength can degrade accuracy or even result in gaps in IFSAR derived DEMs.

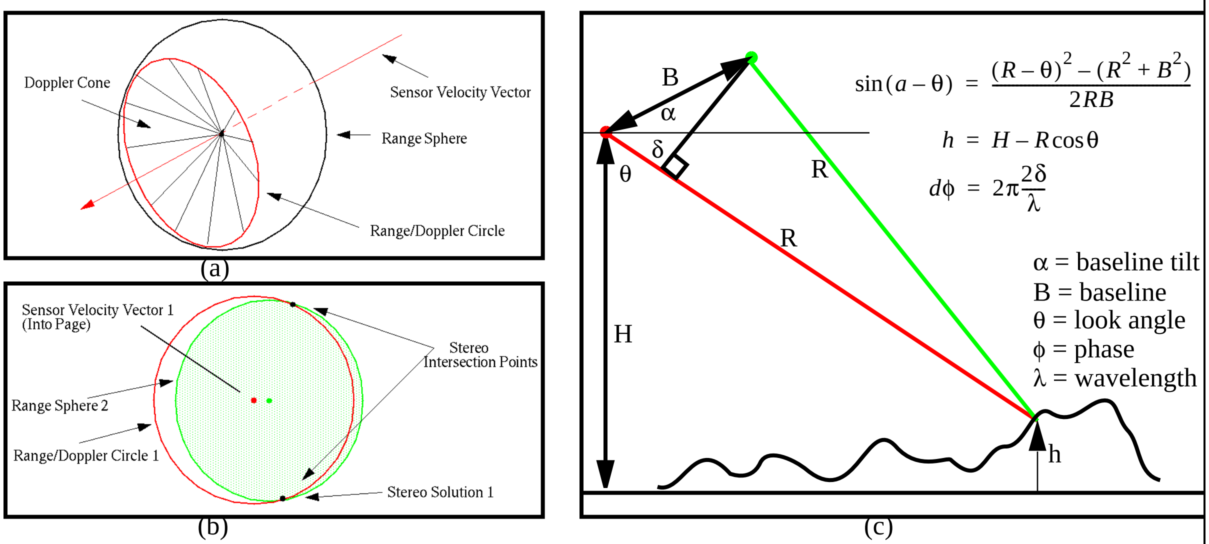

FIGURE 1. Illustration of stereo and IFSAR geometric constraints for determining terrain. Pixels in a single SAR image can orginate from any point on the range/Doppler circle. Vexcel's rigorous stereo intersection solution (b) computes terrain elevation from intersection of range/Doppler circles. Interferometric systems (c) compute the elevation angle δ and ultimately terrain height h from the difference of radar phases $d\phi$.

Limitations have been largely overcome in recent years by researchers familiar with SAR phenomenology. Promising advances in sensor design, processing methods, and compute power have opened exciting avenues for the application of SAR for topographic mapping at a wide range of scales. This paper will attempt to identify the strengths and weaknesses of radargrammetry and interferometry for a variety of existing and planned SAR platforms.

1.2 Advantages of SAR

SAR is gaining increased acceptance as a sensor of choice for terrain elevation extraction. The primary advantages of using SAR sensors are their ability to image at any time during the day or night and their ability to penetrate clouds thereby allowing unsurpassed availability of data of virtually any location at any time.

For stereo applications another advantage is that SAR is a ranging sensor that is insensitive to variations in platform attitude. This platform "wobbling" is sometimes difficult to sufficiently characterize and can result in local distortions in measurements made from optical sensors. A final advantage of radargrammetric vs. photogrammetric data is that SAR image magnitude variation stems largely from variation of terrain structure which provide image features of high contrast in areas which contain terrain relief (local change in elevation); optical imagery will often be saturated and/or featureless in ice and snow covered terrain whereas SAR stereo pairs will be rich with information and easily matchable.

Interferometric SAR offers unprecedented capabilities for topographic mapping. It is especially precise in situations where stereo matching of any kind can be the most problematic — flat featureless terrain. Dual antenna systems provide topography from a single pass and eliminate many problems associated with repeat pass interferometry. Interferometric correlation (Carande 1998) and polarimetric SAR data offer new applications of land use classification from radar data as well.

1.3 Market Demand

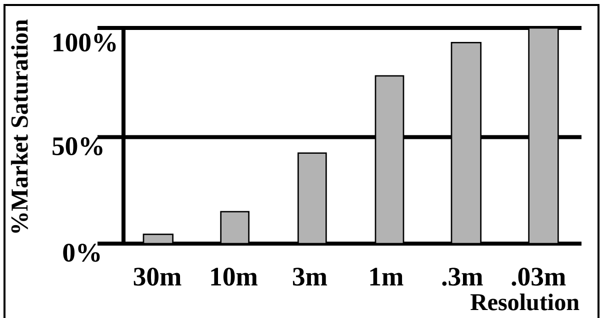

FIGURE 2. Civil Engineering Market saturation model for higher accuracy elevation data (Source: Bechtel Technology & Consulting)

Current applications of DEM extraction from orbital SAR are often limited by the resolution of imagery available from today's commercially available SAR platforms. Elevation estimates from RADARSAT stereo image data, for instance, can meet 10-30m accuracy specifications at best. While many remote areas of the world still need to be mapped at this resolution, there is a far greater demand for affordable 5m level products from the telecommunications, exploration (petroleum and mining), civil engineering, and national government mapping markets. An example of projected DEM market demand as a function of resolution is shown in Figure 2.

IFSAR data from today's repeat pass systems are capable of providing 5-15m accurate products but are sometimes limited by decorrelation, suitable data availability and systematic errors. Each of these orbital platforms has it's inherent limitations that can be partially overcome with the improved designs of future systems.

2. PROCESSING METHODS

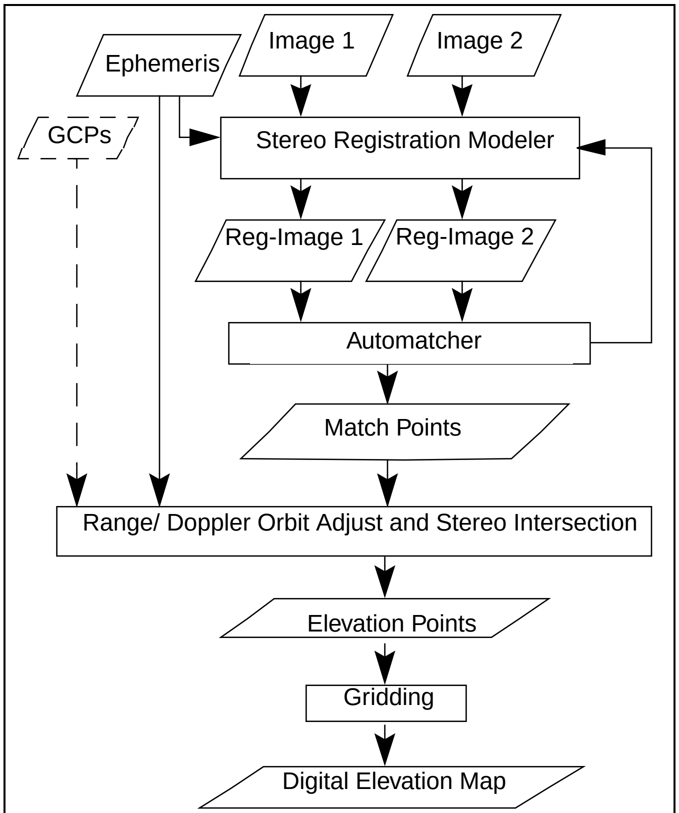

FIGURE 3. Stereo processing flow diagram.

2.1 Stereo

Stereo processing is performed by Vexcel's Radar Stereo Toolkit -- RaST™ a component of the 3DSAR™ system (Curlander 1998). RaST is a highly automated software package designed to ingest orbital SAR stereo pairs in the standard distribution format and produce DEMs and orthorectified SAR images. An overview of the processing flow is shown in Figure 3.

The image formation process can generally be performed by a variety of SAR processing systems which usually provide adequate image quality and precision[1].

Automatching is a critical step in stereo processing that ultimately determines the relative accuracy of the resulting DEM. Vexcel's automatcher is designed to assess the confidence of it's results at every stage of processing and reject candidate matches due to several statistical metrics. This outlier rejection is the key to the system's consistently accurate performance.

Recent advances in Vexcel's stereo matching algorithms have yielded reduced processing time, improved reliability and typically result in a 25% overall reduction in the DEM relative error. This iterative automatching technique provides sub-pixel image registration over the entire scene overlap. It eliminates implausible matching blunders by limiting the

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1. However, for effective ScanSAR stereo processing Vexcel utilizes its FOCUS™ SAR processor due to its precise image formation algorithms. Sub-pixel inaccuracies found in image products derived from other sources can lead to irregular distortions and artifacts in the resulting stereo derived terrain models.

match point search to a one dimensional locus of points over which terrain features can range due to their relative elevation. This type of match search optimization, while widely utilized in photogrammetric applications, is novel to stereo SAR processing to the best of our knowledge.

Relative terrain elevations can be extracted with stereo triangulation methods analogous to those used for photogrammetry applications; a more rigorous range/Doppler intersection model is employed here which greatly reduces the reliance on ground control for an accurate elevation estimate.

Absolute accuracy has also been improved with decreased reliance on often costly ground control points. Radarsat Stereo models were originally susceptible to biases of 100m or more due to SAR position and velocity errors. Residual errors of the radargrammetric model for each pair can now be virtually eliminated using a new minimization technique. Existing sparse elevation models can also be employed to remove overall biases of stereo DEMs with this rigorous adjustment procedure. For large projects involving several to 100's of stereo pairs, a block adjustment developed by Vexcel insures minimal misalignment among all of elevation models as well as the orthorectified imagery. The block adjustment can optionally propagate orbital corrections derived from very sparse ground control to minimize error associated with uncontrolled image pairs. For example, control points along easily accessible coastline features can be used to correct swath positions for images without control within the interior.

2.2 Interferometry

Vexcel's Synthetic Aperture Radar Interferometric processor, PHASE™, is a stand-alone software system designed for DEM extraction as well as differential processing. It is capable of forming and enhancing digital elevation models, and creating orthorectified imagery from spaceborne SAR satellites, including ERS, JERS, and RADARSAT.

PHASE is designed to provide large-scale map generation from interferometric SAR. The software system is controlled from a Java-based Graphical User Interface, which allows the user to operate the system both interactively, and as a batch process. PHASE is capable of producing digital elevation model products from two passes of the SAR satellite. It is also capable of performing two-pass and three-pass differential interferometry for detection of very small scale changes in elevation. This can be used for applications such as crop-growth monitoring and earthquake assessment. Inputting existing digital elevation data for update using the interferometric information is another capability of PHASE.

The software system takes, as input, standard CEOS format SLC-I data in the flight-agency standard formats or alternatively it can be integrated directly with Vexcel's FOCUS™ SAR processor.

The derivation of DEMs was the first, and still primary use of interferometric SAR. The basic premise is to use phase differences between two coherent SAR images to derive elevation. The resulting elevation data is accurate to a fraction of a wavelength; typically a few centimeters.

PHASE includes the following processing features:

- Along-track and range aperture trimming to improve the height accuracy.
- Baseline estimation and interferogram flattening from the image geometry to improve
- phase unwrapping.
- A choice of methods for interferogram filtering to aid phase unwrapping.
- Several methods for phase unwrapping.
- Geolocation and baseline refinement from a small number of ground control points.
- Geocoded output product in GIS compatible format.

With its unique DEM refinement feature, a poor quality DEM can be refined to one of higher accuracy. This method can be used to provide iterative updates to standard map products with recent interferometric data. The procedure can also be useful for merging the results of SAR Stereo with those of SAR Interferometry, or for filling holes caused by layover in a DEM acquired from a different viewing angle.

2.3 Stereo/IFSAR Fusion

Vexcel Corporation has been using wavelet transforms to combine the strengths of DEMs derived from IFSAR and stereo. Interferometric DEMs tend to be very accurate at the fine scale, but are prone to large-scale errors due to uncertainties in the estimates of the spacecraft position, which must be known to centimeters. They are also prone to errors resulting from scene changes occurring between observations, which is known as temporal decorrelation. High frequency errors in IFSAR DEMs result primarily from thermal noise, and are distributed in Gaussian fashion about zero; therefore, the effects of such errors can be reduced by averaging high frequency data from different IFSAR DEMs.

Orthogonal discrete wavelet transforms (DWTs) offer a technique for decomposing an image into components from different spatial frequency bands, allowing separate processing for as many components of the image as one wishes to extract. The separately processed portions can then be recombined into an improved DEM. The orthogonality of the DWTs permits the recombined image to be decomposed again without interference from components of the original DEM that were separately processed; i.e., the decomposition process is reversible.

Vexcel has had success with recombining DEMs for greater accuracy by decomposing perfectly registered IFSAR images taken from different viewing angles using a DWT, and averaging their fine- scale components. This process corrects local errors due to thermal noise, and high-frequency noise interfering with signal in areas of steep slope. In the accompanying figures, the high-frequency components of two IFSAR DEMs are combined to yield an image with fewer high-frequency errors; the images are taken from a Shuttle Imaging Radar (SIR-C) at two different viewing angles. The coarse- scale component of the recombined DEM can be obtained from a stereo SAR derived DEM, which has good accuracy at coarser scales, but does not have the high resolution accuracy obtainable with IFSAR (stereo SAR uses ground control points and match points between images to derive topographical elevation models). This recombination can be done in the transform domain; the improved DEM is then obtained by applying the inverse discrete wavelet transform.

3. EXAMPLES AND SPECIFICATIONS

3.1 RADARSAT Stereo

RADARSAT-1 launched in 1994 by the Canadian Space Agency provides SAR imagery of varying resolutions and look angles that are well suited for stereo data collection. A matrix of list cost and performance trade-offs for various RADARSAT stereo beam modes is shown in table 1. These specs can vary depending on size and location of the project.

Table 1. RADARSAT Stereo DEM production guidelines.

	ScanSAR Narrow	Standard	Fine
Nominal image resolution	50m	25m	8m
Image swath width	300km	100km	50km
Nominal DEM posting interval	150-200m	50-75m	50m
RMS vertical DEM error	45-50m	20-25m	15-20m
DEM production $/km^2	$0.15-$0.25	$1.00-$2.00	$4.00 - $6.00
SAR data costs $/km^2	$0.10-$0.15	$0.50-$1.00	$4.50-$5.50
Minimum project area	60,000km^2	7,000km^2	1,750km^2

While the Fine beam mode provides ideal resolution for a smaller project; standard beam is often chosen when mapping larger areas because it's more economical and yields only a modest reduction in product accuracy. For applications covering vast areas with lower accuracy requirements ScanSAR mode (Marra 1998) provides the largest swath width of any imaging sensor currently available.

ScanSAR Stereo Vertical accuracies of 45m RMS (40m standard deviation) have been obtained using automated processing of ScanSAR Narrow beam images produced with Vexcel's ScanSAR processor. The test DEM shown in Figure 4 (a) spanned a large region between Pittsburgh and Washington, DC and was controlled with 4 GCPs derived from USGS map sheets. These accuracies were validated by comparing each ScanSAR stereo DEM posting against the nearest USGS 30m DEM posting. The stereo parallax angle for this pair ranged from 9-11 degrees.

A qualitative assessment of ScanSAR derived DEMs compared to USGS 30m elevations can be made by inspecting a 150km square region near the PA and WV state border shown in Figure 4 (b-c). The ScanSAR stereo DEM is generally noisier and of a lower resolution than the very precise archived terrain data for this area. However, the ScanSAR stereo DEM reflects minimal distortions of the underlying terrain over vast areas.

ScanSAR imagery has a nominal ground range resolution of 50m and the resulting stereo DEM postings are spaced at a 150-200m interval. A single stereo image pair can be used to map over 80000 km^2 which drives combined production and data costs down to \$0.30/km^2 or less for projects ranging from 60,000 km^2 and beyond. The wide area coverage also provides for rapid turn around where stereo pairs covering entire countries can be acquired and processed in a matter of weeks.

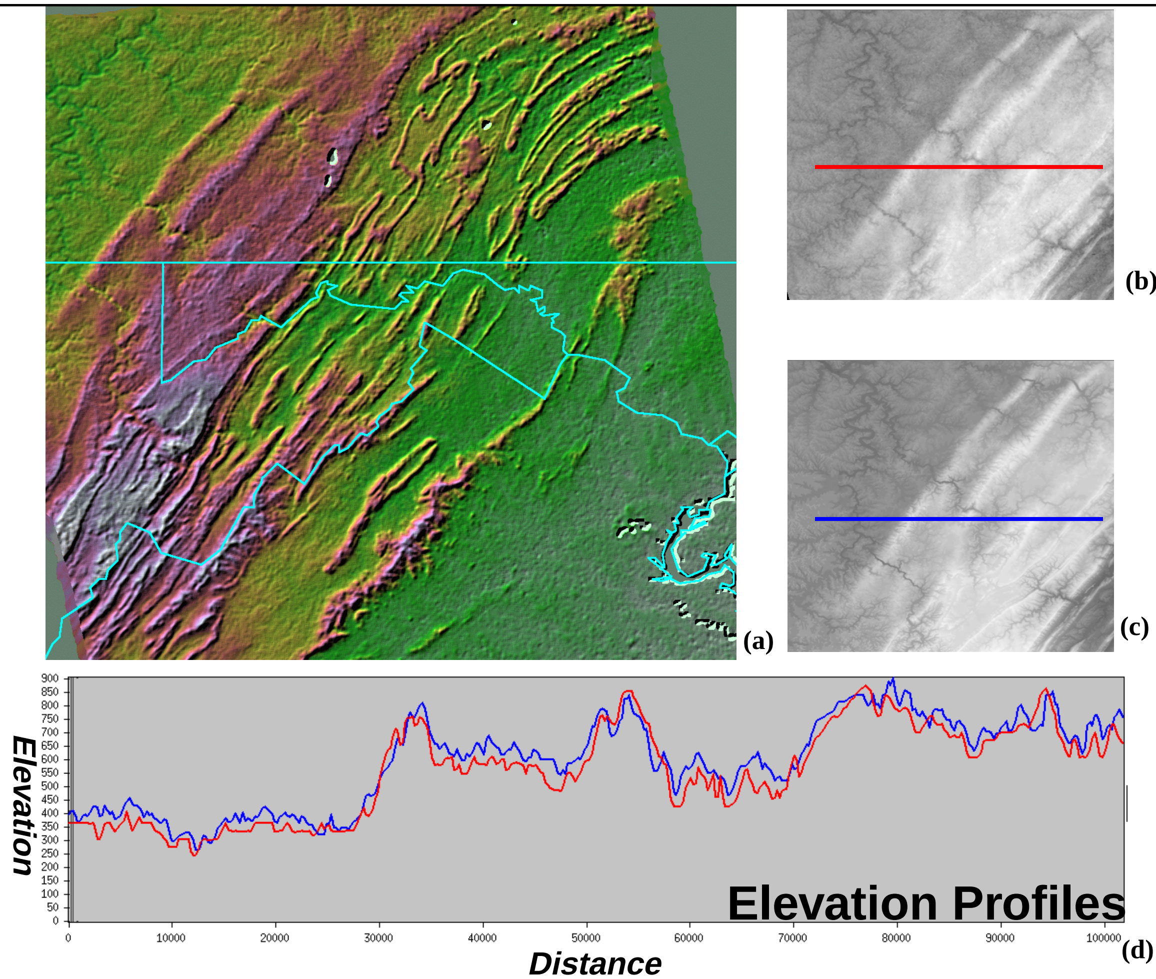


FIGURE 4. RADARSAT ScanSAR stereo DEM shaded relief map (a) of Mid-Atlantic USA. Boundaries of Pennsylvania, West Virginia, Virginia and Maryland are overlaid in cyan. Comparison of a ScanSAR stereo DEM (b) and a USGS DEM (c) for the same 150x150 km region. A profile comparison is also shown (d).

<u>Production Ready</u> Vexcel has been processing DEMs from RADARSAT stereo pairs since the sensor was first launched. The technique has been proven reliable for many terrain types and geographic locations, see Figure 5. All beam modes have been utilized for stereo processing however, we've found that some beam combinations can provide far better results than others depending on terrain types being mapped. We recommend consulting with Vexcel *prior* to ordering data to insure optimal results.

FIGURE 5. Fifteen of the sites over which Vexcel has produced RADARSAT-1 derived DEM and ORI products.

3.2 Stereo/IFSAR trade-offs

This example directly demonstrates the differences between stereo and IFSAR DEMs for the same site within Death Valley, California. The initial products shown in Figure 6 were created with early versions of Vexcel's stereo and IFSAR processors. These crude DEM products dramatically highlight the complementary nature of these two methodologies. The IFSAR DEM (b) has dropouts (shown in black) principally along the steep slopes facing the east looking SAR where correlation is low and phase unwrapping was unsuccessful. There are also some gaps due to temporal decorrelation e.g. in irrigated areas where crops grew between the two observations. The stereo DEM (c) has dropouts primarily in low relief featureless areas that provide little similarity for automatching.

While this IFSAR DEM contains 7% invalid cells, and the stereo DEM is 5% invalid; the combined coverage is 99.7% valid. Virtually everywhere that one technique fails the other technique succeeds.

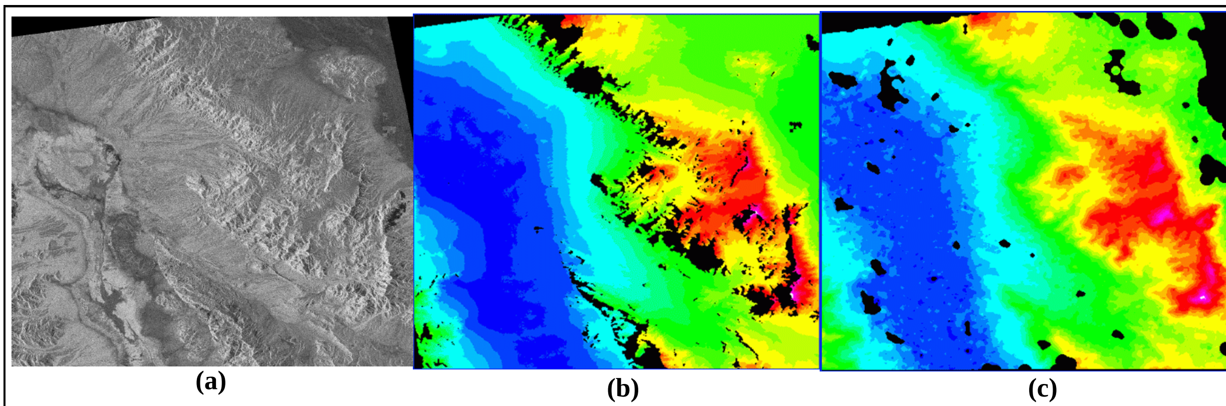
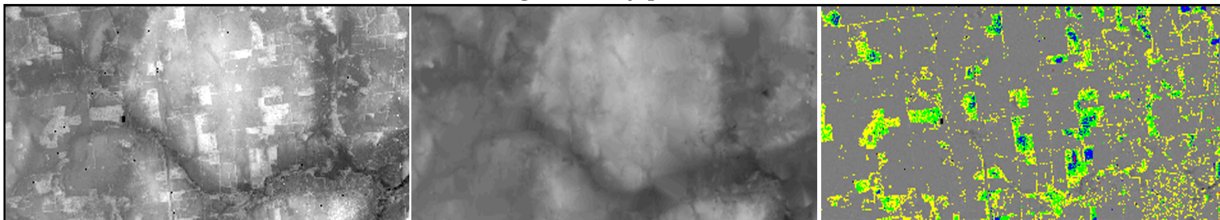


FIGURE 6. A RADARSAT fine beam image (a) was used to produce preliminary interferometric (b) and stereo (c) DEMs. The quality of either of these DEMs is not representative of final models produced by the current releases of either software package; however, they do demonstrate the complementary nature of these distinct techniques. Separately the DEMs are 93% and 95% valid; combined coverage is 99.7%.

3.3 IFSARE

Vexcel's IFMAP™ package (Carande 1998) provides exploitation of interferometric data for non-experts within a COTS GIS environment. The IFMAP system was designed to extract land-use classification, road networks, bald earth elevations, hydrology networks and more from IFSARE[1] data sets in particular. IFSAR elevation measures what has been called the *bottom of the sky* or *fuzzy earth* elevations. This is because IFSAR height measurements are effected by scatterers which lie on or above the terrain such as buildings and trees. Several elevation processing algorithms which exploit the classification results and elevation data have been developed to estimate the height of such elevated scatterers and thus approximate a *bald earth* DEM. The results (see Figure 7) are useful for the identification of elevated structures such buildings or utility poles.



(a) (b) (c)

FIGURE 7. The original elevations (a) computed from airborne IFSAR systems include the heights of tree stands and buildings. Vexcel's IFMAP package computes a land use classification based on many aspects of the interferometric data which is used to estimate the elevation of the bald earth (b) and the heights of above-ground features (c).

3.4 Building Detection

Vexcel has worked with several airborne sensors suitable for detecting and measuring buildings in urban environments. These sensors include the IFSARE and an experimental spotlight SAR platform operated by the Sandia National Labs. A detailed study exploring the capability of these sensors for NIMA made the following conclusions regarding these sensors:

1. Low-resolution (spatial resolutions of 3 meters or more) is of value for performing surveys to locate groups of buildings and performing land-use classification.
2. Medium-resolution IFSAR data (spatial resolutions of 1-3 meters) is of marginally better utility. This resolution is insufficient for measuring small buildings.
3. High-resolution IFSAR data (better than 1 meter resolution) is useful for measuring small buildings. However, building footprints and shapes can be severely distorted by radar phenomenological effects.
4. Multiple aspect high-resolution observations provide data which can be combined to significantly improve measurements.

The results of this study are shown in Figure 8. The test site consisted of a group of small houses and a church surrounded by grassy fields and forest. The 3 meter spatial resolution (a) of the IFSARE sensor provides adequate resolution for detecting groups of small buildings. The individual observations from the 0.5 meter resolution (b) AMPS spotlight interferometric SAR show individual buildings with distortions in both the magnitude and DEMs. Vexcel's combined magnitude and elevation images (c-d) provided the basis for automated algorithms that could produce wire frame models (e) of limited accuracy for each building.

1. IFSARE is 2 antenna X-band IFSAR sensor originally developed by ERIM and JPL for DARPA and US Army TEC. Intermap Technologies currently operates this sensor commercially under the name Star-3i.

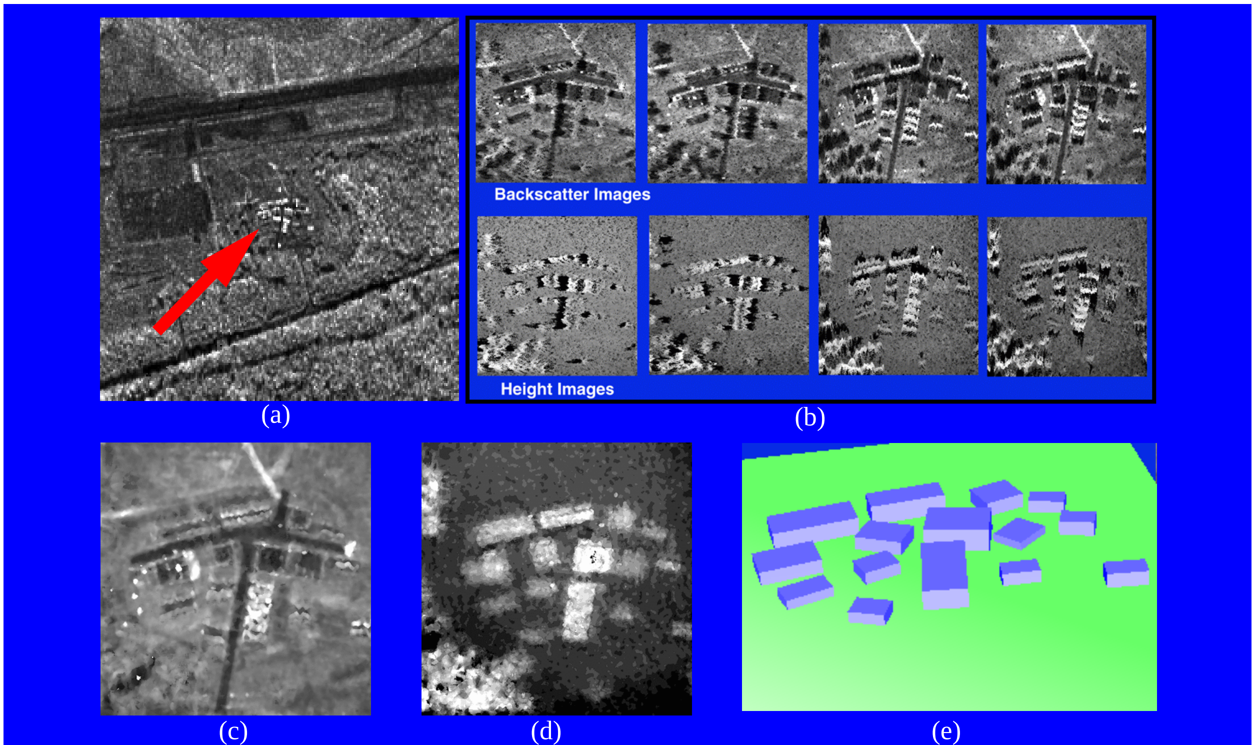


FIGURE 8. A group of buildings within Fort Benning, GA were imaged from various resolutions and perspectives to study building recognition from IFSAR sensors. The buildings are just detectable at the center of the IFSARE magnitude image (a). The same buildings were mapped from 4 perspectives with the AMPS system (b) and combined by Vexcel (c-d) for an automated building extraction demonstration (e).

3.5 Planned Systems

The most promising of all orbital IFSARs is the dual antenna Shuttle Radar Topography Mission (SRTM) designed to collect data in a single pass. NIMA's 30 meter accurate DTED-2 coverage only includes five percent of the earth's land mass. The SRTM is slated to provide similar accuracies within +/- 60˚ latitudes by 2001. This topographic data set will cover over nearly 80 percent of Earth's land surface, home to nearly 95 percent of the world's population. SRTM will thus provide an ideal source of global "low resolution" topography by tomorrow's standards. Soon thereafter, next generation orbital SARs will provide a capability for near global 5 meter accurate DTED-3 coverage.

Two orbital SAR systems are currently scheduled for launch in the 2001 time frame, RADARSAT-2 and LightSAR. Although still in the planning stages, LightSAR's image resolution could approach 1 meter by utilizing a spotlight mode. It is also proposed to have polarimetric sensing capabilities that will provide thematic mapping capabilities unique to any orbital sensor. These platforms are planned to include on-board GPS for improved ephemeris measurements. This will greatly reduce and perhaps eliminate the need for ground control in creating DEMs from stereo.

3.6 Specifications

The following table summarizes the accuracies and characteristics of various SARs (current and planned) used for topographic mapping. Quoted accuracies are representative of performance under suitable conditions. Most systems are not suitable for all terrain types.

Table 2. DEM accuracy specifications for various SAR platforms and modes.

	System Name & mode	Radar Band	Image Resolution	Swath Width	Comments	DEM accuracy (RMS)
Existing Orbital	Radarsat[a] stereo	C	8-50m	50-300km	Reliable and available source, low GCPs required, somewhat noisy	10-50m
	ERS-1/2 IFSAR	C	25m	100km	Mostly limited to archive, best repeat pass orbital IFSAR	5-15m
	JERS-1 IFSAR	L	18m	75km	Long repeat period	10-20m
Proposed[b]	SRTM IFSAR	C,X	30m	80km	Dual antenna on shuttle, global 60° coverage, DEMs scheduled for 2001	20m
	LightSAR stereo/ IFSAR	L,X	1-25m	5-100km	Stereo and IFSAR, 1 week repeat, spotlight, multi-polarizations, high availability, 2002 launch.	3-10m
Airborne	IFSARE (Star-3i)	X	3m	4-10km	Dual antenna flown from Lear jet, comm. available, no GCPs, IFMAP post-processing	2-3m
	AMPS IFSAR	Ku	0.5-2m	0.6-1km	Experimental DOE/Sandia airborne sensor, spotlight mode provides highest accuracy	1-2m

a. See Table 1 for more detailed specifications of RADARSAT derived stereo DEMs.

b. The specifications for the proposed RADARSAT-2 are likely superior to those of the existing RADARSAT but are not currently published.

4. APPLICATIONS

4.1 Wide Area Mapping

Stereo DEMs created from RADARSAT's Standard and ScanSAR modes are capable of filling a niche in the topographic mapping market. In many cases they offer advantages in terms of cost, delivery timing, and accuracy over other terrain mapping technologies including digitizing paper maps. Their ease of access over even the most remote and cloud covered regions is a critical advantage for many sites. Stereo elevation extraction is a robust technique that is not susceptible to the decorrelation problems associated with Interferometric SAR processing. Stereo pairs seldom suffer from any temporal decorrelation except when acquired under radically different conditions such as summer versus winter conditions or during extensive flooding.

Some applications within the telecommunications industry have a strong demand for elevation models at the 30-50 meter accuracy level. Line-of-sight tower siting for antenna networks in remote areas is a prime application for this technology. End users from within this industry often wish to combine DEM and orthorectified image maps from the higher resolution Standard or Fine beam modes for populated areas while utilizing ScanSAR products for the remaining less populated regions.

Government and military mapping agencies have a continuing need for elevation models of entire countries. SRTM will clearly offer a huge improvement in accuracy for global DEM coverage for the moderate latitudes; however, a continued need will likely exist even within the mission coverage to fill inevitable gaps and improve accuracies in critical areas.

RADARSAT stereo provides a spectrum of capabilities suitable for a variety of applications. The ScanSAR mode provides an unparalleled breadth of coverage enabling mapping vast areas at an unprecedented low cost and rapid turnaround.

4.2 Higher Resolution

The petroleum and mining industries require medium to precise knowledge of the terrain elevation. Interpretation of geomorphology and relation of surface structure to subsurface data are primary uses while logistical planning is a secondary application of DEMs in the exploration market. Orthorectified imagery (derived from DEMs) is used to obtain lithological information as well. Accuracy requirements for this market typically fall within 2-10m.

Precise DEMs are used by the telecommunications market for cell planning and clutter mapping for microwave propagation modeling. Building models in urban locations often require better than 1m accurate building footprints and shape models. Building models are also needed in cadastral and government land management activities.

The applications within the construction industry (see Figure 2) clearly require high resolution DEMs for planning and site selection. Accuracies of 0.3-3 meters are desired for designing hydroelectric, sewer, roadway, and storm drainage systems.

Emergency management and disaster relief agencies also need DEMs often quickly and under adverse weather conditions.

5. CONCLUSIONS

The capabilities of today's commercially available SAR data products for DEM creation are already filling an important role. Vast, remote and cloud covered areas can be quickly and reliably mapped to a coarse resolution as never before. Distortions and holes commonly found in conventionally derived topographic maps can now be eliminated with DEMs derived from newly acquired SAR imagery.

Vexcel's expertise in SAR phenomenology and mapping contributes to our products' unique technical advantages. There is a fundamental need to model radar characteristics precisely in exploiting SAR data. Products designed with radar's unique properties in mind actually lessen the need for expertise on the part of the end user.

The future of stereo and interferometric SAR processing holds even greater potential thanks to proposed systems with greatly improved resolutions. Like their optical counterparts, high resolution SAR sensors will no longer be restricted within the exclusive domain of military applications. Commercially distributed high resolution data will provide an unprecedented availability of high resolution DEMs and orthorectified imagery which will contain human scale details. Current advantages of SAR data will be accentuated now that these sensors and the related processing techniques reach maturity.

ACKNOWLEDGMENTS

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