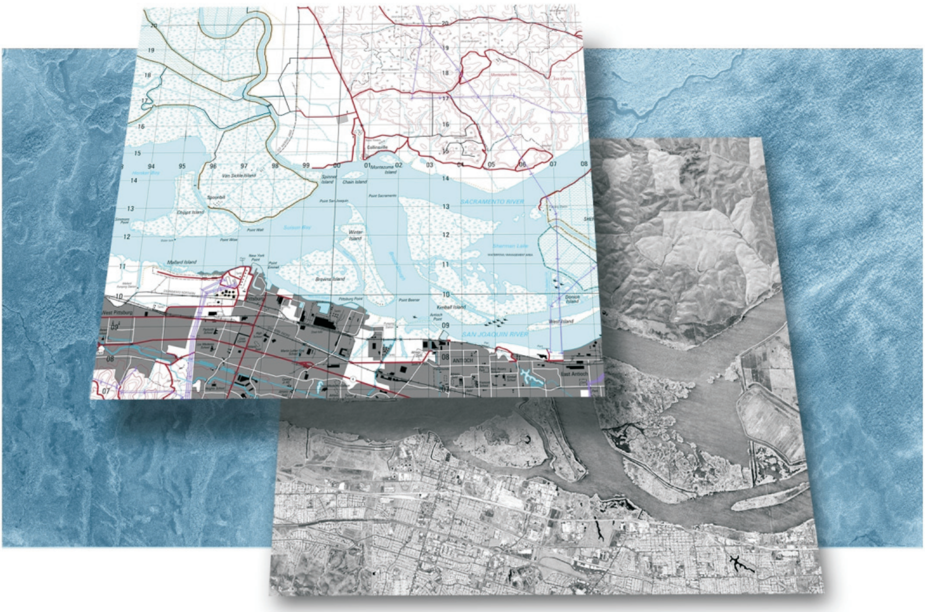

GeoSAR Product Handbook

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Introduction

Welcome to the first edition of Fugro's **GeoSAR Product Handbook.** Written for clients, this manual provides comprehensive information on the GeoSAR radar mapping system capabilities, deliverables, and underlying technology.

GeoSAR is a truly unique system. Mapping through clouds and vegetation, GeoSAR provides highly interpretable imagery and precise elevation data above and below foliage over large regions and entire countries. GeoSAR's contrasting datasets provide a wealth of topographic and thematic information related to land management, natural resources development, national security, and more.

In describing the GeoSAR system and its potential, we have organized the handbook as follows:

- **Overview:** the GeoSAR system and Fugro Geospatial Services
- **GeoSAR Solutions:** application-specific uses of GeoSAR data
- **Mapping Deliverables:** standard and value-added datasets
- **Training:** training on GeoSAR processes and products
- **Data Specifications:** datums, file naming/sizes, and metadata
- **Accuracy & Quality:** accuracy assessment and quality control
- **GeoSAR Technology:** underlying system technology
- **Ordering GeoSAR Services:** procurement process

Also included in the appendixes is a short glossary of terms, as well as answers to frequently asked questions. This section serves as a quick reference guide to the GeoSAR system and its capabilities.

We hope you find this handbook useful. Should you require additional information, or if you would like to inquire about a solution not covered here, please contact your GeoSAR client programme manager, or email us at info@fugroearthdata.com.

Best Regards,

Jake Jenkins

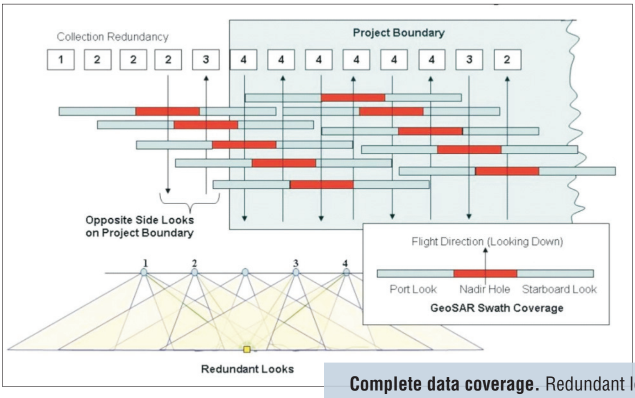
L.G. (Jake) Jenkins
Senior Vice President, GeoSAR Services

Overview

GEOSAR RADAR MAPPING

Operating day or night and penetrating clouds and foliage, the GeoSAR airborne radar mapping system rapidly collects high resolution digital elevation data and radar imagery over regions previously impossible to map due to weather, size, and terrain. The GeoSAR system is based on a technology known as interferometric synthetic aperture radar (IFSAR or InSAR), and is unique in its ability to map high accuracy terrain and surface feature data from a single flight. System highlights include:

- **Mapping above and below foliage.** X- and P-band radar data is collected concurrently from each side of the aircraft. The X-band wavelength penetrates clouds and reflects from tree canopy to deliver surface model data in forested areas and accurate terrain elevation in open areas. The P-band wavelength penetrates both clouds and tree canopy to deliver superior terrain elevation and surface feature extraction in forested areas. These characteristics make GeoSAR ideal for mapping large areas of mixed land cover.
- **Comprehensive data coverage.** As the aircraft traverses a flight line, GeoSAR provides two independent "views" for every point on the ground, in each radar band. Flying successive parallel flight lines allows the collection of overlapping data strips with four or more independent views. Each ground point is typically viewed twice from the left and twice from the right, at a steep and shallow angle, ensuring highly detailed and complete datasets.



Complete data coverage. Redundant looks serve to reduce data artifacts and improved overall data quality.

- **On-board vertical ground control.** GeoSAR incorporates a LiDAR profiler for on-board, high density ground control. The profiler vastly reduces the need for surveyed control points and eliminates the time, costs, and dangers associated with field crews establishing ground control in remote or inhospitable areas.
- **Efficient and reliable large area map production.** Collecting data at an approximate rate of 288 sq km per minute in each radar band and with around-the-clock signal processing capabilities, GeoSAR is ideally suited for large area mapping. GeoSAR production follows ISO 9001:2000-certified mandates to ensure consistent, timely, and high quality data deliverables.
- **Full data ownership.** Fugro does not license GeoSAR deliverables, which means clients own their products without any restriction on use or distribution.

FUGRO N.V.

Operating globally, Fugro collects and interprets data related to the earth's surface and the soil and rocks beneath. With 13,000 employees working from 275 offices located in 50 countries, Fugro comprises three main divisions:

- **Geotechnical Division:** Investigation of and advice regarding the physical characteristics of the soil, foundation design, and construction materials.
- **Survey Division:** Airborne mapping; topographic, hydrographic and geological surveying; geospatial data production and management; support services for offshore and onshore construction projects; precise positioning.
- **Geoscience Division:** Acquisition, processing, and interpretation of seismic and geological data; reservoir modelling and estimation of oil, gas, mineral, and water resources; optimisation of resources for exploration, development, and production.

GeoSAR radar mapping. Utilizing technology originally developed by NASA's Jet Propulsion Laboratory, Fugro commercialised the GeoSAR airborne radar mapping system in 2002. Since that time, Fugro has acquired over a million sq km of data using the GeoSAR system.

FUGRO GEOSPATIAL SERVICES

Fugro's Geospatial Services Group is part of the organization's Survey Division. With operating companies all over the world, we provide complete solutions related to the acquisition, interpretation, and presentation of geospatial data. Clients include those in the natural resources development, construction, government, utility, and transportation markets. Our core geospatial offerings include terrestrial survey, airborne mapping, and geographic information services.

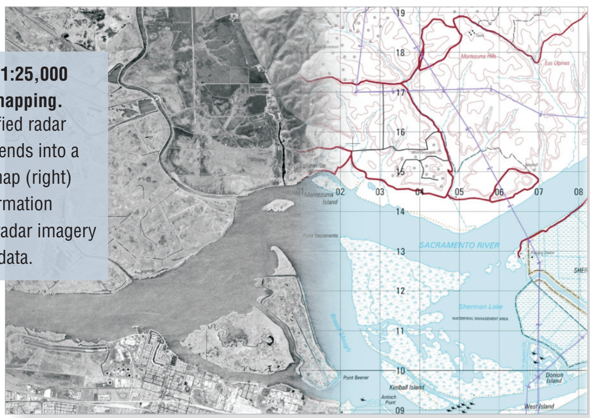
FUGRO EARTHDATA, INC.

GeoSAR is operated by Fugro EarthData, a member of the Geospatial Services Group located in Frederick, Maryland (USA). For over 50 years, Fugro EarthData has delivered customized airborne data collection, mapping, and GIS services to support the geospatial needs of public- and private-sector clients worldwide. Since commercialising the GeoSAR radar mapping system in 2002, Fugro EarthData has successfully acquired millions of sq km of GeoSAR data over varied terrain and in difficult weather conditions for multiple data applications.

GeoSAR Solutions

TOPOGRAPHIC MAPPING

GeoSAR delivers all the information needed to create new, or update existing 1:50,000 and 1:25,000 scale topographic maps anywhere in the world. Mapping through clouds and beneath vegetation, GeoSAR is especially well-suited for work in equatorial and high latitude regions where persistent cloud cover and dense forests dominate, rendering traditional airborne and satellite mapping systems ineffective.



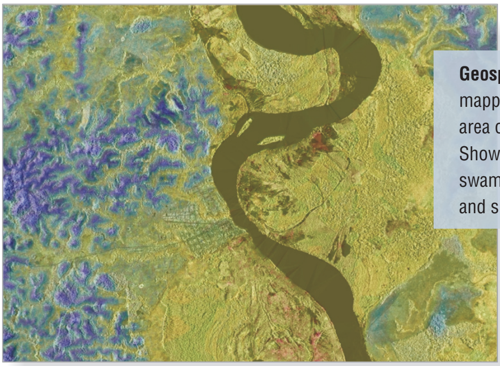
1:50,000 and 1:25,000 topographic mapping. An orthorectified radar image (left) blends into a topographic map (right) depicting information derived from radar imagery and elevation data.

Applications

- **Detailed topographic data.** GeoSAR provides accurate topographic mapping information, including spot heights, breaklines, and contours; the combined X- and P-band elevation data enables near bare-earth elevation modelling in all terrain and land-cover conditions. Together, these topographic data support regional or national decision-making for a variety of engineering, land management, economic development, and military activities.
- **Custom land-cover data:** GeoSAR multi-band imagery and radar elevation data provide detailed thematic information in a variety of information domains, including geology, forestry, agriculture, and hydrology. In addition to standard land-cover classification, GeoSAR data enables identification of soil types, tree types, crops, wetlands, and other features valuable for land-use and natural resource planning, monitoring, and development.

NATIONAL SECURITY

Current and accurate mapping is requisite to national defence and intelligence operations. Collecting radar imagery and 3D elevation data in a single mission, GeoSAR delivers geointelligence data that support strategic and tactical military operations, even in regions with limited or no existing topographic mapping coverage.



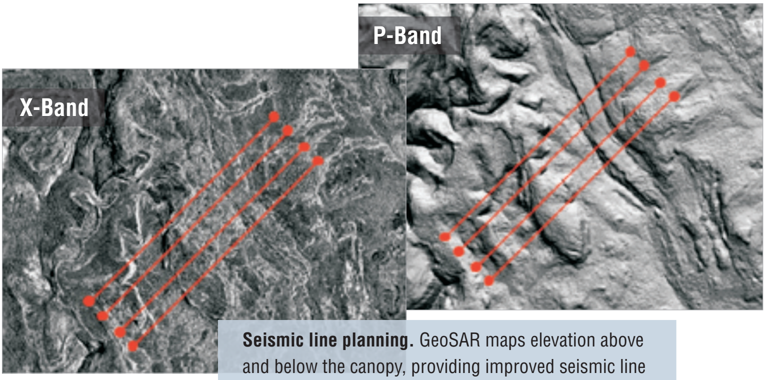
Geospatial analysis. GeoSAR mapping data is useful for large-area obstacle determination. Shown here are water and swamp areas, dense vegetation, and slopes.

Applications

- **Terrain analysis.** Simultaneously mapping near bare-earth and first-surface features, GeoSAR provides military planners accurate information about the natural and built environment, including elevation, transportation routes, vegetation types, surface drainage, standing water, and soil types.
- **Obstacles.** The combination of GeoSAR radar imagery and 3D elevation data enables the mapping of obstacles that can stop, impede, or divert military movement. These include hidden structures, steep slopes, water features, jungle/forests, deserts, trenches, and military wire.
- **Key terrain.** From GeoSAR data, analysts can identify terrain- or vegetation-based choke points, bridges, rivers, and level clearings in rough terrain, all key characteristics for combatant strongholds.
- **Cross-country mobility.** Combining multiple thematic layers, GeoSAR data provides identification of mobility corridors, classifying areas that are unrestricted, restricted, and severely restricted for cross-country mobility.

OIL & GAS

GeoSAR helps oil and gas exploration and production engineers overcome the challenges associated with planning projects in remote areas that are either densely vegetated and/or encompass extreme terrain. Deploying globally, GeoSAR provides the high accuracy mapping needed for critical upstream and midstream activities.



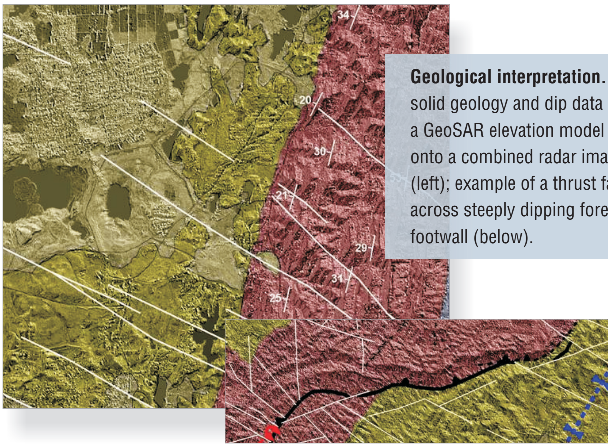
Seismic line planning. GeoSAR maps elevation above and below the canopy, providing improved seismic line planning based on accessibility, slope, hazards, etc.

Applications

- **Geological interpretation.** GeoSAR imagery enables the mapping of fault patterns, fractures, rock outcrops, and soil variations for initial structural interpretation of surface geology.
- **Seismic mission planning.** GeoSAR elevation data provides slope, drainage, and tree height data; with GeoSAR multi-band imagery, users can identify standing water, water bodies, and existing infrastructure for logistical planning.
- **Well-site selection.** Combined GeoSAR terrain and land-cover data can be used to locate the best possible well sites; these data are also beneficial to infrastructure planning.
- **Pipeline routing.** GeoSAR data enables accurate pipeline routing for construction efforts, including slope depiction, cut-and-fill determination, and environmental impact support information.
- **Environmental impact assessment.** GeoSAR users can classify vegetation types, map soil variations, estimate biomass, and locate environmentally sensitive ecosystems using GeoSAR radar imagery and terrain data.

GEOLOGY

GeoSAR provides efficient delivery of detailed image and elevation data over large project areas for geological mapping. Utilizing the system's vegetation-penetrating P-band data and derived terrain information, users can produce regional geological maps that depict the area's main tectono-stratigraphic domains.



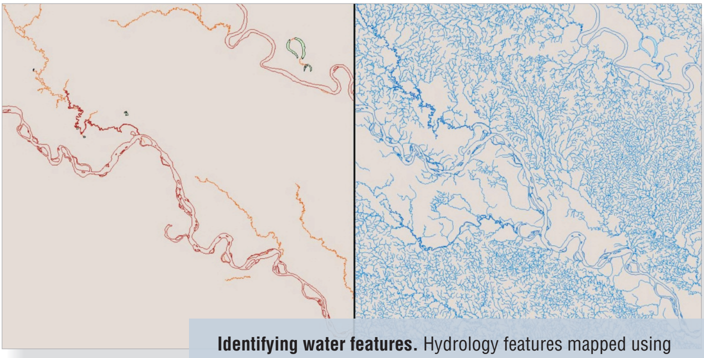
Geological interpretation. Example of solid geology and dip data derived from a GeoSAR elevation model and overlaid onto a combined radar image and DEM (left); example of a thrust fault cutting across steeply dipping forelimb of the footwall (below).

Applications

- **Outcrop mapping and stratigraphy.** GeoSAR data supports the establishment of outcrop limits, the drawing of basement extents, the mapping of sedimentary units and their relation to the basement, the interpretation of cover deposits, and the identification of other recognizable stratigraphic relationships.
- **Lineament sets.** With GeoSAR data, users can outline coherent lineament provinces, determine main sets of features and their character, and produce rose diagrams to show principal stress orientation and tectonic control.
- **Structural modelling.** GeoSAR-based structural models help explain the tectono-stratigraphic evolution, explaining how folding relates to the interpreted faults; how these structures control the fracture networks; and modelling and defining basin geometry and architecture of the regional tectonic grain.
- **Drainage pattern analysis.** Foliage penetration makes it possible to assess river drainage patterns with respect to underlying geology and interpreted fault patterns.

HYDROLOGY

GeoSAR provides efficient delivery of detailed hydrological data over large project areas. As an important input to environmental engineering, policy, and planning, these data help governments understand the potential impacts of development and climate change on its water resources. GeoSAR's hydrological mapping capabilities are especially well suited for regions with little or no existing hydrological data and in climates that render traditional mapping techniques ineffective.



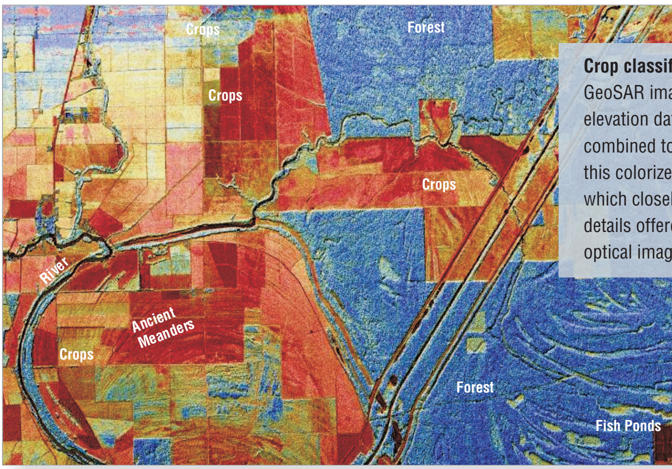
Identifying water features. Hydrology features mapped using traditional techniques (left); the same area produced using GeoSAR data shows that even minor tributaries can be extracted (right).

Applications

- **Water management.** GeoSAR imagery and elevation data enable detailed mapping of drainage features—notably streams and rivers—in support of accurate topographic mapping, water resource modelling, and environmental analysis.
- **Flood risk assessment.** With the ability to accurately map topographic features regardless of vegetation or weather, GeoSAR elevation data provides a valuable tool for regional flood plan determination and flood mitigation planning.
- **Watershed delineation.** By analysing and modelling GeoSAR data combinations, it is possible to accurately define watersheds in both hilly, flat, and marshy areas for regional watershed mapping and catchment areas.
- **Coastal zone studies.** GeoSAR elevation data, imagery and vector extraction capabilities enable accurate mapping not only of the coastal waterline but also of the vegetation extents, information critical to coastal sustainability.

AGRICULTURE

GeoSAR's dual-band radar data offers proven utility for regional crop identification and monitoring. Especially useful where optical imagery acquisition is hindered by cloud cover and ground haze, GeoSAR maps day and night and in nearly any weather condition to ensure full data coverage during the height of the growing season.



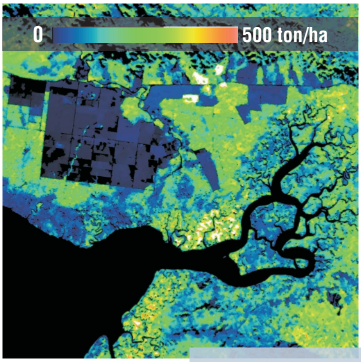
Crop classification. GeoSAR imagery and elevation data was combined to produce this colorized image, which closely mirrors details offered by optical imagery.

Applications

- **Run-off analysis and irrigation planning.** GeoSAR's multi-format data enables the accurate determination of field slopes. When combined with orthorectified imagery, these data can be used to forecast run-off and formulate plans for optimal irrigation, even over large areas.
- **Crop classification and inventory.** GeoSAR has proven an optimal solution for crop identification and inventory yield management. In conjunction with the U.S. Department of Agriculture's National Agricultural Imagery Program, crop-monitoring program, GeoSAR data supports the classification of multiple crop types with a high degree of accuracy.

FORESTRY

GeoSAR, with its vegetation penetrating technology, is ideally suited for forestry management applications. Unique in its ability to derive the best possible terrain data in the world's thickest forests and densest jungles, GeoSAR's multi-radar sensor polarization capabilities also make it possible to accurately determine general tree-height and biomass. GeoSAR development is focused on refining and calibrating biomass estimating that will allow for accurate carbon accounting.



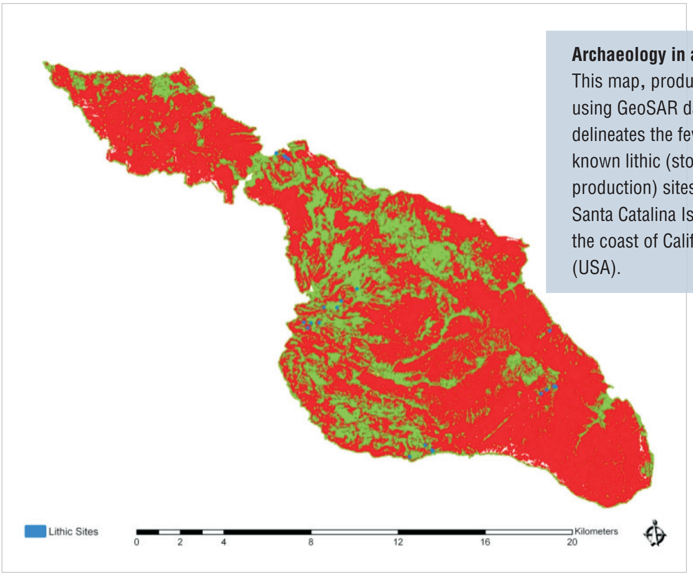
Biomass estimations. Quantitative biomass estimate at high resolution (left); the same area showing terrain classification based on GeoSAR multi-channel data (right).

Applications

- **Forest governance.** GeoSAR imagery and elevation data provide high resolution spatial monitoring that improves the welfare and quality of life for those whose livelihoods depend on the sector.
- **Land-use planning.** The analysis of GeoSAR data supports intelligent forest landscape planning that maximizes the environment, social, and economic impact through effective implementation.
- **Logging studies.** GeoSAR's ability to collect remotely sensed data from high altitudes with no ground footprint supports monitoring and policy enforcement.

HERITAGE MANAGEMENT

GeoSAR offers the ability to identify cultural features long ago obscured by vegetation or even soil. Human occupation is typically associated with buildings and materials of regular geometric shapes, anomalous to the natural topography and vegetation. GeoSAR's multi-band and multi-polarization radar interacts in detectable ways with such past phenomena, making it possible to locate important cultural sites and physical heritage assets.



Archaeology in action. This map, produced using GeoSAR data, delineates the few known lithic (stone tool production) sites on Santa Catalina Island off the coast of California (USA).

Image courtesy of Douglas C. Comer.

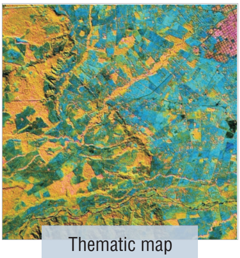
Applications

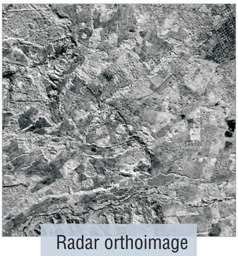
- **Exploration.** Penetrating canopy, P-band helps locate regular geometric features lost for years under soil and vegetation overgrowth while X-band detects patterns in vegetation and similarly-sized stone that can also indicate locations of sites and features. Large areas can be acquired and searched with an auto-feature recognition tool to locate ancient civilization infrastructure.
- **Site limits.** Once a heritage site is discovered, the multi-band radar can be used to indicate site limits and under certain conditions to map out routes and structures.

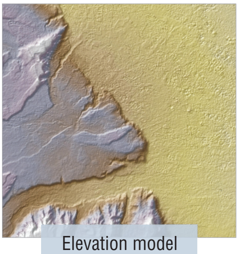
Mapping Deliverables

STANDARD MAPPING DELIVERABLES

GeoSAR delivers a complete set of mapping deliverables for standard 1:50,000 and 1:25,000 scale geospatial projects. Higher resolution and accuracy data collects are available on a case-by-case basis.


Thematic map


Radar orthoimage


Elevation model

Thematic and Topographic Mapping

- **Thematic maps:** Land-cover, slope, watershed delineation, wetlands, etc.
- **Topographic maps:** Accurate contours and spot heights; custom land-cover

Orthorectified Radar Imagery

- **P-band imagery:** 5 m pixel resolution data depicting ground features and structures hidden beneath foliage and very dry soils
- **X-band imagery:** 3-5 m pixel resolution data depicting above ground features

Digital Elevation Models

- **P-band DEM:** 5 m post-spacing near bare-earth surface models with 5-10 m vertical accuracies, root mean square (RMSE), depending on map scale
- **X-band DEM:** 2.5-3 m post-spacing reflective surface models with 2-5 m vertical accuracies, RMSE, depending on required map scale

Training

GEOSAR TRAINING OPTIONS

Fugro EarthData provides introductory, intermediate, and advanced IFSAR training courses for all aspects of the GeoSAR mapping process. Depending on the course selected, training takes place on-site at the client's location or at Fugro's U.S. GeoSAR operations centre in Frederick, Maryland. Courses are customized to ensure understanding and integration of the data products.

Example Training Plans

Below are sample training plans for informational purposes. Actual training plans are customized based on client needs.

Plan 1: Acquisition and Field Operations
[1 week — client location]

- Overview of flight planning methodology to understand the relationship between flight paths, terrain, and radar signals
- Overview of acquisition processes; participants will accompany crew for pre-flight logistics, in-flight acquisition, and post-flight logistics for back ground information
- Overview of ground control of the radar reflectors, GPS ground stations, and LiDAR profiler system

Plan 2: Radar Signal Conversion Processes
[2 weeks — Frederick, Maryland]

- Ingest of data into the signal conversion process
- Radar swath conversion and generation
- Radar edit
- Swath data mosaicking
- Data finishing and formatting

Plan 3: Radargrammetry
[2 weeks — Frederick, Maryland]

- Hardware and software setup and familiarization
- Feature extraction techniques
- Geodatabase development

Plan 4: Field Completion
[2 weeks — client location]

- Field feature verification
- Data validation and accuracy verification

LONG-TERM SUPPORT & TRAINING

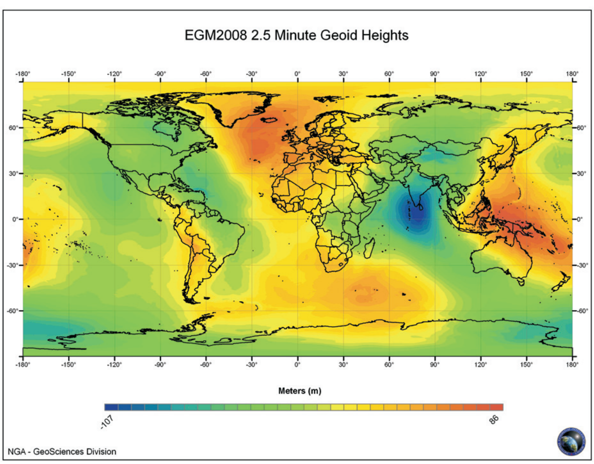
On large national infrastructure programs, Fugro staff offer rigorous training regimes from a variety of disciplines to support a high level of technology transfer within government and academia. This long term support and training will ensure the existence of a sustainable local force to maintain and further develop the base data for national infrastructure programs.

Data Specifications

DATUMS AND PROJECTIONS

A geodetic datum is a set of reference points on the earth's surface against which position measurements are made. Often, an associated model of the shape of the earth (ellipsoid) is created to define a geographic coordinate system. Fugro most often uses the World Geodetic System 1984 (WGS84) datum for GeoSAR projects. The only world referencing system in place today, WGS84 provides a basic reference frame and geometric figure for the earth, models the earth gravimetrically, and provides the means for relating positions on various datums to an earth-centred, earth-fixed coordinate system.

For measuring the height of objects on land, Fugro typically uses the Mean Sea Level (MSL) vertical datum. MSL is determined by measuring the height of the sea surface over a very long period, as this allows an average sea level to be determined, with the effects of waves, tides, and short-term changes in wind and currents removed.

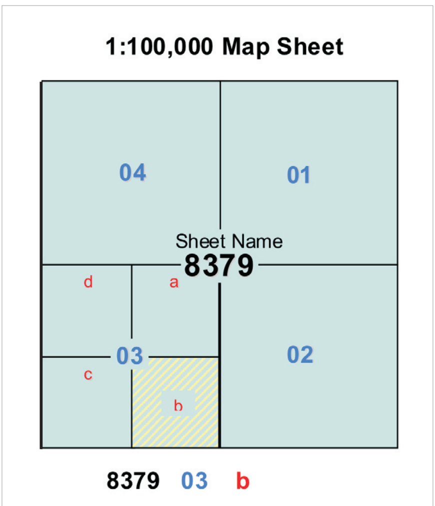


Graphic courtesy of the U.S. National Geospatial-Intelligence Agency.

MSL will not remove the effects of local gravity strength, and so the heights, relative to a geodetic datum, will vary around the world, and even within one country. For this reason, a country will choose the mean sea level at one specific point to be used as the standard "sea level" for all mapping and surveying in that country.

FILE NAMING

Starting with a nominal 1:100,000 map sheet (30′ x 30′), the suggested GeoSAR file naming convention is based on a whole number latitude and longitude of the lower left corner followed by the two digit internal block number, followed by the single alpha character. The file name is then appended with either "X" or "P" for frequency designation, and finally, "DEM" or "ORI" to reflect digital elevation model files and orthorectified radar imagery, respectively. Other deliverable protocol names are also used, as show in the list below.



- **X-band DEM:**
  837903b_X_DEM
- **X-band image:**
  837903b_X_ORI
- **P-band DEM:**
  837903b_P_DEM
- **P-band image:**
  837903b_P_ORI
- **Void mask:**
  837903b_X_Void
  837903b_P_Void
- **Other:**
  837903b_X_<TBD>

FILE SIZES

The following table demonstrates average GeoSAR product delivery file sizes, based on a nominal 7.5 minute tile, with 3 m X-band and 5 m P-band product. File sizes are rounded to the nearest MB.

PRODUCT	GEOTIFF (8-BIT)	ERDAS IMAGE	GEOTIFF (32 BIT)	SOCKET SET
X-band DEM	– MB	78 MB	82 MB	233 MB
X-band image	20 MB	83 MB	82 MB	
P-band DEM	– MB	32 MB	31 MB	233 MB
P-band image	8 MB	32 MB	31 MB	
Void mask(s)	– MB	– MB	– MB	– MB
Metadata	<1 MB	<1 MB	<1 MB	<1 MB
Vector layers	variable; typically less than 2 MB	variable; typically less than 2 MB	variable; typically less than 2 MB	variable; typically less than 2 MB

METADATA

While metadata is always project specific and can easily be tailored to meet client needs, the following list identifies those items that comply with recognized metadata standards. Metadata is typically formatted and delivered in multiple formats, such as *.txt, *.html, and *.xml.

STANDARD GEOSAR METADATA

Project identification Information

- Data creator organizations
- Data creator contact person
- Data creator place of business
- Data collection date
- Edition
- Geographic data type
- File name
- Native data format
- Version/edition
- Project identification
- Project abstract
- Project purpose/data uses
- Tile information
- Key technical words
- Native operating system

Data Quality

- Total pixels or points in tile
- Overall tile statement
- Horizontal accuracy specification
- Horizontal accuracy achieved
- Horizontal accuracy remarks
- Vertical accuracy specification
- Vertical accuracy achieved
- Vertical accuracy remarks
- Data quality origin
- Quality information date
- Procedural project information on QA processes

Specific Tile Information

- Type
- Raster type
- Row count
- Column count
- Raster xsz
- Raster ysz
- Raster origin
- Raster band

Reference Datums

- Geographic unit
- Horizontal datum
- Ellipsoid
- Semi-major axis
- 1/Flattening
- Geographic coordinate system
- Vertical datum
- Vertical datum units
- Vertical datum comments

Customer Information

- Customer contact
- Customer organization
- Customer address type
- Customer address
- Customer city
- Customer state
- Customer country
- Customer telephone

Metadata Information

- Metadata creation date
- Metadata creation organization
- Metadata organization contact person
- Metadata organization contact person position
- Metadata organization address type
- Metadata organization address
- Metadata organization telephone
- Metadata organization fax
- Metadata organization email

GeoSAR Accuracy & Quality

ACCURACY COMPONENTS

GeoSAR data collection and processing is designed to provide highly accurate radar imagery and elevation models over large regions with unprecedented speed and completeness. Fugro further enhances the inherent horizontal and vertical accuracy of GeoSAR data through:

- **Radar reflectors.** Where possible, projects incorporate a number of radar reflectors distributed across the project area to provide bright, easily identifiable point returns in the radar imagery. Reflectors are surveyed within 5 cm and about 90 percent of these reflectors are carried as control in the affine solution, increasing the absolute accuracy of the project. About 10 percent of the reflectors are withheld from the solution for quality verification.
- **On-board ground control.** GeoSAR's LiDAR profiler provides an additional array of precise elevation points for spot checking the elevation accuracy and supplementing the vertical control.

Radar reflector.

- **Affine block adjustment.** Individual strips are tied together into a block adjustment encompassing all project data, or very large contiguous areas of data. The residual error of the tie points for the block adjustment provides a good estimate of the relative internal error to the adjustment. The affine solution for the project block adjustment is worked until the residual error meets the project accuracy specifications.
- **Supplemental data.** The GeoSAR processing system can take advantage of supplemental high accuracy data, such as existing orthophotos or vector layers. These data are incorporated into the affine solution, though some tiles are held aside for use as checkpoints to further validate data accuracy.

In addition to the aforementioned methods, the final accuracy of GeoSAR data is validated using a well-distributed array of ground control points. The ground control must be radar identifiable (such as road intersections) to provide a horizontal assessment of the mapping deliverables.

ERROR ASSESSMENT

There are two types of errors associated with GeoSAR data: relative errors and absolute errors. The following information describes error assessment for individual swaths (as opposed to final map data created from a mosaic of multiple overlapping swaths).

Relative Errors

Relative errors are statistical in nature and vary from pixel to pixel in the GeoSAR DEM. Since these errors are not systematic, they cannot be removed by a rigid transformation such as would come from ground control. Sources for these errors include thermal noise, baseline decorrelation, integrated peak and sidelobe levels, ambiguities, timing jitter, and system phase errors.

X-BAND HEIGHT ERROR CALCULATIONS		
	5 km	**10 km**
Absolute height error	0.86 m (spec: 1.8 m)	0.97 m (spec: 2.5 m)
Relative height error	0.24 m (spec: 0.7 m)	0.27 m (spec: 1m)

P-BAND HEIGHT ERROR CALCULATIONS		
	5 km	**10 km**
Absolute height error	0.98 m (spec: 2 m)	1.11 m (spec: 4 m)
Relative height error	0.56 m (spec: none)	0.62 m (spec: none)

Table 1. Relative system error calculations compared with the design specification.

Absolute Errors

Absolute errors are deterministic or statistical in nature. They typically vary slowly over time and can for the most part be removed by using rigid adjustments, such as ground control. Error sources include receiver group delay, baseline errors, aircraft altitude errors, wavelength errors, and platform position errors. The table on the following page presents the absolute system error calculations compared with the project specifications.

X-band

ERROR SOURCE	ERROR VALUE
Phase noise	
Thermal noise	Per equation sigma_0 = -13dB
Quantization noise	-23 dB
ISLR noise	-20 dB
Azimuth ambiguity	-35 dB
Range ambiguity	Not included
Range error	0.6 m
Baseline error	0.1 mm
Baseline tilt error	15 arc-sec
Altitude error	10 cm
Wavelength error	3×10^{-15} m

P-band

ERROR SOURCE	ERROR VALUE
Phase noise	
Thermal noise	Per equation sigma_0 = -15dB
Quantization noise	-23 dB
ISLR noise	-20 dB
Azimuth ambiguity	-35 dB
Range ambiguity	Not included
Range error	0.6 m
Baseline error	0.5 mm
Baseline tilt error	15 arc-sec
Altitude error	10 cm
Wavelength error	3×10^{-15} m

Table 2: Absolute system error. These tables demonstrate the absolute system error calculations compared with the design specification.

DATA VALIDATION

GeoSAR is designed to provide final data within the 1.5 to 5 m horizontal error limit (RMSE). Fugro makes every effort to ensure that the final RMSE of the product meets the accuracy objectives, which can only be validated in open, unobstructed terrain. The final accuracy of deliverables within forested and urban areas, where editing will be required to produce a terrain surface, is more difficult to validate due to the inherent variability of volume scattering mechanisms.

QUALITY ASSURANCE

Fugro EarthData operates ISO9001:2000-certified quality management systems. ISO9001:2000 is an internationally recognized quality standard that encompasses all aspects of our operations to provide clients with an added level of assurance in the design, development, production, and delivery processes. The foundation of Fugro EarthData's quality policy is the continual improvement of all aspects of the production process to ensure maximum levels of client satisfaction.

The system establishes and documents procedures to maintain product quality standards through the provision of evaluation, inspection, and verification at all stages of production. With a focus on continual improvement, this approach has made quality control an integral part of our project management and production systems and has enabled Fugro EarthData to greatly improve delivery times and product acceptance rates.

In addition to our ISO 9001:2000 certified quality management system, Fugro EarthData recently implemented an occupational health and safety (OHS) program that meets OHSAS 18001:2007 standards. Work is now underway to combine the quality and health and safety programs under a single ISO 9001:2008 standard. Known as a quality, health, safety, and environment (QHSE) system, Fugro EarthData expects to achieve this expanded ISO certification in 2009.

Certificate of Registration

nqa. global assurance

This is to certify that the Quality Management System of:

Fugro EarthData, Inc. - Adminstration and Mapping Services
7320 Executive Way
Frederick, MD 21704

applicable to:

Design, development and production of spatial data, mapping and geographic information systems technologies and services

has been assessed and approved by National Quality Assurance, U.S.A., against the provisions of:

ISO 9001: 2000

For and on behalf of NQA, USA, Acton, MA 01720

Certificate Number:	10569
EAC Code:	33
First Issued:	April 15, 2000
Valid Until:	March 5, 2010
Reissued:	February 8, 2008

ANAB ACCREDITED

This approval is subject to the company maintaining its system to the required standard, which will be monitored by NQA, USA, an accredited organization under the ANSI-ASQ National Accreditation Board.

Quality Assurance and Quality Control

The success of projects is realized through a combination of comprehensive planning and a structured approach to quality control that is designed to prevent the occurrence of errors, omissions, or blunders which disrupt the production workflow and potentially affect the quality of the final geospatial products that will be produced. The following are key components to our quality management system:

- **Criteria for remedial action.** Fugro EarthData production processes are based on many years of successful project completion and contain elements that have been incorporated in response to both internal and client-specified requests. Any time a new specification or new production process is introduced, the criteria for remedial action is reviewed and modified.
- **Remedial actions.** Any quality issue is of immediate concern and is mitigated at the earliest possible opportunity. The quality management system has procedures that are integral to the project management process and addresses all of the project's specifications, to maintain quality and schedule.
- **Verification criteria.** The quality management system contains an array of metrics that are used to monitor cycle times for each production process. These existing tools will provide a means to verify that the quality issue has been successfully mitigated.
- **Notification.** Every large-scale digital land base mapping effort presents challenges and minor technical issues that must be addressed. Technical staff members evaluate and solve an array of problems that may occur throughout the life of any project and will document the nature of the problem and the process used to resolve the problem. In the vast majority of these cases, the quality of the end product is not affected and the delivery schedule is not impacted.
- **Commitment to quality.** Each aspect of quality management described above addresses issues that affect project schedules. Fugro EarthData is committed to providing products that are of the highest possible standards regardless of any issues that may arise. Therefore, the client is assured that any products that are delivered are fully supported and any product found to be deficient at any time in the future will be corrected or replaced.

As part of project quality management plans, all products are tested to ensure that they meet pre-determined acceptance criteria. Testing to verify compliance with these acceptance criteria is performed by Fugro through internal quality assurance processes prior to dispatch of the deliverables to the client for acceptance.

Documentation

Every phase of production has a quality assurance plan that includes checklists, independent review, and automated quality routines for data validation, reports, and interactive quality steps. Delivery reports and metadata are a significant part of the ISO9001:2000 delivery process. These reports detail quality issues and aspects of the data that are pertinent to the future use and maintenance of the GeoSAR data. The client can elect to receive reports on key items such as:

- Procedures
- Interim guidance and change orders/instructions
- Production or project-specific solutions
- Status and project reports
- Source and final product phenomenology
- Subcontractor reviews and status reports (if applicable)
- Milestone reviews

GeoSAR Technology

INTRODUCTION TO RADAR MAPPING TECHNOLOGY

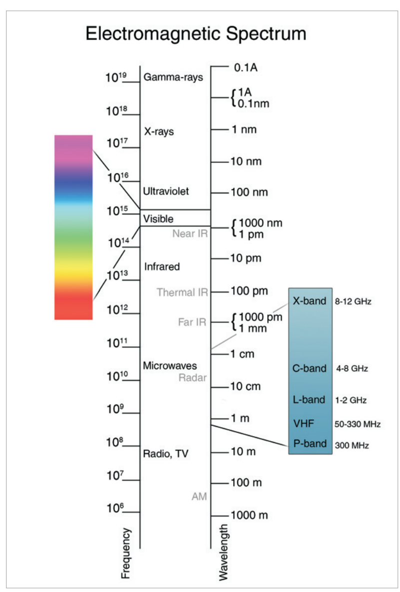
Radars work by bouncing various types of radio waves in the direction of a target to determine the presence of an object at a distance, detect the speed of an object, and/or map something at a distance. Mapping using radar is not a new concept and many current radar mapping systems utilize the method of interferometric synthetic aperture radar. Space shuttles and satellites utilize SAR to map the surface of the Earth, Moon, and other planets to analyse the topography of the object.

The Radar Principle

A typical radar setup, such as you would find at any airport, turns on its transmitter and shoots out a short, high-intensity burst of high-frequency radio waves. The burst might last a microsecond. The radar set then turns off its transmitter, turns on its receiver, and listens for an echo. The radar set measures the time it takes for the echo to arrive, as well as the Doppler shift (frequency change) of the echo. Since radar travels at the speed of light—approximately 300 m per microsecond—the radar set, given a good clock, can accurately measure the distance of a radar pulse reflecting off an aeroplane. Using special signal processing equipment, the radar set can also measure accurately the Doppler shift and determine the speed of the aeroplane.

Radar Bands

Radar operates in a number of “radar bands” designated by letters such a L, S, C, X, K, Ku, Ka, and P. Each of these bands has a unique range of wavelengths, some more suitable than others for extracting certain types of information. For example, the Doppler radar typically used by local weather stations use



Adapted from an illustration credited to Louis E. Keiner, Coastal Carolina University.

L, S, X, or K depending on the weather conditions and the size of the antenna available to the station. Because of its smaller 3 cm wavelength X-band is useful for detecting cloud moisture, and wind velocities.

Synthetic Aperture Radar (SAR)

Environmental monitoring and earth-resource mapping require broad-area imaging at high resolutions. Many times, the imagery must be acquired during inclement weather or at night, as well as day. SAR provides that capability by exploiting the long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics. Additionally, SAR complements photographic and other optical imaging capabilities due to the minimum constraints on time-of-day and atmospheric conditions and because of the unique responses of terrain and cultural targets to radar frequencies.

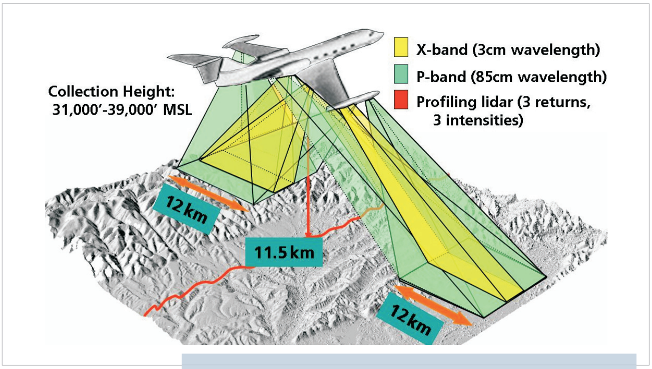
SAR technology has successfully provided image and terrain structural information to mappers for topographic mapping, to geologists for mineral exploration, to environmentalists for oil spill boundaries on water, to navigators for sea state and ice hazard maps, and to military users for reconnaissance and targeting information.

An interferometric SAR system images the same patch of terrain from two slightly displaced viewing locations. The phase difference (time of arrival) between these two offsets is used to infer terrain height.

GEOSAR: DUAL-BAND IFSAR MAPPING SYSTEM

GeoSAR, Fugro's single-pass IFSAR mapping system, simultaneously acquires X- and P-band imagery and digital elevation data. Dual antennas on both sides of the aircraft collect two strips of data per band over ground swaths many hundreds of km long by about 12 km wide. A LiDAR profiler provides in-air ground control simultaneous to the IFSAR mission. The system typically operates for over 4 hours during signal acquisition and can carry out several missions a day.

GeoSAR provides clients with high-resolution, three-dimensional maps of an area by using a combination of X-band and P-band wavelengths. The longer 86 cm P-band wavelength is able to penetrate deeper into the canopy and, coupled with computer modelling, can map beneath the vegetation canopy.



GeoSAR collection. GeoSAR operates at high speeds and altitudes collecting dual-band radar data from each side of the aircraft in a single pass.

System Development

GeoSAR was developed through a public/private partnership with the U.S. government to develop a commercial airborne, radar-based, terrain mapping system utilizing technology originally developed by NASA's Jet Propulsion Laboratory and the Defence Advanced Research Projects Agency. GeoSAR has the ability to acquire three-dimensional images of the earth's surface by interferometry day and night and under almost any weather condition. The system collects X- and P-band radar data at approximately 288 sq km of data per minute.

Dual-Band Radar Capability

X- and P-band data offer distinct benefits. At 3 cm-wavelength, the X-band energy scatters off the vegetation and other first surfaces to provide excellent resolution for first-surface features and feature height. As a complement to X-band first-surface information, the 86 cm wavelength P-band energy penetrates vegetation and scatters off substructure, showing surface features hidden beneath foliage.

	X-BAND	P-BAND
Bandwidth	160 Mhz	160 Mhz
Wavelength	3 cm	86 cm
Polarization	VV	HH & HV or VV & VH
Ground swath	12-14 km on each side	12-14 km on each side
Look-angle range	25-60°	25-60°
Platform altitude	5,000-12,000 m	5,000-12,000 m

Table 3: X- and P-Band Radar. A comparison of the GeoSAR radar frequencies.

A One-of-a-Kind System

Compared to other commercial systems, Fugro's GeoSAR system offers unique advantages through its single-pass simultaneous interferometric collection of dual-frequency radar data from each side of the aircraft. Acquiring both multiple and opposite looks of each feature on the ground, this redundant acquisition strategy inherently improves image and elevation measurement and quality and reduces acquisition coverage risks.

In actuality, the technology Fugro uses in GeoSAR has been readily available for decades. Use of X- and P-band radar to simply map topography is neither new nor is it revolutionary. It is the GeoSAR configuration and collection parameters that make the system unique. When collected jointly, these bands provide complete and contrasting data, which significantly improves results. In addition, Fugro's innovative use of LiDAR technology for in-air vertical ground control, sets GeoSAR apart from any other mapping system, spaceborne or airborne alike.

IFSAR	LIDAR	OPTICAL
Large area coverage; Rapid acquisition	Small area coverage; Rapid acquisition	Small area coverage; Rapid acquisition
Not as precise in urban areas; Good mid resolution imagery; Correlation of DEM and image	Better response to urban structures; intensity imagery	Excellent response to urban structures; Excellent high resolution imagery; Some correlation of DEM and imagery
Weather "resistant"	Weather dependant	Very weather dependent
Dense gridded DEM	Very densely gridded DEMs	User-defined gridded DEMs
Low unit cost	High unit cost	High unit cost
Penetrates dense canopy	Does not penetrate dense canopy	Does not penetrate dense canopy
Very fast acquisition	Slow acquisition; weather dependent	Average delivery; weather dependent
Fast delivery	Slow delivery	Slow delivery

Table 4: Comparisons of mapping system features. IFSAR vs. LiDAR vs. optical.

THE POWER OF P: P-BAND IFSAR CONSIDERATIONS

- Foliage penetration, even in thick jungle and densely forested areas
- All-weather mapping capability
- Ability to provide clear separation between forest/grasslands/crops
- Ability to provide superior near bare-earth height versus typical surface height from other sensors in thick jungle and densely forested areas
- Ability to provide good definition of surface topography and land/water boundaries
- Potential for sub-surface penetration in dry media
- Ability to provide separation of forest types (canopy/woody component) when combined with other wavelengths
- Ability to provide separation of open water and bare ground with additional image processing
- Ability to provide distribution and extent of water under trees
- Ability to detect hidden targets, especially in forested areas
- Ability to provide biomass estimation given volume scattering in all returned polarizations

Ordering GeoSAR Services

BUILDING GEOSPATIAL SOLUTIONS

Fugro customizes GeoSAR solutions based on client needs for application-specific data deliverables. Through a consultative process, we craft GeoSAR solutions to support the full range of goals outlined for any given project.

The process is straightforward and includes:

- **Defining the area of interest.** Clients provide Fugro with a shapefile or list of coordinates that identifies the area for which they require geospatial information.
- **Documenting project considerations.** Fugro works with clients to understand any factors that require consideration, such as time lines, seasons, potential add-on projects, etc.
- **Determining end goals for the data.** Fugro works with clients to understand all intended data applications. Unlike other solutions, GeoSAR projects are designed to meet specific user needs, rather than providing a pre-designed data that clients must then fit into their workflow.

With this information, Fugro staff can prepare an estimate of costs, time lines, deliverables, and any other relevant items. Note that GeoSAR is often scheduled several months in advance; as much advance notice as possible should be considered when preparing a project. That said, it can be possible to accommodate projects into the backlog process. Your GeoSAR advisor can discuss this option with you as necessary.

Appendix A: Terminology & Acronyms

This guide identifies and defines terms related to radar mapping systems, specifically GeoSAR, and the immediate programs and projects related to it. Conventions used in creating this guide include:

- Definitions may include both terminology and proper names (that may include acronyms if they are already in the table).
- Listing is in alphabetical order. Symbols precede numbers, which precede letters. Punctuation marks are ignored when determining alphabetical order.
- Not all of these terms are referenced in the handbook; however, they are of help in understanding radar and geospatial terminology.

Antenna (radio): The component designed to send and/or receive radio waves

Antenna positioning measuring unit (APMU): The APMU is mounted in a pod on the centre of the aircraft fuselage. Lasers and tracking cameras inside the pod are combined with GPS and inertial navigation measurement unit data to precisely determine the orientation of the antennas for each transmitted radar pulse.

Back projection: A flexible SAR processing methodology suitable for processing non-linear flight lines. The aircraft is banked in a circular flight turn around an area of interest, imaging the scene from all aspect angles. Best suited for P-band imaging over small areas of interest, Back Projection provides volumetric information of objects in the scene, improves imagery information content, and allows unprecedented levels of ground and foliage penetration.

Circular collect: (see back projection).

Collection operations: Manage and operate (airborne) collection systems to satisfy client and project requirements. Allocates requirements to specific missions and manages collection resources to optimise performance against requirements.

Contour line: A contour line (or isoline) joins points/heights of equal value. Also the gradient of a slope is always perpendicular to the contour lines. A topographic map is usually illustrated with contour

Coordinates, geographic and Cartesian: A geographic coordinate system enables every location on the earth to be specified, using mainly a spherical coordinate system. There are three coordinates: latitude, longitude, and geodesic height. The purpose is to define coordinates that can accurately state each topographical ground point as an unambiguous set of numbers. Every point that is expressed as spherical coordinate can also be expressed as a Cartesian coordinate (also called rectangular coordinates). Cartesian coordinates are used to determine each point uniquely in a plane through two numbers, called the x-coordinate and the y-coordinate. With the addition of the z-coordinate (for height), a three-dimensional point can be referenced or expressed.

Corner reflector: This dihedral reflecting object reflects and concentrates the radar signal back to the direction from which the signal was propagated.

Datum, horizontal, or geodetic: A surface used as a basis for referencing location coordinates. Horizontal datums are used for describing points on the earth's surface, in latitude and longitude or another X and Y coordinate system. The most common datum is the "The World Geodetic System 1984" (WGS84), which is a geocentric system that provides a basic reference frame and geometric figure for the earth, for relating positions.

Datum, vertical: A surface used for the basis of referencing elevation measurements on the earth's surface. Mean Sea Level (MSL) is the most commonly used datum for measuring the height of features on land. MSL varies from region to region, even around a country. However, its common for each country have a single standard MSL value as the single vertical reference for vertical measurements in that country.

Digital elevation model (DEM): A digital representation of ground surface topography or terrain. DEMs can be developed as a regularly spaced grid of elevation points or as a triangulated irregular network (TIN). DEMs are commonly used in a number of applications, from rectifying remotely sensed imagery to modeling flood events.

Digital surface model (DSM): A digital elevation model that specifically includes all natural (e.g. vegetation) and/or man-made features (e.g. buildings) above the ground.

Digital terrain model (DTM): A digital elevation model that more closely reveals or infers the true ground surface with vegetation and/or structures specifically absent. A DTM typically consists of three-dimensional vector data in the form of contour lines, break lines, and mass points in a GIS or CAD format.

Electromagnetic radiation: Electromagnetic radiation is generally described as a self-propagating wave in space with electric and magnetic components. These components oscillate at right angles to each other and to the direction of propagation. EM radiation carries energy and momentum, which is imparted when it interacts with matter.

Ellipsoid: A reference ellipsoid is a mathematically-defined surface that approximates the geoid, the truer figure of the Earth. Because of their relative simplicity, reference ellipsoids are used as a preferred surface on which geodetic network computations are performed and point coordinates such as latitude, longitude, and elevation are defined.

Foreshortening: A (normal) radar anomaly, usually apparent on steep sloped terrain caused when the signal from the bottom of a slope is returned sooner than the signal from the top of the slope. The signal is shorter than backscatter from a flat area, causing the distance to be mapped shorter between the top and bottom of the slope.

Frequency: The rate of oscillation of a wave.

Geographic information systems (GIS): A system of software and procedures—and often hardware—that supports spatial data use; specifically the acquiring, storing, examining, evaluating, organizing, and presenting of data.

Geographic synthetic aperture radar (GeoSAR): GeoSAR is an airborne radar mapping system owned and operated by Fugro. It is a dual-band, dual-sided IFSAR mapping system that provides (first) reflective surface and foliage penetration for high-accuracy, high-resolution image and elevation datasets. It is further equipped with a high-altitude LiDAR. GeoSAR enables long-range mapping with all-weather and day/night usage.

Geoid: An irregular surface, covering the earth that approximates mean sea level. It is the “mathematical figure of the earth”.

Geospatial analysis: The process of extracting meaning from geospatial data, using geographic information systems to uncover and investigate relationships and patterns in all forms of geospatial data to answer queries.

Geospatial information: Any information that is referenced to a location on the earth.

Imagery analysis: The process of extraction information from imagery, about activities, objects, installations, and/or areas of interest.

Interferometric synthetic aperture radar (IFSAR or InSAR): A radar technique used in geodesy and remote sensing using multiple SAR datasets to generate accurate elevation values, by using differences in the phase of the waves returning to the IFSAR system.

Interferometry: The study of interference patterns caused by radar signals. A technique enables us to generate three-dimensional images of the earth's surface.

Layover: A (normal) radar anomaly where elevated features (e.g., towers and cliffs) lay on top of near-range scene content. Elevated features are superimposed onto nearby near-range features. The linear extent of layover is smallest at steep grazing angles, where shadows are smallest.

Light detection and ranging (LiDAR): A sensing technique that uses lasers to measure distances to reflecting surfaces; selection of range gate on laser returns determines whether first (top reflective surface) or last (ground). An instrument capable of measuring distance and direction to an object by emitting timed pulses of light in a measured direction and converting to the equivalent distance the measured interval of time between when a pulse was emitted and when its echo was received.

Map projection: An orderly system of lines on a plane representing a corresponding system of imaginary lines on an adopted terrestrial datum surface. A map projection may be derived by geometrical construction or by mathematical analysis

MSL: Acronym for mean sea level. See also Datum, vertical.

Nadir: Locus of points on the surface of the earth directly below the radar as it progresses along its line of flight.

P-Band radar: As used in GeoSAR, a frequency band extending from 270 to 430 MHz, offering extensive foliage penetration.

Photogrammetry: The science of accurate measurement from images. For example, the three-dimensional coordinates of points on an object are determined by measurements made in two or more photographic images taken from different positions.

Polarization: In the transmitted radar signal, the electric field is perpendicular to the direction of propagation, and this direction of the electric field is the polarization of the wave. Mapping/imaging radars use variations on horizontal (H), vertical (V) to detect different types of reflections. Mapping radars can generate and receive the same or different polarizations (i.e., transmit H/receive H, transmit H/receive V, transmit V/receive V, and transmit V/receive H). Different materials reflect radar waves with different intensities, but anisotropic materials such as grass often reflect different polarizations with different intensities. Some materials will also convert one polarization into another. By emitting a mixture of polarizations and using receiving antennae with a specific polarization, several different images can be collected from the same series of pulses.

Pulse: A short pulse bust of electromagnetic energy

Radar: An acronym for radio detection and ranging, radar is an active form of remote sensing that operates in the microwave and radio wavelength regions. A radar transmitter emits radio waves, which are reflected by the target and detected by a receiver (typically in the same location as the transmitter).

Radargrammetry: A remote sensing technology in which geometric properties about objects are determined from IFSAR images and DEMs. For example, the three-dimensional coordinates of points on an object are determined by measurements made in two or more radar images in conjunction with the corresponding DEM data.

Remote sensing: In the broadest sense, remote sensing is the measurement or acquisition of information of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object. In practice, remote sensing is the utilization at a distance (as from aircraft, spacecraft, satellite, or ship) of any device for gathering information about the environment. Thus an aircraft taking photographs, earth observation and weather satellites, and space probes are all examples of remote sensing.

Resolution: A term indicating the ability of an imaging system to separate closely spaced objects

RF/RFI: An acronym for radio frequency interference, which occurs where there are transmissions from other radio-wave or micro-wave devices transmitting on similar frequencies to the radar within the same geographic region.

Sensor: A device that senses the electromagnetic energy reflected or emitted from a scene or target.

Shadow: A normal radar anomaly: where an area is not illuminated by the radar because an intervening object blocks the radar energy.

Shuttle Radar Topography Mission (SRTM): A venture to obtain low-resolution elevation data on a near-global scale to generate the most complete digital topographic database of the earth. SRTM obtained digital elevation models from 56 °S to 60 °N. The elevation models are arranged into tiles, each covering one-degree of latitude and one degree of longitude. The resolution of the cells of the source data is one arc second, but this data has only been released for the rest of the world at three arc seconds.

Spatial data: Synonymous with geospatial data and geospatial information.

Surveying: A general term covering all aspects of the science and technique of accurately gathering of spatial information, usually, but not exclusively, associated with positions on the surface of the earth.

SAR: An acronym for synthetic aperture radar, SAR systems use the motion of the radar platform and radio-wave phenomenology to synthesize a large antenna necessary for the acquisition of high-resolution radar data. Because the real aperture of the radar antenna is so small (compared to the wavelength in use), the radar energy spreads over a wide area (usually many degrees wide in a direction orthogonal (right angle) to the direction of the platform (aircraft). By knowing the speed of the platform, target signal return is placed in a specific angle “bin” that changes over time. Signals are integrated over time and thus the radar “beam” is synthetically reduced to a much smaller aperture.

Topographic maps: Maps that demonstrate the relationship between geographic features (both natural and man-made).

Wavelength: The distance between repeating units of a wave pattern. It is commonly designated by the Greek letter lambda. In a sine wave, the wavelength is the distance between the mid-points of the wave.

World Geodetic System 1984 (WGS84): A system that provides a basic reference frame and geometric figure for the earth, and provides the means for relating positions on various datums to an earth-fixed coordinate system. The WGS84 datum is the only world referencing system in place today, and is the default standard datum for coordinates.

X-band: A frequency range used in radar extending from 8-12.5 (usually 9.6) GHz frequency, with wavelengths from 2.4 to 3.8 cm; reflects from the first object struck, essentially the top of the vegetation or manmade surfaces.

Appendix B: Frequently Asked Questions

1. What is GeoSAR?

GeoSAR is an airborne radar mapping system that rapidly produces highly detailed DEMs and radar imagery of unmatched quality over regions previously considered impossible to map due to cloud cover, dense vegetation, and rugged terrain. It is the world's only radar mapping system that simultaneously collects X-band (top surface) and P-band (foliage penetration) interferometric synthetic aperture radar (IFSAR) data simultaneously in a single pass along each flight line from both sides of the aircraft. GeoSAR is available worldwide exclusively from Fugro.

2. What deliverables are produced from GeoSAR data?

GeoSAR provides a number of base products that are offered as deliverables. However, the true value of GeoSAR is its ability to use combinations of base datasets to produce custom solutions for each client and project, such as the creation of comprehensive topographic datasets, flood modelling datasets, and layers of thematic information. Base datasets consist of:

- 3 m posted X-band orthorectified radar imagery
- 3 m posted DSM
- 5 m posted P-band orthorectified radar imagery
- 5 m-posted DTM

Fugro can offer these products at a finer pixel resolution and a denser post-spacing if required, based on client requirement discussions.

3. What are the differences between X-band and P-band data?

GeoSAR's X-band (9630-9790 MHz, or 3 cm wavelength) scatters off the first surfaces of vegetation, buildings, and bare earth, making the 3 m posted X-band image rich in first-surface details.

GeoSAR's unique P-band (270-430 MHz, or 86 cm wavelength) penetrates foliage and scatters off substructure, showing details otherwise hidden beneath foliage, such as road networks, buildings, trails, and other features not apparent in the X-band data. Edges of features such as rivers and roads are more evident in the P-band image because the longer wavelength penetrates vegetation overhanging the feature edges. In addition, P-band reveals many subtle physical aspects of soils and other non-vegetated ground surfaces, including compactness and moisture. The absence of vegetation in the P-band DEM results in a smooth appearance that more closely resembles the terrain relief.

4. What advantages does GeoSAR provide clients, compared to other IFSAR systems?

- **GeoSAR maps above and beneath foliage.** With its simultaneous X- and P-band data collection, GeoSAR is the world's only system that can map through both clouds and vegetation interferometrically in a single pass. This unique capability makes it especially valuable for equatorial regions and large land expanses characterized by dense vegetation and inhospitable terrain where one pass along each flight line acquires full coverage over areas where maps are often outdated or nonexistent.
- **GeoSAR acquisition collects multiple measurements of every point on the ground.** The GeoSAR acquisition flight plans are designed to acquire multiple (typically four or more) views of each point on the ground. This redundant coverage mitigates the risk of losing data in shadows and voids, which means clients receive more complete and more accurate elevation datasets.
- **GeoSAR collects a LiDAR terrain profile to improve data quality.** Nadir looking LiDAR profiles are acquired along with the radar data and used to improve the quality and accuracy of GeoSAR data. The LiDAR data helps locate bare-earth, thus confirming height data and improving the overall accuracy and quality of GeoSAR deliverables. The LiDAR data also eliminates the need for establishing ground control, which can be a costly, time-consuming, and in some regions of the world, a potentially dangerous activity.
- **GeoSAR datasets are reliable and efficient.** GeoSAR's standard-setting redundancy ensures high-quality, reliable data. In addition, GeoSAR ISO9001:2000-certified production processes are stable and reliable and mandate quality control throughout all production stages. Clients can depend on the accuracy of the GeoSAR products they receive.

- **GeoSAR performs circular collects.** Although GeoSAR is best suited to large-area collections, the system is also capable of all-aspect-imaging of small areas of interest (~10 km diameter).
- **GeoSAR clients own their data.** Fugro does not license data. GeoSAR clients own their data without restriction on its use.

5. What advantages does GeoSAR provide clients compared to satellite systems?

As an airborne system, GeoSAR offers the flexibility of collecting data when conditions are optimal. The radio frequencies used by GeoSAR pass through clouds and can collect data day or night. These capabilities permit flexibility in working with air traffic controllers to schedule aerial missions during any time of day to accommodate congested or restricted airspace and in scheduling missions amid adverse weather patterns. In addition, GeoSAR flight plans over large areas are designed to complete collections in consecutive sorties, rather than in temporally dispersed coverages, as dictated by satellite orbital patterns. Flying at an average height of ~12,000 m above sea-level, GeoSAR collects approximately 288 sq km of data per minute, per band, through clouds, which means that large areas can be covered in a few weeks instead of several months or years when compared to satellite systems of similar resolution.

6. What are the applications of GeoSAR data?

Fugro's objective in developing the GeoSAR system was to create a cost-effective mapping tool that would enable clients to acquire current, accurate, and detailed geospatial data for areas where conventional mapping techniques prove either impossible or cost-prohibitive. GeoSAR products will support any number of applications with examples that include:

- **Topographic mapping:** image rectification, map updating, 3D visualization
- **National security:** emergency preparedness, disaster response and relief, and reconnaissance and mission planning
- **Oil and gas:** exploration, seismic mission planning, corridor mapping/routing
- **Geology:** geological interpretation, mineral prospecting,extraction
- **Hydrology:** watershed delineation, flood risk mapping preservation of coastal environments (e.g., mangroves, wetlands)

- **Agriculture and forestry:** timber management, monitoring of agricultural yields, water conservation
- **Heritage management:** site exploration and identification, preservation of cultural heritage and archaeological features.
- **Economic development:** land-use management and planning, urban encroachment studies, infrastructure development, and transportation planning

GeoSAR, with its ability to rapidly and efficiently produce highly accurate geographic information, is an especially valuable tool in regions where economic development and poverty alleviation are critical development issues. GeoSAR products serve as a basis for many economic development choices, including how to balance essential infrastructure, such as the construction of power plants and highways, against the protection of natural resources; how to sustain forests while harvesting lumber; how to manage coastal erosion, urban sprawl, and agricultural output.

7. Can you acquire GeoSAR data anywhere in the world?

GeoSAR is the ultimate tool for capturing a highly accurate and data-rich volume of geospatial information over a large land expanse that may be otherwise impossible to reach and/or map using conventional means. Except where local airspace restrictions apply or when adequate airport facilities are lacking, GeoSAR can acquire data anywhere in the world. That said, GeoSAR is especially well-suited for equatorial regions around the world where dense vegetation and year-round cloud cover make using conventional mapping techniques impossible or cost-prohibitive. GeoSAR is capable of mapping thousands of sq km during each sortie, day or night, and in almost any weather condition to deliver mapping data of a scale, accuracy, and completeness never before possible for this type of environment.

8. You mention that this system is the only one of its kind in the world. What makes GeoSAR unique and what benefits do these unique features convey to clients?

Four capabilities make GeoSAR unique:

- **GeoSAR is the world's only single-pass simultaneous interferometric X- and P-band data collection radar system.** GeoSAR is the only IFSAR system that simultaneously collects interferometric X-band data and interferometric P-band data in a single pass along each flight line. This avoids the potential of mis-registration after acquisition since GeoSAR's bands are collected simultaneously and are thus perfectly co-registered during acquisition. Unlike other systems which fly single-band X- and P-band IFSAR systems on separate aircrafts, GeoSAR's dual-band capability reduces time and cost in flight planning, mobilization, aerial missions, equipment maintenance, labour costs, as well as data processing and production. The single-pass, dual-band, dual-sided data collection feature of GeoSAR also reduces shadow, layover, and other artefacts, which in turn reduces processing and, consequently, time and expense. GeoSAR's dual-band, dual-sided, single-pass X- and P-band interferometric capability collects almost an order of magnitude more interferometric data per flight hour (using a single aeroplane as the competition covers per flight hour (using two different aircraft) yielding the benefits of additional cost- and time-savings plus the benefits of consistently high-quality data.

- **GeoSAR is the world's only dual-sided radar collection system.** GeoSAR is the only system that collects data from both sides of the aircraft along each flight line. Additionally, GeoSAR collects data from two X-band and two P-band antennas on each side of the aircraft. This means that GeoSAR can collect more data (more than four times more data) in the same amount of flying time as other systems.
- **GeoSAR is the only radar system with a LiDAR nadir-terrain profiler.** GeoSAR is the only radar system equipped with a LiDAR profiler. Mounted on the GeoSAR aircraft, the profiler provides a continuous high-accuracy nadir-terrain profile for each flight line. The profiles: (1) provide additional ground control and a direct measurement of foliage density (tree height) which increases accuracy; (2) help to ensure that even tiny gaps in a canopy structure can be exploited to capture bare-earth heights under trees, improving the completeness and accuracy of the dataset; (3) provide information about vegetation and biomass; and (4) aid in mosaicking.

Lack of a LiDAR profiler or similar sensor in other commercial IFSAR systems either reduces ground control available from the flight or requires that control be established on the ground, which presents additional costs and risks. Installation of ground control is expensive (and extensive) in the typically large areas that warrant

IFSAR data collection, plus serious risks to equipment, crews, and mission success can be involved in establishing ground control for collections over areas within hazardous terrain or hostile environments.

- **GeoSAR is the only system to collect multiple looks of every pixel on the ground.** This acquisition redundancy ensures nearly 100 percent project-area coverage, even in very rugged terrain. Redundant collection reduces sampling noise and provides data otherwise obscured by foliage, shadows, and layover, which translates into consistently higher quality data and time-savings through a lesser likelihood of reflights (with redundant data, "we already have it in the can").