GAMMA SAR AND INTERFEROMETRIC PROCESSING SOFTWARE

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ABSTRACT

The *GAMMA* Modular SAR Processor (*MSP*), Interferometric SAR Processor (*ISP*), Differential Interferometry and Geocoding Software (*DIFF&GEO*), and Land Application Tools (*LAT*) are modular software packages useful to process synthetic aperture radar (SAR) images. Data of both spaceborne and airborne sensors including ERS-1/2, JERS-1, SIR-C, SEASAT, RADARSAT StripMap mode, and the single-pass Dornier DOSAR interferometer have been successfully processed interferometrically. State of the art algorithms have been implemented to achieve accurate processing of the data while permitting timely processing of large data sets. Recent projects completed with the software include generation of a continental scale mosaic of Siberia consisting of more 700 JERS scenes in the frame of the SIBERIA project and the generation of subsidence maps for Bologna, Abano, and Mexico City. User-friendly display tools and full documentation in HTML language complements the software. Both binary and source code licenses are available.

Recent developments included the adaptation of the software to the PC operating systems LINUX and NT and the improvement of the functionality for differential SAR interferometry. Furthermore, as part of our ERS AO3 project (ERS AO3-175), software demonstration, training, and testing examples have been developed for distribution to users. Development in the near future will include the adaptation of the software to the processing of ENVISAT ASAR (with data provided through ENV AO-210) and ALOS PALSAR (ALOS AO proposal accepted) data.

Keywords: SAR processing, SAR interferometry, GAMMA Software, ERS, ENVISAT, ALOS

INTRODUCTION

GAMMA Remote Sensing Research and Consulting AG (GAMMA) is a Swiss corporation (Aktiengesellschaft - AG) founded in January 1995 and located near Bern, Switzerland. Research and development, processing and adding value to remote sensing data, license sales for its commercial processing software, and EO-data distribution are GAMMA's primary business elements. GAMMA's declared goal is to maintain a high level of technical and scientific expertise. This is an essential prerequisite for development of new applications, consulting activities, and improving and maintaining the commercial software. To achieve this ambitious goal GAMMA is involved in research projects (ESA, EC, National Projects, etc.) and cooperates with competent partners at universities, public institutes and private companies.

Research and development on new processing techniques is essential to maintaining the advanced level of GAMMA's processing software. GAMMA's competence encompasses technical aspects such as SAR processing, interferometry, differential interferometry, geocoding, and mosaicing as well as fully integrated product generation from EO-data. Typical products are digital elevation models, geophysical displacement maps and landuse products (forest maps, hazard maps, etc.). Pull factors driving GAMMA's R&D on processing techniques originate from demands of existing and new applications, the optimization of the techniques for new sensors, operational requirements, and quality control. New developments presented at conferences and in the literature and new hardware and software are relevant push factors to advance GAMMA's in-house technology. Recent examples include development of new methods for SAR geocoding, glacier velocity mapping, interferogram stacking, and phase unwrapping.

SYSTEM OVERVIEW

GAMMA provides licenses for its user-friendly and high quality software to support the entire processing from SAR raw data to high level products such as digital elevation models, deformation, and landuse maps. The software is grouped into four packages:

- Modular SAR Processor (MSP) – processing of raw SAR data to calibrated SLC and backscatter products

- Interferometric SAR Processor (ISP) – generation of interferometric products such as correlation maps, interferograms, unwrapped phase, and height maps.
- Differential Interferometry and Geocoding (DIFF&GEO) – generation of geocoded and differential interferometric products
- Land Application Tools (LAT) – classification and image analysis tools

The software is written in ANSI-C and has been installed on different UNIX workstations and on PC platforms with LINUX or NT operation systems. Documentation is provided in HTML language. Both binary and source code licenses are available. Attractive discounts are offered for University / Education users.

Each of the packages is very modular. The offered alternatives and parameters read from the command line allow optimization of the processing for specific cases. Shell scripts (e.g. csh, Perl) permit running and documentation of processing sequences in an operational and efficient way. Full frame SAR processing times for ERS and JERS on today's workstations and PCs are well below one hour. The software processes data of spaceborne and airborne SAR, including ERS-1/2, JERS, RADARSAT, and SIR-C. It fully supports the data formats provided by the different space agencies. Parameter estimation and quality control programs complement the main processing sequences. For example a point target analysis is included in the SAR processing suite for verification of processing performance. A complete suite of display programs and utilities based on open source technology are added for convenient access to the input data, intermediate products, and final results.

MODULAR SAR PROCESSOR (MSP)

The *GAMMA* Modular SAR Processor (*MSP*) is a flexible, accurate range-Doppler SAR processor [1]. It allows the generation of complex and real-valued SAR images from raw data of the current generation of spaceborne and airborne sensors. The processing includes radiometric calibration and is phase preserving for interferometric processing. Parameters relating to processing and data characteristics are saved as text files with system parameters referenced using simple keywords. The main modules of the *MSP* are pre-processing and data conditioning, range compression with optional azimuth prefiltering, autofocus, azimuth compression, and multi-look post processing (flow chart see Figure 4). The processed images are radiometrically normalized for the antenna pattern, along-track receiver gain variations, length of the azimuth and range reference functions, and slant range. Multilook images are produced by time-domain averaging of the single look complex image samples. Special features to optimize the processing of data of the current spaceborne sensors are autofocus (all SAR sensors), radio interference filtering (JERS), Doppler ambiguity estimation (JERS, RADARSAT), missing line detection (ERS-1/2, Figure 1), and secondary range migration (JERS, RADARSAT, Figures 2,3). An advanced motion compensation module is also available for processing of airborne SAR data.

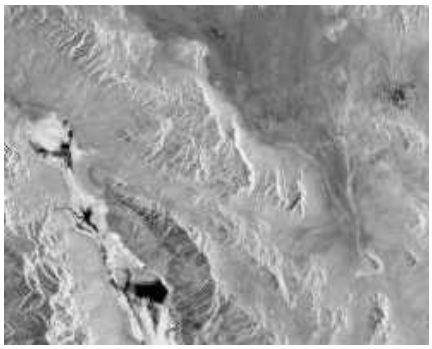

Figure 1. ERS-1 Death Valley: The GAMMA Modular SAR Processor (MSP) rapidly processes full frames to full resolution and includes programs for the assessment of data quality and processing parameters.

Raw data courtesy of ESA. Processing by GAMMA.

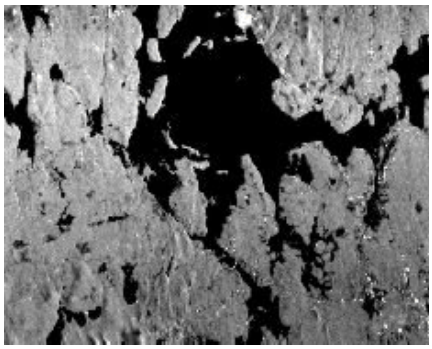

Figure 2. RADARSAT ("fine beam mode"), Bar Harbor, Maine. GAMMA MSP supports processing of all RADARSAT strip map modes.

Raw data courtesy of RSI, Canada. Processing by GAMMA.

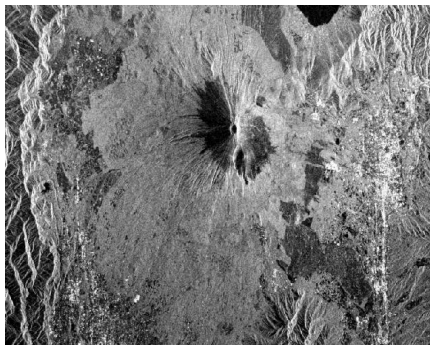

Figure 3. JERS-1, Mount Fuji (Japan): Multi-look intensity image. JERS Processing includes Doppler ambiguity estimation and RFI filtering.

Raw data courtesy of NASDA, Canada. Processing by GAMMA.

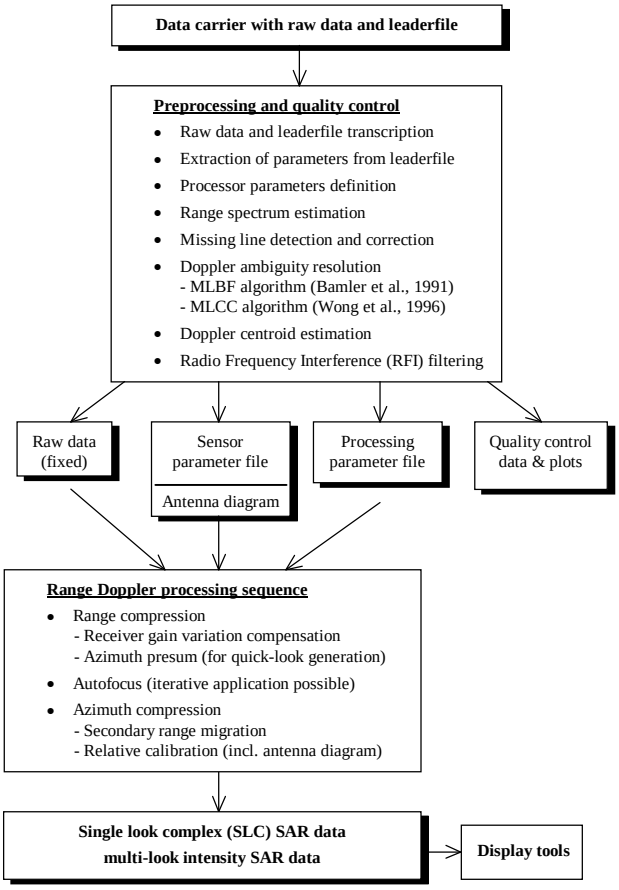

Figure 4. GAMMA Modular SAR Processor (MSP): Flow Chart

INTERFEROMETRIC SAR PROCESSOR (*ISP*)

The interferometric processor gives end to end support in the generation of interferometric products starting with complex SAR data as the SLC products provided by the Processing and Archiving Facilities (PAFs) or as processed by the *GAMMA MSP* [1]. The different modules include:

- baseline estimation from orbit data
- precision registration of interferometric image pairs
- interferogram generation (including common spectral band filtering)
- coherence estimation of the interferogram
- removal of curved Earth phase trend (interferogram phase flattening)
- adaptive filtering of interferograms
- phase unwrapping using a branch cut algorithm
- precision estimation of interferometric baselines from ground control points
- derivation of topographic height
- image rectification and interpolation of interferometric height and slope maps

A flow chart for typical interferometric processing is shown in Figure 5. The display of the final and intermediate products is supported with screen display programs and programs to generate easily portable images in SUN rasterfile and BMP format. Processing related parameters and data characteristics are saved as text files that can be displayed using commercial plotting packages. The main processing sequence is complemented by quality control and display programs.

Examples for interferometric height maps (Figures 6,7) and coherence-backscatter-change composites (Figure 8,9) are shown below for different SAR sensors.

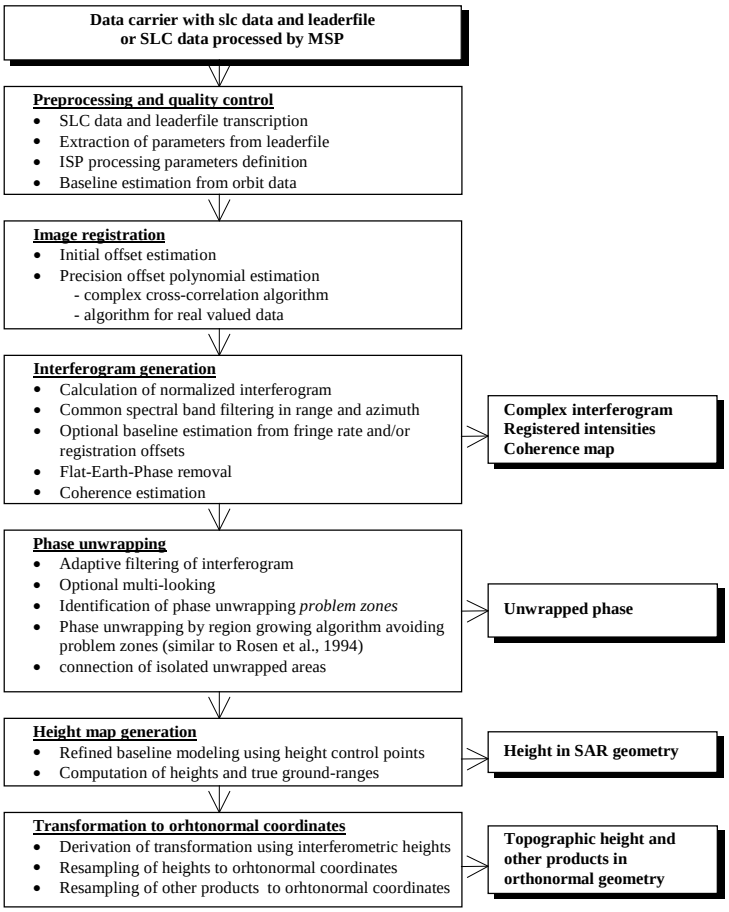

Figure 5. *GAMMA* Interferometric SAR Processor (*ISP*): Flow Chart

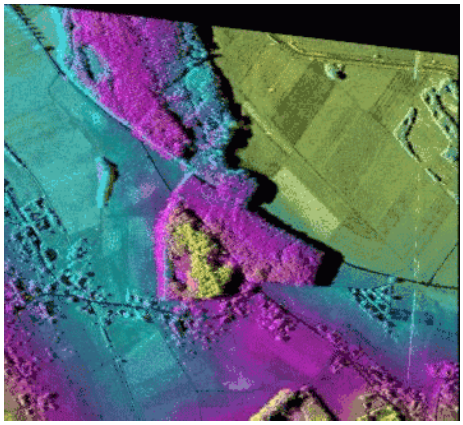

Figure 6. DOSAR, near Solothurn (Switzerland): interferometric height map over agriculture/forest site. SAR processing, motion compensation, and interferometric processing with *GAMMA MSP* and *ISP*.

DOSAR data courtesy of Dornier GmbH and RSL Univ. Zürich.

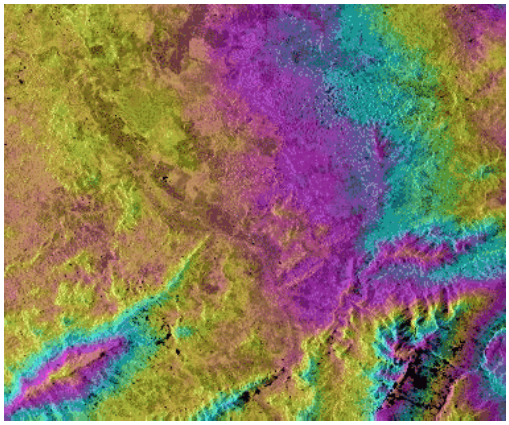

Figure 7. SIR-C, Amazon (Columbia): Interferometric height map generated from SIR-C (L-Band, vv polarization) data for a tropical forest test-site. Interferometric processing with *GAMMA ISP*.

SIR-C SLC data courtesy of JPL/NASA.

Figure 8. JERS mosaic SIBERIA: A 40 x 34 km2 section of a large JERS mosaic over Siberia, including interferometric coverage as shown above.

Raw data courtesy of DLR and NASDA, Processing by GAMMA.

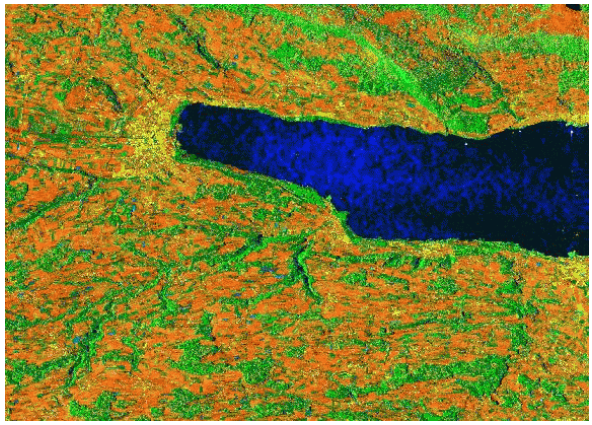

Figure 9. SIR-C, Yverdon (Switzerland): SAR interferometric landuse characterization generated from SIR-C (C-Band, vv polarization) data. Color composite of the interferometric correlation (red), backscatter intensity (green), and backscatter change (blue). Interferometric processing with *GAMMA ISP*.

SIR-C SLC data courtesy of JPL/NASA. Processing by GAMMA.

GAMMA DIFFERENTIAL INTERFEROMETRY AND GEOCODING SOFTWARE (*DIFF&GEO*)

The *GAMMA* Differential Interferometry and Geocoding Software (*DIFF&GEO*) is a suite of programs designed to support differential interferometric processing as well as conversion between range-Doppler coordinates and various map projections. The reason for inclusion of these quite different processes into one software module is that geocoding capability is required for 2-pass differential interferometry where a DEM projected into SAR range-Doppler coordinates is used to generate a synthetic interferogram.

Geocoding: Geocoding is the coordinate transformation between the coordinates of an imaging system, in this case range-Doppler coordinates of the SAR, and orthonormal map coordinates. Geocoding is necessary to combine information retrieved by the imaging system (e.g. the SAR image and products derived from it) with information in map coordinates (e.g. a digital elevation model, a landuse inventory, geocoded information from optical remote sensing)[2]. Figure 10 shows a flow chart characterizing different geocoding approaches supported by the software.

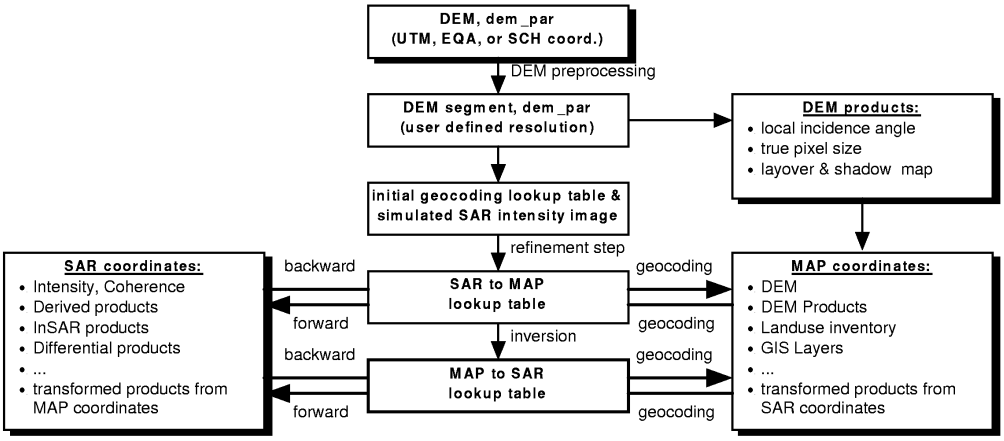

Figure 10. *GAMMA DIFF&GEO* Software: Geocoding Flow Chart

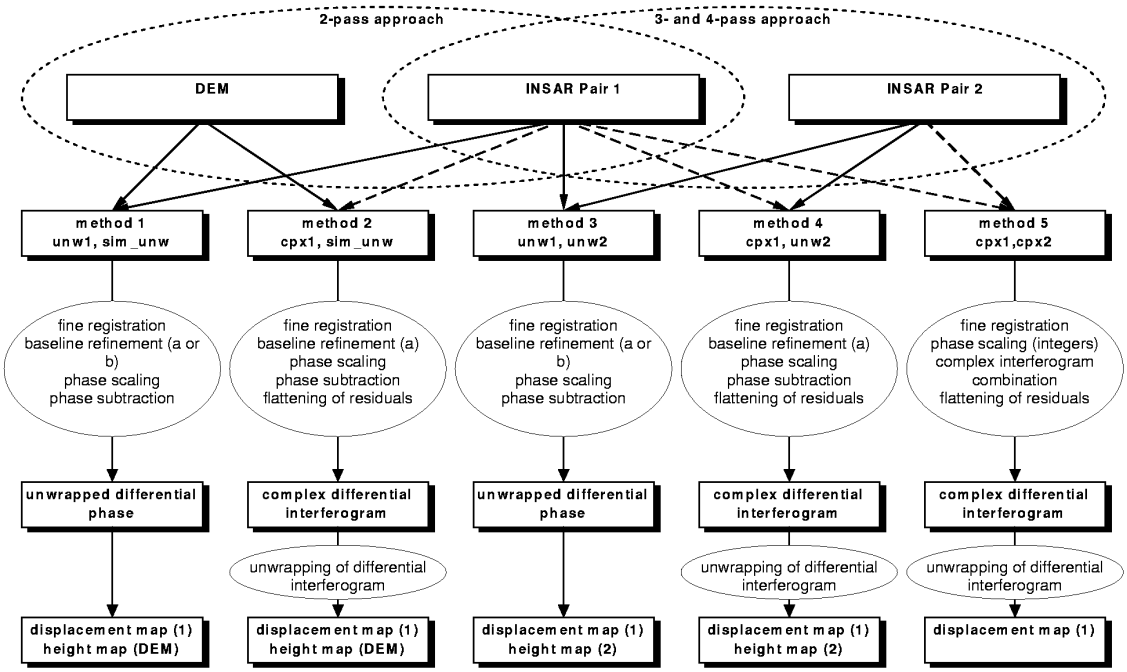

Figure 11. *GAMMA* DIFF&GEO Software: Flow Chart showing Differential Interferometry Approaches

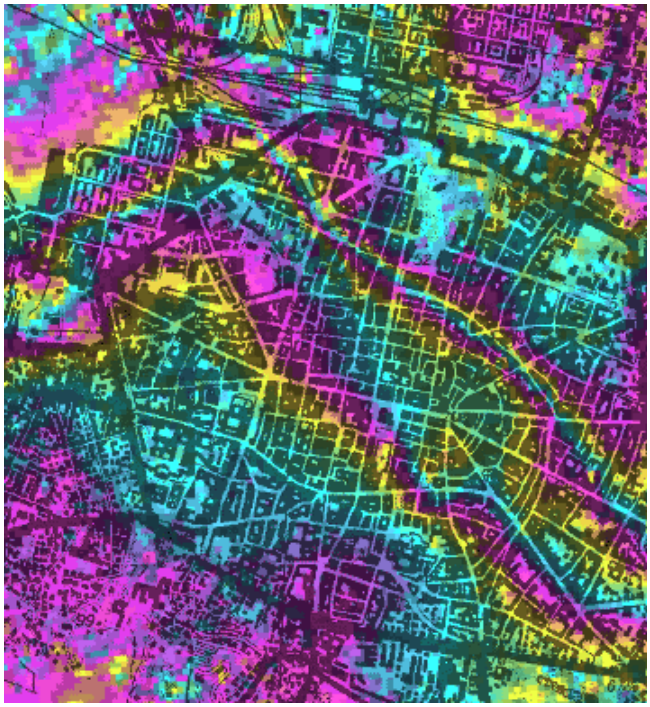

Figure 12. Subsidence map of the urban area of Bologna from ERS differential interferometry. One color cycle corresponds to a subsidence velocity of 1 cm/year starting from the stable base of the Appenini (in the south). Data processing with GAMMA MSP, ISP, and DIFF&GEO. ERS raw data courtesy of ESA.

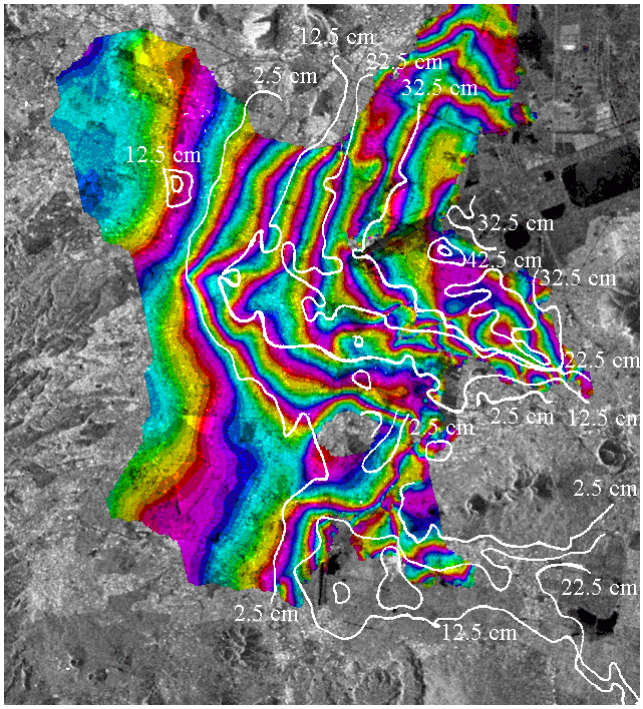

Figure 13. Mexico City: Contour lines of equal ground sinking velocity based on leveling campaigns in 1994 and 1996 (provided by Vega) superimposed on the ERS SAR interferometric subsidence map calculated for the second half of 1996. One color cycle corresponds to 5cm/year subsidence.

Differential Interferometry: The interferometric phase is sensitive to both surface topography and coherent displacement in between the acquisitions of an image pair. The basic idea of differential interferometric processing is to separate the two effects, allowing, in particular, to retrieve a differential displacement map. This goal is achieved by subtracting the topography-related phase. The topography related phase could either be calculated from a conventional DEM (2-pass differential interferometry) or from an independent interferometric pair without phase component from differential displacement (3- and 4-pass differential interferometry). Various approaches are supported by the *DIFF&GEO* leading to high flexibility with respect to the availability of data (DEM, SAR) and the feasibility of phase unwrapping [3] (Figure 11). Figures 12 and 13 show recent results of mapping subsidence over Bologna and Mexico City using ERS data [4], [5].

GAMMA LAND APPLICATION TOOLS (*LAT*)

The *GAMMA* Land Application Tools (*LAT*) are a collection of programs designed to support data processing in the context of using SAR and SAR interferometry for land applications. The *LAT* includes special programs for filtering, parameter estimation, and data visualization. There are programs to select test areas, and to extract the corresponding signatures. In addition, the *LAT* supports simple classification schemes and image mosaicking. Examples for results are shown in Figures 14 and 15.

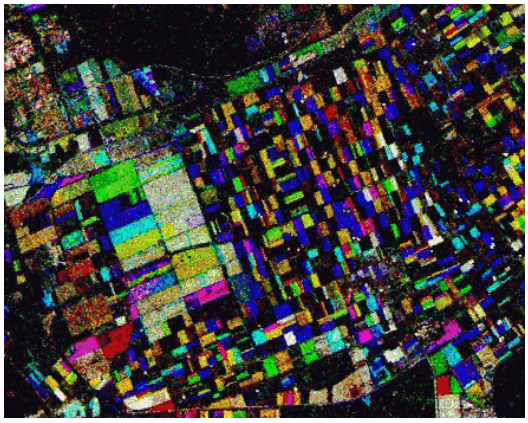

Figure 14. ERS-1, Flevoland (The Netherlands): RGB composite figure of the interferometric correlation of the September 19 / October 4 (red), October 4 / October 19 (green), and October 19 / November 9 (blue) 1991 pairs. ERS data courtesy of ESA, Processing by GAMMA.

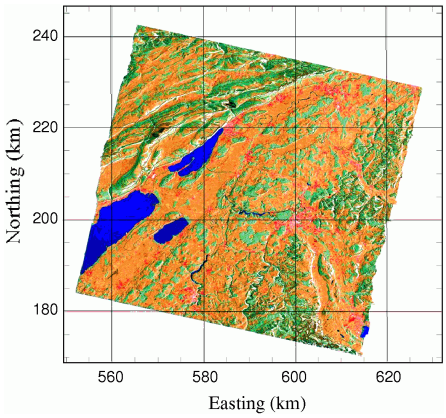

Figure 15. Landuse map for a part of Switzerland derived with ERS SAR interferometry. Data processing with GAMMA MSP, ISP, DIFF&GEO, and LAT. ERS raw data courtesy of ESA. Processing by GAMMA.

DISPLAY TOOLS (DISP)

Essential for making full use of the Gamma software is a set of tools that can display results on the screen and produce raster image products for documentation and archive purposes. The programs within the DISP package are organized by the data type and display functionality. Supported input data include:

- raw SAR data and byte images
- single look complex (SLC) and detected multi-look intensity SAR images
- interferograms, unwrapped phase, and interferometric correlation
- DEMs and interferometric height maps showing both geographic and map-projection coordinates.
- Differential interferometric products such as subsidence maps
- Display and editing of phase unwrapping flag files
- 8 and 24 bit SUN and BMP raster image format files

Within the DISP package are also programs for display of multiple data sets, either by merging the data, such as combining intensity and interferometric phase, or rapidly flickering between images of the same type. Each screen display program can access the original data files to extract the data values at the cursor position (Figure 16). The cursor

coordinates are calculated in map projection coordinates when DEM or raster data are in a map projection format such as UTM (Figure 17). Graphical editing of the files used to support phase unwrapping is also supported.

The screen display programs were developed using the open source GTK+ toolkit (http://www.gtk.org) that can be compiled to run both under the X or Win32 98/NT/2000 graphic environment. Therefore the user has the same display functionality if running either a Linux or Win32 operating system on an X86 compatible platform.

The screen display and raster image generation programs are parallel in terms of functionality. For example, the program for screen display of detected intensity images is called *dispwr*, while the program for generation of a raster image of the same data set is called *raspwr*. Most of the raster image programs support multi-looking in both range and azimuth. The images produced can be displayed using either the DISP program *disras* or other raster image file viewer such as *xv* or *Photoshop*.

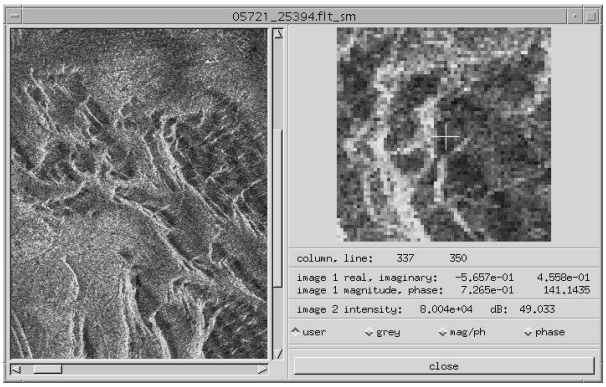

Figure 16. Display of DEM using shaded relief scaling. Latitude and longitude together with the UTM coordinates are displayed for the point in the zoom window

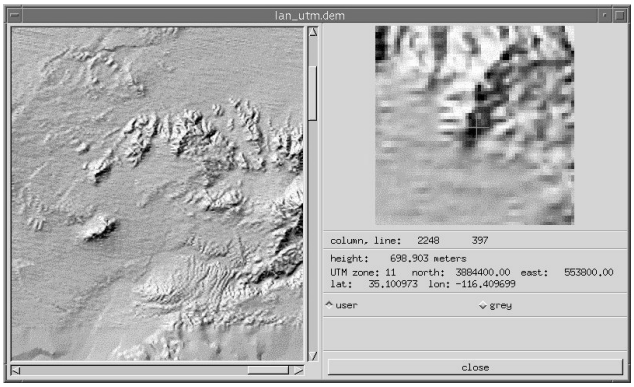

Figure 17. Display of complex interferogram and intensity images showing main image window, zoom window, data values, and color table selection menu.

SUPPORT AND MAINTENANCE

For the purposes of testing, training and demonstration the GAMMA software, processing examples consisting of the required input data, shell scripts to run the processing sequences, and copies of the expected results for validation of the successful processing, have been generated. These examples cover typical processing sequences as often used for SAR processing, interferogram generation, coherence estimation, height mapping, differential interferometry and geocoding. Shell scripts provided with the test data implement entire processing sequences and demonstrate efficient application of the software to users. On the other hand each command can be executed separately which helps the users to understand the role and functionality of each processing step. The data used for these examples was kindly provided by ESA as part of our ERS-AO3 175 project. Permission to distribute these data for the above mentioned use was also given by ESA

SUPPORT OF FUTURE MISSIONS

The modular construction of the software permits rapid integration of support for future SAR instruments and missions including the ENVISAT ASAR and ALOS PALSAR missions planned for launch within the next few years. These missions will be characterized by an increased number of mapping modes and polarisations. The Gamma software currently supports Radarsat-1, which is similar with regard to having a multiple mapping modes. These sensors will also have improved orbit knowledge and control that will have a significant impact on interferometry applications. Gamma has already been approved by ESA under AO project 210 and NASDA to have access to data raw data for upgrading the software and calibration purposes and it is our intention to provide upgraded software as soon as possible after launch.

CONCLUSIONS

With its functionality, flexibility, robustness, efficiency, and competitive price, GAMMA software is an excellent solution for demanding processing jobs. This has been demonstrated by license sales to users at many leading institutes world-wide, since 1995. A distinct advantage of the GAMMA software is the competent user support provided directly by the developers and experienced users of the software. This software is an essential backbone of GAMMA's research

and value adding effort. New algorithms developed in-house and as reported at conferences and the open literature are evaluated for inclusion in the Gamma Software and the modular structure and availability of source code licenses allows users to easily implement and integrate their own processing modules.

Recent software developments includes: full functionality on workstations (UNIX) and PCs (LINUX, NT), use of faster FFT routines to further reduce processing times, improved display tools using GTK with full portability to PCs (LINUX and Win32 98/NT/2000). The functionality, flexibility, and accuracy of the offset estimation programs was further enhanced to allow coherence and feature tracking for monitoring of fast glacier motion and large seismic displacements.

Information on the software may be found at GAMMA's homepage: http://www.gamma-rs.ch and in *GAMMA*'s Brochure *GAMMA SAR AND INTERFEROMETRY SOFTWARE*.

ACKNOWLEDGMENTS

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