SAR Interferometry: Software, Data Format, and Data Quality

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Abstract

SAR interferometry (InSAR) is on the way to becoming operational. The main hurdles of SAR interferometric processing have already been solved. However, solutions for sophisticated processing steps such as phase unwrapping, etc., are still being investigated. Furthermore, research on the potentials and limitations of various applications has been carried out. Nevertheless, some aspects of InSAR software packages such as a common data format and quantitative quality measures for interferometric products are still widely neglected and are the focus of this paper. Basic information about technical specifications of available commercial and non-commercial software packages was collected. A general format for SAR interferometric data is proposed. The importance of the data quality and suitable quality measures for InSAR data is discussed.

Introduction

SAR interferometry is one of the fastest developing research fields in remote sensing. Research has been carried out on the potentials and the limitations of this technique with respect to a large variety of applications. Numerous software packages have been developed to process SAR interferometric data. In order to reach an operational level, the interferometric processing needs to be optimized in terms of accuracy, flexibility, and processing speed. Because the processing of SAR interferometric data is a very complex issue, there is no generally accepted standard procedure for this task. For the development of such a processing scheme, it is essential to have the possibility of comparing the results from different software packages. One of the most effective ways to do that is to define a common data format for SAR interferometric products. A common data standard would also allow the inclusion of information about the processing history and about the data quality. The latter aspect is of specific importance for the user of InSAR products because it indicates whether the data set is suitable for the user's application. In the following sections, more information about the available software packages for SAR interferometric data are provided, and the aspects of data format and data quality are discussed in detail. For a comprehensive introduction in the field of SAR interferometry, the reader is referred to Gens and van Genderen (1996).

InSAR Software Packages

Most of the software packages for SAR interferometric processing have been developed by research institutes that started working in the field of SAR interferometry and observed a lack of commercially available software. Therefore, these packages generally consist of several stand-alone modules created for the different interferometric processing steps. They are mainly for internal use, supporting the research carried out at the respective institutes.

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Meanwhile, a few commercial packages have become available on the market. Some of the InSAR software packages are based on the already mentioned "research" packages. The software integrated into Erdas IMAGINE is based on a development from the Joanneum in Graz, Austria. The interferometry module distributed by PCI was developed by the Institute of Navigation in Stuttgart, Germany. The Gamma software was programmed by scientists from the Remote Sensing Laboratories (RSL) in Zurich, Switzerland, and the Jet Propulsion Laboratory (JPL) in Pasadena, California. Atlantis Scientific Inc. entered into an agreement with PCI, and future releases will be integrated into the existing PCI software package. The InSAR processor from Vexcel Corporation also became available on the market.

Table 1 shows the essential details about the available commercial and non-commercial InSAR software packages in a concise and comprehensive way. It is the result of a questionnaire sent to the various institutes inquiring about the technical specifications of their software package. The information about the commercial software packages was collected from user manuals, from websites, and by means of personal communication. The information, especially about non-commercial software packages, is not easily accessible because the field of SAR interferometry is developing rapidly and more and more research groups are working in this field.

The purpose of this paper is to suggest how compatibility could be achieved between the processed outputs from different packages rather than to compare the individual performance of each software package. The availability of software packages is not the question addressed by this paper. The recommendations made here are mostly for the software designers so that the user community can benefit from them.

Table 1 provides information about the supported sensors and formats as well as the calculated products of 19 commercial and non-commercial software packages.

Most of the supported sensors are from spaceborne systems. This is quite logical because satellite data are regularly acquired and provide global coverage. ERS-1/ERS-2 imagery is supported by all software packages whereas RADARSAT data are still not commonly used in the whole community. Processing airborne data, which is more complex than the processing of satellite data, is included in some selected non-commercial packages. SIR-C/X-SAR data are supported by a number of InSAR softwares because these data sets were widely available for research purposes.

There is no clear preference for a specific input format. Single-look complex (SLC) data are supported without any excep-

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Table 1. Commercial and Non-Commercial InSAR Software Packages*.

		Commercial					Non-commercial													
		Atlantis	Gamma	Joanneum/ERDAS	PCI	Vexcel	ASF	CNES	CORISTA	DLR	INS	ISTAR	IRECE-CNR	JPL	JRC	POLIMI Quicklook	POLIMI InSAR	RSL	UBC	University Stanford
Supported sensors																				
Satellite	ERS-1 / ERS-2	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	JERS-1	•	•			•								•						•
	RADARSAT	•	•	•		•		•				•		•					•	
Airborne	TOPSAR								•				•	•						•
	E-SAR												•							
	DOSAR		•																	
	ERIM Lear jet																			•
Shuttle	SIR-C / X-SAR		•					•	•	•	•		•	•				•		•
	SRTM													•						
Supported formats																				
	RAW	•	•				•	•	•	•		•	•	•		•	•	•		•
	SLC	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•	•	
Calculated products																				
	Interferogram	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Coherence image	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Unwrapped phase	•	•	•	•	•	•		•	•	•	•	•	•			•	•	•	•
	Digital elevation model	•	•	•	•	•	•		•	•	•	•	•	•			•	•	•	
	Differential interferogram	•	•			•		•		•	•	•	•	•	•			•		
	Simulated interferogram	•	•				•	•	•	•	•	•	•	•				•		
	Geocoded products	•	•		•		•			•	•		•	•				•		

*The information presented in this paper does not indicate the expression of any opinion of the authors concerning the capabilities and performance of the mentioned software packages.

tions by all commercial packages and most of the non-commercial packages. Ten packages are even capable of processing both raw data and SLC data.

Most of the software packages have been developed for the generation of digital elevation models (DEMs). Just a few packages do not calculate DEMs because these are mainly used for the study of surface changes which require differential interferograms. Eight software packages calculate all interferometric products and seven out of these include the geocoding of the InSAR products. It should be pointed out that products such as a differential interferogram can be calculated without having included an automatic procedure in the InSAR package. Often, modules developed for a different purpose have been adapted for the use in SAR interferometry.

For specific details about the software packages such as hardware requirements, programming language used, etc., the reader is referred to Gens (1998).

Data Format

The development of a common data format for SAR interferometric products can support the effort to optimize processing performance in terms of accuracy, flexibility, and speed. It is a prerequisite for the comparison of results from different software packages. The SAR interferometric product should be accompanied by a metadata set containing detailed information about the data set itself and each single processing step.

The description of the data set needs to include information about the input data sets. The input data can be identified by the sensor, the orbit, the frame, and the date of acquisition. The input format — raw or single-look complex (SLC) — indicates the corrections which have been applied to the data set at the processing and archiving facility (PAF). The PAFs use different processors to produce SLC data, which might lead to slightly different results. Therefore, the name of the PAF is required. The suitability of a particular data set for interferometric processing and specific applications depends on the viewing geometry during data acquisition. The main parameter of this geometry is the baseline. This baseline can be represented by its length and orientation angle. Alternatively, the vertical and horizontal component or the parallel and perpendicular component of the baseline are given to describe the baseline geometry. Finally, the interferometric product needs to be further specified. Normally, only the calculated products mentioned in Table 1 are stored, but, for one reason or another, it might be useful to include other interferometric results. This needs to be indicated. In the case of a DEM as the final interferometric product, additional information about map projection, grid size, etc., is required. Whenever possible, a quality measure for the interferometric product should be given, which will be discussed in more detail in the next section.

The interferometric processing is carried out by a specific software package. If the name and the version of the package is known, the data sets can be re-processed with the same software for a more detailed analysis of the result. The quality of processing results mainly depends on the algorithm used for the actual calculation. Due to its complexity and the size of the data sets, interferometric processing is usually a trade off between accuracy and the speed of the computation. For registration, three different methods based on intensity values, complex values, or the signal-to-noise ratio are in use. The choice of the method determines the quality of the co-registration. Furthermore, there are several approaches for the interpolation used for resampling during the co-registration. Different filtering methods can be applied at various stages of the processing scheme. Phase unwrapping is probably the most complex issue of the entire interferometric processing. Numerous solutions have been proposed for this difficult task. In order to estimate the quality of processing, as much detail as possible should be given for each processing step.

With these pieces of detailed information about the data set and processing history, the user is capable of estimating the suitability of the interferometric product for the application. A log file as provided by many software packages contains a large amount of information about the parameters used for processing as well as the performance of processing and serves as a starting point for a detailed analysis of the processing result. Its format is not meant for a short overview about the processing and usually requires detailed knowledge of the particular software package in order to extract the relevant information. Furthermore, the log file is not directly linked to the processing result.

All these problems could be overcome by defining a common header file which precedes the data file. A standard size of the header given in ASCII format would simplify the restoration of the relevant information.

Data Quality

As mentioned before, the aspect of data quality of SAR interferometric products is becoming more and more important for the technique at an operational level. In order to be able to decide whether an interferometric product is suitable as input data for one's application, the user needs to have precise information about the quality of the InSAR product.

The International Cartographic Association (ICA) has established a commission for a comprehensive study about spatial data quality. An overview of the results is given by Morrison (1995). The commission defined seven elements to describe spatial data quality, i.e., lineage, positional accuracy, attribute accuracy, data completeness, logical consistency, semantic accuracy, and temporal information. *Lineage*, also referred to as metadata, contains the information about the data history, i.e., the data acquisition, the processing steps (conversions, transformations, analyses, etc.), and the assumptions and criteria which were applied at various stages. The major quality measure is still *positional accuracy*. The root-mean-square error serves as a measure of overall accuracy and the standard deviation serves as a measure of precision. The third element proposed by the commission was *attribute accuracy*. An attribute defines a fact about some location or feature and helps to distinguish between them. *Data completeness* describes an error of omission which is a measurable component of data quality. *Logical consistency* deals with the structural integrity of the data. It describes the fidelity of relationships within this structure. *Semantic accuracy* represents the number of features, relationships, or attributes which agree with the selected model. Finally, details about the acquisition date, the type of update, and the validity period of the data set are stored as *temporal information*.

Because digital elevation models are the most demanded interferometric result, special attention should be paid to a suitable quality measure for this product. A single quality measure for a DEM, as it is usually provided with a root-mean-square error for the height, is not sufficient to describe the quality of the entire data set. It does not contain any information about the distribution of the error or its extreme values. Furthermore, users of DEMs are not necessarily interested in the height values themselves. Digital elevation models are often used for further calculation for which the derivatives of the height serve as an additional input.

Ackermann (1996) stated that, apart from accuracy, quality of a DEM covers aspects such as completeness, reliability, consistency, and uniformity of the accuracy distribution within the DEM. He proposed a more detailed quality measure using the slope accuracy or the variation of vertical accuracy as a function of slope, breakline effects, etc. This refers to the derivatives of the height, which are more sensitive to change than the height itself. The definition of the first two derivatives of the altitude surface — slope and convexity — is given by Evans (1980). A plane tangent to the terrain surface at a point defines the slope, which has two components, slope gradient and slope aspect. The *slope gradient* is the maximum rate of change of elevation whereas the *slope aspect* gives the compass direction of this maximum. These components are measured in the range of 0 to 90 degrees and 0 to 360 degrees, respectively. Convexity is defined as the rate of change of slope and is measured in degrees per 100 meters. It can be split into two components: *profile convexity*, the rate of change of gradient, and *plan convexity*, the rate of change of aspect (Evans, 1980). Slope gradient and aspect can be calculated in several ways. According to a comparative study of these methods by Skidmore (1989), the third-order finite-difference method proposed by Horn (1981) appeared to be optimal for the calculation of slope gradient and aspect from the gridded DEM.

Quality measures given for digital elevation models should be more specific, and should be related to user requirements which differ for various applications. According to the needs of the application, different features are of interest for the user's study. Although different applications may require different data quality measures, the processing of SAR interferometric data as such is application independent. The user must be able to find the required information, but the details regarding data quality should be general enough to serve the variety of potential applications. However, these quality measures are essential for the decision as to whether a product is suitable for a particular application.

Because quality measures are application oriented, it is difficult to suggest generally applicable figures of merit. There are some general measures such as root-mean-square error for the height, slope, aspect, convexity, etc., which can be used to describe the quality of digital elevation models. The disadvantage of these quality measures is that they do not provide any information about their spatial distribution. Therefore, it is preferable to use local quality measures. The coherence map is an indicator providing a spatially dependent figure of merit which is directly derived from the original measurement. However, an error map that is based, e.g., on the propagation of error during processing would serve as an optimal tool, showing the distribution of the quality measure. Because interferometric processing is a very complex issue, it is a difficult task to create a functional model for the error propagation of all parts of the processing scheme. An alternative propagation model based on a simulation approach was proposed by Gens (1998). A spatially distributed data quality measure can only be derived during the data processing itself. Without detailed knowledge about the performance of the processing, it is practically impossible for the user to deduce this information.

Conclusions and Recommendations

Technical specifications of commercial and non-commercial software packages for the processing of SAR interferometric data have been presented. A common data format for interferometric data sets is needed which includes detailed information about the input data, the processing history, and the quality of the output.

The proposed header file should include information about the following items:

- Description of the input data: sensor, orbit, frame, date of acquisition;
- Input data format: raw or single-look complex;
- Processing and Archiving Facility: name of facility, corrections applied;
- Viewing geometry: baseline length and orientation (alternatively, baseline components);
- Interferometric software package: name of the software, version;
- Interferometric product: coherence image, (differential) interferogram, digital elevation model, intermediate products;
- Format of the product: size in rows and columns, unit, value representation;
- Processing details: co-registration method, interpolation used for resampling, filtering applied, phase unwrapping technique, etc.;
- In the case of DEMs: map projection, grid size, etc.;
- General quality measures: root-mean-square error, maximum and mean error of slope, aspect, convexity, etc.; and
- Local quality measures: spatially dependent figure of merit such as coherence, ideally an error map.

More attention needs to be paid to suitable quality measures for SAR interferometric products. Including more specific quality information taking the user requirements into account is an important step for the development of InSAR to an operational level.

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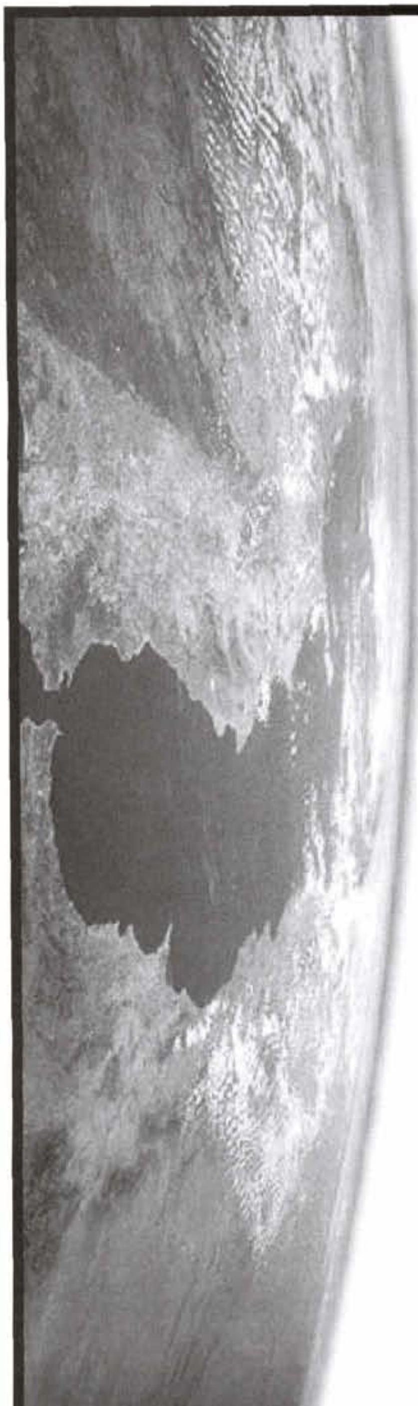

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