Documentation – User’s Guide

Modular SAR Processor - MSP

GAMMA REMOTE SENSING

Version 1.10 – November 2015

GAMMA *Remote Sensing AG, Worbstrasse 225, CH-3073 Gümligen, Switzerland*
tel: +41-31-951 70 05, fax: +41-31-951 70 08, email: gamma@gamma-rs.ch

Table of contents

List of acronyms

ACRES	Australian Center for Remote Sensing
AGC	Automatic Gain Control
ALOS	Advanced Land Observing Satellite
AP	Alternating Polarization
ASAR	Advanced Synthetic Aperture Radar
ASF	Alaska Satellite Facility
CEOS	Committee on Earth Observation Satellites
CCRS	Canadian Centre for Remote Sensing
CRISP	Centre for Remote Imaging, Sensing and Processing
DEOS	Department of Earth Observation and Space Systems
DLR	Deutsches Luft- und Raumfahrtzentrum
ENVISAT	ENVIronmental SATellite
EROS	Earth Resources Observation and Science
ERS	European Remote Sensing (Satellite)
ESA	European Space Agency
ESRIN	European Space Research Institute
FBAQ	Flexible Block Adaptive Quantization
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
IM	Image Mode
JAXA	Japanese Aerospace Exploration Agency
JERS	Japanese Earth Resources Satellite
JPL	Jet Propulsion Laboratory
MLBF	Multi-Look Beat Frequency
MLCC	Multi-Look Cross Correlation
MLI	Multi-look Intensity
MSP	Modular SAR Processor
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
PAF	Processing and Archiving Facility (D = Germany I = Italy, UK =United Kingdom)
PALSAR	Phased Array L-band Synthetic Aperture Radar
PGS	Product Generation System
PRF	Pulse Repetition Frequency
RFI	Radio Frequency Interference
SAR	Synthetic Aperture Radar
SIR	Shuttle Imaging Radar
SLC	Single Look Complex
SNR	Signal to Noise Ration
STC	Sensitivity Time Control
UK	United Kingdom

1. Introduction

The Modular SAR Processor (MSP) is a system for deriving synthetic aperture radar images from raw synthetic aperture radar (SAR) data from both airborne and space-borne sensors. The MSP calculates from raw data single look complex (SLC) and multi-look intensity (MLI) images in radar slant range/Doppler coordinates. Input data files to the processor are the complex raw SAR data coded as 8-bit or 16-bit complex samples. Output images are 32-bit floating point data either in pairs for complex number representation, or as single values of image intensity. The processing steps are illustrated in Figure 1.

The main modules of the MSP are pre-processing, range compression with optional azimuth prefiltering, autofocus, azimuth compression, and multi-look post processing. In addition, an advanced motion compensation module is also available for processing of airborne SAR data.

In the pre-processing characteristic parameters are determined from the CEOS leader file and from the raw data. First of all the raw data and the metadata are transcribed from the storage media to the system on which the data will be processed. To cope with the difficulty to decipher the variable CEOS format used for most SAR data products, the MSP (as well as all other GAMMA Software packages) uses simple data structures for the metadata in the leader file accompanying the image data. Processing related parameters and SAR data characteristics are stored in text files with system parameters referenced using simple keywords. These text files are organized following two structures, the SAR and the PROC structure, which keep track of the sensor specific and scene specific processing parameters respectively. The structures can be initialized and updated using the MSP programs that write out files called the **SAR Sensor parameter file** and the **MSP processing parameter file**.

Additional operations in the pre-processing step include conditioning of the data, manipulation of orbital state vectors, computation of the histogram of the I and Q channels to check for saturation of the raw data, estimation of range and azimuth spectra and RFI frequency interference filtering (only for JERS-1 SAR and PALSAR data).

After pre-processing raw data are ready for range and azimuth compression. The raw data are accompanied by the SAR sensor parameter file and the MSP processing parameter file. In addition there is quality information in form of text files, from which plots can be generated.

In the Range-Doppler processing sequence, range compression is followed by autofocus and azimuth compression. During range compression, data may be decimated in azimuth by prefiltering for quick-look image processing. The autofocus algorithm refines the along-track platform velocity estimate. The azimuth processor uses the range-Doppler algorithm with optional secondary range migration as required for RADARSAT-1 data. The output geometry of the images can be selected to be either deskewed or non-deskewed in azimuth. Deskewed images are projected into geometry of a non-squinted (zero-Doppler) radar acquisition. Deskewed processing has certain advantages for image co-registration and mosaicing.

The processed images are in single look complex (SLC) format. They are radiometrically normalized for the antenna pattern, along track gain variations of the radar, length of the azimuth and range reference functions, and slant range. Multi-look intensity (MLI) images can be additionally generated. These are produced by space-domain averaging of the single look complex image samples. For RADARSAT-1 data the MSP offers the possibility of multi-looking in the frequency domain to obtain PRI-like (Precision Image) imagery.

The image files generated by the MSP can be displayed and saved to SUNraster or bitmap image files with the tools available in the DISP package.

It is recommended that a file name with a <scene_identifier> label be used. The scene identifier could be the orbit number or the date of the acquisition, such as (yy)yymmdd. In the following we will refer to <scene identifier> with the symbol “*”.

When using any of the MSP programs, a report will be printed on the screen (stdout) while running. The report contains various information and execution times. The report can alternatively be saved to ASCII text file. It is recommended that a file name of the type *.out be used. To redirect the report to the ASCII file, at the end of the command line the UNIX redirecting symbol “>” is used followed by the file name. If this information is not provided, the processing report will be printed on the screen (stdout).

Other ancillary files produced by some of the programs of the MSP include the *.dat files, which are ASCII files with data such as the azimuth spectrum, range chirp values, interpolators, and motion data. These data sets can easily be imported in external software for analysis and visualization. Here we use the freely available public domain program *xmgrace*, which is available for all platforms for which the GAMMA Software is available.

Figure 1 shows a typical flowchart for SAR data processing with MSP. Sections 2 to 9 contain information on the main processing blocks. Section 10 includes a description of tools for data quality analysis and SAR data parameters estimation such as azimuth spectrum analysis of SLC data or point target response analysis. The more general description of the available processing tools is followed by an Examples Section containing sensor specific processing sequences.

For details on individual programs as well as batch scripts to run a sequence of commands, it is referred to the Reference Manual. Information on the parameters required by a specific program is also obtained by entering at the command line the name of the program.

This document is organized as follows. Each of the Sections in the main part of this Manual presents one specific step of SAR processing using the programs of the MSP module. Practical examples are provided in the Examples Section. Example A to G show sensor-specific processing chains. The individual commands can be put together in a script to automatize the processing chain. An example of a processing script is provided in Annex A. The ERS data used in Example A and G is part of the standard DEMO-CD provided with the MSP module. All other dataset used in the Examples are available on an additional DEMO-CD that can be obtained on request.

It should be remarked that parameter values provided in the processing examples cannot be considered valid for all cases. It is possible that one or more values might have to be adapted to the specific case being processed. For assistance please get in contact with us (gamma@gamma-rs.ch).

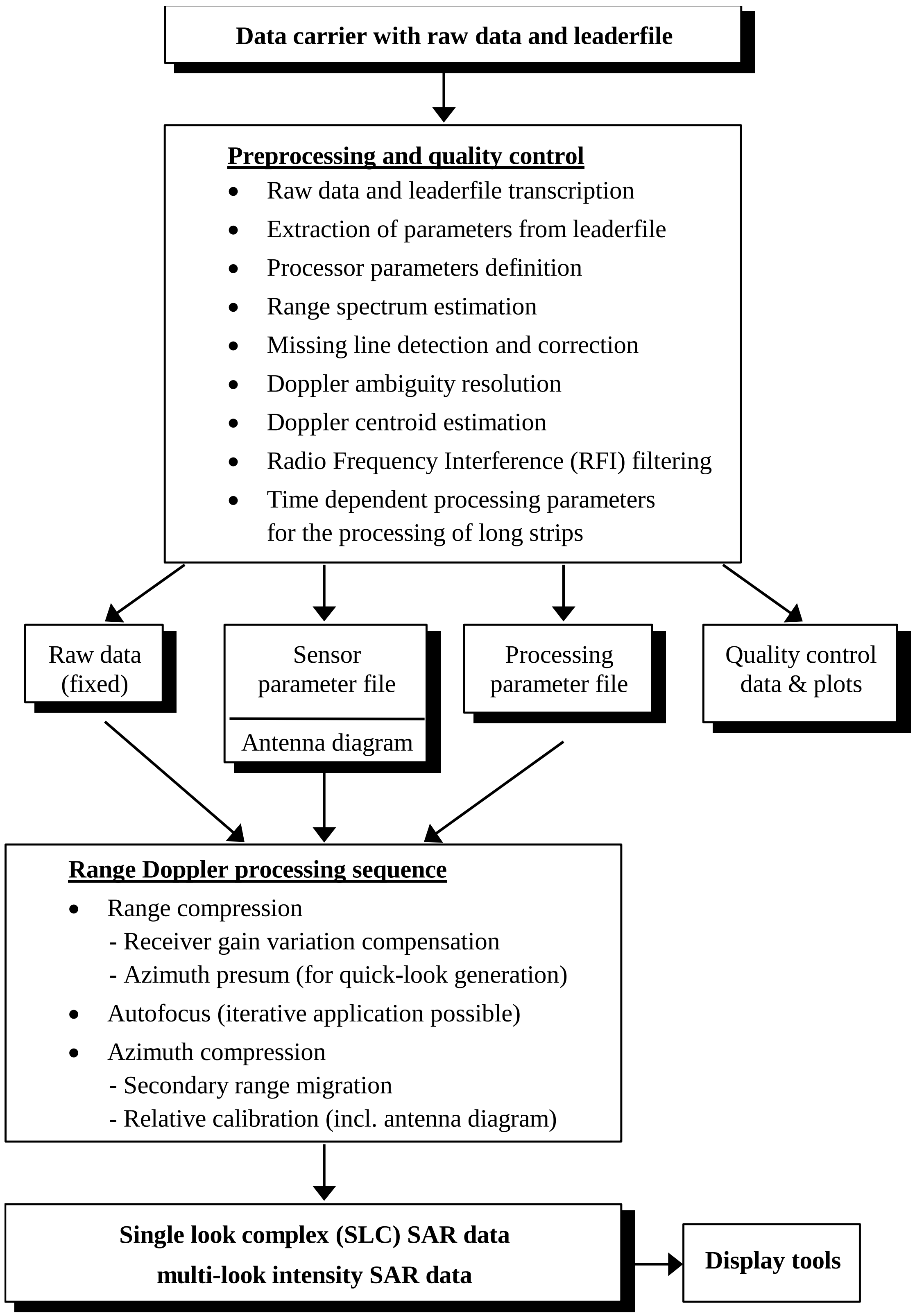

Figure 1. Flow chart of MSP package

2. Raw data and leader file transcription

Raw data are usually distributed on CD-ROM or DVD-ROM. Older data sets from ERS and JERS-1 might be stored on an Exabyte 8 mm tape. SIR-C data are also stored on tapes.

From the support media the CEOS format files need to be copied to a local directory on the machine with sufficient space. The space required for processing depends on the sensor; see Examples Section to have an idea on how much space it is needed for a single scene. Copying data from CD-ROM or DVD-ROM is straightforward. If data is stored on tape (ERS and JERS-1) the GAMMA Software offers scripts for automatically reading in the files necessary for processing (see Sections 2.1 and 2.2). For SIR-C data see Section 2.3.

Tip: It is recommended that a file name of the type *.raw be used. The scene identifier could be the orbit number or the date of the acquisition, such as (yy)yymmdd. The same applies to the SAR leader file, for which we suggest the extension .ldr.

2.1. ERS data transcription from tape

To read the tape and transcribe the ERS data from the tape to a disk directory where the processing will be performed use one of the following scripts.

Program name	**Data type**
ERS_ASF_RAW	Alaska SAR Facility raw data
ERS_CCRS_RAW	Canadian ERS data transcribed by CCRS
ERS_ESA_EIC	ERS raw data in the internal ESA EIC format
ERS_ESA_RAW	ESA ESRIN, D-PAF, ASI, Columbian ERS data

Any of these scripts will create a CEOS raw data file(s) *.raw, a CEOS leader file: *.ldr, a CEOS volume directory file: *.vdf, and a CEOS null volume directory file: *.nvdf.

In the case of ERS data from the UK PAF and CCRS ERS data delivered before 1999, the data were transcribed to 3 Exabyte tapes using only about 100 MB capacity of each 5 GB Exabyte cartridge. The scripts in the GAMMA Software developed for these cases inform the user when to load a new tape in the Exabyte tape reader. Once the 3 segments of the raw data have been read, the files must be concatenated to a single file with the UNIX *cat* command.

Writing the output to a disk different than the one where the original files are located has the advantage that the I/O speed will be greatly improved.

2.2. SIR-C data transcription from tape

SIR-C raw data can be read from 8mm tape using the most recent version of the ceos_reader program (v2.3) supplied by JPL. This program reads SIRC-C CEOS data tapes for both processed and unprocessed data.

```
ceos_reader tape=/dev/rmt/0mnb
```

0mnb is the device file of the tape containing the raw data and will be different depending on the machine used. Be sure to select a device that is no rewind.

3. Pre-processing

3.1. Generation of parameter files

The sensor parameters, the processor parameters and commands for the operation of the processor are contained in the parameter files. These are simple ASCII character files which are read by each program in the processor as required. Keywords are used to identify and document the parameter values. Comments and units are allowed past the values, separated by spaces, tabs or semicolons. Input parameters are separated by spaces, tabs, or new line characters.

When processing raw SAR data with the MSP package to obtain an SLC, the parameters are organized in the SAR and the PROC structures, which keep track of the sensor specific and scene specific processing parameters respectively. These structures can be initialized and updated using the MSP programs that write out files called the MSP SAR Sensor parameter file and the MSP processing parameter file. A description of the function of each of these files is given in Example A. Certain of the processing parameters given in the MSP Processing parameter file can be updated by inputs on the command line for some of the MSP programs.

The SAR Sensor parameter file contains the characteristics that define the SAR instrument. These parameters define chirp and receiver characteristics, ADC configuration, raw data structure and antenna pattern. Typically, the sensor parameters describe static parameters for a particular sensor. While this is true for single-mode radar such as ERS, the numerous modes of SIR-C, PALSAR and RADARSAT-1 require that a MSP SAR sensor parameter file is generated for each processing. This is done automatically when running the programs that set up these files.

The MSP processing parameter file contains parameters for controlling processor operation. Parameters include the amount of data processed, output data format, the range and azimuth resolutions, Doppler and Doppler rate polynomials, platform position and velocity, multi-look parameters, and image dimensions. The processing parameter file is scene dependent and needs to be generated each time a new raw data set is to be processed. Information is read from the leader file accompanying the raw data or, as for example in the ENVISAT ASAR case, from the header at the beginning of the raw data file.

3.1.1. SAR sensor parameter file

It should be noticed that for all spaceborne SAR supported by the GAMMA Software the SAR parameter file is already available or is generated simultaneously to the MSP processing parameter file. For ERS-1/2 and JERS-1 the existing SAR sensor parameter files are provided with the MSP package and are recommended for use. They can be found in the */sensors* directory. For ENVISAT ASAR, PALSAR, RADARSAT-1 and SIR-C, the SAR the sensor parameter file is created simultaneously to the MSP processing parameter file (see below). This is due to the many data acquisition modes of these radars. In this case the MSP SAR sensor parameter file is generated from parameters in the CEOS leader file.

To create a new SAR sensor parameter file (practically never needed) or edit an existing SAR sensor parameter file use the program ***create_sar_par***.

Tip: for the SAR sensor parameter file use a file name of the type <SAR_sensor>.par.

Most ERS raw data now conform to the European Space Agency (ESA) standard format described in the parameter files ERS1_ESA.par and ERS2_ESA.par files. Some Processing and Archive Facilities (PAFs) have slightly different formats regarding length of the record headers and the size of the data records. The list of MSP SAR sensor parameter files available for ERS data is below

Parameter file	Satellite and PAF
ERS1_CCRS.par	CCRS raw data format for ERS-1
ERS2_CCRS.par	CCRS raw data format for ERS-2
ERS_EIC.par	Internal ESA format for ERS-1 and ERS-2 raw data
ERS_CO.par	Columbian receiving station for ERS-1
ERS1_ESA.par	ESA ESRIN, DPAF, ASI raw data format for ERS-1
ERS2_ESA.par	ESA ESRIN, DPAF, ASI raw data format for ERS-2
ERS1_ASF.par	ERS data received at Alaska SAR Facility prior to 1997
ERS2_ASF.par	ERS data received at the Alaska SAR Facility prior to 1997
ERS1_UK.par	ERS-1 data received at UK-PAF by QinetiQ (2002)
ERS2_UK.par	ERS-2 data received at UK-PAF by QinetiQ (2002)

3.1.2. MSP processing parameter file

For each sensor supported by the MSP package, it is possible to generate a MSP processing parameter file using the corresponding program (see below). When running any of the programs, the user is queried if a subset of the raw data should be processed, and about certain processing parameters. If default is accepted, the user should press the enter key otherwise the corresponding value should be entered manually. Accepting all defaults will process the entire raw data frame into an SLC. User specified input parameters include the size of the range FFT, starting range, and the number of echoes to process, and the offset to the first echo to begin processing. An alternative to run the program on the command line is to feed these values to a text file, e. g. with the UNX *echo* or with *awk* command, from which the program used to generate the MSP processing parameter file, will then read the parameters.

If the user wants to create or edit a specific SAR Processing Parameter file for which no program is available, the program ***create_proc_par*** is available. Generally this program is used only to modify the processing parameters for which specific parameter generation program does not exit.

Tip: for the MSP processing parameter file use a file name of the type p*.slc.par. Notice the "p" in front of the filename. This is used to distinguish the processing parameter file generated by the MSP for the raw data from the one generated for the SLC. For the image parameter file of an SLC file name of the type *.slc.par is recommended.

When running each of the programs listed below, the user is queried if a subset of the raw data should be processed, and about processing options. These parameters include the starting echo and number of echoes and the starting range sample. If default is accepted, the user should press the enter key otherwise the corresponding value should be entered manually. Accepting all defaults will process the entire raw data frame into an SLC. An alternative to running the program on the command line is to feed these values to a text file, e. g. with the UNIX *echo* or *awk* command, from which the program being used will then read the parameters.

3.1.2.1. ERS

To create an MSP processing parameter file for the ERS satellites, use one of the programs listed below. This set of programs uses header/leader files as provided with the raw data by different receiving stations / processing facilities. The programs read the input data, search for information needed for MSP processing parameter file and create the MSP processing parameter file. At the present time the following CEOS raw data are supported. Years are reported for the year of processing (not acquisition). The program ***ERS_ENVISAT_proc*** in addition reformats the data to the image format used by the GAMMA Software.

Program name	**Facility**
ERS_ENVISAT_proc	ESA ESRIN data format for ENVISAT data
ERS_proc_ACRES	Australian PAF at the Australian Center for Remote Sensing (ACRES)
ERS_proc_ARG	ASF Level 0 (SKY) CEOS leader (2000)
ERS_proc_ASF	Alaska SAR Facility (ASF) 1997-1999
ERS_proc_ASF_91	Alaska SAR Facility (ASF) 1991-1997
ERS_proc_ASF_2000	Alaskan SAR Facility (ASF) from 2000, raw data produced using the new Level Zero Processor
ERS_proc_ASI	Italian PAF (I-PAF) prior to 1997
ERS_proc_CCRS	Canadian receiving station operated by CCRS
ERS_proc_CRISP	Singapore receiving station (CRISP)
ERS_proc_ESA	ESA ESRIN central PAF, UK PAF, D-PAF, I-PAF (production after January 1997) as well as the ESA-ESRIN PGS processor
ERS_proc_ESRIN_ACS	ESA ESRIN internal data format
ERS_proc_NASDA	NASDA, now JAXA (Japan)
ERS_proc_UK	UK-QinetiQ data after 2002

3.1.2.2. ENVISAT ASAR

The programs used for the generation of an MSP parameter file depend on the acquisition mode of ENVISAT ASAR. So far generation of SLC from raw data is supported for Image Mode (IM) data with the ***ASAR_IM_proc*** program and for Alternating Polarization (AP) data with the ***ASAR_AP_proc*** program. For both programs to work, the antenna pattern file needs to be generated first. This is done with the program ***ASA_XCA***.

To extract the antenna pattern as measured on the ground, which is also used to compensate for the antenna gain across the swath in the SAR processing, it is necessary to get an external characterization file. This file can be downloaded from http://envisat.esa.int/services/auxiliary_data/asar. The correct file should be selected for the date that the data were acquired. ***ASAR_XCA*** reads the ENVISAT ASAR external calibration data file, writes calibration factors for the different modes and data products to the screen and generates antenna diagram files in the format used by GAMMA Software.

ASAR_IM_proc reads the ASAR Image Mode Level 0 data files and generates the MSP processing parameter and SAR sensor parameter files. This program also reformats the raw SAR signal data to be compatible with the MSP. The entire Level 0 data set is converted to 8-bit I/Q unsigned binary complex samples. For more information on ENVISAT raw data format see Annex A in the Documentation to SAR Processing Theory.

MSP processing of the ASAR Level 0 Alternating Polarization data with ***ASAR_AP_proc*** is similar to Image Mode data except that two scenes are processed in parallel. The program reads the Level 0 ASAR AP Mode data and generates the MSP processing parameter and

SAR sensor parameter files along with the two reformatted raw data sets. This program reformats the raw SAR signal data for the two channels to be compatible with the MSP. The entire Level 0 AP data set is converted to 8-bit I/Q unsigned binary complex samples in two files corresponding to the two polarization channels. The filenames should contain the particular polarization of the associated data.

3.1.2.3. JERS-1

To create an MSP processing parameter file for the JERS-1 SAR data, use the program ***JERS_proc***. The program determines the JERS-1 SAR processing parameters from the NASDA/JAXA CEOS leader file. ***JERS_proc*** reads leader file, searches for information needed for processing and creates the MSP processing parameter file. State vectors in the CEOS leader file are interpolated to create those used for processing using a polynomial interpolation scheme. Only the processing parameter file is generated by ***JERS_proc*** since the sensor parameters are constant for this single mode radar. Data generated by the Alaska Satellite Facility (ASF) are supported with the program ***JERS_proc_ASF.***

3.1.2.4. PALSAR

For PALSAR Fine Beam (FB) and Polarimetric (PLR) raw data pre-processing and generation of the MSP SAR sensor and processing parameter files use the program ***PALSAR_proc***. The program determines the PALSAR processing parameters from the CEOS leader file. The program supports both the JAXA EORC and the ERSDAC data format. Because of the several modes in which PALSAR can operate, ***PALSAR_proc*** also generates the MSP SAR sensor parameter file. For multi-polarization raw data a sensor parameter file and MSP processing parameter file are generated for each of the polarization channels.

Contrarily to all other sensors, the pulse repetition interval (PRI) of PALSAR changes along the orbit. It changes 7 times between consecutive descending/ascending nodes, i.e. 3 times per strip, a strip being 2000-3000 km long. ***PALSAR_proc*** can detect changes in the radar pulse repetition frequency (PRF), which is the reciprocal of the PRI.

For Wide Beam (WB) ScanSAR data, use the program ***PALSAR_proc_WB***. The program determines the PALSAR processing parameters from the CEOS leader file. It generates the MSP SAR sensor and the MSP processing parameter file. The user can select for which of the 5 beams of the WB mode the processing should take place and at which PRF the data should be resampled. To process the entire set of 5 beams, the processing shall be run 5 times. For details, it is referred to the document on PALSAR ScanSAR processing, part of the DIFF&GEO module.

The antenna gain pattern differs depending on the acquisition mode. The program ***PALSAR_antpat*** reads in the antenna gain pattern file as provided by JAXA for all acquisition modes and restitutes the antenna pattern for the specific acquisition mode of the image to be processed, in the format compatible with the GAMMA software. The program can be used before or after ***PALSAR_proc*** (for FB and PLR) or ***PALSAR_proc_WB*** (for WB). The antenna pattern is only important for radiometric calibration and has no effect on the interferometric phase or coherence.

3.1.2.5. RADARSAT-1

To create an MSP processing parameter file for Stripmap RADARSAT-1 raw data, use the program ***RSAT_raw***. This program generates the SAR sensor parameter as well. In addition it also reformats the raw SAR signal data to be compatible with the MSP. For data generated by ASF, use the program ***RSAT_proc_ASF.***

3.1.2.6. SIR-C

To create an MSP processing parameter file for SIR-C raw data, use the program ***SIRC_proc***. The program also computes the MSP SAR sensor parameter file. SIR-C is in fact similar to RADARSAT-1 because of the large number of possible modes combining different frequencies (L- and C-band), resolutions, and polarizations. Hence, ***SIRC_proc*** creates a MSP SAR sensor and a MSP processing parameter file for each raw data set provided by NASA through JPL or the EROS data center.

3.1.2.7. COSMO-SkyMed

To create an MSP processing parameter file for COSMO SkyMed raw data, use the program ***CS_proc***. The program requires the original data file in HDF5 format and produces the reformatted image dataset and the sensor and processing parameter files.

3.2. Concatenation and conditioning of raw data files

To concatenate a set of overlapping raw data files acquired on a single satellite track, use the program ***cat_raw***. The program generates one data file with the concatenated data set and generates the related MSP SAR sensor and MSP processing parameter files. The concatenation of raw data files allows SAR processing of longer strips.

In the MSP however specific programs for concatenating ERS, JERS, PALSAR and RADARSAT-1 data sets as well as conditioning (i.e. corrections for range misalignments or missing lines) can be found. Concatenation and conditioning of raw data files for ERS and JERS-1 data can be performed with the ad hoc programs ***ERS_fix*** and ***JERS_fix***. These must be used if the data needs to be conditioned as well. Concatenation of PALSAR frames can be done with ***cat_raw***. Concatenation of RADARSAT-1 data can be performed with the ***RSAT_raw*** program.

All these programs read one or several raw data files, check their contents and concatenate them into one output raw (“fixed”) data file.

Tip: for the concatenated and/or conditioned data is use a file name of the type *.fix.

3.3. Manipulation of orbital state vectors

3.3.1. Generation of additional state vectors

If the number of state vectors provided with the raw data is too small or the state vectors are too coarse for accurate processing of the image data, additional state vectors can be computed. The program ***ORB_prop*** calculates additional state vectors using orbit propagation and interpolation.

3.3.2. Modification of state vectors

The orbit state vectors of ERS and ENVISAT ASAR data provided by the product processing facilities can be improved by substituting the available records with data provided by external sources. Depending on the source of the orbital data, the MSP offers specific programs to determine the state vectors from the external data files and update the state vectors in the MSP processing parameter file.

For ERS there are basically two types of orbital information from external sources available: DELFT orbits provided by DEOS and PRC precision orbits provided by DLR. For ENVISAT there are two types of orbital information from external sources available: DELFT orbits provided by DEOS and DORIS orbits provided by ESA. For more information the user should refer to the Documentation on SAR Processing Theory.

3.3.2.1. DELFT orbits

To improve the state vectors in the MSP processing parameter file with orbital data provided by DEOS, use the programs ***DELFT_proc2***. This program extracts and interpolates Delft ERS-1, ERS-2, and ENVISAT state vectors to calculate or update the MSP processing parameter file state vectors.

The DELFT orbit data are distributed as files (ODR.*) for ERS-1, ERS-2, and ENVISAT. It is suggested to download the ODR files and the arclist to a local directory, from which the orbit files required for processing can be retrieved. Once downloaded both the ERS-1 and ERS-2 ODR files from the website, they should be stored in separate ERS-1 and ERS-2 directories. If this is too much data to download, only the required ODR files for processing can be downloaded. To find the necessary ODR file, the *arclist* file contained in the same directory with the ODR files at DEOS should be used.

3.3.2.2. PRC Precision Orbits

To extract state vectors from ERS-1 and ERS-2 PRC precision orbit state vector files and store then in an MSP processing parameter file, use the program ***PRC_proc***. The program reads ERS-1 and ERS-2 PRC precision state vector files provided by ESA and extracts a specified number of state vectors that bracket the raw data set. The state vectors are written into the MSP processing parameter file along with the start time and time interval between state vectors. The default number of state vectors is 5 spaced at 30 second intervals. This is adequate unless multiple frames are processed. Up to 64 state vectors can be extracted.

It is suggested to download the PRC files from ESA ESRIN ftp site (authorization required) to a local directory, from which the orbit files required for processing can be retrieved.

3.3.2.3. DORIS Precision Orbits

To extract state vectors from ENVISAT ASAR DORIS precision orbit state vector files and store then in an MSP processing parameter file, use the program ***DORIS_proc***. The program reads ENVISAT ASAR DORIS precision state vector files provided by ESA and extracts a specified number of state vectors that bracket the raw data set.

It is suggested to download the DORIS files from ESA ESRIN ftp site (authorization required) to a local directory, from which the orbit files required for processing can be retrieved.

3.4. Histogram computation

Uncompressed raw data might be affected by saturation. To see whether this is the case for a data set, one can look at the histograms of the I and Q channels of the data. To compute the histograms of the I and Q channels of the uncompressed raw data, use the program ***hist_IQ***. The program computes two histograms separately for a user-defined window size. The result is written into an ASCII file, with the integer number in the first column and the normalized I and Q histograms in columns 2 and 3.

4. Range spectrum estimation

The range spectrum is determined to estimate the SNR in the final image. To compute the range power spectrum a set of programs with prefix ***rspec_*** can be used, depending whether the SAR raw data is in complex or real format. For JERS-1 SAR and PALSAR raw data a specific program has been created. In this calculation, the region of the range power spectrum that is primarily noise is compared to the average power level over the chirp bandwidth. The resultant estimate of the image SNR is stored in the SNR_range_spectrum parameter of the MSP processing parameter file.

For ERS, ENVISAT and RADARSAT-1 raw data in complex format (I/Q), the range power spectrum is calculated from the SAR raw data with the program ***rspec_IQ***, If the SAR data is in real offset-video format (e.g. SIR-C), the range power spectrum is calculated from the SAR raw data with the program ***rspec_real***. For range spectra estimation in the case of JERS-1 SAR and PALSAR data, use the program ***rspec_JERS***. The output is then used for the subsequent necessary Radio Frequency Interference (RFI) filtering, which is done with the program ***pre_rc_JERS***.

All programs read in the MSP SAR sensor parameter file, the MSP processing parameter file and the image data, and use FFT to calculate successive spectra. These spectra are then averaged to produce the desired power spectral density that is written out as text file (*.rspec file)

Tip: for ERS. ENVISAT, RADARSAT-1 and SIR-C it is recommended to use a file name of the type *.rspec for the output range spectrum. For JERS and PALSAR it is recommended that the name of the file containing the range power spectrum is of the type *.psd

The individual range power spectra may be extracted from the *.psd file with the program ***extract_psd***. The format of the text file produced by ***extract_psd*** is pairs of numbers (sample number, spectrum value).

5. Azimuth spectrum estimation

5.1. Doppler ambiguity resolution

To estimate the Doppler ambiguity from SAR raw data (IQ data) use the program ***dop_ambig***. This program implements two algorithms described in the Documentation to SAR Processing Theory: the Multi-Look Beat Frequency (MLBF) and the Multi-Look Cross Correlation (MLCC). Due to large memory allocation required by this program, if an entire file needs to be processed the program ***dop_mlcc*** can be used instead. This program implements the MLCC algorithm only.

The determination of the Doppler ambiguity in the case of ERS data is only needed for data collected in the southern hemisphere. For ENVISAT ASAR Image Mode and Alternating Polarization data this should normally not be required because the sensor is nominally yaw-steered to 0 Doppler. JERS-1 and RADARSAT-1 usually have a significant amount of squint causing the Doppler centroid to be several times the PRF. In addition, the MLCC algorithm works best in scenes with low contrast such as forests.

Tip: for the output plot using ***dop_ambig*** use the file name dop_ambig.dat. If ***dop_mlcc*** is used, use a file name of the type *.mlcc.

In both algorithms the signal phase from different complex range looks is used to obtain an unambiguous estimate of the Doppler centroid. This value is stored in the MSP processing parameter file with the DAR_Doppler keyword. The programs ***doppler*** and ***azsp_IQ*** can then use the unambiguous Doppler estimate to determine the Doppler ambiguity number and add it to the accurate, but ambiguous estimate.

The MSP provides a confidence measure for determining if the Doppler ambiguity program ***dop_ambig*** provides an accurate answer. The value of this measure is stored in the parameter DAR_snr. For the MLBF algorithm, the value of DAR_snr is a function of the error that would result in finding the wrong multiple of the PRF. An SNR of 1 denotes that the predicted error is equal to the error that would give the wrong ambiguity, while an SNR of 4 shows that the estimated error in the phase estimate is 1/4 of the value that would give a wrong Doppler ambiguity. The MLCC algorithm value for DAR_snr is a measure of the SNR of the peak in the spectrum found by performing a Fourier transform on the product of the range looks. An SNR less than 4 indicates likely problems in the centroid estimate.

5.2. Doppler centroid estimation (IQ data)

The fractional part of the Doppler centroid can be estimated using either the line to line complex correlation method, or by finding the centroid of the azimuth power spectrum (see Documentation to SAR Processing Theory). The first algorithm is implemented in the program ***doppler***. The second algorithm is implemented in the program ***azsp_IQ***. Depending on the sensor acquiring the data one or the other program should be preferred.

The first approach should be used for RADARSAT-1 and JERS-1 SAR data, which often have a large squint angles causing the centroid to change more than 1/2 PRF across the swath. For ERS SAR and ENVISAT ASAR, data collected with centroid 1 or 2 ambiguities away from 0 (mostly in the Southern Hemisphere) will have a significant change in Doppler centroid across the swath and benefit from this approach. However, in general, for ERS SAR and ENVISAT ASAR processing the second algorithm is sufficient since the centroid of ERS SAR data is quite constant across the swath since the platform yaw steering attempts to avoid large squint angles. PALSAR is yaw steered and therefore the Doppler trend should be minimal. Hence the Doppler can be estimated as constant. In this case it is preferable to use ***azsp_IQ*** rather than ***doppler***.

Sensors such as RADARSAT-1 that are not yaw steered can exhibit Doppler variations of 20 Hz/sec along-track. The Doppler centroid model must then be extended to include this along-track variation if multiple raw data frames are to be processed. This extended parametric model for the Doppler frequency, f_d, is a function both of slant-range, r, relative to center swath and the along-track time, t, relative to the center of the entire raw data set:

$$f_d(r,t) = a_0 + b_0 \cdot t + c_0 \cdot t^2 + (a_1 + b_1 \cdot t) \cdot r + a_2 \cdot r^2 \qquad (1)$$

The programs ***doppler*** and ***doppler_real*** estimate parameters a_0, a_1, and a_2 only. The estimation of the parameters for the extended model is done with the program ***doppler_2d***. A constant Doppler value is best estimated using ***azsp_IQ***.

To check the quality of the fit obtained with ***doppler***, the Doppler function generated by ***doppler*** can be looked at. If the fit is not good, a constant Doppler value would be better.

All programs (***azsp_IQ, doppler*** and ***doppler_2d***) can use the unambiguous estimate of the Doppler centroid derived using the programs ***dop_ambig*** or ***dop_mlcc*** to determine the ambiguity number and add the correct multiple of the PRF to the estimated fractional part of the centroid (recommended). If both the MLCC and MLBF algorithms fail to give a correct answer for the ambiguity, ***doppler*** can accept an integer value for the ambiguity from the command line.

Tip: for the output file use a file name of the type *.doppler.

5.2.1. doppler

The cross correlation algorithm implemented by ***doppler*** obtains a centroid estimate for each range bin. These individual estimates are somewhat inaccurate and a least squares polynomial fit of the Doppler across the swath is required to get a result that can be used for processing. This polynomial is stored in the MSP processing parameter file. The auto-focus program

autof may also be used to resolve the Doppler ambiguity. Each Doppler ambiguity is equivalent to a shift of the Doppler centroid by the pulse repetition frequency (Hz).

5.2.2. doppler_2d

The program ***doppler_2d*** calculates Doppler centroid as a function of slant range and azimuth position using line to line cross-correlation measurements of SAR raw data (IQ ADC format).

For the 2-D implementation that includes the along-track variation in Doppler centroid the line-to line correlation algorithm is applied for a set of along-track blocks. This yields the ambiguous centroid on a 2-D array of points as a function of relative slant range and time. This array of measurements is unwrapped in 2-D by comparison with a parameterized set of Doppler model functions and the model with the least error is used to unwrap the centroid estimates. The unwrapped Doppler centroid estimates are then used to determine the 2-D model parameters a_0, a_1, a_2, b_0 and b_1 and c_0 by performing a least-squares fit.

As previously reported, the global Doppler ambiguity can either be set to a given number or from the unambiguous Doppler centroid estimated by ***dop_ambig*** (recommended). The auto-focus program ***autof*** may also be used to resolve the global Doppler ambiguity. Finally, the user can also optionally select which of the parameters a_1, b_0, b_1, and c_0 are fit.

5.2.3. azsp_IQ

The azimuth power spectrum approach is implemented by the ***azsp_IQ*** program for IQ format SAR data. Short azimuth segments from a region in the center of the range swath are Fourier transformed and the powers are added incoherently to form a periodogram. The program then determines the centroid by finding the frequency that balances the spectrum. This program finds the centroid only at the center of the image.

Tip: for the azimuth spectrum use a file name of the type *.azsp.

Another way to estimate the ambiguity number is to perform autofocus on the range compressed data. The autofocus program ***autof*** estimates the uncompensated range migration between the generated azimuth looks. If this exceeds half of the expected range migration caused by an ambiguity error, the Doppler centroid is updated by the estimated number of multiples of the PRF. This is the best way to estimate the ambiguity for scenes with some contrast.

5.3. Doppler centroid estimation (real valued data)

For raw data in real format the program ***doppler_real*** must be used. The program determines the Doppler polynomial across the swath. This program is used for SIR-C data. For a description of the functionality of ***doppler_real*** see the description given for ***doppler***.

6. Range compression / Azimuth prefilter

Although it is not needed to estimate the Doppler centroid before range compression, unless secondary Doppler range correction is required as in the case of RADARSAT-1, it is strongly recommend that the Doppler estimation is performed before range compression.

In the MSP a set of different sensor dependent range compression programs have been developed as shown below.

These programs all function approximately in the same way, but take into account the sensor dependent variations in compensation for backscatter variation along-track and across the swath. All programs estimate the raw data histogram, and data statistics, including the mean of each channel, standard deviation, and in the case of IQ data, the correlation between the I and Q channels.

Program	Function	Sensor
pre_rc	Range compress and optionally azimuth prefilter/decimate raw IQ format SAR data	ERS ENVISAT ASAR PALSAR
pre_rc_JERS	Range compress and optionally azimuth prefilter/decimate raw IQ format SAR data	JERS-1
pre_rc_RSAT	Range compress and optionally azimuth prefilter/decimate raw IW format SAR data, includes secondary range migration correction	RADARSAT-1 Stripmap
rc_real	Range compress raw offset video SAR data	SIR-C
rc_fmcw	offset-video FMCW radar data	

For determining the sidelobe level and resolution of the range compressed data all programs in the MSP utilize the Kaiser-Bessel window as the weighting function. The relationship between the resolution and sidelobe level can be changed by adjusting the window parameter beta. The default value of beta is 2.12, which leads to sidelobes of approximately -25 dB. For more information see the Documentation to SAR Processing Theory and the HTML MSP Reference Manual.

The range compression programs for ERS, RADARSAT-1 and JERS-1 have the option of decimating the data in azimuth by pre-filtering around the Doppler centroid prior to range compression, followed by sub-sampling. This might be desirable if a quick-look survey product is desired. This step can also be performed after range compression using the ***prefilt*** program. The filter is implemented as a Finite Impulse Response (FIR) filter in the time-domain. The number of taps in the finite impulse response filter determines how closely the azimuth filter approximates an ideal response. The user specifies the desired decimation factor and the relative length of the FIR filter.

Since the Doppler centroid varies in the across-track direction, somewhat better results may be obtained by range compressing the entire data set followed by applying the azimuth bandpass filter and decimation rather than filtering prior to range compression. For decimation in azimuth any integer decimation factor can be used. The program ***prefilt*** performs this function on the range compressed data set.

Tip: for the range compressed data use a file name of the type *.rc

6.1. Range compression of ERS SAR, ENVISAT ASAR and PALSAR data

The program ***pre_rc*** prefilters (decimation, optional) and compresses in range complex IQ SAR raw data. The pre-filtering consists of applying a bandpass filter followed by subsampling. The program can be used for range compression of ERS data since ERS does not change gain along track or across track and does not need special processing. The Fuzzy Block Adaptive Quantizer (FBAQ) mode for ENVISAT ASAR makes it not necessary to change the gain along-track, so the same program can be used for range compression as ERS.

pre_rc allows Radio Frequency Interference (RFI) filtering. This is generally not required for C-Band sensors, but for PALSAR operating at L-Band it is recommended. The theoretical chirp spectrum is used as a model to detect RFI. Notch filtering is applied to those frequency channels where the ratio of the power spectrum relative to the nominal chirp spectrum exceeds a given threshold specified. As a greater fraction of the spectrum is notched out, the range sidelobes of bright targets increases.

6.2. Range compression of JERS-1 SAR data

The program ***pre_rc_JERS*** has been specifically designed for range compression of JERS-1 SAR raw data. This program is similar to ***pre_rc*** allowing in addition the compensation for along-track and across track variations in receiver gain as recorded in the echo-header raw data for each echo. The across track gain variation is called the sensitivity time control (STC) and compensates for increasing range, while the along track variations are related to the on-board automatic gain control (AGC) that adjusts the receiver gain for optimum SNR in the digitized samples.

RFI suppression uses the range spectra contained in the file *.psd (calculated using ***rspec_JERS***) to notch the range reference function spectrum, thereby suppressing narrow-band interference.

If computer memory is limited, process only a portion of the range swath using a smaller range FFT (4096), and set the range offset to process the desired sub-swath.

6.3. Range compression of RADARSAT-1 data

The program ***pre_rc_RSAT*** has been specifically designed for range compression of Stripmap mode RADARSAT-1 SAR raw data, since it must correct for changes in the receiver gain. This program is similar to ***pre_rc*** but also includes secondary range migration and correction of along-track receiver gain variations. Secondary range migration corrects for range defocusing that can occur as a result of relatively high-squint angles typical of RADARSAT-1 SAR data.

6.4. Range compression of SIR-C data

The program ***rc_real*** is specifically designed for range compression of offset video data such as SIR-C SAR data. This program takes the offset video data and shifts it to baseband during the matched filter operation. The matched filter is calculated from the parameters stored in the MSP SAR sensor parameter file and applied using FFT convolution.

6.5. Azimuth prefilter

To filter and decimate range compressed SAR data, use the program ***prefilt***. This may be done to obtain a survey image product suitable for quicklook images or interferograms. This program should not be used if the data have already been decimated by one of the range compression programs ***pre_rc***, ***pre_rc_JERS***, or ***pre_rc_RSAT***.

Tip: for the pre-filtered data use a file name of the type *.prc

7. Azimuth auto-focusing

For precise estimation of along-track velocity the program ***autof*** must be used. The along track velocity estimation is based on range compressed SAR data by SAR azimuth auto-focusing. The program calculates an improved estimate of the along-track velocity of the radar platform using cross correlation of images formed from different parts of the azimuth Doppler spectrum. In particular the program takes two parts of the azimuth spectrum and forms small images of the central region of the scene. If the along track velocity estimate is correct, then these two image sections will overlay after azimuth deskew. The measured offset of these two image patches are used to update the estimate of the along track velocity and thereby focus the image in azimuth. This program should be run several times in order to converge to an accurate estimate of the along track velocity and therefore achieve the best possible focus. Each time the program is run, it takes the previous estimate as a starting point. Generally, if the state vectors are reasonably accurate, the change in along track velocity away from the nominal value will be less than 10 meters/second for space-borne sensors. Autofocus requires that there be some image contrast in the test region or the correlation matching between sub-images will fail.

Tip: for the output text file with the correlation function use a file name of the type *.autof

8. Azimuth compression

For azimuth compression use the program ***az_proc***. This program uses the standard range/Doppler algorithm to perform azimuth compression of range compressed data. In addition it is possible to radiometrically calibrate the resulting SLC image.

Alternatively the program ***az_proc_dop2d*** can be used; this is a SAR range/Doppler azimuth compression processor with along-track Doppler centroid update. With respect to ***az_proc*** it has the added capability to track the azimuth Doppler centroid variations when a 2-D Doppler polynomial is stored in the processing parameter file. This 2-D Doppler polynomial is generated using the program ***doppler_2d***. This program is most useful for multi-frame RADARSAT-1 or JERS-1 data sets.

Tip: for the SLC image use a file name of the type *.slc.

The ***az_proc*** program also supports the radiometric calibration of the processed data. The output data is calibrated for the range spreading loss, antenna gain pattern and ground-range projection factor. Calibration factors are provided for a number of sensors and modes. These are available in the sensors_cal_MSP.dat text file in the $MSP_HOME/sensors directory. The antenna pattern is only important for radiometric calibration and has no effect on the interferometric phase or coherence.

9. Multi-looking

To detect and average incoherently (in space) the SLC produced by the azimuth processor, use the programs ***multi_SLC*** or ***multi_GRD_SLC***. In addition for RADARSAT-1 Standard Beam Stripmap mode a specific program is available, ***RSAT_lks***. This program generates multi-look intensity image from complex SAR SLC image in the azimuth frequency domain rather than the spatial domain.

All programs generate a multi-look intensity image from the SLC image and a new processing parameter file that contains the image size and resolution of the multi-look intensity image. For the programs working in the spatial domain a rectangular window is used to average the data. The user can specify the number of number of range and azimuth samples that are averaged on the command line. Each sample value is normalized by the total number of looks.

multi_SLC and ***RSAT_lks*** leave the image in the slant range geometry while ***multi_GRD_SLC*** projects the image into the ground range geometry that is a cylindrical fit to the earth curvature. The pixels then are square on the ground, and radar look angle dependent changes are removed from the images. Ground range images do not take into account terrain dependent variations in incidence angle and are only of marginal value in images with large terrain height variation. Geocoding of the images based upon a DEM or interferometrically derived height map is required in these regions.

Tip: when using ***multi_SLC*** or ***RSAT_lks*** it is recommended that the MLI image in slant range geometry be named *.mli whereas the corresponding MLI parameter file be named p*.mli.par. When using ***multi_GRD_SLC*** it is recommended that the MLI image in ground range geometry be named *.grd.

10. Tools for analysis of SLC data

10.1. Estimation of Azimuth spectrum / Doppler centroid

To estimate the Doppler centroid from SAR range compressed or SLC data, use the program ***azsp_SLC***. The result is the normalized Doppler spectrum energy as a function of the azimuth frequency. This program can be used with range compressed data prior to azimuth compression which is useful for processing of offset video SAR data to determine the shape of the azimuth spectrum.

10.2. Optimization of Doppler for interferometry

With the ***dop_interf*** program it is possible to optimize for interferometry the MSP Doppler function and processing bandwidth for a pair of images. This program averages the Doppler polynomials from two passes over the same scene to obtain a Doppler centroid for processing the two scenes that improves the correlation. If the Doppler centroid used for processing is within 100 Hz of the actual value there will not be any discernible loss of quality.

This program is particularly useful for processing data from ERS tandem pairs where the average of the ERS1 doppler centroids and ERS2 doppler centroids will differ by a few hundred Hz with respect to the individual values. The program ***dop_interf*** averages the Doppler centroids for only a pair of scenes and updates the MSP processing parameter files. Hence if working with a stack of ERS tandem images it is suggested to pick a value between these and process all the scenes to the same value. To set all images to the same Doppler centroid a text editor can be used. Here only the first term corresponding to the Doppler constant term needs to be edited. The same can be done for ENVISAT ASAR.

Using a common Doppler centroid has the advantage of improving the baseline modelling (See ISP User's Guide).

10.3. Point target response analysis

The program ***ptarg*** is a point target analysis tool for complex SLC SAR data. To estimate the approximate point target location the SLC can be displayed using the DISP program ***disSLC***.

10.4. Estimation of along-track velocity

The estimate of the effective velocity, and thus the focusing, can be improved with the program ***af***. This program requires the SLC image as obtained after range and azimuth compression, and calculates an estimate of the along-track velocity of the radar platform using cross correlation of images derived from different segments ("looks") of the azimuth Doppler spectrum. The program will update the effective velocity so that the original range compressed data can be reprocessed (azimuth compression). The focus of the newly formed SLC image can be checked by rerunning ***af***.

10.5. PALSAR burst synchronization

The synchronisation of PALSAR ScanSAR (Wide Beam) data is not guaranteed by JAXA, which does not enable the use of such data for interferometric purposes. The program ***PALSAR_burst_sync*** resamples two raw SAR datasets to match their synchronisation. The output consists of synchronized PALSAR images and corresponding MSP processing parameter files. For details, it is referred to the document on PALSAR ScanSAR processing, part of the DIFF&GEO module.

Processing examples

In this part a list of processing examples dealing with SAR processing of data from different sensors are presented.

It should be remarked that parameter values provided in the processing examples cannot be considered valid for all cases. It is possible that one or more values might have to be adapted to the specific case being processed. It is advised to look carefully at the messages printed on stdout when running each individual program. For assistance please get in contact with us (gamma@gamma-rs.ch).

Example A – ERS Processing

Example B – ENVISAR ASAR Processing

Example C – JERS-1 Processing

Example D – PALSAR Processing (single image – Fine Beam mode)

Example E – RADARSAT-1 Processing (single image – Fine Beam mode)

Example F – SIR-C Processing

Example G – Processing of multi-polarization raw data

A. ERS Processing

In this Section we illustrate how to process raw data acquired by the ERS-2 SAR to Single Look Complex format. The processing chain applies of course to ERS-1 SAR data as well. Processing consists of the following steps

- Processing setup
- Copy raw SAR data to disk
- Create the MSP processing parameter file
- Manipulation of orbits (optional)
- Conditioning of raw data
- Process the RAW data to SLC
  - Determine the Doppler ambiguity (optional)
  - Determine fractional Doppler centroid
  - Estimate the Doppler centroid across the swath
  - Estimate the range power spectrum (optional)
  - Range compression
  - Autofocus
  - Azimuth compression – SLC generation
  - SLC image detection and generation of multi-look intensity image

For the processing an ERS-2 SAR raw data set acquired over Flevoland, the Netherlands, on August 4, 1995, along orbit number 1508 is used. The data set is also contained on the DEMO CD-ROM. The DEMO CD-ROM contains in the scripts directory a generic purpose script for processing automatically this raw dataset to SLC. The script should be considered as an introduction to scripting and can be used for developing own scripts based on the user's particular needs. If the script is used for processing, it is strongly recommended to adapt it by selecting the programs actually needed for processing and by critically choosing the values of the parameters required by each individual program. For this purpose it is highly recommended to refer to the Reference Guide.

The script below is intended to process the ERS-2 scene as presented in Annex A. For more details on the processing steps, please refer to Annex A, to the specific Subsections dealing with the individual programs and the Reference Manual.

The script is available on the DEMO CD-ROM in the scripts directory under the name run_MSP_Flevoland. The list of commands in this script can be found in the file com_ISP_LasVegas.

The only inputs required are the directory in which processing should take place and the directory on the CD-ROM / DVD-ROM / hard disk containing the raw data. It is recommended to copy the script to the working directory.

All programs described in this example but *az_proc* (azimuth compression / calibration / generation of SLC) require less than 1 minute. The program *az_proc* takes about 10-15 minutes to generate the SLC.

A.1 Processing setup

First create a directory on the disk with the scene identifier. This can be the orbit number, the date of data acquisition, scene identifiers such as track and frame or any name other name you might want to select. In this example we use the orbit number:

```
mkdir 01508; cd 01508
```

For the processing of an entire ERS frame the disk should have a minimum of 1 GB free space to contain the raw data and processed image. There should also be 1 GB temporary space available for the range compressed data, preferably on another disk.

For processing the antenna pattern file and the MSP SAR sensor parameter file are needed. These can be found in the directory $MSP_HOME/sensors. Copy the appropriate raw data/sensor parameter file to this directory for processing the data

```
cp $MSP_HOME/MSP/sensors/ERS2_ESA.par .
```

where "." means the current directory. This file has been provided on the DEMO CD-ROM.

A.2. Copy raw SAR data to disk

Data are usually distributed on CD- or DVD-ROM and need to be copied to the working directory. In particular only the RAW data file and the SAR leader file are needed. Once copied, it is suggested to change names as suggested in Section 2. In this example the data stored on the DEMO CD-ROM needs to be copied to the working directory and then unzipped. With this operation the following files will be transferred: 01508.raw (after decompressing) and 01508.ldr, 01508 nvdf and 01508.vdf. These two last files are not needed during processing.

A.3. Create the MSP processing parameter file

For processing we need not only the MSP SAR sensor parameter file but also the MSP processing parameter file, which contains the parameters including state vectors, data timing, and image size and format. As processing by the MSP proceeds, new parameters will be introduced or updated. Depending on the processing facility that generated the raw data set, the appropriate program for the generation of the MSP processing parameter file must be selected (see Section 3.1.2.1 for details).

In this example we use the program ***ERS_proc_ESA*** and the command line looks as follows:

```
ERS_proc_ESA 01508.ldr p01508.slc.par
```

A.4. Conditioning of raw data

The time delay to the first sample of the ERS raw data varies along-track. Before processing the data all the range lines (echoes) have to have the same delay to prevent image shifts. Furthermore, there are often lines missing from the data set which is catastrophic in case the data shall be used for generation of interferograms. The loss of even a single line causes a shift that almost completely destroys the correlation between SLC images.

To condition the data use the program ***ERS_fix***. In our example the file 01508.fix is generated as follows:

```
ERS_fix ESA/ESRIN ERS2_ESA.par p01508.slc.par 1 01508.raw 01508.fix
```

Since there are no difference between the original raw data set and the fixed data set because there missing lines were not detected, the original data set can be used for processing.

A.5. Manipulation of orbits (optional but recommended)

Updating of the orbital state vectors in the MSP processing parameter file is required for correct geocoding and if the SLC will be used for interferometry.

If the DELFT precision orbital data records are preferred, the program ***DELFT_proc2*** must be used. In this example the command line looks as follows:

```
DELFT_proc2 p01508.slc.par ~/Delft/ers2/dgm-e04
```

It should be noticed that the ODR files with the DELFT orbits required for processing need to be stored on the computer. The program will generate 7 state vectors (default).

If instead the PRC precision orbits are preferred, the program ***PRC_proc*** must be used. The command line in this example looks as follows:

```
PRC_proc p01508.slc.par PRC_950803_01501_rev2 7
```

Also in this case the file containing the orbital information has to be available either in the working directory as in the example or in a directory on the computer. In this case the full path to the directory containing the file has to be provided. In this example the file was available in the working directory and we have chosen to generate 7 state vectors. The DEMO CD-ROM contains the Precision Orbits orbital information saved in the file PRC_950803_01501_rev2.

A.6. Process the RAW data to SLC

Full resolution processing can be done either by entering at the command line the single commands as described in the following subsections or by means of an ad hoc script which goes through all the processing steps in an automatic fashion.

For ERS data, the script ***ERS_PROC*** has been created. If the script is used the following information has to be entered:

- MSP SAR sensor parameter file name
- Scene identifier (e.g. acquisition date or orbit number)
- Desired number of range and azimuth looks

Before running this script, copy the ***ERS_PROC*** script into the same directory where you will process the data. In this way any modifications made to the script while processing the data are kept with the image file.

```
ERS_PROC <sensor> <scene> <RLK> <AZLK> [RAW_dir] [RC_dir] [SLC_dir] [AZ_PATCH]
```

sensor	ERS sensor parameter file
scene	scene identifier (e.g. orbit number or acquisition date)
RLK	number of range looks in the multilook intensity image (MLI)
AZLK	number of azimuth looks in the multilook intensity image (MLI)
RAW dir	SAR raw data file directory
RC dir	range compressed data file directory
SLC dir	single look complex image file directory
AZ PATCH	azimuth patch size: 2046, 4096, 8192 (default = 4096)
SLC_FORMAT	0=FCOMPLEX 1=SCOMPLEX (default=0)

```
ERS_PROC ERS2_ESA.par 01508 1 5 . /s1 . 4096 1
```

After processing, the p*.slc.par file (* = date or orbit) will contain the processing parameters of the Single Look Complex image produced by the processor, and the p*.mli.par file will contain the processing parameters of the multilook image that has been produced. The filename of the SLC image is *.slc, and the multilook intensity image is called *.mli. The complex file is in the form of 4 byte floating point numbers, one complex pair per image sample. The multilook file is proportional to the received image power (intensity) and is stored as 4-byte floating point numbers. Dimensions of the files (number of columns and number of rows) are written to the appropriate processing parameter files. ***ERS_PROC*** uses autofocus to refine the focusing parameters. The script performs the following actions, which we mentioned could be carried out individually instead of running the script.

A.6.1. Determine the Doppler ambiguity (optional)

To determine the Doppler ambiguity, use the program ***dop_ambig***. This is however not needed in this example since the data was acquired in the Northern Hemisphere. In this example the command line will look as follows:

```
dop_ambig ERS2_ESA.par p01508.slc.par 01508.raw 2 – dop_ambig.dat
```

In this example we use the MLCC algorithm. The output is stored in the dop_ambig.dat file that can be plotted with *xmgrace*.

A.6.2. Determine fractional Doppler centroid

To estimate the Doppler centroid the azimuth spectrum use the algorithm implemented in ***azsp_IQ***. In this example the command line will look as follows:

```
azsp_IQ ERS2_ESA.par p01508.slc.par 01508.raw 01508.azsp
```

The output text file containing the azimuth spectrum values as function of frequency, 01508.azsp, can be plotted using a program such as *xmgrace* (Figure A1):

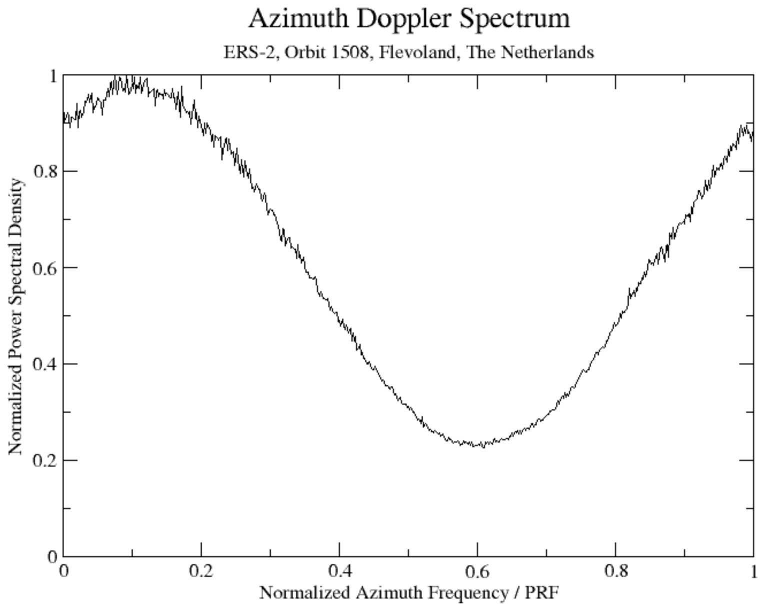

Figure A1. Azimuth spectrum as a function of normalized Doppler frequency.

A.6.3. Estimate the Doppler centroid across the swath

To determine the Doppler polynomial across the swath the program ***doppler*** can be used. This is however not necessary in this case because the platform yaw steering attempts to avoid large squint angles. In this example, the command line is as follows

```
doppler ERS2_ESA.par p01508.slc.par 01508.raw 01508.dop
```

The text file 01508.dop with the Doppler Centroid across the swath and the corresponding linear model is generated. This information can be plotted with *xmgrace* (Figure A2). As can be seen from Figure A2 the variation of the Doppler centroid across range is minimal.

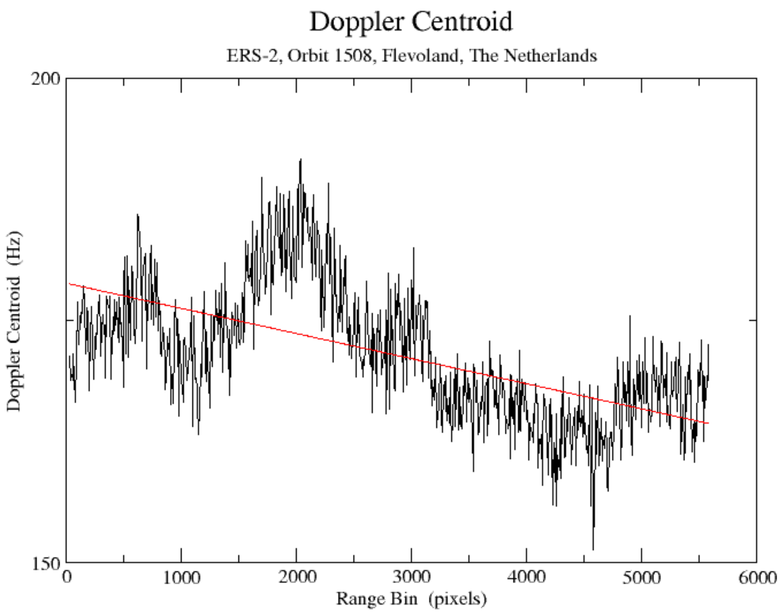

Figure A2. Doppler centroid across swath and linear fit (red line).

A.6.4. Estimate the range power spectrum (optional)

The range spectrum is determined to estimate the SNR in the final image. The region of the range power spectrum that is primarily noise is compared to the average power level over the chirp bandwidth. To estimate the range spectrum use the program ***rspec_IQ***. The resultant estimate of the image SNR is stored in the SNR_range_spectrum parameter of the processing parameter file.

In this example the command line looks as follows:

```
rspec_IQ ERS2_ESA.par p01508.slc.par 01508.raw 01508.rspec
```

The range spectrum is stored in the file 01508.rspec. It can be displayed with *xmgrace* (Figure A3).

A.6.5. Range compression

Range compression is performed with the program ***pre_rc***. In this example the command line is as follows:

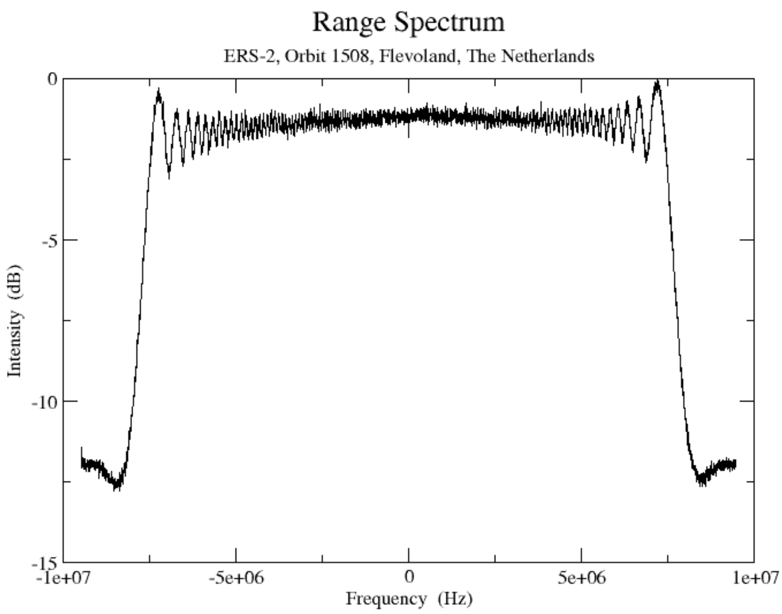

Figure A3. Range spectrum for FFT range size of 4096 pixels and 2048 lines.

```
pre_rc ERS2_ESA.par p01508.slc.par 01508.raw 01508.rc
```

In this example no decimation has been used. In case you want to decimate the data, for example to obtain a quick-look of the image, use any factor after the file name for the range compressed data.

The range compressed image can be displayed with the DISP program ***dismph***. In this example we consider the display of a subset starting at line 5000 and being 2000 lines long. The width of the range compressed image (4912) coincides with the width of the final SLC. The length of the image consists with the number of echoes being processed (13924). This information is contained in the p*.slc.par file.

```
dismph 01508.rc 4912 5000 2000 - - 0
```

A SUNraster/bmp version can be generated with the program ***rasmph***.

A.6.6. Autofocus

With the program ***autof*** focusing in azimuth is achieved. In this example the process is repeated, taking in the second run the estimate from the first run as a starting point.

In this example the command line looks as follows

```
autof ERS2_ESA.par p01508.slc.par 01508.rc 01508.autof 2.0

autof ERS2_ESA.par p01508.slc.par 01508.rc 01508.autof 2.0
```

The text file 01508.autof containing the correlation function in output can be plotted using a program such as *xmgrace* (Figure A4):

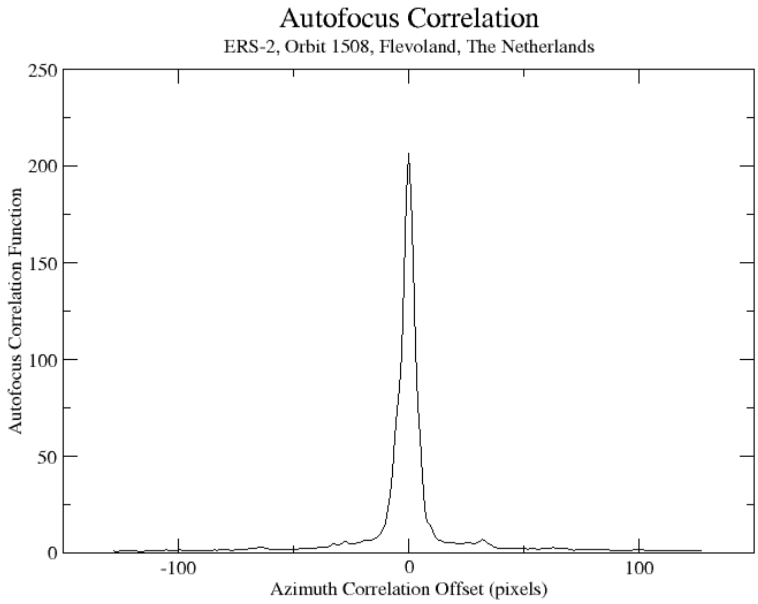

Figure A4. Correlation function as a function of azimuth sample number. The peak of the correlation function is at 0 azimuth offset which means that focus is good.

A.6.7. Azimuth compression

Azimuth compression is performed using the calibrated range/Doppler azimuth processor ***az_proc***. A processing block size of 4096 (default) is recommended for ERS. In this example the command line will look as follows

```
az_proc ERS2_ESA.par p01508.slc.par 01508.rc 01508.cslc 4096 0 -2.8 0 2.120
```

To calibrate the data the antenna pattern file is required. This has been provided in the DEMO CD-ROM (ERS2_antenna.gain). The calibrated SLC in output has FCOMPLEX format and the magnitude corresponds to sigma nought. The calibration constant is available in the $MSP_HOME/sensors/sensor_cal_MSP.data file. For no calibration use the value 0.

The user can also process the SLC to SCOMPLEX format, mostly to save space. In this case the command line would look as follows

```
az_proc ERS2_ESA.par p01508.slc.par 01508.rc 01508.cslc 4096 1 57.2 0 2.120
```

In this case it is better to scale the calibration factor scaled by 60 dB to compensate for the low values that otherwise would be obtained. Hence the factor to be used here is (-2.8 + 60) = 57.2. If no calibration shall be applied the value 60 shall be used.

For a calibrated SLC image it is might be worth considering using an extension *.cslc (instead of *.slc).

To display the (FCOMPLEX) SLC use the program *disSLC* as follows

```
disSLC 01508.cslc 4912 - - - - 0
```

The magnitude of the SLC image is in Figure A5. The different pixel sizes in range (~ 20 m on ground) and azimuth (~ 4 m) shall be noticed. This image has been generated using the ***rasSLC*** program in the DISP package.

```
rasSLC 01508.cslc 4912 - - - - - - - 0 – 01508.cslc.ras
```

A.6.8. SLC image detection and generation of multi-look intensity images

The multilook intensity image is produced with the ***multi_SLC*** program. Inputs are SLC processing parameter file p*.slc.par and the SLC image. Outputs are the multilook intensity image (MLI) and a new processing parameter file p*.mli.par. The image size, and resolution of the MLI image are described in the p*.mli.par processing parameter file. In the example the command line will look as follows:

```
multi_SLC p01508.slc.par p01508.mli.par 01508.cslc 01508.cmli 1 5
```

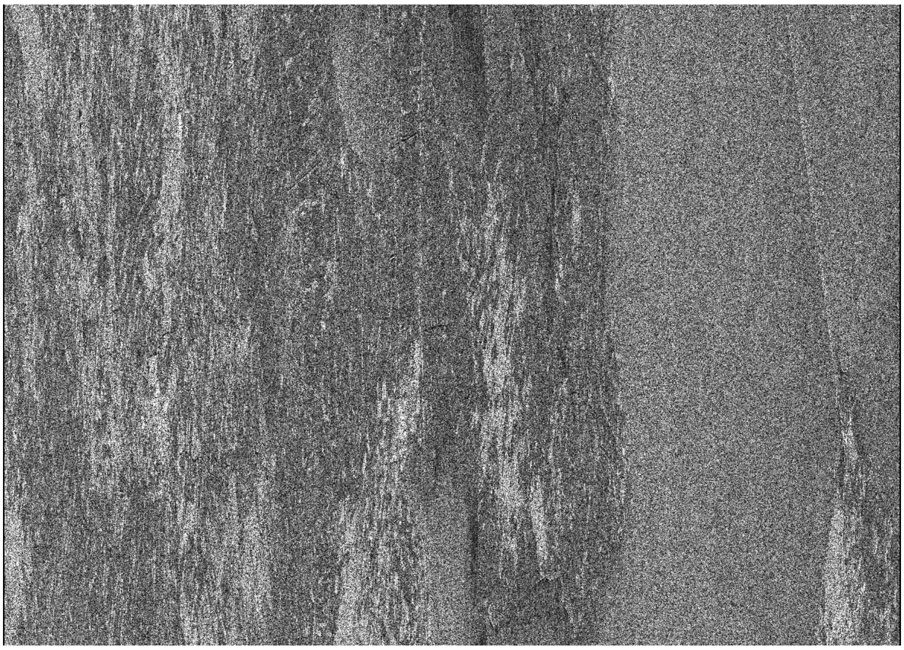

Figure A5. Magnitude of SLC image 01508.slc (size: 4912 pixels in range, 2918 in azimuth).

The multi-look image is in range-Doppler coordinates. A multi-look factor of 1 in range and 5 in azimuth has been applied to obtain squared pixels. The MLI can be displayed with the DISP program ***dispwr*** as follows

```
dispwr 01508.cmli 4912
```

Figure A6 illustrates the multi-look intensity image. Compared to the SLC in Figure A5, several targets are now clearly discernible (e.g. water on the right part of the image, several urban areas which appear very bright, and cultivated fields on the left part of the image). The image in SUNraster format has been generated using the ***raspwr*** program in the DISP package.

```
raspwr 01508.cmli 4912
```

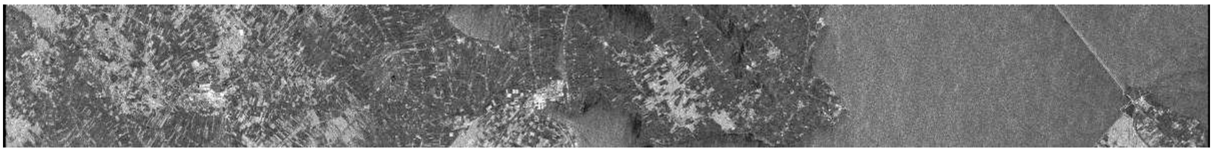

Figure A6. Multi-look intensity 01508.mli (size: 4912 pixels in range, 583 pixels in azimuth). The pixel size is 20x20 m.

The DEMO CD-ROM contains the multi-look image as obtained in this processing as well as the one obtained from ESA for comparison (01508.esa_cmli).

B. ENVISAT ASAR Processing

In this Section we illustrate how to process raw data acquired by the ENVISAT ASAR in Image Mode to Single Look Complex format. Processing consists of the following steps

- Processing setup
- Copy raw SAR data to disk and generation of antenna pattern
- Create the MSP SAR sensor and MSP processing parameter file
- Manipulation of orbits (optional)
- Process the RAW data to SLC
    - Determine the Doppler ambiguity (optional)
    - Determine fractional Doppler centroid
    - Estimate the Doppler centroid across the swath
    - Estimate the range power spectrum (optional)
    - Range compression
    - Autofocus
    - Azimuth compression – Generation of SLC
    - SLC image detection and generation of multi-look intensity image

For the processing an ENVISAT ASAR Image Mode IS2 raw data set acquired over Luxemburg on April 1, 2004 is used. The data set is contained on the <u>additional</u> DEMO CD-ROM.

All programs described in this example but *az_proc* (azimuth compression / calibration / generation of SLC) require less than 1 minute. The program *az_proc* takes about 10-15 minutes to generate the SLC.

B.1. Processing setup

To begin with the MSP processing of ASAR Level 0 Image Mode data create a directory on the disk with the scene identifier (orbit number, date or any other name you wish). In this example we use the date as scene identifier.

```
mkdir 20040401; cd 20040401
```

For the processing of an entire ENVISAT ASAR Image Mode frame the disk should have a minimum of 1 GB free space to contain the raw data and processed image. There should also be 1 GB temporary space available for the range compressed data, preferably on another disk.

B.2. Copy raw SAR data to disk and generation of antenna pattern

Data are usually distributed on CD- or DVD-ROM and need to be copied to the working directory. Copy the Level 0 data product from the support media to this directory. Level 0 files have names that begin with ASA_IM__0.... These files contain both raw data and meta data describing when the data were acquired and the imaging mode (IS1 - IS7). In this example we refer to the image file ASA_XCA_AXVIEC20050803_151945_20030804_000000_20040412_000000. For space reasons a subset of this file is provided on the additional DEMO CD-ROM. For details see Section B.3.

The set of 256 look up tables needed to generate decompressed samples and other ASAR calibration and system parameters are stored in the Instrument Characterization File (ASA_INS_AXVIEC...). These files must be downloaded from ESA and the correct file selected for the date that the data were acquired (see below).

Additionally the external characterization file (ASA_XCA...**)** is required to extract the antenna pattern as measured on the ground and is used to compensate for the antenna gain across the swath in the SAR processing. The program ***ASAR_XCA*** can be used to extract the antenna pattern for the specific scene as follows (IS2, VV polarization):

```
ASAR_XCA       ASA_XCA_AXVIEC20050803_151945_20030804_000000_20040412_000000
ASAR_IS2_VV_antenna.gain IS2 VV
```

From the ESA website both the INS files and the external characterization file (ASA_XCA...) can be downloaded http://envisat.esa.int/services/auxiliary_data/asar.

B.3. Create the MSP SAR sensor and Processing Parameter files

The MSP program ***ASAR_IM_proc*** reads the ASAR Level 0 data files and generates the MSP SAR sensor parameter file and the MSP processing parameter (p*.slc.par) along with reformatting the raw data. In this example the command line looks as follows

```
ASAR_IM_proc  ASA_IM__0CNPDE20040401_095711_000000152025_00337_10912_0829.N1
ASA_INS_AXVIEC20051219_161945_20030211_000000_20061231_000000
20040401.is2.par p20040401.slc.par 20040401.raw ASAR_IS2_VV_antenna.gain
```

The original image (*.N1), the characterization file ASA_INS…and the antenna pattern file ASAR_IS2_VV_antenna.gain are used to generate the MSP SAR sensor parameter file 20040401.is2.par, the MSP processing parameter file p20040401.slc.par and the range aligned raw data set 20040401.raw.

This command does not need to be run by the user when reproducing the processing. A subset of the data containing 5000 echoes already conditioned, with the corresponding parameter files, has been made available on the additional DEMO CD-ROM. In addition the antenna pattern file is also provided. For sake of simplicity the file names are 20040401.raw (in zipped format), 20040401.is2.par and p20040401.slc.par.

B.4. Manipulation of orbits (optional)

Updating of the orbital state vectors in the MSP processing parameter file is required for accurate geocoding and if the SLC will be used for interferometry.

If the DELFT precision orbital data records are preferred, use the program ***DELFT_proc2***. In this example the command line looks as follows:

```
DELFT_proc2 p20040401.slc.par ~/Delft/envisat/eigen-grace01s/
```

It should be noticed that the ODR files with the DELFT orbits required for processing need to be stored on the computer. The program will generate 7 state vectors (default)

If instead the DORIS orbits are preferred, the program ***DORIS_proc*** must be used. In this example the command line looks as follows:

```
DORIS_proc                    p20040401.slc.par                    DOR_VOR_AXVF-P20040514_152100_20040331_215528_20040402_002328
```

where the orbit file DOR_VOR_AXVF has been copied to the working directory before processing.

These orbit files have been provided on the additional DEMO CD-ROM.

B.5. Process the RAW data to SLC

B.5.1. Determine the Doppler ambiguity (optional)

This is not needed since the data was acquired in the Northern Hemisphere. However, to determine the Doppler ambiguity, use the programs ***dop_ambig*** or ***dop_mlcc***. This program in particular is recommended if the number of echoes to be processed exceeds 8192 echoes.

For this reason in this example we use ***dop_mlcc*** and the command line is:

```
dop_mlcc 20040401.is2.par p20040401.slc.par 20040401.raw 20040401.mlcc
```

The output 20040401.mlcc can be plotted with *xmgrace* (Figure B1).

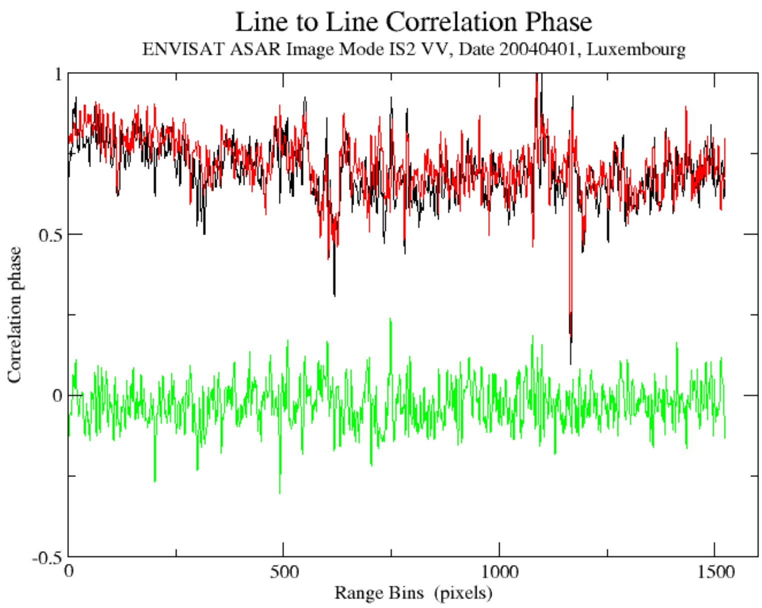

Figure B1. Correlation phase as a function of lines to process for the upper half of the spectrum (black) and the lower part of the spectrum (red). The difference is reported in green.

B.5.2. Determine fractional Doppler centroid

To estimate the Doppler centroid from the azimuth spectrum use the algorithm implemented in ***azsp_IQ***. In this example the command line will look as follows:

```
azsp_IQ 20040401.is2.par p20040401.slc.par 20040401.raw 20040401.azsp
```

The output text file containing the azimuth spectrum values as function of frequency, 01508.azsp, can be plotted using a program such as *xmgrace* (Figure B2).

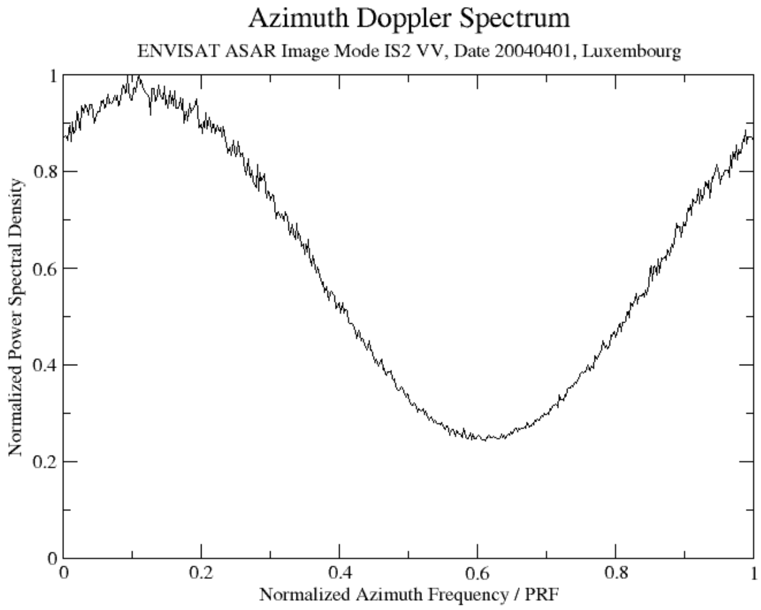

Figure B2. Azimuth spectrum as a function of normalized azimuth Doppler frequency.

B.5.3. Estimate the Doppler centroid across the swath

To determine the Doppler polynomial across the swath the program ***doppler*** can be used. This is however generally not necessary for ENVISAT ASAR because the platform yaw steering attempts to avoid large squint angles.

In this example, the command line looks as follows:

```
doppler 20040401.is2.par p20040401.slc.par 20040401.raw 20040401.dop
```

The text file 01508.dop with the Doppler Centroid across the swath and the corresponding linear model is generated. This information can be plotted with *xmgrace* (Figure B3).

B.5.4. Estimate the range power spectrum (optional)

The range spectrum is determined to estimate the SNR in the final image. The region of the range power spectrum that is primarily noise is compared to the average power level over the chirp bandwidth. To estimate the range spectrum use the program ***rspec_IQ***. The resultant estimate of the image SNR is stored in the SNR_range_spectrum parameter of the processing parameter file.

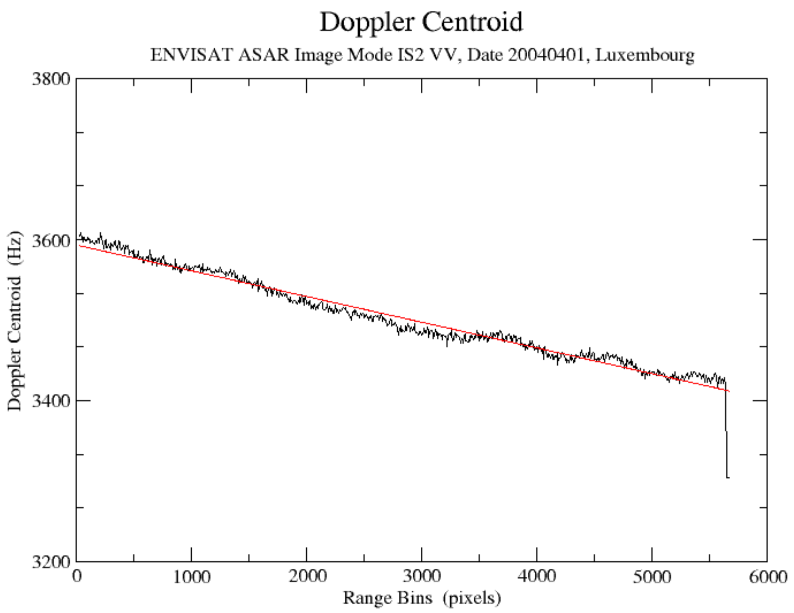

Figure B3. Doppler centroid across swath and linear fit (red line).

In this example the command line looks as follows:

```
rspec_IQ 20040401.is2.par p20040401.slc.par 20040401.raw 20040401.rspec
```

The range spectrum is stored in the file 01508.rspec. It can be displayed with *xmgrace* (Figure B4).

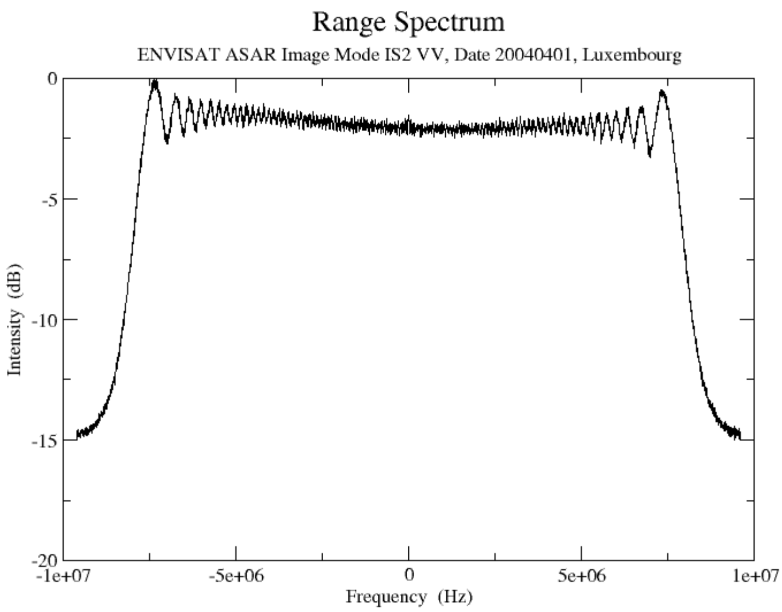

Figure B4. Range spectrum for FFT range size of 4096 pixels and 2048 lines.

B.5.5. Range compression

Range compression is performed with the program ***pre_rc***. In this example the command line looks as follows:

```
pre_rc 20040401.is2.par p20040401.slc.par 20040401.raw 20040401.rc
```

In this case decimation is not used. In case you want to decimate the data, for example to obtain a quick-look of the image, you can use any factor after the file name for the range compressed data.

The range compressed image can be displayed with the DISP program ***dismph***. In this example we consider the display of a subset starting at line 2000 and being 2000 lines long. The width of the range compressed image (5182) coincides with the width of the final SLC. The length of the image consists with the number of echoes being processed (4999). This information is contained in the p*.slc.par file.

```
dismph 20040401.rc 5182 2000 2000 - - 0
```

A SUNraster/bmp version can be generated with the DISP program ***rasmph***.

B.5.6. Autofocus

To focus the image in azimuth the autofocus program ***autof*** is run. The program is used twice to obtain a good estimate of the along-track velocity. In this example the command line looks as follows:

```
autof 20040401.is2.par p20040401.slc.par 20040401.rc 20040401.autof 5.0

autof 20040401.is2.par p20040401.slc.par 20040401.rc 20040401.autof 5.0
```

The correlation SNR is about 64 which means that the autofocus worked well. The text file 200400401.autof containing the correlation function in output can be plotted using a program such as *xmgrace* (Figure B5).

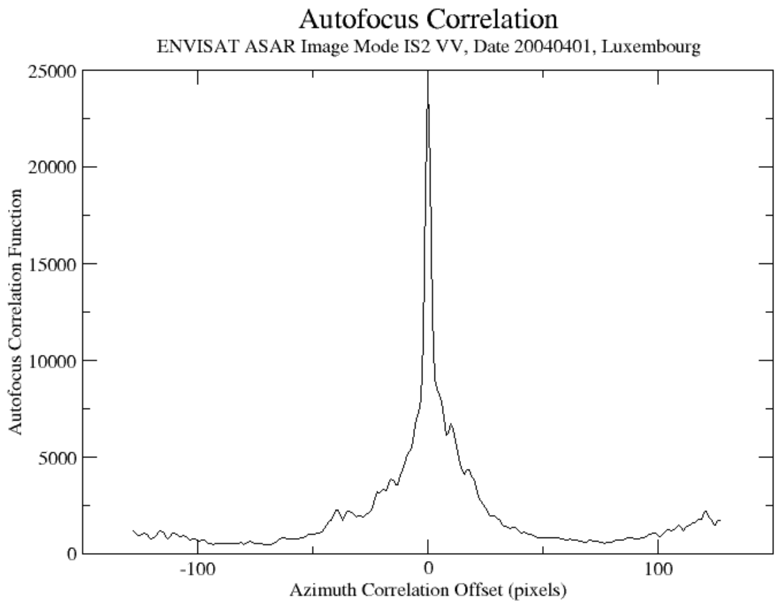

Figure B5. Correlation function as a function of azimuth sample number. The peak of the correlation function is at 0 azimuth offset which means that focus is good.

B.5.7. Azimuth compression

Azimuth compression is performed using the calibrated range/Doppler azimuth processor ***az_proc***. A processing block size of 4096 (default) is recommended for ENVISAT ASAR. In this example the command line will look as follows

```
az_proc 20040401.is2.par p20040401.slc.par 20040401.rc 20040401.slc 4096 0 -31.0 0 2.120
```

The output consists of the Single Look Complex image 20040401.slc with 5182 range pixels and 3934 lines. The SLC is in FCOMPLEX format. The image is calibrated according to the value in the sensor_cal_MSP.dat file in the MSP/sensors directory. For no calibration use the value 0.

If memory availability is an issue, the user can choose to process the SLC to SCOMPLEX format. In this case the command line would looks as follows

```
az_proc 20040401.is2.par p20040401.slc.par 20040401.rc 20040401.slc 4096 1 29.0 0 2.120
```

If we want to obtain the calibrated SLC image in SCOMPLEX format, it is better to scale the calibration factor in the sensor_cal_MSP.dat file by 60 dB to compensate for the low values that otherwise would be obtained. Hence the factor to be used here should be (-31 + 60) = 29. For no calibration use the value 60.

To display the SLC use the DISP program ***disSLC***. In this example the command line is given for a subset of 2000 lines starting at line 1000 and assuming the SLC is in FCOMPLEX format:

```
disSLC 20040401.slc 5182 1000 2000 - - 0
```

The magnitude of a subset of 2000 lines cut out from the SLC image is illustrated in Figure B6. This has been obtained using the DISP program ***rasSLC***. It can be noticed that the image appears "stretched" along the azimuth direction. This is because the azimuth pixel size is far smaller than the range pixel size (4 m against 8 m).

```
rasSLC 20040401.slc 5182 1000 2000 - - - - - 0 – sub_20040401.slc.bmp
```

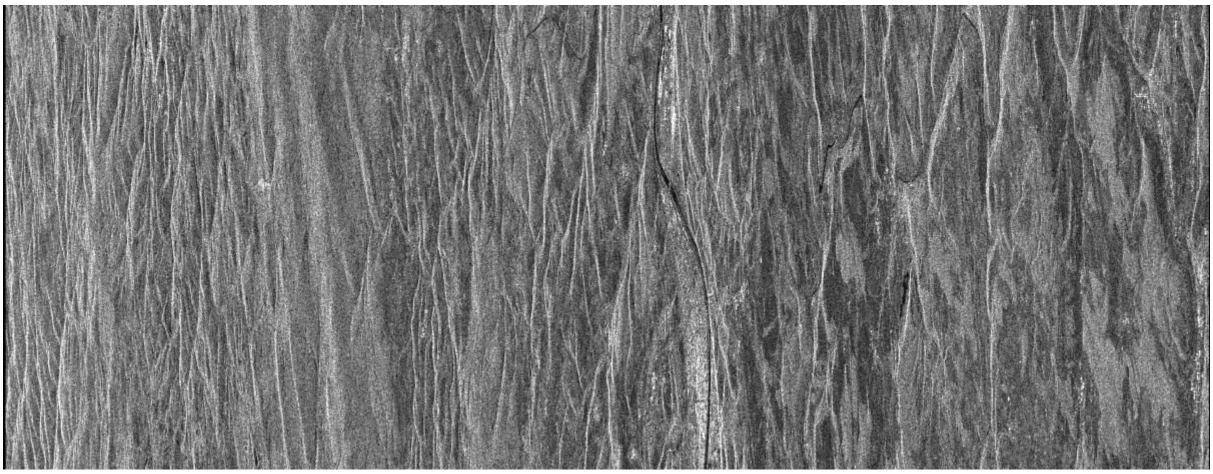

Figure B6. Magnitude of SLC image 20040401.slc (size: 5182 pixels in range, 2000 in azimuth).

B.5.8. SLC image detection and generation of multi-look intensity images

The multilook intensity image is produced with the ***multi_SLC*** program. Inputs are SLC processing parameter file *.slc.par and the SLC image. Outputs are the multilook intensity image (MLI) and a new processing parameter file p*.mli.par. The image size, and resolution of the MLI image are described in the p*.mli.par processing parameter file.

In the example the command line will look as follows, assuming the image is in FCOMPLEX format:

```
multi_SLC p20040401.slc.par p20040401.mli.par 20040401.slc 20040401.mli 2
10 0
```

For processing we considered that in the case of ENVISAT ASAR the range/azimuth ratio to obtain almost squared pixels is 1:5. For this reason we used as multi-look factors 2 and 10 respectively. The output MLI image consists of 2591 range samples and 393 azimuth samples. The multi-look image can be displayed with the DISP program ***dispwr:***

```
dispwr 20040401.mli 2591
```

or saved to SUNraster/bmp format as illustrated in Figure B7. This image has been generated with the DISP program ***raspwr*** as follows:

```
raspwr 20040401.mli 2591 - - - - - - - 20040401.mli.bmp
```

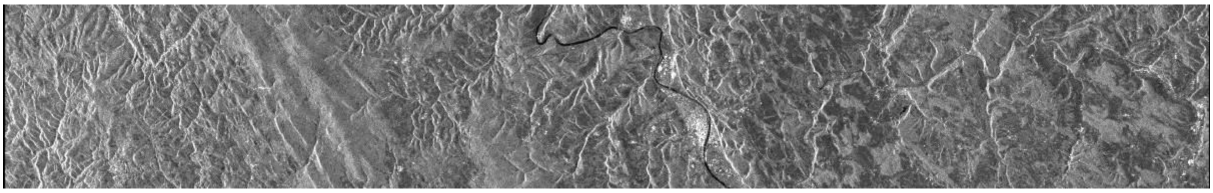

Figure B7. Multi-look intensity 01508.mli (size: 2591 pixels in range, 393 pixels in azimuth). The pixel size is 40x40 m.

C. JERS-1 Processing

In this Section we illustrate how to process raw data acquired by the JERS-1 SAR to Single Look Complex format. Processing consists of the following steps

- Processing setup
- Copy raw SAR data to disk
- Create the MSP processing parameter file
- Conditioning of raw data
- Process the RAW data to SLC
    - Determine the Doppler ambiguity
    - Estimate the Doppler centroid across range
    - Estimate the range power spectrum (optional)
    - Estimate the Radio Frequency Interference
    - Range compression
    - Autofocus
    - Azimuth compression
    - SLC image detection and generation of multi-look intensity image

For the processing a JERS-1 SAR raw data set acquired over the Italian Alps, Trentino Alto Adige region, Italy, on April 16, 1994 (940416) is considered. The data set is also contained on the additional DEMO CD-ROM.

All programs described in this example but *az_proc* (azimuth compression / calibration / generation of SLC) require less than 1 minute. The program *az_proc* takes about 10-15 minutes to generate the SLC.

C.1. Processing setup

JERS-1 SAR data may be specified in terms of the acquisition date; create this directory:

```
mkdir 940416; cd 940416
```

For the processing of an entire JERS-1 frame the disk should have a minimum of 1 GB free space to contain the raw data and processed image. There should also be 1 GB temporary space available for the range compressed data, preferably on another disk.

Copy the antenna pattern JERS1_antenna.gain from the MSP/sensors directory to this directory, where "." means the current directory.

```
cp $MSP_HOME/MSP/sensors/JERS1_antenna.gain .
```

Also copy the appropriate MSP SAR sensor parameter file to this directory for processing the data:

```
cp $MSP_HOME/MSP/sensors/JERS-1.par .
```

Both files are also available on the additional DEMO CD-ROM.

C.2. Copy raw SAR data to disk

Typically on a CD-ROM there is a directory SCENE001 which contains the following files:

VOLD.DAT	Volume Directory File
SARL_01.DAT	CEOS Leader file
SART_01.DAT	Trailer file
IMOP_01.DAT	The SAR data (not range aligned or checked for missing lines
NULL.DAT	Null file

Copy the IMOP_01.DAT file and SARL_01.DAT files from the CD-ROM to the new directory created in Step 1. Eventually rename the SARL_01.DAT file to <scene_name>.ldr and the IMOP_01.dat file to <scene_name>.raw. In this example the command line looks as follows:

```
mv (or cp) IMOP_01.DAT 940416.raw
```

```
mv (or cp) SARL_01.DAT 940416.ldr
```

The original full frame image data for this example is not contained on the additional DEMO CD-ROM for space reasons. The leader file is provided already in the *.ldr format for reference. In this example we use a subset of the original full frame, consisting of all range bins and 5000 echoes (approximately one third of the echoes in the original data file). The data set is called 940416.raw and has to be unzipped before processing.

C.3. Create the MSP processing parameter file

To create the MSP processing parameter file use the program ***JERS_proc***. The processing parameter filename has the file name p*.slc.par. Input to this program is the CEOS leader file supplied with the data.

```
JERS_proc 940416.ldr p940416.slc.par
```

In this example the MSP Processing parameter file is already provided on the additional DEMO CD-ROM, as obtained after extracting the portion of the image data from the original file.

C.4. Conditioning of raw data

For a JERS-1 image frame the time delay to the first range sample varies along track. This time delay can be determined from the raw data telemetry included with each echo. The program ***JERS_fix*** reads the raw data and CEOS leader and makes sure that all the echoes in the output aligned file start with the same starting range delay. This range delay is the delay to the first sample of the first echo of the raw data.

In this example the command line looks as follows:

```
JERS_fix JERS-1.par p940416.slc.par 940416.raw 940416.fix
```

C.5. Process the RAW data to SLC

Full resolution processing can be done either by entering at the command line the single commands as described in the following sub-sections or by means of an ad hoc script which encompasses all steps in an automatic fashion.

For JERS-1 data, the script **JERS_PROC** has been created. If the script is used the following information has to be entered:

- MSP SAR sensor parameter file name (JERS-1.par, nominally)
- Scene identifier (e.g. acquisition date or orbit number)
- Desired number of range and azimuth looks

Before running this script, copy the JERS_PROC script into the same directory where you will process the data. In this way any modifications made to the script while processing the data are kept with the image file.

Synopsis and example

```
JERS_PROC <sensor> <scene> <RLK> <AZLK> [RAW_dir] [RC_dir] [SLC_dir]
[AZ_PATCH]
```

sensor	JERS-1 sensor parameter file
scene	scene identifier (e.g. orbit number or acquisition date)
RLK	number of range looks in the multilook intensity image (MLI)
AZLK	number of azimuth looks in the multilook intensity image (MLI)
RAW dir	SAR raw data file directory
RC dir	range compressed data file directory
SLC dir	single look complex image file directory
AZ PATCH	azimuth patch size: 2046, 4096, 8192 (default = 4096)

```
JERS_PROC JERS-1.par 940416 2 6 . /s1 . 16384
```

After processing, the p*.slc.par file (* = date or orbit) will contain the processing parameters of the Single Look Complex image produced by the processor, and the p*.mli.par file will contain the processing parameters of the multilook image that has been produced. The filename of the SLC image is *.slc, and the multilook intensity image is called *.mli. The complex file is in the form of 4 byte floating point numbers, one complex pair per image sample. The multilook file is proportional to the received image power (intensity) and is stored as 4-byte floating point numbers. Dimensions of the files (number of columns and number of rows) are written to the appropriate processing parameter files. *JERS_PROC* uses autofocus to refine the focusing parameters.

C.5.1. Determine the Doppler ambiguity

JERS-1 usually has a significant amount of squint causing the Doppler centroid to be several times the Pulse Repetition Frequency (PRF) therefore the Doppler centroid is unambiguously determined at this stage. The ***dop_ambig*** and ***dop_mlcc*** programs try to resolve this ambiguity; both estimate the unambiguous Doppler centroid and the SNR value for the estimate in the processing parameter file. Due to memory constraints only 8192 echoes are processed using ***dop_ambig***. If the number of echoes is larger the program ***dop_mlcc*** shall be used.

In this example we use the *dop_mlcc* program since the data has almost 20000 echoes.

```
dop_mlcc JERS-1.par p940416.slc.par 940416.fix 940416.mlcc
```

Figure C1 illustrates the Doppler phase shift for the two range looks as a function of range and the difference between those phase values as a function of range pixel number. The plot has been obtained using a program such as *xmgrace* (Figure C1).

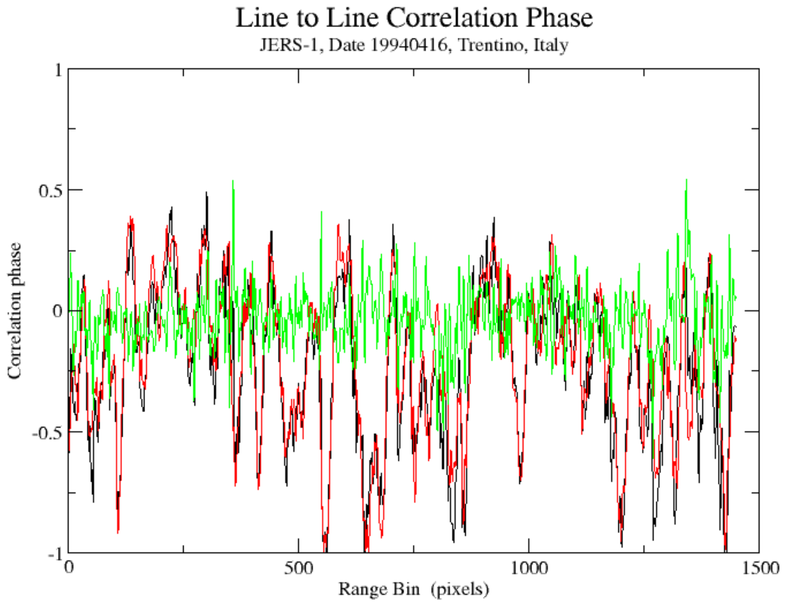

Figure C1. Correlation phase as a function of lines to process for the upper half of the spectrum (black) and the lower part of the spectrum (red). The difference is reported in green.

C.5.2. Estimate the Doppler centroid with cross-correlation algorithm

Since JERS-1 has a large amount of squint, this will cause the Doppler centroid to vary significantly across the swath. To determine the Doppler polynomial across the swath, the program ***doppler*** must be used. The program can use the values of the Doppler ambiguity generated by ***dop_ambig*** or ***dop_mlcc***.

In this example the command line looks as follows:

```
doppler JERS-1.par p940416.slc.par 940416.fix 940416.dop
```

At this command the Doppler polynomial across the swath will be computed. The result is saved in the text file 940416.dop.

The result, i.e. both the measured centroid as a function of range sample and the linear polynomial fit of the centroid data, can be plotted using a program such as *xmgrace* (Figure C2).

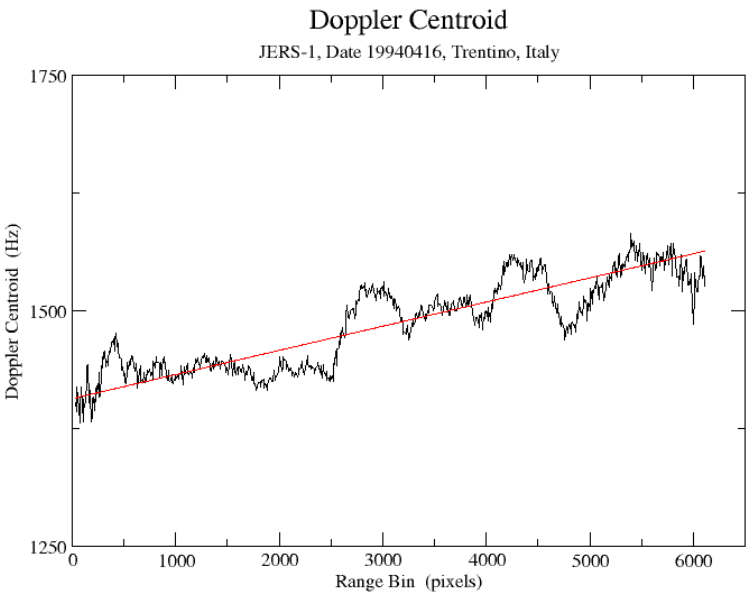

Figure C2. Doppler centroid across swath and linear fit (red line).

If you see in this kind of plot an abrupt and large variation of the Doppler centroid over several thousand Hertz, it means that the linear model of range dependent Doppler variation will lead to incorrect results if used. In such cases it is recommended to use a constant Doppler value. This is obtained by running the program ***azsp_IQ*** instead of ***doppler***. This value should represent the mean Doppler frequency for the part not affected by the abrupt change.

C.5.3. Estimate the range power spectrum (optional)

For JERS-1 data the estimation of the range power spectrum shows also possible interferences. With the ***rspec_IQ*** program it is possible to plot the range spectrum and have an idea concerning the effect of RFI on the spectrum of the SAR signal.

In this example the command line looks as follows

```
rspec_IQ JERS-1.par p940416.slc.par 940416.raw 940416.rspec
```

At this command the range spectrum is computed and the result is saved in the 940416.rspec file (text file). The range spectrum can be plotted with *xmgrace* as follows (Figure C3).

C.5.4. Estimate the Radio Frequency Interference

Since JERS-1 data can be affected by significant Radio Frequency Interference, it is necessary to estimate the Radio Frequency Interference (RFI) spectrum so that it may be suppressed during range compression. To estimate the spectrum the program ***rspec_JERS*** must be used. It averages the spectra of blocks of lines and obtains a good estimate of the signal+RFI spectrum. These spectra are used in ***pre_rc_JERS*** to modify the range chirp spectrum to suppress the RFI.

In this example the command line looks as follows:

```
rspec_JERS JERS-1.par p940416.slc.par 940416.fix 940416.psd
```

At this command the range spectra are estimated from the fixed raw data and the result is saved to the 940416.psd file (binary file).

Individual spectra can be extracted from the range spectra binary data file 940416.psd using the program ***extract_psd***. These plots are useful to evaluate the amount of interference present in the raw SAR data.

```
extract_psd 940416.psd 2 jers_rspec
```

This command will plot the frequency response of the raw data signal for the second block of 1024 echoes in the raw data. The output spectrum written by ***extract_psd*** is a table of ASCII numbers that can be plotted using a program such as *xmgrace (*Figure C4).

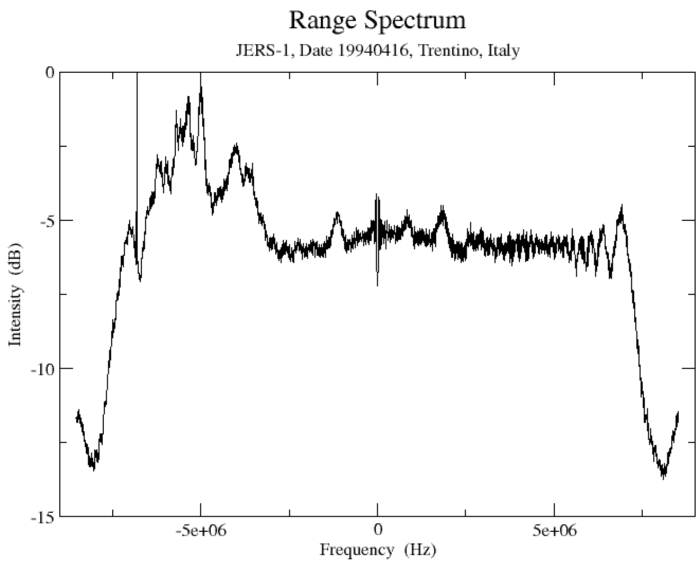

Figure C3. Range spectrum of the JERS-1 raw data set. Spikes due to RFI are evident.

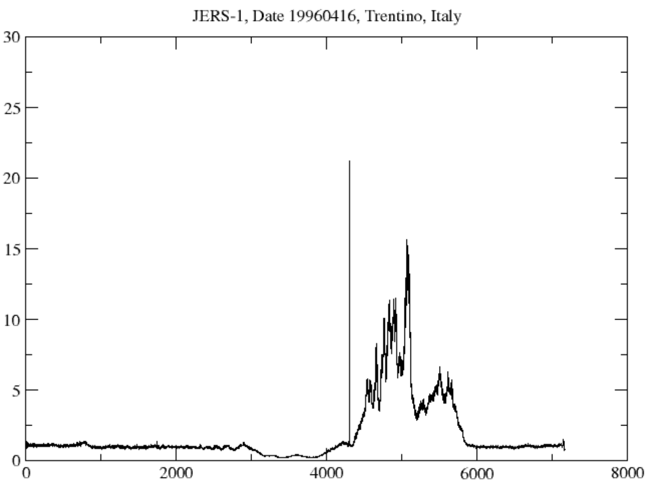

Figure C4. Range power spectrum for the JERS frame 940416.fix.

The program can be used again to analyze the spectrum after having range compressed the data (and filtered for Radio Frequency Interference). With *xmgrace* the frequency response of the notched chirp used to compress the raw data for the second block of 1024 echoes in the raw data can be plotted.

C.5.5. Range compression

Range compression for JERS-1 is performed using a program specifically designed for JERS-1 (***pre_rc_JERS***), since it must correct for changes in the sensor sensitivity time control (STC), receiver gain, and reject interference.

In this example the command line looks as follows:

```
pre_rc_JERS JERS-1.par p940416.slc.par 940416.psd 940416.fix 940416.rc
```

At this command the raw data in input are range compressed using the information stored in the *.psd file. In this program the RFI is also notched out. The output consists of the range-compressed data and the updated version of the MSP processing parameter file.

In this example no decimation is used. In case you want to decimate the data, for example to obtain a quick-look of the image, you can use any factor after the file name for the range compressed data.

The range compressed image can be displayed with the DISP program ***dismph***. In this example we consider the display of a subset starting at line 2000 and being 2000 lines long. The width of the range compressed image (5546) coincides with the width of the final SLC. The length of the image coincides with the number of echoes being processed (4999). This information is contained in the p*.slc.par file.

```
dismph 940416.rc 5546 2000 2000 - - 0
```

A SUNraster/bmp version can be generated with the DISP program ***rasmph***.

C.5.6. Autofocus

To focus the image in azimuth the autofocus program ***autof*** is run. The program is used twice to obtain a good estimate of the along-track velocity.

In this example the command line looks as follows:

```
autof JERS-1.par p940416.slc.par 940416.rc 940416.autof 5.0
```

```
autof JERS-1.par p940416.slc.par 940416.rc 940416.autof 5.0
```

As a result the correlation SNR is rather high (> 37) which means that the autofocus worked quite well. The text file 940416.autof containing the correlation function in output can be plotted using a program such as *xmgrace* (Figure C5).

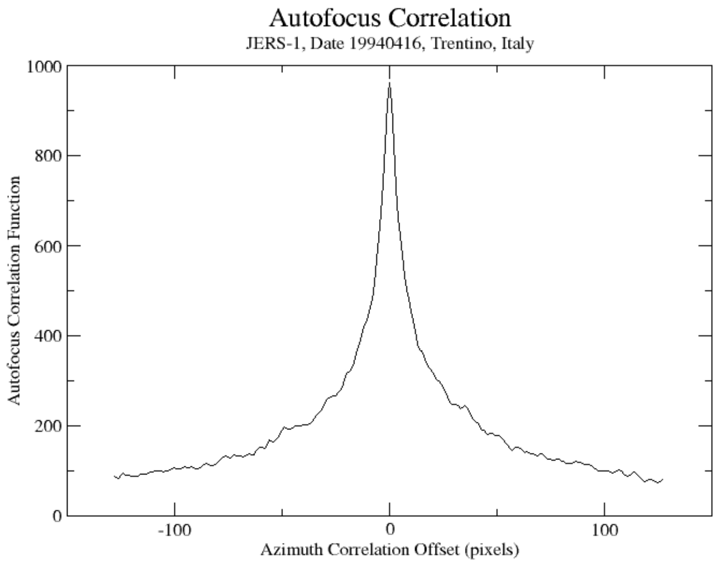

Figure C5. Correlation function as a function of azimuth sample number. The peak of the correlation function is at 0 azimuth offset which means that focus is good.

C.5.7. Azimuth compression

Azimuth compression is performed using the calibrated range/Doppler azimuth processor ***az_proc***. A processing block size of 8192 or 16384 is recommended for full resolution JERS-1 processing. A block size of 4096 will be inefficient unless the processing bandwidth is set to a small fraction (< .6) of the full Doppler spectrum width. In this example the command line looks as follows:

```
az_proc  JERS-1.par  p940416.slc.par  940416.rc  940416.slc  16384  0  -22.1  0
2.12
```

For the processing the antenna pattern file is required. This has been provided on the additional DEMO CD-ROM (JERS1_antenna.gain). The output consists of the SLC image 940416.slc with 5546 range pixels and 1167 lines.

The SLC has been processed to FCOMPLEX format and has been calibrated using the calibration factor provided in the sensor_cal_MSP.dat file in the MSP/sensors directory. For no calibration use the value 0.

If memory availability is an issue, the user can process the data to SCOMPLEX format by setting the corresponding parameter at the command line (1 instead of 0 after the azimuth patch size 16384) and upscaling by 60 dB the calibration factor to avoid that very low intensity values are not represented:

```
az_proc JERS-1.par p940416.slc.par 940416.rc 940416.slc 16384 1 37.9 0 2.12
```

To obtain an uncalibrated image use 60 instead of 37.9.

To display the SLC use the DISP program ***disSLC***. In this example the command line for FCOMPLEX data is given for a subset of 2000 lines starting at line 1000:

```
disSLC 940416.slc 5546 1000 2000 - - 0
```

The amplitude of the SLC can be saved to file with the DISP program ***rasSLC***. This image is illustrated in Figure C6. It can be noticed that the image appears “stretched” along the azimuth direction. This is because the azimuth pixel size is far smaller than the range pixel size

```
rasSLC 940416.slc 5546 - - - - - - - - 0 – 940416.slc.bmp
```

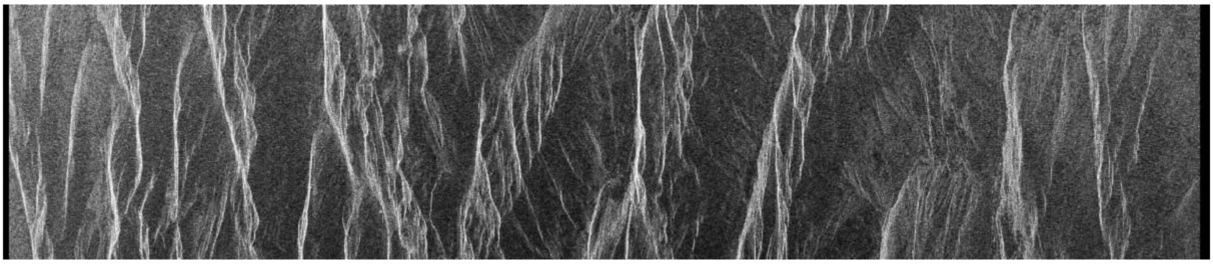

Figure C6. Magnitude of SLC image 940416..slc (size: 5546 pixels in range, 1167 in azimuth).

C.5.8. SLC image detection and generation of multi-look intensity image

The multilook intensity image is produced with the *multi_SLC* program. Inputs are SLC processing parameter file p*slc.par and the SLC image. Outputs are the multilook intensity image (MLI) and a new processing parameter file p*.mli.par. The image size, and resolution of the MLI image are described in the p*.mli.par processing parameter file. In the example the command line looks as follows

```
multi_SLC p940416.slc.par p940416.mli.par 940416.slc 940416.mli 2 6 0
```

For processing we considered that in the case of JERS-1 the range/azimuth ratio to obtain almost squared pixels is 1:3. For this reason we used as multi-look factors 2 and 6 respectively. The output MLI image consists of 2773 range samples and 194 azimuth samples.

The multi-look image can be displayed with the DISP program ***dispwr*** as follows:

```
dispwr 940416.mli 2773
```

To save the multi-look image to SUNraster or bmp format, use the DISP program ***raspwr*** as follows. The image obtained is illustrated in Figure A7.

```
raspwr 940416.mli 2773 - - - - - - - 940416.mli.bmp
```

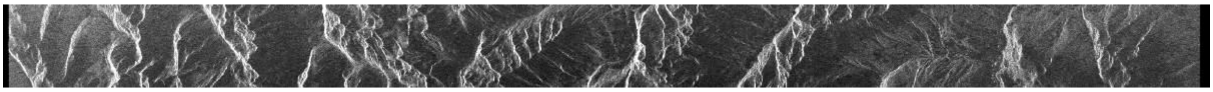

Figure A7. Multi-look intensity 940416.mli (size: 2773 pixels in range, 194 pixels in azimuth). The pixel size is 60x60 m.

D. PALSAR Processing (single image)

In this Section we illustrate how to process raw data acquired by PALSAR to Single Look Complex format. The data used is a test data set provided by JAXA (© JAXA/METI). Processing consists of the following steps

- Processing setup
- Copy raw SAR data to disk
- Create the MSP SAR sensor and Processing parameter files
- Process the RAW data to SLC
    - Determine the Doppler ambiguity
    - Estimate the Doppler centroid across range
    - Estimate the range power spectrum (optional)
    - Estimate the Radio Frequency Interference
    - Range compression
    - Autofocus
    - Azimuth compression
    - SLC image detection and generation of multi-look intensity image

For the processing a single-pol (HH) PALSAR raw data set acquired over the city of Kyoto, Japan on March 21, 2006 (20060321) is considered. The data set is also contained on the additional DEMO CD-ROM.

All programs described in this example but *az_proc* (azimuth compression / calibration / generation of SLC) require less than 1 minute. The program *az_proc* takes about 10-15 minutes to generate the SLC.

D.1. Processing setup

PALSAR data may be specified in terms of the acquisition date; create this directory:

```
mkdir 20060321; cd 20060321
```

For the processing of an entire PALSAR frame the disk should have a minimum of 2 GB free space to contain the raw data and processed image. There should also be at least 3 GB temporary space available for the range compressed data, preferably on another disk.

The MSP SAR sensor parameter file is generated together with the MSP processing parameter file (see Section D.3).

D.2. Copy raw SAR data to disk

Data may be downloaded over the web or available from DVD. Each scene will have a set of CEOS format files associated with it.

For processing, only the CEOS SAR leader file and raw image data are required. Copy the two files to the new directory created in Step 1. Eventually rename the files to <scene_name>.ldr and <scene_name>.raw.

VOL*.*	Volume Directory File
LED*.*	CEOS SAR Leader file
TRL*.*	Trailer file
IMG*.*	The SAR data (not range aligned or checked for missing lines

In this example the name of the files contains the orbit number and frame number (the orbit is 824 and the frame number is 690). The command line looks as follows:

```
mv (or cp) IMG-HH-ALPSRP008240690-H1.0__A 20060321.raw

mv (or cp) LED-ALPSRP008240690-H1.0__A 20060321.ldr
```

On the additional DEMO CD-ROM these two files are not provided for space reasons. See Section D.3 for the data set used in this example.

D.3. Create the MSP processing parameter file and generation of the antenna pattern

Use the program ***PALSAR_proc*** for generating the MSP SAR sensor and processing parameter files for the raw PALSAR data. Input to this program is the CEOS leader file supplied with the data. The output is the MSP SAR sensor parameter file (PALSAR.par) and the MSP processing parameter file (p*.slc.par). If there are changes in the range gate (slant range to the first sample), the output raw data file will be padded to accommodate the extra width. The number of samples/record of the output data file will be different than the input data file because the right fill pixels are removed.

In this example the command line looks as follows:

```
PALSAR_proc LED-ALPSRP008240690-H1.0__A PALSAR.par p20060321.slc.par IMG-HH-ALPSRP008240690-H1.0__A 20060321.raw
```

The full frame raw data set is too big for demo purposes. For this reason a subset consisting of 12000 echoes (out of the 35000 echoes available) has been made available (20060321.raw). The number of echoes has been determined considering that the azimuth reference function used for autofocusing is about 11000 pixel large, therefore more echoes than this value are needed for processing.

The subset is available on the additional DEMO CD-ROM and will be used throughout the rest of the example. On the CD-ROM you can also find the corresponding MSP Processing parameter file (p20060321.slc.par) and the MSP Sensor parameter file (PALSAR.par).

Correction for the antenna pattern is supported with the program ***PALSAR_antpat***. The antenna pattern for all modes as provided by JAXA is read in and the antenna pattern for processing with the MSP the specific image is automatically extracted. At the same time the MSP SAR sensor file is updated. The original file provided by JAXA (palsar_ant_20061024.dat) is provided with the DEMO.

In this example the generation of the antenna pattern file is as follows:

```
PALSAR_antpat PALSAR.par p20060321.slc.par palsar_ant_20061024.dat PALSAR_antpat_MSP.dat
```

D.4. Process the RAW data to SLC

Full resolution processing can be done by entering at the command line the single commands as described in the following sub-sections.

D.4.1. Determine the Doppler ambiguity

PALSAR usually has a significant amount of squint causing the Doppler centroid to be several times the Pulse Repetition Frequency (PRF) therefore the Doppler centroid is unambiguously determined at this stage. The ***dop_ambig*** and ***dop_mlcc*** programs try to resolve this ambiguity; both estimate the unambiguous Doppler centroid and the SNR value for the estimate in the MSP processing parameter file. Due to memory constraints only 8192 echoes are processed using ***dop_ambig***. Alternate the program ***dop_mlcc*** can be used apply the MLCC algorithm to the entire raw data file.

In this example we use the ***dop_mlcc*** program since the raw data file contains more than 10000 echoes.

```
dop_mlcc PALSAR.par p20060321.slc.par 20060321.raw 20060321.mlcc
```

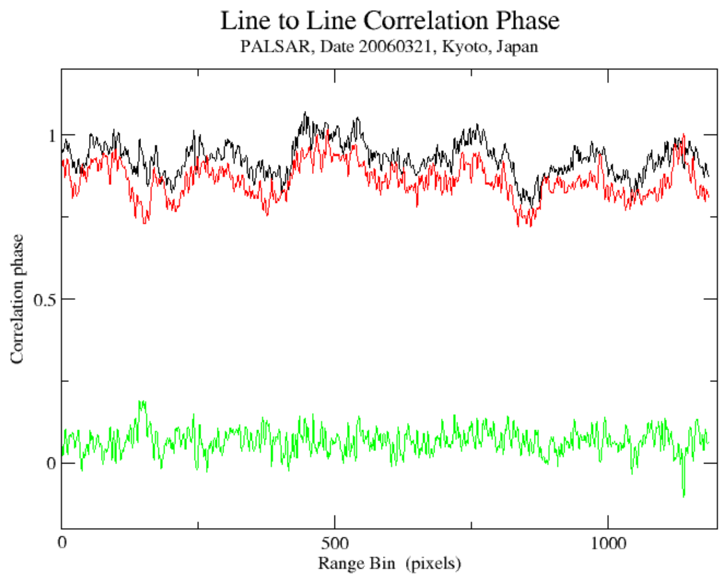

Figure D1. Correlation phase as a function of lines to process for the upper half of the spectrum (black) and the lower part of the spectrum (red). The difference is reported in green.

Figure D1 illustrates the Doppler phase shift for the two range looks as a function of range and the difference between those phase values as a function of range pixel number. The plot can be obtained using a program such as *xmgrace* (Figure D1)

D.4.2. Estimate the Doppler centroid with cross-correlation algorithm

Since ALOS has a large amount of squint, this will cause the Doppler centroid to vary significantly across the swath. To determine the Doppler polynomial across the swath because of the large amount of squint present in PALSAR data, the program ***doppler*** must be used. The program can use the values of the Doppler ambiguity generated by ***dop_ambig*** or ***dop_mlcc***.

In this example the command line looks as follows:

```
doppler PALSAR.par p20060321.slc.par 20060321.raw 20060321.dop
```

At this command the Doppler polynomial across the swath will be computed. The result is saved in the text file 20060321.dop. The result, i.e. both the measured centroid as a function of range sample and the linear polynomial fit of the centroid data, can be plotted using a program such as *xmgrace* (Figure D2):

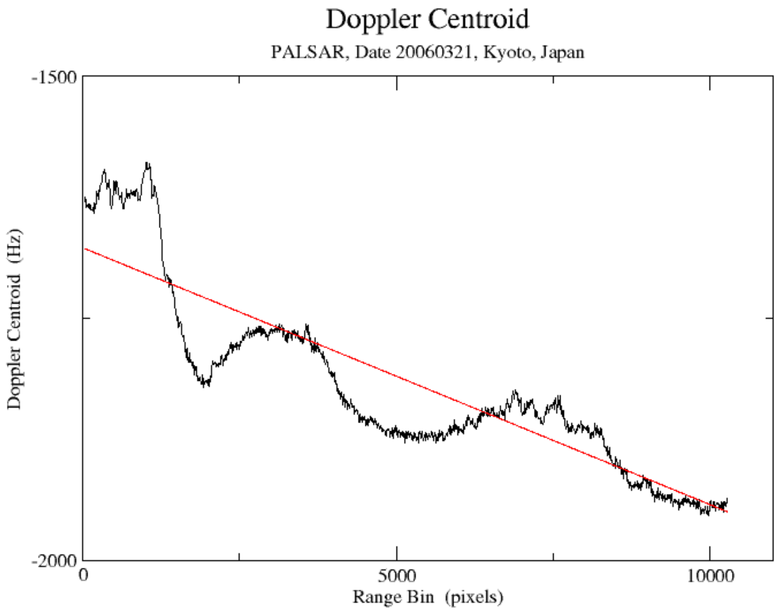

Figure D2. Doppler centroid across swath and linear fit (red line).

It is possible for PALSAR data that this type of plot shows an abrupt and large variation of the Doppler centroid over several thousand Hertz. In this case the linear model of range dependent Doppler variation will lead to incorrect results if used. In such cases it is recommended to set the Doppler polynomial to a constant value. The constant value can be obtained with the program ***azsp_IQ***, which should therefore be preferred to ***doppler***. This value should represent the mean Doppler frequency for the part not affected by the abrupt change.

D.4.3. Estimate the range power spectrum (optional)

For PALSAR data the estimation of the range power spectrum shows also possible interferences. With the ***rspec_IQ*** program it is possible to plot the range spectrum and have an idea concerning the effect of Radio Frequency Interference on the spectrum of the SAR signal.

In this example the command line looks as follows

```
rspec_IQ PALSAR.par p20060321.slc.par 20060321.raw 20060321.rspec
```

At this command the range spectrum is computed and the result is saved in the 20060321.rpsec file (text file). The range spectrum can be plotted with a program such as *xmgrace* (Figure D3):

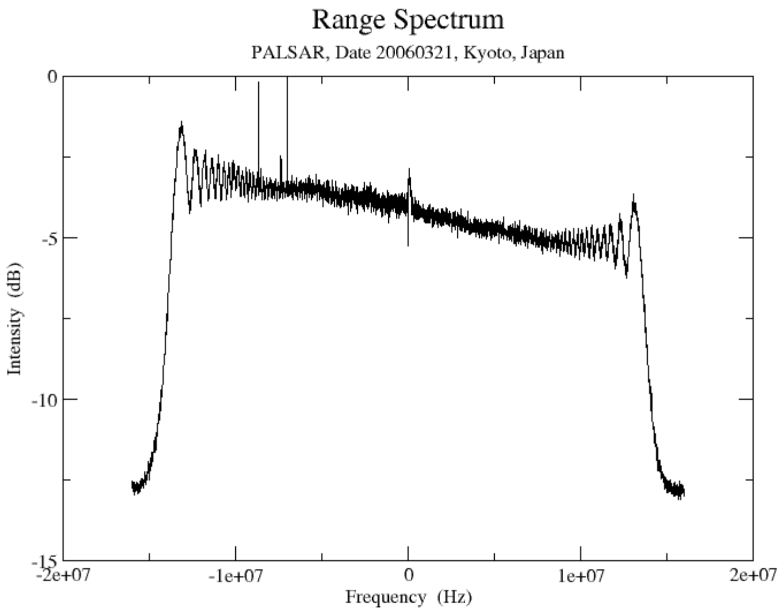

Figure D3. Range spectrum. Spikes due to interference are clearly visible.

D.4.4. Range compression

Range compression for PALSAR is performed using the program ***pre_rc***. Suppression of RFI is supported.

In this example the command line looks as follows:

```
pre_rc PALSAR.par p20060321.slc.par 20060321.raw 20060321.rc - - - - - - - -
- 1 -
```

In this example no decimation is used. In case you want to decimate the data, for example to obtain a quick-look of the image, you can use any factor after the file name for the range compressed data.

The range compressed image can be displayed with the DISP program ***dismph***. In this example we consider the display of a subset starting at line 2000 and being 2000 lines long. The width of the range compressed image (9440) coincides with the width of the final SLC. The length of the image coincides with the number of echoes being processed (11999). This information is contained in the p*.slc.par file.

```
dismph 20060321.rc 9440 2000 2000 - - 0
```

A SUNraster/bmp version can be generated with the DISP program ***rasmph***.

D.4.5. Autofocus

To focus the image in azimuth the autofocus program ***autof*** is run. The program is used twice to obtain a good estimate of the along-track velocity.

In this example the command line looks as follows:

```
autof PALSAR.par p20060321.slc.par 20060321.rc 20060321.autof 5.0
```


```
autof PALSAR.par p20060321.slc.par 20060321.rc 20060321.autof 5.0
```


The correlation SNR is rather high (51) which means that the autofocusing worked well. The text file 20060321.autof containing the correlation function in output can be plotted using a program such as *xmgrace* (Figure D4).

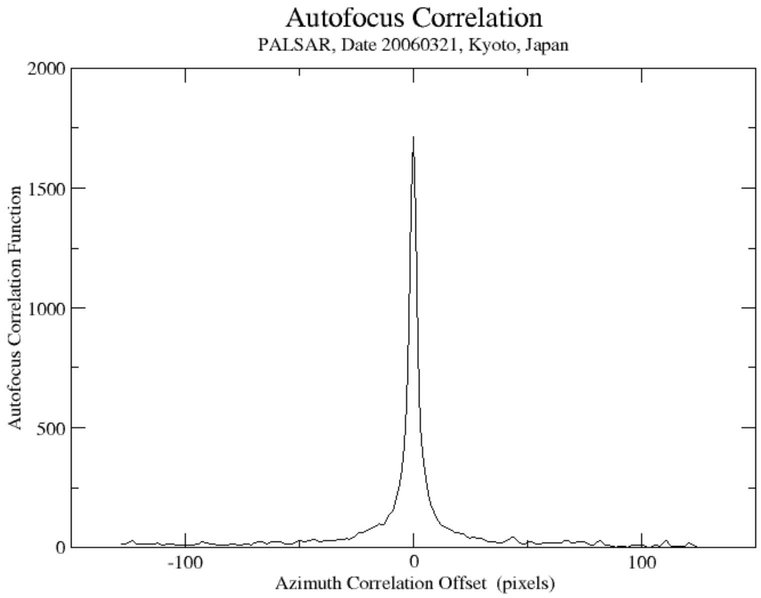

Figure D4. Correlation function as a function of azimuth sample number. The peak of the correlation function is at 0 azimuth offset which means that focus is good.

D.4.6. Azimuth compression

Azimuth compression is performed using the calibrated range/Doppler azimuth processor ***az_proc***. A processing block size of 8192 or 16384 is recommended for full resolution PALSAR processing. A block size of 4096 will be inefficient unless the processing bandwidth is set to a small fraction (< .6) of the full Doppler spectrum width.

The command line for ***az_proc*** is as follows

```
az_proc PALSAR.par p20060321.slc.par 20060321.rc 20060321.slc 16384 0 -49.8
0 2.12
```

The output consists of the Single Look Complex image 20060321.slc in FCOMPLEX format with 9440 range pixels and 4572 lines. The image has been calibrated using the absolute calibration constant (-49.8 dB) as available in the sensor_cal_MSP.dat file in the MSP/sensors directory. For no calibration use the value 0.

If memory availability is an issue, output in SCOMPLEX can be chosen. In this case the command line looks as follows:

```
az_proc PALSAR.par p20060321.slc.par 20060321.rc 20060321.slc 16384 1 10.2
0 2.12
```

In this example the calibration factor corresponds to an upscaling by 60 dB of the calibration coefficient -49.8 dB found in the file sensor_cal_MSP.dat located in the MSP/sensors directory. For no calibration use a factor 60.

To display the SLC use the DISP program ***disSLC***. In this example the command line is given for the FCOMPLEX image for a subset of 2000 lines starting at line 1000:

```
disSLC 20060321.slc 9440 1000 2000 - - 0
```

A subset consisting of 2000 lines is illustrated in Figure D5. This has been obtained using the DISP program ***rasSLC***. The image appears “stretched” along the azimuth direction. This is because the azimuth pixel size (3.1 m) is smaller than the range pixel size. This is 4.7 m in slant range, which corresponds to 7.5 m in ground range because the incidence angle at mid-swath is 38.7 degrees.

```
rasSLC 20060321.slc 9440 1000 2000 - - - - - 0 – sub_20060321.slc.bmp
```

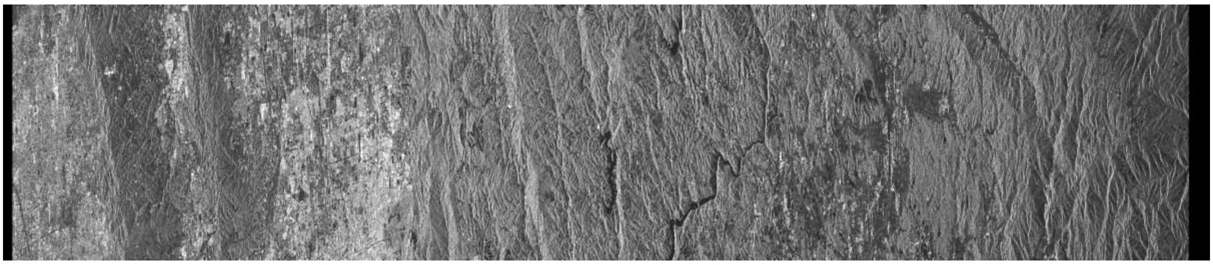

Figure D5. Magnitude of SLC subset image 20060321.slc (2000 lines, 9440 range samples)

D.4.7. SLC image detection and generation of multi-look intensity image

The multilook intensity image is produced with the ***multi_SLC*** program. Inputs are SLC processing parameter file p*slc.par and the SLC image. Outputs are the multilook intensity image (MLI) and a new processing parameter file p*.mli.par. The image size, and resolution of the MLI image are described in the p*.mli.par processing parameter file.

In the example the command line for the FCOMPLEX data looks as follows

```
multi_SLC p20060321.slc.par p20060321.mli.par 20060321.slc 20060321.mli 2 4
0
```

For processing we considered that in the case of PALSAR the range/azimuth ratio pixel size is about 2. For this reason we used as multi-look factor of 2 in range and 4 in azimuth to obtain squared pixels approximately 15 m wide and long. The output MLI image consists of 4720 range samples and 1143 azimuth samples.

To display the multi-look image use the DISP program ***dispwr*** as follows:

```
dispwr 20060321.mli 4720
```

The full multi-look image is illustrated in Figure D6. The image has been generated with the DISP program ***raspwr*** as follows:

```
raspwr 20060321.mli 4720 - - - - - - - 20060321.mli.bmp
```

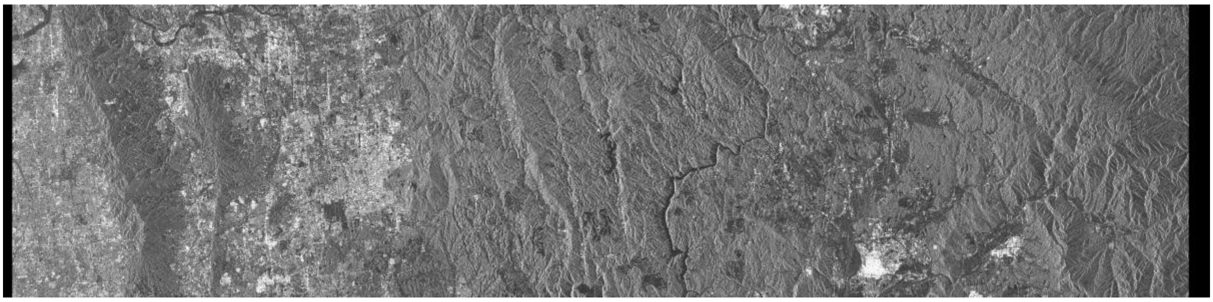

Figure D6. Multi-look intensity 20060321.mli (size: 4720 pixels in range, 1143 pixels in azimuth). The pixel size is approximately 15 m x15 m.

E. RADARSAT-1 Processing

In this Section we illustrate how to process raw data acquired by the RADARSAT-1 SAR Fine Beam 1 to Single Look Complex format. Processing consists of the following steps

- Processing setup
- Copy raw SAR data to disk
- Create the MSP parameter files and data conditioning
- Process the RAW data to SLC
    - Determine the Doppler ambiguity
    - Estimate the Doppler centroid across range
    - Estimate the range power spectrum (optional)
    - Range compression
    - Autofocus
    - Azimuth compression
    - SLC image detection and generation of multi-look intensity image

For the processing a RADARSAT-1 SAR raw data set acquired over the Belridge Oil Field, California, on November 11, 2002 (20021111) is considered. The data set is also contained on the additional DEMO CD-ROM.

All programs described in this example but *az_proc* (azimuth compression / calibration / generation of SLC) require less than 1 minute. The program *az_proc* takes about 10-15 minutes to generate the SLC.

E.1. Processing setup

RADARSAT-1 raw data is usually delivered on CD-ROM, which contains the SAR raw data in the SCENE001 directory. Processing of the data proceeds by first creating a directory where you want to process the data. Make sure that there is sufficient free space for processing the data. A full scene requires approximately 500 MB for the raw data, 500 MB for the fixed data, and about 800 MB for the processed image. There should also be at least 2 GB temporary space available for the range compressed data, preferably on another disk. RADARSAT-1 scene may be specified in terms of the acquisition date, create a directory for the SAR data processing:

```
mkdir 20021111; cd 20021111
```

Copy the antenna pattern RSAT_F1_antenna.gain from the MSP/sensors directory to this directory, where "." means the current directory.

```
cp $MSP_HOME/MSP/sensors/RSAT_F1_antenna.gain .
```

This file is also made available on the additional DEMO CD-ROM.

The MSP SAR sensor parameter file is generated together with the MSP processing parameter file because of the many different operation modes of RADARSAT-1 (see Section E.3. for details).

E.2. Copy raw SAR data to disk

Typically the files to copy from a CD-ROM are data_01.001 and lea_01.001 which are the SAR data and CEOS SAR data leader respectively. Copy these two files to the disk directory created in step 1 and rename them based upon the scene identifier.

```
mv (or cp) dat_01.001 20021111.raw
```

```
mv (or cp) lea_01.001 20021111.ldr
```

In this example the original raw data set is not provided on the additional DEMO CD-ROM because of space reasons (see end of Section E.3 for the raw data set used in this example). The leader file is provided for reference on the additional DEMO CD-ROM.

E.3. Create the MSP processing parameter file and data conditioning

The RADARSAT-1 raw data file needs to be scanned for missing lines, range aligned, and translated from offset 2's compliment binary to unsigned binary format. The program ***RSAT_raw*** combines these functions and produces the range aligned raw data, the MSP SAR sensor parameter file and the MSP processing parameter file.

In this example the command line looks as follows:

```
RSAT_raw 20021111.ldr RSAT.par p20021111.slc.par 20021111.raw 20021111.fix
```

At this command the leader file and the raw data as provided by the processing facility are read in and the raw data in the GAMMA format together with the corresponding MSP processing parameter file are generated. The program generates the MSP SAR sensor parameter file as well.

On the additional DEMO CD-ROM you can find a subset of the fixed data, which we called 20021111.fix consisting of 5000 echoes out of more than 26000 echoes in the original raw data. The RSAT.par is also provided along with the MSP Processing parameter file adapted to the subset of the fixed raw data (p20021111.slc.par).

E.4. Process the RAW data to SLC

Full resolution processing can be done either by entering at the command line the single commands as described in the following subsections or by means of an ad hoc script which encompasses all steps in an automatic fashion.

For RADARSAT-1 data, the script ***RSAT_PROC*** has been created. If the script is used the following information has to be entered:

- MSP SAR sensor parameter file name (RSAT.par, nominally)
- Scene identifier (e.g. acquisition date or orbit number)
- Desired number of range and azimuth looks

Before running this script, copy the ***RSAT_PROC*** script into the same directory where you will process the data. In this way any modifications made to the script while processing the data are kept with the image file.

Synopsis and example

```
RSAT_PROC <sensor> <scene> <RLK> <AZLK> [RAW_dir] [RC_dir] [SLC_dir] [AZ_PATCH]
```

sensor	RADARSAT-1 sensor parameter file, generated by RSAT_proc
scene	scene identifier (e.g. orbit number or acquisition date)
RLK	number of range looks in the multilook intensity image (MLI)
AZLK	number of azimuth looks in the multilook intensity image (MLI)
RAW dir	SAR raw data file directory
RC dir	range compressed data file directory
SLC dir	single look complex image file directory
AZ PATCH	azimuth patch size: 2046, 4096, 8192 (default = 4096)

```
RSAT_PROC RSAT.par 20021111 2 4 . /s1 . 8192
```

After processing, the p*.slc.par file (* = date or orbit) will contain the processing parameters of the Single Look Complex image produced by the processor, and the p*.mli.par file will contain the processing parameters of the multilook image that has been produced. The filename of the SLC image is *.slc, and the multilook intensity image is called *.mli. The complex file is in the form of 4 byte floating point numbers, one complex pair per image sample. The multilook file is proportional to the received image power (intensity) and is stored as 4-byte floating point numbers. Dimensions of the files (number of columns and number of rows) are written to the appropriate processing parameter files. ***RSAT_PROC*** uses autofocus to refine the focusing parameters.

E.4.1. Determine the Doppler ambiguity

RADARSAT-1 usually has a significant amount of squint causing the Doppler centroid to be several times the Pulse Repetition Frequency (PRF) therefore the Doppler centroid is unambiguously determined at this stage. The ***dop_ambig*** and ***dop_mlcc*** programs try to resolve this ambiguity; both estimate the unambiguous Doppler centroid and the SNR value for the estimate in the processing parameter file. Due to memory constraints only 8192 echoes are processed using ***dop_ambig***. Alternate the program ***dop_mlcc*** can be used apply the MLCC algorithm to the entire raw data file.

In this example we use the ***dop_mlcc*** program since the data has 26010 echoes.

```
dop_mlcc RSAT.par p20021111.slc.par 20021111.fix 20021111.mlcc
```

Figure E1 illustrates the Doppler phase shift for the two range looks as a function of range and the difference between those phase values as a function of range pixel number. The plot has been obtained using a program such as *xmgrace* (Figure E1).

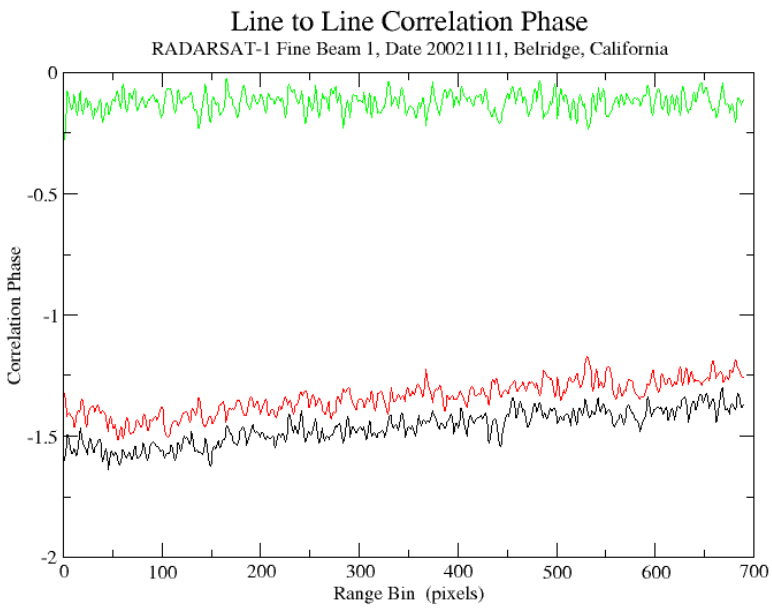

Figure E1. Correlation phase as a function of lines to process for the upper half of the spectrum (black) and the lower part of the spectrum (red). The difference is reported in green.

E.4.2. Estimate the Doppler centroid with cross-correlation algorithm

Since RADARSAT-1 has a large amount of squint, this will cause the Doppler centroid to vary significantly across the swath. To determine the Doppler polynomial across the swath because of the large amount of squint present in RADARSAT-1 data, the program ***doppler*** must be used. The program can use the values of the Doppler ambiguity generated by ***dop_ambig*** or ***dop_mlcc.***

In this example the command line is as follows:

```
doppler RSAT.par p20021111.slc.par 20021111.fix 20021111.dop
```

At this command the Doppler polynomial across the swath will be computed. The result is saved in the text file 20021111.dop. The result, i.e. both the measured centroid as a function of range sample and the linear polynomial fit of the centroid data, can be plotted using a program such as *xmgrace* (Figure E2).

If this kind of plot shows an abrupt and large variation of the Doppler centroid over several thousand Hertz, it means that the linear model of range dependent Doppler variation will lead to incorrect results if used. In such cases it is recommended to set the Doppler polynomial to a constant value. To do this use the program ***azsp_IQ*** instead of ***doppler***. This value should represent the mean Doppler frequency for the part not affected by the abrupt change.

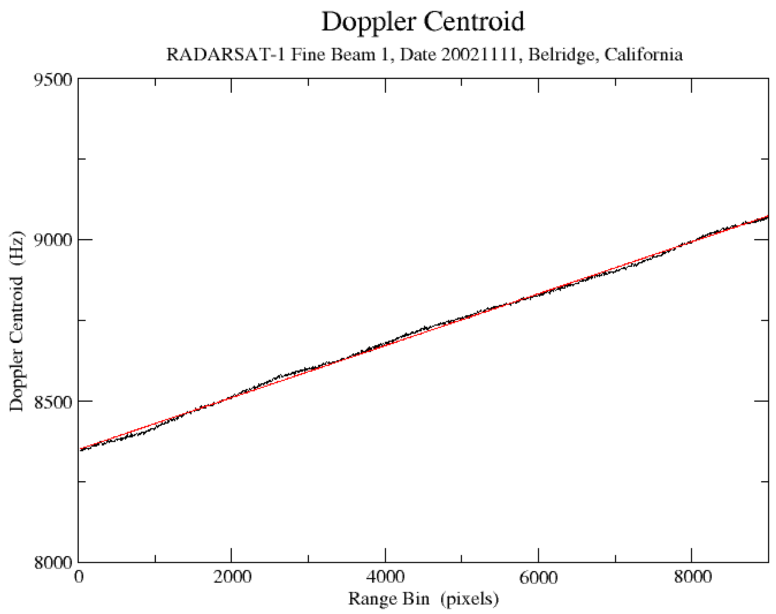

Figure E2. Doppler centroid across swath and linear fit (red line).

E.4.3. Estimate the range power spectrum (optional)

The range spectrum is determined to estimate the SNR in the final image. The region of the range power spectrum that is primarily noise is compared to the average power level over the chirp bandwidth. The resultant estimate of the image SNR is stored in the SNR_range_spectrum parameter of the processing parameter file.

In this example the command line looks as follows

```
rspec_IQ RSAT.par p20021111.slc.par 20021111.fix 20021111.rspec
```

At this command the range spectrum is computed and the result is saved in the 20021111.rspec file (text file). The range spectrum can be plotted with a program such as *xmgrace* (Figure E3):

E.4.4. Range compression

Range compression for RADARSAT-1 is performed using a program specifically designed for RADARSAT-1 (***pre_rc_RSAT***), since it must correct for changes in the receiver gain.

In this example the command line is as follows:

```
pre_rc_RSAT RSAT.par p20021111.slc.par 20021111.fix 20021111.rc
```

At this command the raw data is range compressed. The output consists of the range-compressed data and the updated version of the MSP processing parameter file.

In this example no decimation is used. In case you want to decimate the data, for example to obtain a quick-look of the image, you can use any factor after the file name for the range compressed data.

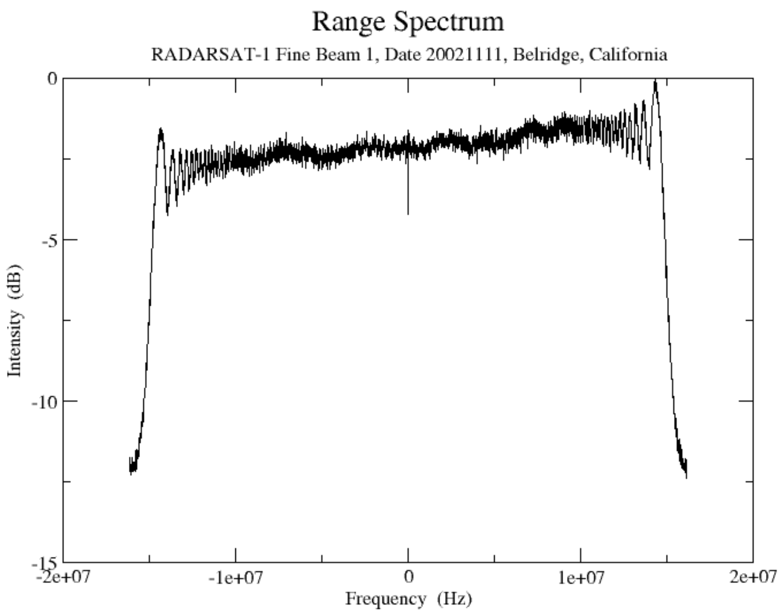

Figure E3. Range spectrum of the RADARSAT-1 raw data set acquired on November 11, 2002.

The range compressed image can be displayed with the DISP program ***dismph***. In this example we consider the display of a subset starting at line 2000 and being 2000 lines long. The width of the range compressed image (7726) coincides with the width of the final SLC. The length of the image coincides with the number of echoes being processed (4999). This information is contained in the p*.slc.par file.

```
dismph 20021111.rc 7726 2000 2000 - - 0
```

A SUNraster/bmp version can be generated with the DISP program ***rasmph***.

E.4.5. Autofocus

To focus the image in azimuth the autofocus program ***autof*** is run. The program is used twice to obtain a good estimate of the along-track velocity. In this example the command line looks as follows:

```
autof RSAT.par p20021111.slc.par 20021111.rc 20021111.autof 5.0

autof RSAT.par p20021111.slc.par 20021111.rc 20021111.autof 5.0
```

The correlation SNR is 10.9 which means that the result of autofocusing is rather good. The text file 20021111.autof containing the correlation function in output can be plotted using a program such as *xmgrace* (Figure E4).

E.4.6. Azimuth compression

Azimuth compression is performed using the calibrated range/Doppler azimuth processor ***az_proc***. A processing block size of 8192 is recommended for full resolution RADARSAT-1 processing, although a 4096 will be adequate for most modes.

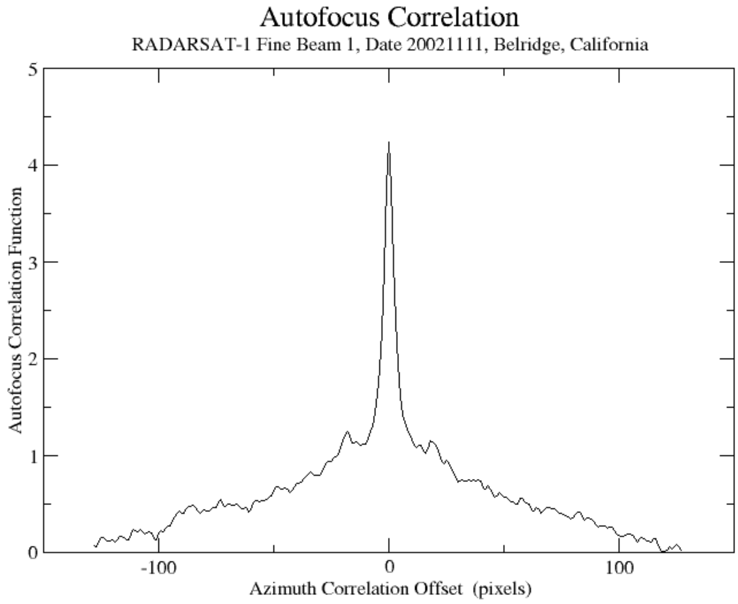

Figure E4. Correlation function as a function of azimuth sample number. The peak of the correlation function is at 0 azimuth offset which means that focus is good.

In this example the command looks as follows

```
az_proc RSAT.par p20021111.slc.par 20021111.rc 20021111.slc 4096 0 0.0 0
2.12
```

The output consists of the SLC image 20021111.slc in FCOMPLEX format with 7726 range pixels and 3525 lines. The image is not calibrated (factor 0 dB used) since calibration information is currently not available for RADARSAT-1.

If memory availability is an issue, the SLC can be obtained in SCOMPLEX format. To obtain the output in FCOMPLEX format set the parameter after the azimuth patch size (4096) to 0. The calibration constant is set to zero. A scaling factor of 60 dB is used to compensate for low amplitude values. The command line looks in this case as follows:

```
az_proc RSAT.par p20021111.slc.par 20021111.rc 20021111.slc 4096 1 60.0 0
2.12
```

To display the SLC use the DISP program ***disSLC***. An example of command line for the FCOMPLEX format image and a subset consisting of 2000 lines starting at line 1000 is:

```
disSLC 20021111.slc 7726 1000 2000 - - 0
```

To obtain an image of the SLC in SUNraster/bmp format use the DISP program ***rasSLC***. For the FCOMPLEX image the command line looks as below and the picture is illustrated in Figure E5. The pixel size in azimuth and range is similar (approximately 5 m).

```
rasSLC 20021111.slc 7726 1000 2000 - - - - - 0 – sub_20021111.slc.bmp
```

Figure E5. Magnitude of SLC subset 20021111.slc (2000 lines, 7726 range samples)

E.4.7. SLC image detection and generation of multi-look intensity image

The multilook intensity image is produced with the ***multi_SLC*** program. Inputs are SLC processing parameter file p*slc.par and the SLC image. Outputs are the multilook intensity image (MLI) and a new processing parameter file p*.mli.par. The image size, and resolution of the MLI image are described in the p*.mli.par processing parameter file.

In the example the command line for the FCOMPLEX image looks as follows:

```
multi_SLC p20021111.slc.par p20021111.mli.par 20021111.slc 20021111.mli 2 4
0
```

For processing we used as multi-look factors 2 and 4 in range and azimuth respectively. The output MLI image consists of 3863 range samples and 881 azimuth samples. The multi-look image has in both directions 20 m pixel size.

To display the image use the DISP program ***dispwr****:*

```
dispwr 20021111.mli 3863
```

The SUNraster/bmp version of it is illustrated in Figure E6. The image has been generated with the DISP program ***raspwr*** as follows:

```
raspwr 20021111.mli 3863 - - - - - - - 20021111.mli.bmp
```

Figure E6. Multi-look intensity 20021111.mli (size: 3863 pixels in range, 881 pixels in azimuth). The pixel size is 20x20 m.

F. SIR-C Processing

In this Section we illustrate how to process L-band raw data acquired by the SIR-C SAR to Single Look Complex format. Processing consists of the following steps

- Processing setup
- Copy raw SAR data to disk
- Create the MSP parameter files and data conditioning
- Process the RAW data to SLC
  - Estimate the Doppler centroid across range (optional)
  - Estimate the range power spectrum (optional)
  - Range compression
  - Autofocus
  - Azimuth compression
  - SLC image detection and generation of multi-look intensity image

For the processing a SIR-C SAR raw data set acquired over the Moreno Glacier, Argentina on October 10, 1994 is considered. The orbit number is 44268. The data set is also contained on the additional DEMO CD-ROM.

All programs described in this example but *az_proc* (azimuth compression / calibration / generation of SLC) require less than 1 minute. The program *az_proc* takes about 10-15 minutes to generate the SLC.

F.1. Processing setup

Processing of SIR-C data proceeds by first creating a directory where you want to process the data. Make sure that there is sufficient free space for processing the data. A full scene requires approximately 400 MB for the raw data, 400 MB for the fixed data, and about 700 MB for the processed image. There should also be at least 1 GB temporary space available for the range compressed data, preferably on another disk. SIR-C scene may be specified in terms of the orbit, create a directory for the SAR data processing:

```
mkdir 44268; cd 44268
```

Copy the antenna pattern constant_antenna.gain to the processing directory. Currently, no correction for the antenna pattern across track is performed:

```
cp $MSP_HOME/MSP/sensors/constant_antenna.gain .
```

where "." means the current directory. In SIR-C processing we nominally do not extract the antenna pattern from the CEOS leader file. This capability could be added if required by users.

The constant antenna gain file can be found on the additional DEMO CD-ROM.

F.2. Copy raw SAR data to disk

Read the raw data from 8mm tape using the most recent version of the ceos_reader program (v2.3) supplied by JPL for reading SIRC-C CEOS data tapes for both processed and unprocessed data.

```
ceos_reader tape=/dev/rmt/0mnb
```

0mnb is the device file of the tape containing the raw data and will be different on your machine. Be sure to select a device that is no rewind. *ceos_reader* creates the *CEOS* raw data file(s) **_img_ceos*, and the *CEOS* leader file: **ldr_ceos*. Change names to the data file and the leader file to the format suggested in this manual, i.e. *.raw and *.ldr respectively.

For space reasons in this example the data provided on the additional DEMO CD-ROM are subsets of an entire frame and have been generated separately. See Section F.3 for details.

F.3. Create the MSP processing parameter file and data conditioning

To create the parameter files use the program ***SIRC_proc.*** This program takes as input the CEOS leader file and generates both the MSP SAR sensor and the MSP processing parameter files. This program will query you as to the section of the image that you want to process including the starting echo, number echoes, starting range sample and the number of range samples. The number of range samples must match the size of the range FFT used to match filter the echo, 4096, 8192, or 16384. Since the SIR-C instrument uses offset-video sampling for the raw data, two input samples correspond to a single complex sample as used by ERS, JERS, and RADARSAT-1. The output samples of the SLC are complex valued.

In this example the command line looks as follows:

```
SIRC_proc 44268.ldr SIRC.par p44268.slc.par
```

The parameter files are already available on the additional DEMO CD-ROM since we are working with a subset of the raw data. The subset is called 44268.raw.

F.4. Process the RAW data to SLC

Full resolution processing can be done either by entering at the command line the single commands as described in the following subsections or by means of an ad hoc script which encompasses all steps in an automatic fashion.

For SIR-C data, the script ***SIRC_PROC*** has been created. If the script is used the following information has to be entered:

- MSP SAR sensor parameter file name (SIRC.par, nominally)
- Scene identifier (e.g. acquisition date or orbit number)
- Desired number of range and azimuth looks

Before running this script, copy the SIRC_PROC script into the same directory where you will process the data. In this way any modifications made to the script while processing the data are kept with the image file.

Synopsis and example

```
SIRC_PROC  <sensor>  <scene>  <RLK>  <AZLK>[RAW_dir]  [RC_dir]  [SLC_dir]
[AZ_PATCH]
```

sensor	SIR-C sensor parameter file, generated by SIRC_proc
scene	scene identifier (e.g. orbit number or acquisition date)
RLK	number of range looks in the multilook intensity image (MLI)
AZLK	number of azimuth looks in the multilook intensity image (MLI)
RAW dir	SAR raw data file directory
RC dir	range compressed data file directory
SLC dir	single look complex image file directory
AZ PATCH	azimuth patch size: 2046, 4096, 8192 (default = 4096)

```
SIRC_PROC SIRC.par 44268 4 4 . /s1 . 4096
```

After processing, the p*.slc.par file (* = date or orbit) will contain the processing parameters of the Single Look Complex image produced by the processor, and the p*.mli.par file will contain the processing parameters of the multilook image that has been produced. The filename of the SLC image is *.slc, and the multilook intensity image is called *.mli. The complex file is in the form of 4 byte floating point numbers, one complex pair per image sample. The multilook file is proportional to the received image power (intensity) and is stored as 4-byte floating point numbers. Dimensions of the files (number of columns and number of rows) are written to the appropriate processing parameter files. ***SIRC_PROC*** uses autofocus to refine the focusing parameters.

F.4.1. Estimate the Doppler centroid across the swath

Since SIR-C has a large amount of squint, this will cause the Doppler centroid to vary significantly across the swath. To determine the Doppler polynomial across the swath because of the large amount of squint, the program ***doppler_real*** must be used.

In this example the command line looks as follows:

```
doppler_real SIRC.par p44268.slc.par 44268.raw 44268.dop
```

At this command the Doppler polynomial across the swath will be computed. The result is saved in the text file 44268.dop. The result, i.e. both the measured centroid as a function of range sample and the linear polynomial fit of the centroid data, can be plotted using a program such as *xmgrace* (Figure F1).

If this kind of plot shows an abrupt and large variation of the Doppler centroid over several thousand Hertz, it means that the linear model of range dependent Doppler variation will lead to incorrect results if used. In such cases it is recommended to set the Doppler polynomial manually in the MSP processing parameter file (p*.slc.par) simply to a constant value. This value should represent the mean Doppler frequency for the part not affected by the abrupt change.

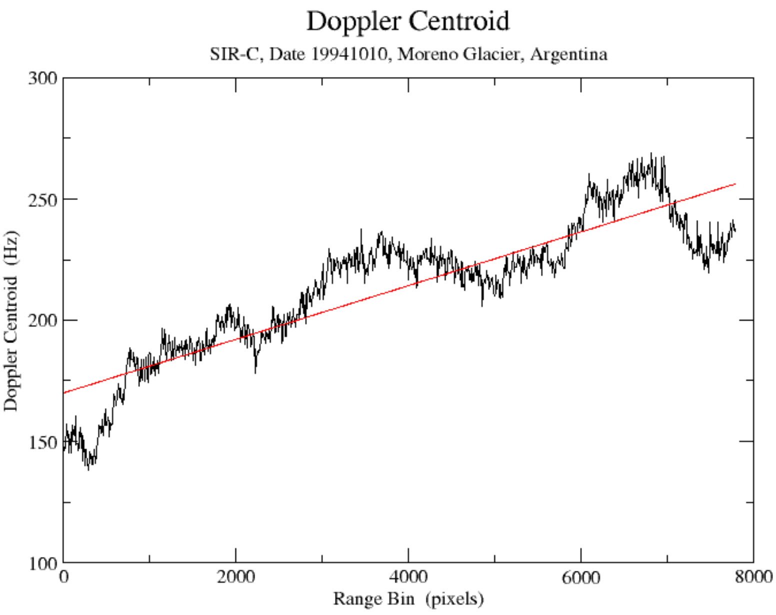

Figure F1. Doppler centroid across swath and linear fit (red line)

F.4.2. Estimate the range power spectrum (optional)

To compute the range spectrum for the real-valued data use the program ***rspec_real***.

In this example the command line looks as follows:

```
rspec_real SIRC.par p44268.slc.par 44268.raw 44268.rspec
```

At this command the range spectrum is computed and the result is saved in the 44268.rspec file (text file). The range spectrum can be plotted with a program such as *xmgrace* (Figure F2).

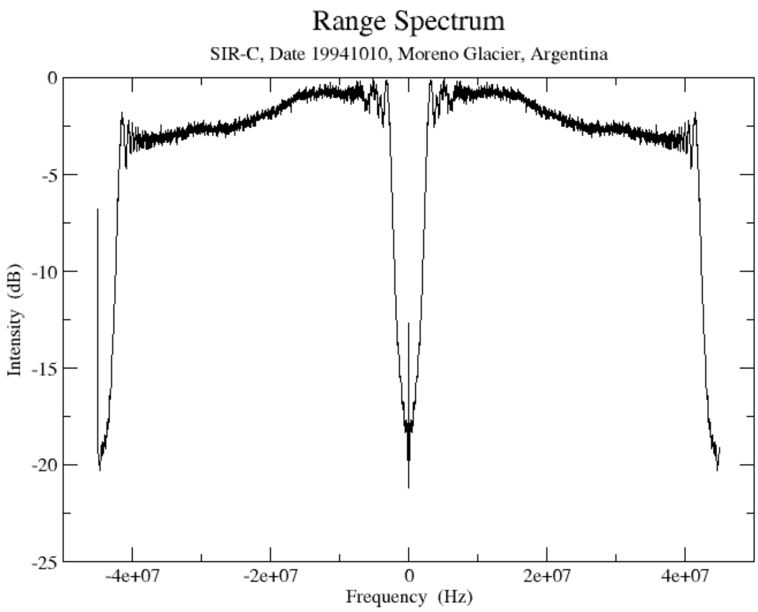

Figure F2. Range spectrum for the SIR-C image 44268.raw.

F.4.3. Range compression

Range compression for SIR-C is performed using a program specifically designed for offset video data**, *rc_real***. This program takes the offset video data and shifts it to baseband during the matched filter operation. If the user prefers to use a digitized chirp waveform rather than the analytic chirp calculated by **rc_real**, the user may enter the chirp data file on the command line. In this example the command line is as follows:

```
rc_real SIRC.par p44268.slc.par 44268.raw 44268.rc
```

At this command the real data is compressed in range. For the processing the default values were used, i.e. the entire frame was processed, and no RFI filtering was applied.

The range compressed image can be displayed with the DISP program ***dismph***. In this example we consider the display of a subset starting at line 2000 and being 2000 lines long. The width of the range compressed image (6291) coincides with the width of the final SLC. The length of the image coincides with the number of echoes being processed (4999). This information is contained in the p*.slc.par file.

```
dismph 44268.rc 6291 2000 2000 - - 0
```

A SUNraster/bmp version can be generated with the DISP program ***rasmph***.

F.4.4. Autofocus

To focus the image in azimuth the autofocus program ***autof*** is run. The program is used twice to obtain a good estimate of the along-track velocity. In this example the command line looks as follows:

```
autof SIRC.par p44268.slc.par 44268.rc 44268.autof 5.0
```

```
autof SIRC.par p44268.slc.par 44268.rc 44268.autof 5.0
```

The correlation SNR is rather high (~ 56) which means that the autofocus worked rather well. The text file 44268.autof containing the correlation function in output can be plotted using a program such as *xmgrace* (Figure F3).

F.4.5. Azimuth compression

Azimuth compression is performed using the calibrated range/Doppler azimuth processor ***az_proc.*** A processing block size of 8192 is recommended for full resolution SIR-C at L-band processing.

In this example the command line looks as follows:

```
az_proc SIRC.par p44268.slc.par 44268.rc 44268.slc 8192 0 0 0 2.12
```

The output consists of the Single Look Complex image 44268.slc with 6291 range pixels and 3963 lines in FCOMPLEX format. No calibration is applied because of missing information.

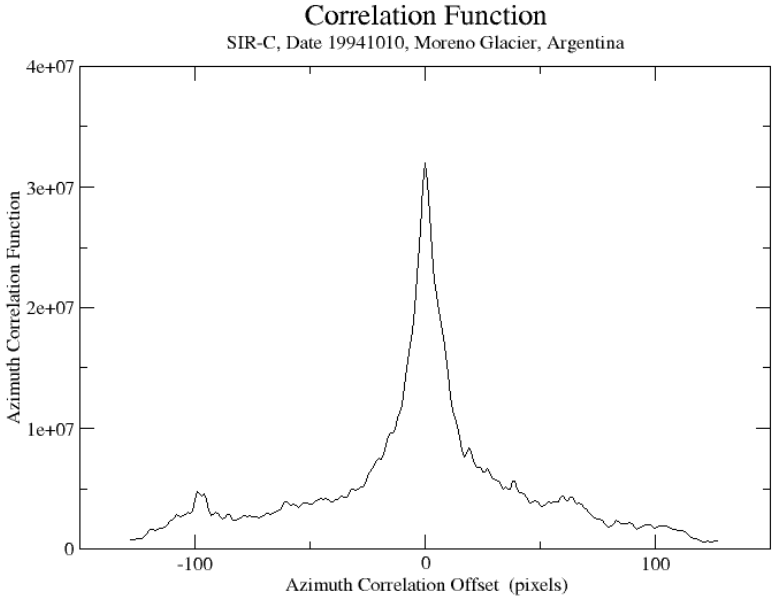

Figure F3. Correlation function as a function of azimuth sample number. The peak of the correlation function is at 0 azimuth offset which means that focus is good.

If memory availability is an issue, the user can process the data to SCOMPLEX format in which case the command line looks as follows

```
az_proc SIRC.par p44268.slc.par 44268.rc 44268.slc 8192 1 60.0 0 2.12
```

A scaling factor of 60 dB is used to allow representing also very low intensity values.

To display the SLC the DISP program ***disSLC*** can be used. For the FCOMPLEX format and a subset consisting of 2000 lines starting at line 1000 the command line looks as follows:

```
disSLC 44268.slc 6291 1000 2000 - - 0
```

To obtain the image in SUNraster/bmp format, use the DISP program ***rasSLC***. A subset consisting of 2000 lines is illustrated in Figure F4. The pixel size is 3.2 m in range and 5.3 m in azimuth.

```
rasSLC 44268.slc 6291 1000 2000 - - - - - 0 - 44268_sub.slc.bmp
```

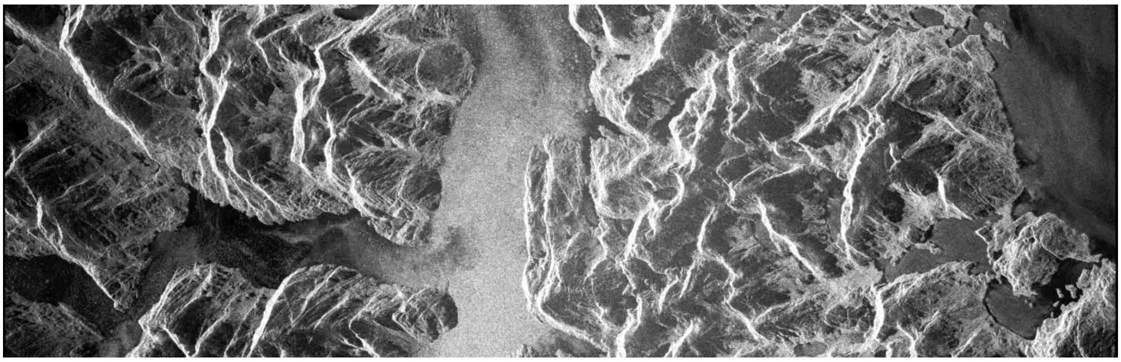

Figure F4. Magnitude of SLC subset 44268.slc (2000 lines, 6291 range samples)

F.4.6. SLC image detection and generation of multi-look intensity image

The multilook intensity image is produced with the ***multi_SLC*** program. Inputs are SLC processing parameter file p*slc.par and the SLC image. Outputs are the multilook intensity image (MLI) and a new processing parameter file p*.mli.par. The image size, and resolution of the MLI image are described in the p*.mli.par processing parameter file.

In the example the command line for the SLC in FCOMPLEX format looks as follows

```
multi_SLC p44268.slc.par p44268.mli.par 44268.slc 44268.mli 4 4 0
```

For processing we used as multi-look factors 4 and 4 in range and azimuth respectively in order to obtain squared pixels. The output MLI image consists of 1572 range samples and 990 azimuth samples. The multi-look image has in both directions approximately 20 m pixel size.

The image can be displayed with the DISP program ***dispwr*** as follows

```
dispwr 44268.mli 1572
```

The image is illustrated in Figure F5. The image has been generated with the DISP program ***raspwr*** as follows:

```
raspwr 44268.mli 1572 - - - - - - - 44268.mli.bmp
```

Figure F5. Multi-look intensity 44268.mli (size: 1572 pixels in range, 990 pixels in azimuth). The pixel size is 20x20 m.

G. Processing of multi-polarization raw data

This Example describes the steps to be performed in order to process multi-polarization raw SAR data. This applies to ENVISAT ASAR AP dual-pol and ALOS PALSAR dual- and quad-pol data. The example refers to quad-pol PALSAR data processing. In addition, the steps required to perform interferometric processing of the SLCs in the case of PALSAR quad-pol data are described. For this programs of the ISP package are used.

G.1. Generation of parameter files and generation of calibration file

Generation of the SAR sensor parameter file and MSP processing parameter file for each channel.

```
PALSAR_proc      PASL10C0606181258510606270007.ldr      20060618_hh.sar_par
p20060618_hh.slc.par  PASL10C0606181258510606270007.raw 20060618_hh.raw 0 0

PALSAR_proc      PASL10C0606181258510606270007.ldr      20060618_hv.sar_par
p20060618_hv.slc.par  PASL10C0606181258510606270007.raw 20060618_hv.raw 0 1

PALSAR_proc      PASL10C0606181258510606270007.ldr      20060618_vh.sar_par
p20060618_vh.slc.par  PASL10C0606181258510606270007.raw 20060618_vh.raw 1 0

PALSAR_proc      PASL10C0606181258510606270007.ldr      20060618_vv.sar_par
p20060618_vv.slc.par  PASL10C0606181258510606270007.raw 20060618_vv.raw 1 1
```

Generation of the calibration file and update of the SAR sensor parameter file for each channel using the external calibration file called palsar_ant_20061024.dat

```
PALSAR_antpat           20061020_hh.sar_par           p20061020_hh.slc.par
palsar_ant_20061024.dat PALSAR_antpat_MSP_hh.dat - 0 0

PALSAR_antpat           20061020_hv.sar_par           p20061020_hv.slc.par
palsar_ant_20061024.dat PALSAR_antpat_MSP_hv.dat - 0 1

PALSAR_antpat           20061020_vh.sar_par           p20061020_vh.slc.par
palsar_ant_20061024.dat PALSAR_antpat_MSP_vh.dat - 1 0

PALSAR_antpat           20061020_vv.sar_par           p20061020_vv.slc.par
palsar_ant_20061024.dat PALSAR_antpat_MSP_vv.dat - 1 1
```

G.2. Estimation of Doppler centroid

The different channels present different start times. For this reason estimation of the Doppler centroid is done for one channel (for example HH) and the Doppler centroid and effective velocity are copied to the parameter files of the other channels. In this way all the images will have the same geometry and phase reference, i.e. they will all overlap.

For this use the program ***doppler*** first on the "master" channel and then the program ***set_value*** to update the MSP processing parameter files of the other channels. Before proceeding it is maybe interesting to look at the variation of the Doppler centroid across range. For this use a program such as xmgrace applied to the Doppler file generated by the program ***doppler***. If the Doppler centroid across range shows an abrupt and large variation of the Doppler centroid over several thousand Hertz, it means that the linear model of range dependent Doppler variation will lead to incorrect results if used. In such cases it is recommended to set the Doppler polynomial to a constant value. To do this use the program ***azsp_IQ*** instead of ***doppler***. This value should represent the mean Doppler frequency for the part not affected by the abrupt change.

```
doppler    20060618_hh.sar_par    p20060618_hh.slc.par    20060618_hh.raw
20060618_hh.dop

a1=`grep  doppler_polynomial   p20060618_hh.slc.par  |cut  -d  :  -f  1  --
complement`

set_value  p20060618_hv.slc.par  p20060618_hv.slc.par  "doppler_polynomial"
"$a1" 0

set_value  p20060618_vh.slc.par  p20060618_vh.slc.par  "doppler_polynomial"
"$a1" 0

set_value  p20060618_vv.slc.par  p20060618_vv.slc.par  "doppler_polynomial"
"$a1" 0
```

G.3. Range compression

Range compression of all channels. For this use the program ***pre_rc***.

```
pre_rc 20060618_hh.sar_par p20060618_hh.slc.par 20060618_hh.raw rc_hh 1 0 -
- 2.12 8 200 200 1

pre_rc 20060618_hv.sar_par p20060618_hv.slc.par 20060618_hv.raw rc_hv 1 0 -
- 2.12 8 200 200 1

pre_rc 20060618_vh.sar_par p20060618_vh.slc.par 20060618_vh.raw rc_vh 1 0 -
- 2.12 8 200 200 1

pre_rc 20060618_vv.sar_par p20060618_vv.slc.par 20060618_vv.raw rc_vv 1 0 -
- 2.12 8 200 200 1
```

It should be noticed that in this case range extension was applied (200 pixels at both ends) to compensate for the narrow swath of the data. Such range extension allowed generating an SLC for the whole swath, though at gradually reducing resolution.

G.4. Autofocus

Estimate autofocus for one channel (for example HH) and copy effective velocity to the other MSP processing parameter files so that all polarization channels will be identical. For the autofocus use the program ***autof***. For copying the velocities estimated with ***autof*** to the MSP processing parameter files of the other channels use the program ***set_value***.

```
autof 20060618_hh.sar_par p20060618_hh.slc.par rc_hh af_hh 5 1 2048 12000

autof 20060618_hh.sar_par p20060618_hh.slc.par rc_hh af_hh 5 1 2048 12000

a1=`grep  sensor_velocity_vector  p20060618_hh.slc.par  |cut  -d  :  -f  1  --
complement`
```

```
set_value p20060618_hv.slc.par p20060618_hv.slc.par
"sensor_velocity_vector" "$a1" 0

set_value p20060618_vh.slc.par p20060618_vh.slc.par
"sensor_velocity_vector" "$a1" 0

set_value p20060618_vv.slc.par p20060618_vv.slc.par
"sensor_velocity_vector" "$a1" 0
```

G.5. Azimuth compression

Azimuth compression of each channel to calibrated SLCs in FCOMPLEX format. For this use the program ***az_proc***. Calibration is also applied using the factors provided in the sensor_cal_MSP.dat file in the MSP/sensors directory. For no calibration use the value 0.

```
az_proc 20060618_hh.sar_par p20060618_hh.slc.par rc_hh 20060618_hh.slc
16384 0 -45.3 0 2.12

az_proc 20060618_hv.sar_par p20060618_hv.slc.par rc_hv 20060618_hv.slc
16384 0 -52 0 2.12

az_proc 20060618_vh.sar_par p20060618_vh.slc.par rc_vh 20060618_vh.slc
16384 0 -54 0 2.12

az_proc 20060618_vv.sar_par p20060618_vv.slc.par rc_vv 20060618_vv.slc
16384 0 -44 0 2.12
```

G.6. Multi-looking

Generation of multi-look intensity image for each SLC with factors 1 and 7 in range and azimuth. For this use the program ***multi_SLC***.

```
multi_SLC p20060618_hh.slc.par p20060618_hh.mli.par 20060618_hh.slc
20060618_hh.mli 1 7

multi_SLC p20060618_hv.slc.par p20060618_hv.mli.par 20060618_hv.slc
20060618_hv.mli 1 7

multi_SLC p20060618_vh.slc.par p20060618_vh.mli.par 20060618_vh.slc
20060618_vh.mli 1 7

multi_SLC p20060618_vv.slc.par p20060618_vv.mli.par 20060618_vv.slc
20060618_vv.mli 1 7
```

G.7. Generation of SUNraster files and display

Generation of SUNraster files for each MLI. For this use the DISP program ***raspwr***.

```
raspwr 20060618_hh.mli 936 1 0 1 1 .8

raspwr 20060618_hv.mli 936 1 0 1 1 .8

raspwr 20060618_vh.mli 936 1 0 1 1 .8
```

```
raspwr 20060618_vv.mli 936 1 0 1 1 .8
```

Display different pairs of images

```
dis2ras 20060618_hh.mli.ras 20060618_vv.mli.ras&

dis2ras 20060618_hh.mli.ras 20060618_hv.mli.ras&

dis2ras 20060618_hv.mli.ras 20060618_vh.mli.ras&

dis2SLC 20060618_hh.slc 20060618_vv.slc 936 936 10000 2000 0 0 .8 .35 0&
```

G.8. Interferometric processing of PALSAR quad-pol data

For PALSAR quad-pol data additional resampling is necessary because there is a half line shift in azimuth between the HH and the VV channel. This can be seen when comparing the channels using ***dis2SLC*** and ***dis2ras***. For the resampling the ISP programs should be used. Notice that the HH and HV channels are co-registered, so do the VV and VH channels.

G.8.1. Generation of SLC parameter files

Generate of ISP SLC parameter file for each channel. For this use the ISP program ***par_MSP***.

```
par_MSP 20060618_hh.sar_par p20060618_hh.slc.par 20060618_hh.slc.par

par_MSP 20060618_hv.sar_par p20060618_hv.slc.par 20060618_hv.slc.par

par_MSP 20060618_vh.sar_par p20060618_vh.slc.par 20060618_vh.slc.par

par_MSP 20060618_vv.sar_par p20060618_vv.slc.par 20060618_vv.slc.par
```

G.8.2. Generation of offset file

Generate the offset file necessary for the co-registration. For this use the ISP program ***create_offset***.

```
create_offset 20060618_hh.slc.par 20060618_vv.slc.par 20060618_hh_vv.off
```

G.8.3. Update of offsets

Introduce the offset in the offset polynomial file (in the offset file). It is just necessary to set the offset value to +.5 or -.5 azimuth lines so that we use shell scripting and the program ***set_value***. In this particular example bash syntax has been used.

```
t1=`grep start_time 20060618_hh.slc.par|cut -c 25-36`

t2=`grep start_time 20060618_vv.slc.par|cut -c 25-36`

echo "start time HH: $t1   start time VV: $t2"

daz=`echo $t1 $t2 | awk '{if ($1 == $2) print 0.0; if ($1 < $2) print -0.5;
if ($1 > $2) print 0.5;}'`

echo "azimuth offset:" $daz
```

```
set_value 20060618_hh_vv.off 20060618_hh_vv.off "azimuth_offset_polynomial"
"$daz 0.0 0.0 0.0" 0
```

```
set_value  20060618_hh_vv.off  20060618_hh_vv.off  "range_offset_polynomial"
"0.0 0.0 0.0 0.0" 0
```

G.8.4. Co-registration

Resample the VV SLC using the offset polynomial. For this use the ISP program ***SLC_interp***.

```
SLC_interp    20060618_vv.slc    20060618_hh.slc.par    20060618_vv.slc.par
20060618_hh_vv.off 20060618_vv.rslc 20060618_vv.rslc.par
```

G.8.5. Generation of HH-VV phase difference and coherence images

Phase difference is generated with the ISP program ***SLC_intf***.

```
SLC_intf      20060618_hh.slc      20060618_vv.rslc      20060618_hh.slc.par
20060618_vv.rslc.par 20060618_hh_vv.off 20060618_hh_vv.diff 1 7 0 - 0 0
```

Coherence is generated with the ISP program ***cc_wave***.

```
cc_wave      20060618_hh_vv.diff      20060618_hh.mli      20060618_vv.mli
20060618_hh_vv.cc 936 5 5 1
```

G.8.6. Generation of SUNraster files and display

To generate SUNraster files of the phase difference and the coherence you can use the programs ***rasmph_pwr*** and ***rascc*** respectively (from the DISP package).

```
rasmph_pwr 20060618_hh_vv.diff 20060618_hh.mli 936 1 1 0
```

```
rascc 20060618_hh_vv.cc 20060618_hh.mli 936
```

You can display and compare the images with the DISP program ***dis2ras***.

```
dis2ras 20060618_hh_vv.diff.ras 20060618_hh_vv.cc.ras&
```