# MEASURING SURFACE DISPLACEMENT WITH SYNTHETIC APERTURE RADAR INTERFEROMETRY (INSAR) AND GAMMA SOFTWARE: A CASE STUDY FROM KAPOHO, ISLAND OF HAWAII

MASTERS OF SCIENCE

IN

GEOLOGY AND GEOPHYSICS

DECEMBER 2006

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# Contents

# Conventions

| | |
|---|---|
| Arial bold | Commands and scripts |
| *Arial italic* | Filenames and paths |
| Arial underlined | Hyperlinks to external websites, internal text files, figures etc. |
| `Courier new` | Snapshots from actual processing flow showing commands and scripts |
| <...> | mandatory input parameter |
| [...] | optional input parameter |

This document will be available in html and as a printable version (PDF). The html version of this manual can be accessed using a web browser (e.g., Mozilla Firefox) either online through the PGF website or offline after copying the necessary files to the local machine (CD). Hyperlinks throughout the document can thus be used. The printable version of this manual is equipped with complimentary documents providing a list of figures and linked text files.

A glossary of acronyms and abbreviations can be found in **Appendix A**.

## Acknowledgements

I would like to thank my thesis committee, consisting of the chair person Ben Brooks who acted as my academic advisor, my committee members Charles Werner, Steve Martel and Janet Becker, who gratefully replaced Neil Frazer in my committee. Charles is one of the founders of GAMMA Remote Sensing has been an essential part in the completion of this user's guise explaining the overall structure and usage of the software GAMMA. Steve became an important part of my academic and personal life about three years ago and provided me with a huge amount of professional and mental support throughout my academic career. Janet is responsible for the advancement in my math skills and gladly joined my committee to support me and my thesis greatly. Neil played a valuable role in the decision making for my Master's route, I received a lot of encouragement and human support from him. Hao Zhou, Matt Patrick and Arjun Aryal were essential in getting started and further improve the usage of GAMMA. Paco Gomez also helped in the development of routines to efficiently process radar data. Mike Poland provided support as well as additional data. Mark Munneke helped out a great bunch as our computer technician. James Foster has been endless source of geophysical, technical and mental help. And last but not least, Joseph Shacat, my lovely husband without whom I would have never gotten this far. He kept me on track and reminded me often what life is really all about.

# 1. Introduction

The principle product of this Plan B Masters is a user's guide for GAMMA InSAR software to produce deformation maps. We demonstrate the software in a case study of Kapoho, located in the Puna district on eastern tip of the island of Hawaii (from here on referred to as the Big Island). This document represents a customized, updated lab guide that should be used in conjunction with the GAMMA software documentation.

Land surface deformation may be associated with a variety of processes that include, for example, faulting, volcanism, glaciation and deglaciation, landsliding, ground water pumping, and mining (Figure 1: Deformation PDF 9.6 MB). Volcanic processes include seismic events, volcanic eruptions, magma-related subsidence and intrusion. These processes can be destructive to life and property. By measuring and modeling the displacement at the surface of the Earth we can learn more about the processes acting in the subsurface. Monitoring of these potentially hazardous processes can be accomplished using Interferometric Synthetic Aperture Radar (InSAR).

The Kilauea lower east rift zone extends subaerially about 60 km from the summit of Kilauea Volcano to the eastern tip of the Big Island [*Delaney et al.*, 1998]. This area has experienced gradual subsidence of about -1.4 cm/year since the M 7.2 Kalapana earthquake in 1975 increasing the tidal pond-area significantly. Coastal communities are particularly susceptible to hazards associated with sea-level change. Causes of sea-level change include or are a combination of global sea-level rise and relative land subsidence [*Caccamise et al.*, 2005]. The community of Kapoho is situated in relatively flat terrain south of Kapoho Bay (Figure 2a: Kapoho PDF 5.4 MB). Coastal subsidence is drastically affecting two residential subdivisions, the Kapoho beach lots and the Kapoho Vacationland. As a result, these properties are flooded during ordinary high water stands (Figure 2b: High water) and major health hazards related to the sewage system are developing. It has therefore become important to further investigate the ground motion in that area using currently available leveling and GPS data and incorporating InSAR.

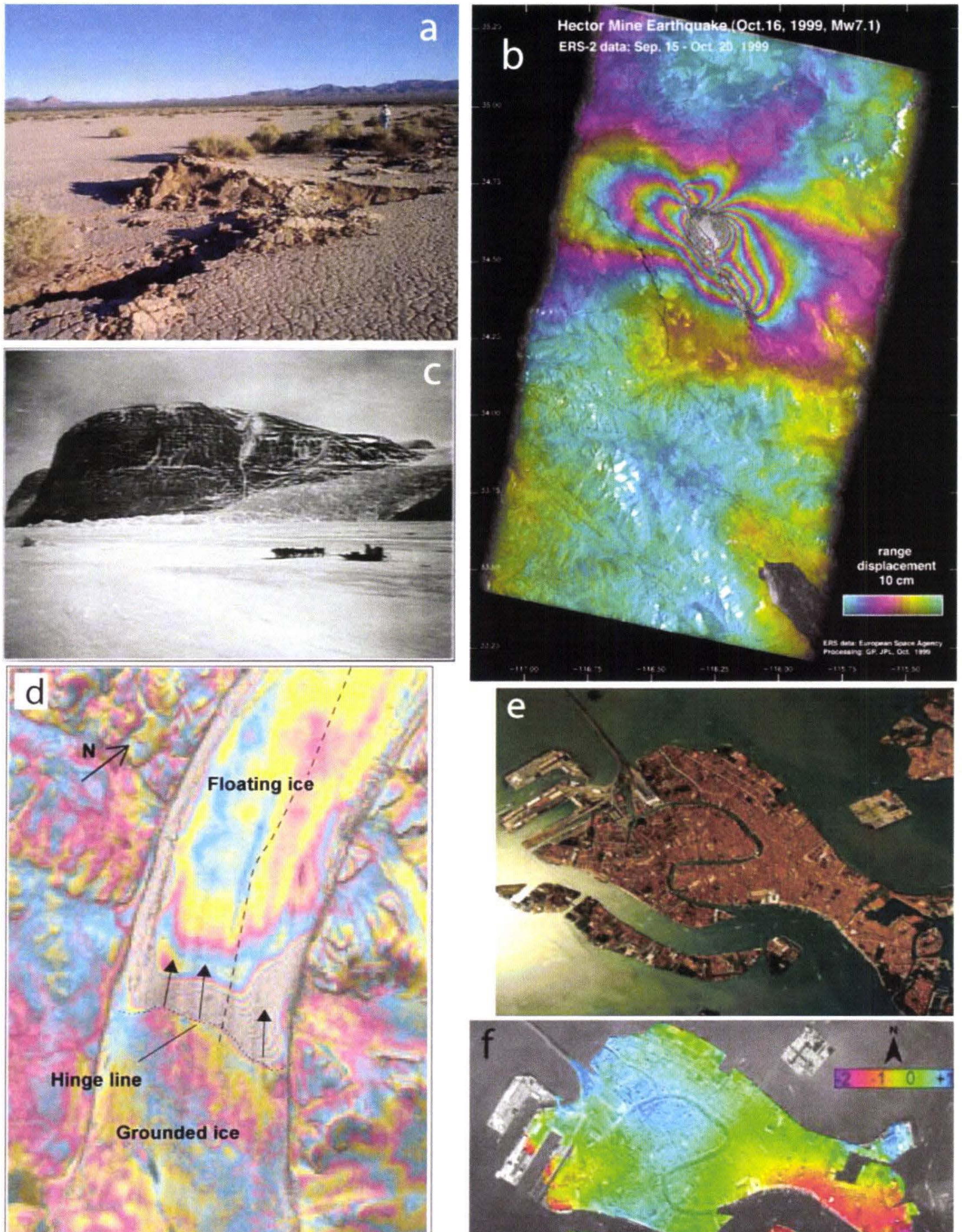



Figure 1: Examples of deformation and interferometric processing results. (a) Surficial expression of the Hector Mine Earthquake (courtesy of Chris Walls), (b) Coseismic deformation pattern associated with the Hector Mine Earthquake (courtesy of G. Peltzer, 2001), (c) Petermann glacier (courtesy of Lauge Koch), (d) Tidal displacements of Petermann glacier (one color-cycle corresponds to 28 mm of range displacement, courtesy of E. Rignot, 1997), (e) Aerial view of Venice, Italy (www.toon.heindl-internet.de), (f) Land subsidence rate of Venice between 1992 and 1996 in mm/year (www.gamma-rs.ch).

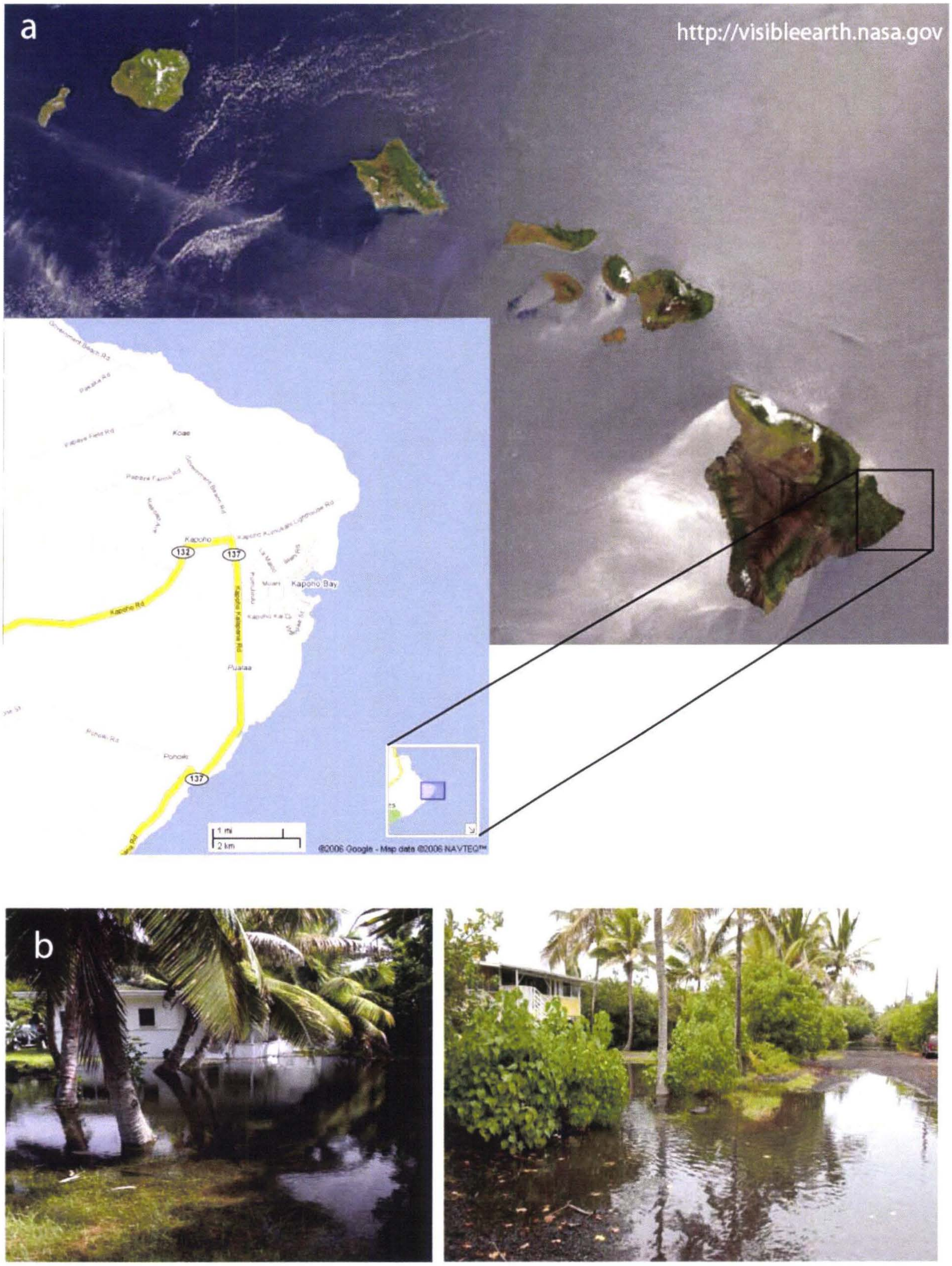
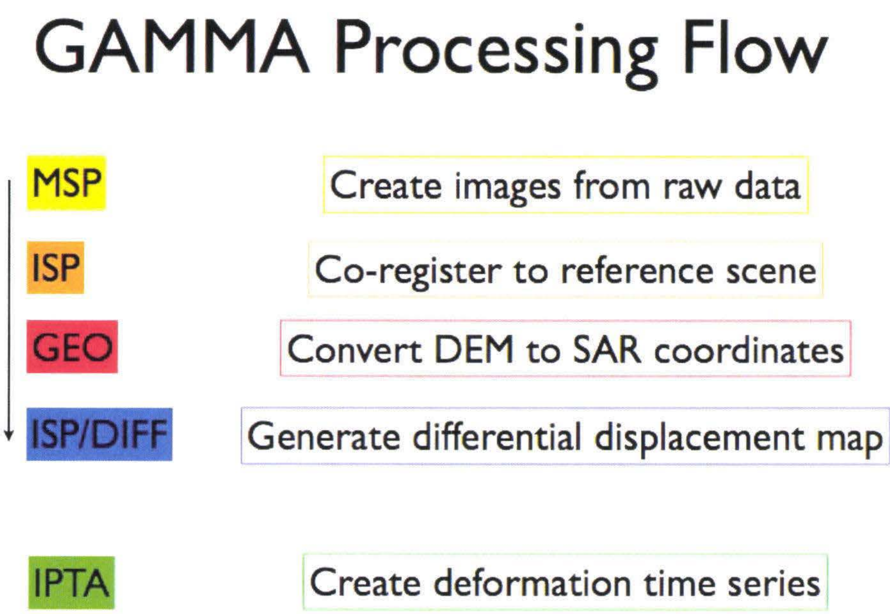


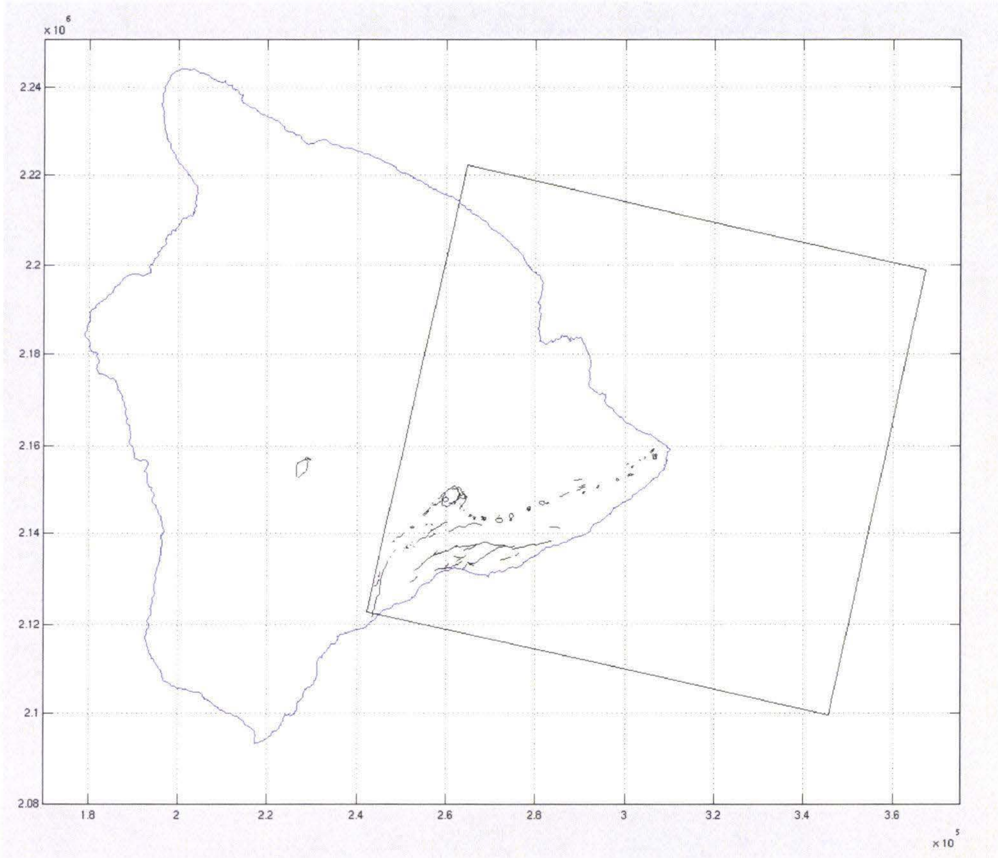

Figure 2: (a) Location of Kapoho, Puna District, Island and State of Hawaii, (b) Residential areas at high tide (courtesy of D. Hwang).

## 2. GAMMA Processing Work Flow

GAMMA software is capable of processing synthetic aperture radar (SAR) data from a variety of Earth orbiting satellite platforms. The software supports processing of raw SAR data and creation of final interferometric products such as digital elevation models (DEM), deformation maps, and land-use maps. GAMMA contains the following packages: Modular (MSP) and Interferometric SAR processing (ISP), Differential SAR Interferometry and Geocoding (DIFF&GEO), Interferometric Point Target Analysis (IPTA), and a Display toolbox (DISP). The flowchart below briefly illustrates the modules, whereas at the beginning of each section one can find a more detailed flowchart of the corresponding module. This manual will describe most of these toolboxes and demonstrate how to use them in the context of an example from Kapoho, Hawaii using data from the Envisat platform.




The Environmental Satellite Envisat, maintained by the European Space Agency (ESA @ http://earth.esa.int/), acquires radar data approximately once per month using an Advanced Synthetic Aperture Radar (ASAR) instrument (for information on other satellites refer to **Appendix B**). The following steps describe a typical, complete work flow in order to process raw Envisat ASAR image mode data to make a final map of surface displacement (see flowchart above). Radar images or scenes are recorded as a sequence of frames in a track, which corresponds to the satellite's ground coverage (for details see **Appendix C**). The frame 3213 from the descending track 429 covers the eastern portion of the Big Island of Hawaii. The 21 scenes for this specific track and frame were acquired in image swath 2, with incidence angles ranging from 19.2° to 26.7° (see **Appendix D** for data availability). The ground coverage of this specific frame is displayed in the figure below.




GAMMA provides different modules in order to fully support interferometric processing. The processing flows will go through most of the modules and show how certain techniques may be applied and how specific commands are run. The manual is accompanied by a processing log (README file) containing individual steps (README link) utilized throughout the processing. The README includes every command and script that is run in chronological order. The manual provides short explanations of scripts and commands as well as examples of various products such as images of interferograms, displacement maps, input parameter files etc. More information can be accessed on line through www.gamma-rs.ch. The existing html software documentation provided by GAMMA is used as the foundation. The GAMMA user guide is divided into the different modular packages and will be referred to in links.

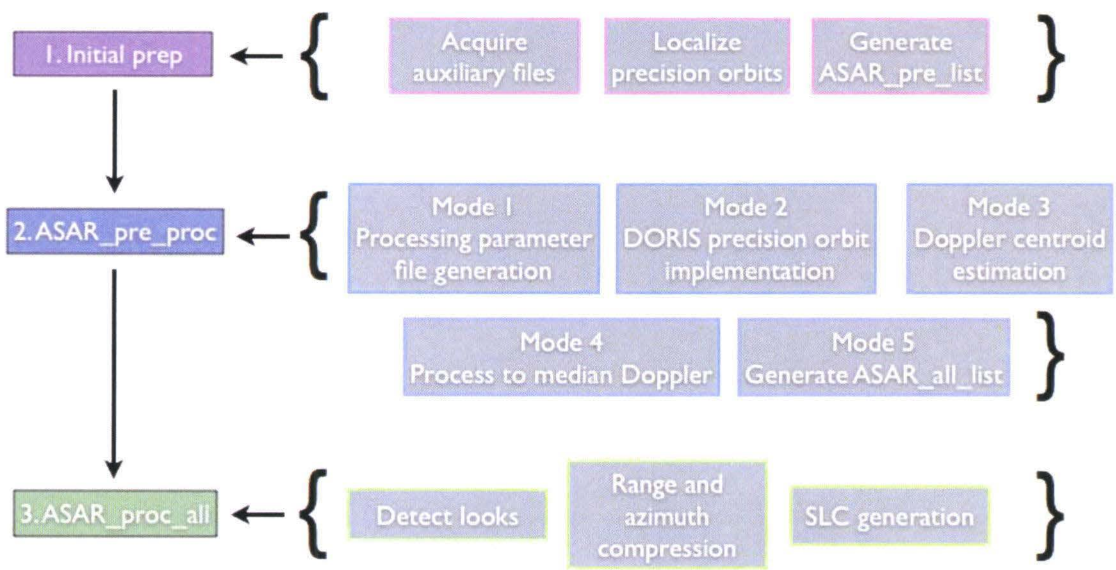
Please note that commands and scripts in GAMMA are all case-sensitive. Every command and script is run inside the processing directory, unless otherwise noted. Scripts are usually used to run commands on the entire list of available data scenes. Please refer to **Appendix E** for a list and syntax of commands and scripts used in this manual.

Radar acquisitions are referred to as scenes or layers in this manual. The entire list of acquired scenes is often referred to as the "data stack". However, the "stacking" process (see ISP/DIFF module) estimates an average linear velocity for each point in the layer throughout the entire "data stack". When this process has been carried out, we refer to the result as the "stacked data" containing of one single map of averaged velocities. Interferograms are also called 'pairs' and are layers of the interferometric "data stack".

## MSP – Modular SAR Processor

In MSP processing raw radar data from current space or airborne sensors is converted to single-look complex images (SLC). The data may be downloaded from WInSAR (online joint data archive) or ordered from ESA (**Appendix D** provides information about data acquisition). Firstly, a set of auxiliary data files such as instrumentation, calibration and precision orbits files is applied to the raw data. The GAMMA modular SAR processor then allows for accurate range-Doppler algorithms, radiometric calibration to perform basic data conditioning and thereby preserves the phase for interferometric processing.

The following flow chart describes the basic processing flow where each step is going to be illuminated in greater detail throughout this chapter. Processing scripts consist of a series of different commands and sometimes can be run in various modes (i.e., mode 0, mode 2 etc.), utilizing a different sequence of commands. Text displayed in the font `courier new` refers to either the content of a file (e.g., *ASAR_pre_list*) or the script/command that is run and their standard output. The input arguments are separated by spaces. For an explanation of the input/output parameters please refer to **Appendix E** (index of commands/scripts and their syntax). A command history can be found in the README file and in the example of the MSP application in **Appendix H**.




### MSP-1 Initial Preparation

In order to run the initial commands a few points need to be checked off first:

- ☐ Current location of auxiliary files on processing machine is determined
- ☐ Auxiliary files are up to date
- ☐ Current location of precision orbits on processing machine is known
- ☐ Precision orbits are up to date
- ☐ Preprocessing list is generated (necessary for running next script, see MSP-1.2)

The following few paragraphs explain these files and provide download information as well as how to use them.

*MSP-1.1* Auxiliary Files

Auxiliary files, (i.e., instrument characterization, external calibration and precise orbit files) are necessary input parameters for the MSP preprocessing and can be obtained through ESA (see **Appendix F**). It is important to determine exactly which auxiliary file is appropriate for a specific date since ESA generates updated versions while keeping previous ones. The instrument characterization files are only updated if the instrument operating parameters change. External calibration files, in contrast, are updated every six months. The most recent processing date (the date when the auxiliary file was created) must be used and the correct date range for the SAR scene must be determined.

Instrumentation characterization files (*ASA_INS_**) contain parameters that characterize the ASAR instrument, such as look-up tables and other ground processing factors. The files contain subsets of the instrument characterization database. The appropriate filename including the full path is specified in a list (*ASAR_pre_list*) during the MSP preprocessing. For example, the date of a SAR raw data file is **February 5th 2003** (20030205) and the following list of *ASA_INS_** files is available,

*ASA_INS_AXVIEC20051219_161945_20030211_000000_20061231_000000*
*ASA_INS_AXVIEC20031212_105841_20021017_162400_20030204_110000*
*ASA_INS_AXVIEC20031209_113259_20021030_110000_20030211_000000*
*ASA_INS_AXVIEC20031202_122530_20020815_131000_20031017_162400*

where for the first example file column three corresponds to the processing date (**20051219*) and columns five and seven (*20030211_*_20061231*) represent the date range that the specific file is to be used for.

For a data scene from February 5th 2003 one would choose the following instrumentation characterization file: *ASA_INS_AXVIEC20031209_113259_20021030_110000_20030211_000000*, where 20031209 is the most recent processing date and 20030205 is in the date range between 20021030 and 20030211.

External calibration files (*ASA_XCA_**) contain calibration data such as the external calibration scaling factor and the in-flight elevation pattern estimates. These files are required to extract the antenna pattern as measured on the ground and they are used to compensate for the antenna gain across the swath. Example filename: *ASA_XCA_AXVIEC20050803_150715_20030211_000000_20030601_000000*, where 20050803 is the processing, 20030211 the start date and 20030601 the end date. The same selection procedure as for the instrumentation characterization files is applied to find the appropriate file if multiple processing dates or date ranges are available.

Precise orbit state vectors (*DOR_VOR_**) are obtained from the DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) instrument. DORIS Doppler-shift data produces preliminary orbit estimates and precise orbit state vectors. Precision orbits often improve baseline estimates allowing a better simulation of the topographic phase, hence resulting in more precise differential interferograms.

Examples of DORIS vector files:

*DOR_VOR_AXVF-P20030415_154900_20030203_215528_20030205_002328*

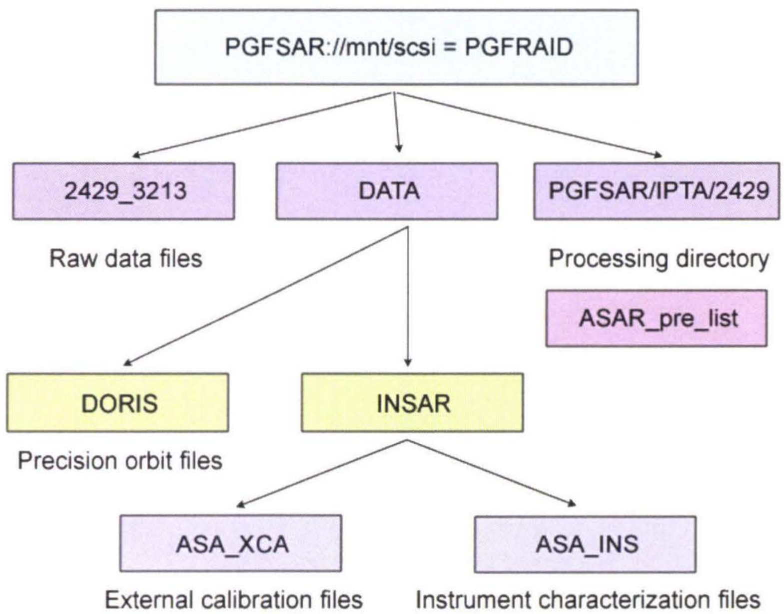
*DOR_VOR_AXVF-P20030415_155000_20030204_215528_20030206_002328*

*DOR_VOR_AXVF-P20030415_155100_20030205_215528_20030207_002328*

For the **February 5$^{th}$ 2003** scene *DOR_VOR_AXVF-P20030415_155000_20030204_215528_20030206_002328* would be the appropriate file to use because 20030205 is in the range *20030204_*_20030206*.

An alternative set of precision orbits (DELFT orbits) is available through the University of Delft, where DORIS tracking data and SLR (Satellite Laser Ranging) are combined.

The schematic below shows the location of the auxiliary files on the processing machine PGFSAR with respect to the local processing directory (*2429_3213*).




*MSP-1.2 ASAR_pre_list*

GAMMA's ASAR raw data preprocessing script requires an input list. This ASAR_pre_list consists of four columns per entry listing the ASAR raw data and associated calibration data:

Column 1: Level 0 (L0) ASAR raw data set, filename includes full path

Column 2: ASAR instrument characterization data file, filename includes full path

Column 3: ASAR external calibration data file, filename includes full path

Column 4: DORIS state vector file, filename does NOT include path

For every available data scene four columns have to be filled with (1) the correct raw data filename, (2) instrument characterization and (3) external calibration files, all with full path information, and (4) the DORIS filename without the path. The four columns must be in one line in a text editor.

Here are the first two entries for two data scenes in an ASAR_pre_list:

```
/mnt/scsi/2429_3213/ASA_IM__0CNPDE20050112_202041_000000152033_00429_15012_5852.N1
/mnt/scsi/DATA/INSAR/ASA_INS/ASA_INS_AXVIEC20051219_161945_20030211_000000_20061231_000000
/mnt/scsi/DATA/INSAR/ASA_XCA/ASA_XCA_AXVIEC20060223_133247_20050101_000000_20050914_000000
DOR_VOR_AXVF-P20050303_101000_20050111_215528_20050113_002328
/mnt/scsi/2429_3213/ASA_IM__0CNPDE20050914_202045_000000152040_00429_18519_2347.N1
/mnt/scsi/DATA/INSAR/ASA_INS/ASA_INS_AXVIEC20051219_161945_20030211_000000_20061231_000000
/mnt/scsi/DATA/INSAR/ASA_XCA/ASA_XCA_AXVIEC20060223_133247_20050101_000000_20050914_000000
DOR_VOR_AXVF-P20051216_153300_20050913_215528_20050915_002328
```

Two lines each four columns long are shown above, appearing as eight lines because of the limited document width. It is essential that the end of every line after the fourth column is marked by a carriage return (ENTER) and that no empty lines exist. In the above example the carriage return is only behind the fourth column (*DOR_VOR*20050113_002328* and *DOR_VOR*20050915_002328*).

After generation of the *ASAR_pre_list*, stored inside the working directory, the script **ASAR_pre_proc** is ready to be run.

### MSP-2 ASAR Raw Data Preprocessing

In the MSP raw data preprocessing the *ASAR_pre_list* is used in the GAMMA script ASAR_pre_proc that is run in modes 1 through 5.

The GAMMA script **ASAR_pre_proc** should be sequentially run in the following five modes:

1: Create processing parameter files and unpack raw data

2: Extract and interpolate DORIS state vectors and update MSP processing parameter files

3: Estimate Doppler centroid

4: Set value a (e.g., median Doppler) in processing parameter files for a keyword:value pair (optional)

5: Generate processing list for use by ASAR_proc_all

#### *Mode 1: Create processing parameter files and unpack raw data (log)*

```
ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_1.log ASAR_all_list 1
```

Within **ASAR_pre_proc** the following commands are run in mode 1 for the entire list of scenes specified in the *ASAR_pre_list*:

**ASAR_XCA**, **ASAR_IM_proc**, **set_value**, **ORB_prop**

- Interpretation of ASAR external calibration data file, used to extract appropriate antenna pattern (the antenna parameter indicated on command line)

```
ASAR_XCA /mnt/scsi/DATA/INSAR/ASA_XCA/ASA_XCA_AXVIEC20060223_133247_20050101_000000_20050914_
000000 raw/ASAR_20050914_IS2_VV.gain IS2 VV
```

- MSP preprocessing for ASAR L0 image mode data

**ASAR_IM_proc** generates MSP sensor parameter (SAR_par example) and processing parameter files

(PROC_par example) from Level 0 (raw) ASAR image mode data. 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. I/Q refers to the real in-phase (I) component and the imaginary quadrature (Q) component of the complex radar return. An unsigned numeric variable can only represent positive numbers.

```
ASAR_IM_proc /mnt/scsi/2429_3213/ASA_IM__0CNPDE20050914_202045_000000152040_00429_18519_
2347.N1 /mnt/scsi/DATA/INSAR/ASA_INS/ASA_INS_AXVIEC20051219_161945_20030211_000000_20061231_
000000 raw/ASAR_20050914_IS2_VV.par raw/p20050914.slc.par raw/20050914.raw raw/ASAR_20050914
_IS2_VV.gain
```

- Set title in the processing parameter file

```
set_value raw/p20050914.slc.par raw/p20050914.slc.par "title" "ASA_IM__0CNPDE20050914_202045_
000000152040_00429_18519_2347.N1 ASAR_20050914_IS2_VV.par"
```

```
keyword found: title    old value: ASA_IM__0CNPDE20050914_202045_000000152040_00429_18519_
2347.N1  new value: ASA_IM__0CNPDE20050914_202045_000000152040_00429_18519_2347.N1 ASAR_
20050914_IS2_VV.par
```

- Calculate additional state vectors using orbit propagation and interpolation

```
ORB_prop raw/p20050914.slc.par 7 10
```

***Mode 2: Extract and interpolate DORIS state vectors and update MSP processing parameter files (log)***

```
ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_2.log ASAR_all_list 2
```

The following command is run in mode 2 for the entire list of scenes: **DORIS_proc**

- Extract Envisat DORIS state vectors and write to a MSP processing parameter file

```
DORIS_proc raw/p20050112.slc.par /mnt/scsi/DATA/DORIS/vor/DOR_VOR_AXVF-P20050303_101000_
20050111_215528_20050113_002328
```

***Mode 3: Estimate Doppler centroid (log)***

```
ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_3.log ASAR_all_list 3
```

SAR takes advantage of the Doppler history of the radar echoes generated by the forward motion of the satellite to synthesize a large antenna. The Doppler effect in combination with the Earth's rotation introduce a frequency shift in the received data, also known as the Doppler shift [*Hanssen*, 2001]. Returns from features in the area ahead of the platform will have upshifted (higher) frequencies, whereas returns from features behind the platform will have downshifted (lower) frequencies. The Doppler shift has to be accounted for in order to combine the information of two scenes into an interferogram. The interferometric correlation is optimized if the scene is observed from the same aspect angle. For a set of scenes this is generally satisfied by processing to a common Doppler centroid.

Zero-Doppler denotes the direction in which the Doppler frequency shift is equal to zero. Returns from the centerline of the beamwidth will show no frequency shift. This direction is perpendicular to the velocity vector of the spacecraft. The actual antenna of the ASAR instrument is aimed almost exactly towards the zero-Doppler line. The Doppler centroid (frequency) is the center frequency of the recorded azimuth spectrum [*Fiedler*, 2005] and is separated from the zero-Doppler line by the squint-angle. The Doppler centroid should be as small as possible over the entire scene. Otherwise repeat-pass interferometry can not be carried through because of errors related to azimuth compression, range migration and calibration caused by a too large Doppler centroid. If the Doppler centroid reaches a value above 1 pulse repetition frequency (PRF) the determination of the Doppler ambiguity becomes a necessary step. However, in modern systems such as ERS and Envisat yaw-steering is employed to maintain the Doppler centroid of the data within ½ of the PRF of the SAR making the Doppler ambiguity determination an optional step (GAMMA MSP documentation) for Envisat data. After Wegmüller [1997] an estimate of the Doppler centroid is then unambiguous because the Nyquist criteria for sampling of band-limited signals is satisfied.

Estimation of the fractional part of the Doppler centroid may be obtained by incoherent summation of azimuth spectra [*Li*, 1985] or cross correlation [*Madson*, 1989]. Since ASAR's yaw-steering avoids large squint angles, it is not necessary to use the cross-correlation algorithms which determine the Doppler centroid across the swath as a function of range. It is sufficient to average the azimuth spectrum.

The following command is run in mode 3 for the entire list of scenes: **azsp_IQ**

- Azimuth spectrum and Doppler centroid estimation for IQ raw SAR data (file format: text)

```
azsp_IQ raw/ASAR_20050112_IS2_VV.par raw/p20050112.slc.par raw/20050112.raw raw/20050112.azsp
```

***Calculate the median Doppler centroid (optional)***

In order to further improve correlation all available scenes to the same median Doppler centroid. MATLAB can read the output of the following UNIX `grep` command if saved appropriately to calculate the median etc.

```
grep doppler_polynomial raw/*par >doppler

-5.73889e+01
-7.20603e+01
-1.58726e+02
-1.81143e+02
-1.61043e+02
-1.40870e+02
-1.53005e+02
-1.50379e+02
-1.56168e+02
-1.43340e+02
-1.52255e+02
-1.51796e+02
-1.56925e+02
-1.26771e+02
-1.21063e+02
-1.56638e+02
-2.09223e+02
-1.10465e+02
-1.12540e+02
-1.12393e+02
-1.29532e+02

matlab&
mean -138.7488
median -150.3790
range  151.8341
```

***Mode 4: Set a value in the processing parameter files for a keyword: value pair (optional) (log)***

```
ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_4.log ASAR_all_list 4
doppler_polynomial "-150.3790 0. 0. 0."
```

The following command is run in mode 4 for the entire list of scenes: **set_value**

- Replace individual Doppler polynomials by median value

```
set_value raw/p20050112.slc.par raw/p20050112.slc.par doppler_polynomial "-150.3790 0. 0. 0."
```

```
keyword found: doppler_polynomial    old value: -1.21063e+02  0.00000e+00  0.00000e+00
0.00000e+00   Hz     Hz/m     Hz/m^2     Hz/m^3  new value: -150.3790 0. 0. 0.
```

***Mode 5: Generate processing list for use by ASAR_proc_all (log)***

```
ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_5.log ASAR_all_list 5
```

Output parameter: ASAR_all_list

**MSP-3 ASAR Processing from RAW Data**

In order to prepare for further processing the multi-look ratio has to be determined. One of the results from the **ASAR_proc_all** run are the multi-look images, created from the SLC.

*MSP-3.1 Detect Looks*

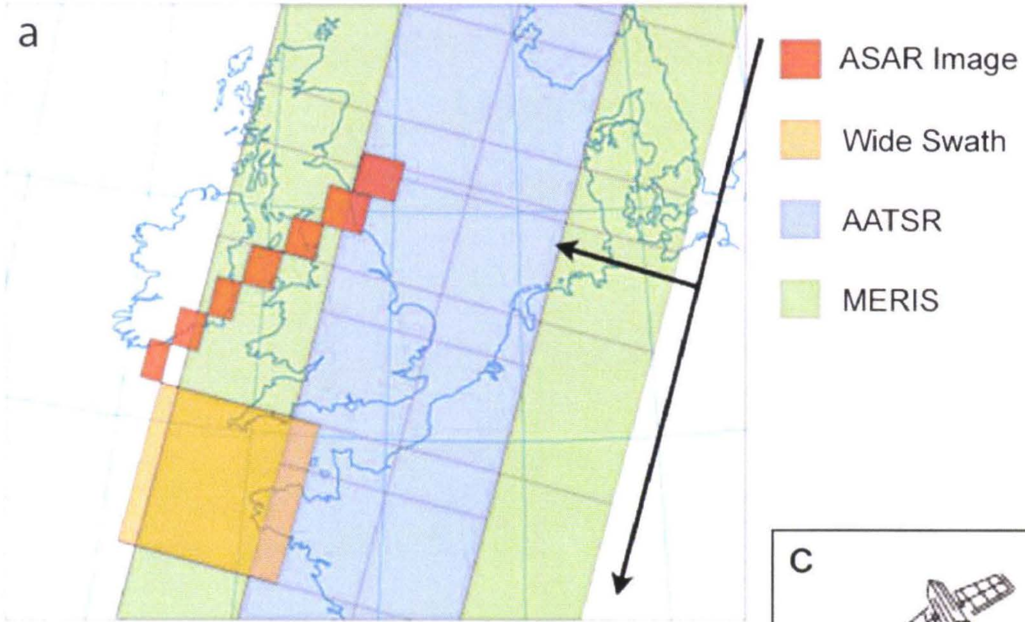
The ASAR instrument aboard the Envisat satellite can maneuver in seven different image swaths when operating as a stripmap SAR (Figure 3a: Envisat ground coverage PDF 650 KB). The beam incidence angle increases with increasing image swath (IS1 - IS7), accordingly the swath width generally decreases.
The slant-range pixel spacing or SRPS (slant-range: satellite's line-of-sight) depends only on the bandwidth of the sensor and is for Envisat approximately 7.8 m. Slant-range can be converted to ground-range by simply applying trigonometry, using the maximum and minimum beam incidence angles for the appropriate image swath.

The azimuth pixel spacing (APS) solely depends on the velocity of the satellite and is 4.1 m for IS2. The beam incidence angle ranges for IS2 from 19.2° to 26.7°, calculating a ground-range pixel spacing (GRPS) that ranges from 23.7 m for the lowest possible incidence angle to 17.4 m for the highest possible incidence angle (Figure 3b: Table of ASAR image swaths & parameters).

Imaging SLC data results in a distorted picture (Figure 4a: SLC PDF 10.1 MB) related to the slant-range projection. In order to show the radar data in a physically logical way, the SLC data needs to be projected to ground-range, i.e., it has to be multi-looked. The appropriate multi-look ratio (MLR) can be determined as follows:

For IS2 a GRPS of 23.7 – 17.4 m was calculated using a constant azimuth pixel spacing of 4.1 m (Figure 3c: Slant-range to ground-range conversion). It can be shown that the ratio between GRPS and APS ranges from 5.78 to 4.24. The average integer is 5, clearly the only possible integer in the middle of the spectrum between 5.78 and 4.24. The ratio therefore is 1:5, meaning the azimuth samples will be averaged by a factor of five while the range sample size remains the same.

a




b

| Image Swath | Swath Width (km) | Ground position from nadir (km) | Incidence Angle Range° |
|---|---|---|---|
| IS1 | 105 | 187—292 | 15.0—22.9 |
| IS2 | 105 | 242—347 | 19.2—26.7 |
| IS3 | 82 | 337—419 | 26.0—31.4 |
| IS4 | 88 | 412—500 | 31.0—36.3 |
| IS5 | 64 | 490—555 | 35.8—39.4 |
| IS6 | 70 | 550—620 | 39.1—42.8 |
| IS7 | 56 | 615—671 | 42.5—45.2 |

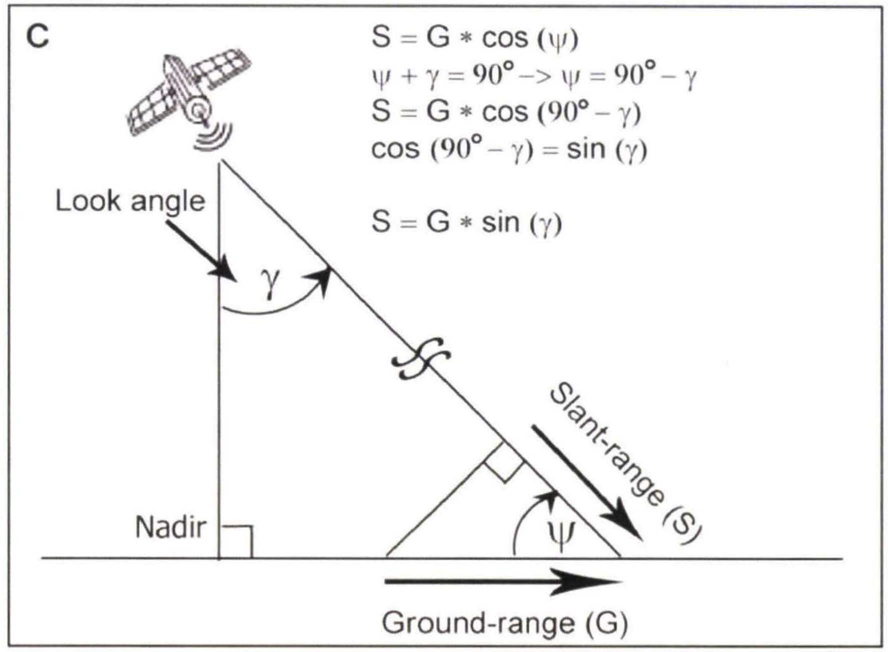



Figure 3: (a) Ground coverage of Envisat's ASAR image mode swaths 7 - 1 (from left to right) descending track, (b) Envisat's image swaths (IS) and corresponding parameters, red box referrs to IS of dataset used in processing example (a, b: www.eurimage.com), (c) Slant-range (S) to ground-range (G) conversion (after ESA @ envisat.esa.int).

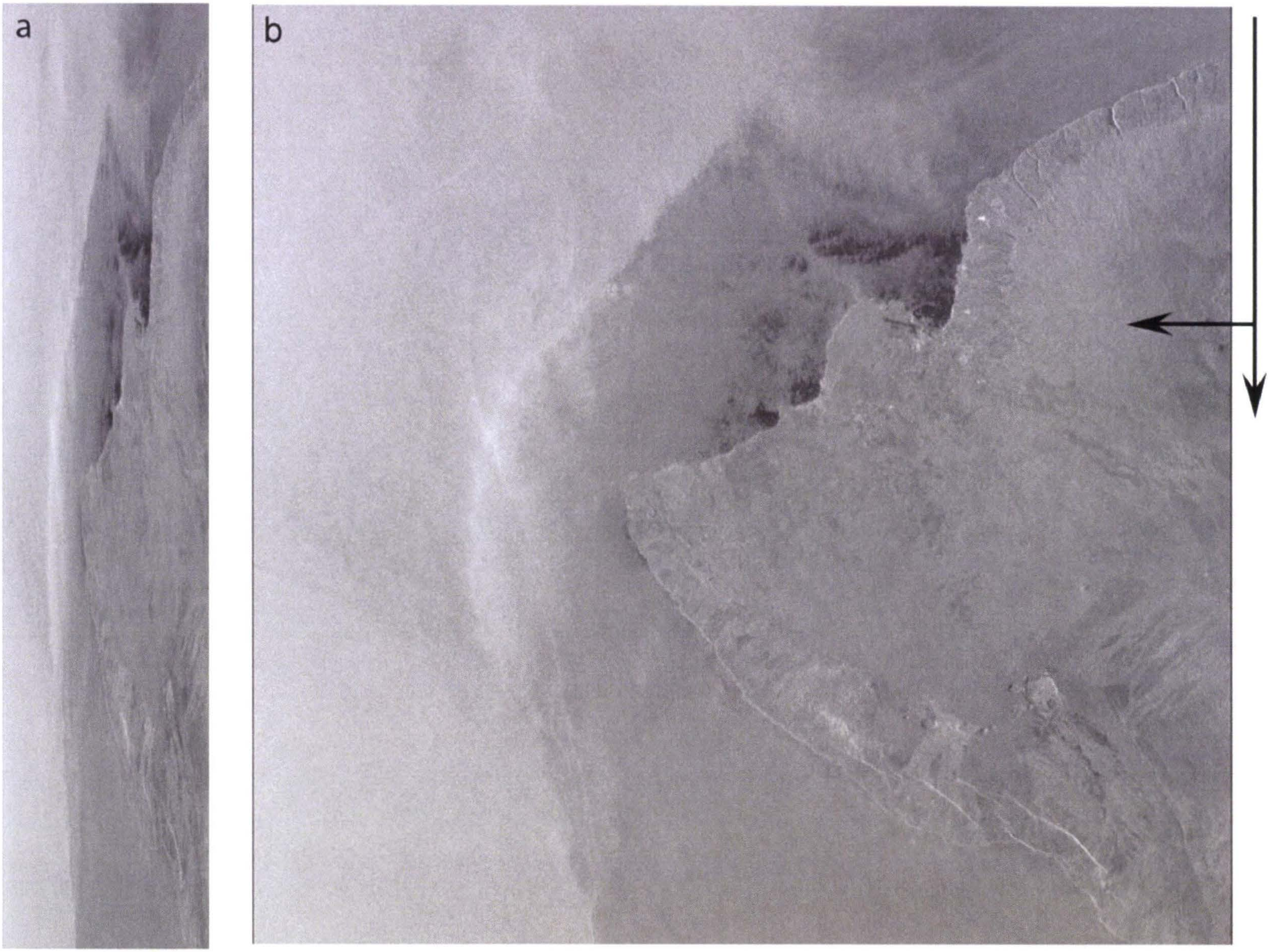



Figure 4: (a) Single-look raster image of the 20030212 single-look complex image (SLC) (MLR 1:1), (b) Multi-look intensity image (MLI) of the 20030212 SLC (MLR 1:5). Envisat ASAR IS2 track 429 frame 3213 (arrows indicte flight and look direction).

| **IS2**<br>APS = 4.1 m<br>SRPS = 7.8 m | **Minimum value** | **Maximum value** |
|---|---|---|
| γ | 19.2° | 26.7° |
| GRPS = SRPS/sin γ | 23.7 m | 17.4 m |
| MLR = GRPS/APS | 5.78 | 4.24 |

For IS6 the multi-look ratio turns out to be 1:3.

| **IS6**<br>APS = 3.9 m<br>SRPS = 7.8 m | **Minimum value** | **Maximum value** |
|---|---|---|
| γ | 39.1° | 42.8° |
| GRPS = SRPS/sin γ | 12.37 m | 11.48 m |
| MLR = GRPS/APS | 3.17 | 2.94 |

Multi-looking reduces the number of azimuth samples by increasing the APS. For example, IS2 data originally has an APS of 4.1 m. Multi-looking it 1:5 increases the APS by a factor of five to 20.5 m. This value is similar to the average GRPS which ranges from 17.4 m for the maximum incidence angle to 23.7 m for the lowest. Five pixels are now joined in one, increasing the signal-to-noise ratio (SNR) because more data (signal) is available for a specific area.

**ASAR_proc_all** is the final script to run in the MSP processing. Depending on the area covered in the scene there are two ways to run this script.

Firstly, these directories need to be generated in the processing directory (*2429_3213/*):

```
mkdir tmp
mkdir slc
mkdir mli_1_5
```

*MSP-3.2 ASAR_proc_all*

Scenes that are mostly covered by land close to the center of the SAR image will have no problem running this script. Scenes in which the center is largely surrounded by water however, are more problematic. One of the commands that is run in this script (**autof**) tries to auto focus over this area of water (no real data values over water) and does not determine a high enough SNR, hence it crashes (ERROR: autofocus rejected, correlation SNR below threshold: 10.00). Therefore the script ASAR_proc_all_no_autof has the two **autof** commands commented out. The main purpose of the script is to perform range and azimuth compression to recover full resolution. To follow is a sequence of commands run by the script ASAR_proc_all that generates the Single-Look Complex image (SLC) and associated parameter files.

```
ASAR_proc_all_no_autof ASAR_all_list raw tmp slc mli_1_5 1 5 0
```

The script runs the following commands for the entire list of scenes:

**set_value**, **set_value**, **pre_rc**, **az_proc_dop2d**, **multi_SLC**, **raspwr**, **par_MSP**, **par_MSP**

- Uses information in *ASAR_all_list* to update Doppler-polynomial (round median Doppler to first decimal)

```
set_value raw/p20050112.slc.par raw/p20050112.slc.par doppler_polynomial "-150.3790 0. 0. 0."
keyword found: doppler_polynomial    old value: -1.21063e+02  0.00000e+00  0.00000e+00
0.00000e+00   Hz     Hz/m     Hz/m^2     Hz/m^3  new value: -150.3790 0. 0. 0.
```

- Set the azimuth bandwidth fraction in the processing parameter file

```
set_value raw/p20030212.slc.par raw/p20030212.slc.par azimuth_bandwidth_fraction 0.8
keyword found: azimuth_bandwidth_fraction    old value: 0.8000  new value: 0.8
```

- SAR data prefilter, decimation and range compression for complex IQ data

A matched filter is applied to the data in range resulting in range compression. The option of decimation in azimuth (prefiltering) exists. Output file format: rc_data

```
pre_rc raw/ASAR_20030212_IS2_VV.par raw/p20030212.slc.par raw/20030212.raw tmp/20030212.rc
```

- SAR range-Doppler azimuth compression with along-track Doppler centroid update

This command reads the sensor and processing parameter files and the SAR range-compressed data. It performs azimuth compression using the range-Doppler algorithm. Radiometric compensation and calibration is applied. Corrections are performed for slant-range, antenna pattern and receiver gain. **Az_proc** creates the SLC which is visualized in Figure 4. The two images appear "flipped" horizontally according to the viewing geometry of the radar on the satellite's descending path (~9° east of north). The reference frame is also referred to as the range-Doppler coordinate system (RDC) describing the SAR geometry. To transform RDC to an Equal-Angle projection (EQA) in latitude/longitude the images would have to be "flipped" horizontally and "rotated" so north is up (see Geocoding chapter for more details). Figure 4a shows the SLC image with a look ratio of 1:1 (single-look), clearly indicating a "stretched" view. Multi-looking adjusts the ground range pixel spacing to create "square" pixels (see section MSP-3.1). The raster image of the multi-look intensity image is shown in Figure 4b.

```
az_proc_dop2d raw/ASAR_20030212_IS2_VV.par raw/p20030212.slc.par tmp/20030212.rc
slc/20030212.slc 6144 0 -30 0 2.12
```

- Calculate a Multi-Look Intensity image (MLI) and MLI_PROC_par from a SLC using the previously determined MLR 1:5

```
multi_SLC raw/p20030212.slc.par mli_1_5/p20030212.mli.par slc/20030212.slc mli_1_
5/20030212.mli 1 5
```

- Generate raster image of the multi-look intensity image (Figure 4b: MLI)

```
raspwr mli_1_5/20030212.mli 5158
```

- Create ISP image parameter file from MSP processing parameter and sensor files

```
par_MSP raw/ASAR_20030212_IS2_VV.par raw/p20030212.slc.par slc/20030212.slc.par
```

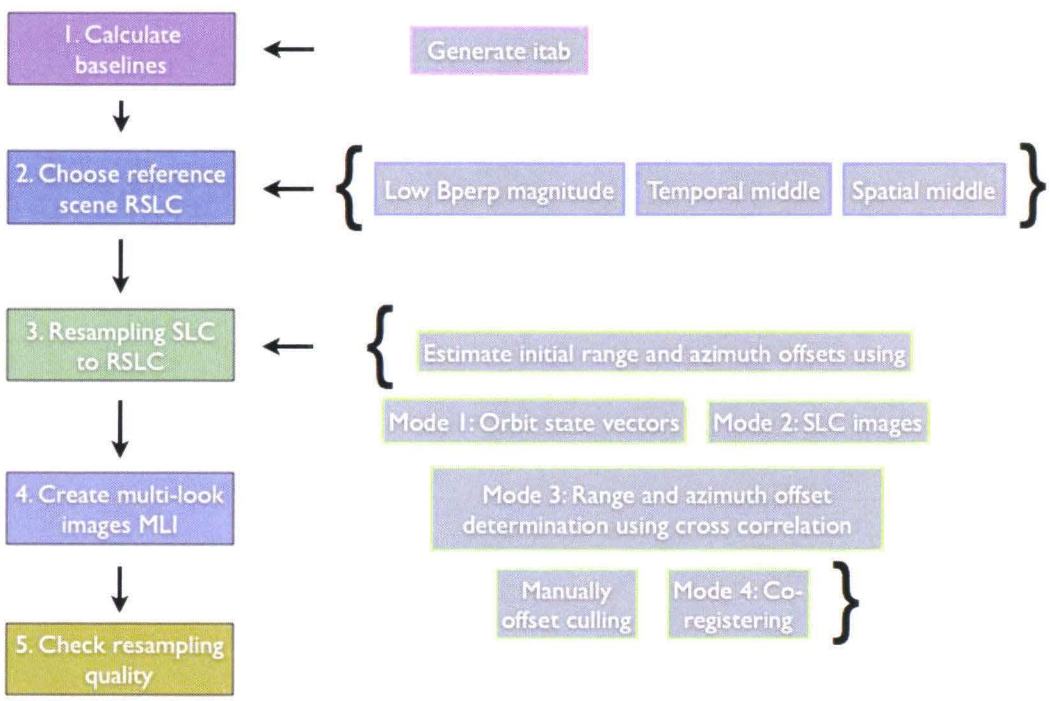
- Create MLI ISP image parameter file from MSP processing parameter and sensor files

```
par_MSP raw/ASAR_20030212_IS2_VV.par mli_1_5/p20030212.mli.par mli_1_5/20030212.mli.par
```

## ISP – Interferometric SAR processor – Resampling

After generating of the single-look complex (SLC) images the resampling process can be started. One scene from the available data set is chosen as the reference scene. All other scenes need to be co-registered to the geometry of this reference scene. This permits the creation of interferograms at a later stage (ISP/DIFF).

The following flow chart describes the basic processing flow where each step is going to be illuminated in greater detail throughout this chapter. Processing scripts consist of a series of different commands and sometimes can be run in various modes, utilizing a different sequence of commands. Text displayed in the font `courier new` refers to either the content of a file or the script/command that is run and their standard output. The input arguments are separated by spaces. For an explanation of the input/output parameters please refer to **Appendix E** (index of commands/scripts and their syntax). A command history can be found in the README file and in the example of the MSP application in **Appendix H**.




In order to prepare for further processing, a list of all the SLC and the corresponding parameter files (two column list), referred to as the SLC_tab, can be created as follows in the processing directory (*2429_3213/*):

```
/bin/ls -1 slc/*.slc > q1
/bin/ls -1 slc/*.slc.par > q2
paste q1 q2 > SLC_tab
```

#### ISP-1 Calculate Baselines and Generate Itab File

In order to choose an appropriate reference scene, the baselines need to be calculated. The baseline refers to the distance between the two satellites at the time of the acquisitions and can be decomposed into a perpendicular and a parallel baseline component. We calculate the perpendicular baselines from every scene with respect to all the other scenes to determine which scene is most appropriate as a reference. The GAMMA command base_calc calculates the baselines; base_calc also creates the itab file, a control file for further processing (example itab). The itab is an interferometric table that associates interferogram stack record numbers with pairs of SLC stack records (list from SLC_tab), enabling selective processing by "turning on or off" individual pairs. The first column in the itab corresponds to the master scene whereas the second column denotes the slave. The number refers to the position in the SLC_tab. The third column in the itab is the pair or record number. The fourth column is used to indicate if that specific pair is to be processed (1) or not (0). The example below shows excerpts from an itab (left) and a SLC_tab (right).

```
1   2    1  1
1   5    2  1
1   8    3  1
1   9    4  1
1  12    5  1
1  14    6  1
1  15    7  1
1  20    8  1
1  21    9  1
2   3   10  1
2   4   11  1
```

```
slc/20030212.slc    slc/20030212.slc.par
slc/20030702.slc    slc/20030702.slc.par
slc/20030910.slc    slc/20030910.slc.par
slc/20031015.slc    slc/20031015.slc.par
slc/20031119.slc    slc/20031119.slc.par
slc/20031224.slc    slc/20031224.slc.par
slc/20040128.slc    slc/20040128.slc.par
slc/20040303.slc    slc/20040303.slc.par
slc/20040512.slc    slc/20040512.slc.par
```

For example, the first pair denoted in the itab (1 2 1 1) has 20030212 as master scene (first entry in SLC_tab) and 20030702 as slave (second entry in SLC_tab). The pair (1 8 3 1) can be identified as the third record because of the number 3 in the third column. This pair has the same master scene but the eight entry from the SLC_tab as slave (20040303). All itab pairs shown here are "turned on" (1) and will be considered in the processing.

The number of pairs is limited in the itab by applying baseline and time span restrictions. The itab can either be a "single-reference" list, where the master (reference) scene in all pairs is the same or it can be an "all-pair" list allowing different master scenes in all interferometric pairs.

The standard output of every run is saved by piping it to a file using the operator >

```
base_calc SLC_tab slc/20030212.slc.par 20030212.bperp.gr 20030212.bperp itab 0 >1
base_calc SLC_tab slc/20030702.slc.par 20030702.bperp.gr 20030702.bperp itab 0 >2
```

### ISP-2 Reference Scene: Selection-criteria and Algorithms

A "good" reference scene has to meet a few criteria. Its perpendicular baseline magnitude with respect to the other scenes should be low (< 200 m), the acquisition date should resemble the approximate temporal middle of all the available scenes and the center lat/long should represent a mean spatial center (see below).

The standard output of the command **base_calc** saved into separate files can be searched for the lowest perpendicular baseline magnitude. Perpendicular baselines can range from a few meters to about 1000 m and can also have negative values (relative positions of satellites).

The "average bperp magnitude" determines the average of the absolute values of the perpendicular baselines, whereas the "average bperp" averages the actual values of the perpendicular baselines which can be positive or negative. The average of the absolute values is used to establish a reference scene.

```
grep average 1
average bperp magnitude (m):  770.556
average bperp (m):  755.511

grep average 2
average bperp magnitude (m):  401.879
average bperp (m):  222.413
```

It is also important to find a reference scene that is temporally in the center of the time span of the set of available scenes. This is done by manually evaluating the acquisition dates.

Another important feature to take into account is the spatial middle of the stack. The satellite usually acquires over the same area, however, for some scenes the center lat/long can be very different. By choosing a scene whose area coverage is close to the areas covered by most of the other scenes in the stack, the area processed is maximized. The MATLAB program scenelocation.m (written by Matt Patrick) can be utilized for this purpose.

A few points need to be checked off before the program scenelocation.m can be run correctly:

- Copy the script *scenelocation.m* (see **Appendix F** for location) to the *raw* directory
- Adjust lines 3 and 29 in the script according to the current path of the *raw* directory
- Check the line number of the center latitude and center longitude in the p*.slc.par and change line 18 appropriately
- Choose a scene for the mid date (line 32), e.g., lowest Bperp, or temporal middle of the stack

Figures 5a and b (MATLAB graphs PDF 6.6 MB) show the MATLAB figure for the list of scenes used in this example. As you can see, the selected scene 20041208 is approximately in the middle in latitude (upper plot) and in longitude (lower plot). There are scenes that might be a little bit better suited geographically, but their Bperp magnitudes are larger.

### ISP-3 Resample Set of SLC to a Common Reference SLC

The GAMMA script SLC_resamp_all is modified to accommodate a few user specific features. Increased number of estimated offsets and a manual offset culling mechanism are implemented. The chosen reference scene is *20041208.slc*. Before the resampling process can be started, the reference scene must be copied into the new directory *2429_3213/rslc*.

```
mkdir rslc
```

#### *ISP-3.1 Copy Reference SLC to RSLC*

In this case the entire SLC area is going to be processed. A smaller area might be chosen if processing times have to be kept low.

```
SLC_copy slc/20041208.slc slc/20041208.slc.par rslc/20041208.rslc rslc/20041208.rslc.par 1
```

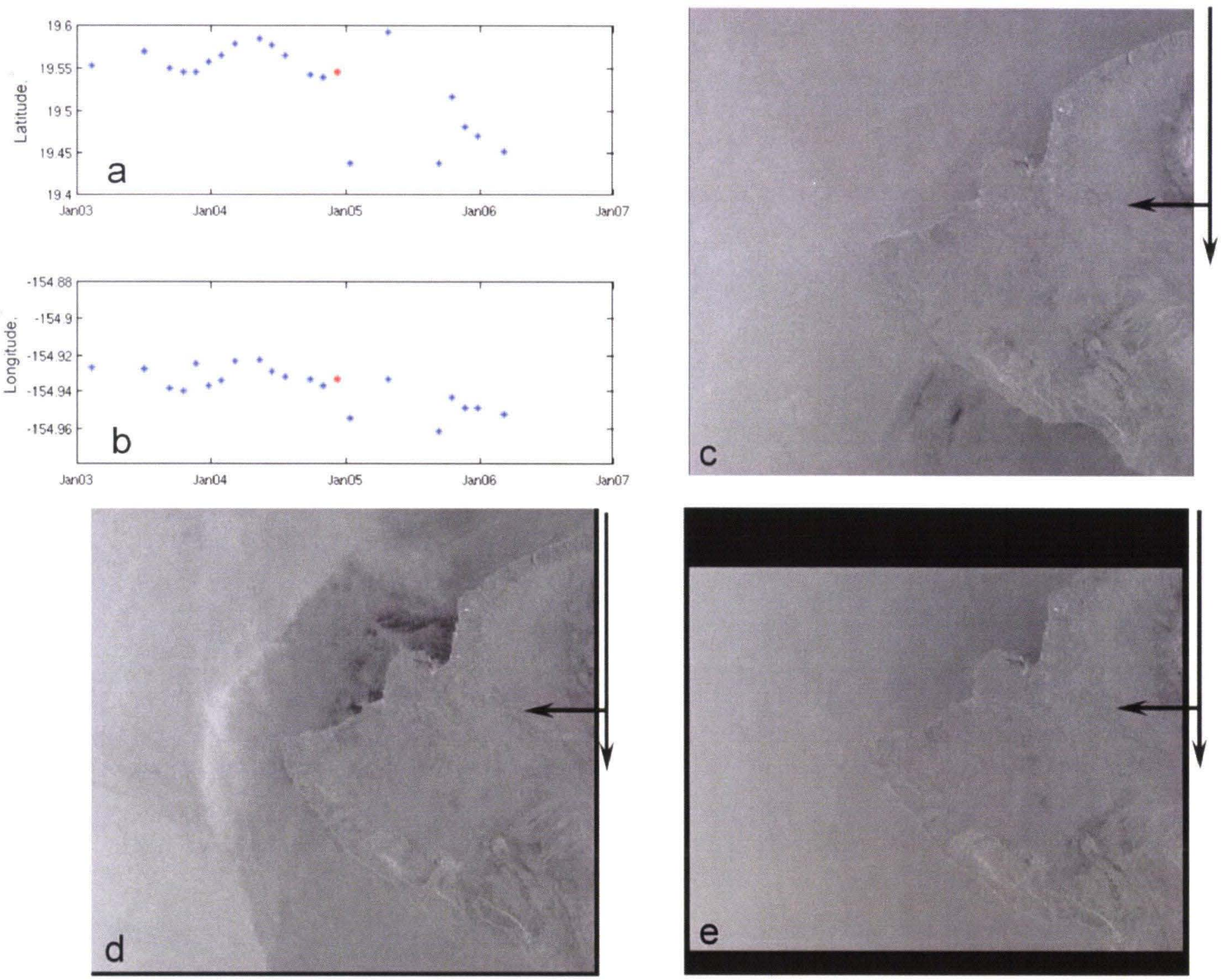



Figure 5: (a), (b) MATLAB figure generated by scenelocation.m, red star indicates reference scene 20041208. (a) Center latitude and (b) center longitude values for all 21 scenes, (c) Multi-look intensity (MLI) image of reference scene 20041208, (d) MLI image of 20030212, notice black stripes around the edges as remnants of the co-registration process to the reference scene, (e) average MLI image, note the small area representing the average covered areaand the smoothness as a result of a high SNR.

In the next step multi-look images are generated. Again, the previously estimated multi-look ratio (MLR) is used.

```
mkdir rmli_1_5
```

*ISP-3.2 Calculate a Multi-Look Intensity (MLI) Image from the Reference RSLC*

```
multi_look rslc/20041208.rslc rslc/20041208.rslc.par rmli_1_5/20041208.rmli rmli_1_
5/20041208.rmli.par 1 5
```

*ISP-3.3 Generate Raster Image of RMLI (Figure 5c: RMLI)*

```
raspwr rmli_1_5/20041208.rmli 5174
```

*ISP-3.4 Resample all SLC to Reference RSLC (RSLC_tab)*

The modified script SLC_resamp_all_cs should be run in the following modes to resample a set of SLC:

0: Create offset parameter files

1: Estimate initial range and azimuth offsets using orbit state vectors

2: Measure initial range and azimuth offsets using SLC images

3: Estimate range and azimuth offset models using correlation of image intensities

4: Resample SLC images using offset models

***Mode 0: Create offset parameter files (log)***

```
SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 0 1 1 5
```

The script runs the following command in mode 0 for the entire list of SLC: **create_offset**

- Create offset parameter files for SLC – RSLC offsets

```
create_offset rslc/20041208.rslc.par slc/20030212.slc.par rslc/20041208_20030212.off <
create_offset.in
```

create_offset.in is created in SLC_resamp_all_cs mode 0 and includes the input parameters for create_offset. Without this file the parameters would have to be specified manually on the command line for each scene.

***Mode 1: Estimate initial range and azimuth offsets using orbit state vectors (log)***

```
SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 1 1 1 5
```

The script runs the following command in mode 1 for the entire list of SLC: **init_offset_orbit**

- Initial SLC image offset estimation from orbit state vector data

```
init_offset_orbit rslc/20041208.rslc.par slc/20030212.slc.par rslc/20041208_20030212.off
```

It is recommended to save the standard output in order to compare the orbit-derived offset estimation to the SLC-derived offset estimation conducted in mode 2.

```
orbit-derived initial range and azimuth offsets:

init_offset_orbit rslc/20041208.rslc.par slc/20030212.slc.par rslc/20041208_20030212.off
initial_range_offset:                    16
initial_azimuth_offset:                 221

init_offset_orbit rslc/20041208.rslc.par slc/20030702.slc.par rslc/20041208_20030702.off
initial_range_offset:                    -9
initial_azimuth_offset:                 674
```

#### *Mode 2: Measure initial range and azimuth offsets using SLC images (log)*

```
SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 2 1 1 5
```

The script runs the following command in mode 2 for the entire list of SLC: **init_offset**

- Determine initial offset between SLC images using correlation of image intensity

In order to avoid ambiguity problems and still achieve an accurate offset estimate, **init_offset** can first be run with multi-looking followed by a second run at single-look resolution. The initial estimates from the first run are used as an initial guess in the second run. In the case of using precise orbits as illustrated in this example, **init_offset_orbit** is run prior to **init_offset**, providing the initial guess and accounting for large registration offsets.

```
init_offset rslc/20041208.rslc slc/20030212.slc rslc/20041208.rslc.par slc/20030212.slc.par
rslc/20041208_20030212.off 1 5 2587 11908
```

It is recommended to save the standard output in order to compare the SLC-derived offset estimation to the orbit-derived offset estimation (see mode 1).

```
SLC-derived initial range and azimuth offsets:
-8 *** (-9) means that -8 is SLC-derived, whereas -9 was orbit-derived

init_offset rslc/20041208.rslc slc/20030212.slc rslc/20041208.rslc.par slc/20030212.slc.par
rslc/20041208_20030212.off 1 5 2587 11908
initial_range_offset:                    16
initial_azimuth_offset:                 221

init_offset rslc/20041208.rslc slc/20030702.slc rslc/20041208.rslc.par slc/20030702.slc.par
rslc/20041208_20030702.off 1 5 2587 11908
initial_range_offset:                    -8*** (-9)
initial_azimuth_offset:                 674
```

#### *Mode 3: Estimate range and azimuth offset models using correlation of image intensities (log)*

```
SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 3 1 1 5
```

The script runs the following command in mode 3 for the entire list of SLC: **offset_pwr**

- Measure range and azimuth registration offset field between reference SLC and RSLC

Cross correlation optimization of detected SLC data is used rather than fringe visibility algorithm (**offset_SLC**)

```
offset_pwr rslc/20041208.rslc slc/20030212.slc rslc/20041208.rslc.par slc/20030212.slc.par
rslc/20041208_20030212.off rslc/20041208_20030212.offs rslc/20041208_20030212.snr - - - 2 100
100
```

Note: The script **SLC_resamp_all_cs** does not run the last **offset_pwr** command completely; it needs to be run manually after mode 3 finishes (the command is printed in std out on the screen).

***Manual culling of offsets***

The script **SLC_resamp_all** was changed in order to interactively cull the estimated offsets. The range and azimuth offset polynomials are computed from the offsets estimated by **offset_pwr**. The program creates polynomial models of range and azimuth offsets using linear least-squares. Particular offsets can be identified as erroneous depending on an indicated SNR (in this case 7.0) and on the deviation of the offset measurement to the current model value. Culling the offsets manually allows the user to observe how many offsets are "thrown out" by setting lower azimuth and range standard deviation thresholds and how that affects the offset-polynomial (here changed to a 4$^{th}$ order polynomial). The commands for all the scenes have to be created manually. In general, a co-registration accuracy better than 0.2 pixels allows to limit the loss of correlation by registration errors to < 10%. It is recommended to save the solution of the offset fit (in the processing README), i.e., the number of offset estimates accepted out of the total number of samples (calculated by **offset_pwr** in mode 3).

```
offset_fit rslc/20041208_20030212.offs rslc/20041208_20030212.snr rslc/20041208_20030212.off
rslc/20041208_20030212.coffs - 6.5 4 1
solution: 27569 offset estimates accepted out of 250000 samples
range offset poly. coeff.:              11.42545   1.74877e-03   5.73562e-05  -1.05131e-08
azimuth offset poly. coeff.:           221.03254  -2.32978e-04   1.81379e-06  -8.40027e-11
model fit std. dev. (samples) range:   0.0994  azimuth:   0.0983

offset_fit rslc/20041208_20030702.offs rslc/20041208_20030702.snr rslc/20041208_20030702.off
rslc/20041208_20030702.coffs - 6.5 4 1
solution: 42089 offset estimates accepted out of 250000 samples
range offset poly. coeff.:              -8.71272   2.12797e-04  -1.91231e-05  -7.35684e-11
azimuth offset poly. coeff.:           672.52513   6.60038e-04  -1.68263e-06  -4.94542e-09
model fit std. dev. (samples) range:   0.0748  azimuth:   0.0997
```

Method of interactively culling the offsets:

(1) Run the command **offset_fit** from above:

```
solution: 51845 offset estimates accepted out of 250000 samples
range offset poly. coeff.: 11.41332 1.74030e-03 7.09690e-05 -1.30885e-08
azimuth offset poly. coeff.: 221.60961 -3.28656e-04 -2.07447e-04 4.72914e-08
model fit std. dev. (samples) range : 1.4857 azimuth: 3.2809
```

The model fit standard deviation (std dev) of the range and azimuth samples should be < 0.1 pixel in our case to absolutely minimize the errors due to misregistration. Usually the azimuth std dev is higher because of the multi-looking in this direction (larger pixel spacing).

(2) Enter the minimum SNR threshold: 6.5

(3) Enter the range and azimuth error thresholds: 10 10

Initial thresholds should be high in order to eliminate outliers.

(4) std out:

```
*** improved least-squares polynomial coefficients 1 ***
solution: 51473 offset estimates accepted out of 250000 samples
range offset poly. coeff.: 11.71386 1.67188e-03 3.97096e-05 -5.85950e-09
azimuth offset poly. coeff.: 220.94872 -2.17446e-04 8.21322e-06 -1.36307e-09
model fit std. dev. (samples) range: 0.2090 azimuth: 0.8535
```

Without outliers the std dev's came down from 1.5 to 0.2 pixel in range and from 3.3 to 0.9 pixel in azimuth.

(5) Iterate and further refine the offset fit? (1 = yes, 0 = no): 1

(6) Enter the minimum SNR threshold: 6.5

(7) Enter the range and azimuth error thresholds: 5 5

Slowly decrease the thresholds.

(8) std out:

```
solution: 51229 offset estimates accepted out of 250000 samples
range offset poly. coeff.: 11.72166 1.67031e-03 3.89725e-05 -5.70626e-09
azimuth offset poly. coeff.: 220.93766 -2.13889e-04 8.41821e-06 -1.46604e-09
model fit std. dev. (samples) range: 0.1754 azimuth: 0.7181
```

This decreased the std dev's only by a small amount, i.e., smaller thresholds can be entered.

(9) Repeat steps 6 and 7, slowly decreasing the thresholds, until the std dev's get close to 0.1 pixel.

Always watch the number of offsets decreasing and how the polynomials change. It is acceptable for the polynomials to only change by a couple of decimals, while the number of accepted offsets falls by thousands. Depending on the dataset the co-registered images will look fine even with few accepted offsets (~1000 out of 250000).

(10) std out:

```
enter the range and azimuth error thresholds: .3 .3
range, azimuth error thresholds: 0.3000 0.3000
SNR threshold: 6.5000
*** improved least-squares polynomial coefficients 1 ***
solution: 33285 offset estimates accepted out of 250000 samples
range offset poly. coeff.: 11.55531 1.71481e-03 4.90487e-05 -8.39746e-09
azimuth offset poly. coeff.: 220.98648 -2.20710e-04 4.05980e-06 -6.85199e-10
model fit std. dev. (samples) range: 0.1191 azimuth: 0.1258
```

Now decrease the thresholds in steps of 0.01 to be sure not to throw out the "good" offsets while approaching values just below 0.1 pixel. Stop iterating when both std dev's are below 0.1 pixel.

(11) std out:

```
solution: 15623 offset estimates accepted out of 250000 samples
range offset poly. coeff.: 11.24656 1.77427e-03 8.84671e-05 -1.65948e-08
azimuth offset poly. coeff.: 221.24406 -2.56562e-04 -7.46270e-05 1.62692e-08
model fit std. dev. (samples) range: 0.0998 azimuth: 0.0997

Iterate and further refine the offset fit? (1=yes, 0=no): 0
```

Summary:

| 250,000 samples | **# Accepted offset estimates** |
|---|---|
| **Initial** | 51845 |
| **Final** | 15623 |

| Polynomials coefficients | Range | Azimuth |
|---|---|---|
| **Initial** | 11.41 1.74e-03 7.10e-05 -1.31e-08 | 221.61 -3.29e-04 -2.07e-04 4.73e-08 |
| **Final** | 11.25 1.77e-03 8.85e-05 -1.66e-08 | 221.24 -2.57e-04 -7.46e-05 1.62e-08 |

| Model fit std dev | Range | Azimuth |
|---|---|---|
| **Initial** | 1.4857 | 3.2809 |
| **Final** | 0.0998 | 0.0997 |

***Mode 4: Resample SLC images using offset models (log)***

```
SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 4 1 1 5
```

Note that the rflag is turned on (1) for measuring offsets to the resampled SLC to confirm the offset model

The script runs the following commands in mode 4 for the entire list of SLC:

**SLC_interp**, **create_offset**, **offset_pwr**, **offset_fit**, **set_value**, **set_value**, **SLC_interp**, **offset_pwr**, **offset_fit**

- SLC complex image resampling using 2-D SINC interpolation and the range/azimuth polynomials

```
SLC_interp slc/20030212.slc rslc/20041208.rslc.par slc/20030212.slc.par rslc/20041208_
20030212.off rslc/20030212.rslc rslc/20030212.rslc.par
```

- Create offset file for offset measurement between the reference SLC and the resampled SLC

```
create_offset rslc/20041208.rslc.par rslc/20030212.rslc.par rslc/20041208_20030212_2.off <
create_offset.in
```

- Measure offsets between reference SLC and RSLC

```
offset_pwr rslc/20041208.rslc rslc/20030212.rslc rslc/20041208.rslc.par rslc/20030212.rslc.par
rslc/20041208_20030212_2.off rslc/20041208_20030212_2.offs rslc/20041208_20030212_2.snr - - - 2
50 50
```

- Estimate the offset polynomial

```
offset_fit rslc/20041208_20030212_2.offs rslc/20041208_20030212_2.snr rslc/20041208_20030212_
2.off rslc/20041208_20030212_2.coffs - - 3
```

Show below is the standard output printed on the screen after running this command.

```
*** improved least-squares polynomial coefficients 6 ***
solution: 448 offset estimates accepted out of 2500 samples
range offset poly. coeff.:              -0.00545  -7.99216e-06   2.36481e-06
azimuth offset poly. coeff.:            -0.06388   1.17525e-05   1.30676e-06
model fit std. dev. (samples) range:   0.1082   azimuth:   0.2766

total number of culling iterations: 6
final solution: 448 offset estimates accepted out of 2500 samples

final range offset poly. coeff.:              -0.00545  -7.99216e-06   2.36481e-06
final range offset poly. coeff. errors:   2.46161e-03   5.75577e-07   7.11318e-08

final azimuth offset poly. coeff.:              -0.06388   1.17525e-05   1.30676e-06
final azimuth offset poly. coeff. errors:   6.29377e-03   1.47162e-06   1.81868e-07

final model fit std. dev. (samples) range:   0.1082   azimuth:   0.2766
```

The just estimated offset polynomial is added to the previously estimated offset polynomial, performed by the script SLC_resamp_all_cs.

- The sum of the range offset polynomials is written in the offset parameter file

```
set_value rslc/20041208_20030212.off rslc/20041208_20030212.off "range_offset_polynomial" "
1.1420000e+01  1.74081e-03  5.97208e-05 -1.05130e-08"
*** update keyword:value based parameter files ***
*** Copyright 2004, Gamma Remote Sensing, v1.2 12-Feb-2004 clw ***

keyword found: range_offset_polynomial    old value: 11.42545    1.7488e-03    5.7356e-05   -
1.0513e-08   new value:  1.1420000e+01  1.74081e-03  5.97208e-05 -1.05130e-08
```

- The sum of the azimuth offset polynomials is written in the offset parameter

```
set_value rslc/20041208_20030212.off rslc/20041208_20030212.off "azimuth_offset_polynomial" "
2.2096866e+02 -2.21227e-04  3.12060e-06 -8.40030e-11"
*** update keyword:value based parameter files ***
*** Copyright 2004, Gamma Remote Sensing, v1.2 12-Feb-2004 clw ***

keyword found: azimuth_offset_polynomial    old value: 221.03254   -2.3298e-04    1.8138e-06   -
8.4003e-11   new value:  2.2096866e+02 -2.21227e-04  3.12060e-06 -8.40030e-11
```

- Resample the SLC again using the refined offset polynomial stored in the offset parameter file

```
SLC_interp slc/20030212.slc rslc/20041208.rslc.par slc/20030212.slc.par rslc/20041208_
20030212.off rslc/20030212.rslc rslc/20030212.rslc.par
```

- Measure offsets between refined RSLC and reference SLC

```
offset_pwr rslc/20041208.rslc rslc/20030212.rslc rslc/20041208.rslc.par rslc/20030212.rslc.par
rslc/20041208_20030212_2.off rslc/20041208_20030212_2.offs rslc/20041208_20030212_2.snr - - - 2
50 50
```

- Fit polynomial to the offsets

```
offset_fit rslc/20041208_20030212_2.offs rslc/20041208_20030212_2.snr rslc/20041208_20030212_
2.off rslc/20041208_20030212_2.coffs - - 3

solution: 444 offset estimates accepted out of 2500 samples
range offset poly. coeff.:               -0.00592    4.21391e-07    2.67473e-07
azimuth offset poly. coeff.:             -0.00636   -6.67370e-07    5.54602e-07
model fit std. dev. (samples) range:   0.1059   azimuth:   0.2719

total number of culling iterations: 6
final solution: 444 offset estimates accepted out of 2500 samples

final range offset poly. coeff.:               -0.00592    4.21391e-07    2.67473e-07
final range offset poly. coeff. errors:    2.41795e-03    5.66593e-07    6.99042e-08

final azimuth offset poly. coeff.:               -0.00636   -6.67370e-07    5.54602e-07
final azimuth offset poly. coeff. errors:    6.20595e-03    1.45423e-06    1.79418e-07

final model fit std. dev. (samples) range:   0.1059   azimuth:   0.2719
```

Compared to the earlier results these std dev's are smaller and therefore the polynomials are accepted as the more precise offset polynomials. One iteration is usually sufficient to improve the models.

### ISP-4 Create Multi-look Images for Individual RSLC and Calculate Average MLI

```
mk_mli_all RSLC_tab rmli_1_5 1 5 1
```

The script runs the following commands for the entire list of RSLC:

**multi_look**, **raspwr**, **ave_image**, **raspwr**, **disras**

- Multi-look the co-registered RSLC using a 1:5 ratio

```
multi_look rslc/20030212.rslc rslc/20030212.rslc.par rmli_1_5/20030212.rmli rmli_1_
5/20030212.rmli.par 1 5
```

- Create a raster image of the RMLI (Figure 5d: RMLI)

```
raspwr rmli_1_5/20030212.rmli 5174 1 4763 1 1 0.9 0.35
```

- Calculate average of input 2D data files (RMLI)

```
ave_image rmli_1_5/mli_list 5174 rmli_1_5/rmli_1_5.ave
```

- Generate raster of average image (Figure 5e: Average RMLI)

```
raspwr rmli_1_5/rmli_1_5.ave 5174 1 0 1 1 .85
```

- Display of Sun raster images

```
disras rmli_1_5/rmli_1_5.ave.ras&
```

- Create parameter file for the average image

```
cp rmli_1_5/20041208.rmli.par rmli_1_5/rmli_1_5.ave.par
```

### ISP-5 Check Quality of the Co-registered SLC

Display the co-registered RSLC (as MLI) and the reference SLC on top of each other (middle mouse button switches between images)

- Alternating display of 2 SUN raster or BMP format images

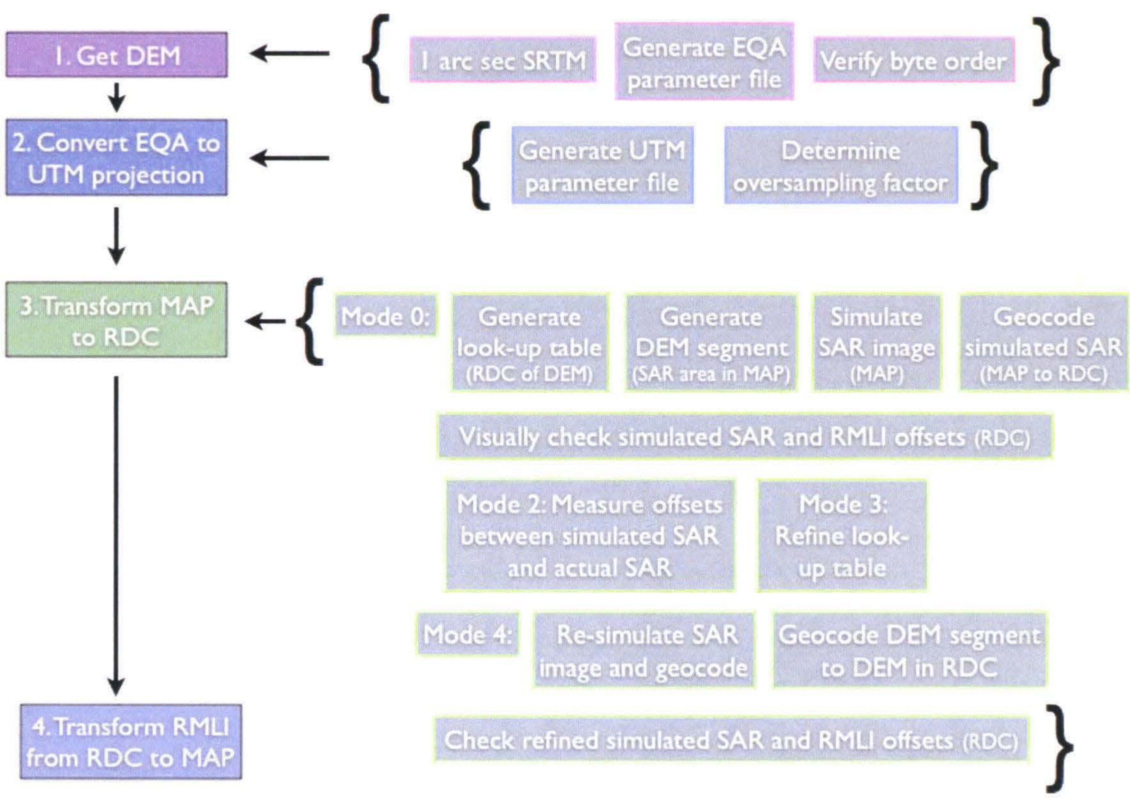
```
dis2ras rmli_1_5/20030212.rmli.ras mli_1_5/20041208.mli.ras
dis2ras rmli_1_5/20030702.rmli.ras mli_1_5/20041208.mli.ras
```

By using the middle mouse button and focusing on the zoom window one can switch between image 1 and image 2 and verify the co-registration. If no obvious differences across the entire scene exist, the resampling process is done. However, for certain datasets there are noticeable offsets of 1 pixel or above. In that case the script SLC_resamp_lt_all needs to be run, which uses a look-up table (map) of offsets instead of a polynomial. The scenes need to all have the same size (width x height) as the reference scene.

## GEO – SAR Geocoding and Image Registration

The idea of interferometric processing is to gather information about the phase after combining two complex SAR images. The interferometric phase consist of signals from surface topography, displacement along the look-vector and noise terms such as atmospheric path delay and errors related to baselines. In order to solve for the deformation signal, the topographic phase contribution has to be simulated and subtracted from the interferogram. As part of the geocoding process described in this chapter, an existing digital elevation model (DEM) will be used to simulate the topographic phase. GAMMA's geocoding module is capable of converting between two different coordinate systems. DEMs in lat/long projection are in MAP coordinates, whereas SAR products such as SAR images and interferograms are in range-Doppler coordinates (RDC). To be able to subtract the topographic phase from the complex interferogram in SAR projection, the DEM needs to be converted to RDC. The result is a differential interferogram, consisting of only deformation, atmospheric distortion and baseline related errors. The term forward geocoding is synonymous for the transformation from MAP to RDC, whereas backward geocoding stands for RDC to MAP conversion.

The following flow chart describes the basic processing flow where each step is going to be illuminated in greater detail throughout this chapter. Processing scripts consist of a series of different commands and sometimes can be run in various modes, utilizing a different sequence of commands. Text displayed in the font `courier new` refers to either the content of a file (e.g., *ASAR_pre_list*) or the script/command that is run and their standard output. The input arguments are separated by spaces. For an explanation of the input/output parameters please refer to **Appendix E** (Index of commands/scripts and their syntax). A command history can be found in the README file and in the example of the MSP application in **Appendix H**.



### GEO-1 Type and Location of Raw DEM Data

The DEM used in the following processing is a product of the Shuttle Radar Topography Mission (SRTM). It was downloaded as the finished data product, delineating and flattening water bodies, better defining coastlines, removing "spikes" and "wells", and filling small voids (steep slopes still may have voids). The data are available at one or three arc sec resolution. One degree of arc is subdivided into 60 arc minutes. One minute of arc consists of 60 seconds. One arc minute of longitude is equivalent to 1853 nm at the equator. In order to calculate the resolution of 1 arc second of longitude at latitude 20, the distance needs to be multiplied by the cosine (lat) which results in an approximate resolution of 29.02 m (2.77e-04 decimal degree) in longitude (USGS SRTM DEM info).

USGS seamless server also provides a meta file, including information on identification, data quality, spatial data organization etc, a header file, giving the dimensions as well as the byte order, a *.blw file including the pixel spacing in lat and long as well as the upper left lat/long coordinates for the downloaded data. The SRTM DEMs are only available in equal angle projection (EQA) and need to be converted to UTM if desired.

### GEO-2 Generation of DEM Parameter File

Parameters from the corresponding files mentioned above are used as the input on the command line.

```
create_dem_par SRTM_BI_1arc_eqa.dem_par
```

### GEO-3 Byte Order Verification

The Byte order of the SRTM DEM is Intel (little-endian, most significant byte (MSB) last). Since GAMMA operations are run on a big-endian machine, the bytes need to be swapped to Motorola (big-endian, MSB first) to continue processing.

- Swap bytes for binary data

```
swap_bytes SRTM_BI_1arc_eqa.dem SRTM_BI_1arc_eqa_swp.dem 2
```

- Display DEM to check area coverage (Figure 6a: DEM in EQA PDF 3.4 MB)

Display DEM with DEM/MAP parameter file as shaded relief to see whether SAR area is fully covered

```
disdem_par SRTM_BI_1arc_eqa_swp.dem SRTM_BI_1arc_eqa.dem_par
```

### GEO-4 Conversion from EQA to UTM

The SAR image has an approximate ground-range pixel spacing of 20 m. The EQA DEM posting is at about 30 m. It is recommended to "adjust" the UTM DEM spacing to the SAR pixel spacing, utilizing one of two different approaches. The first approach, also presented in the following example, chooses 15 m as the UTM DEM spacing, i.e., an approximate oversampling factor of two would be applied during the DEM transformation. The original EQA DEM dimensions are 5492 x 5520, hence the UTM DEM dimensions should be around 10,000 x 10,000 (during UTM DEM parameter file generation). The input parameter <post> in the DEM geocoding script mk_geo_cs is therefore going to be set to 15 m. The script then determines the interpolation factor by dividing the UTM spacing (found in the parameter file) by the input parameter <post>. In this case the interpolation factor for northing and easting is one. The alternative approach leaves the original EQA spacing of 30 m in the generation process of the UTM DEM parameter file. The script **mk_geo_cs** then determines an interpolation of 2, dividing 30 m by the input posting of 15 m. Another important detail to check for is the sign of the latitude/longitude of the first sample as well as for the latitude/longitude posting. By displaying the DEM in GAMMA the correct sign can be determined. Latitude and longitude have to behave in a certain way (increase/decrease) depending on where you are located on the globe. For example, the Big Island of Hawaii is located in the northern hemisphere, therefore latitude has to increase towards north. The latitude of the upper left corner has to be a positive value and the latitude posting value is negative, accounting for increasing latitude with decreasing azimuth. The same concept applies to the longitude. The longitude value is negative, indicating that Hawaii is west of 0° Greenwich. The longitude posting value is positive, accounting for the increasing value with increasing range.

```
create_dem_par SRTM_BI_15m_utm.dem_par rmli_1_5/rmli_1_5.ave.par
```

- Transform EQA DEM to UTM

```
dem_trans SRTM_BI_1arc_eqa.dem_par SRTM_BI_1arc_eqa_swp.dem SRTM_BI_15m_utm.dem_par SRTM_BI_
15m_utm.dem
```

- Display the UTM DEM (Figure 6b: UTM DEM) and the SAR image (Figure 5e: Average RMLI) to check area coverage

```
disdem_par SRTM_BI_15m_utm.dem SRTM_BI_15m_utm.dem_par
gimp rmli_1_5/rmli_1_5.ave.ras
```

**GEO-5 Transforming DEM MAP Coordinates to RDC Geometry**

GAMMA's geocoding script mk_geo was slightly modified, as described below. It can be run in the following seven modes.

0: Generate initial lookup table, simulated SAR image, and DEM segment parameters

1: Generate initial lookup table and simulated SAR image using existing DEM segment to determine image bounds

2: Measure initial offset between simulated SAR image and actual SAR image

3: Perform refinement of lookup table by offset measurement with respect to the simulated SAR image

4: Update lookup table and produce terrain geocoded SAR image and DEM in SAR range-Doppler coordinates (RDC)

5: Ellipsoid geocoding of the SAR image without a DEM: generate new DEM segment parameters

6: Ellipsoid geocoding of the SAR image without a DEM: use existing DEM segment parameters

Terrain geocoding of SAR images with lookup table refinement and transform DEM → SAR range-Doppler Coordinates (RDC). The following example will run **mk_geo_cs** in modes 0, 2, 3 and 4.

***Mode 0: Generate initial lookup table, simulated SAR image, and DEM segment parameters (log)***

```
mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem SRTM_BI_
15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI 15 0 2 2 2 8 1 5 6.5
- - - - 256 256
```

The script runs the following commands in mode 0: **gc_map, geocode, raspwr, dis2ras**

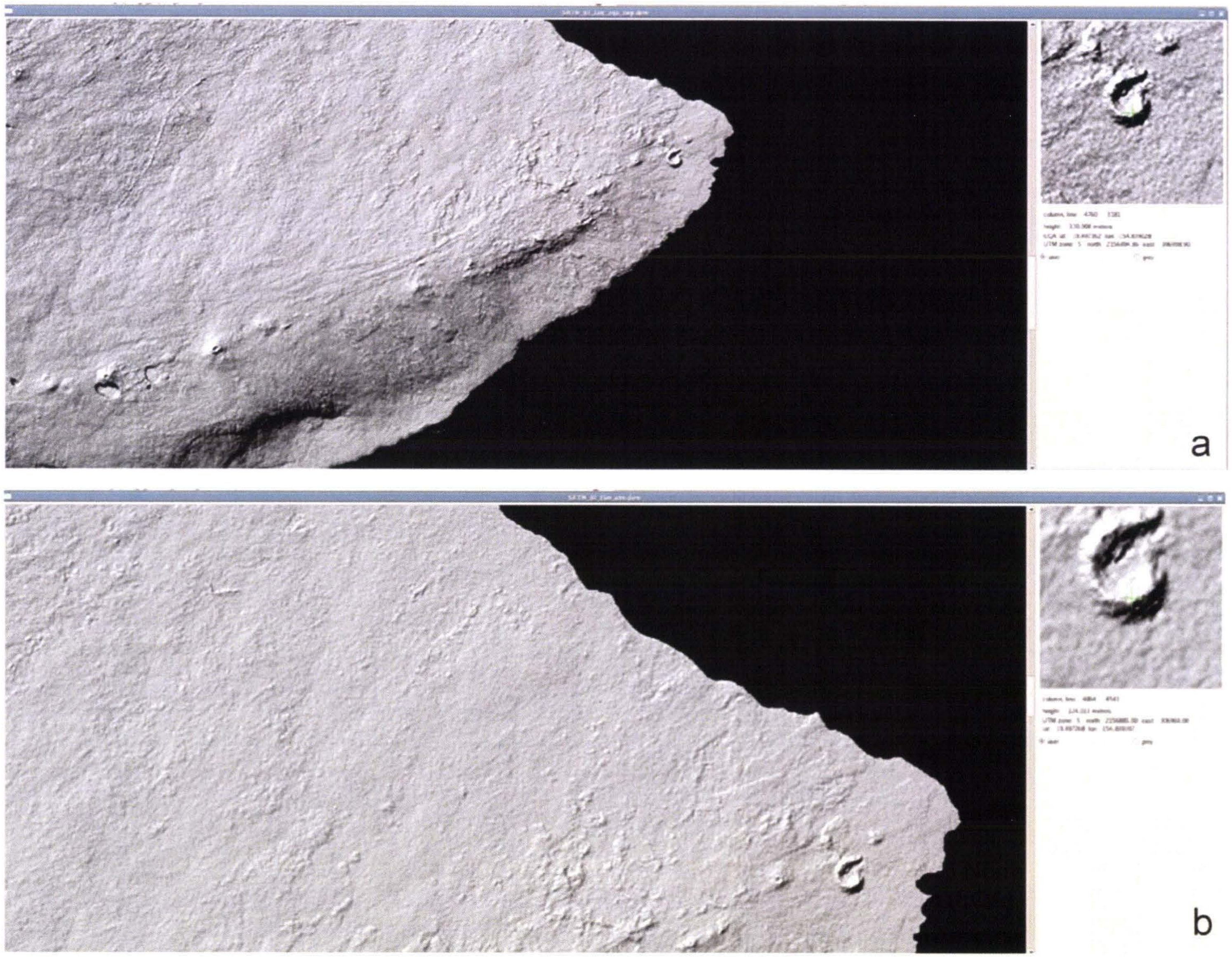



Figure 6: Display of Digital Elevation models (DEMs) using GAMMA disdem_par command. North is up in both MAP geometries. (a) Shuttle Radar Topography Mission (SRTM) DEM in Equal-Angle projection (EQA), (b) DEM in Universal Transverse Mercator (UTM) projection.

In the following processing a segment file will be generated. It represents the section the SAR image would cover on the SRTM DEM. In other words, the script will cut out the radar image section from the DEM. The first step is to remove any existing segment files.

```
rm -f SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par
```

- Derive the geocoding look-up table and simulate a SAR backscatter image (in DEM geometry)

```
gc_map rmli_1_5/rmli_1_5.ave.par - SRTM_BI_15m_utm.dem_par SRTM_BI_15m_utm.dem SRTM_BI_
15m_utm_seg.dem_par SRTM_BI_15m_utm_seg.dem geo/BI_0.map_to_rdc 1 1 geo/BI_0.sim - - - - - - 8
2 2
```

- Forward geocoding transformation using the look-up table

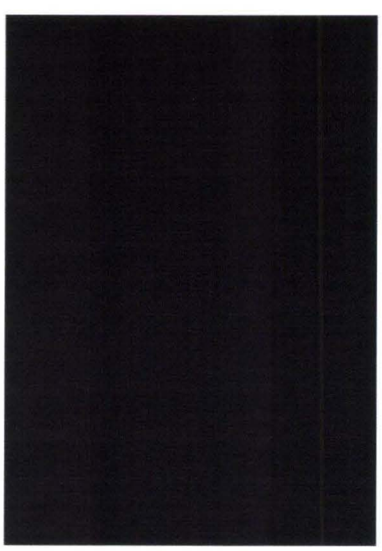
Transform the simulated SAR image (in MAP geometry) to RDC

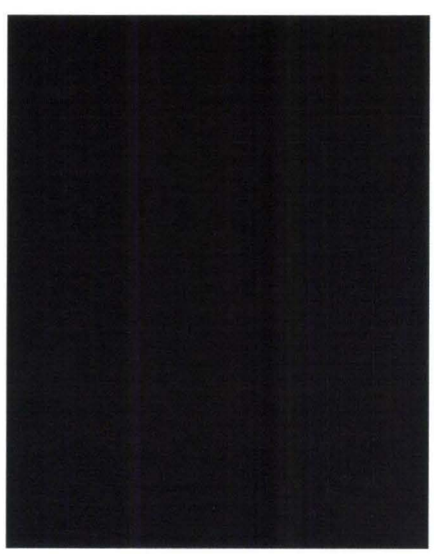
```
geocode geo/BI_0.map_to_rdc geo/BI_0.sim 8334 geo/BI_0.sim_rdc 5174 4763 2 0 1 1 2 8
```

- Create raster image of the initial simulated SAR image in RDC (Figure 7a: Initial simulated SAR image PDF 540 KB)

```
raspwr geo/BI_0.sim_rdc 5174 1 0 1 1
```

The image appears to be "flipped" horizontally arising to the fact that the satellite is on a descending (north to south) track which is slightly rotated to the east by about 9° (see schematic below). The right-looking radar acquires data starting at proximal points on the ground after which more distal ground features are recorded. In the descending example, the SAR at first writes B, the closest features, into the data file, then A. While the satellite progresses along its track, ground features close to C are recorded before D. The imaged ground features (the SAR images) therefore seem flipped horizontally. On an ascending track, the SAR records ground features closest to D before it records C. Further along the flight the SAR writes A before it can "see" B. The ascending data therefore seem flipped vertically. Images in this geometry are in SAR or range-Doppler Coordinates (RDC) and will have the flight and look direction. Images in MAP geometry like EQA or UTM projection will show a north arrow.





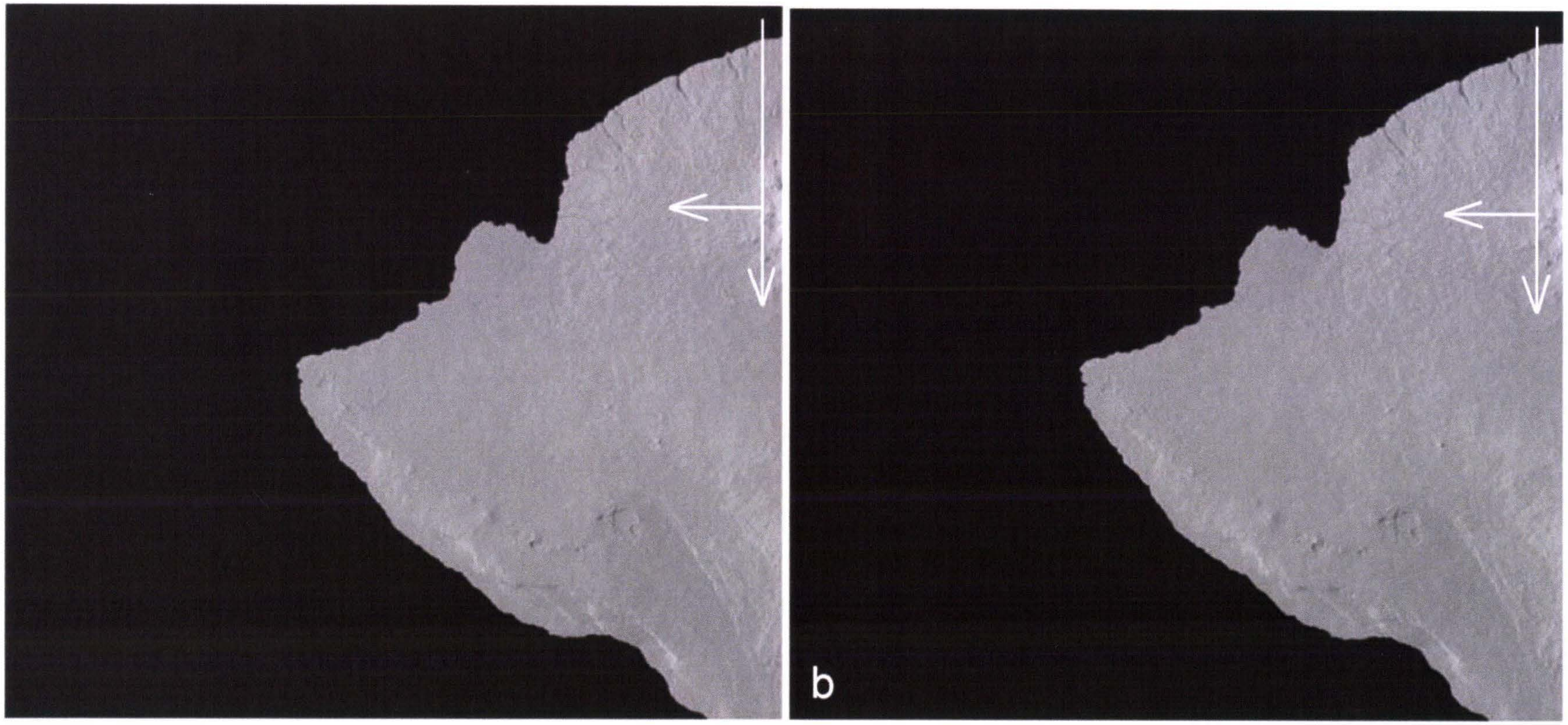



Figure 7: Simulated SAR image in range-Doppler coordinates (RDC). (a) Initial simulation, (b) refined simulation. Differences are in the 1-2 pixel range, hence hardly visible at this scale. The arrow pointing down indicates the satellites flight track wheras the smaller arrow points into the look-direction of the Synthetic Aperture Radar (SAR).

- Display the simulated SAR and the RMLI to detect offsets (Figure 8 PDF 3.2 MB)

```
dis2ras geo/BI_0.sim_rdc.ras rmli_1_5/rmli_1_5.ave.ras&
```

***Mode 2: Measure initial offset between simulated SAR image and actual SAR image (log)***

```
mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem SRTM_BI_
15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI 15 2 2 2 2 8 1 5 6.5
- - - - 256 256
```

The script runs the following commands in mode 2: **create_diff_par**, **init_offsetm**

Depending on the track and frame, the center of the image might be mostly surrounded by water. **Init_offsetm** determines a SNR close to the center of the scene and crashes because it cannot find a high enough value to continue with the initial offset estimation. The command can be run manually to find a better region for the offset estimation. In the case shown below, the region was moved more on land (3000 x 3000 instead of the scene center 2587 x 2381.5).

- Create DIFF_par parameter file for image registration and geocoding

```
create_diff_par rmli_1_5/rmli_1_5.ave.par - geo/BI.diff 1 < geo/BI.diff.in
```

- Initial offset estimation for multi-look intensity images

```
init_offsetm geo/BI_0.sim_rdc rmli_1_5/rmli_1_5.ave geo/BI.diff 1 5 3000 3000 0 0 6.5 128 1
```

***Mode 3: Perform refinement of lookup table by offset measurement with respect to the simulated SAR image (log)***

```
mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem SRTM_BI_
15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI 15 3 2 2 2 8 1 5 6.5
- - - - 256 256
```

The script was changed to increase the number of estimated offset and to manually cull the offsets.
It runs the following commands in mode 3: **offset_pwrm**, **offset_fitm**

- Measure offsets between MLI images using intensity cross-correlation

```
offset_pwrm geo/BI_0.sim_rdc rmli_1_5/rmli_1_5.ave geo/BI.diff geo/BI.offs geo/BI.snr - - - 2
100 100
```

- Range and azimuth offset polynomial estimation

Offsets will be culled manually according to the earlier described method (ISP-3.4).

```
offset_fitm geo/BI.offs geo/BI.snr geo/BI.diff geo/BI.coffs - 6.5 4 1
solution: 1725 offset estimates accepted out of 10000 samples
range offset poly. coeff.:           7.78618    1.68145e-04    6.77191e-04   -2.17621e-07
azimuth offset poly. coeff.:         1.40152   -1.47719e-04   -3.40710e-04    3.55617e-08
model fit std. dev. (samples) range:      0.0964   azimuth:      0.0986
```

***Mode 4: Update lookup table and produce terrain geocoded SAR image and DEM in SAR range-Doppler Coordinates (RDC) (log)***

```
mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem SRTM_BI_
15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI 15 4 2 2 2 8 1 5 6.5
- - - - 256 256
```

The script runs the following commands in mode 4:

**gc_map_fine**, **geocode**, **raspwr**, **dis2ras**, **geocode**, **rasshd**, **disras**, **geocode_back**, **raspwr**, **disras_dem_par**

- Geocoding look-up table refinement (with bi-linear fine registration polynomial)

```
gc_map_fine geo/BI_0.map_to_rdc 8334 geo/BI.diff geo/BI_1.map_to_rdc 1
```

- Geocode the simulated SAR image using the refined look-up table

```
geocode geo/BI_1.map_to_rdc geo/BI_0.sim 8334 geo/BI_1.sim_rdc 5174 4763 2 0 1 1 2 8
```

- Create a raster image of the refined simulated SAR in RDC (Figure 7b: Refined simulated SAR)

```
raspwr geo/BI_1.sim_rdc 5174 1 0 1 1
```

- Display the refined simulated SAR and the RMLI to detect offsets (Figure 9 PDF 3.2 MB)

```
dis2ras geo/BI_1.sim_rdc.ras rmli_1_5/rmli_1_5.ave.ras&
```

- Use look-up table to transform the MAP DEM to RDC

```
geocode geo/BI_1.map_to_rdc SRTM_BI_15m_utm_seg.dem 8334 geo/BI_dem.rdc 5174 4763 2 0 1 1 2 8
```

- Create a raster image of the DEM in RDC as a shaded relief (Figure 10a: DEM in RDC PDF 300 KB)

The GAMMA command rashgt can also be used to create a raster image of the DEM (option of choosing m/color-cycle, see Figure 30b PDF 2.5 MB)

```
rasshd geo/BI_dem.rdc 5174 15 15 1 0 1 1
```

- Display the DEM in RDC

```
disras geo/BI_dem.rdc.ras&
```

- Backward geocoding transformation using the geocoding look-up table

Geocode back the RMLI to MAP geometry (UTM)

```
geocode_back rmli_1_5/rmli_1_5.ave 5174 geo/BI_1.map_to_rdc geo/BI_map.mli 8334 7825 1 0
```

- Generate raster image of MLI in MAP geometry (Figure 10b: RMLI in MAP)

```
raspwr geo/BI_map.mli 8334 1 0 1 1
```

- Display the MLI DEM using the SRTM DEM UTM segment parameter file (Figure 11: RMLI GAMMA display PDF 1 MB)

```
disras_dem_par geo/BI_map.mli.ras SRTM_BI_15m_utm_seg.dem_par&
```

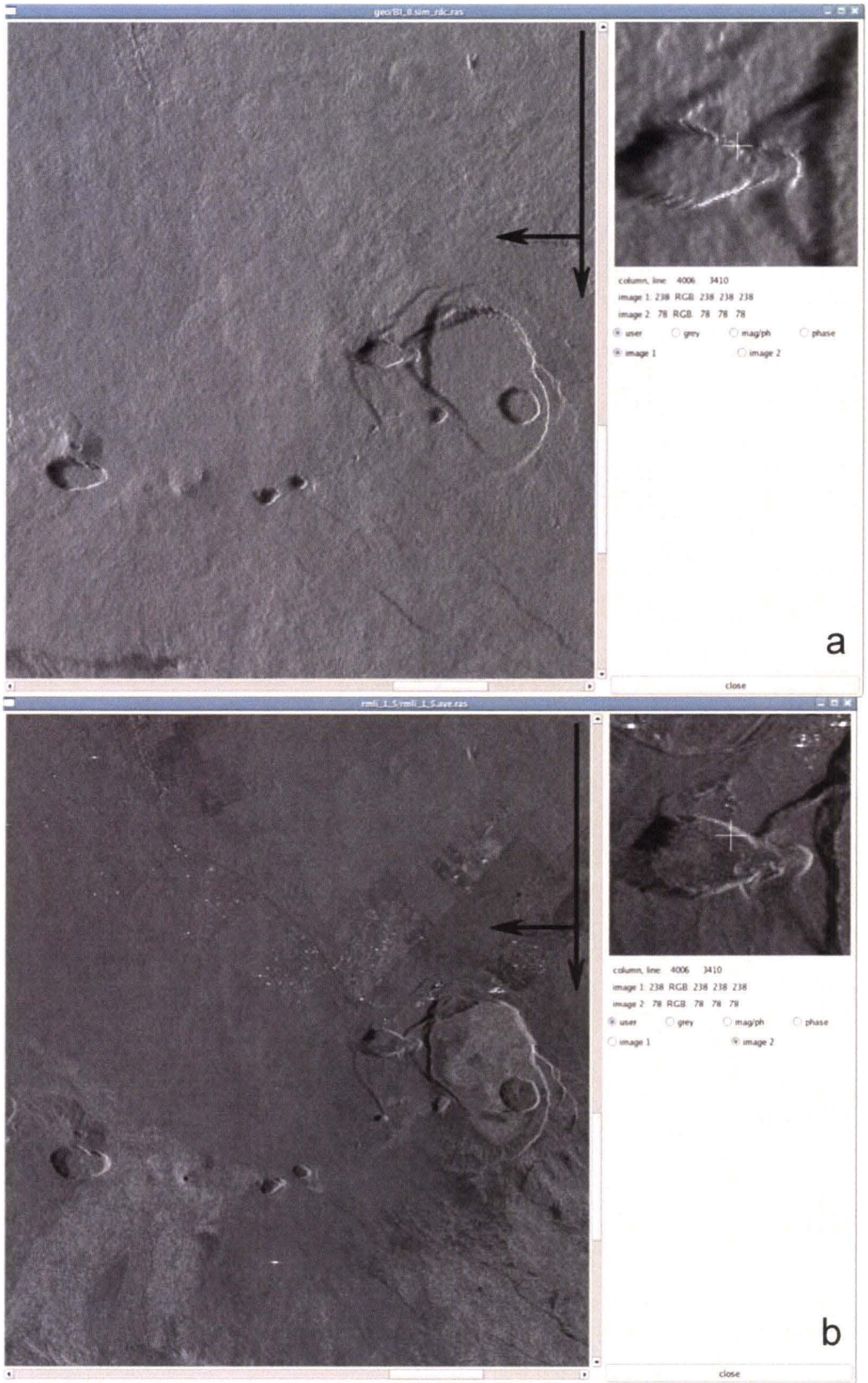



Figure 8: Display of (a) initial simulated SAR image and (b) RMLI using GAMMA dis2ras command. Registration offsets are easiest to detect when focusing on certain features in the zoom window while switching between (a) and (b) using the middle mouse button. Arrows indicate satellite's flight- and the SAR's look-direction.

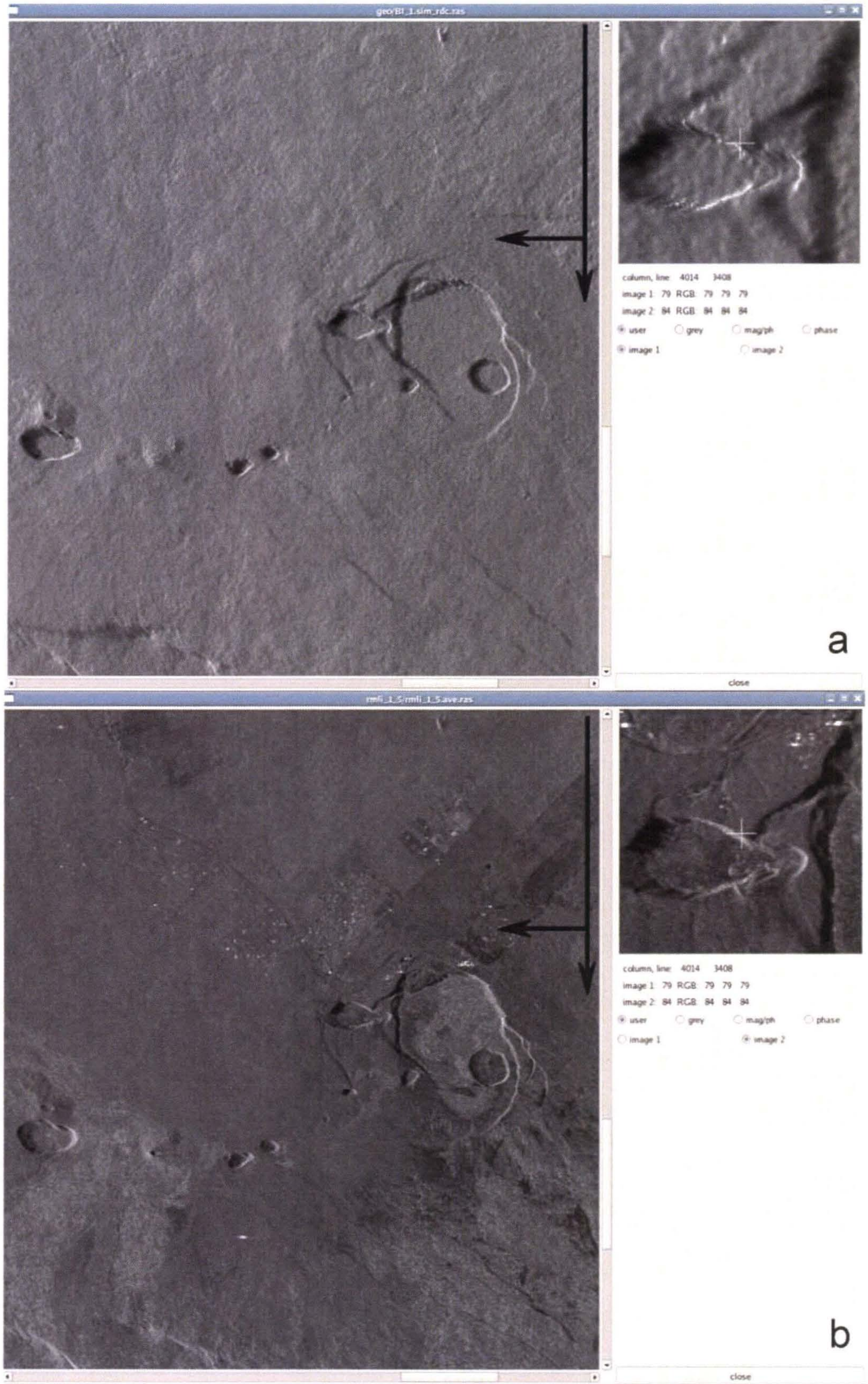



Figure 9: Display of (a) refined simulated SAR image and (b) RMLI using GAMMA dis2ras command. Registration offsets are easiest to detect when focusing on certain features in the zoom window while switching between (a) and (b) using the middle mouse button. Arrows indicate satellite's flight- and the SAR's look-direction.

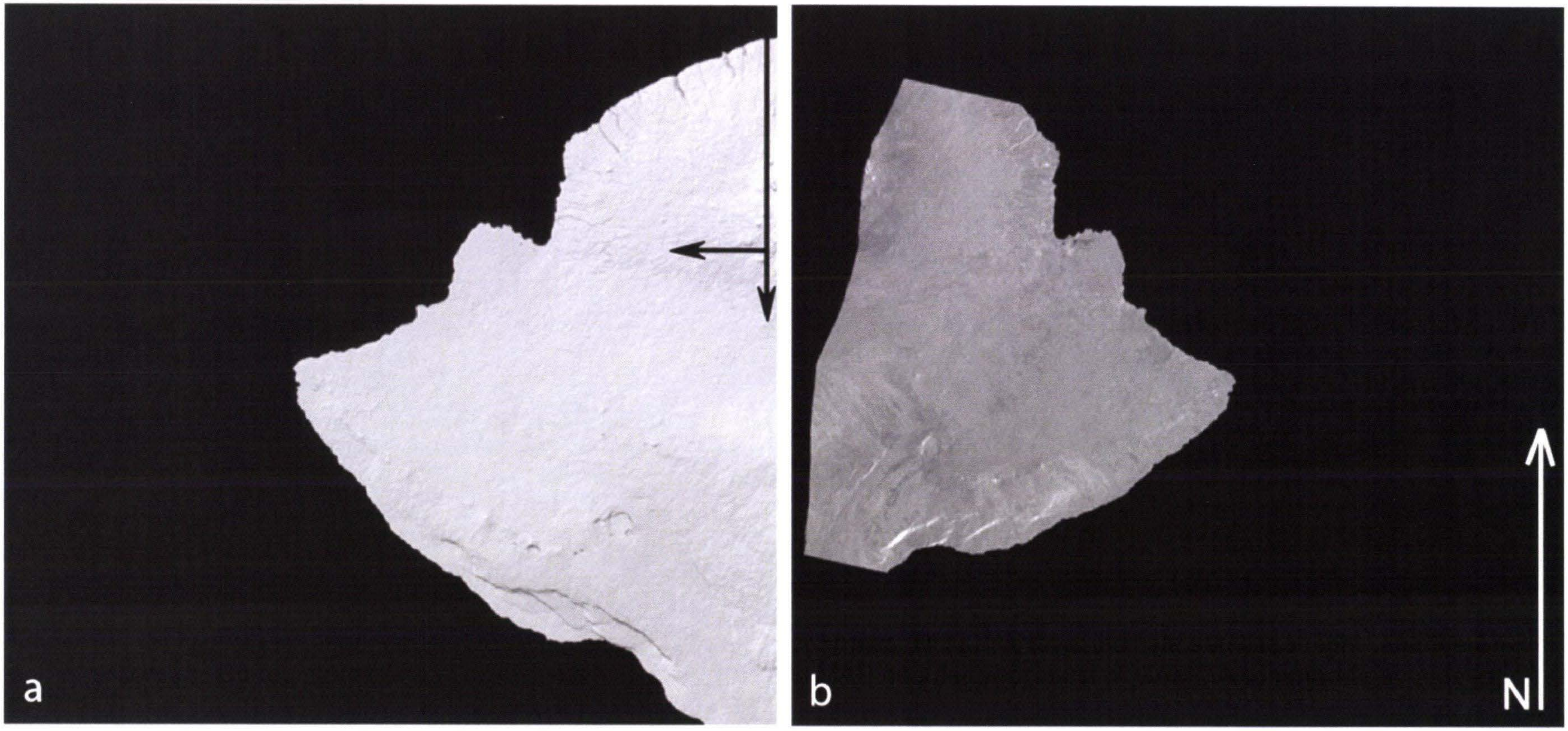


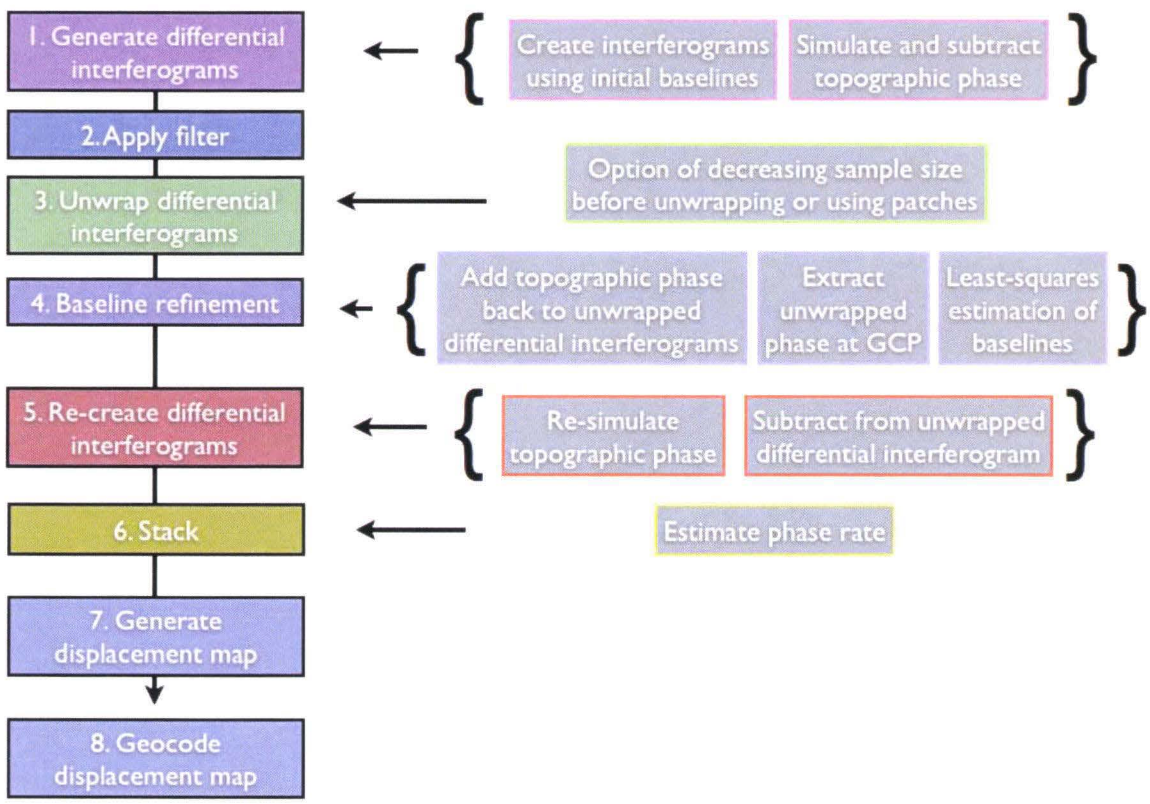

Figure 10: (a) Digital Elevation Model (DEM) in Range-Doppler Coordinates (RDC). Arrows indicate satellite's flight- and the SAR's look-direction, (b) Co-registered Multi-Look Intensity (RMLI) image in MAP geometry (product of GAMMA command geocode_back).

Figure 11: Average co-registered Multi-Look Intensity (RMLI) image converted to MAP geometry (north is up) displayed using GAMMA command disras_dem_par.

## ISP/DIFF – Interferograms and Differential Interferometry

The following chapter will show how to generate interferograms, to simulate topographic phase and to create differential interferograms. The process of unwrapping will be covered as well as filtering and baseline refinement. The chapter will close with the explanation of stacking and how to produce displacement maps. Please note that is essential to save your data because scripts are used multiple times in this sections overwriting previous results.

The following flow chart describes the basic processing flow where each step is going to be illuminated in greater detail throughout this chapter. Processing scripts consist of a series of different commands and sometimes can be run in various modes, utilizing a different sequence of commands. Text displayed in the font `courier new` refers to either the content of a file or the script/command that is run and their standard output. The input arguments are separated by spaces. For an explanation of the input/output parameters please refer to **Appendix E** (Index of commands/scripts and their syntax). A command history can be found in the README file and in the example of the MSP application in **Appendix H**.




### ISP/DIFF-1 Generate Itab with All Possible Pair Combinations

The "all combination" itab (itab_all) is only used in the first mk_diff_2d run in order to evaluate the quality of long baseline pairs.

```
base_calc SLC_tab slc/20041208.slc.par 20041208.bperp.gr 20041208.bperp itab_all 1
```

```
average bperp magnitude (m):   500.162
number of SLC pairs that meet the bperp_max and delta_T_max criteria: 210
```

**ISP/DIFF-2 Generate Differential Interferograms**

The GAMMA script **mk_diff_2d** is used to generate initial differential interferograms using the orbit derived baselines (log – 62 MB)

```
mk_diff_2d RSLC_tab itab_all 0 geo/BI_dem.rdc - rmli_1_5/rmli_1_5.ave rmli_1_5 diff0_2d 1 5 3 1
0
```

The script runs the following commands for all scenes specified in the RSLC_tab:

**create_offset**, **base_orbit**, **SLC_intf**, **rasmph_pwr**, **create_diff_par**, **phase_sim**, **sub_phase**, **rasmph_pwr**, **cc_wave**, **rascc**

- Create interferogram offset files using script generated off_par.in parameters

```
create_offset rslc/20030212.rslc.par rslc/20030702.rslc.par diff0_2d/20030212_20030702.off <
diff0_2d/off_par.in
```

- Estimate baselines from orbit state vectors (DORIS)

```
base_orbit rslc/20030212.rslc.par rslc/20030702.rslc.par diff0_2d/20030212_20030702.base
```

- Interferogram generation from co-registered SLC data

```
SLC_intf rslc/20030212.rslc rslc/20030702.rslc rslc/20030212.rslc.par rslc/20030702.rslc.par
diff0_2d/20030212_20030702.off diff0_2d/20030212_20030702.int 1 5 0 - 1
```

- Create an image of the interferogram (command not run by script)

Interferometric fringes are visible in close-up (Figure 12: Interferogram PDF 5.8 MB).

```
rasmph_pwr diff0_2d_1_5/20030212_20030702.int rmli_1_5/20030212.rmli 5174
```

- Create **.diff_par* using the script generated diff_par.in

```
create_diff_par diff0_2d/20030212_20030702.off - diff0_2d/20030212_20030702.diff_par <diff0_
2d/diff_par.in
```

- Simulate unwrapped topographic phase using DEM heights

```
phase_sim rslc/20030212.rslc.par diff0_2d/20030212_20030702.off diff0_2d/20030212_20030702.base
geo/BI_dem.rdc diff0_2d/20030212_20030702.sim_unw 0 0 - 140
```

- Create image of simulated unwrapped topography (not part of the script) (Figure 13a,b: Simulated topography)

```
rasrmg diff0_2d/20030212_20030702.sim_unw rmli_1_5/rmli_1_5.ave 5174
```

- Subtract the simulated topographic phase from the interferogram to create differential phase

```
sub_phase diff0_2d/20030212_20030702.int diff0_2d/20030212_20030702.sim_unw diff0_2d/20030212_
20030702.diff_par diff0_2d/20030212_20030702.diff 1
```

- Create image of differential interferogram (Figure 13c,d: Differential interferogram PDF 4.7 MB)

```
rasmph_pwr diff0_2d/20030212_20030702.diff rmli_1_5/rmli_1_5.ave 5174
```

- Estimate interferogram coherence

```
cc_wave diff0_2d/20030212_20030702.diff rmli_1_5/20030212.rmli rmli_1_5/20030702.rmli diff0_
2d/20030212_20030702.cc 5174 3 3 1
```

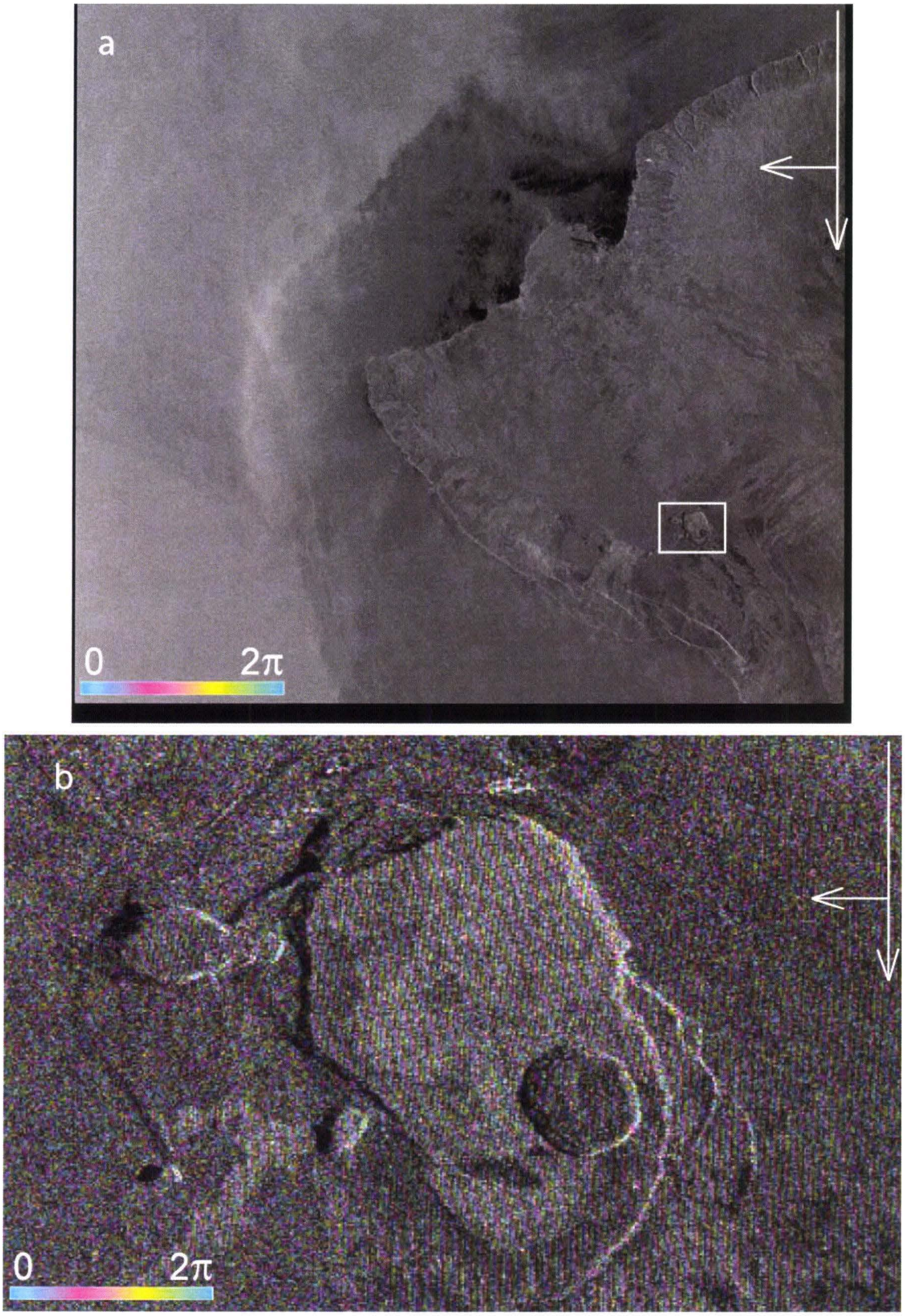



Figure 12: (a) Raster image of wrapped interferogram 20030212_20030702 generated by GAMMA command rasmph_pwr, (b) Fringes of interferometric phase visible in close-up of Kilauea Caldera. One color-cycle corresponds to 2π radians.

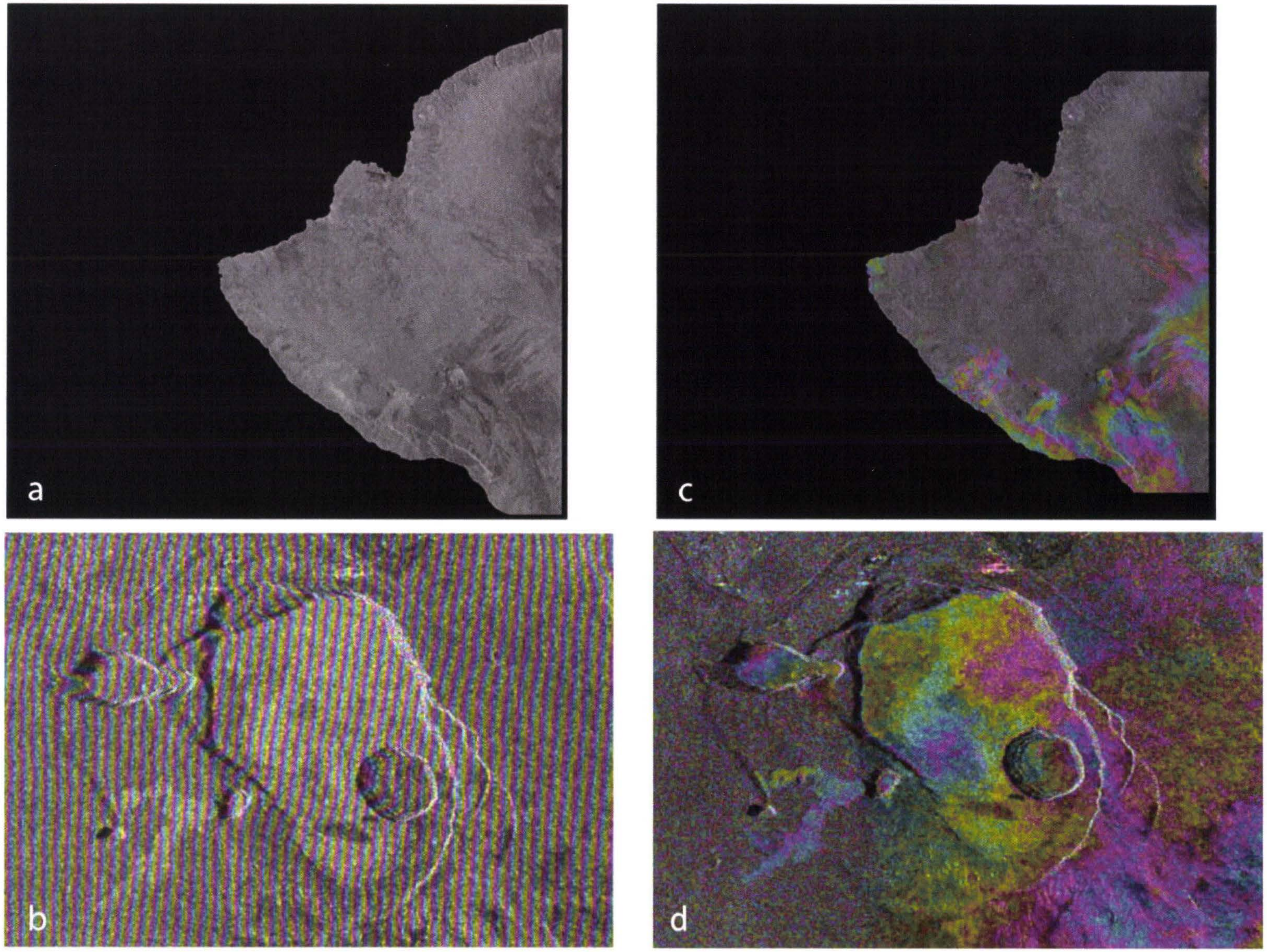



Figure 13: Subtract (a) simulated unwrapped topography from wrapped interferometric phase to generate (c) wrapped differential interferogram. (b) and (d) show a close-up of the Kilauea Caldera. Note how fringes follow topographic features such as the caldera walls. Raster image of unwrapped phase generated with GAMMA command rasrmg, wrapped phase rasters created with rasmph_pwr.

- Generate raster image of correlation coefficient and intensity image (Figure 14: Interferometric correlation PDF 2.5 MB)

```
rascc diff0_2d/20030212_20030702.cc rmli_1_5/rmli_1_5.ave 5174
```

### ISP/DIFF-3 Adjust Itab

Determine for which pairs the processing should be continued (minimum/maximum Bperp) and accordingly adjust the interferometric table.

- View all differential interferograms

```
xv diff0_2d/*.diff.ras&
```

- Based on the quality of the differential interferograms, a new itab is created with perpendicular baselines ranging from -750 m to 750 m.

```
average bperp magnitude (m):  359.564
number of SLC pairs that meet the bperp_max and delta_T_max criteria: 166
base_calc SLC_tab slc/20041208.slc.par 20041208.bperp.gr 20041208.bperp itab 1 0 750 -
```

### ISP/DIFF-4 Apply ADF Filter to the Stack of Differential Interferograms (log)

```
mk_adf_2d RSLC_tab itab rmli_1_5/rmli_1_5.ave diff0_2d 5 .3 32
```

The script runs the following command for every pair specified in the itab: **adf**

- Adaptive spectral filtering for complex interferograms

```
adf diff0_2d/20030212_20030702.diff diff0_2d/20030212_20030702.adf.diff diff0_2d/20030212_
20030702.adf.cc 5174 .3 32 5 8 0 0 .2
```

- Generate raster images of filtered differential interferograms (Figure 15: Comparison filtered and unfiltered phase PDF 12.8 MB)

```
rasmph_pwr diff0_2d/20030212_20030702.adf.diff rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 1. .35
```

### ISP/DIFF-5 Unwrap the Differential Interferograms

In the previous step (ISP/DIFF-2) complex interferograms are generated from the co-registered SLC. The interferometric phase is only known modulo $2\pi$. The correct multiple of $2\pi$ must be found and added using one of the two common unwrapping algorithms. The method used in this example is the minimum cost flow (MCF) unwrapping algorithm. It is a global optimization technique that utilizes masking, adaptive thinning and processing in patches to allow unwrapping of very large scenes. Even critical areas (low coherence, gaps in the data) can be addressed. It is therefore a widely accepted and preferred method. An alternative method is a branch-cut region growing technique [*Rosen, et al.*, 2000]. Areas of low coherence and layover are masked out, as well as locations around which a closed integral of phase differences would lead to a non-zero result (a.k.a. residue). Branch-cuts are constructed and the phase unwrapped without crossing any branch-cuts. This process is continued by region growing for the entire area connected. GAMMA processing strategies for phase unwrapping are described in Wegmüller et al. [2002].

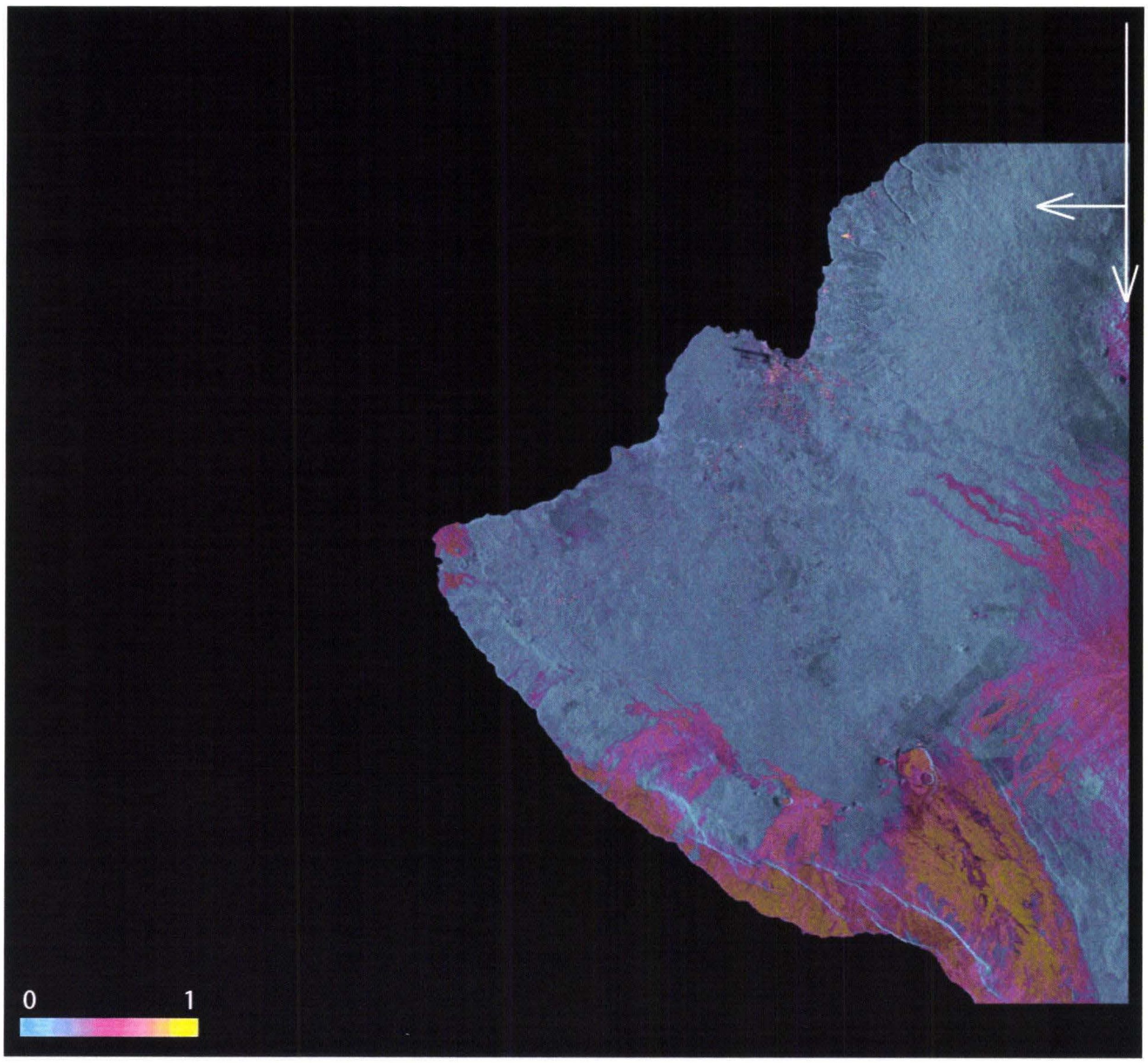



Figure 14: Degree of coherence (interferometric correlation) for pair 20030212_20030702. Color corresponds to interferometric correlation, i.e., low correlation coefficient represented by blue colorsand high coefficient by yellow colors, i.e. very good correlation. Brightness relates to backscatter intensity. Arrows indicate satellite's flight- and the SAR's look-direction.

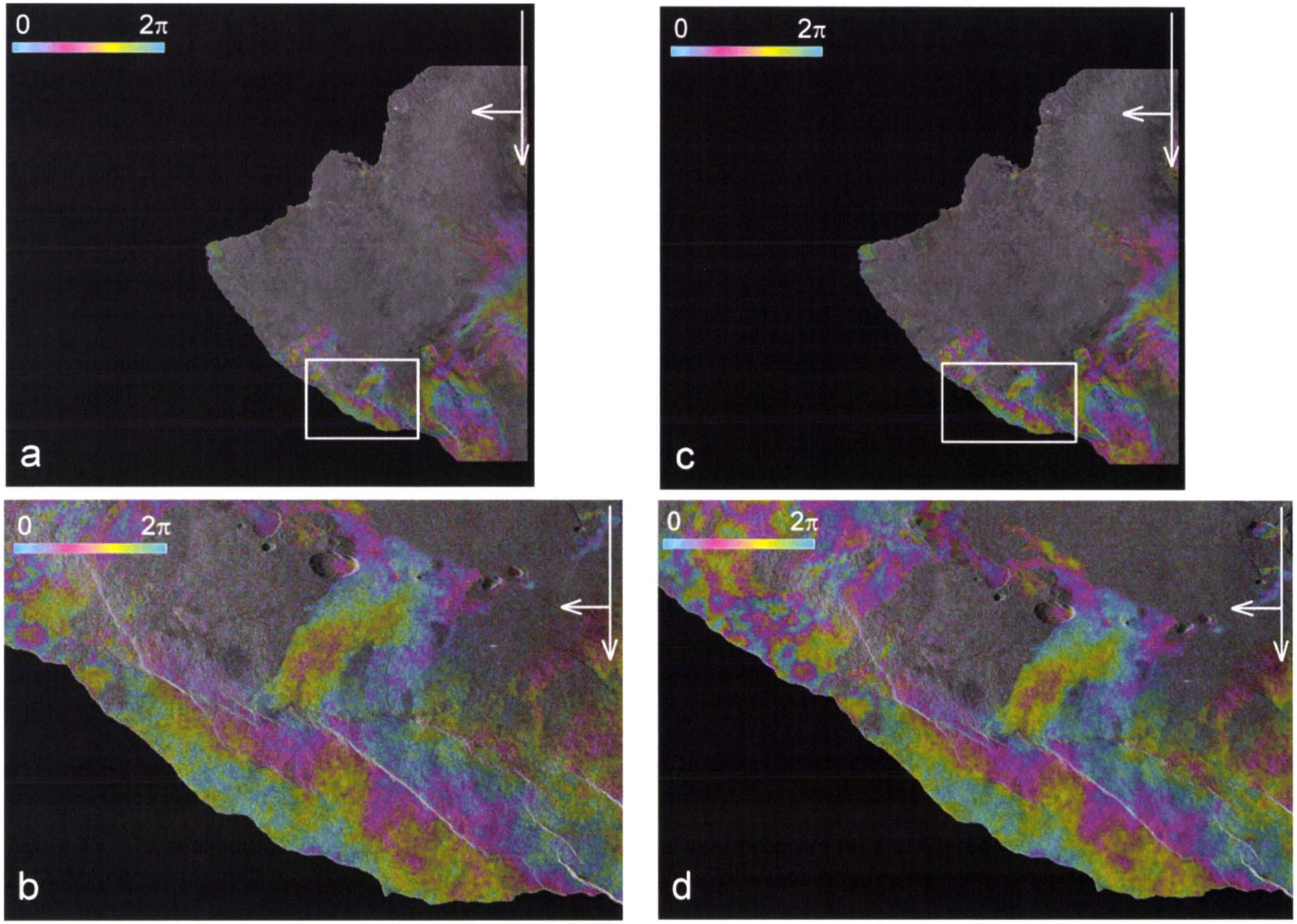



Figure 15: Comparison between unfiltered wrapped differential interferogram (a) and filtered wrapped interferogram (GAMMA command adf) (c). (b) and (d) show close-ups of Hilina Pali. One color-cycle corresponds to 2π radians. Arrows indicate satellite's flight- and the SAR's look-direction.

If the entire scene is processed rather than a small subset, it is recommended to "multi-look down" the wrapped differential interferogram before attempting to unwrap. The differential interferogram as well as the coherence estimate will be scaled down, in this example by a factor of two (-2), cutting the range and azimuth sample size in half. This will minimize the memory allocation necessary for the Minimum Cost Flow (MCF) method (log).

```
mk_unw_2d RSLC_tab itab rmli_1_5/rmli_1_5.ave diff0_2d .4 2 1 1 1
```

The script runs the following commands for every interferogram specified in the itab:
**rascc_mask**, **multi_cpx**, **multi_real**, **mcf**, **multi_real**, **unw_model**, **rasrmg**, **rasrmg**

- Generate phase unwrapping validity mask (Figure 16a PDF 2.8 MB)

Pixels with 0 values are not considered in further processing.

```
rascc_mask diff0_2d_1_5/20030212_20030702.adf.cc rmli_1_5/rmli_1_5.ave 5174 1 1 0 2 2 .4 .3 1.0
1. .35 1 diff0_2d_1_5/20030212_20030702.adf.cc_mask.ras
```

- Multi-look the differential interferogram 2 x 2

Transformation between complex image ↔ multi-look complex image (averaging and oversampling)

```
multi_cpx diff0_2d_1_5/20030212_20030702.adf.diff diff0_2d_1_5/20030212_20030702.off diff0_2d_1
_5/diff2 diff0_2d_1_5/off2 2 2
```

- Multi-look the coherence estimate 2 x 2

Conversion between real image ↔ multi-look real image (averaging and oversampling)

```
multi_real diff0_2d_1_5/20030212_20030702.adf.cc diff0_2d_1_5/20030212_20030702.off diff0_2d_1_
5/cc2 diff0_2d_1_5/off2 2 2
```

- Phase unwrapping using MCF and triangulation

```
mcf diff0_2d_1_5/diff2 diff0_2d_1_5/cc2 diff0_2d_1_5/20030212_20030702.adf.cc_mask.ras diff0_
2d_1_5/unw2 2587 1 0 0 2587 2381.5 1 1 128
```

- Over-sample the unwrapped multi-looked differential interferogram -2 x -2

```
multi_real diff0_2d_1_5/unw2 diff0_2d_1_5/off2 diff0_2d_1_5/unw3 diff0_2d_1_5/off3 -2 -2
```

- Phase unwrapping of the not multi-looked differential interferogram using a model of the unwrapped phase (over-sampled multi-looked unwrapped differential phase)

```
unw_model diff0_2d_1_5/20030212_20030702.adf.diff diff0_2d_1_5/unw3 diff0_2d_1_5/20030212_
20030702.adf.unw 5174 0 0
```

- Create raster images of unwrapped differential phase and intensity data (Figure 17a, b PDF 13 MB)

Notice the difference in the amount of fringes by choosing different phase scale factors.

```
rasrmg diff0_2d_1_5/20030212_20030702.adf.unw rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 1 1. .35 .0
-1 diff0_2d_1_5/20030212_20030702.adf.unw1.ras diff0_2d_1_5/20030212_20030702.adf.cc 1 .2
rasrmg diff0_2d_1_5/20030212_20030702.adf.unw rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 .3333 1. .35
.0 -1 diff0_2d_1_5/20030212_20030702.adf.unw_3.ras diff0_2d_1_5/20030212_20030702.adf.cc 1 .2
```

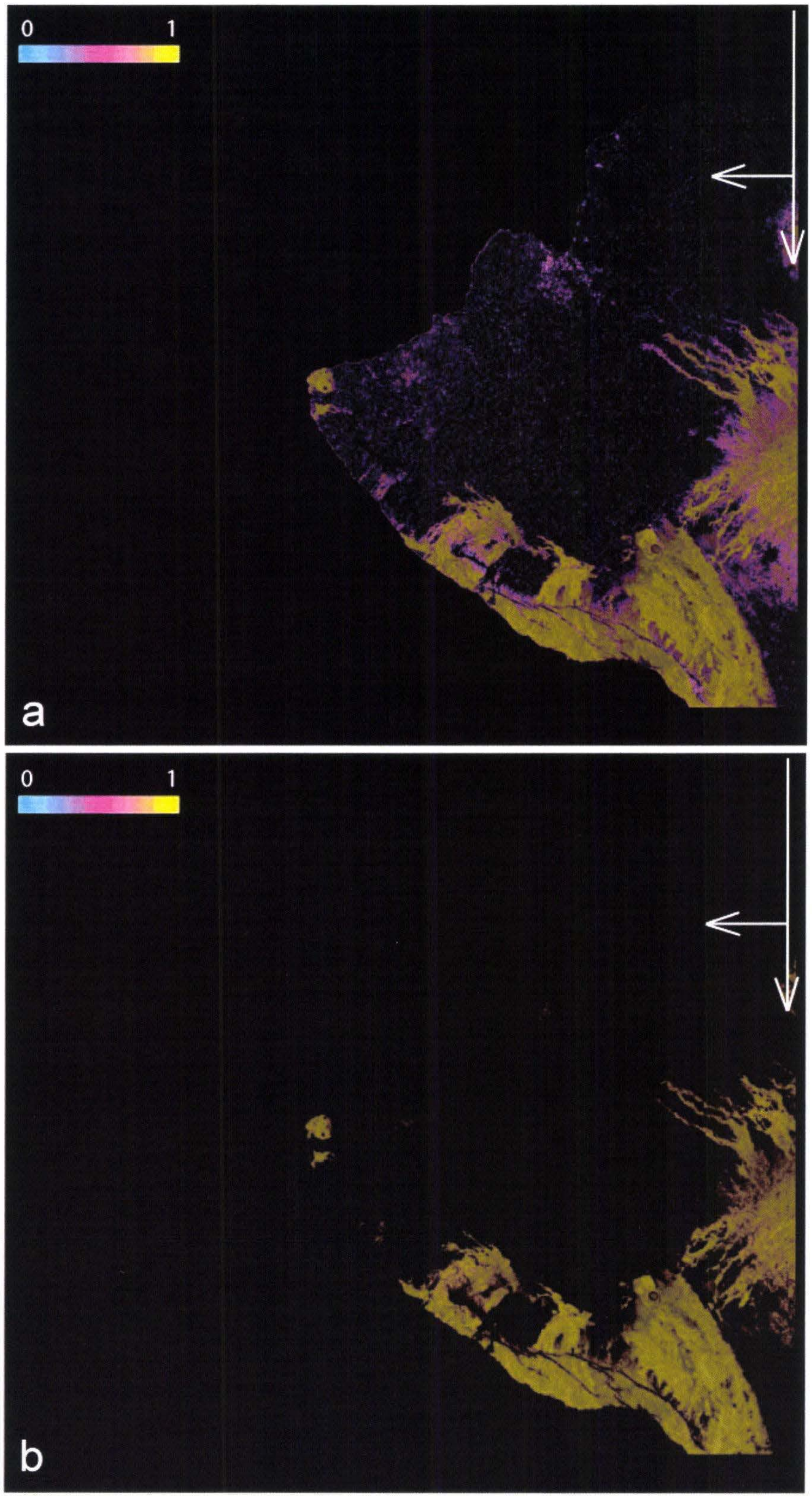



Figure 16: Masks generated using GAMMA command rascc_mask. Thresholds are (a) 0.4 and (b) 0.8, pixels with coherence below these values are set to (0,0,0). Color corresponds to interferometric correlation, i.e., low correlation coefficient represented by blue colorsand high coefficient by yellow colors, i.e. very good correlation. Brightness relates to backscatter intensity. Arrows indicate satellite's flight- and the SAR's look-direction.

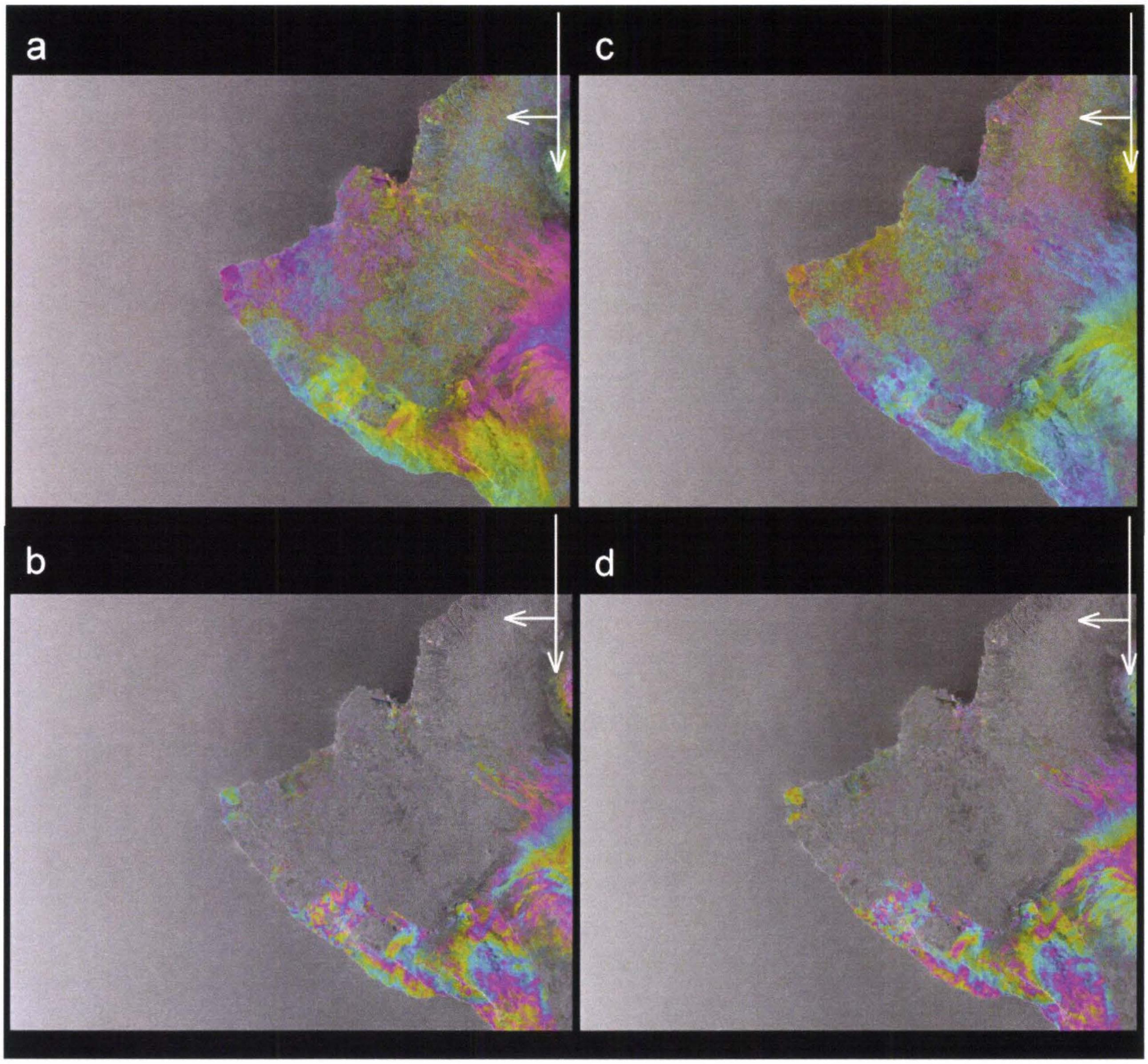



Figure 17: Comparision between unwrapped differential interferograms generated using initial orbit derived baselines (a, b) and refined baselines (c, d). Phase display scale factor 0.3333 (a, c) and 1 (b, d). Arrows indicate satellite's flight- and the SAR's look-direction.

**ISP/DIFF-6 Baseline Refinement**

The two complex SAR images used to create an interferogram can either be obtained from two temporally separated passes of the same satellite or from two satellites during a tandem mission. In either case, the position of the two acquisition times is separated by a certain distance, also referred to as the baseline. (Figure 18: Baseline geometry PDF 200 KB). The baseline can be divided into its components, parallel and perpendicular baseline. Knowing this distance very accurately is most important in interferometric processing. The initial baselines are determined from the state orbit vectors. Precision estimation is crucial for interpretation of the satellite phase as elevation. Once the baseline is refined, the topographic phase will be re-simulated and the differential interferograms are re-calculated.

The baseline refinement is based on selecting valid ground control points (GCP). A mask has to be generated that masks out all incoherent areas like water and decorrelation affected areas like vegetation. The unwrapped phase values at the GCP are then extracted to be used in a least-squares fit to calculated more precise baselines. The GAMMA script mk_base_2d is modified to save the unwrapped interferograms. The topographic phase is re-simulated using the successfully refined baselines (mk_diff_2d_cs), to be subtracted from the now unwrapped interferograms to create unwrapped differential interferograms. No unwrapping is necessary that way.

*ISP/DIFF-6.1 Create Mask*

- Create a mask based upon a very high correlation threshold (Figure 16b)

```
rascc_mask diff0_2d/20030212_20030702.adf.cc rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 .8 .3 1.0 1.
.35 1 diff0_2d/20030212_20030702.adf.cc_mask.8.ras
```

*ISP/DIFF-6.2 Estimate Improved Baselines from Unwrapped Phase and DEM in RDC (log)*

```
mk_base_2d_cs RSLC_tab itab geo/BI_dem.rdc diff0_2d - diff0_2d/20030212_
20030702.adf.cc_mask.8.ras 128 128  5 1
```

The script runs the following commands for the pairs specified in the interferometric table itab:
**sub_phase**, **extract_gcp**, **gcp_phase**, **base_ls**

- Add previously estimated topographic phase back to differential unwrapped interferogram

```
sub_phase diff0_2d/20030212_20030702.adf.unw diff0_2d/20030212_20030702.sim_unw diff0_
2d/20030212_20030702.diff_par diff0_2d/20030212_20030702.unw_int 0 1
```

- Automatically extract GCP from a DEM in RDC

```
extract_gcp geo/BI_dem.rdc diff0_2d/20030212_20030702.off diff0_2d/gcp 128 128 diff0_
2d/20030212_20030702.adf.cc_mask.8.ras
```

- Extract unwrapped phase (gcp_ph) at GCP locations

```
gcp_phase diff0_2d/20030212_20030702.unw_int diff0_2d/20030212_20030702.off diff0_2d/gcp diff0_
2d/20030212_20030702.gcp_ph 3
```

- Precisely estimate the interferometric baseline using GCP, corresponding height and unwrapped interferometric phase in a least squares approach

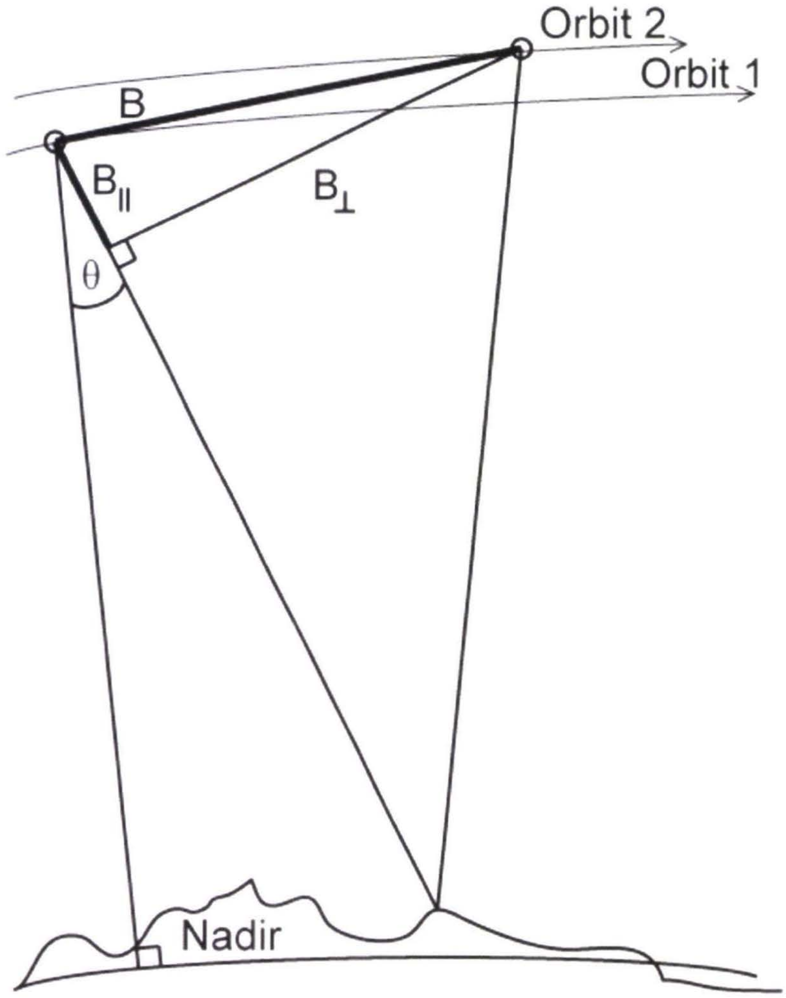



Figure 18: Baseline geometry, after R. Hanssen

```
base_ls rslc/20030212.rslc.par diff0_2d/20030212_20030702.off diff0_2d/20030212_20030702.gcp_ph
diff0_2d/20030212_20030702.base 0 1 1 1 0 1.
```

Check an example by displaying a baseline file:

```
cat diff0_2d/20030212_20030702.base
```

- Copy necessary files to the new directory *diff1_2d* where 1 indicates that refined baselines are used

```
mkdir diff1_2d
cp diff0_2d/*.base diff1_2d/
mv diff0_2d/*.unw_int diff1_2d/
cp diff0_2d/*.off diff1_2d/
```

The **adf.cc* are moved for displaying purposes.

```
mv /mnt/scsi/PGFSAR/IPTA/2429_3213/diff0_2d/*adf.cc diff1_2d/
```

**ISP/DIFF-7 Re-simulate Topography and Create Refined Differential Interferograms**

The modified version **mk_diff_2d_cs** uses the unwrapped interferograms and the refined baselines to calculate the updated differential interferograms. Notice the **.p* naming convention, where p indicates precise.

```
mk_diff_2d_cs RSLC_tab itab 1 geo/BI_dem.rdc - rmli_1_5/rmli_1_5.ave rmli_1_5 diff1_2d 1 5 3 1
0
```

- Create new differential parameter file

```
create_diff_par diff1_2d/20030212_20030702.off - diff1_2d/20030212_20030702.diff_par <diff1_
2d/diff_par.in
```

- Re-simulate topographic phase using refined baseline

```
phase_sim rslc/20030212.rslc.par diff1_2d/20030212_20030702.off diff1_2d/20030212_20030702.base
geo/BI_dem.rdc diff1_2d/20030212_20030702.sim_unw.p 0 1 - 140
```

- Subtract simulated topographic phase from unwrapped interferograms to create refined differential unwrapped interferograms

```
sub_phase diff1_2d/20030212_20030702.unw_int diff1_2d/20030212_20030702.sim_unw.p diff1_
2d/20030212_20030702.diff_par diff1_2d/20030212_20030702.diff_unw 0
```

- Create images of unwrapped differential interferograms (Figure 17c, d)

```
rasrmg diff1_2d/20030212_20030702.diff_unw rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 1 1. .35 .0 -1
diff1_2d/20030212_20030702.adf.diff_unw1.ras diff1_2d/20030212_20030702.adf.cc 1 .2
rasrmg diff1_2d/20030212_20030702.diff_unw rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 .3333 1. .35 .0
-1 diff1_2d/20030212_20030702.adf.diff_unw_3.ras diff1_2d/20030212_20030702.adf.cc 1 .2
```

- Compare the refined baseline interferograms with the initial baseline ones (Figure 17: Comparison initial and refined baselines)

```
dis2ras diff0_2d/20030212_20030702.adf.unw1.ras diff1_2d/20030212_20030702.adf.diff_unw1.ras
```

**ISP/DIFF-8 Stack the Data**

Stacking requires unwrapped phase and gives the average deformation rate over the time period of the different interferograms summed. A list of unwrapped differential interferograms is created only considering pairs with appropriate baseline and time spans. Depending on the project, only short time intervals, short perpendicular baselines or certain times might be considered. The *diff_tab* will consist of two columns, where the first column is a list of the differential unwrapped interferograms (refined) and the second column lists the corresponding delta_t.

- Create diff_tab for all pairs of interest, use **base_calc** output for delta_t
- Stack the data

Estimate the phase rate (linear velocity) by stacking multiple unwrapped differential interferograms. A phase reference region has to be determined by viewing all differential interferograms and finding a stable region that is coherent throughout the entire stack i.e., has values at that point. Xv can be used for displaying. All motion is with respect to the reference region. The expected nominal error for an interferogram with relatively good coherence is about 1/20 of the wavelength accuracy in the path length. The path length errors originate through atmosphere, ionospheric delay, residual topographic phase due to baseline uncertainties and DEM errors. The goal is to determine the deformation due to the path length difference. The approach of stacking averages out the atmosphere and baseline related errors. One complete cycle ($2\pi$) is equivalent to ½ the wavelength difference in path length (the wavelength for Envisat is 5.6 cm). The convention in the GAMMA software is that positive phase in a differential interferogram means negative deformation (i.e., subsidence). This assumes that the interferogram is generated using the earlier scene as the reference. *Sig_ph_rate* and *sig_ph* are standard deviation of (1) the estimated phase rate (in radians/year) and of (2) the residual phases (in radians). For am more detailed discussion see the GAMMA help on stacking.

```
stacking diff_tab 5174 ph_rate sig_ph_rate sig_ph 2041 2413 - - -
```

### ISP/DIFF-9 Create Displacement Map in RDC

- Conversion of unwrapped differential phase to displacement map (m)

```
dispmap ph_rate - slc/20041208.slc.par diff1_2d/20051228_20060308.off ph_rate_disp
```

- Display displacement map in GAMMA to view actual values (Figure 19: Displacement close-ups PDF 9.5 MB)

```
dishgt ph_rate_disp rmli_1_5/rmli_1_5.ave 5174 1 1 0 0.01 1 .35
```

- Create a raster of the displacement (Figure 20a: Displacement in RDC PDF 1.7 MB)

```
rashgt ph_rate_disp rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 .01 1. .35 -1 ph_rate_disp.ras
```

### ISP/DIFF-10 Geocode Back Displacements to Transform to UTM

- Transform the displacement into UTM coordinates

```
geocode_back ph_rate_disp 5174 geo/BI_1.map_to_rdc ph_rate_disp.utm 8334 0 0 0
```

- Transform coherence estimate to UTM

```
geocode_back diff1_2d/20031119_20040303.adf.cc 5174 geo/BI_1.map_to_rdc disp.cc 8334 7825 1 0
```

- Display the UTM displacement in GAMMA (Figure 21: Displacement close-ups in UTM PDF 8.2 MB)

```
dishgt  ph_rate_disp.utm geo/BI_map.mli 8334 1 1 0 0.01 1 .35
```

- Create a raster of the UTM displacement (Figure 20b: Displacement in UTM)

```
rashgt  ph_rate_disp.utm geo/BI_map.mli 8334 1 1 0 1 1 .01 1. .35    1 ph_rate_disp.utm.ras
```

- Create a raster with the pwr image in the background (Figure 22: Displacement map with pwr background PDF 1.3 MB)

Here, you must manually determine out the phase display scale factor to match the m/color-cycle chosen in rashgt.

In this case 0.01 m per color-cycle in rashgt match a phase display scale factor of 630 ($200*\pi$).

```
rasrmg  ph_rate_disp.utm geo/BI_map.mli 8334 1 1 0 1 1 630 1. .35  0 1 ph_rate_disp.utm1.ras
disp.cc 1 .2
```

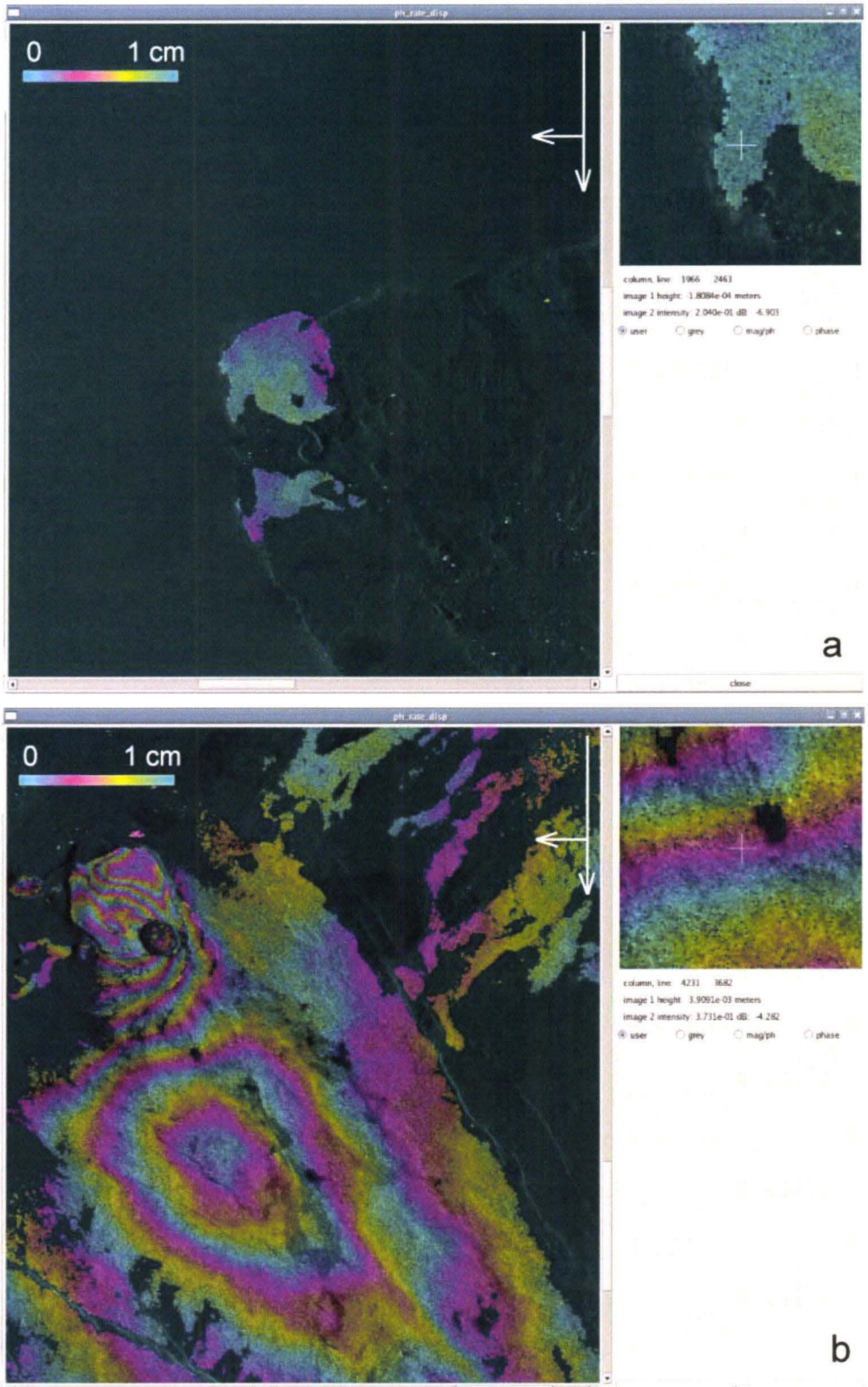



Figure 19: Displacement map in RDC using GAMMA command dishgt at 0.01 m/color-cycle. The displacement is along the look-vector of the SAR and showing the average motion from 20030212 and 20060308. (a) Kapoho region, magenta values range between -2.7 and -3.5 mm, cyan values: -0.14 and -0.25 mm. (b) Kilauea, center of the ellipsoidal shape south of Kilauea caldera measures ~ -10 mm, whereas left of Halemaumau shows values of ~ 50mm. Arrows indicate satellite's flight- and the SAR's look-direction.

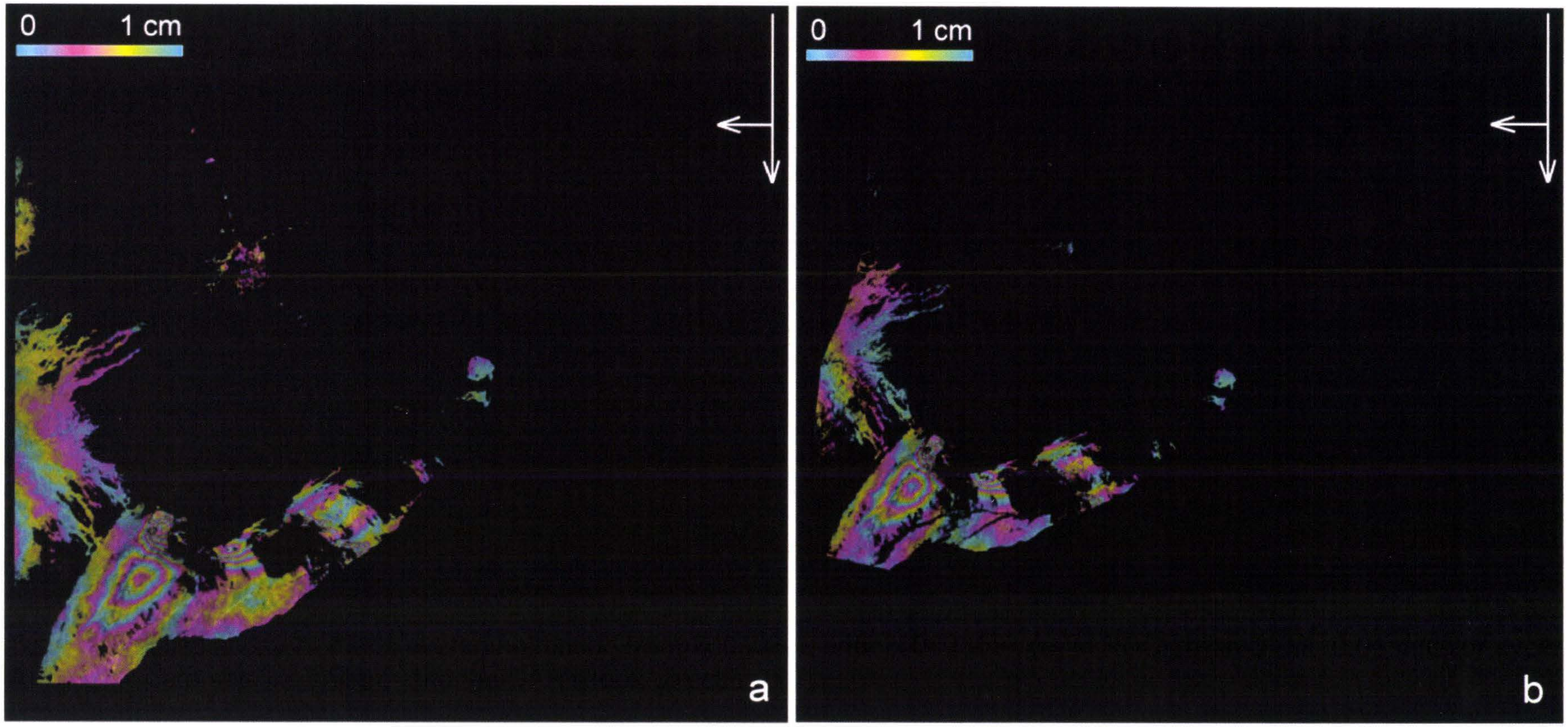



Figure 20: Displacement maps averaging motion from 20030212 until 20060308. (a) in RDC, (b) in UTM. 0.01 m/color-cycle. Arrows indicate satellite's flight- and the SAR's look-direction.

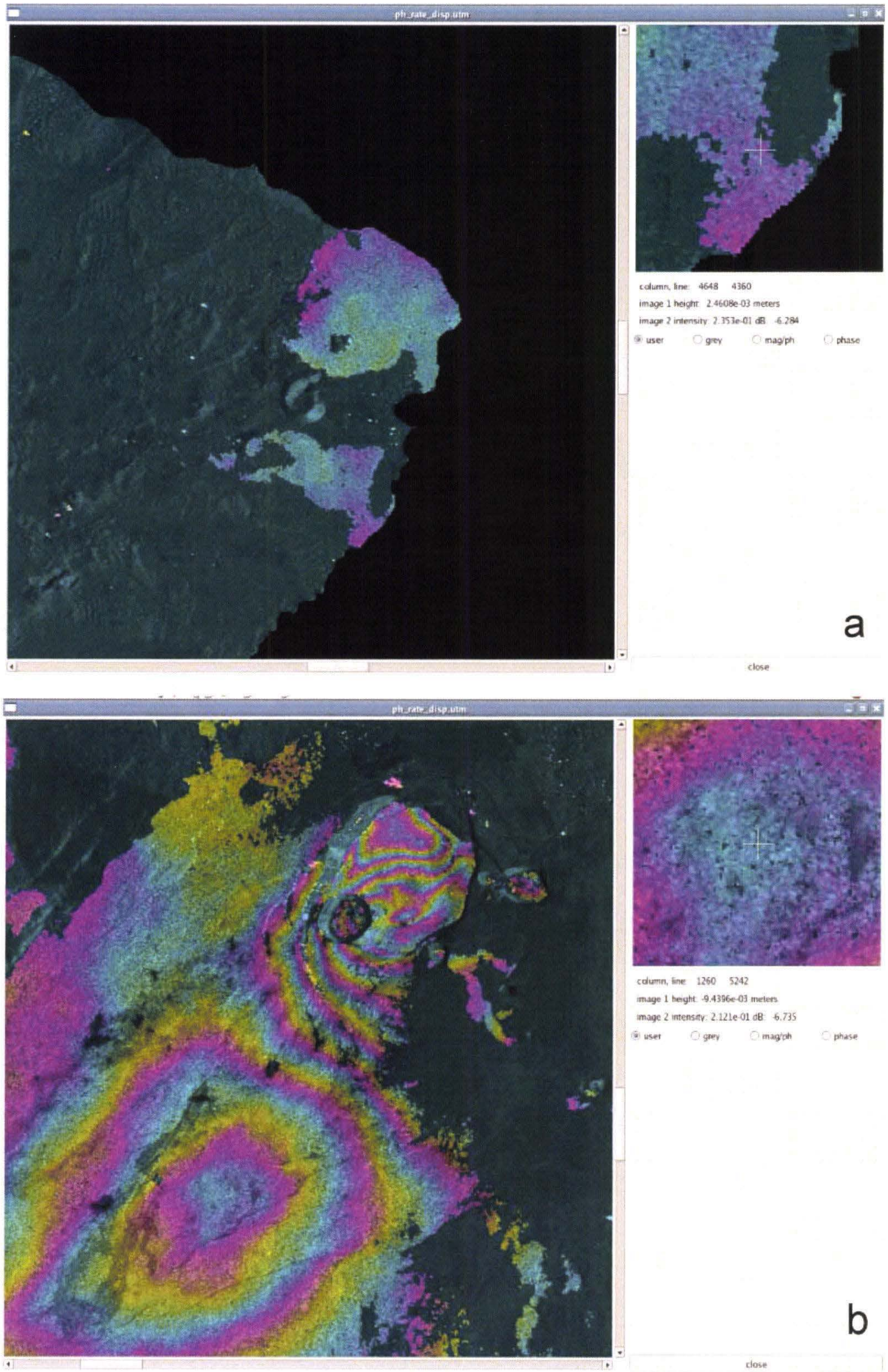



Figure 21: Displacement maps in UTM (0.01 m/color-cycle) showing (a) Kapoho region and (b) Kilauea. North is up.

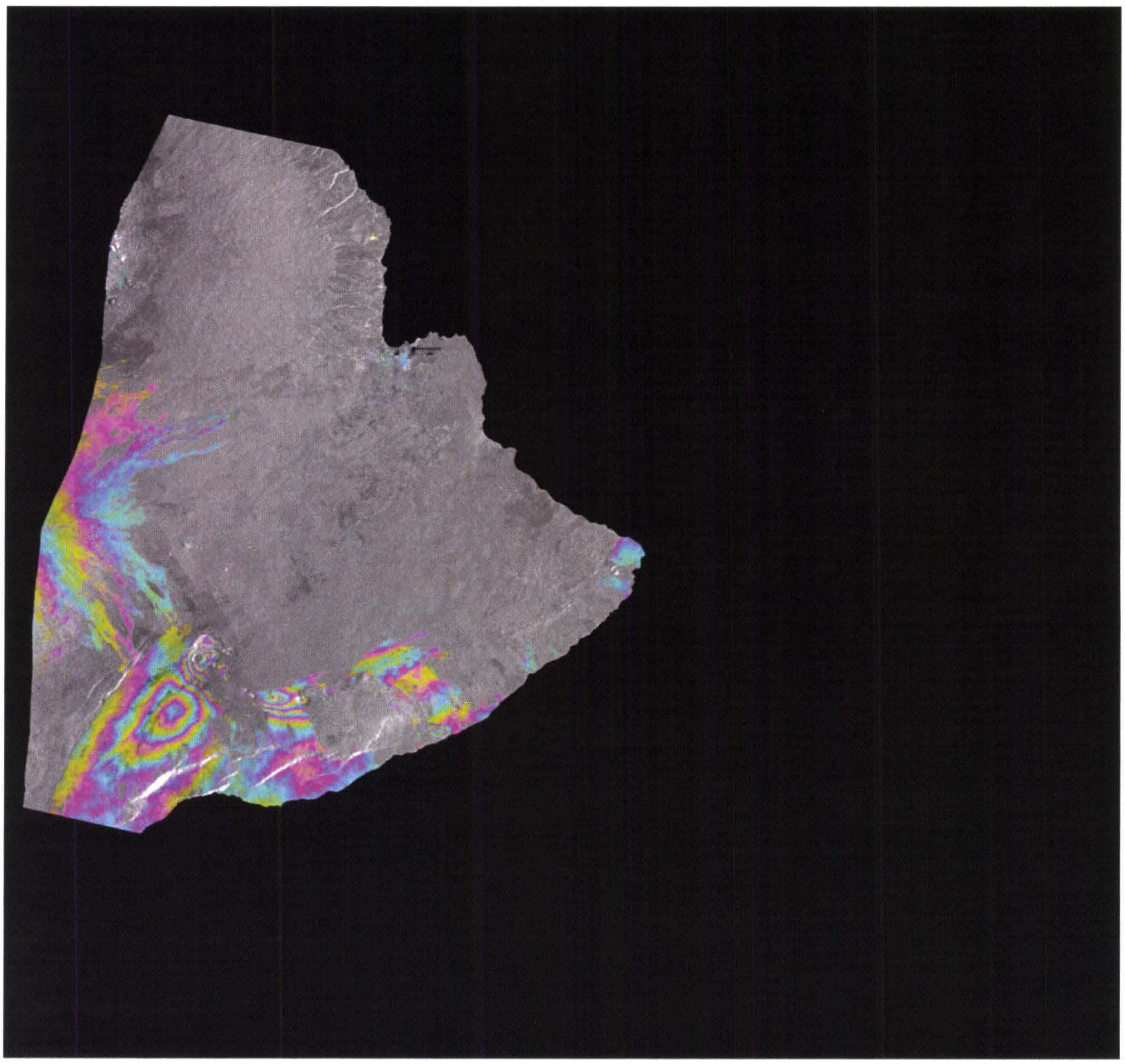


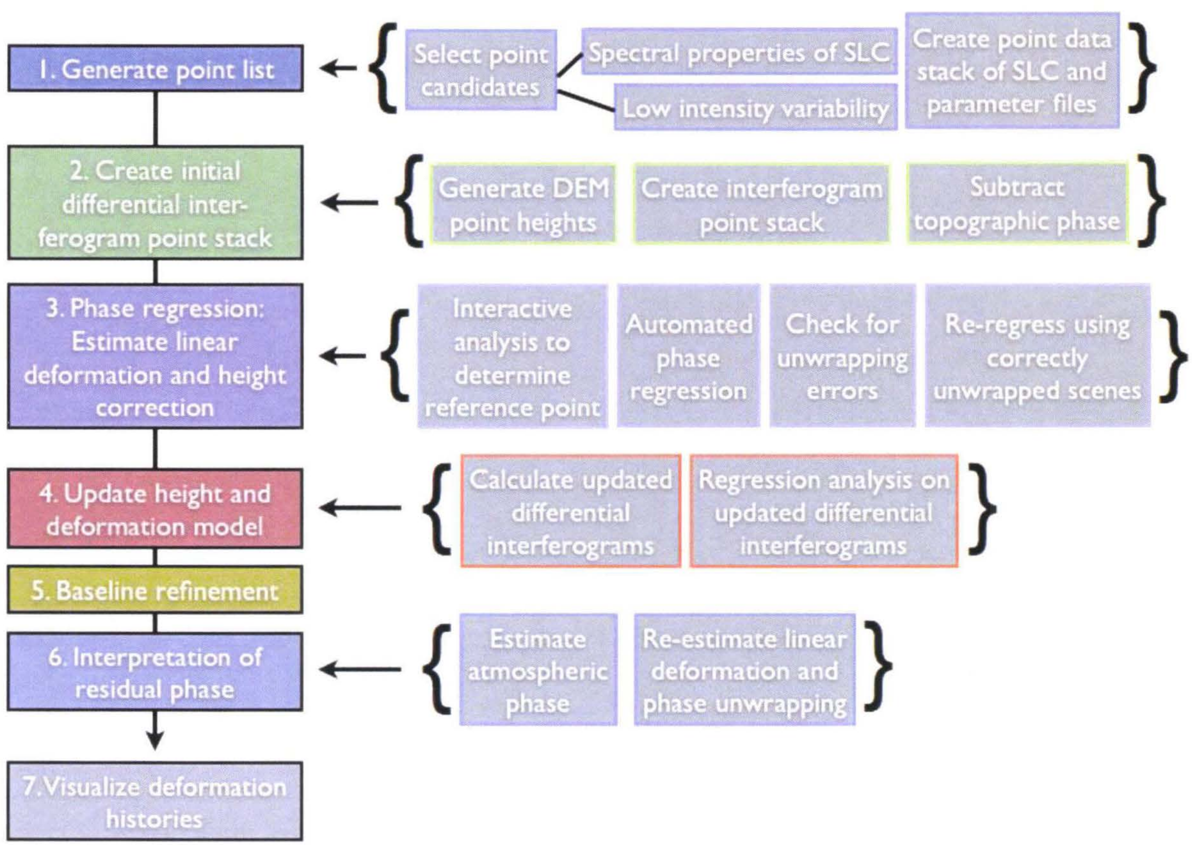
Figure 22: Displacement in UTM averaging motion between 20030212 and 20060308. One color-cycle corresponds to 0.01 m. Raster generated using GAMMA command rasrmg with a phase display scale factor of $200\pi$. North is up.

## IPTA – Interferometric Point Target Analysis

Please also refer to the GAMMA IPTA Processing Example Luxemburg

The IPTA is an alternative approach to the traditional interferometric spatial processing. The phases of points rather than from the entire interferogram are going to be interpreted. The chapter will go through point candidate selection algorithms, interferogram generation, simulation of topographic phase and regression analyses to model unwrapped phase.

The following flow chart describes the basic processing flow where each step is going to be illuminated in greater detail throughout this chapter. Processing scripts consist of a series of different commands and sometimes can be run in various modes, utilizing a different sequence of commands. Text displayed in the font `courier new` refers to either the content of a file or the script/command that is run and their standard output. The input arguments are separated by spaces. For an explanation of the input/output parameters please refer to **Appendix E** (Index of commands/scripts and their syntax). A command history can be found in the README file and in the example of the MSP application in **Appendix H**.




One of the biggest limitations in utilizing SAR interferometry for surface deformation mapping is decorrelation in the temporal and spatial domain. Temporal decorrelation is due to changes in the characteristics of reflectors on the ground, for example caused by changing vegetation and/or low temporal sampling frequency.

Spatial or geometric decorrelation is usually related to long baselines. Interferometric point target analysis (IPTA) is used as an alternative approach to monitor crustal deformation by exploiting the interferometric signatures from pixels on the ground that behave somewhat like point scatterers [*Werner, et al.*, 2003], also referred to as point targets (GAMMA), permanent scatterers [*Ferretti, et al.*, 2001] or persistent scatterers [*Hooper, et al.*, 2004]. Scatterers with point-like characteristics are stable natural reflectors which are coherent over long time intervals. By identifying point targets in low-coherence areas, spatial gaps in deformation maps may be filled and the temporal sampling is improved by inclusion of large baselines pairs [*Wiesmann*, 2004].

**IPTA-1 Focus on Smaller Area of Interest (optional)**

Depending on the nature of the research project, the processing region may be cut down to a smaller area (Figure 23: New area PDF 2.6 MB). This has the advantage of quicker processing and smaller file sizes. The new area dimensions can be obtained by viewing one of the differential interferograms in Image processing software Gimp. It is important to determine the range and azimuth offset to the first sample of the new region as well as the desired width and length. Caution: the azimuth values need to be corrected for the MLR (1:5). That is, if the new area starts at azimuth line 2300 as determined in the multi-looked differential interferogram image, the corresponding RSLC azimuth line is 11500. The cropped files will be saved in a different folder (in this case **_kapoho*).

*IPTA-1.1 Crop the RSLC to Desired Region*

Copy RSLC with options for data format conversion, segment extraction, and swapping

Note the change in width and height: SLC_par_in → SLC_par_out

```
SLC_copy rslc/20030212.rslc rslc/20030212.rslc.par rslc_kapoho/20030212.rslc
rslc_kapoho/20030212.rslc.par 1 - 1912 500 11500 2600
```

*IPTA-1.2 Create new RSLC_tab*

Change the existing RSLC_tab in order to include the new path: RSLC_tab_kapoho

*IPTA-1.3 Generate new RMLI, Average RMLI and Parameter File* (Figure 24: Cropped MLI PDF 930 KB)

```
mk_mli_all RSLC_tab_kapoho rmli_1_5_kapoho 1 5 1
cp rmli_1_5_kapoho/20041208.rmli.par rmli_1_5_kapoho/rmli_1_5.ave.par
```

*IPTA-1.4 Crop DEM (MLI format) to Desired Region (MLI_out_par)*

```
MLI_copy geo/BI_dem.rdc rmli_1_5/rmli_1_5.ave.par geo/BI_dem_kapoho.rdc
geo/BI_dem_kapoho.rdc.par 1912 500 11500 2600
```

- Generate raster image of DEM as shaded relief

```
rasshd geo/BI_dem_kapoho.rdc 500 15 15 1 0 1 1
```

- Display of Sun raster images (Figure 25: Cropped DEM in RDC PDF 1 MB)

```
disras geo/BI_dem_kapoho.rdc.ras&
```

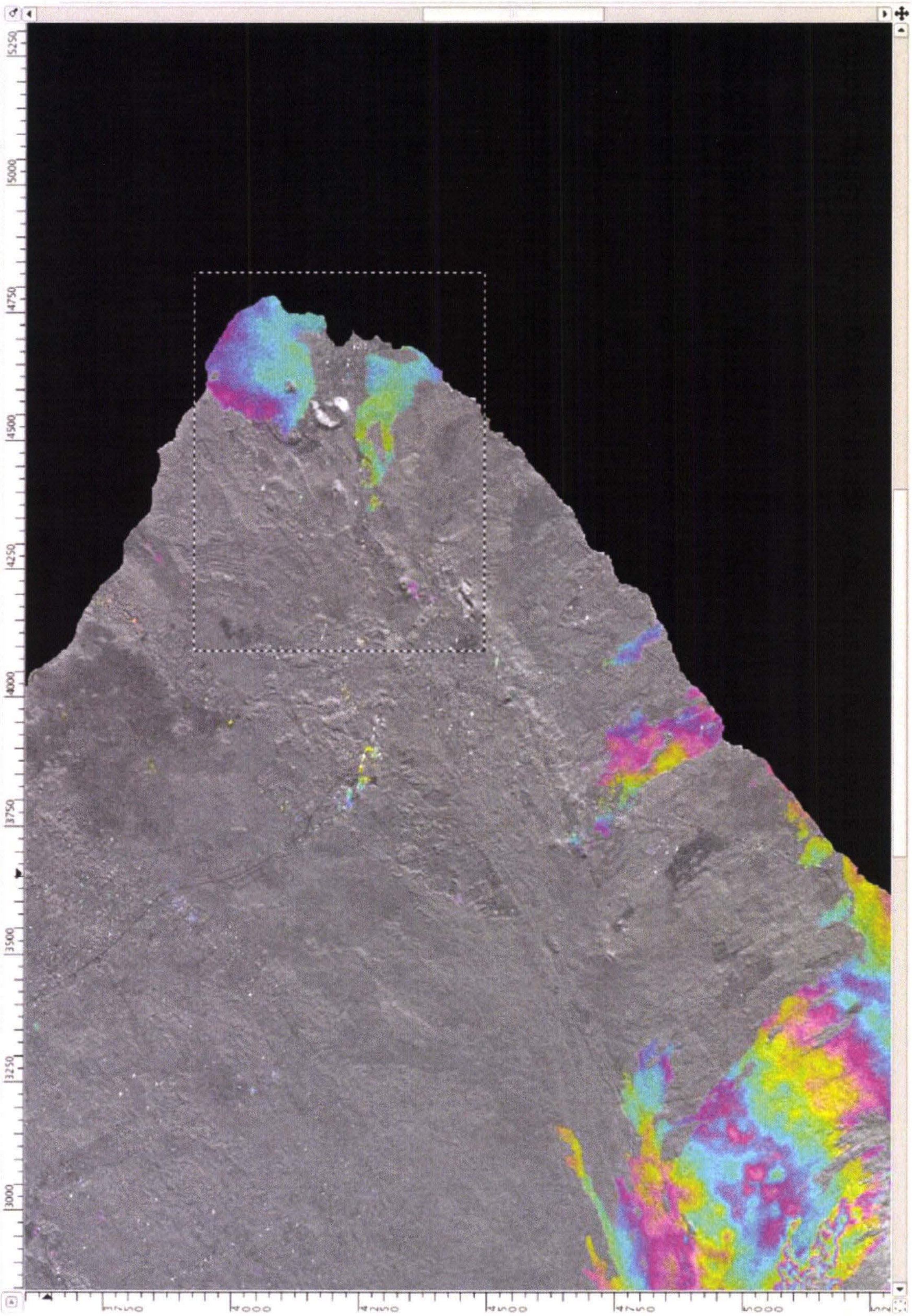



Figure 23: Defining the dimension of a smaller area using the image processing software Gimp. North is up.

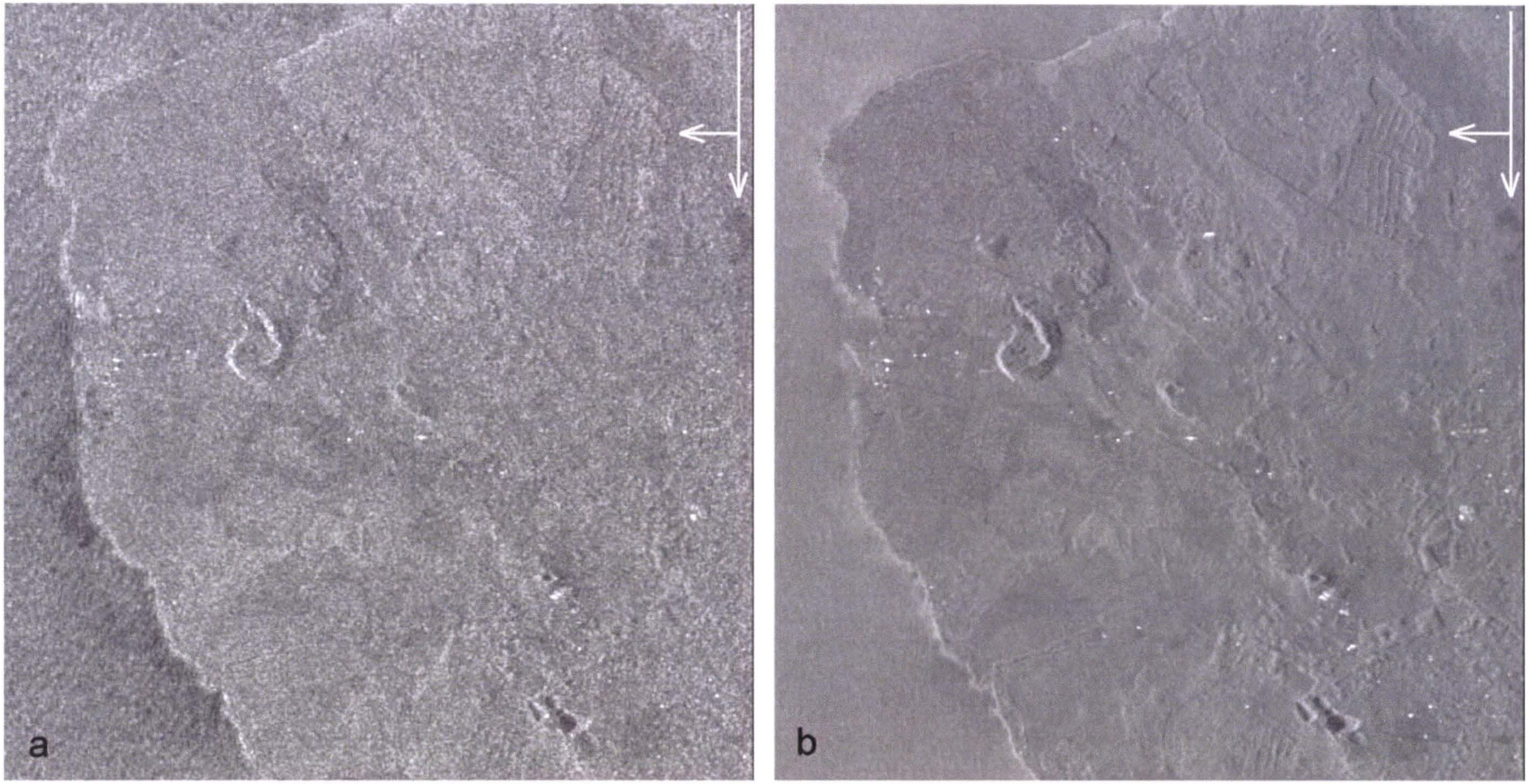



Figure 24: Multi-Look Intensity (MLI) images of the cropped (a) co-registered Single-Look Complex (RSLC) Image and (b) the average image. Arrows indicate satellite's flight- and the SAR's look-direction.

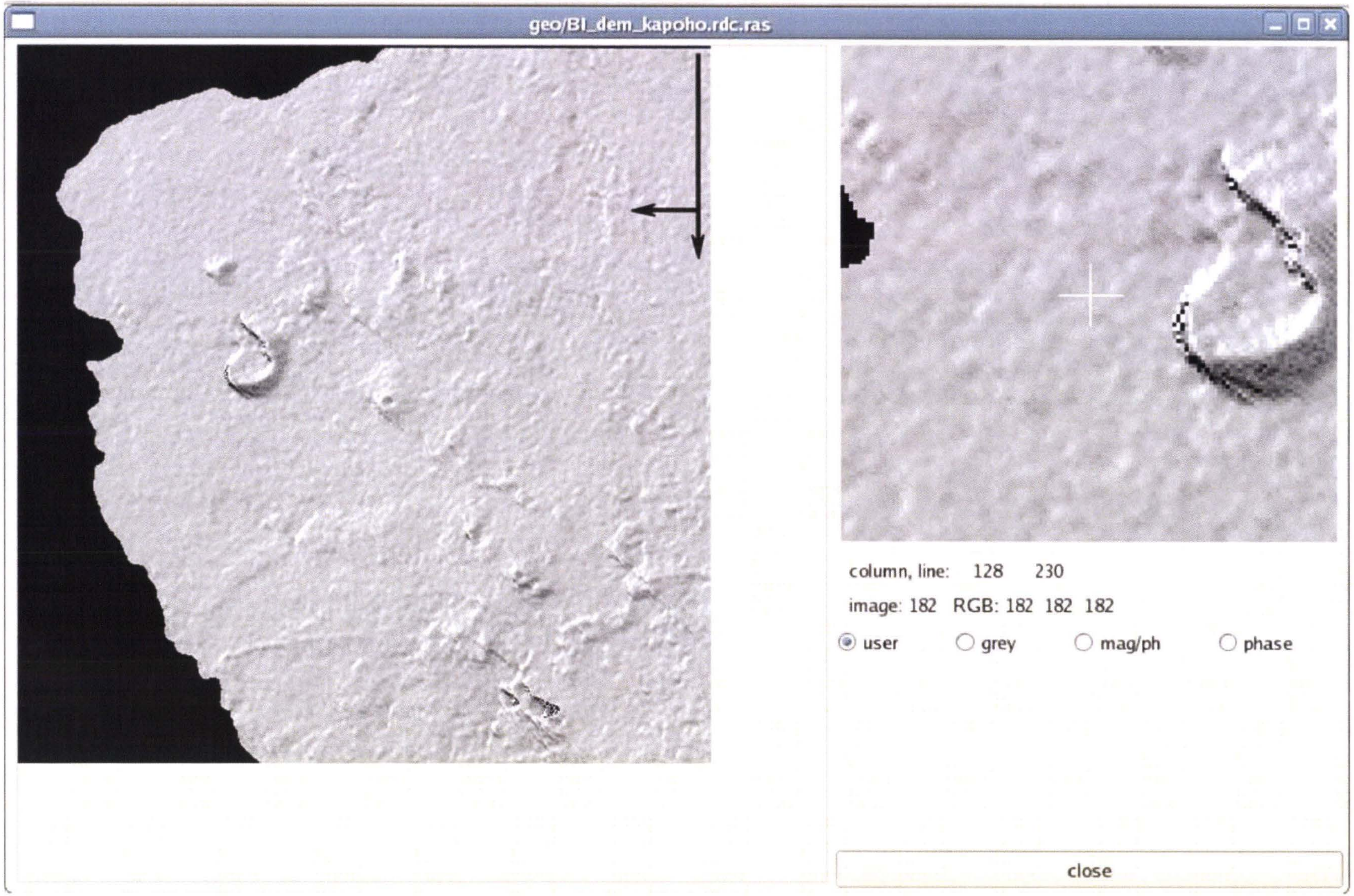



Figure 25: Cropped Digital Elevation Model (DEM) in Range-Doppler Coordinates (RDC) as displayed using GAMMA command disras. Arrows indicate satellite's flight- and the SAR's look-direction.

**IPTA-2 Create** IPTA Interferogram Table

- Use command **base_calc** to create a single-reference table itab_single (click here to see the full std out)

A single-reference itab will only create pairs of the reference scene with every available scene, including the reference scene itself. In contrast, an itab with all possible combinations will include all possible pairs.

```
base_calc RSLC_tab_kapoho rslc_kapoho/20041208.rslc.par 20041208.bperp.gr 20041208.bperp
itab_single 0
```

```
number of baselines in the ITAB with length > 0: 20
average bperp magnitude (m):  391.634
average bperp (m):  141.368
```

**IPTA-3 Generate** Point List

IPTA conducts interferometric analysis on selected points, defined in a point list by range and azimuth coordinates. Candidates are selected as point target based on their stable and point-like scattering characteristics. Point targets have no temporal and low to no geometric decorrelation, which enables inclusion of pairs with very large baselines. Two methods are utilized to select candidate points based on (1) spectral diversity and (2) temporal variability. The first approach considers the spectral characteristics of the co-registered SLC. Low spectral diversity, i.e., high spectral correlation is the selection criteria for this method. The second approach is based on point targets not showing speckle behavior and therefore having low temporal intensity variability (high Mean to Sigma Ratio MSR). The point candidate lists generated by these two methods are then merged to a single point list. Areas of no interest or over water are masked out.

*IPTA-3.1 Generation of Point Target Candidate List Based on Spectral Properties of Individual SLC*

```
mk_sp_all RSLC_tab_kapoho sp 4 4 0.5 0.4 1.2
```

The following commands are run for the entire list of RSLC specified in the RSLC_tab:

**sp_stat**, **ave_image**, **ras_linear**, **ave_image**, **ras_linear**

- Generate point list using low spectral diversity to identify point targets

```
sp_stat rslc_kapoho/20030212.rslc - sp/20030212.sp_cc sp/20030212.sp_msr sp/20030212.pt_ext
500 0.5 0.4 1.2 4 4 - - - - - - 0
```

- Calculate average of spectral correlation (using the MLI_tab as input list)

```
ave_image sp/cc_list 500 sp/ave.sp_cc
```

- Generate raster image of spectral correlation using a linear scale

```
ras_linear sp/ave.sp_cc 500 1 0 1 1 0. 1.
```

- Calculate average of mean/sigma ratio

```
ave_image sp/msr_list 500 sp/ave.sp_msr
```

- Generate raster image of mean/sigma ratio using a linear scale

```
ras_linear sp/ave.sp_msr 500 1 0 1 1 0. 5.
```

*IPTA-3.2 Use Spectral Correlation Average and Different Thresholds to Create Point List*

- Generate point list containing coordinates of image points that satisfy constraints regarding the selected thresholds

```
thres_im_pt sp/ave.sp_cc 500 sp/pt_cc_3 0.3 - 1 1
number of points that satisfy threshold constraints: 49209

thres_im_pt sp/ave.sp_cc 500 sp/pt_cc_318 0.318 - 1 1
number of points that satisfy threshold constraints: 21340

thres_im_pt sp/ave.sp_cc 500 sp/pt_cc_35 0.35 - 1 1
number of points that satisfy threshold constraints: 5828
```

- Draw point list locations on a SUN/BMP raster image (Figure 27: Spectral correlation points PDF 3 MB)

```
ras_pt sp/pt_cc_3 - rmli_1_5_kapoho/rmli_1_5.ave.ras sp/pt_cc_3.ras 1 5

ras_pt sp/pt_cc_318 - rmli_1_5_kapoho/rmli_1_5.ave.ras sp/pt_cc_318.ras 1 5

ras_pt sp/pt_cc_35 - rmli_1_5_kapoho/rmli_1_5.ave.ras sp/pt_cc_35.ras 1 5
```

*IPTA-3.3 Generation of Point Target Candidate List Based on Low Intensity Variability*

- Generate a set of point target lists with different thresholds (determined based on predetermined values by GAMMA)

```
mk_msr_pt RSLC_tab_kapoho rslc_kapoho/20040303.rslc.par rmli_1_5_kapoho/rmli_1_5.ave.par
rmli_1_5_kapoho/rmli_1_5.ave.ras msr .5 2 1.5 1 1.2 10 .1
```

The script mk_msr_pt runs the following commands: **pwr_stat**, **ras_pt**, **npt**

- Generate point list based on temporal variability of SLC intensity

```
pwr_stat RSLC_tab rslc/20040303.rslc.par msr/msr_1.2 msr/pt_1.2 1.2 .5 0 0 - - 0 2 1.5 1
```

- Draw point list locations on a raster image (Figure 28: Low intensity variability points PDF 3.8 MB)

```
ras_pt msr/pt_1.2 - rmli_1_5_kapoho/rmli_1_5.ave.ras msr/pt_1.2.ras 1 5 255 255 0
ras_pt msr/pt_1.4 - rmli_1_5_kapoho/rmli_1_5.ave.ras msr/pt_1.4.ras 1 5 255 255 0
ras_pt msr/pt_1.7 - rmli_1_5_kapoho/rmli_1_5.ave.ras msr/pt_1.7.ras 1 5 255 255 0

ras_pt msr/pt_2.1 - rmli_1_5_kapoho/rmli_1_5.ave.ras msr/pt_2.1.ras 1 5 255 255 0
```

- Determine number of points in a point list

```
npt msr/pt_1.2
```

*IPTA-3.4 Merging of Point Target Candidate Lists to Create the Point List Pt*

- Create a list that contains the chosen cc and msr list

```
ls -1 sp/pt_cc_318 msr/pt_1.7 > plist_tab
```

- Merge the two point lists

```
merge_pt plist_tab pt 1 0 0
```

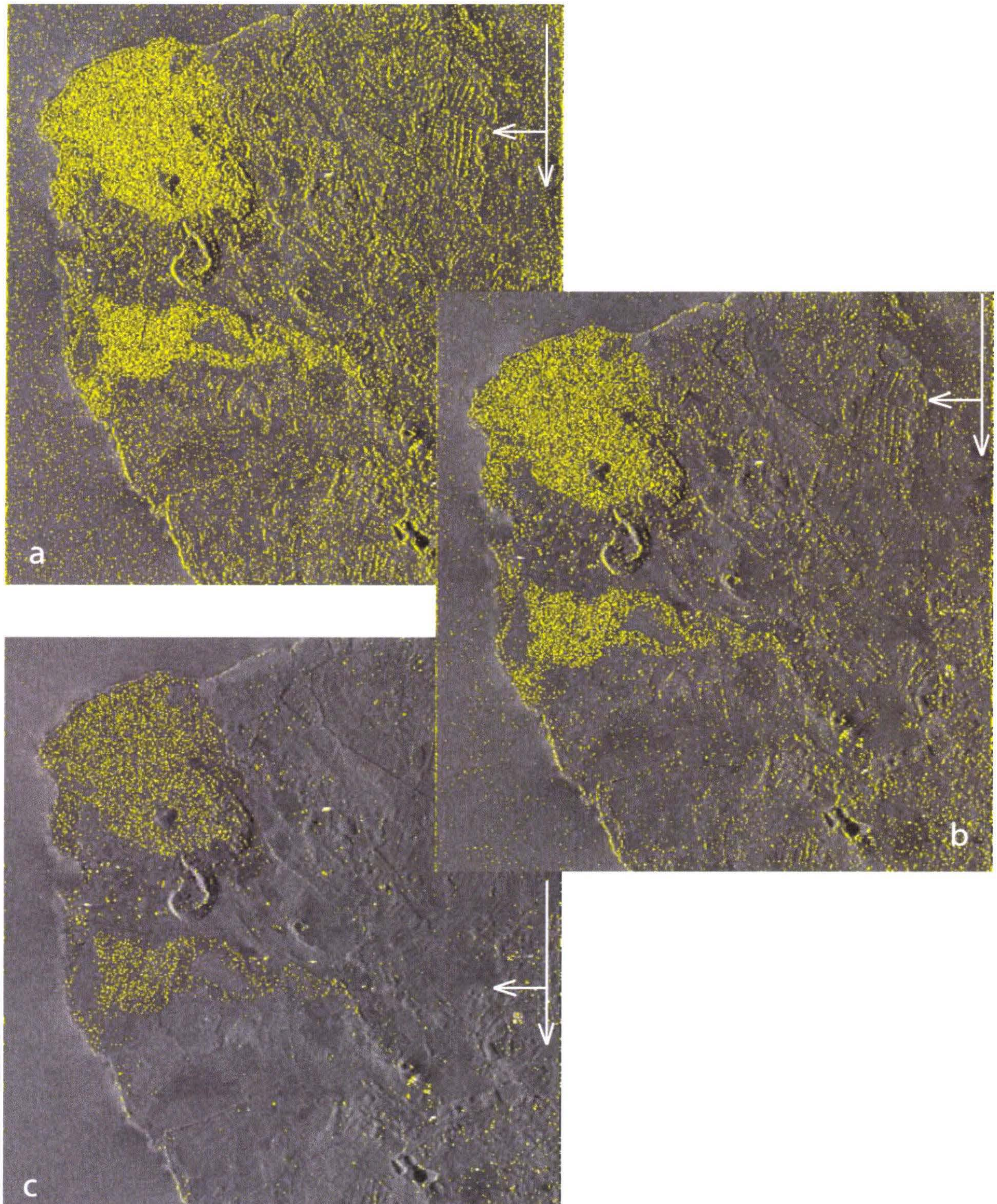



Figure 27: Point locations (shown in yellow dots) of three point lists created using spectral correlation thresholds of (a) 0.3, (b) 0.318, and (c) 0.35. The backscatter intensity image is in the background. Arrows indicate satellite's flight- and the SAR's look-direction.

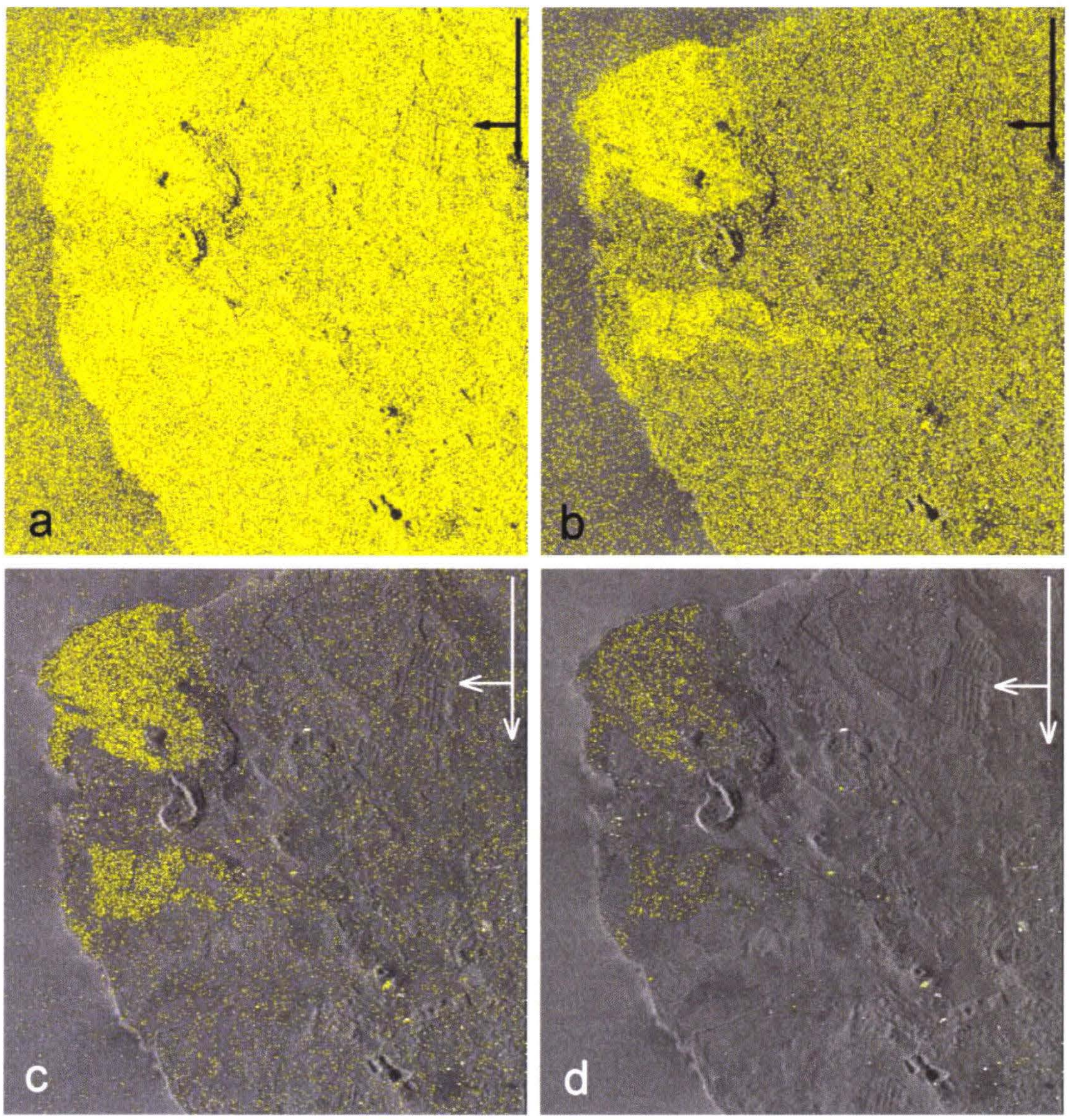



Figure 28: Point locations (yellow dots) of four point lists created temporal variability of SLC intensity thresholds of (a) 1.2, (b) 1.4, (c) 1.7 and (d) 2.1. Backscatter intensity image is in the baackground. Arrows indicate satellite's flight- and the SAR's look-direction.

- Create a raster image of the merged points (Figure 29a: Merged points PDF 2.2 MB)

```
ras_pt pt - rmli_1_5_kapoho/rmli_1_5.ave.ras pt.ras 1 5 255 0 0 3
```

*IPTA-3.5 Create a Mask Raster File*

Use Gimp or equivalent software such as Photoshop, Xv etc. to color all the areas that are not of interest black. Zero values are not considered in the processing.

- Generate a point list and mask vector using a raster image mask

```
msk_pt pt - rmli_1_5_kapoho/mask.ras pt_masked pmask 1 5
```

- Save original point list without mask and rename masked point list to *pt*

```
cp pt pt_nomask
mv pt_masked pt
```

- Create raster of masked points (Figure 29b: Masked points)

```
ras_pt pt - rmli_1_5_kapoho/rmli_1_5.ave.ras pt.ras 1 5
```

**IPTA-4 Generate pSLC_par and SLC Point Data Stacks pSLC (log)**

```
SLC2pt RSLC_tab_kapoho pt - pSLC_par pSLC -
```

The script runs the following commands for the entire list of RSLC specified in the RSLC_tab:

**SLC_par_pt**, **data2pt**

- Read/write record of SLC/MLI parameter stack

```
SLC_par_pt rslc_kapoho/20030212.rslc.par pSLC_par 1 1
```

- Raster to vector format conversion

Extract values from a 2-D data file at specified point locations

```
data2pt rslc_kapoho/20030212.rslc rslc_kapoho/20030212.rslc.par pt
rslc_kapoho/20030212.rslc.par pSLC 1 0
```

**IPTA-5 Generate Initial Differential Interferograms pdiff0**

The initial differential interferograms do not include a height corrected DEM or a linear deformation model.

*IPTA-5.1 Generate DEM Point Data File pdem*

- Convert raster DEM to vector DEM

```
data2pt geo/BI_dem_kapoho.rdc geo/BI_dem_kapoho.rdc.par pt rslc_kapoho/20041208.rslc.par pdem2
1 2
```

- Display point height data

```
pdisdt_pwr24 pt - rslc_kapoho/20041208.rslc.par pdem2 1 rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1
_5_kapoho/rmli_1_5.ave 256. 1
```

The script runs the following commands: pt2data, disdt_pwr24

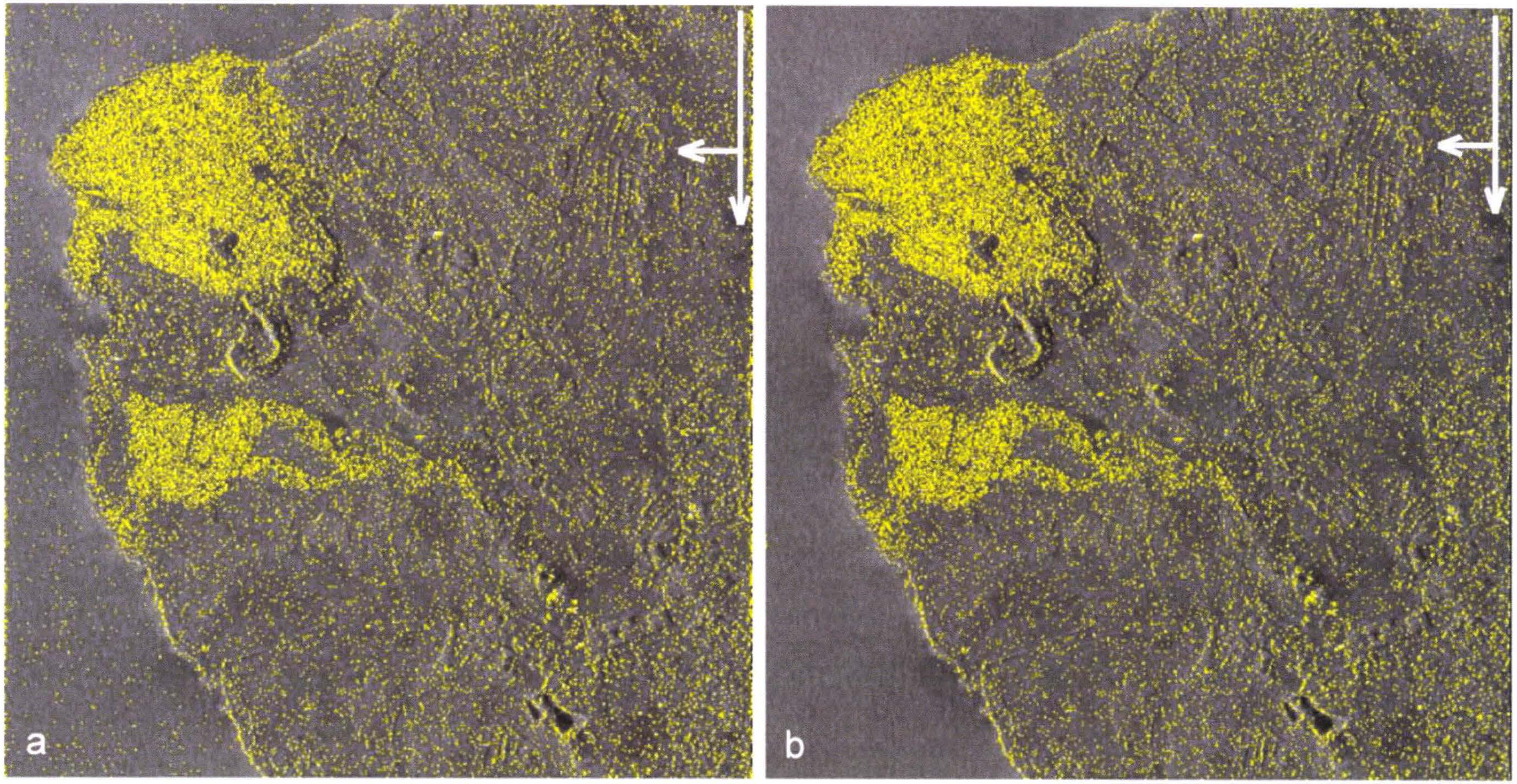



Figure 29: Raster images of (a) merged point list and (b) masked point list. The mask has zero values (black) in areas of water, for this example; other low correlation areas or regions of no interest can also be masked out. Points are shown as yellow dots. Backscatter intensity image is in the baackground. Arrows indicate satellite's flight- and the SAR's look-direction.

- Vector to raster format conversion

Interpolate point data values into a 2-D data file. Uses SLC/MLI parameter file as input.

```
pt2data pt - pSLC_par pdem2 1 tmp.pdisdt_pwr24 rmli_1_5_kapoho/rmli_1_5.ave.par 2 3 4 1
```

- Display float parameter (e.g., height) and intensity image (Figure 30a: Point heights PDF 2.6 MB)

```
disdt_pwr24 tmp.pdisdt_pwr24 rmli_1_5_kapoho/rmli_1_5.ave 500 1 1 0 256. 1. .4
```

*IPTA-5.2 Generate Interferogram Point Data Stack pint0*

Calculate the initial interferograms and display the individual layers

IPTA-5.2.1 Create Interferogram and Baseline Data Stacks (log)

```
mk_int_all pt - pSLC_par itab_single pSLC pbase pint mk_int_all.log
```

The script mk_int_all runs the following commands: **SLC_par_pt**, **base_orbit_pt**, **intf_pt**

- Generate stack of parameter files

```
SLC_par_pt /tmp/slc.par pSLC_par 1 0
```

- Estimate baseline from orbit state vectors (single record or all records)

```
base_orbit_pt pSLC_par itab_single - pbase
```

- Generate interferogram from SLC point data stack (single record or all records)

```
intf_pt pt - itab_single - pSLC pint 0
```

IPTA-5.2.2 Display the Layers of pint0

Generate 2-D images of point data using **pt2data**, **rasdt_pwr24** and **rasmph_pwr24** (log)

```
mk_2d_im pt - itab_single rslc_kapoho/20041208.rslc.par pint 1 - rmli_1_5_kapoho/rmli_1_
5.ave.par 0 3 1.2 1 int0 rmli_1_5_kapoho/rmli_1_5.ave - 0
```

The script runs the following commands for each record in the stack:
**pt2data**, **rasmph_pwr24** (fcomplex) or **rasdt_pwr24** (float)

- Convert vector data to raster format for each record

```
pt2data pt - rslc_kapoho/20041208.rslc.par pint 20 int0/pint_020 rmli_1_5_kapoho/rmli_1_
5.ave.par 0 3 1.2 1
```

Generate 24-bit SUN/BMP raster file of interferogram phase and intensity image (Figure 31: Pint0 PDF 5 MB)

```
rasmph_pwr24 int0/pint_020 rmli_1_5_kapoho/rmli_1_5.ave 500 1 1 0 1 1 .9
```

*IPTA-5.3 Calculate and Subtract Topographic Phase Model psim_unw*

Linear deformation estimates, height corrections, refined baselines and atmospheric distortions are **not** available yet.

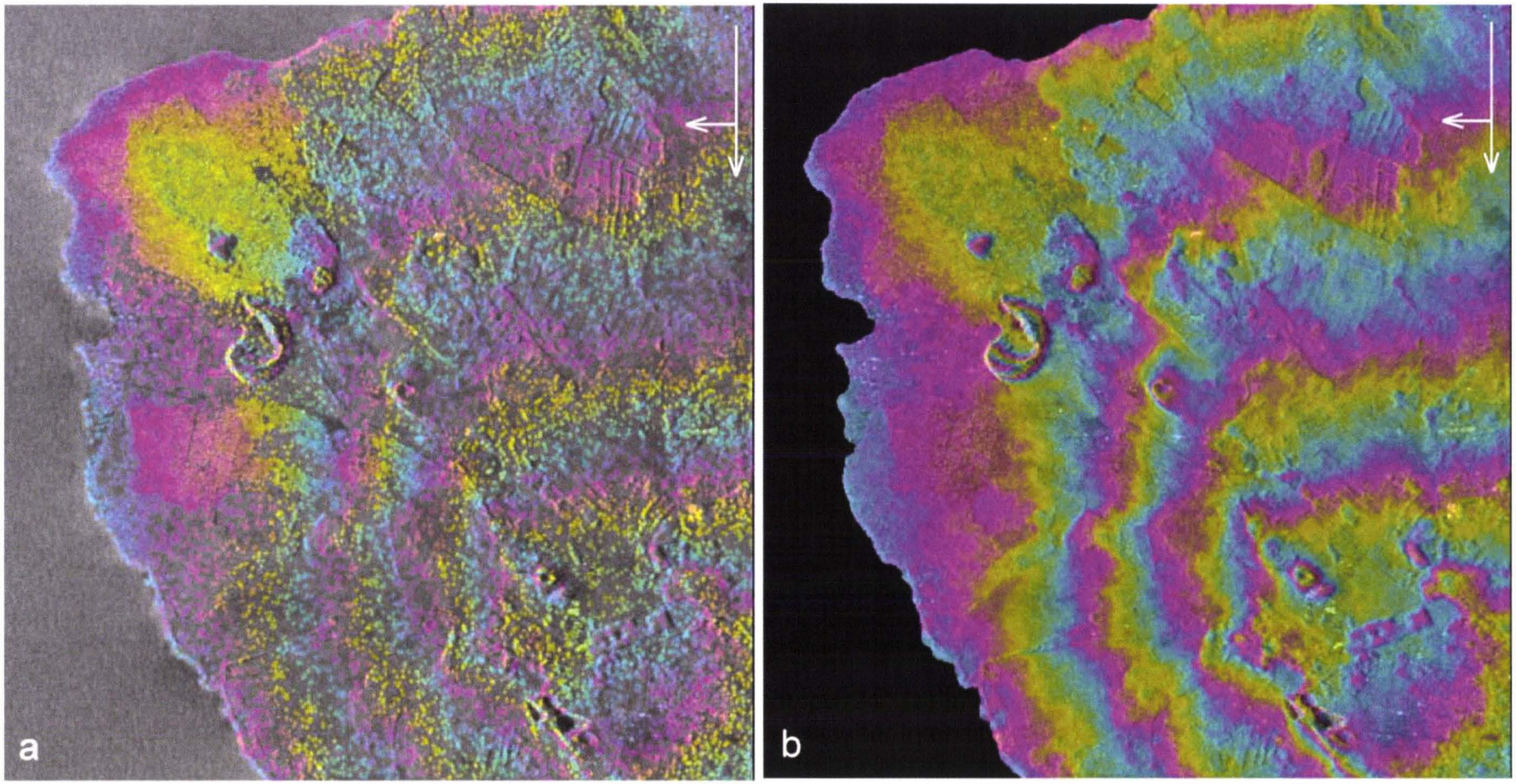



Figure 30: (a) Display of point heights using GAMMA script pdisdt_pwr24. (b) In comparison the DEM heights in RDC generated using rashgt. One color-cycle corresponds to 50 m. Backscatter intensity image is in the baackground. Arrows indicate satellite's flight- and the SAR's look-direction.

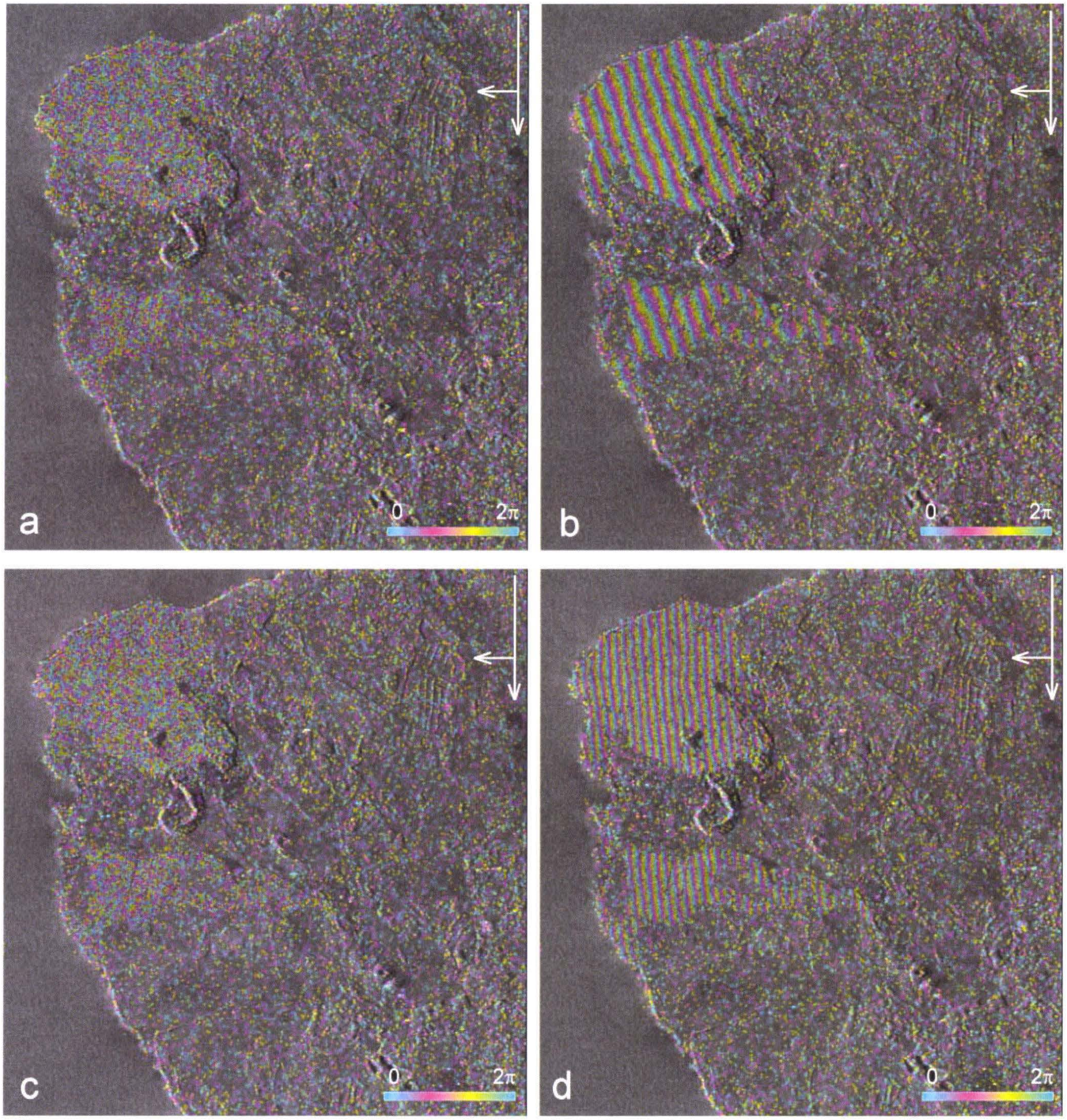



Figure 31: Four layers of the initial wrapped interferometric point data stack pint0: (a) pint0_001, (b) pint0_002, (c) pint0_004, (d) pint0_008. Generated using GAMMA script mk_2d_im. One color-cycle corresponds to 2π radians. Arrows indicate satellite's flight- and the SAR's look-direction.

IPTA-5.3.1 Simulate Topographic Phase and Subtract it from Interferogram (log)

```
mk_diff_all pt - pSLC_par itab_single pbase 0 pint 1 pdem2 - - psim_unw0 pdiff0
mk_diff_all0.log
```

The script mk_diff_all first deletes the simulated phase if it already exists from previous processing.

```
rm -rf psim_unw0
```

Then it runs the following commands: **phase_sim_pt**, **sub_phase_pt**

- Simulate unwrapped interferometric phase

```
phase_sim_pt pt - pSLC_par - itab_single - pbase pdem2 psim_unw0 - 0 0
```

The script **mk_diff_all** then deletes already existing differential interferogram stacks (remnants from earlier processing).

```
rm -rf pdiff0
```

- Subtract phase from interferograms

```
sub_phase_pt pt - pint - psim_unw0 pdiff0 1
```

It is recommended to save the initial differential interferograms, because in future processing the *pdiffs* are going to be overwritten.

```
cp pdiff0 pdiff0_no_phgt
cp -r diff0 diff0_no_phgt
```

IPTA-5.3.2 Create Raster Images of Differential Interferograms (Figure 32: Diff interferograms PDF 5 MB)

```
mk_2d_im pt - itab_single rslc_kapoho/20041208.rslc.par pdiff0 1 - rmli_1_5_kapoho/rmli_1_
5.ave.par 0 3 1.2 1 diff0 rmli_1_5_kapoho/rmli_1_5.ave - 0
```

### IPTA-6 Phase Regression Analysis for Pairs of Points

The general phase model for IPTA is identical to conventional interferometry. The unwrapped interferometric phase may be expressed as the sum of topographic phase, deformation phase, atmospheric phase (also referred to as differential path delay phase) and phase noise (or decorrelation) terms [*Werner, et al.*, 2003]. IPTA is a method to utilize the spatial and temporal characteristics of these phase terms (see table below) to precisely calculate height maps, deformation histories and the atmospheric path delay. The simulated (modeled) unwrapped topographic phase and its model parameters are iteratively improved throughout the process, which also includes a baseline refinement.

The phase model point data stack (simulated topography) may be calculated with respect to a linear deformation rate estimate and/or height corrections for the available DEM. At first, though, no deformation and no height corrections are available. The initial phase model is subtracted from the complex valued wrapped point interferograms to obtain complex valued wrapped point differential interferograms.

The next processing step consists of least-squares regression analyses performed on the stack of differential interferograms. The interferometric phase model suggests linear phase dependence for the perpendicular baseline as well as for time.

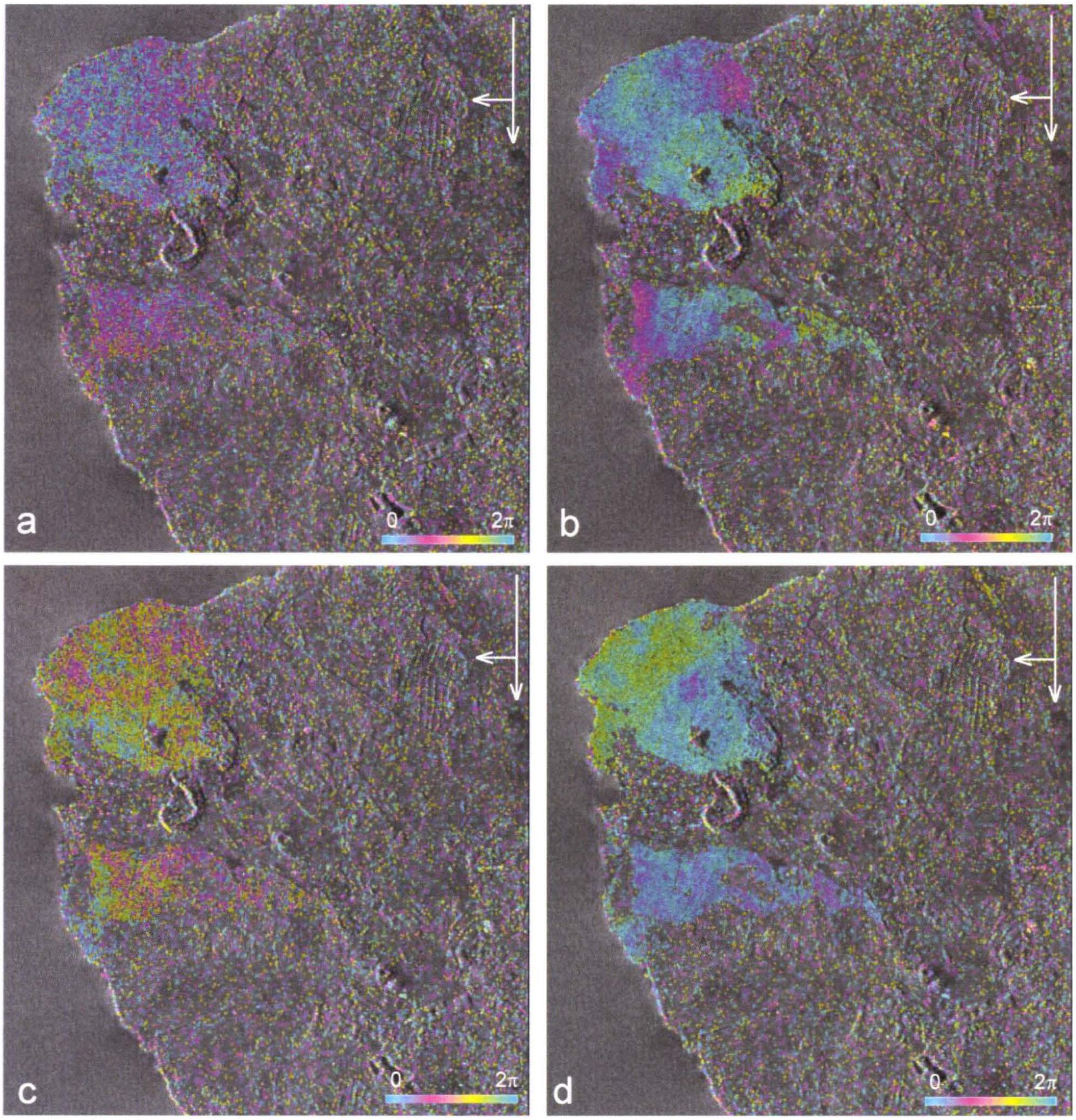



Figure 32: Four layers of the initial wrapped differential interferometric point data stack pdiff0: (a) pdiff0_001, (b) pdiff0_002, (c) pdiff0_004, (d) pdiff0_008. Raster images created using GAMMA script mk_2d_im. One color-cycle corresponds to 2π radians. Arrows indicate satellite's flight- and the SAR's look-direction.

The slopes of the regression represent height corrections and linear deformation rate, respectively. Those terms may then be used to refine the model of the simulated unwrapped topographic phase. The regression analysis is primarily done across the data stack, i.e., in the temporal domain. Additional output parameters are the unwrapped phase, a quality measure and residual phases. The table below shows the spatial and temporal characteristics of the components of the residual phase which have to be utilized in order to be able to distinguish between atmospheric and non-linear deformation phase.

| **Residual phase components** | **Spatial domain** | **Temporal domain** |
|---|---|---|
| Atmosphere | Correlated/Low pass | Random/High pass |
| Non-linear deformation | Correlated/Low pass* | Correlated/Low pass* |
| Baseline errors | Correlated/Low pass | Random/High pass |
| Phase noise | Random/High pass | Random/High pass |

*This is generally the case, non-linear deformation can also be highly uncorrelated (earthquakes, landslides etc.)

There are six models that can be applied for phase regression analysis

1: a0 + a1*bperp [i]

2: a0 + a1*bperp [i] + a2*delta_t [i]) (default)

3: a1*bperp [i]

4: a1*bperp [i] + a2*delta_t [i]

5: a0 + a2*delta_t [i]

6: a2*delta_t [i]

The parameter a0 is an optional phase constant that needs to be calculated if a single SLC is used as the reference for all interferograms. If different SLC are used as references for the interferogram pairs in the stack (**base_calc**: all combinations) the phase constant is 0.0 and does not need to be estimated. Use of the one-dimensional regression models constrains the regression and gives better results for small stacks (25+) or early on in the analysis when large height corrections (50+ m) are expected [*Wegmüller*, 2005].

For the Kapoho project, a two-dimensional phase model is chosen to calculate height corrections and linear deformation simultaneously. Calculating the height corrections in a one-dimensional regression analysis first would limit the number of usable scenes, considering the fact that only short time intervals can be used to prevent hidden deformation signals.

*IPTA-6.1 Interactive Point-wise Phase Regression Analysis*

- Display regressions of phase with respect to time interval and baseline

In the case of wrapped phase values (**dis_ipta_unw** can be used for unwrapped phases) the regression is done in two steps by the script: 1) the best regression function among a predefined set of functions is determined and 2) a least-squares analysis is conducted. The predefined regression functions for 1) are derived based on the indicated height correction and maximum deformation rate. The higher those values, the more regression models are tested, increasing the running time. Allowing a too high maximum height correction further reduces the efficiency and might result in more phase unwrapping errors [*Wegmüller*, 2005]. Choosing values too small might result in failure to resolve the regression for a point with a large height correction or linear deformation rate value. Note that height corrections and linear deformation rate estimates are relative to the reference point, they are not absolute values. The regression is therefore more robust for points near the reference point.

The reference point is determined using **dis_ipta**. It should be close to the region of interest in a relatively stable area. By double clicking the right mouse button the reference point can be locked in and individual regressions can be visually evaluated by using the right mouse button once. The left mouse button changes the zoom window.

Experimenting with the maximum height correction and maximum linear deformation rate resulted in parameter values of 30 and 0.01, respectively for the example of Kapoho. The reference point (23558) for the regression analysis is chosen in the southern flow, close to the town of Kapoho (Figure 33: Dis_ipta output PDF 3.3 MB).

```
dis_ipta pt - pSLC_par - itab_single pbase 0 pdiff0 1 diff0/pdiff0_008.ras 30 0.01 2 - - 3 128
```

```
ref.:23558   x:104   y:1502   point:13003   x:149    y:  714
dphase/dBperp:  1.41411e+03  delta2 - delta1 (m):      0.01192  alpha:  7.06403e-04

look angle (deg.):   19.54137   interior ange (deg.):    2.52874  range (m):  840996.409
number of phase steps: 8  step size:    0.78540
steps nrpm: 27  radians/meter step:  1.52009e-03   steps nrpd: 6  radians/day step:  2.03933e-
03
init. slope (rad./m):-7.600e-04  def rate:-2.039e-03  phase offset:   -1.571  stddev:  1.23941
model 2 slope(rad/day):-1.07310e-03  slope (rad/m):-4.89132e-04  offset:  -1.43635  sigma:
1.24922

delta height (m):            0.6924  estimated uncertainty (m):          0.9815
deformation rate m/year:  1.754e-03  estimated uncertainty (m/year):  1.508e-03
phase constant (rad):       -1.4363  estimated uncertainty (rad):        0.3303
```

*IPTA-6.2 Automated Phase Regression Analysis*

For the automated regression analysis it is recommended to save the results of every run in a different folder. That makes it easier to keep track of the outputs and prevent accidentally overwriting files.

IPTA-6.2.1 Multi-patch Estimation of Linear Deformation, Height Corrections and Residual Phase

```
mkdir multi_def_pt1

multi_def_pt pt - pSLC_par - itab_single pbase 0 pdiff0 1 23558 multi_def_pt1/pres1
multi_def_pt1/pdh1 multi_def_pt1/pddef1 multi_def_pt1/punw1 multi_def_pt1/psigma1
multi_def_pt1/pmask1 30. 0.01 70 1.2 1.0 2 0 -1 -1

number of points with sigma < sigma_max = 1.200 : 19791
```

**Multi_def_pt** uses a multi-patch approach to conduct a regression analysis. Each patch has a local reference point, making the regression more robust. The unwrapping might result in errors related to patch boundaries. It might help to choose smaller/larger patches if the sample size permits it.

- Create images of output (Figure 34 PDF 4.7 MB)

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/pdh1    1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 30.0 1
```

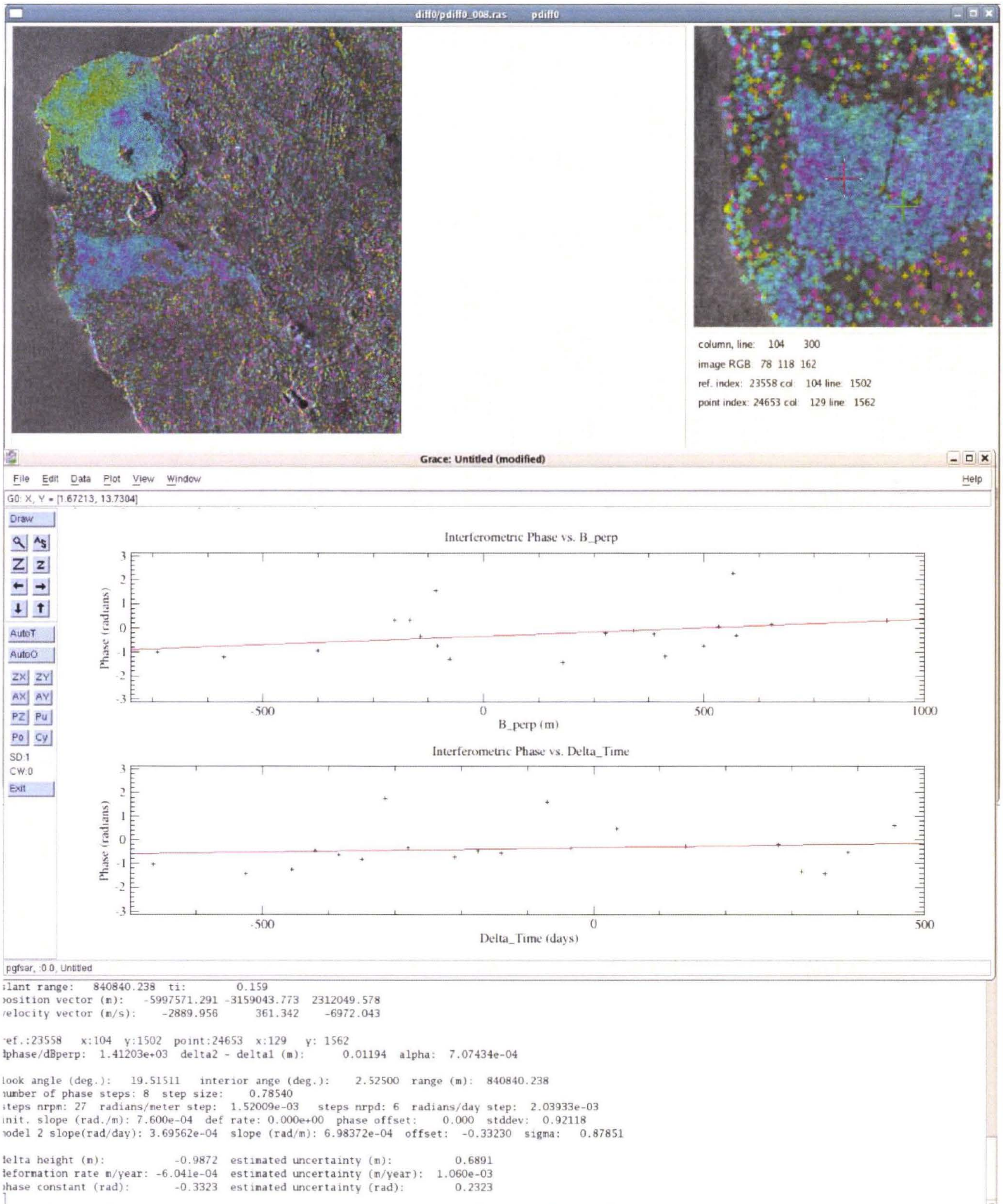



Figure 33: Conducting a manual regression to determine a reference point using GAMMA command dis_ipta. Location of the reference point is indicated by the red cross, the 2nd point for the regression by the green cross. The Grace plot shows the regressions, top: height corrections (Bperp vs. phase), bottom: linear deformation rate (Delta_t vs. phase).

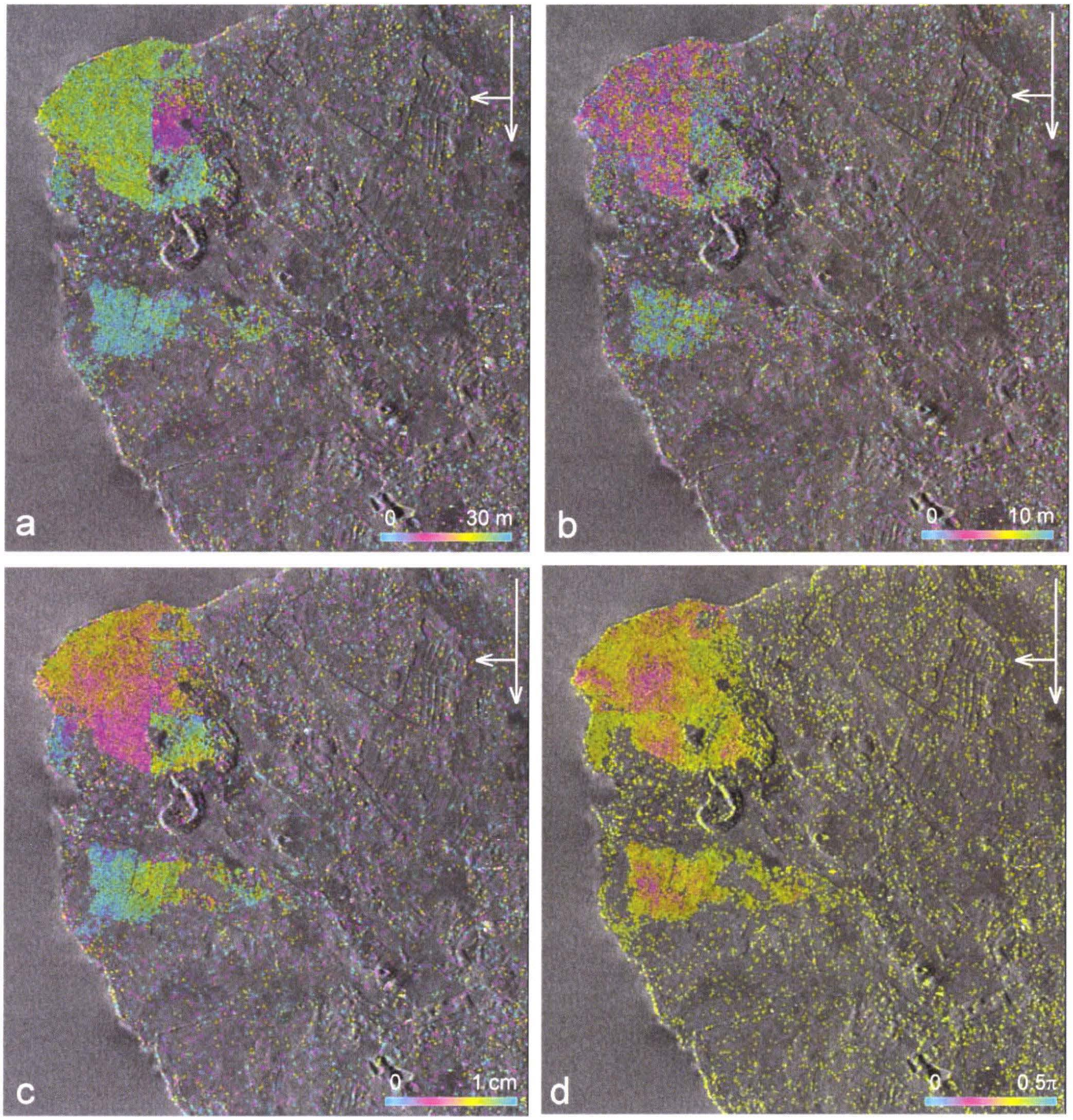



Figure 34: Results from 1st multi-patch regression (GAMMA command multi_def_pt). All initial wrapped differential interferograms used as input point data stack. (a) Height correction pdh1 (30 m/color-cycle, values in the southern flow range from -10 to 10 m), (b) pdh1 (10 m/color-cycle), (c) linear deformation rate (0.01 m/color-cycle, cyan: ~ -1.5 mm, yellow: ~ -2.5 mm), (d) phase standard deviation from regression-fit (1/2 π rad/color-cycle, red: ~ 0.7 rad). Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

The areas highlighted by the selected points on the east tip of the Big Island can be divided in two main areas, a northern and a southern lava flow created in the 1960 eruption. The northern flow shows an obvious color discontinuity in the initial height corrections (Figure 34a, b), related to unwrapping errors along the patch boundaries. The project focuses on the southern flow which does not show any errors. It is therefore acceptable to disregard the patch boundary discontinuities in the northern flow. Height corrections range between -10 and 10 m and will be used to correct the available Digital Elevation Model (DEM). Height corrections are determined through the linear dependence of the interferometric phase on the perpendicular baseline. Note: prasdt_pwr24 creates raster images, whereas pdisdt_pwr24 displays the data in GAMMA so the actual values can be observed.

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/pddef1  1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.01 1
```

The linear deformation rate estimate is based on the linear dependence of the interferometric phase on temporal baseline. Again, the discontinuities in the northern flow (Figure 34c) can be ignored, since the project focuses on the southern flow.

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/psigma1 1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 1.5  1
```

The standard deviation from the regression fit is calculated for each point. It can be used as a quality measure (Figure 34d) for the regression. Sigma increases in value with distance from reference point.

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/pres1   - rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 2.5 1
```

The residual phases (Figure 35: Residuals at 2.5 radians PDF 4.6 MB, Figure 36: Residuals at 12.6 radians PDF 4.7 MB) represent the deviation from the regression fit and are calculated for each record in the stack. Using a phase scale of 12.6 radians results in a smooth southern flow indicating a good phase model [*Wegmüller*, 2005] whereas 2.5 radians is used to show greater detail in the variations.

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/punw1   - rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
```

Unwrapped interferometric phase examples (Figure 37 PDF 4.7 MB) are calculated for each record in the stack.

**Multi_def_pt** unwraps the interferometric phases temporarily throughout the entire stack. Depending on baseline related errors or influence of atmospheric distortions, some of the unwrapping might be incorrect. Looking at each residual record, four scenes with patch related phase unwrapping errors in the southern flow can be identified (2, 3, 7, 12). In the next step **def_mod_pt** is run without those "incorrectly unwrapped" scenes. The IPTA command **def_mod_pt** conducts the regression analysis using a single patch approach, which is possible because the data is already unwrapped.

IPTA-6.2.2 Estimation of Linear Deformation Rate, Height Correction and Residual Phase over the Entire Scene

Re-running the regression analysis for correctly unwrapped layers (itab_selection).

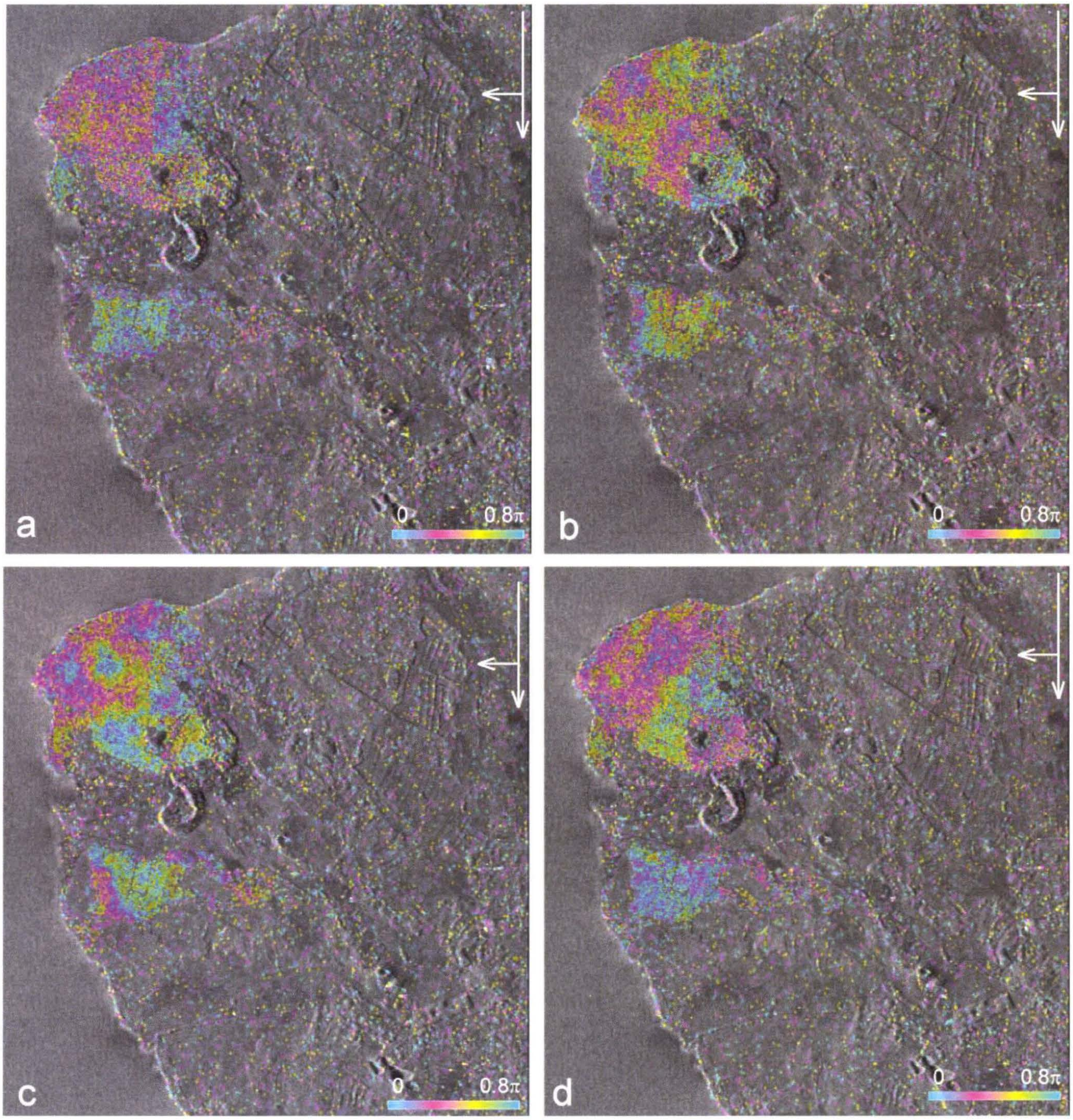



Figure 35: Residual phases from 1st multi-patch regression (GAMMA command multi_def_pt). One color-cycle corresponds to 2.5 rad to show minute difference to residuals from later processing. All initial wrapped differential interferograms used as input point data stack. (a) Pres1_001, (b) pres1_002, (c) pres1_004, (d) pres1_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

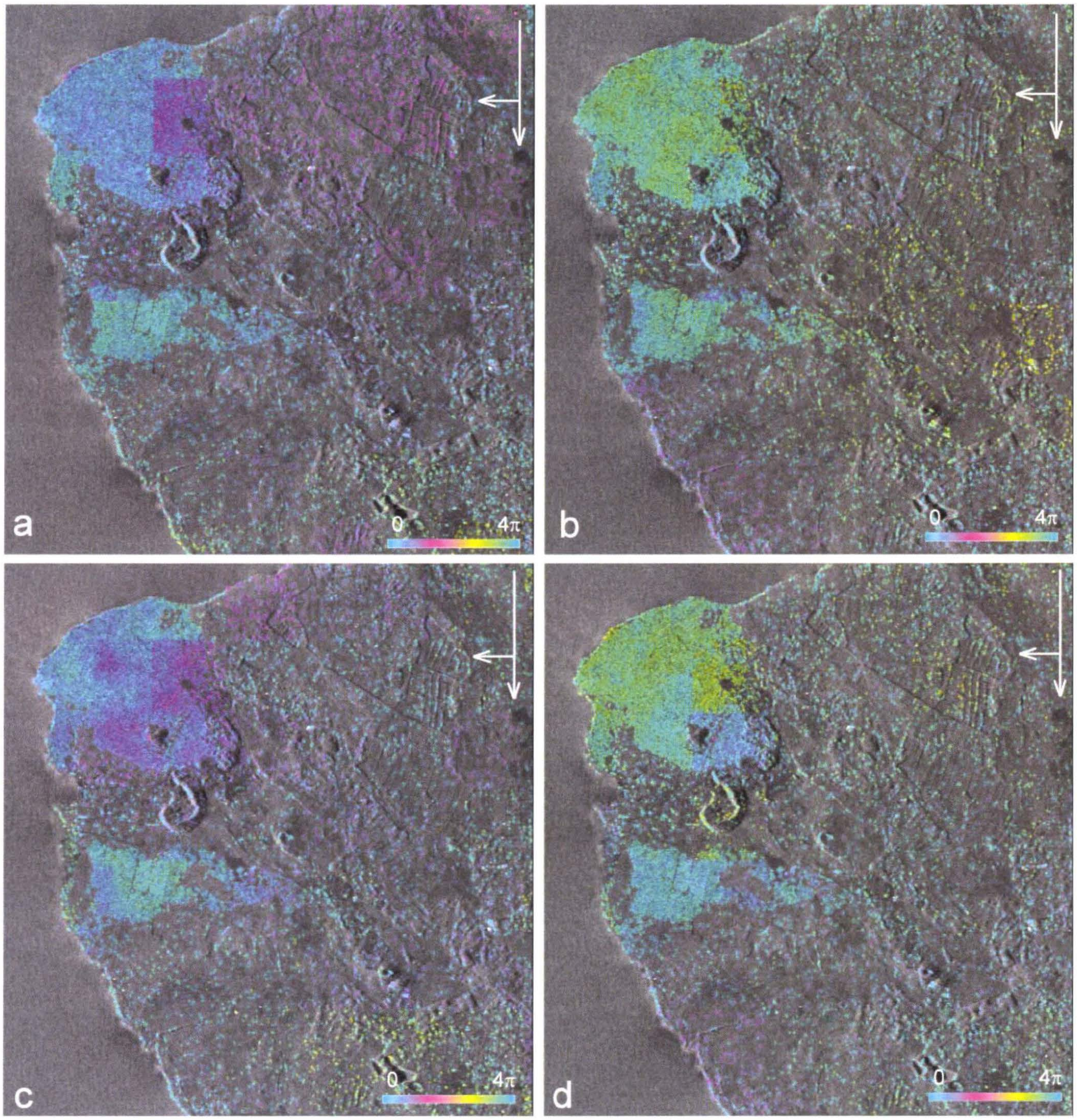



Figure 36: Residual phases from 1st multi-patch regression (GAMMA command multi_def_pt). One color-cycle corresponds to 12.6 rad. All initial wrapped differential interferograms used as input point data stack. (a) Pres1_001, (b) pres1_002, (c) pres1_004, (d) pres1_008. Generated using GAMMA script prasdt_pwr24. Note the smoothness of the southern flow. Arrows indicate satellite's flight- and the SAR's look-direction.

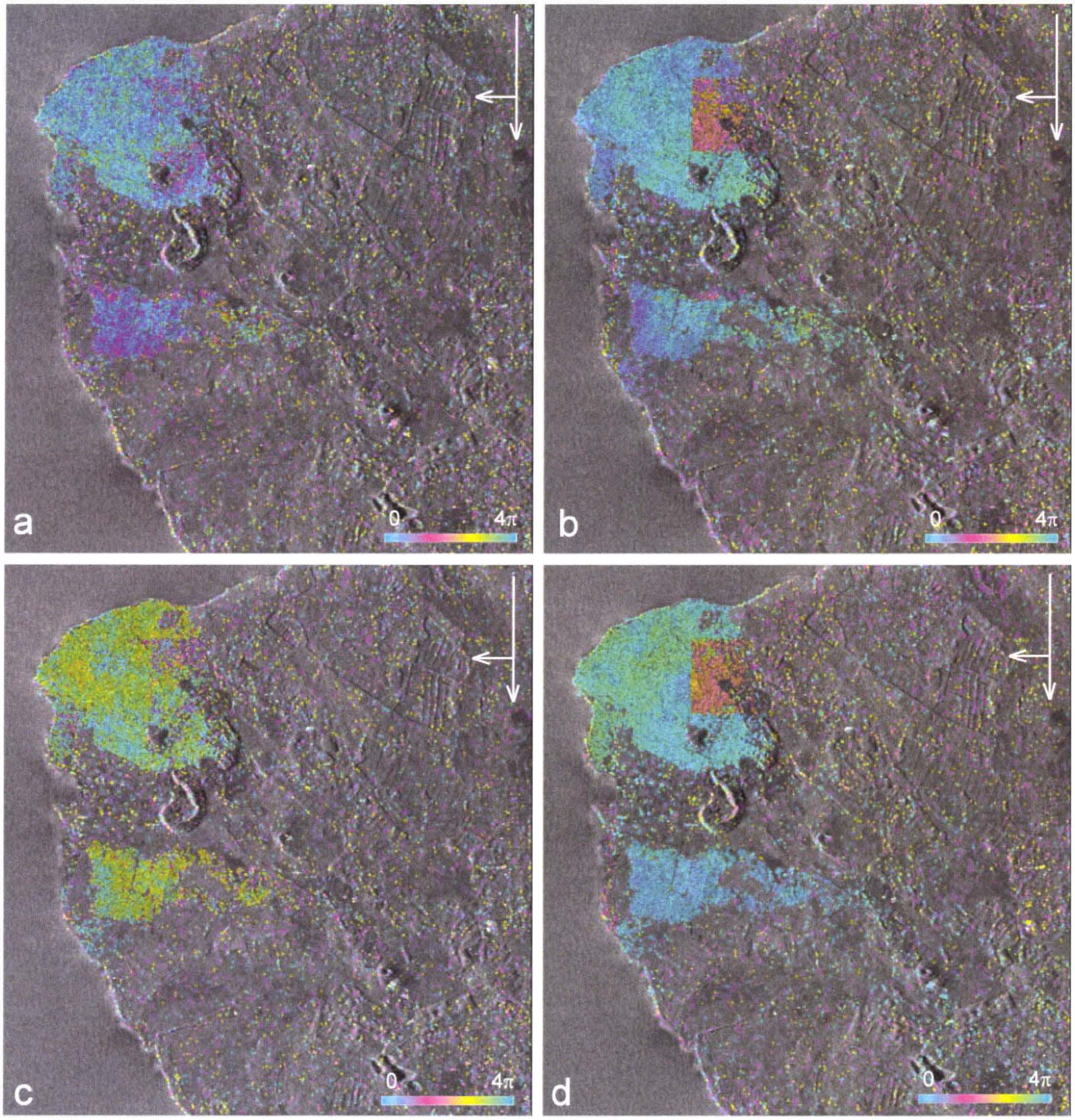



Figure 37: Unwrapped interferometric phases from 1st multi-patch regression (GAMMA command multi_def_pt). One color-cycle corresponds to 12.6 rad All initial wrapped differential interferograms used as input point data stack. (a) Punw1_001, (b) punw1_002, (c) punw1_004, (d) punw1_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

```
mkdir def_mod_pt

def_mod_pt  pt multi_def_pt1/pmask1 pSLC_par - itab_selection pbase 0 multi_def_pt1/punw1 0
23558 def_mod_pt/pres2 def_mod_pt/pdh2 def_mod_pt/pddef2 def_mod_pt/punw2 def_mod_pt/psigma2
def_mod_pt/pmask2 25. 0.03 3.0 2 - - -

number of points with sigma < sigma_max=3.000 : 19646
```

- Create images of output (Figure 38 PDF 4.6 MB)

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/pdh2    1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 30.0 1
```

Height corrections (Figure 38a, b) are a little bit smaller without the influence of "incorrectly unwrapped" data. The northern flow still shows an obvious color discontinuity, related to unwrapping errors, which still can be neglected since the project only focuses on the southern flow. The differences are more visible using a lower phase scaling of 2.5 radians. The slight improvements in the height corrections can be observed by comparing the actual values using the command **disdt_pwr24**.

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/pddef2  1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.01 1
```

The linear deformation estimate (Figure 38c) without influence of "incorrectly unwrapped" data does not change significantly. Again, the discontinuities in the northern flow can be ignored.

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/psigma2 1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 1.5  1
```

The point quality measure sigma (Figure 38d) increases in value with distance from reference point. Notice how the amount of red points increases in the southern flow (especially around the reference point), indicating lower sigma values, hence an improvement in the model.

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/pres2    - rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 2.5 1
```

The residual phases (Figure 39: Residuals at 2.5 radians PDF 4 MB, Figure 40: Residuals at 12.6 radians PDF 4.1 MB) represent the deviation from the regression fit and are calculated for each record in the stack. The scale factor of 2.5 allows detailed comparison to residuals from **multi_def_pt** run (Figure 35). Using a phase scale of 12.6 results in a even smoother southern flow indicating a better phase model [*Wegmüller*, 2005].

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/punw2    - rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
```

Unwrapped interferometric phases (Figure 41 PDF 4.1 MB) are calculated for each record in the stack.

### IPTA-7 Update the Height and Deformation Model

- Calculate linear combination of records in point data stacks

Apply height correction to *pdem*, *phgt1* becomes the current height model

```
lin_comb_pt pt def_mod_pt/pmask2 pdem2 1 def_mod_pt/pdh2 1 phgt1 1 -0. 1. 1. 2 0
```

- Copy the refined linear deformation rate estimate to the current deformation model *pdef1*

```
cp def_mod_pt/pddef2 pdef1
```

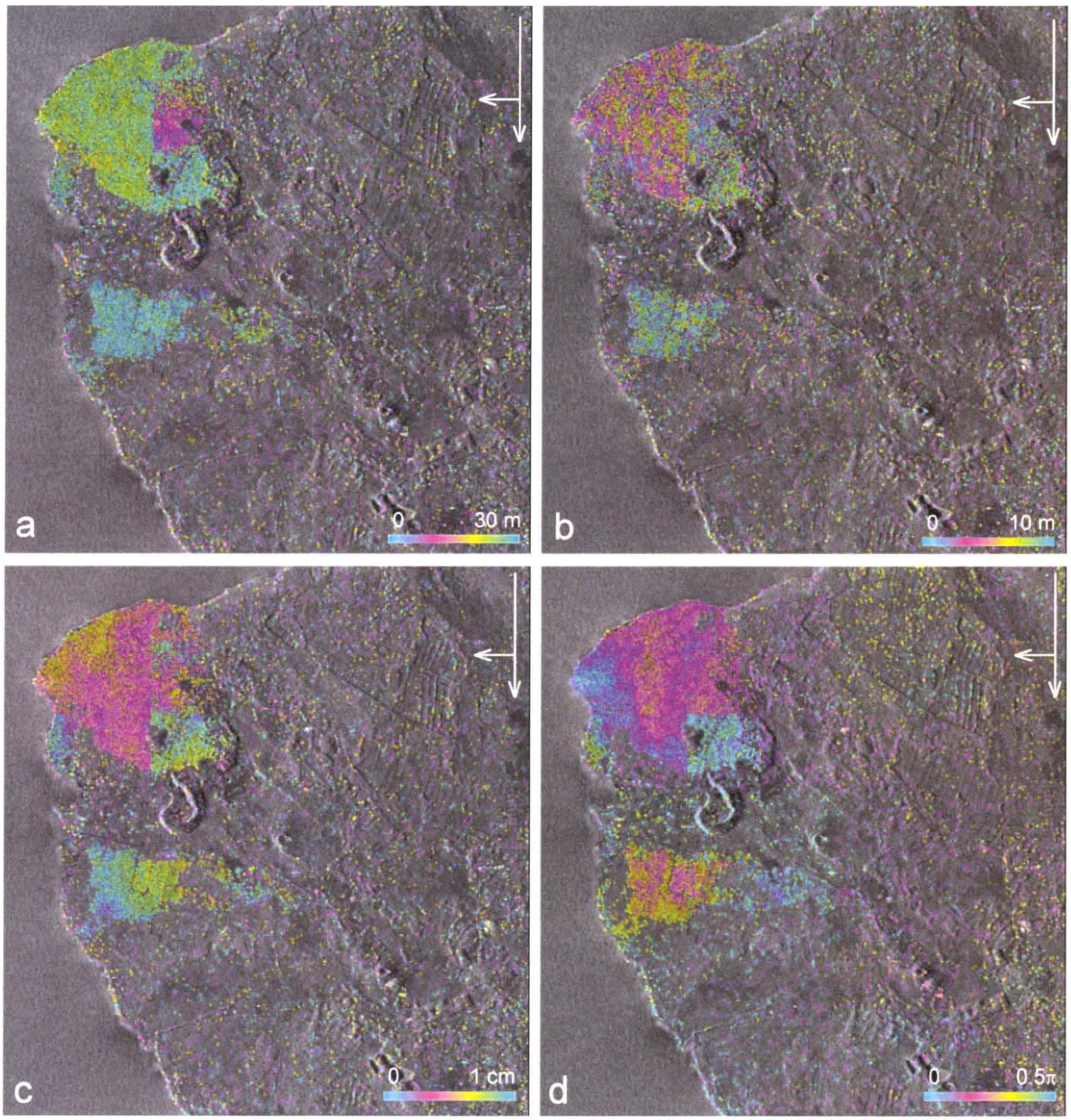



Figure 38: Results from 1st single-patch regression (GAMMA command def_mod_pt). Only correctly unwrapped differential interferograms used as input point data stack. Compare to Figure 34. (a) Height correction pdh2 (30 m/color-cycle, most values in the southern flow are between -8 and 8m, (b) pdh2 (10 m/color-cycle), (c) linear deformation rate (0.01 m/color-cycle, cyan: ~ -1.5 mm, yellow: ~ -2.5 mm), (d) phase standard deviation from regression-fit (1/2 π rad/color-cycle, red: ~ 0.7 rad). Notice the increased number of red sigma values. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

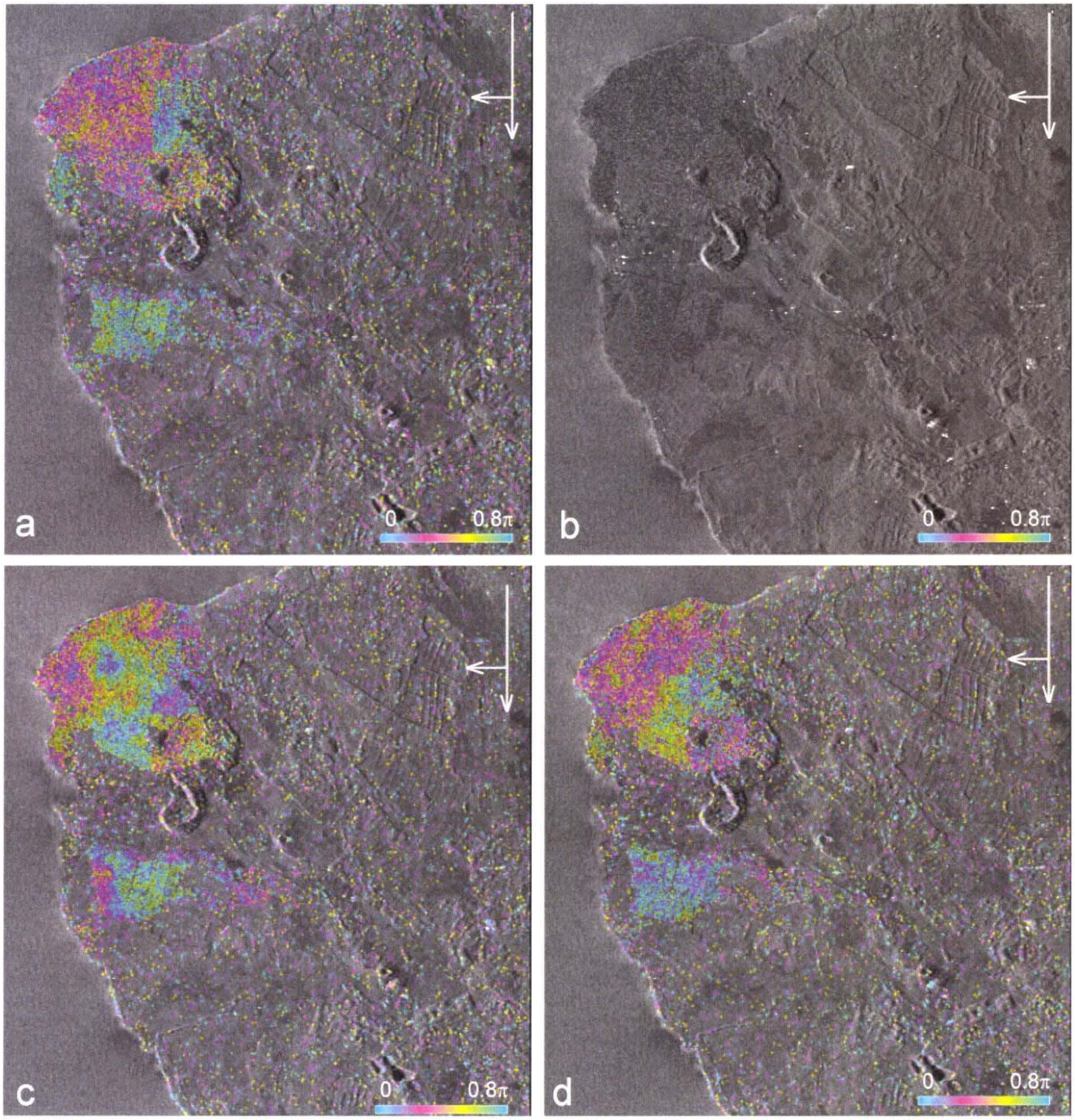



Figure 39: Residual phases from 1st single-patch regression (GAMMA command def_mod_pt). One color-cycle corresponds to 2.5 rad to show minute difference to residuals from earlier processing (Figure 35). Only correctly unwrapped differential interferograms used as input point data stack.
(a) Pres2_001, (b) pres2_002, no data because pres1_002 showed unwrapping errors and was not included in this regression.(c) pres2_004, (d) pres2_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

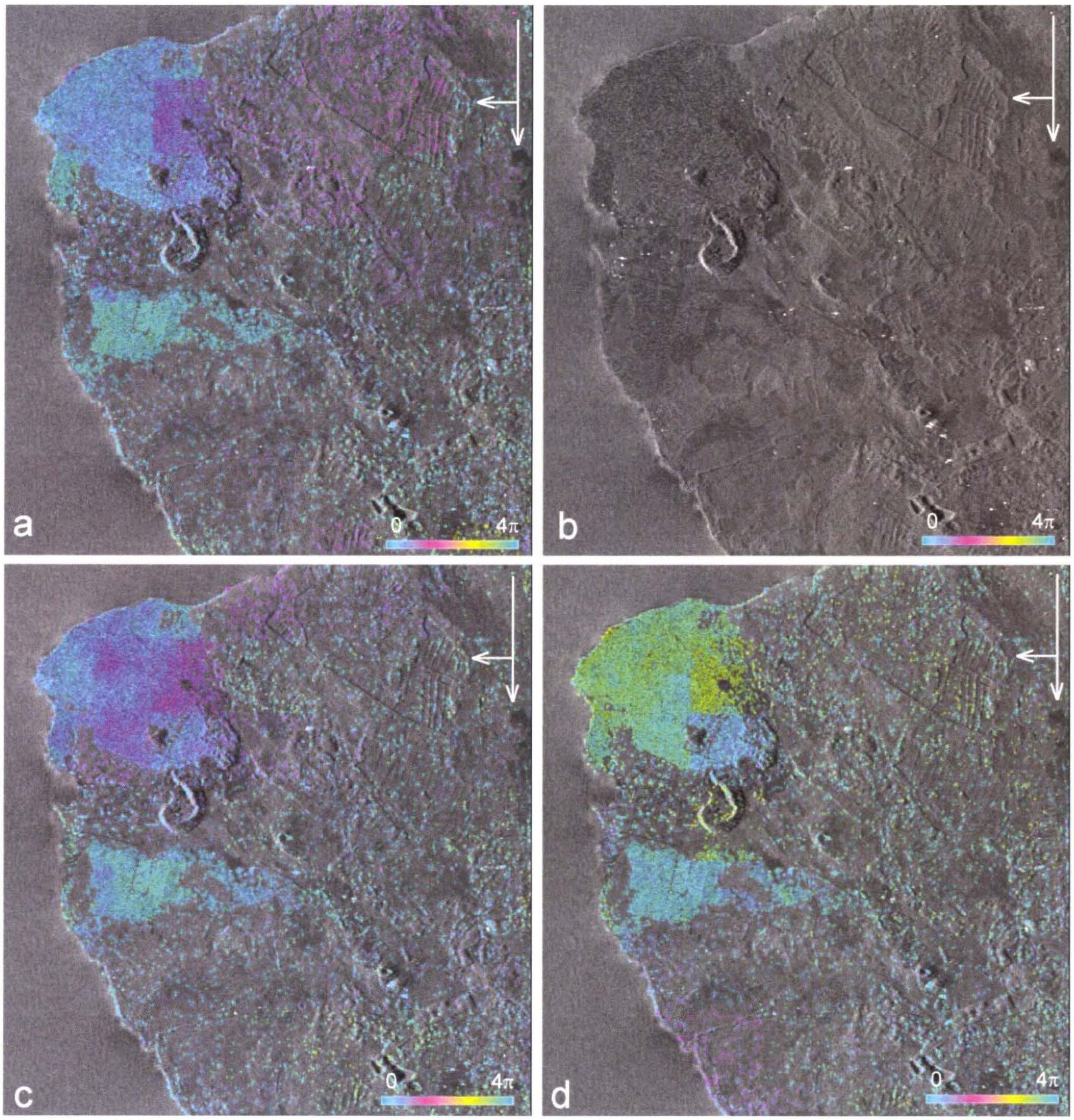



Figure 40: Residual phases from 1st single-patch regression (GAMMA command def_mod_pt). One color-cycle corresponds to 12.6 rad. Only correctly unwrapped differential interferograms used as input point data stack. (a) Pres2_001, (b) pres2_002, no data because pres1_002 showed unwrapping errors and was not included in this regression, (c) pres2_004, (d) pres2_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

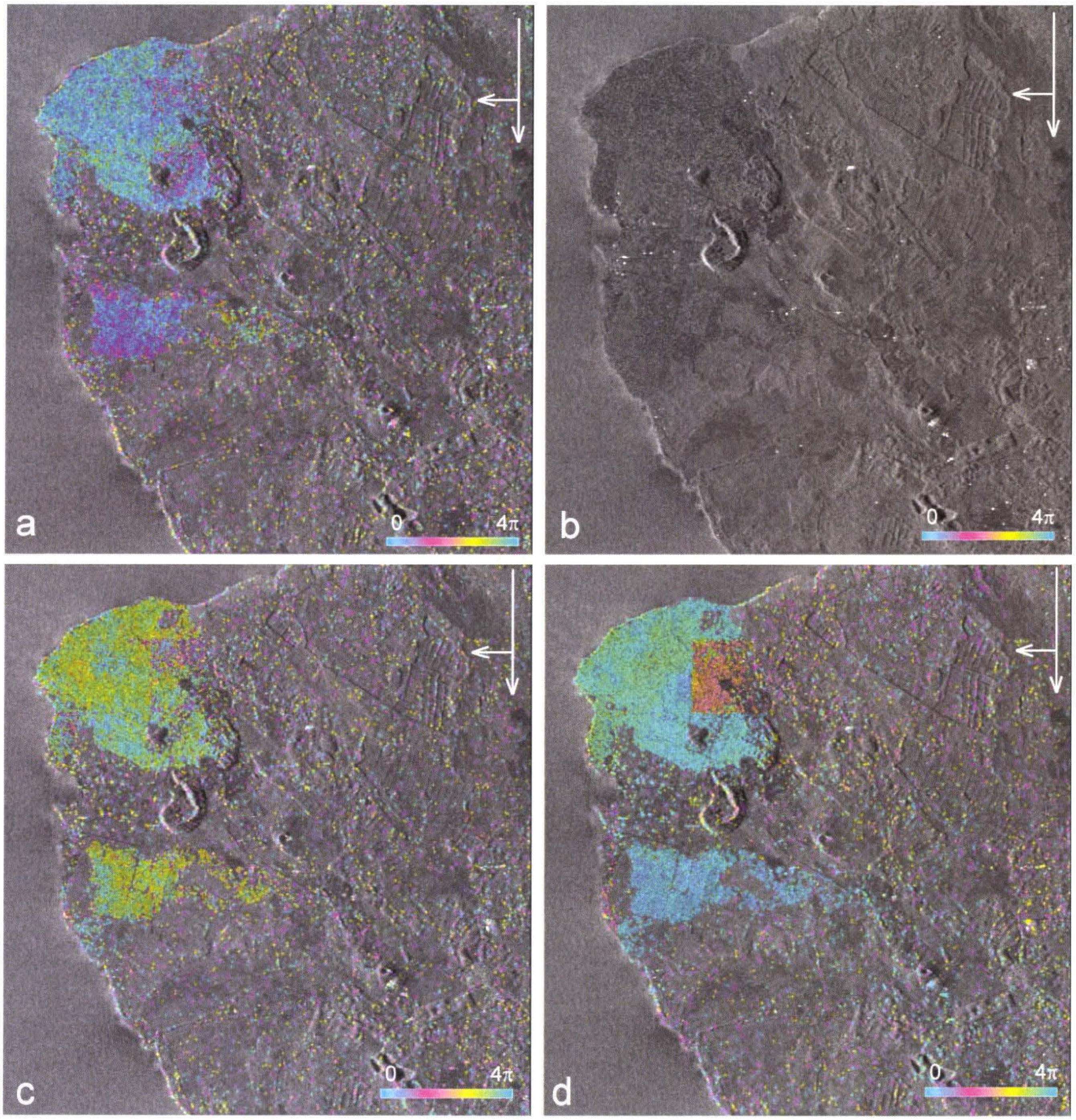



Figure 41: Unwrapped interferometric phases from 1st single-patch regression (GAMMA command def_mod_pt). One color-cycle corresponds to 12.6 rad Only correctly unwrapped differential interferograms used as input point data stack. (a) Punw2_001, (b) punw2_002, no data because pres1_002 showed unwrapping errors and was not included in this regression, (c) punw2_004, (d) punw2_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

**IPTA-8 Calculate Updated Differential Interferograms**

- Calculate differential interferograms using *phgt1* and *pdef1* (log)

```
mk_diff_all pt def_mod_pt/pmask2 pSLC_par itab_single pbase 0 pint 1 phgt1 pdef1 -
def_mod_pt/psim_unw0 def_mod_pt/pdiff0 def_mod_pt/mk_diff_all0.log
```

- Create images of updated differential interferograms (log) (Figure 42 PDF 4.5 MB)

```
mk_2d_im pt def_mod_pt/pmask2 itab_single rslc_kapoho/20041208.rslc.par def_mod_pt/pdiff0 1 -
rmli_1_5_kapoho/rmli_1_5.ave.par 0 3 1.2 1 def_mod_pt/diff0 rmli_1_5_kapoho/rmli_1_5.ave - 0
```

**IPTA-9 Regression Analysis on Updated Differential Interferograms**

- Include additional pairs into solution of model

```
mkdir multi_def_pt2
multi_def_pt pt def_mod_pt/pmask2 pSLC_par - itab_single pbase 0 def_mod_pt/pdiff0 1 23558
multi_def_pt2/pres1 multi_def_pt2/pdh1 multi_def_pt2/pddef1 multi_def_pt2/punw1
multi_def_pt2/psigma1 multi_def_pt2/pmask1 3. 0.003 70 1.3 0.9 2 1 -1 -1
```

```
number of points with sigma < sigma_max = 1.300 : 12728
```

- Create images of output (Figure 43 PDF 3.4 MB)

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/pdh1    1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 30.0 1
```

The height corrections (Figure 43a, b) appear smooth in the southern flow, indicating that major corrections have already been done. The earlier height corrections, applied to the DEM in IPTA-7, corrected errors in the DEM sufficiently.

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/pddef1  1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.01 1
```

The linear deformation rate estimate (Figure 43c) shows a similar behavior, a smooth southern flow, again, indicating that major corrections have already been done.

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/psigma1 1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 1.5  1
```

The point quality measure sigma (Figure 43d) did not change significantly in comparison to Figure 34d.

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/pres1   - rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
```

As one can see in Figure 44 (PDF 3.4 MB), fewer points are displayed in comparison to the residual plots from Figure 34, indicating that only "good" points are used. Higher thresholds have selected better points. The residuals themselves have not changed significantly. Figure 45 (PDF 3.4 MB) shows the residual phases at a phase scale of 12.6.

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/punw1   - rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
```

Example of unwrapped phase can be seen in the four examples in Figure 46 (PDF 3.4 MB).

Check residuals carefully for unwrapping errors: none in this case.

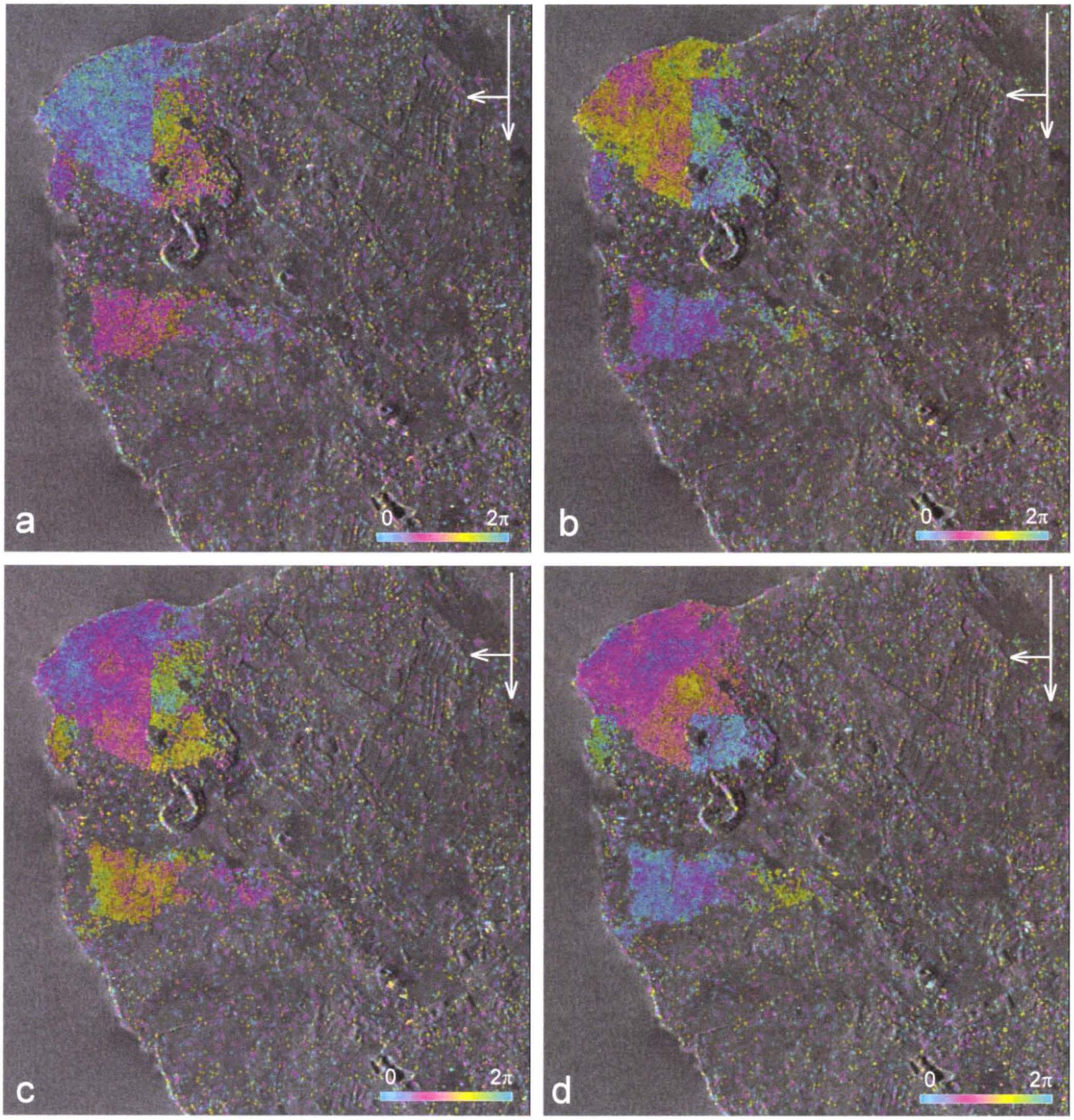



Figure 42: Four layers of the updated wrapped differential interferometric point data stack pdiff0: (a) pdiff0_001, (b) pdiff0_002, (c) pdiff0_004, (d) pdiff0_008. The topographic phase subtracted from the interferograms now accounts for the height corrections and the linear deformation estimate. Generated using GAMMA script mk_2d_im. Arrows indicate satellite's flight- and the SAR's look-direction.

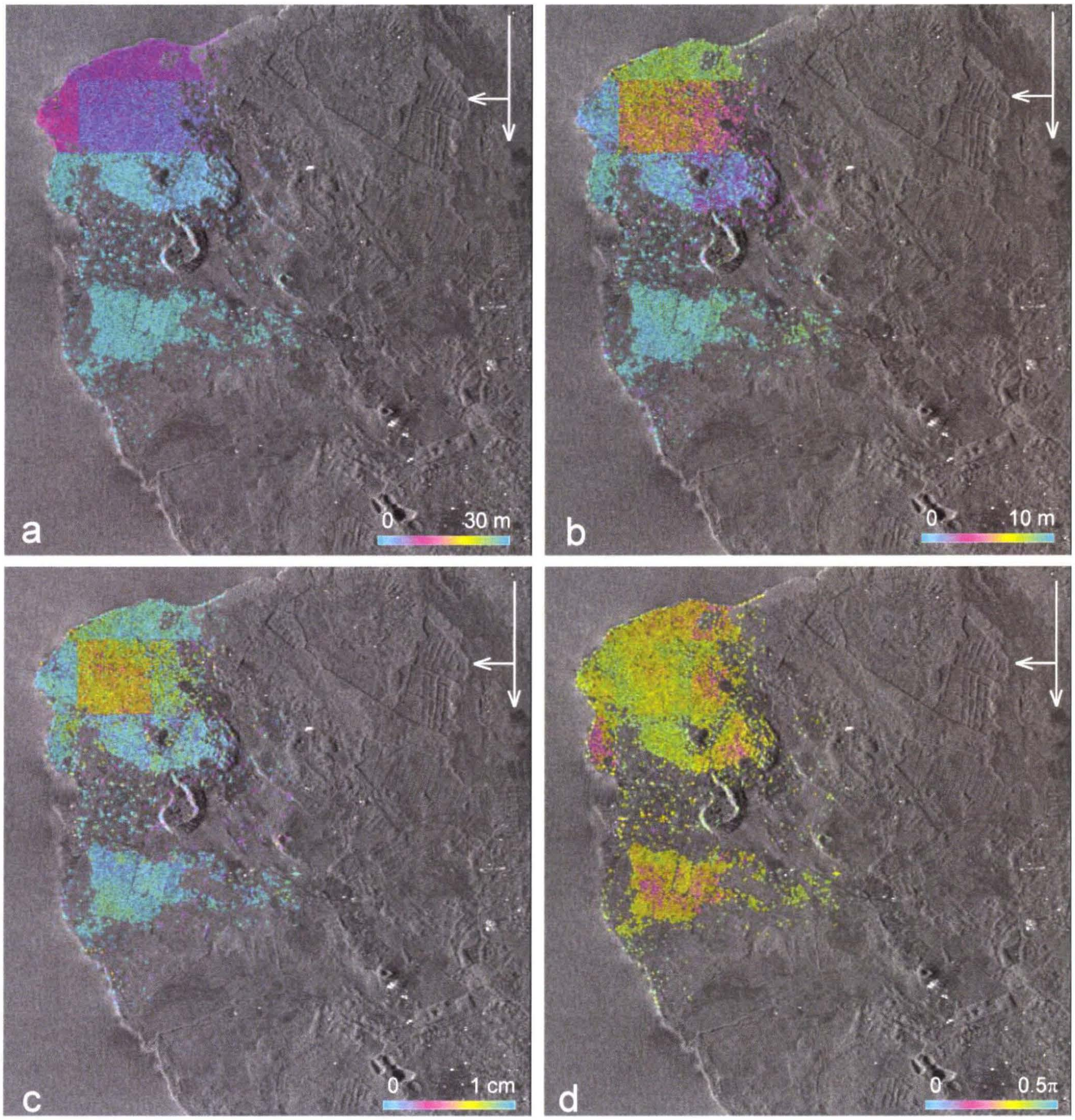



Figure 43: Results from 2nd multi-patch regression (GAMMA command multi_def_pt). Inclusion of previously not accepted wrapped differential interferograms into solution. (a) Height correction pdh1 (30 m/color-cycle, values in the southern flow are mostly below 15 cm), (b) pdh1 (10 m/color-cycle), (c) linear deformation rate (0.01 m/color-cycle, values in submillimeter range), (d) phase standard deviation from regression-fit (1/2 π rad/color-cycle, red: ~ 0.7 rad). Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

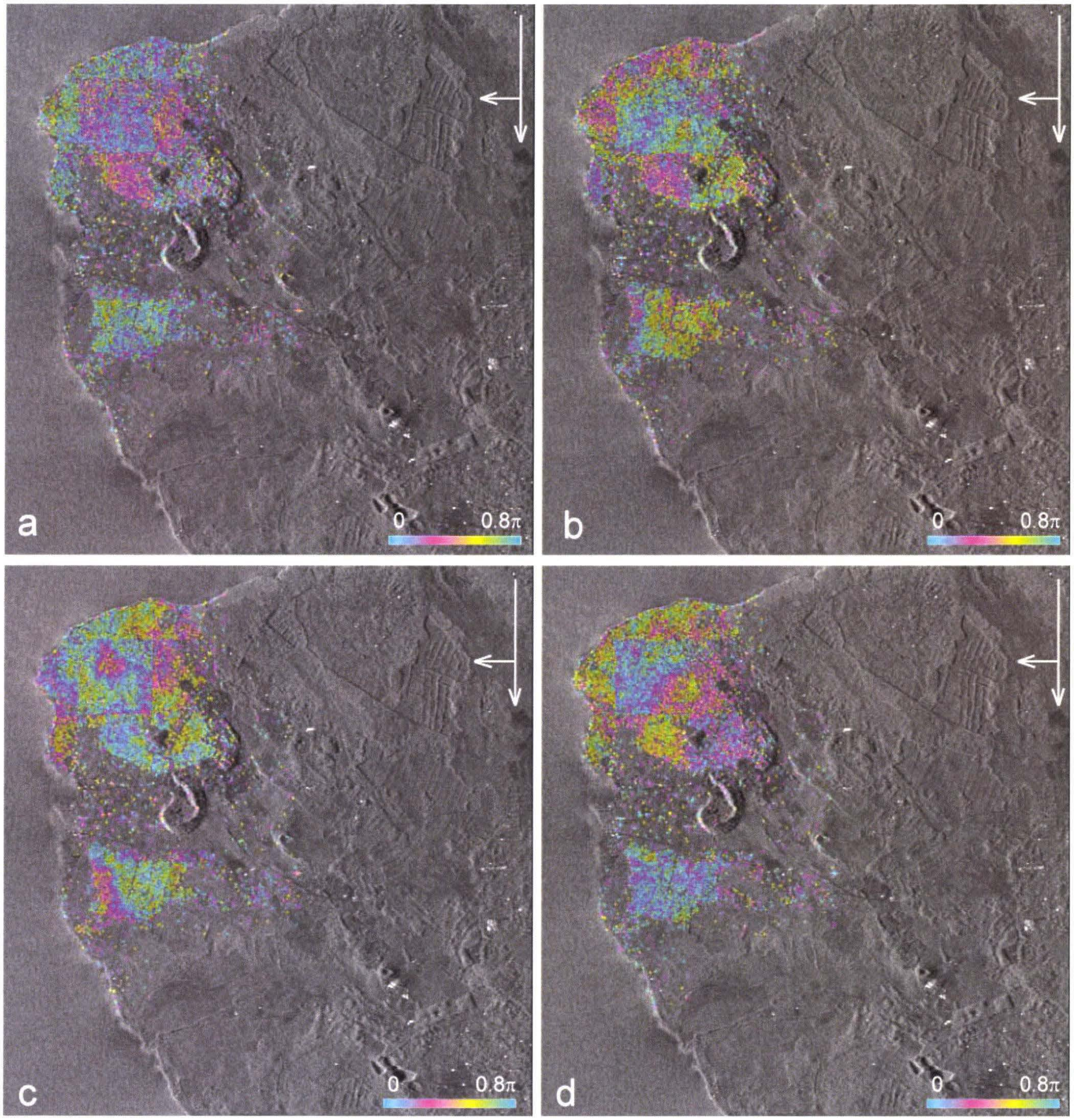



Figure 44: Residual phases from 2nd multi-patch regression (GAMMA command multi_def_pt). One color-cycle corresponds to 2.5 rad to show minute difference to residuals from later processing. Inclusion of previously not accepted wrapped differential interferograms into solution. (a) Pres1_001, (b) pres1_002, (c) pres1_004, (d) pres1_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

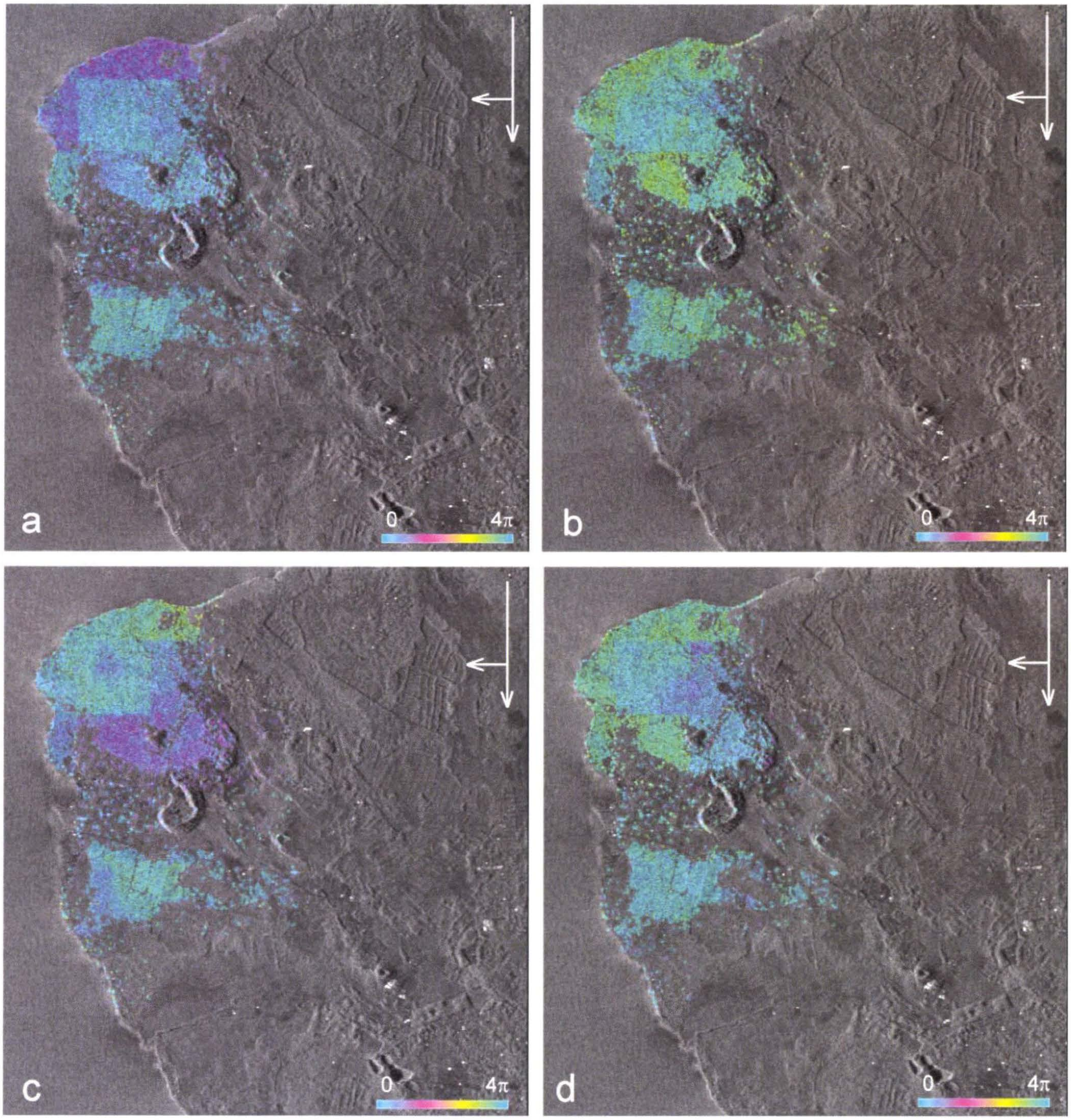



Figure 45: Residual phases from 2nd multi-patch regression (GAMMA command multi_def_pt). One color-cycle corresponds to 12.6 rad to show minute difference to residuals from later processing. Inclusion of previously not accepted wrapped differential interferograms into solution. (a) Pres1_001, (b) pres1_002, (c) pres1_004, (d) pres1_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

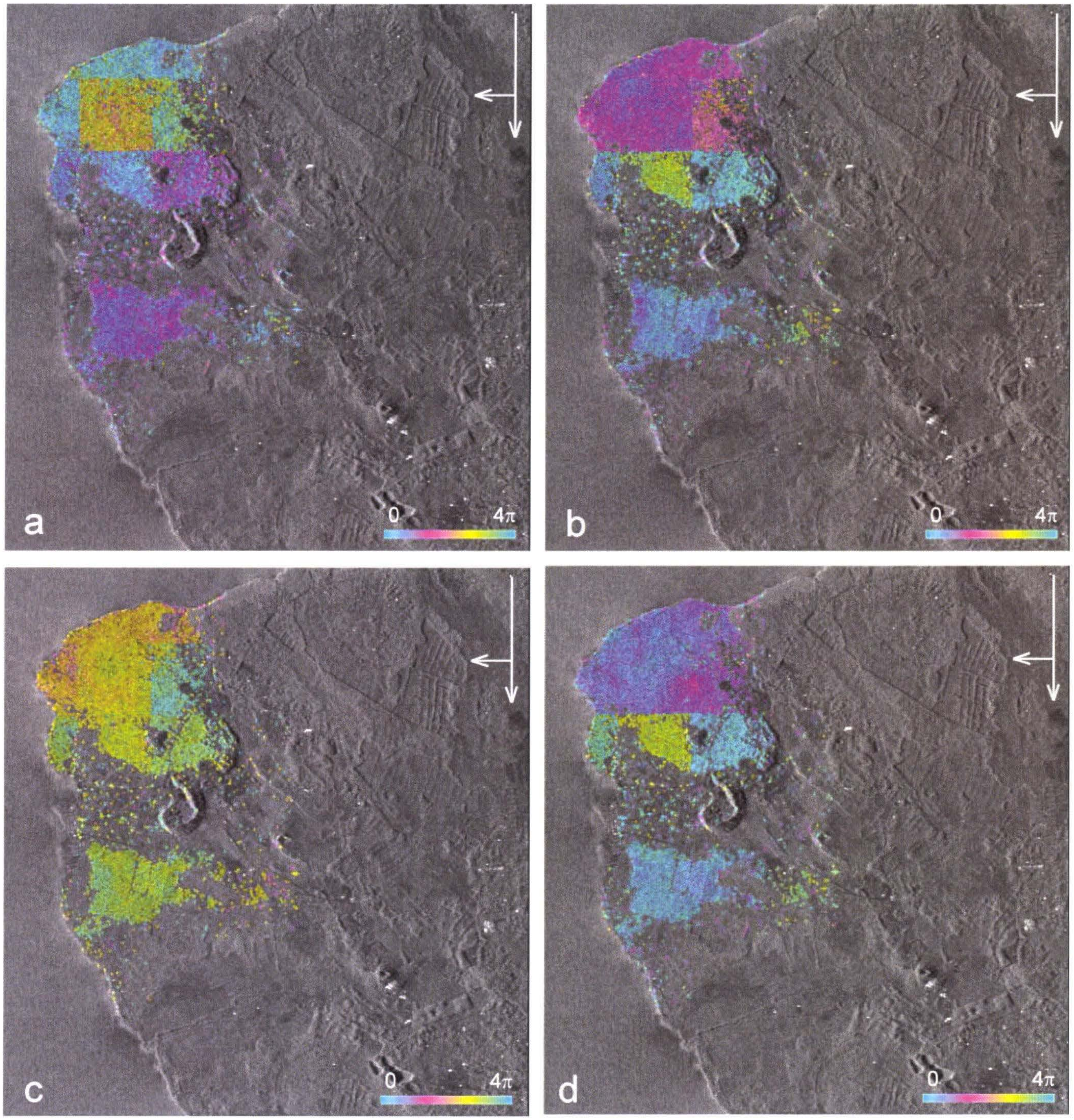



Figure 46: Unwrapped interferometric phases from 2nd multi-patch regression (GAMMA command multi_def_pt). One color-cycle corresponds to 12.6 rad. Inclusion of previously not accepted wrapped differential interferograms into solution. (a) Punw1_001, (b) punw1_002, (c) punw1_004, (d) punw1_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

**IPTA-10 Baseline Refinement**

A baseline refinement can only be done if the area is large enough to provide a sufficient number of points to refine. In this case there were not enough points. In future processing a larger area could be selected to allow a bigger number of good points. The principle flow of commands is similar to the ISP refinement. For details refer to IPTA example by Wegmüller [2005].

**IPTA-11 Interpretation of Residual Phase**

The residual phases are real valued unwrapped phases which can have values outside the interval $(-\pi, \pi)$. The residual phase is considered to be the sum of non-linear deformation phase, atmospheric phase and phase noise (see above). These three components have different spatial and temporal characteristics which can be used to discriminate among them. The non-linear deformation phase is the difference between the total and the linear deformation phase. It can be depicted as non-uniform movements of any scale. Atmospheric path delay is caused by heterogeneities in the tropospheric water vapor content and in the ionosphere. It is largely random in the temporal domain. Atmospheric signatures are usually at a larger spatial scale; however distortions can occur at any scale and are mostly below one phase cycle. Phase noise is temporally and spatially random. The level of phase noise is directly related to the point quality [*Wegmüller*, 2005].

The Kapoho project investigates the small-scale deformation features identified in the differential interferograms. Taking into account the absence of any large-scale non-linear deformation signals, all large-scale deviations from the regression fit are remnants of atmospheric path delay, which is determined to be mostly uncorrelated between different pairs. It also is important to minimize phase noise in order to ensure high quality point deformation.

*IPTA-11.1 Estimate and Apply Atmospheric Phase*

- Spatially filter the residual phases to estimate large-scale components and remove reference point bias

```
spf_pt pt multi_def_pt2/pmask1 rslc/20041208.rslc.par multi_def_pt2/pres1 atm/pres1_spf_25_1 -
2 25 1 -

spf_pt pt multi_def_pt2/pmask1 rslc/20041208.rslc.par multi_def_pt2/pres1 atm/pres1_spf_10_1 -
2 10 1 -
```

- Rename filtered residual phase to "atmospheric phase" (Figure 47 PDF 3.4 MB)

```
cp atm/pres1_spf_25_1 atm/patm1
```

- Calculate atmospheric corrections for the interferometric pairs (auto-interferogram influence)

```
lin_comb_pt pt multi_def_pt2/pmask1 atm/patm1 - atm/patm1 14 atm/patm1x - 0. 1. -1. 2 1
```

- Remove atmospheric phases from unwrapped differential interferograms

```
sub_phase_pt pt multi_def_pt2/pmask1 multi_def_pt2/punw1 - atm/patm1x multi_def_pt2/punw1_noatm
0 0
```

- Display the unwrapped phases (without auto-interferogram influence) (Figure 48 PDF 3.4 MB)

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20041208.rslc.par multi_def_pt2/punw1_noatm   - rmli_
1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
```

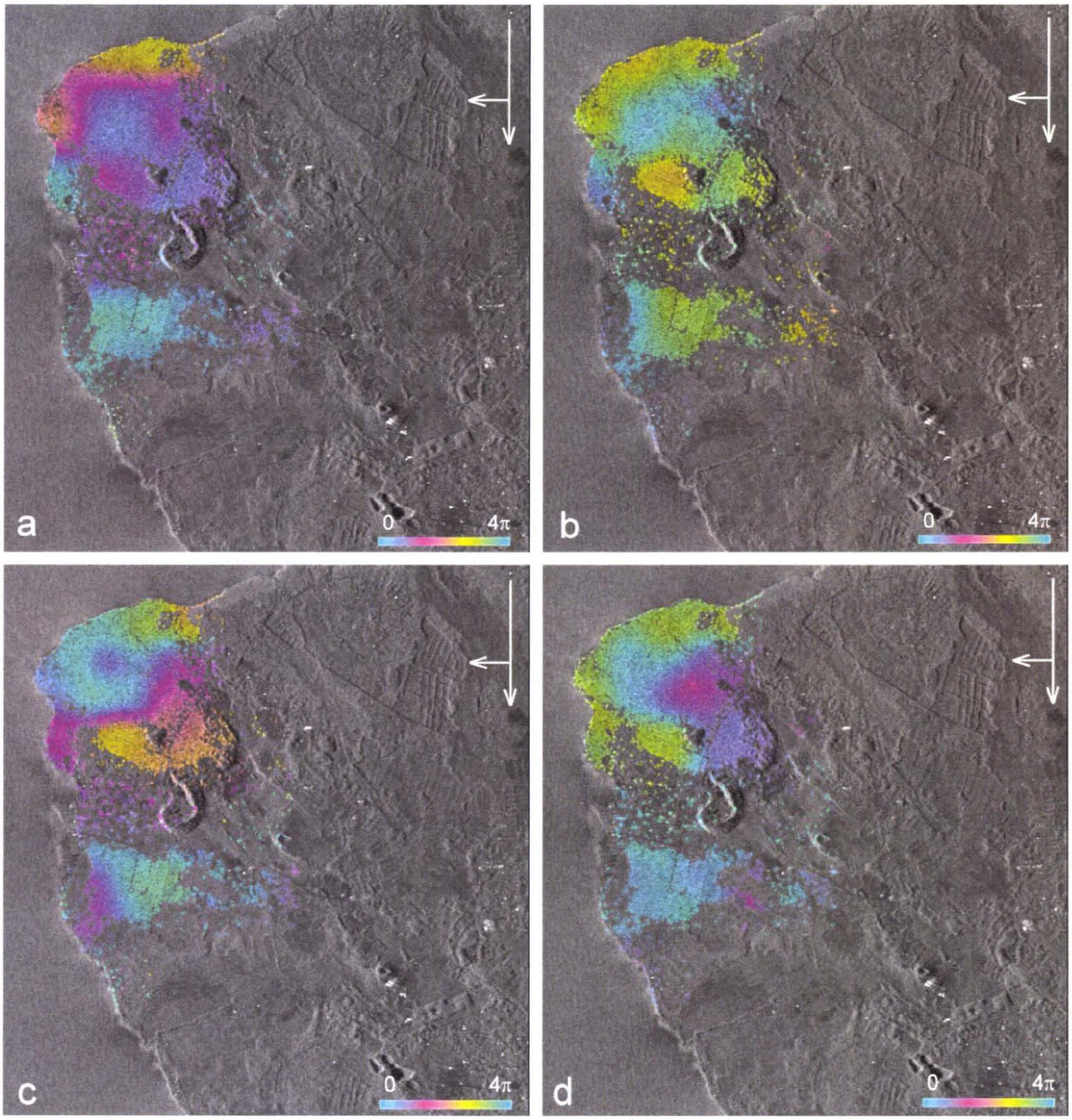



Figure 47: Spatially filtered residual phases from 2nd multi-patch regression (GAMMA command multi_def_pt). Triangular weighted average is the spatial filter used with a 25 sample wide radius. One color-cycle corresponds to 4 rad. (a) Pres1_spf_25_001, (b) pres1_spf_25_002, (c) pres1_spf_25_004, (d) pres1_spf_25_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

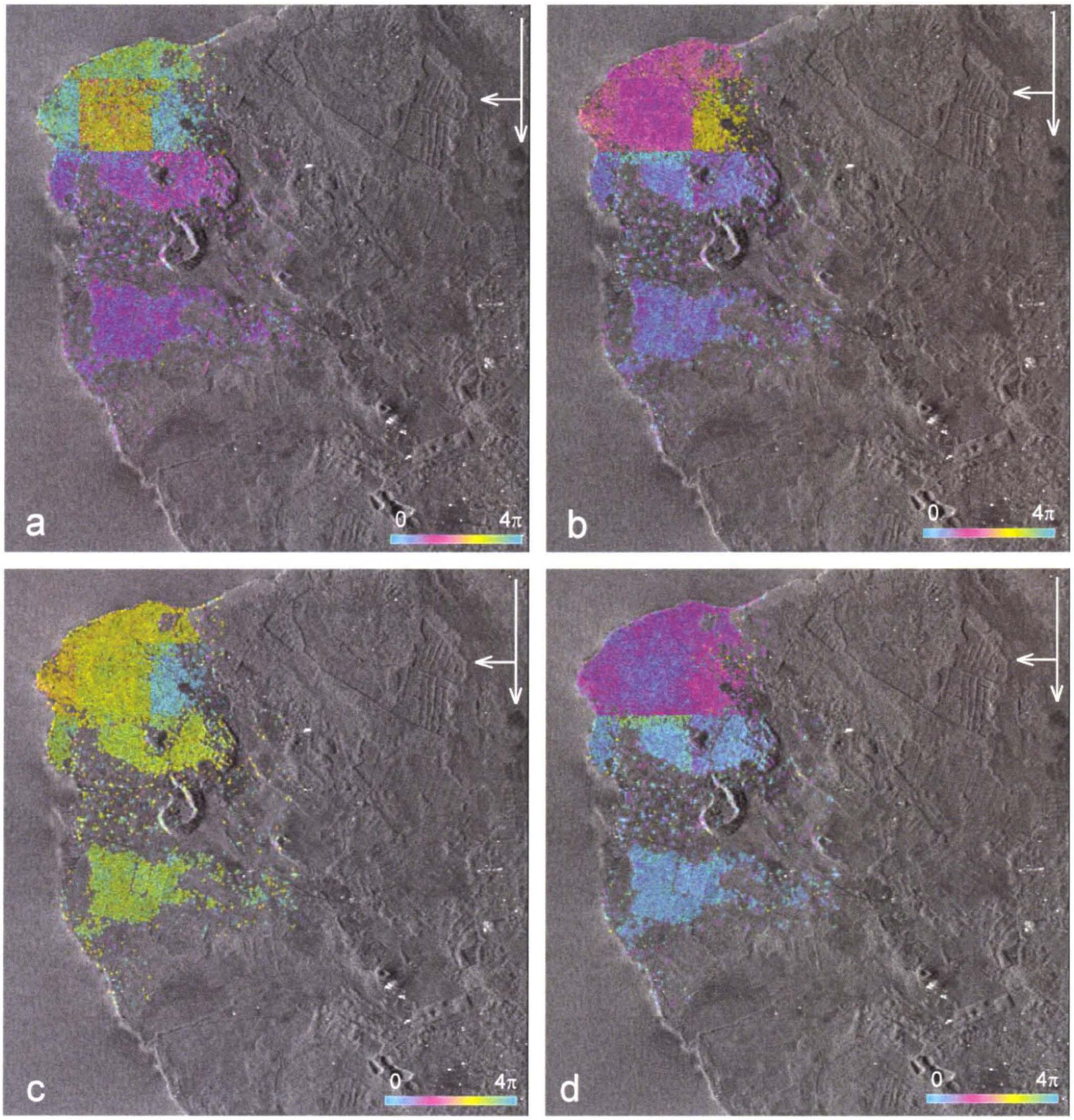



Figure 48: Unwrapped interferometric phases without the atmospheric path delay. One color-cycle corresponds to 12.6 rad. (a) Punw1_noatm_001, (b) punw1_noatm_002, (c) punw1_noatm_004, (d) punw1_noatm_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

- Reduce phase noise of interferometric phase phases relative to reference point

```
spf_pt pt multi_def_pt2/pmask1 rslc/20041208.rslc.par multi_def_pt2/punw1_noatm
multi_def_pt2/punw1_noatm_spf - 2 25 0 - 23558 0
```

- Display the noise-free interferometric phases (Figure 49 PDF 3.4 MB)

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20041208.rslc.par  multi_def_pt2/punw1_noatm_spf  -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
```

*IPTA-11.2 Re-estimate Linear Deformation Rates and Phase Unwrapping*

- Including atmospheric correction and using a filtered reference (*pdiff1_unwa*)

```
mkdir def_mod_pt2
def_mod_pt  pt multi_def_pt2/pmask1 pSLC_par - itab_single pbase 0 multi_def_pt2/punw1
_noatm_spf 0 23558 def_mod_pt2/pres2 def_mod_pt2/pdh2 def_mod_pt2/pddef2 def_mod_pt2/punw2
def_mod_pt2/psigma2 def_mod_pt2/pmask2 25. 0.03 2.0 2 def_mod_pt2/pdh_err2a
def_mod_pt2/pdef_err2a def_mod_pt2/ppc_err2a

number of points with sigma < sigma_max=2.000 : 12721
```

*IPTA-11.3 Visualization of Deformation Histories*

- Update point heights and linear deformation rates

```
lin_comb_pt pt def_mod_pt2/pmask2 phgt1 1 def_mod_pt2/pdh2 1 phgt2 1 -0. 1. 1. 2 0
lin_comb_pt pt def_mod_pt2/pmask2 pdef1 1 def_mod_pt2/pddef2 1 pdef2 1 -0. 1. 1. 2 0
```

- Calculate deformation phase corresponding to estimated linear deformation rates

```
phase_sim_pt pt def_mod_pt2/pmask2 pSLC_par - itab_single - pbase - ptmp1 pdef2 1 0
```

Add last residual phase (incl. non-linear deformation phase and phase noise)

```
lin_comb_pt pt def_mod_pt2/pmask2 ptmp1 - def_mod_pt2/pres2 - pdef_phase1 - 0.0 1. 1. 2 1
```

Note: Atmospheric phase is not included.

- Convert combined unwrapped differential phase to line-of-sight displacement (m)

```
dispmap_pt pt  def_mod_pt2/pmask2 pSLC_par itab_single pdef_phase1 phgt2 pdisp1 0
```

- Create optical reference to select points (displacement at the earliest date (layer 1))

```
prasdt_pwr24  pt  def_mod_pt2/pmask2 rslc_kapoho/20041208.rslc.par pdisp1 1 rmli_1_5
_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.05 0
```

- Display IPTA deformation time series (Figure 50 PDF 3 MB)

```
vu_disp  pt  def_mod_pt2/pmask2 pSLC_par  itab_single pdisp1 pdef2  phgt2 def_mod_pt2/psigma2
def_mod_pt2/pdh_err2a def_mod_pt2/pdef_err2a - pdisp1.ras
```

Using the left-mouse button the deformation histories for each point will display in Grace. The deformation history for the reference point shows zero displacement. Clicking close to the area of interest, subsidence in the order of about 1-2 cm for the time between the first and last acquisition dates (20030212 – 20060308) can be found, corresponding to the blue values. The displacements are relative to the reference point.

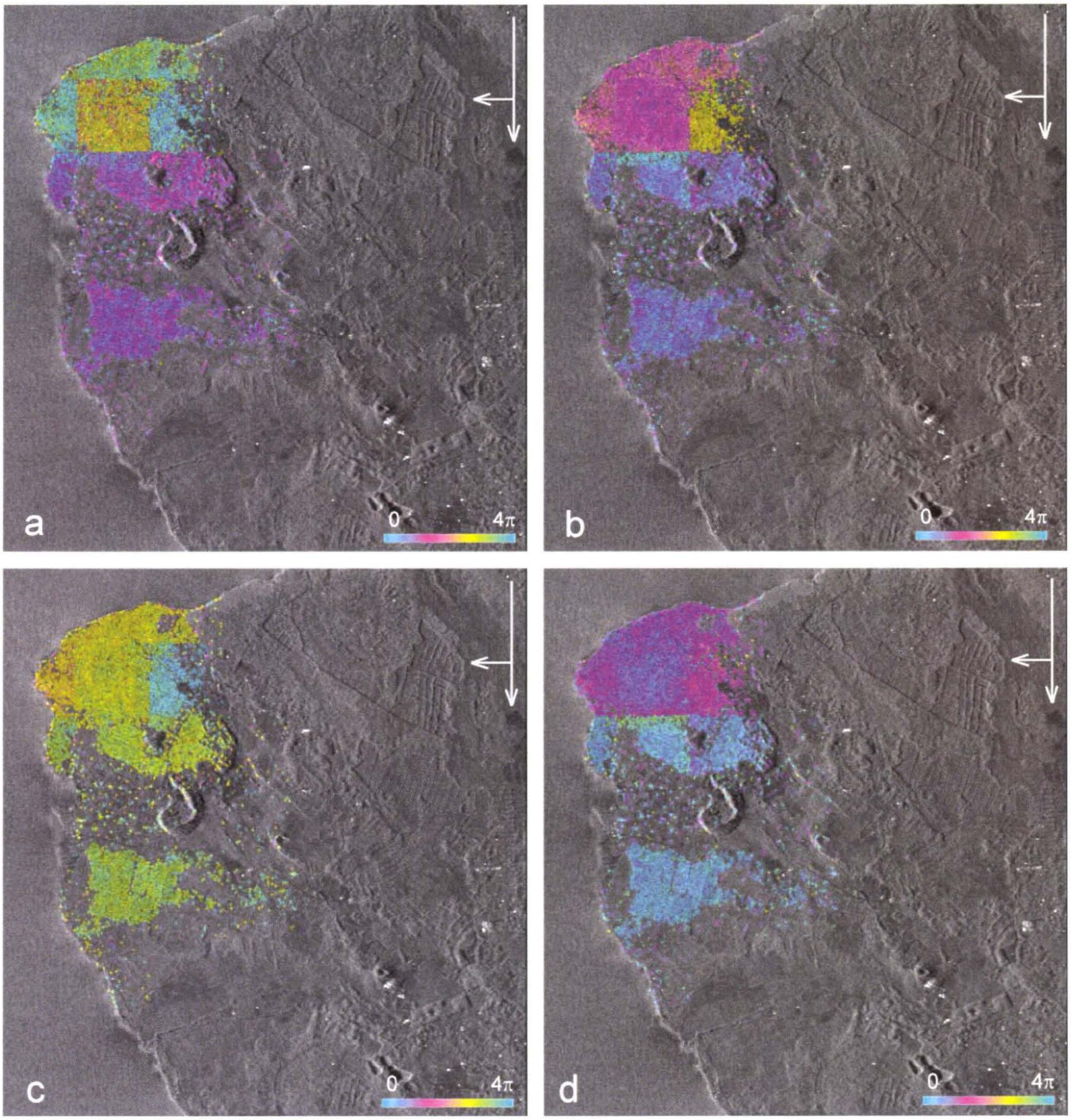



Figure 49: Filtered unwrapped interferometric phases without the atmospheric path delay. The interferometric phase is now noise free. One color-cycle corresponds to 12.6 rad.
(a) Punw1_noatm_spf_001, (b) punw1_noatm_spf_002, (c) punw1_noatm_spf_004,
(d) punw1_noatm_spf_008. Generated using GAMMA script prasdt_pwr24. Arrows indicate satellite's flight- and the SAR's look-direction.

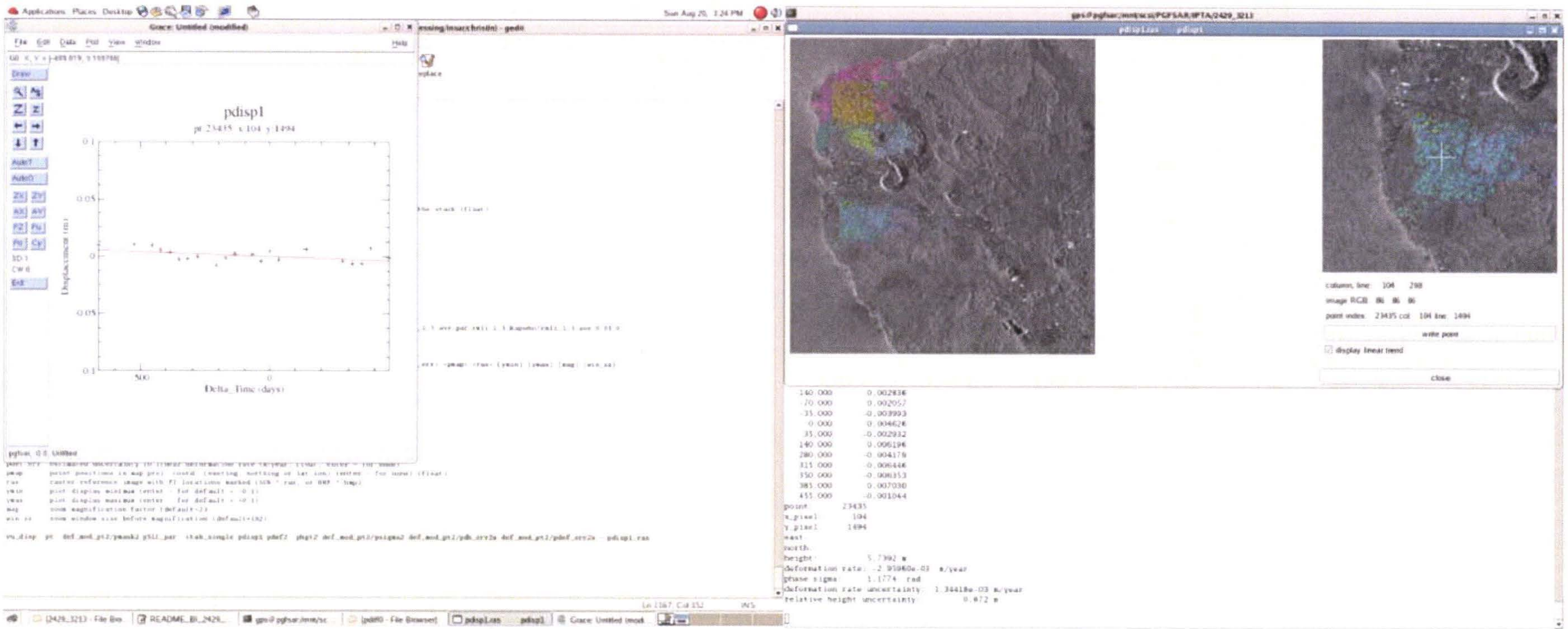



Figure 50: Visual output of GAMMA command vu_disp to view the deformation time series for every point. All deformation is with respect to the reference point.

# 3. References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# Appendices

## Appendix A – Glossary of Abbreviations and Acronyms

| | |
|---|---|
| ALOS | Advanced Land Observing Satellite |
| ASAR | Advanced Synthetic Aperture Radar |
| BPERP | Perpendicular baseline |
| DELFT | University of Delft, Netherlands (precise orbits) |
| DEM | Digital Elevation Model |
| DIFF | GAMMA Differential Interferometry software |
| DISP | GAMMA Display software |
| DORIS | Doppler Orbitography and Radiopositioning Integrated by Satellite |
| ERS | European Remote Sensing Satellite |
| ESA | European Space Agency |
| FFT | Fast Fourier Transform |
| FCOMPLEX | Float Complex (SLC format) pairs of 4-byte-float |
| FIR | Finite Impulse Response (digital filter) |
| GAMMA | GAMMA Remote Sensing Research and Consulting AG |
| GCP | Ground Control Point |
| GEO | GAMMA Geocoding software |
| HH | Horizontal polarization transmitted, Horizontal polarization received |
| I/Q | In-phase (I) (real) and quadrature (Q) component (imaginary) of complex radar return |
| InSAR | Interferometric Synthetic Aperture Radar |
| IPTA | GAMMA Interferometric Point Target Analysis |
| IS | Image Swath |
| ISP | GAMMA Interferometric SAR Processor |
| JERS | Japanese Earth Resource Satellite |
| MATLAB | Matrix Laboratory (MathWorks' computing language) |
| MCF | Minimum Cost Flow (unwrapping method) |
| MLI | Multi-Look Image |
| MSP | GAMMA Modular SAR Processor |
| NASDA | National Space Development Agency of Japan |
| PRF | Pulse Repetition Frequency |
| PRI | SAR Precision Image |
| RMLI | Resampled Multi-Look Image |
| RSLC | Resampled Single-Look Complex Image |
| SAR | Synthetic Aperture Radar |

| | |
|---|---|
| SCOMPLEX | Short Complex (SLC format) pairs of 2-byte-short-integer |
| SLC | Single-Look Complex Image |
| SNR | Signal to Noise Ratio |
| SQR | Square root |
| Std Dev | Standard deviation |
| UTM | Universal Transverse Mercator |
| VV | Vertical polarization transmitted, Vertical polarization received |
| WInSAR | Western North America Interferometric SAR Consortium (online archive) |

# Appendix B – Satellite and Sensor Overview

### ALOS

ALOS (Advanced Land Observing Satellite) has PALSAR (Phased Array type L-band SAR) aboard. Launched in January 2006, it has a high spatial resolution mode (10m) with a 70km swath (HH, VV, HH&HV, VV&VH) and a ScanSAR mode (HH, VV) with a 250-350km swath at 100m resolution.

- Japan Aerospace Exploration Agency – ALOS
- NASDA - ALOS

### Envisat

ASAR (Advanced Synthetic Aperture Radar) is one of 10 instruments aboard the new ESA satellite Envisat (Environmental Satellite). Envisat was launched in March 2002 and has been operating in repeat cycles of 35 days. ASAR's operational modes allow up to 7 different image swaths with widths ranging from 105km to 56km. The image modes can be HH or VV polarization, incidence angles spanning from 15 to 45 degrees. Spatial resolution is on the order of 30m.

- ESA – Envisat overview
- Envisat Instrument description

### ERS

ERS-1 (Earth Remote-Sensing Satellite) operates at C-Band (5.6cm), has VV polarization and a fixed incidence angle of 23 degree. The spacecraft provides a swath width of 100km. ESA launched ERS-1 in July 1991 with a variety of repeat cycles such as a 3-day, 35-day and a 336-day cycle. ERS-2 was launched in April 1995, allowing a 5 year tandem mission (1-day apart) until ERS-1 failed in March 2000.

- European Space Agency ESA – ERS missions
- ESA – ERS overview

### JERS

JERS–1 (Japanese Earth Remote-Sensing Satellite) became operational in May 1992, has a fixed incidence angle of 35 degrees. It is a L-Band (24cm) radar with HH polarization. The SAR has 18m resolution with a 75km swath and its repeat orbit is 44 days. It was discontinued in October 1998. JERS-1 was re-entered in December 2001.

- National Space Development Agency of Japan (NASDA)- Satellites

### RADARSAT

RADARSAT-1 (Radar Satellite) is a Canadian Space agency imaging radar that operates at C-Band (5.6cm). Launched in November 1995, RADARSAT-1 has HH polarization and it's selectable image swaths range from 45km width at 8m resolution to 500km ScanSAR swath width at about 100m resolution. The incidence angle varies from 10 to 58 degrees and it completes an orbital cycle in 24 days. RADARSAT-2 is under development and scheduled to launch in March 2007.

- Alaska Satellite Facility – Data products
- Canadian Space Agency – Satellites

**SIR-C**

SIR-C (Shuttle Imaging Radar) Space Shuttle Instrument was flown twice in April 1994. It operates at L-Band (3.5cm) and C-Band (5.8cm) with HH, VV, VH and HV polarization modes. Spatial resolution is about 30m. X-SAR was also on board, operating at X-band (3.1cm).

- JPL – NASA - SIR-C

# Appendix C – Complimentary Information

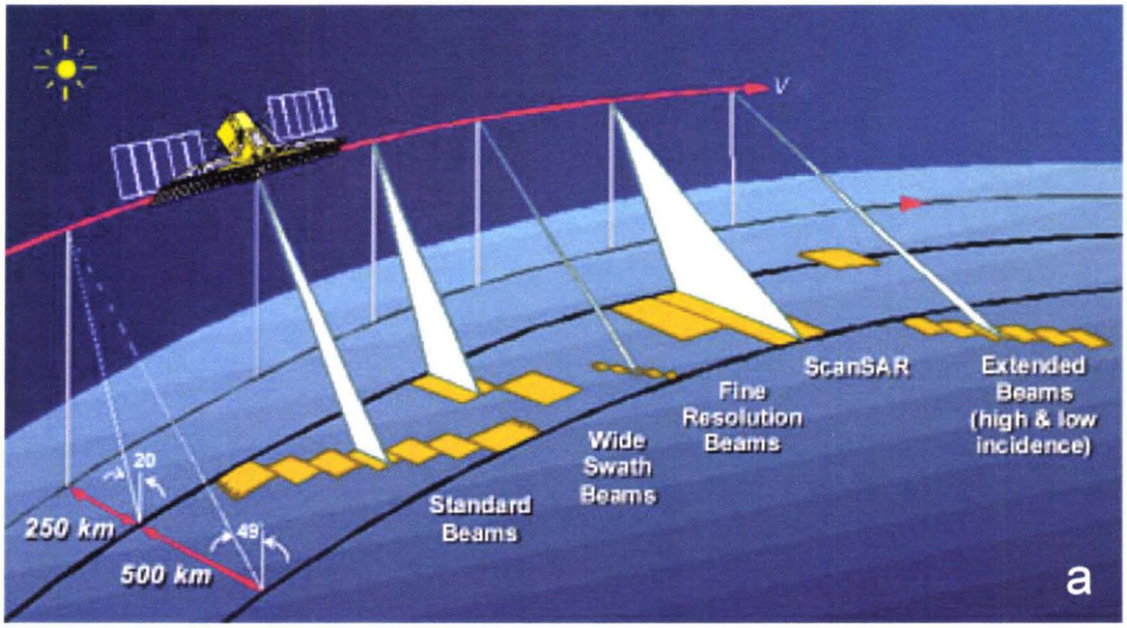
## 1. Synthetic Aperture Radar (SAR)

*Theory*

Radar is an abbreviation for Radio Detection and Ranging. Radar systems send out modulated waveforms using antennas in order to transmit electromagnetic waves. Objects within a certain area will reflect part of the energy (radar returns or echoes) back to the radar. From these radar returns, the radar receiver then extracts information such as velocity and range (distance), angular position, and other identifying characteristics. Synthetic Aperture Radar (SAR) is an active side-looking imaging radar. It can only be utilized by a moving instrument over a relatively immobile target area. Penetrating clouds, smoke, haze and darkness, radar in general is almost completely independent of weather and time of day. This unique feature of all radar makes it an excellent complement to photographic and other optical and passive imaging data sources. Cultural and terrain targets on the ground respond characteristically to certain radar frequencies, enabling monitoring of topographic change.

The satellites being used for InSAR are all orbiting the Earth from north to south in a sun-synchronous pattern to maximize area coverage and minimize the time it takes to get a second acquisition of the same region. The positioning between the satellite and the sun is always the same, which means the area that is covered by the satellite is always being illuminated with the same incidence angle from the sun. The motion of the satellite then matches the motion of the sun across the sky. Satellites in sun-synchronous orbit cross the equator twelve times a day at the same time, making a 98.6° angle with the equator, i.e., 9.8° off north (polar orbits: 90°, aligned with north). Hence, the satellite passes the equator and every latitude at the same time each day.

The direction the satellite is traveling in is known as the along-track direction or azimuth. The across-track direction is called range. Effective across-track resolution is increased by combining accurate range measurements with post processing of the radar data that is done by using the Doppler-effect. The pass of the satellite can either be descending, coming from the northern hemisphere going south or ascending, going north. As mentioned above, the angle between the track and the north direction is about 8.6°. The SAR aboard the satellite is right-looking. Therefore one can get different viewing angles for the same region of interest, once illuminated from the "right" on a descending pass and from the "left" side on a ascending pass providing multiple aspect angles. Envisat, ESA's Environmental Satellite, e.g., can also be operated in different modes, which correspond to swath width, incidence angle and across-track resolution. The most coverage is obtained by operating in the wide swath mode, using ScanSAR (Scanning SAR) techniques, where ASAR (Advanced SAR aboard Envisat) has the capability to illuminate several sub-swaths by scanning it's antenna off-nadir (away from the point directly underneath the satellite) into different positions. Spatial resolution for ScanSAR is rather mediocre, at the order of 150 m at a swath width of 405 km. In image mode, ASAR generates high spatial resolution products (30 m) at swath widths of 56-105 km (Figure 51: RADARSAT image swaths and ground coverage PDF 880 KB).



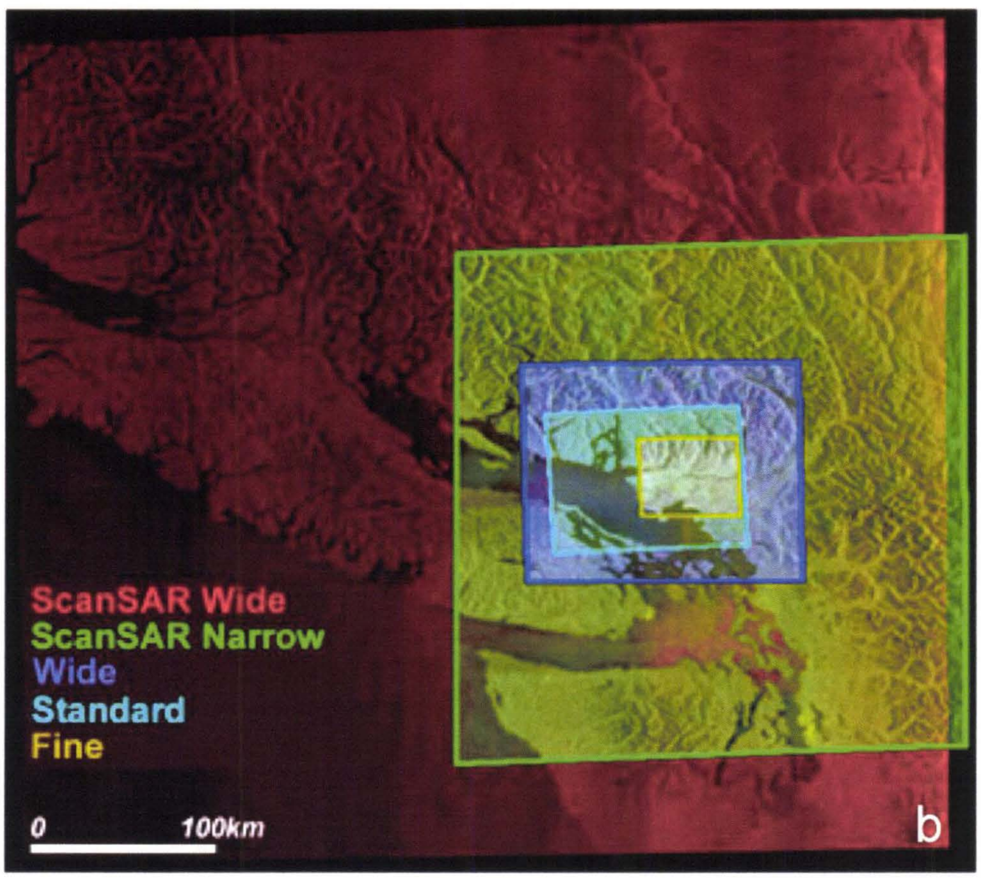




Figure 51: A satellites different operating modes (a) and their ground coverage (b). When operating in image mode, Envisat's seven swaths are similar to the standard beams in (a), where the scene closest to nadir has the largest area coverage (a, b: Canadian Space Agency).

*Data Format*

The following data description is solely for the ASAR instrument on the ESA satellite Envisat. It may be different for different satellites and sensors. The raw data received by the satellite is a serial data bit-stream that is recorded by a demodulator that recovers information content from the carrier wave. The demodulator output is send to a band sub-system. After some further processing carried out by ESA, the data is then stored on High-Density Data Tapes. There are a few data formats being provided by ESA depending on the grade of processing. In addition, the data can be either vertically or horizontally polarized.

- ESA's ASAR handbook link: Product summary by level

Level 0 data is reformatted, time-ordered satellite raw data that is acquired at a high-rate and in a narrow swath and may be from one of seven swaths. The product name will start with *ASA_IM__0C** and can be directly fed into GAMMA. More information about the product type can be found at:

- ESA's ASAR handbook link: Level 0 image mode

By applying a range-Doppler algorithm and calibration data, Level 0 products are transformed to Level 1B baseline engineering products:

- ESA's ASAR handbook link: Algorithms for Level B Products

Some of the data in the PGF archive that was directly ordered from ESA is in Image Mode Single Look Complex format:

- ESA's ASAR handbook link: Level 1 B SLC Products
- ESA's glossaries

**2. Interferometry Technique**

The satellite travels in the along track direction which coincides with the velocity-vector direction, looking to the side and recording microwave echoes as a function of slant-range. Slant-range is the line-of-sight of the radar, also called look-vector. Successive echoes are recorded coherently, building the phase of the data stream. The imaged ground surface (3D) is projected into two dimensions: slant range and azimuth.

Traditionally, radar range is measured by timing the transmitted pulse precisely. Depending on the bandwidth of the ranging signal, accuracy is several meters. In InSAR however, the distance to the ground is measured using the phase information of the electromagnetic wave as well as the magnitude, increasing the accuracy to mm - cm resolution corresponding to 1% of the wavelength that can be resolved. The radar signal z is a complex number, in cartesian coordinated expressed: $z \equiv x + i\,y$ where the magnitude (or complex modulus) is defined as: $|z| = \text{sqrt}(x^2 + y^2)$. The argument of the complex number is the phase $\phi = \arg(z) = \tan^{-1}(y/x)$. For polar coordinates: $z = re^{i\varphi}$, i.e., $r = |z|$. The backscatter phase recorded at the radar includes a propagation phase delay, a function of slant range $\rho$ and wavelength $\lambda$: $\phi = -4\pi\rho/\lambda$. The total return from a resolution cell consists of the coherent sum of contributions from all elemental scatterers. The magnitude reflects the backscatter intensity of many scatterers and is therefore referred to as the brightness. In contrast, the phase consists of propagation time plus the scatter term only known mod $2\pi$.

The range information provides a sphere, a.k.a. the surface of constant range describing the time it takes a radar pulse to propagate to the target and back to the radar [*Rosen, et al.*, 2000]. The surface of constant Doppler is a cone about the velocity-vector (flight direction). The cone angle is proportional to the Doppler frequency. Intersecting the surface of constant range with the cone of constant Doppler leaves a hyperbola on the ground surface. A third measurement is necessary to resolve the 3D location. By imaging the same area from a slightly different viewing angle, hence intersecting two hyperbolas, the point location can exactly be calculated. The second hyperbola has approximately the same orientation, therefore only providing one intersection, rather than two if they are oriented opposite ways. There are two separate interferometry techniques that produce the third measurement: Single-track and repeat-track interferometry. In single-track interferometry the satellite's radar is equipped with two antennas. This allows an absolute precise measurement of the perpendicular baseline, the distance between the two antennas. This kind of interferometry is used to create DEMs, such as SRTM, using the fact that there is negligible temporal separation, i.e., no decorrelation and/or deformation. In contrast, repeat-track interferometry is performed by a single antenna SAR aboard a satellite, which images exactly the same area after completing its orbital cycle. For Envisat the orbital frequency is about 35 days.

To resolve the elevation and/or displacement information (depending on the temporal separation) the two SAR images (i.e., their phases) need to be interfered. This process involves superposing the two waves that are slightly "out-of-phase" received from two different look angles. The path difference is only known mod $2\pi$ and is proportional to the distance.

The SAR images must then be processed to SLC images (Single-look complex), co-registering the SAR image to $1/20^{th}$ of a pixel to prevent the loss of correlation. Once co-registered, an interferogram can be produced.

## Appendix D – SAR Data Availability and Acquisition Tools

EoliSA

EoliSA is ESA's multi-mission catalog service that can be accessed either in form of a web client or as a standalone version (Figure 52 PDF 2 MB). Downloaded on to any operating system, and if connected to Internet, EoliSA has access to the entire ESA data collection, including Envisat, ERS and third party mission products. It displays available scenes in a SLC quick look format along with the tracks and frames plotted on the area of interest. It also allows you to order the data right from ESA.

Descw

Descw is an off-line catalog and image browser very similar to EoliSA, also provided by ESA (Figure 53 PDF 1.3 MB). It has the advantage to show multiple tracks at the same time for one area. It does not provide a quick look SLC image and its libraries need to be updated regularly. A newly adopted feature includes baselines estimates for Envisat data.

WInSAR

WInSAR is a web based archive of radar data that is shared by several universities such as Stanford, Scripps and Caltech (Figure 54 PDF 710 KB). A username and password are necessary to download the data. It is easy to use, but some of the Envisat frame/date information can be incomplete. WInSAR also provides Envisat precise orbit files by day (DORIS). WInSAR will be implemented as a standing committee of UNAVCO, according to a vote of Consortium members this past winter.

PGF Data Archive

The PGF radar data archive can be found on the PGF internal web. An open office calc spreadsheet (similar to Excel) conversion to html was used to create the on-line Envisat archive, in order to easily update the sheets and re-produce the web page (Figure 55 PDF 2.5 MB).

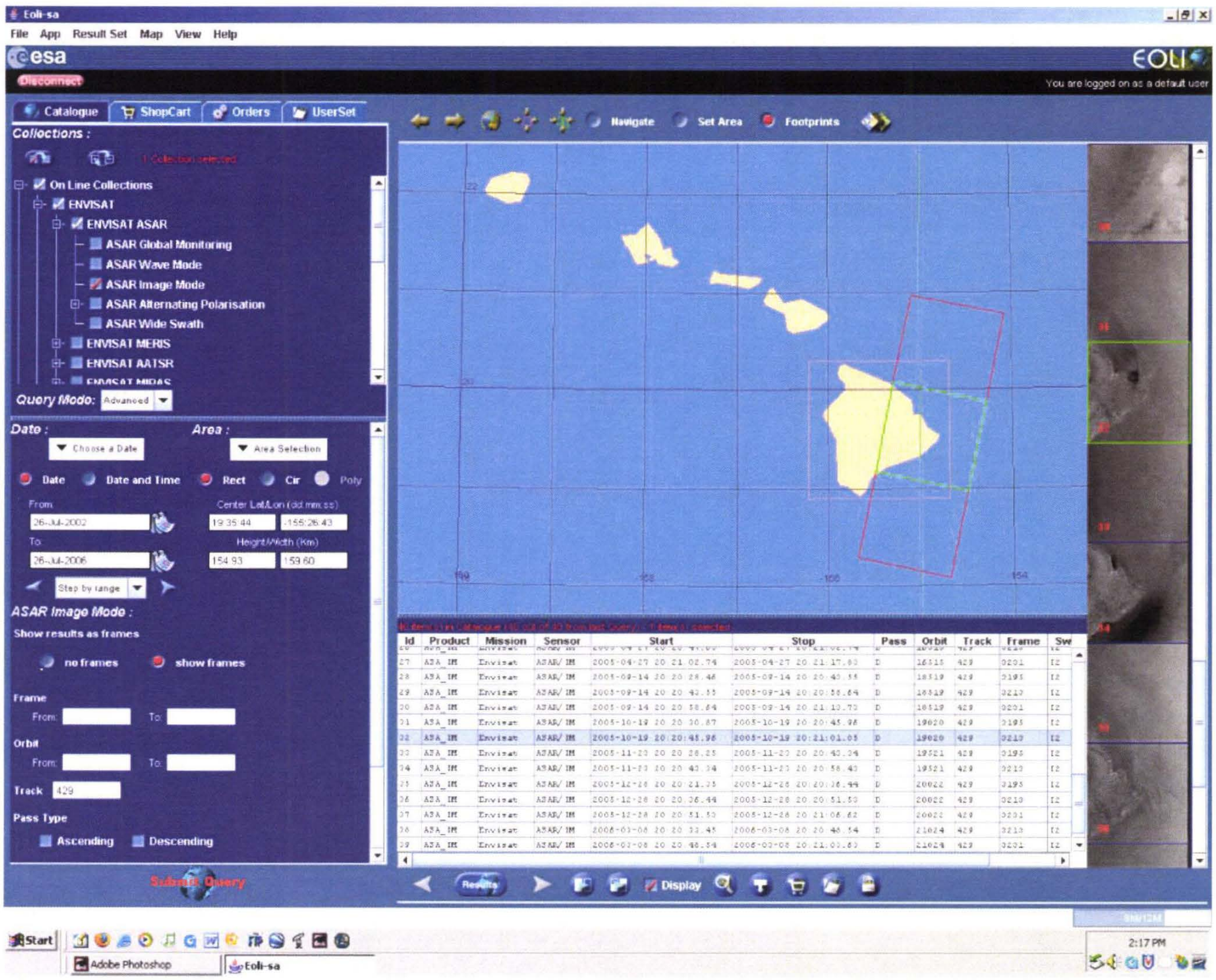



Figure 52: EoliSA software (ESA) used to display Envisat track 429 and frame 3213 (green box).

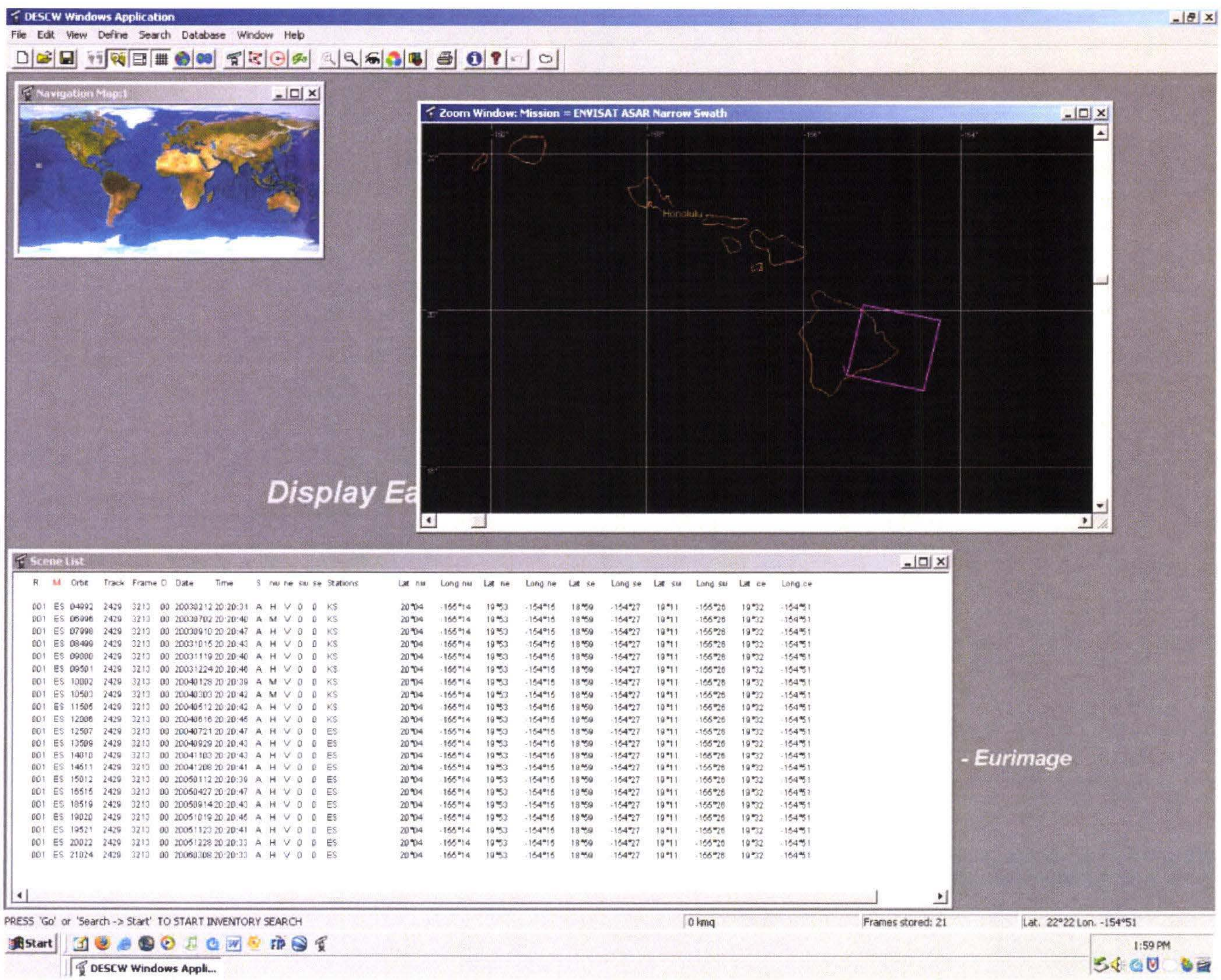
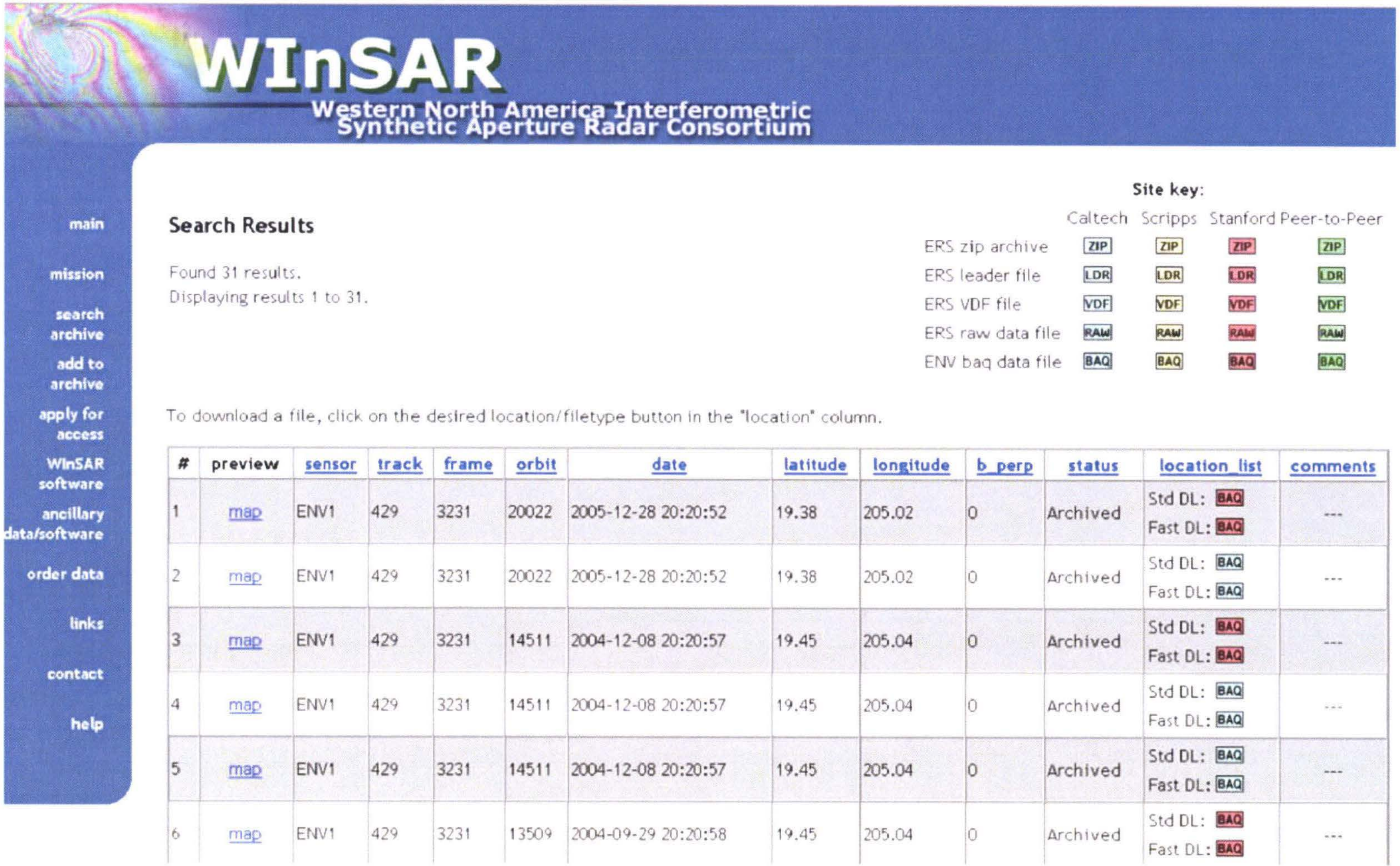



Figure 53: Descw software (ESA) used to display Envisat track 429 and frame 3213 (magenta box).



WInSAR

Western North America Interferometric Synthetic Aperture Radar Consortium

main
mission
search archive
add to archive
apply for access
WInSAR software
ancillary data/software
order data
links
contact
help

**Search Results**

Found 31 results.
Displaying results 1 to 31.

Site key:

| | Caltech | Scripps | Stanford | Peer-to-Peer |
|---|---|---|---|---|
| ERS zip archive | ZIP | ZIP | ZIP | ZIP |
| ERS leader file | LDR | LDR | LDR | LDR |
| ERS VDF file | VDF | VDF | VDF | VDF |
| ERS raw data file | RAW | RAW | RAW | RAW |
| ENV baq data file | BAQ | BAQ | BAQ | BAQ |

To download a file, click on the desired location/filetype button in the "location" column.

| # | preview | sensor | track | frame | orbit | date | latitude | longitude | b_perp | status | location_list | comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | map | ENV1 | 429 | 3231 | 20022 | 2005-12-28 20:20:52 | 19.38 | 205.02 | 0 | Archived | Std DL: BAQ Fast DL: BAQ | --- |
| 2 | map | ENV1 | 429 | 3231 | 20022 | 2005-12-28 20:20:52 | 19.38 | 205.02 | 0 | Archived | Std DL: BAQ Fast DL: BAQ | --- |
| 3 | map | ENV1 | 429 | 3231 | 14511 | 2004-12-08 20:20:57 | 19.45 | 205.04 | 0 | Archived | Std DL: BAQ Fast DL: BAQ | --- |
| 4 | map | ENV1 | 429 | 3231 | 14511 | 2004-12-08 20:20:57 | 19.45 | 205.04 | 0 | Archived | Std DL: BAQ Fast DL: BAQ | --- |
| 5 | map | ENV1 | 429 | 3231 | 14511 | 2004-12-08 20:20:57 | 19.45 | 205.04 | 0 | Archived | Std DL: BAQ Fast DL: BAQ | --- |
| 6 | map | ENV1 | 429 | 3231 | 13509 | 2004-09-29 20:20:58 | 19.45 | 205.04 | 0 | Archived | Std DL: BAQ Fast DL: BAQ | --- |

Figure 54: Online WInSAR archive. Search results are for Envisat track 429 and frame 3231.

**Sheet 8:** ***IS2 T429***

| Swath | Track | Frame | Pass | Orbit | Start Date/Time | Area coverage | ENVI* hsq (WINSAR) | ASA_IM_0CNPD* N1 (Raw data) |
|---|---|---|---|---|---|---|---|---|
| ☐ | 429 | 3195 | D | 7998 | 20030910 20 20 33 | North of F3213 | N/A | |
| ☐ | 429 | 3195 | D | 8499 | 20031015 20 20 29 | | N/A | |
| ☐ | 429 | 3195 | D | 9000 | 20031119 20 20 27 | | N/A | |
| ☐ | 429 | 3195 | D | 9501 | 20031224 20 20 30 | | N/A | |
| ☐ | 429 | 3195 | D | 13509 | 20040929 20 20 28 | | N/A | |
| ☐ | 429 | 3195 | D | 14010 | 20041103 20 20 31 | | N/A | |
| ☐ | 429 | 3195 | D | 14511 | 20041208 20 20 28 | | N/A | |
| ☐ | 429 | 3195 | D | 15012 | 20050112 20 20 25 | | N/A | |
| ☐ | 429 | 3195 | D | 16513 | 20050427 20 20 33 | | N/A | |
| ☐ | 429 | 3195 | D | 18519 | 20050914 20 20 28 | | N/A | |
| ☐ | 429 | 3195 | D | 19020 | 20051019 20 20 31 | | N/A | |
| ☐ | 429 | 3195 | D | 19521 | 20051123 20 20 28 | | N/A | |
| ☐ | 429 | 3195 | D | 20022 | 20051228 20 20 21 | | N/A | |
| | | | | | | | | |
| ☐ | 429 | 3213 | D | 4992 | 20030212 20 20 33 | SLC | 2429_3231_4992 | E20030212_202032_000000152013_00429_04992_0020 |
| ☐ | 429 | 3213 | D | 6996 | 20030702 20 20 41 | SLC | 2429_3231_6996 | E20030702_202040_000000152017_00429_06996_0123 |
| ☐ | 429 | 3213 | D | 7998 | 20030910 20 20 48 | SLC | 2429_3231_7998 | E20030910_202047_000000152019_00429_07998_0311 |
| ☐ | 429 | 3213 | D | 8499 | 20031015 20 20 44 | SLC | 2429_3231_8499 | E20031015_202043_000000152020_00429_08499_0372 |
| ☐ | 429 | 3213 | D | 9000 | 20031119 20 20 42 | SLC | 2429_3231_9000 | E20031119_202041_000000152021_00429_09000_0306 |
| ☐ | 429 | 3213 | D | 9501 | 20031224 20 20 45 | SLC | [illegible] | E20031224_202044_000000152022_00429_09501_1144 |
| ☐ | 429 | 3213 | D | 10002 | 20040128 20 20 41 | SLC | 2429_3231_10002 | E20040128_202040_000000152023_00429_10002_1913 |
| ☐ | 429 | 3213 | D | 10503 | 20040303 20 20 42 | SLC | 2429_3231_10503 | E20040303_202041_000000152024_00429_10503_2666 |
| ☐ | 429 | 3213 | D | 11505 | 20040512 20 20 42 | SLC | 2429_3231_11505 | E20040512_202041_000000152026_00429_11505_1297 |
| ☐ | 429 | 3213 | D | 12006 | 20040616 20 20 46 | SLC | 2429_3231_12006 | E20040616_202046_000000152027_00429_12006_2062 |
| ☐ | 429 | 3213 | D | 12507 | 20040721 20 20 48 | SLC | 2429_3231_12507 | E20040721_202047_000000152028_00429_12507_0841 |
| ☐ | 429 | 3213 | D | 13509 | 20040929 20 20 43 | SLC | 2429_3231_13509 | E20040929_202042_000000152030_00429_13509_2931 |
| ☐ | 429 | 3213 | D | 14010 | 20041103 20 20 46 | SLC | 2429_3231_14010 | E20041103_202045_000000152031_00429_14010_4033 |
| ☐ | 429 | 3213 | D | 14511 | 20041208 20 20 43 | SLC | 2429_3231_14511 | E20041208_202042_000000152032_00429_14511_4940 |
| ☐ | 429 | 3213 | D | 15012 | 20050112 20 20 40 | SLC | N/A | E20050112_202041_000000152033_00429_15012_5832 |
| ☐ | 429 | 3213 | D | 16515 | 20050427 20 20 48 | SLC | 2429_3231_16515 | E20050427_202047_000000152036_00429_16515_9264 |
| ☐ | 429 | 3213 | D | 18519 | 20050914 20 20 44 | SLC | N/A | E20050914_202045_000000152040_00429_18519_2347 |
| ☐ | 429 | 3213 | D | 19020 | 20051019 20 20 46 | SLC | N/A | E20051019_202046_000000152041_00429_19020_3454 |
| ☐ | 429 | 3213 | D | 19521 | 20051123 20 20 43 | SLC | N/A | E20051123_202043_000000152042_00429_19521_4546 |
| ☐ | 429 | 3213 | D | 20022 | 20051228 20 20 36 | SLC | 2429_3231_20022 | E20051228_202037_000000152043_00429_20022_5768 |
| ☐ | 429 | 3213 | D | 21024 | 20060308 20 20 33 | SLC | N/A | E20060308_202035_000000152045_00429_21024_0054 |
| | | | | | | | | |
| ☐ | 429 | 3231 | D | 15012 | 20050112 20 20 55 | South of F3213 | N/A | |
| ☐ | 429 | 3231 | D | 16515 | 20050427 20 21 03 | | N/A | |
| ☐ | 429 | 3231 | D | 18519 | 20050914 20 20 59 | | N/A | |
| ☐ | 429 | 3231 | D | 20022 | 20051228 20 20 52 | | N/A | |
| ☐ | 429 | 3231 | D | 21024 | 20060308 20 20 45 | | N/A | |

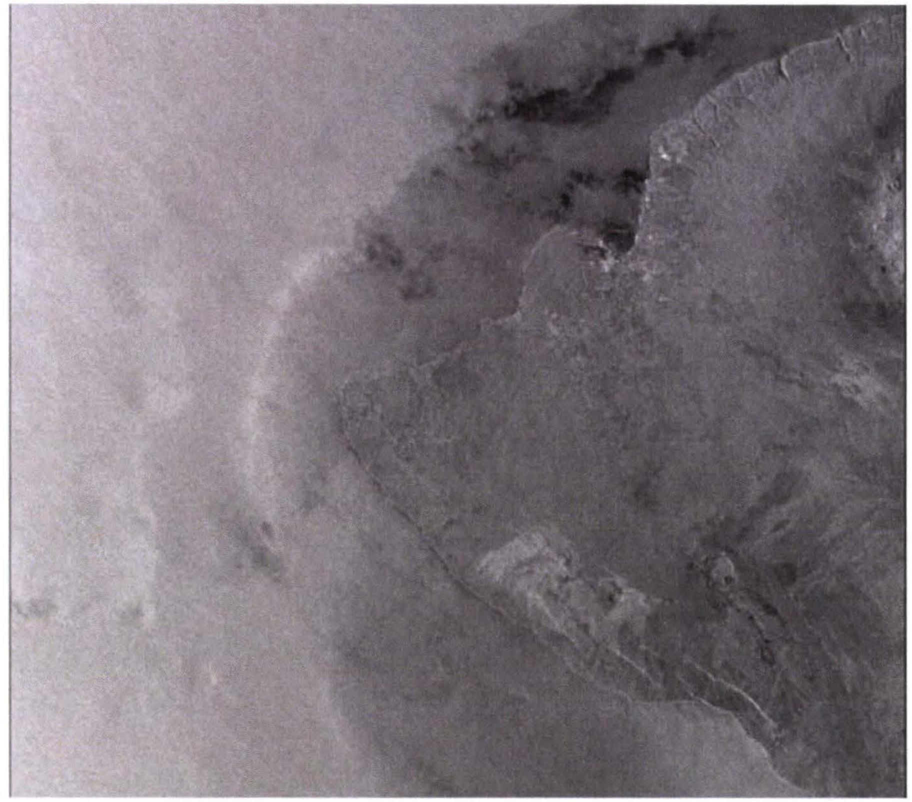


Figure 55: Online PGF archive. Search results are for Envisat track 429 including corresponding SLC image.

## Appendix E – Index of Commands and their Syntax

## Appendix F – File Access Information

### *DORIS precise orbits*

Local: PGFSAR://mnt/scsi/DATA/DORIS/vor

Remote: ESA's EOHelp desk

ftp-ops.fr.envisat.esa.int

IP address: 193.50.83.2

User name: inquire from Ben Brooks

Password: inquire from Ben Brooks

### *WInSAR*

Remote: http://winsar.unavco.org/main.php

User name: inquire from Ben Brooks

Password: inquire from Ben Brooks

### *External calibration files*

Local: PGFSAR://mnt/scsi/DATA/INSAR/ASA_XCA

Remote: http://earth.esa.int/services/auxiliary_data/asar/

### *Instrument characterization files*

Local: PGFSAR://mnt/scsi/DATA/INSAR/ASA_INS

Remote: http://earth.esa.int/services/auxiliary_data/asar/

### *IPTA scripts*

Local: PGFSAR://usr/local/GAMMA_SOFTWARE-20051219/IPTA_v1.2/scripts

### *MATLAB scripts*

Local: PGFSAR://usr/local/matlab/toolbox/pgf_tools

### *Shuttle Radar Topography Mission (SRTM)*

Local: PGFSAR://mnt/scsi/DATA/TOPO

Remote: http://srtm.usgs.gov/

## Appendix G – Index of Figures and Linked Files

## Appendix E – Index of Commands and their Syntax

Note: This list only contains commands and scripts used in the PGF User Guide, for a complete listing of commands please refer to the "Reference Manual" sections of the GAMMA software documentation.

MSP – ISP – IPTA – DIFF/GEO – DISP – LAT

| | |
|---|---|
| adf | |
| <int> <sm> <cc> <width> <alpha> [nfft] [cc_win] [step] [loff] [nlines] [wfrac] | |
| Input parameters | |
| int | interferogram (fcomplex) |
| width | number of samples/line |
| alpha | exponent for non-linear filtering (default = 0.5) |
| nfft | filtering FFT window size (default = 32, 2**N, 8 --> 512) |
| cc_win | coherence parameter estimation window size (odd, default = 7, max = 15) |
| step | processing step (default = nfft/8) |
| loff | offset to starting line to process (default = 0) |
| nlines | number of lines to process (default = 0: to end of file) |
| wfrac | minimum fraction of points required to be non-zero in the filter window (default = 0.7) |
| Output parameters | |
| sm | smoothed interferogram (fcomplex) |
| cc | coherence derived from smoothed interferogram, (enter - to avoid writing out cc) (float) |
| ASAR_IM_proc | |
| <L0> <INS> <SAR_par> <PROC_par> <raw> <ant_gain> [loff] [nl] | |
| Input parameters | |
| L0 | Level 0 image mode ASAR data file (ASA_IM_0P) |
| INS | ASAR instrument characterization file (ASA_INS_AX) |
| ant_gain | antenna pattern file name (derived using program **ASAR_XCA**) |
| loff | offset lines to first line to extract (default = 0, enter - for default) |
| nl | number of lines to extract (default = to end of input, enter - for default) |
| Output parameters | |
| SAR_par | MSP SAR sensor parameter file (example) |
| PROC_par | MSP processing parameter file, (example p<orbit>.slc.par) |
| raw | byte aligned 8-bit I/Q raw data |
| ASAR_pre_proc | |
| <ASAR_list> <DORIS_path> <RAW_dir> <log> <proc_list> <mode> [keyword] [value] | |
| Input parameters | |
| ASAR_list | see above (ASAR_pre_list) |
| DORIS_path | path to DORIS orbit data (i.e. */mnt/scsi/DATA/DORIS/vor*) |
| RAW_dir | directory for output unpacked raw data files and processing parameter files |

| | |
|---|---|
| | */raw* is generated by the script **ASAR_pre_proc** |
| mode | processing mode (see above) |
| keyword | (mode 4 only) search keyword in the MSP processing parameter file<br>(example: doppler_polynomial) |
| value | (mode 4 only) new value delimited by double quotes (example: "317.0 0. 0. 0.") |
| Output parameters | |
| log | **ASAR_pre_proc** processing log file |
| proc_list | processing list for use by **ASAR_proc_all** (the next script to run) |

**ASAR_proc_all_no_autof**

<proc_list> <RAW_dir> <rc_dir> <SLC_dir> <MLI_dir> <rlks> <azlks> <slc_format> [az_patch] [autof_min]

| | |
|---|---|
| Input parameters | |
| proc_list | processing list generated by **ASAR_pre_proc** (8 columns):<br>1. scene_identifier (example: 19960816)<br>2. offset in echoes to start of processed data (enter - for default)<br>3. number of echoes to process (enter - for default)<br>4. range offset in samples (enter - for default)<br>5. number of range samples to process (enter - for default)<br>6. Doppler centroid for scene (Hz)<br>7. Doppler slope for scene (Hz/m)<br>8. azimuth processing bandwidth fraction |
| RAW_dir | data directory containing fixed ASAR raw data files |
| rc_dir | directory to temporally store intermediate range compressed data (example: */tmp*) |
| SLC_dir | directory to store output SLC data (example: */slc*) |
| MLI_dir | directory to store multi-look intensity (MLI) files<br>derived from the SLC data (example: */mli_1_5*) |
| rlks | number of range looks to generate MLI images (nominal: 1) |
| azlks | number of azimuth looks to generate MLI images (nominal: 5 for IS2) |
| slc_format | desired output SLC image format (0 = fcomplex, 1 = scomplex) |
| az_patch | azimuth patch size (default = 6144) |
| autof_min | minimum SNR threshold for autofocus, 0.0 for no autofocus (default = 5)<br>this option does not work |

**ASAR_XCA**

<ASA_XCA> <antenna> [swath] [pol]

| | |
|---|---|
| Input parameters | |
| ASA_XCA | ASAR external calibration data file (binary) |
| swath | ASAR image swath (IS1, IS2, ... IS7; SS1, SS2, ... SS5) |
| pol | polarization (HH, VV, HV, VH) |
| Output parameters | |
| antenna | 1-way antenna gain pattern file or '-' (if not provided) |

| | |
|---|---|
| | or 'all' to generate all ASAR antenna diagrams |

**ave_image**

<MLI_tab> <width> <ave> [start] [nlines] [pixav_x] [pixav_y] [zero_flag]

Input parameters

| | |
|---|---|
| MLI_tab | text file containing list of names of co-registered MLI images in column 1<br>(cc_list generated by **mk_sp_all**) |
| width | number of samples/line |
| start | starting line (default = 1) |
| nlines | number of lines to process (default - : entire file) |
| pixav_x | number of pixels to average in width (default = 1) |
| pixav_y | number of pixels to average in height (default = 1) |
| zero_flag | default: zero_flag = 0 => 0.0 interpreted as missing value |

Output parameters

| | |
|---|---|
| ave | average of input data files (float) |

**az_proc_dop2d**

<SAR_par> <PROC_par> <rc_data> <SLC> [az_patch] [SLC_format] [cal_fact] [SLC_type] [kaiser] [npatch]

Input parameters

| | |
|---|---|
| SAR_par | MSP SAR sensor parameter file |
| PROC_par | MSP processing parameter file |
| rc_data | input range compressed data file |
| az_patch | along-track azimuth patch size (range lines): (2**N 2048, 4096, 8192...) |
| SLC_format | output SLC format flag (default=from MSP processing parameter file)<br>0: FCOMPLEX (pairs of 4-byte float)<br>1: SCOMPLEX (pairs of 2-byte short integer) |
| cal_fact | radiometric calibration factor [dB] (default = 0.0)<br>Proposed factors [dB] for absolute calibration:<br>ERS1 1991-1996: -10.3 dB (49.7 dB for SCOMPLEX output format)<br>ERS1 1997-2000: -12.5 dB (47.5 dB for SCOMPLEX output format)<br>ERS2: -2.8 dB (57.2 dB for SCOMPLEX output format)<br>JERS: -22.1 dB (37.9 dB for SCOMPLEX output format |
| SLC_type | output parameter type (default = 0)<br>0: sigma0 ( SQR(re) + SQR(im) => sigma0 )<br>1: gamma0 ( SQR(re) + SQR(im) => gamma0 ) gamma0 = sigma0 / cos(inc) |
| kaiser | Kaiser window parameter beta for the azimuth reference function (default: 2.120) |
| npatch | number of along-track patches to process |

Output parameters

| | |
|---|---|
| SLC | Single-Look Complex image (FCOMPLEX or SCOMPLEX format) |

**azsp_IQ**

<SAR_par> <PROC_par> <signal_data> <spectrum> [loff] [roff] [nsub] [ambig_flg] [namb]

| | |
|---|---|
| Input parameters | |
| SAR_par | SAR sensor parameter file |
| PROC_par | MSP processing parameter file |
| signal_data | input raw I/Q format SAR data |
| loff | number of lines offset to start of estimation window (default = 0) |
| roff | range samples offset to center of estimation window (enter - for default = center_swath) |
| nsub | number of azimuth sub-apertures for spectrum estimation (default = 12) |
| ambig_flg | Doppler ambiguity resolution mode<br>0 = add multiples of PRF specified by the namb command line parameter<br>1 = use unambiguous Doppler centroid estimate<br>from the PROC_par file (default) |
| namb | number of multiples of the PRF to add to the ambiguous Doppler estimate (default = 0) |
| Output parameters | |
| spectrum | azimuth spectrum (text format for plotting) |
| base_calc | |
| <SLC_tab> <SLC_par> <gr_file> <bperp_file> <itab> [itab_type] [bperp_min] [bperp_max] [delta_T_min] [delta_T_max] | |
| Input parameters | |
| SLC_tab | two column list of SLC filenames and SLC parameter filenames (including paths) (ascii) |
| SLC_par | reference SLC image parameter filename (include path) |
| itab_type | itab type (0: single reference, 1: all pairs) |
| bperp_min | minimum magnitude of bperp (m) (default = all, enter - for default) |
| bperp_max | maximum magnitude of bperp (m) (default = all, enter - for default) |
| delta_T_min | minimum number of days between passes (default = 0, enter - for default) |
| delta_T_max | maximum number of days between passes |
| Output parameters | |
| gr_file | xmgrace plot file name, (to redraw: xmgrace gr_file) |
| bperp_file | file containing a list of bperp and delta_T for interferogram pairs in the itab |
| itab | interferogram table |
| base_ls | |
| <SLC_par> <OFF_par> <gcp_ph> <baseline> [ph_flag] [bc_flag] [bn_flag] [bcdot_flag] [bndot_flag] [bperp_min] [SLC2R_par] | |
| Input parameters | |
| SLC_par | ISP parameter file of the reference SLC |
| OFF_par | ISP interferogram/offset parameter file |
| gcp_ph | ground control point heights + extracted unwrapped phase (text format) |
| baseline | (input/output) baseline parameter file |
| ph_flag | restore range phase ramp (default = 0: do not restore 1: restore) |
| bc_flag | cross-track baseline component estimate |

| | |
|---|---|
| | (0: orbit derived, 1: estimate from data, default = 1) |
| bn_flag | normal baseline component estimate |
| | (0: orbit derived, 1: estimate from data, default = 1) |
| bcdot_flag | cross-track baseline rate estimate (0: orbit derived, 1: estimate from data, default = 1) |
| bndot_flag | normal baseline rate estimate (0: orbit derived, 1: estimate from data, default = 0) |
| bperp_min | minimum perpendicular baseline required for L.S estimation (m, default = 10.0) |
| SLC2R_par | parameter file of resampled SLC, required if SLC-2 frequency differs from SLC-1 |

base_orbit

<SLC1_par> <SLC2_par> <baseline>

Input parameters

| | |
|---|---|
| SLC1_par | SLC-1 ISP image parameter file |
| SLC2_par | SLC-2 ISP image parameter file |

Output parameters

| | |
|---|---|
| baseline | baseline file (text format, enter - for none) |

base_orbit_pt

<pSLC_par> <itab> <rec_num> <pbase>

Input parameters

| | |
|---|---|
| pSLC_par | SLC/MLI parameter stack (binary) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| rec_num | record number to process (default - : all records) |

Output parameters

| | |
|---|---|
| pbase | baseline parameter stack (binary) |

cc_wave

<interf> <pwr1> <pwr2> <corr> <width> <bx> <by> <wgt_flag> <xmin> <xmax> <ymin> <ymax>

Input parameters

| | |
|---|---|
| interf | complex interferogram (complex coherence) filename |
| pwr1 | intensity image of first scene (or - ) |
| pwr2 | intensity image of second scene (or - ) |
| width | number of samples/row |
| bx | estimator window size (columns) (default = 5.0) |
| by | estimator window size (rows) (default = 5.0) |
| wgt_flag | weighting function flag (default: 0 = uniform, 1 = linear, 2 = Gaussian) |
| xmin | starting range pixel offset (default = 0) |
| xmax | last range pixel offset (default = width - 1) |
| ymin | starting azimuth row offset, relative to start (default = 0) |
| ymax | last azimuth row offset, relative to start (default = nlines - 1) |

Output parameters

| | |
|---|---|
| corr | estimated degree of coherence filename |

NOTICE: Instead of the pwr1 and pwr2 files - may be provided to select alternative coherence estimation method based exclusively on complex interferograms

### create_dem_par

<DEM_par> [SLC_par] [terra_alt] [delta_y] [delta_x]

Input parameters

| | |
|---|---|
| DEM_par | (input/output) DIFF/GEO DEM parameter file |
| SLC_par | ISP SLC/MLI image parameter file |
| terra_alt | nominal terrain altitude, default: 0.0 m |
| delta_y | DEM y line spacing for new DEM_par file<br>geographical coordinates (EQA projection latitude) default: -5.0000e-04 deg<br>all other map projections default: -50.0 m (use information from header file) |
| delta_x | DEM x sample spacing for new DEM_par file<br>geographical coordinates (EQA projection) default: 5.0000e-04 deg<br>all other map projections default: 50.0 m |

### create_diff_par

<PAR1> <PAR2> <DIFF_par> [PAR_type]

Input parameters

| | |
|---|---|
| PAR1 | parameter file 1 (see PAR_type option) |
| PAR2 | parameter file 2 (or - if not provided) |
| PAR_type | PAR1 and PAR2 parameter file type:<br>0: OFF_par ISP interferogram/offset parameter files (default)<br>1: SLC/MLI_par ISP SLC/MLI parameter files<br>2: DEM/MAP_par DIFF&GEO DEM/MAP parameter files |

Output parameters

| | |
|---|---|
| DIFF_par | differential interferometry parameter file |

### create_offset

<SLC1_par> <SLC2_par> <OFF_par> [offset_algorithm] [rlks] [azlks]

Input parameters

| | |
|---|---|
| SLC1_par | SLC-1/MLI-1 ISP image parameter filename (reference) |
| SLC2_par | SLC-2/MLI-2 ISP image parameter filename |
| offset_algorithm | offset estimation algorithm:<br>1: intensity cross-correlation (default)<br>2: fringe visibility |
| rlks | number of interferogram range looks (default: 1) |
| azlks | number of interferogram azimuth looks (default: 1) |

Output parameters

| | |
|---|---|
| OFF_par | ISP offset/interferogram parameter file |

### data2pt

<f_in> <par_in> <plist> <SLC_par> <pdata> <rec_num> <type>

Input parameters

| | |
|---|---|
| f_in | 2-D image data file (various types supported) |
| par_in | SLC/MLI parameter file of 2-D image data file |
| plist | point list for sampling (int) |
| SLC_par | SLC parameter file of point list coordinates |
| rec_num | record number in output point data stack (starting with 1) |
| type | data type (0: fcomplex, 1: scomplex, 2: float, 3: int, 4: short, 5: byte, 6: SUN/BMP raster) |

Output parameters

| | |
|---|---|
| pdata | point data stack (same type as f_in) |

def_mod_pt

<plist> <pmask_in> <pSLC_par> <ppos> <itab> <pbase> <bflag> <pdiff> <pdiff_type> <np_ref> <pres> <pdh> <pdef> <punw> <psigma> <pmask_out> [dh_max] [def_max] [sigma_max] [model] [pdh_err] [pdef_err] [ppc_err] [bmax] [dtmax]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask_in | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters (binary) |
| ppos | point data stack of interpolated point target positions<br>(fcomplex, enter - to use plist coordinates) |
| itab_selection | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| pbase | stack of baseline parameters (binary) |
| bflag | baseline flag (0: initial baseline, 1: precision baseline) |
| pdiff | point data stack of differential interferograms (fcomplex or float) |
| pdiff_type | type of pdiff (0: float (unwrapped), default= 1: fcomplex) |
| np_ref | phase reference point number (beginning from 0) |
| dh_max | maximum height correction for initial fit (m, enter - for default: 60.0) |
| def_max | maximum deformation rate difference for initial fit (m/year, enter - for default: 2.0e-02) |
| sigma_max | threshold for phase standard deviation to set mask to valid: (enter - for default: 1.200) |
| model | phase model (see above) |
| bmax | maximum perpendicular baseline (m) considered, (-1 = all records, default = -1) |
| dtmax | maximum time interval (days) considered, (-1 = all records, default = -1) |

Output parameters

| | |
|---|---|
| pres | point data stack of residual unmodeled phase<br>(float, = atmospheric phase, non-linear deformation, baseline error) |
| pdh | point data stack of height correction value (m, float, enter - for none) |
| pdef | point data stack of linear deformation rate (m/year, float, enter - for none) |
| punw | point data stack of unwrapped phase of pdiff (float, enter - for none) |
| psigma | point data stack of phase standard deviation from fit (float, enter - for none) |
| pmask_out | point data stack of mask values indicating accepted points (uchar, enter - for none) |

| | |
|---|---|
| pdh_err | estimated uncertainty in the height correction (m, float, enter - for none) |
| pdef_err | estimated uncertainty in linear deformation rate (m/year, float, enter - for none) |
| ppc_err | estimated uncertainty in phase constant a0 (radians, float, enter - for none) |

dem_trans

<DEM1_par> <DEM1> <DEM2_par> <DEM2> [lat_ovr] [lon_ovr] [Datum_shift] [lookup_table]

Input parameters

| | |
|---|---|
| DEM1_par | DEM parameter file DEM1 |
| DEM1 | input DEM (Digital Elevation Model) file |
| DEM2_par | DEM parameter file of output DEM (transformed coordinates) |
| lat_ovr | latitude DEM/MAP oversampling factor (default = 2.0) |
| lon_ovr | longitude DEM/MAP oversampling factor (default = 2.0) |
| | lat_ovr and lon_ovr are only considered if DEM2_par does not exist |
| Datum_shift | Datum shift flag: |
| | 0: transformed DEM heights not corrected for datum shift |
| | 1: transformed DEM heights corrected for datum shift (default = 1) |

Output parameters

| | |
|---|---|
| DEM2 | DEM in transformed coordinates |
| lookup_table | complex-valued lookup table (DEM2 -> DEM1) |

NOTE: if DEM2_par does not exist, it is created using the same projection parameters as DEM1

dis_ipta

<plist> <pmask> <pSLC_par> <ppos> <itab> <pbase> <bflag> <pdiff> <pdiff_type> <ras> [dh_max] [def_max] [model] [bmax] [dtmax] [mag] [win_sz]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters (binary) |
| ppos | point data stack of interpolated point target positions (fcomplex, enter - to use plist coordinates) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| pbase | stack of baseline parameters (binary) |
| bflag | baseline flag (0: initial baseline, 1: precision baseline) |
| pdiff | point data stack of differential interferograms (fcomplex or float) |
| pdiff_type | type of pdiff (0: float (unwrapped), default = 1: fcomplex) |
| ras | raster reference image with point locations marked (SUN *.ras, or BMP *.bmp) |
| dh_max | maximum height correction for initial fit (m, enter - for default: 60.0) |
| def_max | maximum deformation rate difference for initial fit (m/year, enter - for default: 5.0e-03) |
| model | phase model |
| ~~max_bl~~ | ~~max. baseline (m), only points with baseline lengths < max_bl are considered~~ |
| bmax | maximum perpendicular baseline (m) considered, (-1 = all records, default = -1) |

| | |
|---|---|
| dtmax | maximum time interval (days) considered, (-1 = all records, default = -1) |
| mag | zoom magnification factor (default = 3) |
| win_sz | zoom window size before magnification (default = 128) |
| dis2ras | |
| <ras1> <ras2> [mag] [win_sz] | |
| Input parameter | |
| ras1 | image 1 SUN raster *.ras, or BMP *.bmp format |
| ras2 | image 2 SUN raster *.ras, or BMP *.bmp format |
| | image depth (bits/pixel) of image-1 and image-2 must be identical |
| mag | zoom magnification factor (default = 3) |
| win_sz | zoom window size before magnification (default = 120) |
| disdem_par | |
| <DEM> <DEM_par> [start] [nlines] [exaggerate] [theta0] [phi0] | |
| Input parameters | |
| DEM | Digital elevation model (float or short as specified in DEM/MAP_par) |
| DEM_par | DIFFFF/GEO DEM parameter file |
| start | starting line of DEM (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| exaggerate | relief exaggeration factor to increase contrast of display (default = 2.0) |
| theta0 | illumination elevation angle in degree (default = 45.) |
| phi0 | illumination orientation angle in degree (default = 135.) |
| | (0: right, 90: top, 180: left, 270: bottom) |
| disdt_pwr24 | |
| <data> <pwr> <width> [start_data] [start_pwr] [nlines] [cycle] [scale] [exp] | |
| Input parameters | |
| data | real valued image (float, e.g. deformation rate, terrain height) |
| pwr | intensity image (float) |
| width | number of samples/row of data and pwr |
| start_data | starting line of data (default = 1) |
| start_pwr | starting line of pwr (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| cycle | data value per color cycle (default = 1.0000e-02) |
| scale | pwr display scale factor (default = 1.) |
| exp | pwr display exponent (default = .35) |
| dishgt | |
| <hgt> <pwr> <width> [start_hgt] [start_pwr] [nlines] [m_cycle] [scale] [exp] | |
| Input parameters | |
| hgt | height image (float) |
| pwr | intensity image (float, enter - if not available) |

| | |
|---|---|
| width | samples per row of hgt and pwr |
| start_hgt | starting line of hgt (default = 1) |
| start_pwr | starting line of pwr (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| m_cycle | meters per color cycle (default = 160.) |
| scale | display scale factor (default = 1.) |
| exp | display exponent (default = .35) |

dispmap

<unw> <hgt> <SLC_par> <OFF_par> <disp_map> [mode] [loff] [nlines]

Input parameters

| | |
|---|---|
| unw | unwrapped phase (float) |
| hgt | height map (float) or - to select constant reference height 0.0 |
| SLC_par | SLC parameter file of reference SLC |
| OFF_par | ISP/offset parameter file |
| mode | flag indicating displacement mode: |
| | default = 0: along look vector [m] ( + : towards sensor) |
| | 1: vertical displacement [m] ( + : increasing height) |
| | 2: horizontal displacement [m] ( + : decreasing ground range) |
| loff | number of lines offset to starting line (default = 0) |
| nlines | number of lines to process (default: 0 = entire file) |

Output parameters

| | |
|---|---|
| disp_map | displacement map |

dispmap_pt

<plist> <pmask> <pSLC_par> <itab> <punw> <phgt> <pdisp> [mode]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters (binary) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| punw | point data stack of unwrapped interferometric phases for each point |
| | and each layer in the stack (float) |
| phgt | point data stack of terrain heights (float) (enter - for none) |
| mode | flag indicating displacement mode: |
| | default = 0: along look vector [m] (+ : towards sensor) |
| | 1: vertical displacement [m] (+ : increasing height) |
| | 2: horizontal displacement [m] (+ : decreasing ground range) |

Output parameters

| | |
|---|---|
| pdisp | displacement (m) for each point and each layer in the stack(binary) |

disras

<ras> [mag] [win_sz]

Input parameters

| | |
|---|---|
| ras | SUN raster *.ras, or BMP *.bmp format image |
| mag | zoom magnification factor (default = 3) |
| win_sz | zoom window size before magnification (default = 120) |

disras_dem_par

<ras> <DEM_par> [mag] [win_sz]

Input parameters

| | |
|---|---|
| ras | raster image with same dimensions as in DEM_par (SUN *.ras, or BMP *.bmp format) |
| DEM_par | DIFF DEM/MAP parameter file |
| mag | zoom magnification factor (default = 3) |
| win_sz | zoom window size before magnification (default = 120) |

**DORIS_proc**

<PROC_par> <DOR> [nstate]

Input parameters

| | |
|---|---|
| PROC_par | (input/output) MSP processing parameter file (example p<orbit>.slc.par) |
| DOR | ASAR DORIS data file (DOR_VOR_AXVF) |
| nstate | number of state vectors to extract (enter - for default: 9) |

extract_gcp

<DEM_rdc> <OFF_par> <GCP> <nr> <naz> [mask]

Input parameters

| | |
|---|---|
| DEM_rdc | DEM in range-Doppler coordinates |
| OFF_par | ISP offset/interferogram parameter file |
| nr | number of GCP points in range (default = 32) |
| naz | number of GCP points in azimuth (default = 32) |
| mask | mask image, output set to 0.0 if mask = 0 (SUN raster or BMP format) |

Output parameters

| | |
|---|---|
| GCP | GCP height data file (text format) |

gc_map

<SLC_par> <OFF_par> <DEM/MAP_par> <DEM> <DEM/MAP_seg_par> <DEM_seg> <lookup_table> [lat_ovr] [lon_ovr] [sim_sar] [u] [v] [inc] [psi] [pix] [ls_map] [frame] [ls_mode] [r_ovr]

Input parameters

| | |
|---|---|
| SLC_par | ISP SLC or MLI image parameter file (slant range geometry) |
| OFF_par | ISP offset/interferogram parameter file (enter - if geocoding SLC or MLI data) |
| DEM/MAP_par | DEM/MAP parameter file |
| DEM | DEM data file (or constant height value) |
| DEM/MAP_seg_par | (input/output) DEM/MAP segment parameter file used for geocoding |

NOTE: if this file exists, then the bounds of the DEM segment used for geocoding

are read from the parameter file, otherwise the bounds are estimated
using the SLC parameters and state vectors, and written to the new parameter file

| | |
|---|---|
| lat_ovr | latitude DEM over-sampling factor (default = 2) |
| lon_ovr | longitude DEM over-sampling factor (default = 2) |
| frame | number of DEM pixels to add around area covered by SAR image (default = 8) |
| ls_mode | output lookup table values in regions of layover, shadow, or DEM gaps<br>0: set to (0., 0.), 1: linear interpolation across these regions (default),<br>2: actual value, 3: nn-thinned |
| r_ovr | range over-sampling factor for nn-thinned layover/shadow mode<br>(ls_mode = 3) (default = 2.0) |

Output parameters

| | |
|---|---|
| DEM_seg | segment of DEM used for geocoding interpolated if lat_ovr > 1, or lon_ovr > 1 |
| lookup_table | geocoding lookup table |
| sim_sar | simulated SAR backscatter image (in DEM geometry) |
| u | zenith angle of surface normal vector n (angle between z and n) |
| v | orientation angle of n (between x and projection of n in xy plane) |
| inc | local incidence angle (between surface normal and look vector) |
| psi | projection angle (between surface normal and image plane normal) |
| pix | pixel area normalization factor |
| ls_map | layover and shadow map (in map projection) |

NOTE: enter - as filename to avoid creation of the corresponding output file

gc_map_fine

<gc_in> <width> <DIFF_par> <gc_out> [ref_image]

Input parameters

| | |
|---|---|
| gc_in | geocoding lookup table |
| width | width of geocoding lookup table |
| DIFF_par | DIFF/GEO parameter file containing refinement polynomial coefficient |
| ref_image | reference image, offsets are measured relative to the reference image<br>0: actual SAR image<br>1: simulated SAR image (default) |

Output parameters

| | |
|---|---|
| gc_out | refined geocoding lookup table |

gcp_phase

<unw> <OFF_par> <gcp> <gcp_ph> [win_sz]

Input parameters

| | |
|---|---|
| unw | unwrapped interferometric phase |
| OFF_par | ISP interferogram/offset parameter file |

| | |
|---|---|
| gcp | ground control point data (text format) |
| win_sz | window size for averaging phase for each GCP, must be odd (default = 1) |
| Output parameters | |
| gcp_ph | ground control point data + extracted unwrapped phase (text format) |

geocode

<gc_map> <data_in> <width_in> <data_out> <width_out> [nlines_out] [interp_mode] [format_flag] [lr_in] [lr_out] [n_ovr] [rad_max] [nintr]

| | |
|---|---|
| Input parameters | |
| gc_map | lookup table containing pairs of real-valued output data coordinates |
| data_in | data file (format as specified by format_flag parameter) |
| width_in | width of input data file and gc_map lookup table |
| width_out | width of output data file |
| nlines_out | number of lines for the output data file (enter - for default: all lines) |
| interp_mode | resampling interpolation mode (default = 0) |
| | (0: 1/dist, 1: nearest neighbor, 2: SQR(1/dist), 3: const, 4: Gaussian) |
| format_flag | input/output data format flag (default = 0) |
| | (0: float, 1: fcomplex, 2: SUN raster/BMP format, 3: unsigned char 4: short 5: scomplex) |
| lr_in | input SUN raster/BMP format left/write flipped (default = 1: not flipped, -1: flipped) |
| lr_out | output SUN raster/BMP format left/write flipped (default = 1: not flipped, -1: flipped) |
| n_ovr | interpolation oversampling factor (default = 2) |
| rad_max | maximum interpolation search radius (default = 4*n_ovr: 8) |
| nintr | number of points required for interpolation when not nearest neighbor (default = 4) |
| Output parameters | |
| data_out | output data file |

geocode_back

<data_in> <width_in> <gc_map> <data_out> <width_out> [nlines_out] [interp_mode] [format_flag] [lr_in] [lr_out]

| | |
|---|---|
| Input parameters | |
| data_in | data file (for SUN raster: *.ras, BMP format: *.bmp) |
| width_in | width of input data file |
| gc_map | lookup table containing pairs of real-valued input data coordinates |
| width_out | width of output data file and gc_map lookup table |
| nlines_out | number of lines of output data file (default = 0: all lines of **gc_map**) |
| interp_mode | interpolation mode (default = 0) |
| | (0: nearest-neighbor, 1: spline, 2: spline-log, 3: bilinear, 4: bilinear_log) |
| format_flag | input/output data format flag (default = 0) |
| | (0: float, 1: fcomplex, 2: SUN raster/BMP format, 3: unsigned char, 4: short) |
| lr_in | input SUN raster/BMP format left/write flipped (default = 1: not flipped, -1: flipped) |
| Output parameters | |
| data_out | output data file (for SUN raster: *.ras, BMP format: *.bmp) |

| | |
|---|---|
| lr_out | output SUN raster/BMP format left/write flipped (default = 1: not flipped, -1: flipped) |

init_offset

<SLC-1> <SLC-2> <SLC1_par> <SLC2_par> <OFF_par> [rlks] [azlks] [rpos] [azpos] [offr] [offaz] [thres] [cflag]

Input parameters

| | |
|---|---|
| SLC-1 | single-look complex image 1 (reference) |
| SLC-2 | single-look complex image 2 |
| SLC1_par | SLC-1 ISP image parameter file |
| SLC2_par | SLC-2 ISP image parameter file |
| OFF_par | (input/output) ISP offset/interferogram parameter file |
| rlks | number of range looks (default = 1) |
| azlks | number of azimuth looks (default = 1) |
| rpos | center of patch in range (samples) (enter - for default: image center) |
| azpos | center of patch in azimuth (lines) (enter - for default: image center) |
| offr | initial range offset (samples) (default = 0) |
| offaz | initial azimuth offset (lines) (default = 0) |
| thres | correlation SNR threshold (default: 7.000) |
| cflag | copy offsets to the range and azimuth offset polynomials in OFF_par (default = 0: no, 1: yes) |

init_offset_orbit

<SLC1_par> <SLC2_par> <OFF_par> [rpos] [azpos]

Input parameters

| | |
|---|---|
| SLC1_par | SLC-1 parameter file |
| SLC2_par | SLC-2 parameter file |
| OFF_par | (input/output) ISP/offset parameter file |
| rpos | range position for offset estimation (default=center of SLC-1) |
| azpos | azimuth position for offset estimation (default=center of SLC-1) |

init_offsetm

<PWR-1> <PWR-2> <DIFF_par> [rlks] [azlks] [rpos] [azpos] [offr] [offaz] [thres] [patch] [cflag]

Input parameters

| | |
|---|---|
| PWR-1 | intensity image 1 (float) (reference) |
| PWR-2 | intensity image 2 (float) |
| DIFF_par | DIFF/GEO parameter file |
| rlks | number of range looks (enter - for default: 1) |
| azlks | number of azimuth looks (enter - for default: 1) |
| rpos | center of region for comparison in range (enter - for default: image center) |
| azpos | center of region for comparison in azimuth (enter - for default: image center) |
| offr | initial range offset (enter - for default from DIFF_par) |
| offaz | initial azimuth offset (enter - for default from DIFF_par) |
| thres | correlation SNR threshold (default: 7.0) |

| | |
|---|---|
| patch | correlation patch size (128, 256, 512, 1024, enter - for default: 1024) |
| cflag | copy offsets to the range and azimuth offset polynomials in DIFF_par (default = 0: no, 1 : yes) |

intf_pt

<plist> <pmask> <itab> <rec_num> <pSLC> <pint> <type> [pSLC_par]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| rec_num | record number to process (default - : all records) |
| pSLC | point data stack of interpolated SLC values (fcomplex or scomplex) |
| type | pSLC data type (0: fcomplex, 1: scomplex) |
| pSLC_par | stack of SLC/MLI parameters used for phase correction of ENVISAT/ERS interferograms (binary) |

Output parameters

| | |
|---|---|
| pint | point data stack of interferograms (fcomplex) |

NOTE: if SLC have different carrier frequencies, pSLC_par data are required

lin_comb_pt

<plist> <pmask> <pdata1> <rec_num1> <pdata2> <rec_num2> <pdata3> <rec_num3> <constant> <factor1> <factor2> <type> [zero_flag] [pt_num]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar) |
| pdata1 | point data stack 1 (various formats supported) |
| rec_num1 | record number in pdata1 (starting with 1, enter - : all records) |
| pdata2 | point data stack 2 (same format as pdata1) |
| rec_num2 | record number in pdata2 (starting with 1, enter - : same as rec_num1) |
| rec_num3 | record number in pdata3 (starting with 1, enter - : same as rec_num1) |
| constant | constant value to add to output record elements |
| factor1 | factor to multiply elements of rec_num1 of pdata1 |
| factor2 | factor to multiply elements of rec_num2 of pdata2 |
| type | data type (0: fcomplex, 1: scomplex, 2: float, 3: int, 4: short, 5: byte) |
| zero_flag | zero flag (default = 0: 0.0 is interpreted as NULL, 1: 0.0 is interpreted as valid value) |
| pt_num | use index of pdata2 point value rather than all points |

Output parameters

| | |
|---|---|
| pdata3 | point data stack (same format as pdata1) |

mcf

<interf> <wgt> <mask> <unw> <width> [tri_mode] [roff] [loff] [nr] [nlines] [npat_r] [npat_az] [ovrlap] [r_init]

[az_init] [init_flag]

Input parameters

| | |
|---|---|
| interf | interferogram (*.int, *.flt) (fcomplex) |
| wgt | weight factors (0 -> 1.0) file (float) (enter - for uniform weight) |
| mask | validity mask (SUN raster or BMP format, value 0 -> pixel not used) (enter - if no mask) |
| width | number of samples/row |
| tri_mode | triangulation mode<br>0: filled triangular mesh (default)<br>1: Delaunay triangulation |
| roff | offset to starting range of section to unwrap (default: 0) |
| loff | offset to starting line of section to unwrap (default: 0) |
| nr | number of range samples of section to unwrap (default (-): width - roff) |
| nlines | number of lines of section to unwrap (default (-): total number of lines - loff) |
| npat_r | number of patches in range |
| npat_az | number of patches in azimuth |
| ovrlap | overlap between patches in pixels (overlap >= 7, default (-): 512) |
| r_init | phase reference point range offset (default (-): roff) |
| az_init | phase reference point azimuth offset (default (-): loff) |
| init_flag | flag to set phase at reference point<br>0: use initial point phase value (default)<br>1: set phase to 0.0 at initial point |

Output parameters

| | |
|---|---|
| unw | unwrapped phase image (*.unw) (float) |

merge_pt

<plist_tab> <plist_out> <N_min> <r_tol> <az_tol>

Input parameters

| | |
|---|---|
| plist_tab | text file containing names of input point lists and masks<br>(each line contains one point list and optionally one mask name) |
| N_min | occurrence number minimum to include a point to the output list |
| r_tol | range position tolerance for counting occurrences |
| az_tol | azimuth line tolerance for counting occurrences |

Output parameters

| | |
|---|---|
| plist_out | point list derived from merging input point lists |

mk_2d_im

<plist> <pmask> <itab> <SLC_par> <pdata> <srec> <nrec> <par_out> <type> <imode> <radius> <np_min> <out_dir> <ref_im> <cycle> <sflag> [start] [nlines]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values |

| | |
|---|---|
| | (uchar, pmask[i] = 0 excludes point i, enter - if not available) |
| itab | table associating interferogram stack records with pairs of SLC stack records |
| SLC_par | ISP SLC parameter file of point list coordinates |
| pdata | point data stack (various types supported) |
| srec | starting record number in input point data stack (starting with 1) |
| nrec | number of records to process (enter - for all to end of list) |
| par_out | SLC/MLI parameter file of output 2-D image data file |
| type | data type (0: fcomplex, 2: float) |
| imode | interpolation mode (0: none, 1: 3-pt_bilinear, 2: 6-pt_bilinear, 3: convol, 4: nn_convol, default - : 6-pt_bilinear) |
| radius | window radius used (only used for imodes (3, 4), nominal = 1.2) |
| np_min | minimum number of points required for search region (only used for imodes (3, 4), default: 3) |
| out_dir | directory for output images |
| ref_im | reference multi-look RMLI 2D image used for display of point data (float) |
| cycle | data value per color cycle (applies only for float data, enter - or 0 for fcomplex data) |
| sflag | save data 2-D interpolated data files (0: no, 1: yes) |
| start | starting line to display (default: 1) |
| nlines | number of lines to display (default 0: to end of file) |
| log | not specified, automatically created |

mk_adf_2d

<RSLC_tab> <itab> <rmli> <diff_dir> [cc_win] [adf_exp] [adf_win]

Input parameters

| | |
|---|---|
| RSLC_tab | two column list of resampled SLC filenames and SLC parameter filenames (including paths) (ascii) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| rmli | RMLI reference image with same rlks and azlks value as the interferograms (includes path) |
| diff_dir | differential interferogram directory |
| cc_win | correlation estimation window size (linear weighting) in pixels (default: 5) |
| adf_exp | exponent parameter for adf filtering of the interferogram (nominal range .2 --> .6) default = 0.4 |
| adf_win | window size for adf filter (default = 32) |

mk_base_2d_cs <RSLC_tab> <itab> <DEM_rdc> <diff_dir> <pbase> [mask] [nr] [naz] [gcp_win] [type]

Input parameters

| | |
|---|---|
| RSLC_tab | two column list of resampled SLC filenames and SLC parameter filenames (including paths) (ascii) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| DEM_rdc | terrain height in radar range-Doppler coordinates (meters, float format) |

| | |
|---|---|
| diff_dir | directory containing unwrapped differential interferograms and baselines |
| mask | mask for selection of valid GCP (Sun raster or BMP format, enter - for none) |
| nr | number of GCP selection points in range |
| naz | number of GCP selection points in azimuth |
| gcp_win | window size for averaging unwrapped phase, must be odd (default = 3) |
| type | differential interferogram type:<br>0: unfiltered data (*.unw)<br>1: (default) adf filtered data (*.adf.unw) |

Output parameters

| | |
|---|---|
| pbase | baseline parameter stack (enter - for none) |

mk_diff_2d

<RSLC_tab> <itab> <bflag> <DEM_rdc> <def> <delta_t> <rmli> <rmli_dir> <diff_dir> <rlks> <azlks> <cc_win> [sflag] [mflag]

Input parameters

| | |
|---|---|
| RSLC_tab | two column list of resampled SLC filenames and SLC parameter filenames (including paths) (text) |
| itab | table associating interferogram stack records with pairs of SLC stack records (text) |
| bflag | baseline flag<br>0: use initial baseline estimate derived from orbit data<br>1: use precision baseline and do not derive baseline from orbit data |
| DEM_rdc | terrain height in radar range-Doppler coordinates (m, float, enter - for none) |
| def | deformation rate (m/year) (enter - for none) |
| rmli | reference image with same rlks and azlks value as the interferogram |
| rmli_dir | directory containing RMLI images of the resampled SLC |
| diff_dir | directory for differential interferograms after subtraction of height model phase |
| rlks | range looks to use for interferogram generation |
| azlks | azimuth looks to use for interferogram generation |
| cc_win | correlation estimation window size (linear weighting) in pixels (default: 5) |
| sflag | apply spectral shift filtering (default = 0: off, 1: on) |
| mflag | flag to select baseline estimation method (default = 0):<br>0: orbits, orbits; p1, p2<br>1: offsets, offsets; p1, p2, off<br>2: orbits, fft; p1, p2, off, int<br>3: offsets, fft; p1, p2, off, int<br>4: fft, fft; p1, off, int |

NOTE: mflag values of 1 and 3 only apply to itab files created with base_calc itab_mode = 0 (single reference)

mk_diff_all

<plist> <pmask> <pSLC_par> <itab> <pbase> <bflag> <pint> <int_type> <phgt> <pdef> <patm> <psim_unw> <pdiff> [log]

| | |
|---|---|
| Input parameters | |
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters for the resampled SLC data (binary) |
| itab | table associating interferogram stack records with pairs of SLC stack records (text) |
| pbase | stack of baseline parameters (binary) |
| bflag | baseline flag (0: use initial baseline, 1: precision baseline) |
| pint | point data stack of interferograms (fcomplex or float) |
| int_type | interferogram stack data type (0: float (unwrapped), default = 1: fcomplex) |
| phgt | point data stack of terrain height (m, float, single record, enter - for none) |
| pdef | point data stack of LOS deformation rate (m/yr, float, single record, enter - for none) |
| patm | point data stack of atmosphere phase estimates (enter - for none) |
| Output parameters | |
| psim_unw | point data stack of simulated unwrapped interferometric phase (float) |
| pdiff | point data stack of differential interferograms after subtraction of model phase and atmosphere (enter - for none) |
| log | mk_diff_all log file |
| mk_geo_cs | |
| <MLI> <MLI_par> <DEM> <DEM_par> <DEM_seg> <DEM_seg_par> <GEO_dir> <scene_id> <post> <mode> [ls_mode] [r_ovr] [n_ovr] [rlks] [azlks] [thres] [rpos] [azpos] [roff] [azoff] [r_patch] [az_patch] | |
| Input parameters | |
| MLI | MLI SAR image (including path) |
| MLI_par | ISP image parameter file of the MLI image (including path) |
| DEM | DEM in desired output projection (including path) |
| DEM_par | DEM parameter file (including path) |
| Output parameters | |
| DEM_seg | DEM segment for output image products (including path) |
| DEM_seg_par | (input/output) DEM parameter file for output image products (including path), regenerated each time |
| GEO_dir | directory for output images, lookup tables and DEM products |
| scene_id | scene name to identify output files |
| post | output image sample spacing in meters or degrees for geographic (EQA) projection |
| mode | processing mode (see above) |
| ls_mode | algorithm selection in **gc_map** for regions of layover, shadow, or DEM gaps:<br>0: set to (0., 0.)<br>1: linear interpolation across these regions<br>2: use actual value (default)<br>3: nearest neighbor thinned (nn-thinned) |
| r_ovr | range over-sampling parameter for ls_mode = 3 (nn-thinned) |

| | |
|---|---|
| | in **gc_map** (r_ovr default: 2) |
| n_ovr | interpolation oversampling factor in **geocode** (default = 2.0) |
| rad_max | maximum interpolation search radius (default: 4*n_ovr) |

NOTE: n_ovr and rad_max are parameters used by the program **geocode** for transformation of the simulated image and DEM into SAR geometry. The parameters rlks, azlks, thres, rpos, azpos, roff, azoff are used for estimation of the initial offset of the SAR image with respected to the simulated SAR image.

| | |
|---|---|
| rlks | number of range looks for the initial offset estimate (default: 1) |
| azlks | number of azimuth looks for the initial offset estimate (default: 1) |
| thres | SNR threshold for offset estimates (default: 10) |
| rpos | range position for initial offset (enter - for default) |
| azpos | azimuth position for initial offset (enter - for default) |
| roff | initial range offset estimate (enter - for current value in DIFF_par file) |
| azoff | initial azimuth offset estimate (enter - for current value in DIFF_par file) |
| r_patch | range patch size for offset estimation (default: 256 samples) |
| az_patch | azimuth patch size for offset estimation (default: 256 lines) |

mk_int_all

<plist> <pmask> <pSLC_par> <itab> <pSLC> <pbase> <pint> [log]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters for the resampled SLC data (binary) |
| itab | table associating interferogram stack records with pairs of SLC stack records (text) |
| pSLC | point data stack of interpolated SLC values (enter - for none, fcomplex or scomplex) |

Output parameters

| | |
|---|---|
| pbase | stack of baseline parameters (enter - for none, binary) |
| pint | point data stack of interferograms (enter - for none, fcomplex) |
| log | mk_int_all log file |

mk_mli_all

<SLC_tab> <MLI_dir> <rlks> <azlks> [sflag] [scale] [exp]

Input parameters

| | |
|---|---|
| SLC_tab | two column list of slc filenames and slc parameter filenames (including paths) (ascii) |
| MLI_dir | directory to contain MLI images and MLI image parameter files |
| rlks | range looks for the MLI images |
| azlks | azimuth looks for the MLI images |
| sflag | summation flag, generate sum of MLI images: |
| | 0: no |
| | 1: yes (default) |

| | |
|---|---|
| scale | relative intensity scale factor (default = 0.9) |
| exp | display exponent (default = 0.35) |
| mk_msr_pt | |
| <SLC_tab> <SLC_par> <MLI_par> <MLI_ras> <MSR_dir> [PWR_min] [mode] [MSR_cal] [PWR_cal] [min_MSR] [num_MSR] [delta_MSR] | |
| <u>Input parameters</u> | |
| SLC_tab | two column list of co-registered SLC files and associated SLC parameter files (including paths, text) |
| SLC_par | reference resampled SLC image parameter file (text) |
| MLI_par | image parameter file of reference resampled MLI image (text) |
| MLI_ras | background reference resampled MLI image (SUN raster or BMP format) |
| MSR_dir | directory to contain mean/sigma ratio images, point lists, and point images |
| PWR_min | minimum relative intensity threshold for point target selection (default = 0.5) |
| mode | intensity normalization between SLC scenes<br>(0: none, 1: image average, default = 2: point targets) |
| MSR_cal | mode 2 mean/sigma ratio for point target selection for relative calibration between scenes (default = 1.5) |
| PWR_cal | mode 2 intensity threshold ratio for point target selection for relative calibration between scenes (default = 1) |
| min_MSR | initial mean/sigma ratio threshold for point selection (default = 1.2) |
| num_MSR | number of MSR thresholds to test (default = 8) |
| delta_MSR | increment of MSR threshold (default = 0.1) |
| mk_sp_all | |
| <SLC_tab> <sp_dir> [rlks] [azlks] [PWR_min] [CC_min] [MSR_min] | |
| <u>Input parameters</u> | |
| SLC_tab | two column list of slc filenames and slc parameter filenames (including paths) (ascii) |
| sp_dir | directory to contain **sp_stat** generated msr, cc, and point lists |
| rlks | number of range spectral looks (default - : 4) |
| azlks | number of azimuth spectral looks (default - : 4) |
| PWR_min | intensity minimum threshold to accept a point (0.0 to ignore, default - : 0.5) |
| CC_min | spectral correlation minimum threshold to accept a point (0.4 to ignore, default - ) |
| MSR_min | mean/sigma ratio minimum threshold (relative to spatial average) to accept a point (0.0 to ignore, default - : 1.2) |
| mk_unw_2d | |
| <RSLC_tab> <itab> <rmli> <diff_dir> [cc_thres] [nlks] [npat_r] [npat_az] [mode] [r_init] [az_init] | |
| <u>Input parameters</u> | |
| RSLC_tab | two column list of resampled SLC filenames and SLC parameter filenames (including paths) (ascii) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |

| | |
|---|---|
| rmli | RMLI reference image with same rlks and azlks value as the interferograms (includes path) |
| diff_dir | differential interferogram directory |
| cc_thres | threshold for cc_mask (0.0 --> 1.0) (default = 0.4) |
| nlks | number of looks in range and azimuth to scale before unwrapping (default = 1) |
| npat_r | number of patches in range (default = 1) |
| npat_az | number of patches in azimuth (default = 1) |
| mode | processing mode:<br>0: unwrap unfiltered data (*.diff)<br>1: (default) unwrap adf filtered data (*.adf.diff) using adf correlation measure |
| r_init | phase reference range offset (default: 0) |
| az_init | phase reference azimuth offset (default: 0) |

MLI_copy

<MLI_in> <MLI_in_par> <MLI_out> <MLI_out_par> [roff] [nr] [loff] [nl]

Input parameters

| | |
|---|---|
| MLI_in | multi-look intensity image (float) |
| MLI_in_par | ISP image parameter file for input MLI |
| roff | offset to starting range sample (default = 0) |
| nr | number of range samples (default = 0, to end of line) |
| loff | offset to starting line (default = 0) |
| nl | number of lines to copy (default = 0, to end of file) |

Output parameters

| | |
|---|---|
| MLI_out | selected MLI section (float format) |
| MLI_out_par | ISP image parameter file for output MLI |

msk_pt

<plist1> <pmask1> <mask> <plist2> <pmask2> <rlks> <azlks>

Input parameters

| | |
|---|---|
| plist1 | point list 1 (int) (enter - for none) |
| pmask1 | point data stack of mask values (uchar pmask[i] = 0 excludes point i) (enter - for none) |
| mask | raster image file (8-bit/pixel Sun raster or BMP format)<br>points located in regions set to 0 are masked out |
| rlks | mask file range looks relative to the point coordinates |
| azlks | mask file azimuth looks relative to the point coordinates |

Output parameters

| | |
|---|---|
| plist2 | output list of points within the mask (int) (enter - for none) |
| pmask2 | output mask, matches length of plist1 if plist2 is not specified |

multi_cpx

<cpx_input> <OFF_par_in> <cpx_output> <OFF_par_out> [rlks] [azlks] [loff] [nlines] [roff] [nsamp]

Input parameters

| | |
|---|---|
| cpx_input | input complex image file |
| OFF_par_in | interferogram/offset parameter file for input image |
| rlks | number of range looks |
| | values < -1 interpreted as an image magnification factor (default = 1) |
| azlks | number azimuth looks |
| | values < -1 interpreted as an image magnification factor (default = 1) |
| loff | line offset to starting line (default = 0) |
| nlines | number of lines (default = 0, to end of file) |
| roff | offset to starting range sample (default = 0) |
| nsamp | number of range samples to extract (default = 0, to end of line) |

Output parameters

| | |
|---|---|
| cpx_output | output multi-look or interpolated complex data file |
| OFF_par_out | interferogram/offset parameter file for output, use existing parameter file if available |

multi_def_pt

<plist> <pmask_in> <pSLC_par> <ppos> <itab> <pbase> <bflag> <pdiff> <pdiff_type> <np_ref> <pres> <pdh> <pdef> <punw> <psigma> <pmask_out> [dh_max] [def_max] [rpatch] [sigma_max] [sigma_max2] [model] [noise_min] [bmax] [dtmax]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask_in | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters (binary) |
| ppos | point data stack of interpolated point target positions (fcomplex, enter - to use plist coordinates) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| pbase | stack of baseline parameters (binary) |
| bflag | baseline flag (0: initial baseline, 1: precision baseline) |
| pdiff | point data stack of differential interferograms (fcomplex or float) |
| pdiff_type | type of pdiff (0: float (unwrapped), default = 1: fcomplex) |
| np_ref | phase reference point number (beginning from 0) |
| dh_max | maximum height correction for initial fit (m, enter - for default: 60.0) |
| def_max | maximum deformation rate difference for initial fit (m/year, enter - for default: 2.0e-02) |
| rpatch | patch size in range pixels (enter - for default: 100) |
| sigma_max | threshold for phase std. deviation to set mask to valid: (enter - for default: 1.2) |
| sigma_max2 | threshold for phase std. deviation for patch to patch fit: (enter - for default: 0.75) |
| model | phase model (see above) |
| noise_min | noise minimization for patch to patch processing (default=0:off 1:on) |
| bmax | maximum perpendicular baseline (m) considered, (-1 = all records, default = -1) |
| dtmax | maximum time interval (days) considered, (-1 = all records, default = -1) |

Output parameters

| | |
|---|---|
| pres | point data stack of residual unmodeled phase (float, enter - for none) |
| pdh | point data stack of height correction value (m, float, enter - for none) |
| pdef | point data stack of linear deformation rate (m/year, float, enter - for none) |
| punw | point data stack of unwrapped phase of pdiff (float, enter - for none) |
| psigma | point data stack of phase standard deviation from fit (float, enter - for none) |
| pmask_out | point data stack of mask values indicating accepted points (uchar, enter - for none) |
| multi_look | |
| <SLC> <SLC_par> <MLI> <MLI_par> <rlks> <azlks> [loff] [nlines] [scale] [image_format] | |
| Input parameters | |
| SLC | single-look complex image |
| SLC_par | SLC ISP image parameter file |
| rlks | number of range looks |
| azlks | number of azimuth looks |
| loff | offset to starting line (default = 0) |
| nlines | number of SLC lines to process (default = entire file) |
| scale | scale factor for output MLI (default = 1.0) |
| Output parameters | |
| MLI | multi-look intensity image |
| MLI_par | MLI ISP image parameter file |
| multi_real | |
| <real_input> <OFF_par_in> <real_output> <OFF_par_out> [rlks] [azlks] [loff] [nlines] [roff] [nsamp] | |
| Input parameters | |
| real_input | input real image file |
| OFF_par_in | interferogram/offset parameter file for input image |
| rlks | number of range looks |
| | values < -1 interpreted as an image magnification factor (default = 1) |
| azlks | number azimuth looks |
| | values < -1 interpreted as an image magnification factor (default = 1) |
| loff | line offset to starting line (default = 0) |
| nlines | number of lines (default = 0, to end of file) |
| roff | offset to starting range sample (default = 0) |
| nsamp | number of range samples to extract (default = 0, to end of line) |
| Output parameters | |
| real_output | output multi-look or interpolated real data file |
| OFF_par_out | interferogram/offset parameter file for output, use existing parameter file if available |
| multi_SLC | |
| <SLC_PROC_par> <MLI_PROC_par> <SLC> <MLI> <rlks> <azlks> [slc_format] | |
| Input parameters | |
| SLC_PROC_par | SLC MSP processing parameter file |

| | |
|---|---|
| SLC | single-look complex image |
| rlks | number of range looks |
| azlks | number of azimuth looks |
| slc_format | input SLC format flag (default: from SLC_PROC_par)<br>0: FCOMPLEX (pairs of 4-byte float)<br>1: SCOMPLEX (pairs of 2-byte short integer) |
| Output parameters | |
| MLI_PROC_par | MLI MSP processing parameter file |
| MLI | multi-look intensity image derived from SLC |

npt

<plist> [pmask]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar pmask [i] = 0 excludes point i) |

offset_fit

<offs> <snr> <OFF_par> [coffs] [coffsets] [thres] [npoly] [interact_flag]

Input parameters

| | |
|---|---|
| offs | range and azimuth offset estimates (fcomplex) |
| snr | SNR values of offset estimates (float) |
| OFF_par | ISP offset/interferogram parameter file |
| thres | SNR threshold (enter - for default from OFF_par) |
| npoly | number of polynomial model parameters (enter - for default, 1, 3, 4, default = 4) |
| interact_flag | interactive culling of input data (1 = YES, 0 = NO, default = NO) |
| Output parameters | |
| coffs | culled range and azimuth offset estimates (fcomplex, enter - for none) |
| coffsets | culled offset estimates and SNR values (text format, enter - for none) |

offset_fitm

<offs> <snr> <DIFF_par> [coffs] [coffsets] [thres] [npoly] [interact_flag]

Input parameters

| | |
|---|---|
| offs | range and azimuth offset estimates (fcomplex) |
| snr | SNR values of offset estimates (float) |
| DIFF_par | DIFF/GEO parameter file for the scene |
| thres | SNR threshold (enter - for default from DIFF_par) |
| npoly | number of polynomial model parameters (enter - for default, 1, 3, 4, default = 4) |
| interact_flag | interactive culling of input data (1 = YES, 0 = NO, default = NO) |
| Output parameters | |
| coffs | culled range and azimuth offset estimates (fcomplex, enter - for none) |
| coffsets | culled offset estimates and SNR values (text format, enter - for none) |

offset_pwr

<SLC-1> <SLC-2> <SLC1_par> <SLC2_par> <OFF_par> <offs> <snr> [rwin] [azwin] [offsets] [n_ovr] [nr] [naz] [thres] [pflag]

Input parameters

| | |
|---|---|
| SLC-1 | single-look complex image 1 (reference) |
| SLC-2 | single-look complex image 2 |
| SLC1_par | SLC-1 ISP image parameter file |
| SLC2_par | SLC-2 ISP image parameter file |
| OFF_par | ISP offset/interferogram parameter file |
| rwin | search window size (range pixels, (enter - for default from offset parameter file)) |
| azwin | search window size (azimuth pixels, (enter - for default from offset parameter file)) |
| n_ovr | SLC oversampling factor (integer 2**N (1, 2, 4) default = 2) |
| nr | number of offset estimates in range direction<br>(enter - for default from offset parameter file) |
| naz | number of offset estimates in azimuth direction<br>(enter - for default from offset parameter file) |
| thres | offset estimation quality threshold (enter - for default from offset parameter file) |
| pflag | print flag (0: print offset summary (default), 1: print all offset data) |

Output parameters

| | |
|---|---|
| offs | offset estimates (fcomplex) |
| snr | offset estimation SNR (float) |
| offsets | range and azimuth offsets and SNR data in text format, enter - for no output |

offset_pwrm

<PWR-1> <PWR-2> <DIFF_par> <offs> <snr> [rwin] [azwin] [offsets] [n_ovr] [nr] [naz] [thres] [pflag]

Input parameters

| | |
|---|---|
| PWR-1 | real valued intensity image 1 (reference) |
| PWR-2 | real valued intensity image 2 |
| DIFF_par | DIFF/GEO parameter file |
| rwin | search window size (range pixels, (enter - for default from offset parameter file)) |
| azwin | search window size (azimuth pixels, (enter - for default from offset parameter file)) |
| n_ovr | image oversampling factor (integer 2**N (1, 2, 4) default = 2) |
| nr | number of offset estimates in range direction<br>(enter - for default from offset parameter file) |
| naz | number of offset estimates in azimuth direction<br>(enter - for default from offset parameter file) |
| thres | offset estimation quality threshold (enter - for default from offset parameter file) |
| pflag | print flag (0: print offset summary, 1: print all offset data (default)) |

Output parameters

| | |
|---|---|
| offs | offset estimates (fcomplex) |
| snr | offset estimation SNR (float) |

| | |
|---|---|
| offsets | range and azimuth offsets and SNR data in text format, enter - for no output |

**ORB_prop**

<PROC_par> [nstate] [interval] [extra]

Input parameters

| | |
|---|---|
| PROC_par | (input/output) MSP processing parameter file |
| nstate | number of state vectors to calculate for the MSP image parameter file, enter - for the default value determined from the duration of the state vectors) |
| interval | time interval between state vectors (default: input state vector time interval) |
| extra | extra time for state vector coverage at start and end of image (default= 30.0 s.) |

**par_MSP**

<SAR_par> <PROC_par> <SLC/MLI_par> [image_format]

Input parameters

| | |
|---|---|
| SAR_par | MSP SAR sensor parameter file |
| PROC_par | MSP processing parameter file |
| image_format | image format flag (default: from MSP processing parameter file)<br>0: fcomplex (pairs of 4-byte float)<br>1: scomplex (pairs of 2-byte short integer)<br>2: float (4-bytes/value) |

Output parameters

| | |
|---|---|
| SLC/MLI_par | ISP SLC/MLI image parameter file |

**pdisdt_pwr24, prasdt_pwr24**

<plist> <pmask> <SLC_par> <pdata> <rec_num> <par_out> <mli> <cycle> [radius]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values<br>(uchar, pmask[i] = 0 excludes point i, enter - if not available) |
| SLC_par | SLC parameter file of point list coordinates |
| pdata | point data stack (float) |
| rec_num | record number to process (default - : all records) |
| par_out | SLC/MLI parameter file of 2-D output image data file |
| mli | 2-D image data file used as output image intensity |
| cycle | data value per color cycle |
| radius | interpolation window radius used default: 4.0) |

**phase_sim**

<SLC1_par> <OFF_par> <baseline> <hgt> <sim_unw> [ph_flag] [bflag] [def] [delta_t] [SLC2R_par]

Input parameters

| | |
|---|---|
| SLC1_par | parameter file of reference SLC-1 |
| OFF_par | ISP offset/interferogram parameter file |

| | |
|---|---|
| baseline | baseline parameter file |
| hgt | height map in the same geometry as the interferogram (m, float, enter - for none) |
| ph_flag | range phase trend selection: |
| | 0: unflattened interferogram (default) |
| | 1: flattened interferogram |
| bflag | baseline selection: |
| | 0: initial baseline (default) |
| | 1: precision baseline |
| def | LOS deformation rate map (m/yr, float, enter - for none) |
| delta_t | interferogram time interval (days, required for deformation modeling, enter - for none) |
| SLC2R_par | parameter file of resampled SLC, required if SLC-2 frequency differs from SLC-1 |

Output parameters

| | |
|---|---|
| sim_unw | simulated unwrapped interferometric phase |

phase_sim_pt

<plist> <pmask> <pSLC_par> <ppos> <itab> <rec_num> <pbase> <phgt> <psim_unw> [pdef] [ph_flag] [bflag]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters (binary) |
| ppos | point data stack of interpolated point target positions |
| | (fcomplex, enter - to use plist coordinates) |
| itab | table associating interferogram stack records with pairs of SLC stack records (ascii) |
| rec_num | itab record number to process (default - : all records) |
| pbase | stack of baseline parameters (binary) |
| phgt | point data stack of terrain height (m, float, single record, enter - for none) |
| pdef | point data stack of LOS deformation rate (m/yr, float, single record, enter - for none) |
| ph_flag | phase model flag |
| | 0: unflattened (default) |
| | 1: flattened |
| | 2: height + deformation phase, relative to ref. layer |
| bflag | baseline flag |
| | 0: use initial baseline (default) |
| | 1: precision baseline |

Output parameters

| | |
|---|---|
| psim_unw | point data stack of simulated unwrapped interferometric phase (float) |

pre_rc

<SAR_par> <PROC_par> <signal_data> <rc_data> [prefilt_dec] [loff] [nl] [nr_samp] [kaiser] [filt_lm] [nr_ext] [fr_ext]

Input parameters

| | |
|---|---|
| SAR_par | MSP SAR sensor parameter file |
| PROC_par | MSP processing parameter file |
| signal_data | uncompressed raw SAR signal data filename |
| prefilt_dec | prefilter decimation factor (enter - for default from PROC_par) |
| loff | number of lines offset from start of file (enter - for default from PROC_par) |
| nl | number of lines to range compress (enter - for default from PROC_par) |
| nr_samp | number of range samples (enter - for default from PROC_par) |
| kaiser | range chirp Kaiser window parameter beta (default = 2.120, -30 dB sidelobes) |
| filt_lm | filter length multiplier, FIR length = FIR_lm * prefilt_dec + 1 (default = 8) |
| nr_ext | near range swath extension in samples (default from PROC_par) |
| fr_ext | far range swath extension in samples (default from PROC_par) |
| Output parameters | |
| rc_data | range compressed data filename |
| pt2data | |
| <plist> <pmask> <SLC_par> <pdata> <rec_num> <f_out> <par_out> [type] [imode] [radius] [np_min] | |
| Input parameters: | |
| plist | point list (int) |
| pmask | point data stack of mask values |
| | (uchar, pmask[i] = 0 excludes point i, enter - if not available) |
| SLC_par | SLC parameter file of point list coordinates |
| pdata | point data stack (various types supported) |
| rec_num | record number in input point data stack (starting with 1) |
| par_out | SLC/MLI parameter file of 2-D output image data file |
| type | data type (0: fcomplex, 1: scomplex, 2: float, 3: int, 4: short, 5: byte, default - : float) |
| imode | interpolation mode (0: none, 1: 3-pt_bilinear, 2: 6-pt_bilinear, |
| | 3: convol, 4: nn_convol, default - : 6-pt_bilinear) |
| radius | window radius used (only used for imodes (3, 4), default: 4.0) |
| np_min | minimum number of points required for search region |
| | (only used for imodes (3, 4), default: 3) |
| Output parameters | |
| f_out | 2-D image data file (same type as input point data stack) |
| pwr_stat | |
| <SLC_tab> <SLC_par> <MSR> <plist> [MSR_min] [PWR_min] [roff] [loff] [nr] [nl] [type] [mode] [MSR_cal] [PWR_cal] | |
| Input parameters | |
| SLC_tab | text file containing list of names of co-registered SLC in column 1 |
| SLC_par | SLC parameter file of point list coordinates (i.e. for the reference SLC) |
| MSR_min | mean/sigma ratio minimum threshold to accept a point (0.0 to ignore, default - : 1.5) |
| PWR_min | intensity minimum threshold (relative to spatial average) to accept a point |

| | |
|---|---|
| | (0.0 to ignore, default - : 1.0) |
| roff | offset to starting range of section to analyze (default - : 0) |
| loff | offset to starting line of section to analyze (default - : 0) |
| nr | number of range pixels to analyze (default - : to end of line) |
| nl | number of azimuth lines to analyze (default - : to end of file) |
| type | SLC type (default 0: fcomplex, 1: scomplex) |
| mode | intensity normalization between SLC scenes |
| | (0: none, 1: image average, default = 2: point targets) |
| MSR_cal | mode 2 mean/sigma ratio for point target selection for relative calibration |
| | between scenes: 1.5 |
| PWR_cal | mode 2 intensity threshold ratio for point target selection for relative calibration |
| | between scenes: 1.0 |
| Output parameters | |
| MSR | mean/sigma ratio image (float, enter - for none) |
| plist | point list (int, enter - for none) |
| ras_linear | |
| <pwr> <width> [start] [nlines] [pixavr] [pixavaz] [min] [max] [LR] [rasf] [inverse] [channel] | |
| Input parameters | |
| pwr | intensity image (float) |
| width | samples per row of pwr |
| start | starting line of pwr (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |
| min | minimum value for display (default= 0.0) |
| max | maximum value for display (default = 1.0) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) |
| inverse | inverse flag (default = 1: float_to_raster, -1: raster_to_float) |
| channel | RBG channel flag (default = 1: red, 2: green, 3: blue) |
| rasf | (output/input) raster image (default = *.ras: SUN raster format, *.bmp: BMP format) |
| ras_pt | |
| <plist> <pmask> <ras_in> <ras_out> [rlks] [azlks] [r] [g] [b] [xs] [zflg] [mflg] | |
| Input parameters | |
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| ras_in | raster image (SUN raster or BMP format) |
| rlks | range looks of raster image relative to point coordinates (default = 1.0) |
| azlks | azimuth looks of raster image relative to point coordinates (default = 1.0) |
| r | line color value red (0 --> 255) default: 255 |

| | |
|---|---|
| g | line color value green (0 --> 255) default: 255 |
| b | line color value blue (0 --> 255) default: 0 |
| xs | size of cross in pixels, set to 1 for single points (default: 1) |
| zflg | zero image flag (default = 0: retain image values, |
| | 1: set all image values to 0 except crosses) |
| mflg | mask flag (0: display all points default = 0: display points only where pmask[i] = 1, |
| | 1: display points where pmask[i] = 0) |
| Output parameters | |
| ras_out | raster image with crosses drawn at points (SUN raster of BMP format) |
| rascc | |
| <cc> <pwr> <width> [start_cc] [start_pwr] [nlines] [pixavr] [pixavaz] [cmin] [cmax] [scale] [exp] [LR] [rasf] | |
| Input parameters | |
| cc | correlation coefficient image (float) |
| pwr | intensity data (float, enter - if not available) |
| width | samples per row of cc and pwr |
| start_cc | starting line of cc (default = 1) |
| start_pwr | starting line of pwr (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |
| cmin | minimum correlation value used for linear cc display (default = .1) |
| cmax | maximum correlation value used for linear cc display (default = .9) |
| scale | pwr display scale factor (default = 1.) |
| exp | pwr display exponent (default = .35) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) |
| Output parameters | |
| rasf | raster image (default = *.ras: SUN raster format, *.bmp: BMP format) |
| rascc_mask | |
| <cc> <pwr> <width> [start_cc] [start_pwr] [nlines] [pixavr] [pixavaz] [cc_thres] [cc_min] [cc_max] [scale] [exp] [LR] [rasf] | |
| Input parameters | |
| cc | coherence image (float) |
| pwr | intensity image (float, enter - if not available) |
| width | number of samples/row |
| start_cc | starting line of coherence image (default = 1) |
| start_pwr | starting line of intensity image (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |

| | |
|---|---|
| cc_thres | coherence threshold for masking, all pixels with coherence below cc_thres are set to (0, 0, 0) |
| cc_min | minimum coherence value used for color display (default = .1) |
| cc_max | maximum coherence value used for color display (default = .9) |
| scale | intensity display scale factor (default = 1.) |
| exp | intensity display exponent (default = .35) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) |

Output parameters

| | |
|---|---|
| rasf | validity mask (default = *.ras: SUN raster format, *.bmp: BMP format) |

rashgt

<hgt> <pwr> <width> [start_hgt] [start_pwr] [nlines] [pixavr] [pixavaz] [m/cycle] [scale] [exp] [LR] [rasf]

Input parameters

| | |
|---|---|
| hgt | height data (float) |
| pwr | intensity data (float, enter - if not available) |
| width | samples per row of hgt and pwr |
| start_hgt | starting line of hgt (default = 1) |
| start_pwr | starting line of pwr (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |
| m/cycle | meters per color cycle (default = 160.) |
| scale | display scale factor (default = 1.) |
| exp | display exponent (default = .35) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) |

Output parameters

| | |
|---|---|
| rasf | raster image (default = *.ras: SUN raster format, *.bmp: BMP format) |

rasmph_pwr

<cpx> <pwr> <width> [start_cpx] [start_pwr] [nlines] [pixavr] [pixavaz] [scale] [exp] [LR] [rasf] [cc] [start_cc] [cc_min]

Input parameters

| | |
|---|---|
| cpx | complex image (fcomplex, e.g. interferogram) |
| pwr | intensity image (float) |
| width | number of samples/row of cpx and pwr |
| start_cpx | starting line of cpx (default = 1) |
| start_pwr | starting line of pwr (default = 1) |
| nlines | number of lines to display (default=0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |
| scale | pwr display scale factor (default = 1.) |

| | |
|---|---|
| exp | pwr display exponent (default = .35) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) |
| cc | display threshold data file (float, e.g. correlation) |
| start_cc | starting line of cc data file (default = 1) |
| cc_min | pixels with cc values below cc_min are displayed using grayscale (default = .2) |
| Output parameters | |
| rasf | raster file (enter - for default=*.ras: SUN raster format, *.bmp: BMP format) |
| raspwr | |
| <pwr> <width> [start] [nlines] [pixavr] [pixavaz] [scale] [exp] [LR] [rasf] [data_type] [hdrsz] | |
| Input parameters | |
| pwr | intensity image (float or short integer data type) |
| width | samples per row |
| start | starting line to display (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |
| scale | display scale factor (default = 1.) |
| exp | display exponent (default = .35) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) for descending track |
| data_type | input data type (default = 0)<br>0: float<br>1: short integer |
| hdrsz | line header size in bytes (default=0, ESA PAF for PRI products=12) |
| Output parameters | |
| rasf | raster image (enter - for default = *.ras: SUN raster format, *.bmp: BMP format example) |
| rasrmg | |
| <unw> <pwr> <width> [start_unw] [start_pwr] [nlines] [pixavr] [pixavaz] [ph_scale] [scale] [exp] [ph_offset] [LR] [rasf][rasf] [cc] [start_cc] [cc_min] | |
| Input parameters | |
| unw | unwrapped phase data (float) |
| pwr | intensity data (float, enter - if not available) |
| width | samples per row of unwrapped phase and intensity files |
| start_unw | starting line of unwrapped phase file (default = 1) |
| start_pwr | starting line of intensity file (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |
| ph_scale | phase display scale factor (default = .33333) |
| scale | pwr display scale factor (default = 1.) |

| | |
|---|---|
| exp | pwr display exponent (default = .35) |
| ph_offset | phase offset in radians subtracted from unw (default = .0) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) |
| cc | correlation threshold data file (float): e.g. correlation |
| start_cc | starting line of threshold data file (default = 1) |
| cc_min | pixels with cc values below cc_min are displayed using grayscale (default = .2) |

Output parameters

| | |
|---|---|
| rasf | raster image (enter - for default = *.ras: SUN raster format, *.bmp: BMP format) |

**rasshd**

<DEM> <width> <col_post> [row_post] [start] [nlines] [pixavr] [pixavaz] [theta0] [phi0] [LR] [rasf] [format] [zero_flag]

Input parameters

| | |
|---|---|
| DEM | digital elevation model (float) |
| width | samples per row of DEM |
| col_post | posting between cols (same unit as DEM values) |
| row_post | posting between rows (same unit as DEM, default = col_post) |
| start | starting line of DEM (default = 1) |
| nlines | number of lines to display (default = 0: to end of file) |
| pixavr | number of pixels to average in range (default = 1) |
| pixavaz | number of pixels to average in azimuth (default = 1) |
| theta0 | illumination elevation angle in deg. (default = 45.) |
| phi0 | illumination orientation angle in deg. (default = 135.) |
| | (0: right, 90: top, 180: left, 270: bottom) |
| LR | left/right flipping flag, (default = 1: normal, -1: mirror image) |
| format | data format (default = 0: float, 1: short integer) |
| zero_flag | zero_flag default = 0: 0.0 interpreted as missing value, 1: interpreted as valid value |

Output parameters

| | |
|---|---|
| rasf | raster image (default = *.ras: SUN raster format  *.bmp: BMP format) |

set_value

<PAR_in> <PAR_out> <keyword> <value> [new_key]

Input parameters

| | |
|---|---|
| PAR_in | keyword:value based parameter file |
| keyword | search keyword of keyword:value pair |
| value | new value (note: delimit value with double quotes if it contains spaces or punctuation) |
| new_key | 0 = default: new keyword:value pair not permitted, 1: insert new keyword:value pair |

Output parameters

| | |
|---|---|
| PAR_out | keyword:value based parameter file (can be the same file as PAR_in) |

SLC_copy

<SLC_in> <SLC_par_in> <SLC_out> <SLC_par_out> [fcase] [sc] [roff] [nr] [loff] [nl] [swap] [header_lines]

| | |
|---|---|
| Input parameters | |
| SLC_in | SLC (FCOMPLEX or SCOMPLEX format) |
| SLC_par_in | ISP SLC parameter file for input SLC |
| fcase | data format conversion (enter - for default: output format = input format)<br>1: fcomplex --> fcomplex (default sc = 1.0)<br>2: fcomplex --> scomplex (default sc = 10000.0)<br>3: scomplex --> fcomplex (default sc = 0.0001)<br>4: scomplex --> scomplex (default sc = 1.0) |
| sc | scale factor for input SLC data (enter - for default) |
| roff | offset to starting range sample (enter - for default: 0) |
| nr | number of range samples (enter - for default: to end of line) |
| loff | offset to starting line (enter - for default: 0) |
| nl | number of lines to copy (enter - for default: to end of file) |
| swap | swap data (enter - for default)<br>0: normal (default)<br>1: swap real/imaginary part of complex data<br>2: swap left/right (near/far range) |
| header_lines | number of input file header lines (enter - for default: 0) |
| Output parameters | |
| SLC_out | selected SLC section (fcomplex or scomplex format) |
| SLC_par_out | ISP SLC parameter file of output SLC |
| SLC_interp | |
| <SLC-2> <SLC1_par> <SLC2_par> <OFF_par> <SLC-2R> <SLC2R_par> [loff] [nlines] | |
| Input parameters | |
| SLC-2 | SLC-2 image to be resampled to the geometry of the SLC-1 reference image |
| SLC1_par | SLC-1 ISP image parameter file |
| SLC2_par | SLC-2 ISP image parameter file |
| OFF_par | ISP offset/interferogram parameter file |
| loff | offset to first valid output line (in SLC-1 lines) (default = 0) |
| nlines | number of valid output lines (default = 0: to end of file) |
| Output parameters | |
| SLC-2R | single-look complex image 2 co-registered to SLC-1 |
| SLC2R_par | SLC-2R ISP image parameter file for co-registered image |
| SLC_intf | |
| <SLC-1> <SLC-2R> <SLC1_par> <SLC2R_par> <OFF_par> <interf> <rlks> <azlks> [loff] [nlines] [sps_flg] [azf_flg] | |
| Input parameters | |
| SLC-1 | single-look complex image 1 (reference) |
| SLC-2R | single-look complex image 2 co-registered to SLC-1 |

| | |
|---|---|
| SLC1_par | SLC-1 ISP image parameter file |
| SLC2R_par | SLC-2R ISP image parameter file for the co-registered image |
| OFF_par | ISP offset/interferogram parameter file |
| rlks | number of range looks |
| azlks | number of azimuth looks |
| loff | offset to starting line relative to SLC-1 for interferogram (default = 0) |
| nlines | number of SLC lines to process (enter - for default: to end of file) |
| sps_flg | range spectral shift flag:<br>1: apply spectral shift filter (default)<br>0: do not apply spectral shift filter |
| azf_flg | azimuth common band filter flag:<br>1: apply azimuth common band filter (default)<br>0: do not apply azimuth common band filter |
| Output parameter | |
| interf | interferogram from SLC-1 and SLC-2R |
| SLC_par_pt | |
| <SLC_par> <pSLC_par> <SLC_rec_num> <rw_flag> | |
| Input parameters | |
| SLC_par | SLC/MLI parameter file (enter - for output to std out) |
| SLC_rec_num | record number in the stack of SLC/MLI image parameters (starts with 1) |
| rw_flag | read/write flag (0: read from pSLC_par, 1: write to pSLC_par) |
| Output parameters | |
| pSLC_par | stack of SLC/MLI parameter files (binary) |
| SLC_resamp_all_cs | |
| <SLC_tab> <ref_SLC> <ref_par> <rslc_dir> <RSLC_tab> <mode> [rflag] [rlks] [azlks] [rpos] [azpos] | |
| Input parameters | |
| SLC_tab | two column list of SLC filenames and SLC parameter filenames (including paths) (ascii) |
| ref_SLC | reference SLC (including path) |
| ref_par | ISP image parameter file of the reference SLC (including path) |
| rslc_dir | directory to receive the resampled SLC and ISP image parameter files |
| mode | processing mode |
| rflag | measure offsets to the resampled SLC to confirm the offset model (default = 0:off, 1: on) |
| rlks | number of range looks for initial offset estimation (enter - for default) |
| azlks | number of azimuth looks for initial offset estimation (enter - for default) |
| rpos | center of patch in range (samples) (enter - for default: image center) |
| azpos | center of patch in azimuth (lines) (enter - for default: image center) |
| Output parameters | |
| RSLC_tab | RSLC_tab file for the resampled SLC files |
| SLC2pt | |

| | |
|---|---|
| <SLC_tab> <plist> <pmask> <pSLC_par> <pSLC> <SLC_rec_num> | |
| Input parameters | |
| SLC_tab | two column list of SLC filenames and SLC parameter filenames (including paths) (ascii) |
| plist | point list (enter - for none) (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| Output parameters | |
| pSLC_par | stack of SLC/MLI parameters for the resampled SLC data (enter - for none) (binary) |
| pSLC | point data stack of interpolated SLC values (enter - for none) (fcomplex or scomplex) |
| SLC_rec_num | record number in the output point data stack (starting with 1, default: - for all) |
| log | not specified, automatically created |
| sp_stat | |
| <SLC> <pwr> <cc> <MSR> <plist> <width> [PWR_min] [CC_min] [MSR_min] [rlks] [azlks] [roff] [loff] [nr] [nl] [bx] [by] [type] | |
| Input parameters | |
| SLC | SLC file (fcomplex or scomplex) |
| width | number of samples/row of the SLC data |
| PWR_min | intensity minimum threshold to accept a point (0.0 to ignore, default - : 10.0) |
| CC_min | spectral correlation minimum threshold to accept a point (0.0 to ignore, default - : 0.4) |
| MSR_min | mean/sigma ratio minimum threshold (relative to spatial average) to accept a point (0.0 to ignore, default - : 1.2) |
| rlks | number of range looks to use (default - : 4) |
| azlks | number of azimuth looks to use (default - : 4) |
| roff | offset to starting range of section to analyze (default - : 0) |
| loff | offset to starting line of section to analyze (default - : 0) |
| nr | number of range pixels to analyze (default - : to end of line) |
| nl | number of azimuth lines to analyze (default - : to end of file) |
| bx | window width in SLC pixels used for spectral statistics (default - : rlks) |
| by | window number of SLC lines used for spectral statistics (default - : azlks) |
| type | SLC type (default = 0: fcomplex, 1: scomplex) |
| Output parameters | |
| pwr | intensity image (float, enter - for none) |
| cc | spectral correlation image (float, enter - for none) |
| MSR | mean/sigma ratio image (float, enter - for none) |
| plist | point list of point target candidates (int) |
| spf_pt | |
| <plist> <pmask> <SLC_par> <pdata_in> <pdata_out> [rec_num] [type] [r_max] [spf_type] [np_max] [pt_num] [mode] | |
| Input parameters | |
| plist | point list (int) |

| | |
|---|---|
| pmask | point data stack of mask values (uchar, enter - if not available) |
| SLC_par | SLC parameter file of point list coordinates |
| pdata_in | point data stack (various types supported) |
| rec_num | record number in pdata_in and pdata_out to process (default - : all records) |
| type | data type (0: fcomplex, 1: scomplex, 2: float, default - : float) |
| r_max | maximum radius (range samples, default: 64) |
| spf_type | spatial filter type<br>0: uniform average (default for fcomplex and scomplex)<br>1: triangular weighted average<br>2: linear least-squares (default for float data) |
| np_max | maximum number of neighbor points in the filter window<br>(default - : all points within search radius) |
| pt_num | point index for local filtering about a single point (first point = 0) |
| mode | processing mode (default = 0: spatial filtering, 1: reference point phase bias removal) |

<u>Output parameters</u>

| | |
|---|---|
| pdata_out | spatially filtered point data stack (same type as pdata_in) |

stacking

<diff_tab> <width> <ph_rate> <sig_ph_rate> <sig_ph> <roff> <loff> [nr] [nl] [np_min]

<u>Input parameters</u>

| | |
|---|---|
| diff_tab | 2 column list of unwrapped diff. interferograms and delta_T values in days (text) |
| width | number of samples/line of the interferograms in the stack |
| roff | range pixel offset to center of the phase reference region |
| loff | line offset to center of the phase reference region |
| nr | number of range pixels to average in the phase reference region<br>(enter - for default = 16) |
| nl | number of lines average in the phase reference region (enter - for default= 16) |
| np_min | min. number of phase values required to accept phase rate estimate<br>(enter - for default = nfiles) |

<u>Output parameters</u>

| | |
|---|---|
| ph_rate | average phase rate determined from a weighted sum of phases (radians/year, float) |
| sig_ph_rate | standard deviation of the estimated phase rate (radians/year, float) |
| sig_ph | standard deviation of the residual phases (enter - for none, radians, float) |

sub_phase

<int-1> <unw-2> <DIFF_par> <diff_int> <int-1_type> [sub/add_flag]

<u>Input parameters</u>

| | |
|---|---|
| int-1 | complex or unwrapped interferogram 1 file |
| unw-2 | unwrapped interferogram 2 file |
| DIFF_par | differential interferogram parameter file |
| int-1_type | int-1 type: 0 = unwrapped phase, 1 = complex interferogram |

| | |
|---|---|
| sub/add_flag | 0 = subtract phase of unw-2; 1 = add phase of unw-2 (default = 0) |
| Output parameters | |
| diff_int | differential interferogram output file |
| sub_phase_pt | |
| <plist> <pmask> <pint1> <rec_num> <punw2> <pdiff> <int_type> [inverse] | |
| Input parameters | |
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| pint1 | point data stack of interferograms (fcomplex or float) |
| rec_num | record number to process (default - : all records) |
| punw2 | point data stack of unwrapped phases (float) |
| int_type | data type of pint1 and pdiff |
| | 0: float (unwrapped phase) |
| | 1: fcomplex |
| inverse | subtract/add flag (default = 0: subtract punw2, 1: add punw2) |
| Output parameters | |
| pdiff | point data stack of differential interferograms |
| | (punw2 subtracted/added, same type as pint1) |
| swap_bytes | |
| <infile> <outfile> <swap_type> | |
| Input parameters | |
| infile | input data file |
| swap_type | swap type flag (bytes/value) |
| | 2: (1, 2, 3, 4, 5, 6, 7, 8 ...) --> (2, 1, 4, 3, 6, 5, 8, 7 ...) (short, scomplex) |
| | 4: (1, 2, 3, 4, 5, 6, 7, 8 ...) --> (4, 3, 2, 1, 8, 7, 6, 5 ...) (int, float, fcomplex) |
| | 8: (1, 2, 3, 4, 5, 6, 7, 8 ...) --> (8, 7, 6, 5, 4, 3, 2, 1 ...) (double) |
| Output parameters | |
| outfile | output data file |
| thres_im_pt | |
| <f_in> <width> <plist> <t_min> <t_max> <rlks> <azlks> | |
| Input parameters | |
| f_in | 2-D image data file (float) |
| width | number of samples/row of f_in |
| t_min | minimum threshold value (enter - for none) |
| t_max | maximum threshold value (enter - for none) |
| rlks | number of range looks in the sampled data geometry |
| azlks | number of azimuth looks in the sampled data geometry |
| Output parameters | |
| plist | point list of coordinates of all non-zero points (int) |

Note: It is recommended to try a few different thresholds in order to get a variety point densities. Save the according number of points.

unw_model

<interf> <unw_model> <unw> <width> [xinit] [yinit] [ref_ph]

Input parameters

| | |
|---|---|
| interf | interferogram (*.int, *.flt) (fcomplex) |
| unw_model | approximate unwrapped phase image ( = model, float) |
| width | number of samples/row |
| xinit | offset to phase reference location range pixel (col) |
| yinit | offset to phase reference location azimuth pixel (row) |
| ref_ph | reference phase to use other than value at (xinit, yinit) |

Output parameters

| | |
|---|---|
| unw | unwrapped phase (float) |

vu_disp

<plist> <pmask> <pSLC_par> <itab> <pdisp> <pdef> <phgt> <psigma> <pdef_err> <pdh_err> <pmap> <ras> [ymin] [ymax] [mag] [win_sz]

Input parameters

| | |
|---|---|
| plist | point list (int) |
| pmask | point data stack of mask values (uchar, set to - to accept all points) |
| pSLC_par | stack of SLC/MLI parameters (binary) |
| itab | table associating interferogram stack records with pairs of SLC (enter - for none) (ascii) |
| pdisp | displacement (m) for each point and each layer in the stack (float) |
| pdef | point data stack of linear deformation rate (m/year, float) |
| phgt | point data stack of height (m, float) |
| psigma | point data stack of phase standard deviation from fit (float) |
| pdh_err | estimated uncertainty in the height (m, float, enter - for none) |
| pdef_err | estimated uncertainty in linear deformation rate (m/year, float, enter - for none) |
| pmap | point positions in map projection coordinates (easting, northing or lat, lon) (enter - for none) (float) |
| ras | raster reference image with PT locations marked (SUN *.ras, or BMP *.bmp) |
| ymin | plot display minimum (enter - for default = -0.1) |
| ymax | plot display maximum (enter - for default = +0.1) |
| mag | zoom magnification factor (default = 2) |
| win_sz | zoom window size before magnification (default = 192) |

# Appendix G – List of Figures and Linked Files

Note: Does not include www links

## *2. Introduction*

**Figure 1:** Deformation_fig.pdf

**Figure 2:** Kapoho_fig.pdf

## *3. GAMMA Processing work flow for the Kapoho subsidence project*
README
html GAMMA manual

### *MSP – Modular SAR Processor*
Modular SAR Processor

### *MSP2 ASAR raw data preprocessing*
ASAR_pre_proc

### *MSP2.1 ASAR_pre_list*
*ASAR_pre_list*

### *MSP2.2 ASAR_pre_proc*
ASAR_proc_all
Mode 1 log
antenna
sensor parameter: SAR_par example
processing parameter: PROC_par example
raw
Mode 2 log
Mode 3 log
GAMMA manual
spectrum: text
Mode 4 log
Mode 5 log
ASAR_all_list

### *MSP3.1 Detect looks*

**Figure 3a:** Envisat_range_fig.pdf

**Figure 3b:** Envisat_range_fig.pdf

**Figure 4a:** SLC_MLI.pdf

**Figure 3c:** Envisat_range_fig.pdf

### *MSP3.2 ASAR_proc_all*
ASAR_proc_all_no_autof
rc_data

**Figure 4a:** SLC_MLI.pdf

MLI

MLI_PROC_par

**Figure 4b:** SLC_MLI.pdf

ISP image parameter
MLI ISP image parameter

### *ISP – Interferometric SAR processor – Resampling*

Interferometric SAR processor
ISP_README
SLC_tab

### *ISP1 Calculate baselines and generate itab file*

base_calc
itab: example
SLC_tab

### *ISP2 Reference scene: Selection-criteria and algorithms*

scenelocation.m

**Figure 5a, b:** Matlab_MLIs_fig.pdf

### *ISP3 Resample set of SLC to a common reference SLC*

SLC_resamp_all

### *ISP3.3 Generate raster image of RMLI*

**Figure 5c:** Matlab_MLIs_fig.pdf

### *ISP3.4 Resample SLC to reference RSLC*

RSLC_tab
SLC_resamp_all_cs
Mode 0 log
create_offset.in
Mode 1 log
Mode 2 log
Mode 3 log
Mode 4 log

### *ISP4 Create multi-look images for individual RSLC and calculate average MLI*

**Figure 5d:** Matlab_MLIs_fig.pdf

**Figure 5e:** Matlab_MLIs_fig.pdf

### *GEO – SAR geocoding and image registration*

SAR geocoding and image registration

### *GEO1 Type and location of raw DEM data*

meta
header
*.blw

### *GEO3 Byte order verification*

**Figure 6a:** DEM_EQA_UTM.pdf

### *GEO4 Conversion from EQA to UTM*
UTM DEM parameter file
mk_geo_cs

**Figure 6b:** DEM_EQA_UTM.pdf

**Figure 5e:** Matlab_MLIs_fig.pdf

### *GEO5 Transforming DEM map coordinates to RDC geometry*
mk_geo
Mode 0 log

**Figure 7a:** SIM_SAR_0_1.pdf

**Figure 8:** dis2ras_0.pdf

Mode 2 log
Mode 3 log
Mode 4 log

**Figure 9:** dis2ras_1.pdf

**Figure 10:** DEM_RDC_MLI.pdf

**Figure 30b:** PDEM_RDC.pdf

**Figure 11:** disras_dem_par_RMLI_MAP.pdf

### *ISP/DIFF – Interferograms and differential interferometry*
ISP
DIFF

### *ISP/DIFF1 Generate itab with all possible pair combinations*
itab_all

### *ISP/DIFF2 Generate differential interferograms*
mk_diff_2d
log
off_par.in

**Figure 12:** INT.pdf

diff_par.in

**Figure 13a, b:** TOPO_DIFF.pdf

**Figure 13c, d:** TOPO_DIFF.pdf

**Figure 14:** CC.pdf

### *ISP/DIFF4 Apply adf filter to the stack of differential interferograms*
log

**Figure 15:** ADF.pdf

### *ISP/DIFF5 Unwrap the differential interferograms*
log

**Figure 16a:** CC_MASK.pdf

**Figure 17:** INI_REF_BASELINES.pdf

### *ISP/DIFF6 Baseline refinement*

**Figure 18:** Baseline.pdf

mk_base_2d
mk_diff_2d_cs

### *ISP/DIFF6.1 Create mask*

**Figure 16b:** CC_MASK.pdf

### *ISP/DIFF6.2 Estimate improved baselines from unwrapped phase and DEM in RDC*

log
GCP
gcp_ph
baseline example

### *ISP/DIFF8 Stack the data*

diff_tab

### *ISP/DIFF9 Create displacement map in RDC*

**Figure 19:** Displacement_close.pdf

**Figure 20a:** DISPL_RDC_UTM.pdf

### *ISP/DIFF10 Geocode displacements to transform to UTM*

**Figure 21:** DISPL_UTM.pdf

**Figure 20b:** DISPL_RDC_UTM.pdf

**Figure 22:** DISPL_rasrmg.pdf

### *IPTA – Interferometric Point Target Analysis*

Interferometric Point Target Analysis
GAMMA IPTA Processing Example Luxemburg

### *IPTA1 Focus on smaller area of interest (optional)*

**Figure 23:** new_area.pdf

### *IPTA1.1 Crop the RSLC to desired region*

SLC_par_in
SLC_par_out

### *IPTA1.2 Create new RSLC_tab*

RSLC_tab GAMMA description
existing RSLC_tab (example)
RSLC_tab_kapoho

### *IPTA1.3 Generate new RMLI, average RMLI and parameter file*
parameter file

**Figure 24:** CROP_MLI_AVE.pdf

### *IPTA1.4 Crop DEM (MLI format) to desired region*
MLI_out_par

**Figure 25:** disras_DEM_RDC.pdf

### *IPTA2 Create IPTA interferogram table*
IPTA interferogram table GAMMA description
base_calc
itab_single: full standard output

### *IPTA3 Generate point list pt*
point list GAMMA description

### *IPTA3.1 Generation of point target candidate list based on spectral properties of individual SLC*
MLI_tab

### *IPTA3.2 Use spectral correlation average and different thresholds to create point list*

**Figure 27:** PT_CC.pdf

### *IPTA3.3 Generation of point target candidate list based on low intensity variability*
mk_msr_pt

**Figure 28:** PT_MSR.pdf

### *IPTA3.4 Merging of point target candidate lists to create the point list*
list

**Figure 29a:** MERGED_MASKED.pdf

### *IPTA3.5 Create a mask raster file*

**Figure 29a:** MERGED_MASKED.pdf

### *IPTA4 Generate pSLC_par and SLC point data stacks pSLC*
log

### *IPTA5.1 Generate DEM point data file pdem*

**Figure 30a:** PDEM_RDC.pdf

### *IPTA5.2.1 Create interferogram and baseline data stacks*
log
mk_int_all

### *IPTA5.2.2 Display the layers of pint*
log
**Figure 31:** PINT0.pdf

### *IPTA5.3.1 Simulate topographic phase and subtract it from interferogram*

log
mk_diff_all

### *IPTA5.3.2 Create raster images of the differential interferograms*

**Figure 32:** PDIFF0.pdf

### *IPTA6.1 Interactive point-wise phase regression analysis*

**Figure 33:** dis_ipta.pdf

### *IPTA6.2.1 Multi-patch estimation of linear deformation, height corrections and residual phase*

**Figure 34:** MULTI_DEF_PT1.pdf

prasdt_pwr24
pdisdt_pwr24

**Figure 35**: PRES1.pdf

**Figure 36:** PRES1_126.pdf

**Figure 37**: PUNW1.pdf

### *IPTA6.2.2 Estimation of linear deformation rate, height correction and residual phase over the entire scene*

itab_selection

**Figure 38:** DEF_MOD_PT.pdf

**Figure 39:** PRES2.pdf

**Figure 40:** PRES2_126.pdf

**Figure 35**: PRES1.pdf

**Figure 41:** PUNW2.pdf

### *IPTA8 Calculate updated differential interferograms*

mk_diff_all log
mk_2d_im log

**Figure 42:** PDIFF0.pdf

### *IPTA9 Regression analysis on updated differential interferograms*

**Figure 43:** MULTI_DEF_PT2.pdf

**Figure 44:** PRES1.pdf

**Figure 45:** PRES1_126.pdf

**Figure 46:** PUNW1.pdf

### *IPTA11.1 Estimate and apply atmospheric phase*

**Figure 47:** PRES1_SPF_25.pdf

**Figure 48**: PUNW1_NOATM.pdf

**Figure 49:** PUNW1_NOATM_SPF.pdf

## *IPTA11.3 Visualization of deformation histories*

**Figure 50:** vu_disp.pdf

## *References*

Caccamise
Delaney
Ferretti
Fiedler
Hannsen
Hooper
Li
Madson
Rosen
Wegmueller Luxemburg
Wegmueller GAMMA
Wegmueller Unwrapping
Werner
Wiesmann

## *Appendix C – Complimentary Information*

**Figure 51:** radar.pdf

## *Appendix D – Data availability and acquisition tools*

**Figure 52:** EoliSA.pdf

**Figure: 53:** Descw.pdf

**Figure 54:** winsar.pdf

**Figure 55:** PGF.pdf

## Appendix H – Processing Examples

The processing examples give command summaries for each chapter. Using the information throughout the according chapter as well as the example data on the provided CD (also available as zipped download) and assuming a UNIX system with GAMMA (version 20051219) installed, the user is bale to re-generate all files and images. Please also refer to the README for additional information.

**1) MSP**

```
ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_1.log
ASAR_all_list 1

ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_2.log
ASAR_all_list 2

ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_3.log
ASAR_all_list 3

ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_4.log
ASAR_all_list 4 doppler_polynomial "-150.3790 0. 0. 0."

ASAR_pre_proc ASAR_pre_list /mnt/scsi/DATA/DORIS/vor raw ASAR_pre_proc_5.log
ASAR_all_list 5

mkdir tmp
mkdir slc
mkdir mli_1_5

ASAR_proc_all_no_autof ASAR_all_list raw tmp slc mli_1_5 1 5 0

rasSLC slc/20030212.slc 5158 1 0 1 1 1. .5 1 0 0 slc/20030212.slc.ras
convert -scale 20% -quality 50 slc/20030212.slc.ras slc/20030212.slc.jpg
```

| **Generated Files** | **Compare to Figures** |
|---|---|
| slc/20030212.slc | 4a) SLC, 4b) MLI |

**2) ISP - Resampling**

```
mkdir rslc

SLC_copy slc/20041208.slc slc/20041208.slc.par rslc/20041208.rslc
rslc/20041208.rslc.par 1

mkdir rmli_1_5

multi_look rslc/20041208.rslc rslc/20041208.rslc.par rmli_1_5/20041208.rmli
rmli_1_5/20041208.rmli.par 1 5

raspwr rmli_1_5/20041208.rmli 5174

xv rmli_1_5/20041208.rmli.ras

SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 0
1 1 5

SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 1
1 1 5

SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 2
1 1 5

SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 3
1 1 5

offset_pwr rslc/20041208.rslc slc/20060308.slc rslc/20041208.rslc.par
slc/20060308.slc.par rslc/20041208_20060308.off rslc/20041208_20060308.offs
rslc/20041208_20060308.snr - - - 2 500 500

offset_fit rslc/20041208_20030212.offs rslc/20041208_20030212.snr
rslc/20041208_20030212.off rslc/20041208_20030212.coffs - 6.5 4 1

offset_fit rslc/20041208_20030702.offs rslc/20041208_20030702.snr
rslc/20041208_20030702.off rslc/20041208_20030702.coffs - 6.5 4 1
etc.

SLC_resamp_all_cs SLC_tab rslc/20041208.rslc rslc/20041208.rslc.par rslc RSLC_tab 4
1 1 5

mk_mli_all RSLC_tab rmli_1_5 1 5 1
cp rmli_1_5/20041208.rmli.par rmli_1_5/rmli_1_5.ave.par

dis2ras rmli_1_5/20030212.rmli.ras mli_1_5/20041208.mli.ras
```

| **Generated Files** | **Compare to Figures** |
|---|---|
| rmli_1_5/20041208.rmli | 5c) RMLI of reference scene |
| rmli_1_5/20030212.rmli | 5d) RMLI of a co-registered scene |
| rmli_1_5/rmli_1_5.ave | 5e) RMLI of average intensity image |

**3) GEO**

```
create_dem_par SRTM_BI_1arc_eqa.dem_par

swap_bytes SRTM_BI_1arc_eqa.dem SRTM_BI_1arc_eqa_swp.dem 2

disdem_par SRTM_BI_1arc_eqa_swp.dem SRTM_BI_1arc_eqa.dem_par

create_dem_par SRTM_BI_15m_utm.dem_par rmli_1_5/rmli_1_5.ave.par

dem_trans SRTM_BI_1arc_eqa.dem_par SRTM_BI_1arc_eqa_swp.dem SRTM_BI_15m_utm.dem_par
SRTM_BI_15m_utm.dem

disdem_par SRTM_BI_15m_utm.dem SRTM_BI_15m_utm.dem_par
gimp rmli_1_5/rmli_1_5.ave.ras

mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem
SRTM_BI_15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI
15 0 2 2 2 8 1 5 6.5 - - - - 256 256

mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem
SRTM_BI_15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI
15 2 2 2 2 8 1 5 6.5 - - - - 256 256

mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem
SRTM_BI_15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI
15 2 2 2 2 8 1 5 6.5 3000 3000 - - 256 256

mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem
SRTM_BI_15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI
15 3 2 2 2 8 1 5 6.5 - - - - 256 256

offset_fitm geo/BI.offs geo/BI.snr geo/BI.diff geo/BI.coffs - 6.5 4 1

mk_geo_cs rmli_1_5/rmli_1_5.ave rmli_1_5/rmli_1_5.ave.par SRTM_BI_15m_utm.dem
SRTM_BI_15m_utm.dem_par SRTM_BI_15m_utm_seg.dem SRTM_BI_15m_utm_seg.dem_par geo BI
15 4 2 2 2 8 1 5 6.5 - - - - 256 256
```

| Generated Files | Compare to Figures |
|---|---|
| SRTM_BI_1arc_eqa_swp.dem | 6a) DEM in EQA |
| SRTM_BI_15m_utm.dem | 6b) DEM in UTM |
| geo/BI_0.sim_rdc | 7a) Initial simulated SAR, 8a) dis2ras |
| geo/BI_1.sim_rdc | 7b) Refine simulated SAR, 9a) dis2ras |
| geo/BI_dem.rdc | 10a), 30b) DEM in RDC |
| geo/BI_map.mli | 11) RMLI in UTM |

**4) ISP/DIFF**

```
base_calc SLC_tab slc/20041208.slc.par 20041208.bperp.gr 20041208.bperp itab_all 1

mk_diff_2d RSLC_tab itab_all 0 geo/BI_dem.rdc - rmli_1_5/rmli_1_5.ave rmli_1_5
diff0_2d 1 5 3 1 0

xv diff0_2d/*.diff.ras&

base_calc SLC_tab slc/20041208.slc.par 20041208.bperp.gr 20041208.bperp itab 1 0
750 -
mk_adf_2d RSLC_tab itab rmli_1_5/rmli_1_5.ave diff0_2d 5 .3 32

mk_unw_2d RSLC_tab itab rmli_1_5/rmli_1_5.ave diff0_2d .4 2 1 1 1

rascc_mask diff0_2d/20030212_20030702.adf.cc rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1
.8 .3 1.0 1. .35 1 diff0_2d/20030212_20030702.adf.cc_mask.8.ras

gimp diff0_2d/20030212_20030702.adf.cc_mask.8.ras

mk_base_2d_cs RSLC_tab itab geo/BI_dem.rdc diff0_2d -
diff0_2d/20030212_20030702.adf.cc_mask.8.ras 128 128  5 1

cat diff0_2d/20030212_20030702.base


mkdir diff1_2d
cp diff0_2d/*.base diff1_2d/
mv diff0_2d/*.unw_int diff1_2d/
cp diff0_2d/*.off diff1_2d/
mv /mnt/scsi/PGFSAR/IPTA/2429_3213/diff0_2d/*adf.cc diff1_2d/

mk_diff_2d_cs RSLC_tab itab 1 geo/BI_dem.rdc - rmli_1_5/rmli_1_5.ave rmli_1_5
diff1_2d 1 5 3 1 0

dis2ras diff0_2d/20030212_20030702.adf.unw1.ras
diff1_2d/20030212_20030702.adf.diff_unw1.ras &

stacking diff_tab 5174 ph_rate sig_ph_rate sig_ph 2041 2413 - - -

dispmap ph_rate - slc/20041208.slc.par diff1_2d/20051228_20060308.off ph_rate_disp

dishgt ph_rate_disp rmli_1_5/rmli_1_5.ave 5174 1 1 0 0.01 1 .35

rashgt ph_rate_disp rmli_1_5/rmli_1_5.ave 5174 1 1 0 1 1 .01 1. .35 -1
ph_rate_disp.ras

geocode_back ph_rate_disp 5174 geo/BI_1.map_to_rdc ph_rate_disp.utm 8334 0 0 0

geocode_back rmli_1_5/rmli_1_5.ave 5174 geo/BI_1.map_to_rdc geo/BI_map.mli 8334
7825 1 0

geocode_back diff1_2d/20031119_20040303.adf.cc 5174 geo/BI_1.map_to_rdc disp.cc
8334 7825 1 0

dishgt  ph_rate_disp.utm geo/BI_map.mli 8334 1 1 0 0.01 1 .35
```

```
rashgt  ph_rate_disp.utm geo/BI_map.mli 8334 1 1 0 1 1 .01 1. .35    1
ph_rate_disp.utm.ras

rasrmg  ph_rate_disp.utm geo/BI_map.mli 8334 1 1 0 1 1 670 1. .35  0 1
ph_rate_disp.utm1.ras disp.cc 1 .2


gimp ph_rate_disp.utm1.ras

convert -crop 5040x4460+60+240 ph_rate_disp.ras ph_rate_disp.jpg
convert -scale 70% -quality 60 ph_rate_disp.jpg ph_rate_disp.jpg

convert -crop 4900x6060+0+440 ph_rate_disp.utm1.ras ph_rate_disp.utm1.jpg
convert -scale 70% -quality 60 ph_rate_disp.utm1.jpg ph_rate_disp.utm2.jpg
```

| **Generated Files** | **Compare to Figures** |
|---|---|
| diff0_2d_1_5/20030212_20030702.int | 12) Interferogram |
| diff0_2d_1_5/20030212_20030702.sim_unw | 13a,b) Simulated topography |
| diff0_2d_1_5/20030212_20030702.diff | 13c,d) Differential interferogram |
| diff0_2d_1_5/20030212_20030702.cc | 14) Interferometric correlation |
| diff0_2d_1_5/20030212_20030702.adf.diff | 15c,d) Filtered differential interferogram |
| diff0_2d_1_5/20030212_20030702.adf.cc_mask | 16a) Coherence (CC) mask |
| diff0_2d_1_5/20030212_20030702.adf.unw | 17a,b) Unwrapped differential interferogram |
| diff0_2d_1_5/20030212_20030702.adf.cc_mask8 | 16b) CC mask with very high threshold |
| diff1_2d_1_5/20030212_20030702.diff_unw | 17c,d) Refined unwrapped differential interferogram |
| ph_rate_disp | 19) Displacement in RDC (dishgt),<br>20a)Displacement in RDC (rashgt) |
| ph_rate_disp.utm | 21) Displacement in UTM (dishgt),<br>20b)Displacement in UTM (rashgt),<br>22) Displacement in UTM (rasrmg) |

**5) IPTA**

```
SLC_copy rslc/20030212.rslc rslc/20030212.rslc.par rslc_kapoho/20030212.rslc
rslc_kapoho/20030212.rslc.par 1 - 1912 500 11500 2600

SLC_copy rslc/20030702.rslc rslc/20030702.rslc.par rslc_kapoho/20030702.rslc
rslc_kapoho/20030702.rslc.par 1 - 1912 500 11500 2600

etc.

mk_mli_all RSLC_tab_kapoho rmli_1_5_kapoho 1 5 1

cp rmli_1_5_kapoho/20041208.rmli.par rmli_1_5_kapoho/rmli_1_5.ave.par

MLI_copy geo/BI_dem.rdc rmli_1_5/rmli_1_5.ave.par geo/BI_dem_kapoho.rdc
geo/BI_dem_kapoho.rdc.par 1912 500 11500 2600

rasshd geo/BI_dem_kapoho.rdc 500 15 15 1 0 1 1

disras geo/BI_dem_kapoho.rdc.ras&

base_calc RSLC_tab_kapoho rslc_kapoho/20041208.rslc.par 20041208.bperp.gr
20041208.bperp itab_single 0

mk_sp_all RSLC_tab_kapoho sp 4 4 0.5 0.4 1.2

thres_im_pt sp/ave.sp_cc 500 sp/pt_cc_318 0.318 - 1 1
ras_pt sp/pt_cc_318 - rmli_1_5_kapoho/rmli_1_5.ave.ras sp/pt_cc_318.ras 1 5

thres_im_pt sp/ave.sp_cc 500 sp/pt_cc_35 0.35 - 1 1
ras_pt sp/pt_cc_35 - rmli_1_5_kapoho/rmli_1_5.ave.ras sp/pt_cc_35.ras 1 5

thres_im_pt sp/ave.sp_cc 500 sp/pt_cc_3 0.3 - 1 1
ras_pt sp/pt_cc_3 - rmli_1_5_kapoho/rmli_1_5.ave.ras sp/pt_cc_3.ras 1 5

mk_msr_pt RSLC_tab_kapoho rslc_kapoho/20041208.rslc.par
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave.ras msr .5 2 1.5 1
1.2 10 .1

ls -1 sp/pt_cc_318 msr/pt_1.7 > plist_tab

merge_pt plist_tab pt_merged 1 0 0

ras_pt pt - rmli_1_5_kapoho/rmli_1_5.ave.ras pt_merged.ras 1 5 255 0 0 3

xv pt.ras

msk_pt pt_merged - rmli_1_5_kapoho/mask.ras pt_masked pmask 1 5

cp pt_merged pt_nomask
mv pt_masked pt

ras_pt pt - rmli_1_5_kapoho/rmli_1_5.ave.ras pt.ras 1 5

xv pt.ras
```

```
SLC2pt RSLC_tab_kapoho pt - pSLC_par pSLC -

SLC_par_pt rslc_kapoho/20060308.rslc.par pSLC_par 21 1
data2pt rslc_kapoho/20060308.rslc rslc_kapoho/20060308.rslc.par pt
rslc_kapoho/20060308.rslc.par pSLC 21 0

data2pt geo_kapoho/BI_dem.rdc rmli_1_5_kapoho/rmli_1_5.ave.par pt
rslc_kapoho/20041208.rslc.par pdem 1 2

data2pt geo/BI_dem_kapoho.rdc geo/BI_dem_kapoho.rdc.par pt
rslc_kapoho/20041208.rslc.par pdem2 1 2

pdisdt_pwr24 pt - rslc_kapoho/20041208.rslc.par pdem  1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 256. 1

pdisdt_pwr24 pt - rslc_kapoho/20041208.rslc.par pdem2 1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 256. 1

mk_int_all pt - pSLC_par itab_single pSLC pbase pint mk_int_all.log

mk_2d_im pt - itab_single rslc_kapoho/20041208.rslc.par pint 1 -
rmli_1_5_kapoho/rmli_1_5.ave.par 0 3 1.2 1 int0 rmli_1_5_kapoho/rmli_1_5.ave - 0

xv int0/*ras

mk_diff_all pt - pSLC_par itab_single pbase 0 pint 1 pdem2 - - psim_unw0 pdiff0
mk_diff_all0.log

mk_2d_im pt - itab_single rslc_kapoho/20041208.rslc.par pdiff0 1 -
rmli_1_5_kapoho/rmli_1_5.ave.par 0 3 1.2 1 diff0 rmli_1_5_kapoho/rmli_1_5.ave - 0

xv diff0/*ras

cp pdiff0 pdiff0_no_phgt
cp -r diff0 diff0_no_phgt

dis_ipta pt - pSLC_par - itab_single pbase 0 pdiff0 1 diff0/pdiff0_008.ras 30 0.01
2 - - 3 128

Choose this pt as reference

ref.:23558   x:104  y:1502  point:13003  x:149   y:  714

mkdir multi_def_pt1

multi_def_pt pt - pSLC_par - itab_single pbase 0 pdiff0 1 23558 multi_def_pt1/pres1
multi_def_pt1/pdh1 multi_def_pt1/pddef1 multi_def_pt1/punw1 multi_def_pt1/psigma1
multi_def_pt1/pmask1 30. 0.01 70 1.2 1.0 2 0 -1 -1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/pdh1    1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 30.0 1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/pddef1  1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.01 1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/punw1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
```

```
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/psigma1 1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 1.5  1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/pres1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par multi_def_pt1/pres1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 2.5 1

take out 2,3,7,12

mkdir def_mod_pt

def_mod_pt  pt multi_def_pt1/pmask1 pSLC_par - itab_selection pbase 0
multi_def_pt1/punw1 0 23558 def_mod_pt/pres2 def_mod_pt/pdh2 def_mod_pt/pddef2
def_mod_pt/punw2 def_mod_pt/psigma2 def_mod_pt/pmask2 25. 0.03 3.0 2 - - -

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/pdh2    1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 30.0 1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/pddef2  1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.01 1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/punw2   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/psigma2 1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 1.5  1

prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/pres2   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1
prasdt_pwr24 pt multi_def_pt1/pmask1 rslc/20040303.rslc.par def_mod_pt/pres2   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 2.5 1

lin_comb_pt pt def_mod_pt/pmask2 pdem2 1 def_mod_pt/pdh2 1 phgt1 1 -0. 1. 1. 2 0

cp def_mod_pt/pddef2 pdef1

mk_diff_all pt def_mod_pt/pmask2 pSLC_par itab_single pbase 0 pint 1 phgt1 pdef1 -
def_mod_pt/psim_unw0 def_mod_pt/pdiff0 def_mod_pt/mk_diff_all0.log

mk_2d_im pt def_mod_pt/pmask2 itab_single rslc_kapoho/20041208.rslc.par
def_mod_pt/pdiff0 1 - rmli_1_5_kapoho/rmli_1_5.ave.par 0 3 1.2 1 def_mod_pt/diff0
rmli_1_5_kapoho/rmli_1_5.ave - 0

mkdir multi_def_pt2

multi_def_pt pt def_mod_pt/pmask2 pSLC_par - itab_single pbase 0 def_mod_pt/pdiff0
1 23558 multi_def_pt2/pres1 multi_def_pt2/pdh1 multi_def_pt2/pddef1
multi_def_pt2/punw1 multi_def_pt2/psigma1 multi_def_pt2/pmask1 3. 0.003 70 1.3 0.9
2 1 -1 -1

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/pdh1    1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 30.0 1

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/pddef1  1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.01 1
```

```
prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/punw1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/psigma1 1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 1.5  1

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/pres1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 12.6 1

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20040303.rslc.par multi_def_pt2/pres1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 2.5 1

spf_pt pt multi_def_pt2/pmask1 rslc/20041208.rslc.par multi_def_pt2/pres1
atm/pres1_spf_10_1 - 2 10 1 -

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20041208.rslc.par atm/pres1_spf_10_1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 4 1

spf_pt pt multi_def_pt2/pmask1 rslc/20041208.rslc.par multi_def_pt2/pres1
atm/pres1_spf_25_1 - 2 25 1 -

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20041208.rslc.par atm/pres1_spf_25_1   -
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 4 1

cp atm/pres1_spf_25_1 atm/patm1

lin_comb_pt pt multi_def_pt2/pmask1 atm/patm1 - atm/patm1 14 atm/patm1x - 0. 1. -1.
2 1

sub_phase_pt pt multi_def_pt2/pmask1 multi_def_pt2/punw1 - atm/patm1x
multi_def_pt2/punw1_noatm 0 0

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20041208.rslc.par
multi_def_pt2/punw1_noatm   - rmli_1_5_kapoho/rmli_1_5.ave.par
rmli_1_5_kapoho/rmli_1_5.ave 12.6 1

spf_pt pt multi_def_pt2/pmask1 rslc/20041208.rslc.par multi_def_pt2/punw1_noatm
multi_def_pt2/punw1_noatm_spf - 2 25 0 - 23558 0

prasdt_pwr24 pt multi_def_pt2/pmask1 rslc/20041208.rslc.par
multi_def_pt2/punw1_noatm_spf  - rmli_1_5_kapoho/rmli_1_5.ave.par
rmli_1_5_kapoho/rmli_1_5.ave 12.6 1

mkdir def_mod_pt2

def_mod_pt  pt multi_def_pt2/pmask1 pSLC_par - itab_single pbase 0
multi_def_pt2/punw1_noatm_spf 0 23558 def_mod_pt2/pres2 def_mod_pt2/pdh2
def_mod_pt2/pddef2 def_mod_pt2/punw2 def_mod_pt2/psigma2 def_mod_pt2/pmask2 25.
0.03 2.0 2 def_mod_pt2/pdh_err2a def_mod_pt2/pdef_err2a def_mod_pt2/ppc_err2a

prasdt_pwr24 pt def_mod_pt2/pmask2 rslc_kapoho/20041208.rslc.par
def_mod_pt2/psigma2 1 rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave
1.5  1

lin_comb_pt pt def_mod_pt2/pmask2 phgt1 1 def_mod_pt2/pdh2 1 phgt2 1 -0. 1. 1. 2 0

lin_comb_pt pt def_mod_pt2/pmask2 pdef1 1 def_mod_pt2/pddef2 1 pdef2 1 -0. 1. 1. 2
0
```

```
phase_sim_pt pt def_mod_pt2/pmask2 pSLC_par - itab_single - pbase - ptmp1 pdef2 1 0

lin_comb_pt pt def_mod_pt2/pmask2 ptmp1 - def_mod_pt2/pres2 - pdef_phase1 - 0.0 1.
1. 2 1

dispmap_pt pt  def_mod_pt2/pmask2 pSLC_par itab_single pdef_phase1 phgt2 pdisp1 0

prasdt_pwr24  pt  def_mod_pt2/pmask2 rslc_kapoho/20041208.rslc.par pdisp1 1
rmli_1_5_kapoho/rmli_1_5.ave.par rmli_1_5_kapoho/rmli_1_5.ave 0.05 0

vu_disp  pt  def_mod_pt2/pmask2 pSLC_par  itab_single pdisp1 pdef2  phgt2
def_mod_pt2/psigma2 def_mod_pt2/pdh_err2a def_mod_pt2/pdef_err2a - pdisp1.ras
```

| **Generated Files** | **Compare to Figures** |
|---|---|
| rmli_1_5_kapoho/20040812.rmli | 24a) Cropped RMLI of reference scene |
| rmli_1_5_kapoho/rmli_1_5.ave | 24b) Cropped RMLI of average intensity image |
| geo/BI_dem_kapoho.rdc | 25) Cropped DEM in RDC |
| sp/pt_cc_* | 27) Spectral correlation point locations |
| msr/pt_* | 28) Intensity variability point locations |
| pt | 29a) Merged points |
| pt_masked | 29b) Masked points |
| pdem2 | 30a) Point heights |
| pint | 31) Point interferograms |
| pdiff0 | 32) Point differential interferograms |
| multi_def_pt1 (pdh1,pddef1,psigma1) | 34) Results from 1st multi-patch regression analysis |
| multi_def_pt1 (pres1) | 35,36) Residual phases |
| multi_def_pt1 (punw1) | 37) Unwrapped phases |
| def_mod_pt (pdh2,pddef2,psigma2) | 38) Results from 1st single-patch regression analysis (correct unw) |
| def_mod_pt (pres2) | 39,40) Residual phases |
| def_mod_pt (punw2) | 41) Unwrapped phases |
| def_mod_pt/pdiff0 | 42) Updated differential interferograms |
| multi_def_pt2 (pdh1,pddef1,psigma1) | 43) Results from 2nd multi-patch regression analysis |
| multi_def_pt2 (pres1) | 44,45) Residual phases |
| multi_def_pt2 (punw1) | 46) Unwrapped phases |
| atm/pres1_spf_25_1 | 47) Filtered residual phase (atmosphere) |
| multi_def_pt2/punw1_noatm | 48) Atmosphere w/o auto-interferogram |
| multi_def_pt2/punw1_noatm_spf | 49) Noise-free atmosphere |
| pdisp1 | 50) Deformation time series |