
# DLR's Airborne SAR System

## F-SAR PRODUCT DESCRIPTION

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## General

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**Revision Control**

| Version | Rev. | Date | Pages | Changes | Status |
|---|---|---|---|---|---|
| 2 | 3 | 2013-06-15 | all | First version released | Draft |
| 2 | 4 | 2013-08-01 | 19 | Description of Mosaic Products | Draft |
| 2 | 5 | 2014-12-01 | all | Circular SAR products | Draft |
| 2 | 6 | 2015-06-09 | all | CSAR and HoloSAR products | Draft |
| 2 | 7 | 2015-10-19 | 8,13,<br>29-30 | Pauli basis quicklooks;<br>Specific change detection product components<br>Specific ice sounding product files | Draft |
| 2 | 8 | 2016-06-02 | all | Various changes to improve consistency, added a short explanation relating to binary data formats used, updated the mosaic product description. | Draft |
| 2 | 9 | 2016-10-18 | 5,8,14,16,32 | Added appendix concerning radiometric calibration. Updated INF product definition. Updated GTC-LUT component definition to include polynomial coefficient matrices for "3D Geocoding" | Draft |
| 2 | 10 | 2016-11-25 | 27-29 | Product components for HoloSAR mode updated | Draft |
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| 3 | 0 | 2017-08-16 | 31 | Added remark regarding geocoded change detection results. | Draft |
| 3 | 0 | 2018-03-01 | 17 | Corrected the units of the vertical wavenumber (kz). | Draft |
| 3 | 1 | 2019-07-12 | 34 | Added description of the range-compressed-raw product | Draft |
| 3 | 2 | 2019-11-28 | 7,31-38 | Added description of the auxiliary data, in particular antenna and calibration related information. | Draft |
| 3 | 2 | 2020-03-19 | 9,10 | Added GPS week second row to real and reference tracks | Draft |

## CONTENTS

# 1 Introduction

## 1.1 Purpose

This document presents the structure of F-SAR data products. The structure is also reflected in the archive DIMS (Data Ingestion and Management System) of the German Remote Sensing Data Ceter, where F-SAR data are stored. Except for RAW products all product types can be accessed by the Users via the eoweb- interface (www.eoweb.de) after registration as dedicated F-SAR User and proper configuration of ordering properties.

## 1.2 Structure of the Document

Section 2 lists the available F-SAR products and describes the overall product structure.

Section 3 lists the individual file content for each product's subdirectory.

## 1.3 Binary data formats

F-SAR data products include binary data primarily in the RAT format, which is described in detail in . A source package of Python 3 code for reading RAT files, including the meta-data in the file header, and parsing the XML documents used to store parameters is available online: www.dlr.de/hr/f-sar/data-formats.

In addition, most RAT files are accompanied by .hdr files, which allow the data to be opened in ENVI. The widely used GDAL software library also supports the ENVI format, such that these data can also be opened using free alternatives such as QGis. All of these programs then support export to various other file formats, such as GeoTiff.

For geocoded data (primarily in the GTC product), the hdr file also specifies the parameters of the geographic grid used.

# 2 Product Structure

RAW: Radar Raw Data

| | |
|---|---|
| RAW-PRIM | (internal use only) |
| RAW-NAV | (internal use only) |
| RAW-QL | (internal use only) |
| RAW-AUX | (internal use only) |

RGI: Products in radar geometry (slant range)

| | |
|---|---|
| RGI-SR | (Slant range data) |
| RGI-TRACK | (Sensor position and attitude angles) |
| RGI-RDP | (Processing parameters) |
| RGI-QL | (Quicklooks) |
| RGI-AUX | (internal use only) |

GTC: Geocoded products

| | |
|---|---|
| GTC-IMG | (Geocoded radar data) |
| GTC-DEM | (DSM generated from interferometric processing) |
| GTC-LUT | (Lookup tables for geocoding) |
| GTC-RDP | (Processing parameters) |
| GTC-QL | (Quicklooks) |
| GTC-AUX | (internal use only) |

INF: Interferometric products

| | |
|---|---|
| INF-SR | (Slant range data) |
| INF-TRACK | (Sensor positions) |
| INF-RDP | (Processing parameters) |
| INF-QL | (Quicklooks) |
| INF-AUX | (internal use only) |

Mosaic products

| | |
|---|---|
| GTC-IMG | (Geocoded radar data) |
| GTC-RDP | (Processing parameters) |
| GTC-QL | (Quicklooks) |

# 3 Contents of Individual Product Directories

## 3.1 RAW Product

**RAW-PRIM**

| | |
|---|---|
| raw*.dat | SAR raw data after transcription (proprietary binary format with range line header, no rat format) |
| gh*.xml | global header |
| ch*.xml | channel header |

**RAW-NAV**

| | |
|---|---|
| nav*.xml | navigation data with sampling of the GPS/IMU Systems (e.g. 0.02s). Parameter: sequence counter, GPS second, geogr. latitude, geogr. longitude, height above ellipsoid, speed component in north, speed component in east, vertical speed component, roll angle, pitch angle, heading |
| nav_bin*.bin | same as xml, but in binary format (avoids truncation of float values) |

**RAW-QL**

| | |
|---|---|
| qls*.png | Quicklooks in slant range geometry |
| ns*.png | Navigation Screening:. height above ellipsoid, geogr. latitude, geogr. longitude, vertical speed component, speed component in east, speed component in north, heading, , pitch angle, roll angle |
| ra*.png | Radar Screening: Doppler Centroid over range, range intensity profile, incidence angle along range, azimuth spectrum, range spectrum, radar samples histogram |

**RAW-AUX**

| | |
|---|---|
| ant*.xml | antenna information: [ antenna name, Tx or Rx channel coding, polarisation, look direction, elevation pattern filename, azimut pattern filename, 3D pattern filename, elevation pattern, azimuth pattern, elevation angle, azimuth angle, antenna gain, depression angle, azimuth offset angle, leverarm X, leverarm Y, leverarm Z, leverarm correction dX, leverarm correction dY, leverarm correction dZ, delay to antenna (one structure for Tx and one for Rx) |
| bp*.xml | bounding polygon of the recorded data |
| cal*.xml | calibration data |
| d* | Dynamic data file (old F-SAR proprietary format) |
| d*.sav | Dynamic data file |
| d*.txt | Dynamic data file |
| fsar_transcription*log | Log-files of the transcription |
| rep*.xml | Chirp Replica: chirp duration, modulation rate, sampling rate, Chirp length, chirp start frequency, time delay internal, time delay external, chirp data |
| rep_bin*.bin | binary chirp Replica (same internal format) |

## 3.2 RGI Product

**RGI-SR**

| | |
|---|---|
| amp_*.rat +.hdr | amplitude slant range SAR data, Gamma-0 corrected using the local incidence angle (see ) |
| incidence_*.rat + .hdr | local incidence angle map |
| mask_*.rat + .hdr | mask indicating valid samples in the slant-range imagery |
| slc_*.rat +.hdr | single-look complex slant range SAR data, Beta-0 corrected (see ) |
| pol_full_*.png | full resolution PolSAR colour composite in lexicographic basis (optional) |

| Channel | Polarisation |
|---|---|
| Red | VV |
| Green | HV/VH |
| Blue | HH |

pauli_full_*.png — full resolution PolSAR colour composite in Pauli basis (optional)

| Channel | Polarisation |
|---|---|
| Red | HH - VV |
| Green | HV/VH |
| Blue | HH + VV |

**RGI-TRACK**

Track information is saved at the full resolution. The length of the tracks may therefore be greater than the dimensions of the SLC in azimuth depending on the azimuth presuming carried out during processing (see processing parameter *pre_az* in **RGI-RDP** below).

attit_*.rat — aircraft attitude sampled equidistant in time

| Row | Description | Units |
|---|---|---|
| 0 | Time | [GPS week seconds] |
| 1 | Pitch | [radians] |
| 2 | Roll | [radians] |
| 3 | Heading | [radians] |

attit_resa_*.rat — aircraft attitude resampled equidistant in space (see **attit**)

fixpoint_*.rat — coordinate of origin of local and SAR coordinate systems

| Element | Description | Units |
|---|---|---|
| 0 | Longitude | [degrees] |
| 1 | Latitude | [degrees] |
| 2 | Height over WGS84 | [m] |

reftr_loc_ *.rat — reference track in local coordinates, resampled equidistant in time

| Row | Description | Units |
|---|---|---|
| 0 | Time | [GPS week seconds] |
| 1 | + towards the east | [m] |
| 2 | + towards the north | [m] |
| 3 | + upwards | [m] |

reftr_loc_resa_*.rat — reference track in local coordinates, resampled equidistant in space (see **reftr_loc**)

reftr_sar_*.rat — reference track in SAR coordinates, sampled equidistant in time

| Row | Description | Units |
|---|---|---|
| 0 | Time | [GPS week seconds] |
| 1 | + In flight direction | [m] |
| 2 | + to the left | [m] |
| 3 | + upwards | [m] |

reftr_sar_resa_*.rat — reference track in SAR coordinates, resampled equidistant in space (see **reftr_sar**)

reftr_xyz_resa_*.rat — reference track in WGS84 Cartesian coordinates, resampled equidistant in space

| Row | Description | Units |
|---|---|---|
| 0 | Time | [GPS week seconds] |
| 1 | X | [m] |
| 2 | Y | [m] |
| 3 | Z | [m] |

track_loc_*.rat — real track in local coordinates, sampled equidistant in time (see **reftr_loc)**

track_loc_resa_*.rat — real track in local coordinates, resampled equidistant in space (see **reftr_loc_resa**)

track_sar_*.rat — real track in SAR coordinates, sampled equidistant in time (see **reftr_sar**)

track_sar_resa_*.rat — real track in SAR coordinates, resampled equidistant in space (see **reftr_sar_resa**)

track_xyz_resa_*.rat — real track in WGS84 cartesian coordinates, resampled equidistant in space (see **reftr_xyz_resa**)

**RGI-RDP**

pp_*.xml — processing parameters

step.xsl — xml style file to display XML parameters in a tabular format (see example below)

| Parameter | Value | Units | Remark |
|---|---|---|---|
| **Processor** | STEP-trunk | string | The name of the processor |
| **Build** | 4091 | string | The processor build (SVN version) |
| **Ident** | OP16BF0412 | string | Campaign,flight and pass of the channel |
| **Coding** | T1X1H0_R2X1H0 | string | Coding of the channel transmit and receive paths |
| **Site** | Kaufbeuren | string | Site of the image acquisition |
| **Date** | 23-Jun-2016 13:29:50 | date | Date and time of the acquisition (DD/MM/YYYY) |
| **time_stamp** | 368890190 | 1 | F-SAR RTC time |
| **Band** | X | string | Frequency Band (S/X/L etc.) |
| **polarisation** | HH | string | Transmit and receive polarisation (H or V for each) |
| **Campaign** | 16op16bf | string | Name of the campaign |
| **Flight** | 04 | string | Flight (sensor continuously airborne) |
| **Pass** | 12 | string | Pass (individual acquisition) |
| **prockernel** | EOK | string | The name of the processing kernel used for image formation (EOK,FFBP etc.) |
| **Azbins** | 83160 | 1 | The number of azimuth bins in the raw data |
| **Rgbins** | 28160 | 1 | The number of range bins in the raw data |
| **Prf** | 1201.9231 | Hz | Pulse repetition frequency |
| **Cd** | 1.0016000e-05 | s | Chirp Duration |
| **Rd** | 1.6864000e-05 | s | Range Delay |
| **Rsf** | 1.0000000e+09 | Hz | Range sampling frequency |
| **c0** | 2.9971190e+08 | m/s | Speed of light in air |
| **v0** | 91.148202 | m/s | Sensor velocity |
| **f0** | 9.6000000e+09 | Hz | Centre Frequency |

| | | | |
|---|---|---|---|
| **Lambda** | 0.031219990 | m | Wavelength |
| **Squint** | -1.5077326 | deg | Processed squint angle |
| **Heading** | 91.164020 | deg | Sensor heading |
| **Antdir** | 1 | 1 | Antenna pointing direction (-1/1 for left/right) |
| **h0** | 3047.7072 | m | Sensor altitude |
| **terrain** | 779.59671 | m | Average terrain height |
| **cbw** | 7.6000000e+08 | Hz | Chirp bandwidth |
| **abw** | 233.54506 | Hz | Processed azimuth bandwidth |
| **res_az** | 0.50000000 | m | Processed azimuth resolution |
| **res_rg** | 0.25261143 | m | Processed range resolution |
| **res_az_ml** | 0.50000000 | m | Multi-looked azimuth resolution |
| **res_rg_ml** | 0.50000000 | m | Multi-looked range resolution |
| **looks_az** | 1 | 1 | Number of looks in azimuth after multi-looking |
| **looks_rg** | 1 | 1 | Number of looks in range after multi-looking |
| **ps_az** | 0.30334121 | m | Pixel spacing in azimuth |
| **ps_rg** | 0.14985595 | m | Pixel spacing in range |
| **sub_az** | 1 | 1 | Sub-sampling in azimuth |
| **sub_rg** | 1 | 1 | Sub-sampling in range |
| **sub_az_ml** | 2 | 1 | Sub-sampling in azimuth after multi-looking |
| **sub_rg_ml** | 1 | 1 | Sub-sampling in range after multi-looking |
| **pre_az** | 4 | 1 | Presumming in azimuth |
| **alpha** | [0.540000,0.540000] | 1 | Vector of hanning alpha parameters for spectral weighting in [azimuth,range] |
| **alpha_ml** | [0.540000,0.540000] | 1 | Vector of hanning alpha parameters for spectral weighting in [azimuth,range] in multi-looking |
| **R** | Pointer | m | Vector of one-way range distances for the columns of the slant range image |
| **rref** | 3618.0471 | m | Reference range for processing (ECS only) |
| **nrx** | 46080 | 1 | Number of pixels in azimuth for the processed image |
| **nry** | 14560 | 1 | Number of pixels in range for the processed image |
| **nrx_part** | [15233,61312] | 1 | The [start,end] of the scene in azimuth (if only part of the scene was processed) |
| **nrx_part_to** | [15165,61244] | samples | Part of date processed, with respect to the non-resampled track |
| **nry_part** | [5456,20015] | 1 | The [start,end] of the scene in range (if only part of the scene was processed) |
| **nry_pad** | 24576 | 1 | The number of pixels in range, padded for processing speed |
| **rb_first** | 0 | 1 | The column index of the first valid range bin |
| **rb_last** | 14559 | 1 | The column index of the last valid range bin |
| **calib_type** | 0 | 1 | The type of calibration carried out (-1: none, 0: beta0 (ECS), 1: beta0, 2: sigma0, 3: gamma0, 4: gamma0 w/o DEM slope) |
| **rfi_thresh** | 0.0000000 | 1 | Threshold for RFI filtering (0 deactivates filtering) |
| **topo_moco** | 2 | 1 | The type of topography compensation during processing (0: none, 1: ECS moco, 2: ECS with SATA) |
| **highsquint** | 0 | 1 | Flag to indicate that this data has has exceptionally high squint: Enables high-fidelity MoCo |
| **ang_range** | [15.000000,90.000000] | deg | Range of valid off-nadir angles in the processed image: [min angle, max angle] in degrees. |

Structure **geo_poly**

The bounding polygon of the valid pixels in the processed image. Given in pixels and Longitude/Latitude/Height. Geographic coordinates are with respect to the WGS84 ellipsoid.

| Parameter | Value | Units | Remark |
|---|---|---|---|
| **Pixels** | [0.0000000,167.00000, 14559.000,311.00000, 14559.000,11208.000, 0.0000000,11352.000] | pixels | Pixel coordinates of the valid samples in the processed image: [x1,y1,...,x4,y4]. |
| **Lonlat** | [10.593800,47.873338,795.46507, | Geographic | The geographic coordinates |

| | | | |
|---|---|---|---|
| | 10.592819,47.846476,793.71590, 10.636977,47.846148,738.46193, 10.639179,47.874019,727.46173] | coordinates | corresponding to the points in 'pixels': [lon1,lat1,heigh1,...,lon4,lat4,height4] where 'lon' and 'lat' denote 'longitude' and 'latitude', respectively. |
| **sounder_mode** | 0 | 1 | 1 indicates that this data set was acquired in nadir-looking geometry |

**RGI-QL**

| | |
|---|---|
| amp_full_*.png | high resolution amplitude slant range image (optional) |
| amp_pres_*.png | presummed amplitude slant range quicklooks |
| attitude_*.png | plots of the sensor attitudes |
| pol_pres_*.png | presummed PolSAR colour composite in lexicographic basis (see **pol_full** in **RGI-SR**) |
| pauli_pres_*.png | presummed PolSAR colour composite in Pauli basis (see **pauli_full** in **RGI-SR**) |
| track_*.png | plots of the real and reference tracks in black and red, respectively |

**RGI-AUX** (for internal use only)

| | |
|---|---|
| adc_cal*.txt | ADC Offset und Phase (optional) |
| ant1d_*.sav | 1D antenna diagrams in elevation and azimuth |
| ant2d_*.sav | 2D antenna pattern (elevation and azimuth) for central frequency |
| ant3d_*.sav + .png | 3D antenna pattern (squint,off-nadir,frequency) |
| ant3d_pha_cent* .png | 3D antenna phase center |
| cal*.rat + .txt | The radiometric correction applied for calibration (presummed) |
| calib_pres_*.png | 2D quicklook of the radiometric calibration correction |
| moco1_*.rat | applied first order motion compensation |
| moco1_resa_*.rat | applied first order motion compensation (resampled equidistant in space) |
| offnadir_*.rat + .hdr | Off-Nadir angle for each pixel of the SLC [radians] |
| pol_nesz_*.rat + .png | 2D image of estimated NESZ values (presummed) |
| pol_nesz_vec_*.rat | 1D vector of NESZ values as a function of off-nadir angle |
| pol_profile_*.png | HH/HV/VH/VV intensities as a function of range and co-/cross-pol phase differences |
| replica_*.rat +.png | Chirp replica |
| replica_*.rat + .png | Quicklook of the chirp replica |
| slantdem_*.rat | DEM in slant range geometry |
| tc_vector_*.rat | vector to transform from beam-center to zero Doppler geometry |
| tiepoint_eval*.png | Tiepoint evaluation plots |
| tiepoints_*.sav | Tiepoint coordinates, orientation, image positions and evaluated performance |
| *.log | log-files of the processing |
| *.pbs | pbs-files of the processing |

## 3.3 GTC Product

As indicated by the ENVI hdr files provided, the layout of binary geocoded data on disk follows the GeoTiff convention. When binary geocoded data or lookup tables are read directly from disk (i.e. without using proper GIS software/libraries), it is therefore important to note that:

- The *last* row of data corresponds to the *minimum* northing coordinate and the northing increases towards the first row.
- The *first* column corresponds to the *minimum* easting coordinate and easting increases towards the last column.

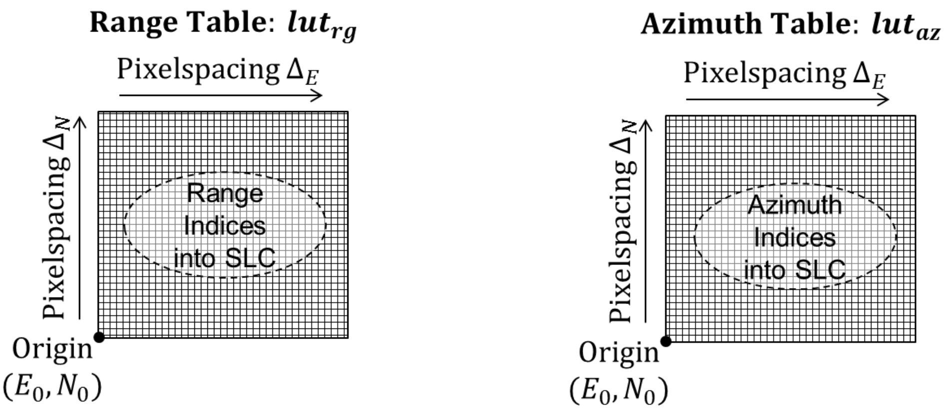
**GTC-IMG**

| | |
|---|---|
| ampgeo_*.rat +.hdr | geocoded amplitudes (see ) |
| maskgeo_*.rat +.hdr | geocoded binary valid sample mask |
| incidencegeo_*.rat +.hdr | geocoded local incidence angle |
| mlookgeo_*.rat +.hdr | geocoded multilooked amplitude |
| mlookgeo_*.png | high resolution geocoded multi-look image (optional) |

**GTC-DEM**

| | |
|---|---|
| demgeo_*.rat +.hdr | geocoded DSM from InSAR processing ([m] over the WGS84 Ellipsoid) |
| hemgeo_*.rat +.hdr | geocoded height error map ([m], height standard deviation) |

**GTC-LUT**




UTM Coordinate $(E, N) \rightarrow$ Slant range $(rg, az)$:

$$rg = lut_{rg}\left[\frac{E-E_0}{\Delta_E}, \frac{N-N_0}{\Delta_N}\right]$$

$$az = lut_{az}\left[\frac{E-E_0}{\Delta_E}, \frac{N-N_0}{\Delta_N}\right]$$

| | |
|---|---|
| sr2geo_az_*.rat +.hdr | geocoded azimuth index into the SLC, denoted $lut_{az}$ in the example above (UTM grid, see ENVI .hdr file for projection parameters) |
| sr2geo_rg_*.rat +.hdr | geocoded range index into the SLC, denoted $lut_{rg}$ in the example above (UTM grid, see ENVI .hdr file for projection parameters) |
| sr2latlon_az_*.rat +.hdr | geocoded azimuth index into the SLC (Lat/Lon grid, see ENVI .hdr file for projection parameters) |
| sr2latlon_rg_*.rat +.hdr | geocoded range index into the SLC (Lat/Lon grid, see ENVI .hdr file for projection parameters) |

**GTC-LUT: Optional files for "3D Geocoding"**

| | |
|---|---|
| sr2geo3d_rg_o[12] *.rat +.hdr | polynomial coefficients for updating the range lookup table to reflect a different DEM height |
| sr2geo3d_az_o[12] *.rat +.hdr | polynomial coefficients for updating the azimuth lookup table to reflect a different DEM height |
| sr2geo3d_h0*.rat +.hdr | ellipsoidal heights used to compute the original lookup tables in sr2geo*rat |

These files are provided to allow users to geocode data onto arbitrary DEMs by computing corrections to the lookup tables held in the sr2geo*rat files. All of the files above contain 2D matrices defined on the same geographic grid as the lookup tables and other geocoded data.

The sr2geo3d_h0*rat file holds the input DEM heights used for geocoding. The range and azimuth lookup tables for a height offset $\delta_h$ relative to this DEM can be obtained from the coefficient matrices as follows:

$$sr2 \geq o_{rg}^{new} = sr2 \geq o_{rg} + \delta_h sr2geo3d_{rg}^{o1} + (\delta_h)^2 sr2geo3d_{rg}^{o2}$$

$$sr2 \geq o_{az}^{new} = sr2 \geq o_{az} + \delta_h sr2geo3d_{az}^{o1} + (\delta_h)^2 sr2geo3d_{az}^{o2}$$

Computing lookup tables for a given absolute ellipsoidal height $h_{new}$ is accomplished by defining

$$\delta_h = h_{new} - sr2geo3d_{h0}$$

**GTC-RDP**

| | |
|---|---|
| pp_*.xml | RGI processing parameters (see **RGI-RDP**) |
| ppgeo_*.xml | geocoding processing parameters |
| step.xsl | xml style file to display XML parameters in a tabular format (see example below) |

| Parameter | Value | Units | Remark |
|---|---|---|---|
| **processor** | STEP-trunk | string | The name of the processor |
| **build** | 4325:4338M | string | The processor build (SVN version) |
| **ident** | AFRISR0812 | string | Campaign,flight and pass of the channel |
| **coding** | T1P1H0_R5P1H0 | string | Coding of the channel transmit and receive paths |
| **site** | Nkok | string | Site of the image acquisition |
| **date** | 12-Feb-2016 10:35:59 | date | Date and time of the acquisition (DD/MM/YYYY) |
| **band** | P | string | Frequency Band (S/X/L etc.) |
| **polarisation** | HH | string | Transmit and receive polarisation (H or V for each) |
| **campaign** | 16afrisr | string | Name of the campaign |
| **flight** | 08 | string | Flight (sensor continuously airborne) |
| **pass** | 12 | string | Pass (individual acquisition) |
| **prockernel** | BACKGEOCODING | string | The processing kernel used |
| **utm_step_east** | 2.0000000 | m | UTM grid sampling east |
| **utm_step_north** | 2.0000000 | m | UTM grid sampling north |
| **utm_file** | … | string | DEM file used as input |
| **ellipsoid** | WGS84 | string | The ellipsoid used for geocoding (default WGS84) |
| **ell_major_axis** | 6378137.0 | m | ellipsoid major axis |
| **ell_minor_axis** | 6356752.3 | m | ellipsoid minor axis |
| **long0_scl** | 0.99960000 | 1 | Scaling factor at central meridian |
| **long0_step** | 6 | deg | difference of central meridians of adjacent UTM zones |
| **flag_datum_change_track** | 0 | 1 | flag to perform datum shift for reference track |
| **track_ax** | 0.0000000 | m | translation in X-axis |
| **track_ay** | 0.0000000 | m | translation in Y-axis |
| **track_az** | 0.0000000 | m | translation in Z-axis |
| **track_rx** | 0.0000000 | rad | rotation around X-axis |
| **track_ry** | 0.0000000 | rad | rotation around Y-axis |

| | | | |
|---|---|---|---|
| **track_rz** | 0.0000000 | rad | rotation around Z-axis |
| **track_scale** | 1.0000000 | 1 | scaling factor |
| **flag_presum** | 0 | 1 | flag to perform presumming/averaging to adjust resolution to UTM grid |
| **file2geocode** | Pointer | string | Array of slant range files to be geocoded |

**GTC-QL**

| | |
|---|---|
| ampgeo_*.png + .kml | geocoded amplitude quicklooks (.kml for Google Earth display) |
| polgeo_pres_*.png + .kml | geocoded PolSAR colour composite (.kml for Google Earth display) |
| demgeo_*.png + .kml | quicklook of DEM from interferometric processing (optional) |

## 3.4 INF Product

**INF-SR**

| | |
|---|---|
| coh_*.rat +.hdr | interferometric coherence |
| kz_*.rat | vertical wavenumber [rad/m] |
| pha *.rat +.hdr | residual or *flattened* interferometric phase (after flat earth and DEM compensation) |
| pha_dem_*.rat +.hdr | the phase that needs to be subtracted from the master – slave interferogram to *flatten* it (i.e. to remove the flat earth and topographic phase components) |
| slc_coreg_*.rat +.hdr | slave SLC image (see **RGI-SR**), coregistered to master geometry |

**INF-SR: Optional files (output during InSAR DEM generation)**

| | |
|---|---|
| insardem_*.rat +.hdr | DEM from InSAR processing (slant-range) |
| pha_cal_*.rat +.hdr | interferometric phase after baseline calibration |
| pha_uw_*.rat +.hdr | unwrapped Phase (optional) |

**INF-TRACK**

| | |
|---|---|
| *track*.rat | slave tracks in master coordinate system (see **RGI-TRACK** in section 3.2) |
| baseline_error_*.rat | residual baseline errors estimated during interferometric processing, stored in a three dimensional array [n_iterations, track_length, axis]. The total estimated residual baseline error is given by summing over the first axis. The result is in the SAR coordinate system (see SAR tracks in **RGI-TRACK** of section 3.2) |

**INF-RDP**

| | |
|---|---|
| pp_*.xml | processing parameters of master SLC |
| ppinsar_*.xml | parameters for InSAR processing |
| step.xsl | xml style file to display XML parameters in a tabular format (see example below) |

| Parameter | Value | Units | Remark |
|---|---|---|---|
| **processor** | STEP-trunk | string | The name of the processor |
| **build** | 4325:4338M | string | The processor build (SVN version) |
| **ident** | AFRISR0812 | string | Campaign,flight and pass of the channel |
| **coding** | T1P1V0_R6P1V0 | string | Coding of the channel transmit and receive paths |
| **site** | Nkok | string | Site of the image acquisition |
| **date** | 12-Feb-2016 10:35:59 | date | Date and time of the acquisition (DD/MM/YYYY) |
| **band** | P | string | Frequency Band (S/X/L etc.) |
| **polarisation** | VV | string | Transmit and receive polarisation (H or V for each) |
| **master_campaign** | 16afrisr | string | campaign name of the master pass |
| **master_flight** | 01 | string | flight ID of the master pass |
| **master_pass** | 07 | string | pass ID of the master pass |
| **prockernel** | FUSAR | string | The processing kernel used |
| **baseline** | [0.347289,62.3161,0.00000] | m | Baseline [horizontal,vertical] |
| **topo** | 1 | 1 | Take into account the slant-range-DEM in InSAR Processing |
| **coreg** | 2 | 1 | Coregistration mode. 1: geometry w/o DEM; 2: geometry with DEM; 3: geometry+offset from data |
| **rgfilter** | 0 | 1 | Perform spectral range filtering; 0: no filter; 1: band-pass; 2: range adaptive |
| **phasetype** | 3 | 1 | Type of phase computed.1: unmodified; 2: flat-earth removed; 3: DEM removed (residual) |
| **presumming** | [1,1] | 1 | Presumming factor in [range,azimuth] for coherence and phase |
| **complexcoh** | 0 | 1 | Derive phase from complex coherence (otherwise only presumming, no filter) |
| **cohalgo** | 1 | 1 | Type of coherence filter. 0: moving average; 1: Gauss |
| **kz** | 2 | 1 | Compute KZ; 0: do not compute; 1: with flat-earth; 2: with |

| | | | |
|---|---|---|---|
| | | | topography |
| **uwalgo** | 0 | 1 | Unwrapping algorithm. 0: no phase unwrapping; 1: region growing; 2: SNAPHU; 3: graph-cuts |
| **bcalalgo** | 0 | 1 | Type of baseline calibration. 0: do not calibrate; 1: with reflectors; 2: with reference DEM; 3: from data (SD) |
| **p2halgo** | 0 | 1 | Phase to height conversion. 0: no phase 2 height; 1: 2D using KZ; 2: 3D Newton |
| Structure **ms** | | | |
| Parameters for residual baseline error estimation | | | |
| Structure **geogrid** | | | |
| Parameters for InSAR DEM geocoding (see ppgeo in GTC-RDP) | | | |

**INF-QL**

| | |
|---|---|
| baseline_*.png | plot of the real interferometric baseline |
| baseline_error*.png | plot of the estimated (and corrected) residual baseline error |
| coh _*.png | presummed coherence quicklook |
| pha _*.png | quicklook of the residual phase (after subtracting flat earth and DEM) |

**INF-QL: Optional files (output during InSAR DEM generation)**

| | |
|---|---|
| insardem_*.rat +.hdr | DEM from InSAR processing (slant-range) |
| pha_cal_*.rat +.hdr | interferometric phase after baseline calibration |
| pha_uw_*.rat +.hdr | unwrapped Phase (optional) |
| insardem_*.png | the corrections applied to the input DEM by interferometric processing |
| kz_*.png | quicklook of the vertical wavenumber |
| pha_uw_*.png | quicklook of the unwrapped interferometric phase |

**INF-AUX** (for internal use only)

| | |
|---|---|
| INSAR_*.log | log-file of Insar-processing |
| INSAR_*.pbs | pbs-File of insar-processing |
| tiepoint_bcal_*.png | evaluation of the baseline calibration using tiepoints (e.g. corner reflectors) |
| tiepoint_height_*.png | tiepoint height error |

## 3.5 Mosaic Product

Mosaic products are generated by combining several GTC products and follow the conventions of standard GTC product (see section **GTC** above) with following omissions:

- There are no lookup tables (GTC-LUT) since there is no slant range product in this case
- Only geocoded amplitudes (gamma-0 corrected) and a valid sample mask are provided

## 3.6 Circular SAR (CSAR) Product

The CSAR products are obtained by focusing a SLC in the (x,y) plane, using a DEM or assuming a flat topography, and with an imaging grid having a pixel spacing of approximately lambda/4. The SLC is focused with the time-domain Fast Factorized Back-Projection (FFBP) by adding coherently the energy of a single circular track. Among others the products contain an analysis of the IRF (if available), a fully-polarimetric image decomposed in the Pauli basis, a GIF animation of subaperture images (10 degrees coherent integration and overlap of 80%), and a GIF animation of subaperture images (10 degrees coherent integration) by adding their intensity.

The products are included in the GTC directory's subfolders, as follows:

**GTC-IMG**

| | |
|---|---|
| incoherent_*.gif + .png | Animation of the geocoded incoherent intensity using incremental subapertures of 10 degrees (one file for every polarimetric channel). The amplitude of the final image is provided as png. |
| maskgeo_*.rat + .png | Geocoded binary valid sample mask. |
| polgeo_full_*.png | Geocoded PolSAR colour composite at the highest resolution grid in the Pauli basis. |
| slcgeo_*.rat + .hdr | Single-look complex and geocoded image with subwavelength sampling. |
| subaperture_*.gif | Animation of the geocoded intensities of subapertures of 10 degrees (80% overlap, one file for every polarimetric channel). |

**GTC-QL**

| | |
|---|---|
| ampgeo_pres_*.png(.kml) | Geocoded amplitude quicklook (one file per channel; .kml for Google Earth display). |
| polgeo_press_*.png(.kml) | Geocoded PolSAR colour composite in the Pauli basis (.kml for Google Earth display). |
| specgeo_*.png | Spectrum of the geocoded SLC in the (kx, ky) plane. |

**GTC-RDP**

| | |
|---|---|
| step.xsl | xml style file. |
| ppgeo_csar_*.xml | Geocoding processing parameters per channel. |

| Parameter | Value | Units | Remark |
|---|---|---|---|
| **Processor** | STEP-trunk | string | The name of the processor |
| **Build** | 2264:2265M | string | The processor build (SVN version) |
| **Ident** | TDXSIM0104 | string | Campaign, flight and pass of the channel |
| **Coding** | T1X3V0_R2X1H0 | string | Coding of the channel transmit and receive paths |
| **Site** | Kaufbeuren | string | Site of the image acquisition |
| **Date** | 11/19/2009 10:31 | date | Date and time of the acquisition (DD/MM/YYYY) |
| **time_stamp** | 156940279 | ? | F-SAR RTC time |
| **Band** | X | string | Frequency |
| **Polarisation** | HH | string | Transmit and receive polarisation (H or V for each) |
| **Campaign** | 09tdxsim | string | Name of the campaign |
| **flight** | 1 | string | Flight (sensor continuously airborne) ??? |
| **pass** | 4 | string | Pass (individual acquisition) |
| **prockernel** | CSAR-FFBP | string | The processing kernel used (FFBP, Capon, CS, Music) |
| **azbins** | 219094 | 1 | The number of azimuth bins in the raw data |
| **rgbins** | 11008 | 1 | The number of range bins in the raw data |
| **prf** | 200.1 | Hz | Pulse repetition frequency |
| **cd** | 5.12E-06 | s | Chirp Duration |
| **rd** | 1.44E-05 | s | Range Delay |
| **idi** | 3.11E-07 | s | Internal Delay Intern (measured in the laboratory) |

| | | | |
|---|---|---|---|
| **ide** | 0 | s | Legacy parameter; unused (see cal_dt parameter) |
| **rsf** | 5.00E+08 | Hz | Range sampling frequency |
| **c0** | 3.00E+08 | m/s | Speed of light in air |
| **v0** | 85.814305 | m/s | Sensor velocity |
| **f0** | 9.60E+09 | Hz | Central Frequency |
| **lambda** | 0.031219558 | m | Wavelength |
| **antdir** | -1 | 1 | Antenna pointing direction (-1/1 for left/right) |
| **h0** | 2497.47 | m | Sensor altitude |
| **terrain** | 35.378059 | m | Average terrain height |
| **cbw** | 3.00E+08 | Hz | Chirp bandwidth |
| **abw** | 1832.8445 | Hz | Processed azimuth bandwidth |
| **cf1** | 3.95E+08 | Hz | Chirp start frequency |
| **cf2** | 95000000 | Hz | Chirp end frequency |
| **sub_az** | 1 | 1 | Sub-sampling in azimuth |
| **sub_rg** | 1 | 1 | Sub-sampling in range |
| **alpha** | [0.5400,0.5400] | 1 | Vector of hanning alpha parameters for spectral weighting in [azimuth, range] |
| **alpha_ml** | [0.5400,0.5400] | 1 | Vector of hanning alpha parameters for spectral weighting in [azimuth, range] in multi-looking |
| **cr** | 5.86E13 | Hz/s | Chirp rate |
| **rs** | 0.29970776 | m | Range sample spacing |
| **r** | Pointer | m | Vector of one-way range distances corresponding to the raw data |
| **rref** | 3811.983 | m | Reference range for processing (ECS only) |
| **da** | 0 | deg | Antenna depression angle |
| **nrx** | 218112 | 1 | Number of pixels in azimuth (subsampled raw data) |
| **nry** | 11008 | 1 | Number of pixels in range (subsampled raw data) |
| **nry_pad** | 16384 | 1 | The number of pixels in range (subsampled raw data), padded for processing speed |
| **rb_first** | 1450 | 1 | The column index of the first valid range bin |
| **rb_last** | 9556 | 1 | The column index of the last valid range bin |
| **ch_shift** | 0.000248 | s | Time offset with respect to the first receiving channel |
| **cal_dphi** | 0 | rad | Phase correction, measured from calibration targets |
| **cal_damp** | 0 | dB | Intensity correction factor, measured from calibration targets |
| **cal_dt** | 3.00E-08 | s | Range delay correction, measured from calibration targets |
| **calib_type** | 0 | 1 | Type of calibration: (-1:none, 1:beta0, 2:sigma0, 3:gamma0, 4:gamma0 w/o DEM slope) |
| **rfi_thresh** | 0 | 1 | Threshold for RFI filtering (0 deactivates filtering) |
| **aarc** | 0 | 1 | Adaptive antenna response correction flag |
| **mode** | csar or holosar | string | Non-linear modes CSAR or HoloSAR |
| **interpMode** | knab or cubic | string | Type of interpolation (knab is the most accurate and fast) |
| **fullres** | true | flag | 1:coherent integration of the full circular aperture |
| **angInt** | 10 | 1 | Along-track angular integration |
| **topo** | true | flag | 1:consider topography in the focusing |
| **rotMode** | 1 | 1 | Depending on the number, it indicates the quadrant number with which the function starts to count the circles |
| **master** | 0 | 0 | Master circle (HoloSAR) |
| **ntracks** | 0 | 0 | Total number of circles (HoloSAR) |
| **tracks** | Pointer | 1 | Range of circles to be combined (HoloSAR), [c_min,c_max] |
| **max_norm_bl** | 1 | m | Maximum perpendicular baseline (HoloSAR) |
| **min_norm_bl** | 1 | m | Minimum perpendicular baseline (HoloSAR) |
| **crit_bl** | [gr, z] | m | Critical baseline (HoloSAR) in [gr,z] |
| **cov_looks** | [az,rg] | 1 | Covariance matrix size [az, rg] |
| **res_xyz** | [res_x,res_y,res_z] | m | Resolution in x, y and z directions |
| **res_ar** | [res_az,res_rg] | m | Resolution in azimuth and range (subaperture processing) |
| **res_el** | 1 | m | Resolution in elevation (subaperture processing) |
| **res_xyz_ml** | [res_x,res_y,res_z] | m | Multilook resolution in x, y and z (amplitude image) |

| | | | |
|---|---|---|---|
| **res_ar_ml** | [res_az, res_rg] | m | Multilook resolution in azimuth and range (subaperture processing) |
| **looks_xyz** | [l_x, l_y, l_z] | 1 | Looks in x, y and z |
| **looks_ar** | [l_az, l_rg] | 1 | Looks in azimuth and range (subaperture processing) |
| **ps_xyz** | [ps_x, ps_y, ps_z] | m | Final pixel spacing in x, y, z |
| **ps_ar** | [ps_az, ps_rg] | m | Final pixel spacing in azimuth and range |
| **ps_el** | 1 | m | Final pixel spacing in elevation |
| | | | |
| **Structure geo_poly** | | | |
| See section 3.2 | | | |
| | | | |
| **Structure geoGrid** | | | |
| See section 3.4 | | | |
| | | | |

**GTC-AUX** (internal use only)

| | |
|---|---|
| amploc_* _ncalib.png | Amplitude of the non-calibrated SLC in local coordinates and per channel. |
| ant1d_*.sav | 1D antenna diagrams in elevation and azimuth. |
| ant2d_*.sav | 2D antenna pattern (elevation and azimuth) for central frequency. |
| ant3d_*.sav + .png | 3D antenna pattern (squint, off-nadir, frequency). |
| attit_*.rat + .png | Real aircraft attitude per channel (see **attit** in **RGI-TRACK**). |
| attit_3D_*.png | 3-D plots of the aircraft attitude. |
| cal_map_loc_*.rat | Complex radiometric correction of the full spotlighted region and applied for calibration (presumed). |
| cal_map_loc_* _phase.png(.kml) | 2-D plot of the calibration phase correction (.kml for Google Earth display). |
| cal_map_loc_* _intdB.png(.kml) | 2-D plot of the calibration intensity correction (.kml for Google Earth display). |
| cal_mask_loc_*.rat | Binary valid sample mask of the full spotlighted region (decimated). |
| cal_mask_loc_*.png | 2-D plot of the binary valid sample mask. |
| demloc_x_*.rat | Imaging grid in the x direction in local coordinates. |
| demloc_y_*.rat | Imaging grid in the y direction in local coordinates. |
| demloc_z_*.rat | Imaging grid in the z direction in local coordinates. |

error_LOS_*_<reflector_name>_<iteration>.rat and .png

PGA estimation error in the line of sight (LOS) for a given reference target. This file saves the estimates independently for each reflector name and iteration number.

| **Row** | **Description** | **Units** |
|---|---|---|
| 0 | Error in the LOS | [meters] |

error_LOS_*.rat — Final error estimate in the LOS. The error is corrected in the range-compressed data by constant shifts along range direction and corresponding phase correction.

error_ sxyz_*_<reflector_name>_<iteration>.rat + .png

PGA estimate of the error in cartesian coordinates (x,y,z). The array contains the horizontal (s) and vertical (z) components for the linear inversion, in order to estimate the x and y components (one file for each reference target and each iteration). Not available, if less than 2 reference targets present.

| **Row** | **Description** | **Units** |
|---|---|---|
| 0 | Error in the horizontal direction | [meters] |
| 1 | Error in x | [meters] |
| 2 | Error in y | [meters] |

| | | |
|---|---|---|
| 3 | Error in z | [meters] |

error_ sxyz_*.rat — Final error estimate in the (x,y,z) space. The error is corrected directly in the track data and before image formation. Not available, if less than 2 reference targets present.

fixpoint_*.rat — Coordinate of origin of the local and SAR coordinate systems per channel (see **fixpoint** in **RGI-TRACK**).

irfloc_*_ncalib_2d.png — 2-D amplitude of the reference targets in local coordinates (one file per channel).
irfloc_*_ncalib_1d.png — 1-D profiles of the reference targets in local coordinates (one file per channel).

*.log / *.pbs — log and pbs-files of the processing

pol_profile_*.png — HH/HV/VH/VV intensities, co- and cross-pol phase differences (averaged profiles as a function of easting), 2D estimate of HH-VV phase and coherence.

pol_profile_phase_*.rat — Co- and cross-polar phase and coherence profiles along easting

| Row | Description | Units |
|---|---|---|
| 0 | Not used | |
| 1 | Not used | |
| 2 | Co-polar HH/VV phase profile | [rad] |
| 3 | Cross-polar HV/VH phase profile | [rad] |
| 4 | Co-polar HH/VV coherence profile | [-] |
| 5 | Cross-polar HV/VH coherence profile | [-] |

pol_profile_inten_*.rat — Intensity profiles along easting of all polarisations

| Row | Description | Units |
|---|---|---|
| 0 | Easting vector in local coordinates | [m] |
| 1 | Co-polar HH/VV phase profile | [rad] |
| 2 | Cross-polar HV/VH phase profile | [rad] |
| 3 | Co-polar HH/VV coherence profile | [-] |
| 4 | VV intensity profile | [-] |

replica_*.rat + .png — Chirp replica and quicklook of the replica .
slcloc_*_ncalib.rat — Non-calibrated SLC in local coordinates (one file per channel).

specloc_*_ncalib.png — Amplitude of spectrum of the non-radiometric calibrated SLC in the (kx, ky) plane (one file per channel).

tiepoints_*.png — Plots of the reference targets in local coordinates.

track_loc_*.rat — Real track in local coordinates (see **reftr_loc** in **RGI-TRACK**).
track_loc_*.png — Plots of the ideal and real tracks in black and red, respectively, and in local coordinates.
track_loc_3D_*.png — 3-D real track visualisation in local coordinates.
envelope_*.png — Envelope indicating where to start counting the circular track. There are four modes, depending on the quadrant.

GTC-LUT and GTC-DEM folders are not needed and empty.

**Intermediate products in slant-range (polar coordinates)**

The products are described by SS: sub-aperture number.

**INF-SR** (internal use only)

| | |
|---|---|
| slcpol_* _s<SS>.rat | SLC in polar coordinates (radiometrically calibrated). |
| amppol_*s<SS>.png | Amplitude of the SLC in polar coordinates (radiometrically calibrated). |
| specpol_*_ s<SS>.png | Spectrum of the SLC in polar coordinates (radiometrically calibrated). |

**INF-AUX** (internal use only)

| | |
|---|---|
| gridpol_*_ s<SS>.rat | 2D polar coordinates (r, alpha). |

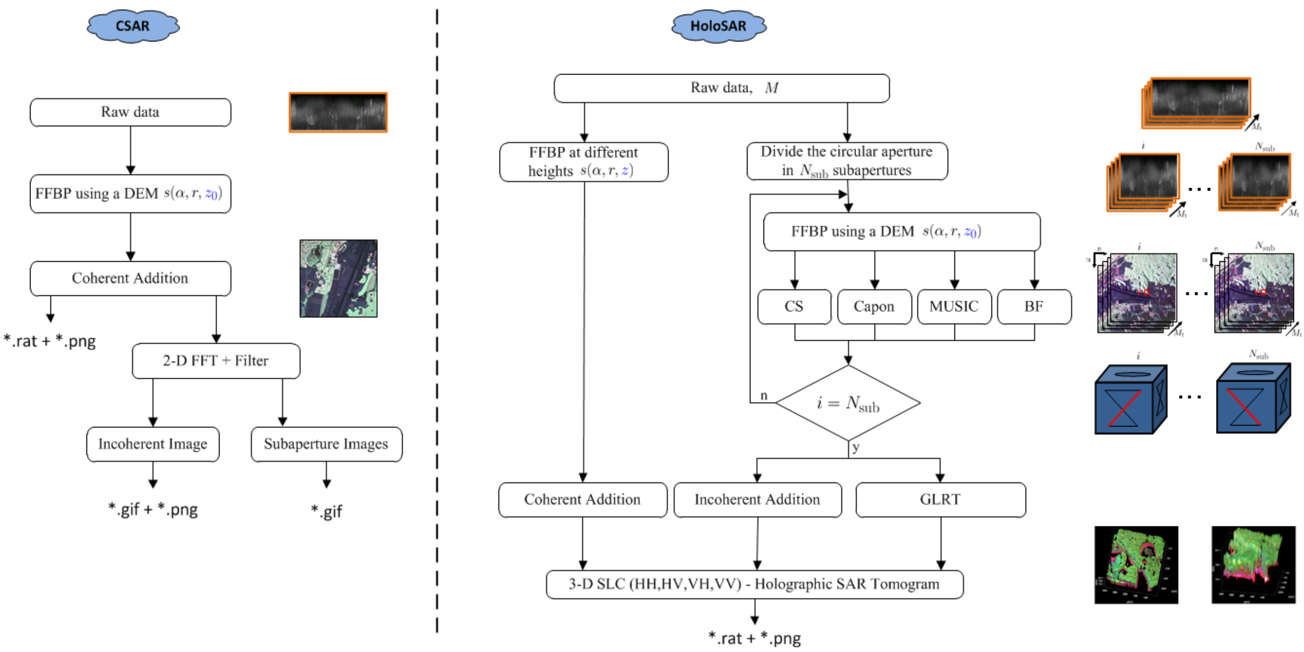
## 3.7 Holographic SAR Tomography (HoloSAR) Product

The HoloSAR products are divided into two categories:

I. For each circular track(s) at nominally constant flight altitude: SLCs in the (x,y) plane using a DEM or assuming a flat topography are generated. The SLCs are focused with the time-domain Fast Factorized Back-Projection (FFBP) by adding coherently the energy of the given track(s), angular persistence and with certain overlap. The pixel spacing can be given by the user, otherwise it takes the theoretical lambda/4. Among others the products contain an analysis of the impulse response function (IRF), if available, a fully-polarimetric image decomposed in the Pauli basis. In case of having several subapertures, the STEP will throw as an output a GIF animation containing all images.

II. 3-D SLC per polarimetric channel in the (x,y,z) plane focused as follows:
   a. Directly with the FFBP by adding coherently the energy of the cylindrical synthetic aperture. The imaging grid has a pixel spacing of approximately lambda/4 in the (x,y) plane and c0/2*cbw in the vertical direction. An AVI video of the 3-D rendering from views is provided.
   b. Incoherent integration of sub-aperture tomograms, which are coherently focused with the FFBP (typically with 10° integration) over the circular aperture and with Capon/MUSIC/CS for the entire elevation aperture. An AVI video of the 3-D rendering from multiple aspect angles is provided.
   c. Either from a. and b., it is possible to select as an output sub-aperture tomograms to analyse the 3-D volumes per aspect angle.

The different processing options are summarized below (see also F-SAR_CSAR_HoloSAR_v2-6.vsd)
.




### 3.7.1 2-D SLC product components

The product files are included in the GTC directory's subfolders with CC: circle number, SS: sub-aperture number, ZZ: vertical slice as follows:

<suffix> = c<CC>_s<SS> **OR** <suffix> = c<CC>_s<SS>_z<ZZ>

**GTC-IMG**

incoherent_*_<suffix >.gif + .png     Animation of the geocoded incoherent intensity using incremental

| | |
|---|---|
| | subapertures of 10 degrees (one file for every channel). The amplitude of the final image is provided as png. CC: circle number. |
| maskgeo_*_<suffix >.rat + .png | Geocoded binary valid sample mask. |
| polgeo_full_*_ <suffix >.png | Geocoded PolSAR colour composite at the highest resolution grid in the Pauli basis. |
| slcgeo_*_<suffix >.rat + .hdr | Single-look complex and geocoded image with sub-wavelength sampling. |
| subaperture_*_<suffix >.gif | Animation of the geocoded intensities of subapertures of 10 degrees (80% overlap, one file for every channel). |

**GTC-QL**

| | |
|---|---|
| ampgeo_pres_*_<suffix >. png(.kml) | Geocoded amplitude quicklook (one file per channel and per track; .kml for Google Earth display). tNr: track number, sNr: sub-aperture number. |
| polgeo_press_*_<suffix >.png(.kml) | Geocoded PolSAR colour composite in the Pauli basis (.kml for Google Earth display). |
| specgeo_*_<suffix >.png | Spectrum of the geocoded SLC in the (kx, ky) plane. |

**GTC-AUX** (internal use only)

| | |
|---|---|
| amploc_* _ncalib_<suffix >.png | Amplitude of the non-calibrated SLC in local coordinates and per channel. |
| cal_map_loc_*_ <suffix >.rat | Complex radiometric correction of the full spotlighted region and applied for calibration (presumed). |
| cal_map_loc_* _phase_ <suffix >.png(.kml) | 2-D plot of the calibration phase correction (.kml for Google Earth display). |
| cal_map_loc_* _intdB_ <suffix >.png(.kml) | 2-D plot of the calibration intensity correction (.kml for Google Earth display). |
| cal_mask_loc_*_ <suffix >.rat | Binary valid sample mask of the full spotlighted region (decimated). |
| cal_mask_loc_*_ <suffix >.png | 2-D plot of the binary valid sample mask. |
| irfloc_*_ncalib_2d_ <suffix >.png | 2-D amplitude of the reference targets in local coordinates (one file per channel). |
| irfloc_*_ncalib_1d_ <suffix >.png | 1-D profiles of the reference targets in local coordinates (one file per channel). |
| pol_profile_*_ <suffix >.png | HH/HV/VH/VV intensities, co- and cross-pol phase differences (averaged profiles as a function of easting), 2D estimate of HH-VV phase and coherence. |
| pol_profile_phase_*_ <suffix >.rat | Co- and cross-polar phase and coherence profiles along easting (see section 3.6). |
| pol_profile_inten_*_ <suffix >.rat | Intensity profiles along easting of all polarisations (see section 3.6). |
| slcloc_*_ncalib_ <suffix >.rat | Non-calibrated SLC in local coordinates (one file per channel). |
| specloc_*_ncalib_ <suffix >.png | Amplitude of spectrum of the non-radiometric calibrated SLC in the (kx, ky) plane (one file per channel). |

### 3.7.2 3-D SLC (coherent or incoherent) product components

Intermediate products (CC: circle number, SS: sub-aperture number).

**INF-SR** (internal use only)

| | |
|---|---|
| slcpol_* _ c<CC>_s<SS>.rat | SLC in polar coordinates (radiometrically calibrated). |
| amppol_* c<CC>_s<SS>.png | Amplitude of the SLC in polar coordinates (radiometrically calibrated). |

| | |
|---|---|
| specpol_*_ c<CC>_s<SS>.png | Spectrum of the SLC in polar coordinates (radiometrically calibrated). |
| slcpol_polsar_*_ c<CC>_s<SS>.png | Amplitude of the area to process in polar coordinates, corresponding to the master track and in the Pauli basis. The master track defines the reference geometry, where all slave images shall be coregistered to focus in elevation. |
| slc3pol_*_ s<SS>.rat | 3-D sub-aperture tomogram in polar coordinates (r,alpha,elevation). |

**INF-AUX** (internal use only)

| | |
|---|---|
| gridpol_*_ c<CC>_s<SS>.rat | 2D polar coordinates (r, alpha). |
| grid3pol_*_ s<SS>.rat | 3D polar coordinates (r, alpha, elevation). |
| | |
| Apol_*_ s<SS>.rat | Steering vector B=AX. |
| Bpol_*_ s<SS>.rat | Measurements B=AX. |

### 3.7.3 Final Products

After processing with PyRAT Tomo tools, the following 3D final products are available:

**GTC-IMG**

| | |
|---|---|
| slc3cart_*.rat + .png | Geocoded 3D holographic SLC tomogram in the geocoded grid (one file per channel). |
| grid3cart_*.rat | Vectors containing the coordinates of the geocoded grid (x,y,z) or final grid. |
| mask3geo_*.rat + .png | Geocoded binary valid sample mask. |
| pol3geo_full_*.png | Geocoded PolSAR colour composite at the highest resolution grid in the Pauli basis. |
| subaperture3_*.gif | Animation of the geocoded intensities of subapertures of 10 degrees (80% overlap, one file for every channel). |
| | |
| Incoherent3_*.gif + .png | Animation of the geocoded incoherent intensity using incremental subapertures of 10 degrees (one file for every channel). The amplitude of the final image is provided as png. CC: track number, SS: sub-aperture number. |

**GTC-QL**

| | |
|---|---|
| amp3geo_pres_ c<CC>*.png | Geocoded amplitude quicklook (one file per channel and per circle; .kml for Google Earth display). |
| pol3geo_press_*.png | Geocoded PolSAR colour composite in the Pauli basis (.kml for Google Earth display). |
| spec3geo_*.png | Spectrum of the geocoded SLC in the (kx, ky,kz) plane. |

**GTC-AUX** (internal use only)

| | |
|---|---|
| irfloc_*_ncalib_3d.png | 3-D amplitude of the reference targets in local coordinates (one file per channel). |
| irfloc_*_ncalib_2d.png | 2-D amplitude of the reference targets in local coordinates (one file per channel). |
| irfloc_*_ncalib_1d.png | 1-D profiles of the reference targets in local coordinates (one file per channel). |

### 3.7.4 Common product components

**GTC-RDP**

| | |
|---|---|
| step.xsl | xml style file. |
| ppgeo_csar_*.xml | Geocoding processing parameters per channel (see section 3.6). |

**GTC-AUX** (internal use only)

| | |
|---|---|
| ant1d_*.sav | 1D antenna diagrams in elevation and azimuth. |
| ant2d_*.sav | 2D antenna pattern (elevation and azimuth) for central frequency. |
| ant3d_*.sav + .png | 3D antenna pattern (squint, off-nadir, frequency). |
| attit_*.rat | Real aircraft attitude per channel (see **attit** in **RGI-TRACK**). |
| attit_*.png | Plots of the aircraft attitude. |
| attit_3D_*.png | 3-D plots of the aircraft attitude. |
| demloc_x_*.rat | Imaging grid in the x direction in local coordinates. |
| demloc_y_*.rat | Imaging grid in the y direction in local coordinates. |
| demloc_z_*.rat | Imaging grid in the z direction in local coordinates. |
| error_LOS_*_<reflector_name>_<iteration>.rat and .png | Residual motion error in the line of sight (LOS) estimated by PGA for a given reference target. This file saves the estimates independently for each reflector name and iteration number. (see section 3.6) |
| error_LOS_*.rat | Final error estimate in the LOS. The error is corrected in the range-compressed data by constant shifts along range direction and corresponding phase correction. |
| error_ sxyz_*_<reflector_name>_<iteration>.rat + .png | PGA estimate of the error in cartesian coordinates (x,y,z). The array contains the horizontal (s) and vertical (z) components for the linear inversion, in order to estimate the x and y components (one file for each reference target and each iteration). Not available, if less than 2 reference targets present. (see section 3.6) |
| error_ sxyz_*.rat | Final error estimate in the (x,y,z) space. The error is corrected directly in the track data and before image formation. Not available, if less than 2 reference targets present. |
| fixpoint_*.rat | Coordinate of origin of the local and SAR coordinate systems per channel (see **fixpoint** in **RGI-TRACK**). |
| *.log / *.pbs | log and pbs-files of the processing |
| replica_*.rat + .png | Chirp replica and quicklook of the replica. |
| tiepoints_*.png | Plots of the reference targets in local coordinates. |
| track_loc_*.rat | Real track in local coordinates (see **reftr_loc** in **RGI-TRACK**). |
| track_loc_*.png | Plots of the ideal and real tracks in black and red, respectively, and in local coordinates. |
| track_loc_3D_*.png | 3-D real track visualisation in local coordinates. |
| envelope_*.png | Envelope indicating where to start counting the circular tracks. There are four modes, depending on the quadrant. |

GTC-LUT and GTC-DEM folders are not needed and empty.

## 3.8 Change Detection Product

In addition to the standard F-SAR products, the data delivery may include intermediate and final results for change detection on specific regions of interest (ROIs). Two different detectors are used: the first one is based on interferometric coherence and SAR amplitude thresholding (coherent change detection), whereas the second one identifies changes in the polarimetric signature (incoherent change detection). The additional files and their contents are located in the INF product component of the slave data set and are described in the following.

**INF/INF-SR**

| | |
|---|---|
| change_mask_roiX_*.rat | A binary mask that equals one for pixels that fall within ROI X. |
| change_block_roiX_*.txt | The extent of ROI X used for change detection between master and slave data. Coordinates given slant range pixel coordinates: start in x, start in y, size in x, size in y. |
| cohchange_mask_nlflt6x6_ roiX_*.rat | The change detection mask for the interferometric coherence change detector (joint non-local means filter commonly applied to master and slave data). |
| cov3x3_<coreg_>ml_roiX_*.rat | 3x3 full rank covariance matrix after presuming. The elements on the diagonal correspond to polarisations HH, HV and VV, in that order. The matrices are available for master and resampled slave. |
| cov3x3_<coreg_>nlflt_ roiX_*.rat | 3x3 full rank covariance matrix after non-local means filtering. The matrices are available for master and resampled slave. |
| cov3x3_<coreg_>nlflt_enl_ roiX_*.rat | The local effective number of looks after speckle filtering. The matrices are available for master and resampled slave. (currently unused) |
| cov6x6_ml_roiX *.rat | The 6x6 PolInSAR covariance matrix after presuming. The two 3x3 blocks on the diagonal correspond to the polarimetric covariance matrices of master and slave acquisitions, respectively, and have the same channel order as the cov3x3 matrices described above. |
| cov6x6_nlflt_roiX*.rat | The 6x6 PolInSAR covariance matrix after non-local means filtering. |
| cov6x6_nlflt_enl_roiX*.rat | The local effective number of looks after speckle filtering. |
| polchange_prob_ml_roiX*.rat | The value of the test statistic output by the polarimetric change detector when applied directly to the presumed covariance matrices (no speckle filter). |
| polchange_prob_nlflt3x3_roiX *.rat | The value of the test statistic output by the polarimetric change detector when applied to filtered covariance matrices (master and slave filtered independently). |
| polchange_prob _nlflt6x6_roiX *.rat | The value of the test statistic output by the polarimetric change detector when applied to the two 3x3 blocks on the diagonal of the speckle filtered 6x6 PolInSAR covariance matrix. |
| slc_flt_*.rat | The common band filtered master/slave SLC data. |

**INF/INF-QL**

| | |
|---|---|
| cohchange_mask_nlflt6x6_ roiX_*.png | Quicklook of the change detection mask for the coherent change detector (joint non-local means filter for master and slave data). |

| | |
|---|---|
| cov3x3_<coreg_>ml_roiX*.png | Quicklook of the 3x3 full rank covariance matrix after presuming. Red, green and blue correspond to the backscatter in HH, HV and VV, channels respectively. |
| cov3x3_<coreg_>nlflt_ roiX*.png | Quicklook of the 3x3 full rank covariance matrix after non-local means filtering |
| cov6x6_ml_roiX *.png | Quicklook of the 6x6 PolInSAR covariance matrix after presuming. The color channels correspond to the first three diagonal elements of the 6x6 matrix (i.e. the master data set) and have the same channel order as the cov3x3 matrices described above. |
| cov6x6_nlflt_roiX*.png | Quicklook of the 6x6 PolInSAR covariance matrix after non-local means filtering. The color channels correspond to the first three diagonal elements of the 6x6 matrix (i.e. the master data set) and have the same channel order as the cov3x3 matrices described above. |
| polchange_prob_ml_roiX*.png | Quicklook of the value of the test statistic output by the polarimetric change detector when applied directly to the presumed covariance matrices (no speckle filter), scaled between 0 (black) and 1 (white). |
| polchange_prob_nlflt [3x3,6x6]_roiX *.png | Quicklook of the value of the test statistic output by the polarimetric change detector when applied to filtered covariance matrices (3x3 or 6x6) ), scaled between 0 (black) and 1 (white). |
| polchange_mask_ [ml,nflt][3x3,6x6]_roiX*.png | Quicklook of the change detection mask obtained by thresholding the correspondingly named test statistic (polchange_prob*) in INF-SR. |

Optionally, change detection results are also geocoded. The geocoded change detection results are then stored in the **GTC/GTC-IMG** component of the **master** acquisition.

## 3.9 Additional files for Ice Sounding Mode

When F-SAR is operated in nadir looking ice sounding mode, some additional files are included:

**RGI/RGI-TRACK**

reftr_geogr_resa_*.rat — The reference track in geographic coordinates, equidistant in space. The sampling interval corresponds to the initial raw data and is an integer factor with respect to the slc data.

| Row | Description | Units |
|---|---|---|
| 0 | GPS second | [sec] |
| 1 | Longitude | [deg] |
| 2 | Latitude | [deg] |
| 3 | Ellipsoidal height | [m] |

range2surface_*.rat — Evaluation of the closest distance from the reference track to the ice surface. The sampling interval corresponds to the one of to the slc data. Vector of the azimuth length of the slc data.

travel_time_*.rat — The delay to the individual range samples of the slc data. Vector of the range length of the slc data.

**RGI/RGI-QL**

gradient_*.png — Quicklook of the gradient of the radargram in logarithmic scale (dynamic range 20dB).

gradient_*_axis.png — Quicklook of the gradient of the radargram in logarithmic scale (dynamic range 20dB) with coordinate annotation along-rack-position vs. height above ellipsoid.

radargram_*.png — Quicklook of the A-scope radargram in logarithmic scale (dynamic range 60dB).

radargram_*_axis.png — Quicklook of the A-scope radargram in logarithmic scale (dynamic range 60dB) with coordinate annotation along-rack-position vs. height above ellipsoid.

## 3.10 Range Compressed Raw Products

Pre-processed range compressed raw data can be provided to support applications that require the analysis of SAR data before azimuth compression. In contrast to the RAW Product described at the beginning of this document, these range compressed raw data have the following advantages:

- Sensor independence
- Easy-to-use file formats (RAT, XML and HDF5)
- Can also serve as an input to the processor, i.e. the data can be modified and re-processed to yield focussed SAR image
- Includes calibration corrections for range delay as well as channel amplitude and phase
- Tracks (position information) are provided for each individual data channel, i.e. each individual antenna phase centre

The range compressed raw format adopts the structure of the RGI product (see section 3.2). The following sub-sections detail the contents of the individual product components.

**RGI-SR**

| | |
|---|---|
| rcraw*.rat | complex, range-compressed raw data before azimuth compression and motion compensation |

**RGI-TRACK**

Per-channel platform attitude angles and track information in the so-called local coordinate system, as well as a fixpoint to relate the local coordinates to global geographic coordinates (see RGI product description for details)

**RGI-RDP**

Per-channel sensor and processing parameters in XML format (see RGI product description for details)

**RGI-AUX**

| | |
|---|---|
| antconf*.xml | XML file indicating, for each channel, which antenna patterns apply on transmit and receive |
| antpatterns*.hdf5 | HDF5 file with the actual 3D complex antenna patterns for each channel (as a function of squint, off-nadir and frequency, see the description of the antconf file in section 3.11) |
| range_comp_kernel*.rat | The 1D kernel, in the time domain, used for range compression (inverse filtering based on this kernel achieves range-decompression) |

With respect to the description of the auxiliary calibration information in section 3.11, it should be noted that the RCRAW product does not include an antcal file with additional, incremental calibration corrections. Any such corrections can be assumed to have already been applied (e.g. to the system parameters, the raw data matrix and the antenna lever-arms in the antpatterns HDF5 file) such that the RCRAW product can be considered calibrated.

The only exception to the rule above is in relation to the mount-angles in the antpatterns file: The attitude angles provided in the RCRAW product do *not* take these into account. The reason is that the attitude angles are required both with and without the mount angle correction:

- Attitudes without the mount angle are appropriate for applying the antenna lever-arm to the track to obtain the antenna phase centre position at each azimuth sample.
- Attitudes with the mount angle correction are appropriate for transformations into the coordinate system of the antenna diagram and are appropriate during the antenna pattern compensation.

As described in more detail in section 3.11, the mount angles are applied to the attitude angles by simple addition.

## 3.11 Auxiliary Data

In addition to the information in the raw data product described in section 3.1, SAR processing and calibration requires certain auxiliary data. This data is typically held in a directory outside the campaign data structure.

**Mission Planning, Testsite and Navigation Data**

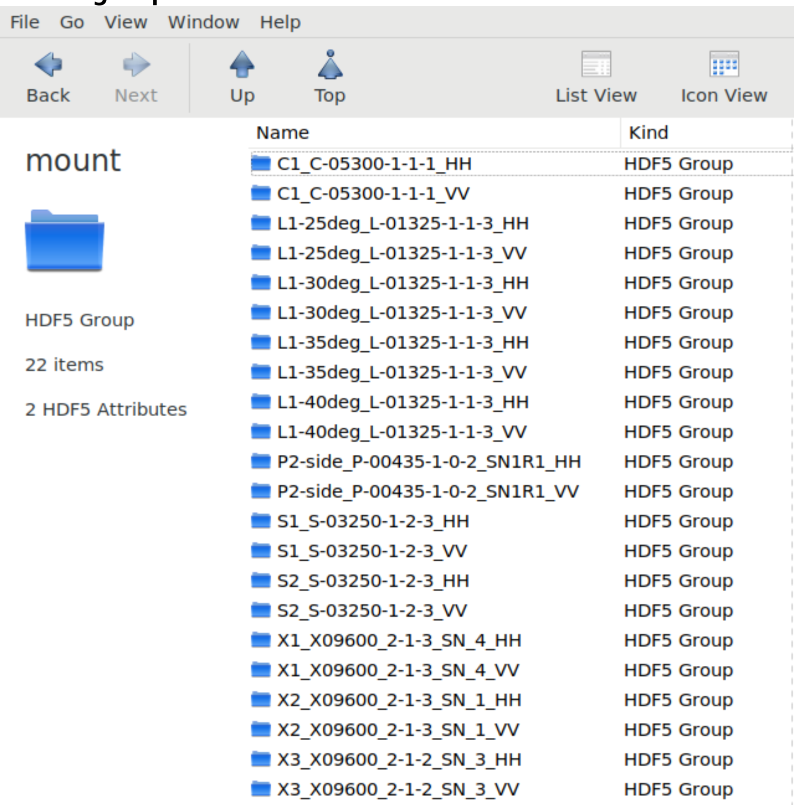
| | |
|---|---|
| igi*.dat | navigation data (Input for Transcription and Processing) |
| mp_*segm*.txt | mission planning file including coordinates for all flown segments (Input for Transcription) |
| mp<mission>.csv | flight planning table (links the planned segments to flown tracks) |
| testsite_NAME.xml | Testsite bounding polygon: four corner coordinates (geogr. Latitude, geogr. longitude, height (Format same as bp*.xml) |
| tiepoints*.csv | tiepoint file (characterizes ground control points, and reference targets such as trihedrals). |
| utmdem*.rat + .hdr | Input-DEM *utmdem*.rat* |

**Antenna Diagrams and Calibration Information**

| | |
|---|---|
| antmap*csv | A table that maps channel coding to the antenna ID as it appears in the HDF5 files. For F-SAR raw data, this ID also appears in the per-channel ant*xml files of the RAW product. |
| antconf*hdf5 | HDF5 data set containing antenna diagrams, antenna phase center positions and calibration constants |
| antcal*hdf5 | HDF5 data set with incremental corrections to the information in the antconf file |

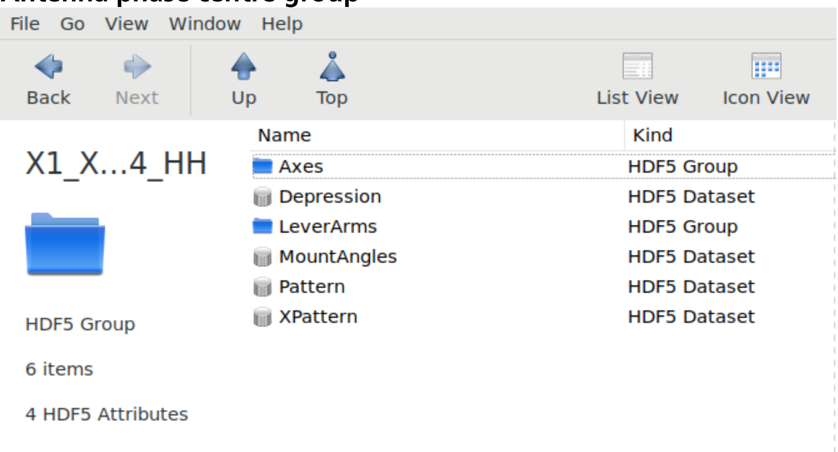
### 3.11.1 HDF5 Structure: antconf

1. **Mount group**



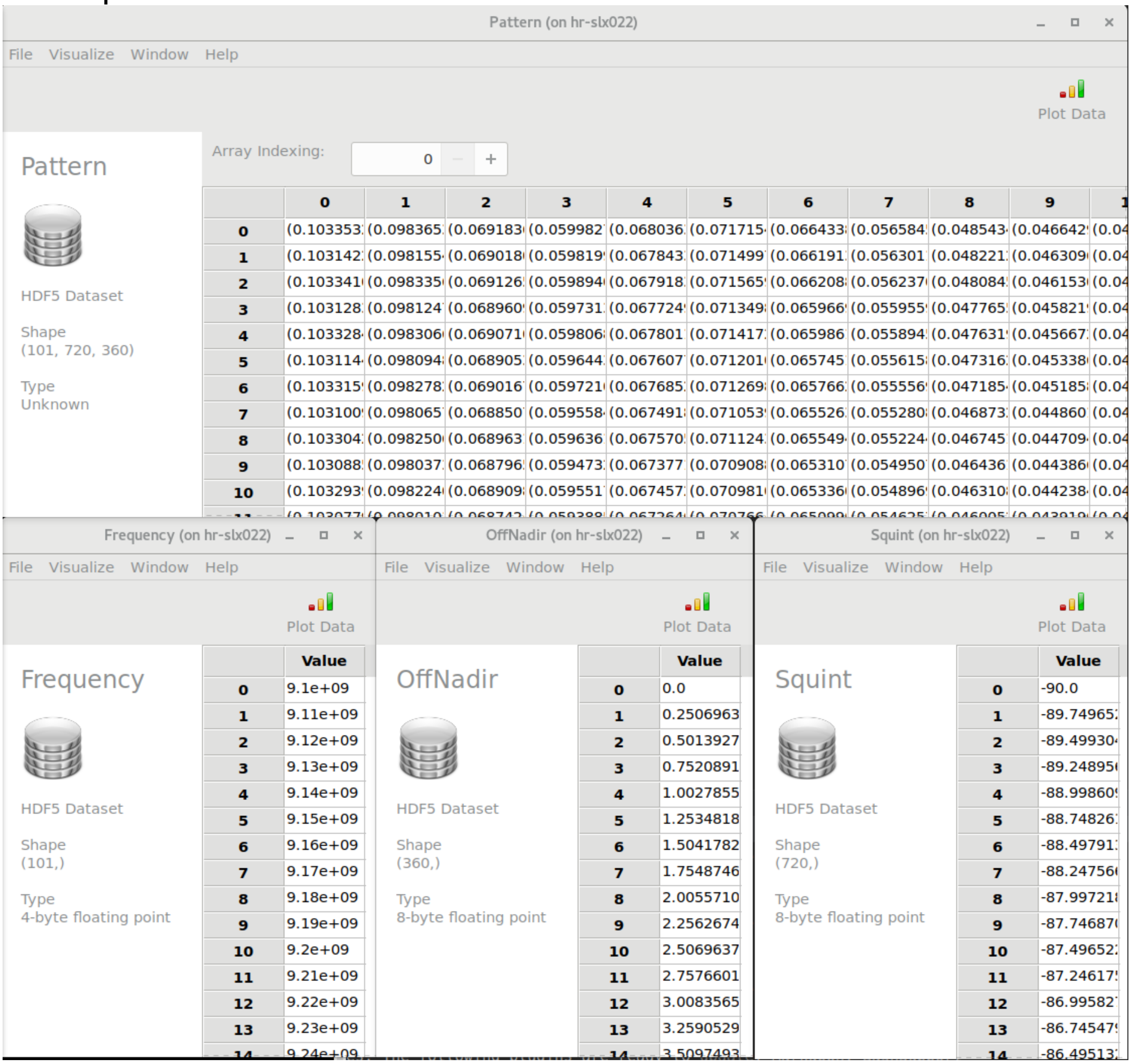

The top-level "mount" group contains one sub-group per antenna phase center. The names of the antennas corresponds to the ID given in the antmap table and, for F-SAR RAW products, the per-channel ant*xml files. By convention, the first two characters of the ID indicate the frequency band and the antenna number. The last character indicates the linear polarization state.

2. **Antenna phase centre group**



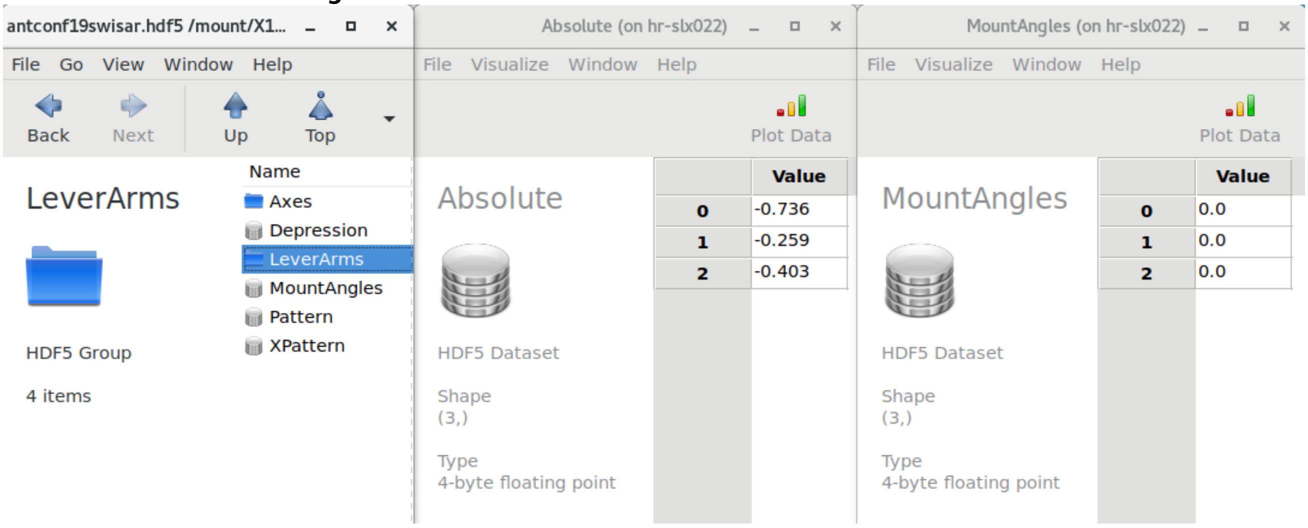

Each antenna group contains various datasets and sub-groups. A brief description of some of this information is given in the following.

## 3. Antenna pattern and Axes




The Pattern dataset contains the 3D, complex valued, one-way pattern of the respective antenna. The three dimensions are the frequency, the squint and the off-nadir angles (in that order). The sampling points along each axis are given by the "Frequency" (Hz), "Squint" (degrees) and "OffNadir" (degrees) datasets in the "Axes" sub-group of each antenna group. The polar coordinate system squint/offnadir has its poles at squint angles of +-90 deg. A squint of +90 deg corresponds to the flight direction.

## 4. Lever-arms and mount-angles

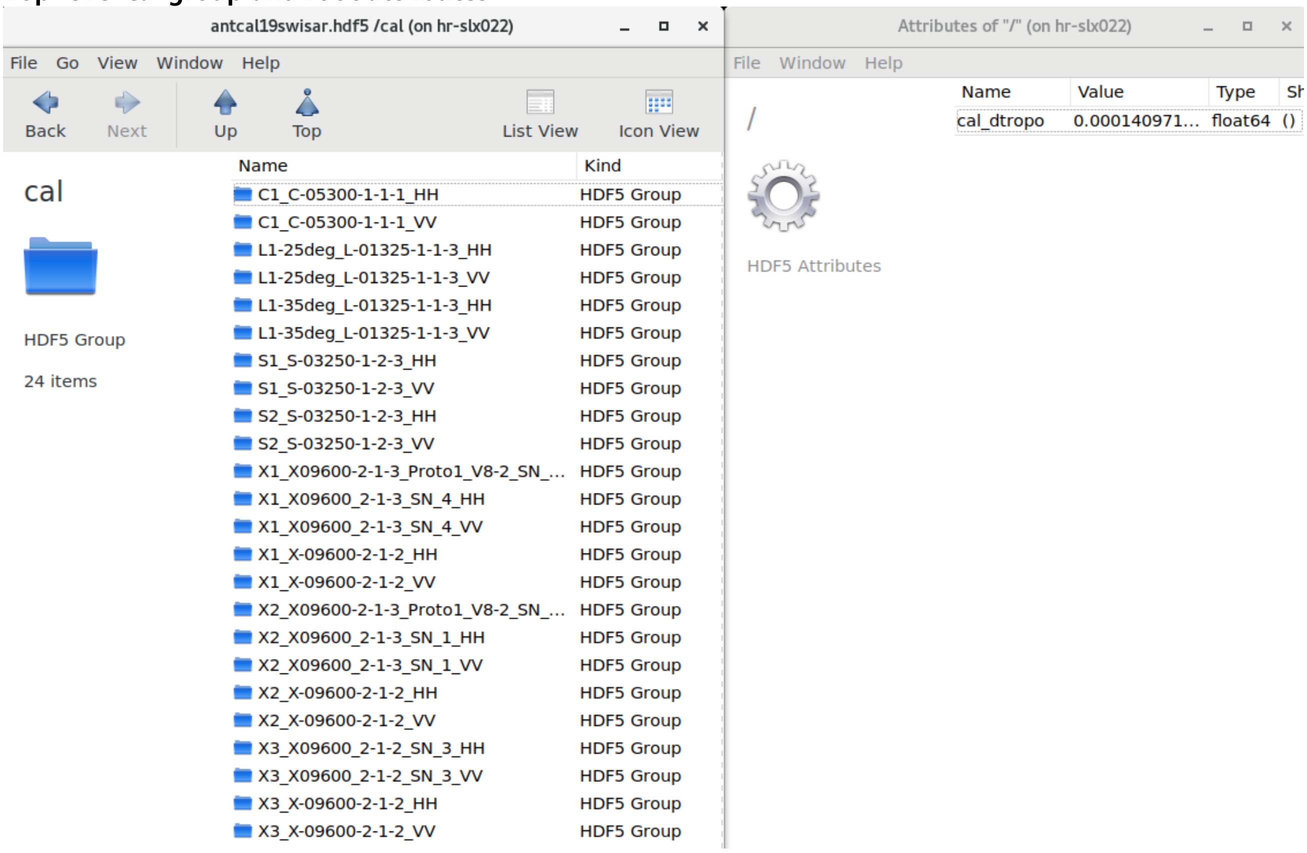



The lever-arm of each antenna corresponds to the 3D displacement, in the instrument rest frame, from the reference point of the navigation data to the antenna phase center. The lever-arm that is relevant to SAR processing is held in the "Absolute" data set of the "LeverArms" sub-group. The lever-arm axes denote offsets in flight direction, towards the left and upwards, respectively. Lever-arms are given in *m*.

The mount-angle of each antenna, meanwhile, denotes the 3D antenna mis-pointing. It measures offsets [delta_roll, delta_pitch, delta_yaw] in degrees. These offsets are be applied additively to the platform attitude angles to obtain Euler angles that can be used to define transformations into the antenna coordinate system (the coordinate system in which the 3D pattern is defined).

### 3.11.2 HDF5 Structure: antcal

1. **Top-level cal group and root attributes**

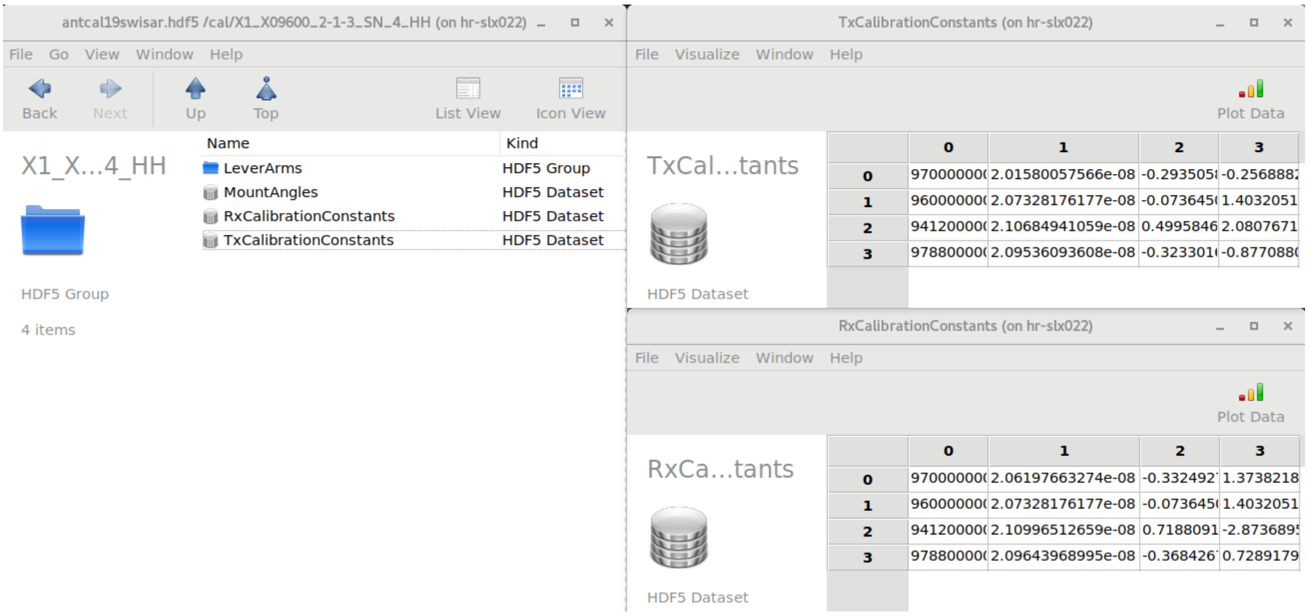



Similar to the antconf structure, the top-level "cal" group contains one sub-group for each antenna ID. In addition, the root element has attributes corresponding to global calibration information.

Currently this global information comprises a tropospheric propagation correction "cal_dtropo". The value represents a refractive index correction to the speed of light in air. Using this parameter, the speed of light in air to be used for SAR image formation is

$$c_{air} = 299707760\ 10^{-0.1\ cal_{dtropo}} m s^{-1}$$

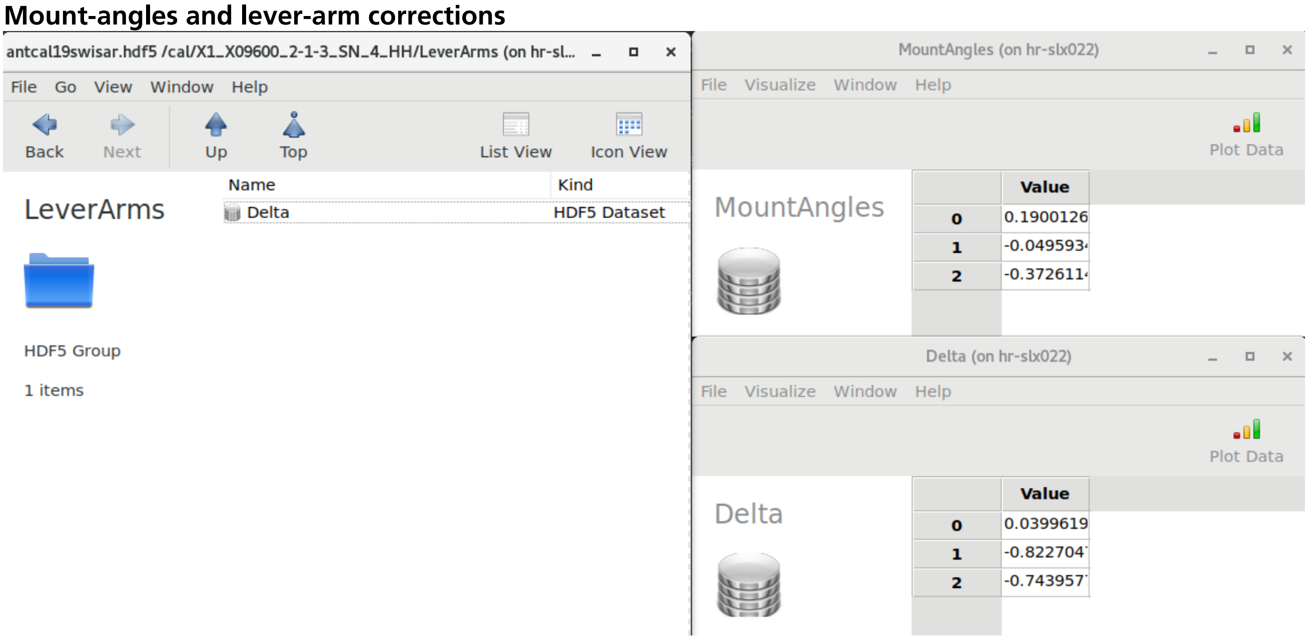
2. **Calibration constants**




Each antenna-sub group contains the data sets "TxCalibrationConstants" and "RxCalibrationConstants" that quantify constant delay, amplitude and phase offsets that affect signals propagating through the antenna upon transmit and receive, respectively. Each of the calibration constant data sets has four columns:
- The centre frequency, in Hz, for which the calibration constants apply
- A delay, in s, affecting signals upon propagation through the antenna
- The gain, in dB, affecting the signal intensity upon propagation through the antenna
- The phase shift, in radians, affecting the complex signal upon propagation through the antenna

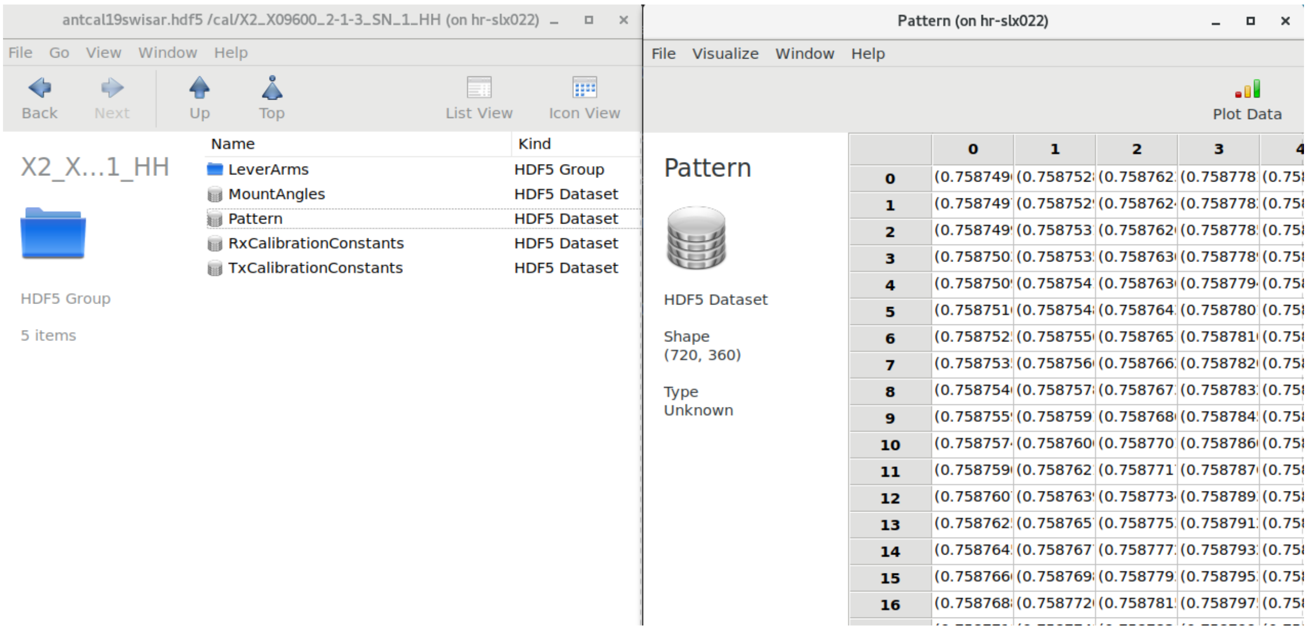
For a given channel of radar raw data, the calibration constants for delay, amplitude and phase are given by summing the transmit and receive contributions of the relevant antenna phase centres. For example, the image above shows calibration constants for the X1 antenna in H-polarization. The delay for the HH channel of the X1 antenna at 9.788 GHz is 20.954 ns + 20.964 ns.

3. **Mount-angles and lever-arm corrections**




Each antenna group provides lever-arm and mount-angle corrections. These are added onto the corresponding values in the antconf HDF5 file. In the case of the lever-arm, for instance, the antenna phase centre position relative to the navigation data reference point is given by the "LeverArms/Absolute" dataset in antconf **plus** the "LeverArms/Delta" dataset in antcal. The same applies to the two "MountAngles" datasets. See the antconf description above for more details concerning the coordinate conventions used for mount-angles and lever-arms.

4. **Pattern Correction**




Antenna groups may optionally include a dataset "Pattern" that contains a 2D or 3D antenna pattern correction. 3D corrections have the exact size of the original "Pattern" in the antconf file. 2D corrections cover the squint and off-nadir axes and apply to all frequencies in the full 3D pattern (this is the case for the example above). The pattern correction is complex valued and is applied multiplicatively to the dataset in antconf.

# Appendix 1: Radiometric Calibration

SAR images are commonly radiometrically corrected in one of three fashions: beta-0, sigma-0 and gamma-0. Which type of correction is appropriate depends on the application at hand. The aim of this appendix is therefore to summarise how F-SAR data can be converted from one type of radiometric calibration to another.

In general, the formula for converting F-SAR imagery to dB values corresponding to any one of the three calibration types is as follows:

$$I_{dB} = 10log(\langle f|I \quad |^2\rangle)$$

where $I$ denotes the input image, *f* denotes a scale factor and <…> denotes spatial averaging or multi-looking. The scale factor *f* depends on the input image and the desired type of radiometric calibration in the output. The following table summarises the factors used for different conversions:

| Input | Product Component | Factor *f* to achieve desired output | | |
|---|---|---|---|---|
| | | **Beta-0** | **Sigma-0** | **Gamma-0** |
| **slc** | RGI-SR, INF-SR | 1 | $sin(\theta_{inc})$ | $tan(\theta_{inc})$ |
| **amp** | RGI-SR, GTC-IMG | $1/tan\,(\theta_{inc})$ | $cos(\theta_{inc})$ | 1 |

The angle $\theta_{inc}$ in the table above refers to the local incidence angle, which is given, for each sample of the image grid, in the **incidence** files that are provided as part of the RGI-SR (see section 3.2) and GTC-IMG (see section 3.3) product components for slant range and geocoded data, respectively.

# Appendix 2: Rat Format

The following table indicates the binary structure of RAT (version 2) files on disk. All floating point and complex data follow IEEE standards and are stored with little endian byte ordering.

**Format description**:

| Group | Tagname | Length [byte] | Type | Example | Description |
|---|---|---|---|---|---|
| RAT (100 bytes) | MagicLong | 4 | 1 x long | 844382546 | Magic number for recognizing RAT |
| | Version | 4 | 1 x float | 2.0 | RAT Version number |
| | NDIM | 4 | 1 x long | 2 | Number of dimensions of data matrix |
| | NCHANNEL | 4 | 1 x long | 1 | Number of channels |
| | DIM | 32 | 8 x long | 1000,2000,0,0,0,0,0,0 | Number of samples per dimension |
| | VAR | 4 | 1 x long | 4 | IDL variable type (1- byte, 2-integer, 4 –float, 6 –complex) |
| | SUB | 8 | 2 x long | 5, 8 | Subsampling factors |
| | RATTYPE | 4 | 1x long | 100 | RAT type |
| | RESERVED | 36 | 9 x long | 9x0 | <empty> |
| INFO (100 bytes) | INFO | 100 | string | | Description of file content |
| GEO (100 bytes) | PROJECTION | 2 | 1 x int | 1 | Projection Type (0=Lat/Long, 1 = UTM, 2 = Gauss-Krüger) |
| | PS_EAST | 8 | 1 x double | 1.0 | Sampling in Easting ([deg] or [m]) |
| | PS_NORTH | 8 | 1 x double | 1.0 | Sampling in Northing ([deg] or [m]) |
| | MIN_EAST | 8 | 1 x double | 436041.00 | Minimum easting (lower left corner) |
| | MIN_NORTH | 8 | 1 x double | 5921365.0 | Minimum northing (lower left corner) |
| | ZONE | 2 | | 32 | Projection zone |
| | HEMISPHERE | 2 | | 1 | Hemisphere (1 – north, 2 - south |
| | LONG0SCL | 8 | 1 x double | 0.99996 | Scaling factor at central meridian |
| | MAX_AXIS_ELL | 8 | 1 x double | 6378137.0 | Ellipsoid major axis |
| | MIN_AXIS_ELL | 8 | 1 x | 6356752.3 | Ellipsoid minor axis |

| | | | | | |
|---|---|---|---|---|---|
| | | | double | | |
| | DATUM_SHIFT | 100 | 7 x double + 64 byte | | Datum Shift Parameters (3x translation, 3x Rotation, 1x Scaling) in case other than WGS-84 ellipsoid is used. |
| | RESERVED | 18 | 18 x byte | | <empty> |
| STAT (100bytes) | STAT | 100 | 25 x long | 0 | Reserved for statistical values of data matrix. |
| DATE (100bytes) | START_TIME | 19 | string | 2012-11-14 T18:20:06 | Start time of data acquisiton |
| | STOP_TIME | 19 | string | 2012-11-14 T18:21:29 | Stop time of data acquisiton |
| | RESERVED | 62 | 62 x byte | | <empty> |
| RESERVED1 | RESERVED | 100 | 25 x long | | <empty> |
| RESERVED2 | RESERVED | 100 | 25 x long | | <empty> |
| RESERVED3 | RESERVED | 100 | 25 x long | | <empty> |
| RESERVED4 | RESERVED | 100 | 25 x long | | <empty> |

Functions for reading and writing the RAT format are available for IDL and python upon request.