Algorithms and Usages of GAMMA Processing Sequence for Generating CEOS-ARD NRB PFS ver5.5 Compliant NovaSAR-1 Analysis Ready Data Products

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Overview

CSIRO have developed the GAMMA software [1] based NovaSAR-1 Analysis Ready Data (ARD) processing workflows on a local Linux PC and also the HPC platform for batch processing of CEOS-ARD Normalised Radar Backscatter (NRB) Product Family Specifications (PFS) version 5.5 Compliant NovaSAR-1 ARD production. This document introduces the processing steps used, along with the algorithms and parameters based on GAMMA reference manuals.

Processing Steps

1. **Source Data Import**
2. **Multi-Look**
3. **Geocoding**
4. **Pixel Area**
5. **Geocoding Refinement**
6. **Update Geocoding Look-up Table**
7. **Geocode Back**
8. **Terrain Flattening**
9. **Generate Per-pixel Metadata Images**
10. **Creation of KML Footprint and Quick-look Images**
11. **Scaling and GeoTiff Output**

1) Source Data Import

with radiometric calibration and thermal noise removal

Usage:

par_NovaSAR_GRD <GeoTIFF> <XML> <polarization> <MLI_par> [MLI] [GRD_par] [GRD] [rps] [radcal] [noise]

<GeoTIFF>	(input) NovaSAR image data file in GeoTIFF format (enter - for none, *.tif)
<XML>	(input) NovaSAR XML annotation file
<polarization>	image polarization: HH, VV, HV, VH, CH, CV
<MLI_par>	(output) MLI parameter file (example: yyyymmdd_pp.mli.par)
[MLI]	(output) MLI data file in slant range geometry (example: yyyymmdd_pp.mli, enter - for none)
[GRD_par]	(output) GRD parameter file (example: yyyymmdd_pp.grd.par, enter - for none)
[GRD]	(output) GRD data file (example: yyyymmdd_pp.grd, enter - for none)
[rps]	slant range pixel spacing (m) (enter - for default: calculated from ground-range parameters)
[radcal]	radiometric calibration flag (enter - for default) 0: beta0 (default) 1: sigma0
[noise]	noise levels flag (enter - for default) 0: do not use noise levels (default) 1: use noise levels

Example:

par_NovaSAR_GRD image_HH.tif metadata.xml HH HH.mli.par HH.mli - - - 1 1

where the radiometric calibration can be specified using the radcal option, either beta0 or sigma0 are available; the thermal noise removal is implemented using the noise option, it corresponds to a subtraction of the noise power.

2) Multi-Look

Usage:

multi_look_MLI <MLI_in> <MLI_in_par> <MLI_out> <MLI_out_par> <rlks> <azlks> [loff] [nlines] [scale] [e_flag]

<MLI_in>	(input) multi_look intensity image (MLI) file (float)
<MLI_in_par>	(input) MLI parameter file
<MLI_out>	(output) multi-looked MLI image (float)
<MLI_out_par>	(output) MLI parameter file for output MLI
<rlks>	range looks for multi-looking
<azlks>	azimuth looks for multi-looking
[loff]	offset to starting line in the input data (enter - for default: 0)
[nlines]	number of input MLI lines to process (enter - for default: to end of file)
[scale]	scale factor for output MLI (enter - for default: 1.0)
[e_flag]	extent flag (enter - for default) 0: only permit pixels with the full number of looks (default) 1: permit pixels without the full number of looks

Example:

multi_look_MLI ../HH.mli ../HH.mli.par PP.mli PP.mli.par 2 2

3) Geocoding

Calculate lookup table and DEM related products, generate accurate layover and shadow map; Calculate terrain-based sigma/gamma nought normalization area; Geocoding lookup table refinement using offset polynomials

Usage:

gc_map2 <MLI_par> <DEM_par> <DEM> [DEM_seg_par] [DEM_seg] [lookup_table] [lat_ovr] [lon_ovr] [ls_map] [ls_map_rdc] [inc] [res] [offnadir] [sim_sar] [u] [v] [psi] [pix] [r_ovr] [az_dec] [mask] [frame] [ls_scaling] [DIFF_par] [ref_flg] [inc_flg]

<MLI_par>	(input) MLI or SLC image parameter file (slant range geometry)
<DEM_par>	(input) DEM/MAP parameter file
<DEM>	(input) DEM data file (or constant height value)
[DEM_seg_par]	(output) DEM segment parameter file (enter - for none)
[DEM_seg]	(output) DEM segment file (FLOAT, enter - for none)
[lookup_table]	(output) geocoding lookup table (FCOMPLEX, original DEM geometry) (enter - for none)
[lat_ovr]	latitude or northing output DEM oversampling factor (enter - for default: 1.0)
[lon_ovr]	longitude or easting output DEM oversampling factor (enter - for default: 1.0)
[ls_map]	(output) layover and shadow map (UCHAR, original DEM geometry) (enter - for none)
[ls_map_rdc]	(output) layover and shadow map (UCHAR, slant range geometry) (enter - for none)
[inc]	(output) local incidence angle map (FLOAT, between surface normal and look vector, original DEM geometry) (enter - for none)
[res]	(output) local resolution map (FCOMPLEX, original DEM geometry) (enter - for none)
[offnadir]	(output) local offnadir (look) angle map (FLOAT, original DEM geometry) (enter - for none)
[sim_sar]	(output) simulated SAR backscatter image (FLOAT, original DEM geometry) (enter - for none)
[u]	(output) zenith angle map of surface normal vector n (FLOAT, angle between z and n, original DEM geometry) (enter - for none)
[v]	(output) orientation angle map of n (FLOAT, between x and projection of n in xy plane, original DEM geometry) (enter - for none)

[psi]	(output) projection angle map (FLOAT, between surface normal and image plane normal, original DEM geometry) (enter - for none)
[pix]	(output) pixel area normalization factor map (FLOAT, enter - for none)
[r_ovr]	range oversampling factor (for layover-shadow calculations, enter - for default: automatic value)
[az_dec]	azimuth decimation factor (for layover-shadow calculations, enter - for default: automatic value)
[mask]	mask values outside swath, use layover and shadow map as a mask (enter - for default) 0: no masking (default) 1: masking values outside swath 2: masking shadow and values outside swath 3: masking layover, shadow and values outside swath
[frame]	number of DEM pixels to add around area covered by SAR image (enter - for default = 8)
[ls_scaling]	scaling of the layover and shadow maps (enter - for default) 0: standard values for further processing (default) 1: scaling optimized for visualization
[DIFF_par]	(input) DIFF/GEO parameter file containing offset polynomial coefficients, for LUT and ls_map_rdc refinement (enter - for none)
[ref_flg]	reference image flag (offsets are measured relative to the reference image) (enter - for default) 0: reference image is the actual SAR image 1: reference image is the simulated SAR image (default)
[inc_flg]	incidence angle flag (enter - for default) 0: [inc] defined as local incidence angle (angle between surface normal and look vector) (default) 1: [inc] defined as incidence angle (angle between ellipsoid normal and look vector)

Example:

gc_map2 PP.mli.par nova_geo.dem_par nova_geo.dem nova_geo.dem_par.tmp nova_geo.dem.tmp lt 1 1 ls_map - inc - offnadir sim_sar u v psi pix - - 2 8 0

4) Pixel Area

Calculate terrain-based sigma0/gamma0 normalization area in slant-range geometry

Usage:

pixel_area <MLI_par> <DEM_par> <DEM> <lookup_table> <ls_map> <inc_map> <pix_sigma0> [pix_gamma0] [nstep] [area_fact] [sigma0_ratio] [gamma0_ratio] [sig2gam_ratio]

<MLI_par>	(input) ISP MLI or SLC image parameter file (slant-range geometry)
<DEM_par>	(input) DEM/MAP parameter file
<DEM>	(input) DEM data file (or constant height value)
<lookup_table>	geocoding lookup table (FCOMPLEX format)
<ls_map>	(input) layover and shadow map (in map projection)
<inc_map>	(input) local incidence angle map in map geometry, (float, enter - for none) NOTE: required for calculation of pix_gamma0, gamma0_ratio, and sig2gam_ratio
<pix_sigma0>	(output) sigma0 normalization area (float, enter - for none)
[pix_gamma0]	(output) gamma0t normalization area (float, enter - for none)
[nstep]	number of steps to divide each dimension of the map pixels (default: 16)
[area_fact]	area factor that is multiplied with the rg/az pixel size to set a lower threshold for the minimal pixel area that is accepted (default: 0.10)
[sigma0_ratio]	(output) ratio between ellipsoid and DEM-based sigma0 normalization areas (enter - for none)
[gamma0_ratio]	(output) ratio between ellipsoid and DEM-based gamma0 normalization areas (enter - for none)
[sig2gam_ratio]	(output) ratio of ellipsoid sigma0 and DEM based gamma0 normalization areas (enter - for none)

Example:

pixel_area HH.mli.par nova_geo.dem_par.tmp nova_geo.dem.tmp lt ls_map inc sigma0 gamma0 40 0.01 sigma0_ratio gamma0_ratio

5) Geocoding Refinement

offset_pwrm - estimate the range and azimuth registration offset fields using cross correlation optimization of the real valued data

offset_fitm - computes registration offset polynomials from offsets file generated by one of the programs offset_pwrm

Usage:

offset_pwrm <MLI-1> <MLI-2> <DIFF_par> <offs> <ccp> [rwin] [azwin] [offsets] [n_ovr] [nr] [naz] [thres] [lanczos] [bw_frac] [pflag] [pltflg] [ccs] [std_mean]

<MLI-1>	(input) real valued intensity image 1 (reference)
<MLI-2>	(input) real valued intensity image 2
<DIFF_par>	(input) DIFF/GEO parameter file
<offs>	(output) offset estimates in range and azimuth (fcomplex)
<ccp>	(output) cross-correlation of each patch (0.0->1.0) (float)
[rwin]	range patch size (range pixels, enter - for default from offset parameter file)
[azwin]	azimuth patch size (azimuth lines, enter - for default from offset parameter file)
[offsets]	(output) range and azimuth offsets and cross-correlation data in text format, enter - for no output
[n_ovr]	MLI oversampling factor (integer 2**N (1,2,4), enter - for default: 1)
[nr]	number of offset estimates in range direction (enter - for default from offset parameter file)
[naz]	number of offset estimates in azimuth direction (enter - for default from offset parameter file)
[thres]	cross-correlation threshold (0.0->1.0) (enter - for default from offset parameter file)
[lanczos]	Lanczos interpolator order 5 -> 9 (enter - for default: 5)
[bw_frac]	bandwidth fraction of low-pass filter on intensity data (0.0->1.0) (enter - for default: 0.8)
[pflag]	print flag (enter - for default) 0: print offset summary (default) 1: print all offset data
[plt_flag]	plotting flag (enter - for default) 0: none (default) 1: screen output 2: screen output and PNG format plots 3: output plots in PDF format
[ccs]	(output) cross-correlation standard deviation of each patch (float)

[std_mean]	patch minimum standard deviation/mean ratio (enter - for default: 0.01)

offset_fitm <offs> <ccp> <DIFF_par> [coffs] [coffsets] [thres] [npoly] [interact_mode]

<offs>	(input) binary file with range and azimuth offset estimates (fcomplex)
<ccp>	(input) binary file with cross-correlation values of offset estimates (float)
<DIFF_par>	(input/output) DIFF/GEO parameter file for the scene
[coffs]	(output) culled range and azimuth offset estimates (fcomplex, enter - for none)
[coffsets]	(output) culled offset estimates and cross-correlation values (text file, enter - for none)
[thres]	cross-correlation threshold (enter - for default from DIFF_par)
[npoly]	number of polynomial model parameters (enter - for default, 1, 3, 4, 6 default=4)
[interact_flag]	interactive culling (1=YES, 0=NO, default=NO)

Examples:

```
create_diff_par PP.mli.par - PP.diff_par 1 0
offset_pwrm gamma0 PP.mli PP.diff_par PP.offs PP.snr 1024 1024 - 1 20 20 0.15
offset_fitm PP.offs PP.snr PP.diff_par PP.coffs PP.coffsets 0.15 6
```

6) Update Geocoding Look-up Table

gc_map_fine - Geocoding lookup table correction using offset polynomials from the DIFF parameter file
pixel_area - Recalculate sigma0 and gamma0

Usage:

gc_map_fine <gc_in> <width> <DIFF_par> <gc_out> [ref_flg]

<gc_in>	(input) geocoding lookup table
<width>	(input) width of lookup table (samples)
<DIFF_par>	(input) DIFF/GEO parameter file containing fine registration polynomial coefficients
<gc_out>	(output) (output) refined geocoding lookup table
[ref_flg]	offsets are relative to the reference image for offset determination. 0: actual SAR image reference, 1: simulated image reference (default)

Examples:

gc_map_fine lt $var7_row PP.diff_par lt_fine 1

pixel_area PP.mli.par nova_geo.dem_par.tmp nova_geo.dem.tmp lt_fine ls_map inc sigma0 gamma0 40 0.01 sigma0_ratio gamma0_ratio

7) Geocode Back

resampling and interpolation using a geocoding look-up table

Usage:

geocode_back <data_in> <width_in> <lookup_table> <data_out> <width_out> [nlines_out] [interp_mode] [dtype] [lr_in] [lr_out] [order] [e_flag]

<data_in>	(input) data file (coordinate system B)(for SUN raster: *.ras, BMP: *.bmp, TIFF: *.tif)
<width_in>	(input) width of input data file and the lookup_table
<lookup_table>	(input) geocoding lookup table (A-->B) (dimension of output data, real valued input coordinates)
<data_out>	output data file (coordinate system B) (for SUN raster: *.ras, BMP: *.bmp, TIFF: *.tif)
<width_out>	width of output data file (width of lookup table)
[nlines_out]	number of lines in the output image (enter - or 0 for default: number of lines in gc_map)
[interp_mode]	interpolation mode (enter - for default) 0: nearest-neighbor 1: bicubic spline (default) 2: bicubic-spline, interpolate log(data) 3: bicubic-spline, interpolate sqrt(data) 4: B-spline interpolation (default B-spline degree: 5) 5: B-spline interpolation sqrt(x) (default B-spline degree: 5) 6: Lanczos interpolation (default Lanczos function order: 5) 7: Lanczos interpolation sqrt(x) (default Lanczos function order: 5) NOTE: log and sqrt interpolation modes should only be used with non-negative data!
[dtype]	input and output data format (enter - for default) 0: FLOAT (default) 1: FCOMPLEX 2: SUN raster/BMP/TIFF format 3: UNSIGNED CHAR 4: SHORT 5: DOUBLE
[lr_in]	input SUN raster/BMP/TIFF format file left/write flipped (enter - for default = 1: not flipped, -1: flipped)
[lr_out]	output SUN raster/BMP/TIFF format file left/write flipped (enter - for default = 1: not flipped, -1: flipped)
[order]	Lanczos function order or B-spline degree (2->9) (enter - for default: 5)
[e_flag]	extrapolation flag (enter - for default) 0: do not extrapolate (default) 1: extrapolate up to 0.5 pixels beyond input edges

Example:

geocode_back PP.mli $var1_cell lt_fine geo.PP.mli $var7_row $var8_col 5 0 - - 3

8) Terrain Flattening

with Gamma0 normalization area, then Geocoding of image data using a refined lookup ta

Usage:

radcal_MLI <MLI> <MLI_PAR> <OFF_par> <CMLI> [antenna] [rloss_flag] [ant_flag] [refarea_flag] [sc_dB] [K_dB] [pix_area]

<MLI>	(input) MLI image (float)
< MLI_par >	(input) SLC parameter file of input MLI image
< OFF_par >	(input) ISP offset/interferogram parameter file (enter - for images in MLI geometry)
< CMLI >	(output) radiometrically calibrated output MLI (float)
[antenna]	(input) 1-way antenna gain pattern file or - if not provided
[rloss_flag]	range spreading loss correction: 0: no correction (default) 1: apply r^3 correction (all modes except ASAR APS) 2: apply r^4 correction (used only for ASAR APS mode) -1: undo r^3 correction -2: undo r^4 correction)
[ant_flag]	antenna pattern correction: 0: no correction (default) 1: apply antenna pattern correction -1: undo antenna pattern correction)
refarea_flag]	reference pixel area correction: 0: no pixel area correction (default) 1: calculate sigma0, scale area by sin(inc_ang)/sin(ref_inc_ang) 2: calculate gamma0, scale area by sin(inc_ang)/(cos(inc_ang)*sin(ref_inc_ang) -1: undo sigma0 area scaling factor -2: undo gamma0 area scaling factor
[sc_dB]	scale factor in dB (default: 0.0)
[K_dB]	calibration factor in dB (default: -(value from MLI_PAR))
[pix_area]	(output) ellipsoid-based ground range sigma0 or gamma0 pixel reference area (float) refarea_flag 1 or -1: sigma0 ref. area refarea_flag 2 or -2: gamma0 ref. area

Examples:

interp_ad gamma0 gamma0i $var1_cell 1 4 9 2 2 1

radcal_MLI HH.mli HH.mli.par - cmli - 0 0 1 0.0 0.0 sigma0_ellips_ref_area

float_math sigma0_ellips_ref_area gamma0i gamma0_norm $var1_cell 3

float_math HH.mli gamma0_norm HH.mli.gamma0_norm $var1_cell 2

geocode_back HH.mli.gamma0_norm $var1_cell lt_fine geo.HH.mli.gamma0_norm $var7_row $var8_col 5 0 - - 3

9) Generate Per-pixel Metadata Images

Mask of layover and shadow; Local Incidence Angle; Gamma To Sigma Ratio; Local Contributing Area

Examples:

Layover and shadow map

ls_map from outputs of pexel_area

Local incidence angle map

float_math inc - inc_deg $var7_row 2 - - - - 57.295779513082323

Gamma To Sigma Ratio

float_math gamma0 sigma0 GammaToSigmaRatio_pix $var1_cell 3

geocode_back GammaToSigmaRatio_pix $var1_cell lt_fine geo.GammaToSigmaRatio_pix $var7_row $var8_col 5 0

Local contributing area for Gamma0

geocode_back gamma0i $var1_cell lt_fine geo.pix_contribute_area_gamma0 $var7_row $var8_col 5 0

10) Creation of KML Footprint and Quick-look Images

Examples:

raspwr geo.HH.mli.gamma0_norm $var7_row - - 10 10 1 .35 1 Map_Overlay_${subdir}_${orbit_path}_${look_direction}.bmp

kml_map Map_Overlay_${subdir}_${orbit_path}_${look_direction}.bmp nova_geo.dem_par.tmp Map_Overlay_${subdir}_${orbit_path}_${look_direction}.kml

11) Scaling and GeoTiff Output

Examples:

Per-pixel Metadata Images as Annotation

```
data2geotiff nova_geo.dem_par.tmp ls_map 5 $output_file4.tif - 1
data2geotiff nova_geo.dem_par.tmp inc_deg 2 $output_file5.tif - 1
data2geotiff nova_geo.dem_par.tmp geo.GammaToSigmaRatio_pix 2 $output_file7.tif - 1
data2geotiff nova_geo.dem_par.tmp geo.pix_contribute_area_gamma0 2 $output_file8.tif – 1
```

Measurement

```
float_math geo.HH.mli.gamma0_norm - geo.HH.mli.gamma0_norm_amp $var7_row 6
float2short geo.HH.mli.gamma0_norm_amp geo.HH.mli.gamma0_norm_amp_cf 14125.3754 1.0 0 1
data2geotiff nova_geo.dem_par.tmp geo.HH.mli.gamma0_norm_amp_cf 6 $output_file1.tif - 1
float_math geo.HV.mli.gamma0_norm - geo.HV.mli.gamma0_norm_amp $var7_row 6
float2short geo.HV.mli.gamma0_norm_amp geo.HV.mli.gamma0_norm_amp_cf 14125.3754 1.0 0 1
data2geotiff nova_geo.dem_par.tmp geo.HV.mli.gamma0_norm_amp_cf 6 $output_file2.tif - 1
float_math geo.VV.mli.gamma0_norm - geo.VV.mli.gamma0_norm_amp $var7_row 6
float2short geo.VV.mli.gamma0_norm_amp geo.VV.mli.gamma0_norm_amp_cf 14125.3754 1.0 0 1
data2geotiff nova_geo.dem_par.tmp geo.VV.mli.gamma0_norm_amp_cf 6 $output_file3.tif – 1
```

Quick look images

```
gdal_translate -ot Byte -scale 0 15600 -outsize 1200 0 -r average $output_file1.tif QL_image_HH.tif
gdal_translate -ot Byte -scale 0 7800 -outsize 1200 0 -r average $output_file2.tif QL_image_HV.tif
gdal_translate -ot Byte -scale 0 15600 -outsize 1200 0 -r average $output_file3.tif QL_image_VV.tif
```

References

1. The GAMMA Software, https://www.gamma-rs.ch/software
2. CEOS Analysis Ready Data https://ceos.org/ard/