Documentation – User's Guide

Land Application Tools - LAT

GAMMA REMOTE SENSING

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List of acronyms

ASAR	*Advanced Synthetic Aperture Radar*
DEM	*Digital Elevation Model*
DIFF&GEO	*Differential Interferometry and Geocoding Software*
DISP	*Display Tools*
ENVISAT	*ENVIronmental SATellite*
ERS	*European Remote Sensing (Satellite)*
ESA	*European Space Agency*
ISP	*Interferometric SAR Processor*
SAR	*Synthetic Aperture Radar*
SRTM	*Shuttle Radar Topography Mission*

1. Introduction

The GAMMA Land Application Tools (LAT) is a collection of programs designed to support the data processing, data visualization, classification and parameter retrieval operations in the context of using SAR and SAR interferometry for land applications. The programs are thematically grouped into:

- Programs for Filtering and Parameter Estimation
- Programs for Test-Area Analysis
- Classification Tools
- Mathematical and Auxiliary Tools
- Visualization Tools
- Retrieval Algorithms
- Mosaicing Tools
- Polarimetric Tools

In the following Sections the set of programs included in a specific group are described. It is referred to the LAT Reference Manual for details on the individual programs, including their syntax and for processing examples.

The use of the programs in the LAT module in most cases does not require a parameter file, unless explicitly stated. This makes the programs of the LAT module extremely versatile as they can be applied to SAR datasets as well as to other image datasets.

2. Programs for filtering and parameter estimation

The information content and application potential of SAR data and interferometric products depends on appropriate filtering. Furthermore, from standard (possibly filtered) SAR and interferometric SAR product, additional images can be obtained which contain information not directly obtained with the original images. For example an image of the SAR texture highlights spatial variations in the backscatter of an image. The generation of additional products goes here under the name of "parameter estimation" where the term parameter stands for SAR parameter.

2.1. Filtering

Due to speckle noise, for example, the backscatter intensity of a single pixel of a SAR image is very poorly correlated to physical scene properties. Recovery of the radar cross section is necessary if the pixel-wise values are to be used in classification or retrieval of bio- and geophysical parameters. Similarly an image of the interferometric coherence might present local noise due to low fringe visibility. Filtering allows eliminating local noise and thus avoiding abrupt results in coherence-based thematic products.

Filtering operations can be performed in several domains (spatial, temporal, frequency). It is not the scope of this document to provide a detailed description of all possible approaches. The use of a specific filter depends on several factors, as well as the kind of result one is interested in. If aiming at obtaining an overall noise-free image, simple methods like spatial averaging are sufficient for the scope. If aiming at preserving/restoring the radar cross section of individual scatterers (e.g. in the case of high-resolution SAR data), the user might want to use an edge preserving or point-wise preserving speckle filter. A temporal approach is quite effective if a stack of images is available. Removal of noise without altering the spatial resolution is the major advantage of using such filter with respect to conventional spatial filters.

The GAMMA software includes a number of programs for filtering SAR and interferometric SAR images.

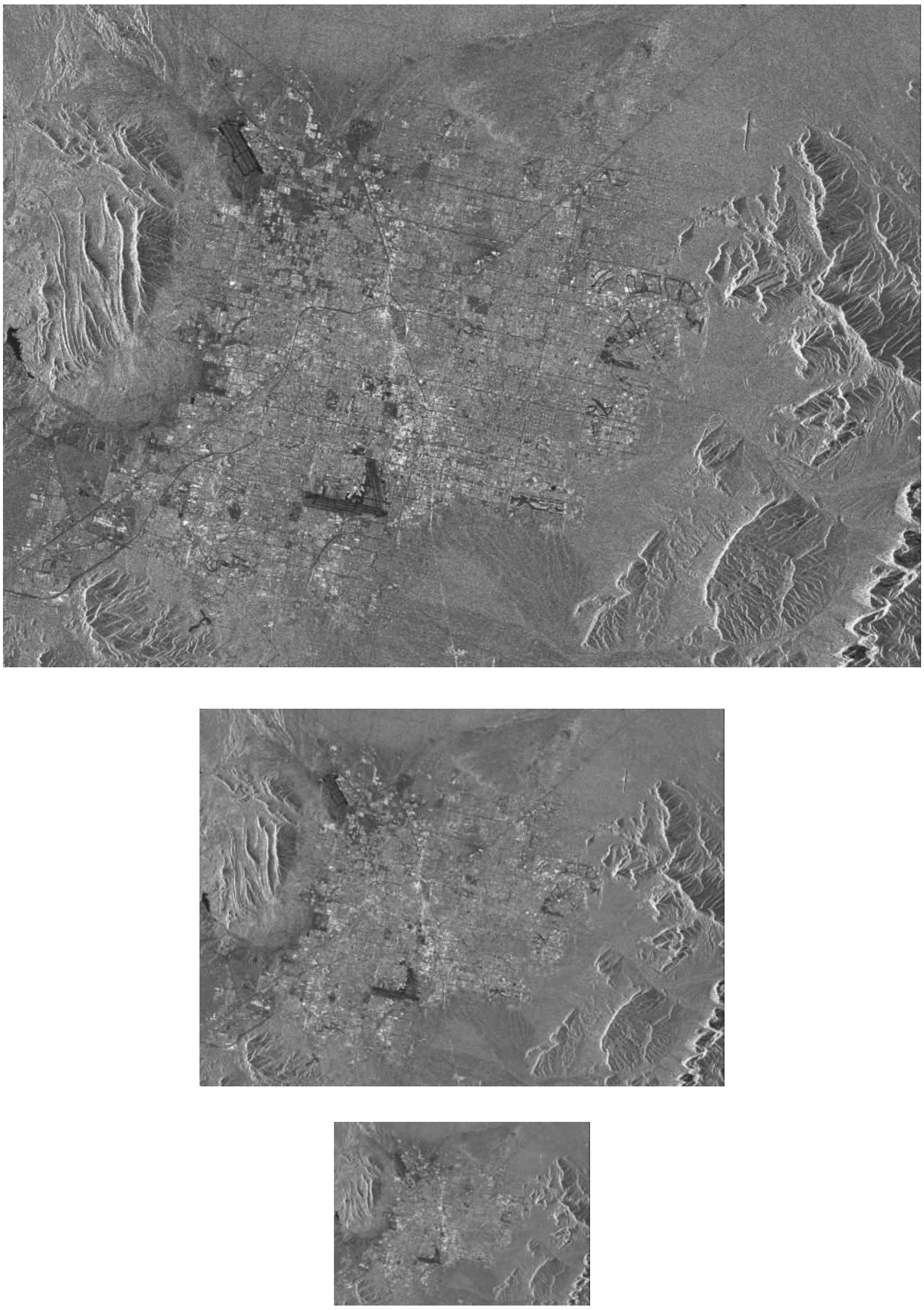
In the case of a single image the software offers the possibility of using a simple average filter, a median filter, and more specific speckle filters. In case of two or more image the user can choose between averaging co-registered images and using a more advanced filter that exploits the multi-temporal signatures of the backscatter using a weighting approach. A short introduction to each program is provided below. For additional details it is referred to the LAT Reference Manual.

Spatial filtering is applied to single images and consists in defining around each pixel a finite-size window and exploit statistical properties of the signal within the window to decrease noise and thus increase the signal content at the specific pixel.

A simple method for decreasing noise is spatial averaging. Only when averaged over a sufficient number of pixels the signal (backscattering or coherence) will become more related to physical scene properties. This operation is referred to as multi-looking. Multi-look factors define the size of the window in which averaging takes place. As a result the average value replaces the set of values in the window. Multi-looking (in space) reduces significantly noise but is also affecting the spatial resolution, which decreases proportionally to the product of the window size. Multi-looking is supported by the program ***reallks*** for real-valued data and by ***cpxlks*** for complex-valued data. In addition, the ISP module includes similar programs for multi-looking (e.g. ***multi_look*** and ***multi_look_cpx***), the difference being that while these programs need the availability of an ISP parameter file. It is referred to the User's Guide and the Reference Manual of the ISP module for details.

Figure 1 shows the result of spatial multi-looking on an ERS SAR intensity image acquired over Las Vegas. Starting from an image with 20×20 m^2 pixel size (top), the corresponding multi-looked versions using a 2×2 and a 4×4 window have been obtained with ***reallks*** (centre and bottom respectively). While speckle noise has substantially decreased, several details have been lost as a consequence of the reduced spatial resolution. The image in the middle represents a 4-looks version of the original SAR intensity image. The image at the bottom represents a 16-looks version of the original version.

The LAT includes a number of programs for filtering in the spatial domain, which leave the size of the image to be filtered unchanged. With average filtering the original pixel value is replaced with the mean value obtained by averaging over the values of the pixels included in the filtering window. Average filter is supported by the program ***average_filter***. This approach is only partially effective in reducing noise, especially speckle noise in SAR backscatter images, since it implies a strong loss of spatial resolution and a biased solution in case of outliers or textured features (such a point targets) within the averaging window. A median filter is less affected by extreme values and is also less prone to produce blurred features. Still resolution is lost and speckle noise cannot be optimally filtered out. A median filter is probably a good option for filtering a coherence image. Median filtering is supported by the program ***median_filter***. More effective for reducing speckle noise in SAR backscatter images, while attempting to preserve spatial resolution and point-wise scattering are filters specifically set up for this purpose. The software supports filtering with the original Lee filter [1] implemented in the program ***lee***, with the enhanced Lee filter [2] implemented in the program ***enh_lee***, with the Frost filter [3] implemented in the program ***frost*** and with the Gamma MAP filter also called enhanced Kuan filter [2] implemented in the program ***gamma_map***. For details it is referred to the Reference Manual.



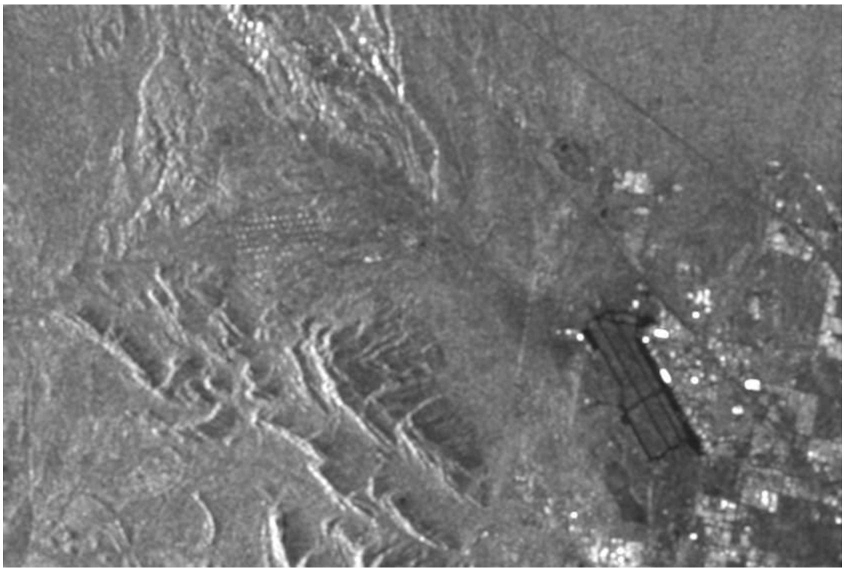
$20 \times 20\ m^2$

$40 \times 40\ m^2$

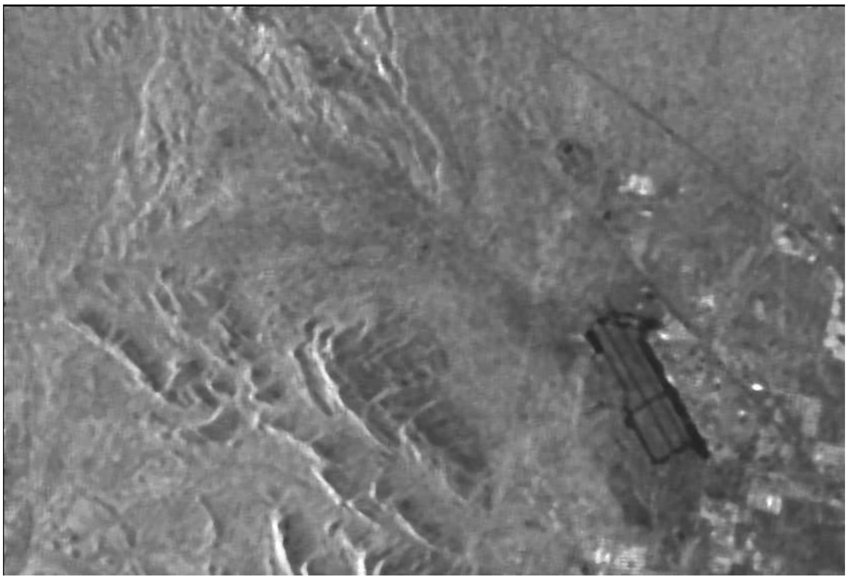
$80 \times 80\ m^2$

Figure 1. ERS-2 SAR intensity image acquired over Las Vegas at three different spatial resolutions. Top: original image. Centre: 2 × 2 multi-looked version. Bottom: 4 × 4 multi-looked version.

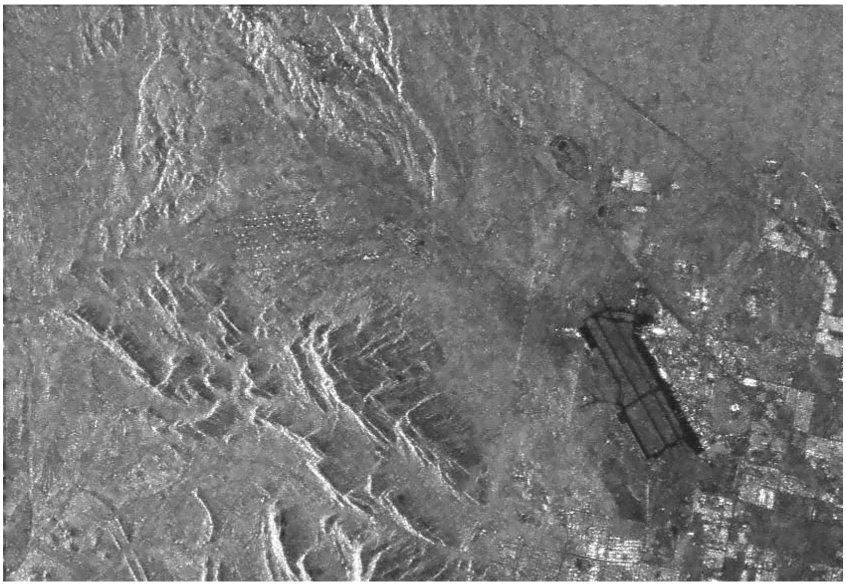
(a) Original SAR intensity image (unfiltered)



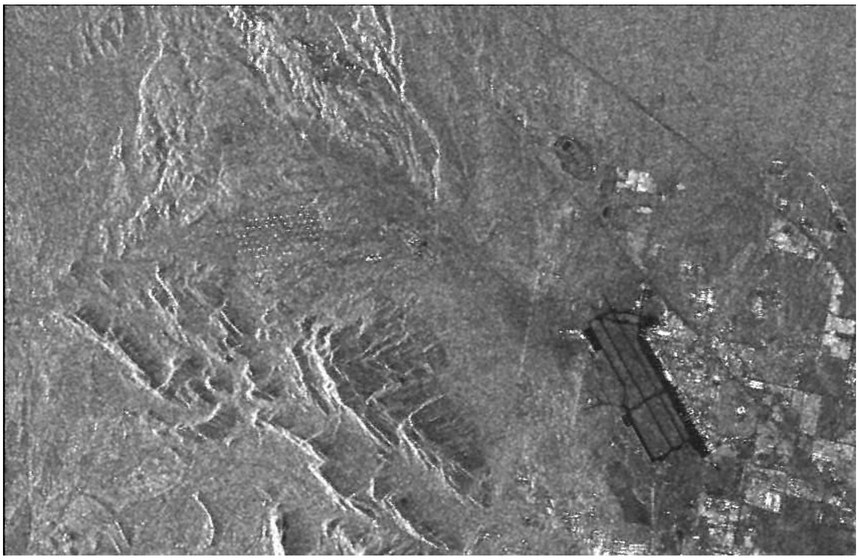
(b) Average filter (7 × 7 window)



(c) Median filter (7 × 7 window)



(d) Lee filter (7 × 7 window)



(e) Frost filter (7 × 7 window)

(f) Gamma MAP filter (7 × 7 filter)

Figure 2. Result of different speckle reduction techniques on an ERS-2 SAR intensity image acquired over Las Vegas.

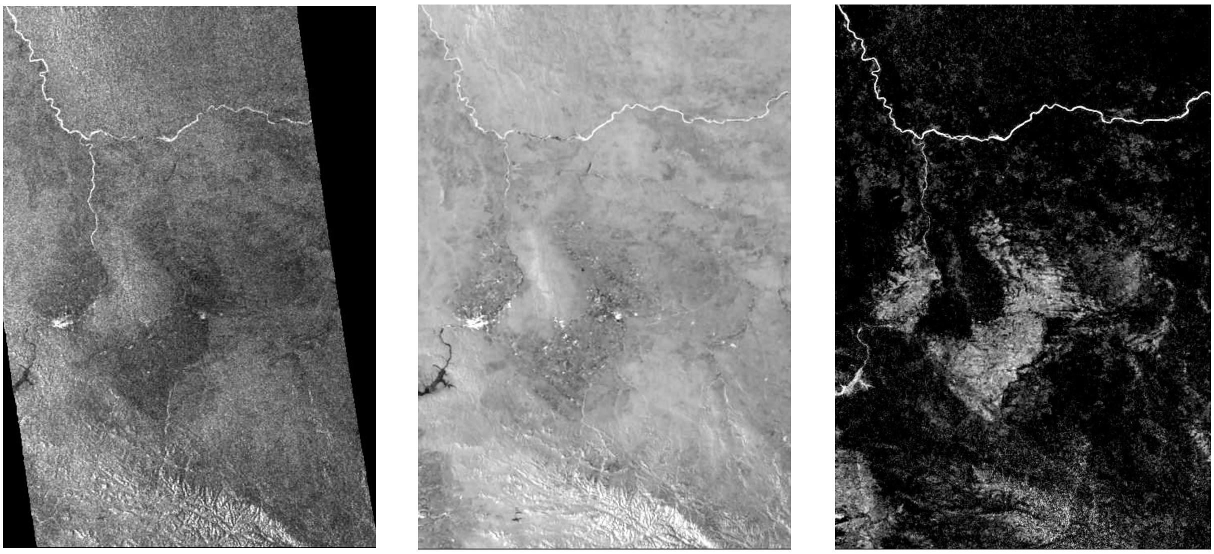
Figure 2 shows the effect of each of the filters described in the previous paragraph for a subset of the ERS SAR intensity image acquired over Las Vegas. The original image is clearly affected by speckle in non-urbanized areas, whereas clear point-wise scatterers appear in the urbanized area located close to the bottom right corner. The image also presents a large range of SAR backscatter values, ranging from very low backscatter in correspondence of the airport (the runways are clearly discernible) and very high backscatter in the urban areas and in mountainous terrain due to layover effects. The average filter substantially reduced speckle but also blurred point-wise significantly, with clear loss of fine scale features. The median filter performed even better but as for the average filter fine details are lost. The Lee, the Frost and the Gamma MAP filtered images show clear speckle reduction without substantial loss in resolution. Preservation of point-wise targets can be improved with the enhanced Lee filter. [4]. Depending on the choice of the filtering parameters the output can be adjusted to match with the expected result after speckle reduction.

Besides the original and the enhanced Lee filter, the LAT module offers a directional Lee filter**, *mt_lee_filt*** [5]. This adaptive filter uses a set of several edge aligned window functions to select the homogeneous area associated with a particular pixel. The algorithm determines the window that best describes the region that a particular pixel belongs to. The filter is than applied to each image in a list of images specified by the user. A reference scene used to compute the weighting coefficient and filter window is required (e.g., an average image). The user has the option to save the weighting factor, edge-aligned filter number, and the mean/sigma ratio. For an example, it is referred to the LAT Reference Manual. For complex-valued data, the filter is supported by the program ***mt_lee_filt_cpx.***

Temporal filtering consists in exploiting the signatures of a scatterer in multiple images to detect the stochastic part of the signal. In this case it can also be referred to multi-looking in the temporal domain. In the LAT module the program ***ave2pwr*** averages two registered real-valued images, e.g. SAR backscatter images. In case one intends obtaining the average image for a larger dataset, the multi-temporal programs ***temp_lin_var*** and ***temp_log_var*** are available. With these programs temporally uncorrelated signals are filtered so that the resulting product appears with less speckle noise, without loss of resolution. More effective speckle reduction is achieved when more than two images are averaged. For this reason it is recommended to use the multi-temporal programs if more than two images are available. While the program ***temp_lin_var*** determines an average value of the original pixel values, the program ***temp_log_var*** determines the average value using a logarithmic scale. This approach should be preferred when working with SAR intensity images. For details it is referred to the Reference Manual. These programs also generate an image of the temporal variability of the signal (i.e. backscatter, coherence). It is recommended to filter the images for noise before proceeding with the computation of the temporal variability. In this context it is advised to use the approach for speckle filter described below for multi-temporal datasets.

Figure 3 shows an example of SAR intensity image acquired by ENVISAT ASAR (C-band) in ScanSAR mode over Siberia, the temporal average based on more than 100 similar images and the corresponding image of temporal variability (also referred to in some cases to MVA image, i.e. mean annual variability) [5]. The temporally filtered image in Figure 3b show less noise but also slightly less contrast with respect to the single SAR intensity image in Figure 3a. Both images show some features namely two major rivers along the east-west and north-south direction, the very bright target corresponding to the city of Krasnoyarsk. The large patches of somewhat lower backscatter correspond to cropland and pasture whereas the bright areas correspond to forest. The image of temporal variability in Figure 3c highlights clearly the rivers and the cropland/pasture areas because of the stronger variations of the SAR backscatter in time with respect to forest and urban areas.

In the case of complex-valued images (e.g. differential interferograms), filtering is implemented in the program ***ave_cpx***. This is a simple approach to decrease stochastic signal due for example to atmospheric disturbances. The program however does not generate the individual filtered version of the input images but just an average of these.

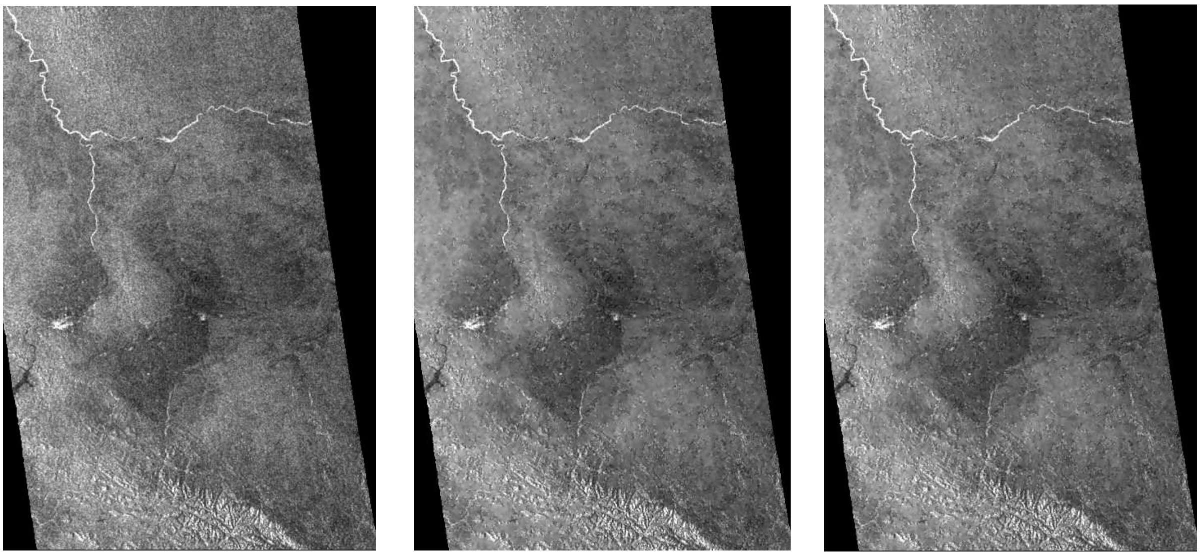


(a) (b) (c)

Figure 3. (a) ENVISAT ASAR Global Monitoring Mode intensity image, (b) temporally averaged intensity image based on more than 100 SAR intensity images, (c) temporal variability of SAR intensity. Area: Siberia.

The output of the temporal filters described above consists of a single image, representing the temporally averaged signal. If the user is interested in obtaining the filtered version of the individual SAR images, multi-temporal filtering of co-registered SAR images is supported by the program ***temp_filt*** and by the more advanced program ***temp_filt_ad***, which uses adaptive spatial mean estimate [5] in support of the filtering. The latter program is more effective in reducing speckle noise since it uses previously determined estimates of speckle-reduced SAR backscatter values using a spatial filter. The most important aspect for the optimal reduction of speckle is that the images used must be uncorrelated. If N SAR backscatter images form the stack of data to be filtered for speckle, the output consists of N filtered images.

Figure 4 shows a comparison between the SAR intensity image of Siberia already displayed in Figure 3 and the corresponding version obtained after multi-temporal filtering using more than 100 SAR intensity images. After multi-temporal filter large part of the speckle noise has been removed while local features have not been distorted. Figure 4 also shows the image obtained after filtering with a Gamma MAP filter. The quality is similar to the image obtained with multi-temporal filtering techniques even though the texture is of poorer quality.



(a) (b) (c)

Figure 4. (a) SAR intensity image unfiltered, (b) filtered version using Gamma MAP filter, (c) filtered version using multi-temporal filter. The image was acquired by ENVISAT ASAR in Global Monitoring Mode over Siberia.

2.2. Parameter estimation

The main purpose of the filtering, averaging is to obtain high-quality images, which can be exploited as such or can be further used for generating additional products ready to be interpreted.

The ratio of two backscatter images allows detecting temporal changes (in case of two images of the same type acquired at different times) or differences in the scattering (in case of two images acquired at different polarizations). A prominent aspect of ratio images is also the independence from topography-induced effects. While the backscatter in SAR images is strongly affected by topography, the ratio of two backscatter images cancels out the same signal due to topography. The generation of a ratio image (which corresponds to the difference of two images in the dB scale) is supported by the program ***ratio***. The image of the ratio is best computed using filtered images although the program ***ratio*** supports averaging around the pixel of interest to reduce the effect of point-wise noise. Figure 5 shows the ratio image between two images acquired by ERS-1 and ERS-2 with one-day temporal separation over Las Vegas. The images have been filtered for speckle before proceeding with the computation of the ratio. Some differences can be seen in correspondence of bare soil areas at the top and the bottom of the image, very likely caused by a variation of soil moisture in consequence of rainfall between acquisitions.

The compensation of topography-induced effects on the SAR backscatter is actually a widely discussed topic. Several methods have been presented in literature, which primarily exploit the local incidence angle, e.g. [6, 7]. For a correct interpretation of SAR backscatter signatures, correction for the effect of both local incidence angle and normalization for the true pixel area is necessary [8]. Basically, pixels located on the slope facing the radar presents higher backscatter compared to the backscatter from pixels located in areas of shadow, due not only to the orientation of a pixel but also to the fact that the area illuminated depends on the orientation. The corrected backscatter in gamma nought, γ^0, format can be obtained from the sigma nought, σ^0, value according to [8, 9]:

$$\gamma^0{}_{pix} = \sigma^0 \frac{A_{flat}}{A_{slope}} \left(\frac{\cos\theta_{ref}}{\cos\theta_{loc}} \right)^n \qquad (1)$$

where θ_{loc} and θ_{ref} represent the local incidence angle and a reference angle for normalization of the backscatter (e.g. the incidence angle at mid-swath), respectively. A_{slope} and A_{flat} represent the true pixel area and the local pixel area for a theoretically flat terrain, respectively. The factor n is related to the opacity of the scattering media. In case of surface scattering it is equal to 1. It can be assumed that n=1 provides an overall acceptable solution also in case of layered media in most cases.

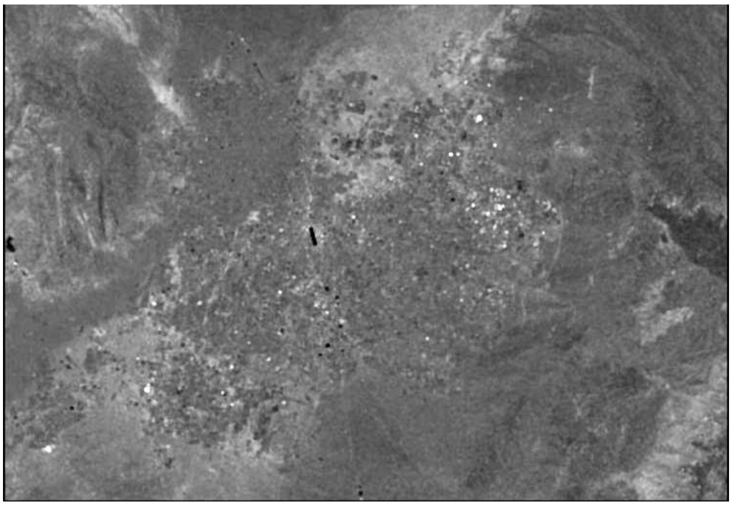


Figure 5. Image of the ratio between two SAR intensity images acquired by ERS-1 and ERS-2 over Las Vegas with one-day temporal separation.

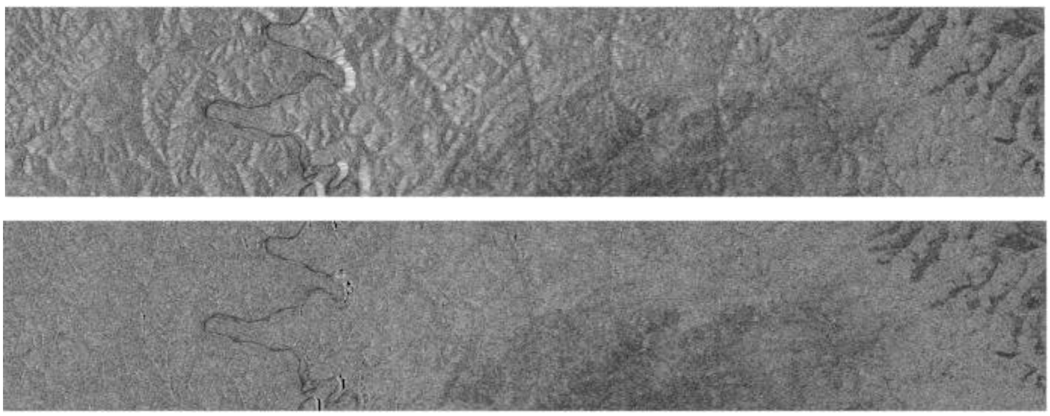


Figure 6. Backscattering coefficient images of an ENVISAT ASAR Wide Swath Mode before (top) and after compensation for topography-induced effects [10].

With the programs available in the LAT module, the compensation for topographic effects as described in (1) can be achieved in two steps. From the sigma zero image, also referred to as sigma nought image i.e. a conventional SAR intensity image, the corresponding gamma zero (or gamma nought) image is obtained by dividing by the cosine of the local incidence angle. The generation of the gamma nought image is supported by the program ***sigma2gamma***. For this an image of the local incidence angle is necessary. This can be obtained with the programs ***gc_map*** or ***gc_map_grd***, which are part of the DIFF&GEO module. A Digital Elevation Model is required. The second step consists in compensating the gamma nought image for the different effect of the pixel area. This is done by taking the product of the gamma nought image times the image of the pixel area normalization factor, which is also obtained by using the programs ***gc_map*** or ***gc_map_grd***. The image of the pixel area normalization factor corresponds to the ratio A_{flat}/A_{slope} in (1). The generation of a product image is supported by the program ***product*** (more information can be found in Section 5).

The same procedure can be applied by using the output of the program ***pixel_area*** (DIFF&GEO) module. The program generates an image of the local incidence angle in map geometry just as above and an image of the pixel area in map geometry. Each pixel represents the area of that pixel in the radar geometry. Dividing the area of a pixel (obtained from the range and azimuth pixel spacing in the ISP SLC parameter file) by the image of pixel area allows obtaining the area ratio in Equation (1).

Finally, the absolute level of the backscatter can be compensated for by multiplying the result from ***product*** for the cosine of a reference angle, θ_{ref}. This can be achieved with the program ***lin_comb*** which will be described in Section 5 in more details. Figure 6 shows the result of compensating for topography-induced effects in the case of a SAR intensity image acquired by ENVISAT ASAR in Wide Swath Mode. For a correct result a DEM with a spatial resolution similar to the pixel size of the SAR image should be used.

The spatial variability of the SAR backscatter is an additional parameter, which is particular useful in land-use mapping since it allows distinguishing for example between urban areas, which are characterized by clear spatial differences due to high backscatter from buildings and low backscatter from roads and flat horizontal surfaces, and forests, which are indeed characterized by a spatially homogeneous backscatter. Texture metrics can be defined in different manners. The LAT includes the program ***texture*** for the computation of a texture image, which corresponds to the ratio between the standard deviation of the pixel values within a finite window size and the corresponding mean value. More details on the implementation and the possibilities offered by this program can be found in the Reference Manual. Figure 7 shows an image of texture defined as the ratio between the standard deviation and the mean for an ERS-2 SAR intensity image acquired over Las Vegas. Texture is particularly high in the urban context whereas the smooth open areas surrounding the city present low texture.

Figure 7. Image of texture for a ERS-2 SAR intensity image acquired over Las Vegas. Window size was 7 × 7 pixels. To avoid loss of resolution Gaussian windowing has been used.

Generation of an interferometric coherence image has been discussed in the ISP User's Guide and the Documentation to interferometric processing. It was mentioned that estimation using an adaptive window size has the advantage to decrease the estimation bias and improve the accuracy of the estimate, while attempting to preserve spatial resolution. The adaptive estimation method is implemented in the program ***cc_ad***. The user can select the minimum and maximum window size, as well as the weighting function in order to decrease the relevance of pixels close to the window edges on the final estimate. This is a measure to preserve spatial resolution. The use of a texture image or a slope image can be of help in improving the coherence estimation in areas of significant spatial variations of the scattering or strong elevation variations respectively. Figure 8 shows a comparison of an ERS-1/2 tandem coherence images over Las Vegas obtained with the ISP program ***cc_wave*** (left) and the adaptive estimation method in ***cc_ad*** (right). The coherence image obtained with the adaptive estimation method presents a stronger contrast due to the fact that low coherence areas have smaller bias. The level of noise has also decreased because of the smaller uncertainty of the coherence estimates, in particular in case of low coherence.

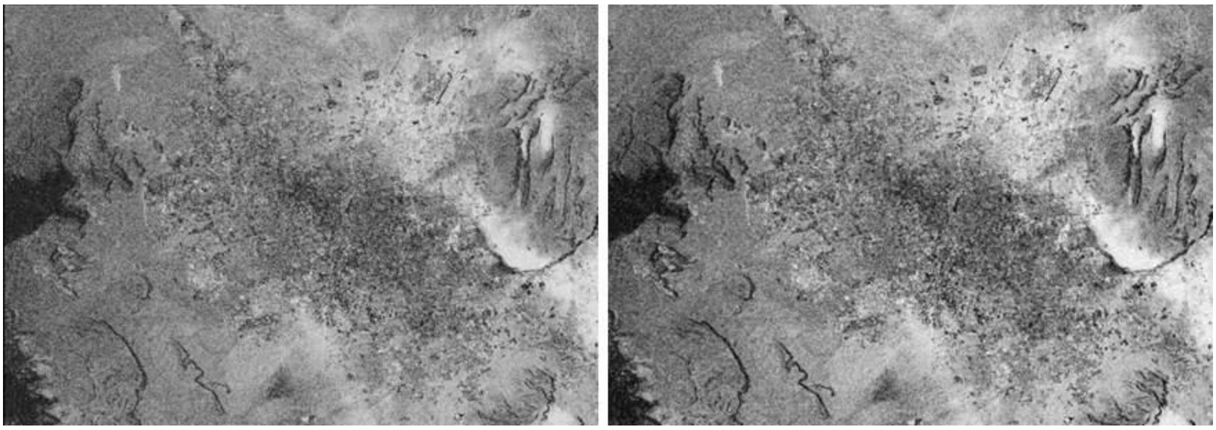


Figure 8. ERS-1/2 tandem coherence images over Las Vegas obtained with fixed estimation window size (5 × 5) and the adaptive estimation method with window size varying between 3 × 3 and 9 × 9 pixels. Larger windows are used in case of lower coherence. Gaussian windowing has been used to avoid loss of resolution in case of large estimation windows.

3. Programs for test-area analysis

The test-area analysis tools are a very useful research tool for signature analysis and retrieval algorithm development. The programs for test-area analysis allow to select polygon regions corresponding to test areas (for example forest stands, agricultural fields, etc.) and to extract the average signatures (mean values) and the statistics (standard deviations, histograms) for such polygon regions, respectively test-areas. The signatures of test-areas are of interest for signature studies. Extracted signatures may be interpreted and related to physical scene properties. Extracted signatures may also be used for quality control purposes. As an example the effect of different processing on the coherence may be investigated.

Selection of polygon regions is supported by the program ***polyras*** (part of the display DISP module). Once a set of polygons has been generated, the user can simply extract values from a SAR or interferometric SAR image, compute mean and standard deviation for each polygon, and determine an histogram.

Extraction of values, to be stored eventually in a text file, is supported by the program ***takethat***. This is a multi-purpose program which allows extracting values also along a given profile or for indicated pixel positions. If the image is in geocoded format, the program ***takethat_dem_par*** allows extraction of values for a subset indicated in terms of map coordinates. For extraction of values along a vertical or horizontal profile the user may prefer the program ***take_cut***. This program is useful for example when evaluating the quality of an image across range (i.e. in the case of a calibrated SAR intensity image).

In case one is interested in determining first order statistics (i.e. mean value and standard deviation) for each polygon selected with ***polyras*** without storing the actual values within the polygons, the programs ***polyx*** and ***polyx_phase*** should be used. In case of data in floating point format (e.g. SAR intensity, coherence images) the program to be used is called ***polyx***. For phase images, the corresponding program is called ***polyx_phase***. It allows extracting phase statistics in case of an interferogram, as well as SAR intensity values from the two images forming the interferometric pair. The output of each of these program consists of a text file with several column, each corresponding to a specific parameter (mean or standard deviation). For details on the specific format of the output it is referred to the LAT Reference Manual.

Another possibility offered by the LAT once a set of polygons has been created with ***polyras*** is to compute the histogram, i.e. the occurrence for a given number of bins, as well as mean and standard deviation, for each polygon given an image. The program ***histogram*** supports calculation of histograms for an image in floating point format. The program ***histogram_ras*** supports the calculation of histograms in case the image is in SUNraster or bmp format. For both programs the user can select the range of values for which the histograms should be computed. The number of bins is fixed and is equal to 50.

With the program ***looks*** it is possible to determine a measure of the effective number of looks of an image given a set of polygons. In this way an indication on the level of speckle noise characterizing the image can be obtained. The program ***looks*** implements two methods for the computation of the equivalent number of looks (ENL). It is referred to the Reference Manual for details. To determine the ENL it is fundamental to select polygons over large areas with homogeneous scattering properties and with intensity well above the noise floor. Typically large forested areas are selected when aiming at determining an estimate of the ENL.

4. Classification tools

There is wealth of straightforward to advanced methods for classification of SAR and interferometric SAR images. The LAT supports classifications based on SAR and SAR interferometric data with a number of relatively simple and therefore transparent classification algorithms. Classification of single as well as multiple datasets is supported. The output consists of images in SUNraster format.

The program ***cc_monitoring*** implements a threshold-based classification approach in the case of a multi-temporal dataset consisting of at least 2 co-registered image. The user defines a single threshold. The number of classes is defined by the number of images to be used in the classification (2^n). If only two images are used the output will consist of a simple change map. If the input consists of more than two images there will be a larger number of classes. For each pixel the algorithm determines if the values of the different input files is above or below the indicated threshold. In this way it is possible to monitor different levels of change due for example to freezing, farming activities, snow cover and so on.

Mapping of a single class based on multiple input files using a threshold-based approach is supported by the program ***single_class_mapping***. For example, given a coherence image and the corresponding two SAR intensity images, a forest/non-forest map can be obtained by setting for each input band a minimum and a maximum threshold so that all values in between correspond to forest. The output consists of a black/white image, with white corresponding to the pixels detected as belonging to the class of interest.

The program ***multi_class_mapping*** implements the functionality of the previous program to obtain a map with more than two classes. For this a table including for each class of interest the minimum and maximum threshold for each of the input bands is required. The output consists of a SUNraster image with a number of levels corresponding to the number of classes the users wants to determine. The user can additionally select a color table for the output. For details it is referred to the LAT Reference Manual.

The result of classification is likely to be affected by point-wise errors, due for example to residual noise or speckle in the input data. To remove local errors the LAT supports majority filtering with the program ***ras_majority***. The user can select the window size. Larger windows have the advantage of a more robust detection of noise however it can also introduce errors in particular in patchier landscapes.

Finally the possibility to set the values of an image in correspondence of one or more specific classes to a certain level is supported by the program ***mask_class***. This is the case if for example the values of a coherence image in correspondence of a certain number of classes defined in a land-cover map shall be excluded from further evaluation of the image.

Validation of a classification result is supported by the program ***validate***. The result of classification is compared against a reference map. The program generates an image indicating areas of agreement, false detection and missed detection. The program also generates a confusion matrix, indicating user's and producer's accuracy and an estimate of the kappa coefficient of agreement. It is referred to the LAT Reference Manual for details.

5. Mathematical and auxiliary tools

The LAT offers a number of programs for different types of operations with images (not strictly SAR images) which can be useful either to convert a dataset into a format compatible with the programs of the GAMMA software or at the post-processing level to improve quality or obtain further products from a set of input images.

5.1. Mathematical tools

Mathematical tools include the possibility to

- Linearly combine two or more images, thus also allowing scaling a single image
- Generate images based on parameters of the histogram of a multi-temporal dataset
- Perform arithmetic on image regions (polygons)
- Perform logical operations on mask files
- Convert between linear and dB scale

Linear combination of two or more images can be used to obtain a set of new images with different properties with respect to the input dataset. The user can also select a single image as input, in which case the programs for linear combination allow the scaling of the image with a specific factor. For real-valued data linear combination is supported by the program ***lin_comb***. For complex-valued data the linear combination is supported by the program ***lin_comb_cpx***. These programs can be used for adding/subtracting images by setting the corresponding coefficients to +1 or -1. The program ***lin_comb_ref*** combines one image with information derived from a second image selected as reference. Information refers to a value derived from the second image for example by averaging within a window of fixed size placed by the user at a certain location. This program is useful to apply corrections to an unwrapped interferogram based on reliable information available in a second (reference) interferogram.

The program ***multi_stat*** allows generating an image representative of a parameter of the histogram of a time series of images (real-valued). The program offers the choice between average, median, rank and percentile images. The user can choose the number of images to be used to determine the histogram parameter. Images such as minimum and maximum backscatter can be generated having available a stack of MLI images (co-registered) of a certain area.

The product of two images is supported by two programs. The program ***product*** is specific for real valued images and is useful to obtain from the magnitude of an image the corresponding intensity image. The program ***product_cpx*** is specific for complex-valued datasets. The possibility to compute the product of an image and the complex conjugate of a second image is supported.

The program ***trigo*** supports several trigonometric operations. It is suited for images containing angle data.

To scale and offset values in a specific region (polygon) the LAT offers the program ***poly_math***. The polygons can be obtained with the program ***polyras*** as described in Section 3.

This program is particularly of aid in phase unwrapping. For details it is referred to the Reference Manual.

Logical operations on mask files can be performed with the program ***mask_op***. With the GAMMA software masks can be obtained with a number of programs such as those used during phase unwrapping (see User's Guide of the ISP module) or by replacing values above/below/equal a certain value with the program ***replace_values*** (see Section 5.2).

For a better interpretation of SAR intensity images it is generally more suitable to work in the dB scale rather than in the linear scale. The dB scale corresponds to taking 10 * $\log_{10}$ of the intensity image. In this way low intensity values are stretched to allow a clearer differentiation. Conversion from linear to dB scale (and vice versa) is supported by the program ***linear_to_dB***. Herewith it is remarked that any operation including speckle filter, geocoding etc. on a SAR intensity image must be done in the linear scale. In other words, the conversion to dB scale should be considered only when the SAR intensity image is in its final format.

5.2. Auxiliary tools

Auxiliary tools include the possibility to

- Convert the format of a file (e.g. from short integer to floating point)
- Replace values
- Interpolate to fill gaps

The values of an image file, assuming that it is in plain binary format, can contain different number of bytes. The LAT supports conversion between several formats with the following programs. It is assumed that the image data file is real-valued.

- ***float2short***: conversion from floating point format (4 byte) to short integer (2 byte)
- ***float2uchar***: conversion from floating point format (4 byte) to character (1 byte)
- ***short2float***: conversion from short integer (2 byte) to floating point format (4 byte)
- ***uchar2float***: conversion from character (1 byte) to floating point format (4 byte)

Conversion to floating point format allows using all programs of the GAMMA software dealing with real-valued data. This is for example the case of DEMs available in short integer format (e.g. SRTM). Conversion from floating point to a smaller number of byte has the advantage of reducing memory usage, thus being recommended when a final product has been obtained (e.g. a DEM from interferometry).

In the case of complex-valued datasets conversion from floating point to short format is supported by the program ***radcal_SLC***, part of the ISP module.

The conversion of an unwrapped interferometric phase image (real-valued dataset) to a complex interferogram (same phase, amplitude equal to 1) is supported by the program ***unw_to_cpx***. This is of use when improving an interferogram.

Replacing values in an image (constant or based on a second image file) is supported by the program ***replace_values***.

Interpolation to fill gaps is supported by two programs. For 1-D interpolation along a specific line the user can use the program ***line_interp***. For 2-D interpolation of real-valued datasets the program ***restore_float*** can be used. It should be noted that the GAMMA software also offers an adaptive interpolator available in the ISP module, implemented in the program ***interp_ad***. For details it is referred to the User's Guide and the Reference Manual of the ISP module. This program supports several formats, not only floating point format. The combined used of interp_ad and replace_values has been in the Appendix of the User's Guide on Geocoding and Image Registration (DIFF&GEO module) how this program can be used to fill gaps in a DEM.

6. Visualization Tools

The visualization tools complement the display tools of the display DISP module. For the display of one or multiple data sets (files of type float) programs to generate SUNraster files are included. Linear and logarithmic scaling (dB scale) is supported. In addition there are programs for the generation of red/green/blue (RGB) and hue/saturation/intensity (HSI) composites of 3 three input data files. RGB composites are particularly well suited to visualize the available information with respect to land applications. The HSI composites are well suited for an alternative display of phase information (in combination with coherence and intensity information) and again for the visualization of classification and parameter retrieval results (by overlaying the result with the SAR image intensity, for example.

The philosophy has been to keep the visualization tools general enough for a wide applicability. In addition to the more generally applicable routines a few routines for more specific tasks (task we typically encountered in interferometric signature analysis studies) were included.

The generation of color composites of three image channels (in SUNraster or bmp format) is supported by two programs, depending on the color coding. For red/green/blue color coding the program ***ras_to_rgb*** shall be used. For hue/saturation/intensity color coding the program ***ras_to_hsi*** shall be used. The output consists of a 24-bit image in SUNraster or bmp format. Generation of color scale image generated with program ***ras_to_hsi*** is supported by the program ***hsi_color_scale***.

Once an image in a color coded format is available, it can be combined with the intensity information from a second file in SUNraster or bmp format to form a further composite. The program ***comb_hsi*** supports this combination. The hue/saturation/intensity (HSI) of the output image corresponds to the hue/saturation of the first and the intensity of the second input image.

Further manipulation of a SUNraster or bmp file can be done with the program ***ras_ras*** which allows multi-looking, format conversion, flipping etc. of the input data file.

For geocoded images, which generally are placed diagonally with respect to the canvas of the image, it is useful to change the color of the background from black to another color (e.g. white). This operation is supported by the program ***frame***. The program supports SUNraster or bmp datasets both in 8- and 24-bit format.

Annotation of a SUNraster or bmp image in form of arcs, polygons, crosses, or points at specified positions is supported by the program ***drawthat***.

7. Retrieval algorithms

The GAMMA software currently supports a retrieval algorithm for soil moisture from multi-temporal ERS data (see Reference Manual for details). This algorithm has been included in the program ***soil_moisture*** as an example of how SAR and interferometric signatures may be used for actual retrieval of geophysical or biophysical parameters.

8. Mosaicing

Mosaicing multiple geocoded images can be extremely useful when targeting the monitoring of large areas. The LAT offers two programs for mosaicing. Both programs generate a mosaic of geocoded images with same format, map projection, and pixel spacing parameters. The program ***mosaic*** requires on the command line the name of each single input file and the corresponding DEM parameter file. The program ***multi_mosaic*** requires on the command line a list of the image files to be mosaiced and the corresponding DEM parameter files. The list must be stored in an ASCII file. The program ***multi_mosaic*** is recommended in case a large dataset of images should be mosaiced. Assuming that the files to be mosaiced have all the extension “geo” and the corresponding DEM parameter files have extension “dem_par”, the list required by ***multi_mosaic*** can be easily generated with the Linux commands ls and paste as follows

*ls –d *.geo > list_geo*
*ls –d *.dem_par > list_dem_par*
paste list_geo list_dem_par > list_multi_mosaic

The first line generates the list of images to be mosaiced and stores it in the text file list_geo, the second line generates a text file containing the list of DEM parameter files, the third line pastes the two lists together to form a third list containing in the first column the list of the images to be mosaiced and in the second column the list of DEM parameter files. The file list_multi_mosaic can be used as input to the program ***multi_mosaic***.

It should be also remarked that the program ***mosaic*** can be used to extract a subset from a geocoded image, assuming that the DEM parameter file for the subset is available. In this way tiling of images is possible.

9. Polarimetric tools

The LAT includes several programs with which a number of polarimetric features and products can be obtained. With these programs also several target decomposition approaches are possible. For further details on the use of the polarimetric tools and their usefulness, it is referred to the manual on Polarimetric Tools. Details on individual programs and the theory behind can be found in the LAT Reference Manual.

The programs ***stokes*** supports the generation of the Stokes parameters from co-polarized and cross-polarized linear polarization SLC images. The Stokes parameters can be used in the program ***stokes_qm*** to derive quantitative measures such as the degree of polarization.

From the Stokes parameters, it is possible to derive the following decompositions (see also the LAT Reference Manual for details)

- *m-alpha* polarimetric decomposition (alpha is a parameter in the *H/anisotropy/alpha* decomposition). This decomposition is supported by the program ***m_alpha***
- *m-chi* polarimetric decomposition for compact polarimetry. The components are proportional to the single-bounce, random, and double-bounce components of the backscatter. This decomposition is supported by the program ***m_chi***
- *m-delta* polarimetric decomposition to obtain the degree of polarization derived from the Stokes parameters and the H/V phase difference. This decomposition is supported by the program ***m_delta***

The Pauli decomposition of the scattering matrix allows the generation of a new set of images used to derive additional polarimetric parameters. The Pauli decomposition is supported by the program ***pauli***. From the Pauli components, the coherency matrix T is generated with the programs ***polcoh***. The program ***haalpha*** supports the decomposition of a polarimetric dataset in entropy, anisotropy, alpha channels and the three eigenvalues from the Pauli decomposition of the scattering matrix [12].

In case of dual-pol data, the Wolf coherence matrix can be generated with the program ***wolf***. for details, it is referred to the Reference Manual.

From the elements of the scattering matrix, the covariance matrix C can be generated with the program ***polcovar***.

Synthesizing compact polarimetric data channels from quad-pol data is supported by the program ***quad2cp***. The user can decide whether the synthesized transmitted data should be right or left circularly polarized. The output consists of the linear polarization H and V received in correspondence of the synthesize compact polarimetric dataset.

The program ***diplane_helix*** supports the decomposition of the scattering matrix expressed in its left and right circular format into the diplane and helix components (Krogager decomposition, [11]).

Other target decompositions are supported by batch scripts running programs of the LAT module

- ***CLOUDE_DEC*** supports eigenvector-based target decomposition proposed in [13]

- ***FD3C_DEC*** supports the surface, double-bounce, volume scattering decomposition proposed in [14].
- ***HUYNEN_DEC*** supports the equivalent single target decomposition, Huynen decomposition

For details on each of the target decomposition approaches and processing examples, it is referred to the Manual on polarimetric tools.

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