SAR training processor (version 1.1)

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This manual describes the SAR training processor (STP) that has been developed to introduce students to the complex field of processed synthetic aperture radar (SAR) data. After a brief introduction into the theoretical background of SAR processing, the manual gives an overview how to use the graphical user interface of the STP. The exercise provides hands-on experience with real data and highlights common issues encountered in the processing of SAR data.

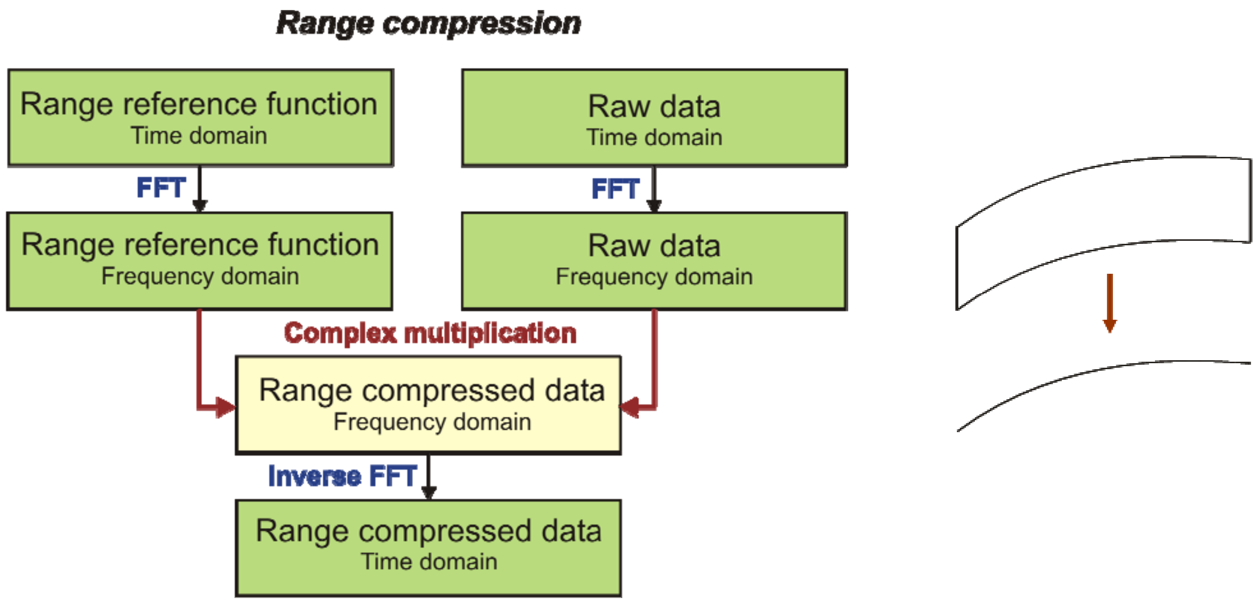
SAR processing

A number of algorithms have been developed to effectively process SAR data from its raw signal into well focused images. The most common SAR processing algorithm is the *range Doppler* algorithm, which accurately and effectively accommodates range varying parameters such as Doppler centroid, azimuth frequency modulation rate, and range cell migration. The *chirp scaling* algorithm achieves an improved image quality over the range Doppler algorithm by replacing the interpolator for the range cell migration correction with a scaling operation in range time/azimuth frequency domain. The *omega-K* algorithm corrects the range migration by a range migration in the two-dimensional frequency domain and is able to handle the widest aperture and highest squints of all algorithms that way. For medium and low resolution data such as quick look imagery the *SPECAN* algorithm was developed. It minimizes the need of memory and computing by using single and short FFT's in the compression operation (Cumming and Wong, 2005).

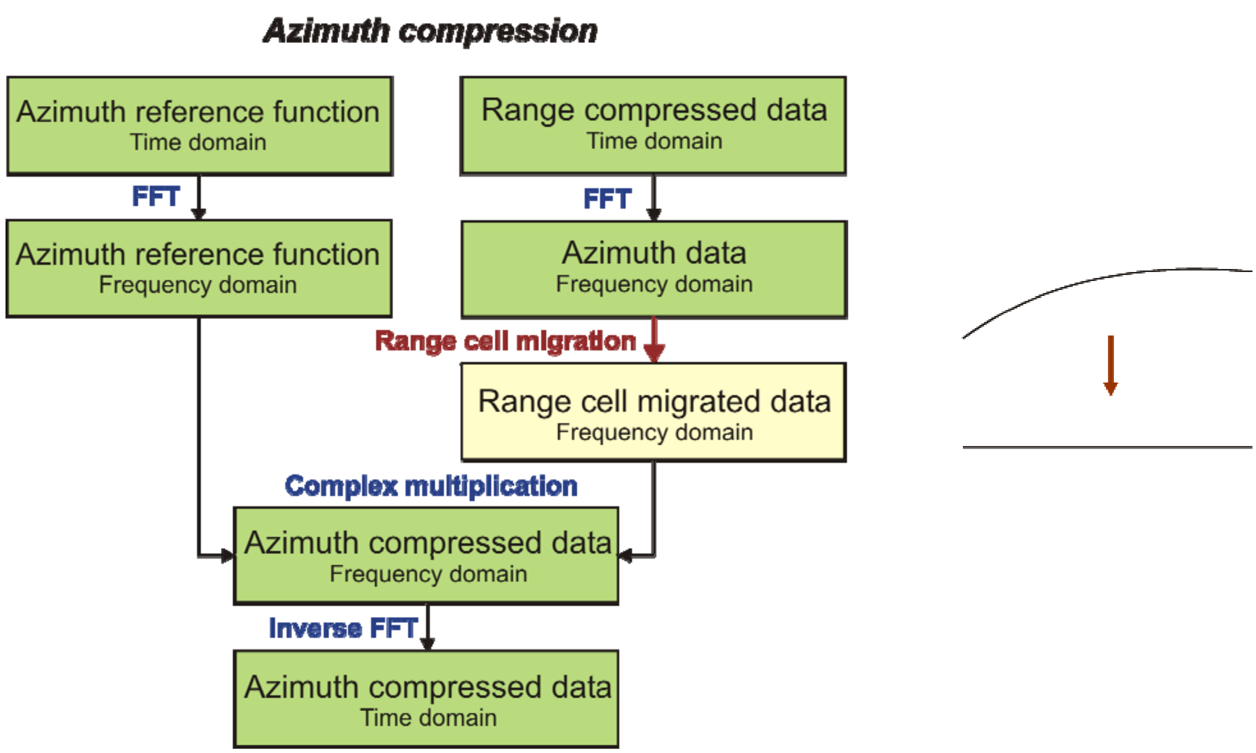
An excellent introduction into the above mentioned algorithm including a side-by-side comparison of these algorithms can be found in Cumming and Wong (2005). Other reference books for SAR signal processing include Curlander and McDonough (1991) as well as Franceschetti and Lanari (1999).

The SAR training processor is an implementation of the range Doppler algorithm. Its debugging mode has been extended to allow the user to manipulate all processing steps of the SAR processing flow, described in more detail below, and to save all intermediate results of the processing.

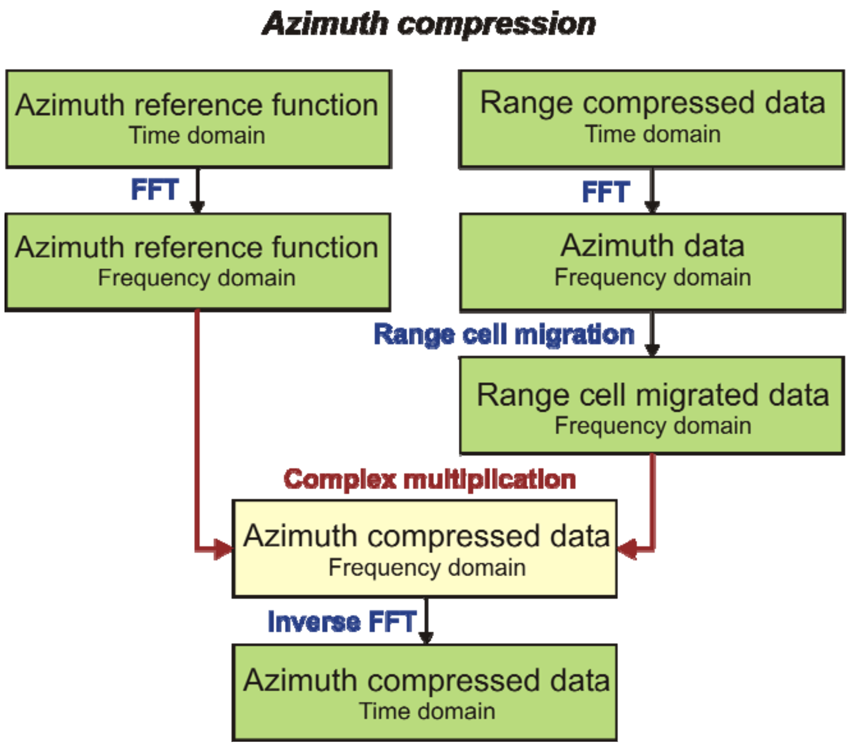
In the range Doppler algorithm the unfocused raw SAR data is compressed in range and azimuth direction making effective use of fast Fourier transforms (FFTs). For the range compression, graphically shown below, the raw data is multiplied in frequency domain by the range reference function. This multiplication is carried out with complex values, i.e. the phase information in the data is preserved. All iso-range lines, i.e. targets having the same slant range of closest approach, are collapsed into one single trajectory.

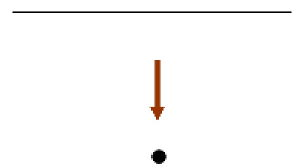


After the range compression is complete, the data needs to be compressed in azimuth. As part of the azimuth compression the target trajectories need to be corrected to account for the fact that the instantaneous slant range changes with azimuth time. This process, usually referred to as range cell migration, moves all responses of a target from the trajectory into a straight line.



The range cell migrated azimuth data can then be multiplied in a complex fashion with the azimuth reference function. This multiplication is again performed in frequency domain. This processing step collapses an azimuth line into a single point, our now fully focused target.

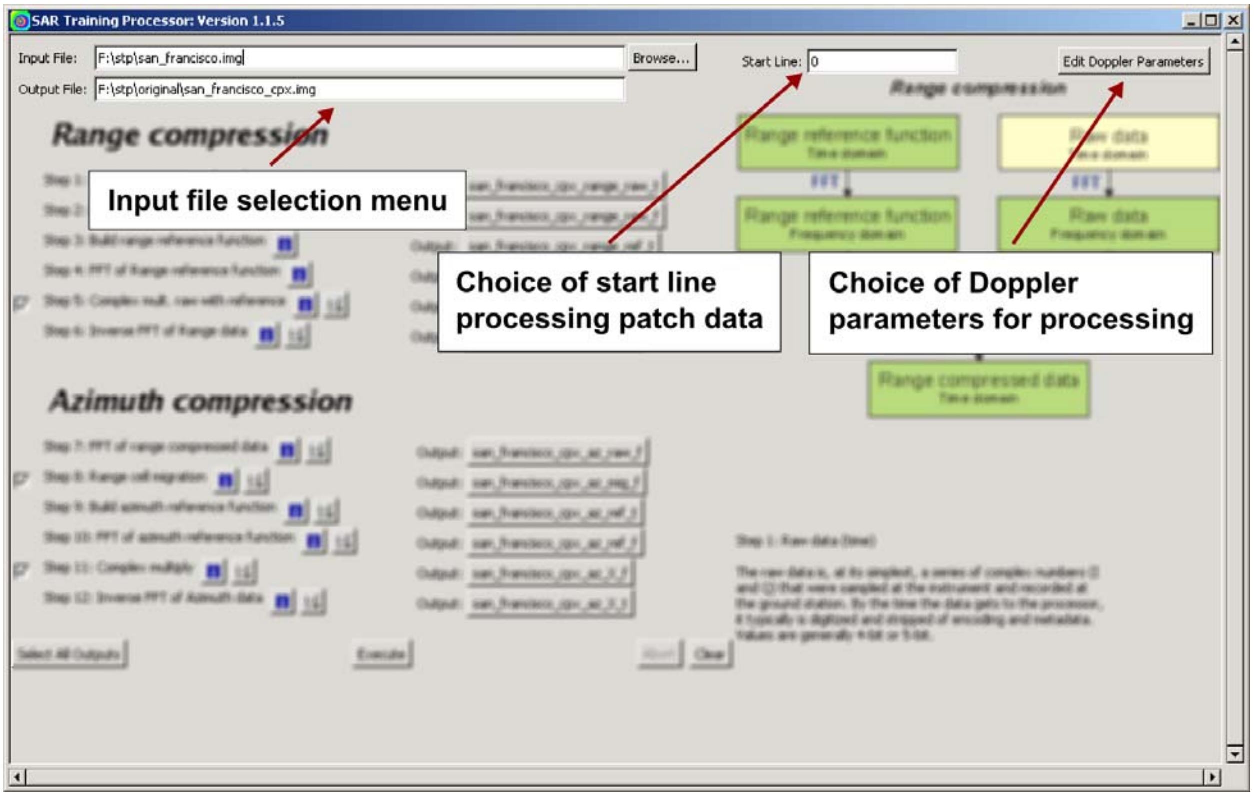




A final inverse FFT brings the focused data back into the time domain, where we can visualize the processed data.

Functionality

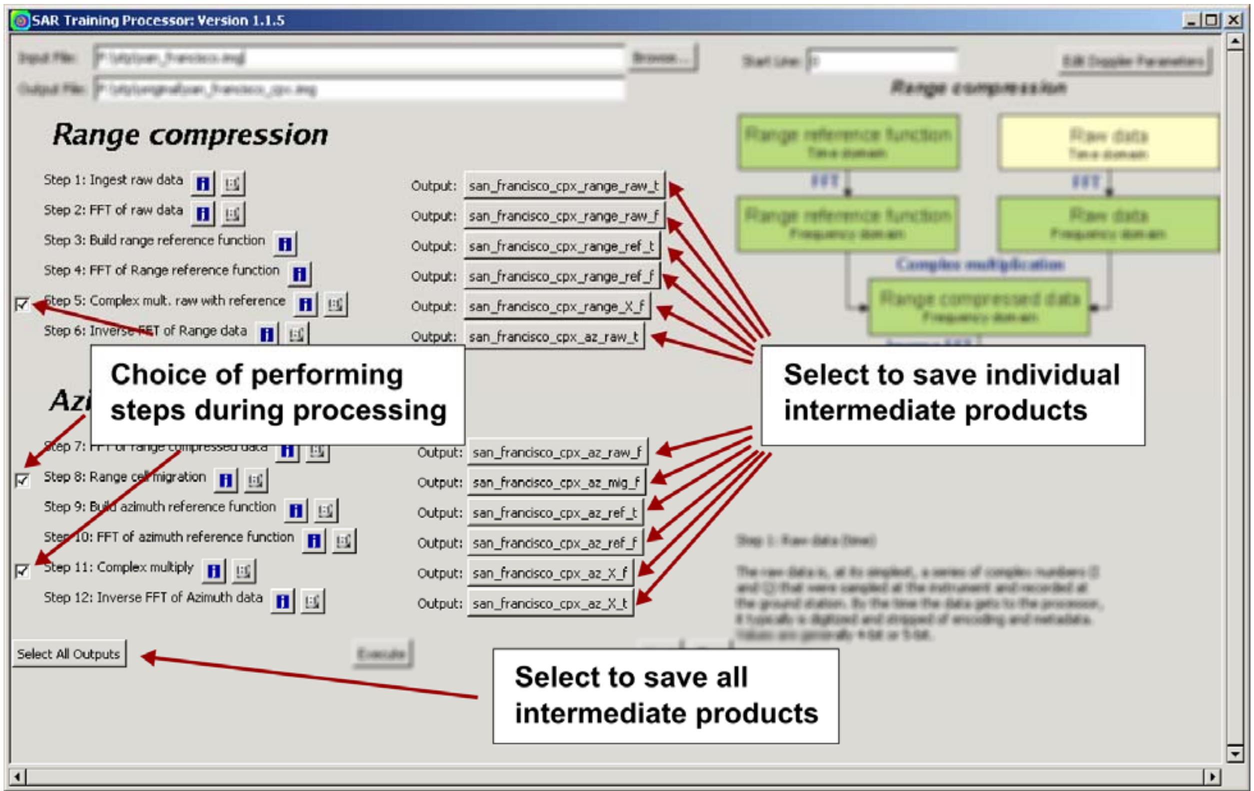
The STP uses a graphical user interface that allows the user to take full control over each aspect of the processing of SAR data. In this section the functionality of the various parts of the interface are explained in detail.



The data set to be processed is selected using a standard browse menu. By default all processing results will be written into the input data directory. Any changes in the output directory need to be manually entered in the output file field.

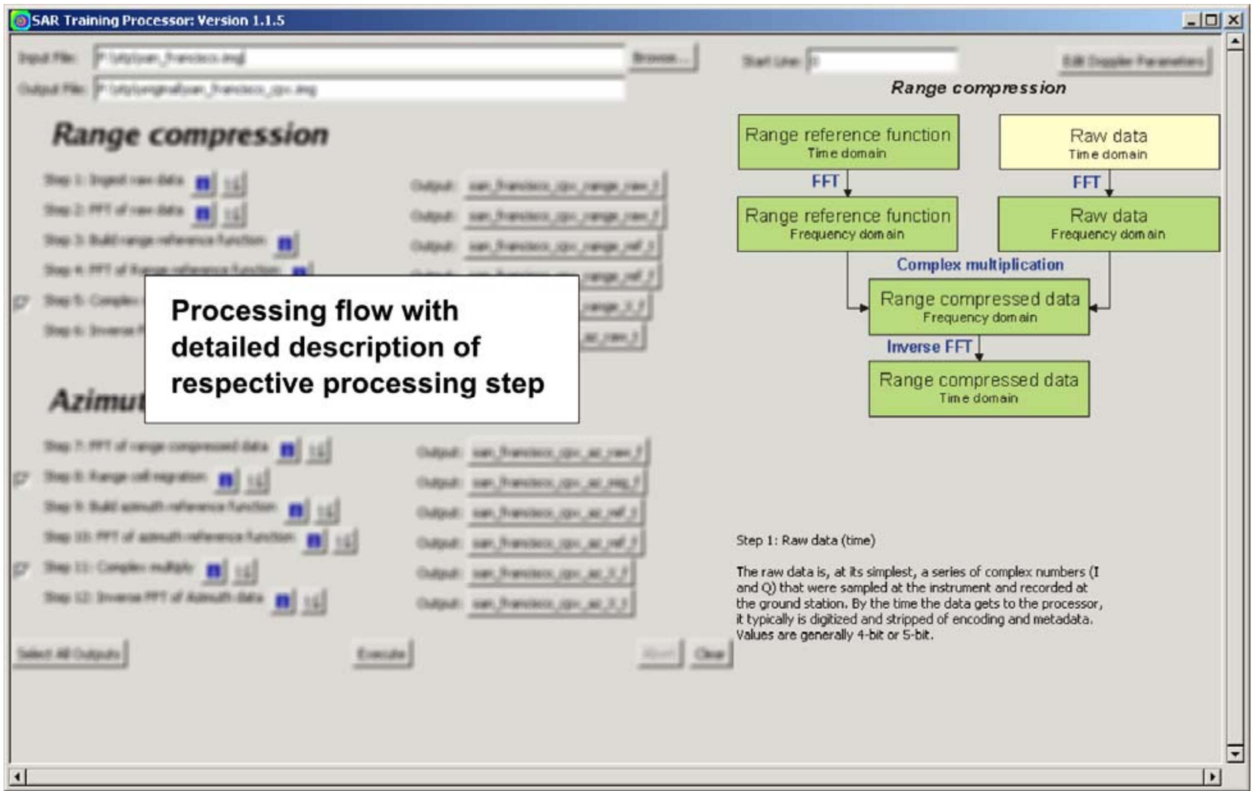
The STP processes one patch of data which is equivalent of about 4000 lines of raw data. If the user wants to analyze a particular part of the SAR image, he can choose an appropriate start line within the SAR image.

The Doppler centroid parameters determine the precise look direction of the sensor and, therefore, can significantly influence the image geometry. The influence of each of the Doppler centroid terms, described by a constant, a linear and a quadratic term, can be studied by changing each of these parameters.

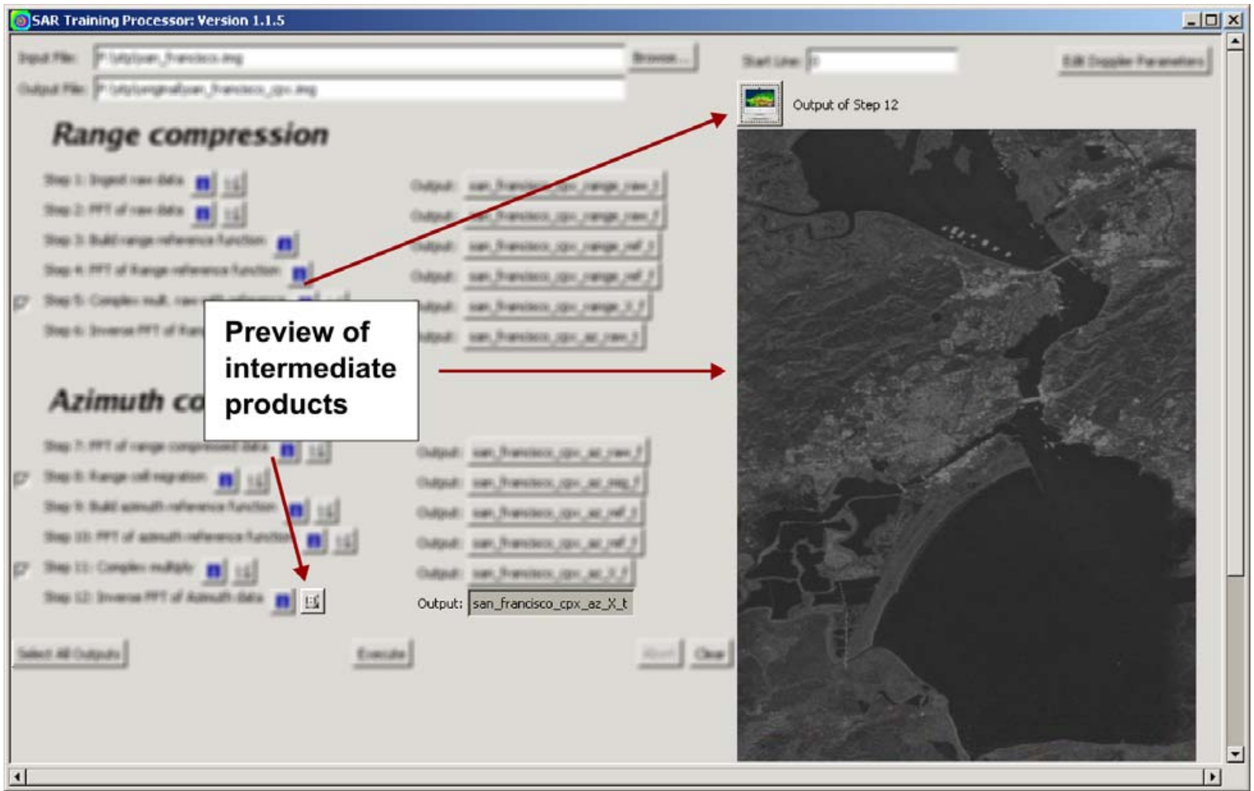


The range Doppler processing consists of two compressions in range and azimuth direction, i.e. two complex multiplications with the respective reference function, and a correction for range cell migration. For a well focused SAR image all these three processing steps need to be carried out. However, the user can study the influence of leaving any of these steps out of the processing flow by changing the status of the check box next to the processing steps.

Intermediate results can be stored for each processing step individually and for all intermediate results by toggling the appropriate output button. For each intermediate result the amplitude and phase, encoded in color, are combined and saved in JPEG format, with the exception of the range reference function in time and frequency domain that is stored in a plain ASCII text format.



Each processing step is explained in detail with a diagram showing the place of the processing step within the general SAR processing flow. This way the user has the context how the particular processing step fits into the overall processing scheme. The information buttons next to the processing steps are used to switch between the descriptions of the individual steps.



The output of each processing step can be visualized using the preview button located next to the information button. For closer examination of the intermediate results the user can view the JPEG images in the common graphics or image processing packages or use the ASF viewer.

Data

The SAR training processor is able to run from a variety of data sources. It supports the frame size data in CEOS level 0 format, swath data in Sky Telemetry Format (STF) as well as data in the internal ASF format.

Data sets ingested with earlier versions of the Convert tool that created ASF internal files with a .raw extensions. These files need to be renamed to a .img file in order to work properly with the SAR training processor from version 1.1 onwards.

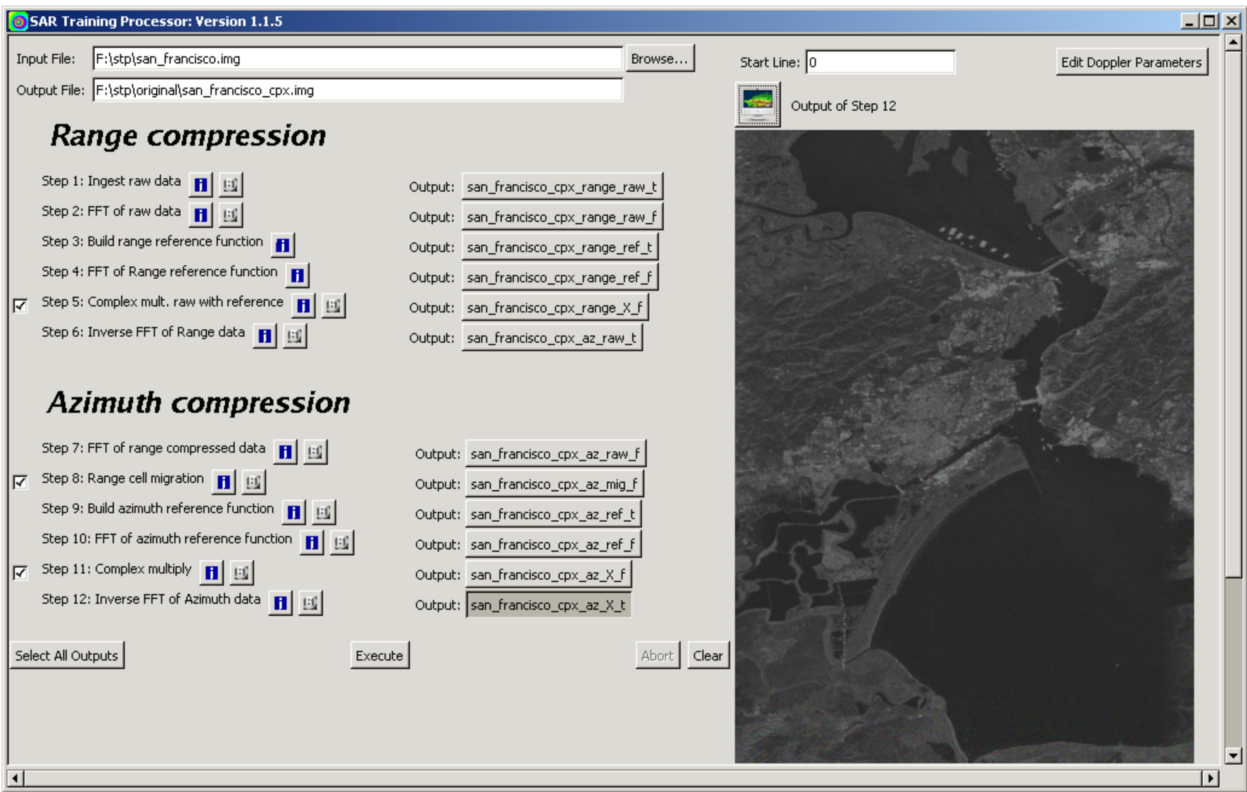
Exercise

In order to demonstrate the functionality of the SAR training processor a RADARSAT-1 fine beam data set from the San Francisco area has been chosen. In this exercise, we will highlight all the features that the STP has to offer to gain a general understanding of the issues related to SAR processing.

Initial processing

In a first step, we want to get an idea what the area of interest looks like in a SAR image without changing any of the processing parameters.

In order to do that we browse for the 'san_francisco.img' file and create a subdirectory 'original' to save our initial processing results.



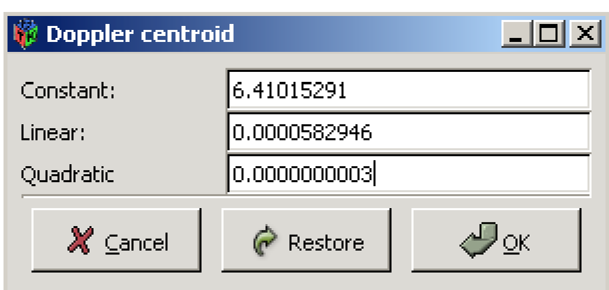
A closer examination of our initial result shows that the image is not crisp and well focused. As it turns out the level zero processor had severe difficulty determining the Doppler centroid based on the contents of just this particular frame.

The level zero processor is generally more successful in determining the Doppler parameters when it is processing larger parts of a swath. In that case it fits a two-dimensional function that describes the Doppler variation as a function of time, i.e. in azimuth direction. This 2-D function is then used to determine the Doppler parameters for a particular frame. Comparing the frame Doppler values with the swath derived Doppler centroid reveals a large PRF ambiguity.

Processing with correct Doppler values

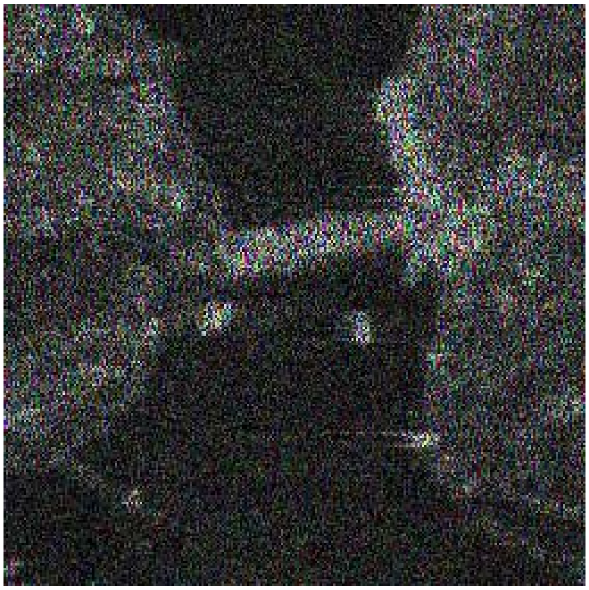
The correct Doppler values determined during the initial level zero swath processing can be found in the 'new_doppler.in' file. The values look a little different from the ones stored in the regular metadata. This is due to the fact that the values in the processing parameter file have been normalized, dividing them by the PRF.

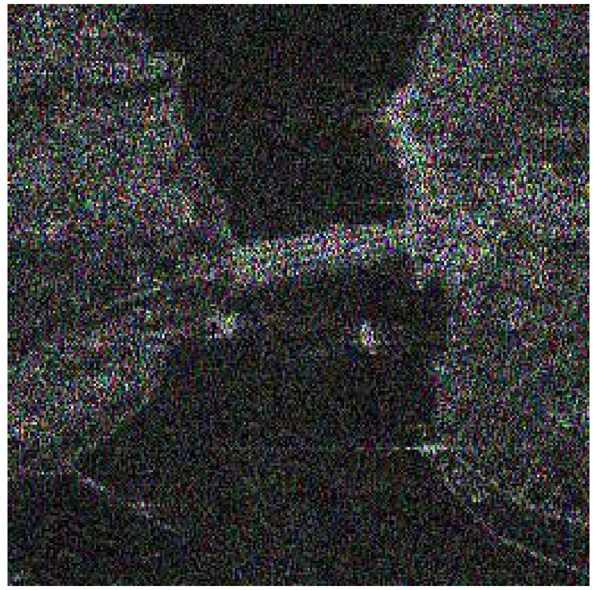
```
ARDOP3.1 SAR Processing Parameter File (asf_import)
1                              ! Debug Flag
0                              ! First line (from 0)
1000                           ! Number of patches
0                              ! i,q byte samples to skip
3490                           ! Output lines per patch
0                              ! Deskew flag
0 7644                               ! 1st range sample, num samples
6.41015291 0.0000582946 0.0000000003                  ! Dopp quad
coefs(Hz/prf)
6370269.0                      ! Earth Radius
7548.099                       ! Body fixed S/C velocity(m/s)
796411.750                     ! Spacecraft Height
966284.750                     ! Range of first sample
1293.200                       ! Pulse Repetition Freq.
9.000000                       ! Single look az. res.
1                              ! Number of azimuth looks
3.231708E+07                         ! Range sampling frequency (Hz)
-7.214000E+11                        ! Chirp Slope (Hz/s)
4.200000E-05                         ! Pulse Length (s)
0.0                            ! Chirp extension
0.056560                       ! Radar wavelength
0.800000                       ! Range spectrum weight
0.000000 0.000000                    ! Bandwidth fractional trunc.
0.000000 0.000000 0.000000 0.000000     ! First patch slope,inter range,az
0 0 0 0     ! Delta per patch slope,inter range,az
```



The new parameters for the Doppler centroid need to be edited before re-running the data set. The difference between the old and new constant Doppler values indicates the presence of an ambiguity of multiple PRFs. The inability of the processor to correctly determine the Doppler centroid can be attributed to the fact that large parts of the image are covered with water that strongly contrasts with the number of very bright man-made features.

Create a subdirectory 'new_doppler' and process the 'san_francisco.img' file saving the final azimuth compressed output.

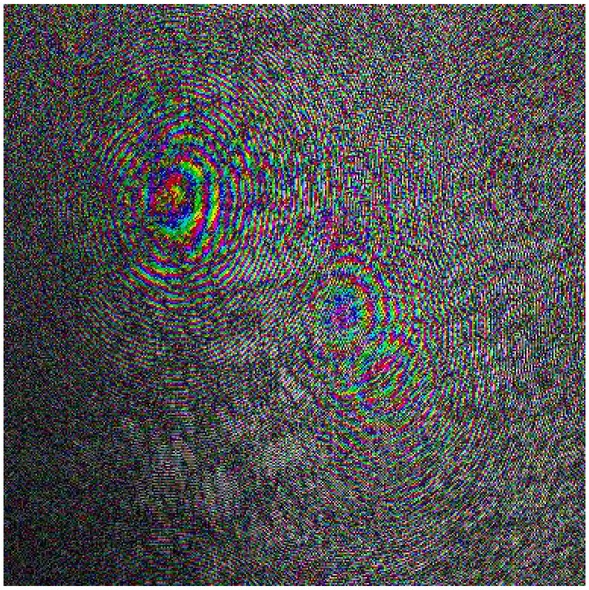


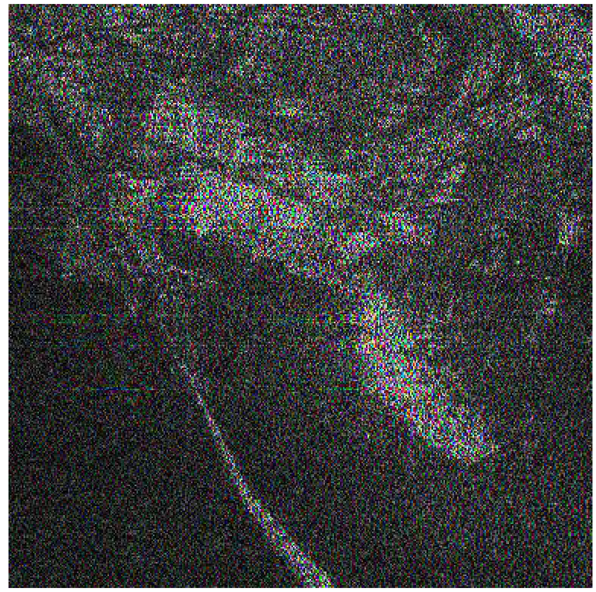


Comparing the processing results (incorrect Doppler on the left, correct Doppler on the right) clearly shows that processing the data with the correct Doppler centroid leads to a completely focused image. The coastline shows up in more detail. And for the bridge several distinct responses from so called double-bouncing and triple-bouncing can be distinguished.

Point targets

Now that we have established the correct Doppler parameters for the processing, let us take a closer look at some point targets and the individual processing steps. *Create a subdirectory 'point_target' and process the 'san_francisco.img' file starting at line 5500 and saving the outputs of the steps 1 and 12, the raw data and the final azimuth compressed output.*

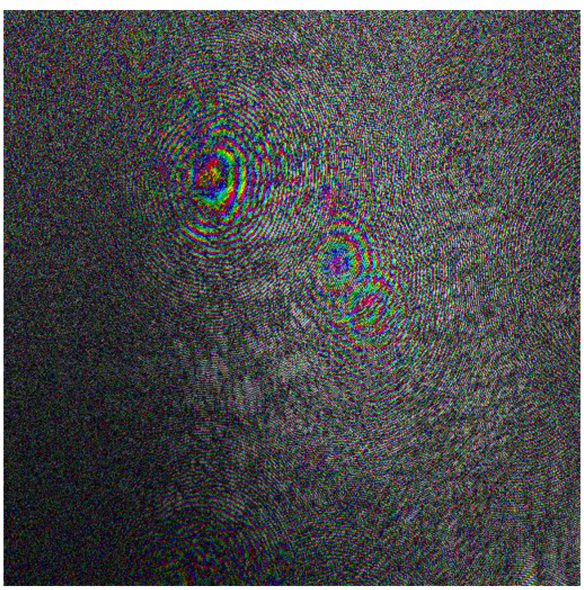


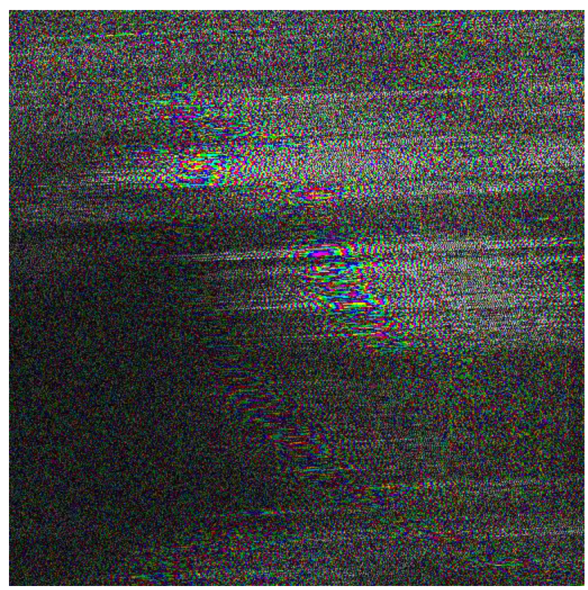


The bright point targets that can be identified in the processed SAR image (on the right) show up as bulls eyes in the raw image (on the left). The amplitude part of the signal does not offer much of an indication for point targets.

Range compression

Create a subdirectory 'range_compression' and process the 'san_francisco.img' file starting at line 5500 and saving the outputs of step 1 and 6, the raw data and the range compressed image.

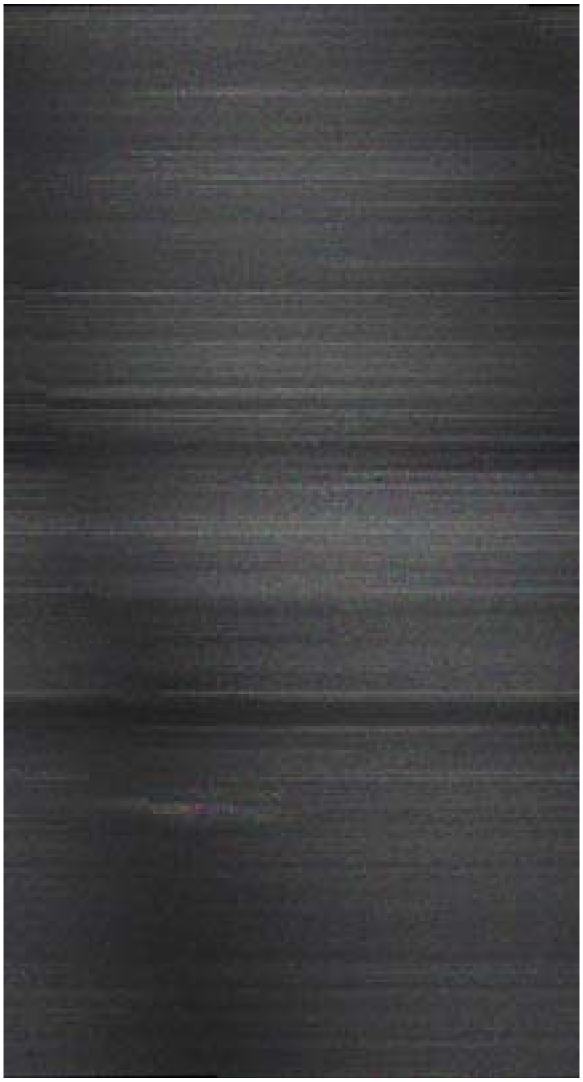


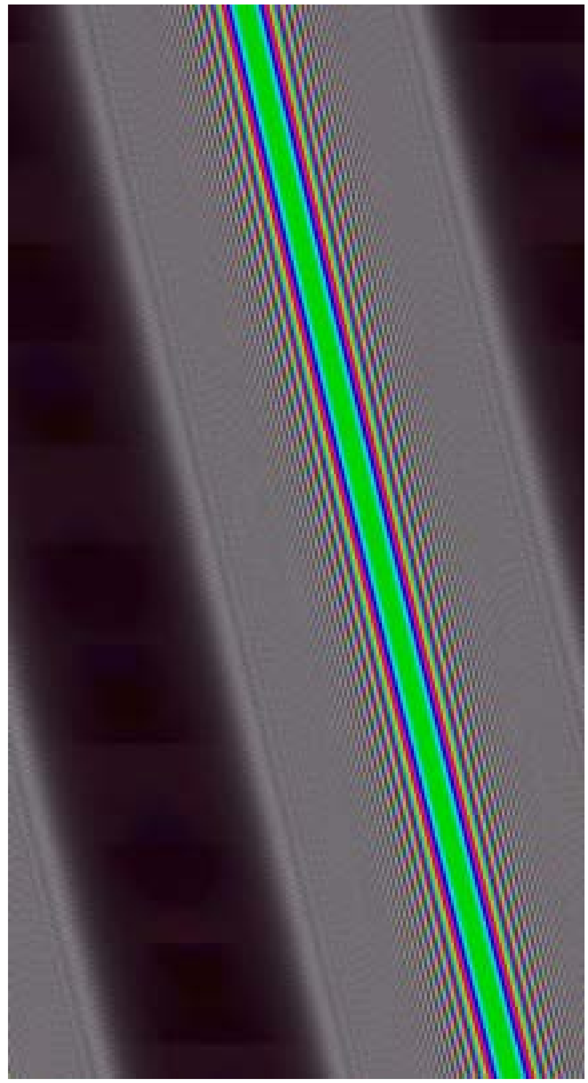


The bright point targets in the range compressed image (on the right) now can be identified a lot easier in the amplitude part of the signal (compared to the raw image on the left) as they show up as elongated bright streaks. The water body is more clearly delineated from the land mass.

Range cell migration

Create a subdirectory 'range_cell_migration' and process the 'san_francisco.img' file starting at line 5500 and saving the outputs of step 8 and 10, the range cell migrated data as well as the azimuth reference function in frequency domain.

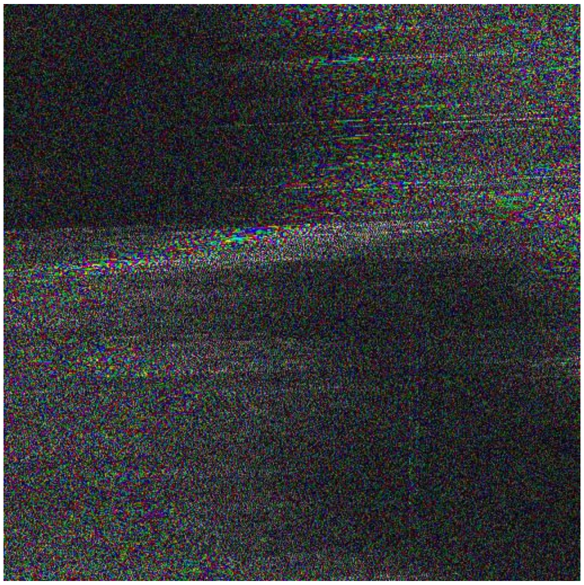


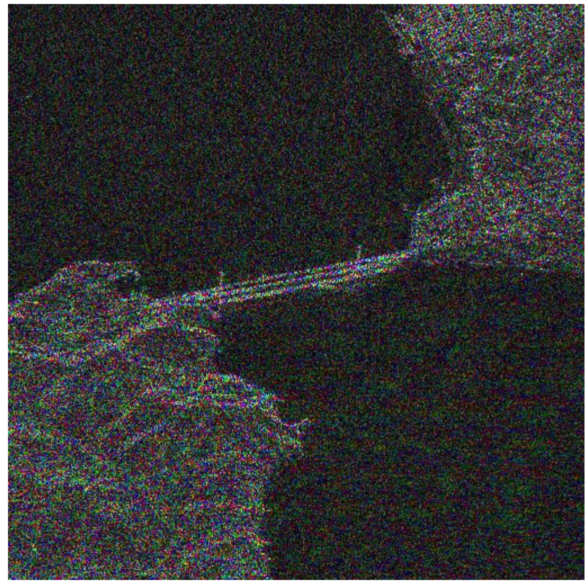


The use of the range cell migration can only be demonstrated in frequency domain (on the left). Moving all responses of a target from the trajectory into a straight line in time domain leads to a shift in frequency domain. The angle of this frequency shift, caused by the Doppler, follows the one in the azimuth reference function (on the right). All individual point targets are now lined up in straight lines.

Azimuth compression

Create a subdirectory 'azimuth_compression' and process the 'san_francisco.img' file starting at line 5500 and saving the outputs of step 6 and 12, the raw data and the azimuth compressed image.

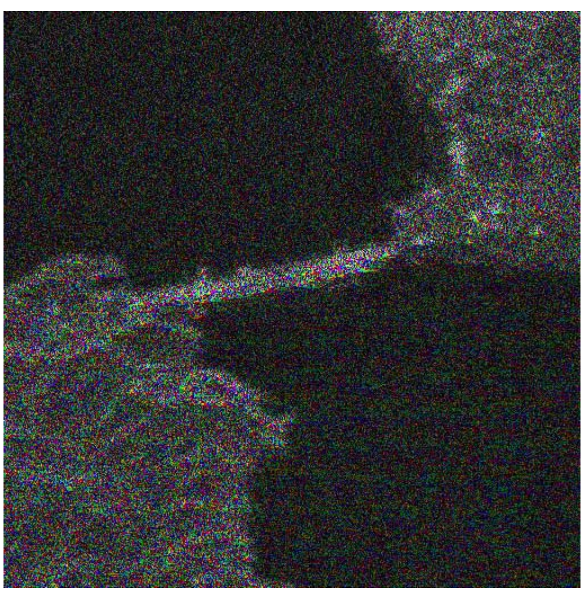


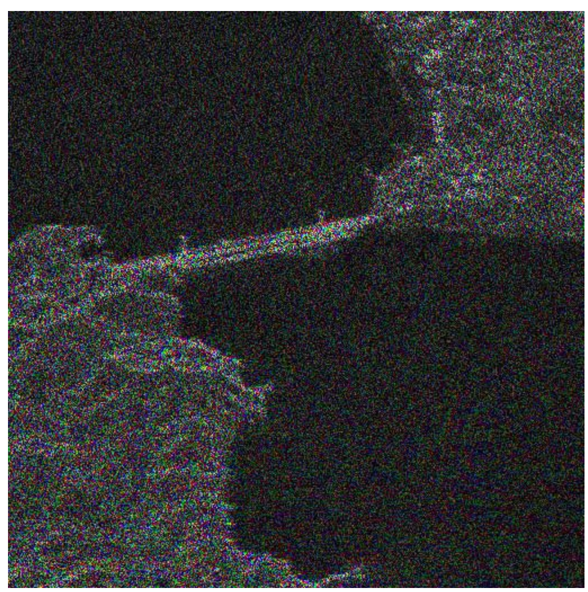


In the final SAR processing step the image is compressed in azimuth direction. All point targets are supposed to be nicely focused to a point. In this comparison of the range compressed image (on the left) and the azimuth compressed image (on the right) the full level of detail in the fully focused image becomes apparent. Even the two pylons of the Golden Gate Bridge are clearly visible.

Processing without range cell migration

Create a subdirectory 'no_rcm' and process the 'san_francisco.img' file starting at line 5500, leaving step 8 out of the processing, and saving the output of step 12, the final azimuth compressed image. Edit the Doppler parameters and restore them to their original values. Create a subdirectory 'original_doppler' and process the 'san_francisco.raw' file starting at line 5500 and saving the output of step 12.

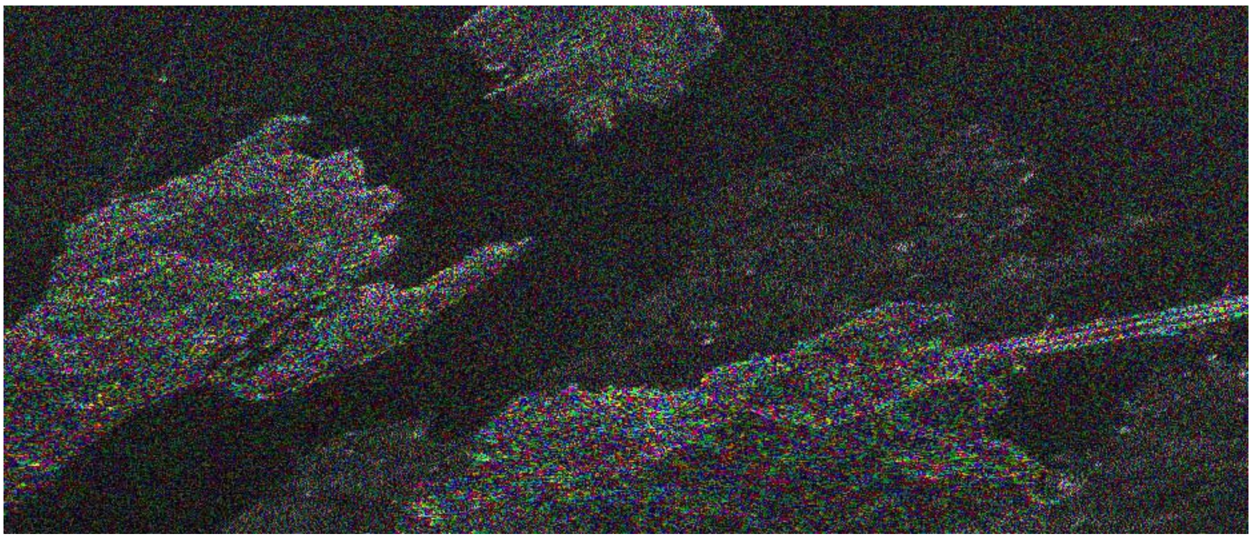




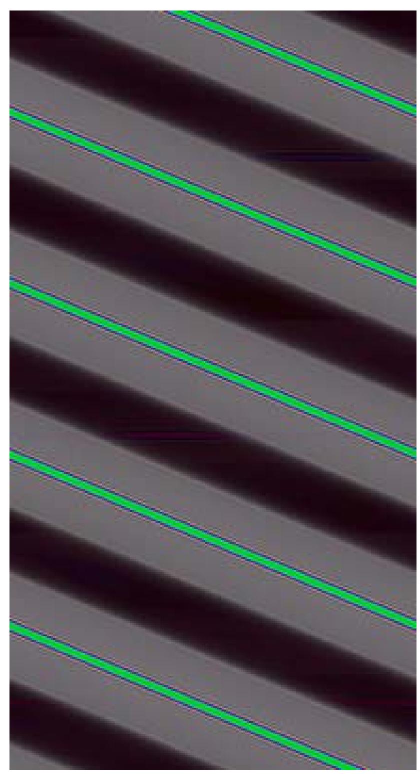
Comparing the two results (processing without range cell migration on the left, processing with original Doppler values on the right) shows that processing without range cell migration leads to a severe defocusing of the image, even more than the processing with a wrongly estimated Doppler centroid.

Changing Doppler parameters

Create a subdirectory 'change_doppler'. Change the linear Doppler parameter by multiplying it by a factor of 10. Then process the 'san_francisco.img' file starting at line 5500 and saving the output of steps 10 and 12.



As we have seen at the beginning of the exercise, a change in the constant Doppler parameter leads to a loss of focus throughout the image. Changing the linear Doppler term introduces a ghosting effect (see image above). In this case of a large water body, the ghosting can be identified relatively easily. However, in the case of complete land cover the ghosting might be a lot less obvious. The only clear indication is a repetitive pattern of point targets that look out of place. A quick look at the azimuth reference function in frequency domain (on the right) helps to verify whether ghosting is the problem. The ghosting occurs in the overlapping parts of the reference function.



References

CUMMING, I.G. and WONG, F.H., 2005. *Digital processing of synthetic aperture radar data: Algorithms and implementation*. Artech House, 660 p.

CURLANDER, J.C. and MCDONOUGH, R.N., 1991. *Synthetic aperture radar: Systems and signal processing*. Wiley, 672 p.

FRANCESCHETTI, G. and LANARI, R., 1999. *Synthetic aperture radar processing*, CRC, 328 p.