Radiometric artifacts on SAR images

Igor Elizavetin
SAR Data Processing Expert

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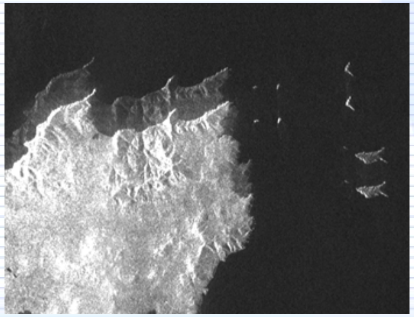
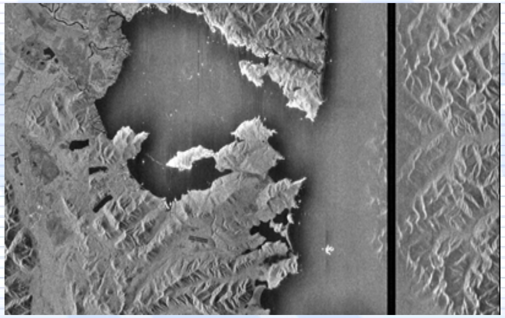
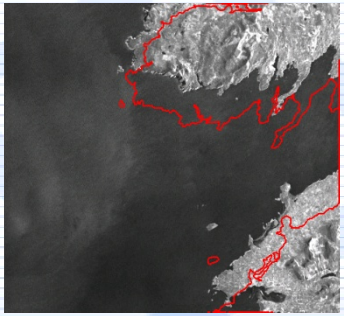
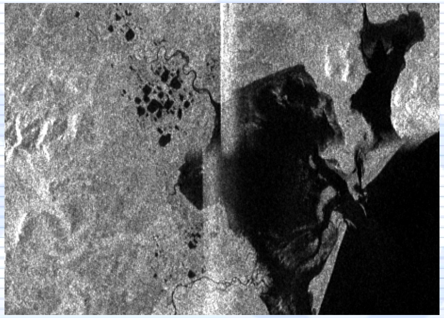
Radiometric artifacts on SAR images

Most important for final identification of objects and processes on SAR images are their brightness properties. These properties mainly depend on the radar signal backscattering level and characterize such objects features as electricity resistance and surface roughness. We should note that brightness properties of radar images are formed by so called radar channel. This channel could be regarded as consisting of blocks of radar equipment, channel of radio waves propagation – atmosphere and ionosphere, backscattering surface, and ground processing facilities which form images as special information products. Each of these components brings it own contribution into final brightness budget and partially influence on objects visibility. It is evidence, that common user want mainly to have deal with brightness contribution derived from signal backscattered from ground surface. Therefore, contributions from other parts of radar channel could be regarded as noise components which interfere with useful signal. As the processing practice shows the responses from ground objects could be overlapped on radar images by atmosphere variations or artifacts formed by applied processing algorithm, so the common user can not distinguish their brightness contributions. Therefore, the detailed analysis of artifacts and errors involved into images on any acquisition and processing stages could be quite interesting from point of view of end user.

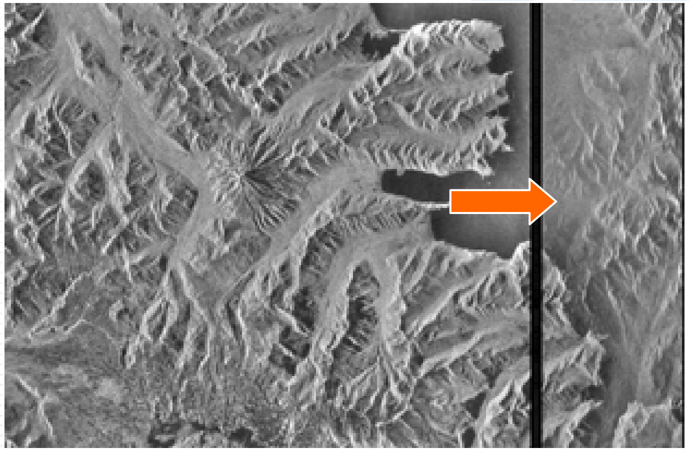
Radiometric artifacts on SAR images

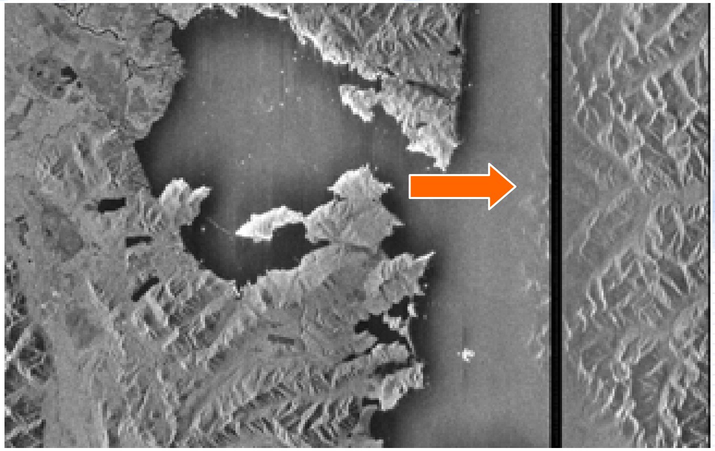
Here we will regard the following most distributed radiometric artifacts inherent to spaceborne SAR images:

- range ambiguity;
- azimuth ambiguity;
- nadir ambiguity;
- objects ghosting due the local Doppler frequency estimation errors;
- objects displacement due the absolute Doppler frequency estimation errors;
- insufficient range antenna pattern compensation;
- data loss;
- changing of range time delay code;
- scalloping;
- **automatic gain control effects;**
- analog-digital converter saturation effects;
- **banding;**
- **ScanSAR beams stitching;**
- **atmosphere effects;**
- **processing effects;**
- **radar viewing nature effects.**

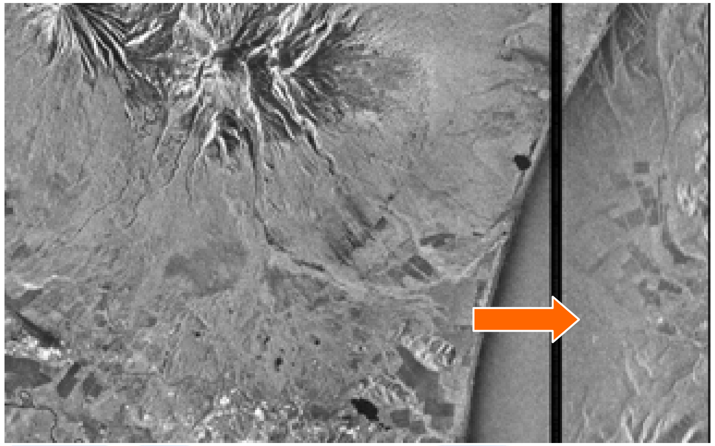
Range ambiguity

Images from SAR on Almaz-1 spacecraft. Orbit 2371. Petropavlovsk-Kamchatsky site.





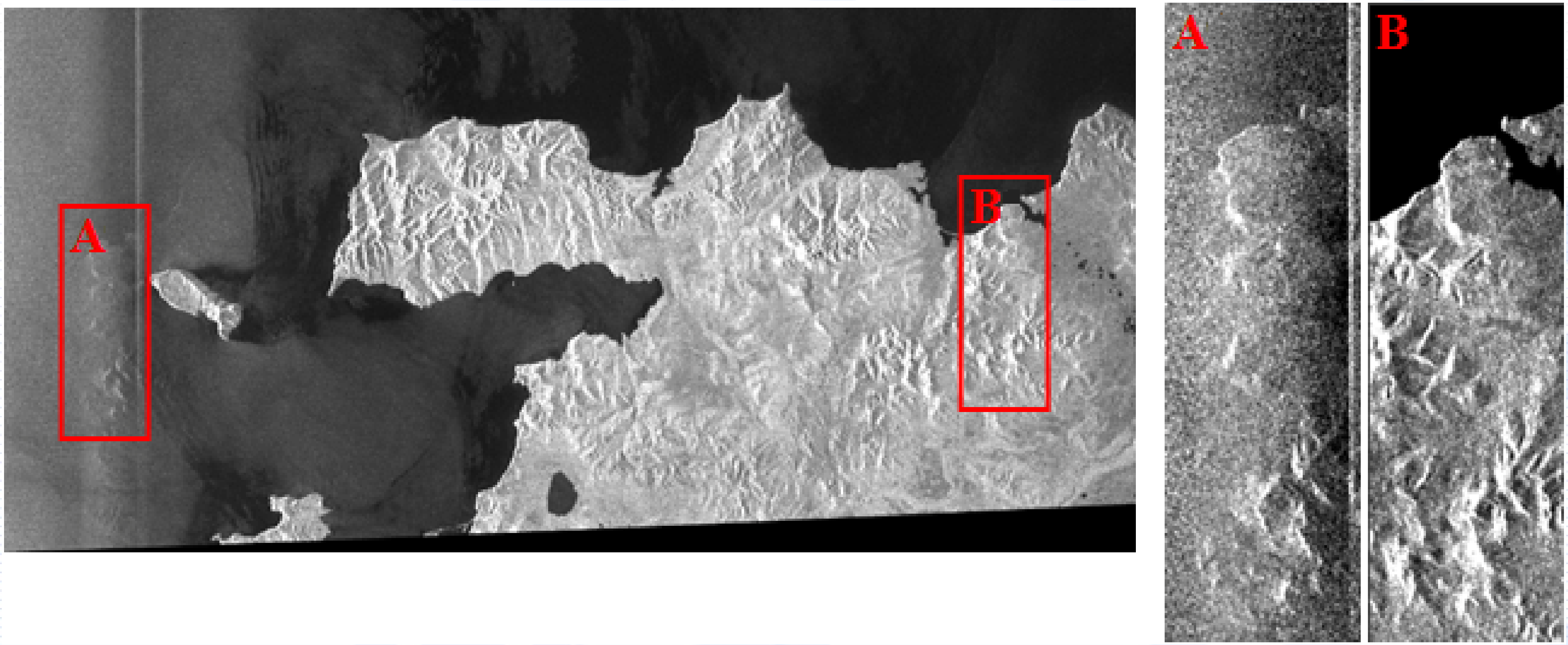
Range ambiguity signal can be seen on the right part of pictures. Imagination of sea surface overlapped by strong signal from mountain area. Actually this area is placed outside of scene.



Range ambiguity effect appears as the ground objects duplication on image along range direction. It caused by overlapping return signals from different pulses which come back to radar on the same time. Appearance conditions are high level of antenna range pattern sidelobes, low backscattering level in mainlobe, and high backscattering level in one of the sidelobes. SAR processor does not correct this effect.

Range ambiguity

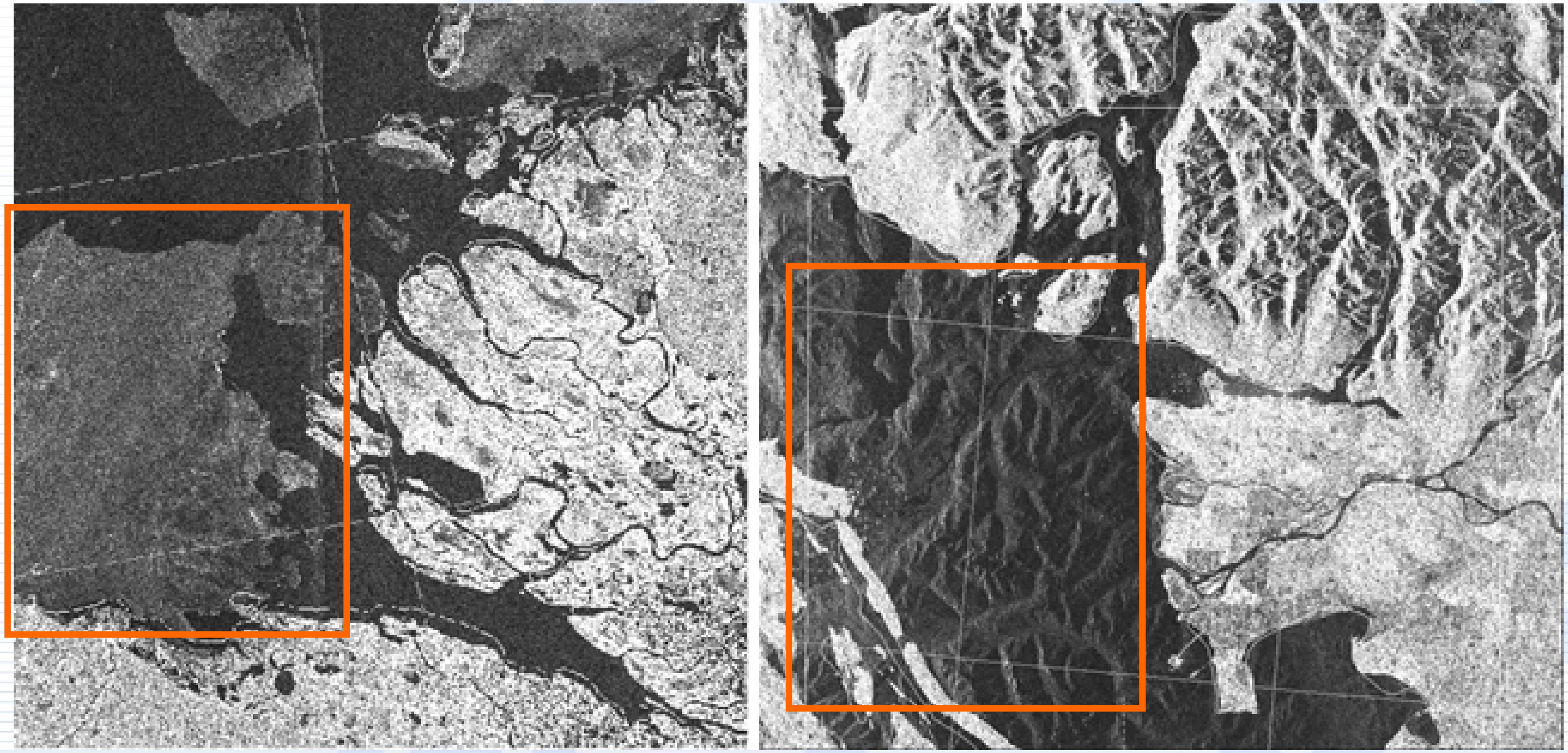
RADARSAT-1 SAR. Orbit 66267. Survey mode SWA (W1+W2+W3_S7)



Range ambiguity signal (A) appears in beam W1 on sea surface. In reality this signal comes through sidelobe from mountain area (B) in beam W3. Bright strip in left part of image designate the nadir ambiguity.

Range ambiguity

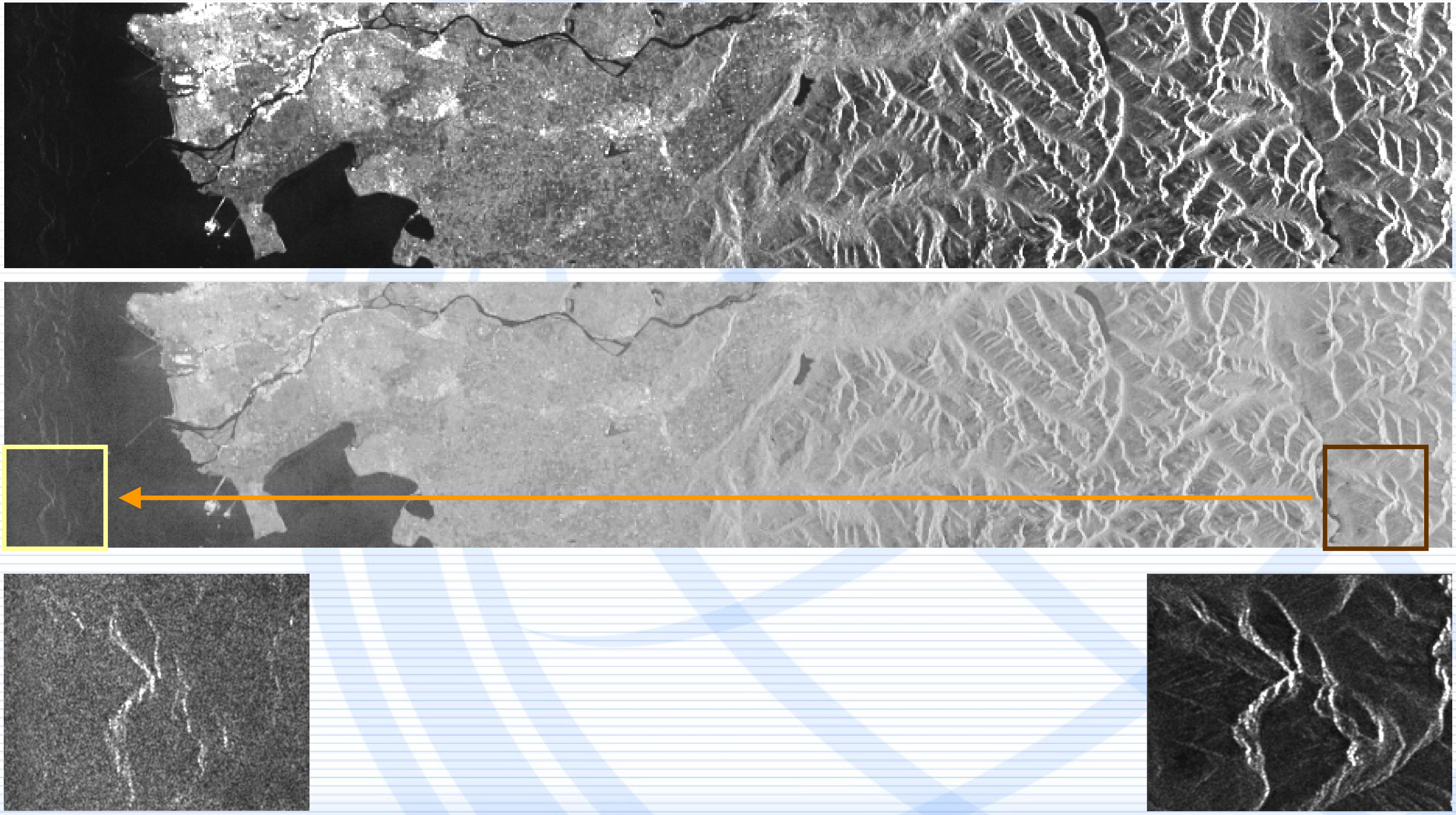
RADARSAT-1 SAR. Beam EH1. RADARSAT International processing. Range ambiguity appears in the left part of pictures on the dark background corresponding to sea surface.



Ambiguity signal may has amplitude high enough to be looks like the true signal. In this case the errors of objects identification may arise.

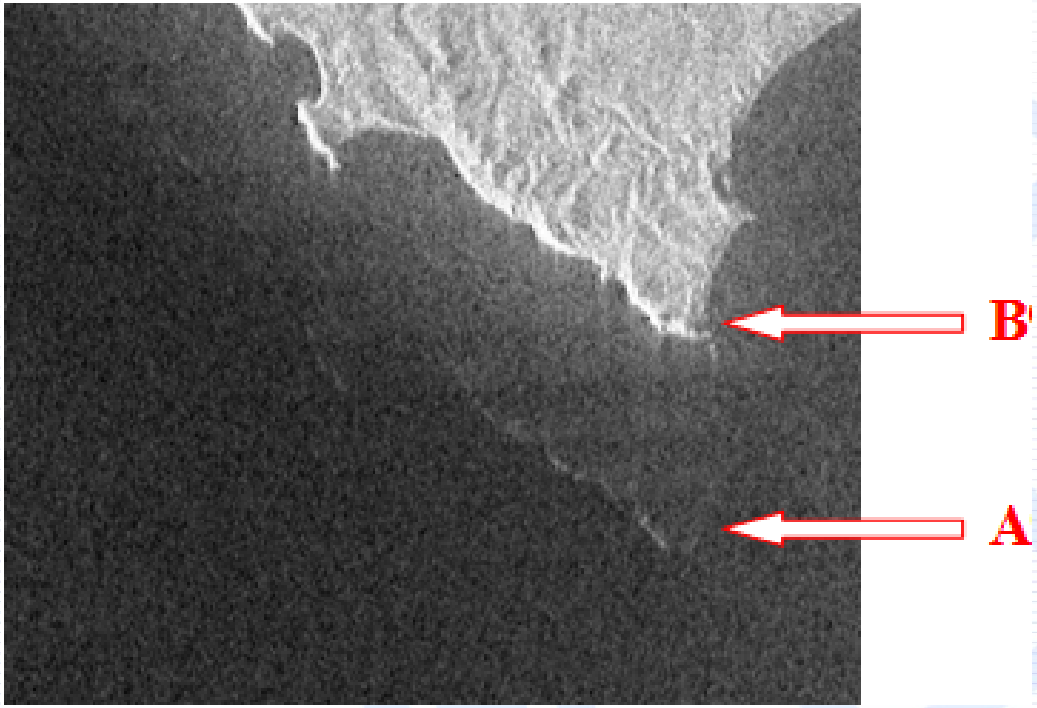
Range ambiguity

RADARSAT-2 SAR. SCWA survey mode. Vancouver site. Range ambiguity appears in the left part of pictures on the dark sea surface. Image is presented with linear look-up-table and with logarithmic one where ambiguity signal becomes visible.



Azimuth ambiguity

RADARSAT-1 SAR. Orbit 66267. Survey mode SWA. Beam S7.

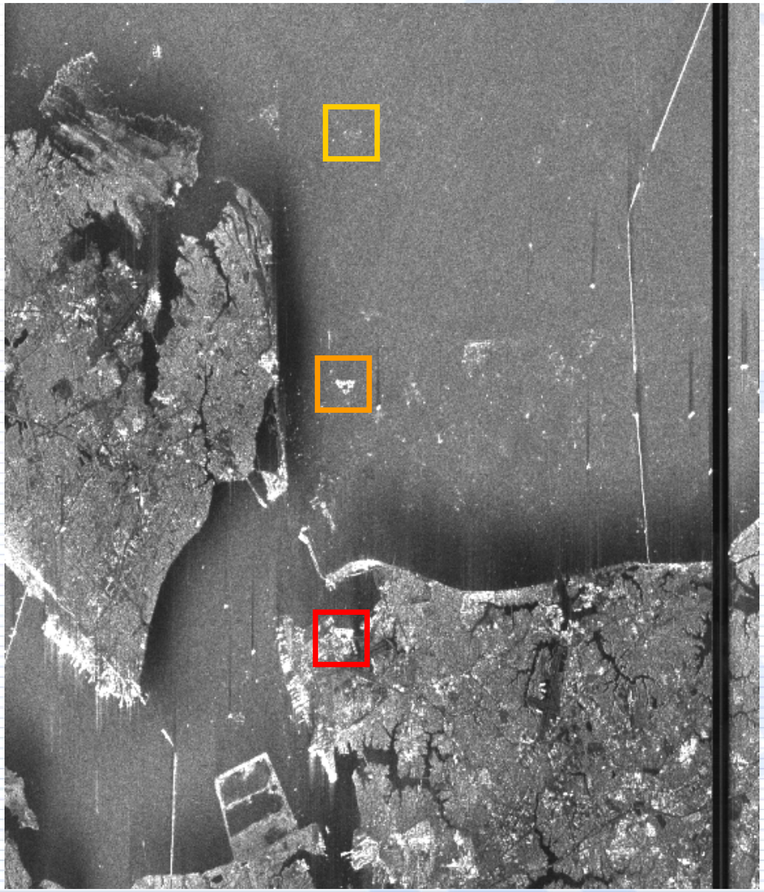


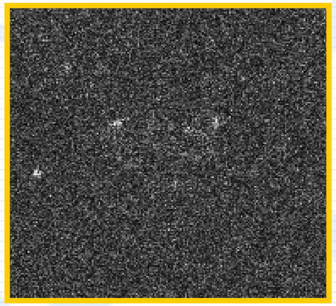
Azimuth ambiguity effect appears as the ground objects duplication on image along azimuth direction. It caused by overlapping return signals from one pulse but with multiply doppler frequencies. Appearance conditions are high level of antenna azimuth pattern sidelobes, low backscattering level in mainlobe, and high backscattering level in one of the sidelobes. SAR processor does not correct this effect.

Azimuth ambiguity signal (A) appears on sea surface with low backscattering level. In reality this signal comes through on of azimuth sidelobe from land area (B) with high backscattering level.

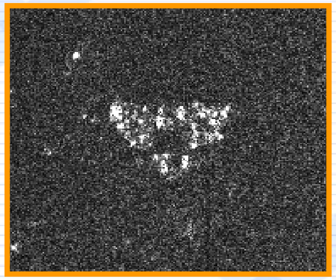
Azimuth ambiguity

Almaz-1 SAR. Orbit 2365A. Norfolk, USA site.





Second duplicate of object.

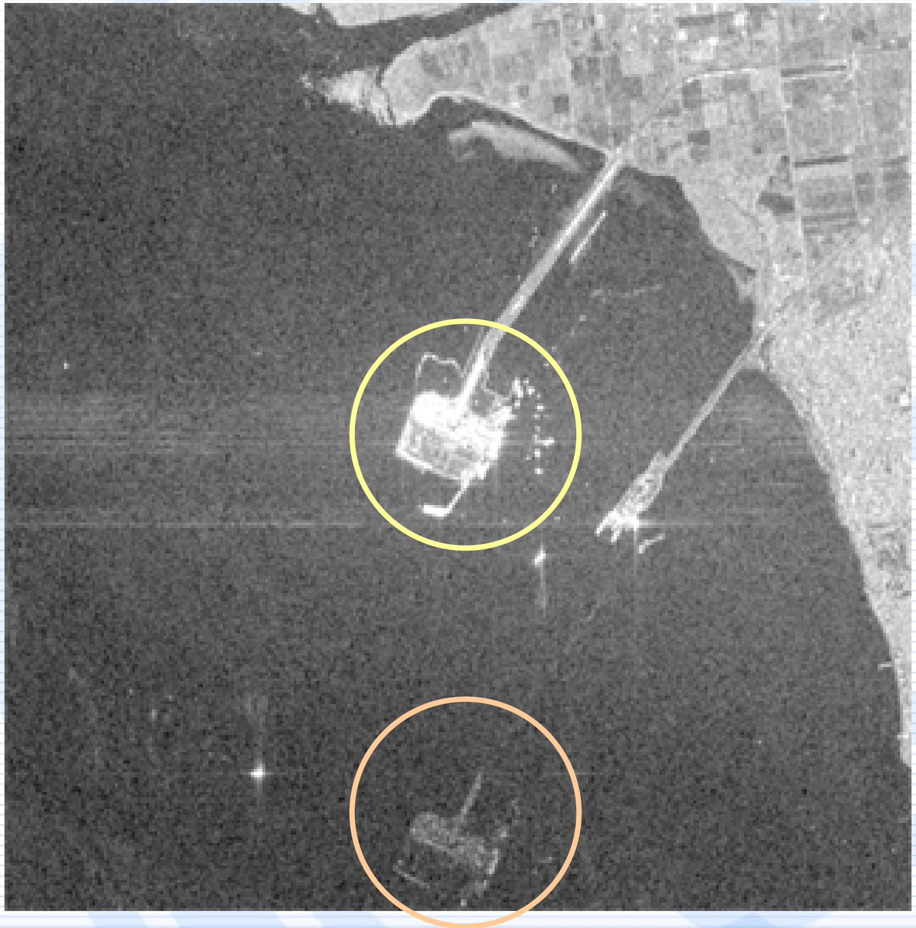


First duplicate of object.

Object on ground surface with high reflectivity.

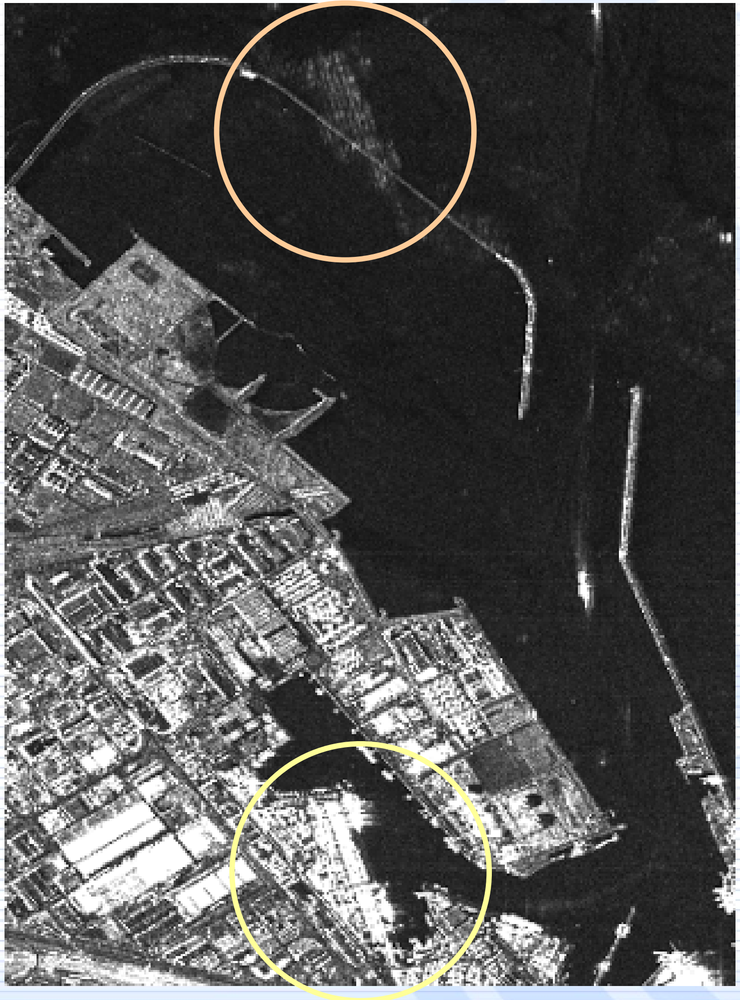
Azimuth ambiguity

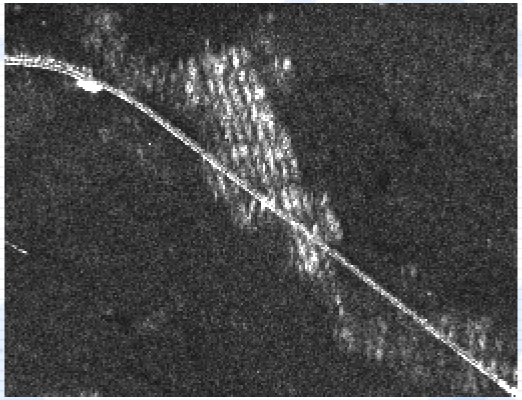
RADARSAT-2 SAR. EH1 beam. Vancouver site. Range ambiguity appears in the lower part of picture on the dark background corresponding to sea surface.



Azimuth ambiguity

TerraSAR-X SAR. SM survey mode. Barselona, Spain site. Range ambiguity appears in the upper part of picture on the dark background of sea surface.



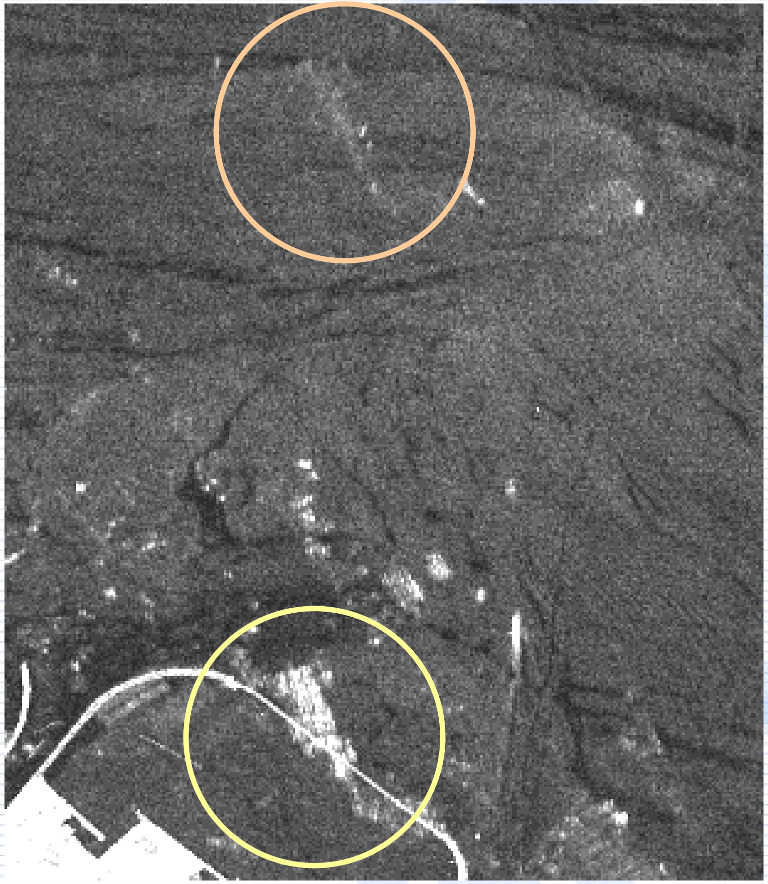


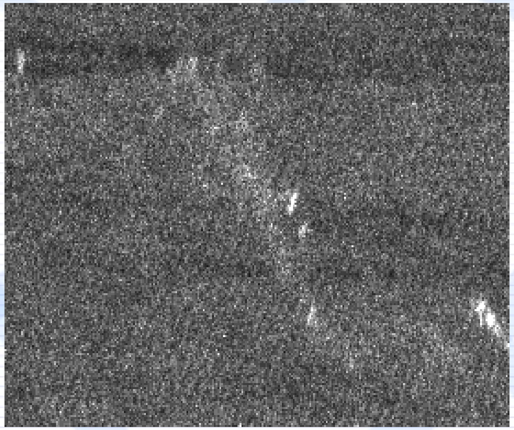
First duplicate of object.

Object on ground surface with high reflectivity.

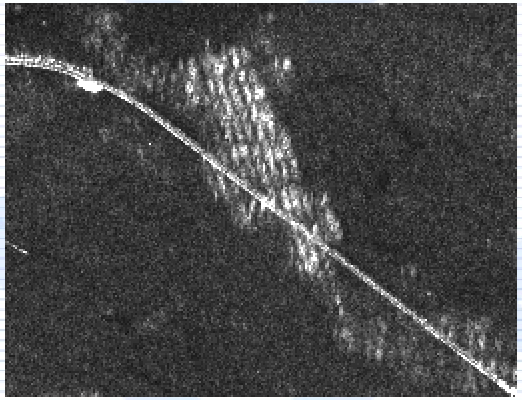
Azimuth ambiguity

Second duplicate of bright object is seen on sea surface after look-up-table adjustment.





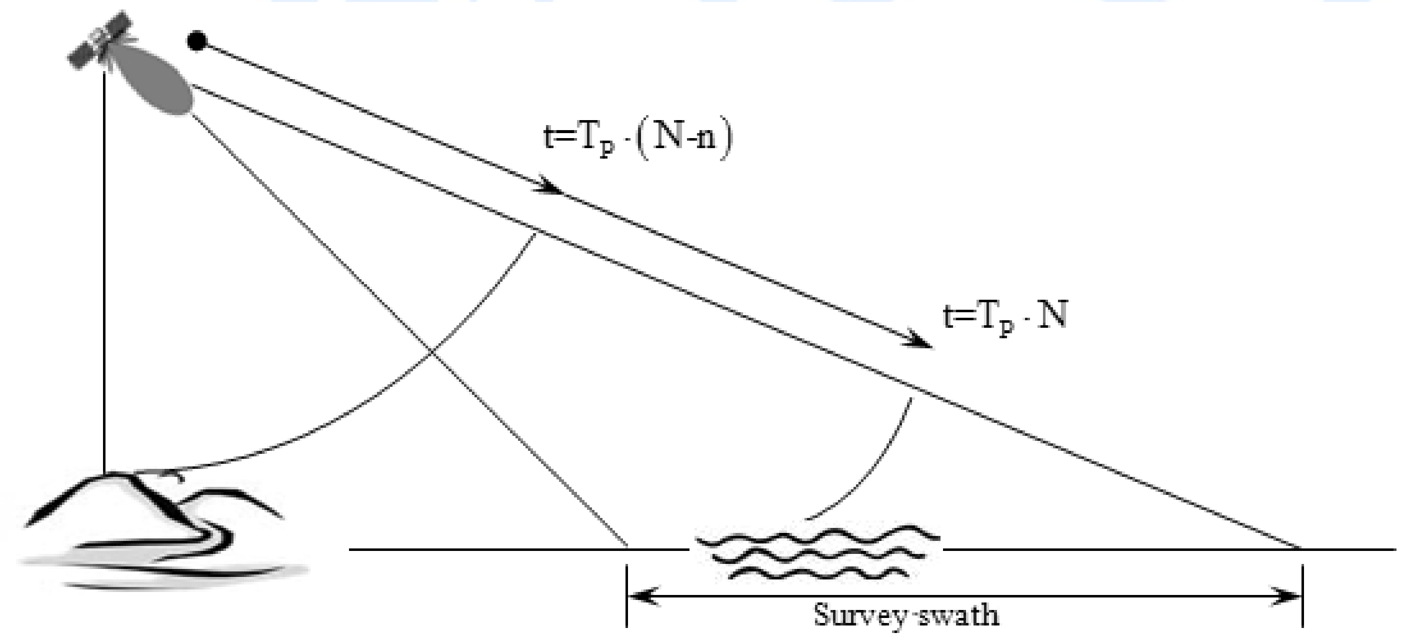
Second duplicate of object.



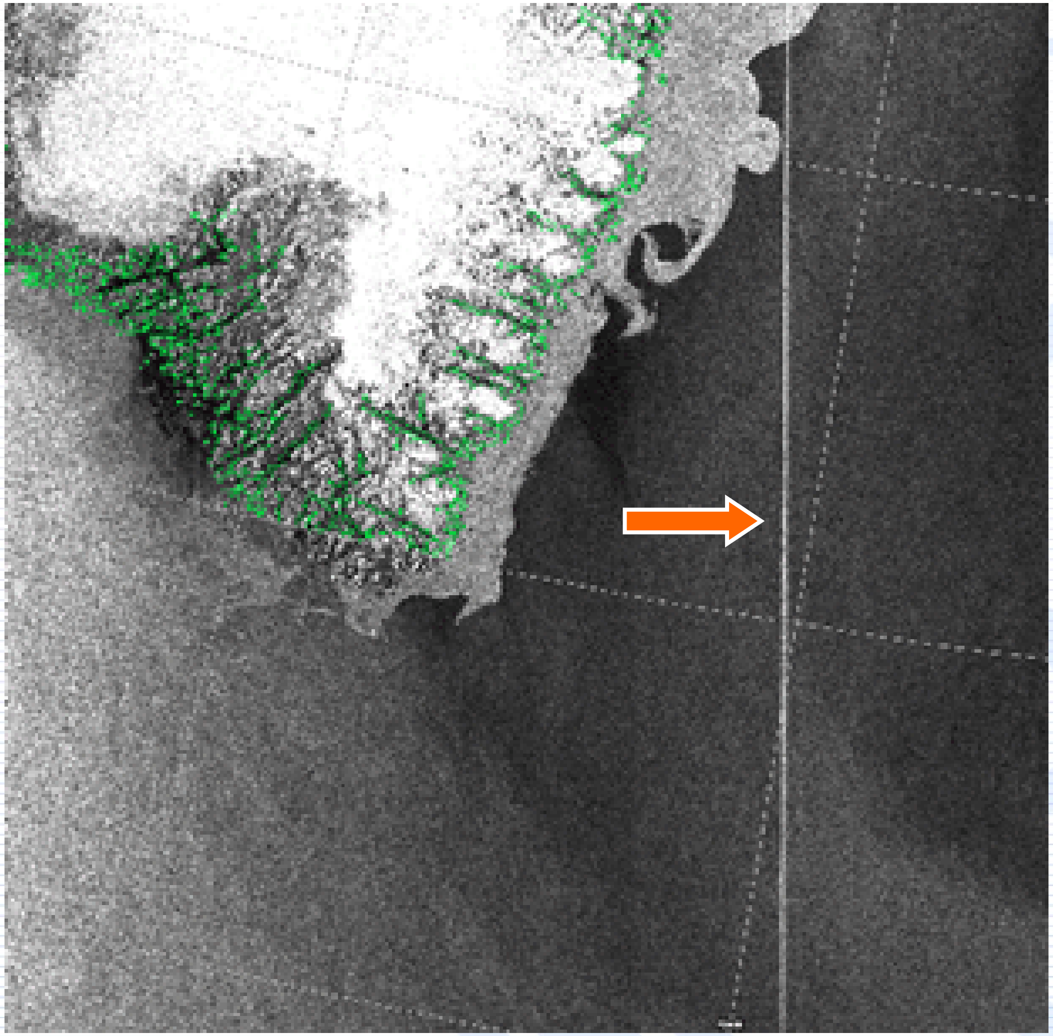
First duplicate of object.

Nadir ambiguity

Nadir ambiguity is a variation of range ambiguity. It appearance is caused by superposition of radar signals from different pulses which come back to radar on the same time. One of pulses is returned from nadir area on ground surface and comes back through range antenna pattern sidelobe. Appearance conditions are high level of antenna range pattern sidelobes in nadir direction, low backscattering level in mainlobe, and high backscattering level from nadir surface.



Nadir ambiguity

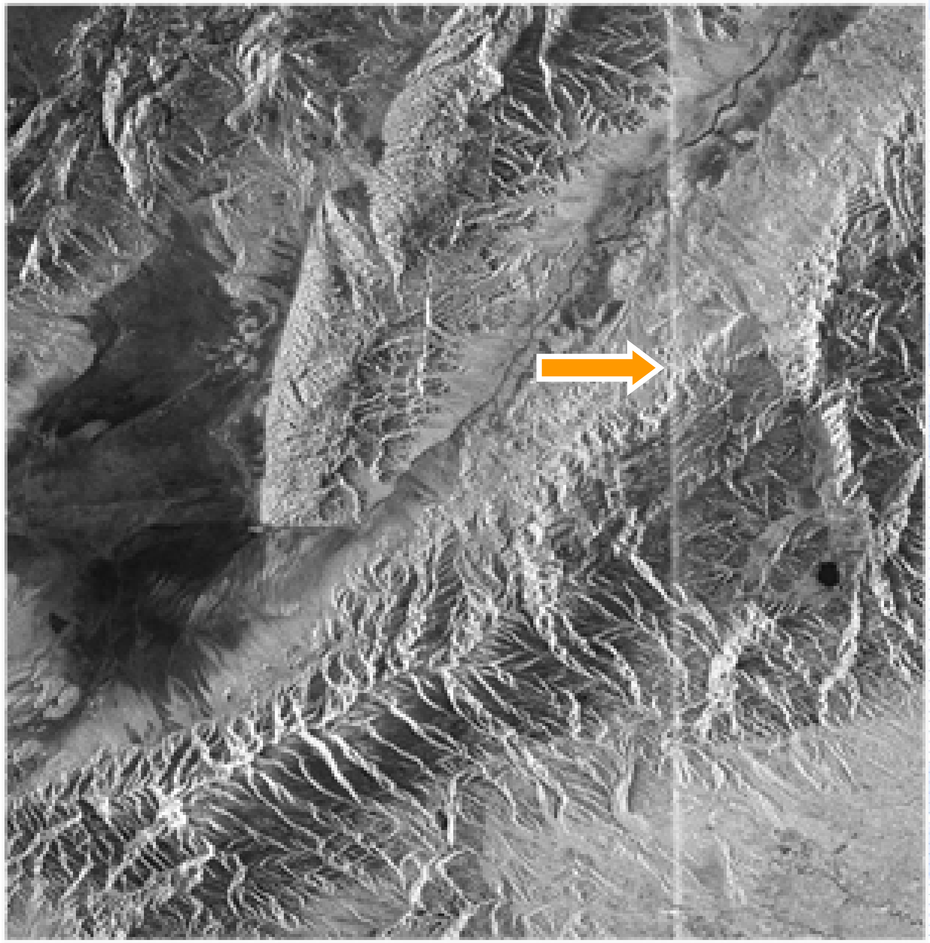


RADARSAT-1 SAR. Beam W3.
RADARSAT International processing.

Most strongly nadir ambiguity appears when it returns from high reflectivity surface and overlap on signal returned from surface with low reflectivity.

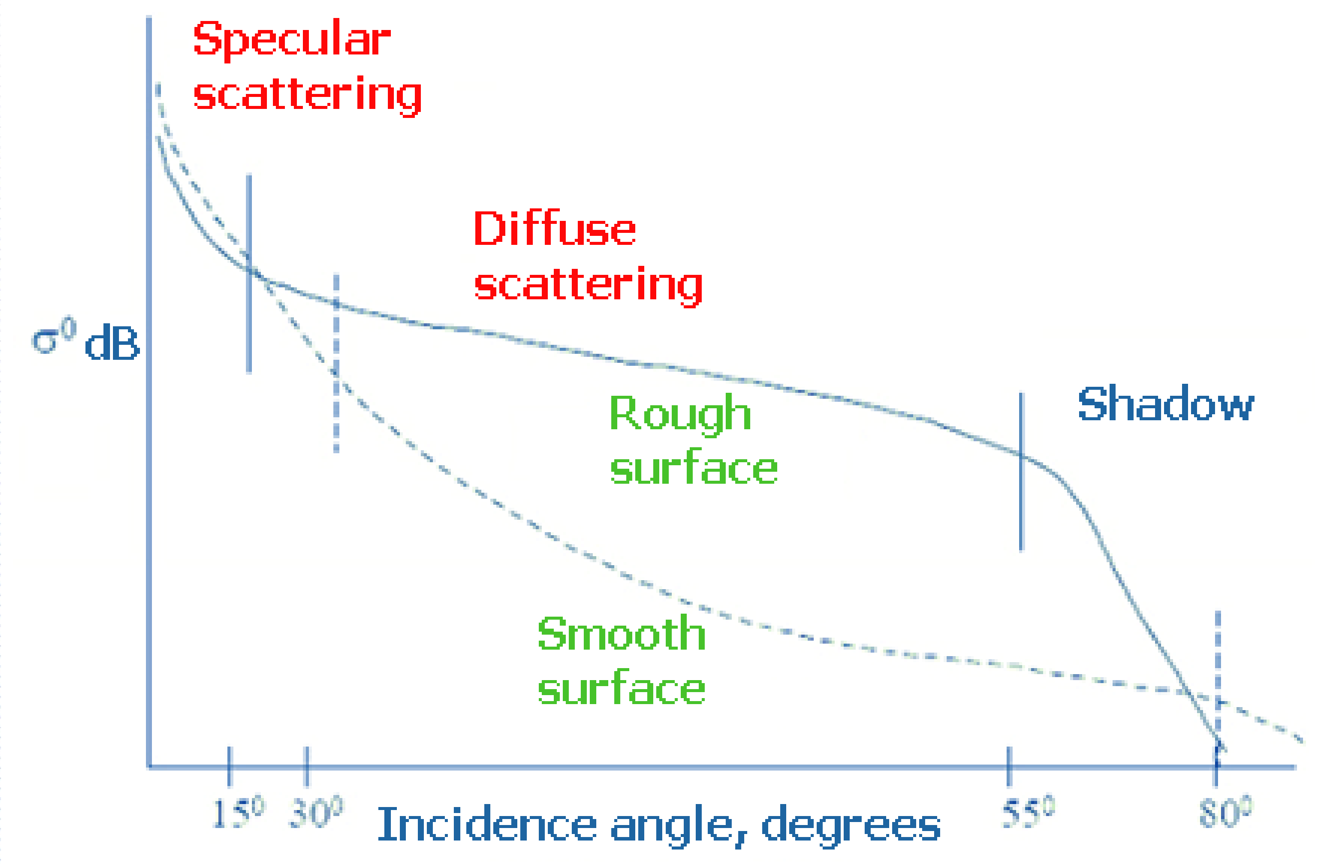
Nadir ambiguity

Nadir ambiguity strip could appear on images with high amplitude of backscattered signal in cases of strong nadir signal and high sidelobes of SAR antenna range pattern .



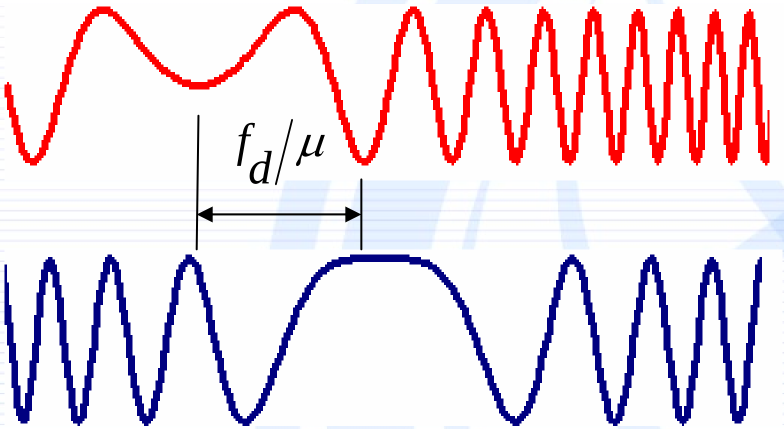
Nadir ambiguity

High power of nadir ambiguity signal could be explained from radar waves scattering dependence of incidence angle. On the small incidence angles scattering type appears as specular one, but for large angles it appears as diffuse one. With approach of incidence angle to zero values (nadir direction) the backscattered power toward to radar increase as exponent.



Ghosting due the local Doppler estimation errors

Estimation of local Doppler frequency is used for generation of azimuth phase history function in SAR processor. In general case, along survey the mean value of azimuth trajectory signal will be shifted from zero and this shift is called Doppler frequency shift. For the correct SAR processing this Doppler frequency should be accurately estimated. If the estimation is completed unproperly the focusing quality may falls and in some occasions ghosts may appear.



Trajectory signal shifted along frequency axis from “zero phase” position (real part).

Real part of reference function (signal replica).

f_d **- Doppler frequency shift**

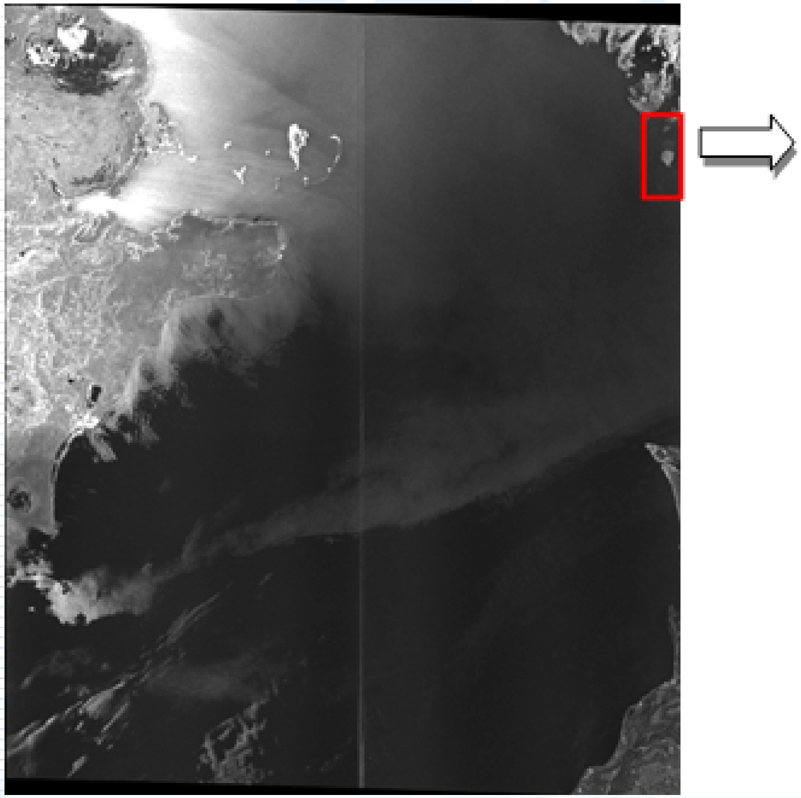
μ **- Linear frequency rate of signal along azimuth direction**

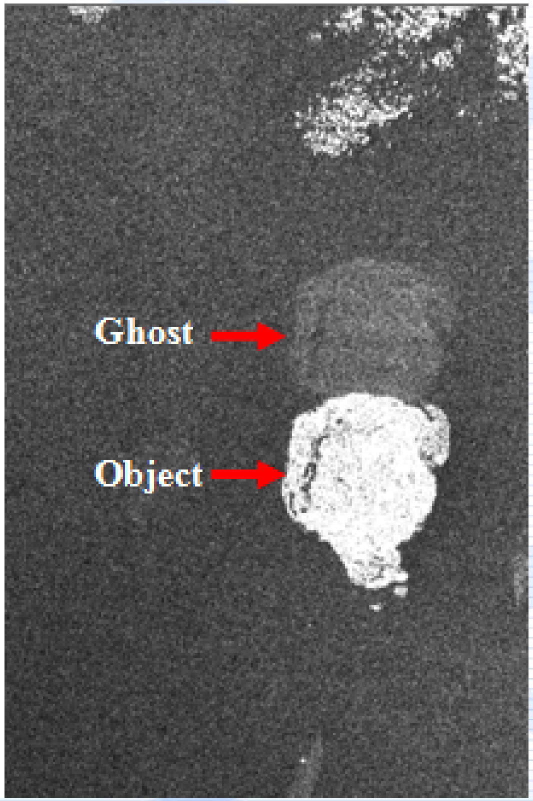
Doppler frequency shift is removed in SAR processor via replica multiplication on some complex function:

$$\dot{d}(t) = \exp\left(-j\left[f_d \cdot t\right]\right)$$

Ghosting due the local Doppler estimation errors

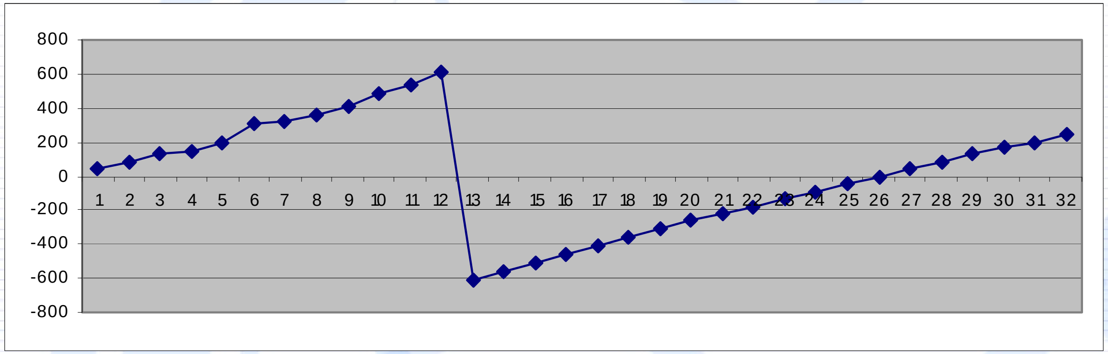
RADARSAT-1 SAR. Orbit 60333, survey mode SNA (w1+W2). Wrong estimation of local Doppler frequency most often occurs on ground surface with "sea - land" boundary. Because of some reasons the values of Doppler centroid for these areas are unstable and chaotic that leads to generation of wrong estimations of Doppler frequency field in SAR processor. Then the duplications of objects on radar images are appear.

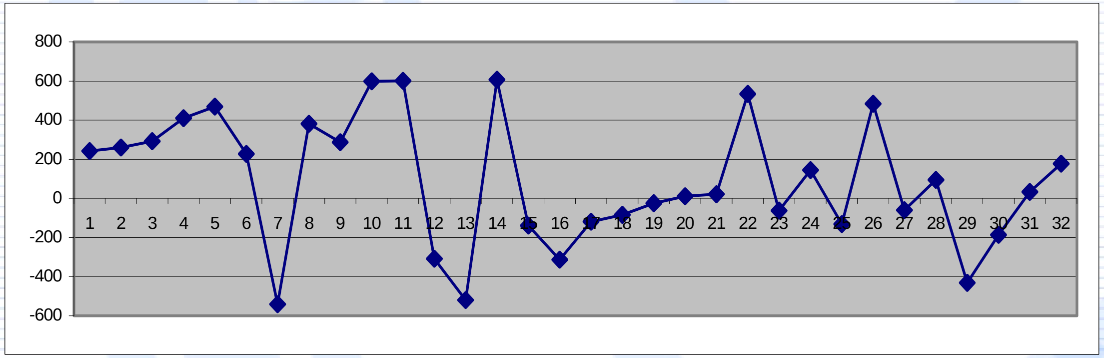




Ghosting due the local Doppler estimation errors

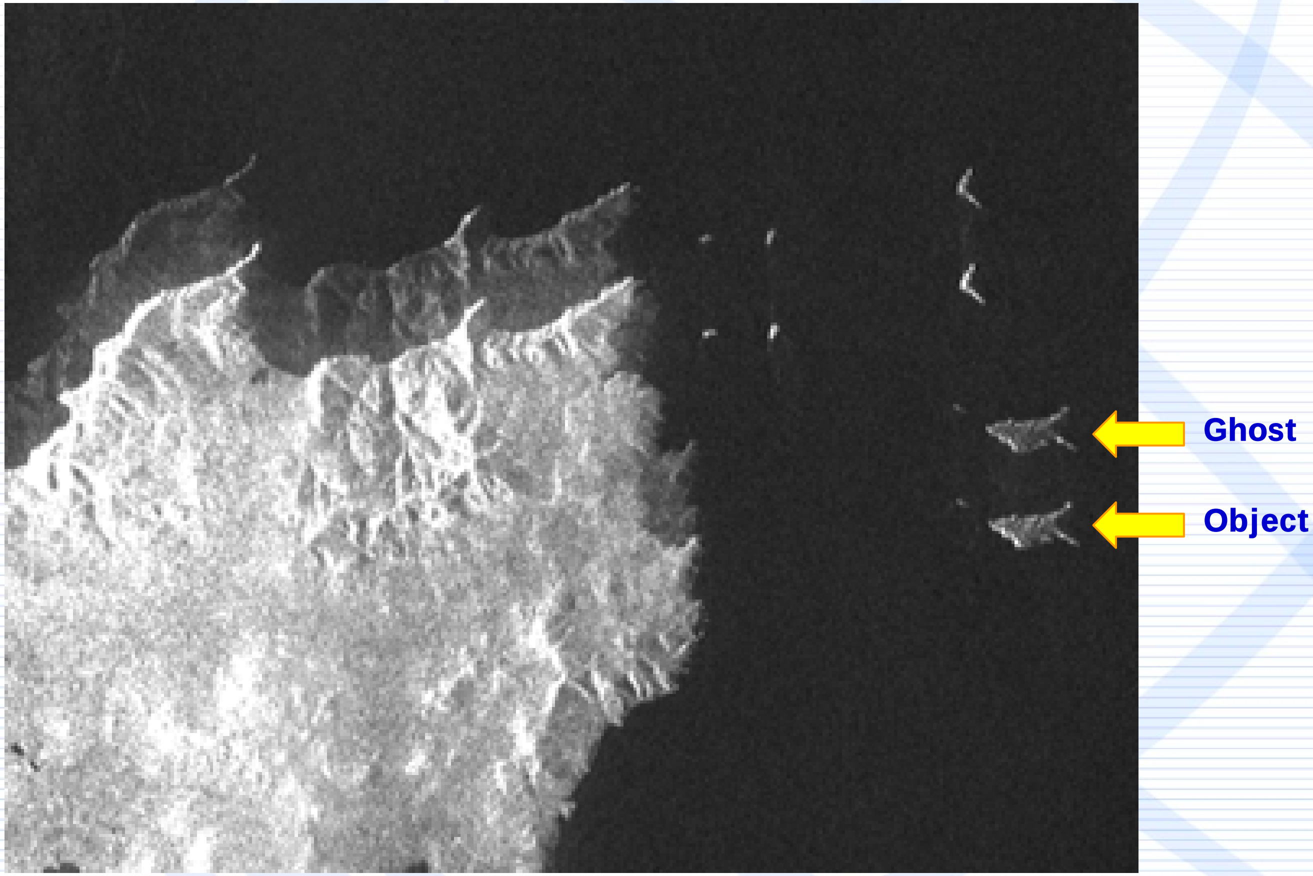
Pictures below show dependences of local Doppler frequency on slant range. Correct Doppler frequency estimation behavior is outlined on the top picture, corrupted estimations - on the bottom one.





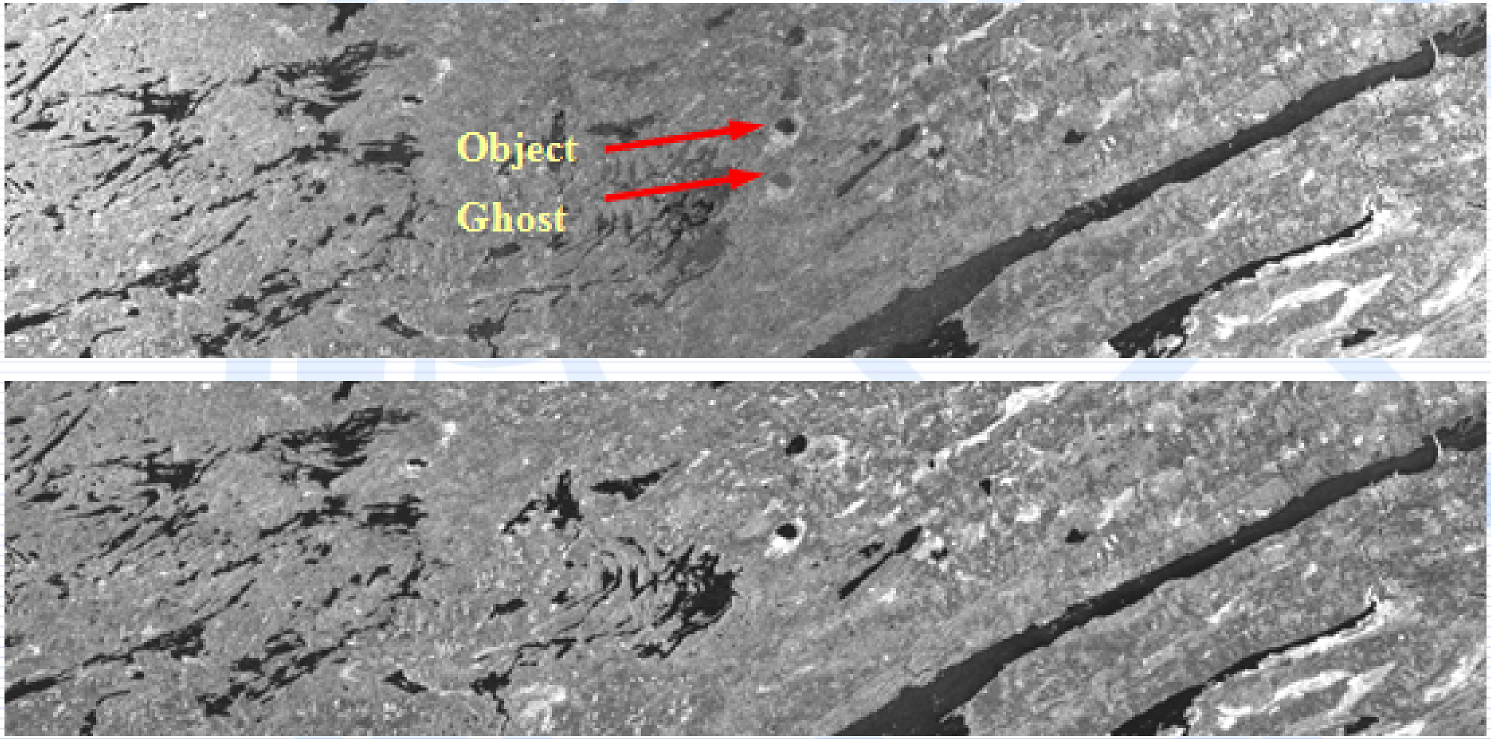
Ghosting due the local Doppler estimation errors

RADARSAT-1 SAR. Orbit 66267, survey mode SWA (w1+W2+W3+S7). Objects doubling (ghosting) is caused by wrong local Doppler frequency estimation. From this picture is seen that for some objects their ghosts have near same brightness level.



Ghosting due the local Doppler estimation error

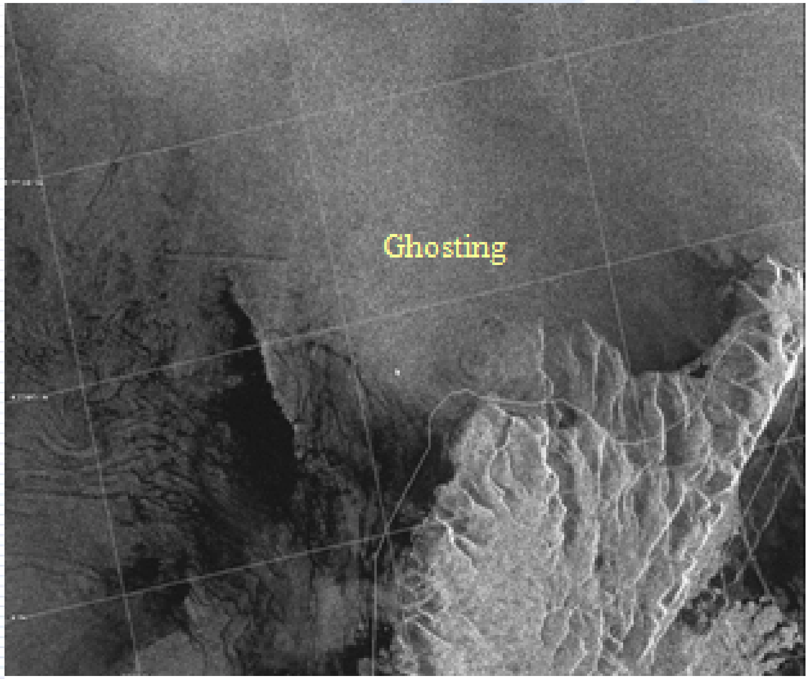
Objects duplication (ghosting) caused by wrong Doppler frequency estimation could be corrected via repetition of azimuth focusing procedure with true values of Doppler field. By simple way correct frequency values could be derived through manual analysis of raw data (radar hologram). In general it reduced to finding the range line with good behavior of local frequencies curve and application of this curve to whole processed scene.

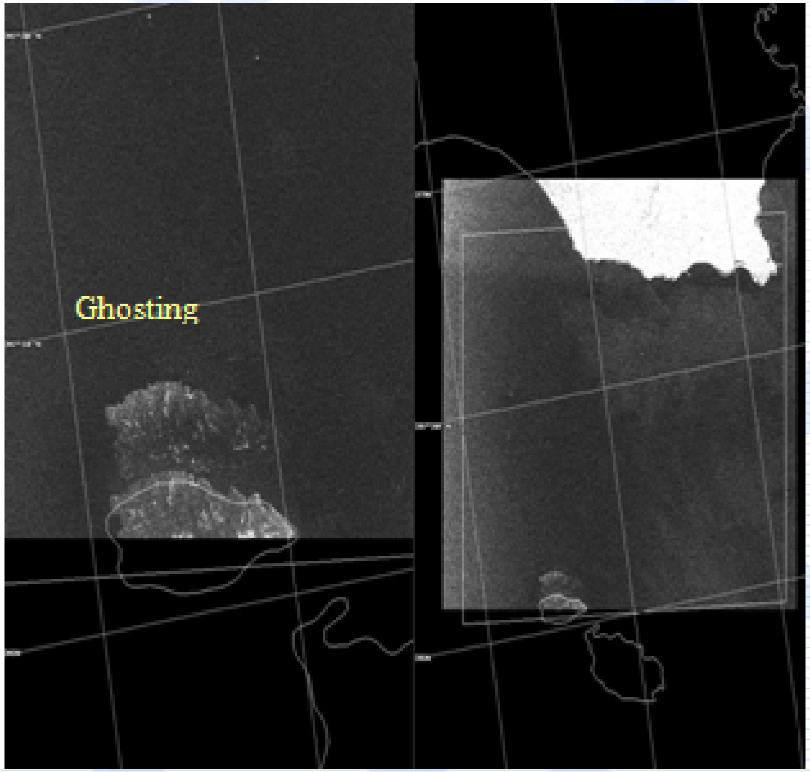


Result of azimuth focusing with wrong Doppler frequency estimation is shown on the top picture and with correct estimation - on the bottom one.

Ghosting due the local Doppler estimation error

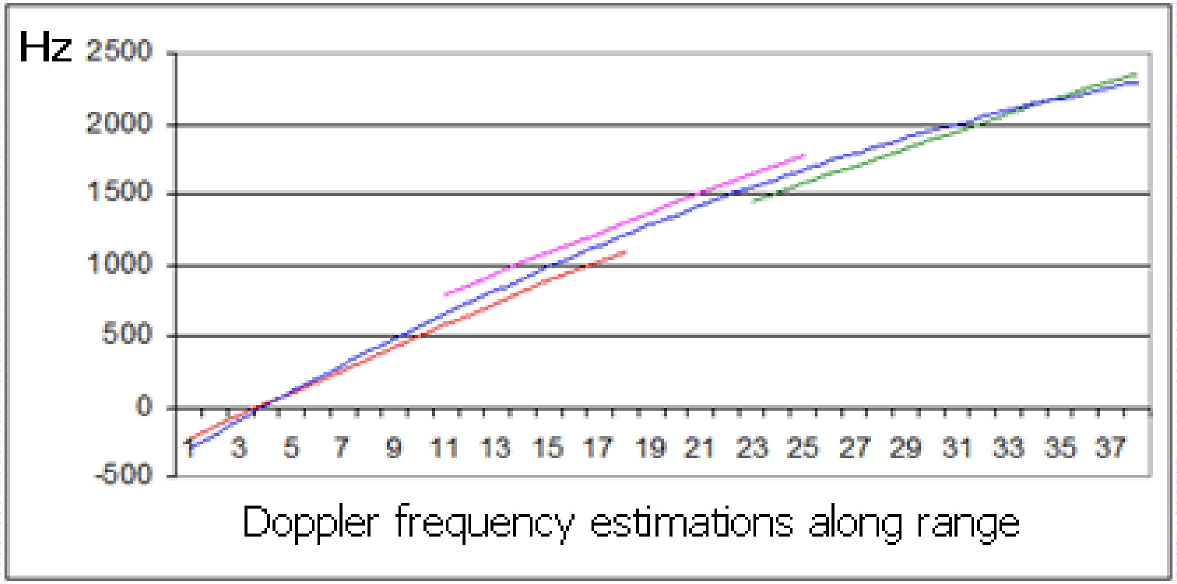
RADARSAT-1 SAR. RADARSAT International processing. Ghosting on image is caused by wrong local Doppler estimation.





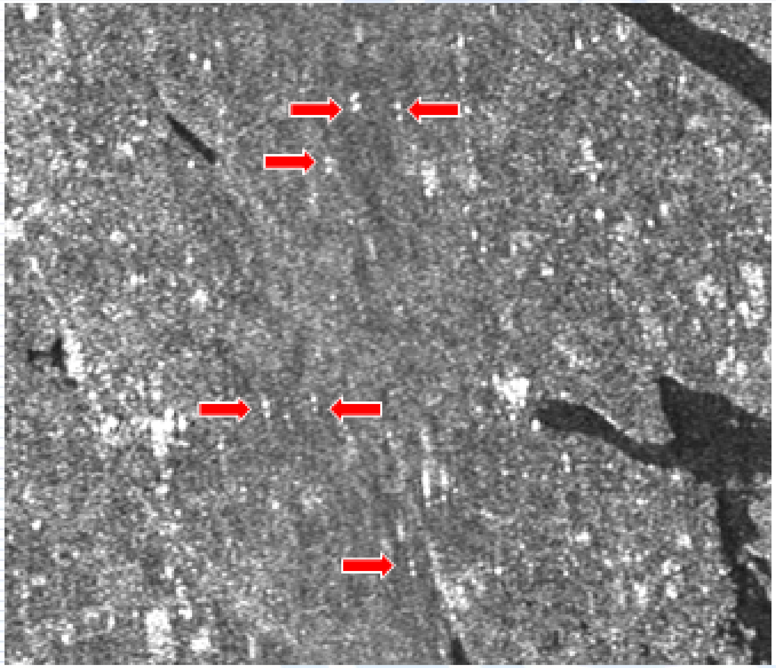
Ghosting due the local Doppler estimation errors

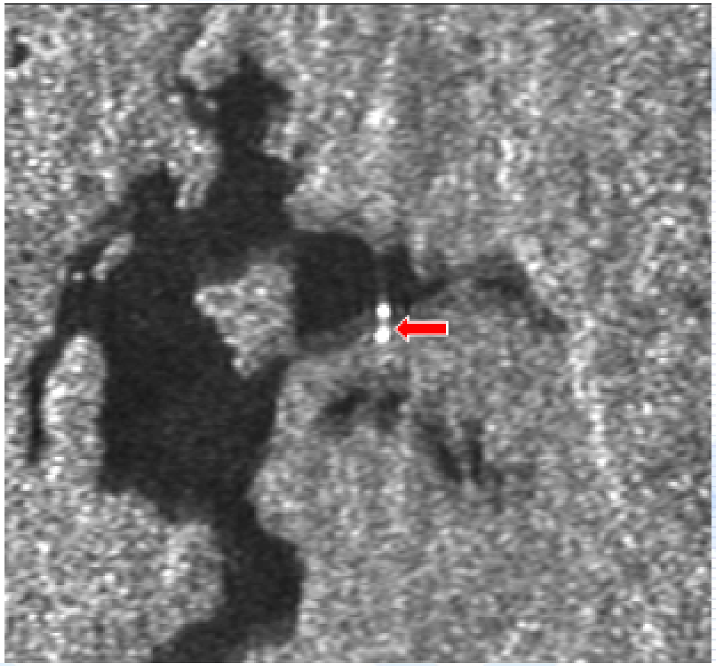
For the scenes acquired with ScanSAR mode the problem of beams unstitching could be appears. It means that neighboring strips shall be cover inaccurately because of wrong applying of Doppler frequency estimations from different beams. In really, the Doppler estimations from the same part of ground surface could be distinguished on the neighboring beams. On the picture bellow the estimations acquired from three neighboring RADARSAT-1 beams (SNB acquisition mode) are shown. The dependencies of Doppler frequency by slant range are marked by different colors. It is shown from the picture that in beams overlapping areas the estimations are not matched.



Ghosting due the local Doppler estimation errors

RADARSAT-1 SAR. Survey mode SNB. Ghosting on the covering area between two neighboring beams is caused by superposition of two beam's images processed with unstitched individual Doppler frequency curves. It should be noted that both estimations in adjacent beams have been done correctly, so there is no formal error here.





Ghosting in areas of beams overlapping could be removed via calculation of common Doppler estimation over all beams of ScanSAR configuration. Azimuth focusing must be performed with use of common frequency-range dependence. Example of this curve is shown by blue color on the picture above.

Displacement due the absolute Doppler estimation error

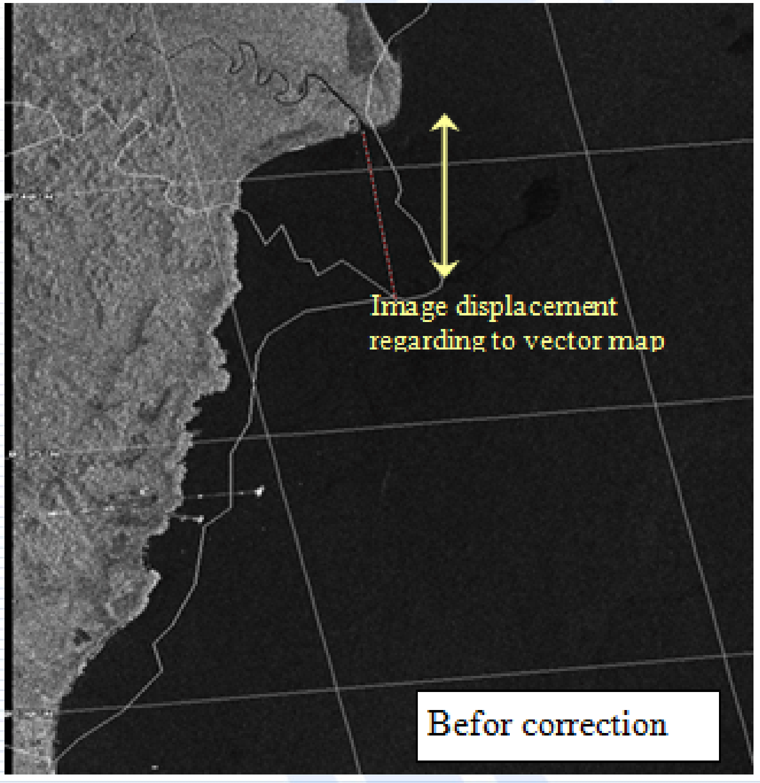
When the SAR processor forms the image from radio hologram which has non zero mean Doppler frequency the error of inaccurate absolute Doppler frequency estimation may occurs. Absolute value of mean Doppler frequency over hologram field if formed as a sum of two components: estimation of local frequency into azimuth signal band, which depends on radar pulse repetition frequency (PRF), and some whole number of PRF.

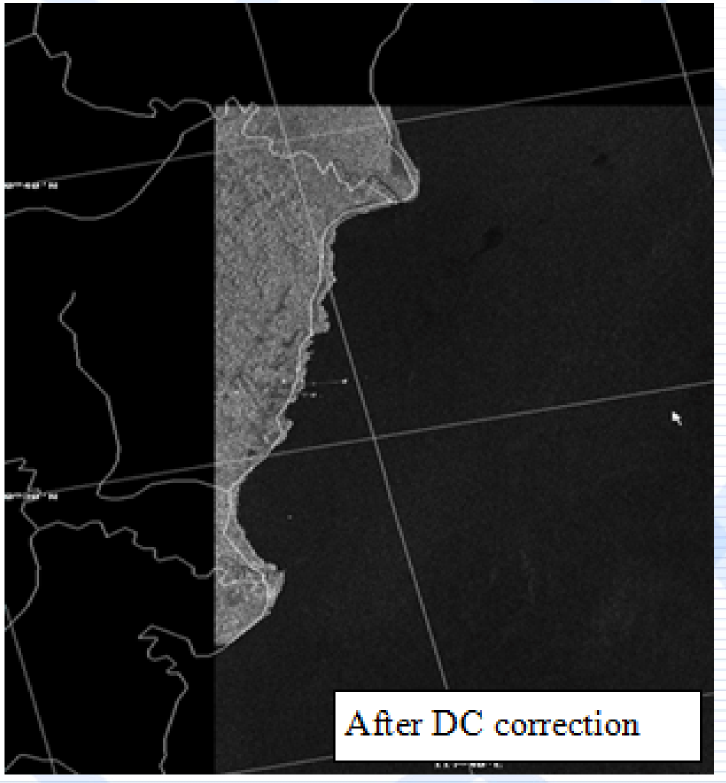
$$F_{ABS} = F_{LOC} + F_{PRF} \cdot N_{PRF}$$

SAR processor performs both estimation of local Doppler frequency and number of PRF which potentially may be defined with error. Obviously estimation errors arise on the scenes which have great number of input data inconsistences or on the scenes acquired over surface with sea – land boundary. The consequence of the error is a wrong definition of output image cartographic coordinates. The image wholly displaces meanly along azimuth direction and slightly along range direction. The value of displacement depend on PRF and imagery latitude. The error of one PRF leads to the image displacement, for instance, from 3 to 6 kilometers along azimuth direction for RADARSAT-1 SAR. An addition, the focusing quality become worse and image noise level increase. In order to remove absolute Doppler estimation error it's necessary to repeat azimuth focusing with true ambiguity value.

Displacement due the absolute Doppler estimation error

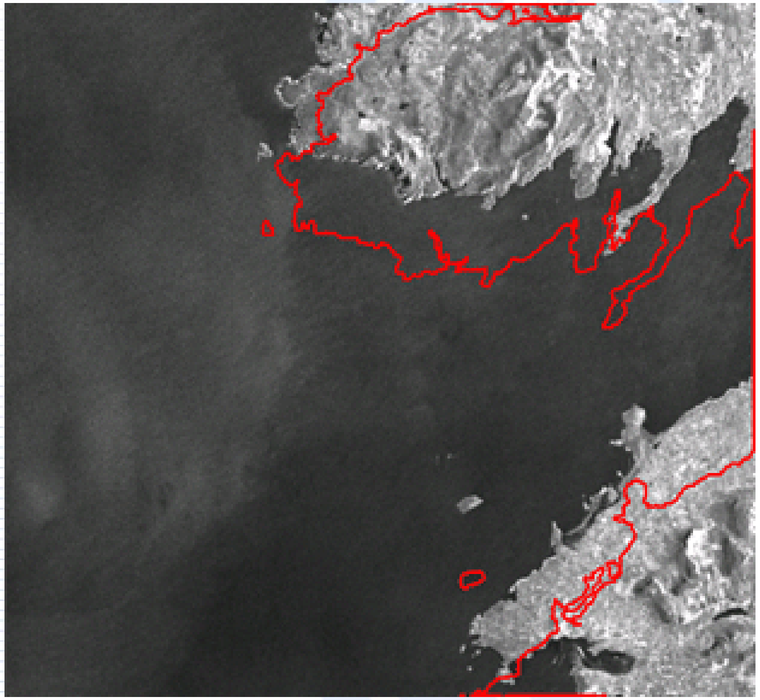
RADARSAT-1 SAR . RADARSAT International processing. Wrong absolute Doppler frequency estimation leads to displacement of image along pass direction (azimuth) and to slight defocusing.

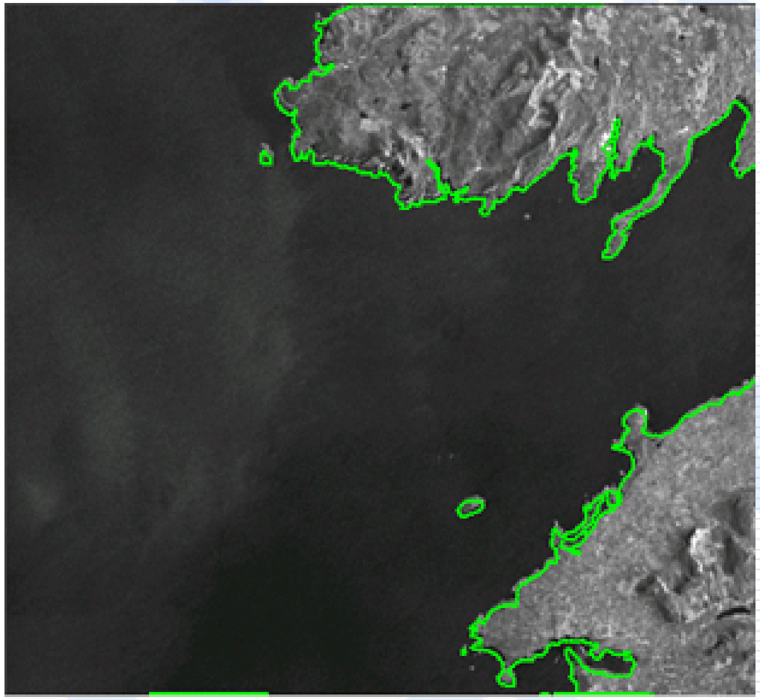




Displacement due the absolute Doppler estimation error

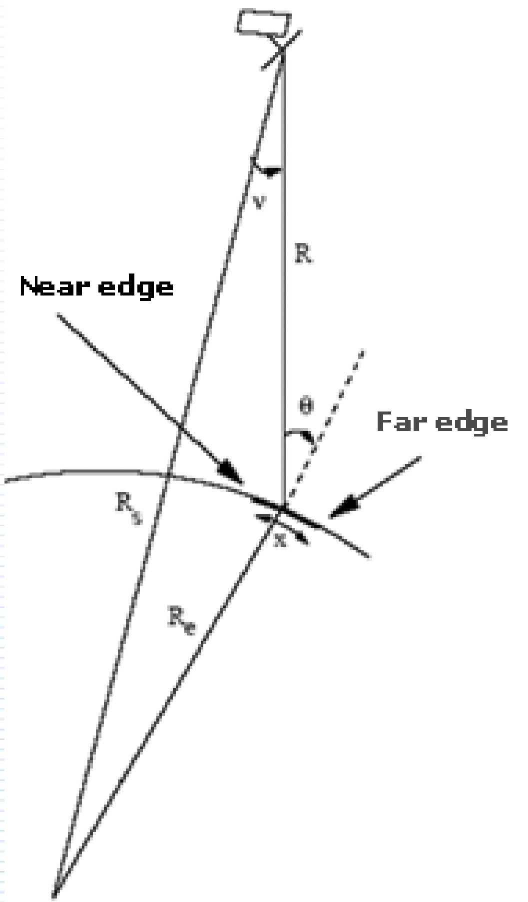
RADARSAT-1 SAR. Below left picture shows the image with ground position error approximately 5.5 km along azimuth direction. This error is caused by incorrect definition of Doppler ambiguity of one PRF. Below right picture shows the result of repeated focusing with accurate value of ambiguity. The previous ambiguity number was N=0, the adjusted number is -1. The position of vector map overlaid on image raster is marked by red and green colors.

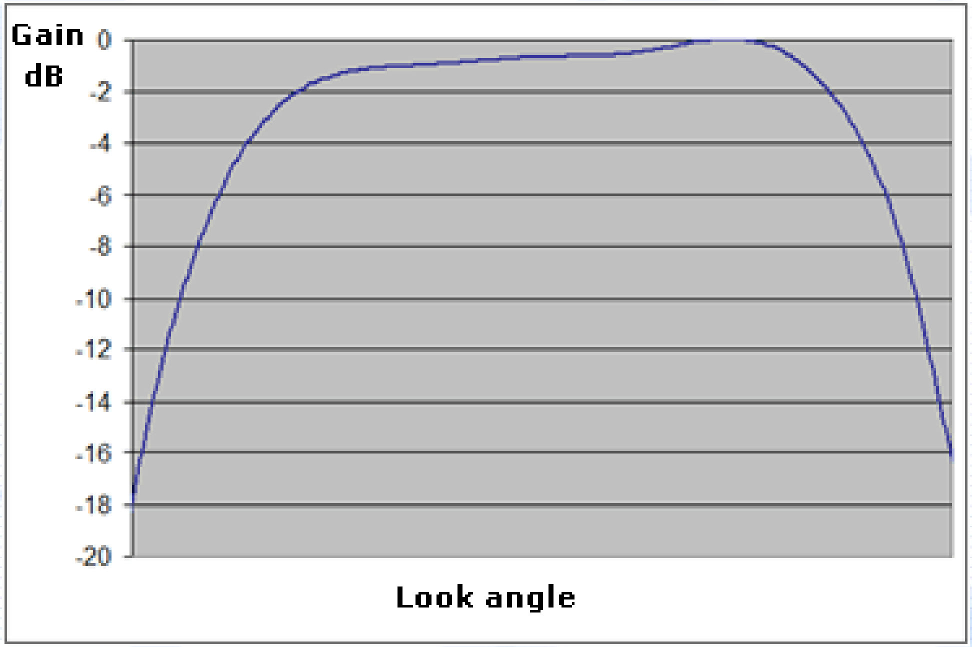




Insufficient range antenna pattern compensation

Sometimes the strips with different brightness appear on the radar images which are caused by insufficient or incorrect taking into account of antenna pattern gains along range cross section.

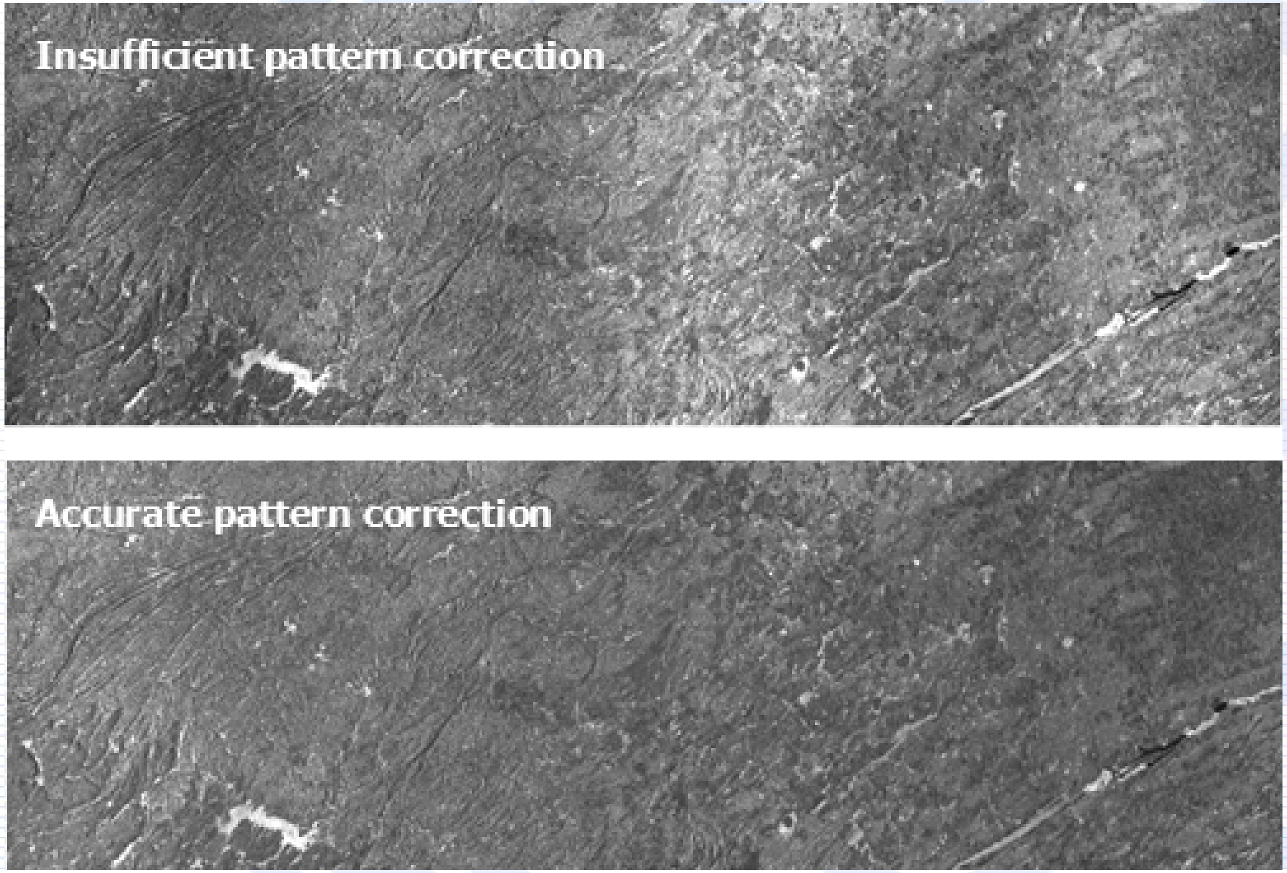




Antenna pattern correction is usually performed in SAR processor. It requires the knowledge of antenna pattern values and antenna beam slant range value which is actual for particular scene. Inaccurate knowledge of these parameters leads to mismatching of applied pattern profile and image. As a rule, most disparity can be observed on the near edge of imaging swath. Example of RADARSAT-1 antenna pattern range profile is outlined on picture above.

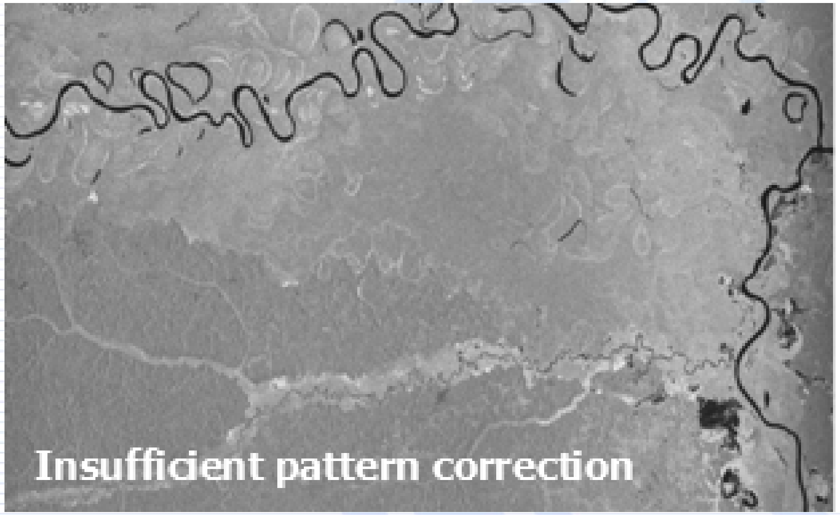
Insufficient range antenna pattern compensation

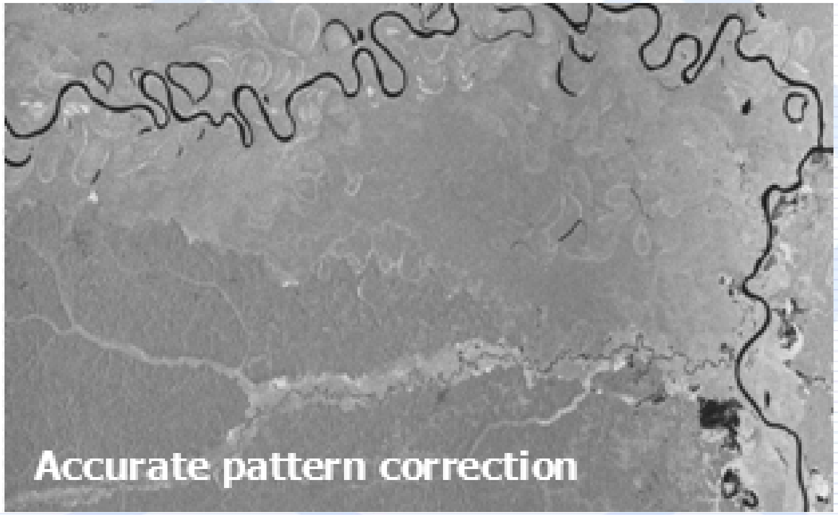
RADARSAT-1 SAR. The effect of inaccurate antenna pattern correction is shown on the picture below. This effect can be avoided through additional processing of image after SAR processor.



Insufficient range antenna pattern compensation

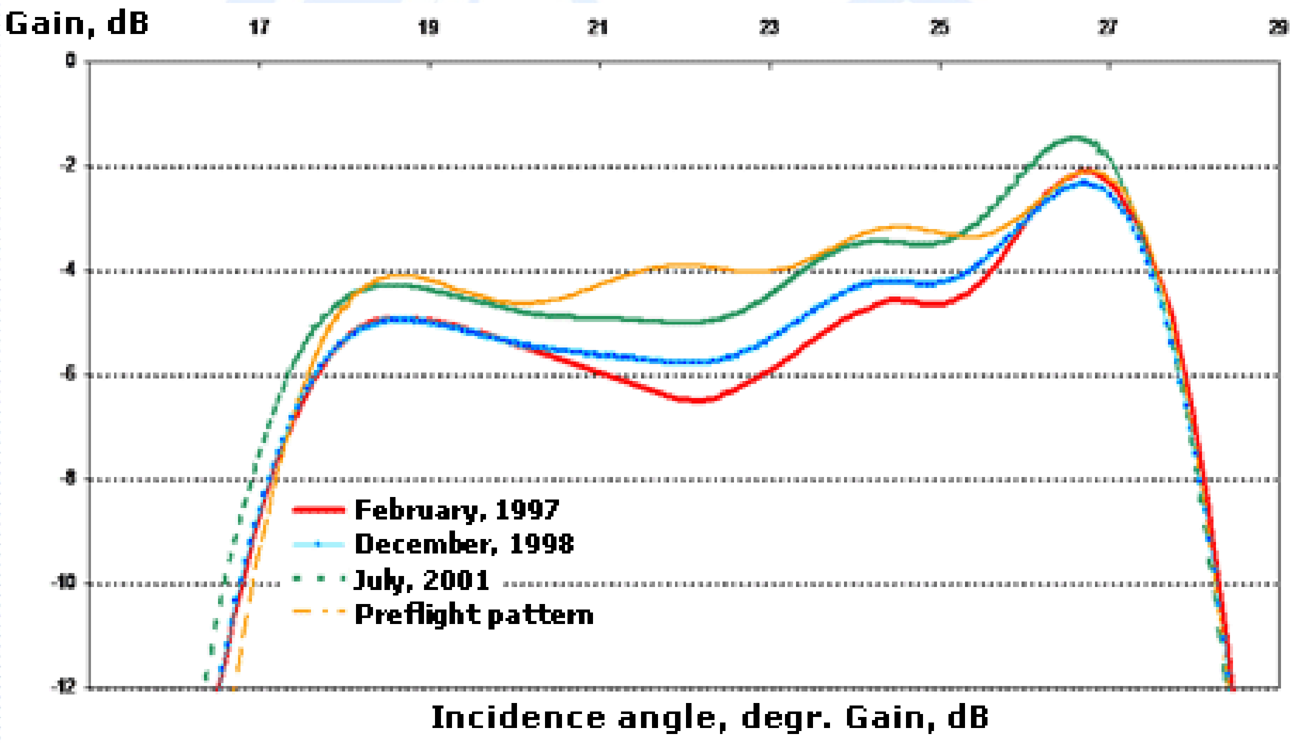
RADARSAT-1 SAR. Survey mode SWA. The effect of inaccurate antenna pattern correction is shown on the picture below.





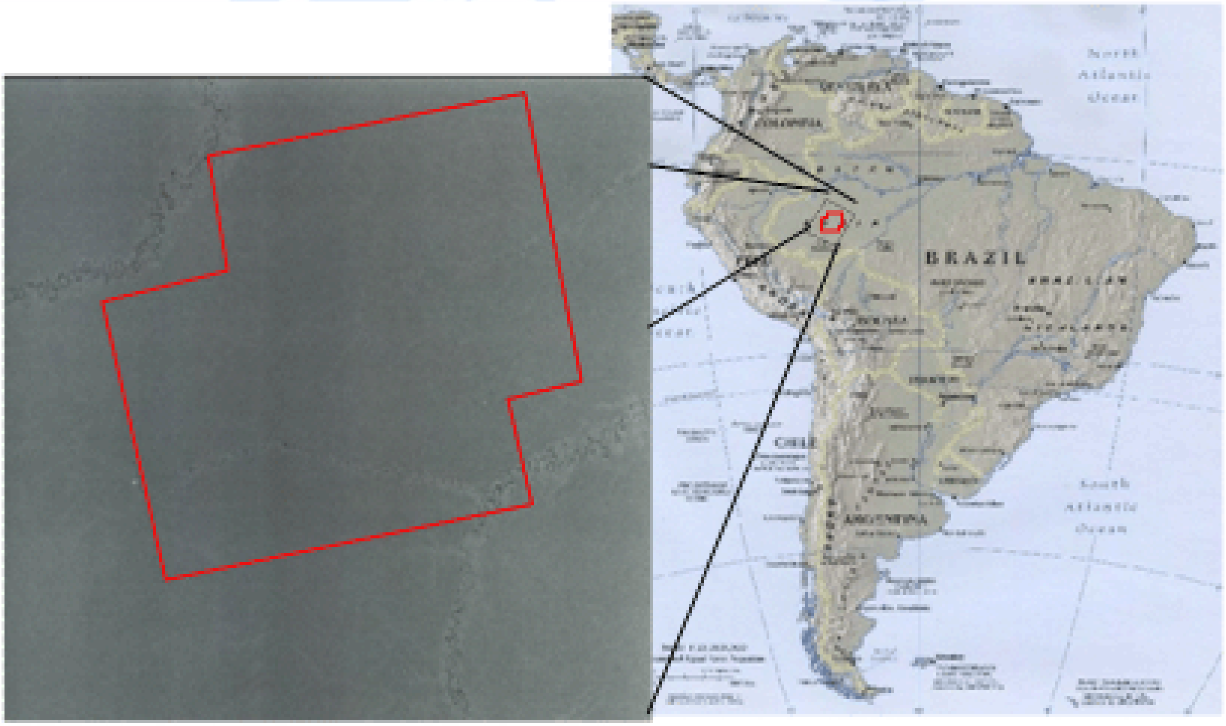
Insufficient range antenna pattern compensation

An important part of quality assistance procedure is the regular calibration of SAR antenna pattern in order to get the real and accurate information on antenna current gain profile. The example of periodic measurements of pattern for RADARSAT-1 SAR beam W1 is shown on the picture below. It illustrate the pattern fluctuation along flight time.



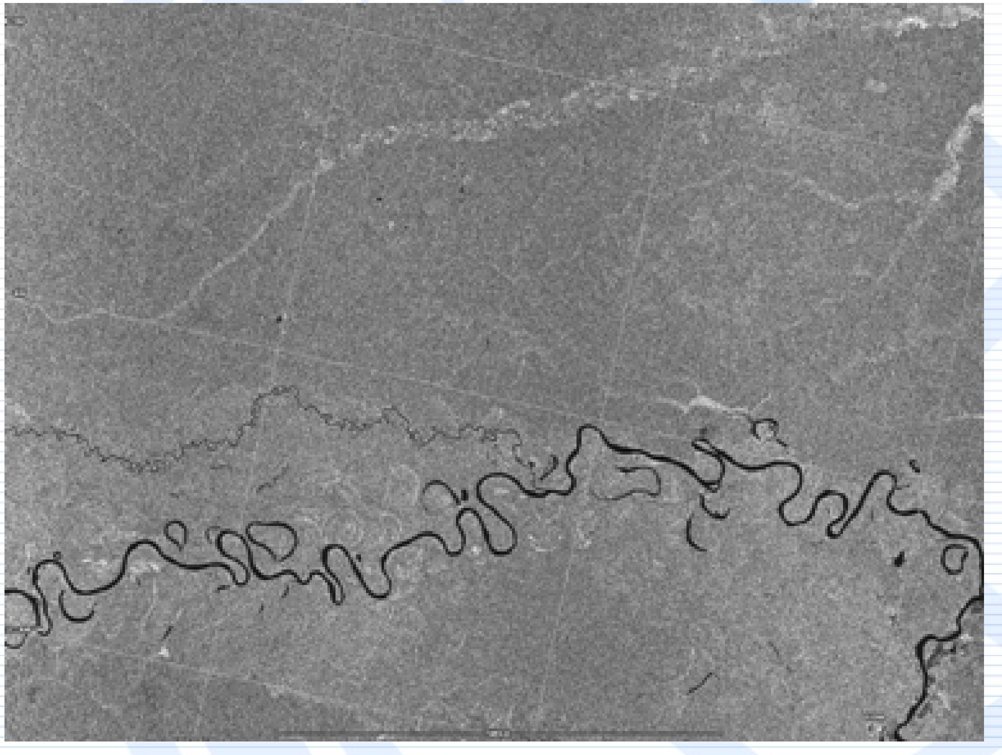
Insufficient range antenna pattern compensation

Most suitable approach to antenna pattern calibration during flight is the regular imaging of ground surface area which has large squire and homogeneous backscattering properties along time and. As example of such area the Brasilian rainfall forests could be exploited.



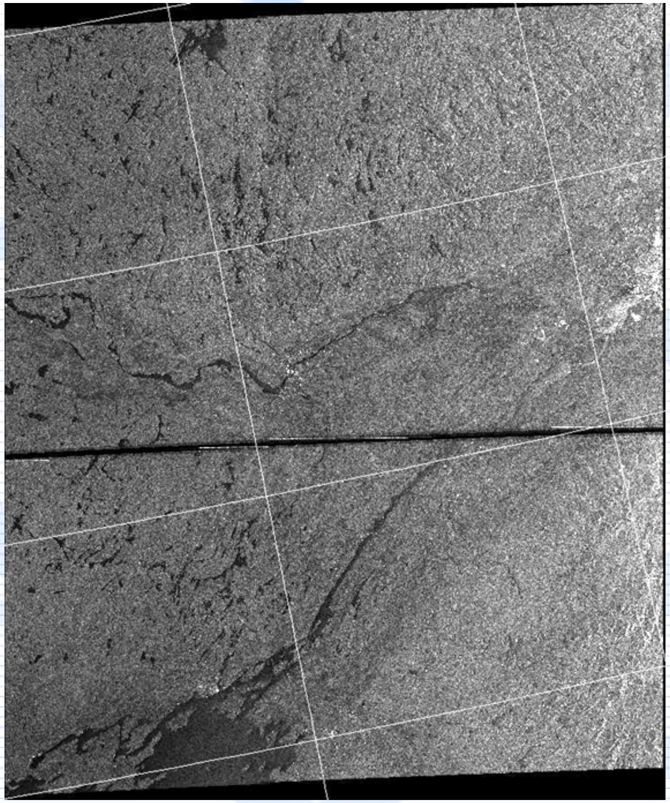
Insufficient range antenna pattern compensation

RADARSAT-1 SAR. Picture below shows radar image over Amazon river basin which could be selected as the area for calibration of speceborne SAR antenna pattern.



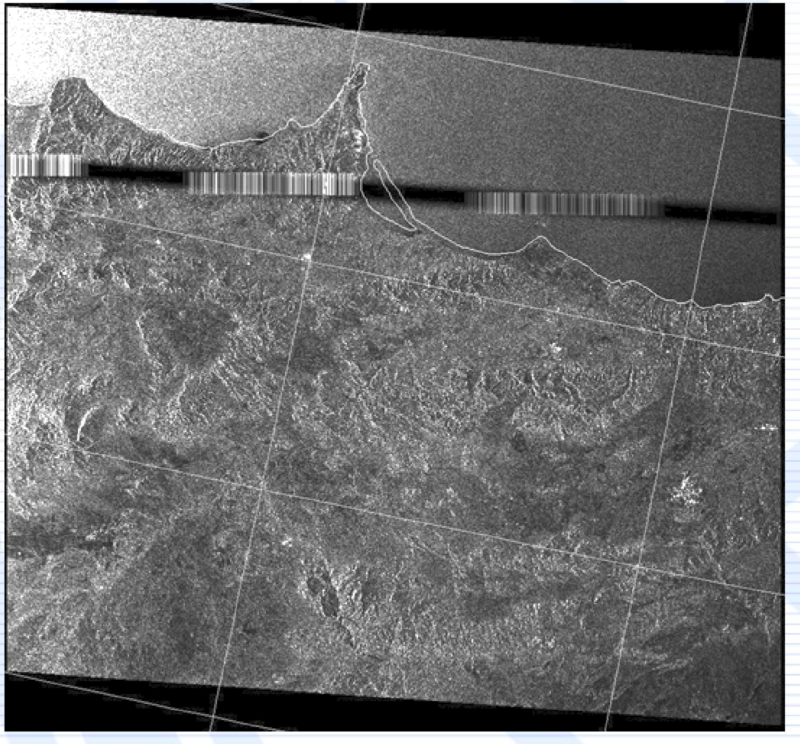
Data loss

Data loss during data acquisition and transmission could be cause by some errors in onboard SAR equipment, downlink equipment, and ground data registration blocks. Along image generation processing, as a general case, lost data are substituted by zero values or previously passed data. It's not allowed to simple ignore data missing because along coherent focusing it will lead to valuable degradation of image in the part where input data absent.



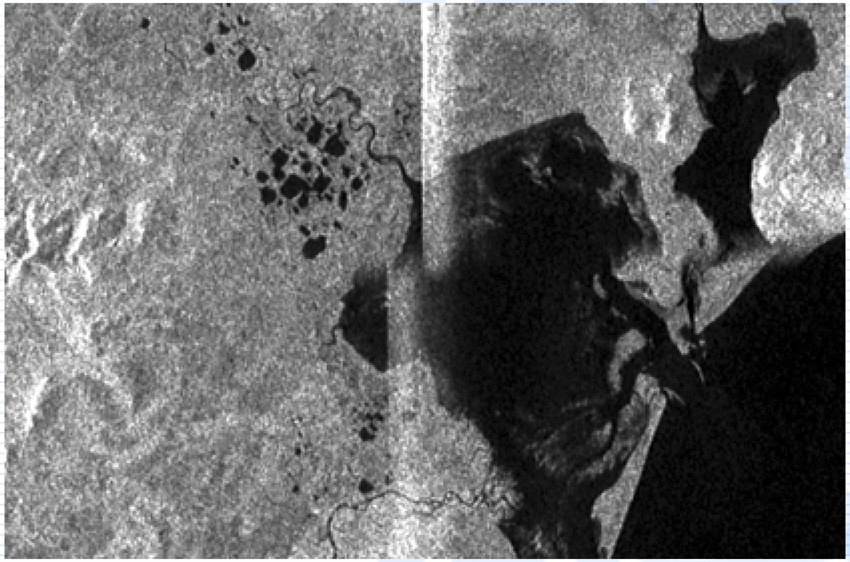
Data loss

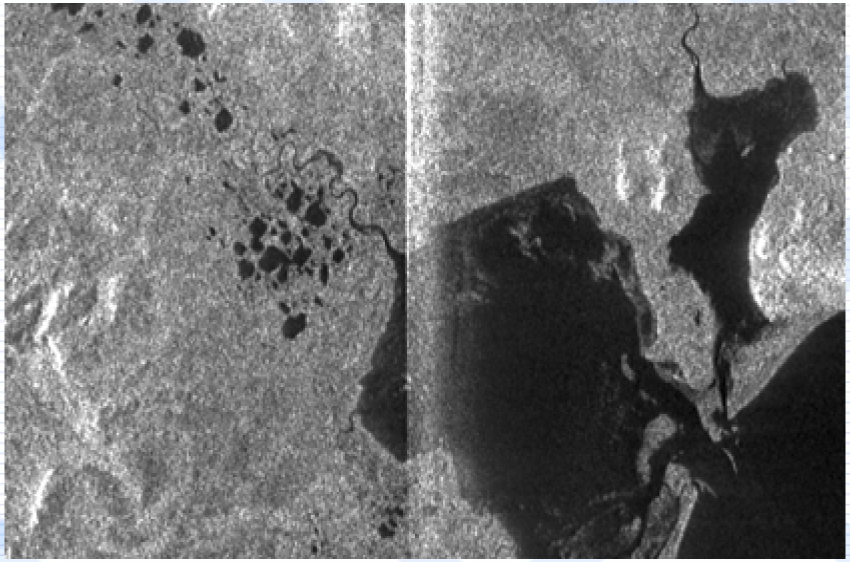
RADARSAT-1 SAR. RADARSAT International processing. The appearance of black and white strips on image is caused of missing lines.



Changing of range time delay code

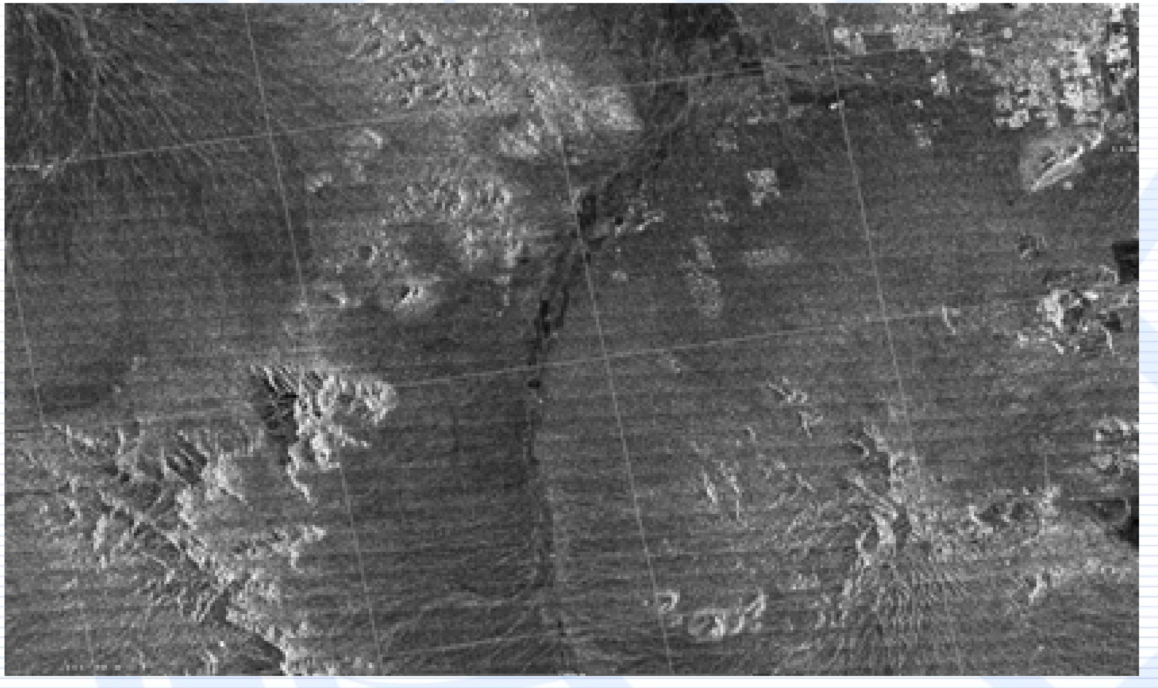
Into onboard SAR systems along imaging the changing of range time delay code may occurs. Obviously it is doing in order to compensate platform altitude variations or programmed reorientation of antenna pattern mainlobe direction. If this feature is not taken into account in SAR processor it will lead to mutual displacement of different parts of image.





Scalloping

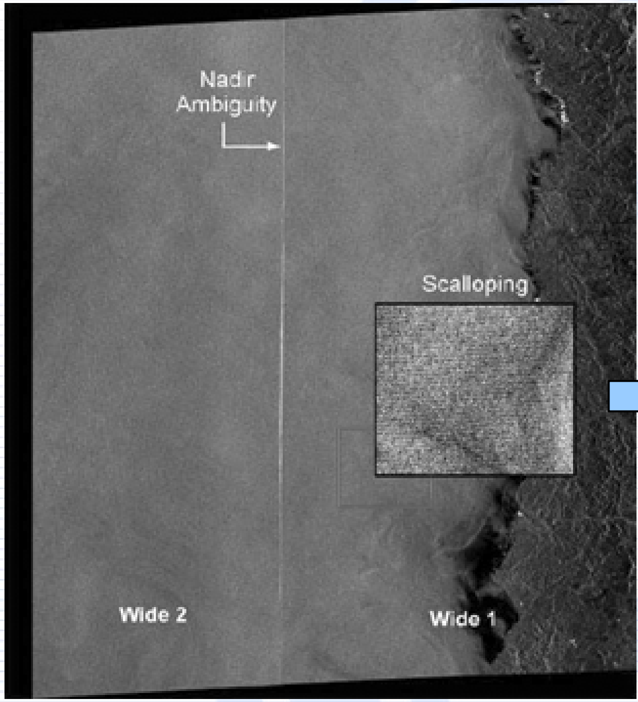
Scalloping on SAR images may appears in case of acquisition in ScanSAR mode. This effect is caused by inaccurate estimation of doppler centroid mean frequency over image area. On SAR image the scalloping appears as sequence of bright and dark strips with tooth structure oriented along range direction.



It should be noted that the scalloping strips are not strictly oriented along range, but with some slope which depend on doppler centroid value. The scalloping could be avoided by two means. The first way is to repeat the image focusing with improved doppler centroid estimation. Second way is to remove scalloping from processed image via spectrum correction.

Scalloping

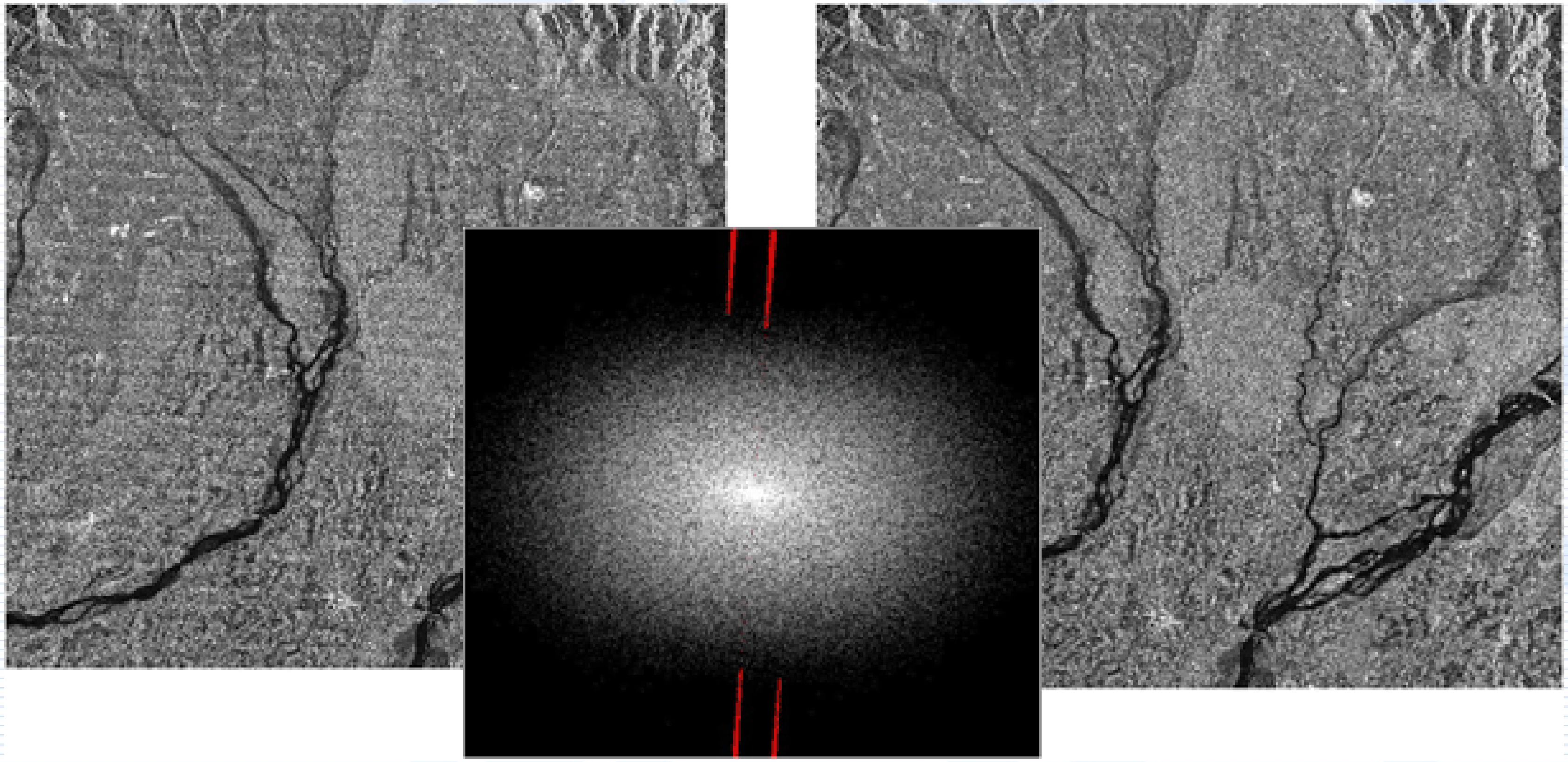
RADARSAT-1 SAR. Imaging mode SNA, 23.03.1997. Processing of Canadian Space Agency. Scalloping could be seen on part of image.



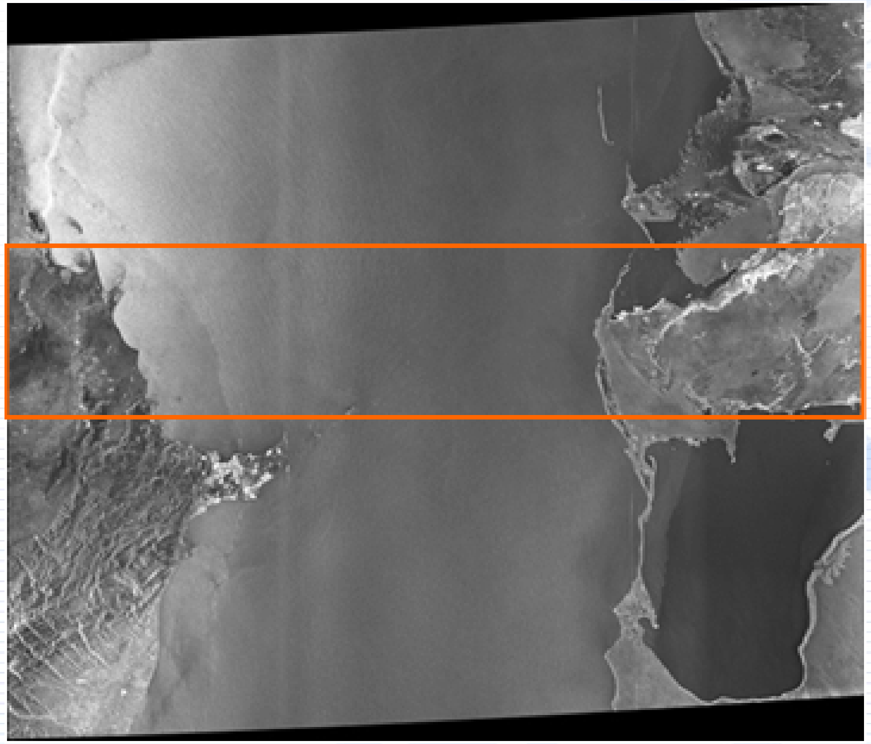
Removing of scalloping effect on postprocessing stage is achieved via correction of processed image spectrum. It is doing in frequency domain with use of Fourie transform. At first the image spectrum is produced via direct Fourie transform. Then the correction of spectrum is applied in order to suppress the frequencies which are responsible to scalloping appearance. After that, the image restoration is performed via inverse Fourie transform.

Scalloping

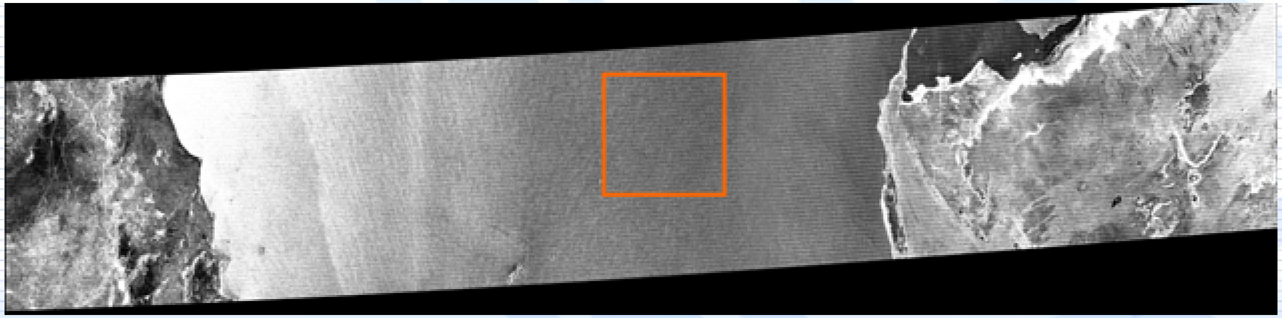
RADARSAT-1 SAR. RADARSAT International processing. On the left picture – fragment of radar image with scalloping. On the central picture – image spectrum. Red lines restrict the area of spectrum correction. On the right picture – improved image after inverse Fourie transform of corrected spectrum.



Scalloping



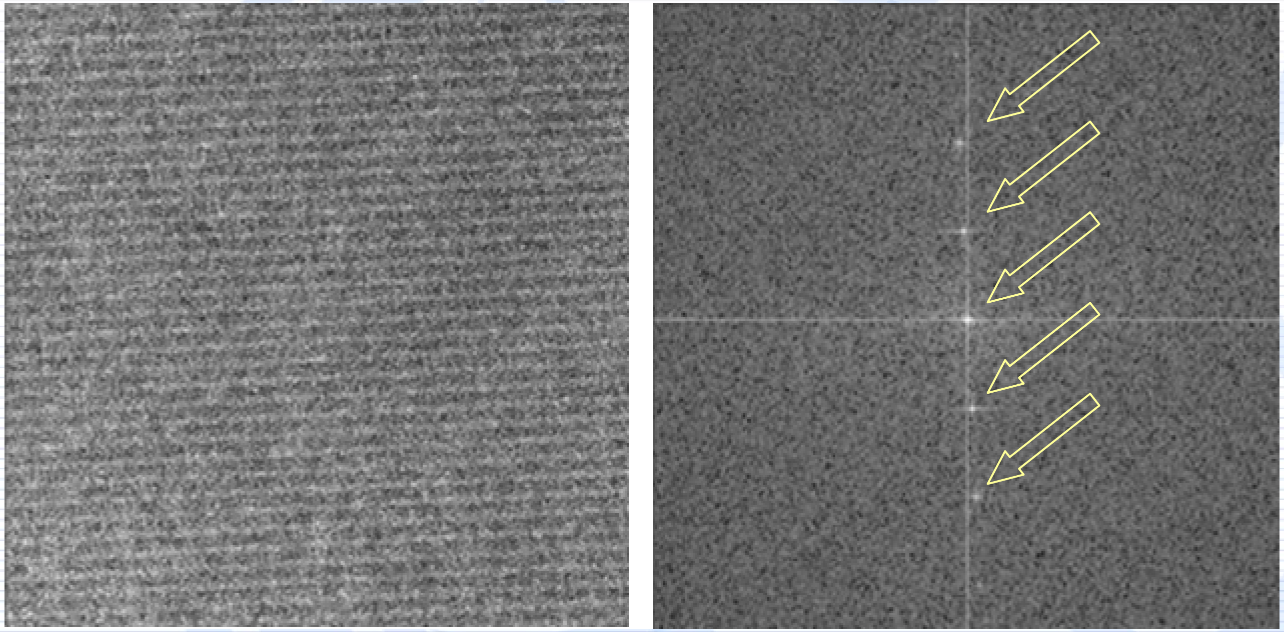
RADARSAT-1 SAR. Orbit 46220. Imaging mode SWA (four beams). Full scene.



Selected part of full scene outlined on the picture. There is scalloping on the sea surface.

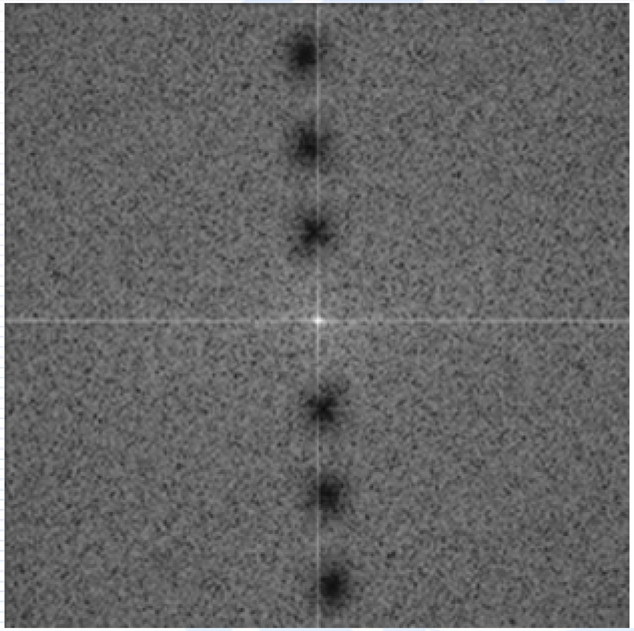
Scalloping

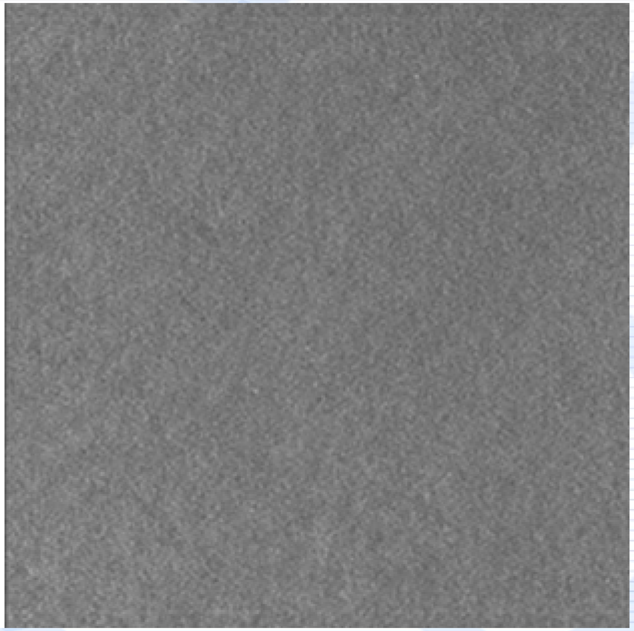
Selected part of previous image with scalloping structures is shown on the left picture. Right picture shows spectrum on image. Arrows appointed on the spectrum components (bright spots) responsible for scalloping appearance.



Scalloping

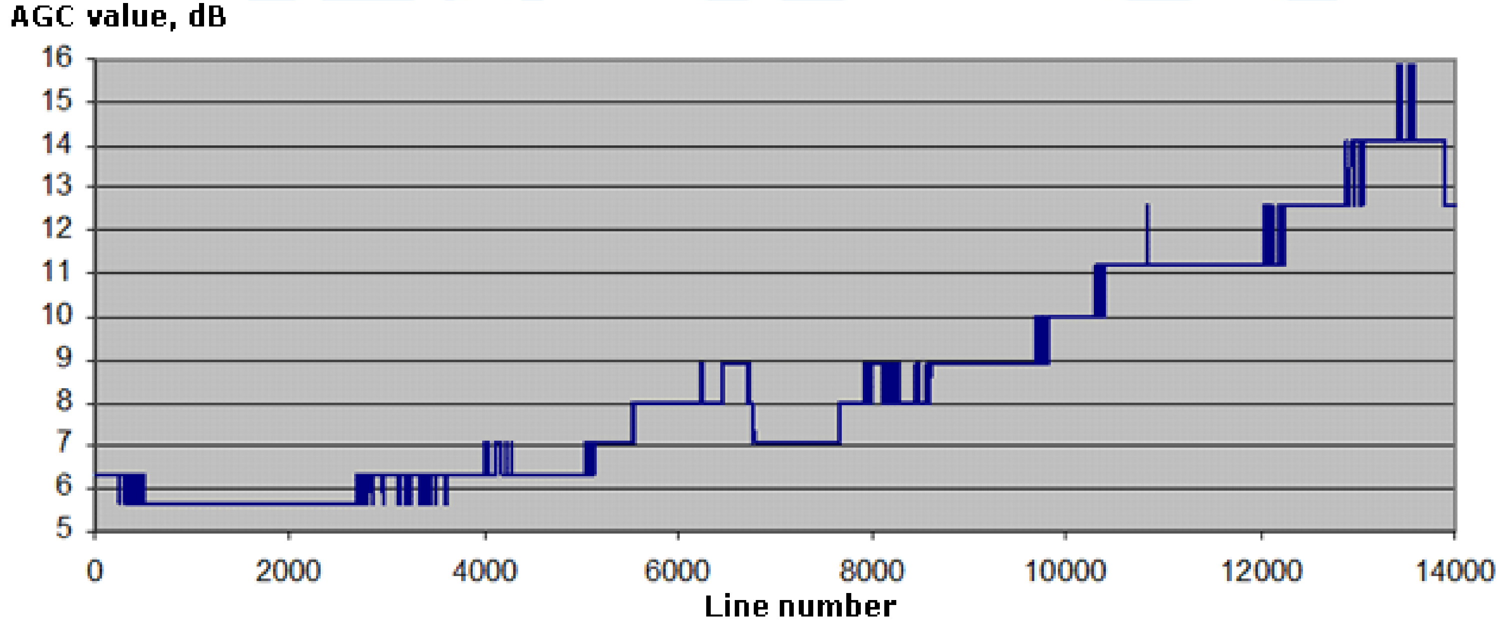
Corrected spectrum is shown on the left picture. Right picture shows restored image after inverse Fourie transform. Components of spectrum responsible for scalloping appearance were suppressed via amplitude weighting.





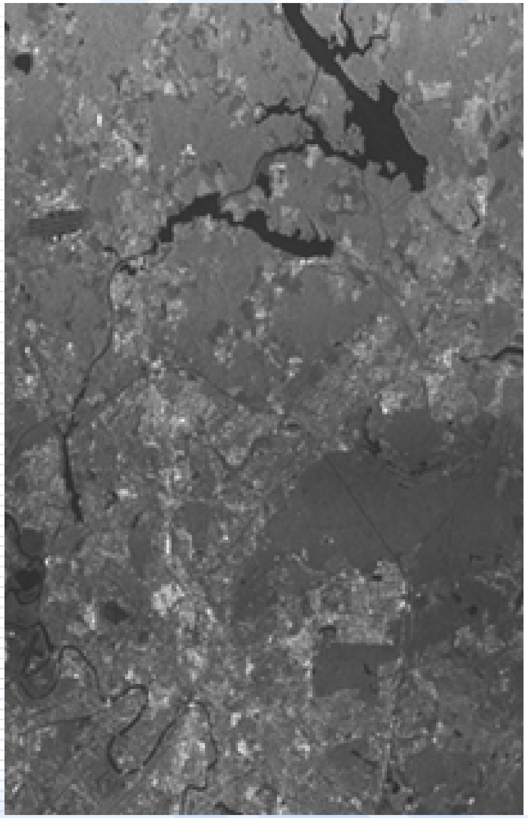
Automatic gain control effects

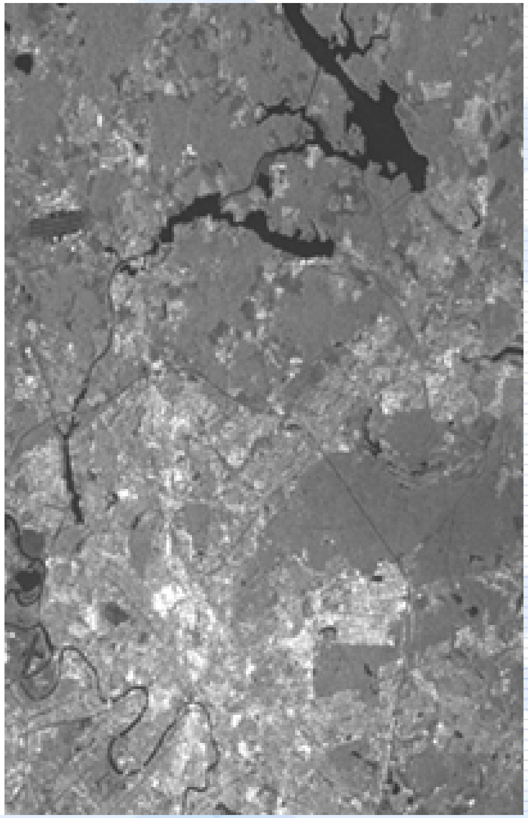
Onboard procedure of automatic gain control is required for proper using of dynamic range of SAR receiver and analog-to-digital converter. Radar signal on the receiver output is normalaized according to some gain factor which depend on input signal level. It realizes so called feedback circuit. Applied gain factors, as a rule, are saved to auxiliary data of signal data range line and are going to processing together with received signal. Along SAR processing gain factors are used for restoring of initial signal level. The example of gain factors application is shown on the picture below for one of RADARSAT-1 image. Horizontal axis corresponds to range lines of trajectory signal or radar hologram, vertical axis corresponds to gain factor values.



Automatic gain control effects

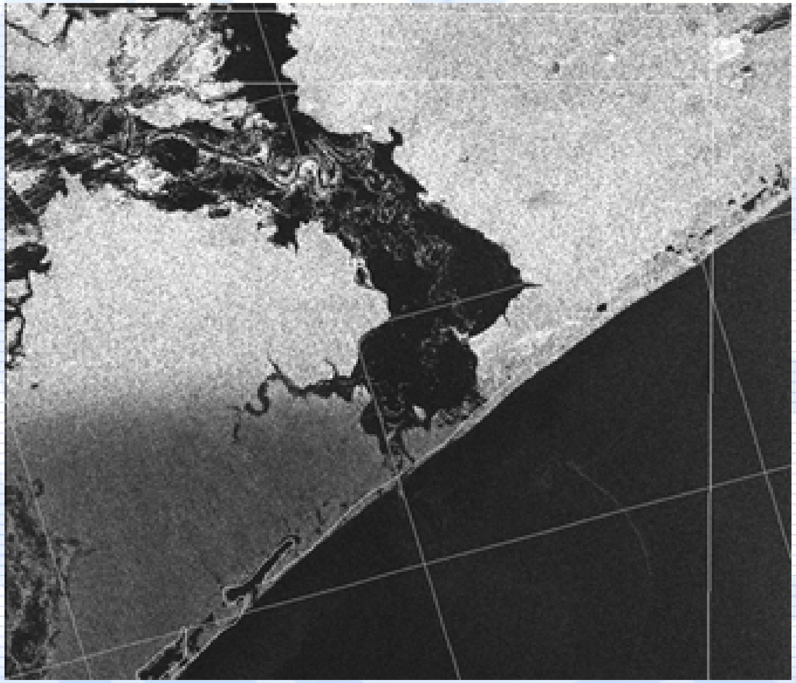
Application example of automatic gain control factors is shown on the pictures below (RADARSAT-1 SAR, Moscow and region site). On the left picture the image generated without using of factors is shown, right picture illustrates the corrected image with use of AGC factors. On the left picture upper and lower parts have approximately equal brightness, although upper part contains natural landscapes of Moscow region, but lower part contains urban area with lot of high reflection objects. Improved with use of AGC factors image on the right picture has proper brightness distribution.





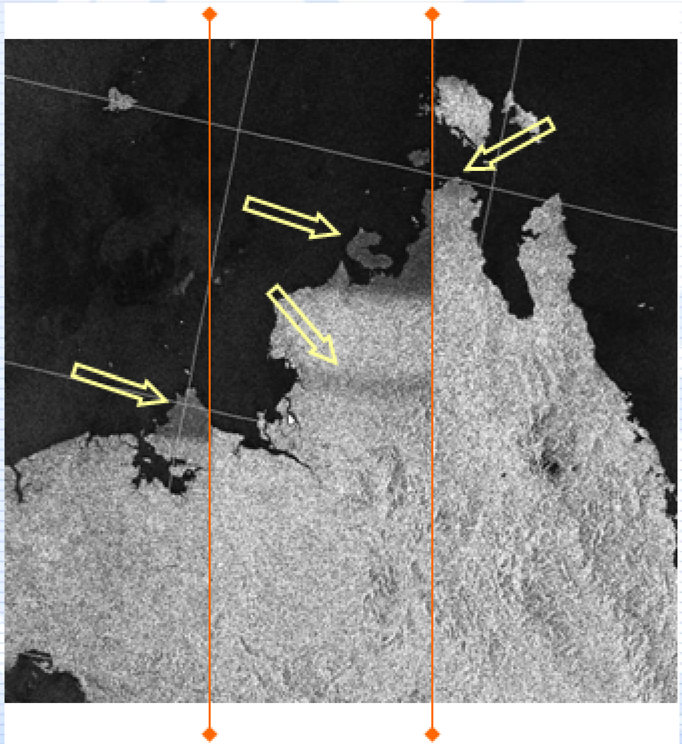
ADC saturation

During AGC factors application the output image brightness may be improved incompletely or may be distorted. The picture below shows the example of such kind of distortion – power loss due of saturation in analog-to-digital converter (ADC). Example – RADARSAT-1 image. Land area in the lower part of image is shaded because the AGC factors were applied. In SAR receiver the AGC gain is calculated over the first third of range line brightness values (on below image this part is placed on the right part). Because of the signal level in this part scene comparatively small the gain factor for these lines will be established on high level. When this gain is applied to land signal it leads to saturation of signal in ADC, so the power of land signal will be lost. During ground processing the inverse multiplication of signal to gain factors is applied. For the land area it will lead to decreasing of brightness comparatively to one before AGC application. Therefore the dark area in this part of image will arise.



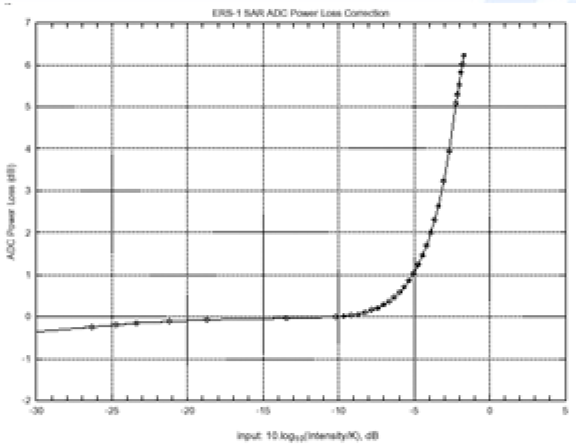
ADC saturation

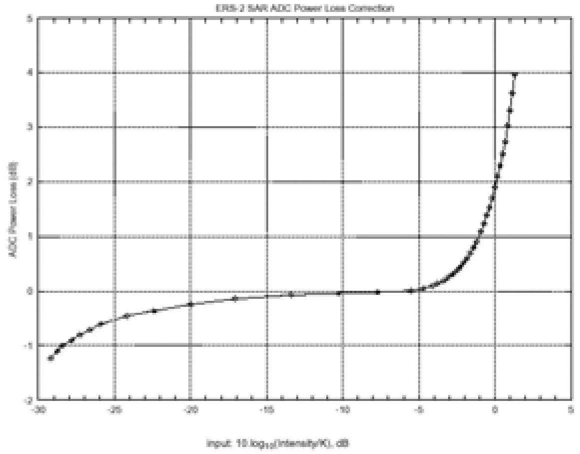
Such kind of effects usually appear on the surface with land – sea boundaries. The sizes of distorted areas and frequency of their appearance are depend on design of automatic gain control circuit in SAR receiver and on dynamic range of receiver. For the images acquired in ScanSAR mode the effects of ADC saturation appear separately of each beam and do not influence on neighbouring beams. The example of distortions caused by ADC saturation is shown on the picture below. RADARSAT-1 image was acquired in ScanSAR mode. ADC saturation distortions are clearly seen on the first two beams and partially on third beam. Each of dark areas are placed on their own beam and did not distribute on neighbouring beams. For all of three beams the distortion effects arise in areas of land – sea boundaries.

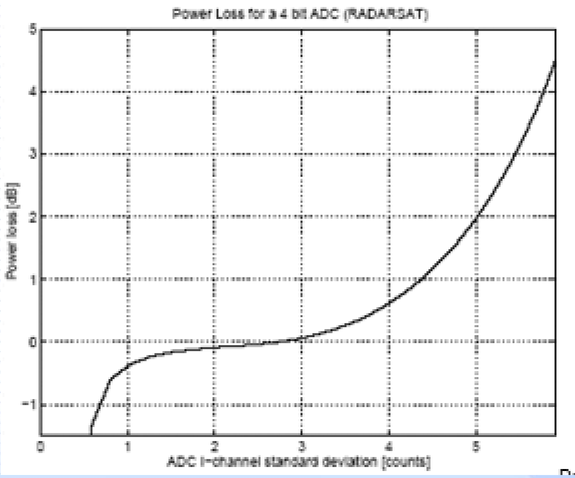


ADC saturation

The brightness effects caused by ADC saturation could be removed from image via appropriate procedures or corrections. In order to do this one should know the dependence of signal power loss in ADC to signal standard deviation over image field. Such dependences are formed on the base of experimental measurements for each SAR system separately. The examples for ERS-1, ERS-2, and RADARSAT-1 systems are shown on picture below.



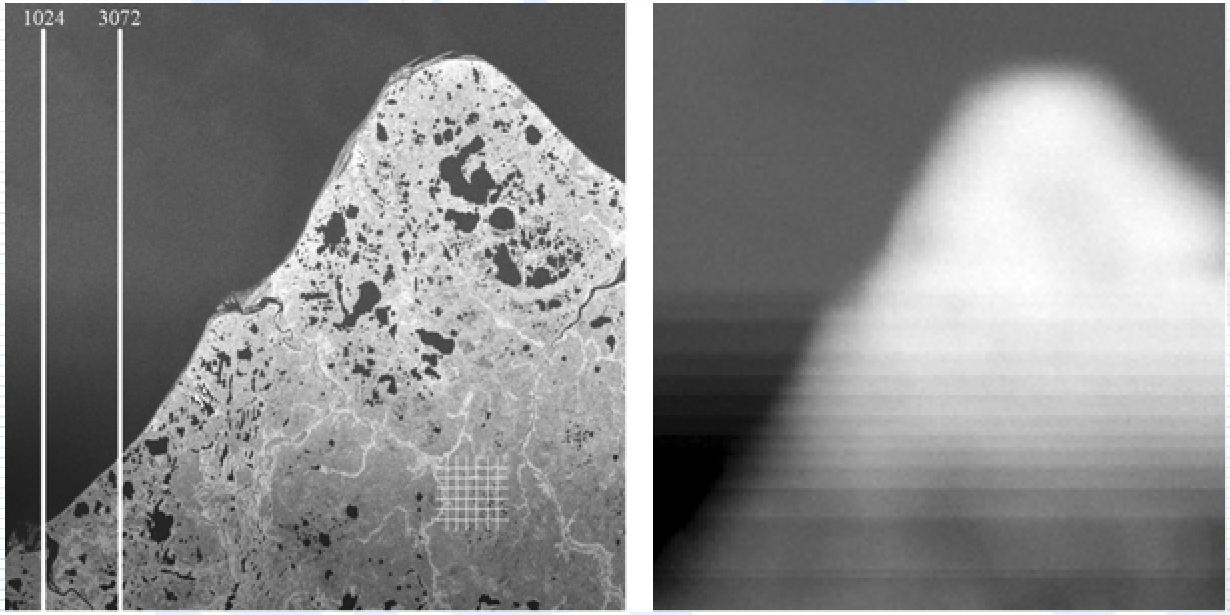




In practice the saturation effects occur for all three radars, though the number of ADC digits is 4 bits for RADARSAT-1 and 5 bits for ERS-1 and ERS-2 sensors. The standard deviation field are created individually for each scene for which the saturation correction procedure in performed.

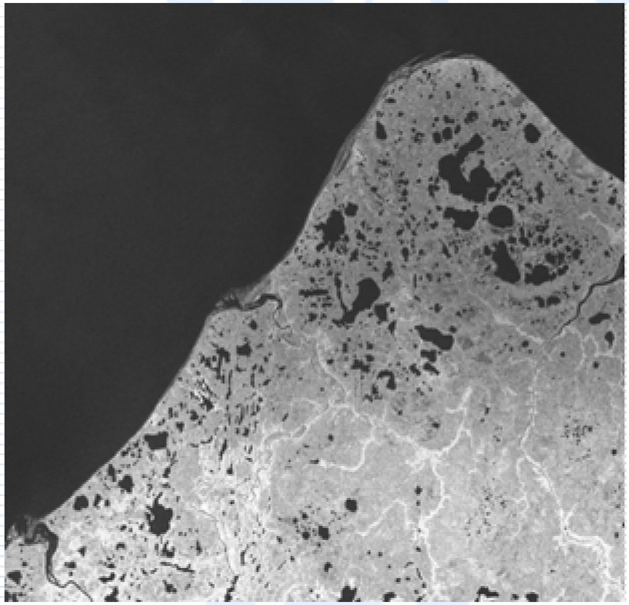
ADC saturation

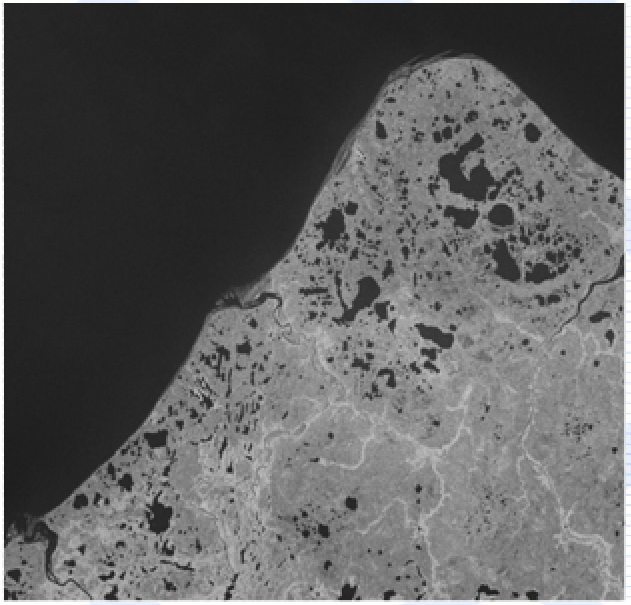
The example of scene with ADC saturation acquired by RADARSAT-1 SAR and measurements of standard deviation field is shown on the picture below. For radar image the AGS correction has not been applied.



ADC saturation

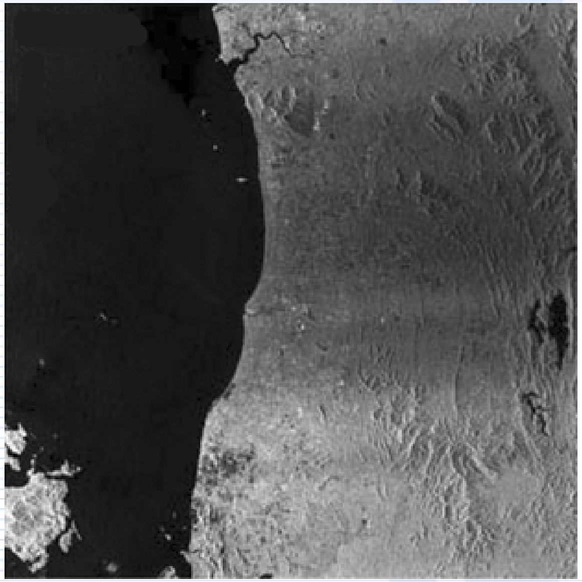
The correction of ADC saturation effects consists in generation of new values of gain factor according to dependences table of power loss to signal standard deviation. The example of correction is shown on the pictures below. The left picture outlines the scene for which the brightness has been corrected with use only AGC factors. It leaded to power loss in image area covered by land, because the signal level estimation has been done over sea area. The right picture outline the scene for which the brightness has been corrected according to improved AGC factors which take into account the ADC saturation effect. It is resulted in uniform brightness of land area on the image.

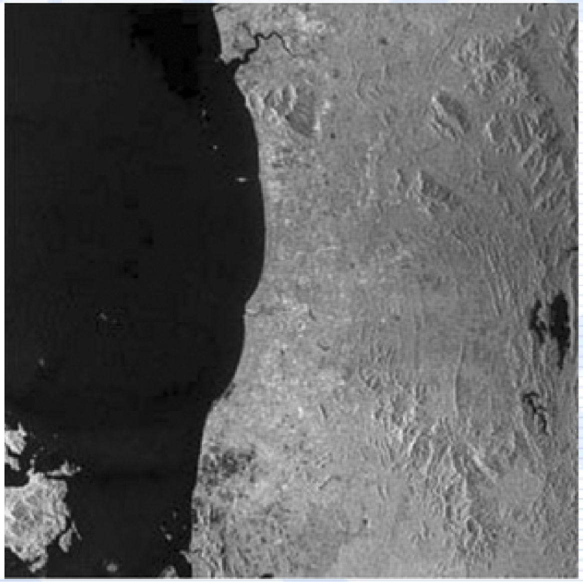


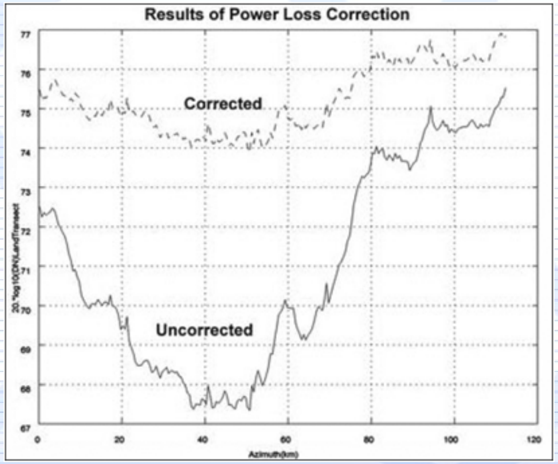


ADC saturation

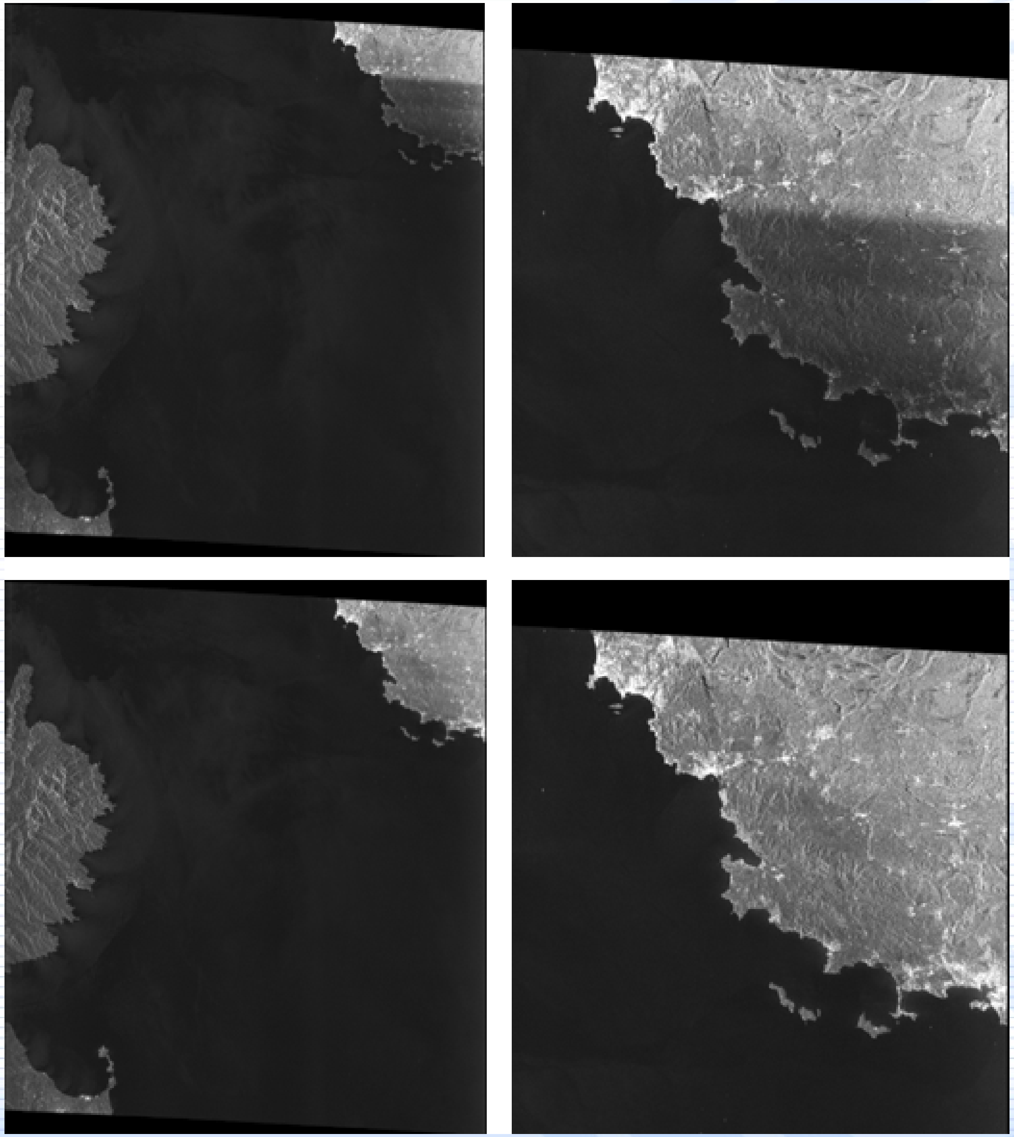
Example of ADC saturation correction is shown on the picture below. RADARSAT-1 SAR, Beam S5, 21.08.1996. Malaysia coast site. Processing of Canada centre for remote sensing, Natural resources Canada. On the left picture the image without ADC saturation correction is shown, on the right picture - with correction. The diagram shows comparison of brightness profiles for corrected and uncorrected scenes.





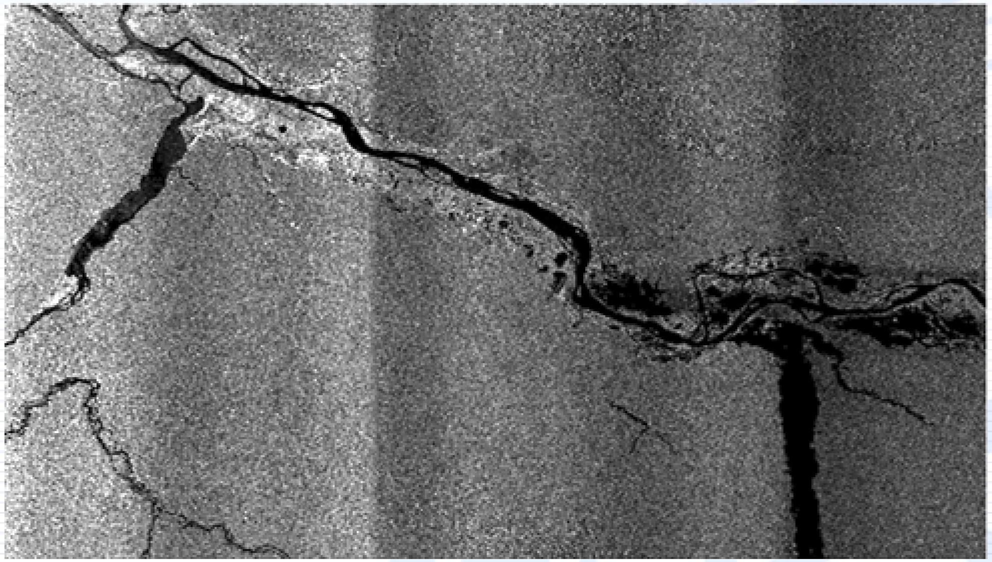


ADC saturation



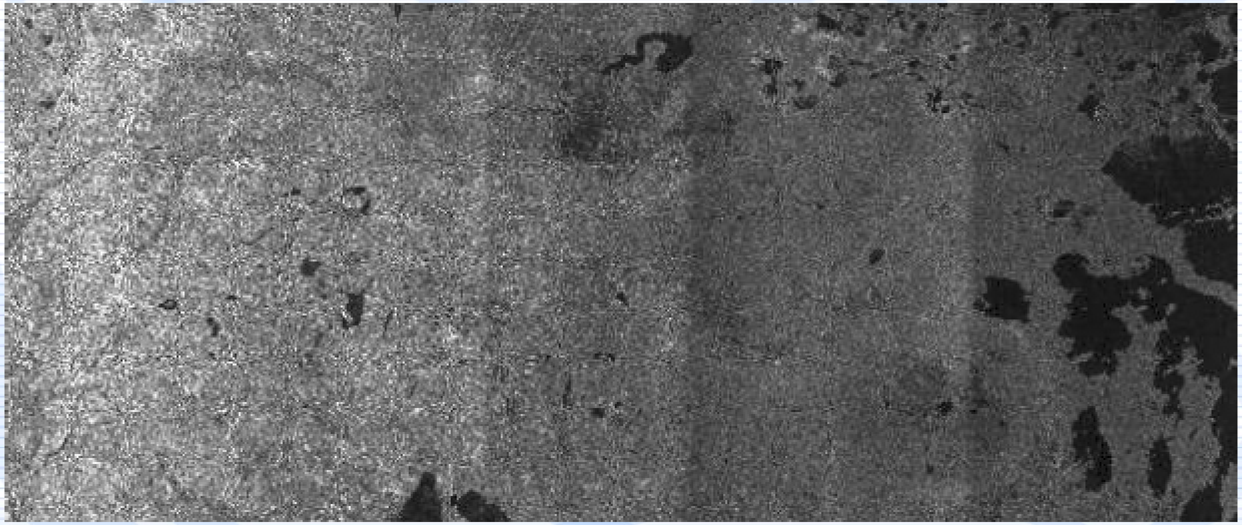
Example of ADC saturation correction is shown on pictures on the left. RADARSAT-1 SAR, ScanSAR Narrow B. All three beams are presented. On the upper left picture the image without ADC saturation correction is shown, on the upper right picture - increased part of third beam. On upper pictures the dark land area clearly seen. In the area the coastal line moved to right and down and in some time only the signal values from sea participate in calculation of AGC factors. Apart of this time the ADC saturation effect appears on the land image. On the lower left picture the image after ADC saturation correction is shown, on the lower right picture - increased part of corrected beam.

Banding



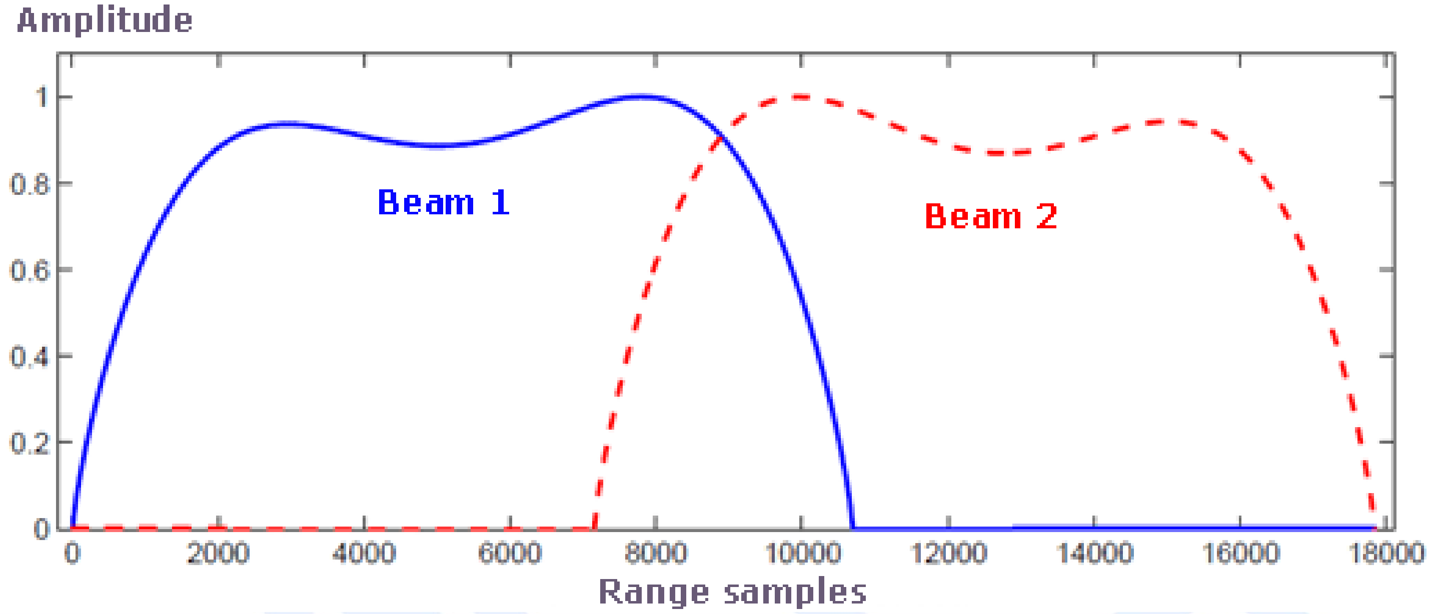
On the radar images acquired in ScanSAR mode and consist of several beams some brightness effects called “banding” may appear. They are caused by different antenna gain for neighbouring beams. Removing of these effects could be performed in SAR processor after step of partial strips creation. At first, the evaluation of mean brightness into each beam should be done. Then these estimates shall be used during building of full scene in order to get image with uniform brightness.

On the pictures the image samples are shown which were acquired in ScanSAR mode by RADARSAT-1 SAR and processed without brightness correction for mean beam values.



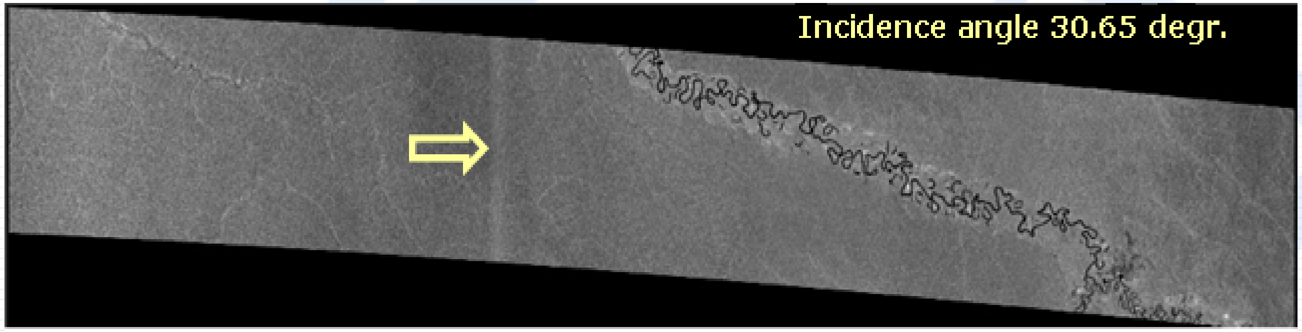
ScanSAR beams stitching

On the images acquired in ScanSAR mode the light and dark strips may appear in areas of neighbouring beams stitching. Their appearance is caused by inaccurate handling of antenna pattern for one or both beams during image formation. It could be deduction of two reasons: antenna pattern profile is known with insufficient accuracy; viewing parameters were calculated inaccurately. As a rule, the stitching of beams in SAR processor is performed with use of dedicated algorithm in order to get the flattened brightness passage in stitching area.



ScanSAR beams stitching

It should be noted that the image brightness in the beams stitching area is very sensitive to knowledge of viewing parameters .



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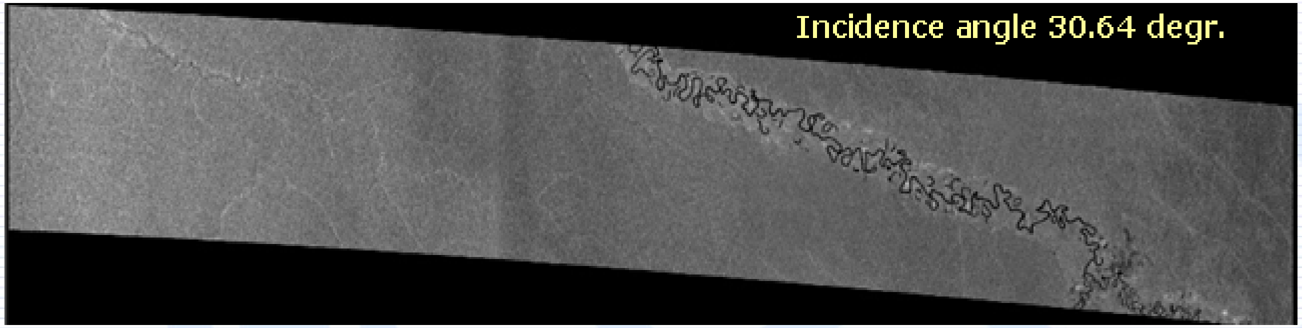
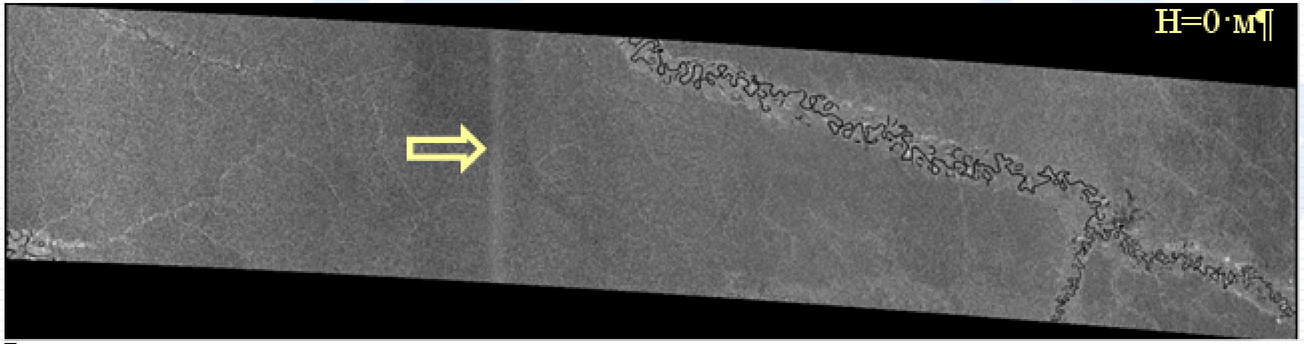


The picture above illustrate importance of accurate knowledge and application of viewing parameters in processing workflow. Presented fragment of RADARSAT-1 SAR image is acquired in ScanSAR mode. Vertical bright line identify the stitching area between the neighbouring beams. Upper picture shows the result of SAR processing in assumption of viewing incidence angle of 30.65 degrees , lower picture shows the processing with this value of 30.64 degrees. The difference of 0.01 degrees changes the stitching line appearance.

ScanSAR beams stitching

The way for suppression of brightness effects caused by inaccurate knowledge of viewing parameters is the evaluation of these parameters during SAR processing and their adaptive correction.



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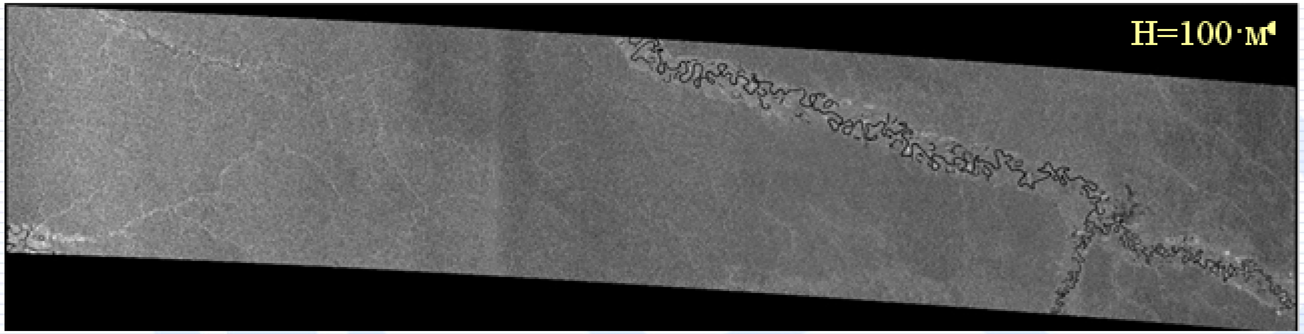


Another example that shows application of viewing parameters in ScanSAR data processing outlined on the picture above. There is fragment of RADARSAT-1 SAR image acquired in ScanSAR mode. Vertical bright line identify the stitching area between the neighbouring beams. Upper picture shows the result of SAR processing in assumption of zero elevation of imaged surface above reference ellipsoid, lower picture shows the processing with this value of 100 meters. The different brightness of stitching lines is quite visible.

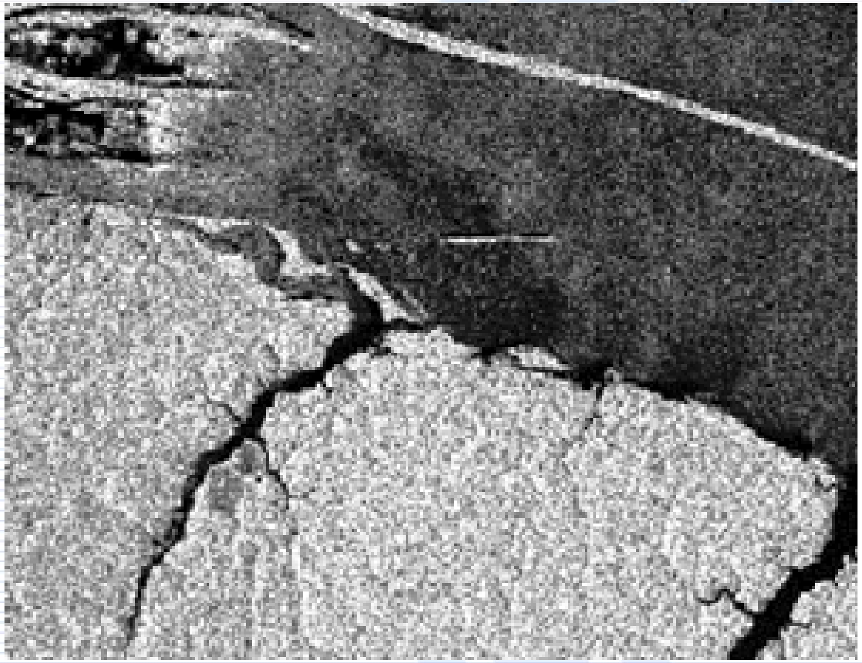
Atmosphere effects

SAR transmission wave band, in which all modern synthetic apertrure radars operate, is the part of microwave spectrum band of electromagnetic band. The selection of SAR wavelength is the compromise between requirements to radar system and equipment parameters restrictions. Modern spaceborne radars are working with X, C, S, and L wavelength band wavelength. Radars with more short wavelength provide in theory the better space resolution. In other hand, the attenuation of transmitted signal in atmosphere increases for shortest wavebands. Already in C-band the influence of atmosphere attenuation could be appears on SAR images, however in common case it may be regarded as insignificant one. In X-band the impact of atmosphere on SAR signal propagation becomes clearly seen.

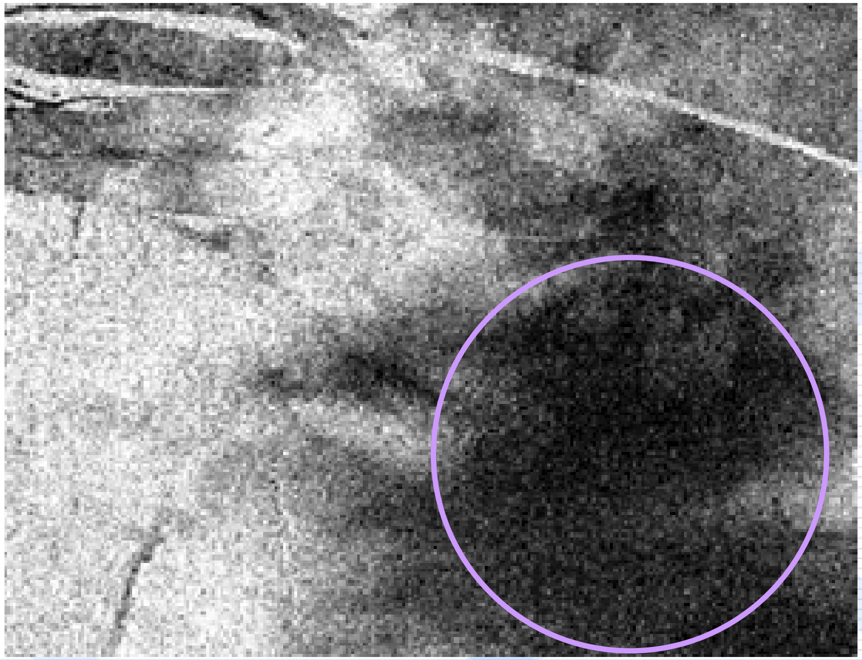
One of the first TerraSAR-X image acquired at X-band over part of Volga river basin. Slightly bright cloud on the left part of image mask the reflections from ground surface. It effect caused by backscattering of X-band microwaves on heavy storm cloud.

Atmosphere effects

SIR-C/X images acquired on April 1994 over the Brasilian rain forest near Manaus. Two images were acquired simultaneously at L-band (left picture) and X-band (right picture) at VV polarization. The dark area in the lower right part of the X-Band image is caused by raindrops, which attenuate the X-band microwaves (W.Alpers, Ch.Melsheimer, 2005).



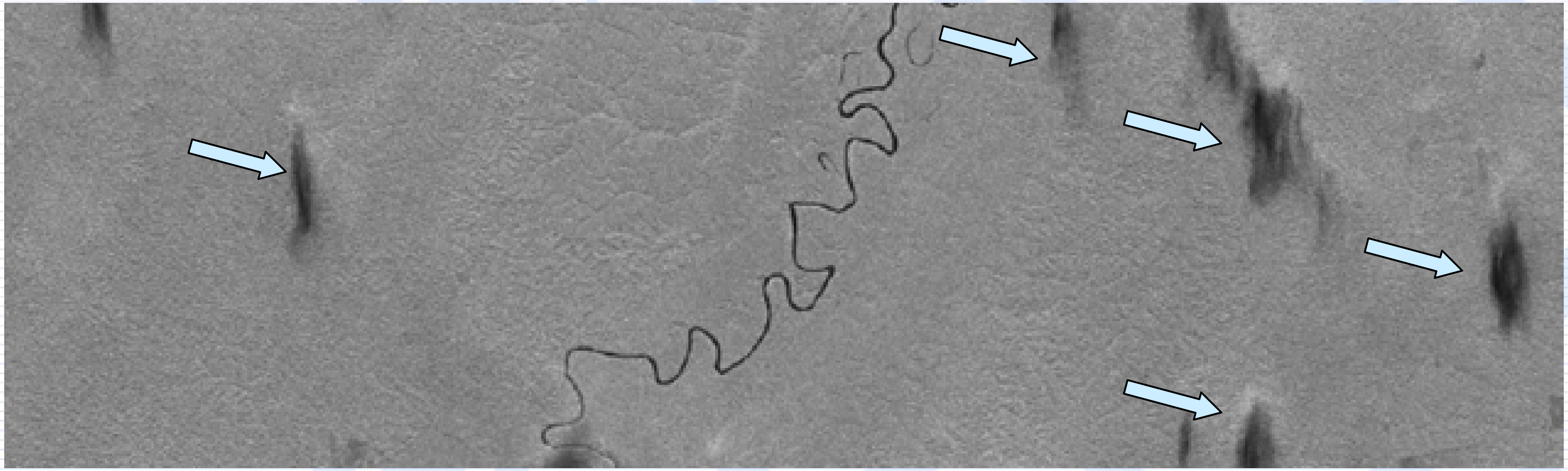
L-band



X-band

Atmosphere effects

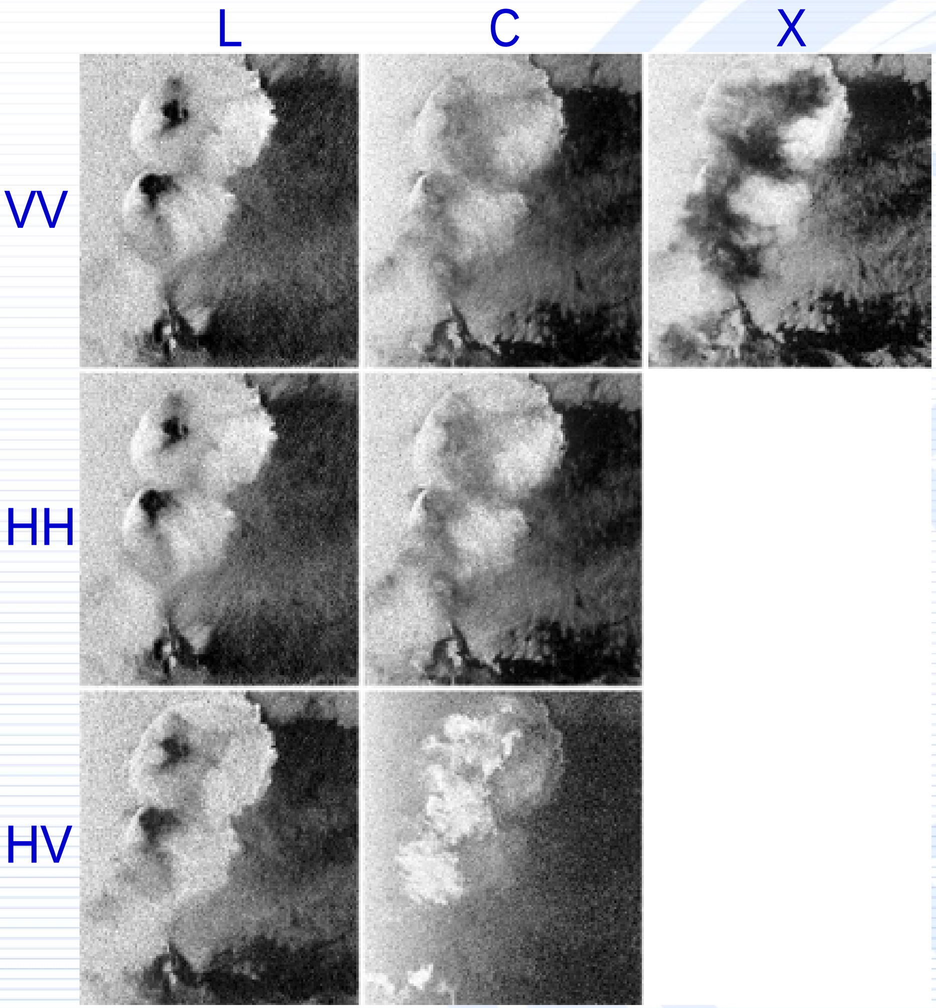
SIR-C/X image acquired on 15.04.1994 over rainfall forest in Brazil at X-band with VV polarization. Several shadows of rain sells are clearly seen in image. These shadows are the result of microwaves attenuation by raindrops in atmosphere. Some of shadows are surrounded slightly bright patches on their near range side. These patches caused by raindrops backscattering in the atmosphere (W.Alpers, Ch.Melsheimer, 2005).



Atmosphere effects

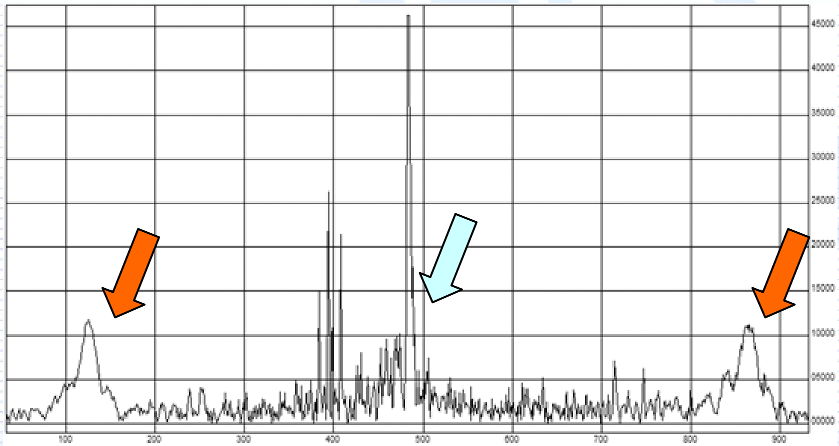
Picture below depicts radar signatures of rain cells. Image was acquired by ERS-1 SAR at C-band on April 1996. over Andaman Sea west of the Nicobar islands with calm wind conditions. The circular bright patterns with dark “hole” in center are the appearance of tropical rain cells. Arrow 1 indicates wind front associated with rain cell and arrow 2 indicates the ocean surface area where Bragg waves are strongly damped by the turbulence generated by rain drops impinging onto the sea surface (W.Alpers, Ch.Melsheimer, 2005).

Atmosphere effects



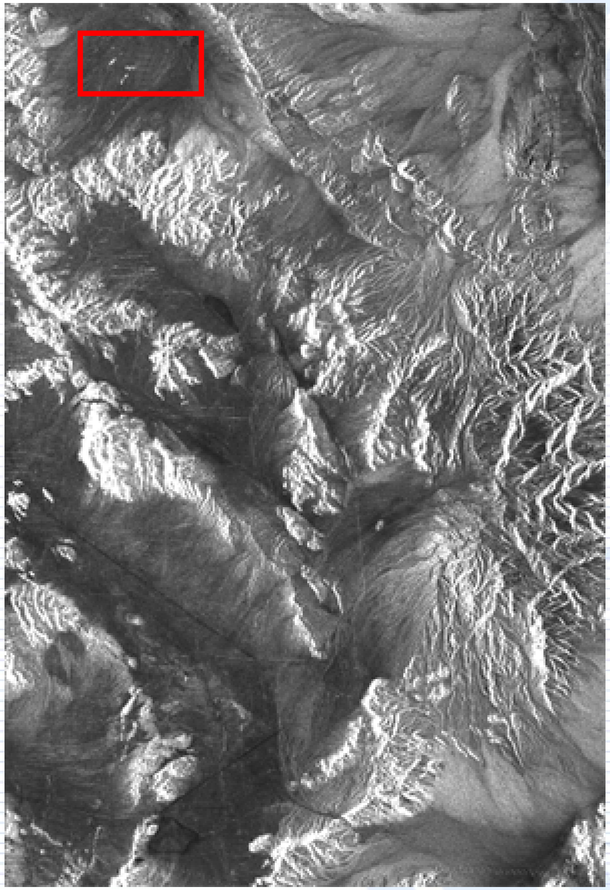
Behavior of rainfall returned signals depend on wavelength band and combination of transmitted and received polarizations. Picture shows SIR-C/X images acquired on 17.04.1994 over Northern Straits of Malacca, Malaysia. (W.Alpers, Ch.Melsheimer, 2005).

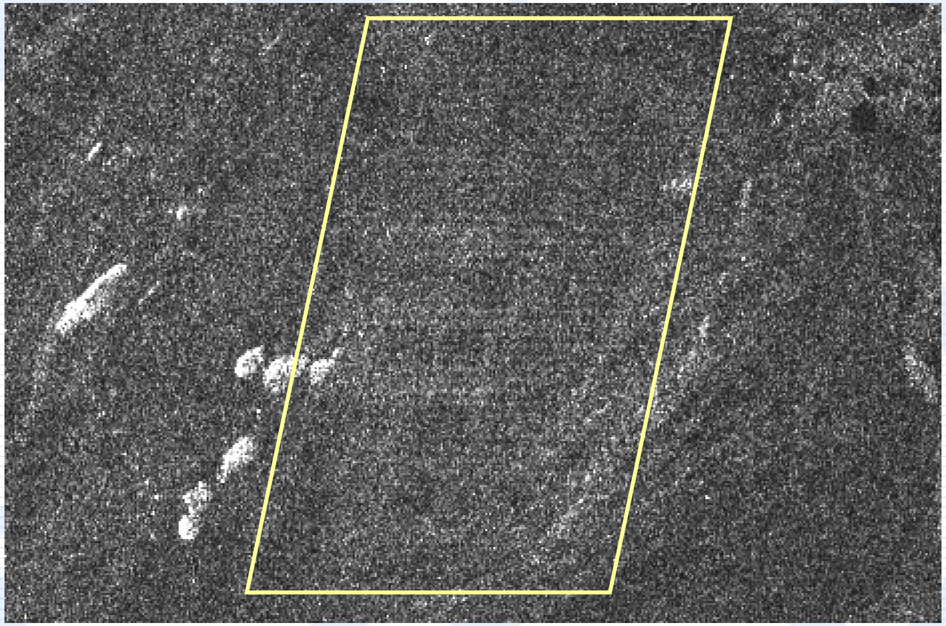
Processing effects



RADARSAT-2 SAR. Beam FQ15, orbit 2058, polarization mode VH, SLC product. Vancouver, Canada site. There is ground object in center of scene with very strong backscattered signal. Along SAR processing this object produces pulse response whose fragments are seen very clearly on background with low scattering level (sea surface). Pulse response profile along range shows bright sidelobes on sides of mainlobe.

Processing effects

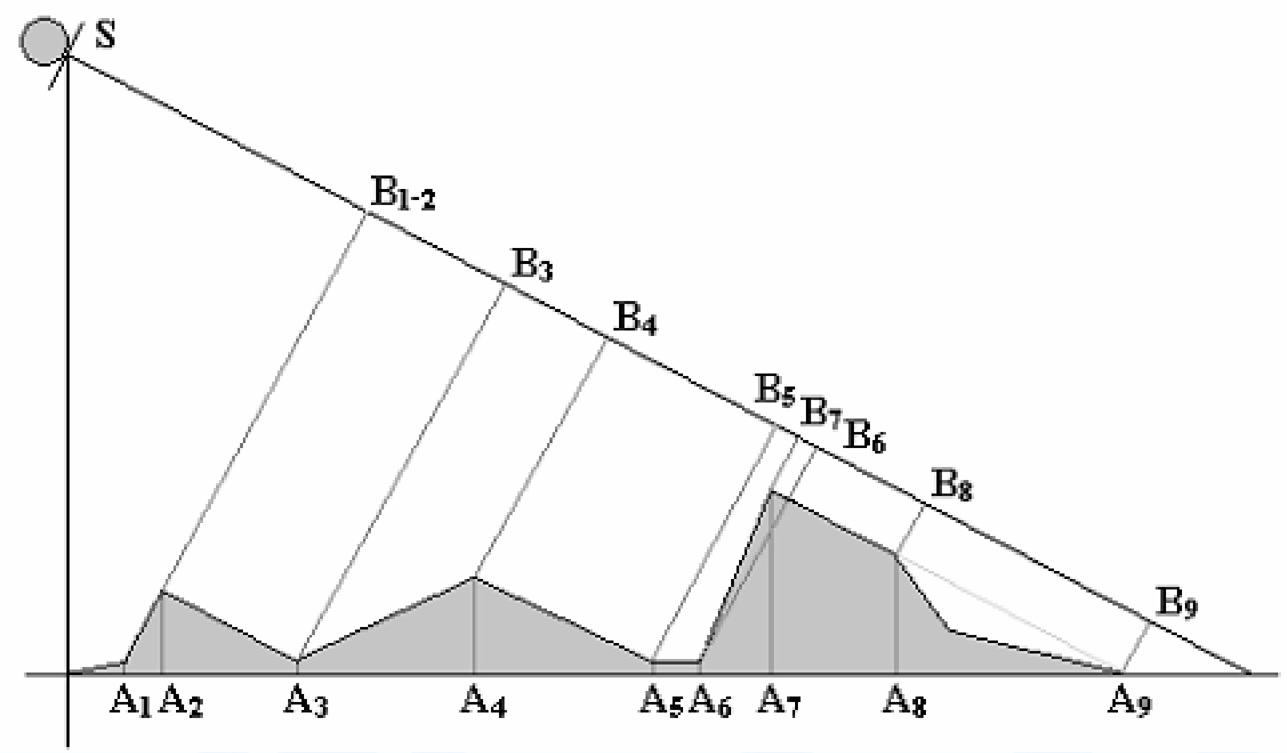




SIR-C/X SAR. C-band. Fort Irwin, USA site. Application of specific algorithm of azimuth focusing which has deal with blocks of range lines leads to appearance of brightness strips on output image oriented along range direction.

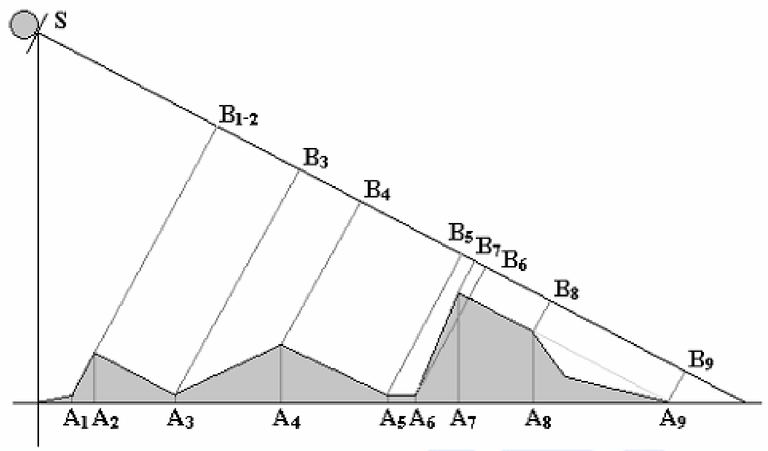
Radar viewing nature

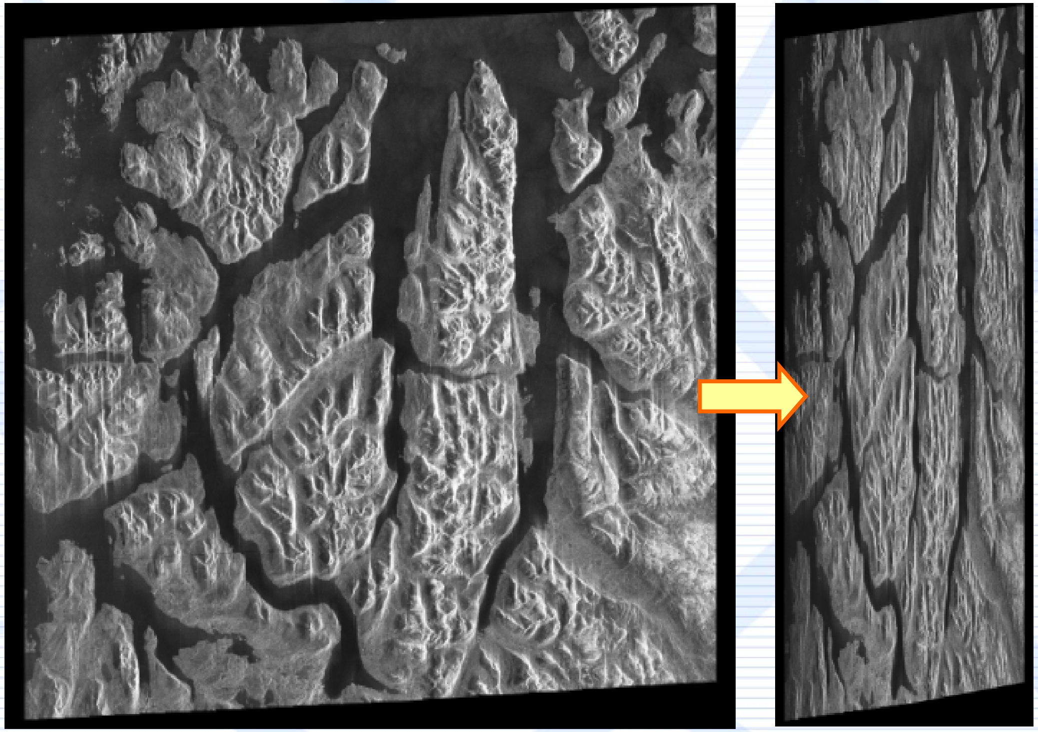
Radar viewing nature reduces to side looking mode of surface imaging. Each element of surface is seen under some angle. Therefore, appropriate distortions are arising on radar images. Main of them are: foreshortening, shadows, and layovers.



Radar viewing nature

Foreshortening is caused by projection of ground surface plane on radar slant range plane. Extent of this effect depends on local surface slope concerning to radar incidence angle. It illustrated by following examples. A3-A4 to B3-B4 – foreshortening will be seen. A2-A3 to B12-B3 – no foreshortening will arises, A1-A2 to B12 – extreme case, maximum foreshortening effect will be achieved, plane will be reduced to line on image.

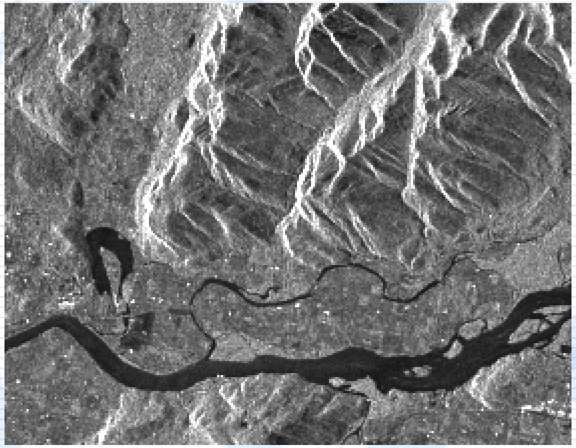




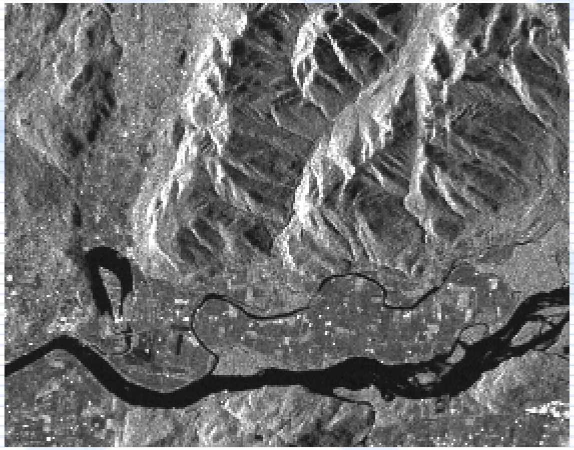
Radar viewing nature

Foreshortening is caused by projection of ground surface plane on radar slant range plane. Extent of foreshortening depends on local surface slope concerning to radar incidence angle.

Look angle 23 degrees



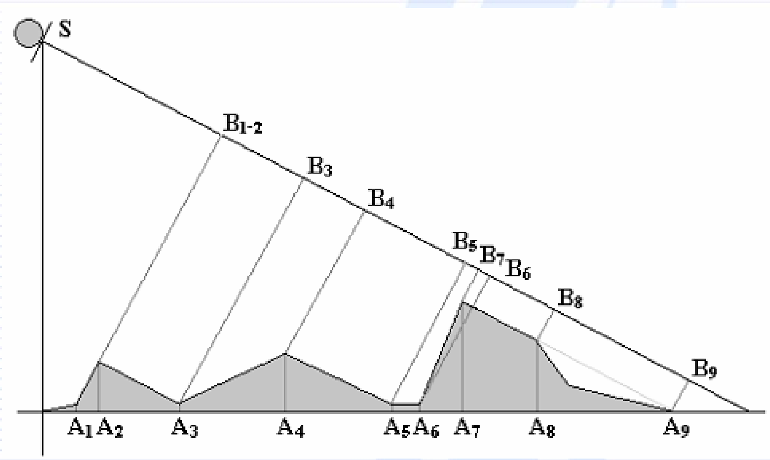
Look angle 36 degrees

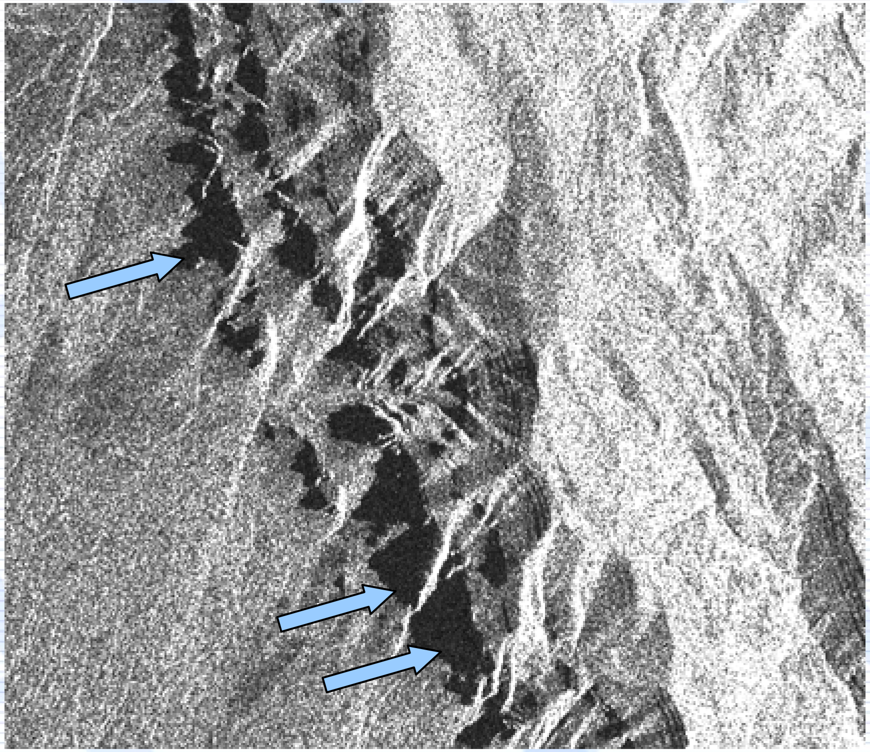


Look angle 47 degrees

Radar viewing nature

Shadows on radar images appear in case of presence of the vertically exaggerated objects on ground. Extent of this effect depends on objects elevation and viewing incidence angle. It illustrated by picture where A8-A9 to B8-B9 indicates shadow appearance.

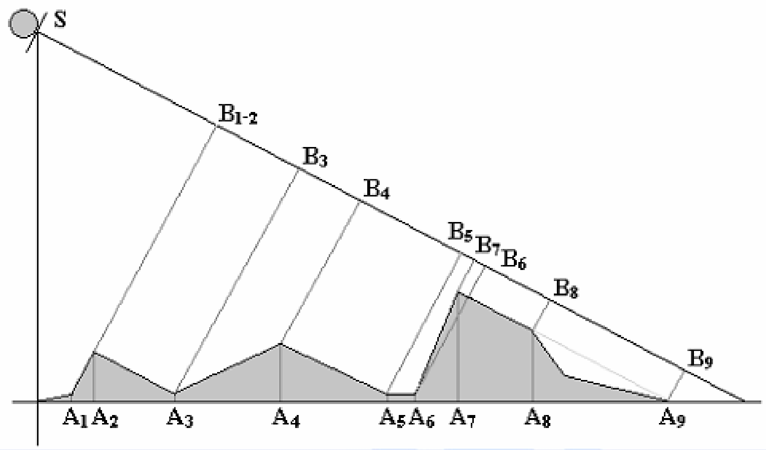


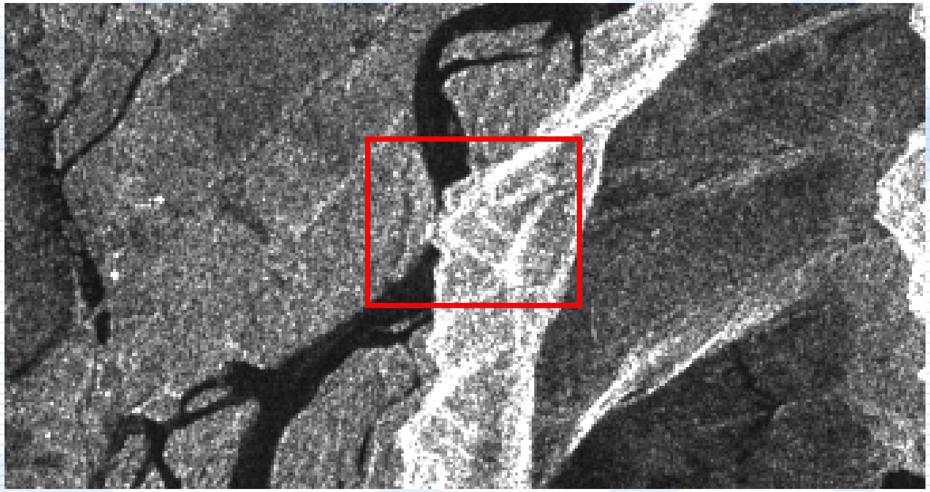


SIR-C/X image. October 1994. White Sands, USA site. Shadow areas are designated by low brightness.

Radar viewing nature

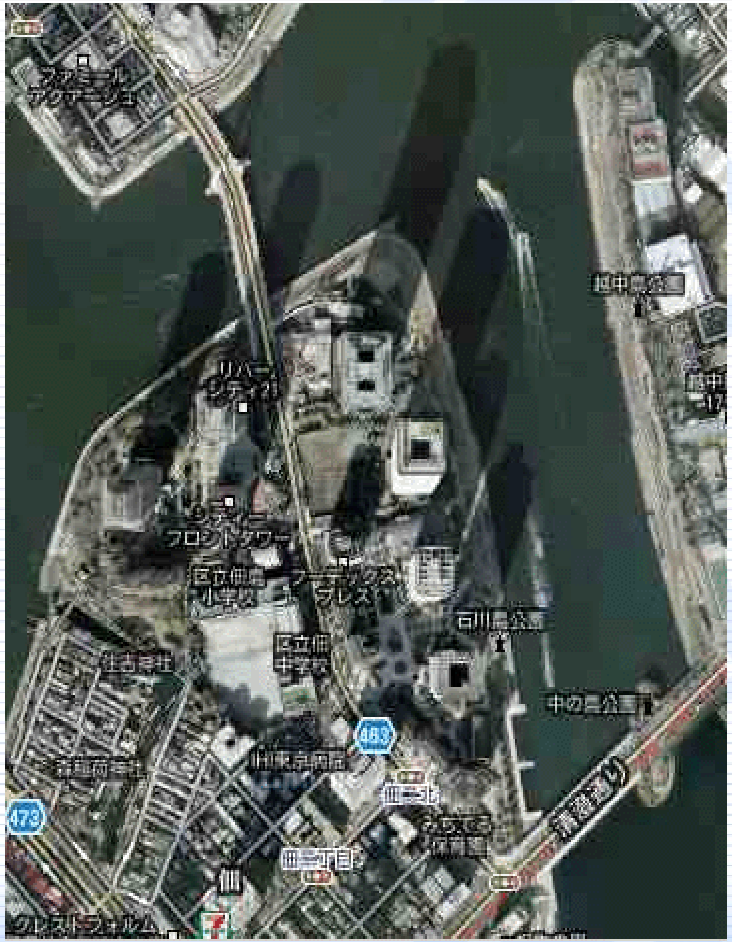
Layover on radar images appear when the surface slope value more than some critical angle. Slope critical angle value depends of radar incidence angle. It illustrated by picture where, at first, area A5-A6 superimpose with area A6-A7 and, on second, area A6-A7 is inverted on radar image concerning to other areas.





Radar viewing nature

Most frequency layover arises on radar images of mountain areas and urban ones. For last case the consequences become quite heavy. Number of object could be superimposed on each other, so their discrimination seems not possible. TerraSAR-X imagery of Tokyo is shown on the right picture, optical imagery from Google maps deposits is on the left one.



Radar viewing nature

The scheme of layover formation in urban area is shown on the picture.