Wavelet based ScanSAR Image Compression Minimizing Block Effects

Jens V. Fischer, Ursula C. Benz
German Aerospace Center (DLR), Institute of Radio Frequency Technology,
Oberpfaffenhofen, P.O. Box 11 16, D-82230 Wessling
Phone: (++49) 8153-28-3057, Fax: -1449, Email: jens.fischer@dlr.de

ABSTRACT

ScanSAR images are important products of modern spaceborne SAR systems. A wide swath is covered during one single data take.
Usual processing of ScanSAR images with a high number of looks not only reduces speckle but also leads to data compression. However, the amount of data can be further reduced, if an appropriate ScanSAR data compression is applied.
In our paper, we propose a new wavelet based compression technique, which adapts to the ac energy distribution in ScanSAR images and minimizes artifacts due to compression. Special attention is paid to reduce block effects.
Our technique is tested on ScanSAR data of RADARSAT and the SIR-C space shuttle mission. Compressing the SIR-C ScanSAR scene of Chickasha/Oklahoma, USA with factor 1:8, we achieve an improvement in the overall signal-to-distorsion-noise ratio (SDNR) from 29.7 dB to 48.03 dB.

1. INTRODUCTION

ScanSAR is an important mode of most future spaceborne SAR sensors. Compared to stripmap mode, a much greater coverage of the earth surface can be achieved by mosaicking several sub-swaths. For example, for the ASAR system of ENVISAT a swath width up to 450 km is intended.

SAR images acquired in ScanSAR mode are mainly[1] processed by multi-looking which creates detected images of reduced speckle. Using multi-looking, a certain data compression is automatically performed. The more looks are used the higher is the achieved compression ratio. Furthermore, due to speckle reduction multi-looking increases inter-pixel correlations. Higher correlation between pixels means increase in data redundancy, which provides good pre-cautions for further data compression.

We use ScanSAR images of two different SAR platforms to test our wavelet based data compression technique. The SIR-C image is more difficult to compress compared to the RADARSAT image due to higher fluctuations in data dynamic. We show that our method overcomes difficulties in both data sets.

Our emphasis in results is not only laid to a high signal-to-distorsion-noise ratio and improved reconstruction of point targets, but also to a scene independent noise to allow proper calibration of SAR products.

2. SCANSAR DATA CHARACTERISTICS

The used RADARSAT image in this study has a geometric resolution of 80 meters in both, azimuth and slant range. The scene is of an extent of 355 km in azimuth and 190 km in range. The original data set possesses a sample distance of 100 meters. It is processed with 2 looks in azimuth and 4 looks in range. Filtering has been applied to remove scalloping effects. In this example, we measure no explicit influence of the applied anti-scalloping filter.

The SIR-C data set depicts a scene around Chickasha/Oklahoma, USA [1]. It has 5 azimuth looks and 5.68 looks in range direction. The resolution in ground range deteriorates from 148 meters in far range to 331 meters in near range. The azimuth resolution ranges from 230 meters in near range to 270 meters in far range. Many strong single scatterers such as in the city area cause high fluctuations in data dynamics, which make a dedicated compression technique necessary.

Inter-pixel correlations

Due to multi-looking, an increase in inter-pixel correlations can be observed in ScanSAR data compared to data acquired in stripmap mode (Fig. 1).

Energy concentration in subbands

Decreased geometric resolution and reduced speckle in multi-look images enable better energy packing compared to stripmap images if a wavelet transform, for instance as in our approach, is applied. In ScanSAR images, most of the ac energy is concentrated in the LL (low-pass/low-pass) subband which allows a dedicated bit assignment. The ac energy in single-look complex

[1] ScanSAR images can also be complex if interferometric or polarimetric applications are considered.

X-SAR stripmap data is not only concentrated in LL subband, half this amount can be found in the other subbands, too. In Fig. 2, we compare the energy content of the LL subband (100 percent) to energy contained in other subbands. Best energy packing is achieved for ScanSAR images.

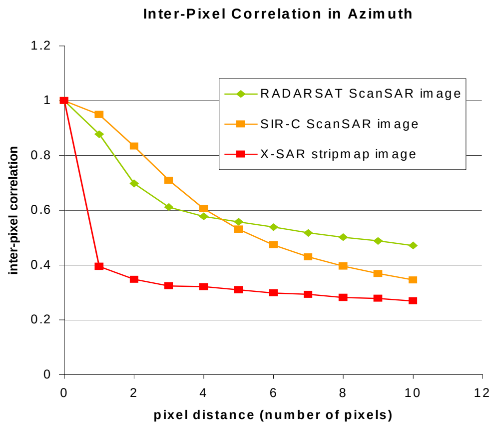


Fig. 1: Inter-pixel correlation in images. The ScanSAR images (RADARSAT and SIR-C) are higher correlated from pixel to pixel compared to a single-look complex X-SAR stripmap image.

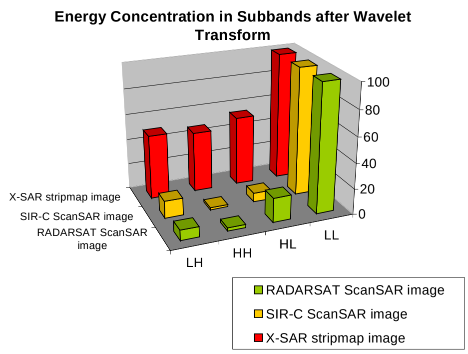


Fig. 2: AC Energy concentration in image subbands. The ScanSAR images (RADARSAT and SIR-C) show better energy packing compared a single-look complex X-SAR stripmap image.

A certain subband can be considered as more important than others if its ac energy is relatively high compared to the other ones. More quantization levels (number of bits) are assigned to those subbands of greater importance. The larger the ratio among the subband energies the more efficient is the bit allocation performed. The used scalar quantization, however, only allows integer number of bits to be assigned. This implies that minor energy ratios between subbands cannot be fully covered.

3. COMPRESSION TECHNIQUE

ScanSAR scenes are of large extent. Due to limited memory, it is not possible to hold the entire ScanSAR image in memory and to perform calculations at the same time. The image must therefore be compressed blockwise. We measured no significant influence of the chosen image block size to energy packing and hence to the compression performance. We therefore propose to choose the size of image blocks as large as possible aiming to minimize computation time. Our method is applied to each image block in the following manner.

After transforming the image block into wavelet domain, a quantization of wavelet coefficients is applied to each subband. All coefficients of a certain subband are quantized with the same number of bits by a block adaptive linear quantizer. The number of bits for a subband is read off a table of bit masks.

Wavelet transform

We perform a one iteration wavelet transform using a Daubechies-8 wavelet. Other wavelets than the Daubechies are of course imaginable [2]. More than 8 coefficients slightly improve the compression performance [2] but lead to enhanced computational expense. Sufficient energy packing can be reached by only performing one wavelet iteration. In our approach, it is not possible to achieve significant better compression results by iterating the wavelet transform more than once. This is mainly due to the fact that – in case the LL subband is again subdivided into four sub-subbands – an even enhanced refinement in bit allocation is necessary to use the additional energy packing. This, however, cannot be done as only integer number of bits can be assigned.

The wavelet transform has to be performed onto overlapped image blocks in order to ensure no invalid pixels[2] within a wavelet transformed image block. An overlap of eight pixels – the number of wavelet coefficients – is sufficient.

Quantization

The quantization of a wavelet transformed image block is performed by quantizing each subband separately. A certain subband is quantized by subdividing its coefficients into small quantization blocks, e.g. 8 by 8 coefficients. A subdivision into small blocks is necessary due to the changing data statistic within the subband. The coefficients within each small

[2] A wavelet transform is leads to invalid pixels in marginal areas within the subbands.

quantization block are quantized using a certain number of bits which is read off a bit mask.

Bit mask generation

To compress a ScanSAR image in wavelet domain, we need an optimal bit mask consisting of four numbers of bits – each for one of the four subbands. The four numbers give a mean number of bits, which – together with the header information – determine the overall compression ratio.

The bit mask is fix for a certain compression ratio; it does not change from image block to image block. We also tested bit masks adapted to each image block. This approach showed no significant improvements.

As a bit mask reflects the typical ac energy packing gained by our wavelet transform, the bit mask can be used for all data of the same SAR platform processed with a certain processing technique, e.g. multi-looking with certain number of looks.

In order to find a suitable bit mask to each data type (SAR platform and processing technique) and each compression ratio, we use a test procedure, which numerically optimizes bit masks by applying test compressions onto small image pieces.

4. MINIMIZING BLOCK EFFECTS

In wavelet domain, the image content is reflected in each subband. And, as described above, each subband is compressed using the same constant number of bits. In case nothing is undertaken to adapt to the changing dynamic within the subbands, those quantization blocks including high dynamic will end up with increased compression noise than others. This finally makes a blocking structure visible indicating the subdivision into quantization blocks. Those block effects can at first be observed in SDNR maps (Fig. 4 and Fig. 12) – a very sensitive measure to show differences between original and reconstructed images. In more severe cases, a high compression ratio for example, the blocking structure even becomes visible in the reconstructed image ruining a homogeneous reconstruction quality across the image.
A simple first approach to minimize block effects is to separate the image content in each subband into 'foreground', i.e. data of high dynamic, and 'background', i.e. data of low dynamic.

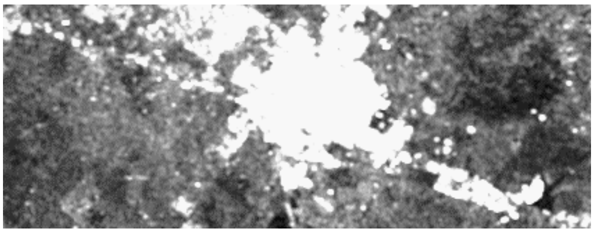
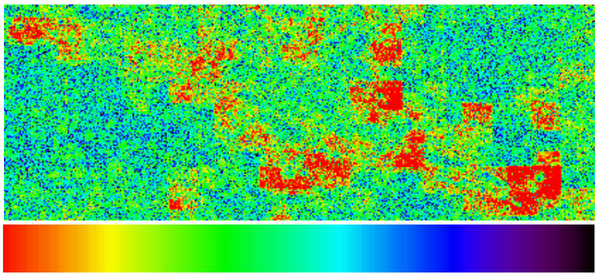


Fig. 3: Detail image in SIR-C ScanSAR image. The city area includes many single scatterers which create high dynamic



<=20 SDNR [dB] >=70

Fig. 4: SDNR map showing sensitively differences between the original (Fig. 3) and the reconstructed image part. Block effects in the environment of high dynamic become visible, compression rate was 1:8.

Normally, those data in SAR images which show very high dynamic compared to their neighborhood make an percentage of far below one percent of the SAR data set. In our first approach for block effect minimizing, we separate in each subband the upper one percent of wavelet coefficients which show highest dynamic in the subband compared to the other coefficients (Fig. 5 to Fig. 8).

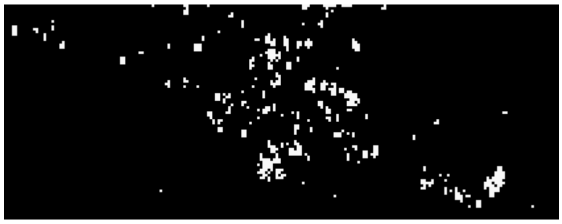


Fig. 5: A map corresponding to the detail image (Fig. 3) indicating where high dynamic data are located (high dynamic =1 (white), low dynamic =0 (black)) in the LH subband.

Those coefficients of high dynamic are stored without compression or they are compressed with small compression ratio. As they make up only one percent of the image, the achieved compression ratio is not decreased considerably. For high compression ratios, we recommend to compress also the high dynamic data using a relaxed compression rate in order to avoid a significant deteriorated overall compression ratio.

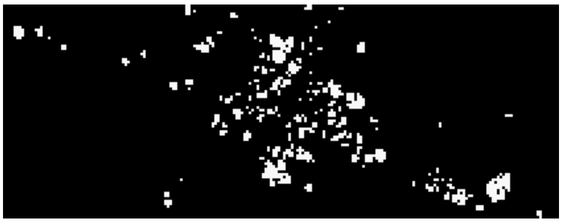


Fig. 6: High dynamic data located in HH subband

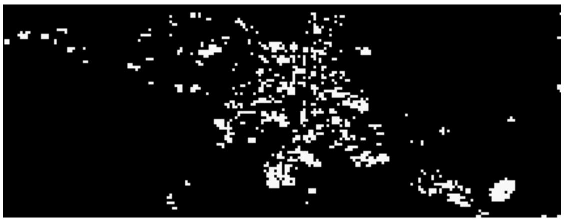


Fig. 7: High dynamic data located in HL subband

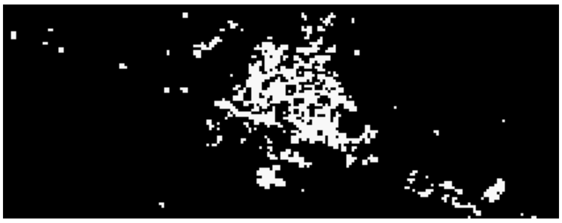


Fig. 8: High dynamic data located in LL subband

The header information is slightly increased by proceeding so, because a binary map indicating the location of high dynamic data by ones and zeros elsewhere has to be added. But due to the high redundancy, this map can be coded easily by using a suitable entropy coder. The slightly increased header information and therefore slightly smaller compression ratio can be accepted since the improved quality in the reconstructed image can make up 20 dB (Fig. 9 and Fig. 10).

Finally, it is to mention that best performance is achieved with approximately the same amount of separated high dynamic data in each subband. In our method, this is assured by the given percentage.

5. RESULTS

In our compression technique, there is necessity to introduce two different kinds of blocks. One adapts to limited computer memory, the other adapts to the changing dynamic of image contents. In some cases, e.g. the SIR-C image of this study, the decomposition into quantization blocks can trigger block effects in reconstructed images due to a rapid change in image dynamic across the scene.

Applying our new technique, we are able to minimize those block effects independent of the data set to compress. Extra treatment of high dynamic data in wavelet domain leads to significant quality improvement in reconstructed images for those ScanSAR scenes depicting many single point targets (see Fig. 9).

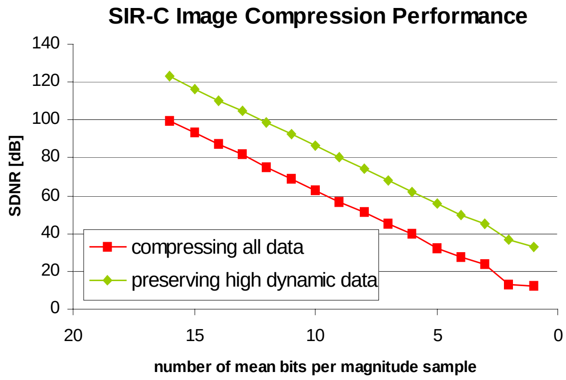


Fig. 9: Compression performance for SIR-C ScanSAR image. Preserving high dynamic data a much better performance is possible.

By proceeding in that way, not only point targets are preserved with excellent quality (infinite SDNR if demanded) but also their environment.

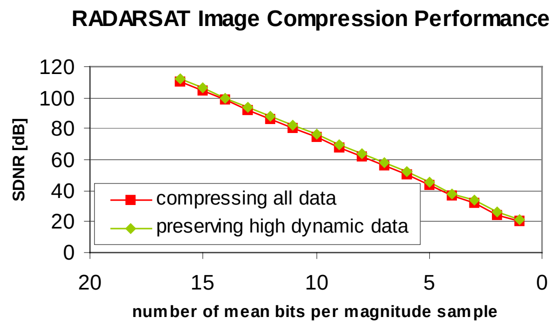


Fig. 10: Compression performance for RADARSAT ScanSAR image. Preserving high dynamic data the performance can not significantly be increased.

Extra treatment of high dynamic data is not necessary for those data sets as the used RADARSAT ScanSAR image in this study. But apart from a minor increase in header information, our method is not disadvantageous for those data sets. It also improves compression performance by small amounts (Fig. 10).

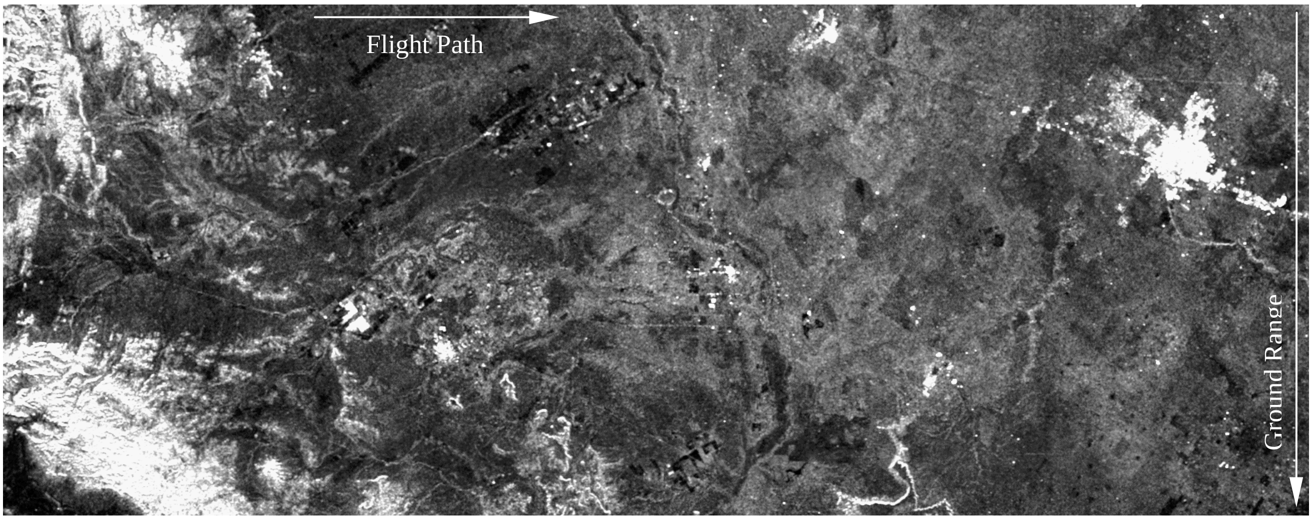


Fig. 11: Part of the original SIR-C ScanSAR image (approx. 200 km x 70 km in azimuth and ground range) depicting an area around Chickasha/Oklahoma, USA.

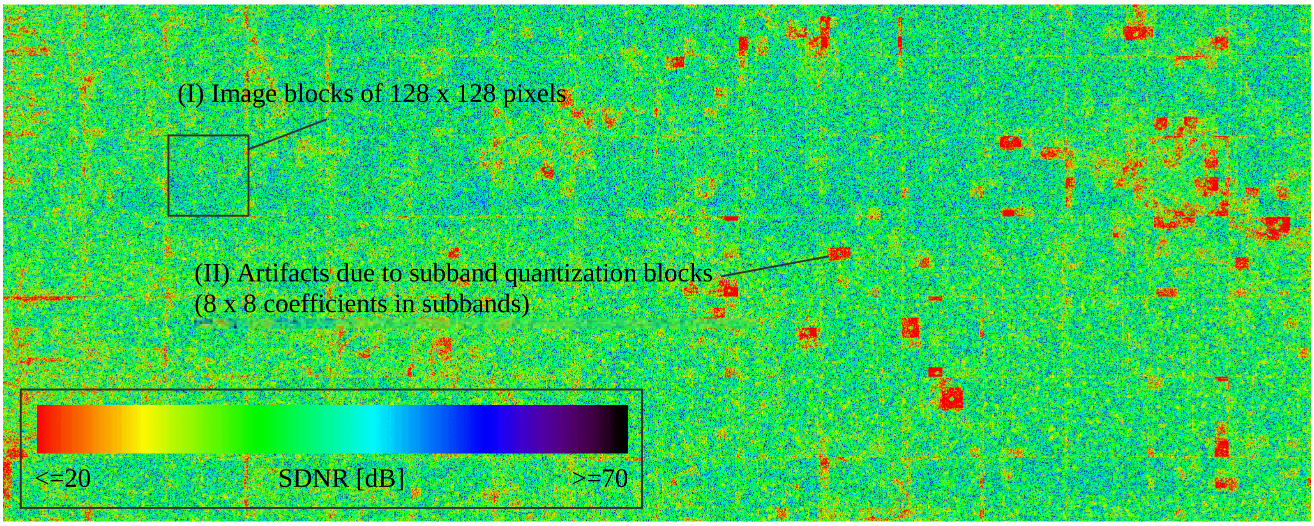


Fig. 12: SDNR map showing block effects due to invalid pixels after wavelet transforming (I) and due to worse SDNR in environments of point targets (II). Image was compressed with factor 1:8. Overall SDNR = 29.71 dB.

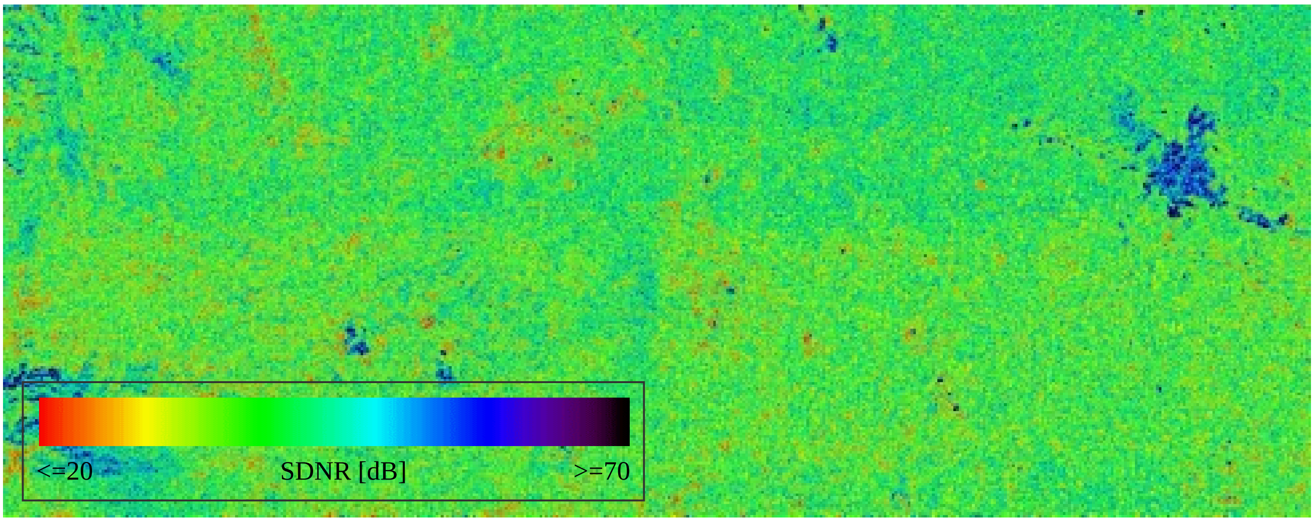


Fig. 13: SDNR map after applying the proposed technique. No block effects visible. Image was compressed with factor 1:8, high dynamic data (approx. one percent) were not compressed. Overall SDNR = 48.03 dB.

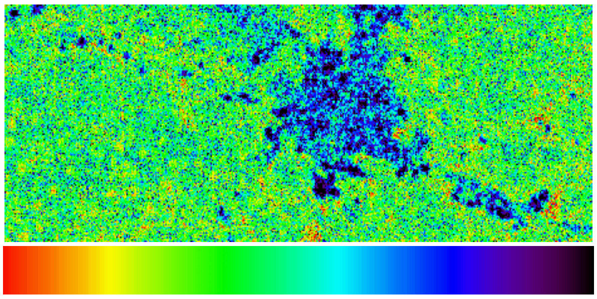


Fig. 14: SDNR map (to Fig. 3) after treating high dynamic data separately (not compressed in this case). White values indicate preserved point targets, no blocking structure is visible (compare to Fig. 4), compression rate was 1:8.

The chosen percentage of separated high dynamic data was approximately one percent for both, the SIR-C and the RADARSAT image. Varying the percentage allows a trade-off between image quality and compression ratio.

Moreover, our intention is not only to reach sufficient overall SDNR but also to achieve a scene independent error distribution. Of course, maps of signal-to-distorsion-noise ratios (SDNR) always show image content but artifacts due to compression should be avoided.

In Fig. 12 and Fig. 13, we compare resulting SDNR maps after decompression of the SIR-C image. Using our technique, we are able to avoid artifacts caused by introduction of necessary blocking in the compression method.

A similar improvement as it is possible for the SIR-C image is not achieved for the RADARSAT image due to the fact that no compression artifacts have to be removed here. We yield an overall SDNR of 36.58 dB after compression with rate 1:8. With extra treatment of 1 percent (high dynamic) data (not compressed), the performance has improved to 38.27 dB. In case an anti-scalloping filter is applied prior to compression the results are 36.81 dB and 38.35 dB, respectively.

6. DISCUSSION

In this paper, we only considered *detected* ScanSAR data. But the same procedure as applied to magnitude data can also be applied to both, the real and the imaginary part of complex ScanSAR data. Proceeding in that way, we still achieve an overall SDNR larger than 30 dB and a standard deviation of phase error[3] below 5° for compression ratios smaller than 1:7.

For compression ratios larger than 1:7, we propose a data format conversion from cartesian to polar format. In this case, the magnitude image is compressed as described in this paper; we recommend for phase compression either no compression or compression by a vector quantizer.

A further refinement of this method can be done. Instead of distinguishing two different types of dynamics in the frequency subbands, more levels of dynamics can be introduced in order to reach a higher adaptability to the reflected image content in subbands.

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3 We apply no averaging prior a phase error measurement. Applying a 3x3 averaging window prior to phase error measurement, the standard deviation of phase error decreases from 5° below 2°.