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Compression of spaceborne SAR images

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ABSTRACT

There is an obvious need for cost-efficient methods for administering and processing remotely sensed data because the amount of data available from different remote sensors is expanding rapidly. Various data compression algorithms have been developed recently, mainly for the purpose of transferring optical or photographic images within telecommunication networks. These algorithms are about to become valuable tools in the field of remote sensing because full resolution and retention of data are not always necessary to evaluate multisensoral images or time series of images. In this study, a subset from an ERS-1-PRI image of parts of the Antarctic peninsula was used to test a fractal encoding procedure, a wavelet encoder and the joint photographic expert group (JPEG) standard for image compression. The peak-signal-to-noise-ratio (PSNR) at any compression rate turned out to be best for the wavelet encoder. The change in information content after compressing the original data at a ratio of 50:1 was interpreted visually for the fractal encoder and the wavelet algorithm. The wavelet encoder returned the best overall results, while retaining most relevant features in the image.

In recent years, an enormous amount of remote sensing data from various platforms has become available. In addition to optical data from Spot, Landsat, NOAA and other systems, SAR data from ERS, JERS and Radarsat are also gaining increasing importance in environmental monitoring. SAR data are especially valuable because of their all-weather characteristic. Multitemporal and multisensoral evaluations of the synergy of the different sources involve processing huge amounts of data.

Data compression algorithms are valuable units within geographic information systems [12] because many applications do not require the full resolution of data at every step of the processing sequence. At the department of physical geography of the University of Freiburg, measures were taken to implement data compression algorithms in the Freiburg regionalization model (FREIM; Figure 1). The theoretical concept behind FREIM is that joint processing of point measurements and time series with spatial data from digital maps, digital terrain models and remote sensing products can provide the basis for deriving valuable secondary datasets for application and planning purposes [4]. Figures 1 and 2 show the processing steps to compress spatially or temporally distributed variables in the Freiburg coding module (FREIKOM), presently under development.

As a consequence of the compression, valuable geoscientific information can be extracted from the data. It is stored as feature vectors, quadtree structures and other compression formats. Furthermore, speckle can be reduced by applying compression algorithms to SAR data. Odegard *et al* [6] have shown that the procedures for image compression and speckle reduction in SAR images can be combined efficiently with the wavelet transform in a single process of decomposition and reconstruction.

Before describing the compression algorithms used in this study, an overview is provided of the geographic content of the original image. In addition, the results of the different compression concepts are presented and compared with respect to the geographic content retained.

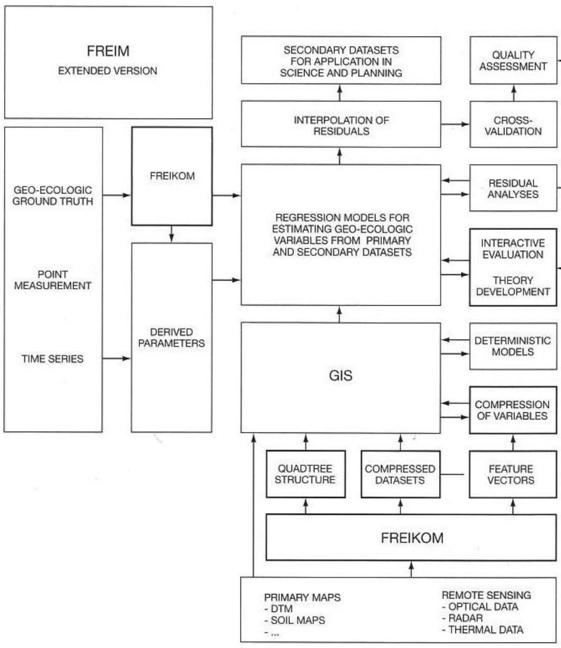

FIGURE 1 Theoretical concept of the Freiburg regionalization model (FREIM)

THE ORIGINAL DATA

The original SAR image of 18 January 1995 (Figure 3) is a subset of 1024 x 1024 pixels from ERS-1-PRI (PRI: pulse repetition interval) images. It depicts parts of Marguerite Bay, which is located on the west coast of the Antarctic peninsula at 68°S 67°W.

Along the left side of the image, the surface of the sea (1) shows irregular patterns attributable to surface motion. Ice floes and icebergs contribute to this inhomogeneous pattern. The ice cliff (2) runs northeast-southwest. In the upper left corner, the mountainous land tip Punt Calmette (3) rises to 600 masl, its slopes characterized by severe layover effects. On the left in

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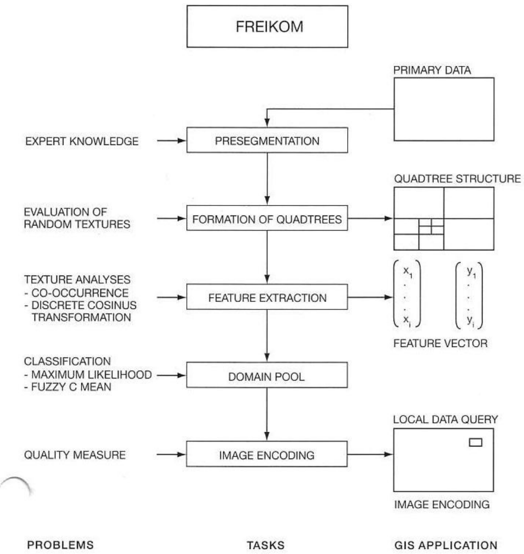

FIGURE 2 Problems, tasks and applications associated with the processing steps of the Freiburg coding module (FREIKOM)

the lower part of the image, two small rocky islands, the Debenham Islands (4), are located in front of the ice cliff. The Argentine reseach base "General San Martin" is located on one of the rocky islands.

Parts of the McClary (5) and Northeast (6) glaciers can be seen in the center and at the lower margin of the image, respectively. These glaciers join to form the west-facing ice cliff. Both ice streams are flanked by ridges with summits between 700 and 1000 masl. These ridges can be easily detected by their layover [7]. The surfaces of the glaciers are softly undulating. In the image, the rather dark tone on the glacier surface adjacent to the ice cliff is attributable to wet conditions in the snow cover, which lead to heavy absorption of the ERS-1 microwave radiation. The transition to lighter tones can be observed farther to the east on higher elevations of the McClary Glacier (8). Here, temperatures in the snow cover are well below zero and the absorption of radiation decreases rapidly because of the almost total absence of liquid water in the snow cover. Consequently, the bright colour results from scattering in ice lenses in the snow [11].

On the McClary Glacier, three corner reflectors were installed to monitor the ice velocity and identify the locations of automatic weather stations. These reflectors (marked with black circles) can be identified as bright white spots in the center of the subset (Figure 3). An additional corner reflector was placed west of the ice cliff, in the vicinity of the Debenham Islands.

METHOD

SPECKLE

Because of speckle in the SAR image, the data could not be compressed without preprocessing. The encoding methods used in this study did not distinguish between high-frequency noise and small-scale features in the image, and speckle would therefore be encoded as though it were real information, leading to immense computational costs and low compression ratios. To reduce speckle, a gamma-map filter [5] was applied to the SAR image before testing the different compression algorithms; the result is shown in Figure 4.

DATA COMPRESSION ALGORITHMS

In this study, a fractal encoder and wavelet image compression algorithms were investigated with respect to compressing spaceborne SAR images. The fractal encoder analyzes the image for repeat structures and

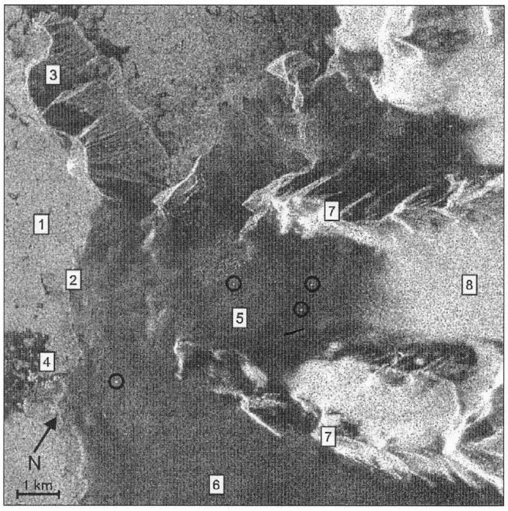

FIGURE 3 ERS-1-PRI subset of 18 January 1995; area depicted (68°S 67°W) covers approximately 164 km^2

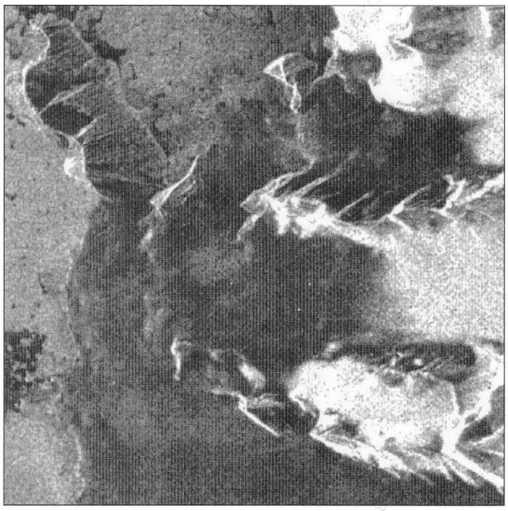

FIGURE 4 ERS-1-PRI image after speckle reduction with a gamma-map filter

makes use of the redundancy within these structures. The wavelet transform—which is becoming widely used in image compression—decomposes a dataset, using orthogonal-basis functions. Orthogonal wavelet decomposition provides multiresolution representations of a signal—in frequency and spatial orientations—and allows compression through quantization of the "important" components (quantize: to subdivide into small, discrete and still measurable increments). Both systems were compared with the joint photographic expert group (JPEG) industrial standard for data compression.

JPEG METHOD

The JPEG transformation procedure is based on the evaluation of quadratic subsets of an image. The image is divided into quadratic blocks, each block being transformed by a discrete cosine transformation (DCT). The coefficients of the transformation are quantized to integers and encoded according to the Huffman method in order to remove redundancy [3]. The DCT makes it possible to represent each block of the image as a linear combination of orthogonal cosine functions.

THE FRACTAL ENCODING PROCEDURE

In the field of fractal theory, the most straightforward method of encoding images is to subdivide the image into quadratic blocks (range blocks). These blocks are approximated by "similar" squares (domain blocks) from the same image. The edges of the domain block are twice as long as the edges of the range block. The set of all affine transformations used to approximate the range block from the domain block make up the fractal code. With the fractal code, it is possible to decode the original image approximately as an attractor of a contractive iterated function system, according to the "collage theorem" [1].

WAVELET COMPRESSION

As with the JPEG method, the wavelet encoder is based on an orthogonal linear transformation. Instead of using subsets from the image, the wavelet procedure transforms the image as a whole. The orthogonal cosine functions of the DCT are replaced by a system of orthogonal wavelet functions. The discrete orthogonal wavelet-basis functions are generated from a singular mother wavelet function ψ by dilations and translations:

$$\psi_{m,n}(t) = 2^{-\frac{m}{2}} \psi(2^{-m}t - n) \qquad m, n \in Z \qquad [1]$$

where ψ is a square summable function in the discrete Hilbert space $l^2(Z)$.

Compactly supported wavelets according to Daubechies [2] were used in this study. The coefficients of the transformation were quantified according to the zerotree method [9] and then compressed using an arithmetic encoder [10]. The wavelet functions enable the analysis of frequency spectra in the spatial domain locally in the image.

RESULTS

Figure 5 shows the peak-signal-to-noise-ratio (PSNR) in dB for the three encoding methods at different compression ratios, as computed for the ERS-1-SAR image subset. It was calculated as

$$PSNR = 20 \times \log_{10}\left(\frac{b}{rms}\right) \qquad [2]$$

where b was the largest positive value and rms was the root mean square error between the original and the compressed image.

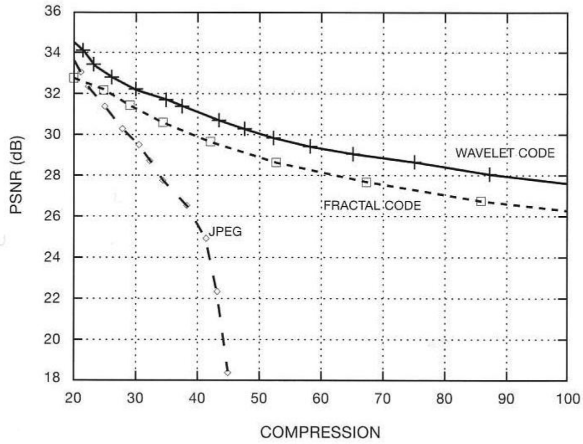

FIGURE 5 Peak-signal-to-noise-ratio for three different compression algorithms, as computed for an ERS-1-PRI subset of 18 January 1995

Although the JPEG method worked fairly well at low compression ratios, it was unsuitable for reducing the image at compression ratios higher than 45:1. The wavelet compression module always produced better overall results than the fractal encoder. It is true, however, that even more advanced encoders than those used in this study have recently become available for fractal and wavelet compression, *eg*, the SPIHT encoder [7]. (For an overview of fractal image encoding procedures, see [8].)

Interpreting the resulting images at a compression ratio of 50:1 (Figures 6 and 7), it is obvious that the wavelet encoder produces better overall results. The corner reflectors, which are easy to detect on the original image even after speckle reduction, can still be observed on the wavelet image, whereas the information on these reflectors has been almost completely lost in the fractally compressed image (Figure 6). However, the line drawn from the ice cliff seems to be better retained in the fractally encoded image, and the same applies to the shore line in the southwest of Calmette Bay. The performance of the fractal encoder seems to be superior for edge detection; on the other hand, smooth structures on the glaciers are reproduced more accurately by the wavelet algorithm. These structures depend on the properties of the snow cover, the slope and aspect of the surface, and the roughness of the snow pack. Changes in roughness may result from crevasses or surface structures of the snow. The use of a wavelet-based encoder rather than a fractal encoder is therefore recommended for extracting information with respect to snow-cover dynamics. The sea surface, structured by surface motion, ice floes and icebergs, is also better reproduced by the wavelet encoder. The fractal encoder produces a coarse "blocky" image from uniform parts of the image. It performs well where it can make use of self-similarities within large-scale linear features such as cliff or

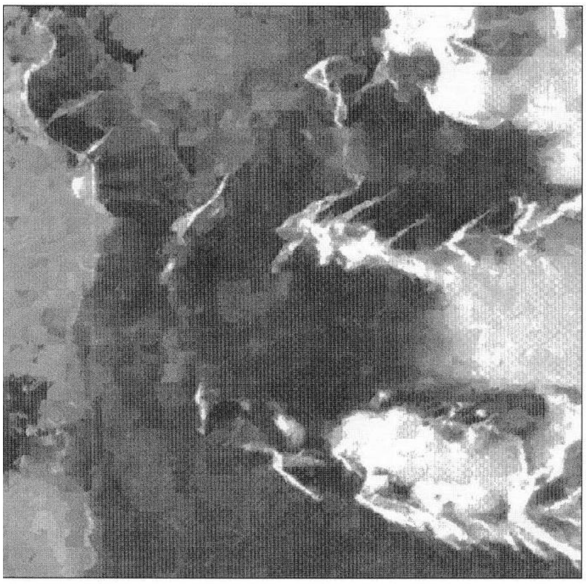

FIGURE 6 ERS-1-PRI image after compression by a factor of 50 using a fractal image encoder

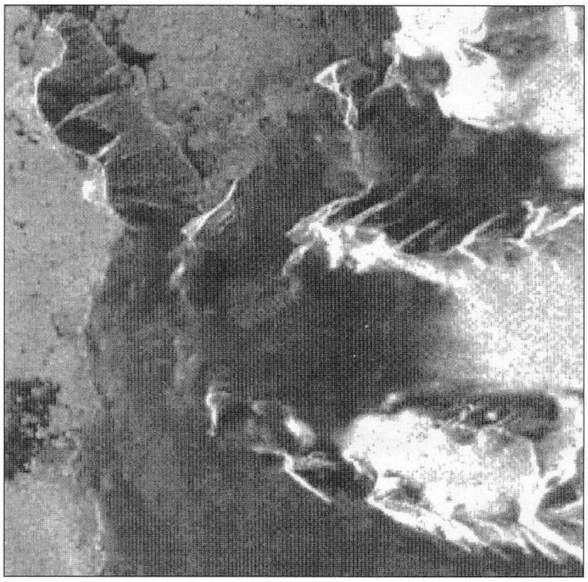

FIGURE 7 ERS-1-PRI image after compression at 1:50 using a wavelet image encoder

shore lines, but is inferior to the wavelet-base method when compressing small-scale phenomena such as backscatter signals from single icebergs, corner reflectors or small features in the snow cover.

CONCLUSION

A wavelet image compression routine and a fractal encoder were tested for their capabilities with respect to compressing ERS-1-PRI data on the Antarctic peninsula. Both methods were suitable tools for handling large amounts of data. Although most details were still retained at compression ratios as high as 50, the algorithms investigated showed different results. Whereas the wavelet encoding procedure performed better with respect to small-scale phenomena, the fractal encoding system was superior for extracting linear features.

Further research is required to determine the best compression ratios for specific user requirements and whether the compression procedures can be extended to single-look-complex (SLC) data.

ACKNOWLEDGMENTS

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RESUME

Il y a un besoin évident de méthodes efficaces et peu coûteuses pour l'administration et le traitement de données de télédétection car le montant de données disponibles à partir de différents capteurs s'accroît rapidement. Divers algorithmes de compression ont été développés récemment, principalement dans le but de transférer des images optiques ou photographiques à l'intérieur de réseaux de télécommunication. Ces algorithmes sont sur le point de devenir des outils valables dans le domaine de la télédétection car la pleine résolution et la rétention de données ne sont pas toujours nécessaires pour évaluer des images multi-senseurs ou des séries temps. Dans cette étude, un sous-ensemble à partir d'image ERS-1-PRI de certaines parts de la péninsule Antarctique a été utilisé pour tester une procédure de codage fractal, un codeur d'ondelette et le "joint photographic expert group" (JPEG) standard pour compression d'image. Le sommet du rapport signal-bruit (PSNR) s'est avéré être le meilleur pour le codeur d'ondelette. Le changement dans le contenu d'information après la compression des données d'origine au taux de 50:1 a été interprété visuellement pour l'algorithme de codeur fractal et d'ondelette. Le codeur d'ondelette a donné les meilleurs résultats dans l'ensemble, tout en gardant les caractéristiques importantes de l'image s'y rapportant.

RESUMEN

Se requieren métodos más eficientes para manejar y procesar los datos de teledetección, porque la cantidad de datos disponibles a partir de los diferentes sensores remotos aumenta rápidamente. Recientemente, se han desarrollado varios algoritmos para la compresión de datos, principalmente para transferir imágenes ópticas o fotográficas en las redes de telecommunicación. Estos algoritmos están a punto de transformarse en herramientas valiosas en el campo de la teledetección, ya que no siempre se requieren resolución y retención completas de los datos para evaluar imágenes multisensorales o series temporales. En este estudio, se usó una subserie de una imagen ERS-1-PRI representando partes de la península antártica, para ensayar un procedimiento de codificación fractal, un codificador de ondas y el conjunto de las técnicas fotográficas ("joint photographic expert group", JPEG) normalmente usado en la compresión de imágenes. Bajo cualquier tasa de compresión, el codificador de onda proporcionó la mejor relación máxima señal-ruido. Después de comprimir los datos originales a una relación de 50:1, se interpretó visualmente el cambio en el contenido de información para el codificador fractal y el algoritmo de onda. El codidficador de onda dió los mejores resultados totales, al mismo tiempo que conservó la mayoría de los rasgos relevantes en la imagen.