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Filtering of radar images for geological structural mapping

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ABSTRACT

Geological structural features may be described on satellite images as thin lines or contours.The extraction of these features is usually performed by enhancement techniques such as filtering and edge detection. However, radar images being characterized by the presence of speckle noise, the classical enhancement techniques do not provide good results in this case. We present here two methods of filtering based on local transformations of the grey-tone function. They provide grey-tone images where the speckle is removed and the continuity and sharpness of thin structures are preserved. The valuation of the methods is done by analyzing the binary images resulting from an automatic thresholding of the filtered images according to two criteria : homogeneity and connectivity.

1. INTRODUCTION

On radar images, topographic variations are enhanced by high contrasts of reflectivity. This property is very useful for geological structural mapping based on the recognition of geomorphological objects such as faults, versant orientations, thalwegs or crest lines. Nevertheless, the speckle noise is one of the main obstacle for digital processing. As a matter of fact, these images do not contain zones with spatially uniform reflectivity : for a given grey level threshold, the pixels are generally not contiguous. Therefore, the classical methods for feature extraction do not provide in this case the satisfactory results obtained from optical images. We present here a panel of filters having the property of reducing the speckle while preserving the radiometrical and the spatial resolution of the initial image. Two classes of methods have been already developped :

(a) statistical methods where the existence of an additive or multiplicative noise is assumed [3].

(b) morphological methods which achieve the smoothing of the grey-tone images thanks to the properties of the morphological transformations [7]. We propose here other filters belonging to both classes.

The tested area is located in western Spitsbergen, centered on the Broggerhalvoya peninsula. It presents a mountainous topography due to the glacier activity. This area has been previously studied by using ERS-1 imagery [6]. The main structural features correspond to sharp crest lines and rock-glacier boundaries. On the other hand, the front of the active glaciers is underlined by morainic accumulations (fig. 1).

2. STATISTICAL FILTERS AND RANK OPERATORS

2.1. Lee filter

The statistical methods of noise removal are based on the minimization of the error between the noiseless image and its estimates, given a model describing the nature of the noise (multiplicative or additive). We have tested this approach by applying to the original image the Lee filter [3]. The principle is the following :

$$z_{i,j} = x_{i,j} + \omega_{i,j}$$

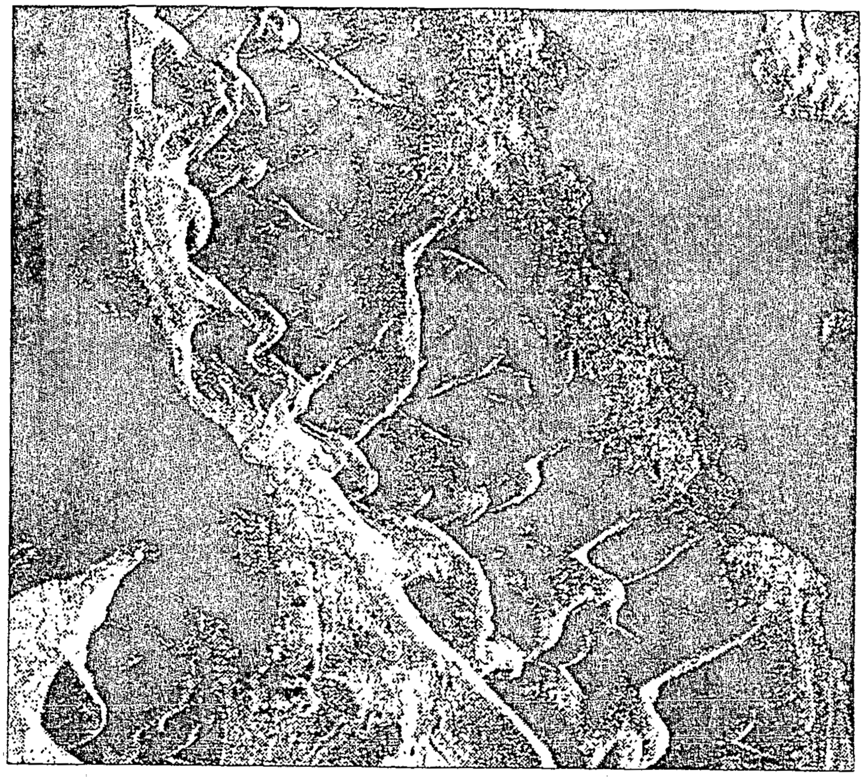

Figure 1.- Original SAR-ERS-1 image

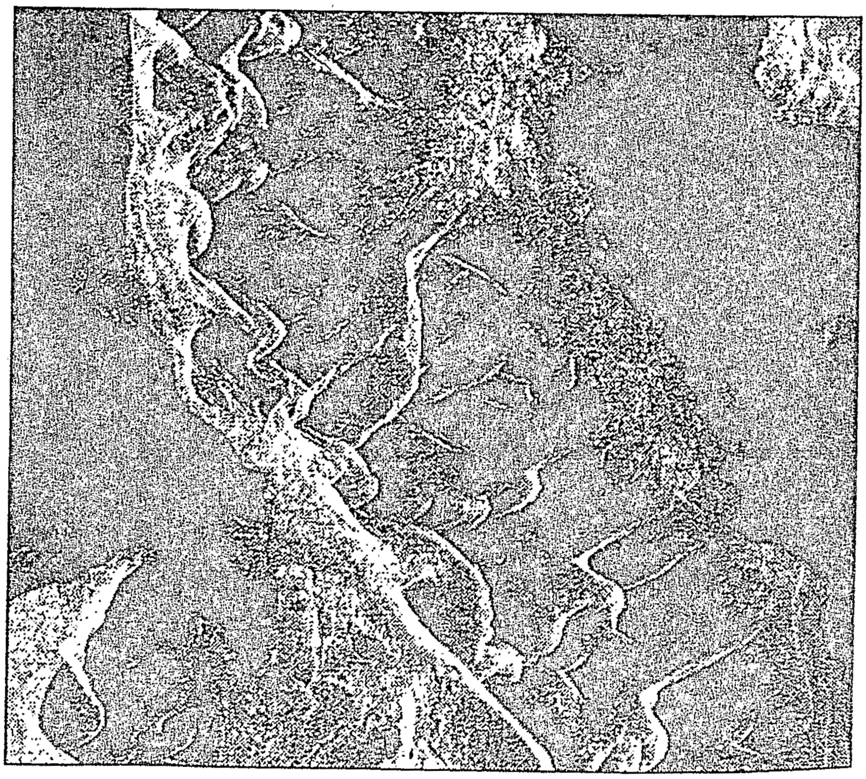

Figure 2.- Lee Filter

where $z_{i,j}$ is the value of the pixel (i,j), $x_{i,j}$ the value of the pixel before degradation and $\omega_{i,j}$ the additivenoise with zero mean and σ^2 variance. It is assumed that the theoretical mean and variance ($\mu_{i,j}$ and $Q_{i,j}$) are approximated by the local mean variance of all pixels in the neighborhood surrounding $z_{i,j}$.

The estimate $\xi_{i,j}$ is given by :

$$\xi_{i,j} = \mu_{i,j} + k_{i,j} (z_{i,j} - \mu_{i,j})$$

where $k_{i,j} = Qi,j \ / \ Qi,j + \sigma^2$

In this version of the Lee filter, the neighborhood is chosen in order to preserve the edges (fig. 2).

2.2. Punctual filter

A similar approach consists in sorting the values of the pixels within a given neighborhood. The median filter is one of the more frequently used for image smoothing. Considering that the speckle corresponds to punctual anomalies, it would be more pertinent to eliminate them. It is done by replacing the isolated values of reflectivity by a statistical estimator (median or mean) computed within 3x3 square neighborhood. The algorithm is the following : the absolute value of the difference between the central pixel and each surrounding pixel is computed. The value of the central pixel is considered as unique when all these absolute values are greater than a given threshold. In this case, the value of the central pixel is replaced on the resulting image by the mean value of the height surrounding pixels; else, the value on the resulting image remains unchanged (fig. 3).

3. MORPHOLOGICAL FILTERS

Morphological filters are not based on any probabilist model of the grey-tone distribution. They are based on Morphological Openings and Closings with a given structuring element. If utilized alone, a Morphological Opening (resp. Closing) smoothes only white (resp. dark) details.
But on a grey-tone image like the radar ones, the noise may be composed both of dark or white details. Classical smoothing filters such as the median filter acts the same manner on high and low values. Many Morphological Filters have been proposed for image smoothing. They are the result of a determined composition of Openings and Closings.
We have applied here two Morphological filters designed for smoothing noisy grey-tone images : the Center filter and the Comparative filter. A third one is proposed which is a Connected filter.

3.1. Comparative filter

Safa and Flouzat [7] have proposed morphological filters to remove speckle on radar imagery and especially one called the Comparative filter. This filter is built from local transformations which are defined as algebraic Openings and Closings. The structuring elements used in these transformations are not convex. In their definition, the center of the structuring element is omitted. The two basic transformations utilized in the comparative filter are :

$$\phi_B f(x) = \mathrm{Max}(f(x), \mathrm{Min}_{B^*} f)$$
$$\gamma_B f(x) = \mathrm{Min}(f(x), \mathrm{Max}_{B^*} f)$$

where $B^* = B(x)\text{-}(x)$. The operator ϕ_B suppresses the "isolated" minima with respect to B and γ_B acts on the minima in the same way. The real implementation is more complex. It is based on operator ψ and ψ' and on a family of structuring elements of increasing radii $B_1, \ldots, B_n$. They are defined in the following way :

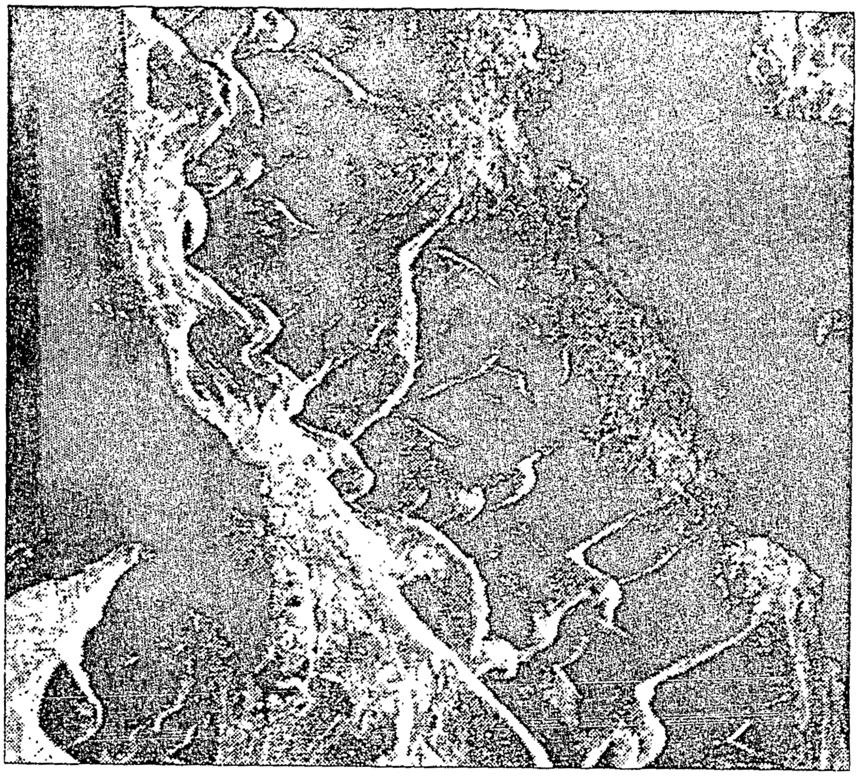

Figure 3.- Punctual Filter

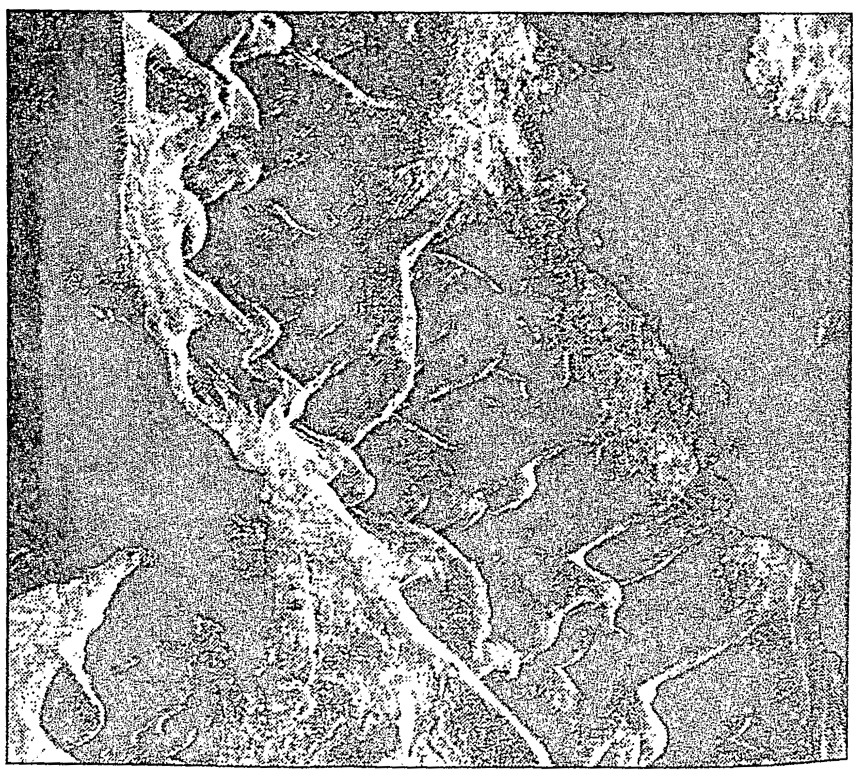

Figure 4.- Comparative Filter

$$\psi_{B1,\ \ldots\ ,\ Bn} f(x) = \mathrm{Max}(f(x), \mathrm{Min} f_{B1^*}, \ \ldots\ , \mathrm{Min} f_{Bn^*})$$

$$\psi'_{B1,\ \ldots\ ,\ Bn} f(x) = \mathrm{Min}(f(x), \mathrm{Max} f_{B1^*}, \ \ldots\ , \mathrm{Max} f_{Bn^*})$$

We used the following step of the filter :

$$m\lambda = \gamma_{B\lambda}\phi_{B\lambda} = (\psi'_{B\lambda})^k (\psi_{B\lambda})^k$$

where k=3 and $B\lambda$ is composed by three circles surrounding the origin and having increasing radii defined from the square grid (fig. 4).

3.2. Center filter

Self duality is one of the property required for grey-tone image smoothing. In this perspective, Serra noticed that the median filter is self-dual but not idempotent and showed are to build filters having both properties from Morphological filters [8]. In the general case of complete lattices $\mathcal{T}$, the centre β between an overfilter ($\vee$ filter) f and an underfilter ($\wedge$ filter) g is given by the general formula :

$$\beta = (I \wedge f) \vee g = (I \vee g) \wedge f$$

Given a Morphological Opening γ with a convex structural element B and the dual Morphological Closing ϕ, the center β is constructed with $f = \phi\gamma\phi$ and $g = \gamma\phi\gamma$. We used here a Morphological Opening (resp. Closing) with a square structural element of size 1 (fig. 5).

3.3. Center connected filter

It has been said that, for geological mapping from radar imagery, thin white structures have to be preserved or even restored. It has been now frequently shown, that connected filters on grey-tone images product grey-tone flat zones. Moreover, filters resulting from a composition of connected Openings and Closings have the same algebraic properties than the equivalent ones made of morphological filters [1].
Given the two filters γ_c and ϕ_c which are respectively an Opening and a Closing by reconstruction, we applied to the original radar image a filter which is the centre β_c between f_c and g_c defined as follows:

$$\beta_c = (I \wedge f_c) \vee g_c$$

where $f_c = \phi_c\gamma_c\phi_c$ and $g_c = \gamma_c\phi_c\gamma_c$

One can see on the figure 6 that the speckle has been partially removed and that the contours of the structures have been restored.

4. COMPARIZON AND VALUATION OF THE FILTERS

The results of the various filters may be visually compared. But visual estimation of the quality of the grey-tone images obtained by filtering is difficult to objectively carry out. The comparizon and the valuation of the filters performed in this paper, are based on two criteria : homogeneity of the texture and

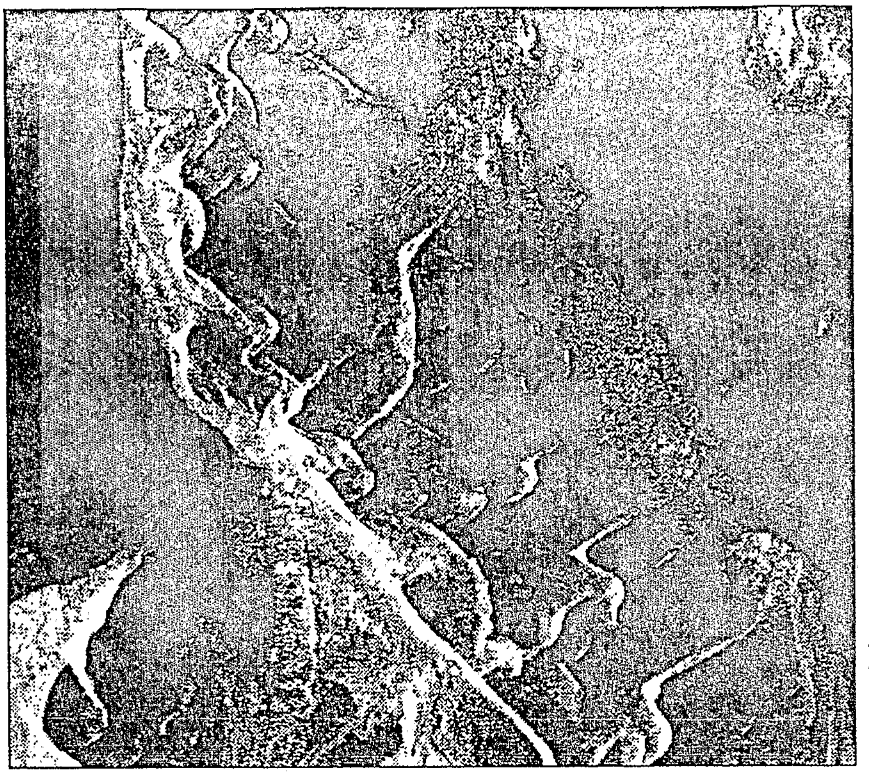

Figure 5.- Center Filter

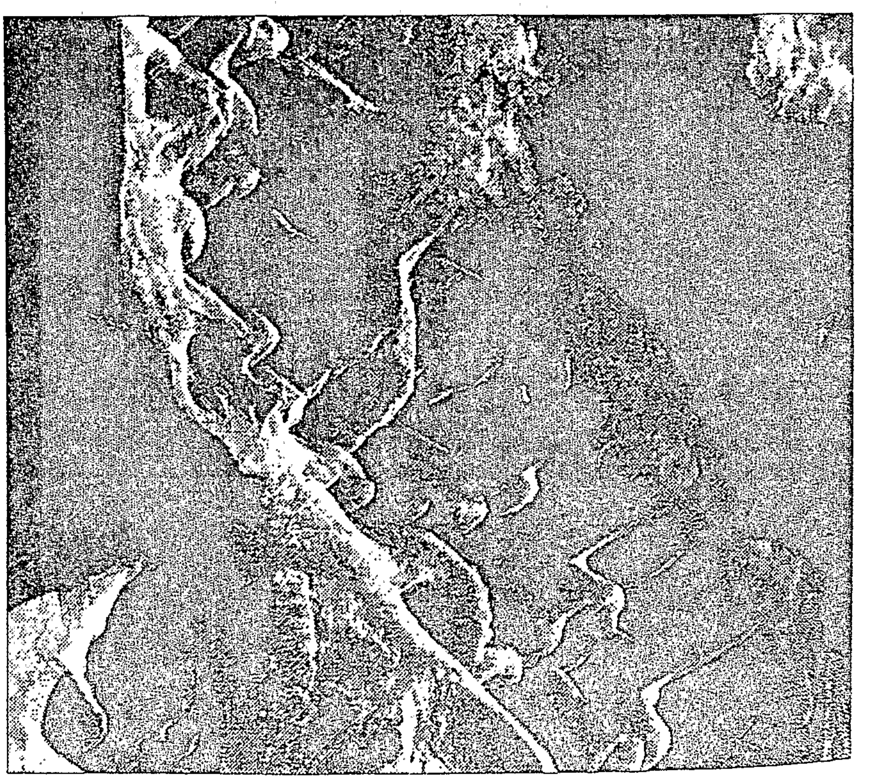

Figure 6.- Center connected Filter

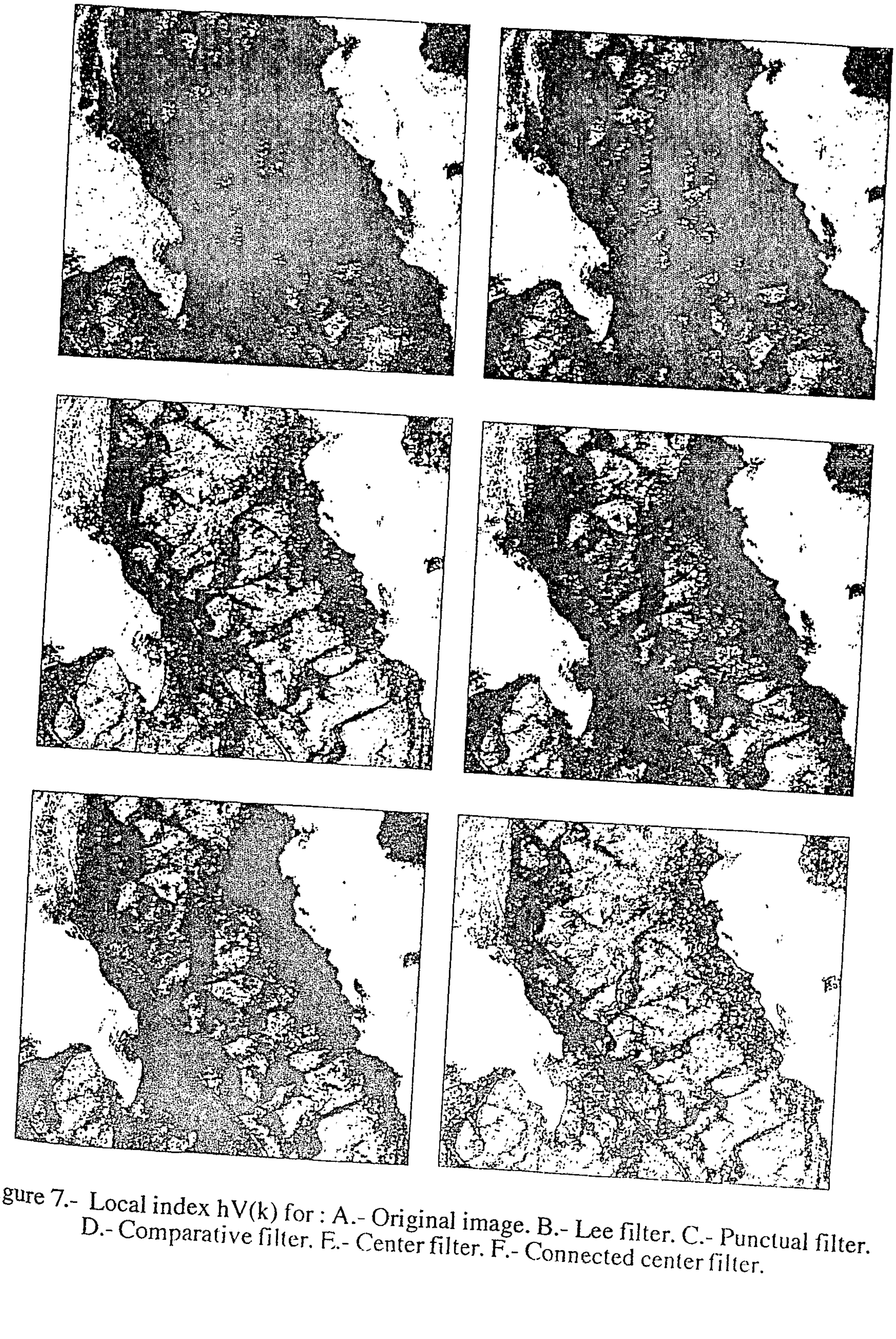

Figure 7.- Local index hV(k) for : A.- Original image. B.- Lee filter. C.- Punctual filter. D.- Comparative filter. E.- Center filter. F.- Connected center filter.

connectivity of the structures, since the filters were designed for removing the speckle while preserv[ing] the structural features.

4.1. Homogeneity

In order to quantify the homogeneity of the texture, we have computed the local occurence $h_V(k)$ of ea[ch] grey-level p(i) inside a neighbourhood V of the pixel i, according to the formula :

$$h_V(k) = \sum_{i \in V} \chi_{[p(i)=k]}(i)$$

where $\chi_{[p(i)=k]}(i)$ is the boolean function defined as follows:

$$\chi_{[p(i)=k]}(i)=1 \text{ if } p(i)=k$$

$$\chi_{[p(i)=k]}(i)=0 \text{ if } p(i)\neq k$$

On figure 7, one can see the images of the local occurence inside a 3x3 sliding window for the si[x] filters described above. According to the local criterium $h_V(k)$, the homogeneous zones on th[e] corresponding filter are the lighter on these images. It can be noticed that the region are mor[e] homogeneous on the punctual filter (fig. 7C) and on the connected center filter (fig. 7F) than on the other ones.

The homogeneity on the whole image I can be quantified by using the index H(k):

$$H(k) = \frac{\sum_{i \in I} \chi_{[p(i)=k]}(i) * h_{V(i)}(k)}{\sum_{i \in I} \chi_{[p(i)=k]}(i)}$$

The 256 values k of this index have been calculated for the original image and the five filters (fig.8). The effect of smoothing of the morphological filters is emphasized by this index.

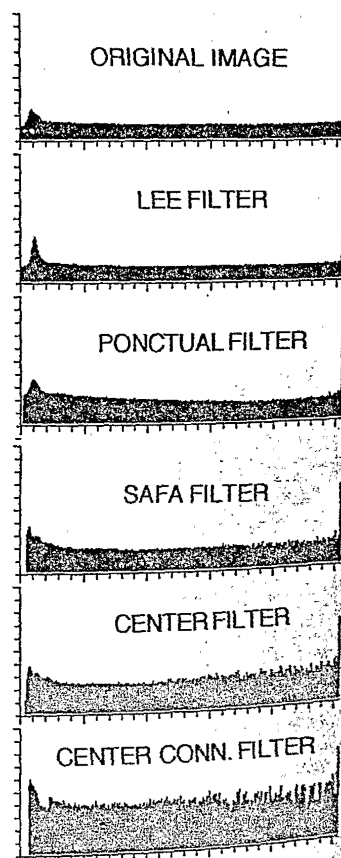

Figure 8.- Variation of index H(k)

4.2. Connectivity

In order to quantify the connectivity of the structures, a quantitative index is defined here to valuate binary images obtained by an automatic thresholding. This index, called here connectivity index, is based on the definition of the geodesic lenght of connected components on binary images [2]. For each connected component of the binary image, the geodesic lenght is computed according to the algorithm of the geodesic euclidian distance function [9]. The connectivity index I_c is defined as follows :

$$I_c = \sum_{i=1}^{N} \frac{lg(X_i)}{N}$$

where $l_g(X_i)$ is the geodesic length of the component X_i, and N is the number of connected components.

A normalized connectivity index NI_c can be defined as :

$$NI_c = I_c \,/\, l_{gmax}$$

where l_{gmax} is the maximal geodesic lenght on the binary image.
These two indexes have been used to compare the results of the filtering.

4.2.1. Connexity index on filtered images

Assuming that the connectivity of white structures, in the case of geological structural mapping, is an index of quality, we thresholded the first decile of the grey-tone distribution of the original image and the five filters formerly described (fig. 9).
The results presented on Table I show clearly that the use of the connected filter enhance the structural features. On the other hand, the use of structuring elements with a central hole (cf. punctual and comparative filters) seems to improve the speckle removal.

Filters	Connexity index	Normalized index
unfiltered image	5,185376	0,005079
Lee filter	5,218167	0,005136
punctual filter	13,619719	0,010164
comparative filter	12,736406	0,011263
center filter	9,826741	0,008486
connected center filter	59,223808	0,031236

Table I.- Connexity index on filters

4.2.2. Connexity index on the residual filtered images

Previously, features have been extracted only by thresholding. The contrast feature extraction by means of a White Top Hat transformation has been also experimented on the filtered images. In order to simplify the residual images which are quite noisy and to enhance the contrasts, a k2 morphological contrast filter [5] has been applied on White Top Hat images. Before the computation of the two connectivity indexes, the thresholding previously described has been used (fig. 10).
Table II shows that the valuation of the filters based on their morphological residues is quite different than the one presented formerly on Table I. In particular, it is not surprising that the β_c gets low values of index. Actually, if the use of connected filters improves the aspect of noisy images better than classical morphological filters, this is not any more true for their residues.

Filters	Connexity index	Normalized index
unfiltered image	5,931391	0,006841
Lee filter	5,938849	0,006850
punctual filter	6,430385	0,021293
comparative filter	9,114911	0,013326
center filter	8,783391	0,017088
connected center filter	8,059291	0,015865

Table II.- Connexity index on residues

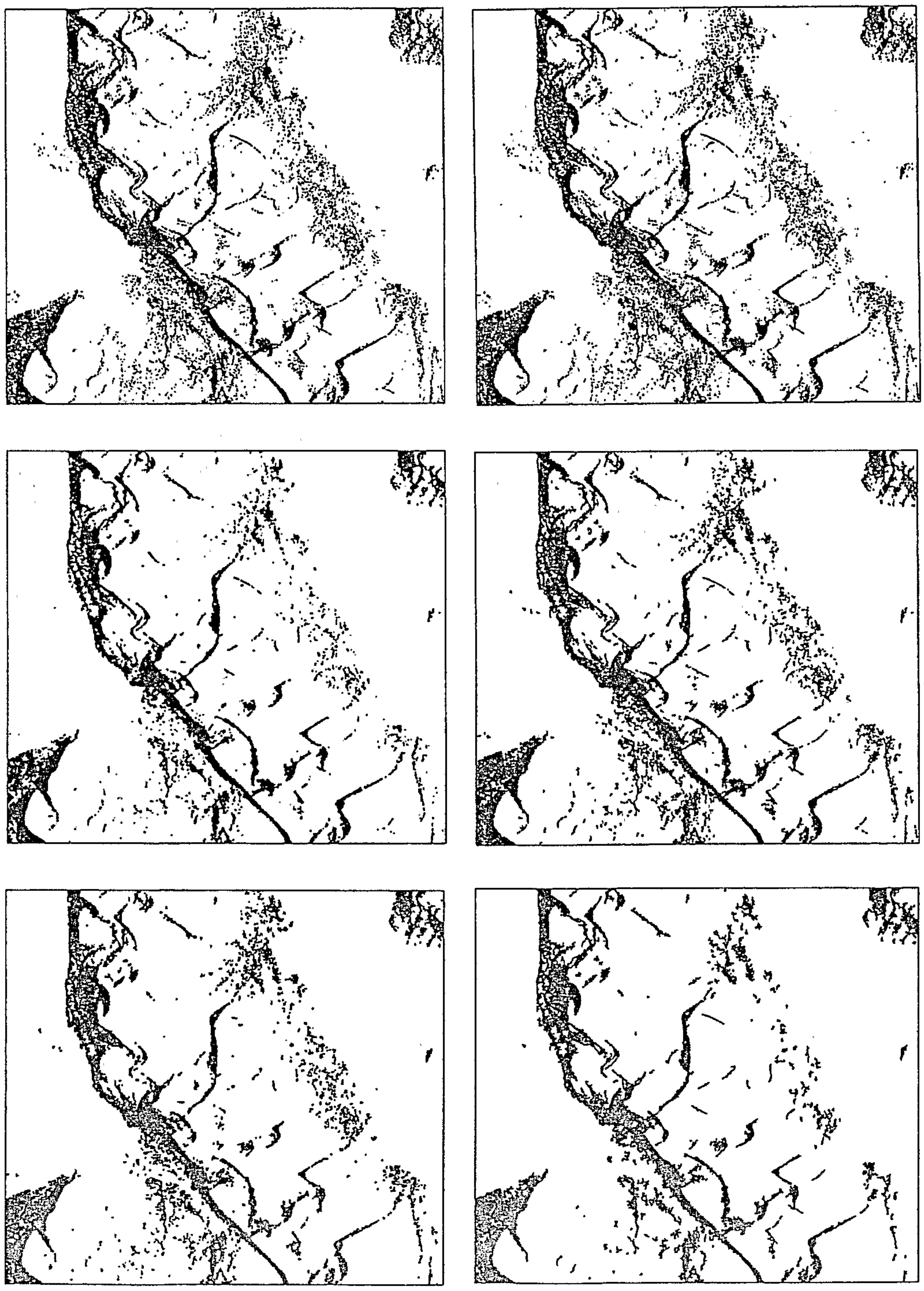

Figure 9.- Thresholding on filtered images : A.- Original image. B.- Lee filter. C.- Punctual filter. D.- Comparative filter. E.- Center filter. F.- Connected center filter.

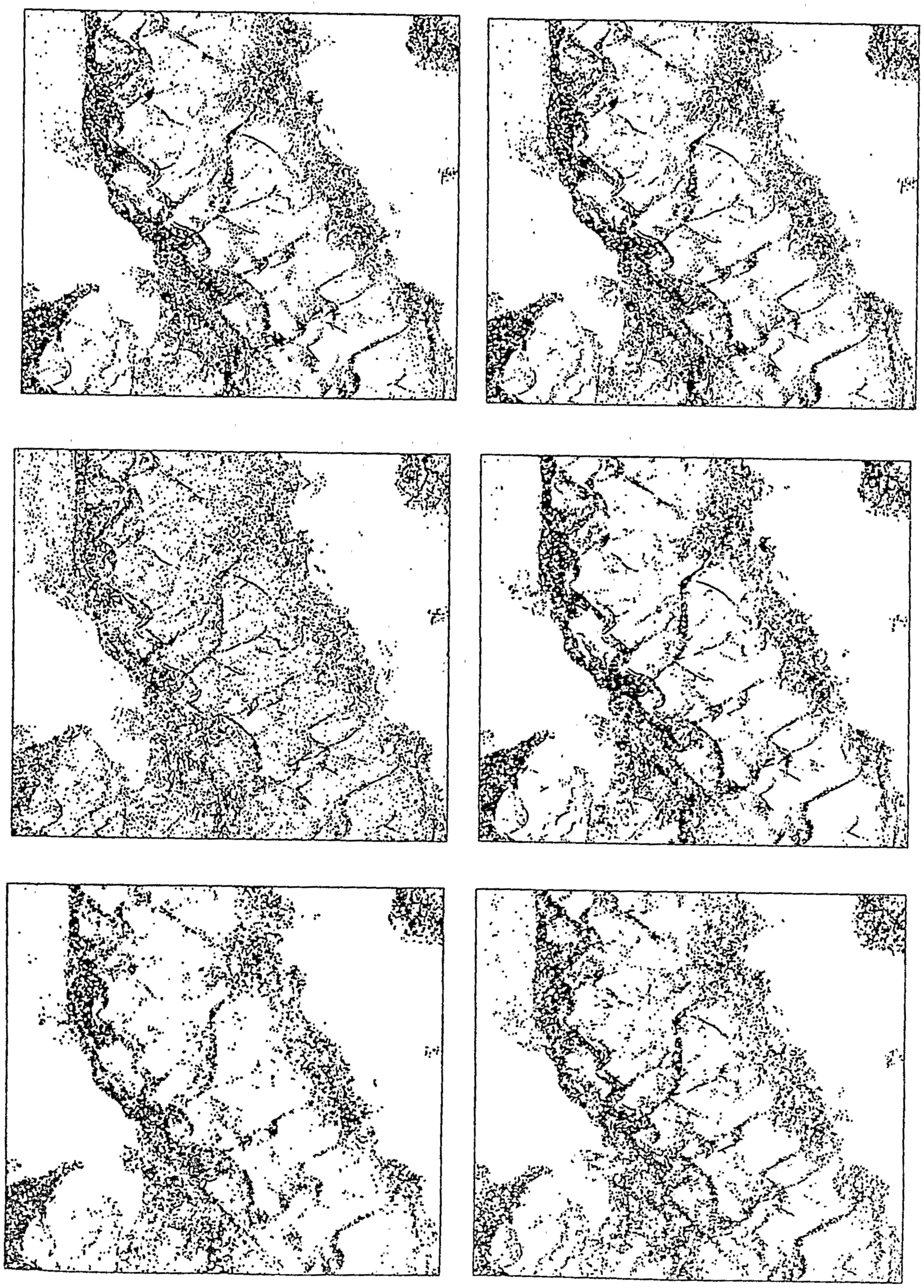

Figure 10.- Thresholding of White Top Hat of filtered images : A.- Original image. B.- Lee filter. C.- Punctual filter.D.- Comparative filter. E.- Center filter. F.- Connected center filter.

5. CONCLUSION

Space radar images are very useful for geological purpose if one can reduce the speckle while preserving the fine structures. A solution of filtering is proposed here based on connected filters. The valuation of this solution led us to define indices of global homogeneity and connectivity.
In this study we compared filters reducing the noise and minimizing the loss of information about fine details. In the general prospect of removing the speckle for image segmentation at larger resolutions, the use of Alternate Sequential Filters should demonstrate good results.

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Titre:	Image and signal processing for remote sensing : 26-30 September 1994, Rome, Italy / Jacky Desachy, chair/editor ; sponsored by the Commission of the European Communities, Directorate General for Science, Research, and Development ... [et al.]
Auteurs:	Desachy, Jacky Commission of the European Communities. Directorate-General for Science, Research, and Development Society of photo-optical instrumentation engineers
Date:	c1994
Editeur:	Bellingham, Wash., USA : SPIE--the International Society for Optical Engineering
Collection:	(EurOpto series) (Proceedings of SPIE--the International Society for Optical Engineering, ISSN 0277-786X ; 2315)
Description:	xiii, 854 p. : ill. ; 28 cm
Notes:	Includes bibliographical references and index.
ISBN:	0-8194-1645-2
Sujets:	Remote sensing -- Congresses Signal processing -- Congresses Image processing -- Congresses G70.6
Collection:	EurOpto series Proceedings of SPIE, the International Society for Optical Engineering, ISSN 0277-786X ; 2315
Langue:	anglais
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