COMMUNICATION AU VIIth INTERNATIONAL SYMPOSIUM FOR STEREOLOGY.
Caen, 2 - 9 september 1987

AN APPROACH OF QUANTITATIVE DESCRIPTION OF SAND-HILLS SHAPES IN THE WEST AFRICAN SAHEL FROM REMOTE SENSING IMAGERY.

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ABSTRACT :

The aim of this work is to estimate morphological parameters of dune systems in West African Sahel from remote sensing images that will be utilized in paleolandform studies. The sample is taken from a MSS Landsat view of the northern part of the Faguibine lake in Mali.
In order to extract the very structure, sequences of morphological transformations are applied to this image and an estimation of its anisotropy is obtained by a *Rose of directions* method.

anisotropy, dunes, mathematical morphology, paleolandform, remote sensing, .

1. Use of remote sensing data for characterization of sand-hills structures.

In order to provide to geomorphological researches concerning genesis of dune systems of West African Sahel, new descriptive parameters from remote sensing images that can be added to the traditional ones (granulometry, morphometry, ground plotting). The estimation of dune systems orientations has to be connected later to climatologic and hydrologic conditions of their setting.
Spatial resolution of MSS Landsat data gives a proper synoptic view of Sahelian dunes and radiometric counting makes visible spatial organization of vegetation as well as local variations of the topography .
Our training zone is the Northern part of Faguibine lake in Mali (17°N, 4°W) where different types of sand-hill structures are placed side by side.
Each one of these structures can be met in the Sahelian region. Moreover, around Faguibine lake, geological and hydrological elements contributing to general knowledge about the genesis of dunes are investigated nowadays.
On the ground, from East to West, there is a succession of three types of structure:
- at the eastern part : rectilinear and regularly spaced *bars of erg Azaouad*, with a NE-SW orientation (Fig.1).
- at the western part : *bars* of *erg Assouarirt*, wider, the shape of each hill having irregular limits, with a NW-SE orientation (Fig.7).
- between both structures, a cross shape (bee's nest), whithout visible main orientation, called *akle* structure.

Rills which are marks of whether ancient or present hydric erosion appear on all these structures. Their orientation is roughly perpendicular to the sand-hills.
The spatial organisation of the vegetation approximately follows the topographical variations:
- Into the interdune depressions, the vegetation (herbaceous and arboreous) is always denser than in the other parts of the hills.
- On gentle slopes, vegetation is more spaced and concentrated inside the *rills* .

- On steep slopes and on crests, herbaceous vegetation merely disappear during the dry season.
To describe these types of structure, we have collected seven samples (square windows of 300 x 300 Landsat pixels) respectively called A,B,..I, along a NE-SW axis on which sequences of filtering and morphological transformations are performed.
The method is based on a modelization of photointerpretation, using both geographical knowledge and visual analysis. Thanks to general properties of morphological transformations (compatibility to translation and change of scale, local knowledge and semi-continuity), one can theoretically build sequences able to set up in the same class of connected components all the elements of the image belonging to the same visible structure (Serra,1982).
For all morphological transformations and measures, we use an isotropic hexagonal structuring element: no hypothesis about the directivity of the bars and the whole structure is to be introduced, thence one don't use here a perceptual graph method applied in some works to the extraction of actual river systems (Merghoub, 1984) building the connection of various components of the structure along a given direction with anisotropic structuring elements.

2. Extraction of main sand-hills structures

MSS Landsat original views consist into four spectral bands, from the green one to the infrared one. As in this study, the characteristics of objects to be recognized are geometrical ones, we don't expect spectral analysis to provide relevant descriptors of the structures. Therefore, a KARHUNEN LOEVE transformation where the first principal component enhance the global contrast, is run on the rough image (Colwell and al,1983). On this very image, two different algorithms are processed : The first one is directly applied to the basic images as the second one includes a high-pass filtering at the first step.

2.1 Analysis of the first principal component image.

Crest areas of the *bars are retained* as significant spatial indicators of the sand-hills structure: Generally, crest areas being partly denuded during dry seasons (cf § 1) and having therefore the highest albedo, can be identified by highest grey tones on the first principal component.
Hence we have processed an algorithm isolating the crests, by extracting the clearest and homogeneous patterns (cf sample A, Fig.1).
The image is smoothed by a sequence of *grey tone opening and closing* by an *hexagonal structural element* with increasing radius from 1 to 2 : we suppose that the structure's heterogeneity has to be ignored inside a radius of two pixels.
On the resulting image (Fig.2), one can distinguish the set of crests (higher grey tones) from the set of interdune depressions (lower grey tones): the structure has been cleaned by the application of the two alterned filters, and one can easily threshold the grey tone function in order to isolate the crests.(Fig.3)
The *skeleton* (median axis reduced to one pixel thickness) is chosen as a pertinent indicator of the structure for this estimation of its main global orientations (Fig.4): *Idempotence* of the skeleton allows its direct association to the original structure. Moreover, as far as we can extract the structure, the length and orientation of its components will be preserved by the *homotopy* and *connectivity of skeleton.*
Practically, the algorithm of *digital skeleton by homotopic thinning* is applied on all the samples. This skeleton is obtained by a L6 sequence of

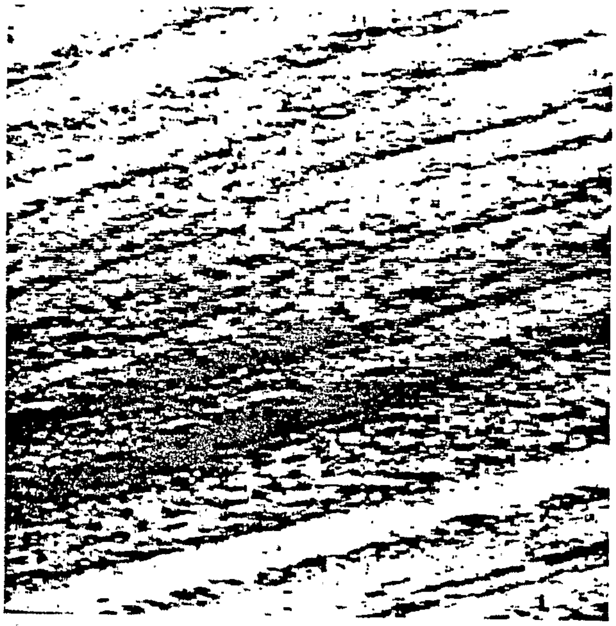

Fig.1: 1° component on A

Fig.2: Alterned filtering on A (rad 1 opening + rad 2 closing)

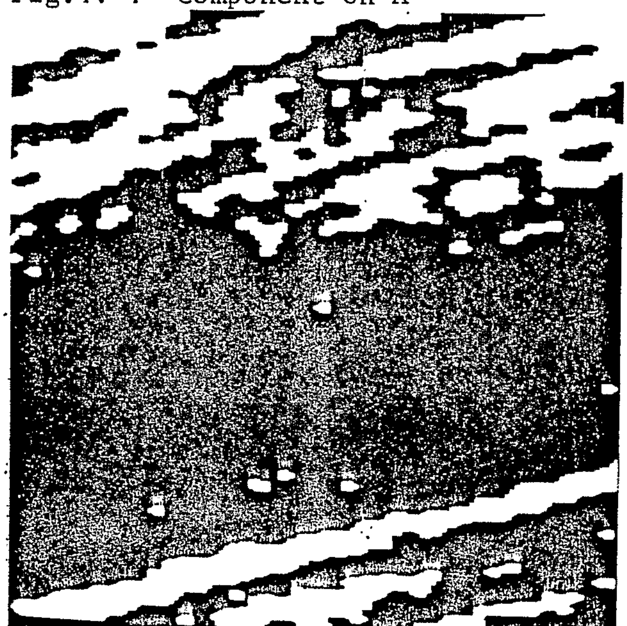

Fig.3: Thresholding on A

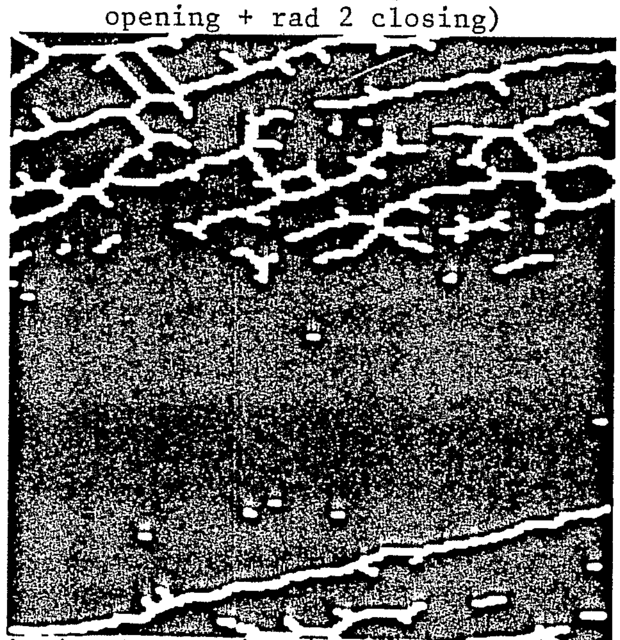

Fig.4: Skeletonization on A

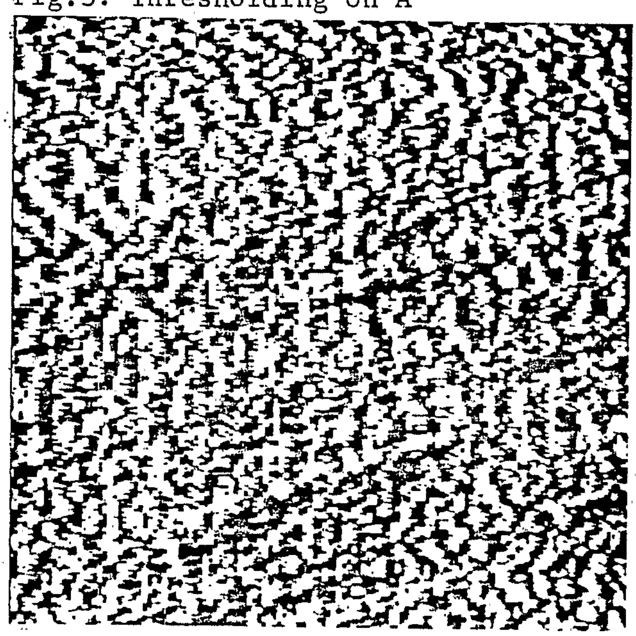

Fig.5: Gabarit filtering on A

Fig.6: Skeletonization on A

rotations of a *L* configuration inside an hexagonal neighbourhood (Lantuéjoul,1978)
This sequence is avalailable as long as the same set (here the crests) is defined by a distinctive interval of values of the grey tone function.
But some times it happens that locally, crests are covered with denser vegetation as for sample A (Fig.1) where the central *bar* and the Northern and Southern interdune depression are made visible by the same grey tone interval. In these cases, the rule is no more efficient and the previous thresholding eliminates these crests (Fig.3). One has therefore to find out another indicator of sand-hills structure on the image.
Nevertheless, on the other samples the skeletons obtained are pertinent characterizations of spatial organisation of the various main structures and make avalaible further measurments , particularly the anisotropy ones.

2.2 Analysis of a *Gabarit* filtering on the first principal component image

The computation of a gradient should provide a general solution: instead of extracting one subset (the crests) we extract the *limits* between two subsets (sand-hills and interdune depressions) which also can be considered as indicators of the spatial organization.
Among all the gradient algorithms (mask filterings, morphological gradient...), we retain the *Gabarit* one, which is a multi-directional gradient based on a convolution product technique : for each pixel one computes the higher gradient among eight directions as well as the code (Fig.10) of the corresponding direction (Robinson,1977).
The resulting eight-directions image (Fig.5) does not provide any hierarchical sorting of the gradients: with this method, all the gradients in the same direction are identified by the same grey tone.
A correspondance can be established between one class of indicator of the structure (crests, interdune depressions, rills) and the grey tones (6-7, 2-3, 8).Therefore the different sub-structures are treated separately .
After having processed a median filtering on the whole image in order to smooth locally the grey tone function, we use two algorithms for each sub-structure:
Extraction of crests employs the same algorithm than in the previous experiment (cf.§2.1): the smaller anisotropic shapes defined with highest values of the grey tone function corresponding to *rills* are eliminated by *a radius 1 opening.* After a *radius 2 closing*, only crests are made visible with highest grey tones. The resulting skeletons provide components less connected to each other than in the previous experiment (Fig.6).
Rills are identified by a short sequence of transformations: A *radius-1 closing* enhance the *rills* shape by smoothing the lower value of grey tone corresponding to the two other components, crests and interdune depressions and made thus possible an extraction of the rills by thresholding and skeletonization (Fig.9).
The algorithms based on the previous transformation sequences, using gradient images, will a priori overestimate the number of connected components of each subset of the structure in every direction .
When the structure has a *rectilinear* shape, as the one of sample A, the rule establishing the correspondance between the original structure and the local gradient is avalaible as far as we look after an estimation of relative anisotropy of the global organization.
When the structure is *concave*, like the one on sample I (Fig.7) this rule is no more efficient and one cannot select properly nor smooth with basic transformations the grey tones corresponding to the proper structure. In this last case, if one can apply the original algorithm (cf §2.1), the

Fig.7: 1° component on I

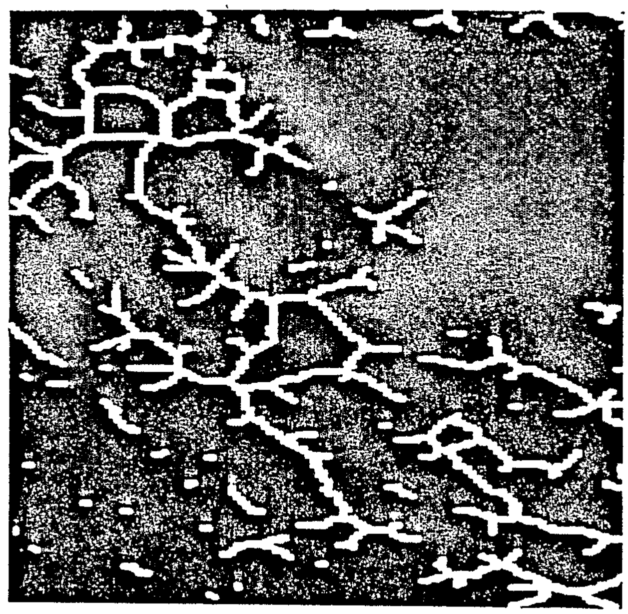

Fig.8: Skeletonization on I

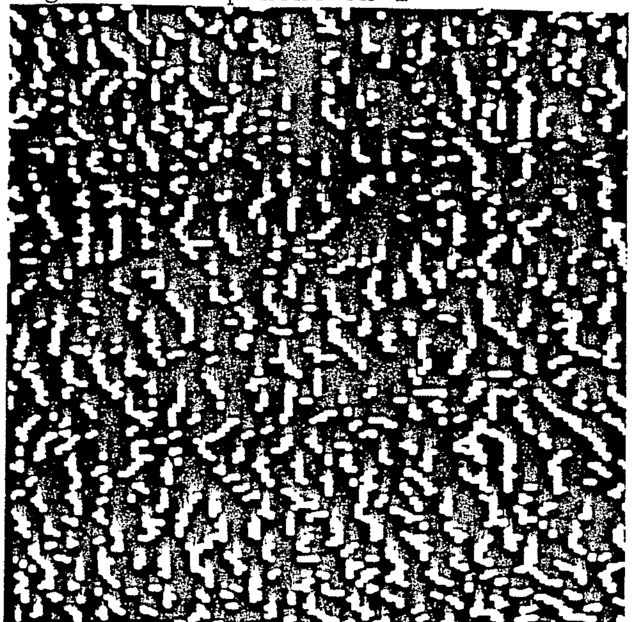

Fig.9: Skeletonization of rills on B

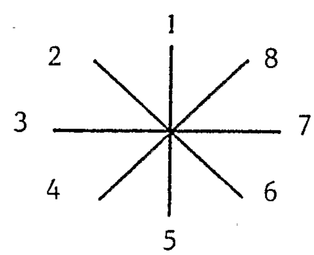

Fig.10: Gabarit coding for 8 directions

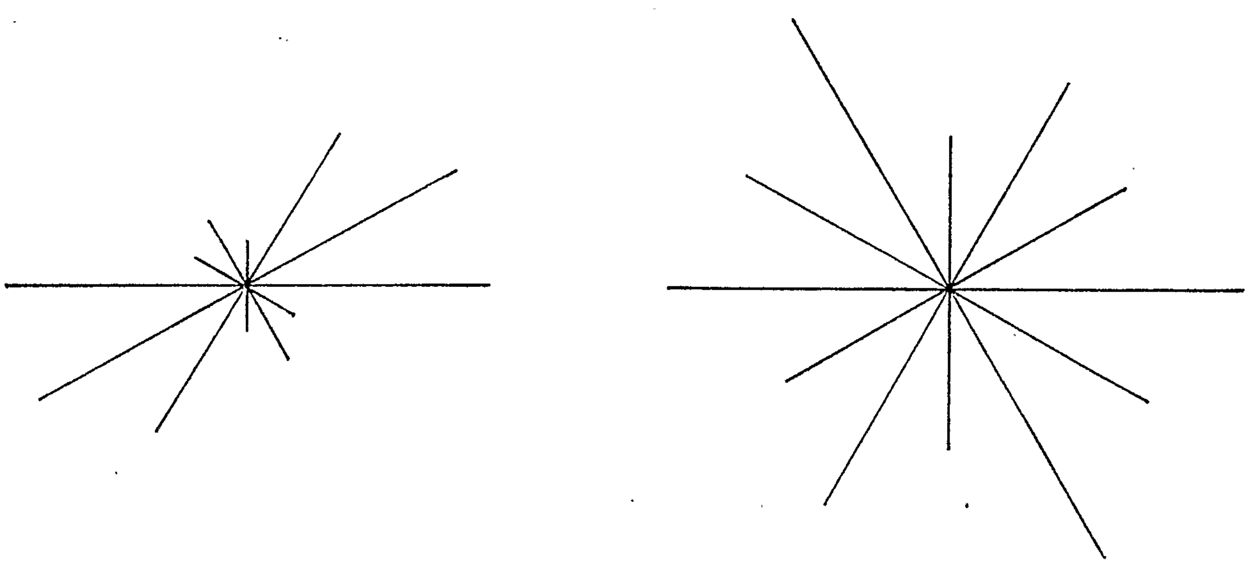

Fig.11: Roses of directions: A (gradient algorithm) - I (direct algorithm)

resulting skeleton (Fig.8) can be utilized for further measurments on anisotropy.

3. Roses of directions of sand hills structures.

In order to estimate the relative orientations of the main structures of each sample, we call for the *Rose of directions* method.
The algorithm is based on the recognition of twelve prototypes of configurations on an hexagonal neighbourghood of size one. Each prototype is associated to one specified direction (from 0° to 180°) and take into account four or five different configurations (cf C. Jacqueminet, "Analyse et mesures des caractères de dunes de forme linéaire sur image satellitaire").
The experimental Roses resulting from both series of skeletons provide generally a main orientation along the horizontal axis, except for the two samples A and I (Fig 11), processed by the first algorithm : as a matter of fact, these two samples have the more visible main orientations. The results concerning the other samples must partly be due to local artefacts created by the shooting conditions and called "horizontal stripping" , enhanced by the choice of an hexagonal structural element.
On samples A and I, the Roses show off clearly one angle of dominating orientation which is respectively ENE-WSW and NNW-SSE.
On the leaving samples (from B to F) , corresponding to the *akle structure*, one observes on the roses the progressive decreasing of the ENE-WSW orientation without any coming out of an obvious dominating new orientation. Only on sample I, the NNW-SSE orientation happens to become clearly the first one.
The *roses* corresponding to *rills* structures are merely invariant on all the samples : the two dominant directions are always the NNW-SSE and NNE-SSW ones.

Conclusion:

The experimental extractions of sand hills structures from MSS Landsat images and measurments of their orientations were made possible with morphological transformations sequences based on elementary analytic rules describing some of their structural and textural characteristics.
As sand hills are complex organizations, it is necessary to point out a typology of sand-hills on satellite images taking into account their spatial organization, their shape and their colour in order to provide avalaible models leading to a further generalization of the extraction and measurment methods.

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