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# A verification trial of the coast morphology of sand embankment by surf waves from LANDSAT-imagery

Résumé

Des zones litorales de mangrove existent presque dans toutes les régions maritimes des pays équatorials.
Ils forment la végétation des grandes deltas fluviales et des estuaires influencés par l'océan,causés par les sables et les sédimentations de vase.
L'estuaire de Wouri au Cameroun est une exemple typique.
On peut observer les dépositions de sable et de vase totalement dans les images de LANDSAT sur la bande 4,5 et couleur false.
Les observations hydrographiques donnent une correlation entre la propagation des vagues dans l'estuaire et les formes des dépositions.
Parcequ'il n'y a possible de réaliser une observation terrestre,ensemblée et detaillée dans le bay,qu'il est affecté par les tides,les recherches océanographiques ne sont qu'executées par des interprétations et des mesurements sur les images de petite échelle.
L'expérience avec des dates structurales et spatiales de l'image avec la géométrie de la dynamique de propagation des vagues présente quelques interrelations quantitatives valables en l'espace d'une certaine tolerance.
Néanmoins il existe des autres sources discrètes,causées par les tides,du vent,de l'influence saisonale,des turbulances,qu'elles trouvent leur limites de solution quantitative dans les grandes costes de l'observation et circumstances difficiles en mesurement terrestre.

## 1. Geomorphological description of the delta and estuary structure of Wouri river

The coastal regions of african equatorial latitudes between $0^{0}$ and $5^{0}$ north(Gulf of Guinea) are highly characterized by mangrove swamps lying in the deltas and estuaries of large sediment transporting rain forest streams (Sanaga,Wouri,Mungo,Akpayafe) affected by the tides and the so called "Kalema" coming from the "Roaring Forties" in the Southern Atlantic.
The streams and rivers are originating in the mountainous areas and therefore show a lot of rapids with high velocity and transport energy.
The mangrove deltas and estuaries have surfaces often more than 500-1000 qkm with the highest elevation of 1 to 3m above sea level.

The meandering creeks or tidal channels is the characteristic pattern and radar images show a typical bright texture.
The estuary consists of a lot of larger creeks which give the typical tree structure and divide the borders into irregular shapes from where the creeks are starting. The mean depth is about 20m in the main creeks and the bay, ranging up to 20km from the oceanic coast from where the depth is slowly increasing.
The bottom of the estuary is changing by duning processes. The sand and slime deposits lie in the zones of shallow water starting around a depth of 5-10m. The embankments show a typical semi-ellipsed form of some kilometers in diameter from which the influence of the tides,the soft surf waves,lesser the breakers and other factors can be concluded.
The complete estuary structure and the oceanic influence is quite different from those of the Guinea-Bissau-Bay, where the sand deposits are diffusely scattered (LANDSAT scene No. E-30357-10411-5).

## 2. The ground observations

As it is the rule for remotely sensed data interpretations that they have to be verified by ground truth,the same has to be done in the case of wave studies.
While the theory of waves is well known since long each coast form shows its special wave influence.
During hydrographic surveys by the students of Survey School,Buea/Cameroon during 1977 the phenomena could be observed which formed the base of the interpretations.
The evident phenomenon is the tide variation seen at the mangrove roots.Parts of the sand and slime embankments are therefore over and under water during the tidal variations.
The LANDSAT-scene shows the situation during the ebb.
When the flood is starting abruptly within a short time the typical surf wave curves are propagating against the shores and change the sediment level.The water level is raising in the creeks and the sand and slime is transported to the shore and the mouths of the creeks.
During the ebb the backstream transports the sediments into the sea,just at those positions of the rims where the flood before was discharging the material.
A typical cross section is developing changing permanently by deposition and denudation.Similar observation were made in (3,15).
This leads to the conclusion that the borders of the sediment surfaces are similar to the curves caused by the refraction of waves against the shore.

## 3. Short outlines of the surf wave theory

The application of the surf waves follows the theory,devel oped by the Russian oceanograph W.W.Schulejekin,who proved it by observations on the sea and in a storm basin

and published it in 1956(2).
The theory is starting with the refraction index $n=c_\infty / c$, where $c_\infty$ is the phase velocity of waves in a sea of unlimeted depth.
Regarding the period of waves T and the wave length $\lambda$ in shallow water one comes from the formula $\lambda_\infty = c_\infty \cdot T$ and the well known relation for the phase velocity in shallow water of a trochoidal wave:

$$c^2 = \frac{g\lambda}{2\pi} \text{ th } 2\pi \frac{H}{\lambda}$$

to the relative depth which is expressed by: $\delta_1 = H/T^2$.
With this formulas a diagram of the interrelation between n and $\delta_1$ can be derived and is represented by the hyperbolic approximation formula $n=1+m/\delta_1$ with the parameter $m=0.05$.
Applying the refraction law of Astronomy the form for a wave ray is: $n \cdot \sin\varphi = n_o \cdot \sin\varphi_o = n_o \cdot \sin\beta_o = \sigma$ ,in which $\varphi$ is the general refraction angle against the normal axis of the shore.
Following the theory of light rays one comes to an expression of:

$$\frac{dy}{dx} = \sqrt{\left(\frac{n}{\sigma}\right)^2 - 1}$$

Regarding that the depth is increasing by a linear function on the formulas given(in the tables at the end) are valid.
Although the integral is simple it can only be solved by graphical integration.
For the practical evaluation the formula of the current refraction angle $\beta_o$ is important which is:

$$\sin\beta_o = \frac{H_o \sin\beta_1}{H_o + mT^2}$$

where $\sin\beta_1$ is the direction angle against the normal axis to the shore in the starting zone of wave propagation.
The same form of refraction theory can be applied in the inverse case caused by land wind.
$\lambda = 5.12\ T^2$ is an empiric formula related from ground observations(15) from which the wave length can be derived.

## 4. Measurement of LANDSAT-imagery,data transformations and application of surf wave theory

The data collection was carried out by point wise coordinate measurements of the deposit shapes on a false colour frame.An older model of coordinate measuring machine of the Astronomical Institute of Bonn University was used which produced a semi-automatic output with a sensitivity of $1\,\mu m$.
The definitions of the points had to be done during the measuring process and was difficult because of the low resulution of the borders of the deposits by the pixels and a nonvariable magnification of the eyepiece.
To minimize the errors and eliminate movements of the

frame, sharp defined points were measured at the beginning and at the end of the measurement which served as control points of the topographical map 1:50 000 of IGN/Cameroon. The final error of the measurement was $\pm$ 16 µm in x and $\pm$ 24 µm in y-direction. For the analysis the coordinates were transformed by a similarity transformation (Helmert) and then translated and rotated into local systems with x-axis parallel to the shore and positive y-axis against the sea.
The formulas described were applied by a stepwise approximation and adjustment procedure proving relations of wave periods ranging from 1-10sec. and $10^{\circ}$ to $80^{\circ}$ of the direction angle with an interval of $10^{\circ}$.
The average slope gradient was around 0.014 according to the ground observations.

## 5. Results and interpretations

A simulation program runned on the IBM 370/168 of RHRZ Bonn University Computer Center gave out a statistic of the mean error in meters between the theoretical model and the geometry of deposit shapes influenced by various direction angles $\beta_1$ of the surf waves against the shore normal axis.
The second test was made in respect to the decreasing refraction angle $\beta_0$ during the wave propagation compared with the respective angle computed from the deposit curve coordinates for the different wave periods within the tolerances $\Delta\beta < 10^{\circ}, 5^{\circ}, 2^{\circ}, 1^{\circ}$. The output was the applicable direction angle $\beta_1$, the refraction angle $\beta_0$ for various periods, the actual angle $\beta_i$ from the coordinates and the period itself.
Correlations with the numbers of digitized points and the numbers of direction angles $\beta_1$ were eliminated by stepwise reductions of the numbers of border points and calculating the differences of the simulations of $\Delta\beta < 5^{\circ}, 2^{\circ}, 1^{\circ}$ against the one of $\Delta\beta < 10^{\circ}$ instead of absulute values.
The reactions of the output datas were the same as in the simulations with the complete data sets. Therefore the following results given are statistically valid for all manipulations carried out:

- The wave directions of $20\text{-}30^{\circ}$ against the normal axis are the most frequent ones (the portion is 40%). The rest of the 60% distributes on the other directions ranging from $10\text{-}80^{\circ}$ (Fig.1).
- With the increasing directions from $40^{\circ}$ upward the deviations of the deposit borders from the theoretical model are becoming smaller. This leads to the conclusion that the waves of these directions are "grinding off" permanently and form certain parts of the rims.
- The stronger the curvature of the deposits are, the smaller the direction angles are, i.e. $20\text{-}30^{\circ}$. It supports the fact that the flood has a greater influence than

the ebbstream in the Wouri-estuary.

- The mean deviation of all deposit curves of the theoretical model was 360 $\pm$ 170m which is around 10% of the average length and 20% of the average width of the deposit surfaces.
- Accumulations of errors are found between 100 and 300 and 400 to 500m with the relation that a ratio of shore length to width of 2:1 corresponds with the lower error and the reciprocal ratio is related to the higher error. The conclusion is that the waves nearer to the shore have greater influence on the deposits of the first type, because the rays are stronger curved in the shallow water(Fig.2).

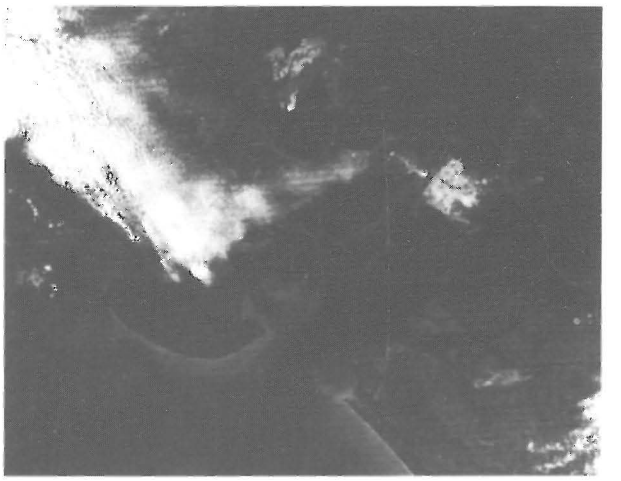
A comparison of the theoretically computed angles $\beta_o$ with those $\beta_i$ simulated by the deposit coordinates gave certain aspects of the dynamics of wave propagation within the range of position errors:

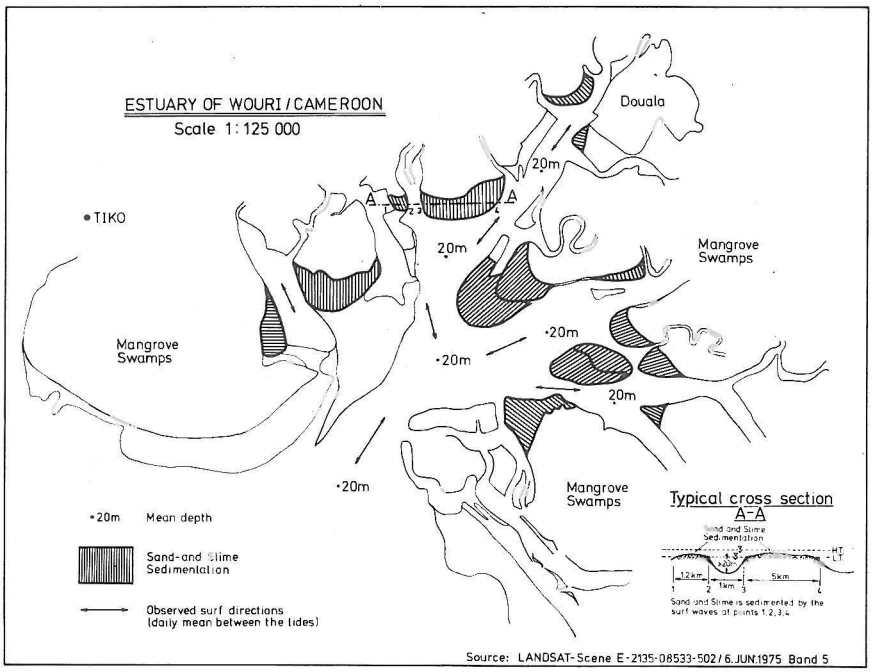
- For the angles $20^o$ and $30^o$ the change of periods from 1 to 7sec. is slow; the periods 8 to 10sec. are changing faster against the shore. The higher the parallelity of wave propagation to the shoreline is, the faster the shorter periods are disappearing in the sea(the obvious base phenomenon mentioned above).
- This fact will also be supported by the graph of the numbers of one and the same period on the deposit curves for all tolerances of $\Delta\beta$ simulated. The number is decreasing rapidly from 5 to 10sec. This process is stopping as soon as the angle tolerances are decreasing. At the tolerance of $\Delta\beta < 1^o$ all periods are equally distributed on the deposit curves(Fig.4).
- An analysis of the trend numbers of the periods being mostly negative are showing a declining tendency of 84% to longer periods, so that these wave types are finally coming to the shore(Fig.5-8).
- Equally curved deposit shapes present the largest numbers of each period type for all direction angles and tolerances.
- This is also valid as soon as the curvature is changing uniformely to increasing or decreasing gradients.
- Further tests for the case $\Delta\beta < 1^o$ stated the existence of an only weak correlation of r=0.21 between the true differences $\Delta\beta$ and the periods.

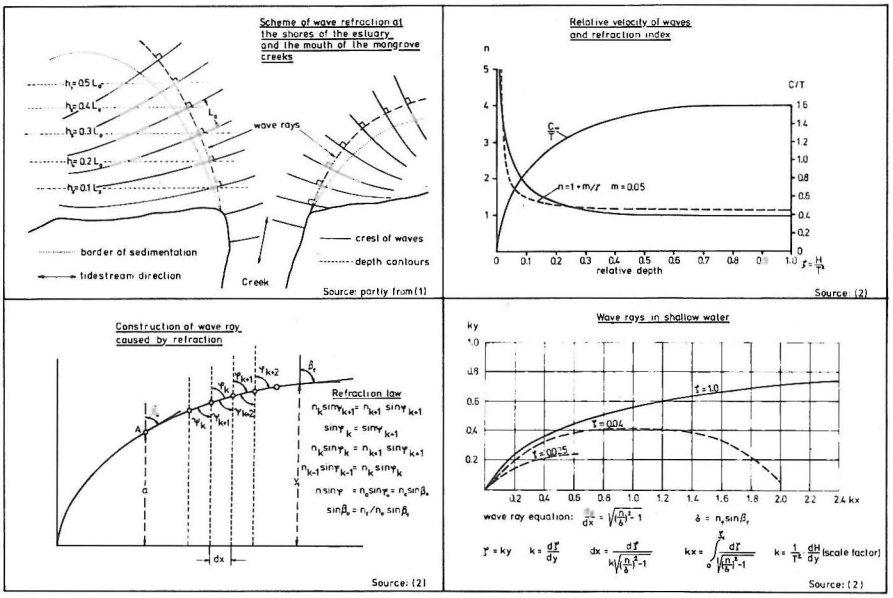
## 6. Final conclusion

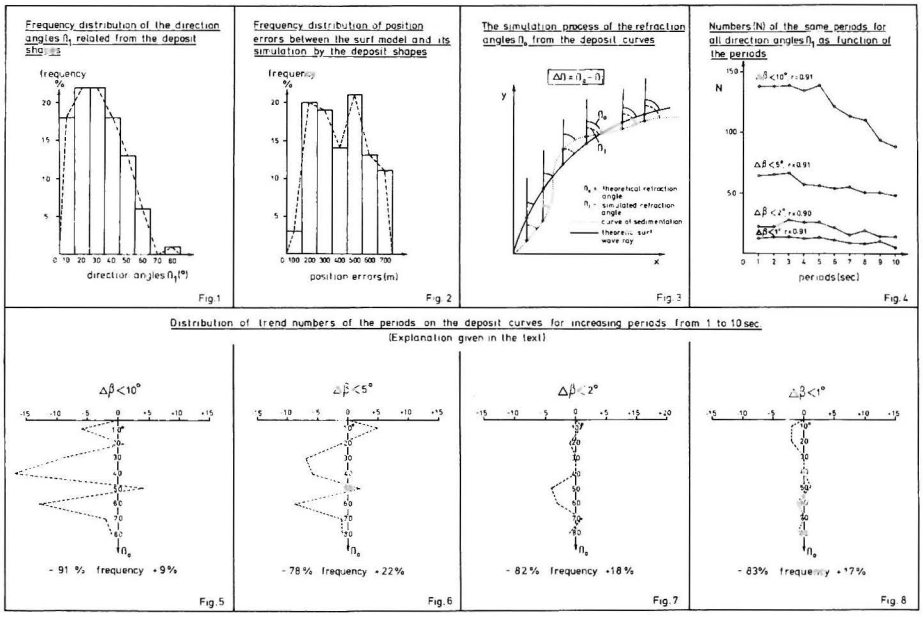
The quantitative and empiric treatment of the surf wave dynamics by simulation with the deposit shapes give indeed an "amazing" significance. It would be to far interpreted that the sedimentation process is caused mainly by soft surf waves. Other factors as wind, ebbstream, turbulences, the

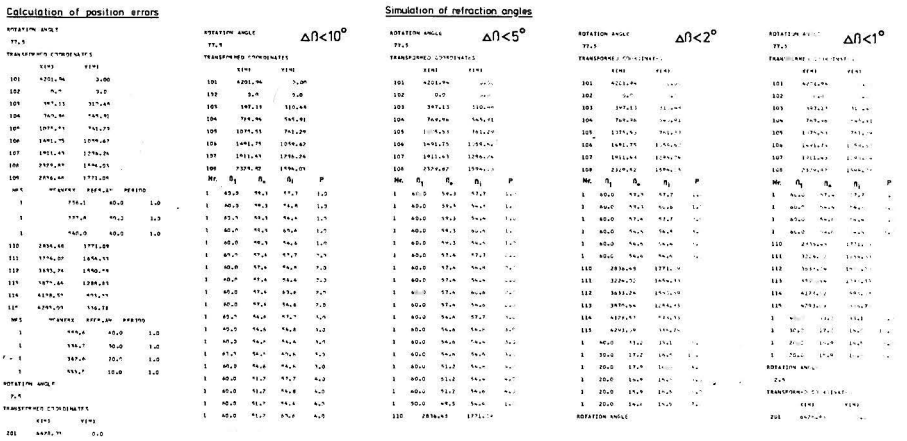
well known phenomenon of the breakers and the fluvial processes play an additional important role which must be taken in consideration for complete quantitative statements.
The trial with this simulation shows that satellite imagery indeed offers observations and interpretations of quantitative complex dynamic coast and oceanic submarine processes within a certain validity which in an other way is only obtainable by difficulties and high,less justified costs.






Scheme of wave refraction at the shores of the estuary and the mouth of the mangrove creeks
wave rays
border of sedimentation
tidestream direction
crest of waves
depth contours
Creek
Source: partly from (1)
Relative velocity of waves and refraction index
relative depth
Source: (2)
Construction of wave ray caused by refraction
Refraction law
Source: (2)
Wave rays in shallow water
wave ray equation:
Source: (2)


Frequency distribution of the direction angles Π1 related from the deposit shapes
frequency
direction angles Π1(°)
Fig.1
Frequency distribution of position errors between the surf model and its simulation by the deposit shapes
position errors (m)
Fig.2
The simulation process of the refraction angles Π1 from the deposit curves
Fig.3
Numbers (N) of the same periods for all direction angles Π1 as function of the periods
periods (sec)
Fig.4
Distribution of trend numbers of the periods on the deposit curves for increasing periods from 1 to 10 sec
(Explanation given in the text)
- 91 % frequency + 9 %
Fig.5
- 78 % frequency + 22 %
Fig.6
- 82 % frequency + 18 %
Fig.7
- 83 % frequency + 17 %
Fig.8

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