

THE INTERACTION OF WIND AND WATER  
IN THE DESERTIFICATION ENVIRONMENT

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ABSTRACT

An appropriate process/response model for the physical basis of desertification is provided by the interactions of wind and water in the desert fringe environment. Essentially, the process of desertification can be thought of as a progressive environmental transition from predominantly fluvial to aeolian processes. This is a simple but useful way of looking at desertification; in this context, desertification is morphogenetic in character. To illustrate the model, a study of drought-related changes in central Mali will serve to trace the interrelated responses of geomorphologic processes to drought conditions.

INTRODUCTION

Desertification has been described as "the spread of desert-like conditions in arid or semiarid areas up to 600 mm, due to man's influence or to climatic change" (Rapp, 1974); it has similarly been defined by Glantz (1977) as "the development of desert-like conditions where none had existed before." The physical processes that lead to "desert-like" conditions have been more elusive, largely because there are multiple potential causes and multiple physical processes involved. Some causes and processes are climatic; some are biospheric; some are geologic/geomorphologic; some are socioeconomic. In addition, the consequences of desertification include both short-term, human-timescale effects as well as longer-term, geologic timescale effects. The urgency of shorter term effects has been such that these have become the best studied aspects of desertification (e.g. UNCOD, 1977).

A number of authors and symposia have treated various components of the desertification system; for the sake of brevity, the reader is referred to these works (e.g. Glantz, 1977; UNCOD, 1977; Reining, 1978). This paper will attempt to address some of the geomorphologic aspects of the problem: specifically, the dynamic interaction of wind and water processes within the context of desertification.

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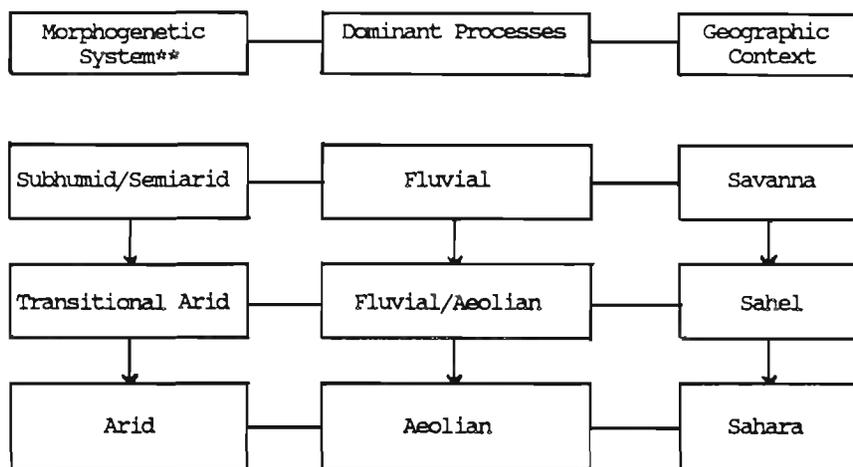
\*Presented at the Twentieth International Symposium on Remote Sensing of Environment, Nairobi, Kenya, 4-10 December 1986.

#### WIND/WATER PROCESS TRANSITION MODEL

Topsoil loss has been cited as a significant problem for the Sahel; soil erosion, loss of soil productivity and loss of vegetation are hallmarks of desertified regions (Warren and Maizels, 1978). An understanding of the dynamics of soil erosion in desertifying areas thus is fundamental to understanding desertification. Within this context, the interactions of aeolian and fluvial dynamics in the Sahel provide a useful, simple process/response model.

Aeolian processes dominate in the true desert environment (e.g. Bagnold, 1941; McKee, 1978; Mainguet, 1983; Greeley and Iverson, 1985). In contrast, the predominant erosion mechanism for temperate climates is fluvial (e.g. Wilson, 1973). Desertification can then be redefined as the geomorphologic transition from predominance of fluvial to aeolian processes through time. This is presented schematically in Figure 1.

Within this context, the Sahel is presented as a transitional environment, or morphogenetic region. This is in fact consistent with relict landforms and other evidence indicating multiple episodes of widespread Sahelian desiccation and recovery through the course of the Quaternary (e.g. Grove and Warren, 1968; Talbot, 1980).



(\*\*Morphogenetic systems adapted after Wilson, 1968)

Figure 1: Desertification can be modeled as a progressive transition from predominantly fluvial processes to predominantly aeolian activity. This shift in geomorphologic processes is tied to precipitation and vegetation cover, and serves as a simple way to relate desertification processes to climatological variables and landform evolution.

## THE INLAND NIGER DELTA OF MALI: APPLICATION OF THE MODEL

The Inland Niger Delta (IND) is characterized by a complex of anastomosing distributary channels formed on the widened floodplain of the Niger River in central Mali. Although the water resources of the Niger River's annual floods have helped to ameliorate the effects of the Sahelian drought which started in 1968, analysis of multitemporal Landsat image data for a portion of the area indicates the presence of drought-related damage.

In order to assess the response of geomorphologic systems in the Inland Delta through the drought years, a multiyear study of the upper reaches of the delta was performed. The study consisted of analysis of Landsat digital image data, together with field mapping. Preliminary geologic mapping was done on Landsat base images derived from a Landsat 2 MSS scene acquired February 7, 1976 (MSS I.D. 8238109564500). Five weeks of field mapping followed, during which landforms and processes were documented and correlated with image data. Additional Landsat data were acquired contemporaneously with the field study (MSS I.D. 85035010082X0, taken February 14, 1985, nine years after the earlier image). Following the field work, these data were coregistered with the 1976 scene and were normalized to remove additive atmospheric contributions to scene brightness. The data then were compared to assess the locations and magnitudes of changes that had occurred between the two scene dates. The data reduction and analysis procedures are described elsewhere in this volume (Jacobberger, 1987).

Predominantly, changes observed in the satellite data are in the form of panchromatic brightness increases that are spatially correlated with landforms (Figure 2). The greatest increases in brightness are associated with bodies of water that were present in 1976 and dry in 1985, including ponds, lakes and distributary stream channels. Field mapping of these desiccated landforms revealed recent sapping features, rill and gully formation, soil disaggregation and vegetation destruction. Natural levees along the rivers and distributaries show the next greatest brightening; in the field, these landforms had less than 10% vegetation and were composed of laminated silts with trampled and fragmented surface crusts. In addition, localized brightening occurs in areas occupied by stabilized dunes; field investigation commonly showed remobilization of the crests of these old aeolian features.

The satellite data also show changes in the morphology and surface hydrology of the Niger and its distributaries. Major distributaries were dry in 1985 data; in the field, these channels were clogged with sediment. Spectral signatures of water in the Niger and a major tributary, the Bani, also increased 1976-1985; the effect is most pronounced in the Bani. This is consistent with the shallow water depth and high levels of turbidity observed in the field. Point bars and beaches dominate the Niger's channel margins in 1985 data, but are not pronounced in 1976 data; these deposits may simply be more visible because of low stream flow in 1985, or may represent recent deposition of sediment by a river whose competence has been reduced. Areas of brightened floodplain are commonly found downwind from fluvial channels; in the field, these bright regions are sites of aeolian activity (Figure 3).

Bright halos characteristically surround villages in 1976 satellite data. In 1985, these bright areas had spread. In the field, these halos are seen to be composed of bare (vegetation-free), trampled, disaggregated floodplain silts with incipient radiating drainage patterns. Villages in the Inland Delta typically are situated on tells above the level of the floodplain, and rill and gully formation are most pronounced at the tell margins. Development of this erosional style is probably associated with the increased gradient, land use and lack of vegetation around the villages (Figure 4).

These data suggest a close relationship between the fluvial and aeolian dynamics of the upper Inland Niger Delta. Between 1976 and 1985, fluvial erosion of slopes has been vigorous, while deposition in low-energy floodplain channels has proceeded. The association between these deposits and downwind aeolian landforms suggests that fluvial sediments deposited during periods of lowered river competence are available for subsequent aeolian transport, and thus provide the source material for locally-derived aeolian landforms.

Prior to the onset of drought in 1968, the Inland Niger Delta was a predominantly fluvial environment. As a result of reduced flow in the system over the years of drought, there has been an apparent rejuvenation of aeolian activity, consisting primarily of redistribution of silts and sands deposited because of the decreased competence of the local fluvial environment, but also including remobilization of formerly stabilized dune crests. Reduced vegetation is clearly a factor in both the increased fluvial erosion and subsequent aeolian transport of soils and sediments formerly stabilized by plant cover, and in the remobilization of formerly stabilized aeolian landforms. The transition from predominantly fluvial to aeolian processes is intimately associated with brightness increases observed for this portion of the Sahel over the interval of study; between 1976 and 1985, there has been sufficient water to initiate and sustain fluvial erosion, and enough wind energy to erode and transport soils and sediment. Significant and characteristic landform/process associations have resulted from the interaction of these two dynamic systems.

#### CONCLUSIONS

The interaction of wind and water in erosional, transport and depositional processes is significant in Sahelian desertification, and one of the serious long-term consequences of this interaction is the efficient removal of topsoil and surface sediments. Morphologic evidence for past fluvial activity is common in areas which are now true desert (Hagedorn, 1980; McCauley et al., 1986). It is useful and important to think of these ancient fluvial systems not only as sources of water but as agents of erosion, or as former Sahelian-style environments.

Although the simple, functional approach of the wind/water process transition model is particularly apt for the Sahel, the model is transportable and could provide insights for other desertification studies. To understand the root causes of desertification, it is essential that we come to a better understanding of the physics of the associated environmental processes. This is one means of bridging the gap between regional desertification issues and desertification in the global context.

#### ACKNOWLEDGEMENTS

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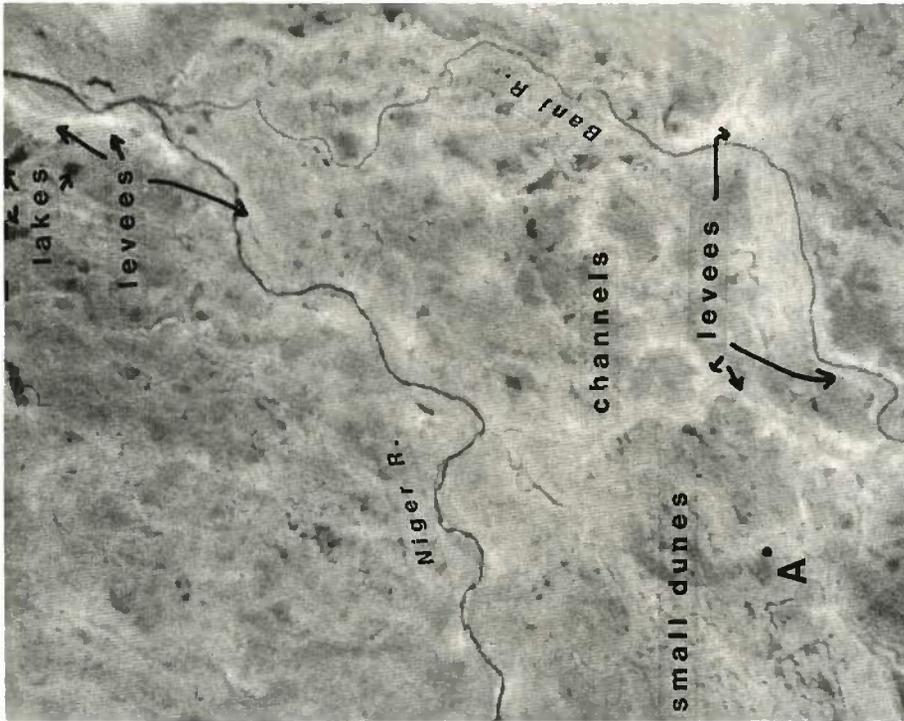


Figure 2: Comparison of brightness changes observed in Landsat MSS data for the upper Inland Niger Delta, 1976-1985 (shown at left), with the geomorphology of the region (shown on Landsat image at right) reveals a strong correlation between specific landforms and severity of change. Through spectral analysis and field documentation, these changes were related to amount and character of erosion, soil moisture and vegetation density.



Original Figure in Color.

Figure 3: Aeolian activity downwind from sites of fluvial deposition demonstrates the relationship between river competence and the availability of materials for aeolian transport. This image was taken in February, 1985, at the point marked "A" on Figure 2, downwind (west) of the desiccated Mayo Manga distributary channel. The dominant transport mechanism is aeolian.

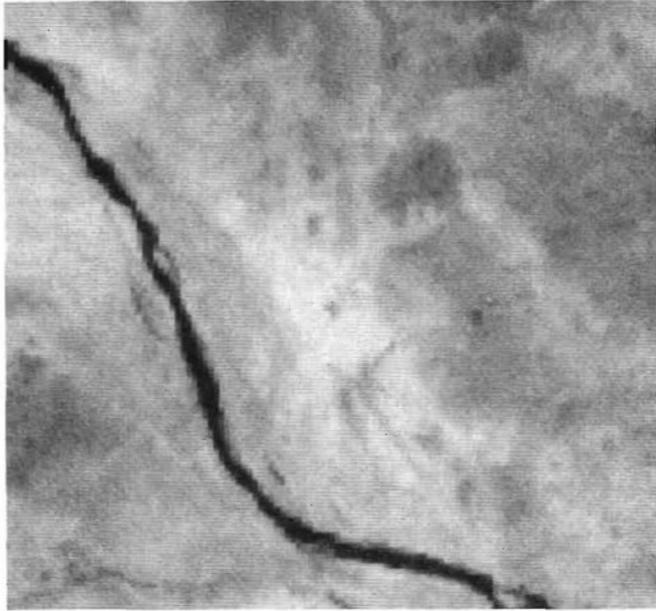
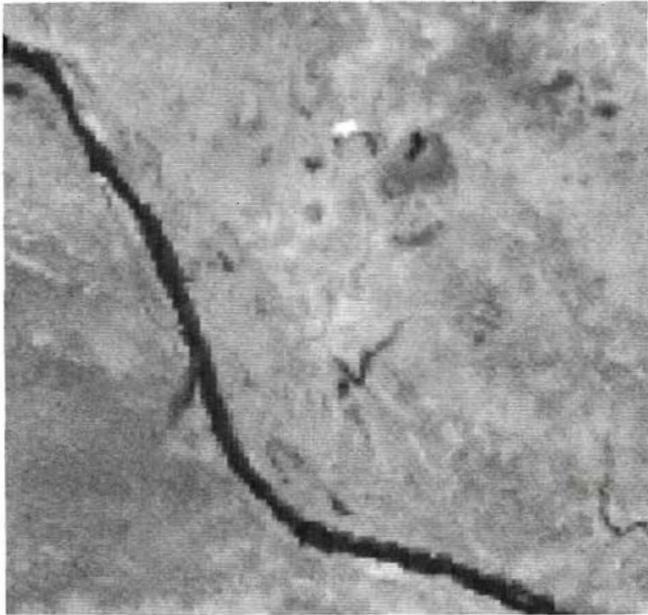
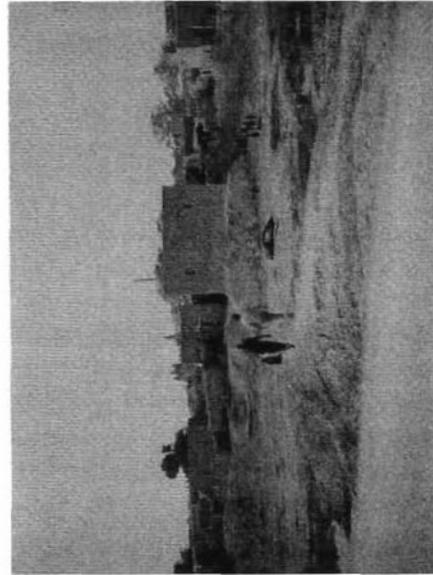


Figure 4: Expansion of bright halos around villages is observed in satellite data 1976-1985. Field evidence points to a combination of soil damage by wind, water and mechanical means, as well as losses of soil moisture and vegetation. Note the development of rill and gully erosion at the village margin.



Original Figure in Color.