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OBSERVATIONS OF THE INLAND DELTA OF THE NIGER RIVER BY NIMBUS 3 HIGH-RESOLUTION INFRARED RADIOMETER (HRIR)

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ILLUSTRATIONS

OBSERVATIONS OF THE INLAND DELTA
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HIGH-RESOLUTION INFRARED RADIOMETER (HRIR)

Designed primarily as a weather satellite, Nimbus 3 carries among its experiments the high-resolution infrared radiometer, which produces remarkable imagery of the earth's surface. HRIR is a scanning radiometer that receives reflected solar radiation at a wavelength about 1 micrometer during daylight and emitted radiation about 4 micrometers at night. HRIR imaging of earth-surface features in daytime portions of the Nimbus orbit depends upon differences in reflectance at 1μ m of water (about 5 percent), sand (about 60 percent), vegetation (also about 60 percent), clouds (about 90 percent), and other surfaces. Features with high reflectance appear bright in HRIR photofacsimile images; those with low reflectance are dark.

The series of HRIR images presented here, showing the inland delta of the Niger River in the Republic of Mali, West Africa, demonstrates the use of such data in natural-resource studies. The information gleaned from the imagery on seasonal plant and surface-water changes in the inland delta is based on two features of HRIR that are unique in space photography: the distinct contrasts between surface water and most other surface features, and the repetitive (daily) large-scale coverage of the area, which generates a time-lapse series of images of changing phenomena.

The "inland delta" of the Niger River (Figure 1) is not a true delta like those of the Nile or the Mississippi, formed at a river mouth. This delta is the result of a redirection of the stream flow of the Upper Niger from a northward course toward the Senegal River to the present northeasterly course. The deltaic form is fortuitous, being controlled by outcroppings of thick ferruginous crusts widespread in that region. A true delta does exist, however, as a relic of the Quarternary Age north of Segou, at the southwest corner of the inland delta: This "fossil" delta is a remnant of the course of the Upper Niger to an inland sea thought to have existed in the present Hodh area, and to have been drained by the Senegal River.

Man has occupied this region for millennia, although neither agriculture nor industry is well developed. Shifting agriculture and nomadic grazing have influenced the vegetation profoundly; indeed, man may have been the principal cause of the shift in the course of the Upper Niger, by increasing the sedimentation (and therefore levee-building) along the Niger channels, through grazing, burning, and other practices carried on over a long period.

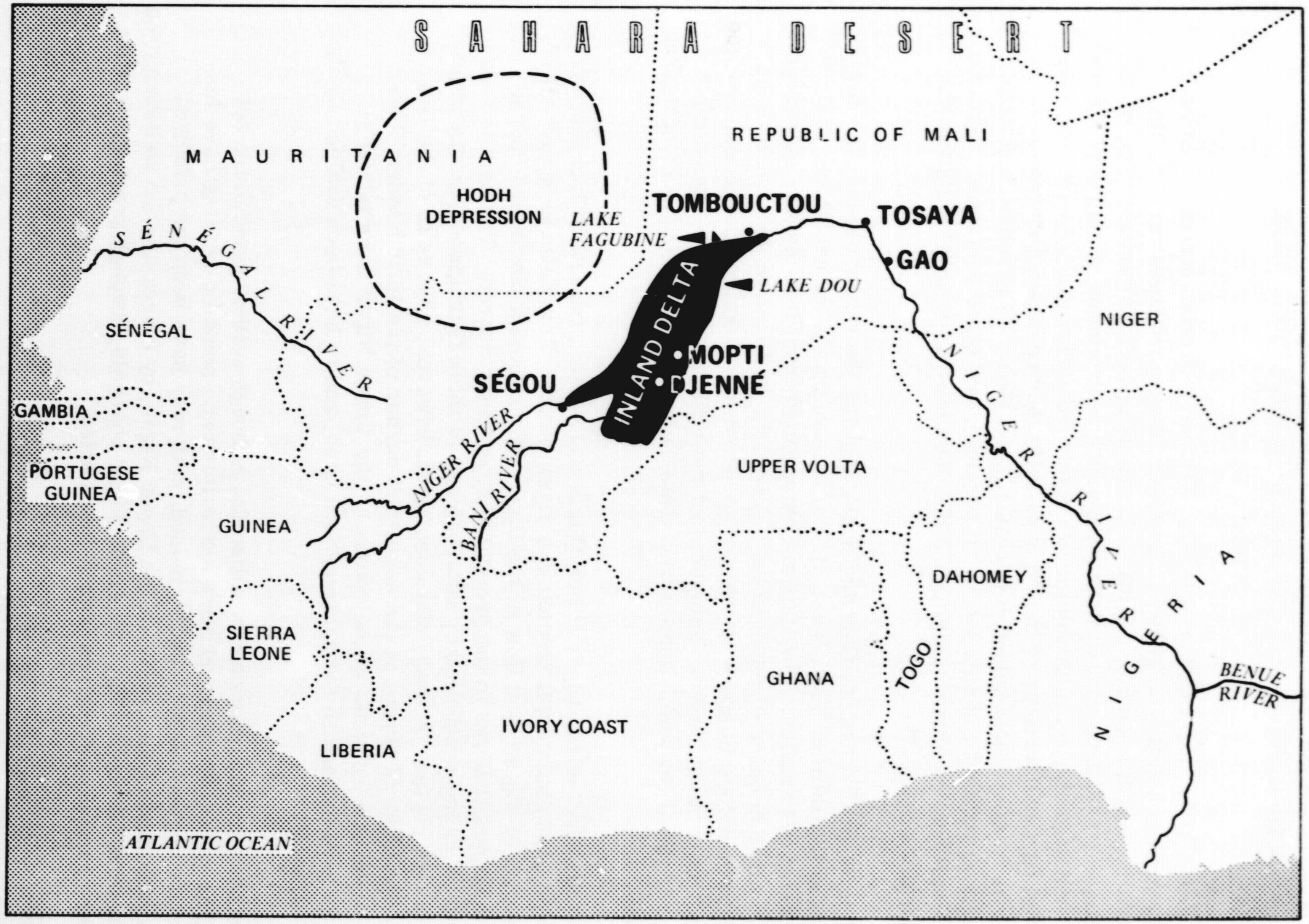

Figure 1. Map of West Africa, Showing Course of Niger River

Located just south of the Sahara Desert and north of the highlands on the south coast of West Africa, the inland delta is arid except during the summer monsoon. Although the coastal highland receives some rainfall during most of the year, the principal period of precipitation is from May to September. Precipitation in the region was especially heavy and prolonged in 1969; however, Tombouctou, at the northern apex of the delta, received only 5 inches of rain during the monsoon period. For the remainder of the year, the climate of Tombouctou and the delta generally is dominated by dry hot dusty winds from the Sahara.

Three great bands of vegetation in the southern portion of West Africa appear in more detail in HRIR imagery than in regional-vegetation maps: going from the south coast to the Sahara, the regions are (1) broadleaf-evergreen rainforest, (2) tall-grass savannah, (3) desert steppe. The hydric vegetation in the delta proper is sharply bounded by adjacent savannah and steppe: two types of plant community exist within the delta, one of grasses permanently located in areas above the flood level, the other of floating islands of grasses which move with the annual flood.

Figures 2 through 8 are HRIR images taken from May through November, 1969, showing both the flooding of the inland delta and the growth of the savannah during the monsoon period. The illustrations strongly indicate a movement of water, either surficial or subsurface, in the ancient channels to the Senegal River.

In May (Figure 2), the delta is hardly visible; only the small differences in reflectance of the plant communities in and adjacent to the delta offer sufficient contrast to determine the boundaries. Lake Fagubine and Lake Dou always have some water in them and are, therefore, visible in each image. The shape of Lake Fagubine—a thin arrowhead pointing west—results from outcrops of ferruginous crust like those that govern the shape of the entire delta. Photographs made by Apollo 9 show the shape of the lake distinctly, as well as its salt-encrusted shoreline. Fagubine is a singular lake, in that its inflow occurs only during the flood stage and outflow occurs only at the ebb of the flood. The HRIR image also shows that the clouds associated with the monsoon do not penetrate much beyond the highlands of Guinea, Upper Volta, and the Ivory Coast. The northern slopes of these highlands constitute the major portion of the watershed of the inland delta.

In June and July (Figures 3 and 4), monsoon storms have spread into the Upper Niger basin. These images show increased contrast between the Upper Niger and its surroundings; the ancient river course north of Segou also becomes visible. It is reasonable to assume that the increasing contrast results from an increase in the area of surface water; the only other surface that shows as dark in the HRIR images is basalt, such as the outcropping of the Ahaggar Mountains in the north central Sahara, which do not change in form from month to month; whereas

Figure 2. HRIR Image of Niger Basin, May 12, 1969, Data Orbit 378

Figure 3. HRIR Image of Niger Basin, June 11, 1969, Data Orbit 780

Figure 4. HRIR Image of Niger Basin, July 13, 1969, Data Orbit 1209

Figure 5. HRIR Image of Niger Basin, August 24, 1969, Data Orbit 1772

Figure 6. HRIR Image of Niger Basin, September 15, 1969, Data Orbit 2067

Figure 7. HRIR Image of Niger Basin, October 17, 1969, Data Orbit 2496

Figure 8. HRIR Image of Niger Basin, November 23, 1969, Data Orbit 2992

the regions being inundated by floodwaters do change both in shape and in tone, and can thereby be identified.

By August (Figure 5), the monsoon storms extended well into the Niger basin, so far in fact that the image of August 24 shown here was the only one during mid- and late August sufficiently clear of clouds to show the delta region. The old course of the river north of Segou is also easily visible here. Again, the change of tone from light to very dark indicates the flow or spread of water into that area; the image also shows that the delta itself is beginning to fill with water. Furthermore, the region of savannah begins to show greater contrast than before to the desert area at the north. (These statements are based on analysis of every HRIR image for the entire May-to-November period; the inherent variations in photographic processing could lead to wrong conclusions in an analysis that relied on the relative contrast in a single image.) The grasses that grow in the savannah are known to be dormant in periods free of rain and to grow vigorously during the monsoon; the changes that appear in plant reflectance from May to August (and later) are thought to result from the increased depth of the grass canopy, and the consequent increase in entrapment of incident solar radiation. This should mean less energy reflected from the plant canopy and, therefore, a darker tone in the HRIR image.

By September (Figure 6), the southern portion of the delta appears very dark because it is covered by the flood. The northern section, not fully covered with water, is not quite as dark in tone. Maps and Apollo 9 photographs of the delta show that the northern section is filled with linear sand dunes that, although no longer active, remain higher in elevation than their surroundings in the delta.

The October image (Figure 7) shows the Upper Niger no longer filled with water, and the intrusion of water along the old channel to the Senegal is no longer apparent; the delta, however, is now full of water and the outflow toward Tosaya is becoming dark. These are indications that the flood has reached, or is about to reach, its crest.

In November (Figure 8), the outflow from the delta is conspicuous. Plant growth has produced a marked contrast between savannah, steppe, and desert; however, the monsoon clouds no longer appear over the highlands or indeed over Mali, although a few clouds are present along the coast. The rains in the delta region have ceased.

Much of the information derived from the HRIR images is available from other sources: for instance, several stations in the delta region record rainfall, stream flow, degree of cloudiness, etc. However, the satellite-borne HRIR observes the phenomena in one scene and locates them in time and space in relation to one another as they occur in nature. These observations immediately provoke inquiry into the possibility of using them in the interpretation of aerial or ground surveys and in the management of the observed resources. The HRIR images might furnish answers to questions such as:

> Is the annual flood in the inland delta usable—and is it being used—for irrigation in this arid region?
>
> Does the former northern course of the Upper Niger valley exist to a degree that would make it useful to man?
>
> Do the patterns of plant growth and the amount of rainfall suggest that this region was once a forest? Could agricultural practices be changed to take advantage of these factors?
>
> Are current cultural practices well related to, or coordinated with, the observed vegetative, climatic, or hydrologic patterns?

This list is only a beginning; all the questions concern the discovery and management of natural resources. The use of HRIR imagery like that obtained by Nimbus brings under observation at a single moment an area large enough to permit the study of natural resources on a regional scale. Additional effort could make these results more quantitative, and other measurements (for instance, Nimbus records of surface temperatures) could be integrated with the HRIR data. Work on this is now in progress. The qualitative study of HRIR imagery offers a challenge in itself, however, as it presents man with a new view—from its perspective in space—of the resources available to him in earth's environment.