SECTION 5

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ORIGINAL CONTAINS COLOR ILLUSTRATIONS

# NIMBUS HYDROLOGICAL OBSERVATIONS OVER THE WATERSHEDS OF THE NIGER AND INDUS RIVERS

by

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## INTRODUCTION

The sensors on the Nimbus Meteorological satellites have permitted daily and synoptic observations that cover large regions. Although these sensors have a relatively low spatial resolution capability they nevertheless give one a unique perspective for studying the hydrological features over large watersheds and for observing their inter-relationship in the total watershed system. This capability has been utilized to increase our understanding of the Niger and Indus River watershed systems. The size of the two watersheds and the major rivers are given in Table 1 along with comparative statistics showing the size of the Missouri River and its drainage area. As one can easily ascertain, these systems are all considerably larger than the areal extent of the entire state of Texas. Besides the general objective of better understanding the major physical processes occurring in these watersheds, the study of these watersheds has also been conducted so that one might better identify the location of those hydrological phenomena requiring the use of higher spatial resolution systems on future earth resources satellites.

## NIGER RIVER RESULTS

For the mapping of surface water, one of the most useful spectral regions is the near infrared where the solar reflectance contrast between water and vegetated or bare soil surfaces is relatively large. Observations in a portion of this spectral region, namely 0.7-1.3μm, are available from the Nimbus 3 High Resolution Infrared Radiometer (HRIR) which was launched in April of 1969. The HRIR is a horizon to horizon scanning radiometer with a spatial resolution at the subsatellite point of 8 kilometers.

The imagery and digital data from the HRIR was utilized to study regional features and large scale changes in Western Africa and the Niger River watershed. A particular feature and process that was examined was the flooding in and around the Niger Inland Delta that occurred between May and November of 1969. Fig. 1 shows seven HRIR views of West Africa taken in each of these seven months. As can be seen from the map in the center, the Niger River originates in Gambia, flows northeastward through the Republic of Mali, and then goes south-southeastward through Nigeria toward the Atlantic. The arrows radiating from the map locate the position of the Niger Inland Delta in each of the imagery frames proceeding counter-clockwise from May 1969 in the upper right-hand corner. Another point for comparision is Lake Fagubine just above the northeastern portion of the Delta. This lake remains filled with water throughout the period shown in this slide and its reflectance changes very little.

There are at least five major features and/or events that can be located in these imagery frames. One can most easily note the general decrease in the reflectance of the total Niger Delta as one proceeds in time from May through November. This results from the inundation of the delta as flooding progresses. Closer examination of the imagery reveals that the progression in flooding from the southwestern portion of the Delta toward the northeast can be seen, particularly from August through November. It is also possible to see the high flow in the river west of the Delta in July, August, and September. In October and November this high flow to the west disappears and appears to the east of the Delta, thereby indicating how the presence of the Delta acts like a detention basin and slows the progression of the flood down the river.

The response of the Savannah vegetation to monsoonal rainfall can also be observed as manifested by decreased reflectance which is associated with greater plant growth and vigor. This progression of the vegetation response is most visible in the August through November imagery.

One may note, furthermore, that we are possibly seeing the ancient cource of the Niger River as it proceeded north from Segou toward a joining with the Senegal River. The interesting tonal feature suggesting this interpretation can be seen in the June through November images. The greatest contrast in the images along the ancient path travelled by this river appears in August and September suggesting plant and soil moisture response to subsurface flow coming from the Niger and moving along the route of the old channel.

Corroboration of the interpretations obtained from these images is best achieved by examining digitized HRIR data. This has been done for the images obtained in May, July, and November and the results as obtained after careful registration, interpolation, and contouring of the data on a 1:400,000 scale are presented in color processed form are shown in Fig. 2. The range in normalized reflectance represented in these results goes from 0.5 percent to 17.0 percent. Low reflectances are blue and green, higher ones are tan and red. One can see that the reflectance in the Delta goes from an average reflectance near 12 percent to 5 percent between May and November as a result of the flooding during this period. The higher reflectances in the northeastern portion of the Delta are also visible in all three sets of results. Furthermore, one can see the northward progression between May and July of the vigorous vegetation and dense canopy boundary as represented by the green shades in Fig. 2. Some retreat southward between July and November in the vigorous vegetation area is indicated which would be associated with the decrease in the monsoonal rainfall.

## INDUS RIVER RESULTS

The Niger River results showed the progression of runoff down the course of the river as observed in 0.7-1.3μm spectral region by the Nimbus 3 HRIR. Another aspect of watershed hydrology is the deposition of the precipitation on the watershed and its relationship to surface runoff. In this regard, the Indus River watershed situation encourages the application of satellite technology because of its generally larger size, its inaccessibility for monitoring by conventional techniques, and the fact that most of its flow results from the melting of snow deposited in the Western Himalayas. The location of the portion of the Indus River watershed that was most closely examined is shown in Fig. 3. The volume of flow in this river is roughly equal to that of the Columbia River System in the U.S. and affects the lives of millions of people who depend on it for irrigation and development of agriculture in this semi-arid region of the world. The Tarbella Dam which is being built a few miles above Attock will contain 5 million acre-feet of water and provide irrigation water for 300,000 acres of land.

The most appropriate satellite sensor on Nimbus 3 and 4 for observing snow cover was the Image Dissector Camera System because it had the best spatial resolution (4km) and monitored reflected solar radiation in the visible portion of the spectrum where the contrast between snow and bare soil or rock surfaces is greater then in the near or far infrared. Fig. 3 shows six IDCS frames taken over the Indus River watershed above Attock, Pakistan during the major snowmelt months of May, June and July for two years, 1969 and 1970. These IDCS frames were obtained in 70mm black and white positive transparency form and used to construct Fig. 4. The outline of that portion of the watershed above Attock was sketched and superimposed on the original 70mm black and white transparencies; therefore, this outline can be seen in the views presented in Fig. 4.

The bright shades seen over the Indus watershed generally correspond to the snow-covered portions of the watershed. Some ambiguity can be introduced where clouds are present, but only in the June 1969 frame do some clouds exist over the watershed and obscure a small portion of the snow-covered area. It is readily apparent that in both 1969 and 1970 the areal extent of the snow cover and its change with time can be observed. Closer study of the photographs reveals that the snow cover decreases in a spatially systematic way as time progresses from May to July. Generally the snow cover disappears first from the northwestern and southern portions of the watershed and by July only persists in the highest and northeastern parts of the watershed that contribute to flow of tributaries like the Shyok and Nubra Rivers lying in the Baltistan and Ladakh regions of Kashmir.

In order to quantify the changes in snow cover observable in Fig. 4, the original black and white 70mm transparencies were enlarged and the percent of the watershed covered by snow measured by planimetering. In an operational way one is very much interested in the relationships between observations such as presented here and surface runoff. Therefore, the results obtained from planimetering the areal extent of the snow cover in that portion of the watershed above Attock, Pakistan have been graphically related in Fig. 5 to the runoff observed at Attock. The areal extent of the snow cover has been plotted in such a way as to relate a decrease in the snow cover to an increase in the mean monthly runoff with the areal extent results for 1969 and 1970 being plotted as dashed lines and the runoff as solid lines.

The first result to notice in Fig. 5 is that the areal extent of the snow cover is consistently less in 1970 as compared to 1969. Secondly, the change with time in the snow cover is very similar in both years. The decrease in the overall snow cover in 1970 is reflected in the lower overall runoff observed in 1970. In addition, it is encouraging to see that there is some correlation between the change in the snow cover from month to month and the mean monthly runoff, particularly in 1969.

The results so far suggest that some success might be achieved in predicting the total runoff volume or the level of peak discharge if one were to use the satellite to monitor the areal extent and location of the snow cover in late winter and early spring. It is intended that a few more years data be analyzed to see if this hypothesis can be established. At the very least, these results indicate that the satellite data can be used as an additional source of information and understanding in the management of the water resources in this region.

## CONCLUSIONS

As a result of studying the Nimbus imagery over these two large watersheds, it is felt that a perspective and understanding of the large scale hydrological processes and their interrelationship has been obtained which could be obtained by no other means in so short a time. In the case of the Niger River a much better appreciation of the flooding process has been obtained along with the role of the Inland Delta in this process. Obviously a knowledge of the spatial and temporal distribution of the snow-melt process in the Indus River watershed is now available that was obtained with minimal effort as compared to the effort and time that would be required using conventional methods. It seems clear that even the low resolution data easily available from meteorological satellites can be a valuable source of information in the better management of the water resources in these regions. In addition, it has also been substantiated and concluded that the daily and synoptic views over large regions provided by these types of sensors will be in future studies a valuable and even necessary set of information to be combined with the relatively high resolution sensor data forthcoming from systems like the Earth Resources Technology Satellite (ERTS).

TABLE I. A COMPARISON OF THE DRAINAGE AREA AND RIVER LENGTH ASSOCIATED WITH THE NIGER AND INDUS RIVERS, THE MORE FAMILIAR MISSOURI RIVER, AND THE AREA OF THE STATE OF TEXAS

**NIGER RIVER**

TOTAL DRAINAGE AREA = 580,000 sq. mi. (1,502,000 sq. Km.)

LENGTH OF MAIN RIVER = 2,600 mi. (4,184 Km.)

**INDUS RIVER**

TOTAL DRAINAGE AREA = 372,000 sq. mi. (970,000 sq. Km.)

LENGTH OF MAIN RIVER = 1,900 mi. (2,900 Km.)

**MISSOURI RIVER**

TOTAL DRAINAGE AREA = 529,400 sq. mi.

LENGTH OF MAIN RIVER = 2,466 mi.

AREA OF TEXAS = 267,338 sq. mi.

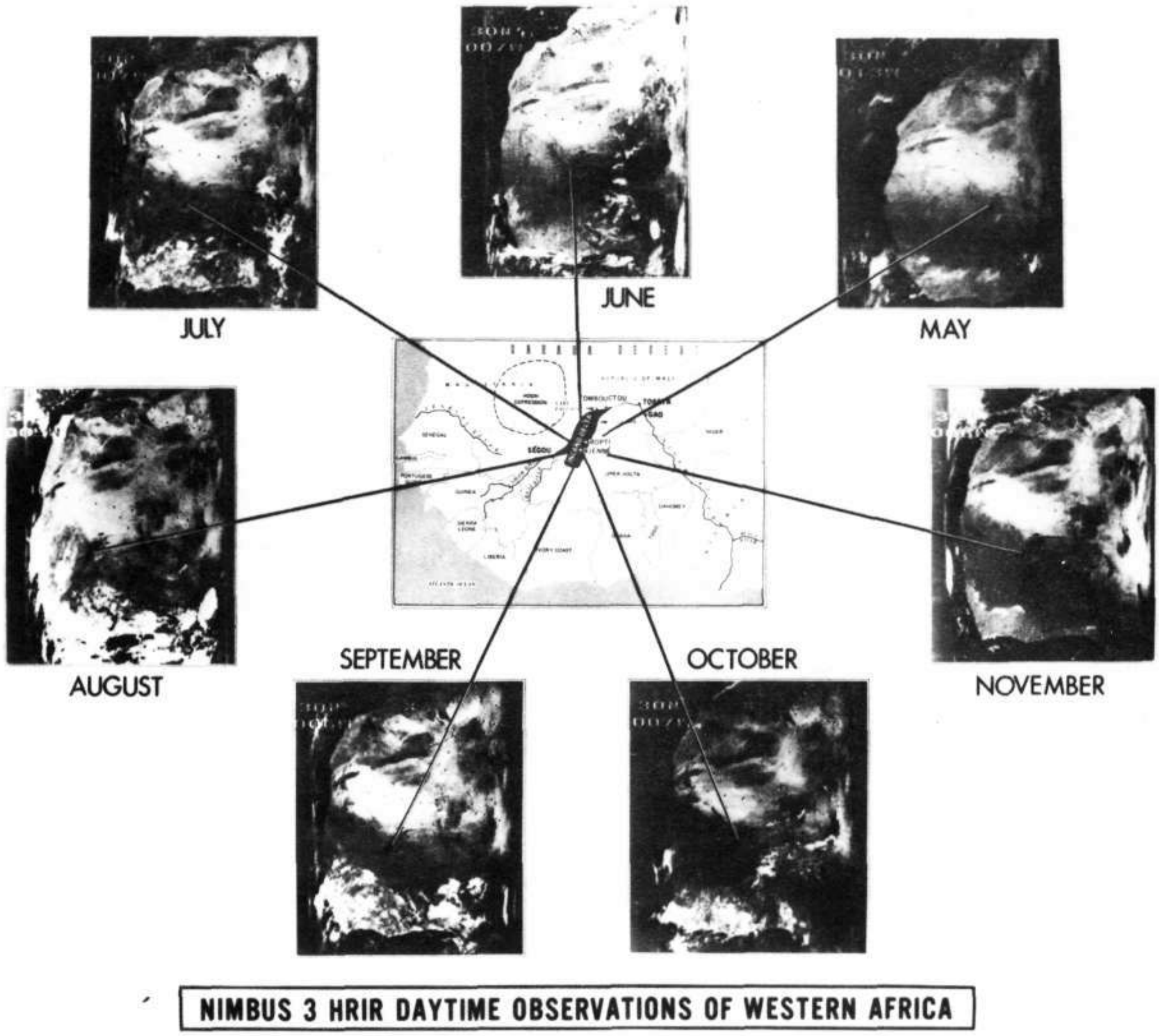
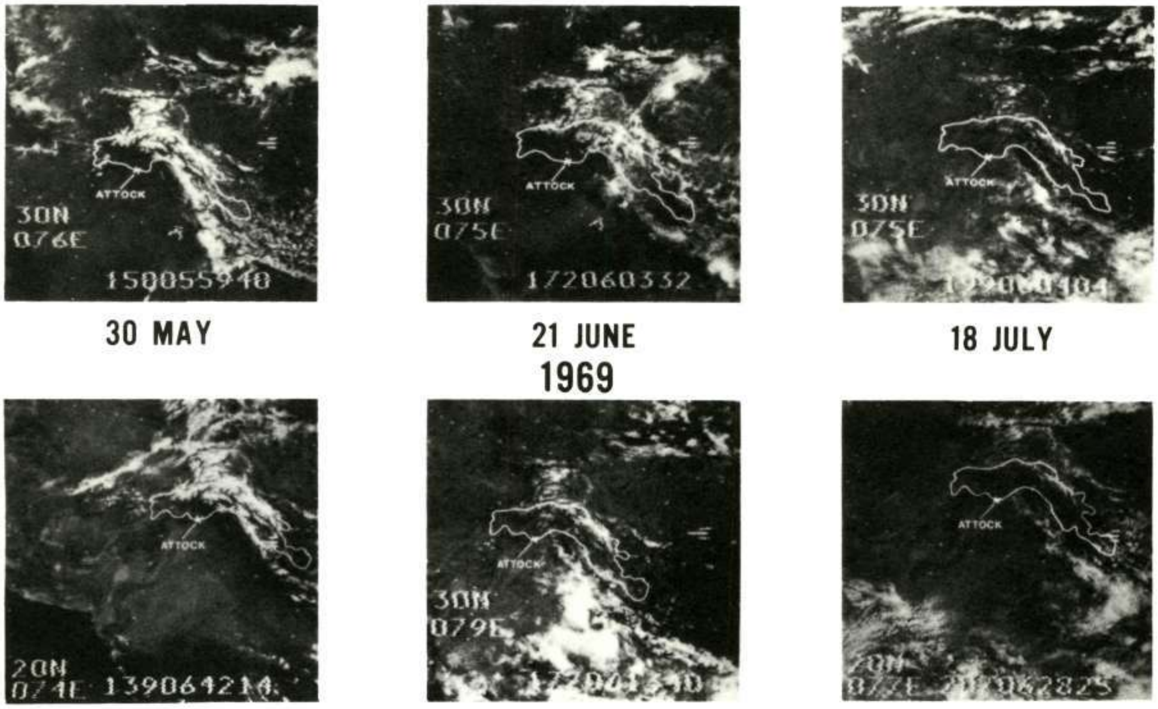



Figure 1.-Nimbus 3 HRIR images over Western Africa showing the progression in the flooding of the Niger Inland Delta


Figure 2.-Nimbus 3 HRIR data that has been processed to show quantitative changes in reflectance over the Niger Inland Delta


Figure 3.-A map of the area in the Western Himalayas where observations of snow cover were made using the Nimbus 3 and 4 Image Dissector Camera System (IDCS). The dark boundary delineates that portion of the Indus River watershed above Attock, Pakistan.




**30 MAY** **21 JUNE** **18 JULY**

**1969**

**19 MAY** **26 JUNE** **26 JULY**

**1970**

**NIMBUS 3 AND 4 IDCS OBSERVATIONS OF SNOW COVER OVER THE INDUS RIVER WATERSHED DURING MAJOR SNOWMELT PERIOD**

Figure 4.-Six views of the Indus River Watershed above Attock, Pakistan showing satellite-observed changes in snow cover

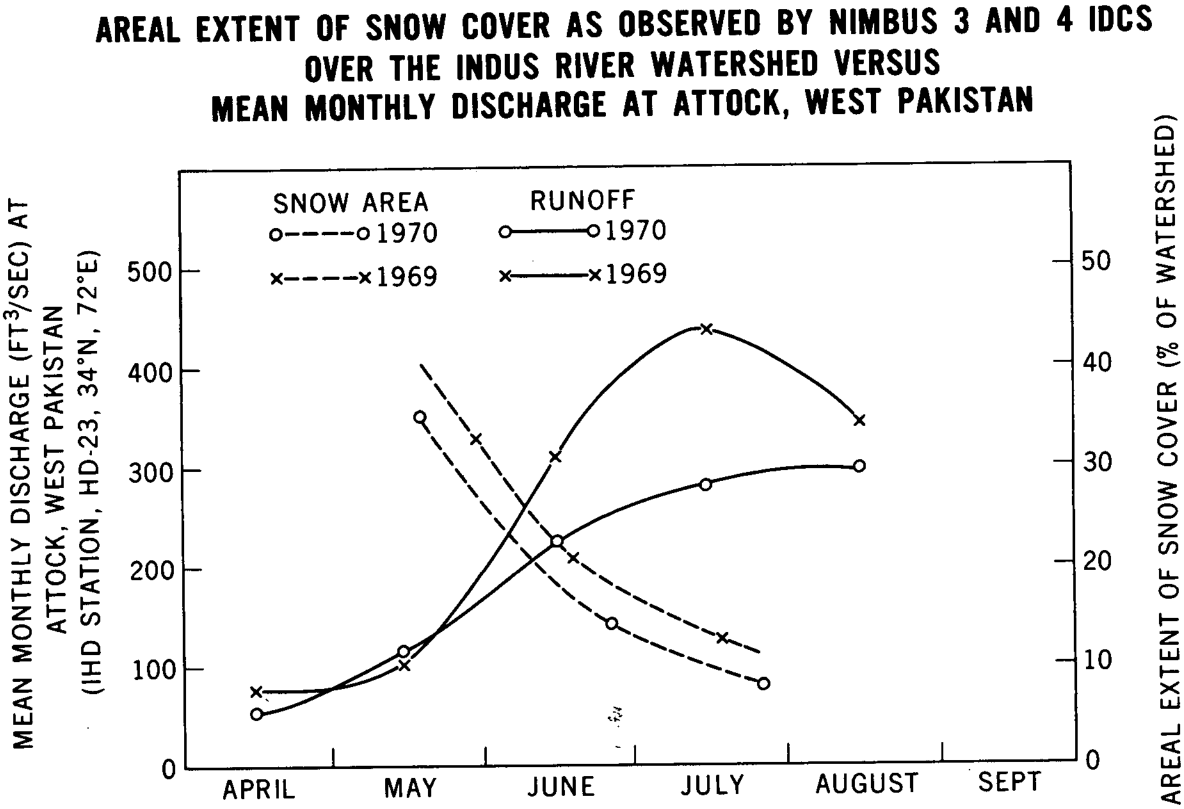



Figure 5.-A graph showing the observed relationship between mean monthly discharge measured at Attock, Pakistan and the snow cover over the Indus River watershed.