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REMOTE DETECTION OF TERRAIN FEATURES FROM NIMBUS I HIGH RESOLUTION INFRARED RADIOMETER NIGHTTIME MEASUREMENTS

by Jean Pouquet

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ABSTRACT

Brightness temperature analyses were made from nighttime Nimbus I High Resolution Infrared Data (HRIR) in the 3.5—4.2μ region. Data for the Northeast Sahara Desert and the Nile delta regions, obtained during September 1964, were selected. The brightness temperatures were found very useful because they detect: (1) the widespread humidity in the upper soil horizons, and (2) the heat storage capacity in various rock formations such as sands and alluvial deposits.

ZUSAMMENFASSUNG

Messungen der nächtlichen Strahlungstemperatur der Erdoberfläche im 3.5—4.1μ-Bereich mit dem hochauflösenden Infrarot-Radiometer (HRIR) des Satelliten Nimbus I im September 1964 über der nordöstlichen Sahara und dem Bereich des Nildeltas wurden analysiert. Die Infrarot-Strahlungsmessungen erweisen sich als sehr brauchbar, da sie 1. die Verbreitung der Bodenfeuchtigkeit im obersten Horizont und 2. die unterschiedliche Wärmekapazität verschiedener Bodenformationen, wie Sand und alluviale Ablagerungen, abzuleiten gestatten.

RESUME

Les températures nocturnes du sol, d'après les radiations infra rouges dans la bande spectrale 3.5—4.1μ, haute résolution (HRIR), transmises par le satellite Nimbus I ont été utilisées à propos du Sahara Nord-Oriental et la région du delta du Nil, lors de deux orbites sélectionnées en septembre 1964. Les températures ainsi analysées se sont révélées particulièrement utiles en ce qu'elles permettent de déceler à distance: 1) la présence d'humidité dans les horizons supérieurs des sols, et 2) les possibilités différentes d'emmagasinement de la chaleur solaire de diverses formations rocheuses telles que sables, formations alluviales.

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INTRODUCTION

The results presented in this paper were obtained on two separate days in September 1964. Longer radiation coverage over North Africa during 1964 was made impossible by the termination of the career of Nimbus I. The areas studied were scanned during the end of the summer, after long months of the usual hot and dry weather in this section of the northern Sahara Desert. In this case, the temperature contrasts were sharper than at other seasons thus facilitating a better understanding of the link between equivalent black-body temperatures and surface geomorphological features.

METHOD OF ANALYSIS

Orbits 258, September 14, 1964 and 345, September 20, 1964, were selected after a careful study of numerous Nimbus I photofacsimile prints showing that at night the sky is clear over most of Northern Africa. The "brightness" of the ground features was directly read out in terms of equivalent black-body temperatures T_{BB} on a computer-produced mercator grid print map at a scale of 1:1,000,000. The high resolution obtained was such that two separate grid-print data crosses represent points only 8 miles apart.

Isotherms were drawn for every 2° Kelvin. "Equivalent black-body temperature" expresses a "brightness" rather than a numerical surface temperature. When two similar soil formations—one wet, the other dry—are placed side by side, the latter will be outlined by "cooler" T_{BB} values at night. With an equal amount of moisture, a sandy formation made of silica sands will contain lower T_{BB}

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values than a clayish-sandy formation. A granite rich in biotite will appear "warmer" than a granite rich in muscovite and poor in biotite.

It is well known that a fault acts as a trap for the circulation of underground water. So, a tight temperature gradient without a topographical feature such as a steep slope may indicate a hidden fault (other factors mainly topographical, being duly considered).

Studies have shown that nighttime contrasts in brightness temperatures are stronger during the summer. Note that during June through September, the distinction between "hot" and "cold" areas is mainly related to the difference in elevation (with a dry adiabatic, roughly 10°K per 1,000 meters). Actually the contrasts are considerably smoothed in autumn or at the end of spring, as shown by the experience of Nimbus II.*

THE NILE DELTA AND SURROUNDINGS (FIGURE 1, TOP AND BOTTOM)

The warmest areas are in the Red Sea, the Gulf of Aqaba, and the Dead Sea (294-296°K); while the coolest are at higher elevations (286°K and below) (Figure 1). Except for these extreme cases, the topography of the rest of the area does not confirm the general pattern of the equivalent black-body temperatures. For example, the Qattara Depression (Figure 1, top map), 2 to 133 meters below sea level, is overhung by flat plateaus at an elevation of approximately 70 meters to the south, 130 meters to the northwest and 250 meters to the north. The maximum vertical distance is 300 meters to the north, along 28°E. On that spot, the temperature difference is 7°K, 4°K more than can be explained by the altitude difference. Some cliffs (Minqar) overhang the hottest part. The talus at the foot of these slopes have a greater heat capacity than the surrounding loose and heterogeneous material. Similarly, there is no relation between the cooler areas, inside the saucer-like depression and the topography. For example, the long tongue striking N-S between 27 and 28 degrees longitude east is 2 to 4°K cooler than the immediate vicinity. Furthermore, the altitude is 120 meters below sea level, while the warmer vicinity is only at -2 meters. Following the well known 1:1,000,000 map "Alexandria," there is, just along that "path," a long ridge of sand dunes (Ghard Badr El-Din), material having a lesser heat capacity than the "sand and scrub," the "soft" or "soft and wet" soil formations showing up at the location of the warmer areas, regardless of the elevations. (The preceding expressions in quotes are so read on the map.)

The warmer areas are associated with a greater soil moisture content. Examples are shown at El Fayoum Depression, some parts of El Qattara Basin, the Nile Delta, coastal plains along the Mediterranean Sea, the Gulf of Aqaba and the Dead Sea. Other "warm" areas are seen along existing or extinct river beds; also where finer debris have been deposited at the foot of cliffs in most of the cases. Finally, certain soil formations, in a strict sense, rich in organic matter and clay are characterized by higher T_{BB} values.

*The above statement was confirmed without exceptions over the arid lands of the southwest United States during a study of Nimbus II HRIR data for June-November 1966. The accuracy of the Nimbus I HRIR measurements belongs, now, to the common knowledge: see, for example, Kunde (V. G.) Theoretical Relationship between T_{BB} and Surface Temperatures. . . ., in *Observations from the Nimbus I Meteorological Satellite*. . .

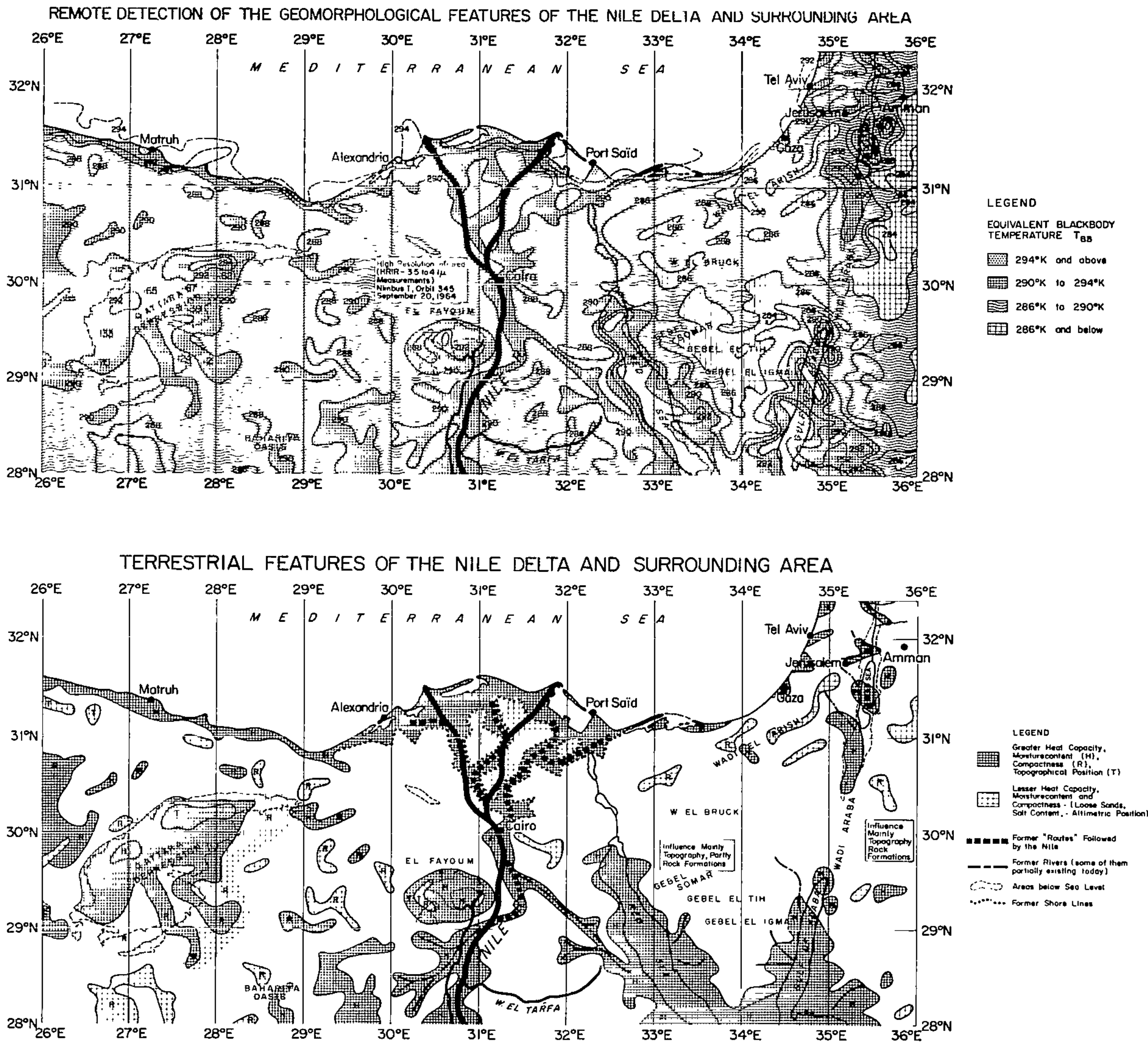

Figure 1—Remote detection of the geomorphological features of the Nile Delta and surrounding area.

On the other hand, the cooler areas are tightly linked to coarse materials without enough fine particles, or to materials with low organic-matter content. Furthermore, the heat capacity is a function of the "freshness" of the sands, or alluvial deposits.

Actually, a "fresh" sand is "clean," without the usual "cortex," coating by clay and oxides. This "varnish" shows the evidence of the elapsed time, geologically speaking, and is the result of a weathering that has lasted a long time. In short—with few exceptions, the "younger" a soil is, the cooler is its brightness temperature.

Over the Nile Delta, it is surprising how the narrow stripes of warmer areas (the former course of the river) are only occasionally linked to the present course of the river, the present course intersecting the former course and being independent of it. Periodically, usually in spring, the flood of the Nile enriches the soils with the solid load carried by the river, such as silt, clay, and sands. When deposited, this is a "skelettic" soil, which is not weathered. After several thousand years the weathering transforms this material, following the pedological processes. The "clean" formations become richer in organic matter and clay. The general color is darkened, and the "horizons" are elaborated.

Take, for example, the sandy alluvial deposits of the Nile Delta. When fresh, this material is not able to store enough water; hence, its heat capacity is rather low and its albedo is high. After pedologic evolution begins, the soil is enriched in clay and organic matter, and its moisture capacity is increased. In such a case, the alluvium deposited approximately 10,000 to 12,000 years ago, at the end of the last glacial age, has been weathered and transformed, and has acquired a larger heat capacity. These areas coincide exactly with the elongated warmer stripes visible on the map (Figure 1, top). It is then possible to redraw some of the main courses of the river (Figure 1, bottom). The word "course" is here used broadly, involving areas affected by the channels of the river, and by the spreading of moisture through the alluvial masses, and by the endless meanderings of an unstable river switching from side to side.

Other rivers that behave like the Nile can be found on either side of the Dead Sea, the Red Sea, and the Gulf of Aqaba. Consider the southern prolongation of the Dead Sea, along the elongated depression below sea level (average-80m). I believe that this area is warmer, not because of its lower elevation but because of its greater moisture content. The Wadi* come into existence after a rain, thus wetting the soils. I believe but cannot prove that this depressed basin, not so long ago, was a continuation of the Dead Sea that has been shrinking ever since. From south to north, one can read on the topographical map, Ein el Weiba, Ain el Hufera, Ein Quseib, Ein Arus, Ein Aheimi (Ain or Ein means spring, or source). These springs are obviously related to the water table, and the moisture of the top soil gives them a lesser albedo and a greater heat capacity. These springs, showing up as warmer area, indicate an existing but hidden source of soil water.

On the assumption that a source of soil moisture exists (such as dew, or a water table near the surface of the ground), soil moisture usually moves toward the cooler part of the soil profile. During the heat of the day, the moisture is driven downward in the desert. As soon as the surface soil is cooled to a depth of several centimeters, the opposite movement begins. That is why, at night, the top soil is slightly moist when some water exists about a meter below the surface.

Future NIMBUS and ESSA satellites will carry multi-channel radiometers with very high resolution. The 5-channel medium resolution radiometer now in use is not suitable for geomorphology. The 10-μ channel will be the most useful for the earth sciences, because it will allow day and night measurements to be compared.** The HRIR data used in this study were obtained at night. The daytime HRIR data cannot be quantitatively interpreted, but may be used as reference or illustration,

*Wadi, arabic plural for rivers, the singular being Wed (phonetic spelling).

**This subject is discussed in J. Pouquet & E. Rashcke, "A Preliminary Study of the Detection of Geomorphological Features over Northeast Africa by Satellite Radiation Measurements in the Visible and Infrared," NASA Technical Note in process, 1968.

similar to the TV-Automatic Vidicon Camera System (AVCS) or the Gemini's pictures. In the case of a 10-μ very high-resolution channel, with a view angle of 1/2 degree or even less, the areas that are warmer than surrounding areas (the difference being especially sharp at night) might be investigated for subsoil moisture.

THE NORTH-EASTERN SAHARA (FIGURE 2)

Elevation is not a major factor in the radiation analysis of this area, with the exception, perhaps, of the Gebel Nefoussa (7°K for an elevation difference of approximately 250-300 meters) (Figure 2, top). But, even in that case, the contrast between warm and cool spots is due to the moisture, which is greater at the northern foot of the mountainous ridge than at any other place. The moisture of the top soil must be considered, also the stage reached by pedologic processes ("soil formation" being used in a broad sense).

Roughly speaking, in the arid lands of the Sahara, only the regions appearing darker on the map to the (left)—Figure 2 (a) and (b)—have agricultural possibilities. Agricultural activities are already visible in the long administrative district politically known as Oasis Sahariennes, and along the shorelines west and east of Tripoli—Figure 2 (c) and (d). Most of these latter areas are still mapped with the symbol usually affixed to swamps, and have recently been reclaimed.

The long, almost straight row of "warmer" land linking the vicinity of Tripoli to the eastern fringe of the Grand Erg Oriental indicates not only more moisture, but also a fault line—Figure 2 (a) and (b). The collapsed compartment to the north is covered by a mantle of debris storing the lower level of atmospheric humidity, and mainly the moisture rising from the water table to the surface of the soil. This row also indicates the existence of a former wide stream that linked the mountainous region of Gebel Nefoussa to the present location of the Grand Erg Oriental. Today, this very area is characterized by an unbelievable density of streams east of longitude 9° 40'. The penetration of that warm ribbon amidst the sand dunes of the Grand Erg Oriental cannot be explained by topographical maps. Possibly damper sands overlie the former pattern of drained valleys. The existing streams today, like their predecessors at the time of the glacial stage, are running toward the Grand Erg which occupies a depression at altitude 200-250 meters, as compared with 400-500 meters in the eastern neighborhood. Some "hassi" (wells) have been mapped around the mass of sand dunes, with a few of them in the sand dunes: Hassi Mariksene, west of Gadames, Hassi Ali Ben Amar by 31° 20' of latitude north and 10° longitude east, Bir ez Zoba by almost 32° latitude N., 9° 30' longitude ("Bir," also, means "well").

These hidden possibilities for water cannot be detected unless someone tries to drill wells every mile or so. But the maps drawn with the radiometric measurements allow a good, even a precise preselection of the spots suitable for agriculture.

In the cooler areas, two facts must be considered: the high reflectivity of "fresh" sands (mostly silica sands, bright, sometimes frosted by the action of the wind, and still perfectly glossy, but in any case incapable of keeping the moisture or the heat of the daytime) and the high

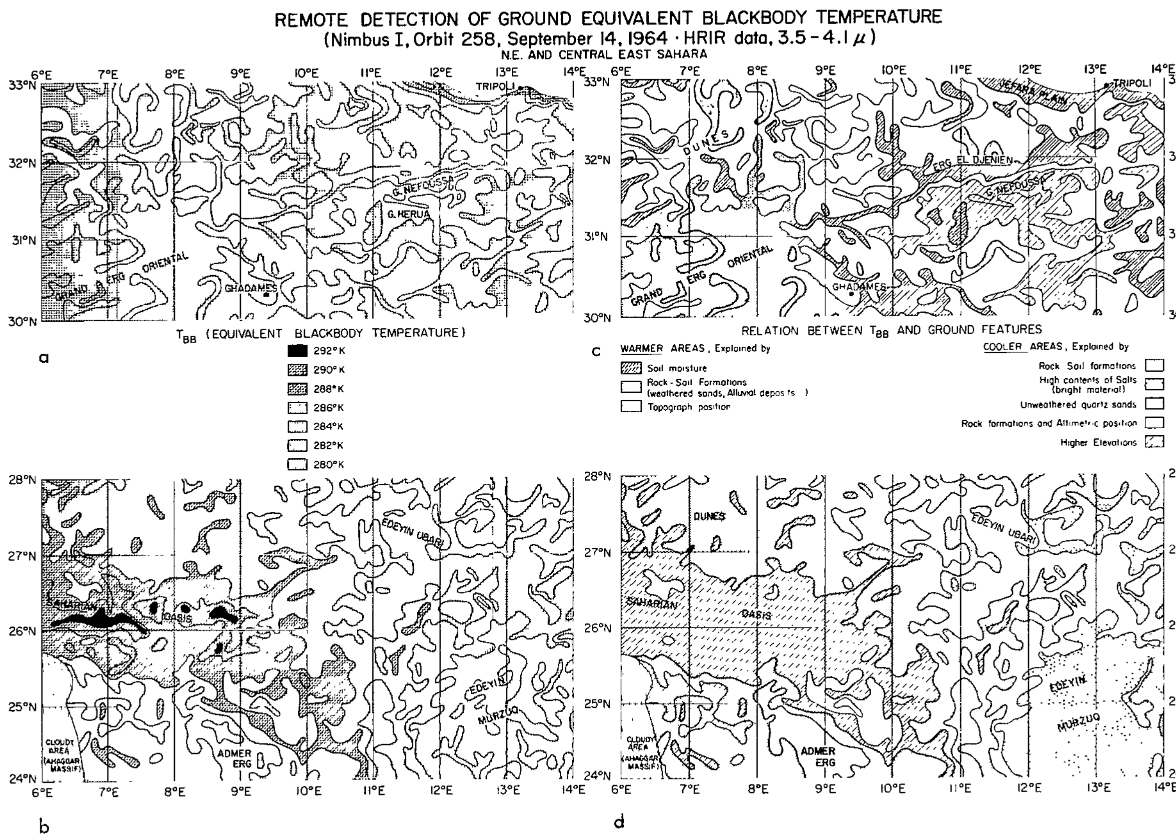

Figure 2—Remote detection of ground equivalent black-body temperature (Nimbus I, Orbit 258, September 14, 1964 · HRIR data, 3.5—4.2μ) N. E. and Central East Sahara.

reflectivity of the salts common on the floor of the playas (dry lakes) in arid lands. In both cases, these regions will look "cool" on the radiation charts—Figure 2 (a). The Edeyin Murzuq and the Edeyin Ubari* are conspicuous examples of how unattractive to man these Saharan sectors might be.

When the soil or rock formations are responsible for the cooling or the warming up, we get immediately a good picture of the stage reached by the general evolution of the soils. Of course, the evolution is speeded up when water is available. Most of the sand particles of the dunes are "old," or weathered, hence a higher equivalent black-body temperature. An exception is recently blown sands, or those removed by wind or by intermittent running waters (sheet-floods, wash-floods, rill-floods—all very common in arid lands). In such cases the fragile clay particles are washed away, leaving only the analogy to a lifeless skeleton that can store no moisture.

The detection of soil erosion offers some possibilities. By washing away the A_0-A_1 horizons, erosion reveals the A_2 horizon which is lighter in color, poorer in clay and humus, and consequently shows up as a cooler region on the grid-print maps and photo-facsimile pictures obtained

*"Edeyin" means "depression."

from Nimbus I HRIR data. With the B horizons exposed at the surface of the ground, the difficulty is greater as they will differ little from the top soil horizon (as far as equivalent black-body temperatures are concerned) with the exception of the group of soils known as "Pedocals." In that case, the odds are in favor of a cooler temperature linked to the exposed B horizons.

CONCLUSION

Although this study has been concerned with two days in Northeast Africa, it has possibly shown the usefulness of spacecraft radiometers in the domain of geomorphology and pedology. The use of the High Resolution Infrared Radiometer data offers a good possibility of detecting hidden sub-soil water and ascertaining the stage reached in the evolution of soils. (This method of dating is used loosely.) Unfortunately the 3.5- to 4.2-μ wavelength region restricts us to nighttime analysis and, of course, provides only reliable surface "brightness" temperatures during cloudless conditions. In the very near future the nighttime restriction will be removed by the use of the very high-resolution 10-μ channel.

The analyses and conclusions drawn from the equivalent black-body temperatures necessarily refer to pedologic rather than geologic maps. Using these temperatures to detect sub-soil water may have economic advantage.

I am more and more convinced that the growing need for food and water that faces the world today could be resolved by interpretation of radiation data collected by weather satellites.

ACKNOWLEDGMENT

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Greenbelt, Maryland, November 6, 1967
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