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A PRELIMINARY STUDY OF THE DETECTION OF GEOMORPHOLOGICAL FEATURES OVER NORTHEAST AFRICA BY SATELLITE RADIATION MEASUREMENTS IN THE VISIBLE AND INFRARED

by Jean Pouquet and Ehrhard Raschke

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ABSTRACT

Measurements from the meteorological satellite Nimbus II of reflected solar and emitted infrared radiations, day and night, over Northeast Africa were used to investigate some geomorphological features of the ground. It has been found that: (1) the daytime measurements of emitted longwave radiations are deceptive because of the differences in local solar times across a scan; (2) nighttime measurements are closely related to solar reflectances over the same areas; (3) when nighttime infrared measurements depart from the general trend shown by the reflectance, this opposition helps in the detection of such geomorphological features as rock formation and soil moisture.

These investigations are no more than a tentative approach restricted chiefly because of the low resolution of the Medium Resolution Infrared Channels of Nimbus II.

RESUME

Les auteurs ont utilisé les renseignements fournis par le satellite météorologique NIMBUS II afin de detecter à distance quelques faits significatifs en ce qui concerne la géomorphologie de l'Afrique du Nord-Est. En comparant la reflectivité du sol et les températures aussi bien diurnes que nocturnes traduites d'après les valeurs des radiations infrarouges, les auteurs ont trouvé que: (1) Les températures diurnes sont, pour le moment, presque inutilisables en raison, notamment des différences d'heures locales; (2) temperatures nocturnes et valeurs de reflectivité sont étroitement solidaires; (3) lorsque températures nocturnes et reflectivité sont en désaccord, cette opposition contribue à la detection de faits significatifs dans le domaine de la géomorphologie.

Ce travail ne doit être considéré que comme une tentative, laquelle est freinés par les données fournies par NIMBUS II, notamment en ce qui concerne la résolution insuffisante des canaux de MRIR (Medium Resolution Infra Rouge).

ZUSAMMENFASSUNG

Geomorphologische Erscheinungen von Nordost-Afrika werden mittels Messungen der reflektierten Sonnenstrahlung und der emittierten Wärmestrahlung (Tag und Nacht) untersucht, die vom meteorologischen Satelliten Nimbus II aus gewonnen wurden. Es wurde gefunden, dass (1) Werte der am Tage emittierten Strahlung sehr stark von der Ortszeit der beobachteten Gebiete abhängen und so kaum Informationen liefern, während (2) nächtliche Werte in enger Beziehung zum Reflexionsevermögen der beobachteten Gebiete stehen, (3) jedoch lassen Abweichungen von dieser allgemeinen Beziehung auf Besonderheiten, wie verschiedene Gesteinsformationen oder verschiedener Feuchtegehalt des Untergrundes, schliessen.

Die vorliegenden Untersuchungen sind nur ein einfacher Versuch bereits vorhandene Satellitenmessungen geomorphologisch zu interpretieren.

CONTENTS

A PRELIMINARY STUDY OF THE DETECTION OF GEOMORPHOLOGICAL FEATURES OVER NORTHEAST AFRICA BY SATELLITE RADIATION MEASUREMENTS IN THE VISIBLE AND INFRARED

by

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INTRODUCTION

This investigation into a comparison of reflectivity and infrared radiance temperatures of the ground is no more than a tentative approach. Northeast Africa was chosen because one of the authors (Reference 1) has already published a study of the geomorphological features of the same areas using the emitted infrared radiation received by Nimbus I in September 1964. The present goal was to seek a new tool that might help further research in the earth sciences, without pretending to solve the problems encountered.

The equivalent black-body temperatures read by the satellite are influenced by numerous properties of the geological formations, such as porosity, permeability, texture, moisture content, etc., all of which govern rock *heat capacity* (Reference 1). The amount of heat stored depends on the quantity of solar energy absorbed by the ground. As a consequence, knowledge of the ground reflectance allows a first approximation of the fraction of solar energy not used for heating the surface. Logically, a high reflectance should correspond to a low nighttime temperature and a low reflectance to a high nighttime temperature. As we shall see, there are exceptions to that simple rule: exceptions of great value, for they lead to a better understanding of the terrestrial features.

THE NIMBUS II EXPERIMENTS‡

Nimbus II was launched on May 15, 1966, into a sun-synchronous orbit. At an average height of 1140 km above the earth's surface, the satellite passes over the equator near local noon when

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‡For further and more complete descriptions, see References 2, 3, and 4.

northbound and around local midnight when southbound. As a function of its height and its orbital period of 107 minutes, its measurements "cover" every area of the earth at least once during the day and once during the night within a 24-hour period. Table 1 summarizes the experiments relevant to this study.

Table 1

Radiation Experiments Aboard Nimbus II.*

Instrumentation	Spectral Regions
Advanced Vidicon Camera System (AVCS), 3 cameras	Visible (Television pictures)
High Resolution Infrared Radiometer (HRIR)	3.5-4.2μ (Nighttime temperatures of clouds and earth)† (Reference 2)
Medium Resolution Infrared Radiometer (MRIR), 5 channels:	
Channel 1	6.4-6.7μ (H_2O band, Tropospheric water vapor) (Reference 5)
Channel 2	10-11μ (Surface, clouds temperature, day and night)
Channel 3	14-16μ (CO_2 band, Stratospheric temperatures) (References 6 and 7)
Channel 4	5-30μ (Planetary Radiation balance) (Reference 8)
Channel 5	0.2-4μ

*The references cited in Table 1 are only selected for a description of possibilities to interpret quantitatively the Nimbus II MRIR measurements.

†The HRIR daytime data are not used in this study because of the considerable sun reflection interferring with the emissivity of the ground.

For a comparative study, the following items have a special interest:

1. *AVCS photographs* whose spatial resolution of about 1.5 to 2 km permits the observation of fine details in the ground features. These photographs (Figure 1) were used for the selection of the orbits needed to identify the ground features and discover the clouds which are an impassable obstacle to the infrared radiations emitted by the earth.

2. *MRIR channel 5 measurements of reflected and scattered solar radiations,* which gave the reflectance and hence the albedo of the ground-atmosphere system. By definition, the reflectance R is the ratio between the measured radiation and the vertically incident solar irradiance, expressed by

$$R(\lambda, \phi) = \frac{\pi N(\lambda, \phi)}{S \cdot \cos \zeta(\lambda, \phi)}$$

where λ and ϕ represent the longitude and latitude, respectively, of an observed area; πN the measured radiation; S the solar irradiance within the spectral region of the instrument (0.2 to 4.0μ), and ζ the sun's zenith distance over the observed area. In our calculations, S was obtained by integrating, over all wavelengths, the product of the effective spectral response of the instrument and the spectral solar irradiance at the top of the atmosphere, as described by Johnson (Reference 9).

The reflectance R actually depends on the viewing angle with respect to the sun and on the zenith angle of observation at ground level. This is caused by atmospheric scattering and reflection of the ground: for instance, the areas seen near the ground specular point of the sun appear brighter than their surroundings, which are at a different angle of view. This angular dependence must be taken into account when computing the planetary albedo from satellite measurements (Reference 8), but it should have little influence on the comparative study. This is concerned with relative reflectances in the Northeast Sahara, rather than exact numerical values. Since in a clear atmosphere the contribution of atmospheric back-scattering to the totally reflected solar radiation is everywhere nearly the same, the reflectance map patterns are strongly related to the reflectance of the ground itself.

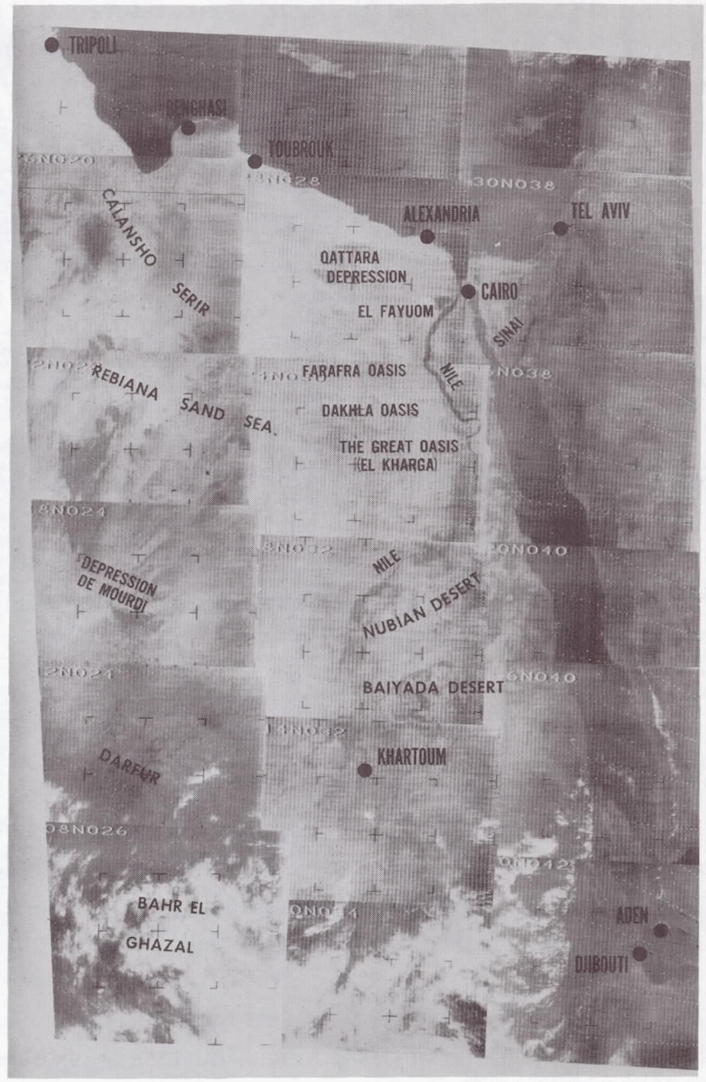


Figure 1—AVCS photographs; orbit 680; cameras 1, 2, and 3.

3. Measurements of *infrared radiations* in the spectral ranges of 10 to 11μ (MRIR channel 2) and 3.5 to 4.2μ (HRIR) are tightly linked to the thermal radiation of clouds or the ground surface. The atmospheric interaction in both spectral regions is relatively weak; thus, equivalent blackbody temperatures (hereafter called T_{BB}) which can be determined from measurements of the emitted radiation are slightly smaller than the actual surface temperatures. Absorption and reemission in absorption lines of atmospheric water vapor, carbon dioxide, ozone, and other minor constituents, decrease the T_{BB} values from 5 to 10 degrees in the MRIR range (References 6 and 7) and from 2 to 5 degrees in the HRIR range (Reference 10), depending on the water-vapor content and the optical pathlength in the atmosphere (References 6 and 7).

We did not try to map the exact temperatures of the ground, our goal being only to visualize the "warm" and "cool" areas. Furthermore, since our study is restricted to a rather small area, it may be assumed that the total mass of the atmospheric water vapor (the only one of the previously mentioned gases subject to significant change) and the vertical temperature profile do not change considerably over the areas, and hence have little effect on the relative temperatures.

These considerations of the atmospheric interference with the outgoing longwave radiation are valid only for a completely cloudless atmosphere. Cloud cover, dust, fog, haze, etc., intercept the infrared radiations emitted by the ground, just as they veil the terrestrial features and forbid their observation in the visible spectrum. Therefore, we selected the orbits from AVCS photographs, in order to ensure that the regions to be studied were completely cloudfree.

REFLECTANCE AND GROUND TEMPERATURE DISTRIBUTIONS

Figure 1 shows one of the montages of AVCS photographs, obtained on June 30 and July 5, 1966, from orbit 680. The sea contrasts strongly with the land, while the clouds, shown as bright surfaces, occur only south of 16 degrees North.

Reflectance Maps (Figures 2 and 3)

The spatial resolution for the computer-derived maps was chosen to be about 65 × 65 km on the ground; consequently, coast-lines and islands do not show as clearly as they do in the AVCS photographs. These maps show clearly that the reflectance over the seas is only 5 to 10 percent. These low values are almost entirely due to back-scattering solar radiation in the atmosphere. Inland from the coastlines toward the Sahara desert and Saudi Arabia, the reflectance rises sharply to values between 20 and 35 percent, depending on the surface cover and the brightness of the rock formations. For instance, the Great Sand Sea is characterized by reflectances as high as 37.5 and 40 percent, thanks to the exceptional brightness of the sandy formation, while the dense vegetal cover of the Nile Delta is responsible for values below 25 percent.

Maps of Equivalent Black-Body Temperatures (Figures 4, 5, and 6)*

These maps were drawn at the small scale of 1:5,000,000 in order to match the reflectances. They show not only the distribution of the equivalent black-body temperatures but also, for daytime data (Figures 4 and 5), the difference in local solar times of different regions seen by the satellite in the same scan. We can determine the height of the sun and the length of solar illumination. The sun's declination was about +22 degrees for both days. (Figures 4 and 5 are without correction.)

*The channel 2 nighttime measurements (MRIR) were not available for the June 30 orbit; therefore the HRIR measurements were used.

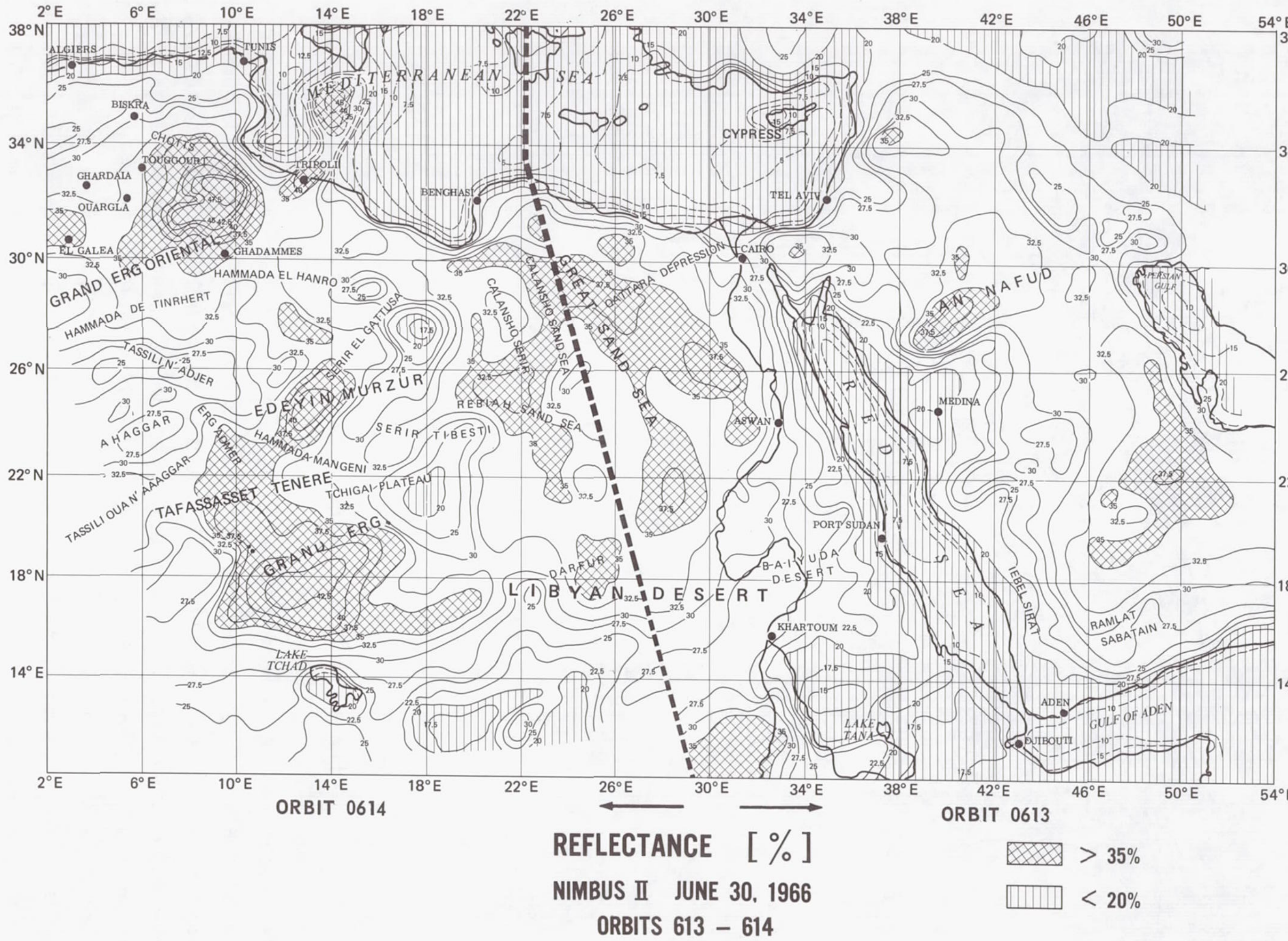
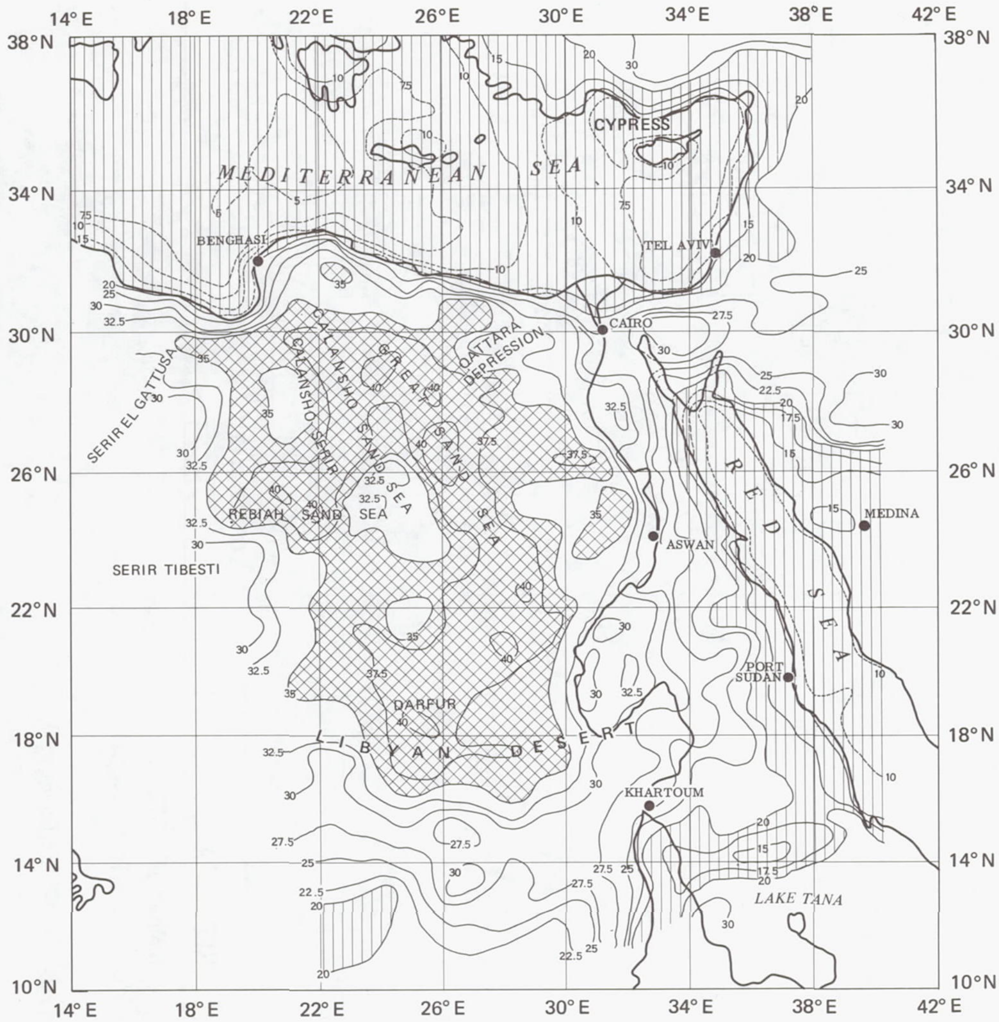


Figure 2—Reflectance map, orbit 0613-0614, June 30, 1966.



REFLECTANCE [%] > 35%

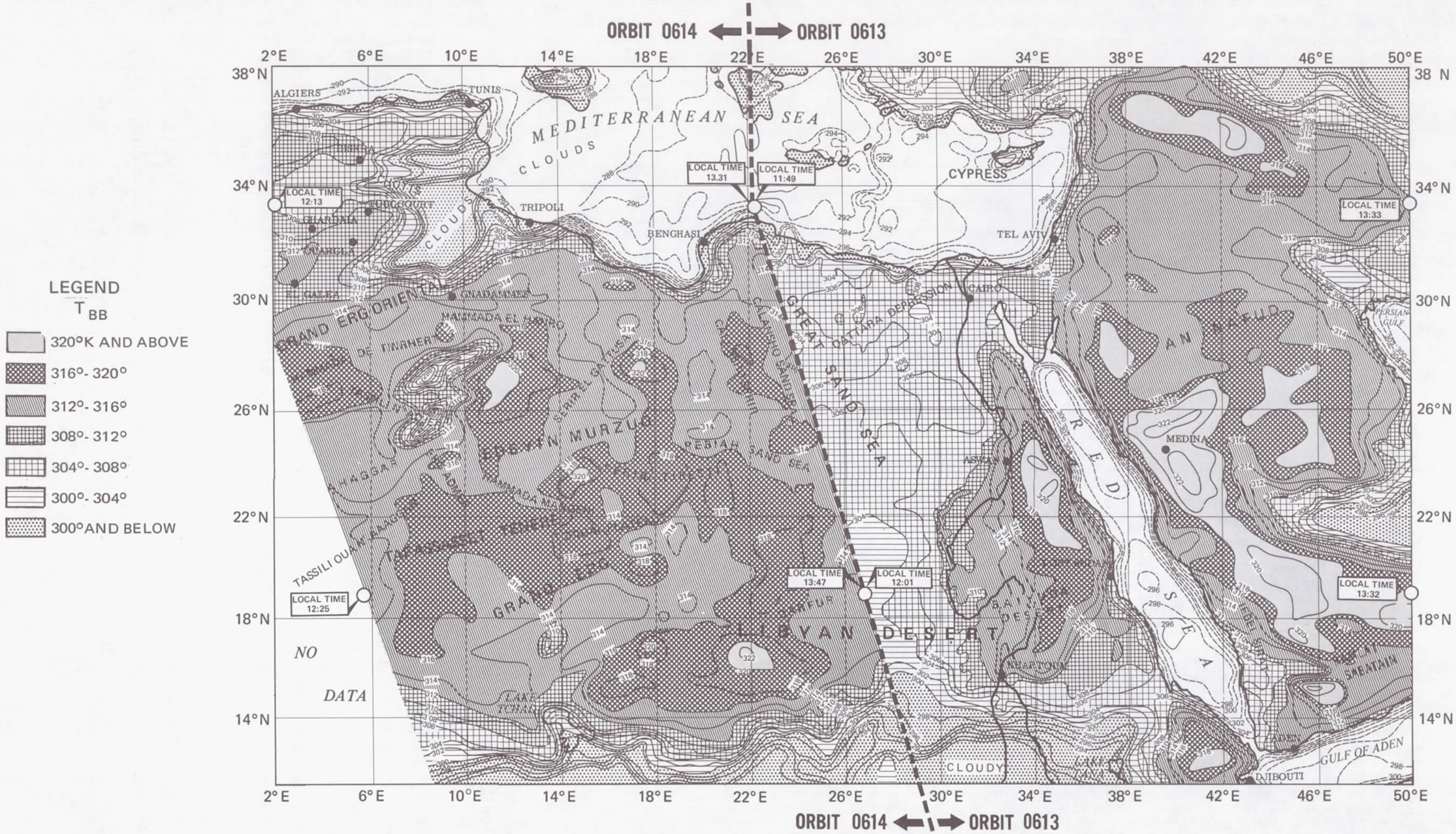
NIMBUS II JULY 5, 1966 < 20%

ORBIT 680

Figure 3—Reflectance map, orbit 680, July 5, 1966.

A short digression may be useful for meteorological purposes. Several areas with daytime temperatures below 300°K did not appear even slightly cloud-covered on the AVCS photographs, as over Saudi Arabia (Figure 4) and over western Lybia at 26 degrees North. The rather low temperature is probably due to thin layers of clouds, or broken clouds; these cannot be seen on the AVCS photographs, because the brightness of the terrestrial features overwhelms their effect. In the infrared, these almost invisible clouds evoke a singularity in the radiation field, by the absorption of radiation from the hot surfaces underneath and emission of radiation with their own but much lower temperature. Thus measurements of daytime infrared radiations appear to be a helpful tool to detect thin cloudiness over highly reflecting land surfaces.

The two daytime equivalent black-body temperature maps have the same general structure, with the cold and warm areas seen at the same places. During the hot summer days, the sea is



NIMBUS II - DAYLIGHT MRIR (CHANNEL 2)

EQUIVALENT BLACKBODY TEMPERATURE

(WITHOUT CORRECTIONS)

ORBITS 0613 AND 0614 JUNE 30, 1966

Figure 4—Daytime equivalent black-body temperatures, map, orbits 0613 and 0614, June 30, 1966.

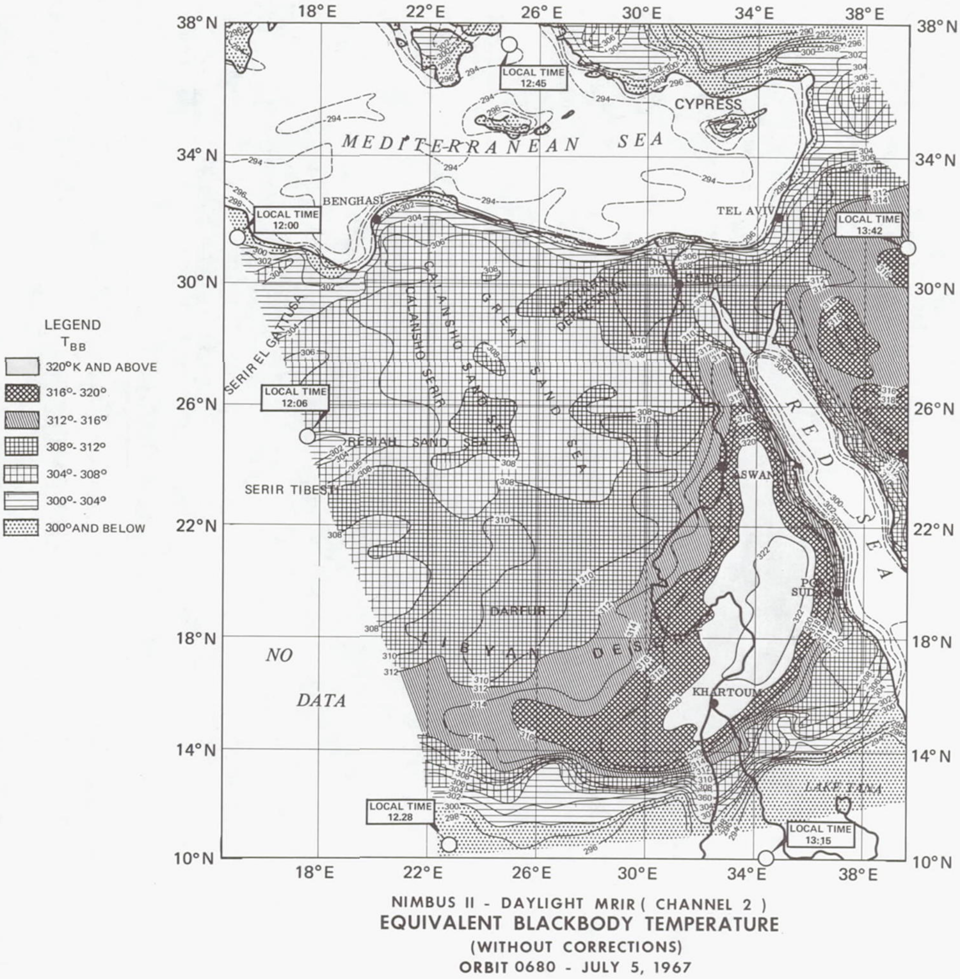


Figure 5—Daytime equivalent black-body temperatures, map, orbit 0680, July 5, 1967.

much cooler than the land. At night (Figure 6), the opposite is true: radiative cooling causes a considerable drop of surface temperatures over land, while the water surface temperatures remain nearly constant. Hence, continents' temperatures are more extreme than those of the seas'.

Much more valuable are the similarities and differences between day and night ground temperatures, as seen with the common parts of Figures 4 and 5 (daytime) and Figure 6 (following night):

1. *Similarities:* At low latitudes, thanks to vegetation and atmospheric humidity, one observes the same general patterns on both maps. For instance, when going westward from Khartoum, ground temperatures are generally cooler from East to West. By day and night the isotherms are

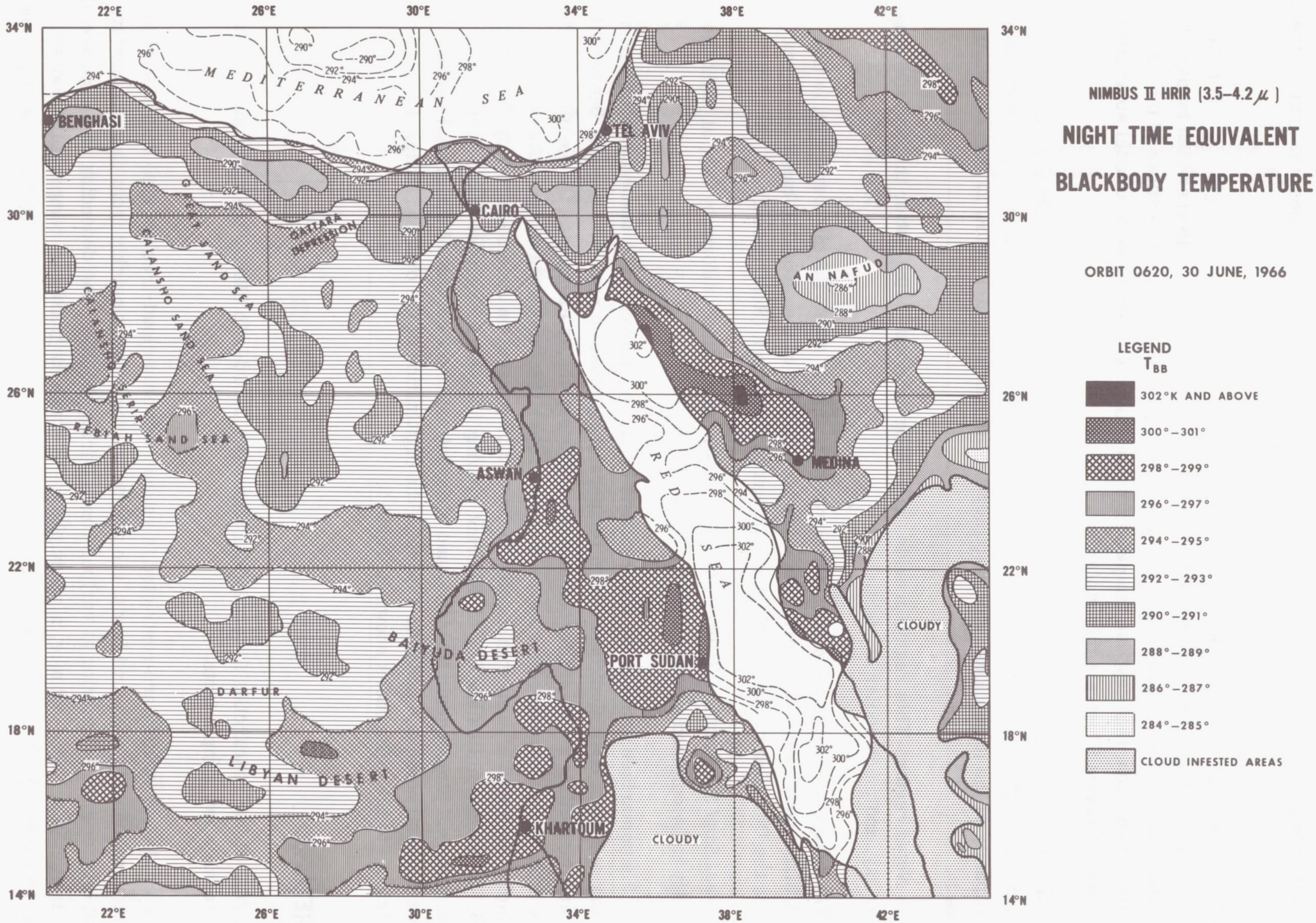


Figure 6—Nighttime equivalent black-body temperatures, map, orbit 0620, June 30, 1966.

parallel to the shorelines, at least when rather close to them; at lower latitudes, the general trend is E to W.

2. *Contrasts:* Much more striking are the differences between day and night T_{BB}. For the same general areas, the pattern of ground temperatures at night is more diverse than by day. Perhaps it is because the intense solar heating warms the ground uniformly regardless of the differences in rock formation, that daytime temperatures are more closely related to local solar time. The following examples illustrate this statement.

Baiyuda Desert: One observes the switching of the warmer areas which are, during the day, across and north of 22 degrees North, and south of that parallel during the night. Obviously, the heat capacity of the formations, whatever they are, is much greater below 22 degrees North than above it.

An Nafud region: This region provides a striking contrast; being hotter than surrounding regions by day, and much cooler at night.

The trough of the Dead Sea does not show up by day; at night, the differentiation in the equivalent black-body ground temperatures allows a fair view of the elongated basin below sea level where the Dead Sea occupies only a small part of the trough (Reference 1).

Great Sand Sea, Qattara Depression: Both areas are rather uniform by day; at night there are perfectly individualized patches at 294°, 292°, and 290°K.

Table 2 summarizes some of the observations briefly mentioned. The last column (differences between day and night equivalent black-body temperatures) must be read with caution, because the local solar times differ considerably between the regions given as examples. On the other hand, there are differences between reflectances measured over the same area on two different days. For example, An Nafud is seen with a reflectance of 37.5 percent on June 30, and only 30 percent on July 5. These anomalies are due to different viewing angles with respect to incoming solar radiation, different atmospheric turbidity, and different moisture content of the ground surface. Slight instrumental noise and possible errors in the digitization of the original analog data, may also contribute to the differences shown in Table 2.

INTERPRETATION

The goal of our researches is terrestrial features. In order to clarify the following explanation, we recall a few simple facts.

First of all, our studies are restricted to regions not only cloud-free but also rather barren for obvious reasons. In such arid lands, the ground warms up very quickly from dawn to midday, with peak temperatures occurring at various times during the afternoon depending on the nature of the rock formations. (For instance, a sandy plain will reach its maximum temperature sooner than a rocky surface.) The cooling immediately after sunset is also a "differential" cooling. Sand

Table 2

Evolution of Reflectance and Equivalent Black-Body Temperatures.

Locations	Reflectance (percent)		Equivalent Black-Body Temperatures			Difference Between Daytime and Nighttime T_{BB}, June 30, 1966 °K
			Daytime (MRIR)		Nighttime (HRIR)	
	June 30	July 5	June 30 °K	July 5 °K	June 30 °K	
Cairo	27.5	25	306	310	290	16
Tel Aviv	20	15	306	302	296	10
Dead Sea Trough (Tel Aviv latitude)	25	15	308	308	294	14
Red Sea (26°N - 36°E)	7.5	10	300	300	298	02
Medina	20	15	320	318	296	24
An Nafud (28°N - 40°E)	37.5	30	316	314	286	30
Aswan	27.5	27.5	316	318	290	26
Baiyda Desert (18°N - 34°E)	25	25	316	322	298	18
Libyan Desert (18°N - 22°E)	27.5	32.5	316	310	294	22
Darfur (19°N - 26°E)	35	37.5	314	310	292	22
Qattara Depression (30°N - 27°E)	35	35	306	308	292	14
Great Sand Sea (26°N - 26°E)	35	40	306	306	290	16
Calansho Serir (28°N - 22°E)	32.5	35	318	306	293	25
Rebiah Sand Sea (25°N - 22°E)	32.5	37.5	314	306	292	22
Sinai (30°N - 34°E)	32.5	30	308	310	288	20

cools very rapidly and becomes very cold, while the hard rocky formation will keep the heat of the day for a much longer time. The factors involved have already been stated, but let us recall that the soil moisture plays a predominant role, allowing the impregnated formations to store the solar energy absorbed during the day.

Night and Day Equivalent Black-Body Temperatures

The moisture of the soils and rocks moves toward the cooler part of the profile; not toward the warmer (References 11 and 12). By day, the heat drives the moisture downward; the influence of the humidity is annihilated and a general tendency to uniformity is realized (everything else being equal). Daytime heating is weakened, as already stated, by large bodies of water (Red Sea, Mediterranean Sea), and by a dense vegetal cover, mainly, in our example, at low latitudes.

After sunset, land surfaces cool rapidly in such arid regions, allowing the humidity that had been driven downward to move upward toward the cooler surface, bringing its stored heat. One of the best examples is the Dead Sea region, whose trough is clearly seen through the moisture showing up (Reference 1). Other good examples are on either side of the Red Sea, with striking ones between Medina and the eastern fringes of the Red Sea; between Port Sudan and Aswan; in the warm spots north of Khartoum, in the Baiyuda Desert, etc.

Because of the extreme density of wadi (rivers) flowing toward the depression of Borkou, in the Libyan Desert, at 22 degrees North and 16 degrees East, the warm spots are clearly understandable, especially at night. The Great Sand Sea is particularly cool at night, especially in the southern part (young and bright sands), while the northern section composed of older weathered sands is slightly warmer. The presence of water is attested to by the numerous Birs (wells) shown in topgraphical maps. The hot row between Medina and the Red Sea is explained by the great abundance of moisture. As a matter of fact, this area is characterized by a particular density of streams. Finally, the amazingly cool area of An Nafud (which is very hot during the day) is closely related to huge sandy plains that cannot store daytime heat.

The fields of equivalent black-body temperature over continental areas are further somewhat modulated by surface elevations. Thus, in such studies as done here the satellite measurements should be "reduced" to a reference level. Suitable relations for such reductions can possibly be obtained accurately from measurements of infrared radiation from a geosynchronous satellite (see page 15, top).

Reflectance and Equivalent Black-Body Temperatures

In theory, a high albedo (high reflectance) should correspond to a low heat capacity, and a low albedo to a high heat capacity. During the daytime, it would be difficult to link reflectance and ground temperatures. For instance, the Red Sea is characterized by low reflectance and low daytime temperature. The Grand Erg, with a reflectance greater than 35 percent, is nevertheless a very hot area.

The relations between reflectance and nighttime T_{BB} are obvious and easy to understand; high reflectances give lower night temperatures and low reflectances give higher night temperatures. That rule is broken several times; three interesting exceptions are listed below.

1. *Region south of Medina:* As the reflectance is low, we should observe rather high T_{BB} values. Such is not the case, since the temperature decreases instead of rising. We do not know the explanation. This is the region of Jebel Radwa, but the presence of that mountain does not explain the singularity. Probably the night temperatures reflect some particularities of the rock formations.

2. *Region located at 22 degrees N and 28 degrees E:* Despite a very high reflectance, more than 35 percent, the heat capacity is much greater than one would have supposed. In that part of the Libyan Desert, the terrain consists of sands, stretching over wide flat areas. We suspect that the weathering of the sand has progressed as far as slightly loamy formations, able to store the heat of the day. Perhaps, too, the moisture of such a soil causes the higher ground temperatures at night.

3. *Region located at 26 degrees N and 31 degrees E:* Once more, the ground temperatures at night are higher than the reflectance (over 35 percent), would have let us suppose. Immediately to the south of that region, a great number of oases are observed, indicating the presence of a water table. We suppose that the proximity of the water table explains the contrast; the moisture rising at night, bringing a little of the stored heat; while by day the moisture of the surface is driven downward, leaving the surface dry and bright.

CONCLUSION

Our aim has been to attract the attention of specialists to the possibilities offered by a comparison of solar albedo and infrared equivalent black-body temperatures. We left most of the problems without even trying to find their solution, for two reasons: (1) this study was only a tentative approach and we had no opportunity to map and scrutinize all of the orbits available; and (2) (above all) the results must be checked on the field. This absolutely essential field control could not be accomplished with our facilities.

This last remark leads to the real conclusion. We hope we have shown what splendid possibilities exist with the data obtained through the satellites. Furthermore, the exceptions to the rule linking the values of reflectance and nighttime T_{BB} are most fruitful because they lead to recognition of terrestrial idiosyncracies.

On the other hand, the study of the daytime equivalent black-body temperatures is rather deceptive. Note the immense differences due to the differences in local solar time (due to longitude differences) in the arid lands where the ground is very sensitive to the action of the burning sun. In a short while (one to three hours) the temperature difference between the eastern ridge of the scanned area and its western border is too big to allow a fair comparison: the east is always too hot, the west too cool as measured from Nimbus II daytime data (Figure 7).

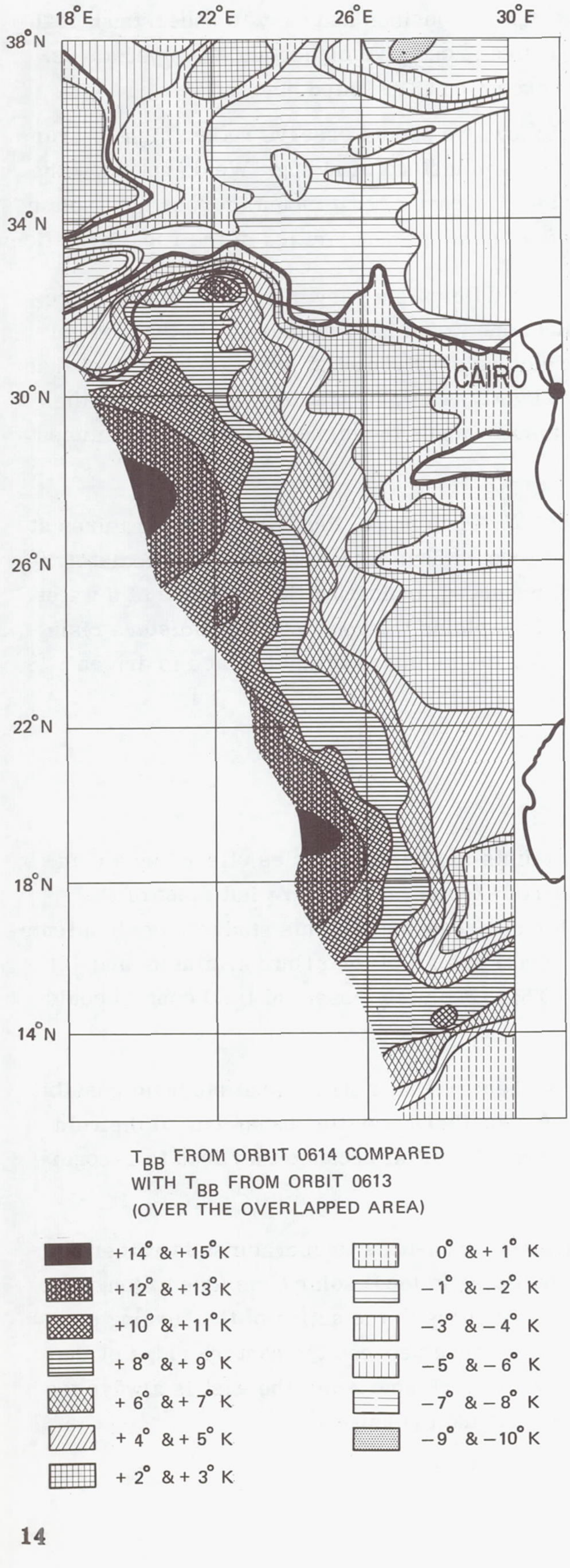


Figure 7—Influence of local time over land and sea, orbits 0614 and 0613 overlapping; observations of common area; June 30, 1966.

The facts would be quite different if we could obtain data collected by a sun-synchronous satellite, provided that the resolution is acceptable. In the near future, Applications Technology Satellites (ATS) will be launched and placed in a geosynchronous orbit. At a height of roughly 35,000 km and with a view angle of 0.3 milliradian (radiometer containing an 8-inch aperture Cassegrain telescope) (Reference 13), the ground resolution will be approximately equivalent to the HRIR resolution of Nimbus II. In that case, we could obtain data taken every 20 minutes or so, over the same area, allowing a reading of the "time history." With a previous knowledge of the heating ratio of different geological formations, easily acquired in the laboratory, we shall be able to detect geomorphological features with an ease unknown before the Space Age.

Finally, we do not think that, in the long run, geological, geomorphological and pedological maps will be constructed exclusively from satellite data. Field work is, and will always be, imperative. The new possibility offered by the Space Age must be considered as only a tool, albeit a marvellous one, used to select in advance, with a precision unknown in the past, areas of interest which can then be investigated on the ground more carefully than would have been possible without the spacecraft.

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160-44-03-96-51

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