DEPARTMENT OF ATMOSPHERIC SCIENCES
UNIVERSITY OF WASHINGTON

THIRD SEMI-ANNUAL REPORT
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# ON THE USES OF INTERMEDIATE INFRARED AND MICROWAVE INFRARED IN METEOROLOGICAL SATELLITES

by

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Prepared for

National Aeronautics and Space Administration
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# PREFACE

This progress report is the third in a series of semi-annual status reports on this contract and covers the period from October 1, 1965 to March 31, 1966. During this period work has progressed on the analysis of the Nimbus HRIR grid point data, theoretical studies of surface emissivity in the intermediate infrared region and meteorological modeling for the microwave study. Modifications and calibrations of the microwave radiometer as enumerated in the first annual report have been nearly completed. In addition, plans for further experimental emissivity measurements in the intermediate infrared region are outlined herin.

# HRIR GRID DATA ANALYSIS

The Nimbus HRIR grid point data for orbit 195/96 for the daytime pass over the area from the Equator to 20°N, 66° - 84°W have been carefully analyzed. As an example of land-water contrasts, the clearly-defined island of Jamaica is at a temperature of 290 - 295°K, while the surrounding ocean is about 15° cooler. This suggests that the temperatures are about 20 - 25°K too low, since the tropical ocean should be around 300°K. Hot spots at 12.5°N and 77.5°W as well as at 14°N, 75.5°W are 15 to 20 degrees warmer than the surrounding ocean in a region where there are no islands. There are also cold spots about 10° colder than ambient temperatures. We hope to identify these with various types of cloud once the weather data for this region have been received.

The mysterious cellular system around 78°W, 10°N (7cm up and 5cm from the right side of p.3 in the Nimbus HRIR catalog (1) ) shows a warm center with up to 300° surrounded by a cool area in the 270's. The system just to the south of it is both smaller and shows a smaller temperature range. Since this is in the region of specular reflection, it could be due either to different heights or reflectivities of clouds; the weather data should enable us to draw some definite conclusions about this.

Another puzzle is the bright line in the Orinocco region clearly visible in the picture on p.3 of the catalog (about 6cm from the bottom and 1/2cm from the right edge) -- it is not to be found in the grid point data. The dodging of the catalog print would only enhance such a line, not create it, so it seems likely that smoothing of the data has somehow washed out the thin cold line.

In the east of the picture at 66°W and around 4 to 6°N we find cold mountains with temperatures around 276° to 279°K while the surrounding territory has temperatures in the 290's.

Progress is also being made in the analysis of the Mediterranean area grid point data for orbit 207 over the area from 350° to 6°W and 30° to 50°N; and orbit 1[illegible]1 covering the area from 270° to 290°W; 55° to 65°S, a well-defined South American frontal system.

A problem complicating the interpretation of these data is the presence of APT interference of unknown magnitude. It should be noted, however, that it is extremely unlikely that this could have caused the line resembling the Orinocco on the print since numerous physical features, coastlines, rivers, mountains, islands and lakes have been identified on the catalog prints. It is very unlikely that the APT would create a solitary ficticious feature in just the place where a real feature would appear.

Two more facts make the high albedo of vegetation at 3.5 - 4 microns very likely:

1. The submolecule basic for organic matter, C - H, has characteristic stretching vibrations in the 3.0 - 3.7 micron area.

2. R. Zirkind (2) shows reflectances of orange trees which are strongly but irregularly increasing from 3.2 to 3.7 μ. They are as high as over deserts. Measurements, unfortunately, end at 3.7 microns, but the trend at that value indicates still higher albedos for wavelengths greater than 3.7 microns. Extrapolating Zirkind's data up to 4 microns yields an albedo of 21% for orange trees.

## THEORETICAL EMISSIVITY INVESTIGATIONS IN THE INTERMEDIATE INFRARED.

A computer program is being developed, which calculates the equivalent black body temperature observed by a radiometer under open sky, when viewing agitated or calm ocean. For the very simple situation that has been looked into so far the difference from true surface temperature was on the order of 0.5°K for both calm and rough ocean. This value is large enough to be significant in certain applications of radiometry to oceanography.

In short the program has the following components. For the area viewed a slope distribution is assigned with $K$ categories of slope angle $\phi_k$; each category covering a certain percentage, PC $(\phi_k)$, of the projected surface area. The goniometric emissivity averaged over the wavelength region of interest is determined for each category of slope from Fresnel formulas and Centeno's data on complex index of refraction (3). The equivalent black body temperature of the area of the sky reflected by a certain slope is calculated by a subprogram.

The formula used for rough ocean and the radiometer in zenith is as follows:

$$N\ (T_x) = \sum_{k=1}^{k=K} \left[ E\ (\phi_k) \int_{WL_1}^{WL_2} B(T_s,\ \lambda)\ d\lambda + \{1-E(\phi_k)\} \cdot \int_{WL_1}^{WL_2} B(T_{sky}\ (2\phi_k),\ \lambda)\ d\lambda \right] . PC(\phi_\kappa)$$

N - radiance

$T_x$ - equivalent black body temperature of the wavy ocean

$\kappa$ - dummy index for slope category

$K$ - number of slope categories

E $(\phi_\kappa)$ - emissivity of water at angle $\phi_\kappa$ from zenith

$WL_1$ $Wl_2$ - lower and upper limit of Planckian integration

$B(TT,\lambda)$ - the Planckian for temperature TT and wavelength $\lambda$

$T_s$ - true ocean surface temperature

$\lambda$ - wavelength of electromagnetic radiation

$T_{sky}$ - equivalent black body temperature of the sky at the angle $2\phi$ from zenith See figure 1

$PC(\phi_k)$ - percentage of the area viewed having slope $\phi_k$

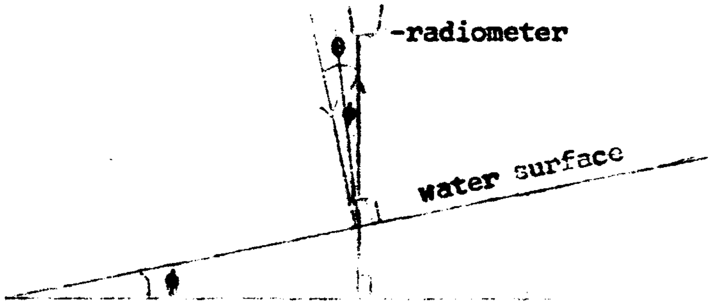

Figure 1

The program has been tested with a slope distribution derived from a simple two dimensional sine wave of 2 units amplitude and 20 units wavelength divided into 7 categories of slope. The 7.6 - 12 micron wavelength region was used with index of refraction data every 0.4 microns. An analytic formula for the equivalent sky temperature $T_{sky}$ as a function of zenith distance ($\theta$) was derived from radiation measurements with Barnes IT2 radiometer (8 -- 12 microns) taken on a clear day in Seattle summer 1965 (4). The formula is $T_{sky} = A + B \sec^{1/2}\theta$, where A and B are empirical constants. For this situation the deviation from true surface temperature was approximately 0.4°K for both the flat and rough sea.

This theoretical approach to ocean emissivity will be extended to include a more realistic slope distribution. From measurements of the sun's glitter pattern Cox and Munk (5) have developed an analytic formula for the probability of a certain slope as a function of wind speed. This formula can easily be incorporated into the present program. The situation for different seastates, different sky conditions, overcast or partially cloudy, different regions of the electromagnetic spectrum, the radiometer positioned at an angle from zenith, oil slicks present on the ocean surface, etc. will be investigated in the future.

A small test program was also written in connection with our Nimbus I HRIR studies. We were curious about how much the calculated emissivity would differ, if it had been obtained on the one hand from data of radiance and true temperature, and on the other from solar reflection data. For the 4 micron window we have the sun's energy at the earth's distance corresponding approximately to that of a 350°K black body. However, while the sun's energy curve has its maximum to the short wavelength end of the window, a 350°K body would have the maximum to the long wavelength end. We assume a very steep spectral emissivity curve $E(\lambda)$, with $E(\lambda) = 96\%$ at 3.3 microns and 60% at 4.2 microns, decreasing monotonically between, with data every 0.05 microns. The Nimbus filter curve $\phi(\lambda)$ is given in the catalog (d). These two spectral curves are superimposed on the Planckian energy curve of a 350°K body, and also on the Planckian energy curve for 6000°K reduced by a fractional value, $Fr = 2.0/\sigma\ 6000^4$ to account for the distance of the earth from the sun. 2.0 is the solar constant in ly/min, and we assume no loss due to the atmosphere for the window, $\sigma 6000^4$ is the total energy output of a 6000°K black body, and $\sigma$ is Stefan Boltzmann constant in units of $\text{ly/min}^\circ\text{K}^4$. The sun is assumed at the zenith. From the above an average emissivity can be calculated for each case, designated $\overline{E}_y$ and $\overline{E}_z$ respectively.

The formulas for the calculations are the following:

$$\bar{E}_y = \frac{\int_{3.3}^{4.2} E(\lambda) \cdot \phi(\lambda) \cdot B(350,\lambda)d\lambda}{\int_{3.3}^{4.2} \phi(\lambda) \cdot B(350,\lambda)d\lambda}$$

$$\bar{E}_z = \frac{\int_{3.3}^{4.2} E(\lambda)\, Fr \cdot \phi(\lambda) \cdot B(6000,\lambda)d\lambda}{\int_{3.3}^{4.2} Fr \cdot \phi(\lambda) \cdot B(6000,\lambda)d\lambda}$$

The result for this extremely steep spectral emissivity curve was: $\bar{E}_y$ = 73.6% and $\bar{E}_z$ = 76.7%.

There is a certain temperature dependence for $\bar{E}_y$ such that at T = 240°K $\bar{E}_y$ = 72.1%, while at T = 310°K $\bar{E}_y$ =73.2%.

## PROPOSED INFRARED EXPERIMENT

The average infrared emissivities of terrestrial materials as acquired by Lyon and Burns (6) from spectrometer data show some notable differences from those values measured by Buettner and Kern (7) with the emissivity box. A third method of measurement is needed to clear up the discrepancy. The proposal here is to compare directly the infrared signal from the substance of interest with that of a known black body at the same temperature. The Barnes IT-2 Infrared Thermometer is to be pointed alternately at the sample and the aperture of a black body cavity. The resulting outputs give the average emissivity of the surface over the 8 - 12μ region by the ratio

$$\bar{\varepsilon}(T) = \frac{\int_{8}^{12} q(\lambda)\, \varepsilon(T,\lambda)\, B_\lambda(T,\lambda)\, d\lambda}{\int_{8}^{12} q(\lambda)\, B_\lambda(T,\lambda)\, d\lambda}$$

where $q(\lambda)$ is the filter function of the instrument and $B_\lambda(T,\lambda)$ is the black body spectral radiance.

The blackbody radiation will be produced by a cavity of 2 slender, hollow cones soldered base-against-base with an aperture at one apex and with a uniform temperature controlled by a flow of water over the outside. If the interior is painted with Parson's Black an emissivity greater than 0.995 can easily be obtained.

Since the sample is not black, one must worry about the sample signal being too large due to reflected radiation from its surroundings. To avoid this, the sample is placed in a container kept at dry ice temperature, 195°K. The additional term due to 195°K emission in the expression for $\bar{\varepsilon}$ should be about 2% of the sample radiance, down to the noise level of the instrument, and can be measured along with the lesser effects of multiple reflections from sample and shield by replacing the sample by a cold metal mirror.

Inherent in the design of the apparatus will be the capacity to measure the angular variation in the infrared emission. Other properties not yet fully studied that will be investigated are various kinds of sands and dune structure and the IR emission of wet versus dry snow.

## The Microwave Study

Emphasis during the past six months has been given to the theoretical aspects of atmospheric probing using a passive microwave system. Consideration has been given to the methods for data collection and to interpretation of the data. Computer programs for the absorption coefficient and brightness temperature over the frequency range of 1-40 gc/s have been written and a number of simple models have been constructed to aid in the interpretation of observations. An observational program has not yet begun primarily due to delays in obtaining antenna range time, but is scheduled to begin shortly.

## Methods of Data Collection

In previous reports it was stated that the 19 gc/s radiometer had been constructed with two operational configurations in mind. The first using a rather large parabola for sky, rainfield and terrain emissivity observations and the other using a small horn antenna for emissivity measurements on small samples. The possibility of using a compact version of this radiometer on a light aircraft has also been mentioned. Thoughtful consideration as to which methods would provide the most relevant and significant data has led to the abandonment of the measurement of the emissivity of small samples and to increased emphasis on aircraft flights. The observational program will begin with ground based measurements but a cooperative program with the Boeing Company whereby high altitude flight time on a 707-320C could be obtained on an unscheduled basis is being pursued. The main difficulty in establishing this cooperation lies in the expenditure required to design and install a special antenna to meet required safety and aerodynamic specifications on this aircraft.

## Computer Programs

For the purpose of modeling the meteorological situation corresponding to a set of observations a general program capable of representing several basic models is being written. This program is designed to calculate the total absorption along a specified atmospheric path and the brightness temperature looking along the same path. Gaseous absorption is assumed to be adequately described by the Van Vleck equations for oxygen and water vapor. For particulate matter measured values of one-way attenuation are used to describe the extinction of atmospheric radiation. Scattering is being ignored for the time being, but will be introduced as the modeling develops. A number of theoretical cases will be calculated for the purpose of predicting the brightness temperature and changes of brightness temperature under real conditions.

## Radiometer Testing and Modification

During the past six months the microwave radiometer which was described in the first annual report on this contract has been repackaged to reduce its size and weight. The antenna radiation pattern has been obtained on the 2000 foot pattern range of the Boeing Company and was found to have the following characteristics for vertical polarization:

Beamwidth between half-power points---

Azimuth = 2.33° Elevation = 2.50°

Beamwidth between one-tenth-power points---

Azimuth = 3.92° Elevation = 4.67°

Maximum side lobe level = 21.0 db

Approximate antenna gain = 36.0 db

This performance is less than calculated and is probably due to misalignment of the feed horn. It is hoped than an adjustment can be made and a new pattern obtained at a later date.

The IF post-amplifier bandwidth has been increased from 3 mc/s to 8 mc/s by substituting an LEL amplifier for the AIL amplifier of the original model and the radiometer is now undergoing some bench and field testing to determine its present characteristics. Several solar drift curves have been obtained along with sky brightness temperature measurements. Recorder sensitivity of 100°K per inch has been achieved and will be increased substantially when the range of the balance voltage circuit is extended.

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