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Spectral Measurements of
Infrared Sky Radiance

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SPECTRAL MEASUREMENTS OF INFRARED SKY RADIANCE

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ABSTRACT

Recent measurements of the thermal infrared radiance of the sky are presented, showing the spectral distribution of radiation from the zenith. Samples of the data are compared with computer calculations for similar meteorological conditions. The computer calculations are based on the computer program LOWTRAN 3B,¹ and were presented at last year's passive conference.² In general, the data confirm expectations that Tucson, with clear skies and dry air, is a good location for infrared radiative cooling systems. For an *idealized* selective surface at 25°C (described in the body of this paper) the average cooling rate would have been 89 w/m² in Tucson (8/14/78 to 10/5/78), and 65 w/m² in San Antonio (9/21/78 to 10/6/78). If this idealized selective surface were allowed to cool down, it would reach an average temperature of -21°C in Tucson and -7°C in San Antonio.

1. INTRODUCTION

Infrared radiative cooling is a natural process continually underway in our environment. As a consequence, this process contributes in an important manner to the heat balance of buildings. It therefore behooves the passive designer to take advantage of heat flows due to

infrared radiation when possible, and to interfere with radiative energy flows which are detrimental. Probably the most important potential application for the use of infrared transfer is for summertime cooling to displace conventional air conditioning.

In order to compute the heat transfer of infrared radiation between an exposed surface and the sky, it is necessary to have a knowledge of the infrared radiance of the sky. Depending on the application, it may be necessary to obtain a division of the sky radiation into its angular components (that is, position in the sky) and spectral components (wavelength). Routine information of this type has apparently never been gathered; most observations are limited to several days at a time. To provide this information, the filter spectrometers described here were designed and constructed. They are intended to provide data records at 30 minute intervals for weeks and months of continuous operation.

2. DESCRIPTION OF THE SPECTROMETERS

The spectrometer design incorporates a Barnes Corporation model 12-880 radiometer equipped with an eight-position filter wheel, germanium lens, and pyroelectric detector. Of the eight filter positions, one is an open hole and one is a closed hole used to determine the instrument's zero offset. The remaining 6 filter positions contain infrared interference filters with "halfpower" cuton and cutoff points given in microns by (8.1, 13.7), (8.3, 9.1), (9.4, 9.9), (10.0, 11.4), (14.0, 15.8), and (16.6, 21.6). In addition to a stepping mechanism

which allows the filter wheel to be positioned automatically, the instrument contains a rotating mirror assembly which allows the instrument's 2° field of view to be pointed in the vertical direction or into a 70°C black body cavity. The entire instrument is under microprocessor control and is accessible to Lawrence Berkeley Laboratory through a MODEM telephone link. The accumulating data is transmitted over this link at intervals of one to three days.

Several measurements are made to supplement the basic radiometer data. Total infrared radiation is monitored with an Eppley pyrgeometer. Temperature and dewpoint are measured using standard techniques. The presence or absence of rain is also monitored.

Three radiometers are located in the field at the time of this writing. Systems were installed at Tucson, Arizona in August, 1978; at San Antonio, Texas in September, 1978, and at Gaithersburg, Maryland in November, 1978. At the end of January, 1979, these instruments will be recalled for maintenance, and will be modified to make radiance measurements at several non-zero zenith angles. The instruments will then be relocated in the field for the summer of 1979, to obtain further data during periods of high air conditioning load.

3. SAMPLES OF THE DATA

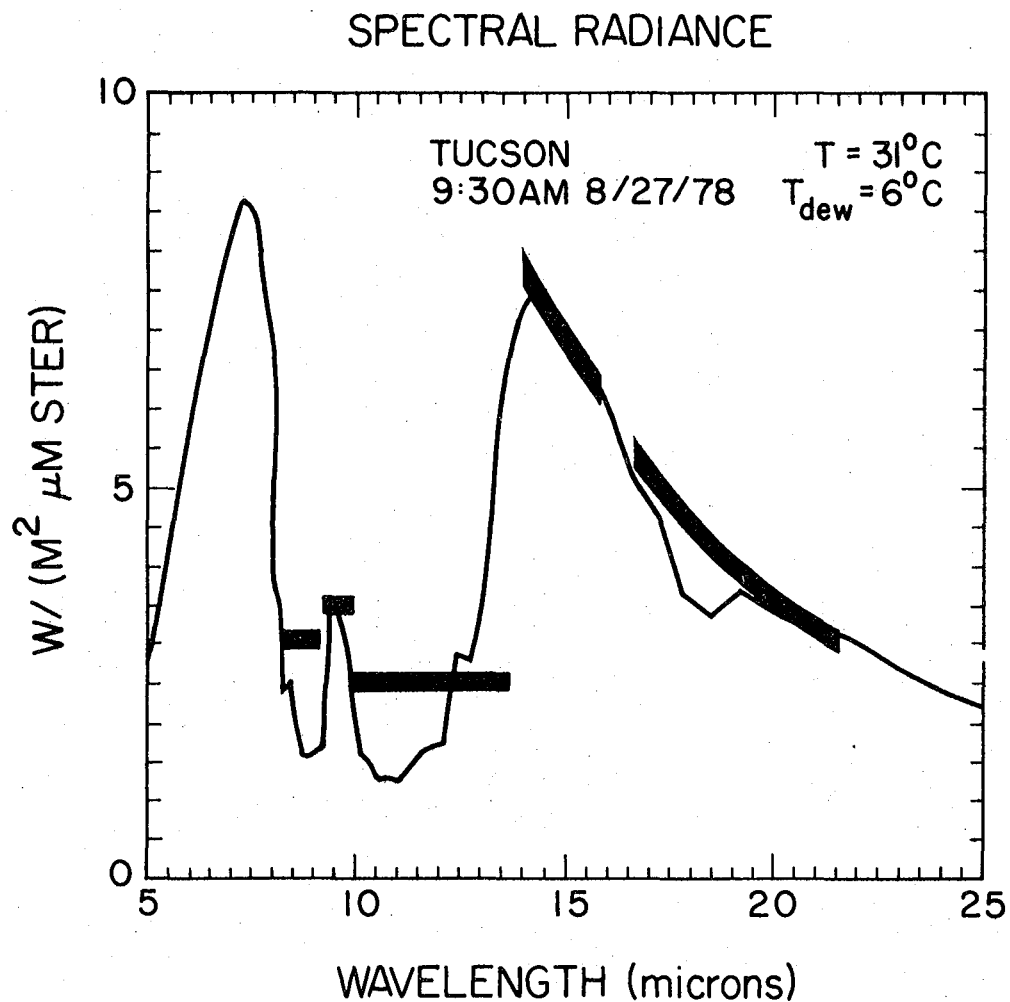
The Figures show samples of the radiometer data, superimposed on calculated spectra for similar meteorological conditions (identical air temperature and dewpoint). The measured radiances are assumed to be constant within each filter passband, or to be a segment of a black

body curve, whichever is more appropriate. The calculated spectra are obtained from a modification of the computer program LOWTRAN 3B.¹ This program produces low-resolution infrared transmittances based on the water vapor, carbon dioxide, ozone and temperature along atmospheric paths. A careful use of Kirchhoff's law permits an evaluation of the corresponding infrared radiances. Except as constrained by surface air temperature and humidity, the atmospheric constituents were assigned typical midlatitude summer values. Thus the agreement obtained here is an indication that reasonable accuracy can be obtained from calculations which do not employ radiosonde data.

The general agreement between the calculated and measured values of spectral sky radiance confirms that both the computer program and the radiometer produce reliable information. However, a detailed comparison between theory and experiment would require a knowledge of radiosonde data (temperature and humidity profiles), and it would also require that the detailed spectral characteristics of the infrared bandpass filters be taken into account. We plan a comparison of this type for later in the year.

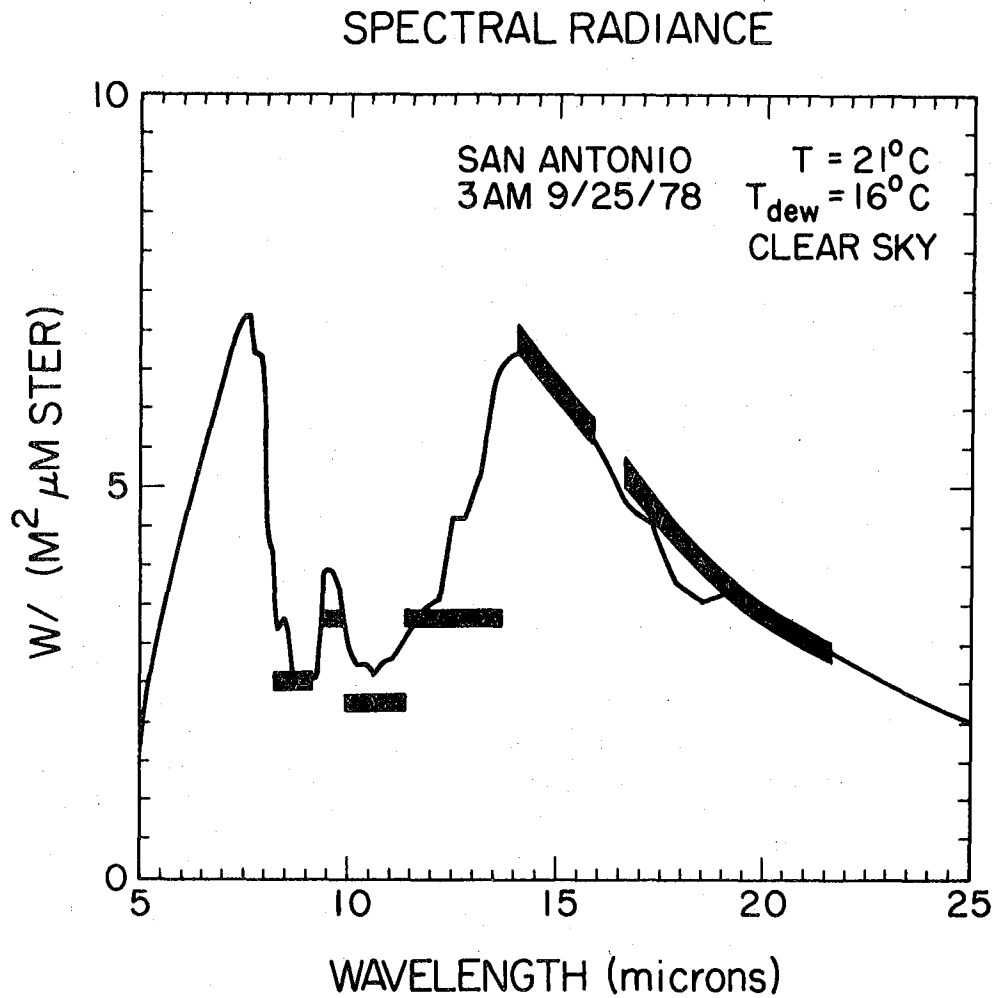
4. SUMMARY OF WARM-WEATHER DATA FOR TUCSON AND SAN ANTONIO: 8.1 TO 13.7 MICRON FILTER

The most important measurement obtained to date is the zenith radiance as seen through the 8.1 to 13.7 micron filter. In the next section of this paper this data will be interpreted in terms of the cooling rate of an idealized selective surface; here we merely present average values, based on measurements made every 30 minutes, 24 hours/day.



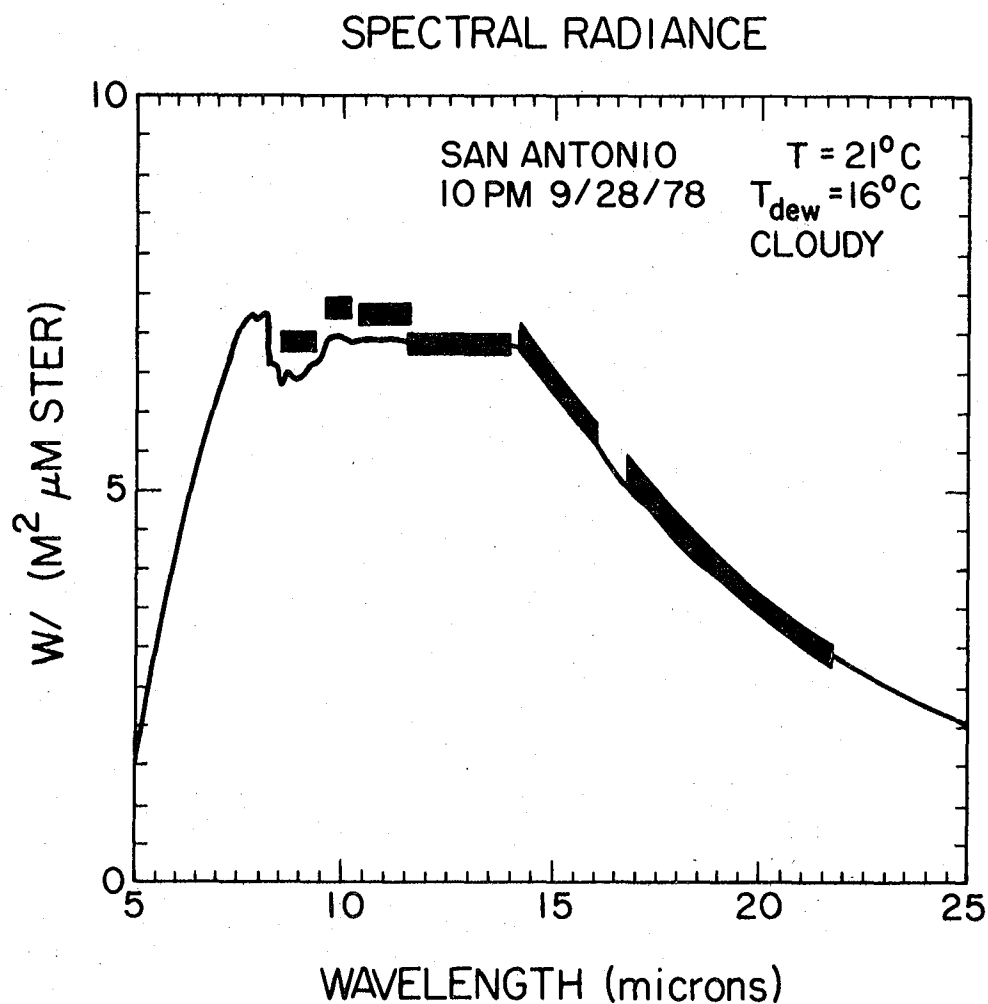
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Fig. 1. Spectral radiance, both computed and measured for clear sky conditions at Tucson, Arizona. The 10.7 micron filter is absent. Radiance in the 9.9 to 13.7 micron band is deduced from the 8.1 to 13.7 filter, after adjusting for the filters at 8.7 and 9.6 microns.



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Fig. 2. Spectral radiance, computed and measured for clear sky conditions at San Antonio, Texas. Radiance in the 11.4 to 13.7 micron band is deduced from the 8.1 to 13.7 filter, after adjusting for the filters at 8.7, 9.6, and 10.7 microns.



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Fig. 3. Spectral radiance, computed and measured under conditions virtually identical to those of Fig. 2, but with a cloud in the field of view. In the computed spectrum, the cloud is regarded as a black body with an elevation of 4 km.

TUCSON DATA		August 16-31	Sept. 1-15	Sept. 22-30	Oct. 1-5	Units
A	Spectral radiance 8.1 to 13.7 μm .	3.99	4.18	3.49	3.71	$\frac{w}{(\text{m}^2 \cdot \mu\text{m} \cdot \text{ster})}$
B	Temperature of a black body with the same radiance.	-20	-18	-26	-23	$^{\circ}\text{C}$
C	Calculated spectral radiance (8.1 to 13.7 μm) of a black body with a temperature of 25 $^{\circ}\text{C}$.	9.00	9.00	9.00	9.00	$\frac{w}{(\text{m}^2 \cdot \mu\text{m} \cdot \text{ster})}$
D	Cooling rate of a black surface @ 25 $^{\circ}\text{C}$ in the 8.1 to 13.7 μm band, in the vertical direction. (Row C - Row A)	5.01	4.82	5.51	5.29	$\frac{w}{(\text{m}^2 \cdot \mu\text{m} \cdot \text{ster})}$
E	Cooling rate of an idealized selective surface @ 25 $^{\circ}\text{C}$. (Row D x 5.6 μm x π ster)	88	85	97	93	wm^{-2}
F	Air Temperature	29.9	28.7	27.7	26.6	$^{\circ}\text{C}$
G	Dew Point Temperature	11.7	12.7	10.5	8.0	$^{\circ}\text{C}$
H	Hours per day with opaque clouds overhead	3.9	3.7	1.1	3.5	hrs.

Table 1. Radiometer data from Tucson, together with auxiliary weather data. The presence or absence of clouds was inferred from the radiometer data.

SAN ANTONIO DATA		Sept. 21-30	Oct. 1-6	Units
A	Spectral radiance 8.1 to 13.7 μm	5.06	5.42	$\frac{w}{(\text{m}^2 \cdot \mu\text{m} \cdot \text{ster})}$
B	Temperature of a black body with the same radiance	-8	-6	$^{\circ}\text{C}$
C	Calculated spectral radiance (8.1 to 13.7 μm) of a black body with a temperature of 25 $^{\circ}\text{C}$	9.00	9.00	$\frac{w}{(\text{m}^2 \cdot \mu\text{m} \cdot \text{ster})}$
D	Cooling rate of a black surface @ 25 $^{\circ}\text{C}$ in the 8.1 to 13.7 μm band, in the vertical direction. (Row C - Row A)	3.94	3.58	$\frac{w}{(\text{m}^2 \cdot \mu\text{m} \cdot \text{ster})}$
E	Cooling rate of an idealized selective surface @ 25 $^{\circ}\text{C}$. (Row D x 5.6 μm x π ster)	69	63	wm^{-2}
F	Air Temperature	23.3	23.8	$^{\circ}\text{C}$
G	Dew Point Temperature	16.9	17.2	$^{\circ}\text{C}$
H	Hours per day with opaque clouds overhead	10	10	hrs.

Table 2. Radiometer data from San Antonio, together with auxiliary weather data. The presence or absence of clouds was inferred from the radiometer data.

5. DATA INTERPRETATION

The units of spectral radiance make the present results difficult to interpret; they correspond to an energy transfer per unit time, per unit area, per unit wavelength (μm), per unit solid angle (steradian). For this reason we imagine an idealized selective radiating surface. Consider a selective surface which is a perfect reflector at all wavelengths (visible and infrared), except for the wavelength range of 8.1 to 13.7 microns, where it has an absorptivity (and emissivity) of unity. This imaginary surface has a surrounding reflector which allows it to view only the zenith region of the sky.³ It is also completely isolated from heat transfer by convection and conduction. For these conditions we can calculate the cooling rate of the surface based on the values in row D of the tables. One multiplies by the bandwidth of the filter, 5.6 microns, and then multiplies by π steradians (the "effective" solid angle), giving the results in row E. The lowest temperatures achievable with this system are given in row B of the tables.

A summary of the 8.1 to 13.7 micron data in terms of our idealized system is as follows. If the selective surface is maintained at a temperature of 25°C (by heating), it will reject 89 w/m^2 in Tucson and 65 w/m^2 in San Antonio for the periods covered by the data reported here. If allowed to cool it would reach an average of -7°C in San Antonio and -21°C in Tucson. Maximum cooling rates observed were 125 w/m^2 in Tucson and 115 w/m^2 in San Antonio. These cooling rates were observed during periods of clear atmospheric conditions.

Minimum cooling rates observed were 25 w/m^2 in Tucson and 12 w/m^2 in San Antonio. These minimum rates were observed during the presence of low clouds and/or fog.

6. ACKNOWLEDGEMENTS

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7. REFERENCES AND FOOTNOTES

- 1) J. Selby et al., "Atmospheric Transmittance from 0.25 to 28.5μ : Supplement LOWTRAN 3B". Available from the U.S. National Technical Information Service, Springfield, Virginia 22161.
- 2) P. Berdahl and M. Martin, "The Resource for Radiative Cooling", Proc. of the Second National Passive Solar Conf., Philadelphia (1978) Vol. II, p. 684.
- 3) If one omits the reflective surface, and allows the selective surface to view the entire sky, the rates of energy flow (at 25°C) cited in this section will be reduced by a small amount, perhaps 20%. However, the coldest temperatures achievable will be substantially increased.

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