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TECHNICAL REPORT NO. 41

INVESTIGATION OF THE SPECTRAL ENERGY DISTRIBUTION FROM CLOUDS AND BLUE SKY IN THE NEAR INFRARED

By

KEITH PIERCE

MCMATH-HULBERT OBSERVATORY

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SUMMARY

In general, the infrared spectrum of the blue sky shows a Rayleigh-type scattering in the region 0.7 to 1.0 micron. Beyond 1 micron there is a large contribution of scattered radiation approximating that of pure sunlight.

The energy distribution from clouds appears to be that of scattered sunlight with a slow uniform decrease in intensity from 0.6 to 2.6 microns. In addition, the water vapor bands are greatly strengthened except for cirrus-type cloud formations.

The cloud brightness is from 60 to 200 times that of the blue sky at 1 micron.

OBSERVATIONS

Equipment

A brief investigation is reported in which observations of the spectrum of clouds illuminated by sunlight, and of blue sky, were compared with sunlight reflected from white cardboard or an aluminum sheet. The spectral region covered was from 0.6 micron to 2.2 microns.

The observations were made with a Perkin-Elmer infrared spectrometer, Model 12-C, with a CaF_2 prism. The instrument was attached to the tail piece of the F. C. McMath 24 inch diameter Cassegrain-type reflector. The large telescope fed an F/4 beam to the first slit and filled the aperture of the prism. The spectrometer was greatly modified so as to use an uncooled Cashman-type[(1)] lead sulfide receiver. This modification involved adapting the exit optics of the instrument so as to image the second slit on the receiver. By introduction of a sector and motor to chop the entrance radiation at 1080 cps, we were able to use a Wilson[(2)] AC amplifier whose output was fed to a smoothing filter and a Brown recorder. The first slit, 1 mm x 10 mm as projected through the telescope optics, corresponds to 1/40 x 1/4 of a degree in the sky, so that it was this area of 1/160 of a square degree of the sky or of a cloud that was observed.

Observations of the Blue Sky

On 5 or 6 days repetitive runs were made on the light scattered by the sky. This sky light has its origin in sunlight incident upon the earth's upper atmosphere. The scattered radiation is not intense, and it was necessary to use slits of 0.5 to 0.8 mm in width and a fairly high amplifier gain, which tended to lower the resolution. With such wide slits a good many of the finer features of the spectrum were lost entirely and the stronger water vapor bands filled in by the low spectral purity. Figure 1A shows a typical trace of the sky spectrum. The vertical scale gives the intensity and the horizontal scale the wavelength in microns. The intensity is a function of the response of the lead sulfide cell and the characteristics of the spectrometer.

Since the sky light is derived from sunlight, it is logical to make a comparison between sky light and sunlight. Unfortunately, the comparison cannot be made directly by pointing the telescope first to the sun and next to the sky because of the great difference in intensity. Direct sunlight is too bright for the very sensitive receiver and amplifier employed. To reduce the light entering the spectrometer, sunlight was reflected from a white card or an aluminum sheet and observed with low amplifier gain and the same slit widths as were used for the sky observations. The reflectivity of the aluminum plate and white card should be practically constant within 5 percent over the spectral region concerned. Hence, the light reflected from the card or plate should have an energy distribution closely similar to that of direct sunlight but reduced in intensity.

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(1) Jour. Opt. Soc. Amer., 36, 356A, 1946
(2) Astrophysical Jour., 106, 246, 1947

From the work of Abbot and others we know that the energy distribution of sunlight approximates that of a black-body radiator at a temperature of about 6000°C. However, radiation reaching the observer is greatly modified by absorption of water vapor and other constituents of the atmosphere. Figure 1B shows the observed spectrum of sunlight and the presence of water vapor bands at 0.92, 1.1, 1.4, and 1.8 and 2.6 microns.

The ratio of blue sky to sunlight at each wavelength is given in Figure 2A. We observe that if sky light were merely re-radiated sunlight the ratio would be unity for all wavelengths. The λ^{-4} line indicates the energy distribution to be expected from a scattering medium obeying the Rayleigh law, in our case the blue sky. This law applies to those cases in which the scattering particles are very small compared with the wavelengths of the incident light(3). The observations, as indicated by the points near the upper heavy solid line which defines a mean, follow very well the Rayleigh law from 0.7 to 1 micron, while from 1 to 1.6 microns they deviate very strongly in the direction of a large solar component. In this figure all observations have been reduced so as to pass through intensity unity at a wavelength of 1 micron. One observing day was characterized by a slightly milky, whitish sky and gave quite a different curve from that of a typical blue sky. This particular day is indicated by circles in Figure 2A. The total intensity of sky light for this run was much larger than that from a corresponding clear day and has been greatly reduced in plotting it on the figure so that it passes through the point (1.0, 1.0).

The most interesting result from these observations is the fact that the sky is not nearly so black in the infrared beyond one micron as would be expected on the basis of the Rayleigh theory and its fit with observations at shorter wavelengths. It is logical to conclude that sky light is the sum of two components: (1) light from molecular scattering obeying the λ^{-4} law and (2) light scattered and diffracted from larger dust and ice particles which in a first approximation re-radiate the normal energy distribution of sunlight. The work of H. Zanstra,(4) on halos and the aureole about the sun and moon, indicates that the scattered light is probably produced by small ice crystals and would extend in diminishing intensity over the complete sky. It also seems likely that the point of separation of the two curves at one micron would probably vary with the elevation of the observer and perhaps slightly with the purity of the sky, but as yet no observations to test this point have been made.

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(3) A more complete discussion of scattering in the atmosphere is given by H. C. Van de Hulst in Chapter 2 of The Atmospheres of the Earth and Planets, edited by Kuiper, 1949, in The University of Chicago Press.

(4) Monthly Notices, Royal Astron. Soc., 103, 265, 1943.

It is also possible that the energy between 1μ and 1.6μ could be from scattered radiation from the surroundings of the instrument. However, several large modifications of the instrumental arrangement were tried with no difference in results. Therefore, it is felt that the observed energy is a real contribution from the atmosphere. In order to test this in another way, runs were made just before and just after sunset. The results are not conclusive because the energy at sunset is so weak, but they suggest that the sunlight component beyond 1 micron tends to disappear in the twilight sky.

Observations of Clouds

Figure 2B illustrates the energy distribution from clouds as compared with direct sunlight observed through the intermediary of reflection from a white card or an aluminum sheet. The considerable scatter of observations is due to the difficulty of following the cloud with the telescope and to its rapidly changing form and intensities. The cloud types that were observed were: (1) cumulus clouds, "face" illuminated with sun 90°-180° away; (2) stratus, illuminated mostly by transmitted light; (3) bright cloud edges illuminated by reflected and transmitted sunlight about 30° from sun; and (4) dark cloud centers about 30°-90° from sun. The figure shows that the energy distributed from clouds is essentially that of scattered sunlight. The only exception to this is the great additional absorption which appears in the water vapor bands at 0.8, 1.1, 1.8, and 2.0 microns in cumulus-type formations.

A rough estimate of the intensity of cloud edges at 1 micron in comparison with the blue sky gives a ratio of about 50 to 200 to 1. This ratio varies greatly with the nature of the cloud and the mode of illumination and its distance in degrees from the sun. The work of Abbot[5] shows that for equal areas the sun is approximately 1.5×10^5 times as bright as light reflected from clouds.

Several runs were made on clouds near the sun. When sufficiently thick they appear dark in the central regions and have brillianly illuminated edges. Again the center and edge repeat the sunlight distribution, but the dark center may be 10 to 50 times less bright than the edges.

This investigation originated with Director R. R. McMath of this Observatory and was carried out by the author.

(5) Ann Astrophys, Obs. Smithsonian Inst., 2, 136, 1922

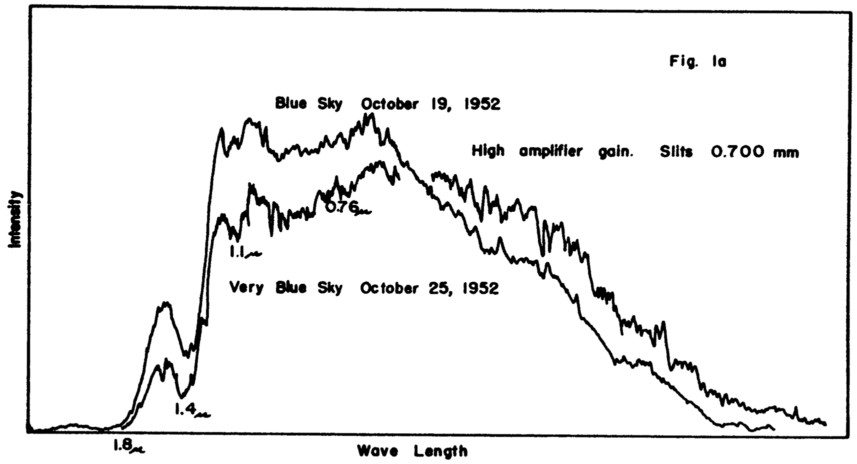
Fig. 1a
Blue Sky October 19, 1952
High amplifier gain. Slits 0.700 mm
0.76μ
1.1μ
Very Blue Sky October 25, 1952
1.4μ
1.8μ
Intensity
Wave Length

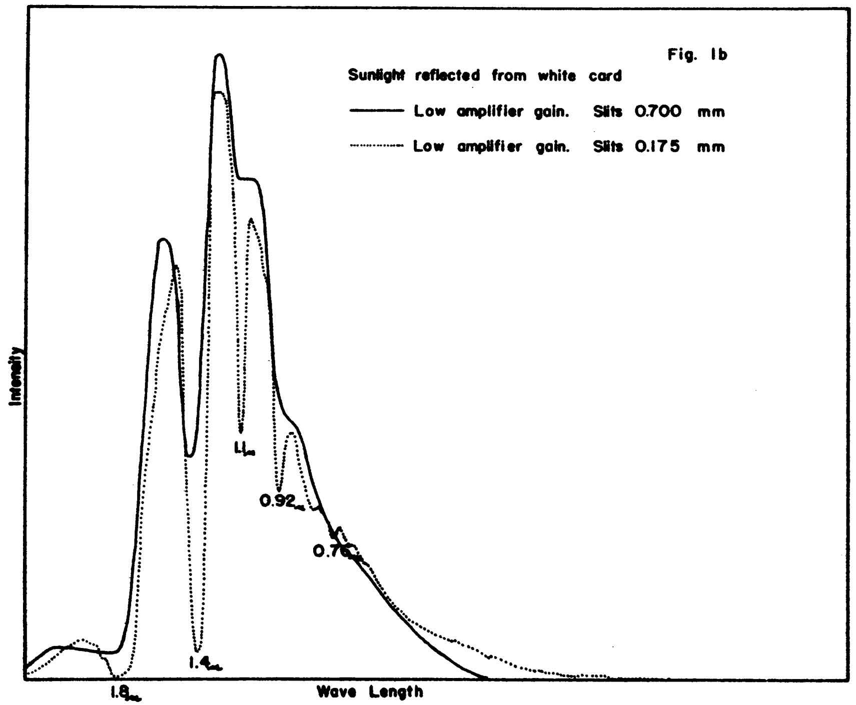
Fig. 1b
Sunlight reflected from white card
Low amplifier gain. Slits 0.700 mm
Low amplifier gain. Slits 0.175 mm
1.1μ
0.92μ
0.76μ
1.4μ
1.8μ
Intensity
Wave Length

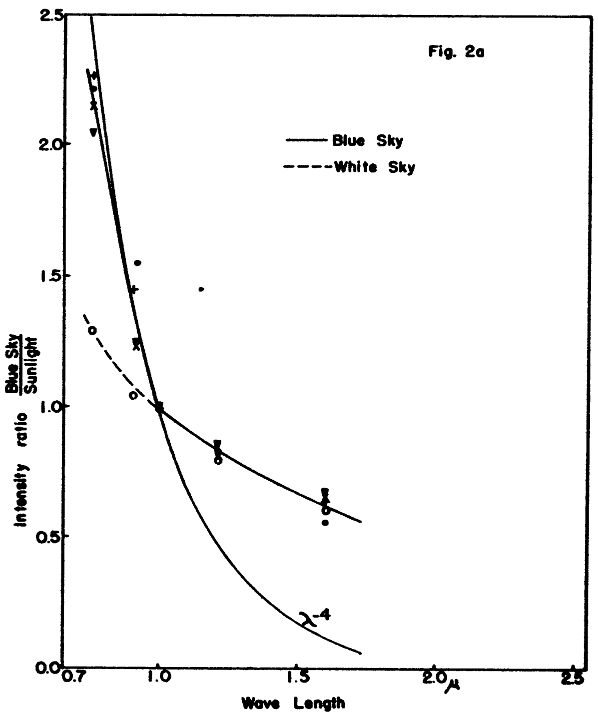
Fig. 2a
Blue Sky
White Sky
λ-4
Intensity ratio Blue Sky/Sunlight
Wave Length
0.0
0.5
1.0
1.5
2.0
2.5
0.7
1.0
1.5
2.0μ
2.5

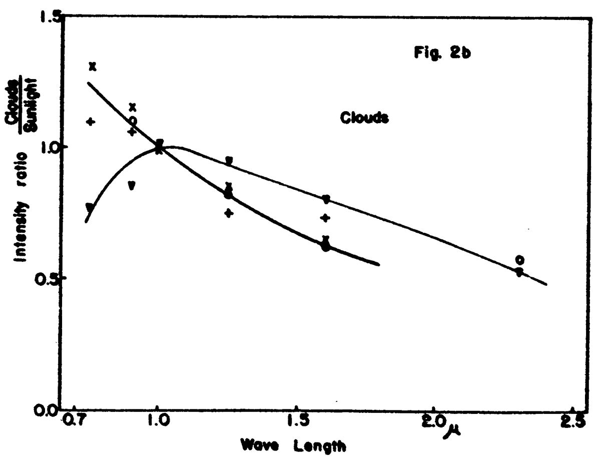
Fig. 2b
Clouds
Intensity ratio Clouds/Sunlight
Wave Length
0.0
0.5
1.0
1.5
0.7
1.0
1.5
2.0μ
2.5

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