The second Umkehr observed in Zenith sky twilight and its interpretation

by K. R. RAMANATHAN, P. D. ANGREJI and G. M. SHAH *,

Physical Research Laboratory
Ahmedabad 9.

RÉSUMÉ. — *Les observations de l'effet umkehr sur le ciel au zénith étaient effectuées à l'aide d'un spectrophotomètre Dobson à Ahmedabad sur 3 paires de longueur d'onde, A, C et D, de 1962 à 1965. Les observations s'étendaient jusqu'au moment où le soleil était de 8 à 10 degrés sous l'horizon. On constate l'existence de deux autres renversements après l'effet umkehr normal. Les derniers effets umkehr sur la paire de longueurs d'onde D se présentent quand le soleil est plus bas sous l'horizon que pour les observations sur C et A. Lorsque nous prenons la différence des effets umkehr A-C, A-D ou C-D, il y a un renversement pour toutes les différences, pour une dépression solaire de 5 à 6 degrés sous l'horizon.*

Sur un certain nombre de cas, quand les observations de l'effet umkehr sont faites, les brillances crépusculaires à 70° du zénith dans le plan méridien du soleil sont aussi mesurées, et le taux maximum de variation de brillance avec le changement de hauteur des rayons rasants du soleil se présente pour une dépression solaire de 5 à 6 degrés. On suggère que les deux phénomènes sont en liaison et sont dus à la diffusion de la lumière par des aérosols dans la basse stratosphère à des altitudes variant entre 20 et 28 km.

ABSTRACT. — *Zenith sky umkehr observations were made with a Dobson spectrophotometer at Ahmedabad on three wave-length pairs A, C and D from 1962 to 1965. The observations extended to times when the sun was 8° to 10° below the horizon. They show the existence of two more reversals after the normal umkehr. The later umkehrs on the D wave-length pair occurred when the sun was lower down than when observations were made on C and A. When we take the difference umkehrs A-C, A-D or C-D, all of them show reversals when the solar depression below the horizon is 5° to 6°.*

On a number of occasions when the umkehr observations were taken, twilight sky intensities at 70° from the zenith in the sun's meridional plane were also measured, and the maximum rate of change of intensity with change in the height of the grazing rays of the sun was found to occur when the solar depression was 5° to 6°. It is suggested that the two phenomena are related and are due to the scattering of light by aerosols in the lower stratosphere at varying heights between 20 and 28 km.

* Now working in the Meteorological Office Toronto, Canada.

Ann. de. Geophys. 25, 129–134,

Observations on the C wavelength pair made at Mt. Abu in 1952 by R. N. Kulkarni showed on some days a second reversal in log I'/I when the sun was about 3° below the horizon. I' and I are the intensities of 3324 Å and 3114 Å respectively. Dütsch reported a similar phenomenon at Arosa in 1959. Its presence has also been reported by WARDLE, WALSHAW and WORMELL [1963]. Observations of this phenomenon have been continued at Ahmedabad on all three wavelength pairs A, C and D since 1961 by G. M. Shah and P. D. Angreji. The frequency of such observations was increased towards the end of 1963 when the bright twilight glows following the volcanic eruption at Mt. Batur in Bali Island in Indonesia began to be measured. Some preliminary results of these observations were reported at the Albuquerque Symposium in September 1964. In 1964-65, there were carried out on many clear days, observations both of umkehrs and of twilight airglows and the results of these observations and their discussion are given in this paper.

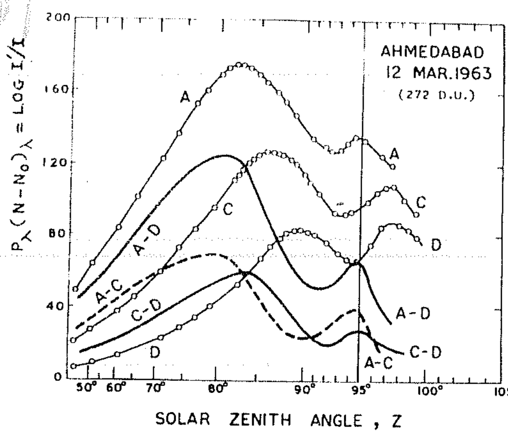

FIG. 1

Umkehr curves on λλ' A C and D obtained at Ahmedabad on 12 March 1963. Difference-umkehrs A-D, A-C and C-D are also shown.

Figure 1 shows the three umkehrs observed on 12 March 1963. It will be noticed that the first minimum of the umkehr took place after sunset on the A, C and D wavelengths when the solar zenith angles Z were about 92° and 93° and 95°. This is followed by a second maximum or hump at about 95° on A and 97°-98° on C and D wavelengths. The second hump is most prominent on D and least prominent on A. When we plot the difference-umkehr curves A-D, A-C and C-D, the humps are seen to occur in all the three wavelength pairs at $Z = 95°$, or when θ, the solar depression below the horizon, is 5°. Nine months later, on 9 January

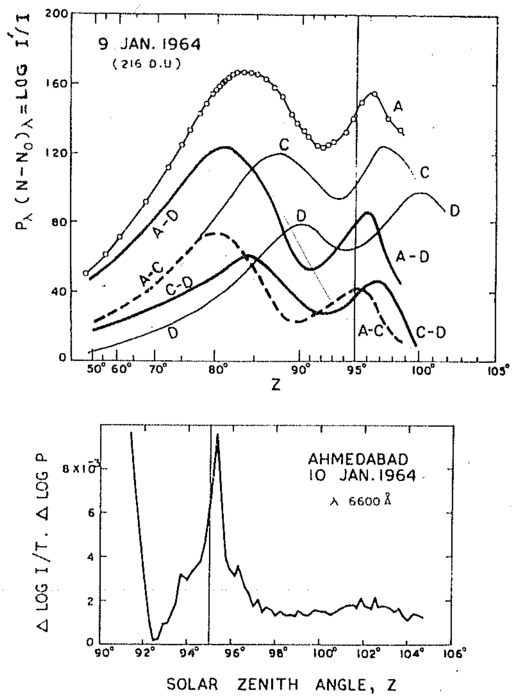

FIG. 2

Umkehr curves on λλ' A, C and D at Ahmedabad and Difference-umkehrs on 9 January 1964; and changes in twilight-sky intensity on 6600 Å at 70° zenith distance in the sun's meridian plane at Ahmedabad on 10 January 1964.

1964, when the twilight glow was very bright, similar observations were made. The post-sunset umkehrs were more prominent, and the second hump in D occurred when θ was about 10°. The humps in the difference-umkehrs were at θ = 6°-7°. On the next day, 10 January 1964, twilight brightness measurements were made on 6600 Å at an altitude of 20° above the horizon in the sun's meridian plane. In the same Figure 2 are plotted the values of $\Delta \log I/(T \Delta \log p)$, the rate of change of sky-brightness with height against θ, the depression of the sun below the horizon. The value of p corresponding to θ was calculated on the assumption that the screening height for red light was 6 km. It will be noticed that there is a prominent maximum of the ratio, when θ was a little greater than 5°. The rapid rise in the ratio from θ = 3° to θ = 5° means that we are getting much more light from the sky at that time than from molecular scattering alone and the subsequent fall in the ratio means that the sun's rays have passed above the layer responsible for the additional scattering.

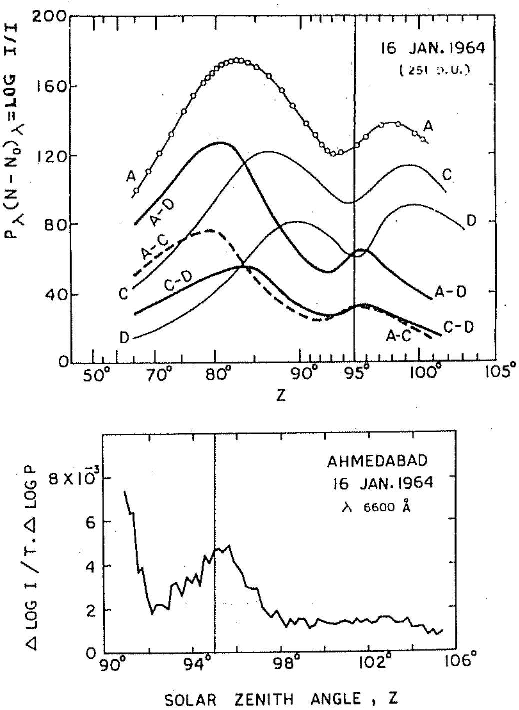

FIG. 3

Umkehrs and sky intensity on 6600 Å ($Z = 70°$) during twilight at Ahmedabad on 16 January 1964.

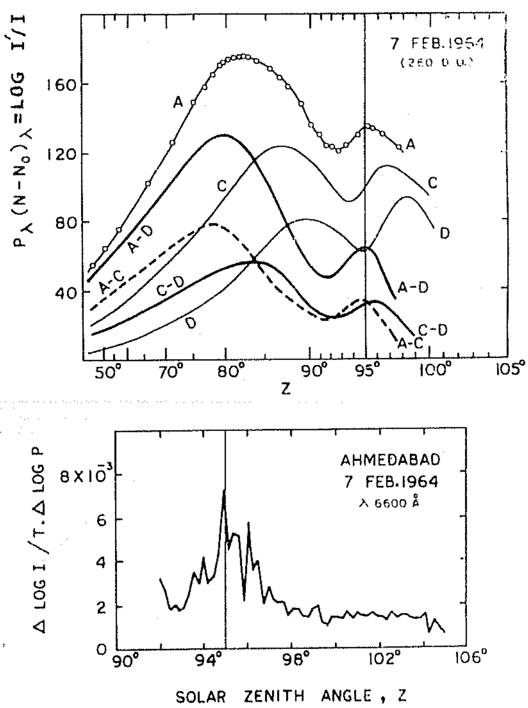

FIG. 4

Umkehrs and twilight sky intensity on 6600 Å and $Z = 70°$ during twilight at Ahmedabad on 7 February 1964.

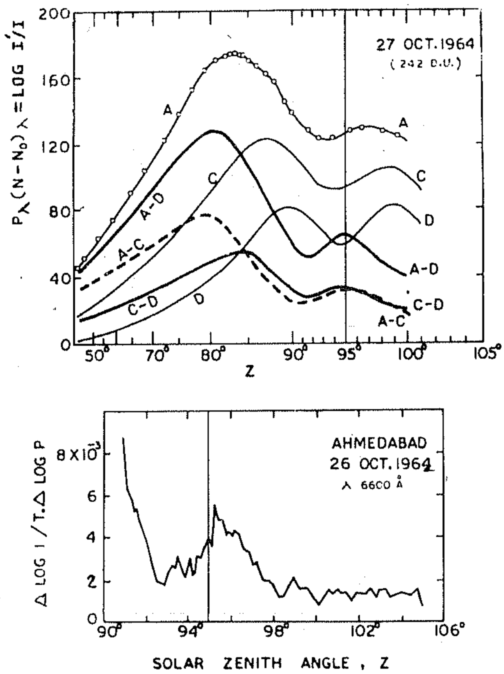

FIG. 5

Umkehrs on 27 October 1964 and twilight sky intensity on 6600 Å and $Z = 70°$ on 26 October 1964.

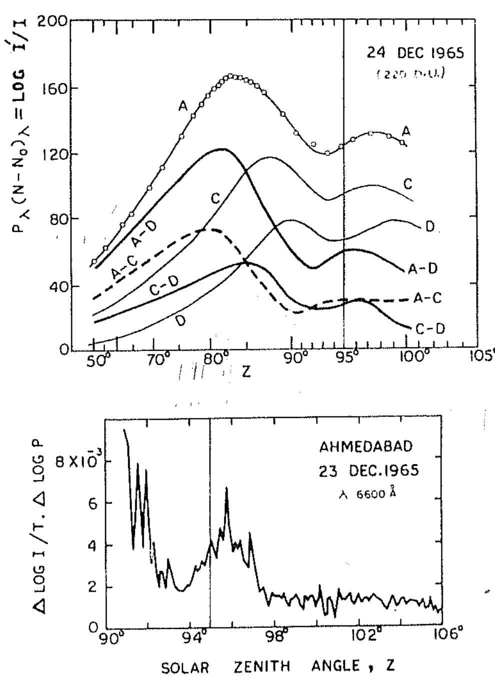

FIG. 6

Umkehrs on 24 December 1965 and twilight sky light on 23 December 1965 ($Z = 70°$).

Similar curves obtained on 16 January 1964 are shown in Figure 3. The humps are flattened and are less conspicuous than on 9 January 1964, but the humps in the difference-umkehrs remain at about $\theta = 5°$. The sky-brightness curves at 20° altitude towards the sun is also less conspicuous than on the 10th, and occurs at 5° to 6° solar depression. Similar curves obtained on 7 February 1964, 27 October 1964 and 23-24 December 1965 are shown in Figures 4, 5 and 6. In all these cases, the humps in the difference-umkehr curves occur at about $\theta = 5°$ to 6°, although the amplitudes of the humps differ. The significance of the difference-umkehrs is that the solar depressions at which they occur are only slightly influenced by the brightness of the twilight sky. That large differences occur in the second maximum of the umkehrs is well shown in the observations taken on 6 January 1961 and 9 January 1964 (Fig. 7).

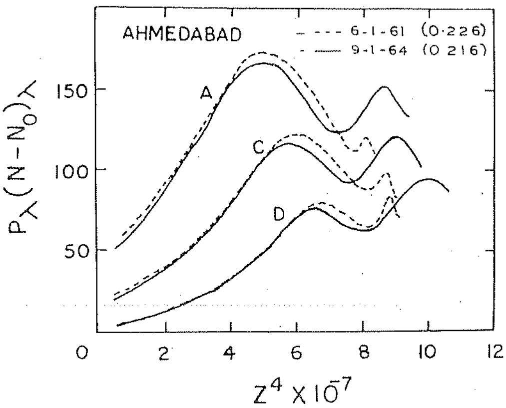

FIG. 7

Comparison of umkehrs on 6 January 1961 and 9 January 1964.

Large-particle scattering also affects the polarisation of the light from the sky. (Dave and Ramanathan 1956, Dave 1956), This is well seen in the zenith sky polarisation observed on 11 January 1964 and 1 February 1964 when the twilight glow was prominent (Fig. 8 and 9).

The question is: what is the origin of the second hump? Can it be explained by the suspected night-time increase in the partial pressure of ozone above 50 km which has been found by some rocket ascents at night? Or, is the second hump due to the illumination of the atmosphere above the region of ozone maximum by light scattered by aerosols in the stratosphere? Considerable evidence for such aerosols is now available from observations of twilight made in many countries and from direct balloon observations by Junge and his collaborators and by Newkirk and Eddy.

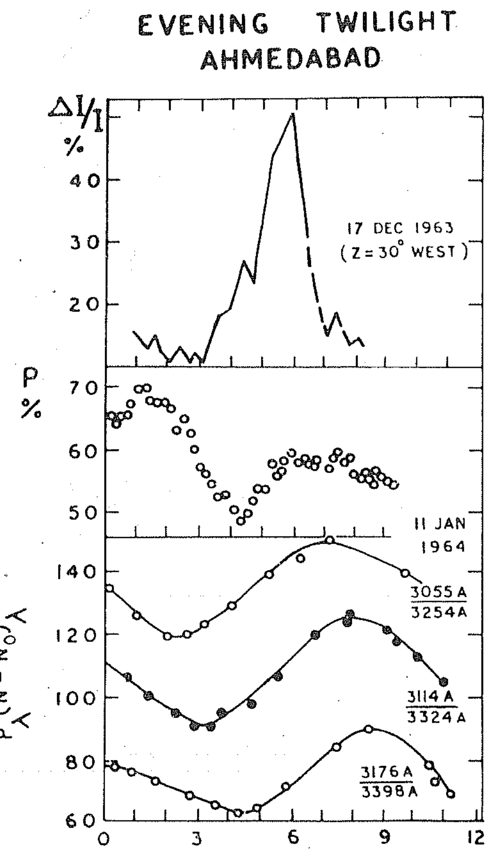

FIG. 8

Polarisation of Zenith-sky light during twilight on 11 January 1964. Umkehrs on the same evening.

In Figure 10 are plotted the intensities of primary and multiply scattered light of wavelengths 3025, 3225 and of 3175 and 3400 coming downward from the zenith sky to the ground when z is 85°, as calculated by Dave and Furukawa. The calculations refer to Rayleigh scattering from a plane parallel atmosphere when the total ozone amount is 0.323 atm—cm. It will be noticed that the intensities of the long and short wave radiations cross over at a height of about 40 km in the case of 3025, 3225 Å and at about 32 km in the case of 3175 and 3400 Å. From above the cross-over point, the light of the shorter wavelength is stronger. As the sun goes down, the shorter waves like 3055 Å and 3114 Å come only from the upper part of the ozone maximum region, while the longer-wave-length light continue to come from the lower layers also. When later, owing to increasing ozone-path, the longer wave-lengths

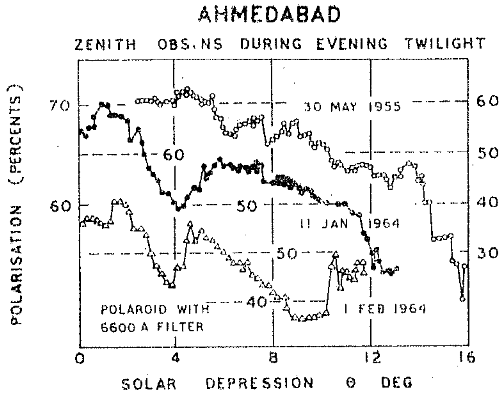

Fig. 9

Zenith sky polarisation on 30 May 1955, 11 January 1964 and 1[er] February 1964. Twilight glow was bright on the latter two evenings.

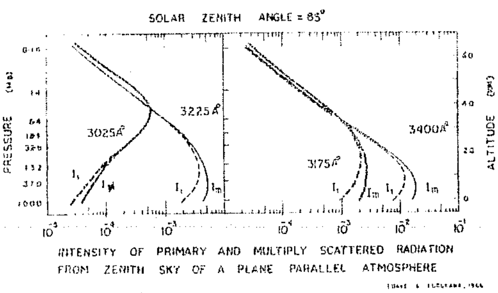

Fig. 10

Intensity of primary and multiply scattered radiation from Zenith sky of a plane parallel Atmosphere at $Z = 85°$ Data after Dave and Furukawa [1966].

are also absorbed in the region of the ozone maximum, we may expect that the ratio log I'/I will gradually attain a steady value. It has been found that the subsequent fall in the difference umkehr curve when $\theta = 5°$ or $6°$ cannot be explained on the basis of pure molecular scattering, even if there is a small increase in ozone concentration above 55 km.

Now consider Figure 11 in which is shown an aerosol layer at 20-25 km traversed by grazing rays from the sun. When the sun is 5° to 6° below the horizon, the zenith of the observer at Q will be in the direction QQ'. The light from the sun of the

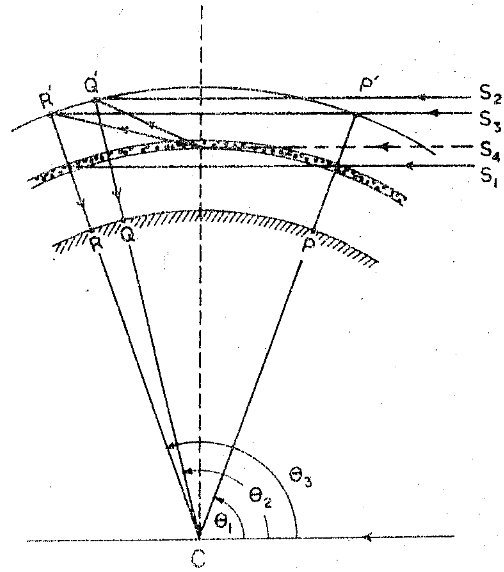

Fig. 11

Sketch diagram illustrating the effect of an aerosol layer on umkehrs obtained when the sun is below the horizon.

shorter wavelength coming in the directions S_1, S_4 and a few kilometers above S_4 will be almost completely absorbed, but the upper part of the atmosphere will be illuminated by direct solar rays and also by light scattered by the upper part of the aerosol layer. Owing to the large solid angle subtended at by the aerosol layer and the favourable direction, the scattered light from the aerosols can be a significant fraction of the sun's direct radiation. As the sun goes further down and the observation point is at R, the light of the longer wavelength also which is received from the aerosols at R' will be attenuated. Ultimately, what will be left will be multiply scattered light from above the ozone layer and the airglow radiations of the twilight and night sky. In effect, the stratospheric aerosol layer acts as a secondary source when the sun's rays graze the upper part of the aerosol layer and the second umkehr is the result. The almost stationary position of the difference-umkehr at about 5° of solar depression in spite of the great variability in the amplitude and flatness of the hump is strong evidence for this.

Manuscrit reçu le 8 octobre 1968.

REFERENCES

CHAGNON C. W. and JUNGE C. E., "Sub-micron particle profiles over India," *A.F.C.R.L. Research Report* 7690. India-US Balloon Project, 1961.

DAVE J. V. and RAMANATHAN K. R., "On the intensity and polarisation of light from the sky during twilight," *Proc. Ind. Acad. Sc.*, 43, 67-78, 1956.

DAVE J. V., "On the intensity and polarisation of light from the sky during twilight (Part II)," *Proc. Ind. Acad. Sc.*, 43, 336-358, 1956.

DAVE J.V. and FURUKAWA P.M., "Scattered radiation in the ozone absorption bands at selected levels of a terrestrial Rayleigh atmosphere," *Am. Met. Soc. Meteorological Monographs*, 7, 29, 1966.

DÜTSCH H. U., "Vertical Ozone distribution over Arosa," *A.F.C.R.L., Report AF* 61(514)-915, 1959.

MEINEL M. P. and MEINEL A. P., "Late twilight glow of the ash stratum from the eruption of Agung Volcano," *Science*, **142**, 582, 1963.

NEWKIRK G. and EDDY J. A., "Light-scattering by Particles in the Upper Atmosphere," *J. Atmos. Sc.*, **21**, 35-60, 1964.

WARDLE D. I., WALSHAW C. D. and WORMELL T. W., "A new Instrument for Atmospheric Ozone," *Nature*, **199**, 1177-78, 1963.