Note on Lidar Observations of Particulate Matter in the Stratosphere

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Numerous lidar observations here have revealed layers and patches of particulate matter in the clear atmosphere. In the troposphere, such layers can be associated with discontinuities in the temperature or humidity profiles and can readily be ascribed to dust or water substance in concentrations too sparse to be readily visible (Collis *et al.*, 1964; Collis, 1965). This note describes observations recently made of the higher atmosphere with an advanced lidar, the characteristics of which are shown in Table 1. Primary interest was in the detection of particulate matter in the mesosphere and thermosphere (60 to 120 km) such as has been reported by Fiocco and Smullin (1963). Although observations were made on some 16 nights during August and September 1965, including those of the Perseid meteor shower, no positive detection of significant returns from these levels was made.[1] Significant returns were regularly obtained from the stratosphere, however, which are now described.

In the receiver system used, signals are evaluated by recording a binary pulse in each 150-m range increment (i.e., 1-μsec intervals) in which one or more photoelectrons are detected by the photomultiplier for each lidar pulse transmitted. While this technique is suitable for the low photoelectron counts from high altitudes, it is overloaded below about 20 km. In any case, the recorded pulses can only be related to the mean inintensity of the return on a statistical basis. It is thus necessary to average data from successive observations and from extended range intervals in order to derive meaningful intelligence. (System noise is extremely low and the probability of recording a pulse due to internally generated noise in any 1-μsec interval is $\sim 10^{-4}$.)

With the low data rate (approximately one observation per two minutes) and with the low signal levels involved, the difficulty in such averaging lies in obtaining sufficient samples within the natural variability of the observed phenomena in space and time. The lumping together of samples from too long a time interval can readily obscure the structure that we have found to exist.

On each of the thirteen nights on which adequate runs of data were acquired, recorded counts were aggregated for each group of ten successive observations within height increments of 1500 m (10-μsec periods).

TABLE 1. Characteristics of SRI Mark II 1965 lidar.

	Transmitter
Laser	(Two)* 3″×½″60° orientation ruby crystal, rooftop and Brewster angle ends uncoated
Q-switch	Rotating prism
Pulse length	30 nanoseconds
Peak power	10 megawatts
Optics	12½″ Newtonian reflector telescope
Beam width	Approximately 0.01°
P. R. F.	2 per minute (each laser)
	Receiver
Photomultiplier	(Two)* 16 stage ITT type FW130G S-20 cathode
Optics	12½″ Newtonian reflector telescope
Beam width	0.01° to 0.7° max.
Bandpass	Approximately 4 Å
Display	Tektronix 555 dual beam oscilloscope and range gated threshold discriminator and digital counter

* This equipment comprises two separate transmitter and receiver systems capable of operating successively through the same optical system at intervals as short as 0.75 msec. Provision is made for varying the polarization of the transmitted energy and analyzing the received energy.

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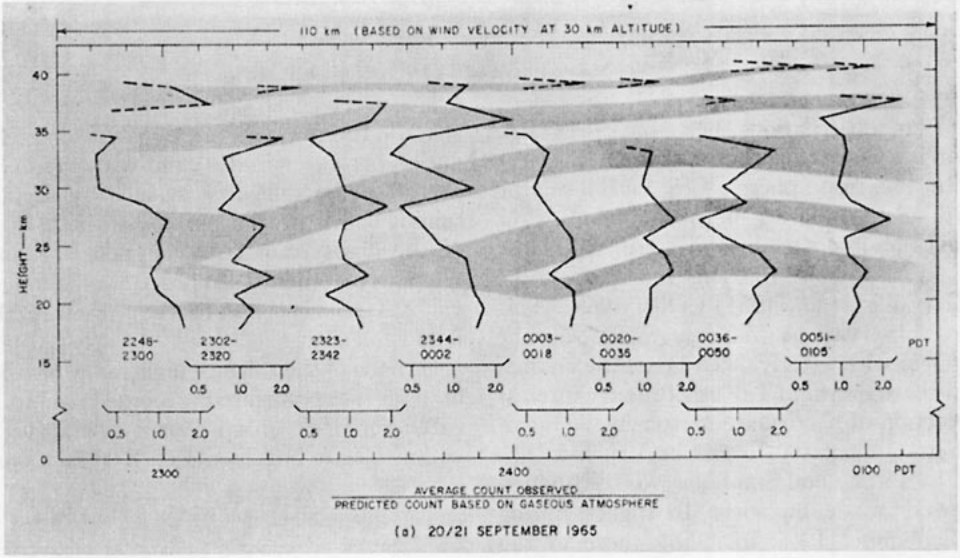
[1] The details of this investigation will be submitted for publication separately at a later date. In the meantime preliminary indications are that the overall sensitivity of the system used here was sufficient to have detected echoes from targets having volume back-scattering cross-section coefficients comparable to those reported by Fiocco and Smullin.

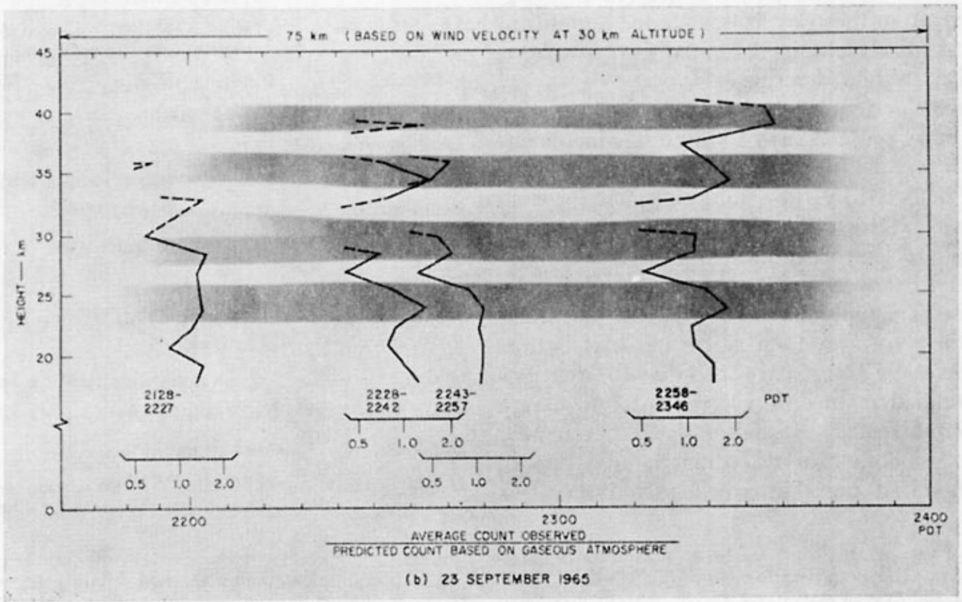
The average count for each layer was then compared with that predicted on the basis of the calibrated system performance and the volume back-scattering coefficients of a purely gaseous standard atmosphere (after Elterman, 1964).

On every night, variations were observed with height, many of which were consistent from one group of ten observations to another. On approximately 50 per cent of the nights a layered structure could be traced in such consistencies. For example: Fig. 1a shows the results of 80 observations made on the night of 20/21 September 1965. It shows the ratio of the average count observed to that predicted for each group of ten observations, for each 1500-m height interval. The fact that values less than would be expected from a gaseous atmosphere (ratios of <1) occur is due to imperfect absolute calibration of the system and the effects of varying degrees of attenuation in the lower atmosphere. The ratios are plotted on a log scale to facilitate ready comparison of the excursions of the curves irrespective of their absolute magnitudes. The average statistical variability in each group of ten observations at each level (one standard deviation divided by the mean) is 0.15 at 20 km, 0.25 at 25 km, 0.5 to 30 km, 0.7 at 35 km and 1.0 at 40 km.

A possible organization of the apparent structure is indicated. Fig. 1b shows in similar fashion the data derived from 40 observations made on the night of



(a) 20/21 SEPTEMBER 1965



(b) 23 SEPTEMBER 1965

FIG. 1. Lidar echoes from the stratosphere based on the ratio of observed counts to those predicted on basis of a gaseous atmosphere. Averages of groups of ten observations with counts averaged over 1500-m increments. a) 20–21 September 1965, b) 23 September 1965.

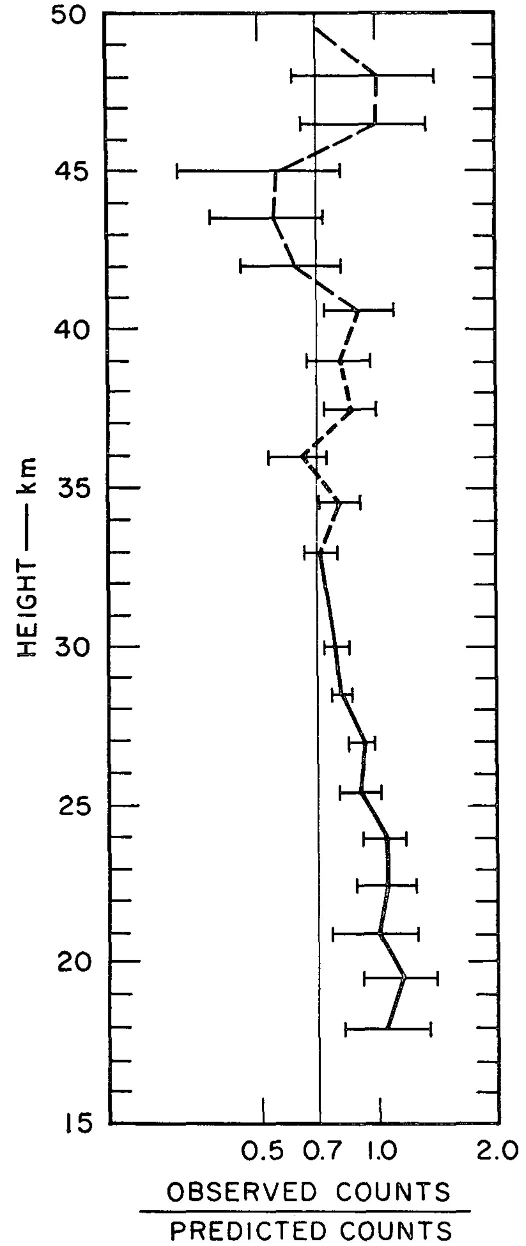


FIG. 2. Variations of lidar echo intensity with height based on the ratio of observed counts to those predicted on basis of gaseous atmosphere. Average of 430 observations, 9–30 September 1965, with counts averaged over 1500-m increments. Error bars indicate one standard deviation of count fluctuations.

23/24 September 1965. On the basis of the limited upper wind data available, a rough indication of the equivalent horizontal scale of the observations is also shown in each case. By aggregating data over larger groups of observations the statistical error residual in the plots shown in Figs. 1a and 1b is reduced; by the same token any variability in the true profile is smoothed out, although plots made of the averages of groups of *twenty* observations continue to show a marked consistency from group to group. Data averaged over all the 430 observations obtained during the study (Fig. 2) show enhanced reflectivity in the region of 19 km decreasing with height. (Valid data were not available below 18 km.)

If scattering at 33 km and higher is assumed to be due only to molecular scattering, and is used as a datum, the average scattering observed at 19 km is some 1.7 times greater than would be expected from a purely gaseous atmosphere. The enhancement in scattering due to layers of particulate matter on any given occasion would clearly be much larger than this. Having regard to the difference of time and place, these data are compatible with the findings of others, including Elterman and Campbell (1964), working with a searchlight, and Fiocco and Grams (1964), and Clemesha *et al.* (1965), working with lidars. The enhancement factors for the particulate matter layer found by these workers at around 20 km are approximately 1.5, 2.5, and 3.0, respectively. Because of the consistency of the fluctuations shown on a short-term basis, the present observations show in addition that particulate matter concentrations can occur in the stratosphere in much the same patchy or layered manner as has been observed by lidar in stable conditions in the clear lower atmosphere. This appears to confirm and extend the findings of Bigg (1964), who detected a highly variable stratification of particulate matter in the stratosphere using a twilight scattering technique.

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