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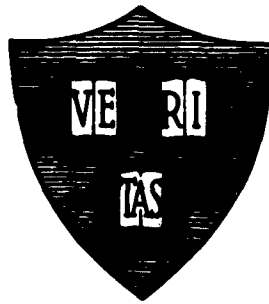
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Blue Hill Meteorological Observatory

Division of Engineering & Applied Physics  
Harvard University

TWILIGHT INTENSITY AT 20° ELEVATION  
Results of Observations



By

F. E. Volz

December, 1961

AF19(604)-4546 Scientific Report No. 2

Prepared for

Geophysics Research Directorate  
Air Force Cambridge Research Center  
Air Research & Development Command  
United States Air Force - Bedford, Massachusetts

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**HARVARD UNIVERSITY**

**Division of Engineering and Applied Physics**

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**Prepared for**

**GEOPHYSICS RESEARCH DIRECTORATE  
AIR FORCE CAMBRIDGE RESEARCH CENTER  
AIR RESEARCH AND DEVELOPMENT COMMAND  
UNITED STATES AIR FORCE  
BEDFORD, MASSACHUSETTS**

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Twilights 1 to 103 with omission of TW 23, 28, 29, 55, 67, 81, 87, 92, 95, 96	

Corrigenda for Report I ('Twilight Intensity at 20° Elevation', by F. Volz and R. M. Goody, 1960, AFCRC-TN-60-284).

p. 2, line 14. Should read ' ... the diameter of the earth's shadow varies ... '.

p. 19. Formulae in centre of page should read

$$\sum = \int \sigma(\theta) d\omega.$$

p. 21. Table 5. For  $\theta = 60^\circ$  replace 25 by 80. For  $\theta = 25^\circ$  replace 200 by 300.

Fig. 13. Replace  $d \log I_L / d\theta$  by  $d \log I_L / d \log I_D$ .

p. 32. Table 6. The ozone distribution employed corresponds to that in fig. 14c.

p. 39, line 3. Should read ' ... a weighted mean inverse scale height ... '.

## 1. Introduction

A previous report (Volz and Goody, 1960; hereafter referred to as Rep. I) gave a general outline of our twilight research. The aim of the measurements is detection and quantitative analysis of dust scattering in the atmosphere as high as possible having regard to interference by the airglow and unwanted scattering effects (in practice these give a useful upper limit of 80 km). The brightness of the twilight sky is recorded in 5 filter ranges from 380 to 660 m $\mu$ , at an angle of elevation of 20 $^{\circ}$ , in the sun's vertical\*. The instrumentation has been described in Rep. I, and a few results together with some twilight computations were presented.

A total of about 100 twilights have been recorded, mainly between September, 1959, and September, 1960, with a few up to November, 1961. In this report, the results at 20 $^{\circ}$  elevation will be presented in chronological sequence in the form of logarithmic intensity gradients ( $d \log I/d\delta$ ), color ratios (CR) and absolute green intensities, all as functions of the sun depression. Weather maps and cloud cross-sections along the path of the setting (or rising) sun provide some information on possible cloud interference. Daytime turbidity data, visual purple light observations and astronomical data are also given. Details of the measurements, evaluation procedures and data reduction will be discussed, together with procedures and results of instrument calibrations. Discussion of the results and interpretation in terms of vertical dust distributions will however be treated in subsequent

---

\* Apart from a few special investigations where measurements were made at 7 $^{\circ}$ , 90 $^{\circ}$  and 160 $^{\circ}$  elevation.

papers.

## 2. Instrumentation and measurements

A detailed description of the instrumentation has been given in Rep. I, but the general features will be repeated here for better understanding of the results.

A photometer of 41 cm effective focal length, with maximum aperture  $f/3.3$  at the focal plane and  $f/0.6$  at the photomultiplier, was used. Sky-light measurements from daytime to about  $5^\circ$  sun depression were made with a circular field of view  $0.67^\circ$  in diameter (field stop D), and in the later twilight with a rectangular field,  $0.79^\circ$  vertical by  $4.45^\circ$  horizontal. A removable objective cover provided further means of changing the light flux into the instrument in order to restrict the range of amplifier gain and range of illumination of the photomultiplier. Cover openings of 3 and 10 mm diameter were used at and shortly after sunset, and the full objective opening was used for sun depressions greater than  $6^\circ$ .

Four spectral bands were isolated by interference filters, having peak response at 380  $m\mu$  (UV), 431  $m\mu$  (B = Blue), 516  $m\mu$  (G = Green) and 605  $m\mu$  (O = Orange) and half widths of 10 to 14  $m\mu$ . The fifth spectral band was formed by an RG2 absorption filter in conjunction with the 10 stage RCA photomultiplier 6217 (spectral response S-10), giving an effective wavelength of 659  $m\mu$  (R = Red) with a half width of about 100  $m\mu$ . These filters, together with suitable neutral density filters to equalize mean deflections, are mounted on a rotating disc and each filter is held in position for 6 seconds.

The multiplier output is fed to an amplifier with a phase-sensitive

detector. A chopper interrupts the light beam inside the photometer 150 times per second and also provides the reference signal for the sharply-tuned amplifier. A gain switch at the amplifier input permits 7 gain changes by a factor of 2. The amplifier output is recorded on a Leeds and Northrup Speedomax Recorder with single trace, a time constant of 1 sec, and a chart speed of 2.5 cm per minute. The performance of the whole equipment was generally excellent.

Several methods were used to monitor the sensitivity of the instrument. The fundamental calibrations involved the measurement of sun and star intensities (see §3.4) which were periodically compared with an internal sub-standard (LI) consisting of a layer of Undark Luminescent Paint (U. S. Radium Corp., Pale Green Paint, type 12 M) which could be placed in front of the filters. This internal sub-standard could be frequently and directly compared with the twilight sky and could reasonably be expected to hold its intensity (subject to temperature corrections) between sun comparisons. Unfortunately, a reading from the paint could only be taken with the green filter, and it was necessary to assume constancy of color ratios. This point was investigated by means of solar observations (§3.3.2 and fig. 2) and with the aid of laboratory sub-standard lamps (LII and LIII) illuminating ground-glass screens through filters simulating the color of twilight (BG 28 and Kodak Wratten CC 50 M).

The twilight measurements were always made with the same schedule of electronic and optical gain settings. Electronic and optical gain changes kept deflections greater than 1/4 full scale, except for UV which sometimes gave a smaller deflection.

The azimuthal direction of the photometer was adjusted each 20 min.; deflection changes during adjustment were less than 2% in all colors.

The twilight measurements were generally made by the author, but a few were made by V. J. Walker and J. Gille (TW. 74, 75, 77, 79 and TW. 85 to 92). These twilights, and also the first 10 twilights, lack detailed visual observations of the purple light.

Measurements were always made with a cloud-free sky at the time of twilight, and good to moderate visibility. No effort was made to avoid distant clouds near or below the horizon.

### 3. Calibrations

#### 3.1 Gain calibrations

As already described in Rep. I, an optical calibration of the amplifier gain switch was in good agreement with electrical calibrations. Tests on the amplifier failed to detect any deviation from linearity. Linearity of the multiplier tube was also demonstrated indirectly. Further special tests on gain and linearity have not been made apart from comparisons of solar and star magnitudes as discussed below. Gain factors due to changes of aperture and field of view were derived from recorded deflections during laboratory tests and on twilight records. The factors depend slightly on wavelength.

#### 3.2 Temperature dependence of photometer sensitivity

The twilight measurements were made in the open air and the instrument temperature varied over a wide range. The temperature dependence of the sensitivity of the photometer in the different filter ranges was determined three times on cold days using the standards LI (radium luminescent paint)

and LII (tungsten lamp) as light sources. Deflections were recorded with the cold instrument, then at room temperature, after heating the instrument in a large box, and then again at room temperature. LII and its controls were always at room temperature, while the built-in LI was at instrument temperature.

Temperature (T) can influence both the emission of the luminescent paint,  $I^L(T)$ , and the sensitivity of the photomultiplier. Since twilight measurements are compared directly with paint intensity in green light only the former affects the absolute intensity measurements in green light. If we define a temperature coefficient ( $\alpha_g$ ) by

$$I^L(T) = I^L(T_0) (1 + \alpha_g(T - T_0))$$

its best value was found to be  $\alpha_g = -1.5 \times 10^{-3} \text{ } ^\circ\text{C}^{-1}$ .

Since standardization is only made in green light the differential response to temperature of the photomultiplier for different wavelengths had to be found from the comparisons with LII. If CR(T) is a color ratio measured with the instrument at temperature T, and if

$$CR(T) = CR(T_0) (1 + c_{CR}(T - T_0)),$$

we found the best values given in Table I.

All observations were corrected to standard conditions, although even for changes as large as  $30^\circ\text{C}$  the corrections are small.

TABLE I

Temperature coefficients of measured color ratios

Color ratio	R/G	O/G	G/B	B/U
$\alpha_{CR} \times 10^3$	+0.3	+1.0	-3.0	+4.5

### 3.3 Absolute calibration of the photometer

#### 3.3.1 General considerations

The problem involved in making an absolute calibration can be stated briefly as follows. Measurements at a normal twilight embrace a brightness range of about  $10^{5.5}$ , a constant recorder deflection being maintained by changing electronic gain settings and optical apertures. The latter are calibrated against the former by means of accurate deflection measurements with alternate aperture and gain changes, and are therefore as accurate as the electrical calibration of the gain switch (see Rep. I for discussion). A theoretical discussion of the twilight data requires that they be expressed in terms of the solar flux  $F^{\odot} = I_{\odot} \omega_{\odot}$  where  $I_{\odot}$  is the mean solar brightness, about 5.5 orders of magnitude greater than the brightness of the daytime sky, and  $\omega_{\odot}$  is the (variable) solid angle subtended by the sun.

To calibrate our instruments directly against the sun in its low-intensity ranges requires measuring a brightness ratio of  $10^{11}$ . This problem is in the same class as the measurement of the sun's stellar magnitude, an astrometric problem of the greatest difficulty. To avoid direct involvement in such difficult problems the calibration can be performed in two parts:

(i) Comparison of solar intensity using lowest optical and electrical gain settings with standard LI. This will vary from time to time as LI varies and must be periodically repeated.

(ii) Comparison of lowest and highest optical and electrical gain settings. This may be presumed not to vary with time and can be determined once and for all.

In Rep. I we discussed two methods of performing (1). First we constructed a calibrated neutral density filter with a transmission of  $8 \times 10^{-6}$  in green light. The difficulties in using such a filter are however legion, and the attempt was soon abandoned. Secondly, we proposed to make direct comparisons with the moon, which has a brightness about  $10^{-5.7} I_{\odot}$ , and is therefore suitable for spanning the gap between sun and early twilight. However, the moon's albedo is variable, phase sensitive and poorly determined, and further thought showed that it was better to use an artificial diffusing surface of known optical characteristics. A Lambert's law diffuser has a brightness  $I_{\odot} \omega_{\odot} \cos i/\pi$  where  $i$  is the angle of incidence. Since  $\omega_{\odot} = 6.75 \times 10^{-5}$  radians, the loss function is close to  $10^5$ , and suitable for direct comparison of sun and early twilight sky. This gives a comparison of LI to  $F_{\odot} = I_{\odot} \omega_{\odot}$ , suitable for low gain settings. It is referred to as the sun calibration and is discussed in §3.3.2.

(ii) can be accomplished by having faith in the linearity of the gain switch. Let us consider two instrument conditions, suitable for early and late twilight respectively:

Condition I     $\equiv$  Gain setting 1; objective aperture 2 mm.

Condition II    $\equiv$  Gain setting 7(=64x); full objective aperture.

If the instrument inspects a source of brightness  $I$ , with angular field of view  $\omega^*$ , the deflection recorded will be

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\* For sun, moon and stars, recorded with aperture greater than that of the source,  $\omega$  is the angular size of the source. For diffuse sources  $\omega$  refers to the stop in the focal plane.

$$D = g \omega I \quad (1)$$

where  $g$  is a gain factor, including both optical and electrical effects. Our problem is to discover the ratio  $g_I/g_{II}$ . Calibrating optical against electrical settings and assuming the latter to be linear, we find

$$R_e = \frac{g_I}{g_{II}} = 5.4 \times 10^{-6}.$$

Two methods have been devised to verify this figure. Measurements have been made on the total flux of fixed stars (§3.3.3, star calibrations). Knowing the stellar magnitude of the sun this leads to a ratio  $R_s$ .

The second method involves direct measurements on the moon and on a diffusor plate, similar to that used for the sun measurements, when illuminated by moonlight. This gives a gain ratio close to  $R$ , and comparison yields a third independent factor  $R_M$  (§3.3.4).

### 3.3.2 Sun calibration

With the instrument in electrical and optical condition I, and field stop D (see Rep. I, table 1), a magnesium oxide diffusor is placed at  $45^\circ$  to the optical axis of the photometer. The instrument is then pointed at right angles to the sun so that the angle of incidence is also  $45^\circ$  ( $\cos i = 1/\sqrt{2}$ ). Let  $f$  be the departure from Lambert's law (including absorption effects), and let  $D^\ominus$  be the recorded deflection. From equ. (1)

$$D^\ominus = g_I \omega_D \frac{f F^\ominus}{\pi \sqrt{2}}. \quad (2)$$

Since the amplifier gain varies we refer simultaneously to the paint deflection ( $D^L$ ) using condition I and field stop A. These conditions are

always reproduced and hence we may write

$$D^L = K g_1 I^L, \quad (3)$$

and include in the constant K corrections for the fact that the light standard is inside the instrument and not in the sky. We do not need to know the magnitude of K. From (2) and (3)

$$\frac{D^{\odot}}{D^L} = \frac{\omega_D}{K I^L} \frac{f F^{\odot}}{\pi \sqrt{2}}. \quad (4)$$

The diffusor consists of magnesium oxide smoke deposited on an aluminum plate. A diaphragm in front of the diffusor limits the amount of skylight reaching it to about 1% of noontime solar radiation. The smoke is prepared shortly before each measurement as recommended by de Vaucouleurs (1951). Five layers of smoke from magnesium ribbon strips about 10 cm long should eliminate the optical properties of the substrate. The values of f (the deviations from the cosine law) were measured by de Vaucouleurs for the conditions used here. They are 0.945 and 0.918 at 400 m $\mu$  and 600 m $\mu$  respectively for freshly-prepared diffusors. After 5 months, f is 0.86 and 0.895 for the same wavelengths.

$F^{\odot}$  varies with the air mass ( $\sec z$ ,  $z$  = zenith angle) and solar distance (r) according to

$$F^{\odot} = F_0^{\odot} e^{-\tau \sec z} \left(\frac{r}{r_0}\right)^2, \quad (5)$$

where  $\tau$  is the optical depth of the atmosphere, and  $F_0^{\odot}$  the solar constant.

If we write

$$D_o^\ominus = D^\ominus e^{\tau \sec z} \left(\frac{\bar{I}}{r}\right)^2, \quad (6)$$

equ. (4) becomes

$$\frac{D_o^\ominus}{D^L} = \frac{\omega_D f F_o^\ominus}{K I^L \pi \sqrt{2}} \quad (7)$$

On some occasions  $\tau$  was determined with the aid of a small sun photometer (Volz, 1959), while on others measurements were made over a range of zenith angles and the intercept ( $\sec z = 0$ ) of the curve of  $\log D^\ominus$  as a function of  $\sec z$  determined.

The only variable quantity on the R.H.S. of equ. (7) is  $I^L$ , and the ratio  $D^L/D_o^\ominus$  is therefore a direct measure of the variability of the phosphor. Fig. 1 shows how the ratio has varied with time over two calendar years.

From September, 1959, to November, 1960, the photometer was kept outside under a thin wooden shelter and was subjected to a wide range of temperatures. A very slow, temperature-dependent diffusion of radon, trapped in the binder glue of the paint could perhaps explain the seasonal variation of the brightness of the phosphor.

A few values of  $D_o^\ominus$  for all filters are presented in Fig. 2, after applying a correction for variable  $f$  of the diffusor plates, in the form of solar color ratios. These data, taken together with a few laboratory measurements of color ratios for LII, indicate no change with time of transmission of the filters or of spectral sensitivity of the photomultiplier. In the data presented in the body of the report, color ratios of skylight are presented in units of these solar color ratios.

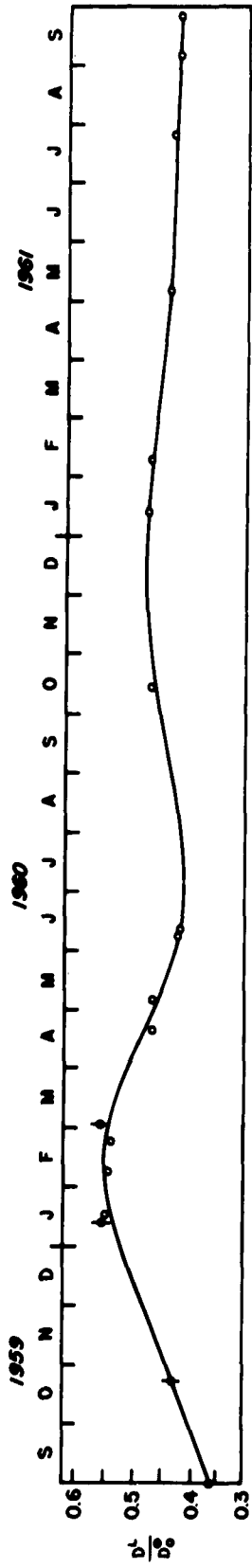


Fig. 1. Time variation of brightness of the standard source.  
Wavelength 576 mμ. All readings reduced to 15°C.

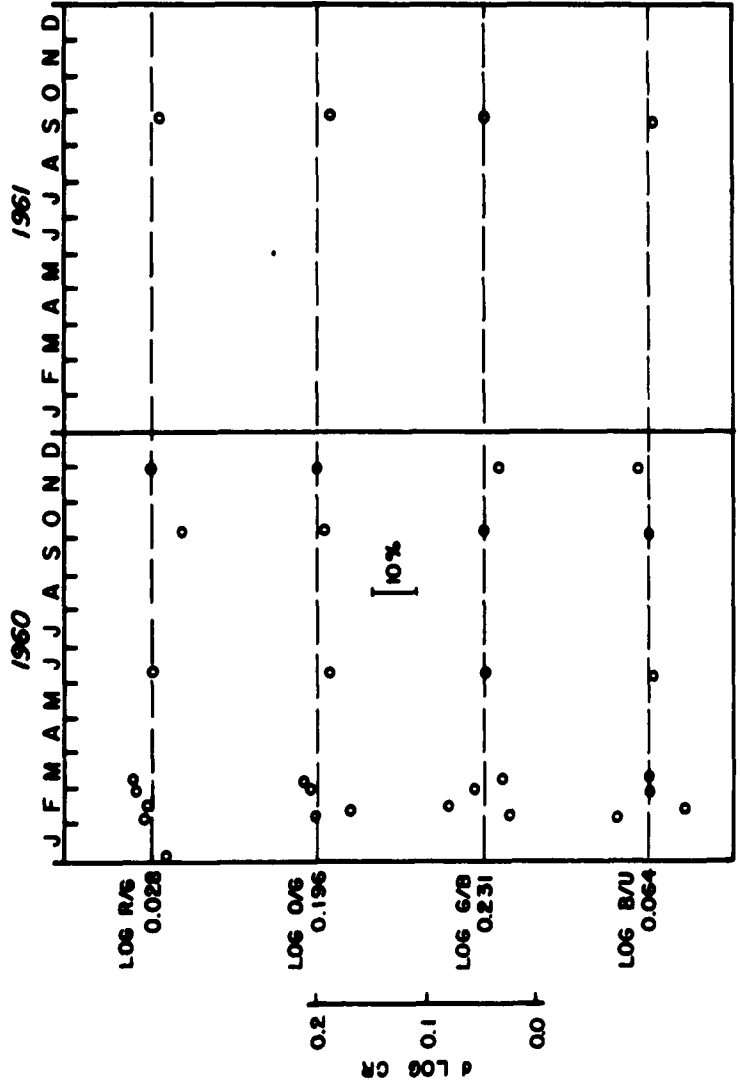


Fig. 2. Solar color ratios. 1960/61.

### 3.3.3 Star calibrations

With the instrument set in condition II, a star of zero magnitude at 516 mμ is allowed to drift across the field of view and the deflection  $D_o^*$  at zero air mass is deduced. This reading is obtained by making measurements on a number of bright stars at different zenith angles. Johnson (1957) gives visual and blue magnitudes (see Allen, 1955, for details of equivalent wavelengths) for the fifty brightest stars referred to AOv stars as a base. With these data, all star recordings can be reduced to zero magnitude AOv at 516 mμ, and the extrapolation to zero air mass is accomplished by plotting the results as a function of this parameter.

From equs. (1) and (3), we have

$$\frac{D_o^*}{D^L} = \frac{S_{II}}{S_I} \frac{F_o^*}{KI^L}, \quad (8)$$

and from equ. (7)

$$\frac{D_o^*}{D_o^\ominus} = \frac{1}{R_s} \frac{F_o^*}{F_o^\ominus} \frac{\pi\sqrt{2}}{\omega_D f}. \quad (9)$$

From a number of different observations, we find an average value

$$\frac{D_o^*}{D_o^\ominus} = 0.19 \pm 0.01.$$

The quantity

$$m(516) = -2.5 \log_{10} F_o^\ominus / F_o^*, \quad (10)$$

is the stellar magnitude of the sun at 516  $\mu$ . According to de Vaucouleurs\* the sun is a G2v star, with visual magnitude -26.73, corresponding to a magnitude of -26.62 at 516  $\mu$  or  $F_{\lambda}^{\odot} / F_{\lambda}^{\odot} = 4.47 \times 10^{10}$ . There is some doubt as to the visual magnitude of the sun, and the absolute scale of stellar photometry. The figures given here differ, for instance, from those of Allen (1955). There are also uncertainties attached to interpolating to  $\lambda = 516 \mu$ .

The value of  $\omega_D$  to be inserted in equ. (9) was found to differ from values given in Rep. I, Table 1, which were obtained by geometric reduction of measurements on the angular size of field stop A. New direct measurements have been made on the field stop D using drift curves of the planet Jupiter and the displacement of a distant light source. The effective angular diameter was found to be  $0.67^{\circ}$ . Inserting these figures in equ. (9), we find

$$R_s = 5.3 \times 10^{-6} .$$

#### 3.3.4 Moon measurements

The procedure here was to measure the recorder deflection under condition I using a field stop larger than the angular size of the moon:

$$D^M = g_I \omega_I^M .$$

Almost simultaneously a measurement was made in condition II, with field

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\* Private communication. This figure is supposed to be the best value to use in conjunction with Johnson's stellar magnitudes.

stop D, using a large diffusing plate employed in a manner analogous to that of the sun calibrations. The surface brightness of the plate is

$$I = \frac{I_M \omega_M f}{\sqrt{2} \pi}$$

and the deflection is

$$D_M^M(\text{diff}) = s_{II} \omega_D \frac{I_M \omega_M f}{\sqrt{2} \pi}.$$

We have therefore

$$R_M = \frac{s_I}{s_{II}} = \frac{D_M^M}{D_M^M(\text{diff})} \frac{f}{\pi \sqrt{2}} \omega_D.$$

Measurements of  $D_M/D_M(\text{diff})$  were complicated by the interference of diffuse sky-light, which was eliminated by making additional measurements with the moon artificially eclipsed. There resulted

$$\frac{D_M}{D_M(\text{diff})} = 0.241,$$

and hence

$$R_M = 5.5_5 \times 10^{-6}.$$

#### 4. Turbidity measurements

Primary scattering in the twilight occurs principally at high levels, and is modified on the downward path to the instrument by the variable haze extinction in the lower atmosphere. All observations given in this report have been multiplied by a factor

$$T_{\lambda}^{-1} = e^{\tau_{\lambda}/\sin \epsilon}, \quad (11)$$

where  $\tau_{\lambda}$  is the optical depth of atmospheric haze separated from that of the molecules, and  $\epsilon = 20^{\circ}$  is the angle of elevation of the photometer axis.

The turbidity coefficient

$$B_{\lambda} = 0.434 \tau_{\lambda}, \quad (12)$$

was usually measured before sunset or after sunrise at 440 and 640  $\mu$  with a small auxiliary photometer (Volz, 1959). Measurements close to the twilight were sometimes impossible; on these occasions the uncertainty in B may be as high as 0.01. Its value at 500  $\mu$  is given in the data sheets while for other wavelengths it is sufficient to use the relation

$$B_{\lambda} \propto \lambda^{-1.5}. \quad (13)$$

It is emphasized that all data have been multiplied by  $T_{\lambda}^{-1}$ , but the correction can be removed, if desired, with the aid of the turbidity coefficients given in the data sheets.

##### 5. Evaluation of twilight records

As in Rep. I, the results are presented in terms of the derivative of log intensity with respect to sun depression and color ratios. In addition, the green intensity is compared with that of a representative twilight (TW 7), whose absolute intensity is given in Table 3.

A preliminary evaluation disregarded the gain factor and worked on a time scale rather than a scale of sun depression. Color ratios (CR) were

computed each minute, and also the 'slope' or ratio of deflections for each filter at beginning and end of each minute (the logarithm of the 'slope' is proportional to  $d \log I/dt$ ). These slopes are very sensitive to the care with which the analysis is undertaken, and frequent checks had to be made. All unusual or interesting features were checked personally by the author, although short-lived deviations, which were clearly not associated with large-scale atmospheric phenomena were sometimes not explored in detail.

The factor  $dt/d\delta$  is required to convert from the 'slope' to the data given here. The factor for  $42^{\circ}13'N$  is given in fig. 3. The abscissa was then altered to be linear in  $\delta$ .

Color ratios were corrected for instrument temperature (Table 1) and for tropospheric turbidity. From equs. (11), (12) and (13), we have

$$\begin{aligned} \log \frac{T^{-1}(\lambda_1)}{T^{-1}(\lambda_2)} &= \frac{B(\lambda_1) - B(\lambda_2)}{\sin \epsilon} \\ &= \left[ \left(\frac{\lambda_1}{500}\right)^{-1.5} - \left(\frac{\lambda_2}{500}\right)^{-1.5} \right] \frac{B(500)}{\sin \epsilon} \\ &= k \frac{B(500)}{\sin \epsilon} \end{aligned} \quad (14)$$

Table 2 shows the values of  $k$  used in the reduction. If the exponent

TABLE 2

Turbidity correction factor, k.

R/G	O/G	G/B	B/U
+0.285	+0.20	+0.30	+0.25

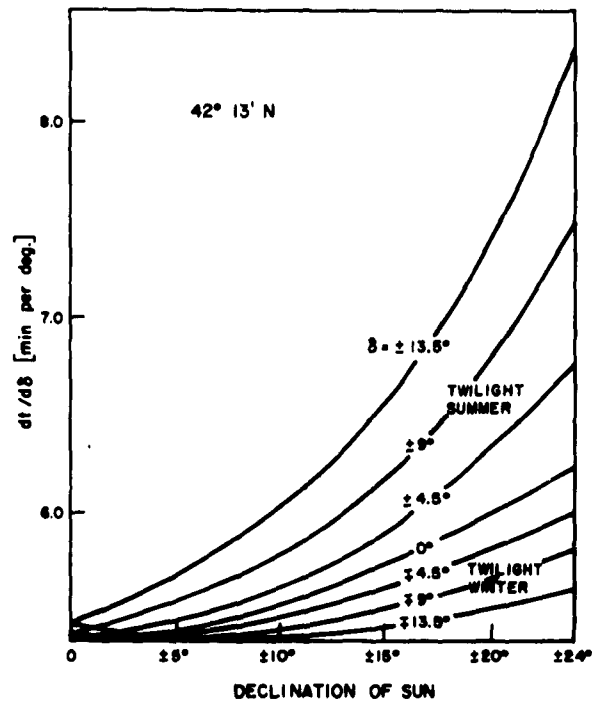


Fig. 3. The factor  $dt/d\delta$  (min deg<sup>-1</sup>) as a function of  $\delta$  and declination

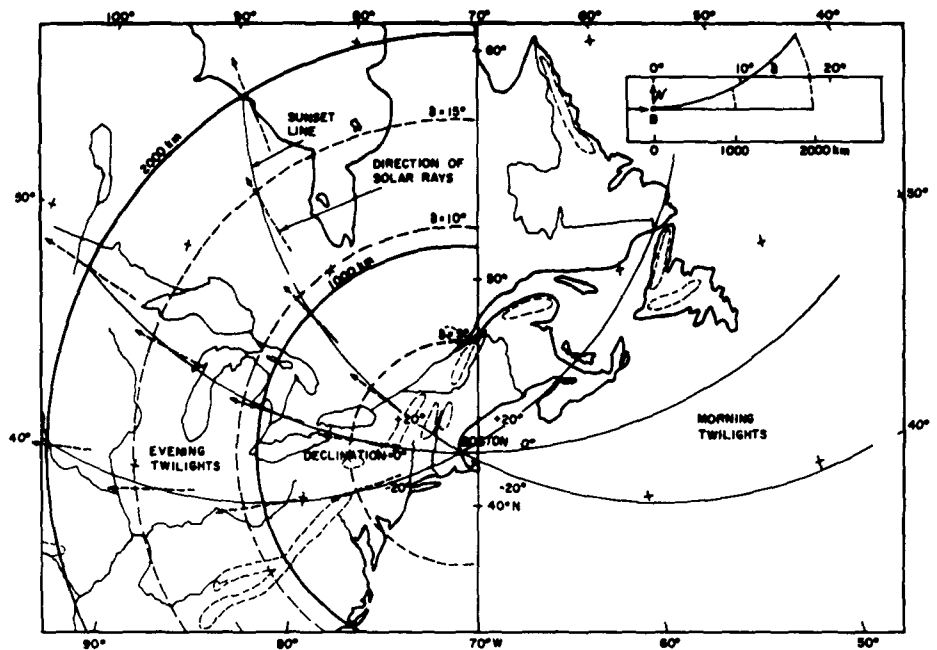


Fig. 4. Paths of the sunset point (sunset line) for  $D = 0, \pm 20^\circ$ .  
 The arrows show the direction of the sun. Broken lines give values of  $\delta$  along the sunset line. Dotted contours indicate ranges of hills capable of interfering with the twilight ray. The insert illustrates how data along the curved sunset line are projected onto the linear axes used in presenting the data.

in equ. (13) were increased or decreased by 0.5, for typical turbidity conditions, log CR would change by  $\pm 0.03$  - a relatively small uncertainty. No attempt has been made to allow for changing values of the exponent.

The rapid decrease of the sky brightness during twilight makes it inconvenient to give absolute intensities of all or even one color for a whole twilight. More instructive, enabling quick comparison between different twilights, is a graphical representation of deviations of the intensity of twilight from a standard twilight. These relative intensities were computed for each twilight in green light only; the intensities for other colors can be calculated from the color ratios, if required.

Deviations from the standard twilight were corrected for solar distance, sensitivity of the amplifier and the tropospheric haze. As a standard we chose one of a series of closely similar twilights in Fall, 1959, apparently undisturbed by cloud effects. Intensities for this twilight, based on the reduction factor  $R_e$ , are given in Table 3.

#### 6. Weather maps and cloud cross-sections

During twilight the troposphere is opaque to sunlight with wavelength less than about 500  $\mu$ . For longer wavelengths however, the troposphere is translucent and haze, clouds or mountains located at a distance from the observer in the direction of the sun will intercept the solar rays and increase the height of the earth's shadow. Isolated clouds cause the 'crepuscular rays' which are often observed during the twilight. In order to obtain a rough impression of the cloud-cross section along the path of the

TABLE 3

Intensities for the standard twilight (TW 7)

$$\lambda = 516 \text{ m}\mu, \epsilon = 20^\circ$$

$\delta^\circ$	$(\log_{10} I/F) + 8$	$\delta^\circ$	$(\log_{10} I/F) + 8$	$\delta^\circ$	$(\log_{10} I/F) + 8$
		2.5	5.502		
-4	6.619	3	5.329	10	1.953
		3.5	5.120		
-3	6.531	4	4.882	11	1.511
		4.5	4.63		
-2	6.423	5	4.383	12	1.134
		5.5	4.144		
-1	6.288	6	3.907	13	0.809
0	6.117	7	3.434	14	0.543
1	5.918	8	2.956	15	0.324
2	5.654	9	2.451	16	0.248

Note: TW 7 in fact was only measured to  $11^\circ$  sun depression; the extension to  $16^\circ$  is based on TW 3 and 4.

setting sun, appropriate sections of weather maps were prepared\*.

In fig. 4 are plotted positions of the setting sun and directions of the sunlight for three declinations (D). For convenience the location of stations in the weather maps presented here has been given with respect to a straightened sunset line (see insert in fig. 4). Data for the maps were taken mainly from working weather maps of the Department of Meteorology at MIT for 0 and 12 h GMT (19 and 07 h EST), or if these were not available from Weather Bureau Daily Weather Maps. From these data, tentative cloud cross-sections along the sunset line were constructed. Because the angle between the sunset line and the direction of sunlight is large for sun depressions  $> 10^\circ$ , cloud cross-sections should have been constructed along the instantaneous path of sunlight. However, the sparsity and the low information content of weather reports did not allow for such details, or for consideration of the movements of cloud systems between the time of the map and the twilight observation.

The weather maps were prepared and analyzed by J. Wagner of MIT.

## 7. General comments on data presented on twilight graphs and data sheets

### 7.1 Logarithmic gradient

The sun depression scale has been calculated for sea level, without considering atmospheric refraction.

The scale of  $d \log I/d\delta$  is given only for Red, but can be transposed for use with other colors. This scale is slightly non-linear (it is linear

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\* Direct observation of low-elevation clouds are recorded on the data sheets.

in the 'slope', see §5). Crosses or heavy dots denote carefully checked values. The line is drawn freehand.

The  $\delta$ -scale on the graphs of every tenth twilight (TW 1, 11, 21, etc.,) has been supplemented by values of median scattering height ( $H_m$ ) in Red and Blue as derived from calculations of twilight models in Rep. I. Features on the gradient curves for different colors of undisturbed twilights sometimes occur at equal  $H_m$ .

### 7.2 Color ratios

Ordinates are decadic logarithms of color ratios in units of color ratios for the extraterrestrial sun. The curves are usually not labeled and confusion can occur sometimes with R/G and C/G. This can always be resolved because for  $\delta \approx 5^\circ$ , the R/G curve is invariably above the O/G curve. The amount by which the observed values of log R/G were lowered to allow for tropospheric haze attenuation is indicated by a mark ( $\top$ ) at the bottom scale at  $\delta = 0$ .

Visual observations of purple light intensity and crepuscular rays are noted near the top of the CR curve. Unaided eye observations of the purple light are very difficult, and were made with brownish sun glasses, looking into a convex spherical mirror in order to increase both the saturation of red colors and the field of view. The purple light scale (PL) is from 0 to 5. Peak intensities are usually from 3 to 5<sup>o</sup> sun depression. Reported intensities refer to elevation 20 to 30<sup>o</sup>; purple lights at lower elevation usually have a longer duration.

The twilight arch is often interrupted by darker, bluish beams, diverging from the location of the sun (crepuscular rays). The brightness and color

contrast to the (apparently) unshadowed twilight arch is usually very small. Up to about  $6^\circ$  sun depression, shadows often extend to the anti-twilight, but may be too weak to be seen near the zenith. Just before complete disappearance, at about  $8^\circ$  sun depression, the shadows usually extend to no more than  $10^\circ$  elevation. Only shadow beams passing through the field of view of the photometer are of direct interest for the discussion of our measurements and, in TW 72, alternate measurements were made in the dark and bright segments. The half circles above the color ratio curves denote the twilight arch: crepuscular shadows are marked by black; an open half circle by itself at  $\delta = 7^\circ$  indicates that no trace of shadows could be seen throughout the twilight.

Occasionally aurorae were noticed in the late twilight, and sometimes rocket trails were observed. The occurrence of these phenomena is also noted on the color ratio curves.

In addition to interference by the airglow and Boston city lights, many of our measurements in the late twilight are affected by scattered moon light. Letters under the number of the twilight on the color ratio curves indicate the state of the moon according to the scheme in Table 4 (appropriate to the evening twilight).

Because of a counterplay of Moon brightness and scattering phase function of air and haze, the influence of the moon on late twilight intensity can be of the same order for cases MQ to MF. For MT the influence may be neglected.

TABLE 4

Moonlight intensity code

Time sequence of evening twilight.

Code	Position of Moon	Moon phase
		Moon rise 1 hr. after start of astronomical twilight
MO	No Moon	to 2 days after New Moon
MQ	In twilight arch	to 6 days after New Moon
ME	In southern sky	to 4 days before Full Moon
MF	Full Moon rising on eastern horizon	to 1 to 2 days after Full Moon (Moon rise at start of astronomical twilight)
MT	Shortly after Full Moon; i.e., late twilight measurement taken shortly before Moon rise	to  Moon rise 1 hr. after start of astronomical twilight.

### 7.3 Relative green intensity

Here the logarithms of Green intensity of the twilight, referred to a standard twilight, are given. Standard values (TW 7) were presented in Table 3.

### 7.4 Weather map and cloud cross-section

The sunset (or sunrise) section of weather maps is shown. The sunset line, which is curved on ordinary maps, has been rectified. The North direction for Boston is marked by an arrow. Under the weather map is drawn the cloud cross-section, showing the vertical distribution and amount of cloud along the sunset line, as estimated from the weather map.

### 7.5 Twilight data sheets

Daytime sky: Visual observations of color and brightness of circumsolar sky light, characterizing the aerosol size distribution (Volz, 1961).

Turbidity types refer to the sky from about  $50^\circ$  to  $3^\circ$  distance from the sun;

Aureole types to scattering near the sun. Turbidity type 1 is characterized by a steady increase of sky brightness and a decrease of bluishness from about  $50^\circ$  to about  $2^\circ$  from the sun. With types 2 and 3, the sun is surrounded by a bright disc of about  $20^\circ$  radius of nearly constant brightness. The disc of type 2 is uniformly whitish, while the outer border of the disc of type 3 is brownish and the inner part bluish.

The description of the Aureole types a, b and c is virtually the same as for Turbidity types 1, 2 and 3 if angles are reduced by a factor 10 to 20. The Aureole intensity scale is from 0 (no Aureole) to 3 (inner part of Aureole somewhat glaring with 8% transmitting sun glasses). This scale can be extrapolated with the aid of sun glass transmitting 0.6%.

Relations between Turbidity type and twilight are only expected if a finite fraction of atmospheric aerosol is located above the tropopause.

Turbidity coefficient: Decadic attenuation coefficient of haze alone, at 500 m $\mu$ , per unit air mass.

Visibility: Based on observations of distant mountains shortly before sunset.

Sunset or Sunrise: Calculated in Eastern Standard Time, for longitude and latitude of Blue Hill Observatory, for center of sun. No account is taken of the altitude of the site or atmospheric refraction.

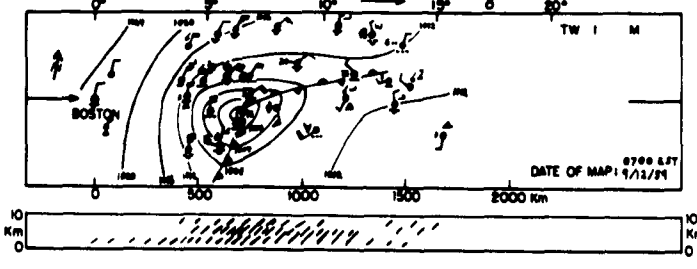
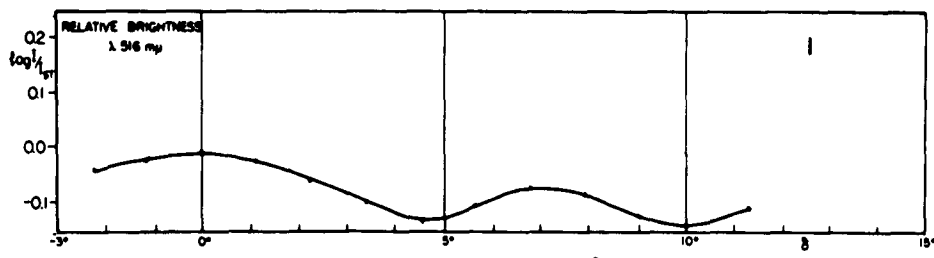
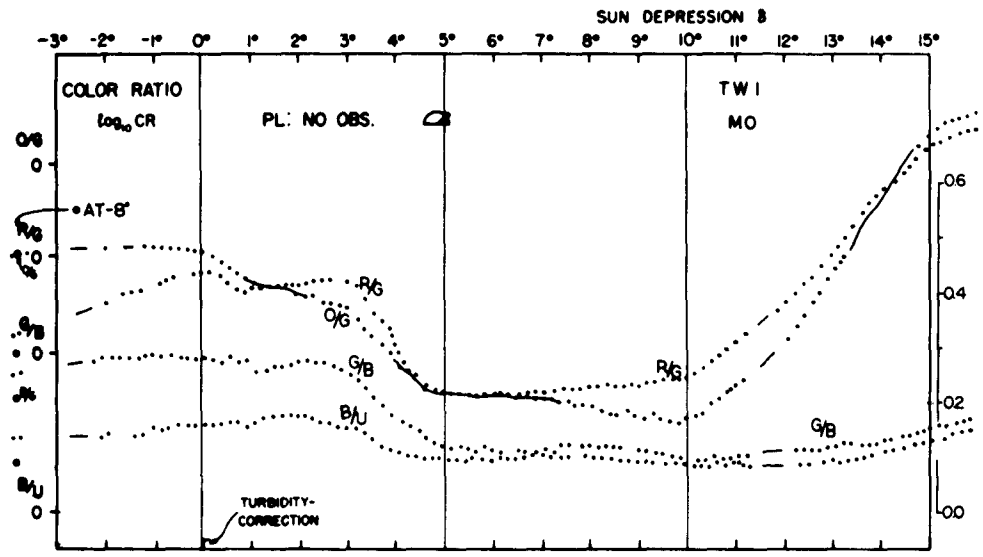
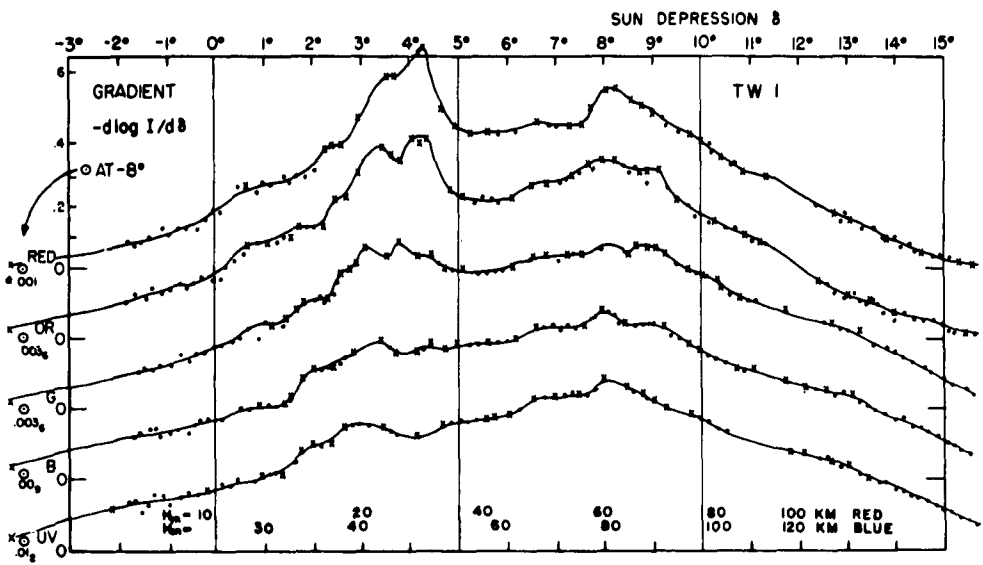
Horizon: Haze and cloud observations. Observations of near-horizon haze structure and of clouds during twilight in azimuth of measurements.

8. References

- Allen, C.W. 1955 'Astrophysical Quantities'. Univ. of London Press.
- Johnson, H.I. 1957 'The fifty brightest stars'. Sky and Telescope 16, p. 470.
- deVaucouleurs, G. 1951 'Constantes de la diffusion Rayleigh dans les gaz et les liquides'. Ann. de Phys. 12. Ser. 6, pp. 213 - 324.
- Volz, F., and Goody, R.M. 1960 'Twilight intensity at 20° elevation'. AFCRC-TN-60-284.
- Volz, F. 1959 'Photometer mit Selen Photoelement zur spektralen Messung der Sonnenstrahlung und zur Bestimmung der Wellenlängcnabhängigkeit der Dunsttrübung'. Arch. Meteor. Geophys. Bioklim., B 10, pp. 100 - 131.
- 1961 'Scattering function and polarization of skylight in the ultraviolet to the near infrared region, with haze of scattering type 2'. Journ. Meteor. 18, pp. 306 - 318.

9. Results of observations

Twilights 1 to 103 with omission of TW 23, 28, 29, 55, 67, 81, 87, 92, 95,  
96.



TWILIGHT 1

September 12, 1959, Morning

Daytime sky: Turbidity type: 1.3  
Aureole type: al\_

Turbidity coefficient: 0.02

Visibility: 100 km

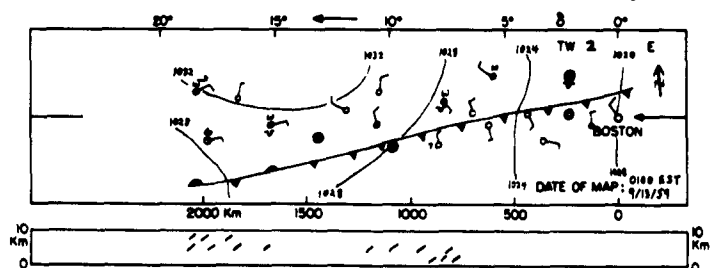
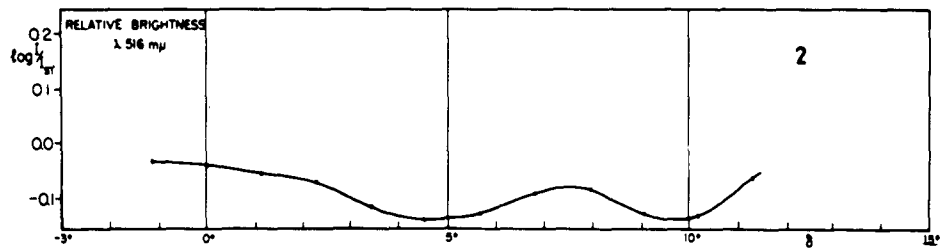
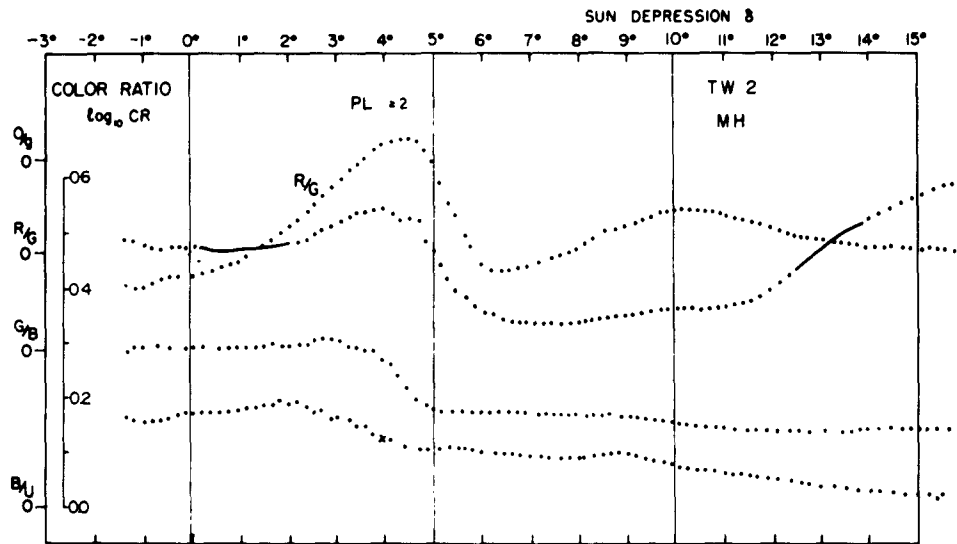
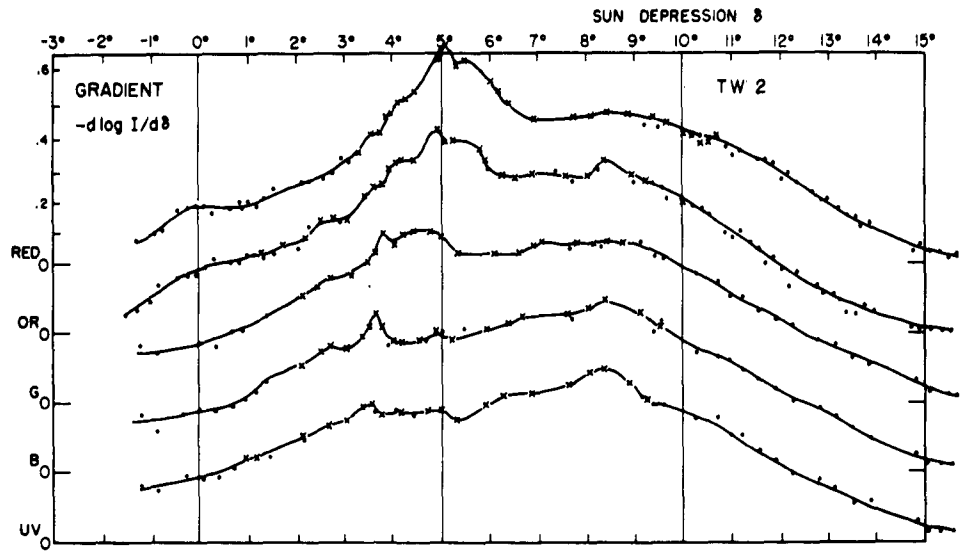
Sunrise: 05 25 EST

Declination:  $+4.3^{\circ}$

Instrument temperature:  $+10^{\circ}$

Horizon: Distant, low Sc over sea.

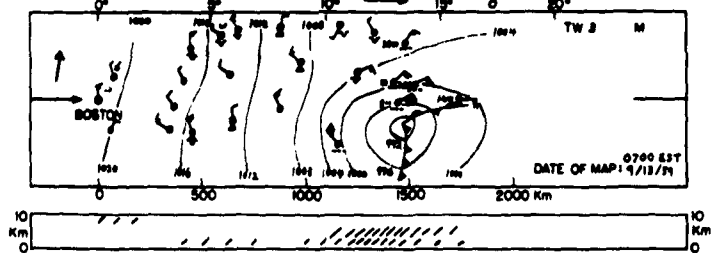
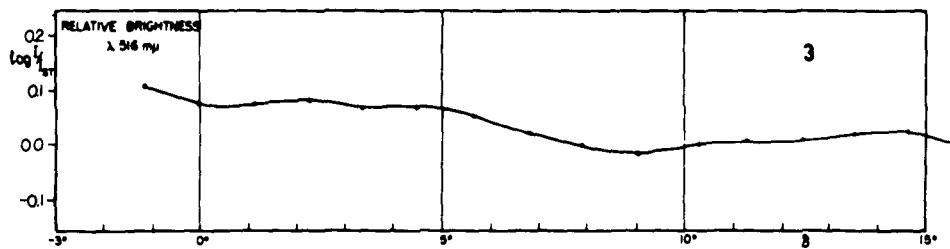
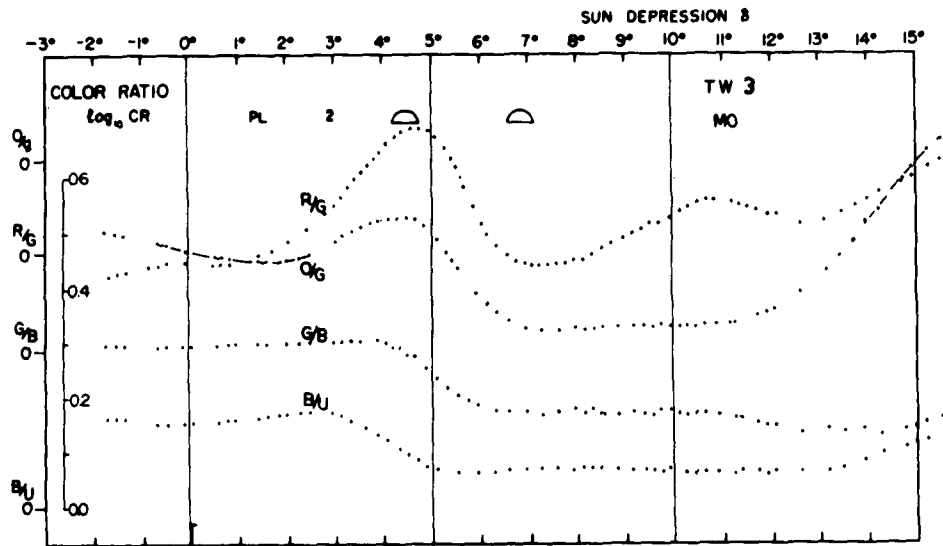
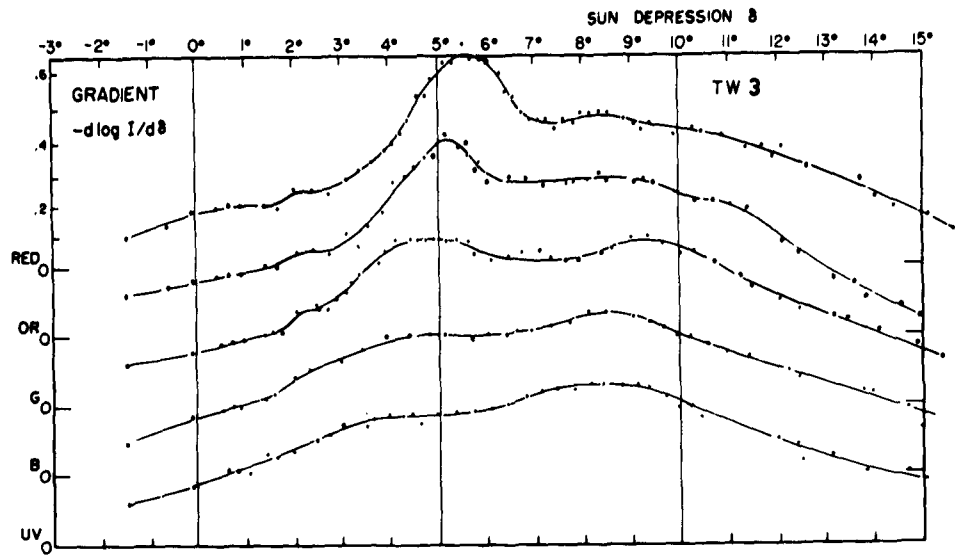
Color ratio graph: Points of log CR at  $\delta = -8^{\circ}$ ; for  
B/G replace G/B, and add R/G to  
the circle near log G/B = 0.



**TWILIGHT 2**

**September 12, 1959, Evening**

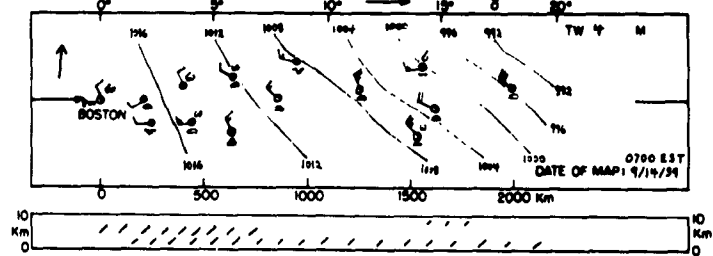
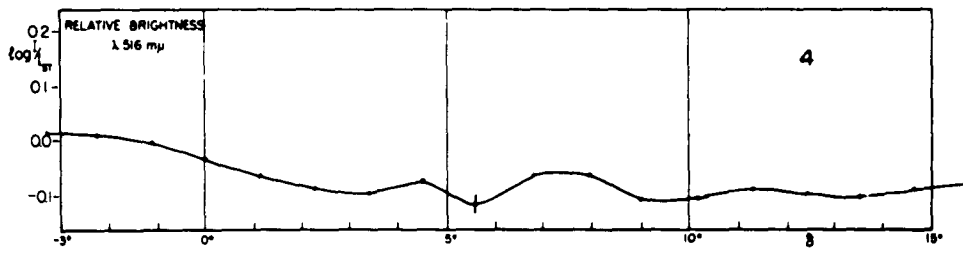
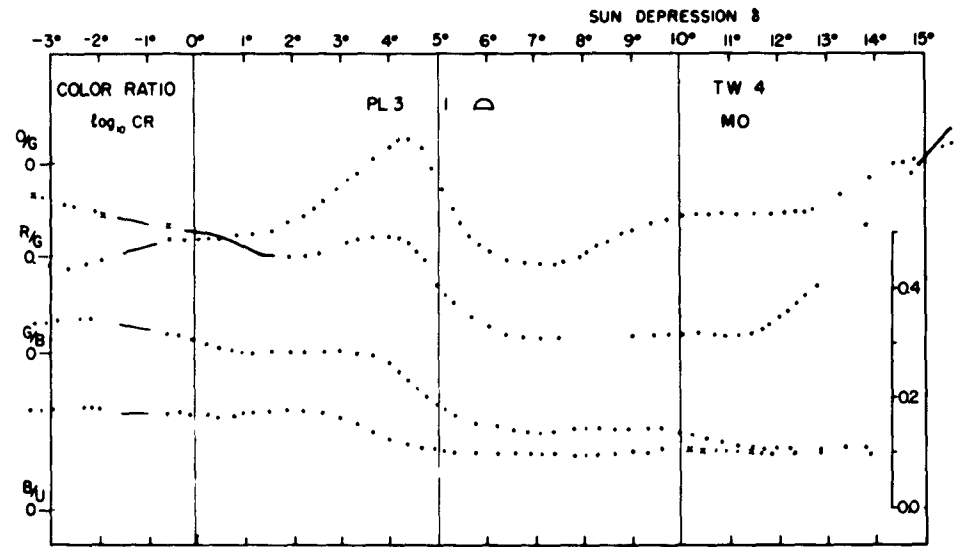
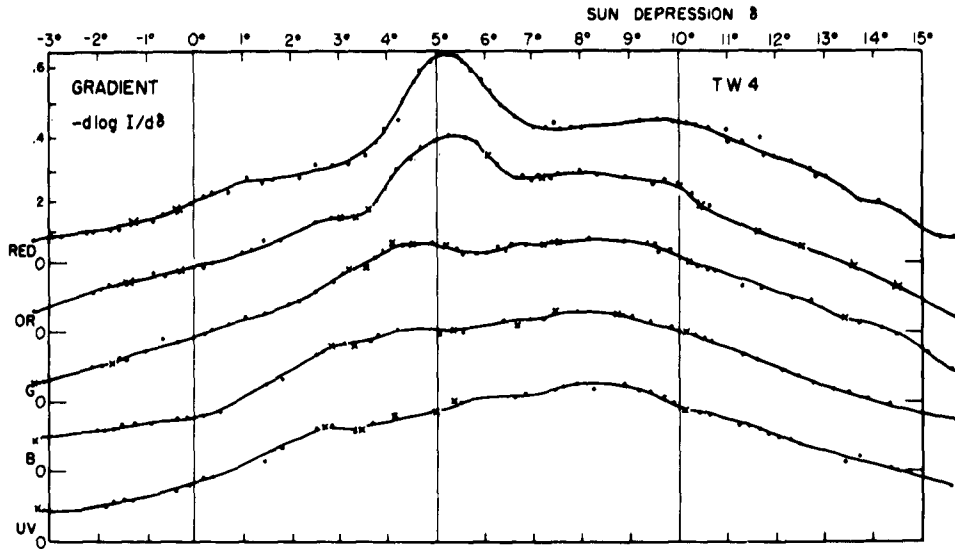
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.7</b>
	<b>Aureole type:</b>	<b>ab2_</b>
<b>Turbidity coefficient:</b>		<b>0.02</b>
<b>Visibility:</b>		<b>120 km</b>
<b>Sunset:</b>		<b>17 57</b>
<b>Declination:</b>		<b>+4.2</b>
<b>Instrument temperature:</b>		<b>20°C</b>
<b>Horizon:</b>		<b>In West below 1° elevation</b>
		<b>hazy</b>



**TWILIGHT 3**

**September 13, 1959, Morning**

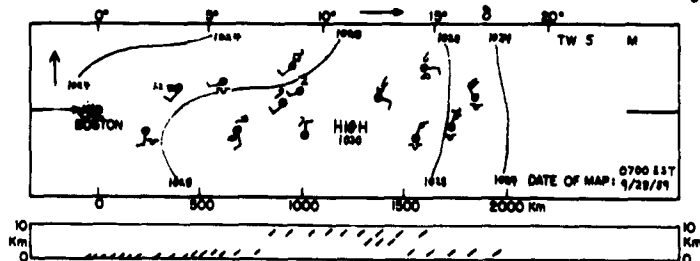
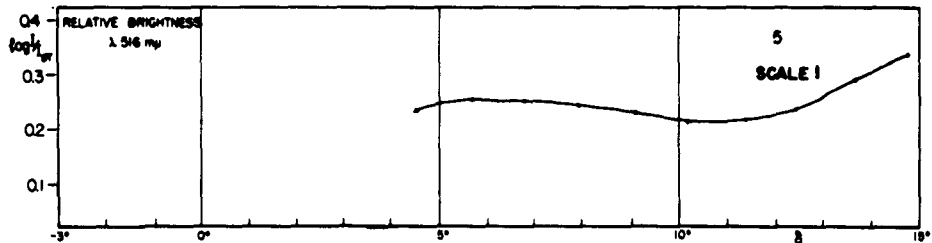
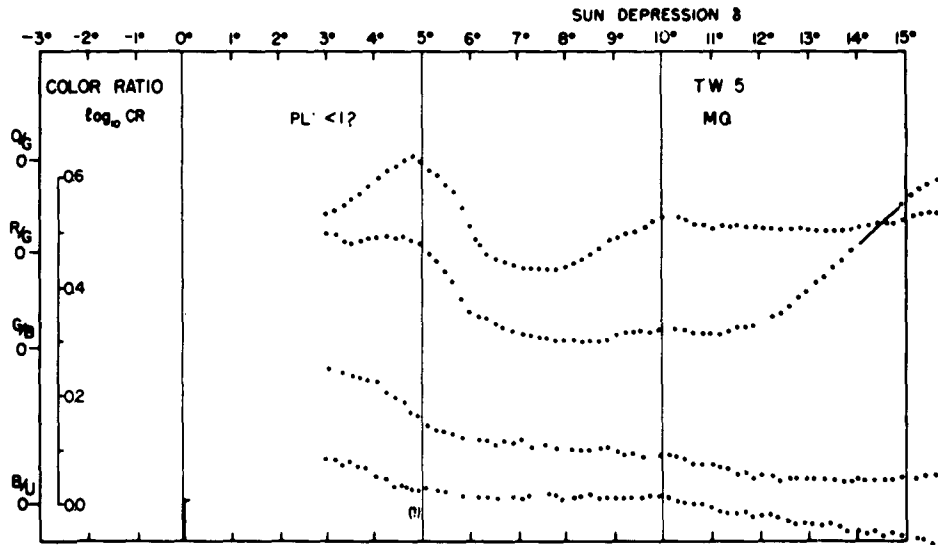
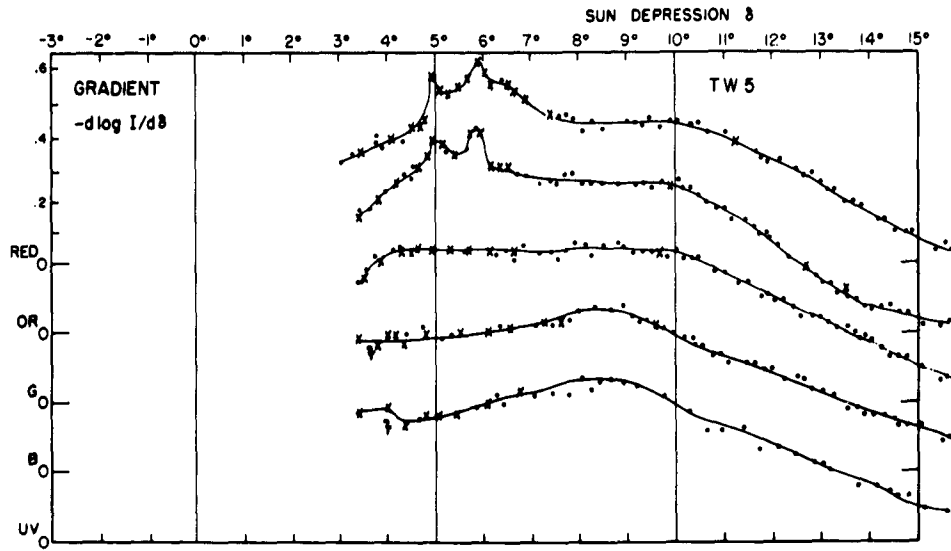
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.7</b>
	<b>Aureole type:</b>	<b>ab2</b>
<b>Turbidity coefficient:</b>		<b>0.04</b>
<b>Visibility:</b>		<b>65 km</b>
<b>Sunrise:</b>		<b>05 26.5</b>
<b>Declination:</b>		<b>+3.85°</b>
<b>Instrument temperature:</b>		<b>+11°</b>
<b>Horizon:</b>		<b>Single faint haze strips up to 5° elevation before sunrise.</b>



TWILIGHT 4

September 14, 1959, Morning

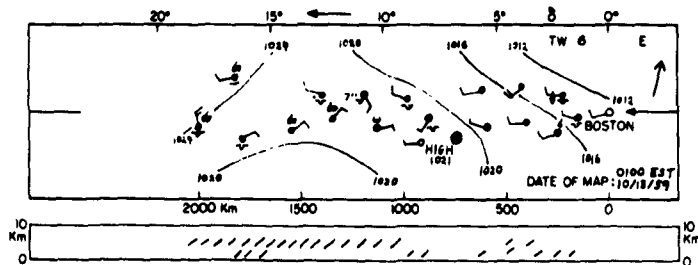
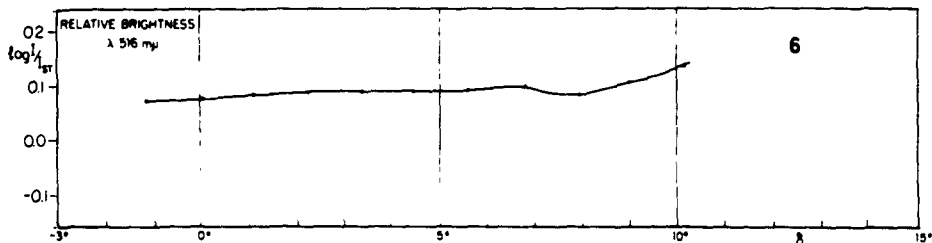
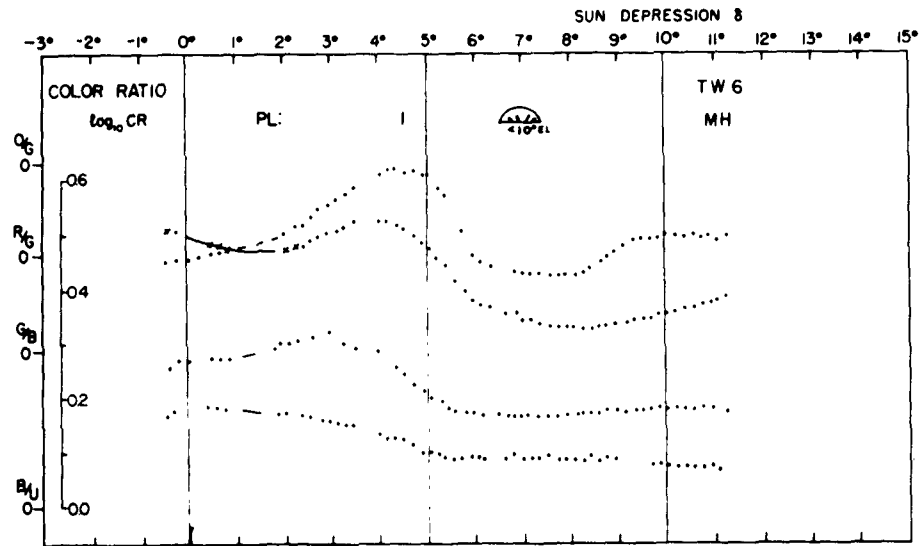
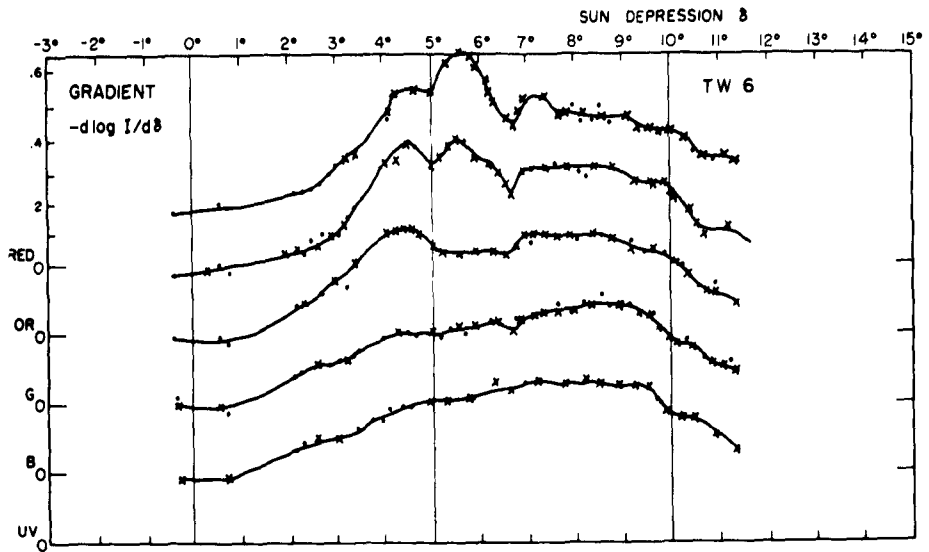
Daytime sky:	Turbidity type:	1.7
	Aureole type:	ab2
Turbidity coefficient:		0.02+
Visibility:		100 km
Sunrise:		05 27
Declination:		+3.6
Instrument temperature:		+10°
Horizon:		Hazy below 2° elevation.
Weather:		During twilight Ac in NW appearing, covering sun soon after sunrise.



TWILIGHT 5

September 28, 1959, Morning

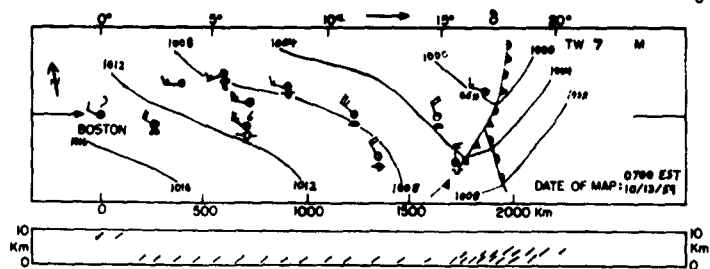
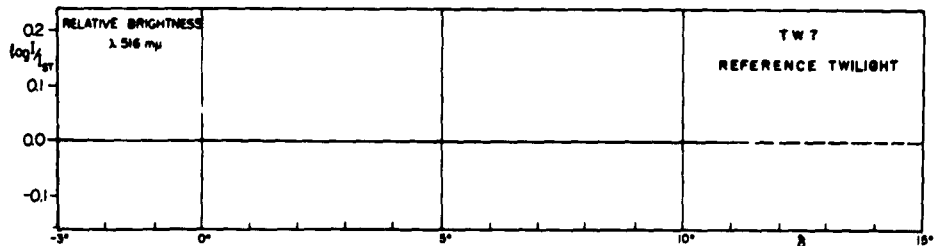
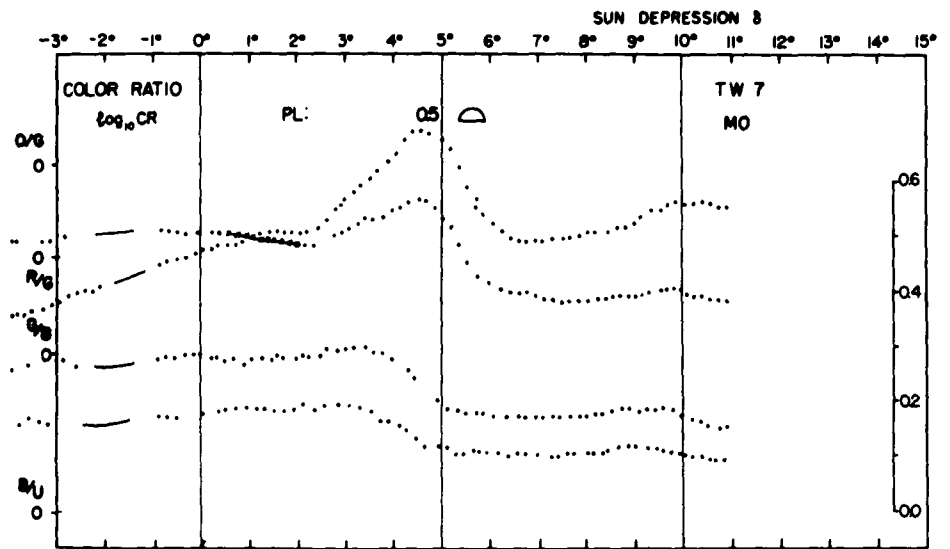
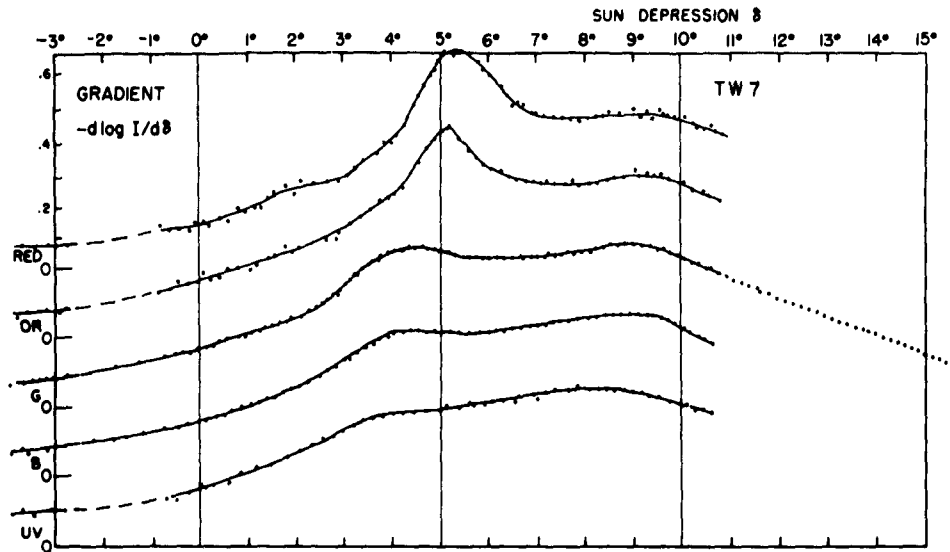
Daytime sky: Turbidity type:	1.9	}	As foregoing day and at noon
Aureole type:			
Turbidity coefficient:	> 0.085		
Visibility:	≈ 30 km		
Sunrise:	06 42		
Declination:	-1.7°		
Instrument temperature:	10°		
Horizon:	Before PL dense Ci fil. appearing, record discontinued.		



**TWILIGHT 6**

**October 12, 1959, Evening**

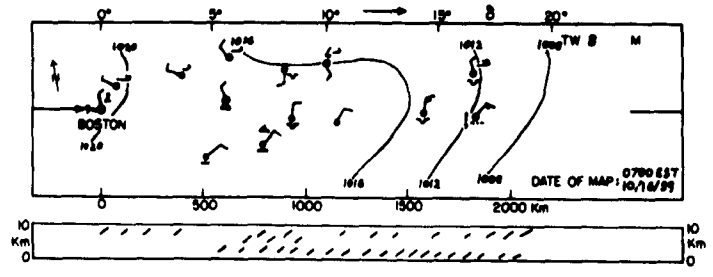
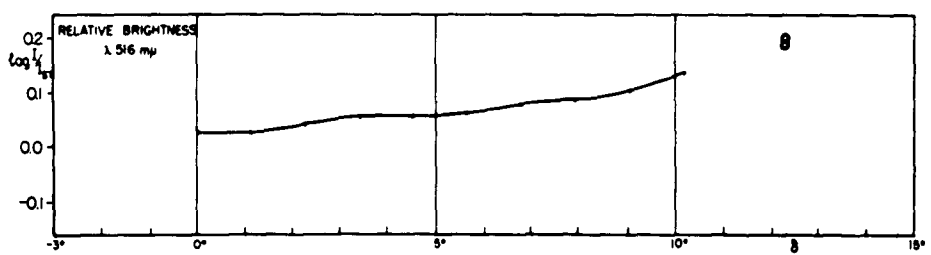
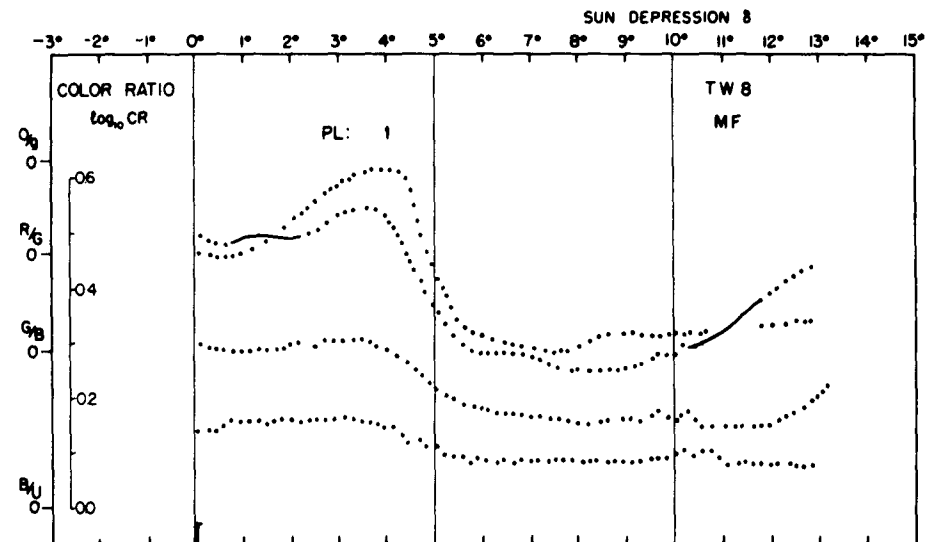
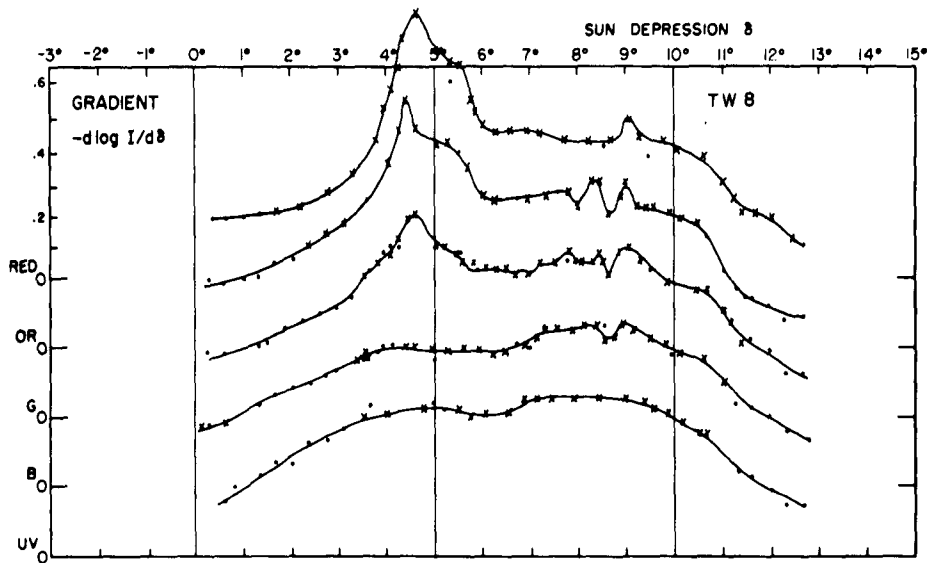
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.4</b>
	<b>Auraole type:</b>	<b>ab4</b>
<b>Turbidity coefficient:</b>		<b>0.03</b>
<b>Sunset:</b>		<b>17 04</b>
<b>Declination:</b>		<b>-7.2°</b>
<b>Instrument temperature:</b>		<b>10°</b>
<b>Horizon:</b>		<b>Scattered Ac below 2°.</b>
		<b>Haze lenses &lt; 8°</b>



**TWILIGHT 7**

**October 13, 1959, Morning**

<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.7</b>
	<b>Aureole type:</b>	<b>a0</b>
<b>Turbidity coefficient:</b>		<b>0.02</b>
<b>Visibility:</b>		<b>100 km</b>
<b>Sunrise:</b>		<b>05 59</b>
<b>Declination:</b>		<b>-7.4</b>
<b>Instrument temperature:</b>		<b>8°</b>
<b>Horizon:</b>		<b>Sc &lt; 1°. Shortly before SR fine haze strips below 6°.</b>



**TWILIGHT 8**

October 16, 1959, Morning

Daytime sky: Turbidity type: 1.6  
Aureole type: al

Turbidity coefficient:  $\approx 0.05$

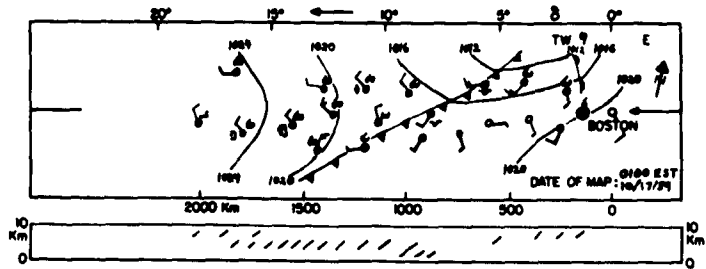
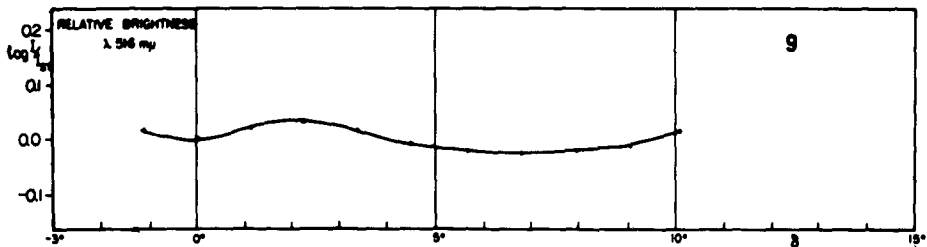
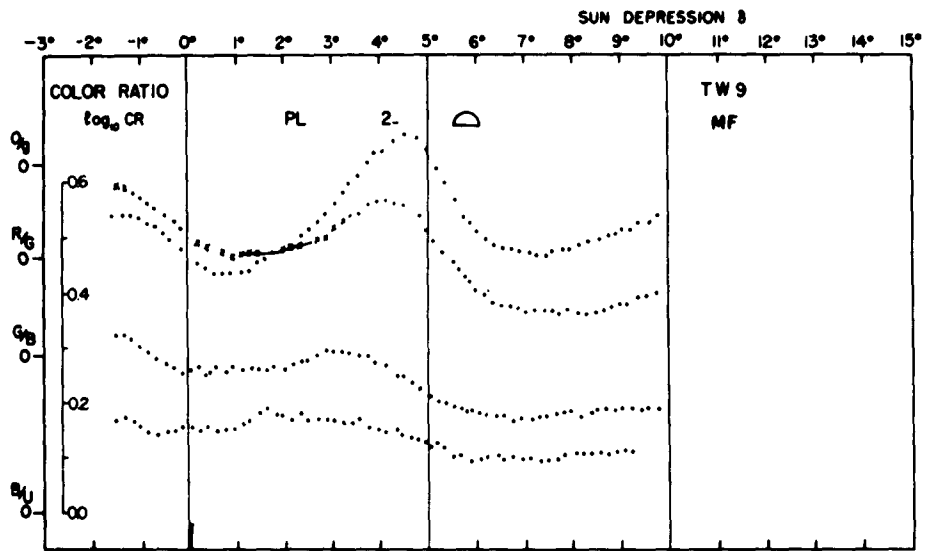
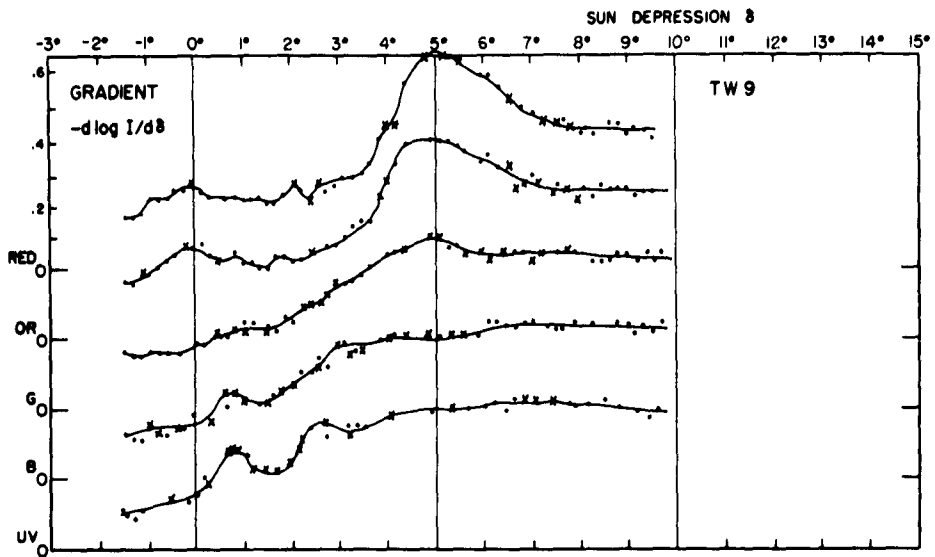
Visibility: 30 km

Sunrise: 06 03

Declination:  $-8.6^\circ$

Instrument temperature:  $+5^\circ$

Horizon: 05 40 Ac below  $10^\circ$ . Horizon very  
haze below  $5^\circ$ .  
05 20 Azimuth shift because of Ci  
traces.



TWILIGHT 9

October 16, 1959, Evening

Daytime sky: Turbidity type: 1.7  
Aureole type: al

Turbidity coefficient: 0.05

Visibility: 40 km

Sunset: 16 58

Declination:  $-8.6^{\circ}$

Instrument temperature:  $12^{\circ}$

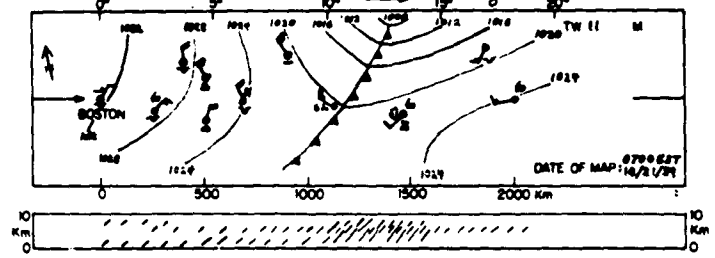
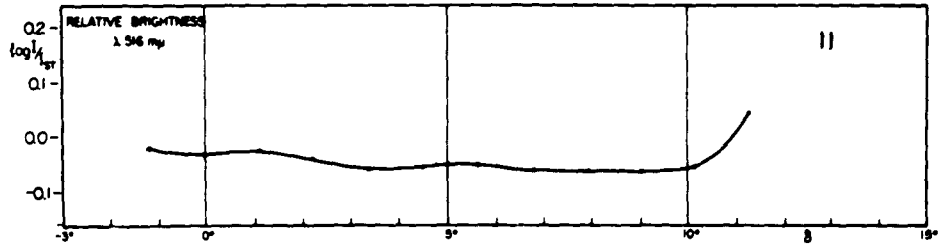
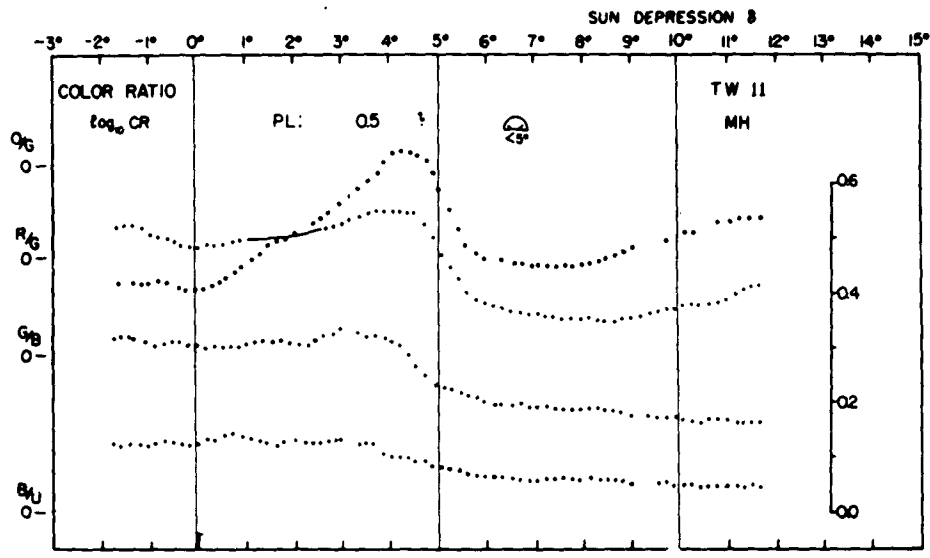
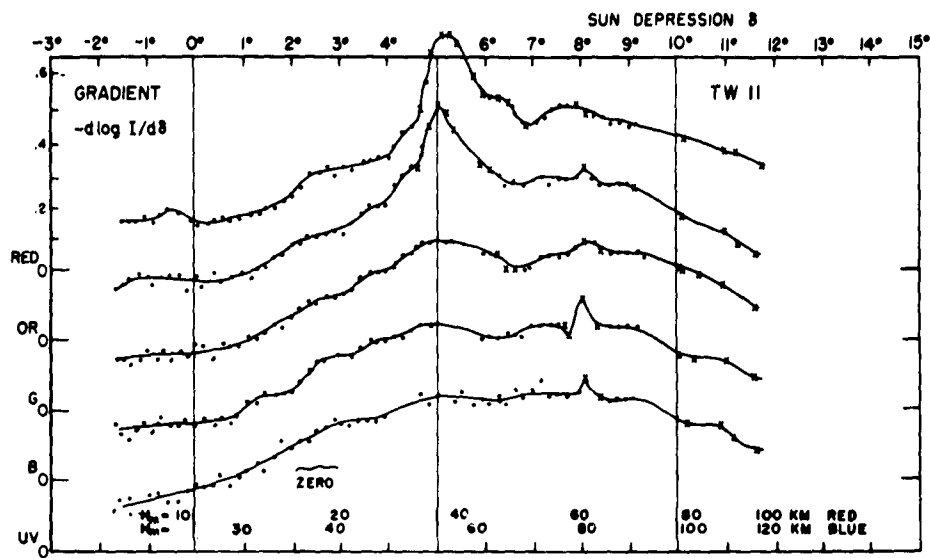
Horizon: Shortly after sunset, fine haze  
veils up to  $20^{\circ}$ .



TWILIGHT 10

October 20, 1959, Evening

Daytime sky:	Turbidity type:	1.4
	Aureole type:	a6
Turbidity coefficient:		0.07 <sub>5</sub>
Visibility:		30 km
Sunset:		16 52
Declination:		-10°
Instrument temperature:		+12°
Horizon:		Haze below 3°
		Distant St clouds from NW to NE.
Remarks:		Details of gradient in B and UV partly obscured by undulatory zero drifts of recorder due to chopper trouble.



**TWILIGHT 11**

**October 21, 1959, Morning**

**Daytime sky: Turbidity type: 1.4**  
**Aureole type: al**

**Turbidity coefficient: 0.03**

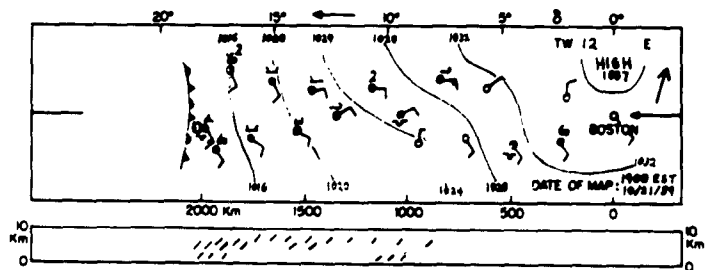
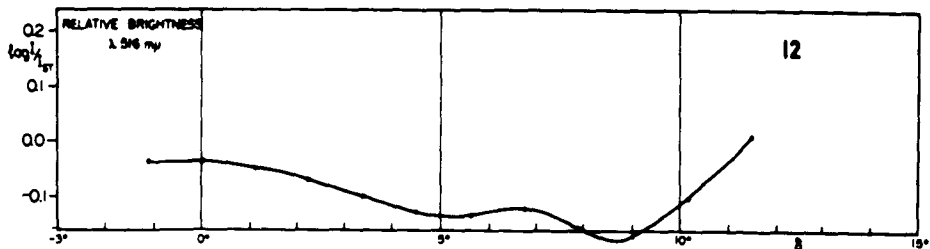
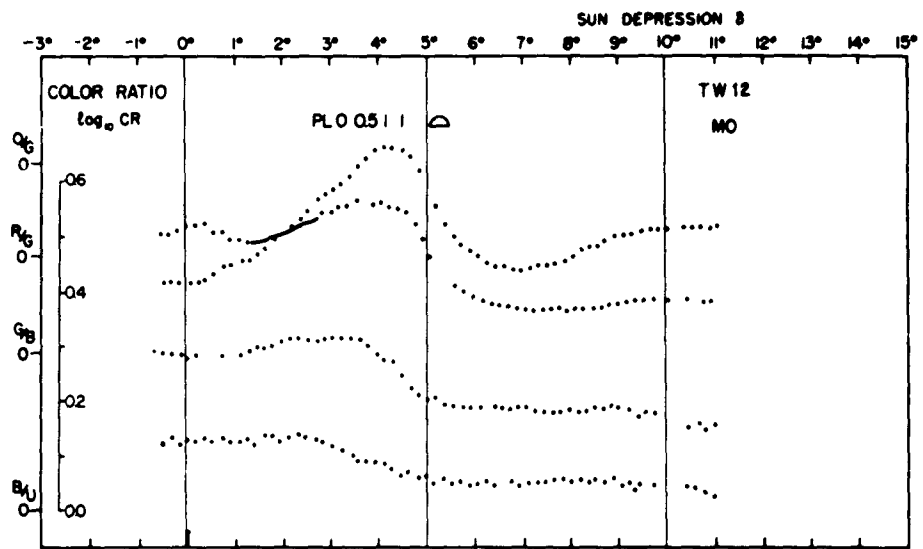
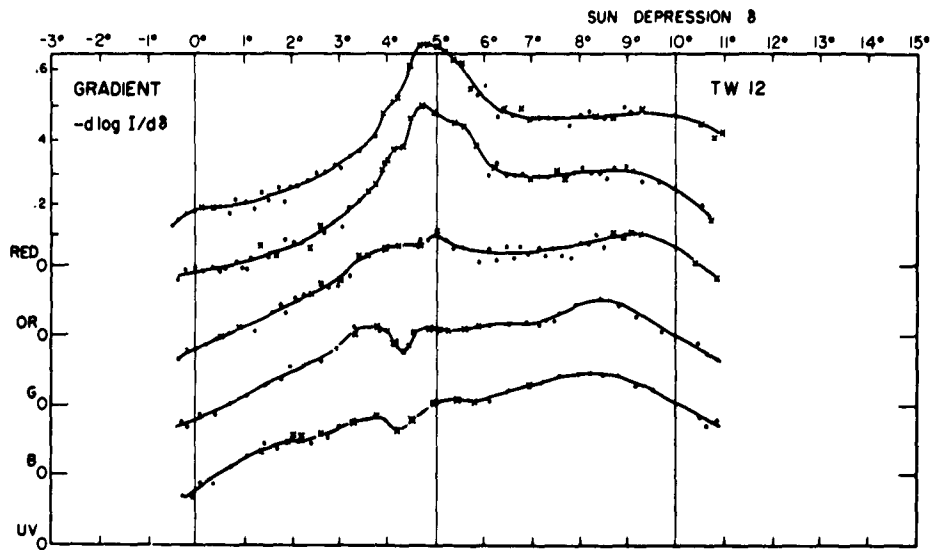
**Visibility: 100 km**

**Sunrise: 06 08**

**Declination:  $-10.6^{\circ}$**

**Instrument temperature:  $+2^{\circ}$**

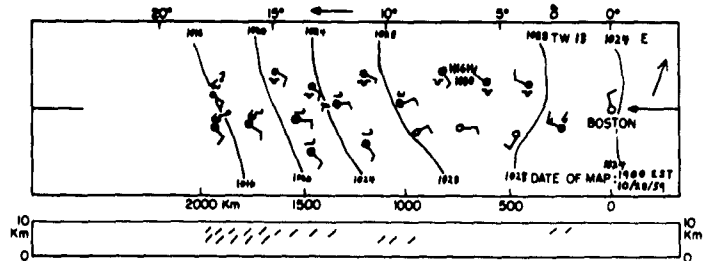
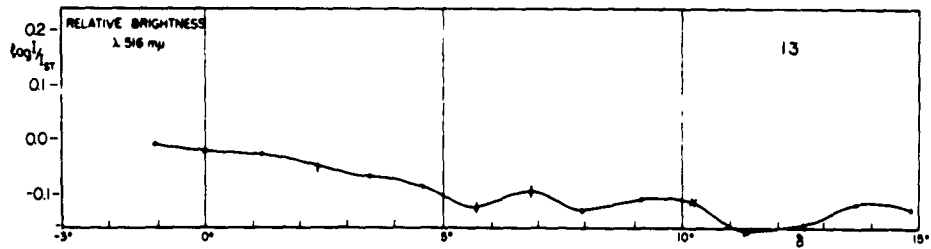
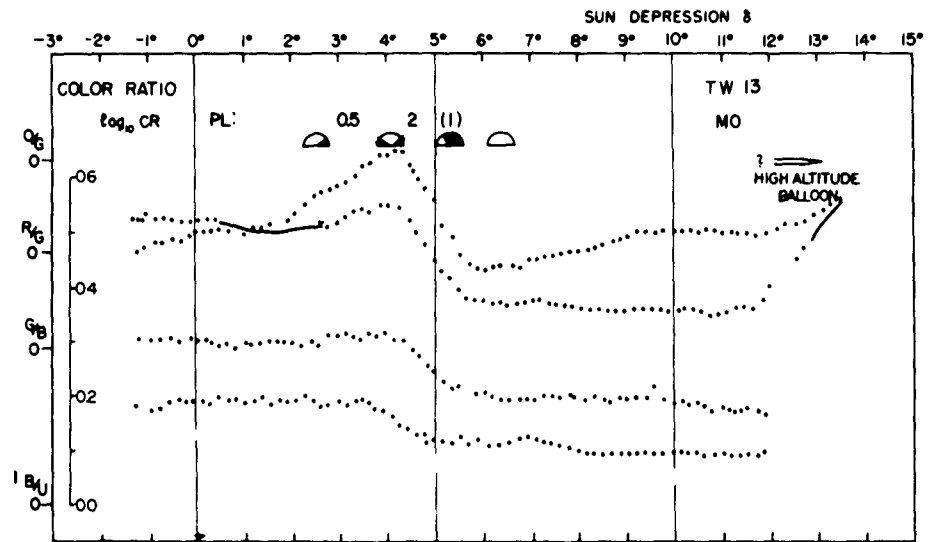
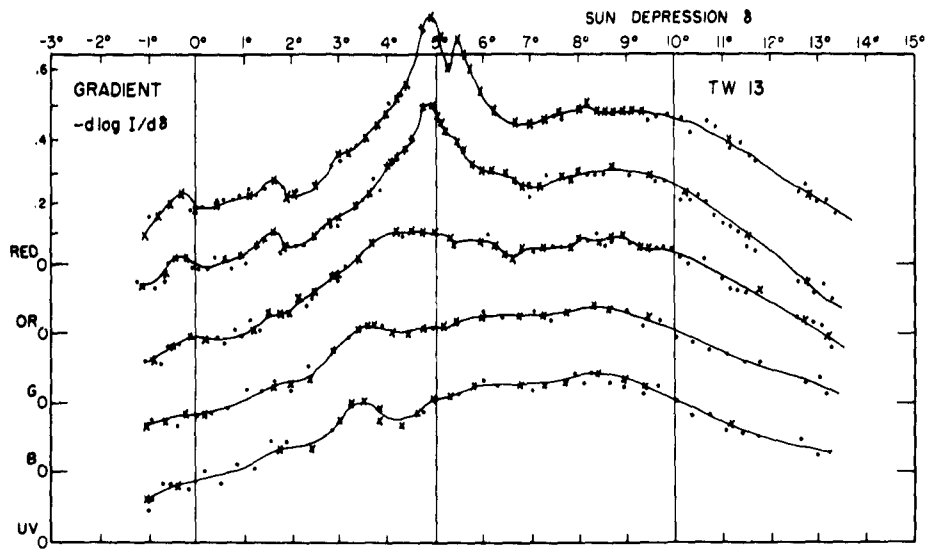
**Horizon: At  $\delta = 6^{\circ}$  Sc traces in field  
of view, at  $2^{\circ}$  thin Ci; azimuth  
changed.**



TWILIGHT 12

October 21, 1959, Evening

Daytime sky:	Turbidity type:	1.5
	Aureole type:	a2
Turbidity coefficient:		0.03
Visibility:		≤ 80 km
Sunset:		16 51
Declination:		-10.7
Instrument temperature:		+3°
Horizon:		Boston haze in West below 2°.



TWILIGHT 13

October 28, 1959, Evening

Daytime sky: Turbidity type: 1.5  
Aureole type: a2

Turbidity coefficient: 0.01

Visibility: 115 km

Sunset: 16 40

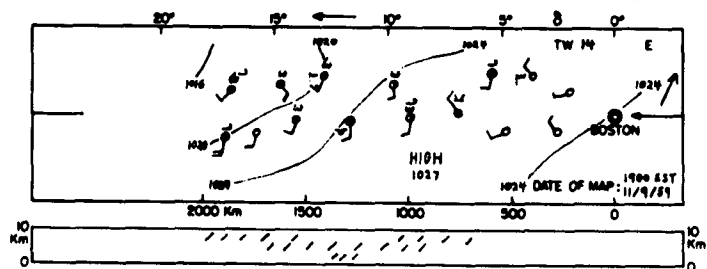
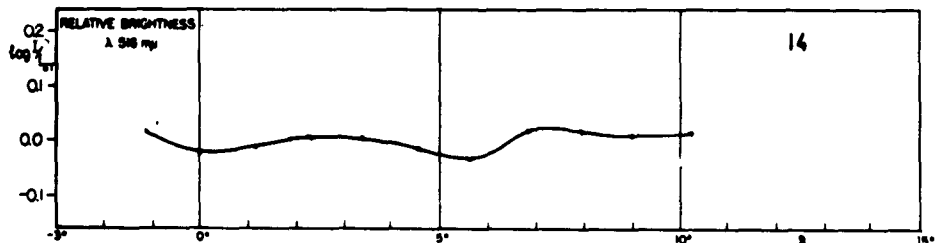
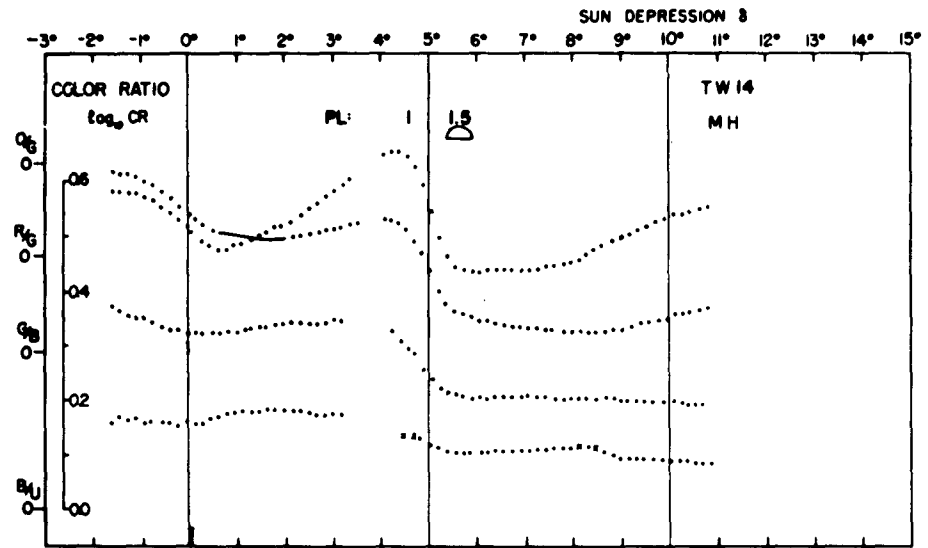
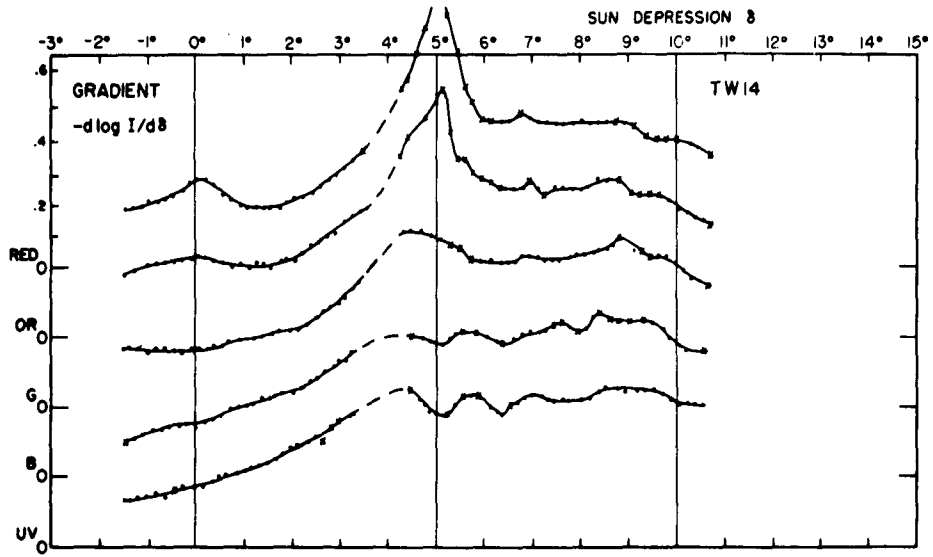
Declination:  $-12.9^{\circ}$

Instrument temperature:  $+5^{\circ}$

Horizon: Shortly after sunset; fine haze  
up to  $10^{\circ}$ ; few Cu clouds below  
 $1^{\circ}$  in NW.

Before the end of twilight: Sc  
banks below  $2^{\circ}$  in West.

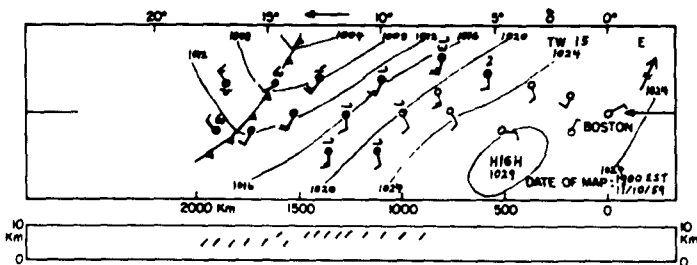
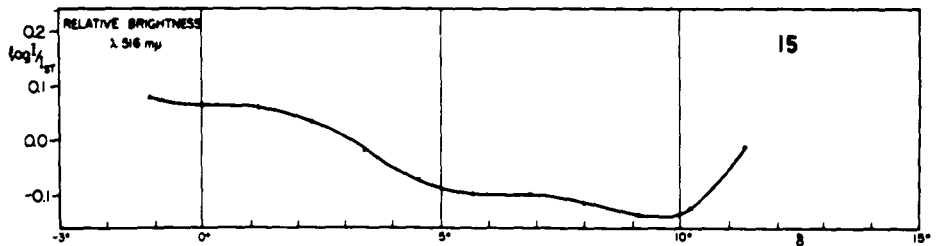
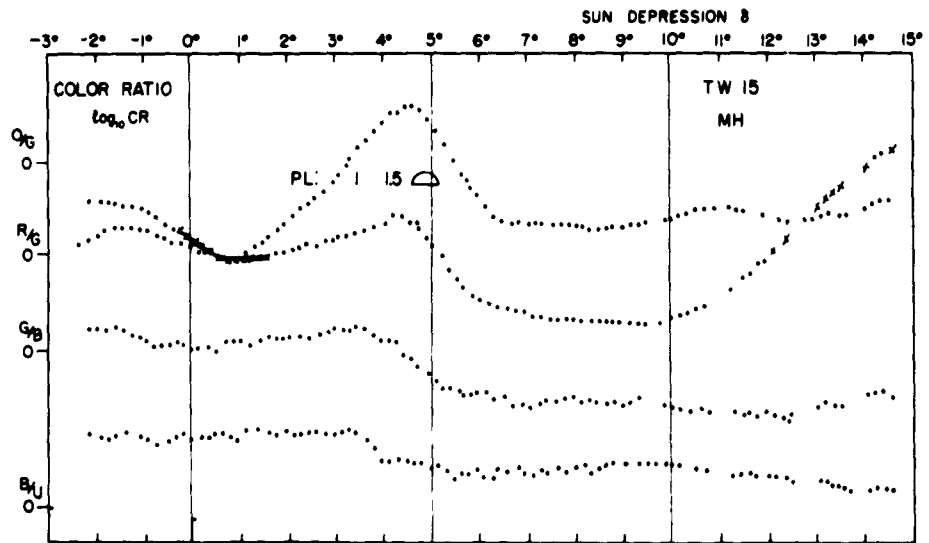
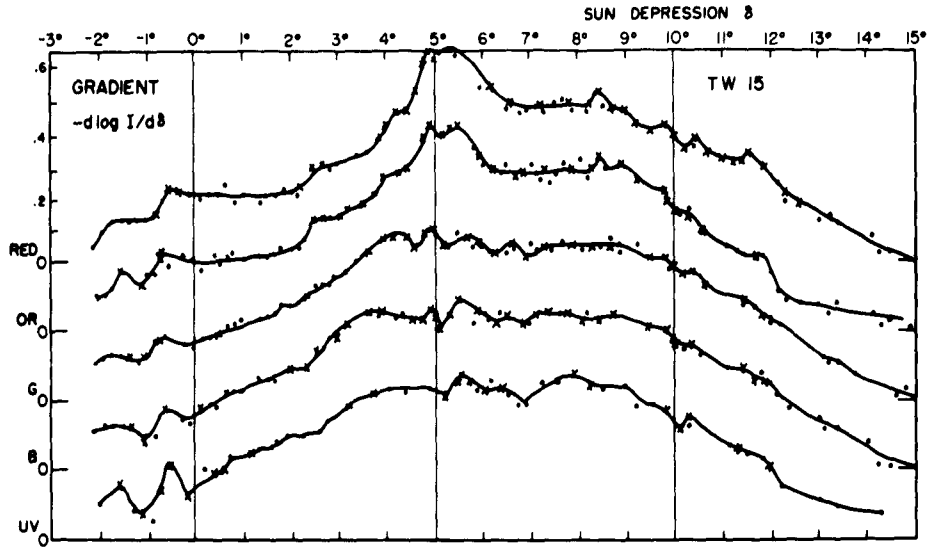
Balloon: Large High Altitude Balloon  
observed from  $12$  to  $13^{\circ}$  sun  
depression; brightness rapidly  
decreasing. Elevation about  $7^{\circ}$ ,  
azimuth ca  $235^{\circ}$ .



**TWILIGHT 14**

**November 9, 1959, Evening**

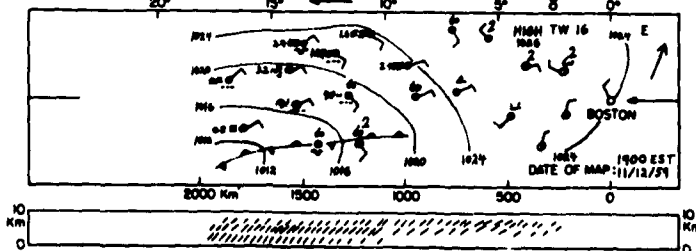
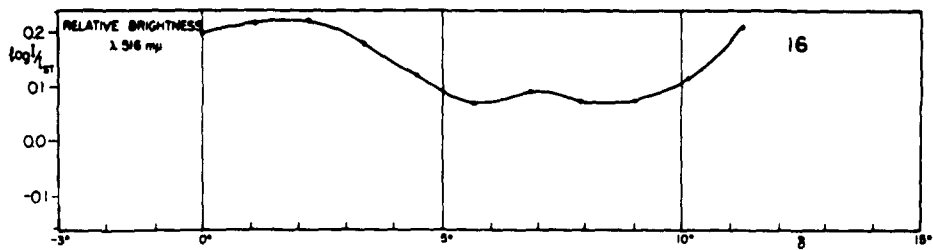
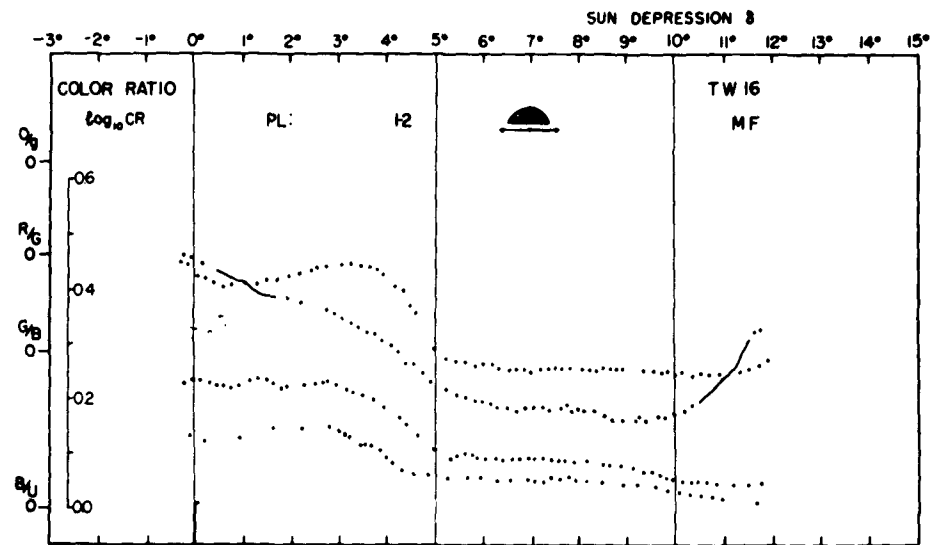
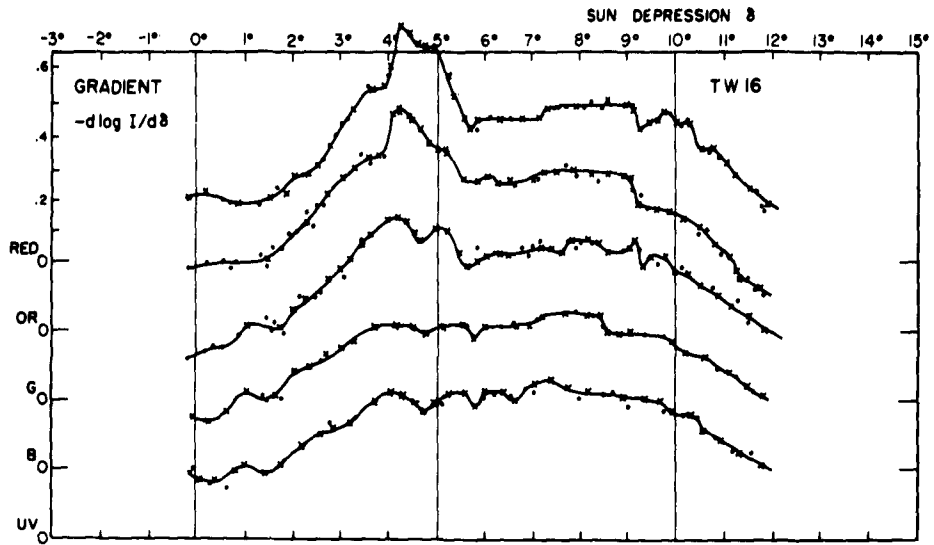
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.8</b>
	<b>Aureole type:</b>	<b>a3</b>
<b>Turbidity coefficient:</b>		<b>≥0.03</b>
<b>Visibility:</b>		<b>70 km</b>
<b>Sunset:</b>		<b>16 25</b>
<b>Declination:</b>		<b>-16.8</b>
<b>Instrument temperature:</b>		<b>+5°</b>
<b>Horizon:</b>		<b>Rather hazy below 1°, fine haze below 15°</b>
<b>Gradient graph:</b>		<b>Maximum of gradient in Red is 0.83 at 5.0° sun depression.</b>



TWILIGHT 15

November 10, 1959, Evening

Daytime sky:	Turbidity type:	1.8
	Aureole type:	a3
Turbidity coefficient:		0.046
Visibility:		70 km
Sunset:		16 24
Declination:		-17.1°
Instrument temperature:		+14° C



TWILIGHT 16

November 12, 1959, Evening

Daytime sky: Turbidity type: - -  
Aureole type: a0.5

Turbidity coefficient: .09<sub>2</sub>

Visibility: 17 km

Sunset: 16 22

Declination: -17.6°

Instrument temperature: +8°

Horizon: At sunset haze layer up to  
8°, later black haze border  
up to 2°

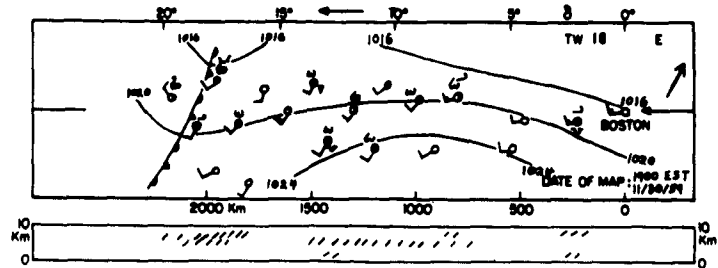
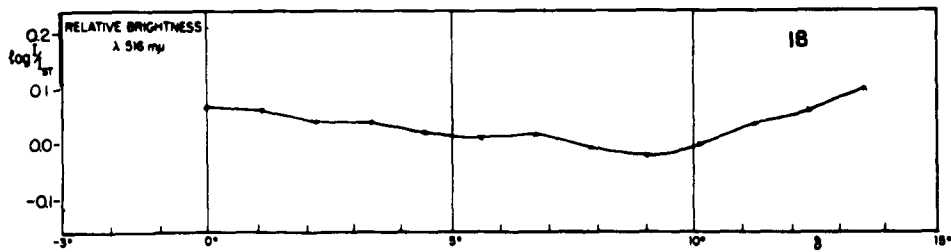
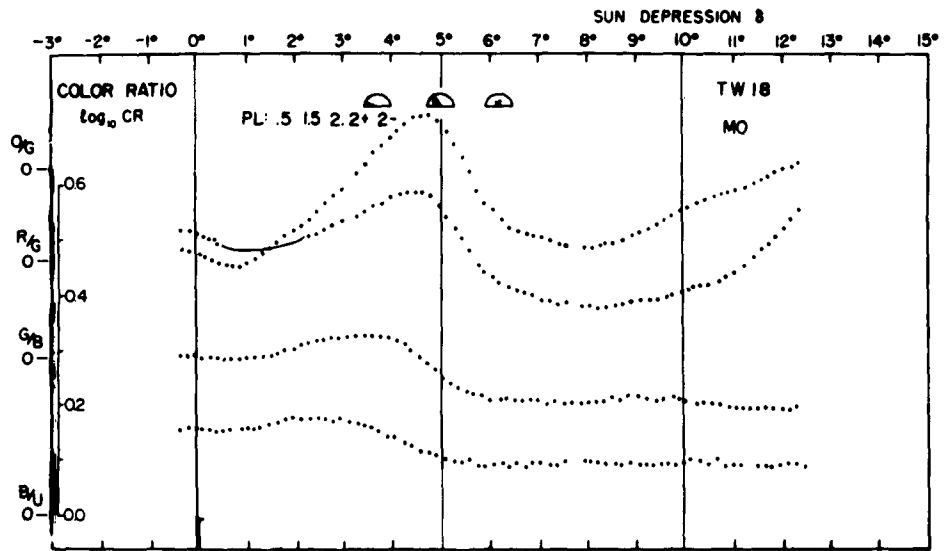
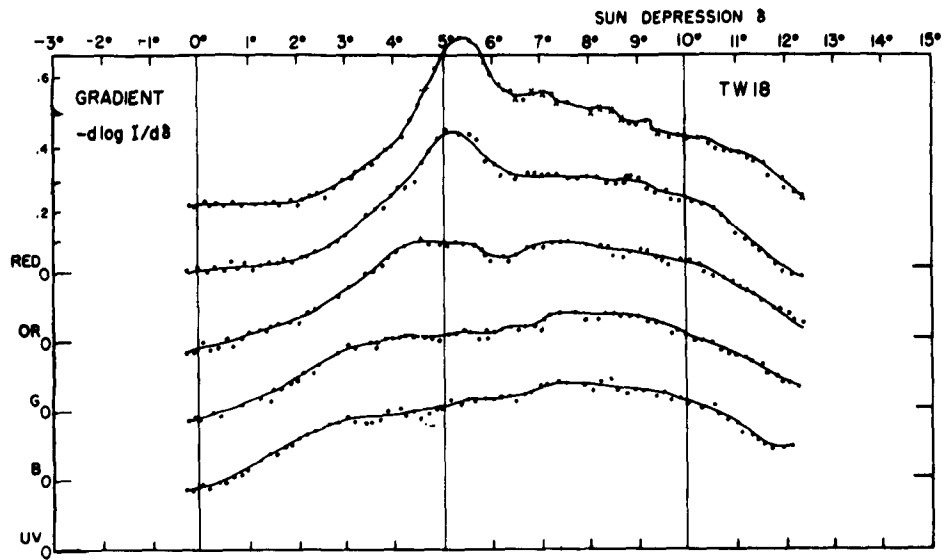
Weather: After 5° sun depression thin  
Ci fields from West



## TWILIGHT 17

November 26, 1959, Morning

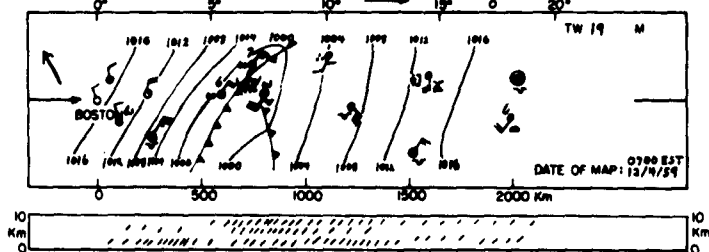
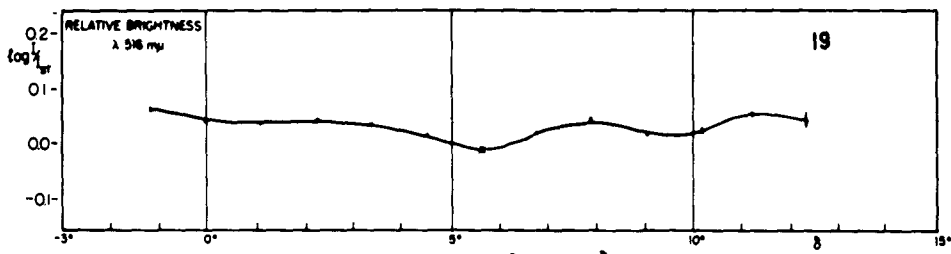
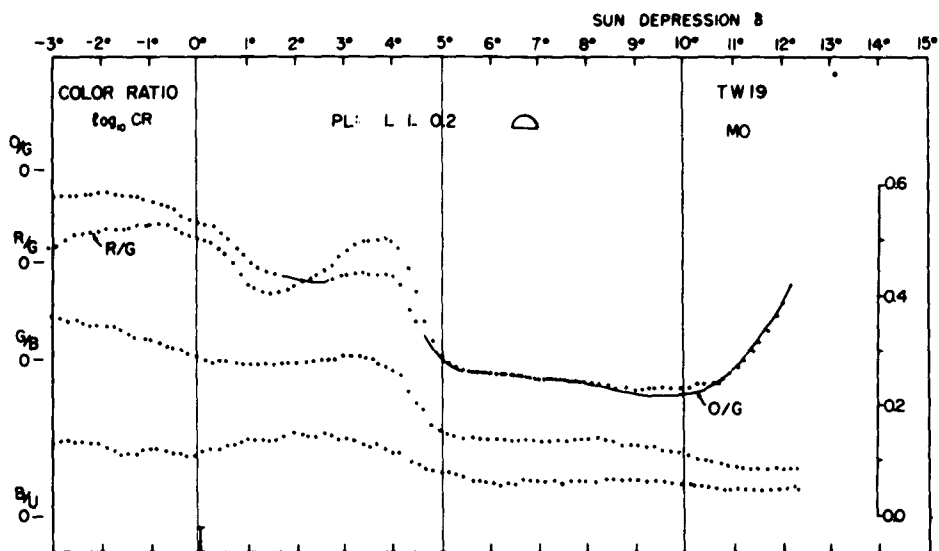
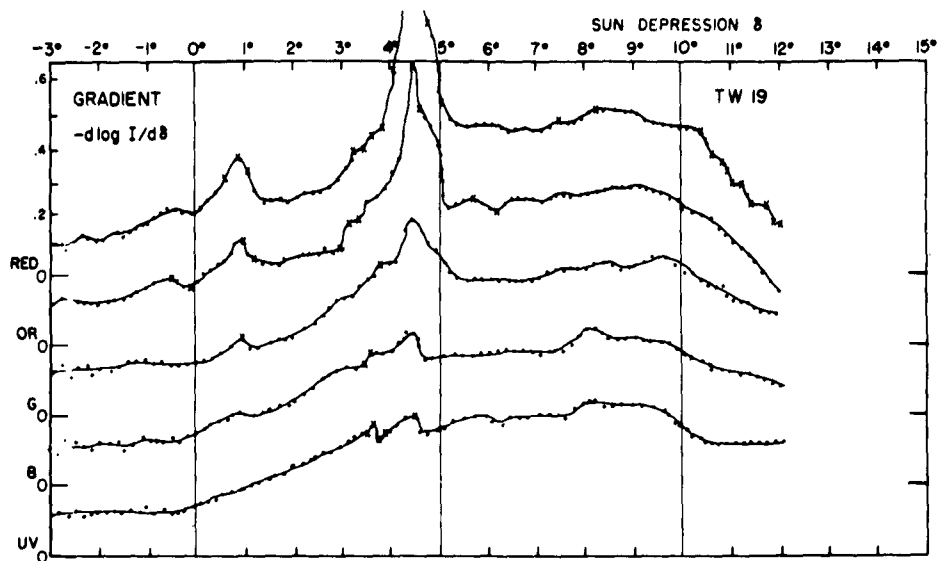
Daytime sky:	Turbidity type:	1.7
	Aureole type:	al
Turbidity coefficient:		0.01 <sub>5</sub>
Visibility:		57 km
Sunrise:		06 54
Declination:		-20.8
Instrument temperature:		+2°C
Horizon:		Shortly after sunrise vertical light pillar up to 10° eleva- tion.
Weather:		At 5° sun depression small Cu fra. passing. Shortly after sunrise Ac9 in waves
Evening:		PL 1.5 - 2, slightly shadowed. Shortly after sunset Ci appear- ing.



TWILIGHT 18

November 30, 1959, Evening

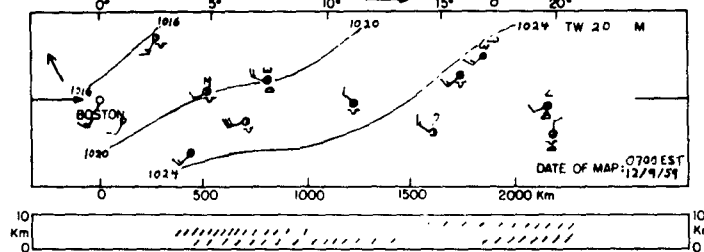
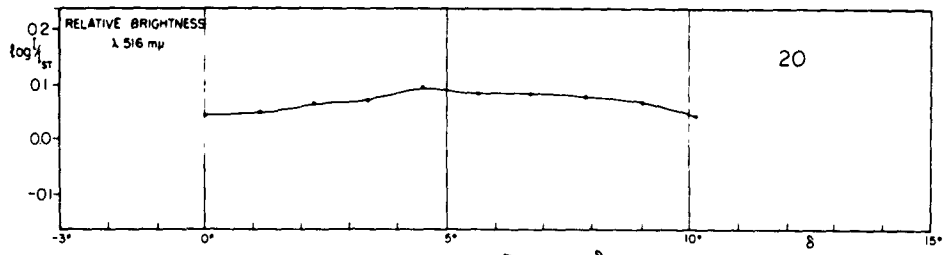
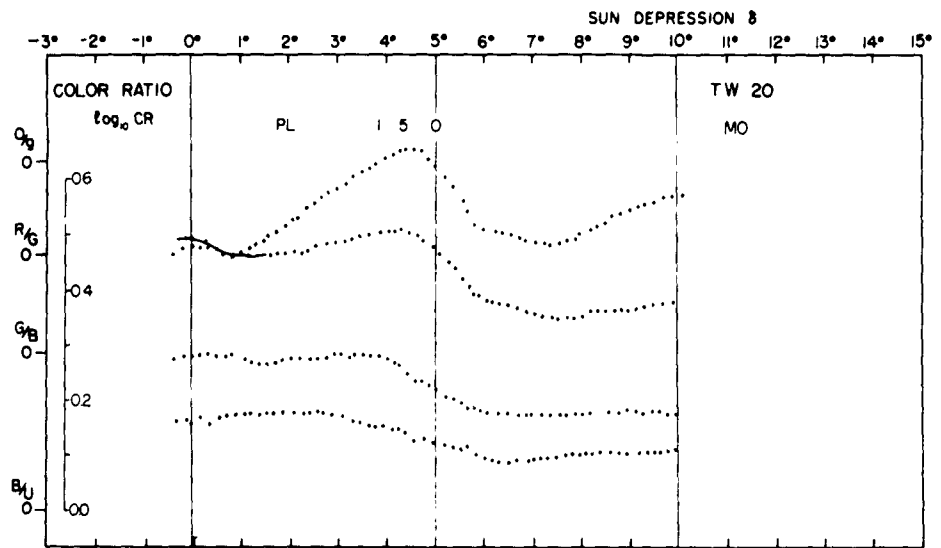
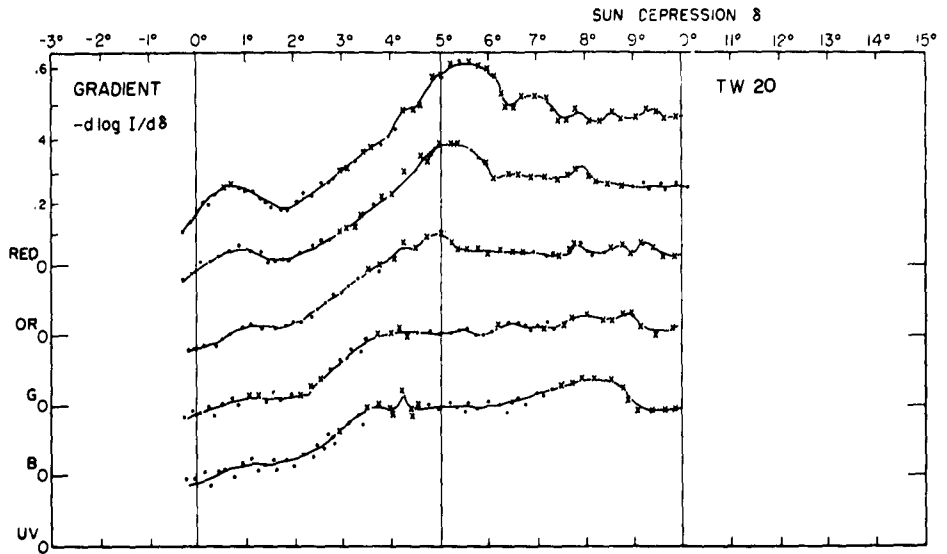
Daytime sky:	Turbidity type:	1.9
	Aureole type:	a0.5
Turbidity coefficient:		0.06
Visibility:		38 km
Sunset:		16 08.8
Declination:		-21.6°
Instrument temperature:		0°C
Horizon:		Haze up to 12° elevation.
		In West St. layer from 1
		to 2° elevation.



TWILIGHT 19

December 4, 1959, Morning

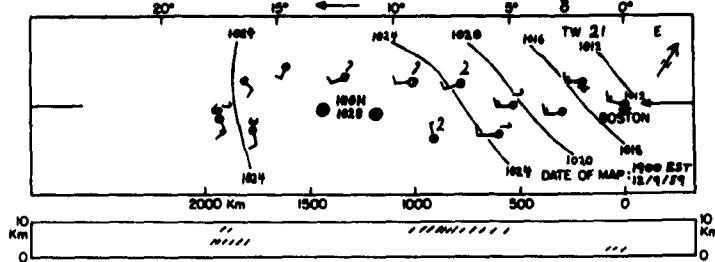
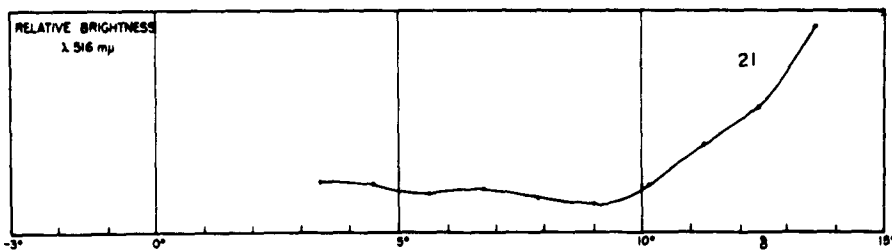
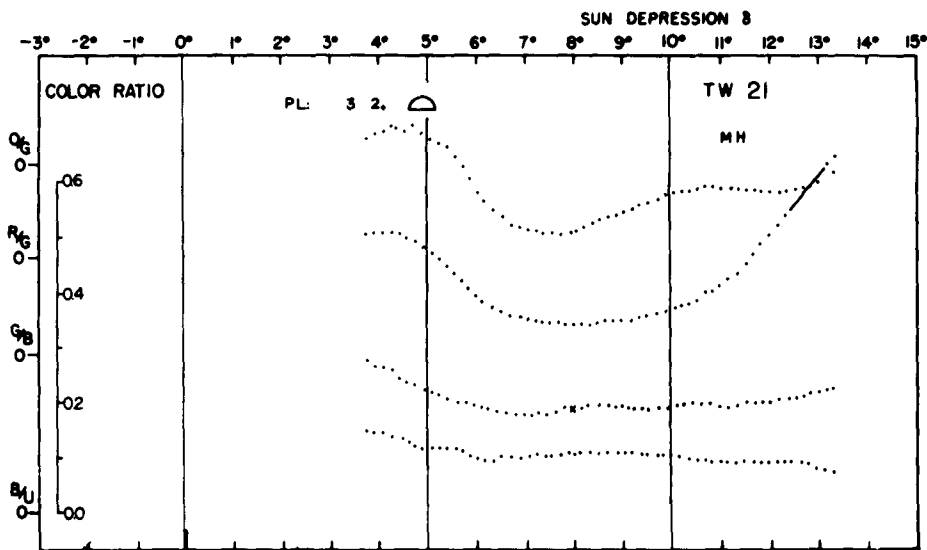
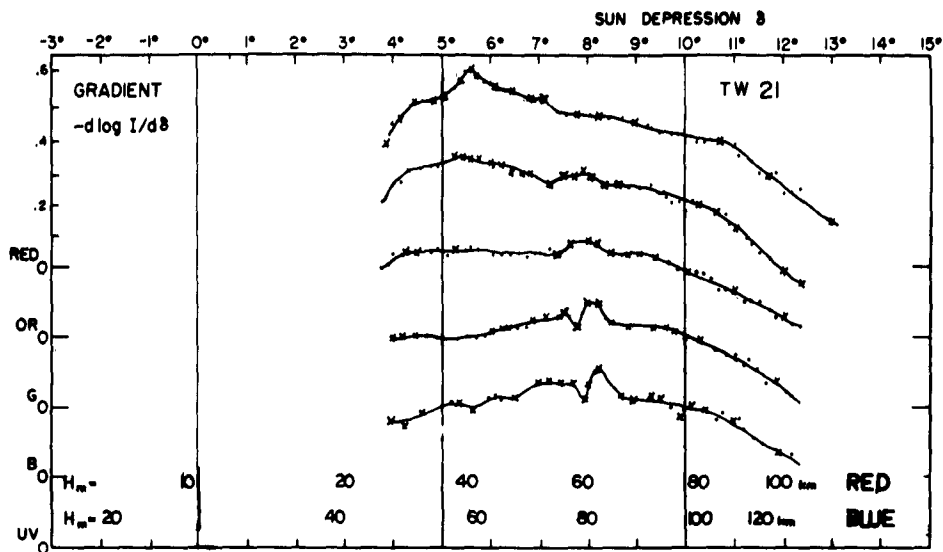
Daytime sky:	Turbidity type:	1.9
	Aureole type:	a3
Turbidity coefficient:		0.047
Visibility:		16 km
Sunrise:		07 03
Declination:		-22.4°
Instrument temperature:		+4°
Horizon:		Sunrise in haze bands, which contain Ac strips; haze up to 2° elevation. Haze top apparently only $\approx$ 200 m above observer.
Gradient graph:		Maximum of gradient in Red is 0.93 at 4.5° sun depression.



**TWILIGHT 20**

**December 9, 1959, Morning**

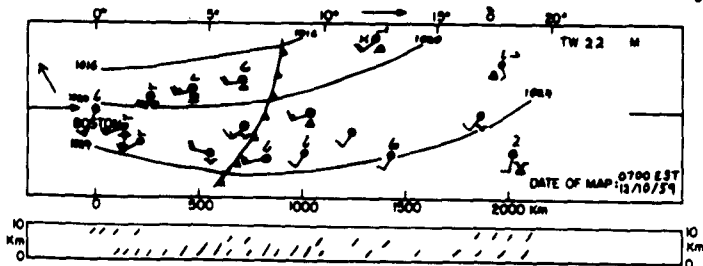
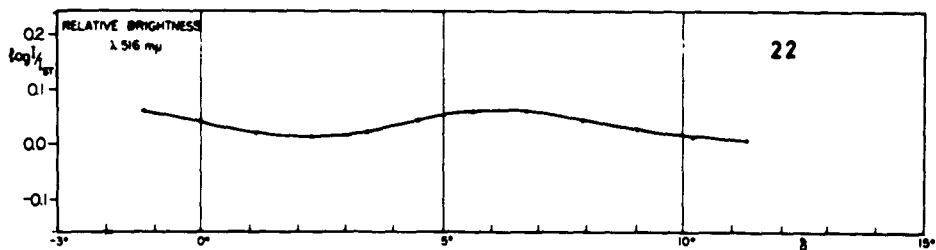
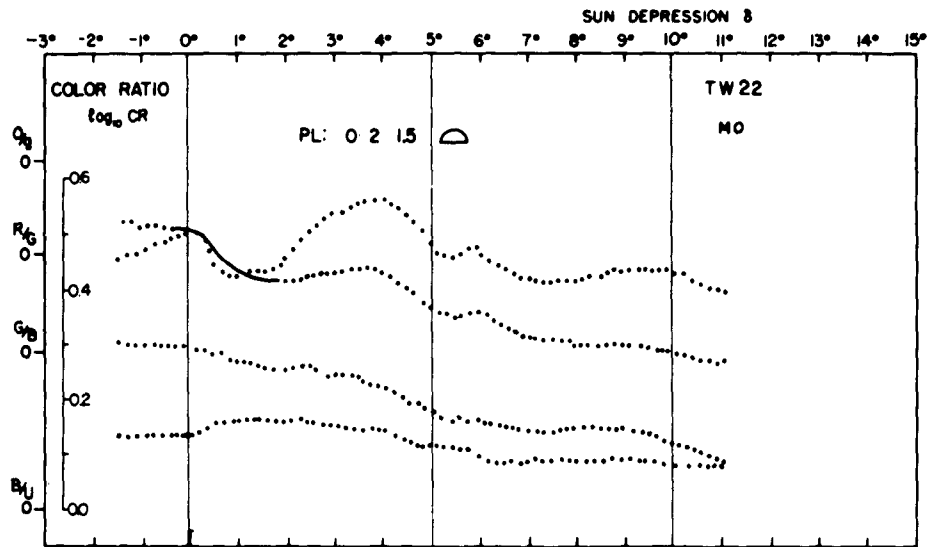
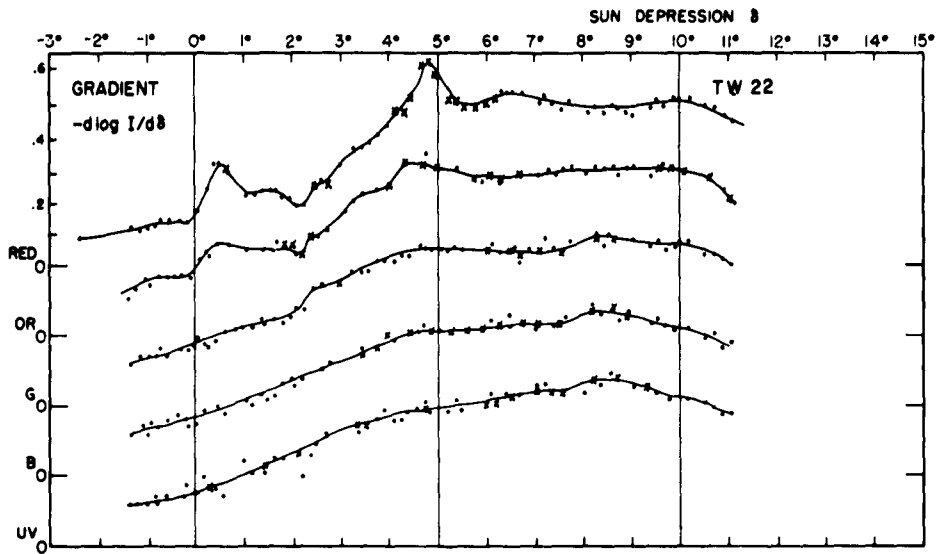
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.3+</b>
	<b>Aureole type:</b>	<b>a0</b>
<b>Turbidity coefficient:</b>		<b>0.01<sub>4</sub></b>
<b>Visibility:</b>		<b>30 km</b>
<b>Sunrise:</b>		<b>07 08</b>
<b>Declination:</b>		<b>-22.9°</b>
<b>Instrument temperature:</b>		<b>-5°</b>
<b>Horizon:</b>		<b>Sharp haze border at 2° elevation, Observatory just below haze top.</b>



**TWILIGHT 21**

**December 9, 1959, Evening**

<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.7</b>	}	<b>at noon</b>
	<b>Aureole type:</b>	<b>a2-3</b>		
<b>Turbidity coefficient:</b>		<b>0.03<sub>7</sub></b>		
<b>Visibility:</b>		<b>65 km</b>		
<b>Sunset:</b>		<b>16 07.2</b>		
<b>Declination:</b>		<b>-22.9°</b>		
<b>Instrument temperature:</b>		<b>+4°</b>		
<b>Horizon:</b>		<b>Dense haze up to 2.5°</b>		



## TWILIGHT 22

December 10, 1959, Morning

Daytime sky: Turbidity type: 1.8  
Aureole type: a5

Turbidity coefficient: 0.03

Visibility: 70 km

Sunrise: 07 05

Declination:  $-22.9^{\circ}$

Instrument temperature:  $0^{\circ}\text{C}$

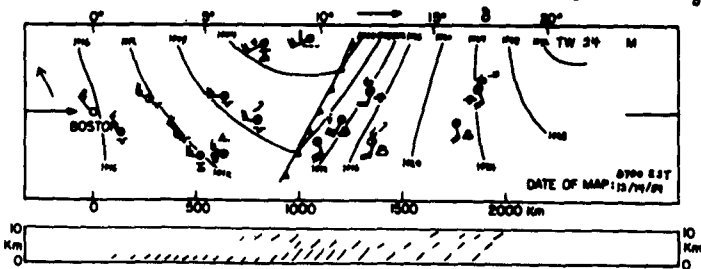
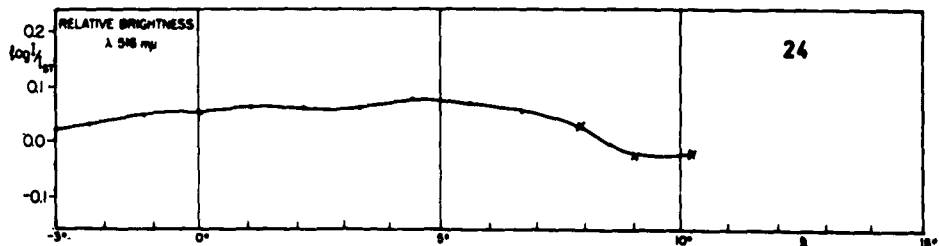
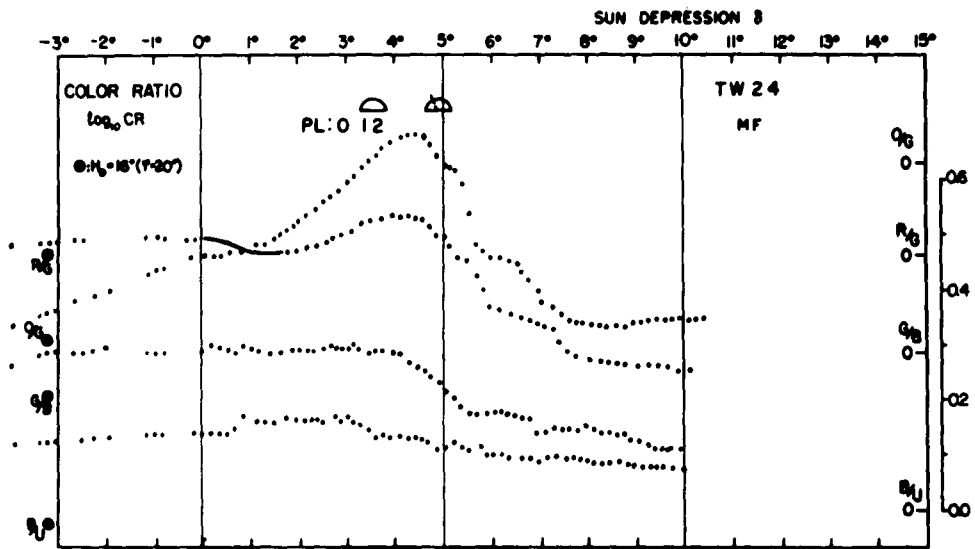
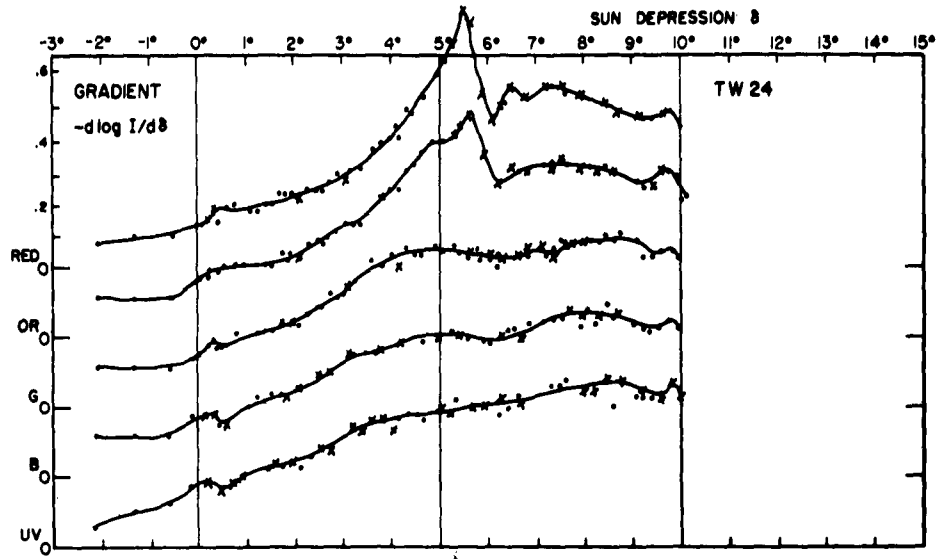
Horizon: At horizon (S to NE) St and Ac  
clouds up to  $5^{\circ}$  elevation.  
At  $7^{\circ}$  sun depression yellowish  
haze up to  $8^{\circ}$  elevation, appar-  
ently in higher tropospheric  
levels.  
At sunrise, faint haze strips  
up to  $5^{\circ}$  elevation.

Remarks: Twilight 23 only from  $6$  to  $11^{\circ}$   
sun depression measured; data  
not presented.

## TWILIGHT 23

December 10, 1959, Evening

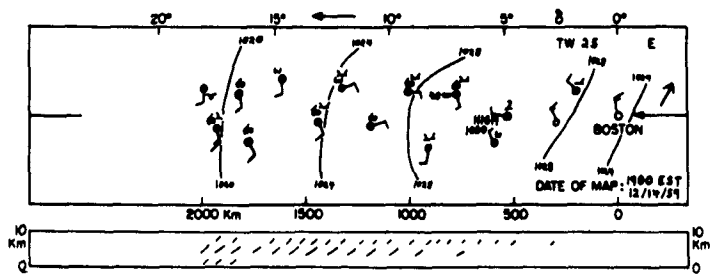
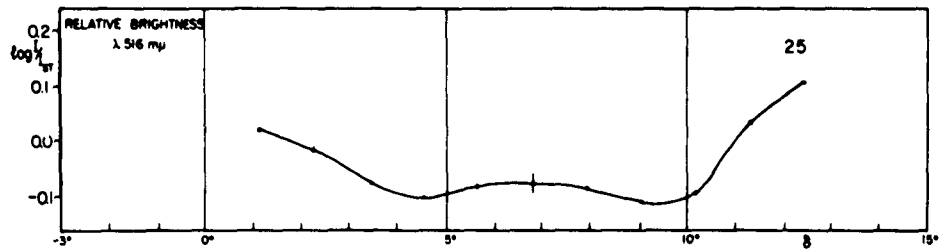
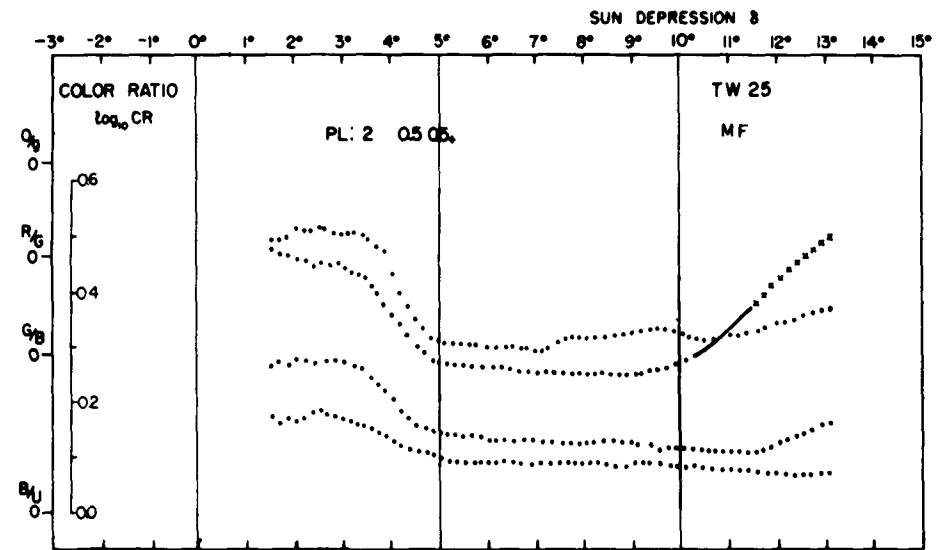
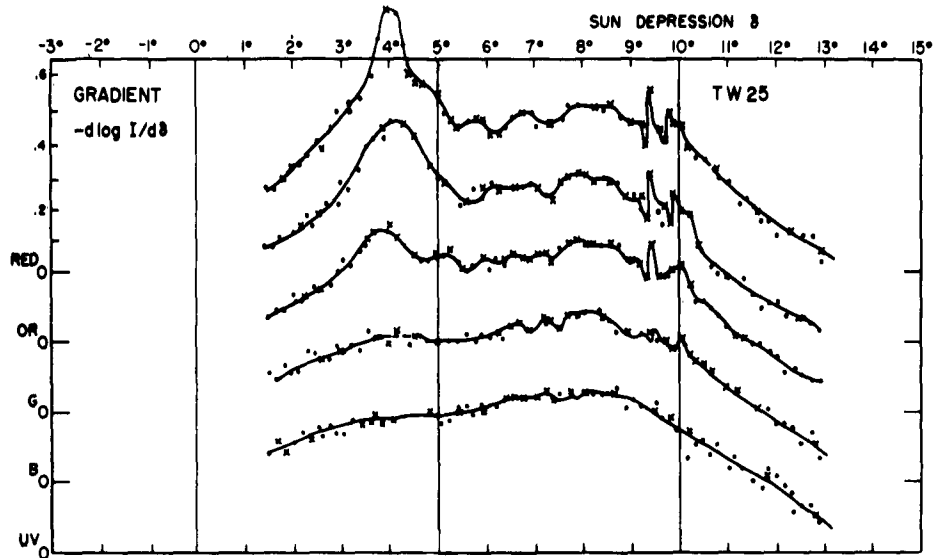
Observations started at  $4.5^{\circ}$  sun depression after disappearance of  
Ci traces out of field of view. Data and graphs not presented but  
quite similar to the ones of Twilight 22.



TWILIGHT 24

December 14, 1959, Morning

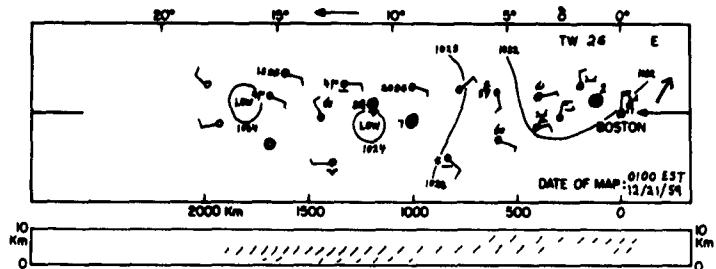
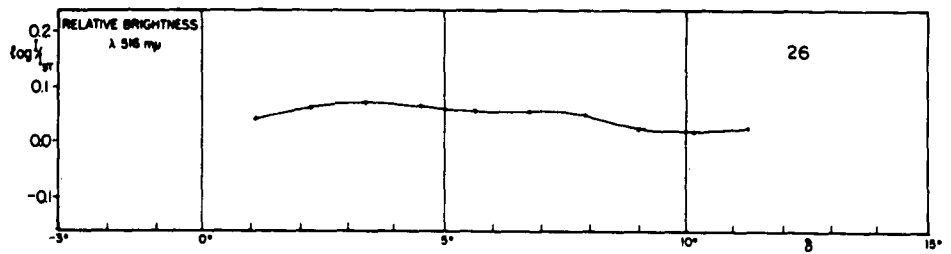
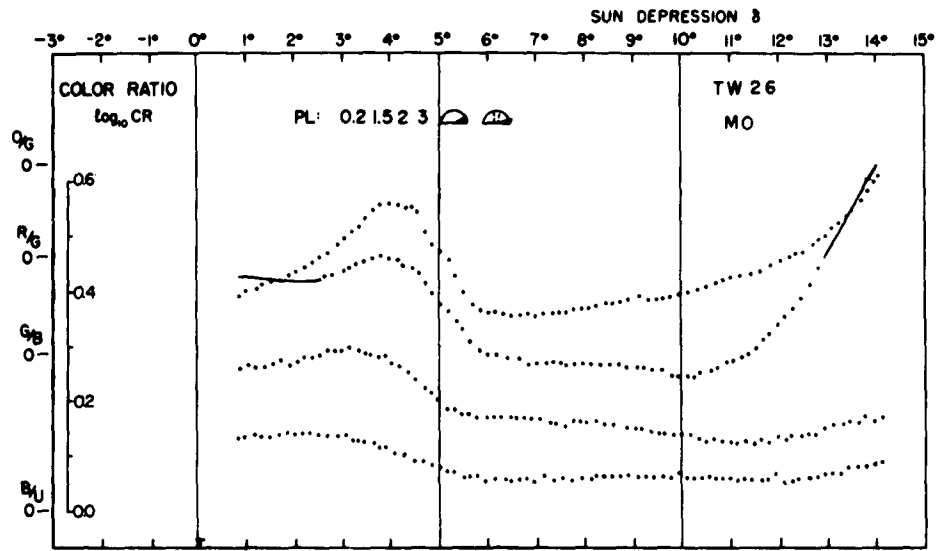
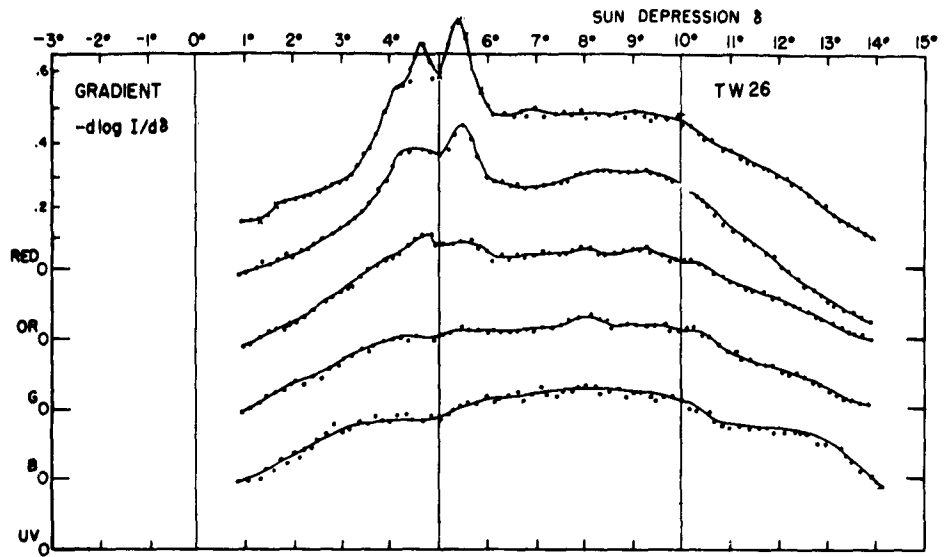
Daytime sky:	Turbidity type:	1.7
	Aureole type:	al
Turbidity coefficient:		0.01 <sub>6</sub>
Visibility:		80 km
Sunrise:		07 12
Declination:		-23.2°
Instrument temperature:		-4°
Horizon:		At about 4° sun depression faint haze waves from 12 to 18° elevation. Some city haze very low over sea.



## TWILIGHT 25

December 14, 1959, Evening

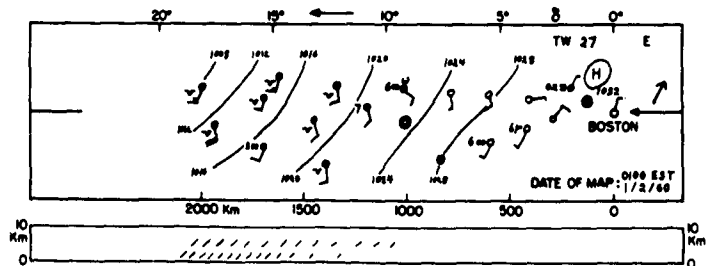
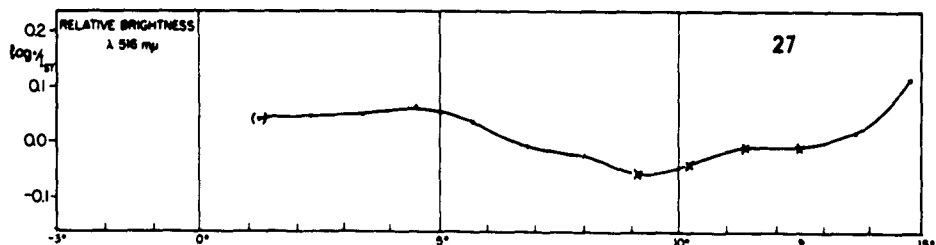
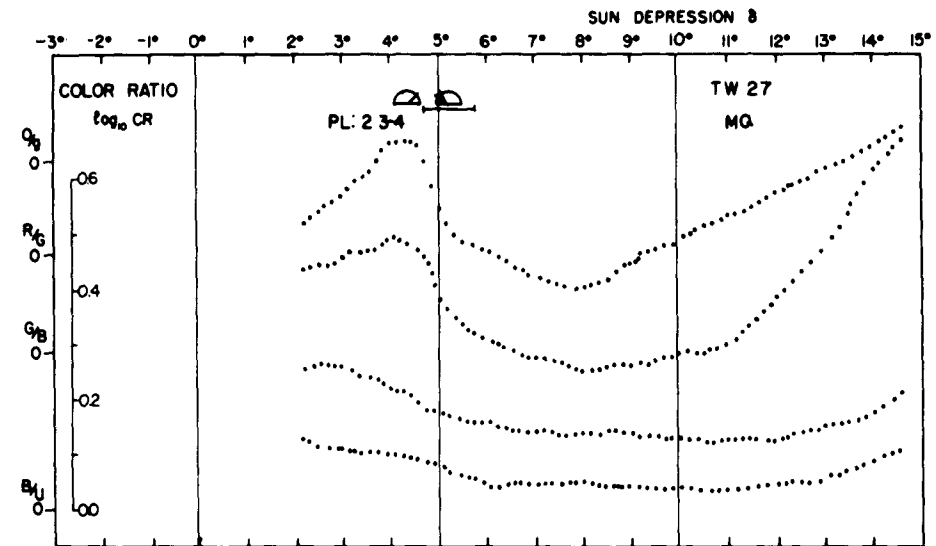
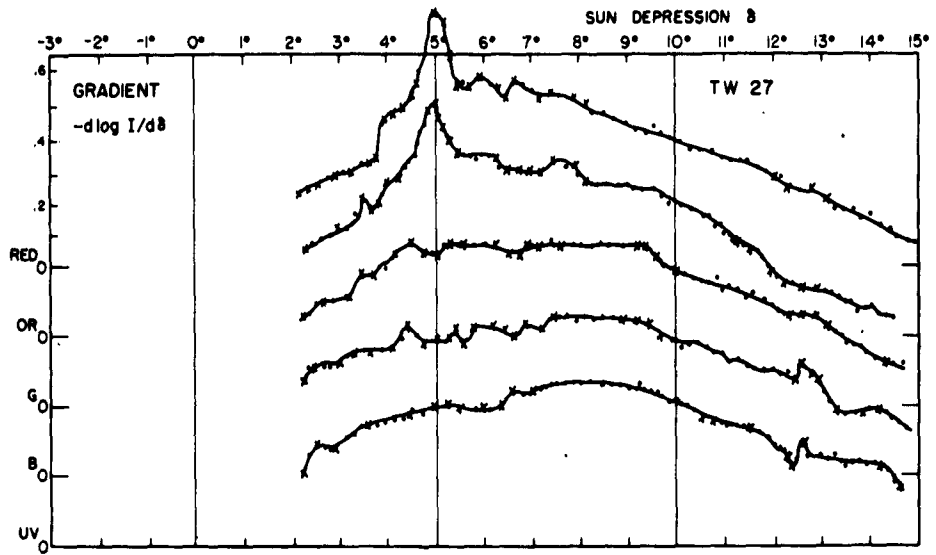
Daytime sky:	Turbidity type:	1.4
	Aureole type:	a2
Turbidity coefficient:		0.01 <sub>7</sub>
Visibility:		100 km
Sunset:		16 07.5
Declination:		-23.2 <sup>o</sup>
Instrument temperature:		0 <sup>o</sup>
Horizon:		Thin Ci in west up to 5 <sup>o</sup> elevation.
Anti-twilight:		Earth shadow at sunset in 2 <sup>o</sup> elevation, northern part 2 <sup>o</sup> higher.



TWILIGHT 26

December 20, 1959, Evening

Daytime sky:	Turbidity type:	1.7
	Aureole type:	a2
Turbidity coefficient:		0.02_
Visibility:		115 km
Sunset:		16 09.2
Declination:		-23.4°
Instrument temperature:		-5°
Horizon:		Up to 10° elevation distant Ac and St clouds.
Anti-twilight:		Irregular shape of earth shadow before sunset



## TWILIGHT 27

January 1, 1960, Evening

Daytime sky: Turbidity type: 1.3  
Aureole type: --

Turbidity coefficient: .013

Visibility: 130 km

Sunset: 16 16.5

Declination:  $-23^{\circ}$

Instrument temperature:  $0^{\circ}$

Horizon: Strong haze strips up to  $3^{\circ}$   
elevation.

Anti-twilight: Upper border of earth shadow  
sharp from S to NE, but not in  
N direction (compare purple  
light observations).

## TWILIGHT 28

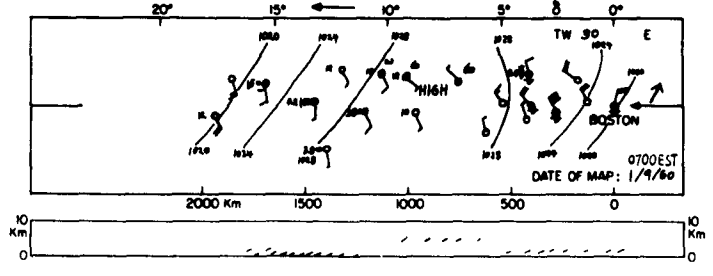
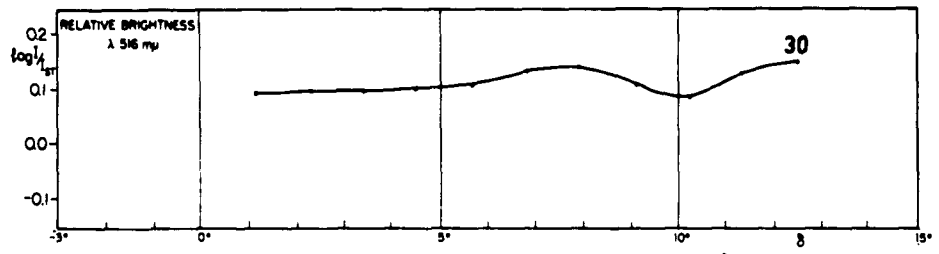
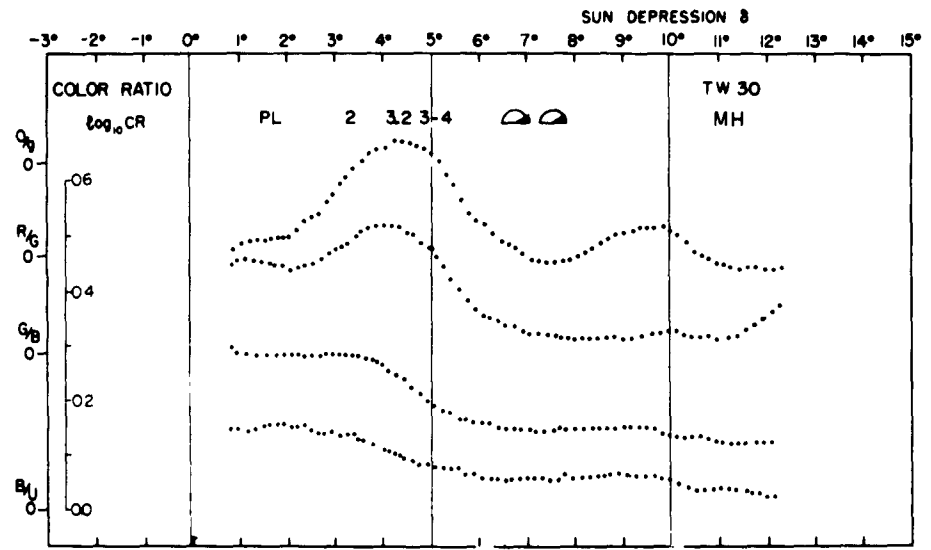
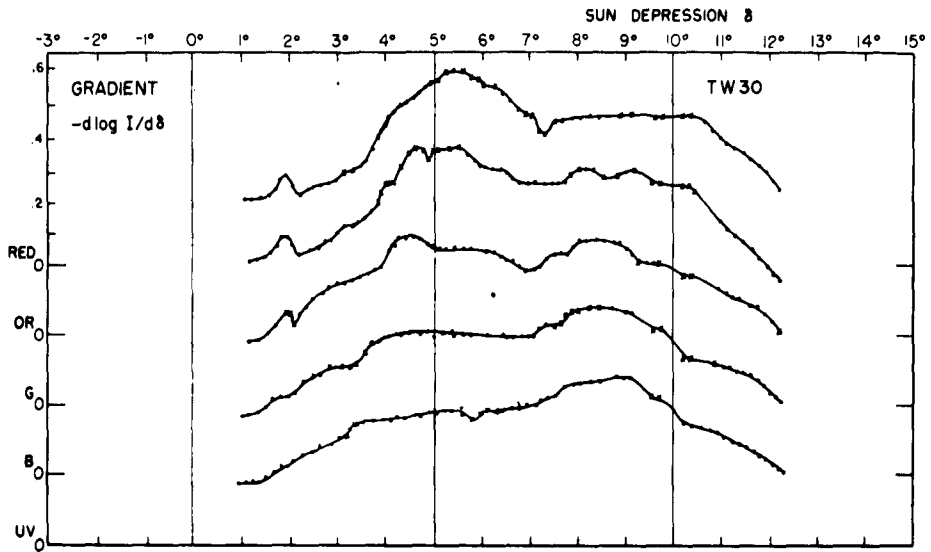
January 3, 1960, Evening

Local Sc clouds interfering from  $4$  to  $6^{\circ}$  sun depression; measurements not continued. At  $4^{\circ}$  sun depression PL 2.

## TWILIGHT 29

January 6, 1960, Evening

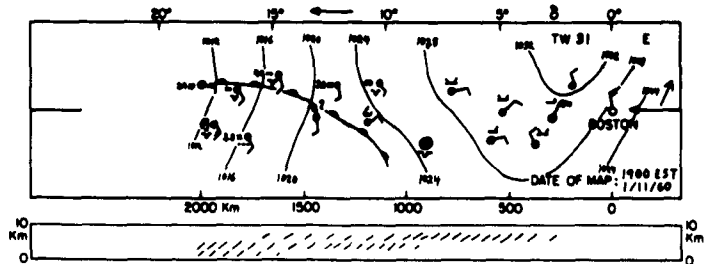
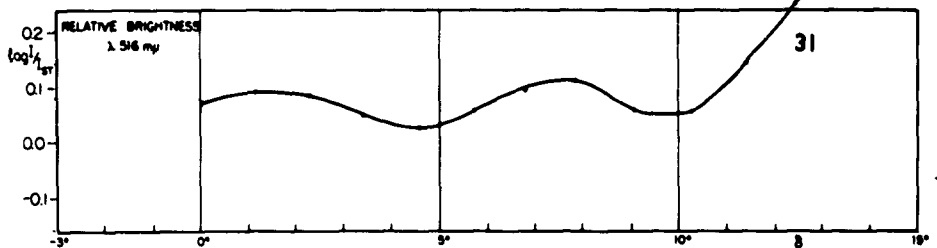
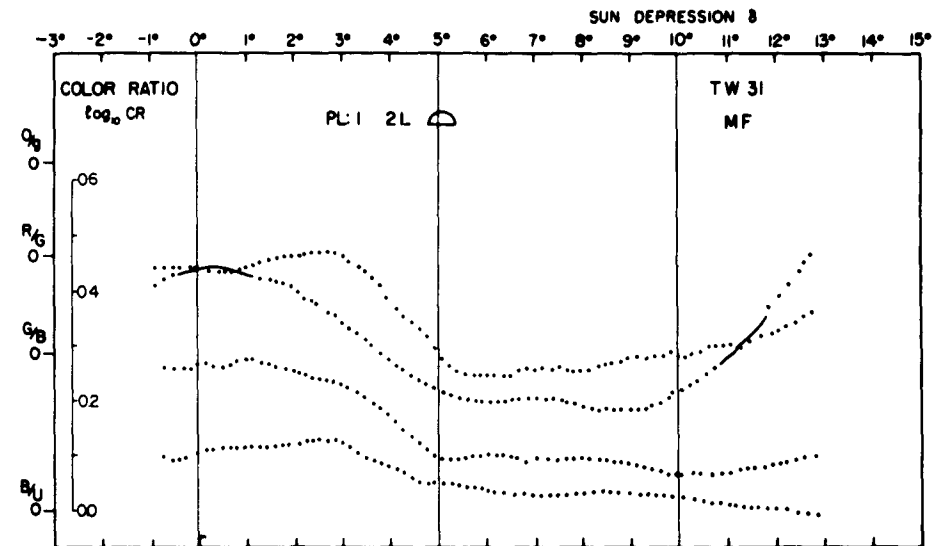
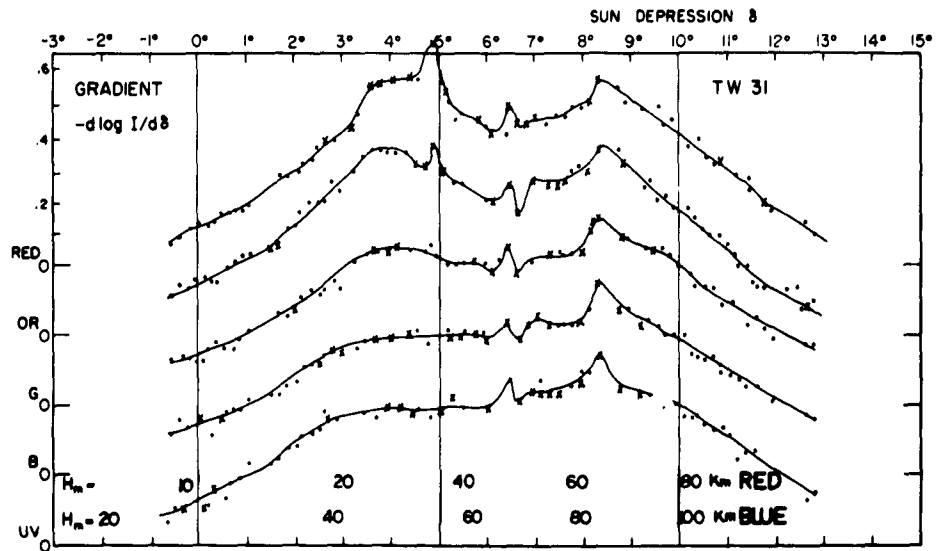
Very hazy. At  $3^{\circ}$  sun depression, measurements discontinued because of local Ac clouds. At  $3.5^{\circ}$  sun depression PL 1 - 2.



**TWILIGHT 30**

**January 9, 1960, Evening**

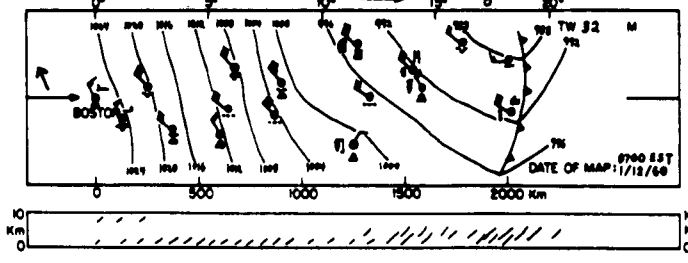
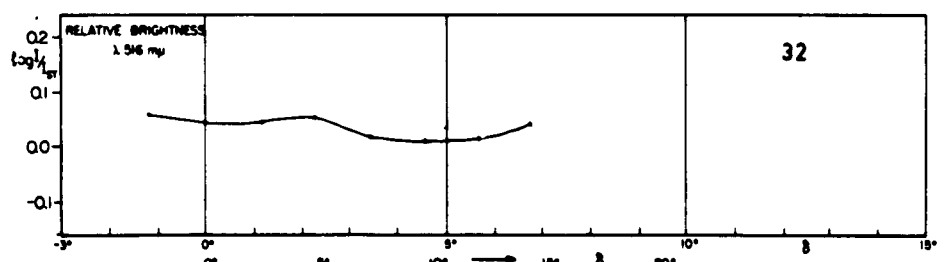
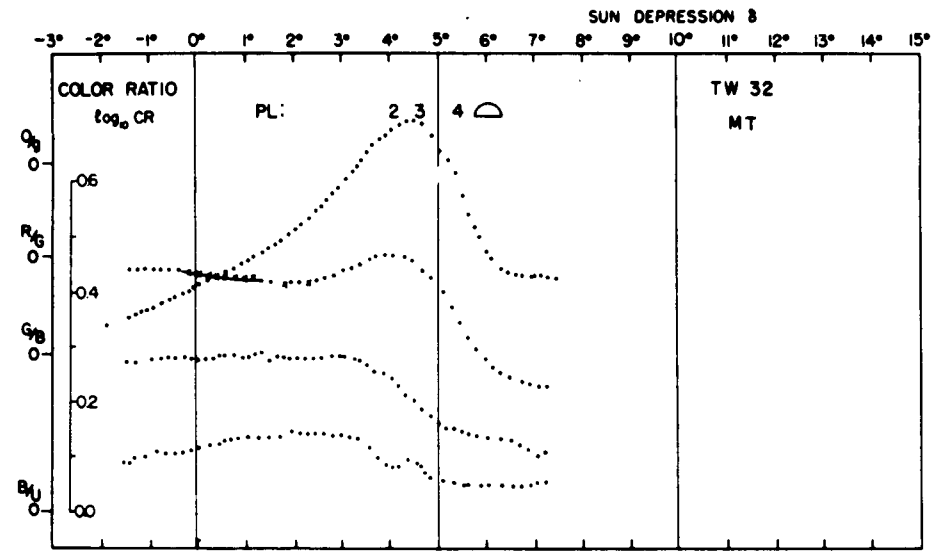
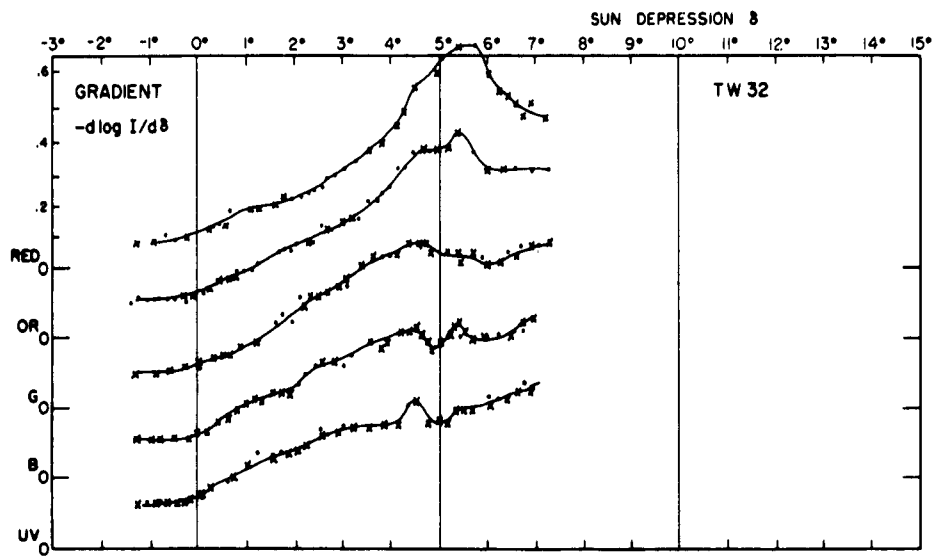
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.6</b>
	<b>Aureole type:</b>	<b>a3</b>
<b>Turbidity coefficient:</b>		<b>0.015</b>
<b>Visibility:</b>		<b>115 km</b>
<b>Sunset:</b>		<b>16 23</b>
<b>Declination:</b>		<b>-22.3°</b>
<b>Instrument temperature:</b>		<b>-10°</b>
<b>Anti-twilight:</b>		<b>Earth shadow at 4° sun depression very irregular.</b>
<b>Weather map:</b>		<b>Before midnight front system moving rapidly from SW into sun- set line.</b>



**TWILIGHT 31**

**January 11, 1960, Evening**

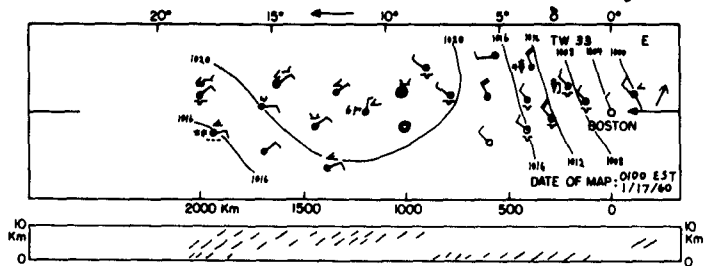
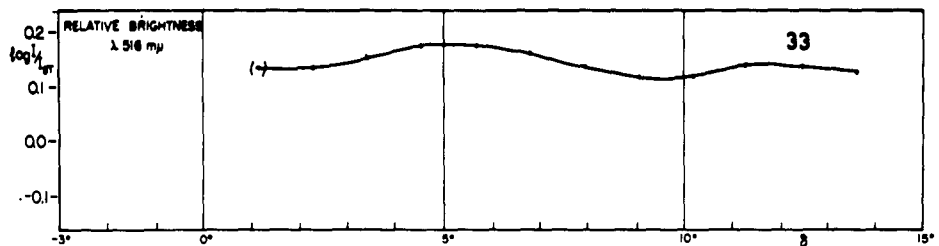
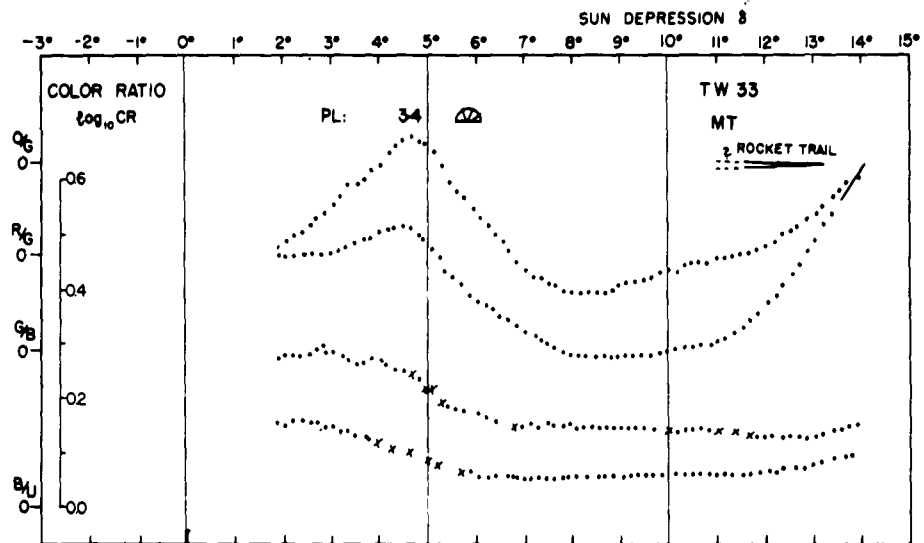
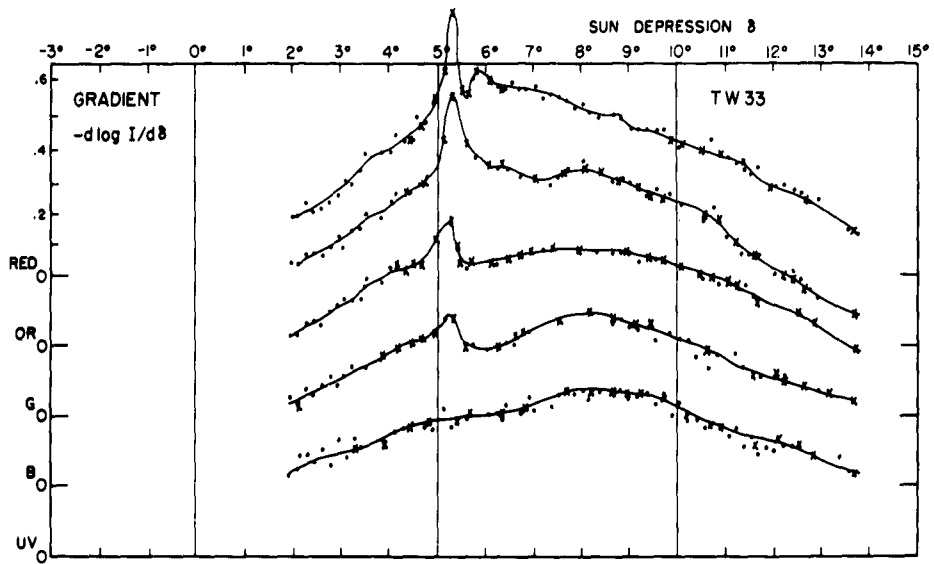
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.7</b>
	<b>Aureole type:</b>	<b>a2</b>
<b>Turbidity coefficient:</b>		<b><math>\approx 0.02</math></b>
<b>Visibility:</b>		<b>130 km</b>
<b>Sunset:</b>		<b>16 25.5</b>
<b>Declination:</b>		<b>-22.0</b>
<b>Instrument temperature:</b>		<b>-6°</b>
<b>Horizon:</b>		<b>Haze border at 2° elevation</b>



TWILIGHT 32

January 12, 1960, Morning

Daytime sky:	Turbidity type:	1.4 <sub>-</sub>
	Aureole type:	a0
Turbidity coefficient:		0.015
Visibility:		130 km
Sunrise:		07 18
Declination:		-21.9°
Instrument temperature:		-12°C
Horizon:		Low Sc clouds over sea.
Anti-twilight:		At 3° sun depression in S direction partly shadowed by Ci clouds which are visible in SE.



TWILIGHT 33

January 16, 1960, Evening

Daytime sky: Turbidity type: 1.8  
Aureole type: a2

Turbidity coefficient: 0.025

Visibility: 80 km

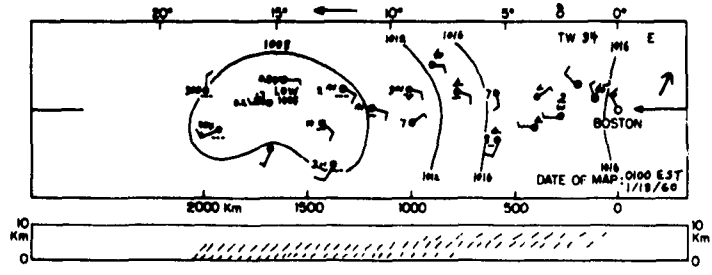
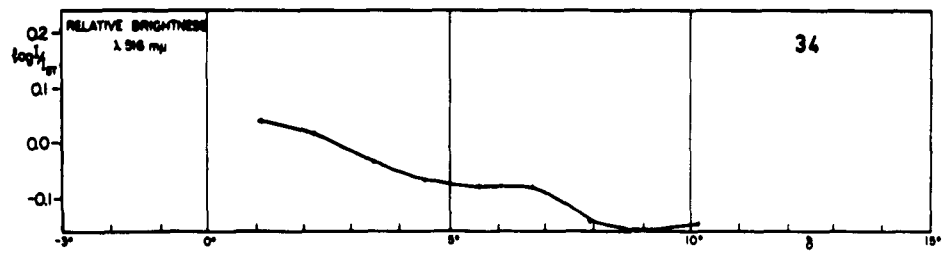
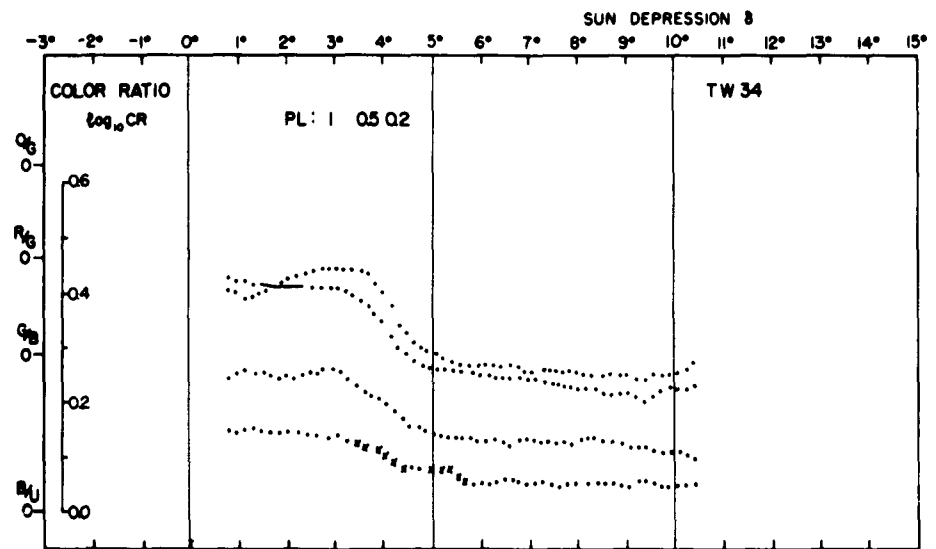
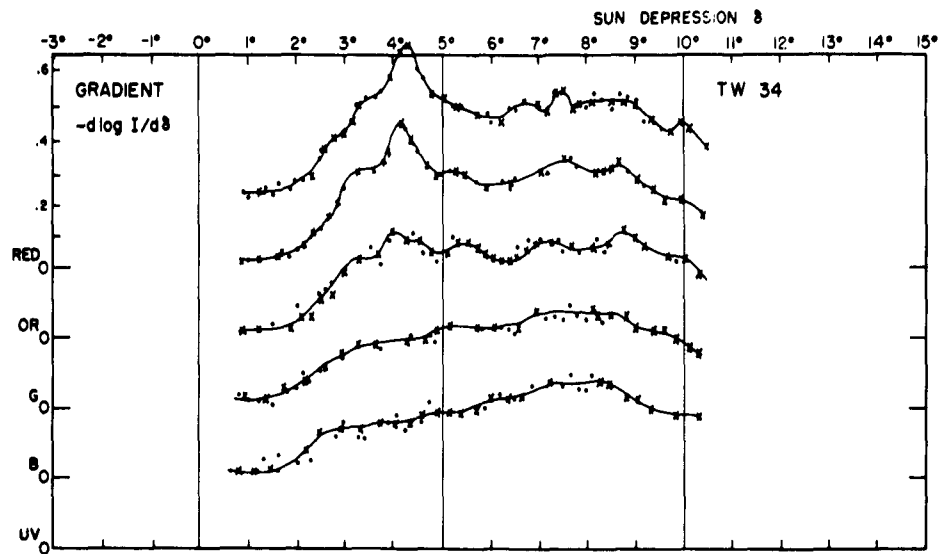
Sunset: 16 31

Declination:  $-21.2^{\circ}$

Instrument temperature:  $-5^{\circ}$

Horizon: Haze strips up to  $20^{\circ}$  elevation, clearly visible up to  $7^{\circ}$  sun depression. At about  $7^{\circ}$  sun depression, reddish haze strips up to  $3^{\circ}$  elevation.

Rocket trail: Bright, distorted rocket trail in left edge of twilight segment first observed at  $11.5^{\circ}$  sun depression (17 40 EST). Trail extending from about  $5$  to  $10^{\circ}$  elevation, azimuth  $212^{\circ}$  (sun at  $250^{\circ}$ ). Color photograph at  $\delta = 12.7^{\circ}$ . Brightness of trail quickly diminishing at  $\delta = 13^{\circ}$ ; trail no more visible after  $\delta = 13.5^{\circ}$ .



TWILIGHT 34

January 17, 1960, Evening

Daytime sky: Turbidity type: 1.8<sub>-</sub>  
Aureole type: a2<sub>-</sub>

Turbidity coefficient: 0.01<sub>0</sub>

Visibility: 135 km

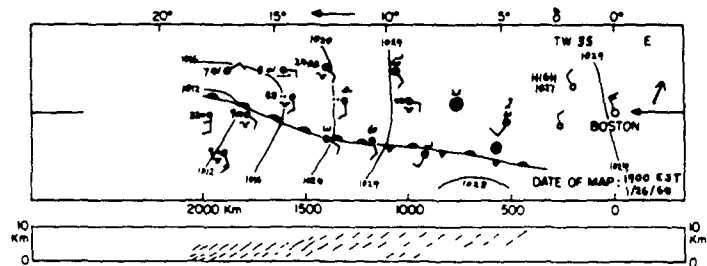
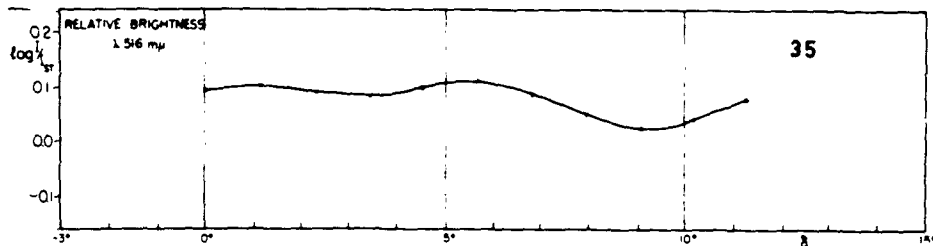
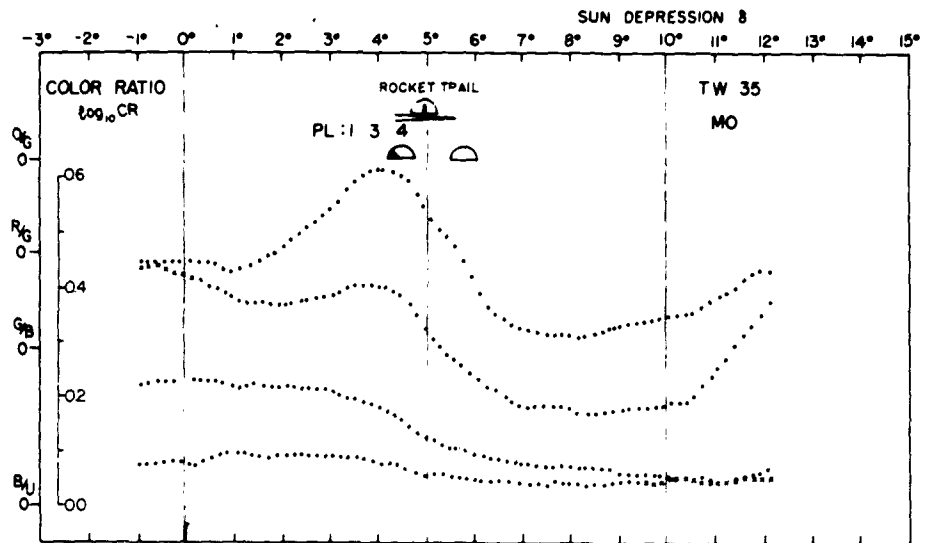
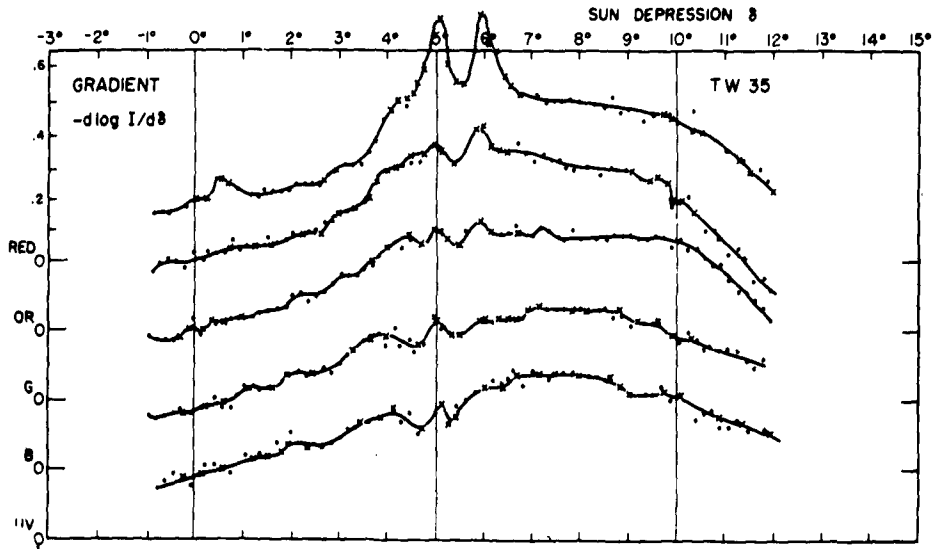
Sunset: 16 34

Declination: -21°

Instrument temperature: 0°C

Horizon: In early twilight strong haze  
strips up to 15° elevation .  
Moderately dense Ci below 2°  
elevation.

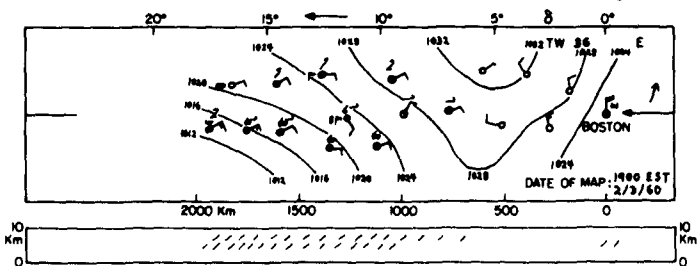
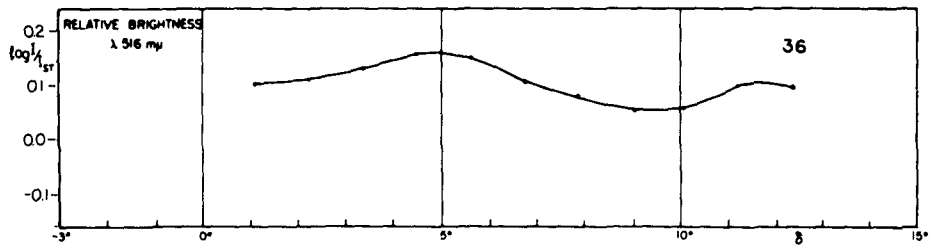
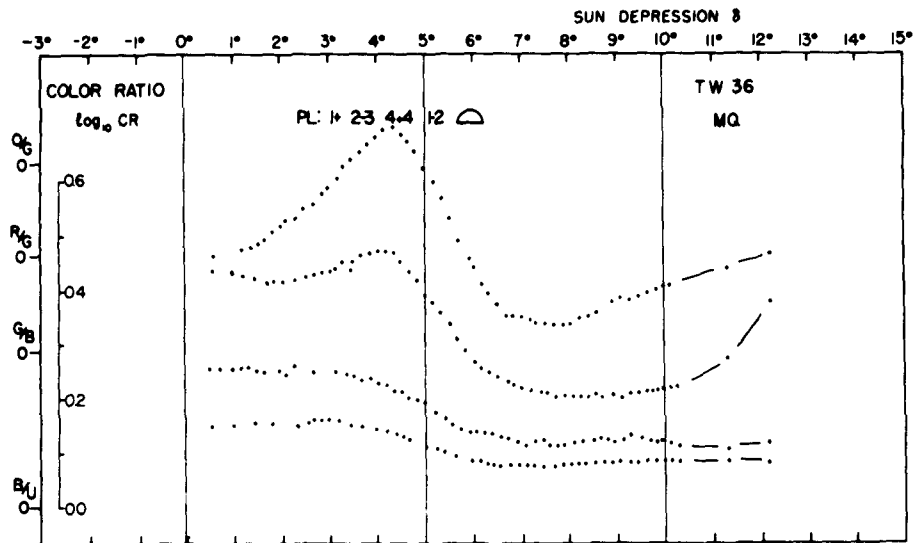
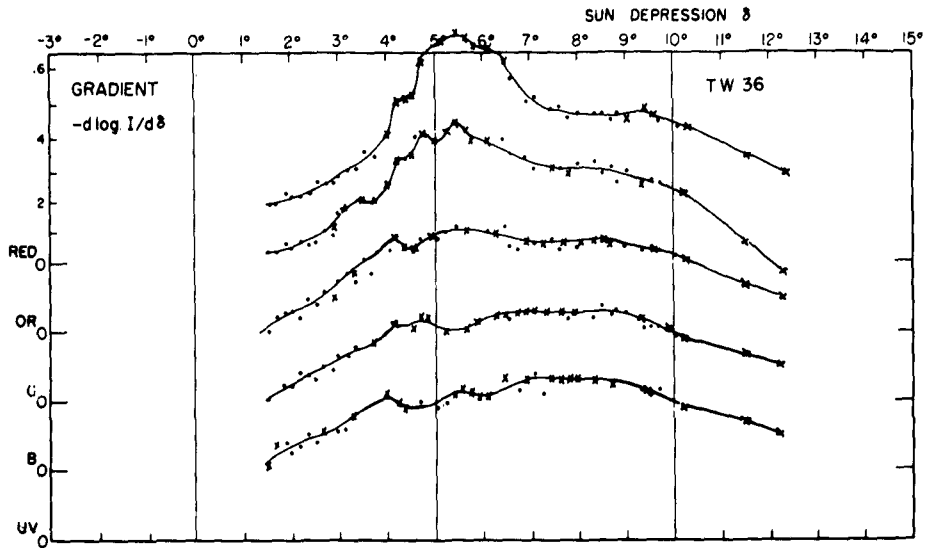
Moon: MO



## TWILIGHT 35

January 26, 1960, Evening

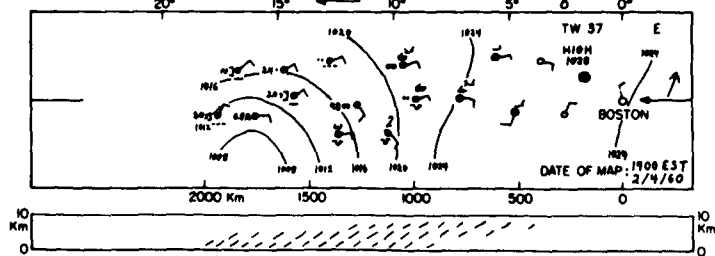
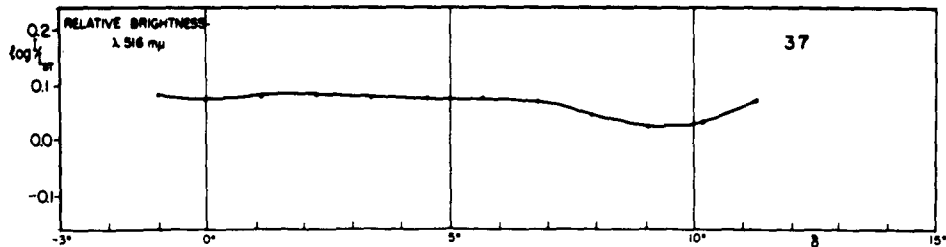
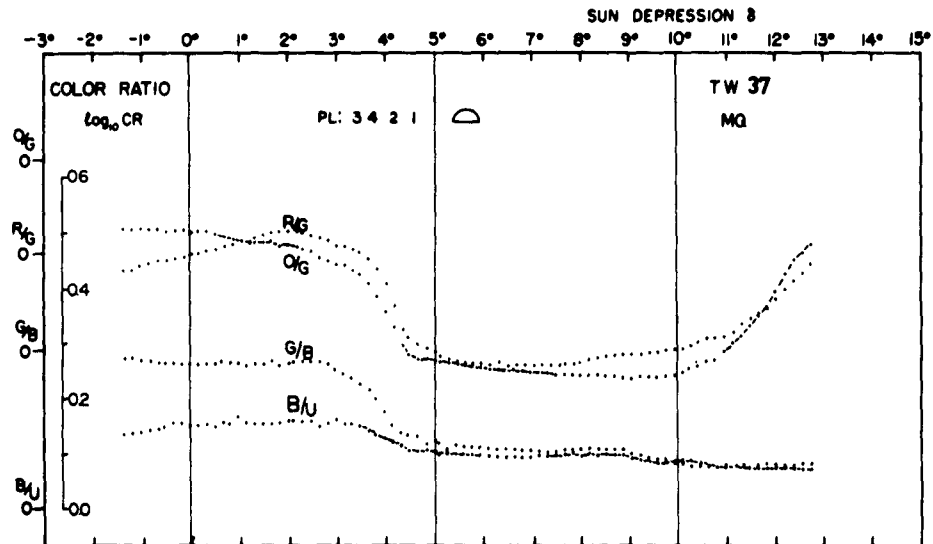
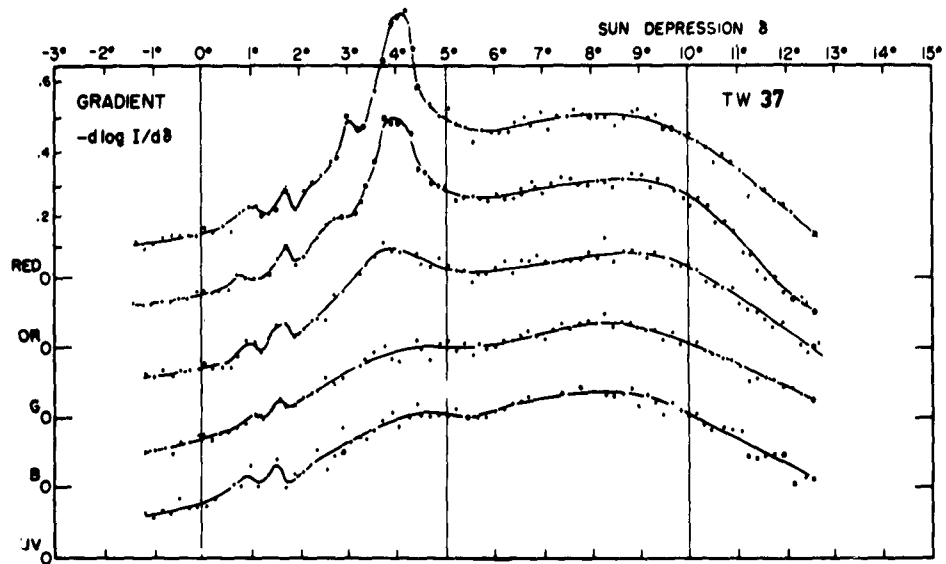
Daytime sky:	Turbidity type:	1.7
	Aureole type:	a4
Turbidity coefficient:		0.032
Visibility:		75 km
Sunset:		16 43.2
Declination:		-19.0°
Instrument temperature:		0°C
Horizon:		Below 3° elevation a few thin Ci clouds and haze. Very distant, vertical rocket trail, extending to about 1° elevation, in center of twilight segment. Trail gives raise to a sharp crepuscular ray at sun depression 4.4 to 5.5°. At beginning, trail bright and orange, at 5.5° sun depression dark red, and illumination ceasing.



**TWILIGHT 36**

**February 3, 1960, Evening**

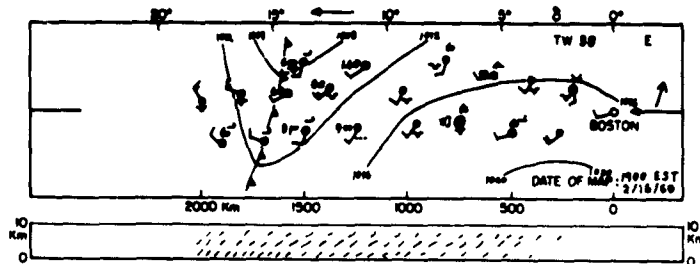
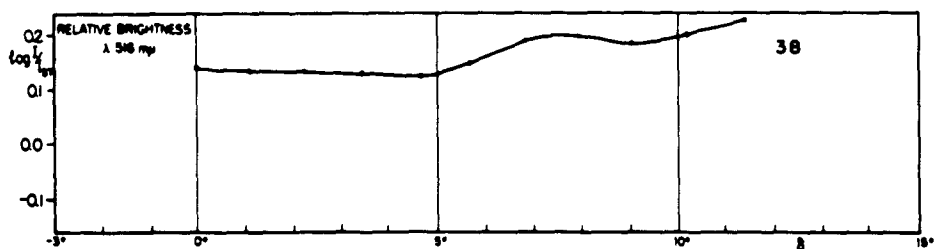
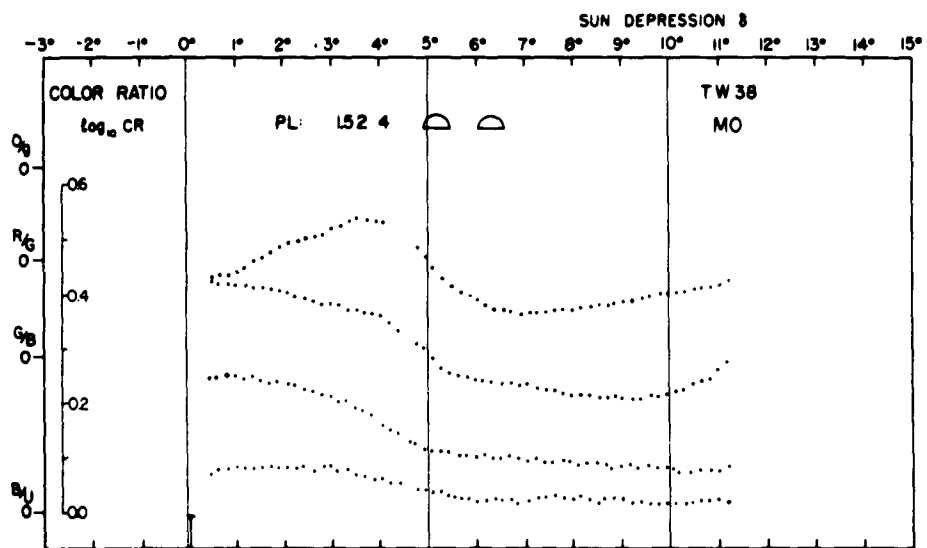
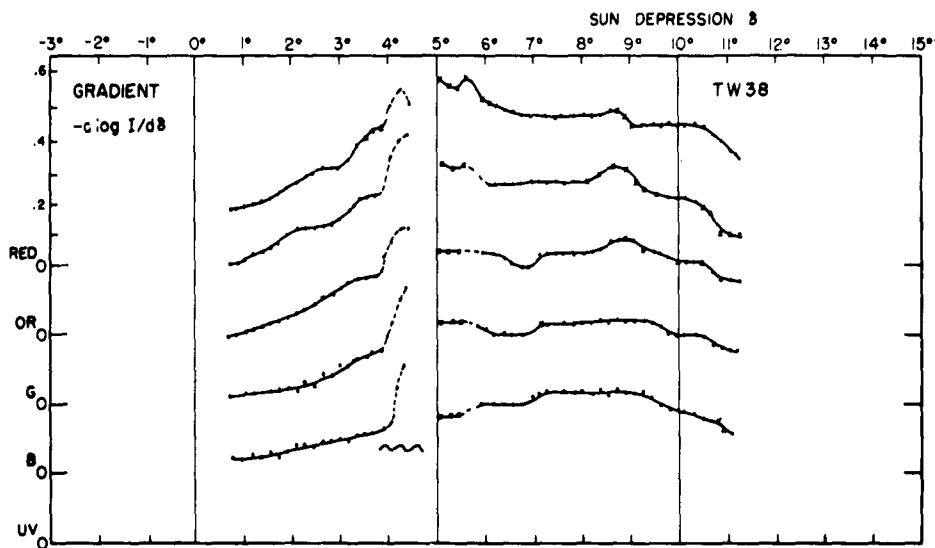
<b>Daytime sky:</b>	<b>Turbidity type:</b>	<b>1.2</b>
	<b>Aureole type:</b>	<b>a2</b>
<b>Turbidity coefficient:</b>		<b>0.01</b>
<b>Visibility:</b>		<b>130 km</b>
<b>Sunset:</b>		<b>16 54</b>
<b>Declination:</b>		<b>-16.8°</b>
<b>Instrument temperature:</b>		<b>+5°</b>
<b>Anti-twilight:</b>		<b>Very bright and colorful</b>
<b>Remarks:</b>		<b>Details of gradient in Blue and UV from 3 to 6° sun depression partly obscured by undulatory zero drifts of recorder due to chopper trouble.</b>



TWILIGHT 37

February 4, 1960, Evening

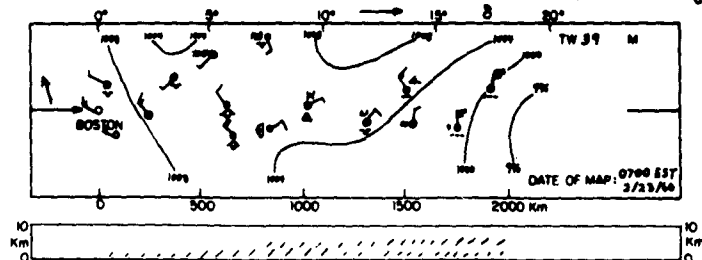
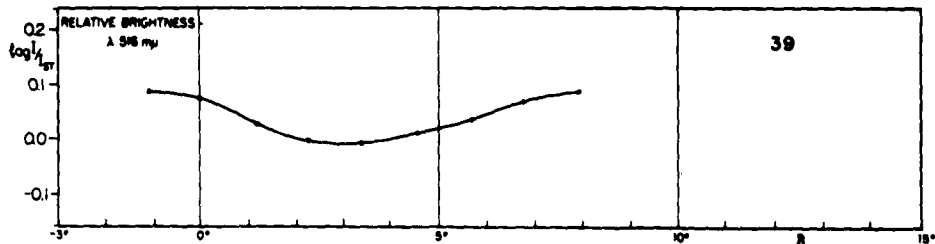
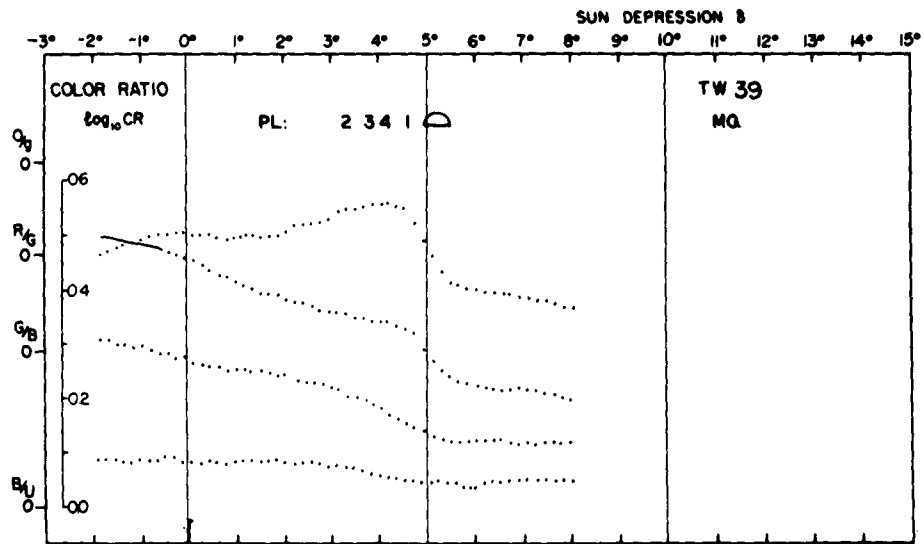
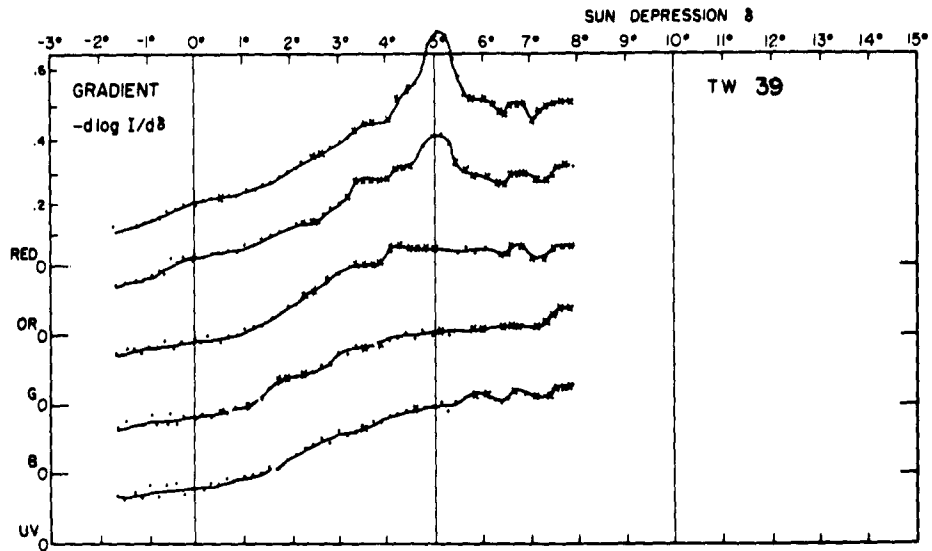
Daytime sky:	Turbidity type:	1.2
	Aureole type:	a2
Turbidity coefficient:		0.015
Visibility:		115 km
Sunset:		16 55.2
Declination:		-16.5°
Instrument temperature:		+8°
Horizon:		Dense haze strips (of industrial origin) below 5° elevation. Some clouds visible below 0.5° elevation.



TWILIGHT 38

February 16, 1960, Evening

Daytime sky:	Turbidity type:	1.6	} at noon
	Aureole type:	al	
Turbidity coefficient:		0.065	
Visibility:		65 km	
Sunset:		17 11	
Declination:		-12.8°	
Instrument temperature:		+2°	
Horizon:		Rather hazy up to 3°, haze strips up to 20° elevation.	
Remarks:		Course of gradients near 4° sun depression questionable because of uncertainty of zero position on chart.	



TWILIGHT 39

February 23, 1960, Morning

Daytime sky: Turbidity type: 1.8\_  
Aureole sky: al-2

Turbidity coefficient: 0.034 (before 07 00)  
later on 0.025

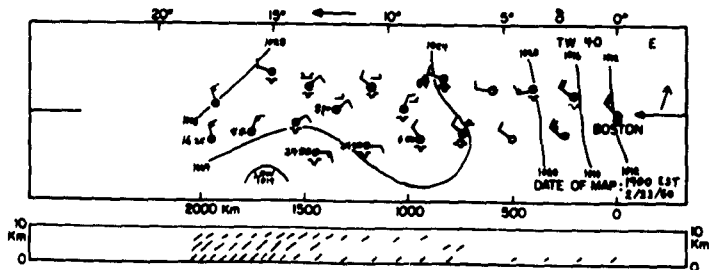
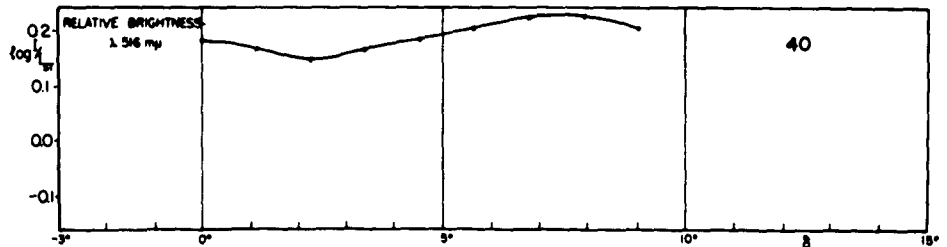
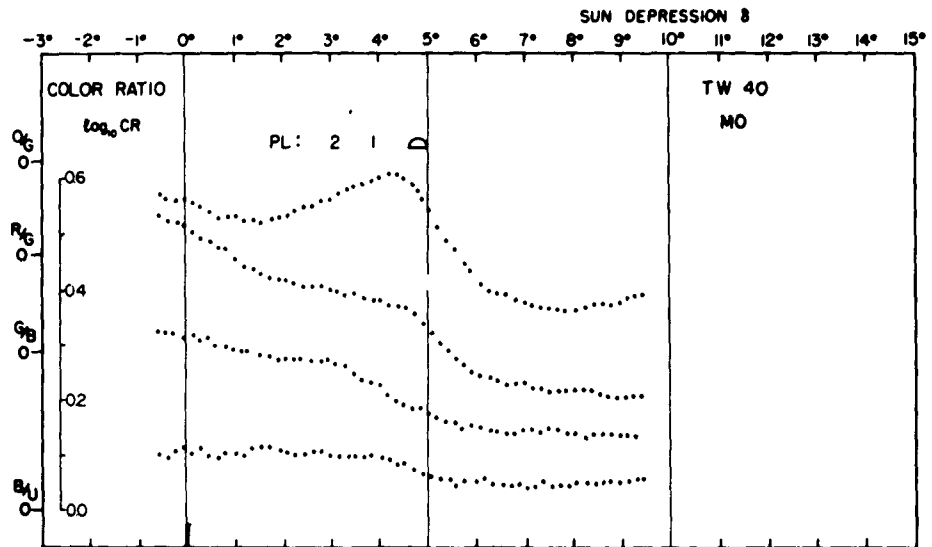
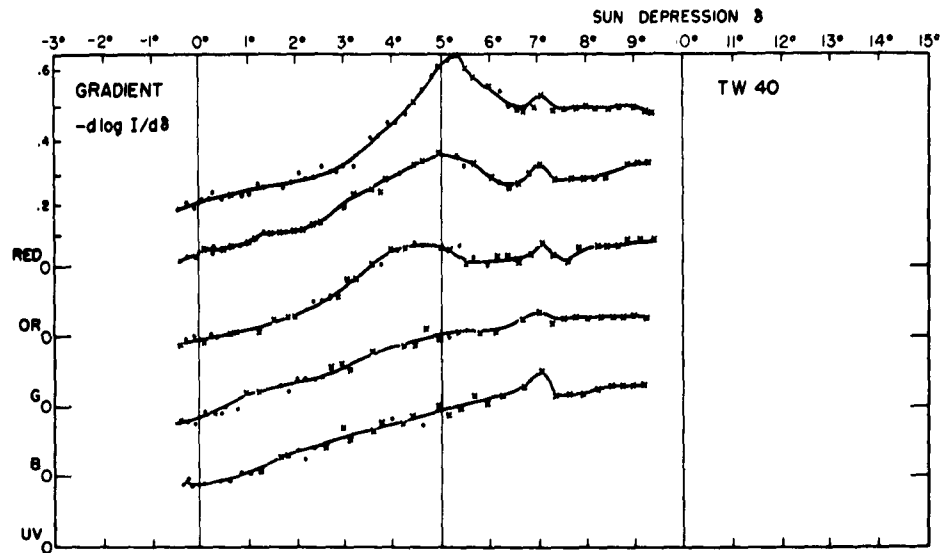
Visibility: 50 km

Sunrise: 06 37

Declination: -10.2

Instrument temperature: -3°

Horizon: Toward E strong sea haze up to  
2° elevation. Around 06 00 haze  
strips up to 6° elevation.  
Shortly after sunrise, up to  
07 30, cloudy, banded haze on  
eastern horizon below 8° eleva-  
tion observed. Haze was appar-  
ently located in upper tropospheric  
levels.



**TWILIGHT 40**

**February 23, 1960, Evening**

**Daytime sky: Turbidity type: 1.7**  
**Aursole type: a2-3**

**Turbidity coefficient: 0.047**

**Visibility: 100 km**

**Sunset: 17 19**

**Declination: -10.2**

**Instrument temperature: +0.5°**

**Horizon: Partly dark gray haze bands up to**  
**8° elevation.**  
**Cu fra clouds very close to hori-**  
**zon in W to N.**