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RELATIONSHIP BETWEEN METEOROLOGICAL CONDITIONS AND OPTICAL PROPERTIES OF THE ATMOSPHERE

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INTRODUCTION AND SUMMARY

This is the final report under Contract NObsr--95251, Task III, a part of NAVAIRSYSCOM Project FAMOS. The purpose of this study was to determine the relationship between meteorological weather patterns and those optical properties of the atmosphere of importance to the measurement of sea state and wind speed from meteorological satellite photographs.

The satellite camera sees the apparent radiance of the sea which contains the space-averaged radiance of the surface of the sea plus the path radiance due to sunlight and skylight scattered toward the satellite by the atmosphere throughout the path of sight. Another component arises from the daylight which has penetrated into the depths of the sea and has been redirected upward by the scattering processes within the water. Fortunately, this scattered component can be eliminated completely if the satellite makes its observations in terms of red or infrared light. This is because the water molecule absorbs red light very strongly. Thus the red component of the daylight which enters the ocean is absorbed so completely that no appreciable amount of it is scattered upward toward the satellite.

The surface wind velocity can be calculated if the inherent radiance of the surface of the sea and the distribution of the radiance of the sky above the sea are known. The inherent space averaged radiance of the surface of the sea under a prevailing sky condition and with a prevailing solar altitude is a problem that has been studied in the past and concerning which much is known and published.[1,2]

The precision with which sea-state information can be inferred from the non-glitter region of meteorological satellite pictures depends upon whether a sufficient portion of the light reaching the satellite comes from the surface of the sea despite the contribution due to scattering in the atmosphere. If the atmospheric component is not too great and if its magnitude can be ascertained, then measurements of the apparent radiance of the sea can be interpreted in terms of the inherent radiance of the ocean and, therefore, of optical sea state. Recently techniques have been developed[3] and validated[4] for getting the necessary atmospheric data by means of shipboard or ground-based instruments. A small catalog of optically documented atmospheric conditions exists already and is growing. Soon meteorologists may be able to specify a pertinent optical package for use with any specific satellite photograph. This report will be concerned with the relationship between meteorological conditions and optical properties of the atmosphere.

Optical data, previously measured by the Visibility Laboratory at various sites, were available for this study. These data had values for beam transmittance, total sky illuminance/irradiance, and in some cases path radiance.

These data were examined together with historical weather records in the form of local surface observations, radiosonde data, surface and 500 mb. charts. The optical data were examined for correlations with specific meteorological parameters such as surface pressure, ground visibility, temperature, relative humidity, wind direction and velocity, inversions, and heights of standard levels in the radiosonde. No correlations could be found with any of these specific parameters. Optical data for similar sun zenith angles, at each separate location, were compared and a correlation between the type of air mass and the beam transmittance and also between the air mass type and total illuminance were seen. Superior air masses showed highest values for both beam transmittance and total illuminance as a function of the zenith angle of the sun while stable maritime air masses exhibited lowest values. The relationship between path radiance as a function of the sun zenith angle and the type of air mass also appeared but was evident to a lesser degree because of the fewer data. The values for path radiance were higher for stable maritime air masses and lowest for unstable dry air masses. Values for path radiance can be calculated if the sky radiance has been measured at the proper angle from the sun. This was not always part of the data packages collected in the past because the nature of these experiments did not require this datum.

The values for beam transmittance and total illuminance as a function of sun zenith angle separated by air mass in the following order from highest to lowest:

1.	cTk or sTk	unstable continental tropical (summer) or unstable superior (winter)
2.	cTw or sTw	stable continental tropical (summer) or stable superior (winter)
3.	mPk	unstable maritime polar
4.	cPk	unstable continental polar
5.	cPk→mTw	unstable continental polar becoming modified with stable maritime tropical
6.	cPw	stable continental polar
7.	mTk	unstable maritime tropical
8.	mPw	stable maritime polar
9.	mTw	stable maritime tropical

NOTE: Not all of these air masses were present at each site.

Values for path radiance were not available for all types of air masses. When the values were available however, they generally fell in the reverse order from the above list, that is, values for mTw air mass were higher than those for mTk air mass for the same sun zenith angle. The values of path radiance for sTk as a function of sun zenith angle were lowest.

Data were examined for eight different collection sites. All of the locations were land stations and, except for some of the data collected on the roof of one of the buildings of the Visibility Laboratory in San Diego, the air mass characteristics had been modified by passage over land. These measurements usually were made with photopic sensitivity and also with red sensitivity at some of the data collection sites. When data collected with red sensitivity were available the relationships were similar to those for photopic sensitivity.

It is not intended that these results be applied to ocean areas. Because the correlations do appear it is recommended that a survey of optical and meteorological conditions at sea be undertaken. This could be accomplished either at small island stations or on ocean-going research vessels. These data should be taken with red sensitivity so as to eliminate the contribution due to sunlight which has penetrated into the depths of the sea and would be redirected upward by the scattering processes within the water. This concept has been explained in detail in an earlier report.[5]

PATH RADIANCE

The contribution due to sunlight and skylight scattered toward the satellite by the atmosphere throughout the path of sight is the *path radiance.* This path radiance may be derived from ground based measurements of beam transmittance and the sky radiance as follows:

$$N^*_\infty(\infty, \theta, \phi) = N^*_\infty(0, \theta', \phi')\left[\frac{1-T_\infty(\infty, \theta)}{1-T_\infty(0, \theta')}\right] \tag{1}$$

where

$N^*_\infty(\infty, \theta, \phi)$ is the path radiance of the downward inclined path of sight, θ, ϕ from the surface of the sea to any altitude outside the atmosphere (∞),

$N^*_\infty(0, \theta', \phi')$ is the path radiance (i.e., the radiance of the sky as seen from the surface of the sea) of an upward inclined path of sight θ', ϕ' which has the same angle from the sun as does the downward inclined path of sight, θ, ϕ,

$T_\infty(\infty, \theta)$ is the beam transmittance of the downward inclined path of sight θ, ϕ from the surface of the sea to any altitude outside the atmosphere (∞),

and

$T_\infty(0, \theta')$ is the beam transmittance of the path θ', ϕ' from space to the surface of the sea.

The beam transmittance for the path of sight from space to the surface of the sea in the direction of the sun $T_\infty(0, \theta_s)$ is obtained directly from the solar transmissometer measurements of the apparent radiance of the sun ${}_sN_\infty(0, \theta_s, 0)$ and the inherent radiance of the sun outside the atmosphere of the earth ${}_sN_0(\infty, \theta_s, 0)$ by the following equation:

$$T_\infty(0, \theta_s) = \frac{{}_sN_\infty(0, \theta_s, 0)}{{}_sN_0(\infty, \theta_s, 0)} \tag{2}$$

The inherent radiance of the sun outside the atmosphere of the earth, ${}_sN_0(\infty, \theta_s, 0)$, has been deduced from the literature.[6]

Data from the solar transmissometer, after relative optical air mass correction,[7] provide the two values of beam transmittance needed for equation (1). This is the only time that optical air mass reference will be used, all other air mass references are to meteorological air mass types.

The values of beam transmittance required in equation (1) are obtained from solar beam transmittance by means of the relations

$$T_\infty(\infty, \theta) = T_\infty(0, \theta_s)^{\cos\theta_s/\cos(180^\circ-\theta)} \tag{3}$$

and

$$T_\infty(0, \theta') = T_\infty(0, \theta_s)^{\cos\theta_s/\cos\theta'} \tag{4}$$

The radiance of the sky as seen from the ground or the surface of the sea along the upward inclined path of sight θ' and ϕ' is measured by means of a telephotometer on the ground. It should be noted that ordinarily there are a number of skyward directions for which the path of sight has the same angle from the sun as does the path of sight looking down from space to the surface of the sea. Data for any of these paths may be used in Equation (1) and should produce the same value of $N_{\infty}^{*}(\infty, \theta, \phi)$. Ordinarily the measurement is made for an upward inclined path 90° from the sun. Figure 1 illustrates the position of the telephotometer for measuring the sky radiance at the azimuth 180° from the sun, for the same angle (β) from the sun as for a satellite camera looking vertically downward. The diagram is drawn representing a plane passed through the azimuth of the sun.

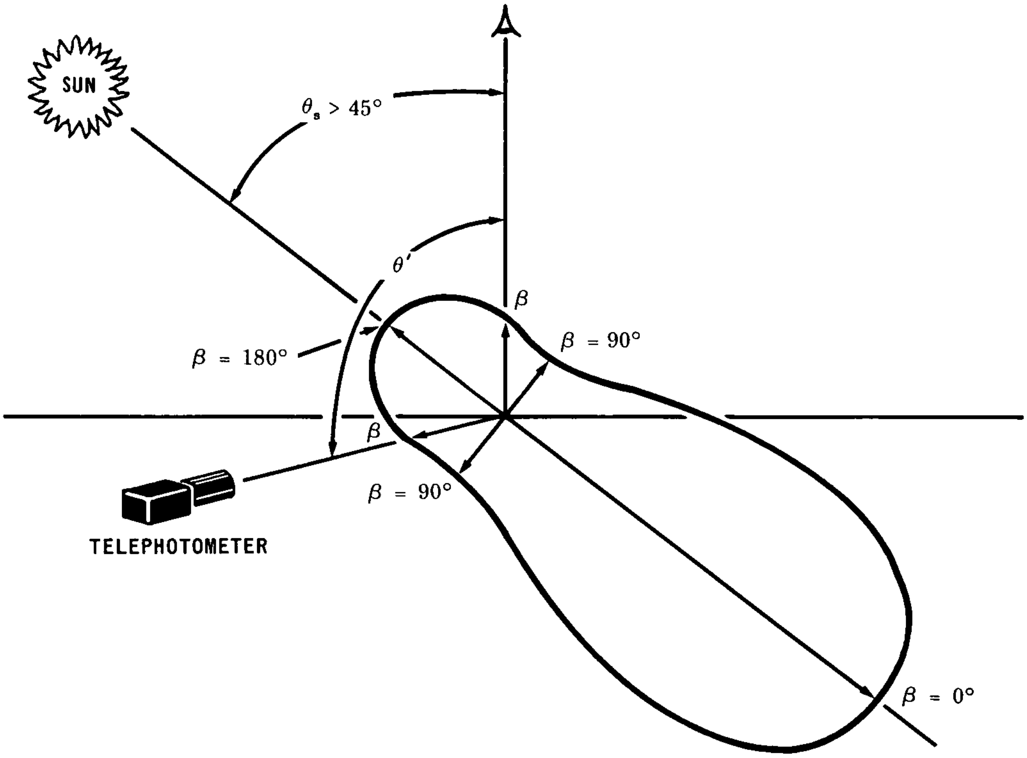

Figure 1. Scattering Angle from the Sun (β) for Observer and Telephotometer

If the sky contains scattered or broken clouds the measurements of sky radiance must be made in clear portions of the sky only. If no appropriate clear region of the sky can be found, the method cannot be used.

TOTAL SKY ILLUMINANCE

Measurements of total sky illuminance/irradiance have been made by the Visibility Laboratory at a number of locations under various "clear day" conditions. The total illuminance on a fully exposed horizontal plane at sea level in clear weather has been tabulated as a function of the zenith angle of the sun by Brown.[8] The position of the sun and the relative contribution of the sun to the total illuminance have a major effect upon the inherent luminance of objects and backgrounds.

AVAILABLE DATA

Optical data measured by the Visibility Laboratory at eight different ground-based locations were available for this study. Table 1 shows the location of data gathering, the type of data available and the method used to measure the data. The Visibility Laboratory has participated in several programs in conjunction with the Navy, Air Force and NASA in which ground-based data were collected. Four generations of instruments have been constructed and used in the data collection. Instrument development has kept pace with the experimental and theoretical research programs; the apparatus has gradually grown simpler and smaller. The first equipment required major laboratory facilities and could not be separated from the laboratory building. The second and third versions were housed in a trailer van that took them to geographic locations from California to Ohio. The fourth version is small enough to be transported in a private automobile and can be operated by one man. It has been modified recently to include a temperature control and an automatic memory unit. A photograph of that instrument, known as the contrast reduction meter, is presented in Fig. 1.1.

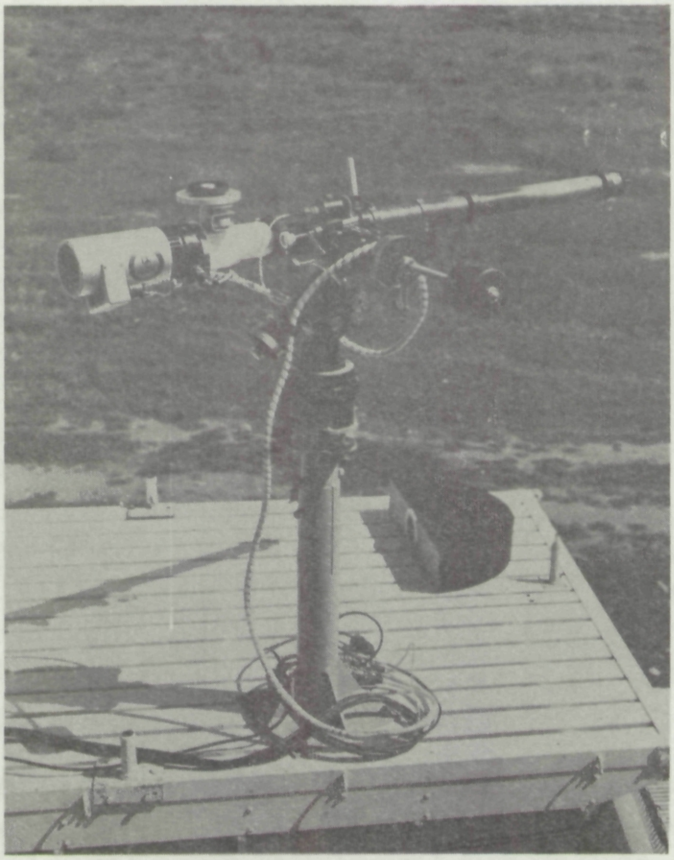

Figure 1.1. Portable Contrast Reduction Meter Mounted on Roof of Carryall at Montgomery Field.

PROCEDURE

Meteorological data were procured for each site where ground-based optical data had been collected and values measured or calculated for vertical beam transmittance and total illuminance (or total irradiance) of the sky. These consisted of:

a. Surface weather charts 06Z and 18Z (ESSA-Daily Synoptic Map)
b. 500 mb charts 00Z (ESSA-Daily Synoptic Map)
c. Hourly observations
d. Radiosonde data – at least two daily soundings

The optical data were collected under various "clear weather" conditions and at various times of day, that is, various sun zenith angles. Data for cloudy or partly cloudy days were not included in the analysis except for the clear portions of those days.

These data were examined to determine where correlations existed between meteorological and optical data. No correlations could be found with surface pressure, surface visibility, ground temperatures, temperature inversion data, haze layer height (if available), relative humidity at any level, wind direction, wind velocity, or the height of any standard level in the radiosonde sounding.

The surface maps and the radiosonde data were examined to determine the type of air mass present in the lower layers. A study by Cornell Aeronautical Laboratory[9] indicated a relationship existed between the presence of continental polar air masses and high contrast "transmittance" and between maritime tropical air masses and low contrast "transmittance". Another study by Robinson[10] reported that there was a relationship between the turbidity of the atmosphere and air masses. The turbidity of the atmosphere is assumed to be due to water vapor and dust. This turbidity would relate to the term we denote as beam transmittance which is a measure of air clarity. The relationship of turbidity as a property of air mass has also been reported by Volz and Bullrich[11]. Unfortunately it is not always possible to compare average values obtained at different places because of the different procedures adopted by different observers, some of whom take measurements on clear and cloudless days only, while others make use of each gap in the clouds to make a quick measurement. Data from these other sources were examined but are not included in this report.

Data measured by the Visibility Laboratory at similar sun zenith angles were compared and a correlation between the type of air mass and the beam transmittance and also between the air mass type and the total illuminance/irradiance were seen. The type of air mass present often had a corresponding range of visibility, e.g., unstable (k) air masses had greater visibilities than stable (w) air masses. The relative humidity was also dependent upon whether an air mass was maritime or continental in character and upon the amount of modification of the air mass.

TYPICAL EXAMPLE

Data taken at the Naval Ordnance Test Station (NOTS), China Lake, California during July and August 1962 were examined first. The surface and 500 mb charts and the radiosonde data indicated that the data were collected with continental tropical (cT) air mass for the entire period. The meteorological observations were all made at NOTS. The radiosonde soundings were taken at G-range and the winds aloft and optical measurements at C-range.

In the summer, thermal low pressure prevails at the surface over southwestern Arizona and southern California. The circulation at 700 mbs is rather weak from the south to southwest.

Although the air mass was continental tropical for the entire period there were variations in pressures, winds, and temperatures at all levels. Visibility day and night was a persistent 15+ miles. The relative humidity during data runs varied from 7 to 38 percent but most of the time was 20 percent or less at all levels to 100 mbs. The greatest amount of clouds reported was .4 on 20 July. Most of the time the amounts reported were .1 or .2 or "few" reported in a particular quadrant. The temperatures ranged from a minimum of 62°F to a maximum of 102°F with a daily average of 83.74°F. During data collection the temperature range was 66-97°F. The surface pressure ranged from 1009.5 to 1016 mbs. The winds aloft to 10 000 feet varied from light and variable to moderate to strong at all levels. Radiosonde data were taken at 0630, 0800, 0930, 1100, and 1200 local time. Optical data were collected between 0700 and 1400 local time. No correlations were found with any specific meteorological parameter.

Data for various sun zenith angles were tabulated and matched for beam transmittance and total illuminance within ± 3 percent, the precision level of the instruments. No values for path luminance for NOTS were available. Further examination of the data indicated that the values for beam transmittance as a function of sun zenith angle were dependent upon whether the air mass was stable or unstable. Fig. 1.2 is a plot of the various values of beam transmittance as a function of the sun zenith angle. The data contained a considerable number of points over a broad span of sun zenith angles for both cTw and cTk air masses. A least squares fit has been calculated for each air mass type. These fits show that the unstable air with greater mixing of layers has higher values for beam transmittance, that is, the air is more transparent than the stable air with less mixing through the layers. Although the separation is not great, about .065, it does separate the one type air mass from the other. This separation of air mass types also shows in a plot of total illuminance as a function of sun zenith angle, Fig. 1.3. Underlying these data is the basic curve by Brown mentioned earlier. When the data taken at NOTS are compared with this basic curve it can be seen again that the cTk air mass has higher values of total illuminance for a particular zenith angle than does the cTw air. No attempts have been made to fit a curve to these data because of the small number of points in comparison with those used by Brown.

The data from each site were handled in the same manner and Figs. 1.4 to 1.8 show the separation by air mass of beam transmittance as a function of sun zenith angle for sites where data gathering was extensive. Plots for the other sites were made and are available.

Derived data for beam transmittance as a function of sun zenith angle and the type of air mass for Wright Patterson Air Force Base are shown in Fig. 1.4. Least squares fits have not been drawn for each air mass because the range of sun zenith angle is relatively small. However, it can be seen that for a particular sun zenith angle the values of beam transmittance are higher for unstable continental polar air than for continental polar air becoming modified with stable maritime tropical air. These in turn are higher than the values for stable continental polar air and values for stable maritime tropical air which are the lowest.

Values for beam transmittance as a function of sun zenith angle derived from measurements made with the automatic data gathering equipment in San Diego in 1964 are shown in Figs. 1.5 and 1.6. These values show a banding according to the type of air mass. The beam trans-

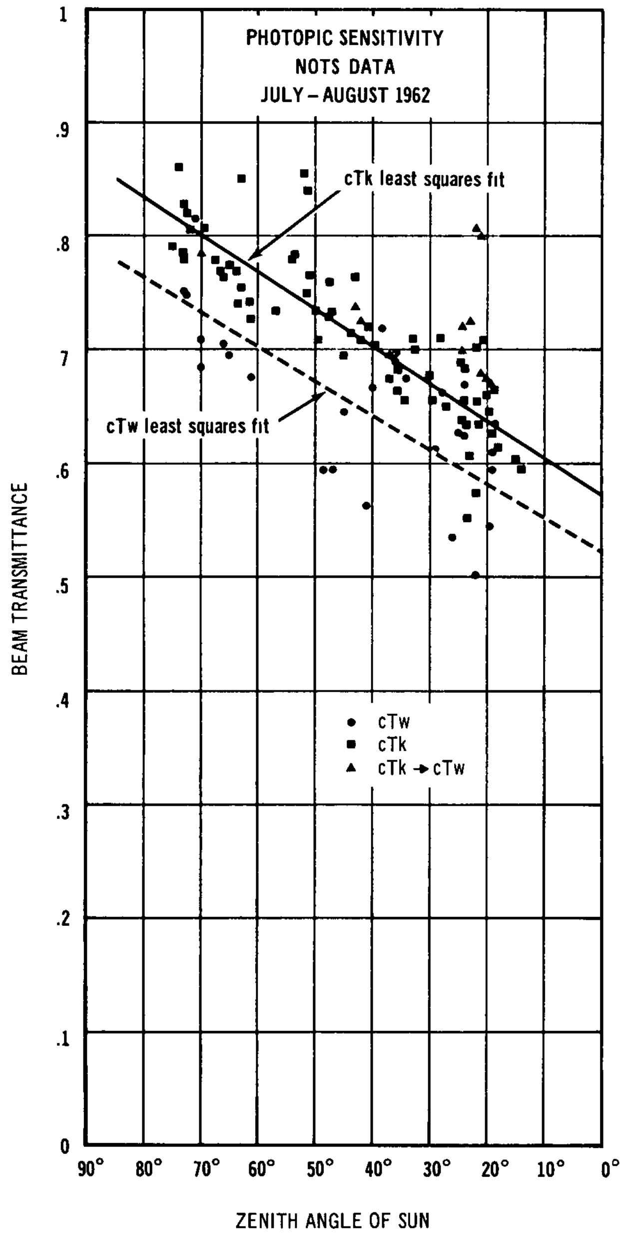

Figure 1.2

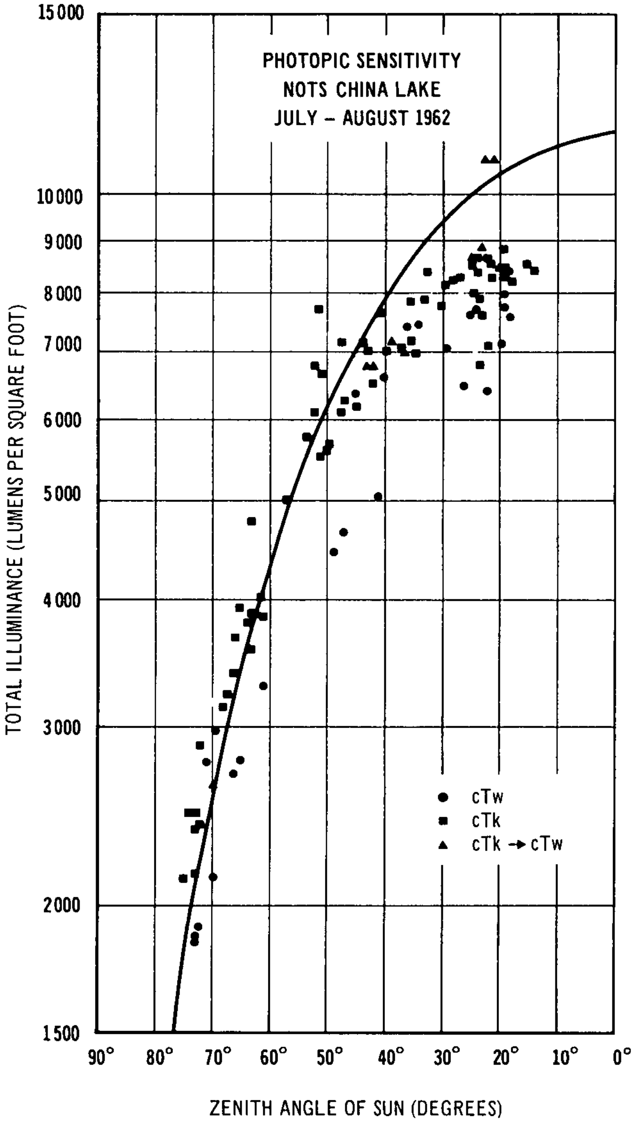

Figure 1.3

mittance values for unstable maritime polar air generally were in the range .68 to .80, except for one day, while the values for stable maritime polar air were in the range .54 to .68. When the air mass in San Diego was dry, as in the case of unstable superior air, the values for beam transmittance were .80 to .85, Fig. 1.6. However, when the air mass was changing from maritime to superior, or vice versa, the air clarity was lower, in the range .68 to .77 also shown in Fig. 1.6.

Data for beam transmittance derived from measurements made at Laredo, Texas with two different phototubes in the assembly of the portable contrast reduction meter are shown as

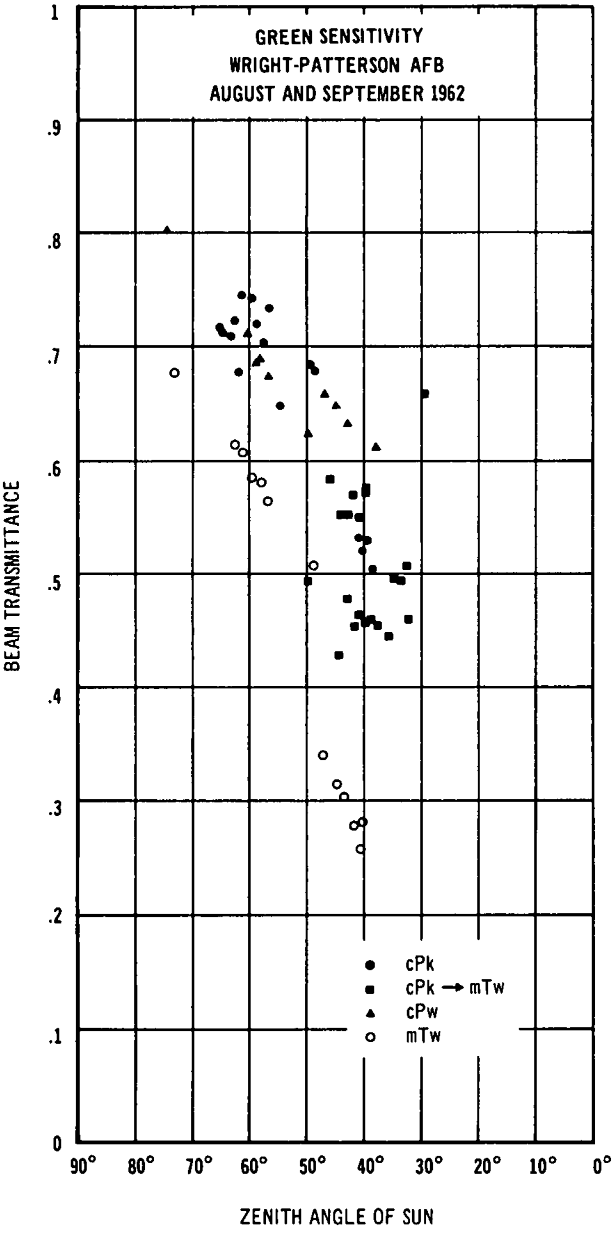

Figure 1.4

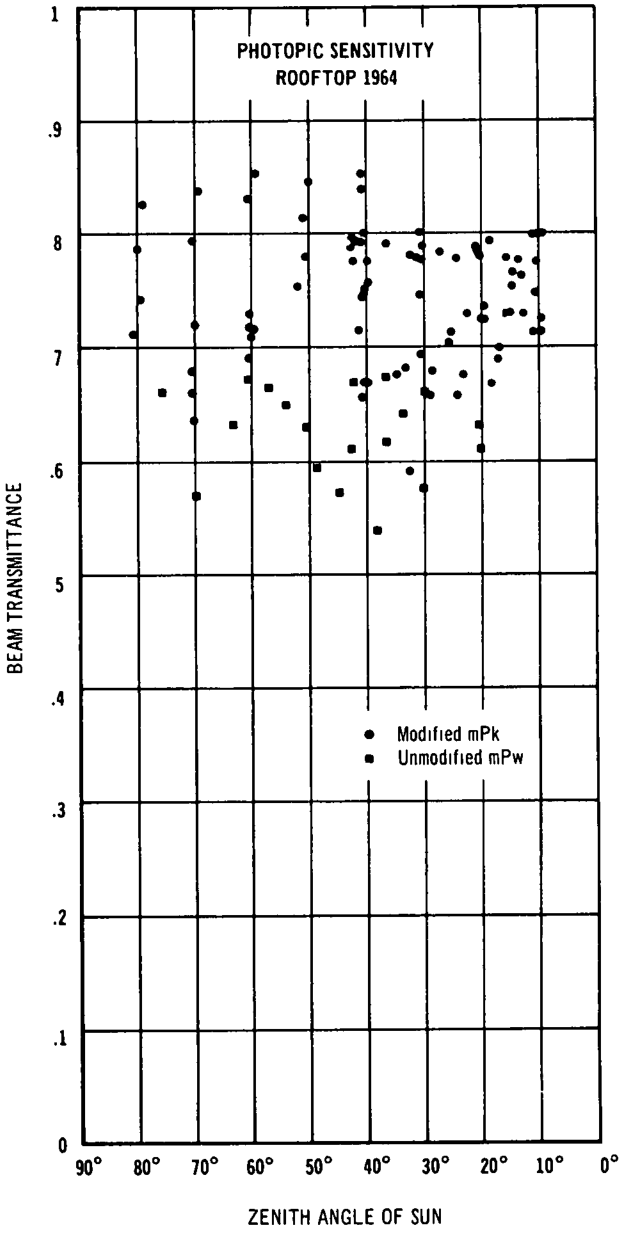

Figure 1.5

Laredo 1 in Fig. 1.7 and Laredo 2 in Fig. 1.8. Again the range of sun zenith angle is relatively small and lines of least squares fits would have little meaning. It can be seen for a particular zenith angle that the values generally are higher for unstable continental polar air than for continental polar being modified by maritime tropical air. Both of these are higher than the values for stable maritime air.

Figures 1.9 to 1.12 show the distribution of total illuminance/irradiance as a function of sun zenith angle. The data for Wright-Patterson Air Force Base are shown in Fig. 1.9. No basic curve, such as the Brown curve, has been calculated for green sensitivity. Values for the Brown

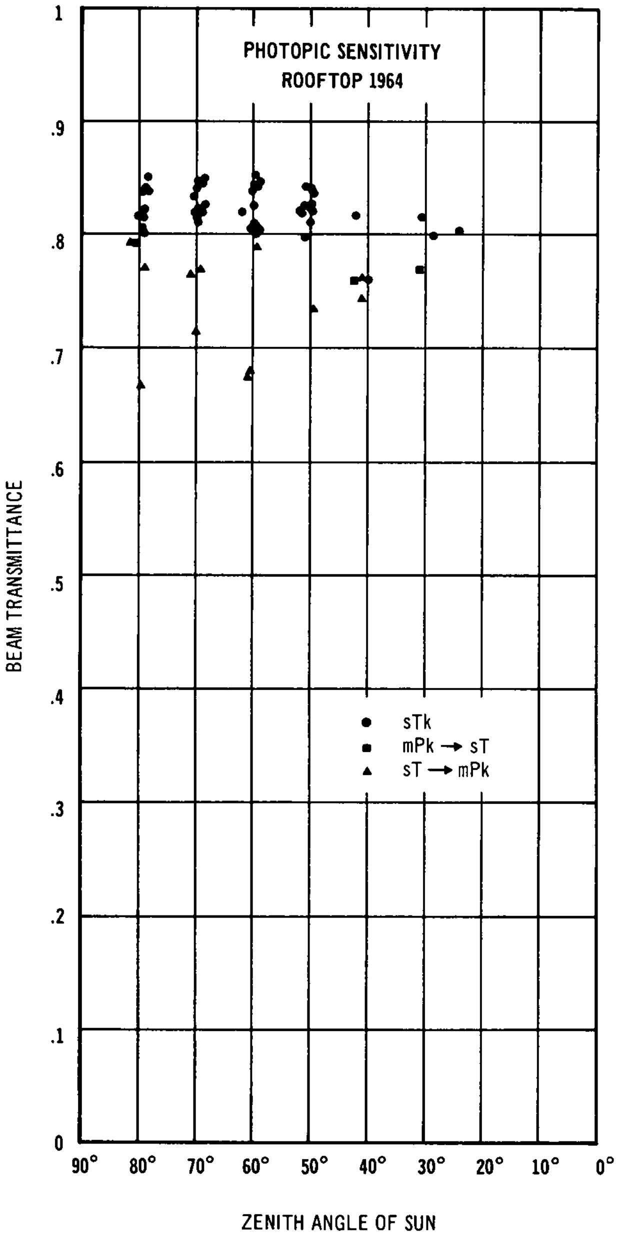

Figure 1.6

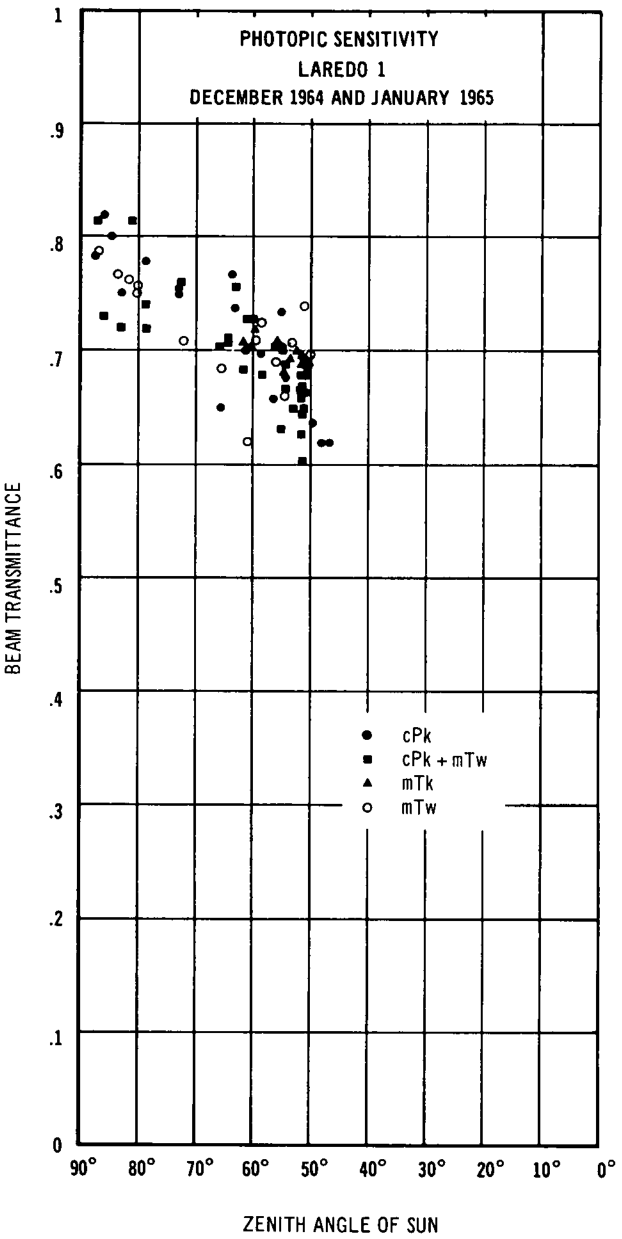

Figure 1.7

curve were divided by 1250. The factor has no significance other than to show the separation of the higher values for unstable continental polar air and continental polar being modified by maritime tropical air from the lower values for stable continental polar and stable maritime tropical air.

The values of total illuminance as a function of sun zenith angle that were measured by the automatic data gathering equipment on the Rooftop of the Visibility Laboratory in 1964 are shown in Fig. 1.10. The basic curve of Brown is used as a reference. Most of the values are higher than the basic curve and it will be noted for a particular sun zenith angle that the values are greatest for unstable continental tropical air, lower for unstable maritime air, and lowest for

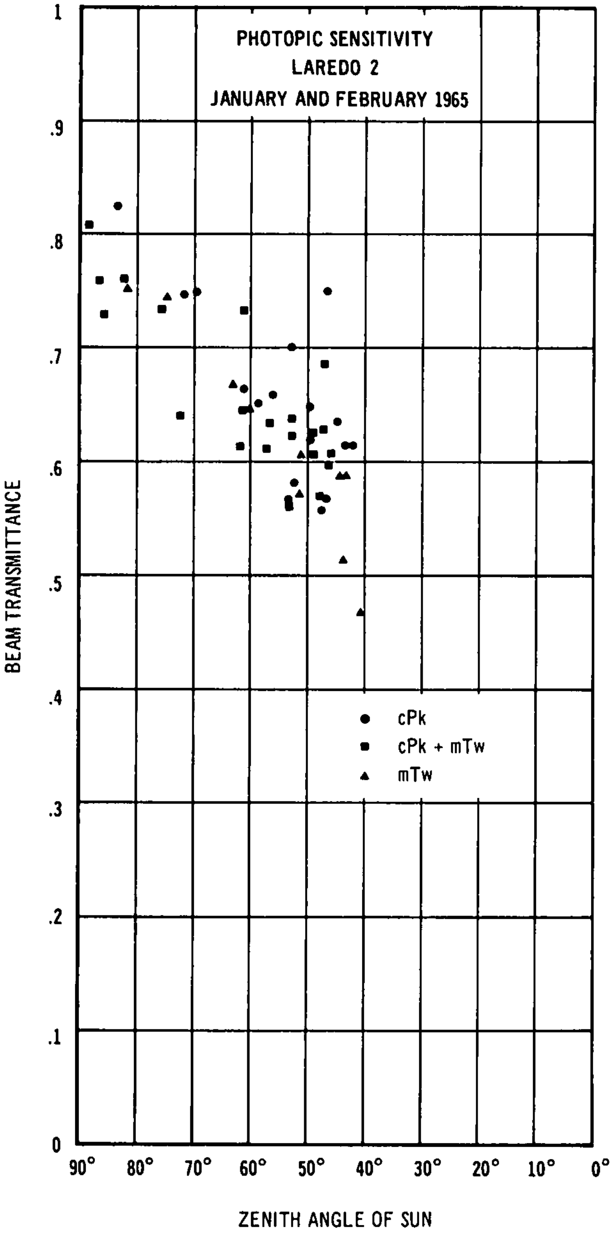

Figure 1.8

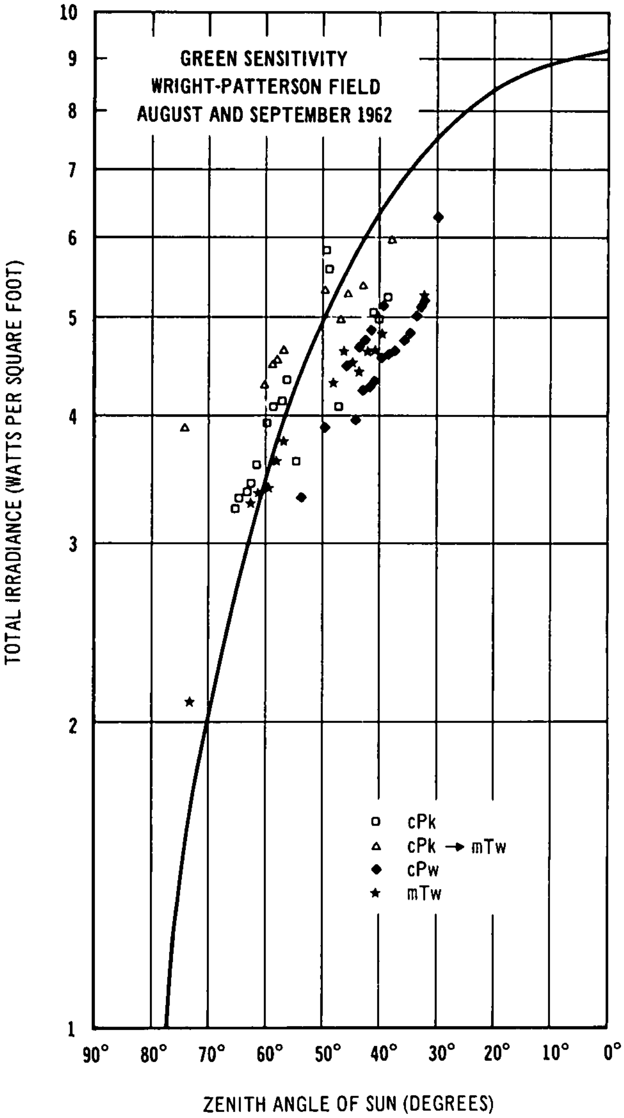

Figure 1.9

stable maritime air.

Data for total illuminance as measured with two different phototubes in the assembly of the contrast reduction meter at Laredo are shown in Figs. 1.11 and 1.12, with the basic curve from Brown as a reference. In Fig. 1.11 the distribution of values is fairly equal above and below the basic curve. In general, the values for a particular sun zenith angle are highest for unstable continental polar air, then continental polar mixed with maritime tropical (except for one day), followed by unstable maritime tropical and stable maritime tropical air. Data taken with the second phototube are shown in Fig. 1.12. Most of the values are lower than the basic curve but

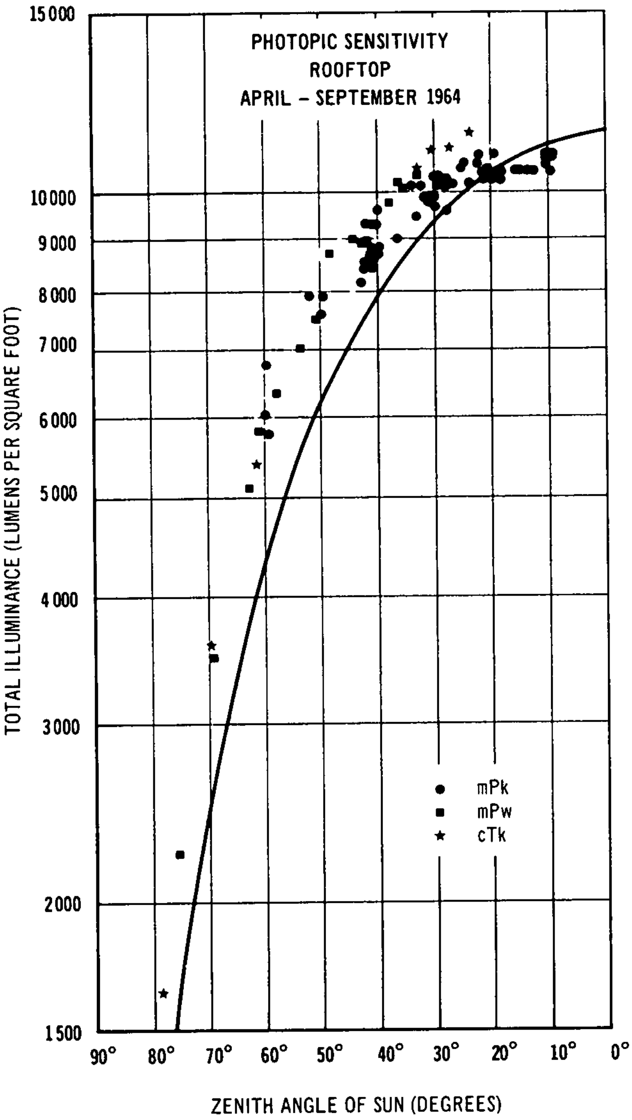

Figure 1.10

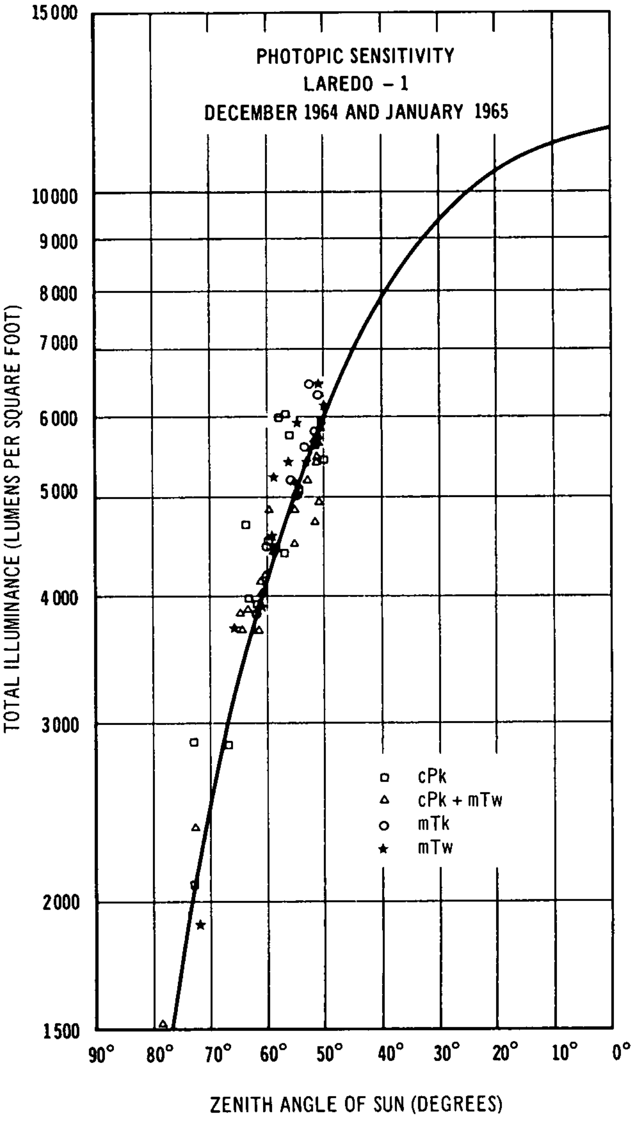

Figure 1.11

again the values are higher for unstable continental polar, lower for continental polar mixed with maritime tropical and lowest for stable maritime tropical air for a particular sun zenith angle.

Figures 1.13 to 1.16 show the distribution of the derived values for path radiance as a function of sun zenith angle. Data for Wright-Patterson Air Force Base are presented in Fig. 1.13. The data are not so numerous as those for beam transmittance and total irradiance because sky radiance could not always be measured at the proper angle from the sun. For the low sun angles the path radiance values fall in the following order: stable maritime tropical, stable continental polar, unstable continental polar and continental polar mixed with maritime tropical. One set of values for unstable continental polar appears to be excessively high. For higher sun angles the order is: stable maritime tropical, continental polar mixed with maritime tropical, stable continental polar and unstable continental polar.

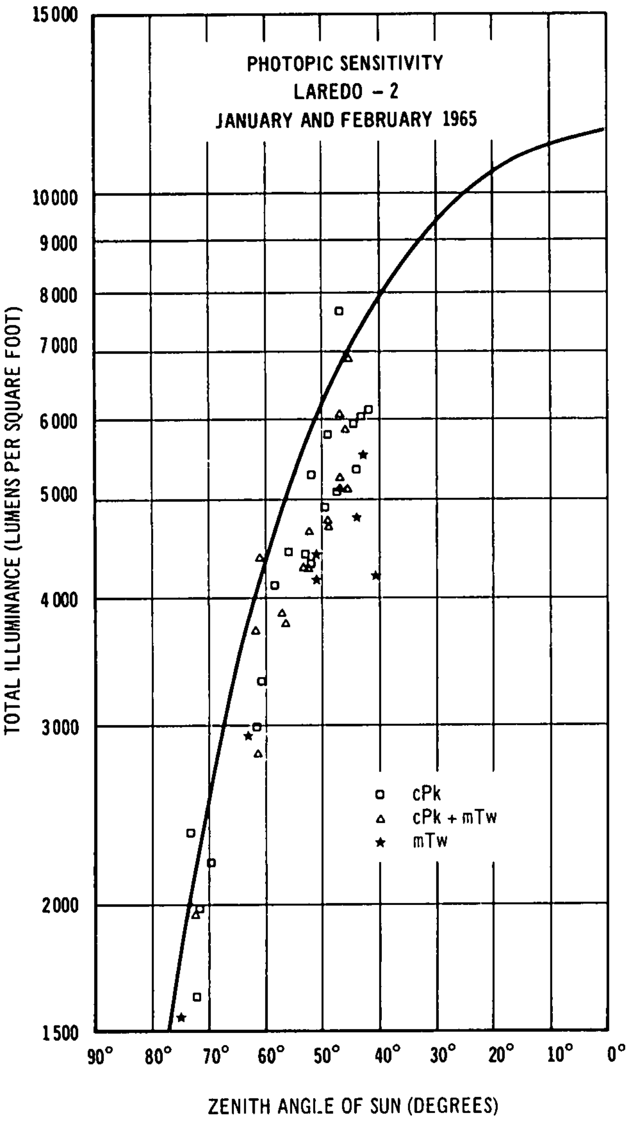

Figure 1.12

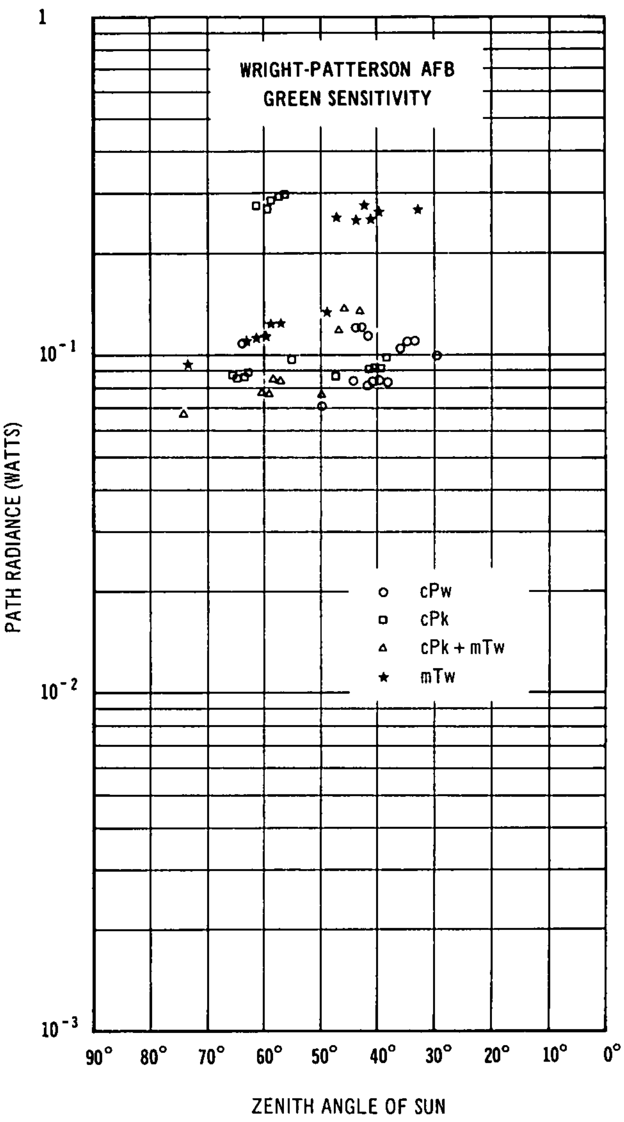

Figure 1.13

Values for path luminance as derived from the measurements made on the Rooftop of the Visibility Laboratory in 1964 are shown in Figure 1.14. For a particular sun zenith angle it will be seen that the values are higher for stable maritime air, lower for unstable maritime air and lowest for superior air which is a reversal of the order for beam transmittance and total illuminance.

Figures 1.15 and 1.16 show the distribution of values for path luminance for Laredo 1 and Laredo 2. In Fig. 1.15 with relatively few values for path luminance the descending order of values is: unstable continental polar, stable maritime tropical, unstable maritime tropical and continental polar mixed with maritime tropical. Except for the continental polar air the values fall in the reverse order from the values of beam transmittance. Values for Laredo 2, shown in Fig. 1.16, fall as follows: unstable continental polar, continental polar mixed with maritime

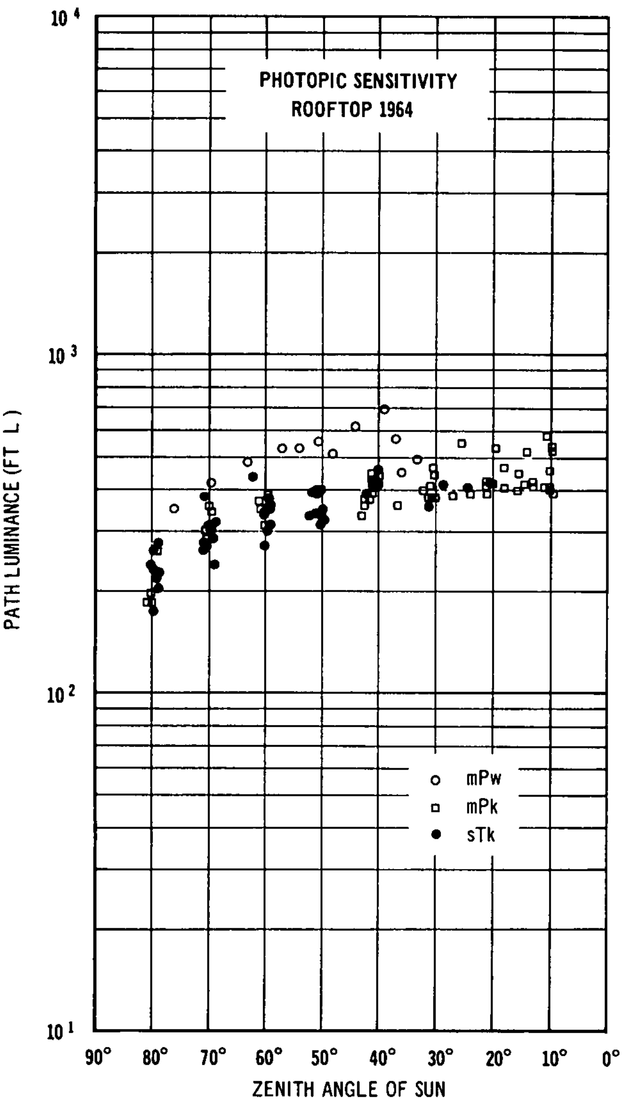

Figure 1.14

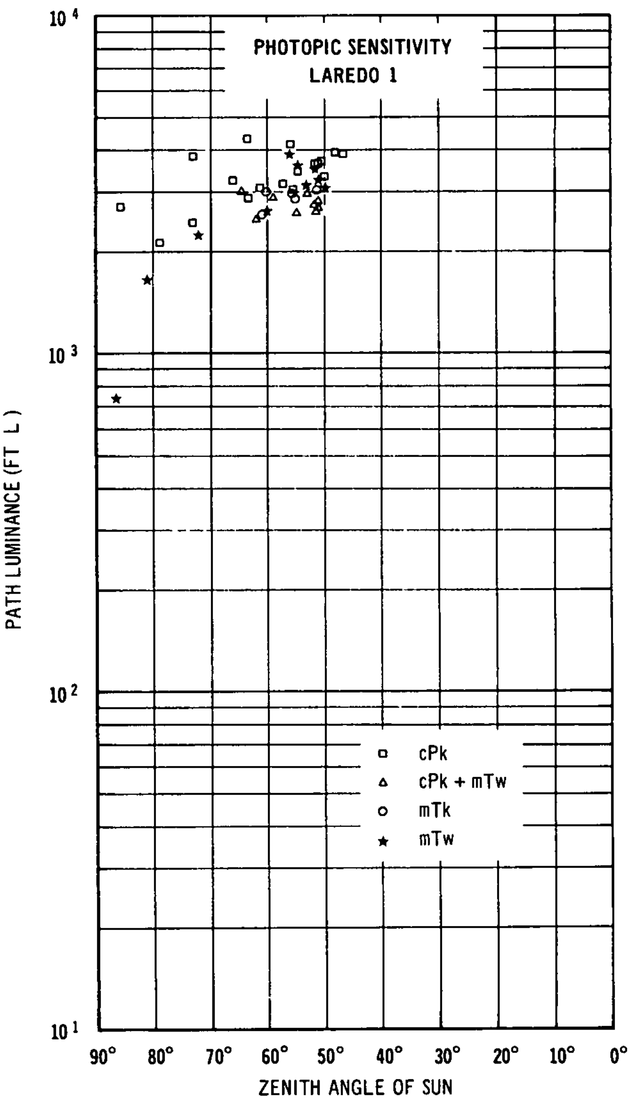

Figure 1.15

tropical and stable maritime tropical. This is the same order as that for beam transmittance and total illuminance.

AIR MASS CLASSIFICATION

Air mass classification was made by examining the surface charts for the data collection periods to determine the source region of the air mass and by examining the radiosonde for the site to determine the nature of the stability. Often the air mass was modified by having been present over the same area for a few days. Some of the maritime polar air at San Diego was modified by passage over central California. The stable maritime polar air (mPw) at San Diego was on-shore flow.

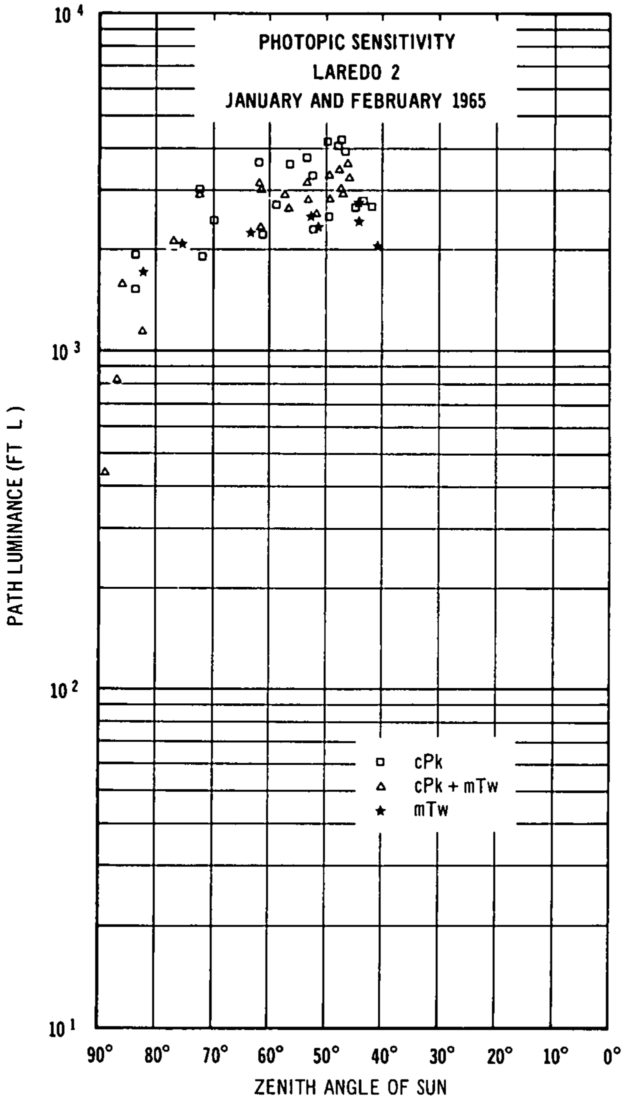

Figure 1.16

The definition of superior (sT) air is taken from Barber[12]. The northeastern sector of the Pacific Anticyclone, when it extends over continental North America, serves a primary source region for an upper air mass above an altitude of 5000 feet. Subsidence effects within the anticyclone lead to the formation of sT air. It is believed that the air which finally becomes an sT air mass might be originally from equatorial sources in southern Mexico. sT air may occur throughout the year but most characteristically when the Pacific anticyclone is displaced inland over the continent in winter. This situation normally produces Santa Ana conditions in the Los Angeles-San Diego area.

In some cases such as NOTS, San Diego and Wright-Patterson Air Force Base the radiosonde data were taken at the same site or within a short distance of the site where the optical data were collected. At other locations the radiosonde station was more than 50 miles distant. Since the NOTS soundings did not show correlations with any of the optical properties of the atmosphere the soundings were used primarily to determine the nature of the air mass. Crater Lake, for example, is 60 miles from Medford, Oregon, but the temperature profile as measured by the C-130 aircraft, which operated in conjunction with the ground station, is in agreement with the Medford sounding taken about the same time. Because of this corroboration, up-stream radiosonde soundings were used when none were available for the actual data-gathering location.

AIR MASS EFFECT

Data taken at NOTS, Laredo, and Wright-Patterson Air Force Base have a distinct slope of beam transmittance with sun zenith angle. Data from other locations are too sparse to evaluate. The beam transmittance is greater with greater zenith angle, i.e., lower sun. This is true for all types of air masses. The data taken on the Rooftop of the Visibility Laboratory in 1964 do not exhibit this characteristic, rather they show a band of beam transmittance for a particular type air mass.

Data from various sites also separate by air mass in a study of total illumination as a function of sun zenith angle.

The values for beam transmittance and total illuminance as a function of sun zenith angle separate by air mass in the following order:

1.	cTk or sTk	unstable continental tropical (summer) or unstable superior (winter)
2.	cTw or sTw	stable continental tropical (summer) or stable superior (winter)
3.	mPk	unstable maritime polar
4.	cPk	unstable continental polar
5.	cPk → mTw	unstable continental polar becoming modified with stable maritime tropical
6.	cPw	stable continental polar
7.	mTk	unstable maritime tropical
8.	mPw	stable maritime polar
9.	mTw	stable maritime tropical

Values for path radiance were not available for all types of air masses. When the values were available however, they fell in the reverse order from the above list, that is, values for mTw air mass were higher than those for mTk air mass for the same sun zenith angle. The values of path radiance for sTk air as a function of sun zenith angle were lowest. Table 2 shows the number of data packages collected with each of the various types of air mass by location. Data were not always collected in the same manner nor with the same equipment, refer to Table 1. Inter-comparisons of the data from different locations should not be attempted unless the data span a similar range of sun zenith angle and were collected in the same manner.

REPEATABILITY

To check the repeatability of the optical data with a particular synoptic situation which had occurred when data were collected on the Rooftop, additional data were collected at Montgomery Field, San Diego. This site was selected because ESSA has an upper air station there and data

TABLE I. SENSITIVITY OF DATA AVAILABLE AND METHOD OF MEASUREMENT

Location	Lat/Long	Beam Transmittance	Total Illuminance/ Irradiance	Path Radiance	Instrumentation
NOTS China Lake, Calif.	35.75N 117.75W	Photopic	Photopic	–	Irradiometer
WPAFB Dayton, Ohio	39.80N 84.08W	*Green	*Green	*Green	Trailer Scanner, Beam Transmissometer and Irradiometer
Pahrump, Nevada	36.66N 115.50W	Photopic Red	Photopic Red	Photopic Red	Trailer Scanner, Beam Transmissometer and Irradiometer
Vis Lab Rooftop	32.70N 117.03W	Photopic Red	Photopic Red (April-Sept. Only)	Photopic Red	Sky Scanner, Beam Transmissometer, and (April-Sept.) Irradiometer (Automatic Data Logging Equipment)
Laredo, Texas (1)	27.50N 99.50W	Photopic Red	Photopic Red	Photopic Red	Contrast Reduction Meter (Phototube 1)
Laredo, Texas (2)	27.50N 99.50W	Photopic Red	Photopic Red	Photopic Red	Contrast Reduction Meter (Phototube 2)
Crater Lake, Ore.	42.88N 122.01W	Photopic	Photopic	Photopic (Some)	Contrast Reduction Meter
Colorado Springs, Colorado	39.00N 105.00W	Photopic	Photopic	Photopic	Contrast Reduction Meter
Montgomery Field San Diego, Calif.	32.81N 117.01W	Photopic Red	Photopic Red	Photopic Red	Contrast Reduction Meter

* The narrow band green response of Wright-Patterson data yielded results so similar to those obtained with broad band photopic responses that they have been compared to the photopic data.

TABLE II. AIR MASS TYPES BY LOCATION – PHOTOPIC MEASUREMENTS ONLY

	cTw	cTk	cPk	cPk→mTw	cPw	mTw	Mod mTk	mPk	mP+cP	mPw	mPk→cTk	cTk→mPk	Total Measurements
NOTS	(6) 39	(10) 65											104
W-P (Green)			(2) 17	(2) 10	(2) 21	(3) 21							69
Laredo 1			(4) 23	(5) 32		(5) 16	(2) 10						81
Laredo 2			(3) 20	(3) 24		(2) 8							52
Crater Lake								(3) 23					23
Colorado Springs			(6) 14										14
	sTw	sTk											
Rooftop	(1) 4	(11) 70						(24) 97		(4) 15	(2) 8	(1) 6	200
Australia			(3) 3					(1) 3	(1) 1				7
Totals	(7) 43	(21) 135	(18) 77	(9) 66	(2) 21	(11) 45	(2) 10	(28) 123	(1) 1	(4) 15	(2) 8	(1) 6	550
		sTk											
Montgomery Field		(3) 14						(1) 4		(1) 6		(1) 4	28
Rooftop (CRM)								~~(11) 20~~		(7) 29			29

NOTE Figures in parenthesis mean the number of days with particular air mass cases, i.e., number of measurements taken on those days.

LEGEND
s = Superior, P = Polar
c = Continental, k = Unstable
m = Maritime, w = Stable
T = Tropical

could be collected at the same time as a radiosonde sounding was being made. Montgomery Field is ten miles from the Rooftop data collection site and about eight miles inland from the ocean. These data were collected with the portable contrast reduction meter, Fig. 1.1, during the period February to April 1967. This instrument is the same one used to collect data at Laredo, Crater Lake and Colorado Springs.

These data were reduced and the results compared with data collected previously. The first data collection days were with superior air masses as San Diego was experiencing Santa Ana conditions much the same as the period during February 1964 when data were collected on the Rooftop of the Visibility Laboratory. Data for beam transmittance as a function of sun zenith angle were available from the earlier study for February. These data showed a banding with air mass, that is, for sTk air masses the values ranged from .80 to .84 (Fig. 1.6) and were fairly steady throughout the day and did not vary with the zenith angle of the sun. The new data from Montgomery Field (Fig. 1.17) show the same trend as data collected at sites other than the Visibility Laboratory with the portable equipment, that is, lower values of beam transmittance with higher sun angle.

Data later were collected with stable maritime polar air masses. The data plotted in Fig. 1.17 show that for a particular sun zenith angle the values for beam transmittance are higher for unstable superior air than for superior air changing to maritime air, and both of these are greater than values for stable maritime air for a particular sun zenith angle.

Comparison data for total illuminance were available for superior air for only one day, 2 September 1964. The data collected with superior air at Montgomery Field agreed with these data and also with the unstable continental tropical air mass data collected at NOTS. Fig. 1.18 shows the data collected at Montgomery and on the Rooftop of the Visibility Laboratory with the contrast reduction meter in 1967. Underlying the data is the basic curve from Brown. Again, for a particular sun zenith angle the values are highest for unstable superior, then lower for unstable maritime and lowest for stable maritime air, the same order as previously noted.

Data computed for path radiance for the straight downward look are shown in Fig. 1.19. There is not a sufficient array of points at a particular sun zenith angle to draw conclusions about the three air masses. Between 40 and 50 degrees of sun zenith angle, however, it can be seen that superior air changing to maritime has higher values than the superior air. This is opposite of the order of values for beam transmittance and total illuminance.

As mentioned previously, the data on beam transmittance as a function of the zenith angle of the sun in most cases showed a decrease with higher sun angle (smaller zenith angle), Figs. 1.2, 1.4, 1.7 and 1.8. The one exception to this was the data collected on the Rooftop of the Visibility Laboratory with the permanent installation, Figs. 1.5 and 1.6. These data showed a banding according to the type of air mass. In order to determine whether this characteristic was related to the instrumentation or was attributable to the proximity of the sea, the portable contrast reduction meter that was used to collect data at Montgomery Field was placed on the Rooftop. Unfortunately, the instrumentation previously used during the period January to September 1964 is no longer operable since the instruments have been dismantled. Therefore, only one set of data could be gathered. To reassemble and make operative the Rooftop equipment would be an expensive operation. The results of the data collected on the Rooftop, with the CRM in April, May and June 1967, Fig. 1.20, show the same decrease in beam transmittance with higher sun

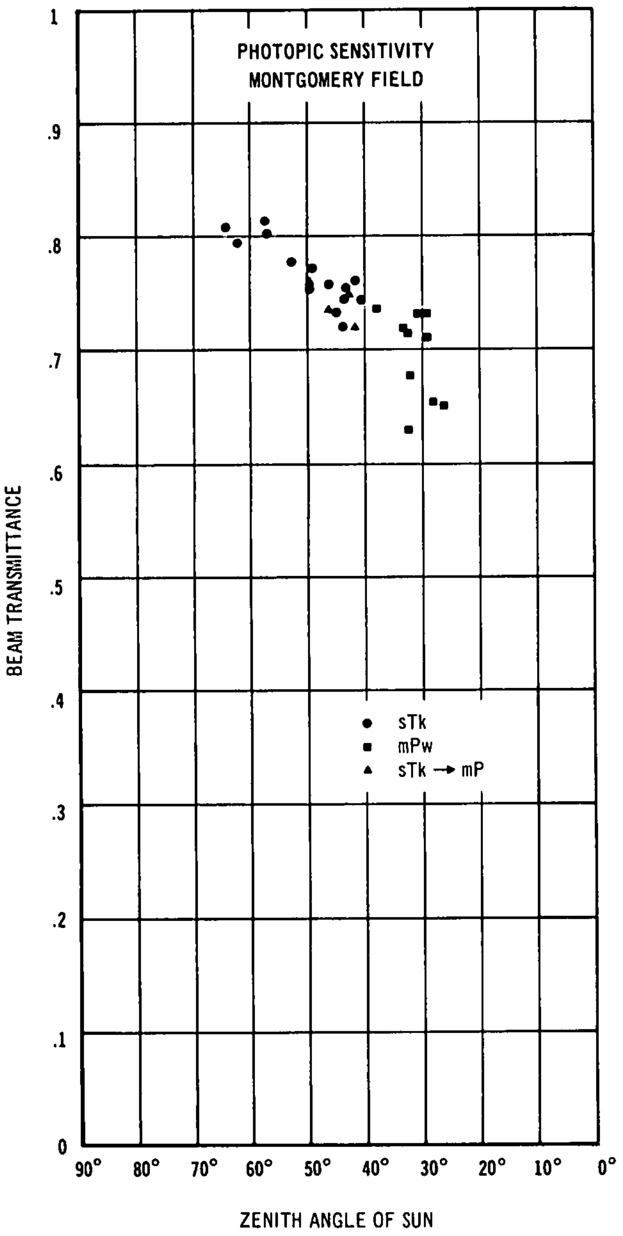

Figure 1.17

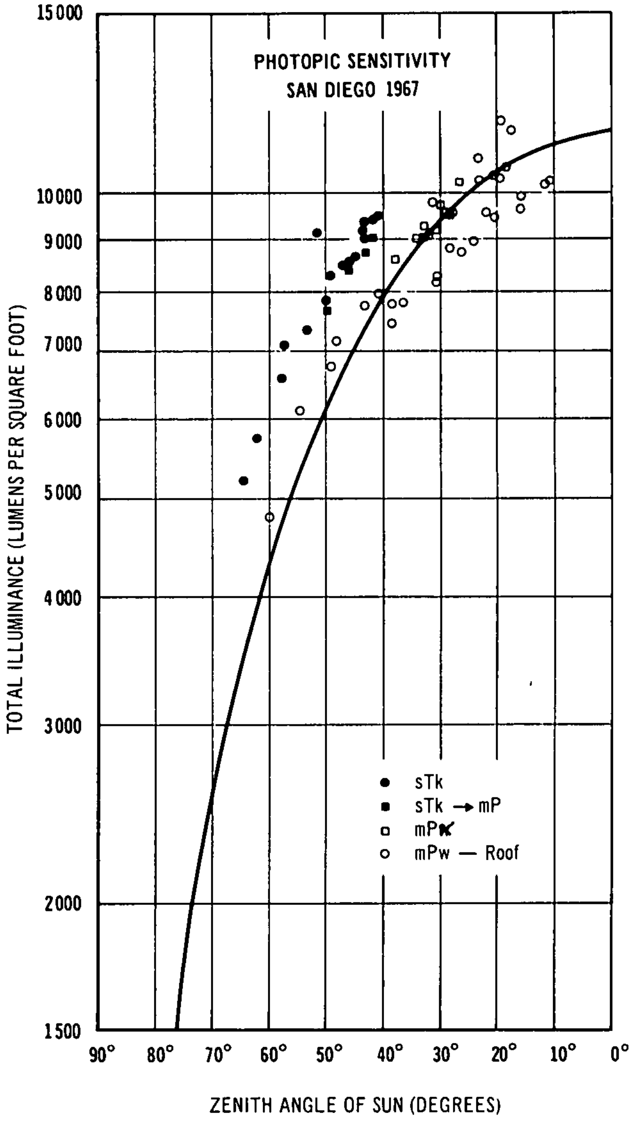

Figure 1.18

angle as the data collected at all the other sites. Data points for 26 April and 2 May are connected so that the relationship may be more easily seen. The data collected on 2 June also evidenced the same characteristic but the slope is less pronounced. The period April through June is one of persistent stable maritime air in San Diego and data could not be collected with other air mass types. The relationship of beam transmittance as it varies with sun angle is a subject that requires additional study. Additional experimentation at Montgomery Field was conducted using a slotted attachment on the contrast reduction meter in an attempt to devise a relatively simple instrument for shipboard use. This device is shown in Fig. 1.21. It is a slotted

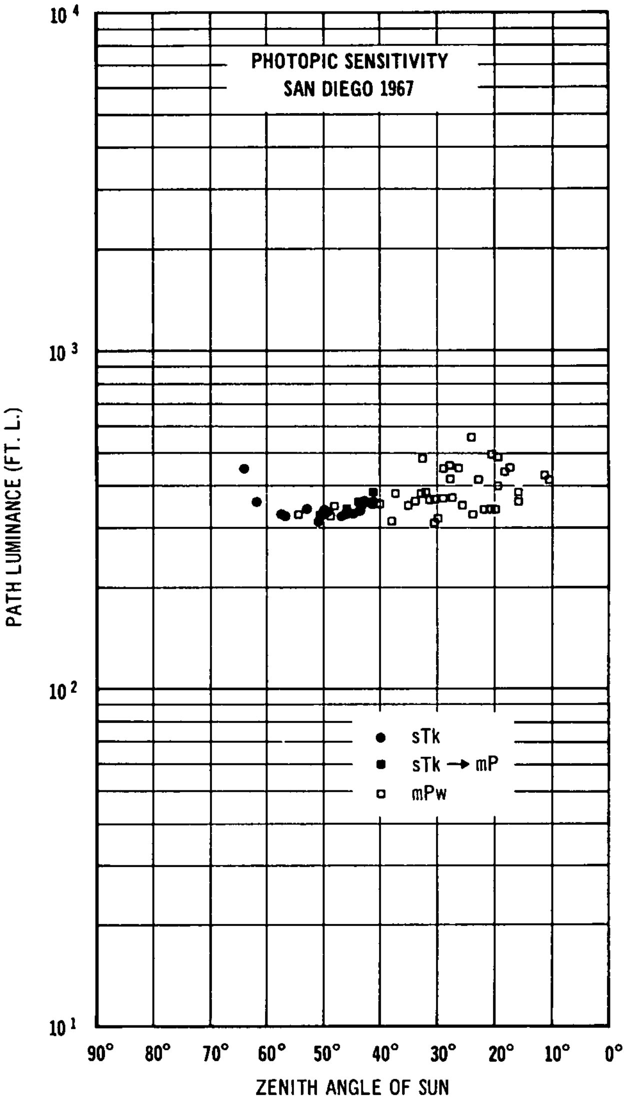

Figure 1.19

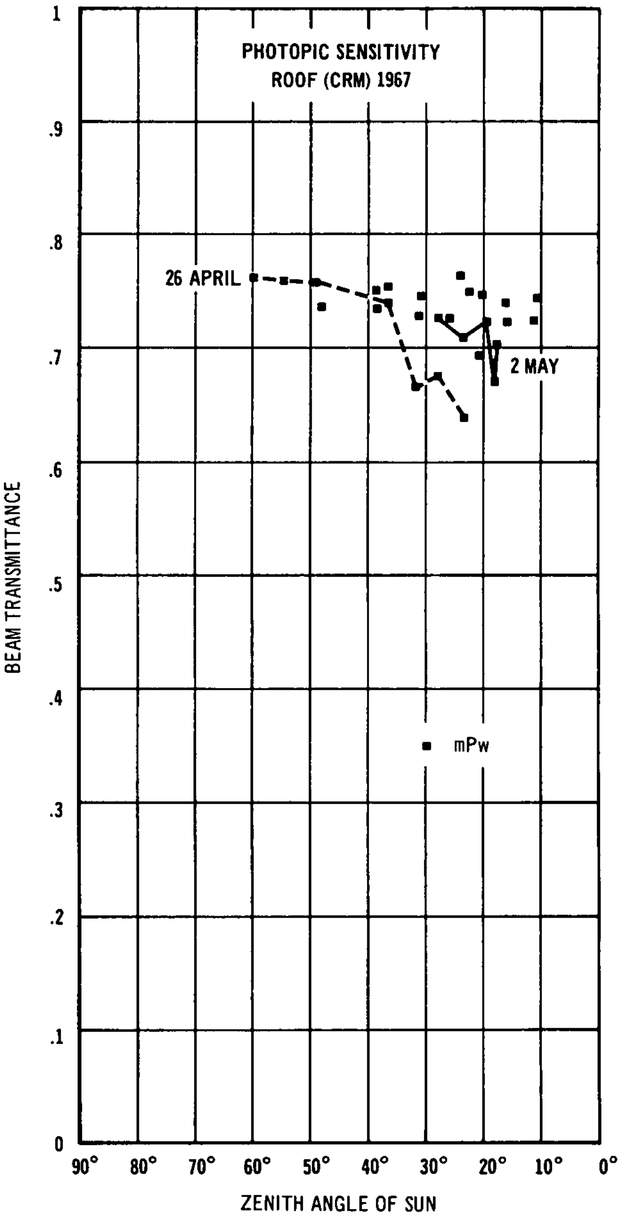

Figure 1.20

aperture sky scanner. Its field of view is approximately five degrees wide and 85 degrees long. It is oriented to measure the integrated radiance from a portion of sky 5° wide which extends from the zenith to within 5° of the horizon. The device rotates 360° in azimuth, so that in one revolution it scans the entire upper hemisphere. It is a prototype device intended to generate data equivalent to standard irradiometer data plus low resolution sky radiance distribution patterns. Data reduction techniques have not yet been fully established.

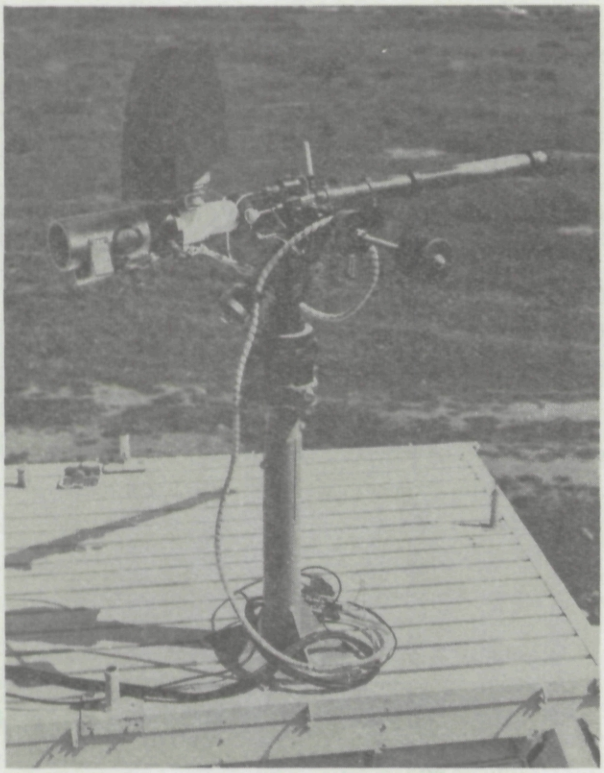

Figure 1.21. Portable Contrast Reduction Meter with Slotted Gershun Attachment

CONCLUSIONS

On the basis of the material examined it may be concluded that there are correlations between beam transmittance, total illuminance, and path radiance as a function of solar zenith angle and air mass type. Superior air masses showed highest values for both beam transmittance and total illuminance as a function of the zenith angle of the sun while stable maritime air masses exhibited lowest values. The relationship between path radiance as a function of the sun zenith angle and the type of air mass also appeared but was evident to a lesser degree because of the fewer data. The values for path radiance were higher for stable maritime air masses and lowest for unstable dry air masses. Path radiance values, when available, fell in the reverse order from those for beam transmittance and total illuminance.

SUGGESTIONS

These data were all collected at land stations and it is not intended that the results be applied to ocean areas. Because there are correlations with the various types of air masses, it is recommended that a survey of optical and meteorological conditions at sea be conducted either at small island stations or on ocean-going research vessels. The optical data should be collected with a red sensitivity. The data gathering ship or station should have a complement of meteorological personnel to document the weather conditions and ascertain the air mass type. This survey should be conducted on a year around world-wide basis. When the data have been collected and evaluated, it should be a straightforward matter to store them either in the form of a book of tables or in the memory of digital computers so that sea-state information will be readily available from satellite photographs as soon as a meteorologist has identified the air mass type prevailing in the ocean area of interest.

In addition to the survey of meteorological and optical data, information is needed on the fractional area of the surface of the sea covered by white water in order to determine sea state from meteorological satellite photographs. This should be determined from vertical aerial photographs for the complete range of ocean sea states of interest to the Navy. This might be done by a Navy photographic squadron assisted by surface ships. The reflectance of white caps should be measured for the near vertical paths of sight. Also needed are spectral measurements of the reflectance of the optically deep water beneath the surface of the open ocean.

When these needs have been met it is felt that a technique for obtaining sea state from satellite photographs can be produced. Validation of the technique will require optical and meteorological documentation from a surface ship and perhaps from an aircraft when a satellite is in the vicinity.

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This report describes a study of the relationship between meteorological weather patterns and those optical properties of the atmosphere of importance to the measurement of sea state and wind speed from meteorological satellite photographs. Correlations between values of beam transmittance, total illuminance, and path radiance as a function of the zenith angle of the sun and the type of air mass are noted.

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