Estimating the Probability of Clear Lines-of-Sight from Sunshine and Cloud Cover Observations[1]

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ABSTRACT

Observations of hourly sunshine, angular elevation of the sun above the horizon, cloud cover, and a three-dimensional cloud model, were utilized to derive a set of cloud width, thickness, and spacing values for estimating the probability of clear lines-of-sight from any angle. Data for Tampa, Florida, were used to illustrate cloud parameters that satisfy the cloud model. The observed "typical" values of cloud width and spacing fit the model very well. The computed average earth cover was much less than the observed average cloud cover because the observers did not see all the spaces between clouds.

1. Introduction

The climatic probability of a cloud-free line-of-sight depends on the distribution and dimensions of clouds along the path. Since such detailed cloud information is not routinely observed, an effort was made to derive it from available data. This paper describes how this was done.

A cloud model was used to determine a set of cloud dimensions which was consistent with observed "typical" clouds and the observed average amount of bright sunshine received at the earth's surface. The cloud dimensions were then used together with the cloud model to estimate the probability of a clear line-of-sight from any angle. A clear line-of-sight was defined as one which permits sufficient bright sunshine (radiation) to pass through the atmosphere to activate the sunshine recorder. The path length was the depth of the atmosphere from the top of all clouds to the surface of the earth.

It was assumed that the only information available for deriving the probability of clear lines-of-sight was hourly observations of sunshine, the solar altitude, cloud cover observations, and estimates of the average width, thickness, and spacing of clouds. Brief comments are made about the observations that are required.

An example is given to illustrate how the cloud dimensions were determined, what effect changing the viewing angle has on the probability of a clear line-of-sight, and the seriousness of incorrectly estimating the cloud parameters. Evidence is presented to show that the earth cover (portion of the earth directly overlain by clouds) was much less than the cloud cover reported by the observers. Observations taken at Tampa, Florida, were used in the example.

2. Sunshine and solar altitude

Observations of the presence, or absence, of bright sunshine have been routinely taken at numerous observing stations throughout the world. More than 100 stations have continuous records for over 50 years. These records provide information on clear lines-of-sight between the instrument and the sun. Since the instrument often fails to record early morning and late evening sunshine, the observer subjectively corrects these observations. It is these subjectively corrected observations that were used in this study as the probability of a clear line-of-sight.

The line-of-sight between the sun and the recorder is not always cloud free when bright sunshine is indicated because some thin clouds are not detected.

Even if the sunshine recorder traced a perfect record of clear lines-of-sight between the sun and the instrument, a long series of sunshine observations would not provide sufficient information to estimate directly the probability of clear lines-of-sight, since the observations are taken toward the sun only. A model is required to estimate the probabilities at angles other than toward the sun. This paper describes such a model.

In order to apply the model it is necessary to know the sun's angular elevation above the horizon (solar altitude) at the time the sunshine observations are taken. For this paper, the solar altitude was computed with the use of the following equations (see List 1958, p. 497):

$$C=0.067(\theta_s-\theta), \tag{1}$$

$$t_T=t_0+C+E, \tag{2}$$

$$H=15(|12-t_T|), \tag{3}$$

$$\sin a=\sin\phi\,\sin\delta+\cos\phi\,\cos\delta\,\cos H, \tag{4}$$

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where

C = time correction in hr
θ_s = time zone meridian in deg
θ = longitude of the observer in deg
ϕ = latitude of the observer in deg
t_T = true solar time
t_0 = local standard time
E = equation of time (correction to be applied to mean solar time to obtain apparent solar time)
H = hour angle of the sun (angular distance from the meridian of the observer) in deg
δ = declination of the sun in deg
a = altitude of the sun (angular elevation above the horizon).

The values for E and δ were interpolated from the values in Table 169 found in List (1958).

The solar altitude on the 15th day of each month was computed for the half-hour of each hour when the sun was above the horizon. The computed values were used as approximations of the sun's position at each hour of the day throughout the month. The solar altitudes were then associated with the climatic values of observed hourly per cent of possible sunshine obtained from the U. S. Weather Bureau. The per cent of possible sunshine values were used to estimate the probability of clear lines-of-sight.

3. Cloud model

The cloud model resembles that of Blackmer and Harllee (1960) except that a third dimension was added and the field of view was eliminated from consideration. The field of view can be reintroduced if it is required.

The clouds were assumed to be rectangular in vertical cross section, square in horizontal cross section, uniform in shape and size, and uniformly spaced with sides at right angles to the horizontal component of the sun's rays.

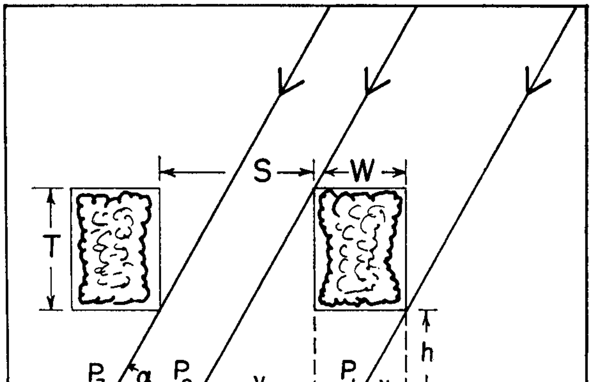

FIG. 1. Geometry of the cloud problem (vertical cross section).

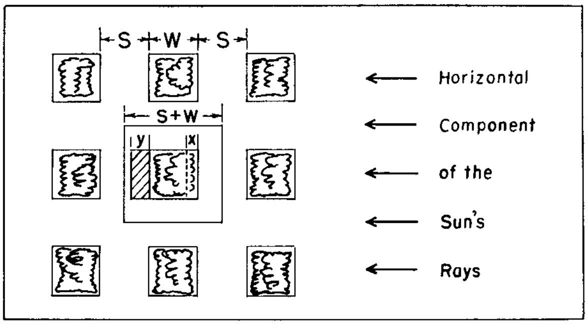

FIG. 2. Geometry of the cloud problem (horizontal cross section).

The notation also follows closely that of Blackmer and Harlee. Fig. 1 shows a vertical cross section and Fig. 2 a horizontal cross section through the clouds. The symbols T, W and S represent the thickness, width, and spacing of the clouds; h represents the height of the cloud base; x represents the horizontal distance under the cloud where the view is unobstructed; y represents the horizontal distance under the spacing where the view is obstructed; and α is the viewing angle.

4. Probability estimates

Sunshine observations are used to estimate the probability of a clear line-of-sight. The sun's rays are assumed to be parallel to each other and obstructed by a cloud between points P_1 and P_2 in Fig. 1 and unobstructed between points P_2 and P_3. From Figs. 1 and 2 it can be seen that the obstructed area, A is

$$A = Wy + W(W-x) \qquad (5)$$

where

$$x = h \cot\alpha \qquad (6)$$

and

$$y = (h+T)\cot\alpha. \qquad (7)$$

Substituting (6) and (7) into (5) and simplifying,

$$A = W^2 + WT \cot a. \qquad (8)$$

For this paper, the symbols ○, ⦶ and ⊕ represent less than 1/10 cloudiness, 1/10 to 9/10 cloudiness, and more than 9/10 cloudiness, respectively. The Greek letter tau (τ) is used to indicate that only thin clouds are observed, and $\bar{\tau}$ indicates that clouds other than thin clouds are observed. Thin clouds are defined as clouds which permit sufficient bright sunshine to pass through to activate the sunshine recorder. The letter C represents a clear line-of-sight. A bar over the C, symbolizes no clear line-of-sight. The probability of an obstruction (a given point on the ground is shaded by cloud), given that the sky is cloudy with not just thin clouds, $P(\bar{C}\,|\,⦶,\bar{\tau})$, is

$$P(\bar{C}\,|\,⦶,\bar{\tau}) = \frac{W^2 + WT\cot\alpha}{(S+W)^2}, \quad \text{when } \cot\alpha < \frac{S}{T}, \qquad (9)$$

since the simplifying assumptions permit the cloud pattern to be represented by observations within the area $(S+W)^2$.

The probability of a clear line-of-sight, $P(C|\text{⦷},\bar{\tau})$, is then

$$P(C|\text{⦷},\bar{\tau})=1-\frac{W^2+WT\cot\alpha}{(S+W)^2}, \tag{10}$$

when $\cot\alpha<S/T$. When $\cot\alpha\geq(S/T)$, the probability becomes

$$P(C|\text{⦷},\bar{\tau})=\frac{S}{S+W} \tag{11}$$

since y is $\geq S+x$ and the clouds appear as continuous streets in the same direction as the sun's rays.

With the simplifying assumptions stated in Section 3, the probability of a clear line-of-sight is independent of the height of the vehicle above the ground.

When the sky is clear, or only thin clouds are observed, the probability of a clear line-of-sight is assumed to be 100 per cent. When it is overcast and the clouds are not thin, the probability is assumed to be 0 per cent. During cloudy (1/10 to 9/10 cloudiness) periods, (10) and (11) are used to estimate the probability of a clear line-of-sight. Expressed mathematically,

$$\begin{aligned} P(C|\bigcirc)=P(C|\text{⦷},\tau)&=P(C|\oplus,\tau)\\ &=100\text{ per cent}, \end{aligned} \tag{12}$$

$$P(C|\oplus,\bar{\tau})=0. \tag{13}$$

The probability of a clear line-of-sight $P(C)$ is,

$$\begin{aligned} P(C)&=P(\bigcirc)+P(\tau)+P(C,\text{⦷},\bar{\tau})\\ &=P(\bigcirc)+P(\tau)+P(\text{⦷},\bar{\tau})P(C|\text{⦷},\bar{\tau}) \end{aligned} \tag{14}$$

by Bayes' Theorem and the probability of cloudy with not just thin clouds is,

$$P(\text{⦷},\bar{\tau})=1-P(\bigcirc)-P(\oplus)-P(\text{⦷},\tau). \tag{15}$$

Rearranging (14),

$$P(C|\text{⦷},\bar{\tau})=\frac{P(C)-P(O)-P(\tau)}{P(\text{⦷},\bar{\tau})}. \tag{16}$$

The value of $P(C|\text{⦷},\bar{\tau})$ is substituted into (10) or (11) depending upon whether $\cot\alpha<S/T$, or not, to obtain a set of cloud parameters consistent with the cloud model and the observed sunshine and cloudiness. The observed per cent of possible sunshine is used as the estimate of $P(C)$ in (14) and (16).

Since (10) and (11) are both functions of more than one variable, it is not possible to solve for the cloud parameters without first estimating two of the variables from cloud pictures, radar records, other observations, or theoretical considerations. (Only two parameters appear in (10) but the third, T, is required in order to determine whether (10) is the proper equation to use.) The estimates can be adjusted subjectively until all of the parameters appear "reasonable." For example, if estimates of S and W result in values of T much larger than usually observed, the value of S might be decreased to satisfy the equation and be consistent with what is known about the average thickness of clouds at the given location and time of day. It may be necessary to adjust the cloud parameters several times before they agree with available knowledge on cloud dimensions.

An objective procedure for adjusting the cloud parameters has not been developed, but the model has been tested on August data for Tampa, Fla., by making subjective corrections to estimates based on cloud photographs. The test is described in the next section of this paper.

There was some difficulty in arriving at a consistent set of cloud parameters for the late afternoon and evening but, in general, the dimensions used in the model agreed quite well with those estimated from the photographs. Further tests are required to determine whether subjectivity is a serious limitation to the model.

5. An example of determining probability estimates

Since a substantial amount of sunshine and cloud data for Florida was readily available, these data were used to determine subjectively whether the cloud model and probability equations would yield consistent and realistic cloud parameters. The data consisted of ob-

TABLE 1. Average per cent of possible sunshine recorded at Tampa, Fla., during the hours ending at the times shown (1905–1938).

	Local standard time														
Month	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Jan			39	43	53	66	72	75	75	71	64	55	52	48	
Feb		43	48	52	62	74	79	81	81	78	71	61	55	54	
Mar		50	52	59	72	80	84	86	84	82	77	68	59	57	
Apr	62	58	61	70	81	87	89	89	87	84	80	72	63	57	60
May	62	63	66	76	83	87	88	87	84	82	75	67	58	52	50
Jun	62	63	67	74	81	84	83	80	76	70	64	54	46	40	37
Jul	67	70	71	77	81	82	81	77	73	66	56	47	35	28	25
Aug	67	67	70	77	82	85	83	80	75	67	58	48	36	29	24
Sep		62	66	73	80	82	82	80	74	66	56	45	34	33	
Oct		56	58	63	74	78	80	79	75	68	61	52	47	42	
Nov		55	55	60	71	76	79	79	77	71	61	55	54		
Dec			43	46	56	67	73	74	74	68	61	54	51		

Table 2. Solar altitude (in degrees) at Tampa, Fla. on the 15th of each month.

	Local standard time												
Month	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830
Jan		1	12	23	32	38	41	40	34	26	16	4	
Feb		4	15	28	38	45	49	48	42	33	22	10	
Mar		10	23	36	47	60	60	58	50	39	27	14	1
Apr	4	17	31	44	56	66	71	66	56	44	31	17	4
May	10	22	36	49	62	74	81	73	60	47	34	21	8
Jun	11	23	36	49	63	76	85	76	63	49	36	23	11
Jul	9	22	34	48	61	74	84	76	64	50	37	24	11
Aug	6	19	32	45	58	70	76	71	59	47	34	20	7
Sep	2	16	29	41	53	62	65	61	51	40	27	14	1
Oct		12	25	36	46	52	54	50	42	31	19	6	
Nov		7	19	29	37	43	44	41	34	24	13	1	
Dec		3	14	24	32	37	39	37	31	22	12	1	

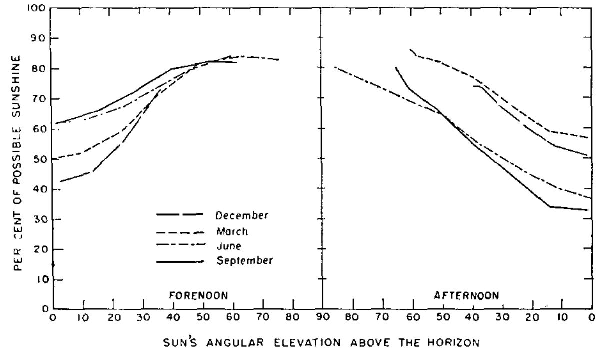

Fig. 3. Sunshine observed at Tampa, Fla., plotted as a function of solar altitude.

servations taken at several locations over different time periods.

1. Sunshine and solar angle at Tampa, Fla. Sunshine data for Tampa. Fla., for the 34-yr period from 1905 through 1938 were used in this example because they were readily available. More recent observations are more accurate, since instrumentation has improved, but these early records, with observers' corrections when the sun was near the horizon, were considered adequate. The data were extracted from U. S. Weather Bureau records entitled "Original monthly record of observations (hourly sunshine)." The per cent of possible sunshine is equal to the observed number of hours of sunshine divided by the total time period. For example, during the 34-yr period (1054 August days), the total sunshine between 1200EST and 1300EST was 843 hours or 80 per cent (843/1054) of possible. For the morning hour in which the sun rises, the per cent of possible sunshine is the total number of minutes of sunshine divided by the total number of minutes from sunrise to the end of the hour. A similar correction is made for sunset.

The average per cent of possible sunshine at Tampa for each daytime hour and month observed during the 34-yr period is shown in Table 1. The values vary from 24 per cent at 2000EST in August to 89 per cent near noon in April. Some of the variation in sunshine is due to diurnal and seasonal variations in cloudiness and some of the variation is due to the changes in the sun's angular elevation above the horizon. The per cent of possible sunshine for the first month of each season is plotted as a function of solar altitude in Fig. 3. The per cent of sunshine is almost the same during all months when the sun is about 50° above the horizon in the forenoon, but large differences are observed in the morning and afternoon, especially between March and September. It is obvious that any model of cloudiness at Tampa must provide for large diurnal and seasonal changes.

The observing station at Tampa, Fla., is located at 27°58′N, 82°32′W. The solar altitude on the 15th of each month is given, for each daytime hour, in Table 2. The average per cent of possible sunshine and the sun's angular elevation above the horizon at Tampa, in August, plotted as a function of local standard time, is shown in Fig. 4. The angular elevation curve is almost perfectly symmetrical about 1230EST (Tampa, at 82°32′W is almost exactly midway between the standard meridians 75° and 90°), but the sunshine is markedly different in the afternoon from the forenoon.

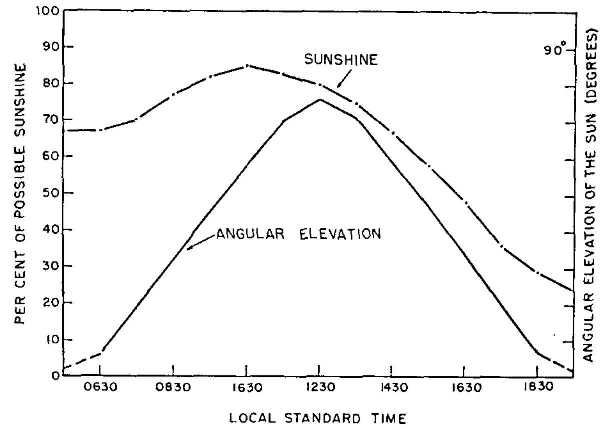

Fig. 4. Average per cent of possible sunshine and the sun's angular elevation above the horizon at Tampa, Fla., in August, plotted as a function of local standard time.

TABLE 3. Probability (in per cent) of clear, cloudy, and overcast, with and without thin clouds only, at Tampa, Fla., in August (1946–1951).

	Local standard time														
	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930
$P(\bigcirc)$	20	13	8	5	4	2	1	1	1	1	1	1	1	1	1
$P(⦶,\tau)$	8	8	8	8	8	8	8	7	7	6	5	4	3	2	1
$P(⦶,\bar{\tau})$	61	67	72	75	76	78	78	78	75	72	69	67	65	65	65
$P(\oplus,\tau)$	4	4	4	4	4	3	3	1	0	0	0	0	0	0	0
$P(\oplus,\bar{\tau})$	7	8	8	8	8	9	10	13	17	21	25	28	31	32	33

2. Cloud cover. Hourly observations of cloud at Tampa (MacDill AFB) for August 1946–1951 showed that the probability of clear skies $P(\bigcirc)$ decreased from morning until night while the probability of overcast $P(\oplus)$ increased. Thin clouds only were observed more frequently in the morning than later in the day. This is shown in Fig. 5. The points plotted near the bottom of the figure show the observed relative frequency of clear skies and the points plotted near the top of the figure show the observed relative frequency of not overcast. Smooth curves were drawn through the plotted points. These curves were used to estimate the cloud probabilities required by the equations. The probabilities are given in Table 3.

3. Observed typical clouds in August. For this study, attention was confined to cloudiness in August because some information was readily available on typical clouds observed in Florida during that month.

The probability of a clear line-of-sight according to (10) is a function of the viewing angle and the thickness, width, and spacing of the clouds. Mr. Vernon G. Plank,* of the Air Force Cambridge Research Laboratories, supplied some photographs of typical clouds taken in Florida during August. These pictures are shown in Fig. 6. His data of typical cloud spacing and width (Plank, 1964) are plotted in Figs. 7 and 8. During the early morning hours clouds are small and closely spaced. As the clouds become wider, the spacing between them increases. After about 1430EST there are insufficient data to identify clearly the changes of spacing and width of clouds.

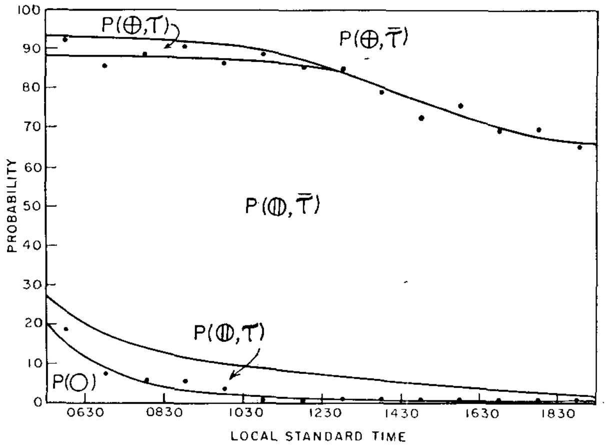

FIG. 5. The probability (in per cent) of overcast, cloudy and clear skies (with and without thin clouds only) over Tampa, Fla., in August.

4. Computed typical clouds. The average spacing and width of the clouds during each hour of the day was estimated by fitting a curve through the points in Figs. 7 and 8 by eye. These estimated values were substituted into (10) and (11) along with the solar angles and the observed per cent of possible sunshine, and the equations were then solved for cloud thickness. The thickness values were plotted and adjustments were made in the width and spacing curves until the thickness curve appeared "reasonable." The final curves are shown in Fig. 9. The data used to prepare Fig. 9 are shown in Table 4, where the estimated values are labeled $\hat{T}$, $\hat{W}$ and $\hat{S}$. The angles in Table 4 are such that $\cot\alpha \geq (S/T)$ at 0530, 0630, 1830 and 1930EST. In these cases the estimates of S (spacing) were considered fixed and W (width) was determined using (11). For all other hours (10) was used to solve for T (thickness). The model appeared to fit the data quite well up until mid-afternoon, however, for the late afternoon hours it was necessary to increase the width of the clouds and reduce their spacing (because of the small amount of sunshine recorded) more than cloud width and spacing data indicated. It may be that the coastal band of clouds which so frequently exists to the west of Tampa and the failure of the sunshine recorder to record sunshine at low elevation angles will account for the need to force more cloudiness into the model in the late afternoon.

5. Importance of viewing angle. Fig 10 was prepared to illustrate how the probability of a clear line-of-sight changes as the angle is varied. All of the probabilities were computed by entering the Tampa cloud parameters in (10) except that when a was 22°, $\cot\alpha$ became $>(S/T)$ at 0530, 1130, 1230, 1330, 1430, 1530, and 1630. In these cases (11) was used to solve for the probabilities.

The estimated probability of a clear line-of-sight from 90° (looking straight down) was usually about 20 per cent higher than from 22°. The small differences in the late evening are attributed to the fact that the clouds are much wider than they are thick during these hours.

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* Personal communication.

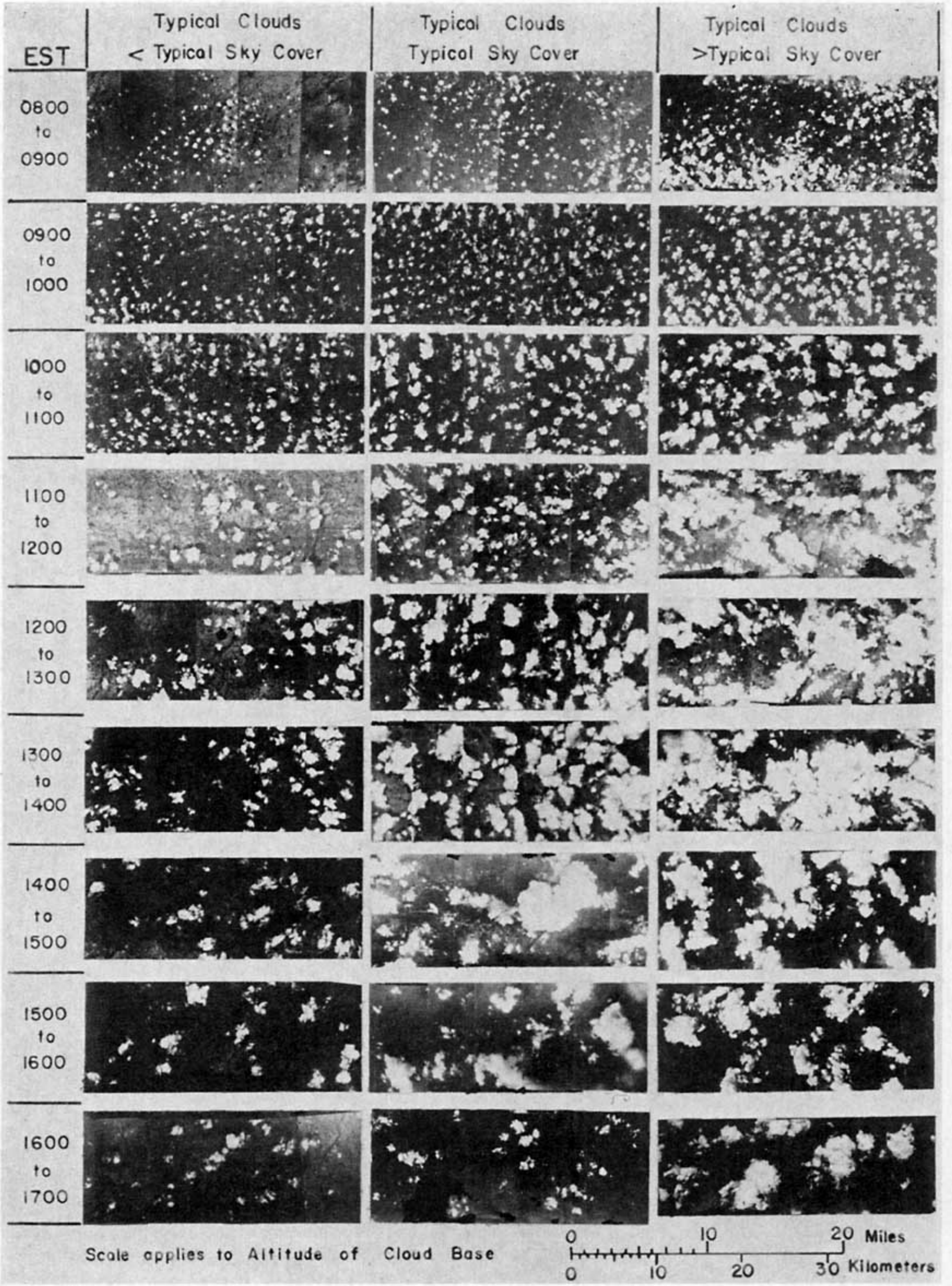

Fig. 6. Typical diurnal cloud cycle for Florida in August.

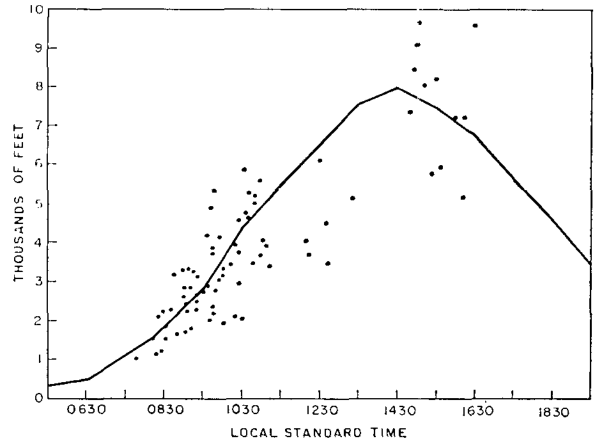

FIG. 7. The spacing of typical cumulus clouds observed in Florida in August.

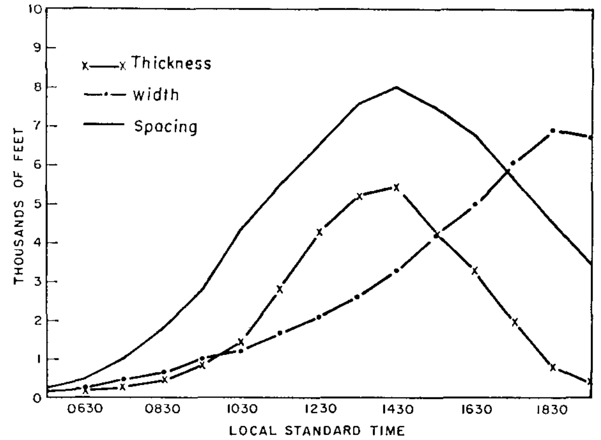

FIG. 9. Estimated typical cloud thickness, width, and spacing for Tampa, Fla., in August, plotted as a function of local standard time.

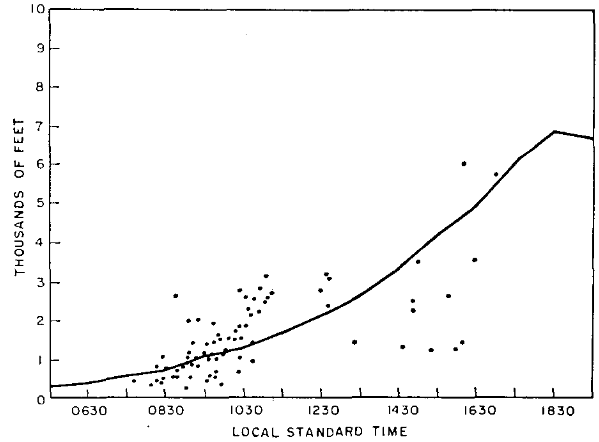

FIG. 8. The width of typical cumulus clouds observed in Florida in August.

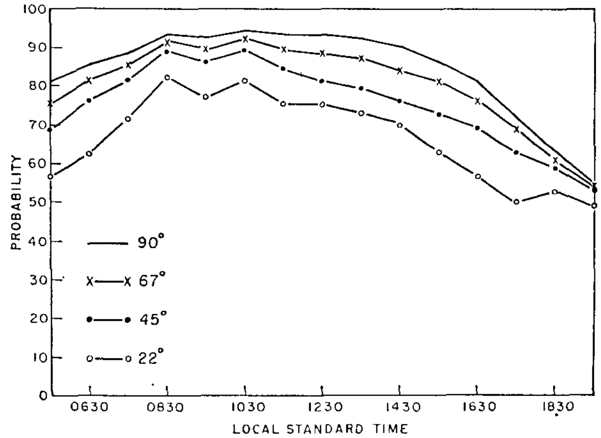

FIG. 10. The probability (in per cent) of a clear line-of-sight at 22°, 45°, 67° and 90° from Tampa, Fla., when typical August clouds are present.

6. Effect of errors in estimating cloud parameters. Fig. 11 was prepared to illustrate the magnitude of the errors in the probability estimates that would be introduced by incorrectly estimating the cloud parameters. If the true values of T, W and S were exactly equal to the estimated values ($\hat{T}$, $\hat{W}$ and $\hat{S}$), and the model was perfect, the probability of a clear line-of-sight at 45° would, at each hour of the day, be the values connected by the solid line in Fig. 11. If T (true thickness) was equal to $1.5\hat{T}$ (estimated thickness),

TABLE 4. Values of the parameters for Tampa, Fla., used to prepare Fig. 9.

	Local standard time														
	0530	0630	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830	1930
Angular (α) elevation (deg)	2	6	19	32	45	58	70	76	71	59	47	34	20	7	2
$P(C\|\Phi,\bar{\tau})$	57	63	69	80	87	92	91	91	89	83	75	64	49	40	34
Cloud ($\hat{T}$) thickness (ft)	150	200	308	405	877	1425	2870	4290	5232	5455	4234	3390	2017	800	400
Cloud ($\hat{W}$) width (ft)	226	294	500	600	1000	1200	1700	2100	2600	3300	4200	5000	6100	6900	6794
Cloud ($\hat{S}$) spacing (ft)	300	500	1000	1800	2800	4400	5500	6500	7600	8000	7500	6800	5700	4600	3500

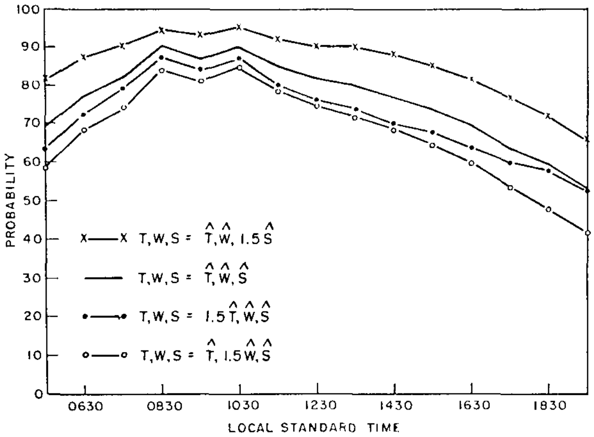

FIG. 11. The probability (in per cent) of a clear line-of-sight at 45° from Tampa, Fla., with typical August clouds and four different combinations of cloud thickness, width, and spacing values.

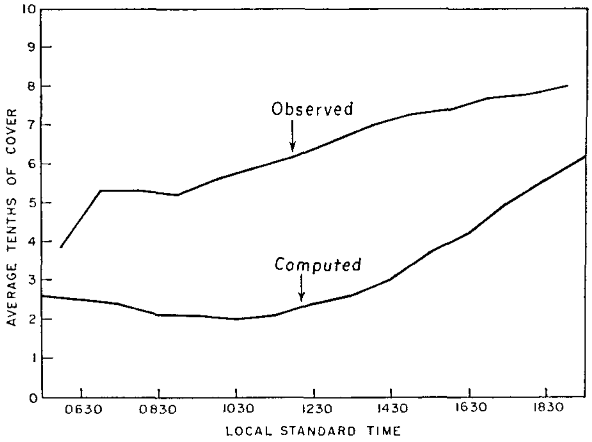

FIG. 12. Observed average cloud cover and computed average earth cover for Tampa, Fla., in August.

but the other parameters and the model were correct, errors of from 1 to 7 per cent would be introduced, as seen by comparing the line with the solid dots with the solid line. If $W=1.5\hat{W}$, the probability estimates using $\hat{W}$ instead of W would be from 5 to 12 per cent too high, as seen by the line with the open dots in Fig. 11. If

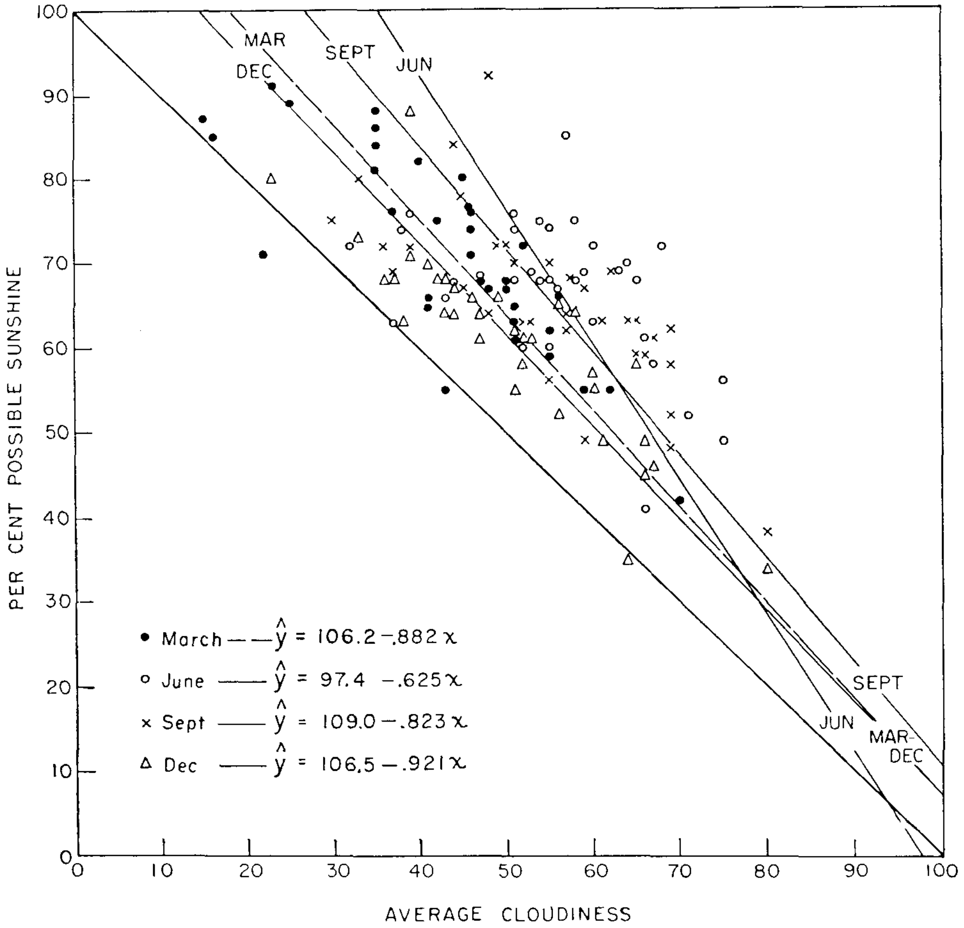

FIG. 13. Monthly average daytime cloudiness and corresponding values of per cent of possible sunshine recorded at Tampa, Fla. (1905–1938).

$S=1.5\hat{S}$, the probability estimates using $\hat{S}$ instead of S would be from 5 to 13 per cent too low.

This example only illustrates the magnitude of the errors when viewing at 45° and underestimating one of the cloud parameters. Many combinations of errors can be introduced including compensating errors which result in perfect estimates of the probabilities.

6. Observed average cloud cover and computed average earth cover

The observed average cloud cover as determined from surface hourly observations may not provide a good estimate of the probability of clouds overhead (earth cover), since the observer views most of the sky at low elevation angles. The viewing angle of the observer is especially critical when the clouds are low and scattered so the observer cannot see the spaces between them. This has been pointed out by Appleman (1962) and others.

The cloud dimensions determined by the cloud model were substituted into (9) to find $P(\bar{C}|\text{⦷},\bar{\tau})$ when the viewing angle is 90°. This value was substituted into the following equation to estimate the average earth cover:

$$\begin{aligned}\text{Average earth cover} &= 1.0[P(\oplus,\bar{\tau})+P(\oplus,\tau)]\\ &\quad +0.5[P(\text{⦷},\tau)]+0.0[P(\bigcirc)]\\ &\quad +P(\bar{C}|\text{⦷},\bar{\tau})P(\text{⦷},\bar{\tau}). \qquad (17)\end{aligned}$$

The observed average sky cover and the corresponding computed average earth cover are shown in Fig. 12. The computed values are much smaller than the observed values, illustrating the importance of distinguishing between sky cover and earth cover.

7. Sunshine versus cloudiness

In order to further illustrate the need for differentiating between observations of cloudiness and clear lines-of-sight, the monthly average daytime cloudiness observed at Tampa (1905–1938), and the corresponding values of per cent of possible sunshine for March, June, September and December are plotted in Fig. 13. Also shown in the figure are the best least squares regression lines to the data for each month and the line which would represent a perfect (negative) correspondence between average cloudiness and per cent sunshine. All but 4 of the 136 points lie above the line of perfect correspondence, suggesting more cloudiness is reported by the ground observers than indicated by the sunshine recorder. One reason for the excess sunshine is suggested by the comment "sunshine through thin upper clouds" found on many of the observation forms. That the occurrence of thin high clouds can account for the large discrepancies seems unlikely. Since the elevation angle of the sun at Tampa is always less than 40° in December and less than 90° at all times, and since the recorder sometimes fails to indicate sunshine at low angles, the need for adjusting surface observations of sky cover before applying them to line-of-sight problems is readily apparent.

8. Discussion

The operational value of optical and infrared search and tracking systems, for example, depends on the probability of a clear line-of-sight between the points of interest. It has been shown that routinely taken observations of either sunshine or cloud cover, give some information on this probability, but the value of these data can be enhanced by properly relating them through the use of a simple cloud model. The model might be improved by assuming clouds have circular bases and parabolic tops but these added complications did not appear warranted in these first approximations. The assumption of circular bases would eliminate the need for assuming that the sides of the clouds are at right angles to the horizontal component of the rays of the sun, but some other assumption, or definition, would be required when $S=0$. Since cloud cover usually decreases with altitude near the cloud tops, a cloud model of the form of an inverted elliptic paraboloid might be better than rectangular parallelepiped shaped clouds but this refinement has been left to later studies.

The cloud model and the sunshine data indicate that much less of the earth is covered by clouds than is indicated from surface observations of cloud cover. This is understandable because the observer sees the sides of clouds as well as their bases. This fact is important in designing and evaluating optical systems that require clear lines-of-sight through the atmosphere. Past evaluations of such systems, based on surface cloud observations, may have underestimated their usefulness.

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