TECHNICAL REPORT 186

AIR WEATHER SERVICE

ESTIMATING MEAN CLOUD and CLIMATOLOGICAL PROBABILITY of CLOUD-FREE LINE-OF-SIGHT

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PREFACE

There are many military problems involving cloudiness and certain of them require a knowledge of the amount of cloud to be expected climatologically at one or more levels or within a layer of the atmosphere. Examples of such problems are those concerning aircraft icing and refueling rendezvous. Still other problems require information about the likelihood of clouds interfering with the sighting of a target for various observer-target arrangements, as with aerial or satellite reconnaissance and aircraft-missile interception.

This report describes a method of using standard surface-observed cloud data to estimate the mean cloud amount at and between levels and the probability of cloud-free line-of-sight between any two levels at any angle to the horizon. The method may be used manually by those who become familiar with it and who have access to summaries of mean cloud amount below various heights for the area of interest. However, manual application is not recommended because the method has been programmed for the IBM 7044 computer and is being used at the Environmental Technical Applications Center (ETAC), USAF where the basic input data are readily available for most locations.

AWS units that may have a need for information to be drawn from the programmed mean cloud and cloud-free line-of-sight outputs are invited to contact ETAC through appropriate channels, normally their squadron and wing technical services offices.

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Washington, D. C. 20333
22 November 1965

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Chapter 1

ESTIMATING MEAN CLOUD AMOUNT AT AND BETWEEN LEVELS

In 1960 Elizabeth de Bary and Fritz Möller published in German [1] a summary of more than 25,000 aerial weather reconnaissance flights made over Germany from 1936 through 1940. The data are unique in that each observation describes a complete vertical cloud analysis. The data are summarized according to 40 classifications: combinations of five cyclonic and five anticyclonic weather situations, by winter or summer half-year and by morning or afternoon time of day. The summaries are presented in table and graph form.

In 1963 de Bary and Möller published in English [2] equivalent summaries for the four all-weather classifications (winter/summer, morning/afternoon combinations) and the graph for the winter-morning flights. This graph and its table are reproduced here (Figure 1, Table 1). The tables and graphs in this report show the mean cloudiness at each kilometer level and between any two levels. (The published tables omit the 5-km through 9-km reference levels, but the values for these levels may be read from the graphs.)

The values given in Table 1 are the percent mean cloud amounts between the altitudes of observation (column heading) and the various row-identified altitudes. The values along the lower-left to upper-right diagonal are the mean cloud amounts at the indicated observation altitudes. For example, in Table 1, the mean cloud amount between 2 km and 5 km is 42.4% and the mean cloud amount at 2 km is 21.0%. Only the tabular data equivalent to that in the first column (or by symmetry, the bottom row), which correspond to the "0" curve of Figure 1, are available directly from the records of surface observations.

Using the equivalent of the surface-observed data, we wish to estimate the remaining cloud statistics which describe the vertical cloud distribution. Notice on Figure 1 that by knowing the "0" curve (mean cloud amount below given levels), we also know the points where the other curves intersect the 0-km level. Similarly, if we knew the "10" curve (mean cloud amount above given levels), we would also know where the other curves intersect the 10-km level. Further, if we knew the minimums or kink points for each curve (mean cloud amount at each given level), we could estimate reasonably well the rest of the graph by constructing the remaining lines through respective 0-km, 10-km, and minimum points and, as nearly as possible, "parallel" to the "0" and "10" curves. Of course, too, a check would have to be maintained to provide that the value where, say, the 2-km curve crosses the 5-km level is the

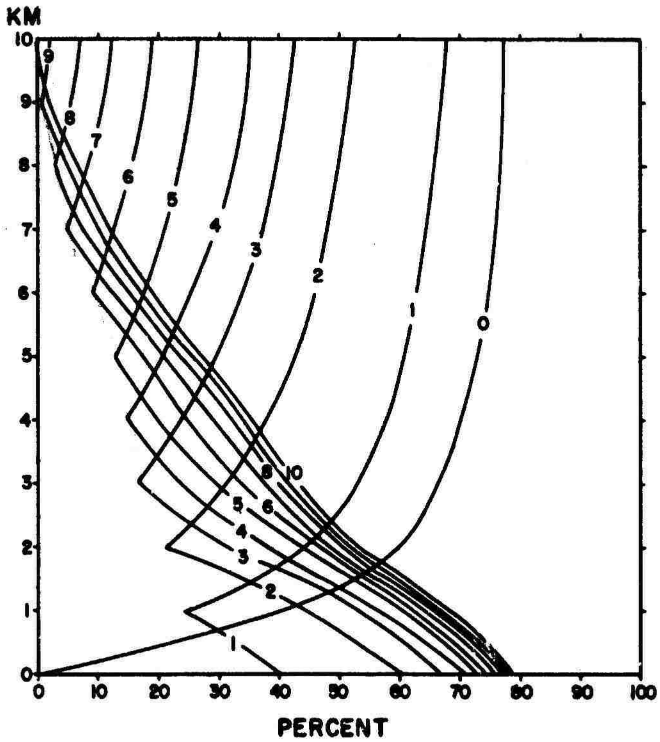

Figure 1. Average Vertical Distribution of Cloud Cover as Seen from Altitudes 0-10 Km. Winter morning flights at 10 German weather flight stations, 1936-1940 (from E. de Bary and F. Möller [2]).

TABLE 1

Average Vertical Distribution of Cloud Cover (%).

Altitude (km)	Altitude of Observation, km						
	0	1	2	3	4	5	10
10	77.4	67.6	53.0	42.7	35.3	26.4	0
5	72.4	60.6	42.4	29.5	20.3	13.0	26.4
4	70.1	57.6	37.9	23.5	15.0	20.3	35.3
3	66.6	53.0	31.1	16.6	23.5	29.5	42.7
2	60.4	44.5	21.0	31.1	37.9	42.4	53.0
1	40.5	24.8	44.5	53.0	57.6	60.6	67.6
0	C	40.5	60.4	66.6	70.1	72.4	77.4

same as the value where the 5-km curve crosses the 2-km level, etc.

Let us assume that we know, from surface-observed data, the mean cloud amount below the given levels; i.e., between the surface and each higher level. Let the mean cloud amount between the surface and the i-th kilometer (i-km) level be represented by p_i. We wish to estimate the mean cloud amount at each kilometer level above the surface. Call the mean cloud amount at the i-km level C_i.

Above the surface, clouds that exist at any given kilometer level either had their bases between that level and the next lower kilometer level or they existed at the next lower kilometer level. Assuming the amount of cloud bases occurring in a layer is the same when the observer cannot see into the layer as when he can see into the layer, an expression for the mean cloud amount with bases in the layer from i minus one (i-1), to i kilometers is

$$(1) \qquad \frac{p_i - p_{i-1}}{1 - p_{i-1}} = \pi_i$$

Then

$$(2) \qquad C_i = a_i \pi_i + b_i C_{i-1}$$

where a_i and b_i are coefficients describing the proportion of clouds reaching the i-km level that had their bases in the (i-1)- to i-km layer, and those that existed at (i-1) km, respectively.

Assuming no clouds at the surface, $C_0 = p_0 = 0$. Then for $i = 1$, equation (2) reduces to

$$(3) \qquad C_1 = a_1 p_1$$

A value of $a_1 = .63$ satisfies the complete set of de Bary-Möller data.

A better fit to all forty of the subgroups of C_1, p_1 data is obtained by

$$(4) \qquad C_1 = .88 p_1 - .09$$

Further refinements according to season/time-of-day groupings are as follows:

For all seasons, morning hours

$$(5) \qquad C_1 = .84 p_1 - .10$$

For all seasons, afternoon hours

$$(6) \qquad C_1 = .88 p_1 - .06$$

For <u>winter</u>, <u>all</u> hours

(7) $C_1 = p_1 - .16$

For <u>summer</u>, <u>all</u> hours

(8) $C_1 = .75\ p_1 - .03$

For <u>summer</u>, <u>morning</u> hours

(9) $C_1 = .68\ p_1 - .04$

For <u>summer</u>, <u>afternoon</u> hours

(10) $C_1 = .75\ p_1$

According to various groupings of the de Bary and Möller data, the best estimates of C_i for i = 2, 3, ..., 10 are obtained with the values of a_i and b_i shown in Table 2.

TABLE 2

Values of a_i and b_i.

Parameters	i (km)								
	2	3	4	5	6	7	8	9	10
a_i	.60	.60	.60	.60	.60	.60	.60	.32	.25
b_i	.24	.35	.50	.50	.42	.20	.10	.05	.05

Table 3 shows the errors in the estimates of C_1 through C_5 for various groupings of the data. Values of C_1 were made by the appropriate refined expressions (4) through (10).

Tabular data for C_6 through C_{10} are not available in the de Bary and Möller article but can be read from the 40 individual graphs. Values for four groups, each with a large number of observations, were read from the graphs and compared with the corresponding computed estimates of C_6 through C_{10}. Table 4 shows the errors.

Note that the errors in the estimates of C_i are in the "direction" one would expect. The coefficients a_i and b_i used to estimate C_i may be thought of as measures of cloud thickness. Hence, for those cases with clouds having less than average vertical development, the estimate gives too much cloud at a level, as with the winter-morning-anticyclone group; and for those cases with clouds having more than normal vertical development, the estimate gives too

TABLE 3

Errors in Percent of Estimated Mean Amount of Cloud
at Given Levels, 1 to 5 Km.
(Error = Estimate - True)

Level (km)	All	Winter	Summer	Anti Cycl	Cycl	Morn	Aftn
1	-0.2	0.0	0.2	0.3	-0.3	0.8	-0.5
2	-0.2	3.3	-2.9	4.0	-2.9	0.5	-1.5
3	-0.2	0.6	-0.7	3.6	-1.6	-0.1	-0.8
4	0.0	-0.4	-0.1	3.0	-0.2	0.2	-0.4
5	-0.3	-1.2	0.3	2.6	-0.2	0.8	-1.3
No. of Obs	25,448	12,297	13,151	12,451	12,997	15,771	9,677

Level (km)	Winter				Summer			
	Morn Anti	Morn Cycl	Aftn Anti	Aftn Cycl	Morn Anti	Morn Cycl	Aftn Anti	Aftn Cycl
1	3.4	1.8	-1.0	-2.6	1.7	0.9	0.5	-2.0
2	8.2	0.4	7.1	-0.8	1.8	-3.2	-0.5	-6.8
3	5.6	0.2	3.9	-2.3	2.7	-2.2	1.5	-3.5
4	3.4	0.5	2.6	-1.7	3.1	1.3	2.5	-0.9
5	2.8	1.3	1.2	-3.4	3.5	3.1	2.6	-2.0
No. of Obs	3,745	3,901	2,320	2,331	3,994	4,131	2,392	2,634

little cloud at a level, as with the summer-afternoon-cyclonic group.

Estimates of cloud amount at a level can be adjusted to allow for a subjective interpretation of the cloud climatology of any set of data being analyzed.

Return to the vertical cloud distribution graph, Figure 1. Knowing the "0" curve (mean cloud amount below the levels) from the surface-observed data, and having made estimates of the minimum points on the other curves (mean cloud amount at the levels), we now wish to estimate the "10" curve (mean

TABLE 4

Errors in Percent of Estimated Mean Amount
of Cloud at Given Levels, 6 to 10 Km,
for Four Data Groups.

Level (km)	HW[1] Winter Morn	ZK[3] Winter Aftn	HS[2] Summer Morn	ZK[3] Summer Aftn
6	2.0	-1.8	1.1	0.7
7	1.3	-1.0	0.3	-1.2
8	2.4	0.3	1.0	-1.4
9	1.1	0.3	0.8	-0.6
10	0.3	0.3	0.3	0.1
No. of Obs	1,188	1,410	913	1,658

[1] HW: Observations made in western portion of anticyclone.

[2] HS: Observations made in southern portion of anticyclone.

[3] ZK: Observations made in cold cyclonic air mass.

cloud amount above the levels).*

Call the mean cloud amount above the i-km level q_i. By our assumption, $q_0 = p_{10}$ and $q_{10} = 0$. That is, the mean cloud amount above the surface equals the mean total cloud amount, which, assuming no cloud above 10 km, equals the mean cloud amount below 10 km. Having estimated the mean cloud amount with bases in a layer (1), we can similarly express an estimate of the mean cloud amount having tops in the same layer, and hopefully relate these expressions by a proportionality factor which is a function of the height of the layer:

$$(11) \qquad \frac{q_i - q_{i+1}}{1 - q_{i+1}} = k_i \frac{p_{i+1} - p_i}{1 - p_i} = k_i \pi_{i+1}$$

* In the event clouds are reported at or above 10 kilometers, reference to the "10" curve and the subscript "10" should be replaced by the height of the first kilometer level above all clouds.

We thus assume in (11) that the amount of clouds having tops within the layer is proportional to the amount of clouds having bases within the same layer, with k_i being the proportionality factor.

Knowing both q_0 and q_{10}, expression (11) can be worked from above and from below to solve for values of $q_1, q_2, \ldots, q_9$. Working up, (11) reduces to.

(12) $$q_i = \frac{q_{i-1} - k_{i-1}\,\pi_i}{1 - k_{i-1}\,\pi_i}$$

For $i = 1, 2, \ldots, 5$, the best single value of k_{i-1} to fit the de Bary-Möller data was 1.2, but this gave rather large errors in estimating q_1 and q_2. Better estimates of q_1 and q_2 can be made from Figures 2 and 3 where q_1 is found as a function of p_1 and q_0, and q_2 is found as a function of π_2 and q_1; i.e., of p_1, p_2, and q_1. Then for $i = 3, 4, 5$,

(13) $$q_i = \frac{q_{i-1} - 1.2\,\pi_i}{1 - 1.2\,\pi_i}$$

Working down, (11) reduces to:

(14) $$q_i = q_{i+1} + k_i\,(1 - q_{i+1})\,\pi_{i+1}$$

For $i = 9, 8, \ldots, 5$, The best single value of k_i was 1.5.

Thus, Figures 2 and 3 and equation (13) provide estimates of q_1 through q_5 and equation (14) provides estimates of q_5 through q_9.

Of course, the two q-curves may not meet at the 5-km level and tests of this method against the de Bary and Möller data suggest that a q-curve that is a compromise of the upper and lower curves produces the smallest errors.

The estimated values of q_i constitute the "10" curve of the vertical cloud distribution graph (see Figure 1). The "0" curve is known from surface-observed data. The estimated values of C_i constitute the minimum or kink values of the "1" through "9" curves. The points of intersection of the "1" through "9" curves with the 0-km and 10-km levels are available from the "0" and "10" curves. The estimated vertical cloud distribution graph may now be completed by constructing the "1" through "9" curves as nearly as possible "parallel" to the "0" and "10" curves yet through their respective 0-km, 10-km, and minimum points. In constructing the curves, a check must be maintained to provide that the values of respective pairs of curves and intersect levels agree. For example, the value where the "3" curve crosses 6 km must be the same as the value where the "6" curve crosses 3 km. It may also be necessary in some cases to make small adjustments in the upper portions of the $\underline{C}$ and $\underline{q}$ curves to insure that the values of $\underline{C}$ are always less than $\underline{q}$. (Recall that C_i is the minimum point for the i-km level.)

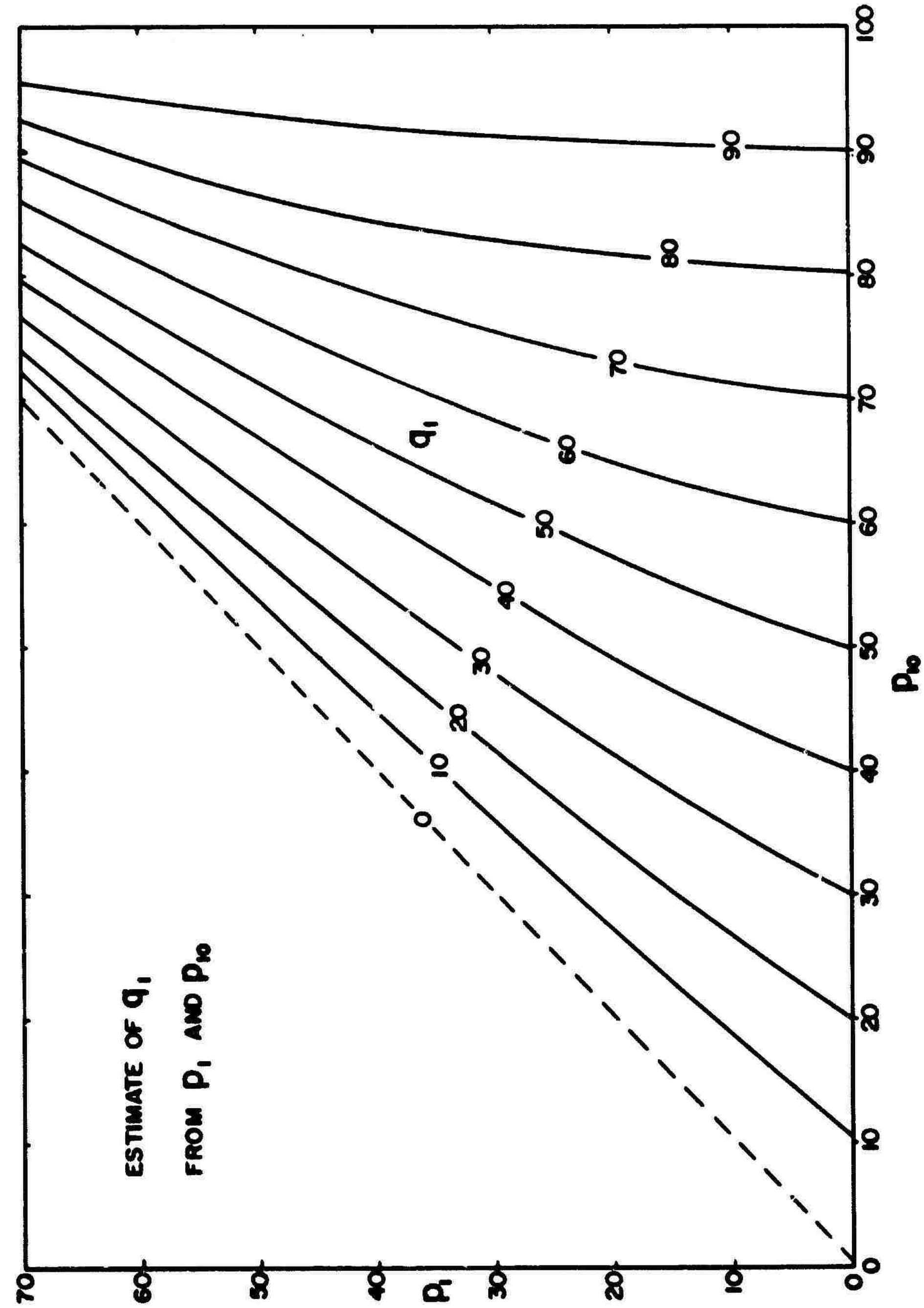

Figure 2. Estimate of q_1 from p_1 and p_{10}.

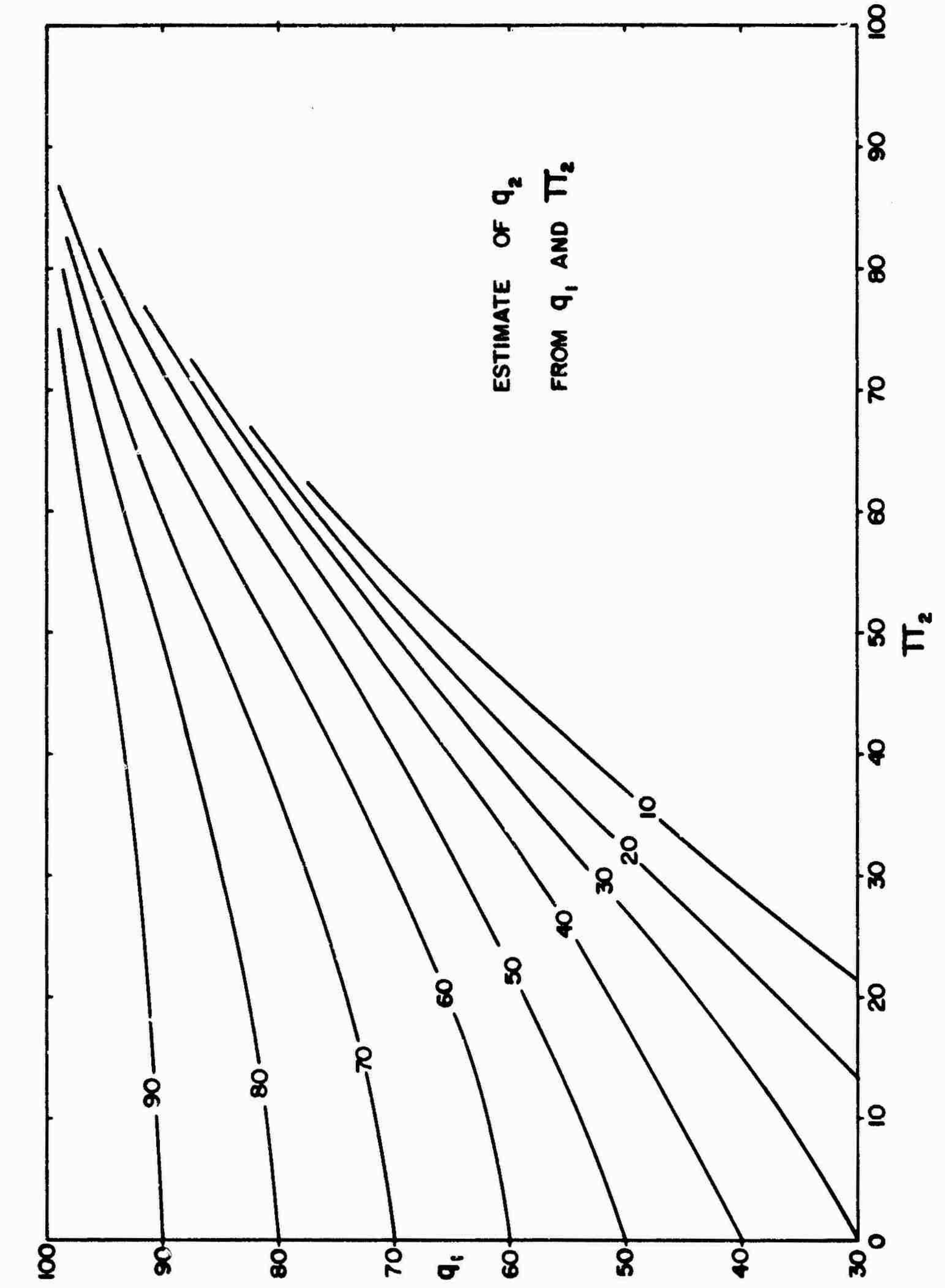

Figure 3. Estimate of q_2 from q_1 and π_2.

The de Bary and Möller cloud data are for Germany but within season-synoptic groupings probably are representative of most mid-latitude regions. However, if we wish to apply the estimating technique at lower latitudes, we must allow for occurrences of clouds above 10 km. One possible approach is to assume very few stratospheric clouds and estimate the depth of the troposphere from tropopause data, then divide the troposphere into ten equal thickness layers, and treat each of the layers and levels as equivalent to the 0- to 10-km cases. This implies that the coefficients a_i and b_i would apply to somewhat thicker layers at correspondingly higher altitudes in the lower latitudes.

Chapter 2

ESTIMATING PROBABILITY OF CLOUD-FREE LINE-OF-SIGHT

In addition to the standard cloud observations, many locations have long period records of the occurrence of "bright sunshine." For some of these locations, US Weather Bureau summaries provide data on the mean percent of bright sunshine by month and hour of the day, where percent of bright sunshine is defined as the percent of time of possible sunshine that bright sunshine occurred. These data can be compared with the mean of observed cloud cover by month and hour of the day to show the relationship between percent of bright sunshine and mean cloud amount as a function of the sun angle. Figures 4, 5, and 6 are plots of May-October afternoon data for 20 US locations showing percent bright sunshine versus mean cloud cover for sun angles of 0°-10°, 30°-35°, and 55°-60°, respectively. Plots for the winter half-year (November-April) and morning hours show similar patterns. That is, for very low sun angles (0°-10°) the points tend to fall along the diagonal where sunshine equals one minus the cloudiness. As the sun angle increases, there is a marked tendency for the amount of sunshine to increase for a given amount of cloud cover.

Figure 7 is the result of an attempt to consolidate all of the sunshine, cloud cover, and sun-angle data. Similar diagrams were first drawn for the combinations of the winter and summer half-years by morning and afternoon times of day, but the differences among diagrams appeared small compared to the rather large amount of scatter in the original plots.

Thus, Figure 7 presents an overall average relationship of sunshine, cloud cover and sun angle for the locations considered. To the extent that bright sunshine is recorded when there is essentially a cloud-free line-of-sight between the sun and the recorder, Figure 7 provides a means of estimating probability of cloud-free line-of-sight through the whole atmosphere as a function of the mean total cloud cover and viewing angle. For example, if the mean total cloud cover for a location, season and time of day is 50%, then Figure 7 indicates that an estimate of the probability of a cloud-free line-of-sight to a surface target from levels above all clouds is about 91% looking straight down (zero nadir), about 80% looking 45° to nadir and about 60% looking 75° to nadir (15° to horizontal).

It is known that sunshine recorders often record the occurrence of "bright sunshine" through thin clouds, especially at high sun angles. And the same recorders often fail to record sunshine at very low angles when there are no clouds. Also of interest, a weather observer reports as total cloud cover the

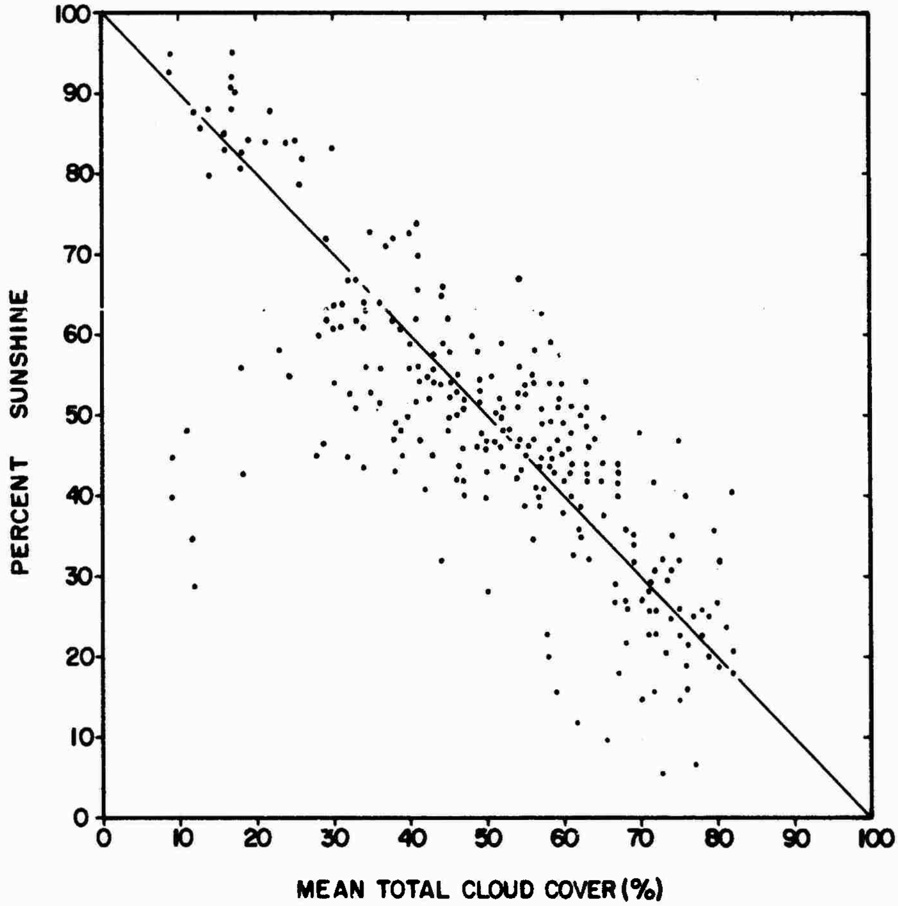

Figure 4. Percent Sunshine Versus Mean Total Cloud Cover for Sun Angles 0°-10°, 20 US Locations, May-October, Afternoon Data.

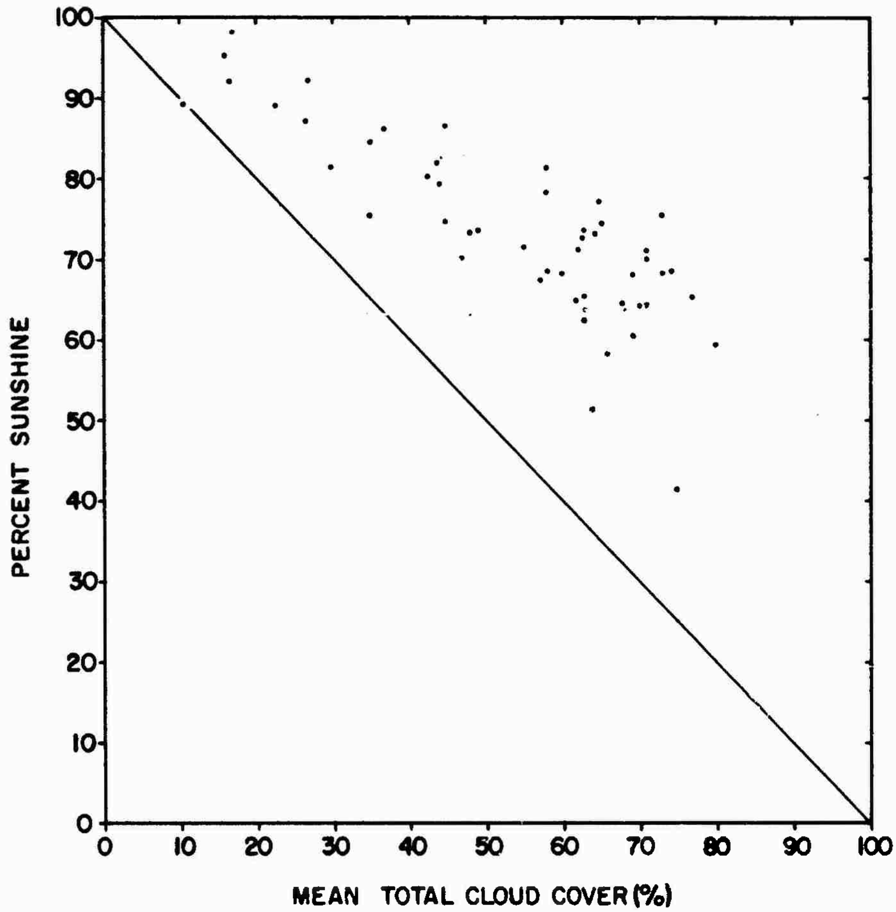

Figure 5. Percent Sunshine Versus Mean Total Cloud Cover for Sun Angles 30°-35°, 20 US Locations, May-October, Afternoon Data.

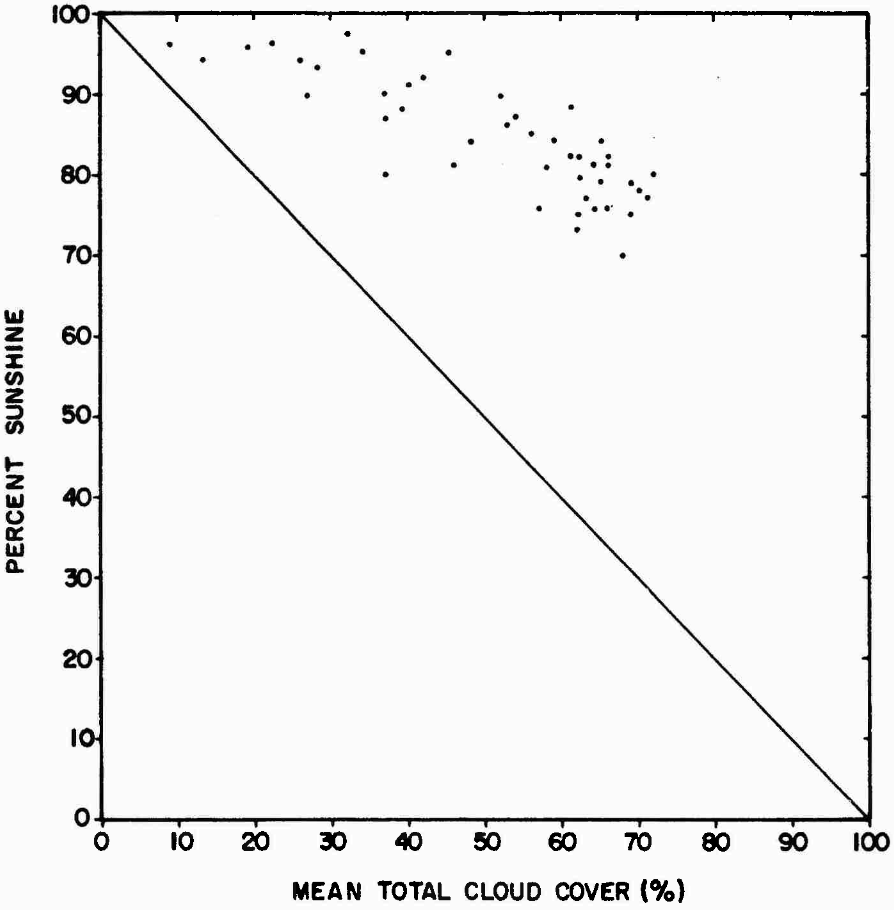

Figure 6. Percent Sunshine Versus Mean Total Cloud Cover for Sun Angles 55°-60°, 20 US Locations, May-October, Afternoon Data.

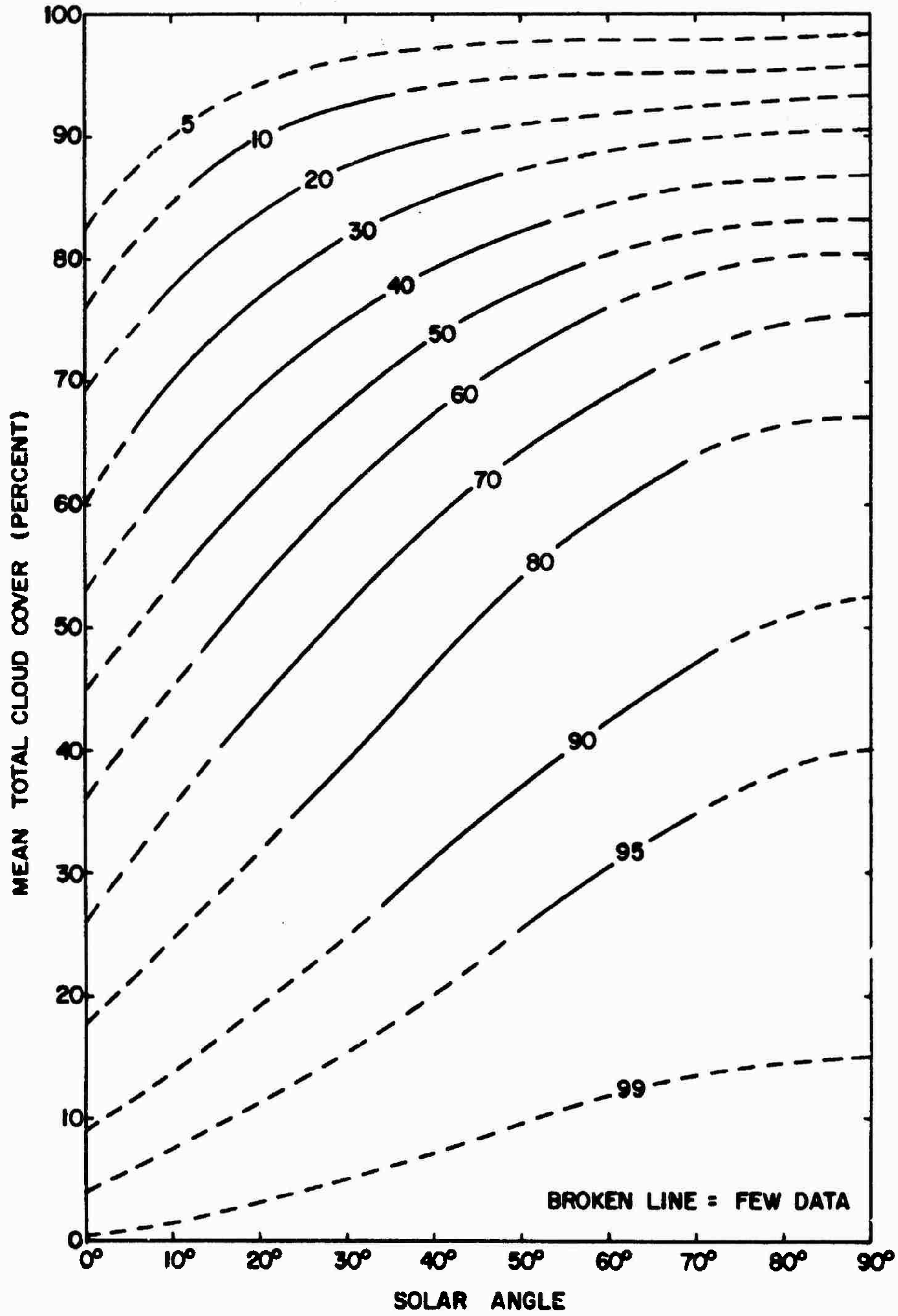

Figure 7. Approximate Mean Sunshine (%) as Function of Cloud Cover and Sun Angle.

total area of the sky dome that is covered by cloud. Half of the area of the sky dome over which the observer integrates to get his total sky cover is less than 30° above the horizon. Thus, it is often the case that the observer's view of the sky is more blocked by the sides of clouds than by their bases, and over a period of time the amount of cloud overhead is much less than the cloud cover reported by the observer.

In order to provide an estimate of the climatological probability of cloud-free line-of-sight between any two levels at any viewing angle, the mean cloud amount between these two levels should be known. If one of the levels is the surface, the mean cloud amount between it and any higher level can be determined from standard surface observations. If the two levels are both above the surface then the mean cloud amount between them can be estimated by the method described in Chapter 1. The estimate of cloud-free line-of-sight probability between the levels is read from Figure 7 as a function of the mean cloud amount between the levels and the viewing angle. That is, we assume that all clouds above the upper level and all clouds below the lower level are removed and we estimate the percent of sunshine that would then be recorded according to the various sun angles. In effect, this assumes that the percent of sunshine recorded through a layer is primarily related to the layer's mean cloud amount and sun angle and that the thickness of the layer can be neglected. There may be serious objections to this assumption because we know that cloud thickness is an important consideration of the low-angle line-of-sight problem. However, the cloud amount between two levels generally decreases as the distance between them decreases. Thus, the probability estimates for thin layers, as read from Figure 7, are derived from cases averaging small total cloud amounts that probably favored thin cloud situations.

Under the above assumptions and having estimated an average vertical distribution of cloud cover from surface-observed data, we can prepare a profile of the estimated probability of cloud-free line-of-sight from (or to) any level. For example, from Figure 7 we determine that the 80% line of such a profile would be located where the observer-to-target viewing angle and mean cloudiness were respectively: 10° and 24%, 30° and 39%, 60° and 60%, 90° and 67%. For the vertical distribution of cloud cover given in Figure 1 and an observer at 3 km, the 80% line of the profile would intersect the following points: The surface (0-km) directly beneath (90° depression) the observer, 0.8-km level at 60° depression, 1.7-km level at 30° depression, 2.4-km level at 10° depression, 4.1-km level at 10° elevation, and 7.8-km level at 30° elevation. The 80% line would not intersect the 60° elevation ray because the mean cloud amount between 3 km and any higher level is less than 60%. From Figure 1 we see that the mean cloud amount between 3 km and 10 km or higher is 42.7%. Figure 7 shows that for this mean cloud amount the 80% cloud-free line-of-sight

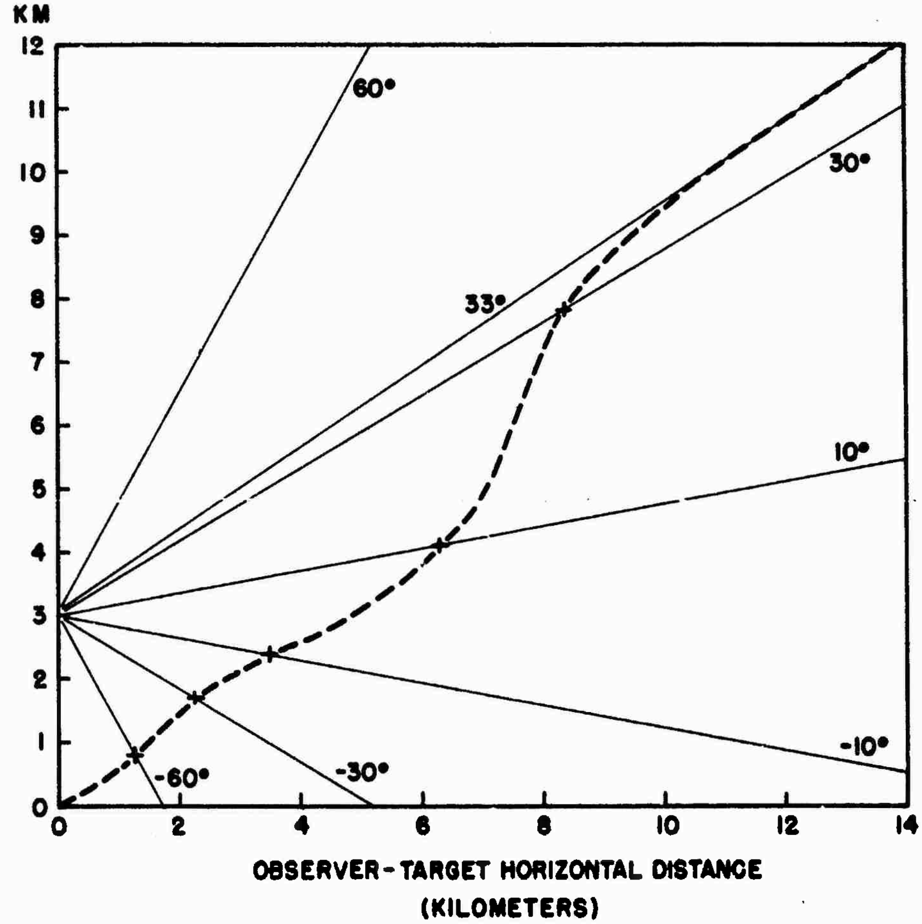

Figure 8. Example of Construction of 80% Line of Cloud-Free Line-of-Sight Probability Profile for 3-km Reference Level.

probability would be achieved at an angle of about 33°. Thus, on the profile, the 80% line above 10 km would be the 33° elevation ray (see Figure 8).

Figures 9a through 9d show the estimates of the probability of cloud-free line-of-sight for Washington, D. C. (Andrews AFB) during summer (June through August) for four reference levels: The surface; 10,000 feet; 20,000 feet; and 30,000 feet. This type of presentation allows comparisons of "seeability" according to a wide range of observer-target relationships.

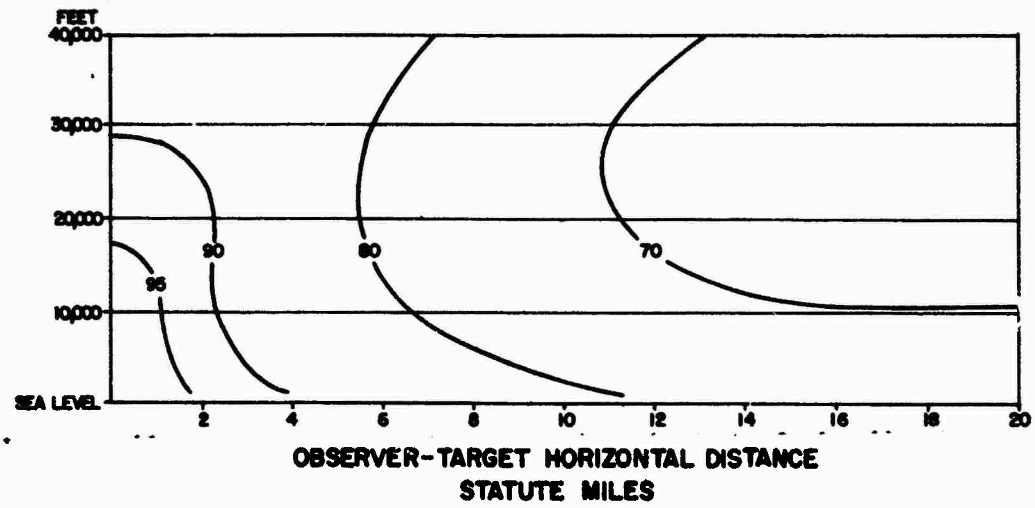

Figure 9a. Estimate of Probability of Cloud-Free Line-of-Sight from (or to) Surface Level, Washington, D. C., Summer.

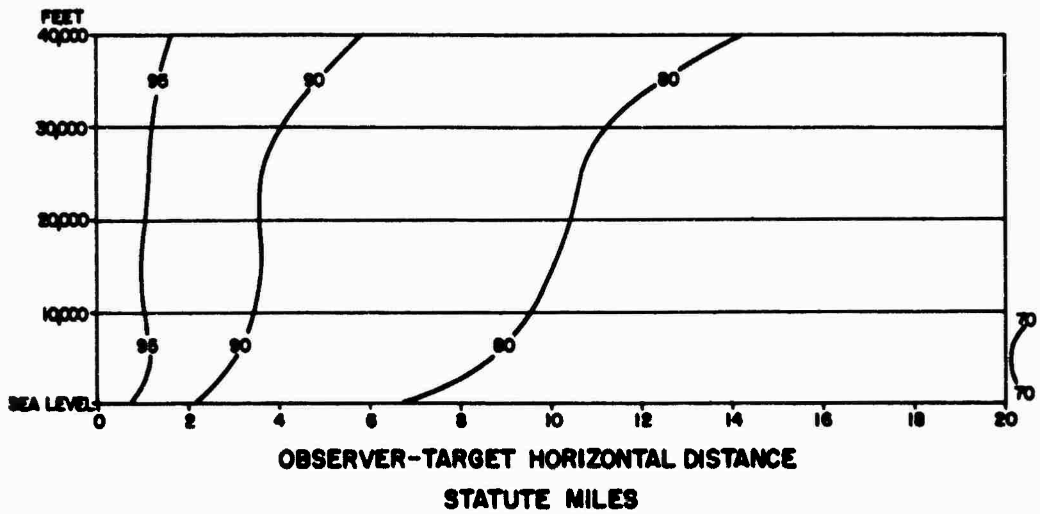

Figure 9b. Estimate of Probability of Cloud-Free Line-of-Sight from (or to) 10,000-Foot Level, Washington, D. C., Summer.

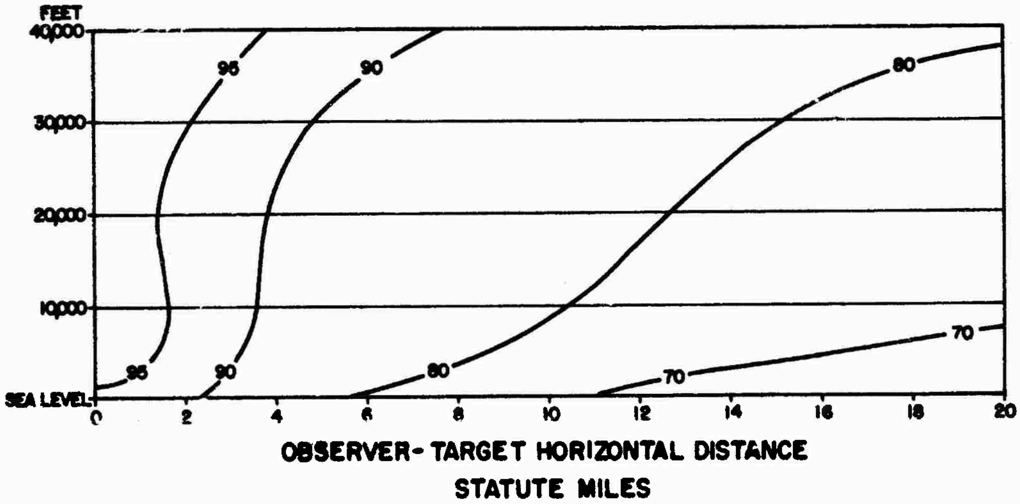

Figure 9c. Estimate of Probability of Cloud-Free Line-of-Sight from (or to) 20,000-Foot Level, Washington, D. C., Summer.

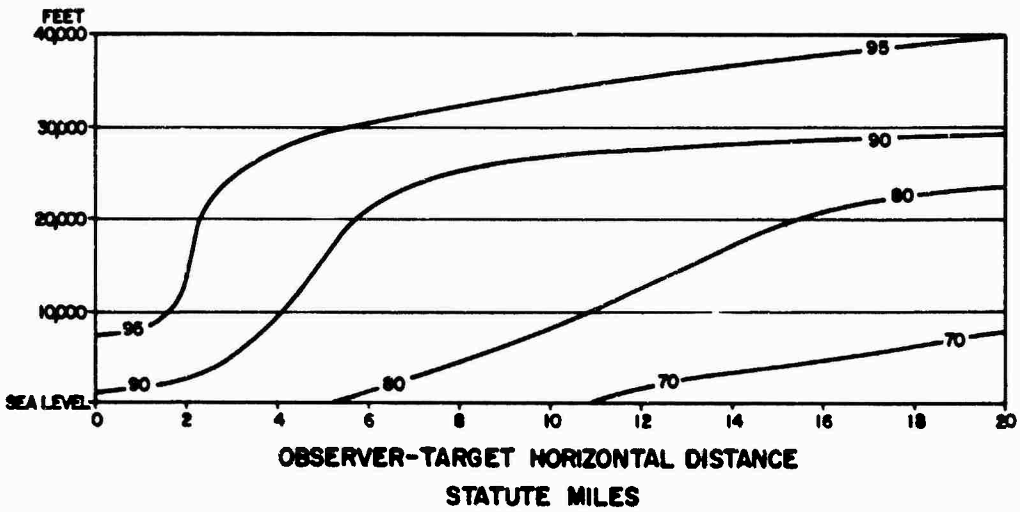

Figure 9d. Estimate of Probability of Cloud-Free Line-of-Sight from (or to) 30,000-Foot Level, Washington, D. C., Summer.

Chapter 3

AUTOMATED PRODUCTS

A method of computing estimates of mean cloud amount at and between kilometer levels, from zero to 15 km based on procedures described in Chapter 1 has been programmed for the IBM 7044 computer at ETAC. The computer method differs slightly from the Chapter 1 method in that it has the advantage of using a variety of cloud-thickness coefficients, the a_1 and b_1 of equation (2), according to season and time-of-day of the data sample. Extension of the method from a maximum height of 10 km to 15 km was achieved by using the 10-km coefficients for all higher levels. Figure 10 is a sample of the program print-out.

A tropical model has also been programmed which computes estimates of mean cloud amount at and between levels from zero to 22.5 km. It is based on the assumption that the coefficients a_1 and b_1, derived from the 1-km interval German data, would apply to 1.5-km layers in the tropics.

The Chapter 2 procedure for computing estimates of probability of cloud-free line-of-sight profiles has also been automated to provide print-outs of profile plots for any or all selected reference levels. Figures 11a and 11b are samples of 0-km and 3-km reference level print-outs. Isolines of percent probability have been added to show the continuity of the probability field.

SEATTLE, WASHINGTON (1951-1956 DATA) - AUTUMN - ALL HOURS

ESTIMATE OF MEAN CLOUD AMOUNT AT AND BETWEEN LEVELS

TOP (KM)

BASE (KM)	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	BASE (KM)
00	0.000	0.385	0.522	0.592	0.622	0.647	0.666	0.685	0.700	0.706	0.710	0.710	0.710	0.710	0.710	0.710	00
01		0.249	0.376	0.458	0.465	0.529	0.555	0.584	0.622	0.622	0.628	0.628	0.628	0.628	0.628	0.628	01
02			0.196	0.296	0.341	0.385	0.420	0.459	0.511	0.515	0.535	0.535	0.535	0.535	0.535	0.535	02
03				0.156	0.207	0.273	0.310	0.351	0.402	0.406	0.429	0.429	0.429	0.429	0.429	0.429	03
04					0.122	0.167	0.208	0.253	0.311	0.325	0.365	0.365	0.365	0.365	0.365	0.365	04
05						0.101	0.145	0.187	0.243	0.254	0.293	0.293	0.293	0.293	0.293	0.293	05
06							0.075	0.123	0.177	0.188	0.223	0.223	0.223	0.223	0.223	0.223	06
07								0.049	0.108	0.117	0.146	0.146	0.146	0.146	0.146	0.146	07
08									0.033	0.047	0.050	0.050	0.050	0.050	0.050	0.050	08
09										0.008	0.020	0.020	0.020	0.020	0.020	0.020	09
10											0.000	0.000	0.000	0.000	0.000	0.000	10
11												0.000	0.000	0.000	0.000	0.000	11
12													0.000	0.000	0.000	0.000	12
13														0.000	0.000	0.000	13
14															0.000	0.000	14
15																0.000	15

Figure 10. Estimate of Mean Cloud Amount.

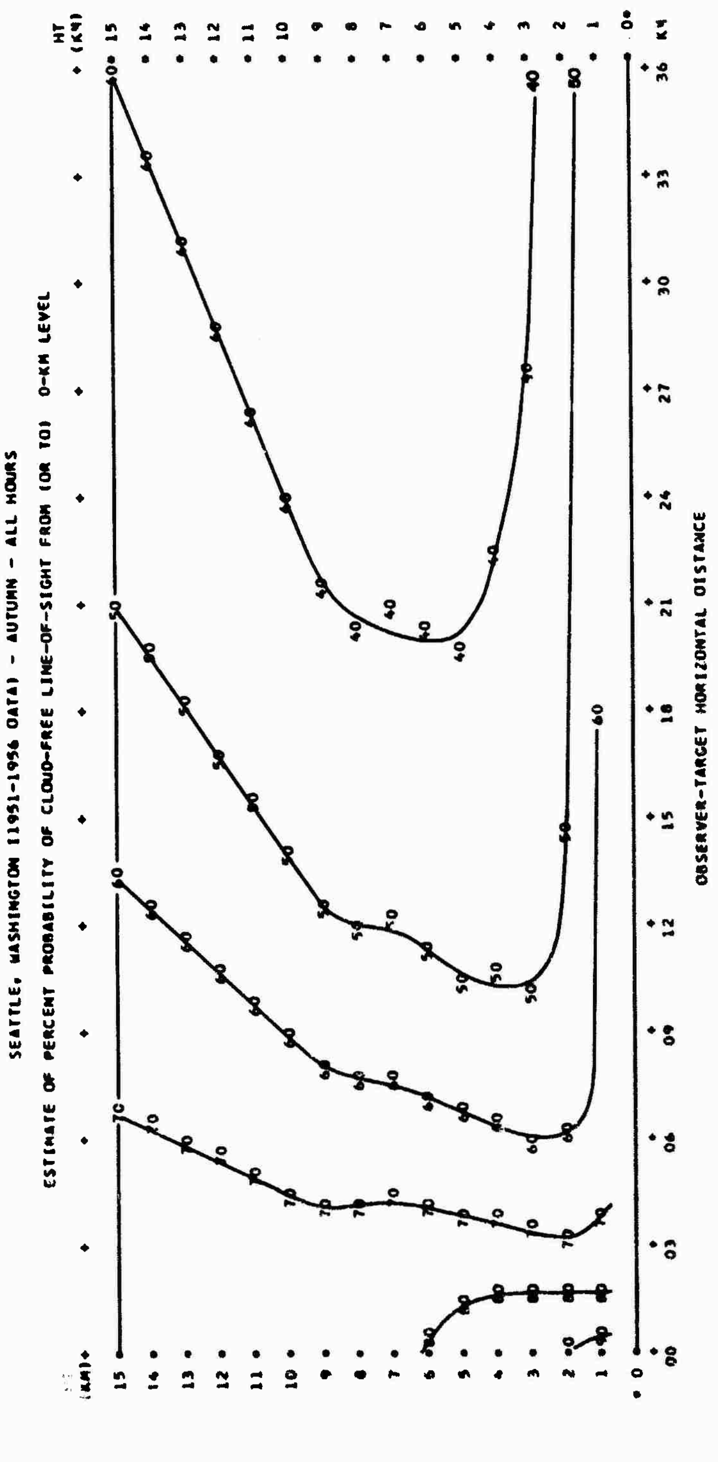

Figure 11a. Estimate of Probability of Cloud-Free Line-of-Sight from the Surface.

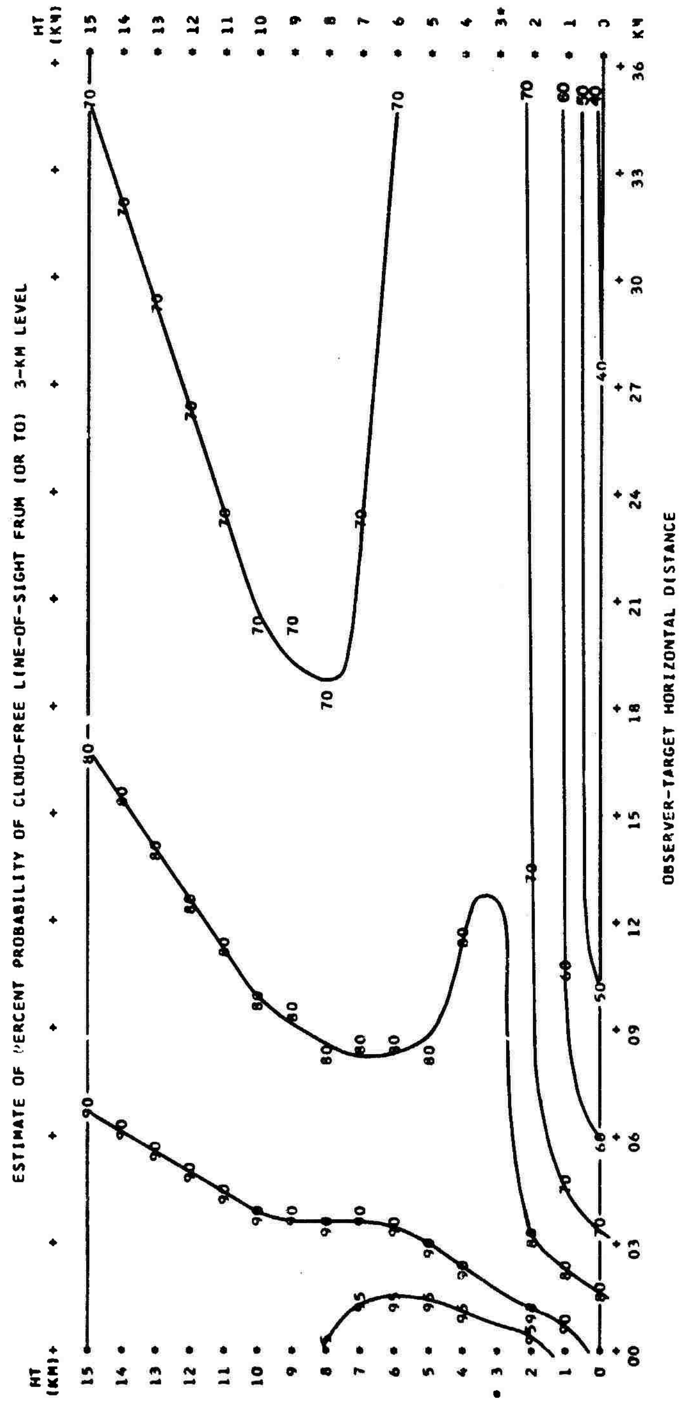

Figure 11b. Estimate of Probability of Cloud-Free Line-of-Sight from the 3-Km Level.

Chapter 4

CONCLUSIONS

The accuracy of estimates of mean cloud amount and probability of cloud-free line-of-sight made by the described methods depends chiefly on the assumptions of the method. The main assumptions are:

a. The mean amount of cloud having bases within a layer is independent of the observer's being able to see into the layer. The effect of this assumption on the method accuracy depends on how often the layer in question is obscured. That is, for locations with small total cloud amount, or for layers of the atmosphere with little cloud below, the effect of the assumption is small; while for locations where layers are often obscured by lower clouds, the effect of the assumption may be great.

b. When "bright sunshine" is recorded, there is a cloud-free line-of-sight between the sun and the recorder.

c. The relationship of the mean amount of "bright sunshine" to mean total cloud amount as a function of sun angle is representative of the relationship of probability of cloud-free line-of-sight through a layer to the mean cloud amount of the layer as a function of the viewing angle.

Applications of the methods are limited to areas of homogeneous cloudiness. That is, they cannot be applied directly to, say, coastal areas where there is a higher frequency of clouds in a particular (seaward) direction. For such cases it would probably be desirable to analyze two homogeneous areas — one offshore, the other inland. The application of the method is also limited to areas where sufficient data are available to develop the required input statistics; i.e., the mean cloud amount below each kilometer level. Often, when observed data are lacking, a trained climatologist can estimate the input statistics from a variety of sources including cloud data for nearby locations, a knowledge of terrain, and information drawn from atlas-type charts of cloudiness, tropopause heights, etc.

The estimates of mean cloud amount at and between levels and probability of cloud-free line-of-sight offer information of value, at least in a comparative sense, to a variety of flight and operation planning problems. While the tabular data can be used to select areas, altitudes and periods of minimum cloudiness, the profiles, when compared by location, season, and time of day, infer an optimum area, level, and period for maximum or minimum "seeability" according to problem specifications.

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[2] de Bary, E. and Möller, F.: "The Vertical Distribution of Clouds," J. Appl. Meteorol., Vol. 2, pp. 806-808, 1963.

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13. ABSTRACT

A method is described which provides an estimate of the probability of cloud-free line-of-sight between any two levels at any angle to the horizon for locations having standard surface-observed cloud data.

The method uses the mean cloud amount between the surface and each higher kilometer level to estimate the mean cloud amount at any level, the mean cloud amount above any level and the mean cloud amount between any two levels.

Analyses of sunshine and total cloud cover by time of day provide a basis for estimating probability of cloud-free line-of-sight through the whole atmosphere as a function of mean total cloud cover and viewing angle. This relationship is used to estimate the probability of cloud-free line-of-sight at any angle between any two levels for which the mean cloudiness between the levels is known or estimated.

Height vs distance profiles of estimated probability of cloud-free line-of-sight can be prepared manually or by computer for any kilometer height reference levels.

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