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ESTIMATES OF PROBABILITY OF A CLOUD-FREE LINE OF SIGHT FOR RAPTOR TALON

E. Bauer

July 1994

Prepared for
Ballistic Missile Defense Organization

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FOREWORD

The problem addressed in this document arose in the following context. RAPTOR TALON includes an airborne optical surveillance system, and the Probability of a Cloud-Free Line of Sight (PCFLOS) is a major factor in the performance of such systems. Investigation of PCFLOS for RAPTOR TALON was done by METSAT, Inc., under subcontract to Lawrence Livermore National Laboratory. The initial briefing on RAPTOR TALON to the review group (which includes POET) was not given by METSAT, or by anyone who could explain what METSAT had done. The initial METSAT results did not seem reasonable: there were two pictures of PCFLOS as a function of range to target that showed no variation with cloudiness and no uniform decrease in PCFLOS with increasing range or path length. Other calculations (by the USAF and Boehm) were requested. These calculations were numerical and rather different from the initial METSAT results; they seemed reasonable, but it was not clear that they were correct.

POET asked me to look at the problem. I tried to establish a simple and intuitive methodology that would explain the range of results in a plausible way. I succeeded in doing this by using generally accepted methodologies. The problem was discussed at CIDOS-93,* a November 1993 meeting of the community of DoD employees and contractors working in this technical area. This document presents a simple approach that may be of use for other similar problems. It must be stressed, however, that PCFLOS problems can be quite subtle, and thus systems analysts are urged to contact experts from the CIDOS community for discussion and review of their approaches to PCFLOS problems.

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* CIDOS stands for Cloud Impacts on DoD Operations and Systems.

PREFACE

This document was prepared for the Ballistic Missile Defense Organization under the task "POET."

The author gratefully acknowledges help from a number of people, in particular Al Boehm, Hughes-STX Corp.; Amnon Dalcher, IDA/STD; Ken Eis, STC-METSAT; Jennifer Hartney, MIT-LL/POET; and LtCol John Roadcap, USAF-PL/WE.

This document was reviewed by Al Boehm, Amnon Dalcher, and Brian Staunton, Aerospace Corp.

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BACKGROUND

RAPTOR TALON is a concept that includes the optical sensing of rocket plumes from low altitudes (2 km) through burnout from an air vehicle at 18–20 km, at a range R ~ 20–100 km. The presence of clouds can interfere with optical sensing. Therefore, it is important to establish the Probability of a Cloud-Free Line of Sight (PCFLOS) at locations and times of concern.

Initial estimates of PCFLOS for RAPTOR TALON for Iraq and Korea, made by METSAT, Inc., were generated as part of the BMDO Boost Phase Intercept Study and presented to the BMDO Program Review Group in early 1993. The results were counter-intuitive in that they show no decline in PCFLOS with increasing range, R, and two cases with cloud cover varying by a factor of almost two show essentially no difference in PCFLOS. These cases could not be explained to the Review Group: they consisted of a high-resolution statistical sampling based on one month each of satellite data for Iraq and Korea. Some further calculations were made (by USAF-PL and by Hughes-GTX) and POET was asked to resolve the discrepancy, which was accomplished following discussion at the CIDOS (Cloud Impacts on DOD Operations and Systems) Conference of November 1993. This document represents closure of the problem.

METHODOLOGY

The various estimates of PCFLOS are based on different ways of looking at clouds and analyzing the observations:

- Ground-based observations of the sky dome, typically by using an "all-sky camera."
- Predominantly downward-looking weather satellite observations.
- Limb-viewing observations from the NASA SAM/SAGE satellites.
- Aircraft observations (Bertoni, 1977).
- Space Shuttle photography.

- The USAF "3DNEPH" and "RTNEPH" computer codes, which combine ground-based and space-based observations.[1]

The present approach, taken to resolve the initial discrepancy, is entirely conventional. It uses results based on the SRII modification of the USAF-PL-GD (Lund and Shanklin) ground-based all-sky camera observations at Columbia, Missouri, and presents a range of values for PCFLOS that is consistent with the actual variability of meteorological conditions at a given space/time location.

CONCLUSIONS

RAPTOR TALON is a concept that includes the optical sensing of rocket plumes from low altitudes (2 km) through burnout from an air vehicle at 18–20 km, at a long range of R ~ 20–100 km. Since the presence of clouds can interfere with optical sensing, it is important to establish the Probability of a Cloud-Free Line of Sight (PCFLOS) at locations and times of concern.

There were discrepancies in initial PCFLOS estimates for RAPTOR TALON for Iraq and Korea as made by different people. Here, I present some simple semi-analytical PCFLOS estimates with a view to providing a plausible range of values; the present methodology can easily be applied to other comparable problems. We ask for the PCFLOS for paths from 18 km altitude—above all clouds—to 2 km, at a slant range of about 20–100 km, at two locations (Baghdad, Iraq, and Seoul, Korea) for January and July at average cloudiness.

Figure S-1 shows these predictions. Note the wide range of variability of the PCFLOS. For "good" weather conditions, such as Iraq in summer, we can expect PCFLOS of 0.9 to 0.95 for ranges of 20–100 km. However, during "bad" weather conditions, such as Korea in summer, we can expect PCFLOS of only 0.4 to 0.7 for ranges of 20 to 100 km, which does not seem promising for the RAPTOR TALON concept, especially considering that a knowledgeable enemy can choose weather conditions that reduce actual PCFLOS to even lower values.

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1 The motivation for the METSAT analysis was the assertion—not uniformly accepted within the CIDOS community—that the USAF RTNEPH computer code uses mainly ground-based data of inadequate spatial resolution.

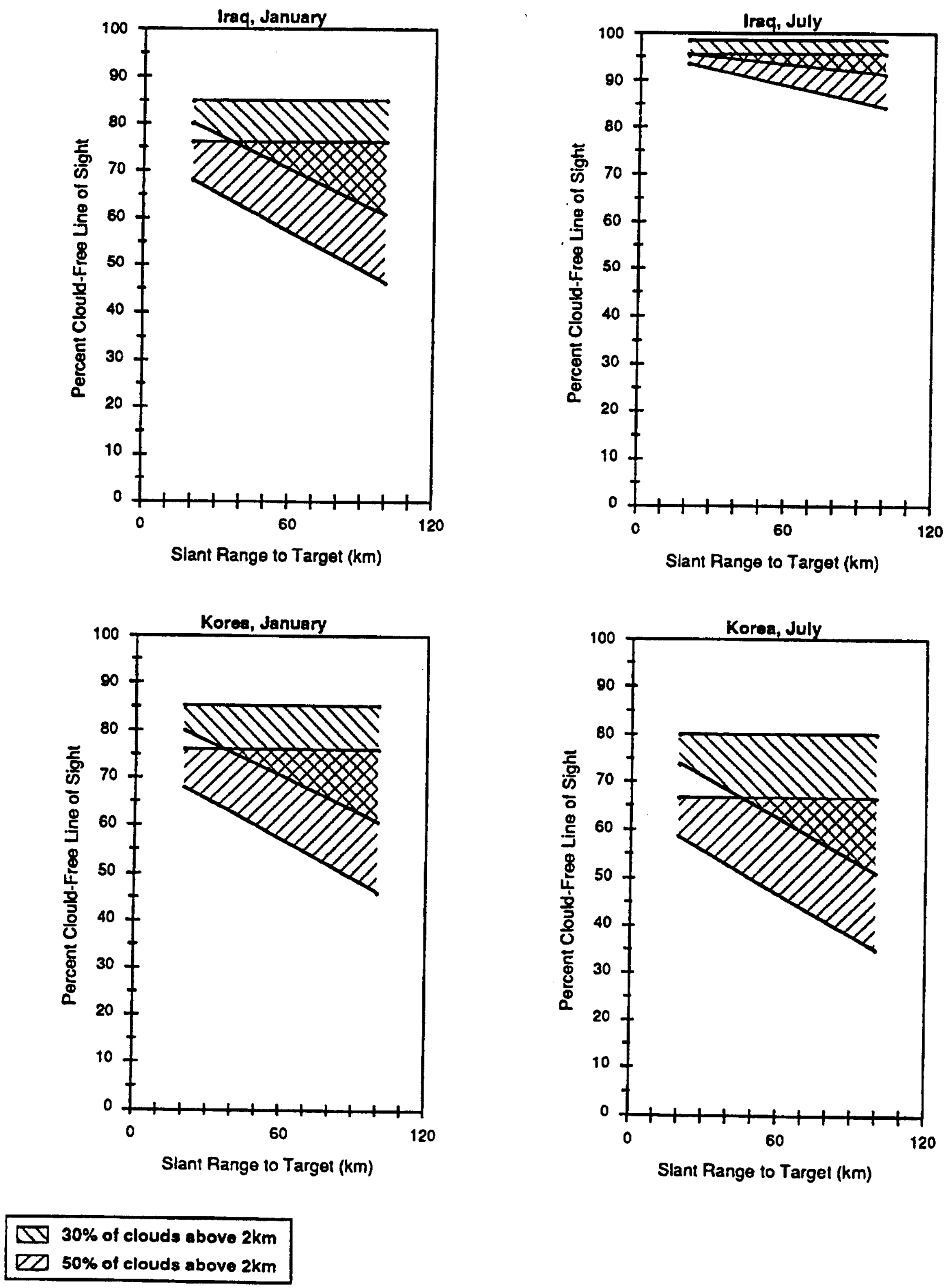

Figure S-1. PCFLOS for Iraq and Korea

I. THE PROBLEM

The RAPTOR TALON concept involves the optical sensing of rocket plumes at low altitude (i.e., 2 km) through burnout from an air vehicle at 18–20 km altitude. For missiles of ranges betwen 200 and 1,000 km, burnout may occur between 25 and 60 km; clouds are essentially limited to the troposphere, i.e., to altitudes below 8 km in the Arctic, 11 km at mid-latitudes, and 16 km in the equatorial region. Thus a sensor at 18 km should have no cloud obscuration when looking upward. Figure 1 shows the geometry of the problem. It is critical to know how frequently the optical path along the slant range from sensor to target is cloud free, i.e., what is the Probability of a Cloud-Free Line of Sight (PCFLOS) between 2 and 18 km for depression angles, θ, of 39° and 9°, corresponding to ranges R between 20 and 100 km, as a function of season at different locations. Iraq and Korea are chosen as examples for comparison.

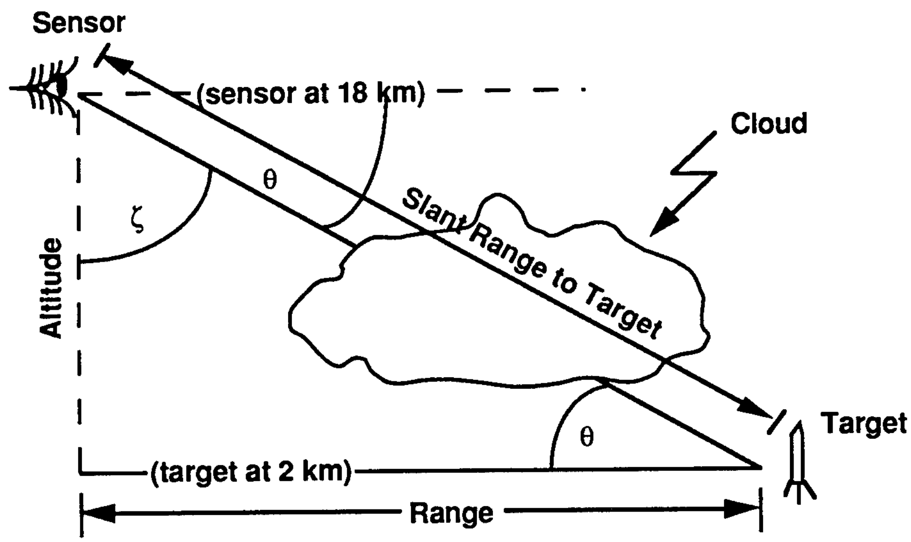

Figure 1. Geometry of the Problem

The issue of PCFLOS has potential significant impact on the anticipated effectiveness of RAPTOR TALON in at least two different senses:

1. RAPTOR TALON is a defensive system which must counter the attacker who can presumably choose the time in his favor, i.e., attack when clouds are forecast as likely to obscure the sensor.

2. The defense has to ensure that their system will work not only on the average—for which a climatological model of cloud cover is needed—but also for the specific case of a possible attack, which the attacker may choose to schedule for cloudy conditions.

Here we can clearly only analyze the climatological average problem. Cloudiness varies considerably with location, altitude, season, and time of day, in addition to the random variability associated with the local meteorological conditions. Table 1 lists mean cloudiness at a number of different locations worldwide for both January and July, including the percentage of low clouds (below 2 km). These are old data representative of a number of locations worldwide.

Table 1 comes from "early" 3DNEPH results, which list cloud heights determined from the effective temperature in the 11-μm channel observed from the Defense Meteorological Satellite Program (DMSP) or from the National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites. The numerical values of cloudiness, in particular of the height distribution, can be improved upon for specific location, season, and time of day, but they provide an overall orientation. Essentially, all clouds lie below 18 km, so that Table 1 gives an indication both of worldwide cloudiness and of that fraction of cloudiness that contributes to obscuration in the present application. Note the considerable variation with both location and season in both total cloudiness and in the fraction of low clouds.

On looking into this problem ab initio, it is easy to become confused by the different quantitative measures of cloud cover depending on the different geometry of view (see Fig. 2) and on the differences in notation for cloud cover employed by different workers in the field (see Table 2). S, E, R, etc., are defined as the fraction of the area viewed that is covered with clouds. Different relations between sky cover (S) and earth cover (E) have been developed by Malick and Allen (SRII) and by Boehm, et al. (Hughes/STX). Henderson-Sellers and McGuffie, 1990, have examined this problem, and suggest that in practice it is adequate simply to take

$$S = E \quad , \tag{1}$$

bearing in mind that differences of 10–20 percent in cloud cover measures are not generally significant.

There are a number of different approaches to the estimation of PCFLOS that are based on different ways of looking at clouds and analyzing the observations:

Table 1. Cloudiness at "Representative" Locations in the Northern Hemisphere. (Source: SRII—Malick and Allen, 1978, 1979).

Location		Total Sky Cover and Percent of Low Clouds*	
		January	July
China Lake, CA	(36°N; 117°W)	.38 (42%)	.18 (21%)
Grand Forks, ND	(48°N; 95°W)	.63 (52%)	.56 (40%)
Maui, HI	(21°N; 156°W)	.40 (67%)	.50 (63%)
Hudson Bay	(60°N; 88°W)	.36 (70%)	.29 (23%)
N. Atlantic S.	(52°N; 35°W)	.81 (83%)	.70 (75%)
N. Atlantic N.	(62°N; 30°W)	.76 (76%)	.72 (82%)
Jan Mayen Is.	(71°N; 10°W)	.81 (90%)	.85 (90%)
Thule	(76°N; 68°W)	.35 (53%)	.73 (64%)
Barrow, AK	71°N; 156°W)	.34 (72%)	.64 (77%)
Arabian Sea	(8°N; 65°E)	.23 (70%)	.55 (56%)
Teheran	(36°N; 52°E)	.38 (52%)	.22 (50%)
Ionian Sea	(39°N; 18°E)	.54 (78%)	.06 (76%)
Moscow	(56°N; 39°E)	.61 (78%)	.46 (48%)
Tyuratam	(46°N; 64°E)	.49 (67%)	.30 (47%)
Lop Nor	(40°N; 91°E)	.48 (50%)	.57 (46%)
Vladivostok	(43°N; 132°E)	.43 (65%)	.66 (77%)
Seoul	(37°N; 127°E)	.48 (56%)	.72 (65%)
Japanese Trough	(35°N; 150°E)	.67 (81%)	.37 (67%)
Anadyr	(64°N; 177°E)	.59 (46%)	.75 (72%)
Murmansk	(69°N; 34°E)	.70 (67%)	.66 (61%)

* We show total sky cover and the percent of low clouds (below 2 km). The data come from "early" 3DNEPH results, so that the total cloudiness is better than the fraction of low clouds.

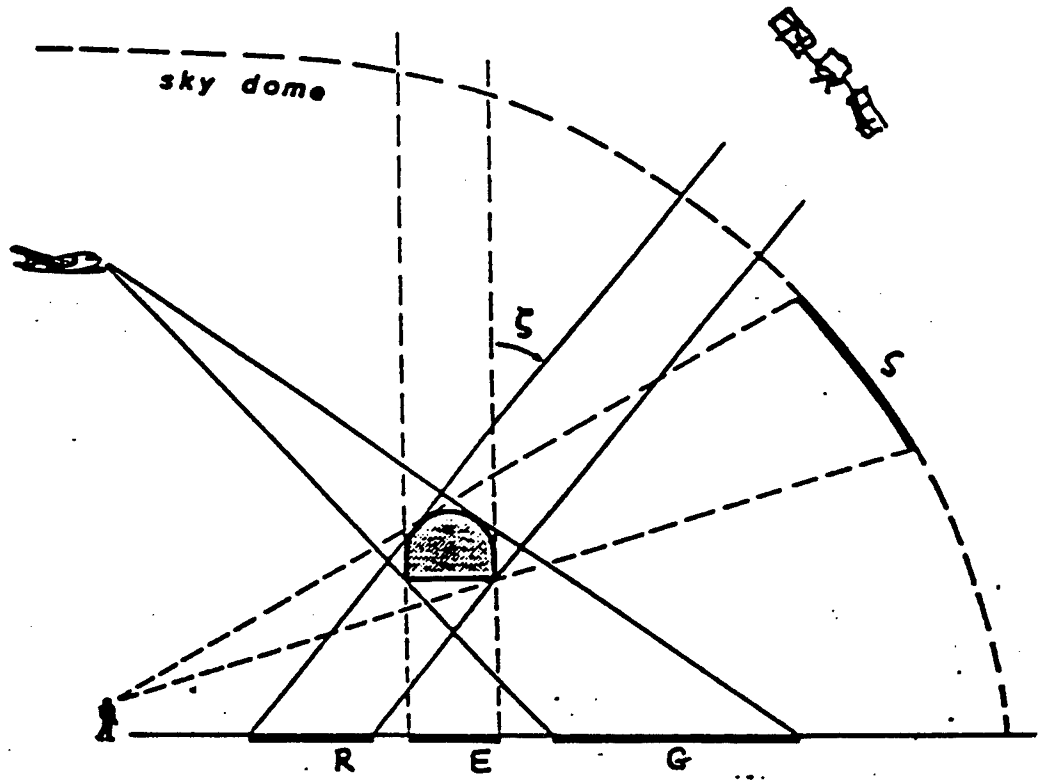

Figure 2. Different Definitions of Cloud Cover. (After Snow, 1990, and Henderson-Sellers and McGuffie, 1990). See Table 2 for Notations: R = satellite sensor view; E = earth cover; S = sky cover; G = aircraft view; $\zeta = \pi/2 - \theta$ = view angle.

Table 2. Different Notations for Cloud Cover in Five Calculations

Henderson-Sellers, 1990	Snow, 1990	SRII (Malick and Allen, 1979)	Boehm, 1991	EB, Present Document
Satellite sensor view R	Apparent cloud cover S			
Earth view E	Cloud cover C	Q	Mean ground cover Mg	E
Aircraft view	Ground cover G			
Sky cover[a] S	Sky cover N	S	Mean sky cover[a] Ms Std. Dev. of Ms S	S Σ

[a] Whole dome

Note: Henderson-Sellers and Snow use values from specific observations, while Malick and Allen and Boehm use mean values taken over a series of observations.

(i) Ground-based observations of the sky dome, frequently using an "all-sky camera" (see Lund and Shanklin, 1972; Lund, 1973; Shanklin and Landwehr, 1971).

(ii) Predominantly downward-looking weather satellite observations (see Malick and Allen, 1978–1979; Malick, Allen and Zakanycz, 1979).

(iii) Limb-viewing observations from the NASA SAM/SAGE satellites (see McCormick et al., 1979; Livingston and Malick, 1983; Dalcher, 1992; Kay, in publication).

(iv) Aircraft observations (see Bertoni, 1977).

(v) Space Shuttle photography (Snow, 1990; Snow, Tomlinson et al., 1985, 1986).

(vi) The USAF "3DNEPH" and "RTNEPH" computer codes, which combine (1) ground-based and (2) space-based observations (see Fye, 1978; Boehm et al., 1993; Kiess and Cox, 1988; Steeves and Boehm, 1991; see also Jursa, 1985).

(vii) The motivation for the METSAT analysis was the assertion—not uniformly accepted within the CIDOS community—that RTNEPH uses mainly ground-based data of inadequate spatial resolution, and that therefore one should devise a new methodology based on high-resolution satellite imagery. (See Eis et al., 1993; Reinke et al., 1992, 1993).

Work on PCFLOS for RAPTOR TALON was done by METSAT, Inc., under subcontract to Lawrence Livermore National Laboratory, as part of the BMDO Boost Phase Intercept Study. The initial briefing on RAPTOR TALON to the BMDO review group for the study (which includes POET) was not given by METSAT, or by anyone who could explain what METSAT had done. There were two vu-graphs of PCFLOS vs. range to target (for Iraq and Korea); the initial METSAT results and some others are shown here in Fig. 3.[1] The initial METSAT results[2] showed essentially no decrease in PCFLOS with either increasing cloud cover (Korea vs. Iraq) or with increasing range; this is clearly not

1 Provided by Jennifer Hartney, MIT-LL/POET.

2 "RAPTOR Transmissivity and Cloud Climatology Study," K. Eis et al., METSAT report to LLNL, January 1993, with transmittal memo from A. Parziale and N. Colella, LLNL, to Jennifer Hartney, POET, 5 March 1993.

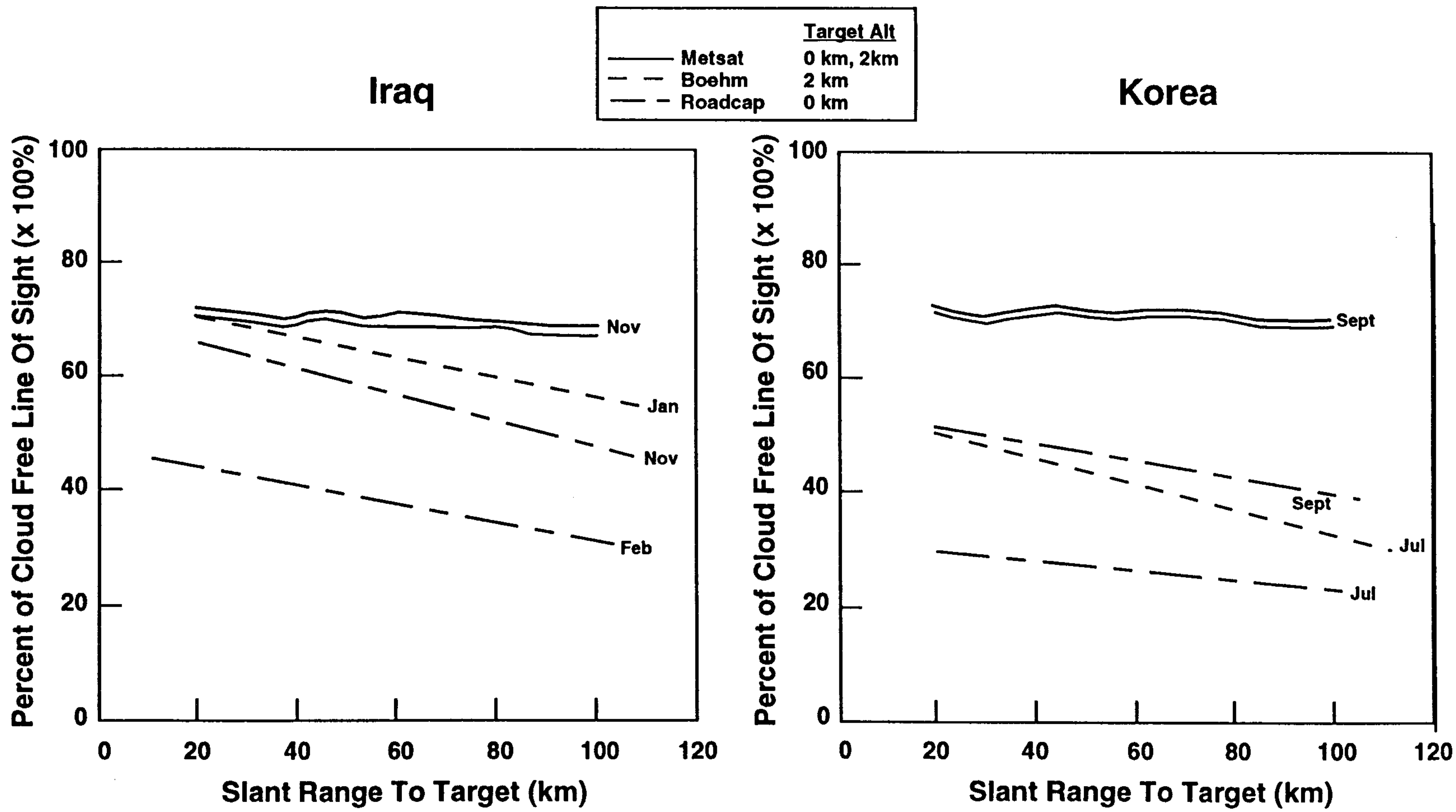

Figure 3. Preliminary PCFLOS Results for Iraq and Korea. Figure shows METSAT, Boehm (Hughes-GTX), and Roadcap (USAF-PL) Results With Target Altitudes Indicated. (Of the two METSAT Lines, the upper one goes to 2 km, the lower one to the ground.)

qualitatively reasonable behavior. Thus other calculations (by LtCol. Roadcap[3] and Al Boehm[4]) shown in Fig. 3 were requested. These calculations were numerical and rather different from the initial METSAT data; they seemed reasonable, but it was not clear that they were correct, and thus POET asked the author to look at the problem. This document presents a simple and intuitive methodology, using generally accepted concepts, to predict the range of numerical results to be expected. Figure 3 shows the initial estimates for PCFLOS for designated high-altitude to low-altitude paths in Iraq, with CLDGEN (Air Weather Service code) values provided by LtCol Roadcap, USAF-PL/WE, and LOS/C Cloud S values provided by Al Boehm, Hughes/STX.

Note that the METSAT results for PCFLOS—unlike the others—show no decrease in PCFLOS with increasing range, even though the path length and thus the probability of encountering clouds increases. Further, the METSAT numerical values are essentially the same for Iraq in November and Korea in September, even though the cloud cover varies by almost a factor of two. In contrast, the Boehm (Hughes/STX) and Roadcap (USAF-PL/WE) values fall off significantly with increasing range and also vary with cloud cover.

Table 3 displays the numbers that are plotted in Fig. 3. These are described in the following (Al Boehm, private communication):

> CLDGEN is a Monte Carlo generator that simulates clouds on the sky dome. It is based on correlations from whole-sky photos, and thus it produces more clouds on the horizon than straight up. The observed distribution of sky cover, not just the mean, is needed to tailor the simulation to a given location.
>
> Some early (and statistically limited) GOES results from STC-METSAT were calculated by building up cloud fields based on GOES imagery, and, in particular, the tops of clouds using observed radiances. Given the cloud field, the probability of an intersection of an LOS with a cloud can be calculated by geometry.
>
> METSAT described their work as follows:
>
> Geostationary satellite cloud images over Korea and Iraq were collected for a one month period (Nov. 79 for Iraq and Sept. 84 for Korea). These medium-resolution IR data were combined with USAF balloon sounding data to build a 3-dimensional layered cloud data base for 0000 and 12000 UTC. The database was analyzed at specific locations from a constant

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3 "PCFLOS" memo from Jennifer Hartney, POET/LL, to Al Parziale, LLNL, 3 March 1993 (includes LtCol Roadcap's material on PCFLOS sent to Jennifer Hartney on 30 November 1992).

4 Cloudy LOS computations from Al Boehm, sent by LtCol Roadcap to Jennifer Hartney on 8 March 1993.

18-km altitude to various altitude target/distance combinations. The output was a 360 deg azimuth-averaged CFLOS value. . . . The study's values represent the probability of seeing a given distance/altitude combination for the stated month, times, and locations, and is not based on statistical assumptions about correlation lengths.

Table 3. Comparison of Initial Estimates of PCFLOS for Iraq and Korea

	Iraq (Baghdad)				Korea (Seoul)			
	Jan.	April	July	Oct.	Jan.	April	July	Oct.
Sky cover S_{tot}[a]	.48	.44	.08	.23	.47	.57	.68	.48
Boehm	Mideast, Jan.		Mideast, July		Korea, Jan.		Korea, July	
P(20)	.66		.95		.72		.48	
P(100)	.58		.91		.63		.39	
METSAT[b]	Nov. 79 (S_{av} = .33)				Sept. 84 (S_{av} = .6)			
P(20)	.7				.7			
P(100)	.7				.68			
Roadcap[c]	Teheran (Feb., S_{tot} = .38)		Baghdad		Pyongyang July		Pyongyang Sept.	
P(20)	.43		.65		.2		.5	
P(100)	.30		.5		.2		.4	

P(20) = PCFLOS for range R = 20 km.

P(100) = PCFLOS for range R = 100 km.

[a] Data from A. Boehm's Code S-Cloud for Baghdad (33.23; 44.00) and Seoul (37.58; 127.05), respectively.

[b] Preliminary results: not statistically significant.

[c] Looking down to surface, not to 2 km.

S_{tot} = total sky cover.

A. Boehm, Hughes/STX, has done calculations using two additional models, namely:

LOS/C Cloud S Models. These are based on Bertoni's, 1977, LOS data, which consisted of 265,000 aircraft observations taken over a 5-year period, and specially processed for Korea and the Middle East. For lines of sight extending all the way to the surface, the graphs were normalized to the C Cloud S (Climatology of Cloud Statistics) data base which is a statistical blend of a vast number of surface observations and Nimbus 7 satellite data.

SAGE/SLIDE model. This model, developed by Dalcher, 1992, gives the PCFLOS based on 1-μm observations of the sun viewed from the limb-viewing SAGE satellite. It requires a fairly robust assumption called SLIDE to make calculations for a given path length. The SAGE/SLIDE assumption is most appropriate for near-horizontal paths.

Table 4 summarizes the contents of the different computational models.

Table 4. Data and Methodologies Used in Different Calculations

Author	Data/Methodology		Target height
Bauer	Conditional PCFLOS vs. view angle, based on space shuttle photos and on Lund-Shanklin/SRII analysis. It is assumed that 30–50% of all clouds lie above 2 km.		2 km
Boehm	250,000 aircraft observations of LOS (Bertoni, 1977)	LOS/C Cloud S Models, anchored to surface observations	0, 2 km
METSAT	1 month of GOES imagery at each location	Cloud fields and radiance built up from GOES imagery	0, 2 km
Roadcap	CLDGEN, Monte Carlo generator that simulates clouds on the sky dome, based on correlations from whole-sky photos.		0 km
SRII (Malick and Allen)	3DNEPH data before 1978, plus angular distribution based on Lund-Shanklin methodology.		2 km

II. A SIMPLE ANALYSIS

It seemed appropriate to make some simple calculations based on a model of Conditional PCFLOS as a function of angle of view θ (Fig. 1) and of fractional sky cover, $n/10 = S$. Figure 4 has been produced by Snow (1990) using the Lund and Shanklin (1972) all-sky camera results and methodology as modified by Malick and Allen (1978–79). Thus the figure and the present analysis are consistent with the standard U.S. CFLOS models; for comparison in Fig. 4 we also show the standard Eastern European or Russian model of Feigelson (1984). (The difference between the U.S. and Russian models is presumably due to the higher latitude and greater cloudiness in Russia.)

To compute PCFLOS from 18 km (essentially above all clouds) down to 2 km, one has to estimate what fraction of the total sky cover, S_{tot}, lies above 2 km. Based on Table 1, two assumptions, which roughly bound the value of the effective sky cover (S_{eff}), are made:[5]

- Case K: 50 percent of all clouds lie above 2 km, so that $S_{eff} = 0.5\ S_{tot}$.
- Case L: 30 percent of all clouds lie above 2 km, so that $S_{eff} = 0.3\ S_{tot}$.

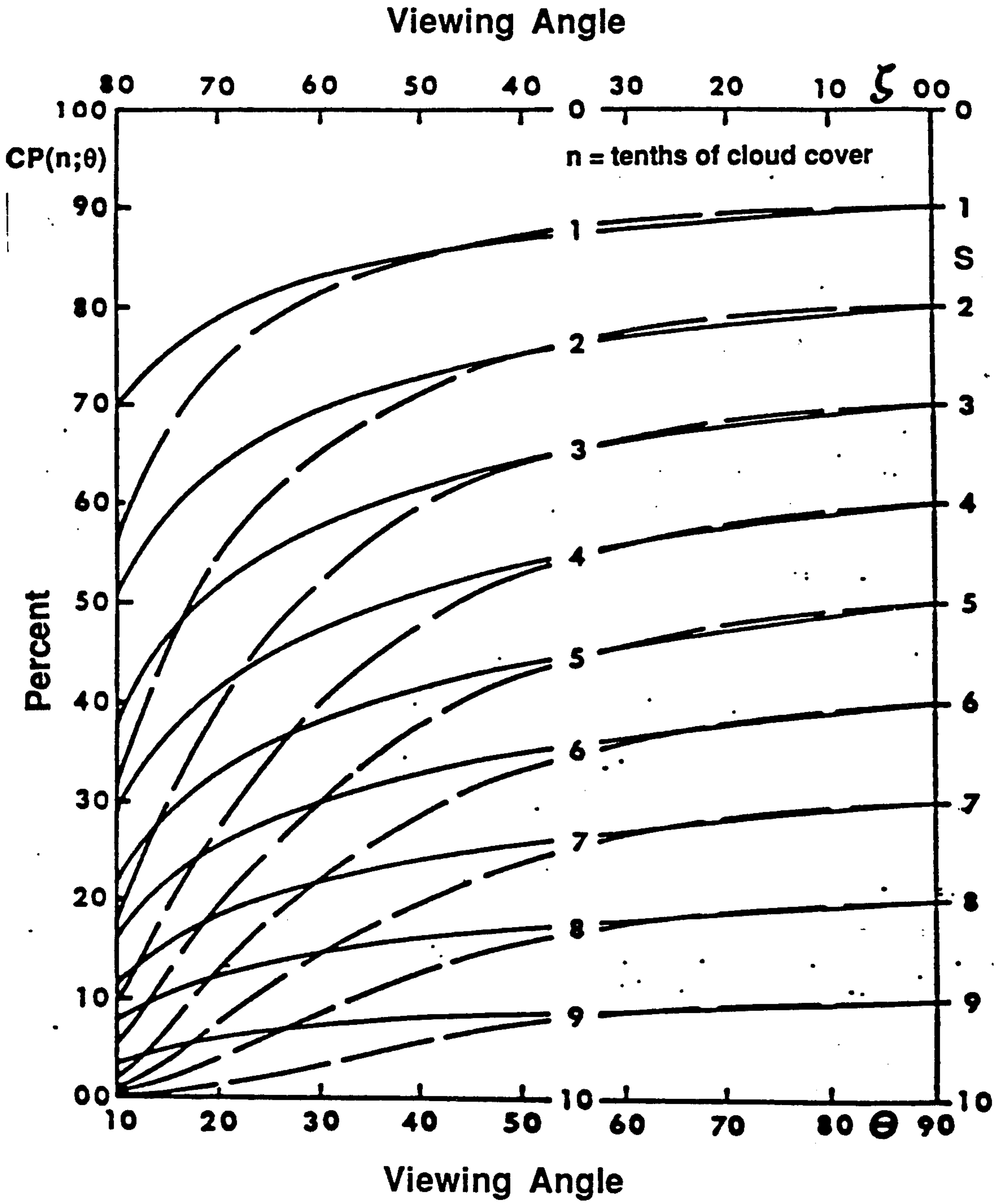
Let $CP(n,\theta)$ denote the probability of having a cloud-free line of sight at an angle θ (measured from the horizontal; note that $\theta = 90° - \zeta$) if the fractional cloud cover is n tenths ($n = 0,1,...10$). Figure 4 shows this conditional probability $CP(n,\theta)$ as a function of θ for different values of n. The climatological probability of a cloud-free line of sight for viewing angle θ is given by the sum of $CP(n,\theta)$ weighted by $F(n)$, the climatological probability of fractional sky cover n/10 at the location considered :

$$CP(\theta) = \Sigma_{n=0}^{n=10} CP(n,\theta)F[n] \quad . \tag{2}$$

Thus, to evaluate $CP(\theta)$ from Fig. 4, one needs not just the total sky cover S_{tot}, which is the sum

$$S_{tot} = \Sigma_{n=0}^{n=10} (n/10)F[n] \quad , \tag{3}$$

5 Note that there may be clouds both above and below 2 km.



Legend:
$\zeta = 90° - \theta$.
Solid curves—SRII or Malick and Allen model (modified Lund-Shanklin model).
Broken curves—Eastern European or Russian model (from Feigelson, 1984).
Cloud amount parameter is S. All curves converge to zero at $\theta = 0$.

Figure 4. Conditional PCFLOS as Function of Viewing Angle and Cloud Amount (Snow, 1990)

but also the frequencies, F[n]. An intuitive way of getting a feel for CP(θ) is by using two ways of obtaining a given cloud cover S_{tot}:[6]

- **Limit 1**: Assume that the fractional cloud cover is the same all the time, so that F[n] = 1 when n/10 = S_{tot} and F[n] = 0 otherwise, so that

$$CP\ (1; \theta) = CP[10\ S_{tot}; \theta] \quad . \tag{4}$$

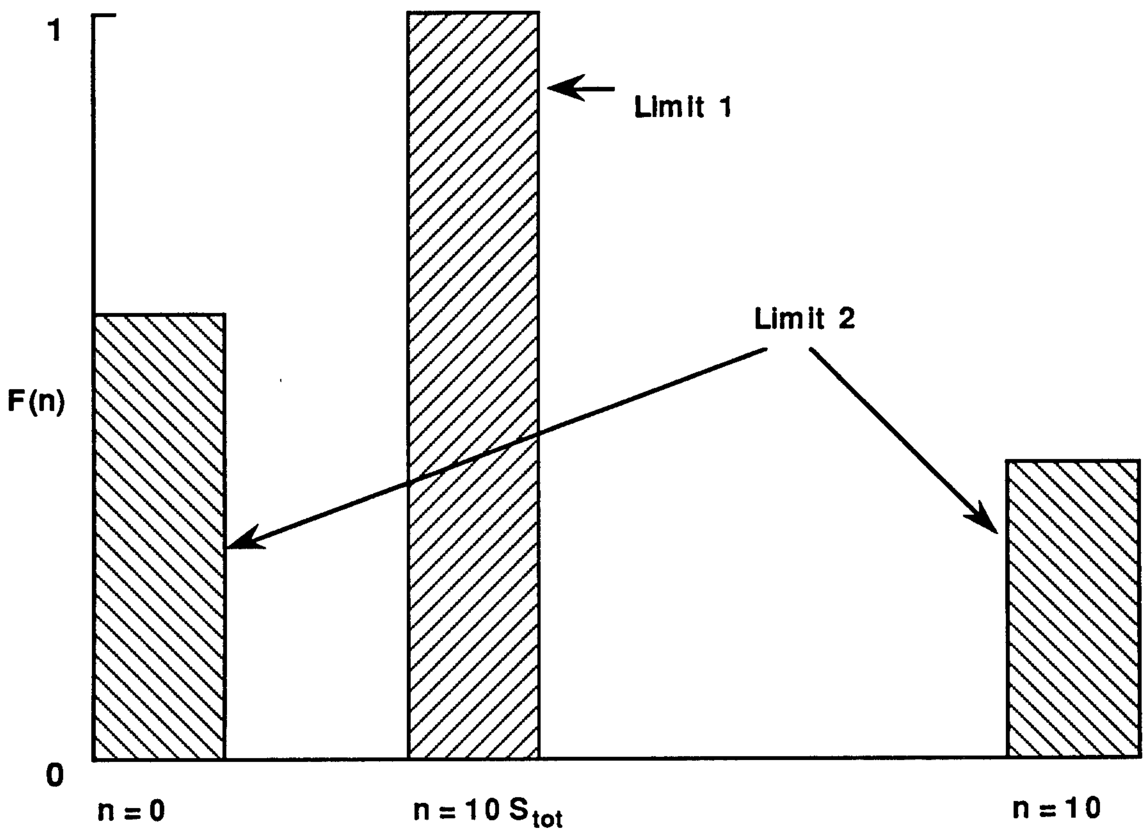
- **Limit 2**: Assume that the sky is always either totally clear or totally covered, so that the distribution of S-values is simply the sum of terms with n = 0 (so that CP [10 S_{min}, θ] = 1 and n = 10 (so that CP[10 S_{max}, θ] = 0), i.e.,

$$F[0] = 1 - S_{tot};\ F[10] = S_{tot};\ \text{all other F-values } (n = 1, 2, \ldots, 9) = 0 \quad . \tag{5}$$

Figure 5 illustrates these two limits of cloud cover distribution, and Fig. 6 shows numerical values for Conditional PCFLOS (CP) as a function of sky cover, S_{tot}, for these two limits (1 and 2) and for representative viewing ranges R = 20 km and 100 km. It seems at least intuitively likely that limits 1 and 2 are absolute bounds.

A simple numerical example is given next. From Fig. 1, range 20 km corresponds to tan θ = 16/20 = tan 39°, and range 100 km corresponds to θ = 9°. Thus for 4/10 cloud cover, from Fig. 4 we find CP(4, 39°) = 0.51, CP(4, 9°) = 0.27 (these are "Limit 1" for the respective ranges), while "Limit 2" is 0.6 for 4/10 cloud cover.

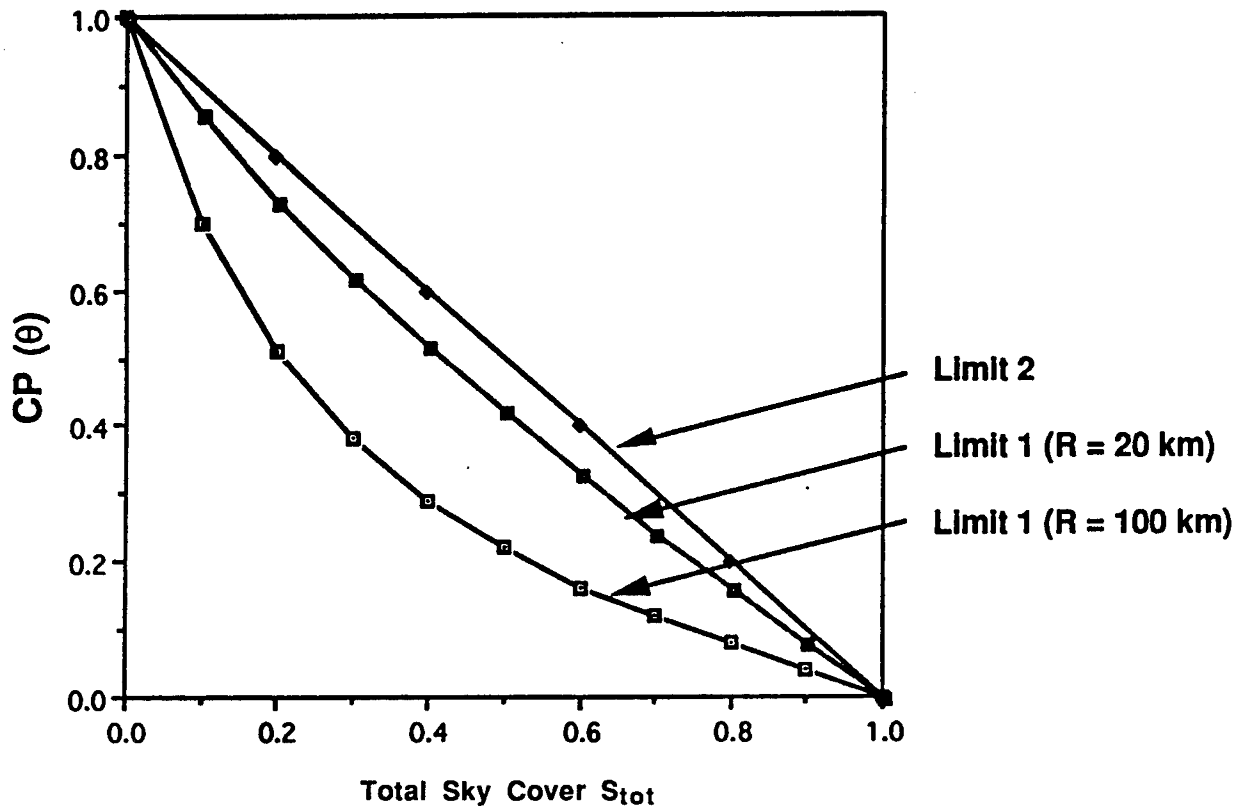
6 If cloud cover information in tenths is available, one can of course compute the PCFLOS without these approximations.



Limit 1: Fractional Sky Cover is Always Equal to Total Sky Cover.

Limit 2: Fractional Sky Cover is either 0 or 1, weighted to give correct Total Sky Cover.

Figure 5. The Two Limits (1 and 2) of obtaining Total Sky Cover as a Function of Sky Cover Distribution



Limit 1: Fractional Sky Cover is Always Equal to Total Sky Cover.

Limit 2: Fractional Sky Cover is either 0 or 1, weighted to give correct Total Sky Cover.

Figure 6. Two Plausible Bounds for Conditional PCFLOS as a Function of Sky Cover S_{tot}

III. DISCUSSION

In discussion at the CIDOS-93 conference it became clear to me that the initial METSAT results shown in Fig. 2 are not strictly comparable with the other computations ; therefore, they have been taken out of the present intercomparison. [METSAT's scientific objective was to demonstrate certain problems with the conventional CFLOS analyses, in particular the issue of cloud size (and resolution) and the use of ground-based as against space-based cloud imagery.]

Thus, at present, results of PCFLOS for RAPTOR TALON for Iraq and Korea can use the analyses of Boehm, Roadcap, Malick and Allen (SRII), and Bauer. Roadcap's analysis has to go down to the surface rather than to 2 km, which naturally gives somewhat lower values for PCFLOS than do the other treatments since there are more clouds in the path.

Table 5 and Fig. 7 summarize the results of different PCFLOS estimates: P(20) = PCFLOS for R = 20 km, P(100) = PCFLOS for R = 100 km. Many of the numbers given are not strictly comparable, and they need to be reviewed and worked over.

a. Results are listed for ranges R from 20 to 100 km, i.e., to viewing angles θ (from Fig. 1) of 39° to 9°. Reference to Fig. 4 shows that there are no data for $\theta < 10°$, or for ranges R > 100 km, although data exist for horizontal viewing from aircraft. While one can obviously extrapolate the present results to longer ranges, it should be noted that there are no really adequate data for this.

b. My estimates are expressed in Table 5 and in Fig. 7. Results are given for both Case K (50 percent of clouds contribute to obscuration) and also for Case L (30 percent of clouds contribute to obscuration), which may be considered bounds in the sense that deviations outside them seem always to be small (A. Dalcher, private communication).

c. The SRII estimates of Table 5 correspond to all clouds above 2 km.

d. Roadcap's CLDGEN estimates are plotted from Fig. 2. They go down to the surface and therefore are not strictly comparable to the present results.

The present answer is physically transparent, does not depend upon a computer code, but uses a simple physical model and essentially one data point, namely the total sky

Table 5. Comparison of Revised Results of PCFLOS for Iraq and Korea

	Iraq (Baghdad)				Reference Calculation[a]	Korea (Seoul)			
	Jan.	April	July	Oct.		Jan.	April	July	Oct.
Sky cover S_{tot}[b]	.48	.44	.08	.23	.8	.47	.57	.68	.48
EB[c]	Jan.		July.			Jan.		July	
K:P(20)	.68 – .76		.94 – .96		.50 – .60	.68 – .76		.59 – .66	
K:P(100)	.46 – .76		.84 – .96		.28 – .60	.46 – .76		.35 – .66	
L:P(20)	.80 – .85		.96 – .98		.68 – .76	.80 – .85		.73 – .80	
L:P(100)	.61 – .85		.91 – .98		.46 –.76	.61 – .85		.51 – .80	
Boehm	Mideast, Jan.							Korea, July	
P(20)	.66							.48	
P(100)	.58							.30	
Roadcap[d]	Teheran (Feb., S_{tot} = .38)				Baghdad	Pyongyang July		Sept.	
P(20)	.43				.65	.2		.5	
P(100)	.30				.5	.2		.4	
SRII	A[e]				A[d]	S_{tot} = 0.48		S_{tot} = 0.72	
P(20)	.78				.85	.6		.41	
P(100)	.69				.76	.52		.31	

a Reference calculation for very cloudy conditions, sky cover S_{tot} = 0.8.

b Data from A. Boehm's Code S-Cloud for Baghdad (33.23; 44.00) and Seoul (37.58; 127.05), respectively.

c Calculation by the author. Case K corresponds to 50 percent of clouds below 2 km, so that 50 percent of cloud cover S_{tot} contributes to obscuration, while Case L corresponds to 70 percent of clouds below 2 km, so that only 30 percent of clouds contribute to obscuration. Conditions generally lie between these bounds.

d Looking down to surface, not to 2 km.

e No data for Iraq; use average of Teheran and Arabian Sea for January (S_{tot} = .32) and Ionian Sea for July (S_{tot}= 0.055).

S_{tot} = total sky cover.

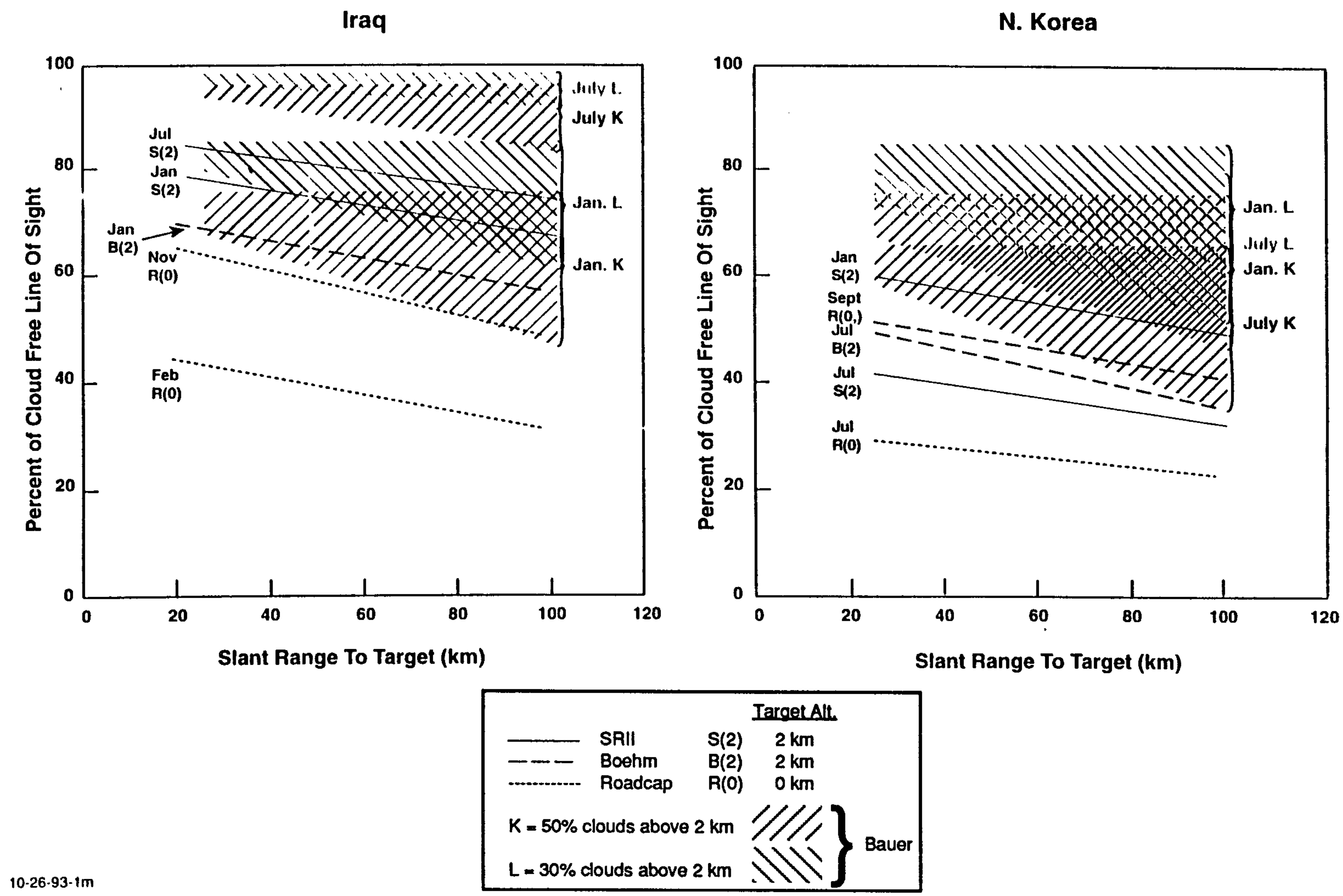


Figure 7. PCFLOS Results for Iraq and Korea—Revised. We show results of SRII (Malick and Allen), Boehm (Hughes-STX), Roadcap (USAF-PL/WE), and Bauer (Models K and L). All estimates correspond to a target at 2-km altitude viewed from above the cloudy atmosphere except for the Roadcap values, which refer to a target at the surface, so that these paths go through all clouds and thus have a relatively small value of PCFLOS.

cover, S_{tot}, and Fig. 4 as a methodology. This model entails a number of assumptions that are not necessarily quantitatively correct but can easily be corrected should more data become available; more to the point, the results of these assumptions are certainly qualitatively reasonable, and sufficient information is presented here so that a potential user can readily vary the assumptions and compute his/her own estimates.

Reality probably lies between the bounds defined by these ranges. Note that the results of the other computations shown in Fig. 7 and in Table 5 display some quantitative variation. This should be interpreted as characteristic of the concept of PCFLOS whose numerical values are inherently not very precise.

In conclusion, we ask for the PCFLOS for paths from 18-km altitude—above all clouds—to 2 km, at a slant range of about 20–100 km, at two different locations (Baghdad, Iraq, and Seoul, Korea) for January and July at average cloudiness. There are very few clouds in Iraq during the summer, so for this case PCFLOS ~ 0.9–0.95. For the other cases considered here, the mean cloud cover ranges between 0.4 and 0.7, and the PCFLOS values range between 0.6 and 0.7 at R = 20 km, and between 0.4 and 0.6 at R = 100 km. Estimates made by a variety of workers are generally consistent with this.

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GLOSSARY

3DNEPH	3-D Nephanalysis (USAF Cloud Cover Code, replaced by RTNEPH)
C Cloud S	Climatology of Cloud Statistics (code used by Hughes-STX Corp.)
CLDGEN	cloud cover code used by the Air Weather Service, USAF
CP	symbol used here for conditional PCFLOS
DMSP	Defense Meteorological Satellite Program (Polar Orbiting Weather Satellite)
GOES	Geostationary Operational Earth Satellite (Weather Satellite)
LOS	line of sight
NOAA	National Oceanic and Atmospheric Administration
PCFLOS	probability of cloud-free line of sight
RTNEPH	Real Time Nephanalysis (USAF Cloud Cover Code, current)
S	sky cover (cloud cover viewed from the ground) (see Fig. 2 and Table 2)
S_{eff}	effective sky cover within line of sight (i.e., for clouds above 2 km)
S_{tot}	total sky cover (at a given location and season)
SRII	Stanford Research Institute International
STC-METSAT	METSAT Inc., Ft. Collins, CO (303-221-5420), now a subsidiary of STC (Science & Technology Corp., Hampton, VA)

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13. ABSTRACT *(Maximum 180 words)*

RAPTOR TALON is a concept that includes optical sensing of rocket plumes from low altitudes (2 km) through burnout from an air vehicle at 18-20 km, at a long range, i.e., R ~ 20 - 100 km. The presence of clouds can interfere with optical sensing, and thus it is important to establish the Probability of a Cloud-Free Line of Sight (PCFLOS) at locations and times of concern. Some previous estimates of PCFLOS were counter-intuitive and provided varying results; POET was asked to resolve the discrepancies. Here we ask for the PCFLOS for paths from 18 km altitude–above all clouds–to 2 km, at a slant range of about 20 - 100 km at two different locations (Baghdad, Iraq, and Seoul, Korea) for January and July at average cloudiness. There are very few clouds in Iraq during the summer, so for this case PCFLOS ~ 0.9 - 0.95. At the other locations and seasons the mean cloud cover ranges between 0.4 and 0.7, and the PCFLOS values range between 0.6 and 0.7 at R = 20 km, and between 0.4 and 0.6 at R = 100 km. Estimates made by a variety of methods are generally consistent with this finding.

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