NOTES

Methodologies and Comparisons for Lund's Two Methods for Calculating Probability of Cloud-Free Line-of-Sight

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12 May 1984 and 20 August 1985

ABSTRACT

To help in the implementation of Lund's probability of cloud-free line-of-sight (PCFLOS) calculations (method A and method B) for limited altitudes, a methodology for cumulative cloud cover calculation (required for both methods) is introduced and a methodology for cumulative cloud form determination (required for method B) is developed. To study the PCFLOS differences between the two methods, Lund's master matrices are investigated and the derived PCFLOS results of Hamburg, Germany, are compared and analyzed for variations in selected environmental parameters. Based upon numerical studies performed in this research effort, it is strongly recommended that Lund's method B should always be adopted for general purpose worldwide PCFLOS calculations.

1. Introduction

Estimates of probability of cloud-free line-of-sight (PCFLOS) through the atmosphere are required in designing and evaluating optical and infrared communications, search and tracking systems. In recent years, the need and interest for calculating PCFLOS has grown significantly in government communities. Among all available methods, Lund's (1973) approach is well-known and satisfactory to many government agencies.

Based on three years' whole sky photographs taken at Columbia, Missouri, Lund and Shanklin (1972, 1973) develop two methods—called method A and method B—for estimating PCFLOS from the ground through the entire atmosphere. Method A considers only sky cover, while method B requires both sky cover and cloud-type information. Due to variations in the distribution of cloud types for different geographical locations, Lund claims that method A is applicable for use at locations where the cloud type distribution resembles that observed at Columbia, while method B is more universal and applicable for use at all geographical locations.

In Lund's papers, the calculation of PCFLOS applies only from the ground to an infinite altitude. In real world applications, however, PCFLOS values from the ground up to limited altitudes are often needed. Therefore, practical implementation of method A requires the calculation of cumulative cloud cover for a designated altitude, while the implementation of method B requires the determination of cumulative cloud form in addition to the calculation of cumulative cloud cover.

Although method B is known to be theoretically superior to method A, only evidence of the use of method A is seen in application. The lack of method B's implementation may be attributed to the following reasons: 1) The methodology for determining cumulative cloud form is not available; 2) the calculation of method A is much simpler than that of method B;[1] and 3) an apparent lack of knowledge for empirically comparing methods A and B results in erroneously regarding method A as a good approximation for method B.

To help practitioners in implementing method B and in realizing the significant differences between PCFLOS resulting from the two methods, this paper seeks to accomplish the following:

1) Develop methodology for determining cumulative cloud form for method B.
2) Investigate the difference between Lund's master matrices for the two methods.
3) Empirically compare the derived PCFLOS results

[1] In actual implementation in this research, method B, on the average, consumes five times the resources (both computing time and memory) required for method A.

of the two methods for Hamburg, Germany; and investigate the individual effects of season, diurnal cycle, weather code, elevation angle, and altitude on the differences in PCFLOS between method A and method B.

All the relevant methodologies and PCFLOS calculations in this paper are based on the 3DNEPH (Feddes, 1974) data base of weather observations.

2. Basic methodologies for Lund's PCFLOS calculation

Given elevation angle and altitude, Lund's method A, as adapted for finite altitudes, estimates PCFLOS from the ground to that altitude as a function of the corresponding distribution of cumulative cloud cover (see Section 3), treating all types of clouds the same. Lund's master probability matrix **M** contains a row for each of 9 elevation angles (10°–90°) and 11 columns representing tenths of sky cloud cover from 0 to 10 tenths. The user-supplied distribution of cumulative cloud cover is contained in a vector (**K**) of relative frequencies in 10% increments (0–10 tenths). For a specified elevation angle, the row from the master matrix **M** is multiplied by the vector **K** to obtain a scalar representing PCFLOS from ground to the designated altitude. Multiplying the entire matrix **M** by **K** results in a vector of PCFLOS for all nine elevation angles.

Given elevation angle and altitude, the adapted Lund's method B estimates PCFLOS from ground to that altitude as a function of six distributions of cumulative cloud cover, each corresponding to one of six cloud forms. These six distribution vectors are denoted by $K_1, K_2, \ldots, K_6$ which are similar in format to the single vector **K** of method A. Method B uses six master probability matrices (denoted by $\mathbf{M}_1, \mathbf{M}_2, \ldots, \mathbf{M}_6$) which correspond to Lund's six categories of cloud forms described in Table 1. Each $\mathbf{M}_i$ matrix is similar in format to the single matrix **M** of method A. Summation of the multiplications $\mathbf{M}_i \times \mathbf{K}_i$ for $i = 1$ to 6 results in a vector of PCFLOS for all nine elevation angles.

TABLE 1. Lund's six categories of cloud forms for method B.

Category	Form	Cloud type
1	Cirriform	Cirrocumulus Cirrostratus Cirrus
2	Middle	Altocumulus *Altocumulus castellanus Altostratus
3	Cumuliform	Cumulonimbus *Cumulonimbus mammatus Cumulus *Fractocumulus
4	Stratiform	*Fractostratus Nimbostratus Stratocumulus Stratus
5	Mixed	Mixtures of more than one form
6	None	No clouds of any type reported

* See Table 2 for explanation.

TABLE 2. Conversion of 3DNEPH cloud types to Lund's cloud forms.

	3DNEPH code	3DNEPH Type(s) of clouds	Lund's category
Low clouds	0	Type unknown or not present	6
	1	Stratocumulus (SC)	4
	2	Stratus (ST)	4
	3	Cumulus	3
	4	Cumulonimbus (CB)	3
	5	SC and ST	4
	6	SC and CU	5
	7	SC and CB	5
	8	ST and CU	5
	9	ST and CB	5
	10	CU and CB	3
	11	SC, ST and CU	5
	12	SC, ST and CB	5
	13	SC, CU and CB	5
	14	ST, CU and CB	5
	15	SC, ST, CU and CB	5
Middle clouds	0	Type unknown or not present	6
	1	Altocumulus (AC)	2
	2	Altostratus (AS)	2
	3	Nimbostratus (NS)	4
	4	AC and AS	2
	5	AC and NS	5
	6	AS and NS	5
	7	AC, AS and NS	5
High clouds	0	Type unknown or not present	6
	1	Cirrus (CI)	1
	2	Cirrocumulus (CC)	1
	3	Cirrostratus (CS)	1
	4	CI and CC	1
	5	CI and CS	1
	6	CC and CS	1
	7	CI, CC and CS	1

3. Cumulative cloud cover calculation

The cumulative cloud cover calculation is accomplished using the computer routine ADDCLD developed by the United States Air Force Environmental Technical Applications Center (ETAC) which modifies the basic approach proposed by de Bary et al. (de Bary and Moller, 1983). The detailed methodology of ADDCLD is explained and illustrated in the Appendix.

4. Cumulative cloud form determination

In method B, different cloud forms are associated with different master probability matrices. Therefore,

TABLE 3. Rules for cumulative cloud form determination.

Accumulation of clouds from ground to just-previous layer (I-1)	Present layer (I) cloud cover	Lund cumulative cloud form from ground to just-previous layer (I-1)	Present layer (I) Lund cumulative cloud form	Rule number
		Low cloud layers		
0	0	6	6	1
0	>0	6	3, 4, or 5*	2
>0	⩾0	3, 4, or 5	3, 4, or 5†	3
		Middle cloud layers		
0	0	6	6	4
0	>0	6	2, 4, or 5*	5
>0	0	2, 3, 4, or 5	2, 3, 4, or 5	6
>0	>0	2 or 4	2 or 4**	7a
>0	>0	2, 3, 4, or 5	5#	7b
		High cloud layers		
0	0	6	6	8
0	>0	6	1	9
>0	0	1, 2, 3, 4, or 5	1, 2, 3, 4, or 5	10
>0	>0	1	1**	11a
>0	>0	2, 3, 4, or 5	5#	11b

* The exact Lund cloud form will depend upon which 3DNEPH cloud type is reported.

† This Lund cloud form will be exactly the same as that determined for the just-previous layer since 3DNEPH data report only one cloud type each for low, middle, and high cloud layers.

** This is true if the Lund cloud form in the present layer matches the Lund cumulative cloud form from ground to the just-previous layer.

This is true if the Lund cloud form in the present layer does not match the Lund cumulative cloud form from ground to the just-previous layer.

for an accumulation of clouds, not only its cumulative cloud cover needs to be calculated, but also its associated cloud form must be determined.

In the 3DNEPH data base, cloud types for low, middle, and high clouds are recorded in different classifications than those of Lund's six cloud forms. Thus, the observed types of low, middle, and high clouds from the 3DNEPH data base must first be converted to the equivalent Lund cloud form categories. Then, an algorithm is developed to determine the "cumulative" cloud form for an accumulation of clouds. A detailed explanation and an example follow.

1) *A conversion of the 3DNEPH code for types of low, middle, and high clouds to Lund's six cloud forms*—see Table 2.

In Table 2, all 3DNEPH codes for low, middle, and high cloud types are mapped to one of the six cloud forms specified by Lund. These six cloud forms and the various cloud types to be included in each as dictated by Lund were seen in Table 1. However, there are four cloud types (denoted by *) in Lund's six cloud form table (Table 1) having no proper correspondence with the 3DNEPH cloud types. They are: altocumulus castellanus, cumulonimbus mammatus, fractocumulus, and fractostratus. Since these four cloud types

TABLE 4. An example of cumulative cloud form determination.

3DNEPH cloud type	Lund's cloud form	3DNEPH layer	Cloud cover in layer	Cumulative cloud form	Used rule number
		Low clouds			
5	4	1	0	6	1
		2	0	6	1
		3	0	6	1
		4	0	6	1
		5	20	4	2
		6	0	4	3
		7	0	4	3
		8	25	4	3
		Middle clouds			
1	2	9	0	4	6
		10	60	5	7b
		11	0	5	6
		12	85	5	7b
		High clouds			
3	1	13	80	5	11b
		14	80	5	11b
		15	0	5	10

TABLE 5. Comparison between Lund's master PCFLOS matrices of methods A and B for three elevation angles and eleven sky covers.

Elevation angle	Type*	Sky cover (tenths) 0	1	2	3	4	5	6	7	8	9	10
90	A	1.00	0.97	0.92	0.87	0.81	0.77	0.70	0.62	0.48	0.31	0.08
	B1	0.98	0.95	0.92	0.88	0.85	0.79	0.73	0.67	0.60	0.53	0.25
	%Δ	+	+			−	−	−	−	−−−	−−−−	−−−−
	B2	1.00	0.94	0.88	0.82	0.77	0.71	0.65	0.55	0.41	0.25	0.02
	%Δ		+	+	+	+	++	+	++	++	++	++
	B3	0.99	0.94	0.88	0.83	0.78	0.74	0.68	0.56	0.41	0.25	0.03
	%Δ		+	+	+	+	+	+	+	++	++	+
	B4	1.00	0.97	0.95	0.91	0.88	0.79	0.65	0.53	0.38	0.31	0.03
	%Δ			−	−	−−	−	+	++	++		+
	B5	1.00	0.97	0.94	0.90	0.87	0.81	0.72	0.63	0.49	0.30	0.12
	%Δ			−	−	−−	−	−				−
	B6	0.99	(Remaining elements of this vector do not apply since Lund's cloud form 6 indicates no clouds)									
	%Δ											
45	A	0.99	0.955	0.89	0.84	0.77	0.72	0.63	0.565	0.435	0.28	0.075
	B1	0.965	0.93	0.875	0.815	0.74	0.685	0.64	0.585	0.535	0.43	0.205
	%Δ	+	+		+	+	+		−	−−	−−−	−−−
	B2	1.00	0.925	0.85	0.78	0.73	0.665	0.60	0.50	0.37	0.19	0.02
	%Δ		+	+	+	+	+	+	++	++	++	+
	B3	0.99	0.935	0.865	0.82	0.76	0.705	0.645	0.52	0.355	0.205	0.025
	%Δ		+	+	+				+	++	++	+
	B4	0.985	0.935	0.875	0.825	0.765	0.655	0.55	0.44	0.325	0.225	0.02
	%Δ		+				+	++	+++	+++	+	+
	B5	0.98	0.925	0.88	0.845	0.815	0.745	0.65	0.56	0.435	0.26	0.095
	%Δ		+			−	−	−			+	−
	B6	0.98	(Remaining elements of this vector do not apply since Lund's cloud form 6 indicates no clouds)									
	%Δ											
20	A	0.98	0.90	0.83	0.75	0.67	0.59	0.50	0.42	0.33	0.21	0.05
	B1	0.94	0.86	0.79	0.70	0.59	0.55	0.50	0.45	0.42	0.30	0.13
	%Δ	+	+	+	+	++	+		−	−−	−−	−−
	B2	0.97	0.87	0.78	0.70	0.64	0.57	0.50	0.41	0.28	0.12	0.01
	%Δ		+	+	+	+	+		+	+	++	+
	B3	0.98	0.89	0.80	0.73	0.64	0.57	0.50	0.37	0.24	0.12	0.02
	%Δ			+	+	+	+		+	++	++	+
	B4	0.97	0.88	0.79	0.73	0.66	0.54	0.42	0.31	0.21	0.13	0.02
	%Δ		+	+	+	+	+	++	++	+++	++	+
	B5	0.94	0.85	0.79	0.75	0.71	0.62	0.52	0.42	0.32	0.19	0.06
	%Δ	+	+	+		−	−	−			+	
	B6	0.97	(Remaining elements of this vector do not apply since Lund's cloud form 6 indicates no clouds)									
	%Δ											

* Table values are defined as

1. A = Row vector for a specific elevation angle from Lund's method A master PCFLOS matrix **M**
2. B_i = Row vector for a specific elevation angle from Lund's method B master PCFLOS matrix $\mathbf{M}_i$ for cloud form i
3. %Δ = Absolute difference of $B_i - A$ for a given elevation angle and sky cover with difference denoted as

− Δ = 2 ∼ 5	+ Δ = −2 ∼ −5
−− Δ = 6 ∼ 10	++ Δ = −6 ∼ −10
−−− Δ = 11 ∼ 15	+++ Δ = −11 ∼ −15
−−−− Δ = 16 ∼ 25	

TABLE 6. Summary of comparison between Lund's master PCFLOS matrices of methods A and B.

Master matrix vectors compared	B_i lower than A			B_i higher than A			
	+++	++	+	–	––	–––	––––
B1 vs A		1	12	6	4	3	2
B2 vs A		9	20				
B3 vs A		6	19				
B4 vs A	3	6	12	3	1		
B5 vs A			6	12	1		

mentioned by Lund do not appear in the 3DNEPH data base, they are not considered further.

2) *Rules for cumulative cloud form determination*—see Table 3.

In Table 3, the cumulative cloud form is determined, layer by layer, as a function of layer altitude, previous accumulation of clouds, present layer cloud cover, previous cumulative cloud form, and present layer cloud type. Since in 3DNEPH, only one cloud type is recorded for low clouds, this cloud type is therefore applied to all low cloud layers having some coverage. The same reasoning holds for middle and high cloud layers. Thus, this algorithm can only provide an "approximation" to the determination of "real" cumulative cloud form due to the roughness of 3DNEPH cloud type records. Should cloud type be recorded for individual cloud layers, the determination of exact cumulative cloud form can then be obtained by the same reasoning underlying the current algorithm.

Also notice that the definition of low, middle, or high cloud layers in 3DNEPH is a function of terrain. For example, for terrain ⩽ 1750 feet, the low, middle and high cloud layers are 1–8, 9–12, and 13–15, respectively. For terrain > 5500 and ⩽9500 feet, these layers change to be 1–10, 11–13, and 14–15.

3) *Example*—see Table 4 which makes use of the rules presented in Table 3.

5. Comparison between Lund's master matrices

The PCFLOS calculations always involve multiplication by Lund's master matrices showing elevation angle by sky cover in tenths. The inherent difference (if there is any) between method A's single master PCFLOS matrix and method B's six master PCFLOS matrices certainly will contribute to the final PCFLOS differences resulting from the different methods. Therefore, a close look at this "source of difference" may prove worthwhile. Table 5 shows PCFLOS values in a detailed comparison for three elevation angles: 90°, 45°, and 20°, and for eleven sky covers in tenths: 0, 1, 2, . . . , 10. This comparison is further summarized in Table 6.

These comparisons in Tables 5 and 6 reveal that, in general, method B's master matrices' values are lower than those of method A, except for part of the cirriform and mixed clouds (Lund's cloud forms 1 and 5). Consequently, it seems very likely that method B's PCFLOS will often be lower, in worldwide application, than those of method A. This helps explain Lund's original comparison at Columbia, Missouri, which is shown in Table 7. In this table, method B's PCFLOS values are apparently smaller than those of method A for a majority of the elevation angles, although theoretically they should be exactly the same. Comparing the PCFLOS of both method A and method B to the PCFLOS actually observed (Table 7), Lund also claims that method B is generally more accurate.

6. Comparison at Hamburg

The PCFLOS values using both methods A and B are calculated for Hamburg, Germany (54°N, 10°E, 52 feet above sea level). These calculations are based

TABLE 7. Comparisons among methods A and B, and observed PCFLOS for Columbia, Missouri (Lund and Shanklin, 1973).

Angle (deg)	Method A	Method B	Observed	B − A*	Method closer to observed*
90	0.509	0.513	0.492	–	A
80	0.506	0.508	0.497	–	A
70	0.504	0.503	0.493		B
60	0.500	0.498	0.489	+	B
50	0.496	0.489	0.485	++	B
40	0.483	0.474	0.476	++	B
30	0.463	0.454	0.457	++	B
20	0.437	0.427	0.437	++	A
10	0.392	0.392	0.382		same

* Notation is explained in Table 5.

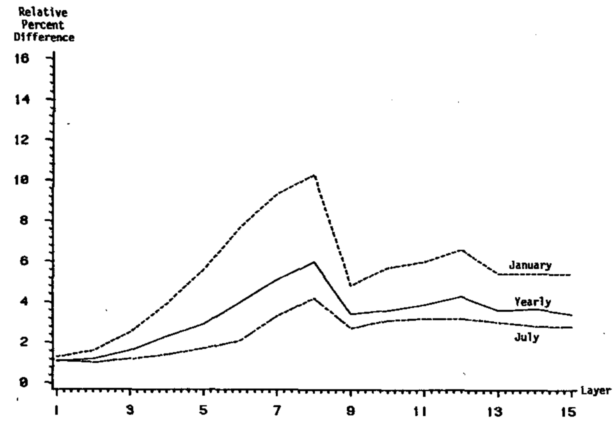

FIG. 1. The effect of seasonal variation on relative difference of method A PCFLOS over method B PCFLOS.

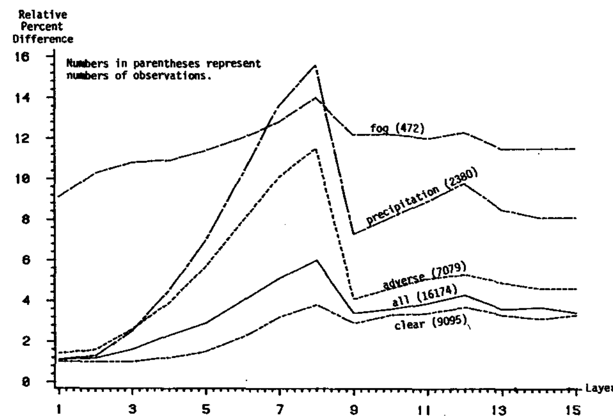

FIG. 3. The effect of weather variation on relative difference of method A PCFLOS over method B PCFLOS.

on a major portion of the 3DNEPH weather data base over a six-year period (1973–1978). A total of 16174 once-every-3-hour observations are used.

To investigate the effects of individual weather parameters on the difference between PCFLOS resulting from the two methods, several cases are examined. In each case, only one parameter is allowed to vary while the remaining parameters are kept the same as those of the base case. The cases examined include

Base case: Yearly, daily, all 3DNEPH weather codes (0–9), elevation angle 45°.

Seasonal variation: Yearly, January, July.

Diurnal variation: Daily, daytime, nighttime.[2]

Weather variation: All (weather code = 0–9), clear (0), adverse (1–9), precipitation (5–9), fog (4).

Elevation angle variation: 90°, 45°, 20°.

For each case, the absolute and relative differences of PCFLOS are plotted against the 3DNEPH altitude layer number.[3] Curves representing the relative difference—100× (PCFLOS(A) − PCFLOS(B))/PCFLOS(A)—are shown in Figs. 1–4, while curves of the absolute difference—100× (PCFLOS(A) − PCFLOS(B))—are shown in Figs. 5–8. All analyses are based on relative difference figures, while absolute difference figures are used primarily to illustrate the actual magnitudes of the differences.

The comparisons illustrated in Figs. 1–8 show that method B's PCFLOS values are *always* lower than those of method A, a conclusion which matches quite well with the original differences between master matrices of the two methods. In each of Figs. 1–4, all the

[2] Daytime is defined as the hours between sunrise and sunset, while nighttime is the remaining time.

[3] The actual height (in feet) of the top of each 3DNEPH layer is as follows: 1—150, 2—300, 3—600, 4—1000, 5—2000, 6—3500, 7—5000, 8—6500, 9—10000, 10—14000, 11—18000, 12—22000, 13—26000, 14—35000, 15—55000.

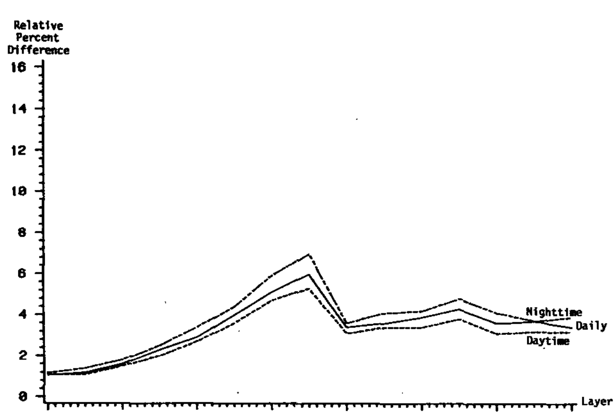

FIG. 2. The effect of diurnal variation on relative difference of method A PCFLOS over method B PCFLOS.

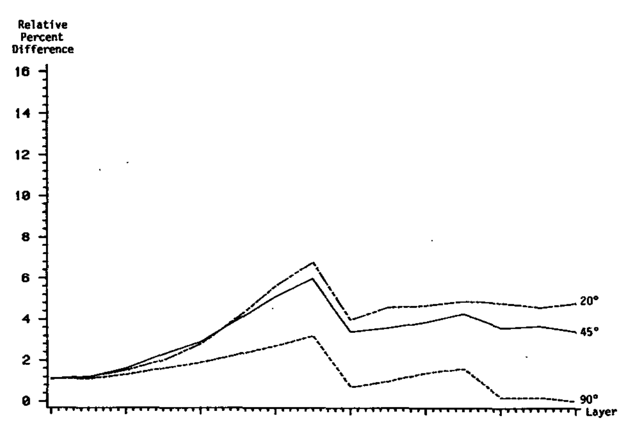

FIG. 4. The effect of elevation angle on relative difference of method A PCFLOS over method B PCFLOS.

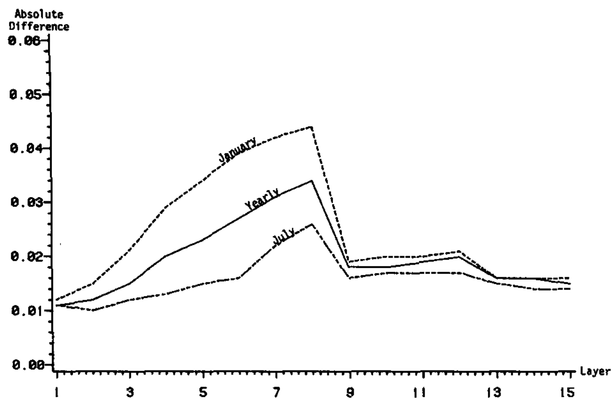

FIG. 5. The effect of seasonal variation on absolute difference of method A PCFLOS over method B PCFLOS.

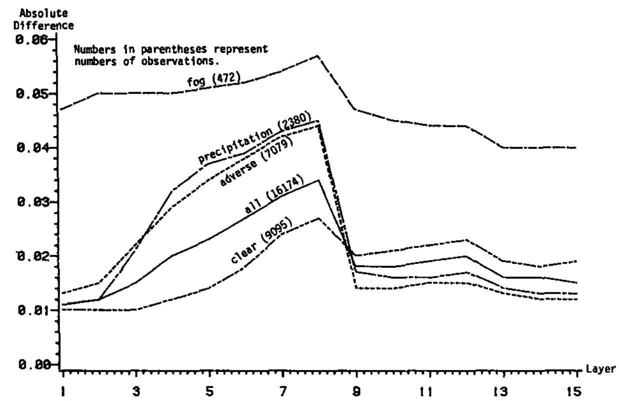

FIG. 7. The effect of weather variation on absolute difference of method A PCFLOS over method B PCFLOS.

curves are clearly separated and in an apparently increasing trend in the range of low clouds (layers 1–8). This evidence strongly suggests that the PCFLOS differences between the two methods are *significantly* affected by individual variations in season, diurnal cycle, weather condition, elevation angle, and altitude. Among these five parameters, the PCFLOS differences are most sensitive to the variations in weather condition and altitude. Theoretically, the PCFLOS differences between methods A and B for a particular location are attributed to the differences of the distribution of cloud types between that location and Columbia, Missouri. All the above results, therefore, further imply that the distribution of cloud types is quite likely to vary significantly for different locations, seasons, diurnal cycles, weather conditions, and altitudes.

7. Conclusion

To help in the actual implementation of Lund's method A and/or method B for PCFLOS calculations at limited altitudes, this paper has introduced a methodology for cumulative cloud cover calculation required for both methods. Of equal importance, this paper has developed the methodology for cumulative cloud form determination required for method B. Both methodologies have been numerically illustrated to assist practitioners.

Recall that Lund's master PCFLOS matrices for both methods are based on three years of daytime whole-sky photographs at Columbia. Also, the distribution of cloud types is quite likely to vary significantly for different locations, seasons, diurnal cycles, weather conditions, and altitudes. Therefore, theoretically, the application of method A should be limited to locations having cloud form distributions similar to Columbia, Missouri; otherwise, results may be quite inaccurate. Unfortunately, due to the lack of extensive field PCFLOS observations, it is difficult empirically to justify the adoption of either method.

Even though there is a lack of field PCFLOS obser-

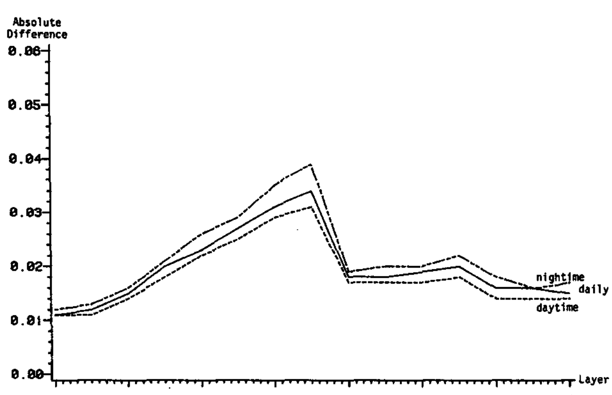

FIG. 6. The effect of diurnal variation on absolute difference of method A PCFLOS over method B PCFLOS.

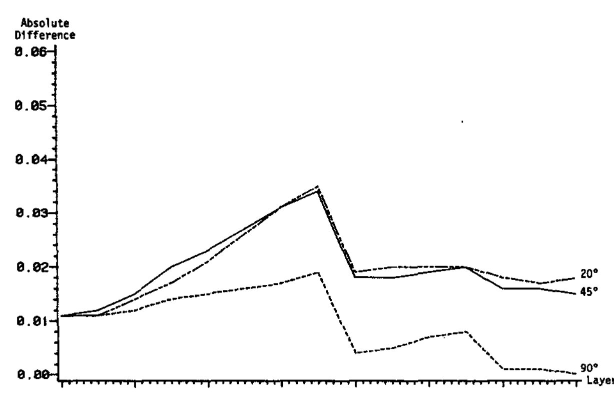

FIG. 8. The effect of elevation angle on absolute difference of method A PCFLOS over method B PCFLOS.

vations, all the numerical studies in this paper have presented empirical evidence that significant differences do exist between the two methods' PCFLOS results for variations of location, season, diurnal cycle, weather condition, and altitude. Therefore, since method B is theoretically superior to method A and empirically yields significantly different PCFLOS results, method B should always be adopted for general purpose worldwide PCFLOS calculations whenever possible.

APPENDIX

Methodology for Cumulative Cloud Cover Calculation

The computer routine ADDCLD developed by ETAC calculates cumulative cloud cover from 3DNEPH (Feddes, 1974) weather observations. The routine considers the degree of independence of "cloud decks" as a function of the vertical distance between them. Hence the greater the vertical separation, the greater the cumulative cloud cover (i.e., less overlap). In this routine, cloud deck represents one or more 3DNEPH altitude layers containing clouds and bounded above and below by a 3DNEPH altitude layer which is cloud free; however, the first cloud deck may be bounded below by ground level, and the last cloud deck may be bounded above by a user-specified ending altitude.

The ADDCLD algorithm starts at a user-specified beginning altitude (usually ground level) and systematically accumulates sequential 3DNEPH cloud layers up to a user-specified ending altitude as follows[4]:

- A_2 Cloud cover of the individual layer having the maximum cloud coverage within the first cloud deck
- A_3 Highest layer number of the first cloud deck or the previous cloud deck
- B_1 Lowest layer number of the new (next) cloud deck
- B_2 Cloud cover of the individual layer having the maximum cloud coverage within the new (next) cloud deck
- T_p Cumulative cloud cover in the previous step
- T Cumulative cloud cover in the new (next) step
- R Randomness factor as a function of cloud deck separation and cloud deck altitude as follows:

R	$B_1 < 10$	$B_1 \geq 10$
1		$(B_1 - A_3) \geq 4$
0.75	$4 < (B_1 - A_3) < 10$	$(B_1 - A_3) < 4$
0.50	$(B_1 - A_3) \leq 4$	

Algorithm

1. Locate the first and second cloud deck and obtain A_2, A_3, B_1 and B_2.
2. For $A_2 \geq B_2$, $T = A_2 + (1 - 0.01A_2)B_2R$
   For $A_2 < B_2$, $T = B_2 + (1 - 0.01B_2)A_2R$
3. Locate the new (next) cloud deck and obtain B_1 and B_2.
4. For $T_p \geq B_2$, $T = T_p + (1 - 0.01T_p)B_2R$
   For $T_p < B_2$, $T = B_2 + (1 - 0.01B_2)T_pR$
5. Go to step 3 and repeat until the user-specified ending altitude is reached.

Example

A numerical example of this calculation is presented as follows:

Given:

	3DNEPH Altitude Layer														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Percent cloud cover	0	20	25	10	0	0	0	35	40	0	0	30	0	60	0

Desired: Cumulative cloud cover at top of 3DNEPH layer 15.
Procedure:

Four cloud decks can be identified below the top of layer 15:

	Cloud deck			
	1	2	3	4
3DNEPH layer	2, 3, 4	8, 9	12	14

For cloud decks 1 and 2:
$A_2 = 25, A_3 = 4; B_2 = 40, B_1 = 8;$
Since $B_1 < 10$ and $B_1 - A_3 = 4$, $R = 0.50$
Since $A_2 < B_2$, $T = B_2 + (1 - 0.01B_2)A_2R$
$= 40 + (1 - 0.01 \times 40) \times 25 \times 0.50 = 47.50$

For cloud deck 3:
$T_p = 47.5, A_3 = 9; B_2 = 30, B_1 = 12;$
Since $B_1 \geq 10$ and $B_1 - A_3 = 3$, $R = 0.75$;
Since $T_p > B_2$, $T = T_p + (1 - 0.01T_p)B_2R$
$= 47.5 + (1 - 0.01 \times 47.5) \times 30 \times 0.75 = 59.31$

For cloud deck 4:
$T_p = 59.31, A_3 = 12; B_2 = 60, B_1 = 14;$
Since $B_1 \geq 10$ and $B_1 - A_3 = 2$, $R = 0.75$;
Since $T_p < B_2$, and $T = B_2 + (1 - 0.01B_2)T_pR$
$= 60 + (1 - 0.01 \times 60) \times 59.31 \times 0.75 = 77.79$

[4] The word "layer" means 3DNEPH altitude layer. All cloud covers are measured in terms of percentage.

Using the procedure for each of the 3DNEPH altitude layers gives

3DNEPH layer	Percent cumulative cloud cover
1	0
2	20*
3	25*
4	25
5	25
6	25
7	25
8	43.13*
9	47.50
10	47.50
11	47.50
12	59.31
13	59.31
14	77.79
15	77.79

* Only a portion (below the user-specified ending altitude) of the entire cloud deck is considered.

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