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ABSTRACT

An analysis of cloud amount classification is carried out on the basis of the cloud distribution over different regions of the World Oceans at different seasons. The following satellite based atlases served as a primary data source for the analysis:

1. Relative cloud cover atlas by Miller and Feddes (1971),
2. Charts of Environmental Satellite Imagery (1975, 1976),
3. Cloud nephanalysis atlas by Sadler (1969),
4. Cloud nephanalysis atlas over the Pacific Ocean by Sadler, Oda, and Kilonsky (1976).

Additional data on cloud types were found from the ship observations taken during the period of the IGY and the IQSY.

To carry out a statistical analysis of cloud amounts over different regions, trapezoids quasi-equal in area were used. Cloud amounts over elementary areas of three different sizes were compared: 2.5 by 2.5°, 5 by 5°, 10 by 10°. It was determined that for many climatological problems 5 by 5° basic area units would be a satisfactory resolution; this resolution is quite sufficient for the examination of the cloud distribution above the World Oceans.

The following classification is proposed which groups elementary trapezoids into five categories according to the values of mean monthly cloud amounts (in tenths) N:

A - trapezoids where $0 < N < 0.2$;

B - trapezoids where $0.2 < N < 0.35$;

C - trapezoids where $0.35 < N < 0.5$;

D - trapezoids where $0.5 < N < 0.65$;

E - trapezoids where $0.65 < N < 1.0$.

The longest published uniform time-series of cloud amount data deduced from satellite nephanalyses are given by Sadler et al. (1976). These data cover the years 1965-1972. A comparison of the data presented by Miller and Feddes (1971) with satellite nephanalysis data by Sadler et al. (1976) shows that the latter data are 1.5 to 1.75 times higher in cloud amount than the former despite coming from the same basic satellite observations. The possible causes of these differences are analyzed. It is shown that it is possible to calculate the extension of Sadler's cloud amount time-series using a second-order regression curve.

Annual variations of cloud categories over different ocean regions are analyzed. It is shown that over the World Oceans there are regions in which the mean monthly cloud amount categories do not change during a year. Multiyear trends in the global distribution of cloud amounts are also analyzed. The data by Sadler et al. (1976) show that the global cloud amount decreased in the years 1965 to 1972. The amount of decrease (1 to 14 percent) depends on the season and the geographic co-ordinates.

It is shown that it is expedient to use the beta distribution for describing the cloud amount distribution above the World Oceans using 10 by 10^{0} and larger trapezoids. The beta distribution is superior to other distributions investigated since it is versatile, bounded at both ends (0.1), and is capable of assuming a wide variety of shapes. A preliminary analysis demonstrated that the mean monthly cloud amounts over adjacent 10 by 10^{0} trapezoids, in most cases, can be considered unrelated quantities. In smaller trapezoids (2.5 by 2.5^{0}, 5 by 5^{0})

the monthly mean cloud amounts in the adjacent trapezoids are interdependent.

Assuming that future successful cloud climatology monitoring methods must be fully automatic, questions related to cloud amount analyses using satellite albedo and emitted flux measurements are discussed. Preliminary results concerning the interrelation between cloud amount and satellite-based albedo and emitted radiation are promising. A number of more definite studies are underway.

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1.0 INTRODUCTION

The evaluation of mean cloud cover from satellites may seem, at first sight, to be a straightforward and easy task to perform. However, Smith (1978) pointed out that the accuracy demands of different cloud climatology applications are frequently higher than the existing satellite cloud data sets are able to guarantee.

It is possible to divide satellite global cloud climatologies into three groups according to the aim:

1) Investigations in support of other space and research programs, for which cloud information may be of key significance;
2) Research in computer modelling of physical processes in the real atmosphere;
3) Studies in tracing processes in the general circulation of the atmosphere and investigations of climatological variation of cloud cover.

For the greater part of the tasks of the first group, it is not usually necessary to determine all of the physical and geometrical cloud cover parameters; e.g. in remote sensing missions to determine the Earth's resources the cloud amount over certain areas is the decisive parameter in determining the probability of a "clear line of sight". Nevertheless, there exists a large number of problems (e.g. the determination of global energy and moisture budgets, cloud modelling in general circulation studies etc.) where all cloud climatology parameters are needed. The STRATEX Program AD HOC Working Group (meeting in Boulder; 29 November - 2 December 1976) recommended that the following cloud climatological parameters should be monitored from space:

1) global and temporal series of cloud amount;

2) cloud top heights;

3) cloud types;

4) H_2O phase in clouds; and

5) diurnal, seasonal, interannual as well as spatial variability.

It must be pointed out that the spatial resolution of the satellite sensors plays a crucial role in determining cloud geometry parameters.

A review of the currently available cloud climatologies is given in a report by Suomi, et al (1977), as well as in Smith (1978). The main limitation of the available cloud climatology data is its non-comparability and the lack of accuracy; i.e. currently available cloud data do not approach the sampling and accuracy requirements suitable for climate diagnostic and modelling applications.

Considering the range of potential users of satellite cloud climatology data, as well as the growing available data amount, we agree completely with the statements made by Smith (1978); Harris and Barrett (1978) that the future successful cloud climatology monitoring methods must be fully automatic. An important future goal is deriving a special compressed set of irradiance (short-wave and longwave) information about sufficiently small grid areas as basic units and in a form from which the necessary cloud parameters can be derived. Several attempts have been made to work out special algorithms for cloud climatological parameter detection. Techniques include: 1) Multi-dimensional radiation histograms, see e.g. Mosher (1976), Smith (1978), and Feigelson and Krasnokutskaya (1978); 2) Bi-spectral methods, see Reynolds and Vonder Haar (1976, 1977), and Mendola and Cox; 3) Combination of brightness and texture measurements, see Harris and Barrett (1978). However, there is not yet a well documented technique which satisfies the accuracy demands of cloud climatological studies. Therefore, the Joint Organizing Committee of the FGGE strongly supports the research and special field programs aimed to improve the parameterization of cloudiness information in terms of satellite radiation measurements.

In this paper a joint effort by scientists from Colorado State University, Fort Collins (T. H. Vonder Haar, S. K. Cox, E. A. Smith, G. G. Campbell, D. DeMasters) CIRES, University of Colorado, Boulder (E. Steiner), Institute of Oceanology, Leningrad (K. S. Shifrin), Institute of Astrophysics and Atmospheric Physics, Tartu (O. A. Avaste, O. Ü. Kärner) was started to solve some of the problems connected with the satellite cloud climatology:

1) Investigation of the possibility of classifying cloud amounts on the basis of distribution over different regions and seasons.

2) Estimation of the accuracy of a general and simple mathematical description of the world-wide cloud amount distribution, which can be used in long range weather forecasting as a boundary condition.

3) Determination of the size of an elementary basic area, which gives a sufficiently detailed description of the cloud climatology processes which we are studying.

4) Comparison of existing satellite cloud climatology data sets and an estimation of their accuracy.

5) Detection of multi-year trends in global distribution of cloud amounts.

6) Investigation of the use of radiation data from Nimbus-3 (1969-1970) and from NOAA satellites (1974-1977) for refining the cloud

climatology parameter estimates.

7) Carry out a detailed analysis of cloud variability and to study cloudiness-radiation relationships over the GATE A-scale area ($5^{o}S$ - $20^{o}N$; $50^{o}W$ - $10^{o}W$).

2.0 CLOUD AMOUNT DISTRIBUTION ESTIMATES ABOVE THE WORLD OCEAN (60°N TO 60°S)

Following is a discussion of the possibility of classifying cloud amounts on the basis of distributions over different regions and seasons. Cloudiness is estimated over trapezoids of 10x10°. Three-digit indicators of these trapezoids coincide with the numbers given in the Handbook of Ship Observations (1974): the first digit denotes the octant, the second digit signifies latitude, the third one indicates longitude (see Figure 1). The characteristic cloud amount is given as an absolute cloud amount in tenths (i.e. as a ratio of the area covered with clouds in the trapezoid to the total area of this trapezoid). For trapezoids which partially lie over dry land only the area above the ocean is considered.

2.1 Primary data

The global atlas of relative cloud cover by Miller and Feddes (1971) and the charts of the Environmental Satellite Imagery (1975-1976) served as primary data sources for the following analysis. The atlas by Miller and Feddes (1971) presents cloud cover data for four years (1 January 1976 to 31 December 1970), which are given according to the observations made aboard the ESSA satellites. Brightness fields were determined once a day at 14 hr. to 16 hr. local time (LT). Cloud amounts were calculated from brightness fields recorded by AVCS (Advanced Vidicon Camera System). Spatial resolution in the nadir direction was approximately 4 km. An elementary square was approximately 40x40 km. Brightness fields were converted to cloud amounts with the help of empirical formulae. Cloud cover estimates were computed for

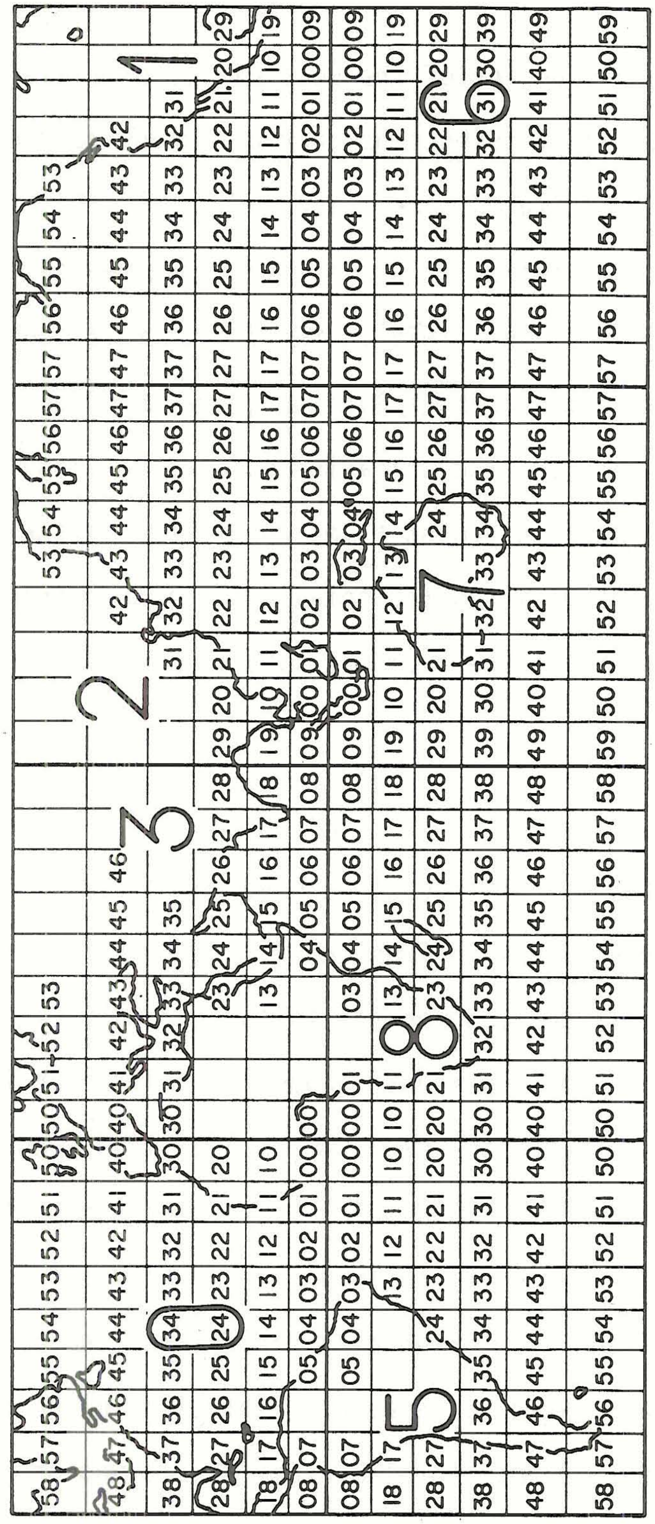


Figure 1 World map showing the trapezoid numbers.

each elementary area using a set of empirically derived weights. These weights were adjusted by comparing automated cloud-cover amounts with manual estimates from daily digitized satellite brightness pictures. Weights were selected to achieve the best agreement in cloud amounts between manual, visual estimates, and automated estimates (Miller and Feddes, 1971). In this atlas the charts of mean monthly, semiannual, and annual cloud amounts were given using 9 brightness steps showing the frequencies of occurrences of weak cloudiness (0 to 2 octas), medium cloudiness (3 to 5 octas) and heavy cloudiness (6 to 8 octas). It should be mentioned that the charts presented in the atlas in Miller and Feddes (1971) give explicitly overestimated values of medium cloudiness over snow or ice covered regions.

The monthly charts of brightness of the Environmental Satellite Imagery (1975-1976), represent the results of measurements from the NOAA-4 satellite. In our analyses we used the charts based on the measurements of a scanning radiometer in the visible spectral region (0.5 to 0.7 μm).

2.2 Cloud amount estimates

The following procedure was used: from the data of the Environmental Satellite Imagery charts the cloud amount was deduced for every 10x10° region making use of an auxiliary grid. This grid was within the latitude zone of 30° - 60° divided into 3x3 subregions and within the equatorial belt (0 - 30°) it was divided into 5x5 subregions. From the brightness data of each subregion three cloud situations were distinguished: "black" means that the particular subregion is cloud-free, "spotted" denotes 5 tenths of clouds and "white" indicates a continuous cloud cover (10 tenths). On a discrete day the cloud amount was calculated over the whole 10x10° region by averaging cloud estimates over these subregions. Using the daily cloud amount estimates obtained, histograms were plotted for all months. Histograms were smoothed by using the formula

$$\hat{f}_i = \frac{1}{4} f_{i-1} + \frac{1}{2} f_i + \frac{1}{4} f_{i+1}, \qquad (1)$$

where f_i is the original frequency of the i-th amount of clouds. Such a smoothening allows one to reduce the weight of random over- or under-estimates.

The mean monthly cloud amounts were also presented using four-year data from the atlas in Miller and Feddes (1971). It should be mentioned that the Environmental Satellite Imagery charts give cloud amount estimates approximately at 9 hr. LT, the atlas data (Miller and Feddes, 1971) refer to 14-16 hr. LT. Besides measuring errors, differences between these two estimates are also caused by daily and annual cloud amount variations. According to a limited number of ground observations (Kärner, 1973), these differences can reach values up to 0.15. Estimates of the daily variations over the trapezoids 011, 012 (situated near Africa) reveal the same order of values (Burlitskii, 1976).

2.3 Classification

The first statistically sound global cloud amount classification was proposed in the report by Sherr et al. (1968). Altogether, 29 different cloud climatological regions were recommended. It must be remembered that these regions were based primarily on seasonal distributions of mean monthly cloud amounts. Moreover, the peculiarities of annual cloud cover distributions as well as those of precipitation distributions were considered. Five cloud amount categories were determined: 1) no clouds; 2) 1 to 3 tenths; 3) 4 to 5 tenths; 4) 6 to 9 tenths; 5) overcast (10 tenths). The frequencies of occurrence of these cloud amount categories were given for all the months at eight times (01, 04, 07, 10, 13, 16, 19, 22 LT); see Sherr et al. (1968). The final statistics for each region was derived from a representative ground station. Satellite data were used only occasionally. Due to gross overestimates of cloud amounts from ground stations as suggested by the model calculations of Avaste (1969), Avaste et al. (1972), and Malberg (1973a), statistical estimates in this paper are only comparable, with certain reservations, with the data given by Sherr et al. (1968).

Our classification is based on mean monthly cloud amount values, their variances and histograms having been taken from data in the atlas by Miller and Feddes (1971) and Environmental Satellite Imagery (1975, 1976). As a first approximation we divide cloud amount into four categories: A, B, C, D (see Figures 2-6). The monthly mean cloud amount values are given in ascending order:

A - trapezoids with mean cloud amounts ranging from 0 to 0.2,

B - trapezoids with mean cloud amounts ranging from 0.2 to 0.35,

C - trapezoids with mean cloud amounts ranging from 0.35 to 0.5,

D - trapezoids with mean cloud amounts more than 0.5.

In case there is some uncertainty in the determination of the category, the assigned category is the one for which the distribution of lower clouds and that of the clouds of vertical development are "closer" (see

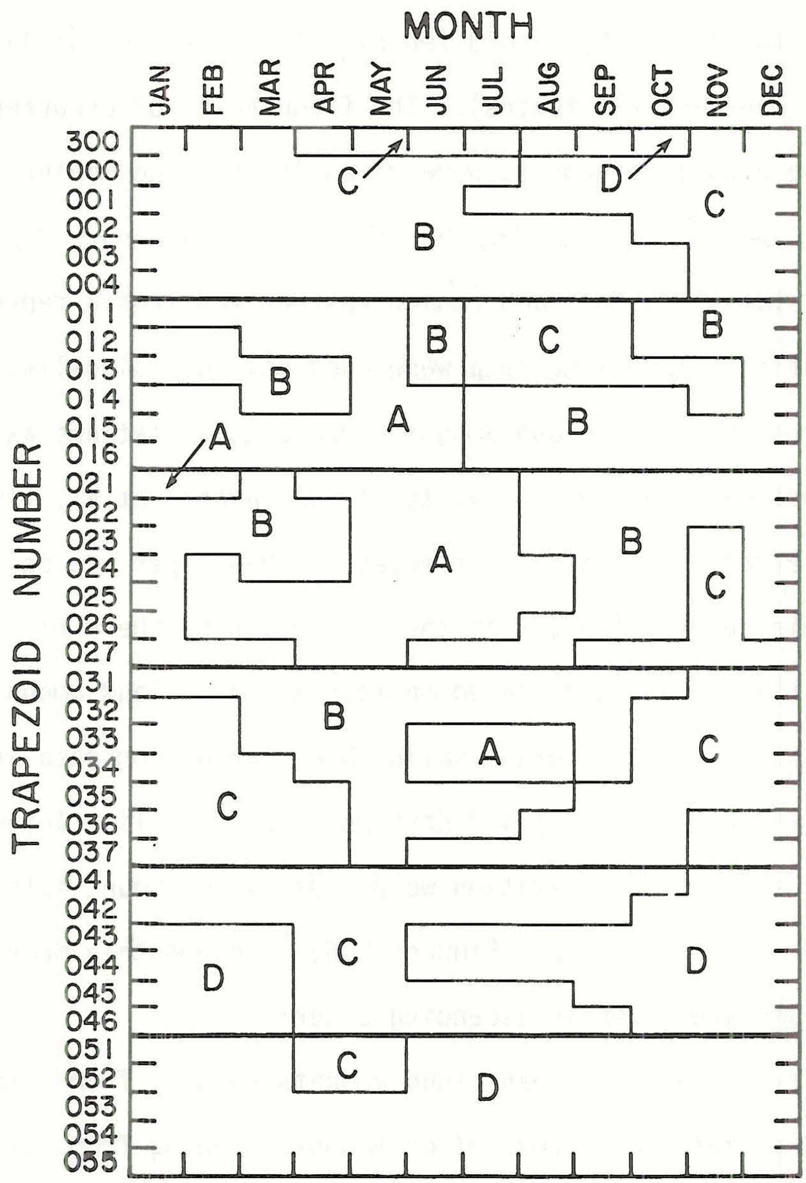


Figure 2 Annual variability in cloud amount over the northern half of the Atlantic Ocean.

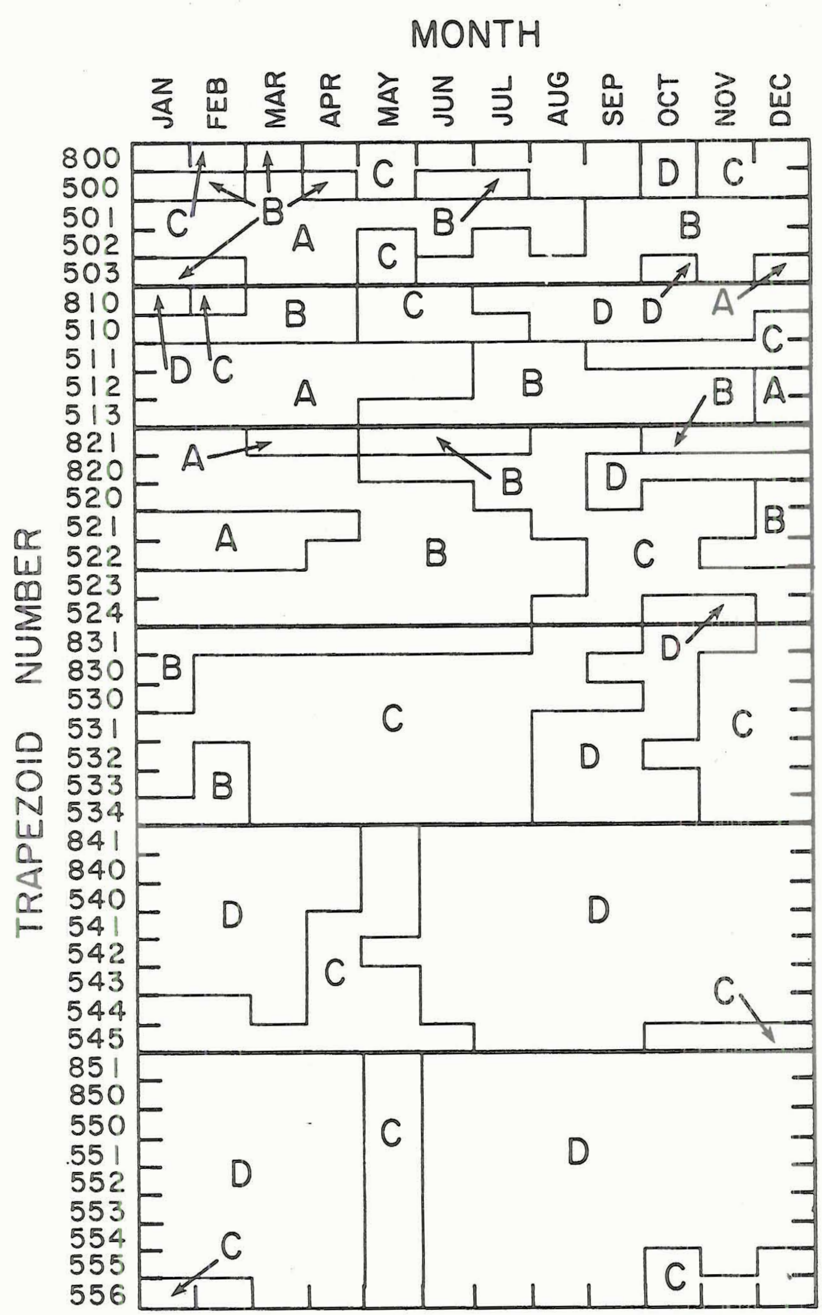


Figure 3 Annual variability in cloud amount over the southern half of the Atlantic Ocean.

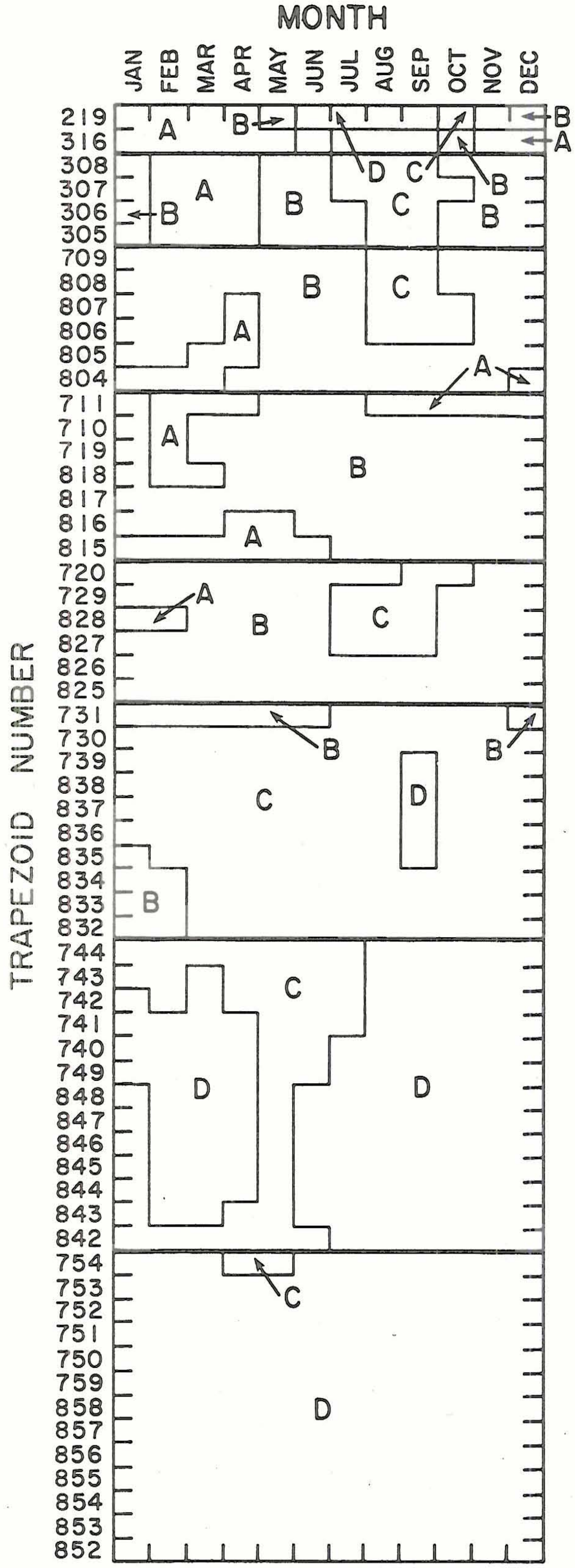


Figure 4 Annual variability in cloud amount over the Indian Ocean.

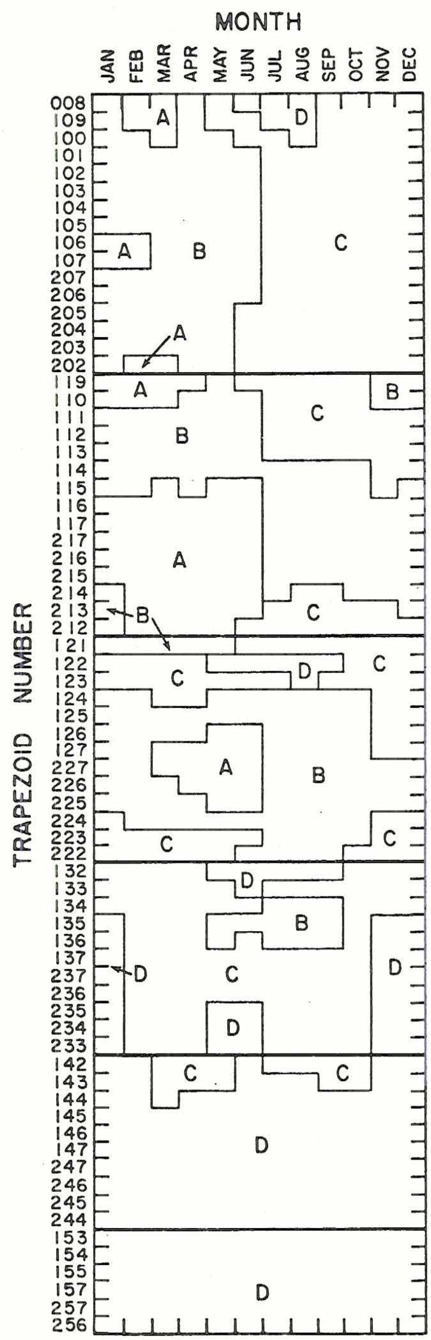


Figure 5 Annual variability in cloud amount over the northern half of Pacific Ocean.

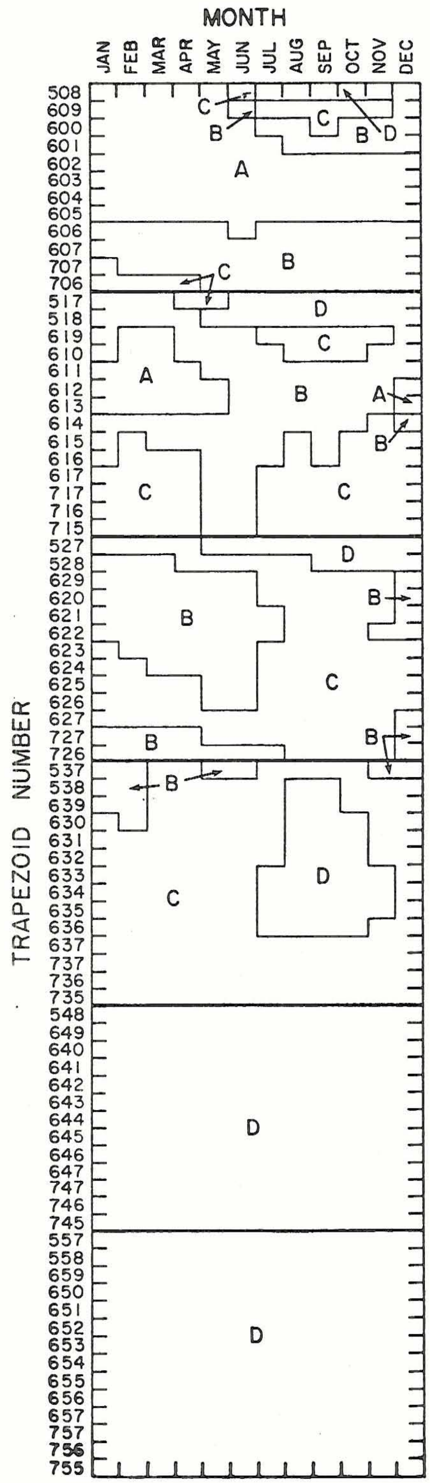


Figure 6 Annual variability in cloud amount over the southern half of Pacific Ocean.

Table 1). The "closeness" to a certain distribution is estimated using the following procedure. Let f_{ik}(i=1...5; k=A,B,C,D) be the frequency of cloud type (i) and cloud category (k), which can be determined using a trapezoid in which there is no uncertainty in the determination of cloud category according to Kravtsova (1970) and Lobanova (1966). Noting by f_i the frequency of cloud type in a trapezoid containing an uncertainty in the determination of cloud category, we assign to this trapezoid the category (k) for which the value max $(f_i - f_{ik})$ (for i = 1...5) is a minimum.

Following the method of Kravtsova (1970) and Lobanova (1966), we used a modified cloud-type classification, combining various cloud-type categories given in their reports. The classification scheme is given below (values in parentheses indicate the original code numbers):

1 - clear sky (0);

2 - cumulus clouds (1 + 2);

3 - stratocumulus clouds (4 + 5 + 8);

4 - stratus clouds (6);

5 - heavy weather clouds (7 + 9).

Table 1 gives frequencies of certain cloud-type categories over our trapezoids in percent.

Mean values of cloud amount in the trapezoids over the five-year period were calculated for a given cloud-type category, using the formula

$$\bar{x}_i = \frac{4}{5}\bar{x}_i^{(2)} + \frac{1}{5}\bar{x}_i^{(3)}, \tag{2}$$

where $\bar{x}_i^{(2)}$ is the four-year mean cloud amount given in the atlas by Miller and Feddes (1971); $\bar{x}_i^{(3)}$ is the mean annual cloud amount derived

AN, January

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	1334	12	57	16	1	14
B	4708	8	40	31	4	17
C	11192	6	27	36	7	24
D	7842	6	18	40	12	24

AN, July

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	6294	9	53	20	3	15
B	10775	10	49	21	3	17
C	13244	16	35	27	7	15
D	8584	11	19	39	15	16

AS, January

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	839	9	52	20	2	17
B	2309	14	47	24	3	12
C	294	9	34	36	5	16
D	300	9	22	45	11	13

AS, July

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	88	10	41	35	6	8
B	4159	14	41	27	4	14
C	1600	9	22	45	8	16
D	558	12	5	67	8	8

I, January

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	306	14	59	9	2	16
B	2015	11	52	20	2	15
C	285	11	31	41	7	10
D	-	-	-	-	-	-

I, July

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	-	-	-	-	-	-
B	3240	6	48	23	2	21
C	1736	17	31	27	5	20
D	-	-	-	-	-	-

PN, January

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	724	8	41	27	7	17
B	4585	8	40	33	5	14
C	5081	7	23	48	8	17
D	8370	4	20	41	11	24

PN, July

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	-	-	-	-	-	-
B	9676	4	49	29	4	14
C	12421	7	28	38	10	16
D	10836	8	7	48	25	12

Table I. (Page 1.)

PS, January

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	685	11	49	30	2	8
B	833	8	44	28	5	15
C	1392	10	34	35	5	16
D	447	7	19	41	16	15

PS, July

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	321	10	65	15	2	8
B	1513	9	52	22	5	12
C	3142	7	37	31	5	20
D	749	7	33	32	6	22

Northern Hemisphere

Winter

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	2058	11	51	20	3	15
B	9293	8	40	32	4	16
C	16273	6	26	40	7	21
D	16212	5	19	41	11	24

Summer

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	6294	9	53	20	3	15
B	20451	7	49	25	3	16
C	24665	12	33	32	8	15
D	19420	9	12	44	21	14

Southern Hemisphere

Winter

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	409	10	60	19	3	8
B	8912	10	45	25	4	16
C	6478	10	32	33	6	19
D	1307	9	21	47	7	16

Summer

Cloud Category	Number	Cloud Type 1	2	3	4	5
A	1830	11	52	22	2	13
B	5157	12	48	23	3	14
C	1971	10	34	36	5	15
D	747	8	20	43	14	15

Table I. Distribution of different cloud types in the cloud amount categories A, B, C, D.

Part of the Ocean	Cloud Category	$\bar{x}_i^{(2)}$	σ_i^2	$x_i^{(3)}$ 75-76	s^2 75-76	n 75-76
AN	A	.16	.027	.16	.014	1766
AS	A	.17	.027	.16	.012	1461
I	A	.15	.027	.15	.014	827
PN	A	.14	.027	.14	.014	2017
PS	A	.16	.027	.17	.015	1002
Σ	A	.15	.027	.15	.014	7073
AN	B	.28	.042	.25	.027	3359
AS	B	.26	.042	.29	.024	1492
I	B	.28	.042	.27	.033	1673
PN	B	.29	.042	.26	.032	2390
PS	B	.27	.042	.29	.032	2180
Σ	B	.28	.042	.28	.032	11094
AN	C	.46	.042	.41	.044	3772
AS	C	.44	.042	.45	.041	1339
I	C	.43	.042	.45	.048	907
PN	C	.43	.042	.43	.057	1513
PS	C	.44	.042	.45	.060	1600
Σ	C	.44	.042	.44	.053	9131
AN	D	.60	.065	.56	.056	3072
AS	D	.64	.065	.62	.054	1628
I	D	.62	.065	.59	.062	1434
PN	D	.61	.065	.64	.061	2138
PS	D	.56	.065	.62	.062	2882
Σ	D	.60	.065	.60	.060	11154

Table 2. Statistical estimates of cloud amount over the World Oceans.

from the histograms of the Environmental Satellite Imagery (1975, 1976). The third column of Table 2 presents these $\bar{x}_i^{(2)}$ values, the fifth column gives $\bar{x}_i^{(3)}$ values. Data in Table 2 illustrate the variability of mean annual and five-year cloud amount values over different parts of the World Ocean: AN denotes the northern half of the Atlantic, AS signifies the southern half of the Atlantic, I designates the Indian Ocean, PN indicates the northern half of the Pacific, PS stands for the southern half of the Pacific and Σ designates the total territory of the World Ocean between 60°N and 60°S. In order to determine variances in cloud amounts, we assumed that the distribution of mean monthly cloud amounts will have an asymtotically normal distribution and the corresponding variances of monthly cloud amounts are

$$\tilde{\sigma}_1^2 = \frac{\sigma_A^2}{30}, \quad \tilde{\sigma}_2^2 = \frac{\sigma_B^2}{30}, \quad \tilde{\sigma}_3^2 = \frac{\sigma_C^2}{30}, \quad \tilde{\sigma}_4^2 = \frac{\sigma_D^2}{30}. \qquad (3)$$

Assuming that the value $\bar{x}_i \pm 2\tilde{\sigma}_i$ (where $\bar{x}_i$ is the mean monthly cloud amount) covers the whole interval of variation of cloud amounts in a certain cloud amount category, we can calculate the theoretical estimates of variances for every category by using the formula

$$\left.\begin{aligned} &\bar{x}_1 + 2\tilde{\sigma}_1 \geqq 0.2; \quad \bar{x}_2 + 2\tilde{\sigma}_2 \geqq 0.35; \quad \bar{x}_3 + 2\tilde{\sigma}_3 \geqq 0.5; \\ &\bar{x}_2 - 2\tilde{\sigma}_2 \leqq 0.2; \quad \bar{x}_3 - 2\tilde{\sigma}_3 \leqq 0.35; \quad \bar{x}_4 - 2\tilde{\sigma}_4 \leqq 0.5. \end{aligned}\right\} \quad (4)$$

The results of the estimated variances σ^2 (i = A,B,C,D) are given in the fourth column of Table 2. The variances of cloud amounts on the basis of charts of the Environmental Satellite Imagery (1975, 1976) are presented in the sixth column. The last column in Table 2 gives the total number of observations according to the Environmental Satellite Imagery (1975, 1976). Table 2 demonstrates that these two estimates of variances are essentially different for the cloud amount categories A and B. This is probably due to the instability of cloudiness: there might exist periodicities in cloud amounts which are longer than one year. The question remains open for further research.

2.4 Approximation of the cloud amount distribution above certain trapezoids

Let us examine the procedure of determining histograms of the cloud cover above the North Atlantic according to the data of the Environmental Satellite Imagery (1975-1976). We have a random variable distributed in the interval [0;1]. Moments uniquely determine the distribution function (Kendall and Stewart, 1966). One might also expect to find interannual periods in the variability of cloud amount. Then the estimates of the moments calculated from the experimental data will reveal a certain trend. Sample estimates of the moments of the whole population distribution parameters do not appear to be the most effective characteristics. Nevertheless, by using these moments it is possible to derive a mathematical expression of the distribution which satisfactorily describes an experimental sample. Approximating the cloud amount distribution over the region which is larger than the observation area for the ground observer, the normal distribution in the paper by Greaves et al. (1971) was used. A shortcoming of such an approximation lies in the fact that the symmetric normal distribution function is unlimited. Such an approximation will give too high weights depending on the values of the variance to the unreal values of $x < 0$, $x > 1$. In the paper by Falls (1974) it was found that the best agreement between the empirical and theoretical distributions is given by the beta distribution. A comparison was carried out using the Kolmogorov-Smirnov criterion between various distributions: normal, ZOLD (zero order logarithmic distribution), exponential ones as well as the Weibull distribution and the first and the second kind of the Fisher-Tippett distribution. The beta distribution is superior to any of the above mentioned distributions, as it is versatile, bounded at both ends (0;1) and it is capable of assuming a wide variety of shapes. It should, however, be mentioned that in the paper by Falls (1974) the primary data obtained from ground stations and from satellites were used simultaneously without any correction factor. As pointed out in Avaste (1969) and Avaste et al. (1972), the ground surface observations always give overestimates of cloud amounts and strictly, such a joint analysis of both data sets without correction factors, is erroneous.

Yet the beta distribution is the most convenient one in approximating cloud amount distributions over the 10 x 10° regions. One can become convinced of that when one uses Pearson's method of fitting theoretical distributions.

In case of any central sample moments m_2, m_3, m_4 the parameter

$$\kappa = \frac{\beta_1 (\beta_2 + 3)^2}{4(2\beta_2 - 3\beta_1 - 6)(4\beta_2 - 3\beta_1)}, \qquad (5)$$

(where $\beta_1 = \frac{m_3^2}{m_2}$, $\beta_2 = \frac{m_4}{2}$) indicates the existence of the beta distribution when $\kappa < 0$. In our case this condition was fulfilled for all cloud amount categories (A, B, C, D). In some cases there are small deviations at both bounds of the inteval [0,1].

The density of the beta distribution is given by the formulae

$$B(x,p,q) = \frac{\Gamma(p+q)}{\Gamma(p)\,\Gamma(q)} x^{p-1} (1-x)^{q-1}, \qquad (6)$$

$$p = \frac{mq}{1-m}, \quad q = \frac{1-m}{\sigma^2} [m(1-m) - \sigma^2], \qquad (7)$$

where m is the mean value and σ^2 is the variance. Values m and σ approach zero at the points x = 0, x = 1 when p > 1 and q > 1. The real cloud amount densities are not equal to zero at the bounds of the interval [0,1] in categories A and D, but for all practical purposes this circumstance is not too serious a restriction. It is easy to show that the integrals

$$\int_0^{0.05} B(x,p,q)\,dx \text{ and } \int_{0.95}^{1} B(x,p,q)\,dx, \qquad (8)$$

yield a sufficiently adequate approximation of the real frequencies at the bounds [0,1] for all the cloud amount categories A, B, C, D. If we replace m and σ^2 with the sample estimates $\bar{x}$ and s^2 (using the data on the World Ocean) we can find the parameters p and q. To compare the distribution function

$$F(x) = \int_0^x B(t,p,q)\,dt \qquad (9)$$

with the empirical function $F_n(x)$ (deduced by summing up the histogram data for a given cloud category) we used the Kolmogorov-Smirnov criterion. The values

$$D_n = \max|F(x_i) - F_n(x_i)|, \quad i = 1,2\ldots10 \qquad (10)$$

give estimates of deviations between these distribution functions. Critical values $D_n^* = \Delta_{\alpha,n}$ at the $1 - \alpha = 95$ percent confidence level were found from the asymptotic formula in Tiit, et al. (1977)

$$\Delta_{\alpha,n} = \sqrt{\frac{-\ln(\alpha/2)}{2n}}\,. \qquad (11)$$

For instance, for the northern half of the Atlantic Ocean we received the following D_n values (for categories A, B, C, D respectively): 0.025, 0.020, 0.017, 0.025. The corresponding critical values $\Delta_{\alpha,n}$ = 0.032, 0.023, 0.022, 0.025 show that at the 95 percent confidence level our samples could be considered as samples of the beta distribution. The parameters p and q have the following values in different cloud amount categories:

	p	q
A	1.37	7.25
B	1.48	4.45
C	1.96	2.81
D	2.04	1.60

2.5 Estimates of correlation

Let us assume that we have sample estimates of cloud amounts over a particular trapezoid and we are interested in drawing conclusions on cloud-cover conditions over large territories. The question arises: is it allowed to use our sample estimates of cloud amounts as independent values? Let us first deal with the cross-correlation of cloud amount estimates within the limits of one cloud amount category. We carried out such an estimate in the summer period above the North Atlantic. From the handbook by Kramer (1975) we obtain approximate confidence levels to test if the correlation coefficients r_{xy} are practically equal to zero. R. Fisher (see e.g. Kramer, 1975) showed that for two samples of the normal distribution the parameter

$$\zeta = \frac{1}{2} \log \frac{1+r}{1-r} \qquad (12)$$

has a normal distribution for small r values, with the mean value being

$$\overline{\zeta} = \frac{1}{2} \log \frac{1+\rho}{1-\rho} + \frac{\rho}{2(n-1)} \qquad (13)$$

and the variance

$$\sigma^2 = \frac{1}{n-3} . \qquad (14)$$

Here n denotes the sample size, ρ signifies the correlation coefficient of the population, r indicates the sample correlation coefficient. Let us use the 95 percent confidence level for r and assume that $\rho = 0$. Then we receive correlation matrices (given in Tables 3-5) of cloud amounts over the trapezoids in the summer period for the cloud amount categories A, B, C. The corresponding 95 percent confidence level intervals of the zero correlation equals $\pm$ 0.44 (when n = 92). This fact allows us to consider the occurrences of cloud amounts over different trapezoids of the same category as independent events.

2.6 Cloud amount distribution above large marine areas

By processing the data in the Environmental Satellite Imagery (1975, 1976), it is possible to give estimates of cloud amounts over large regions, compared with our 10x10° trapezoids. By way of an example let us analyze the cloud situation over the latitude belt 60°N to 0° over the northern half of the Atlantic Ocean. The weights on different trapezoids are given by special scaling constants, which take into account the relation of an individual trapezoid areas to the area of the region for which we need estimates. Figure 7 illustrates the empirical density of the cloud amount distribution over the above mentioned part of the ocean in the time interval March, 1975 - February, 1976. The parameters of the derived beta distribution are p = 10.22, q = 23.62 and the values of deviations were correspondingly $D_n = 0.016$, $\Delta_{\alpha,n} = 0.071$. The coincidence of the empirical distribution with the assumed beta distribution is rather good.

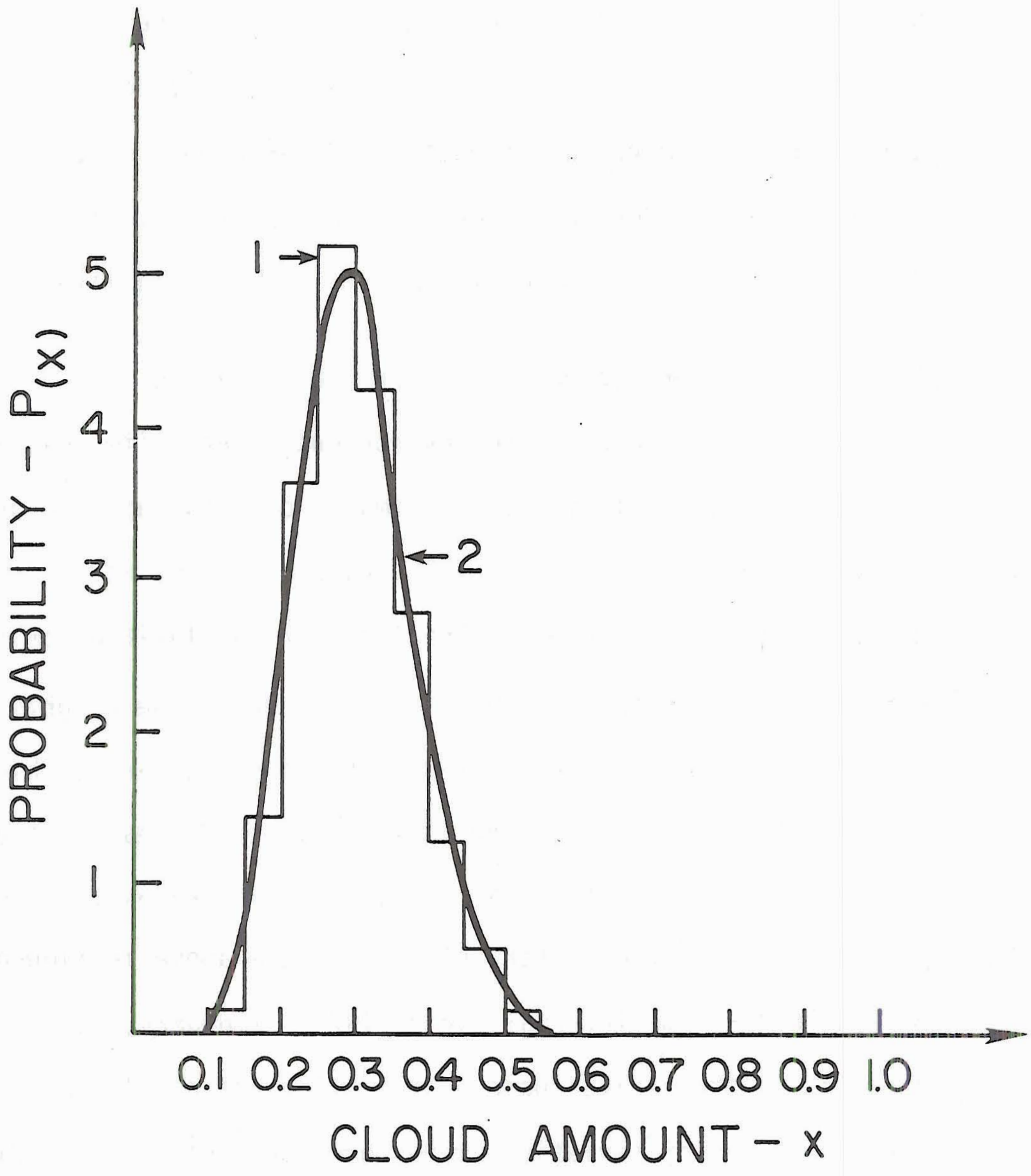


Figure 7 Probability density function of cloud amount. Curve 1 shows the northern part of the Atlantic Ocean derived from the Environmental Satellite Imagery (1975-1976). Curve 2 shows beta distribution.

	014	015	016	021	022	023	024	025	026	027
014	1	.34	.17	.27	.17	-.11	.32	.15	.17	.37
015	.34	1	.52	.16	-.07	.04	.22	.23	.22	-.04
016	.17	.52	1	.23	-.01	.08	.08	.36	.37	-.01
021	.27	.16	.23	1	.40	.24	.37	.26	.16	.32
022	.17	-.07	-.01	.40	1	.42	.29	.10	.19	.16
023	-.11	.04	.08	.24	.42	1	.44	.08	.26	-.12
024	.32	.22	.08	.37	.29	.44	1	.08	.14	.12
025	.15	.23	.36	.26	.10	.03	.08	1	.45	.14
026	.17	.22	.37	.16	.19	.26	.14	.45	1	.22
027	.37	-.04	-.01	.32	.16	-.12	.12	.14	.22	1

Table 3. Correlation matrix of cloud amounts over trapezoids of the A category (Summer, 1975).

	000	001	002	003	004	036	037
000	1	-.07	.03	-.06	.11	-.19	-.17
001	-.07	1	.10	-.09	-.03	-.01	-.00
002	.03	.10	1	.12	.02	.17	.05
003	-.06	-.09	.12	1	.41	-.01	.01
004	.11	-.03	.02	.41	1	-.05	-.03
036	-.19	-.01	.17	-.01	-.05	1	.23
037	-.17	-.00	.05	.01	-.03	.23	1

Table 4. Correlation matrix of cloud amounts over trapezoids of the B category (Summer, 1975).

	041	042	043	044	045	046
041	1	.18	.14	.02	-.14	.03
042	.18	1	.41	.04	.23	.10
043	.14	.41	1	.14	.11	.00
044	.02	.04	.14	1	.32	.03
045	-.14	.23	.11	.32	1	.31
046	.03	.10	.00	.03	.31	1

Table 5. Correlation matrix of cloud amounts over trapezoids of the C category (Summer, 1975).

2.7 Possibility of comparing cloud amounts according to different authors

The cloud amounts classification (Sherr et al., 1968) is based on the ground-surface and ship data. Satellite data were used in (Winston, 1969; Godshall et al. 1969; Srinivasan, 1968; Lyosakov and Milashenko, 1974; Titov and Golovleva, 1977; Momose, 1975; Abramow et al. 1976; and Malberg, 1973a, 1973b). The global classifications proposed by Sherr et al. (1968) and Winston (1969), are useful also when cloud amounts over all the quadrants of interest are compared. In the paper by Titov and Golovleva (1977) the chart of the mean cloud amount in the Northern Hemisphere in July, 1973, and the charts of differences in cloud amounts between July and January are presented. The other above mentioned papers carry out comparisons only over limited territories. It should be mentioned that these estimates of the mean cloud amount over a definite territory show a tendency to decrease. As a rule, the later estimates are smaller over the same region. This may be explained by the fact that earlier estimates were made using only the ground surface and the ship data. The earlier satellite data had too small a spatial resolution. The tendency is quite clearly illustrated in the paper by Winston (1969). The main difficulty is in carrying out comparisons over different scales of averaging. The following papers (Miller and Feddes, 1971; Winston, 1969; Godshall et al. 1969; Srinivasan, 1968; Lyosakov and Milashenko, 1974; Titov and Golovleva, 1977; Momose, 1975; and Malberg, 1973a, 1973b) present charts of mean cloud amounts over small regions, which were considered as "units." These charts give a good visual aid for tracking cloud assemblies but do not give any information on the mutual dependence of cloud amounts in adjacent "unit areas." A trivial estimate of cloud amounts over larger territories with the assumption that there is no dependence of cloud amounts in adjacent "unit areas" leads to undeterminable errors. Summarizing the above argument, we point out that it is impossible to carry out sufficiently exact comparisons of the published data on mean cloud amount values. Crude comparison shows that the largest differences in cloud amounts occur in the latitude zones 10-30°N and 10-30°S over the Atlantic Ocean.

2.8 Summary

An attempt has been made to classify cloud amount distributions over the World Ocean using published satellite cloud amount data. The cloud amount distribution was approximated by theoretical distribution functions, while the "unit" territory of averaging was 10x10°. The chosen beta distribution (the first kind of distribution in the family of Pearson's distributions) is sufficiently simple and gives a good approximation of sample distribution densities over the interval (o;1).

Our analysis shows that the following questions must be solved in future investigations:

1. The question, "How is the cloud amount classification used here, influenced by daily and longer (more than one year) periodical variations?" needs further clarification. Our analysis shows that there are at least some latitudes where experimental distribution functions reveal gross differences from theoretically predicted values.

2. The annual trend of cloud amount values near the equator is too strongly smoothed when "unit" 10 x 10° trapezoids are used. The effect of the Gulf stream on cloud classification is also not apparent when

such a scale of averaging is used. To track the above mentioned effects more clearly, it is recommended in future research to use averaging areas of 5 x 5^{o} or smaller.

3. Around the latitudes 60^{o}N, some trapezoids in the autumn season reveal cloud amounts of sizes 0.7 to 0.8. For a more detailed investigation, it will be reasonable to add one more cloud category, E, (trapezoids in which cloud amounts are larger than 0.65).

3.0 COMPARISON OF CLOUD AMOUNT DATA IN THE LATITUDE BELT BETWEEN 30^{o}N and 30^{o}S

3.1 Introduction

In the previous section the cloud amount statistics were investigated using 10 x 10^{o} trapezoids as the basic area. Here we shall study the effect of the averaging over such large basic units. It should be noted that the 1967-1970 data of cloud amounts used in the previous section of this report were deduced from the atlas of Miller and Feddes (1971). As it was pointed out in the monograph by Barrett (1974), the automated technique of Miller (1971) used by Miller and Feddes (1971), underestimates small cloud amounts since the vidicon camera system cannot sense small amounts of small cumulus or thin cirrus cloud. Miller and Feddes claim that the automated cloud amount values are at least as good as those that can be derived by an observer from a satellite picture.

The question, "How close are both these estimates to the true cloud amount?" is still open to discussion. Is it at all possible to carry out sufficiently exact comparisons with the nephanalysis data? As mentioned in the paper by Sadler et al. (1976), there is no satisfactory "ground truth" for comparison. Nephanalysis probably gives an overestimate of cloud amount. Significant variability between the total cloudiness estimates made by other analysts was found by Young (1967) when he performed a "torn paper" test. The mean error was one octa and the overestimation was the greatest when the total cloudiness was less than four octas and the "torn paper picture" resembled a cumulus population typical of the tropical and trade wind regime.

There is a similar overestimation of cloud amount made by ground observers due to the apparent coalescence of cloud elements near the horizon. The "apparent" cloudiness increases with increasing zenith angle. This overestimation of the cloud amount is also greatest with cumulus clouds of 4 octas. According to papers by Avaste (1969), Avaste et al. (1972), Barnes (1966), and Malberg (1973b), the overestimate of cloud amount by ground observers is 1-2 tenths (0.8 - 1.6 octas).

It is important to compare the cloud amounts derived by different methods over the same spatial and temporal scales. This gives us an estimate of the discrepancies between the methods and allows us to use differently deduced temporal series of cloud amounts to analyze the multi-year cloud amount trends.

3.2 Data sets for cloud amount comparison

We shall use the 2.5x2.5° elementary areal averaged cloud amount data deduced from nephanalysis (Sadler, 1969; Sadler et al. 1976; Steiner, 1978). Table 6 shows the suggested relationship between "neph" categories and cloudiness. The nephanalysis averages are assumed to be roughly equivalent to "eights", or standard WMO octas of cloudiness. In the last column of Table 6 the cloud amount is also given in tenths. As can be seen from Table 6 each nephanalysis category of cloudiness was assigned an odd numerical value ranging from 1 to 9 (see column 3). The first atlas by Sadler (1969) gives the cloud amount data for the tropical belt between 30°S and 30°N for the 24 month sample: February, 1965 to January, 1967 inclusive. Sadler et al. (1976), in the second atlas, give the mean cloud amounts and daily variances over the Pacific for the nearly complete eight-year period: February, 1965 to December, 1972 inclusive. The data sources for the atlases (Sadler, 1969; Sadler et al. 1976) were operational nephanalyses prepared by the Data Pro-

"Neph" category (Symbol)	Range of cloudiness (per cent)	Assigned value	Approximate cloudiness	
			Octas	tenths
Open (O)	< 20	1	0 - 1	0 - 1
		2	2	
Mostly open (MOP)	20 - 50	3	3	2 - 5
		4	4	
Mostly covered (MCO)	50 - 80	5	5	5 - 8
		6	6	
Covered (C)	> 80	7	7	8 - 9
		8	8	
Heavily covered (+C)		9	8	10 [10]

Table 6. Suggested relationship between "Neph" categories and cloudiness.

cessing and Analysis Division of the National Environmental Satellite Service (NESS), a division of NOAA. The nephanalyses were hand drawn from interpretations of photographs from the vidicon cameras of TIROS IX and X, ESSA 1,3,5 and 7, ITOS-1, NOAA-1 and from the visual channel of the scanning radiometer of NOAA-2 satellites. The transit times of all satellites prior to NOAA-2 were near to 1400 local time. NOAA-2 which was launched in November, 1972, had a transit time near 0900 local time.

The atlas prepared by Sadler, et al. (1976) is the first 8-year uniquely analyzed cloud data from space. These data were also used in the paper by Steiner (1978) to derive the 5x5° averaged monthly mean cloud amount values over the Tropical Pacific. Thanks to the courtesy of NCAR, we were able to use, for comparison, the nephanalysis data tape which stored the 2.5x2.5° elementary trapezoid data (of monthly mean cloud amount values) over the tropical belt 30°S to 30°N from February, 1965 to July, 1973.

For a more detailed comparison we chose an area from the GATE satellite data set ($5^{o}S$ - $20^{o}N$; $50^{o}W$ - $10^{o}W$) as it is suitable for the future comparison of detailed radiation data and cloud data with the aim to develop algorithms for determining cloud parameters (amount, height, and type) from the radiation data (Cox and Kraus, 1975; Smith and Vonder Haar,, 1976; and Mendola and Cox, 1978).

3.3 The refinement of cloud amount classification

3.3.1 Assumptions

We shall solve the problem of estimating the effect of the averaging scale in three steps: first of all we use as basic units the 2.5x2.5° trapezoids from the data of Sadler et al. (1976). Then we calculate, as in the paper by Steiner (1978), the cloud amounts for $5x5^0$ trapezoids and also for 10x10° trapezoids. To count these trapezoids we will make use of the chosen coordinate system, i.e. trapezoid numbers as given in Figure 1. Trapezoid numbers should be determined as in the Ship Observation Handbook (1974).

We shall use the following two basic assumptions:

1) the optimal distribution function for cloud amounts is the beta distribution (see Falls, 1974);
2) cloud amounts over elementary trapezoids will have an annual variation, i.e. we must consider twelve monthly random cloud amount values X (j = 1,...12), over every trapezoid i(i = 1,....n).

According to these assumptions we shall use as primary data random variables x_{ijk}, where i designates the elementary trapezoid (i = 1,...n), j notes the month (j = 1, ...12), and k shows the year (k = 1,...K).

3.3.2 Classification

For every k value according to the sample mean value the following classification should be carried out:

Category	Cloud Amount	
	In Tenths	In Octas
A	$0 \leq x_{ij} \leq 2$	$0 \leq x_{ij} \leq 1.6$
B	$2 < x_{ij} \leq 3.5$	$1.6 < x_{ij} \leq 2.8$
C	$3.5 < x_{ij} \leq 5$	$2.8 < x_{ij} \leq 4$
D	$5 < x_{ij} \leq 6.5$	$4 < x_{ij} \leq 5.2$
E	$6.5 < x_{ij} \leq 10$	$5.2 < x_{ij} \leq 8$

Table 7. Classification of trapezoids according to the cloud amount values.

3.4 The choice of the area of the basic trapezoid

As was pointed out in part 2.0 of this report the 10 x 10^{o} elementary trapezoids were too large for a detailed investigation of the cloudiness over the ITCZ.

For the detailed analysis of the annual variability of cloudiness in the tropical zone we chose the area 10^{o}S to 20^{o}N; 50^{o}W to 10^{o}W, i.e. an area approximately representing the 1974 GATE A-Scale experimental region. Figure 8 demonstrates the effect of areal averaging on the cloud amount classification from 1965 to 1972.

The main conclusion from the comparison of different scales of averaging is that the basic 5x5^{o} units describe with sufficient detail the distribution of the Near-Equatorial Maximum Cloud Zone. It should be noted, as in Sadler et al. (1976), that this zone has been often equated to the ITCZ. However, prior to satellite observations, the ITCZ was usually defined as a feature of the pressure and/or wind field with the assumption that the pressure trough (the line of "clash of the trades") and the Maximum Cloud Zone coincided (Sadler et al. 1976). As Sadler (1975) pointed out, this assumption is not valid over much of the tropics and it is preferable to refer to the Near-Equatorial Zone of deep convective cloudiness as the Maximum Cloud Zone (MCZ).

The basic 10x10^{o} units smooth out the main peculiarities of the Near-Equatorial MCZ. It should be mentioned that in the review paper by the JOC Study Conference on Parameterization of Extended Cloudiness and Radiation for Climate Models, Smith (1978) recommended the use of a space resolution for cloud investigation of 250 km. At tropical latitudes (30^{o}S - 30^{o}N) 5^{o} longitude is equivalent to 483 km whereas at the equator it is equivalent to 555 km. This means that we will be able to determine global cloud distribution using half of the spatial resolution recommended by Smith (1978).

3.5 The multi-year variation of monthly mean cloud amount

The annual changes in the years 1965 to 1973 of the monthly mean cloud amount over the GATE A-Scale area are given in Figure 9. Figure 9 demonstrates the wave-like change within the latitude of the Near Equatorial MCZ: in January the MCZ lies in the latitudinal belt from 0 - 5^{O}N; in July - August it shifts to the belt 5 - 15^{O}N.

From Figures 8, 9 and 10 it is possible to draw some conclusions about the changes in the cloud amount over the GATE region:

1) the year-to-year variations in cloud amount over the GATE region for the latitudes 0-5°N are smaller than for the 5-10^{O}N belt. Note also that the mean cloud amount in the 0-5° belt is smaller.
2) It is typical that the correlation of the cloud amounts in adjacent 5x5° trapezoids is very high in the same latitudinal belt.
3) In the latitudinal belt 10-20°N cloudiness increases approximately 1 to 2 octas (from 10°W to 40°W), i.e. cloud amount increases with the increasing distance from the coast of Africa.
4) In the period from June to November (inclusive) cloud amount in the 5-10°N belt is higher than in the 0-10°N by approximately 1-1.5 octas. This is connected with the earlier mentioned northward shift of the Near-Equatorial MCZ in the summer.
5) Figure 10 illustrates the eight-year (1965-1973) trend of cloud amount in the central area of the GATE region (0-10^{O}N, 30-20^{O}W) and also in the larger area (10°S-20°N, 40°W-10°W). There are two main features in these curves: a) the year-to-year variation of

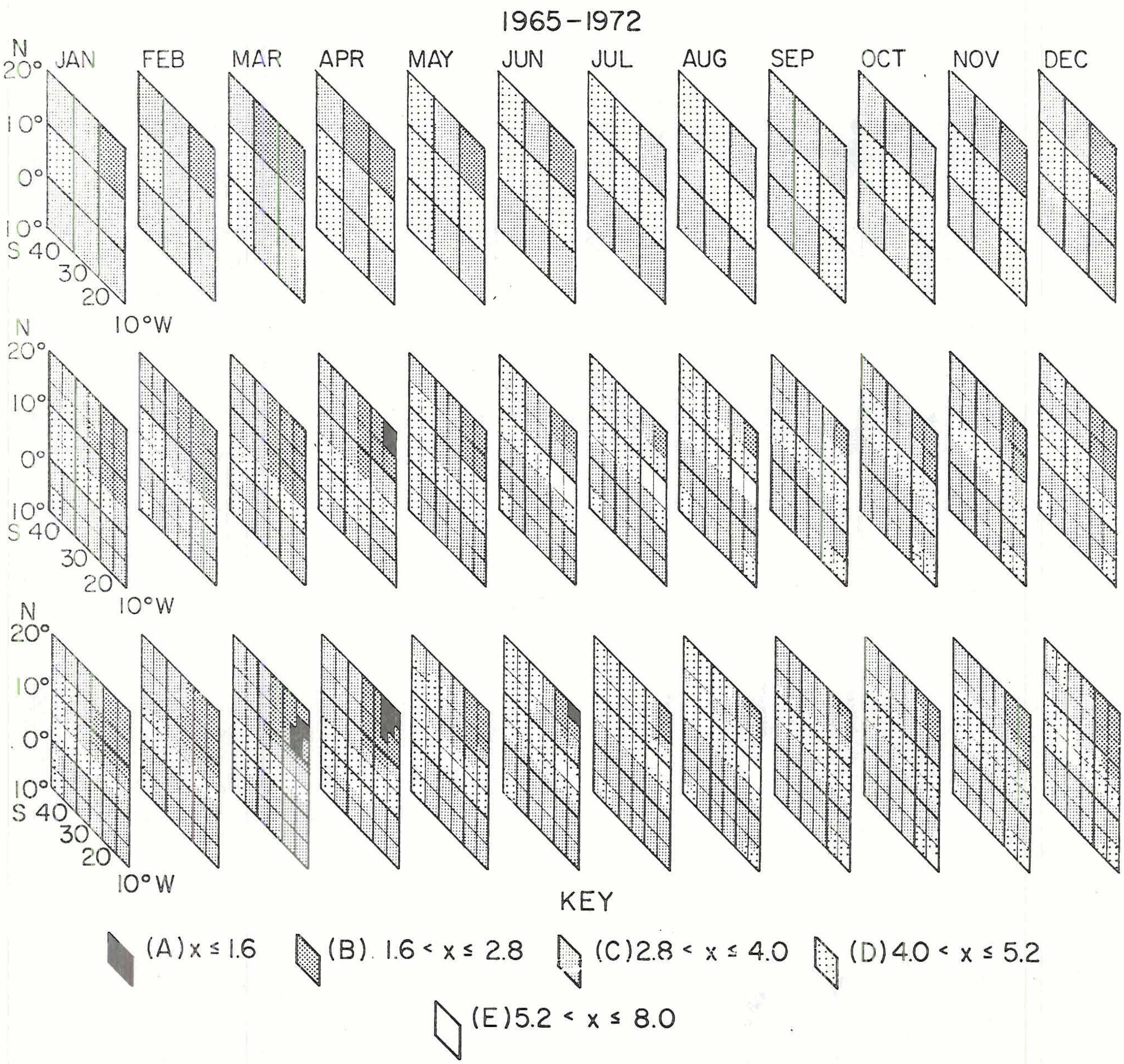


Figure 8 Monthly mean cloud amounts over the GATE area averaged over the years 1965-1972
a) 10 x 10° trapezoids
b) 5 x 5° trapezoids
c) 2.5 x 2.5° trapezoids.

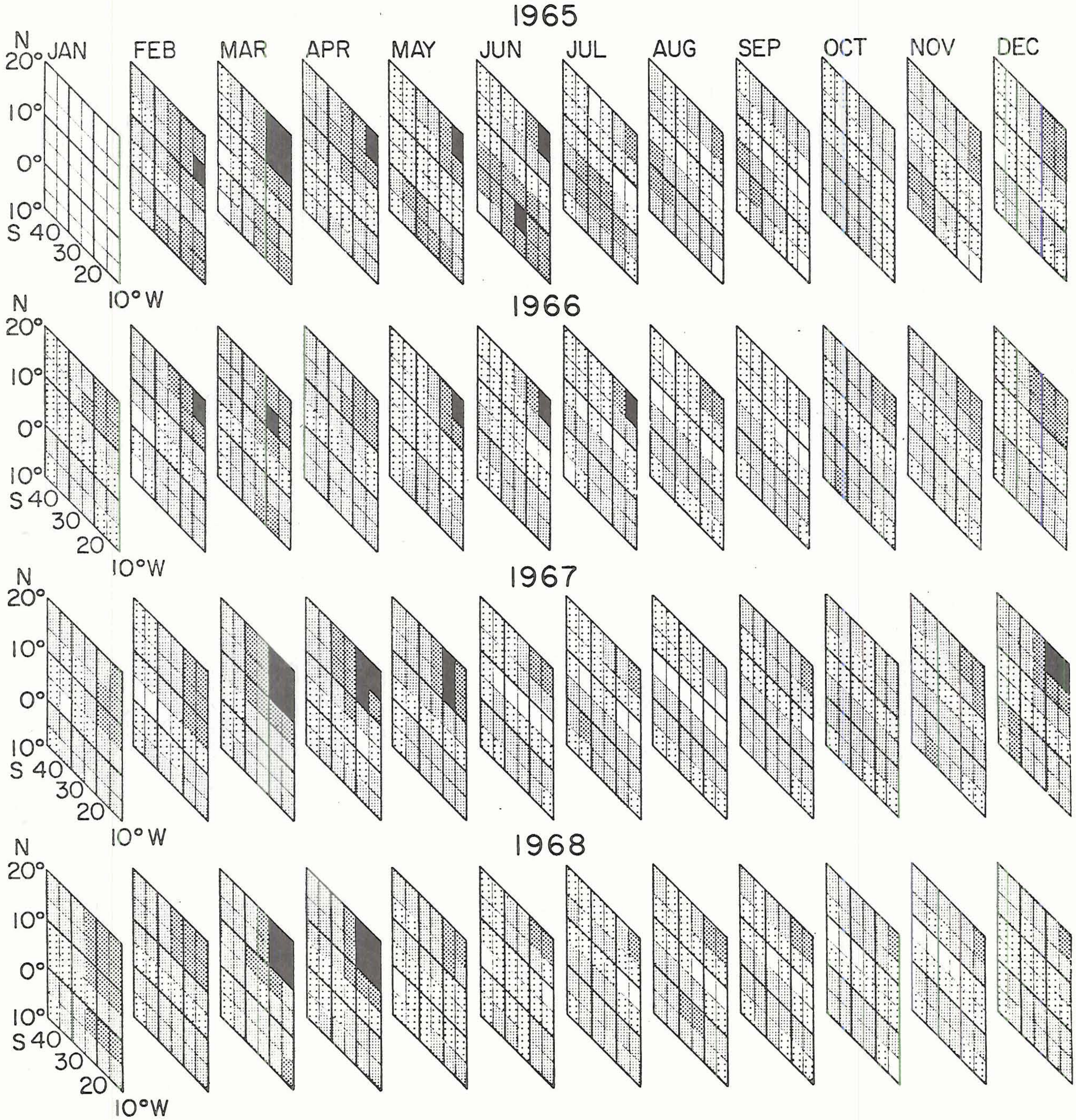


Figure 9a Monthly mean cloud amount variation over the GATE area for the years 1965 through 1968 (5 x 5° trapezoids). For key to shading see Figure 8.

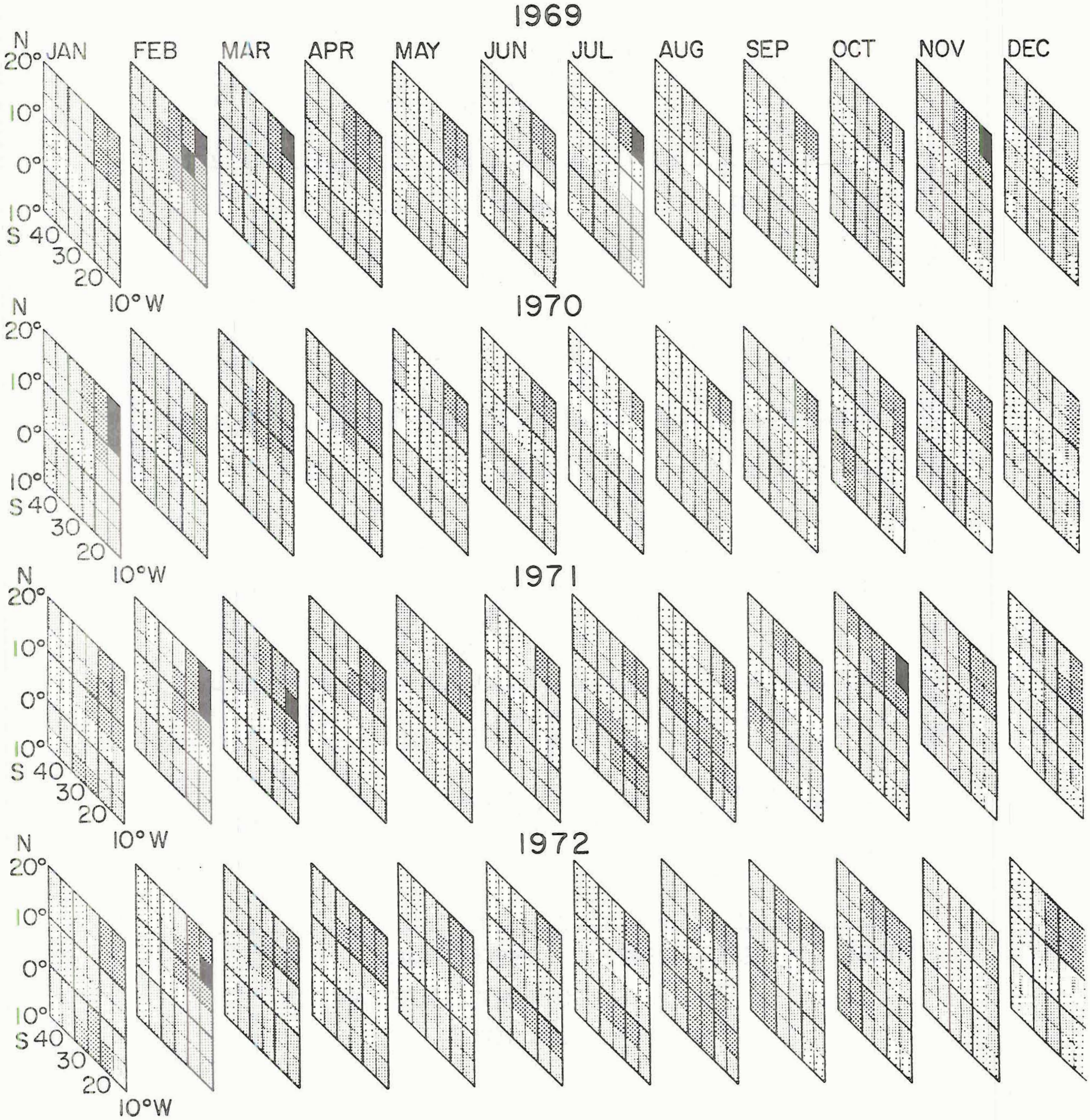


Figure 9b Monthly mean cloud amount variation over the GATE area for the years 1968 through 1972 (5 x 5° trapezoids). For key to shading see Figure 8.

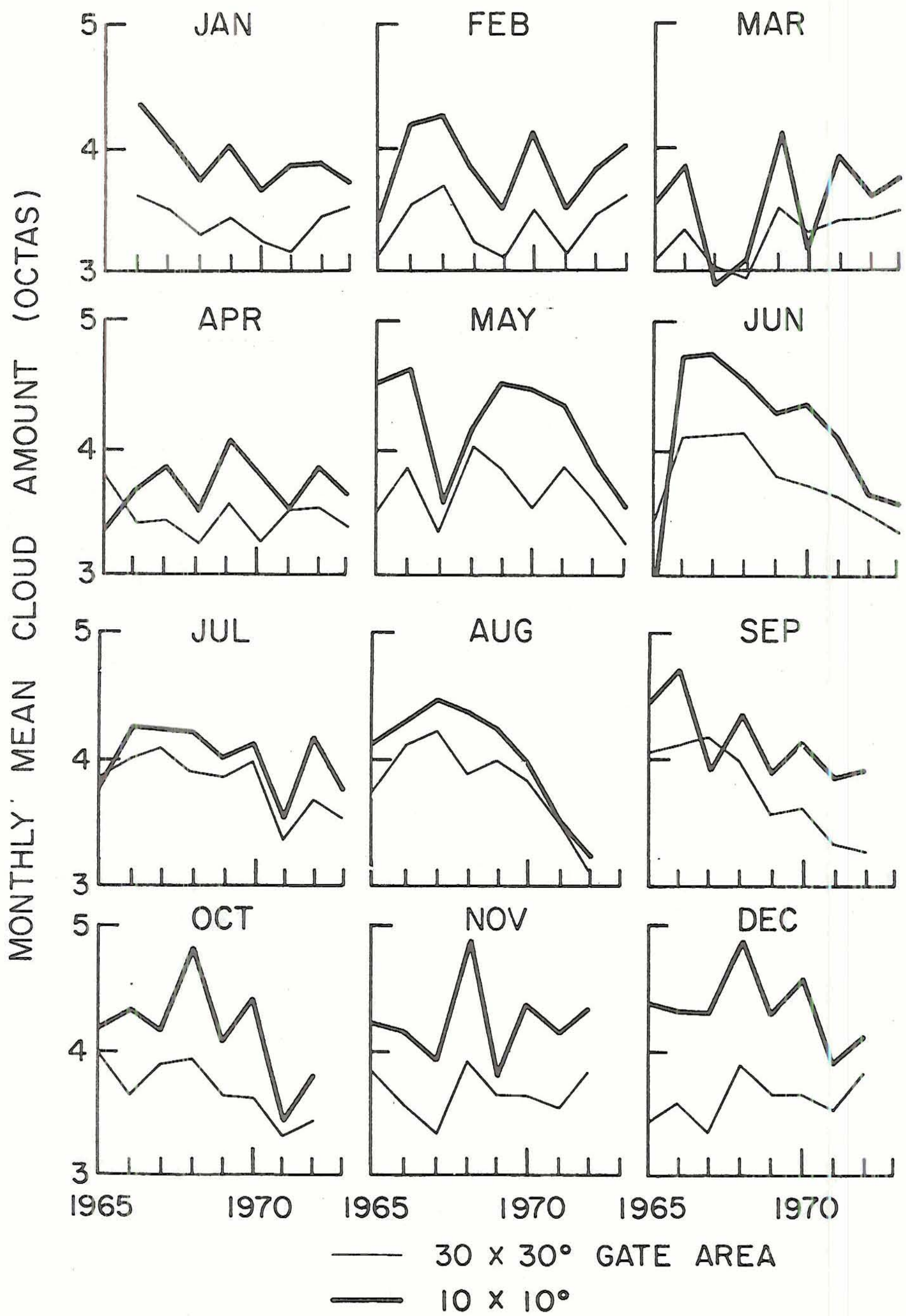


Figure 10 Trend of cloud amount in the GATE region at two scales.

cloud amount in the smaller area is larger than in the area 30°x30°. This is caused by the variability of the synoptic situation in different years; b) there is a clear tendency for the monthly mean cloud amounts to decrease in May to October.

6) The analogous decrease of cloud amount also takes place in the case of the zonally averaged values. In the case of small latitudinal belts the year-to-year random changes of zonally averaged monthly mean cloud amounts are larger than 1 octa, therefore, it is more reasonable to study the multi-year trends in larger areas (e.g. in 30° wide latitudinal belts).

7) Figure 11 gives the monthly mean variations in cloud amount for the latitudinal zones 60-30°N, 30-0°N, 0-30°S over the Pacific Ocean. The cloud amounts in the tropical zones (0-30°S and 0-30°N) are highly correlated. In the midlatitude zone (30°-60°N), the cloud amount is 1-1.5 octas higher and has considerably larger year-to-year variation. Higher year-to-year variations might be caused by the variability of monsoon circulations.

8) Figure 12 shows the variations in the annual mean cloud amount values for the GATE area and zonal averages: 30-60°N, 0-30°N, 0-30°S and 30°S-30°N. These curves seem to indicate that there is an overall decrease in cloud amount in the years 1966-1972.

Table 8 gives decreases in monthly mean cloud amounts in the years 1966 to 1972. It is worth noting that during the years 1966-1971, solar activity was increasing; monthly mean sunspot numbers increased from 20 to approximately 110. However, cloud amount data for a longer period of time is needed before we can have more confidence in the

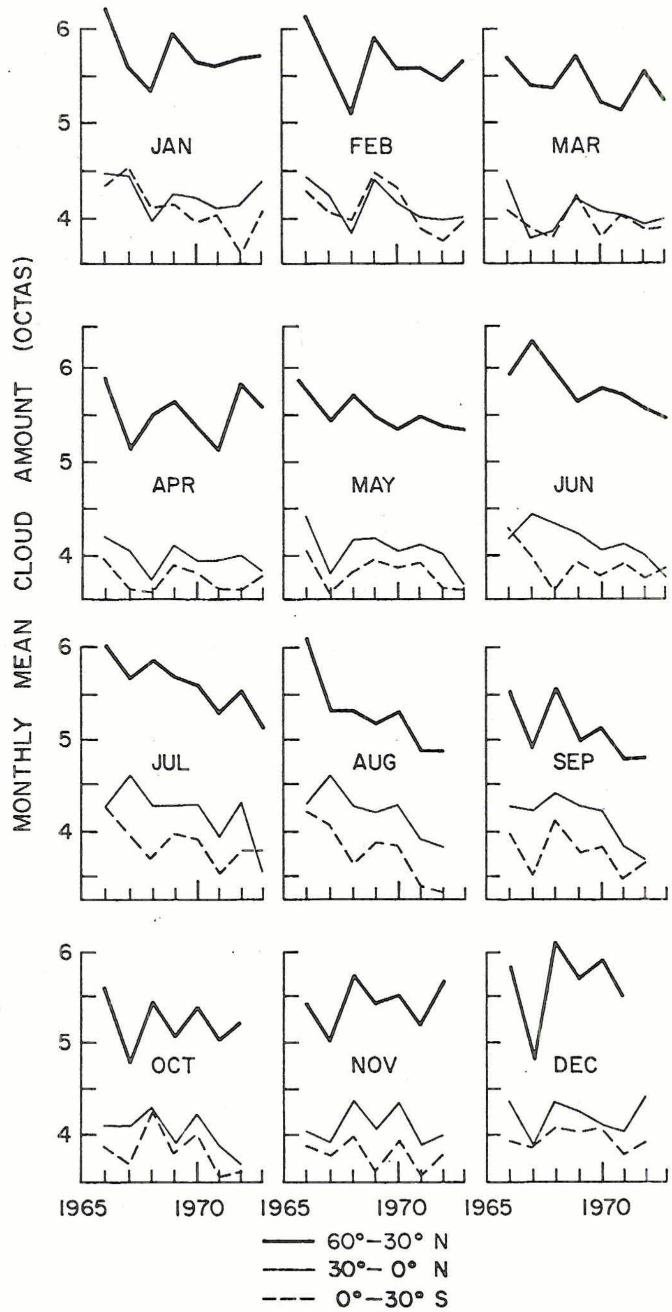


Figure 11 Monthly mean variations of cloud amount for three latitudinal zones over the Pacific Ocean.

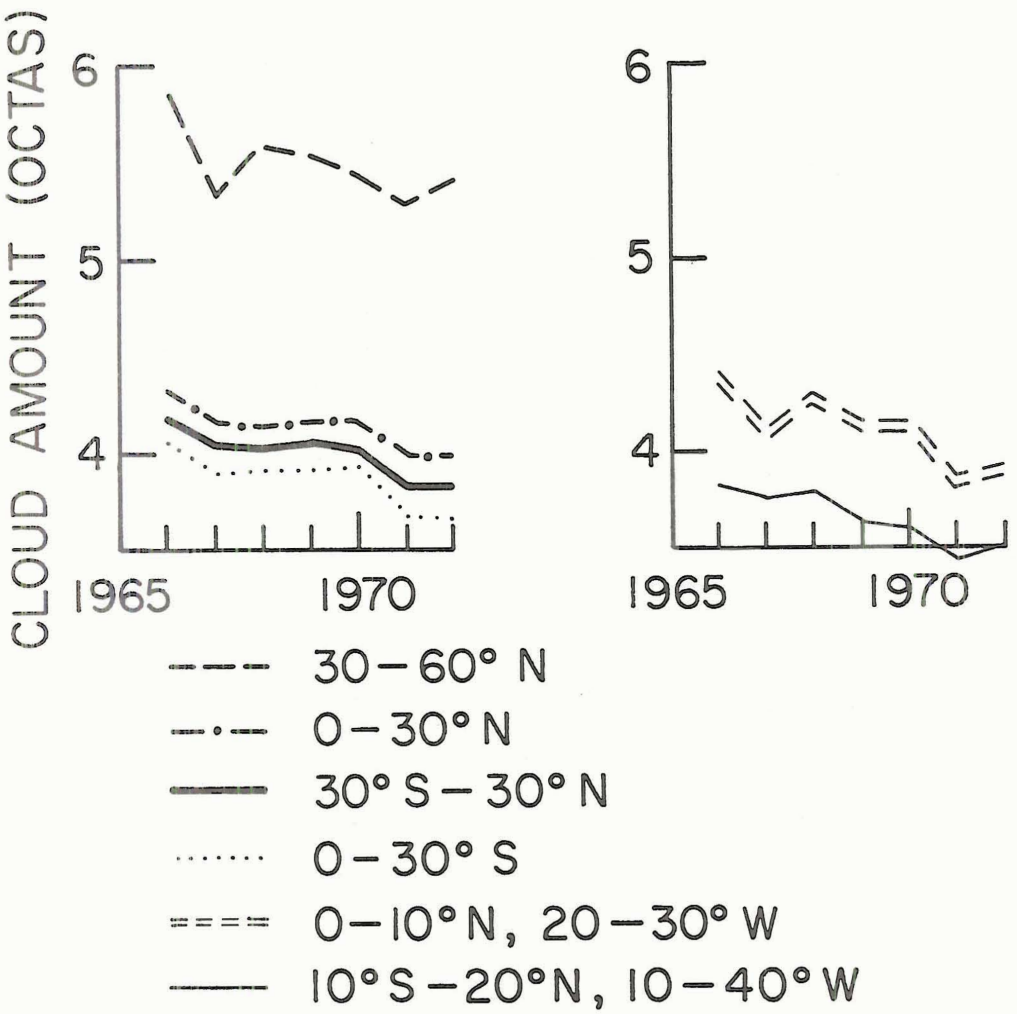


Figure 12 Variations in the annual mean cloud amount for the GATE area and four zonal averages.

Region		Decrease of cloud amount (in percent)		
		Yearly mean	April-September	October-March
GATE	0°-10°N, 30°-20°W	14	16	12
GATE	10°S-30°N, 40°-10°W	7	14	1
Zonal average over the entire Pacific	30°-60°N	8	9	7
Zonal average over the entire Pacific	30°N - 30°S	9	11	8

Table 8. Decrease of yearly and seasonal mean cloud amounts in different regions in the years 1966 to 1972.

hypothesis that total cloud amount decreases in the years that solar activity increases.

3.6 Comparison of Sadler's and Miller and Feddes' 1967-1970 data

According to the cloud categories described in Section 3.3.2, the nephanalysis data of February, 1965 to July, 1973 was used to draw the mean annual variation charts for all trapezoids in the 30°S-30°N zone. The amounts are given in Figures 13-17, according to the classifications given in Table 7.

Comparison with Sadler's data (see Figures 2-6) show large discrepancies in cloud amounts. Sadler's data nearly always gives cloud amounts one category higher than Miller and Feddes' data. Another important difference is that Sadler's data indicates many trapezoids in which the annual variation of cloud amount is so small that the cloud amount does not change through the year. See, e.g. trapezoids 014, 015, 016, 021, 022 in the North Atlantic; 502, 512, 513 in the South Atlantic; 709, 808, 805, 826, 225 in the Indian Ocean; 102, 107, 207, 206, 205, 204, 203, 112, 113, 117, 217 in the North Pacific; 601, 602, 603, 604, 605, 606, 611, 612, 613, 617, 717, 624, 625, 626, 627, 727 in the South Pacific.

In shorter periods the annual variation could have the same peculiarities and the overall picture does not change too much. Figure 18 provides an illustration based on Sadler's atlas (1969) and presents the average annual variation (1966 and 1967). When one compares Figure 18 with Figure 13, one can conclude that in the years 1966 and 1967 the cloud amount over the Northern Atlantic (0-30°N) was higher than the eight-year average. The only exception is the trapezoid 021 where in

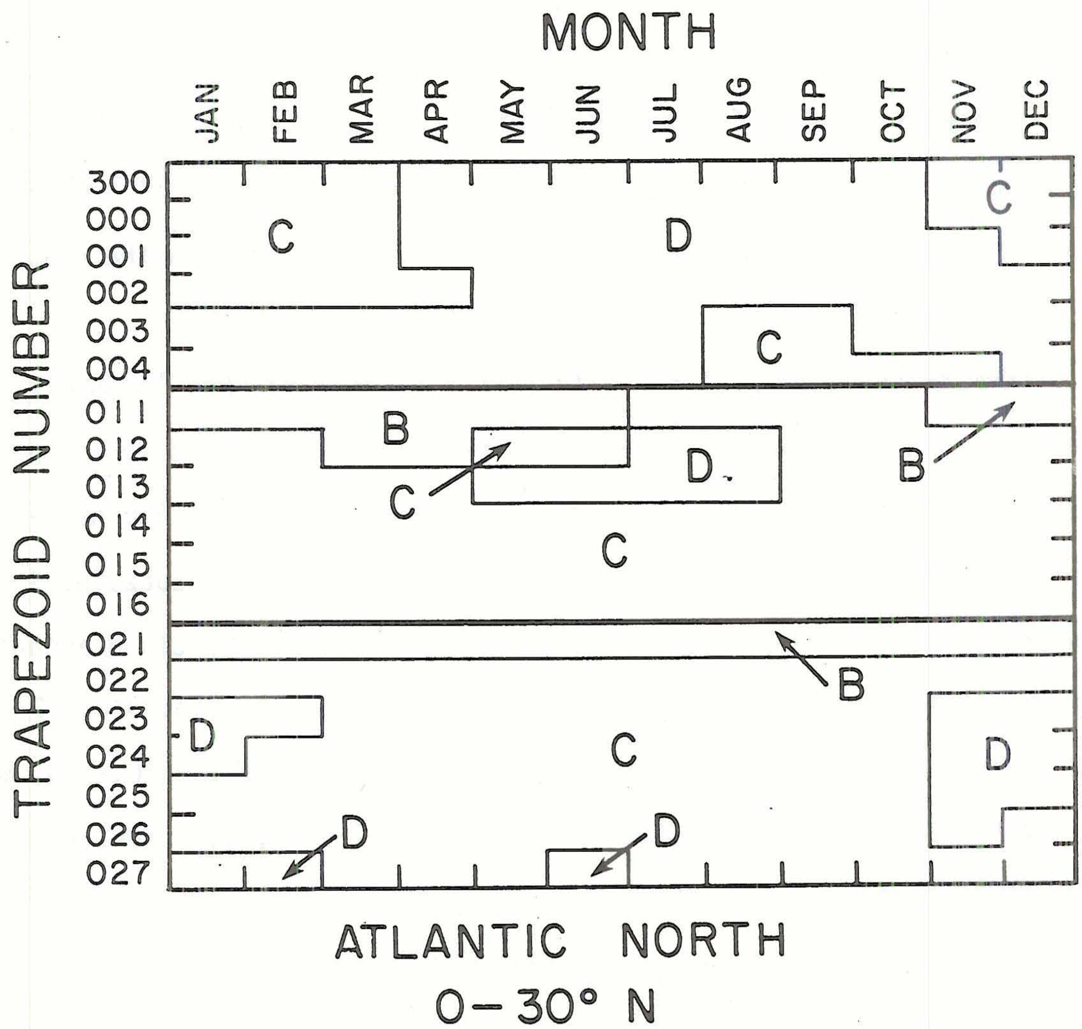


Figure 13 Monthly mean cloud amounts (1965-1973) derived from neph-analysis for the northern Atlantic Ocean (0-30°N).

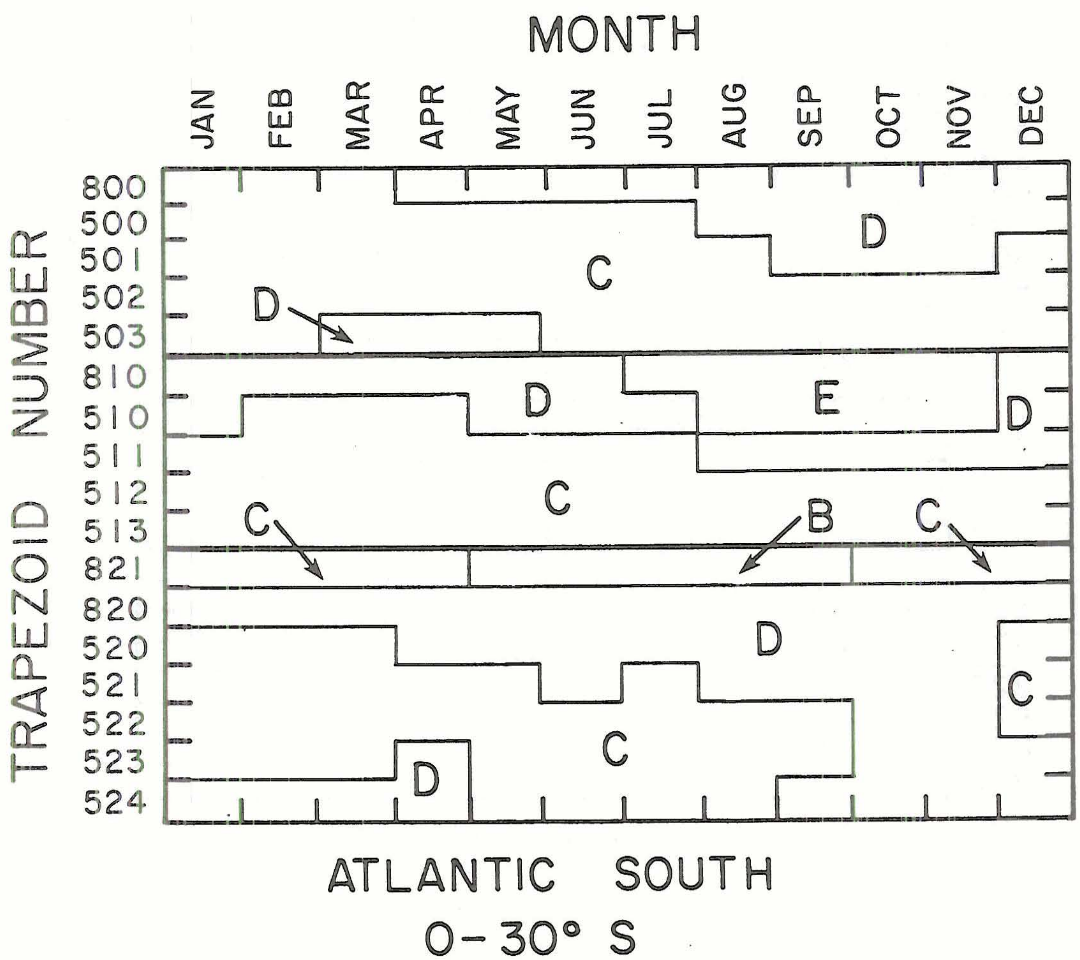


Figure 14 Monthly mean cloud amounts (1965-1973) derived from neph-analysis for the southern Atlantic Ocean (0-30°S).

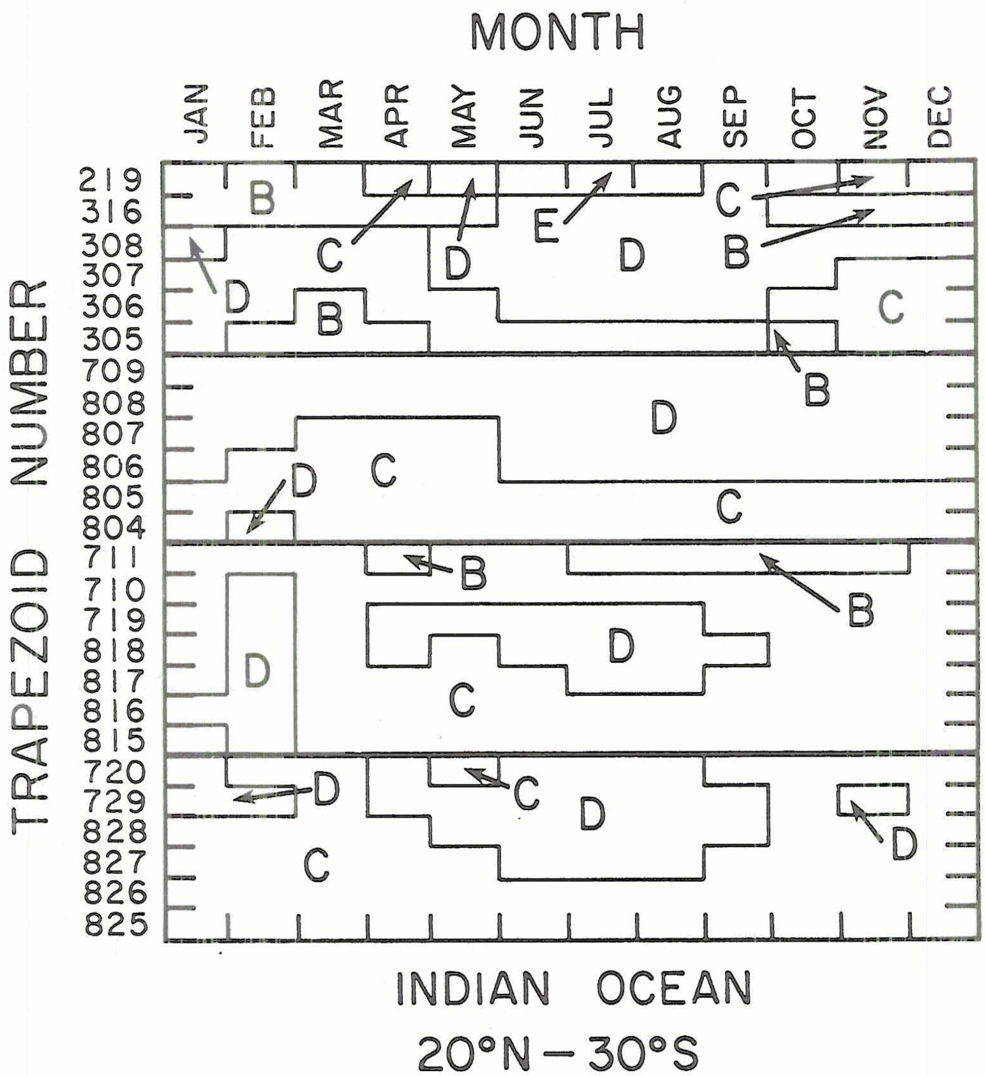


Figure 15 Monthly mean cloud amounts (1965-1973) derived from neph-analysis for the Indian Ocean (20^{O}N - 30^{O}S).

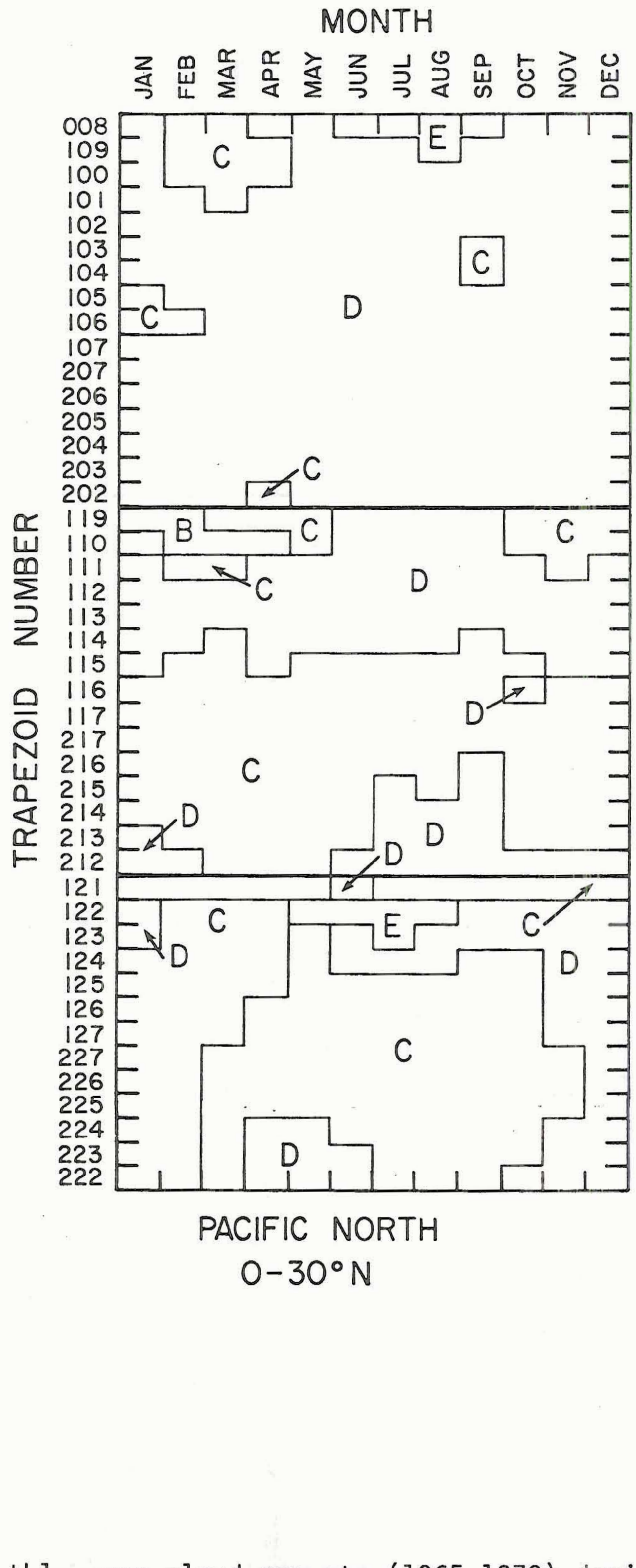


Figure 16 Monthly mean cloud amounts (1965-1973) derived from neph-analysis for the northern Pacific Ocean (0-30°N).

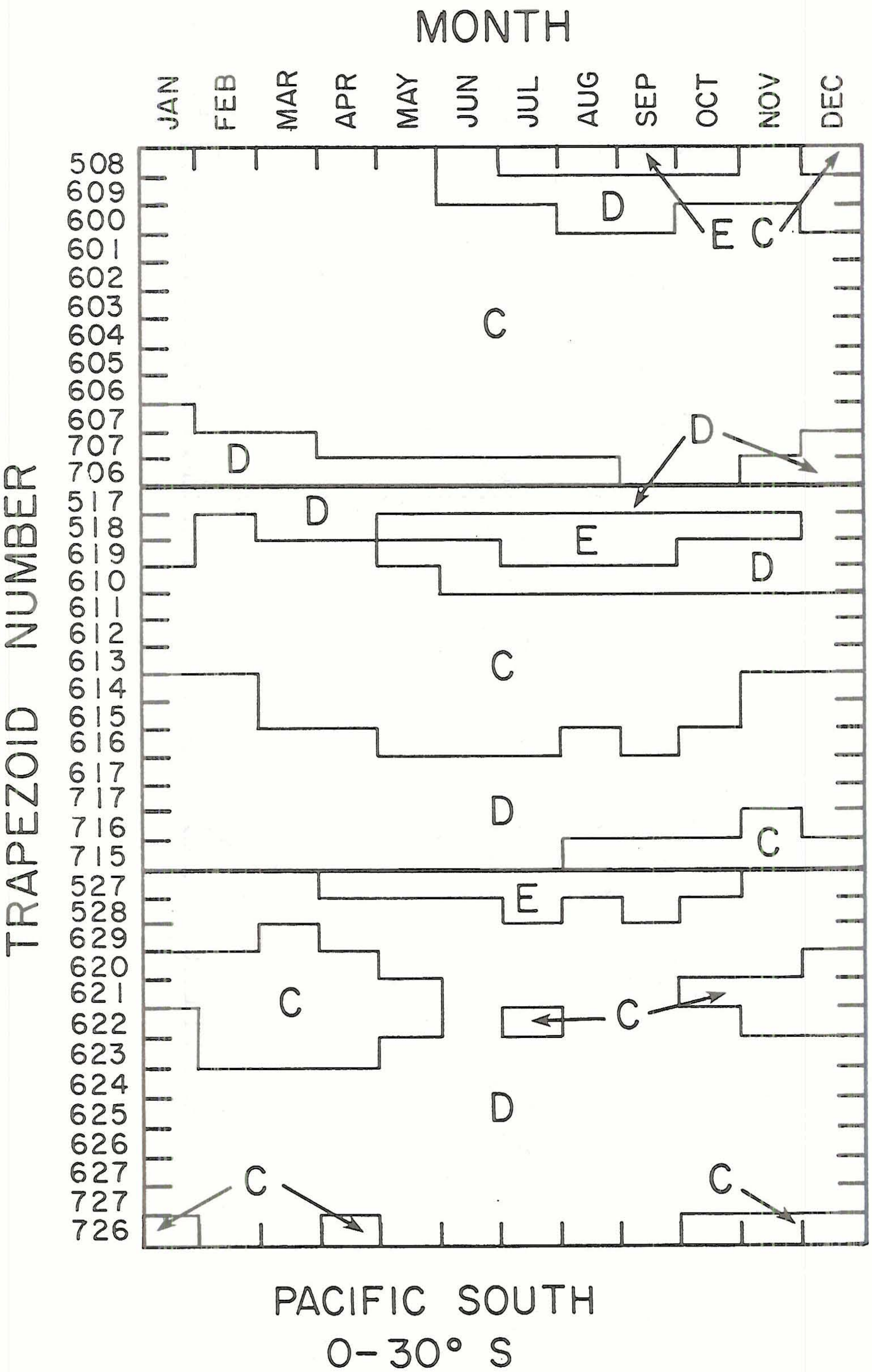


Figure 17 Monthly mean cloud amounts (1965-1973) derived from neph-analysis for the southern Pacific Ocean (0-30°S).

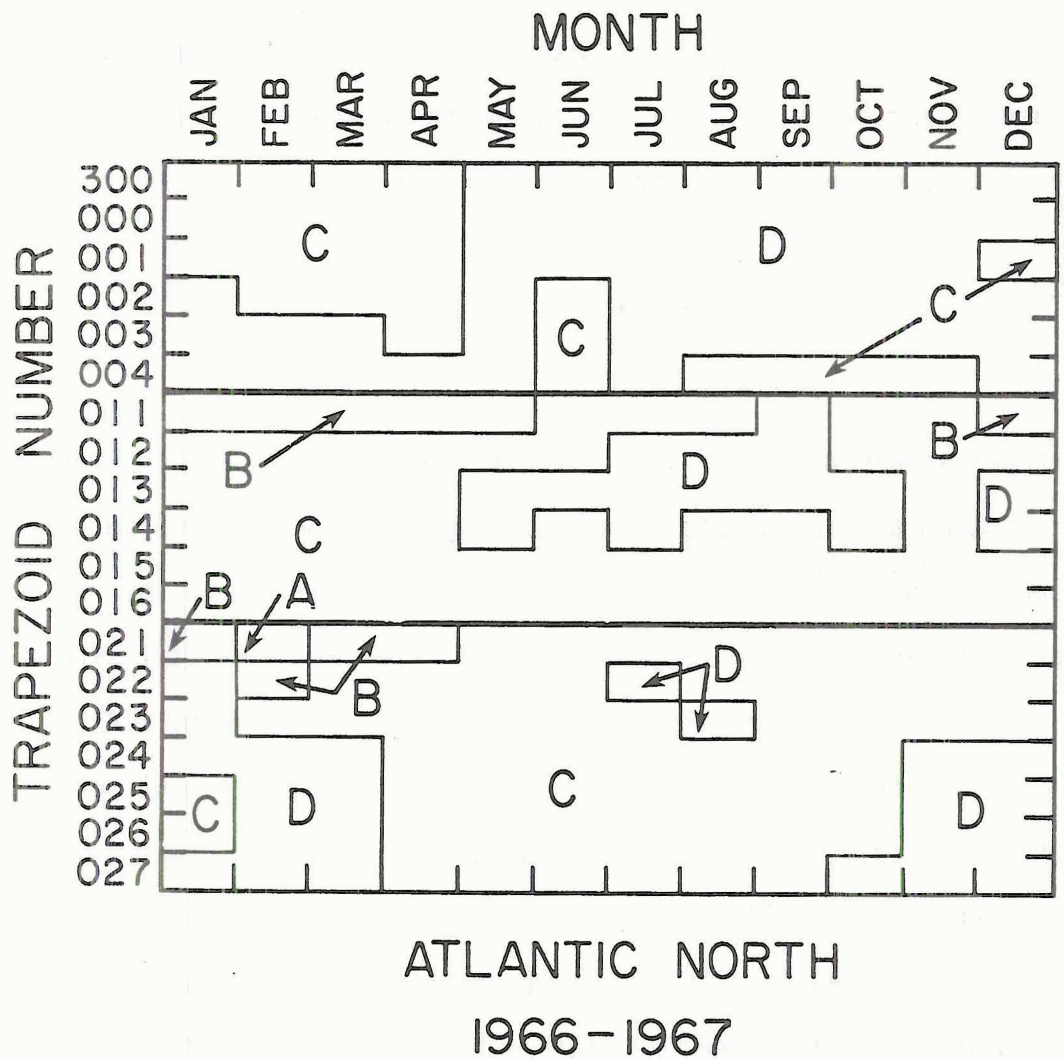
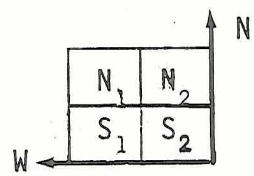


Figure 18 Annual cloud amount variation (1966 and 1967) from Sadler's atlas (1969).

February of 1966-1967, the cloud amount was less than the multi-year average. The annual variation of cloud amount can be described in more detail if we incorporate $5^{0} \times 5^{0}$ trapezoids. Figure 19 illustrates the annual variation of cloud amount in the subregions of $10^{0} \times 10^{0}$ trapezoids as given in this depiction:



The reader should note in Figure 19 that the subregions are ordered from top to bottom and in an east to west arrangement, hence 300S indicates the southern $5^{0} \times 5^{0}$ trapezoids. Noticeable differences in the variation of annual cloud amount can only be seen in the latitudinal belt 0-10^{0}N (e.g. for trapezoids 300, 000, 001, 002, 003 and 004). In this zone, in the summer season, cloud amounts greater than 65% are present (June-July). The region 10^{0}-30^{0}N can be described using the 10×10^{0} trapezoid data (compare Figures 19 and 13). Using the same four-year data base (1967-1970), Sadler et al. (1976) compared their cloud amount estimates over the Pacific Ocean with those of Miller and Feddes (1971). They pointed out that the pattern of cloudiness and the position of the maximum and minimum areas or zones of cloudiness are in good agreement, but cloud amount values differed consistently. The values given by Sadler et al. (1976) were, on the average, 1 octa higher. The maximum difference of more than 1 octa was observed in the near-equatorial minimum zone. The difference was less in the maximum cloud areas. Sadler et al. (1976) pointed out that the differences

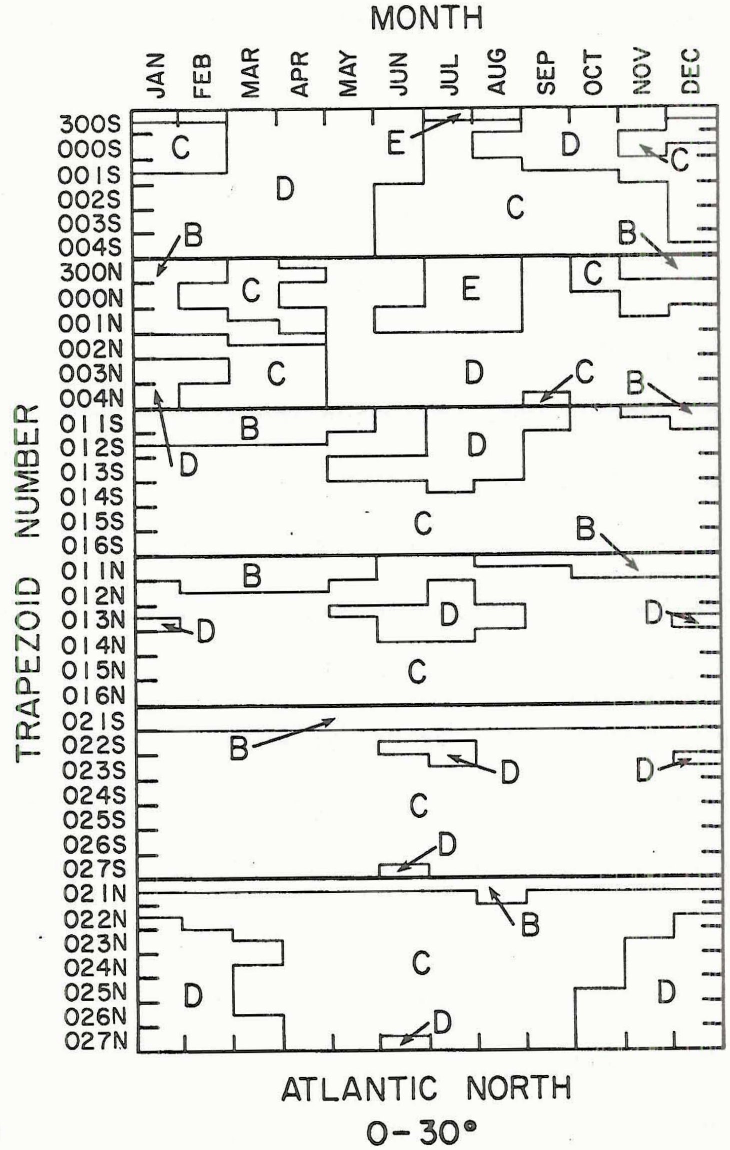


Figure 19 Annual cloud amount variation at higher resolution (1966 and 1967) from Sadler's atlas (1969).

may be attributed to any one or a combination of the following factors:

1) an overestimation of cloud amounts by the nephanalysists (see Young 1967);
2) Sadler's choice of assigned values to the neph categories (see column 3 versus column 1 of Table 6);
3) Sadler's choice of equating assigned values to octas (see column 3 versus column 4 of Table 6);
4) Miller and Feddes' choice of weighting factors, relating brightness ranges and cloud amount.

The objective of our research is to determine the best mean-square fit between the two above mentioned data sets and the standard deviations in different cloud amount categories (A to E). We compared the monthly mean values averaged over the years 1967-1970 over the North Atlantic. Results are illustrated in Figure 20, which gives the data of Sadler et al. versus Miller and Feddes' data. The best fit was given by the formulae

$$N_S = a_1 N_{MF} + a_2 N_{MF}^2, \qquad (15)$$

where N_S is monthly mean cloud amount in octas by Sadler et al. (1976), and N_{MF} - the same by Miller and Feddes (1971). Coefficients were a_1 = 1.95, a_2 = -.119. Table 9 summarizes the comparison of Sadler's et al. (1976) data with Miller and Feddes' (1971) data.

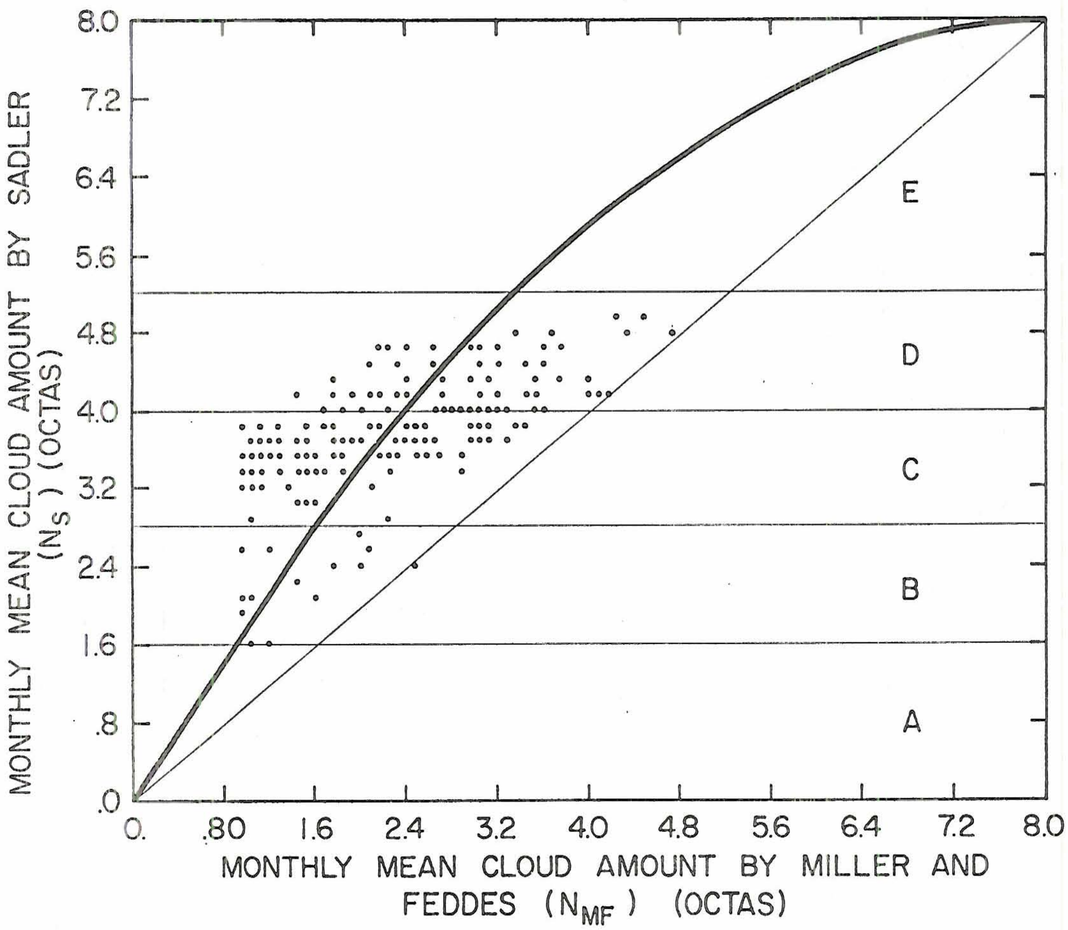


Figure 20 Comparison of Sadler's and Miller & Feddes' monthly mean cloud amounts averaged over the years 1967-1970 for the northern Atlantic Ocean.

Cloud category determined by Sadler et al. data	B $1.6 < N_s \leq 2.8$	C $2.8 < N_s \leq 4$	D $4 < N_s \leq 5.2$
Mean cloud amount in the given category by Miller, Feddes data ($\overline{N}_{MF}$)	1.42	2.07	2.90
Standard deviation $\sigma_{N_{MF}}$	0.33	0.25	0.25
Mean cloud amount in the given category by Sadler et al. data ($\overline{N}_s$)	2.19	3.62	4.35
$k = \frac{\overline{N}_s}{\overline{N}_{MF}}$	1.54	1.75	1.50

Table 9. Comparison of Sadler and Miller and Feddes' data of cloud amounts based on the years 1967-1970 over the North Atlantic.

The comparison carried out in this section leads to the conclusion that Miller and Feddes' data (1971) and Environmental Satellite Imagery data could be used for extending the cloud amount time series given by Sadler et al. (1976). The algorithm for the processing of the data is given by equation (15). As an example, we carried out the computation for the yearly mean cloud amount above the central part of the GATE region (0 - 10^{0} N; 30 - 20^{0} W) in the year 1975 using the data from Environmental Satellite Imagery. The result was $\overline{N}_s$ (1975) = 3.76. Comparison of the above value with the data given in Figure 9 shows good agreement.

3.7 Estimation of cloud amount from radiation budget components.

In the above discussion, different cloud estimation techniques have been compared. We found systematic differences between them, although the spatial variation was consistant. Another estimation technique is to assume a linear relationship between cloud amount and albedo Eq. (16).

$$A(t,\theta,\phi) = A_s(t,\theta,\phi)\left[1 - N(t,\theta,\phi)\right] + N(t,\theta,\phi)\ A_c(t,\theta,\phi) \qquad (16)$$

A = albedo of some region around θ,ϕ at time t

A_s = surface albedo in region

N = cloud amount in region

A_c = cloud albedo in region

The above equation could be used to estimate cloud albedo or cloud amount.

Below we discuss a comparison between a set of albedo measurements and cloud amount measurements. Only time averages (monthly) were available so Eq. (16) must be time averaged to Eq. (17). This requires

$$\overline{A}(\theta,\phi) \approx \overline{A}_s(\theta,\phi)\left[1 - N(\theta,\phi)\right] + \overline{A}_c(\theta,\phi)\ \overline{N}(\theta,\phi) \qquad (17)$$

where the overbar indicates a monthly average. In addition, there is an underlying assumption that cloud amount and cloud albedo are uncorrelated in time. This is certainly not always true, but for a first approximation it is a reasonable assumption. No time overlap between albedo measurements and cloud measurements was available so a climatological comparison was made. An 8-year time average (1965-1972) of Sadler's cloud amount was used in accordance with average albedo data measured by a series of NOAA-Satellite Scanning Radiometers in the .5 to .7 μm band pass (see Gruber, 1977). The data are available for the period 6/74 to 2/78 on a 2.5^o by 2.5^o grid. There are some systematic errors in both these data sets, however, they are of the same order of error as our time average assumption.

Figures 21a and 21b show scatter plots of all the corresponding albedo and cloud amount estimates over the ocean for the month of March. The ocean was chosen because its surface albedo is uniform, as opposed to land regions. These scatter plots show a linear relationship, however, extrapolating to zero cloud amount implies that the surface albedo is negative. This indicates that Eq. (17) is not applicable to the whole cloud amount range. The scatter plots do show a linear relation around .4 cloud amount.

A more detailed analysis of each 2.5^o latitude zone shows moderately high correlation coefficients between albedo and cloud amount (Table 10). A two parameter least squares fit was performed on the data generating the other values in the table. These results are interesting but not definitive because of the biases in the measurements and non-overlapping measurement periods.

The correlations between emitted flux and cloud amount were also examined (Figs. 21c and 21d and Table 11). First the regions with stratus cloud were removed. Again moderately high correlations (.7 to .8) were found but this might be explained by the high correlations between emitted flux and albedo ($\approx$.9). The use of both emitted flux and albedo

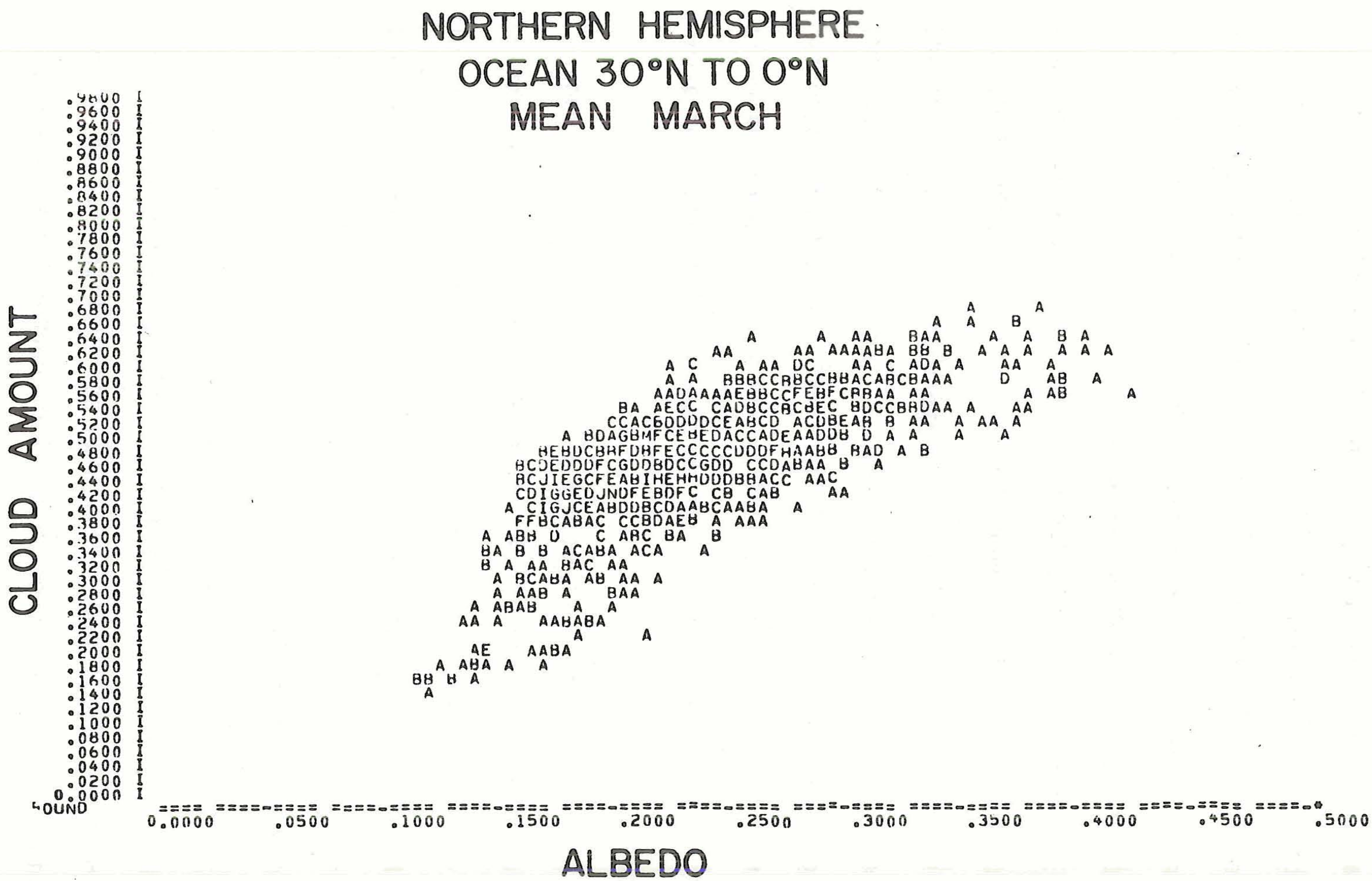


Figure 21 Spatial correlations of time mean Sadler cloud amount and time mean scanning radiometer measurements. Each letter represents a 2.5° latitude by 2.5° longitude region. The letter A represents 1 occurrence, B = 2, C = 3, etc.

a) Northern Hemisphere (Albedo - Cloud Amount)

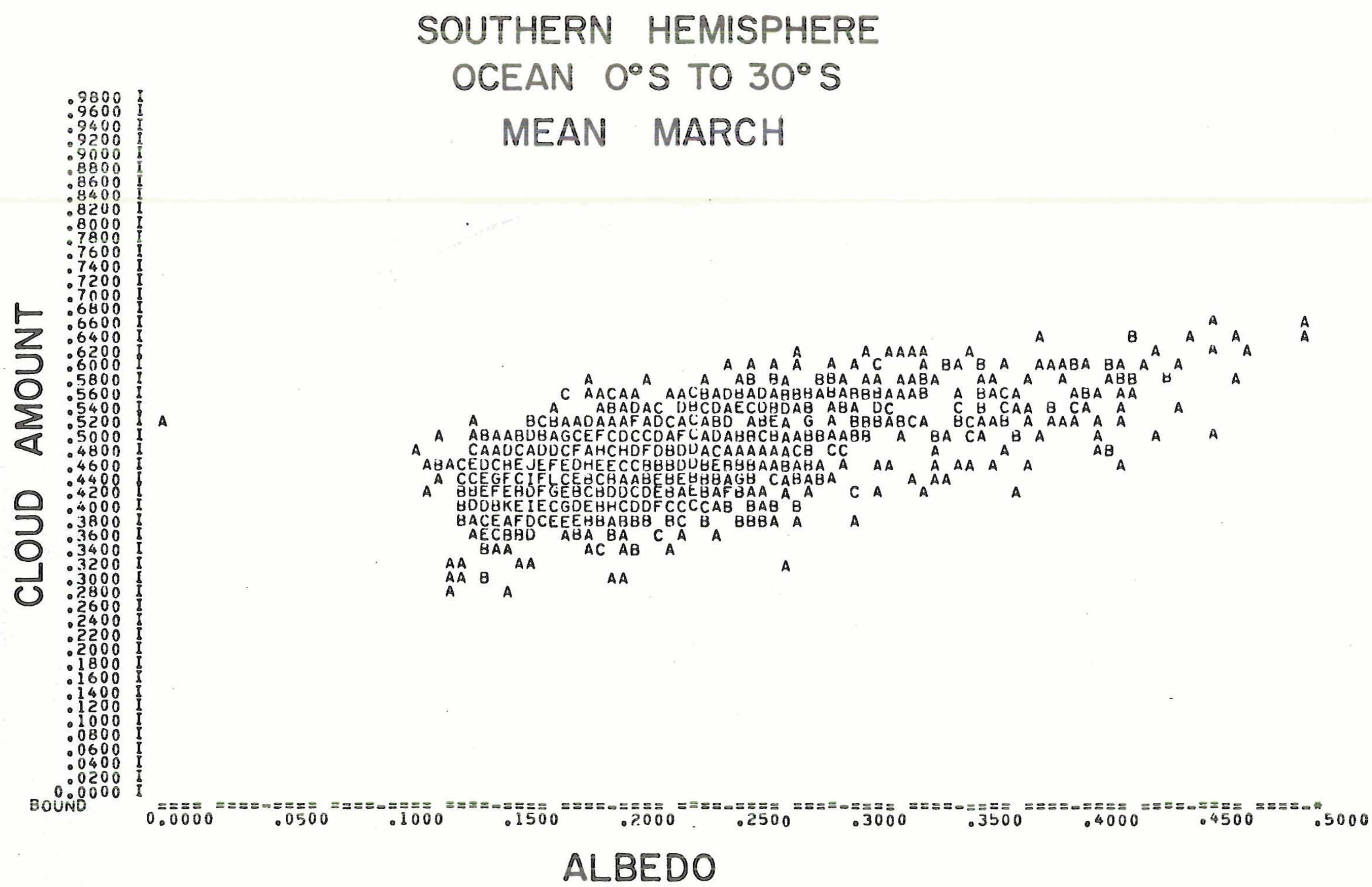


Figure 21b Southern Hemisphere (Albedo - Cloud Amount)

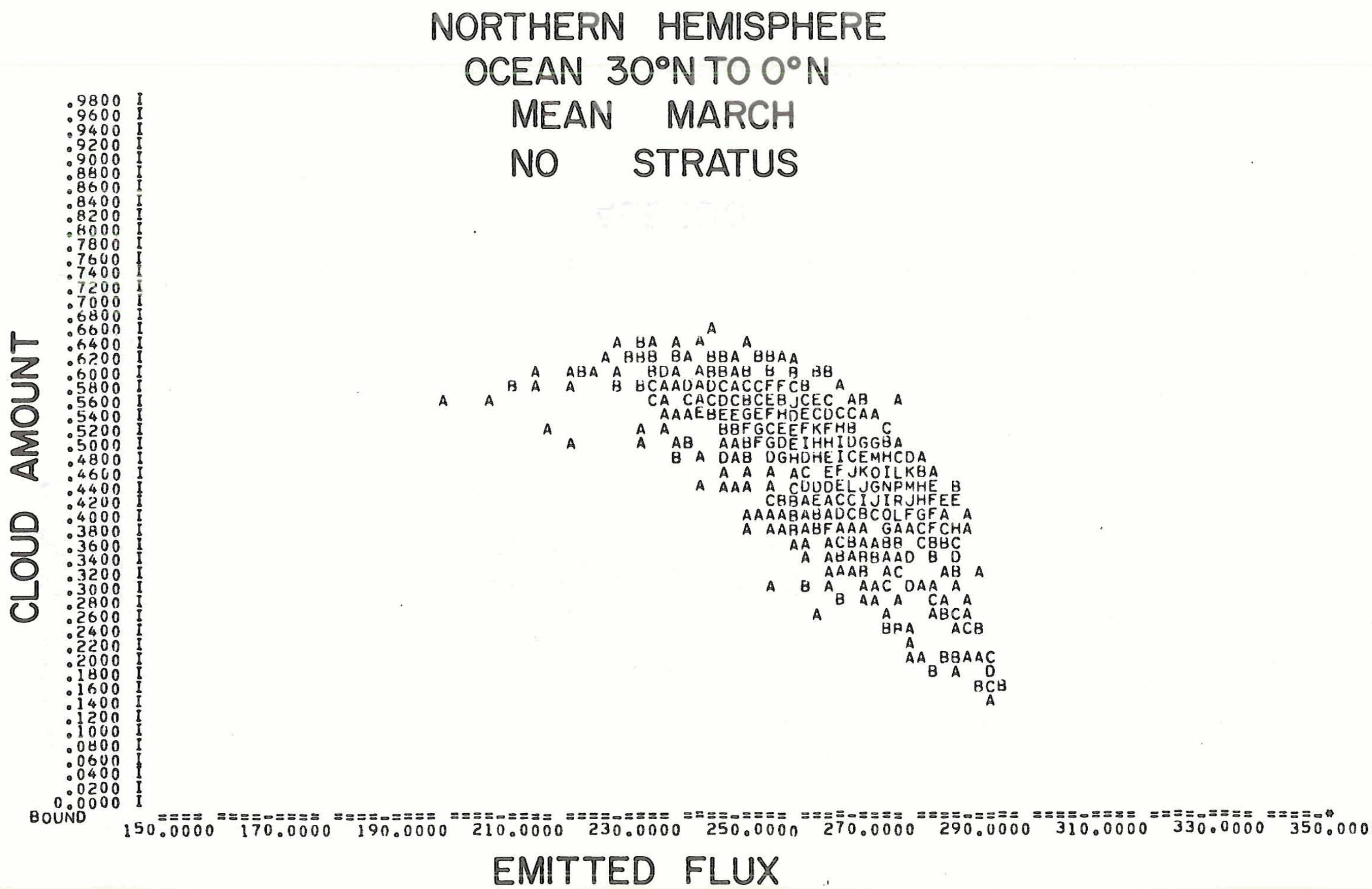


Figure 21c Northern Hemisphere (Emitted Flux - Cloud Amount)

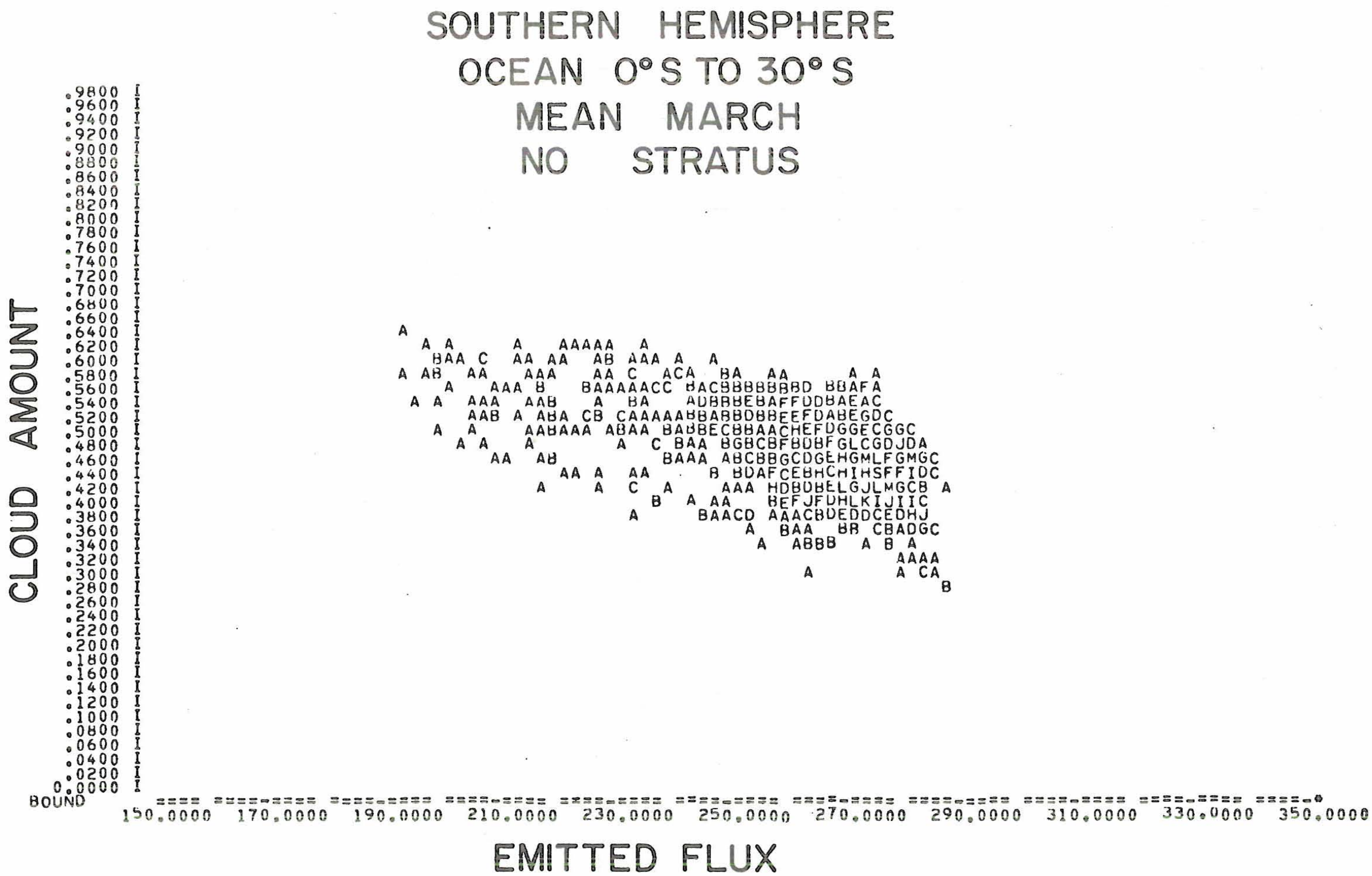


Figure 21d Southern Hemisphere (Emitted Flux - Cloud Amount)

for cloud amount estimation requires studies of higher space and time resolutions.

A number of more definitive studies are underway. We are comparing Nimbus-3 measurements of albedo for about six months of 1969 and 1970 with the cloud amounts. This has the advantage that simultaneous measurements are available and that a minimum albedo was recorded. This will allow us to estimate cloud albedo directly.

Another study using SMS-1 GATE radiation measurements (Smith and Vonder Haar, 1976) will be used to estimate the accuracy of the time average transformation from Eqs. (16) and (17). These data have high resolution in space (4 x 4 miles) and time (hourly). Cloud amounts will be estimated by counting 4 x 4 mile samples above designated thresholds in the reflected and emitted counts. The effect of averaging over different space scales ($2.5^o \times 2.5^o$, $5^o \times 5^o$, and $10^o \times 10^o$) on cloud amount estimates and on albedo cloud correlations will also be examined.

If Eq. (17) is found to be reasonably applicable and if the cloud albedoes from the Nimbus-3 study are reasonably accurate, cloud amounts will be estimated over the NOAA Scanning Radiometer periods. This would extend the cloud amount time series begun by Sadler, and Miller and Feddes to 1978. Also, this technique will allow extension into the future using the TIROS-N and GOES data (see Vonder Haar, 1978).

3.8 Summary

The analysis carried out in this section showed that;

1) In many applied climatology problems it is reasonable to use 5° by 5° basic area units; this resolution is sufficient for detailed examination of global cloud distributions.

2) The longest uniform time-series of cloud amount data deduced from satellite nephanalysis (Sadler et al., 1976) shows that in the years 1965-1972 global cloud cover decreased. The amount of the decrease depends on the season and the geographic co-ordinates, ranging from 1 to 14 per cent.

3) It is possible to calculate the extension of Sadler's cloud amount data time series using the second order regression curve between Miller and Feddes -- as well as the Environmental Satellite Imagery data.

4) On the average, the Sadler et al. (1976) cloud amount data are 1.50 to 1.75 times higher than Miller and Feddes' (1971) and Environmental Satellite Imagery data.

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15. Supplementary Notes

16. Abstracts

An analysis of cloud amount classification is carried out on the basis of the cloud distribution over different regions of the World Ocean's at different seasons. Operational satellite imagery served as the basis for cloud amount estimation. To carry out a statistical analysis of cloud amounts over different regions, trapazoids quasi-equal in area were used. It was determined that for many climatological problems 5^o by 5^o basic area units would be satisfactory for the examination of cloud amount above the world oceans. The possible causes of differences between various satellite nephanalyses are examined. Annual variations of cloud categories over different ocean regions are analyzed. It is shown that it is expedient to use the beta distribution for describing the cloud amount distribution above the World Oceans. The interdependence of cloud amount over various space scales is examined. Preliminary results concerning the relationship between cloud amount and satellite derived radiation budget quantities are presented.

17. Key Words and Document Analysis. 17a. Descriptors

1. Global Cloud Amount
2. Satellite Determined Cloud Parameters
3. Cloud Amount Variability
4. Statistical Distribution of Cloudiness

17b. Identifiers/Open-Ended Terms

1. Cloud Amount

17c. COSATI Field/Group

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