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Final Report

QUANTITATIVE INTERPRETATION OF LOW-LEVEL CUMULIFORM CLOUD PATTERNS AS SEEN ON METEOROLOGICAL SATELLITE VIDEOGRAPHS

(Preliminary Results)

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ABSTRACT

Interpretation of the cloud patterns as seen from the altitude of meteorological satellites in terms of quantitative meteorological parameters is a complex problem. This study is confined to the low-level cumuliform cloud types associated with the relatively simple synoptic conditions of the semi-permanent oceanic anticyclone.

Statistical methods in the form of discriminant analysis techniques are used to determine the synoptic parameters which make a significant contribution in determining the patterns of these low-level cumuliform clouds.

Preliminary results have demonstrated the validity of this technique in determining the parameters when the sample size is large.

INTRODUCTION

There can surely be no doubt remaining anywhere that the meteorological satellite has proven itself as a prodigious observational tool. The total area placed on videographs since April 1, 1960, is almost beyond comprehension. The number of these videographs available is an astounding figure in itself. In reality, it is this figure together with the date format that could, as a limiting process, form a monstrosity. Such a process would indicate that it is only a matter of time until this tool goes "the way of the dinosaur," or if you prefer "dyna-soar." Preventing this evolutionary change requires a major effort in environmental adjustments. These necessary changes are principally in the field of data analysis and interpretation; an area of satellite meteorology which, using the words of Tepper (1963) (not necessarily in the same order), constitutes, "A problem in search of a solution."

The use of satellite meteorological data for research work has tended to be along the lines of case studies. Operationally, the meteorological satellite has proven to have its primary value as a reconnaissance vehicle in locating and tracking severe storms. These two uses, important as they may be, represent gainful employment for only a minute portion of the available data. Exceptions to the general rule outlined above can be enumerated, notably the works of Erickson and Hubert (1961), and of Conover (1962), who have tackled the problem of identifying and interpreting cloud patterns in pictures taken at satellite altitudes.

Leese and Epstein (1963) used a two-dimensional extension of the familiar power spectrum analysis to identify and quantify the statistically preferred dimensions and orientations of the cloud patterns. This method suffers from the fact that data must possess a quantitative format and the spectra must then be computed—expensive and time-consuming operations. To justify operational use of such a procedure it would be necessary first to demonstrate significant and useful relations between these statistical quantities and the state of the atmosphere.

One of the simplest cloud patterns to interpret in terms of general synoptic conditions is that of the cellular cloud patterns which are so frequent over oceanic regions. A major factor to be considered when attempting to study these cloud patterns is the quantity as well as the quality of conventional meteorological information over most of the oceans. A qualitative description represents a method more compatible with the present state of the art in nephanalysis of satellite cloud pictures operationally.

This study is concerned with utilizing statistical methods in an attempt to determine the nature of convective transfer processes in the atmosphere and the interactions of the ocean and the atmosphere. Specifically this has the form of using discriminant analysis techniques to determine the synoptic parameters which made a significant contribution in determining the patterns of these low-level cumuliform clouds. These results are then used in an effort to gain quantitative information from the cloud patterns.

CLOUD ANALYSIS PROCEDURES

Low-level cumuliform clouds appear quite regularly as an exclusive pattern in association with anticyclones, especially over the oceans. Some of the most interesting patterns are those associated with the moving anticyclones of mid-latitudes. However, the lack of conventional meteorological data over most of the oceans outside the normal shipping lanes precludes selecting of pictures to be analyzed solely on the basis of picture content. Thus, the study of the cloud patterns associated with these moving anticyclones must be restricted to those observed in the regions of the Atlantic and Pacific shipping lanes. This restriction has caused us to confine the study to the region of the Eastern North Pacific during the summer months when this area is dominated by the Pacific Anticyclone.

During the period August 15, to September 5, 1961, this region was under extensive surveillance by TIROS III cameras. A similar condition prevailed in the same period of 1962 with TIROS V. This study is confined to these two time periods and includes the region of the Pacific Ocean between 20N and 50N latitudes and east of 180W longitude.

Much of the information about the cloud patterns needed for this study was already available on nephanalyses made on an operational basis. However, these nephanalyses were found to be too coarse for this study. Hubert (1962) points out that inconsistencies exist between the computed grids and the operational nephanalysis, and that the computed grids should be better in overall accuracy. These two considerations made it desirable to obtain the cloud observations from the original pictures superposed on the computed grids. It was assumed that these computed grids were accurate to within approximately 2° latitude of the true location.

A cloud observation was then defined to be an area on the TIROS cloud picture of at least 4° "square" comprised of a cloud pattern having uniform coverage and pattern arrangement. The location of the observation is the latitude and longitude at the center of the area. (Four degrees "square" is defined as the area included by two latitude circles separated in latitude by 2° and two longitude circles separated by 2° long. This yields an average area between 20° and 50° latitude of approximately 40,000 km^2, with a maximum deviation of about 20%. Deviations from equal area are neglected.) Each observation is composed of the amount of cloud cover, the cumulus cell size, and the size of the bands if they are present. The amount of cloud cover falls in one of six groups composed of:

1. clear,
2. clear to scattered,
3. scattered,
4. scattered to broken,
5. broken, or
6. broken to overcast, and overcast.

Since a cloud observation is by definition an area having uniform coverage, these groups refer primarily to the actual amount of clouds present as opposed to a description of nonuniformity, as might be suggested by the nomenclature of groups 2, 4, and 6. Quantitatively, these six groups correspond to the following amounts of cloud cover:

Group	1/8's
1	0
2	1, 2
3	3, 4
4	5
5	6
6	7, 8

The cumulus cell size over the area is recorded as one of the following six groups:

1. none,
2. small,
3. medium,
4. large,
5. mixed, or
6. undetermined.

The cell size is determined by inspection. Individual cells less than 10 km are classified as small, between 10 and 20 km as medium, and greater than 20 km as large size. Any of these three groups could result from an unresolved agglomeration of individual cells, and especially in oceanic areas it is realistic to assume that a sizable portion of the observations in the group of large size are the result of this agglomeration. Even so, the scale of agglomeration is of interest. For clouds in lines or bands, the cell size was given as the width of the band. The group composed of mixed size are those observations in which size of the cells could be determined but did not fit any of the other three specific categories. No attempt was made to be more explicit by subdividing this category. The size was undetermined when the amount of cloud cover was overcast or breaks in the cloud cover were so few that determining a cell size was unrealistic. The category of none is primarily composed of observations of clear but also contains observations in which only a few clouds existed over the area, in which case it was felt that assigning a specific cell size to the whole area based on so few clouds would be unrealistic.

The question of bands in the cloud pattern was a simple yes or no based on whether or not bands were obvious over the area. If bands were present, the size was classified as small when the spacing was less than about 30 to 40 km and large for the remainder. This subjective method of determining the presence of bands in the cloud pattern undoubtedly missed cases in which banding was not obvious by sight and which would have been found by a more objective technique, such as two-dimensional spectral analysis. It is highly probable that a bias toward the occurrence of cloud bands with lesser amounts of cloud cover has been incorporated in this subjective technique because of the lesser likelihood of having the bands obscured in this case.

Since this study is intended to be confined to dealing with the relatively simple case of one specific cloud pattern, i.e., low-level cumuliform, all the observations were subjected to close post-screening especially for large amounts of cloud cover in close proximity to fronts, to insure further that this was the case.

SYNOPTIC DATA

ANALYSIS PROCEDURES

The large scale synoptic features of the Eastern North Pacific at this time of the year are dominated by the quasi-stationary pattern of the Pacific Anticyclone. During the month of August, the mean position of the center of this system is near 38N, 149W (U.S. Navy, 1956).

The northern half of this region can be under the influence of the polar front and accompanying migratory anticyclones periodically at this time of the year. The quasi-stationary conditions of the southern half of the region are also interrupted by smaller-scale perturbations in the form of tropical storms moving into the region. Data from TIROS III (Sadler, 1962) have shown that frequent storms move westward across the Eastern North Pacific but tend to remain at latitudes below 20N (the southern boundary for the region used in this study).

A relatively large number of surface meteorological observations are available from this area, but these tend to be concentrated into the two shipping lanes; one connecting California and Hawaii and the other between the West Coast of the United States and the Far East. This leaves a region across the center of the grid with relatively sparse data coverage, especially in the western half. Upper air observations in this region are available on a regular basis from two stations in Hawaii, Midway Island, two weather ships ("N" 30N, 140W, and "P" 50N, 145W), and dropsondes from regular weather reconnaissance flights. Sporadic upper air observations are also available from ships traveling through the region.

The basic surface parameters obtained from shipboard meteorological observations consist of the pressure, air temperature, dew-point temperature, and seawater temperature. The quality of these observations often leaves much to be desired. Undoubtedly, the most notorious of the four in this respect is that of seawater temperature. Saur (1963) made a comprehensive study of the differences between seawater temperatures reported in the Log of Ship's Weather Observations and specially observed sea-surface temperatures. He found that the differences not only vary from ship to ship, but also exhibit a large degree of variability between trips of a given ship, or even during a trip. He concludes that the sea-temperature data currently reported are for the most part adequate only for general climatological studies.

In order to use the three different temperatures on a synoptic basis in this study, special procedures were used to obtain the analysis over the region. In the case of seawater temperatures, the 1200 GMT observations for three different days were plotted on the same map and the analysis was assumed to be valid for the three days. Although the same quantity of data could be obtained by using all the observations at the four different times each day, the method used has the advantage of spreading observations from the same ship over a larger area and makes it easier to detect persistent errors in the observations from a given ship.

The air and dew-point temperatures were analyzed on a daily basis. Observations of these parameters made at 1800 GMT the previous day, as well as the 0000 and 0600 GMT observations of the day to be analyzed were plotted on the same chart. During the analysis the 0000 GMT observations were subjectively weighted more than the other two times to achieve a distribution valid at 0000 GMT. Since the observations of air temperature were almost all made in the daytime any bias in these would most likely be that the temperatures are too high due to radiational heating of the ship in areas of few or no clouds.

It was felt that no improvement could be achieved in the six-hour continuity available in the Northern Hemisphere Surface Analysis completed by the National Weather Analysis Center, and, therefore, the 0000 GMT analysis was used to obtain the surface pressure.

Values of these four variables were read at grid points spaced at 200-km intervals over the region. Surface pressure was read to the nearest millibar and the temperature to the nearest degree Fahrenheit.

Errors of analysis are not only bound to occur, but may on occasion be quite large, especially when the spatial derivative of the variable is large. Another source of error which may be substantial is that of defining the position of the center of the cloud observation. Crudely expressed,

$$e_t = e_s + E_p \cdot \nabla S$$

where e_t is the total error, e_s is the error in the analysis of the synoptic variable S, and E_p is the vector error in the position of the cloud observation. In general, E_p is of finite size and therefore, if ∇S is large, the second term will tend to dominate the righthand side of the above expression. In other words, the greater the gradient of a synoptic variable across the area, the less significant are the inaccuracies of the analysis.

SYNOPTIC VARIABLES

The synoptic meteorological variables used in the statistical study are all made up at least partly of various linear and nonlinear combinations of the four primary variables discussed in the previous section.

The three observed temperatures can be combined to form three temperature differences only two of which are independent. The geostrophic approximation is used to determine the total wind speed and its easterly and northerly components, from the surface pressure field. This approximation is justified since it represents a finite difference over an interval of 400 km on the grid used and can be relied upon to give a more representative single wind estimate over the area of a cloud observation than could an analysis of the observed wind field.

The surface pressure field is converted to a 1000-mb height field by using the empirical pressure-height relationship that 100 ft represents 3.75 mb. The geostrophic vorticity on this 1000-mb surface is then computed for each grid point by adapting Fjortoft's graphical technique as outlined by Petterssen (1956) to an electronic computer program.

The quantities necessary for the determination of sensible and latent heat fluxes can be prescribed quite explicitly from theoretical considerations (cf. Sverdrup, 1957). However, the availability of useful methods for the practical determination of these quantities is still an open question. Manier and Moller (1961) have developed a method to determine these quantities, but their results do not appear to be much different from those using the much simpler relationships of other authors (cf. Montgomery, 1940). Using Sverdrup's theory, Rhiel, et al. (1951) determined the flux of latent heat as:

$$Q_e = (q_o - q_z)V_z \times 10^{-3} \text{ cal cm}^{-2} \text{ sec}^{-1} \qquad (1)$$

where

q_o = specific humidity corresponding to the temperature of the water

q_z = specific humidity of the air at level Z

V_z = wind speed at level Z
with V_z measured in cm/sec and q_o, q_z, in gm/kg.

The flux of sensible heat is given by:

$$Q_s = 4.16 \times 10^{-7}(T_o - T_z)V_z \text{ cal cm}^{-2} \text{ sec}^{-1} \qquad (2)$$

where

V_Z = same as in Eq. (1)

T_σ = water temperature

T_Z = air temperature at level Z

with T_O and T_Z expressed in degrees centigrade.

Using Eqs. (1) and (2) with the method outlined by Leese and Young (1963), the sensible and latent heat fluxes were determined at each cloud observation point.

The latent heat flux is proportional to the product of the wind speed and the saturation specific humidity differences between the sea surface and the level of observation. The quantity obtained by forming the product of the wind speed and the water-dew-point temperature difference will be highly correlated but essentially independent variable because of the nonlinear relationship between the dew-point temperature and the specific humidity. This quantity was included as a variable primarily to see how it compared with the latent heat flux when used in the statistical analysis.

To introduce the vertical stability into the analysis, an 850-mb chart was computed from the surface pressure and temperature, assuming an adiabatic lapse rate existed between these two levels. The deviation of this computed 850 from the observed 850-mb height field was used as an index of the stability of the air near the ocean surface. The interpretation of this quantity can become somewhat ambiguous. A region having a strong subsidence inversion well below the 850-mb level would give a relatively high value for this difference, but so would a situation of moist adiabatic lapse rate in a region with widespread cloud cover between the two levels. This ambiguity must be taken into account when interpreting the results of a statistical analysis in which this quantity appears.

Latitude and longitude were also included as "synoptic" variables to help interpret climatological tendencies in both the synoptic and cloud data.

In summary, the variables used in this study of cloud cover consists of:

1. latitude (°)
2. longitude—100 (°)
3. deviation of computed 850-mb ht from observed (m)
4. U-component of wind speed (m sec^{-1}) (East wind positive)
5. V-component of wind speed (m sec^{-1}) (South wind positive)
6. total wind speed (m sec^{-1})
7. air-dew-point temperature difference (°F)

8. water-air temperature difference (°F)
9. water-dew-point temperature difference (°F)
10. sensible heat flux (cal m^{-2} sec^{-1})
11. latent heat flux (cal m^{-2} sec^{-1})
12. product of wind speed and water-dew-point temperature difference (m sec^{-1} °F)
13. relative vorticity (10^5 sec^{-1})
14. absolute vorticity (10^5 sec^{-1})

This list is reduced to 13 at any one time since only two of the variables 7, 8, 9 can be used at once. There is also a functional (nonlinear) relation between number 2 and the difference between numbers 13 and 14.

CLOUD OBSERVATIONS

GEOGRAPHICAL DISTRIBUTION

Observations were recorded for all passes of TIROS III which produced pictures over the region and were within the specified dates. A total of 72 passes were examined, and after screening the observations for proximity to fronts and the edges of the grid, a total of 879 observations remained. Tables showing distribution of these observations over the region, and within subregions of 5° latitude and longitude, for each of the cloud variables are given in the Appendix.

A more natural breakdown of the distribution of the cloud observations is the frequency of occurrence of these various cloud patterns within quadrants of the Pacific Anticyclone. The lines of 35N latitude and 155W longitude serve as the interior boundaries of these quadrants. Such a distribution for the cloud variables is given in Table I. The two northern quadrants have quite similar distributions of cloud amount. The southeast quadrant shows a more frequent occurrence of lesser cloud amounts but maintains a shape in the overall distribution quite similar to the two northern quadrants. The frequency distribution of cloud amount in the southwest quadrant shows a very unique shape. Approximately 87% of all the observations in this quadrant contained cloud amounts of clear to scattered or scattered. One reason for this distribution will be discussed in the next section.

The distributions of the cumulus cell sizes of small, medium, large, and mixed in the four quadrants are also shown in Table I. These categories of cell size are associated with the cloud amount in groups 2 to 5. Large and mixed sizes predominate in the two northern quadrants, with the northwest quadrant having almost 73% and the northeast having 60% of the observations of the four sizes in these two categories. The four size groups are about equally likely in the southeast quadrant. The southwest quadrant again, as in the distribution of cloud amount, shows a very unique shape in the frequency distributions of cell size. Nearly 48% of the observations in these four categories are classified as small, whereas less than 8% are large size.

The greatest likelihood of banding is in the southeast quadrant, as shown by the distributions of band size in Table I. Nearly one observation in four shows some type of banding in this quadrant. The northeast quadrant is the least likely to have banding in any given observation; only about one observation in twelve shows this type of pattern. Reference to Table A-III (Appendix) shows that 10 of the 17 occurrences of banding in this quadrant were below 40N latitude and adjacent to the southeast quadrant. The two southern quadrants contain more than 75% of the occurrence of small banding, whereas

TABLE I

DISTRIBUTION OF OBSERVATIONS OF CLOUD AMOUNT, CELL SIZE, AND BANDING IN THE FOUR QUADRANTS

Quadrant		Cloud Amount							Cell Size (cloud amount in groups 2-5)						Band Size		
		1	2	3	4	5	6	Total	2	3	4	5	Total		2	3	Total
NW	F*	12	41	40	6	19	41	159	6	17	33	28	84		10	14	24
	%	7.5	25.8	25.2	3.8	11.9	25.8		7.1	20.2	39.3	33.3		% (all obs)	6.3	8.8	
NE	F	25	38	37	3	32	69	204	20	23	34	30	107		9	8	17
	%	12.2	18.6	18.1	1.5	15.7	33.8		18.7	21.5	31.8	28.0		% (all obs)	4.4	3.9	
SW	F	19	116	88	3	3	5	234	86	45	14	35	180		29	11	40
	%	8.1	49.6	37.6	1.3	1.5	2.1		47.8	25.0	7.8	19.4		% (all obs)	12.4	4.7	
SE	F	29	76	87	14	33	43	282	36	45	48	53	182		30	35	65
	%	10.3	26.9	30.9	5.0	11.7	15.2		19.8	24.7	26.4	29.1		% (all obs)	10.6	12.4	
All	F	85	271	252	26	87	158	879	148	130	129	146	553		78	68	146
	%	9.7	30.8	28.7	3.0	9.9	18.0		26.8	23.5	23.3	26.4		% (all obs)	8.8	7.7	

Cloud Amount:
1 - clear
2 - clear to scattered
3 - scattered
4 - scattered to broken
5 - broken
6 - broken to overcast, and overcast

Cell Size:
2 - small
3 - medium
4 - large
5 - mixed

Band Size:
2 - small
3 - large

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*F = frequency.

they have about 59% of the total number of observations. The occurrences of large band size tend to be concentrated in the southeast quadrant which has 51% of the occurrences, but only 32% of all the observations.

COMPARISON OF SATELLITE AND SURFACE CLOUD OBSERVATIONS

The significance of the distributions of the amount of cloud cover on a synoptic scale as determined from satellite observations, and discussed in the previous section, can perhaps be made more meaningful if compared with surface observations during the same time periods. However, because of the restrictive nature of the satellite observations as to what constitutes an observation and the desire to work with only one type of cloud pattern, such comparisons cannot be made for the whole region. A comparison cannot be made at all for the northern half of the region because of the frequent presence of the polar front. The major factor which would affect such a comparison in the southern half of the region is the presence of tropical storms, since no satellite observations were recorded in close proximity to these. Such tropical storms affect only a small portion of the total area and the number of occurrences in this time period was small so that the number of surface observations in these quadrants could not have a noticeable effect if allowed to remain in the set.

It was pointed out in the previous section that the frequency distributions of cloud amount differed between the southwest and the other quadrants. In order to made a more valid comparison of the two different types of observations, the surface observations were also separated into the same two subregions. The satellite observations were divided into nine groups, corresponding to the cloud amounts by equally subdividing groups 2, 3, and 6.

The frequency distributions of the surface cloud observations made at 1800, 0000 and 0600 GMT (primarily daytime) in the southeast and southwest quadrants as well as the satellite observations are shown in Table II. These distributions show that the surface observations of these low-level cumuliform clouds have a much greater frequency of occurrence of higher cloud amounts which is to be expected. The surface observations show that in the southeast quadrant approximately 43% of all observations had a cloud amount of broken or greater ($\geq 6/8$). By comparison only about 27% of the satellite observations showed a cloud amount of broken or greater. The southwest quadrant shows an even greater difference in these particular cloud amounts. The surface observations show 27% of the total had a cloud amount of broken or greater in this quadrant while only a little more than 3% of the satellite observations had a cloud amount this large.

Although these two methods of observing the cloud cover show completely different distributions of cloud amount, it is reasonable to expect that the mean of the two sets would, as the number of observations becomes very large,

TABLE II

DISTRIBUTION OF SURFACE AND SATELLITE OBSERVATION OF CLOUD AMOUNT

Quadrant	Observation		Cloud Amount									Total
			0	1	2	3	4	5	6	7	8	
SW	Surface	F*	3	33	108	91	83	46	62	43	30	499
		%	0.6	6.6	21.6	18.2	16.6	9.2	12.4	8.6	6.0	$\bar{N} = 4.0$
	Satellite	F	19	58	58	44	44	3	3	2	3	234
		%	8.1	24.8	24.8	18.8	18.8	1.3	1.3	0.8	1.3	$\bar{N} = 2.4$
SE	Surface	F	11	62	121	140	118	65	117	135	136	905
		%	1.2	6.9	13.4	15.4	13.0	7.2	12.9	14.9	15.0	$\bar{N} = 4.7$
	Satellite	F	29	38	38	43.5	43.5	14	33	21.5	21.5	282
		%	10.3	13.5	13.5	15.5	15.5	5.0	11.7	7.5	7.5	$\bar{N} = 3.6$

*F = frequency.

approach the same limit, i.e., the average amount of cloud cover. The average amount of cloud cover (in eighths) for the southeast quadrant as given by the surface observations is 4.7. The same quantity in the southwest quadrant is 4.0. The satellite observations yield an average cloud amount in the southeast quadrant of 3.6. This compares quite favorably with the value of 4.7 given by the surface observations. One can be confident that the true value of the average cloud amount in the southeast quadrant during this time period was very close to 4.0, or 50% cloud cover.

The satellite observations give an average cloud amount in the southwest quadrant of 2.4. The difference of 1.6 between the satellite and surface observations is larger than would be expected if the true mean is less than 4.0. Part of this discrepancy can be attributed to the fact that this quadrant had fewer surface observations than did the other quadrant. But with a total of nearly 500 surface observations, the mean of this set could be expected to be quite a stable estimate of the true mean, and this factor could be only a minor part of the discrepancy. The major factor in this discrepancy involves not only the actual distribution of the cloud amounts as given by the two types of observations, but also the distribution of the cumulus cell sizes derived from the satellite observations (Table I). In this quadrant, for observations that fit one of the four size categories, i.e., small, medium, large, and mixed, approximately 48% were assigned to the class of small size and only 8% were given the value of large size. This indicates that the cumulus clouds in this region show a much greater tendency to occur as individual cells than as clusters which occur in the other quadrants. As individual cells these clouds have a high probability of being smaller than the limit of resolution possible with the TIROS cameras. This factor can also account in large part for the unique distribution of the cloud amount from the satellite observations in this quadrant which was pointed out in the previous section. The distribution of the cell size in the satellite observations, as well as the distribution of the cloud amount given by surface observations, both point to the fact that observations of cloud amount obtained from satellites can yield an estimate which is too low in many cases. Because of this apparent tendency for cumulus to occur as individual and relatively small cells in the southeast quadrant of this region, it is reasonable to expect that the surface observations will give a more realistic distribution of cloud amounts even on the synoptic scale than those obtained from low-resolution satellite pictures over this quadrant.

A counter argument is that the satellite cloud observations used for this study are not a representative sample of the cloud cover in this particular quadrant. No estimate is available of the areas on the videographs which were thrown out because they did not meet the requirements for a cloud observation so that the importance of this factor cannot be determined. However, the comparison of the satellite observations with the surface observations has also served to clear up quite a mystery to Dr. Jean Rieker and this author which occurred while recording'the satellite observations. The videographs made over the southeast quadrant frequently appeared to be of inferior quality in the contrasts shown by the gray scale as compared to the videographs taken over the other regions. Many of these pictures, although apparently quite free of cloud cover, contained very little contrast between the water and the clouds present. It is now quite clear that this low contrast was the result of integrating very small and unresolvable cumulus clouds with the very dark background of the water.

STATISTICAL ANALYSIS

MULTIPLE-DISCRIMINANT ANALYSIS

The technique of multiple-discriminant analysis is used in the statistical analysis of the cloud and synoptic data. This study utilizes the modifications, described by Miller (1962), to the method originally developed by R. A. Fisher. The overlying principle in these preliminary analyses is that of statistical specification of the cloud variables using the synoptic data as predictors (or better, specifiers) and no time lag. The principle advantage of using this method of statistical analysis is that the variables to be specified need not be ordered but can be classified into groups.

Multiple-discriminant analysis selects from a set of "predictors" a subset that efficiently discriminates between two or more "predictand" groups. It is possible to achieve a further reduction in dimensions by determining several linear combinations of predictors that will discriminate without any loss of efficiency. The discriminant function Y_j is then defined as:

$$Y_j = V_{j1}X_1 + V_{j2}X_2 + \ldots V_{js}X_s \qquad (3)$$

where the X's are predictors selected by the screening discriminant analysis and the V's are weights obtained by a technique which assures that the linear combination Y_j is a better discriminator than any other possible linear combination of the X's.

The criterion used for selecting the predictors in Eq. (3) is one which maximizes the distance between the vector means of the discriminant function and minimizes the spread of the points about the vector means. The ratio of the sums of squares between groups over the sums of squares within groups is a measure of the ability to discriminate between groups. This value λ is given by:

$$\lambda_1 = \frac{SSB(Y1)}{SSW(Y1)} \qquad (4)$$

The statistical criterion used for determining the significance of a predictor S selected by the screening discriminant analysis is

$$(D_S^2 - D_{S-1}^2) > \chi^2_{(\alpha^*/P)} \qquad (5)$$

where

$$D_S^2 = (n\text{-}G * S) \text{ trace } W^{-1}B(X^{(1)} \ldots X^{(s)})$$

in which case

n = one less than the total number of observations in the sample.

G = number of groups.

Trace $W^{-1}B(X^{(1)} \ldots X^{(s)})$-sum of the diagonal elements of the matrix formed from the product of the inverse of the matrix of sums of products within groups (W) times the matrix of sums of products between groups (B) and where the predictors $X^{(1)} \ldots X^{(s-1)}$ have already been chosen.

$(\chi^2_{\alpha *}/P)$ is the critical value of χ^2 with a true level of significance given by $\alpha *$, but which has been corrected for the probability of selecting a predictor by chance by dividing the desired level of significance by the number of predictors (P) from which it was possible to select the predictor S. The .05 level of significance is used throughout this report as the value of $\alpha *$.

The maximum number of discriminant functions such as Eq. (3) is given by the minimum (G-1, PP), where (G-1) is one less than the number of groups and PP is the number of predictors selected.

Probabilities can be assigned to occurrences of the groups of the predictand by computing the Euclidean distance between observations in the discriminant space and then choosing the h closest points. The ratio of the observed frequencies in each of the groups to the total number h determines estimates of the conditional probabilities for the occurrences of each group.

A computer program for selecting the predictors and computing the discriminant function has been written for use with multiple groups. The computer program to determine the conditional probabilities has been completed for the special case of two groups only. Several computer runs have been made using more than two groups to select predictors only. Since the computer program for use with these multiple groups has not been completed, it was not possible to attempt any detailed interpretation of the predictors selected. The results presented in the following sections should be considered as preliminary only.

CLOUD AMOUNT

Although observations of the amount of cloud cover are classified into six groups, the statistical analysis thus far has been primarily concerned with various subgroups, and no attempt has been made up to now to discriminate among all six groups at the same time. One computer run was made for this cloud variable in which the six groups were combined into three groups made up individually of the two on each end and the two in the middle. The screening analysis was halted after the first five predictors were selected. The first two predictors selected were latitude and longitude which could be expected from the geographical distributions of cloud amount shown in Table A-I (Appendix) and the frequency distributions of these observations in the four quadrants shown in Table I. The three meteorological variables selected were the latent heat transfer, the surface geostrophic wind velocity and the U-component of the surface wind in that order. Since the values of the two discriminant functions resulting from this screening analysis have not been computed, it is impossible to make a physical interpretation of the contribution made by the three meteorological variables after accounting for the effects of latitude and longitude. Also, it has not been determined that no more of the predictors in the remaining list would be selected if the analysis were allowed to continue. The results of this particular run do, however, demonstrate the feasibility of obtaining statistically significant predictors for one of the cloud variables combined into more than two groups.

One of the computer runs with two groups involved the screening analysis for selecting predictors when using the two extremes of cloud amount, i.e., mostly clear and broken to overcast. Such an analysis could be expected to yield one of the best results insofar as the ability to discriminate between groups is concerned. For this particular run, the two groups were made up of an equal number of observations in each group. The 245 observations of cloud amount classed as either broken, broken to overcast, or overcast were combined into one group. The second group consisted of the 85 observations of clear plus 160 observations of clear to scattered selected by a random process from the total of 271 observations in this category. The screening analysis of these two groups selected five predictors with the last one just marginally significant at the true level of .05. In this case the variables of latitude and longitude were again selected as the first two predictors. The first meteorological variable selected was the surface geostrophic wind speed. The fourth and fifth predictors selected were respectively, the U-component of the surface wind speed and the sensible heat transfer. The value of λ, which is a measure of how good the discrimination is between these two groups, was 0.246. This value for λ would probably not be considered very respectable for a study, such as that by Miller (1962), who computed a value of λ of 3.3 for the first discriminant function when discriminating among ceiling heights in five groups, but is among the highest values achieved so far in discriminating among groups of cloud variables. The discriminant function determined for these two groups of cloud amount is:

$$Y = 6.34X_1 - 1.47X_2 + 5.36X_3 + 3.24X_4 + 3.45X_5 \qquad (6)$$

where

X_1 = latitude of cloud observation (°)

X_2 = longitude of cloud observation minus 100 (°)

X_3 = surface geostrophic wind velocity (m $\sec^{-1}$)

X_4 = U-component surface geostrophic wind velocity (m $\sec^{-1}$)

X_5 = sensible heat transfer (cal m^{-2} $\sec^{-1}$).

It must be kept in mind that the particular weights assigned to the predictors in Eq. (6) are valid only for the specific units in which the synoptic variables were measured in this study and since the synoptic variables have not been normalized a physical interpretation would also be meaningless unless the range of values of each of these predictors is considered. The value of the discriminant function was computed for each of the 490 observations. In general, the group comprised of observations of mostly clear had much lower values for the discriminant function than did the group comprised of large cloud amounts. A histogram of the number of observations within a specified range of these values is shown in Figure 1.

According to Eq. (6), for given values of the three meteorological variables, a geographical location at low latitude and high (west) longitude favors low cloud amounts and vice versa. This is, of course, just pointing out more explicitly what had already been demonstrated in the frequency distributions of the cloud amounts for the four quadrants shown in Table I. The actual mean value of the latitude and longitude for these two groups was 32.8N, 152.9W for the observations with little or no clouds and 37.5N, 145.7W for the groups with a large amount of cloud cover.

Equation (6) also shows that for the first meteorological variable selected, the total wind speed, a high value favors larger cloud amounts. This also shows up in the mean values of the wind speed for the two groups. The mean wind speed of the group comprised of little or no clouds was 6.0 m $\sec^{-1}$, while the other group had a mean wind speed of 7.2 m $\sec^{-1}$. The contribution of the other two predictors to the value of the discriminant function is somewhat more complicated than the previous three predictors because they can each take on positive and negative values. (For the U-component of the surface wind velocity an east wind is defined as positive.)

Equation (6) is consistent with the favoring of large cloud amounts in the northeast quadrant of the Pacific Anticyclone. The coefficients for the latitude and longitude variables show that the effect of latitude is greater than that of the longitude. This is also the location where a westerly (negative U) component of the wind would be expected. Thus, it happens that

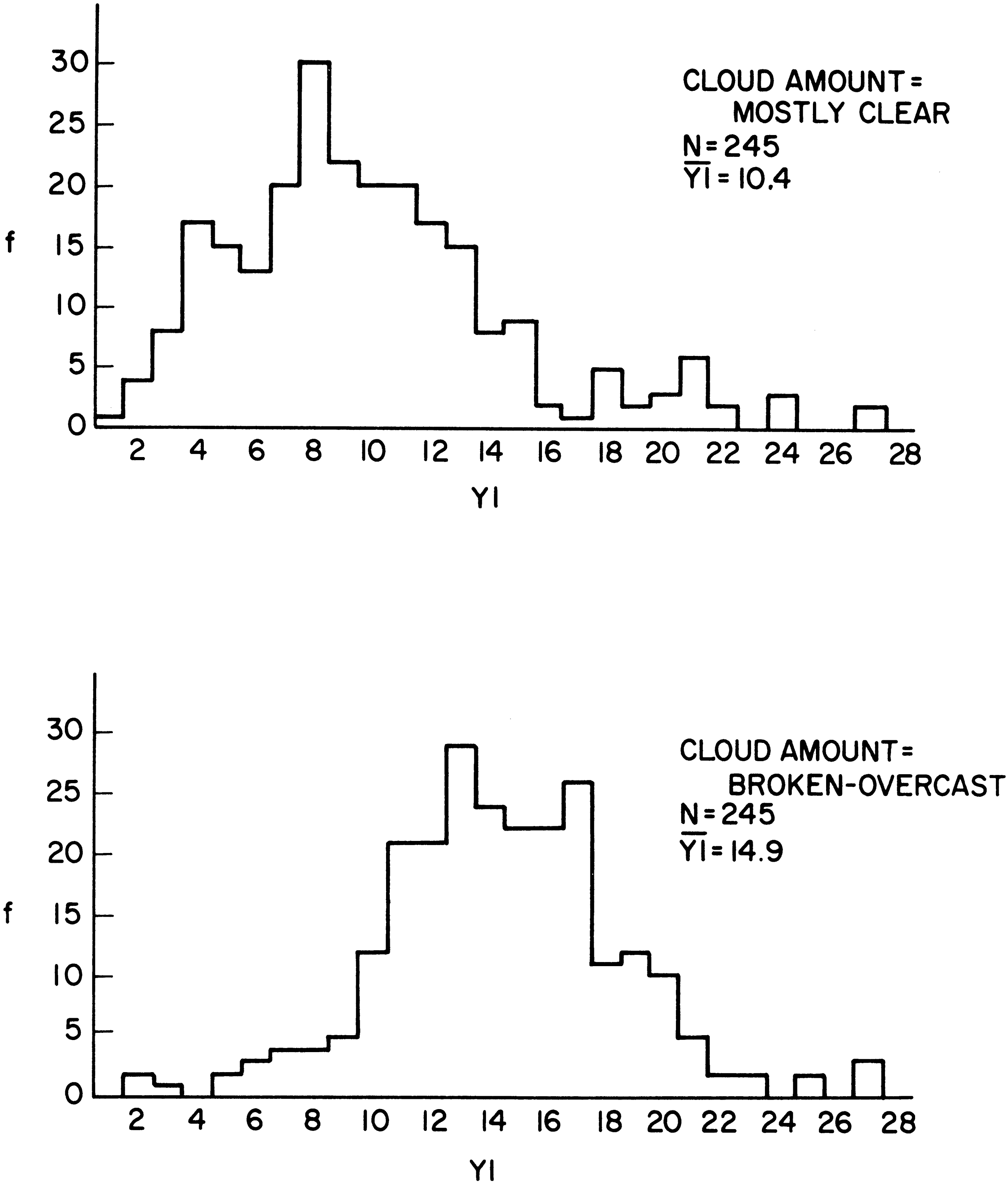

Figure 1. Distribution of discriminant function values using equal size groups of mostly clear and broken-overcast cloud amounts.

after the effects of latitude and longitude have been accounted for, the contribution made by the U-component of the wind speed is opposite in sign to what could be expected by the relationship between U and these two groups of cloud amount without first taking latitude and longitude into account.

Our interpretation of the sensible heat term is simply that the larger the transfer of sensible heat from the ocean to the atmosphere the more negative the vertical gradient of entropy in the atmosphere and the more convection required to accomplish the upward transfer. Negative sensible heat transfer implies a large positive vertical gradient of entropy and high atmospheric stability which retards convection.

It can be seen by examination of Figure 1 that, for the dependent sample, the conditional probability of mostly clear skies, is greater than 0.5 for values of the discriminant function less than 11, and it is less than 0.5 for values of Y which exceed about 11. If one were to use this criterion for a prediction, the accuracy, with respect to the dependent sample, would be about 70%. This figure, however, is not very meaningful. It was first pointed out to the author by Mr. Allan Murphy that although one can equalize the sizes of the groups by discarding observations when selecting predictors, it is not meaningful to compute conditional probabilities in the same way. To do so is to neglect the climatological frequencies of the two groups.

Probably just as important as correct specifications are the cases in which the value of the discriminant function tended to be extreme in the wrong direction. Figure 1 shows that this occurs most often for the observations of clear. There were 43 observations in this group for which the value of the discriminant function was greater than 14. A check on the location of these particular observations showed that half of them were directly adjacent to the North American coastline, where the contribution of latitude and longitude contributed to large values of Y and nearly all were associated with wind speeds much greater than average. A number of the remaining 42 observations occurred directly behind cold fronts. Although it is not possible to ascertain the reason for the occurrence of these clear areas behind cold fronts on the basis of so few observations, the analysis indicates that they are not the same conditions associated with clear conditions occurring in the Pacific Anticyclone.

Another analysis made with the cloud amount using two groups was to discriminate between scattered and broken cloud cover. One group was comprised exclusively of the 252 observations in which the cloud amount was classed as scattered while the other group was made up of the 112 observations which had scattered to broken or broken cloud amount. In this analysis the screening program was allowed to run until five predictors were selected regardless of the statistical significance of any of the predictors. Only two of the predictors selected proved to be significant at the .05 level or better. These were, in order of selection, the air-dew-point temperature difference and the longitude. The third predictor selected, latitude, was significant at only about the .25 level, when the number of predictors from which it was possible to select this particular one is taken into account, but might also be retained. The number of observations available for the analysis of these two groups is probably smaller than one would need to be able to determine all the significant predictors especially when one considers that we are attempting to discriminate between two adjacent groups of cloud amount. The remaining two predictors selected were the sensible heat transfer and the V-component of the surface geostrophic wind velocity. In order for a predictor to be considered statistically significant at the .05 level in this analysis it was necessary to have a value of χ^2 of seven or greater. The value of $(D_s^2-D_{s-1}^2)$ obtained when these last two predictors were selected was less than two. This indicates that these two predictors would not become significant even with a substantial increase in the number of observations.

The question which immediately arises as a result of this last analysis is whether or not the relative amount of moisture in the air is the only significant meteorological variable if we consider the four groups of cloud amount other than clear and overcast as separate entities. A screening analysis using these four groups showed that this was not the case and of the five predictors selected, four proved to be statistically significant at the .05 level or better. These four predictors, in the order of selection, are the latent heat transfer, longitude, air-dew-point temperature difference, and the absolute vorticity. The fifth predictor selected was the deviation of the adiabatic 850-mb height from the observed 850-mb height.

It is particularly noteworthy to point out at this time that of all the statistical analyses performed thus far using cloud amount, cell size, and band size, the only times when the total wind speed was not selected as a predictor in elementary form were the two cases in which cloud amounts in the middle ranges were used in different groups. The surface geostrophic wind velocity did not appear as a predictor in any form when scattered and broken cloud amounts were combined into two groups; and the mean wind speed associated with each of these two groups differed by less than 0.1 m sec^{-1}. However, the total wind speed is present implicitly in the analysis of the four groups appearing both in the latent heat transfer predictor and; in a much more involved manner, in the absolute vorticity.

CELL SIZE AND BAND SIZE

Attempts to discriminate among multiple groups consisting of either the cumulus cell size or the size of the bands have not achieved the same degree of success in identifying statistically significant predictors as was experienced using cloud amount. The two principle reasons for this are the smaller number of observations of these cloud variables and the very uneven distribution of the observations within the different groups. As in the case of cloud amount, if we assume that an increase in the number of observations would show the same distribution of the synoptic variables within the groups of cloud variables it is quite simple to estimate the effect of this increased number on the factor of statistical significane. The effect of a large disparity in the number of observations within different groups with this method of statistical analysis is that the group having the largest number of observations gets weighted much heavier than the groups with fewer observations. It is more often the case in meteorology that the rare event is the most important with regards to prediction. Such is the case when considering the occurrences of cloud bands in different sizes which appear as rare events when compared to the number of occurrences of clouds with no apparent banding. Miller (1962) suggests that in such a case one should make the group frequencies more nearly equal when selecting the predictors so as to emphasize the prediction of the important groups. In this preliminary analysis of these cloud variables the group frequencies were used as they occurred climatologically.

The observations of cell size were screened for selecting predictors twice; first, using the four groups of sizes including the "catch-all" category of mixed, and then using only the three specific size ranges of small, medium, and large. The number of observations within each of these groups were:

small	56 observations
medium	68 observations
large	116 observations
mixed	120 observations

Each time the program was allowed to run until five predictors were selected regardless of the statistical significance of the predictor. In the first run, which included the mixed size group, the five predictors selected along with the χ^2 value needed for statistical significance at the true level of .05 and the actual value ($D_s^2-D_{s-1}^2$) obtained is shown in Table III.

TABLE III

SELECTED PREDICTORS FOR THE FOUR GROUPS OF CELL SIZES

Order of Selection	Predictor	$(D_s^2-D_{s-1}^2)$	$\chi^2_{.05/p}$
1	Longitude	22.6	13
2	Latitude	26.5	13
3	850-mb height (deviation from observed)	7.0	13
4	Surface geostropic wind velocity	5.1	13
5	U-component surface wind	5.5	12

Table IV presents the same type of information as given in Table III, but is valid for the analysis of cell size in the three specific groups of small, medium, and large.

TABLE IV

SELECTED PREDICTORS FOR THE THREE SPECIFIC CELL-SIZE GROUPS

Order of Selection	Predictor	$(D_s^2 - D_{s-1}^2)$	$\chi^2_{.05/p}$
1	Longitude	21.1	11
2	Latitude	27.3	11
3	Relative vorticity	5.3	11
4	V-component surface wind	5.1	11
5	Surface geostropic wind velocity	4.7	10

For each of these analyses the only variables selected which are significant at the .05 level are the two which give the geographical location. The importance of these two variables was previously shown in Table I, where the small cell size was predominant in the southwest quadrant whereas the large cell size dominated the observations in the northern half of the Pacific Anticyclone.

Although none of the meteorological variables appeared as significant predictors for either case, it is not unreasonable to expect any one or all of them to achieve this status if the number of observations was increased by a substantial amount. Considering the number of observations used for these analyses the value of $(D_s^2 - D_{s-1}^2)$ is well above the noise level observed in the analyses of cloud amount in different groups. It is quite precarious, however, to attempt to interpret the results of these two analyses in any physical sense. The important thing shown by these analyses is the influence of the relatively large number of observations in the mixed size groups on the selection of meteorological predictors. The predictors selected when using four groups is most strongly influenced by the two groups of large and mixed sizes, whereas the large size alone exerts a strong influence on the selection of predictors with three groups. A physical interpretation of the results involves the unraveling of these complicated features and leaves room for a large range of errors so that simplifications are in order before this is attempted.

One computer run was made for the analysis of cloud banding in which were included all the observations for which the cloud amount was either scattered, scattered to broken, or broken. These observations were classed into the three groups of cloud bands, i.e., no bands, small-, and large-band spacing. The problem of disproportionate group frequencies is especially severe for this cloud variable. Of the 365 observations in this sample, 248 were included in the group of no bands, 64 with small bands and 53 with large bands. None of the predictors selected were statistically significant at the .05 level. The first predictor selected was the longitude which had a value of D_1^2 equal to 10.5 compared to a χ^2 value of 11 needed for statistical significance. The value of $(D_2^2-D_1^2)$ dropped off quite sharply for the second predictor to 4.2 and considering the frequency distribution of the observations is probably not far above the noise level. This particular predictor was the water-air-temperature difference. The third predictor selected was the surface geostrophic wind velocity and had a value of 4.1 for $(D_3^2-D_2^2)$. The small number of observations in the two-band size groups makes any attempt at a physical interpretation quite futile. Perhaps the best that can be accomplished at this stage is to speculate that based on this analysis of using the climatological frequencies of the occurrences of different classes of banding a larger sample size in the band spacing groups would show more definitely that the significant surface parameters are the same two which Woodcock (1940) found discriminated between banding and no banding in his observations of the soaring habits of birds with different combinations of wind speed and air-sea-temperature difference.

INDICATIONS AND FUTURE PLANS

The results of this preliminary analysis have succeeded in demonstrating the validity of the technique used in determining statistically significant conventional meteorological parameters which contribute to the low-level cumuliform cloud patterns so common over the oceans. The ability to determine these parameters were seen to be dependent to a great extent on having a large sample size without disproportionate frequencies within the various groups. The results so far indicate that in order to discriminate among more than two groups, with the quality of data used, the minimum sample size should be on the order of 500 observations.

The physical interpretation of the results could probably be simplified if the predictors were normalized prior to the analysis and it is planned to include this in future analysis procedures.

The observations are now assumed to be independent of time even though they are spread over a 12-hour period during the three weeks. It is planned to include the time of observation as a variable to eliminate this unnecessary assumption.

It is also planned to perform a similar analysis on the satellite cloud observations available from TIROS taken during the same three-week period over this region in 1962.

The goal of this study is to determine the amount of quantitative information which can be derived from an analysis of these low-level cumuliform cloud patterns. To accomplish this the roles of the satellite cloud data and the synoptic data will be reversed in the statistical analysis methods now used in an effort to determine which, if any, meteorological variables can be quantitatively specified, and within what limits of accuracy.

ACKNOWLEDGMENTS

Dr. Jean Rieker of the Swiss Meteorological Service, Zurich, Switzerland, was associated with this project at The University of Michigan during the summer of 1963. The author acknowledges the contributions of Dr. Rieker, especially for his critical and discerning views on the approach to the problem.

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APPENDIX

TABLE A-I

FREQUENCY DISTRIBUTION OF CLOUD AMOUNT

TIROS III, August 15, to September 5, 1961
(Eastern and southern boundaries of 5° longitude and latitude grid)

			LONGITUDE(W)												
LAT	AMT		180	175	170	165	160	155	150	145	140	135	130	125	120
50	1	*	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	*	0	0	0	1	0	0	1	0	0	0	0	0	0
	3	*	0	0	0	0	0	1	2	0	1	1	0	0	0
	4	*	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	*	0	0	0	0	0	0	1	0	0	0	0	0	0
	6	*	0	0	0	1	3	2	0	1	1	1	0	0	0
45	1	*	0	0	0	0	0	0	0	0	0	0	1	1	0
	2	*	0	1	1	1	0	0	0	1	0	1	0	3	0
	3	*	0	0	1	0	2	1	2	2	2	1	0	0	0
	4	*	0	0	0	0	0	1	0	0	0	0	0	0	0
	5	*	0	0	0	1	1	1	3	0	3	0	1	0	0
	6	*	1	2	8	4	5	4	0	3	3	3	7	0	0
40	1	*	1	0	0	0	0	2	1	0	0	2	4	4	0
	2	*	0	0	1	1	1	3	3	1	0	3	2	6	0
	3	*	1	3	3	3	4	1	3	3	2	1	3	1	0
	4	*	0	2	0	1	0	0	0	1	0	0	0	0	0
	5	*	1	3	3	2	2	2	3	2	3	1	2	0	0
	6	*	1	2	2	1	1	3	4	3	5	7	7	3	0
35	1	*	0	1	3	0	2	3	1	0	0	0	4	6	1
	2	*	3	5	6	3	9	5	5	3	2	3	3	1	0
	3	*	0	0	6	5	7	2	2	4	2	2	3	0	0
	4	*	1	1	0	0	0	0	0	1	1	0	0	0	0
	5	*	0	1	0	0	1	1	0	3	5	2	2	0	0
	6	*	0	0	0	0	0	1	4	4	3	3	1	4	3
30	1	*	4	4	1	0	3	3	3	0	1	3	5	3	3
	2	*	4	7	18	12	8	6	11	3	4	2	5	6	1
	3	*	2	5	8	4	7	4	6	7	5	2	3	1	0
	4	*	0	0	1	0	0	0	3	1	0	2	3	0	0
	5	*	0	0	0	0	1	0	3	0	2	0	4	1	1
	6	*	0	0	1	0	0	0	0	4	3	0	4	3	6
25	1	*	0	2	0	0	1	0	0	0	5	3	1	1	0
	2	*	2	4	9	6	7	6	7	4	6	2	4	2	0
	3	*	2	4	5	1	6	6	7	5	2	2	3	0	0
	4	*	0	0	0	0	0	0	0	0	1	0	0	0	0
	5	*	0	0	0	0	0	0	0	0	1	1	1	3	0
	6	*	0	0	1	2	0	0	0	0	1	2	2	2	0
20	1	*	0	1	0	0	0	0	0	0	1	0	0	0	0
	2	*	0	1	7	7	10	2	6	2	4	3	3	1	0
	3	*	0	1	7	5	7	14	10	7	10	9	5	2	1
	4	*	0	0	1	0	1	0	0	1	2	0	0	1	0
	5	*	0	0	0	0	1	1	1	0	4	1	8	2	0
	6	*	0	0	1	0	0	0	0	0	5	4	3	4	0

CCDE FOR CLOUD AMOUNT
1 CLR   2 CLR TO SCTD
3 SCTC   4 SCTD TO BRKN
5 BRKN   6 BRKN TO OVC AND OVC

TABLE A-II

FREQUENCY DISTRIBUTION OF CELL SIZE

TIROS III, August 15, to September 5, 1961
(Eastern and southern boundaries of 5° longitude and latitude grid)

									LONGITUDE(W)						
LAT	SIZE		180	175	170	165	160	155	150	145	140	135	130	125	120
50	1	*	0	0	0	1	0	0	1	0	0	0	0	0	0
	2	*	0	0	0	0	0	1	0	0	0	0	0	0	0
	3	*	0	0	0	0	0	0	1	0	0	0	0	0	0
	4	*	0	0	0	0	0	0	1	0	1	0	0	0	0
	5	*	0	0	0	0	0	0	1	1	0	1	0	0	0
	6	*	0	0	0	1	3	2	0	0	1	1	0	0	0
45	1	*	0	0	1	0	0	0	0	1	0	1	1	2	0
	2	*	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	*	0	1	0	0	0	0	0	0	0	0	1	2	0
	4	*	0	0	2	2	3	1	3	3	3	1	1	0	0
	5	*	0	0	0	0	0	2	2	0	2	1	0	0	0
	6	*	1	2	7	4	5	4	0	2	3	2	6	0	0
40	1	*	1	0	0	0	1	5	2	1	0	2	4	6	0
	2	*	0	0	0	0	0	0	2	1	0	2	1	1	0
	3	*	0	0	2	1	0	0	0	1	0	1	2	4	0
	4	*	1	5	0	4	5	2	5	3	3	0	3	0	0
	5	*	1	3	5	2	1	1	1	2	4	2	2	0	0
	6	*	1	2	2	1	1	3	4	2	3	7	6	3	0
35	1	*	2	4	7	2	6	4	3	1	0	0	5	6	1
	2	*	0	0	0	1	2	2	3	2	3	3	1	1	0
	3	*	0	1	3	3	4	2	2	2	1	3	2	1	0
	4	*	0	1	1	0	4	2	1	2	1	0	3	0	0
	5	*	2	2	4	2	3	1	0	4	5	2	1	0	0
	6	*	0	0	0	0	0	1	3	4	3	2	1	3	3
30	1	*	5	5	3	5	5	7	8	1	2	4	6	4	4
	2	*	3	7	14	5	2	3	2	3	3	1	4	3	0
	3	*	0	0	8	4	7	3	7	1	3	0	5	3	0
	4	*	0	1	0	1	1	0	2	1	2	2	2	1	0
	5	*	2	3	3	1	4	0	7	6	3	2	3	1	1
	6	*	0	0	1	0	0	0	0	3	2	0	4	2	6
25	1	*	1	4	2	1	4	0	0	2	6	5	1	1	0
	2	*	3	6	10	5	5	3	2	1	4	1	1	1	0
	3	*	0	0	2	1	2	5	5	2	2	1	5	1	0
	4	*	0	0	0	0	1	2	1	1	2	0	1	3	0
	5	*	0	0	0	0	2	2	6	3	1	1	1	1	0
	6	*	0	0	1	2	0	0	0	0	1	2	2	1	0
20	1	*	0	1	3	2	0	0	2	0	3	0	1	0	0
	2	*	0	2	3	5	6	4	4	2	1	1	2	0	0
	3	*	0	0	2	2	4	5	3	3	5	4	3	3	0
	4	*	0	0	1	2	3	3	2	3	8	6	8	3	0
	5	*	0	0	6	1	6	5	6	2	4	2	2	1	1
	6	*	0	0	1	0	0	0	0	0	5	4	3	3	0

CODE FOR CELL SIZE

1 NONE	4 LARGE
2 SMALL	5 MIXED
3 MEDIUM	6 UNDETERMINED