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CLOUD STATISTICS IN EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS) MISSION PLANNING

VINCENT V. SALOMONSON

AUGUST 1969

GSFC

GODDARD SPACE FLIGHT CENTER
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ABSTRACT

Early in the 1970's Earth Resources Technology Satellites (ERTS) will be launched into orbit with sensors on board that are designed to map mineralogical, oceanographic, hydrological, and agricultural resources. In order for satisfactory measurements to be made by these sensors, clear skies are necessary. Therefore, in order to permit proper evaluation and design of these satellite systems, cloud statistics defining the frequency and size of cloud free areas at specific locations and times over the globe need to be developed.

A review of available results shows that several studies exist which describe the mean cloudiness over the earth. There are only a few studies which give the frequency distribution in space and time of cloud cover categories, but these are the most useful results for ERTS mission planning and evaluation. The available studies of the latter kind show that relatively small portions of the earth are free enough from clouds to expect that at a high probability level two or more passes out of five will be free from clouds. Over the United States the best viewing conditions for ERTS appear to exist during the fall and the worst conditions occur in the spring.

More data are needed to increase the level of confidence that can be placed on existing cloud statistics. Data from several sources will have to be utilized; therefore, substantial efforts also need to be placed on studying the way basic characteristics inherent in the data affect cloud statistics. These basic characteristics include the length-of-record, geographical coverage, frequency of observations, basic sampling area size, perspective, and resolution associated with each data source. The effect of resolution is one that particularly needs to be evaluated carefully because studies underway indicate that existing sensors on meteorological satellites cause an overestimation of cloudiness in broken cumuliform situations and an underestimation where cirrus is the predominant cloud form. For evaluating the frequency of cloud free areas commensurate with the high resolution sensors to be placed on ERTS, future studies should use very high resolution photography such as that available from aircraft and various Apollo missions to serve as a "ground truth" aid in interpreting the vastly greater volume of other forms of satellite and conventional data.

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CLOUD STATISTICS IN EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS) MISSION PLANNING

1. INTRODUCTION

Scientists and engineers have been successful in recent years in developing instrumentation for use on earth-orbiting satellites that will be of great assistance in the understanding, development, and management of the earth's resources and environment. In particular, "remote sensors" have been developed which are designed to map certain parameters that permit the evaluation of mineralogical, hydrological, oceanographic, and agricultural resources from platforms such as the Earth Resources Technology Satellites (ERTS) scheduled for launching in the early 1970's. These sensors will primarily obtain data in the visible, near infrared, and far infrared portions of the electromagnetic spectrum. Because of these characteristics, satisfactory measurements can only be made when a large proportion of the area being viewed is free from clouds. Therefore, in order that the design of the ERTS system be evaluated accurately and optimized, it is necessary that the frequency of occurrence of cloud free areas of appropriate size be known and the probability of achieving satisfactory measurements estimated.

The broad objective of cloud statistics studies that are directly relevant to the objectives of the ERTS program and its design can be stated as follows:

> For a location with geographical coordinates (ϕ , λ) and time of day (t), and defining the cloud free portion of the sky as consisting only of "elemental areas" (of say, a square grid overlay of mesh size D) each of which is completely devoid of clouds, what is the probability $P(\phi, \lambda, t, D)$ that a "basic sampling are" will be at least, f% cloud free?

It is the purpose of this report to review the climatological and statistical information already available to see how this information contributes to the attainment of the objective described above. The data sources obtainable for augmenting these existing results will also be reviewed and the problems outlined that are associated with the interpretation and utilization of these data.

2. AVAILABLE MEAN CLOUDINESS INFORMATION

Several efforts of various kinds have been made to compile and summarize information that describes the distribution in space and time of the mean cloudiness over large portions of the earth. Some of the major studies of this kind have been listed in Table 1 along with details and remarks that describe major features of these studies.

One group of these studies consists of those in which mean cloudiness estimates were derived from conventional (ground-based) weather observations (Environmental Technical Applications Center (USAF), 1968; Fifth Weather Wing (USAF), 1966; Seide, 1954; and Landsberg, 1945). As a result of the reliance on conventional observations, these studies are most representative over land areas, particularly in the Northern Hemisphere, and least representative over large ocean areas.

Another group of studies includes those studies in which satellite nephanalyses were utilized when finding the mean cloudiness over major portions of the earth (Clapp, 1964, 1968; Sadler, 1969; Godshall et al., 1969). Because of the relatively short time that satellite nephanalyses have been available, the length of record for each of these studies is short in comparison to those studies included in the first group. Inter-comparison of these results must be done carefully in that there were changes in the satellite nephanalysis codes during the time spanned by these studies and differently sized basic sampling areas were used. However, these results are quite valuable in that they rather accurately describe the mean cloudiness over large portions of the ocean regions, particularly in the tropics where conventional observations are very sparse and less representative.

The locations of areas where clouds tend to persist can be determined by using satellite information that is strongly affected by cloudiness. Representative studies include those using the digitized brightness data obtained from the Advanced Vidicon Systems (AVCS) on board Environmental Science Services Administration (ESSA) satellites (Taylor and Winston, 1968), digitized data obtained from meteorological satellite photographs (Arking, 1964), and satellite radiometer observations in the far infrared (Allison et al., 1969). Also included in this group of studies are those in which the primary objective was to evaluate the global radiation balance of the earth-atmosphere system (Winston and Taylor, 1967; Vonder Haar, 1968; and Raschke, 1968). The globally distributed fields of emitted radiation, net radiation, and, in particular, albedo presented in these studies have been strongly affected by cloudiness and, as a result, show where clouds tend to persist.

Other studies which obtained cloud statistics have been conducted using satellite photographs as the basic input information. Careful interpretation of individual meteorological satellite photographs has been done by Barnes et al. (1968) in order to arrive at mean cloud cover estimates in the tropics. Photographic compositing techniques have been used to arrive at representations of the mean cloud patterns during various times over the globe by Kornfield et al. (1967).

Estimates of mean cloudiness or delineations of areas where clouds persist such as those described above do not provide information that is directly applicable to the generation of probability estimates of cloud cover at specific locations and times. Frequency distributions of various cloud cover categories, such as those obtainable from Godshall et al. (1969) are needed in order to arrive at valid probability estimates. There may be certain geographical areas in which a relationship between the mean cloudiness and the frequency distribution of the cloud cover can be determined. This would allow greater utilization of the studies listed in Table 1 for ERTS mission planning and evaluation; however, this hypothesis has not been proven as yet.

3. STATISTICAL AND PROBABILISTIC CLOUD COVER INFORMATION

In Table 2 studies are listed which contribute to the establishment of the frequency of cloud cover categories and the probability of observing a given cloud cover situation at a specific location and time of day. The list is not completely exhaustive, but represents those studies which are considered at this point in time to be most relevant to present and furture needs in ERTS mission planning.

When accumulating cloud cover statistics from satellite data, or from any data source, it is imperative that the data be interpreted as carefully as possible. For instance, when comparing results from differing satellite sensors or when comparing results derived from satellite data with results relying on ground-based observations, differences in perspective, resolution, and basic sampling area size are among the factors that must be considered and their effect on the final results evaluated. Methods contributing to the accurate interpretation of cloud cover from satellite photographs have been given by Conover (1962). Comparisons between satellite data and other data sources such as conventional ground observations have been made and discussed by Barnes and Chang (1968), Blackmer and Alder (1965), and Sherr et al. (1968).

Some studies connected with atmospheric temperature sounding from satellite attitudes have already been accomplished that are of interest for ERTS purposes because atmospheric soundings using spectral measurements in the infrared require frequent observations where clear areas of a given dimension are present. The relationship between sensor resolution and the spatial and temporal frequency of observations has been studied by McCulloch and Smith (1969), Williamson and Warnecke (1969), and Stamm (1969). In addition, the study by Stamm (1969) discusses a very practical problem involving the use of digitized satellite data and the importance of the method by which the cloud-no cloud brightness threshold is chosen in computerized evaluations of cloud cover.

The studies mentioned on the previous page all conclude that the effective global coverage increases as the spatial resolution of the observing instrument increases. This conclusion must be tempered, however, by the fact that increased resolution results in greater instrumental difficulties such as a decrease in the signal-to-noise ratio. This subject as it relates to cloud statistics is discussed by Arking, Weinstein and Fleishman (1969).

The study by Smith and Shafman (1968) cited in Table 2 had the objective of providing estimates of the probability of having nearly clear skies (less than 30% cloud cover) given the viewing and orbital characteristics of a future ERTS. The frequency of nearly clear skies for each of the four seasons derived from this study have been listed in Figure 1 at thirty-five locations in the United States. Based on the binomial probability law, the >0.8 and <0.5 probability areas for observing less than thirty percent cloud cover on at least two out of five passes of a satellite have been delineated on Figure 1. Similar probability estimates based on the frequency of clear skies at each station can be obtained from the graph given in Figure 2 for at least 1, 3, 4, and 5 successful observations in 5 passes. One will note from Figure 1 that the fall season provides the best opportunity over the United States for observing clear sky conditions and the worst conditions exist in the spring.

Unconditional and conditional probabilities of observing various sky conditions at specific locations have been developed by Blackmer and Alder (1965) and Sherr et al. (1968). Blackmer and Alder (1965) show the probabilities of observing a ground location on an unplanned satellite pass and the probabilities of changes in cloudiness within 10° latitude by 10° longitude areas centered on the intersections of 15°N, 30°N, and 45°N latitude and 100°W, 10°E, and 110°E longitude. Seasonal and geographic variations in the persistence of sky cover at specific locations are also discussed in this report.

Sherr et al. (1968) have divided the world into 29 homogeneous cloud climatic regions. A map showing the distribution of these 29 regions is given in Figure 3. Using the data included by Sherr et al. in their report for July at 1000 hours local time, shading has been employed to delineate those regions where less than 30% cloudiness can be expected 0-25%, 25-50%, 50-75%, and 75-100% of the time. Reference to Figure 2 shows that a relative frequency of 50% corresponds to an approximate probability of 0.8 for at least 2 successes out of 5. Figure 3 illustrates that one can expect to see nearly clear skies in at least 2 passes out of 5 at better than the 0.8 probability level in only a relatively small portion of the world.

The division of the world into homogeneous cloud climatic regions is an approach which can be used to expedite and summarize cloud statistics data that may be used in satellite mission planning. Sherr et al. (1968) have used one carefully selected station within a cloud climatic region to represent the cloudiness frequency distribution for the whole region. By following this procedure a cloud statistics data base consisting of both unconditional and conditional probabilities was developed which was of a size that could be incorporated into satellite mission analyses performed on digital computers. Further examples of how such a data base may be used in mission planning and simulation are given by Greaves et al. (1968). In particular, the application of Monte Carlo methods is described.

As one might expect, there is always a certain amount of variation in the cloud cover over a "homogeneous" cloud climatic region that will result in differences between the predicted amounts of cloudiness based on one station record representing the whole region and the observed amounts at other locations within a region. As an illustration of this point, the relative frequency of clear and less than 30% cloud cover is given in Figure 4 for region 11 (see Figure 3) as represented by Belleville, Illinois at 1000 and 1600 local times during the year. Superimposed on the less than 30% frequency distribution at 1000 hours are the seasonal ranges in the 10 year average frequency of 0-30% cloud cover for United States stations within region 11 as they were obtained from the results computed by Smith and Shafman (1968).

It is easy to see in Figure 2 that ranges such as those depicted in Figure 4 can result in appreciable ranges in the probabilities of success in five passes over the Northeastern United States. It may be that ranges as large as these are too large and will not satisfy confidence requirements in the probability estimates of success needed in mission planning. Further breakdown of large areas into even more homogeneous cloud climatic regions would then need to be accomplished.

Other statistical techniques and concepts may be appropriately used to amplify or provide results that would be of utility in assessing the probability of viewing a specific location from a satellite at a given time. Persistence, probability estimation, Markovian, and non-Markovian statistical procedures are among the topics considered by Chu (1968) and McCabe (1968). When time or other factors limit the amount of data that can be collected, statistical-predictive techniques such as those cited above must be employed in satellite mission planning and cloud statistics development.

4. BASIC FACTORS TO CONSIDER IN CLOUD STATISTICS DATA ACCUMULATION

In Table 3 the major data sources available for the augmentation of existing cloud statistics are listed along with some characteristics of these data sources.

Sunshine (Lund, 1965) and airplane data sources have not been listed in that they are not considered primary sources of data for cloud statistics. However, it is noted that a considerable number of photographs that include clouds have been taken by the NASA Convair 990 high altitude research aircraft, the U.S. Air Force (Planck, 1969), and from U-2 aircraft (Blackmer and Serebreny, 1962). Each one of the data sources listed in Table 3 has some advantages and disadvantages that generally relate to six major factors that should be considered when accumulating and interpreting data from one source or several sources. The factors are (1) length-of-record, (2) geographical coverage, (3) frequency of observations, (4) size of the basic sampling area, (5) perspective, and (6) resolution.

A great deal of information concerning clouds and associated spatial and temporal statistics are and will continue to be available from meteorological satellites. One of the greater disadvantages of satellite observations at present is the relatively limited time over which observations have been taken as compared to the period of record associated with conventional weather stations in the United States. The period of record that is needed to produce statistically stable cloudiness frequency distributions is not firmly established, but a period longer than 10 years appears to be desirable (Sherr et al., 1968). If all satellite observations are considered, the desirable length-of-record is not achieved and several different sensors with different observational characteristics affecting the cloud statistics are involved. This is a significant observation in that Sherr et al. (1968) have noted that year to year variations can affect cloudiness frequency distribution considerably. Therefore, the length-of-record factor should be carefully considered, and, if possible, adjustments applied, when preparing or using statistics derived from satellite data.

It is clear that conventional, ground based weather observations offer the best source of data from the length of record standpoint, but the geographical coverage and representativeness is quite limited over sparsely populated areas such as the oceans. The data available in pictorial form from the Apollo flights is also limited in geographical extent being largely confined to the tropical latitudes. The most complete spatial coverage is provided by the polar-orbiting ESSA and Nimbus satellites. The ATS I and ATS III satellites observe a large portion of the globe also, primarily in the Western Hemisphere.

The TIROS satellites provided observations that were spaced irregularly in time for any given location and as a result these observations are least attractive when considering the frequency-of-observation factor. The Nimbus and ESSA satellites are in sun-synchronous orbits that provide observations from each satellite at one local time during daylight hours. With the infrared observations available from sensors on board the Nimbus satellite series observations at near midnight local times are also available. It is possible to take useful observations during daytime hours from the geostationary ATS satellites at twenty minute intervals. Observations are commonly taken at first order weather stations every hour. The latter two sources are the most desirable in terms of frequency of observations and offer the best data for evaluating diurnal and shorter period variations in cloudiness.

Perspective is a factor which can cause bias in estimates of cloud cover. This is particularly true in the case of ground-based observations of scattered and broken conditions (Appleman, 1962). In this instance, an overestimation tends to occur in the ground based observations. The tendency for overestimation due to perspective should also be considered when using ATS data at geographical locations where the local zenith angle of the satellite is large. The ESSA, Nimbus, and Apollo data provide the data most analogous to ERTS sensors in this respect in that the observations are available at or very near the nadir.

The size of the basic sampling area used in collecting cloud statistics can affect the character of the resulting frequency distributions of cloudiness. The way in which this factor affects a frequency distribution can be illustrated very easily. Over a point on earth, the cloud cover can only be described as clear or overcast. Over the entire earth, the cloud cover probably will remain very near the mean (~30 to 35%) with very little variance. In between these two extremes, as the size of the sampling area becomes larger, the frequency distribution will go from one with square or U-shaped characteristics to one with a more bell-shaped appearance. A quantitative description of how this transition occurs and its dependence on the type of meteorological situation remains to be accomplished.

The resolution of the sensors that have been included on satellites varies considerably (Table 3). The resolution factor is a most important one and must be carefully considered in comparing cloud statistics from different sources. In addition to those studies mentioned in section 2 that consider the effect of resolution on cloud cover estimates, some comparisons of cloud cover, estimates from ESSA, ATS and Apollo data have been made by William E. Shenk* of NASA, Goddard Space Flight Center. These estimates were made along a path of Apollo 6 in the Atlantic on April 4, 1968, using the pictures from a camera on board the unmanned Apollo spacecraft and the concurrent pictures obtained from ATS III and ESSA 3. The respective resolutions are 0.035, 3.7, and 3.7 kilometers. The results show a general overestimation of cloud cover in scattered to broken cumuliform situations by the ESSA 3 and ATS III camera systems. An underestimation by ESSA 3 and ATS III occurred in regions of cirrus clouds when the

*Personal communication.

cirrus was the only cloud type detected by the Apollo 6 photography. When isolated cumuliform clouds exist an underestimation by the ESSA and ATS systems may occur in that the presence of clouds may not be recorded at all.

The Apollo 6, 7, and 9 data are very appropriate for determining the frequency of cloud free areas that are much smaller than the resolution elements of the meteorological satellites. Where the quantity and geographical extent of these data are too limited for studying the effect of resolution and frequency of small cloud free areas, the data should be supplemented with aircraft data such as that mentioned at the beginning of this section. Certainly these data should be used wherever possible as a source of "ground truth" in evaluating estimates of cloud amount from other sources.

5. CONCLUSIONS

This review of clouds statistics for use in ERTS mission planning has shown that there is a considerable amount of available information, but a large portion of this information is not in a form that is adequate for ERTS mission simulation and planning. Some cloud statistics have been developed which show the frequency of various degrees of cloud cover over the U.S. and over the world, but this information needs to be augmented and refined. In particular, more unconditional and conditional cloud cover statistics need to be collected and compiled so that analyses of ERTS and other satellite systems may be produced that can be used with a high degree of confidence.

Several sources of data are available, including meteorological satellite data and pictures taken from Apollo spacecraft, that can provide the statistics needed. These data must be compiled carefully, however, in that length-of-record, geographical coverage, frequency of observation, basic sampling area size, perspective, and resolution factors vary from one data source to another. Substantial efforts need to be expended in showing how the effects of each of these factors can be normalized so that internally consistent sets of data can be derived.

REFERENCES

Allison, L. J., E. R. Kreins, F. A. Godshall, and G. Warnecke, 1969: Monthly Global Circulation Characteristics As Reflected in TIROS VII Radiometric Measurements, Part I. Examples of the Usefulness of Satellite Data in General Circulation Research (to be published as a NASA Technical Note, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, Md.).

Appleman, H. S., 1962: A Comparison of Simultaneous Aircraft and Surface Cloud Observations. Journal of Applied Meteorology, 1, 548-551.

Arking, A., 1964: The Latitudinal Distribution of Cloud Cover from TIROS Photographs. Science, 143, 569-572.

__________, F. Weinstein, and J. Fleischmann, 1969: Cloud Statistics Affecting The Sounding of The Lower Atmosphere From a Satellite. Preliminary report, Institute for Space Studies, Goddard Space Flight Center, NASA, New York, N. Y., 15 pp.

Barnes, J. C., D. W. Beran, and A. H. Glaser, 1968: Apollo Landmark Sighting: An Application of Computer Simulation to a Problem in Applied Meteorology. Journal of Applied Meteorology, 7, 768-779.

__________, and D. Chang, 1968: Accurate Cloud Cover Determination and Its Effects on Albedo Computations. Final Report, Contract No. NAS5-10478, Allied Research Associates, Concord, Mass., 82 pp.

Blackmer, R. H., Jr., and J. E. Alder, 1965: Distributions and Characteristics of Various Broadscale and Special Cloud Systems. Final Report, Contract AF 19 (628)-1681, Project No. 8624, Task No. 862401, Stanford Research Institute, Menlo Park, California, 117 pp.

__________, and S. M. Serebreny, 1962: Dimensions and Distributions of Cumulus Clouds as Shown by U-2 Photographs. Scientific Report 4, Contract AF 19(604)-7312, Stanford Research Institute, Menlo Park, California, 57 pp.

Chu, S. T., 1968: Determination of Cloud Cover Persistence by a Non-Markovian Stochastic Chain. Air Force Report No. SAMSO-TR-68-353, Contract No. FO4 695-67C-958, Aerospace Corporation, El Sequndo, California. 46 pp.

Clapp, P. F., 1964: "Global Cloud Cover for Seasons Using TIROS Nephanalyses. Monthly Weather Review, 92, 495-507.

____________, 1968: Northern Hemisphere Cloud Cover for Selected Late Fall Seasons Using TIROS Nephanalysis. ESSA Technical Memorandum WBTM NMC 44, National Meteorological Center, U.S. Weather Bureau, ESSA, Washington, D. C., 21 pp.

Conover, J., 1962: Cloud Interpretation from Satellite Altitudes. Research Note 81, Meteorological Research Laboratory Project 6698, Air Force Cambridge Research Laboratories, Office of Aerospace Research, United States Air Force, Hanscom Field, Mass., 77 p.

Environmental Technical Applications Center (USAF), 1968: Northern Hemisphere Cloud Cover Summary. Offutt Air Force Base, Nebraska, United States Air Force, 432 pp.

Godshall, F. A., L. J. Allison, E. R. Kreins, and G. Warnecke, 1969: An Atlas of Average Cloud Cover over the Tropical Pacific Ocean, Part II. Examples of the Usefulness of Satellite Data in General Circulation Research, (to be published as a NASA Technical Note, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, Md.).

Greaves, J. R., P. E. Sherr, and A. H. Glaser, 1969: Cloud Cover Statistics and Their Use in the Planning of Remote Sensing Missions (to be published in the Journal of Remote Sensing, Volume 1, Number 2).

Kornfield, J., A. F. Hasler, K. J. Hanson, and V. E. Suomi, 1967: Photographic Cloud Climatology from ESSA III and V Computer Produced Mosaics. Bulletin of the American Meteorological Society, 48, 878-883.

Landsberg, H. E., 1945: Climatology. Handbook of Meteorology, New York, McGraw-Hill, 928-997.

Lund, I. A., 1965: Estimating the Probability of Clear Lines-of-Sight from Sunshine and Cloud Cover Information. Journal of Applied Meteorology, 4, 714-722.

McCabe, J. T., 1968: Estimating Conditional Probability and Persistence. Technical Report No. 208, Air Weather Service, United States Air Force, 17 pp.

McCulloch, A. W., and W. L. Smith, 1969: Proposal for a High Resolution Temperature Sounder for Nimbus F. Goddard Space Flight Center, Greenbelt, Md., 26 pp.

Planck, V. G., 1969: The Size Distribution of Cumulus Clouds in Representative Florida Populations. Journal of Applied Meteorology, 8, 46-67.

Raschke, E., 1968: The Radiation Balance of the Earth-Atmosphere System From Radiation Measurements of the Nimbus II Meteorological Satellite, NASA Technical Note TN D-4589, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, Md., 81 pp.

Sadler, J. C., 1969: Average Cloudiness in the Tropics from Satellite Observations. Honolulu, East-West Center Press, 46 pp.

Seidi, R., 1954: The Distribution of Cloudiness by Type and Height in the Northern Hemisphere for Spring and Fall: M. Sc. Thesis, College of Engineering, New York University, 34 pp.

Sherr, P. E., A. H. Glaser, J. C. Barnes, and J. H. Willand, 1968: World-Wide Cloud Cover Distributions for Use in Computer Simulations. NASA Contract Report, NASA CR-61226, Contract No. NAS8-21040, Allied Research Associates, Inc., Concord, Mass., 140 pp.

Smith, C. R., and T. F. Shafman, 1968: Cloud Cover Limitations on Satellite Photography of the United States. A paper presented at the 46th annual meeting of the American Geophysical Union, Washington, D. C., April 8-11, 1966, 10 pp.

Stamm, A., 1969: Preliminary Report on a Cloud Statistics Study. NASA Contract NAS5-11542, Madison, Wisc., Space Science and Engineering Center, The University of Wisconsin, Madison, 29 pp.

Taylor, V. R., and J. S. Winston, 1968: Monthly and Seasonal Mean Global Charts of Brightness From ESSA 3 and ESSA 5 Digitized Pictures, February 1967 - February 1968. ESSA Technical Report NESC 46, National Environmental Satellite Center, ESSA, Washington, D. C., 18 pp.

Fifth Weather Wing (USAF), 1966: Revised Uniform Summary of Surface Weather Observations, Part D. 5th Weather Wing Pamphlet No. 105-1-1, Headquarters, 5th Weather Wing, Langley Air Force Base, Virginia, 53 pp.

Vonder Haar, T., 1968: Variations of the Earth's Radiation Budget. Ph. D. Dissertation, Department of Meteorology, The University of Wisconsin, Madison, Wisc., 118 pp.

Winston, J. S., and V. R. Taylor, 1967: Atlas of World Maps of Long-wave Radiation and Albedo for Seasons and Months Based on Measurements from TIROS IV and VII. ESSA Technical Report NESC 43, National Environmental Satellite Center, ESSA, Washington, D. C., 32 pp.

Williamson, E. J., and G. Warnecke, 1969: The Influence of Cloud Distribution on the Global Coverage of Remote Sounding Systems (to be published in the Quarterly Journal of the Royal Meteorological Society)

Table 1

A listing of major summaries and their various features that can either be used directly to obtain mean cloudiness estimates over large portions of the globe or used to infer the locations of persistent cloud cover.

SUMMARY (AUTHOR AND/OR TITLE)	BASIC SAMPLING AREA	LENGTH OF RECORD	GEOGRAPHICAL COVERAGE	TYPE OF DATA	REMARKS
Landsberg (1945)			Global	Conventional Observations	Charts of mean cloud cover for several months.
Seide, R. (1954)	5° Lat. by 10° Long.		Northern Hemisphere	Conventional Data	Data sources are from before 1950.
Revised Uniform Summary of Surface Weather Observations - Part D (5 WW, USAF, 1966)		Variable No Data Before 1945	U.S. Weather Bureau Stations and U.S. Air Force Installations including those outside U.S.	Conventional Observations	Percentage frequency of tenths of total sky cover is given for each station for different hours and months.
Northern Hemisphere Cloud Cover Summary (ETAC, USAF, 1968)	5° Lat. Grid	Sept. 1963-Aug. 1968	Northern Hemisphere	All Available Data	Percentage frequency of eighths of total sky cover. Values generally not available south of 22.5°N.
Clapp (1964)	5° Lat. by 5° Long.	March 1962-Feb. 1963	60°N - 60°S around the globe	Satellite Nephanalyses	Seasonal averages.
Clapp (1965)	5° Lat. by 5° Long.	Oct.-Dec. 1962, 1963, 1964	Northern Hemisphere	Satellite Nephanalyses	Late fall season average.
Sadler (1966)	2.5° Lat. by 2.5° Long.	Feb. 1965-Dec. 1968 Jan. 1963-Dec. 1964	30°N - 30°S around the globe	Satellite Nephanalyses	
Godshall et al. (1969)	2° Lat. by 2° Long.	Aug. 1962-April 1969	100° W - 130° E 30° N - 25° S	Satellite Nephanalyses	Percentage frequency of various nephanalyses categories is given for each analysis area.
Allison et al. (1969)	5° Lat. by 5° Long.	June 1963-Dec. 1964	60°N - 65°S around the globe	TIROS VII 8-12μ MRIR Radiometer Data and Conventional Observations	Conventional observations were analyzed between 10°N and 70°N.
Barnes et al. (1967)	1° Lat. Circles	May 15-Aug. 1966 Oct. 1966-Feb. 1967	35°S - 35°N	Satellite Pictorial Data	Nimbus II and ESSA III data.
Arking (1964)	250,000 Elements per picture	July-September 1961	60°S - 60°N around the globe	Brightness Data	TIROS III
Taylor and Winston (1968)	5° Lat. by 5° Long.	Feb. 1967-Feb. 1968	Global	Brightness Data	Monthly and seasonal means from ESSA III and V mesoscale brightness data.
Kornfield et al. (1967)		Jan. 1967-July 1967	Global	Pictorial Data	Photographic averages
Winston and Taylor (1967)	5° Lat. by 5° Long.	Feb.-June 1962, July 1963-May 1964	70°N - 70°S around the globe	MRIR Data from TIROS IV and VII	Monthly and seasonal composite maps of albedo and long-wave radiation
Vonder Haar (1968)	10° Lat. by 10° Long.	Nov. 1959-May 1960, Feb.-June 1962, and June 1963-Nov. 1965	Global	Low Resolution Hemispheric and Flat Sensors Plus MRIR Radiometers on Explorer VII and TIROS IV and VII	Monthly, seasonal, and yearly mean maps are available.
Raschke, E. (1968)	260 X 280 km at 60° Lat. on Polar Ster. Projection. 5° Lat. by 5° Long. at Equator on Mercator Projection	May - July 1966	Global	Nimbus II MRIR Data	Outgoing long-wave flux, net radiation flux, and albedo semi-monthly mean maps are presented on Mercator and polar stereographic projections.

Table 2

Studies which give cloud statistics or describe techniques, both interpretative and statistical, which could be used in ERTS mission planning.

AUTHOR(S)	TITLE	BRIEF DESCRIPTION
Conover, J. (1962)	Cloud Interpretation From Satellite Altitudes	Interpretation procedures are described which facilitate more accurate determination of cloud statistics from satellite photographs.
McCulloch, A. W. and W. L. Smith (1969)	Proposal for a High Resolution Temperature Sounder for Nimbus F	Nimbus II HRIR data is used to show that 5-10 N. mile resolution adequately observes clear areas near fronts and storms.
Stamm, A. (1969)	A Preliminary Report on a Cloud Statistics Study	The effect of spatial resolution on the estimated percentage of clear by a given sensor is discussed.
Williamson, E. J. and G. Warnecke (1969)	The Influence of Cloud Distribution on the Global Coverage of Remote Sounding Systems	Nimbus I and II HRIR data were used to estimate the effect of field-of-view on percent global coverage by atmospheric sounding systems.
Smith, C. R. and T. E. Shafman (1968)	Cloud Cover Limitations on Satellite Photography of the United States	The probability of observing clear skies at various locations and times is discussed for an earth resources satellite mission. 35 stations, 2 times of day, and 4 seasons are considered.
Blackmer, R. H. and J. E. Alder (1965)	Distributions and Characteristics of Various Broad Scale and Special Cloud Systems	Comparisons and discussions of surface observations, satellite photographs, U-2 photographs, and vertically pointing radar are given. Probabilities of observing various cloud cover conditions at specific locations along 15°N, 30°N, and 40°N are given.
Sherr, P. E., A. H. Glaser, J. C. Barnes, J. H. Willand, (1968)	World Wide Cloud Cover Distributions for Use in Computer Simulation	Probability distributions for 29 homogeneous cloud climatic regions covering the world have been prepared for 12 months and 8 times of day. Spatial and conditional probabilities, Monte Carlo techniques, and combinatorial analyses are discussed.
Greaves, J. R., P.E. Sherr and A. H. Glaser (1968)	Use of Cloud Statistics in Remote Sensing Missions	Monte Carlo simulation of an earth observation program employing a cloud statistics data bank is discussed.
Barnes, J.C., and D. Chang (1968)	Accurate Cloud Cover Determination and its Effects on Albedo Computations	Comparisons between satellite observations and surface observations of cloud cover are made.
Chu, S. T. (1968)	Determination of Cloud Cover Persistence by a Non-Markovian Stochastic Chain	Estimation of persistence of clear and cloud conditions are shown to agree with observed results at selected stations.
McCabe, J.T. (1968)	Estimating Conditional Probability and Persistence	Statistical methods for generating conditional probability information from unconditional probability statistics are discussed. Examples of cloud cover persistence probability are shown.

Table 3

Major data sources for cloud statistics along with relevant descriptive data and remarks describing the characteristics of these data.

DATA SOURCE	AREA VIEWED (KM. SQ.) (NADIR ANGLE=0°)	RESOLUTION (KM.) (NADIR ANGLE=0°)	PERIOD OF AVAILABLE DATA	REMARKS
TIROS I, II	[illegible]06	0.4	4/60-6/60, 11/60-2/61	
TIROS IV-VI	765	1.9	2/62-10/63	
TIROS I-X	1130-1290	2.[illegible]	4/60-2/67	Occasional breaks in time continuity from 6/60-6/62
TIROS II, III, IV, and VII	Scanning Radiometer	60	11/60-4/61 (TIROS II) 7/61-9/61 (TIROS III) 2/62-6/62 (TIROS IV) 6/63-6/65 (TIROS VII)	
ESSA 1	1290	2.8	2/66-5/67	Early afternoon, sun synchronous
ESSA 2	3200	3.7	2/66-	
ESSA 4	3200	3.7	1/67-6/67	ESSA 2, 4, 6, 8 have APT cability and were launched into sun synchronous, morning, southbound orbits
ESSA 6	3200	3.7	11/67-	
ESSA 8	3200	3.7	12/68-	
ESSA 3	3200	3.7	10/66-10/68	ESSA 3, 5, 7, 9 have the Advanced Vidicon System (AVCS) and were launched into sun-synchronous, afternoon, north-bound orbits. Digitized brightness tapes are available in mesoscale (48 km) format from Feb. 1967. Full resolution (6 km) and "Supermesh" resolution (3 km) data are available in limited quantities.
ESSA 5	3200	3.7	4/67-12/68	
ESSA 7	3200	3.7	3/68-4/69	
ESSA 9	3200	3.7	2/69-	
Nimbus I (AVCS)	610 X 2940 km - Apogee 278 X 1200 km - Perigee	0.9	8/64-9/64	
Nimbus I (APT)	1850	1.5	8/64-9/64	
Nimbus I (HRIR)	Scanning Radiometer	9	8/64-9/64	3.5 - 4.1 microns
Nimbus II (AVCS)	3500 X 740 km	0.9	5/66-11/66	
Nimbus II (APT)	2220	3.2	5/66-11/68	
Nimbus II (HRIR)	Scanning Radiometer	9	5/66-11/66	3.5 - 4.1 microns
Nimbus II (MRIR)	Scanning Radiometer	55	5/66-7/66	5 channels available (6.4-6.9, 10-11, 14-16, 5-30, and 0.2-4.0 microns).
Nimbus III (IDCS)	1390	3.2	4/69-	
Nimbus III (HRIR)	Scanning Radiometer	7	4/69-	3.4-4.2 microns (nighttime) and 0.7-1.3 plus 2.5 microns (daytime).
Nimbus III (MRIR)	Scanning Radiometer	55	4/69-	5 channels are available (6.5-7.0, 10-11, 14.5-15.5, 20-23, and 0.2-4.0 microns.
ATS I	108° Lat. X 161° Long.	4.6	12/66-	256 brightness levels, subsatellite point 0° Lat., 151°W. Long.
ATS III	163° Lat. X 163° Long.	3.7	11/67-	256 brightness levels, subsatellite point 0° Lat., 45-96°W. Long.
Apollo 6	150	0.035	4/63	Unmanned flight. All pictures taken at nadir angle = 0° ± 5°.
Apollo 7	150	0.035	10/68	Apollo flights were over low latitudes only.
Apollo 9	150	0.035	3/69	Apollo photographs were taken visible and near infrared at nadir angle = 0° ± 15°.
Conventional Observations	74	0.010	Variable	Sparce over large ocean areas.

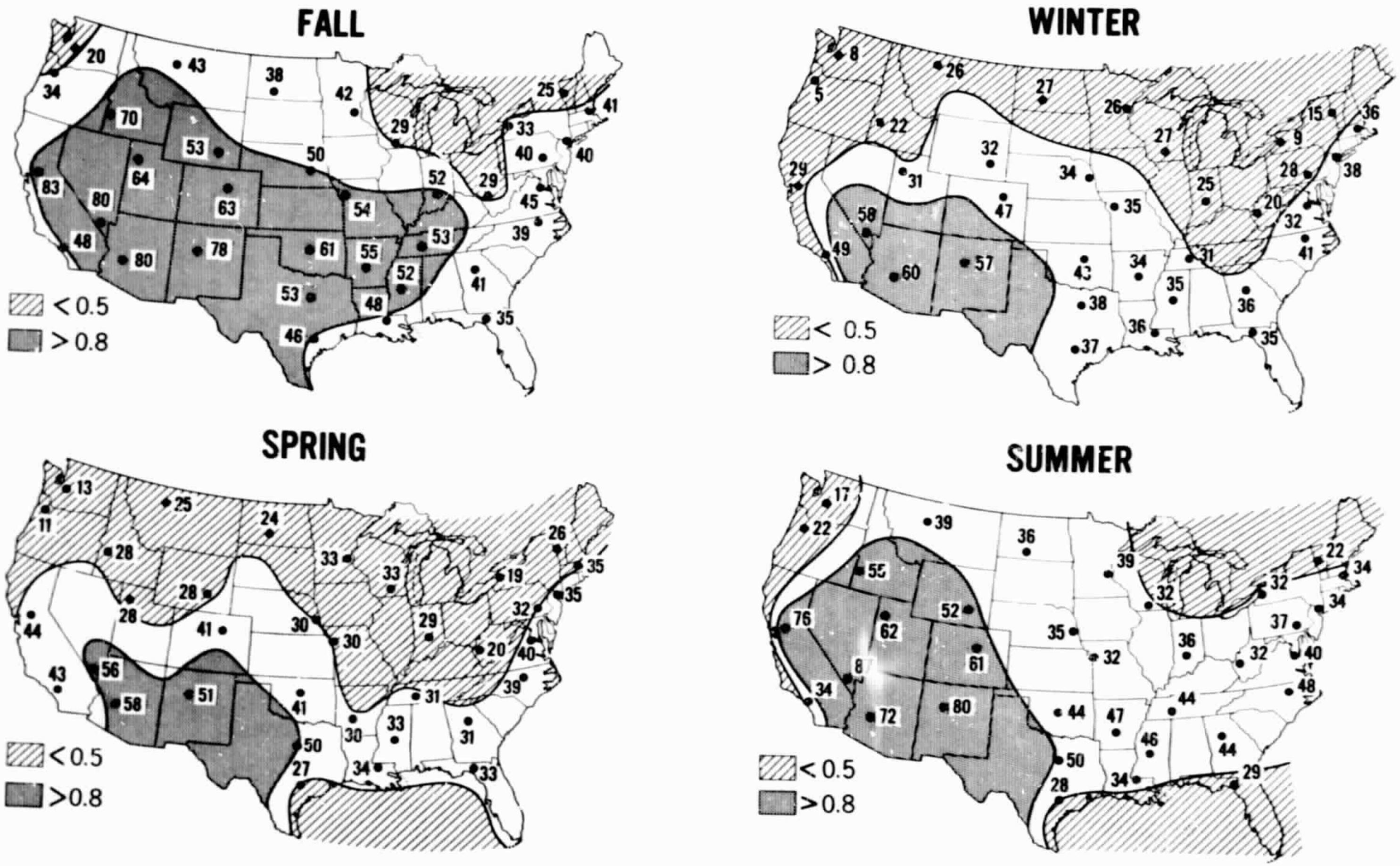

Figure 1. Four maps of the United States showing the frequency in percent of 30% or less cloudiness at 35 stations and the general locations where the probability is >0.8, 0.5–0.8, and <0.5 of seeing 30% or less cloudiness on at least 2 out of 5 passes during a season. The frequencies shown were compiled for the four seasons by Smith and Shafman (1968) and are based on ten years of record at each station.

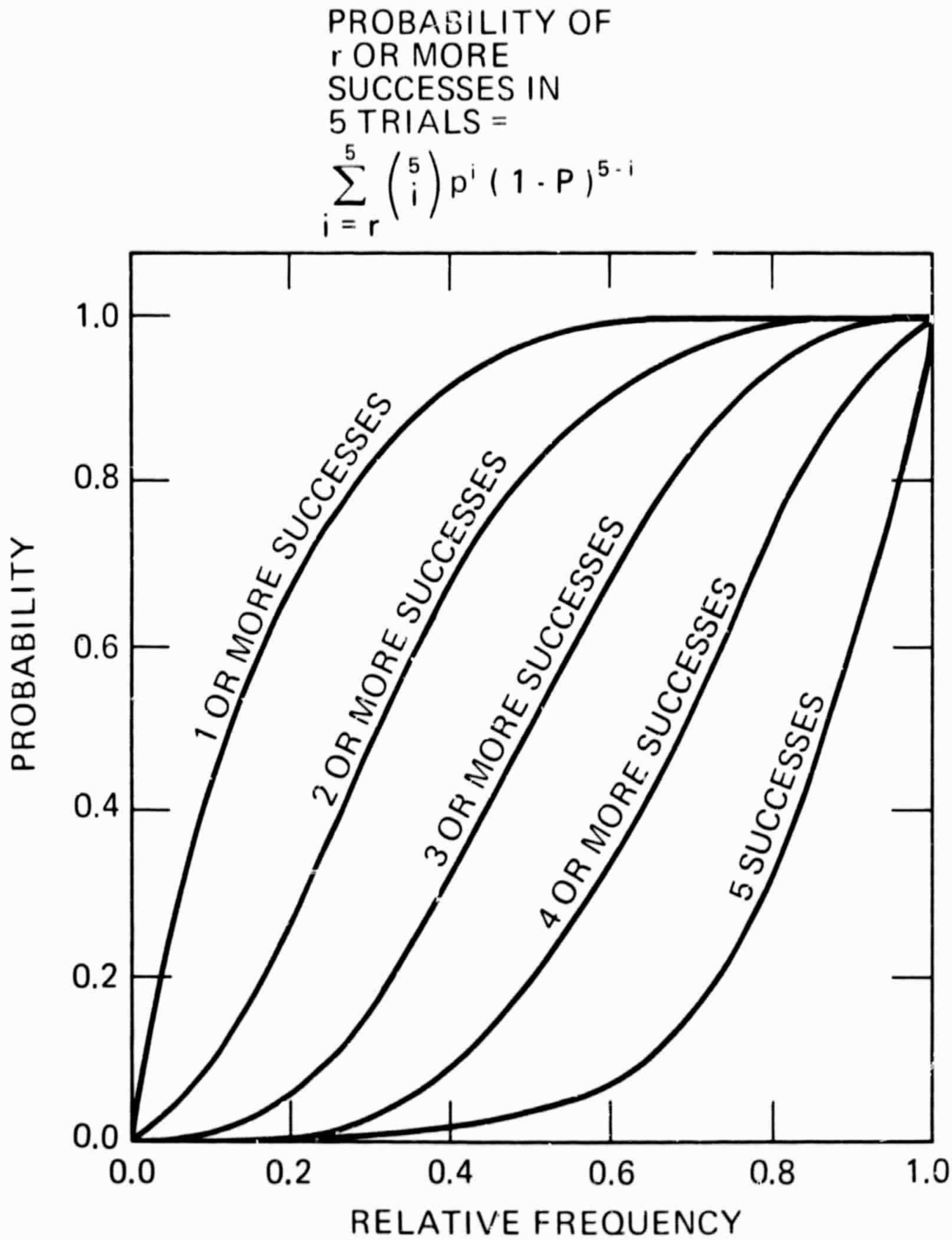

Figure 2. A graph showing the relative frequency of an event versus the probability of the event occurring at least 1, 2, 3, 4, and 5 times in five trials based on the binomial probability law.

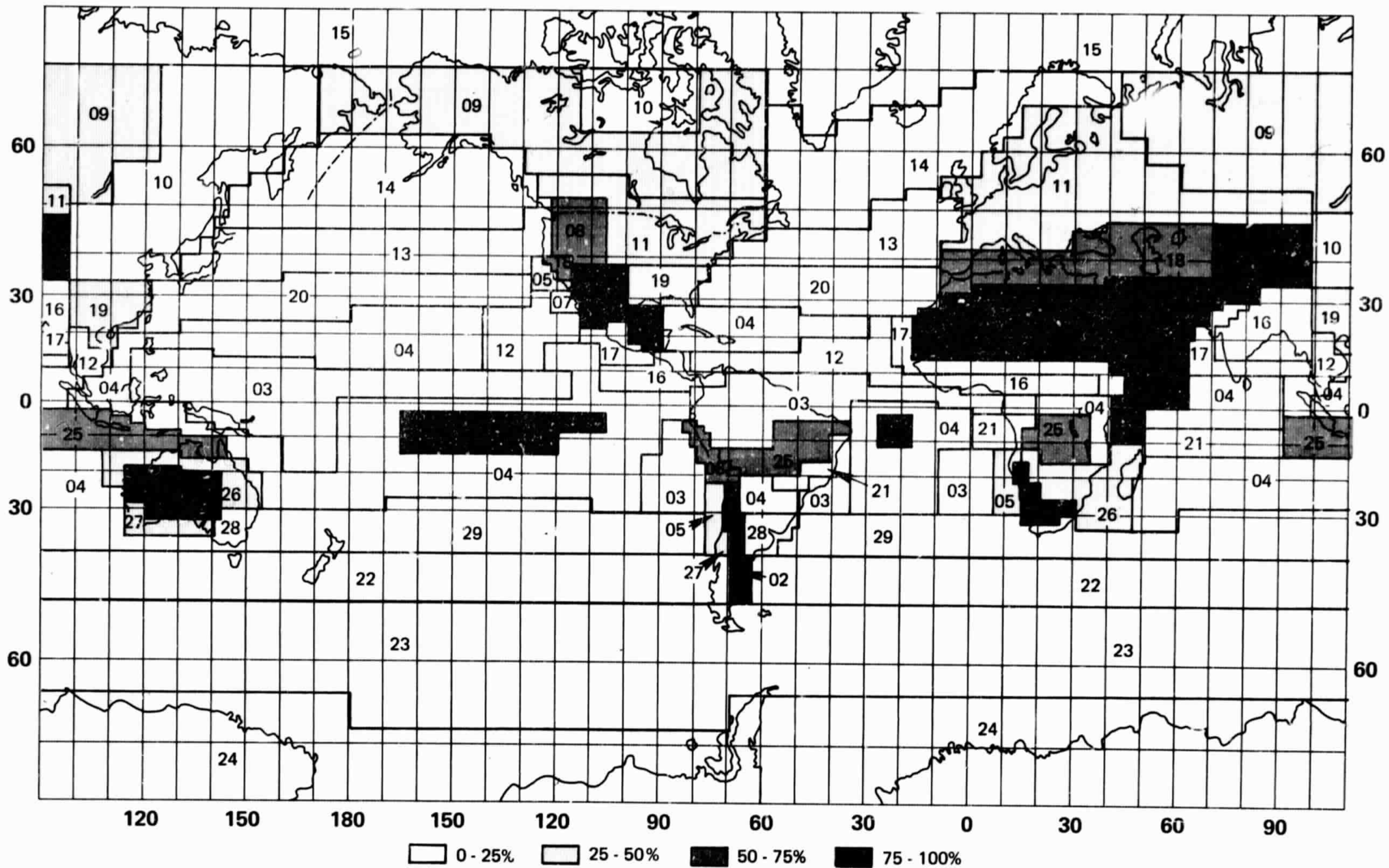

Figure 3. A map showing the distribution of the 29 homogeneous cloud climatic regions delineated by Sherr et al. (1968). Areas of the world in which 30% or less cloudiness occurs 0–25%, 25–50%, 50–75%, and 75–100% of the time are delineated by shading.

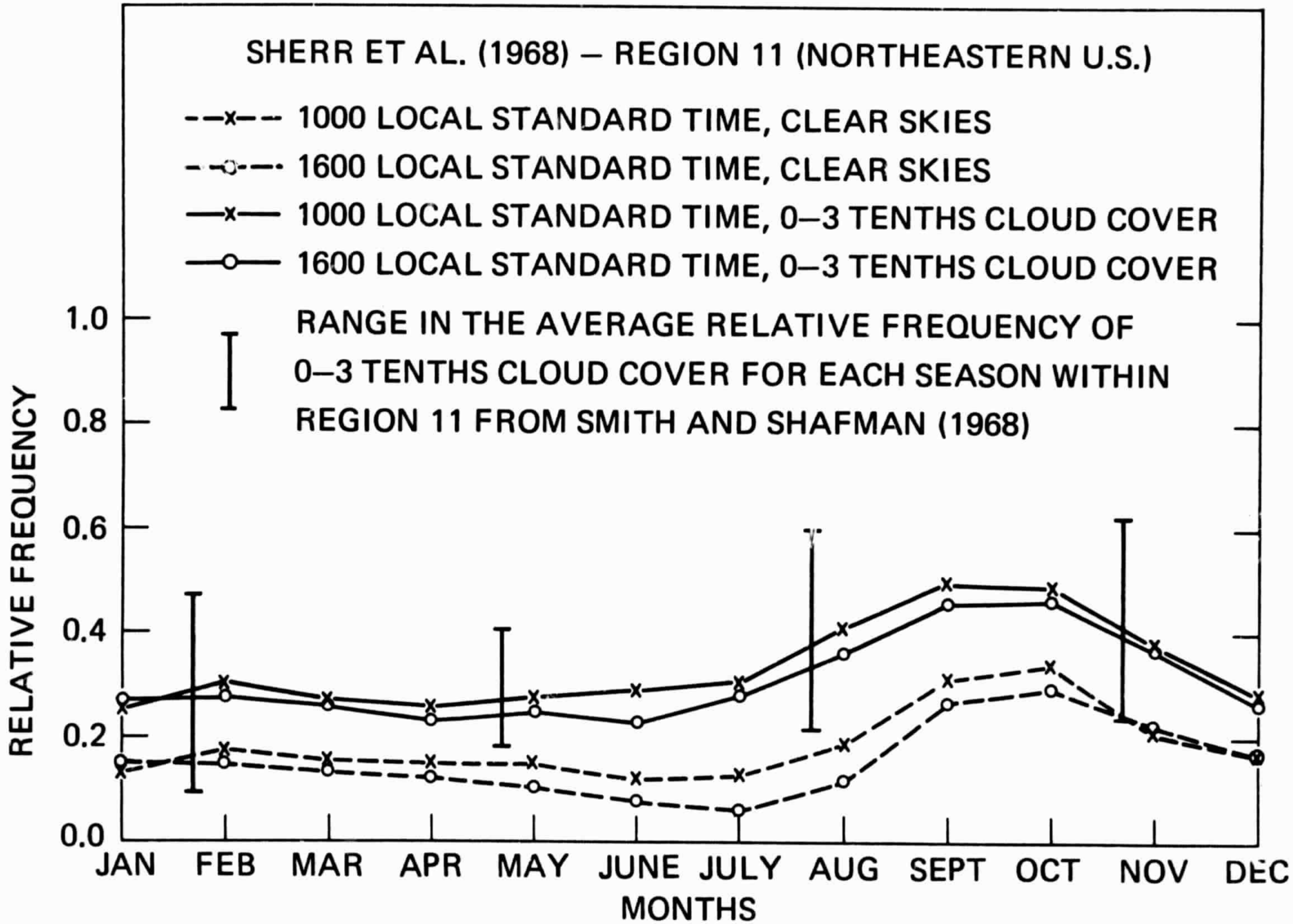

Figure 1. The annual variation of clear and nearly clear (<30% clouds) skies in homogeneous cloud climatic region 11 (Sherr et al., 1968). The range in the average relative frequency of nearly clear skies based on results obtained from Smith and Shafman (1968) is also given.