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THE LATITUDINAL DISTRIBUTION OF CLOUD COVER FROM TIROS III PHOTOGRAPHS

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ABSTRACT

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Television pictures from the TIROS III satellite have been analyzed on a computer to give the latitudinal distribution of cloud cover during the summer of 1961. The results, which will be useful in studying the heat balance of the atmosphere, and in the determination of vertical motion, show good agreement with the long term average cloudiness derived from data accumulated during a half century of ground observations.

Author

Introduction. The global distribution of cloud cover is presently being investigated by the analysis of photographs from TIROS meteorological satellites. The aim of this cloud cover study is to derive basic information on the radiation energy balance of the atmosphere, and on the vertical atmospheric motions which are revealed by the existence of clouds. The type of information yielded by the present analysis is important for studies of climate and for investigations of the general circulation of the atmosphere.

The energy input which sets the atmosphere in motion is given by the difference between the incoming solar energy, consisting of radiation primarily in the visible part of the spectrum, and the outgoing energy, consisting of radiation from the earth and the atmosphere in the far infrared part of the spectrum. The main control over the incoming solar radiation is provided by clouds, which can reflect up to 80% of the incident visible radiation, depending upon their thickness and type. Reflection by the atmosphere and the underlying surface is much less: about 8-10% for the atmosphere, from 3-20% for most terrains, and, in general, only a few percent

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for large bodies of water. Calculations of the available solar energy are thus strongly dependent on knowledge of the cloud cover distribution.

The most important factors which govern the distribution of the outgoing infrared radiation are the ground temperatures, the amount of water vapor in the atmosphere, and particularly the extent and height of the clouds.

It is thus seen that the distribution of cloudiness plays an important role in the determination of both the inflow and the outflow of energy through the earth's atmosphere. Thus far, the distribution of clouds -- amount, types, and approximate heights -- have all been taken from ground-based observations. Satellite observations enable us to obtain extensive cloud cover data on a global scale in a relatively short period of time.

Each TIROS satellite contains two television camera systems which photograph the cloud cover. Some satellites (TIROS II, III, IV, and VII) contain, in addition, radiometers to measure emitted infrared radiation and reflected visible radiation from the earth, atmosphere, and clouds. The data from the visible and infrared radiometers would ordinarily be sufficient for deriving the energy balance, but only on TIROS IV and VII did the visible radiometer channel provide appreciable data. From the cloud cover distribution, however, one can estimate the reflected radiation in the visible spectrum and hence, the incoming solar radiation.

Use of the radiation data in determining the energy balance is discussed in a simultaneous publication by S.I. Rasool (1964) in which references are made to other studies of the radiation data. Although the cloud cover pictures have been used extensively for their synoptic value in the detection and tracking of storms and in present methods of weather forecasting, the analysis of the pictures to obtain statistical data on cloud cover, for application to energy balance studies, has not been undertaken previously.

Method of Analysis. The analysis of the cloud cover photographs was performed on an IBM 7090 computer. Photographs are converted into digital form for insertion into the computer by dividing the photographic image into 250,000 picture elements to form a 500x500 matrix of numbers, each number representing the brightness of the corresponding picture element.

The main problem in the computer analysis of cloud pictures is the choice of a criterion, suitable for machine execution, which will distinguish clouds from clear areas. The brightness of the picture element should be a suitable criterion, since clouds will have higher reflectivities than clear areas except in snow-covered regions. The analysis is complicated by the fact that a cloud of given reflectivity can have a range of brightness depending on the relative angles of the sun and camera with respect to the surface appearing in the photograph, the structure and thickness of clouds, and the nature of the underlying terrain. In addition, there may be variations in the characteristics of the vidicon tube and associated electronics after the satellite is put into orbit. Nonetheless, it was found, by analysis of sample pictures, that the difference between the reflectivities of clouds and the underlying terrain is great enough so that it is possible to choose a brightness threshold which defines the cloud boundaries reliably (Fig. 1). It was further found that the threshold may vary considerably for pictures taken during different orbits, but it varies only slightly from picture to picture within an orbit. It was therefore necessary to determine a new threshold for each orbital sequence but not for each picture. This method does not distinguish between clouds and snow-covered terrain, and, furthermore, it may result in an overestimation of the cloudiness over regions of bright sand. However, only a very small fraction of the earth is covered by bright sand, and the season and regions covered by TIROS III rule out extensive snow-cover.

The location of cloudy and clear areas on a world map requires precise knowledge of the satellite's position and angular orientation at the time the photograph was taken (see Fig. 2). These data were supplied by the Meteorological Satellite Laboratory of the Weather Bureau and the Aeronomy and Meteorology Division of the Goddard Space Flight Center. The transformation from the image plane of the photograph into geographical coordinates is described by Frankel and Bristor (1962) and Mach (1962).

Results. There were 1447 TIROS III photographs available on video tape which were free from excessive noise and for which we were able to obtain all the data required for the transformation to geographical coordinates. All the pictures were processed on the 7090 computer and form the basis of the results presented here.

The end product of the computer analysis is a magnetic tape which contains a summary of every picture analyzed. A computer program interrogates this tape to provide the mean cloud cover percentage over any specified geographic region during any interval of time. For the purposes of this introductory note, however, we will present only the latitudinal distribution of cloud cover for the summer of 1961.

The geographical distribution of the pictures is shown in Fig. 3; each asterisk on the map represents a single photograph. All were taken during daytime between July 12 and September 30, 1961, between latitudes 60°S and 60°N. The number of pictures in the Southern Hemisphere is appreciably less than in the Northern Hemisphere and, consequently, errors due to statistical sampling will be greater for southern latitudes. There may also be some statistical bias in northern latitudes due to the sparseness of photographs over Asia.

The average latitudinal distribution of cloud cover is shown in Fig. 4 for the period July 12 to September 30, 1961. The solid horizontal bars give the mean percentage of earth area covered by clouds in 10° latitude intervals as determined from the TIROS III photographs. The vertical lines passing through the bars indicate the uncertainty estimated to arise in the threshold determination. Possible errors due to statistical sampling are not shown.

The results in Fig. 4 show that the cloud cover in middle latitudes is the same in the northern and southern hemispheres. However, in tropical latitudes there is an asymmetry, with a local maximum of the cloud cover in the tropics centered at 10°N latitude. This is the average position of the "thermal equator" during the period July 12 to September 30.

The broad features of the latitudinal distribution of cloud cover obtained from the TIROS photographs are consistent with the known pattern of the general circulation (see, for example, Haurwitz & Austin, 1944). Air rising at the thermal equator produces condensation and a relative maximum in the cloud cover, while on the average there is downward motion of cool, dry air at 30°, which explains the relative minimum of cloudiness. The relationship between cloud cover distribution and vertical air currents suggests that the TIROS cloud cover statistics may have an important application in the determination of vertical motions in the atmosphere.

It is of considerable interest to compare the TIROS observations for the summer of 1961 with the climatological distributions of cloudiness found in the literature for the same season. Such distributions have been published by Haurwitz & Austin (1944), Landsberg (1945) and others for the globe; and, based on more extensive data, by Telegadas and London (1954) for the Northern Hemisphere. The climatological results for the summer season are shown by the dashed histogram in Fig. 4. The Northern Hemisphere data are taken from Telegadas and London (1954); the Southern Hemisphere data are taken from Landsberg (1945).

The TIROS results for 1961 are seen to be in good agreement with the long-term mean of cloud cover distribution obtained from ground observations. The degree of correspondence between our results and the ground-based data gives us confidence in this method of analysis of satellite photographs. The availability of more data from subsequent satellites will permit the determination of the geographical distribution of cloud cover over short intervals of time. An increase in the density of observations, coupled with improvements in the techniques for picture analysis presently being developed, should eventually lead to the use of cloud cover pictures automatically analyzed on a computer, to provide the cloud cover distribution as a function of time for use in studies of atmospheric dynamics and long-term changes in climate.

We wish to express our appreciation to Professor Julius London of the University of Colorado for his suggestion of the original investigation, and for his detailed criticism of our results. We are also grateful to Professors J. Charney and R. Goody for helpful suggestions, and to Messrs. Burton Kaufman, John Borgelt and other members of the staff of Computer Applications Inc. who developed the programs required for the reduction of the TIROS cloud cover tapes.

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Captions

Fig. 1. Brightness criteria used in discriminating clouds from clear areas. A series of two-level images, in which intensities greater than a given threshold appear white and all others black, is shown in the bottom row for five different thresholds. The number underneath each two-level image is the brightness level used as the threshold for the discrimination. The original full-tone image, on top, is compared with each two-level image to find the threshold which most closely reproduces the cloud boundaries reported by the human observer in the original image.

Fig. 2. Geometry of TIROS photography. The two television cameras point along the principle or spin axis of the satellite, which is fixed in space. The angle between the principle axis and the normal to the earth, the nadir angle, changes as the satellite orbits the earth. The intersection of the principle axis with the earth is called the principle point, denoted by P, and the point immediately below the satellite, called the sub-satellite point, is denoted by S. As the satellite rotates, the image on the vidison tube appears to rotate about the point P. The angle between PS and a fixed reference line on the vidicon tube defines the roll angle, γ, the value of which is required, in addition to the geographic positions of P and S, to transform from picture coordinates to geographic coordinates.

Fig. 3. The geographical distribution of the 1447 TIROS III pictures taken between July 12 and September 30, 1961, which were used in the analysis.

Fig. 4. The latitudinal distribution of cloud cover. The solid horizontal bars are the results derived from TIROS III photographs from July 12 to September 30, 1961. The vertical lines show the estimated uncertainty due to threshold determination. The dashed histogram represents the climatological mean cloud cover based upon ground observations, taken from Telegadas and London (1954) for the Northern Hemisphere and from Landsberg (1945) for the Southern Hemisphere.

DETERMINATION OF BRIGHTNESS THRESHOLD OF CLOUDS

Grey Levels 1-32

17 19 21 23 25

Threshold of Two Level Representation

Fig. 1

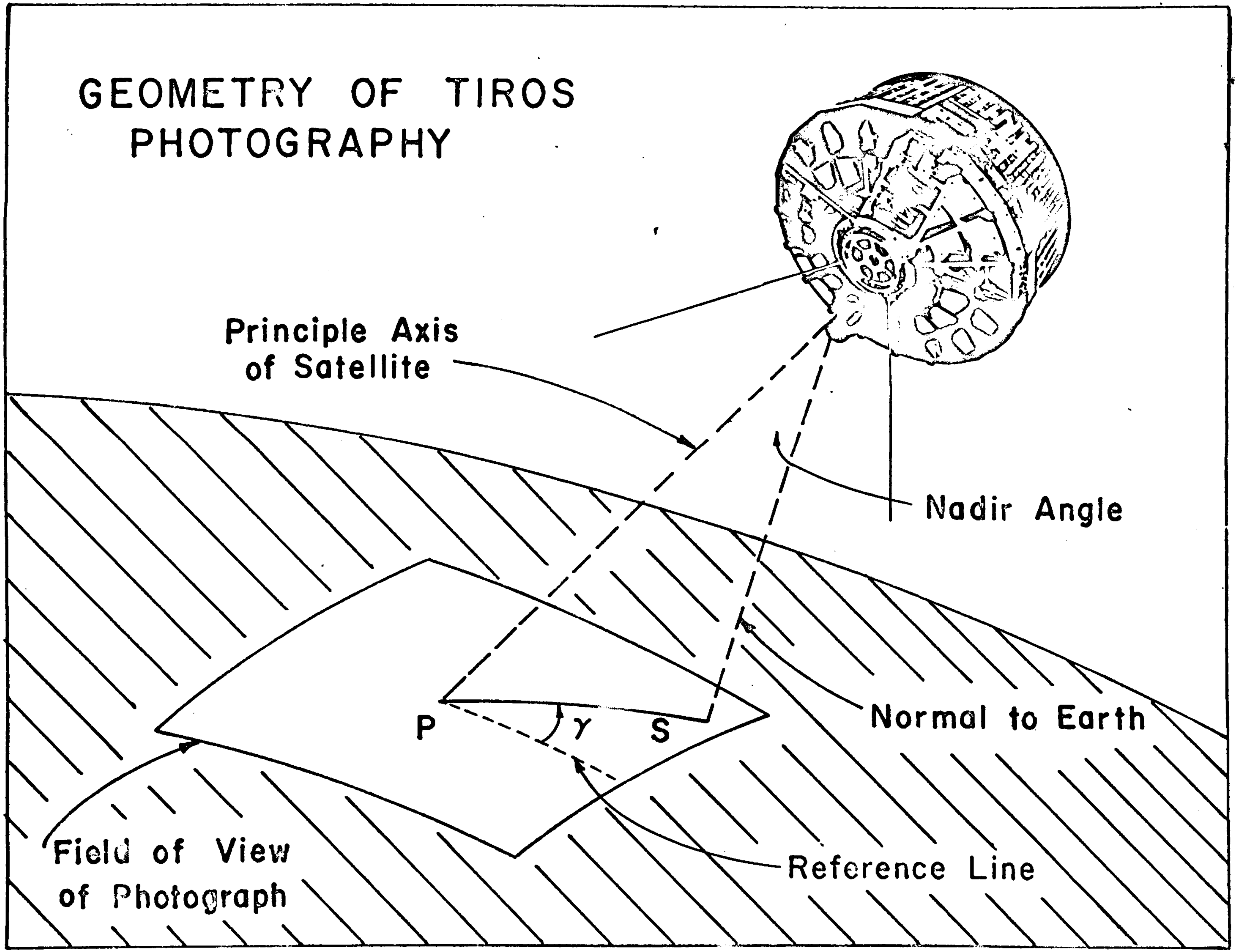
GEOMETRY OF TIROS
PHOTOGRAPHY
Principle Axis
of Satellite
Nadir Angle
P
γ
S
Normal to Earth
Field of View
of Photograph
Reference Line

Fig. 2

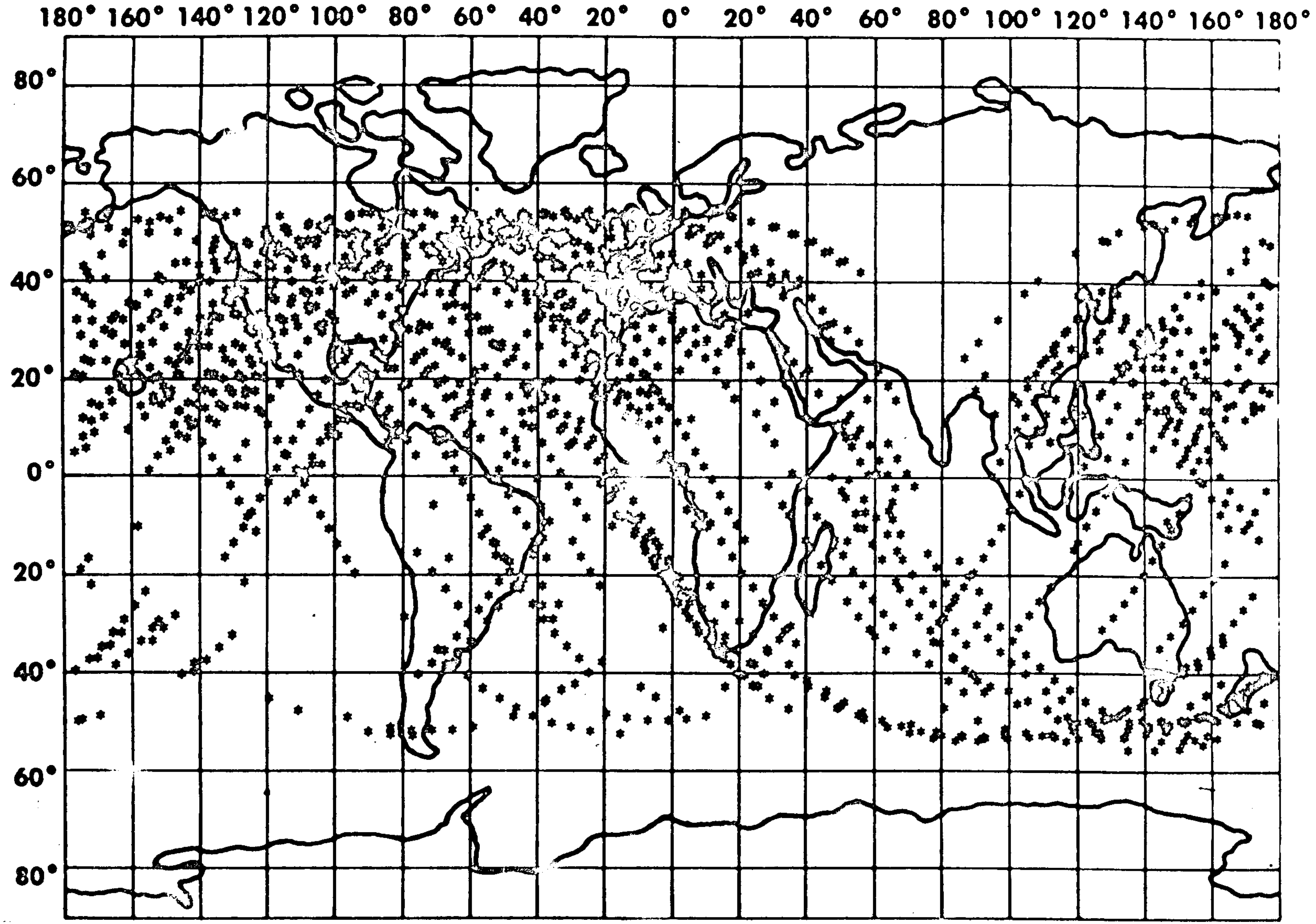
180° 160° 140° 120° 100° 80° 60° 40° 20° 0° 20° 40° 60° 80° 100° 120° 140° 160° 180°
80°
60°
40°
20°
0°
20°
40°
60°
80°

Fig. 3

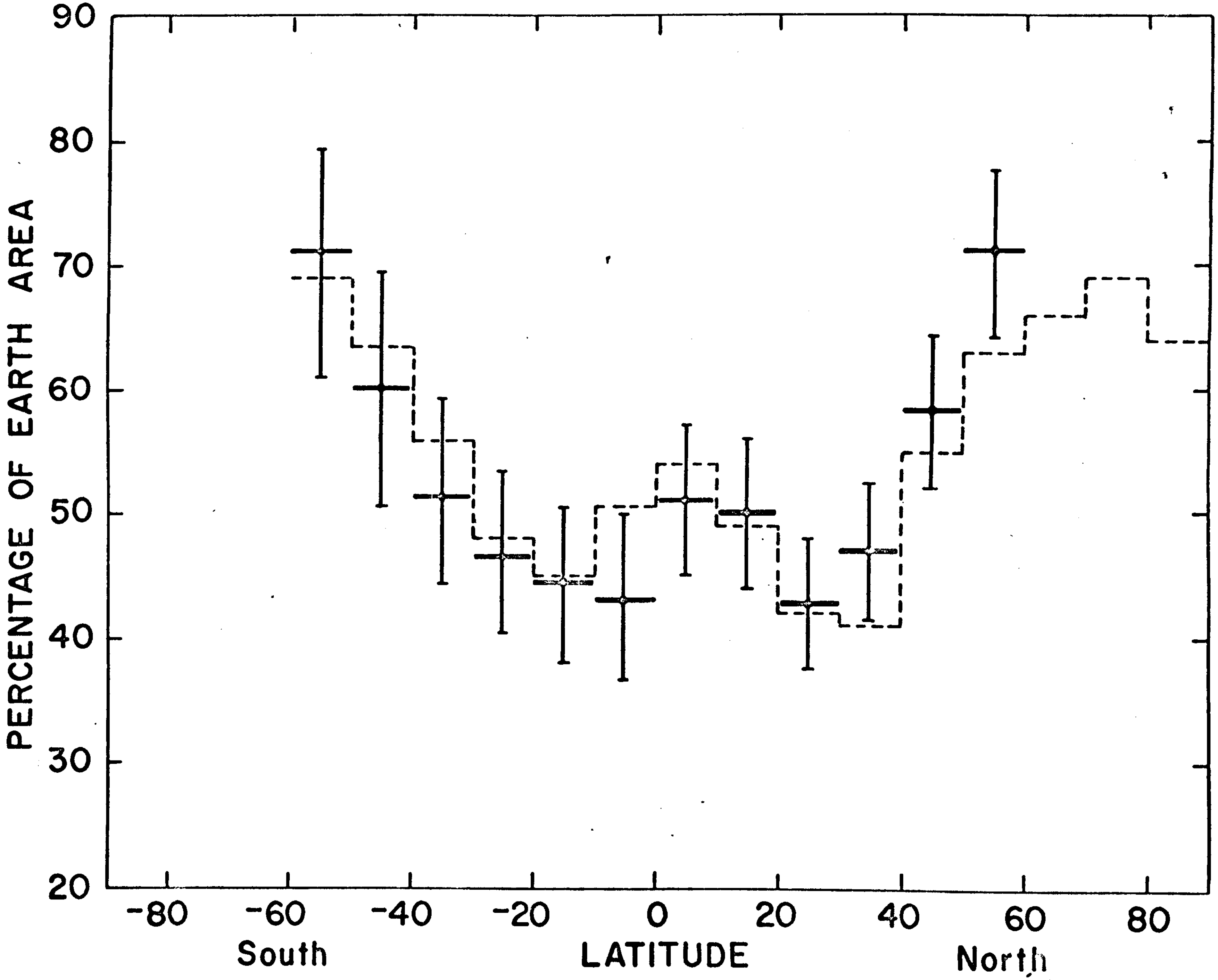
90
80
70
60
50
40
30
20
PERCENTAGE OF EARTH AREA
-80
-60
-40
-20
0
20
40
60
80
South
LATITUDE
North

Fig. 4