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Albedo Climatology Analysis and the Determination of Fractional Cloud Cover

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ABSTRACT

In a previous paper we developed a transformation of surface albedo to albedos at the top of clear, totally cloud covered, and fractionally cloud covered realistic atmospheres. In this paper we present monthly and zonally averaged surface cover climatology data, which we use to construct monthly and zonally averaged surface albedos. Our albedo transformations are then applied to the surface albedos, using solar zenith angles characteristic of the Nimbus 6 satellite local sampling times, to obtain albedos at the top of clear and totally cloud covered atmospheres. We then combine these albedos with measured albedo data to solve for the monthly and zonally averaged fractional cloud cover. The measured albedo data were obtained from the wide field of view channels of the Nimbus 6 Earth Radiation Budget (ERB) experiment, and consequently our fractional cloud cover results are representative of the local sampling times. These fractional cloud cover results are compared with recent studies. The cloud cover results not only show peaks near the intertropical convergence zone (ITCZ), but the monthly migration of the position of these peaks follows general predictions of atmospheric circulation studies.

ALBEDO CLIMATOLOGY ANALYSIS AND THE DETERMINATION OF FRACTIONAL CLOUD COVER

1. INTRODUCTION

Cloud cover data plays an important role in modeling the energetics of the earth-atmosphere system (see Hoyt, 1976), climate, and weather. The importance of zonally averaged cloud cover data in climate models has been recently discussed by Cess (1976), Hoyt (1977), and Cess (1977), where Hoyt (1977) and Cess (1976, 1977) give a thorough reference list of the cloud cover literature. Hoyt (1976) discusses the possible differences between the ground based determination of fractional cloud cover of his Model A and the preferred satellite derived values of his Model B.

Nack and Curran (1978) (hereafter, referred to as NC) show how fractional cloud cover information can be extracted from surface cover climatology data, surface and cloud albedo assumptions, and satellite albedo data. Given this cloud cover data which is consistent with the satellite albedo data NC show how it can be combined with the solar zenith angle dependence of their albedo model to produce daily and monthly time averages of albedo and reflected irradiances.

In this paper we apply the albedo transformations of NC to the surface cover climatology data to obtain albedos at the top of cloud free and total cloud cover atmospheres. These transformations are parameterizations of the extensive radiative transfer calculations of Dave and Braslau (1974, 1975). The cloud free albedo we compute in this manner compares favorably with the "minimum albedo" which Vonder Haar and Ellis (1975) derived from satellite data, even though our calculation uses only two parameters to model the effective albedos of land and ice (or snow) covered surfaces over the whole globe.

The cloud free and total cloud cover albedos are then combined with the Earth Radiation Budget (ERB) wide field of view (WFOV) albedo data of the Nimbus-6 satellite discussed by Smith et al. (1977) to obtain fractional cloud cover using Eq. 27 of NC.

Our results for fractional cloud cover depend on one cloud parameter related to the globally averaged cloud albedo or optical thickness. This cloud albedo parameter is tuned so that agreement is achieved with the globally averaged climatological value of fractional cloud cover, and the value of 0.396 is used from Model B of Hoyt (1976). Consequently, our cloud cover results are tuned by this one cloud albedo parameter to be consistent with climatological averages. The interannual variation in the globally and annually averaged fractional cloud cover for our 22 months of ERB albedo data is about 2.5 percent, which is consistent with the error bars of our input data, but inconsistent with a recent extrapolation of regional cloud cover data by Hoyt (1978) who suggests that interannual variations in total cloud cover on global scales are of the order of a few tenths of a percent.

Since we use monthly and zonally averaged albedo data acquired at the same local time over the month our fractional cloud cover results are determined only for these Nimbus-6 sampling times. If high spatial resolution fractional cloud cover data was available for some zones at the same months and sampling times of our data then this high resolution data could be spatially and temporally averaged to allow comparison with our results.

Advantages of this technique for determining fractional cloud cover are that (1) it is a satellite derived determination that is (2) consistent with global climatological values. Since the ERB albedo data has been preprocessed with spatial and temporal averaging (3) we can compute monthly and zonally averaged fractional cloud cover for a given solar zenith angle near local noon with a minimal amount of data processing. Our value of fractional cloud cover is (4) consistent with both our albedo data and our albedo model of Eqs. 21 and 48 of NC. If albedo data was acquired at a given location more than once a day then values of fractional cloud cover could be determined for these sampling times, and they could be used to model diurnal trends in fractional cloud cover. This diurnal model could be used in Eq. 69 of NC to compute daily and monthly averages of irradiance and albedo. If only the single values of fractional cloud cover are available during the day, such as the values supplied in this paper, then one can assume fractional cloud cover to be constant over the day and use Eqs. 70 to 73 to compute daily and monthly averages of irradiance and albedo.

2. ALBEDO MODEL

The work of NC will be used to develop our albedo model. We first decompose the surface of each latitude zone into fractions which have distinct albedos. The three dominant surface albedos we will use are those for ice or snow covered surfaces (a_I), land surfaces free from ice or snow cover (a_L), and ocean surfaces covered by water and free from ice (a_W).

We then need the fractions of the surface of a latitude zone covered by land (f_L) and ocean (f_O). These fractions are further subdivided into the fractions of land covered by ice and snow (f_{LI}), and ocean covered by ice (f_{OI}) and water (f_{OW}). These fractions satisfy

$$\begin{aligned} 1 &= f_L + f_O = [f_{LI} + (f_L - f_{LI})] + [f_{OI} + (f_O - f_{OI})] \qquad (1) \\ &= (f_{LI} + f_{OI}) + (f_L - f_{LI}) + (1 - f_L - f_{OI}), \end{aligned}$$

$$f_{OW} = f_O - f_{OI} = 1 - f_L - f_{OI}, \quad (2)$$

$$f_I = f_{LI} + f_{OI}, \quad (3)$$

which corresponds to Eq. 10 of NC. Our spatially averaged surface albedo then satisfies

$$a = (f_{LI} + f_{OI})\, a_I + (f_L - f_{LI})\, a_L + (1 - f_L - f_{OI})\, a_W \quad (4)$$

where $(f_L - f_{LI})$ is the fraction of the zone covered by land which is free of ice and snow. This corresponds to Eq. 11 of NC.

These surface albedos can then be transformed to albedos at the top of realistic cloud free $[A_S\,(a, \theta_0)]$ and total cloud cover $[A_C\,(a, \theta_0, \tau_C)]$ atmospheres using the simple parameterizations of Eqs. 1 through 8 of NC, where θ_0 is the solar zenith angle, and τ_C is the optical thickness of a typical cloud at a wavelength of 0.555 μm. Following Dave and Braslau (1974, 1975) and most albedo climatology data sources [e.g. Budyko (1974)] we will assume surface albedos are independent of wavelength as a first order approximation. A future second order approximation might be to characterize a surface by four separate albedos in the four broad spectral bands of the Landsat multispectral scanner, and then develop four separate albedo transformations in each band.

The computed values of A_S and A_C can then be combined to form the total albedo

$$A = (1 - f_C)\, A_S + f_C\, A_C \quad (5)$$

which is measured when a fraction of the zone (f_C) is covered by randomly distributed clouds of optical thickness τ_C. The form of the dependence of A on a, θ_0, τ_C, and f_C is discussed in Section 4 of NC.

The values of A we use are monthly averaged values of the ERB WFOV albedo data for a given zone and solar zenith angle characteristic of Nimbus 6. Consequently, when we solve Eq. 5 for fractional cloud cover

$$f_C = (A - A_S)/(A_C - A_S) \qquad (6)$$

we obtain the monthly and zonally averaged value at θ_0 of Nimbus 6, or $f_C(\theta_0)$.

In NC the τ_C dependence of A_C (a, θ_0, τ_C) is implicitly expressed in terms of A_C (0, 0, τ_C). In our use of Eq. 5 we assume our measured values of A satisfy

$$A = A_S \quad \text{if} \quad f_C = 0 \qquad (7)$$

$$A = A_C \quad \text{if} \quad f_C = 1 \qquad (8)$$

$$A_S < A < A_C \quad \text{if} \quad 0 < f_C < 1 \qquad (9)$$

so that realistic values of a_I, a_L, a_W, and A_C (0, 0, τ_C) must be used to allow our data to satisfy the constraints of Eqs. 7, 8, and 9.

Albedo and surface fraction data will be expressed as a function of the midpoints of latitude zones ϕ_i running from the south (-90°) to the north (90°) poles, and the midpoints of the 12 months t_m running from January through December. The indices of the (ϕ_i, t_m), or ($\phi_i - \Delta\phi$, $\phi_i + \Delta\phi$) and ($t_m - \Delta t$, $t_m + \Delta t$) bins will be i = 1, ... , 36 and m = 1, ... , 12, with $\Delta\phi = 2.5°$ and $\Delta t = 0.5$ mon.

3. SURFACE COVER CLIMATOLOGY

A sufficient set of data for our albedo analysis using Eqs. 1 to 4 is given by f_L (ϕ_i), f_{LI} (ϕ_i, t_m), and f_{OI} (ϕ_i, t_m). The values of f_L and f_O, f_{LI}, f_{OI}, and f_I are shown in Tables 1 to 4 where values for a zone were deleted if they were all zero, except at the poles. In Figure 1 the maximum differences between f_O and f_L occur at the poles and -60°, and the asymmetry between the hemispheres is apparent. The values of f_O and f_L are shown in the behavior of the annual means of f_{OI} and f_{LI} at the poles as illustrated in Figure 2, but this asymmetric behavior is not present in f_I. The monthly variation of f_I is shown in Figure 3a for southern zones, and Figure 3b shows the northern zones. In both Figure 3a and 3b the

Table 1. Fraction of Latitude Zone Covered by Land (f_L), Ocean (f_O), and Area of Zone in 10^6 km^2 Units

LAT	f_L	f_O	AREA
-87.50	1.000	0.000	0.98
-82.50	1.000	0.000	2.93
-77.50	0.893	0.107	4.85
-72.50	0.614	0.386	6.74
-67.50	0.205	0.795	8.57
-62.50	0.003	0.997	10.30
-57.50	0.001	0.999	12.00
-52.50	0.015	0.985	13.60
-47.50	0.025	0.975	15.10
-42.50	0.036	0.964	16.40
-37.50	0.066	0.934	17.70
-32.50	0.158	0.842	18.70
-27.50	0.216	0.784	19.70
-22.50	0.246	0.754	20.50
-17.50	0.236	0.764	21.10
-12.50	0.204	0.796	21.60
- 7.50	0.231	0.769	22.00
- 2.50	0.241	0.759	22.10
2.50	0.214	0.786	22.10
7.50	0.243	0.757	22.00
12.50	0.235	0.765	21.60
17.50	0.292	0.708	21.10
22.50	0.348	0.652	20.50
27.50	0.404	0.596	19.70
32.50	0.423	0.577	18.70
37.50	0.432	0.568	17.70
42.50	0.488	0.512	16.40
47.50	0.562	0.438	15.10
52.50	0.593	0.407	13.60
57.50	0.550	0.450	12.00
62.50	0.688	0.312	10.30
67.50	0.713	0.287	8.57
72.50	0.345	0.655	6.74
77.50	0.229	0.771	4.85
82.50	0.131	0.869	2.93
87.50	0.000	1.000	0.98

Table 2. Fraction of Latitude Zone Covered by Land and Ice
(f_{LI})

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-82.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-77.50	0.86	0.85	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
-72.50	0.55	0.50	0.54	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.59
-67.50	0.10	0.05	0.07	0.12	0.16	0.18	0.19	0.19	0.19	0.19	0.18	0.15	0.15
42.50	0.30	0.31	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.17	0.08
47.50	0.49	0.49	0.42	0.30	0.10	0.00	0.00	0.00	0.00	0.15	0.35	0.45	0.23
52.50	0.54	0.53	0.44	0.30	0.10	0.03	0.00	0.00	0.00	0.20	0.40	0.52	0.26
57.50	0.53	0.52	0.52	0.40	0.20	0.06	0.01	0.00	0.00	0.30	0.43	0.51	0.29
62.50	0.68	0.68	0.67	0.60	0.33	0.16	0.02	0.02	0.02	0.50	0.63	0.66	0.41
67.50	0.71	0.71	0.71	0.71	0.55	0.37	0.05	0.05	0.05	0.60	0.70	0.71	0.49
72.50	0.35	0.35	0.34	0.33	0.30	0.24	0.08	0.08	0.12	0.34	0.34	0.34	0.27
77.50	0.23	0.23	0.23	0.23	0.23	0.22	0.20	0.19	0.20	0.23	0.23	0.23	0.22
82.50	0.13	0.13	0.13	0.13	0.13	0.12	0.10	0.10	0.10	0.13	0.13	0.13	0.12
87.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3. Fraction of Latitude Zone Covered by Ocean and Ice
(f_{OI})

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
−87.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
−82.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
−77.50	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
−72.50	0.35	0.32	0.34	0.38	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.38	0.37
−67.50	0.37	0.21	0.25	0.48	0.61	0.69	0.74	0.76	0.76	0.75	0.72	0.56	0.57
−62.50	0.05	0.01	0.03	0.11	0.29	0.48	0.63	0.69	0.70	0.70	0.52	0.23	0.37
−57.50	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.19	0.23	0.22	0.13	0.04	0.08
52.50	0.02	0.04	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01
57.50	0.10	0.11	0.12	0.11	0.07	0.05	0.02	0.00	0.00	0.00	0.03	0.07	0.06
62.50	0.15	0.16	0.16	0.16	0.14	0.11	0.08	0.06	0.05	0.06	0.08	0.12	0.11
67.50	0.18	0.18	0.18	0.17	0.16	0.15	0.13	0.09	0.07	0.08	0.11	0.17	0.14
72.50	0.49	0.51	0.51	0.50	0.50	0.48	0.44	0.36	0.27	0.36	0.42	0.48	0.44
77.50	0.75	0.76	0.75	0.74	0.74	0.72	0.68	0.58	0.52	0.53	0.62	0.67	0.67
82.50	0.87	0.87	0.87	0.87	0.87	0.87	0.86	0.84	0.81	0.85	0.87	0.87	0.86
87.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4. Fraction of Latitude Zone Covered by Ice
$(f_I = f_{LI} + f_{OI})$

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-82.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-77.50	0.96	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
-72.50	0.90	0.82	0.88	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97
-67.50	0.47	0.26	0.32	0.60	0.77	0.87	0.93	0.95	0.95	0.94	0.90	0.71	0.72
-62.50	0.05	0.01	0.03	0.11	0.29	0.48	0.63	0.69	0.70	0.70	0.52	0.23	0.37
-57.50	0.00	0.00	0.00	0.00	0.01	0.04	0.10	0.19	0.23	0.22	0.13	0.04	0.08
42.50	0.30	0.31	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.17	0.08
47.50	0.49	0.49	0.42	0.30	0.10	0.00	0.00	0.00	0.00	0.15	0.35	0.45	0.23
52.50	0.56	0.57	0.47	0.33	0.12	0.04	0.00	0.00	0.00	0.20	0.40	0.53	0.27
57.50	0.63	0.63	0.64	0.51	0.27	0.11	0.03	0.00	0.00	0.30	0.46	0.58	0.35
62.50	0.83	0.84	0.83	0.76	0.47	0.27	0.10	0.08	0.07	0.56	0.71	0.78	0.53
67.50	0.89	0.89	0.89	0.88	0.71	0.52	0.18	0.14	0.12	0.68	0.81	0.88	0.63
72.50	0.84	0.86	0.85	0.83	0.80	0.72	0.52	0.44	0.39	0.70	0.76	0.82	0.71
77.50	0.98	0.99	0.98	0.97	0.97	0.94	0.88	0.77	0.72	0.76	0.85	0.90	0.89
82.50	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.94	0.91	0.98	1.00	1.00	0.98
87.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

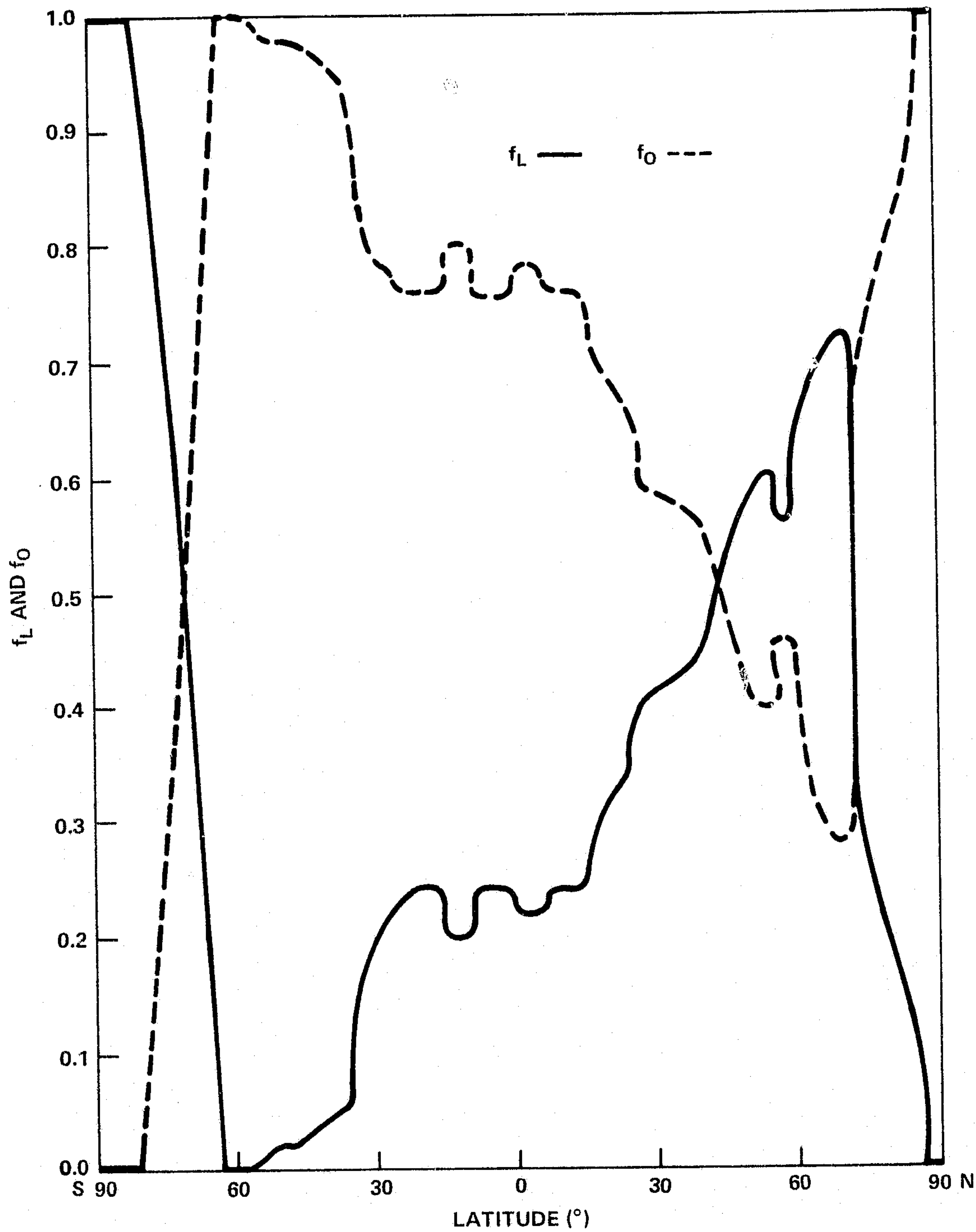

Figure 1. Fraction of Latitude Zone Covered by Land (f_L) and Ocean (f_O)

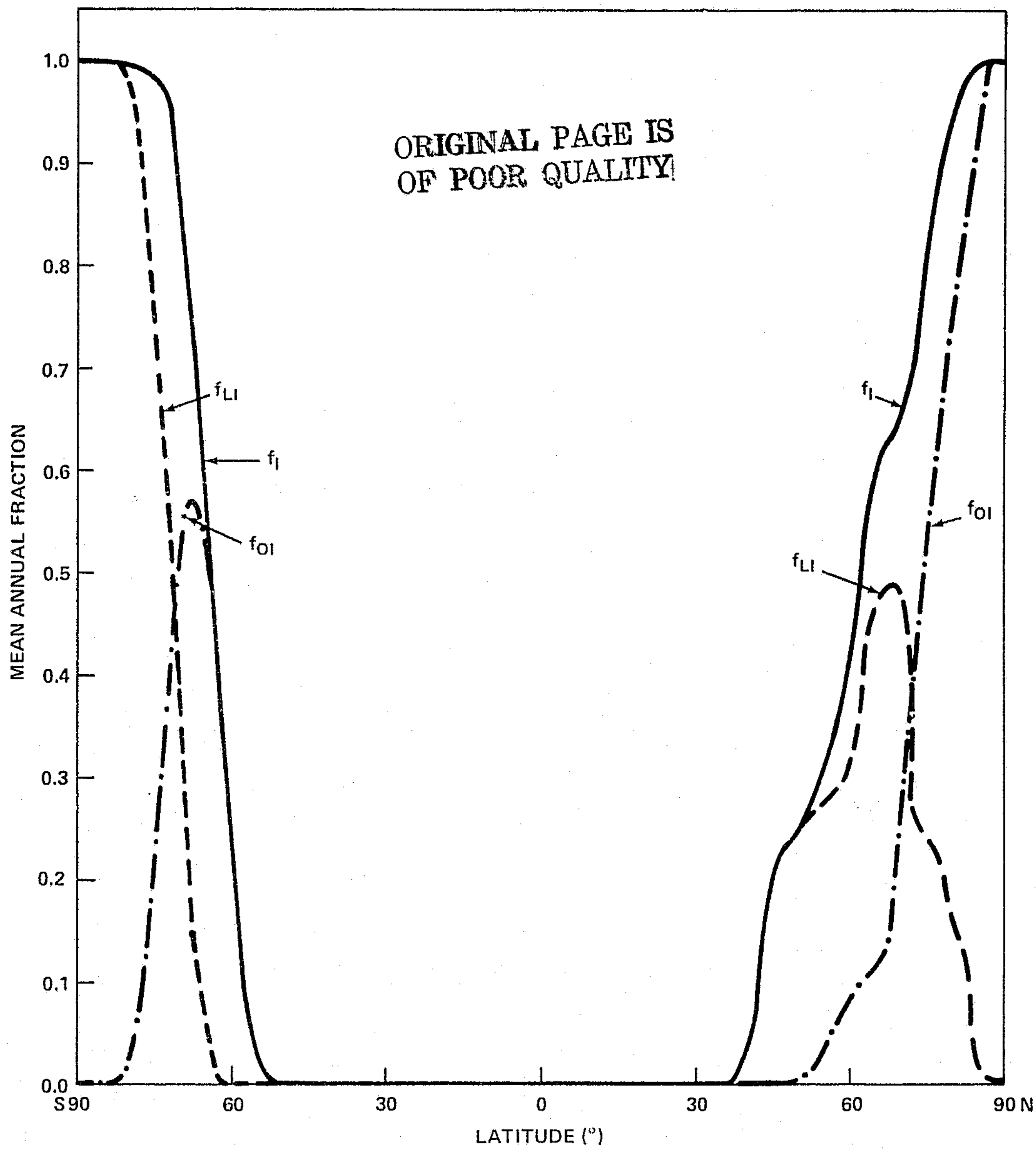

Figure 2. Mean Annual Fraction of Latitude Zone with Ice Covered Land (f_{LI}), with Ice Covered Ocean (f_{OI}) and Total Ice Fraction (f_I)

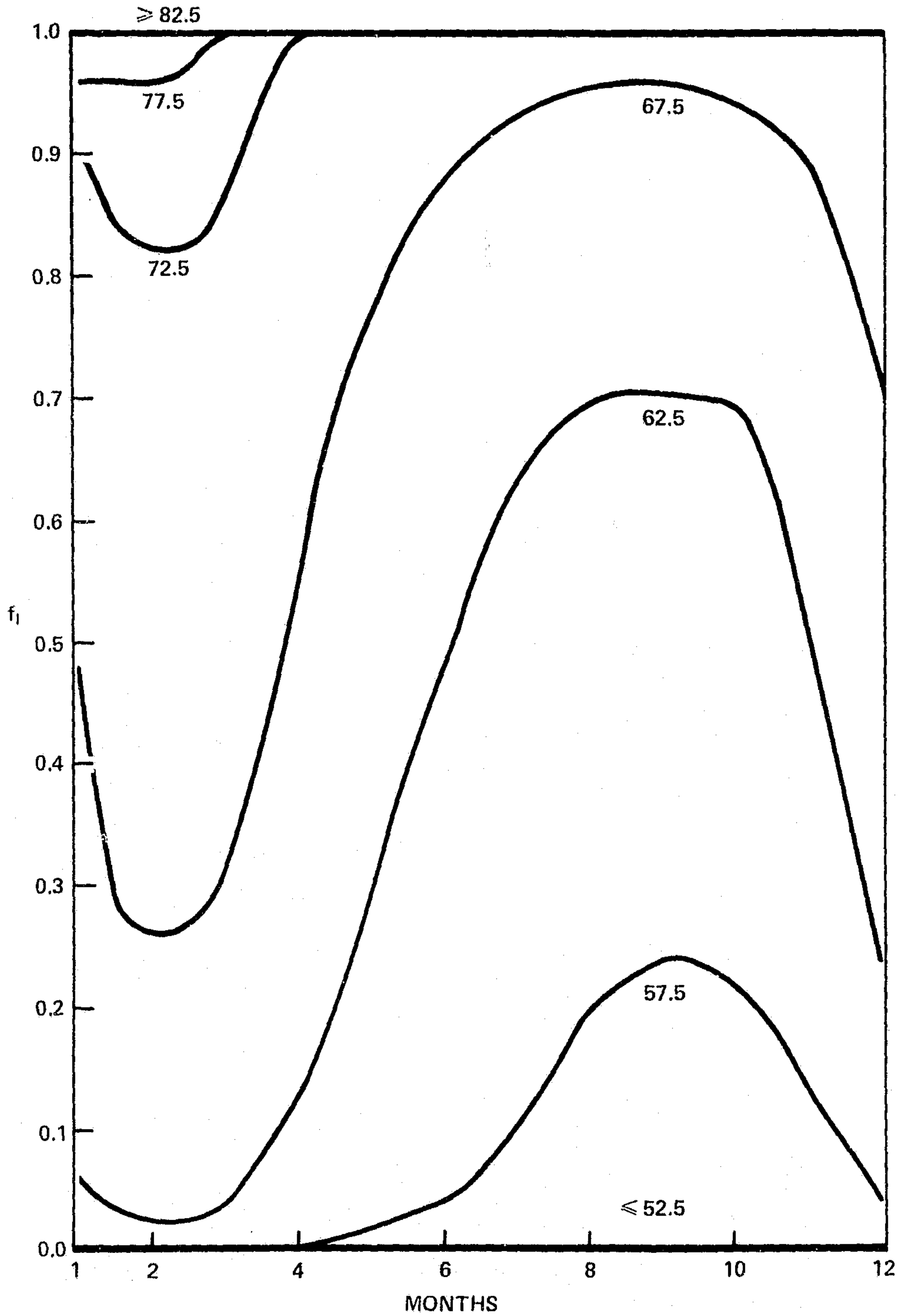

Figure 3a. Monthly Variation of Latitude Zone
Covered by Ice for Southern Zones

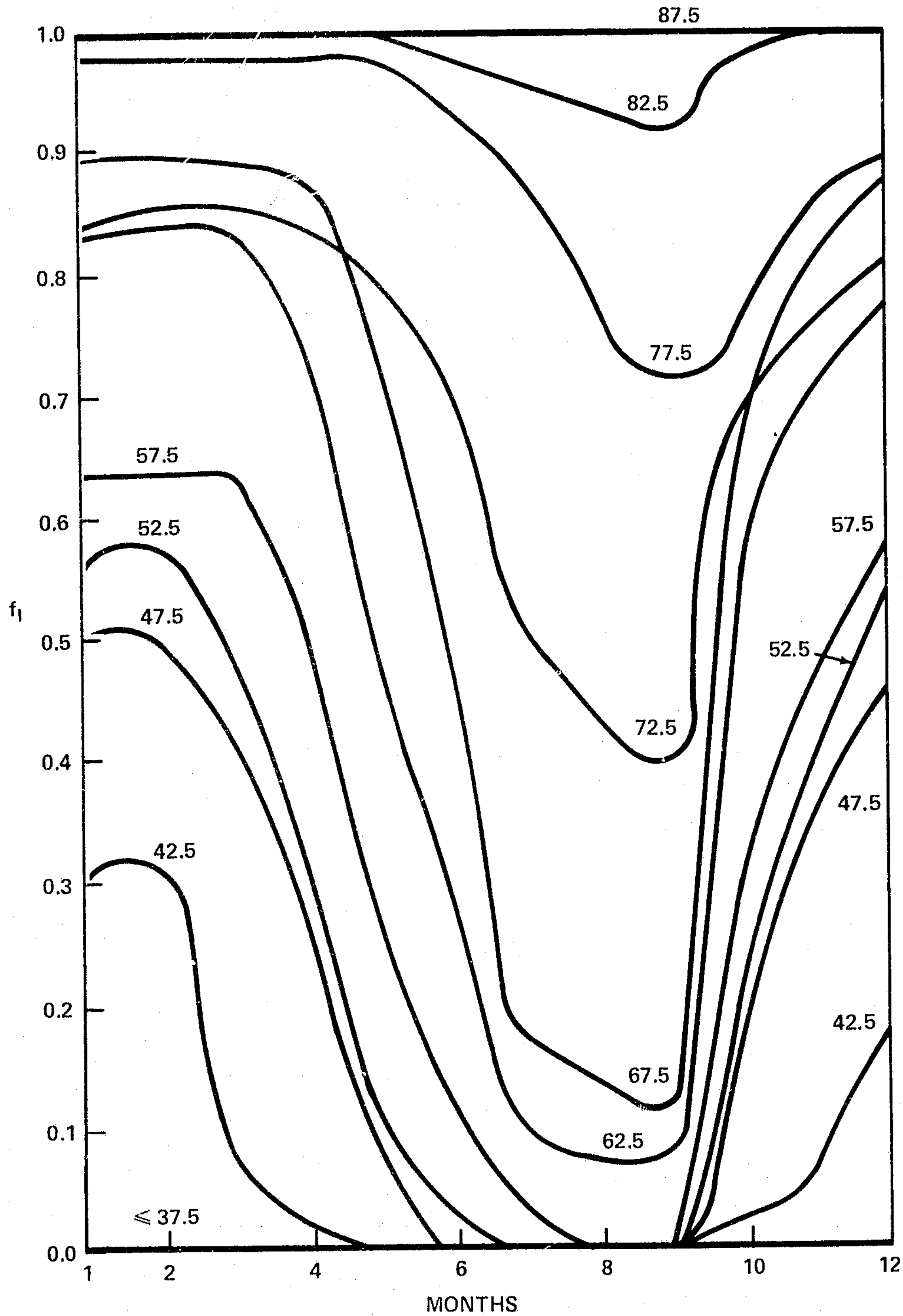

Figure 3b. Monthly Variation of Latitude Zone Covered by Ice for Northern Zones

minimum occurs during the summer months and the maximum during the winter months, with these seasons being 6 months out of phase for each hemisphere.

As shown in Figure 1, the land fraction is negligible for southern latitudes between 65° and 35°. Since the ocean surface temperature remains close to freezing (warmed by antarctic circumpolar currents) and land surface temperature tends to follow the temperature of the atmosphere, those latitudes less than 60°S do not support ice cover. This is illustrated in Figure 3 by noting the lack of contours in the southern hemisphere portion 3a, as opposed to the many contours of the northern hemisphere 3b. This effect is also evident in Figure 2, where the ice fraction for southern zones less than 55°S is near zero contrasted against the northern zones which have appreciable values down to 45° latitude. The land fractions for northern latitudes 45°N to 55°N are greater than 0.5, and less than 0.03 for comparable southern zones.

The zonal area $\alpha(\phi_i)$ is also shown in Table 1, and will be used to compute southern (S) and northern (N) hemispheric and global (G) averages of f_C with the following equations;

$$\alpha = \sum_{i=1}^{18} \alpha(\phi_i) = 254.97 \times 10^6 \text{ km}^2, \tag{10}$$

$$f_{CS}(t_m) = \frac{1}{\alpha} \sum_{i=1}^{18} \alpha(\phi_i)\, f_C(\phi_i, t_m), \tag{11}$$

$$f_{CN}(t_m) = \frac{1}{\alpha} \sum_{i=19}^{36} \alpha(\phi_i)\, f_C(\phi_i, t_m), \tag{12}$$

$$f_{CG}(t_m) = \tfrac{1}{2}[f_{CS}(t_m) + f_{CN}(t_m)] = \frac{1}{2\alpha} \sum_{i=1}^{36} \alpha(\phi_i)\, f_C(\phi_i, t_m). \tag{13}$$

The zonal land and ocean fractions, and area were gathered from the Smithsonian Meteorological Tables (1958). In Table 4 the values of f_I for ϕ_i = (-87.5, . . ., -57.5) were used to generate the corresponding values of f_{LI} and f_{OI} by using

$$f_{LI} = f_L f_I \tag{14}$$

$$f_{OI} = f_O f_I = (1 - f_L) f_I \tag{15}$$

so that

$$f_I = f_{LI} + f_{OI} = f_L f_I + (1 - f_L) f_I \tag{16}$$

is satisfied.

Ice cover data in Table 4 for f_I over the Antarctic was calculated for a period of 16 months from July 1973 to October 1974 using false color photographs from the Electrically Scanning Microwave Radiometer (ESMR) on Nimbus 5. The radiometer is sensitive to radiation at 19.35 GHz. The brightness temperature (T_B) of the ocean is generally 130 to 160K depending on surface roughness. First year ice has a T_B exceeding about 175K depending on its thickness. The ice-water boundary was chosen to be the 175K isotherm. There was almost always a sharp gradient of T_B between 160 and 190K so that no great error would arise from this choice. Areas of either ice or water were obtained in 5° latitude belts by means of a planimeter.

Ice cover over the Arctic Ocean could not be obtained in the same manner because of the numerous islands. Snow free land surfaces have a high T_B (exceeding about 250K) so that there were ambiguities in the interpretation of the T_B patterns. For this reason the values of f_{OI} over the Arctic Ocean were obtained from the Arctic Sea Ice Analyses 1972 - 1975 of the U.S. Navy Fleet Weather Facility.

Wiesnet and Matson (1975) have prepared northern hemisphere snow cover charts during the years 1966 - 1975 for the months December through March. These charts were prepared from photo interpretation of the satellite imagery obtained from ESSA, ITOS, NOAA and SMS-1 satellites. Separate unpublished charts of snow cover for June through September were obtained from Wiesnet and Matson. From these charts areas of snow cover were computed for the 5° latitude belts and these values of f_{LI} are shown in Table 2. Snow cover for the missing months were "guessed at" by eye interpolation of the graphs.

It was pointed out by Wiesnet and Matson that the average hemispheric snow cover for a particular month is relatively constant for different years. This is because lower than average snow cover over one region is compensated by higher snow cover in another region. There was no evidence of a systematic change in total snow cover over the 10 year period. These studies suggest that the percentages of ice or snow for one year over a latitudinal belt is not likely to be different from the annual mean by more than a few percent.

The variation in ice cover in the northern hemisphere for the same month in different years was very small, generally varying by less than 2%. For example at 72.5° the range of variation for the four years 1972 - 1975 was less than 2% for all months except August and September. In August it was 3%. In September it was relatively constant at about 36% for the years 1972 - 1974, but in 1975 there was 7% more ice due to the fact that the Bering Sea was mostly frozen north of 70°.

4. ERB ALBEDO DATA

The Earth Radiation Budget (ERB) experiment on Nimbus-6 is a complex, 22 channel instrument designed to provide accurate determinations of the incident solar flux density on the earth and both the reflected solar and emitted thermal flux densities coming from the earth-atmosphere system. For the present analysis, the data obtained with the wide angle channels were selected. A complete discussion of the ERB instrument is given by Smith et al. (1977).

The Nimbus-6 satellite permits observation of the earth at only two local times per orbit per latitude belt. This perculiarity is due to the sun synchronous orbit in which the satellite is situated. Figure 4 shows the local time as a function of latitude for the Nimbus-6 orbit. Consequently, monthly averaged values of either albedo or fractional cloud cover determined from albedo data are only representative of these local sampling times. A proper diurnal model or data set is needed to obtain true daily and monthly averages.

The sampling times of Figure 4 for a given latitude zone are used in Eqs. 49 and 50 of NC to compute the solar zenith angle θ_0 at the mid-month sampling times, and these values are shown in Table 5. Here, we let values of $\theta_0 > 90°$ be equal to $90°$ near the poles.

The values of albedo $A(\phi_i, t_m)$ are shown in Tables 6 and 7. The segregated values for April through September near the south pole and for October through February near the north pole are interpolated from the Nimbus-6 ERB data because there is no solar input in these zones during these months. The remaining values are real data points taken from the wide field of view channel 13 (0.2 - 5.0 μm) of ERB at a particular time of day averaged over one month. In Figure 5 the (a) annual mean for the periods 7/75 to 6/76 and 5/76 to 4/77, and (b) a comparison of 8/75 with 8/76 are shown. There is little year to year variation in either comparison, though the data of 1/77 did vary significantly from 1/76 and other nearby months. This was the only large variation and it is not clear

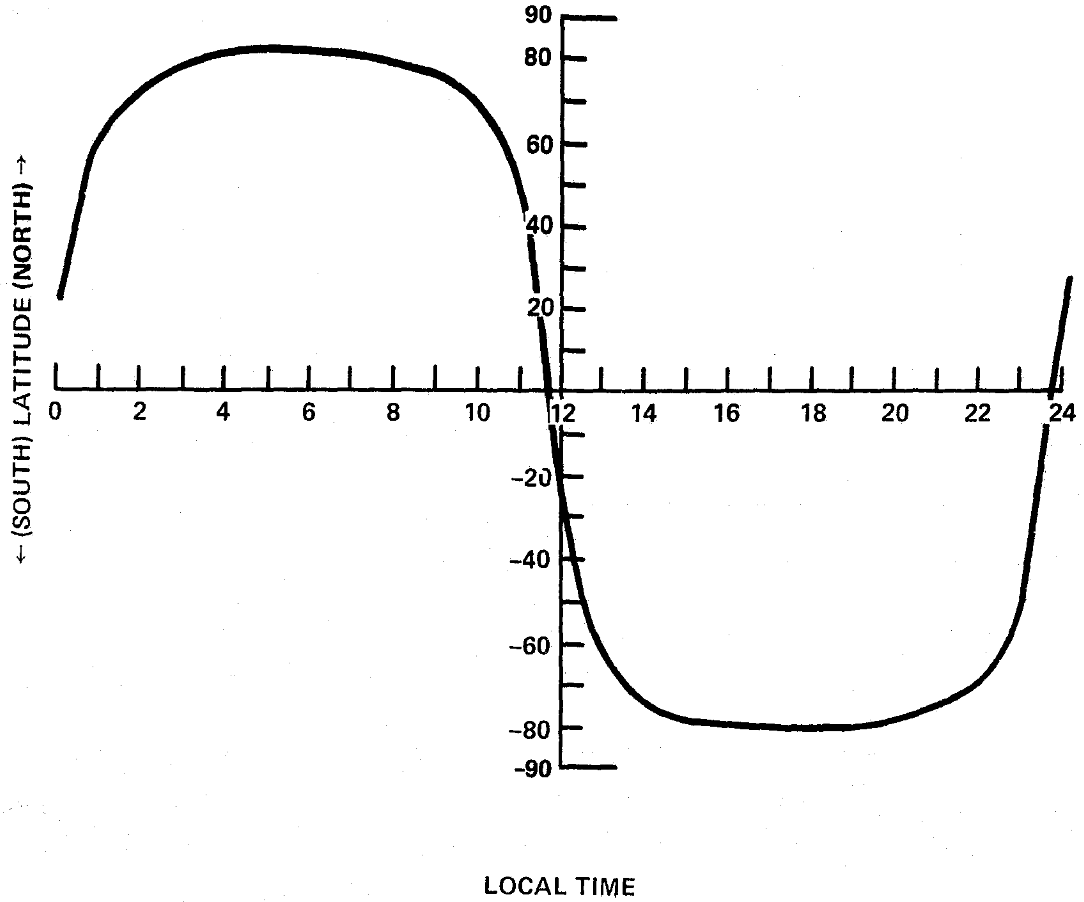

Figure 4. Nimbus-6 Local Sampling Times
for Nadir Point as a Function of Latitude

whether the data of 1/77 was a true anomaly or whether there might have been an instrument malfunction during this month. In the August data we note small maxima at 17.5 for 8/75 and at 12.5 for 8/76 north of the equator, and these peaks are probably due to the intertropical convergence zone (ITCZ). This will be discussed further in Section 6.

In Figure 6 we show the monthly variation of the albedo data during 5/76 to 4/77 for the (a) southern and (b) northern zones. We note that even though there is a discontinuity of one year between the fourth and fifth months most of the graphs connect

Table 5. Solar Zenith Angles
at Mid-Month Sampling Times for Nimbus-6

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	68.9	77.2	87.7	90.0	90.0	90.0	90.0	90.0	90.0	81.7	71.7	66.9	82.8
-82.50	69.1	77.3	87.8	90.0	90.0	90.0	90.0	90.0	90.0	81.7	71.8	67.1	82.9
-77.50	60.4	68.6	79.0	90.0	90.0	90.0	90.0	90.0	84.3	72.9	63.1	58.4	78.1
-72.50	53.9	62.0	72.4	84.2	90.0	90.0	90.0	88.6	77.8	66.4	56.6	51.9	73.7
-67.50	48.5	56.7	67.1	78.8	87.8	90.0	90.0	83.2	72.4	61.1	51.2	46.5	69.4
-62.50	43.2	51.4	61.7	73.4	82.4	86.9	85.2	77.9	67.1	55.7	45.9	41.2	64.3
-57.50	37.7	45.9	56.3	68.0	77.0	81.5	79.8	72.5	61.6	50.3	40.4	35.7	58.9
-52.50	32.4	40.6	51.0	62.8	71.8	76.2	74.6	67.2	56.4	45.0	35.2	30.5	53.6
-47.50	27.4	35.5	45.9	57.7	66.7	71.1	69.5	62.1	51.3	39.9	30.1	25.4	48.5
-42.50	22.0	30.2	40.6	52.4	61.4	65.9	64.2	56.9	46.0	34.6	24.7	20.0	43.2
-37.50	16.9	25.0	35.5	47.3	56.3	60.8	59.1	51.8	40.9	29.4	19.6	14.9	38.1
-32.50	11.7	19.9	30.4	42.2	51.3	55.8	54.1	46.7	35.8	24.3	14.4	9.7	33.0
-27.50	7.0	15.0	25.4	37.2	46.3	50.8	49.1	41.7	30.8	19.4	9.6	5.1	28.1
-22.50	2.0	9.8	20.3	32.1	41.2	45.7	44.0	36.6	25.7	14.2	4.4	1.5	23.1
-17.50	3.6	4.7	15.2	27.1	36.2	40.7	39.0	31.6	20.7	9.1	0.8	5.6	19.5
-12.50	8.6	0.3	10.2	22.1	31.2	35.7	34.0	26.6	15.7	4.1	5.8	10.6	17.1
- 7.50	13.7	5.5	5.4	17.2	26.2	30.7	29.0	21.7	10.8	1.7	10.9	15.7	15.7
- 2.50	18.8	10.7	3.0	12.5	21.4	25.8	24.2	16.9	6.4	6.6	16.1	20.8	15.3
2.50	23.9	15.7	6.1	8.0	16.6	21.0	19.3	12.2	3.8	11.5	21.1	25.9	15.4
7.50	28.9	20.8	10.7	4.9	12.0	16.3	14.6	8.0	6.2	16.5	26.2	30.9	16.3
12.50	34.1	26.0	15.9	6.6	8.5	12.1	10.7	6.1	11.1	21.7	31.4	36.1	18.3
17.50	39.3	31.2	21.1	10.7	7.2	9.0	8.1	8.0	16.1	26.9	36.6	41.3	21.3
22.50	44.5	36.4	26.3	15.5	9.3	8.3	8.4	12.0	21.2	32.1	41.8	46.5	25.2
27.50	49.5	41.4	31.2	20.1	12.6	9.8	10.7	16.2	26.1	37.1	46.8	51.5	29.4
32.50	54.5	46.4	36.2	24.9	16.7	13.1	14.4	20.7	30.9	42.1	51.8	56.5	34.0
37.50	59.7	51.5	41.3	29.9	21.6	17.6	19.1	25.7	36.1	47.2	56.9	61.7	39.0
42.50	64.8	56.7	46.4	35.0	26.4	22.3	23.9	30.7	41.1	52.3	62.1	66.8	44.0
47.50	69.7	61.5	51.1	39.6	30.9	26.6	28.2	35.2	45.8	57.1	66.9	71.7	48.7
52.50	75.0	66.8	56.5	44.9	36.2	31.9	33.5	40.6	51.2	62.5	72.3	77.0	54.0
57.50	80.3	72.1	61.8	50.2	41.4	37.1	38.7	45.8	56.5	67.8	77.5	82.3	59.3
62.50	85.5	77.3	67.0	55.3	46.5	42.2	43.8	50.9	61.7	72.9	82.7	87.5	64.4
67.50	90.0	83.2	72.9	61.3	52.4	48.1	49.7	56.9	67.6	78.8	88.6	90.0	69.9
72.50	90.0	88.2	77.9	66.2	57.3	52.9	54.6	61.8	72.5	83.9	90.0	90.0	73.8
77.50	90.0	90.0	84.4	72.7	63.8	59.4	61.0	68.3	79.1	90.0	90.0	90.0	78.2
82.50	90.0	90.0	90.0	80.5	71.5	67.0	68.7	76.0	86.9	90.0	90.0	90.0	82.5
87.50	90.0	90.0	90.0	80.4	71.3	66.8	68.5	75.9	86.8	90.0	90.0	90.0	82.5

Table 6. Wide Field of View ERB Albedo Data from Nimbus 6 for 7/75 to 6/76

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	0.68	0.71	0.72	0.75	0.77	0.78	0.79	0.78	0.78	0.77	0.71	0.68	0.74
-82.50	0.69	0.70	0.71	0.74	0.75	0.76	0.77	0.77	0.76	0.75	0.71	0.69	0.73
-77.50	0.69	0.68	0.70	0.72	0.74	0.75	0.75	0.75	0.75	0.74	0.70	0.69	0.72
-72.50	0.68	0.66	0.68	0.71	0.73	0.73	0.74	0.74	0.73	0.72	0.69	0.68	0.71
-67.50	0.63	0.60	0.64	0.68	0.70	0.71	0.72	0.72	0.71	0.70	0.65	0.64	0.67
-62.50	0.55	0.54	0.58	0.63	0.65	0.66	0.66	0.65	0.66	0.65	0.59	0.57	0.61
-57.50	0.47	0.47	0.52	0.56	0.58	0.59	0.58	0.60	0.59	0.57	0.51	0.49	0.54
-52.50	0.42	0.41	0.45	0.49	0.53	0.54	0.51	0.53	0.51	0.49	0.44	0.42	0.48
-47.50	0.37	0.37	0.41	0.44	0.48	0.50	0.47	0.46	0.44	0.42	0.39	0.37	0.43
-42.50	0.32	0.34	0.37	0.40	0.43	0.45	0.43	0.40	0.39	0.37	0.34	0.33	0.38
-37.50	0.28	0.31	0.33	0.36	0.38	0.39	0.38	0.36	0.35	0.33	0.30	0.29	0.34
-32.50	0.25	0.28	0.30	0.32	0.34	0.34	0.33	0.32	0.32	0.29	0.27	0.26	0.30
-27.50	0.24	0.25	0.27	0.28	0.30	0.29	0.30	0.29	0.30	0.26	0.25	0.24	0.27
-22.50	0.23	0.24	0.25	0.26	0.27	0.26	0.27	0.26	0.27	0.25	0.23	0.24	0.25
-17.50	0.23	0.24	0.24	0.23	0.24	0.24	0.24	0.24	0.25	0.23	0.23	0.24	0.24
-12.50	0.24	0.24	0.23	0.22	0.23	0.23	0.23	0.22	0.24	0.23	0.23	0.24	0.23
- 7.50	0.24	0.24	0.23	0.22	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.24	0.23
- 2.50	0.24	0.24	0.23	0.22	0.22	0.22	0.23	0.22	0.23	0.23	0.23	0.24	0.23
2.50	0.24	0.23	0.23	0.23	0.23	0.23	0.24	0.23	0.24	0.24	0.23	0.24	0.23
7.50	0.23	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.23	0.24	0.24
12.50	0.24	0.22	0.22	0.22	0.25	0.25	0.26	0.26	0.26	0.25	0.24	0.25	0.24
17.50	0.26	0.24	0.23	0.22	0.24	0.25	0.26	0.27	0.25	0.24	0.24	0.26	0.25
22.50	0.29	0.27	0.26	0.24	0.25	0.25	0.26	0.26	0.24	0.24	0.26	0.29	0.26
27.50	0.32	0.31	0.29	0.27	0.26	0.25	0.26	0.26	0.25	0.25	0.29	0.32	0.28
32.50	0.35	0.35	0.33	0.30	0.29	0.27	0.26	0.26	0.26	0.28	0.32	0.36	0.30
37.50	0.39	0.39	0.36	0.33	0.31	0.29	0.28	0.27	0.28	0.30	0.36	0.40	0.33
42.50	0.44	0.43	0.40	0.36	0.33	0.32	0.30	0.30	0.32	0.34	0.41	0.45	0.37
47.50	0.50	0.48	0.44	0.39	0.36	0.35	0.32	0.33	0.35	0.38	0.46	0.50	0.40
52.50	0.55	0.54	0.48	0.42	0.39	0.37	0.35	0.36	0.37	0.42	0.51	0.54	0.44
57.50	0.59	0.61	0.54	0.47	0.43	0.39	0.37	0.38	0.41	0.47	0.55	0.59	0.48
62.50	0.62	0.68	0.61	0.54	0.49	0.42	0.40	0.40	0.48	0.54	0.59	0.61	0.53
67.50	0.77	0.76	0.68	0.60	0.55	0.47	0.43	0.44	0.53	0.59	0.66	0.75	0.60
72.50	0.67	0.67	0.66	0.64	0.61	0.53	0.49	0.48	0.59	0.63	0.65	0.66	0.61
77.50	0.70	0.69	0.69	0.67	0.66	0.61	0.57	0.54	0.65	0.66	0.68	0.69	0.65
82.50	0.71	0.71	0.71	0.70	0.69	0.64	0.61	0.59	0.68	0.70	0.70	0.71	0.68
87.50	0.72	0.72	0.72	0.72	0.71	0.65	0.62	0.62	0.67	0.69	0.70	0.71	0.69

Table 7. Wide Field of View ERB Albedo Data from Nimbus 6 for 5/76 to 4/77

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	0.64	0.72	0.76	0.77	0.78	0.78	0.78	0.78	0.77	0.76	0.71	0.69	0.75
-82.50	0.65	0.72	0.76	0.77	0.77	0.77	0.77	0.77	0.76	0.75	0.71	0.70	0.74
-77.50	0.66	0.71	0.73	0.76	0.77	0.78	0.78	0.78	0.77	0.74	0.72	0.70	0.74
-72.50	0.66	0.69	0.71	0.70	0.73	0.75	0.76	0.76	0.75	0.73	0.71	0.69	0.72
-67.50	0.60	0.64	0.67	0.67	0.72	0.74	0.74	0.73	0.73	0.71	0.68	0.65	0.69
-62.50	0.48	0.57	0.60	0.62	0.66	0.68	0.68	0.68	0.68	0.66	0.61	0.57	0.63
-57.50	0.40	0.49	0.53	0.56	0.58	0.59	0.60	0.62	0.61	0.58	0.53	0.49	0.55
-52.50	0.32	0.43	0.46	0.49	0.53	0.54	0.55	0.55	0.52	0.49	0.45	0.43	0.48
-47.50	0.27	0.38	0.41	0.44	0.48	0.50	0.50	0.47	0.44	0.42	0.40	0.39	0.43
-42.50	0.24	0.35	0.38	0.40	0.43	0.45	0.44	0.41	0.39	0.37	0.36	0.35	0.38
-37.50	0.22	0.31	0.34	0.35	0.38	0.39	0.38	0.36	0.34	0.33	0.32	0.31	0.34
-32.50	0.22	0.28	0.30	0.31	0.34	0.34	0.34	0.32	0.31	0.30	0.29	0.27	0.30
-27.50	0.22	0.25	0.27	0.28	0.30	0.29	0.30	0.29	0.28	0.27	0.25	0.24	0.27
-22.50	0.23	0.23	0.24	0.25	0.27	0.26	0.26	0.26	0.26	0.25	0.23	0.22	0.25
-17.50	0.24	0.22	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.23	0.22	0.22	0.23
-12.50	0.26	0.22	0.23	0.23	0.23	0.23	0.22	0.23	0.23	0.23	0.23	0.22	0.23
- 7.50	0.27	0.23	0.23	0.23	0.22	0.22	0.21	0.22	0.22	0.23	0.23	0.23	0.23
- 2.50	0.28	0.24	0.24	0.24	0.22	0.22	0.21	0.22	0.22	0.24	0.24	0.23	0.23
2.50	0.28	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.25	0.25	0.23	0.24
7.50	0.28	0.23	0.23	0.23	0.24	0.24	0.24	0.25	0.24	0.25	0.25	0.23	0.24
12.50	0.26	0.22	0.22	0.22	0.25	0.25	0.25	0.26	0.24	0.25	0.25	0.24	0.24
17.50	0.27	0.23	0.23	0.22	0.24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
22.50	0.30	0.26	0.25	0.24	0.25	0.25	0.25	0.25	0.26	0.25	0.27	0.27	0.26
27.50	0.34	0.30	0.27	0.27	0.26	0.25	0.26	0.25	0.26	0.27	0.30	0.30	0.28
32.50	0.39	0.33	0.31	0.30	0.29	0.27	0.27	0.26	0.28	0.30	0.33	0.35	0.31
37.50	0.45	0.38	0.35	0.33	0.31	0.29	0.28	0.29	0.30	0.34	0.37	0.41	0.34
42.50	0.50	0.43	0.39	0.36	0.33	0.32	0.31	0.32	0.33	0.38	0.42	0.47	0.38
47.50	0.55	0.49	0.44	0.40	0.36	0.35	0.34	0.34	0.36	0.42	0.48	0.53	0.42
52.50	0.58	0.54	0.49	0.44	0.39	0.37	0.36	0.36	0.39	0.47	0.54	0.59	0.46
57.50	0.61	0.59	0.54	0.49	0.43	0.39	0.37	0.38	0.42	0.52	0.59	0.63	0.50
62.50	0.66	0.63	0.59	0.54	0.49	0.42	0.39	0.41	0.46	0.58	0.63	0.67	0.54
67.50	0.68	0.66	0.64	0.60	0.55	0.47	0.43	0.45	0.51	0.62	0.67	0.68	0.58
72.50	0.70	0.69	0.67	0.64	0.61	0.53	0.48	0.50	0.57	0.65	0.68	0.70	0.62
77.50	0.69	0.68	0.68	0.67	0.66	0.61	0.55	0.58	0.62	0.66	0.67	0.68	0.65
82.50	0.70	0.69	0.68	0.70	0.69	0.64	0.60	0.63	0.66	0.68	0.69	0.69	0.67
87.50	0.73	0.73	0.72	0.72	0.71	0.65	0.62	0.66	0.68	0.70	0.71	0.72	0.70

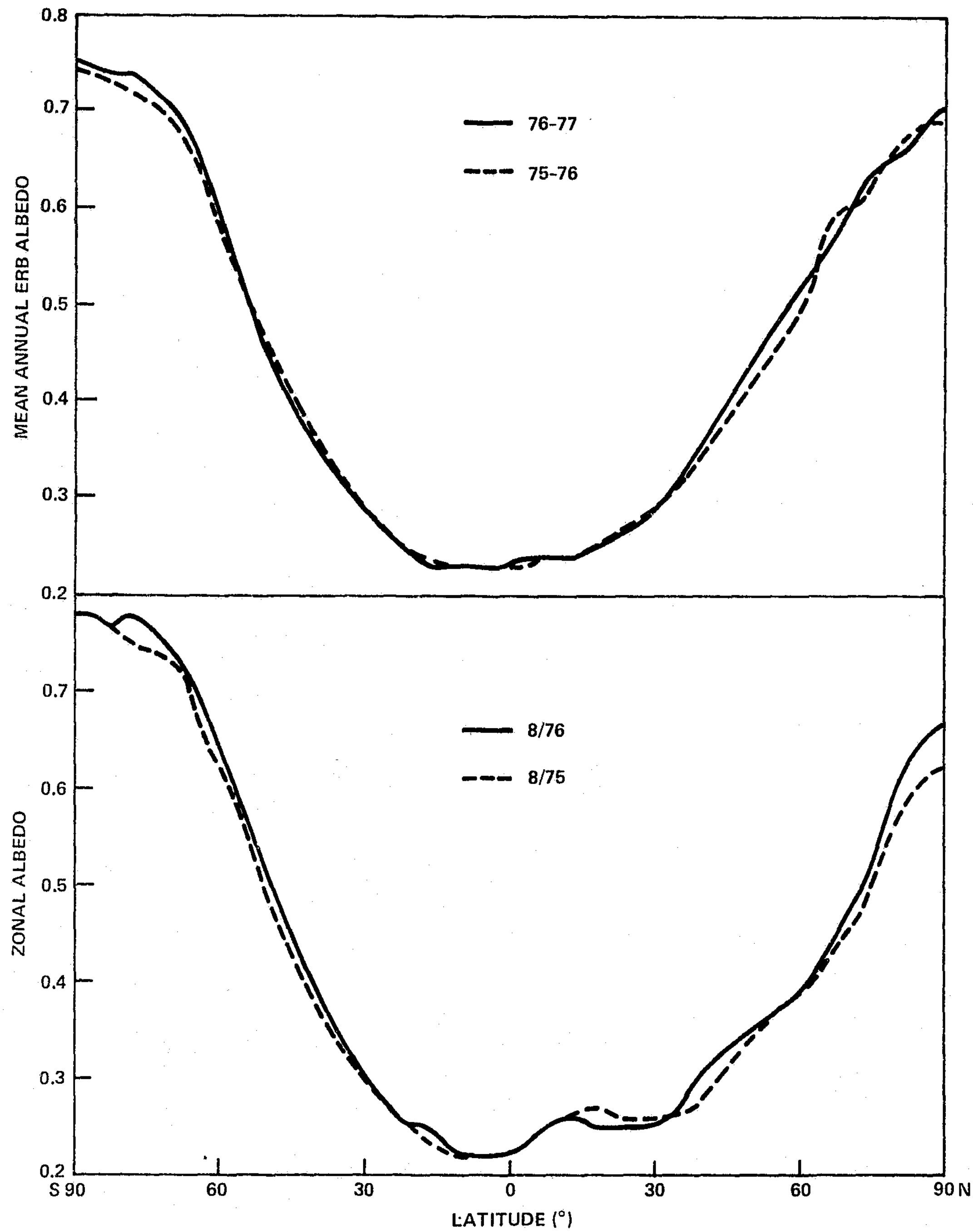

Figure 5. Zonal ERB Albedo Data; (a) Annual Mean for the Periods 7/75 to 6/76 and 5/76 to 4/77, and (b) Comparisons for 8/75 and 8/76

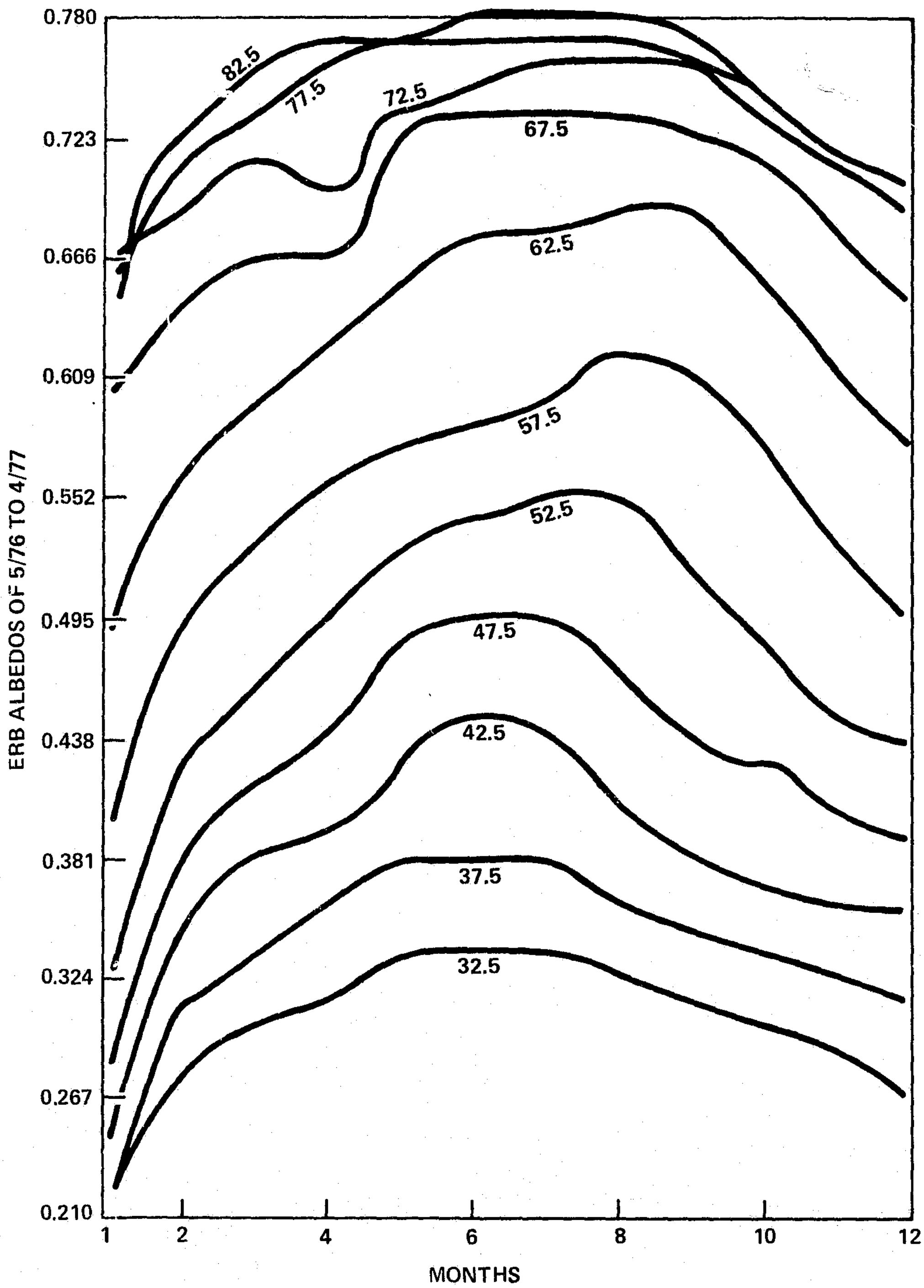

Figure 6a. Monthly Variation
of Zonal ERB Albedos for Southern Zones

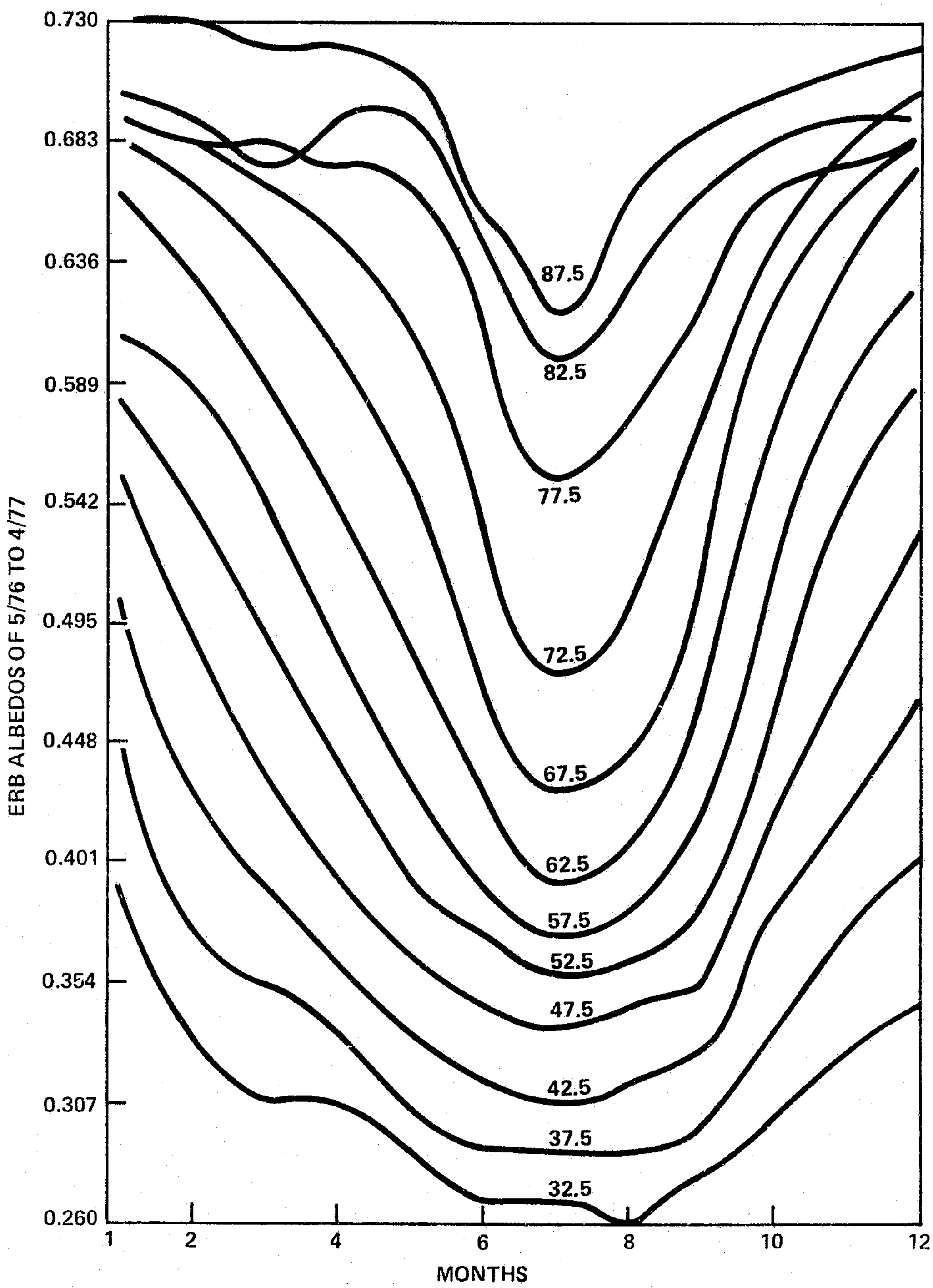

Figure 6b. Monthly Variation
of Zonal ERB Albedos for Northern Zones

smoothly across this discontinuity. Also, minima occur during the summer and maxima occur during the winter of each hemisphere.

5. CLOUD FREE AND TOTAL CLOUD COVER ALBEDOS

We now construct a surface albedo using the surface cover fractions of Section 3 and the values

$$a_L = 0.18 \tag{17}$$

$$a_I = 0.75 \tag{18}$$

which are consistent with Tables 6 and 7 of Budyko (1974). For $a_W(\phi_i, t_m)$ we use the values of Table 8 of Budyko (1974), and these are shown in Table 8, where the segregated polar values were determined by extrapolation from the values given by Budyko. The substitution of these values into Eq. 4 produces the surface albedo values $a(\phi_i, t_m)$ shown in Table 9.

In future work we might use tables of values of $a_L(\phi_i, t_m)$ and $a_I(\phi_i, t_m)$ for a_L and a_I, however, this increase in complexity of our model does not seem warranted at this time.

Given our values of $a(\phi_i, t_m)$ we can then use Eqs. 1 to 8 of NC to compute cloud free $A_S(a, \theta_0)$ and total cloud cover $A_C(a, \theta_0, \tau_C)$ albedos. To do this we need to know $\theta_0(\phi_i, t_m)$ and $A_C(0, 0, \tau_C)$. A value of $A_C(0, 0, \tau_C) = 0.48$ will be used so that our albedo data satisfies $A \leqslant A_C$. Our values of a_I, a_L, and a_W allow $A \geqslant A_S$. The choice of $A_C(0, 0, \tau_C)$ was designed to result in a value of globally and annually averaged fractional cloud cover to be near the climatological value of 0.396 taken from Model B of Hoyt (1976). We use values of $\theta_0(\phi_i, t_m)$ from Table 5 corresponding to the mid-month sampling times of Nimbus 6 to support our analysis of albedo data from the Earth

Table 8. Albedo of Water at the Earth's Surface

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	0.11	0.12	0.15	0.18	0.26	0.30	0.30	0.26	0.18	0.13	0.11	0.11	0.18
-82.50	0.10	0.11	0.14	0.17	0.25	0.28	0.28	0.25	0.17	0.12	0.10	0.10	0.17
-77.50	0.10	0.11	0.14	0.17	0.25	0.28	0.28	0.25	0.17	0.12	0.10	0.10	0.17
-72.50	0.09	0.10	0.13	0.15	0.23	0.25	0.25	0.23	0.16	0.11	0.09	0.09	0.16
-67.50	0.09	0.10	0.13	0.15	0.23	0.25	0.25	0.23	0.16	0.11	0.09	0.09	0.16
-62.50	0.08	0.09	0.10	0.14	0.19	0.21	0.20	0.16	0.11	0.08	0.08	0.07	0.13
-57.50	0.08	0.09	0.10	0.14	0.19	0.21	0.20	0.16	0.11	0.08	0.08	0.07	0.13
-52.50	0.07	0.07	0.08	0.11	0.14	0.16	0.16	0.12	0.09	0.07	0.07	0.06	0.10
-47.50	0.07	0.07	0.08	0.11	0.14	0.16	0.16	0.12	0.09	0.07	0.07	0.06	0.10
-42.50	0.06	0.06	0.07	0.08	0.11	0.12	0.11	0.09	0.08	0.07	0.06	0.06	0.08
-37.50	0.06	0.06	0.07	0.08	0.11	0.12	0.11	0.09	0.08	0.07	0.06	0.06	0.08
-32.50	0.06	0.06	0.06	0.07	0.08	0.09	0.09	0.08	0.07	0.06	0.06	0.06	0.07
-27.50	0.06	0.06	0.06	0.07	0.08	0.09	0.09	0.08	0.07	0.06	0.06	0.06	0.07
-22.50	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06
-17.50	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06
-12.50	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
- 7.50	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
- 2.50	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2.50	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
7.50	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06
12.50	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06
17.50	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.06
22.50	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.06
27.50	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.08	0.09	0.07
32.50	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.08	0.09	0.07
37.50	0.11	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.08	0.11	0.12	0.08
42.50	0.11	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.08	0.11	0.12	0.08
47.50	0.16	0.12	0.09	0.07	0.07	0.06	0.07	0.07	0.08	0.11	0.14	0.16	0.10
52.50	0.16	0.12	0.09	0.07	0.07	0.06	0.07	0.07	0.08	0.11	0.14	0.16	0.10
57.50	0.20	0.16	0.11	0.08	0.08	0.07	0.08	0.09	0.10	0.14	0.19	0.21	0.13
62.50	0.20	0.16	0.11	0.08	0.08	0.07	0.08	0.09	0.10	0.14	0.19	0.21	0.13
67.50	0.25	0.23	0.16	0.11	0.09	0.09	0.09	0.10	0.13	0.15	0.23	0.25	0.16
72.50	0.25	0.23	0.16	0.11	0.09	0.09	0.09	0.10	0.13	0.15	0.23	0.25	0.16
77.50	0.28	0.25	0.17	0.12	0.10	0.10	0.10	0.11	0.14	0.17	0.25	0.28	0.17
82.50	0.28	0.25	0.17	0.12	0.10	0.10	0.10	0.11	0.14	0.17	0.25	0.28	0.17
87.50	0.30	0.26	0.18	0.13	0.11	0.11	0.11	0.12	0.15	0.18	0.26	0.30	0.18

Table 9. Albedo at the Earth's Surface
for an Albedo of Land = 0.18, an Albedo of Ice = 0.75

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
-82.50	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
-77.50	0.73	0.72	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
-72.50	0.69	0.64	0.68	0.74	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.74	0.73
-67.50	0.41	0.28	0.34	0.51	0.63	0.68	0.71	0.72	0.72	0.71	0.69	0.56	0.58
-62.50	0.11	0.10	0.12	0.21	0.35	0.47	0.55	0.57	0.56	0.55	0.43	0.23	0.35
-57.50	0.08	0.09	0.10	0.14	0.20	0.23	0.25	0.27	0.26	0.23	0.17	0.10	0.18
-52.50	0.07	0.07	0.08	0.11	0.14	0.16	0.16	0.12	0.09	0.07	0.07	0.06	0.10
-47.50	0.07	0.07	0.08	0.11	0.14	0.16	0.16	0.12	0.09	0.07	0.07	0.06	0.10
-42.50	0.06	0.06	0.07	0.08	0.11	0.12	0.11	0.09	0.08	0.07	0.06	0.06	0.08
-37.50	0.07	0.07	0.08	0.09	0.11	0.12	0.11	0.10	0.09	0.08	0.07	0.07	0.09
-32.50	0.08	0.08	0.08	0.09	0.10	0.10	0.10	0.10	0.09	0.08	0.08	0.08	0.09
-27.50	0.09	0.09	0.09	0.09	0.10	0.11	0.11	0.10	0.09	0.09	0.09	0.09	0.09
-22.50	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09
-17.50	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09
-12.50	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.09
- 7.50	0.09	0.09	0.09	0.09	0.09	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09
- 2.50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
2.50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
7.50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.09
12.50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.09
17.50	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
22.50	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.10
27.50	0.13	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.13	0.11
32.50	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.13	0.12
37.50	0.14	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.12	0.12	0.14	0.15	0.12
42.50	0.32	0.31	0.17	0.13	0.12	0.12	0.12	0.12	0.12	0.13	0.17	0.25	0.17
47.50	0.45	0.43	0.38	0.30	0.19	0.13	0.13	0.13	0.14	0.23	0.36	0.43	0.28
52.50	0.49	0.48	0.41	0.33	0.21	0.16	0.14	0.14	0.14	0.27	0.39	0.47	0.30
57.50	0.55	0.53	0.52	0.44	0.30	0.20	0.15	0.14	0.14	0.33	0.45	0.52	0.36
62.50	0.66	0.66	0.64	0.60	0.43	0.31	0.21	0.20	0.20	0.49	0.59	0.63	0.47
67.50	0.69	0.69	0.69	0.67	0.57	0.46	0.27	0.24	0.24	0.56	0.65	0.69	0.54
72.50	0.67	0.68	0.66	0.64	0.62	0.57	0.46	0.41	0.38	0.57	0.62	0.66	0.58
77.50	0.74	0.75	0.74	0.73	0.73	0.71	0.67	0.61	0.58	0.61	0.68	0.70	0.69
82.50	0.75	0.75	0.75	0.75	0.75	0.74	0.73	0.71	0.70	0.74	0.75	0.75	0.74
87.50	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

Radiation Budget (ERB) instrument. Here we let values of $\theta_0 > 90°$ near the poles be set equal to 90°. The values of the albedos at the top of cloud free and total cloud cover atmospheres obtained from transforming the surface albedos of Table 9 using the Nimbus 6 solar zenith angles of Table 5 are shown in Tables 10 and 11, respectively.

The values of the annual mean "minimum albedo" determined by Vonder Haar and Ellis (1975) (VE) using Nimbus 3 data from the visible channel of the medium resolution infrared radiometer (MRIR) are also shown in Figure 7 and Table 10 for comparison. The VE results might be a bit high due to cloud contamination of some of their "cloud free" data. A fairer comparison with VE would use a θ_0 (ϕ_i, t_m) table determined from the Nimbus 3 sampling times.

In NC we discuss how to properly compute daily and monthly averages of cloud free albedos for a fixed surface albedo. That discussion emphasizes that the values of A_S and A_C computed in this paper are dependent on θ_0 and are not to be viewed as proper time averages. The closer our values of θ_0 (ϕ_i, t_m) of Table 5 from the Nimbus 6 sampling times come to the local noon values, or the minimum solar zenith angle values, the more we are underestimating A_S since Table 2 of $A_S\,(a, \theta_0)$ from NC shows that for a fixed value of a less than 0.65 the largest values of A_S are achieved for large values of θ_0 near sunrise and sunset.

6. DETERMINATION OF FRACTIONAL CLOUD COVER

We now use Eq. 6 to solve for $f_C = f_C\,(\theta_0)$. Three problems can arise with this solution. The solution is undetermined if $A_C = A_S$, however, our values of $a < 0.90$ preclude this possibility (see Section 3 of NC). If $A > A_C$ then $f_C > 1$, however, the choice of $A_C(0, 0, \tau_C) = 0.48$ was designed to satisfy $A \leqslant A_C$. If $A < A_S$ then $f_C < 0$, however, a

Table 10. Albedo at the Top of a Cloud Free Atmosphere for a Surface Albedo from Table 10

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	VE
–87.50	0.59	0.58	0.58	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.60
–82.50	0.59	0.58	0.58	0.59	0.59	0.59	0.59	0.59	0.59	0.58	0.58	0.59	0.59	0.58
–77.50	0.58	0.57	0.58	0.59	0.59	0.59	0.59	0.59	0.58	0.58	0.59	0.59	0.58	0.55
–72.50	0.55	0.52	0.54	0.58	0.59	0.59	0.59	0.59	0.58	0.59	0.59	0.59	0.58	0.51
–67.50	0.36	0.27	0.33	0.46	0.54	0.57	0.58	0.57	0.57	0.57	0.55	0.47	0.49	0.39
–62.50	0.15	0.14	0.17	0.27	0.40	0.48	0.50	0.48	0.47	0.46	0.37	0.23	0.34	0.29
–57.50	0.12	0.13	0.15	0.21	0.28	0.33	0.33	0.30	0.27	0.23	0.18	0.13	0.22	0.24
–52.50	0.11	0.11	0.13	0.17	0.22	0.26	0.25	0.19	0.14	0.12	0.11	0.10	0.16	0.20
–47.50	0.11	0.11	0.13	0.16	0.20	0.23	0.22	0.18	0.14	0.11	0.11	0.10	0.15	0.18
–42.50	0.10	0.10	0.12	0.13	0.17	0.19	0.18	0.15	0.13	0.11	0.10	0.10	0.13	0.15
–37.50	0.10	0.10	0.12	0.13	0.16	0.18	0.17	0.14	0.13	0.11	0.10	0.10	0.13	0.14
–32.50	0.11	0.11	0.11	0.13	0.14	0.15	0.15	0.14	0.12	0.11	0.11	0.11	0.12	0.14
–27.50	0.11	0.11	0.12	0.13	0.14	0.15	0.15	0.14	0.12	0.11	0.11	0.11	0.13	0.14
–22.50	0.11	0.11	0.12	0.12	0.13	0.14	0.13	0.13	0.12	0.11	0.11	0.11	0.12	0.13
–17.50	0.11	0.11	0.11	0.12	0.13	0.13	0.13	0.13	0.12	0.11	0.11	0.11	0.12	0.14
–12.50	0.11	0.11	0.11	0.11	0.12	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.14
– 7.50	0.11	0.11	0.11	0.11	0.12	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.12	0.14
– 2.50	0.12	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.11	0.11	0.12	0.12	0.12	0.14
2.50	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.15
7.50	0.12	0.12	0.11	0.11	0.11	0.12	0.11	0.11	0.11	0.12	0.12	0.13	0.12	0.15
12.50	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.13	0.12	0.14
17.50	0.14	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.14	0.12	0.15
22.50	0.14	0.14	0.13	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.13	0.17
27.50	0.16	0.15	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.15	0.16	0.14	0.17
32.50	0.17	0.15	0.14	0.13	0.13	0.13	0.13	0.13	0.14	0.15	0.16	0.17	0.14	0.18
37.50	0.18	0.16	0.15	0.14	0.13	0.13	0.13	0.14	0.14	0.16	0.18	0.19	0.15	0.17
42.50	0.31	0.29	0.19	0.15	0.14	0.14	0.14	0.14	0.15	0.17	0.21	0.27	0.19	0.19
47.50	0.40	0.38	0.34	0.28	0.19	0.15	0.15	0.15	0.16	0.24	0.34	0.39	0.27	0.21
52.50	0.44	0.42	0.37	0.30	0.21	0.17	0.16	0.16	0.17	0.27	0.37	0.43	0.29	0.22
57.50	0.48	0.46	0.44	0.38	0.27	0.20	0.17	0.17	0.18	0.33	0.42	0.47	0.33	0.23
62.50	0.54	0.53	0.52	0.49	0.37	0.29	0.22	0.22	0.23	0.43	0.51	0.54	0.41	0.28
67.50	0.57	0.56	0.55	0.54	0.47	0.40	0.26	0.25	0.27	0.48	0.55	0.57	0.46	0.33
72.50	0.56	0.56	0.54	0.52	0.51	0.47	0.39	0.36	0.37	0.50	0.55	0.56	0.49	0.38
77.50	0.58	0.59	0.58	0.57	0.58	0.57	0.54	0.50	0.49	0.54	0.56	0.57	0.56	0.44
82.50	0.59	0.59	0.59	0.58	0.59	0.58	0.57	0.56	0.56	0.58	0.59	0.59	0.58	0.51
87.50	0.59	0.59	0.59	0.58	0.59	0.59	0.59	0.58	0.58	0.59	0.59	0.59	0.59	0.53

Table 11. Albedo at the Top of a Cloudy Atmosphere for a Surface Albedo from Table 10, and $A_C(0, 0, \tau_C) = 0.48$

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	0.80	0.85	0.91	0.93	0.93	0.93	0.93	0.93	0.93	0.87	0.82	0.79	0.88
-82.50	0.80	0.85	0.91	0.93	0.93	0.93	0.93	0.93	0.93	0.87	0.82	0.79	0.88
-77.50	0.76	0.80	0.86	0.93	0.93	0.93	0.93	0.93	0.89	0.82	0.77	0.75	0.86
-72.50	0.73	0.75	0.81	0.89	0.93	0.93	0.93	0.92	0.85	0.79	0.75	0.73	0.83
-67.50	0.66	0.68	0.74	0.83	0.90	0.92	0.92	0.88	0.82	0.76	0.71	0.68	0.79
-62.50	0.59	0.62	0.68	0.77	0.84	0.88	0.88	0.83	0.77	0.71	0.65	0.60	0.74
-57.50	0.56	0.60	0.65	0.72	0.79	0.83	0.82	0.77	0.70	0.64	0.59	0.56	0.69
-52.50	0.54	0.57	0.62	0.69	0.75	0.78	0.77	0.72	0.65	0.59	0.55	0.54	0.65
-47.50	0.53	0.55	0.60	0.66	0.72	0.75	0.74	0.69	0.62	0.57	0.54	0.52	0.62
-42.50	0.52	0.54	0.57	0.63	0.68	0.71	0.70	0.65	0.60	0.55	0.52	0.51	0.60
-37.50	0.51	0.52	0.56	0.60	0.65	0.68	0.67	0.63	0.58	0.54	0.51	0.50	0.58
-32.50	0.50	0.51	0.54	0.58	0.62	0.65	0.64	0.60	0.56	0.52	0.51	0.50	0.56
-27.50	0.50	0.51	0.53	0.56	0.60	0.62	0.62	0.58	0.54	0.52	0.50	0.50	0.55
-22.50	0.50	0.50	0.52	0.55	0.58	0.60	0.59	0.56	0.53	0.51	0.50	0.50	0.54
-17.50	0.50	0.50	0.51	0.53	0.56	0.58	0.57	0.55	0.52	0.50	0.50	0.50	0.53
-12.50	0.50	0.50	0.50	0.52	0.54	0.56	0.55	0.53	0.51	0.50	0.50	0.50	0.52
- 7.50	0.51	0.50	0.50	0.51	0.53	0.54	0.54	0.52	0.50	0.50	0.50	0.51	0.51
- 2.50	0.51	0.50	0.50	0.51	0.52	0.53	0.53	0.51	0.50	0.50	0.51	0.52	0.51
2.50	0.52	0.51	0.50	0.50	0.51	0.52	0.52	0.50	0.50	0.50	0.52	0.53	0.51
7.50	0.54	0.52	0.50	0.50	0.50	0.51	0.51	0.50	0.50	0.51	0.53	0.54	0.51
12.50	0.55	0.53	0.51	0.50	0.50	0.50	0.50	0.50	0.50	0.52	0.54	0.56	0.52
17.50	0.57	0.55	0.52	0.50	0.50	0.50	0.50	0.50	0.51	0.53	0.56	0.58	0.53
22.50	0.59	0.56	0.53	0.51	0.50	0.50	0.50	0.51	0.52	0.55	0.58	0.60	0.54
27.50	0.62	0.58	0.55	0.52	0.51	0.51	0.51	0.51	0.53	0.57	0.61	0.63	0.55
32.50	0.64	0.61	0.56	0.53	0.52	0.51	0.51	0.52	0.55	0.59	0.63	0.66	0.57
37.50	0.67	0.63	0.58	0.55	0.52	0.52	0.52	0.53	0.56	0.61	0.66	0.69	0.59
42.50	0.73	0.68	0.61	0.56	0.54	0.53	0.53	0.55	0.58	0.63	0.69	0.73	0.61
47.50	0.77	0.72	0.67	0.61	0.56	0.54	0.54	0.56	0.61	0.67	0.74	0.78	0.65
52.50	0.81	0.76	0.70	0.63	0.58	0.56	0.56	0.58	0.63	0.71	0.78	0.82	0.68
57.50	0.85	0.79	0.74	0.67	0.61	0.58	0.58	0.61	0.66	0.75	0.82	0.86	0.71
62.50	0.89	0.84	0.78	0.72	0.66	0.62	0.61	0.64	0.69	0.79	0.87	0.90	0.75
67.50	0.92	0.88	0.82	0.75	0.70	0.67	0.64	0.67	0.73	0.84	0.91	0.92	0.79
72.50	0.92	0.91	0.84	0.77	0.73	0.70	0.69	0.72	0.78	0.87	0.92	0.92	0.82
77.50	0.93	0.93	0.89	0.82	0.77	0.75	0.75	0.78	0.84	0.92	0.92	0.92	0.85
82.50	0.93	0.93	0.93	0.87	0.82	0.79	0.80	0.84	0.90	0.93	0.93	0.93	0.88
87.50	0.93	0.93	0.93	0.87	0.81	0.79	0.80	0.84	0.91	0.93	0.93	0.93	0.88

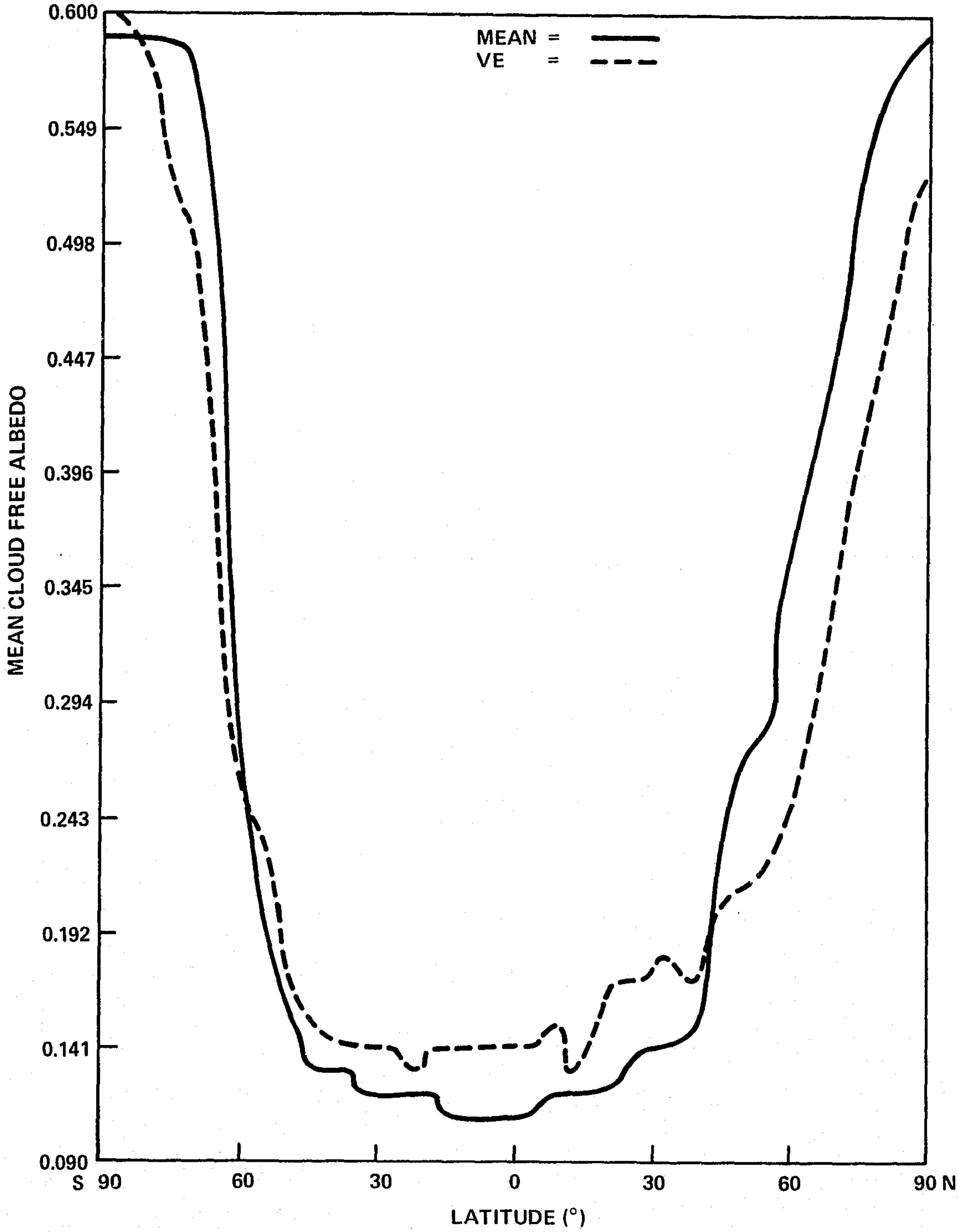

Figure 7. Mean Annual Zonal Cloud Free Albedo
Compared with Measured Results of Vonder Haar and Ellis (1975)

reasonable interpolation scheme for values of A during the months of the zero solar input for the polar zones avoided this from occurring. Proper choices of a_I, a_L, and a_W were also required to avoid $A < A_S$.

The values of f_C for our two sets of albedo data are shown in Tables 12 and 13. The annual means are shown in Figure 8a and a comparison of 8/75 with 8/76 in Figure 8b. Two peaks are shown at approximately ±60°, with the southern peak being dominant. The year to year variation is small, and both pairs of graphs of Figures 8a and 8b exhibit the same structure as a function of latitude. The ITCZ peak is weak in Figure 8a due to the monthly average, but is quite strong in Figure 8b at about 15° north of the equator. In Figure 9 the monthly scatter about the two annual means are shown with minimal dispersion near and just south of the equator and large dispersion elsewhere. Again, the data of 1/77 seems anomalous and was not graphed in Fig. 9b.

The gross structure of our cloud cover results, two peaks at approximately ±60° latitude and a third due to the ITCZ about 7° to 10° north of the equator, are consistent with the role of atmospheric general circulation in the hydrologic cycle, as discussed, for example, in Section 9.8 of Wallace and Hobbs (1977). They show a graph of zonally averaged annual evaporation (E) and precipitation (P), and the direction of water vapor flux which was adapted from Sellers (1965), and is consistent with the precipitation minus evaporation (P – E) curves of Figures 6, 14, and C.6 of Hoyt (1976). The peaks in the P – E curves are roughly at the positions of our cloud cover peaks, and the relatively larger southern hemisphere P – E peak is consistent with out greater cloud cover peak in the southern hemisphere. The large size of the P – E peak near the ITCZ is more consistent with our weak cloud cover peak at this latitude if the zonal area weights of Eqs. 10

Table 12. Fraction of Latitude Zone Covered by Clouds
During 7/75 to 6/76

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	0.45	0.48	0.42	0.48	0.54	0.57	0.60	0.57	0.57	0.64	0.52	0.47	0.53
-82.50	0.48	0.44	0.39	0.45	0.48	0.51	0.54	0.54	0.51	0.59	0.52	0.49	0.49
-77.50	0.63	0.49	0.45	0.39	0.45	0.48	0.48	0.48	0.55	0.65	0.61	0.61	0.52
-72.50	0.75	0.58	0.52	0.43	0.42	0.42	0.45	0.47	0.56	0.68	0.66	0.69	0.55
-67.50	0.88	0.81	0.76	0.59	0.44	0.40	0.41	0.48	0.56	0.69	0.63	0.81	0.62
-62.50	0.90	0.82	0.80	0.72	0.57	0.45	0.43	0.48	0.65	0.75	0.77	0.90	0.69
-57.50	0.80	0.72	0.73	0.69	0.58	0.52	0.50	0.63	0.75	0.84	0.81	0.83	0.70
-52.50	0.70	0.65	0.66	0.63	0.59	0.55	0.51	0.65	0.73	0.79	0.75	0.74	0.66
-47.50	0.62	0.59	0.60	0.56	0.54	0.52	0.49	0.56	0.63	0.68	0.65	0.64	0.59
-42.50	0.53	0.55	0.55	0.53	0.50	0.50	0.48	0.50	0.56	0.58	0.58	0.56	0.54
-37.50	0.45	0.48	0.49	0.48	0.44	0.42	0.42	0.44	0.50	0.51	0.50	0.48	0.47
-32.50	0.37	0.41	0.43	0.42	0.41	0.37	0.38	0.40	0.46	0.44	0.41	0.40	0.41
-27.50	0.32	0.35	0.37	0.36	0.35	0.31	0.33	0.34	0.41	0.38	0.34	0.35	0.35
-22.50	0.31	0.32	0.33	0.31	0.30	0.27	0.30	0.30	0.38	0.34	0.31	0.32	0.32
-17.50	0.32	0.32	0.31	0.28	0.27	0.25	0.26	0.26	0.34	0.31	0.30	0.32	0.29
-12.50	0.33	0.33	0.30	0.26	0.26	0.24	0.25	0.25	0.32	0.30	0.30	0.33	0.29
- 7.50	0.32	0.32	0.30	0.26	0.24	0.23	0.24	0.25	0.30	0.29	0.29	0.31	0.28
- 2.50	0.31	0.31	0.30	0.28	0.25	0.26	0.26	0.26	0.30	0.30	0.28	0.30	0.29
2.50	0.29	0.30	0.31	0.31	0.29	0.29	0.30	0.31	0.33	0.32	0.29	0.30	0.30
7.50	0.27	0.26	0.29	0.30	0.33	0.32	0.34	0.35	0.36	0.33	0.28	0.28	0.31
12.50	0.28	0.26	0.28	0.29	0.35	0.34	0.37	0.39	0.37	0.32	0.27	0.27	0.32
17.50	0.29	0.27	0.28	0.27	0.33	0.33	0.36	0.39	0.33	0.29	0.25	0.28	0.31
22.50	0.32	0.32	0.32	0.30	0.32	0.32	0.35	0.36	0.29	0.27	0.27	0.31	0.31
27.50	0.34	0.37	0.37	0.36	0.36	0.33	0.34	0.33	0.28	0.26	0.29	0.34	0.33
32.50	0.39	0.43	0.43	0.43	0.40	0.36	0.34	0.33	0.30	0.29	0.34	0.39	0.37
37.50	0.43	0.48	0.48	0.47	0.45	0.41	0.37	0.35	0.33	0.33	0.38	0.42	0.41
42.50	0.32	0.36	0.49	0.50	0.49	0.46	0.41	0.39	0.38	0.37	0.41	0.38	0.41
47.50	0.27	0.29	0.29	0.33	0.46	0.51	0.44	0.43	0.41	0.32	0.28	0.27	0.36
52.50	0.30	0.35	0.35	0.38	0.50	0.52	0.47	0.47	0.44	0.35	0.33	0.29	0.40
57.50	0.29	0.46	0.33	0.31	0.46	0.50	0.48	0.49	0.47	0.36	0.33	0.31	0.40
62.50	0.21	0.50	0.34	0.20	0.40	0.42	0.45	0.45	0.53	0.30	0.24	0.19	0.35
67.50	0.57	0.63	0.49	0.26	0.34	0.27	0.46	0.44	0.56	0.30	0.30	0.51	0.43
72.50	0.30	0.32	0.41	0.47	0.47	0.25	0.32	0.33	0.55	0.35	0.28	0.28	0.36
77.50	0.34	0.31	0.35	0.41	0.43	0.21	0.12	0.16	0.45	0.31	0.33	0.33	0.31
82.50	0.36	0.36	0.35	0.42	0.47	0.28	0.16	0.10	0.35	0.34	0.33	0.36	0.32
87.50	0.39	0.39	0.39	0.47	0.54	0.32	0.15	0.15	0.28	0.30	0.33	0.36	0.34

Table 13. Fraction of Latitude Zone Covered by Clouds During 5/76 to 4/77

LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
-87.50	0.23	0.54	0.52	0.54	0.57	0.57	0.57	0.57	0.54	0.62	0.55	0.50	0.53
-82.50	0.27	0.52	0.53	0.54	0.54	0.54	0.54	0.54	0.51	0.57	0.56	0.53	0.51
-77.50	0.45	0.61	0.56	0.51	0.54	0.57	0.57	0.57	0.61	0.65	0.68	0.67	0.58
-72.50	0.63	0.73	0.61	0.39	0.42	0.48	0.51	0.53	0.64	0.71	0.76	0.76	0.60
-67.50	0.80	0.90	0.83	0.57	0.50	0.49	0.47	0.53	0.64	0.74	0.77	0.86	0.67
-62.50	0.76	0.88	0.84	0.71	0.59	0.50	0.48	0.58	0.72	0.79	0.86	0.92	0.72
-57.50	0.62	0.77	0.75	0.69	0.58	0.52	0.56	0.69	0.79	0.85	0.85	0.85	0.71
-52.50	0.49	0.69	0.68	0.62	0.59	0.55	0.58	0.58	0.74	0.78	0.78	0.76	0.66
-47.50	0.39	0.61	0.61	0.55	0.54	0.52	0.53	0.57	0.62	0.67	0.68	0.69	0.58
-42.50	0.34	0.56	0.57	0.53	0.50	0.50	0.50	0.52	0.55	0.60	0.62	0.61	0.53
-37.50	0.30	0.49	0.51	0.47	0.44	0.42	0.44	0.46	0.48	0.52	0.54	0.53	0.47
-32.50	0.28	0.41	0.44	0.41	0.41	0.37	0.39	0.40	0.43	0.45	0.45	0.42	0.40
-27.50	0.27	0.34	0.37	0.34	0.35	0.31	0.32	0.35	0.37	0.38	0.37	0.33	0.34
-22.50	0.29	0.29	0.32	0.30	0.30	0.27	0.28	0.31	0.35	0.33	0.31	0.29	0.30
-17.50	0.33	0.28	0.29	0.28	0.27	0.25	0.24	0.29	0.32	0.30	0.29	0.28	0.29
-12.50	0.38	0.30	0.30	0.29	0.26	0.24	0.23	0.28	0.30	0.30	0.30	0.29	0.29
- 7.50	0.40	0.31	0.31	0.30	0.24	0.23	0.22	0.26	0.27	0.30	0.30	0.29	0.29
- 2.50	0.40	0.33	0.33	0.31	0.25	0.26	0.24	0.28	0.28	0.32	0.31	0.28	0.30
2.50	0.40	0.32	0.33	0.32	0.29	0.29	0.28	0.31	0.30	0.35	0.32	0.28	0.32
7.50	0.37	0.28	0.30	0.30	0.33	0.32	0.33	0.34	0.32	0.35	0.32	0.25	0.32
12.50	0.32	0.26	0.27	0.28	0.35	0.34	0.36	0.37	0.33	0.32	0.30	0.25	0.31
17.50	0.32	0.25	0.27	0.28	0.33	0.33	0.35	0.35	0.33	0.30	0.28	0.25	0.30
22.50	0.35	0.29	0.29	0.31	0.32	0.32	0.34	0.32	0.33	0.29	0.29	0.28	0.31
27.50	0.39	0.34	0.33	0.37	0.36	0.33	0.35	0.32	0.33	0.31	0.32	0.30	0.34
32.50	0.47	0.39	0.39	0.43	0.40	0.36	0.36	0.34	0.34	0.35	0.36	0.37	0.38
37.50	0.54	0.46	0.46	0.47	0.45	0.41	0.39	0.38	0.37	0.41	0.40	0.43	0.43
42.50	0.47	0.35	0.49	0.52	0.49	0.46	0.44	0.43	0.41	0.46	0.44	0.44	0.45
47.50	0.40	0.31	0.30	0.35	0.46	0.51	0.47	0.46	0.43	0.42	0.34	0.37	0.40
52.50	0.39	0.36	0.37	0.41	0.50	0.52	0.50	0.48	0.47	0.45	0.41	0.40	0.44
57.50	0.36	0.39	0.34	0.37	0.46	0.50	0.49	0.50	0.50	0.47	0.43	0.41	0.43
62.50	0.34	0.32	0.28	0.23	0.40	0.42	0.44	0.47	0.50	0.41	0.35	0.36	0.38
67.50	0.31	0.32	0.34	0.27	0.34	0.27	0.43	0.48	0.53	0.39	0.32	0.32	0.36
72.50	0.38	0.37	0.43	0.48	0.47	0.25	0.28	0.39	0.49	0.39	0.36	0.39	0.39
77.50	0.31	0.28	0.34	0.41	0.43	0.21	0.04	0.28	0.36	0.32	0.30	0.31	0.30
82.50	0.33	0.30	0.27	0.41	0.47	0.28	0.12	0.25	0.30	0.28	0.30	0.30	0.30
87.50	0.42	0.42	0.39	0.49	0.54	0.32	0.16	0.32	0.30	0.33	0.36	0.39	0.37

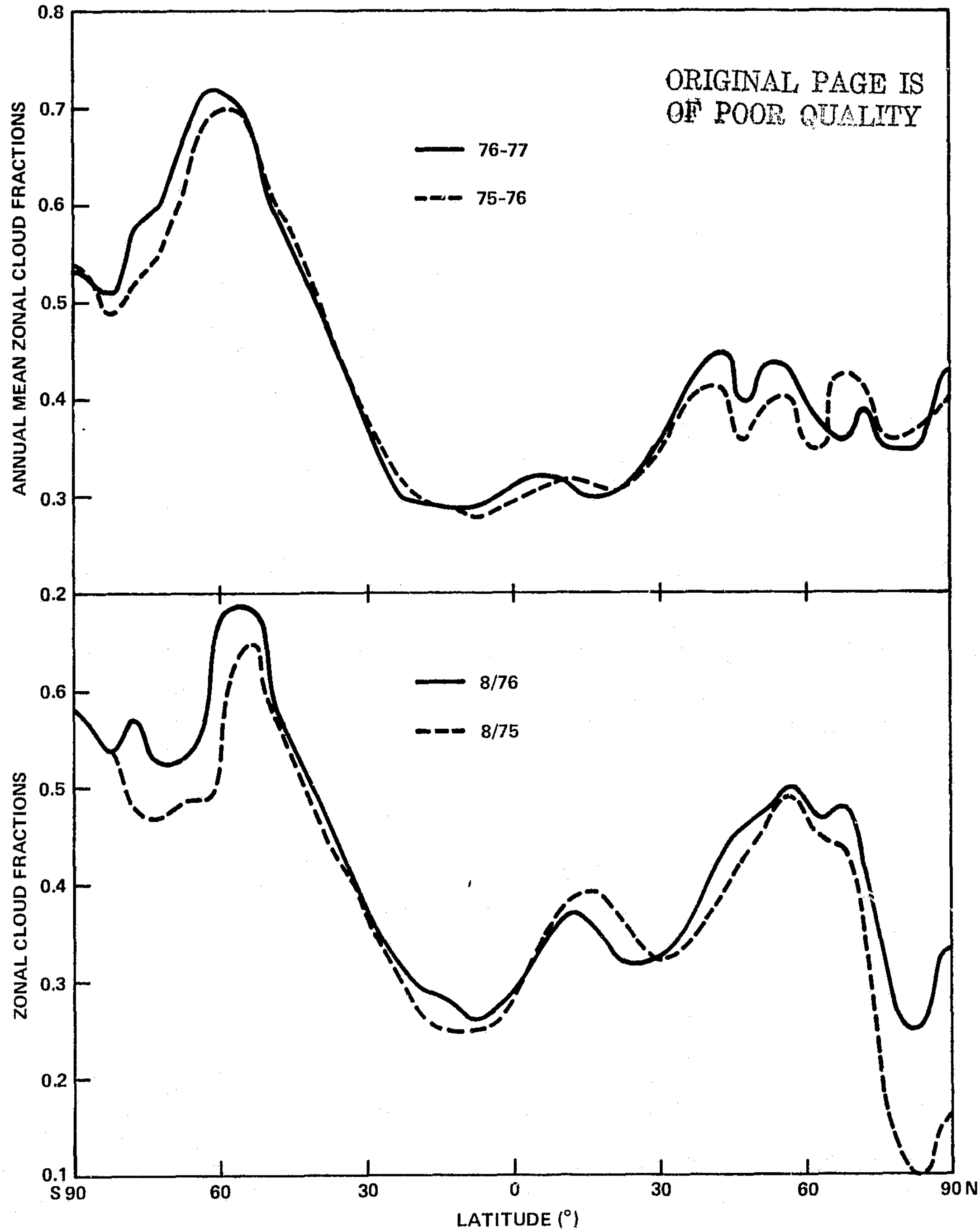

Figure 8. Derived Zonal Cloud Fractions; (a) Their Annual Mean for the Periods 7/76 to 6/76 and 5/76 to 4/77, and (b) Comparisons for 8/75 and 8/76

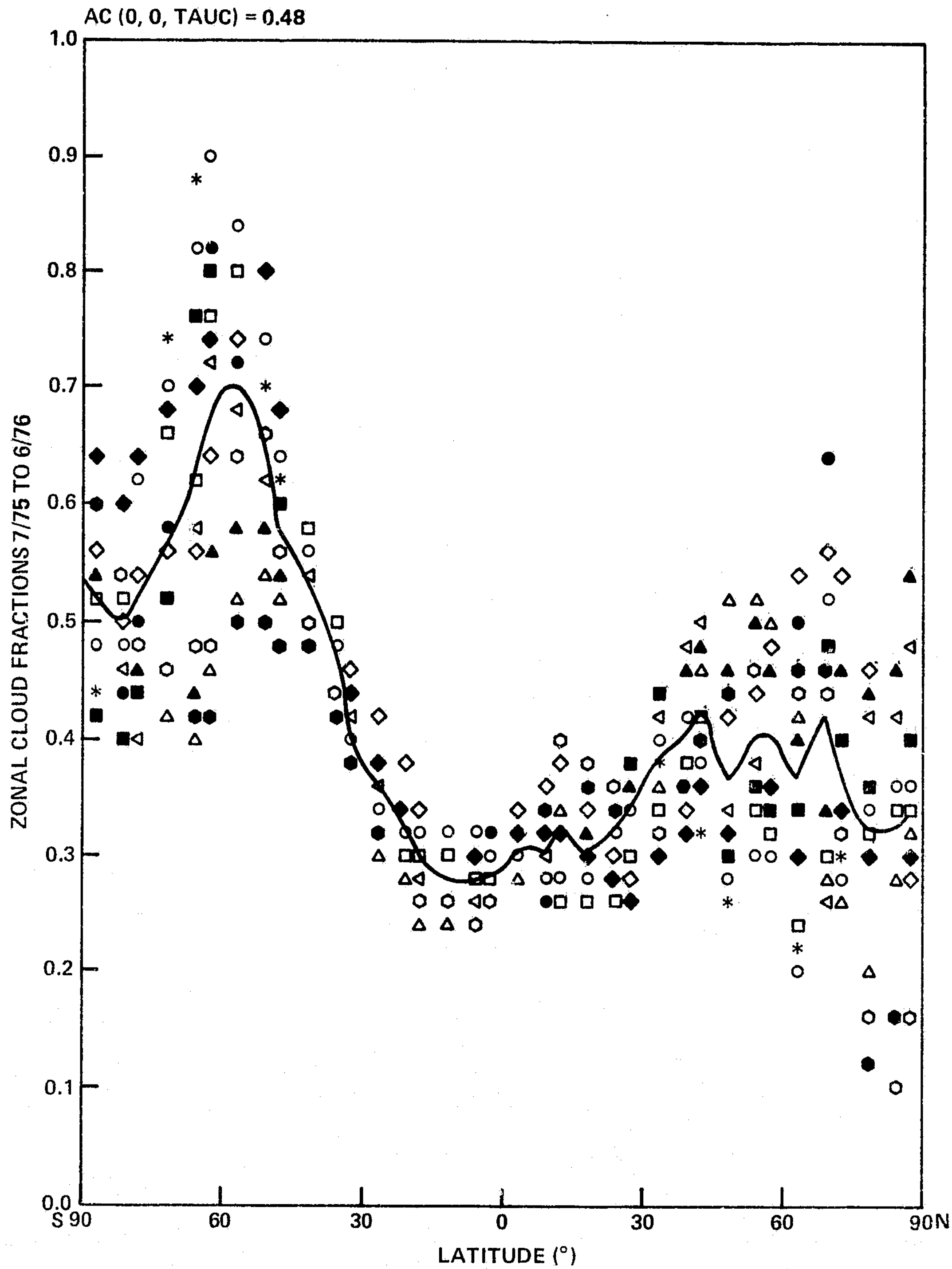

Figure 9a. Monthly Scatter of Zonal Cloud Fractions About Their Annual Means for the Periods of 7/75 to 6/76 and 5/76 to 4/77

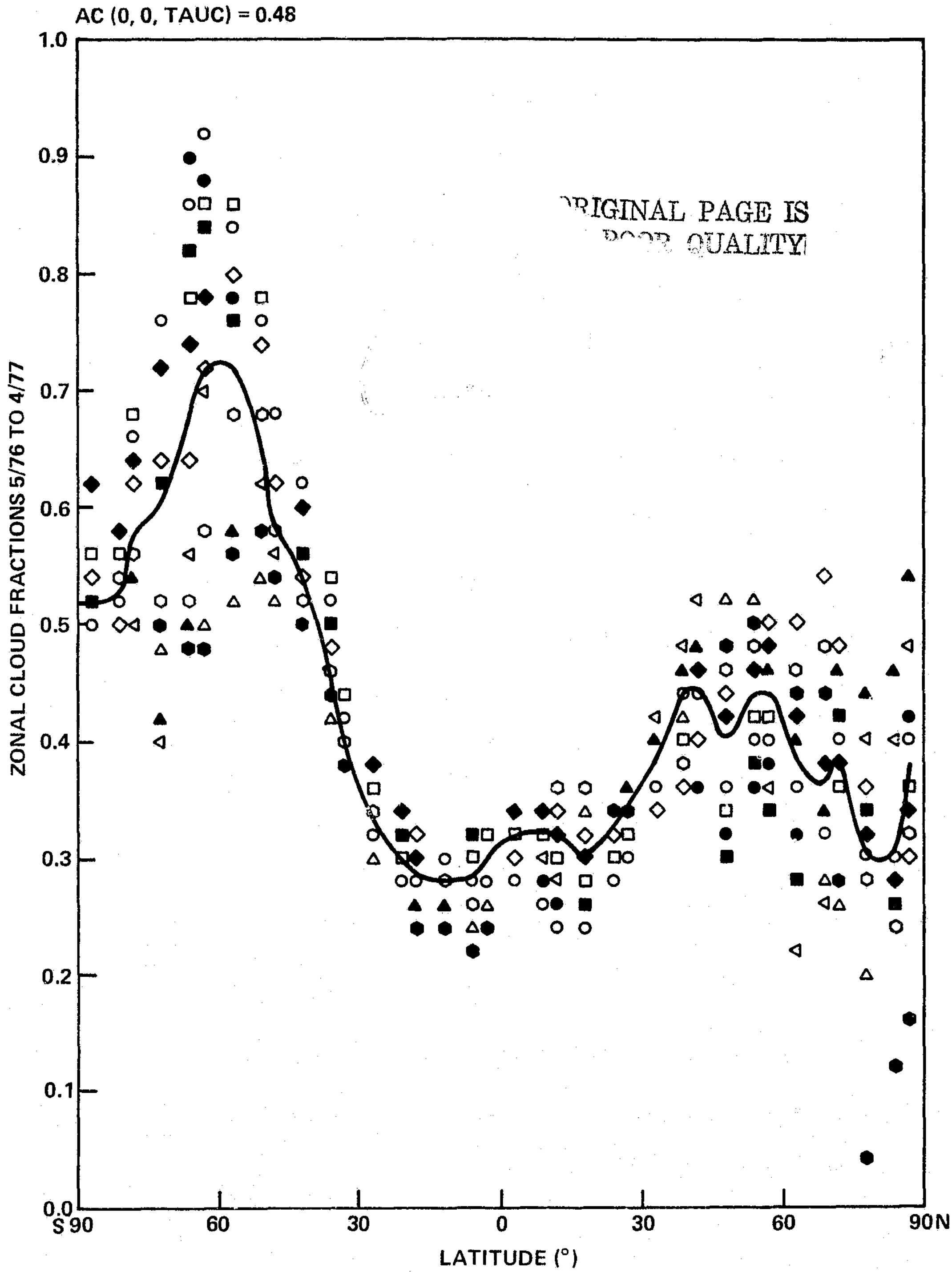

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Figure 9b. Monthly Scatter of Zonal Cloud Fractions About Their Annual Means for the Periods of 7/75 to 6/76 and 5/76 to 4/77 to 13 were folded into our cloud cover results, since these weights would strengthen the equatorial results relative to the higher latitudes. General circulation arguments of Wallace and Hobbs (1977) support the "transport of water vapor from source regions, where $E > P$, into sink regions, where $P > E$," and our cloud cover peaks are in these sink regions.

The fine structure of the latitudinal position of our ITCZ cloud cover peaks as a function of month and season are in general agreement with the discussion of the water-vapor convergence around the equatorial trough between the Hadley cells of both hemispheres of Palmén and Newton (1969). In Section 14.1 of Palmén and Newton (1969) they note the equivalence between the terms ITCZ, trade confluence, equatorial trough, and monsoon trough. They note that "the boundary between these circulation cells shows an average meridional displacement from an extreme southern position near 5°S during northern winter to an extreme northern position near 13°N during northern summer." Our ITCZ cloud cover peaks for both years of data in Tables 12 and 13 are delineated, and they show this monthly migration of the peak from about 12.5°S during the winter to 12.5°N during the summer. The exact position of the rise in cloudiness due to the ITCZ might be displaced due to the coarse resolution of the ERB albedo data.

The graphs of $f_C(\phi_i, t_m)$ for fixed latitude as a function of month are also shown in Figure 10 for the southern zones of 7/75 to 6/76. The behavior does quite often show cyclical trends. For example, the -37.5° zone of the 75 - 76 data shows sinusoidal oscillations peaking in March and October with minima in January and June, so that a 6 month cycle is exhibited. Large oscillations occur for the -62.5° zone with a 12 month cycle where cloud cover changes of over 100 percent are shown.

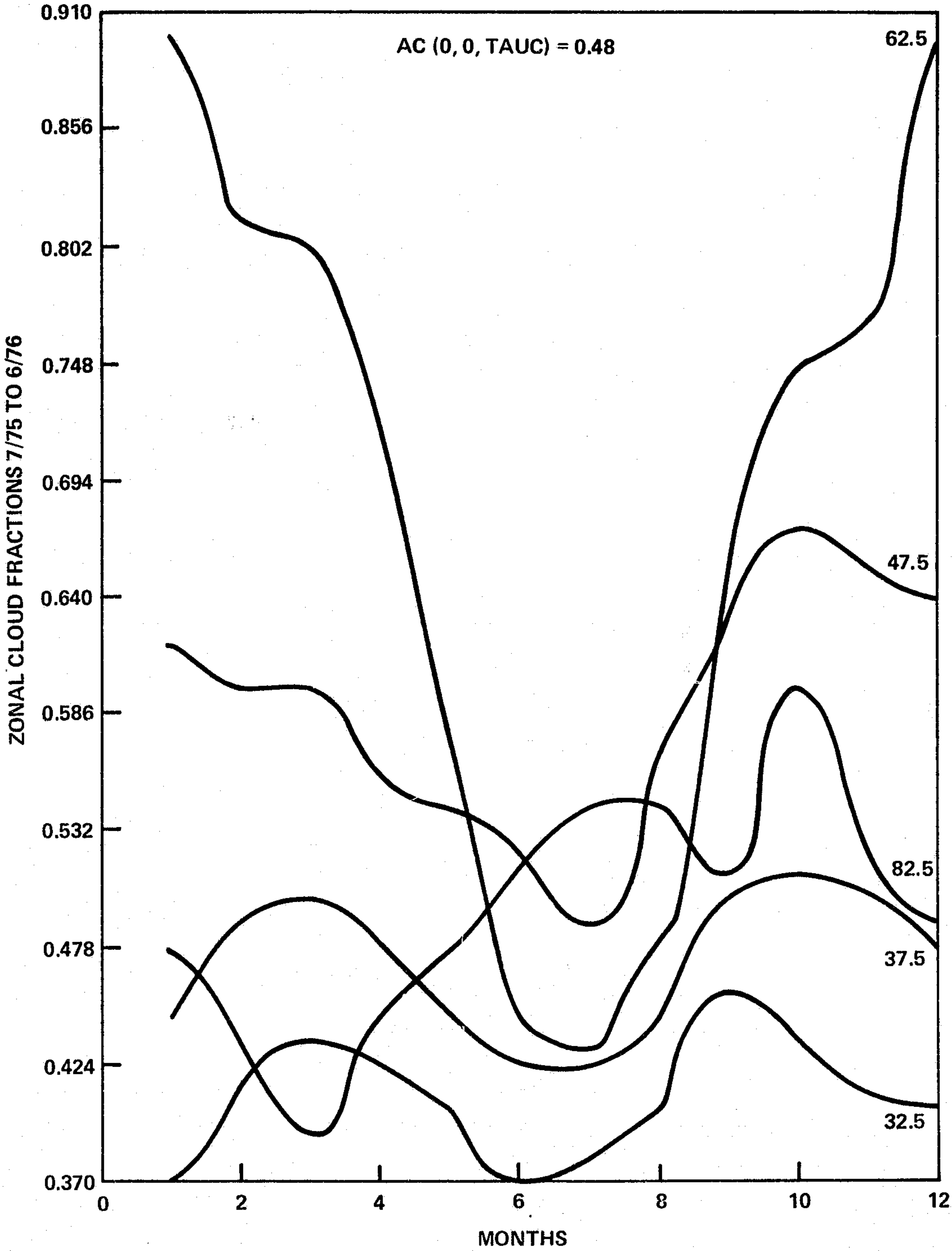

Figure 10. Monthly Variation of Zonal Cloud Fraction
for Southern Zones During 7/75 to 6/76

We next form the hemispherical and global averages of our cloud cover results using Eqs. 10 to 13. These values are displayed in Table 14 and graphed in Figure 11. The first feature to observe is that the selection of $A_C (0, 0, \tau_C) = 0.48$ caused the global annual mean values to be in close agreement with the 0.40 value of Hoyt's (1976) Model B. The other features of our results that agree with Hoyt's (1976) are that the southern hemisphere is more cloudy than the northern hemisphere, and maximum cloudiness occurs in the summer and minimum cloudiness occurs in the winter of each hemisphere. Again, we must exclude the anomalous month of 1/77 for these rules to hold.

7. CONCLUSIONS

The parameterization by NC of the radiative transfer calculations of Dave and Braslau (1974, 1975) allow the formation of a simple transformation of surface albedo to albedos at the top of the atmosphere for the clear, total and fractional cloud cover cases. This transformation is applied to a surface albedo model dependent on only a few parameters coupled with surface cover climatology data and one cloud albedo parameter to produce realistic cloud free and total cloud cover albedos at the top of the atmosphere. The cloud free case compares favorably with the results of Vonder Haar and Ellis (1975). The fractional cloud cover parameterization of NC is used to couple the cloud free and total cloud cover albedos with the ERB albedo data so that a solution for fractional cloud cover is obtained. The cloud cover results are in good agreement with the climatological results of Model B of Hoyt.

Table 14. Spatial Averages of Southern and Northern Hemispherical Zonal Cloud Fractions (f_{CS} and f_{CN}), and Global Average [$f_{CG} = ½ (f_{CS} + f_{CN})$] Compared with Model B Seasonal Results of Hoyt (1976)

MONTH	7/75-6/76			5/76-4/77			HOYT (1976) MODEL B		
	f_{CS}	f_{CN}	f_{CG}	f_{CS}	f_{CN}	f_{CG}	f_{CS}	f_{CN}	f_{CG}
1	0.47	0.32	0.39	0.40	0.39	0.39	0.45	0.34	0.40
2	0.46	0.35	0.41	0.47	0.33	0.40	0.45	0.34	0.40
3	0.45	0.35	0.40	0.47	0.34	0.40	0.43	0.36	0.40
4	0.42	0.35	0.38	0.42	0.36	0.39	0.43	0.36	0.40
5	0.39	0.39	0.39	0.39	0.39	0.39	0.43	0.36	0.40
6	0.36	0.37	0.37	0.37	0.37	0.37	0.41	0.39	0.40
7	0.36	0.37	0.37	0.37	0.37	0.37	0.41	0.39	0.40
8	0.39	0.37	0.38	0.42	0.38	0.40	0.41	0.39	0.40
9	0.46	0.37	0.42	0.46	0.37	0.42	0.43	0.36	0.40
10	0.48	0.31	0.40	0.49	0.36	0.43	0.43	0.36	0.40
11	0.46	0.30	0.38	0.49	0.34	0.42	0.43	0.36	0.40
12	0.48	0.32	0.40	0.48	0.33	0.40	0.45	0.34	0.40
MEAN	0.43	0.35	0.39	0.44	0.36	0.40	0.43	0.36	0.40

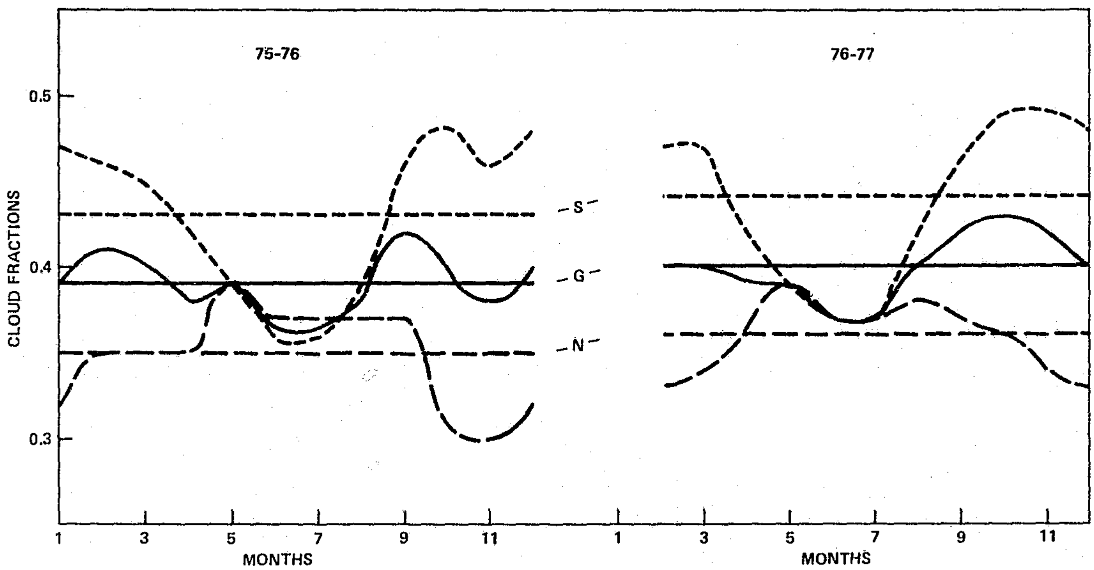

Figure 11. Monthly Variation of Southern and Northern Hemispheric and Global Cloud Fractions for the Period 7/75 to 6/76 (a) and the Period 5/76 to 4/77 (b)

A surprising feature of our cloud cover results are the appearance of peaks near the ITCZ in spite of the coarse resolution of our data. In some of the monthly results the peaks are quite strong, and their position follows the monthly and seasonal migration pattern predicted by atmospheric circulation studies. It is this characteristic of monthly migration which tends to weaken the appearance of the peak in our annual mean results. Due to the coarse resolution of the ERB wide field of view data the position of the peaks is not exact, but it is remarkable that this ITCZ cloud cover feature is visible in our results when our cloud analysis technique is applied to the ERB data.

Future work will combine these fractional cloud cover results, which are designed to be consistent with the ERB albedo data, with the albedo parameterization of NC to perform proper daily and monthly averages of the ERB albedo and reflected irradiance data.

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