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Study of the Consistency of Climatological
Products of Nimbus-7.

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INTRODUCTION

The research project entitled "The Study of Consistency of Climatological Products from Nimbus-7" was carried on by Prof. Harbans L. Dhuria effective October 1, 1987. This research was sponsored by the National Aeronautics and Space Administration and administered by the University of the District of Columbia Washington D. C. Dr. H. L. Kyle worked as technical monitor and had been an active participant in this research. The research was pursued according to proposed study.

This annual report presents the outcome of our efforts in research work. The scope of research was expanded. The study in addition to investigating the consistency of Climatological Products from Nimbus-7 THIR and ERB experiments focussed on the climatological analysis of the specified regions of the Earth. The Climatological Study consisted of the effects of various types of clouds on the net radiation, albedos, and emitted radiation. In addition to correlational study for determining consistency level of data, a population study of the regions was formulated and conducted. The regions under this study were formed by clustering the target areas (Pl. refer to Global Map for target areas) using the criteria of Climatological conditions

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such as geography, Ocean, and Land. The software and organization of data base, of course provide the analytical results of all the 2070 target areas for the month of July, October 1979, and January and April 1980. However our research is limited to Tropics from 18 Deg. North to 18 Deg. South. The correlational study indicates that there is high positive correlation between high clouds and albedo, and a reduced negative correlation between albedo and net radiation. The correlation between LWTF and net radiation is small and can be either positive or negative.

As a result of this research a paper entitled "CLOUD TYPES AND THE TROPICAL EARTH RADIATION BUDGET" was presented at the AGU Spring 1988 meeting at Baltimore. Draft of the report of research and paper is enclosed.

A draft of the paper entitled "CLOUD TYPES AND THE EARTH RADIATION BUDGET" for publication has been prepared. After review and including some figures the paper will be submitted for publication. The copy of the draft of the paper is enclosed.

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SOFTWARE DEVELOPMENT

Data Organization

THIR (Cloud) and ERB Data SETS: The daily data of Total Clouds, High Clouds, Mid Clouds, and Low Clouds in ascending node (A. N.) and descending node (D. N.) for each target areas of the earth were retrieved from CMATRIX tapes. The daily data of Long Wave Terrestrial Flux (LWTF) (A. N. and D. N.), average of LWTF (A.N. and D.N.), Albedo and Net radiation were obtained from ERB Matrix tapes. The documentation of CMATRIX tapes and ERB matrix tapes written by RDS were used for tracking the appropriate data. The daily Clouds' Data Sets and ERB data sets were further processed and merged into data base on a magnetic tape. This data base consisted of climatological products, under investigation, from Nimbus-7 THIR and ERB experiments for each target area on the globe and for each valid day of the months of July and October 1979, and January and April 1980, forms the basis of the study.

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Computer Programs Development

IBM-3081 computer system of computer center at NASA Goddard Space Flight Centre was used for data processing. The data files of climatological products were organized on magnetic tapes and the computer programs (FORTRAN and JCL along with data of regions consisting of target areas) were organized on disk online to computer system. The computer programs were used to retrieve the climatological products data from CMATRIX and ERB matrix tapes and to organize it on a tape using a scheme most suitable for processing the data.

Computer programs were designed and develop to accomplish the following tasks:

The data for processing and the results with in the programs were organized in the form of matrices, the columns representing the variables of climatological products and the rows representing the observations for the valid days of the months and the target areas of the specified region. The data pertaining to the target areas of the regions was merged into matrices representing the regional data of several target areas.

Filters were designed and implemented with in the programs to (1) eliminate the invalid data (2) to obtain the

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type of data such as data when total cloud present was equal to or grater than 95% (3) to obtain data for valid data of Cirrus or Deep Convective Cloud. Correlation coefficients for data of each target areas and the regions between the variables were computed. After inspection of the data and its analysis the authors found that the scope of the study could be extended. A population study was devised.

The study provided interesting and useful results. This led us (the principal investigator and Dr. Lee Kyle a senior scientist at NASA) to present a paper at 1988 AGU meeting. The presentation at AGU meeting included the results of the study of 10 regions, each region consisting of 20 target areas. The data of five regions that belong to monsoon ocean area of northern tropics and other five regions that belong to southern ocean desert, for the month of July was considered for this study.

The global map was further studied considering the climate, geography, ocean and land to make population study effective and meaningful. A complicated task of outlining the regions consisting of target areas 9 to 35 was carried out.

A method of processing the data of the different sized regions was devised and implemented in the program. The

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program provided the output that allowed correlational and population studies. The output also included (1) the standard deviations, and means of the regional data; (2) the average values of the climatqlogical data within the specified ranges of cloud and Net radiations that were considered under this study.

Thus a sophisticated software was developed that allowed the authors to study and manipulate the results and prepare a draft of a paper for publication. After reformatting the draft and including some figures the paper will be submitted for publication.

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SCOPE OF THE STUDY

Following the suggestions of Dr. Shiffer's review panel and the discussions between the Principal Investigator and Dr. Lee Kyle, the scope of study was modified and expanded. Apart from viewing only the correlation profiles of each target areas and parameter as specified in the proposal we included the climatological analysis of the regions of the Globe. Regions under consideration were composed of target areas. The number of target areas and the location of the region depended on the geography, climate, land, and ocean criteria. The initial study was limited to the months of July 1979 and January 1980. The parameters are considered are LWTF (A.N., D.N. and average of A.N. and D.N.) Albedo, Net radiation, Total Clouds (A.N. and D.N.), Low, Mid, and High Clouds, Cirrus and Deep Convective Clouds, and the averages of clouds (A.N. and D.N.). The study of relationship of those climatological variable and the effects of clouds on net radiation was included. A part of the answer to the question of CONSISTENCY of the Climatological products of Nimbus-7 will be obtained as byproducts of the analysis of the results obtained under study. The results of this extended study led us to present a paper at Spring 1988 AGU meeting and prepare a paper for publication.

Draft of the Paper for publication

CLOUD TYPES AND THE TROPICAL EARTH RADIATION BUDGET

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1. INTRODUCTION

The Nimbus-7 Earth Radiation Budget (ERB) and cloud data sets are compared in the tropics for the months of July 1979 and January 1980. A knowledge of the effects of clouds on the Earth's radiation budget is important both for accurate medium-range weather forecasting (Slingo, 1987) and in studying possible climate change. It has been proposed (Platt, 1981) that tropical cirrus clouds tend to increase net radiation (absorbed minus emitted) while the presence of deep convective or low clouds (Hartmann and Short, 1980) will decrease the net radiation. However, Cess and Potter (1987) compared the estimates of the effects of clouds on the radiative budget as determined by six different general circulation models (GCM's) and found a considerable lack of agreement. Each model incorporated a unique set of model physics and a distinctive numerical configuration. The problem is complex both because of the multiple effects clouds can have and because in the past there was a scarcity of reliable global observations. The availability of new global data sets such as the Nimbus-7 ERB (Jacobowitz et al., 1984) and Cloud (Hwang et al., 1988) results allow a better look both at the complexity of the problem and at global statistics. Some of our colleagues (Ardanuy et al., 1988) are using the two data sets to examine the global statistics. They use an analysis scheme which compares clear-sky and average (all) sky radiance fields. Ramanathan et al. (1988) also study the problem by comparing clear-sky and all-sky radiances. They consider the month of April 1985 and use data from the new Earth Radiation Budget Experiment (Barkstrom et al., 1989).

In this paper we restrict ourselves to a comparative study of the complex interaction between clouds and net radiation in the tropics. We do not consider a clear-sky case, but rather consider various types of clouds and varying amounts of cloud cover. Our purpose is to illustrate the wide range of interactions between clouds and the radiation budget that occur in the tropics.

2. DATA SOURCES

The Nimbus-7 Earth radiation budget (Kyle et al., 1985) and cloud (Hwang et al., 1988) data sets were used for this study. Daily estimates of fractional clear, low, mid, and high altitude cloud cover near noon and midnight for fixed $(500\ \text{km})^2$ target areas are available from the Cloud MATRIX tapes. There are 2070 target areas (TA) which cover the globe. A special cold and dim subset of the mid and high altitude daytime clouds are termed cirrus clouds. A second, cold and very bright, subset of the daytime high altitude clouds are called deep convective. The ERB scanner data are available on the same $(500\ \text{km})^2$ TA basis and the observations were taken within minutes of the cloud measurements. The

ERB products include noon and midnight outgoing longwave radiation (OLR) measurements and daily averaged values of the albedo, OLR, and net radiation.

During daylight hours, the Nimbus-7 cloud identification scheme uses a bispectral algorithm utilizing 11.5 μm radiances from the Temperature Humidity Infrared Radiometer (THIR) and 0.37 μm reflectivities from the Total Ozone Mapping Spectrometer (TOMS) both on the Nimbus-7 satellite. In the dark, only the 11.5 μm radiances are available. Stowe et al. (1988) report that the 0.37 μm reflectivities are chiefly used to identify low clouds with little thermal contrast with the surface. The Earth radiation budget measurements come from the ERB scanner as recorded on the ERB MATRIX tapes. Kyle et al. (1985 and 1986) report that the scanner longwave measurements are about 3 W/m^2 too low due to an error in a calibration coefficient, while the albedos are about 12% (three and one-half albedo units) too high, apparently due to the difficulty in differentiating between clear and cloudy scenes (Arking and Vemury, 1984). This makes the calculated net radiation 9 or 10 W/m^2 too low. These problems should, however, introduce few errors into relative comparisons of the Earth radiation budget products in different regions or at different times. Our study involves the daily comparison of ERB and cloud products for each TA.

The Nimbus-7 ERB scanner data are being reprocessed to correct these observed defects. A procedure similar to that discussed in

Arking and Vemury (1984) has been used to produce monthly averaged target area values of the albedo, OLR, and net radiation. The radiances are sorted by their satellite zenith angle and the viewing azimuth angle and then are converted to fluxes by direct numerical integration. This method is named the Sorting into Angular Bins (SAB) algorithm. The new SAB net radiation has been plotted in the January and July monthly maps (Figures 1 and 3); but in the detailed studies, we have used the available daily values on the old Nimbus-7 ERB MATRIX tapes. Since our principal interest is in relative comparisons, we have made no attempt to correct the values read from the MATRIX tapes.

While the THIR, used to detect clouds, was on continuously, the ERB instrument was on a three-day-on/one-day-off schedule. Thus, only about 23 days of ERB data are available in a normal month for each TA. Also some of the ERB and/or cloud products are missing from some TA's on various days. In order to obtain larger measurement samples for statistical evaluation, the targets are grouped in regional blocks of about 20 TA's each. The TA's in a given region are chosen to have roughly similar cloud and net radiation characteristics. After rejecting TA days with some data missing, each region normally has between 300 and 450 TA days available for analysis.

3. THE TROPICAL NET RADIATION BUDGET

Figure 1 shows the Nimbus-7 ERB net radiation map for July 1979 as derived from the Sorting into Angular Bins (SAB) data set. The southern hemisphere is an energy sink from 10°S latitude to the south pole. Positive net radiation increases from 10°S latitude to a maximum near 23°N and then slowly declines again towards the north pole. There is, however, considerable longitudinal structure in the net radiation and this is particularly so at about 25°N. The major difference is, of course, between the land and ocean as pointed out previously by Randal et al. (1984) and Kyle et al. (1986). Note the maxima of 130 W/m^2 or larger below Japan, near the date line, and north of the Dominican Republic. Then note the minimum of -18 W/m^2 in the eastern Sahara. But also note the local minimum of 40 W/m^2 in the Pacific just west of Baja, California. Figure 2 is the Nimbus-7 total noontime cloud cover map for July 1979 derived from the cloud MATRIX tape. Note that over the ocean the net radiation maxima mentioned above occur in regions of about average cloudiness (30% to 60%), but so does the minimum off Baja, California.

Figures 3 and 4 show the net radiation and total cloud cover for January 1980. In January, the northern hemisphere above 15°N latitude has become a heat sink, while the southern hemisphere shows positive net radiation even beyond 60°S latitude. At about 30°S latitude a row of hot spots in the Pacific, south Atlantic, and Indian Oceans occur which are again associated with moderate to average cloud cover.

In the present study we pick six tropical regions to study the varying interrelationship between clouds and net radiation. These regions, identified in Table 1, exemplify the range of interactions that occur in the tropics; they should not be considered as average regions.

4. ANALYSIS SCHEME

Two analysis schemes are utilized. The first is a matrix showing the correlation between the various Earth radiation budget components themselves and also with the principle cloud products from the CMATRIX. In the second procedure the albedo, OLR, the various cloud types, and the number of TA days considered are examined as functions of the net radiation. In each region, 12 net radiation bins are set up. The net radiation range -125 to +125 W/m^2 is divided into ten bins each 25 W/m^2 wide. The two additional bins are net radiation <-125 W/m^2 and net radiation >125 W/m^2. A matrix is formed by considering four total cloud categories for each net radiation bin. These are: percent total cloud cover; total cloud cover $<20\%$; $\geq 20\%$ and $\leq 80\%$; and $>80\%$. See Table __ as an example. The characteristics of the clouds in each net radiation bin are then analyzed. Six regions, identified in Table 1, were chosen in this study for extensive analysis in order to sketch out the varying effects of clouds on the net radiation.

The general radiation and cloud characteristics of these regions are shown in Table 2.

Ocean Regions A and B lie just south of the Equator, receive roughly equal amounts of solar insolation, and during these two months (July 1979 and January 1980) have nearly equal net radiation. However, Region A is part of the tropical rain belt around Indonesia and has moderate cloud cover in July and heavy cloud cover in January. On the other hand, Region B lies in the perennial high pressure region west of South America and has below average cloud cover in both July and January.

Region C includes the July high net radiation region in the ocean below Japan, while Region D includes the local minimum off Baja, California. In July, they receive about the same solar insolation and during the day the total cloud is the same. But the net radiation of Region C is much higher than that of Region D, 117.4 W/m^2 versus 66.8 W/m^2. Note that noon and midnight OLR for Region D is nearly identical and the same is true for Region C. Thus, any average noon to midnight shift in the cloud cover is not affecting the net radiation.

Regions E and F lie on the land. Region E includes the central Sahara and Arabian Deserts, while Region F covers the Congo rain forest and straddles the Equator. Thus, the solar insolation at Region E is considerably larger in July than in January, while the insolation at Region F is only 3% smaller in July than January.

However, the cloud cover over the Congo region is about 60% versus about 14% over the central Sahara. Regions E and F represent tropical extremes in the relationship of clouds and net radiation over land. A more detailed analysis of these three pairs of regions is given below.

The mean net radiation is determined by the equation:

$$NR = (1-A)\ SI - LW \tag{1}$$

where

NR	=	net radiation
A	=	albedo
SI	=	solar insolation (diurnal average)
LW	=	diurnally averaged OLR

Clouds can effect the net radiation by changing their properties. Normally the albedo of clouds is higher than that of the underlying surface. Thus, a decrease in cloud optical thickness and/or in cloud amount tend to decrease the albedo. The higher the cloud altitude the colder the cloud top temperature. Thus, decreasing the cloud top altitude and/or the cloud amount in the tropics tends to increase the OLR. Thus, increasing cloud top altitude and decreasing their optical thickness will increase the net radiation in a region. On the other hand, decreasing cloud top altitude and increasing the optical thickness will decrease the net radiation. These points should be kept in mind as the three pairs of study regions are reviewed.

5.0 ANALYSIS OF SELECTED REGIONS

5.1 Southern Tropical Ocean, Regions A and B

These two regions (see Table 1) lie just south of the Equator between 0° and 18°S latitude. They receive about the same solar insolation and absorb approximately the same amount of net radiation (see Table 2), but their climate and cloud cover are very different. As Table 2 indicates, our samples from Region A (Indonesian rain belt) show a 41% average cloud over in July 1979 when the Sun is north of the Equator, but nearly 90% cloud cover in January 1980. Further, most of the cloud tops were classified as middle or high in both months. In the Nimbus cloud classification, equatorial high cloud tops are over 7 km above sea level, while mid cloud tops lie between 2 km and 7 km. Region B (western Pacific high pressure area) has an average cloud cover of 21% in both months and about half the cloud tops are classified as low. The amount and types of clouds present over the tropical ocean depend not just on the absorbed solar energy, but also on sea-surface temperature and general atmospheric circulation patterns (see, for instance, Emanuel, 1988). The sea-surface temperature is normally lower in Region B than in Region A.

Figure 5 compares for July 1979 the effect of cloud cover on the measured daily top of the atmosphere net radiation for both regions. The total cloud cover is divided into three ranges: relatively clear (0% to 20%), partly cloudy (20% to 80%), and overcast (80% to 100%). In the relatively clear areas, the existing clouds are almost always low or mid clouds. In the Indonesian region (A), the partly cloudy TA's show a mixture of low, mid, and high cloud tops with the mid clouds dominating for high net radiation and the high clouds for low net radiation. The overcast areas are chiefly a mixture of high and mid clouds with the high clouds dominating for high net radiation (note the increase in cloud fraction at both high and low net radiation). In the western Pacific region there are no overcast regions and almost no high clouds. The cloud tops are slightly higher in the partly cloudy areas compared to relatively clear areas. The high energy (75 to 100 W/m^2) tail in Region B represents a single TA-day with 11% cloud cover during the day followed by 76% cloud fraction (mostly mid and high) at night.

The average albedo and OLR are shown in Figure 6 for these three cloud cover categories as a function of the net radiation. In Region A, for partly cloudy and overcast areas, both the albedo and OLR decrease as the net radiation increases. This is an optimal situation. More solar energy is absorbed, but less low temperature, longwave radiation is exhausted to outer space. In Region B, the OLR is always relatively high and high net radiation is associated with low albedos. It should be noted that in July the Sun is north of the Equator and that TA's just south of the Equator receive a mean solar insolation of 385 W/m^2 (averaged over 24 hours), while the TA's between 13.5 and 18°S latitude have a mean insolation of only 317 W/m^2. Due to the Sun being lower in the sky, these more southerly TA's also have a slightly higher albedo for identical cloud cover situations. Thus, in July the further south TA's have a lower average net radiation than do those nearest the Equator. Hence, some of the spread observed in graphs is due to the range in latitudes included in the study regions. However, the basic interrelationship between clouds and net radiation is seen in the individual TA's.

[SHOW 1 OR 2 PLOTS FOR INDIVIDUAL TA'S FOR FIGURES 7 AND 8.]

Figure 9 shows cloud cover versus net radiation for the two regions in January when the Sun is south of the Equator. Note in Table 2 that both the solar insolation and the net radiation have increased by approximately 100 W/m^2 in both regions. However, note the different distribution in net radiation measurements between the two locations. In the ocean around southern Indonesia, 41% of the measurements indicate net radiation greater than 125 W/m^2 and the majority of these show overcast conditions. However, the tail of measurements extends beyond -75 W/m^2. The net radiation measurements in Region B, in the western Pacific, are grouped fairly tightly about the mean value of 107.9 W/m^2. Only 16.9% of measurements show net radiation greater than 125 W/m^2 and only 5.7% of these belong to the relatively clear category. Thin (relatively dark) cool or cold clouds do appear to increase the net radiation.

Figure 10a and b shows the albedo and OLR associated with each of the cloud cover categories as a function of the net radiation. In Region A, the monsoon region, bright cold (deep convective) tops are associated with low, often negative, net radiation. However, these storm centers are surrounded by large areas of thin mid and high altitude clouds associated with high values of net radiation. This results in a high average net radiation. In Region B, the few clouds present also appear, in the net, to be relatively neutral.

The types of clouds observed in the two regions at noon during January 1980 are shown in Figure 11a,b as a function of the net radiation. Recall (Section 2) that the cirrus category is a subset of the high clouds, together with the colder mid altitude clouds, while deep convective is a subset of just the high clouds. The cirrus and deep convective subsets can be identified only during the day when the TOMS 0.37 μm reflectivities are available (Stowe et al., 1988). In Region A, cloud cover approaches 100% for low net radiation, with high cloud cover alone being over 80%. However, for high net radiation, mid clouds become as plentiful as high clouds and for net radiation over 125 W/m^2, mid cloud is the dominant type. Note that deep convective clouds become prominent at low net radiation. The cirrus clouds cover between 10% and 20%

of the area at most net radiations, but there is no marked increase in cirrus clouds at high net radiation.

For net radiation greater than 125 W/m^2, the total noon cloud cover is 74.1%, which is broken into high (27.0%), mid (40.9%), and low (6.3%). The deep convective cloud cover is 2.1% and the cirrus is 19.5%. This leaves a cloud cover of 52.5% most of which either acts to increase the net radiation or is neutral. Apparently, the dominant mid cloud, which has a low albedo, was considered too warm by the Nimbus cloud algorithm (Stowe et al., 1988) to be classified as "cirrus." Some of it, of course, may be high, very thin cirrus which passes considerable surface radiation and, therefore, is classified as rather warm mid level cloud.

Figure 11b shows the patterns found in the western Pacific high pressure region (B). Here there are few high clouds of any type, while mid and low clouds appear in about equal amounts, except in the few low net radiation regions where mid altitude clouds dominate. Noontime cloud cover passes through a minimum of 15% for net radiation between 25 and 100 W/m^2 and then increases again up to 25% for net radiation greater than 125 W/m^2. However, the identified cirrus cloud cover is only 0.7% for these warm regions. This suggests that in the tropics thin water clouds may be at least as important as thin cirrus in creating high net radiation regions.

Comparing July and January we see Regions A and B sharply increased their net absorbed solar energy in January by very different strategies. In Region A the cloud cover doubled, high cloud tops increased over 500%, the albedo rose from 22% to 35%, but the OLR dropped from 264 W/m^2 to 189 W/m^2. In Region B, the cloud cover remained at about 21%, the albedo actually decreased from 15.3% in July to 14% in January while the OLR also slightly decreased from 292 W/m^2 to 283 W/m^2. The decrease in albedo maybe mostly associated with the Sun being higher in the sky in January (see Taylor and Stowe, 1984), while the OLR reduction is probably related to a modest increase in cloud top altitudes.

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Table 2

Radiation and Cloud Characteristics of Six Tropical Study Regions in
July 1979 and January 1980

	OLR					CLOUDS									
REGION	NR W/m^2	A %	F_{AV} W/m^2	F_D W/m^2	F_N W/m^2	T_C %	$T_C(D)$ %	$T_C(N)$ %	$L_C(D)$ %	$M_C(D)$ %	$H_C(D)$ %	$L_C(N)$ %	$M_C(N)$ %	$H_C(N)$ %	I_S W/m^2
JULY 1979															
A	10.1	22.1	263.8	264.0	263.5	41.0	37.9	44.1	11.1	19.1	7.7	13.8	23.0	1.3	352.87
B	7.0	15.3	291.9	292.1	291.8	21.3	20.8	21.8	9.4	11.3	0.1	8.2	13.4	0.2	351.7
C	117.6	22.2	240.3	240.7	239.9	57.8	51.2	64.3	10.0	25.0	16.1	17.8	29.4	17.1	460.29
D	66.8	26.7	272.5	272.9	272.0	42.5	51.7	33.2	30.1	20.2	1.5	3.6	27.9	1.7	462.94
E	11.5	31.2	305.1	322.9	283.2	9.1	5.8	12.4	3.8	1.8	0.2	1.9	9.3	1.2	460.10
F	16.2	35.1	240.0	246.6	233.5	60.4	59.1	61.7	7.7	38.3	13.1	5.0	34.9	21.8	399.63
JANUARY 1980															
A	106.1	35.2	188.7	189.2	188.2	89.5	84.8	94.3	4.3	35.4	45.0	8.8	36.9	48.6	454.56
B	107.9	14.0	283.3	285.3	281.1	20.5	20.7	20.4	10.1	9.4	1.1	7.7	11.7	1.0	454.88
C	-62.6	31.2	267.6	269.6	266.0	51.7	48.1	55.4	16.3	28.1	3.6	18.0	32.2	5.2	298.14
D	-60.1	24.6	245.8	246.8	245.0	51.0	51.3	50.7	8.4	30.4	12.5	3.0	34.6	13.3	284.04
E	-71.3	36.7	260.4	276.0	247.6	18.1	14.2	22.0	3.1	7.1	4.0	0.2	18.1	3.7	298.90
F	55.91	30.91	228.9	239.4	218.4	58.9	50.5	67.4	2.4	32.1	16.0	3.8	36.4	27.2	412.87

In the tropics, the Nimbus cloud altitude classification is: cloud tops below 2 km-low, cloud tops between 2 km and 7 km-mid, and cloud tops above 7 km-high. NR = net radiation, A = albedo, D = day, N = night, T = total, and L, M, H = low, mid, high. I_S = solar insolation.

APPENDIX

Draft of the report of research until MAY 31, 1988 including the presentation at AGU SPRING 1988 meeting at Baltimore

by

Prof. H. L. Dhuria and Dr. Lee Kyle.

CLOUD TYPES AND THE TROPICAL EARTH RADIATION BUDGET

H. L. Dhuria, University of the District of Columbia

H. L. Kyle, NASA/Goddard Space Flight Center

ABSTRACT

A correlative study of the Nimbus-7 Earth Radiation Budget (ERB) and cloud data sets is being carried out for the purpose of determining the effect of clouds on the Earth's radiation budget. Concurrent ERB albedo, noon and midnight outgoing longwave radiation (OLR) and net radiation are compared with noon and midnight cloud cover statistics. Noontime, total, low, mid, and high altitude clouds and deep convective cirrus cloud types are considered; midnight total and low altitude cloud types are also compared. Daily averages over $(500\ km)^2$ fixed target areas are used. Our preliminary study examines two tropical ocean regions during July 1979. One hundred northern tropical ocean target areas are centered on the summer monsoons around India and stretching eastward to the date line. Another 100 target areas in the southern tropics, westward from the coast of Peru, represent a relatively clear high pressure region. The target areas are normally examined in blocks of 20. The effect of clouds on the net radiation varied markedly with cloud type. On a large scale, clouds decreased the net radiation. However, gray (thin) medium and high altitude clouds had little effect on the net radiation and could at times increase the net radiation. This was especially true in the monsoon regions where such clouds are common. Bright (thick) clouds (low, medium, or high) always decreased the net radiation. It is planned to extend the study to cover the rest of the tropics and then the whole globe. Other seasons will also be considered.

A report on our preliminary results was presented at the AGU Spring Meeting held in Baltimore, May 17, 1988. That report is included here.

Dhuria, H. L. and H. L. Kyle, "Cloud Types and the Tropical Earth Radiation Budget," Spring Meeting, American Geophysical Union, Baltimore, MD, May 16-20, 1988, EOS Transactions, American Geophysical Union, 69, No. 16, p. 311, April 19, 1988.

Cloud Types and the Tropical Earth Radiation Budget

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H L Kyle (Code 636, NASA/Goddard Space Flight Center, Greenbelt, MD 20771; 301-286-9415)

Nimbus-7 Earth radiation budget and cloud data sets were used for this study. The purpose was to investigate the relationship between the cloud types and the albedo, net radiation, and emitted longwave flux. Daily data of $(500\ km)^2$ regions in the tropics related to cloud types and Earth radiation budget for the month of July 1979 were used for this study. Correlation coefficients between total, low, mid, high clouds and albedo, emitted longwave flux, and net radiation were computed. The analysis showed: (1) strong correlation between high clouds and albedo and (2) negative high correlation between high cloud and emitted longwave flux and net radiation. The net Earth radiation budget (absorbed - emitted) strongly depends on cloud type. For example, in the monsoon region over the bay of Bengal in July 1979 we considered regions which, on a particular day, were at least 99% cloud-covered. Depending on cloud type, the net radiation varied from -55 W/m^2 (deep convective clouds) up to 126 W/m^2 (thin medium and high clouds: cirrus and others). But on comparing cloudy and clear regions, the net radiation on the average was markedly reduced in the regions covered by monsoon clouds.

CLOUD TYPES AND THE TROPICAL EARTH RADIATION BUDGET

H. L. Dhuria, University of the District of Columbia
H. L. Kyle, NASA/Goddard Space Flight Center

A Comparative Study of the Nimbus-7 Earth Radiation Budget (ERB) and Cloud Data Sets With Emphasis on the Relationship Between Clouds and Net Radiation

Background

- The Nimbus-7 satellite is in a Sun-synchronous orbit and passes over the tropics and mid-latitudes within an hour of local noon and local midnight

- Both Cloud and ERB (scanner) data fields consist of daily averages over (500 km)^2, 4.5° by 4.5° at the Equator, Target Areas (TA's)

- Comparisons made for both individual TA's and for blocks of 20 TA's

- Present Study: July 1979, Tropical Ocean
  (a) Northern Monsoon (b) Southern Clear Area

CLOUDS AND NET RADIATION

NR	=	(1-A) SI - LW
NR	=	Net Radiation
A	=	Albedo (Diurnal Average)
SI	=	Solar Insolation (Diurnal Average)
LW	=	Diurnally Averaged Outgoing Longwave Radiation (OLR)

To Increase Net Radiation:

Decrease Albedo

- Fewer Clouds and/or
- Thinner Clouds

Decrease OLR

- High Level Clouds

Optimal:

Thin high level clouds during the day with thicker clouds at night

To Decrease Net Radiation: Increase albedo and increase OLR

FIGURE CAPTIONS

Figure 1. July 1979, Global Cloud Cover Map.
The northern tropical ocean region studied extends from Saudi Arabia to the date line. Most of this region is covered by the summer monsoons. The Bay of Bengal is given special attention. The southern tropical study region extends from the coast of South America westward to the date line. This is chiefly a high pressure region with low, scattered clouds. The twenty target area region given most attention includes the eastern edge of the clear (cloud minimum) region plus the western edge of the coastal cloud fields.

The effect of clouds on the Earth radiation budget components varies markedly with cloud type. To better resolve the problem, blocks of twenty target areas (TA's) were assembled; ten in the northern tropics and ten in the southern (see Table 1). When periods where one or more parameters were missing were discarded, 250 to 450 (TA/day) were available for study in each block. Then the data were sorted into net radiation bins each 25 W/m^2 in width and divided into overcast (greater than 80% cloud cover), partially cloudy (20% to 80% cloud cover), and rather clear (less than 20% cloud cover).

The resulting data were then analyzed.

Figure 2. Histograms of clear, partly cloudy, and overcast TA/days versus net radiation in and near the Bay of Bengal for July 1979. This is a monsoon period and the region was heavily overcast. Note the large fraction of overcast and partly cloudy regions where the net radiation is as large or larger than in the clear regions.

Figure 3. Plot of outgoing longwave radiation (OLR) and albedo versus net radiation for three types of cloud fractions: relatively clear, clouds < 20%; partly cloudy, clouds 20% to 80%; and overcast, clouds > 80%. Note the large separation in OLR for clear, partly cloudy, and overcast cases and the large range in albedos for the overcast case.

Figure 4. As in Figure 2, but for a high pressure, partly cloudy region in the southern tropical ocean off the coast of South America. In this case, the few overcast regions are all associated with low net radiation. Very few high clouds are found in this region. Although some of the partly cloudy target areas show high net radiation most do not. There is a large spread in net radiation for the clear areas. In July the Sun is well north of the Equator and this twenty target area regions has an average net radiation of just 10 W/m^2. The target areas just south of the Equator have the highest net radiation, while the target areas 16°S of the Equator have net radiations of -50 W/m^2 to -100 W/m^2 even when clear.

Figure 5. As in Figure 3, but for the southern tropical region illustrated in Figure 4. Note that there is very little variation in the OLR for the clouds <20%, clouds 20% to 80%, and clouds >80% target areas. This is a common feature of regions with predominately low clouds. The more southerly clear target areas, with higher solar zenith angles, generally have a slightly higher albedo than the ones closest to the Equator.

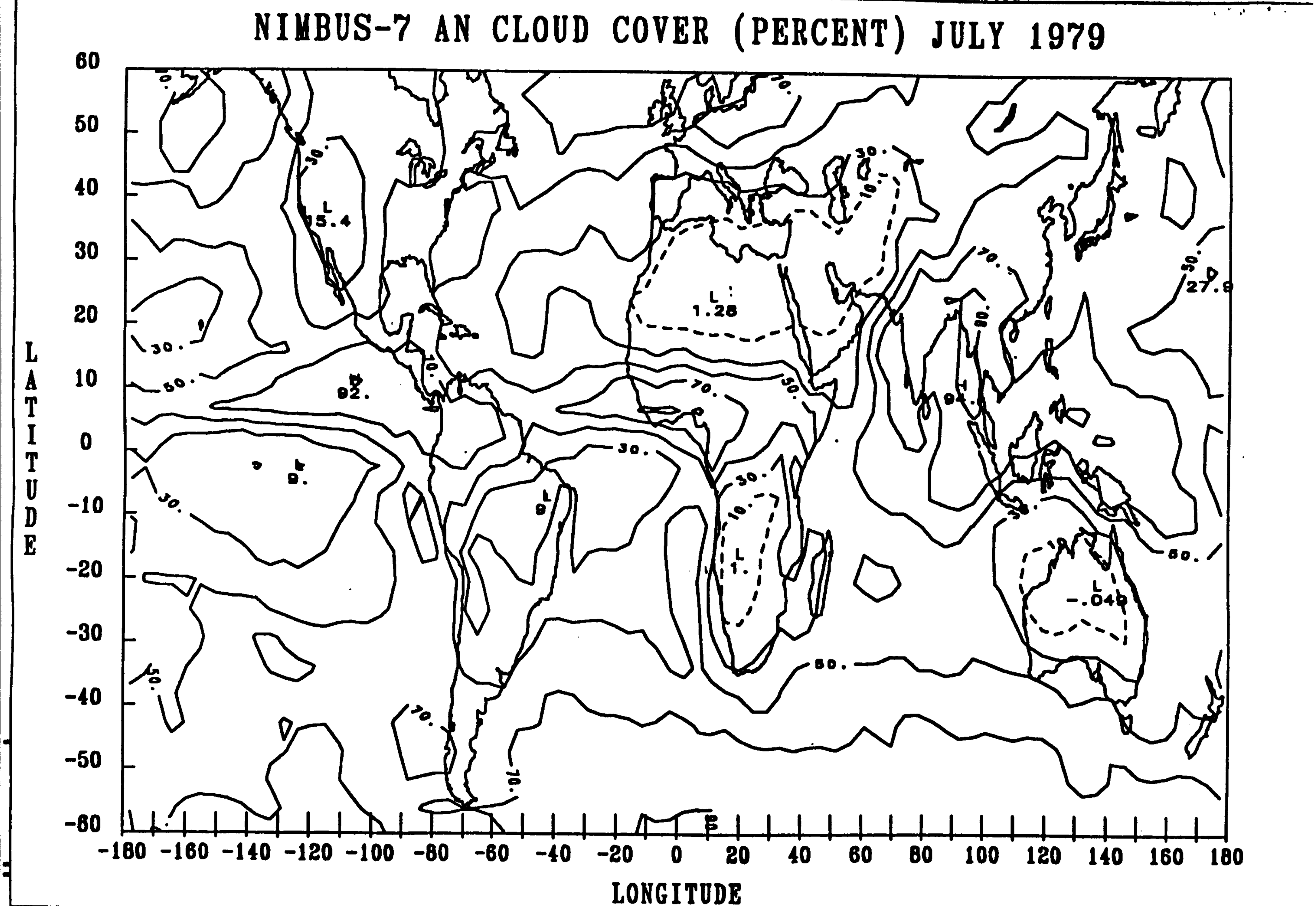
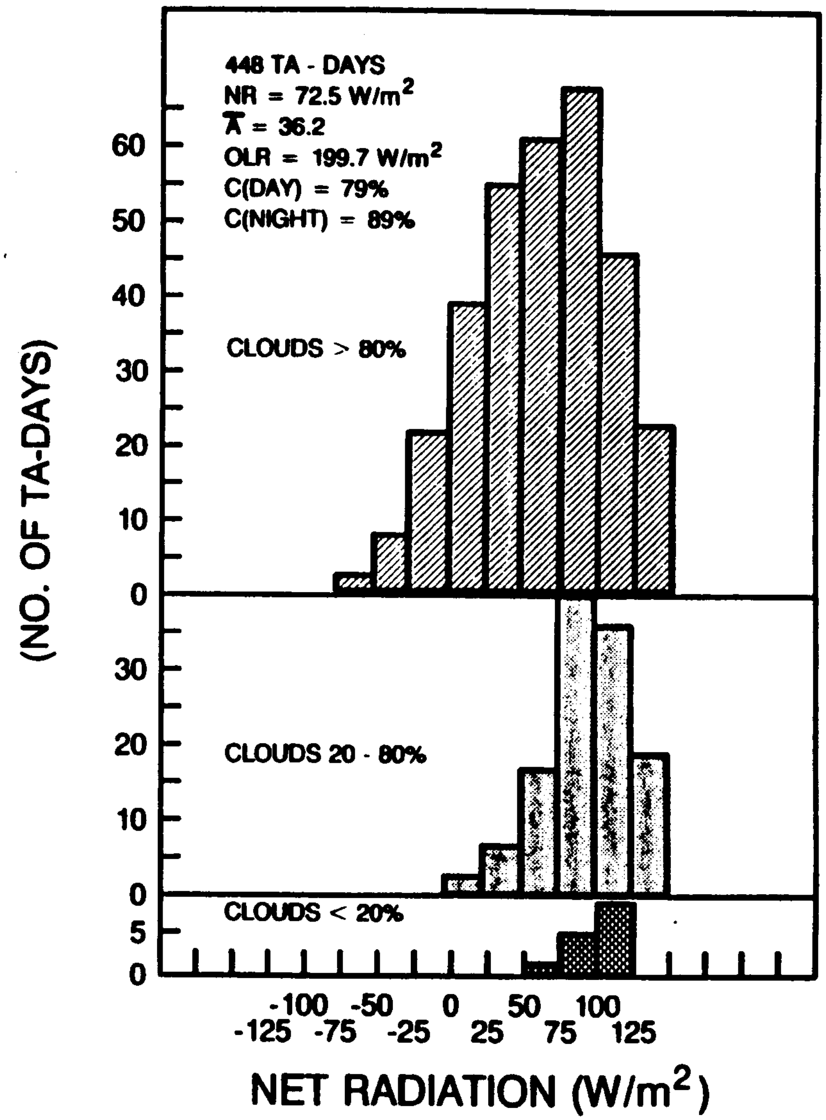

NIMBUS-7 AN CLOUD COVER (PERCENT) JULY 1979
LATITUDE
LONGITUDE
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-180
-160
-140
-120
-100
-80
-60
-40
-20
0
20
40
60
80
100
120
140
160
180
L
5.4
92.
9.
1.28
1.
-.049
27.9
30.
50.
70.
10.

Fig 1

JULY 1979

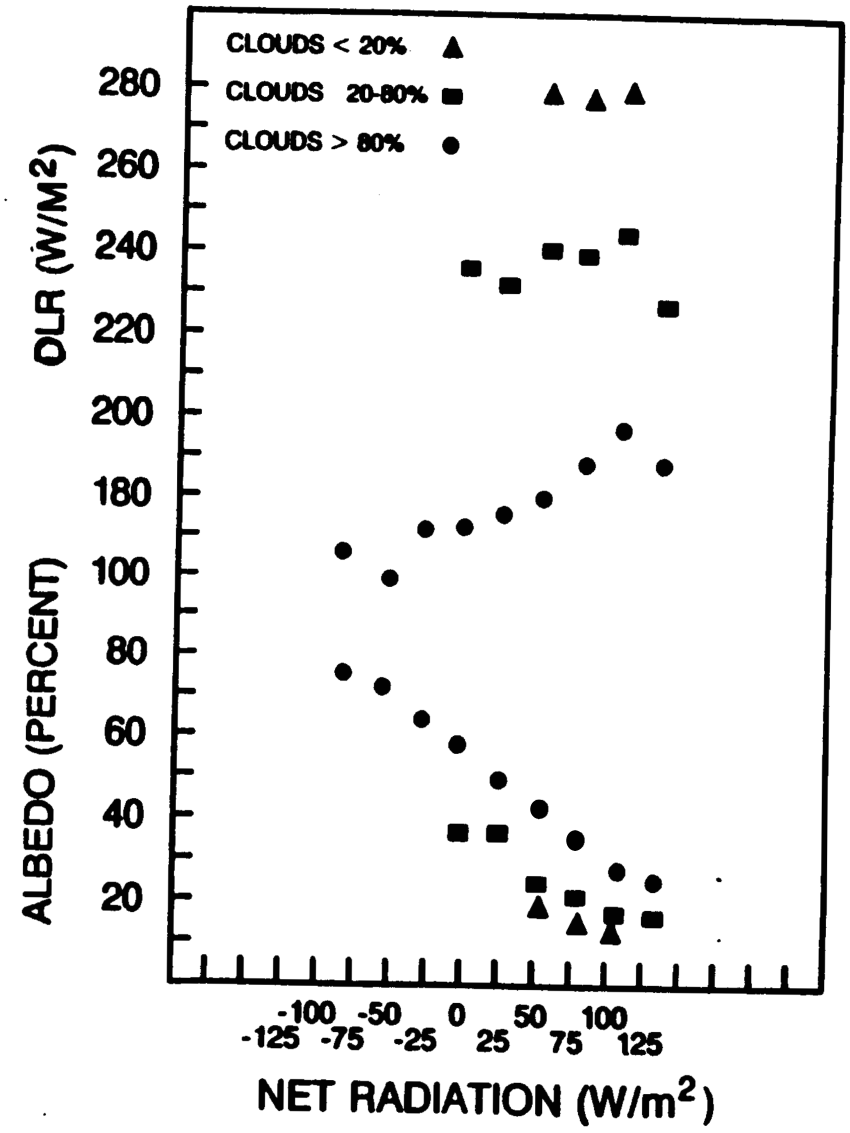
MONSOON OVER OCEAN - BAY OF BENGAL TO BORNEO



E35.002

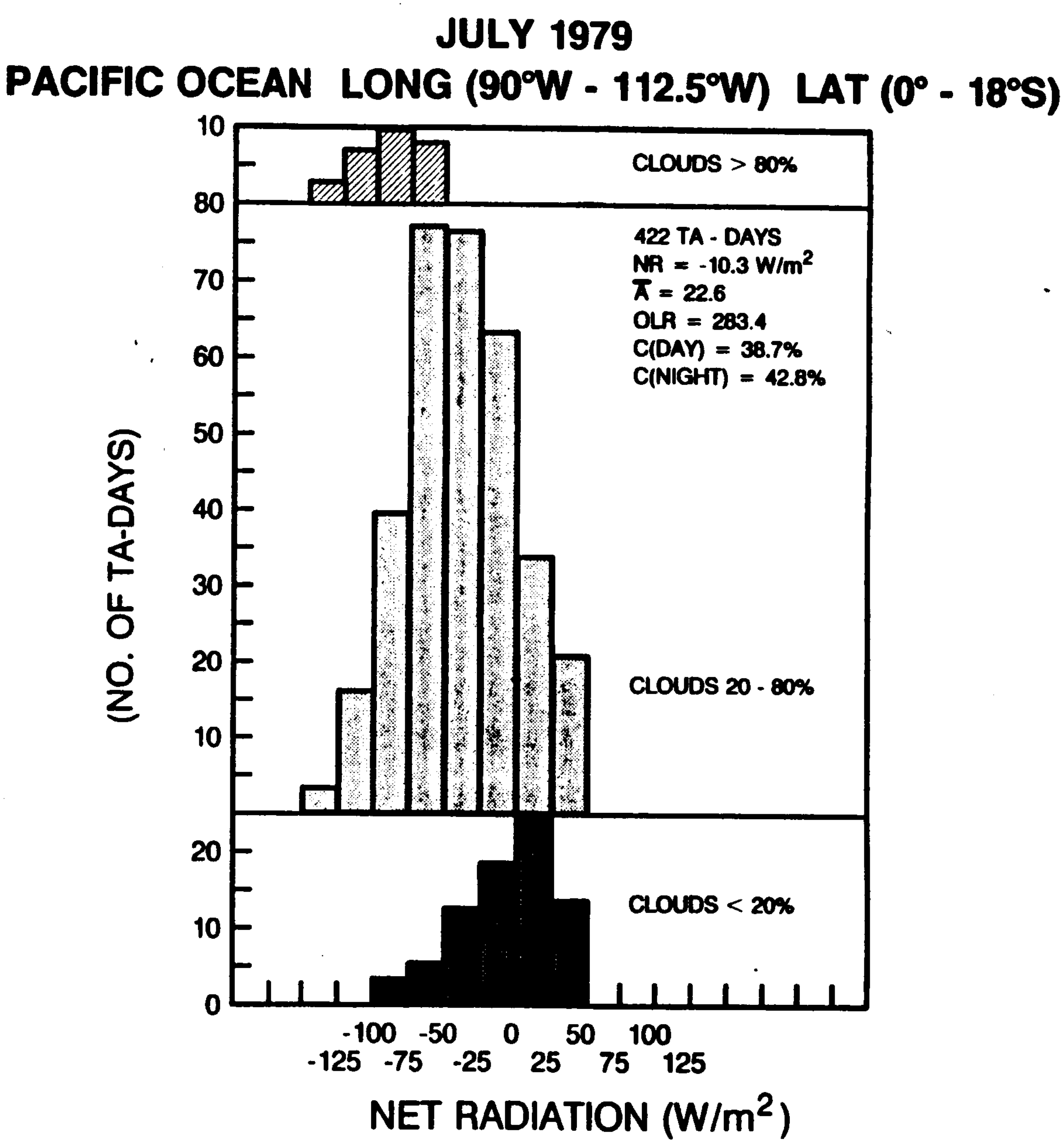
Fig 2

JULY 1979 MONSOON OVER OCEAN BAY OF BENGAL TO BORNEO



E35.001

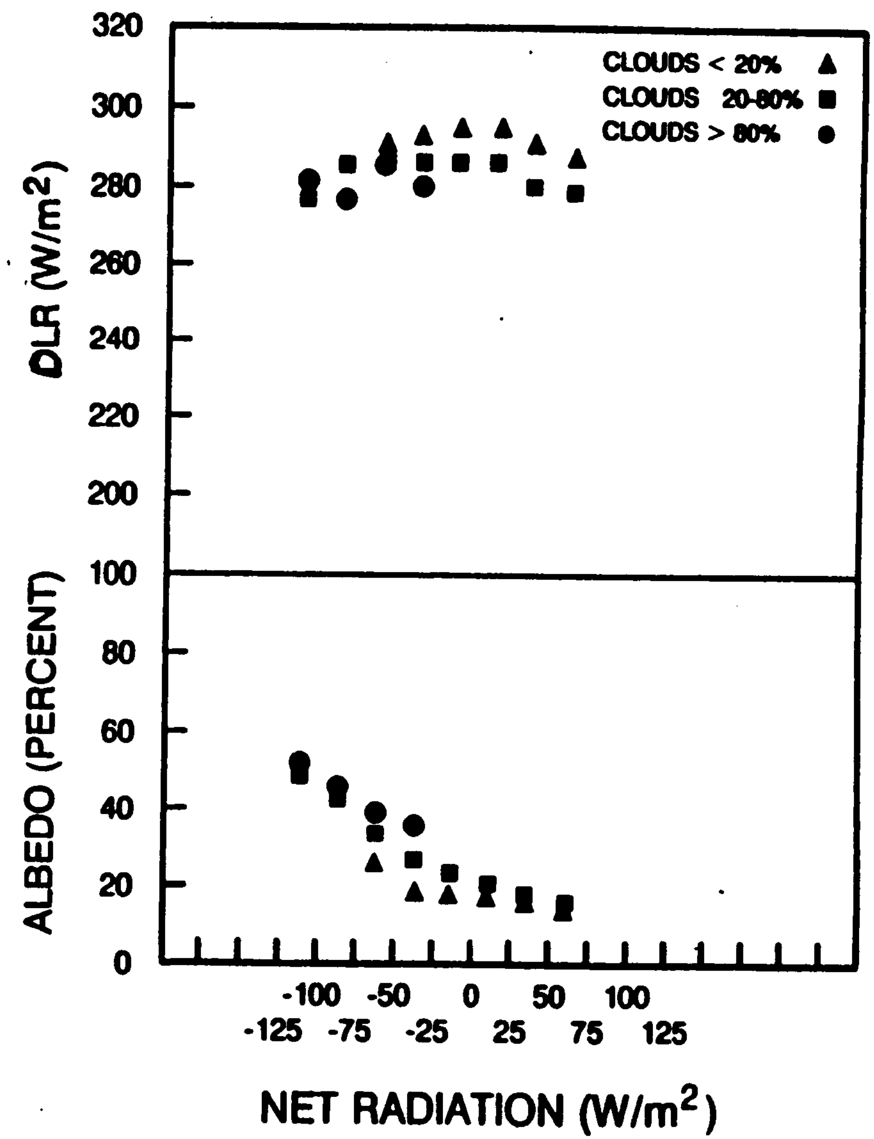
fig 3


JULY 1979
PACIFIC OCEAN LONG (90°W - 112.5°W) LAT (0° - 18°S)
CLOUDS > 80%
422 TA - DAYS
NR = -10.3 W/m²
Ā = 22.6
OLR = 283.4
C(DAY) = 38.7%
C(NIGHT) = 42.8%
CLOUDS 20 - 80%
CLOUDS < 20%
(NO. OF TA-DAYS)
10
80
70
60
50
40
30
20
10
20
10
0
-100 -50 0 50 100
-125 -75 -25 25 75 125
NET RADIATION (W/m²)

E35.004

fig 4

PACIFIC OCEAN JULY 1979 LONG (90°W - 112.5°W), LAT (0° - 18°S)



E35.003

fig. 5

TABLE CAPTIONS

Table 1 shows for each of the 10 (20 TA) regions considered the correlation of the net radiation with the outgoing radiation (OLR), albedo, total cloud (day) and total cloud (night). In the monsoon regions, 2-4, there is a correlation coefficient of about 0.5 with the OLR, indicating that the regions with high OLR also have the highest net radiation. However, in regions with predominately low scattered clouds, there is often no significant correlation between OLR and net radiation. There is a significant negative correlation (-0.7 to -0.9) between albedo and net radiation. Bright regions have a low or negative net radiation. Total daytime clouds have a negative correlation (generally -0.3 to -0.6) with the net radiation. The reduction in absorbed solar radiation caused by the presence of clouds is indicated by this negative correlation. Physically nocturnal clouds should decrease the OLR and thus increase the net radiation. However, our study shows a slight negative (0 to -0.4) correlation between nighttime clouds and net radiation. This arises from the strong continuity tendency (night clouds mean there will be day clouds) in the cloud fields. This is indicated in Table 2 by the positive correlation (0.3 to 0.6) between the albedo and the nighttime cloud coverage.

Table 2. Cloud/ERB product correlations. In the tropics clouds are identified by the cloud algorithm as having 11.5-micron radiances colder than the estimated clear-sky radiances. During the daytime clouds can also be identified as brighter than the

expected clear-sky brightness at 0.37 microns. This table displays the correlations between the albedo and outgoing longwave radiation (OLR) and between the albedo, OLR, and net radiation and the total cloud cover fractions for the 10 study regions defined in Table 1. In the monsoon areas, there is a strong (-0.8 to -0.95) negative correlation between the albedo and the daytime OLR. Bright clouds have cold (low OLR) tops. But in regions (6-8) dominated by low scattered clouds, the correlation coefficient drops (-0.2 to -0.4).

In all ten regions the albedo is well correlated (0.5 to 0.85) with total daytime cloud. This shows both that albedo is a good index of cloud cover over the ocean and that the cloud and ERB data sets are reasonably consistent. The correlation of OLR to total cloud ranges from (-0.29 to -0.85) at noon and (-0.3 to -0.82) at midnight. The correlation is poorest in regions where scattered low clouds predominate. Net radiation has relatively low negative correlation (-0.13 to -0.57) to total cloud fraction in all regions. This was indicated also in Table 1. Here the net radiation is correlated with the average diurnal cloud fraction. As a point of interest, note the correlation (0.3 to 0.6) between the albedo and the midnight cloud cover. This is an indication of the persistence of cloud cover from day to night.

RELATIONSHIP BETWEEN CLOUDS AND NET RADIATION IN THE TROPICS

- On a large scale, higher albedos produce lower net radiation. The correlation is ~ -0.75

- Thin medium and high altitude daytime clouds do not decrease the net radiation and some may even increase it slightly

- Daytime clouds are, on the large scale, associated with decreases in the net radiation

- Physically, night clouds should help increase the net radiation. A low negative (~ -0.25) correlation was obtained. This probably reflects the probability of day clouds carrying over into the night

- In monsoon areas, the OLR is positively correlated (~ +0.5) with the net radiation; but in regions of scattered low clouds, there is no significant correlation.

NET RADIATION AND TROPICAL CLOUD TYPES (JULY 1979)

The Nimbus-7 cloud data set organizes clouds into high, middle, and low clouds. Deep convective and cirrus clouds are a subset of the colder mid and high clouds. High, deep convective, and cirrus classifications were significant only in the northern tropics, while low clouds were significant only in the south.

Northern Tropics:

- Thin middle altitude clouds too warm for the cloud algorithm to call "cirrus" were most important in high net radiation regions, but "cirrus" were prominent

- High clouds and particularly "deep convective" clouds were associated with low (often negative) net radiation

Southern Tropics:

- Thin mid altitude clouds during day often with increased cloud cover at night were associated with high net radiation

- Bright (thick) daytime clouds were associated with low net radiation

TABLE 1

JULY 1979 TROPICAL OCEAN REGIONS (LAND EXCLUDED)

CORRELATION COEFFICIENTS OF NET RADIATION WITH

REGION	LAT	LON	OLR	ALBEDO	TOTAL CLOUD DAY	TOTAL CLOUD NIGHT
NORTHERN MONSOON						
1. PACIFIC	(0-18°N)	(167.5-180°E)	0.319	-0.776	-0.183	-0.042
2. PACIFIC	(0-18°N)	(135-167.5°E)	0.525	-0.875	-0.575	-0.244
3. PHILLIPINES	(0-22.5°N)	(112.5-135°E)	0.565	-0.861	-0.569	-0.270
4. BAY OF BENGAL	(0-22.5°N)	(81-112.5°E)	0.482	-0.859	-0.511	-0.185
5. INDIAN OCEAN	(0-22.5°N)	(58.5-81°E)	0.148	-0.749	-0.438	0.079
SOUTHERN TROPICS						
6. S. AM. COAST	(0-31.5°S)	(72-90°W)	0.020	-0.758	-0.319	-0.059
7. PACIFIC	(0-18°S)	(90-112.5°W)	0.018	-0.812	-0.655	-0.369
8. PACIFIC	(0-18°S)	(112.5-135°W)	-0.122	-0.689	-0.575	-0.239
9. PACIFIC	(0-18°S)	(135-167.5°W)	0.193	-0.679	-0.591	-0.224
10. PACIFIC	(0-18°S)	(167.5-180°W)	0.160	-0.695	-0.579	-0.241

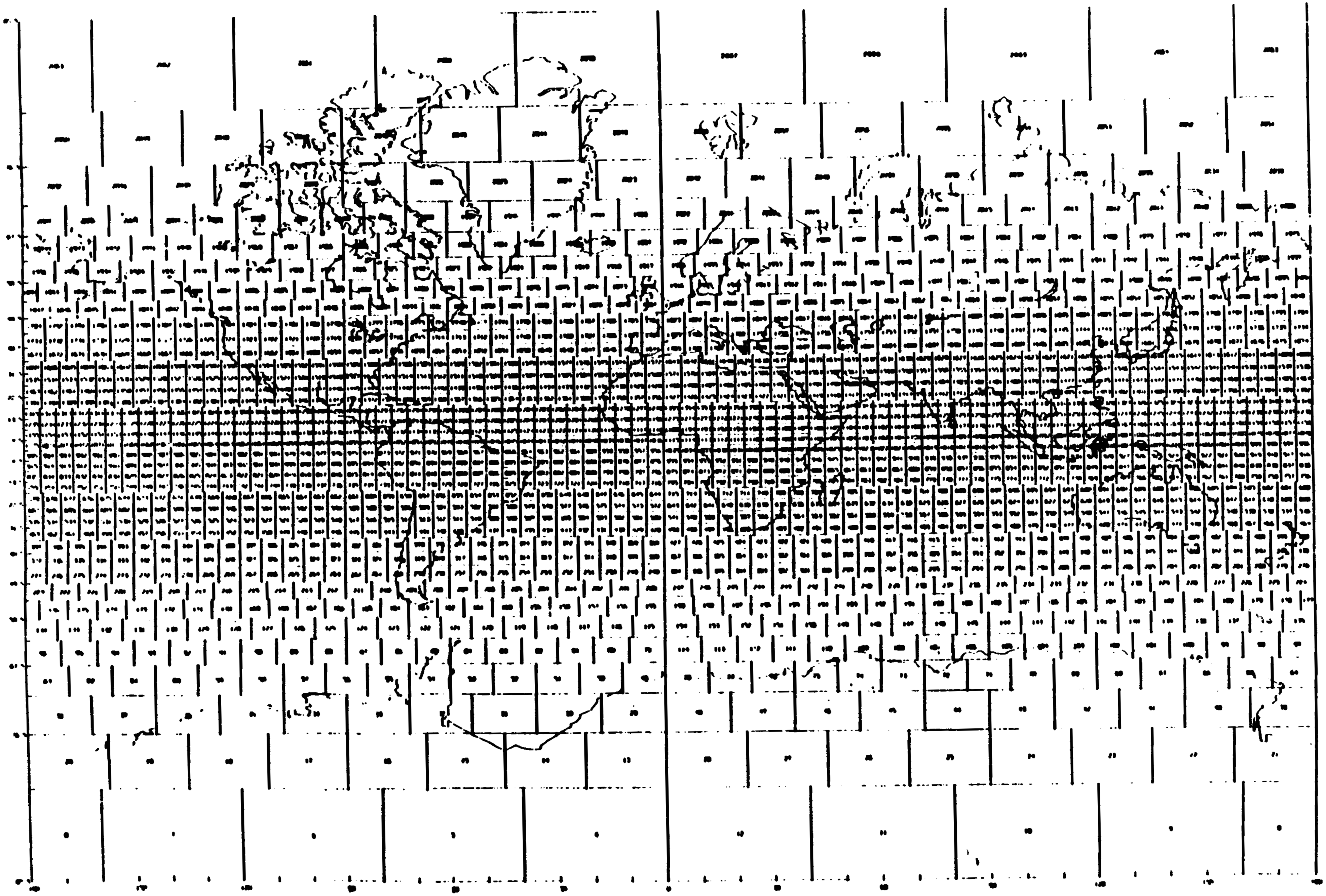
TABLE 2

CLOUD/ERB PRODUCT CORRELATIONS

REGION	OLR (D) A	T_{CLD} (D) A	T_{CLD} (N) A	T_{CLD} (D) OLR	T_{CLD} (N) OLR	T_{CLD} (D&N) NET RAD
1	-0.920	0.507	0.462	-0.598	-0.809	-0.128
2	-0.936	0.750	0.512	-0.813	-0.759	-0.460
3	-0.941	0.764	0.544	-0.847	-0.751	-0.466
4	-0.927	0.766	0.465	-0.850	-0.731	-0.398
5	-0.770	0.778	0.428	-0.808	-0.795	-0.202
6	-0.231	0.728	0.319	-0.292	-0.300	-0.193
7	-0.406	0.864	0.468	-0.470	-0.423	-0.569
8	-0.287	0.747	0.282	-0.352	-0.481	-0.451
9	-0.789	0.870	0.550	-0.781	-0.737	-0.439
10	-0.807	0.856	0.602	-0.765	-0.820	-0.436

REGIONS ARE DEFINED IN TABLE 1:

OLR = OUTGOING LONGWAVE RADIATION
A = ALBEDO
T_{CLD} = TOTAL CLOUD FRACTION
D = DAY
N = NIGHT



Global map: 2070 Target Areas for study of numbers-7 Climatological Products

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