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RADIATION MEASUREMENTS FROM POLAR AND GEOSYNCHRONOUS SATELLITES

T. H. Vonder Haar, Principal Investigator

ANNUAL REPORT

DEPARTMENT OF ATMOSPHERIC SCIENCE
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

RADIATION MEASUREMENTS FROM POLAR AND

GEOSYNCHRONOUS SATELLITES

Annual Report

for

National Aeronautics and Space Administration
Grant NGR 06-002-102
(Period: 1 October 1974 - 30 September 1975)

by

Thomas H. Vonder Haar, Principal Investigator
Department of Atmospheric Science
Colorado State University

August, 1976

with contributions by
Stanley Q. Kidder
James S. Ellis
Donald W. Hillger

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SUMMARY

The fifth year of grant sponsorship saw continued work on the under-
standing of the role of radiation in the dynamics of climate. Towards
that end, a climatology of radiation budget data has beeen compiled
(Vonder Haar and Ellis, 1974) and several aspects of the problem are un-
der study:

    a) minimum albedoes;

    b) diurnal variation in cloudiness and the radiation budget;

    c) the partitioning of energy loss to space between land,

        ice, ocean and atmosphere; and

    d) the effects of clouds on the radiation budget.

Also continuing is a study of one of the major contributors to the
general circulation - oceanic precipitation - using Nimbus 5 microwave
data. Finally, a new study of mesoscale applications of satellite infra-
red temperature and moisture soundings got under way.

1.0 INTRODUCTION

During the annual period October 1974 through September 1975, research under this grant continued to emphasize radiation budget studies of climate and climate change and oceanic precipitation frequency determination from Nimbus 5 Electrically Scanning Microwave Radiometer data. Research on mesoscale applications of satellite infrared soundings was also begun. Eight areas of research are discussed in Section 2.

Several papers sponsored by this grant were presented at national and international scientific meetings. A cumulative summary of papers and publications sponsored by this grant appears in Appendix C.

The grant fully sponsored M.S. candidate S. Kidder and partially supported Ph.D. candidate J. Ellis and several research staff.

2.0 DISCUSSION OF SCIENTIFIC RESULTS

2.1 Climate Data Sets

The completion of one and the preparation of another set of radiation budget statistics from satellite measurements for climate studies took place during the reporting period. The first set entitled, "Atlas of Radiation Budget Measurements from Satellites (1962-1970)" was published (Vonder Haar and Ellis, 1974). It has frequently been referred to as the 17 season data set and includes 10^0 latitude-longitude gridding, individual seasons, mean seasons, annual means and a mean annual 17 seasons composite. This is the very same data set which was applied as an upper boundary in the mean annual Northern Hemisphere heat balance study of Vonder Haar and Oort (1973).

Preparation of a second set, composited from 29 individual months of measurements into month, season and annual means, was largely

completed. The principal advantages of this set over the former is that it allows monthly studies and includes data which were not available for the former set. This set will be published under the title, "Zonal Average Radiation Budget Measurements from Satellites for Climate Studies" (Ellis and Vonder Haar, 1976). It has already permitted completion of a large part of a new study on the heat balance of the Northern Hemisphere for monthly periods (Oort and Vonder Haar, 1976). Additionally, a well defined annual variation in the global mean net flux of energy with space has been observed from this data 29 month analysis. The theoretical basis for such variation is under study.

2.2 Large-Scale Cloud Effects on the Planetary Radiation Budget

Considerable effort was expended in comparing large scale cloudiness and the planetary radiation budget for climate studies. The objective has been to determine the effects of large scale cloudiness on the planetary radiation budget and to express the results in mean zonal, hemispherical and global analyses.

The first phase of the study looked at the so call·· ·ciprocity" of cloudiness. Regions of clouds are generally brighter and cooler as measured from space than cloudfree regions. As clouds are introduced into an atmospheric column, reflected shortwave flux to space increases as longwave thermal flux decreases. There may be virtually no change in the net radiation flux with space in which case a high degree of reciprocity exists between shortwave and longwave flux with changes in cloudiness. The extent of the reciprocal nature between the two fluxes has been examined by latitude zone, by season and for an annual mean. Nimbus 3 satellite measured flux was the data set from which the results were

computed. The results   presented at the Second Conference on Atmos-
pheric Radiation of the .   :an Meteorological Society, 29-31 October,
1975 (Ellis, 1975). An extended abstract giving specific results ap-
pears in Appendix A.

A second phase of the study to derive climate sensitivity para-
meters from satellite radiation budgets measurements began during the
reporting period. Theoretical and empirical sensitivity of radiation
flux at the top of the atmosphere to effective cloud amount and cloud
height for the mean global atmosphere-earth column have been presented
by Schneider (1972). Parameters which he examined theoretically using
very limited observations can be evaluated from satellite measurements.
Some of the parameters are $\partial F_{IR}/\partial A_C$, $\partial Q_{ABS}/\partial A_C$,and $\partial F_{IR}/\partial T_S$
using his notation with:

$$F_{IR} = \text{longwave thermal flux to space;}$$
$$Q_{ABS} = \text{incoming shortwave absorbed flux;}$$
$$A_C = \text{cloud amount; and}$$
$$T_S = \text{surface temperature.}$$

As in Phase I, Phase II is based on the measurements of Nimbus 3 scanning
medium resolution infrared radiometer (MRIR). It seems that satellite
measurements can now be used to derive information about climate sensiti-
vity to cloudiness changes which has previously been limited mostly to
theoretical and empirical type studies.

2.3 Minimum Albedo

Minimum albedoes, which may be interpreted as nearly cloud-free
albedoes of the earth-atmosphere system, vary both spatially and temporally

and have important applications in a broad range of the atmospheric sciences. Nimbus 3 Medium Resolution Infrared Radiometer (MRIR) data have been analyzed by Vonder Haar and Ellis to yield seasonal minimum albedoes Their results were presented and analyzed in a paper entitled, "Albedo of the Cloud-Free Earth Atmosphere System" (see Appendix B) at the second Conference on Atmospheric Radiation of the American Meteorological Society at Arlington, Virginia, October 30, 1975.

2.4 Diurnal Variation in Cloudiness and the Radiation Budget

The premature failure of the GVHRR onboard the ATS-6 satellite has caused a delay in this study. However, full disk data from the VISSR onboard the SMS satellites which have been archived by W. Shenk and F. Hasler at NASA Goddard Space Flight Center along with sectorized SMS data from White Sands Missile Range will permit this study to continue.

2.5 Arctic Region Energy Budget

North-South transports by the atmosphere into the polar cap of sensible heat, potential energy, latent energy and kinetic energy have been computed from radiosonde (RAOB) data for January-February, 1970 Nimbus 3 data period. This preliminary work gave correct horizontal patterns for the transport terms. However, absolute values of transport terms for each latitude zonal averaged value are very sensitive to the scalar analysis method used in going from RAOB station data to grid point data. The sensitivity is greater than physically-real year-to-year variations in transport terms.

The sensitivity problem can be, to a large extent, circumvented by partitioning transports into mean and eddy terms along with imposing an atmosphere mass balance constrai..t in the polar cap. The amount of data processing time involved is quite large. A. Oort is processing the same atmospheric data set for the transport terms with a partitioning between mean and eddy terms and imposed mass balance. His calculations were not completed during the year but should become available during the next period.

2.6 Ocean Transport

During the year T. Vonder Haar and J. Ellis began cooperating with A. Oort of GFDL, Princeton University, on a study of the required energy transport by the ocean on a seasonal basis (see Vonder Haar and Oort, 1973). The above-mentioned radiation budget statistics (sec. 2.1) are being combined with atmospheric transport statistics from GFDL and an ocean storage term. The work is progressing steadily, and the results should be published during the coming year.

2.7 Tropical Oceanic Precipitation Frequency from Nimbus 5 Microwave Data

Dur+ng the year the first phase of a project to determine tropical oceanic precipitation frequency from the 1.55 cm data of the Nimbus 5 Electrically Scanning Microwave Radiometer (ESMR) was completed.

It had earlier been found that over the ocean ESMR brightness temperatures varied with scan angle in a manner not explainable either as increased path length through the atmosphere nor as changing sea surface emittance (Vonder Haar, 1975). To correct this problem, Pacific Ocean

data from the December-January-February 1972-73 data set shown in Fig. 1 were examined. In each of 104 10^0 latitude-longitude squares the three-month mean brightness temperature was calculated as a function of scan angle for both noon and midnight observations*. Because the brightness temperatures have been corrected by NASA** to eliminate a cross polarization grating lobe, the three-month mean brightness temperature should be independent of scan angle. This not being the case, a correction was developed by calculating the average difference of the mean brightness temperature at scan angle u and mean T_B at nadir. Figure 2a shows the resulting curve for noon observations. An additional correction was added to the midnight data to eliminate a 5.8K bias between noon and midnight brightness temperatures. Figure 2b shows the midnight correction. When these corrections are subtracted from the brightness temperatures on the Calibrated Brightness Temperature Tapes, the three-month mean brightness temperatures over the Pacific Ocean are independent of scan angle and local time.

Precipitation frequencies were derived from the corrected brightness temperatures by means of threshold brightness temperatures. The rainfall rate brightness temperature curves of Wilheit et al. (1975) (Fig. 3) were combined with zonal mean freezing levels (Fig. 4) to yield zonal mean threshold brightness temperatures for the season December-Janaury-February (Fig. 5). The fraction of the observations of the data set in

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*The data for pairs of scan angles were averaged to reduce bulk processing.

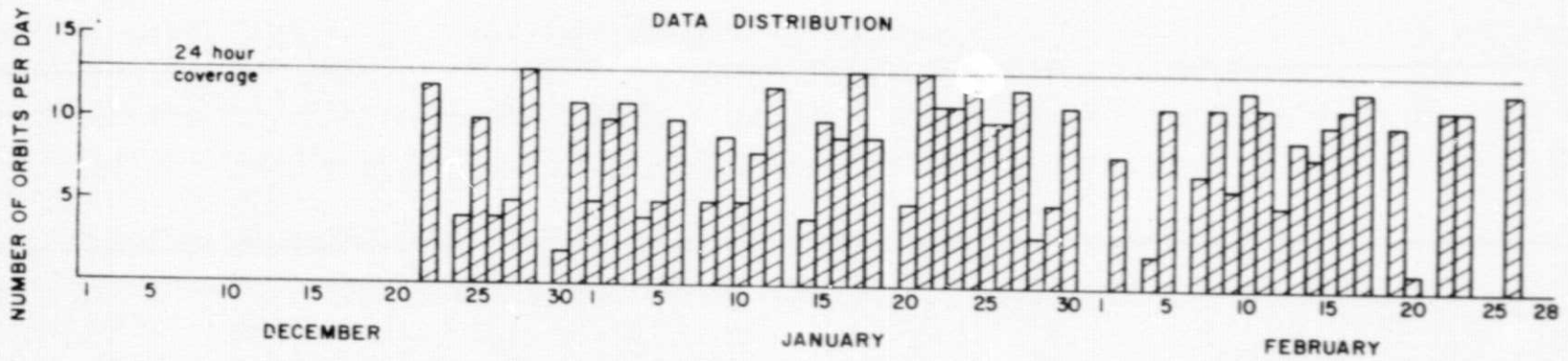**Nimbus 5 data catalog, Vol. 2, p. 5-4.

Figure 1. Distribution of the Nimbus 5 ESMR data used in this study.
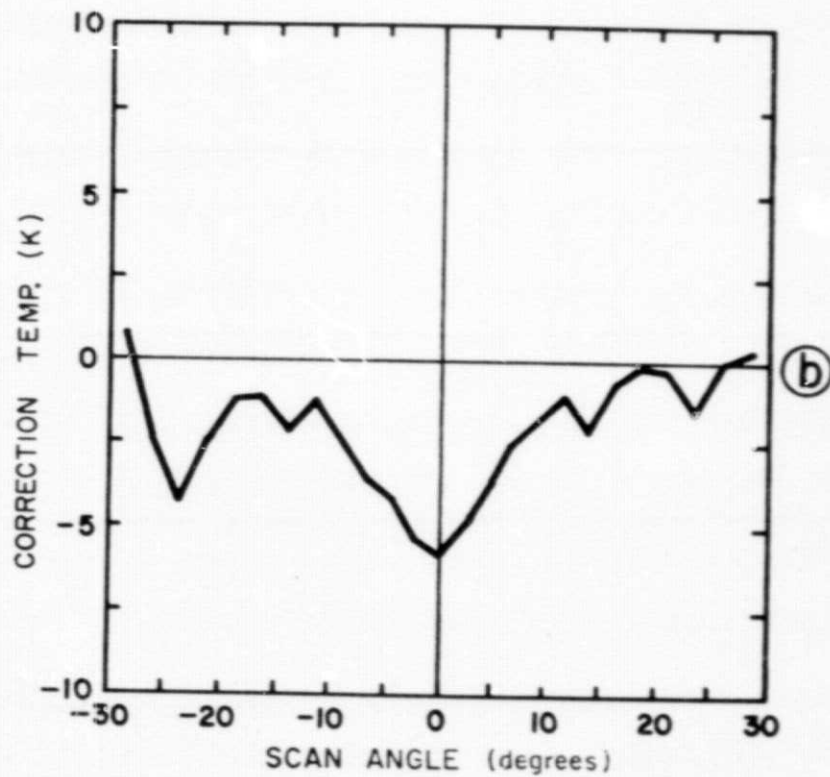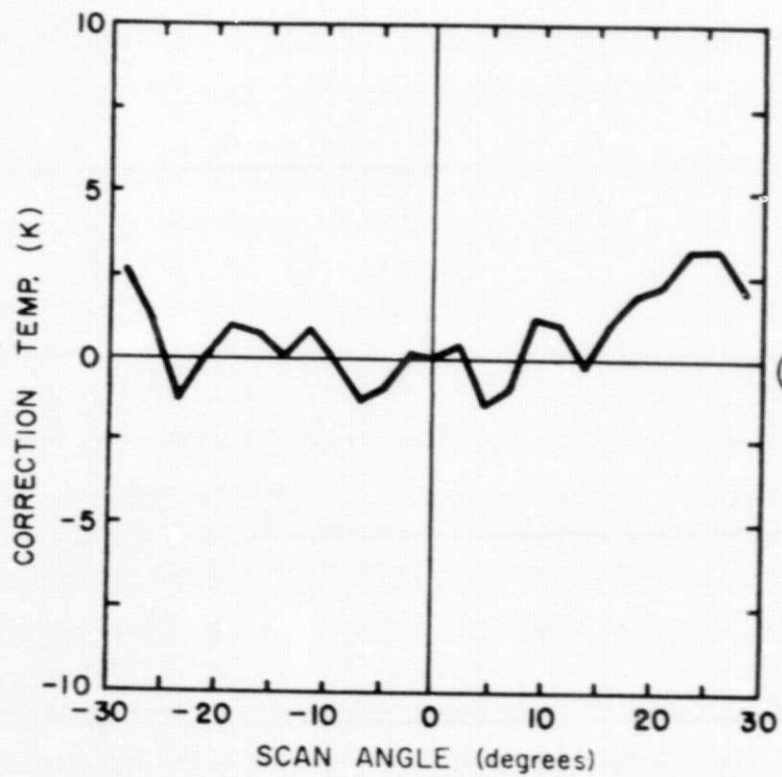
Figure 2. Scan angle correction temperatures, (a) noon correction, (b) midnight correction.
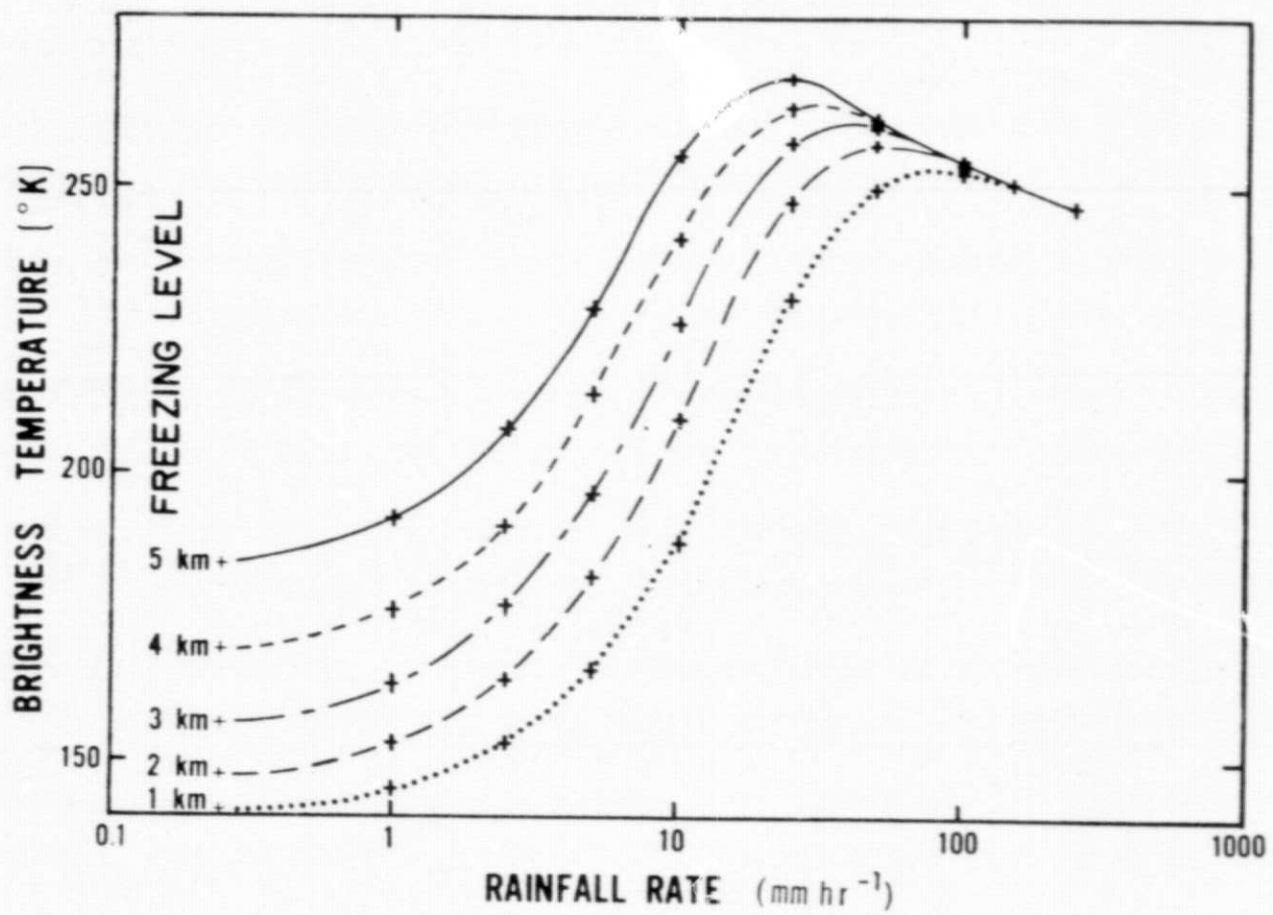
8

Figure 3. 1.55 cm brightness temperature versus rainfall rate.
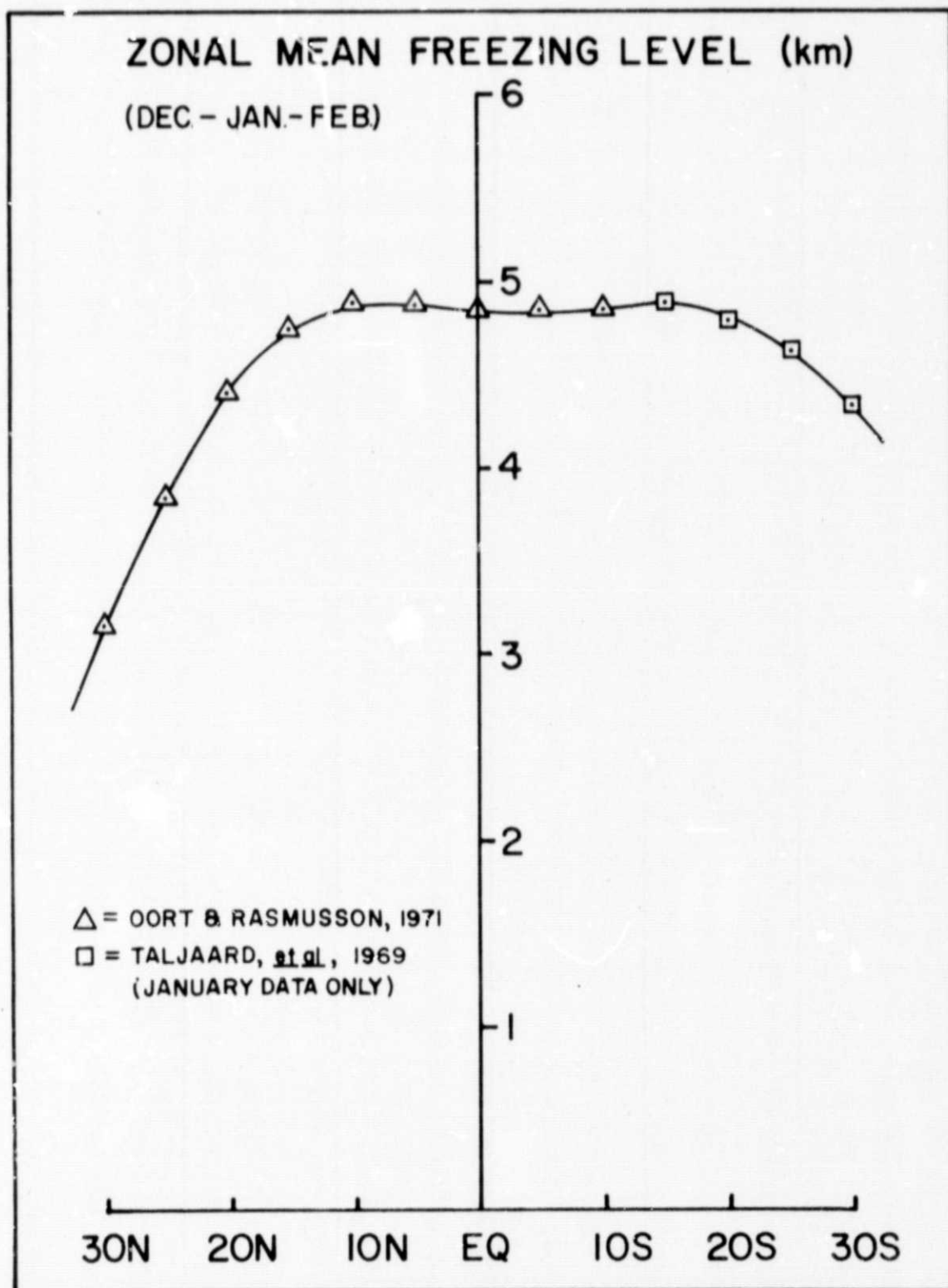(After Wilheit et al., 1975).

Figure 4. Zonal mean freezing levels for the season December-Janaury-February. (After Oort and Rasmussen, 1971 and Taljaard et al., 1969).
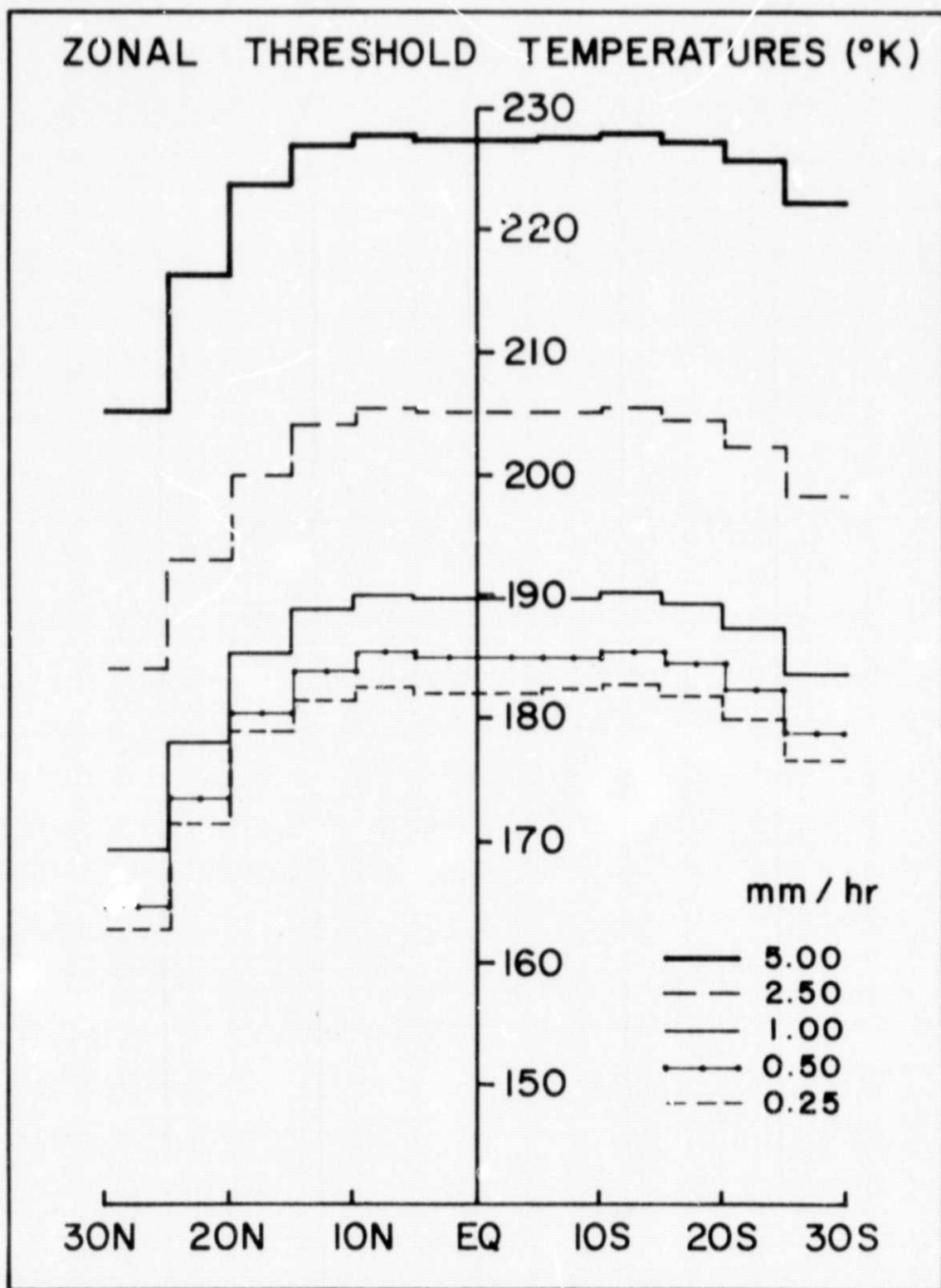
Figure 5. Zonal 1.55 cm threshold brightness temperatures for the detection of oceanic precipitation during the season December-January-February.

Fig. 1 in each 5° latitude-longitude square between 30^ON and 30^OS with brightness temperatures above each of the threshold temperatures was determined. Fig. 6 shows the frequency of any type of precipitation for the season December 1972-February 1973 assuming that the 0.25 mm hr^{-1} threshold temperatures mark the rain/no rain border (noon and midnight frequencies have been averaged).

Some of the important and expected features of Fig. 6 are as follows:

1. dry eastern oceans;

2. narrow convergence bands;

3. splitting of the ITCZ in the Western Pacific.

The high precipitation frequencies in the northwest oceans are probably caused by wind bias (see Wilheit, 1972). Possibly the most interesting feature of Fig. 6 is the position of the mid-Pacific precipitation frequency maximum at approximately 175^OW. McDonald's (1938) climatological maximum precipitation frequency (Fig. 7) is at approximately 165^OE. This eastward shift supports Ramage's (1975) contention that 1972-1973 was an anomolous period under the influence of a strong El Niño.

An interesting clue to the operation of the troposphere is found in the diurnal variation of oceanic precipitation. Although data from this study is available only near local noon and local midnight, an indication of the diurnal variation of precipitation frequency may be obtained. Table 1 shows the ratio of the noon precipitation frequency to the sum of the noon and midnight frequencies averaged over all oceanic areas from 20^ON to 30^OS. These figures may be interpreted as the average fraction of total noon and midnight precipitation events which occur at local noon. The data have been stratified into dry (<5% precipitation frequency)
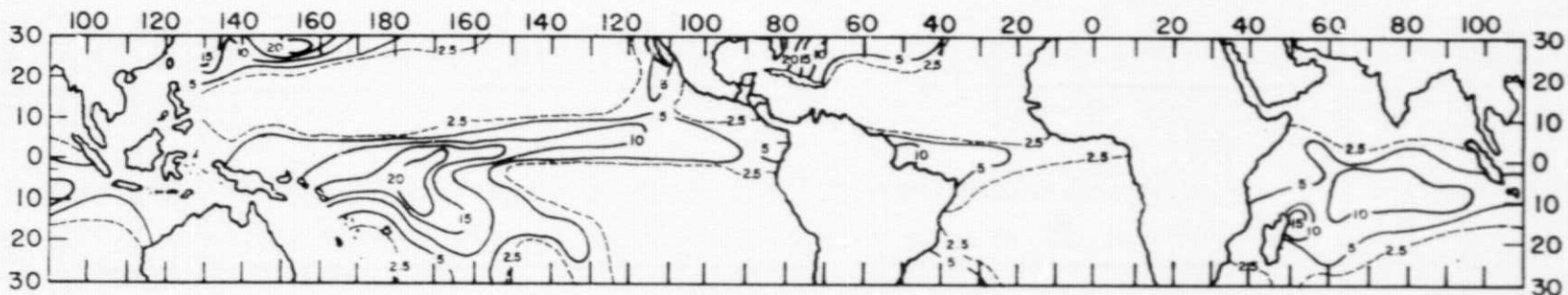
Figure 6. Frequency of precipitation (in percent of observations) for the season December 1972 through February 1973 as derived from Nimbus 5 ESMR data. (The noon and midnight frequencies have been averaged).
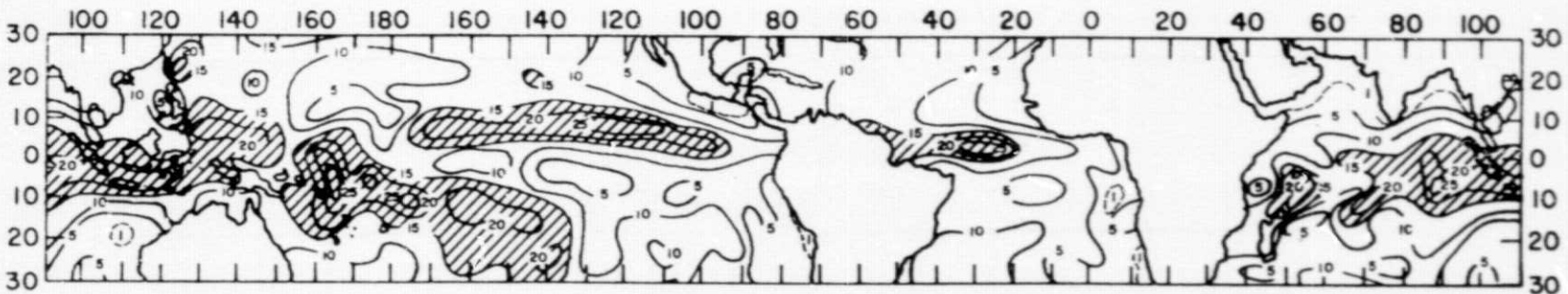
Figure 7. Frequency of precipitation (in percent of observations) for the season December-January-February from ship observations taken at Greenwich noon (After McDonald, 1938).

TABLE 1

FRACTION OF THE TOTAL OF NOON AND MIDNIGHT PRECIPITATION EVENTS
OCCURRING NEAR LOCAL NOON IN OCEANIC REGIONS BETWEEN 20°N AND 30°S

	$\frac{D}{D+N}$ (%)		
RAINFALL CATEGORY	DRY REGIONS (0-5%)*	WET REGIONS (5-100%)*	ALL REGIONS (0-100%)*
Light Rain (0.25-1.0 mm hr^{-1})	47	50	48
Moderate Rain (1.0-2.5 mm hr^{-1})	48	52	49
Heavy Rain (2.5-5.0 mm hr^{-1})	49	54	51
Very Heavy Rain (>5.0 mm hr^{-1})	53	61	57
All Rain	49	52	50

*Precipitation frequencies

and wet (>5%) regions, and into various rainfall rates. There seems to be little difference between noon and midnight precipitation frequencies, as expected (Lavoie, 1963; Jacobson and Gray, 1976) but the heavier rainfall rates tend increasingly to occur near local noon.

These results were presented at the Second Conference on Atmospheric Radiation of the American Meteorological Society at Arlington, Virginia in October 1975. During the next reporting period an expanded version of this study will be published as a CSU Atmospheric Science Paper.

2.8 Mesoscale Applications of Remote Infrared Soundings

A computer algorithm is under development which will provide meso-scale remote satellite soundings from the Vertical Temperature Profile Radiometer (VTPR) on NOAA operational polar-orbiting satellites. The algorithm is expected to provide soundings at every scan spot (every 70 km) for the VTPR using an iterative relaxation formula. As an initial guess in the iteration, a radiosonde sounding which is in close proximity in space and time will be used. It is hoped that the combined use of satellite sounding radiances along with the initial guess radiosonde sounding will provide mesoscale temperature and moisture information with better accuracy than by using satellite soundings alone. The proposed area of study is over the central U.S. The combined satellite-radiosonde data will provide added coverage and resolution over land areas where satellite sounders are not operationally used.

3.0 PROGRAM FOR THE NEXT REPORTING PERIOD

A proposal for the extension of grant research was accepted by NASA for the period 1 November 1975 - 31 October 1976. It outlines in detail plans to apply some of the newer satellite data (SMS-1, 2 and Nimbus 5, 6) to problems in climate and mesoscale weather.

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APPENDIX A

RADIATIVE PROPERTIES OF LARGE SCALE

CLOUDINESS FOR CLIMATE MODELS

by

James S. Ellis

Colorado State University

Satellite radiation budget data, albedo and infrared exitance to space (IR), and cloud cover data are brought together for determining radiative properties of cloudiness on synoptic to global scales. Large scale cloud contribution to albedo and IR of a cloud-free earth-atmosphere system is quantified in daily to monthly time scales using "minimum albedo" technique.

Of particular concern is what is commonly called "reciprocity" of cloudiness in the satellite measured radiation budget of the earth-atmosphere system. By "reciprocity" is meant that decreased clear column absorption in the shortwave part of the spectrum due to cloudiness is offset by a decrease in clear column IR loss to space, i.e., clouds are brighter and cooler than their environment. The degree of reciprocity for individual cloud elements is a function of cloud type, height, thickness, cloud microphysics and the underlying surface.

Winston (1967) showed an inverse correlation between albedo and IR with largest negative correlations over tropical ocean areas. Thus, clouds in the tropics demonstrate a high degree of reciprocity. Budyko (1969) sets global cloud cover to a constant 50% in his semi-empirical climate model. His justification was that variable cloudiness would have minimal effects in the model due to cloud reciprocity.

The radiation properties of large scale cloudiness are important to climate modeling. These properties can now be computed from satellite radiance data.

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Radiative Properties of Large Scale Cloudiness for Climate Models
=======

Cloudiness has an effect on the energy exchange between earth and space. Theoretical studies by others have shown possible magnitudes of this effect. Results derived from earth-atmosphere radiation budget measurements of the Nimbus-3 MRIR experiment show us this magnitude in annual to seasonal mean time scales.

Minimum albedoes and maximum infrared exitance to space, which nearly represent cloud free conditions, were computed from the Nimbus-3 MRIR data set for the periods May 1-15, July 16-31, October 3-17, 1969 and January 21-February 3, 1970. Some residual cloudiness was not removed by this technique. Differences between cloud free and cloudy net radiation budgets represent cloud effects on the exchange of energy between earth and space. The attached figure shows a zonally averaged net radiation budget difference profile for the annual case which was computed from the four individual semi-monthly periods. By averaging this profile over all latitude zones, one gets a global value of approximately -20 watts/meter^2. Thus, clouds reduce the energy available to a globally averaged earth-atmosphere column by about 20 w/m^2 on an annual basis. Large variability exists in this cloud effect with latitude and season of the year. The range in seasonal values (not shown here) is largest in near polar regions varying between a few positive w/m^2 to a negative 65 w/m^2. These results will aid in quantitatively understanding cloud effects in the earth's radiation budget and they will augment future efforts on cloud parameterization for climate simulation and model validation.

ANNUAL NET (CLOUDY - CLOUD FREE)
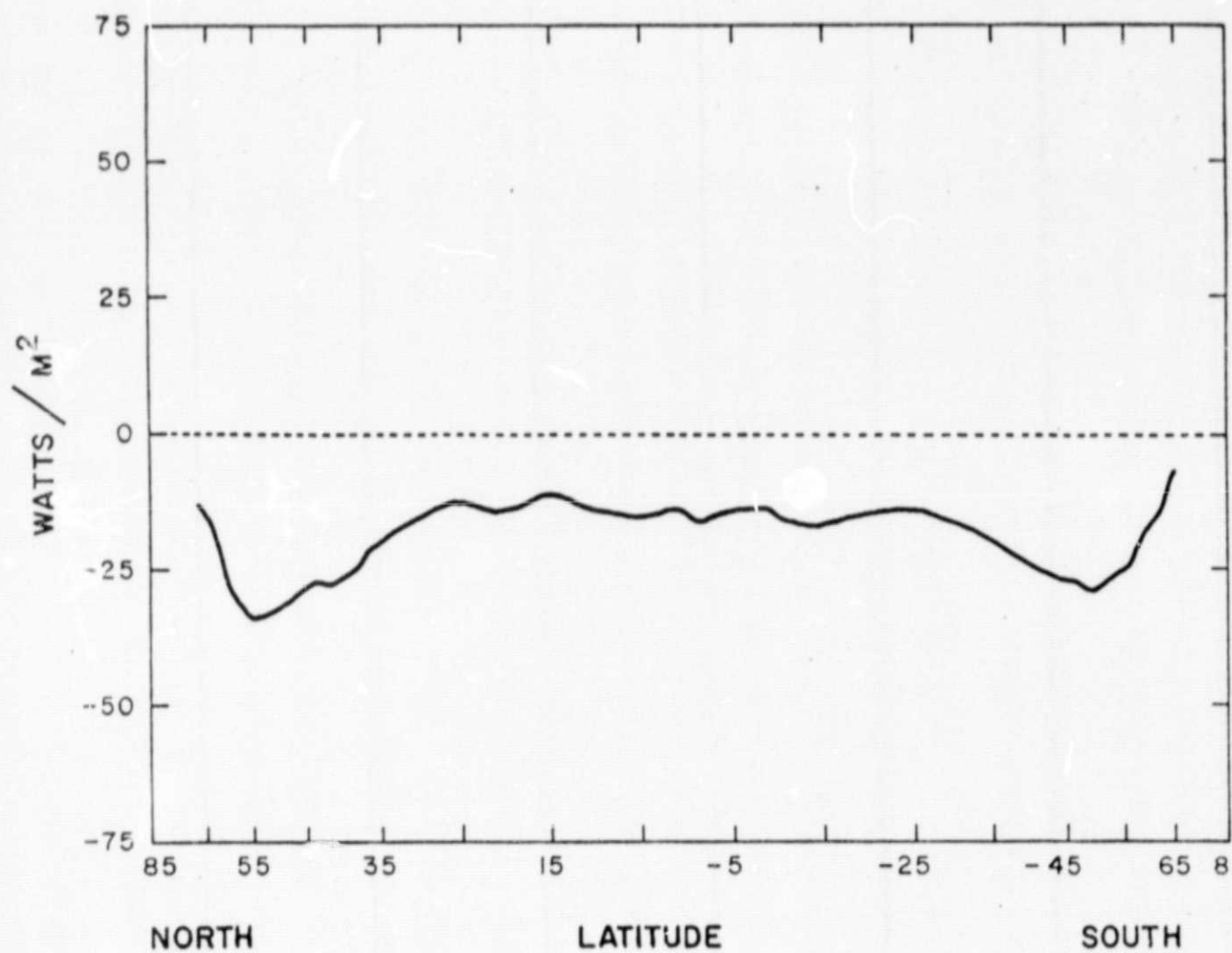
APPENDIX B

ALBEDO OF THE CLOUD-FREE EARTH-ATMOSPHERE SYSTEM

by

T.H. Vonder Haar and J. Ellis
Colorado State University, Ft. Collins 80521

Measurements of the cloud-free albedo of the earth-atmosphere system have application to weather forecast models, climate and global circulation models, regional and global energetic studies, and for assessing both natural changes to and man's impact on his environment. A set of nearly cloud-free albedo data are now available for 10 semi-monthly periods on a regiona! to global spatial scale. These albedoes are more properly called "minimum albedoes" after the technique applied in obtaining them.

Minimum albedoes were determined at a ground resolution of 250 to 500 km in one dimension from reflectance measurements taken by a medium resolution infrared radiometer (MRIR) on the Nimbus 3 polar orbiting satellite. Daily average reflected solar radiation in the 0.2 to 4.0μm spectral interval were computed by Raschke et al. (1973) by applying anisotropic bidirectional reflectance corrections to radiance data and integrating over length of a day. From daily average reflected radiation, albedo was calculated. Minimum albedo is obtained by selecting a smallest albedo value at each horizontal grid area over a specified time period, i.e., approximately 15 day periods.

These data are a first order approximation to the earth's surface albedo. Variations in atmospheric transmission due to molecular and particle scattering and absorption, and some residual cloudiness suggest that minimum albedo determined from satellite data is not quite the earth's surface albedo. However, to a second order approximation, minimum albedo is a cloud free albedo. Some residual cloudiness of a very persistent nature and sub-resolution tropical "popcorn" cumulus may not have been completely eliminated by the minimum albedo process.

Analysis of these data in the present study yields minimum albedo approximating an annual average from four semi-monthly periods in figure 1. This shows the continents to be bright relative to the oceans as expected. The polar ice caps are well defined. In all, there are no very bright areas over the oceans indicating a significant amount of residual cloudiness not having been removed.

The data have also been stratified into various groups representing different types of vegetation and then compared to earlier low flying aircraft measurements of albedo by King et al. (1964). This comparison for the North American continent is shown in Table 1; their work is enclosed in parenthesis; snow covered surfaces are indicated with an asterisk. For snow free surfaces the two different albedo sets are in good agreement. There appears to be a tendency for minimum albedo data of the present study to be systematically higher than the aircraft data, i.e., broadleaf deciduous forest, prairies and steppe are 1 to 2% higher

and desert is 2 to 3% higher. Since minimum albedo appears systematically larger, the data can be adjusted for effects of the intermediate atmosphere, (presently underway).

Since Nimbus 3 minimum albedo have better spatial integrity in the continental to global scale than any previous work, and are comparable to earlier work of Kung et al. (1964) over North America, they should be considered the best to date representation of earth surface albedo for other continental areas. The african continent is of special interest.

In figure 2 the annual average zonal albedo for the earth from 17 seasons of measurement (Vonder Haar, 1972) is shown in the upper curve while the lower curve is the measured cloud-free (minimum) albedo. It is obvious that clouds are very important to the earth's total planetary albedo. The extent to which clouds contribute to earth's albedo above what would exist without clouds is evidenced by tables 2 and 3. Table 2 shows the albedo and the cloud-free albedo (in parenthesis) for the northern and southern hemispheres and globe for various seasons and a year. Similarly constructed, table 3 shows the difference between albedo and cloud-free albedo. As evident from table 2, the earth, as a planet, is brighter in the northern hemisphere spring season than any other season. However, a cloud-free globe is brightest in the northern hemisphere continents due to snow and a return of sun light to the south polar cap during southern hemisphere summer.

Cloud contribution to albedo above what would exist with no cloud is shown in difference table 3. Obvious from the table is that southern hemisphere cloud albedo contributes more to that hemisphere's albedo in all seasons than do clouds in the northern hemisphere. It is sometimes noted that the southern hemisphere is more cloudy than the northern hemisphere. For the same period, infrared radiant exitance to space is about 3% less in the southern hemisphere, which certainly agrees with more cloudiness and the elevated cold antarctic continent.

Additionally, cloudiness increases global planetary albedo in the annual average by about 11% (from 18% to 29%). Clouds have the direct effect of reducing the radiative equilibrium temperature of the globe from a cloud-free 264°K to a cloudy 255°K.

In summary, cloud-free albedoes can be determined from satellites; from these data information can be obtained about both surface conditions and atmospheric cloudiness. Results are applicable to studies of atmospheric variability and climate change within the earth-atmosphere system.

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TABLE 1: ALBEDO STRATIFIED BY VEGETATION FROM NIMBUS 3 MINIMUM ALBEDO

	TUNDRA	MT. CONIFER FOREST	PRAIRIE/ GRASSLAND	STEPPE/ DRY GRASSLAND	DESERT/ SHRUBLAND	BROADLEAF DECIDUOUS FOREST
			15-30 APRIL 1969 (14-17 APRIL 1963)			
RANGE	50-54* (67-83)*	30-62* (58)*	17-21 (17-19)	17-22	19-23 (19-25)	14-18
AVERAGE	54*	33-38* 14-16 (14)	18	17-19 NORTH 20-22 SOUTH (21-23)	21-22	15-17 (16-17)
			1-15 JULY 1969 (28 JUNE - 3 JULY 1963)			
RANGE	14-27	13-26	16-18	16-21	16-24 (15-25)	14-21
AVERAGE	15-17	13-15	17	16-17 NORTH (14-18) 18-20 SOUTH (17-19)	22 (17)	(14-16)
			3-17 OCTOBER 1969 (5-10 SEPTEMBER 1963)			
RANGE	58* NORTH 19 SOUTH	14-59*	18-36*	52* NORTH 21 SOUTH	18-22 (21-27)	16-23
AVERAGE			21 NORTH (16-18) 18 SOUTH	(19-22)	20	16-18 (14-16)
	MISSING		21 JANUARY - 3 FEBRUARY 1970 (17 MARCH 1963)			
RANGE	(60-83)*	36-87* (59-67)*	64* NORTH 19 SOUTH	70* NORTH 22 SOUTH	41* NORTH (17-26)*	45* (20-40)*
AVERAGE			(50-53)* (15-18)	(65)* (19-22)	20 SOUTH 22-23 (19-20)	19 (13-17)

*snow covered surface

( ) data of Kung et al. (1964)

TABLE 2   Albedo and Minimum Albedo Nimbus 3 data

	N.H.	S.H.	G
MAM	30.2(19.3)	26.9(13.9)	29.1(17.4)
JJA	29.0(18.1)	26.1(14.6)	28.1(17.0)
SON	27.0(17.5)	29.1(17.7)	28.2(17.7)
DJF	27.3(19.1)	28.7(18.3)	28.3(18.6)
ANNUAL	28.7(18.3)	28.2(17.1)	28.5(17.7)

TABLE 3   Difference Between Albedo and Minimum Albedo

	N.H.	S.H.	G
MAM	10.9	13.0	11.7
JJA	10.9	11.5	11.1
SON	9.5	11.4	10.5
DJF	8.2	10.4	9.7
ANNUAL	10.4	11.1	10.8
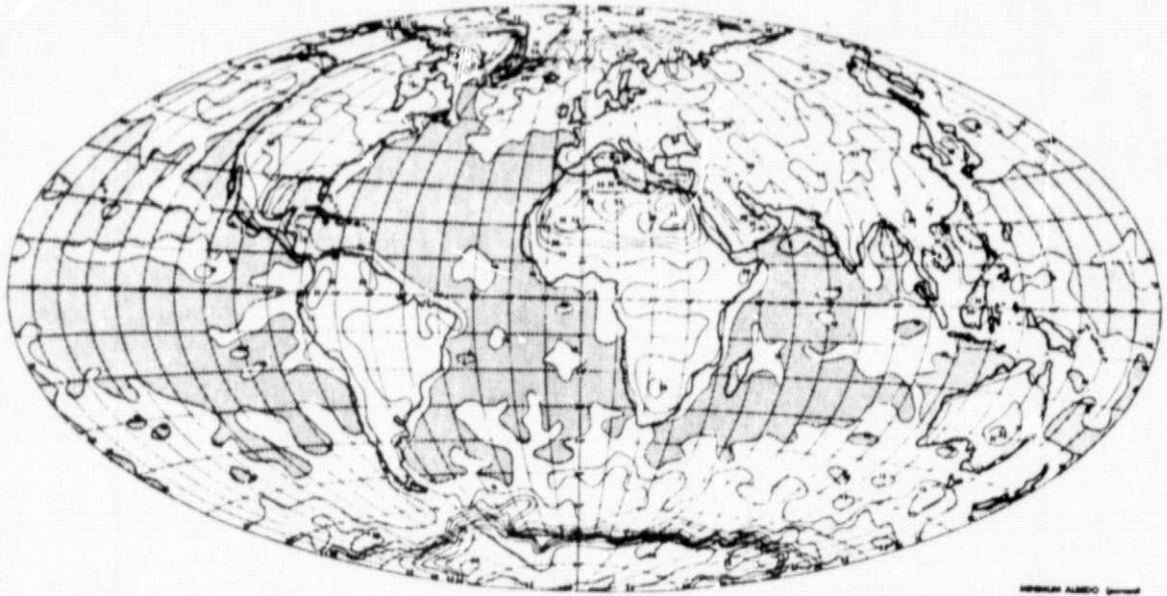
Figure 1
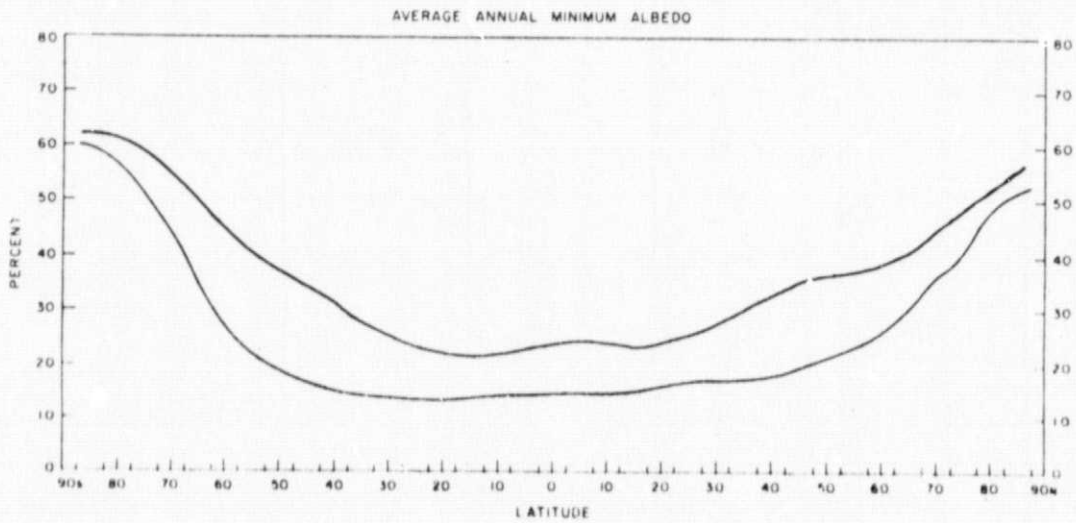
Figure 2

APPENDIX C: Papers and Publications Sponsored by Grant NGR 06-002-102

Vonder Haar, T., E. Raschke, M. Pasternak and W. Bandeen, 1971: Global
    measurements of energy exchange between earth and space during the
    1960's including latest results from the Nimbus-III satellite.
    Paper presented at the Annual Meeting of the AMS, San Francisco.

Raschke, E., T. Vonder Haar, W. Bandeen and M. Pasternak, 1971: The
    radiation balance of the earth-atmosphere system during June and
    July, 1969, from Nimbus-III radiation measurements. Space Research
    XI, Akademie-Verlag, pp. 661-667.

Vonder Haar, T., E. Raschke, M. Pasternak and W. Bandeen, 1971: Measure-
    ments of solar energy reflected by the earth and atmosphere from
    meteorological satellite . Invited paper presented at the Inter-
    national Solar Energy Society Conf., Greenbelt, MD. Solar Energy,
    14,2.

Raschke, E. and T. Vonder Haar, 1971: Climatological studies of the
    earth's radiation budget and its variability with measurements of
    the satellite Nimbus-III. Presented at the Symposium on Physical
    and Dynamical Climatology, Leningrad.

Vonder Haar, T., 1971: Global radiation budget and cloud cover by satel-
    lite measurements. Presented at the Remote Sensing Workshop, Miami.

Vonder Haar, T., E. Raschke, M. Pasternak and W. Bandeen, 1972: The
    radiation budget of the earth-atmosphere system as measured from
    the Nimbus-III satellite (1969-70). Presented at the XIV meeting
    of COSPAR, Seattle. Space Research XII.

Vonder Haar, T. and E. Raschke, 1972: Measurements of energy exchange
    between earth and space from satellites during the 1960's. Atmos-
    pheric Science Paper no. 184, Colorado State Univ., Ft. Collins.

Downey, P., S. Lassman and T. Vonder Haar, 1972: A study of extreme and
    persistent cloudiness based on satellite observations (1969-70).
    Tech. Report, Dept. of Atmos. Sci., Colorado State U., Ft. Collins.

Vonder Haar, T., 1972: Natural variation of the radiation budget of the
    earth-atmosphere system as measured from satellites. Paper presented
    at the Intern. Radia. Symp., Sendii, Japan, May. Also presented at
    the Conf. on Atmos. Rad., sponsored by AMS, Ft. Collins.

Korff, H. and T. Vonder Haar, 1972: The albedo of snow in relation to
    the sun position. Presented at the Conf. on Atmos. Rad., sponsored
    by AMS, Ft. Collins, Aug.

Raschke, E., T. Vonder Haar, M. Pasternak and W. Bandeen, 1973: The
    radiation balance of the earth-atmosphere system from Nimbus-3
    radiation measurements. NASA Tech. Note.

Downey, P., 1972: Distribution and parameterization of absorption of solar radiation in the atmosphere. M.S. thesis, Colorado State Univ., Ft. Collins, August.

Ellis, J., 1972: Interannual variations in the earth's radiative budget and the general circulation. M.S. thesis, Colorado State U., Ft. Collins, August.

Dittberner, G. and T. Vonder Haar, 1973: Large-scale precipitation estimated using satellite data; application to the Indian monsoon. Archiv fur Meteor, Geophysik and Bioclimat., Ser. B., 21.

Vonder Haar, T., 1973: Measurements of the planetary albedo from satellites. Presented at the Smithsonian Symp. on Solar Radiation Meas. and Instrumentation. Rockville, MD., Nov.

Vonder Haar, T., 1973: Global heat balance. Presented to the Joint Session of Radiometry and Photometry and Atmospheric Optics Tech. Groups, 1973 meeting of the Optical Society of America, Denver, CO.

Vonder Haar, T., 1973: Satellite observations of the earth's energy budget. Presented at the 1973 National Center for Atmospheric Res. Summer Climate Meeting, Boulder, CO

Vonder Haar, T., 1973: Measurement of albedo over polar snow and ice fields using Nimbus 3 satellite data. Presented at the Interdisciplinary Symposium on the Study of Snow and Ice Resources, Monterey, CA.

Vonder Haar, T. and A. Oort, 1973: New estimate of annual poleward energy transport by northern hemisphere oceans. J. Phys. Ocean., 3, 169-172.

Raschke, E., T. Vonder Haar, W. Bandeen and M. Pasternak, 1973: The annual radiation balance of the earth-atmosphere system during 1969-70 from Nimbus 3 measurements. J. Atmos. Sci., 30, 3, 341-364.

Vonder Haar, T. and J. Ellis, 1974: Satellite measurements of the interannual variations of the equator-to-pole radiation gradient, the effect of clouds and the response of the large-scale circulation. Presented at the 1st IAMAP Special Assembly, Melbourne, Australia.

Vonder Haar, T. and J. Ellis, 1974: Atlas of radiation budget measurements from satellites (1962-1970). Colorado State Univ. Atmos. Sci. Paper No. 231, Ft. Collins.

Ellis, J.S., 1975: Radiative properties of large scale cloudiness for climate models. Presented at the Second Conf. on Atmos. Radia. of the AMS, Arlington, VA., Oct.

Vonder Haar, T. and J. Ellis, 1975: Albedo of the cloud-free earth-
    atmosphere system. Presented at the Second Conf. on Atmos. Rad.
    of the AMS, Arlington, VA., Oct.

Kidder, S. and T. Vonder Haar, 1975: Day-night variation of oceanic
    precipitation frequency inferred from Nimbus 5 electrically scanning
    microwave radiometer data for December 1972-February 1973. Presented
    at the Second Conf. on Atmos. Radia. of the AMS, Arlington, VA., Oct.

Vonder Haar, T. and J. Ellis, 1975: Satellite radiation budget data
    applied to climate studies. Presented at the Intern. Union of
    Geophysics and Geodesy Conf., Grenoble, Aug., 1975: