VOL. 82, NO. 15 JOURNAL OF GEOPHYSICAL RESEARCH MAY 20, 1977

Seasonal Oceanic Precipitation Frequencies From Nimbus 5 Microwave Data

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Microwave brightness temperature data from the Nimbus 5 satellite have been analyzed by using threshold brightness temperatures to yield tropical oceanic precipitation frequencies for several classes of rainfall rates during the season December 1972 through February 1973. Data taken near local noon and near local midnight were analyzed. The overall results are consistent with both climatological precipitation frequency and with concurrent satellite-derived frequency of highly reflective clouds. The difference between the local noon and the local midnight frequency is small, but the heavier rainfall rates tend to occur more frequently near local noon. The ratios of the frequencies of light, moderate, and heavy rain were observed to be relatively constant over the tropical oceans. Passive microwave measurements from space seem to be an important step toward accurate measurement of oceanic precipitation.

INTRODUCTION

Knowledge of oceanic precipitation is of fundamental importance to meteorology. Approximately 80% of the earth's precipitation falls in the ocean [*Sellers*, 1965], where fewer than 10% of the world's weather stations exist. Yet latent heat released over the ocean plays a major role in the maintenance of the general circulation and affects almost everything known as 'weather.'

Many ingenious attempts to determine oceanic precipitation from surface observations have been made [e.g., *McDonald*, 1938; *Tucker*, 1961; *Jacobs*, 1968; *Allison et al.*, 1969], but such observations have not the spatial nor temporal resolution necessary for accurate measurement of anything except long-term climatological precipitation. Satellite data offer much better resolution, but until the launch of Cosmos 243 in 1968 and Nimbus 5 in 1972, all satellite data were from the visible or infrared portions of the electromagnetic spectrum in which precipitation cannot be observed directly because of the opacity of clouds. (See *Martin and Scherer* [1973] and *Dittberner and Vonder Haar* [1973] for a review of precipitation estimation techniques using visible and infrared satellite data.)

Several authors have shown the usefulness of microwave imagery from the Nimbus 5 electrically scanning microwave radiometer (ESMR) in depicting oceanic precipitation zones [*Theon*, 1973; *Sabatini and Merritt*, 1973; *Allison et al.*, 1974*a*, *b*; *Wilheit et al.*, 1976]. The present study uses Nimbus 5 ESMR data to infer tropical oceanic precipitation frequencies for the season December 1972 through February 1973. This approach is a first step toward measuring seasonal precipitation amounts, and the results may be of interest to modelers of the general circulation.

THE RADIOMETER

Nimbus 5 is a sun synchronous satellite which crosses the equator at 1130 and 2330 LT and has an orbital period of 107 min. The ESMR receives radiation in a 250-MHz band centered at 19.35 GHz (1.55 cm), with a noise equivalent temperature difference of approximately 2 K. The antenna electrically scans across the spacecraft track from 50° left to 50° right in 78 steps every 4 s. In this study, only data within 30° of nadir were used. The radiometer half-power resolution is 25 × 25 km at nadir and degrades to 42 km crosstrack by 30 km downtrack at 30° from nadir.

In the course of this study it was found that the ESMR brightness temperatures vary with scan angle in a manner not explainable as increased path length through the atmosphere or as variation of the sea surface emissivity. Also, a small offset between noon and midnight data was found. Additive corrections, amounting to at most 6 K, were developed by requiring the 3-month mean brightness temperature over nonraining areas of the Pacific Ocean to be independent of scan angle and local time [*Kidder*, 1976].

MICROWAVE DETECTION OF OCEANIC PRECIPITATION

Because the physics of the transfer of microwave radiation through the atmosphere has been described in detail elsewhere [e.g., *Wilheit*, 1972], only a brief summary will be given here. The 19.35-GHz brightness temperature of the ocean surface (emissivity 0.4) is approximately 120 K, which is colder than any thermodynamic temperatures encountered in the atmosphere. The active constituents of an atmospheric column (oxygen, water vapor, and liquid water) over the ocean are therefore seen in emission; they add to the upwelling radiation stream in the normal process of absorption and reemission. A nonraining atmospheric column, however, is more than 96% transparent; thus it adds only a small amount to the satellite-observed brightness temperature, which ranges from 125 to 175 K over the ocean in the absence of precipitation. Raindrops, which are comparable in size to the 1.55-cm ESMR wavelength, interact strongly with microwave radiation and rapidly increase the brightness temperature of an atmospheric column over the ocean. *Wilheit et al.* [1975] have done preliminary calculations of the 19.35-GHz brightness temperature as a function of rainfall rate and freezing level (Figure 1). Comparisons between radar data and ESMR data and between ground-based radiometer data and rain gage data indicate that these curves are accurate to within a factor of 2.

In this study, zonal mean freezing levels [*Oort and Rasmusson*, 1971; *Taljaard et al.*, 1969] were combined with the curves of Figure 1 to obtain zonal threshold brightness temperatures for the detection of precipitation during the season December–February (Figure 2). Brightness temperatures corresponding to the 0.25 mm h^{-1} rainfall rate were selected as thresholds to differentiate raining from nonraining observations on the basis that the curves of Figure 1 become relatively flat at 0.25 mm h^{-1}. The use of a threshold temperature to detect precipitation has several problems; among them are that (1) precipitating areas which do not fill the beam (500 km² at nadir) may

Paper number 7C0054.

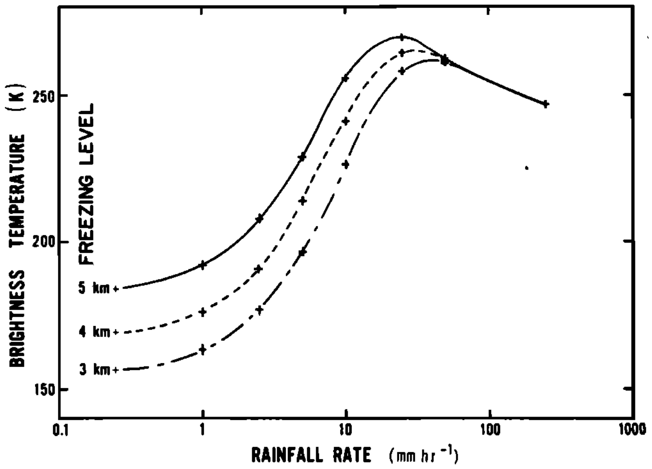

Fig. 1. Theoretical satellite-observed 19.35-GHz brightness temperature versus rainfall rate [after *Wilheit et al.*, 1975].

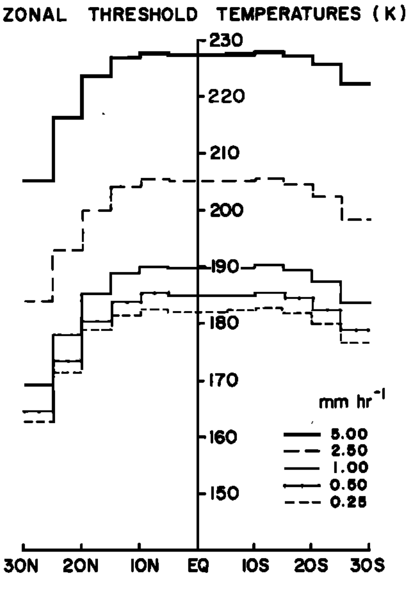

Fig. 2. Zonal 19.35-GHz threshold brightness temperatures for the detection of oceanic precipitation during the season December–February.

not be detected and (2) local atmospheric and surface conditions may deviate from those used to calculate the brightness temperature versus rainfall rate curves. However, comparison of radar data and ESMR data shows that the 170 K brightness temperature contour (which corresponds to a 0.25 mm h^{-1} rainfall rate when the freezing level is 4 km) closely follows the radar echo [*Allison et al.*, 1974*a*].

DATA ANALYSIS AND RESULTS

Data from the period December 22, 1972, through February 26, 1973, were stratified by position (5° latitude-longitude squares) and local time. The data in each category were first corrected for scan angle, and then the fraction of the observations above each of the brightness temperature thresholds was calculated. Figure 3 shows the fraction of observations above the 0.25 mm h^{-1} threshold, which may be interpreted as the frequency of precipitation regardless of intensity. Noon and midnight frequencies have been averaged. Figure 4 shows, for comparison, the precipitation frequencies of *McDonald* [1938] compiled from ship observations.

The microwave precipitation frequencies reproduce the expected general pattern: (1) narrow convergence bands, (2) dry eastern oceans, and (3) the splitting of the ITCZ in the mid-Pacific. The precipitation frequencies in the northwest oceans may be biased upward by the more frequent occurrence of strong winds in those areas [*McDonald*, 1938]. Strong winds, by forming foam on the sea surface, increase the surface emissivity and thus the observed brightness temperature [*Nordberg et al.*, 1971].

The microwave precipitation frequencies are generally lower than those of McDonald, and the mid-Pacific precipitation maximum seems to be about 20° further west. These findings are in agreement with *Ramage* [1975], who in his study of the 1972–1973 El Niño found that the frequency of highly reflective clouds was generally less in December 1972 than in the more normal period of December 1971 and that the position of maximum cloudiness had shifted westward in December 1972.

Figures 5–7, showing the frequencies of light (0.25–1.0 mm h^{-1}), moderate (1.0–2.5 mm h^{-1}), and heavy (>2.5 mm h^{-1}) precipitation, indicate that the ratios of the frequencies in these categories do not vary appreciably over the tropical ocean.

Finally, an indication of the diurnal variation of precipitation frequency was obtained by comparing the noon and midnight frequencies. Table 1, showing the percentage of the total of noon and midnight precipitation events occurring near

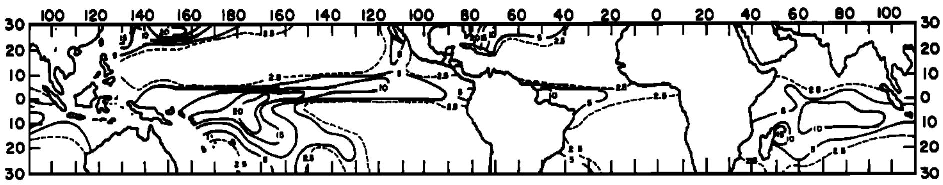

Fig. 3. Frequency of precipitation (in percent of observations) for the season December 1972 through February 1973 as derived from Nimbus 5 ESMR data. The noon and midnight observations have been averaged.

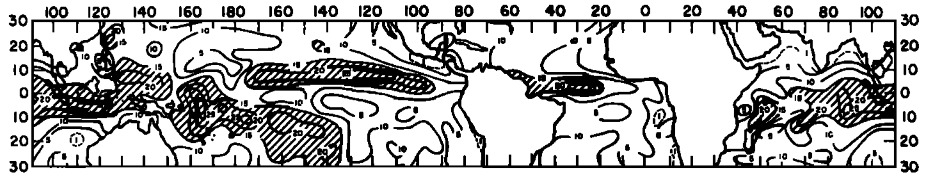

Fig. 4. Frequency of precipitation (in percent of observations) for the season December–February from ship observations taken at noon, universal time [after *McDonald*, 1938].

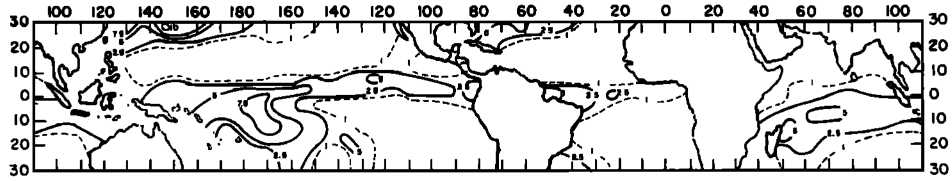

Fig. 5. Same as in Figure 3 except for frequency of light precipitation (0.25–1.0 mm h^{-1}).

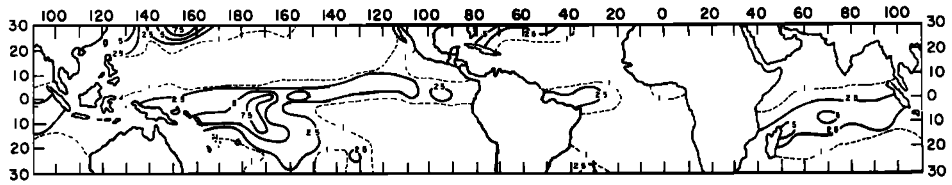

Fig. 6. Same as in Figure 3 except for frequency of moderate precipitation (1.0–2.5 mm h^{-1}).

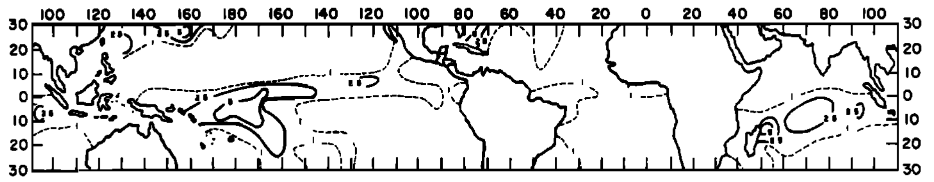

Fig. 7. Same as in Figure 3 except for frequency of heavy precipitation (>2.5 mm h^{-1})

TABLE 1. Percentage of the Total of Noon and Midnight Precipitation Events Occurring near Local Noon in Oceanic Regions Between 20°N and 30°S During the Season December 1972 through February 1973

Rainfall Category, mm h^{-1}	Precipitation Frequencies: Dry Regions (0–5%)	Wet Regions (5–100%)	All Regions (0–100%)
Light (0.25–1.0)	47	50	48
Moderate (1.0–2.5)	48	52	49
Heavy (2.5–5.0)	49	54	51
Very heavy (>5.0)	53	61	57
All rain	49	52	50

local noon in oceanic regions between 20°N and 30°S, indicates that there is little difference between noon and midnight precipitation frequencies. Although a diurnal variation of tropical oceanic precipitation with an early morning maximum and a late afternoon minimum has been observed, little difference is to be expected between noon and midnight frequencies [*Lavoie*, 1963; *Jacobson and Gray*, 1976]. However, the increasing tendency, shown in Table 1, for the heavier precipitation events to occur near local noon supports the early morning maximum.

CONCLUSIONS

Nimbus 5 ESMR data have yielded reasonable seasonal precipitation frequencies over the tropical oceans by use of preliminary calibration curves. Other investigators are working on obtaining oceanic precipitation amounts [*Rao et al.*, 1976] and on improving the calibration curves. Soon we will be able to accurately measure this important atmospheric parameter and its interannual variation.

Acknowledgments. This research was sponsored by the National Aeronautics and Space Administration under grant NGR-06-002-102. Acknowledgment is also made to the National Center for Atmospheric Research, which is sponsored by the National Science Foundation, for the computing time used in this research.

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(Received September 24, 1976;
revised January 17, 1977;
accepted January 17, 1977.)