New Features of Global Climatology Revealed by Satellite-Derived Oceanic Rainfall Maps

Abstract

Analysis of satellite-derived oceanic rainfall maps reveals certain distinctive characteristics of global patterns for the years 1973-74. The main ones are: 1) the forking of the Intertropical Convergence Zone in the Pacific, 2) a previously unrecognized rain area in the South Atlantic, 3) the bimodal behavior of rain belts in the Indian Ocean, and 4) the large interannual variability in oceanic rainfall. These interesting features are discussed.

1. Introduction

Based upon the selective response to liquid water in the atmosphere of the Electrically Scanning Microwave Radiometer (ESMR), quantitative rainfall maps over the oceanic areas of the globe were derived from the Nimbus-5 satellite ESMR data. Weekly, monthly, seasonally, and annually averaged maps for the period December 1972 through February 1975 were published in the form of an atlas (Rao et al., 1976).1 The method adopted to obtain rainfall values from satellite observations and the degree of reliability of the values (in their absolute and relative senses) are discussed fully in that publication and by Wilheit et al. (1977).

Several interesting aspects of global climatology are disclosed from a study of these maps. The objective of this contribution is to describe briefly four outstanding features: 1) characteristics of the Intertropical Convergence Zone (ITCZ) in the Pacific, 2) a previously unrecognized rain area in the South Atlantic, 3) the bimodal behavior of rain belts in the Indian Ocean, and 4) interannual variation.

1 The figures in this paper are extracted from the Atlas. The number inside each 4° latitude by 5° longitude grid cell in the maps represents the average rain rate (in millimeters per hour) over the area of the grid cell for the period indicated.

Fig. 1. ESMR-derived global oceanic average rainfall rate for June 1973, illustrating the forking of the ITCZ.

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2. Characteristics of the ITCZ in the Pacific

Although it has been known for some time that there is a dry zone near the Gilbert Islands in the Pacific (mean position 1°S, 174°E) flanked by wet regions to the north and south (Seelye, 1950), the precise structure of the ITCZ in the Pacific has remained obscure. Extensive observations of tropical cloudiness, such as those compiled by the U.S. Department of Commerce and the U.S. Air Force (1971) and by Sadler et al. (1976), provide useful information on the extent to which reliance can be placed on the relationship between cloudiness and rainfall. Furthermore, the mean monthly rainfall maps, based on island observations, drawn up by Taylor (1973) indicate a maximum along both hemispheres with a minimum along the equator. However, it should be remembered that island reports are not necessarily representative of the surrounding ocean because: 1) there are vast oceanic areas where there are few islands, and 2) even in regions with a fair number of islands, orographic effects modify air flow. Rainfall values derived from the ESMR system throw further light on the rain pattern, not only because of the more complete coverage provided by the satellite but also because of the direct approach in estimation. From the typical ESMR-derived oceanic rainfall map shown in Fig. 1, it is seen that as we move eastward along the equator in the Pacific, the rain belt of the ITCZ bifurcates in the neighborhood of 170°E; the upper branch proceeds eastward, maintaining itself slightly north of the equator, whereas the lower branch runs east or southeastward and merges with the southern Pacific rain zone (path of storms) in the vicinity of 160°W. This feature is also discernible in the annual average rainfall map for 1974 presented on the cover.

From the quantitative observations of rainfall over the oceans (derived from ESMR), zonally averaged rainfall rates were computed separately for each of the three major oceanic areas of the world, viz., the Pacific, the Atlantic, and the Indian oceans. Figure 2 shows the plot of the zonal averages of rainfall in the Pacific Ocean. This analysis confirms that the rain belt of the ITCZ splits in two, not just seasonally but during nearly all months of the year. However, it should be pointed out that the southern branch and the contiguous cyclone path in the westerlies of the southern Pacific (which extends ultimately to the southern polar front) attain their maximum development during the austral summer period (December through February).

3. Previously unrecognized rain area in the South Atlantic

In the Atlantic, to the southeast of South America, there is an extensive area of rainfall in the region approximately between 25°S–50°S and 50°W–25°W (see Fig. 1 and also the cover picture). This rainy region was not known before; it does not appear on any existing map of global rainfall (e.g., Haurwitz and Austin, 1944; Geiger, 1971), probably because few ships traverse the area. Although visible and infrared observations may indicate gross features, the quantitative rainfall maps show a specific area with an annual rainfall of 900 mm (average rain rate of 0.1 mm/h). The inference of rainfall from visible and infrared imagery depends upon...
crude correlations, but ESMR observations have made possible the first quantitative estimates of rainfall. This rain area revealed in ESMR-derived maps is possibly an extension of the southern Pacific rain zone mentioned previously. In other words, rainfall in both areas could be produced by the same dynamical circulation pattern, the flow being modified and the rain pattern interrupted at the land protrusion of the South American continent and an area to the immediate west of the land. Furthermore, this rain area is in conformity with the general global pattern of relatively dry regions close to the west coast of continents and wet regions close to the east coast, where greater baroclinity due to increased temperature contrast may be expected.

4. Bimodal behavior of rain belts in the Indian Ocean

Meridional profiles of zonally averaged rainfall rates in the Indian Ocean are displayed in Fig. 3. Two distinct rain maximums are evident in the tropics between 20°N and 20°S (apart from a third extratropical maximum obviously related to the polar front, far to the south at ~40°S). Because a lower cutoff limit of 1 mm/h of individual rain rate in the tropics was imposed (to avoid noise attributable to factors such as surface wind and water vapor), the smaller of the two maximums is obliterated in some of the months. However, in general the maximum at northern latitudes appears to grow at the expense of the maximum immediately to the south of the equator as the monsoon advances, and vice versa as it retreats. During June–August the amplitude of the northern maximum is 3 times that of the other equatorial maximum, whereas during December–February the southern tropical maximum grows in amplitude to 3 times the northern. This study leads to a modification of the beliefs of two schools of thought in tropical meteorology: 1) that the atmospheric monsoon current is a progressive advance over the Indian Ocean from the Southern Hemisphere across the equator to the Southeast Asian landmass, and 2) that monsoon rainfall is due to moisture picked up entirely in the Northern Hemisphere, mainly in the Arabian Sea. It seems necessary to postulate a circulation mechanism involving both hemispheres, not necessarily demanding a regular progression of the entire monsoon airstream from the Southern to the Northern Hemisphere but affecting both in a coordinated way so as to sustain the bimodal changing wave pattern outlined above. This question is important (considering that the monsoon affects the lives of hundreds of millions of people) and is under further investigation.

5. Interannual variation

The extent of variation of rainfall over the oceans from year to year has been largely a matter of conjecture until the present time. The weekly, monthly, seasonally, and annually averaged maps generated from ESMR data provide new insight into this problem. A typical example is the rainfall over the Pacific in the month of January for the years 1973 and 1974 (Fig. 4). In January 1973, intense rainfall occurred over a wide region all along the equator (between 0° and 8°N) and also to the south of the equator (between 170°E and 160°W). This was at the time of the El Niño phenomenon (warm ocean current attended with relaxation of upwelling along the coasts of Ecuador and Peru), with its disastrous effect on the plankton and fish in the waters of the Pacific off the west coast of South America. In the corresponding month of 1974 (non–El Niño year), we see that the region was relatively dry. The ratio of rainfall in the equatorial
Pacific in the period December 1973–February 1974 to the rainfall in the period December 1972–February 1973 (see Fig. 2) is 1:6. Whether such variation is true for other el Niño and non-el Niño periods can be determined only after satellite rainfall data for many more years are processed.

In any event, this is a distinctive example of a rainfall anomaly. Investigations of similar anomalies and their correlations are very valuable in weather as well as in climatic studies.

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References