NOTES

A Comparison of Oceanic Precipitation as Measured by Gage and Assessed from Weather Reports

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ABSTRACT

The problems of using raingages on ships are discussed, and methods of estimating rainfall from weather reports at sea are reviewed, with emphasis on discussion of efforts to verify the assessments derived by Tucker (1961). A raingage was used on cruises of the NOAA ship *Oceanographer* in the eastern Pacific during 1975 and 1976, and rainfall was estimated from weather reports using Tucker's assessments. In extratropical latitudes (mainly 40–60°N), a catch of 35 cm was obtained; estimates from the weather reports gave a value of 31 cm. Thus Tucker's assessments are essentially in agreement with catches from a small gage in this region. In the tropics, however, the agreement was not good. Almost three times as much rain was caught as was estimated; hence Tucker's coefficients will need to be reevaluated for this area.

1. Introduction

Knowledge of the precipitation distribution over the oceanic areas of the world is woefully lacking. Not only is this knowledge needed for a basic understanding of the hydrologic cycle and the energetics of the atmosphere, but rainfall affects the salinity distribution of the oceans and consequently the mass distribution. As recently pointed out by Budyko (1974), there are still many uncertainties in oceanic rainfall estimates, and unequivocal statements about the amount and patterns over many oceanic regions cannot be made. One conclusion that has emerged (Tucker, 1961; Reed and Elliott, 1973; Kilonsky and Ramage, 1976) is that maps prepared by direct extrapolation of coastal and island rainfall amounts to sea are not reliable, and oceanic rainfall frequently tends to be overestimated. In addition, most attempts at measuring rainfall with gages aboard ship have not been successful (World Meteorological Organization, 1962).

While satellite observations offer hope that ultimately the amount of precipitation falling over the sea will be measurable, as yet the methods of making this estimate are highly experimental in nature. A method devised by Tucker (1961) to estimate seasonal precipitation over mid-latitude areas (to be described briefly below) has been used also by Reed and Elliott (1973) to obtain estimates of precipitation using weather observations aboard Pacific ocean weather station vessels. Annual means were determined, and reasonable monthly mean precipitation was derived for three sites which had more than 10 years data each. This note describes some comparisons of calculations using Tucker's method with actual gage observations aboard the NOAA ship *Oceanographer* in the eastern Pacific during 1975 and 1976. The data provide some insight into the areas where Tucker's method is applicable and where it must be modified. Before discussing the estimates of rainfall using the present weather observations (ww code), we will review briefly some of the problems with using raingages on ships.

2. Measurements with gages

Much of our knowledge about the use of raingages on ships has been gained from measurements on European vessels manning the various Atlantic ocean weather stations. The results of these and other studies have been summarized in a 1962 report of the World Meteorological Organization (hereafter called WMO report). The WMO report notes four major sources of error in making rainfall measurements aboard ship: 1) the disturbing effect of the ship itself on airflow, 2) creation of turbulent airflow by the gage, 3) motion of the gage caused by accelerations of the ship and 4) the effect of spray. The most common practice appears to be mounting relatively large gages (like those used on land) in an exposed location on an upper deck; the WMO report concludes that such an arrangement generally results in catches of only about half the true amount because the gages are located where the ship is disturbing airflow, and the large gages cause turbulent eddies in the relatively strong winds often encountered at sea.

The WMO report notes that mounting gages in gimbals cause many complexities that are not present with rigid mountings, and it is not known if windshields on the gages are of value. It also notes that errors caused by ship motion are not severe (a maximum deficit of 12% was estimated) and that the effect of spray can normally be neglected if the gages are more than 16 m above the waterline. The report concludes that fairly reliable results can be obtained if very small, conical gages are mounted high in the rigging or on a mast where the ship does not disturb airflow. In addition, Elliott and Reed (1973) compared various gages on an exposed beach and on a spar buoy off the Oregon coast; they concluded that in winds over 10 m s^{-1} there were appreciable deficits in the catches in large gages but that small, 3-inch (7.6 cm) diameter gages yielded catches that were probably within 10% of the true value.

3. Assessments from weather reports

Early maps of oceanic rainfall were constructed solely from data on land. On considering the precipitation-evaporation balance, however, Wüst (1936) noticed that precipitation needed to be reduced to yield plausible values of surface salinity. Jacobs (1951) considered these effects in the oceanic rainfall maps that he prepared. Budyko (1974) noted that some authors had used oceanic precipitation frequency with the mean intensity of land rainfall for various zonal bands; the practice was criticized, however, because the mean intensity of rainfall at sea may be appreciably different than over land. Tucker (1961) refined this approach considerably by determining quantitative values for each precipitation category in the standard present weather (ww) code from observations and measurements at British land stations. The assessments were then extended to weather reports at Atlantic ocean weather stations to obtain rainfall estimates. Although the method has not been rigorously calibrated at sea, one would intuitively expect it to give satisfactory results provided that there are a sufficient number of categories to achieve a realistic gradation of rainfall and that there are not large biases between the observer's estimates at sea and on land. It is less certain that the assessments can be applied to climatic regions markedly different than where they were derived.

Tucker's (1961) assessments have recently been investigated by Capt. G. P. Britton (personal communication, World Meteorological Organization report, in press). He concluded that estimates with Tucker's assessments may be about 10% too low, mainly as a result of Tucker's neglect of the ww 20 series of code observations (precipitation during the past hour but not at the time of observation). Subsequently, Capt. Britton derived new coefficients which he applied to 1954–59 data at ocean station P. We used Tucker's coefficients with the same data and found that Tucker's values gave a mean annual estimate only 3% less than Britton's.

As noted above, there is no absolute, *in situ* calibration at sea of Tucker's assessments. Elliott and Reed (1973), however, did present data which strongly support the applicability of the assessments to the northeast Pacific. Catches were obtained during the October–April period of two years with 7.6 cm diameter gages at 11 m above the water on a spar buoy (maximum tilt about 10°) off Oregon, and Tucker's method was applied to the data from lightships at three sites along the coast (from 40° to 48°N). The ratios of lightship-coastal land station amounts were nearly constant and were virtually identical to the ratio of the catches at the spar buoy to amounts measured at Newport, Ore. Considering the large amount of data, it is very difficult to see how this result could be fortuitous, and we feel that Tucker's method gives a reasonable estimate of rainfall in this region.

4. Observations

In 1975 a 7.6 cm diameter raingage [identical to that used by Elliott and Reed (1973)] was installed on the *Oceanographer*. Following recommendations of the WMO report, the gage (obtained from Science Associates, Princeton, N. J.) was carefully leveled and mounted on a strut about 2 m forward of the forward mast. The gage is at a height of about 34 m above the waterline; the top of the mast is ~3 m above the gage, although there are some shipboard instruments atop the mast. The gage was connected to thick-walled plastic tubing which led down the mast to a metal receiver, and the catch was periodically emptied and measured in a graduated cylinder. In order to compare the measurements with assessments from weather reports, observations of present weather (ww code) were made each hour by the quartermasters on bridge watch.

During 1975 and 1976, catches were measured and recorded at various intervals while the ship was at sea in the eastern Pacific; duration of the intervals varied from two days to three weeks, with a typical period being about 10 days. Estimates of rainfall were also derived from the hourly present weather observations using Tucker's (1961) assessments. During a few periods the weather observations were started a few hours later than the measurements; this would result in a deficit in the estimated rainfall, but the total error from this cause is almost certainly not greater than 5%. It should also be noted that, in using Tucker's assessments, the original values of the parameters were used without the varying monthly ratios applied by Tucker. There is no significant difference in the annual means, but use of the original values results in the most realistic seasonal distribution for the northeast Pacific (Reed and Elliott, 1973).

Upon initially examining the data, it was immediately apparent that the differences between measured and estimated amounts were generally greater for areas in the tropics than for mid-latitude regions. Consequently, the data have been grouped as tropical and extratropical. The tropical area was generally considered to be the ship's tracks between 2°S and Hawaii (21°N), with east-west boundaries of 123 and 157°W. Although the extratropical group did have some tracks south of 40°N, 89% of the measured precipitation occurred on cruises solely within the Gulf of Alaska or off the Oregon-Washington coast (that is, from 40 to 60°N). A comparison of measured and estimated precipitation for the two groups of data is presented in Table 1. Although Tucker (1961) derived a random error for his data, it may not be valid to extrapolate this value to the Pacific. It seems reasonable to assume, however, that the random error (considering the number of days of data) for neither group in Table 1 exceeds 10%.

The measured and estimated precipitation (Table 1) in the extratropical region are in close agreement; the difference is only 11%, and (as noted above) the estimates are probably slightly low because of some missing weather reports at the start of a few periods. Although the results for individual periods vary greatly, the close agreement for the entire group of data suggests that there are no large errors in the amounts caught by the gage and that Tucker's assessments can be used to derive satisfactory amounts in this region. While it is possible that neither method gives the correct amount of rainfall, this seems quite unlikely because of the comparisons presented by Elliott and Reed (1973) and the data presented in the WMO report; furthermore, the comparison suggests that useful data can be obtained with suitable, properly placed gages on ships. On the other hand, Tucker's assessments in the tropics do not give satisfactory agreement with the measured amount, which is almost three times the estimate.

TABLE 1. Comparison of measured precipitation and that estimated from the present weather observations using Tucker's (1961) assessments. The data are from 1975–76 cruises of the *Oceanographer* in the eastern Pacific and are grouped as extratropical or tropical according to the location of the ship's track.

Region	Number of days	Total precipitation (cm) Measured (gage)	Estimated (ww code)
Extratropical	117	35	31
Tropical	249	112	39

5. Discussion

The comparison (Table 1) suggests that Tucker's assessments are suitable for use in this mid-latitude region (40–60°N) but are not suitable in the tropics. There are insufficient data between 20 and 40°N to determine their reliability there. Since the data showed no higher incidence rain in ww 20's in the tropics than elsewhere, it seems likely that the disparity in the tropics may result from more intense rainfall in this region than in mid-latitudes. Because rain appears to result mainly from organized, large-scale convective activity (Kilonsky and Ramage, 1976), it would not be surprising to find that "heavy, continuous rain" in the tropics would be of greater intensity than this category in Great Britain, where Tucker's (1961) assessments were derived. This conclusion can be roughly checked with recent data from the Pacific. The annual precipitation estimated by Tucker's method (Reed and Elliott, 1973) for ocean stations N, P and V (30–50°N) was compared to the annual frequency of rainfall from new maps (in press) prepared by the U. S. Naval Weather Service; the ratio at all three sites was 4 cm $(\%)^{-1}$. Comparing the amount from 2°S to 20°N (Kilonsky and Ramage, 1976) to frequency gave a value of 14 cm $(\%)^{-1}$, or 3.5 times the intensity of extratropical rain.

Thus it seems that while Tucker's general method is valid, the numerical values will need to be reevaluated in some climatological regions. We feel that the coefficients are adequate north of 40°N and are probably valid north of 25–30°N; they are also probably usable in the mid-latitude Southern Hemisphere. Although the data presented here cannot be used to examine seasonal rainfall, Reed and Elliott (1973) showed that Tucker's method is suitable for that purpose if long time-series are available.

The tropical measurements reported here give a value of 112 cm for 249 days in 1975 and 1976; extrapolating this to one year yields 164 cm. Although less than a year's observations during only two years cannot be used to derive a reliable climatological mean value, the value of 164 cm is a plausible annual mean. From the data of Kilonsky and Ramage (1976), which were based on satellite-derived estimates of large-scale convective activity, we estimated an annual mean value from 2°S to 20°N of 155 cm $year^{-1}$. Additional measurements in this region should prove enlightening, especially if they were concentrated over a few narrow bands of latitude. We plan to continue our studies with a view toward verification of previous estimates and establishment of intensity values for the various ww codes.

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