CORRESPONDENCE

Comments on "The Relationship Between the Amount and Frequency of Precipitation Over the Ocean"

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14 March 1980 and 18 June 1980

In this article, Reed (1979) uses the Tucker (1961) technique to estimate rainfall at ocean station vessels (OSV). Tucker's technique correlates rainfall with visually observed precipitation in the present weather part of the synoptic observations. This estimate is then a standard from which Reed "calibrates" the amount of rainfall per frequency of observed precipitation. Observed precipitation includes all types (rain, drizzle, etc.) and intensities (light rain, heavy rain, etc.) of the present weather observation that are associated with any precipitation. It is stated that this frequency technique is necessary because of the "fair weather bias" and the insufficient number of reports available to apply the Tucker method directly to the marine weather observations. In addition, Reed suggests that the Tucker estimates need to be corrected for a seasonal bias.

Reed's system contrasts to that of Dorman and Bourke (1978). They compared measured precipitation to the Tucker estimates for coastal and island stations from a broad range of latitudes in the Atlantic and the Pacific and found that the Tucker method is a function of the air temperature. South of about 50°N, the Tucker method increasingly underestimates the rainfall with higher temperature, and exceeds a factor of 3 underestimate in the tropics. Dorman and Bourke proposed that the temperature-corrected Tucker estimates be applied to ships-of-opportunity to derive oceanic rainfall. Because Reed did not apply the temperature correction to the OSV based Tucker estimates, this standard will generally be significantly less than Dorman and Bourke's (1978) estimates for the same ocean station vessels. Therefore, Reed's frequency system will be generally less than Dorman and Bourke temperature corrected estimates, and up to a factor of 2 less in midlatitudes.

Reed seems to have chosen not to make the temperature correction to his OSV based Tucker estimates because of some limited ship measurements by Reed and Elliott (1977). In the study, a ship was instrumented with a special raingage that was placed so as to minimize the effect of the ship on the measurements. Based on 117 days of observation mostly north of 40°N in the northeastern Pacific, Reed and Elliott concluded that the Tucker estimates were about correct. But with 249 days of observations between Hawaii and 2°S, Reed and Elliott found that Tucker estimates were about a factor of 3 less than measured rainfall. No measurements were taken in the general subtropics between 21 and 40°N which raises the question of how the ratio of Tucker estimates to measurements changes by a factor of 3 in the subtropics. Of course, a step change between the tropics and the nontropics would not be physically realistic. Actually, these measurements could be interpreted as support for the temperature correction to the Tucker estimates. Reed and Elliott's short record taken over a large area with significant rainfall gradients could not be expected to resolve the existence of a small temperature correction north of 40° latitude. In the tropics, the temperature correction to the Tucker estimates is a factor of 3 or 4, which is also statistically similar to what Reed and Elliott found considering that they again averaged a short record over an extensive area with very large rainfall gradients. A reexamination of the Reed and Elliott raingage data in light of the Dorman and Bourke temperature study suggests that Reed was in error by not including the temperature correction to his standard.

Reed discusses a seasonal correction to the Tucker estimate and suggests that this improves the precipitation estimate. In his Fig. 1, he shows the Tucker estimate uncorrected and then corrected by monthly seasonal weights proposed in Tucker's (1961) original paper. The Tucker estimates in Reed's Fig. 1 could also be corrected to a typical seasonal trend by applying the Dorman and Bourke temperature correction. It is of interest that in a more recent paper Dorman and Bourke (1979) found likely rainfall seasonal trends for temperature corrected Tucker estimates at OSV's in the Pacific. Dorman and Bourke (1979) also computed seasonal

0021-8952/80/091131-03$04.75

amplitude and phases from the temperature corrected Tucker estimates based upon ship observation and found that they compare well with Pacific island and coastal stations (Hsu and Wallace, 1976). At this time, it is not clear that Reed's frequency method produces a more reasonable seasonal trend than the temperature corrected Tucker method.

Another difference between the two methods is in their sensitivity to precipitation types. Dorman and Bourke (1978), and the basic Tucker system (that Reed uses as a standard), differentiate between the intensities and types of the observed weather. This distinction is eliminated in Reed's system as all types of precipitation are mixed to compute one grand frequency of occurrence. For example, Reed's system would indicate that the same rain total would occur at a station with all light rain as one with all heavy rain, whereas the Tucker method (corrected or not) and physical intuition would indicate that the latter would have more rainfall. It would seem that Reed's elimination of this distinction would result in a loss of significant information and cause serious errors.

Reed cites the "fair weather bias" as a reason for using his frequency method. The fair weather bias is the hypothesized skewing of observations toward fair weather because ships try to avoid storms. However, Reed proposes to use the *Marine Climate Atlas* (Meserve, 1974) for frequency of precipitation which is computed for small selected areas of the oceans and most of these areas are based on ship-of-opportunity observations. Any systematic adjustments for fair weather bias could be applied to both the Tucker estimates as well as Reed's frequency estimates. It would seem that there is no advantage of the frequency method over a ship-of-opportunity based Tucker method because of fair weather bias.

The analysis of the fair weather bias on the Tucker estimates (and also Reed's frequency method) is incomplete. For example, how significant is the effect of the fair weather bias on the rainfall estimates? Do ships equally avoid storms in all areas in an equal manner for all seasons? Reed cites Quayle (1974) as supplying the evidence of the fair weather bias. Yet after plotting a limited number of ship tracks, Quayle also found that those ships seem to set courses right through storms which is in conflict with the fair weather bias argument. In a more recent article, Dorman and Bourke (1979) found that rainfall estimates based on ships-of-opportunity compared well with those based on ocean station vessels. Thus, it could be that there is no significant effect of fair weather bias on rainfall estimates based on ships-of-opportunity.

Reed further cites that another advantage of the frequency method is the limited number of ship-of-opportunity observations available per area of reasonable size. He cites Tucker (1961) as needing ~1200 observations to make an estimate within 95% confidence interval. But, if the ocean is divided into five longitude by two latitude blocks, most blocks have more than 1200 modern observations in the North Pacific and the North Atlantic outside of the tropics. This sort of block averaging is reasonable for the known zonal extent and synoptic scale of oceanic climate. Even areas with <1200 observations are simply to be interpreted with less confidence and compared to surrounding area for consistency. Thus, it is erroneous to suggest that there are not enough ship-of-opportunity observations in the North Pacific and the North Atlantic to support a Tucker-based analysis.

The advantages of the temperature corrected Tucker estimates based on ships-of-opportunity can be reviewed for contrast. In a more recent paper, Dorman and Bourke (1979) made estimates of Pacific Ocean rainfall (30°S to 60°N) from temperature corrected Tucker estimates based on ship-of-opportunity observations. These results are collaborated by Taylor (1973) who produced an atlas of Pacific Rainfall between 30°S and 30°N based primarily on small coral atolls with practically no relief. Rao and Theon (1977) reported satellite microwave measurements of rainfall over the oceans and found maxima for the Pacific and the Atlantic correspond to those found by the temperature-corrected Tucker method (Dorman and Bourke, 1978, 1979). Hsu and Wallace (1976) computed phase and amplitude of the annual rainfall for coastal and island stations over the Pacific which compare well with the annual amplitude and phase computed by Dorman and Bourke (1979). Finally, Reed and Elliott's (1977) limited special raingage ship measurements are close to the estimates made by the temperature-corrected Tucker method. Thus, there are different oceanic rainfall estimating techniques that collaborate the temperature-corrected Tucker estimates based on ships-of-opportunity.

Discussion

Reed's (1979) system for estimating oceanic rainfall has been examined here. A major difficulty with this system is that the Dorman and Bourke (1979) temperature correction to Tucker's estimates were not used during its calibration. Reed's system also eliminates the distinction between different types and intensities of rainfall which could lead to serious errors. There are additional criticisms of the basic assumptions behind the system and of the claims that the system is necessary.

A related system of Dorman and Bourke (1978) is cited for comparison. The important distinction

between the two is that Dorman and Bourke's (1979) includes a temperature correction to the Tucker estimates that are based on data from ships-of-opportunity. This system will generally produce estimates significantly more than Reed's system, and a factor of 2 greater in midlatitudes. Studies based on different techniques are cited that support the Dorman and Bourke system. Evidence for the Dorman and Bourke system is, indirectly, evidence against Reed's system since the two differ so greatly in absolute amounts.

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