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A Comparison of Surface Heat Flux Estimates from Ocean Weather Station V and Merchant Vessels in Its Vicinity in the Western North Pacific Region, 1956–1970

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ABSTRACT

In this report the estimates of large-scale heat fluxes derived from merchant vessel data within a 4° quadrangle centered on the position of Ocean Weather Station V in the western Pacific Ocean are compared with the estimates from the assumed higher quality weather reports at OWS-V during 1956–70. Comparison of the anomalies of the 6-monthly mean latent heat flux estimates from the long-term means of the two data sets revealed significantly different patterns in the latent heat flux, particularly during the 1956–66 period.

Investigation of the monthly mean properties used to compute the heat flux estimates showed a statistically significant trend in the differences between the sea surface temperatures. The trend in the SST differences is believed to result from the inclusion of low-precision merchant vessel data collected prior to 1962. There is also a suggestion that this trend may have resulted from sampling bias (in terms of data density and bias in location of the observations).

The results indicate that the use of time- and space-averaged properties or heat flux estimates derived from the TDF-11 file requires careful screening of the reports to provide unbiased estimates of air-sea energy transfer processes.

1. Introduction

The increasing research efforts toward understanding the mechanisms of climatic change require knowledge of the air-sea energy transfer processes over large ocean areas. The only source of historical and modern data over large ocean areas which can be used to estimate the energy transfers is the file of surface marine weather observations, collected primarily by merchant vessels, which is archived at the National Climatic Center (NOAA, EDIS) in Tape Data Family-11 (TDF-11). These data have been used in recent climatological summaries of surface heat flux estimates for the eastern North Pacific Ocean by Clark *et al.* (1974) and for the North Atlantic Ocean by Bunker (1976). An important concern is the representativeness of the heat flux estimates derived from the merchant vessel data, given the possible sources of error in these data, such as the nonrandom distribution of the reports, fair weather bias and sampling errors.

Recently some comparisons have been made between long-term means of merchant vessel surface weather data in areas surrounding ocean weather stations and the assumed higher quality ocean weather station (OWS) data. Quayle (1974) investigated the possible fair weather bias in merchant vessel reports by comparing the percentage departures of the monthly mean values in 2° latitude-longitude squares surrounding OWS's with the overall OWS monthly means. He reported that the wind speed comparisons showed no significant differences but that the precipitation and visibility comparisons did show possible avoidance of bad weather, i.e., less precipitation and greater visibility reported by the merchant vessels. Bunker (1976) compared the long-term averages of TDF-11 data within subareas surrounding OWS's with the long-term OWS averages in the North Atlantic. The results indicated that the merchant vessel observers measured higher sea and dew-point temperatures and lower wind speeds and cloud cover than those at OWS D and E. Based on comparisons using more than 500 observations, the probable error in the latent heat flux computations was estimated to be less than 10%.

In this report the time series of 6-monthly and monthly mean estimates of the turbulent heat flux from OWS-V (34°N, 164°E) and the surrounding 4° square are compared for the 1956–70 period. The differences in the patterns of the anomalies of the 6-monthly estimates are described. The objective in comparing the two sets of calculations was to determine whether meaningful anomalies of energy transfer can be computed from the merchant vessel

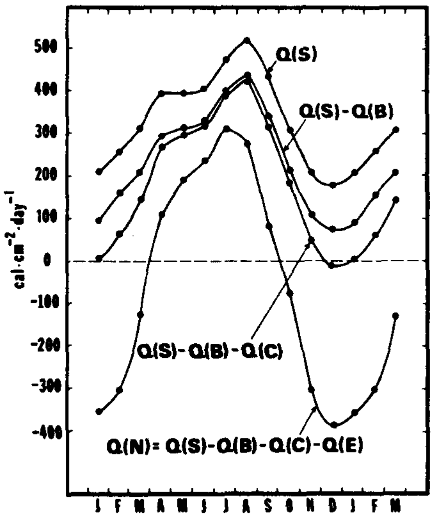

FIG. 1. Mean annual cycle of components of heat exchange across the sea surface at Ocean Weather Station V, 1956–70. $Q(S)$, radiation from sun and sky; $Q(B)$, effective back radiation; $Q(C)$, sensible heat flux; $Q(E)$, latent heat flux; and $Q(N)$, net heat exchange.

data. The factors contributing to differences in the heat flux estimates are discussed.

2. Data processing and heat flux computations

Monthly means of air, sea and dew-point temperatures and wind speed and cloud amounts were calculated from the TDF-11 data for the 4° square surrounding OWS-V and for the 3 h synoptic weather reports from the OWS vessels for the 1956–70 period. The number of observations per month for the 4° square ranged from 21 to over 800, with an average of 120, while for the OWS-V reports the numbers ranged from 137 to 248, with 98% of the months having more than 200 observations. Gross error checking was performed on each report to determine only if the reported values were within normal climatic limits.

TABLE 1. Six-monthly heat exchange processes, 1956–70 (cal cm^{-2} day^{-1}).

	October–March		April–September	
	4° square	OWS-V	4° square	OWS-V
$Q(S)$	285	238	497	429
$Q(B)$	−110	−106	−91	−86
$Q(C)$	−74	−70	−11	−13
$Q(E)$	−328	−329	−152	−137
$Q(N)$	−227	−267	243	193

$Q(S)$, incident solar radiation: $Q(B)$, effective back radiation: $Q(C)$, sensible heat flux: $Q(E)$, latent heat flux: $Q(N)$, net heat exchange.

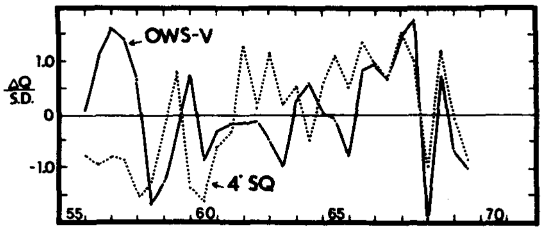

FIG. 2. Time series of standardized anomalies of 6-monthly latent heat flux at OWS-V (solid line) and within 4° square surrounding OWS-V (dashed line). The two 6-monthly periods are October–March and April–September.

The energy transfer processes, that is, the turbulent fluxes of latent and sensible heat and the effective back radiation from the sea surface, were estimated using the standard bulk exchange formulas with a constant drag coefficient referred to the 10 m reference height. The formulas are described in Husby and Seckel (1975). The identical formulas were used with the monthly mean properties from both sets of data. Although the heights of the wind speed observations and that for the air and dew-point temperatures were different for both the OWS vessels and the merchant vessels, the anemometer heights on the merchant vessels cannot be determined. Thus, the heat flux computations were performed using the original observations, unadjusted for the difference in heights, and the drag coefficient for the 10 m reference height.

3. Anomalies of latent heat flux

During the months from October through March there is a net loss of heat from the ocean to the atmosphere at OWS-V which averages 267 cal cm^{-2} day^{-1} (129 W m^{-2}) and during the April to September months the ocean gains an average of 193 cal cm^{-2} day^{-1} (92 W m^{-2}) (Fig. 1). The latent heat flux $Q(E)$ is the largest term contributing to the annual cycle of heat exchange aside from the solar radiation $Q(S)$ reaching the sea surface, particularly during the cooling portion of the annual cycle from October to March. Table 1 lists the 15-year means from the two sets of data for the terms comprising the net heat exchange during the two 6-month portions of the annual cycle. There was very little difference in the long-term means of the 6-month estimates of the heat flux terms. The differences arise when the anomalies of the 6-month means from the long-term averages of both data sets are examined.

Fig. 2 displays the anomalies (deviations from the respective long-term 6-month means) of the latent heat flux estimates for the two data sets for the two 6-month segments of the annual cycle. The positive anomalies denote greater than average latent heat flux from the ocean to the atmosphere and the nega-

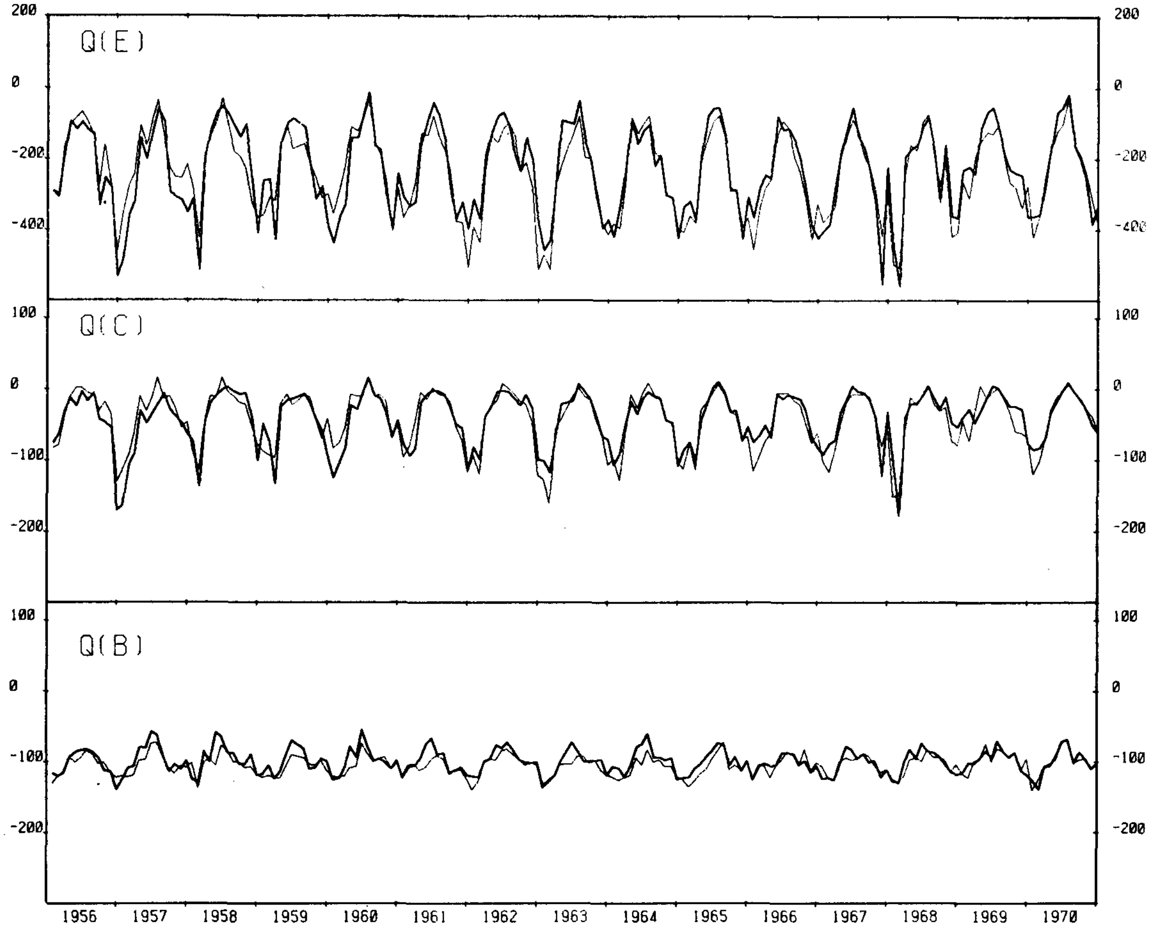

FIG. 3. Time series of monthly latent heat flux (upper panel), sensible heat flux (middle panel), and effective back radiation (bottom panel) at OWS-V (heavy lines) and within 4° square surrounding OWS-V (light lines). Units are cal cm^{-2} day^{-1}.

tive anomalies less than average latent heat flux. The anomalies are transformed into standardized variables by dividing the anomaly value by the standard deviation of the 6-month anomalies for the 15-year period. Prior to 1966 the 6-month anomalies based on the 4° square data are radically different from the OWS-V 6-month anomalies. Large differences are evident during the 1956–58 period. Also noted are the large, positive anomalies in the TDF-11 data for October 61–March 62, October 62–March 63, April 65–September 65 and April 66–September 66. The differences between the individual 4° square and the OWS-V 6-month means were of the same magnitude as the 6-month anomalies of the OWS-V values.

The differences in the patterns of the 6-month anomalies of the latent heat flux are readily explained in the comparison of the monthly values (Fig. 3). Particularly during the winter months from 1956 to 1963, the latent heat flux estimates derived from the TDF-11 data seem to be consistently biased compared to the OWS-V values. There are periods of 3–6 months in succession when the $Q(E)$ values are consistently less or greater than those derived from the OWS-V data. During the winters of 1956–57, 1957–58 and 1959–60 the 4° square $Q(E)$ estimates were consistently less than those for the OWS-V data and during the winters of 1961–62 and 1962–63, the reverse was true. Hishida and Nishiyama (1969) noted a long-term trend in the monthly anomalies of latent heat flux over a large portion of the western North Pacific Ocean during the 1954–63 period based on the marine climatological tables of the Japan Meteorological Agency. The monthly anomalies in latent heat flux in selected 2° × 5° latitude-longitude quadrangles were predominantly negative in the 1954–59 period and positive from 1960–63. The authors suggested that the

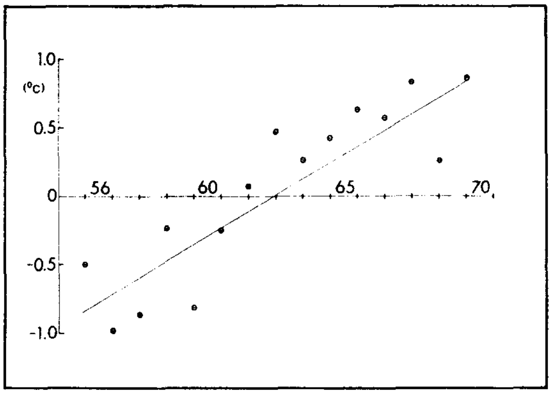

FIG. 4. Difference in October to March mean sea surface temperature between 4° square surrounding OWS-V and OWS-V. Straight line indicates linear regression of temperature difference on the year.

anomalies in the evaporation rate were related to anomalies in the wind speed, particularly in January and February.

4. Comparison of monthly mean meteorological properties

To investigate these non-random differences in the $Q(E)$ estimates, monthly mean values of sea surface temperature, air temperature, wind speed and vapor pressure of the air were compared. The Mann-Kendall rank statistic was computed for each series of differences to test the series for randomness versus the alternative hypothesis of a trend (Mitchell *et al.*, 1966). Only the sea surface temperature (SST) differences showed the probability of a trend, significant at the 95% level. Fig. 4 displays the differences in the October–March mean SST values for the 1956–70 period. The differences range from about −1°C in 1957 to +1°C in 1970.

The Behrens-Fisher statistic was computed to test the hypothesis that there was no difference between the monthly SST means (Fisher and Yates, 1970). The hypothesis could be rejected for only 40% of the months in this comparison; however, nearly 50% of the comparisons for the October–March months produced differences which were significantly greater than zero at the 95% level. A possible cause for the disagreement in the SST monthly means is the inclusion of low-precision SST values in the TDF-11 file for the 1956–61 period.

From 1956 to 1961 nearly 50% of the reports were derived from Deck 119, Japanese Ship Observations (Fig. 5). The SST values in Deck 119 were calculated from the difference between the reported air-sea temperature difference and the reported air temperature which are given to the nearest whole degree Celsius. Thus these SST values contain an uncertainty of ±0.5°C in addition to other sampling errors. The other decks contributing to the 4° square data contained SST values reported to the nearest tenth of a degree Celsius. Uncertainties in the SST means alone of 0.5–1.0°C could produce uncertainties in the latent heat flux estimates of 10–20%. However, correcting the monthly SST values for the linear trend did not significantly alter the differences in the latent heat flux estimates.

The mean wind speeds, air temperatures and vapor pressures of the air were generally higher for the 4° square data than for the OWS-V reports although no significant trends were detected; the root-mean-square (rms) differences were 1.0 m s^{-1}, 0.5°C and 0.9 mb, respectively. The magnitudes of the sampling errors of the individual merchant vessel and OWS measurements cannot be determined due to the variety of methods and instruments used; however, considerable variation in the mean properties is expected *a priori* due to the errors in interpolating the mean property within the 4° square to the midpoint of the area. The 4° square means may be biased toward certain shipping lanes and possibly toward a certain time period during the month.

The spatial bias in the monthly mean properties was examined by calculating the rms distances of the 4° square reports from the position of OWS-V for the individual months. The rms distances did not show any appreciable changes or trends from month-to-month, but were relatively constant at about 0.6° latitude (~67 km). However, there was a slight trend in the monthly mean location of the 4° square reports which consisted of a decrease in the mean latitude of the reports of 0.5° latitude from

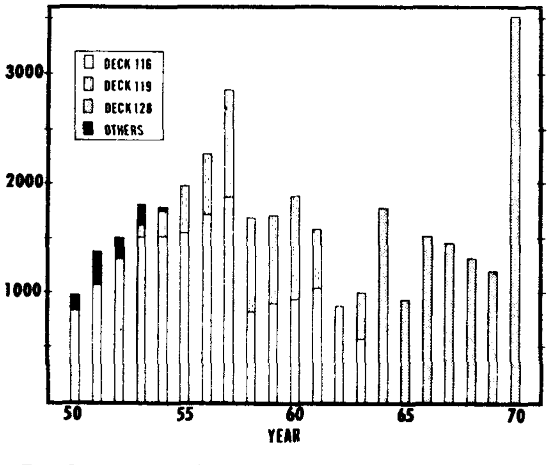

FIG. 5. Annual number of reports within the 4° square surrounding OWS-V and the source of the reports within each year. Deck 116, U.S. Merchant Marine observations; Deck 119, Japanese Ship Observations No. 2; and Deck 128, International Marine Observations.

1956 to 1970. The magnitude of this trend was not sufficient to explain the trend in the sea surface temperatures mentioned earlier. The sea surface temperature gradients are primarily meridional in the vicinity of OWS-V throughout the year and, based on historical oceanographic data, the gradients range from 0.4°C per degree latitude in the summer to 0.9°C per degree latitude in the winter (Japan Oceanographic Data Center, 1975).

5. Summary

The record of climatic-scale fluctuations in the upper ocean must presently depend on the routinely collected surface weather observations from merchant vessels. An important component of the energy budget of the ocean is the turbulent transfer of energy between the atmosphere and ocean. The anomalies of the 6-month latent heat flux means from the long-term (15-year) average for the two data sets did not show good agreement in the winter months (October–March) for the 1956–66 period. In fact, the anomalies were of different sign during 1956–58, 1963 and 1965–66.

The discrepancies in the 6-monthly and monthly estimates of latent heat flux appear to be primarily related to the inclusion of low-precision data in the time series of sea surface temperature reports in the TDF-11 file during the 1956–61 period. A slight negative trend in the mean latitude of the TDF-11 reports was identified which, by itself, was not sufficient to explain the differences in the monthly mean properties or the derived heat flux estimates.

The pitfalls in using the bulk aerodynamic formulas with a constant drag coefficient and with monthly mean properties have been discussed by many investigators. The calculation of the turbulent energy transfers with the bulk formulas is usually made with the intention of providing relative indices of the month-to-month or interannual variations in the energy transfers rather than determining the absolute magnitudes of the processes. The results of this comparison throw some doubt on the use of the merchant vessel data even for relative indices of air-sea interaction at least in this portion of the western North Pacific. The poor comparisons of the heat flux anomalies underscore the need for careful screening of the merchant vessel reports prior to the heat flux computations.

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