1983 USA WRIGHT + WALLACE,

t_m was found to be approximately one hour or less. With $t_m = H_w^2/(\pi^2 A_z)$ the vertical diffusivity A_z is estimated from

$$A_z \simeq \frac{H_w^2}{\pi^2 t_m} = \frac{c^2 V_w^3}{\pi^2 t_m}$$

Thus, A_z is proportional to the work done by the surface wind stress. This is reasonable as long as $H_w < H_{mi}$ because no significant work is done by wind waves to transform potential energy, which is stored in the stratification, into kinetic energy.

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Analysis of the Marine Data Set

Sea surface temperature and atmospheric data have been recorded from ships for more than a century and provide a potentially valuable source of data for the investigation of climatic changes. We are analyzing a preliminary version of the Fletcher *et al.* (1983) Comprehensive Ocean-Atmospheric Data Set (COADS). Initial results indicate serious problems with inhomogeneities, which may make deductions about interdecadal (10-100 years) climatic change very difficult.

Monthly mean sea surface temperature (SST) data in 2° squares for the Pacific region, nominally for the years 1854-1969, were obtained from this marine data set. The number of observations changed tremendously during this period, ranging from 4700 in 1870, through 61,080 in 1930, to 400,500 in 1966. First, we found for each calendar month the mean SST for the reference period 1949-68, accepting values only where at least ten years were present. Small gaps were filled by linear interpolation, but a few large areas remained empty (Figure 1 shows an example). Then, for every individual month, the corresponding means were subtracted from the data to obtain anomalies. These anomalies were then averaged over ten squares, the average being accepted if at least one square was present, to give anomalies in 4° latitude × 10° longitude boxes. Finally, we defined nine large regions (Figure 1) and averaged the anomalies over these regions for each year.

The time series of the annual mean SST anomalies in regions 1-7 show (Figure 2) a number of interesting features. Several regions showed a rapid fall within a few years of 1900, and all the regions experienced a sudden rise in value close to 1940. Table 1a shows the magnitude of the latter rise in each region. The time series for region 4 exhibits the Southern Oscillation signal, and the series for regions 2 and 3 are inversely correlated, as discussed by Wright (1983). The short-term fluctuations are more evident in plots of monthly values (not shown).

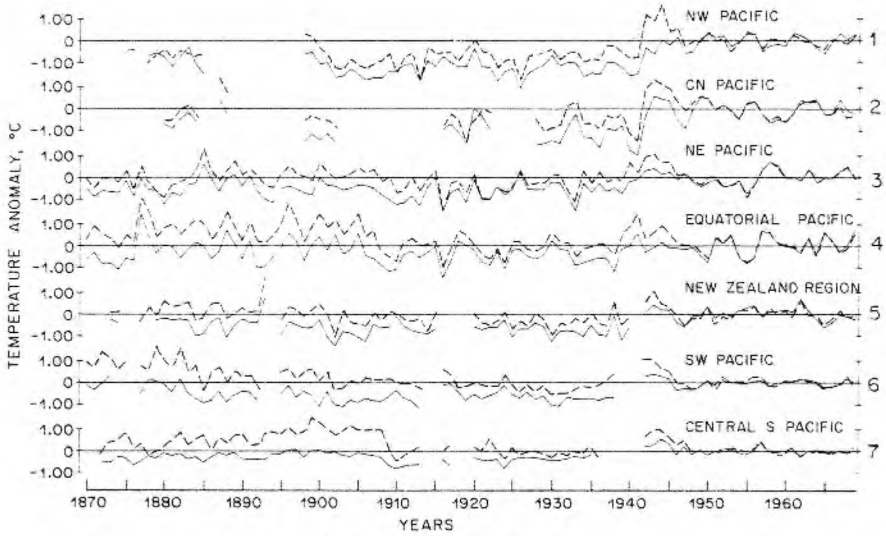

FIGURE 2 (*Wright and Wallace*)
Annual mean SST (solid lines) and air temperature (dashed lines) anomalies in seven regions (shown in Figure 1) during 1870-1969.

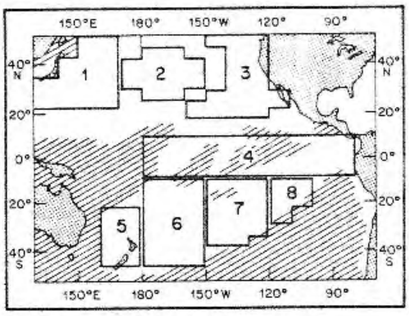

FIGURE 1 (*Wright and Wallace*)
Shaded areas have insufficient data in a sample month during 1949-68 to produce reliable mean SST values.

To help assess whether any of the long-term variations in the time series might be due to artificial rather than real climatic changes, the analysis was repeated on the air temperature (AT) data obtained from the same marine data set. The results are shown in Figure 2. It is reassuring that on the interannual time scale the air and sea temperature time series follow one another extremely closely. However, on the interdecadal time scale there are some systematic differences between the two time series. In all regions, between 1896 and 1910 AT decreased more than SST. AT, as SST, showed a rise between the 1930s and the 1950s in most regions, but of much lower magnitude (Table 1b).

Physical reasoning leads us to believe that, when averaged over a large region of ocean, SST minus AT in any given calendar month or averaged over the year must be almost constant. The observed interannual variations during 1950-69 (Figure 2) conform to this hypothesis. If the hypothesis is true, the values in Table 1c must represent a systematic error in either the SST series or the AT series, or both. The time pattern of the SST anomaly minus AT anomaly is very similar in all regions and is shown averaged over the entire area in Figure 3. The war years have been omitted because the number of observations was very small.

TABLE 1 (*Wright and Wallace*)
(a) Change in sea surface temperature (SST) from 1920-39 to 1949-68, (b) change in air temperature (AT) from 1920-39 to 1949-68, (c) a minus b, and (d) mean 1949-68 SST minus mean 1949-68 AT.

Region	(a)	(b)	(c)	(d)
1 NW Pac	1.25	0.67	0.58	1.35
2 CN Pac	0.95	0.35	0.60	0.88
3 NE Pac	0.57	0.28	0.29	0.67
4 Eq Pac	0.50	0.07	0.43	0.62
5 NZ Reg	0.72	0.33	0.39	0.93
6 SW Pac	0.69	0.17	0.52	1.14
7 CS Pac	0.39	0.02	0.37	0.74
8 SE Pac	0.20	−0.16	0.36	0.76
9 SAm Coast	0.63	0.27	0.36	0.27

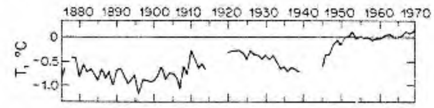

FIGURE 3 (*Wright and Wallace*)
Annual mean SST anomaly minus AT anomaly averaged over all available 4° x 10° boxes.

Several colleagues have pointed out that the proportion of ships measuring SST by intake instead of by bucket increased during the period, but no information is available as to the proportions in any year. Contrary to the prevalent opinion that almost all observations are now made by intake, WMO (1982) suggests that currently about 30-40% of ships use the bucket method. Estimates based on field comparison suggest that intake temperature values are about 0.3-0.5°C greater than accurate bucket measurements (Saur, 1963; James and Fox, 1972; Tabata, 1978). This could account for part of the change in the level of the curve in Figure 3. On the other hand, bucket temperature measurements might be too low if readings are not taken immediately, due to the cooling of the water by evaporation and conduction (Collins *et al.*, 1975). This effect would be positively correlated with the actual SST minus AT difference. Table 1 shows that the "error" in SST in the earlier period relative to the later (1c) is greater in regions where the sea is warmest relative to the air (1d). When the data in each region are stratified by month, the same relationship is even more evident. The "error" follows the seasonal cycle of SST minus AT difference in the northwest Pacific, equatorial Pacific, and New Zealand regions in both amplitude and phase.

Thus the data are consistent with the following hypotheses: (1) the proportion of ships using the intake temperature method increased from 1920 to 1950, (2) the intake method gives readings that are somewhat too high, and (3) bucket temperature measurements are on average too low when the air is colder than the sea. However, not all the "error" in SST can be thus accounted for. Numerous other factors of a nonclimatic nature might be suggested that could cause systematic errors in SST measurements, and there could be errors in the AT series due to similar artificial factors. One should therefore be cautious in making deductions about interdecadal climatic changes from these data.

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Long Term Trends in Temperature Over the Ocean Estimated from Historical Ship Observations

There has been a surge of interest in the last decade in estimating surface air temperature (AT) changes over the globe. Such estimates, to be reliable, require that changes in the surface temperature over the oceans be estimated. It appears at this time that this can only be done from the historical archive of ship observations, hereafter loosely called the Marine Deck. This note explores the adequacy of this data set to estimate small, long-term changes in surface temperature over the ocean. A more complete discussion of the problem will appear in Barnett (1983), and readers interested in the details of the study are referred to that article. For now, we present only the main results.

The basic problem is that sea surface temperatures (SST) in olden times were obtained from bucket measurements. More modern estimates of SST are thought to come largely from injection temperatures. Given the fact that injection temperatures are known to be biased high relative to bucket values, one can easily envision a scenario in which an apparent increase in SST could arise simply from a change in the relative abundance of bucket versus injection temperatures. No one knows for sure how the different measurements have been blended together over the decades.

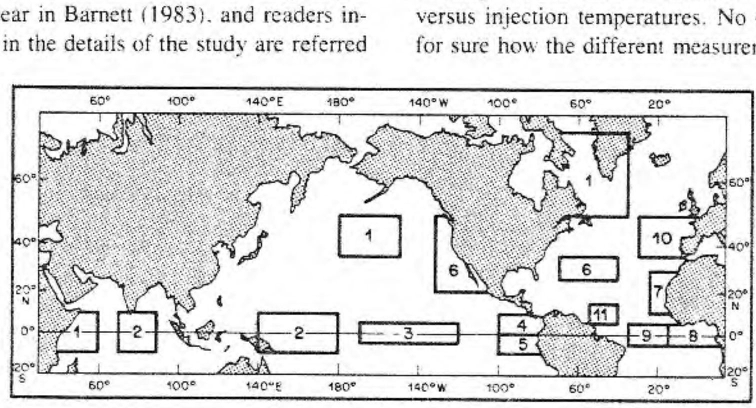

FIGURE 1 (*Barnett*)
Large area averaging regions used in this study.

The first approach to evaluating the potential problem was to take large area averaged SSTs from the Marine Deck and compare them with estimates of surface temperature obtained from hydrographic data averaged in exactly the same way. The geographic regions where this procedure was carried out are shown in Figure 1. Figure 2 shows comparisons, for proxies of the Northern Hemisphere oceans, of the estimated pentad to pentad changes in surface temperature from the two measurement techniques. The results suggest that in the last three to four decades the SSTs measured by the ships are indeed higher than the hydrographic data by approximately the amount expected from the bucket/injection temperature bias. However, the limited, noisy nature of the hydrographic data preclude a more quantitative comparison.

It is also interesting to note on Figure 2 that both measures of SST appear to deviate substantially in their phasing from the Northern Hemisphere AT estimated by Jones *et al.* (1982). This suggests that the behavior of surface temperature over the oceans may be significantly different than that over land, a result discussed earlier by Paltridge and Woodruff

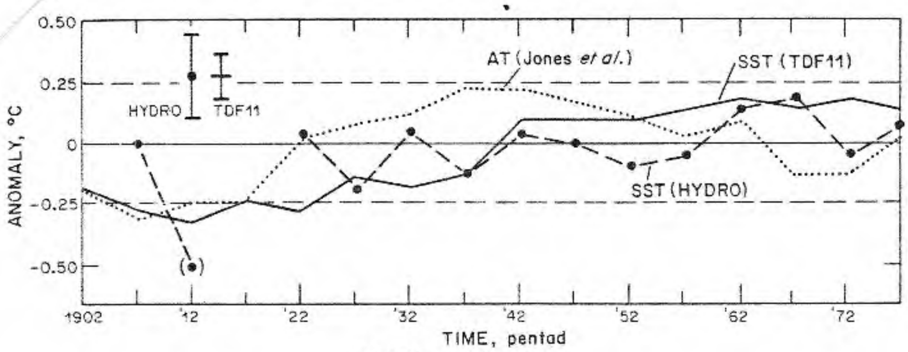

FIGURE 2 *(Barnett)*

Pentad averaged SST anomalies from the Marine Deck (solid line) and from hydrographic data (dashed line) representative of the Northern Hemisphere oceans. The error bars refer to ±1 "typical" standard deviation computed from the five yearly values used to obtain the pentad average. Dots in parentheses denote two years of data or less. Also shown for comparison is an estimate of Northern Hemisphere air temperature (AT) from Jones et al. (1982) based mainly on land data.

(1981). If this conclusion is true, then an adequate representation of Northern Hemisphere temperature change and certainly "global" temperature change has yet to be made.

Another approach to investigating the potential SST bias problem was to compare the SSTs in the large averaging areas shown in Figure 1 with estimates of AT obtained from the ship data. Note that the AT values and averaging are carried out in exactly the same manner as the SST calculations. One result of these considerations, shown in Figure 3, suggests that the AT anomalies measured from the ships were larger in the period 1900 to 1940 than the SST anomalies. The reverse situation appears to apply from 1940 to the present. These results are graphically demonstrated in Figure 4. As an aside, Figure 3 also demonstrates that AT measured by the ships seems to follow the SST with regard to phasing (but not magnitude) and again to differ substantially from estimates of Northern Hemisphere AT made largely from land data.

The results of Figure 4 suggest a rather abrupt change in the difference of anomalies of SST and AT occurring in the 1940s. The possibility that this abrupt change represents the change of climatic state was explored by Barnett (1983). For present purposes it is simply stated that part of the change may be real, but part of it also appears to be due to merging data sets wherein the SSTs were presumably taken largely by bucket prior to 1940 and largely by injection after 1940.

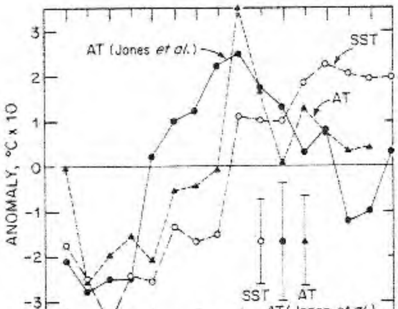

FIGURE 3 *(Barnett)*

Pentad averages of anomalies of SST from the Marine Decks and surface AT from the same source. The series are representative of the Northern Hemisphere oceans. Also shown for comparison is an estimate of Northern Hemisphere AT from Jones et al. (1982) based mainly on land data. The error bars refer to ±1 "typical" standard deviation computed from the five yearly values used to obtain the pentad average.

The important point of Figure 4, if it does truly represent conditions over all the oceans, is that it appears that a significant fraction of the change in SST over the ocean since 1900 may in fact be due simply to the replacement of bucket measurements with injection temperature measurements. Since nobody knows how these two measurement techniques were blended over the period of record, it is difficult to say much more. An apparent *a priori* correction scheme for this effect was introduced by Folland and Kates (1982) and is also shown on Figure 4. The origin of this correction scheme is unknown to the author.

The data sets used to obtain the result shown on Figure 3 include decks from the Historical Sea Surface Temperature Data (HSSTD) projects, which were thought to be largely free of the injection/bucket bias problem, plus decks known to include both types of observations. The apparent bias effects are equally clear in both types of data. This result suggests that either the HSSTD sets are subject to contamination via instrument bias or that the ocean and atmosphere had rather large relative temperature differences between the first forty years of this century and the last forty years. This latter conclusion is hard to rationalize, particularly in light of the number of studies that have shown clearly a bias between bucket and injection temperatures.

If one excludes this possibility, it appears that the data sets thought to be "clean" and not subject to bucket/injection temperature problems are indeed contaminated. This conclusion, if true, will make it very difficult to reliably estimate the magnitude of temperature change over the surface of the oceans since the turn of the century.

It appears that hemispheric and global estimates of surface temperature change must include estimates of AT changes over the world oceans. These estimates, in turn, will be exceedingly hard to make in a precise manner since instrument bias problems seem to have substantially affected the data sets. Indeed, 30-50% of the apparent change in surface temperatures over the oceans could well be due to these bias effects.

The Marine Decks have provided us with virtually all the information we now have regarding changes in ocean climate. It is abundantly clear that these data sets represent a gold mine for future studies of climatological variability. It is important to realize, however, that the sets do have limitations. Perhaps in time and with additional study, many of the apparent problems discussed in this note can be "fixed." Until that time, the user had best exercise caution in studying relatively minor climate changes with a large, noisy, and potentially biased data set.

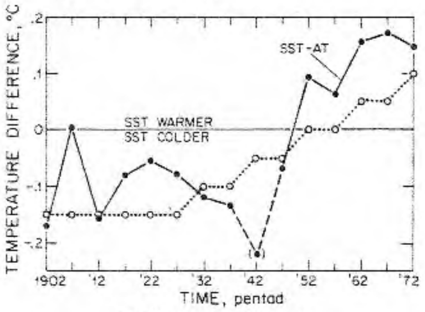

FIGURE 4 *(Barnett)*

Pentad averaged differences between SST from the Marine Deck and AT from the same data source (solid line). The a priori instrument bias corrections suggested by Folland and Kates (1982) are shown by open circles and dashed line.

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Notice

El Niño and the Southern Oscillation: A Scientific Plan, a 72-page report published in September 1983 by the National Academy of Sciences, outlines a multi-year program of observations and research to advance our understanding of the El Niño phenomenon and the Southern Oscillation. A limited number of copies are available from the NAS Board on Atmospheric Sciences and Climate, 2101 Constitution Avenue, Washington DC 20418 (tel: 202-334-3518).

Meetings

AGU Fall Meeting, 5-10 December 1983, San Francisco

Sessions of interest are (a) El Niño 1982-83 and (b) El Niño in the California Current System. Contact American Geophysical Union, 2000 Florida Avenue NW, Washington, DC 20009 (tel: 202-462-6903).

Ocean Sciences Meeting, 23-27 January 1984, New Orleans

Sessions of interest are (a) El Niño and Climate Variability, (b) Ocean Heat Transport: Climate, Paleoclimate, and (c) El Chichón, Global Climate, Chemistry. Contact American Geophysical Union, 2000 Florida Avenue NW, Washington, DC 20009 (tel: 202-462-6903).

SEQUAL/FOCAL Meeting, 27 February-1 March 1984, Paris

The third SEQUAL/FOCAL meeting will be held at the UNESCO building in Paris. Primary objectives are (1) a review of the field program, including presentation of data and preliminary results, and (2) a discussion of data exchange and future collaboration. Contact Dr. Yves Tourre, Muséum National d'Histoire Naturelle, Laboratoire d'Océanographie Physique, 43-45 Rue Cuvier, 75231 Paris Cedex 05, France (tel: 707-85-44; telex: 270686).

Sixteenth International Colloquium on Ocean Hydrodynamics, 7-11 May 1984, Liège, Belgium

This year's subject will be "Coupled Atmosphere-Ocean Models," with emphasis on the physical basis of climate predictability for time scales from several weeks to decades. Contact Dr. J. C. J. Nihoul, Modelenvironnement, University of Liège, B6, Sart Tilman, B-4000, Liège, Belgium (tel: 041-56-13-59).

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