Comparison of Observed and Model Wind Velocities

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(Manuscript received 11 July 1981, in final form 9 November 1981)

ABSTRACT

The global band wind analysis produced by the Fleet Numerical Oceanography Center (FNOC) has been compared with direct buoy observations of winds in the Central Equatorial Experiment. Using the six months of available data it is concluded that the FNOC winds are generally lower in variability than the actual observations. In most cases the spectral coherence between the wind products and the buoy observations is not good. Discrepancies in model results versus buoy observations do not appear to be related to lack of real-time input data for analysis.

1. Introduction

Adequate knowledge of tropical winds over the oceans is important in attaining an understanding of the large-scale, low-frequency oceanic variability in that area. At present, most of the data concerning tropical surface marine winds comes from routine but scattered mariners' reports and island observations. Geostationary satellite cloud-wind data have recently been used to infer surface-wind velocity (Halpern, 1979) and may thus be a future source of low-level wind data. In spite of the sparse data, a synoptic 12 h global tropical wind analysis has been produced by the Fleet Numerical Oceanography Center [FNOC (formerly Fleet Numerical Weather Central, FNWC)], Monterey, since 1971. Could this wind information be useful for scientific studies?

Estimation of the tropical wind fields presents special problems:

1) In the equatorial zone the geostrophic flow does not dominate the surface wind, rendering it impossible to calculate winds from pressure gradients.

2) Ship traffic is relatively sparse and so there is a paucity of mariners' surface reports except along well-traveled trade routes.

3) "Weather" is often associated with subgrid-scale convection.

4) The Intertropical Convergence Zone (ITCZ) represents an extremely important, but nearly discontinuous, feature of the wind field. In view of these problems it is surprising that a comparison of the FNOC product with an independent set of wind data has not been published previously in the open literature. In view of the possible scientific utility, yet unknown quality, of the FNOC product such a comparison seems overdue.

Two independent anemometer wind data sets have been collected from automatic buoys moored at 1) 6, 7 and 8°N along 150°W in the central equatorial Pacific from November 1977 to March 1978; and 2) 8.5°N, 151°W from August 1976 to October 1976. Different statistical properties of these data have been compared with areal averages of simultaneous FNOC tropical wind estimates from nearby grid points. Note these buoy positions are in, or very close to, the ITCZ and so offer a unique and demanding test of the FNOC fields. The results of these analyses are presented after a discussion of the FNOC tropical field analysis and the buoy wind observations.

2. Wind observations and analyses

a. *FNOC operational tropical wind analysis (global band)*

Surface winds in the tropical Pacific, representative of nominal 19.5 m anemometer heights, were obtained from FNOC. The FNOC wind analyses were 12 h synoptic fields on a Mercator secant projection grid with 2.5° spacing in longitude and latitude at the equator. The grid extends around the world (Grayson, 1971). Although only 0000 and 1200 GMT analyses were archived, the analyses actually proceed in 6 h synoptic steps. From 15°N to 15°S a first estimate of the FNOC field is made by combining 90% of the previous analysis with 10% of

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0021-8952/82/030314-07$05.75

the climatological wind field. This field is then blended with recent observations to develop a "final" analysis. The blending procedure involves a two-cycle interpolation process with relatively small influence radii of 555 and 278 km, respectively. In each cycle, wind observations within the radius of influence are allowed to modify the first guess field. The weight of each observation in this modification process depends inversely on its distance from a grid point, lapsed time since observation, and type of reporting platform. If there were no new data in a synoptic period, the first estimate becomes the final analysis for the next synoptic period. In this way the analysis would decay exponentially to climatology with an *e*-folding time of 2½ days. However, there is generally some scattering of new information fed into the final analysis product. In the regions and periods of this study, the number of reports for any 12 h period never exceeds 10. Such high values were rare and the number of reports per 12 h period is generally less than 4. By extrapolation, the average number of reports in a 6 h synoptic period within a 555 km radius of influence would, on average, be less than 2, and within a 278 km radius of influence would usually be less than 1. Clearly, the analysis for this region will be smoothed and weighted by climatology.

b. *Buoy winds*

The observed winds used in this study come from measurements made by a vector averaging wind recorder (VAWR) mounted at 3.5 m above the sea surface on a moored buoy [described by Halpern (1978, 1979)]. Since the measurement periods are normally accompanied by wave heights that are less than a meter high, the wind sensors were practically never in the shadow of a wave crest. Halpern (1979) has found that the measured winds are probably accurate to within ±1 m s^{-1} in speed and ±20° in direction.

The buoy data available for independent comparison with the FNOC products were collected in two different latitude regions at two different times of the year. The first data set, hereafter called Case 1, were obtained during the NORPAX Pre-Shuttle Experiment and generally extend from 6 November 1977 through 22 March 1978. The buoys were located at latitudes 6, 7 and 8°N and longitude 150°W. The length of record at the two southern latitudes was a maximum possible (138 days) while at 8°N a 102-day record was obtained. During this time period the ITCZ passed over the buoy array. The second set of observations (Case 2) come from a buoy moored at 8.5°N, 151°W. The period of observations extends from 2 August 1976 to 29 October 1976 for a total of 88 days. All buoy data were available as 15 min averages. For comparison purposes they were center-averaged to represent time 0000 and 1200 GMT to conform with the time that the FNOC product was produced.

3. General characteristics

a. *Case 1*

The individual buoy time series of zonal and meridional winds were averaged together to give a single time series for each component. FNOC winds at four grid points around 7°N, 150°W were also averaged to give a comparable areal mean time series. The averaging was done for several reasons. First we are interested in performing a large-scale comparison between the model and observed. The spatial average will help us to do this by reducing high-frequency fluctuations which the model winds could not be expected to reproduce. Furthermore, separate analysis (Halpern, 1979) has showed that fluctuations in the wind field observed by the buoys were all highly coherent, thus suggesting the averaging process. The FNOC winds on the scale which we were studying are also highly coherent for a single buoy located at 7°N, 150°W and a single FNOC grid point located at the same position. Results of that analysis are fundamentally the same as those presented below. Thus we feel that the averaging exercise has not affected the general conclusions we will draw.

The time series of u and v components for the FNOC and buoy data are shown in Fig. 1. The slope, mean, standard deviation, minimum, maximum and associated 95% confidence limits for the u and v series are shown in Table 1. The results are as follows:

1) The FNOC 102-day mean winds were higher by 2 m s^{-1} in the u component and nearly 4 m s^{-1} in the v component. The mean meridional component computed from the moored observations was near zero because during the test period the position of the ITCZ moved from 8N to 6°N (Halpern, 1979). The difference between the 102-day mean FNOC and buoy v components may be due to the influence of low-level cloud motion vectors on the FNOC analysis, since the cloud motions are not representative of the surface meridional motion near the ITCZ (Halpern, 1979). The possibility that the differences could be accounted for by the difference in buoy anemometer height (3.5 m) and the nominal 19.5 m height for the FNOC product was investigated by raising the buoy winds to an equivalent 19.5 m height assuming a logarithmic wind profile and a von Kármán's constant of 0.4. Typical roughness lengths were used as were drag coefficients representative of both stable and unstable (ITCZ) conditions. We found that no reasonable choice of parameters gave large enough increases in the buoy winds to explain the difference in the means. The average number of ship observations contributing to an FNOC analysis

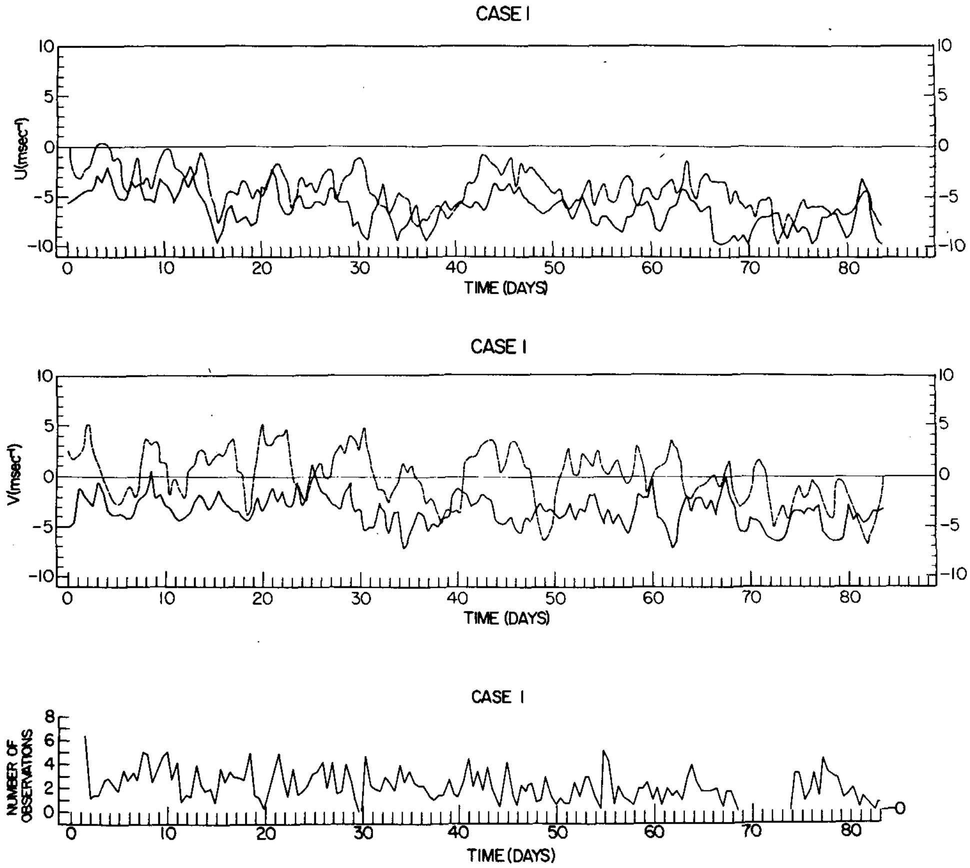

FIG. 1. Upper two panels: Time series of *u* and *v* components for buoy observations (dashed) and FNOC analysis (solid) for the period November 1977–January 1978. Lower panel: Average number of ship observations contributing to the FNOC analysis at each grid point in the region of interest.

at any grid point in the region of interest is shown in Fig. 1. Discrepancies between FNOC and buoy time series do not appear to be related to these numbers of observations.

2) The standard deviations of the FNOC product are roughly one-half of those of the observed wind. This is not surprising considering the manner in which the FNOC winds are constructed. The distribution of this variance difference in frequency space is discussed in Section 4.

TABLE 1. Case 1: Statistics for buoy and FNOC winds for the period 7 November 1977–29 January 1978 near 7°N, 150°W. Also shown are the 95% confidence limits where appropriate.

	Buoy	FNOC
u component		
Mean (m s^{-1})	−4.51 ± 0.26	−6.58 ± 0.12
Standard deviation (m s^{-1})	2.02 ± 0.24	0.93 ± 0.11
Slope (m s^{-1} day^{-1})	−0.043 ± 0.178	−0.038 ± 0.186
Minimum (m s^{-1})	−9.99	−9.80
Maximum (m s^{-1})	0.50	−1.95
v component		
Mean (m s^{-1})	−0.07 ± 0.34	3.65 ± 0.20
Standard deviation (m s^{-1})	2.66 ± 0.32	1.59 ± 0.19
Slope (m s^{-1} day^{-1})	−0.042 ± 0.053	−0.022 ± 0.157
Minimum (m s^{-1})	−6.80	−7.20
Maximum (m s^{-1})	5.10	1.07

3) The regression slope for the *u* and *v* components are not statistically different from zero.

b. *Case 2*

The time series of buoy anemometer winds at 8.5°N, 151°W, and FNOC winds are shown in Fig. 2 for the 88-day period, 2 August 1976–29 October 1976. The FNOC analysis was again interpolated from the four nearest grid points to the buoy location in order to create a single time series for comparison purposes. As above, the spatial homogeneity of the FNOC field (Section 2) showed this interpolation did not significantly effect the comparison.

A linear regression again was made on the zonal and meridional wind components. The mean and standard deviation (after trend removal) plus the slope, minimum and maximum for the *u* and *v* components are presented in Table 2. The results were as follows:

1) The FNOC 88-day mean winds were ~1.5 m s^{-1} less than the mean buoy wind. This difference

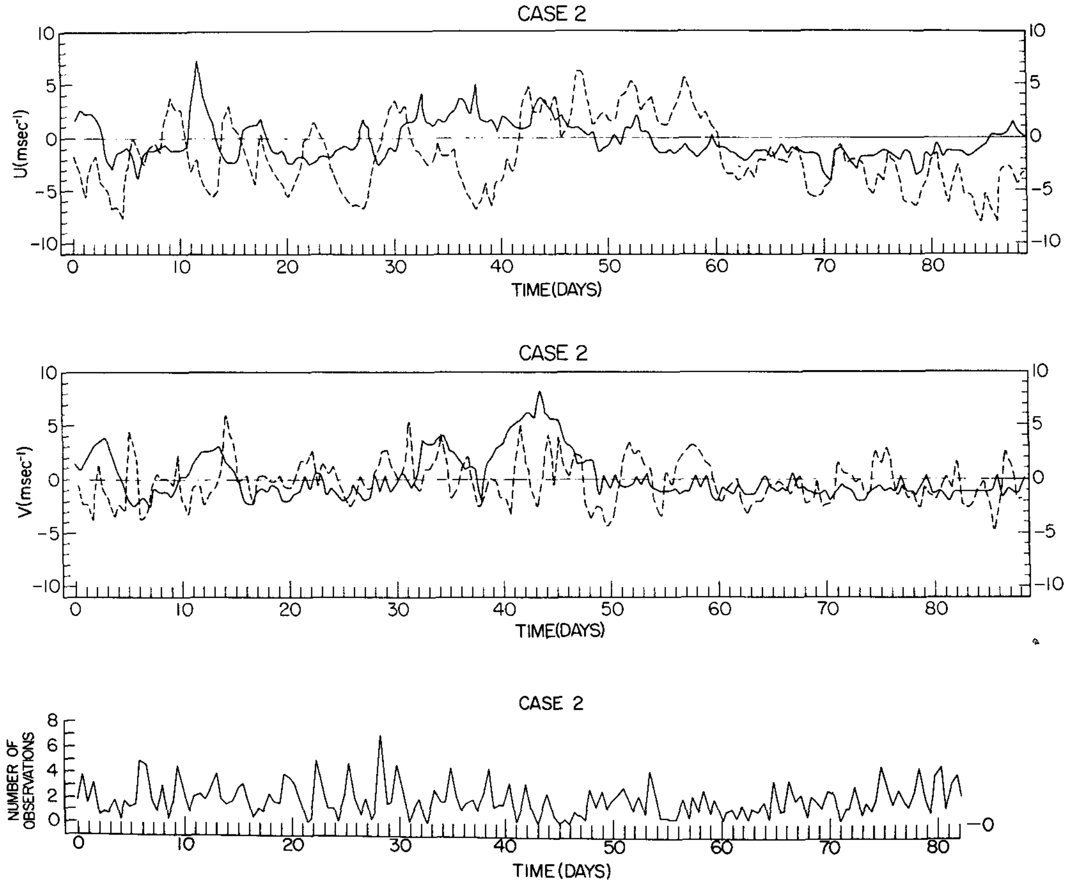

FIG. 2. Upper two panels: Time series of u and v components for buoy observations (dashed) and FNOC analysis (solid) for the period August 1976–October 1976. Lower panel: Average number of observations contributing to the FNOC analysis at each grid point in the region of interest.

obviously cannot be explained in terms of anemometer height differences and a logarithm wind profile. The v components means are essentially zero and indistinguishable from each other at the 95% level.

2) The standard deviations of the FNOC product are again a factor of 2 less than that observed for the u component but virtually identical to that observed for the v component.

3) The regression slopes show the same tendency for both components but are significantly different from zero only for the buoy v component (and then just barely).

4. Spectral comparisons

In this section we compare the spectra and cross-spectra computed from the buoy and FNOC time series.

a. Case 1

Spectral estimates for the spatially averaged, detrended time series of the u and v components (Section 3) are shown in Fig. 3. The agreement between the buoy and the FNOC product for the u component is good although the latter tends to underestimate both the very lowest and highest frequency energy by approximately a factor of 2. The power spectra for the v components shows that the FNOC product is generally low by a factor of ~3 for frequencies below ~0.5 cycles per day (cpd). In either case, a

TABLE 2. Case 2: Statistics for buoy and FNOC winds for the period 2 August 1976–29 October 1976 near 8.5°N, 151°W. Also shown are the 95% confidence limits where appropriate.

	Buoy	FNOC
u component		
Mean (m s^{-1})	−1.89 ± 0.42	−0.43 ± 0.23
Standard deviation (m s^{-1})	3.43 ± 0.40	1.89 ± 0.22
Slope (m s^{-1} day^{-1})	−0.014 ± 0.072	−0.018 ± 0.026
Minimum (m s^{-1})	−7.95	−4.35
Maximum (m s^{-1})	6.10	7.31
v component		
Mean (m s^{-1})	0.42 ± 0.26	0.00 ± 0.27
Standard deviation (m s^{-1})	2.10 ± 0.24	2.18 ± 0.25
Slope (m s^{-1} day^{-1})	−0.006 ± 0.005	−0.021 ± 0.026
Minimum (m s^{-1})	−4.80	−2.60
Maximum (m s^{-1})	5.70	7.00

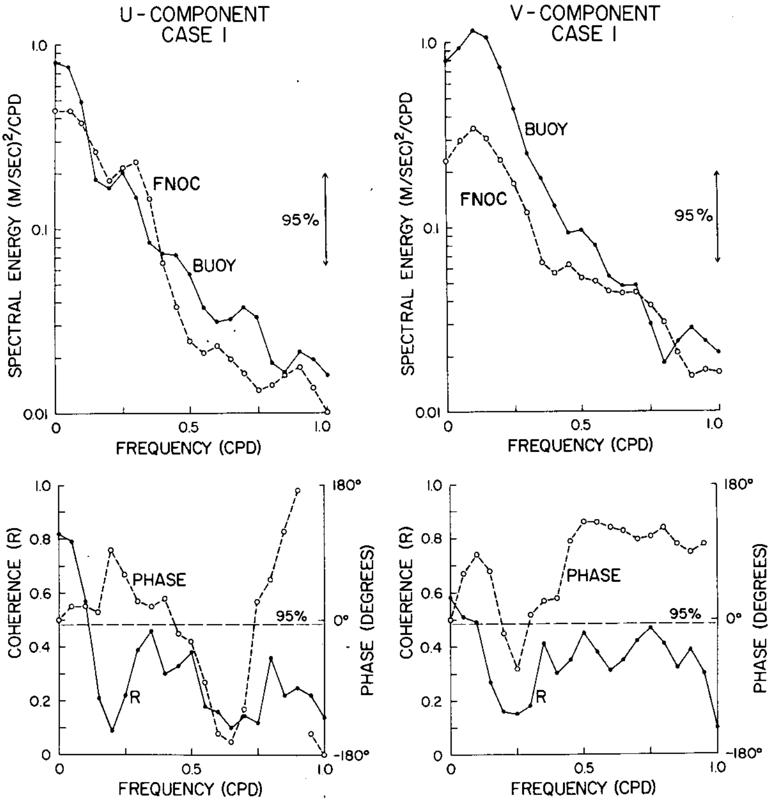

FIG. 3. Upper panels: Power spectra of the u and v components from buoy and FNOC wind analyses (Case 1). Lower panels: Coherence and phase between simultaneous estimates of u and v (Case 1).

strong diurnal cycle is not apparent in either the buoy data or the data from RNOC.

In view of the confidence limits, we conclude that the comparison of the power spectra shows that (i) the agreement between the u components is good at all but the lowest frequencies (0.05 cycles day^{-1}) where the FNOC winds appear low, (ii) the power spectra of the model v-components are generally lower by factors of 2–3 than those observed for frequencies below 0.5 cycles day^{-1}; and (iii) the general shape of the power spectra are comparable within 95% confidence limits.

At low frequencies (i.e., <0.1 cpd) the coherences between the u components of the FNOC and buoy wind data (Fig. 3) were significant at the 95% confidence level and the phase differences were such that ~40% of the total variances can be explained by a linear relationship, not significant considering the size of the coherence. This indicates that ~40% of the total variances can be explained by a linear relationship. At frequencies >0.1 cpd the coherences of the u and v wind variations were too small to be significant with 95% confidence. At frequencies below 0.1 cpd, the phase difference is significant with the buoy winds leading FNOC estimates by approximately two days.

The phase difference may be an artifact of the FNOC analysis, since winds from the previous day may figure prominently in the next day's product. The general conclusion to be drawn from the illustration is (again) that averages of the FNOC products over periods of 10 days or longer during the time period covered by Case 1 would give a reasonable approximation to the v variations although the magnitude of the fluctuations will be underestimated.

b. Case 2

The power spectra of the detrended time series for the u and v components is shown in Fig. 4. Many of the observations regarding these power spectra are similar to those that were drawn in Case 1. Inspection of the figure and consideration of the associated confidence limits suggest the following conclusions:

1) The power in the u components observed from the buoy are higher by a factor of 2–3 across the entire frequency range. Again the FNOC model is underestimating the natural variability.

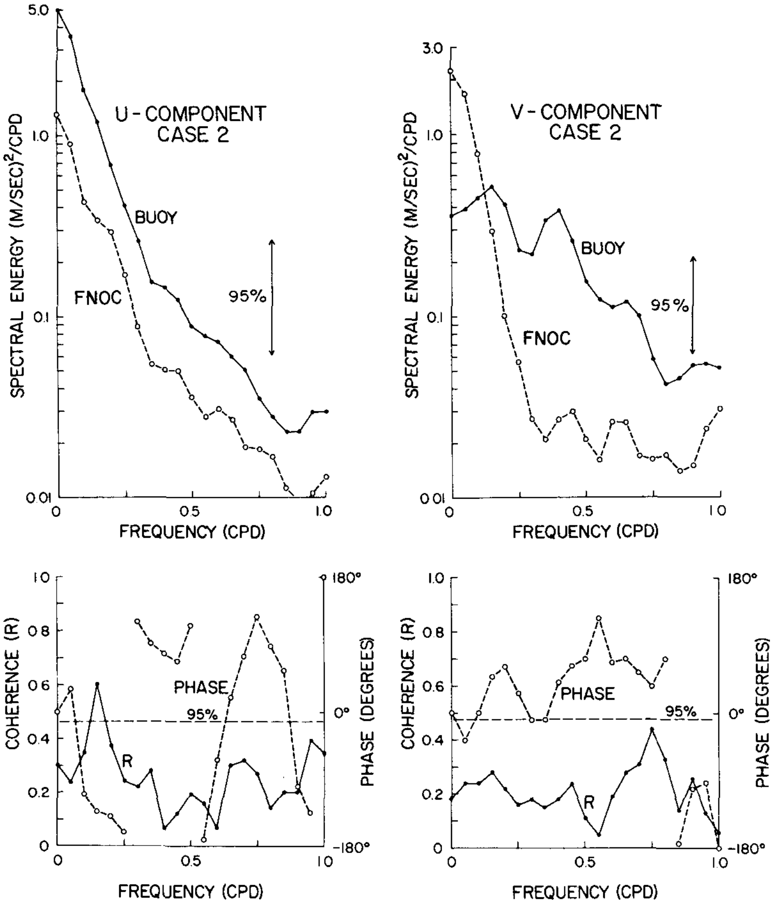

FIG. 4. Upper panels: Power spectra of the u and v components from buoy and FNOC wind analyses (Case 2). Lower panels: Coherence and phase between simultaneous estimates of u and v (Case 2).

2) The power spectra for the model v components are lower by factors of 5–10 over much of the frequency range between 0.2 and 1.0 cpd. The model power spectrum is more energetic at the lowest frequencies than the spectrum of observed wind. This is apparently due to the several "episodic events" that the model time series demonstrates (see Fig. 2). The reality of these events seems suspect based on the buoy observations. In fact the "events" may be due to the inclusion of direct observations into a field that is otherwise at its climatological norm. Also in this case the shapes of the power spectra for the v components are not in good agreement.

3) From Fig. 4 we conclude that there is little or no significant coherence between the model estimates of u and v components and those observed from the buoys. These results are in contrast to that found in Section 4a where it was concluded that for relatively low frequencies the model results and observations were in fair agreement.

5. Summary

If the cases reported in this study are representative then we may make the following conclusions:

1) The FNOC product generally shows temporal variability that is 2–4 times lower than that estimated for the observed winds. The 102-day means also differ significantly between the product and observation. Part of this difference may be due to the fact that the observed winds represent more or less a point in space whereas the FNOC winds represent a large-scale average. However, this problem cannot explain the difference in means nor the dissimilarity at low frequencies.

2) In general the low-frequency coherence between the observation and model winds is only fair. In one case it was marginally significant, in another it was not significant at all. Thus it appears that the quality of the FNOC product is rather variable in time (and probably space also). It would be most

useful if a "quality index" were provided with the product since it would be useful to know if wind estimates are basically climatology or heavily infused with direct observations; a "quality index" of the FNOC product should be given careful consideration based on this research.

3) In view of the present uncertain quality of the model results, it is doubtful if they can be used at this time for specific scientific studies.

4) The framework and methodology developed by FNOC to provide the global band analysis offers considerable promise if additional data can be made available for the wind field estimates. It seems most likely that this data will come from satellite cloud motion products or other satellite sensing systems.

Acknowledgments. The authors wish to thank the Fleet Numerical Oceanography Center for their cooperation, in particular Lt. Cmdr. Will Rogers, Jr., for his assistance with the data, and for information regarding the global band analysis. The excellent drafting was done by Fred Crowe.

This work was funded by the National Science Foundation under Grant OCE 76-80183.

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