NOTES AND CORRESPONDENCE

Examination of the Strengthening of Wintertime Mid-latitude Westerlies over the North Pacific in the 1970s

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Abstract

Strengthening of the wintertime mid-latitude westerlies over the North Pacific since the mid-1970s is examined in wind velocity and sea level pressure (SLP) fields computed from the ship-report data archived in the Comprehensive Ocean-Atmosphere Data Set. Changes in the observed wind fields between 1966–75 and 1976–85 are consistent with geostrophic winds based on the difference of the SLP fields between the two decades. This fact confirms that the strengthening of wintertime mid-latitude westerlies in the latter decade over the North Pacific occurred in the real world. Wind fields of the annual mean and the other three seasons are also examined by the same method, and the ship-report wind velocity fields for these averages also have features consistent with the wind fields estimated from SLP.

1. Introduction

Marine meteorological elements such as air temperature, sea-level pressure (SLP), wind velocity, and humidity are key variables for understanding air-sea interactions. By using these data, air-sea heat and momentum transfers between ocean and atmosphere can be estimated, and these fluxes are important for the response of the ocean to the atmospheric forcing and its reverse response. Therefore, observing and/or monitoring marine meteorological conditions in the whole ocean, and archiving these data are important aspects of field observation and monitoring programs such as the Tropical Ocean and Global Atmosphere (TOGA; Webster and Lukas, 1987), the World Ocean Circulation Experiment (WOCE; *e.g.*, U.S. WOCE, 1992), and the Global Ocean Observing System (GOOS).

As well as ongoing field programs, a great deal

of effort has been made to prepare datasets of marine meteorological elements. In 1987, the Comprehensive Ocean-Atmosphere Data Set (COADS) was released by NOAA (Woodruff *et al.*, 1987). Subsequent investigations have studied various aspects of air-sea interaction processes using the COADS and a great amount of knowledge has been accumulated.

In the course of studies, there are claims of long-term changes in wind fields estimated from the COADS: in some regions, long-term trends of increasing wind speeds have been documented (Cardone *et al.*, 1990; Ward, 1992; Kutsuwada, 1994). Cardone *et al.* (1990) examined the long-term ship-report data in detail. They pointed out that the trend toward strengthening wind can be attributed to two main reasons: one is the incorrect conversion from Beaufort force to wind speed, and the other is the increasing height of anemometers on ships. Ward (1992) also showed that in several selected regions there is a mean increase in reported

wind speed of 16 % which cannot be explained by trends in geostrophic winds derived from seasonal mean SLP. Kutsuwada (1995, personal communication) investigated the heights of anemometers on ships and reported that the average height was 26 m in 1970 and 37 m in 1989.

Recently, Yasuda and Hanawa (1996) calculated the temporal change of the Sverdrup transport for the North Pacific Ocean, and pointed out that a spin-up of the North Pacific subtropical gyre has occurred since the mid 1970s. They used the dataset of wind stress estimated from the raw data archived in COADS by Tohoku University (Iwasaka and Hanawa, 1990; Tanimoto, 1993). They also showed that the spin-up of the gyre expected from the Sverdrup transport is consistent with the temporal change of the heat content difference between both sides of the Kuroshio Extension. That is, this qualitative agreement of Sverdrup transport and heat content difference suggests that the temporal change of the wind stress data is significant and plausible. The strengthening of the wintertime mid-latitude wind stress fields since the mid 1970s can be also seen in the other two independent datasets by the JMA (1994) and Kutsuwada and Teramoto (1987) which are also computed from ship-report wind data (not shown here).

Changes in the North Pacific atmospheric circulation and ocean conditions during the mid-1970s have been documented by many authors, *e.g.*, Nitta and Yamada (1989), Trenberth (1990), and Tanimoto *et al.* (1993). By singular value decomposition analysis of SST and 500 hPa geopotential height anomaly fields, and SST and SLP fields in winter, Tanimoto *et al.* (1996) found an atmospheric disturbance similar to the PNA (Pacific/North American) teleconnection pattern as the perturbation. The PNA-like disturbance documented by Tanimoto *et al.* has been actively excited since the mid-1970s. This corresponds to an eastward shift and development of the Aleutian Low in winter, and stronger wintertime mid-latitude westerlies in the decade since 1976 than in the decade before 1975. This is the same finding as by Trenberth (1990), and Trenberth and Hurrell (1995).

The purpose of this paper is to check whether or not the strengthening of wintertime mid-latitude westerlies over the North Pacific since the mid 1970s is a real phenomenon. Specifically, we will show that the difference in wind field between the two decades of 1966–75 and 1976–85 is significant. The remainder of this paper is organized as follows. In Section 2, the data used and the method employed are described. In Section 3, the results are presented for the Northern Hemisphere winter season, and in Section 4, the results for the annual mean fields and the other three seasons are described. A summary is given in Section 5.

2. Data and method

2.1 Data

The datasets of wind and SLP used are those computed from the individual ship-reports archived in the COADS. Monthly means are calculated for the 5° latitude-longitude areas for the world ocean and the data length is 41 years from 1950 to 1990: the data from 1950 to 1979 were prepared by Iwasaka and Hanawa (1990), and from 1980 to 1990 by Tanimoto (1993). Please refer to the original articles for details on the data processing procedures.

In the present study, seasonal mean data are calculated using monthly mean values: winter values, for instance, are calculated as the average of the three consecutive months from December of the previous year to February.

2.2 Adjustment of pressure observation to sea level

In the ship reports, the atmospheric pressure is not the “observed pressure” but, instead, a corrected “sea level pressure (SLP)”. In order to convert from the observed pressure to the SLP, the Japan Meteorological Agency (JMA, 1985) prepares the correction tables in the book of “Guideline for Marine Meteorological Elements Observation”, by which the correction factor can be easily obtained from the atmospheric temperature and the height of the barometer from the sea surface.

The COADS, therefore, do not suffer from the height change of barometers installed on the merchant vessels, in contrast with anemometer data. Note that no attempt has been made to adjust the wind observations to sea level values.

2.3 Verification method

A simple verification method is employed, which has been used previously by Ward (1992). That is, the difference of SLP fields between the two decades of 1966–75 and 1976–85 is calculated, and the geostrophic wind is calculated for this pressure difference field. If the estimated geostrophic wind fields and the ship-report wind fields are consistent in magnitude and direction, it can be said that the ship-report wind fields are trustworthy.

Of course, since the observed wind is the one within the atmospheric boundary layer above the sea surface, exact coincidence between the two cannot be expected. In general, the magnitude of the observed wind is smaller than that of the estimated geostrophic wind due to surface drag, and the direction tends to slightly veer towards the direction of the pressure gradient force due to the Ekman layer dynamics: from high pressure to low pressure.

3. Results

3.1 Differences in the wind fields in the two decades

Figure 1 shows the difference (the latter minus the former) of mean wintertime wind fields between

Fig. 1. Difference field of mean wintertime winds observed between the two decades of 1966-75 and 1976-85.

Fig. 2. As in Fig. 1 but for difference field of SLP. The contour intervals are 0.5 hPa.

1966-75 and 1976-85. A large-scale cyclonic anomalous flow centered on 45°N, 170°W appears in the difference field. This pattern is consistent with a southward shift of the climatological surface westerlies in the latter decade. Areas of increasing wind greater than 2 m/s are found in the zonal band from 27.5°N to 32.5°N from 170°E to 150°W and in the region off the northern North America. For the southernmost latitude (0-5°N), all of the vectors exhibit a northerly component, though somewhat noisy. This wind distribution is in line with expectation from the state of SST warming: Nitta and Yamada (1989) have shown a warming of the entire equatorial Pacific since 1976.

3.2 Differences in the SLP fields in the two decades

Figure 2 shows the difference of mean wintertime SLP fields for the two decades. We can clearly see the strengthening and eastward shift of the Aleutian Low in the decade of 1976-85 with a pressure drop of 5 hPa centered at 45°N, 170°W. The zero pressure difference extends east-west at approximately 20°N. High pressure anomalies with small amplitude appear over the tropical ocean. High pressure anomalies also appear off the northern North American Continent and over the Okhotsk Sea.

It is noteworthy that if SLP data suffered from the long-term changes in vessel barometer height, the difference field must be low pressures everywhere over the North Pacific basin. However, the

Fig. 3. Geostrophic wind difference field calculated using the SLP difference field shown in Fig. 2.

Fig. 4. (a) Scatter plot of observed and calculated geostrophic wind differences. (b) Frequency distribution of the angle difference between the observed and calculated geostrophic wind directions. The angle bin size is 10 degrees. See the text for the definition of sign of angle.

SLP difference fields shown in Fig. 2 are systematically organized. Therefore, as mentioned before, SLP fields are reliable and capable to detecting wind field changes.

3.3 Comparison with geostrophic wind

By using the SLP difference field, we calculate the geostrophic wind. The geostrophic winds are estimated at the same grids as those of the wind vectors using a centered differential scheme. Calculations for the zonal band from 20°N to 55°N are shown in Fig. 3. The resemblance between the ship-report wind differences shown in Fig. 1 and the calculated geostrophic wind differences is apparent.

Figures 4a and b show the scatter plot of ob-

served and calculated geostrophic wind differences, and the frequency distribution of angle difference between the two winds, respectively. The sign of the angle difference is defined as positive anticlockwise measured from the calculated geostrophic wind differences to the observed wind differences. Magnitudes of the observed wind differences are, on average, 25 % smaller than those of the calculated geostrophic wind differences and most of the data take the angle difference from -10 degrees to 40 degrees with a mean value of 15 degrees.

A mean reduction rate of 25 % in magnitude of observed wind speed and alignment of 15 degrees in observed wind direction are quite reasonable, because their values are similar to those empirically ex-

Fig. 5. Differences of annual and seasonal mean wind fields between the two decades of 1966-75 and 1976-85 (the latter minus the former). (a) Annual mean, (b) spring, (c) summer, and (d) autumn.

pected from the Rossby number similarity law (*e.g.*, Kondo, 1982). In conclusion, the detected wind difference from the ship-report wind data between the two decades of 1966-75 and 1976-85 are consistent.

4. Difference fields for annual mean and other seasons

Examinations for the annual mean field and those of the other three seasons were also made. Figure 5 shows differences of annual and seasonal mean wind fields for the two decades, as in Fig. 1. In the annual mean, spring, and autumn, the wind difference fields in the mid-latitude have the same tendency as in winter: stronger westerlies, while in summer an elongated anticyclonic gyre appears. This summertime feature may indicate a strengthened subtropical high.

Figure 6, as in Fig. 3, shows geostrophic wind difference fields calculated using the SLP differences (not shown here). It is clear that the calculated geostrophic wind difference fields with the observed wind difference fields are very similar to each other, although the calculated geostrophic wind difference vectors distributed somewhat irregularly compared with those of the observed wind difference vectors. The data points associated excessive geostrophic winds are seen in near-coastal regions and in the Okhotsk Sea. SLP data taken in these regions seem to be erroneous due to the lack of sufficient data.

A scatter plot of the observed and calculated geostrophic wind speed differences (not shown here),

and frequency distributions of the angle difference between the two winds (not shown here), show almost the same tendency as those for winter calculation.

In conclusion, even in the annual and each seasonal mean wind fields, the ship-report wind fields can be well explained by those SLP estimated under the assumption of the geostrophic wind.

5. Summary

In the present paper, we examined the strengthening of the wintertime mid-latitude westerlies over the North Pacific since the mid 1970s in wind velocity, using SLP fields computed from the ship-report data archived in the Comprehensive Ocean-Atmosphere Data Set. It was found that changes in the observed wind fields between the two decades of 1966-75 and 1976-85 were consistent with geostrophic winds based on the difference of the SLP fields between the two decades. Therefore it was confirmed that the strengthening of wintertime mid-latitude westerlies in the latter decade over the North Pacific occurred in the real world. Wind fields of the annual mean and other three seasons were also examined by the same method, and the ship-report wind velocity fields for these averages also had features consistent with the wind fields estimated from SLP.

Fig. 6. As in Fig. 5 but for differences of geostrophic wind fields calculated from the SLP differences. (a) Annual mean, (b) spring, (c) summer, and (d) autumn.

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1970年代の北太平洋上冬季中緯度偏西風強化の検討

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1970年代半ば以降の北太平洋上冬季中緯度偏西風の強化を、船舶通報海上気象要素を収集した統合海洋気象データセット(COADS)から得られた風速と海面気圧を用いて検討した。その結果、1966年から75年と1976年から85年の2つの10年間の間の風場の差は、2つの10年間の間の海面気圧の差から地衡風の仮定のもとに計算された風場でよく説明できることがわかった。この事実は、北太平洋上で後者の10年間に冬季中緯度偏西風の強化が実際に起こっていたことを確認するものである。また、年平均の風場や他の季節に対しても同様の検討を行い、船舶通報海上風の2つの10年間の間の差は、同様に海面気圧の差から求めた風場でよく説明できることがわかった。