Marine Surface Wind Changes During 1978-1992: An Estimation Based on COADS

Henry F. Diaz
(NOAA/ERL/CDC, 325 Broadway, Boulder CO 80303, U.S.A)

Xiaowei Quan
(CIRES, University of Colorado, Boulder, CO 80309-0449, U.S.A)

Congbin Fu
(IAP/CRL, P.O. Box 2718, Beijing 100080, China)

Abstract

We have investigated the spatial pattern of marine surface wind changes for the month of January over the North Atlantic and North Pacific Oceans from 1978 to 1992. Compared to the correlation pattern of observed wind and geostrophic wind based on monthly mean NMC analysis data, the correlation of COADS surface winds with geostrophic wind based on COADS monthly mean sea level pressure are satisfactory over the regions where the number of observation is high enough to allow more than five observations per 4-degree box per month on average.

EOF analysis for the regions of high observed vs. geostrophic wind correlation produce similar patterns of the leading EOFs in the observed and geostrophic wind fields. Over both the North Atlantic and North Pacific Oceans, the large-scale wind changes exhibit a zonally symmetric dipole structure, i.e. westerly anomalies increase in the westerly wind belt at middle to high latitudes, and easterly anomalies increase in the trade wind region at lower latitudes.

Introduction

The existence of observational bias in the marine surface wind reports from ships has been a major concern when using such data to detect long-term climate signals and trends over the ocean (Ramage, 1987; Wright, 1986). The bias is especially significant during the periods from the middle 1960's to the end of the 1970's when major changes in the application of the Beaufort scale standards and the increasing use of anemometers were taking place (Cardone et al., 1990; Isemer and Hasse, 1991). Since the end of the 1970's, the methods used to observe the surface wind have become more consistent. As shown in Table 1, the relative ratio of the number of anemometer measurements versus those based on Beaufort estimation has increased by less than ten percent during the 10 years from 1980 to 1989. This is relatively small compared to about a forty percent change during the previous 13 years 1965 to 1977. Consequently, the systematic biases induced by such changes should be correspondingly reduced.

In a previous study of the zonal averages over the global oceans based on COADS interim product (Diaz et al., 1992), we showed that there had been an improvement in the agreement between zonal components of observed wind and geostrophic wind derived from the COADS sea level pressure field starting in the late 1970's. The improvement was reflected in closer agreement of the linear trends in area-average indices for January and July of the two wind fields. In the Northern Hemisphere both the observed wind and derived geostrophic wind had shown a strengthening of the westerly circulation although the magnitude is more or less according to season and latitude.

In this work, we further investigate the spatial structure of surface wind change at the ocean basin scale using EOF analysis. We will argue that due to the much smaller anemometer bias during the last decade, the time changes revealed in the monthly mean ocean surface wind data of COADS should reflect real climatic signals on the interannual to decade time scale, rather than the artificial effects.

Evaluation of the geostrophic wind method with monthly mean data

Following Ramage (1987), the surface pressure field, or the geostrophic wind derived from the pressure field, can be used as an non-biased reference to evaluate the changes in the observed wind fields. One uncertainty in the calculation of the geostrophic wind field is the irregular distribution of the ship observations both in time and space. Another concern is the non-geostrophic effects. Several methods have been proposed to improve the calculation. Lindau et al. (1990) suggested a method in which they first calculated mean observed wind direction, the angle between the base-line connecting two ships and the mean wind direction (β) and the geostrophic wind component normal to the base-line (Vgn); then by fitting sinusoidal functions to the curves of Vgn vs. β for each Beaufort Scale number they were able to obtain the geostrophic wind speed and ageostrophic angle. This method was devised to apply to individual ship reports. Ward (1992) calculated geostrophic wind using two-degree box seasonal mean pressure field converted from the COADS monthly mean product. In his calculation Ward deduced some preferred directions of the wind field for different ocean regions, the geostrophic wind is calculated only along these preferred directions with an allowance of $\pm 20°$ shift of the geostrophic wind direction from a prescribed preferred direction. He used an empirical formula (Garrat, 1977) to include the effect of friction on the wind speed. Deser (1993) used regression method to determine the friction term and she noted that over the tropical Pacific (20°N-20°S) the inclusion of the friction term is more important for calculation of the meridional component.

The data we have used here is the monthly mean product of COADS Release-1a (Woodruff et al., 1993), namely the observed wind fields, which were compared to the geostrophic wind calculated from the monthly surface pressure field in 4×4 degree boxes, assuming only simple geostrophic balance. In the following we first give an evaluation of our geostrophic wind calculations.

Ideally, the surface pressure field used to calculate the geostrophic wind should be observed simultaneously with the surface wind. However, this condition is not often able to be satisfied in many parts of the ocean by the network of ship observations. The use of monthly mean values will induce errors in the calculated geostrophic winds and weaken its correlation to the observed wind due to arbitrarily shifting the time of the observations within a month and the positions within a box. In order to evaluate how much this kind of error will affect our results, we have made similar calculations using the NMC analysis data of both twice daily and monthly mean products. The twice daily data used to calculate the geostrophic wind covers 90 days from December 1, 1991 to February 28, 1992 providing a total of 180 time points for each grid point. The monthly mean data set covers 84 months from January 1985 to December 1991.

The correlations between the observed wind and geostrophic wind are shown in Fig. 1. High correlation patterns are obtained for both zonal and meridional wind components. When the monthly mean data is used, the correlations are still high over most of the extra tropical oceans for the zonal wind component but they are significantly reduced for the meridional wind component. Since the NMC daily analysis are generally complete for each grid point, the difference between the correlation patterns of daily data and monthly mean data actually describes the effect of removing the short time and small spatial scale eddies. It is clear that for the purpose of using geostrophic wind to estimate the change of wind speed or the full vector wind field, it would be better to use the data with daily time resolution. Since the smaller scale eddies have a greater impact on the relative accuracy of the derived meridional geostrophic wind component, data that are capable of resolving these scales of atmospheric motions are necessary to get a good representation of the meridional wind by its geostrophic component.

Comparing the pattern of correlation coefficients between the observed wind and geostrophic wind based on COADS monthly mean (Fig. 2) to that of NMC monthly mean, we note that most of the NMC monthly mean correlation can be reproduced by COADS in the North Atlantic and North Pacific Oceans for the zonal wind component. Within these regions the number of observations is high enough to allow at least one data per month per box, and the number of observations range from 5 to 291 per month per box (see Fig. 2b of Diaz et al., 1992). In the Southern Hemisphere the high correlations in the correpsonding NMC monthly data are not reproduced by the COADS data, because there are much fewer observations in the southern oceans. For the meridional wind component the coverage of high correlation is even more reduced with the COADS monthly mean.

We have included a friction term in the calculation of geostrophic wind and found that the inclusion of this term has only a minor impact on the correlation patterns. We conclude that the largest source of error affecting the correlation pattern between geostrophic and observed wind comes from the distribution and number of observations.

The spatial structure of changes of the zonal wind over the northern mid-latitude oceans

To verify the wind changes shown in the time series of zonal means (Diaz et al., 1992), the spatial structure of the changes of surface zonal wind over the North Atlantic (70°N-10°N) and Northern Pacific (60°N-10°N) Oceans are further examined by means of EOF analysis. The geostrophic wind and observed wind show similar spatial and temporal patterns of change during the last decade.

North Atlantic Ocean (10°N- 70°N)

The EOF-1 patterns of the observed and geostrophic wind fields over the North Atlantic Ocean are shown in Figs. 3a & b. The north-south dipole of the North Atlantic Oscillation is the most significant feature in the behavior of both wind fields. One amplitude center is at 55°N with another of opposite sign at 30°N while the zero line tilts from 50°N in the west to the 38°N in the east. Fig. 3c shows the time series of the projections of the observed wind and geostrophic wind on its EOF-1 mode, i.e. the time series of the PC-Is, respectively. The strongest signal in the EOF-1 patterns may be contributed mostly by the interannual variations in the wind field. Although comparatively weaker to the interannual variability, an upward trend in the PC time series of this mode can still be observed. An increase of westerly anomalies in the middle and high latitudes (40°N-65°N) is shown together with an increase of easterly anomalies in the mid-to-low latitudes (10°N-40°N). The two PC-1 time series agree with each other very well as shown by the high value (0.94) of their correlation coefficient. In the EOF-2 of the observed wind (Fig. 4a), centers of the maximum amplitude of the change are found at the latitudes of zero amplitude in its EOF-1 mode. This observed mode is well reproduced by the EOF-3 of the geostrophic wind (Fig. 4b). Time series of both the PC-2 of observed wind and PC-3 of geostrophic wind show increasing values which corresponding to an intensification of these modes (Fig. 4c).

North Pacific Ocean (10°N-60°N)

The EOF-1 mode of observed wind over the North Pacific Ocean also shows a dipole structure. A positive center of maximum variability is located at about 25°N latitude while a negative one is at 50°N and the zero line at about 40°N. This mode is reproduced by the EOF-2 of the geostrophic wind (Figs. 5a & b). The time series of the PCs of these two modes show good agreement, with a correlation coefficient of r=0.90 (Fig. 5c). The low frequency trends appear to be in greater agreement than the interannual variations. The westerly anomalies have intensified at 50°N and easterly anomalies have intensified at 25°N during the last decade. The reason for the EOF-1 geostrophic wind not being able to represent the EOF-1 of observed wind is due to much larger variability in the geostrophic wind at the low latitudes. When we calculate the EOFs for the latitudes from 20°N to 60°N, the EOF-1 of observed wind is well reproduced by the EOF-1 of geostrophic wind (Figs. 6a & b) and the correlation coefficients of the two PC-1's is 0.67 with their linear trend being almost the same value (Fig. 6c).

Surface wind changes during 1979-92

Figure 7 shows the time series of the regional means of the zonal wind components of 1979-92. Regions are chosen according to two requirements: (i) presence of high geostrophic vs. observed wind correlation coefficients, and (ii) region encompassing the maximum centers of variability in the EOF-1 modes in the North Atlantic and North Pacific. The areas chosen for Fig. 7 and the trends and their t-test values are listed in Table-2. The largest observed increase of the surface zonal wind is the westerly anomalies over the mid-latitude North Atlantic. The linear trend is about 0.3 m/s per year. The westerly anomalies over the mid-latitude North Pacific showed a linear trend of about 0.1 m/s per year. Within the low latitude regions, the easterly anomalies over the subtropical

North Pacific and subtropical North Atlantic Oceans, the linear trends are smaller but of similar magnitude, about 0.2 m/s per year.

Conclusions

Using the geostrophic wind field as a non-biased reference, we have analyzed the surface wind change during the period 1978-92 based on the COADS Release-1a monthly mean product. The validation of the method is evaluated by comparing the pattern of geostrophic vs. observed wind correlation coefficient calculated from COADS monthly mean to those calculated from both of the NMC twice daily analysis and its monthly means. The latter ones are considered to be the optimum fields based on currently available data. The pattern of correlation coefficient of the NMC monthly means are well reproduced by COADS data for both the zonal and meridional wind components over the oceans where the number of observations are high enough to allow more than five data per box per month on average. High correlation values between u and ug cover extensive oceanic areas only for the zonal wind components. The meridional geostrophic wind calculated from the monthly mean pressure field exhibits good correlation compared to its observed counterpart only over small ocean regions. Thus, the geostrophic wind is not useful for evaluating the changes in observed meridional wind using the available monthly mean data, although its use may be adequate for this purpose, provided higher data densities are available.

Results of both the EOF analysis and regional means are consistent with the results based on zonally averaged wind data. The monthly mean zonal wind for January displays a clear signal that westerlies over the mid-latitude North Atlantic and midlatitude Pacific oceans and easterlies over the northern subtropical oceans have strengthened in the past decade. The largest increases are observed over the North Atlantic Ocean with a linear trend of about 0.3 m/s per year. The linear trend is about 0. 1 m/s per year over the North Pacific Ocean, and about 0.2 m/s per year over the subtropical Atlantic and subtropical Pacific oceans. The signals in the observed wind are well reproduced in the geostrophic wind field for zonal means, regional means and leading EOF modes. On such basis, we conclude that an increase of the January surface zonal wind observed from 1979-92, is likely a real climatic signal, rather than the result of artificial biases.

Acknowledgments

The NMC data made available by Kathy Smith, and Sandy Lubker of CIRES provided much technical support for extraction and manipulation of COADS data.

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Table 1: Ratio of number of Voluntary Observing Fleet ships with anemometers to total number of ships:

Year	Ratio(%)
1980	42.7
1981	42.8
1982	42.8
1983	43.7
1984	45.3
1985	45.5
1986	47.3
1987	46.7
1988	46.5
1989	48.7

Table 2: Percentage of the explained variance with each of the first 5 EOF's

	N. Atlantic		N. Pacific	
EOF-#	u	gu	u	gu
1	34.43	22.26	40.29	25.61
2	18.68	15.70	27.22	20.78
3	14.25	11.89	6.58	10.58
4	8.26	9.76	6.15	8.64
5	7.98	7.93	4.72	7.97

Table 3: Linear Trend of Surface Zonal wind over Selected Regions:

Region	Trend(u) m/s/yr	t-test value	Trend(gu) m/s/yr	t-test value
North Atlantic				
I: (60°N-44°N, 60°W-0)	0.31	1.58	0.36	-1.69
II:(28°N-12°N,70°W-10°W)	-0.19	-1.71	-0.28	1.54
North Pacific				
III:(52°N-32°N,130°E-120°W)	0.11	1.14	0.16	1.54
IV:(28°N-8°N, 130E-120°W)	-0.18	-2.53	-0.22	-2.09

n-2=12 α=0.1 tα=1.782

Table 4: Changes of the zonal wind between 1979-85 and 1986-92

	1979-85	1986-92	1979-92	
u(m/s)				Δ u/u %
Region				
I	3.27	5.63	4.45	53.0
II	-4.13	-5.46	-4.80	27.7
III	3.22	4.41	3.82	31.2
IV	-3.70	-5.55	-4.62	40.0
gu(m/s)				Δ gu/gu %
Region				
I	4.75	7.42	6.09	43.8
II	-6.46	-8.39	-7.42	26.0
III	4.02	5.40	4.71	29.3
IV	-6.57	-8.79	-7.86	28.9

Figure 1a: Correlation coefficient of observed vs. geostrophic wind for NMC twice daily analysis, zonal wind component

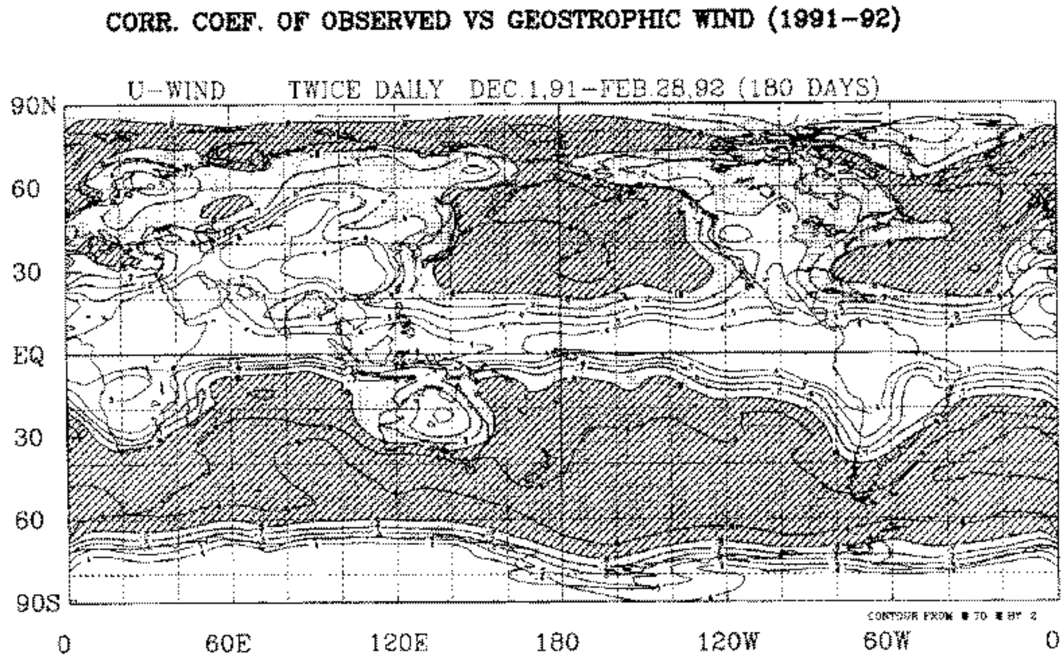

Figure 1b: Correlation coefficient of observed vs. geostrophic wind for NMC twice daily analysis, meridional wind component

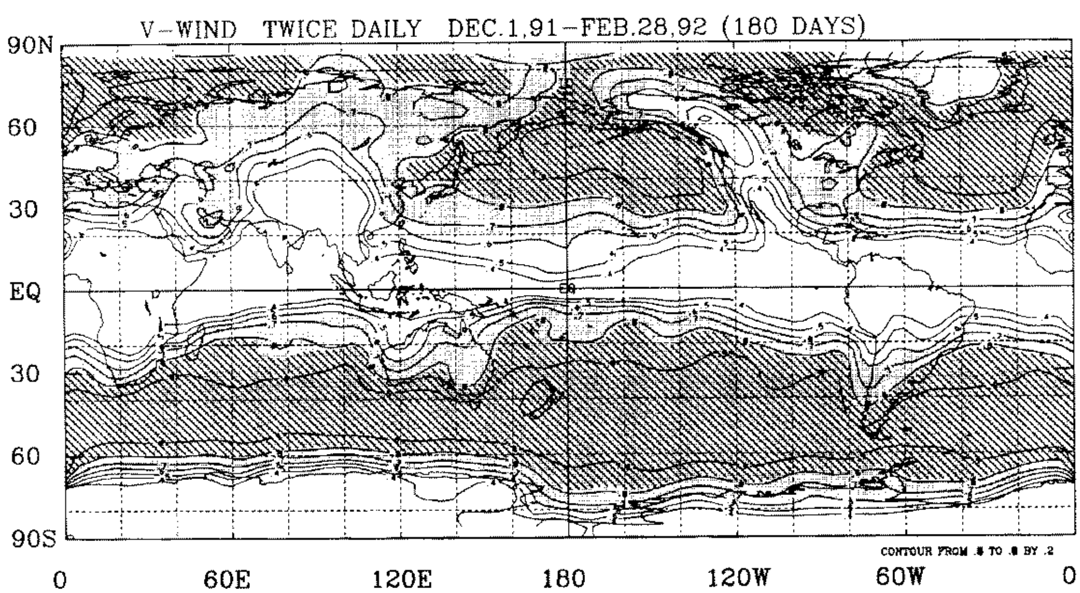

Figure 1c: Correlation coefficient of observed vs. geostrophic wind for NMC monthly mean, zonal wind component.

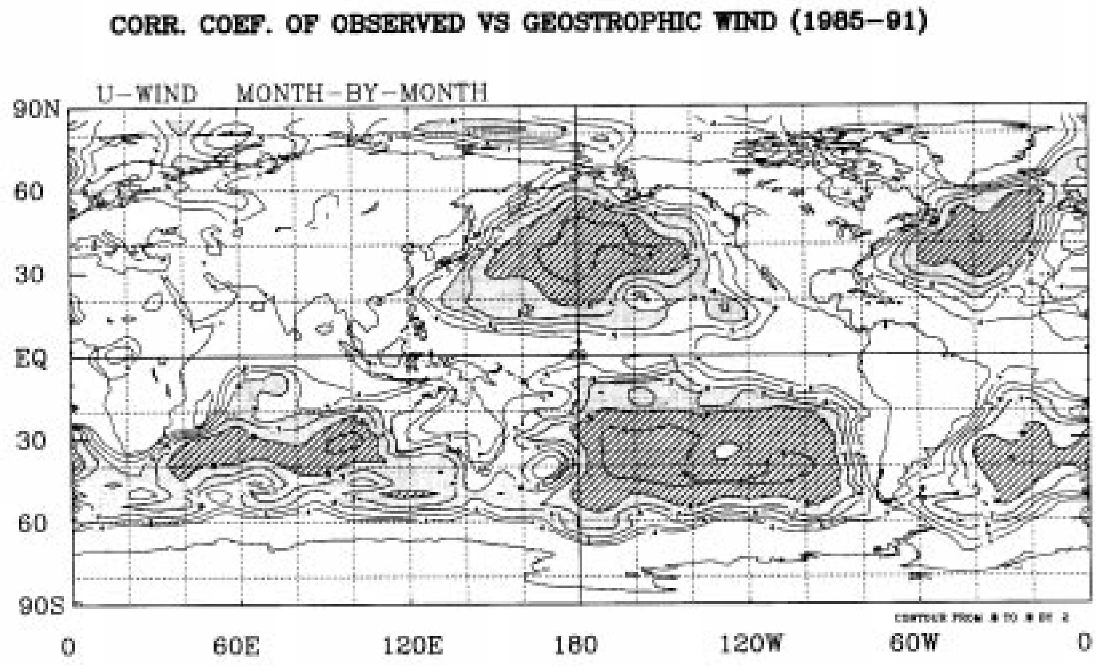

Figure 1d: Correlation Coefficient of observed vs. geostrophic wind for NMC monthly mean, meridional wind component.

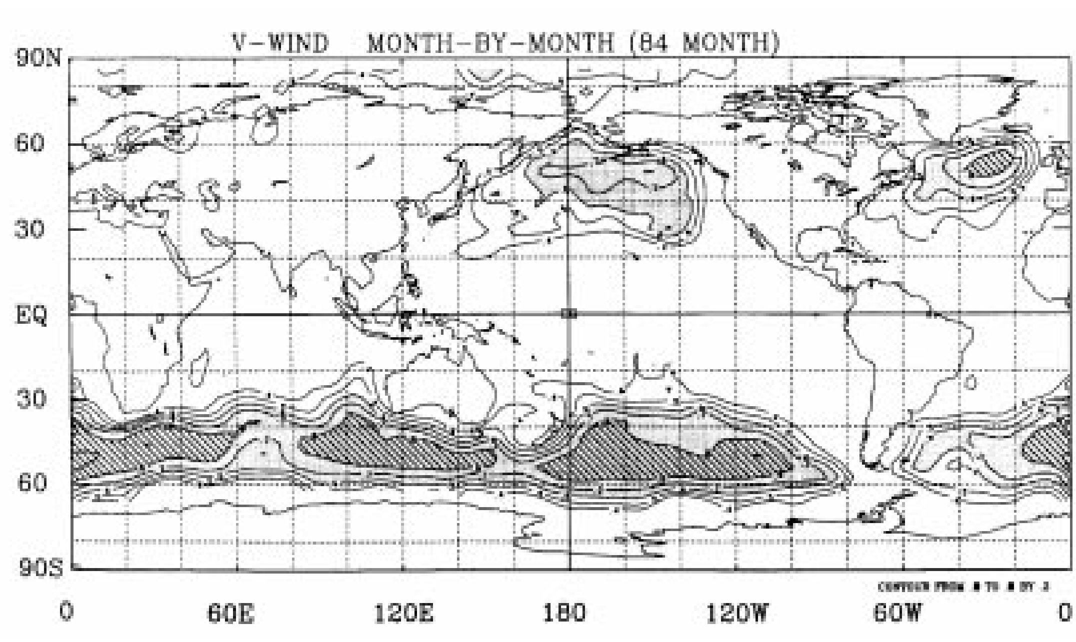

Figure 2a: Correlation coefficient of observed vs. geostrophic wind for COADS monthly mean, zonal wind component

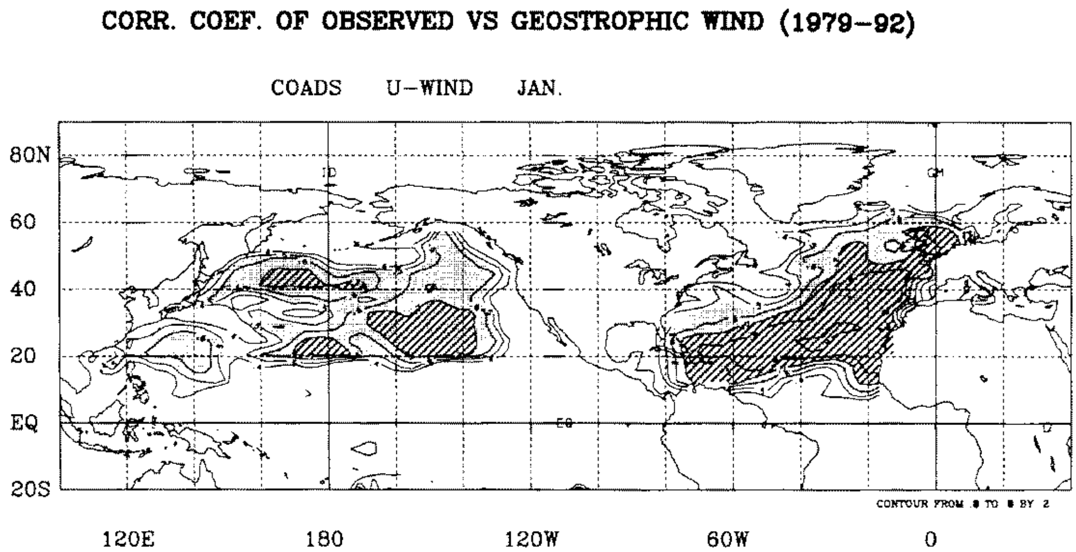

Figure 2b: Correlation coefficient of observed vs. geostrophic wind for COADS monthly mean, meridional wind component.

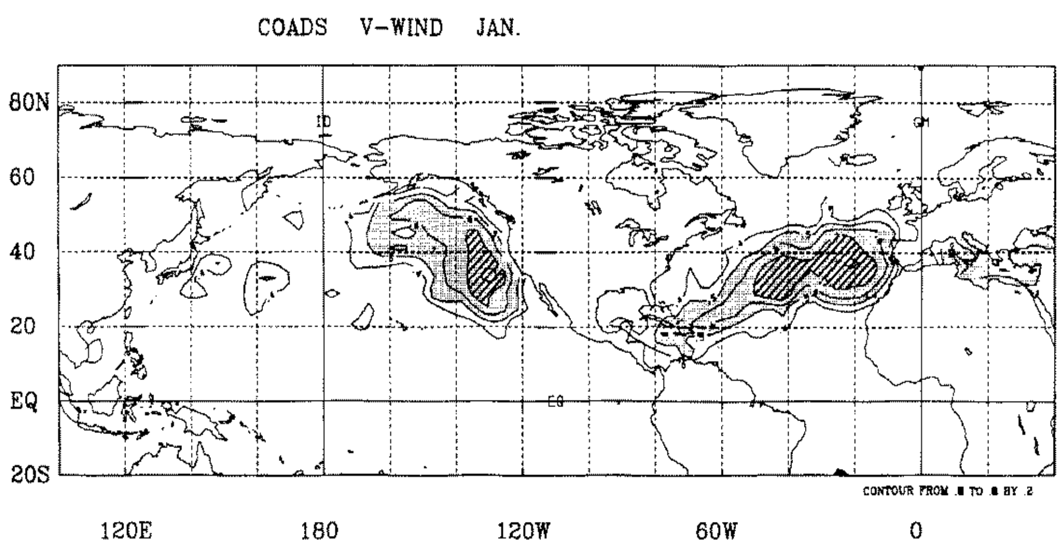

Figure 3a: EOF-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N): EOF-1 of the observed wind

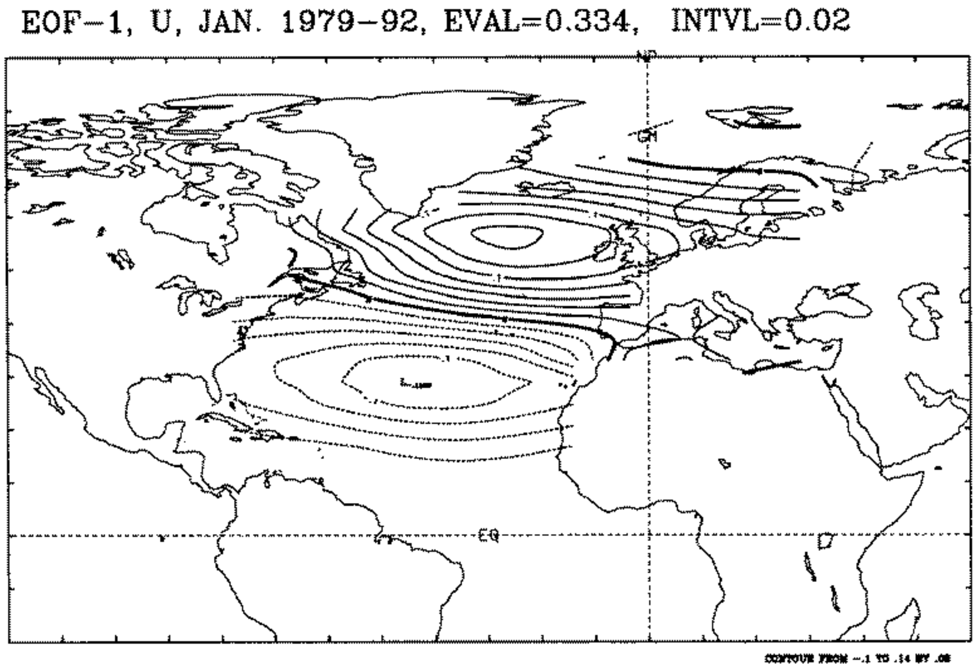

Figure 3b: EOG-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N) EOF-1 of the geostrophic wind.

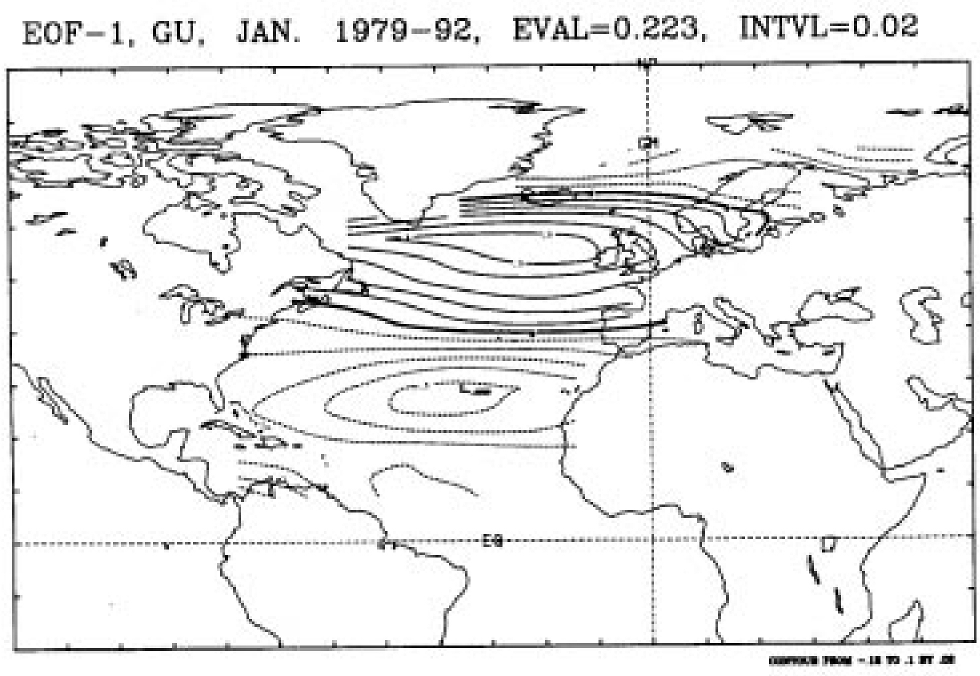

Figure 3c: EOF-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N); Time series of the projection of the observed (solid line) and geostrophic (dashed liine) zonal wind field on their EOF-1 modes respectively.

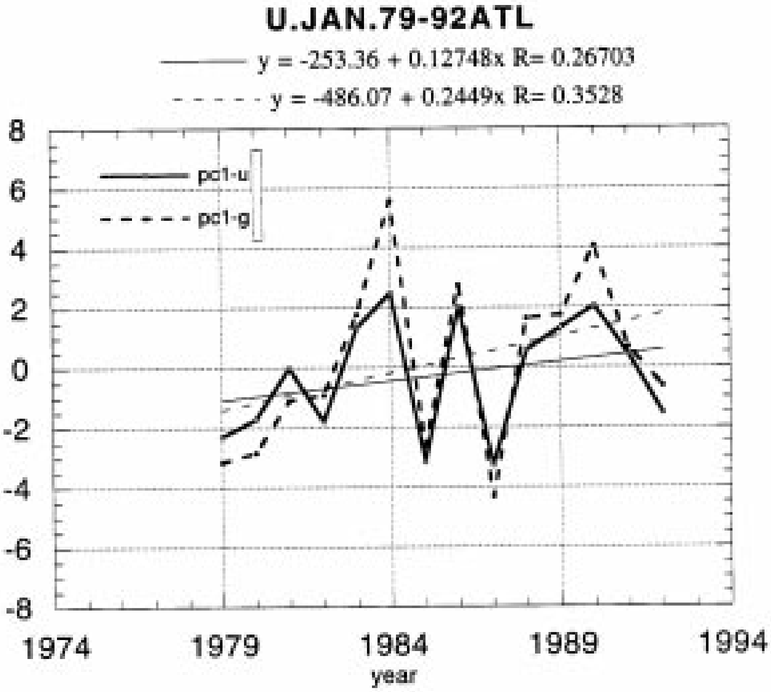

Figure 3d: EOF-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N); Scatter diagram of the two time series.

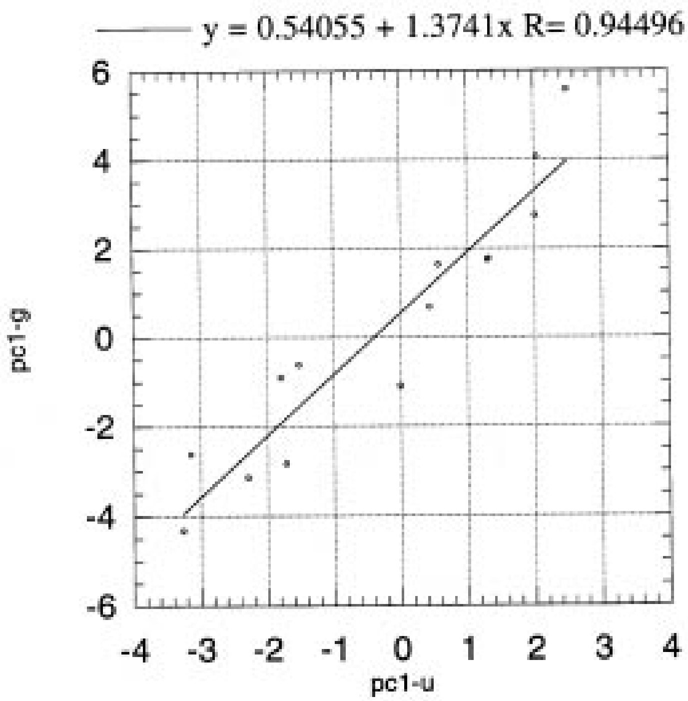

Figure 4a: EOF-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N); EOF-2 of the observed wind

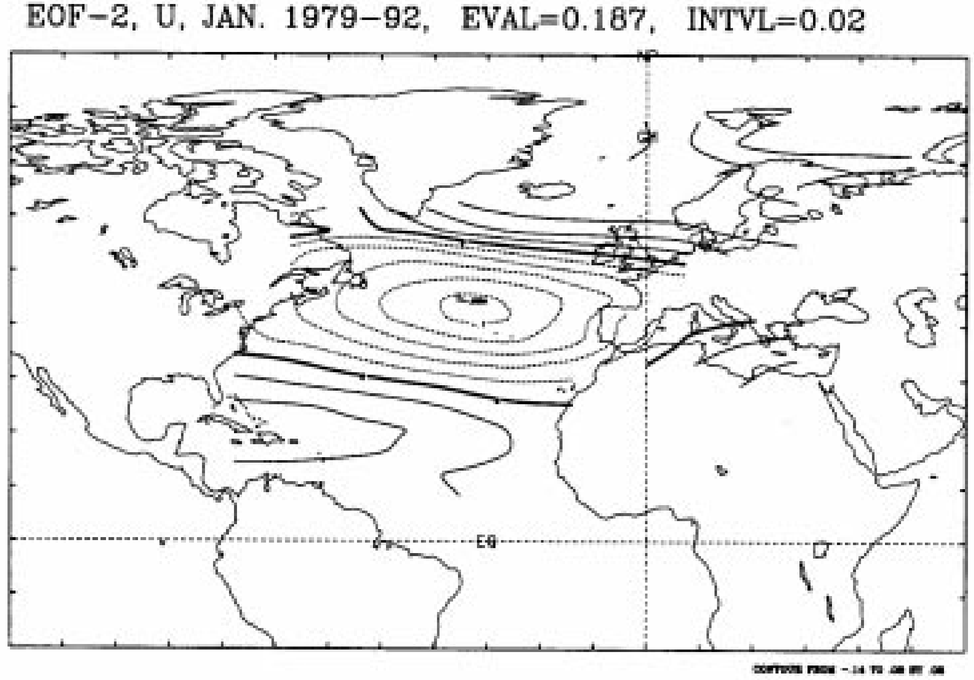

Figure 4b: EOF-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N); EOF-3 of the geostrophic wind.

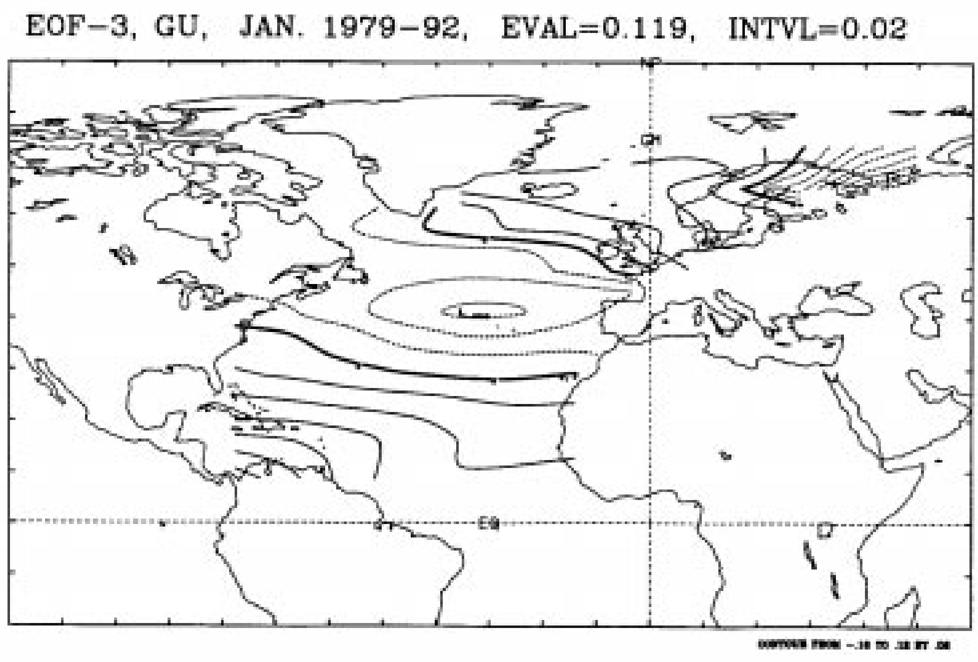

Figure 4c: EOF-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N); time series of the projection of the observed zonal wind field on its EOF-2 mode (solid line) and the geostrophic zonal wind field on its EOF-3 mode (dashed line), PC-3 of the geostrophic wind has been inverted to match the sign of PC-2 of the observed wind

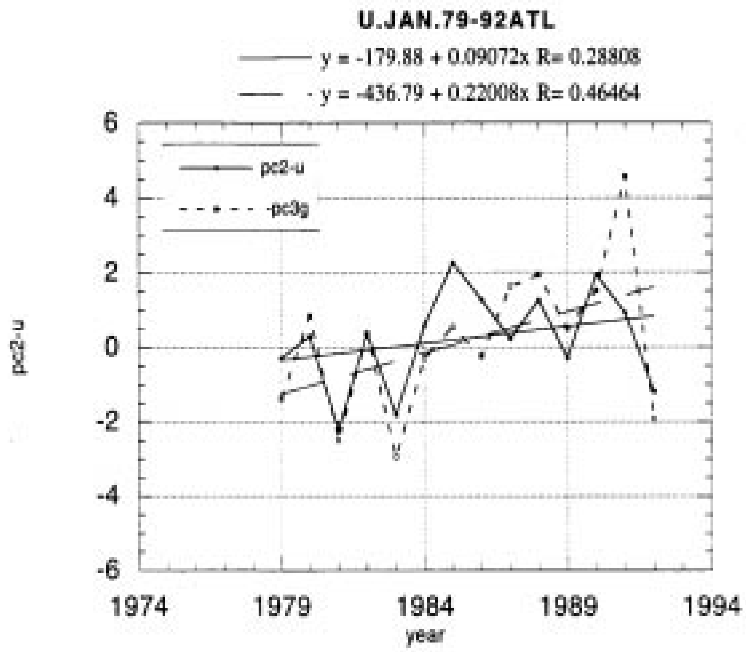

Figure 4d: EOF-modes of the surface zonal wind field over the North Atlantic Ocean (70°N-10°N); Scatter diagram of the two time series

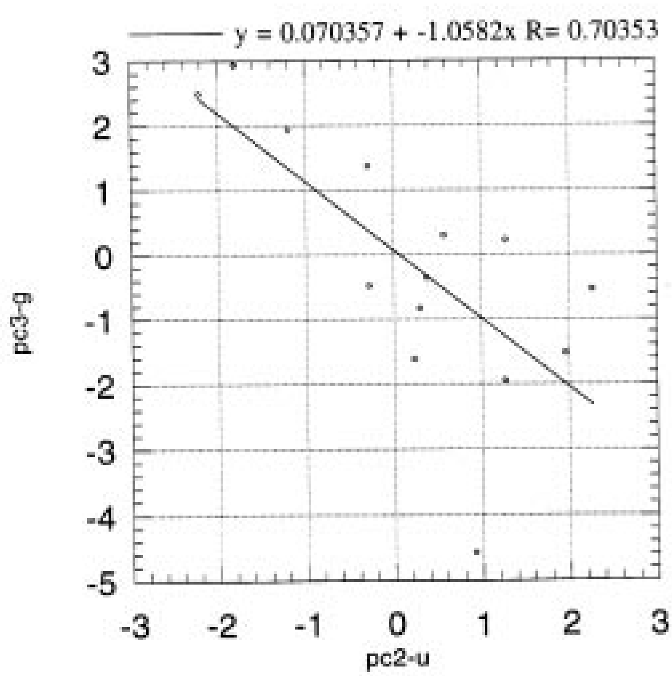

Figure 5a: EOF-modes of the surface zonal wind field over the North Pacific Ocean (60°N-10°N); EOF-1 of the observed wind

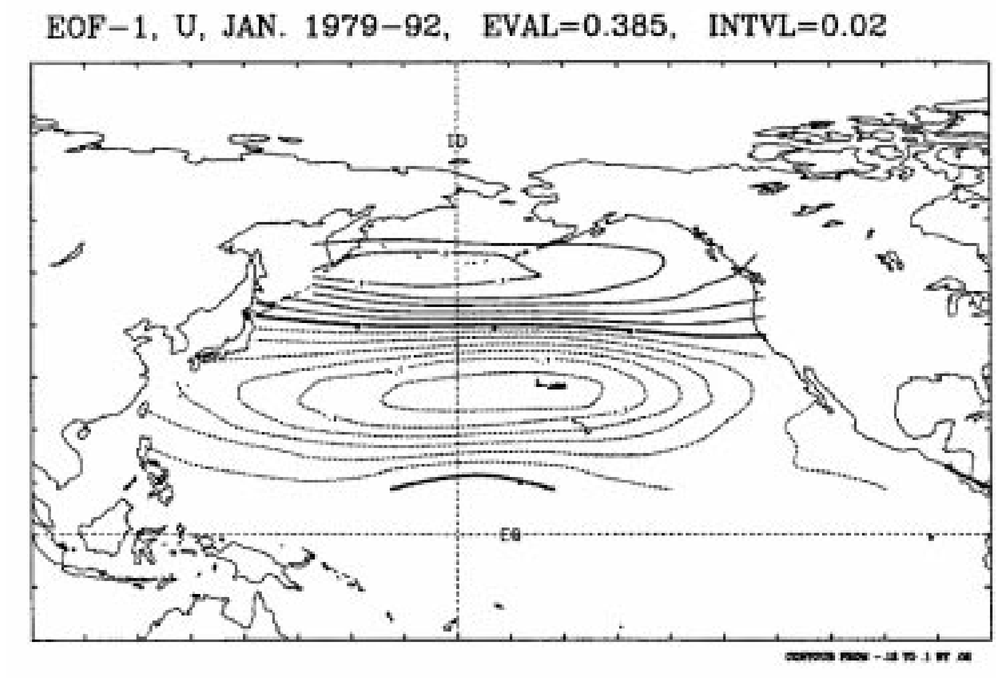

Figure 5b: EOF-modes of the surface zonal wind field over the North Pacific Ocean (60°N-10°N); EOF-2 of the geostrophic wind

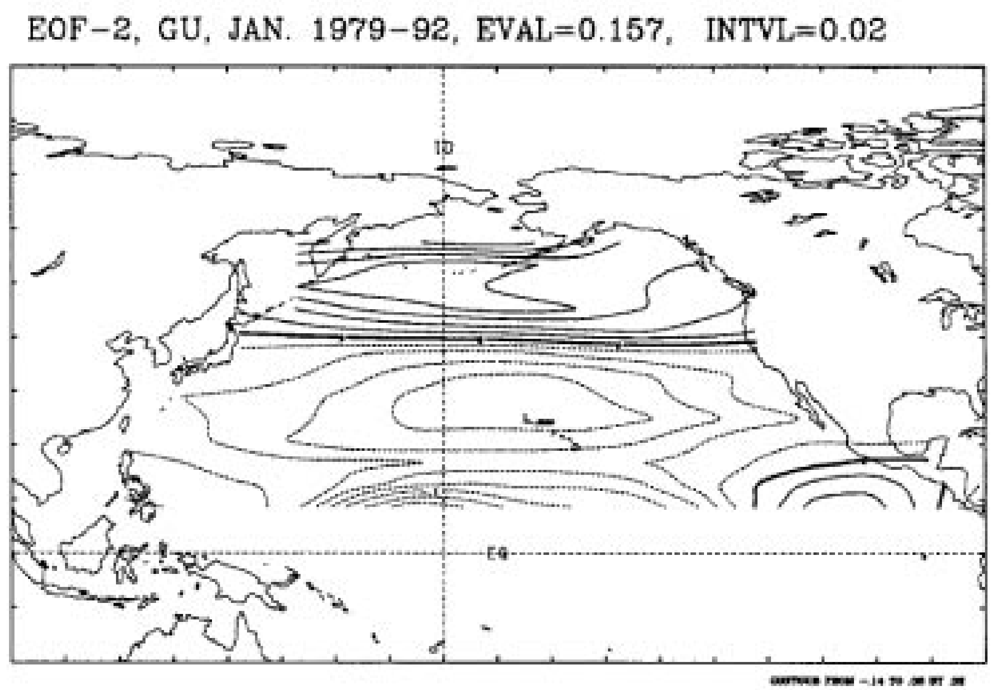

Figure 5c: EOF-modes of the surface zonal wind field over the North Pacific Ocean (60°N-10°N); time series of the projection of the observed wind field on its EOF-1 mode (solid line) and the geostrophic wind field units EOF-2 mode (dashed line).

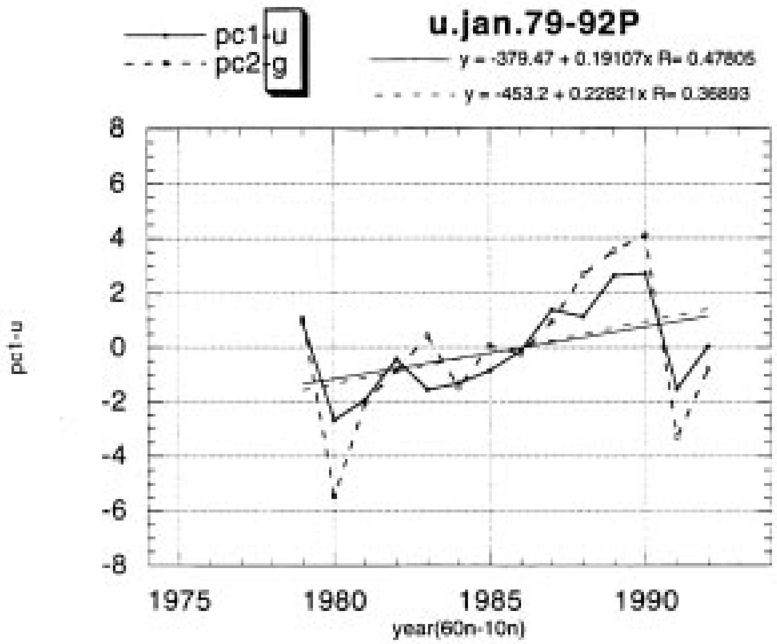

Figure 5d: EOF-modes of the surface zonal wind field over the North Pacific Ocean (60°N-10°N); Scatter diagram of the two time series.

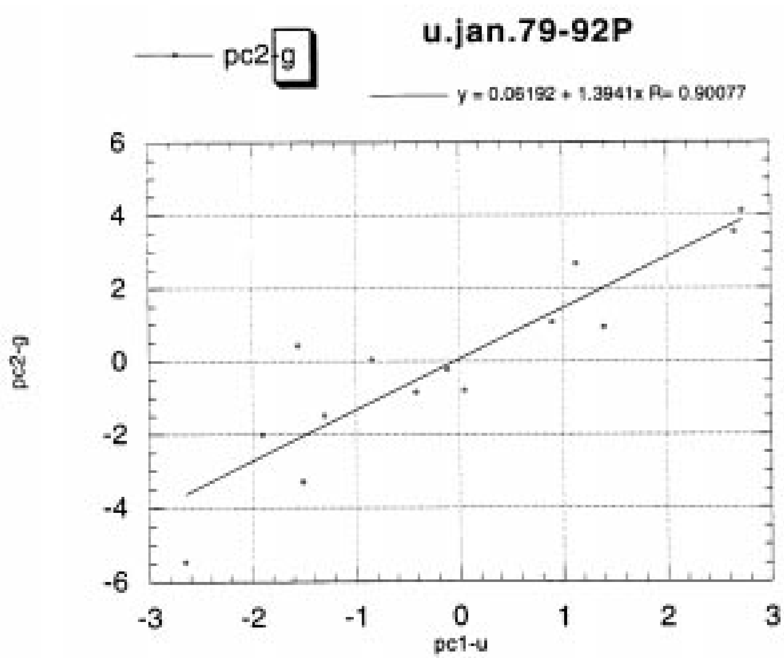

Figure 6a: EOF-modes of the surface zonal field over the North Pacific Ocean (60°N-20°N); EOF-1 of the observed wind.

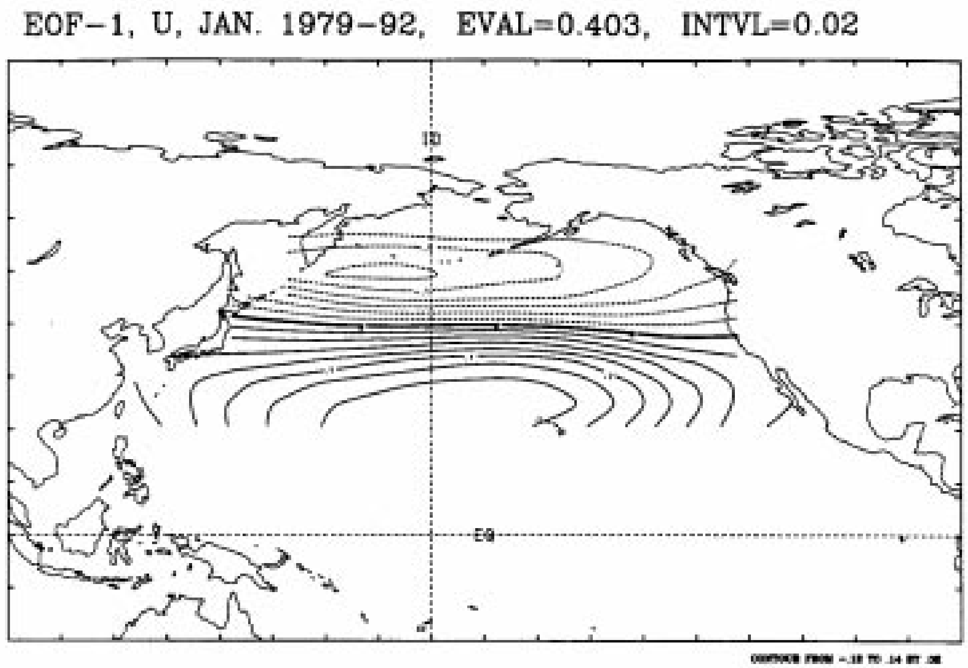

Figure 6b: EOF-modes of the surface zonal wind field over the North Pacific Ocean (60°N-10°N); EOF-1 of the geostrophic wind.

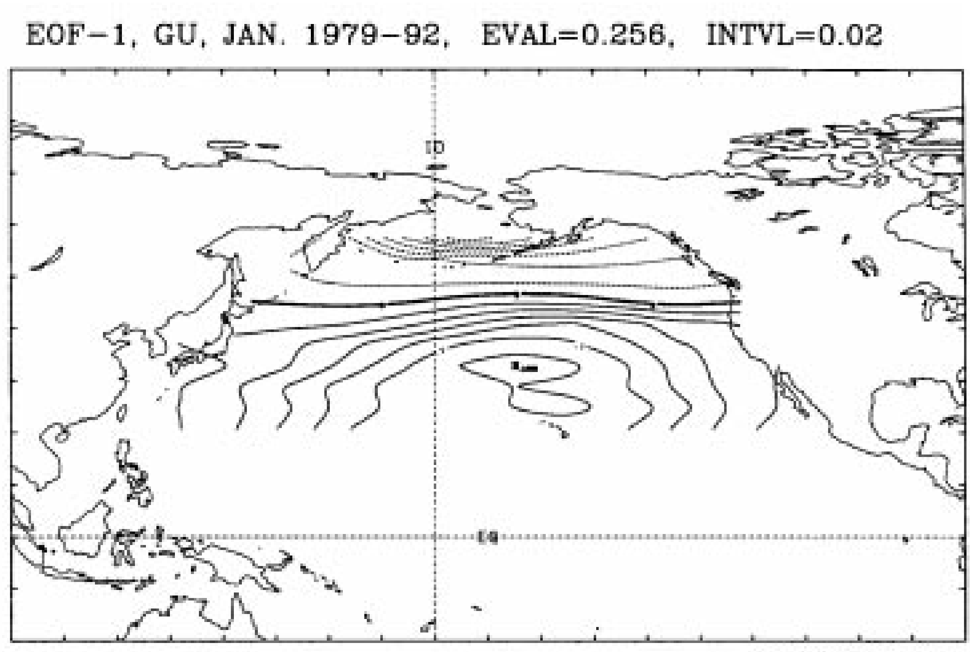

Figure 6c: EOF-modes of the surface zonal wind field over the North Pacific Ocean (60°N-10°N); time series of the projection of the observed (solid line) and geostrophic (dashed line) zonal wind field on their EOF-1 modes respectively.

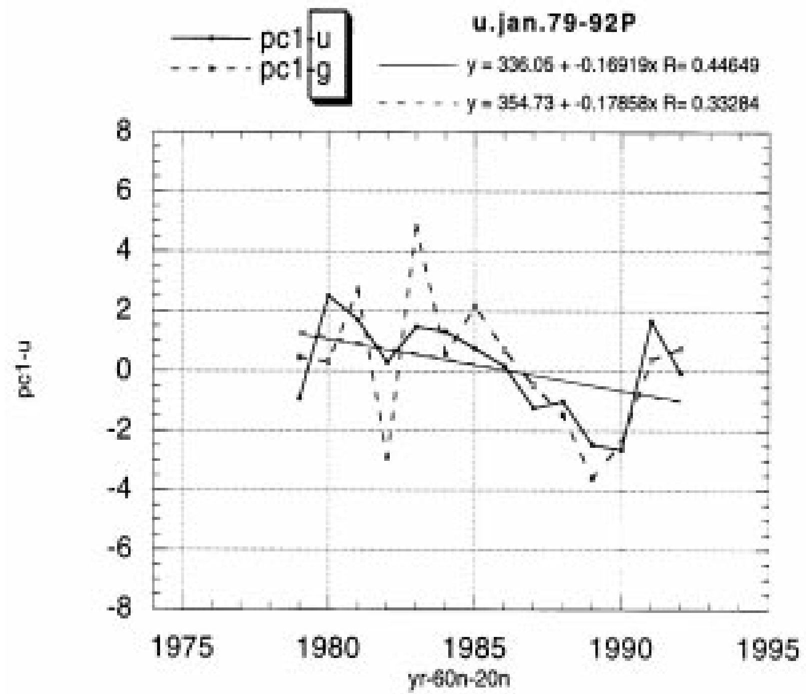

Figure 6d: EOF-modes of the surface zonal wind field over the North Pacific Ocean (60°N-10°N); Scatter diagram of the two time series.

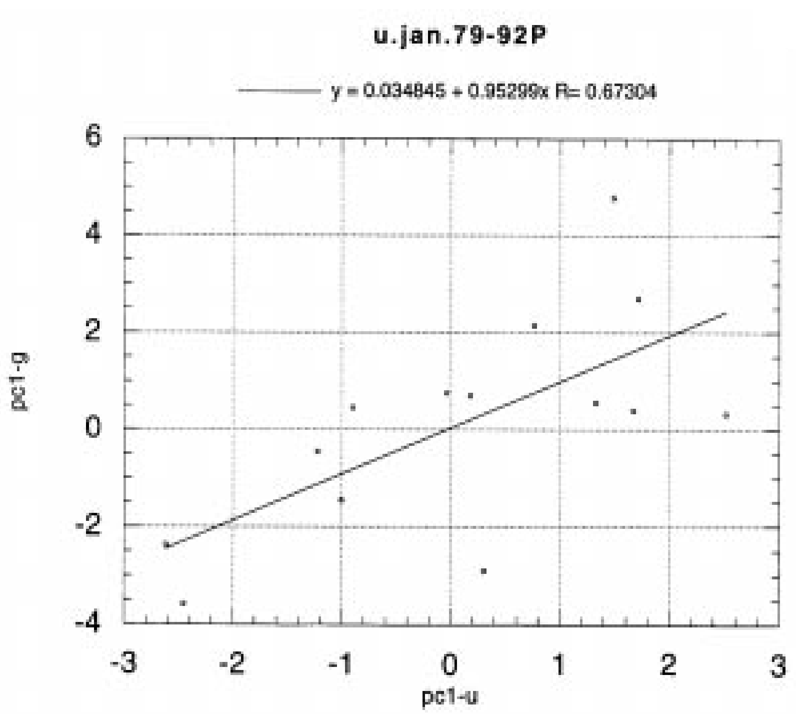

Figure 7a: Time series of the regional means of the surface zonal wind over North Atlantic, solid lines for observed wind, dashed lines for geostrophic wind, see Table 3 and 4 and text for details.

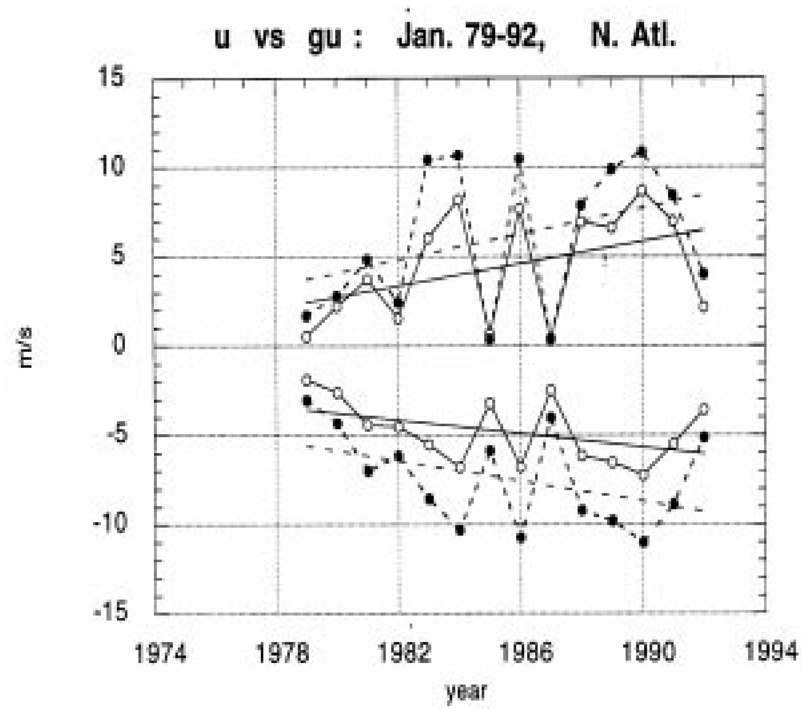

Figure 7b: Time series of the regional means of the surface zonal wind over North Pacific, solid lines for observed wind, dashed lines for geostrophic wind, see Table 3 and 4 and text for details.