Trends in Marine Surface Wind Speed: Ocean Weather Stations versus Voluntary Observing Ships

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Introduction

This study is concerned with the reliability of the apparent rise of surface marine wind speed over much of the World Ocean after about World War II, which has been identified from data sets of uncorrected wind reports of the Voluntary Observing Fleet (VOF), such as the Comprehensive Ocean-Atmosphere Data Set (COADS, see e.g. Woodruff et al., 1987). Some studies point out that this positive wind speed trend is a true climate signal or is at least partly real, and that estimates of derived heat budget variables such as latent heat flux have changed accordingly in the mentioned period (e.g., Bunker 1980, Whysall et al. 1987, Flohn et al. 1990, 1992). Others indicate that observed wind trends, also in earlier records, are mainly an artefact produced by e.g. changing observational methods. From very detailed investigations of the VOF surface wind records itself, Cardone et al. (1990) conclude that the most likely explanation for most of the observed wind trends is non-climatic. Ramage (1987), Wright (1988) and Ward (1992), using horizontal pressure gradients from averaged sea level pressure fields based on VOF pressure observations, could not find evidence which support the apparent wind trends in different regions of the World Ocean. Posmentier et al. (1989) confirm that the apparent positive wind trend in the Pacific trade wind region after 1960 is not in accordance with independent evidence from sea surface temperature and sea level data. All these studies suggest that the observed surface wind speed rise since about 1950 is not real, and that the real trend, if any, might be difficult to detect from VOF wind data. Note especially, that i) the mentioned studies draw their critical conclusion from other than measured wind data, and ii) a real wind speed change over the ocean, if any, cannot be estimated or bounded quantitatively from the data used. Controversial discussions on the subject may also be found in the present workshop proceedings (see, e.g., Fletcher 1995, and Hansen and Bezdek 1995).

A number of restrictions limit the value of VOF data for study of climate change, especially irregular distribution of the observations in space and time, and inhomogeneous or unknown measurement and observational techniques. Changes in ship types may introduce changes in reported wind speed or other variables, which may be misinterpreted as climate signals. Additionally, the VOF data contain a mixture of Beaufort estimates and anemometer measurements, which are not necessarily compatible. The ratio of Beaufort estimates to measurements varies with time, thus introducing additional time dependent artefacts into the time series of VOF-based marine wind speed.

Some of the deficiencies in the VOF records may be at least partly avoided by using observations made at Ocean Weather Stations (OWS) which were permanently occupied for certain periods by Ocean Station Vessels (OSV). In this study, we use all available OWS surface meteorological records, which are of appropriate length for trend studies (Table 1 and Fig. 1), and calculate multiyear trends of monthly scalar wind speed. We compare these results with trends calculated from VOF records extracted from the COADS for the same OWS regions in order to verify or disproof the apparent changes in the COADS, and to specify an estimate of the real wind trend, if any. Additionally, radiosonde data from some of the OWSs are considered and trends of monthly scalar wind speed on pressure levels in the lower troposphere are investigated and compared to those of the surface winds. This comparison with independent data, which are based on a completely different measurement technique, is performed in order to obtain additional confidence in the trend results of the OWS surface wind speed records.

Data and Methods

Surface Reports from Ocean Weather Stations

The Ocean Weather Station surface data used in this study were obtained from the National Climatic Data Centre (NCDC) at Asheville, NC, U.S.A. A complete overview of all OWS data available at NCDC and the data processing involved is given by Diaz et al. (1987). Two different periods are covered by the OWS records: 1) the earlier period, starting at the end of the 1940s and ending in the early 1970s (13 stations in the Atlantic and Pacific Ocean), and 2) the later period from the mid 1970s to the end of the 1980s (four stations only in the Atlantic Ocean). For details see Table 1. The only homogeneous record covering the full length of both periods is at OWS M. Unfortunately, a discontinuity at OWS C in the mid-1970s, when the national responsibilities for this station changed leading to a significant change in ship type, and, hence, flow distortion and anemometer level, that makes this record doubtful for studies of wind changes over the complete 40 year record. OWS T in the Pacific Ocean was occupied only during the summer periods. Here, data from May to October of each year are considered.

The OWS monthly wind records (except at OWS T) are continuous in time for the periods considered. Usually, three-hourly (in some periods and at some stations even one-hourly) meteorological surface observations were performed on OSVs. Subperiods with fewer data still contain at least two observations per day on average. Discussions with experts of the different national weather services and institutes, which were responsible for the OSVs, yield that wind reports from OSVs are exclusively based on anemometer measurements, not on Beaufort estimates. We find this confirmed by the distributions of reported wind speed analysed from the NCDC files, which in contrast to VOF records do not show a predominance of the equivalent wind speeds of the Beaufort equivalent wind scale.

A very limited number of individual vessels have been used by the European countries (20 vessels total, but only 10 at the same time), Canada (four vessels total, but only two at the same time), Japan (between two and six vessels at the same time) and the former Soviet Union (six vessels). Moreover, some of the mentioned vessels are of the same type with identical ship dimensions and anemometer levels. The United States of America used a much larger number of vessels from their Coast Guard fleet. However, most of these cutters belong to only four different classes with almost identical ship dimensions.

The following two features restrict the value of OWS records: 1) Available OWS data are limited to periods after World War II, and, 2) only a small number of Ocean Weather Stations were occupied, all of them in the extratropical North Atlantic and North Pacific Oceans.

COADS-MSTG Wind Speeds

The Monthly Summary Trimmed Group (MSTG) version of Release 1 and Release la of the COADS (see Woodruff 1995 in this volume) is used. This version consists of individual monthly means of meteorological surface variables, defined on a regular $2° \times 2°$ longitude/latitude grid net for the World Ocean. We use scalar wind speed from this record throughout this study. Note, that the averages were calculated from both anemometer measurements and Beaufort estimates. OSV reports are mixed with the VOF reports in the COADS. Hence, for comparison with the OWS trends, time series of wind speed for local OWS areas are extracted from COADS MSTG, which are based on data from a $3° \times 3°$ grid box area centered on the nominal OWS positions, but excluding the central gridpoint of this area, because a large fraction of the individual reports within this central 2° grid point stem from the OSVs. For presentation of the large-scale trend features (Fig. 2) individual monthly means for $10° \times 10°$ Marsden Squares (MS) are formed from all 2° grid averages inside a MS by unweighted averaging.

Radiosonde Data at Ocean Weather Stations

Individual twice-daily radiosonde (RS) ascents made onboard of OSVs in the Atlantic Ocean were obtained from the British Meteorological Office and from NCDC (see Diaz et al., 1987). These records provide wind speed and direction, air temperature and humidity on both standard pressure levels and additional levels. Compared to the surface wind records the OSV RS data are more irregularly distributed in time, with larger gaps and somewhat different periods covered. Upper-air time series at OWSs M, A, B, C, D, I, J, L are used here. For comparison with the surface wind speed trends we calculate trends of upper air wind speed on standard pressure levels between 950 and 700 hPa. Unfortunately, pressure levels with continuous data coverage vary from station to station. For example, at OWS A, wind speed at 900, 850, 800 and 700 hPa are nearly continuously available while, at OWS B, the lowest reliable level with enough data for trend studies is 800 hPa. However, in general three or four levels between the surface and 700 hPa with enough data for trend investigations are available per station.

Methods

Monthly and Annual Time Series

Individual monthly means of scalar wind speed are calculated from the OWS surface wind speeds and also from the upper air pressure level wind data in order to obtain a comparable data form as is available from COADS MSTG. The annual cycle is extracted by applying a 25 point Hamming filter. This filter is used instead of forming conventional anomalies in order to avoid aliasing (see, e.g., Edwards 1987).

Trend Statistics

We will restrict ourselves to linear trends in the time series using the simple model

$$w(t) = a + b*t + e_w \qquad (1)$$

where time, t, is the independent variable, and w(t) is monthly wind speed. The coefficient of linear regression against time, b, is obtained from an unweighted linear fit to the monthly wind speed time series. e, is the deviation from the resulting trend line. Student’s t–test is used to test $b \neq 0$ against the null hypothesis $b = 0$. The aim of this study is to look for changes within periods of typically 20 years, or more. We applied (1) and the t–test to both monthly anomalies and annual averages of scalar wind speed. Although, trend results from both data forms show mostly small numerical differences, both methods give essentially the same results, especially, the significance test results are the same in general. Hence, only results based on monthly filtered data are given throughout the paper.

Results

The Large-scale Picturefrom COADS

The large-scale coherent picture for the tropical and northern parts of the Pacific and Atlantic Oceans is that of an apparent significant positive trend of scalar wind speed (Fig. 2), typically of order 0.2 to 0.4 m/s per decade. Only two out of 45 MS in the Atlantic Ocean, and one out of 96 MSs from the Pacific Ocean show a significant negative trend. Highest positive trends exceed 0.6 m/s per decade west of Norway and around the southern coast of Greenland in the Atlantic Ocean, and around the Indonesian islands and in the western Bering Sea in the Pacific Ocean. Especially the time series from the region between 50° and 60°N in the Atlantic Ocean do not indicate a significant change of surface wind speed.

Surface Wind Speed Trends at Ocean Weather Stations from 1949 to 1972

Results of trend analysis of the OSV series at OWSs are given for the longest reliable periods available (Fig. 3). The only OWS with a significant positive wind speed trend is OWS M off the Norwegian coast with a linear 0.45 ±0.33 m/s per decade increase of wind speed from 1949 to 1975. Also, for the whole period available the positive wind speed trend is significantly different from zero at this station. All other stations show a non-significant wind speed change, or, at OWSs I, J in the Atlantic Ocean, and for the summer time series of OWS T in the Pacific Ocean, even a significant negative trend. Figure 3 suggests that in the North Atlantic Ocean between 30°N and 70°N there is no significant trend of surface wind speed except for two limited areas. West of Ireland, two stations indicate a decrease, while, between Norway and Iceland, one station indicates a strengthening of surface wind speed.

Comparison with VOF Data from COADS

The trend results for the OWS areas from the COADS-MSTG (Fig. 3) agree in general with the results of the respective MS they are extracted of (Fig. 2). Exceptions are found at OWSs B and C. All OWS areas in the Pacific Ocean show an apparent significant increase of surface wind speed. In the Atlantic Ocean, the northernmost station area (OWS M) and the southern areas D, E and K show an apparent significant rise of wind speed, in the other areas, except at OWS A, wind speed apparently did not change significantly. These areas are situated between 50° and 60°N. OWS A is the only area with a significant decrease of surface wind speed as apparent from COADS-MSTG.

Comparison of the OWS results with the VOF results from COADS-MSTG (Fig. 3) indicates that at all stations, except at OWS A in the Atlantic Ocean, the VOF trends are more positive (or less negative, respectively) than the OWS trends. For a qualitative comparison three types of trend results might be considered, significantly positive, significantly negative and nonsignificant changes. In these terms, agreement between OWS and VOF results are obtained only at OWSs B and C (nonsignificant changes) and at OWS M (significantly positive).

Surface Wind Speed Trends at Ocean Weather Stations from 1976 to 1989

In the later period, none of the four stations with available OSV data in the Atlantic Ocean shows a significant change of surface wind speed while at three stations (C, L, R) the COADS-MSTG data indicate a significant increase of surface wind speed (Fig. 4). Agreement between both data records, indicating no significant wind speed change, is obtained only at OWS M.

Upper Air Wind Speed Trends at Ocean Weather Stations

The intention here is not to detail the vertical structure of wind changes at all stations but to check whether the surface wind changes in the OSV records are supported by those in the lower troposphere from the OSV radiosonde (RS) records. At all stations and both periods investigated here, trend results show a high degree of vertical homogeneity. As an example, Table 2 depicts trend results for all available levels from the surface up to 700 hPa at OWSs A and C. At both stations wind speed tended to decrease in the lower troposphere, however, only at OWS A is this trend significantly negative at 850 hPa and higher levels. OWS A is the only station among those investigated here with a significant trend in lower tropospheric wind speed, and this trend is negative. At this station the decrease of wind speed with time grows monotonically with height from the surface up to 800 hPa and shows little change higher at 700 hPa. This feature suggests the following physically meaningful interpretation. The significant decrease of wind speed in the lower free troposphere outside the planetary boundary layer (PBL), which is presumably controlled by the change of the large-scale pressure gradient, might have been weakened by an opposite trend of physical processes inside the PBL (e.g. a change of frictional forces, stability, or advection). For all stations with available RS data, trend results of the two lowest pressure levels are compared to the surface results in Fig. 5. At all stations in both periods the trends of the upper air winds do not contradict those of the surface winds. If the trend at the surface and that at the lowest available pressure level indicate different signs, both are never significantly different from zero (Table 2). Especially noteworthy is that there is no significant positive trend of wind speed at either station in either period at either pressure level below 700 hPa.

Summary and Conclusion

There is no significant increase of monthly surface scalar wind speed, derived from anemometer measurements performed regularly onboard of Ocean Station Vessels (OSV) at extratropical Ocean Weather Stations (OWS) in the North Atlantic and North Pacific Oceans, in the period from the late 1940s to the early 1970s. The only exception is at OWS M off the Norwegian coast at 66°N and 20°E. Here, an increase of surface wind speed of +0.30 ±0.18 m/s per decade for the period 1949 to 1989 is observed. However, this result at OWS M is strongly dependent on the chosen period. Excluding the years 1950 to 1953, which show anomalous low wind speeds, changes the trend result to insignificant (not detailed here). Also, for the *later* period after 1975, no significant change in surface wind speed is detectable in the OSV records at four OWSs in the North Atlantic Ocean.

Wind speed in the lower troposphere, derived from radiosonde ascents at North Atlantic Ocean OWSs, support the trend results of the surface anemometer measurements. At these stations, there is no significant positive trend of wind speed at either station in either period at either pressure level below 700 hPa detectable. The only significant trend signal is a wind speed decrease at OWS A between Iceland and Greenland in the period 1949 to 1972 (Table 2).

The COADS-MSTG wind records, which are based on a mixture of Beaufort estimates and anemometer measurements from VOF ships, show, in general, a more positive (or less negative) wind speed trend at the OWS areas compared to the OSV records. This is true for both the earlier and later periods. Exceptions are found in the north-western part of the Atlantic Ocean at OWSs A, B and C, in the period from the late 1940s to the early 1970s. The COADS-MSTG winds show a significant increase in the earlier eriod at the southern Atlantic Ocean OWSs D, E, K) and, in particular, at all Pacific Ocean OWSs, and at three out of four OWSs in the later period (1976 to 1989) in the Atlantic Ocean.

The OSVs provide for a much more reliable data set than the VOF, especially with respect to homogeneity of the measurement technique. Therefore, the significant positive wind speed trends in the COADS-MSTG records from the OWS areas have to be judged as questionable. This leads to the conclusion that COADS-MSTG in particular, and presumably VOF records in general, seem to be an unreliable data source for detection of interdecadal wind speed trends.

There is a number of possible reasons for artefacts in the VOF wind speed records which may lead to the apparent wind speed rise. These include the gradual change from estimation technique to measurements on VOF ships. However, artefacts are likely to be hidden also in the record of Beaufort estimates itself. Observers on VOF ships from different nations seem to have followed quite different observation rules leading to systematic differences in the “national” Beaufort equivalent scales (e.g. Isemer 1992, Lindau 1995). A change of the national contributions to VOF data sets like the COADS would inevitably lead to artificial wind speed changes providing that only one scale is used to transfer Beaufort estimates back into wind speed (as is common practice today). The merging of different national or international data decks into one data set, where the individual decks cover different time periods of the overall record, may consequently contaminate the homogeneity of the entire data set. The latter reason may have caused at least part of the unrealistic positive wind speed trend in the COADS-MSTG especially at OWSs in the Pacific Ocean. Until discrepancies, which are as striking as those in the OSV and VOF time series of wind speed at OWS P (see Fig. 6), can be removed from the VOF records, results on wind climate change from uncorrected VOF wind data should be interpreted with utmost care.

This study does not rule out that parts of the World Ocean may have seen a strengthening of surface wind speed. It is, however, stressed that uncorrected VOF data records are an unreliable tool to detect and quantify them. The large-scale coherent picture of wind speed increase which can be derived from e.g. the COADS-MSTG (Fig. 2) is not likely to represent the real distribution of wind speed changes over the oceans, both qualitatively and quantitatively.

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References

Bunker, A.F., 1980: Trends of variables and energy fluxes over the Atlantic Ocean from 1948 to 1972. *Mon. Wea.Rev.*, 108, 720-732.

Cardone, J.S., J.G. Greenwood and M.A. Cane, 1990: On trends in historical marine wind data. *J Climate*, 3, 113-127.

Diaz, H.F., C.S. Ramage, S.D. Woodruff, and T.S.Parker, 1987: Climatic Summaries of Ocean Weather Stations. U.S. Department of Commerce, NOAA,ERL,CIRES, Boulder, Colorado, USA. 48 pp plus tables and maps.

Edwards, H.B., 1987: Sampling theory applied to measurement and analysis of temperature for climate studies. *J. Climate Appl. Meteor.*, 26, 73 1-73 6.

Fletcher, J.O., 1995: The importance of COADS winds for understanding climate change. In: Proceedings of the International COADS Winds Workshop, Kiel, Germany, 31 May - 2 June, 1994 (this volume).

Flohn, H., A. Kapala, H.R. Knoche and H. Mädchel, 1990: Recent changes of the tropical water and energy budget and of midlatitude circulations. Climate Dyn., 4, 237-252.

Flohn, H., A. Kapala, H.R. Knoche and H. Mächel, 1992: Water vapour as an amplifier of the greenhouse effect: new aspects. *Meteorol. Zeitschrift,* N.F. 1, 122-13 8.

Hansen, D.V. and H.F. Bezdek, 1995: Testing winds against other variables from COADS. In: Proceedings of the International COADS Winds Workshop, Kiel, Germany, 31 May - 2 June, 1994 (this volume).

Isemer, H.-J., 1992: Comparison of estimated and measured marine surface wind speed. In: Diaz, H.F. et al., (Ed.): Proceedings of the international COADS workshop, Boulder, Colorado, 13-15 January 1992, p 143-158.

Lindau, R., 1995: A new Beaufort equivalent scale. In: Proceedings of the International COADS Winds Workshop, Kiel, Germany, 31 May - 2 June 1994 (this volume).

Posmentier, E.S., M.A. Cane and S.E. Zeblak, 1989: Tropical Pacific climate trends since 1960. *J Climate*, 2, 731-736.

Ramage, C.S., 1987: Secular change in reported surface wind speeds over the ocean. *J.Clim.Appl. Met.*, 26,525-528.

Ward, M.N, 1992: Provisionally corrected surface wind data, world-wide oceanatmosphere surface fields, and Sahelian rainfall variability. *J. Climate*, 5, 454-475.

Whysall, K.D.B., N.S. Cooper and G.R. Bigg, 1987: Long-term changes in the tropical Pacific surface wind field. *Nature*, 327, 216-219.

Wright, P.B., 1988: On the reality of climatic changes in wind over the Pacific. *J. Climatol.*, 8, 521-527.

Woodruff, S.D., 1995 : Project Report I : Update plans and unresolved issues. In: Proceedings of the International COADS Winds Workshop, Kiel, Germany, 31 May - 2 June 1994 (this volume).

Woodruff, S.D., R.J. Slutz, R.L. Jenne and P.M. Steurer, 1987: A comprehensive oceanatmosphere dataset. *Bull. Amer. Meteor. Soc.*, 68, 1239-1250

Table 1: List of Ocean Weather Stations in the Atlantic and Pacific Oceans, data periods with reliable data, nominal locations number of individual OWS wind reports available from the NCDC files for the reliable periods, and responsible countries. Data periods are identified by the first and last month/year combination.

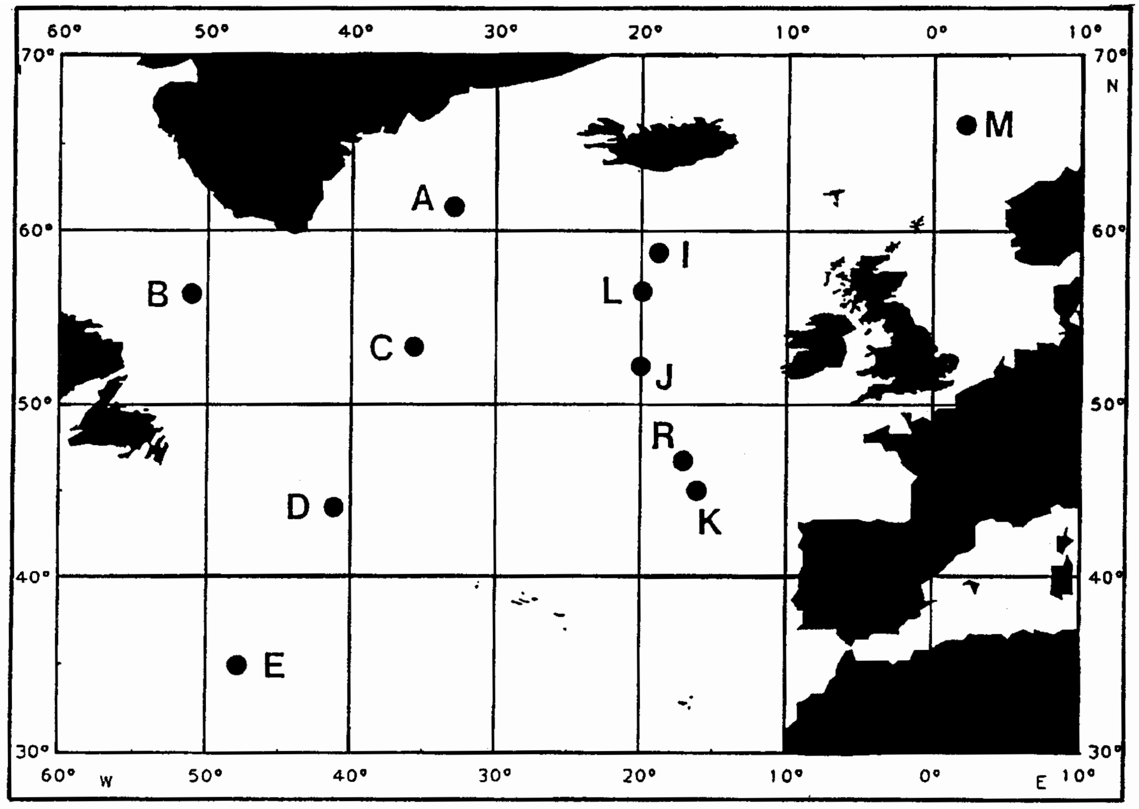
OWS	Period	Location	Reports	Countries
M	1/49/12/89	66°N°/ 2°E	107171	N,NL
A	10/47-12/73	62N°/33°W	76828	US, F, N, NL, UK
B	1/49-7/73	56.5N°/51°W	71864	US
C	1/49-12/73	52.5N°/35.3°W		US
	7/75-12/89	52.5N°/35.5°W	118270	USSR
D	10/49-12/72	44N°/41°W	68398	US
E	10/49-12/72	35N°/48°W	67327	US
I	4/50-1/53	59N°/19°W		
	8/54-11/74	59N°/19°W	6886	NL, UK
J	4/50-12/74	52.5N°/20°W	74914	F, NL, UK
K	7/49-12/74	45N°/16°W	70274	F, NL, UK
L	10/75-12/89	57N°/20°W	35191	F, UK
R	12/76-12/85	47N°/17°W	24027	F
P	1/50-6/81	50N°/145°W	90061	CAN
N	7/46-11/50	30N°/140°W		
	1/54-12/72	30N°/140°W	69225	US
V	4/55-12/71	34N°/164°E	47964	US
T*	6/49-10/70	29N°/135°E		
	6/78-10/81	29N°/135°E	38472	JAP

* OWS T was occupied only during the summer seasons. Data from June to October of each year are used.

Table 2: Trend statistics of surface and upper air wind speed at OWSs A and C. Periods are 1948-1970 at OWS A and 1949-1973 at OWS C. "d" is the 95% confidence interval for b, and $P(t_b)$ is the t-probability of significance (in %) for $b \neq 0$. Units of b and d are m/s per decade.

OWS/Level	b	d	$P(t_b)$
OWS A			
Surface	-0.14	0.28	68
900 hPa	-0.24	0.41	76
850 hPa	-0.35	0.32	96.4
800 hPa	-0.49	0.34	99.2
700 hPa	-0.42	0.39	96.4
OWS C			
Surface	-0.10	0.23	60
850 hPa	0.05	0.44	19
800 hPa	-0.23	0.48	67
750 hPa	-0.39	0.45	91
700 hPa	-0.36	0.52	84

Figure 1: Locations of Ocean Weather Stations in the Atlantic and Pacific Oceans.



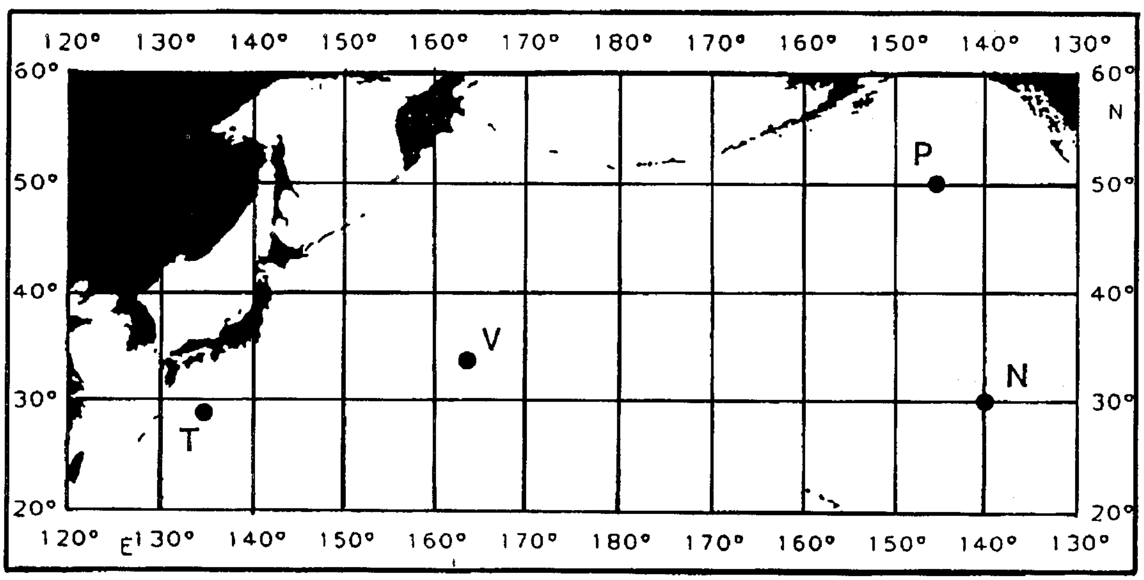


Figure 2a: Apparent linear trend of scalar wind speeds [cm/s per decade] in the Atlantic Ocean, base on the MSTG.2 version of COADS. Only significant trends results (at the 5% error level) are plotted, Marsden squares (MS) with non-significant trends contain only the sign of the linear trend. MSs with insufficient data coverage for calculating a meaningful trend are left blank. Note that the author is thoroughly convinced that this result from the COADS dataset is largely influenced by non-climatic reason and does not give the distribution of the real wind trend over the oceans.

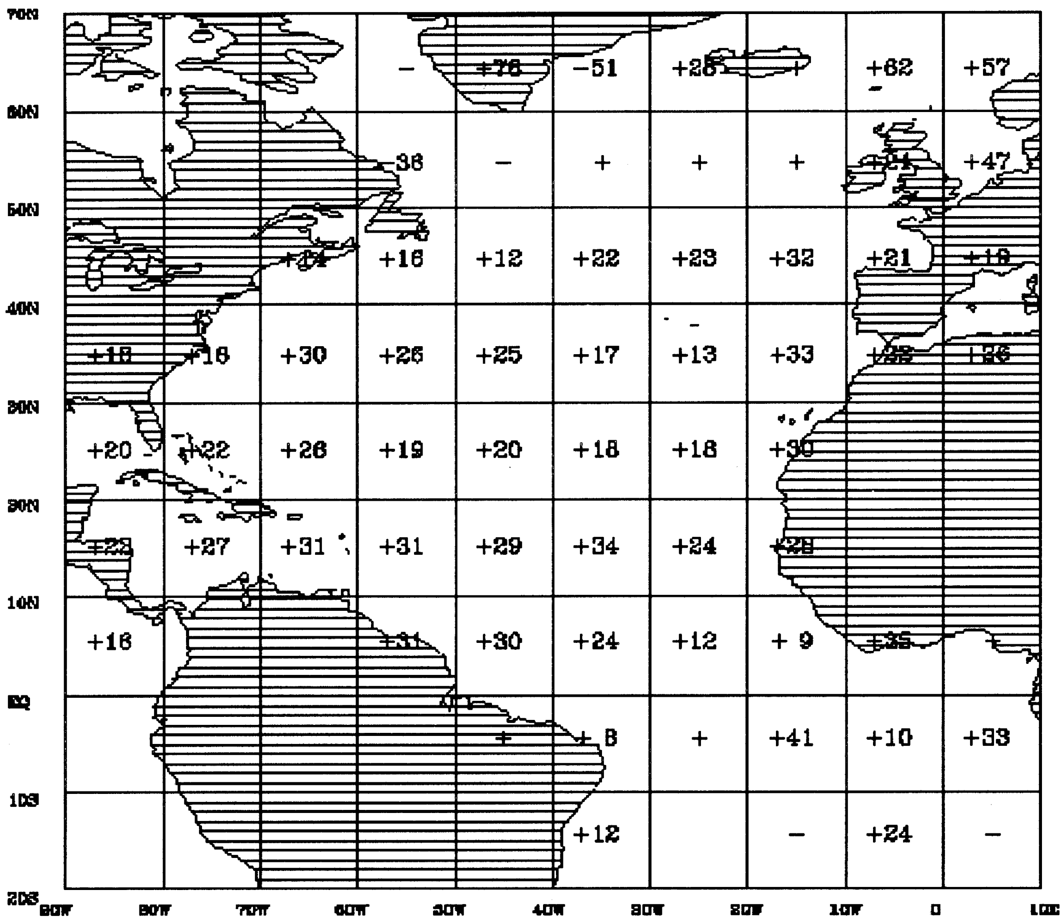


Figure 2b: As in Figure 2a, but for the Pacific Ocean.

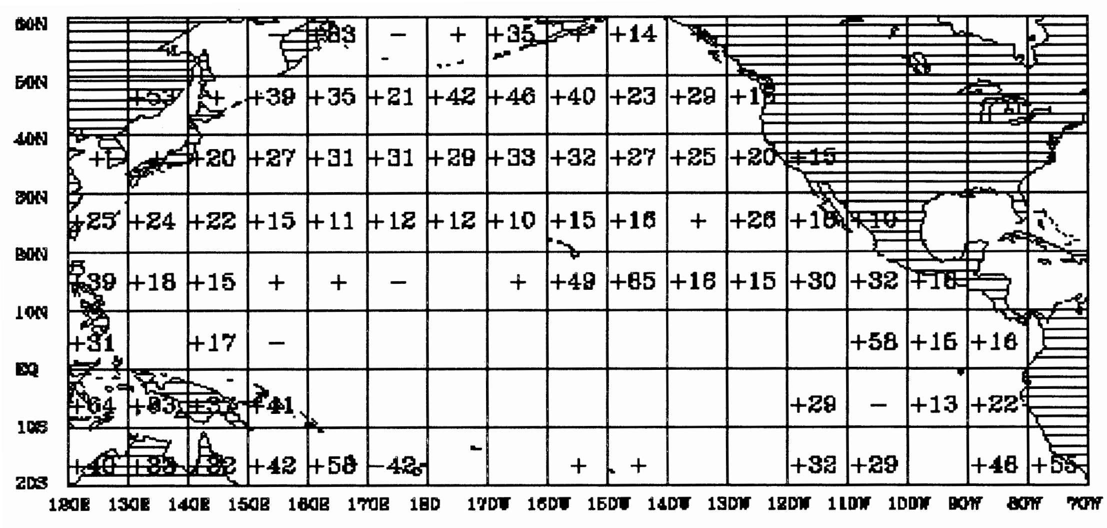


Figure 3: Linear trends of surface wind speed [m/s per decadde] in the earlier period (late 1940’s to early 1970’s) at OWSs M, A, B, C, D, E, I, J, K in the Atlantic Ocean, and at OWSs P, N, V, T in the Pacific Ocean. The upper number of the two, given for each station, is the OSV result, the lower one the VOF result from COADS-MSTG. One, two and three stars indicate level of significance at 5%, 1% and 0.1% error level respectively. No star indicates random result.

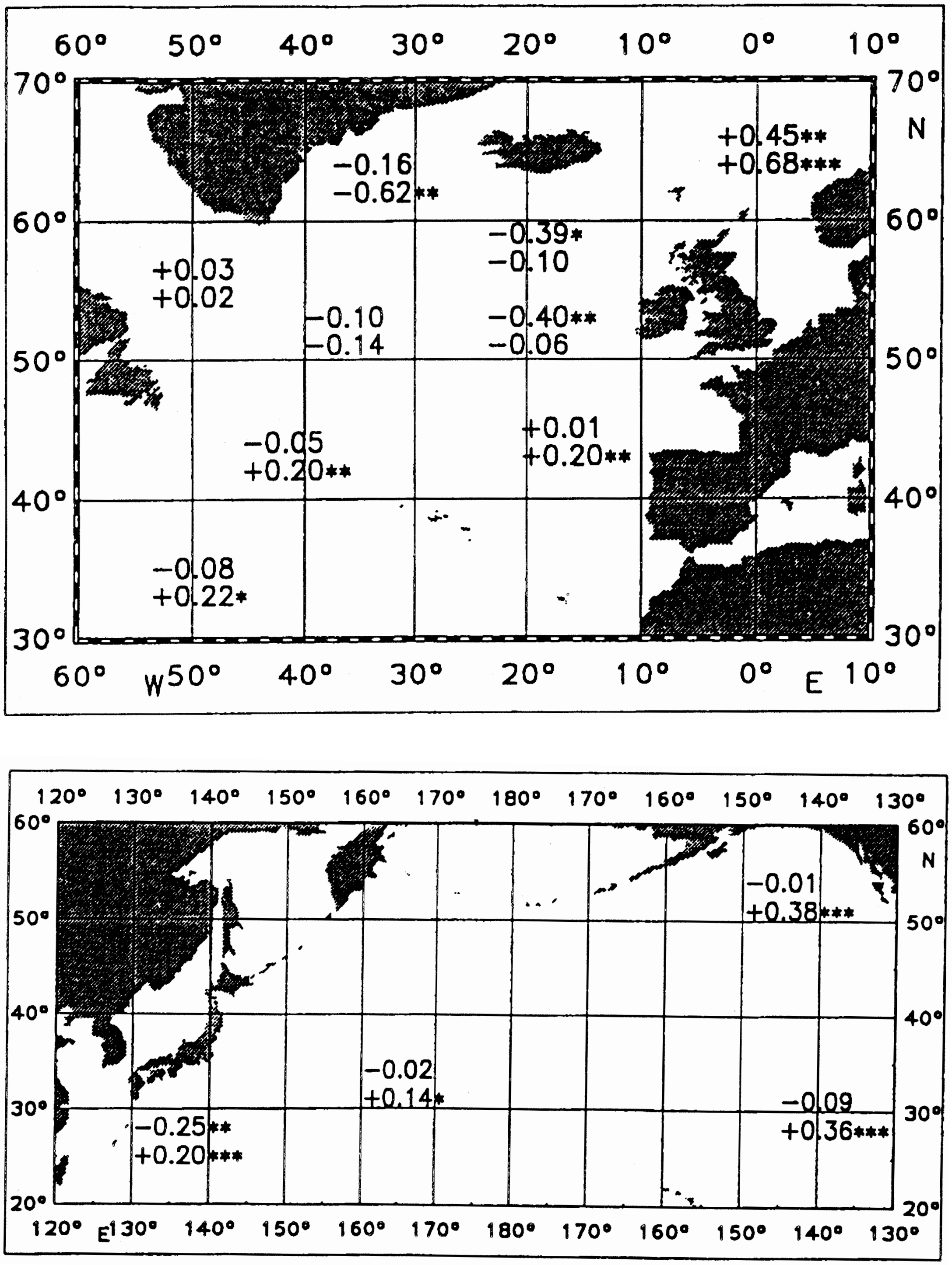


Figure 4: As in Figure 3, but trend results at OWSs in the Atlantic Ocean in the recent period (mid 1970's to the late 1980's).

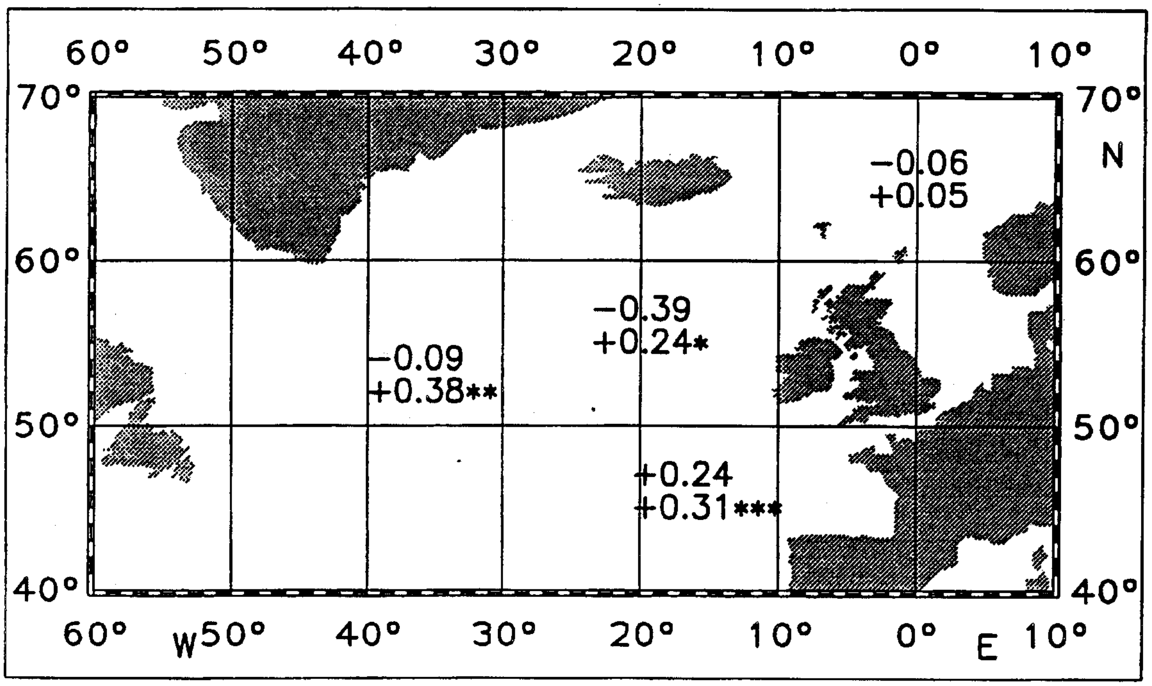


Figure 5: As in Figure 3, but linear trends of surface and upper-air wind speed at OWSs in the Atlantic Oceans for the early period (a) and the later period (b). Three numbers are given for each station considered, indicating the trend at the surface (bottom) and in the two lowest pressure levels with available data.

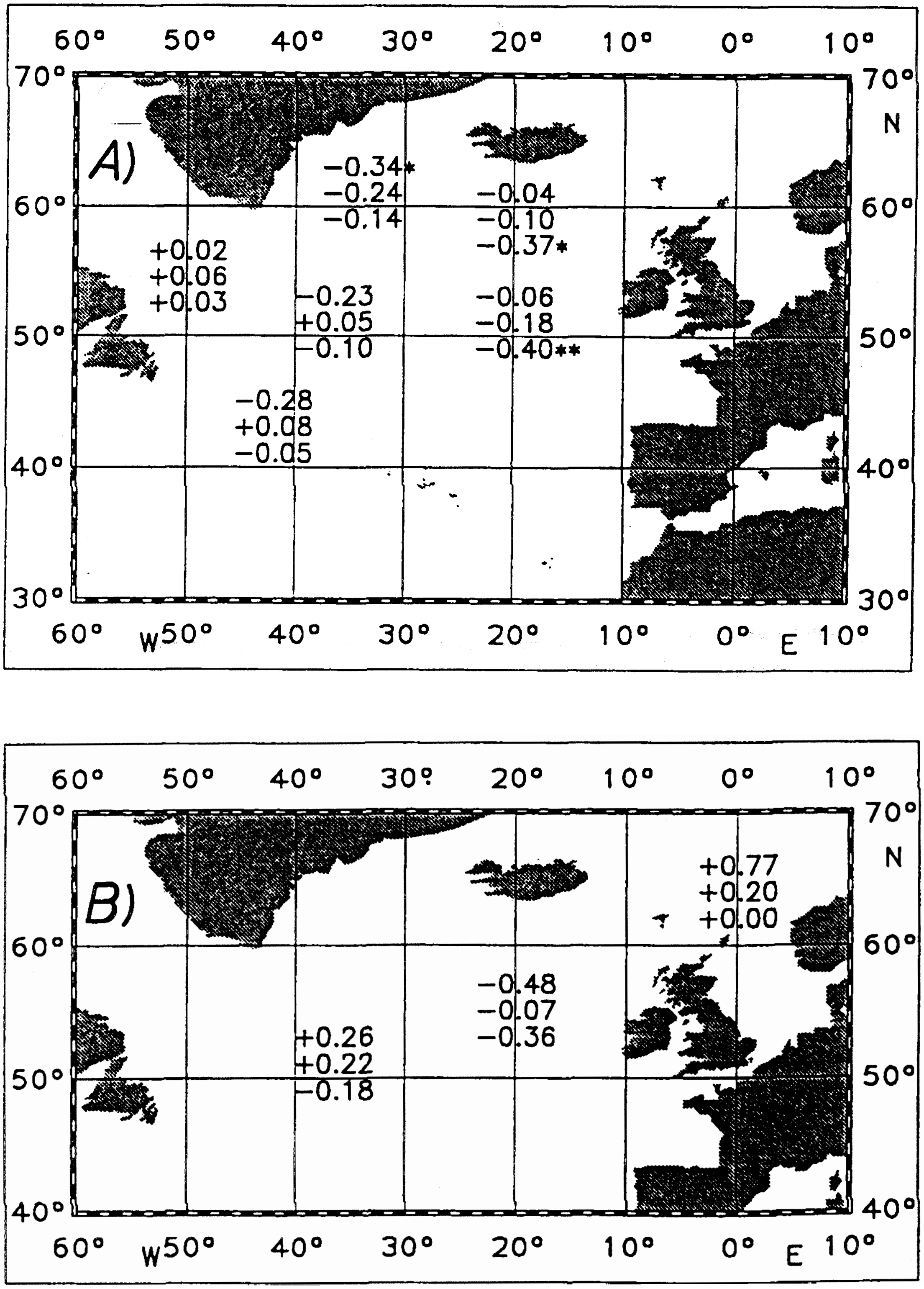


Figure 6: Time series of annual wind speed anomalies [m/s] at OWS P calculated from the OSV record (top and from the COADS-MSTG record (bottom). The linear trends in the OSV record is -0.02 ms/ per decade, a purely random result, while the COADS-MSTG record indicates a trend of +0.52 m/s per decade, highly significant at the 0.01% error level. The latter is considered as non-real.