ISSN 0097-8078, Water Resources, 2019, Vol. 46, No. 6, pp. 926–933. © Pleiades Publishing, Ltd., 2019.
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HYDROPHYSICAL PROCESSES

Data of Wind Field Reanalysis over the Caspian Sea for Calculating the Regime of Wind Waves

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Received January 21, 2017; revised September 30, 2018; accepted October 18, 2018

Abstract—Calculating the regime of waves, in accordance with recommendations of the World Meteorological Organization, requires a database covering not less than 30 years. Continuous measurements for a time interval as long as that are available only for a small number of coastal water areas. Commonly such data are derived from calculations by numerical (spectral) hydrodynamic models of wind-induced waves. The inputs in such cases are data on wind obtained by reanalysis. However, reanalysis cannot be applied to calculations for some seawater areas without pretreatment. Data on the Caspian Sea are used to demonstrate an approach to correcting NCEP/NCAR reanalysis data. The results of the application of this procedure are given.

Keywords: the Caspian Sea, wind fields, reanalysis, wind at weather stations, regression

DOI: 10.1134/S0097807819060125

INTRODUCTION

The progress of navigation and the development of World Ocean resources require detail data on sea waves. The concept of acquiring wave data is based on three major principles:

the formation of a database by calculating waves with the use of numerical spectral models;

calculation of statistical characteristics of sea dynamics (including wind and waves) by probabilistic models with the use of the database mentioned above;

application of high-performance computer technologies, which enable the creation and treatment of data arrays (wind and wave fields) for several decades with any space and time resolution.

This approach has been in widest use all over the world, including Russia, for solving many scientific and applied problems [7]. The applicability of this approach was confirmed by the reference books of a new generation for the regime of wind and waves in seas, published by the Russian Register of Shipping [2].

The hydrodynamic models of waves are based on solving balance equations of wave energy in spectral form; therefore, they are referred to as spectral, and the wave climate derived from the results of such simulation is referred to as *spectral wave climate*.

The general scheme of calculating the wave climate includes the following main steps:

preparation of input data (bathymetry, ice conditions, wind fields, etc.) for calculating waves;

calculating (hindcasting) wave spectra and the visible elements of waves in nodes of a regular space and time grid by hydrodynamic models;

statistical generalization of wave calculation results by probabilistic (stochastic) models.

Each stage can be divided into different number of steps.

Currently, the database for calculating wind fields by hydrodynamic models consists of data from reanalysis arrays. The reanalysis has been made for all meteorological characteristics, the parameters of which are given in the nodes of a regular grid covering the Earth with different detail and a time step of 6 h and more. Nowadays, the best known is the reanalysis project NCEP/NCAR, developed in the United States for the entire globe, and similar projects ERA-15, ERA-40, and ERA-INTERIM, which have been implemented by the European Center for Medium-Range Weather Forecasts (ECMWF). Regional projects with a greater spatial detail are available for some regions. Information about the composition of reanalysis data and their space and time resolution can be found in [12]. A brief

Table 1. Reanalysis data used to simulate the parameters of the main hydrometeorological characteristics

Array name (reference)	Coverage	Years	Resolution	Parameters
NCEP/NCAR Reanalysis 1	Global	1948–now	Gaussian grid 192 × 94 points, time step 6 h	Pressure, meridional and zonal wind components, sea surface temperature, air temperature, total precipitation, heat fluxes, cloudiness type, ice concentration (sea area under ice, etc.)
ERA Interim Reanalysis	Global	1979–now	Gaussian grid 256 × 512, time step 6 h	Pressure; meridional and zonal wind components; temperature (of sea surface, air, ice, snow); total precipitation; heat fluxes; cloudiness type; ice concentration; average parameters of wind-induced waves (period, direction, considerable wave height)
NOAA WAVEWATCH III® CFSR Reanalysis Hindcasts	Global	1979–2007	Regular grid 0.5°	Sea-wave parameters obtained from WAVEWATCH III model
ERA 40	Global	September 1957–August 2002	Gaussian grid 320 × 160, time step 6 h	Pressure; meridional and zonal wind components; temperature (of sea surface, air, ice, snow); total precipitation; heat fluxes; cloudiness type; ice concentration; average parameters of wind-induced waves (period, direction, considerable wave height)

review of reanalysis data from different sources is given in Table 1.

In this study, NCEP/NCAR [9] reanalysis was chosen for the analysis and the subsequent corrections of data because it covers the widest time range, which allows it to be used in the future to hindcast the wave regime of the Caspian Sea over more than half-century.

WIND DATA DERIVED FROM REANALYSIS AND MEASUREMENTS AT WEATHER STATIONS

The source data on wind are represented in the reanalysis as sets of meridional (U) and zonal components (V) at an elevation 10 m above sea level. The main drawback of wind reanalysis fields over a sea is the dependence of their quality on the availability of observation data for the region. Figure 1 gives the results of comparison of the series of wind speed in the Caspian Sea by measurements at coastal weather stations (WS) and NCEP/NCAR reanalysis. As can be seen from Fig. 1a, the space–time heterogeneity of wind fields on a relatively small water area of the Northern Caspian is differently reproduced by global models. Moreover, reanalysis data can deviate from WS measurement data toward either larger (Fig. 1b) or lesser values.

When the deviation of the reanalysis data from observation data is systematic and a high statistical correlation exists between them, the former data can be "corrected" with the use of a regression model. This approach to improving wind data by measurements at WS has been described in [1, 2, 10]. A similar procedure is proposed in this study. The data on wind measurements were taken from [8] and [4].

The quality of WS data for the Caspian Sea was checked with rejecting overestimates of wind speed. The result was the selection of seven representative stations (Makhachkala, Fort-Shevchenko, Turkmenbashi, Lagan', Atarau, Peschanyi Isl., and Tyulenii Isl.), which are situated near reanalysis grid

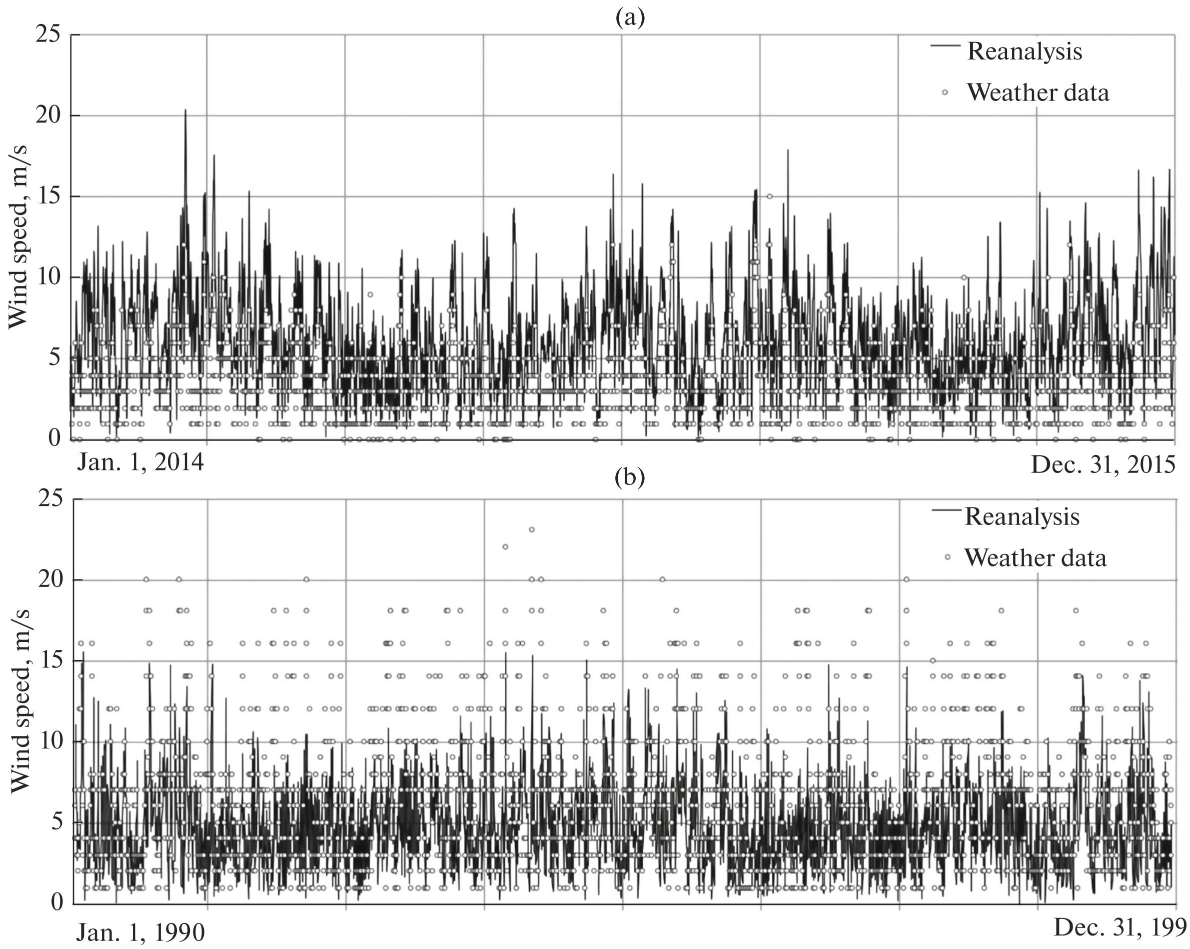

Fig. 1. Regular measurements (with 6-h interval) of wind speed by data of (a) Atyrtau WS, (b) Peschanyi Isl. WS, and NCEP/NCAR reanalysis.

nodes and provide a consistent pattern of wind field without considerable outliers and artefacts.

CORRECTING REANALYSIS DATA

The pair comparison of weather and reanalysis data at individual WS showed no systematic difference between reanalysis and measurement data on the coastal WS of the Caspian Sea. Therefore, at the detail analysis of wave conditions in sea water area (unlike the corrections proposed, for example, in [5, 6, 11]), the use of a single equation for data correction all over the water area will result in a coarse averaging of the space and time variations of wind fields over the entire water area [6]. Because of this, the sea was divided into individual regions, for which coefficients of regression model were evaluated with subsequent correction of reanalysis data.

The comparison of the data of NCEP/NCAR reanalysis with measurements at chosen WS was used to construct a series of regression relationships for correcting the calculated fields of wind given in Fig. 2. The data of all WS show a nonlinear dependence and a high statistical correlation with reanalysis data (the determination coefficient is ≥0.9). The regression parameters are given in Table 2. Data of Fig. 2 and Table 2 show that the difference in wind speed varies from N to S. The seasonal regressions (for winter from November to March and for summer from April to October) are similar in both sign and magnitude. This suggests a conclusion that, in the correction of reanalysis for the Caspian region, the principal attention should be paid to wind speed. The water area of the Caspian Sea can be divided into several regions by the type of regression, depending on the diversity of wind conditions and, accordingly, by the dominating type of atmospheric circulation. In particular, along the western coast of the Caspian Sea, reanalysis underestimates wind speed over the sea. This can be seen most clearly in the data of Tyulenii Island WS. This tendency persists in the central part of the sea as well (Peschanyi Island WS). The extreme northeastern

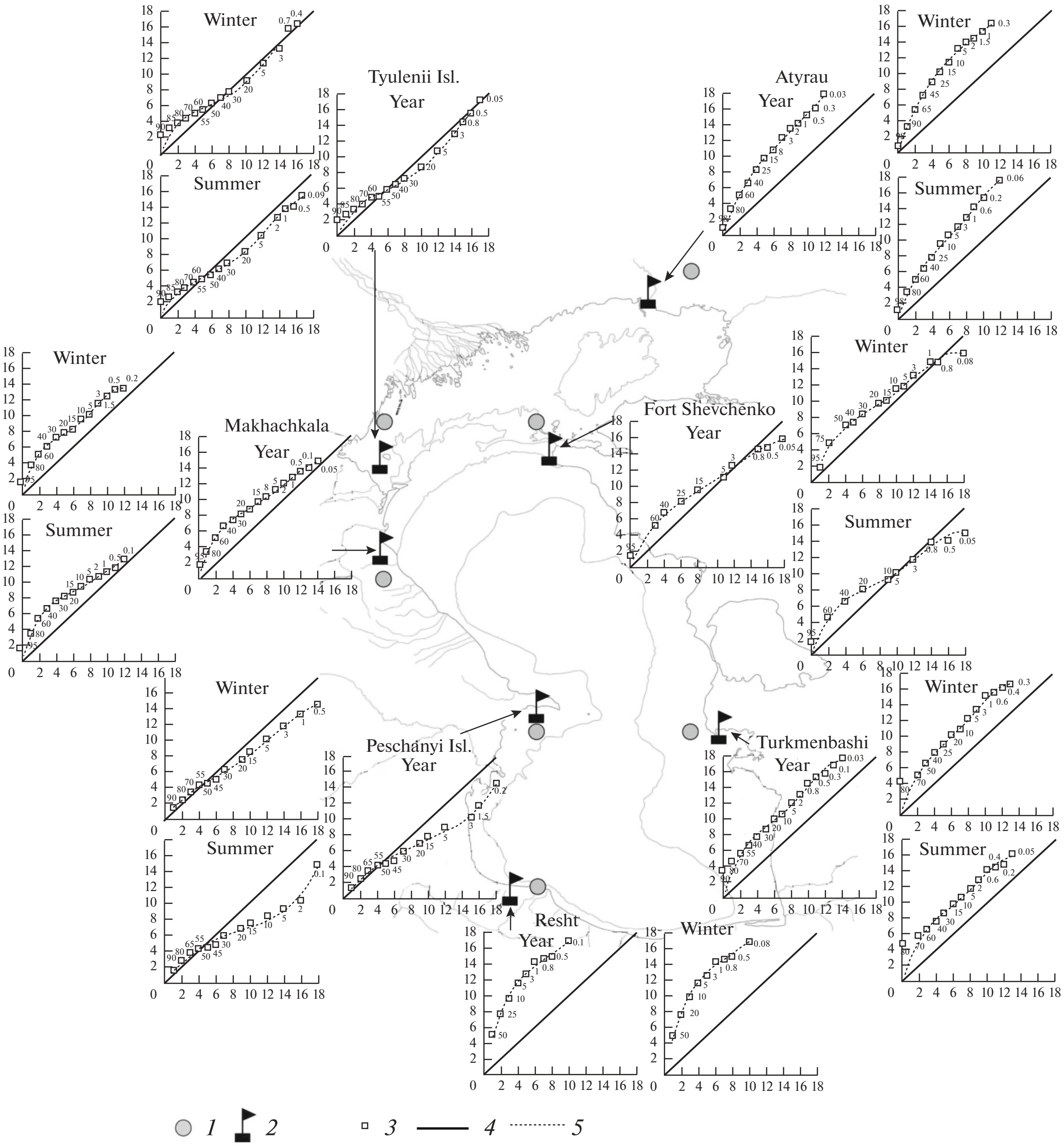

Fig. 2. Quantile biplots of regular measurements of wind speed (*V*, m/s) by data of (*1*) NCEP/NCAR reanalysis and (*2*) measurements at WS over the year and for two seasons: (*3*) quantiles, (*4*) the bisecting line of the coordinate angle, (*5*) regression line (calibration curve). The abscissa is observation data; the ordinate is reanalysis. Figures on the plot correspond to the exceedance probability (%) of quantiles. Winter: November–March. Summer: April–October.

part of the water area (Atyrtau WS) shows specific time variations of wind speed. On the western coast of the Caspian Sea, in particular, in its central part near Mangyshlak Peninsula (Fort Shevchenko WS), the reanalysis slightly underestimates large values (by 9–10%) and overestimates small values (<10 m/s) of wind speed.

Of interest are the data on storm conditions at Turkmenbashi WS (former Krasnovodsk) and Peschanyi WS. Plots in Figs. 3 and 4 show that at wind speed >15 m/s, reanalysis considerably underestimates wind speed.

Thus, the correction of data on wind in NCEP/NCAR reanalysis uses regression relationships with coefficients given in Table 2. In particular, for

Table 2. Parameters of nonlinear regression: $y = ax^4 + bx^3 + cx^2 + dx$ between reanalysis data and measurements at weather stations (WS) (y is wind speed by reanalysis data, x is wind speed estimate)

WS	Longitude	Latitude	Regression equation parameters											
			year				winter				summer			
			a	*b*	*c*	*d*	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*
Atyrau	51.85	47.12	–0.00060	0.02228	–0.33190	3.14630	–0.00080	0.02670	–0.36550	3.36070	–0.00170	0.04700	–0.48600	3.30820
Makhachkala	47.50	42.97	–0.00170	0.05490	–0.61910	3.57170	–0.00390	0.10280	–0.92600	4.10280	–0.00200	0.06390	–0.70850	3.86610
Peschanyi	50.00	40.30	–0.00080	0.00130	–0.07580	1.30540	–0.00040	0.01360	–0.16920	1.52500	0.00020	–0.00160	–0.06040	1.27410
Resht	49.60	37.32	–0.00230	0.07390	–0.88340	5.43230	–0.00230	0.07490	–0.89640	5.48130	No data available			
Turkmenbashi	53.00	40.05	–0.00210	0.06480	–0.68450	3.87450	–0.00220	0.06130	–0.61040	3.59480	–0.00180	0.05400	–0.57650	3.53400
Tyulenii	47.50	44.50	–0.00060	0.02530	–0.31990	2.13470	–0.00090	0.03570	–0.42370	2.50840	–0.00070	0.02780	–0.32240	2.01890
Fort-Shevchenko	50.24	44.55	–0.00050	0.01900	–0.28410	2.47610	–0.00070	0.02770	–0.37110	2.78040	–0.00080	0.03280	–0.43830	2.95360

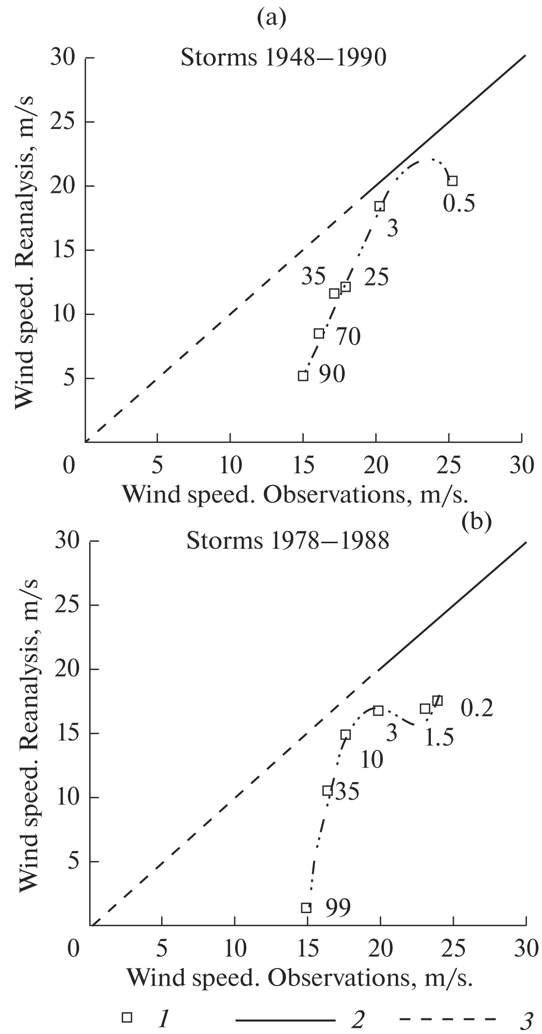

Fig. 3. Quantile biplots of regular measurements of wind speed ($V > 15$ m/s) by NCEP/NCAR reanalysis data in grid nodes and measurements at (a) Turkmenbashi WS and (b) Peschanyi WS: (*1*) quantiles, (*2*) the bisecting line of the coordinate angle, (*3*) regression line (calibration curve). Figures on the plot correspond to the exceedance probabilities (%) of quantiles.

water area from the western coast to the central part of the sea, it is proposed, successively moving from the north to the south, to use regression coefficients for WS: Tyulenii Island, Makhachkala, and Peschanyi Island. For the eastern coast, these are the Atyrtau, Fort Shevchenko, Turkmenbashi, and Resht.

CONCLUSIONS

The data of reanalysis of the fields of atmospheric pressure and wind were used to calculate wave climate by a statistical ensemble of wind fields over several decades. The reliability of the data of wind reanalysis is not the same not only for different water areas, as shown by studies [2, 11], but also within a single sea. This was demonstrated in the case of the Caspian Sea. For wind speed <15 m/s, reanalysis generally overestimates the values compared with measurements at coastal WS, while at the speed ≥15 m/s, the values are underestimated. Therefore, to reconstruct the full picture of wind waves, including storm situations, with the use of mathematical simulation, a successive procedure of data correction should be applied—separately for each region of the sea and for storm situations.

FUNDING

This study was supported by the Russian Foundation for Basic Research, project no. 16-35-60046 mol_a_dk) and

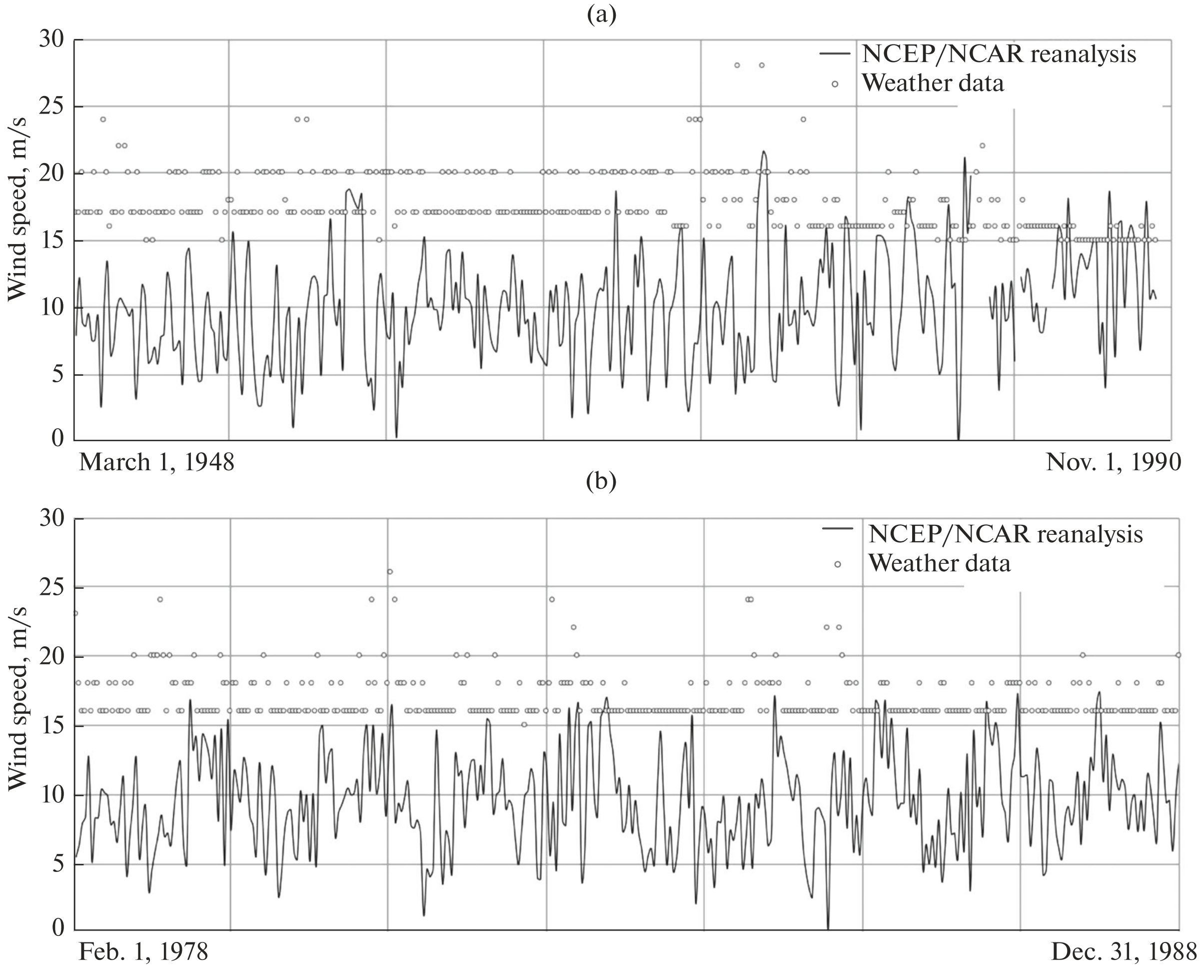

Fig. 4. Comparison of wind speed ($V > 15$ m/s) by data of NCEP/NCAR reanalysis and meteorological observations at (a) Turkmenbashi WS and (b) Peschanyi WS for storm situations from 1948 to 1990.

the Russian Foundation for Basic Research RGO, project no. 17-05-41190 RGO_a.

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Translated by G. Krichevets