A structure of the wind continuous field on the Black Sea surface

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Abstract

The continuous vector field of a wind over the Black Sea is constructed with use of the discrete data [11]. Analytical expressions are obtained for calculation of probabilities of a wind of any direction of velocity and duration for two types of winds: \( v \leq 5 \text{ m/s} \) and \( v > 5 \text{ m/s} \). The obtained results allow to define more probabilistic directions, velocities and durations of winds over the Black Sea surface for any time interval.

1. The studying of a wind regime has a large practical value. His knowledge is necessary for an estimation of climatic power resources, establishment of a trajectory of spreading of polluting substances in the atmosphere, agroclimatic researches, struggle against forest fires, in sphere of aviation service etc. The knowledge of the wind regime over water areas of oceans and seas is especially important as it almost uniquely defines parameters of surface waves and drift currents. In turn, the drift currents caused by a wind predetermine distribution of various polluting substances in oceans and seas.

   The studying of a wind regime is possible by construction of a continuous field of a wind. In adjoining to an underlying surface atmospheric layer the construction of a continuous field of a wind, basically, is carried out on the basis of the discrete data on the module and direction of horizontal component of a vector of wind velocity. Accuracy of the constructed field depends on errors of measurement of the discrete data and a method of construction of a field, but both the period of observation and a number of cases in this period crucial importance have. In comparison with other meteorological parameters, the values determining the wind regime, are characterized by a large dispersion and the establishment of their accuracy often requires special researches. [1 - 14]

2. For an establishment of a wind regime rather large information is given in the atlas [11]. Both the wind direction and velocity, and also the duration of different synoptic processes in the given atlas is determined on the basis of the decade data (1946 - 1955). For an establishment of probabilities of strong gales is used 17 years period (1946 - 1962). All data on wind velocities divided into two subgroups: an average wind velocity \( v \leq 5 \text{ m/s} \) and \( v > 5 \text{ m/s} \); on a direction they are divided on eight rhumb system, i. e. 45°th angle, if a direction is separable from 0 up to 360°.
(counting starts to the east from a meridian). Southern and south-western directions are incorporated (from 157.5° up to 247.5°) and make 90° angle. Thus, 7 synoptic situations are selected, to which the eighth subset is added, joining the cases of winds not having clear definite direction, i.e. cyclonic winds. The separate types (set) are divided into subsets both on velocities and duration of winds. Often at the solution of practical problems, the representation of probabilities of a direction, velocities and duration of a wind by continuous distribution is expedient. It is possible by usage of given atlas [11], if interannual changes of probabilities of a direction, velocities and durations of a wind we shall express analytically. In that case, certainly, the error of construction of a field will be not less error of parameters, given in [11]. Construction of a field of vectors of a wind on a surface of the Black sea by usage of the data of [11] is described below.

3. Discrete interannual distribution (p) of probabilities of monthly median wind velocities having value 5 m/s and less, is given in Fig.1. These probabilities are calculated in all cases in view of that probability of a wind, having velocities \( v \leq 5 \text{ m/s} \) on the surface of the Black Sea during one year makes 52.2 %; numbers (n) on an abscissa axis correspond to 15th data of each month.

\[
p(n)=\sum_{i=0}^{5} A_i n^i,
\]

is constructed, and the empirical factors determined on a method of the least squares are given in Table 1.

<table>
<thead>
<tr>
<th>Empir. factors</th>
<th>( A_0 )</th>
<th>( A_1 )</th>
<th>( A_2 )</th>
<th>( A_3 )</th>
<th>( A_4 )</th>
<th>( A_5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical values</td>
<td>( 3.40 \cdot 10^{-2} )</td>
<td>(-1.64 \cdot 10^{-2} )</td>
<td>(-8.26 \cdot 10^{-3} )</td>
<td>(-9.89 \cdot 10^{-4} )</td>
<td>(-2.76 \cdot 10^{-5} )</td>
<td>(-5.75 \cdot 10^{-7} )</td>
</tr>
</tbody>
</table>

Fig. 1. Interannual distribution of probabilities of a wind \(( v \leq 5 \text{ m/s}) \) on a surface of the Black Sea.

The curve in Fig.1 with the help of a polynomial of 5th order

\[
p(n)=\sum_{i=0}^{5} A_i n^i,
\]

is constructed, and the empirical factors determined on a method of the least squares are given in Table 1.
The root-mean-square deviation of the actual values [11] of the probabilities $p(n)$, makes 0.003; the error of approximation is equal to 5.8 % [11], does not give a pattern of wind distribution with velocities $v \leq 5 m/s$ on directions.

Using the probabilities of monthly average wind distribution for four, with 5 m/s step, ranges of velocities, when $v > 5 m/s$ we carried out an extrapolation of every separate month data in the range of low wind velocities ($v \leq 5 m/s$). After that we could obtain the distribution of probabilities on months of the given small velocities on the basic sunoptic situations i.e on directions with corresponding weights.

Both for arbitrary time and direction distribution of probabilities of winds with $v \leq 5 m/s$ velocities above the Black Sea surface is given in Fig. 2, as spatial distribution (a) and its projection (b).

![Fig. 2](image_url)

**Fig.2.** Distribution of probabilities of winds with small velocities ($v \leq 5 m/s$) above the Black Sea surface on directions and to months (probabilities are normalized with the general number of cases): (a) spatial distribution; (b) projection.

On coordinate axes the season, a direction of a wind and probability of small wind velocities (a vertical axis) are chosen. The same picture in coordinate system of time and direction is given as a projection, where isolines are carried out on constant values of probabilities. For interconsistency of values of probabilities on southern and southwest directions the recurrences incorporated under 90°th angle have divided approximately on two equal parts.
4. The information given in [11], enables to construct continuous fields of probabilities of directions, velocities and durations for a wind $v > 5$ m/s. The annual mean data of probabilities of directions, which are normalized in relation to the general number of winds with velocities $v > 5$ m/s are shown in Fig. 3. (just as in case of $v < 5$ m/s winds, here integrated [11] southern, and southwest winds, are too.

Fig.3. Distribution of probabilities on a direction of winds $v > 5$ m/s above the Black Sea surface.

Values in Fig. 3 are approximated by a polynomial of 8th order

$$p(\alpha) = \sum_{i=0}^{8} B_i \alpha^i,$$  \hspace{1cm} (2)

where $p(\alpha)$ a probability of wind directions, averaged on $45^0$th angle, of center defines a direction $\alpha$, $B_i$ are empirical factors given in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Empir factors</th>
<th>$B_0$</th>
<th>$B_1$</th>
<th>$B_2$</th>
<th>$B_3$</th>
<th>$B_4$</th>
<th>$B_5$</th>
<th>$B_6$</th>
<th>$B_7$</th>
<th>$B_8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numeric values</td>
<td>16.6</td>
<td>-1.04974·10^-3</td>
<td>3.48208·10^-1</td>
<td>-1.03094·10^-2</td>
<td>1.21886·10^-1</td>
<td>-7.35886·10^-2</td>
<td>2.41122·10^-1</td>
<td>-4.0907·10^-2</td>
<td>2.82012·10^-16</td>
</tr>
</tbody>
</table>

If factors $B_i$ we shall define in four-unit figures ($10^{-4}$), then an average deviation between actual and calculating values by the formula (2) is equal to 22.8 %. Deviation decreases up to 9.5 % if values of factors we shall define with accuracy of five-unit figures $10^{-5}$, and in a case of six-unit figures the deviation will decrease up to 0.2 %. Therefore in Table 2 factors $B_i$ are given to within of six-unit figures. Thus, distribution of probabilities on a direction of the winds having velocity $v > 5$ m/s, is possible by the formula (2), which defines probability of a wind of any direction above the Black Sea surface, averaged inside $45^0$th angle.
With the purpose to obtain analytical formulas of distributions of probabilities, \( p(\alpha, v) \) of the basic synoptic situations and any wind velocities when \( v>5 \text{ m/s} \), we shall make normalization of mid-annual winds \( (v > 5 \text{ m/s}) \) with the taking into account repeatability of all velocities. The obtained values of probabilities are given in Table 3 on four ranges of wind velocities (cyclonic processes which probability is less 0.4 % in the table are not taken into account).

Table 3

Probabilities of wind velocities on synoptic situations (in %)

| velo-cities | a directio | N-E | 22.5-67.5º | E | 67.5º-112.5º | S-E | 112.5º-157º | S-W | 157.5º-247º | W | 247.5º-292.5º | N-W | 292.5º-337.5º | N | 37.5º-22.5º |
|-------------|-----------|-----|-------------|---|-------------|-----|-------------|-----|-------------|---|-------------|-----|-------------|---|
| 5-10        | 57.8      | 59.6 | 76.9        | 68.3 | 72.6        | 71.6 | 69.3        |
| 10-15       | 36.5      | 34.7 | 21.5        | 30.0 | 24.4        | 25.2 | 28.7        |
| 15-20       | 3.5       | 3.7  | 1.2         | 1.6  | 2.8         | 2.8  | 2           |
| >20         | 2.2       | 2    | 0.4         | 0.1  | 0.2         | 0.4  | 0           |

If we suggest, that in each range values of a wind velocities lay in the middle of every range (at the big numbers of cases) then in ranges of wind velocities, given in the Table 3, average velocities will be accordingly: 7.5, 12.5, 17.5 and 22.5 m/s to the range of \( v > 20 \text{ m/s} \). The average velocity 22.5 m/s.

The distributions of probabilities normalized on separate synoptic situations, are shown in Fig. 4. Discrete values, shown on diagrams, are approximated by polynomials of 7th order

\[
p(\alpha, v_j) = \sum_{i=0}^{7} C_{ij} \alpha^i, \quad j = 1, 2, 3, 4. \tag{3}
\]

The submitted four equations characterize distributions of probabilities on directions for average velocities 7.5, 12.5, 17.5 and 22.5 m/s. Values of empirical factors \( C_{ij} \) are given in the Table 4.

Fig. 4. Distribution of the probabilities normalized on synoptic situations on directions at average velocities \( v_1 = 17.5 \text{ m/s}, \) (a); \( v_2 = 12.5 \text{ m/s}, \) (b); \( v_3 = 17.5 \text{ m/s}, \) (c), and \( v_4 = 22.5 \text{ m/s}, \) (d), on the surface of the Black Sea.
The factors obtained at different synoptic situations have the certain dependence about changes of velocity. With the purpose of an illustration, these dependences for empirical factors $C_{ij}$ and $C_{ij}$ are given in Fig. 5.

<table>
<thead>
<tr>
<th>V</th>
<th>$C_{ij}$</th>
<th>$C_{ij}$</th>
<th>$C_{ij}$</th>
<th>$C_{ij}$</th>
<th>$C_{ij}$</th>
<th>$C_{ij}$</th>
<th>$C_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5</td>
<td>69.3</td>
<td>304297</td>
<td>-4.44935E-2</td>
<td>9.55807E-4</td>
<td>-8.31915E-6</td>
<td>3.52314E-8</td>
<td>-7.23582e-11</td>
</tr>
<tr>
<td>12.5</td>
<td>28.7</td>
<td>-995193</td>
<td>6.02894E-2</td>
<td>-1.09875E-3</td>
<td>8.983E-6</td>
<td>-3.69128E-8</td>
<td>7.4561E-11</td>
</tr>
<tr>
<td>17.5</td>
<td>2</td>
<td>-142407</td>
<td>8.71226E-3</td>
<td>-1.50571E-4</td>
<td>1.15697E-6</td>
<td>-4.47799E-9</td>
<td>8.57389E-12</td>
</tr>
<tr>
<td>22.5</td>
<td>8.8124E-16</td>
<td>0.0104494</td>
<td>2.73903E-3</td>
<td>-6.12323E-5</td>
<td>5.16807E-7</td>
<td>-2.11326E-9</td>
<td>4.21536E-12</td>
</tr>
</tbody>
</table>

It is possible to describe the change of introduced in Fig. 5 factors $C_{ij}$ and $C_{ij}$ (also of all factors $C_{ij}, \ldots, C_{ij}$) on velocity can be represented by polynomial of 3rd order sufficiently well.

$$C_i = - \sum_{j=0}^{3} D_{ij} V^j, \quad i = 0, 1, 2, \ldots, 7.$$

Fig. 5. Change of empirical factors $C_{ij}$ and $C_{ij}$ on an averaged wind velocity

Included in (4) numerical values of empirical factors are given in Table 5.
Thus the formula (3) defines probability of any direction of a wind at \( v > 5 \) m/s on a surface of the Black Sea for four discrete, average velocities of a wind. Connection of factors, included in (3), with wind velocity can be presented by (4).

From (3) and (4) we have

\[
p(\alpha, v) = \sum_{i=0}^{7} \sum_{j=0}^{3} D_{ij} \alpha^i v^j ,
\]

Comparison of the results, obtained by (5), with the discrete values given in [11], shows, that (5) well reflects probability of any direction of a wind for average annual values in a range of velocities from \( v = 7 \) m/s up to \( v = 20 \) m/s. The average error of calculations when empirical factors are determined with accuracy \( 10^{-6} \) is within the framework of several percents. Outside the specified range, i.e. from 5 up to 7 m/s and for velocities \( v > 20 \) m/s, the error grows and can reach some ten percents.

It is also necessary to note, that practical application of (5) is inconvenient. Therefore below, parameters determining a wind regime or probability distributions of wind vector field change on time (n), direction (\( \alpha \)), velocity (v) and duration of process (\( \tau \)) we attempted to present it in graphical form. With this purpose we have made normalization of [11] probabilities data for total numbers of cases of winds with velocities \( v > 5 \) m/s and constructed a series of isopleths, which determine changes of probabilities of velocity \( p(n, v) \) and duration of process \( p(n, \tau) \) on time on the Black Sea surface for eight basic synoptic situations. They are given in Fig. 6 accordingly for \( p(n, v) \) and \( p(n, \tau) \). Unfortunately, for want of the data about eastern winds duration probabilities here is a lack of corresponding figure (see Fig. 6 b, (2))

Thus, the continuous vector field of a wind over the Black Sea, constructed with use of observational discrete data, is given by analytical expressions, which allow to calculate the probabilities of, any direction and duration, wind for two types of winds: \( v \leq 5 \) m/s and \( v > 5 \) m/s. The obtained results allow to define more probabilistic directions, velocities and durations of winds over the Black Sea surface for any time interval.
Fig. 6. Interannual distribution of probability both of wind velocity at v > 5m/s on the Black Sea surface (a) and duration (b). 1—north-east, 2—eastern, 3—south-eastern, 4—south and south-eastern, 5—western, 6—north-western, 7—northern winds, 8—cyclonic circulation.
Fig. 6 Continued
References


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რეზიუმე