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On the use of wind direction field for the estimation of wind speed field

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ABSTRACT. This paper describes an objective scheme to estimate wind speed from the available isogonal field in the interior region and wind speed and direction for the boundary region. As a first step, the mean monthly wind field is taken as a guess field for the interior region. The divergence field is then computed, which along with the wind direction for the interior region is used to improve the guess field in successive scans, so as to match it with the wind field along the boundary.

This method has been tested over central India, a region of good conventional network. The results of the scheme which has potential advantages for augmenting data in otherwise sparse data region, is discussed.

1. Introduction

The analysis of weather charts in the tropical areas is handicapped because of the lack of data. Specially over India we are faced with two data-hole regions, one over the Bay of Bengal and the Arabian Sea, and the second over the Middle-East countries. To have a satisfactory analysis, it is therefore necessary to utilise every bit of information available from any source. The areas which are covered by geostationary satellites have been utilising the pictures obtained from them for calculating the speed and direction of the wind. This is possible by making time-lapse loops of the geostationary Application Technology Satellite (ATS) pictures.

However for our area, we have only the facility of receiving pictures by Automatic Picture Transmission (APT) device which can only give the estimation of wind directions. Datta and Nagle (1971) gave the scheme of using these APT pictures for the analysis of 500-mb contour pattern.

In this paper an objective method has been suggested to work out the wind speed field for any level if the wind direction field is available, say from APT pictures.

Mancuso (1970) was first to bring out an objective method for estimating the wind speeds from known wind directions. The method consisted of computing the wind speeds within the interior of a region by stepping down-wind along the streamlines from the known wind speed values at the in-flow boundary. He assumed the divergence to be constant along each streamline and determined it in a manner that minimised the differences between the computed and known wind speeds at the out-flow boundary.

In this paper we have attempted this problem from a different angle. The normal wind velocity field for the month is taken as the first guess for the interior region. Based upon this as well as the known wind velocity field for the outer boundary the divergence field has been calculated. The first guess field is then improved upon in successive scans by imposing upon it the streamline field. Relaxation method similar to Liebmann relaxation technique is adopted for improving the guess field. Successive scanning cycles modify the inner wind speed field in such a manner, that it matches with the divergence field, the known boundary wind field and the internal area isogonal field.

2. Data : Input Data

The distribution and movement of low clouds under influence of the prevailing winds at that level, are sometimes clearly observed in the APT pictures. These low level movements can well be attributed to represent the streamline field at a low level, say 850 mb, or some other suitable level. Likewise, the movement and distribution of clouds (cirrus canopy and jet clouds) at the upper level can safely be attributed to represent the streamline field at 200-mb level. Streamline fields for 850 and 200 mb can therefore be discerned from the satellite cloud pictures with reasonable accuracy. It may, however, be difficult to sort out the wind field at any intermediate level. But the computation method is general and holds equally good for any

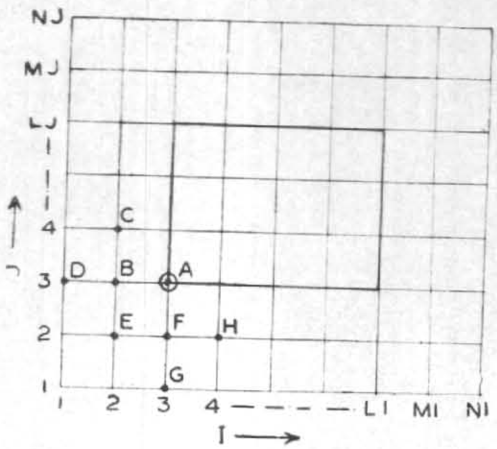

Fig. 1. Grid

level for which the wind direction can be made available.

The area chosen for computation purposes is between 12° to 32° N and 68° to 88°E. The data required are:

(1) The wind direction as read from the streamline field, based on the satellite cloud pictures or any other source, for the inner grid points.

(2) Known wind speed and direction for all the grid points of the outermost boundary and the next inner one.

(3) Normal wind speed and direction for the month, for the rest of the inner grid points.

3. Computation Procedure

This may be explained in the following three steps:

Step I — The zonal and meridional components of the wind, U and V respectively, at each grid point, are calculated from the available wind direction and velocity. From this, in turn, is calculated the divergence at the grid points.

Step II — The U and V field for the inner grid point is modified with the help of the divergence field calculated in Step I but keeping the streamline field constant. This step is further illustrated below.

Suppose we start with the point A (Fig. 1), initially the values of U and V at this point will only be normal values (as fed) and can naturally differ from the actuals, in view of the divergence field at the previous point B (or F) and known U and V components at the other three points, *i.e.*, C, D and E (or E, G and H) around B (or F). Now the divergence (Div.) at the point B (or F), if it is exactly balanced by the U and V components at A, C, D and E (or A, E, G and H) is given by:

$$\text{Div.}_{\text{E}} = U_{\text{A}} - U_{\text{D}} + V_{\text{C}} - V_{\text{E}} \qquad (3 \cdot 1)$$

$$\text{Div.}_{\text{F}} = U_{\text{H}} - U_{\text{E}} + V_{\text{A}} - V_{\text{G}} \qquad (3 \cdot 2)$$

If however, the value of U or V differs from what is required to balance, we get a residual (Res.) for the point A, leading to a new value of U (or V) given by:

$$\text{Res.}_{\text{B}} = \text{Div.}_{\text{B}} - U_{\text{A}} + U_{\text{D}} - V_{\text{C}} + V_{\text{E}} \quad (3 \cdot 3)$$

and $U_{\text{A}} = U_{\text{A (initial)}} + 1.2 \times \text{Res.}_{\text{B}}$

or $\text{Res.}_{\text{F}} = \text{Div.}_{\text{F}} - U_{\text{H}} + U_{\text{E}} - V_{\text{A}} + V_{\text{G}} \quad (3 \cdot 4)$

and $V_A = V_{\text{A (initial)}} + 1.2 \times \text{Res.}_{\text{F}}$

The factor 1.2 in the above equation gives the relaxation factor as in the standard Liebmann's Relaxation Scheme. To make the solution converge faster we tried various over-relaxation factors such as 1.1, 1.2, 1.3, etc. It was found that the present type of solutions were converging faster with a factor of 1.2.

The choice between calculating U or V at A which means selecting the point B or F for computation of divergence, depends upon the wind direction at A.

If we divide the wind direction (geometrical 0°-360°) into four segments, as shown in Fig. 2

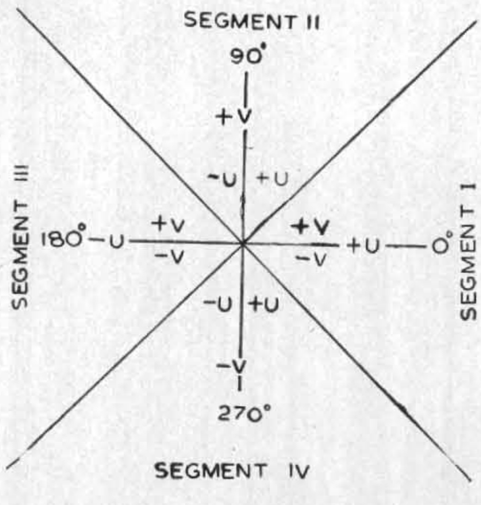

Fig. 2

Segments for wind direction (Beta)

it can immediately be seen that for direction β lying within segment I, U is positive and within segment III it is negative, but in either case the magnitude of U is greater than the corresponding V component. Similarly in segments II and IV the magnitude of component V is greater than the corresponding U value. In order to control the magnitudes of U and V, we compute U by considering the divergence at point B for segments I and III (Eqn. 3·3) and V by considering the point F for segments II and IV (Eqn. 3·4).

Before accepting this value of U (or V) we check for its sign, to see if it is in conformity with that detemined by the streamline field (wind direction) at that grid point. If so, it is accepted, otherwise, we assign it the average value of U (or V) with the required sign. For cases of $\beta=0°$ (or 360°), 090°, 180° and 270° (geometrical), the corresponding U or V value is made zero, while the other one is computed from the equation (3·4) or (3·4) as the case may be. Here again, the computed value is accepted only if its sign is in accordance with that demanded by the value of β, and is otherwise assigned the average value with appropriate sign.

After one of the components U or V is computed and passed through the above checks, the corresponding value of V (or U) is calculated from the relation :

$$\tan \beta = V/U \qquad (3\cdot5)$$

The whole process is repeated till we find no significant change in U and V values compared to the values of previous scan.

Step III — At the last step we combine U and V to get the required wind speed field by using the usual equation :

$$\text{Velocity} = \sqrt{U^2 + V^2}$$

4. Results and Conclusions

Quite a few cases were studied. However, the results of two typical cases, one of 850 mb and the other of 200-mb level are discussed here.

Case 1 : 850 mb — An interesting case of a western disturbance was chosen for 850-mb level at 00 GMT of 21 January 1971. The streamline field for that day is shown in Fig. 3. Computation results are given in Table 1, where the actual and computed wind speeds are shown one below the other. It can be seen that the computed values are in good agreement with the actuals. Root mean square error (RMSE) was calculated by comparing the computed wind speeds with the actuals. It was found to be 4·0 knots in this case.

Case 2 : 200 mb — For 200 mb streamline field for the same day (00 GMT of 21 January 1971) was chosen. It was a case of strong westerly jet stream over north India (chart not presented). The picked up wind speed from actual analysis and those worked out by the present scheme are presented in Table 2. Here too the results are in agreement within practical limits. The RMSE value was found to be 18.9 knots.

It is thus seen that this scheme can be useful for estimating, to a good approximation, the wind speed field for a data sparse region, provided the

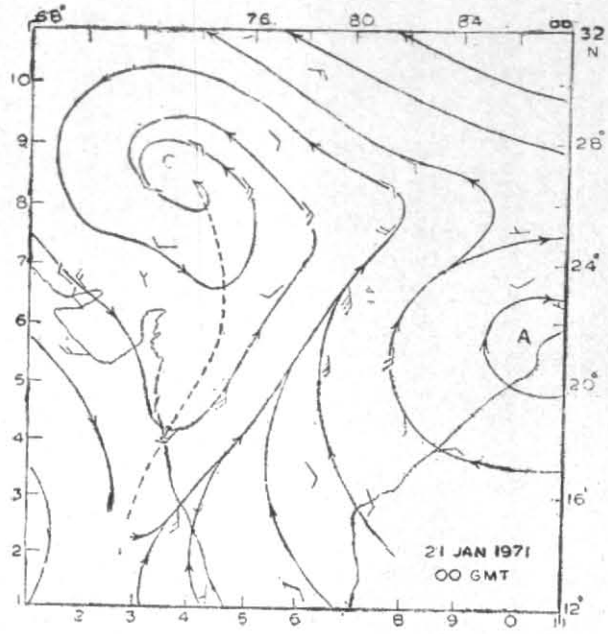

Fig. 3

Streamline anvalysis of 850-mb level

TABLE 1

Wind speed (kt) at 850 mb, 00 GMT of 21 January 1971

J		I: 1	2	3	4	5	6	7	8	9	10	11
1	A	10	2	10	5	5	10	15	15	15	10	10
	C	10	2	10	5	5	10	15	15	15	10	10
2	A	10	10	15	10	10	10	10	10	10	10	10
	C	10	10	15	10	10	10	10	10	10	10	10
3	A	10	15	5	15	10	10	10	10	10	10	10
	C	10	15	4	6	7	6	6	6	8	10	10
4	A	10	15	10	15	10	10	15	10	10	10	5
	C	10	15	6	9	11	7	5	4	7	10	5
5	A	15	15	10	15	20	20	20	12	10	5	5
	C	15	15	8	5	12	11	9	7	7	5	5
6	A	15	15	10	5	10	15	25	15	10	5	5
	C	15	15	8	4	9	9	10	7	5	5	5
7	A	20	15	10	10	10	15	20	15	10	5	5
	C	20	15	7	6	6	5	10	10	6	5	5
8	A	20	15	10	10	15	15	15	20	5	5	5
	C	20	15	7	4	13	9	8	7	5	5	5
9	A	15	15	15	15	15	15	15	10	10	5	5
	C	15	15	6	5	19	12	11	8	7	5	5
10	A	15	15	15	15	15	15	15	10	10	10	10
	C	15	15	15	15	15	15	15	10	10	10	10
11	A	10	10	10	10	10	10	10	10	10	10	10
	C	10	10	10	10	10	10	10	10	10	10	10

RMSE—4·0 kt; A—Actual; C—Computed

TABLE 2

Wind speed (kt) at 200 mb, 00 GMT of 21 January 1971

		I										
J		1	2	3	4	5	6	7	8	9	10	11
1	A	35	35	35	30	25	25	25	25	25	20	20
	C	35	35	35	30	25	25	25	25	25	20	20
2	A	35	35	35	35	30	25	25	25	25	20	20
	C	35	35	35	35	30	25	25	25	25	20	20
3	A	35	35	35	35	35	30	30	25	25	25	25
	C	35	35	24	22	28	48	48	21	30	25	25
4	A	50	50	45	40	40	35	35	35	35	30	30
	C	50	50	46	34	37	44	71	59	77	30	30
5	A	70	70	65	65	55	55	50	50	50	50	50
	C	70	70	61	42	39	29	46	50	41	50	50
6	A	95	90	90	85	85	80	80	75	75	75	75
	C	95	90	79	57	37	37	47	62	51	75	75
7	A	120	115	110	105	100	95	90	90	90	90	90
	C	120	115	91	80	52	53	41	57	66	90	90
8	A	140	140	140	135	125	115	105	95	90	90	90
	C	140	140	102	104	68	70	73	88	87	90	90
9	A	125	130	135	145	150	140	125	110	100	95	95
	C	125	130	109	138	140	154	162	183	165	95	95
10	A	90	95	105	120	130	135	145	130	115	105	95
	C	90	95	105	120	130	135	145	130	115	105	95
11	A	60	65	75	85	95	105	110	115	120	115	110
	C	60	65	75	85	95	105	110	115	120	115	110

RMSE—18·9 kt ; A—Actual ; C — Computed

streamline field for that area is made available from the satellite cloud pictures or otherwise.

This wind field can probably be used as input for the wind contour analysis using balance equation, in the way discussed by Datta and Singh (1972).

Instead of the normal wind field as a first guess it may also be possible to use the previous synoptic hour wind field or the forecast wind field valid for the time of analysis.

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