NOTES AND CORRESPONDENCE

An Example of Objective Analysis of Mesoscale Wind Field over Thunderstorms with Steady Movement*

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1. Introduction

The necessity of development of the technique in the mesoscale objective analysis has been recognized among the meteorologists concerned with mesoscale severe phenomena. The problems involved in the mesoscale analysis are different in many way from these in the analysis of large or medium-scale fields. For example, the horizontal density of observation stations is, not always, enough to resolve the mesoscale systems. Some time lag or lead between the observation time and analysis time, which is insignificant in the large-scale analysis, also would not be negligible in the mesoscale analysis.

One of the useful technique to overcome the problems mentioned above would be the "time to space conversion". For the system with quasi-steady movement, the local time change and spatial variation of a certain scalar quantity a are approximately related as

$$\frac{\partial a}{\partial t} \div -c \frac{\partial a}{\partial s} \quad (1)$$

where c and s is the propagation speed of the system and the distance measured along the direction of the movement. The technique of "time to space conversion" based on eq. (1) was very effectively used by Fujita (1955) in his subjective mesoscale analysis.

The kinematic relation of eq. (1) was used as a constrain in the variational objective analysis of the surface wind field of thunderstorms by Sasaki (1970). Barnes (1971) also used the "time to space conversion" of observation position in his

mesoscale objective analysis in the lower troposphere over the thunderstorms.

In the present note, the "time to space conversion" is introduced in the mesoscale objective analysis of tropospheric wind field of thunderstorms of May 28, 1967, which developed over the NSSL aerological observation network.

2. Observation data and space to time conversion

The aerological data used in the present analysis are obtained by NSSL network (including 9 stations) in the central part of the state of Oklahoma U. S. A. The distance between the adjacent stations is averaged at about 70 km. The radiosondes are released five times from each stations with the time interval of about 1.5 hour, *i.e.* at about 11.0, 12.5, 14.0, 15.5 and 17.0 CST. The observation point at a certain standard pressure surface is, of course, different from the released point due to the drift of the radiosonde. The observation time is also different from the released time. As an example the position of the radiosonde at the 250-mb surface for the sonde of 3rd release (*i.e.* about 14 CST) are presented in Fig. 1. In the figure, open circles, black circles and numerals indicate the released point, observation point at the 250-mb surface and the observation time (CST) respectively.

The radar observation revealed the quasi-steady movement of the thunderstorms of this day. The x and y component of the propagation velocity of the storms, c_x and c_y determined by the radar observation is $24 \text{ km} \cdot \text{hour}^{-1}$ and $16 \text{ km} \cdot \text{hour}^{-1}$ on an average. By applying the "space to time conversion" the position (x_a , y_a) of the observation relative to the system at a certain map time t_a is expressed as

$$x_a = x_0 + c_x(t_a - t_0) \quad (2)$$

$$\text{and} \quad y_a = y_0 + c_y(t_a - t_0)$$

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where (x_0, y_0) and t_0 stand for the observation point and time respectively.

Fig. 1. The grid system, position of the radio-sonde at 250 mb (black circle) and the released point (open circle). The numerals indicate the time (CST) when the sonde arrived 250 mb. (The unit of the time for the fraction of hour is not given in minute but in the unit of one-hundredths of hour.)

3. Analysis of wind field at a standard pressure level

The analysis of wind field is made at nine standard pressure level with 100 mb interval between 950 and 150 mb for six map times of 1 hour interval between 12 and 17 CST. The grid system is shown in Fig. 1.

The scheme of interpolation used here is quite similar to the classical scheme proposed by Cressman (1959). The individual observations are, however, weighted according to both their distance from grid point and their time difference between the observation and analysis. The correction at the grid point $\epsilon(x, y)$ is, thus, determined from the correction $E(x_a, y_a)$ at the observation point at the analysis time (see eq. (2))

$$\text{as } \epsilon(x, y) = \frac{\sum E(x_a, y_a) \cdot B}{\sum B} \quad (3)$$

The weighting function B in eq. (3) is defined as

$$B = \begin{cases} 0 & \text{for } r^2 \geq R^2 \text{ and/or } \Delta t^2 \geq T^2 \\ \frac{R^2 - r^2}{R^2 + r^2} \cdot \frac{T^2 - \Delta t^2}{T^2 + \Delta t^2} & \text{for } r^2 < R^2 \text{ and } \Delta t^2 < T^2 \end{cases}$$

where r and Δt is the distance between grid point (x, y) and observation point at analysis time (x_a, y_a) and the time difference between t_a and t_0 . The value of constant R and T (i.e. influence distance and time) should be chosen by considering the horizontal and time scale of the phenomena and the density of the observations. The two calculation, i.e. #1 and #2 were made and the value of R and T in each scans for these calculation are given in Table 1. The initial guess is given

Table 1. Values of R and T corresponding to successive scans for calculation #1 and #2.

scan	calculation # 1		calculation # 2	
1	9 d	2.0 hour	9 d	1.5 hour
2	7 d	1.5	7 d	1.25
3	5 d	1.5	5 d	1.00
4	3.5 d	1.25	3.5 d	1.00
5	2.1 d	1.00	2.1 d	0.75
6	1.8 d	0.75	1.8 d	0.75

by the averaged value of u or v of all observations within ± 2.0 and ± 1.5 hour for calculation #1 and #2 respectively.

The five-point smoothing

$$\bar{a} = \frac{1}{8} [4a_{i,j} + a_{i-1,j} + a_{i+1,j} + a_{i,j-1} + a_{i,j+1}] \quad (5)$$

is applied after the 2nd, 4th, 5th and last scans. In both calculation #1 and #2, the correction made in the last scan would be said to be very small, since the variance of them (i.e. $\sigma^2_{\epsilon_u}$ and $\sigma^2_{\epsilon_v}$) is only 0.01 (m/sec)^2 .

Now let us compare the results by calculation #1 and #2. The variance of the difference between the wind velocity of these calculation within the (200 km) square for 6 map time is, for example at 250 mb* level, 0.27 (m/sec)^2 . The variances of ∇V and ζ (vorticity) at 250 mb for the calculation #1 are $0.18 \times (10^{-5} \text{ sec}^{-1})^2$ and $0.52 \times (10^{-5} \text{ sec}^{-1})^2$ while these for calculation #2 are $0.17 \times (10^{-5} \text{ sec}^{-1})^2$ and $0.52 \times (10^{-5} \text{ sec}^{-1})^2$ respectively. In a word, we can not find any significant difference between the results by calculation #1 and #2.

Since a detailed subjective analysis on the same storms were made fortunately by Fankhauser (1969), we can compare the results by him and

* The most remarkable change of wind around the thunderstorms are seen at the lower layer (950 mb) and the upper outflow layer (250 mb).

the present analysis. As far as we look the isotach and streamline, any significant difference is not found between them from the morphological view point.

4. Correction of ω and V

The morphological coincidence between the results by subjective and objective analysis, however, does not assure the physical validity of the analysis. One of the simple check on the validity of the analysed wind field would be the inspection of the vertical velocity on the top of the atmosphere. The vertical velocity at 100 mb, $\omega(100\text{ mb})$ is obtained by vertically integration of the horizontal divergence from the surface to 100 mb. If the wind field was accurately analyzed, the $\omega(100\text{ mb})$ would be very small. The standard deviation of $\omega(100\text{ mb})$ for the present analysis is, unfortunately as large as 28 mb hour^{-1} . This kind of the unfavorable situation is usually found in the kinematic evaluation of vertical velocity. O'Brien (1970) suggested the necessity of the modification of the divergence field for these situation to make ω vanish at the top of the atmosphere. The value of the correction of the divergence $(\nabla \cdot V)_c$ for the layer between 900 mb and 100 mb is given as

$$(\nabla \cdot V)_c = -\frac{\omega(100\text{ mb})}{800\text{ mb}}$$

(6)

The corrections of the horizontal velocity component u_c and v_c corresponding to the value of

$$(\nabla \cdot V)_c \text{ are given by}$$
$$u_c = -\partial \chi_c / \partial x, \quad v_c = -\partial \chi_c / \partial y$$

(7)

and

$$\nabla^2 \chi_c + (\nabla \cdot V)_c = 0$$

(8)

The χ_c is solved by means of the relaxation under the proper boundary condition as explained by Miyakoda (1960). The variance of the corrected value of velocity $(u_c^2 + v_c^2)^{1/2}$ is $0.20\text{ (m}\cdot\text{sec}^{-1})^2$. The analyzed wind velocity components are given by

$$u = u_a + u_c \quad \text{and} \quad v = v_a + v_c$$

(9)

Fig. 2. $V_{950\text{mb}}$ at 1400 CST. The radar echoes are shown by blacked area.

Fig. 3. $V_{950\text{mb}}$ and $V_{250\text{mb}}$ at 1500 CST. The radar echoes are shown by thin lines.

where u_a and v_a are the values obtained by the calculation in section 3. Although the erroneous values of ω at higher levels are corrected from the procedure mentioned above, the physical validity of the correction seems to be rather obscure. More physical method of analysis will be required in the future.

As examples of the results, the map of $V_{950\text{mb}}$ at 14.00 CST and the map of $V_{950\text{mb}}$ and $V_{250\text{mb}}$ at 15.00 CST are given in Fig. 2 and Fig. 3 respectively. Since the detailed morphological description of the wind field over the area of the thunderstorms' development will be presented somewhere, we will give only the very brief description in the present section. The radar observations showed that the thunderstorms developed along the northern boundary of the southerly wind area in the lower layer as the horizontal gradient of v in the lower layer increased quite rapidly during one hour between 13 and 14 CST. It is also found that the upper outflow is formed at 250 mb over the thunderstorms in the mature stage (see the map of $V_{250\text{mb}}$ at 15.00 CST).

5. Remarks

An example of mesoscale objective analysis on the tropospheric wind field of thunderstorms with quasi-steady movement is presented. The calculation scheme includes the "time to space conversion" of observation point relative to the mesosystem and weighting on the time difference

between the observation and analysis time.

Obtained wind fields coincide well with these by subjective analysis. The scheme presented here seems to be useful so far as the qualitative or morphological description of the phenomena is concerned.

The physical meaning of the some part of the scheme, for example, the weighting and smoothing, however, are rather obscure. For the purpose of the quantitative discussion, more refined scheme should be developed.

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ほぼ定常的に移動した雷雨の周辺の中規模風速場の客観解析の一例

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