THE PROBLEM OF DETECTING MESO-SCALE MOTION SYSTEMS

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ABSTRACT

The problem of spacing surface observations to insure reasonable analyses with respect to the horizontal extent, duration, and velocity of the motion system required to be detected is discussed in relation to the motion system's rate of growth or intensification. An approach is utilized that suggests that important weather-producing meso-scale motion systems, once detected, can become hidden within the data at a critical stage of their growth. Forecast verification data are presented to illustrate the effect upon the issuance of timely forecasts of weather phenomena associated with such motion systems.

1. INTRODUCTION

In a previous paper [3] a procedure for determining the optimum spacing of upper-air observations was presented. Subsequently, the requirements for observations needed for the detection and prediction of small-scale weather events were reported [7]. In both reports it was stressed that, in order to determine satisfactory network densities of surface and upper-air observations, the probable horizontal extent, duration, and velocity of the motion system needs to be considered. The practical problem is apparent when it is realized that forecast improvement is limited by the extent to which the observational network approaches the optimum with respect to the scale of the phenomena which must be predicted. It is also important to remember that the ability of the forecaster to become specific with respect to an anticipated event is related to the accuracy of the basic analysis. If the motion system is not properly described in time and space by the network supplying observational data, the forecaster cannot hope to forecast properly the event.

In most cases the meteorologist can use climatology and observational experience to assist in the problem of specifying the horizontal dimensions, duration, and velocity of the motion system that needs to be detected. From a consideration of data from [6], [8], and [9] and operational experience, the average horizontal dimensions of meso-scale high and low pressure systems associated with severe local storms are on the order of a few tens of miles along the short axis to several times as much along the long axis. Generally speaking, attempts to specify the dimensions of pressure systems associated with such meso-scale systems have been centered around their active stages, and several fine examples are illustrated in [8] and [9]. Unfortunately, few data exist in suitable form to establish similar dimensions for the incipient stage. However, forecast experience seems to indicate that the first synoptic evidence of the existence of the incipient stage may be present in the sea level pressure and wind field a few hours prior to the development of the active stage. Further, its horizontal dimensions and rate of movement appear to be of the same order as those of the active stage.

Assuming that climatology and the forecasters' experience partially, at least, describe the time and space scales of the motion systems combining to produce severe local thunderstorms, we can arrive at some further estimate of the optimum spacing of stations required to detect and predict these storms. This is the purpose of this paper.

2. FORECAST EXPERIENCE

Since 1961 the Severe Local Storms Forecast Center (SELS) has actively attempted to issue its forecasts with the maximum possible lead time. In practically all cases the last hourly observations from the area of concern receive some consideration and have some influence upon the forecast. So, for the purposes here, lead time is defined as the time interval between the last hourly observational data set and the beginning of the valid period of the forecast. Using forecast verification data available from 1961 through 1963 and the foregoing definition as a basis, figure 1 has been constructed showing the number of forecasts and percent correct of the forecasts issued during the lead time interval specified.

As perhaps was to be expected, the verification of forecasts was best for those issued with short lead time intervals. On the other hand, the success of forecasts issued in the lead time interval of 2–3 hr. was no better than those issued in the interval 5–6 hr. Some additional skill is shown for those issued in the intervening time intervals.

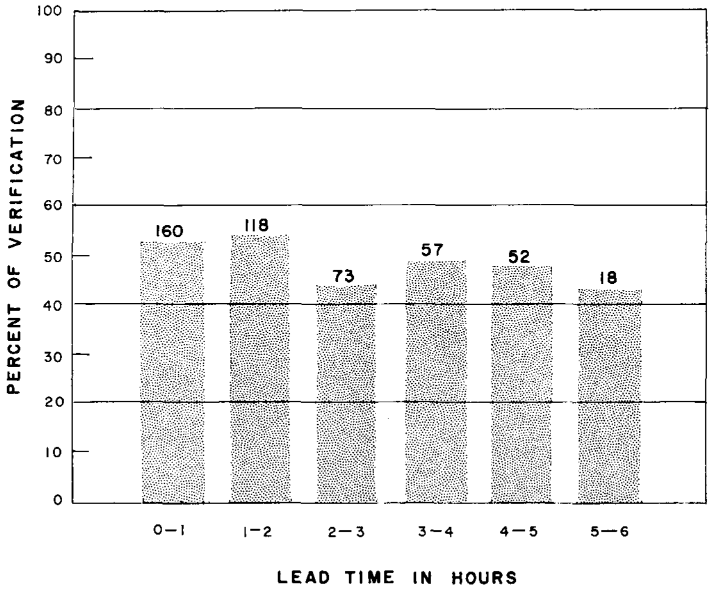

FIGURE 1.—Verification of 478 tornado forecasts issued in 1961, 1962, and 1963 in terms of lead time. The percent of verification is the ratio of the total number of correct forecasts issued during the 1-hr. interval of specified lead time to the total number of forecasts issued during the same 1-hr. interval. The number of forecasts issued in each interval is indicated.

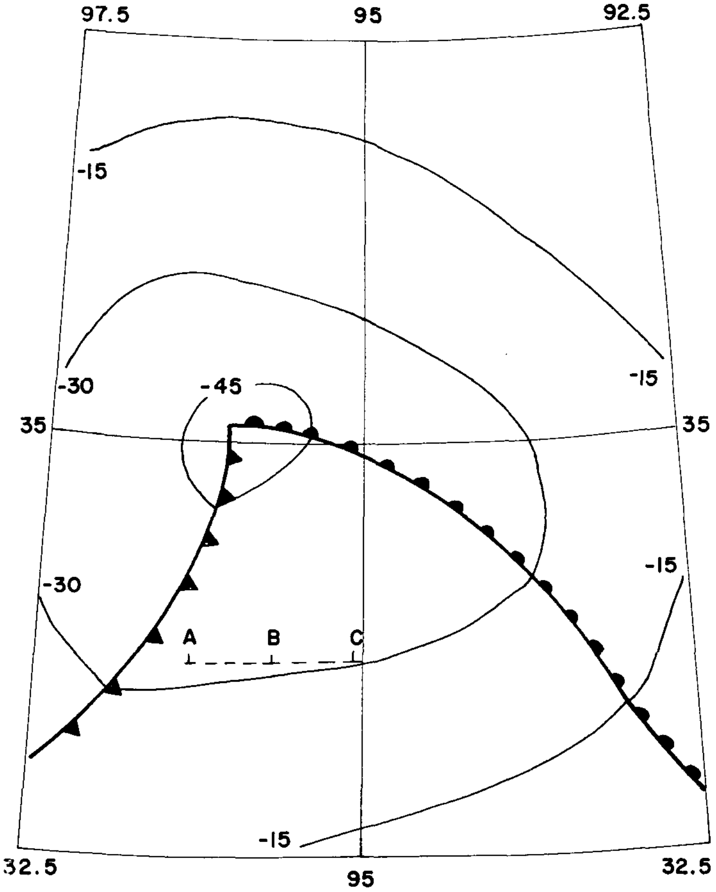

FIGURE 2.—1000-mb. contour pattern at initial time. Contours are drawn for 15-m. intervals.

There seems to be no doubt that the skill shown in the first two lead time intervals was due, at least in part, to the facts that: (1) thunderstorms were more likely to have been in existence, (2) severe weather may have already been in progress, (3) radar observations supplied more specific information, and (4) meso-scale pressure and wind disturbances were already in existence and their detection was possible.

On the other hand, forecasts issued during the last three time intervals (3–4, 4–5, 5–6) were most often issued when thunderstorms did not exist. Such forecasts are most likely to be based upon the larger scale tropospheric motion systems and weighted heavily toward those mid-tropospheric motions most favorable for the production of significant perturbations and thermally unstable air masses.

The difficulties in the detection of the growth of small-scale motion systems seem to be supported by the relatively lower verification in the interval 2–3 hr. Certainly, the forecaster's experience indicates this to be true, not only as judged by the verification statistics but also by a marked tendency of the analyst to lose or smooth perturbations from his analysis 2 to 3 hr. before the activity begins.

3. SYNOPTIC EXPERIENCE

A hypothesis concerning the formation of the incipient stage of the instability line was presented in [2]. Of particular interest here is the rate of growth of the perturbation in the contour field illustrated in that case. Since that report was written, additional operational experience has become augmented by many studies of the rate of growth of such perturbations as evidenced by the relative geostrophic vorticity patterns associated with instability line formations. The bulk of available evidence [4] and [9] suggests that the geostrophic relative vorticity at sea level increases at an accelerated rate.

To relate this evidence to observational requirements for the detection and analysis of such motion systems, consider that the problem is primarily one of determining the rate of growth of a perturbation of short wavelength and of low amplitude superimposed upon a 1000-mb. contour configuration of much longer wavelength. Such

TABLE 1.—*Values of amplitude (A_1, A_2), wavelength (L_1, L_2) and distance along x axis (x_1, x_2) used in equation (1) and its derivatives at the time interval specified*

	At initial time	At initial time+2 hr.	At initial time+4 hr.	At initial time+6 hr.
A_1		5.0 m.	10.0 m.	20.0 m.
A_2	37.5 m.	37.5 m.	37.5 m.	37.5 m.
L_1		120n. mi.	60n. mi.	60n. mi.
L_2	475 n. mi.	475n. mi.	475n. mi.	475n. mi.
x_1		$=x_2$	$=x_2+30$	$=x_2+30$

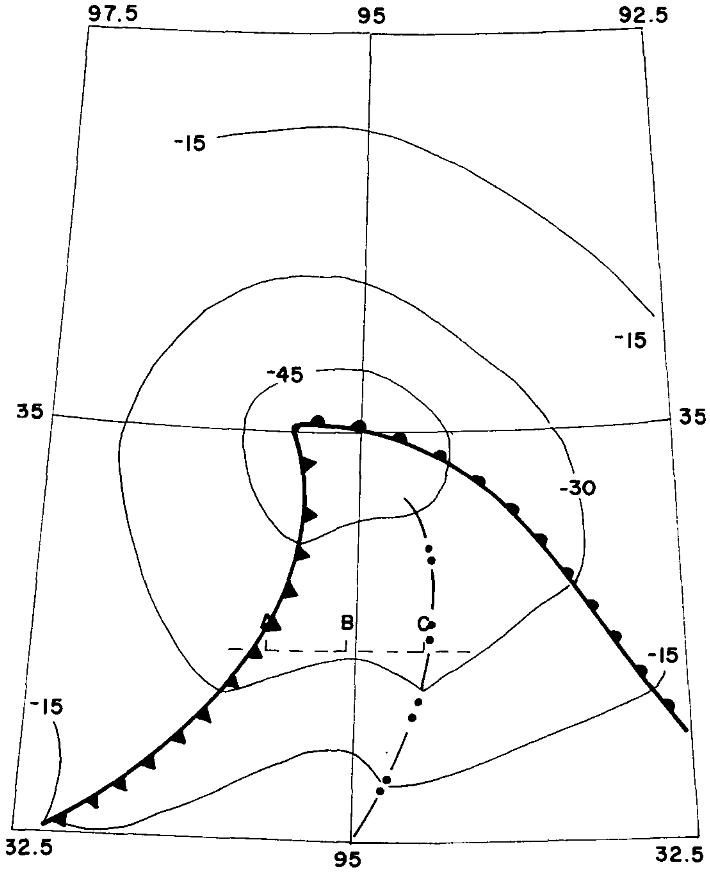

FIGURE 3.—1000-mb. contour pattern 2 hr. after initial time. Contours are drawn for 15-m. intervals.

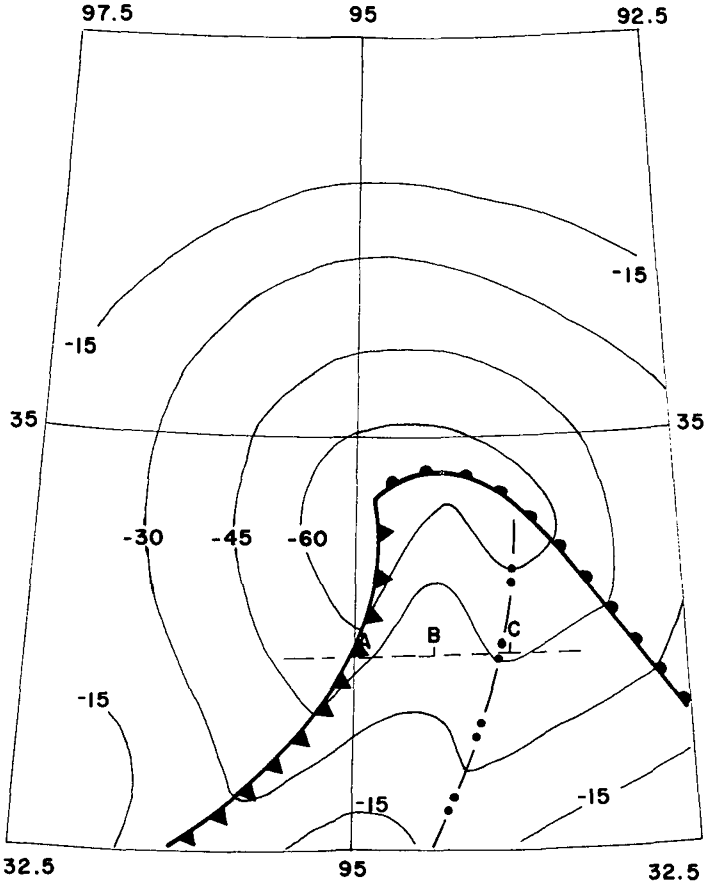

FIGURE 4.—1000-mb. contour pattern 4 hr. after initial time. Contours are drawn for 15-m. intervals.

a perturbation in the contour field, in two dimensions, can be described by the equation

$$y=y_0+A_1 \cos\left(\frac{2\pi}{L_1}x_1\right)-A_2 \cos\left(\frac{2\pi}{L_2}x_2\right) \qquad (1)$$

where A_1, A_2, L_1, L_2, x_1 and x_2 are amplitude, wavelength, and distance along x axis and are specified in table 1.

Figure 2 depicts the initial 1000-mb. height field typical of a wave cyclone prior to the development of an instability line. To assist in evaluating the requirements for data and analyses, the axis A–C has been selected along which all computations have been made. Further, it is assumed that the system is moving in a generally easterly direction and the axis A–C is fixed to the motion system and moves with the speed of the system. It is further assumed that the second derivative with respect to time of the relative geostrophic vorticity is equal to -23×10^{-2} hr.$^{-3}$ at point B on axis A–C, which is consistent with the rate of growth of the perturbation in the contour heights described by the values of table 1. These are of the same order of magnitude as frequently computed in operational practice (see, for example, [5]).

On the basis of the foregoing assumptions, figures 3, 4,

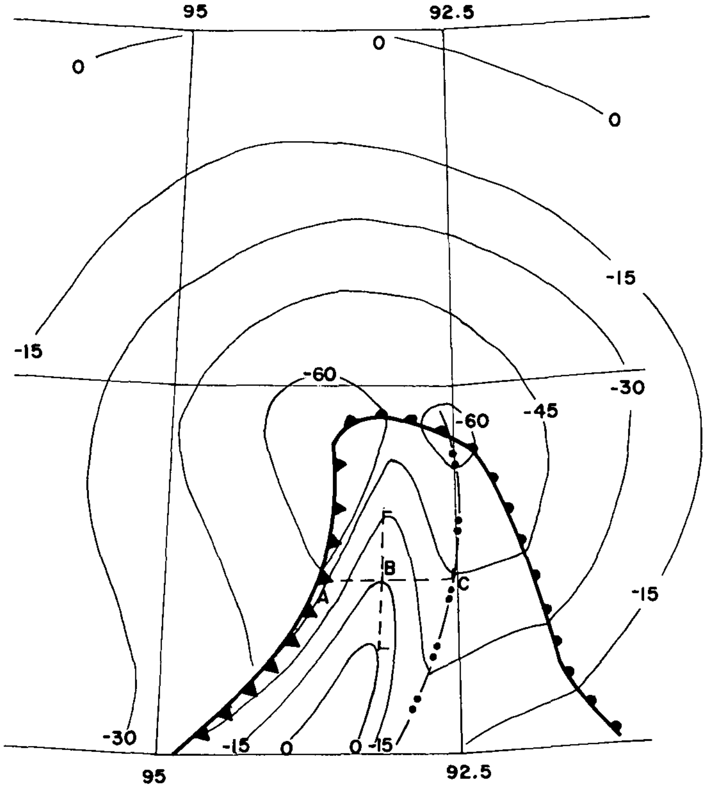

FIGURE 5.—1000-mb. contour pattern 6 hr. after initial time. Contours are drawn for 15-m. intervals.

and 5 have been constructed to illustrate the changes that take place in the pressure distribution at 2-hr. intervals.

By applying the principles developed in [3] and further discussed in [7], the optimum spacing of stations that would detect the existence of the contour height distribution along the line B–C can be determined from

$$d=2\left(\frac{3\sigma}{y'''}\right)^{1/3} \qquad (2)$$

where d is the optimum spacing of stations, σ is standard error of observation and for purposes here is set at 3 gpm. This is equivalent to an error of about 0.3 mb. or 0.01 in. of mercury. This is somewhat less than the error permitted in the station barometer. (See, for example, *Circular N, Manual of Surface Observations* (*WBAN*), 7th ed., Weather Bureau Addendum, Par. A7233.5.) y''' is the third derivative of equation (1) integrated between the limits of $x=35$ n. mi. and $x=55$ n. mi.

The optimum spacing of stations required to detect the interval B–C is of the following order: (1) at initial time, $d=210$ n. mi.; at initial time plus 2 hr., $d=58$ n. mi.; at initial time plus 4 hr., $d=23$ n. mi.; at initial time plus 6 hr., $d=18$ n. mi.

Peterson and Middleton [10] seem to object to the foregoing approach on the basis that, since only two sample values are to be used for interpolation, one must conclude that, the less reliable the measurement, the fewer are needed. Such a conclusion represents only a casual interpretation of (2). This formula should, of course, be used to draw conclusions only under the circumstances of its derivation; i.e., the minimization of error in determining horizontal gradients from two individual measurements. A correct interpretation of the formula reveals that: (1) The analyses of more complex and higher order variations in the gradient of atmospheric properties are possible with more reliable observations. (2) The closer the spacing of observations, the more reliable they must be to avoid the analysis being one of observational error. (3) For a given variation in the gradient of an atmospheric property and a known observation reliability, there is an optimum spacing of stations. The spacing of stations closer than the optimum is not justified for the sole purpose of determining gradients from pairs of observations.

In the case illustrated in figures 2 and 3, the perturbation can be defined by the analysis of data from the surface observational network that exists over most of the United States east of the Continental Divide. The network's capability for detection deteriorates rapidly beyond the second hour after growth of the wave begins at the rate specified.

Many variations in the wavelengths and amplitudes of perturbations are to be expected, and their rate of growth will vary from one situation to another. However, analysis and forecast experience indicate that the magnitudes of conditions here selected are equaled, or are exceeded, in about one-half of the severe local storm cases. Operational experience further indicates that, if thermal characteristics of the air mass are favorable, thunderstorms probably will be in existence or in the process of development along the segment B–C shortly after the perturbation reaches the configuration illustrated by figure 4. The development of the small-scale anticyclone frequently proceeds to that of figure 5 before beginning to dissipate. See, for example, Fujita's [1] analysis of the Fargo tornado and Williams' [9] report of the analyses of data from the NSSP Beta network in Oklahoma as well as his earlier report [8] on pressure wave observations in the central Midwest.

4. CONCLUSION

The foregoing considerations support the contention that the successful and timely prediction of weather events associated with mesoscale motion systems is directly related to the ability of the observational and analysis programs to detect the existence and the rate of growth of such systems. Operational forecast experience indicates that during the incipient and dissipating stages of the instability line, the analyses of observational data must be accomplished at a time interval no greater than 2 hr. and preferably at 1-hr. intervals. Even so, the average dimensions of the pertinent motion systems are such that, with the present areal distribution of observational stations, the chance of missing significant changes in their rate of growth is high.

REFERENCES

1. T. Fujita, "A Detailed Analysis of the Fargo Tornadoes of June 20, 1957," *Research Paper* No. 42, U.S. Weather Bureau, 1960, 67 pp.
2. D. C. House, "The Mechanics of Instability-Line Formation," *Journal of Meteorology*, vol. 16, No. 2, Apr. 1959, pp. 108–120.
3. D. C. House, "Remarks on the Optimum Spacing of Upper-Air Observations," *Monthly Weather Review*, vol. 88, No. 3, Mar. 1960, pp. 97–100.
4. D. C. House, "Forecasting Tornadoes and Severe Thunderstorms," *Meteorological Monographs*, vol. 5, No. 27, American Meteorological Society, Boston 1963, pp. 141–155.
5. D. C. House and M. E. Pautz, "Forecasting Tornadoes and Severe Thunderstorms," *Conference Review of Third A. M. S. Conference on Severe Local Storms*, Urbana, Ill., 1963.
6. M. Tepper, "Pressure Jump Lines in Midwestern United States," *Research Paper* No. 37, U.S. Weather Bureau, Washington, D.C., 1954, 70 pp.
7. U.S. Weather Bureau, "Observational Requirements for the Detection and Prediction of Small-Scale Weather Events," *Technical Planning Study* No. 8, Washington, D.C., 1963, 38 pp.
8. D. T. Williams, "Pressure Wave Observations in the Central Midwest," *Monthly Weather Review*, vol. 81, No. 9, Sept. 1953, pp. 278–289.
9. D. T. Williams, "Analysis Methods for Small-Scale Surface Network Data," *NSSP Report* No. 17, U.S. Weather Bureau, Washington, D.C., 1963, 23 pp.
10. D. P. Peterson and D. Middleton, "On Representative Observations," *Tellus*, vol. 15, No. 4, Nov. 1963, pp. 387–405.

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