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RADAR-BASED SHORT-TERM PREDICTION OF SEVERE RAINSTORMS-PRELIMINARY RESULTS

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SYNOPSIS

A new method is developed in order to track and predict in short-term (15 min-2 hr lead times) the spatial configurations, the velocity vectors and the rain intensity textures of the potentially flood producing rain fields that are detected on a radar scope. First, the rain field is decomposed into simple, tractable elements. Then a statistical adaptive forecasting scheme is developed in order to predict the evolution of each of these elements in time and space. The composition of these elements forms the complete rain field with respect to its spatial configuration, location and rain intensity texture at each prediction lead time. The method is currently being applied to the radar data of rain fields. Some preliminary application results are given.

INTRODUCTION

The most dominant cause of flash floods over U.S.A. is the midlatitude convective weather systems. Since these systems evolve within several hours, the "short-term prediction" will mean forecasting the time-space behavior of these systems at time increments of 5 to 10 minutes up to a lead time of at most one hour at each forecasting stage. These forecasts can then be updated at the forecast time increments as the evolution of the rain field is tracked on the weather radar scope.

A radar-based short-term rain field prediction scheme which can detect a rain field several hours in advance of its arrival onto a geographical region of interest and which can then extrapolate the spatial configuration, the rain intensity texture and the complex motion of this field in time and space onto the region several hours ahead of its actual arrival is yet nonexistent at real time operational level over the U.S.A. However, countries like Canada, England and Japan have already developed such schemes for the short-term forecasting of rain fields (Browning, 1982).

The Canadian short-term prediction scheme, developed by Bellon and Austin (1976), is called the Short-Term Automated Radar Prediction (SHARP) method. This method utilizes simple cross-correlation analysis of the entire radar-observed rain field to determine the average translation of the field with time. Hence, the method results in one translation and forecast error for the entire rain field. As such, this method is useful for those storms where the organization of rain areas at microscale and small mesoscale within the rain field are not pronounced. However, in the case of severe convective storms such as multicell storms and squall lines there is a very pronounced rain intensity variation within the rain field due to the concentration of high rain intensity rates at the microscale convective cells. Therefore, the SHARP method is not suitable for the short-term prediction of severe convective rain storms.

The English short-term prediction scheme, as described by Conway and Browning (1988), is basically a rain field centroid tracking method. In this method the radar-observed rain field data are preprocessed using a low threshold to classify areas as containing rain or no rain. Adjacent grids of rain are combined into clusters. The centers of mass of the clusters are determined without regard to actual precipitation intensity, thus areal centers of mass are determined. These centers are then extrapolated individually. This method is superior to SHARP within the context of convective rain field prediction since it is possible to track and extrapolate the individual clusters within a rain field by means of their centers of mass. However, this method does not account for the significant rain intensity variation within a convective rain field since it only considers rain and no-rain areas. Furthermore, the individual rain field clusters are translated with a constant motion vector and constant spatial configuration without regard to the evolution in the motion of the rain cluster and to the growth/decay of the size of the cluster.

The Japanese short-term prediction scheme (Ishizaki et al. 1989) uses mainly the echo-tracking method where the sequential rain fields, as observed on the radar screen, are correlated. Then based on these correlations, the fields are extrapolated. Also the growth and decay of the rain fields are taken into account. Ishizaki et al. (1989) report very satisfactory prediction results for one-hour-ahead lead times.

The first attempts in the development of a remote sensor based short-term prediction scheme for severe rain storms were carried out in the U.S.A. by Greene and Clark (1974). In their extrapolation scheme Greene and Clark considered only the prediction of the movement of a radar-detected rain field in time and space. They predicted the movement of the rain field through the use of motion vectors. They estimated the mean motion vectors of the rain field by a statistical binary matching procedure. The application results of Greene and Clark show that the statistical binary matching technique for the estimation of the mean vector displacement of the rain fields in time yields reasonably satisfactory results at the storm scale. However, the same application results show that the binary matching technique cannot predict the movements of the small mesoscale areas and rain cells within the rain fields. Hence, the extrapolation scheme of Greene and Clark (1974) can not predict the change of the rain intensity pattern within a rain field as the field moves from its initial position of radar detection towards the geographic region of interest. Furthermore, this extrapolation scheme can not predict the change in the spatial configuration of the rain field which is very important in deciding how the rain field covers the geographical region of interest.

More recently Georgakakos and Bras (1984) presented a precipitation model which uses as its inputs the ground level temperature, pressure and dew point temperature observations at a ground station. The model then predicts the rainfall rate at the ground station. However, the prediction of rainfall rates at a single location, as obtained by Georgakakos-Bras model, can not supply the crucial information about the highly varying spatial distribution of rainfall rates due to a convective storm over a basin. Secondly, the Georgakakos-Bras model, since it utilizes only the ground level information at a station, can not account for the change in the spatial configuration and the complex motion of a mesoscale convective rain field as the field moves over a watershed of interest. However, such features are crucial in the realistic prediction of floods on a given watershed.

From the above survey it can be concluded that a short-term remote-sensor based comprehensive prediction scheme which can extrapolate in time and space the evolving spatial configuration, motion and fine intensity texture of a severe rainstorm is yet to be developed in U.S.A. This paper discusses the development of such a predictive scheme.

METHODOLOGY

The basic components of a short-term rain field prediction scheme are (i) the detection of a rain field by a remote sensor on a fine time-space grid several hours in advance of its arrival onto a geographical region of interest, and ii) the extrapolation of the remote sensed rain field in time and space in order to predict whether and how the rain field will cover the region of interest.

Presently, the National Weather Service (NWS) uses the weather surveillance radar (WSR-57) in observing and tracking the rain fields. WSR-57 scans the rain fields azimuthally and displays their signals on a plan view, called as plan position indicator (PPI). With WSR-57 PPI scope one can easily detect the horizontal location, areal configuration, orientation, and rain intensity distribution of rain fields which are approaching a geographical region of interest. The WSR-57 is a non-coherent type radar where "no account is taken of the phase of the returning radar wave with respect to the phase of the transmitted wave" (Battan, 1973). As such, WSR-57 can not measure the motion of a rain field directly. The motion trajectories of rain fields are observed indirectly by tracking their evolution in time, as they are observed on the WSR-57 radar PPI scope. Our study is based on WSR-57 radar observations of rain fields.

In order to predict the rain fields in time and space for short lead times it is necessary to develop a statistical scheme which can extrapolate in time and space the spatial configurations, the velocity vectors and the rain intensity textures of the rain fields that are detected on a radar scope.

The statistical binary matching technique employed by Greene and Clark in their extrapolation scheme falls within the realm of pattern recognition. The limited success of Greene and Clark is basically due to the fact that the binary matching scheme can only differentiate between two rainfall intensity levels which were taken as zero intensity and positive intensity by Greene and Clark. Therefore, it is not possible to differentiate the fine rain intensity features of the rain field, and hence, it is not possible to detect the change in the rain intensity distribution within the field as the field evolves in time. One can describe the fine rain intensity texture of a radar-detected rain field and track the change in the texture in time and space as well as the change in the spatial configuration of the rain fields by the "contours" method of pattern recognition theory (Nieman, 1981). Using this method, one describes the rain intensity maps of a rain field at a fixed time in terms of a number of rain intensity contours. Then one can track and describe the change in the spatial configuration and rain intensity distribution of the complete rain field in terms of the change in the spatial configuration and location of each individual rain intensity contour with time. Since the composition of all individual rain intensity contours comprises the complete rain field, the evolutions in individual contours, when contours are combined together to form the complete rain field, actually yield the time-space evolution in the spatial configuration and rain intensity texture of the whole rain field.

At this point a basic problem is how to describe mathematically the geometry of an individual rain intensity contour and how to describe mathematically the change in the location and spatial configuration of this contour. This problem requires a substantial amount of research. A promising solution avenue at present is the decomposition of a contour shape into some simple geometric shapes, the so called "simple constituents" of the pattern recognition theory (Niemann, 1981). These simple constituents can be a) a group of triangles which are combined together, b) a group of circles which are combined together, c) a group of ellipses which are combined together d) a group of polygons which are combined together, e) any combination of triangles, circles, ellipses and polygons which are combined together in order to form the irregular shape of a contour. Among these alternatives, the approximation of a rain intensity contour by a combination of circles has already been investigated by Kavvas et al.,(1987). However, in this study we use polygons whose combinations yield the rain field shapes.

Once a contour is approximated by a polygon, then its evolution in space can be tracked and described in terms of the evolution in the edges which make up the polygon and of the evolution of the centroid location of the polygon. Consequently, the prediction of the future spatial location and of the future evolution in the spatial configuration and the rain intensity texture of a rain field reduces to the prediction of the future centroid locations and future shapes of the polygons each of which make up the individual rain intensity contours. In turn, the individual rain intensity contours combine to form the complete rain field. The tracking of the centroid location of a polygon will yield the information about the evolution in the velocity vector of the rain intensity contour which this polygon represents. Finally, the velocity evolution of the individual contours, when these contours are combined together to form the rain field, will yield the necessary information about the evolution in the complicated motion of the complete rain field. In short, once a rain field is decomposed first into rain intensity contours, then decomposed further into simple constituents, the tracking and the prediction of the evolution of this rain field in time and space becomes equivalent to the tracking and the prediction of the changes in the parameters which describe these simple constituents.

The next step is the short-term adaptive statistical prediction of the change in the parameters of the polygon which we selected to make up the rain field. It may be remarked that this prediction is not only in time but also in space. Therefore, the grids employed for this prediction exercise are 3-dimensional time-space grids which preferably will have a time increment of about 5 to 15 minutes and a spatial increment of about 1 to 4 km^2 in order to detect and to predict the highly varying rain intensity structure of the rain fields.

Due to the fine time-space grid size which is necessary for the proper prediction of the rain field evolution, the statistical prediction procedure will be computation-intensive. Furthermore, very little historical data is available for the calibration of the forecasting scheme prior to the on-line, real time forecasting.

In this research effort forecasting techniques, exhibiting a range of complexity, are tested in order to find the most suitable one in terms of i) requiring the fewest computations, ii) requiring the smallest computer memory, iii) ease of calibration in the face of very limited historical data, iv) being most adaptable to the highly varying nature of the rain field evolution, and v) yielding the best forecasts in terms of the smallest forecast errors (e.g. in terms of the minimum mean-square-error).

We consider the well-documented methods of i) Exponential Smoothing, and ii) Kalman Filter as possible candidates for the adaptive forecasting scheme. These methods are adaptive to the changes in the forecasted parameter, and, thereby, are suitable for the rapid evolution of severe convective storms.

The exponential smoothing employs the concept of negative feedback where the new forecast is adjusted for the error committed in the previous forecast. It also allows the option for varying the relative weight given to recent versus past observations. This is particularly relevant to convective rain fields where the field evolution may demand that the history of simple constituent parameters focus primarily on recent observations. Furthermore, this method requires very little storage memory, with only the present observation and the previous forecast of the parameter required to make a new forecast.

As a preliminary step we have used exponential smoothing for the adaptive statistical prediction of the change in the parameters which describe the spatial location and shape of the polygons to make up the rain field. Some sample results of this prediction method are given below.

A SAMPLE OF THE PRELIMINARY PREDICTION RESULTS

In this study we are using the weather radar data of the Cincinnati Airport in U.S.A. This airport is equipped with the WSR-57 radar which takes photographs of the rain fields that are depicted on the radar PPI scope which has an effective radius of 201.13 km. The photographs of rain fields are taken at least every 5 min and as often as every 40 sec during the passage of a rain field on the radar scope. The processing of the original radar data was discussed by Kavvas and Herd (1985). In its final processed form the radar data is provided in PPI microfilms where the rain fields are represented in terms of 6 rain intensity contours. Again, Kavvas and Herd (1985) explain in detail these contours with respect to their rain intensities and to their interpretation. Since we have 12 years of voluminous radar microfilm data of the Cincinnati Airport we have concentrated our prediction studies only on those potentially flood producing convective storms during the first 20 days of April of each of the 12 years of record. In Figures 1-5 below, our prediction methodology is illustrated in terms of its application to the evolution of a second-intensity level rain contour (with an intensity range 0.508-2.79 cm/h) which represents a raincore that was detected on the radar scope in April 5, 1982 during 18:36-23:56 GMT. In each Figure we give a) the current (present) location and spatial configuration of the rain contour, b) the forecasted location and spatial configuration of the rain contour for a 30 min lead time, and c) the observed location and spatial configuration of the rain contour for the 30 min lead time as the field evolved on the radar scope. For the initial 30 min lead time, since there is no information about the motion and shape of the rain contour at the time of its first appearance on the radar we have based this initial forecast on the statistical information which we have obtained by the analysis of the historical rain field data, obtained by the weather radar. This initial forecast which is made at the current time of 5 min after the appearance of rain contour on radar screen, is shown in Fig. 1. The subsequent 30 min lead-time forecasts at every 30 min increment are shown in Fig. 2-5. From these figures one can also note the observed and the forecasted contour centroids at 15 min time increments. As seen from these figures, our forecasting methodology can adapt to the rapid changes in the motion direction and in the shape of a rain intensity contour which is very typical of the severe convective rainstorms observed over the Midwestern U.S.A. which our weather radar partly covers.

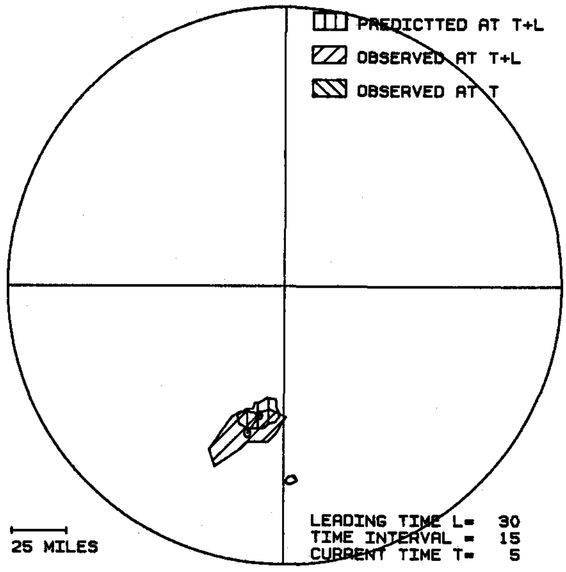

Fig. 1 30 min lead time forecast of a rain field from the current time of 5 min.

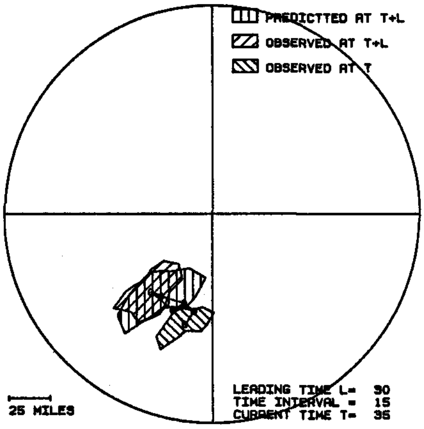

Fig. 2 30 min lead time forecast of a rain field from the current time of 35 min.

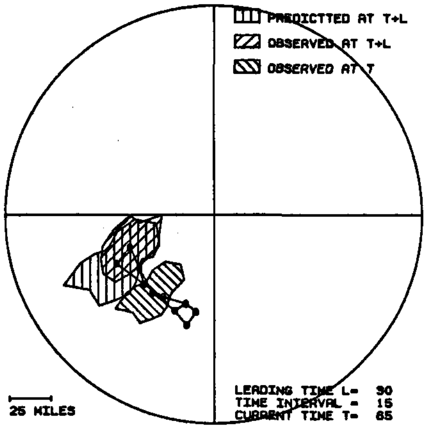

Fig. 3 30 min lead time forecast of a rainfield from the current time of 65 min.

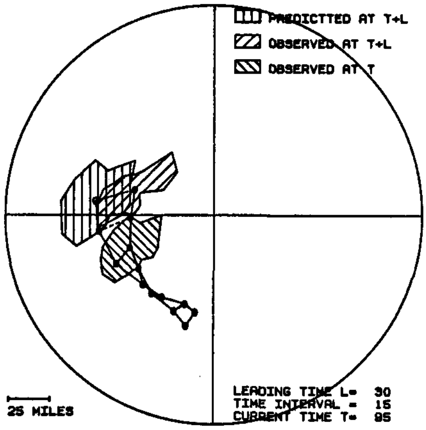

Fig. 4 30 min lead time forecast of a rain field from the current time of 95 min.

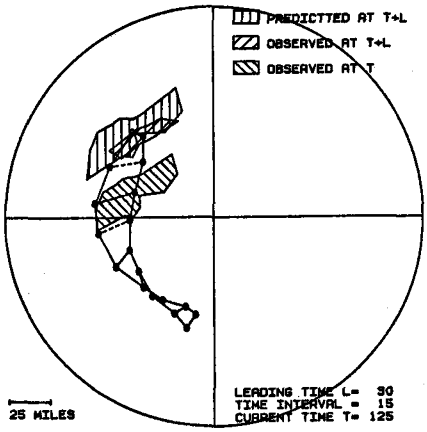

Fig. 5 30 min lead time forecast of a rainfield from the current time of 125 min.

DISCUSSION AND CONCLUSIONS

We have presented above the preliminary results of a new method for the short-term radar-based prediction of severe rainstorms. Currently, we are applying our method to the prediction of complex severe rain field evolutions. We are also incorporating Kalman Filtering into the prediction methodology. One very important feature of the severe rainstorm evolutions is that during the lifetime of a rainband many raincells and raincores appear and dissipate on the radar screen. We are also developing a methodology for this feature. The new developments shall be reported in the near future.

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