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PLAN FOR THE DEVELOPMENT OF ADVANCED SEVERE WEATHER ALGORITHMS FOR NEXRAD/AWIPS SITES

Wayne E. McGovern

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1. INTRODUCTION

The development of meteorological software for the next generation weather radars (NEXRAD) has long been recognized as an integral and important component in the overall modernization of the National Weather Service (NWS). In fact, through most of the 1980's, the NWS Techniques Development Laboratory (TDL) was actively involved in the development of a statistical Severe Weather Probability/Potential (SWP) algorithm for incorporation into NEXRAD. This effort built on earlier developments within TDL aimed at providing a diagnostic-statistical relationship for the Oklahoma area that estimates the SWP of a thunderstorm based upon the distribution of the vertically integrated liquid water (VIL) within a specified thunderstorm (Elvander, 1980). Radar observations collected intermittently from 12 specially equipped radar sites, located in the midwest and east, over the last 5-8 years, have provided the necessary data to permit the development and subsequent evaluation of a first generation SWP algorithm for NEXRAD. Originally, as discussed by Saffle (1989), the aim of this task was to develop a single station SWP relationship for each of the 12 RADAP-II (Radar Data Processor-model II) sites, with interpolated values for nearby sites. For more distant sites, the equation from the RADAP site which best matched the climatological characteristics of the new site would have been selected. Testing in the intervening 2 years, however, has revealed that for most RADAP II sites a slightly different approach appears to be more beneficial. The details of this decision will be discussed more fully in the next section.

With the completion of the development of a first generation SWP algorithm, it became necessary to outline plans for future improvements. This plan is designed to outline projected efforts that will be undertaken to improve upon the first generation SWP efforts, to develop a new prognostic capability for projections of at least 1 hour, and to extend these capabilities to a quantitative precipitation forecasting (QPF) effort. The later QPF developmental efforts will be described in a separate section. As such, this plan will outline in general terms those steps that should be undertaken in the near term to ensure a progressive adoption of these developments, initially within a NEXRAD context, and subsequently within the Advanced Weather Interactive Processing System (AWIPS). Finally, this plan will also update TDL Office Note 89-1 since the relatively rapid changes in this program have resulted in an effective "lifetime" of these plans of the order of 2 to 3 years. Therefore, projected dates in the near term (1-2 years) will be treated as milestones; details associated with longer term items (i.e., incorporation of large doppler data sets) will be treated as goals rather than as a set of precise milestones.

2. REVIEW OF FIRST GENERATION SWP ALGORITHM DEVELOPMENT

The history of the development of the SWP algorithm is long and complex. In brief terms, however, the recognition by Green and Clark (1972) of the potential usefulness of VIL, followed by the work of Elvander (1977 and 1980) and Saffle and Elvander (1981), established the relationship between VIL and the potential for detecting severe weather (i.e., hail ≥ 2 cm, high winds ≥ 50 kts, or a tornado). The SWP algorithm is essentially a static nowcasting tool which deduces from reflectivity characteristics of a particular storm whether that storm is capable, at the time of observation, of producing severe weather. No effort is made to differentiate the nature of the severe weather (hail, high winds, or tornadoes), though in theory with a sufficiently large data sample the general SWP algorithm could be tailored to differentiate between hail and high winds. Dut to the relatively small size of most tornadoes and the predominant dynamic nature of a tornado, a tornado detection algorithm is best approached through the use of doppler wind data, rather than reflectivity data alone.

Experimental tests, in Oklahoma City, of these pioneer efforts confirmed the applicability of the approach (McGovern et al., 1984) and the overall superior capability of the approach (Winston and Ruthi, 1986). The need to collect a climatologically diverse SWP data set (Beasley, 1986) stimulated the archiving of RADAP-II data during the late 1980's from the aforementioned 12 sites (see Fig. 1 and Table 1). From these data, it was anticipated that individual SWP equations would be developed for each of these 12 sites. For non-RADAP sites, but climatologically similar regions, the anticipated SWP equations were to be a blending of near-by RADAP sites, and for distant stations, a subjective construction. To test the validity of this approach, the single station (SS) SWP algorithms were compared to various statistical alternatives for the nine sites with the largest archives of data (AMA, BGM, BNA, GCK, ICT, LIC, OKC, TBW, and UMN--see Table 1). These alternative equations included developing (a) a pure generalized operator equation with data from all sites (GO), (b) a generalized operator with data from nearby regional sites (GOR), (c) a generalized operator with a local climatological correction, and (d) the original NEXRAD default equation, developed by Elvander (1980) and based on spring 1972 Oklahoma data. A summary of these extensive efforts can be found in the technical memorandum by Kitzmiller, McGovern, and Saffle (1992). The various tests revealed that for producing categorical (severe/nonsevere) forecasts, a generalized operator with a locally determined threshold yielded results comparable to those from individual single station SWP equations. The relative success for each type of procedure or equation was evaluated by calculating the critical success index (CSI). Additional advantages of using the generalized operator/local threshold approach can be summarized as follows:

- Rapid field assimilation of the technique which entails determining only a local threshold that appears to have good regional/spatial continuity [see Kitzmiller, McGovern, and Saffle (1992), Fig. 13].
- Subsequent ease of comparison of capability among sites.
- The ability to readily adjust threshold values for seasonal tailoring.
- Ease of NEXRAD and AWIPS implementation.
- The guarantee of an initial SWP equation for all sites at the time of installation by the NEXRAD program of the local <u>W</u>eather <u>S</u>urveillance <u>R</u>adar-19<u>88</u> <u>D</u>oppler (WSR-88D) equipment.

The initial generalized operator equation that has been forwarded to the WSR-88D Operational Support Facility (OSF) in Norman, Okla. is given by Kitzmiller, McGovern, and Saffle (1992), Equation 7, along with the optimum initial threshold values for various RADAP sites for which a value could be determined. In addition to this equation, a comprehensive package will be forwarded to each WSR-88D site detailing the properties of various VIL predictors at specific RADAP sites. It is expected that this documentation will assist, especially at non-RADAP sites, in assimilating severe thunderstorm procedures associated with the SWP equation. For historical reasons, the initial SWP algorithm structure was limited to only five VIL predictors (VIL weight and VIL predictors values corresponding to areas covered by VIL values that equal or exceeded 10, 15, 20, or 25 kg/m^2). In testing over the past 2 years, it was determined that three predictors would suffice and that the addition of two remaining predictors (VIL thresholds of 15 and 25) added no significant information. This accounts for the structure of the generalized operator equation forwarded to the OSF.

However, all the alternate approaches noted above suffer from two major limitations, specifically;

- The SWP equations are diagnostic, not prognostic, and

- Only a limited number of predictors were tested.

The period over which a phenomenon can be treated in a linear fashion, to a first approximation, can be called the linear lifetime of the phenomenon. The average linear lifetime of a severe thunderstorm, during its mature phase, is of the order of 20 to 30 minutes. During this phase, the thunderstorm is assumed to undergo no major changes in growth or decay of intensity and its external characteristics remain fairly constant, including the potential for the occurrence of severe weather. Therefore, the diagnostic SWP algorithm can and has been extended as a very short-range prognostic tool for such periods. However, the present SWP is a diagnostic/nowcasting algorithm and was not designed as a forecasting algorithm.

The second limitation is that only five specific VIL predictors could be used in this initial development. Additional predictors in the VIL family alone (e.g., VIL maximum, or partial VIL) could be of value in, for example, constructing an SWP algorithm at the longer ranges of the WSR-88D reflectivity capability. Other families of predictors such as potential energy within the precipitation mass, volume of the weak echo region, and the extent of the overhang region should improve upon our diagnostic capabilities. In the next section, we will examine an expanded list of predictors and try to gauge those areas most likely to be improved by a significantly expanded predictor set.

Similarly, in Section 4, experiments that aim at converting the present nowcasting SWP type algorithm into a true 0-1 h short-range forecasting procedure will be discussed. In this way, we expect that the present SWP effort will lead to a 0-1 h predictive capability over the next several years. If successful, this forecasting effort could, in turn, be modified to encompass the 1- to 3-h range.

3. SECOND GENERATION SWP ALGORITHM

As noted, a major limitation of the first generation SWP algorithm was the historical requirement of allowing only five VIL predictors to be used in the construction of the algorithm. Subsequent testing has suggested that an expanded list of SWP predictors could be valuable in discerning storms that produce hail or high winds and in providing specific predictors for various locations. Also, it was recognized that partial VIL values associated with the upper levels of a storm could possibly be used to assess potential severe weather at the longer ranges of radar reflectivity coverage (> 230 km). The curvature of the earth combined with the nearly straight line propagation path of a radar beam prevents the monitoring of low level storm VIL values at these longer ranges. In addition to the use of an expanded set of VIL predictors, the collection of 5-8 years of 3-dimensional volumetric RADAP-II data, in contrast to 2-dimensional base level radar reflectivity data, allows the development of a new class of volumetric radar reflectivity predictors (e.g., volume of the weak echo region), as well as new predictors that are related to the thunderstorm's vertical structure (e.g., potential energy). A list and short description of these new reflectivity predictors can be found in the Appendix.

Doppler radar data will add a whole new dimension to our radar data base. However, it will be several years before an adequate archive of doppler data is collected and before effective statistical testing can be undertaken. In the meantime (approximately 2 years), there are additional highly worthwhile lines of study which will both complement and assist in focusing future developmental activities associated with the forthcoming doppler data.

Milestones for monitoring the projected progress in this area, associated with the development of new generation of SWP algorithms, are given for 1992 and 1993. Specifically, nine major milestones are envisioned with this task. These are, with expected dates of completion:

- Develop, test and evaluate new predictor software; January 1992.
- Complete preliminary testing, on dependent data, of the relationships between second generation predictors and the occurrence of severe weather; February 1992.
- Extend testing of above and prepare preprint article on preliminary results; March 1992.
- Complete testing for two sites; June 1992.
- Complete testing for all sites; November 1992.
- Complete development of second generation SWP algorithm; January 1993.
- Complete documentation; April 1993.
- Full documentation for possible independent testing in ERL's Storm field programs; June 1993.
- Initial examination completed of dominant predictors for different synoptic or air mass conditions (early 1994).

The initial predictor software, for constructing these predictors from RADAP-II data, is scheduled to be certified as correct shortly after the publication of this plan. This checkout is planned to be run on two different climatological data sets (Tampa Bay, Florida, and Amarillo, Texas). The initial linear regression runs will help pinpoint the effectiveness of the new predictors and assist in evaluating the impact of the new predictors in various climatological regions (3/1/92). Complete testing for two sites and all sites is planned for June 1 and November 1, 1992, respectively. It is anticipated that these efforts will be followed (6/1/93) by full documentation and subsequent independent testing within ERL's Storm Program, planned for spring, 1993. If progress is satisfactory, operational implementation will be via the OSF. Simultaneously, during these latter phases, an examination of dominant predictors for different synoptic situations will be undertaken.

Beyond this period, it is difficult to project precisely, but it is envisioned that in the FY 1993-1994 timeframe, this effort will have been fully merged with efforts to develop an extended predictive capability. This parallel effort is discussed in the next section.

4. DEVELOPMENT OF 0-1 H STORM TRACK PREDICTIVE CAPABILITY

The single most important limitation to the present SWP type algorithm is its static characteristic. While effective in a nowcasting context (0-30 minutes), an extension of these procedures out to an hour would be valuable both for hail and high-wind warnings.

Past efforts at forecasting of convective systems have generally focused on extrapolative methods utilizing primarily low-level radar reflectivity data; these efforts have been of somewhat limited success. The primary reason for this situation is that the complex non-linear dynamics steering these storms can presently be only roughly approximated by linear extrapolative techniques. Numerical models capable of simulating a storm are under continuing development and are of the order of a decade or more away from replicating the full life-cycle of a storm. The time required to develop forecasting models capable of accurately positioning an individual severe storm, one to several hours in advance, is obviously even further away. In the meantime, techniques need to be developed to assist in this problem.

As a point of departure in this effort, it is envisioned that a series of increasingly complex linear approximations can be used to develop an effective severe storm motion vector (SMV). Our initial aim is to develop a relatively simple extrapolative/statistical method for forecasting the track of storms already in existence.

During the initial phase of development, several techniques (e.g., advection by environment winds, extrapolation, or pattern matching correlation techniques) will be compared in forecasting the movement of high VIL value cells (VIL > 10 kg/m^2) for periods out to one hour, longer if warranted. Since the lifetime of most cells is less than an hour, it probably will be necessary to develop an internal discriminator which limits the extent of our forecast period depending upon initial cell characteristics. Testing of extrapolation techniques will be from RADAP-II historical cases, with the goal of developing an individual displacement vector for each cluster of high VIL values (i.e., potential severe thunderstorms). The temporal resolution of the historical data is 10 minutes, and expected VIL projections are for 10, 20, 30, and 60 minutes. Upon completion of the testing of the individual extrapolation procedures, one procedure or another will be chosen, if it shows consistently superior results. If, as a result of our testing, there is no consistently superior technique, then a specific extrapolation technique determined by the procedure which best matches the immediate past 30 minute history of a given storm will be selected for that local storm. This so-called adaptive selection process may incorporate a statistical correction. The specific milestones anticipated with this effort are

- Completion of initial testing of pattern matching techniques (binary and linear correlation); April 1992.

- Completion of testing of correlation technique against environmental winds; June 1992.

- Report on the possibility of introducing time rate-of-change predictors; November 1992.

- Evaluation of adaptive strategy completed; February 1993.

- Assimilation of all components of SMV procedure into SWP procedure; October 1993.

- Final testing and documentation; February 1994.

It is anticipated that inclusion of the SMV effort with the results from the second generation SWP efforts will provide an opportunity to upgrade the SWP algorithm in time for the succeeding storm season. This new SWP algorithm will be considered for direct implementation into the WSR-88D. Subsequent upgrades, based on doppler data, are envisioned for the AWIPS era.

5. EXTENSION OF METHODOLOGY TO 0-1 H QPF

A short range (0-3 h), high areal resolution (4-20 km) QPF product is in the beginning stages of development. This product will be generated initially (1992-1994) for time periods of 0-30 minute and 0-1 h. A longer term goal (1994-1996) is to extend the technique to 1-3 h with an associated spatial resolution of the order of 20 km. The product is intended primarily to support the flash flood warning mission at the future Weather Forecast Office (WFO) and will be a candidate for incorporation into the WFO Flash Flood Potential technique.

The QPF algorithm will be based on statistical relationships utilizing radar-based predictors such as reflectivity, VIL, echo tops, and radar-estimated observed rainfall. It is anticipated that much of the development methodology involved in the SWP derivation will also be utilized in the QPF effort. A key feature of the technique will be the extrapolated forecast of the movement of the predictor fields during the forecast interval. This extrapolation will use the SMV techniques discussed in Section 4. Since the QPF will be intended mainly for flash flood episodes, the major criterion for deciding upon a "best" SMV will be the skill in extrapolating the stronger features of the predictor fields. The forecast relationships will be derived by statistically relating observed and extrapolated predictor values to radar-estimated precipitation over the forecast interval.

The development data for the QPF algorithm will be RADAP II archives of reflectivity data and hourly climatic rain gauge data. Since the rain gauge network yields incomplete coverage of the rain accumulation field, radar-based estimates will be used for observed precipitation amounts in the relationship development procedure. The rain gauge values will be used as independent data for verifying the relationships.

The output of the algorithm will consist of the probability of rainfall accumulation above certain threshold amounts (0.1, 0.5, 1.0, and 2.0 inch) for 0-30 minute and 0-60 minute periods, and the expected total accumulation for each period. The spatial resolution of the forecasts will be chosen based on verifications of skill, but the goal is to have a resolution of 4 km for the 0-30 minute period and at least 10 km for the 0-1 h period. Regardless of the forecast spatial resolution, the algorithm will interpolate the forecast values to grid resolutions required for other purposes.

6. AWIPS PROTOTYPE SWP ALGORITHM

The development of this type of algorithm, which combines data from several observing systems, is in its early stages and therefore the exact nature of an AWIPS era algorithm is still somewhat unclear. What is clear is that to effectively merge the SWP radar-reflectivity algorithm with additional non-radar data sources, it probably is necessary that the associated information of the new data systems be largely independent of the radar information, yet comparable in scale. Potential candidates that fit this description are observations from lightning and profiler networks. These observing systems are comparable in scale to severe thunderstorms in either time (profiler) or space or both (lightning) and appear to provide new information not available from radar.

In the case of lightning, the information received from the observational system is not a state variable (i.e., temperature, pressure, density, or humidity) used so often to initialize a numerical model, but is a consequence of complex dynamic and physical processes occurring within a thunderstorm. The first question is how best to use this forthcoming information. The answer to this is still unclear in that there may be several ways in which to treat this data source. While lightning location data from current automated networks have already been used for climatological verification purposes, it is also possible that certain properties associated with lightning flashes (e.g., flash density, time rate of change of flashes, polarity, peak electromagnetic signal strength, and nature of flashes--intracloud or cloud-to-ground) could be valuable as predictors for determining the potential of severe weather. There is also the distinct possibility of using lightning data in a new context as a precursor signaling the transition from a given phase to a later phase of a storm. These "flags" or signatures could be useful in linearizing, to some extent, the overall non-linear thunderstorm forecasting problem by subdividing the various stages of a severe storm into smaller, more nearly linear components. Examples of the possible use of lightning in this context are, for instance, (a) the onset of intracloud lightning, which often occurs 15-20 minutes before the onset of cloud-to-ground lightning, and may signal the use of a special algorithm designed specifically for the early mature phase of a storm, or (b) when 20 to 30 percent or more of lightning flashes are of a positive polarity and the rate of strike activity is decreasing, the storm may be entering its latter phases when severe weather is unlikely. This last example is supported by preliminary results within TDL through examining joint radar and State University of New York at Albany (SUNYA) lightning data from Florida. For a half-dozen or so cases, we have noted that if 20 percent or more of the strikes are positive, then the VIL values associated with the storm are relatively low, suggesting the above possibility. It must be noted, however, that regional variations exist in the use of flash polarity since high positive flash rates have also been shown to be related to the occurrence of larger severe storms in Oklahoma and Kansas (Reap and MacGorman, 1989). Additional potential areas of development include the use of lightning as a longer range (1-3 h) tracking system especially for larger storm systems, examining the relationship between high positive flash rates and low precipitation super cells which often produce high wind and significant hail, and the changes in flash rate with the occurrance of tornadoes.

In short, lightning data have been and will continue to be used as both predictor and predictand data sets. Now, however, we are also interested in expanding the possible role of this unique data set by using it to assist us in linearizing what is essentially a non-linear problem--predicting the evolution of thunderstorms.

Data from systems that provide state variables (density, temperature, pressure, etc.) will continue to be used in a classical sense as predictors. These include, at a minimum, profiler and aircraft winds, Automated Surface Observing System (ASOS) data, and numerical model output. Of initial interest will be the impact of higher resolution wind fields from these systems and the capability to infer local stability conditions. The increased frequency of ASOS data will also be valuable in this context. Initially it is expected that our overall efforts in this task will be divided between assessing the impact of lightning as a predictor in our SWP effort and in developing lightning "rules of thumbs" as they relate to severe weather from our RADAP-II radar archive data. In addition, we anticipate using state variables from models and new observational systems to infer local stability changes which would provide added predictive capabilities out to one hour, possibly beyond.

Specific goals include an initial evaluation of environmental factors on stability and their subsequent impact on developing an extended SWP algorithm. Additional goals in this area, and in assimilating lightning data, are hard to set due to the uncertainty in available resources. Nevertheless, it is anticipated that progress will be made in assessing the impact of lightning data on a future SWP type algorithm during the next 2 years. In a similar timeframe, it is expected that the impact of environmental wind fields (profiler, or upper air) on an SWP algorithm will be evaluated leading to increasing use of WSR-88D doppler data in this context. By late FY 1994, efforts in this area are expected to be focused upon incorporating doppler velocity data which by that time are expected to be readily available. More specifically, we expect to develop a methodology for incorporating doppler velocity data with the current cell attribute database during 1994-1995.

7. LOCAL FORECASTING BEYOND ONE HOUR

In the preceeding sections, the emphasis has been on diagnostic and short-range prognostic (0-1 h) forecasting efforts associated with SWP and QPF. In this section, our efforts turn to possible methodologies for extending these forecasting capabilities beyond one hour, possibly to as long as 2 to 3 hours.

Both forecasting areas (SWP and QPF) involve atmospheric processes that are highly non-linear in nature. Therefore, the direct application of linear techniques to individual cells, whose expected lifetimes are of the order of 30 minutes, are unlikely to prove successful. Beyond 30 to 60 minutes, individual cells blend into clusters, and lines of cells are often associated with forcing functions on the sub-synoptic scale (i.e., squall lines, sea breezes, fronts, etc.). When the linear lifetime of such forcing functions extend well beyond 1 hour, then simple advection procedures can be used effectively. However, when rapid subsynoptic scale changes are occurring, and the effective linear lifetime of the forcing function is shorter than the prediction period, it is likely that the resulting forecast will exhibit little skill.

With this background, it is apparent that a necessary first step in this effort is to develop procedures capable of rapidly assessing the expected linear lifetime of larger cell groupings. Several approaches will be tested including developing relationships between linear lifetime and such quantities as VIL MASS, VIL WEIGHT, and storm volume. If successful, this procedure will effectively filter out smaller cell clusters while retaining larger convective systems. Lightning data (flash density, polarity, etc.) and profiler wind shear information may assist in determining the expected lifetime but may be effective only in a limited sense. Obviously, factors external to the scale of the phenomena could be critical to the projected lifetime as well as being instrumental in the genesis of new cells. At this point, linear assumptions may be inadequate and non-linear numerical model input will be necessary. Where these transition zones are, between the applicability of linear models and the need for nonlinear input, has yet to be determined from an operational standpoint for these zones will vary with the degree of specificity required for any given type of forecast. Part of our effort will be to better define these transition zones and to determine the valid extent of linear procedures as a function of scale for both severe storms (hail and high winds) and for quantitative precipitation forecasting.

Our initial aim will be to develop an algorithm to define the probability of severe weather within a 20 x 20 km square area during the period 1-3 hours (or 1-2 and 2-3 hours) after the initial time. The probability will likely be a function of the environmental wind, moisture, and stability fields, as well as both current and forecast radar information over and near the verification area. The algorithm is projected to take into account information from these fields and the strength, position, and forecast movement of convective systems that are within approximately 75 to 100 km of the verification region. The relative importance of the environmental wind and radar observations, as an advective mechanism, will be accounted for by screening regression procedures. The projected strength of the convective system will be linked to the expected lifetime of the cell cluster, and the future movement and position will depend upon the selected advective mechanism.

The expected predictand data are:

- Severe local storm reports from the National Severe Storms Forecasting Center (NSSFC) log;
- Manually Digitized Radar (MDR) archive data, to determine the presence and strength of echoes during the verification period;

- RADAP II archive data, when available for the majority of the verification period, to better define the presence and strength of echoes.

Severe local storm and MDR reports will be verified within fixed MDR grid blocks, or Hydrologic Rainfall Analysis Project (HRAP) coordinates, that encompass populated areas near the center of the local radar umbrella. Over the 1-3 h period, it may be too difficult to track individual cells, thus an Eulerian approach to the storm verification may be necessary.

The expected predictor data from radar fields would include:

- Maximum VIL and zero-tilt reflectivity (ZTR) over and near the verification grid block at initial time (to describe the current convective activity). ZTR should be included as a predictor, since the verification area will often be affected by new systems that are not mature enough to have measurable VIL at initial time.

- Maximum VIL and ZTR values forecast, through advection of the initial fields to move over the verification area during the period;

- Local maximum VIL and ZTR existing nearby (to account for climatically-favored movement of convective systems, if extrapolative forecasts lack sufficient skill);

Synoptic, subsynoptic, and other fields that would be examined would include:

- Upper-level steering winds (model, and profiler or WRS-88D winds, if available);

- Projected model generated thermodynamic fields, especially stability;

- Precipitable water and mean relative humidity;

- Moisture divergence;

- Hourly surface data;

- Time of day;

- For initial tests, synoptic-scale factors could be derived from Nested Grid Model (NGM) or, if available, ETA model forecasts.

It is anticipated that initial developmental efforts, with present staff and contract levels, will commence in FY 1994 and concentrate upon those dates and times for which convective activity was observed by RADAP-II for at least 30 minutes prior to the onset of the forecast period. Amarillo, Texas, and Oklahoma City, Oklahoma, are likely initial testing sites due to the availability of the necessary data.

The general methodology will consist of preparing for each suitable case an extrapolated forecast of the radar echo out to the end of the required period. The motion vector will probably be determined from environmental winds or movement observed during the previous 30-minute period. The exact procedure followed will depend to a large extent upon the success of efforts in

Section 4 and to what extent these efforts can be extrapolated forward in time even with a decrease in spatial resolution.

For each verification grid block, the predictors noted previously will be stored, as well as the presence or absence of severe weather during the appropriate validation period. Upon collection of the necessary data, a forecast of the ZTR field and/or maximum VIL threshold likely to be exceeded in the 1-2 h or even 2-3 h period for a given area would be made. From these fields, we expect to estimate the probability of severe weather in the appropriate time frame. This would contribute to providing input to a storm watch.

In the QPF arena, the same basic approach will be tried with the same temporal and spatial resolution as found in the above effort. This will likely permit hourly forecasts of precipitation probabilities for amounts in excess of 0.5 inch per hour, again for 1-2 h and 2-3 h periods.

The initial severe storm effort is expected to take at least 2-3 years with at least one additional year or two for the QPF effort. Finally, we need to reiterate that this task, of all the tasks outlined, is the task requiring the greatest degree of experimentation before committing to field implementation. This is due in large part to the non-linear nature of the problem and the basic linear approaches being applied, irrespective of the spatial resolution of the final product. If the plan outlined does not prove to be successful, in a meteorological sense, it may be necessary to reexamine incorporating numerical model output into these approaches even as early as 1 to 2 hours into the forecast period. The technical difficulty of this effort is mirrored in the fact that specific milestones associated with this effort can not be presented at this time. It is a concensus view that at present personnel levels, 3-5 years will be required, at a minimum, to develop a reasonable product (1994-1996).

8. INCORPORATION OF DOPPLER DATA

The introduction of the WSR-88D will provide additional new types of data. These major new data sets consist of doppler radial wind fields surrounding the radar site as well as their associated spectrum widths.

As WSR-88D wind data and associated products are collected and archived over the next few years, it will become possible to experiment with these new data sets in order to improve upon both the advanced version of the SWP algorithm and the QPF procedure. Early examination of the doppler wind data suggests that they may be comparatively noisy and require considerable care when incorporating them into existing algorithms. For this reason, early application of these data is expected to be straightforward such as testing directly the maximum radial wind within the SWP algorithm. A slightly more sophisticated approach would be to use the WSR-88D winds to update various stability indices and to treat these as new SWP predictors. With time, additional WSD-88D predictors will be tested including fields that are derived from the winds (i.e., divergence, shear), direct product output (i.e., mesocyclone algorithm), and/or the rate of change of selected fields. As discussed previously, these new parameters will be blended with past efforts to the extent possible.

The development and integration of this effort into an AWIPS context has been projected to require between 4 to 7 years at least, and due to the efforts noted earlier will be undertaken no earlier than 1995. As in the last section, the total efforts required are uncertain due to the exploratory nature of this task. Finally, a summary of this plan, with developmental period, general methodology and expected product can be seen in Table 2.

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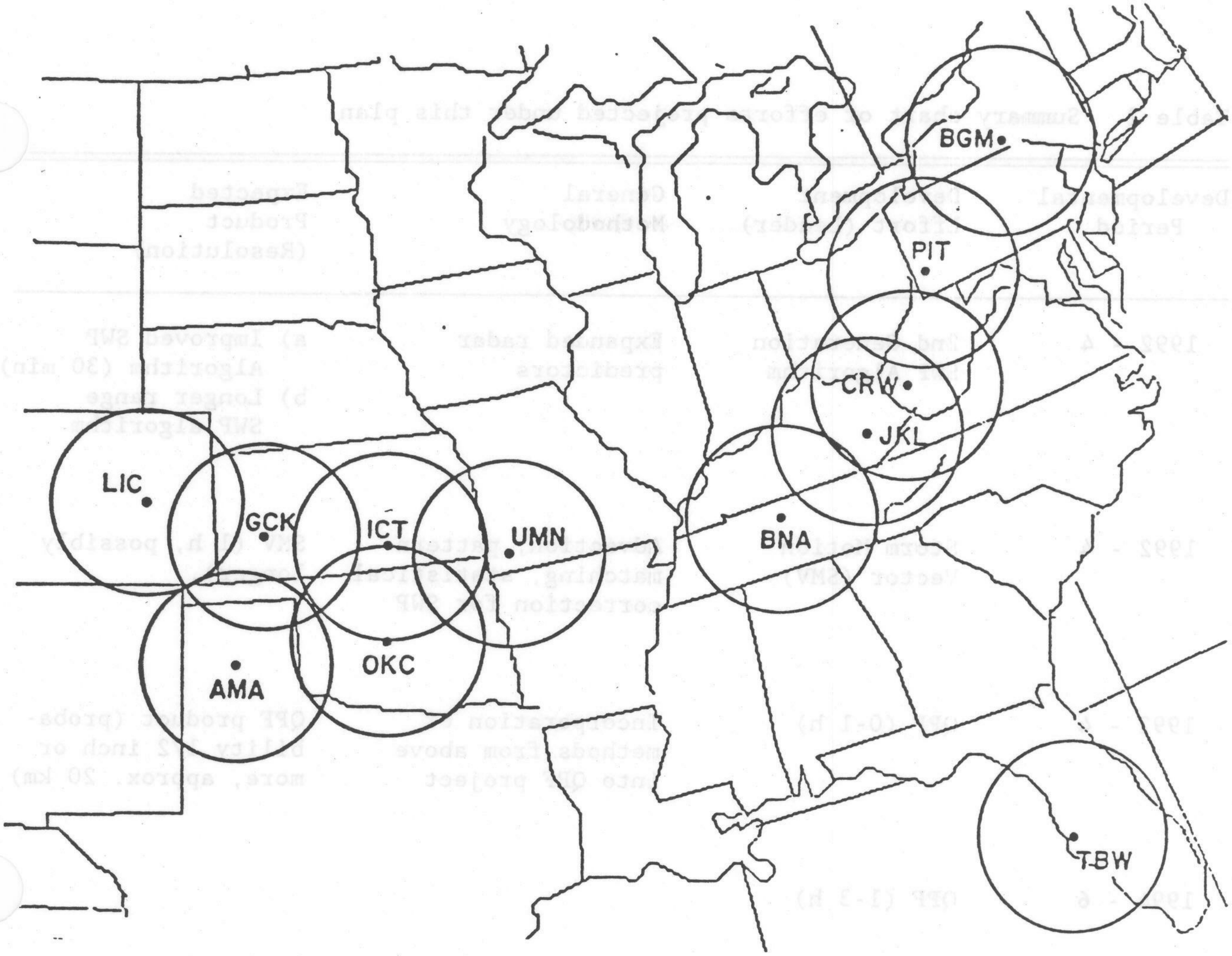

Figure 1. Locations of WSR-57 sites equipped with RADAP II. The circles about each site show the 230 km range.

Table 1. RADAP II sites.

Station	Call letters	Latitude		Longitude	
		(deg)	(min)	(deg)	(min)
Amarillo, Tex.	AMA	35	13	101	42
Binghamton, N. Y.	BGM	42	12	75	59
Charleston, W. Va.	CRW	38	23	81	36
Garden City, Kans.	GCK	37	55	100	42
Jackson, Ky.	JKL	37	35	83	18
Limon, Colo.	LIC	39	11	103	42
Monett, Mo.	UMN	36	52	93	53
Nashville, Tenn.	BNA	36	15	86	34
Oklahoma City, Okla.	OKC	35	24	97	36
Pittsburgh, Pa.	PIT	40	32	80	13
Tampa Bay, Fla.	TBW	27	42	82	24
Wichita, Kans.	ICT	37	39	97	26

Table 2. Summary chart of efforts projected under this plan.

Developmental Period	Development Effort (Leader)	General Methodology	Expected Product (Resolution)
1992 - 4	2nd Generation SWP Algorithm	Expanded radar predictors	a) Improved SWP Algorithm (30 min) b) Longer range SWP algorithm
1992 - 4	Storm Motion Vector (SMV)	Advection, pattern matching, statistical correction for SWP	SMV (1 h, possibly longer).
1992 - 4	QPF (0-1 h)	Incorporation of methods from above into QPF project	QPF product (probability 1/2 inch or more, approx. 20 km)
1994 - 6	QPF (1-3 h)		
1992 - continuing	AWIPS SWP algorithm	Incorporation of non-radar data sources	Improved SWP algorithm
1994 - 96	Extension of SMV	Uncertain - dependent upon previous results	Longer ranger SWP and QPF products (1 to 3 h)
1995 - continuing	Incorporation of doppler data into previous efforts	Uncertain	Improved SWP/QPF products

APPENDIX

Description of Second Generation SWP Predictors

This appendix lists and then describes the second generation SWP predictors which can be computed from three dimensional radar reflectivity fields. Currently, RADAP II archive data is the only large source of this type of data and will be used in this near term development. Each entry in the list below is described following the list.

1. Max partial VIL above 15000 ft
2. Max VIL potential energy
3. Max VIL potential energy above 15000 ft
4. Max base level reflectivity
5. Max reflectivity between sfc and 10000 ft
6. Max reflectivity between 10000 and 20000 ft
7. Max reflectivity between 20000 and 30000 ft
8. Max reflectivity between 30000 and 40000 ft
9. Max reflectivity between 40000 and 50000 ft
10. Max reflectivity between surface and 24000 ft
11. Max reflectivity between 24000 and 33000 ft
12. Max reflectivity between 33000 and 66000 ft
13. Number of pixels greater than 40 DBZ in 30000 to 40000 ft layer
14. Number of pixels greater than 50 DBZ in 30000 to 40000 ft layer
15. Number of pixels greater than 40 DBZ in 40000 to 50000 ft layer
16. Number of pixels greater than 50 DBZ in 40000 to 50000 ft layer
17. Sum of the VIL above 15000 ft
18. Sum of the VIL potential energy
19. Sum of the VIL potential energy above 15000 ft
20. Total volume of reflectivity
21. Volume of storm with reflectivity greater than 40 DBZ
22. Volume of storm with reflectivity greater than 50 DBZ
23. Height of 40 DBZ reflectivity
24. Height of 50 DBZ reflectivity
25. Max height of echo top
26. Height of max reflectivity
27. Volume of weak echo region
28. Area of overhang
29. Max rain water concentration
30. Vertically integrated VIP

Description of 2nd generation predictors derived from volumetric reflectivity:

MAX PARTIAL VIL ABOVE 15000 FT

- Maximum value of the vertically integrated liquid water content found above 15,000 ft.

- The VIL above 15,000 ft may be more useful than total VIL above the surface because more intense storms will likely extend well above the 15,000 ft level. Since this predictor does not consider the lower part of the storm, it may be less range dependant.

MAX VIL POTENTIAL ENERGY

- Maximum value of the potential energy of the liquid water content in the cell.

- Units of VIL POTENTIAL ENERGY are in newtons/meter. Here we use (10 x LOG base 10) to make the size of the number more manageable.

- This predictor is related to the distribution of the VIL. This value should be largest when high reflectivities are found higher in a storm. This predictor may also be able to indicate which storms have "precipitation overloading." Such storms have a high amount of liquid suspended aloft by the updraft. A wet downburst may be imminent.

MAX VIL POTENTIAL ENERGY ABOVE 15000 FT

- Maximum value of the potential energy of the Liquid water content found only above 15,000 ft.

- Focus is on the upper levels of the storm.

- Less range dependent than VIL potential energy above the surface.

MAX BASE LEVEL REFLECTIVITY

- Maximum reflectivity expressed in DBZ found in the cell during the lowest elevation angle scan (usually 0.5 degrees).

MAX REFLECTIVITY 00-10

- Maximum reflectivity expressed in DBZ found between the surface and 10,000 ft within the cell.

- This and similar predictors listed below slice the storm up into sections giving a picture of the intensity for the specified layer.

MAX REFLECTIVITY 10-20

- Maximum reflectivity found between 10,000 and 20,000 ft within the cell.

MAX REFLECTIVITY 20-30

- Maximum reflectivity found between 20,000 and 30,000 ft within the cell.

MAX REFLECTIVITY 30-40

- Maximum RADAP II reflectivity found between 30,000 and 40,000 ft within the cell.

MAX REFLECTIVITY 40-50

- Maximum RADAP II reflectivity found between 40,000 and 50,000 ft within the cell.

MAX REFLECTIVITY SFC-24

- Maximum reflectivity found between the surface and 24,000 ft within the cell.

- This product is currently scheduled to be computed by NEXRAD.

MAX REFLECTIVITY 24-33

- Maximum reflectivity found between 24,000 ft and 33,000 ft within the cell.

- This product is currently scheduled to be computed by NEXRAD.

MAX REFLECTIVITY 33-66

- Maximum reflectivity found between 33,000 ft and 66,000 ft within the cell.

- This product is currently scheduled to be computed by NEXRAD.

NUMBER OF PIXELS GREATER THAN 40 DBZ IN 30-40,000 FT LAYER

- Number of 4 X 4 km pixels within the 30,000 to 40,000 ft level in which the maximum reflectivity is at least 40 DBZ. 40 DBZ is equivalent to VIP 3 or RADAP category 6.

NUMBER OF PIXELS GREATER THAN 50 DBZ IN 30-40,000 FT LAYER

- Number of 4 x 4 km pixels within the 30,000 to 40,000 ft layer in which the maximum reflectivity is at least 50 DBZ. 50 DBZ is equivalent to VIP 5 or RADAP category 12.

NUMBER OF PIXELS GREATER THAN 40 DBZ IN 40-50,000 FT LAYER

- Number of 4 X 4 km pixels within the 40,000 to 50,000 ft level in which the maximum reflectivity is at least 40 DBZ.

NUMBER OF PIXELS GREATER THAN 50 DBZ IN 40-50,000 FT LAYER

- Number of 4 x 4 km pixels within the 40,000 to 50,000 ft layer in which the maximum reflectivity exceeds VIP 6 (equivalent to RADAP category 9).

SUM OF THE VIL ABOVE 15,000 FT

- Summation of VIL above 15,000 ft over entire area of storm. Computed by adding the VIL of all 4 x 4 columns together which contain VIL above 15,000 ft.

- This gives an indication the total water content above 15,000 ft, not just the maximum for an individual 4 x 4 km column.

SUM OF THE STORM VIL POTENTIAL ENERGY

- Summation of the total Potential Energy over entire area of storm. Computed by adding the VIL POTENTIAL ENERGY of all 4 x 4 km columns compositing storm.

SUM OF THE STORM VIL POTENTIAL ENERGY ABOVE 15,000 FT

- Summation of the Potential Energy above 15,000 ft over entire area of storm.

VOLUME OF STORM WITH REFLECTIVITY GREATER THAN 40 DBZ

- Volume of 3-D reflectivity pixels are at least 40 DBZ in storm.

- These 3-D reflectivity blocks are 4 x 4 km x range dependent depth.

VOLUME OF STORM WITH REFLECTIVITY GREATER THAN 50 DBZ

- Volume of 3-D reflectivity pixels which are at least 50 DBZ in storm.

TOTAL VOLUME OF REFLECTIVITY PIXELS

- Total volume of 3-D reflectivity pixels (intensity not important) contained in storm.

HEIGHT OF 40 DBZ REFLECTIVITY

- Height to which reflectivity of 40 DBZ or greater extends.

HEIGHT OF 50 DBZ REFLECTIVITY

- Height to which reflectivity of 50 DBZ or greater extends.

MAX ECHO TOP

- Highest level to which reflectivity of any intensity extends.

HEIGHT OF MAX REFLECTIVITY

- Highest level to which the maximum reflectivity in the storm extends.

VOLUME OF WEAK ECHO REGION

- Volume of weak echo region.

- Volume is calculated by summing the volume of each 3-d volume pixel in which the surrounding echoes on 3 sides or above are greater than volume in question. The surrounding echos must be at least 46 DBZ (VIP 4), while the weak echo must be less than 29 DBZ (VIP 2).

- The volume of each reflectivity pixel is calculated by multiplying the area (4 x 4) km by the range dependant depth.

AREA OF OVERHANG

- Area of overhang in km^2.

- To be counted as overhang, a 4 x 4 km area must have at least a 30 DBZ (VIP 2) mean reflectivity in the 20-30 thousand foot layer directly over a mean reflectivity less than 18 DBZ (VIP 1) in the sfc-10 thousand foot layer.

MAX RAIN WATER CONCENTRATION

- Maximum value of (VIL/ECHO TOP) in the cell.

- This gives the rain water concentration in grams per cubic meter.

- The theory behind the use of this predictor is that shorter storms may behave similarly to tall storms if the rain water concentration is similar.

MAX VERTICALLY INTEGRATED VIP

- Computed by summing the VIP level in each of the 10,000 ft mean reflectivity levels (sfc-10, 10-20, 20-30, 30-40, 40-50, 50-60).

- This predictor will not provide any additional information than VIL but may prove useful to sites which are equipped with a standard WSR-57 radar which must be operated manually to look at the vertical structure of a storm.