

THE INTERACTIVE MODIFICATION OF GRIDDED FORECASTS

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1. INTRODUCTION

Since 1985, the Techniques Development Laboratory (TDL) has been building and evaluating techniques which enable the forecaster to interactively prepare digital forecasts of weather elements. These techniques are being developed to test concepts and to gain experience in preparation for the Advanced Weather Interactive Processing System (AWIPS) scheduled for deployment by the National Weather Service starting in 1996.

In the AWIPS era, it is envisioned that nearly all routinely-issued user products will be automatically composed and formatted from a common digital forecast database. The forecaster will prepare this database by graphically modifying fields initialized from digital forecast guidance. Therefore, the user interface in the interactive forecast entry and modification process will be critical to the success of the AWIPS-equipped Weather Forecast Office (WFO). Unless the interface is efficient and easy to use, proposed WFO staffing levels could prove inadequate.

This paper describes the techniques developed at TDL which enable the forecaster to interactively modify gridded forecast fields by changing the positions and values of contours representing those fields, and by directly modifying values displayed at grid points. The paper presents the graphical techniques that can be used by the forecaster to draw, erase, and modify contours on the display screen, as well as the method by which gridpoint values are computed from these contours. Techniques which enable the forecaster to directly manipulate gridded data by value assignment, incrementing and decrementing, areal translation, and smoothing are also discussed.

2. BACKGROUND

Interactive techniques which enable the local forecaster to prepare digital weather forecasts

began to be developed at TDL in 1985 on the Automation of Field Operations and Services (AFOS) system. These techniques, in combination with programs translated to AFOS from software used to format zone forecasts from MOS guidance, comprised the earliest version of the Interactive Computer Worded Forecast (ICWF) system (Ruth and Peroutka, 1993). The ICWF allows the forecaster to adjust matrices of basic forecast elements (e.g., temperature, cloud, wind, weather) displayed over a map of the local forecast area. These digital forecasts are then used to produce products in several formats.

From June of 1986 until the present, evolving versions of the ICWF system have been used operationally at several Weather Service Forecast Offices (WSFOs). The most successful of these implementations has been conducted at WSFO Charleston, W. Va. As a result of ICWF technology, this WSFO now automatically generates routine public and fire weather products, and has increased its level of service by adding several agricultural, hydrologic, and public products to the existing product suite (Rezek and Parke, 1990).

Although the ICWF supports the automated generation of numerous public and closely-related products, the long-term goal for entering and modifying digital weather forecasts in a common digital database is to support the generation of almost all routine NWS forecast products, including domestic and international aviation terminal forecasts (FTs and TAFs) and transcribed weather broadcasts (TWEBs). In order to accomplish this, the digital database must include forecast information with both higher spatial and temporal resolutions than are available in the ICWF. A database to support aviation product generation also must explicitly define multiple cloud decks. Recognizing these needs, TDL initiated the development of the more comprehensive Forecast Entry and Formatting System (FEFS) in July 1987 (Ruth and Vercelli, 1989).

FEFS takes incoming station guidance in the form of probabilities and categories and converts it to

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hourly grids of sensible weather forecasts. FEFS provides the forecaster with a graphical interface to view, enter, and modify these forecast gridded fields quickly and intelligently. Gridded information is then summarized into zone-based matrices for the generation of public, agricultural, and fire weather forecast products; station matrices for the generation of domestic and international terminal forecasts; and route-based matrices for the generation of transcribed weather broadcasts.

Preferred techniques for interactively entering and modifying forecasts of a common digital database are highly dependent upon the particular forecast elements being entered or modified. TDL's experience with the ICWF indicates that forecasters quickly develop methods of interacting with the database which "work best for them." Therefore, FEFS was designed to provide the forecaster with an interactive toolkit to manipulate gridded fields of digital forecasts. This includes tools which directly manipulate digital values on the display screen (i.e., increment or decrement points or areas, assign values to points or areas, move forecast fields across the grid), perform time interpolation of quasi-continuous fields such as temperature, interpolate discrete areas of clouds and weather in space, and adjust contours.

In the spring of 1989, several months before the first operational testing of FEFS was to begin, work was suspended in favor of porting the field-tested ICWF software to the Pre-AWIPS Demonstration System. The initial phase of this conversion was completed when TDL installed the ICWF on the Pre-AWIPS system in Norman, Okla., in January 1992.

The NWS has specified that AWIPS will have upon initial deployment the capability to interactively modify gridpoint values through graphical techniques for hydrologic purposes. Since experience in such techniques was limited, TDL has recently continued work with graphical editing in order to more clearly specify what is needed in AWIPS. The results of this work will support, on the Pre-AWIPS system, the production of gridded quantitative precipitation forecasts (QPF) at Norman for use at the Tulsa River Forecast Center, the production and use of QPF being a high priority NWS risk reduction activity. The techniques developed will also enable us to enhance the ICWF by providing a graphical forecast overview and tools to enable the forecaster to work with temperature, probability of precipitation, snow amount, and QPF graphically. Such enhancements should increase forecaster acceptance of this new method of producing forecasts.

3. FORECAST MODIFICATION TECHNIQUES

The ICWF Grid MODification (GMOD) software enables the forecaster to interactively modify a gridded scalar field by drawing, erasing, and modifying contours representing the gridded field using a mouse. Modifications made to contours are reflected in the data values of the gridded field. GMOD also allows the forecaster to directly modify data values plotted on the grid.

GMOD facilitates the coordinated use of capabilities which adjust contours directly and capabilities which adjust the underlying data values, by recomputing gridpoints from adjusted contours and recontouring adjusted gridpoints as appropriate. A mathematically consistent set of forecaster-adjusted contours and technique-drawn contours produced from the gridded field computed by GMOD are virtually the same. Mathematically inconsistent contours are identified on the display screen.

3.1 Manipulation of contours

GMOD draws contours which are unbroken, piece-wise continuous between adjacent boxes on a grid mesh four times finer than the one for which gridpoint values are computed. No smoothing of the contours is applied. Special steps are taken to ensure adjacent contours do not touch or cross.

The paths of automatically-generated contours and contours interactively entered or modified on the display screen by the forecaster are identified on the fine-mesh grid as a series of forward and backward pointers in eight directions. Associated contour values are also maintained for points on the fine-mesh grid.

The forecaster can assign a value directly to any contour on the screen. Newly-drawn contours are initially labelled with the value of the nearest gridpoint to the starting point for that contour. The forecaster is able to increment and decrement any contour label on the screen by clicking the mouse button over that label.

⁴A set of mathematically consistent contours unambiguously partitions a surface into areas which are greater than, and areas which are less than, the values of the contours bounding the area. When an area is bounded by contours having more than two unique values, these contours are mathematically inconsistent. Also, when an area is bounded by contours having one value, the contours bounding adjacent areas are inconsistent if they are not all greater than (or all less than) the value of that contour.

The forecaster draws contours using the mouse to specify a continuous path across the screen. This can optionally be done by specifying the positions of endpoints of contour segments. The forecaster is able to move any portion of an existing contour. The software prevents the forecaster from drawing contours with paths that cross.

GMOD enables the forecaster to specify contours or portions of contours for erasure. This is done by pointing to any point on that contour with the mouse. When drawing a new contour, or specifying a different path for an existing contour, the most recently-drawn portion of that contour can be erased by tracing backward over the contour using the mouse. GMOD distinguishes whole contours and segments of contours drawn or modified by the forecaster from technique-provided contours by use of color.

3.2 Computation of Gridpoint Values from Contours

GMOD uses a method called the Systematic Interpolative Radial Search (SIRS) to compute gridpoint values from forecaster-drawn contours. In addition to the SIRS approach, known techniques for computing gridded fields from contours employ one of two basic methods: collecting a sample of points from each contour and then performing an objective analysis, or using functions to define a surface which can be evaluated at any point.

In a program developed to obtain gridpoint data from AFOS vector graphics (Fors, 1982), an objective analysis is performed by sampling points from each contour. More recently, an objective analysis using the Barnes approach (Barnes, 1973) has been employed at the Ohio River Forecast Center in Cincinnati, Ohio, to define grids from contours of precipitation amounts. A significant disadvantage to this approach is that gridpoint values computed from contours do not necessarily fall within the range of values of the contours which surround the gridpoint. For example, a gridpoint located in an area bounded by contours of 30 and 35 can take on a value of 36 if a 40 contour is also found nearby. When grids computed from contour values by this method are recontoured, the positions of original contours are not necessarily maintained.

In a forecast production system developed by the Canadian Atmospheric Environment Service (Dickinson et al., 1989), B-splines are used to fit a surface onto a coarse grid from which values can be extracted onto a finer grid. Although this approach performs adequately for relatively smooth fields on synoptic-scale grids, the interactive techniques to manipulate fields defined by these functions may not

provide the forecaster with the necessary precision to define a local-scale gridded field which includes sharp discontinuities in the forecast for areas containing coastlines, mountains, or cities.

The primary advantage of SIRS is that it allows the forecaster to use contours to define a grid with great precision. A new contour entered to represent cooler temperatures along a lake shore does not affect the placement of a warmer temperature contour the forecaster had previously positioned around a nearby urban area. Contour intervals need not be uniform. For example, a contour interval of 5 degrees can be used to define temperatures over the plains of Colorado while a 10-degree interval can be used for the mountainous terrain beyond the Front Range. When redrawn from a grid computed by SIRS, contours appear virtually identical to ones the forecaster entered by hand.

SIRS identifies contours by performing a multi-directional radial search for contours from each gridpoint to be computed. Gridpoints which are coincident with a contour simply take on the value of that contour. Values for all other gridpoints are computed in one of the following ways: averaging the values of the nearest contours, weighted inversely by the distance from the gridpoint to the contour; averaging values determined from directional gradients defined by contours; and averaging values of adjacent gridpoints and contours. The computation performed for any particular gridpoint depends upon the relative positions and values of its surrounding contours.

The following steps summarize the procedure used in SIRS to compute gridpoint values from contours. A detailed explanation of SIRS with step-by-step examples is provided by Ruth (1992).

STEP 1: Compute weighted average for gridpoints between contours of different values.

SIRS performs a multi-directional radial search for contours from each gridpoint to the edge of the grid. The nearest contour for each distinct contour value is selected from the contours closest to the gridpoint in each direction. Values for gridpoints are determined by averaging the values of the selected contours, weighted inversely by the distance from the gridpoint to the contour. If the set of contours is mathematically consistent, only two contour values are used in the weighted average for any gridpoint. In Figure 1, gridpoints in areas labelled with the letters B, E, and F would be computed by taking a weighted average.

STEP 2: Compute values for gridpoints not between contours of different values using gradients.

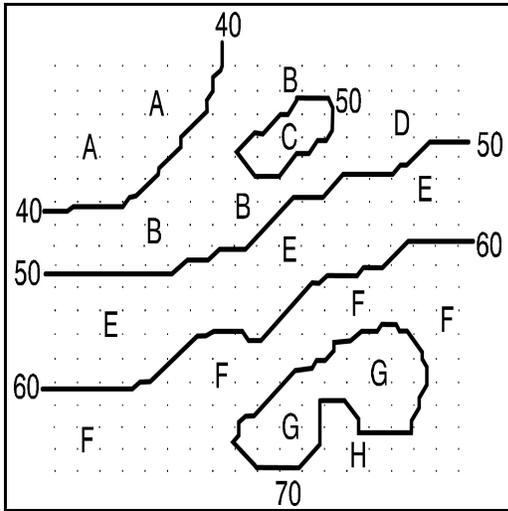


Figure 1. Partitioning of grid according to contours for the computation of gridpoint values by SIRS.

When all contours nearest a gridpoint in each direction have the same value, gradients are used to compute the value of the gridpoint. A gradient is calculated for each direction where at least one contour is crossed. If a second, more distant, contour with a different value is available in any direction, the gradient is determined from the difference of the contour values over the distance between those contours. If only one contour is available in a direction, the value of the edge gridpoint in the appropriate direction is used to determine the gradient. If this gridpoint has been computed using a weighted average (STEP 1), the computed value is used to determine the gradient. If this gridpoint has not been computed, a gradient of zero is used for this direction. In Figure 1, areas on the grid labelled with the letters A, C, D, and G would be computed from gradients.

STEP 3: Compute values for gridpoints not between contours of different values from adjacent gridpoints.

When no gradient is available in any direction (i.e. all gradients are zero), values for gridpoints behind contours of equal value are computed by averaging adjacent gridpoints which have already been computed. This case occurs when an area of the grid falls into the "shadow" of contours representing a maximum or minimum. The letter H in Figure 1 shows a "shadow area" of the grid.

Shadow areas are filled from the edge of the shadow to the center until all gridpoints have computed values. The average includes the adjacent gridpoint value from each of eight directions having

a computed value. If an adjacent gridpoint with a computed value lies on the opposite side of one or more contours, the value of the nearest intervening contour is taken and slightly adjusted for use in the average. The relative values of that contour, any other intervening contour(s), and the adjacent gridpoint determine the sign of the adjustment. The adjustment is necessary to preserve the position of forecaster-drawn contours on the grid in areas with weak or ill-defined gradients.

STEP 4: Smooth computed values.

For implementations of SIRS where the number of search directions must be limited to achieve reasonable response times, it is often desirable to smooth computed areas of the grid. This is done by computing an average for a gridpoint using the gridpoint value and the values of adjacent gridpoints from eight directions. In directions where the adjacent gridpoint lies on the opposite side of one or more contours, the value of the nearest contour is used in the average. This keeps gridpoint values consistent with forecaster-drawn contours. Figure 2 shows smoothed gridpoint values computed by SIRS.

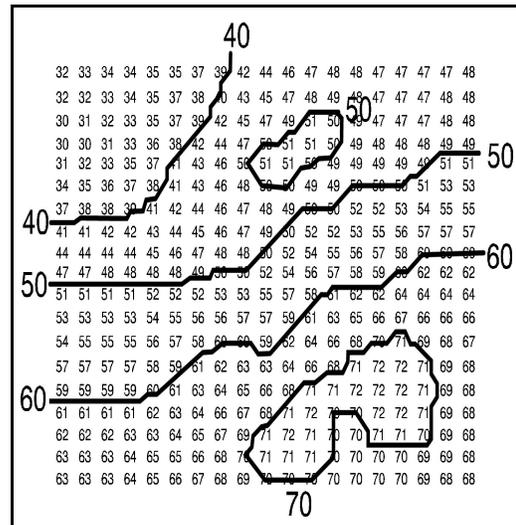


Figure 2. Gridpoint values computed from contours by SIRS.

3.3 Direct Manipulation of Gridded Values

GMOD enables the forecaster to manipulate gridded values plotted on the display screen. Collections of gridpoints are highlighted by passing the cursor over those gridpoints with the mouse. The forecaster is also able to highlight all points in an area of the grid enclosed by contours by clicking the mouse button. Highlighted gridpoints can be

manipulated in four ways: value assignment, increment/decrement, translation, and smoothing.

Value assignment enables the forecaster to specify a new value for the highlighted gridpoints. Incrementing (decrementing) allows the forecaster to increase (decrease) the highlighted gridpoints by a specified change value. The forecaster is able to increment all points having values less than or equal to the value of a specified gridpoint within the highlighted area, and to decrement all points having values greater than or equal to the value of a specified point within the highlighted area.

Incrementing and decrementing with a uniform change value applied to all gridpoints within the highlighted area is referred to as "raising" and "flattening" the grid area respectively. The forecaster may optionally apply a change value which decreases in magnitude as distance increases. This is referred to as "pushing" and "pulling" the grid area. When "pushing" and "pulling", the change value linearly decreases to zero from a specified gridpoint within the highlighted area to the boundary of the highlighted area in all directions. In each case, the change value is zero at gridpoints outside the highlighted area.

GMOD's value assignment and increment/decrement functions are suited to adjust fields of all continuous weather elements. Because the forecaster defines the specific area of influence by highlighting gridpoints, the features which "push and pull" and "flatten and raise" surfaces can be used to forecast sharp discontinuities along frontal boundaries and in areas containing coastlines, mountains, or cities.

Translation allows the forecaster to use a mouse to "drag" the highlighted area of gridpoints across the screen. As a highlighted gridpoint is moved over a non-highlighted gridpoint, its value replaces the non-highlighted gridpoint value. Gridpoints in the "wake" of the translated area maintain the value of the back edge of the highlighted area.

For example, a forecaster can use GMOD's translation feature to reposition an area of the grid containing forecast quantitative precipitation amounts greater than one inch. The size and shape of the maximum quantitative precipitation amounts are maintained while gridpoints in the vacated area take on a value of one inch. The translation of areas on a grid can be accomplished in less time than it would take a forecaster to reposition individual contours with a mouse.

GMOD enables the forecaster to smooth the highlighted area of gridpoints. The forecaster has the option to smooth with and without respect to contours. Smoothing is performed by computing a weighted average for a gridpoint using the gridpoint value and the values of adjacent gridpoints in eight directions. Smoothing with respect to the contours computes a weighted average for a gridpoint using the gridpoint value and the values of the nearest gridpoint or contour in eight directions. The forecaster can use smoothing to "clean up" artificial discontinuities after interactive operations on the grid or to smooth a rough initialization of the grid by guidance.

4. PLANS FOR THE FUTURE

GMOD is currently a "laboratory technique" which still requires field-testing and tuning. The software was developed to satisfy interactive gridded field modification requirements for the initial operating capabilities of AWIPS. At the second AWIPS pre-planned product improvement around 1998, the NWS will implement more sophisticated graphical forecast editing tools as part of the AWIPS Forecast Preparation System (see Wakefield et al., 1992). This system is currently under development by the Forecast Systems Laboratory and TDL jointly. Operational acceptance of these systems by NWS forecasters will depend not only on these expert editing tools, but on the systems' ability to take advantage of model guidance, and on the strength of their database's integration with product generation software.

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