MODEL-OUTPUT POST-PROCESSOR ALGORITHM DEVELOPMENT WITH INTERACTIVE VISUALIZATION SOFTWARE

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Abstract

An "interactive" algorithm development methodology for creating meteorological forecast products is described. Using interactive grid manipulation software, gridded model forecast parameters are compared to either human forecasts, or to actual verification data. Algorithms for desired weather elements are developed using the interactive software. Two such projects have been completed at the US Air Force Weather Agency (AFWA). Model output grids were combined to make severe weather forecasts and surface visibility forecasts. GrADS and IDL were the grid analysis software systems used to develop these algorithms. The interactive process and reasons for the success of this method of meteorological product algorithm development are discussed.

1. Introduction

Even before the advent of computers to assist in operational meteorology, weather forecasters created composites of several parameters believed to be useful in predicting atmospheric phenomena. One early example was Miller's (1972) severe weather composite chart in which many severe convective parameters from many vertical levels, all in an iconified form, were placed on a map. Creation and analysis of these charts led to the advice: "Where the biggest mess is, that is where you forecast severe weather." Extending Miller's methodology, Janish et al. (1996) advocated a composite chart approach for winter weather. Their winter composite charts were created to help the weather forecaster determine locations of sufficient conditions for winter type precipitation as determined by pre-selected parameters. One of their wishes was that, "Computer generated composites incorporating both model-derived and observational data, which allow forecaster interaction with the data, should be a logical progression in using composite charts more efficiently in operational forecast offices." Computer generated charts could eliminate some of the drawbacks of hand-drawn charts such as lack of standardization and need for customization, and could generate sophisticated parameterized methods.

Doswell et al. (1996) developed an "ingredients methodology" approach for forecasting the potential for flash-flood producing storms, using the "basic ingredients" of rainfall rate and duration. They defined "ingredients" as physical processes leading to, in their case, heavy precipitation. Their definition of ingredient went beyond the idea of "diagnostics," such as warm advection. Their concept of an ingredient could include for example, "rising motion" which might be indicated by warm advection or other physical mechanisms, or by diagnostic parameters. Wetzel and Martin (2001) also described an "ingredients methodology" whereby model data is parameterized into five necessary components for winter weather. Most of the components are derived on interactive computer workstations.

There have been many instances of software to help the meteorologist visualize, manipulate, and interact with digital data, and produce new products. One of the first was the "Man computer Interactive Data Access System" (McIDAS) (Lazzara et al. 1999). Another system, the "GEneral Meteorology PAcKage" (GEMPAK) (desJardins and Petersen 1985) was originally developed by the Severe Storms Laboratory at the Goddard Space Flight Center of NASA starting in the early 1980's. During the 1990's, a display program known as the "Personal Computer based Gridded Interactive Display and Diagnostic System" (PCGRIDDS) (Petersen 1993) was popular on the desks of many National Weather Service forecasters. The National Weather Service's current operational system is the "Advanced Weather Interactive Processing System" (AWIPS). The Grid Analysis and Display System (GrADS), used by many research meteorologists, is billed as "an interactive desktop tool that is used for easy access, manipulation, and visualization of earth science data" (Doty et al. 1997).

McIDAS, developed at the University of Wisconsin's Space Science and Engineering Center at Madison, Wisconsin has been used at many universities, at NASA, the NWS/National Severe Storms Forecast Center (now the Storm Prediction Center), and commercial airlines. GEMPAK is popular as a display and research tool at many universities, and is the backbone of NCEP's N-AWIPS workstation. Many forecaster applications, using GEMPAK's "command language," were written by Dr. Russell Schneider in support of the Hydrometeorological Prediction Center of NCEP. These scripts were distributed nationwide with GEMPAK.

The command line language of the PCGRIDDS interactive visualization and analysis program has been used by many forecasters to write hundreds of macros (programs) to aid in interpreting model grid data. Macros were distributed throughout the National Weather Service, arranged by weather categories, and documented. A feature of PCGRIDDS' macros was that they ran extremely quickly. Contours and threshold values could be modified and re-displayed within seconds. The rapid speed encouraged the development of many different

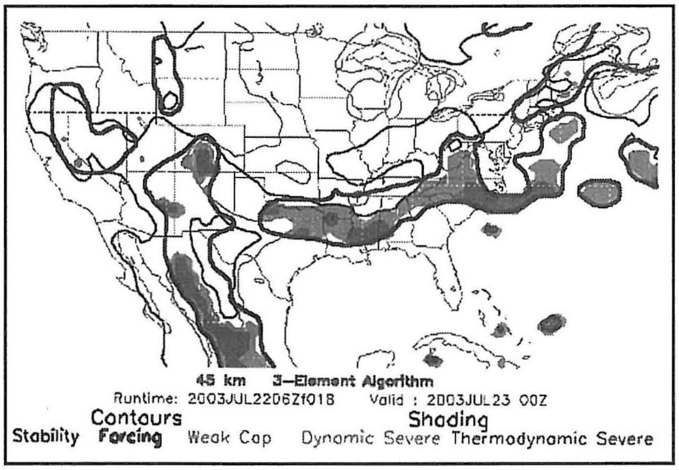

Fig. 1. Sample 3-Element / MM5 severe weather forecast algorithm output. Areas forecast to be severe are shaded. Contours indicate the instability, forcing and cap elements as indicated in the legend.

macro programs by operational forecasters. Additionally, the programs were of high scientific quality, and extremely applicable to forecasting. Thresholds were carefully selected, and tested by many forecasters on many cases. The displays were crafted so that the target area for weather was easily seen.

As an example of a workstation macro, the following parameters might be combined to find areas favorable to Mesoscale Convective System (MCS) development: 850 mb and 700 mb warm advection, a threshold value of precipitable water, and boundary layer convergence. Where the parameters all exceed threshold values, watch for MCS development.

The projects described herein have gone a step beyond typical display applications designed as forecaster diagnostic aids. At AFWA, two algorithms, each generating a forecast guidance product, were developed using interactive display and analysis software. One algorithm has been developed to forecast severe weather and another to forecast surface visibility. For both, AFWA MM5 model gridded data (described in section 2) was displayed using the interactive software discussed in section 3. Different software and verification data were used for each project, and are discussed in some detail in sections 4 and 5 specific to each project. Section 6 contains specifics of how the interactive software aided algorithm development, as well as some meteorological lessons learned, and is followed by a summary in section 7.

2. Data

Gridded output from the AFWA MM5 model was used as predictor data for both the severe weather and the visibility forecasting projects. The AFWA MM5 outputs data in three-hourly intervals from 00 to 72 hours. The 0600 UTC model forecasts valid through 42 hours were generally used to develop forecasts of "today's" and "tomorrow's" weather, although not exclusively. Since verification data naturally depended on the project, details on the verification data will be discussed in the section on that project.

3. Software

"Interactive software" for science is generally a combination of data visualization capabilities and some form of programming language. Typically there is a command line into which algebraic-like data manipulation commands are typed, or commands are given that create contours or other types of visualizations onto the screen. "Scripts," sequences of commands, can be written into a text file, and the stored sequence of commands can be run as a "program."

Several aspects of interactive visualization were key to our development of model forecast guidance products. Features of this kind of software allow the developer to:

- Display many model parameters one at a time, in rapid succession
- "Threshold' model parameters one at a time
- Overlay more than one model parameter
- Algebraically combine model parameters that are over threshold values
- Create "derived" parameters (advection, divergence, etc.)
- Save sequences of commands, creating "programs"

It is a significant benefit to the meteorologist if the software calculates and displays these parameters rapidly.

The new AFWA algorithms were developed using GrADS and IDL software packages. GrADS is a meteorological display system with a scripting language (Doty et al. 1997; also see Web site http://grads.iges.org), and allows easy production of graphical displays. In particular, GrADS displays model grib data easily, making it moderately simple to modify the cosmetic appearance of model output. Both contouring and shading can be done easily with GrADS. The scripting capability of GrADS allows a programmed sequence of commands to be run, supporting tasks involving complex or repetitive calculations.

The Interactive Data Language (IDL) is a full-fledged interactive programming language (see Web site: http://www.rsinc.com). Its array-oriented syntax is appropriate to the physical sciences, and has been adopted by astronomers and some meteorologists. IDL has extensive plotting, contouring, shading, and 3-D graphics rendering capabilities.

A useful feature of interactive software packages is that it is easy to schedule programs to be run automatically by the computer, which saves time for the developer. Also, verification statistics can be calculated if the verification data is available and amenable to quantification.

Both of the software systems mentioned above have associated Internet mailing lists or newsgroups, and user-contributed libraries that are useful to researchers or developers in meteorology.

4. Severe Weather Algorithm Development

Civilian forecasts for severe weather nationally in the United States are produced by the NOAA/NWS/Storm Prediction Center (SPC). Until recently, similar forecasts of military-oriented severe weather hazards for the continental United States were produced by AFWA. The responsibility for convective severe weather forecasts was shifted to regional centers in January 2003. The SPC out-lines areas where severe weather (tornado, hail larger than .75 inch, wind speed of 50kts and greater, or wind damage) is anticipated to occur on "Day 1", "Day 2", and "Day 3." The SPC product is known as the "AC" ("Area Convection"), and the AFWA product was known as the Military Weather Advisory (MWA).

The severe weather project emerged in response to a forecaster request to quantify a severe weather composite chart that was part of the automated suite of products derived from the AFWA MM5 model. A number of days later, the "3-Element / MM5 Severe Forecast" (unpublished) was born (Fig. 1). The 3-Element forecast was meant to serve as automated guidance similar to the SPC and (at the time) AFWA hand-drawn outlook products.

MM5 model output data was used as the input data to the forecast. Verification consisted of the comparable AFWA MWA forecast, and the SPC's AC. Also, actual reports were used if they were available in near real-time.

All of the development was done in near real-time. "Yesterday's" forecast was not re-done to achieve a better result using hindsight. (Digital data was saved for statistical tuning and verification once the algorithm was mature.) Generally the 0600 UTC run of the AFWA MM5 was used as input to the severe weather algorithm, and either the "Day 1" or "Day 2" severe weather outlooks from the SPC or AFWA were used as targets for the computer forecast. Note that the computer forecasts are valid at instantaneous points in time. Since severe weather is strongly diurnal in nature, 3-Element severe forecasts valid at 2100 UTC were most often validated and tuned to match severe weather reports for the day.

The initial forecast for severe weather was arbitrarily assigned to areas where the Convective Available Potential Energy (CAPE) was at least 2500 J Kg^{-1}. Where this area was seen to be inaccurate, other parameters were added that corresponded to severe weather potential. The addition of new parameters often changed the areal coverage of a forecast, which sometimes necessitated refinement of previous parameter thresholds. Note that some parameters are favorable toward severe weather, the addition of which caused an increase in forecast severe weather coverage, and some parameters inhibit severe weather, causing a decrease in coverage. Algorithm development was therefore an incremental and iterative process, consisting of adding additional parameters and threshold adjustments.

From experience, the developer knew that a single measure of instability would not be sufficient to forecast severe thunderstorms in all parts of the country. Therefore three different instability parameters were selected: CAPE, Lifted Index, and the Total Totals index. CAPE works quite well in the summer, Lifted Index is effective in the winter, and Total Totals is useful in high elevations (the western United States). If any of these indices exceeded their threshold, the *instability element* was triggered.

The second major element turned out to be forcing. Over a number of days, testing showed that any of three forcing mechanisms had a good correlation to severe weather, and that any of them could be the triggering mechanism by themselves. The forcings selected were 850-mb warm temperature advection, 700-mb MM5 model vertical velocity (heavily smoothed with the software), and boundary layer convergence. Again, if any of these exceeded their threshold value, the forcing element was deemed to be present. The interactive software allowed the threshold values of these forcing parameters to be adjusted easily, thus creating the optimal forecast with a relatively short trial-and-error process.

The AFWA MM5 provides two different thunderstorm "cap" indices. Experimentation with different permutations showed the best results when a *combination* of the two was used. Therefore, in order to forecast severe weather, the Convective Inhibition (CIN) had to be more than –100 J Kg^{-1}, and the Lid Strength Index (LSI) had to be less than six degrees Celsius. Again, this combination was found by trial and error. The interactive software allowed this to occur easily.

By this iterative process the 3-Element algorithm was developed during the warm season to forecast severe weather, producing a product that is similar to the SPC's hand-drawn product.

GrADS, the software used for development of this algorithm, encouraged the development of an algorithm that specified *necessary conditions* for severe weather. GrADS does not have an efficient "if" statement that can be used on single gridpoints. Therefore, grid "masking" was called for, with grids having a value of "1" where a condition was present, and "0" elsewhere. Within this framework, forcing, instability, and a weak cap were identified and coded as three separate and necessary "elements" for severe weather. Where all were present, severe weather was forecast to occur. The software, therefore, encouraged the developer to create the algorithm as three separate and necessary elements for severe weather.

The 3-Element algorithm is therefore:

IF	(instability)	AND
	(forcing)	AND
	(weak cap)	
THEN	forecast "severe"	

Where:

- INSTABILITY: either CAPE, LIFTED, or TOTAL TOTALS are over their threshold values;
- FORCING: either 850-mb warm advection, average boundary layer convergence, or model 700-mb vertical velocity are above their thresholds;
- WEAK CAP: both CIN and LSI are below their threshold values.

There are therefore 8 model *parameters* that comprise the 3 *elements* for severe weather. The GrADS software was used to derive some of the 8 parameters as combinations of simpler raw model parameters.

In the wintertime, testing showed that strong, dynamically-forced frontal systems could lead to the formation of squall lines, which might produce hundreds of severe criteria wind reports in a single day. Such a scenario can occur with minimal instability, such as Lifted Indices of only -2 degrees.

The stability and dynamic parameter thresholds that had been developed during the warm season were therefore inadequate. It was clear that strong dynamic forcing parameters could overcome sub-threshold instability values. The solution chosen was to provide *additional* thresholds for the instability and forcing parameters. In the winter, weak instability was allowed to trigger severe weather forecasts, provided there were also strong forcing terms. The warm season thresholds were not changed in any way. Severe weather was allowed to occur with either strong instability and weak forcing elements (warm season), or weak instability and strong forcing (cold season). A set of "medium" thresholds for instability and forcing parameters was also created. The three different threshold combinations can be triggered at any time of year. In fact the different threshold combinations can be triggered in one single storm system. It is common for the southern portion of a storm system to have strong instability combined with weak forcing, and the northern end to have weak instability with strong forcing. The addition of the winter thresholds was technically simple, and did not require a modification of the 3-Element algorithm. The thresholds are not changed with the seasons. The different threshold combinations allow for any sufficient combination of forcing and instability to trigger a severe storm forecast at any time of year (given that there is also a weak cap).

5. Visibility Algorithm Development

The existing AFWA MM5 visibility forecast did a good job of forecasting areas of low visibility in the early morning hours due to fog. However, it did this at the expense of a high false alarm rate. That is, it overforecast areas of low visibility. The old formula was an empirically derived regression equation correlating visibility to the model's forecast of the surface layer relative humidity (RH). High RH is favorable to fog formation and low visibility, but low visibility does not always occur when the RH is high. GrADS software was used to display and discover parameters that suppressed fog formation (such as strong low-level wind shear, midlevel clouds, low values of boundary layer humidity), and these parameters were displayed and compared to observations. Subjective examination of many cases revealed the threshold values at which these predictors would begin to decrease fog formation.

Since the above factors reduce the likelihood of fog formation, the new visibility algorithm was designed to lower the "effective" model output RH, which resulted in higher values of forecast visibility. The strength of the predictor determined the magnitude of the RH change, and therefore the visibility change.

Conversely, model output values of rain, snow, and cloud water (Stoelinga and Warner 1999) were found to correspond to lower visibility. Depending on the intensity of these parameters, the effective surface RH was increased, which has the effect of reducing visibility. Again, the use of interactive visualization software was an effective method of relating model predictor values with corresponding maps of surface visibility.

The new surface visibility algorithm is as follows:

Effective RH = Forecast RH

- wind shear term

- midlevel cloud term

- boundary layer humidity term

+ snow term

+ cloud water term

+ rain water term

+/- low-level vertical motions

In this equation, the negative terms inhibit fog formation, and therefore lower the effective model RH. The positive terms increase the effective model RH. And finally, the effective model RH was converted to visibility by a regression equation, satisfying the Air Force need for a quantitative visibility forecast. A more extensive explanation of the algorithm can be found in Kuchera (2002). An example of the product is shown in Fig. 2.

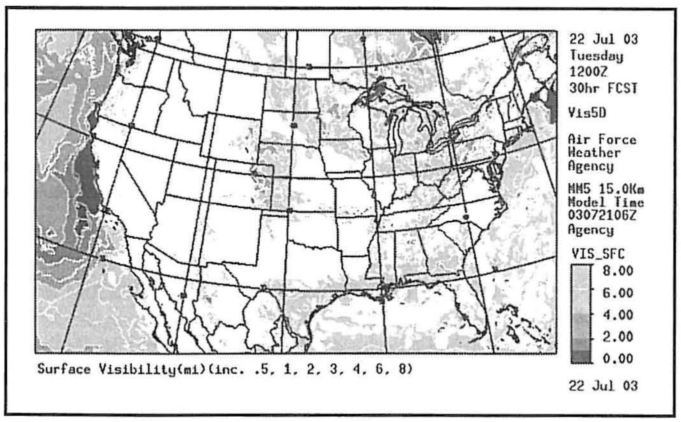

Fig. 2. Sample of new MM5 surface visibility forecast algorithm output. Visibility indicated by the legend, with darker colors indicating lower visibilities. The operational graphic has seven color levels which were reduced to four grayshades for publication.

Once the visibility forecast was tuned in a subjective manner, observations were directly compared to the nearest model grid point using the IDL interactive software package. A significance threshold of three miles was chosen (as this is when visibility becomes an operational problem), and binary yes/no statistics were calculated for a two-month data set. Thresholds were perturbed and statistics re-run to determine the optimal predictor thresholds. Finally, more data and more statistical methods were used to evaluate the new thresholds at different valid times and significance thresholds. The resulting algorithm outperformed other algorithms in most statistical measures. The "tuning" of the algorithm was possible due to the ease of manipulation and evaluation using IDL.

6. Discussion

a. Interactive visualization/analysis software and algorithm development

There are many potential difficulties with the interactive software algorithm development approach: sufficient occurrences of the desired weather, visualization difficulties, seasonal variations in weather processes, programming difficulty and more. However, neither of the developers found any part of the process to be especially difficult. In this section reasons for successful algorithm development will be noted, in particular, features of the interactive visualization software that facilitated algorithm development. While the points made in this section are based on the development of the severe weather and visibility forecast products discussed in this paper, the authors believe that the interactive development process is general enough to be used in the creation of many additional sophisticated model-based guidance products.

One of the simple but important conveniences of interactive visualization software was that nearly all of the raw model output parameters could be visualized quickly. With an appropriate list of raw model parameters, the parameters could be keyed in manually, or a script could be written to do so. With both GrADS and IDL, the up-arrow key could be used to recall the previous command, which could be quickly modified to display another parameter or display the parameter differently. Dozens of model output parameters could be viewed in a few minutes' time. Viewing many parameters quickly serves as inspiration to the developer, who can visually note which parameters appear to correspond to the verification. The ability to see the forecast, in a map plane, allows one to rapidly compare the forecast grids to the verification data, also displayed in a map plane on the developer's computer.

Derived parameters (combinations of more than one model output parameter) were also important to algorithm development. Temperature advection, surface vertical velocity (which is coded as terrain advection), convergence, and others are easily coded with the software. Working code for these operations can be found from mailing lists on the Internet. Once a routine is programmed to perform the calculations, the software quickly calculates and displays the results.

Algorithm design and structure was perhaps the most challenging aspect of the development process. However, neither of the developers had any difficulty deciding how to combine the various predictors. In the severe weather project, previous work had led the developer to attempt to categorize severe weather parameters into familiar terms: instability, forcing, and weak cap. GrADS was able to accomplish the algebraic manipulations adequately. In some cases grid manipulation had to be done "the GrADS way," with "grid masks." Although this was not immediately intuitive to the programmer, the GrADS way turned out to be an effective way to design the severe weather algorithm.

The visibility developer noted from literature searches, observation, and the old AFWA algorithm that low visibility occurred mostly when the surface relative humidity was over 80%. He decided to increase or decrease the "effective" model relative humidity when certain conditions were noted. The interactive visualization software allowed the developer to create the algorithm as a series of additions or subtractions to the relative humidity. This easily coded technique was all that was needed for an effective algorithm.

In both cases, the design of algorithms to forecast severe weather and low visibility was not a major difficulty. The algorithms seemed to evolve quickly and naturally as the developers examined model output parameters.

Another advantage of interactive visualization software is that it allowed the developers to visualize the algorithm output during development. During the 3-Element severe weather forecast development, the areas where the forecast called for severe weather were shaded. In addition, color-coded contour lines were used to outline areas where instability, forcing, and weak cap elements exceeded their individual thresholds. Therefore, the integrity of the algorithm could be seen easily, and checked for correctness. These contour lines were retained in the final product, so that forecasters could make adjustments should they disagree with the model's forecast of any of the three severe weather elements.

Contouring of individual components was also useful in developing the visibility algorithm. Since there are many terms in the visibility algorithm, it was not possible to retain all of them in the final product. However, the ability to contour multiple parameters was critical to the development process.

In addition to map contours, other forms of visualization were important. The visibility developer utilized the capability of GrADS to visualize model soundings. From these soundings, new parameterizations suggested themselves. A parameterization of low-level moisture based on vertical soundings was created and tested, although it was not used in the final algorithm. The exclusion of this parameter was due to model accuracy in forecasting low-level relative humidity, not in the programming of this new parameter. Again, the interactive visualization software was helpful in diagnosing the true problem.

There were occasions when the raw model data needed smoothing. In extreme cases, model output fields had excessive detail that made visualization difficult, as was the case with 700-mb vertical velocity. Due to large gridpoint-to-gridpoint fluctuations of this parameter as output from the model, smoothing was necessary to produce a guidance product spatially consistent with the SPC's forecast. Smoothing was easily accomplished with the software, and the smoothed 700-mb vertical velocity was used in the final severe weather algorithm. No smoothing was necessary for the visibility algorithm.

The setting of thresholds in general was much easier than anticipated. After only a few days, the thresholds were close to their final values. After the algorithms were developed, mature, and stable, extensive statistical optimization was performed on both algorithms. The optimization efforts generally showed that the human-set thresholds were already very close to optimal. It is perhaps surprising that nearly optimal thresholds were found in near real-time, with only a few days of data. **The use of**

interactive software facilitated rapid fine tuning of the threshold values used in the algorithms.

Since both projects began in the warm season, difficulty was anticipated as development continued into the cold season. It turned out that the algorithms did not need to be significantly altered. The visibility algorithm had to wait until winter to be adapted to the occurrence of snowfall reducing visibility. When snowfall began, the interactive software allowed for quick visualizations of observed visibility versus model forecast snow. The model's snow forecasts were tuned to fit the regression equation in the same manner as the other predictors. Adding the new parameter was not a problem at all with the visibility algorithm. Since the presence of a parameter either adds or subtracts from the base state relative humidity, adding another parameter was as simple as adding a variable to an equation.

In the case of the 3-Element severe weather algorithm, it was not even necessary to add any new parameters for the cold season. The only change to the algorithm was to allow weaker instability thresholds for severe weather, provided the forcing parameters were strong enough to compensate. While not successful in all cases, the modification was extremely effective. The varying balance between dynamic forcing and instability seems to be echoed in the real atmosphere.

b. Meteorological lessons learned

In both projects the algorithm developers were able to apply their education and synoptic meteorology experience successfully to computer programs and model data. The visibility developer noted that nighttime radiation fog should not occur with wind shear or midlevel clouds. These conditions were therefore parameterized, which performed as expected. With the severe weather algorithm, the developer anticipated that three different instability indices would be needed. This was based on his experience with severe weather across the continental United States and with severe weather in the winter. The different instability parameters appear to have performed as anticipated by the developer.

In both projects it is seen that there are both *causes* and *inhibitors* that are favorable and unfavorable to the weather in question. In the case of the visibility algorithm, the favorable and the unfavorable parameters are clearly indicated by the sign of the terms in the visibility equation.

In the case of the severe weather algorithm, based on the success of the forcing element, one might conclude that any one of the three forcing parameters are by themselves sufficient mechanisms to trigger severe weather (given also the presence of sufficient instability and weak cap). Similarly, it is probably safe to say that there are different vertical profiles of atmospheric instability that can trigger storms. The apparent success of the instability element, composed of three different instability indices, lends support to this hypothesis.

The capping element clearly works as an inhibitor, precluding any possibility of severe weather. If the cap is too strong, no severe weather occurs, no matter how strong the forcing. Many times forecasters discuss the possibility that a forcing parameter, such as boundary layer convergence, will be sufficient to break the cap. If the 3-Element formulation is completely correct, it suggests that the MM5 model has already taken the forcing into account, or that this line of thinking is perhaps not correct. It is also possible that the combination of strong forcings and weak cap thresholds should be examined more closely.

The makeup of the capping element of the severe weather algorithm provided new insight to the developer's thinking about capping indices, and led to a *Severe Local Storms* conference paper on the subject (Keller 2002). The algorithm states that *both* the CIN and LSI must be below threshold values. One might think that a weakness in the cap in any part of a sounding might provide sufficient trigger for convection. However, the work done in the referenced paper suggests that neither a weak LSI nor a weak CIN value is by itself sufficient for convection. Physical mechanisms for this hypothesis are suggested in Keller (2002).

Both severe weather and visibility have a strong diurnal nature. The severe weather algorithm suffers in that it over-forecasts for the late-night and morning hours. This has not been addressed except by noting this bias in documentation accompanying the forecast. While most visibility problems occur in the early morning, the visibility algorithm works adequately well over the United States at 0000 UTC, mostly because of the inclusion of snow and rain, which cause more low visibility than fog at that time of day.

Both developers readily acknowledge that their algorithms cover only what appears to be the major causes of severe weather and low visibility. Many other factors not included in their algorithms can affect each of these forecasts and should be investigated in future research. What the developers appear to have accomplished, however, is a quantitative encoding of the "most important" parameters. The algorithms provide a fine first-guess model forecast, which merits serious attention from forecasters. Additionally, the success of the algorithms allows them to serve as a framework for understanding the processes most important to forecasting severe weather and visibility. The exact formulation of the algorithm provides insight as to how the component parameters interact with each other.

7. Summary

Two automated weather guidance products have been created at the Headquarters Air Force Weather Agency using interactive visualization and analysis software. Two key features of this type of software are the ability to immediately visualize a gridded quantity, and the ability to run commands on a command line and/or by use of scripts. Seeing the trial forecast in a map form, and comparing it with a similar map of verification, provides immediate feedback on the latest trial of the algorithm. With a few keystrokes, threshold values can be changed, and the effect is quickly seen with a contour map. The best threshold can be found within minutes.

Using this software, the visibility forecast algorithm developer visualized model parameters that could affect visibility. He parameterized these conditions using thresholds and scaling factors that were determined by interactively comparing model forecasts to observed visibility. The developer of the severe weather algorithm, applying previous experience with severe weather, determined which model parameters fit three "elements" that were necessary for severe weather to occur. Using the interactive software, he was able to visualize severe threat areas and the contribution of each "element" to develop the best thresholds for each model parameter. With both algorithms, the interactive process was quite effective, so much so that statistical optimizations performed later did not appreciably change the human-derived thresholds in either case.

New parameters can also be developed with such visualization software. If the meteorologist believes that a process in the atmosphere has an effect on weather, that parameter can be programmed and visualized. The forecaster will quickly verify, either favorably or unfavorably, if that parameter actually corresponds to the weather that is observed.

There are many potential pitfalls to developing post-processed model algorithms: seasonal differences, lack of understanding of the atmosphere, the ability to parameterize the desired forcing, the ability to design algorithms, and the ability of the model to accurately forecast a parameter. For the visibility and severe weather algorithms, none of the above factors precluded development of useful forecast guidance products. In the end, the use of interactive visualization software resulted in post-processed model forecast guidance products. Study of the resulting algorithms also resulted in an increased understanding of the atmosphere.

Acknowledgments

The authors are extremely grateful for the thorough, constructive, and relevant reviews of Dr. Celia Miner and Mr. Brad Herold.

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