Whelping of the LFM
Or
Where Angels Fear to Tread

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On September 29, 1971, the Limited-area Fine-mesh Model (LFM) was made a part of the operational cycle at the National Meteorological Center - Washington (NMC), which was then located in Suitland, Maryland. As of 12Z on that date, LFM products began to appear on nationwide facsimile networks by order of Dr. George Cressman, Director of the National Weather Service (NWS). In a short time, the LFM became established as a major contributor to the suite of NWS numerical guidance products. The LFM continued in operation for the next 24 years and 5 months - nearly a quarter of a century. Finally, on February 29, 1996, the LFM was withdrawn from operations by order of Dr. Louis Uccellini, the Co-Chairman of this event, in his then capacity as Director of the NWS Office of Meteorology. When I retired from Federal service, Louis wrote, regarding the LFM, "You started it - my memo ended it - what a ride!"

By the early 1960s, the US Weather Bureau, the Air Force and the Navy had developed and were operating their own numerical hemispheric prediction models of the atmosphere. Given the computer and data resources available and the level of scientific knowledge, these models were state of the art. Those models had their roots in the pioneering modeling efforts of the scientists who had joined together to form the Joint Numerical Weather Prediction Unit in Washington fifty years ago. At every opportunity as time advanced, the civil and military services expanded their resources and efforts to exploit improvements and expansions in computer technology, data resources and advancing scientific knowledge.

In 1963, the USAF Air Weather Service (AWS) proposed a "fine-mesh" modeling project as part of their Plan for Computer Technique Development. The purpose of that project was to devise and construct an operational numerical weather prediction model with high enough resolution to capture and accurately depict small-scale atmospheric disturbances. Then, the model could be expected to predict the motion and development of those small-scale disturbances more accurately because of the truncation error control

afforded by the high-resolution grid. Another motivation for such a project was the possibility of expediting the delivery of guidance materials to forecasters. The speed-up would be accomplished by limiting the model's domain of integration to an area of relatively dense data coverage and good communication networks, as for example, over the conterminous United States. By taking advantage of early data collections in an area significantly smaller than the hemisphere, and by operating the model over just that limited area, guidance could be made available as much as several hours earlier than from a hemispheric model that could not be started until sufficient data from the hemisphere had been gathered and processed.

As fate would have it, I had been chosen by the AWS to take part in the fine-mesh (FM) experiment. Following graduate course work at the University of Chicago, I was given military orders to report to the Director of the NMC in Suitland in July 1963 to serve as a Liaison Officer to the NMC. Specifically, the AWS wanted me to become familiar with NMC operations and models and, in cooperation with members of the NMC, to investigate the feasibility of constructing a limited-area fine-mesh model.

When I reported to the Office of the Director, Dr. Cressman welcomed me, asked who I was and what I was doing there. We managed to get that straightened out and, during the ensuing interview, Dr. Cressman expressed concern at my lack of appropriate computer programming skill, which was limited to rather elementary FORTRAN. He immediately enrolled me in a course to learn IBM assembly language programming. All programming on the NMC computer, the IBM 7094, was done in machine language and he said it was essential to my mission that I become skillful in using it. So my first task was to be trained, and then tutored by NMC staff members. I eventually became a fairly skillful programmer.

Initial work on the FM task was directed toward constructing a model based on the barotropic vorticity prediction equation to provide circulation forecasts for the 500mb level. The FM model had a grid-length half that of the NMC operational model and was initially written using time invariant lateral boundary conditions. It was modified later to use boundary values interpolated in both space and time from stream function tendency forecasts made in the hemispheric model run 12 hours prior to the FM model's initial time. Experiments with that model were sufficiently successful, from the standpoint of truncation control and stability, to encourage construction of a multilevel baroclinic

model.

In 1962, the NMC began using a three-level baroclinic numerical prediction model developed by Cressman to produce daily operational forecasts. By late 1963, Dr. Cressman had written and was testing a four-level extension of the three-level model. The model under development was a potential candidate to replace the operational model. In progressing to the next step in the FM project, I was encouraged to study the four-level baroclinic model and to use it as a pattern for an FM model. This was to be the culmination of my work at the NMC and, if successful, it would provide an FM model to be used as a part of AWS support to USAF tactical operations. In fact, other events progressed faster than expected and that FM model was never completed and Cressman's four-level model was never adopted as the replacement for the NMC operational model.

An important event in the history of the LFM occurred in July 1964, when Captain A.J. Desmarais, after attending graduate school at the University of Utah, was assigned to work at Suitland. He was assigned to an AWS Detachment, commanded by Major George Kronebach that was collocated with the NMC. The Detachment's mission was to do tasks of interest to the AWS and USAF, regularly using scheduled time purchased on the NMC computer. "Des" was assigned to work with the satellite data people. I first met Des when he stopped at my desk to introduce himself to a fellow "blue-suiter." In the conversation that followed, he asked what I was doing at the NMC. At that moment, I was converting some of Cressman's subprograms to operate on the FM grid and was not getting comparable results in the fine and coarse versions with one of those routines. He asked if he could help and I said he sure could. I handed him an octal dump of the entire core of the IBM 7094 computer that I had made when my code had failed. The core dump was a single-spaced printout about an inch and a quarter thick. He came back the very next day with my error identified and the fix ready to insert in the card deck. I was very impressed. For years thereafter I welcomed any suggestions or help he offered.

Eventually, Des and I became a team. As part of our duties, the AWS directed us to construct a FM model patterned after a six-level model that had been used in the daily operational runs at the USAF Global Weather Central (AFGWC) since early 1965. That model was developed at the 3rd Weather Wing at Offutt AF Base and was patterned after Cressman's three-level model. The Air Force modelers had increased the number of

information levels in the vertical from three to six and had incorporated several simplifying physical assumptions that were designed to reduce the running time of the model to fit the time period allotted to the operational model at the AFGWC.

As had been done with the fine-mesh model we had been constructing at the NMC, we halved the mesh length and used a quarter of the hemispheric domain used in the operational model. We also adopted the time dependant boundary conditions that we had previously designed. To reduce its running time on the already loaded computer system devoted to operations, the FM model was written to retain only the four lowest information levels (constant pressure surfaces at 850, 700, 500 and 300mbs). We also "capped" the model with a forecast 300-200mb vertical motion field interpolated from the previous 12-hour coarse mesh forecast. In that form, the FM was tested and turned over to the AFGWC for implementation. Subsequently, the FM model was used frequently for special purposes at AFGWC but, to my knowledge, did not become a part of their routine daily run. This task took more than a year of our time to complete. It required a great deal of collaboration and work with modelers at the Global Weather Central, as well as many temporary duty trips to Offutt AF Base. But we considered that our mission was accomplished.

The filtered FM model was not adopted at the NMC. Its use as a truncation control device was compromised by the implementation of a fourth-order differencing scheme developed by Shuman and Vanderman that, when applied to advective terms, worked well in reducing the effects of truncation errors in the filtered models. Moreover, in June 1966, the Six Level Primitive Equation Model (6LPE) developed by Shuman and Hovermale was introduced as the primary operational model at NMC. It raised the state of the art of numerical weather prediction to a new plateau and its introduction suspended effort to develop a limited-area fine-mesh model at NMC.

Shortly after the 6LPE model became the NMC's operational model, the AWS directed Des and me to translate it to operate on the UNIVAC computers that were being procured for operational use at the AFGWC. FORTRAN had been used extensively, but not exclusively, in coding for the 6LPE. This somewhat simplified our conversion from the code operated on NMC's CDC 6600 computers to the code that would operate on the UNIVAC 1108 computer at the AFGWC. But sometimes I felt that we were spending a great portion of our time debugging the UNIVAC compiler. Again, our mission was

successfully completed; and, in the process, Des and I acquired a detailed knowledge of the new primitive equation model.

One might suppose that the concept and design of the LFM came from some joint conference or series of meetings of senior members of the NWS and the AWS. But such was not the case. Actually, its original conception came during an extended coffee break sometime in 1969. Des and I had just completed translating the 6LPE to operate at the AFGWC and had delivered the fruits of our labors to the AWS. That task had occupied a great deal of our time, and now that it was done, we were less busy than we were accustomed to being and felt somewhat at loose ends. While wondering what and where our next assignment might be and reminiscing about things we had done, we arrived at a somewhat interesting thought. If we were to combine the expertise gained from our FM modeling experiences with our recently acquired detailed knowledge of the NMC primitive equations, we thought we just might be uniquely and well prepared for the task of examining the feasibility of developing a FM model using the primitive equations. The more we thought of it, the less far-fetched such a project seemed. So we decided to ask for an appointment with the Director of the NMC to discuss the matter with him.

When we met with Dr. Fred Shuman, Des and I outlined our thoughts and sought his opinion. His response, as he gazed up at the ceiling, was to softly and perhaps kindly say, "Where angels fear to tread." Upon leaving the Director's office, Des and I agreed that we had <u>not</u> heard words that definitely said we should <u>not</u> do it. We considered that we therefore had some sort of tacit approval to proceed with the LFM, but at our peril.

We subsequently reported our sense of that meeting to our supervising officer at AWS Headquarters. We did not receive a definite negative there either. So Des and I made a giant leap to the conclusion that we were "good to go" and the way was clear - at least until we were told that our services were required elsewhere. So now Des and I were looking forward to the rather staggering and very interesting task upon which we had chosen to embark. We hoped we were not being foolish in stepping forward with our proposal to develop the LFM. All things considered, I don't think we were.

Our first task in our new project was to make fundamental decisions concerning the geographical properties of the LFM grid. If we had learned anything from our modeling tasks, it was that the fine meshing task was far easier if one adopted as much of the original model features as possible. Probably one of the most useful things to do was

to retain the same grid shape and number of points as in the coarse mesh model. If one then adopted a fine mesh length of one-half the coarse mesh length, then the fine mesh grid would cover one-fourth the area of the hemispheric grid. Also, it would fit very nicely over the North American continent with its boundaries a comfortable distance away from the conterminous U.S. The orientation of the 6LPE grid was centered on 80 degrees west longitude, but we decided to position our new grid so that its center grid column fell along 105 degrees west longitude and to place its lower right corner just inside the hemispheric grid. This seemed to present a more pleasing aspect for the LFM. (See slide #1)

These decisions concerning the LFM grid were made rather arbitrarily. Although the grid and its placement were of major importance to the LFM project, its adoption was quite easy since Des and I were just about the only ones really interested at that time and what we were doing seemed reasonable. However, we did discuss the grid location with experienced modelers and forecasters who were accustomed to dealing with model output. Those who expressed an opinion said that our proposed LFM grid and its positioning would probably be acceptable.

The LFM was a "system" of interrelated programs that involved data processing, analysis, numerical prediction, data post-processing and display of model output. Des and I felt confident that we could handle the prediction and post-processing parts of the system, but we were concerned with development of an analysis scheme specifically tailored to identify the smallest scale circulation features resolvable on the LFM grid. Interpolation from the operational analyses was simply inappropriate, although we would do just that to get the project started. To have any hope of completing the LFM in a reasonable length of time, it was clear that we had to entrain the support of members of the NMC staff into our project.

Fortunately, several of meteorologists at Suitland were reserve officers in the USAF and were attached for training to the small unit that I commanded at the Suitland complex. Because I had to approve and certify their weekend training, it was fairly easy to recruit them to be members of our team and to give them an opportunity to be current in matters relating to modeling projects of interest to the AWS. One reservist was an NMC expert in data handling and analysis techniques and he devoted many of his training periods to LFM work. Another reservist constructed fine-mesh mountains using

detailed terrain data obtained from government geodetic files. To further our recruitment efforts, we managed to get other NMC staff members, with whom we were well acquainted, interested in the project. They offered to help by volunteering programming services and support in their areas of expertise. These included the critical areas of processing and initializing data, post processing model output, and displaying meteorological data in a form suitable for operational use. As things moved along, we also received much encouragement and support from the Directors of the NWS and NMC, as well as the NMC Division Chiefs. Actually, we really did build a joint services team and could truthfully say that the LFM was a Joint Project of the AWS and the NWS. It seemed just a bit odd to me when I realized that I had come around to the point where I was now doing exactly what I had been sent to the NMC to work on in 1963.

In less than a year, we put together a model ready to run, test and debug. At that point in time, the model was able to get through a couple of its time-step iterations. That version used initial fields interpolated from the hemispheric model and lateral boundaries remaining invariant with values from the initial analyses. The model output was in the form of line-printed contour charts obtained by using the GRDPRT code. As we added the codes and fields constructed especially for the LFM, the model became more neat and respectable and was able to get through a multi-hour forecast. In the autumn of 1970, we thought we were ready for pre-operational testing of the LFM and we stated as much to Dr. Shuman at a status report briefing. He agreed. Then he decreed that we should undertake to run the model on 30 test cases and arrange to have the model output critiqued by forecasters in the Forecast Division of the Center and by scientists in the Development Division.

The first of the 30 test cases was made with initial data from 12Z on October 26, 1970. As with all these test cases, an attempt was made to run the model to 36 hours. The run produced forecasts of surface pressure, 500mb heights and quantitative precipitation at 12-hour forecast intervals. Reviewers judged the precipitation forecast to be very good; in fact, it may have been the best in all cases of the test series. (See slide #2) In both the surface and upper air forecasts, some improvements in gradients and positioning of circulation features could perhaps be seen, but it was noticed that the absolute values of the isobars and contours were much too high. It was gratifying just to have had a successful test, but the excellent precipitation forecast in this case aroused a

great deal of interest and assured an increased level of support for the project.

The 26 October case was interesting from several viewpoints. The increase in the values of the isobars and contours highlighted a serious model problem. We had seen some of this effect in earlier pretest runs, but in this case the average surface pressure of the grid points had risen by 13.6 millibars over the course of a 24-hour forecast. Such a forecast would be unbelievable to any forecaster. This particular effect has been referred to as “the pillow.” Reducing the pillow was one of the major problems dealt with during the testing period.

The boundaries of the LFM were embedded in meteorologically active areas of the hemisphere. The LFM pillow apparently resulted when the boundaries were initiated with conditions that caused either a net gain or loss of mass within the limited LFM volume of the atmosphere. The LFM boundaries, which were invariant in time during the testing period, almost always had active weather systems falling on them and the pillow effect could vary from a lot to little or none. Diagnosis of the problem showed that the “pillow” could be kept within an acceptable limit of a few millibars by initially adjusting the net flow across the boundaries.

The 26 October case, in addition to introducing us to the pillow effect, also revealed something to us concerning the computational stability of the model. The case was one in which very strong winds were flowing into and along the boundaries. This effect seemed to induce stratospheric exhaustion and resulting failure of the model. In the first eleven cases, there were four model failures due to computational instability at some time during the run to 36 hours. None failed to reach 36 hours after we installed a routine into the LFM to reduce a portion of the calculated tendencies at grid points near the boundaries.

Finally, in July 1971, the various components of the LFM had been programmed, checked out and tested on the thirty cases. Plans to implement the LFM as an NMC operational program were being coordinated at Headquarters level in the NWS, with inputs from the NMC and the NWS Regions. On August 10, 1971, Dr. Cressman sent a memorandum to all Regions and First Order NWS Field Stations, revealing plans to implement the LFM later in that year. He stated that the new mode of operation with the LFM was designed to get guidance material into the hands of the forecaster as quickly as possible. The general approach was (1) to run the LFM to 24 hours twice daily and

disseminate its output rapidly, (2) run the hemispheric 6LPE on its same schedule, and (3) provide guidance packages from the LFM to the NMC Analysis and Forecast Division forecasters significantly earlier than the materials received from the 6LPE.

He further stated that NWS planned to transmit three new facsimile charts twice per day over the National Facsimile circuit, one containing analyses and two containing predictions. The forecasts were to be composite 4-panel charts, each panel containing elements all of which verified at the same time. An attachment to this memorandum shows a sample 24-hr forecast displaying the meteorological information the composite chart would contain. (See slide #3)

At some point in this process, control of the LFM sort of passed from our development team and into the hands of the headquarters people, as of course it had to do. In the planning for the operational implementation, we were allotted a time slot of one hour and 35 minutes in which to operate the LFM model from data "dump" to completion of all post-processing and display programs. We were bounded on the early side by the time at which sufficient data arrived from the North American area; in general, this would be about two hours after the 00Z and 12Z observations were taken. On the late side, all programs of the LFM had to be completed, and off the computer, by the start time of the 6LPE model. To give the LFM a timely start, NWS authorized upper-air observing stations to release their balloons and instruments 15 minutes before scheduled times and ordered that Part A, the mandatory levels of the Rawinsonde observations, be sent as early as possible. Thus, the time slot available for the LFM to run was from 0200Z until 0335Z using 00Z data; and for the 12Z cycle, from 1400Z to 1535Z.

Perhaps the most optimized code in the LFM was the module that did the actual numerical forecasting. In that era, the LFM required two minutes to make a one-hour forecast. The time needed to run all the other codes associated with the LFM forecast required appreciable time and, when everything was added up, the 95 minutes of clock time allotted for the entire LFM system permitted only a 24-hour forecast.

We avoided the heartache and pain of getting slots on the facsimile circuits; the Headquarters people took care of that. And, other that arguing about a few words in the description of the model, we also had very little trouble with the Data Review Group that oversaw and approved NWS operational implementations on the computer systems. I

attribute that to the fact that the push for the implementation was coming from the top and not up from the "trooper" level. But all necessary things did happen, and the LFM was implemented on September 29, 1971.

During all this business, both Des and I retired from the Air Force in 1970 and were hired by the NMC to finish the LFM project. Later, effective 12Z February 7, 1973, we made a model upgrade by introducing time variable boundaries into the model. Doing so required more core space and more time on the computer, neither of which were available. We thought it was an important change to make, so we modified the grid used for the forecast by removing 12 rows from the top and resized all the fields from 53 by 57 points to 53 by 45 points. Thus, enough computer resources were "freed up" to give the space needed to hold the preprocessed boundary values from the 6LPE and to give the necessary computer time to refresh the LFM's lateral boundaries at 6-hour intervals. It was a satisfying thing to do and no doubt did some good. The LFM analysis grid was not changed and continued to use the full 53 by 57 grid.

In 1973, I was selected to fill a Branch Chief position in the NMC Automation Division, and the care and feeding of the LFM was passed to Mr. Jack Newell in the Development Division. The NOAA central computer system was upgraded in 1974 by replacing the CDC6600 computers with IBM 360-195s. The new computers were faster and the total run time of the 36-hour LFM could fit into the allotted time slot in the operational cycle; it was entered into the operational run in 1975. And so the long suppressed call of the forecaster was finally heard and he was given more LFM guidance. In 1976, apparently more time was found to run the LFM to 48 hours. There were other computer procurements and speed-ups that induced changes and improvements to the LFM in the following years. However, we are getting quite far from the birthing, or whelping, of the LFM. The lateness of the hour dictates that we stop this discourse, but not before we take a last look at one of the last operational charts produced by the LFM on Leap Year Day of 1996. (Slide #4)

In this presentation, I have not acknowledged by name the many, many Air Force and NWS people who were a part of the LFM project. If I had tried to do so, I certainly would have missed someone and that may have been interpreted as having slighted him or her. But you who helped know who you are. Believe it when I say that working with you "LFMers" has provided me with some of the happier memories of my life.

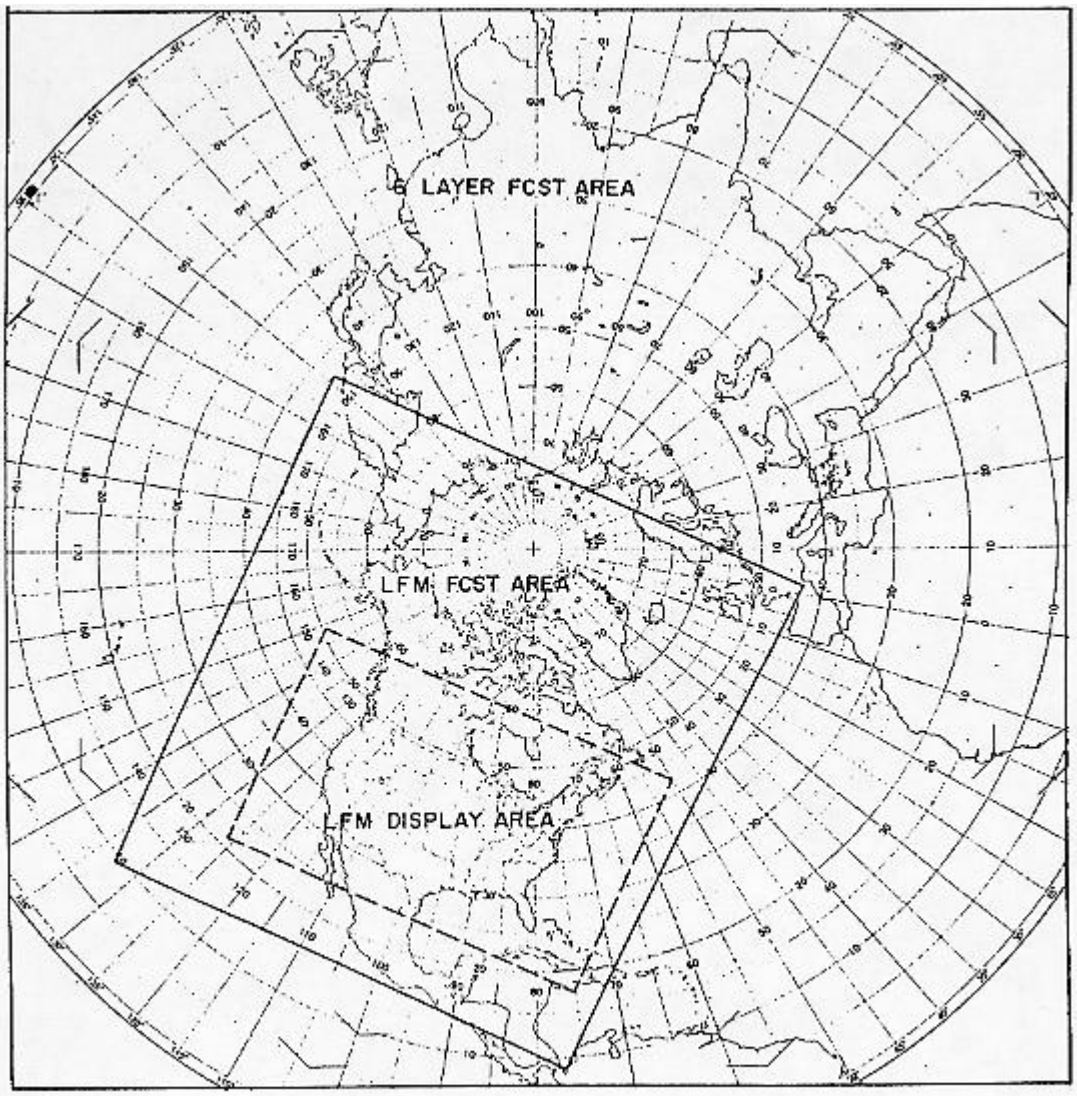
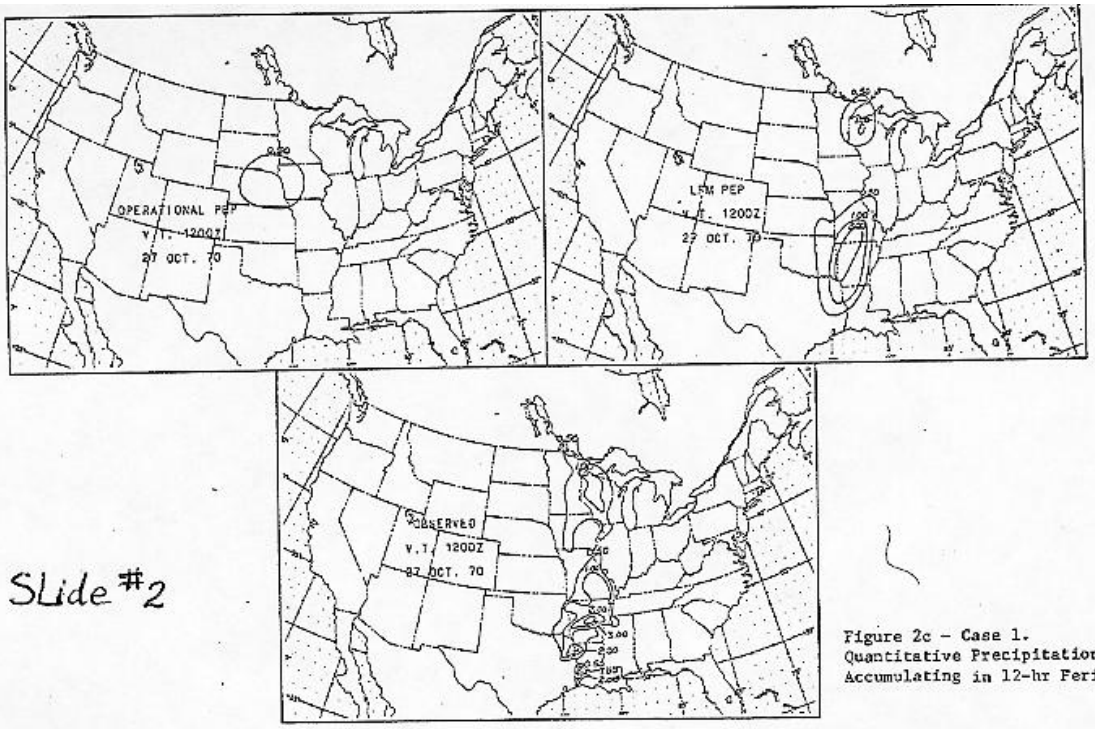


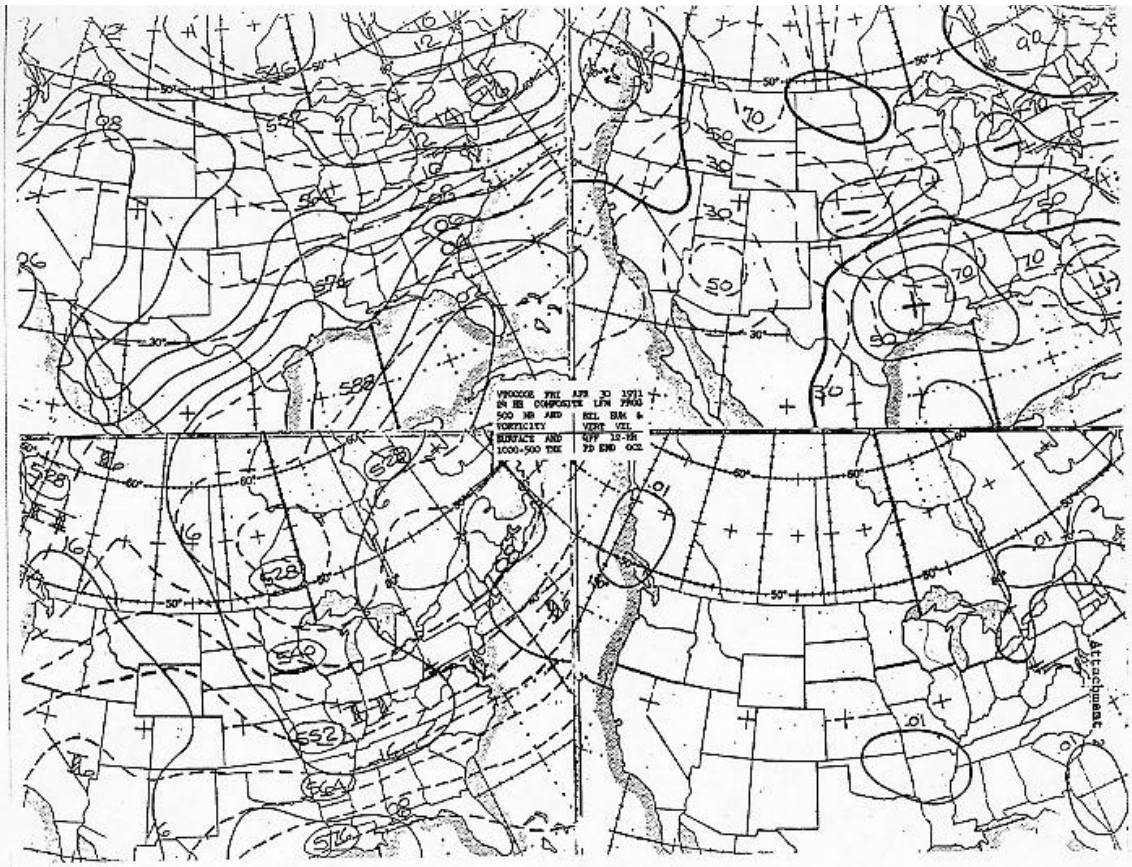
Figure 1. LFM and PE forecast areas.

Slide #1

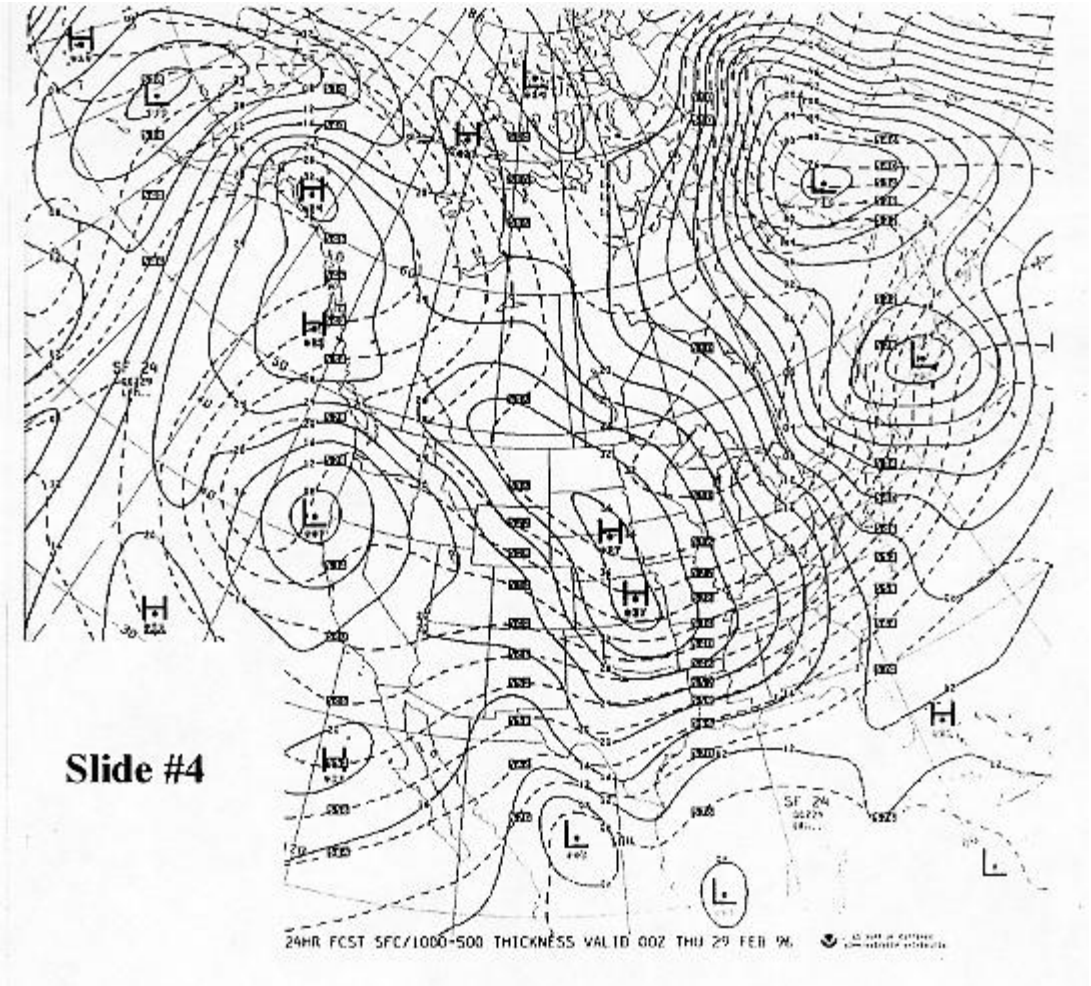


Slide #2

Figure 2c - Case 1.
Quantitative Precipitation
Accumulating in 12-hr Period.


VTOCCOE FRI APR 30 1971
24 HR COMPOSITE LFM PROG
500 MB AND REL HUM &
VORTICITY VERT VEL
SURFACE AND QPF 12-HR
1000-500 THK PD END OCZ
Attachment 2

Slide #3



Slide #4