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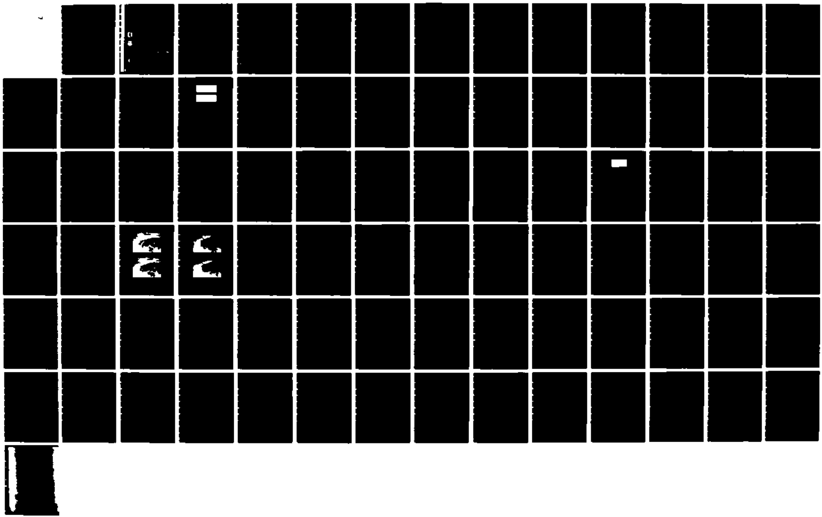

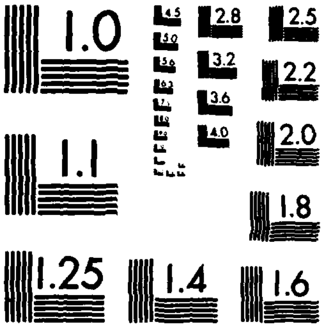

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An Assessment of Interactive Graphics Processing in Short-Range Terminal Weather Forecasting

DONALD A. CHISHOLM
ARTHUR J. JACKSON

18 January 1984

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FOR THE COMMANDER

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A mesoscale forecast experiment used data from 20 winter/spring east coast storm episodes in the AFGL McIDAS facility. The mesoscale forecast experiment assessed many display and analysis products tailored to provide mesoscale detail from remotely-sensed and conventional data sources, and the ability of forecasters to prepare short-range terminal forecasts of windspeed and direction, total cloud amount, ceiling height and 6-hr quantitative precipitation forecasts. The forecast experiments were conducted in the summers of 1982 and 1983 using winter and early spring storm episodes archived on McIDAS from the 1981-82 and 1982-83 seasons, respectively.

The products judged most useful in preparing short-range terminal forecasts included: (1) conventional geographic data displays presented simultaneously as four quadrant panels on one screen, (2) regional scale surface analyses, plots and data listings of basic

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variables, (3) satellite-based trajectory technique, (4) tailored plot displays such as the station-model time-series display, and (5) mapped displays of forecast guidance derived from the NMC LFM model. The importance of half-hourly visible and IR imagery from GOES in short-range terminal forecasting was confirmed in this experiment. The forecasters relied more heavily on it to prepare their forecasts than any other data source. The manipulation of digital imagery in a computer-based interactive graphics system through time-series looping, color enhancements, and overlaying conventional plots and analyses on it, provides a wealth of qualitative and quantitative guidance for forecasting. The numerical forecasts yielded superior rmses compared to persistence for all forecast intervals and for each forecast element. Probability forecasts were substantially better than persistence probability and sample climatology. GEM showed skill relative to persistence probability but yielded larger rmses than did persistence in its numerical form. MOS guidance was found to be useful for forecast intervals of 4 hr or longer.

Preface

The Mesoscale Forecast Experiment could not have completed successfully without the support and participation of several individuals in AFGL's Atmospheric Sciences Division (LY) and its contractor (Systems and Applied Sciences Corp.). The principal participating forecasters were Dr. H.A. Brown, Dr. H.S. Muench, Mr. A.J. Jackson, Captain D.V. Ridge, and Mr. J. Arck of AFGL/LY and Messrs. M.E. Niedzielski, R. Schechter, and C.F. Ivaldi of SASC. Mr. J. Pazniokas and Mr. L. Jorrens provided invaluable support as test evaluators and data analysts. The above-mentioned SASC personnel, working closely with Mr. R. Fournier of AFGL/LY, developed and integrated many new and/or modified application software packages into the McIDAS operating system. Ms. Betty Blanchard ably prepared draft and final manuscript versions.

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An Assessment of Interactive Graphics Processing in Short-Range Terminal Weather Forecasting

1. INTRODUCTION

The practical emergence of computer-driven interactive graphics display systems has spurred a move, in both civilian and *military terminal weather operations*, from a manual mode to a more automated mode. Conventional weather data, presently available in weather stations via teletype and facsimile, can be accessed for plotting, analyzing, manipulating, and displaying in virtually an unlimited number of ways by resident software once the basic data are ingested into the computer system. Add to that the potential and routine availability of imagery from polar orbiting and geostationary weather satellites, conventional and Doppler radar, and other remote sensors and you have a dramatic increase in the amount and rate at which information can be made available to the forecaster-user.

Because of the amount of data and the wide range of options available to the forecaster to manipulate it in the interactive display system, careful consideration must be given to the methods available to effectively use the system. As was stated in the first report on this study,[1] the potential exists for inundating the base

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(Received for publication 17 January 1984)

[1] Chisholm, D.A., Jackson, A.J., Niedzielski, M.E., Schechter, R., and Ivaldi, C.F. (1983) The Use of Interactive Graphics Processing in Short-Range Terminal Forecasting: An Initial Assessment, AFGL-TR-83-0093, AD A137165.

weather station forecaster with more information and data-usage options than can be handled, especially when he or she is trying to cope with a complicated and ever-changing weather situation. Conversely, if the system is properly structured and the forecasters have been adequately trained on its usage under various weather situations, such systems offer the opportunity for major advances in weather station operations, wide-ranging weather support, and terminal forecast accuracy.

The USAF has embarked on a base weather station modernization program called Automated Weather Distribution System (AWDS) which, when fully implemented, will provide base level support to operations worldwide and to deployed Air Force and Army tactical units. With AWDS, environmental data and products will be acquired, stored, displayed, analyzed, and forecast through modernized computer and dedicated communication systems. The principal weather data sources available through AWDS will be provided from the Air Force Global Weather Central (AFGWC) and the Automated Weather Network (AWN). The AWN collects, edits, reformats, and transmits weather data between base weather stations worldwide. These data include alphanumeric products such as hourly and special surface weather observations, twice-daily rawinsonde (upper-air) observations, plain language text including advisories, terminal forecasts, and map discussions, which are presently received at base weather stations via the COMEDS teletype circuits. Products available in weather stations from AFGWC include various surface and upper-air analysis and forecast maps that are received via the Air Force's facsimile circuit (AFDIGS). With AWDS these data products will flow directly into an on-site computer facility designed to store, process, and display weather data fields on alphanumeric and color graphic terminals. Resident software in the base weather station's AWDS computer will allow the weatherman-user to request the execution of a wide range of analysis and forecast-guidance procedures.

With AWDS there will be an important difference in the format of data flowing from AFGWC in that objectively-determined analysis and forecast products will be Uniformly Gridded Data Fields (UGDF). That is, the individual, regularly-spaced gridpoint values will be transmitted to base weather stations where they can be contoured and displayed in map form, as required by the weatherman-user. In addition, data flowing from AFGWC will include vector graphic products to describe weather maps, charts, and figures and raster scan products (initially limited to AFGWC's Satellite Global Data Base). The Satellite Global Data Base (SGDB) is comprised mainly of 3-nm resolution visible and IR satellite imagery for each hemisphere. Raw imagery input to the SGDB comes from available polar-orbiting satellites (for example, DMSP and NOAA), which is integrated into the SGDB in real-time after imagery from each quarter-orbit is received at

AFGWC. At any one point in time, therefore, the individual pixel values on the global SGDB may come from observations made several hours apart. This characteristic greatly limits the value of the SGDB in mesoscale or short-range forecasting applications.

The McIDAS facility at AFGL has access to most of the data that will be available with AWDS. (The major exceptions being UGDF and SGDB from AFGWC.) They can, however, be reproduced in McIDAS to a large extent by analyzing observational data and forecast guidance from the National Weather Service (NWS). In addition, other data sources (for example, GOES imagery) and capabilities available within our McIDAS are germaine to short-range terminal forecasting applications. See Chisholm et al[1] for a description of McIDAS and its residence software capabilities.

A research and development study was undertaken, using the McIDAS as an AWDS prototype, to examine benefits and/or problems inherent in video display systems for the preparation and monitoring of short-range terminal forecasts. A 2-yr mesoscale forecast experiment (MFE) was conducted to assess:

(1) The value of certain mesoscale objective plot, analysis, and forecast procedures in the preparation of short-range terminal forecasts,

(2) The relative difficulty in preparing certain forecasts (elements) using an interactive graphics system,

(3) The value of certain remotely sensed data in short-range terminal forecasting, and

(4) The performance of forecasters, in weather episodes with substantial mesoscale variability, in generating both numerical (deterministic) and probabilistic terminal forecasts using an interactive graphics system. The forecast preparation and met-watching aspects of the experiment were structured to simulate the process and requirements of providing the base weather station support stated above.

2. MESOSCALE FORECAST EXPERIMENT (MFE)

The procedure that was established to assess aspects of interactive systems, data sources, and weatherman-user effectiveness was to conduct a forecast test experiment addressing a particular set of short-range terminal forecasting requirements using research meteorologists. Two MFE test periods were established; the first was conducted in the summer of 1982, the second in the summer of 1983. This report combines the results of the 1982 and 1983 tests; an initial assessment based on the 1982 test has been published previously.[1] In order to conduct the tests most efficiently, data from significant weather episodes were archived during the 1981-1982 and 1982-1983 winter and early spring storm seasons in the Northeast U.S. The archived data sets were then restored in McIDAS for each foreca experiment. Twenty archived episodes were used in the experiment, ten during the summer of 1982 and ten during the summer of 1983. The 1983 episodes are described in Appendix A of this report, the 1982 episodes in Chisholm et al. [1]

The MFE tests were conducted such that the time available for forecast preparation was controlled to real-time limits. The forecasters had a singular task and objective during the tests; prepare terminal forecasts for two locations using as many of the resources available to them through McIDAS for the purpose of evaluating new and standard products and data sources. One forecast experiment was conducted each week (typically in two 4-hr periods per forecaster and with three forecasters working together to evaluate the weather situation but independently preparing their forecasts). At the conclusion of each case, each forecaster completed evaluation forms in which the products used and the forecast aspects of the case were assessed. These then, formed the basis for addressing purposes (1), (2) and (3) of the MFE as described in the INTRODUCTION.

2.1 Experimental Procedures

The forecasters were required to forecast (on an hourly cycle) windspeed and direction, total cloud amount, and ceiling height for periods of 1, 2, 4, and n hr ahead. The period n was the closest interval (greater than 4 hr) between forecast time and 06, 12, 18, or 00 GMT. In addition, 6-hr quantitative precipitation forecasts (QPF) were prepared each hour for the "next" full 6-hr period ending at 06, 12, 18, or 00 GMT. Forecasts for two airfield locations were required for each case; the specific locations were predicated on the availability of FOUS bulletins containing model output statistics (MOS), LFM-II guidance, and 3-D trajectory forecasts that were made available to the forecasters for guidance purposes. Logan International Airport, Mass. (BOS), being the closest candidate location to AFGL, was a forecast location in each of the cases used in the test. The second location varied among Bradley International Airport, Conn. (BDL), Kennedy International Airport, N.Y. (JFK), and Green Airport, R.I. (PVD), depending on factors related to the episode being tested.

For windspeed and direction, a numerical or deterministic forecast was prepared. With each of the other elements, both categorical or numerical forecasts and probability forecasts were prepared. For total cloud amount, the category (clear, scattered, broken, or overcast) and the probability of occurrence of each category were required; for ceiling height, a specific height category and probabilities for the categories listed in Table 1; and for QPF, the 6-hr precipitation amount (in inches) and the probabilities for the categories listed in Table 2. The category breakdown for total cloud amount, ceiling height, and 6-hr QPF are compatible with categories of MOS and related guidance.

Table 1. Ceiling Height Categories

Category	1	2	3	4	5	6
Height (100 ft)	0-1	2-4	5-9	10-29	30-74	>75

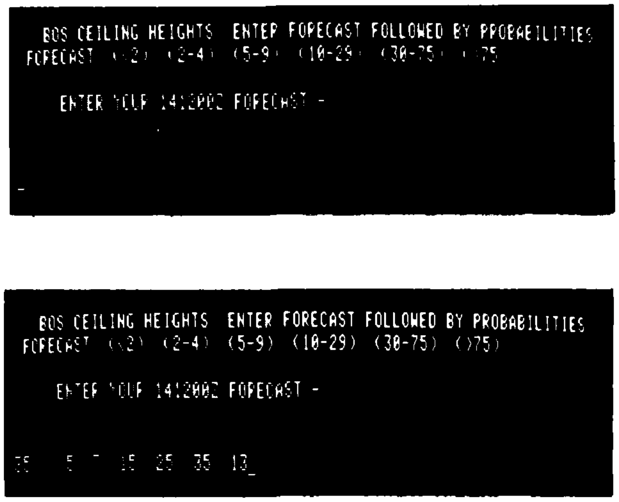
Table 2. Six-hr QPF Categories

Category	1	2	3	4
QPF (in.)	0-0.24	0.25-0.49	0.50-0.99	>1.00

The computer-based forecast entry and verification procedure referred to as the Mesoscale Forecast Facility (MFF) is a "menu-driven" interactive system designed to ingest individual forecasts into a data file through the use of formatted interrogation/response messages via the McIDAS' keyboard alphanumeric CRT terminal interface. Figure 1 depicts a sample message in its interrogation format (a) and response format (b). Each of the principal participants in the experiment had reserved storage in McIDAS in which individual forecasts and verification statistics were accumulated.

The assessment forms completed after each case are shown in Appendix B. The purpose of the Mesoscale Forecast Variable Assessment was to establish the relative difficulty in preparing forecasts of each element and to try to isolate the reason(s) for the difficulties encountered. An assessment form was completed for each of the forecast elements. The Product Usefulness Assessment was used to measure the relative value in terminal forecasting of the objective display features in McIDAS, especially the new ones created for this experiment. The forecasters were directed to judge the most and least useful products (for the case just completed) and give reasons why they were so rated.

After each case, the numerical, categorical, and probability forecasts were verified within the MFF, accumulated statistics were summarized and made available to the forecasters for review. Figure 2 is a sample of the accumulated



```
  BOS CEILING HEIGHTS  ENTER FORECAST FOLLOWED BY PROBABILITIES
FORECAST (<2) (2-4) (5-9) (10-29) (30-75) (>75)

   ENTER YOUR 141200Z FORECAST -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  BOS CEILING HEIGHTS  ENTER FORECAST FOLLOWED BY PROBABILITIES
FORECAST (<2) (2-4) (5-9) (10-29) (30-75) (>75)

   ENTER YOUR 141200Z FORECAST -


35   5  7  15  25  35  13_
```

Figure 1. Example of "Menu-Driven" Interactive Procedure Used for Forecast Entry Into Automated Verification Phase of MFE: (a) Interrogation Format and (b) Response Format

verification statistics compiled for each forecaster. Separate statistics were computed for predictions verified for Logan (BOS), which are denoted PRIMARY, for the other station (denoted SECONDARY), and for the combined verification. The error statistics calculated were: mean absolute error and rmse for numercal and categorical forecasts and the p-score and cumulative p-score and Heidke skill score vs persistence for probability forecasts.

The method of comparison for the study was persistence, measured directly and in sample (unconditional) climatology form. The Heidke skill score, which measures the percent difference (improvement) of verification scores relative to a set of control forecasts, was calculated using persistence as the control. The rms vector error results were used to calculate the Heidke skill score for wind forecasts, and the cumulative p-score was used for the other forecast elements. The equations for calculating the verification scores are described in Chisholm et al.[1] The persistence probability forecast was generated by (a) directly assigning a probability of 1.0 to the category that pertained at forecast (initial) time and a probability of 0.0 to the categories that did not pertain and (b) using sample climatology statistics. The latter was not determined for QPF because of its limited sample size. For total cloud amount, the unconditional 2-yr sample climatology was clear (0.05), scattered (0.08), broken (0.07), and overcast (0.80). For ceiling height it was category 1 (0.02), 2 (0.01), 3 (0.11), 4 (0.30), 5 (0.26), and 6 (0.30), where the category numbers are those defined in Table 1.

```
PREDICTAND         1 HOUR FORECAST             2 HOUR FORECAST             4 HOUR FORECAST             N HOUR FORECAST

WIND            NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108
                            PRIMARY   54                PRIMARY   54                PRIMARY   54                PRIMARY   54
                          SECONDARY   54              SECONDARY   54              SECONDARY   54              SECONDARY   54
                MEAN ABS. ERROR:    3.88    MEAN ABS. ERROR:    4.75    MEAN ABS. ERROR:    6.13    MEAN ABS. ERROR:    7.72
                       PRIMARY      3.55           PRIMARY      4.44           PRIMARY      5.21           PRIMARY      7.62
                     SECONDARY      4.21         SECONDARY      5.05         SECONDARY      7.05         SECONDARY      7.82
                RMS ERROR:     4.59         RMS ERROR:     5.65         RMS ERROR:     7.47         RMS ERROR:     8.54
                   PRIMARY     4.24            PRIMARY     5.04            PRIMARY     6.36            PRIMARY     8.50
                 SECONDARY     4.92          SECONDARY     6.21          SECONDARY     8.44          SECONDARY     8.59
                HEIDKE SCORE:     .01       HEIDKE SCORE:     .06       HEIDKE SCORE:     .17       HEIDKE SCORE:     .29
                     PRIMARY      .25            PRIMARY      .33            PRIMARY      .40            PRIMARY      .39
                   SECONDARY     -.24          SECONDARY     -.21          SECONDARY     -.05          SECONDARY      .19                 QPF

CLOUD AMOUNT    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 104
                            PRIMARY   54                PRIMARY   54                PRIMARY   54                PRIMARY   54                PRIMARY   52
                          SECONDARY   54              SECONDARY   54              SECONDARY   54              SECONDARY   54              SECONDARY   52
                MEAN ABS. ERROR:     .13    MEAN ABS. ERROR:     .07    MEAN ABS. ERROR:     .10    MEAN ABS. ERROR:     .20    MEAN ABS. ERROR:   12.47
                       PRIMARY       .11           PRIMARY       .06           PRIMARY       .13           PRIMARY       .33           PRIMARY      7.21
                     SECONDARY       .15         SECONDARY       .09         SECONDARY       .07         SECONDARY       .07         SECONDARY     17.73
                RMS ERROR:      .38         RMS ERROR:      .30         RMS ERROR:      .35         RMS ERROR:      .64         RMS ERROR:    21.55
                   PRIMARY      .38            PRIMARY      .24            PRIMARY      .41            PRIMARY      .86            PRIMARY    12.59
                 SECONDARY      .38          SECONDARY      .36          SECONDARY      .27          SECONDARY      .27          SECONDARY    27.75
                P-SCORE:     .20            P-SCORE:     .13            P-SCORE:     .14            P-SCORE:     .20            P-SCORE:     .40
                   PRIMARY   .15               PRIMARY   .09               PRIMARY   .18               PRIMARY   .30               PRIMARY   .19
                 SECONDARY   .26             SECONDARY   .16             SECONDARY   .13             SECONDARY   .11             SECONDARY   .60
                CUMULATIVE P-SCORE:  .04    CUMULATIVE P-SCORE:  .02    CUMULATIVE P-SCORE:  .03    CUMULATIVE P-SCORE:  .08    CUMULATIVE P-SCORE    .09
                          PRIMARY    .03              PRIMARY    .01              PRIMARY    .03              PRIMARY    .08              PRIMARY    .08
                        SECONDARY    .04            SECONDARY    .03            SECONDARY    .02            SECONDARY    .02            SECONDARY    .13
                HEIDKE SCORE:     .17       HEIDKE SCORE:     .67       HEIDKE SCORE:     .78       HEIDKE SCORE:     .74       HEIDKE SCORE:     .54
                     PRIMARY      .23            PRIMARY      .67            PRIMARY      .70            PRIMARY      .58            PRIMARY      .61
                   SECONDARY      .10          SECONDARY      .68          SECONDARY      .86          SECONDARY      .89          SECONDARY      .47

CEILING HEIGHT  NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108    NUMBER OF FORECASTS: 108
                            PRIMARY   54                PRIMARY   54                PRIMARY   54                PRIMARY   54
                          SECONDARY   54              SECONDARY   54              SECONDARY   54              SECONDARY   54
                MEAN ABS. ERROR:   67.15    MEAN ABS. ERROR:   35.83    MEAN ABS. ERROR:   33.45    MEAN ABS. ERROR:   93.59
                       PRIMARY     74.56           PRIMARY     33.19           PRIMARY     37.44           PRIMARY    103.56
                     SECONDARY     59.74         SECONDARY     38.48         SECONDARY     29.48         SECONDARY     83.63
                RMS ERROR:   217.09         RMS ERROR:   126.40         RMS ERROR:   104.31         RMS ERROR:   255.97
                   PRIMARY   228.94            PRIMARY   112.38            PRIMARY   136.84            PRIMARY   282.30
                 SECONDARY   204.55          SECONDARY   139.02          SECONDARY    55.09          SECONDARY   226.60
                P-SCORE:     .48            P-SCORE:     .58            P-SCORE:     .76            P-SCORE:     .88
                   PRIMARY   .49               PRIMARY   .65               PRIMARY   .72               PRIMARY   .79
                 SECONDARY   .46             SECONDARY   .51             SECONDARY   .81             SECONDARY   .97
                CUMULATIVE P-SCORE:  .05    CUMULATIVE P-SCORE:  .07    CUMULATIVE P-SCORE:  .10    CUMULATIVE P-SCORE:  .12
                          PRIMARY    .05              PRIMARY    .08              PRIMARY    .09              PRIMARY    .09
                        SECONDARY    .05            SECONDARY    .06            SECONDARY    .11            SECONDARY    .15
                HEIDKE SCORE:     .30       HEIDKE SCORE:     .41       HEIDKE SCORE:     .47       HEIDKE SCORE:     .52
                     PRIMARY      .31            PRIMARY      .43            PRIMARY      .57            PRIMARY      .66
                   SECONDARY      .29          SECONDARY      .40          SECONDARY      .37          SECONDARY      .38
```

Figure 2. Example of Verification Statistics Compiled for Each Forecaster After Each Episode

Each climatology is based on the 240 observations that comprised the conditions that existed at forecast (initial) times for the 20-episode MFE sample.

Although not used for direct comparisons in the experiment (that is, compared by means of skill score), the Generalized Exponential Markov (GEM) technique was adapted to McIDAS and evaluated on the 20-case sample. The GEM technique is a fundamental statistical weather forecasting procedure recently developed through the pioneering research of Miller.[2] Miller defines GEM as "a statistical technique for predicting the probability distribution of local surface weather elements hour by hour. It uses only the current local surface weather conditions as predictors. From these probability distributions, categorical predictions are made for each surface weather element." For its use in the MFE, the GEM technique was adapted to McIDAS to generate wind, cloud cover, and ceiling height forecasts for both forecast locations, which were verified at 1-, 2-, 4-, and 6-hr intervals coincident with MFE-forecaster verifications. We adapted the minicomputer version of GEM to McIDAS, which unfortunately could not be easily adapted to the variable nature of our n-hr forecast. For that reason, only the 1-, 2-, and 4-hr GEM results will be presented. Figure 3 is an example of a GEM forecast for BOS during one forecast episode. Three things must be recognized regarding the application of GEM in the MFE. First, GEM is founded on a Markov assumption (that is, the future state is completely determined by the present state and is independent of the way in which the present state has developed). Second, it uses multivariate linear regression equations that were developed from continuous observational samples that spanned a 10-yr period (1954-1965) at a number of locations and, as such, are climatologically and statistically sound. Third, it was applied to cases in the MFE that represented "heavy weather" and do not, therefore, reflect the characteristics of the full sample from which the GEM statistical operators were developed. It was felt, however, that GEM's universal and easy applicability made it proper and appropriate to include its performance in the qualitative assessment of the MFE.

Forecast guidance information derived from NMC's LFM (FOUS Bulletins) was available to the forecasters in teletype form during the 1982 forecast experiments and was available directly from McIDAS during the 1983 forecast experiments. It included the MOS forecasts (FOUS 12),[3] LFM Guidance forecasts (FOUS 60-78),[4] and 3-D trajectory forecasts (FOUS 50-57).[5] The NMC guidance information is ingested into McIDAS via the FAA WB-604 data link, then decoded and formatted for display and analysis. The guidance information is available to the forecasters in a listing-type form that can be viewed on the alphanumeric terminal or a hardcopy. Many of the guidance parameters can be analyzed and

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References 2 through 5 will not be listed here. See References, page 69.

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 GGG  EEEEE M   M
G     E     MM MM                 TOL AND NIEDZIELSKI
G GGG EEE   M M M                 FOR AFGL
G   G E     M   M                      FOR STATION BOS
 GGG  EEEEE M   M            VALID FOR 6 HOURS AFTER  MAR 26, 11 LOCAL

        FORECAST INTERVAL =  1 HOUR(S)
    CLOUD AMOUNT-    CLEAR    SCATTERED    BROKEN    OVERCAST
                      -1          0            6         95

    CEILING HEIGHT-    <2    2-4    5-9    10-29    30-75    >75
                        0     13     63      18        7       1


        FORECAST INTERVAL =  2 HOUR(S)
    CLOUD AMOUNT-    CLEAR    SCATTERED    BROKEN    OVERCAST
                      -2          1            9         93

    CEILING HEIGHT-    <2    2-4    5-9    10-29    30-75    >75
                        0     11     53      24       11       1


        FORECAST INTERVAL =  4 HOUR(S)
    CLOUD AMOUNT-    CLEAR    SCATTERED    BROKEN    OVERCAST
                      -4          4           12         89

    CEILING HEIGHT-    <2    2-4    5-9    10-29    30-75    >75
                        0     10     33      33       19       7


        FORECAST INTERVAL =  6 HOUR(S)
    CLOUD AMOUNT-    CLEAR    SCATTERED    BROKEN    OVERCAST
                      -3          5           13         85

    CEILING HEIGHT-    <2    2-4    5-9    10-29    30-75    >75
                        0      9     23      35       20      12

-----------------------------------------------------------------------------
! HOUR !  TT  DPD   VV   WEATHER       DDFF  PPP   C1    H1  C2   H2   TS   CIG !
!      !                                                                        !
!  11  !  52    3  1000                1715  9876  OVC    5  CLR  UNL  OVC    5 !
!      !                                                                        !
!  12  !  52    3  1000                1715  9876  OVC    5  CLR  UNL  OVC    5 !
!      !                                                                        !
!  13  !  52    3  1000                1715  9876  OVC    5  CLR  UNL  OVC    5 !
!      !                                                                        !
!  15  !  52    3  1000  RW-           1715  9876  OVC    7  CLR  UNL  OVC    7 !
!      !                                                                        !
!  17  !  52    3  1000  RW-           1715  9876  OVC    7  CLR  UNL  OVC    7 !
-----------------------------------------------------------------------------
```

Figure 3. Example of Probability and Numerical (Categorical) Forecasts Generated by Generalized Exponential Markov (GEM) Based on Surface Observation at BOS at 1100 LST, 26 March 1982

viewed on the color monitor. Examples of the analyzed guidance products are shown in Figures 4 through 6. The forecasters have the option of viewing one analysis on the entire screen (with the ability of overlaying another) or a four-panel analysis displaying one parameter over four forecast periods or four parameters, which is useful in determining guidance suggesting movement and intensity changes. The verification of MOS was limited to the forecasts which verified at 06, 12, 18, or 00 GMT.

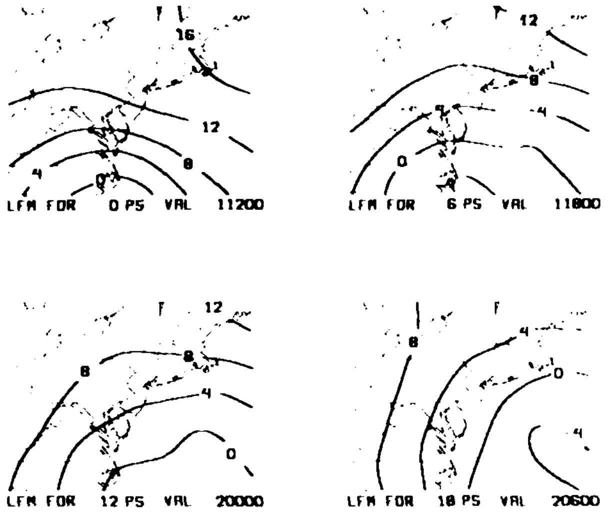


Figure 4. LFM Guidance (FOUS 60-78). Surface pressure analysis (0 PS) and 6-hourly forecasts (6 PS, 12 PS, and 18 PS) from 1 March 1983, 12 GMT; units in mb deviation from 1000 mb

2.2 Test Sample

The weather episodes selected for study in the MFE were 1981-1982 and 1982-1983 winter-early spring storm events occurring over the Northeast U.S. To be considered as a forecast experiment, a case must have met two basic requirements. First, a 12- to 24-hr period of significant weather in the form of changing cloud cover, ceiling height or winds, and or the occurrence of precipitation in southern New England was required to fully test the utility of an interactive graphics system and forecast aids in preparing short-range mesoscale forecasts. Second, a complete 24-hr data set, consisting of conventional hourly surface observations, upper-air data, satellite imagery, manually digitized radar (MDR), and operational computer guidance was required. This would provide 6 to 12 hr of data for pre-forecasting familiarization with the weather situation, 6 hr for forecasting and up to 12 hr for verification.

The 20 cases chosen for the MFE were selected from among 31 cases that had been archived. They comprised three general synoptic situations: midwest cyclones, New England cold fronts, and east coast cyclogenesis, each bringing significant weather changes to New England. Table 3 lists the date, forecast times, forecast stations, and a brief synoptic description for each forecast experiment. It should be noted that Boston was the primary forecast station for all 20 experiments. The secondary station (PVD, BDL, or JFK) was chosen according to the completeness of that station's data sets and the potential of the weather

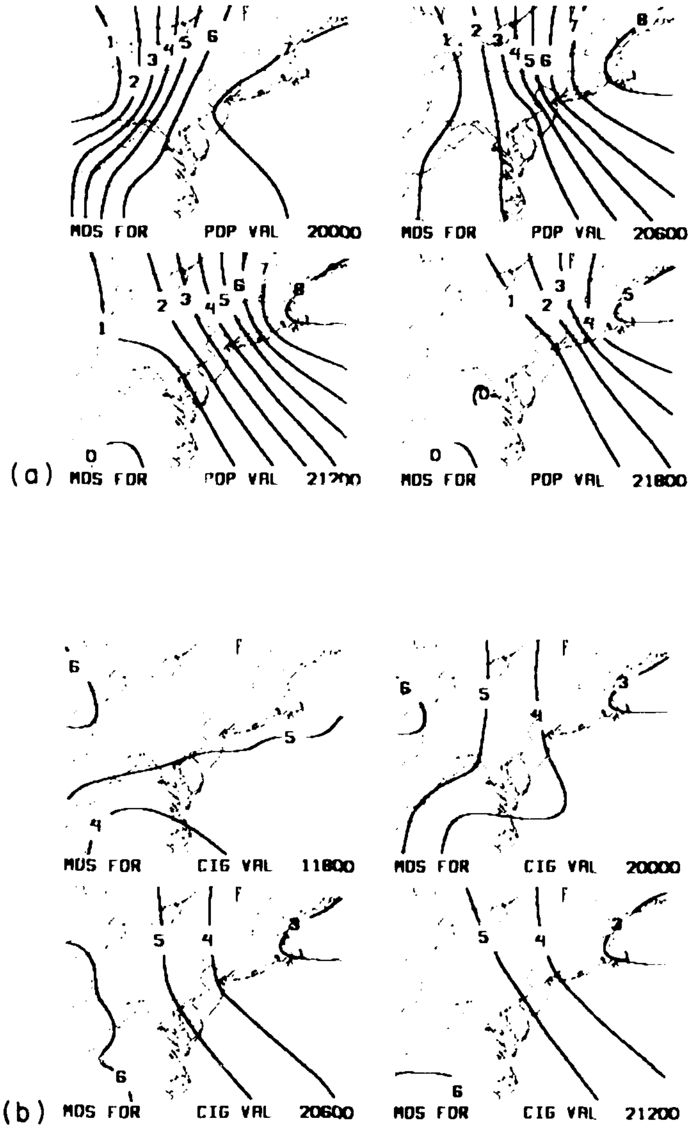
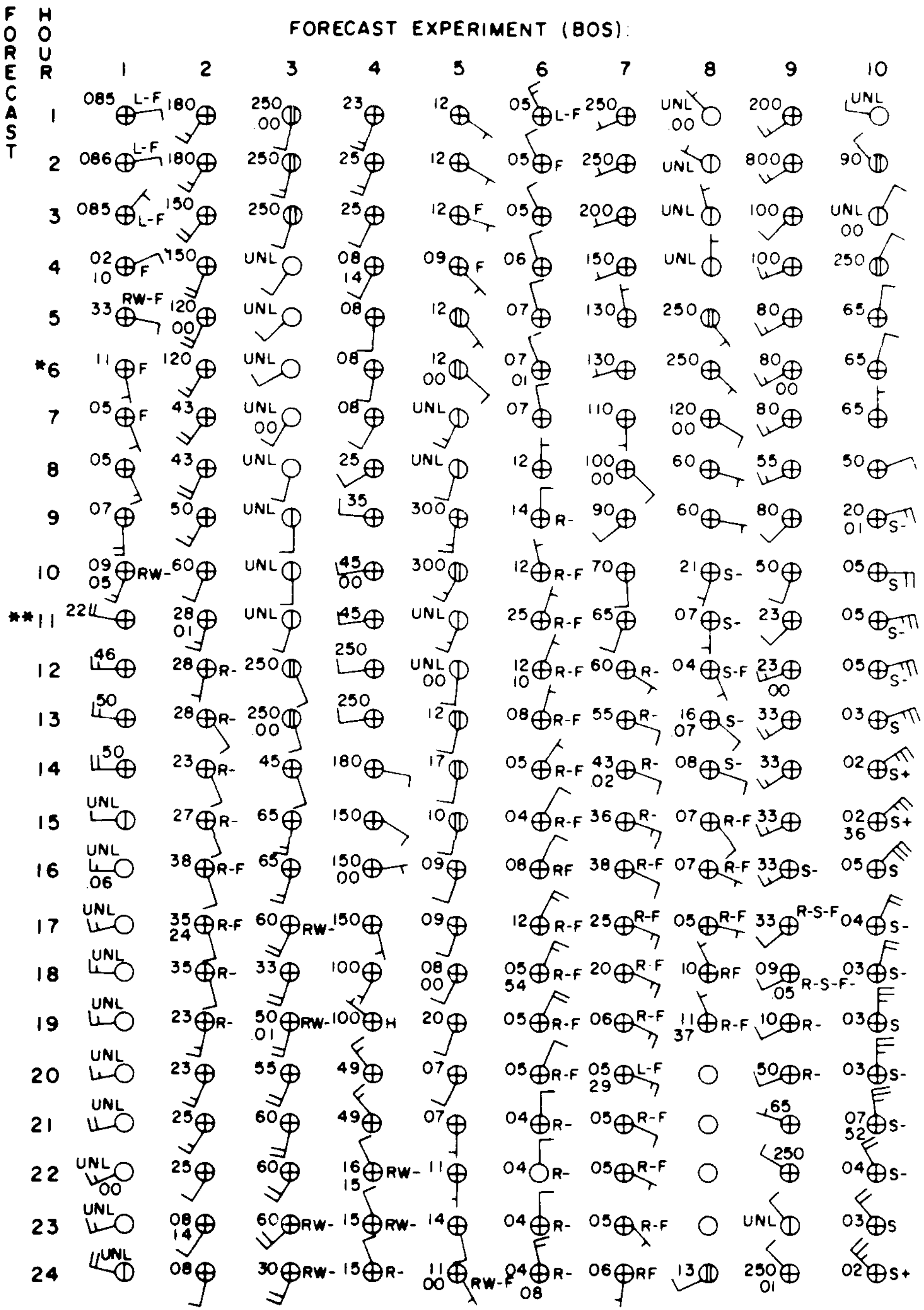


Figure 5. MOS Guidance (FOUS 12): (a) Probability of Precipitation (POP) Forecasts at 6-hourly Intervals (12, 18, 24, and 30 hr) From 1 March 1983, 12 GMT, Units in 10-percent Increments; (b) Ceiling Height (CIG) Forecasts at 6-hourly Intervals (6, 12, 18, and 24 hr) From 1 March 1983, 12 GMT, Units in 100-ft Increments

Table 3. MFE Test Cases (Brief Description)

Forecast Experiment No.	Forecast Date	Forecast Times	Forecast Stations	Forecast Situation
1	3/26/82	14-19Z	BOS/JFK	Cold front moving through New England
2	4/26/82	19-00Z	BOS/PVD	Weak frontal wave moving toward New England
3	3/31/82	05-10Z	BOS/PVD	Approaching pre-frontal cloud band
4	4/27/82	14-19Z	BOS/JFK	Cold front moving through New England
5	3/11/82	18-23Z	BOS/PVD	Approaching pre-frontal cloud band
6	12/15/81	18-23Z	BOS/JFK	Rapidly deepening cyclone approaching New England
7	12/1/81	17-22Z	BOS/JFK	Warm frontal wave approaching New England
8	3/4/82	17-22Z	BOS/PVD	Cold front approaching New England
9	12/22/81	06-11Z	BOS/BDL	Overrunning precipitation
10	4/6/82	04-09Z	BOS/BDL	Explosive coastal cyclogenesis
11	10/25/82	15-20Z	BOS/PVD	Occluded cyclone south of New England
12	11/5/82	15-20Z	BOS/PVD	Cold front moving through New England
13	11/13/82	06-11Z	BOS/JFK	Approaching cold front and frontal wave
14	1/15/83	12-17Z	BOS/JFK	Major coastal snowstorm
15	2/3/83	14-19Z	BOS/BDL	Midwest cyclone and approaching cold front
16	2/11/83	16-21Z	BOS/BDL	Coastal cyclogenesis
17	1/15/83	23-04Z	BOS/BDL	Midwest cyclone
18	2/23/83	16-21Z	BOS/PVD	Cold front approaching New England
19	3/2/83	13-19Z	BOS/PVD	Large ocean storm, significant rainfall
20	3/21/83	15-20Z	BOS/BDL	Weak frontal wave approaching New England



* 1st FORECAST MADE AT 6th HOUR ** LAST FORECAST MADE AT 11th HOUR

Figure 7. Twenty-four Hourly Observations for Logan International Airport (BOS) for the Ten 1982 Cases of the Mesoscale Forecast Experiment; Hours 6 to 11 Represent Forecast Times. ${}^{CCH}_{QPF}\oplus_{WX}$ CCH - ceiling height (hundreds of feet), UNL - unlimited, OBS - obscured), QPF - 6-hr precipitation amount in inches, and WX - Weather symbols (windflags in knots)

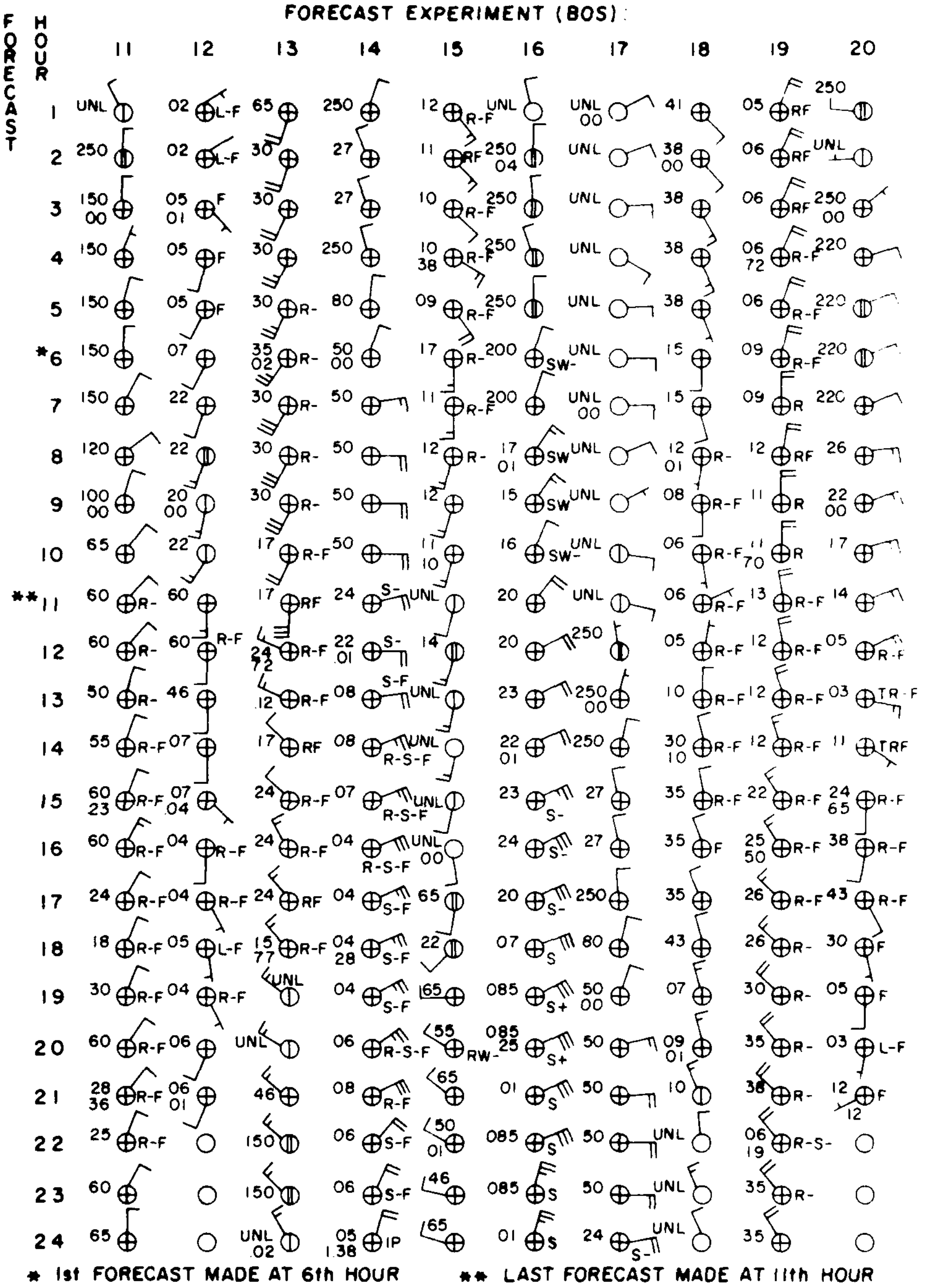
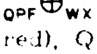


Figure 8. Twenty-four Hourly Observations for Logan International Airport (BOS) for the Ten 1983 Cases of the Mesoscale Forecast Experiment; Hours 6 to 11 Represent Forecast Times.  CCH = ceiling height (hundreds of feet, UNL = unlimited, OBS = obscured), QPF = 6-hr precipitation amount in inches, and WX = Weather symbols (windflags in knots)

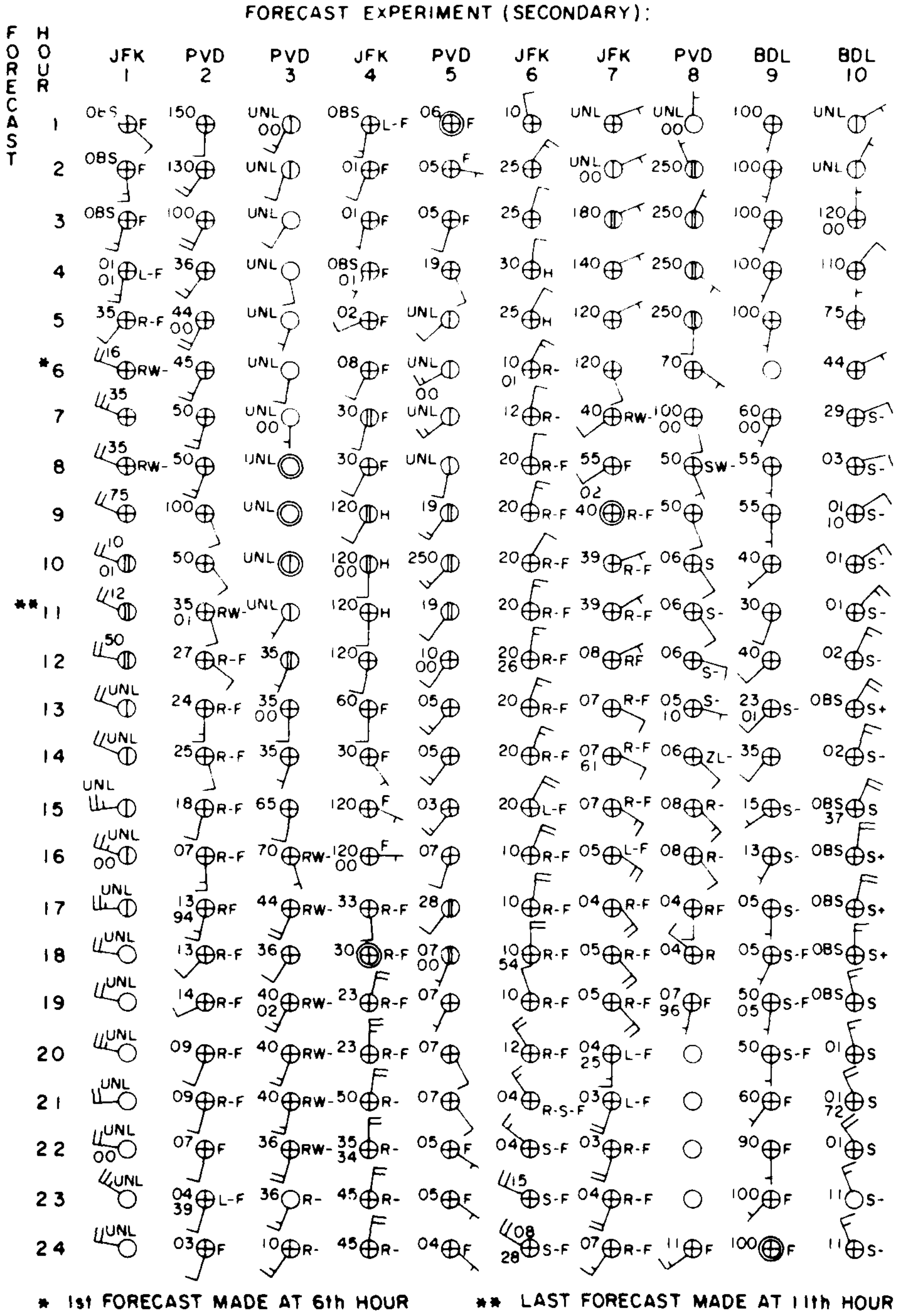
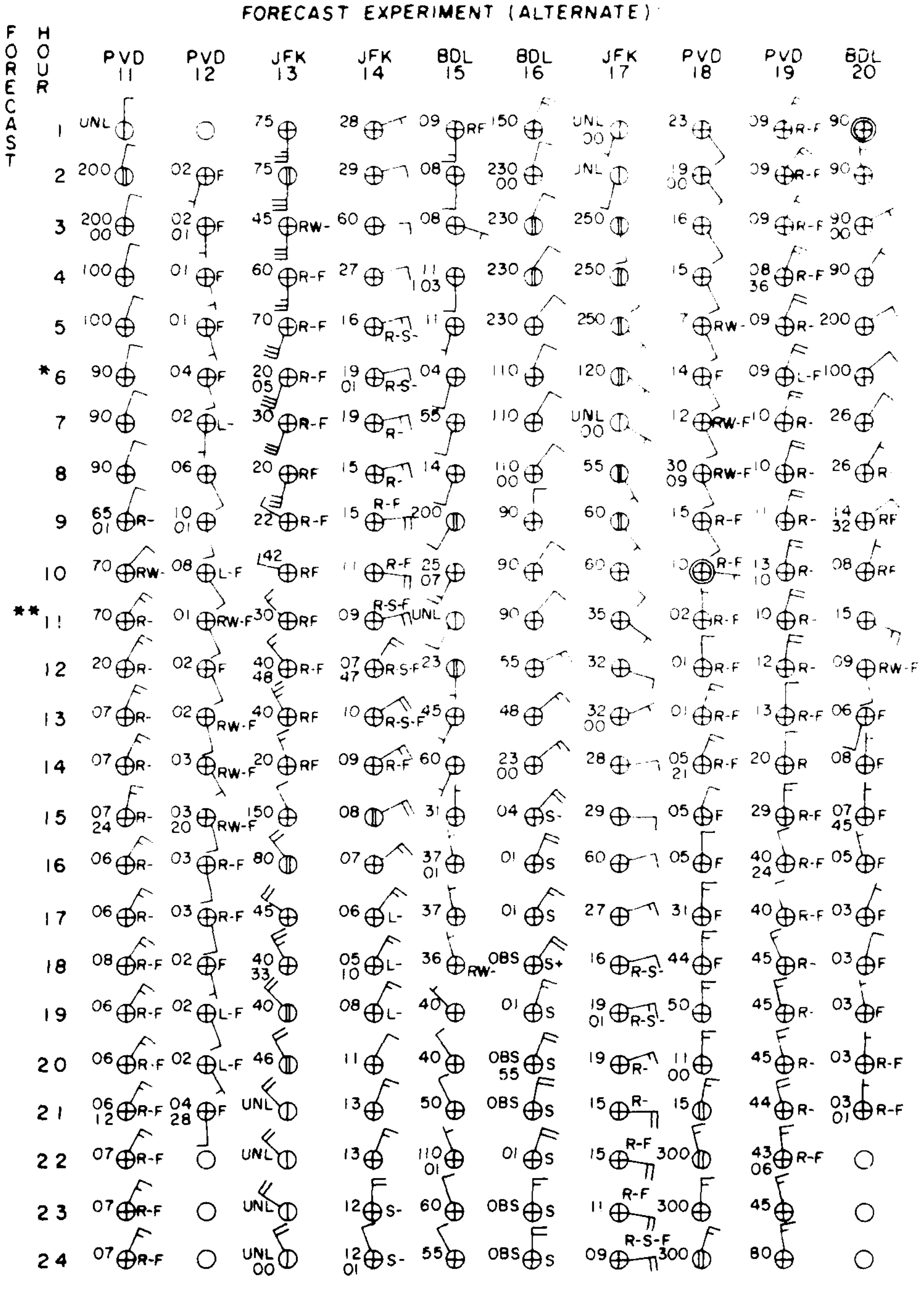


Figure 9. Twenty-four Hourly Observations for Secondary Station (BDL, JFK, or PVD) for the Ten 1982 Cases of the Mesoscale Forecast Experiment; Hours 6 to 11 Represent Forecast Times. CCH QPF ⊕ WX CCH = ceiling height (hundreds of feet, UNL = unlimited, OBS = obscured), QPF = 6-hr precipitation amount in inches, and WX = Weather symbols (windflags in knots)



* 1st FORECAST MADE AT 6th HOUR ** LAST FORECAST MADE AT 11th HOUR

Figure 10. Twenty-four Hourly Observations for Secondary Station (BDL, JFK, or PVD) for the Ten 1982 Cases of the Mesoscale Forecast Experiment; Hours 6 to 11 Represent Forecast Times. $^{CCH}_{QPF}\oplus_{WX}$ CCH = ceiling height (hundreds of feet, UNL unlimited, OBS = obscured), QPF = 6-hr precipitation amount in inches, and WX = Weather symbols (windflags in knots)

3. MFE 1982-83 TEST RESULTS

The major aspects of the MFE dealt with (1) an evaluation of the usefulness of certain display products, (2) an assessment of the relative difficulty in forecasting certain weather elements and the products and/or data sources that were found to be useful to those forecasts, and (3) a statistical evaluation of forecaster performance. The results of these aspects are presented in Sections 3.1, 3.2, and 3.3, respectively. There may appear to be a certain amount of overlap in the discussions presented in Sections 3.1 and 3.2. By necessity, however, the results of the forecast difficulty assessment are predicated on the availability and utility of particular products in regard to the problem of forecasting specific weather elements.

3.1 Product Assessment

In the course of the 1982-1983 MFE tests, the participating forecasters were encouraged to use, to their fullest advantage, any and all of the data sources, display products, and analysis/forecast techniques available within McIDAS in the preparation of their forecasts. In that regard they were specifically instructed to use each of the new techniques at least once during each test episode. In so doing, it was felt that a reasonable and fair assessment of these aspects of McIDAS would be accomplished.

Table 4 lists certain aspects of the assessment process for products that were used frequently. The "product key-in" refers to the keyboard instruction that activates the generation of a discrete product on McIDAS. Those products listed in Table 4 without an asterisk are part of the previously existing McIDAS suite of available routines. Their primary function is listed below:

IA - Geographic (map) plot of weather variable(s) on the color monitor; used with either surface or upper-air data; can include one to four panels per screen; can be plotted over satellite imagery

ZI - Decoded listing of surface observations on alphanumeric terminal (for example, by stations in a state for a specific time or a time series for a specific station)

ZK - Surface analysis using one-pass Cressman technique on color monitor; ideal for broad-view/quick-look assessment

MR - Contoured geographic analysis of manually-digitized radar (MDR) on color monitor; displayed independently or in conjunction with concurrent satellite imagery and/or surface observations

ZP - Map plot of one variable on the alphanumeric terminal

Table 4. McIDAS Product Assessment Summary

Product Key In	Generation Time on McIDAS (sec)	No. of Uses	Usefulness	
			Most	Least
IA	30	681	46	0
ZI	3	657	0	0
ZK	40	286	0	0
MR*	45	270	2	18
ZP	5	266	0	0
ENT/ET	8	260	5	0
KZ*	70	213	10	6
PF*	5	126	3	6
FI	3	117	4	0
BS**	5	109	0	19
MS*	35	85	23	1
CC	20/2	79	8	3
KY	25	53	0	0
FK GUI**	25	51	2	2
FK MOS**	25	9	0	0
FK TRA**	25	2	1	3
FA**	18	48	0	2
GT	20	43	4	8
ZC	65	14	0	0
TP*	60	11	2	17
TS	75	9	0	13
FCS*	0	--	0	4

*new products that were made available for 1982 experiments; see Section 3.1 for detailed discussion of product function.

**new products that were made available for 1983 experiments; see Section 3.1 for detailed discussion of product function.

ENT/ET - GOES IR imagery color enhancement based on defined temperature thresholds (in the case of ET, the user defines the threshold)

KZ - Surface analysis using five-pass Barnes technique on color monitor; retains more mesoscale detail

PF - 2-D trajectory forecast model based on analyzed rawinsonde observations

FI - Decoded display of FOUS bulletins (MOS, LFM Guidance, and 3-D trajectories) on alphanumeric terminal

BS - Listing of the GEM technique's forecast displayed on the alphanumeric terminal or the printer (hardcopy)

FK GUI - Analysis of several LFM guidance forecast (FOUS 60-78) parameters on color monitor (parameters: 700-mb vertical velocity, relative humidity, lifted index, 1000-500 mb thickness, boundary layer streamlines, boundary layer windspeed, boundary layer temperature, sea-level pressure, 6-hr precipitation amount)

FK MOS - Analysis of several MOS forecast (FOUS 12) parameters on color monitor (parameters: precipitation probability, thunderstorm probability, snow amount category, temperature, dewpoint temperature, surface streamlines, windspeed, cloud category, ceiling category, visibility category)

FK TRA - Analysis of several 3-D trajectory forecasts (FOUS 50-57) on color monitor (parameters: temperature and dewpoint temperature at 700 mb, 850 mb or surface; K-index)

FA - Plot of trajectory forecast on color monitor indicating origin, 6-hourly position and rising or sinking motion along the path for a parcel terminating at a station at the surface, 850 or 700 mb

MS - Station model time series display on color monitor; depicts surface observations for up to six stations for up to 6 hr

CC - Algorithms to estimate cloud cover and 1-hr precipitation amount from GOES visible and IR imagery displayed on alphanumeric terminal

KY - Upper-air analysis (constant pressure surface) using a two-pass Barnes technique on color monitor

GT - Individual variables line or bar graph time series display on color monitor

ZC - Contours a previously analyzed and stored grid array and displays it on the color monitor

TP - Log p-skew T display of rawinsonde observations on color monitor

TS - Surface analysis using five-pass Barnes technique on color monitor. Uses a time-space weight function in which 1- and 2-hr old observations are advected downstream and included in the analysis

FCS - Menu-driven forecast decision-assistance procedures using the alphanumeric terminal

The second column indicates the approximate "wall-clock" time (in seconds) it takes McIDAS to generate a product from the time the "key-in" action is requested to when the product is fully displayed. Since McIDAS' graphics device is considerably slower than state-of-the-art devices and its CPU is a 24-bit machine without hardware multiply-divide capability, one can presume substantially shorter generation time can be achieved. In each case these times reflect the creation of products on the local scale typically used in this experiment (that is, as generated by McIDAS state and city displays). The generation of national or regional (for example, eastern US) maps generally increases the times indicated by a factor of 3 or 4. Obviously, none of these routines are very time consuming in that most are executed in well under 60 sec.

The new routines, tailored to increase the depiction of mesoscale information, do not result in substantial increases in wall-clock time. The KZ analysis takes 30 sec longer than the ZK analysis. This increase results from going to a five-pass procedure that recovers a large portion of the mesoscale detail suppressed in the one-pass technique. Neither of the tailored plot routines (MS and GT) are time consuming (35 and 20 sec, respectively). Even the multi-step procedure of remapping, analyzing, and displaying MDR data (MR key-in) takes less than a minute while the application of the forecast guidance technique based on 2-D trajectories (PF) and satellite algorithms (FOR) has a combined wall-clock time of 25 sec. Note that key-ins that use the black and white alphanumeric terminal (ZI, PF, ZP, and FI) require 5 sec or less wall-clock time.

The "Number of Uses" column reveals the extent to which each key-in was invoked by the forecasters during the 20-episode test period. The overwhelming popularity of the key-in IA, indicates its all-around use both early in the forecast process when large amounts of data are digested to gain an overall understanding of the evolving synoptic situation, and later in the forecast process when the forecasters concentrated on the mesoscale aspects that would result in hour-to-hour weather changes. The IA key-in was used early in the forecast process in conjunction with the ZI and ZK key-ins (second and third most used, respectively). Two typical four-panel displays used by the forecasters during this mesosynoptic learning process are shown in Figures 11 and 12.

Figure 11 is a four-panel display of the weather situation that existed at 1200 GMT, 15 January 1983. It shows (a) surface pressure analysis with overlayed wind flags, (b) ceiling height plot, (c) cloud amount plot, and (d) an MDR analysis with overlayed weather symbols. Due to the poor resolution of the hard-copy capabilities, this figure is shown here as four separate figures although it

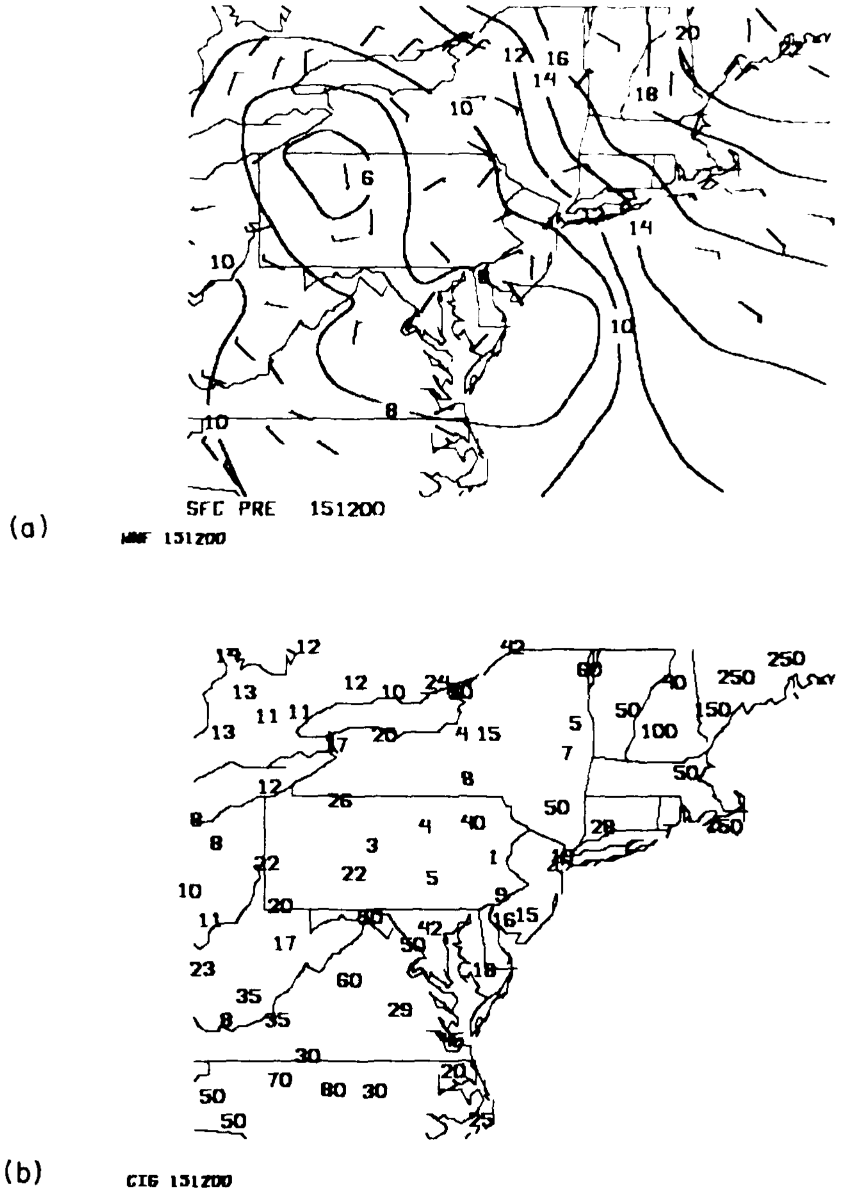
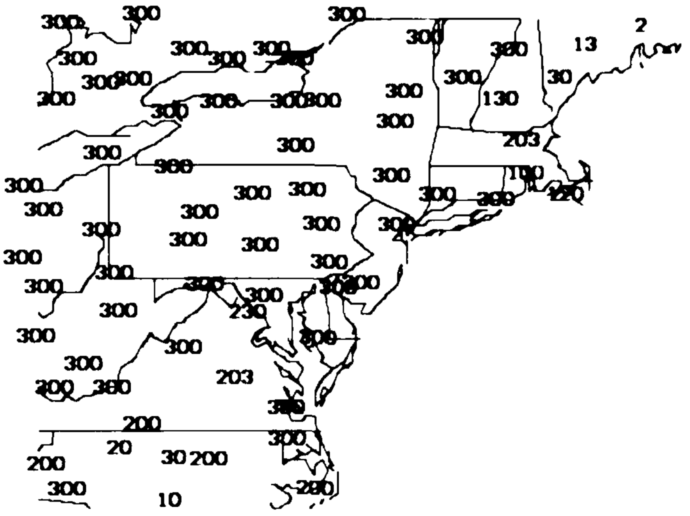
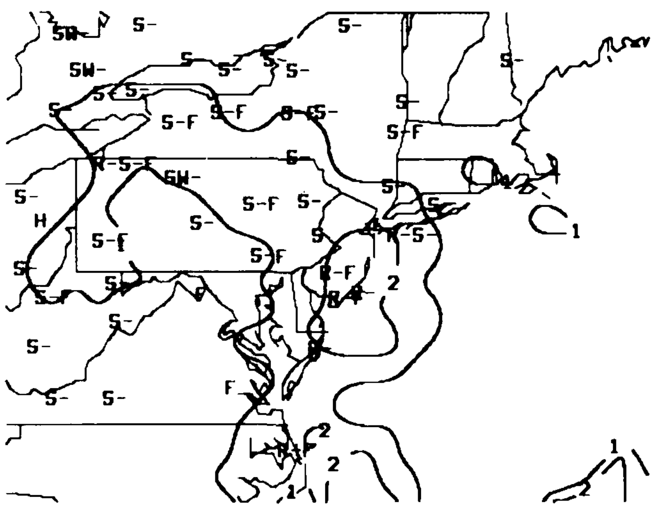


Figure 11. Four-panel Analysis of General Weather Situation (Regional): (a) Pressure (mb Deviation from 1000 mb) and Surface Windflags, (b) Ceiling Heights (Hundreds of Feet), (c) Layered Cloud Amount Categories (From the Left; Low, Middle, and High Cloud Amount; 0-Clear, 1-Scattered, 2-Broken, and 3-Overcast), and (d) MDR Analysis With Plotted Weather Symbols



(c) CLD 131200



(d) WX 131200 MDR SFC 151230

Figure 11. Four-panel Analysis of General Weather Situation (Regional): (a) Pressure (mb Deviation From 1000 mb) and Surface Windflags, (b) Ceiling Heights (Hundreds of Feet), (c) Layered Cloud Amount Categories (From the Left; Low, Middle, and High Cloud Amount; 0-Clear, 1-Scattered, 2-Broken, and 3-Overcast), and (d) MDR Analysis With Plotted Weather Symbols (Contd)

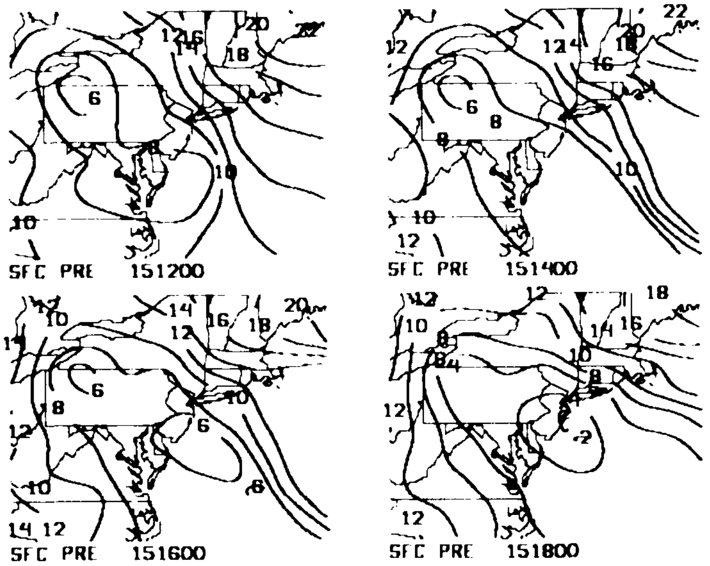


Figure 12. Four-panel Surface Pressure Analysis at 2-hr Intervals (mb Deviation From 1000 mb)

would be viewed by the forecasters as a four-panel display on one screen. Figure 12 is a four-panel display of the surface pressure analysis every 2 hr, beginning at 1200 GMT. These plots and analyses would be displayed on regional map backgrounds (state). The first four-panel display (Figure 11), accomplishes the task of familiarization with the current situation, and the second (Figure 12, which could just as well have been a display of MDR or ceiling height plots every 2 hr) informs the forecaster of the movement and intensity changes in the system over the past several hours. The ZI key-in was used to view several hours of observations at a particular station or to view data in a particular region at one observation time.

In the later stages of the forecast process, the forecasters tended to use the IA and KZ (seventh most-used) key-ins on a mesoscale map background (city) to zoom in on the mesoscale aspects of the forecast situation. Here again, four-panel displays of several forecast parameters (a combination of IA's and KZ's) or one parameter over the past 4 to 8 hr was used to view all forecast parameters at once or to follow the movement or intensity changes of a particular parameter over the past several hours.

ZP, the fifth most-used key-in, was called upon most often when a four-panel analysis was displayed on the color video monitor and a forecaster desired a "quick-look" (5-sec generation time on the alphanumeric video screen) at a very specific point of interest without having to clutter/erase the four-panel display. Typical ZP displays were 3-hr pressure changes, 6-hr precipitation amount, numerical plot of windspeed and direction, and ceiling and weather symbol plot.

In the middle and later stages of the forecast process, the forecasters used the tailored products (MR, KZ, MS, GT) and various guidance products (FI, FK GUI, PF, CC, etc.), to focus on specific aspects of the present forecast problem and to consult guidance for the longer range forecasts.

LFM products (FI, FK GUI, FK MOS, FK TRA, and FA) and GEM were made available as forecaster guidance on McIDAS for the 1983 experiments. Forecasters found the listings of the LFM guidance forecast (FOUS 60-78) and MOS (FOUS 12) output to be valuable guidance for the longer forecast intervals (4 and 6 hr). Analyses of LFM output were used minimally although the analysis of it was sometimes good as guidance for storm development, movement, and position for the later forecast periods. The relatively large number of uses for the GEM guidance (BS) must be tempered by the fact that the forecasters concluded that it gave little useful information in rapidly changing situations of the type used in these tests.

The limited use of other tailored products (TP, TS, FCS) was attributed to several different factors. The routine to display log p-skew T soundings of radiosondes (TP) was found to be of limited value in short-range mesoscale forecasting because of a lack of timeliness (soundings taken only every 12 hr) and poor horizontal representativeness. The time-space surface analysis technique (TS), which uses a forecaster-chosen motion vector to advect data from the previous 2 hr to be included in the analysis, was often found to produce inconsistent analyses. Forecasters used it mostly for ceiling analyses which, due to its discontinuous nature spatially, yielded analyses that the forecasters could have little confidence in. The cold front decision assistance procedure, FCS, was generally judged to be too time consuming for the forecasters who were all quite familiar with McIDAS's interactive capabilities. Recall, however, that the long-range intent of developing such procedures was for use in training forecasters new to a particular region or to using an interactive system.

The use of GOES imagery (visible and IR) was extensive throughout the forecast experiments, especially for storms developing and moving up the east coast where a large portion of the developing and advecting weather was out over the water, where conventional data coverage was sparse at best. The conventional GOES imagery display options, which include animation (time series looping), channel switching (alternating visible and IR images to evaluate cloud layering), color enhancement of brightness and IR gray scales and overlaying conventional analyses and data plots, were used extensively. This capability is judged to be central to effective short-range terminal forecasting. The only aspect of satellite imagery the forecasters were specifically asked to assess was a procedure for enhancing the IR images (ENT/ET) according to temperature. The ENT/ET key-ins (sixth most used) were found to be useful to study the movement and development of weather systems, particularly in tracking the evolution of substantial precipitation areas within the storm system as identified by cloud top temperatures below a specific value(s).

The information presented in Table 4 under the heading "Usefulness" summarized the concensus assessment of the forecasters on the relative usefulness in terminal forecasting of the products and data sources available to them. The numbers shown reflect the total number of times a participating forecaster judged a product most (or least) useful. (See first page of Product Usefulness Assessment in Appendix B for form completed.) There were up to six forecasters participating in each of the 20 test episodes, thus there was the potential of 120 responses in each category (most and least). In fact, a total of 110 assessments were completed because several episodes involved less than six forecasters.

The IA data plot was found to be the most useful product evaluated (Table 4). Most often used as a four-panel display, the IA key-in was used extensively in both the early learning stages of the forecast process and the later stages when the forecasters were most interested in timing and accuracy. Forecasters found the IA key-in so useful because a large amount of data could be presented quickly in a four-panel display showing four different variables at one observation time or one variable every 1 or 2 hr to track the movement or intensity changes of various fields. The IA key-in was also used regularly in overlaying surface observations upon satellite imagery.

The MS (station model time series plot, Figure 13) was found to be the second most useful product. The usefulness or value of the MS routine was arrived at despite the fact that many other products were used in the experiments to a much greater extent (Table 5). This illustrates the potential value of having routines available that allow the forecaster to tailor displays to the specifics of the weather situation he or she is dealing with. The display exhibited several qualities found useful by the forecasters. The first is the ability (and ease) to specify the stations to be included in the cross-section and to tailor it to the episode under consideration. The second is that it provides a wealth of basic information central to the terminal forecast problem in a format that permitted extensive subjective interpretation to track one or more elements and define its spatial extent. Forecasters found it most useful for the 1- to 4-hr forecast interval of the type required in base weather stations in support of aircraft arrivals and local area requirements, and in tracking wind shift lines (fronts) and the leading or trailing edge of

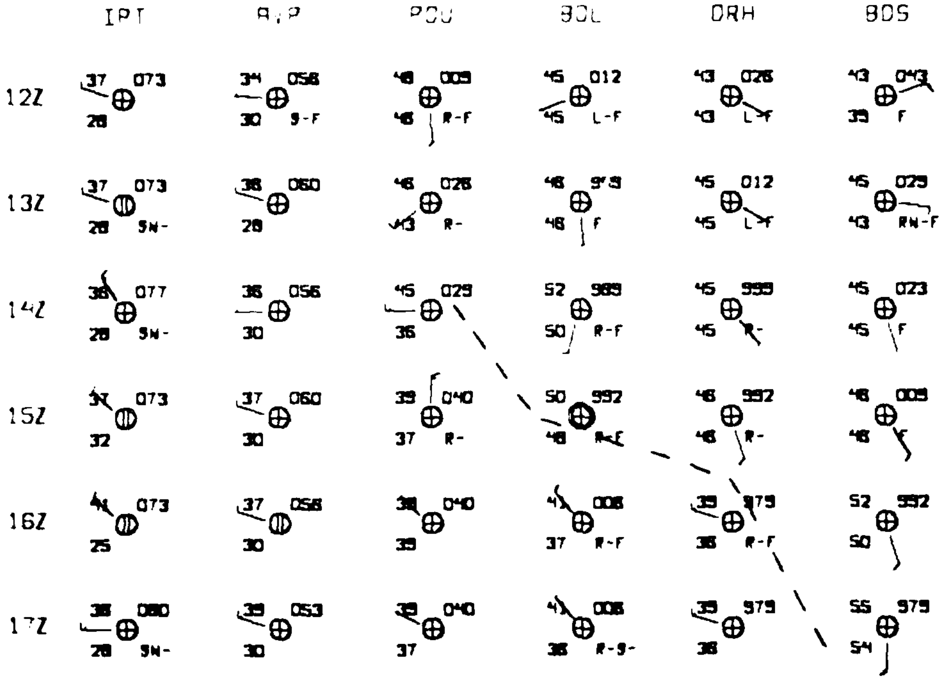


Figure 13. Station-Model Time-Series Display for 26 March 1982

Table 5. Assessment of Products and Data Sources as a Function of Forecast Parameter

	Was Satellite Imagery Useful?		Was MDR Useful?		Were McIDAS Plot and Analysis Routines Useful?		Was Guidance (LFM GUI, MOS, TRA, GEM) Useful?		Was The Wisconsin Trajectory Model Useful?	
Forecast Parameter	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Ceiling	67	45	24	74	92	19	53	45	22	71
QPF	104	7	69	30	56	52	75	26	28	59
Cloud Amount	109	0	22	79	77	31	56	47	24	64
Wind	10	99	0	98	107	4	67	30	1	87

```
RAINFALL =    [illegible]  CLOUD COVER =   [illegible]
RAINFALL =    [illegible]  CLOUD COVER =   [illegible]
RAINFALL =    [illegible]  CLOUD COVER =   [illegible]
RAINFALL =    [illegible]  CLOUD COVER =   [illegible]
RAINFALL =    [illegible]  CLOUD COVER =   [illegible]
RAINFALL =    [illegible]  CLOUD COVER =   [illegible]
```

Figure 15. Example of 2-D Trajectory Forecast Guidance Model; Hourly Rainfall and Cloud Cover Forecasts for BOS Based on 1200 GMT 700-mb Trajectory (Figure 14) and 1600 GMT GOES Visible and IR Imagery

The products found to be least useful are, beginning with the least useful, GEM (BS key-in), MDR (MR key-in), log p-skew T (TP), and the time-space analysis technique (TS). Forecasters found GEM did not depart sufficiently from persistence, even in active weather regimes. Not surprisingly, it is not adept at forecasting the onset or the end of precipitation. A typical example of GEM's inability to depart from persistence sufficiently to simulate the observed weather associated with an approaching or departing storm is shown in Figure 16. Figure 16(a) shows that as worsening weather approaches, GEM's ceiling forecast follows persistence in the 1 and 2 hr forecasts, then lowers the ceiling somewhat (to 3000 ft), not nearly enough to account for the very low ceilings (hazardous to aviation) that were observed in the 6-hr forecast period (400 ft). With improving conditions Figure 16(b) GEM forecast persistently low ceilings when the ceiling was observed to improve dramatically. GEM actually decreased the ceiling in the 4- and 6-hr forecast periods when no ceiling was observed. As can be seen from Figure 16, GEM forecasts were quite poor in predicting the onset and end of precipitation. In general, GEM did not forecast precipitation until it had begun. The value of its wind guidance is diminished by broadly defined wind direction and speed categories.

The negative assessment of MDR's usefulness (in the product assessment) is the result of its inconsistent availability. During several episodes, as precipitation approached the forecast stations, key MDR stations did not report until the precipitation began. This resulted in erratic and unrealistic analyses that seriously diminished the ability to forecast the movement and intensity of approaching precipitation areas. In the episodes with reliable and continuous MDR data, the MR key-in was used frequently and was found to provide good qualitative information for the QPF and ceiling height forecasts. On the other hand, the results shown in Table 5 (discussed in the next section) indicate that MDR data was useful in the QPF forecast 70 percent of the time. This suggests that although MDR data availability is often a problem, valuable information on precipitation coverage, movement, or intensity can be attained from MDR analyses during an episode.

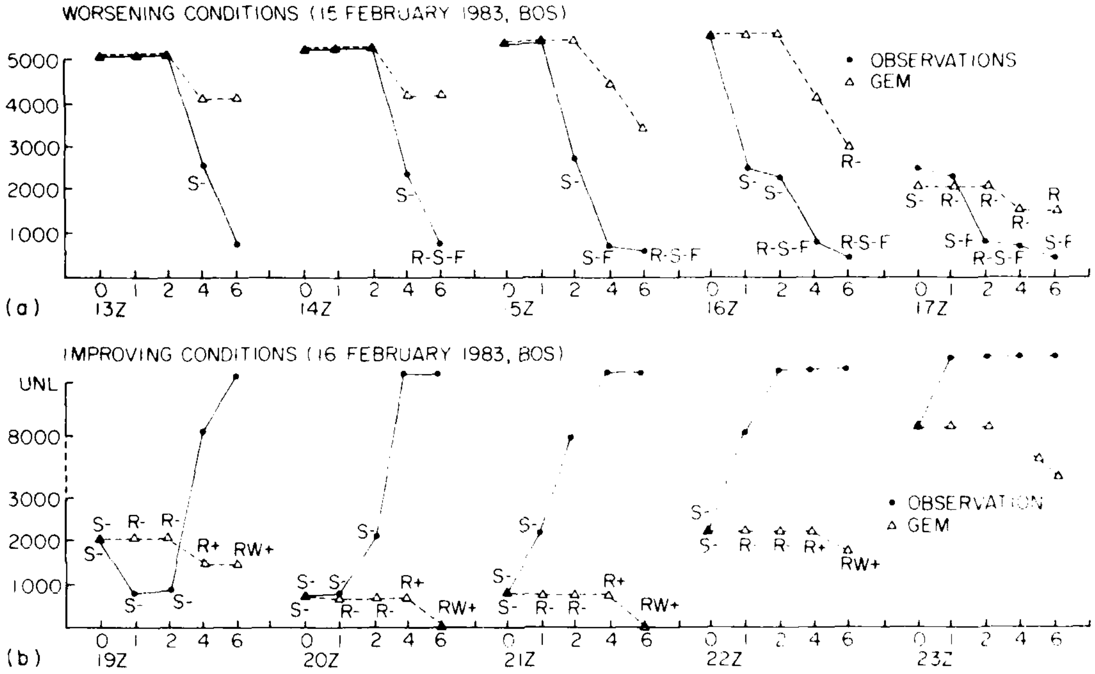


Figure 16. Example of GEM Ceiling Height and Weather Forecasts vs Observations for 15 February 1983 for BOS

3.2 Forecast Difficulty Assessment

The second aspect of the forecaster assessment of the MFE dealt with the terminal forecasts themselves. The forecasts that were prepared included windspeed and direction, total cloud cover, ceiling height, and 6-hr QPF for intervals of 1, 2, 4, and n hr (10 hr or less based on criteria cited in Section 2.1). These elements and intervals were selected to represent the primary forecast responsibility in base weather station support to aircraft takeoff/landings and local area missions. After each case, each forecaster completed a Mesoscale Forecast Variable Assessment form (shown in Appendix B), for each of the four variables.

Table 5 presents the data tabulated from the Forecast Variable Assessment forms suggesting qualitatively which products available to the forecasters on McIDAS were most (and least) useful. It shows some interesting results concerning the usefulness of various data sources for each forecast element considered. Details on their usefulness will be presented later in this section, but some of the generalities are:

(1) Satellite data is shown to be most useful for the QPF and cloud amount forecasts, while providing useful information more often than not for the ceiling height forecast. It was occasionally useful for wind forecasts through the timing of frontal windshifts and the location and movement of coastal developments and their associated windspeed and direction changes,

(2) Manually digitized radar is shown to be useful about 70 percent of the time for QPF forecasts and 25 percent of the time for ceiling height forecasts. McIDAS plot and analysis routines (IA, ZK, KZ) were found to be useful more often than not for all the forecast parameters while being useful nearly always for the wind and ceiling height forecasts,

(3) Guidance forecasts (LFM guidance, MOS, trajectory, and GEM forecasts) were useful for all forecast parameters more often than not while being most useful for the QPF and wind forecast, and

(4) The 2-D trajectory model (PF) showed limited use for all forecast parameters mainly because it depends on rawinsonde winds, which lose value as one departs from 00 12 GMT.

Table 6 presents statistics on the forecast difficulty assessment. Sixty-one of the 111 respondents judged ceiling height forecasting most difficult, 27 judged 6-hr QPF most difficult, 14 judged windspeed and direction most difficult while cloud amount was judged to be most difficult by nine respondents. Conversely, 64 of 111 respondents judged total cloud amount the easiest of the four parameters to forecast, 30 judged 6-hr QPF easiest, 17 judged windspeed and direction, and no one judged ceiling height easiest of the four variables to forecast. Thus, for this set of 20 winter-early spring weather episodes, the forecasters determined the ranking of the forecast parameters to be, from most difficult to easiest: (1) ceiling height, (2) 6-hr QPF, (3) windspeed and direction, and (4) total cloud amount (Table 7).

In each case the forecasters were also asked to indicate the forecast interval beyond which they had little confidence in their forecasts. For ceiling height that interval averaged 2.4 hr (for the 20 experiments) ranging from 0 to 6 hr. For 6-hr QPF it averaged 5.2 hr and ranged from 0 to 18 hr. For windspeed and direction it averaged 4.3 hr and ranged from 1 to 12 hr. For total cloud amount it averaged 6.4 hr and varied from 1 to 16 hr. These results confirm the ranking of ceiling height as the most difficult parameter to forecast and total cloud amount

Table 6. Forecast Parameter Difficulty Assessment

Forecast Parameter	Most Difficult ---------------- Easiest 1	2	3	4	Hours of Confidence
Ceiling	61	33	17	0	2.4
Winds	14	28	52	17	4.3
6-hr QPF	27	34	20	30	5.2
Cloud Amount	9	16	22	64	6.4

as the easiest. The somewhat contradictory confidence interval for 6-hr QPF (considering its ranking as second most difficult) is a result of the great variability in the episodes regarding the difficulty in preparing the precipitation forecast. This is also evident in the distribution shown in Table 6, where the forecaster-replies for the 6-hr QPF forecast are well distributed from most difficult to least difficult.

The difficulty in accurately forecasting cloud ceiling heights at airfields has been recognized for a number of years. The inherent variability of storm system low clouds (in space and time), their sensitivity to local factors (terrain, water bodies, etc.), the limits in our ability to observe and report on their characteristics, and the limits in our understanding of the complex physics by which they evolve, all serve to diminish the extent to which cloud ceiling can be forecast. Short-range terminal forecasting is especially dependent on the observational component and it was deficiencies in that component that created the most difficulty for the forecasters. While half-hourly GOES satellite imagery substantially increases observational data on storm system evolution, it provides only inferential data on ceiling conditions at best. Several of the episodes occurred at night when only IR imagery was available thereby limiting the extent to which forecasters could try to deduce lower cloud conditions through an integrated evaluation of visible and infrared imagery. On more than one occasion low stratus ceilings advected into the forecast locations from the ocean areas to the east and south under a middle and/or high cloud shield that precluded the detection of the stratus in the GOES imagery. Two other nighttime observation shortfalls complicated the already difficult forecast problem. First, certain surface observation locations operate on a limited daily schedule in which operations are curtailed at night (for example, midnight to 06 LST). Second, some observers fail to detect and/or report changes in cloud conditions in a timely manner (that is, the "sunrise special" observation was not uncommon) thereby adding more "noise" to the naturally variable time and space character of low clouds in these kinds of weather systems.

Table 5 indicates that McIDAS plot and analysis routines, especially the plot of ceiling height and weather through the IA key-in, and the bar graph display of cloud observations through the GT key-in, were most useful overall for ceiling forecasts. The four-panel time series display of ceiling height (IA four-panel plot) was relied on heavily in determining ceiling height trends and also in reinforcing the extent to which cloud fields were irregularly distributed, which resulted in flatter probability forecasts. Satellite imagery, useful about 60 percent of the time for ceiling height forecasts (Table 6), provided valuable information on the movement of cloud areas and the leading and trailing edges of cloud shields. Satellite imagery was particularly useful in predicting lowering ceilings caused by low stratus advecting inland from over the ocean. FOUS/MOS guidance provided useful information on the longer term ceiling conditions more often than not. The trajectory model (PF key-in) occasionally provided useful information on the trend of ceiling heights. Shortcomings in the trajectory model were attributed to evolving wind fields diminishing the representativeness of the trajectories and terrain-related cloud patterns that were not translated effectively. Information on the ceiling could sometimes be inferred from MDR data. In summary then, the forecasters used the IA mesoscale plot (city map background), GT bar graph, and satellite imagery for the 1- to 4-hr forecasts and the FOUS/MOS guidance, 2-D trajectory model, IA regional plot (state map background), and satellite imagery time loops for the longer range forecasts.

GOES satellite imagery, MDR analyses, and the satellite/trajectory-based forecast guidance (PF/CC), products not expected to be immediately available within the initial AWDS configuration, were found to be especially useful in 6-hr QPF forecasting (Table 5). The integrated displays of present weather and MDR analyses superimposed on the GOES imagery provided a visual confirmation of the portions of the cloud systems that are producing precipitation. Then satellite imagery, with or without MDR analyses, can be used effectively to track the progression of rain areas in order to time its arrival at forecast locations. When the storm system was out over the Atlantic, satellite imagery provided the only valuable source of current information. In the absence of hourly rainfall amounts, the intensity changes in the visible and IR imagery were used to approximate the 6-hr QPF totals. The color enhancement of IR imagery based on temperature thresholds (ENT/ET) aided in evaluating the growth or decay of rain-producing cloud masses. Sequencing (looping) of the color enhanced half-hourly imagery for a 2 to 3 hr period was a commonly used procedure for resolving the onset and duration estimates at the forecast locations. During daylight portions of cases, the forecasters were able to use both visible and IR loops. Nighttime periods were obviously limited to IR only but for precipitation forecasting purposes, it provides valuable guidance by itself.

The ability to remap the MDR analysis and geographically overlay it on concurrent GOES imagery and to then plot observations (for example, present weather symbols) on both, demonstrated some of the real potential inherent in computer-driven interactive color display systems. Figure 17 is an example of such an integrated display for 1 March 1983. In a forecast situation, these figures would be viewed in an animated time-series loop. This particular loop shows the steady northward movement of precipitation and its increasing intensity indicated by the expanding DVIP level 2 area. Figure 17 shows a four-panel MDR analysis with overlayed weather symbols (2-hr interval). The integrated real-time description (nowcast) these analyses present to an aviation or local area forecaster, especially when sequenced through several hours in an animated time-series loop, can provide the subjective basis for improved understanding of the evolving weather system and for improved short-range forecasts. The forecaster's ability to understand the complexity of the system (and to more properly forecast it) can be seriously limited by the lack of MDR and, in particular, GOES-type satellite imagery.

The satellite-trajectory precipitation guidance technique (CC) was the fourth most useful product to the forecasters (Table 4). It was useful as a first guess in both timing the arrival or departure of precipitation and determining precipitation amount. The trajectory-algorithm guidance is only applicable under daytime conditions (needs both visible and IR imagery) and must be constrained to the central 75 to 80 percent of the daytime regime due to the sensitivity of the algorithms to solar angle variations.

Without satellite and/or radar data, a forecaster must rely on hourly precipitation intensity observations (light, moderate, heavy, etc.) as the basis for departing from FOUS or other centrally-generated guidance. There are times, unfortunately, when the hourly intensity values can be quite inconsistent with 3- or 6-hourly amounts. The station model time-series display (MS) was found to be most useful in tracking the leading or back edge of the precipitation shield, particularly when used in conjunction with four-panel displays (IA) to define the geographic precipitation distribution. The LFM-based precipitation guidance (FOUS 60-LFM Guidance and FOUS 12-MOS) provided excellent guidance on the precipitation potential of the storm system; guidance which the forecasters could adjust to information on actual storm tracking and intensity. The 6-hr QPF FOUS guidance was found to be more useful than the guidance for the other forecast variables (Table 5).

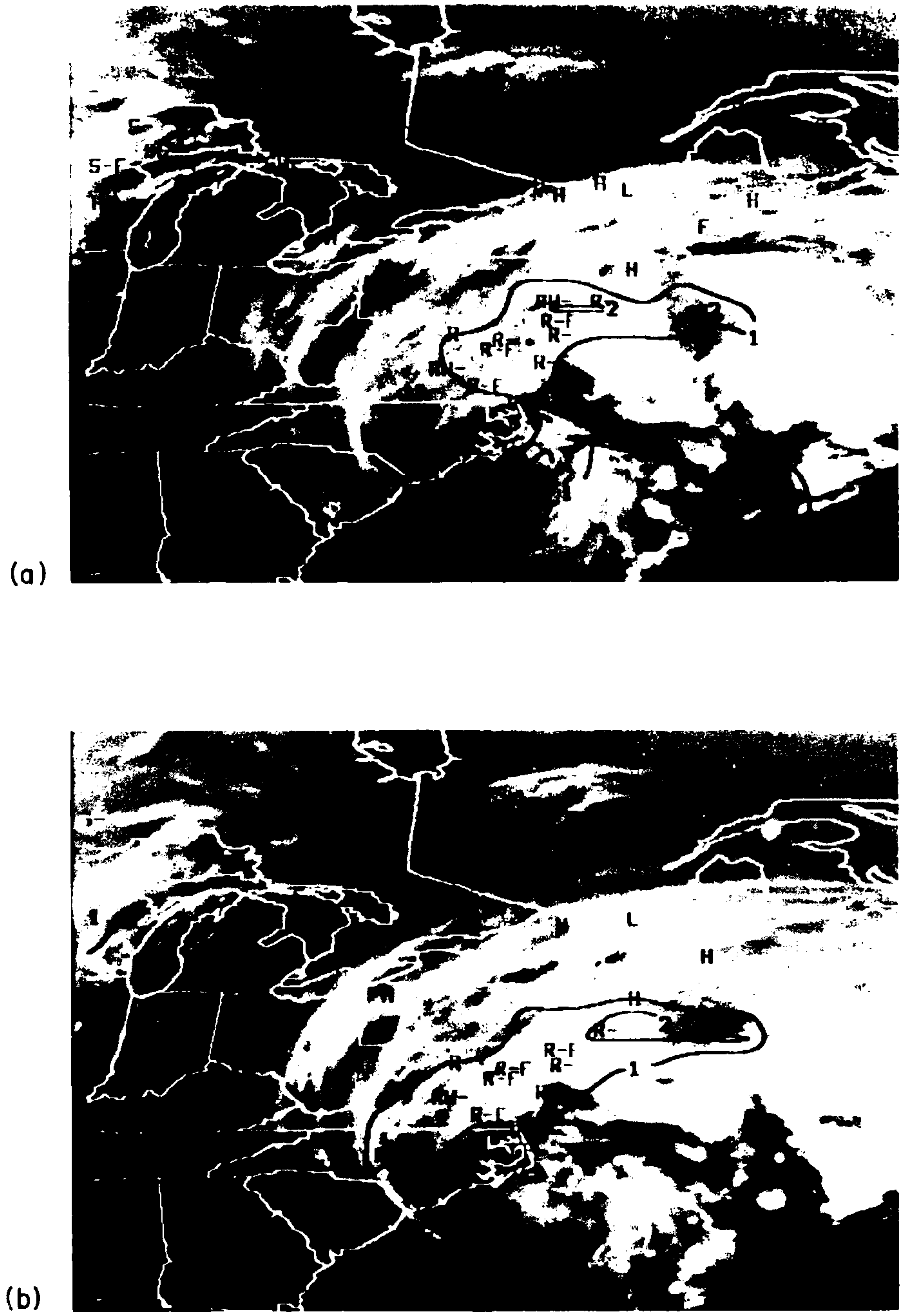


Figure 17. Example of Integrated Display of GOES Imagery, MDR Analysis, and Plotted Weather Symbols for 1 March 1983: (a) 1730, (b) 1930, (c) 2130, and (d) 2330 GMT. MDR and weather symbols remapped to satellite geography

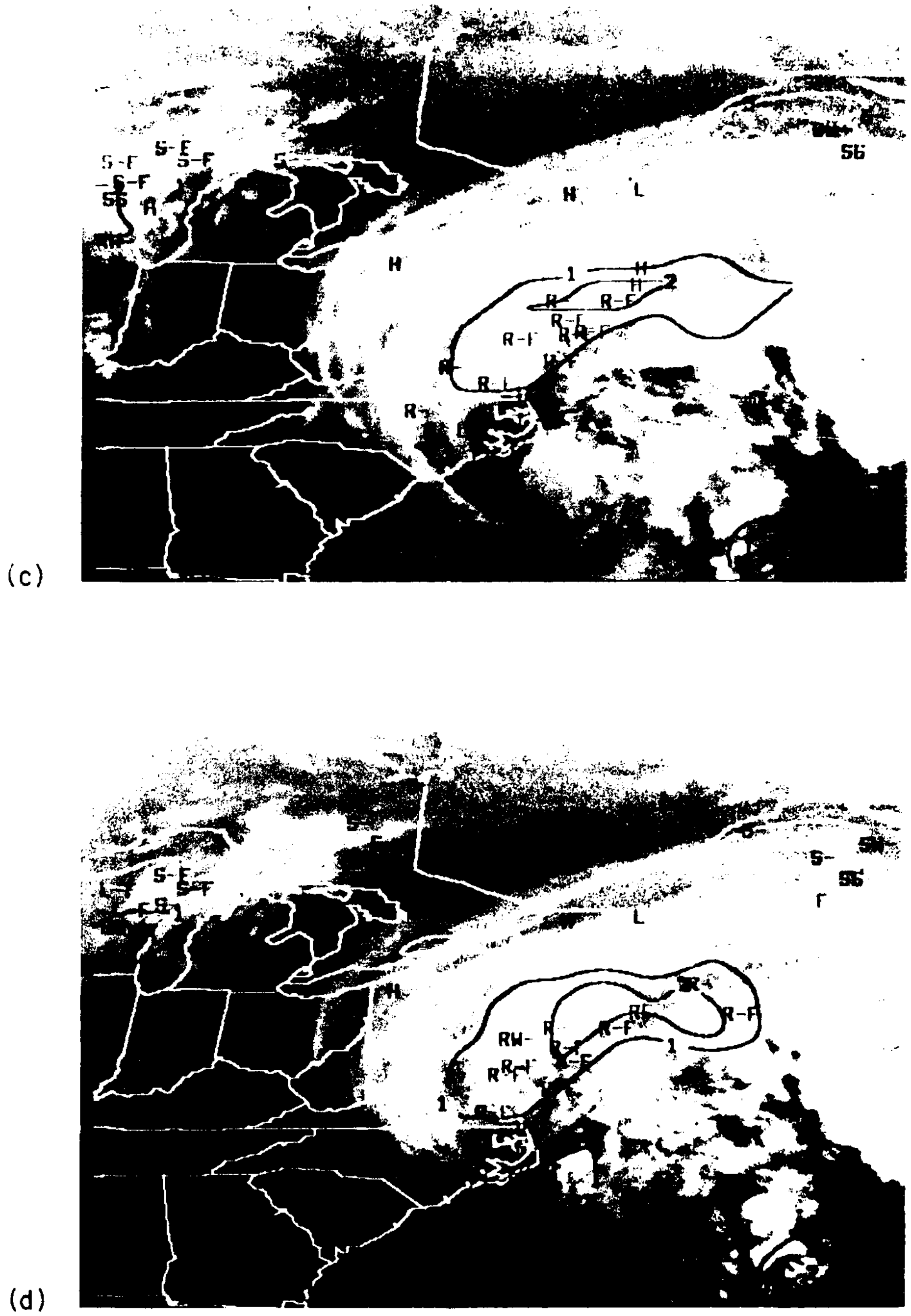


Figure 17. Example of Integrated Display of GOES Imagery, MDR Analysis, and Plotted Weather Symbols for 1 March 1983: (a) 1730, (b) 1930, (c) 2130, and (d) 2330 GMT. MDR and weather symbols remapped to satellite geography

Like ceiling height, terminal area winds can be variable, particularly during an evolving winter storm or cold front situation, and they can be especially sensitive to local factors (terrain, water bodies, etc.). While the 1-min mean wind observation, taken each hour for aviation purposes, better serves the needs of flying safety, it has been shown through an analysis of wind spectra[6] that a 30-60 min mean wind vector and some measure of variability would be more appropriate for short-range prediction purposes. Unfortunately, the hourly 1-min mean winds contain considerable high-frequency variance, which represents noise in the prediction process. While supplemental cloud and precipitation related observations can be obtained from satellite imagery and MDR analyses for data void regions (especially over water), remote sensing sources are not presently available for surface or near-surface winds.

The mesoscale plot and analysis routines (IA, MS, KZ, etc.) were found to be the most useful products in resolving the location and movement of mesoscale/synoptic scale wind perturbations such as inland convergence zones, sea breeze fronts, frontal boundaries, mesohighs and lows, isallobaric centers, etc., which aided in resolving the terminal wind forecasts (Table 5). Typically, forecasters would generate a detailed surface pressure and/or streamline analysis with overlayed wind flags (KZ and IA) to gain an initial understanding of the wind distribution and to locate mesoscale features such as mesohighs or surface troughs. They would then use a four-panel surface pressure or streamline analysis with overlayed wind flags (2-hr intervals, every 2 hr) to determine movement and intensity changes of the mesoscale and synoptic scale features. The station model time series (MS) was also used by constructing an alignment of stations from the forecast station through a particular feature depicted in the surface analysis to a station perhaps 50 to 100 km beyond. The combination of these products provided the necessary time-space representation of wind-related features that could be obtained given the limits of available observations. The surface and boundary layer windspeed and direction forecasts presented in the FOUS bulletins (FOUS 12-MOS and FOUS 60's) were found to provide useful guidance (Table 5), especially for the 4- and n-hr forecast intervals. GOES satellite imagery, MDR, and the 2-D trajectory forecast model were of little value to the wind forecasting aspects of this experiment (Table 5).

Clearly, total cloud amount (or cloud cover) was found to be the easiest variable to forecast during these winter-early spring east-coast storm situations. The relative ease herein was aided by the availability of half-hourly updates of visible and IR imagery. In most situations it provided all the information needed

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[6] Muench, H.S. (1982) An Appraisal of the Short-Range Forecast Problem Using Power Spectra, AFGL-TR-82-0353, AD A129315.

to prepare the cloud cover forecast. When the middle and high cloud leading edge of a storm system's cloud shield advanced into the forecast region during nighttime periods, inconsistencies between satellite IR depictions of cloud cover and concurrent surface observations of sky conditions would occasionally exist. Invariably this was attributable to untimely surface observations that nonetheless provided some uncertainty in the forecast process in which some forecasters tried to factor "observer-deficiencies" into their cloud category probability forecasts. Timing and duration of cloud cover characteristics were generally resolved through repeated time series looping of visible and/or IR digital imagery.

The most widely used non-satellite products for tracking total cloud amount conditions were a four-panel plot of total cloud amount (every 2-hr, IA), the station model time series (MS), and the bar graph display of cloud observations (GT), particularly for tracking the leading (trailing) edge of overcast and ceiling conditions. The forecasts for the 4 and n hr periods were often finalized after giving consideration to the FOUS (MOS) guidance.

3.3 Forecast Verification Statistics

Numerical and probability forecasts were generated for two locations for 20 east-coast storm episodes over two winter seasons (1981-1982 and 1982-1983). Each episode involved up to six forecasters, each preparing terminal forecasts each hour (for six hr) of cloud cover, ceiling height and surface wind vector for intervals ranging from 1 to 10 hr and 6-hr QPF. A computerized verification procedure was implemented to accumulate and update forecast verification statistics on each forecaster shortly after each case was completed. Updated statistics were provided to participating forecasters, in the form illustrated in Figure 2, prior to the next forecast experiment in order to provide timely feedback on individual and group performance. A total of 109 forecaster-days occurred during the two MFEs, which translates into a total of 1308 terminal forecasts being generated of each variable for each forecast interval (109 × 6 forecasts/case × 2 stations/case).

Objective terminal forecast guidance was available to the forecasters from three sources: MOS, LFM Guidance, and GEM. In the 1983 experiment they were accessible through McIDAS via simple keyboard entry procedures while in 1982 they were available only in hardcopy form. MOS and LFM Guidance forecasts could be displayed on the alphanumeric screen in teletype message form or could be displayed in analyzed map form on the color monitor in either single panel or four-panel format based on forecaster preference. The four-panel MOS format is illustrated in Figure 5.

It was noted earlier that the nature of MOS limits evaluation of it to the six-hourly intervals its forecasts are tailored to (00, 06, 12, and 18 GMT). As such, the verification statistics compiled in these tests for MOS were limited to its particular verification times and were stratified into 1-, 2-, 4-, and n-hr forecasts consistent with the structure of the MFE. For example, a MOS forecast valid at 1800 GMT (for example, a 6-hr forecast from the 1200 GMT model run) would be verified as a 4-hr forecast for the MFE forecasts generated from 1400 GMT observations, a 2-hr forecast for MFE forecasts generated from 1600 GMT observations, and an 1-hr forecast from 1700 GMT. In other words, we used it consistent with its operational availability in order to quantify its guidance value in evolving terminal forecasting applications.

3.3.1 NUMERICAL (DETERMINISTIC) FORECASTS

Figures 18 to 20 summarize the rmse statistics of the numerical or deterministic predictions of surface wind (Figure 18), cloud cover (Figure 19), and ceiling height (Figure 20), respectively. Part (a) shows results for each experiment (MFE 82 and MFE 83) and the combined set of forecaster consensus (MFE 82-83), where the numbers in parenthesis are the percent improvement relative to a persistence error for each sample. Part (b) compares overall forecaster performance, persistence, and GEM for the 20-episode data set (MFE 82-83). In the case of ceiling height (Figure 20), the MFE 82 results have not been included due to a change in the numerical forecast parameter from the specific height value (in 1982) to a categorical forecast in 1983. The evaluation of the 1982 version was rejected because the procedure formulated to treat "no ceiling" forecasts and observations introduced artificially-large height errors values. Therefore, Figure 20(a) has been excluded and it contains just the MFE 83 (not MFE 82-83) results.

In each figure the results are accumulated over all episodes for both forecast locations, for all forecasters as a group, for persistence and for GEM. In Figures 18(b), 19(b) and 20 the range in individual forecaster performance is indicated by the vertical bar through each group mean verification statistic. It represents the range from worst to best individual performance over the full extent of the experiment(s). Recall that the n-hr forecasts ranged in length from 5 to 10 hr; the length being determined by the interval from "forecast" time to the verification time of 00, 06, 12, or 18 GMT. No attempt has been made to further separate the n-hr forecasts.

Consistent with the MFE 82 results, the forecasters outperformed persistence by an impressive margin for each forecast variable, especially at the 4- and n-hr intervals. Although forecaster error increased with forecast length (as would be expected in rapidly changing winter storm situations), persistence error grew

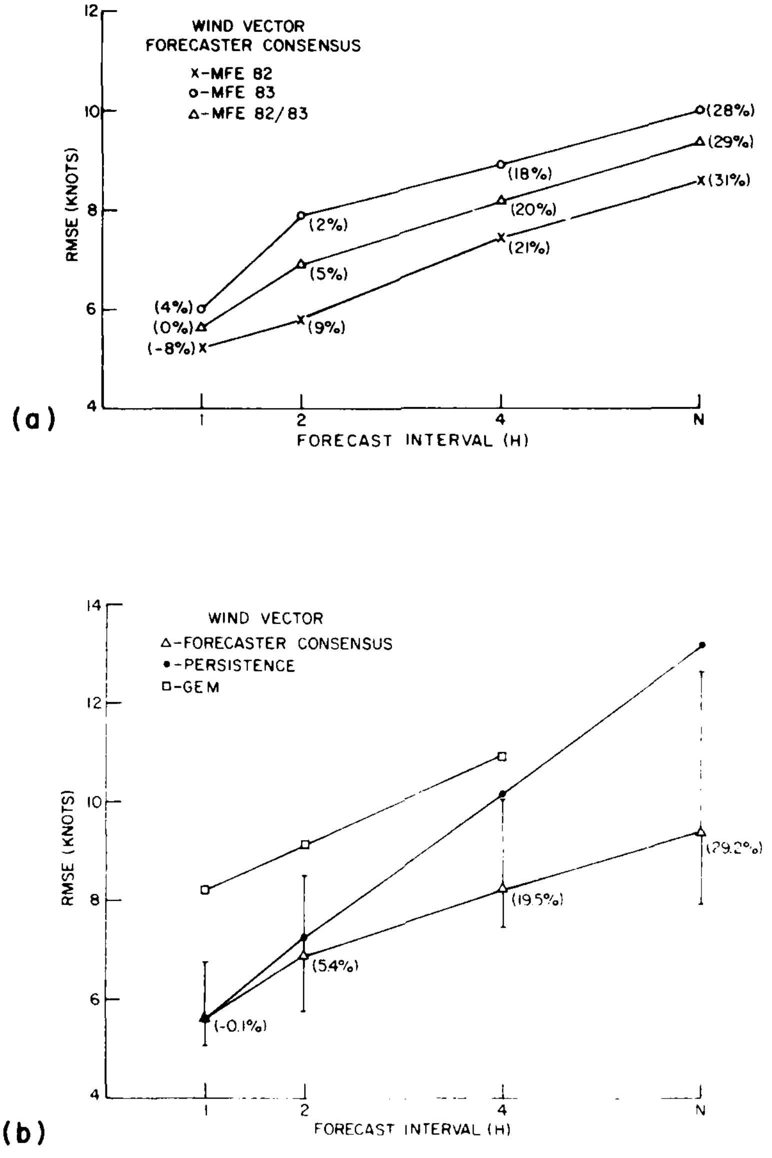

Figure 18. Root Mean Square Error (RMSE) Results for Mesoscale Forecast Experiment (MFE) Wind Forecasts: (a) All Forecasters (Consensus) and (b) Compared to Persistence and Generalized Exponential Markov (GEM) for MFE 1982-1983

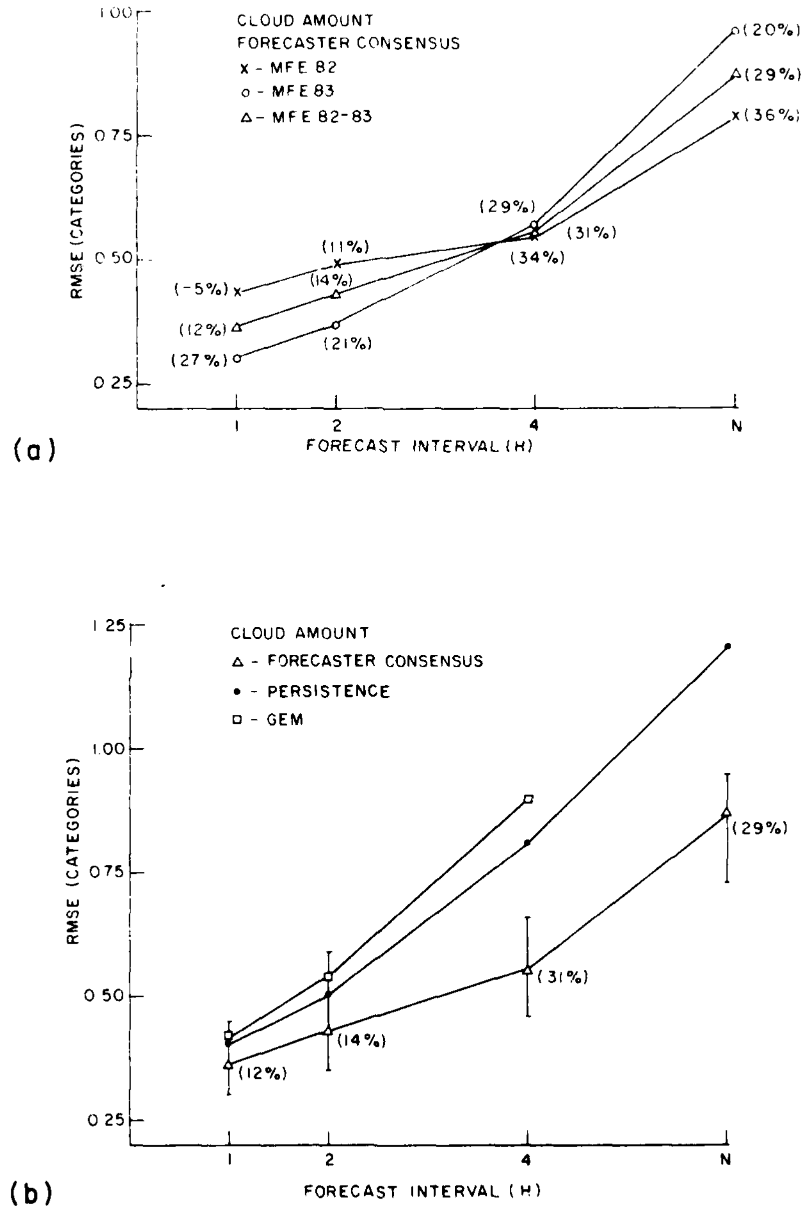

Figure 19. Root Mean Square Error (RMSE) Results for Mesoscale Forecast Experiment (MFE) Cloud Amount Forecasts: (a) All Forecasters (Consensus) and (b) Compared to Persistence and GEM

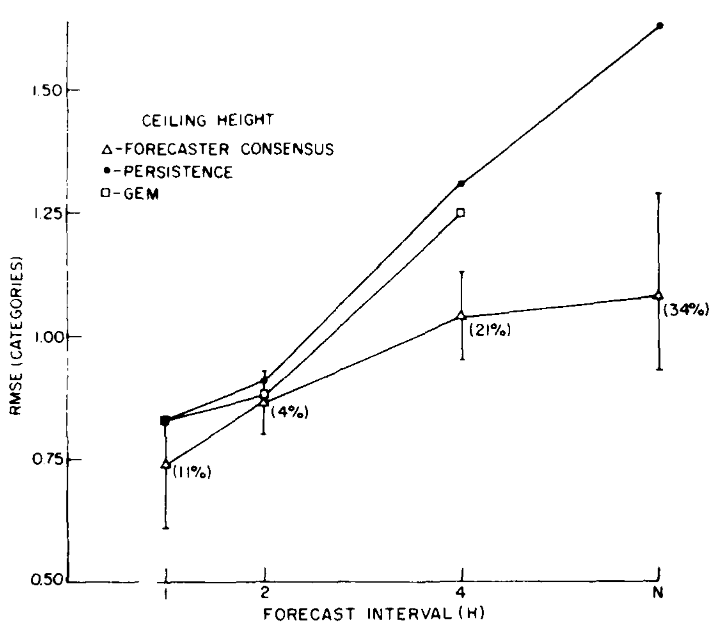

Figure 20. Root Mean Square Error (RMSE) Results for Mesoscale Forecast Experiment (MFE) Ceiling Height Forecasts: 1983 Results of All Forecasters (Consensus), Persistence, and GEM

even faster resulting in widening percent improvement statistics for the longer intervals. The comparison of 1982 results to 1983 for wind forecasts [Figure 18(a)] would suggest that the 1983 episodes selected for testing comprised windier conditions (higher rmse scores). Relative to persistence though, forecaster skill remained about the same. With cloud amount, however, persistence error from 1- to n-hr was nearly identical in 1983 as compared to 1982. The better percent improvement scores for the 1- and 2-hr forecasts [Figure 19(a)] can be attributed to the implementation of an improved cloud-cover tracking procedure that improved the short-range timing forecast on cloud category extrapolation. This procedure can be implemented with a light pen option on an interactive graphics system. In its absence (as was the case with McIDAS), a return to basics using hardcopy maps and the manual placement of successive (hourly) boundaries can be employed. The larger forecaster error at n hr in 1983 is attributed to cases in which clearing was forecast prematurely too often. There was a fairly substantial range in forecast skill among the participating forecasters, for each element and forecast length. This, despite the fact that all forecasters had access to the same resources. In this regard, consideration of the relationship between forecaster experience and skill is addressed in Section 3.3.4.

The GEM did not generate better forecasts than persistence for wind and cloud cover but did for ceiling height during these winter storm episodes. Except for the 1- and 2-hr wind forecasts, the difference between them is not significant. Bear in mind though that initial conditions at forecast time were typically much more degraded than the climatological norm on which GEM's statistical operators were developed. Further, the MFE cases generally involved prolonged periods of inclement weather. Due to its Markov basis, GEM would tend to forecast conditions back towards normal thereby tending to increase its error relative to persistence.

The 6-hr precipitation amount forecast error for the 20 MFE 82-83 episodes (for the forecasters as a group) was 0.21 in., ranging from 0.17 to 0.26 in. Given the weather situations chosen to test, the modest range in individual forecast skill among forecasters probably reflects the greater emphasis on the use of GOES imagery, MDR and FOUS guidance, each of which provided more quantitative information on precipitation amount than they did for the other forecast variables.

3.3.2 PROBABILITY FORECASTS

Probability forecasts were generated for total cloud amount categories (clear, scattered, broken, and overcast), for ceiling height categories (listed in Table 1) and for 6-hr QPF categories (Table 2). In each case, these categories correspond exactly to those used in MOS and related NWS probability guidance. The results are summarized in two forms: (1) against the probability of persistence being maintained and (2) against the MFE sample climatology (except 6-hr QPF). Persistence probability forecasts resulted in assigning a value of 1.0 (100 percent) to the category existing at initial (forecast) time and a value of 0.0 to the other categories.

Figures 21 and 22 summarize the percent improvement in cumulative p-score (cp) statistics of the forecasters vs persistence probability for cloud cover and ceiling height, respectively. The results for MFE 82 and MFE 83 are shown separately and as a combined outcome. The results of GEM applied to the twenty case sample is shown for comparison. Here again we find substantially better results vs persistence at all forecast intervals. While there was little difference in the ceiling height results in 1983 vs 1982, the cloud cover results were better in 1982, especially at the 6-hr interval. The recurring problem of forecasters moving cloud systems out of the forecast region too quickly is reflected in the uncharacteristic dip in skill (from 44 percent at 4-hr to 28 percent at 6 hr) in the 1983 exercise. In its probability form, GEM yielded 20-30 percent improvement vs persistence over the 2-yr experiment, for both cloud cover and ceiling height.

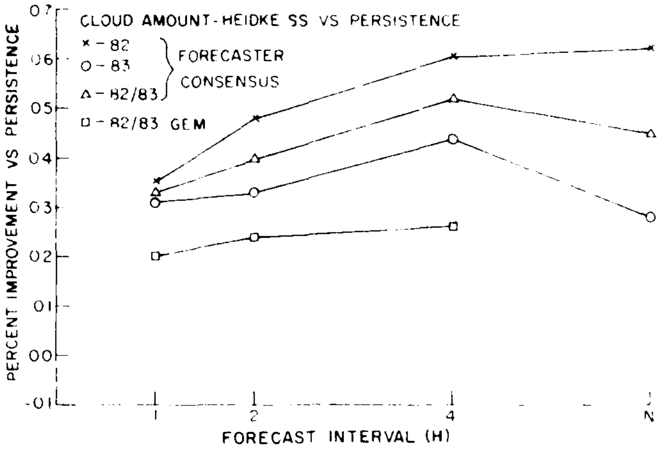

Figure 21. Percent Improvement in Cumulative p-score of Mesoscale Forecast Experiment (MFE) Cloud Amount Forecasts vs Persistence Forecasts for All Forecasters (Consensus) and for GEM

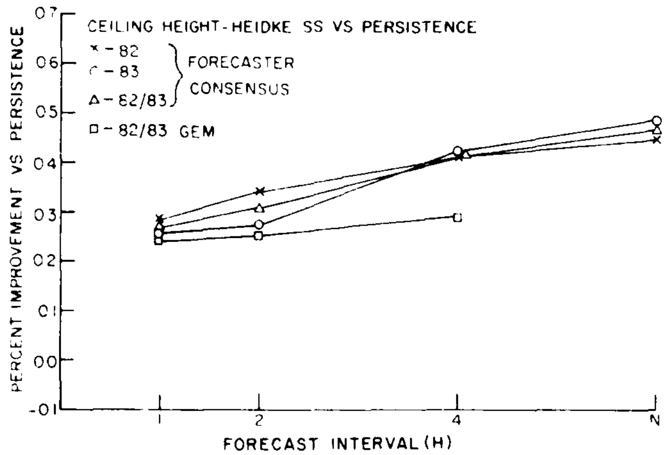

Figure 22. Percent Improvement in Cumulative p-score of Mesoscale Forecast Experiment (MFE) Ceiling Height Forecasts vs Persistence Forecasts for All Forecasters (Consensus) and for GEM

The results of the 6-hr QPF probability forecasts were 46 percent improvement in 1982, 58 percent in 1983, and 52 percent over MFE 82-83. Over two seasons, individual forecaster skill ranged from 36 to 61 percent based on cumulative p-score.

Figures 23 and 24 summarize forecaster consensus and GEM vs the two-season sample climatology. The cumulative p-score of the climatology model does not vary substantially as the forecast interval increases. Since forecaster and GEM p-scores do degrade with increasing forecast interval, the percent improvement of forecaster consensus and GEM generally decreases with time as seen in Figures 23 and 24. Here again the over-aggressive forecasts of clearing skies at n-hr, characteristic of some of the 1983 cases, is reflected in the "worse-than-climatology" results for n-hr cloud amount.

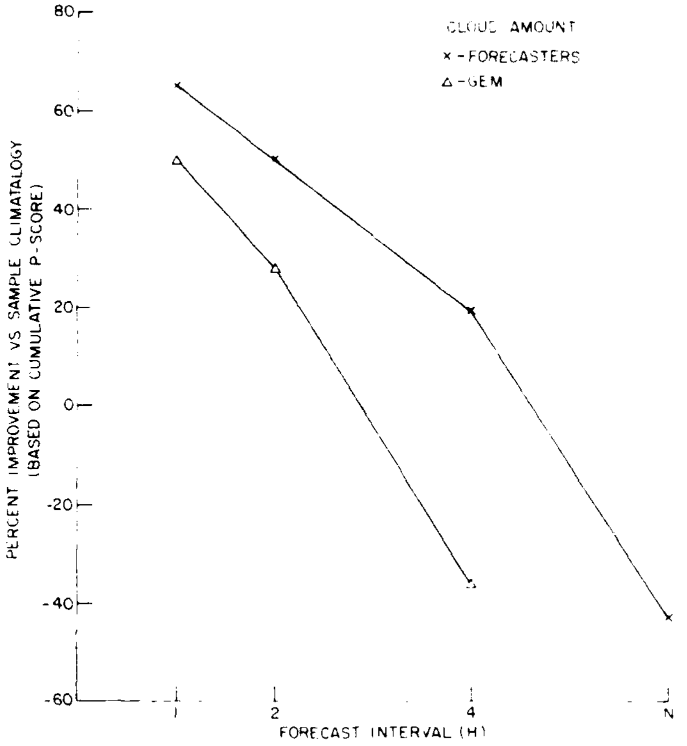

Figure 23. Percent Improvement in Cumulative p-score of Mesoscale Forecast Experiment (MFE) Cloud Amount Forecasts vs Sample Climatology Forecasts for All Forecasters (Consensus) and for GEM

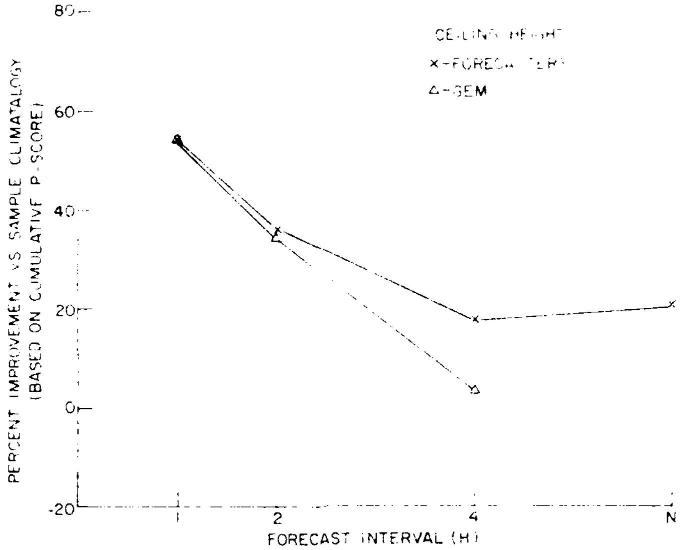

Figure 24. Percent improvement in Cumulative p-score of Mesoscale Forecast Experiment (MFE) Ceiling Height Forecasts vs Sample Climatology Forecasts for All Forecasters (Consensus) and for GEM

3.3.3 MOS RESULTS

A quantitative evaluation of the MOS forecasts for this experiment must be viewed with a good deal of caution because of the limited sample sizes available for analysis for reasons cited earlier. One can infer little more than an indication of comparative value. Figures 25 through 27 depict rmse statistics for MOS and persistence for wind, cloud cover, and ceiling height, respectively. The persistence errors are for the full 2-yr test sample while the MOS results are for those instances (the number of forecasts are shown in parentheses) when a MOS forecast could properly be made. It is only at n-hr that these numbers are coincident. Note that ceiling height results are for 1983 only. Not surprisingly MOS yields worse results than persistence at 1 and 2 hr. Bear in mind though that 1- and 2-hr MFE forecasts correspond to MOS forecasts based on initial conditions for MOS that existed 11 and 10 hr before verification time, respectively. MFE forecasts of 3-hr duration and longer are supported by MOS guidance forecasts (of wind, cloud cover, and ceiling height, at least) that improve upon persistence. The results for wind forecasts are particularly revealing in regards to the "stability" of the MOS rmse with increasing time, a characteristic of MOS noted by Muench.[7] In fact, if one compares the MOS wind results

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[7] Muench, H.S. (1983) Experiments in Objective Aviation Weather Forecasting Using Upper Level Steering. AFGL-TR-83-0328 (in press).

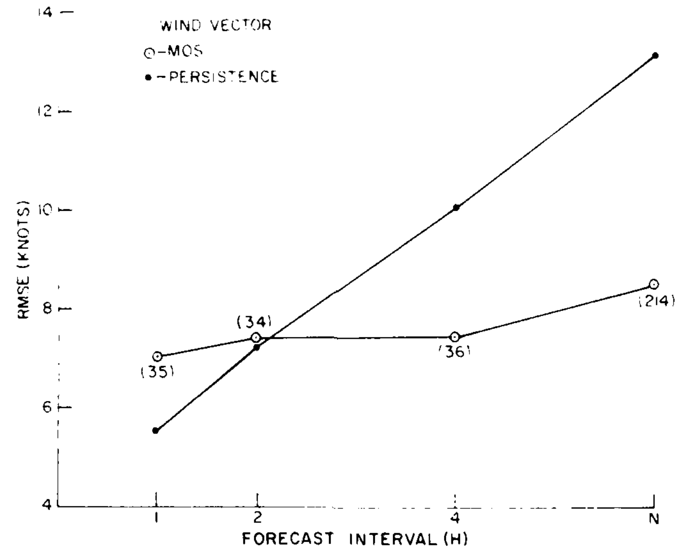

Figure 25. Root Mean Square Error (RMSE) for Model Output Statistics (MOS) and Persistence for Wind Forecasts

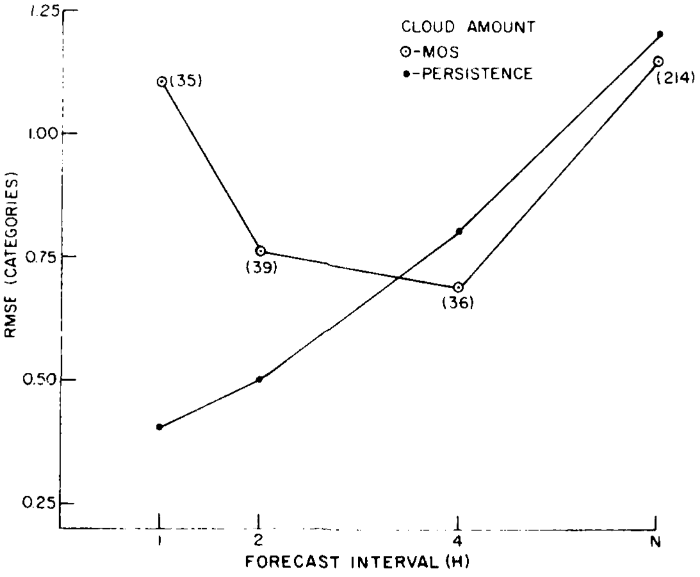

Figure 26. Root Mean Square Error (RMSE) for Model Output Statistics (MOS) and Persistence for Cloud Amount

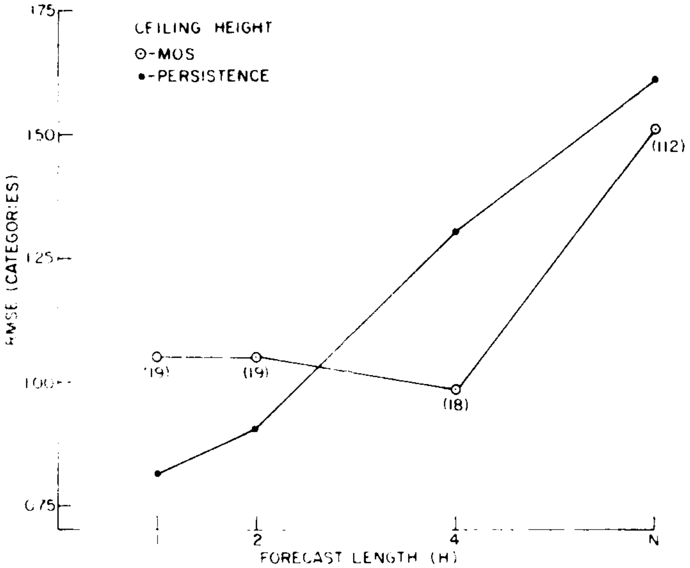

Figure 27. Root Mean Square Error (RMSE) for Model Output Statistics (MOS) and Persistence for Ceiling Height

here with the forecaster consensus results in Figure 18, MOS yielded slightly lower rmse results over the 2-yr test sample.

MOS probability forecasts of cloud cover and ceiling height compared to forecaster consensus and GEM are shown in Figures 28 and 29. These results are comparable to the rmse results that suggest that 1- and 2-hr usage of MOS is of questionable value. While at 4-hr and beyond it will generally yield better guidance than GEM and persistence during winter storm conditions. In fact, MOS was slightly better than forecaster consensus for both variables at n-hr. The percent improvement of MOS 6-hr QPF probability forecasts over persistence was 42 percent compared to 52 percent for the forecasters with an associated rmse of 0.27 in. which compares to 0.21 in. for the forecasters.

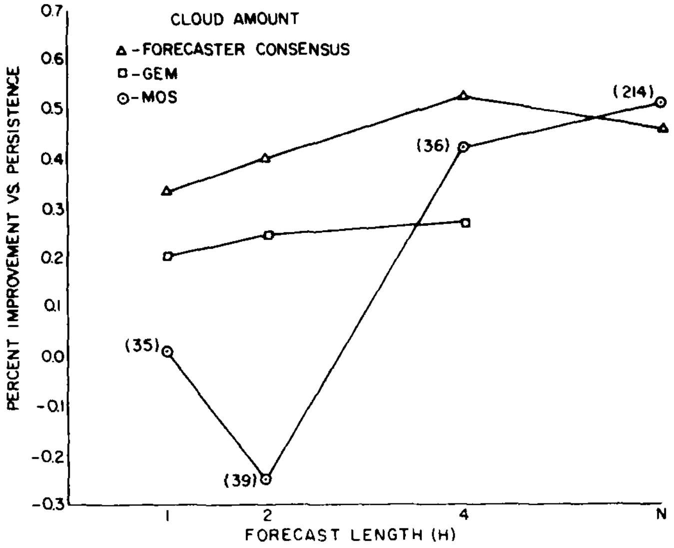

Figure 28. Percent Improvement in Cumulative p-score of Model Output Statistics (MOS) Cloud Amount Forecasts vs Persistence, for All Forecasters and for GEM

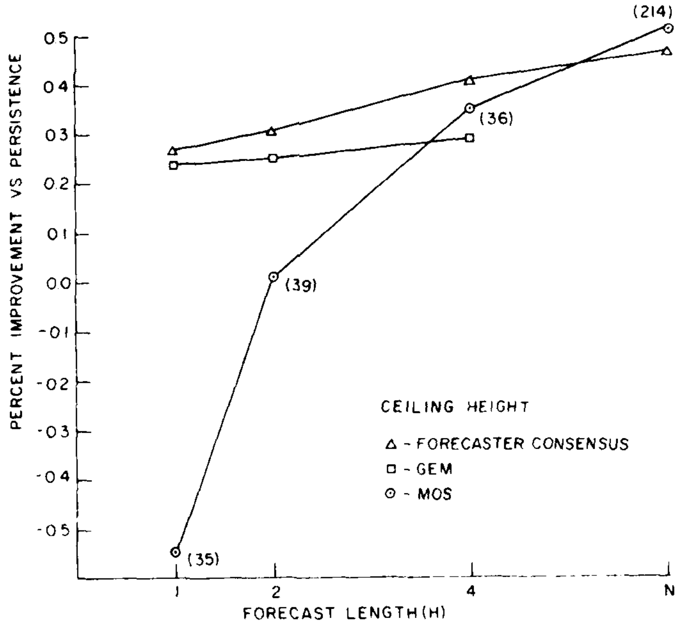

Figure 29. Percent Improvement in Cumulative p-score of Model Output Statistics (MOS) Ceiling Height Forecasts vs Persistence, for All Forecasters and for GEM

3.3.4 IMPLICATION OF FORECASTER EXPERIENCE

One outcome of these tests was the fairly wide range in individual forecaster skill that resulted in all aspects of the experiment. In view of the varying levels of forecasting experience among the participating forecasters, particularly with regard to probability forecasting, an index of forecasting experience was established in order to evaluate the relationship between experience and skill. The experience index (EI) was defined as follows for the numerical forecasts:

$$EI = 0.6(OF) + 0.2(CFE) + 0.6(MFE) + 0.4(MN) + 0.3(IF)$$

and for probability forecasts:

$$EI = 0.4(OF) + 0.2(CFE) + 0.8(MFE) + 0.6(MN) + 0.4(IF) \quad ,$$

where

OF - operational forecasting experience

CFE - semester/year-long college forecast exercises

MFE - prior Mesoscale Forecast Experiments

MN - AFGL Mesonetwork Experiment in 1970s

IF - intangible factor based on perceived day-to-day interest in forecasting.

Each factor was quantified in terms of years (or equivalent years) of experience. The weights were assigned to reflect relative value (as judged by the senior author) of the experience(s) for the purposes of the MFEs. For that reason the weights assigned to prior probability forecast experiments (for example, MFE and MN) were increased and OF decreased for the evaluation of probability forecasts.

Figures 30 through 32 depict the simple regression lines of best fit between forecaster error (rmse) and the EI for the numerical forecasts of wind, cloud amount, and ceiling height for the 1-, 2-, 4-, and n-hr forecasts. A "goodness-of-fit" measure (correlation coefficient) for each regression line is also shown. The ceiling height results are for the 1983 MFE only. With the exception of the 1- and 2-hr wind forecasts, the anticipated relationship between skill and experience was realized; that is, decreasing error with increasing experience. There is also reasonable consistency among the regression lines for each forecast variable in that the slopes closely approximate each other (again with the exception of the short-term wind forecasts) and the y-intercepts increase with increasing forecast interval.

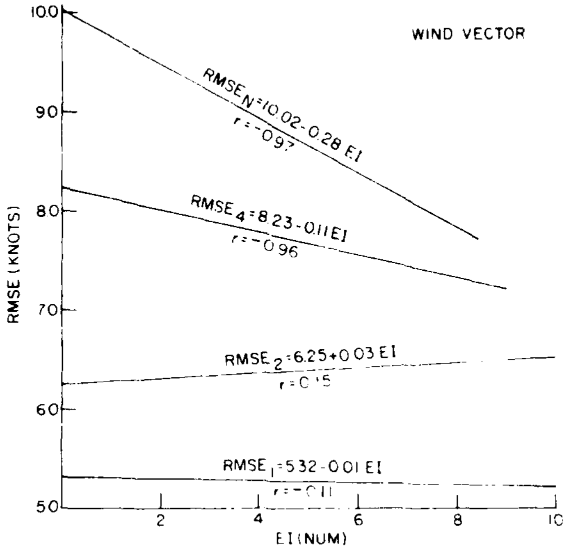

Figure 30. Root Mean Square Error (RMSE) for Mesoscale Forecast Experiment (MFE) of Forecasters vs Experience Index (EI) for Wind Forecasts

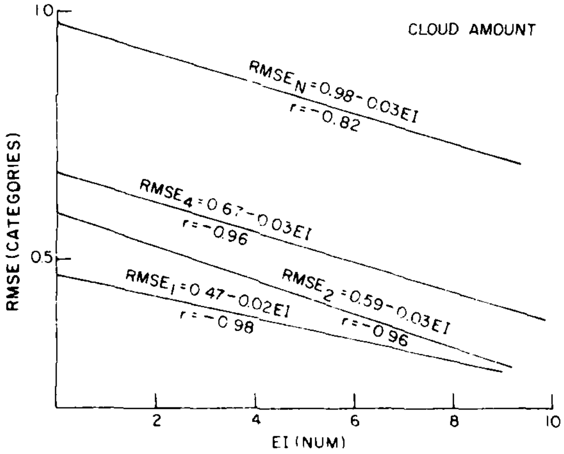

Figure 31. Root Mean Square Error (RMSE) for Mesoscale Forecast Experiment of Forecasters vs Experience Index for Cloud Amount Forecasts

Figures 33 and 34 show the regression fit of the skill scores vs persistence and EI for cloud amount and ceiling height probability forecasts for the full MFE 82-83 period. Here again, the strong hint of experience contributing positively to skill is evident, in this case increasing skill score with increasing

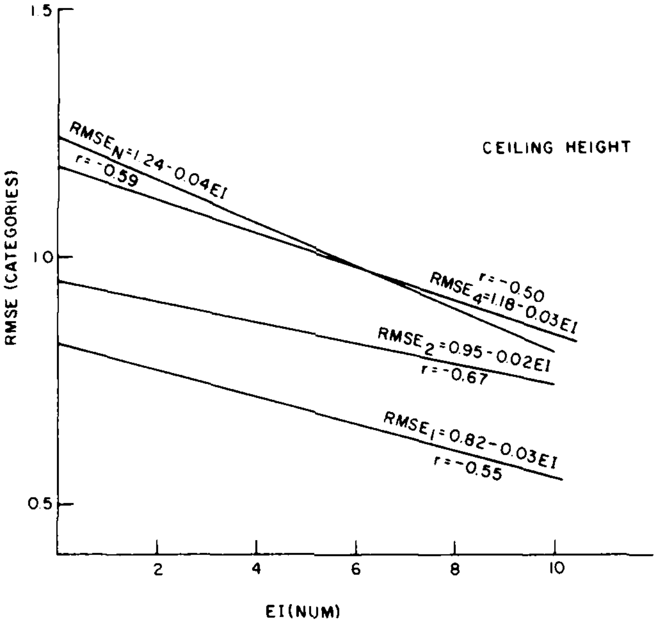

Figure 32. Root Mean Square Error (RMSE) for Mesoscale Forecast Experiment (MFE) of Forecasters vs Experience Index (EI) for Ceiling Height Forecasts

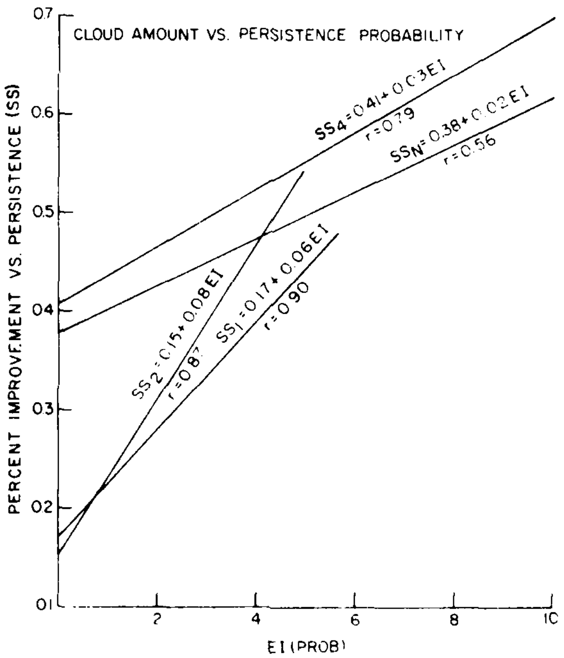

Figure 33. Percent Improvement in Cumulative p-score of Mesoscale Forecast Experiment (MFE) of Forecasters vs Experience Index (EI) for Cloud Amount Probability Forecasts

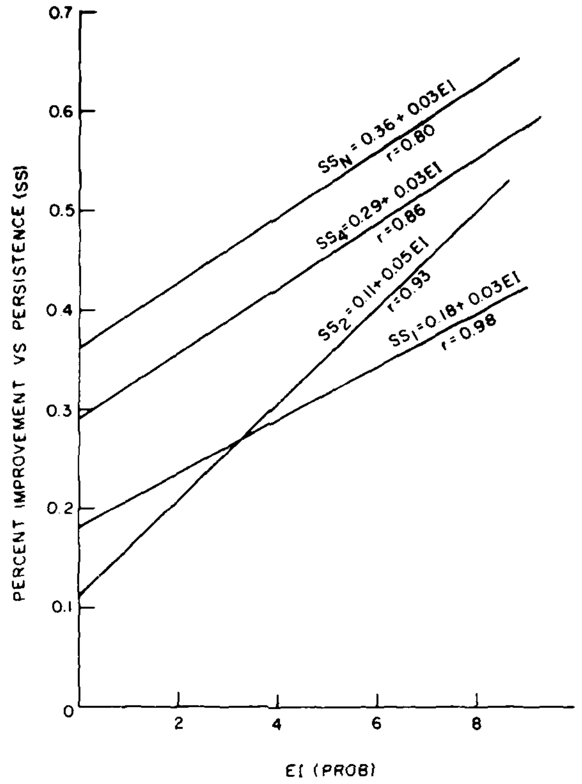

Figure 34. Percent Improvement in Cumulative p-score of Mesoscale Forecast Experiment (MFE) of Forecasters vs Experience Index (EI) for Ceiling Height Probability Forecasts

experience. Reasonable consistency is maintained among the regression slopes, though not as well as for the numerical forecasts. The "goodness-of-fit" measures are generally higher (across the board) with these data than with the numerical forecast results.

4. CONCLUSIONS

An MFE was conducted over a 2-yr period using the AFGL McIDAS facility and data from 20 winter/early spring east-coast storm episodes. The MFE was structured to emulate aspects of the aviation terminal weather support functions in base weather stations, using a computer-driven interactive graphics display system of the type envisioned with the AWDS. Data available to the MFE forecasters included that which will be part of the initial AWDS and that which could be made available in future, expanded AWDS configurations. The MFE was designed to assess numerous display and analysis products tailored to provide mesoscale detail, of remotely-sensed data sources, and of the ability of forecasters to prepare certain short-range terminal weather forecasts.

Each participating forecaster completed two assessment forms after each of the individual forecast episode exercises. The first form addressed the value of certain display products and data sources in preparing short-range terminal forecasts of windspeed and direction, total cloud amount, ceiling height, and 6-hr QPF. The second form dealt with the relative difficulty in forecasting each of the four elements accompanied by a discussion of the products/data sources important to the forecast preparation process. Over the course of the 20-episode test, there were 110 sets of assessment forms completed. In addition, a statistical verification of forecaster performance was conducted for the numerical and probability forecasts that were generated.

The products judged to be most useful in the preparation of short-range terminal forecasts included: (1) conventional geographic data displays presented simultaneously as four quadrant panels on one screen, (2) regional scale surface analyses, plots, and data listings of basic variables, (3) satellite-based trajectory technique, (4) tailored plot displays such as the station-model times-series displays, and (5) mapped displays of forecast guidance derived from the NMC LFM model. Products such as log p-skew T soundings, analyses of derived surface and upper-air variables such as vorticity or temperature advection, 3-D trajectory guidance and GEM were found to be of very limited value due to their lack of timeliness and/or poor horizontal representativeness.

The current operational availability of surface and sounding data (in 3-D space and time) is not compatible with the needs for mesoscale data for short-range terminal forecasting purposes. This incompatibility forces the forecaster to rely most heavily on data presented in fairly basic form (listings, plots, and simple analyses of basic variables), which can be interpreted and filtered subjectively in order to build an understanding of the atmospheric processes taking place in the forecast region. The tailored products that were most relied on retained or highlighted mesoscale aspects of the basic variables associated with the extratropical storm systems being dealt with in the MFE.

Half-hourly imagery (visible and IR) from geosynchronous weather satellites like GOES represent the single-most important data source for short-range aviation terminal forecasting. The MFE forecasters relied more heavily on it to prepare their cloud cover, 6-hr QPF, and ceiling height forecasts than any other available source. The ability to manipulate GOES imagery interactively on the graphics display provides a wealth of qualitative and quantitative guidance for forecasting purposes. This capability includes time-series looping, rapid channel switching (visible to IR and vice versa), selective color enhancement and remapping, and overlaying conventional data plots and analyses on the imagery's geographic coordinates. Manually digitized radar (MDR) national summaries, objectively analyzed and displayed on the color monitor, were found to be most valuable for 6-hr QPF, and to a lesser extent, ceiling height forecasting purposes. The most serious limitation or drawback of MDR data was its sporadic availability for various and sundry reasons. This created an erosion of confidence in it as a reliable data source.

Consistent with the results reported in Chisholm et al,[1] ceiling height was found to be the most difficult element to forecast due to its inherent variability during storm situations, its sensitivity to terrain considerations, and the limits of our ability to fully observe and report it from either ground-based or satellite perspectives. Terminal wind conditions were deemed to be the second most difficult variable to forecast. The forecasting of 6-hr QPF is aided more than the other elements by the availability of half-hourly GOES imagery and MDR displays. As a result it was viewed to be the second easiest variable to forecast, while total cloud amount was judged easiest. In most cases, forecasters used GOES imagery almost exclusively to forecast total cloud amount, especially for periods less than 4 hr.

The 2-yr forecast experiment resulted in over 1300 forecasts of each variable for each forecast interval. A statistical verification of the forecasters' numerical and probability forecasts was conducted with comparisons made to persistence, sample climatology, and two forecast guidance techniques; namely, MOS and GEM. While the primary evaluation involved grouped forecaster performance (consensus), individual performance and its implications were also evaluated. The MFE forecasts yielded superior rmse compared to persistence for each variable (windspeed and direction, total cloud amount, ceiling height, and 6-hr QPF) for all forecast intervals (1, 2, 4, and n hr). At 4 hr, the improvement over persistence ranged from about 20 percent for wind and ceiling height to about 30 percent for total cloud amount. The forecasters probability forecasts were substantially better than persistence probability at all forecast intervals and showed skill vs sample climatology, except at the n-hr interval. While GEM yielded skill relative to persistence probability, in general it yielded higher rmse scores than did persistence in its numerical form. Its guidance value was deemed to be minimal in "heavy" weather episodes of the type used in the MFE. Lastly, MOS was found to provide useful guidance for forecast intervals of 4 hr and beyond, particularly as regards wind forecasts. The variation in individual forecaster skill was found to be fairly substantial and attributable, in part, to forecasting experience.

Based on the 2-yr MFE, the following conclusions are reached vis-a-vis the use of interactive graphics display systems for short-range terminal forecast preparation and monitoring:

(1) Software for user-specified data plotting and analysis in tailored form (for example, four-panel plot and analysis displays, station-model time-series displays) is essential to allow selective but substantial amounts of basic data to be viewed and manipulated interactively.

(2) Fundamental to (1) is the presumed availability of a recent history file (at least the latest 24 hr) of basic surface and upper-air observations in the resident computer terminal, such that products can be prepared and displayed within a minute or so of its request.

(3) The current observational density (in space and time) for both surface and upper-air operational data sources seriously limits the extent to which mesoscale features can be detected and used for short-range forecasting purposes. As a result little value can be found in computing and displaying more complex derived fields such as moisture convergence/advection, vorticity, and divergence.

(4) A key to progress in improved short-range terminal forecast support lies in geosynchronous weather satellites, which not only can provide continuously repeating views of a geographical area to provide valuable imagery information for translation/extrapolation of clouds and precipitation features, but also fills in the data voids between widely separated surface and radiosonde stations. With the continued development of GOES temperature and water vapor sounder capabilities, the importance of satellites for short-range forecasting support globally will increase over the next several years.

(5) Although there is a wide range of research underway for modeling small-scale weather systems (both physically and numerically), we are still many years away from the widespread practical application of such models in operational forecasting in view of the required (and generally unavailable) data and computer capacity. Short-range forecasting must continue to focus on detecting, tracking, and extrapolating the movement and evolution of mesoscale systems. Resident software in an interactive graphics system should, therefore, be tailored to presenting weather depictions as specified by the forecaster-user. They should be capable of incorporating all available operational data sources, especially those like MDR, which often provide vital information between conventional surface observation sites.

(6) Training for, and familiarization with, the use of an interactive system is essential. Like any advance in technology, there will be a "learning" period during which forecaster performance (including forecast skill) will be somewhat degraded. The speed with which familiarity with the system's capabilities and requirements will be acquired, will vary due to any number of human behavior

factors. Given the general educational background and basic weather forecasting training provided to all AWS forecasters, the transition period from the current manual mode to a more automated mode using interactive graphics systems should be short and the new skills needed easily acquired.

(7) The trend towards "user-friendly" interactive procedures (touch screen, etc.), while advantageous, should not be overdone. Although the keyboard entry methodology of McIDAS is rudimentary, and at first glance may appear to be a little complicated, familiarity with its structure and options is acquired with reasonable speed even by those of us who matured in the pre-electronic wizardry days. It, and many other systems, has extensive built-in default parameters (for example, contour intervals for each parameter), which simplify keyboard entry. Again, the key to effective use of the system does not lie in its keyboard entry method but rather on the resident data and software in it that can generate the display products required by the forecaster for base weather station support requirements.

References

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2. Miller, R.G. (1981) GEM: A Statistical Weather Forecasting Procedure, NOAA-TR-NWS-28.
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4. National Weather Service (1981) FOUS 60-78 Bulletins, NOAA-NWS Tech. Proc. Bull. No. 294.
5. Reap, R.M. (1972) An operational three-dimensional trajectory model, J. Appl. Meteorol. 11:1193-1202.
6. Muench, H.S. (1982) An Appraisal of the Short-Range Forecast Problem Using Power Spectra, AFGL-TR-82-0353, AD A129315.
7. Muench, H.S. (1983) Experiments in Objective Aviation Weather Forecasting Using Upper Level Steering, AFGL-TR-83-0328.

Appendix A

1983 Episodes

Forecast Experiment 11: At 15 GMT, 25 October 1982, a well developed, occluded cyclone was centered over Cape Hatteras beneath a 500 mb low (Figure A1). Light to moderate rain was falling from southeastern New York southward to the Carolinas. With little further development expected as the cyclone moved slowly toward the northeast, the main forecast problem consisted of timing the arrival of the precipitation, 6-hr precipitation amount and ceiling height forecasts.

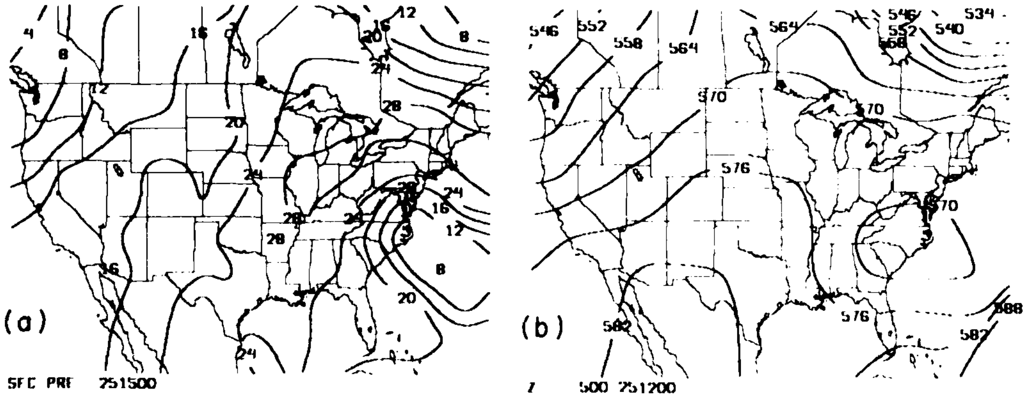

Figure A1. General Weather Situation for MFE Case No. 11: (a) Surface Pressure Analysis for 1500 GMT, 25 October 1982 and (b) 500-mb Height Analysis for 1200 GMT, 25 October 1982

Forecast Experiment 12: At 15 GMT, 5 November 1982, a strong, but slow, eastward-moving cold front was oriented north to south across eastern New England (Figure A2). Rainfall was occurring ahead of the front with scattered showers behind the front. More than an inch of rain fell as the front marched eastward in a band from Quebec southward through Vermont and eastern New York and eastern Pennsylvania. With the approaching front within 50 to 60 km of Boston and Providence the timing of FROPA and its associated wind shift and improving ceiling and cloud conditions were of most concern.

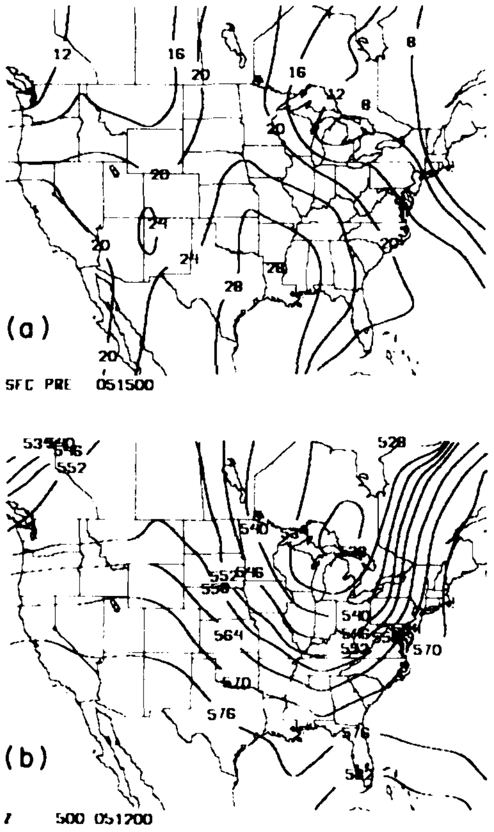

Figure A2. General Weather Situation for MFE Case No. 12: (a) Surface Pressure Analysis for 1500 GMT, 5 November 1982 and (b) 500-mb Height Analysis for 1200 GMT, 5 November 1982

Forecast Experiment 13: The 6 GMT, 13 November 1982, surface pressure analyses (Figure A3) showed a surface pressure trough associated with a potent slowly moving cold front approaching western New England. With strong vorticity advection along the cold front, plentiful moisture, and a weak frontal wave developing along the New Jersey coast the most immediate forecast problem was for 6-hr precipitation amount and the strong winds that were already occurring (at 6 GMT Boston reported southerly wind at 26 knots, gusts to 38 knots). In the later periods timing the frontal passage and the associated wind shift, and since significant rainfall was occurring behing the front, 6-hr precipitaton amount were the greatest forecast concerns.

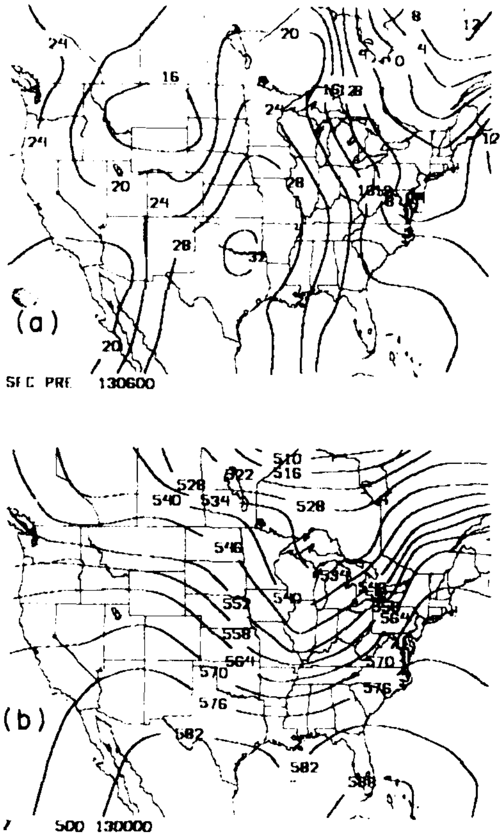

Figure A3. General Weather Situation for MFE Case No. 13: (a) Surface Pressure Analysis for 0600 GMT, 13 November 1982 and (b) 500-mb Height Analysis for 0000 GMT, 13 November 1982

Forecast Experiment 14: The surface pressure analysis at 12 GMT, 15 January 1983, (Figure A4) showed a broad area of low pressure moving across the mid-Atlantic states. A primary low was located in northwestern Pennsylvania with a secondary developing near the Maryland coast. With a potent 500-mb trough (Figure A4) and strong PVA overspreading the mid-Atlantic coast the secondary would likely become a major snowstorm for the Northeast. With the potential for a major snowstorm approaching the Northeast, heavy precipitation amounts, strong winds, and low ceilings were likely forecast problems.

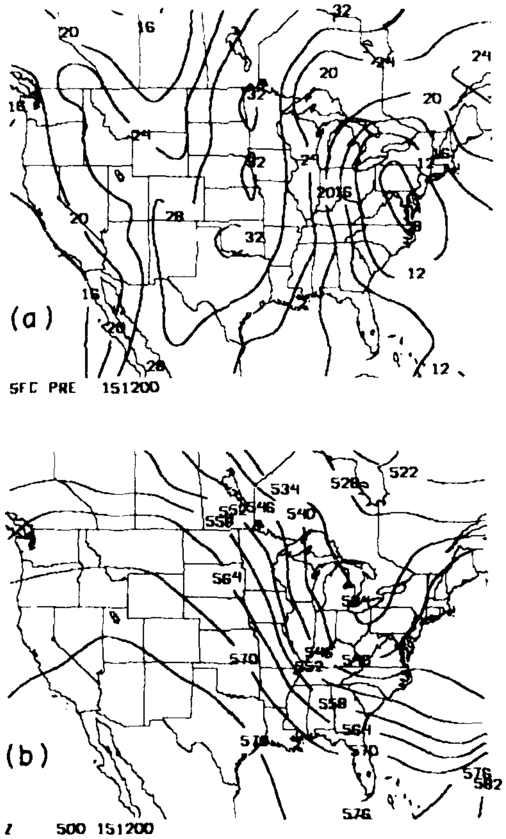

Figure A4. General Weather Situation for MFE Case No. 14: (a) Surface Pressure Analysis for 1200 GMT, 15 January 1983 and (b) 500-mb Height Analysis for 1200 GMT, 15 January 1983

Forecast Experiment 15: At 14 GMT, 3 Feb 1983, a large low pressure system (Figure A5) was affecting much of the eastern third of the U.S. At 14 GMT Boston and BDL were in the warm sector with a cold front approaching from the southwest. Precipitation was ending and some breaks were developing, thus timing the cold frontal windshift and improvements in ceiling and cloud amount were the primary forecast concerns.

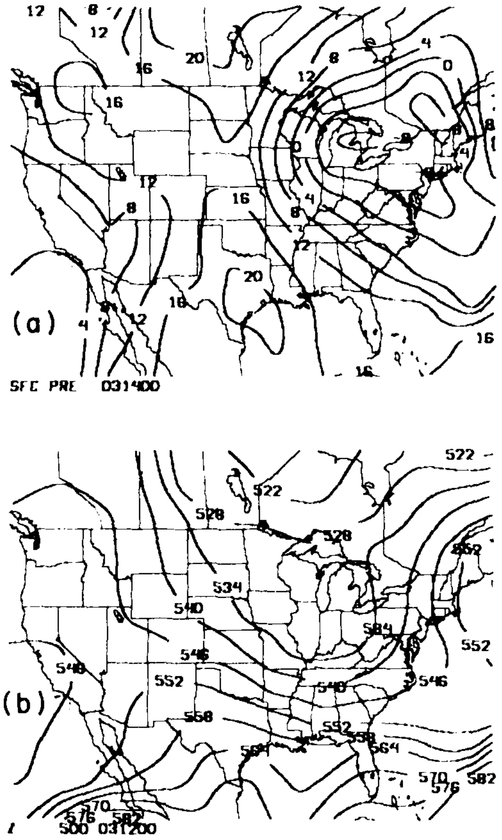

Figure A5. General Weather Situation for MFE Case No. 15: (a) Surface Pressure Analysis for 1400 GMT, 3 February 1983 and (b) 500-mb Height Analysis for 1200 GMT, 3 February 1983

Forecast Experiment 16: At 16 GMT, 11 Feb 1983, an intensifying cyclone was located along the Carolina coast (Figure A6) while a very strong cold high pressure system (1040 mb) was centered in eastern Canada extending southeastward over New England. The strong pressure gradient between these two systems generated a strong, moist easterly flow. The combination of the moist easterly flow and strong warm advection at 850 and 700 mb were combining to produce extreme snowfall rates (1 to 5 in. /hr). Satellite imagery showed the cloud shield steadily moving toward the NNE suggesting the potential for heavy snow in southern New England. With near blizzard conditions approaching from the south, winds, heavy snow and very low ceilings were likely forecast problems.

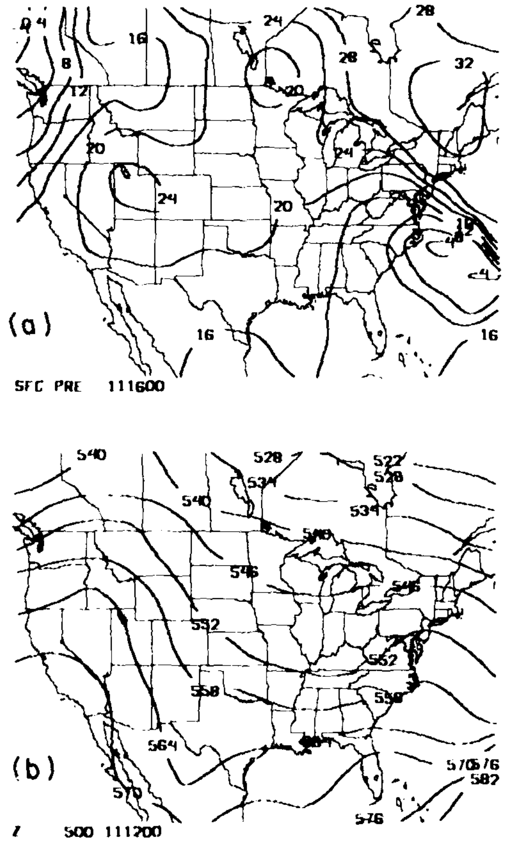

Figure A6. General Weather Situation for MFE Case No. 16: (a) Surface Pressure Analysis for 1600 GMT, 11 February 1983 and (b) 500-mb Height Analysis for 1200 GMT, 11 February 1983

<u>Forecast Experiment 17</u>: The 23 GMT, 14 Jan 1983 surface pressure analysis (Figure A7) showed an occluded low centered over northern Ohio. Clear skies still covered much of New England at 23 GMT while significant weather was still several hundred miles to the west. Thus the main forecast problem was increasing cloud amount and gradually lowering ceilings in the later forecast periods.

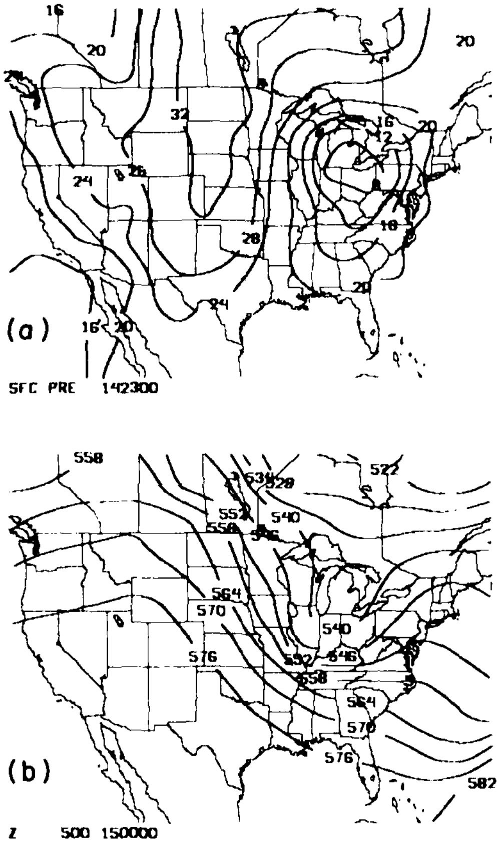

Figure A7. General Weather Situation for MFE Case No. 17: (a) Surface Pressure Analysis for 2300 GMT, 15 January 1983 and (b) 500-mb Height Analysis for 0000 GMT, 16 January 1983

<u>Forecast Experiment 18:</u> A cold front in eastern New York, associated with a low pressure system over southeastern Canada at 16 GMT, 23 Feb 1983, was moving steadily eastward toward southern New England (Figure A8). The combination of the approaching cold front and a low pressure system developing over eastern North Carolina whose precipitation shield was expected to graze southern New England, bringing a period of light rain to Boston and Providence. The main forecast problem was timing the cold frontal passage and its wind shift and the worsening ceiling conditions associated with the light rain.

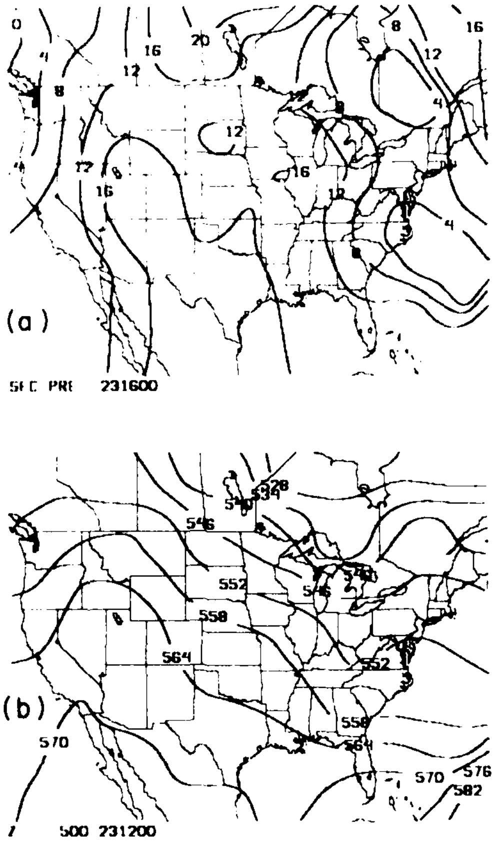

Figure A8. General Weather Situation for MFE Case No. 18: (a) Surface Pressure Analysis for 1600 GMT, 23 February 1983 and (b) 500-mb Height Analysis for 1200 GMT, 23 February 1983

Forecast Experiment 19: At 14 GMT, 2 Mar 1983, an intense cyclone was located approximately 300 km off the Delaware coast moving toward the northeast (Figure A9). A large rain shield that had already dumped over an inch of rain at Boston and Providence stretched from Maine southward to Virginia. As this large ocean storm continued to move slowly toward the northeast with a continuation of moderate rain, 6-hr precipitation amount was the main forecast problem.

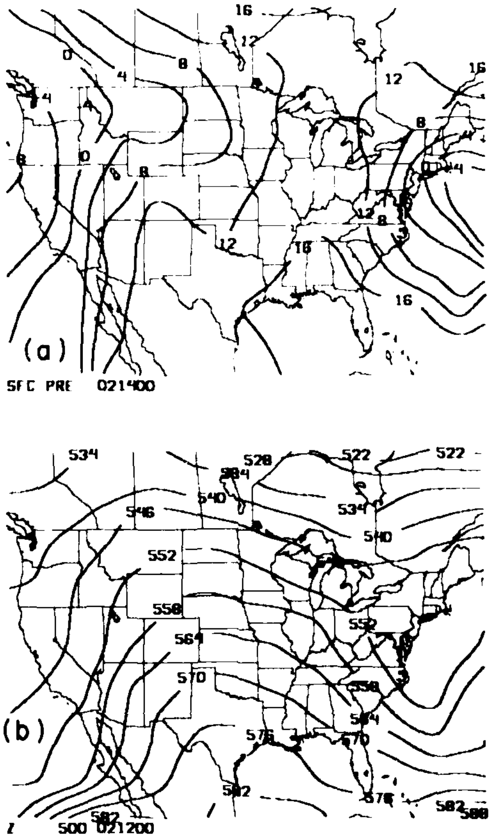

Figure A9. General Weather Situation for MFE Case No. 19: (a) Surface Pressure Analysis for 1400 GMT, 2 March 1983 and (b) 500-mb Height Analysis for 1200 GMT, 2 March 1983

Forecast Experiment 20: The 15 GMT, 21 Mar 1983, surface pressure analysis (Figure A10) showed an area of low pressure oriented from southwestern Pennsylvania southeastward to northern Virginia. A weakening occluded cyclone was located in northwestern Pennsylvania with a developing frontal wave at the triple point in northern Virginia. In the early periods of the experiment the main forecast problem was timing the approach of overcast conditions and lowering ceilings. Later, it was timing the approaching warm front and its heavy rain showers and eventually a cold frontal passage and the associated wind shift.

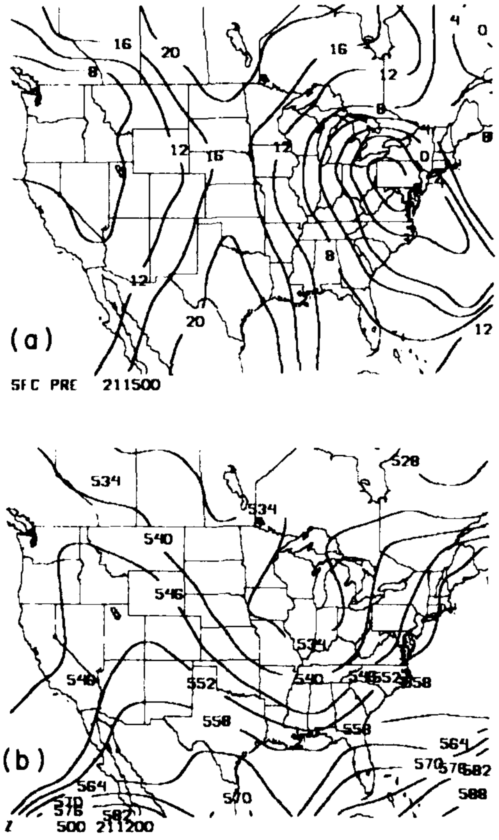

Figure A10. General Weather Situation for MFE Case No. 20: (a) Surface Pressure Analysis for 1500 GMT, 21 March 1983 and (b) 500-mb Height Analysis for 1200 GMT, 21 March 1983

Appendix B

Assessment Forms

Product Usefulness Assessment

Case No. ____________ Case Date ______________ Forecaster ______________

Forecast Stations BOS and __________

First Forecast Time ______ Z Last Forecast Time ______ Z

Circle the products you used in this case:

MS GT MR PF KZ TS FA FK-TRA FK-MOS

FK-GUI BS IA

1. Most Useful
   - A. What product was most useful to you?
   - B. Why was it so useful?
   - C. How did you use it?
   - D. In what situations was it most useful?
   - E. In what situations was it not useful?
2. Least Useful
   - A. What product was least useful?
   - B. What made it so useless?
   - C. In what situations was it most useful?
   - D. In what situations was it least useful?
   - E. How could the product be improved?

Mesoscale Forecast Variable Assessment

Case No. ____________ Case Date ____________ Forecaster ________________

Forecast Stations BOS and _______

First Forecast Time _______ Z Last Forecast Time ________ Z

Ranking of Forecast Variable, in order of difficulty using facilities available through McIDAS and MFF

A. The most difficult variable to forecast was ________________________;
beyond ______ hours, I had little confidence in my forecasts.

Was satellite imagery useful? If so, how?

Was MDR useful? If so, how?

Were the mesoscale plot and analysis routines useful? If so, how?

Was guidance information useful?
If so, which guidance (GEM, MOS, LFM Guidance, 3-D Trajectory) and how?

Were the Wisconsin trajectory models useful? If so, how?

Was this forecast variable affected by local (non-translatory) factors?
If so, how did you factor that into your forecast?

B. The next most difficult variable to forecast was ________________________;
beyond _________ hours, I had little confidence in my forecasts.

Was satellite imagery useful? If so, how?

Was MDR useful? If so, how?

Were the mesoscale plot and analysis routines useful? If so, how?

Was guidance information useful?
If so, which guidance (GEM, MOS, LFM Guidance, 3-D Trajectory) and how?

Were the Wisconsin trajectory models useful? If so, how?

Was this forecast variable affected by local (non-translatory) factors?
If so, how did you factor that into your forecast?

C. The next most difficult variable to forecast was __________________________;
beyond ________ hours, I had little confidence in my forecasts.

Was satellite imagery useful? If so, how?

Was MDR useful? If so, how?

Were the mesoscale plot and analysis routines useful? If so, how?

Was guidance information useful?
If so, which guidance (GEM, MOS, LFM Guidance, 3-D Trajectory) and how?

Were the Wisconsin trajectory models useful? If so, how?

Was this forecast variable affected by local (non-translatory) factors?
If so, how did you factor that into your forecast?

D. The easiest variable to forecast was ______________________________;
beyond __________ hours, I had little confidence in my forecasts.

Was satellite imagery useful? If so, how?

Was MDR useful? If so, how?

Were the mesoscale plot and analysis routine useful? If so, how?

Was guidance information useful?
If so, which guidance (GEM, MOS, LFM Guidance, 3-D Trajectory) and how?

Were the Wisconsin trajectory models useful? If so, how?

Was this forecast variable affected by local (non-translatory) factors?
If so, how did you factor that into your forecast?

END

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