Forecasting for a Large Field Program: STORM-FEST

EDWARD J. SZOKE, JOHN M. BROWN, JOHN A. MCGINLEY, AND DENNIS RODGERS

NOAA Forecast Systems Laboratory, Boulder, Colorado

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ABSTRACT

Stormscale Operational and Research Meteorology–Fronts Experimental Systems Test (STORM-FEST) was held from 1 February to 15 March 1992 in the central United States as a preliminary field systems test for an eventual larger-scale program. One of the systems tested was a remote operations center, located in Boulder, Colorado, which was significantly displaced from the main field concentration of scientists and research aircraft. In concert with the remote operations center test was a test of remote forecasting support, also centered in Boulder. The remote forecasting for STORM-FEST was the first major cooperative effort for the Boulder–Denver Experimental Forecast Facility (EFF), a cooperative effort between operations and research aimed at finding more effective ways of addressing applied meteorological problems. Two other newly formed EFF's, at Norman, Oklahoma, and Kansas City, Missouri, also played key roles in the forecasting/nowcasting support. A description of the design and function of this remote forecasting and nowcasting support is given, followed by an assessment of its utility during STORM-FEST. Although remote forecasting support was deemed plausible based on the STORM-FEST experience, a number of suggestions are given for a more effective way to conduct forecasting experiments and provide forecasting support during a field program.

1. Introduction

From 1 February through 15 March 1992 the experiment STORM-FEST (Stormscale Operational and Research Meteorology–Fronts Experimental Systems Test) took place in the central United States (Fig. 1) (Furlong 1992). STORM-FEST (hereafter FEST) was designed to be a relatively small "test" program that would enhance the probability of a successful full-scale experiment as part of the overall STORM program.

Although the actual STORM field phase, which originally was scheduled to occur in the central, eastern, and western United States over a 10-year period, has yet to occur, many believe there remains a strong need for such a program (National Research Council 1990; Subcommittee on Atmospheric Research 1992). This is especially true in light of the modernization of the National Weather Service (NWS), which will enable mesoscale detail to be operationally observed and monitored with data from Doppler radars, wind profilers, and surface mesonet stations—instruments that were previously available only during special field programs. STORM is envisioned as helping the modernized NWS through improved understanding of mesoscale processes, leading to the development of conceptual models that can be passed quickly to operational forecasters and allow for better use of the new observations.

Corresponding author address: Dr. Edward J. Szoke, National Center for Atmospheric Research, Mesoscale and Microscale Meteorology Division, P.O. Box 3000, Boulder, CO 80307-3000.

Several research aircraft were used in FEST, including a National Oceanic and Atmospheric Administration (NOAA) P-3 long-range aircraft. Other enhanced observational capabilities included the experimental wind profiler network; an array of 45 National Center for Atmospheric Research (NCAR) Portable Automated Mesonet (PAM II) stations, most of which were located in Missouri; 12 Cross-chain Loran Atmospheric Sounding System (CLASS) rawinsonde stations (Fig. 1) operated by NCAR and the National Severe Storms Laboratory (NSSL); special NWS and military sounding launches; and several research Doppler radars. The aircraft were based, along with most of the scientific investigators, at the Richards–Gebaur Air Force Base (GVW), located about 30 km southeast of Kansas City, Missouri.

The general goal of FEST was to carry out an experiment focused on testing the various systems or components that would be involved in the STORM program. The "systems" that were tested included performance of various observing tools, flight plans and experimental design, methods of data management, the concept of a main remote operations center with other smaller remote centers of control, and—the focus of this paper—remote forecasting and nowcasting support. It is unusual to establish an operations center that is remote from most of the scientists and the support aircraft. Certainly, for field programs covering a smaller area, such as the recent Convection and Precipitation Electrification Experiment (CaPE) (Gray 1991) held near the Kennedy Space Center in central Florida in

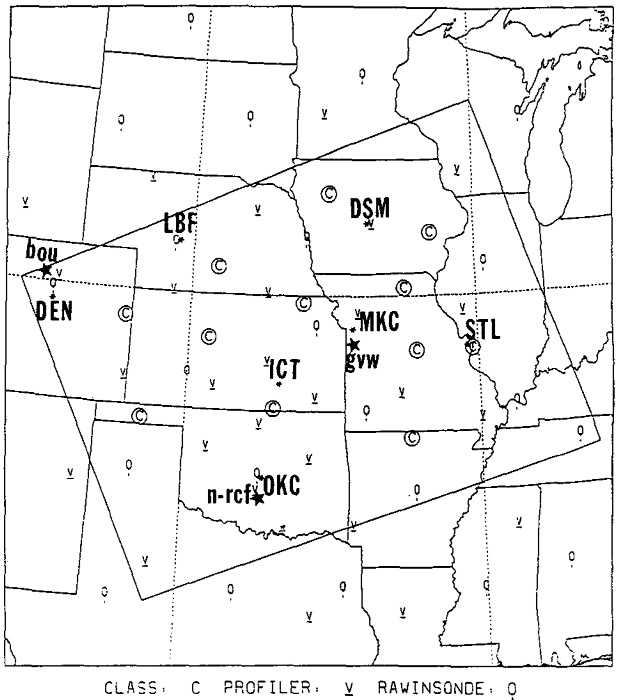

FIG. 1. Research and forecast area for FEST (tilted rectangle), with sounding and wind profiler sites. The seven-point forecast sites (for the Boulder–Denver EFF) are shown (capital letters), along with the three EFF sites (stars with small-case letters).

1991, the operations center and forecasting, nowcasting, and aircraft support activities were all conducted in close proximity. Even larger programs such as GALE (Genesis of Atlantic Lows Experiment) (Dirks et al. 1988) in the eastern United States in 1986, or the Oklahoma–Kansas Preliminary Regional Experiment for STORM-Central (PRE-STORM), held in 1985 in Oklahoma and Kansas (Cunning 1986), have operated from a principal operations center collocated with the main contingent of scientists and aircraft. The idea of a secondary level of control functions for aircraft and radar operations was tested to a limited extent in GALE by transferring control for some missions to a location on Cape Hatteras, away from the main control center.

The program most similar to FEST in terms of a remote operations center and remote forecasting and nowcasting was the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA), held from December 1988 into February 1989 along the eastern North American seaboard (ERICA Project Office 1988). The focus of ERICA was on rapidly developing cyclones in the northwestern Atlantic, roughly from the North Carolina coast northward to St. John's, Newfoundland, Canada, and was in some ways a follow-up to GALE. The main operations center was located at the National Meteorological Center (NMC) World Weather Building in Camp Springs, Maryland, and was the site of the program director, the data center, and the main project forecasting and nowcasting activities. The forecasting and nowcasting was done by a team of university meteorologists in a cooperative effort with NMC forecasters and National Environmental, Satellite, Data and Information System (NESDIS) personnel. The primary site for the research aircraft and aircraft scientists (the ERICA Aircraft Operations Center) was located at the Naval Air Station in Brunswick, Maine. ERICA was a cooperative effort with the Atmospheric Environment Service (AES) of Canada. The Canadian Operations Center was located in the Maritimes Weather Centre at Bedford, Nova Scotia, Canada, and was the site of coordinated AES field activities that included forecasting and nowcasting for specific AES research goals and evaluating new products, displays, and data, as well as coordinating with the ERICA forecasters on potential target storms. The separated operations during ERICA enabled the aircraft to be located at a suitable facility that was strategically situated for studying oceanic storms, while taking advantage of the facilities and expertise at NMC to provide forecasting and nowcasting support.

The idea for a remote operations center and remote forecasting/nowcasting support as a systems test during FEST was that if a true multiscale, expansive effort like a full-fledged STORM program eventually comes about, then a system like the one used during ERICA might be expanded to have several points of aircraft origination but with one main forecast and operations center that would take advantage of existing facilities. An argument for dispersing the aircraft is to avoid the tendency toward intensive study only within a fairly restricted area around a common site. The logistics of how a multisite operation might evolve will not be covered here, though they are certainly a point for discussion. Another motivation for testing the remote operations center concept was the idea that it might be more cost-effective to have one well-equipped, more permanent center that would not only house the most current communications and display facilities but would also be the data management center for various field programs.

The main operations center for the overall control and coordination responsibility for FEST was located at the NCAR Research Application Program's (NCAR/RAP) Aviation Weather Development Laboratory in Boulder, Colorado, and officially designated B-OCC for Boulder Operation Control Center (STORM Project Office 1992). The NOAA Forecast Systems Laboratory (FSL) in Boulder was tasked with providing and organizing the remote forecasting, which took place at FSL, approximately 4 km from the B-OCC. The two secondary control facilities were the Kansas City Regional Control Facility (KC-RCF), located at GVW, and the Norman Regional Control Facility (N-RCF), housed at the Norman, Oklahoma, NWS Forecast Office (WSFO).

The objective of this paper is to describe and provide an assessment of the remote forecasting and nowcasting systems test based on our experiences during FEST. We hope to stimulate further exchange on forecasting and operational issues related to STORM or any large field program, so that the most effective methods of providing forecasting and nowcasting support might be used in the future. We will also discuss the means whereby the operational sector can most benefit from field programs, through methods of incorporating experimental forecasting and forecast research into the design of the program. Points relevant to the NWS modernization effort will also be addressed.

2. Forecasting support and activities during STORM-FEST

The scheme for developing the forecast and nowcast requirements to support FEST arrived out of a series of meetings among project scientists and personnel. A consensus was reached concerning the products to be provided by the remote forecasting site (FSL in Boulder). Although the primary remote forecasting site for operations was located in Boulder, several other sites were involved in the program and provided forecasting/nowcasting support. Two of these sites were Experimental Forecast Facility (EFF) locations, one in Norman and the other in Kansas City. The Fleet Numerical Oceanographic Center (FNOC) in Monterey, California, and the NMC in Washington, D.C., also took part. Because EFFs have been a significant component of STORM planning and are envisioned as playing a major role in the transfer of research results to operations, the concept of an EFF will be briefly discussed here before proceeding.

a. The EFF concept

The concept of EFFs is discussed in the first document proposing the STORM program (University Corporation for Atmospheric Research 1983), and indeed, the "O" in STORM indicates the "operational" ties that are desired. Briefly, an EFF, in its broadest sense, is a means to promote and sustain a working relationship among operational, research, and academic professionals aimed at solving local forecast and operational problems through the application of science and technology (Auciello and Lavoie 1993). The goal of establishing sites (EFFs), where by virtue of proximity the potential for such a relationship exists, is to improve the cooperation between research and operations, to the end that the research side becomes more aware of the challenges facing operational forecasters, and operational forecasters are given the time, encouragement, and means to pursue research on forecast problems. The challenges facing operational forecasters include those imposed by deadlines and other operational constraints, as well as those stemming from lack of conceptual understanding of mesoscale systems. Potential forecast methods developed from research of such mesoscale systems stand a better chance of being useful in an operational setting when the researchers are aware of the constraints of operations. The net result then of such cooperation is research directed toward specific forecast problems that can be readily applied, using the new datasets available in the modernized NWS.

An important function of an EFF is to test new conceptual models, methods, and algorithms, and evaluate uses of new types of data through experimental forecasting. Additionally, EFFs are an ideal location for a research model or previously untested research result to be evaluated in a real-time forecast mode. These activities should be at a heightened level during a field program, when additional verification data would be available.

b. Specific EFF responsibilities during FEST

1) NORMAN

Four forecasters were specifically assigned to the Norman EFF during FEST, in addition to an operations director from the NOAA Office of Hydrology. During FEST the Norman EFF was collocated with the N-RCF at the Norman WSFO. Because the Norman WSFO is a test site for the Advanced Weather Interactive Processing System (AWIPS), the interactive workstation that will replace Automation of Field Operations and Service (AFOS), Pre-AWIPS workstations (in addition to an AFOS station), and a WSR-88D Doppler radar display were available that the EFF could share on a noninterference basis. The EFF also had its own, limited Pre-AWIPS workstation, as well as two Sun workstations, and a PC-McIDAS (man–computer interactive data access system) workstation (a limited version of the McIDAS workstation). It was hoped that the Sun workstations would be used to display special sounding data taken during the experiment, as well as output from The Pennsylvania State University (PSU)/NCAR Mesoscale Model (MM4) (Anthes et al. 1987) and hourly analyses from the Local Analysis and Prediction System (LAPS) (McGinley et al. 1991), both run at Boulder, but this capability was never realized for FEST. A limited set of products from an isentropic 60-km grid analysis and short-range forecast model run at FSL called the "Mesoscale Analysis and Prediction System" (MAPS) (Benjamin et al. 1991) was available through the WSFO Pre-AWIPS workstation.

The main emphasis for the Norman EFF was on the hydrology component of FEST, which focused on estimating precipitation from the WSR-88D and other Doppler radars in Oklahoma. The specific region of study was a relatively small area called the "Little Washita Watershed" in southwestern Oklahoma, which was instrumented with a 36-station raingauge network. To better quantify the radar reflectivity and surface precipitation measurements, aircraft flights to specifically measure drop size were planned for FEST.

The N-RCF had the responsibility of calling for an Intensive Observational Period (IOP) for the hydrology experiment. To support the IOP planning the Norman EFF issued graphical forecasts for the FEST area valid at 0000 and 1200 UTC (the following day) by about 1800 UTC, with an accompanying forecast discussion. Also issued each day were 6-h quantitative precipitation forecasts (QPF) out to 24 h ending at 1800 UTC the following day in graphical form (contours of precipitation amount) for all of Oklahoma and an actual estimate of basin-averaged rainfall for the Little Washita Basin. If an IOP was called for the Little Washita area, the N-RCF planned radar operations and potential aircraft support and directed the aircraft. During such times the Norman EFF provided nowcast support (0–6-h predictions updated every 6 h or more frequently as required by operations). This support was also planned for any other IOP involving aircraft operations near the Norman area. Extra personnel required during the more intensive nowcasting periods were drawn from NSSL and Norman WSFO volunteers.

The Norman EFF also undertook experimental daily forecasts of lightning (yes/no occurrence) that accompanied the QPFs and point temperature forecasts for seven locations in Oklahoma valid at the same time as the graphical weather depiction forecasts, 0000 and 1200 UTC. The intent of issuing temperature forecasts was a specific Norman EFF goal of trying to improve forecasts of the timing and strength of Arctic fronts, while lightning research has been an ongoing activity at the adjacent NSSL.

2) Kansas City

The EFF at Kansas City was established just before FEST and had two full-time staff stationed at the KC-RCF. The KC-RCF was located in a large airplane hangar facility containing a number of offices. A trailer housing the communication equipment for aircraft coordination along with other displays, including several field operations center workstations for displaying weather data and aircraft tracks, was also inside this hangar, but away from the EFF forecasters and their weather information. The EFF activity took place near the briefing room at the KC-RCF (the implications of this are discussed later); however, there was a dedicated phone line between the two locations. In the same room with the EFF forecasters were a standard DIFAX for hardcopy AFOS products, a McIDAS workstation, a Sun workstation display for the MM4 model with a high-speed communications link (T1) to Boulder, and a separate display system for LAPS.

The main FEST forecasting responsibilities for the Kansas City EFF were to prepare and provide preflight weather briefings to aircraft crews and ground personnel. The EFF also was to provide any nowcasting support for aircraft when operations were within local radio range and being directed from the KC-RCF.

3) Boulder–Denver

To fulfill the forecasting requirements for FEST, an EFF-type activity was initiated between the Boulder research facilities (principally FSL) and the Denver WSFO, with 14 forecasters participating from each facility. In addition, four forecasters from the Canadian AES also took part, with two forecasters in Boulder at a given time; this was an offspring of earlier AES/FSL cooperative efforts. As was noted, the official main remote operations center, designated the B-OCC, was located at NCAR/RAP. That location, however, did not have sufficient meteorological facilities for forecasting or the communications requirements for the daily FEST briefing, which was therefore held at the FSL weather briefing room (hereafter referred to as FSL), approximately 4 km from the B-OCC. The B-OCC was located at the NCAR site because of the availability of display and communication equipment for direct aircraft communication that could not be located for FEST at FSL. Forecasters from the Boulder–Denver (BOU–DEN) EFF were present at the B-OCC only when nowcasting from Boulder was required.

The main written forecast product in support of FEST was a set of forecast graphical depictions of weather systems and associated precipitation areas at 6-h intervals for the first 24 h (beginning at 0000 UTC), and then for the midpoint of the next 24 h (0600 UTC of day 2). An example from the largest snow event is given in Fig. 2. A narrative accompanied these day 1 and day 2 forecasts. The forecasts for the next day were often needed for early planning because of the preflight

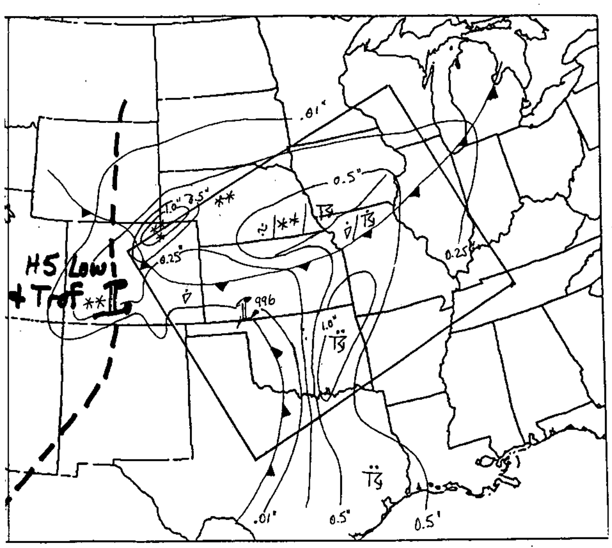

FIG. 2. Example of a graphical forecast map produced by the BOU–DEN EFF. Shown is a day 2 forecast made on 7 March at 1800 UTC, and valid for 0600 UTC on 9 March.

and crew requirements of the longer-range aircraft such as the P-3. Such aircraft requirements can make for difficult decisions based at times on still uncertain forecasts, and sometimes required early updates before the regular daily weather briefing. A list of all the B-OCC products is given in Table 1, and a schedule for issuing these products is shown in Fig. 3. The experimental forecasts included probability of precipitation forecasts for several categories of rain and snow amounts, and aviation forecasts, both out to 24 h, for the seven sites shown in Fig. 1, as well as a 24-h outlook for in-cloud supercooled liquid water for the Denver area. The motivation for some of the experimental forecast products was the involvement of FSL in developing advanced aviation products and in the Winter Icing and Storms Program (WISP) (Rasmussen et al. 1992). The aviation forecasts were fashioned after current NWS terminal forecasts except that a "chance" or "occasional" group was not permitted. Instead, the attempt was made to be more specific in timing of changes in weather, visibility, cloud ceiling height, or significant wind. The precipitation forecasts were intended to investigate whether the increased data and model input could allow for more specific forecasts in the form of categorical probability of precipitation forecasts. In addition to the forecasts, a more quantitative evaluation of LAPS and MAPS based on "value-added" very short range forecasting—whereby forecasters would make predictions initially without, and then with, LAPS or MAPS—had been planned but could not be performed due to display limitations at the B-OCC.

A number of advanced displays and model output suites were available at FSL, as listed in Table 2. There

TABLE 1. Forecast and nowcast products issued by the BOU-DEN EFF during FEST.

Products	Comments
Forecast maps:	Day 1—every 6 h (valid 0000, 0600, 1200, 1800 UTC) Day 2—midpoint (valid 0600 UTC)
Forecast discussions:	One for each day
Experimental forecasts:	Precipitation (seven sites—valid 1800–1800 UTC) Probabilities for categories of snow and liquid amounts Aviation (seven sites—valid 1800–1800 UTC) No "chance" categories allowed Icing (supercooled liquid water) outlook Denver only—valid 1800–1800 UTC
Long-range outlook:	No written product
Nowcasts:	Maps—3 and 6 h ahead Point precipitation (seven sites, 0–6-h period) [snow (0–6 h) and melted (0–3, 3–6 h)] (issued every 3 h) Hourly Denver precipitation, temperature, and wind

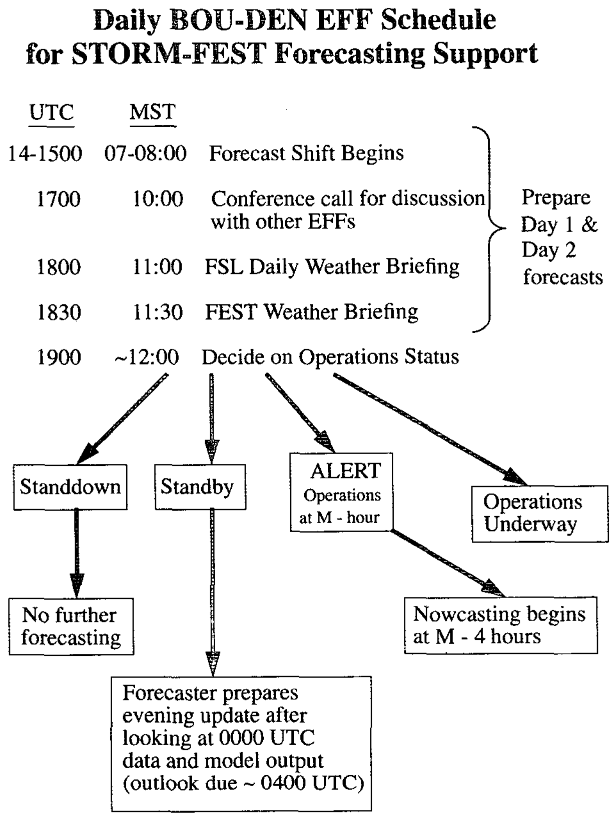

FIG. 3. Daily schedule for the BOU–DEN EFF during FEST.

were two Pre-AWIPS workstations (similar to those available to the Norman EFF forecasters) that displayed all standard AFOS products and model output, as well as gridded model output from the NGM (every 50 mb and at 6-h intervals) and MAPS (pressure levels at every 50 mb and isentropic levels at 10 K intervals, at 3-h intervals out to 12 h), satellite imagery on various scales, LAPS surface analyses over Colorado, profiler data, and Doppler radar images from the Mile High 10-cm wavelength radar (similar to the NWS WSR-88D radar) located near Denver. The LAPS model was also run for the FEST area, both for analyses of surface fields and at 50-mb intervals in the vertical, but a separate terminal was required to display the output. Another Pre-AWIPS workstation was located in a separate room down the hall from the FSL forecast site. Two other Pre-AWIPS workstations located in a neighboring building provided access to gridded data from the Aviation (AVN) model as well and to long-range predictions from the Medium Range Forecast Model (MRF) for days 6–10 (through day 5 was available at the main site).

Two other models available at NOAA/FSL during FEST included the MM4 model (Anthes et al. 1987) and the NMC eta model (Mesinger et al. 1988; Janjic 1990). These models were not displayable on the Pre-AWIPS workstations. Instead MM4 used a Sun work-

TABLE 2. Numerical models available on the BOU–DEN EFF during FEST.

Model	Abbreviation	Scale	Δx (km)	Δt (h)	t_{end}	Available by	Displayed on
Limited fine mesh	LFM	>US	180	12	48 h	~8:15 A.M.	Pre-AWIPS
Nested grid	NGM	>US	80	6	48 h	~8:50 A.M.	Pre-AWIPS
Aviation (spectral)	AVN	>US	105 (T126)	12	72 h	~10:00 A.M.	Pre-AWIPS
Eta	Eta	US	80	6	48 h	~8:30 A.M	486 PC
NCAR/PSU mesoscale	MM4	US	20/60	1	36 h	~8:30 A.M.	Sun
Mesoscale analysis and prediction system	MAPS	US	60	3	12 h	~8:30 A.M.	Pre-AWIPS
Local analysis and prediction system	LAPS	FEST/CO	10	0	0 h	0 h + 20 min	Pre-AWIPS

station, which was also used at the Kansas City EFF, and eta was displayed on a 486-PC using the program PC-GRIDDS (PC-Gridded Interactive Display and Diagnostic System) developed at NMC by Ralph Peterson (examples of its use are found in Zubrick and Thaler 1993; Shea and Przybylinski 1993; and others), which allowed for downloading and displaying of gridded output from NMC from the 80-km "early eta," the version of the eta model run twice daily at NMC before the NGM. NCAR's Mesoscale and Microscale Meteorology Division provided one person to operate the Sun workstation and help interpret the model output. (A dedicated person was not available for the MM4 display at the Kansas City EFF.) MM4 had the best resolution of any forecast model, with a nested grid over the FEST domain of 20-km horizontal spacing and forecasts out to 36 h. The running of MM4 in real time for the duration of FEST (including some of the evening updates) was an ambitious undertaking, which included assimilation of MAPS analyses to provide the input to the model runs. Although it is a research model, the MM4 ran quite rapidly in real time by simultaneously using all the processors on the NCAR Cray YMP, and its products usually arrived for display before the NGM but often in a tie with the early eta.

The shifts that were required for any 24-h period to provide the necessary nowcast and forecast support consisted of one day shift, an optional evening shift, and three possible nowcast shifts. After all conflicts were accounted for, the average breakdown of shifts per forecaster consisted of three to four day forecast shifts, one potential evening forecast shift, and about five potential nowcast shifts ("potential" since they were dependent on the weather and, in the case of nowcasting, where the aircraft were flying). Because the day forecast shift had the larger workload, two forecasters were assigned, one forecaster with a research background paired with one operational forecaster; the other shifts generally had only one forecaster. With the fairly large number of forecasters and relatively rapid turnover (in as many cases as possible forecast shifts for any forecaster were consecutive), an additional forecaster (either Szoke or McGinley) was present at each forecast shift to help provide continuity, record notes, interpret model output, load the eta model for display, etc.

After much discussion in planning meetings for FEST, a compromise for the time of the daily briefing of 1830 UTC (1130 MST) was reached, as shown in Fig. 3. The majority of the scientists had pressed for an earlier time, while the forecast group suggested a later time. More will be written about the effects of the compromise time later. Forecasters could begin earlier than 1400 UTC (0700 MST), and in many cases did, although there was not much of the new 1200 UTC data and output to examine before about 1330 UTC. The FEST briefing was scheduled immediately after the FSL daily weather briefing, whose preparation required the forecasters to share the two Pre-AWIPS workstations during weekdays. Also, those workstations were unavailable to the FEST forecasters during the briefing itself (1800–1830 UTC), although the other display hardware for MM4 and eta could be used during this time, as well as other nearby workstations.

To coordinate forecasts and views with the Norman and Kansas City EFFs, a conference call was scheduled for 1000 MST, at which time each group was to have formulated an initial forecast. It was decided that it would be very beneficial to FEST forecasters if NMC was also included in the conference call, especially since the forecasters were using the new eta model. Since the time for the briefing preceded (barely) the issuance of the model discussion by NMC (AFOS designation PMDHMD), it was hoped that the participation in the conference call would not entail too much extra work for the NMC forecaster who could elaborate on the main points of that discussion, while also giving NMC forecasters an opportunity to participate in FEST. An additional participant added to the conference call was a forecaster from the FNOC, who was tasked with coordinating a limited number of sets of special soundings closely spaced along the West Coast (the so-called picket fence) and a very limited number of aircraft dropsonde missions over the ocean. These limited resources had to be scheduled in concert with potential FEST cases downstream, requiring a careful examination of the longer-range forecasts. Indeed, the long-range forecast became an important part of the daily briefing (although no formal written product was issued), and it was found that the input from NMC in the conference call was particularly important for that portion of the forecast, since they had access to a broader range of longer-range forecast products from the European numerical models.

A typical daily briefing lasted about 30 min, followed by 30–60 min of open discussion. As shown in Fig. 3, a decision as to the status would be reached after the discussion, although often not until the mission scientists had a "closed door" meeting at the KC-RCF. Depending on the complexity of the weather, a decision was reached as early as 1915 UTC or as late as about 2100 UTC. If the weather situation warranted, an evening update from FSL was required. Because the KC-RCF is in the central time zone, this update briefing was held at 0400 UTC (2100 MST), with the caveat that it would be informal and no written products would be expected, since many of the 0000 UTC model runs would have arrived only recently. MM4 was occasionally run from 0000 UTC data to support the evening update.

Nowcasting, ideally beginning about 4 h before the beginning of the mission (time M-4 in Fig. 3), took place only from the B-OCC when an aircraft was flying and was out of range of communications from the KC-RCF or the N-RCF. This was an infrequent occurrence and limited the amount of nowcasting that was done at the B-OCC. In fact, many of the forecasters at the BOU–DEN EFF never experienced a nowcasting shift. As noted earlier, the weather displays available at the B-OCC were not as complete in some key areas as those at FSL. The primary difference was that the B-OCC had a very limited version of the Pre-AWIPS-type workstation that did not have MAPS or LAPS output. LAPS was available (both for the FEST area and Colorado) at the B-OCC through a separate terminal that was, however, somewhat cumbersome to use. A Sun workstation to display the MM4 output was available at the B-OCC, though without a dedicated operator. A display available at the B-OCC that was unavailable at FSL was a field operations center workstation like those at the KC-RCF, which had displays of satellite, radar, local research radar, surface mesonet, and sounding data, along with aircraft tracks.

The logistical approach to the forecast briefings had never been tried and constituted a big part of the test of both the remote operations center concept and remote forecasting. It consisted of a video conference link between the project participants at the KC-RCF and the briefing room at FSL, with a telephone link between the N-RCF and the FNOC (as diagrammed in Fig. 4). The video conferencing used two live cameras configured so the audience at the KC-RCF could see the audience at FSL, and vice versa; this mode was used during open discussion periods. During the weather briefing one camera, aimed at the projection screen at FSL, displayed the weather products from the Pre-AWIPS workstations, or another source (the MM4 or LAPS output; eta output could not be displayed on the screen). The other camera was used to project view graphs. The video conference link remained on at all times to facilitate discussion between personnel at Boulder and the KC-RCF.

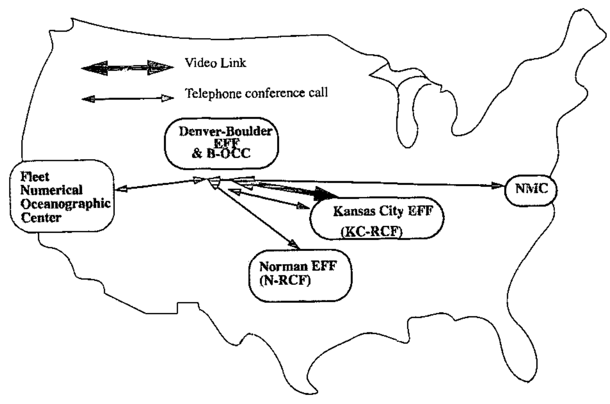

FIG. 4. Schematic illustrating the communication links between the various sites.

3. Assessment of forecasting activities during FEST

In addition to the forecast discussions, notes were kept by the forecasters, as well as by the extra person (Szoke or McGinley). A written survey of the BOU–DEN EFF forecasters was also taken after the field program and a few of the forecasters took the opportunity to elaborate in more detail on the overall experience. Additionally, at the end of the field program one of the authors (Szoke) interviewed the two forecasters at the Kansas City EFF and attended a debriefing of the overall program by the principal scientists. A few months after FEST a meeting among some of the EFF participants was held, at which time the Kansas City and Norman EFF forecasters submitted more formal assessments. All of this information was used to formulate the assessment of the FEST forecasting, which is summarized here.

Among the questions in the survey, which again applies just to the BOU–DEN forecasters excluding the four AES forecasters from Canada, were two that asked the forecaster to list the three most positive and the three most negative aspects of the program. The most common positive response was "working with some of the new models (eta and MM4)." This was interesting in that both the forecasters and researchers that took part in this activity have been at the forefront of new technology and modeling as the developers and/or users of the Pre-AWIPS workstation. Perhaps this indicates a positive attitude to new information even when time to examine it might be limited, and despite the fact that the eta and MM4 output could not be examined on the Pre-AWIPS workstation. Other positive responses included the "chance to get more diverse experience" (a frequent WSFO forecaster response, indicating a desire to be more involved in EFF-type activities); "working with different forecasters" (both parties listed this as a positive, again showing the potential of an EFF); the "challenge to make forecasts" (an FSL response where most are not involved in operational forecasting); the "direct forecasting for operational decision making" (a WSFO forecaster response, implying some frustration with the lack of user feedback to most operational forecasts issued, whereas in FEST the forecasters were talking directly with the user); the "preparation of graphical forecasts" (another WSFO response, indicating that the trend toward producing graphical forecast products in the future might meet with some enthusiasm, given that such forecasts can provide a means to more completely communicate the forecasted weather); "the conference call" (most enjoyed the interaction with other forecasters at the different sites, although there was some concern about the amount of time that the call took away from forecast preparation), and the "chance to contribute to science" through a major field program.

On the negative side, the list was more difficult to summarize in that it was quite diverse. The most common complaint was that "there was too much to do in too short a time." Although during the planning stage we thought that the forecast maps, discussions, and experimental forecasts could be completed before the daily briefing, in most cases only the forecast maps and discussions were done in time to be faxed to the KC-RCF and the N-RCF, just before the briefing began at 1830 UTC. The experimental forecasts were usually done after the discussion following the daily briefing, resulting in a generally long and busy shift (typical of a WSFO day shift).

Another complaint, which undoubtedly contributed to the above problem, was that "the work environment at FSL was too confusing and had too many interruptions" (a problem familiar to operational forecasters). The forecasts were prepared in a large room that was host to diverse activities not necessarily associated with FEST, so it was impossible to isolate the forecasters. Interestingly, often the interruptions came from other scientists, both within FSL and in other parts of NOAA. Some forecasters noted that the discussions that ensued could be very useful; however, because of the limited time before the 1830 UTC FEST briefing, the luxury of such insight could usually not be afforded. The issue of principal scientific investigators who were in Boulder rather than at the KC-RCF and were "dropping by" to examine the weather before the FEST briefing highlights the tension between the desirability of one-on-one discussion between scientist and forecaster to facilitate mission planning, and the need for forecaster concentration to prepare the briefing and project forecasts under a very tight deadline.

An important negative aspect was a frustration expressed at times in dealing with the audience at the KC-RCF at the other end of the video link. A principle contribution to this problem was the inability to see certain colors clearly at the KC-RCF because the image was from a camera at FSL pointed at the projection screen, which already had a reduced image quality from that displayed at the workstation itself. Had it been feasible, a direct video connection from the workstation to the video link would have likely given a much clearer image at the KC-RCF. Such technology will likely be easier to obtain for future experiments. The interruptions ("give us the date" was a common one, indicating that it was often difficult to read some of the text that was more visible at FSL) often flustered the briefer and may have contributed to some reluctance to show more complex graphics.

Additional negative aspects expressed in the survey included the lack of familiarity with the eta and MM4 models; the general lack of proper spinup time before the program started (the two weeks set aside for this were instead spent putting all the equipment in place); and the geographical separation between the project scientists and the forecasters. An issue raised frequently was that most of the forecasters would have preferred to have had more consecutive shifts. Often by the time they became familiar with the routine, their string of three to four day forecast shifts was ending.

The nowcasting performed from the B-OCC presented additional negative comments; the overwhelming one was frustration because of the lack of meteorological display capability and information compared to that available at the nearby FSL site where the briefings were held. As noted earlier, this was due to the limited version of the Pre-AWIPS workstation at the B-OCC, a problem that could not be corrected before FEST. There were other data at the B-OCC displayable on the NCAR Field Operations Center workstation; however, the forecasters generally felt that this did not compensate for the lack of gridded NMC model output or MAPS model output. Particularly missed was MAPS, which they felt was ideally suited for the 0–6-h very short range forecasts and for providing guidance to the aircraft mission scientist. For the last major event of FEST a forecaster was actually stationed at FSL while nowcasting was conducted at the B-OCC, with information (mainly MAPS model output) faxed to both the B-OCC and the KC-RCF or discussed over the video link with the KC-RCF. During another mission to study a jet streak the researchers were also aided in their planning by the faxing of a number of products from LAPS and MAPS from the BOU–DEN EFF to the KC-RCF.

A better display device for the LAPS model would have rendered it more useful at the B-OCC, even though the model had no forecast component. The MM4 was available; although without the operator provided by NCAR/MMM at the FSL site, the model was underused. Another important source of frustration were the problems with communications with the aircraft. Although at times quite good, they were not consistently so, and this led to some problems in transferring important information to the aircraft scientists. When the communications were good and useful information could be passed along to the aircraft scientists, most of the nowcasters enjoyed the direct feedback, sensing a real involvement in the experiment. The importance of good communications and nowcasting support was also noted by Dirks et al. (1988) regarding GALE.

Many of the positive and negative factors expressed by the BOU–DEN EFF forecasters were also noted by the forecasters at the Norman and Kansas City EFFs. A consensus of a positive response concerned the chance to be part of a field program and interact with the scientific investigators. A consensus of a negative aspect involved the lack of spinup time before FEST began. The problems with insufficient spinup time were also noted for PRE-STORM (Doswell et al. 1986; Howard et al. 1986). Complicating the lack of preparation time was the fact that both operations at Norman and Kansas City became formal EFFs only a few months before FEST, so essentially both the EFF operation and its responsibilities to FEST were begun at the same time. This lack of preparation time was reflected in unreliable hardware for some meteorological displays and a lack of training on how to use the displays that were functioning correctly, as well as some uncertainty as to what was expected in terms of supporting FEST. The Kansas City EFF forecasters specifically mentioned a delay in getting one of their primary meteorological workstations operating properly until after FEST had begun. The delay was critical in that the scientists at the KC-RCF looked for meteorological information elsewhere, and when the workstation began functioning properly it was difficult to recapture their interests, despite the additional information available on the workstation.

At the Norman EFF there was a sense of being overwhelmed by the amount of new and different display devices (a likelihood noted by Howard et al. 1986) and at the same time being frustrated because some of the expected data and output were limited, difficult to display, or not available (no MAPS or eta, and unusable LAPS, for example). As an example, the Norman WSFO had far better Pre-AWIPS workstations than the more limited version available at the EFF, which caused frustration for the EFF forecasters who were attempting to issue detailed experimental forecasts. This parallels what the BOU–DEN EFF forecasters experienced when nowcasting at the B-OCC.

The comparison of the use of MM4 at Boulder and at the KC-RCF illustrates some of the problems discussed above. With little time for advanced training, the Kansas City EFF forecasters found it cumbersome to use the MM4 menu system, and this resulted in an underuse of the system. By contrast, the availability of the MM4 research model at the BOU–DEN EFF proved to be a highlight of the FEST experience. The forecasters were very receptive to using MM4 products, despite some important limitations that included unfamiliarity with the model and the Sun workstation that displayed its output, an inability to compare output directly with the other more "standard" models since MM4 was not on the Pre-AWIPS workstation, and a lack of time to look at the wealth of information from MM4 (including output at hourly intervals). A key to overcoming these obstacles was the meteorologist provided by NCAR/MMM at the FSL forecast site to help with the MM4 output and its interpretation, assistance that was regarded as an absolute necessity. A like comment was made by the BOU–DEN forecasters regarding having an extra person to bring up the eta model and display various products.

A similar problem besieged the more primitive LAPS display that was also underused at the KC-RCF, and we believe LAPS could have been useful for nowcasting had someone been assigned to operate the system. An important lesson for field programs is that there must be sufficient funding not just to provide resources (in this case the computer hardware/software and the model runs) but also for personnel to operate the equipment and possibly help interpret the displays. A possibility would be for graduate students taking part to be tasked with operating and helping to evaluate such systems.

Both the BOU–DEN and Kansas City EFF forecasters found it somewhat difficult to use the MM4 model because of rather arbitrary contour intervals used in the color displays. This made comparison with the NMC models more difficult. In response to forecaster complaints, a special set of displays from MM4 that could be compared with standard levels from the other NMC models was generated by the second week of FEST. Another contribution to the problem of trying to directly compare the models was that they were displayed on different workstations, whereas the standard NMC models were all on the Pre-AWIPS workstations. A lesson relevant to both future programs and NWS modernization is that no matter how effective a modeling system is, its potential value to the forecaster may be lost without an effective user interface. In particular, output displayed from all models (including those run locally at the WFO) must be easy to access, be displayable on a common platform if possible, where appropriate have common contour intervals, and have hard copy accessibility. Consideration should be given to these points if research models are to be fairly evaluated in an operational or pseudo-operational environment.

A final but obviously important issue for the forecasters using the MM4, eta, MAPS, or LAPS models was whether to believe the greater mesoscale detail that was often displayed. As a general assessment, forecasters commented that they were impressed with the detail but were not always sure of the verification (especially of MM4 and eta, which had forecasts farther out in time than MAPS). Unfortunately, there was not enough time for systematic post analyses and verification. This indicates that verification, consistently viewed as unimportant, should be an important function of any field program with a model assessment component. Certainly, as computer power continues to increase, the ability to run mesoscale models in real time during a field program will improve. This will provide an excellent opportunity to evaluate model performance when run in a real-time forecast mode. Although this cannot substitute for in-depth individual case studies performed after the experiment, documenting daily evaluation can reveal model characteristics that may be overlooked in studies of just a few cases that are often restricted to the more impressive events. In fact, events with more subtle meso-alpha-scale features (e.g., weak short-wave troughs) presented the greatest forecast challenge. A strong consensus in model forecasts was often absent in such cases, with the eta and MM4 often showing the most detailed precipitation, though occasionally not at the same location or time. The biggest FEST snowstorm (depicted in the forecast map in Fig. 2) was well predicted by the forecasters, who were able to correctly interpret the model differences.

A concern from both the BOU–DEN and Norman EFF forecasters, who provided written forecasts for FEST in addition to producing experimental forecasts, was that the workload was usually excessive. Consequently, the experimental forecasts were often hastily done and thus were not the tests of the effects of additional mesoscale data or model output that they were designed to be. This was particularly true of the aviation forecasts at the BOU–DEN EFF and the point temperature forecasts at the Norman EFF. Contributing to the lack of time was a working environment that did not provide enough privacy from interruptions so that the forecasts could be carefully completed. As noted earlier, however, some of the interruptions were from the scientists who wanted to better plan potential missions, indicating a desire to have more detailed forecaster involvement beyond just a project briefing. Indeed, a specific point raised by the Kansas City EFF forecasters was that they should have been involved in the mission planning meetings that followed the 1830 UTC FEST project briefings and general discussion in order to contribute such specific meteorological information. Solutions to these apparent conflicts are addressed in the next section.

4. Summary of lessons learned and suggestions for improvement

Despite what seems like a long list of difficulties discussed in the previous section, in general the "systems test" of a remote operations center with remote forecasting and nowcasting was demonstrated as being feasible. Communications and some video problems experienced presumably could be overcome as technology continues to advance. At the KC-RCF review meeting at the end of FEST, the scientists were satisfied that sufficient forecasting and support on the synoptic scale were available to carry out the missions. There was concern raised over some lack of success in diagnosing or predicting mesoscale features, a portion of which can be attributed to the underuse discussed earlier of the mesoscale analyses and short-term predictions that were available at FSL and the KC-RCF. The scenario outlined below arises from a consideration of the issues discussed in this paper, the responses of the forecasters in FEST, and the discussion from a post-FEST meeting of some of the EFF participants. It addresses a possible way to improve the forecasting and nowcasting support, as well as the potential feedback to NWS operations.

a. Collocation of forecasters and scientists

A very open debate remains as to the best means of providing forecast support. This is especially true concerning the issue of remote versus on-site forecasting. Among the most outspoken critics of the idea of not being at the common operations facility were those who also took part in Oklahoma–Kansas PRE-STORM in 1985, where the forecasters and scientists were stationed at the Will Rogers International Airport in Oklahoma City. The forecaster layout in PRE-STORM actually had the forecasters stationed at the (then) WSFO, which was "separated" by about a 5-min walk from the operations center. This short separation was felt to be an advantage in that it allowed for the desired interactions between forecaster and researcher yet permitted the forecaster to "get down to business" and finish the preparation of the daily briefing and forecast without interruption, since the distance was apparently just enough to be inconvenient for easy access. A PRE-STORM project rule that the forecaster work area was off limits to nonforecast personnel was primarily to minimize interruptions to NWS operations, but it also served to insulate the forecasters from the chaos of project operations. One of the major problems with not being collocated during FEST was a sense of not having a good feel for what the scientists were really after on a given day so that one could concentrate more on those aspects of the weather. An attempt to get this information from the EFF forecasters at the KC-RCF was made through the conference call, but this was not always effective and only represented one-way communication. Missing was the direct feedback one might get from being collocated, as well as the one-on-one interaction with the scientists in terms of conveying and discussing the forecast and its details.

Logically, using many of the arguments listed above, there would seem to be little reason one would want to be remote from the main center of operations in a field program. One important issue is whether it is more cost-effective to have a permanently located site with state-of-the-art equipment for field operations or a transportable facility. Our experience in FEST [and a similar experience in GALE (Dirks et al. 1988)] made it clear that it is critically important to have all available weather information easily displayable on state-of-the-art workstations at the forecast or nowcast site, as well as advanced communication equipment. It is possible that in the future sufficient information might be accessible from a central computer and server by a variety of smaller workstations at different locations. However, ease of use and certain display requirements like looping and overlaying fields would be necessary, at least for those workstations used by the project forecasters.

Another issue is whether the actual STORM (or any large field) program would have one main operations center or, rather, aircraft dispersed over a number of sites, in which case there would be by default no one main center of operations. It would indeed seem that one advantage of dispersion would be avoidance of oversampling one geographical area, a sort of natural selection process if most of the facilities are collocated. Although such detailed sampling may be desirable for some missions, it would be possible to accomplish over more locations if the aircraft were dispersed. In addition, systems might be followed more completely as they moved through the network if bases of operations were dispersed. The scattering of facilities might also enhance the number of sites where EFF-type activities during a field program could occur, although it is apparent that aircraft operations and EFF activities are not necessarily compatible. Perhaps the best solution would be to locate the operations center where data, processing, scientists, research aircraft, and facilities are at a maximum density, if the considerations of weather display capabilities noted above could be met. This "center of mass" concept may be applied even if operations are dispersed by necessity.

b. Five functions of field program forecast support

The support for a large field program that is envisioned is schematically illustrated in Fig. 5 and elaborated below. An EFF would be a natural place to carry out such support, with other groups also likely involved either enhancing activities at an EFF or located elsewhere.

1) ISSUING EXPERIMENTAL FORECASTS

The testing of new forecast methods and types of forecasts by issuing experimental forecasts, using mesoscale datasets or mesoscale model output that are enhanced during a field program, is an integral part of any EFF-type activity. Although such forecasting would likely be a routine EFF function, it would be at an increased level during any field program when new observations and more intensive numerical prediction activity could be evaluated and used to test new types of mesoscale forecasts. The enhanced data taken during the field program would also enable better verification of such forecasts.

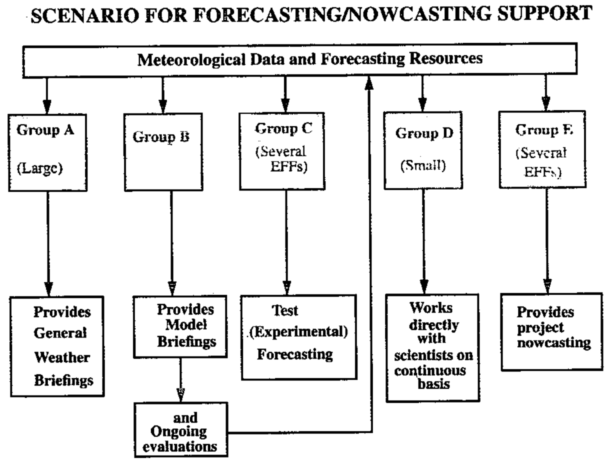

FIG. 5. Schematic showing a possible plan for forecasting and nowcasting support for a large field program.

2) REAL-TIME MODEL EVALUATION

Although the experimental forecasting would use new models, it would be desirable to have a separate model evaluation team that could closely examine the models and provide real-time verification. The "model group" would be responsible for leading a separate daily meeting (which would *not* be mandatory for all project personnel) to discuss the day-to-day model verifications, which could be extremely useful in using new research models. As noted earlier, this would help in the daily use of the models for forecasting during the project in terms of understanding the reliability of the model forecasts. Although real-time evaluation cannot replace detailed case studies done after the experiment, there are substantial and valuable systematic evaluations that can be effectively done on a real-time basis, which would be very difficult to produce after the experiment.

3) GENERAL PROJECT WEATHER BRIEFINGS

A separate team would be tasked with providing the general project weather briefings. These types of briefings are necessary to bring the entire project staff up to an "even" level and keep everyone informed, especially as the project grows in scope. Unfortunately, it became apparent during FEST that it was difficult to go into sufficient detail to satisfy everyone during a briefing that lasted only 30 min.

4) Specific mission support

This points to the need for a fourth group, which would comprise a set of forecasters and nowcasters who would work more closely with the scientists in a more "mission-specific" mode. The forecasters involved in this group would have to be familiar enough with the scientific issues so that they could provide the most useful input and at times help plan scientific missions, and actually work the entire mission (including, at times, flight participation). Such an arrangement, used during ALPEX (WMO 1982), can be quite effective. An advantage of this follow-through type of forecasting/nowcasting support is that forecast-related issues would likely be given greater consideration in the execution of scientific field operations. As noted by Doswell et al. (1986), very useful information could be gained by learning more about precursor conditions and null cases. Without a strong forecast input, such data are likely to be lacking from a field exercise since operations tend to focus more on the well-developed or mature phases of a weather event. [As Doswell et al. (1986) have pointed out, often it is deemed too risky to commit experimental resources based on a forecast.] For example, forecasters might argue for a mission to closely examine an area where they are confident a mesoscale convective system (MCS) will form. If the MCS does not form, valuable data will be obtained on a null case, and if the MCS does form, valuable data on the prestorm environment will be gathered.

5) General nowcasting

While some of the information from nowcasting support could be provided by group D (Fig. 5), nowcasting also needs to be part of an operations center that is providing aircraft coordination. The question remains whether this should be done from one main center or is the responsibility of the satellite center closest to the concentration of operations (as the nowcasting was done in FEST).

It appears that the above structure would require more staff than could possibly exist. However, one of the main complaints from the BOU–DEN FEST forecasters was that the number of shifts was too limited; in other words, the staff was available. Under the above scenario the larger forecasting staff would be divided into different groups that would provide each of the functions discussed above. Additionally, a number of EFFs and other special forecast teams could be involved in a major field effort like STORM, with components of the activities listed above divided or shared among the various groups.

c. Do not lock into "dayshift" style support

Among other lessons learned in FEST is that a briefing at 1830 UTC simply did not allow sufficient time to carefully examine the 1200 UTC model runs. Unfortunately, in most field programs it is difficult to break the "convective cycle mold," which espouses that decisions must be made early in the day, even though the weather being studied may be little influenced by the daytime heating cycle (MCSs, winter storms). To counter this tendency, one suggestion made in post-FEST meetings was to have two "daily" briefings. One would be fairly early, perhaps 0830 LT, that would by default be too early to look at any of the 1200 UTC model output but instead would concentrate on the previous evening's model runs and the new data. The other would take place about midafternoon (local time), by which time the model output could be more fully examined. Such a two-briefing plan would acknowledge the general yearning for information early in the day. It would, however, be important to make certain that the experiment personnel had the understanding that extra briefings such as the early general weather briefing and the model briefing were optional. One complaint from the scientists at the KC-RCF during FEST was the excessive number of briefings. Although it appears that more briefings are being proposed, they are more specific in nature and would not necessarily require attendance by all personnel.

d. Summary

A number of the lessons learned from FEST have some applicability to the modernization effort taking place within the NWS. The issue of a two-week spinup time [supported by the forecasters and also noted by Howard et al. (1986) for PRE-STORM] to become more familiar with the experimental procedures and the suggested MM4 "training" workshop gives testimony to the need for sufficient training with any new system or equipment. Although spinup time is often planned for a field exercise, it seldom occurs because unforeseen problems develop as the experimental period approaches. The results from FEST reenforce the necessity that such preexperiment familiarization be given a high priority.

The forecasters were quite receptive to using new models that provided more mesoscale details and to issuing new types of forecasts; however, as noted earlier, effective perusal and comparison of output from the new models was awkward since they were on different systems. Last, the issue of "information overload" (or, as L. Bosart put it, "model massacre") was prominent during the FEST forecasting, a result of an abundance of information, restrictive deadlines, and an overambitious forecast load. Unfortunately, such conditions often face the operational forecaster today and are likely to continue with an increased availability of model and observational products. Most forecasters would argue against limiting access to new data or improved models. Thus, given that a sudden increase in staffing is unlikely, more effective ways to use the information will be needed. Finding these more effective ways is one area where research programs such as STORM can make a significant difference.

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REFERENCES

Anthes, R. A., E.-Y. Hsie, and Y-H. Kou, 1987: Description of the Penn State/NCAR Mesoscale Model Version 4 (MM4). NCAR Tech. Note NCAR/TN-282+STR, 66 pp.

Auciello, Z. I., and R. Lavoie, 1993: Collaborative research activities between NWS operational offices and universities. *Bull. Amer. Meteor. Soc.,* **74,** 625–629.

Benjamin, S. G., K. A. Brewster, R. Brummer, B. F. Jewett, T. W. Schlatter, T. L. Smith, and P. A. Stamus, 1991: An isentropic three-hourly data assimilation system using ACARS aircraft observations. *Mon. Wea. Rev.,* **119,** 888–906.

Cunning, J. B., 1986: The Oklahoma–Kansas Preliminary Regional Experiment for STORM-Central. *Bull. Amer. Meteor. Soc.,* **67,** 1478–1486.

Dirks, R. A., J. P. Kuettner, and J. A. Moore, 1988: Genesis of Atlantic Lows Experiment (GALE): An overview. *Bull. Amer. Meteor. Soc.,* **69,** 148–160.

Doswell, C. A., R. A. Maddox, and C. F. Chappell, 1986: Fundamental considerations in forecasting for field experiments. Preprints, *11th Conf. on Weather Forecasting and Analysis,* Kansas City, MO, Amer. Meteor. Soc., 353–358.

ERICA Project Office, 1988: Experiment on Rapidly Intensifying Cyclones over the Atlantic. Field Operations Plan.

Furlong, E., 1992: Scientists to test new weather monitoring systems this winter in Midwest. *Bull. Amer. Meteor. Soc.,* **73,** 358–359.

Gray, B. M., 1991: CaPE experiment proceeds in Florida. *Bull. Amer. Meteor. Soc.,* **72,** 1287.

Howard, K. W., D. R. Devore, R. A. Maddox, C. A. Doswell, and K. Crawford, 1986: Fundamental considerations for designing and implementing the Experimental Forecast Center Concept. Preprints, *11th Conf. on Weather Forecasting and Analysis,* Kansas City, MO, Amer. Meteor. Soc., 359–363.

Janjic, Z. I., 1990: The step-mountain coordinate: Physical package. *Mon. Wea. Rev.,* **118,** 1429–1443.

McGinley, J. A., S. C. Albers, and P. A. Stamus, 1991: Validation of a composite convective index as defined by a real-time analysis system. *Wea. Forecasting,* **6,** 337–356.

Mesinger, F., Z. I. Janjic, S. Nickovic, D. Gavrilov, and D. G. Deaven, 1988: The step-mountain coordinate: Model description and performance for cases of Alpine lee cyclogenesis and for a case of an Appalachian redevelopment. *Mon. Wea. Rev.,* **116,** 1493–1528.

National Research Council, 1990: *Advancing the Understanding and Forecasting of Mesoscale Weather in the United States. Committee on Meteorological Analysis, Prediction, and Research.* National Academy Press, 56 pp.

Rasmussen, R., M. Politovich, J. Marwitz, W. Sand, J. McGinley, J. Smart, R. Pielke, S. Rutledge, D. Wesley, G. Stossmeister, B. Bernstein, K. Elmore, N. Powell, E. Westwater, B. B. Stankov, and D. Burrows, 1992: Winter Icing and Storms Project (WISP). *Bull. Amer. Meteor. Soc.,* **73,** 951–974.

Shea, T., and R. W. Przybylinski, 1993: Assessing vertical motion fields in a winter storm. Preprints, *13th Conf. on Weather Forecasting and Analysis,* Vienna, VA, Amer. Meteor. Soc., 10–14.

STORM Project Office, 1992: STORM Fronts Experiment System Test STORM-FEST Operations Plan. National Center for Atmospheric Research, Boulder, CO, 316 pp.

Subcommittee on Atmospheric Research, 1992: Predicting our weather—A strategic plan for the U.S. Weather Research Program. Committee on Earth and Environmental Sciences, Washington, D.C., 36 pp.

University Corporation for Atmospheric Research, 1983: The National STORM Program—Scientific and technological bases and major objectives. UCAR Report prepared for NOAA, Boulder, CO, 524 pp.

WMO, 1982: ALPEX Field Phase Report. Vol. 6A, WMO, 181 pp.

Zubrick, S. M., and E. Thaler, 1993: Enhancements to the operational forecast process using gridded model data. Preprints, *13th Conf. on Weather Forecasting and Analysis,* Vienna, VA, Amer. Meteor. Soc., 5–9.