FORECASTER'S FORUM

Whither the Weather Analysis and Forecasting Process?

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ABSTRACT

An argument is made that if human forecasters are to continue to maintain a skill advantage over steadily improving model and guidance forecasts, then ways have to be found to prevent the deterioration of forecaster skills through disuse. The argument is extended to suggest that the absence of real-time, high quality mesoscale surface analyses is a significant roadblock to forecaster ability to detect, track, diagnose, and predict important mesoscale circulation features associated with a rich variety of weather of interest to the general public.

1. Introduction

By any objective or subjective measure, weather forecasting skill has improved significantly over the last 40 years. By way of illustration, Fig. 1 shows the annual threat score for 24-h quantitative precipitation forecast (QPF) amounts of 1.00 in. (2.5 cm) or more over the contiguous United States for 1961–2001 as produced by forecasters at the Hydrometeorological Prediction Center (HPC) of the National Centers for Environmental Prediction (NCEP). The day-1 threat score has improved from roughly 0.16 to 0.25 over this 41-yr period, a skill improvement of more than 50%. The day-2 threat score has similarly improved from near 0.07 to near 0.20, and the day-2 threat scores in recent years are at the level of the day-1 threat scores for the 1975–80 period. The trend in the day-2 threat score is mirrored by the day-2 ''update'' (a later forecast for day 2 issued after the initial day-2 forecast was released) that ceased after 1998. Day-3 forecasts commenced in 2000, and the threat scores for the 2-yr sample are roughly comparable to the day-2 threat scores produced in 1990. For perspective purposes, the annual cumulative areal extent of events of 2.5 cm or more precipitation over the contiguous United States ranges from roughly 40×10^6 to 70×10^6 km^2.

A different perspective on QPF skill is afforded by Fig. 2, which shows the annual HPC forecaster threat scores for day-1 24-h QPF amounts of 1.00 in. (2.5 cm) or more for 1991–2001. Also shown in Fig. 2 are 24-h day-1 QPF scores made by selected NCEP models, including the Nested Grid Model (NGM; Hoke et al. 1989), the Eta Model (Black 1994), and the Aviation Model [AVN, now called the Global Forecast System (GFS); Kanamitsu et al. (1991); Kalnay et al. (1998)]. The key point to be made from Fig. 2 is that HPC forecasters have been able to sustain approximately a 0.05 threat score advantage over the NCEP numerical models during this 12-yr period (and longer, not shown) despite the steady improvements to numerical weather prediction models in general and an increase in the associated model QPF skills in particular. This continuing skill advantage by HPC forecasters over the models represents an extraordinary achievement and is indicative that dedicated and trained forecasters can extract maximum advantage from improvements in operational weather prediction models to improve further their QPF skills to the benefit of forecast users and the general public. Also of interest from Fig. 2 is that the steady increase in skill of the NGM from 1991 through 1998 likely indicates ongoing improvements to the global analysis and initialization schemes, given that the NGM has been a ''frozen'' model since 1989. In this context, the sharp plunge in NGM forecast skill beginning in 1999 is puzzling and may indicate some internal ''tweaking'' of the model and/or the analysis and initialization scheme without formal documentation in the refereed literature.

The focus of this note is on the difficulties that can arise in trying to keep human forecast skills honed in an environment of steadily improving model forecasts and model-generated guidance. My contention is that roadblocks to real-time monitoring and analysis of mesoscale weather systems must be removed if human

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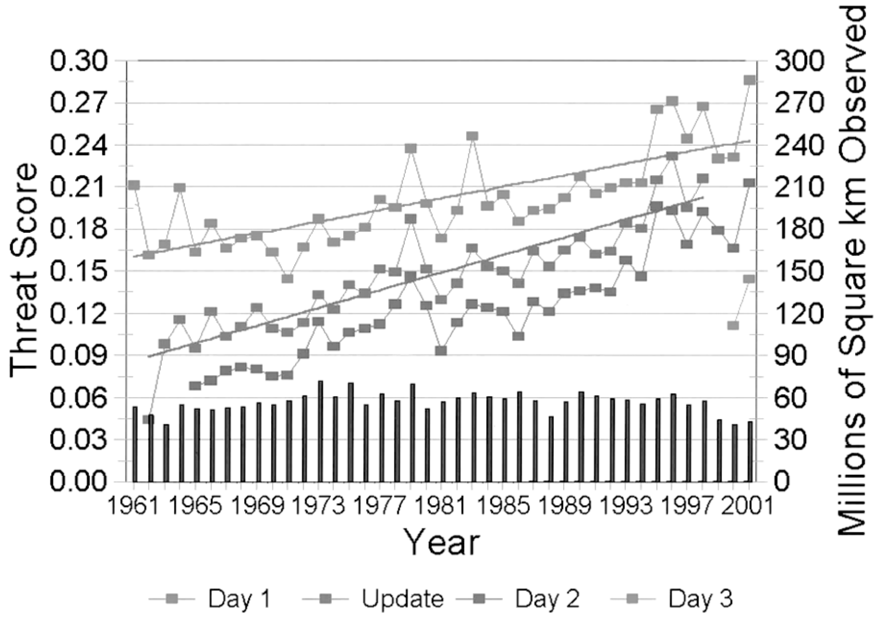

FIG. 1. (left) Annual NCEP/HPC threat scores for 24-h precipitation forecasts of 1.00 in. (2.5 cm) or greater for (top) day 1, (middle) update, (bottom) day 2, and (bottom right) day 3 (2000 and 2001 only) for 1961–2001 for the contiguous United States. (right) Annual cumulative areal extent of all observed rainstorms of 1.00 in. (2.5 cm) and greater is given by the histogram plot along the bottom (10^6 km^2). (Figure downloaded from www.hpc.ncep.noaa.gov.)

forecasters are to continue to extract the maximum advantage from steadily improving model and guidance forecasts as NCEP/HPC forecasters have done for several decades now (as noted above).

2. The weather analysis and forecasting process

a. Background information

Attention is now directed to the ''mischief'' and problems that can arise when human forecasters are not always actively engaged in the forecast process (broadly defined). One possible way to envision the weather analysis and forecasting process is shown in Table 1. All six elements listed in Table 1 must be addressed if the weather analysis and forecast process is to work properly. In reality, however, it is possible to ''cheat'' and to focus only on item 5 in Table 1 (What is going to happen?). This situation can arise because the NCEP (and other) operational prediction models have improved to the point that statistical–dynamical forecasts of 24-/48-h maximum and minimum temperature and probability of precipitation derived from model output [e.g., model output statistics (MOS); Glahn and Lowry (1972)] have become routine and are very competitive with similar forecasts produced by National Weather Service (NWS) and private-sector forecasters.

Vislocky and Fritsch (1995) carried the MOS analysis one step farther. They examined the skill of 597 participants in the 1994/95 National Collegiate Weather Forecasting Contest (NCWFC) and compared the skills of the forecasters relative to three combinations of MOS and direct NCEP model output as follows: 1) NGM MOS temperatures plus NGM explicit precipitation, 2) AVN MOS temperatures plus Eta explicit precipitation, and 3) consensus NGM–AVN MOS temperatures and NGM–Eta explicit precipitation. They found (their Table 8) that the AVN MOS temperatures plus Eta precipitation (NGM MOS temperatures plus NGM precipitation) ranked 108th (187th) out of 597 forecasters. For comparison purposes, forecasts of ''persistence'' and ''climatology'' ranked 558th and 594th, respectively (it is presumed that the three human forecasters who lost to climatology are now in administrative jobs somewhere). The overall performance by the NGM and AVN MOS and NGM and Eta explicit precipitation forecasts in the 1994/95 NCWFC was clearly very respectable. Much more impressive, however, was the performance of the consensus NGM–AVN MOS temperature plus NGM–Eta explicit precipitation. The model consensus forecast ranked 17th and beat the human consensus, which was at 59th. That a model consensus forecast should do much better than individual model forecasts should be no surprise and is strikingly similar to the results for human consensus forecasts (e.g., Sanders 1963; Bosart 1975).

b. Application to the 25 January 2000 ''surprise'' snowstorm

Given the results of Vislocky and Fritsch (1995) and others (not shown), it is perhaps not surprising and is

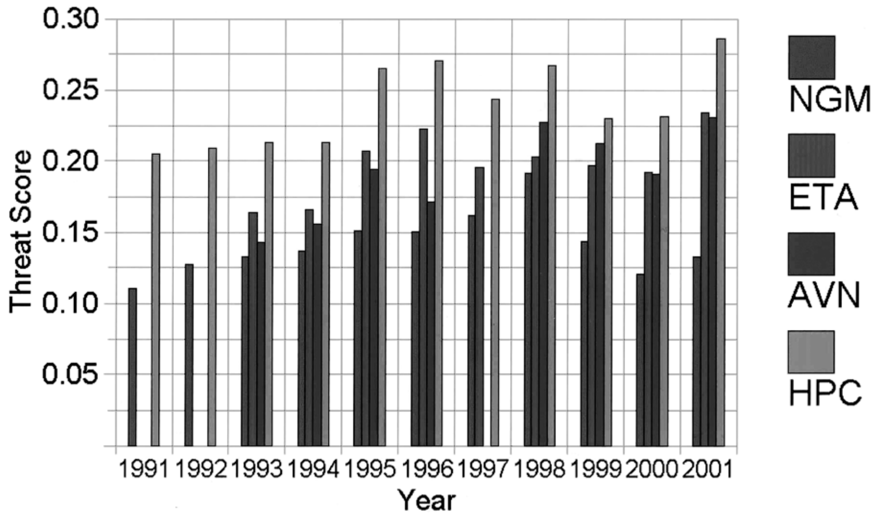

FIG. 2. Annual NCEP/HPC threat scores for 24-h precipitation forecasts of 1.00 in. (2.5 cm) or greater for day 1 for 1991–2001. Shown for comparison are the threat scores for the explicit day-1 precipitation forecasts from the NCEP NGM, Eta, and AVN (now GFS) models. For a given year the bars from left to right indicate NGM, Eta, AVN (GFS), and HPC. (Figure downloaded from www.hpc.ncep.noaa.gov.)

readily understandable that human forecasters can cheat by placing most (or all) of their emphasis on item 5 in Table 1. They can get away with this strategy because the vast majority of the time MOS temperature forecasts and explicit model QPF are highly competitive with similar forecasts made by individual humans. As a consequence, there is a risk that human forecasting skills can atrophy over time from disuse (Snellman 1977). Forecasters who grow accustomed to letting MOS and the models do their thinking for them on a regular basis during the course of their daily activities are at high risk of ''going down in flames'' when the atmosphere is in an outlier mode.

A classic example of this problem occurred during the 25 January 2000 surprise snowstorm over the eastern part of the United States (e.g., Zhang et al. 2002). The NCEP NGM, Eta, and AVN model forecast runs initialized through 1200 UTC 24 January 2000 were all forecasting a developing East Coast storm to be sufficiently far enough offshore to spare the major cities along the Interstate-95 corridor from North Carolina to New England a major snowstorm. Human forecasters took the model bait hook, line, and sinker, and the result was a consistent forecast of ''no snow'' in the Washington, D.C., area for 25 January through the early evening hours (and in the local news) the day before. Nearly everyone (in effect) elected to go down with the sinking forecast ship all guns blazing. The agonizing reappraisal began as a trickle after the 1800 UTC 24 January AVN run was received, turned into a roaring stream after surprise 2.5–5.0 cm h^{-1} snowfall rates broke out in the Raleigh–Durham, North Carolina, region after 0000 UTC 25 January, and then became a raging torrent after the first NGM and Eta forecasts were received from the 0000 UTC 25 January model runs as the Carolina snows accumulated rapidly and spread into southern Virginia. Although the forecast reappraisal came in time to allow responsible regional officials in the Washington, D.C., area to have sanders, salters, and plows operational before morning and thus to avert a regional transportation disaster, it was too late to warn many members of the general public in the D.C. area who had already gone to bed blissfully content that the next morning would dawn cloudy (at worst) and dry. Still, the weather analysis and forecast process failed on 24 January 2000 as the now-famous boldface headlines and highly critical articles of the ''snow job'' in the *Washington Post* (and other newspapers) the next day made abundantly clear.

TABLE 1. The weather analysis and forecasting process.

1) What happened?
2) Why did it happen?
3) What is happening?
4) Why is it happening?
5) What is going to happen?
6) Why is it going to happen?

It is my contention that some of the damage to forecaster credibility in the 25 January 2000 storm was self-inflicted. Shown in Fig. 3 is the water vapor (WV) image for 1215 UTC 24 January 2000. A clear signal of classical extratropical cyclogenesis is already apparent in the form of the ''S shaped'' back edge to the area of the mid- and upper-level WV over Georgia and the western Carolinas. This classic S-shaped WV signature, also seen in the operational NWS Doppler radar imagery (not shown), was first evident in the WV image for 0615 UTC 24 January 2000 (not shown). (A reviewer pointed out that an apparent sounding miscoding problem

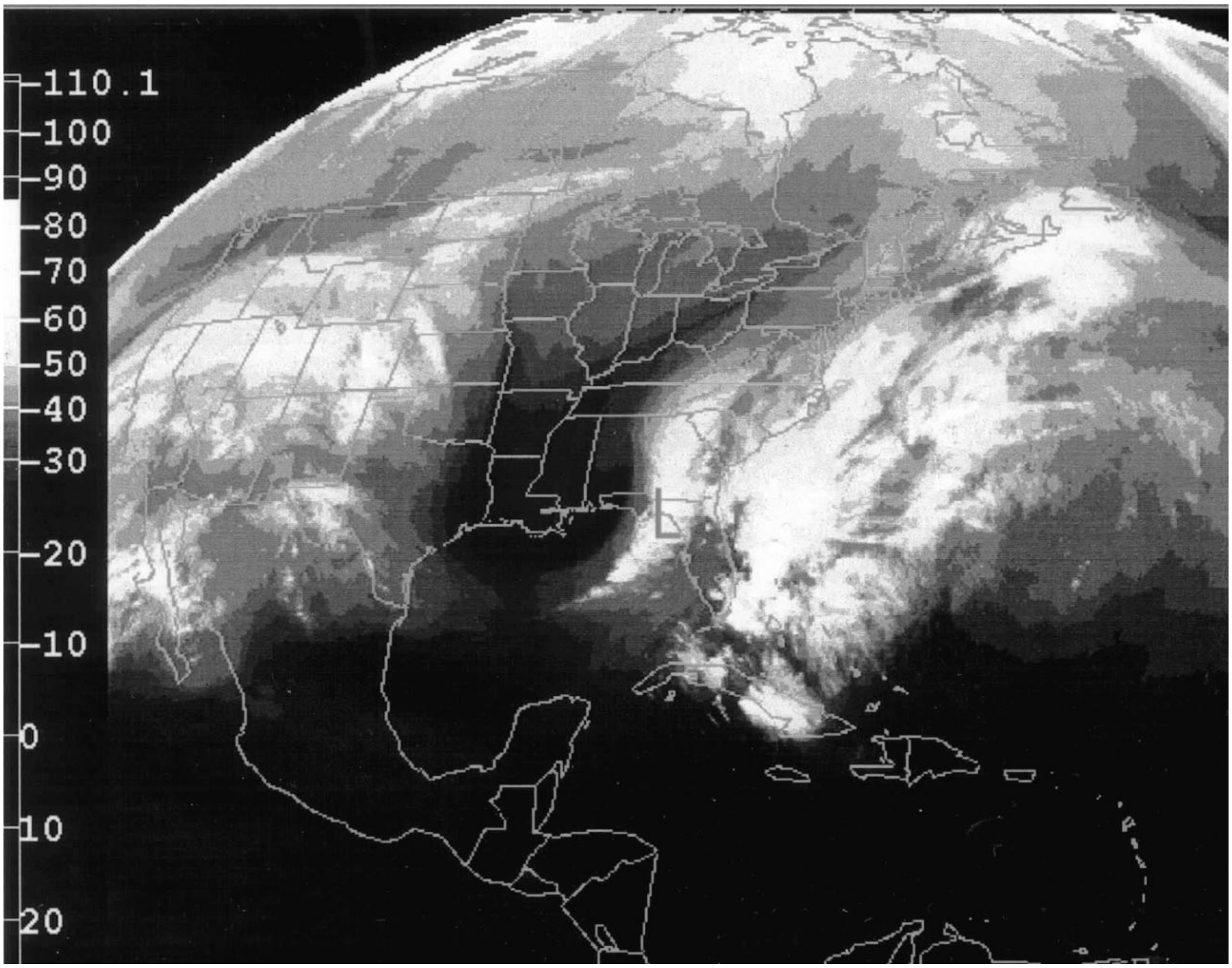

FIG. 3. Water vapor image for North America and vicinity for 1215 UTC 24 Jan 2000.

caused the automated NCEP quality-control program to exclude all data from 200 hPa and above from the 0000 UTC 24 January 2000 Dodge City, Kansas, sounding. The resulting loss of a legitimate 80 m s^{-1} jet-level wind maximum at 200 hPa may have partially compromised the analysis of a mesoscale upper-level disturbance that was dropping southeastward toward the Gulf of Mexico coast and that later influenced the developing trough shown in Fig. 3. This situation illustrates the potential hazard of running automated quality-control systems on autopilot and suggests the importance of local quality control before sounding data are transmitted to NCEP.) Subsequent WV images (e.g., 1815 UTC 24 January 2000; not shown) only acted to reinforce the ominous news of cyclogenesis occurring stronger and closer to the coast than forecast by the NCEP models runs initialized through 1200 UTC 24 January 2000. It is clear that a majority of forecasters, addicted to MOS and the models, failed to smell a rat and chose to ignore compelling observational evidence pointing to a strong coastal storm. My working hypothesis is that forecaster failure to consider and act upon items 1–4 and 6 in Table 1 likely contributed to the forecast ''conflagration.'' The massive forecast failure in the face of compelling observational evidence that the model and guidance forecasts were ''going off the rails'' also raises the possibility that forecaster big-picture satellite and radar analysis and interpretation skills have deteriorated from disuse. This conjecture needs to be explored.

c. *Problems detecting mesoscale systems*

Closely linked to the larger-scale WV imagery interpretation problem is the difficulty of detecting and documenting many mesoscale weather systems in real time. Bosart et al. (1998) used surface mesoanalyses based on principles originally elucidated by Fujita (1955, 1963) to identify three distinct mesoscale circulation features that were responsible for the bulk of the observed precipitation and were mostly undetected and unforecast in conjunction with the East Coast storm of 4 January 1994. As seen in this and other storms, a potential problem is that mesoscale weather systems can often hide in plain sight for the reasons given in Table

TABLE 2. Possible reasons why mesoscale weather systems can hide in plain sight.

1) Detailed quality real-time mesoanalyses are generally unavailable.
2) Disparate observations are synthesized inadequately.
3) Routine synoptic-scale surface analyses are often degraded.
4) Quality problems persist with Web-based analyses.
5) There is too much looking and not enough seeing.

2. Given that it is hard enough to find quality real-time synoptic-scale surface analyses (e.g., Sanders and Doswell 1995), it is probably not surprising that trying to find quality real-time mesoscale analyses is even more difficult. The absence of reliable-quality national mesoanalyses on a regular basis makes it very difficult for a forecaster to address items 1–4 in Table 1. Fujita (1955, 1963) pioneered the development of surface mesoanalysis based on the concept of time-to-space conversion and the synthesis of disparate observations. Although mesoscale analyses can be prepared in a research mode using Fujita's method, very few students or meteorologists are willing to invest the time and effort needed to learn how to construct research-quality mesoscale analyses. To reinforce this point, in my 33 years in the classroom the number of students who have had the motivation and ''gumption'' to learn how to produce research-quality surface mesoanalyses can be counted on the fingers of both hands. There is a critical difference between ''seeing'' and ''looking'' when it comes to detecting mesoscale features in surface analyses. There appears to be too much of the latter and not enough of the former in operational practice.

Until fairly recently, it was common practice at NCEP (and other operational centers) to ignore surface observations in data assimilation and initialization. The justification for doing so was that surface observations were unrepresentative of conditions on the scale of model grid volumes and that model assimilation and initialization procedures would ''spin up'' a dynamically consistent ''surface'' analysis. From the perspective of mesoscale meteorologists and operational forecasters, however, this strategy seemed to be counterproductive because the observations of which we have the most were the ones least used. Part of the problem is that until very recently (see Koch and Saleeby 2001) it has been very difficult to ''teach'' a computer how to make a quality mesoanalysis. Indeed, Sanders and Doswell (1995) and Sanders (1999a,b) have recently stressed the scientific importance and operational utility of preparing detailed surface mesoanalyses of potential temperature and other quantities such as mixing ratio to help to identify critical surface boundaries and true fronts. Sanders (2000) provided an example of the application of detailed surface mesoanalyses of potential temperature to uncover the role of frontogenetical forcing in a serious inland flooding event. Last, Sanders and Hoffman (2002) presented a climatological description of surface baroclinic zones and illustrated it with representative examples.

d. The lower Mississippi rainstorm of 16–17 November 1987

The mesoscale analysis challenge can be illustrated with an example. On 16–17 November 1987, heavy rains in amounts upward of 50–60 cm fell over the lower Mississippi River valley in conjunction with twin mesoscale convective systems (MCSs) that formed in conjunction with mesoscale disturbances in the upper troposphere that rotated through the base of a larger-scale trough (Bracken and Bosart 1994). A noteworthy feature of this case was the existence of long-lived, well-defined wake lows and wake troughs associated with the MCSs. Depiction of the actual surface mesoscale pressure and wind structure in routine analyses posed a real challenge, however. The NCEP–National Center for Atmospheric Research (NCAR) reanalysis (Kalnay et al. 1996; Kistler et al. 2001) sea level pressure distribution for 1800 UTC 16 November 1987 is presented in Fig. 4. The surface pressure pattern depicted in this large-scale analysis is highly smoothed as would be expected from a $2.5° \times 2.5°$ analysis. A 1006-hPa low pressure center is situated over northern Louisiana at the southern end of a north–south-oriented trough. The corresponding manually prepared real-time NCEP surface analysis is shown in Fig. 5. Although the cyclone is deeper (1003 vs 1006 hPa) and is shifted somewhat farther southward in the manual NCEP surface analysis, there is overall good agreement between Figs. 4 and 5 with the exception that the manual analysis shows more of a trough in northwestern Mississippi.

The corresponding manually prepared research mean sea level pressure analysis for the same time is depicted in Fig. 6. This analysis was prepared using the time-to-space mesoscale analysis method described by Fujita (1955, 1963). The surface observations (both regular hourly and special observations) from first- and second-order NWS stations, Federal Aviation Administration stations, and military stations were manually digitized from the original weather records obtained from the National Climatic Data Center. All available microbarogram records (usually a 7-day clock) were also digitized and were used to derive time-to-space off-time pressure observations. This last step was accomplished by blowing up the microbarogram traces on a copier to facilitate data reading, data transcription, and time checks. Base maps with plotted hourly and space-shifted observations, and copies of segments of the blown-up microbarogram traces, were then taped to a classroom blackboard. Manual analyses derived from this procedure were then fine-tuned by overlaying 16-mm microfilm radar imagery for individual NWS radar sites on top of the base maps. This last step was accomplished by manually optimizing the distance of the 16-mm projector from the blackboard so that the distance scale on

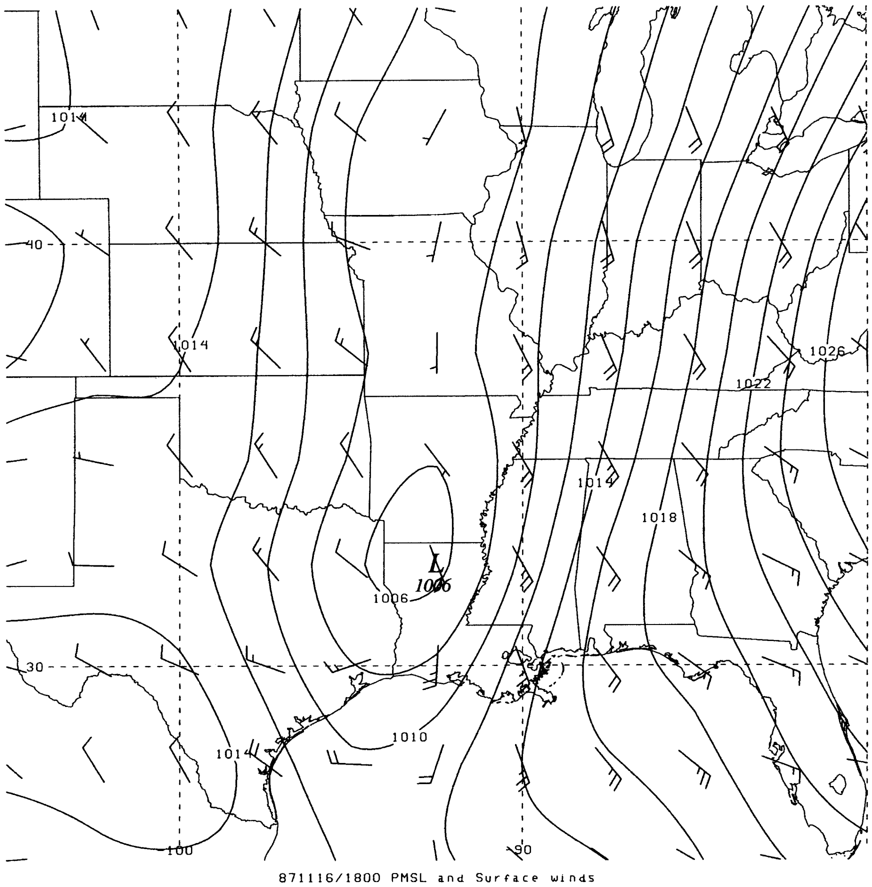

FIG. 4. NCEP–NCAR-reanalysis mean sea level pressure analysis (solid contours every 2 hPa) for 1800 UTC 16 Nov 1987. Winds in knots are plotted according to standard convention (barb is 10 kt; half barb is 5 kt).

the plan position indicator radar display closely matched the scale on the base maps taped to the blackboard. Comparison of Fig. 6 with Figs. 4 and 5 quickly shows that the research-mesoscale analysis is able to represent wake troughs (e.g., Pedgley 1962; Williams 1963; Johnson and Hamilton 1988; Loehrer and Johnson 1995; Johnson 2001), bubble highs (e.g., Fujita 1963; Johnson 2001), and large-amplitude inertia–gravity waves (e.g., Bosart et al. 1998; Koch and Saleeby 2001) associated with the MCSs. A similar analysis at 2100 UTC 16 November 1987 (not shown) shows the progression and evolution of the prominent mesoscale sea level pressure features. The bottom line is that a comparison of Figs. 4–6 shows that significant mesoscale weather systems can easily ''hide'' within routine automated and manual surface synoptic-scale analyses.

3. Concluding discussion

The purpose of this note was to raise two issues related to the weather analysis and forecasting process. First, there is a risk that human forecaster skills will atrophy from disuse in an environment in which the quality of the numerical models and forecast guidance is steadily improving unless steps are taken to ensure that forecasters remain actively engaged in the complete weather analysis and forecasting process. Second, progress in detecting, analyzing, and forecasting important mesoscale weather systems is hindered by the inadequate synthesis of disparate observations and the lack of real-time high quality surface mesoanalyses on a national basis.

Progress on the first problem requires an appreciation that with 120+ local NWS forecast offices the individual county warning areas are too small to permit forecasters to experience the rich variety of weather that is common to mobile synoptic-scale weather systems. The risk that individual forecasting skill will atrophy is high if forecasters are always forced to view the weather analysis and forecasting process from the perspective of a stamp on an envelope. One possible solution to this perceived problem might be the creation of a national winter weather desk at NCEP to address the multiscale aspects of forecasting winter storms. Forecasters from individual NWS offices could be rotated through the NCEP winter weather desk for training and experience.

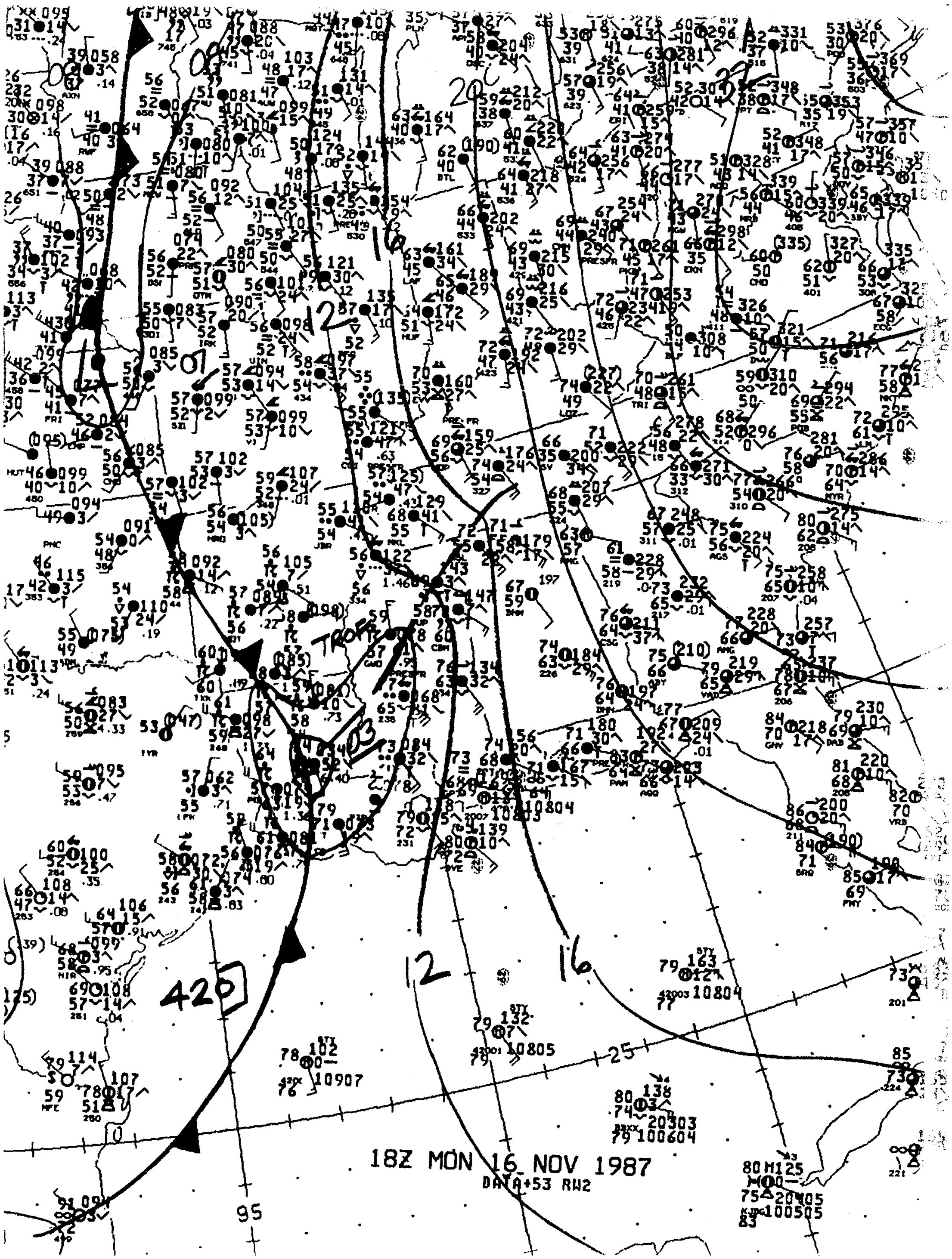

FIG. 5. As in Fig. 4, but for the NCEP manual mean sea level pressure analysis (contours every 4 hPa).

As an alternative, forecasters on station might also be able to take advantage of virtual weather simulations (e.g., the new NWS weather-event simulator) to hone and perfect their weather analysis and forecast process skills.

Progress on the second problem requires an appreciation that although most of the weather that the general public really cares about is associated with mesoscale features embedded in larger-scale circulation features, these mesoscacle features are at risk of going undetected

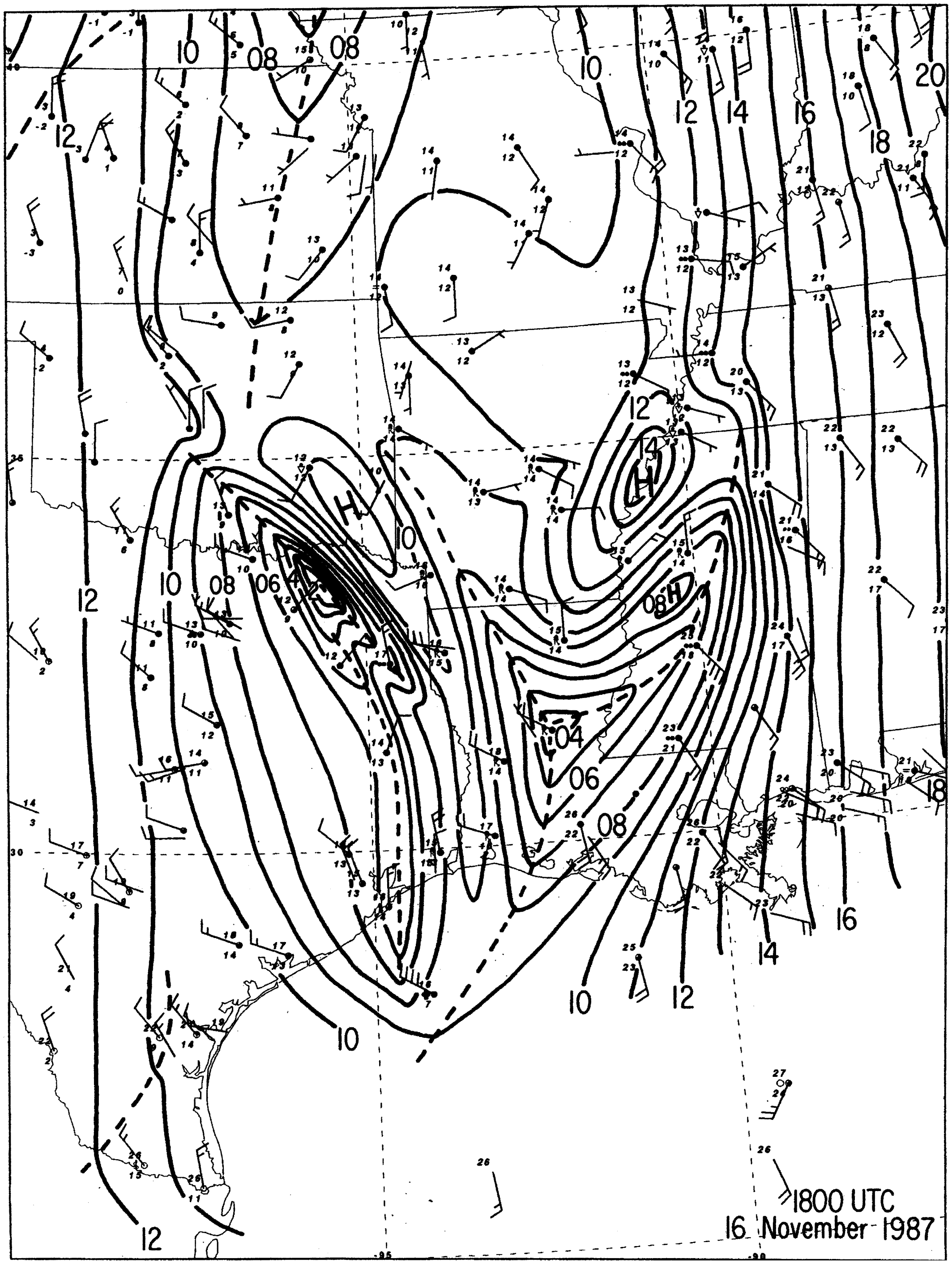

FIG. 6. As in Fig. 4, but for the manually prepared research analysis. Mean sea level pressure is contoured every 1 hPa. Dashed contours denote positions of surface troughs.

in the absence of real-time, high quality surface mesoscale analyses. It is imperative that real-time, high quality mesoanalyses be perfected and made operational on a national basis to address this problem. A forecaster cannot understand, let alone predict, what he or she cannot see. It is also critical that greater use be made of the abundant observations that we already possess in the preparation of detailed surface mesoanalyses. Although it is impractical to expect every NWS forecast office to develop the expertise to prepare real-time, high quality mesoanalyses, this necessary task might be accomplished regionally and/or nationally through a combination of objective and manual procedures. Successful implementation of national real-time mesoanalyses will also require critical managerial oversight to ensure that observations from disparate mesoscale data networks are quality controlled and assimilated properly and that data taken but generally not used (e.g., 1-min Automated Surface Observing System observations) are also extracted, processed, and assimilated.

A related problem is that a substantial and increasing portion of the population of the United States now lives within 100 km of a coastline. Because of this population increase and migration toward the coast, the waters within 100 km of the coast are seeing a corresponding rapid increase in commercial, recreational, and military activity. Given this increase in human activity in the coastal waters, it is increasingly urgent that attention be devoted to the preparation of real-time mesoanalyses for the coastal strip and offshore waters from a public safety perspective. The first oceanic mesoanalyses were presented by Sanders (1972). He collected and analyzed meteorological data obtained from many sailboats caught in unexpected severe squalls during the June 1970 Bermuda Yacht Race to construct the first oceanic mesoanalyses of a severe-weather event at sea. His oceanic mesoanalyses, not subsequently duplicated to my knowledge, revealed the existence of important mesoscale convective lines and mesoscale vortices, both associated with high winds that disrupted the fleet, that were unknown to forecasters and models of the day alike. Because of the curvature of the earth and the placement of some NWS coastal Doppler radars in elevated locations, the wind structure in the marine boundary layer is only partially sampled (at best) in the immediate coastal waters. To obtain critical mesoscale data in the offshore waters will also require enhancing and expanding atmospheric and oceanic data collection platforms in the nearshore waters using direct (e.g., moored buoys) and indirect (e.g., satellite-derived scatterometer winds) measurements.

Last, there is increasing emphasis in the public and private sector on making automated forecasts on finer and finer spatial and temporal scales using direct fields output from high-resolution mesoscale prediction models. Although high-resolution mesoscale numerical models are capable of simulating all kinds of mesoscale detail, it is by no means obvious how to sort out the limited wheat from the abundant chaff in such forecasts. The absence of independent high-resolution, real-time mesoscale analyses makes it very difficult for forecasters to evaluate critically the abundance of detailed output from these models. Just because one can now generate, say, model hourly surface temperatures on a 2-km grid does not automatically mean that forecasters, let alone the general public, should pay any attention to such forecasts without some form of manual and automated quality control. Also, one could ask how it will be possible for human forecasters to assimilate properly the output from high-resolution mesoscale model runs and produce, say, hourly temperature forecasts for hundreds of points within an individual county warning area in the absence of a detailed knowledge of model biases and in the absence of independent high-resolution mesoscale analyses. It may turn out that the only practical way to sort out the wheat from the chaff in mesoscale models will be through MOS-like statistical–dynamical and ensemble techniques applied directly to mesoscale model output parameters. Perhaps this issue will be addressed in the future in conjunction with the verification of mesoscale weather forecasts prepared for special events such as the Atlanta (1996) or Salt Lake City (2002) Olympics.

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