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Limitations on NOAA's Ability to Forecast the Weather: A Brief Statement

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LIMITATIONS ON NOAA'S ABILITY TO FORECAST THE WEATHER: A BRIEF STATEMENT

The weather service was first established by Congress to warn of hazardous weather extremes, and this remains its prime mission. NOAA's increasing ability to do this over the years has come from many sources, which can be grouped into three broad classes. I will state these negatively, as limitations on our ability to forecast. Although these limitations have been relaxed over the years, they are still with us. At times, one or another limitation dominates, but for continued progress, all must be pressed. The three factors are limitations on 1) data, 2) understanding, and 3) processing capability. I expand on these below.

1. Data. Information about the current state of the atmosphere and oceans is limited. In part this is due to the state of the art in the technology of observing, but is also due in part to limited resources. The greatest weakness in the observing system of importance to the continental United States is over the eastern half of the Pacific Ocean. That area is upstream from the U. S., and the result of sparse data there shows up in comparisons of our forecast skill over eastern and western U. S. Forecasts by NMC for the area west of the meridian through Denver are systematically inferior to those to the east. Technology exists that could be used greatly to enhance the data base over the eastern Pacific. An example would be dropsondes from reconnaissance aircraft flying carefully chosen routes. Even for the West, this limitation is not overriding; relaxation of the other limitations would lead to improvements.

2. Our understanding of the physical processes involved and our knowledge of the appropriate methodologies and equations. Good examples of this limitation are for tornadoes, isolated thunderstorms, and the intensification of hurricanes, none of which are well understood. Relaxation of this limitation is largely a matter of time, for it involves the unknown, and therefore research and learning. The pace is affected, however, by the amount of resources devoted to it. Neither this limitation, nor the first one, is now overriding for the relatively large atmospheric systems that NMC deals with, especially for the eastern half of continental U. S.

3. Our capability to process information in a timely fashion. This limitation involves availability of manpower and the manageability of the data processing problem itself. More to the point of this discussion, however, are the state of the art in computer technology, and the availability of the fastest computers to NMC.

Essential to the advances in weather forecasting that have occurred during the past 20 years have been several spectacular breakthroughs in computer power. These have led to NOAA's present operational computer, the IBM 360/195, being 600 times faster than NOAA's first, the IBM 701. Figure 1 shows an example of the result on skill in forecasts issued to the public from WSFO's.

These statistics, like most others, are for forecasts made every day, at least once per day. They therefore do not clearly reveal successes and failures for extreme changes of weather, for example onsets of cold waves. Such changes are infrequent, and progressive ability to predict them tends to get lost in annual or similarly long-term averages. Although infrequent, extreme events are of paramount importance to the public, and indeed are the original raison d'etre for the forecast service. I believe we have substantially improved our performance in predicting extreme events during the past twenty years, but little documentation exists. Certainly last week's storm (February 6-7, 1978) that crippled the Northeast provides an example of a quality in guidance products that NMC could not have begun to attain a decade ago.

Among all the forecasting services, even with the many improvements, one stands out like a sore thumb. It is the forecasting of heavy precipitation. For 15 years, our statistics on the skill of NMC guidance for rainfall accumulation of over one inch during the first 24-hours have been level. Here again, our overall statistics may be hiding some significant improvements, but they can't be very great if they are not reflected at all in statistics.

Heavy precipitation is an infrequent event, and is hazardous. It causes flash floods, we have very recently several times seen its effects when it is in the form of snow, and it causes traffic accidents and ties up transportation. Furthermore, it is of vital importance to such interests as water management and agriculture. Forecasting heavy precipitation is thus a prime mission of the National Weather Service.

We are on the verge of substantially increasing our skill in precipitation forecasting. We will need, however, access to a much faster computer than the IBM 360/195, in order to produce the improved guidance in a timely fashion. The reason is that more computations will have to be made. The key to the problem is higher resolution in our models--more levels in the vertical, but in particular, more closely spaced points in the horizontal.

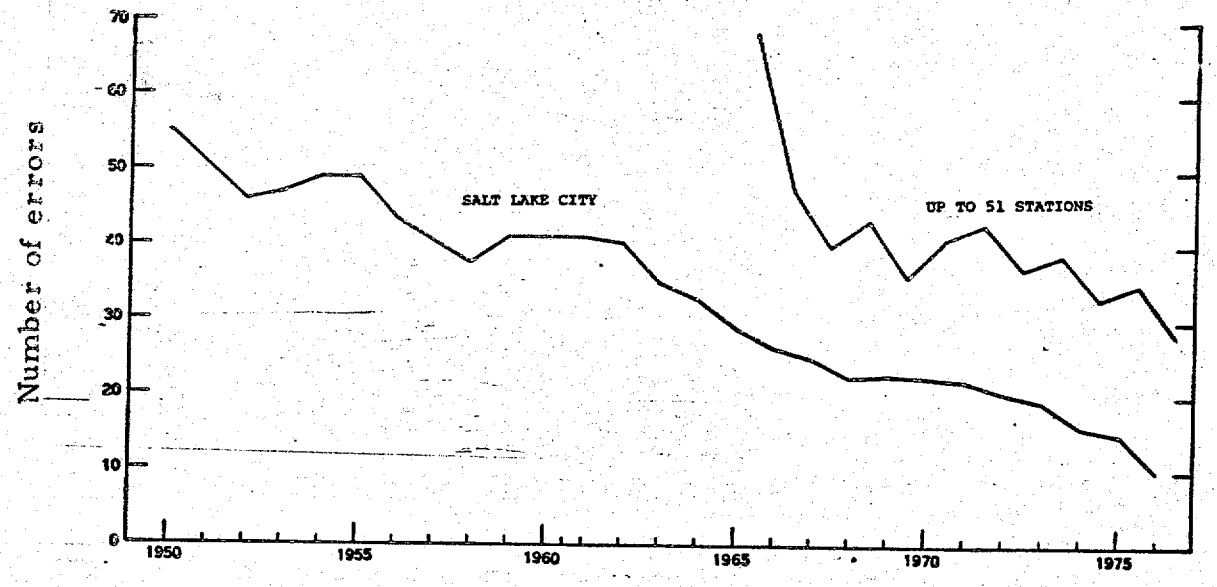

Figure 1 Forecast temperature errors greater than 10°F. Salt Lake City is the only station that has kept a consistent record of this for over 20 years, and its record is shown to illustrate improvements over a longer period. The shorter record is for forecasts local to WSFO's, which are scattered fairly uniformly about the country, and is the average number per WSFO. Both curves are for forecasts 36-48 hr in advance. The Salt Lake City record is for one forecast per day (365 each year). The shorter record is for two forecasts per day, but only for the colder half of the year, Oct. 1 to Mar. 31. The difference in level of the two curves is largely due to two factors. 1) It is more difficult to forecast temperature in the colder seasons because temperature variations are larger. 2) The variation of temperature over the Great Basin is smaller than elsewhere, for example, over the Great Plains. To remove large fluctuations that appear year-to-year in single-station records, data for Salt Lake City have been smoothed with weighting factors 1:2:4:2:1.

Figure 2 illustrates the problem. The main observed pattern of over 1" is on a long axis from the Gulf of Mexico to Maine, with several smaller patches scattered west of the main pattern. Patches with over 2" are scattered about the main axis. Note the hatch of four intersecting line segments forming a square, drawn over the Atlantic on the left-hand chart. The intersections are a sample of four adjacent grid points of the model used to make the forecast on the right. Note that even the largest observed area of over 1" is not very well defined by such a grid interval. There are not more than three grid points to define the variation across the axis. Even worse, most areas with over 2" would fit neatly within the box whose corners are grid points.

The forecast on the right in Figure 2 was made operationally at NMC, with a model implemented just a week before the storm. The model only captured the pattern about the main axis, and even it is too fat. It gave ample notice to forecasters in the East of the likelihood of over 2", but it could do little in locating such events accurately.

The 1" (liquid equivalent) over Ohio, Michigan, and Indiana fell in the form of more than 10 inches of snowfall, and paralyzed some sections for days. From the standpoint of service, this failure of the forecast was its principal weakness.

NMC has been experimenting with more highly resolved models, particularly during the past year. The technical problem involved is that the atmosphere for our purposes is a continuous medium, whereas computers are digital and can only handle sets of discrete data. Approximations must therefore be made to the physical prediction equations. The larger and faster that computers become, the more the errors of approximation can be reduced. A contributing factor is that, for the forecast to be useful, a limited amount of time is available to complete the calculations. The reduction of errors is accomplished in a straightforward way. With faster computers, we can perform the same calculations at more points and still meet operational deadlines. With the additional points, the spacing between the points is smaller, and the continuous nature of the atmosphere is more closely approximated.

Figure 3 shows the effects on precipitation forecasts of reducing this kind of error for a particular case. Only areas of 12-hourly accumulation of precipitation over one inch are shown. The "operational" forecast was made with one of our new models, the so-called 7L PE (for seven-layer primitive equations), whose spacing between points is about 175 kilometers. The grid used for the experimental forecast has a spacing of about 100 km. It also has more levels (10) in

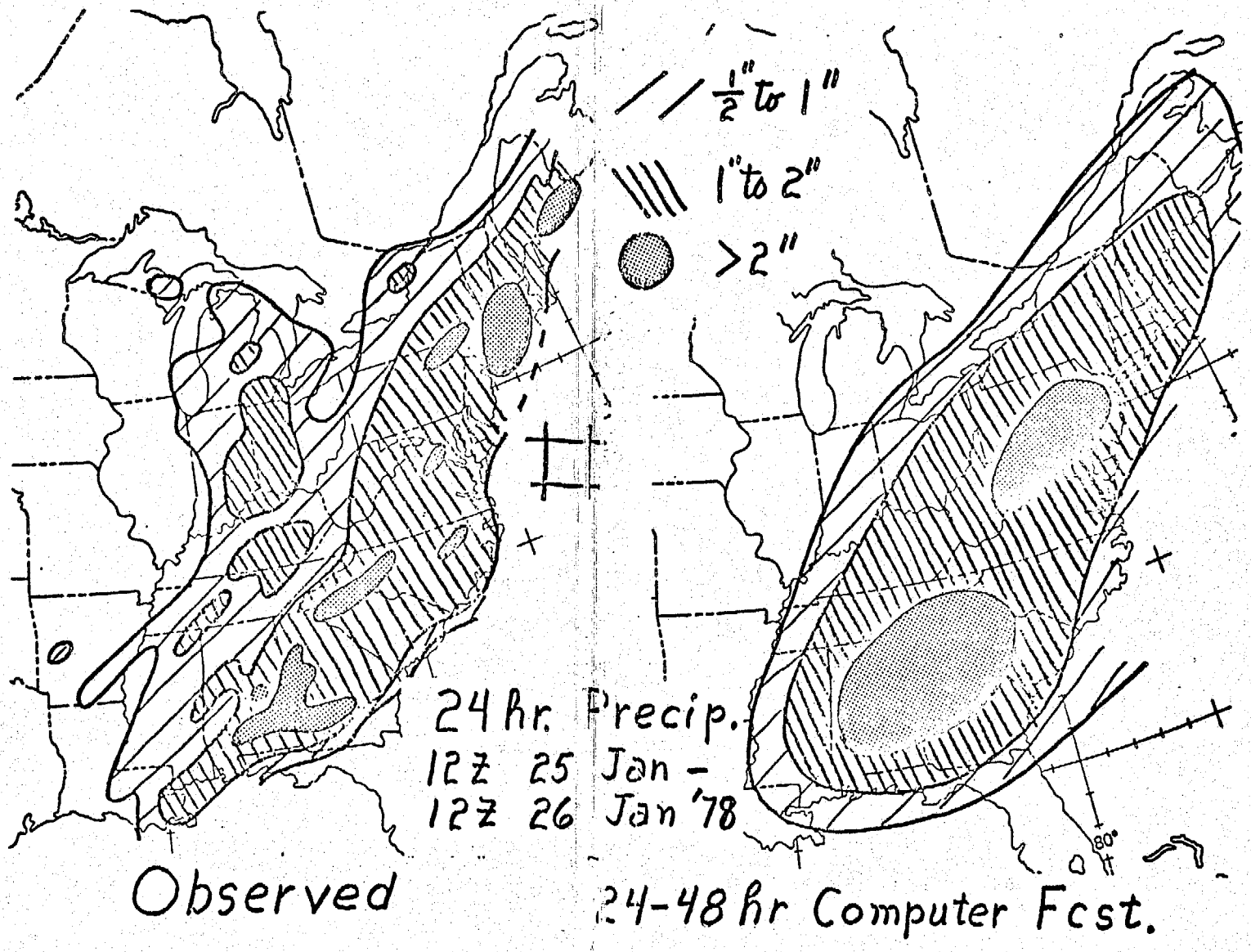

Figure 2. Observed and forecast accumulation of precipitation for the 24-hour period ending 7:00 A. M. EST January 26, 1978. The forecast was made operationally with the new 7L PE model.

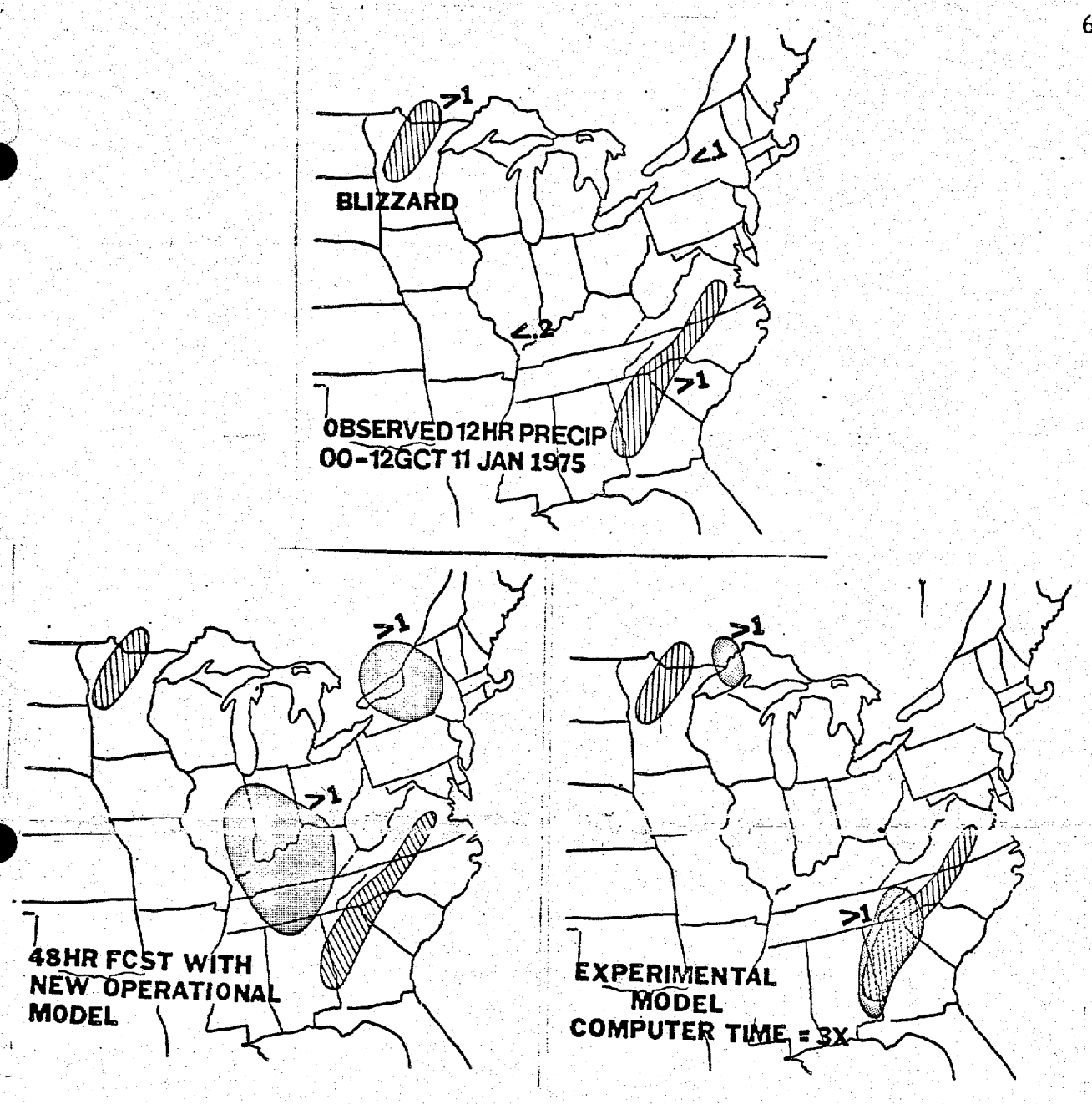

Figure 3. Observed and two forecasts of precipitation accumulated during the 12-hour period ending 7:00 A.M. EST January 11, 1975. Areas with amounts greater than one inch are shown. TOP: Observed. These areas are copied on the other two charts for ready comparison. LEFT: Forecast made with a run of the operational model that was implemented on January 19, 1978. The top chart shows that for the two areas where greater than one inch was predicted, less than 0.2 inch fell in one area, and less than 0.1 in the other. RIGHT: Forecast made by an experimental model that requires three times as many calculations as the operational model.

the vertical. The beneficial effects of the closer spacing are clearly evident in the Southeast, where the experimental model predicted rainfall correctly over a considerable area. The experimental model also predicted heavy snowfall (10" of snow is about 1" of water) in the northern Great Plains, but did not locate it accurately. Such guidance, however, would have alerted forecasters to the possibility of heavy snow over a wider area. As indicated in the label of the chart, the experimental model, to become operational, would require a computer three times faster than the IBM 360/195.

We now have a model that is operational with a grid spacing of 100 km. It covers an area of only 5000 x 5000 km, however, roughly three times the area of the 48 contiguous states. Because of its impact on operational computer schedules, the model is not run regularly, but is on call to be run when major disastrous flash floods threaten. It was run four times during the fall and winter of 1976-77, and the table below shows its accuracy relative to two other models with larger grid intervals.

Average threat scores for predicted 12-hourly accumulations of precipitation of over 1/2 inch. Four fall and winter cases.

Grid spacing	Threat scores 12-24 hr	24-36 hr	36-48 hr
350 km	.34	.14	.02
175 km	.32	.25	.03
100 km	.52	.36	.30

Threat score, by the way, is the ratio:

$$\text{Threat score} = \frac{\text{Hits}}{\text{Observed} + \text{Forecast} - \text{Hits}}$$

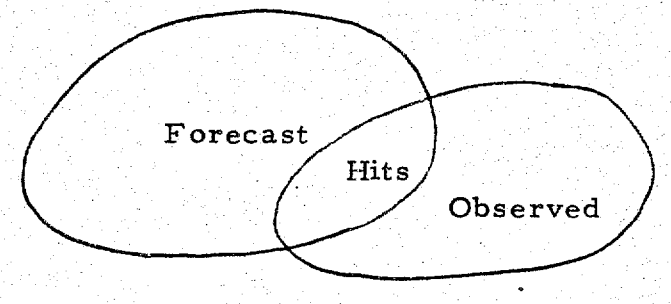

Figure 4. Schematic of elements in threat score.

The numerator is the area of precipitation correctly forecast, indicated in Figure 4 by "Hits," the denominator the total area either forecast or observed.

The table shows a characteristic that appears to be typical of the effects of model resolution on skill. In the range 12-24 hr, a change from 350 km to 175 km did not significantly affect skill. For this early period there is a resolution threshold below 175 km, for the model with 100-km spacing shows a substantial increase in skill. In the longer range of 24-36 hr, however, the model with 175-km spacing did show a relative increase of skill over the model with 350-km spacing. For the longest range, 36-48 hr, the two coarser-mesh models had virtually no skill by this measure. The model with 100-km spacing, however, not only maintained significant skill in the longest range, but at a level comparable to the skill of the other two in the shortest range. The table illustrates that for a given range, there tends to be a threshold of resolution for realizing increased skill in forecasting precipitation amount.

The model whose scores are shown with a 100-km grid is also run operationally with an even smaller grid interval (60 km), and over a smaller area (3000 x 3000 km). This version is also run only when called. With it NMC has successfully produced guidance for tracking hurricanes, particularly for landfall, the most important aspect of hurricane forecasts to the public. Hurricanes are considerably smaller circulations than the others that NMC deals directly with. Indeed, a grid interval of 60 km cannot adequately describe the variation of winds within a hurricane. For example, the ring of maximum wind about the eye of a hurricane typically would fit nicely into a square 60 km on a side. We thus "model" and play with circulation patterns until we get one that tracks realistically. This part of our modeling effort is more art than science. Numerical prediction of changes in intensity cannot be attempted, yet experimental evidence suggests that prerequisites for more accurate hurricane tracking are a faithful representation of the vortex and its evolution. Again in this area, this can be achieved only by a reduction in grid size, which in turn requires much more powerful computers.

In summary, an increase in computer power will enable significant improvements in forecasts of important weather phenomena for which there are sufficient data and which are "understood." At the present time these are phenomena such as blizzards, state-size area of heavy rain and snow, daily maximum and minimum temperatures, high winds, and freezing rain which are associated with the storms depicted on the usual

weather maps of the eastern two-thirds of the United States. Improvements in the west (including Alaska and Hawaii) are also likely, but they are more dependent on better data, particularly over the Pacific Ocean. Some improvement in hurricane tracking may also be possible, and we may be able to get at the problem of intensification of hurricanes. Here also, however, adequacy of data is a problem. Markedly better forecasts of thunderstorms, hailstorms, tornadoes, and other small destructive storms are most likely at the present time to be achieved through efforts of the research laboratories in NOAA and elsewhere.

I should also say that our experience has shown that research and experimentation with advanced models brings out only a portion of the total benefits to be gained. Once advances are operationally implemented, they undergo intense daily scrutiny by hundreds of professionals both at NMC and in the field. I have never known a forecaster to be bashful when it comes to criticizing NMC guidance. Such feedback is invaluable in pointing the way to realizing the full potential of innovations.

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