1.1.1 ON THE POTENTIAL USE OF RADAR-DERIVED INFORMATION IN OPERATIONAL NUMERICAL WEATHER PREDICTION

Ronald D. McPherson

National Meteorological Center
Washington, D. C. 20233

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HISTORICAL PERSPECTIVE OF OPERATIONAL NUMERICAL WEATHER PREDICTION

Operational numerical weather prediction has historically been concerned with the prediction of atmospheric flow patterns and associated sensible "weather", which have characteristic length scales of 2000 km and greater, and periods longer than a day. The physical basis for this approach was established in the late 1940s and early 1950s, and rests upon the approximate balance between the forces associated with the equator-to-pole gradient of pressure and the earth's rotation. Mathematically, numerical weather prediction is posed as an initial value problem. Its solution thus depends on specifying the state of the atmosphere at the initial time of the forecast period, providing a mathematical "model" of the physical laws which govern the evolution of the atmosphere, and access to sufficient computational power to advance the model solution forward in time.

For the quasi-horizontal, quasi-balanced flows with relatively large length and time scale which have been the principal focus of operational numerical weather prediction, the initial state specification was provided at the beginning of the operation NWP era by balloon-borne measurements of temperatures and wind as functions of pressure. The measurements were taken at locations mostly in populous areas of the Northern Hemisphere, with an average distance between locations of 300-500 km. Soundings were obtained generally twice per day. From these measurements were derived digital representations of the three-dimensional mass distribution of the atmosphere at a given time. Such representations served as the initial conditions for early prediction models.

During the years since the beginning of operational numerical weather prediction in 1955, the data base has expanded, especially from satellite-based observing systems. Atmospheric models have steadily grown in realism, and improved in accuracy. In parallel, the necessary computing technology has advanced to enable the improvements in modeling. Nevertheless, the object of numerical weather prediction has remained the same: the forecasting of large-scale atmospheric flow patterns and associated precipitation. The data base for this operation, while expanded, remains concentrated on sampling the slowly evolving flow patterns twice per day. Such a data base cannot profit very much from radar-derived information, where one of the principal advantages lies in frequent temporal sampling. Indeed, radar measurements have played virtually no role in numerical weather prediction thus far.

However, it is widely known that many important precipitation events occur on a much smaller space and time scale than the flow pattern in which they are imbedded. Such events are poorly predicted by present operational NWP methods. This is manifest in the long-term performance records of operational NWP centers: forecasts can be readily demonstrated. No such increase is apparent with respect to numerical predictions of precipitation.

EXTENSION OF OPERATIONAL NWP METHODOLOGY TO SMALLER TIME AND SPACE SCALES

In recent years, major advances have occurred in understanding the physical processes associated with many smaller-scale major precipitation events coupled with advances in the numerical modeling of those processes. A growing consensus has resulted that an extension of operational NWP to smaller scales is feasible, and in view of the deficiency in the skill of precipitation forecasts, is highly desirable as well. To be successful, however, the recent advances in modeling must be accompanied by an appropriate enhancement of the observing system, and of course, more powerful computers. In an agreeable conjunction of circumstances, modern computing and observing technologies appear able to produce the required enhancements. In the latter, radar technology will evidently play a major role.

This may be illustrated by an examination of the requirements likely to be placed on an augmented observing system by numerical weather prediction. Such requirements cannot be specified with any accuracy very far in advance because the frontier of our knowledge advances by a sequence of creative imbalances. Thus, the recent advances in modeling have resulted in an imbalance between models and observations, and efforts are being made to redress the imbalance by enhancing the observing system. After information from the improved observing system has been studied, it may be that deficiencies in the models will be revealed, and the modelers will respond. Thus the process is a dynamic one which may result in frequent revision of the requirements. Nevertheless, we may attempt some estimates.

One of the most important conceptual advances in recent years is the recognition that major precipitation events, especially those in the warm season, are usually associated with organized convective systems. Examination of cloud imagery from geostationary satellites has revealed some of the characteristics of these systems. They appear with a wide spectrum of characteristic dimensions, ranging from a few hundred kilometers to almost synoptic scale (>2000 km). It is difficult, and perhaps misleading, to assign one number as a characteristic horizontal length, but for this discussion perhaps 1000 km will serve. The convective systems generally occupy most of the troposphere, so we may assign a characteristic vertical dimension of about 10 km. Sequences of satellite images, plus surface-based observations, show a typical life cycle of perhaps 12 hours; occasionally, a system will persist longer, but even so, often displays a diurnal variation in intensity. Thus we may take 12 hours as a characteristic time dimension.

If we require that our observing system must sample the phenomenon of interest at least 10 times per characteristic dimension, then the observing network suitable for accurately describing the "typical" convective system as outlined in the previous paragraph must have the following characteristics:

Horizontal resolution	100 km
Vertical resolution	∿1 km*
Temporal resolution	∿1 hr

*The vertical resolution should, of course, be substantially higher in the planetary boundary layer.

By contrast with the existing large-scale observing network, where observations are required only twice per day, the mesoscale observing system is required to sample once per hour. It is in this connection that radar-based observations will play a major role.

To summarize our estimates of the requirements likely to be levied on a new observing system for mesoscale meteorology, observations of wind and temperature are required with horizontal resolution of approximately 100 km, and vertical resolution of at least 1 km in the free atmosphere and perhaps an order of magnitude greater in the boundary layer. Atmosphere moisture measurements are also required, but with greater spatial resolution in view of the notoriously inhomogeneous character of moisture fields.

In addition, it is important that the mesoscale model of the atmosphere should know where and at what rate the real atmosphere is precipitating at the initial time. This requires knowledge of the horizontal and vertical distribution of precipitation, as well as the precipitation rate.

POTENTIAL OBSERVING SYSTEMS FOR OPERATIONAL NUMERICAL WEATHER PREDICTION ON THE MESOSCALE

Several observing systems developed in recent years offer potential application to the mesoscale numerical weather prediction problem. Summarized in the list below are systems which have not been used or fully exploited in operational meteorology.

Temperature

1. Thermodynamic Profiler: This is an experimental six-channel radiometer, based at the surface and pointed upward. It derives profiles of temperature from infrared radiation emitted from relatively deep atmospheric layers. It thus has relatively coarse vertical resolution and is adversely affected by precipitation at the observing site. Soundings can be produced each hour, and the integrated measurements (e.g., heights of standard isobaric surfaces) are quite accurate. The greatest accuracy is found in the lower levels. Scanning is not possible, so horizontal resolution is limited.

2. VAS (VISSR Atmospheric Sounder): This is an infrared radiometer on the Geostationary Orbiting Earth Satellite. Temperatures are derived from upwelling radiation, in the same way as with the thermodynamic profiler. VAS has the advantage of scanning, and thus offers good horizontal resolution. It also offers high frequency soundings in time. The soundings are most accurate in the higher atmosphere. VAS soundings suffer from coarse vertical resolution, and are not available in cloudy areas.

Wind

3. Wind Profiler: This is a clear-air Doppler radar, surface-based, with two orthogonal beams pointing upward at 15° from the zenith. Wind profiles can be produced each hour or even more frequently, from about 500 m above the ground into the lower atmosphere. The profiles have acceptable vertical resolution above the boundary layer. Scanning is not possible, so horizontal resolution depends on the spacing between instrument sites. Preliminary estimates suggest that the wind measurements are of acceptable accuracy.

4. Doppler Surveillance Radar: The National Weather Service has embarked on a program (NEXRAD) to install new weather surveillance radars at approximately 160 sites in the US. It will be possible to derive winds from the radar measurements when precipitating clouds, or other targets such as insects, are present. The accuracy is good, vertical resolution is good, and the data may supplement the wind profiler in the boundary layer. Winds are not available under all conditions; in particular, clear air in the cold season will be void of data from this source.

5. Automated Aircraft Data: Modern wide-bodied commercial jet aircraft are being equipped with communication devices which relay temperatures and winds measured by the aircraft's sensors and inertial navigation systems to the ground. Observations of wind and temperature will be available at roughly 100-km intervals in level flight, and 10 mb intervals on ascent and descent. Slant profiles will therefore be available in the vicinity of major airports. The accuracy of the winds obtained from this source is good, but the temperatures are less accurate.

Moisture

6. Moisture Profiler: A two-channel radiometer has been developed to provide frequent, accurate measurements of the total water content of the atmosphere above the radiometer. Profiles are not available. No scanning is done, so horizontal resolution is determined by the distance between observing sites.

7. VAS: Frequent estimates of total water content can also be determined from the VAS instrument. Scanning is done, however, so the horizontal resolution is quite good.

It is clear from this brief summary that no single component listed above satisfies all the requirements of the data base for operational mesoscale numerical weather prediction. Instead, the requisite observing system will be a composite of all the above elements, plus the existing network which is part of the synoptic scale observing system.

The cornerstone of the network is likely to be the wind profiling radar. Because of the accuracy and frequency of the radar wind observations, it will be possible to estimate not only the wind field at any one time, but also its tendency, with considerable accuracy. The former is extremely important, indeed vital, to mesoscale prediction; the latter is important because it can be used through the hydrodynamic equations to enhance the vertical resolution of the coarsely resolved temperature profiles, thus indirectly enhancing the accuracy of the prediction.

CONCLUDING REMARKS

The National Meteorological Center is convinced that a mesoscale observing system, with elements as described above, will be a reality within a few years. It thus becomes a matter of some importance to devise a four-dimensional data assimilation system capable of intelligently treating data from these various sources. The Center has committed substantial resources to this development project, and recognizing the long lead time necessary in such endeavors, work is already underway. Experiments with simulated observations will begin in 1987. Read data experiments will begin with the availability of wind profiler data from a 30-station demonstration network in 1989. As NEXRAD installations proceed, efforts will be made to incorporate wind data from this source, also.