1. Introduction

For approximately 30 years, the rawinsonde has been the standard method of obtaining atmospheric profiles of wind, temperature, and humidity for operational purposes. Temperature soundings by polar-orbiting satellite were added in the 1960s, and have been found valuable in areas where other information is lacking (e.g., over the oceans). These satellite soundings are, however, of limited value over land because the derived pressure heights and temperature profiles are rendered inaccurate (especially at lower heights) by radiation from the ground.

In the past three years, no less than three additional methods of acquiring these profiles have been demonstrated. The first of these methods is the Safesound system (Cole and Bargen, 1981), an improved version of the in situ, balloon-borne sensor approach. Its primary advantage is that it obtains wind profiles of considerably improved accuracy by replacing the single-station, antenna angle-measuring radio system with a multi-station, radio phase-measuring system. Improvements also have been made in the temperature and humidity sensors.

The second method is the Profiler, a Doppler radar/microwave radiometric system that continuously and automatically provides wind, temperature, and humidity profiles using ground-based remote-sensing techniques (Hogg et al., 1983). Its primary advantages are the complete temporal continuity and high temporal resolution (typically, a few minutes) of the data, and the high accuracy of the wind data relative to the rawinsonde. Its primary limitation is that the height resolution of the temperature and humidity profiles is considerably poorer than that of the rawinsonde. Relative to the satellite soundings, it has the advantage of providing highly accurate wind profiles (not yet available from satellites) and better accuracy and height resolutions in the measurements of lower tropospheric temperature and humidity profiles.

The third new atmospheric/temperature/humidity sounding system is the VAS (VISSR Atmospheric Sound) system aboard the GOES geostationary meteorological satellites. Unlike the polar-orbital sounding systems, it provides quasi-continuous temporal and spatial coverage, with excellent temporal (~1 h) and spatial (~15 km) resolution. Its disadvantages relative to the polar-orbiting satellites lie in limited latitude coverage (±50° versus complete global coverage) and the loss of sounding capabilities in regions of continuous clouds.

Recognizing that the progress made by these new systems would be of major interest to both research and operational numerical weather prediction communities, NOAA's Wave Propagation Laboratory recently hosted a Workshop on Atmospheric Profiling. Its purpose was to bring together representatives of the new observing systems and atmospheric modeling experts from universities and the National Weather Service in an informal workshop to explore the capabilities, limitations, and potential research and operational input of these new observational systems. The workshop, which was chaired by John Hovermale of NOAA's National Meteorological Center, was deemed by its participants to be of sufficient significance to warrant the preparation and publication of this report.

The workshop convened on 3 March 1983. Much of the discussion involved presentations. The breadth of subjects was quite large, ranging, for example, from radiometric sensing to atmospheric adjustment theory. But there was ample time for free wheeling discussion, especially when operating within the context of panel discussions that were guided to encourage extensive audience participation. The background theme, maintained throughout, was that of how best to proceed with a two-track observational implementation program; one that would improve operational forecasting and simultaneously provide improved, reliable data bases to answer pressing research questions arising now and those that are expected to arise within the next decade.

2. Advances in observational technology

After the sessions were opened with formal welcoming remarks by G. Little and a general purpose and outline of the workshop provided by J. Hovermale, the group heard brief presentations pertaining to three primary, state-of-the-art observing systems currently in assessment status. All hold the promise of being in operational readiness during the 1980s.

The so-called Safesound system was described by B. Serafin. Its ease of use and economic operation, as well as its versatility for operations and research purposes, was stressed. Its primary advantage is that it obtains wind profiles of considerably improved accuracy by replacing the single-station, antenna angle-measuring radio system with a multi-station, radio phase-measuring system. Improvements also have been made in the temperature and humidity sensors.

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tional rawinsondes. This instrument is the strongest candidate available for providing high quality and high vertical resolution data in the lower troposphere.

K. Hayden gave a progress report on data-processing problems and quality assessment studies with VAS sounding data. Numerous technical problems have plagued the project, but a positive impact on forecasts over the eastern Pacific and western United States has been verified with the National Meteorological Center’s regional prediction system.

Comparative studies of these data with temperature data from the Profiler system have been encouraging. These studies show that, to some extent, the instruments complement one another to overcome respective weaknesses. Indications are strong that gradients in time and horizontal space are the most valuable information available from VAS, but processing systems that combine VAS data with independent systems have yet to prove this conclusively.

G. Little described current operating Profiler assessment programs and gave performance statistics for wind, temperature, and humidity measurements. It is clear that the passive parts of the system (those measuring temperature and moisture) are subject to some of the same problems as satellite-based radiometers, whereas the active elements (radar wind measurements) have extremely high accuracy. The total system still is evolving; acoustic or radar reflections from inversions can be employed to improve details of the temperature structure, and radar power and frequency can be varied to obtain more detail in wind structure or make wind measurements at greater heights.

Even at its current stage of development, several powerful measurement capabilities of the Profiler deserve immediate application if the need for such information can be shown to exist. First, the wind accuracy with a resolution of 0.5 km in the vertical to the tropopause is beyond the accuracy of any current operational measurement system, as well as significantly more accurate than estimates that can be obtained quasi-geostrophically from temperatures and pressures. Moreover, the more-or-less continuous availability of this information makes it potentially of much greater value in short-range forecast problems than conventional procedures, and at an overall cost competitive with these procedures.

While comparative studies with radiosonde temperatures suggest rms differences of 2°C and temperature structures with considerably less detail than in situ observations, it has been shown on the basis of well-constructed studies that the Profiler provides standard-level geopotential height information as good as, if not better than, that from the radiosonde. Thus, in terms of the information provided to current numerical models, the Profiler seems to provide information for the terms in the equations of motion up to or beyond current standards. Its present inability to provide detailed vertical temperature structure may not be significant for some problems, but probably requires some compensation of the information in the general case. A similar but stronger case may be made regarding the need for an improvement in the vertical resolution of moisture that is measured by the Profiler. Current information provides less detail than the radiosonde.

More dynamical and diagnostic studies were called for so that new potentials and requirements of future composite observing systems would be understood better. M. Shapiro provided insight into the considerable detail discernible from time-height sections obtained from the Denver-Stapleton Airport Profiler instrument. Strong low-level jets and sharply sloping mesoscale fronts were readily distinguishable. The sections revealed a highly balanced character in slowly varying situations, with stronger ageostrophic implications in rapidly changing circumstances. The results suggested strong qualitative relationships between phenomena observed in time sections and those features normally reflected in spatial cross sections.

The participants at the workshop then directed their attention to potential applications of high-resolution and high-quality observing system packages. The group was expected to expand its time horizons as far as possible to see whether other limitations besides data input would stand in the path of research advances or improved prediction capability.

3. Nowcasting applications

E. Zipzer, who chaired a panel discussion on nowcasting, began with a plea for a careful definition of terms. The term “nowcasting” should imply only the dissemination of current information. Observations should have their meaning expanded by professional interpretation. Extrapolation forward in time by any means takes information out of the nowcasting realm. Short-term extrapolation (0–2 h) has come to be termed “very short-range forecasting” and should be distinguished from nowcasting. Working from these definitions, the group saw little need for a dynamically complete picture in order to operate effectively in the nowcasting realm; rather, timely delivery of current weather conditions and their effective communication was their first priority. For very short-range forecasts, on the other hand, a dynamically complete atmospheric description is crucial. Quasi-steady state mesoscale phenomena, as well as transient conditions, require the most sophisticated numerical weather prediction (NWP) technology to be predictable beyond several hours. The temporal resolution achievable with VAS and Profiler information is expected to be extremely valuable in such short-range, rapidly evolving situations. The concern that inadequate resolution of the moisture variables would eventually turn out to be the limiting factor in forecasting rapidly evolving severe weather events was raised again.

4. Opportunities and problems in data assimilation

The attention of the group then was directed toward problems and opportunities foreseen in the area of data assimilation in forecast models. The subject was covered first in presentations by a panel of experts that was chaired by J. Tribbia. Descriptions of some mesoscale data sensitivity studies pointed to both winds and moisture as pivotal variables in determining the evolution of frontal-related events. The studies did not address directly the importance of temperature measurements in mesoscale prediction, but one obtained the impression that diagnostic specification of any of the basic
atmospheric variables, while helpful as a framework for data assimilation, could not substitute for complete measurements for mesoscale prediction.

Data requirements on the mesoscale were also explored through interpretation of spectra characteristics. Little evidence of a “spectral gap” was noted, reflecting that, on the average, energy is cascading down from large scales to small scales. It was pointed out, however, that “ intermittency” is a strong feature of the mesoscale; thus, at times of most significant activity, the small-scale end of the atmospheric energy spectra exhibits a character quite different from that in the average case.

The Sasaki variational method was used by N. Phillips to estimate the relative value of temperature and wind observations in producing a geostrophic analysis. (Linear adjustment theory tells us that departures from a geostrophic analysis disperse as free gravity waves. Nonlinear initialization methods refine this by adding to a geostrophic analysis those nongeostrophic fields that are “bound” to a slowly changing, nearly-geostrophic field and are necessary to prevent nonlinear generation of additional free-dispersing gravity waves.) Phillips’s results can be summarized in the equation:

\[
\frac{1}{(\Delta T_{\text{ana}})^2} = \frac{1}{(\Delta T_{\text{obs}})^2} + \left[ \frac{g}{fT} \tan \alpha \right]^2 \frac{1}{(\Delta v_{\text{obs}})^2}, \tag{1}
\]

where \( \tan \alpha \) is the slope of a temperature (or a potential temperature) surface, \((\Delta T_{\text{ana}})^2\) is the analysis error variance, and \((\Delta T_{\text{obs}})^2\) and \((\Delta v_{\text{obs}})^2\) are the observational errors. For a typical value of 0.01 for \( \alpha \), the \( \tan \) coefficient has a value of 11 m sec\(^{-2}\) deg\(^{-1}\). Presumed rms Profiler errors of 2 K and 1 m sec\(^{-1}\) show that the winds would contribute 40 times as much to the analysis “accuracy,” \(1/(\Delta T_{\text{ana}})^2\), than would temperature measurements. A typical raob error of 0.5\(^0\), on the other hand, would be matched in contribution by a wind component error of 1.7 m sec\(^{-1}\).

Phillips also emphasized that this result may be somewhat unfair to the temperature Profiler because the previous analysis assumed no correlation between temperature errors at neighboring Profiler sites. He recommended that simulation studies should be made on the temperature Profiler to estimate the spatial error covariance in \( x \) and \( z \) of that system in typical assumed temperature cross sections, and that such a study be followed by reapplication of the Sasaki variational analysis, taking into account the estimated 2-dimensional spatial temperature error covariance structure.

Through this approach, Phillips was attempting to add some more precise quantitative information to the debate concerning the primary role of wind observations in short-range forecasting. Many arguments have drawn only upon the theory of geostrophic adjustment to reach the general conclusion that winds are the most important information source in any data assimilation process. This consideration cannot be ignored, because during the initial stages of model integrations, errors in winds, as well as the valid portion of the winds, will tend to overwhelm information (and misinformation) in the temperature fields. If temperatures are introduced without properly translating their information into winds, much of their impact will be lost. Phillips’s contention is that this does not mean that we should dismiss the importance of temperature measurements, but rather that we should make our best attempts to translate accurately temperature information “intelligently” into wind estimates before starting a forecast. This will not be an easy task for subsynoptic scales.

There was considerable controversy in regard to this point, before, during, and after the workshop. The debate stemmed from concerns by some of the group that too much reliance was being placed on the potential positive impact of the apparently high-accuracy Profiler wind measurements when establishing detailed vertical temperature structure. It was correctly pointed out that shallow layer structures (i.e., very small \( \alpha \) in Phillips’s equation) do not obey the general wind dominance-rapid geostrophic readjustment rule and that, in fact, mass (temperature-pressure) fields dominate the adjustment process in shallow layers more slowly.

Unfortunately, this debate has not adequately accounted for the points raised by Phillips, nor has it considered the possibility that high time-resolution wind Profiler data may yield accurate temperature estimates with no approximate balance relationships. The theoretical possibility of this latter point may be seen by expressing the divergence equation in the following manner in standard notation:

\[
\nabla^2 \phi = -\beta \mu - \nabla \cdot \mathbf{F}_w + \mathbf{f}_w \cdot (\nabla \times \mathbf{V}) + \nabla \cdot \left( \frac{\mathbf{dV}}{dt} \right). \tag{2}
\]

The term on the left is proportional to the geostrophic vorticity, and its vertical pressure derivatives may be used to obtain hydrostatic temperatures. Thus, the temperatures may be obtained as solutions of a boundary value problem whose forcing functions are determined by: 1) the vorticity of the actual wind (third term on the right, usually the largest forcing term); 2) small terms related to the curvature of the earth and eddy viscosity (first and second terms on the right); and 3) the divergence of individual parcel accelerations. Whether determined by terms in their Eulerian expansion or from actual trajectories from wind Profiler measurements, parcel accelerations should be derivable to a degree of accuracy heretofore unachievable. With the limits on accuracy set only by the small truncation and instrument errors of a wind Profiler network, the exact relationship described by the divergence equation should permit temperature inferences of extremely high quality from the winds. The question is not how well winds dominate the mass field in the geostrophic adjustment process, but how well the exact state of balance described in the divergence equation can be portrayed in a 4-dimensional wind profiling network, with certain small—but nonzero—observational and aliasing errors.

5. Observing system simulation experiments

Such questions as these have great significance, not because anyone is contemplating the day when temperature measurements are no longer needed, but because answers may serve to guide planners of composite data-gathering systems of the future. Generally speaking, planners want to maximize complementary aspects of observing systems while minimiz-
ing their redundancies. Exact answers regarding observing system design are difficult to come by, but planners have been able to gain considerable insight by carrying out simulations with existing data assimilation and forecast systems. The third panel discussion of the workshop, on the careful design of these so-called Observing System Simulation Experiments (OSSE) and the interpretation of their results, was chaired by R. McPherson. He keynoted the discussion with his experienced view that some OSSE in the past have led to excessive optimism regarding the positive impact of new data systems. He emphasized the need for design creditability in such experiments, with typical atmosphere-model inconsistencies, as well as both random and nonrandom data error characteristics, accounted for.

The control solutions must be highly realistic in the physical sense in order to build confidence that we are trying to “measure” and predict phenomena that will actually be challenging the prospective observing system in the atmosphere. This, of course, means that the model does not have to have the reputation of good forecasts every time, but rather that it has a good “track record” in handling actual events, is based on sound physics and numerics, and shows excellent ability to simulate “generic” events. With these characteristics, the model should have the ability to create realistic control solutions that respond to errors in roughly the same way as the atmosphere for the particular phenomena of interest.

These views were supported by much of the audience, as well as the chairman, but there also was some pessimism. The thrust of the dissent was related to how well the goals mentioned previously could be satisfied and how much reliance could be placed on the results. It was noted in seeking a common ground that the OSSE approach is only one source of information that should be employed to establish observing system designs; hydrodynamic theory and statistical methods also are useful tools. The case study approach will continue to be invaluable due to the extreme nature of the phenomena we hope to predict.

Currently, both the assimilation and the forecasting parts of NWP technology, as they would be applied to mesoscale or subsynoptic-scale problems, have significant weaknesses and, at the present time, only broad inferences regarding data requirements should be drawn with regard to ultimate needs.

6. Science/service opportunities

The discussion then moved to major opportunities for research and services using composite observing systems. A panel chaired by T. Schlatter led off the discussions, and a “strawman” operational system composed of Profilers, satellite soundings, and Safesondes was presented by R. Carbone. Costs and technological problems were explored, and the Next Generation Radar (NEXRAD) Doppler radar system was discussed as an integral part of any new observing system design.

The group then discussed the wide range of problems that could be attacked using the future monitoring system as a base. Topics included mesoscale convective complexes, fronts and jet streaks, and orographic influences. The ideas were very much in line with the goals laid down in the National Storm Program. It was clear that the group was confident that many short-term research and operational problems could be attacked more effectively with a well-designed system based on the emerging observing technology. It also was just as evident that with this technology, some basic research questions could be addressed adequately for the first time.

This discussion had to be shortened due to time constraints and a need to sum up the major opinions gained from the 10 hours or so of exchanges. J. Hovermale discussed some opinions that he thought to be consensus views and encouraged comments and additions.

7. General views during summary session

The group had no hesitancy in accepting the view that the new sources of data would rapidly expand our knowledge of, and improve our ability to predict, weather events. We are beginning to measure precisely those rapidly evolving weather phenomena that until a few years ago could only be inferred. Most exciting is the prospect of a nearly-continuous monitoring of the atmosphere, rather than seeing only two “pictures” per day. Questions on how to proceed were more difficult. Here several broad guidelines can be agreed upon.

A parallel-track approach should evolve that results in immediate payoffs operationally while research activities are accelerating. Cost will be an important factor, for while the ultimate system will be economically competitive with current observational technology, much of the expense is “up front.” Planners will have to be convincing in their proposals for a rapid evolution in our observing technology, and this is difficult to do with the composite nature of the atmospheric sensing problem.

Many questions were raised that can preoccupy minds and obscure the overall picture; however, each question still is important and must be solved. For example: How can we best adapt the current data assimilation system to treat smaller scale weather phenomena? What would be the optimum blending of sensing technologies in a composite system? What vertical resolution of atmospheric structure is required for short-range prediction problems? Where are the major weaknesses in our current and proposed observing systems? How much should observing system simulation experiments guide our decision making? Are models capable of reliably predicting short-fused weather events? Do small errors grow so rapidly in some mesoscale phenomena that they must be considered “inherently unpredictable”? These were questions that the group raised again in its final discussion. Most individuals believed that the questions had answers, and that the answers raised problems that had solutions.

G. Ludwig pointed out that governmental-professional decisions to move toward an evolution of our atmospheric-monitoring-prediction system will probably proceed along one of several conventional paths, i.e.: 1) Research results will be sufficiently convincing to point the way; 2) Simulation experiments will be conclusive; 3) A ground swell of enthusiasm will develop within the community; or 4) The societal benefits will become obvious.
Some examples of current programs that are influencing the move toward new technology were raised, e.g., WINDSAT, PROFS, etc.

An opinion from the group was sought in regard to a new initiative currently being developed within the Environmental Research Laboratories (ERL) and the Weather Service regarding an ambitious assessment program for the wind Profiler. Briefly, it involves an array of many (50-100) wind-only profilers distributed between the Rockies and the Mississippi River designed to monitor jet-front phenomena and the broad-scale interactive features of mesoscale convective complexes. Then, as a carry-on study, the system would be applied downscale to obtain a better picture of the internal dynamics of large convective systems. Even though the system would be interspersed with the conventional radiosonde network, there was some concern that some extra temperature and humidity data would be needed to take full advantage of such high-density wind coverage. The cost of such an endeavor ($1000000) was contrasted with costs for other parts of the Weather Prediction System (e.g., computers) and found reasonable considering the probable payoffs.

The view was brought forth and generally accepted that the true value of the Profiler could not be realized or demonstrated conclusively unless a rather large array was distributed to monitor the structural details of an entire weather-producing system. To go only partway would not provide the data necessary for a full evaluation.

8. A call to action

Most of the scepticism at this point centered around the perceived difficulties (or perhaps impossibilities) of obtaining support for such an undertaking. R. Hallgren did much to overcome this prediction by providing a very “upbeat” view of the potential for success in bringing new observing technology on line. He pointed out that no single system would be a panacea. The atmosphere is a complex engine that requires a composite approach to measure its behavior; thus, ongoing operational programs like NEXRAD, ASOP (Automation of Surface Observations Program), and AFOS should be complemented as soon as possible with the proven technology discussed at the workshop. High temporal resolution should be gained with VAS and the wind Profiler. Until remote sensing can achieve the required vertical resolution in the temperature and moisture fields, we should back up the primary observations (winds) with as much detail as the prediction system demands. The Safesound looks like an inexpensive way to do this, especially if its wind-measuring aspect is removed.

An integrated science/service concept is becoming attractive to a society that is becoming increasingly aware of the impact of weather on its activities. The problem is not convincing society that new technology has to be applied, but convincing ourselves that a single program can satisfy our research needs and at the same time ensure that advances are translated into improved services.

Hallgren concluded by asking that the concept of a new composite observing system not be allowed to cool down and encouraged the planning of another workshop within a few months.

The meeting adjourned Friday afternoon, 4 March.

References


Deadlines Calendar

**Fellowships, grants, etc.**

- **15 June 1983** Macelwane Annual Award (this issue, p. 1088)
- **15 June 1983** Hanks and Orville Scholarships (this issue, p. 1088)
- **7 November 1983** Exchange Program with China (August 1983 BULLETIN, p. 911)
- **31 December 1983** Alan T. Waterman Award (this issue, p. 1060)

**Call for papers**

- **16 December 1983** Second International Symposium on Applications of Laser Anemometry to Fluid Mechanics (July 1983 BULLETIN, p. 819)
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