Forecasting

THE HUMAN ELEMENT IN WEATHER FORECASTING

by Charles A. Doswell III (1)
NOAA/Environmental Research Laboratories
Weather Research Program
Boulder, Colorado 80303

ABSTRACT

Weather forecasting is evolving in a world characterized by accelerating scientific and technological change. This scientific and technological change has led to some confusion and concern about the role of humans in forecasting the weather. Therefore, this essay tries to find the proper perspective for understanding how humans contribute value to the prediction process.

Scientific weather forecasting proceeds by combining a diagnosis of the atmosphere's current state with a prognosis. It is argued that the diagnostic step involves both quantitative and qualitative knowledge of the meteorology, if the maximum possible understanding is to be gained. Since machines do not have access to qualitative information, they cannot provide as complete a diagnosis as humans. Further, in humans, the diagnostic and prognostic steps are blurred, allowing qualitative knowledge to influence the forecast as well.

Many aspects of the current operational forecasting system are discussed which suggest that this system is steadily disconnecting humans and their skills from the weather forecasting process. The educational system, which functions largely as a certification process for forecasters, is shown to be contributing to this erosion of roles for humans in weather forecasting. Some possible implications for the future are described, along with some alternative approaches which can reverse current trends.

1. INTRODUCTION

It should come as no surprise that industrialized societies throughout the world are now being confronted with what Toffler (2) has called the "Third Wave", a technological revolution as profound as the Industrial Revolution itself. The concerns we feel about the role of humans in the weather forecasting services of the future have their origins within this ongoing societal upheaval. Like Toffler, the author is cautiously optimistic about the potentially positive impact of the technology, but intend to be forthright about the problems associated with the transition from industrialized mass society to one in which individual freedom is enhanced by the technology. Science fiction has offered some pretty gloomy pictures of what a future dehumanized, technological society might be like. These depressing scenarios are not inevitable, but it is up to us to seek more positive paths which recognize the value of humans while enjoying the benefits of the technology.

It is necessary to distinguish between "science" and "technology" because it seems that the terms often are used interchangeably, which they are not. For this paper, science is defined as the formulation, testing and revision of models of the natural world, in order that we might comprehend that world. On the other hand, technology may be defined as the development of physical tools used in the furtherance of human goals (one of which is the advancement of science). These definitions may not satisfy everyone.

Characteristically, science and technology build upon themselves, so that their rate of growth tends to be exponential. The present weather forecasting environment certainly reflects the effect of technology's explosive growth. Ponderous bureaucratic procedures tend to make governmental weather services lag behind the proverbial "state of the art" in technology. Even so, public forecasting services have experienced the impact of new technologies: satellite imagery, computer forecast models, word processing, etc. Whether one thinks the pace of technological change is annoyingly slow or alarmingly fast, there are even more dramatic new technologies on the near horizon: Doppler radar, radiometric sounding systems, automated surface observations, etc. Symptomatic of these changes is the fact that there are about as many CRT's in the forecaster's working environment as there are people, with CRT's on the increase and people on the decline. One might ask whether or not there will be any room (literally and figuratively) for humans in the weather service of the future.

By equating technology and science, we create the illusion that better science is being done in weather forecasting than ever before, as new technologies are introduced into operations. This author contends that the quality of science is on the wane in weather forecasting, and this paper shall try to show why this is the case. It explores the human element by concentrating on how technology has changed things since the beginning of Toffler's Third Wave, when forecasting was still undeniably a human activity.

2. THE WEATHER FORECASTING PROCESS

In keeping with the need to put discussions in broader contexts, the weather forecasting process will be described in generalized terms. If we are to understand how people fit in, we have to consider what the overall process is and how it seems to work. Prediction of anything, be it the weather or the stock market, can be described as the combination of a diagnosis with a trend, or prognosis. Mathematically, this is simply a verbal description of the first two terms of a Taylor's Series expansion: the state of the atmosphere at some time in the future is the sum of its current state plus its time rate of change. This formalism is the heart and soul (if that is an appropriate metaphor) of numerical weather prediction, but it only captures a part of the process for humans, as this essay tries to show.

a. Diagnosis

It is impossible to overstate the importance of diagnosis in weather forecasting. In order to make scientific predictions of the weather (i.e., excluding forecasts from an almanac or by reading goat entrails), a person must have knowledge of the weather processes ongoing at diagnosis time. Each weather event is a combination of constituent processes, evolving together to yield the weather at a particular instant. It is convenient to classify those processes according to space and time scales, but it must be recognized that processes operating on a particular scale do not act independently of those at other scales. This relationship among constituent processes is referred to as "scale interaction".

It is the aim of diagnosis to integrate our understanding of those processes into a coherent picture of the event. Science provides the basis for understanding the constituent processes, but it often treats them as if they were isolated from other processes, in order to make them easier to understand. By the same token, science also forms the foundation for synthesizing our analysis of these processes into the diagnosis of the event as a whole. The fact that our science is incomplete and imperfect does not mean meteorological science is without value in trying to understand the weather. A courageous individual recognizes these limitations and tries to make the best of what knowledge is available. It is axiomatic that the best forecasters base their forecasts on knowledge of the atmosphere (a part of the natural world) by applying models of the atmosphere (e.g., the Norwegian polar front model). That those models are not always "objective" or quantitative does not mean they are without value. If a forecaster learns continually from experience, from scientific journals, from colleagues, or whatever, then it is reasonable to expect some on-the-job testing and revision of those models. Thus, by this author's definition, those forecasters are acting as scientists whether they recognize it or not!

Many proponents of new technology believe that it is important to relieve forecasters of the "burden" of weather map analysis. From the author's perspective, this is terribly wrong! Performing map analysis is an essential component in diagnosis — it allows one to compare models of atmospheric behavior to the data. This is the way a forecaster forms an understanding of what is happening in the atmosphere. Rather than freeing time to do science, taking map analysis away from forecasters minimizes their opportunity to function as practitioners of meteorological science.

To illustrate why this is so, suppose that one surface observing site has values of meteorological variables (pressure, temperature, humidity, wind, etc.) which differ substantially from those at surrounding stations. From a purely "objective analysis" viewpoint, the data at that site either can be rejected as unrepresentative, or treated like any other station's data (creating a "bump" in the resulting isolines). However, a human can employ the qualitative information that the site experienced a thunderstorm (or whatever) the previous hour to build a qualitative model of those local events which comfortably incorporates all those "anomalous" data. In effect, the analyst is using knowledge of typical thunderstorm processes in combination with the limited data to guess at what the convective system looks like (3, 4).

This hypothetical structure may be seriously wrong because the sample does not provide enough data to be certain of the detailed distribution of the variables. However, the next hour's data may confirm (or deny) the basic validity of the forecaster's qualitative model. Given that the observations are always limited in space and time resolution (now and in the foreseeable future), it makes sense to employ all of the data and all available meteorological knowledge. We cannot afford to turn our backs on important meteorological input simply because it is non-quantitative or subjective. In fact, it is this integration of diverse data and abstract knowledge which humans are so good at and which is so hard to teach to a computer since the synthesis is not totally quantitative.

At best, the human diagnostic process is capable of success far beyond that of automated objectivity. At worst, the model in a forecaster's mind can be wrong to an extent that no purely objective scheme would ever achieve. There is no way to avoid the errors completely, but there is a way to minimize them. Forecasters should be in close touch with the data (i.e., doing map analysis), and should be as scientifically aware as is humanly possible. It is inconceivable that these goals can be achieved if diagnosis is relegated to computerized schemes. To what end are the data presented if not for analysis? If the forecaster is not doing diagnosis, how is the time on an operational shift to be spent?

Furthermore, the best way to lose diagnostic skill is not to use it. When diagnosis is not a routine part of the forecasting process, those analysis skills may not be at one's disposal in the really challenging weather situations where diagnosis is needed the most (e.g., when the computer is down in a "hot" situation). Note that time is most available for diagnosis before the weather situation becomes critical. Thus, it makes sense to concentrate on diagnosis during relatively calm weather, in order to anticipate the arrival of a challenging weather situation. It is hard to imagine forecasters doing diagnosis without using their meteorological knowledge to anticipate how the present situation might be evolving, unless they are simply "drawing lines" on the maps, a process not considered to be equivalent to true diagnosis.

b. Prognosis

The advance of technology has given forecasters some new tools with which to address the issue of prognosis. Generally, these tools are referred to as "guidance" products. How might humans go about integrating the information contained in guidance with more traditional approaches, as eptiomized by the classic monograph by Riehl et al. (5) to forecasting? In order to answer this, we should briefly consider the history of numerical weather prediction (NWP), the most obvious new prognostic tool.

The basic equations which are presumed to describe atmospheric motion have been known for quite some time, but solutions could only be obtained for special, quite restrictive situations (6). With the advent of computers in the early 1950's it became possible to solve those complex equations with something much closer to full generality. Given this new capacity, foreshadowed by the visionary work of Richardson (7), the notion of "objective forecasting" became a real possibility.

For the first time, meteorologists could envision their science taking its place alongside certain select branches of physics as a "hard" predictive science. Unfortunately, the excitement generated by the early successes of NWP may be responsible in no small way for the erosion of meteorological skill in the operational office. It seemed possible to eliminate fallible humans by using objective numerical models, so diagnostic skills seemed to diminish gradually in significance. Synoptic meteorology lost stature throughout the profession.

Today, there are some problems with this concept which make the end of human intervention in weather forecasting somewhat less imminent. For one thing, the huge successes with large scale models in the early days of NWP have not been so easy to repeat as our attention turns to mesoscale and convective processes. Another problem is that, while NWP has proven its skill at forecasting weather patterns, translating those patterns into forecasts of tangible weather is considerably more difficult. It is time to overcome our intoxication with NWP as a panacea for weather forecasting. It is hard to believe that "numerical prediction models" and "the science of meteorology" are equivalent concepts!

Modeling, be it numerical, mathematical, conceptual, or whatever, is an integral part of meteorological science; but proposing a model, and using that model successfully in operational forecasting are rather different accomplishments. We need not be ashamed of our science simply because we have not eliminated subjectivity and intuition. Rather, it seems artificial and foolish to reject information which cannot be reduced to a set of equations or a computer algorithm. Indeed, if one accepts the fact that science is a human activity reducing meteorology on only that which is objective is really antiscientific!

1). Empiricism vs. Objectivity

An apparent dichotomy which arises in forecasting is empiricism vs. objectivity. Pure empiricism is defined to mean forecasting methods derived directly from observations and experience. This could be called "Weather Lore School of Forecasting" because it does not differ in principle from "Red sky in the morning/Sailors take warning..." Such approaches may be dressed up by shrouding them in a fog of statistics, of course, since the basic idea is to infer cause and effect from correlations seen in the data. There may well be valid scientific reasons why one event is associated with another, but without knowing those reasons, it is risky to rely on such empiricisms. As a somewhat lighthearted illustration, it can be asserted that pickles are the cause of crime, because a high percentage of criminals have eaten pickles at some time prior to committing their crimes. Empirical forecasting (often called "rules of thumb") may be all that one has to deal with in a situation and, if so, one should recognize that there may be times when the empiricism will not work as expected. If we remain ignorant of why the association works, it is impossible to know in advance when the rule will fail.

By casting rules of thumb in a statistical mold, one can make empiricism appear "objective", in the sense of objectvity discussed by Glahn (8), who defines an objective forecast as giving one and only one prediction from a given set of imput data. Examples of objective forecasts might include the output from NWP models, or certain types of decision trees, as well as statistical prediction equations. Once an objective scheme is built, it become a "black box" about which one may choose to know nothing, save the output. Interestingly, when one is ignorant of the contents of such a system, it is hard to anticipate when and where it might fail. Thus, at the core, empirical and objective forecasting methods are not really at opposite poles of a dichotomy at all.

Instead, the reason for rethinking of empiricism and objectivity as opposite approaches has its origins in a real dichotomy, one which we all carry in our heads. People who study the way our brain works have found that the brain's right and left sides operate differently. The left half is associated with analytic, quantitative, language-oriented thinking, while the right half is associated with intuitive, creative, nonverbal thinking. There is a physical connection between the two sides which allows these distinct thought processes to interact.

The so-called "art" in weather forecasting seems to come from the right side of the brain. All of us know forecasters who seem to have a great deal of forecasting success but are unable to say how and why they make predictions the way they do — they just seem to know what the atmosphere is going to do. However, such individuals are relatively rare, and most forecasts are produced more or less by rote (following rules of thumb, guidance, or whatever), with little or no intuition. Interestingly, the same split seems to exist within the research community, with the most important research accomplishments seemingly coming as a flash of insight (intuition) and then being verified quantitatively much later.

It is this intuition which is labeled (erroneously) the "empirical" approach to forecasting. Thus, the real dichotomy is between left-brain and right-brain dominance in individual forecasters. Trying to communicate with someone dominated by the opposite half of the brain is quite difficult, if not impossible. Left-brain dominance is characteristic of Western civilization, while right-brain dominance is the hallmark of Eastern civilization. Since the human body carries the physical connection, the dominance of one side over the other must be, at least in part, the result of training and environment. Many of the schisms in meteorology may come from this "East-West" conflict. They will not be bridged until our education and training are changed to encourage people to exercise both the analytic and the intuitive modes of thought (9).

2). Application of Objective Guidance

It should be obvious by now that this author believes the best basis for forecasting is the science of meteorology — having an understanding of our models (numerical, conceptual, or whatever) gives us a tremendous advantage in using them. We are wary of depending on them when their limits of applicability are approached. We are alerted to their obvious failures, when they do not satisfy sound physical principles. We can account for their known flaws and limitations. We are also aware of the very real value which the guidance provides, and when it is most useful.

All this is fine, but it seems to be asking a lot to expect forecasters to know the contents of every guidance product's black box. Given the variety and complexity of guidance materials, one would have to be a veritable "Renaissance Person" to achieve this. Although forecasters may not hurt themselves by making the attempt, it really is not feasible to learn all those details (which are changing constantly, anyway).

Instead, a forecaster can employ guidance to the best advantage in a couple of special ways. First, if diagnosis is done properly (not just "drawing lines"), some prognosis is bound to develop in the forecaster's mind. When guidance is consistent with that, confidence in both guidance and the subjective prognosis increases. When the guidance differs substantially from the scenario built up during diagnosis, the job must be to resolve that conflict. Is it the subjective scenario or the guidance which is wrong (or both)? Also, there is more than one guidance product, and there is no guarantee that all the guidance products agree. The correct interpretation must be determined by meteorological knowledge (which certainly includes experience and rules of thumb, but should not be limited to that). Users of weather forecasts have a right to expect meteorologist/forecasters to make that determination correctly most of the time.

Second, the real strength of virtually all guidance is in dealing with large-scale, more or less "ordinary" weather situations. For some high percentage of the time, they are equal or superior to human-derived forecasts in this regard. However, their skill in dealing with many significant weather situations is quite limited — in other words, when the forecaster needs guidance the most, it is generally the least useful. Further, objective guidance can provide the broad patterns but it is up to the forecaster to provide the details, which are often directly related to the tangible weather events. The guidance is difficult to beat in relatively benign weather situations. Unless there is clear reason to depart from guidance, it is foolish to play "verification games" by small departures (say, 5° or 20%) from the guidance. However, when the meteorology says that guidance is probably "out to lunch", a forecaster should make forecasts in line with that meteorological reasoning, once again avoiding verification games. If the guidance says the precipitation probability is 5% and one's meteorological reasoning suggests a 70% chance, go for the 70% rather then trying to hedge with a 30% forecast.

The basic point is not to get a better verification score than the guidance (although that may well be a result), but to provide a better service to the users of the forecasts by being a live, practicing meteorologist instead of a casualty to "meteorological cancer" (9). There are those who would advocate removing humans from the system — giving in to meteorological cancer makes the job of these dehumanizers quite a bit easier. A major key to knowing what role humans should play is determined by how one employs the new technological tools. It is clearly not possible to return to the pre-technological era (short of a nuclear holocaust, perhaps), nor should anyone want to do so.

3. THE FORECASTING SYSTEM

The application of meteorological science to forecasting cannot be talked about without mentioning the system in which applications occur. However one may feel about that system, it should not be hard to get most to agree that it is not yet the best of all possible systems. One assessment is that it is the system which has encouraged the metastasizing of meteorological cancer. If not everyone agrees with this assessment, let us bring the disagreements into the open. If we agree that our discussions should focus on solutions to problems, then we should not be afraid to face the problems, first.

a. Forecaster Responsibilities

Characteristic of modern weather service offices is a diversity of forecaster responsibilities. These are broken down into four categories, for purposes of discussion. Not included in this list are the non-meteorological responsibilities shouldered by many forecasters, which may in fact account for a rather too-large percentage of a duty shift.

General Forecasts: Perhaps the most common task is for more or less generalized forecasts of weather conditions within the office's area of responsibility. Typically, these products are issued at regular intervals, and disseminated widely, especially via the communications media and private meteorologists (for whom the public forecast can be considered "guidance" -- with all the implications of the term). The content of general forecasts is more or less fixed, although certain situations may call for special additions (weather watches, advisories, special weather statements, etc.) to the routine fare. Given the nature of what is being attempted in these products, updates may be required at irregular times.

Specialized Forecasts: Specialized products can be subdivided into two major subcategories -- those produced locally and those produced at a centralized office which specializes in those products. Most of the discussed below latter deal with specific threats to life and/or property.

Aviation forecasts constitute a major local forecast effort (with some products becoming centralized). The history of the US public weather services is entwined with the growth of aviation and its need for weather information. Other areas of specialized forecasting include marine and agricultural products. As with aviation, it appears there is an effort to extricate the public forecasting service from these responsibilities.

The main issues with forecasting for these special groups are: not all the potential special users are being served, and these products serve only a tiny fraction of the total public. With the current political emphasis on letting the private sector serve these "special interest groups", there is considerable uncertainty about the future of these specialized programs in the public weather services.

Source for Meteorological Information: A large part of a local forecaster's effort is serving as a source of weather information for their communities. People of all sorts turn to their local weather office for a variety of needs involving the weather (or things which may only be perceived to be of a meteorological nature). Requests are usually made via the phone, seeking such things as how to set a newly-purchased home barometer, the weather and climate of intended vacation sites, whether or not to buy lightning rods, etc. Local groups may want to tour the office for educational purposes. It is not uncommon for people to ask the local weather office for information about meteor showers, UFO sightings, earthquakes, and so on. In many areas, the local weather office is the only presence of a technically-directed federal organization around. It is fair to say that the vast majority of these requests are handled remarkably well, despite their interference with forecasting duties.

Another sort of needed weather information comes under the heading of weather emergency preparations. The local office often serves as the primary source of meteorological input to community preparations for weather disasters: severe thunderstorms, floods, tropical storms, winter storms, etc. The extent to which the develops liaison between the local weather office and the community is governed by:

1. the capacity and ability of the local office's staff,
2. the commitment of weather service management to function in this way,
3. the capacity and commitment within the community to prepare for weather disasters, and
4. the frequency of hazardous weather in the area.

Note that this is distinct from the responsibility of the office in the event that the hazardous weather (or the perception of a threat for such weather) actually arises. Providing meteorological input to planning for threats to life and property occurs primarily during fair weather.

Threats to Life and Property: It has been argured that the primary responsibility of local weather offices is in providing warnings of hazardous weather phenomena. Irrespective of how one feels about this argument, there is certainly a need for this service. By the nature of the task, it is inevitable that false alarms and detection failures will occur. Part of the problem is meteorological; the science simply does not provide a basis for infallible warning strategies. Part of the problem is educational; the forecasting community is not always up-to-date with what the science can provide. Part of the problem is organizational; the weather services and the communities may not employ all the means at their disposal to deal with weather hazards.

The issues involved here are complex and their disucssion can arouse strong emotional responses. At the core is our imperfect ability to forecast the weather. Our responsibility must be to do the best we can with the existing situation, and to make a real commitment to improving on that situation.

b. Learning How to Forecast

The responsibilities just enumerated are rather awesome, so it would be logical to assume that a well-thought out, rigorous program for teaching people how to forecast the weather exists. As discussed in Doswell et al. (10), this assumption is quite unwarranted. The meteorological community is more than willing to pay lip service to this concept, but rather less than willing to make a commitment of resources in active support of turning the forecaster education/training concept into reality.

It is worthwhile to distinguish between education and training. Education gives students a basic understanding of the concepts behind their profession, and an introduction to the tools by which that understanding is gained. On the other hand, training gives the trainees experience in applying those tools and concepts to the task for which the training is given. Note that concept acquisition is mostly intuitive, while skill acquisition is primarily analytic. A proper education program should include elements of both, as has already been suggested.

In the essay by Doswell et al. (10), many aspects of forecaster training have been discussed. In the United States, the basic road to forecasting is assumed to follow a path which includes a B.S. degree in meteorology, an entry into the public service as an intern (whose main duties in that status may well be the nasty tasks that the senior staff does not wish to do), stepping up the grade ladder through various forecasting duties (usually involving one or more changes in duty station), perhaps a trip back to school or enrollment in correspondence courses, and culminating in a lead forecaster position. Along the way, the individual may or (more likely) may not acquire the M.S. degree in meteorology. Promotions beyond lead forecaster are invariably into administrative positions, so further advancement is not considered here.

Certainly there are exception to this path, which may not even be typical of the majority of lead forecasters. A substantial number of forecasters in the public service have had at least one tour with the military service (an interesting topic, but not to be pursued here). The "ideal" implicitly assumes that a B.S. degree in meteorology gives the new graduate all the meteorology she or he needs to be a forecaster. Meaningful training for forecasting is simply left to chance and on-the-job experience.

Education, particularly that offering meteorological theory, is generally accepted to be irrelevant to forecasting. It merely must be endured in order to get that diploma, one's ticket into the forecasting system. Since forecasters rather infrequently are asked to derive equations on the job, the university experience is quickly discarded as a hindrance to learning the task. It does not take a great deal of insight to discover that being a real forecaster is not exactly like synoptic laboratory. One might more legitimately compare it to being a clerk than to being a scientist. By the time our intern is ready to become a forecaster, most of the enthusiasm for meteorology may be buried in a heap of rotating shifts, meaningless paperwork, petty annoyances, verification games, "brain-dead" colleagues, incompetent management, and hours of boredom punctuated with occasional periods of sheer panic. It takes a tremendous commitment to forecasting if our hypothetical forecaster is to maintain the enthusiasm felt at the time of graduation. Many do not have that much, so they end up enduring their forecasting careers (just as they endured their education), waiting for retirement.

Instead of having the chance to learn forecasting by doing it, one quickly discovers that the forecasting world is a lousy place for learning. In the rush to get products out, there are few opportunities for leisurely consideration of the meteorological issues. If one makes a bad forecast, there are few opportunities to go back and see what could have been done to avoid that problem. A forecaster usually has only limited opportunities for a meteorological dialogue with her or his colleagues -- they are working other shifts and one literally may see them only a handful of times all year, and then only briefly. After a shift, it may be rather difficult to find the motivation to curl up at home with a good book on dynamics. And so on.

c. System Response Capability

Irrespective of forecaster training, we should critically examine the system by which the hazards to life and property are addressed. Presumably, one has more time to deal with the less threatening aspects of forecasting (although this may not be the case, of course). Ideally, the process works as shown in Fig. 1, with a rather linear progression as the products focus down to the event with time. A basic assumption is that the focusing down scale is made possible by the passage of time: an "outlook" is rather broad-brush, because the event is still hours away, while the "warning" is for a small area because the event is imminent or actually underway.

From a scientific viewpoint, the assumption underlying this focusing process is untenable. As real weather events develop, such as tornadoes and flash floods, the timing and location is governed by processes on scales about which meteorological knowledge (and the data to which the knowledge can be applied) is increasingly unavailable. In this sense, it becomes more difficult to forecast imminent events than to delineate broad regions within which the small-scale events may eventually occur.

Some idea of the system in which this process is supposed to operate is shown in Fig. 2, where the local office is connected to a variety of agencies, both public and private. The forecaster has a host of routine duties which must be performed in fair weather and foul, in addition to myriad non-routine products and activities (created by threatening weather) which generally require immediate attention. No amount of meteorological skill can make the real system (which is considerably more complex even than Fig. 2) respond as idealized in Fig. 1. Unless the forecaster has anticipated the deterioration of weather, he may be reduced to playing "catch-up" within the mess depicted in Fig. 2, with both routine and non-routine product quality likely to suffer. Putting new technology into this sytem simply creates more chances for things to go wrong at a critical moment. Is it any wonder that forecasters may be reluctant to embrace the new hardware additions to their operating environment? It is a tribute to their real commitment to perform (which, in a crisis, overrides their cynical malaise), rather than to the wisdom and foresight of those who created the system, which is really incapable of responding as it is envisioned that it should.

d. Needs vs. Abilities

It has already been suggested that the science of meteorology falls rather short of giving us a basis for near-perfect weather forecasts. While we might be able to do a pretty fair job of forecasting 500 mb heights, does anyone actually live at 500 mb? Our scientific knowledge may well be growing by leaps and bounds, but we are kidding ourselves if we think that this knowledge growth necessarily means a commensurate increase in skill at forecasting the tangible weather. Perhaps the only truly firm ground in the whole science of meteorology is associated with large scale extratropical weather systems (quasigeostrophic theory, baroclinic instability, etc.). While it cannot be denied that we are making progress in other areas (e.g.), this progress has not yet attained the level of understanding we have for large scale systems. Since a rather high percentage of tangible weather is associated with processes operating on

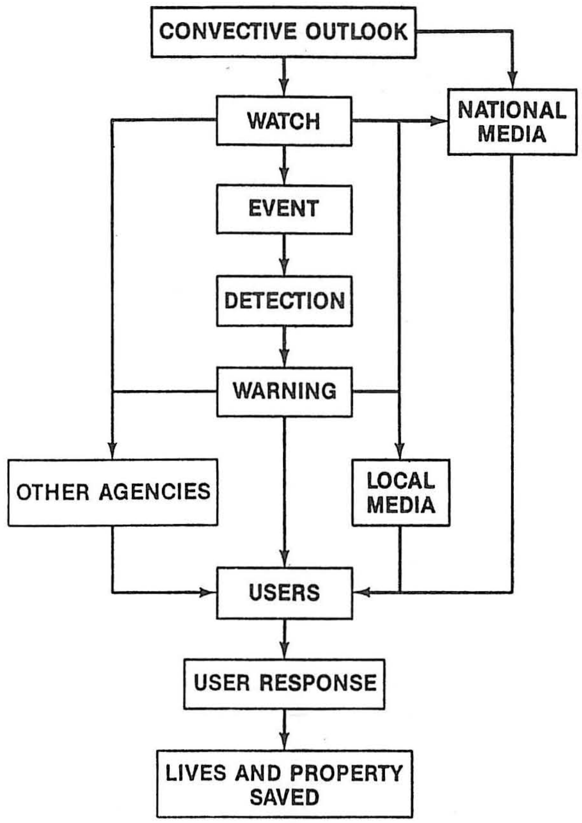

Fig. 1. Idealization of the operational system for dealing with weather hazards to life and property.

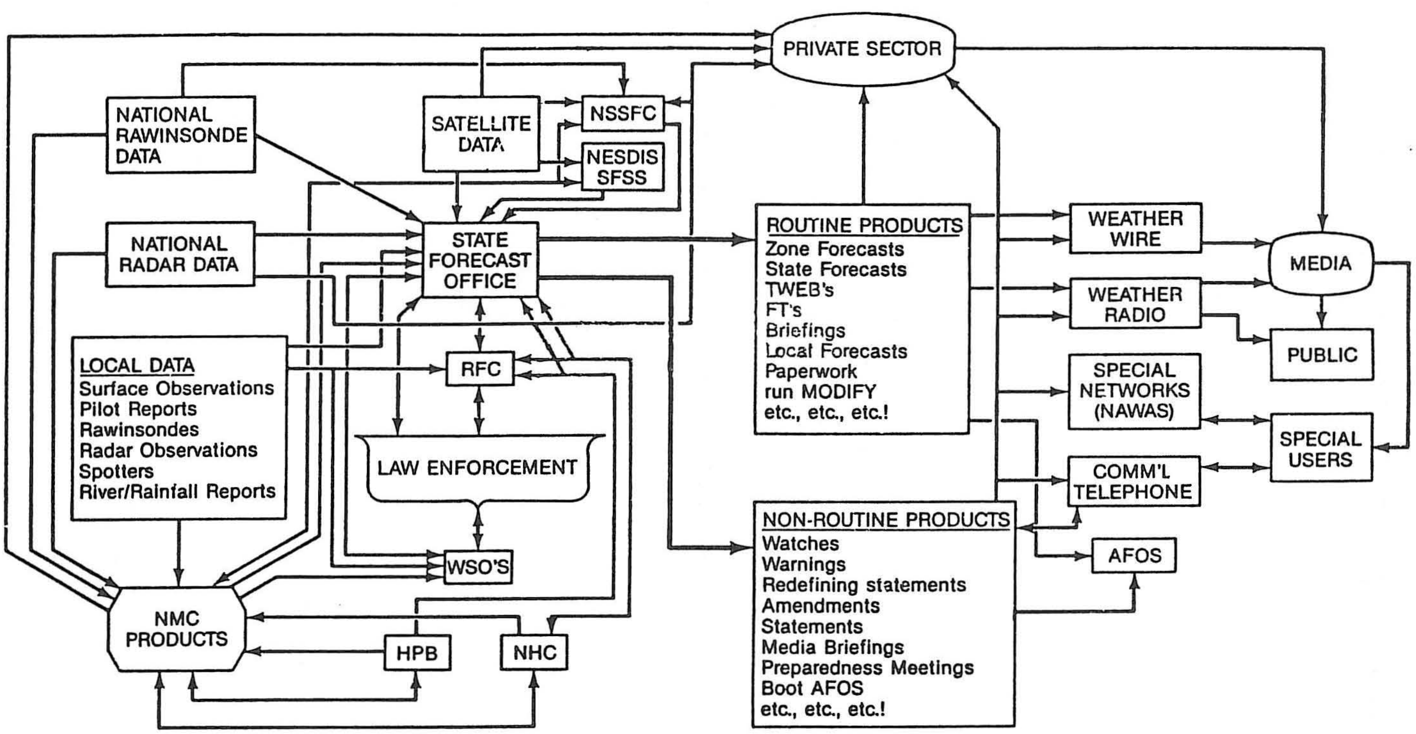

Fig. 2. Schematic of the U. S. system for forecasting, as seen in a local weather forecast office.

scales well below that of the extratropical cyclone, we really do not know much about forecasting the weather. Further, we have no mechanism in place for transferring science and technololgy into operations.

So why are we engaged in this task which, like the hero in a Greek tragedy, is doomed from the start? The obvious answer is that weather has a tremendous impact on society, so even our meager abilities may have a net benefit. While our societies may need more from us than we are ready or able to give, it is a dangerous game to promise more than our abilities permit. Technology seems awfully promising, especially to non-forecasters and non-meteorologists, and, since science offers few unqualified answers, acquiring technology looks like a way to be doing something concrete to improve the situation. Unfortunately, it is not only the tools which define the boundaries of what can be done -- in fact, it is mostly the knowledge and skills and opportunities available to the tool users which limit what is possible within the forecast office.

4. A VIEW OF THE FUTURE

Most of this paper on the human element has dealt with technology and its impact on weather services, because it is technology which is changing the role of humans in forecasting. Those who are unqualified proponents of "technological fixes" can argue, with some validity, that it makes no sense for humans to be engaged in routine, repetitive, boring tasks. To them, perhaps, much of a forecaster' work appears to be of this sort, and their intention is to remove this burden. While this is a laudable intent, it is hoped that this paper has been successful in showing this to be a superficial analysis of what humans do in forecasting the weather. No one can know the future, but a bit of simple extrapolation can give a glimpse of how weather services might look, at least in the near term, if we continue to introduce new technologies into the forecaster's workplace.

If automation of meteorological analysis continues, we can expect a steady erosion of meteorological skills, both diagnostic and prognostic. This creates a self-fulfilling prophecy for the advocates of automated prediction, because forecasters who lose those skills will be increasingly incapable of adding any value to the guidance. This, in turn, creates an argument for decreasing the staffing further. Our practitioners will have less and less in common with researchers, so the gap between them will widen and it will become more difficult to put new scientific ideas into practice (except for new "objective" techniques). Since researchers are not in intimate contact with real weather on a daily basis, this will lead to a decrease in the quality of meteorological science, even as we develop new and exciting data sets by implementing new technologies. The net result for the public will be forecasts which do not fulfill the potential inherent in what the technology offers and, perhaps, dissatisfaction with the broken promises of better forecasts through (expensive) technology.

Rather than being a latter-day Luddite, this author is excited about what the new technologies have to offer, and would be among the last to propose halting technololgical change. However, technology seems to be molding humans, rather than the other way around. In a broader sense, we humans cannot avoid having our viewpoints changed by new technological developments, but our practitioners seem to have been shut out of the process. Decisions are being forced from the top down about such things as how the technology is to be used, how it is designed, what it produces, and how much access to its inner workings forecasters need. Bureaucracies are a natural development of industrial mass society which requires its members to fit the needs of the society as a whole. This essay is not the forum for a full discussion of these issues, but right now the bureaucracy stands as a barrier to the most productive implementation of the new technology, even though it appears to be an advocate of that technology.

The author is constantly being told that he has to accept certain realities about the forecasting environment. From the forecasters' standpoint, it usually amounts to a list of problems with the working situation. From the administrator's, it usually amounts to a list of reasons why something to address the working situation can not be done. The real challenge during this period of technological ferment is to figure out how to put the science of meteorology back into the process of forecasting. It is this author's opinion that our present bureaucracies will be anything but an impediment to this process. Thus, a program of positive change probably will have to take place at the "grass-roots" level. If this sounds subversive, that is not an entirely inappropriate conclusion.

An alternative view of the future of weather forecasting is presented in three basic areas: education/training, technology and the working environment, and the research/operations interaction. One view of how these areas will have to change in order to serve the need for making the science of meteorology relevant and useful to forecasting will be presented.

a. Education/Training

Within the academic system, it is the norm to treat the topics within the subject area of meteorology (as well as the different subject areas which pertain to meteorology) as if each were inside a box having impermeable walls. There is no effort to emphasize the connections which link all these individual subjects into a coherent whole. In fact, I suspect that virtually no communication between instructors ever occurs with the intent of coordinating course material. The student learns "dynamics" as if it were somehow distinct from "synoptics", or "boundary layer theory", or "thermodynamics". If the connections are to be made, it is up to the student to make them. These connections are too important to be left up to chance -- in reality, it is this coherent picture of the science which is the real subject of study, not the little individual pieces.

This is especially true for forecasters, whose classroom experience never really provides the linkages between theory and the real weather.

Given the challenges of forecasting, it seems absurd to assume that a B.S. degree equips forecasters to cope with increasingly sophisticated science and technology. Unfortunately, it is difficult for forecasters to see the benefit to graduate education when the all-important linkages between theory and practice are not taught. Universities rightfully argue that it is not their responsibility to train forecasters. One response is that education seems to take place without the students leaving the hallowed halls with the concepts and tools they were supposed to get. When giving "training" sessions to forecasters, time is spent educating the students in things they were supposed to know already. Our universities emphasize analysis and neglect synthesis — this can be seen as left-brain dominance. We might see a dramatic change in the behavior of the majority of our graduates if universities spent as much time on developing the right-brain as they do on the left-brain. This calls for more time addressing the connections between the pieces, to a level comparable to what we do for the pieces themselves.

If one has the concepts and tools of meteorology at one's disposal, this does not guarantee skill at forecasting, but it does offer the chance to approach forecasting as a part of meteorological science. However, the potential for accomplishing a task is greatly enhanced if one is also trained in using those concepts and tools pertaining to the task. A meaningful training program requires two things: a recognition of the need for investing in people as well as technology, and knowledge of what must happen in the training program if the trainees are to become successful practitioners. These two parts shall be dealt with in a moment, but let it be added that job-centered training can never be made to work if the education which must precede it has not been successful in giving the trainees those concepts and tools required for the training!!

While it is difficult to find anyone today who would deny the need for training, at least in principle, it is quite difficult to get across the point that we cannot make up for a 40-year gap in our forecasters' understanding of the science of meteorology with two-week workshops, or some sessions with an inneractive videodisk. It does no good to put sophisticated Doppler radar in the hands of someone whose concept of convection is limited to the Thunderstorm Project's schematics. It does no good to put complex display systems in the hands of someone whose understanding of large-scale systems is limited to "PVA equals vertical motion". Training designed to teach what makes the hardware work properly or how to call up products on the system does not replace the required learning.

It would be hard to find a single office that does not have at least one living, caring, motivated person on the staff. The nucleus of quality people is there if we are willing to invest in them. Without investing millions in our people, we are wasting the **billions** to be spent in acquiring new technology. If the universities can not or will not provide the education needed to make training meaningful, the public weather services may have to provide it themselves, prior to sending their people to true training for the job of forecasting. Lest the university departments set up too large a howl of protest, let us ask how many of them are educating their students in mathematics because the math departments are failing to give the meteorology students what they need?

The second point to be made about the training program is that they tend to be developed by administrators, researchers, and university professors, whose knowledge of forecasting reality is virtually nonexistent. The forecasters themselves have been "removed from the loop", apparently because they are deemed too ignorant to contribute to the process. It seems that others claim to know what is best for forecasters. There is really no training being developed with the active participation of forecasters. Their input is sought and then ignored, except for trivial administrative matters. The real agenda of the training development committee meetings is determined by political power, a commodity forecasters remain deficient in.

A truly useful training program, involving the forecasters directly in its design and modification, must not be frozen into a hard, bureaucratic structure when the forecasting environment is constantly changing. Ideally, forecasters would participate as trainers, as well as trainees, with a total staff turnover every few years, drawing on the field for replacements. Guest lecturers could supplement the staff, but their primary role should be "training the trainers" in order to have maximum impact. The training facility should be perceived as a growth experience for the trainers as well as the trainees, so that field forecasters would welcome an ex-trainer back into the forecasting world, as a real addition to the skills and knowledge of the local forecasting staff. Conversely, drawing an assignment to the training facility would have to be regarded as a real benefit to the individual, with forecasters queuing up to bid on the next facility opening.

A major emphasis in any training program must be to connect the formal concepts and skills learned during education to the actual practice on the job. This necessitates simulating the real working environment to the maximum extent possible, with considerable effort doing real-time diagnosis and prognosis. Although it is not desirable to include all of the non-meteorological distractions which forecasters face in the "real world" during the training, timed diagnostic and prognostic exercises with real-time data are essential. This sort of learning requires the instructors to be able to discuss whatever subjects the meteorology of the moment dictates, rather than being guided by a syllabus. It also requires that the training cover a large enough fraction of a year to provide a range of meteorological situations for the trainees to experience. It would be the responsibility of the instructors to provide the feedback and connections to theory, so that the forecaster can be convinced of the real value of understanding the science of forecasting.

It is inconceivable that we spend billions of dollars on hardware and virtually nothing on training. Technology will enable us to do as well or better than our present performance without any substantial investment in our people. Any real impropvement in the performance of our forecasting system must come from advances in the concepts and tools provided to the people operating that system — giving a word processor to someone whose knowledge of English is deficient does not make the writing any better than when it was done with pencil and paper. And the word processor cannot do the writing by itself.

b. Technology and the Working Environment

The true impact of technology on the forecasting environment would also require another whole essay, but some essential points should be emphasized. First of all, every new piece of technology has an "overhead" associated with it — hardware and software maintenance — which in the past typically has been downloaded to the forecasters. We cannot continue to burden our meteorologists with these duties, necessary though they are. It is absurb to think that we can do without more staffing (again, short of automating the whole business) simply because we have implanted modern technological tools. Let the forecasters speak about the impact of AFOS in the US if you want to hear how it has reduced their workload! If we want the benefits which are latent within the new technologies, this overhead must be properly accounted for in terms of appropriate staffing augmentation.

Second, we must figure out a way to allow forecasters to spend more of their duty time functioning as meteorologists, if new scientific advances are to be incorporated into the forecasting process. In fact, the current "fair weather" staffing virtually precludes the application of what science and technology we already have. But a suggestion shall be offered when discussing how the research/operations interaction may be made productive.

Third, the biggest problem forecasters have is leadership which is indulging in "micromanagement" rather than vigorously pursuing the ways and means to improve the working environment. The operating administrative principle is for solutions to be imposed from the top down, rather than coming from the bottom up. This is characteristic of large bureaucracies, but Peters and Waterman (11) convincingly show that such an approach is inferior in terms of productivity. Things do not have to be this way. As Toffler (2) has suggested, new technologies are driving our society toward less dehumanizing forms, where the bureaucracy is increasingly obsolete. Thus, we may envision a time when the working environment will have evolved to allow more local individuality and initiative, with the local office becoming more responsive to local needs and capabilities. In such a forecasting environment, the staff would not be completely independent of the larger organizational structures, but would be given considerable freedom to adapt its resources to suit the local circumstances.

Fourth, how can the current mechanism for selecting personnel be made to respond to the real needs and stituations? The implicit assumption made by the present system is that people are interchangeable modules, each with comparable skills and knowledge so that one person "replaces" another as gaps in the organization appear. This situation is dehumanizing, demeaning, and ignores reality to an extraordinary degree. Generally speaking, it is only in spite of this system that motivated, capable people are brought into forecasting and administrative positions. It is quite difficult to unseat the incompetent and those to whom the job is only a way to make a living. People who really care about the quality of forecasting find this a frustrating situation. How can this system be changed? It is devastating to morale among forecasters.

Organizational structure seems to be a virtual irrelevancy to the question of productivity and quality. An intrinsically bad structure can be made to work if the staff really wants to make it work. Conversely, the best structure in the world will fail to be productive if the mixture of people is wrong, or if a majority of people are not committed to making it work. What seems to occupy administrators are the details of the table of organization, which is precisely why bureaucracies are so unresponsive to real problems — most of those problems are associated with people issues. Dealing primarily with structural issues is like putting a band-aid on the chest of someone having a heart attack.

Finally, there is an unstated message in the efforts to bring new technology to operations without a comparable commitment to the people: hardware is more important than people. No organization can continue to send out that message without creating morale problems, or worse. It is time to recognize that our people are the most important part of our forecasting service organizations. This does not mean that we should quit investing in technology. In fact, we should be seeking to get the best technology, as appopriate to our forecaster's real needs as we can. However, the forecasters should be equal participants in the process, rather than recipients of "solutions" to problems they never posed. No organization which draws on the knowledge and talents of its working-level staff in making decisions can go too far wrong.

c. Research/Operations Interactions

It is suggested that forecasters spend far too little time on real meteorology during their shifts, mostly for reasons out of their control. Introducing new technologies into the operational environment tends to increase, rather than decrease, the time spent on non-meteorological duties. The large gap between the science of meteorology and the real process of forecasting the weather has been pointed out. It is inconceivable that the programs currently under consideration can work to the benefit of forecast quality in these circumstances. If we are to have a positive impact on what happens in forecasting, a different approach is called for, rather than one which emphasizes technology at the expense of forecasters.

Introduction of new technology has tended to follow a rather predictable path, perhaps exemplified best by the advent of weather radars in the early 1950s. Radars began appearing in weather offices long before science understood how to interpret radar data. The hardware was brought into the office without any personnel training, and running the radar simply became another duty imposed on the staff. Radar was hailed as a breakthrough, the advent of a new age in forecasting. While science began to grapple with the radar cluster, forecasters had to develop interpretation methods on their own, most of which are now recognized to be deficient (12) but which were all that forecasters had. The science moved onto Doppler radars, having developed concepts in the 1960s which provided a scientific basis for interpreting radar reflectivity patterns. Prior to the work of Lemon (13), those concepts were almost completely unknown in the operational community, since researchers had not taken the time to share their knowledge with operations (other than via publications in journals). Significantly, Lemon was working in a group (the Techniques Development Unit attached to the National Severe Storms Forecast Center in Kansas City, Missouri), doing research in support of operations.

In this paper, the history of such research groups cannot be explored in the detail it deserves, but it has become clear that the only way to introduce science and technology into operations successfully is to:

1. have researchers participate in forecasting, in order to gain a real understanding of the process,
2. have researchers work together with forecasters in developing new science and technology to suit the needs of the forecasters,
3. allow sufficient time for exploring the territory, without mandating in advance what the problems are, or what form the solutions must take,
4. have forecasters participate in research, in order to develop an appreciation of what science has to offer, and
5. hire people who are deeply committed to the idea of making the research/operations interaction work.

In view of the current emphasis on "relevance", most of science and technology takes on the appearance of "a solution in search of a problem". It is not desirable to force research scientists and engineers to work only on operational problems, but it is reasonable to ask that, when introducing new science and technology into operations, the schemes implemented be tailored to serve real needs. These needs must be identified with the active participation of those who are going to have to deal with them via the new techniques.

If technology is to be used properly, the users must know what constitutes proper use, and there must be ample opportunity to use it in the proper way. The primary barriers to successful implementation of new technology are inadequate staffing, inadequate (or inappropriate) development, and inadequate training. The concept behind the Techniques Development Unit (or TDU — a concept which now may be going under the label of an Experimental Forecast Center, of EFC) is the only way to create a situation wherein science and technology can be introduced successfully. The details which are essential to this concept are enumerated above, but the basic mechnism which allows a TDU/EFC to work is the augmentation of the staff. By increasing the staffing, the TDU/EFC can address the issues forecasters have neither the time nor (currently) the training and education to attack. Such a unit can help with training and education, as well as do the development making new science and technology fit real needs. The unit staff should be integrated routinely (not as fill-in for gaps in the shift schedule) into the operational forecasting duties of the staff, but limited to no more than 30% of their annual time (and no less than about 15%). Free time for the regular forecasters created by researchers working forecast shifts is to be given over to research, post-mortems of bad forecasts, meteorological dialogues with colleagues, scientific paper preparation, etc.

There is adequate evidence to assert that researchers will not make the move to interact with operations in any great numbers. There is no real motivation for them to do so. Perhaps the best we can do is to create a structure which gives the seemingly rare researcher interested in operations an opportunity to become involved on a non-superficial level. The individual TDU/EFC units will not be uniformly successful. In fact, all it takes to make one a nearly total failure is a bad mix of people. However, even if the unit has little or no success at implementing new science and technology, some positive results may arise through the process of freeing forecaster time for involvement in meteorological science beyond the basic tasks of forecasting.

5. SOME CONCLUDING THOUGHTS

Given the rapid changes in science and technology, there is little sense to introducing either science or technology into operations without a mechanism for allowing the operational implementation of them to evolve continuously and naturally. When one has a simple, clearly defined task to perform, such as drilling a hole, it is feasible to give detailed specifications for the tool to be used. The technology of the electric drill changes only slowly, because its role is so straightforward. Perhaps one might change it to make the drill do more (like drive screws) or to make it more convenient (like making a cordless version). Frequently, such add-ons or changes to the design are inferior to a tool designed specifically for the task.

In contrast, the new technologies are not so straightforward. Although one may know more or less how a computer is used, the details are established by what it is to be used for. Computers are inherently open-ended — that is their strength.

If a forecast office gets a computer, it makes no sense at all to impose arbitrary limits on what it is to be used for. Doing so freezes the specifications, and should it become desirable to use that computer for something else, the office would probably be forced to acquire more hard- and software.

Interestingly, the new sensing technologies have fairly obvious objectives (to gather certain types of data), but it is not always possible to specify how those data are to be used, especially in an operational setting. As with radar, it may be decades after the data first become operationally available before the best strategies for using the data begin to emerge. Again, it is shortsighted to impose hard specifications when acquiring the systems for operations.

The obvious implication of technological change is that weather services have to account for the probable evolutionary character of new technologies right from the start. The TDU/EFC concept is one candidate for doing so -- it represents a "front-end" cost which must be borne if the technological and scientific changes are to have a beneficial impact on operational forecasting. Hardening these new systems in advance ensures that they will be difficult (and expensive) to modify as science and technology grow, so as much flexibility as is feasible should be designed it into the systems from the start. This flexibility must include the staffing needed to take advantage of it. As AFOS has so clearly demonstrated, saving a few dollars by cutting down on a system's capacity during the design phase has a much higher cost later during the lifetime of that system. Further, if the local TDU/EFC is to have any real chance to adapt the system to real needs, the inner workings of the system must be accessible. As an example, look at the success of CSIC (14) as a model of how to introduce new systems into operations, with the direct participation of forecasters.

In summary, the human element in forecasting may be changing so as to blur the distinction between researcher and forecaster. As technology makes individual creativity on the job more feasible, it will be challenging forecasters to be participants in meteorological science. Should we, as a profession, follow the path of making forecasters an integral component of the changing public weather services, it is possible to be quite optimistic about the future.

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NOTES AND REFERENCES

1. Chuck Doswell acquired his B.S. degree at the University of Wisconsin in 1967, and his M.S. and Ph.D. at the University of Oklahoma in 1969 and 1976 (respectively). He was drafted in 1969 and served a year in Viet Nam, as well as a year at the Atmospheric Sciences Laboratory, White Sands, NM, while in the Army. He has been employed at the National Severe Storms Laboratory (1974-1976, Norman, OK), the National Severe Storms Forecast Center (1976-1982, Kansas City, MO), and most recently at the Weather Research Program (1982-present, Boulder, CO). Apart from weather and forecasting (which includes chasing severe thunderstorms in the spring), his interests include hiking, photography, tennis, weightlifting, and music appreciation.

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EDITOR'S NOTE

The National Weather Digest is conducting an on-going call for papers. If there is some trick of operational meteorology you know of and others would like to hear about, send us a paper about it. If you disagree, or agree, with something you have seen in the Digest, write a letter to the Editor.

But remember, this journal is for the operational meteorologist who probably has not derived the equation of motion since Dynamic Meteorology, and for the layman who may not have ever derived the equation of motion. Students especially can benefit from this. When I was in college, the Digest published an article of mine that was actually a transcript of a talk I gave in my Natural Disasters Seminar.

Remember, having an article published always looks good on your resume.

Carrin Goodall
Editor