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Science, Numerical Models, and Forecasting An Overview Pertinent to Convection

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1. INTRODUCTION

One thing should be clear to all people in the weather business: the ways we have been accustomed to doing things are undergoing something more than evolutionary changes. Although changes may never seem more than incremental, the *accumulation* of those incremental changes is pointing toward a revolution in the way we do business.

For me, an important catalyst in my recognition of the coming revolution in our business began with the notions that Brooks and Doswell (1993) enunciated: numerical modeling has come to the point where it too must consider revolutionary change. New numerical methods will not necessarily be simply higher-resolution versions of the old approaches, or fancier, more sophisticated versions of the same old physical packages. Choices must be made about where to invest an ever-shrinking resource base: in advanced versions of the old methods or in such completely different approaches such as ensemble forecasting (considered in more detail in Doswell 1996b). New methods in numerical weather prediction (NWP) need to be evaluated and mechanisms developed for their practical application, and it is not yet clear where the emphasis should be in the next 5-10 years. NWP once was a revolution of and to itself; now, NWP is on the verge of its own internal revolution

In addition to that, a presentation by Fritsch (unpublished, but given at the 1994 AMS Conf. on Wea. Analysis and Forecasting) suggested that a forecaster 5-10 years from now may not be doing operating in anything like the ways in which forecasting has been done for the past 40 years or so. According to Fritsch, the explosive development of information technology has sounded the death knell for the traditional ways of formulating and disseminating weather information.

Fritsch uses zone forecasts as a prototype of the traditional forecasting product, perhaps because they are the quintessential example of an outmoded view of weather forecasting. The zones always have involved an arguable geographic subdivision and the atmosphere never has been prone to recognize the reality of those arbitrary divisions of the real estate. High gradients in either forecast or observed weather do not fall along zone boundaries often enough to justify their reification in our product suite. Instead, weather varies along (literally and figuratively) fluid boundaries that shift and evolve according to their own dynamics, and specifically *not* according to our geopolitical whims. The actual content of a weather forecast, down to detailed fields of meteorological variables, can now be made available to virtually anyone with an appropriate network connection. Preparation of that material into arbitrary zone configurations only distorts the information and creates problems for the forecaster in the process. Information network connection is increasingly widespread and its spread is going to continue. In this age, does it make sense for forecasters to continue much longer to pound away at text that attempts to describe awkwardly in words what can be made available in complete graphical form virtually on demand anywhere, to any user? Tradition is an inadequate rationalization to continue doing things the old-fashioned way.

Finally, there is the question of *value* associated with human intervention in the forecast process. In this age when numerical weather prediction (NWP) models and their associated statistical algorithms for producing sensible weather forecasts (e.g., MOS) are getting inexorably better, what is the role of humans to be? Is there a role for humans in this brave new world of models,

MOS, and computerized weather data dissemination? This issue is going to be dealt with in what follows, but is also covered a bit more extensively in an essay accessible via the World Wide Web at:

<http://www.nssl.uoknor.edu/~doswell/future/dosfuture.html>

2. FORECAST VALUE

I have discussed elsewhere (Doswell 1996a) some of the notions of how our users derive value from what we meteorologists can provide them. In the weather business, accuracy and value are not equivalent; in fact, I recommend Murphy (1993) for a clear enunciation of the concepts related to value in forecasting. Most anyone can be right a significant fraction of the time simply by forecasting with simple forecast models, such as climatology or persistence. If one takes the fairly substantial step of simply accepting the output of a combined (NWP model)-(model output statistics [MOS]) system (hereafter, the N-M system), the majority of day-to-day forecasts can be correct the vast majority of days. See Brooks and Doswell (1996) for some specifics about this related to an "ordinary" weather forecast, the maximum temperature.

Therefore, for the majority of weather forecasts, it is clear that most (perhaps as much as 95 percent!) of the time, a detailed forecast of the weather as it comes out of the N-M system (unsullied by human intervention) will provide most of the value offered by today's cumbersome system of having humans type text describing what the N-M system is forecasting. What sort of product does the N-M system produce?

Generally speaking, the N-M system generates a mediocre forecast by the standards of the *best* human forecasters. Nevertheless, this forecast is, by many standards, quite acceptable. For instance, if the temperature forecasts are within 5°F (~3C) 95% of the time, this is good enough for many purposes. Of course, it we're talking about power company users, it might be nice to have a more accurate forecast than that. Perhaps this can be interpreted as creating a niche for private-sector forecasters, assuming that their product can add value over and above the "plain vanilla" forecast produced by the N-M system. I am inclined to agree with this view. The somewhat mediocre forecast produced by N-M has a big advantage over human interpreters of weather data: it's dirt cheap!! The computer programs that do this "one size fits all" forecast run for pennies a day, do not require overtime and retirement benefits (although they do take "sick leave" from time to time!), etc. In an era when gridded forecast products are readily accessible from the information networks, the only thing users need is an *interpretation* of the output. Interpretive software can be provided by private-sector companies that already are springing up along the "information superhighway" like wildflowers (or weeds, depending on your viewpoint). Often, the interpretive products of the private sector are better than those done "on the cheap" in the public sector.

There are at least two areas where this wonderfully automated system will not suffice to serve the public need (perhaps you can think of others?). First, there are times when the N-M system produces forecasts that have unacceptably large errors, even for the public at large. A related situation arises when the ordinary limits of acceptability shrink owing to certain physically significant situations (e.g., when the temperatures are near freezing). In these situations, the "untouched by human hands" product may not be an adequate product to send out unchanged.

In a way, this is reminiscent of why we have pilots on commercial airplanes. The technology already exists to do landings and takeoffs without human intervention and an "ordinary" flight could be fully automated. But what happens when something goes awry, when the flight becomes *extra*ordinary? Then we want a real live human being at the controls, to deal with the aspects of the situation that have not be programmed into the routine operation of the system. None of us would readily fly on a commercial flight without a pilot, even though the odds of that pilot being needed are pretty small on any flight chosen at random. We don't want *our* flight to be automated, no matter what the odds.

This role for humans, however, is not entirely without its problems. If a human doesn't use a skill, what happens to that skill? It's *lost*. A pilot that didn't actually fly the airplane regularly might not be able to function on the rare occasion when human intervention was really needed. If forecasters are intended to perform only as forecast *monitors* in the future, is it plausible to believe that they could step in and perform on the rare occasions when the N-M system produces egregious errors? Would they even *recognize* in time that it was necessary for them to intervene?

Second, a significant fraction (although by no means all) of *hazardous* weather events is not going to be dealt with properly by the N-M system. A major part of the broad spectrum of hazardous weather (tornadoes, blizzards, freezing precipitation, downslope windstorms, tropical cyclones, etc.) is not forecast all that well by the current N-M system. Either the models don't handle the quantitative aspects well, or MOS doesn't account properly for it, or both. The modeling world is having to accept the fact that extrapolating the rapid advance of product quality in large-scale modeling to the mesoscale is not going to be valid (see Brooks et al. 1992). An awful lot of science remains to be done with mesoscale processes, and there is ample anecdotal evidence for "sensitive dependence on the initial conditions" (see, e.g., Doswell 1987, Rockwood and Maddox 1988) in mesoscale and convective scale events.

Therefore, it seems that a significant continuing role for humans in forecasting hazardous weather will involve their ability to incorporate diverse information with experience and scientific understanding to go *beyond* what science is presently able to validate objectively. Humans, at their best, still outperform models when it comes to hazardous weather. Unfortunately, there are some flies in this particular jar of ointment. Not *all* the human forecasters have the skills necessary to refine the available input into consistently good forecasts of hazardous weather. If we consider the run-of-the-mill forecaster, the "9-to-5 clock puncher," then the situation looks a lot different than if we consider only the top few percent of human forecasters. Many forecasters fail to add value consistently to the N-M "guidance" products; the job is not an easy one.

3. A FORECAST ... OR A DREAM?

So where does all this leave us at the moment and for the foreseeable (by me!) future? Let me try to suggest what might be a plan that would be acceptable to the bureaucrats and politicians and yet which does not compromise the meteorology (I think!). It would involve a drastically reduced human staffing in the public sector, which appears to be a political and economic necessity. It also includes the potential for a substantially strengthened and invigorated private sector, such that unemployment amongst today's meteorologists need not become a crisis. And it changes the mix of job skills needed in a forecast office.

First , if we consider the implications of the general utility of the N-M system's output, this means that there will only be a few opportunities to add value to the N-M system output on a given day, within areas of responsibility at the current sizes.[1] In order to have a reasonable activity level in the office on any given day, the number of offices must decrease, perhaps drastically. In order to be an appropriate size, an office must encompass a large enough area that weather elements can vary substantially across the area of responsibility. In areas of minor topographical variation, this might be an area roughly comparable to an extratropical cyclone's scale size (~[1500 km]^2). In regions with significant topographical diversity, this might be correspondingly reduced to match the scale of variation associated with the interaction between the topography and an extratropical cyclone, but no less than say ~[500 km]^2. There always

[1] I hasten to add that this statement is valid only in the U.S., since most of the 48 contiguous states have more than one weather office issuing forecasts. It is arguably invalid for Australia, with only a handful (7?) of regional forecast offices in an area comparable to the 48 contiguous states of the U.S. In effect, I see the future of the U.S. looking much like Australia is at present.

can be synoptic situations wherein not much is happening meteorologically, but we would want the *majority* of days in such a forecast office to include at least one situation demanding significant human intervention over and above the N-M system's capabilities.

Second, with the increasing capabilities of automation in remote sensing (notably in radar), it is not at all clear that warnings for hazardous weather have to be issued from within the areas where they are needed. With the possible exception of an unusually widespread extent of intense hazardous weather, it should be possible to do a reasonable job of handling hazardous weather (in the sense I have developed in Doswell 1996a) from a remote, centralized office. In unusual situations, it might stretch the capabilities of an automated system to funnel the information from a large number of radars into a single office. In this regard, it might be reasonable to associate the area of responsibility with the number of radars that the office would be expected to handle in a worst-case scenario. For a regular staff of two individuals, it is arguably possible to handle the activity from 3 radars on occasions, especially if is possible to call in another staffer to help out. The larger the routine staff, the more radars one might reasonably be expected to manage. The details of this could be worked out on the basis of some experimentation, and on current experience with the existing system; I will leave that to those more qualified than I to judge.

Third, suppose the new public weather services take on the responsibilities I have suggested in Doswell (1996a); namely, the task of working in close partnership with the users of weather information, in order to use effectively what we are capable of providing. Then the staff of these offices of the future should include a group (at this point of indeterminate size) of *full-time specialists in user education and community partnerships*. This group would need to be large enough to deal with the workload produced by close association between the weather service and the user community.

Moreover, the meteorologist has no need to be doing much time answering the phone in response to questions from the user community. There need to be *meteorological technicians or their equivalent* to offload this burden from the forecasters, who need *uninterrupted time to think about the weather*.

Fourth, I believe that with a smaller staff of forecasters at a reduced number of forecast offices, it becomes plausible to develop a *significant training and education program*, both at entry-level and as a continuing process. If my vision of operational forecasters is ever to become reality, they need to be the "top guns" of the meteorological profession. It should be a badge of honor to be called an operational forecaster, with substantial training required even to *qualify* (with a majority of applicants *not* qualifying!), and a continuing evaluation and periodic *re-certification* necessary to maintain the status of operational forecaster. Only the best of the best should be admitted and they should be well-paid and highly respected for what they do.

Fifth, with such people, motivation is never a problem so they will need to be well-equipped with the tools of the trade. For instance, virtually all offices today have an electronics technician to maintain the hardware. I believe that every office in the future needs *at least one full-time software technician* to assist our forecasters in developing new and better analysis and forecasting tools for their jobs. This also means that the staffing at these new centers needs to be sufficient to allow the *forecasters* to have *20% of their duty hours spent doing research and development projects*. If, as I have argued elsewhere (Doswell 1996c) verification is a critical role in every forecast office, then each office needs *at least one full-time verification specialist*.

As you can see, my view of the future is not necessarily a "bare-bones" world, with a single lonely forecaster working in a computer-filled office. The mixture of skills and the types of activities change drastically from the present, however. What we cannot afford is forecasters doing what is essentially technician work: putting into words what the model (or MOS) says about the forecast. This mode of operation is obsolete and represents an obstacle to a 21st century form of operational forecasting.

The forecaster of the future will sit at the apex of a staff designed to assist that forecaster in the mission of putting out information useful to the users. That forecaster will be a full partner in the scientific community, as well, with useful insights and the ability to contribute them as an equal among meteorologists. There is too much to gain on *both* sides of the operations-research schism for us to permit that gulf to remain open indefinitely.

I believe there is considerable room in this system of the future for the growth of private-sector forecasting. If the public-sector forecasts are a "plain vanilla" product designed to suit the generic needs of the public, then that leaves many niches unfilled: aviation, marine, agricultural, and other commercial needs would support a number of private forecasting companies, without the unfair competition of a "free" public-sector product. The marketplace would demand a definable increase in value over the typical "public" forecast, that private forecast companies would have to be able to provide to their users at a reasonable cost. If there are any forecasters who end up unemployed through staffing reductions in the public sector, there should be a growing need for *good* forecasters in private companies. If someone is cut from the public rolls and is not willing to put in the effort to become a good forecaster, then it is up to that individual to find a new career. There is decreasing room in the profession for mediocre forecasters!!

4. DISCUSSION

Is this a purely utopian view? Perhaps, but we need to consider the alternatives. I am constantly being told that I have to be "realistic" by those who insist on maintaining the status quo, and who are unwilling to take the system in new and innovative directions. Is it realistic to possess all the capabilities of *today's* technology, much less tomorrow's, and have our forecasters typing verbal descriptions of what they see on their screens? Is it realistic to have forecasters doing impossible tasks with minimal resource support and be expected to produce high-quality forecasts while working only as *part-time* meteorologists on the job? Is it realistic in a world of shrinking budgets and deficit spending to continue to permit unmotivated, mediocre forecasters to continue putting out forecasts that are indistinguishable from N-M system guidance? Is it realistic to expect the public to pay for our fancy new hardware and not expect to see a marked increase in forecast quality, relative to the ever-higher standards set by the N-M system? Is it realistic to expect the public to take our word that they are getting more value from what we produce? I don't pretend to speak for the public, but I am a taxpayer, too. I know enough about what is going on to know that we meteorologists are mostly a conservative lot, afraid to experiment and unwilling to change our comfortable patterns of doing our business. I don't believe it is realistic to expect the present pattern of business to remain unchallenged.

In the U.S., the barbarians are already hammering at the gates of our budgets. Are we witnesses to the fall of an empire and unwilling to admit what is happening in front of our eyes? I will leave that for history to judge, of course, and I am by no means a doomsayer. We can address the challenges of the next century, but we need to be prepared to accept revolutionary change, not necessarily because we want to; rather, it is because revolution is being *forced* on us by the pace of technological change.

This paper attempts to predict the future, and so is prone to all the potential sources of uncertainty associated with nonlinear systems. Nevertheless, it is clear that barring unforeseen upheavals within society in the near future, the dawning of the 21st Century is going to see much that is new and different in the weather business and the time to consider those changes is *now*.

We can simply drift along, continuing to believe that the future is going to look like a jazzed-up version of today, or we can confront some of the tough issues that I believe are facing us and make intelligent choices based on a review of likely trends. We can begin to take some control of that revolution, instead of letting it control us. This choice is ours to make. At the same time, many scientific and technical decisions are being made *for us*, on the basis of political and

economic exigencies. Perhaps the political/economic arena is beyond our ability to control, but I continue to believe that we *must* consider what will be our strategies if the bureaucrats and politicians give us any choice whatsoever about our destiny.

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