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OBJECTIVE GUIDANCE FOR WEATHER FORECASTS

William H. Klein

Cooperative Institute for Climate Studies
Department of Meteorology, University of Maryland
College Park, Md. 20742

1. INTRODUCTION

This review paper summarizes the history and development of objective (statistical) methods for forecasting surface weather elements in the United States on the synoptic scale. The main emphasis is placed on guidance forecasts prepared at the National Meteorological Center (NMC) for periods from 12 to 60 hours in advance.

The decade of the 1940's was dominated by the use of scatter diagrams (graphs) applied manually at the local level and based on a lag relation between initial conditions and the weather at some later time (the classical method or pure statistical weather forecasting). Good examples may be found in papers by Brier (1946) and Thompson (1950). During the 1950's, two historic developments revolutionized objective forecasting; namely, the advent of high-speed electronic computers and the introduction of numerical weather prediction. The computers also made it feasible for statistical methods to consider a large number of potential predictors. A forward selection procedure for doing so, called screening, was introduced to meteorology by Miller (1958). Screening has been widely used since then to develop automated guidance forecasts. The first technique to capitalize on these events was the Prefect Prog (PP) method (also called specification) of combining numerical and statistical forecasting. The PP method derives regression equations between surface weather elements and near-concurrent circulation variables and then applies these equations to the output of numerical prognoses. This method was the principal source of objective guidance during the 1960's, but for only a few weather elements.

Since its introduction by the Techniques Development Laboratory (TDL) in 1968, the method of Model Output Statistics (MOS) has become widely accepted, and it now dominates the field of dynamical-statistical weather prediction. By going directly from the numerical forecast to the predicted weather, MOS properly accounts for some of the bias and errors of a fixed numerical model. It routinely provides excellent guidance for almost all weather elements needed by the public, and MOS forecast bulletins are now prepared twice a day at NMC for approximately 500 civilian and military stations in the continental United States. For further explanation of the PP and MOS methods, see Klein and Glahn (1974) and Glahn (1985).

The greatest weakness of MOS has been its inability to keep up with changing numerical models. This problem has become even more acute in recent years because of increasing computer power and rapidly evolving dynamical forecast systems at NMC. Recently, several new approaches, involving revisions of both MOS and PP, have been suggested to solve the problem, and NMC and TDL plan to test them over the next few years. It now appears likely that the decade of the 1990's will see increased use of objective forecast guidance prepared by some modification and blending of MOS and PP.

Section 2 of this paper discusses the evolution of the PP method. The history of MOS in summarized in Section 3. Section 4 describes current attempts to revise and combine the two techniques in response to the problem of rapidly changing numerical models.

2. THE PERFECT PROG METHOD

Although the name "Perfect Prog" was introduced by Veigas (1966), the PP concept was first used by Klein et al. (1959, 1960) to develop multiple regression equations for 5-day mean temperatures at a network of 39 surface stations across the United States. The equations were applied to 700-mb heights forecast by barotropic and baroclinic models, and the resulting temperature predictions were used as guidance by the Extended Forecast Section of the U.S. Weather Bureau.

A few years later, objective predictions of daily mean temperature were produced by Klein et al. (1962) and Klein (1966) for use as guidance by forecasters at NMC. In 1968, the first nationwide objective guidance for any weather element to be transmitted to the field by NMC began for forecasts of daily maximum (max) and minimum (min) temperature developed by Klein et al. (1967), Klein and Lewis (1970), and Klein et al. (1971). These PP temperature forecasts were produced at NMC routinely from 1965 to August 1973, when they were replaced by MOS. However they are still used for internal guidance at NMC for 3 to 7 days in advance.

The PP method has also been utilized to provide guidance for other weather elements. For example, Klein et al. (1965) derived equations to predict daily precipitation and cloudiness, while

Klein (1971) developed an automated system for forecasting daily precipitation probability. The latter system was used to provide internal guidance at NMC for almost a year until it was replaced by MOS in January 1972. TDL made extensive use of PP in developing objective guidance for extratropical storm surges along the Atlantic coast (Pore et al., 1974; Richardson and Gilman, 1983) and over Lake Erie (Richardson and Pore, 1969), as well as for beach erosion (Richardson, 1978). Guidance based upon some of these PP techniques is still transmitted on an operational basis from NMC to the field. Finally, it should be noted that the first TDL objective forecasts of surface dew point were based on the PP method (Elvander, 1971), but guidance for this element was not implemented until a MOS system was derived by Jensenius and Dallavalle (1981).

3. MODEL OUTPUT STATISTICS

MOS was first proposed by Dr. H. R. Glahn in the early 1960's, but it did not develop into a complete forecasting system until after TDL was founded in 1964. One of its earliest applications was to predict the probability of precipitation (PoP) for 12-h periods in the eastern United States from the output of a subsynoptic advection model (Glahn and Lowry, 1969). Other elements forecast early by MOS were surface wind (Glahn, 1970; Barrientos, 1970), severe local storms (Bonner et al. 1971), and ceiling height (Bocchieri and Glahn, 1972). After the publication of a definitive paper on MOS by Glahn and Lowry (1972), TDL expanded its MOS system from the eastern half to the entire country and based it on the output of NMC's primitive equation model and TDL's 3-dimensional trajectory model (Klein and Glahn, 1974). The first NMC transmission of nationwide MOS forecasts began in January 1972 for PoP. A year and a half later, MOS replaced PP as the source of max/min temperature guidance (Klein and Hammons, 1975). A great deal of comparative verification during this period confirmed that MOS forecasts are more accurate than PP forecasts (Annett et al., 1972; Klein and Marshall, 1973; Klein and Glahn, 1974).

Since 1973, MOS guidance forecasts have been transmitted regularly from NMC for numerous weather elements. The numerical model on which MOS was based, however, was changed from the PE and trajectory models to the limited area fine mesh (LFM) model in 1978. MOS forecast techniques were described in refereed journals for ceiling and visibility by Bocchieri et al. (1974), quantitative precipitation by Bermowitz (1975) and Bermowitz and Zurndorfer (1979), surface wind by Carter (1975), frozen precipitation by Glahn and Bocchieri (1975) and Bocchieri and Glahn (1976), cloud amount by Carter and Glahn (1976), PoP by Lowry and Glahn (1976) and Glahn and Bocchieri (1976), max/min temperature by Hammons et al. (1976) and Carter et al. (1979), wind on the Great Lakes by Feit and Pore (1978), precipitation type by Bocchieri (1979), thunderstorm probability by Reap and Foster (1979), and computer worded forecasts by Glahn (1979).

In the decade of the 1980's, TDL expanded its MOS guidance system to stations in Alaska. It has also improved MOS for old products and extended it to new products. Some examples of progress in the former category are Dallavalle et al. (1980) for max/min temperature, Burroughs (1982) for coastal winds, Bocchieri and Maglaras (1983) for precipitation type, Burroughs (1984) for winds over the Great Lakes, Erickson and Dallavalle (1986) for daytime max and nocturnal min, Reap and Charba (1987) for convective storms, and Dallavalle (1988) for max/min temperature. Examples in the latter category are papers by Jensenius and Dallavalle (1981) for spot time temperature and dew point, Bocchieri (1983) for snow amount, Dallavelle and Jensenius (1985) for 3-5 day PoP and max/min temperature, and Jensenius (1988) for percent of possible sunshine.

4. NEW DIRECTIONS

In theory, MOS should be applied only to an unchanging numerical model. This assumption did not pose a major problem to TDL until NMC replaced its LFM model and analysis system in March 1985 by the Regional Analysis and Forecast System (RAFS), which incorporates the Nested Grid Model (NGM) (Hoke et al., 1985). Because the new system has a different set of biases than the old system, the LFM-based MOS could not be applied successfully to it. Furthermore, RAFS underwent frequent and sometimes drastic changes during the first few years of its operation, so that it was pointless to archive its output for MOS development.

This problem was handled in three ways. First, NMC agreed to continue running its LFM system for the sole purpose of supplying MOS guidance to the field. Second, TDL developed and implemented a modified PP method for forecasting max/min temperature, PoP, cloud amount, and surface wind from output of RAFS (Jensenius et al., 1987). This method differs from the traditional PP by using as potential predictors 10 years of initial analyses of the LFM interpolated to station locations, rather than the field of observed variables. Furthermore, some predictors were interpolated from short range LFM forecasts for times of day when upper air soundings are not available. This permitted use of potential predictors (model winds, vertical motion, quantitative precipitation, etc.) not previously available to PP. Although forecasts made by the modified PP technique have verified quite well, especially for wind, they are still not as good as the LFM-based MOS (Carter, 1987; Erickson, 1988; Dallavalle, 1988). As a third step, therefore, TDL reran the current version of RAFS on historical data for 1986-87, combined it with a more stable set of operational RAFS forecasts for 1987-88, and is now using these data to derive a RAFS-based MOS forecast system. Implementation of forecasts for the first four weather elements occurred in July 1989, a full 4 years after RAFS became operational!

In view of this experience, a joint TDL/NMC committee was formed last year to propose and evaluate alternatives for the design and implementation of a statistical guidance system that would be more responsive to NMC's evolving dynamical forecast models. Its final plan (Glahn and Kalnay, 1989) calls for the following steps for 2-7 day forecasts of max/min and PoP: 1) TDL to derive a new set of traditional PP equations. 2) NMC to calibrate its model fields to adjust for recent biases and deflate the predictions towards climatic values. TDL can then evaluate the new set of PP equations based on these fields. 3) Another set of PP equations to be derived from calibrated output variables by applying a new predictor selection procedure developed by Dr. E. S. Epstein that partially compensates for the inability of the numerical model to predict some variables with a high degree of accuracy. 4) TDL to modify the raw PP forecast product by removing its bias and deflating it toward climatology.

For the 24-60 h projections, the committee recommended the following additional steps: 5) TDL to blend LFM-based MOS forecasts with model forecast variables from RAFS. In a similar manner, equations that blend RAFS-based PP forecasts with RAFS fields can also be derived. 6) A method of augmenting MOS proposed by Lewis (1985, 1987) to be developed and tested. This method derives its regression equations from a variance-covariance matrix obtained from a short period of new model output and a long period of observed values. The new matrix approximates what would have been obtained had the model been run over the extended period of the observed data. Application of this method to forecast 6-10 day mean temperature has been discussed by Klein et al. (1988). Further details about this entire section can be found in a paper by Carter (1987).

Of course, the plan calls for all forecasts produced by the six different approaches outlined above to be carefully verified and compared. When all experiments are completed, a decision will be made as to which method (or combination of methods) is best suited to the development of a statistical guidance system for the future. Although it may take several years for the plan to be fully executed, the 1990's promise to be an exciting period of continuing improvements in objective weather forecasting, not only on the synoptic scale, but also for both larger and smaller scales.

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