MOS Forecast Guidance and Operations in the United States

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ABSTRACT

Model Output Statistics (MOS) is a system that provides objective weather forecast guidance to forecasters in the National Weather Service (NWS) of the United States. The original system was designed in the early 1970's in the Techniques Development Laboratory (TDL), and has evolved with significant improvement during the past three decades. The current TDL MOS system provides weather forecast guidance products based on the Nested Grid Model (NGM), the Aviation (AVN) model, the Medium-Range Forecast (MRF) model, and ensemble runs of MRF. The products are disseminated to the NWS forecasters, the Federal Aviation Administration (FAA), the U. S. military services, and the private sector in the form alphanumeric messages and graphics.

The MOS system consists of meteorological data archives, computer software libraries, forecast equation files, and verification data archives. The data archives include hourly surface observations for stations throughout the United States, gridded model output, and climate data. Computer software modules for preparation of data, development of statistical forecast equations, computation of operational forecast elements, and verification of forecasts are stored in the software libraries. The statistical forecast equations are stored in an equation file system which is accessed to produce weather element forecasts. Various post-processors are then used to generated guidance products from the weather element forecasts, and these guidance products are distributed to the users. The NWS field offices use the MOS guidance as a tool in issuing their public and aviation weather forecasts. Samples of the local forecasts and MOS guidance data are collected, stored in the TDL archives, and verified. The analyzed verification data are then distributed and used to improve forecast equation development techniques and local weather forecasters' skills.

TDL prepares and implements the software which collects the meteorological data in the TDL archive system. Observed data are collected from the NWS observation system, the U. S. military services, and other agencies. These data are transmitted to the National Centers for Environmental Prediction (NCEP). TDL software is the used to decode the surface reports and store them in a tabular format. After applying quality control, these data are stored in digital form in the TDL hourly data archive system. Selected gridded data are extracted form the output of numerical weather prediction (NWP) models run by the NCEP, and stored in the TDL archives of model output for every individual NWP model.

Data from the TDL archive system are used to compute predictor and predictand data which, in turn, are used in the development of MOS forecast equations. In the normal development, model output gridded data are interpolated to station locations, and used together with station-based observed hourly and climate data. Predictand values are computed from observed data. Values of a predictor can be computed from previous observations, interpolated model output, or climate data. A forecast equation for a predictand in terms of several predictors is then developed by using multiple linear regression. Forecast equations for some predictands are developed simultaneously to enhance meteorological consistency among them. These equations are the implemented in the operational job stream and are evaluated, as appropriate, to generate daily weather forecast guidance.

In the presentation, the TDL data archives and software systems are described. The techniques of multiple linear regression equation development are also explained. Some possible problems in the MOS forecast equations, such as meteorological consistency, are discussed, and verification results presented.

1.Introduction

Model Output Statistics (MOS) is a system that provides objective weather forecast guidance to forecasters in the National Weather Service (NWS) of the United States. The MOS system provides forecasts for a group of meteorological elements (predictands) based on a numerical weather prediction (NWP) model. Each predictand is related statistically to a group of predictors, which are mostly NWP model forecasts but also may include observations and climate data. The TDL MOS system consists of several guidance packages, and each of them is based on a different NWP model. The original MOS system was designed in the Techniques Development Laboratory (TDL) in the early 1970's (Glahn and Lowry 1972), and has evolved with significant improvement during the past three decades.

In this article, details of the current TDL MOS system are presented. The system itself is described in Section 2. Statistical techniques for the development of MOS forecast equations are explained in Section 3. The operational MOS system and its products are briefly explained in Section 4. An overview of TDL MOS guidance products and the dissemination of these products are described in Section 5. Improvement of the developmental techniques requires the knowledge of the robustness of MOS guidance which relies on the evaluation (and verification) of MOS forecasts. The AFOS-Era Verification (AEV) system which evaluates weather forecasts is described in Section 6 (note that AFOS is the acronym of Automation of Field Operations and Services). Remarks on the evolution of the MOS system are then given in Section 7.

2.Description of the MOS System

The MOS system consists of meteorological data archives, computer software libraries, forecast equation files, and verification data archives.

The meteorological data archives include hourly surface observations and climate data for stations, and gridded model output data of NWP models. Observed data are collected from weather observation sites throughout the United States, including NWS sites, military bases, and others. These data are transmitted to the National Centers for Environmental Prediction (NCEP). TDL software is then used to read the surface reports and store them in a tabular format. After applying quality control, these data are stored in digital form in the TDL hourly data archive system. Selected gridded data are extracted from the output of NWP models run by NCEP, and stored in the TDL archives of model output. Data are saved for several of the NCEP models.

Computer software modules for preparation of data, development of statistical forecast equations, computation of operational forecast elements, and verification of forecasts are stored in the software libraries, along with corresponding documentation files for all individual modules. The documentation files explain the usage and restrictions of software modules. The data preparation software includes those programs that collect meteorological data and store them in TDL archives. Other components use the archive data to compute predictors and predictands for the development of forecast equations. To develop forecast equations, the developmental software is used to perform linear regression analysis and calculate coefficients of the forecast equations. The software also analyzes the reduction of variance of each predictor within the equation. The operational software includes the programs that compute the weather element forecasts by using the forecast equations and that perform the post-processing tasks. The verification software is used to collect local forecasts and MOS guidance data that have been transmitted to NCEP from sample stations in the United States, store the data in the TDL AEV data archives, and evaluate the local and MOS forecasts.

The forecast equations based on individual NWP models are stored in a structured file system which is accessible by the operational software. The latter uses the equations to compute weather element forecasts from the real-time output of the appropriate NWP model, and real-time surface observations if needed.

The verification data archives mentioned above contain a sample of local and MOS forecast data from NWS forecast offices. The collected forecast data include maximum and minimum temperatures, probability of precipitation (PoP), wind direction and speed, and other meteorological elements at the sample stations. These data are used to evaluate the skill of the local and MOS forecasts, and to compare the former to the latter.

3.Development of MOS Guidance System

The MOS system development procedures include data preparation, regression analysis, and testing. In these procedures, forecast equations are developed for weather elements to be predicted (predictands) from other meteorological variables (predictors). Predictors can be NWP model output variables, surface observations, and climate data. Predictand and predictor data are prepared from the archives and used as the input for the regression analysis which produces the forecast equations. The collection of predictand and predictor data is divided into a developmental sample and a testing sample, and the latter can be a subset of the former. The testing sample is used to evaluate experimental forecasts from the equations just developed. The test is a dependent test if the testing sample is a subset of the developmental sample, and is an independent test otherwise.

Before the predictand and predictor data are prepared, suitable variables must be defined. Types of predictands include station-specific, area-specific, and conditional (Dallavalle and Erickson 1993). For example, temperatures (maximum, minimum, and surface), dew point, wind direction and speed, opaque cloud cover, ceiling height, visibility, obstruction to vision, precipitation type, and precipitation amount are station-based predictands; thunderstorm and severe thunderstorm predictands are area-based; precipitation type and severe thunderstorms are conditional predictands, that is, the predictand is conditional upon an event (precipitation or thunderstorms) occurring. Several types of predictor variables are also defined, including continuous, point-binary (Su 1993), grid-binary (Jensenius 1992), and logit variables. A point-binary variable has a discrete value of zero or one only, while a grid-binary variable has any value between zero and one. A logit variable is formed from a continuous variable by using a logistic transformation function. Data are prepared from the archives according to the definitions of predictands and predictors. Some spatial and temporal smoothing schemes, and sometimes a temporal differencing scheme, are applied to the variables over the NWP model grid points. The prepared data are then used as developmental and testing samples.

Prepared data are usually stratified for several seasons throughout the year to preserve intra-annual variations of the data. For some predictands, such as precipitation amount, a seasonally-stratified sample is not sufficient for developing statistically well-behaved forecast equations for a single station. In this case, groups of stations with similar characteristics are collected to form regions, and sample sizes are thus increased. Single station forecast equations are developed for some predictands, such as temperature and dew point, which have hourly readings and larger sample sizes for many stations. Regional equations are developed for other predictands, such as precipitation amount and probability of precipitation, for which grouping data in regions increases the number of cases when the event occurs.

In the development of forecast equations, multiple linear regression is used to determine the statistical relationship between a predictand and multiple predictors. Usually, many potential predictors are offered to the regression analysis software. A forward selection regression technique is used, in which the first predictor selected contributes the most to the reduction of variance; each additional predictor selected contributes the most to reducing the remaining variance. The number of predictors selected depends on the cut-off value of the contribution, which is a function of the predictand and depends on the equation developer's judgment. (Settelmaier and Jensenius 1993).

Some forecast equations may produce guidance with problems of meteorological consistency. Examples of inconsistencies in MOS forecasts can be briefly explained here. A predicted dew point could exceed the predicted temperature for the same projection because the MOS system does not have any constraint to prevent it. A ceiling is defined as opaque clouds which cover more than 50 % of the sky, and MOS forecasts could predict a ceiling height with scattered clouds for the same projection. Within a 12-h period, the MOS forecast of 12-h PoP could be less than the predicted 6-h PoP valid for one of the two 6-h periods. A more complicated case may occur when MOS forecasts indicate high PoP and snow from the precipitation type guidance while the predicted temperature is well above freezing. Two techniques are used to enhance the consistency. One is used during the development of forecast equations, such as, developing simultaneously the PoP forecast equations valid for a 12-h period and the two 6-h periods within the same 12-h period. The other is done by the post-processing of MOS forecasts. Some inconsistencies can be reconciled by forecasters with their interpretation of the meteorological conditions. Despite potential inconsistencies, MOS forecasts usually represent realistic conditions. (Dallavalle and Erickson 1993)

Two kinds of testing methods may be used to evaluate the skill of experimentalforecast equations: independent and dependent tests using their respective samples mentioned above. Independent tests are preferred whenever sufficient data are available.

4.MOS System in Operation

MOS guidance products are produced within the NWS operational job stream, and are disseminated to forecasters and other users as soon as available. MOS forecasts are generated from the forecast equations, and alphanumeric and graphic products are produced by using appropriate software. The operational MOS products include two groups: the short-range and medium-range forecasts.

The current short-range MOS forecast products include mainly Nested Grid Model (NGM)-based MOS guidance products. They are generated twice daily during the 0000 and 1200 UTC forecast cycles. For each cycle, the MOS forecasts are available for projections out to 60 hours at an increment of three hours. The forecasts are available for more than 560 stations in the contiguous United States and 60 stations in Alaska, about four hours after the beginning of each forecast cycle.

A limited set of short-range MOS forecast products is also available from the Aviation (AVN) run of the NCEP global spectral model (see below). The global spectral model is run twice: once to produce the AVN forecasts and once to produce the medium-range forecasts (MRF). The AVN-based MOS guidance products are available for the 0000 and 1200 UTC forecast cycles, around six hours after the beginning of each cycle. The MRF-based MOS guidance products are available around nine hours after the beginning of the 0000 UTC forecast cycle only. Both the AVN and MRF guidance products have a temporal resolution of about 12 hours, with AVN MOS guidance for projections out to 72 hours and MRF MOS guidance out to 192 hours. The AVN MOS guidance provides a limited sample of short-range forecasts while the MRF MOS guidance provides medium-range forecasts. Both forecasts are available for more than 200 stations in the contiguous United States, 14 stations in Alaska, and 12 stations in Canada.

5.MOS Guidance Products and Dissemination

As mentioned previously, the current TDL MOS system provides weather forecast guidance products based on the NGM, the AVN model, the MRF model, and the ensemble runs of the MRF. The NGM, AVN and MRF all produce forecasts of temperature and probability of precipitation. AVN and MRF (excluding ensemble runs) guidance products also include forecasts of cloudiness. In addition, the NGM MOS system generates guidance for wind direction and speed, opaque cloud cover, precipitation type and amount, visibility, obstruction to vision, ceiling height, and probabilities of thunderstorm and severe weather.

The guidance products are provided in the format of alphanumeric messages and graphics, which are prepared for various electronic transmission methods. The MOS system is implemented in the NWS operational computer job stream. As soon as the output of a NWP model is available, the corresponding MOS guidance products are generated. Each package of MOS guidance is usually disseminated to the users within one hour after the completion of the corresponding NWP model run.

MOS guidance products are disseminated to the NWS forecasters on the AFOS system. The Federal Aviation Administration (FAA) and the U. S. military services receive MOS products directly via a different route. For the private sector, these products are disseminated through the Domestic Data Service of the NWS Family of Services.

6.Verification of MOS Guidance

The MOS guidance is verified as a part of the National AEV Data Processing system which was developed in TDL (Dagostaro 1985) according to the National Verification Plan (NVP) (National Weather Service 1982). This system was designed to verify local NWS forecasts and became operational in October 1983. Verification of NGM-based MOS guidance is done within the system to provide a basis for comparison with the accuracy of the local forecasts.

The AEV data processing begins at Weather Service Forecast Offices (WSFOs). The local forecasts and verifying observations are collected by using local software. The complete collection of AEV data which includes weather observations, local forecasts, and the MOS guidance for selected sites is complied and stored locally for further use by the WSFO, if desired. The meteorological elements included in the AEV data are: maximum/minimum temperature, PoP, precipitation amount, precipitation type, snow amount, wind direction, wind speed, cloud amount, ceiling height, and visibility. The AEV data from WSFOs are transmitted through the NWS telecommunications Gateway to NCEP. These data are then extracted from the NCEP real-time data files by using TDL's AEV data archive software, and are stored in TDL files.

The archived AEV data are checked in TDL by executing a quality control program at the end of each month. The program reads the AEV data and passes them through a basic data checklist for good quality, and flags the erroneous data. The erroneous data will not be selected for further processing.

Along with these data, climatic normals and experimental guidance forecasts, which are prepared by using a TDL software program, may also be used in the verification processing. Another TDL software program is then used to select data for desired stations, dates, and weather elements; to collate the data; and to write the collated data to a file. The collated data for a given weather element include the observed value, the local forecast, the MOS guidance, and possibly climate data and other forecasts. The next step is to rearrange these data by using a reformatting program so that each record contains data for only one station, for each date and projection from a given cycle. The reformatted data are then used by the verification program to calculate scores and print reports.

Verification scores are computed for temperature, precipitation, precipitation type, snow amount, wind direction and speed, cloud, ceiling height, and visibility. The verification reports provide many types of skill scores as defined in the NVP. Also provided are improvements over MOS guidance, climatology, and persistence. The AEV system produces timely reports for about 100 stations throughout the United States for every 6-month period.

7.Remarks

So far, each TDL operational MOS guidance package has been developed based on one individual NWP model which generates deterministic forecasts of meteorological elements. The MOS system added the probabilistic aspect to the forecasts. Scientists of NCEP recognized that forecasts are stochastic (probabilistic) and that forecast ensembles of multiple model runs (each with slight modification) provide a rational basis for assessing the range and likelihood of alternative scenarios (Tracton and Kalnay 1993). NCEP established an ensemble prediction system which was implemented in December 1992. Forecast ensembles are generated by using the MRF model with perturbations in the initial condition and with time lagging. TDL has generated a package of ensemble-based MOS forecasts for the 0000 UTC cycle, by using the current MRF-based MOS forecast equations on each of 11 NCEP's MRF ensemble runs. The current ensemble-based MOS provides experimental forecasts of maximum/minimum temperature and PoP for approximately 200 stations in the United States. The experimental ensemble MOS forecasts are not disseminated but are being evaluated. The evaluation results will be used to design an efficient way of disseminating the ensemble MOS forecasts to the guidance users (Erickson 1996).

As a part of TDL's continuous improvement effort, the MOS-2000 system is currently being designed and developed. MOS-2000 is a new generation of the MOS system, and is designed to improve its efficiency and to keep up with new NWP models. The new system is applicable on both large-scale computers and work stations; the primary data archives are kept on a large-scale computer and are accessible to both hardware systems. The MOS-2000 system also has applicability to objective weather forecasting guidance for various time scales used in the aforementioned MOS guidance and in the LAMP system. LAMP is the acronym for Local AWIPS (Automated Weather Interactive Processing System) MOS Program, is a local MOS system that provides forecast updates for short time scales, and is another system that was developed and has been maintained by TDL.

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