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AN OVERVIEW OF NWS QPF PRODUCTS

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1. INTRODUCTION

Until recently, forecasts of flooding and flash flooding issued by the National Weather Service (NWS) have relied heavily on observed precipitation, with relatively little weight given to quantitative precipitation forecasts (QPF). This situation existed for several reasons. First, forecasts of precipitation amount generally have less precision than forecasts of other variables such as temperature, largely because precipitation fields are much more variable in space and time than most other meteorological variables. Second, precipitation forecasts have been unavailable at the spatial scale needed by the hydrologic forecaster. Model output at grid points 100 km apart are of little use to a forecaster attempting to predict flash flooding in a 50 km^2 drainage basin. Third, precipitation forecasts have not been available in a format that is useful to the hydrologic forecaster. Hydrologic models employed by the River Forecast Centers (RFC's) use the average precipitation amount over a drainage basin, but QPF has traditionally been in the form of point forecasts.

The advent of higher-resolution numerical weather prediction (NWP) models is leading to improvements in precipitation forecasting skill and in the spatial detail of the forecasts, and QPF products are now being developed in a format that meets the needs of the hydrologic forecaster. Consequently, QPF is becoming an increasingly important component in the flood and flash flood forecasting process. The use of QPF in hydrologic forecasting increases the lead time for a reliable forecast, which in turn increases the amount of time available to users to protect lives and property.

This note describes present and planned QPF products in the NWS and their respective places in the "end-to-end" forecast process--a coordinated flow of information between several NWS organizations (Figure 1) to maximize the quality and timeliness of service (Graziano, personal communication). The second section of this note describes present and planned contributions of the Environmental Modeling Center (EMC) in the form of numerical weather prediction (NWP) model-based QPF. The third section presents "value-added" products being produced and developed by the Techniques Development Laboratory (TDL) based on output from the EMC models. The fourth section outlines the manual guidance produced for the contiguous 48 states by the Hydrometeorological Prediction Center (HPC), based in part on adjustments to the EMC model QPF; and the fifth section describes the QPF products produced by the Weather Forecast Offices (WFO's) for the River Forecast Centers (RFC's) based on the guidance from the other sources.

2. EMC'S CONTRIBUTION: GRIDDED MODEL OUTPUT QPF PRODUCTS

EMC provides QPF output from a suite of NWP models at various spatial and temporal scales, ranging from short-range, high-resolution models covering the 48 contiguous states (the Meso Eta and the Rapid Update Cycle (RUC) model), to a global model providing forecasts out to 16 days [the Medium Range Forecast (MRF) model]. The current and planned contributions of EMC are described in this section, and are also summarized in Table 1.

A. The Eta model

The first large-scale model that is run during each 12-h EMC model cycle is the Eta (Black 1994; National Weather Service 1993c; National Weather Service 1995a; Rogers et al. 1995), which was introduced in June 1993. It is run twice daily with initialization times (corresponding to the time of the model initial field) of 0000 and 1200 UTC, and a data cutoff time (corresponding to the time model preprocessing begins) approximately 75 minutes later. The model grid covers North America and adjacent ocean areas at a resolution of 48 km in the horizontal with 38 vertical layers. Since the grid covers only part of the globe, conditions at the edge of the model domain (boundary conditions) are provided every 3 hours by forecasts from the previous run of the aviation (AVN) model (see below). The Eta produces grid-scale precipitation wherever the relative humidity exceeds 95 percent and uses the Betts-Miller Scheme (Betts 1986, Betts and Miller 1986), with modifications by Janjic (1994) to parameterize subgrid-scale convective precipitation.

QPF output from the early Eta consists of gridded output fields of the accumulated 6-h precipitation, plus the grid-scale and convective components of that total. In the future, 3-h accumulations will be available. These fields are available in GRIB (GRIdded Binary) format on several AWIPS (Advanced Weather Information Processing System) grids. Grid #211 is a Lambert conformal grid covering the 48 contiguous states and adjacent regions; grid #207 is a 95-km polar stereographic grid covering Alaska and nearby areas. In the future, output will be available on grid #212 (a 40-km version of grid #211) and on grid #216 (a 45-km grid covering a somewhat larger area than grid #207). These grids are described further in Stackpole (1994). In addition to the gridded data, hourly sounding data files containing forecasts of hourly precipitation and convective precipitation amounts are available for over 500 locations in North America.

The Eta is so named because it uses an eta vertical coordinate, as opposed to the sigma coordinate used by most other EMC models. The equation for the eta coordinate is given below:

$$\eta=\left(\frac{p-p_T}{p_{sfc}-p_T}\right)\left(\frac{p_{ref}(z_{sfc})-p_T}{p_{ref}(0)-p_T}\right).$$

In the first term in parentheses, p is the pressure at the point of interest while p_T is the pressure at the top of the model domain (25 hPa) and p_{sfc} is the surface pressure. This term represents the sigma coordinate, and it is scaled from 0 (at the top of the atmosphere) to 1 (surface). The sigma coordinate is commonly used because it greatly simplifies many model computations.

The second term in parentheses is a scaling term that converts the sigma coordinate to the eta coordinate. The reference pressure, $p_{ref}(z)$ is a function of height above sea level that is based on the standard atmosphere; z_{sfc} is the elevation above sea level of the ground surface at the point of interest, and $p_{ref}(0)$ is the mean sea level pressure at the point of interest. In essence, the eta coordinate scales the pressure field from the top of the atmosphere to the mean sea level pressure rather than the surface pressure.

The primary advantage of the eta coordinate over the sigma coordinate is that it produces more accurate estimates of the geostrophic wind, which is crucial to correctly balancing the wind and pressure fields within the model. The geostrophic wind must be calculated on constant pressure surfaces, so the wind components and the pressure gradient must be interpolated from the model surfaces to the constant pressure surfaces. When the sigma surfaces are steep, the interpolation errors can be sizeable, resulting in significant errors in the estimated geostrophic wind (Mesinger et al. 1988). Since the eta coordinate surfaces are relatively horizontal, the geostrophic wind estimates are more accurate, but the ease of computation afforded by the sigma coordinate is preserved.

The use of the eta coordinate also allows steeply sloping terrain to be represented more accurately than when the sigma coordinate is used (Black, personal communication). In models using the sigma coordinate, the ground surface is the lowest sigma level (by definition), and this tends to produce excessively spread-out model topography (for example, the exaggerated elevations in the High Plains in the NGM topography). By contrast, the Eta topography consists of "steps" connecting the eta levels, which allows the model topography to be as steep as necessary.

B. The Nested Grid Model (NGM)

The Nested Grid Model (NGM) (DiMego et al. 1992; Hoke et al. 1989; Petersen et al. 1991; Petersen and Stackpole 1989), which was introduced in March 1985, is the second large-scale model that is run during an EMC production cycle. The Regional Analysis and Forecast System (RAFS) comprises the NGM run plus the preprocessing and postprocessing phases. RAFS is run twice daily, with initialization times of 0000 UTC and 1200 UTC and data cutoff approximately 2 hours later. The NGM is so named because it contains two polar stereographic model grids with two different resolutions: a C-grid with a horizontal resolution of 83 km (at 45 degrees north) covering all of North America and extending over the North Pole into northern Europe and Asia, and a 166-km B-grid covering the remainder of the Northern Hemisphere. There is no nesting in the vertical domain, however; the entire model regime contains 16 vertical layers. Grid-scale precipitation is handled in the same manner as in the Eta, but the NGM employs a modified Kuo (1965) scheme for convective precipitation. A Betts-Miller (1986) scheme was tested for the NGM, but was not used because the resulting changes in the model output were significant enough to compromise the performance of the NGM MOS (see below for details on NGM MOS).

Like the Eta, the NGM is a limited-area model, and so boundary conditions are necessary. The NGM assumes that most variable fields are symmetric across the equator; that is, that the value of a parameter at a specific longitude and latitude north of the equator will be the same as at the same longitude and latitude south of the equator. Meridional winds are an exception: they are assumed to be opposite in sign on opposite sides of the equator, which results in no wind across the equator.

Output fields, including 6-h total precipitation, are available every 6 hours out to 48 hours. Fields of 6-h precipitation totals are available in GRIB format on AWIPS grid #202 (a 190.5-km polar stereographic grid covering North America and adjacent areas), grids #207 and #211 (see above), and grid #213 (a 95.25-km version of grid #202).

C. The Global Spectral Model (GSM)

The Global Spectral Model (GSM) (Kanamitsu 1989; Kanamitsu et al. 1992; Petersen and Stackpole 1989) produces both short-range and medium-range forecasts. The short-range model run is referred to as the Aviation (AVN) run, while the longer-range version is the Medium Range Forecast (MRF) model run. The AVN is run four times daily (initialization times at 0000, 0600, 1200, and 1800 UTC with data cutoff 2 hours 45 minutes later). Only the 0000 and 1200 UTC runs are presently disseminated outside EMC, but at some future time all four runs will be available. The MRF is run once daily at 0600 UTC for a 0000 UTC initialization time, so its initial field is based on more observations than the corresponding AVN run. Additional runs of the MRF and of the 0000 and 1200 UTC AVN are made for ensemble forecasting (see below).

The GSM is substantially different from the Eta and NGM in two important respects. First, the GSM is a global model, so no boundary conditions are necessary (in fact, the AVN run provides the boundary conditions for the Eta, as mentioned previously). Second, while the Eta and NGM are finite difference models, representing data fields as a set of values at discrete grid points, the GSM is a spectral model representing each data field as a set of mathematical relations called spherical functions. This is done only in the horizontal; the model uses distinct vertical layers because the presence of boundaries at the earth's surface and at the top of the atmosphere make spectral representation in the vertical very difficult. The GSM originally used the Kuo (1965, 1974) scheme for convective precipitation, like the NGM, but it now uses the Pan-Grell scheme (Morone, personal communication).

The use of spherical functions makes it difficult to specify a model resolution per se; the AVN has Triangular truncation 126-wave (T126) resolution, which is roughly equivalent to 105-km grid resolution, and 28 vertical layers. An increase in horizontal resolution to T170 (approximately 78 km) with 42 vertical levels is planned (Berry and Wolf 1995). Model output, from the AVN, including 6-h total precipitation, is available every 6 hours out to 72 hours in spectral coefficient form and also in gridded form on AWIPS grids #203 (a 190.5-km polar stereographic grid covering Alaska and large portions of the Pacific Ocean), #211, and #213 (see above). (The AVN is actually run out to 16 days with T62 resolution, but these data are used for ensemble forecasting and is not transmitted with the first part of the AVN run; see below for more on ensemble forecasting.) The MRF also uses T126 resolution out to 7 days and then T62 (215 km) resolution out to 16 days; output is available in 12-h intervals on AWIPS grids #201 (a 381-km grid covering the Northern Hemisphere) and #213.

D. The mesoscale Eta model

A mesoscale version of the Eta (Black 1994) is also operational, but unlike the other EMC models the output is not sent out to the other offices but must be retrieved over the Internet. The meso Eta, as it is called, has a 29-km grid covering the contiguous 48 states and adjacent waters, and 50 vertical layers, easily the finest resolution of all of the operational models in the EMC suite. It is run twice daily, with an initialization time 3 hours after the Eta run and data cutoff 50 minutes after the initialization time. Like the Eta, the Meso Eta uses AVN forecasts for boundary conditions, and the 3-h delay allows the Meso Eta to use boundary conditions from the current AVN run. Plans have been made to begin running the meso Eta four times daily beginning sometime in 1997 (Black, personal communication), which will correspond with the running of the AVN every 6 hours. The physics package of the meso Eta is essentially the same as for the Eta, including its handling of grid-scale precipitation and the use of the Betts-Miller scheme (Betts 1986, Betts and Miller 1986) for subgrid-scale convection.

The gridded forecast fields are the same as for the Eta except that they cover 3-h periods. They are available on AWIPS grid #212 (40-km resolution) at 3-h intervals out to 33 hours; hourly forecasts are planned, along with output on AWIPS grid #215 (a 20-km version of grid #212).

A version of the meso Eta is being tested with a 10-km, 60-layer nested grid that can be placed over the eastern or western United States. The eastern nest will be used to support the 1996 Olympics in Atlanta, and eventually forecasts from both nested grids will be available operationally. Testing on a nonhydrostatic version of the meso Eta has also begun (Mitchell, personal communication).

E. The Rapid Update Cycle (RUC) model

The Rapid Update Cycle (RUC) model (National Weather Service 1994b) is a high-resolution model intended for short-range forecasting. It is initialized every 3 hours beginning at 0000 UTC, with a data cutoff 1 hour 20 minutes later, and generates forecasts to 12 hours after the initialization time. It has a 60-km polar stereographic grid covering the contiguous 48 states and nearby waters and 25 vertical layers, and uses NGM forecasts for boundary conditions, though a switch to Eta boundary conditions is planned. The RUC uses the Grell (1993) parameterization for convective precipitation.

Gridded output from the RUC is presently available at 3-h intervals on AWIPS grid #211 (80-km resolution). Three forms of precipitation output are available: instantaneous rate of precipitation, 3-h total grid scale precipitation, and 3-h total convective precipitation. The RUC will eventually be run hourly on AWIPS grid #212 (40-km horizontal resolution) with 40 vertical layers and will produce hourly forecasts on that grid.

The vertical coordinate system of the RUC is unique in EMC's model suite. The RUC uses a hybrid-b vertical coordinate, which consists of the sigma coordinate in the lowest layers and an isentropic (constant potential temperature) coordinate for higher layers. Specifically, all 25 layers of the RUC are associated with specific values of virtual potential temperature; however, when the height of a given layer becomes close to the ground (by exceeding a predefined pressure level), then the layer is kept at that predefined pressure level in the form of a sigma coordinate.

The RUC is chiefly intended to be an aviation forecasting model for forecasting upper-level wind fields (Morone, personal communication), but its isentropic vertical coordinate should be beneficial for precipitation forecasting as well. Adiabatic transport in the atmosphere occurs along surfaces of constant potential temperature, so using an isentropic vertical coordinate transforms this 3-D transport process into a two-dimensional process that can be simulated more easily and accurately (Johnson et al. 1993). Also, because transport of moisture from above the oceans to continental areas generally follows isentropic surfaces prior to the start of condensation, moisture fields tend to be more coherent on isentropic surfaces, which allows the model to more accurately capture their structure (Benjamin 1989). The use of isentropic coordinates also reduces the precipitation "spin-up" problem (see Johnson et al. 1993 for an explanation). Finally, an isentropic vertical coordinate allows areas of interest such as fronts to be depicted in more detail, since the isentropic surfaces are closer together in those areas than elsewhere. This last feature can represent a drawback in a well-mixed boundary layer, where isentropes will be quite far apart; however, substituting a sigma surface for the isentropic surface within 1-2 km of the earth's surface allows the model to capture the structure of the boundary layer as well.

Studies on a model using the hybrid-b coordinate by Johnson et al. (1993) on hypothetical initial conditions and by Zapotocny et al. (1993) on a case study support this reasoning. In the latter study, the hybrid model also more closely predicted the magnitude of the precipitation maximum, which is significant since models typically perform poorly on forecasts of the magnitude of the heaviest precipitation.

F. The Nested Regional Spectral Model (RSM)

Experiments are presently being conducted on a version of the Global Spectral Model that has a higher-resolution nested region surrounding North America (Juang and Kanamitsu 1994). The global model, whose skill is greatest at large scales, provides a large-scale base state for the nested region. Perturbations to this base state within the nested region are computed with a separate set of equations and added to the base state values from the global model. The nested region of the RSM is planned to be approximately the same size as the inner NGM grid with the equivalent of 50-km horizontal resolution (Mitchell, personal communication).

G. Ensemble Forecasting

Ensemble forecasting (Brooks et al. 1995; Tracton and Kalnay 1993; Toth et al. 1995) consists of running the same model numerous times with slight perturbations to the initial conditions in each model, in addition to a "control" model with the original initial conditions. This makes a variety of possible forecast scenarios available to the user.

The rationale for ensemble forecasting is rooted in chaos theory: the atmosphere is a nonlinear system in which small errors in the initial conditions can grow into large errors in the forecast field as time passes. Studies by Reynolds et al. (1994) and others indicate that, in the midlatitudes, errors in the initial conditions contribute more to forecast error than deficiencies in the global NWP model. This leads to the conclusion that while some gain in forecast skill is still possible through improved model physics and initial conditions, more improvement may be achieved by determining the effects of the errors in the initial conditions on the model forecasts.

Ensemble forecasting began at EMC in December 1992. At present, a 46-run ensemble from the GSM is used, with 17 new forecasts generated each day--12 MRF forecasts at 0000 UTC and five AVN forecasts at 1200 UTC, all out to day 16. The specific model runs are:

1) The MRF run at T126 out to day 7, T62 out to day 16;
2) The MRF "control" run at T62;

3-12) Ten MRF runs at T62 with perturbed initial conditions.
13) The AVN run at T126 out to day 3, T62 out to day 16;
14-17) Four AVN runs at T62 with perturbed initial conditions.

The ensemble consists of the MRF forecasts from the current day and the previous 2 days plus the AVN forecasts from the previous 2 days, for a total of 46 forecasts for the 0-14 day time period.

The information from all ensemble members is presently available in gridded format over the Internet, and total accumulated precipitation is one of the available output fields. This is a tremendous amount of data; however, two products that greatly simplify interpretation of the ensemble forecasts will soon be available (Tracton, personal communication). One will be a forecast of the probability that the 24-h precipitation amount will exceed specific thresholds. The other product will be what is commonly known as a "spaghetti chart": a plot containing all of the 24-h forecasts of the position of the forecast isohyets for a specific value.

At present, ensemble forecasting is done operationally only in the medium range. However, experimental work with ensemble forecasting is being done with both the Eta model and the RSM, and it is envisioned that this information will eventually become available on an operational basis, including QPF products such as those for the MRF ensemble.

3. TDL'S CONTRIBUTION: VALUE-ADDED FORECAST PRODUCTS

At the Techniques Development Laboratory (TDL), a number of products are available or are under development that enhance model output through Model Output Statistics (MOS) (see Table 2 for a summary). Based on an approach developed by Glahn and Lowry (1972), MOS forecasts use statistically-derived empirical relationships between numerical model output, observations, and climactic variables (such as location and time of year), and the value of the desired forecast variable. (Observations are not used in the precipitation-related equations, however.) MOS has several advantages over model output alone: it accounts for some systematic model biases and can express uncertainty in a forecast (probability of precipitation, for example), it incorporates local effects into a forecast (crucial given the relatively coarse terrain in the operational models), and it can generate output products not available from the raw model, such as the probability of .01 inch or more of precipitation during a given period.

A. NGM MOS

The most complete set of MOS products available at this time are based on the NGM (Antolik 1995; National Weather Service 1992; 1993a). Using equations derived from a 5-year development sample of NGM output and observations, MOS generates point forecasts of the probability of precipitation (PoP) for 6-h periods beginning 6 hours after the model initialization and for 12-h periods beginning 12 hours after the model initialization, out to 60 hours--12 hours beyond the end of the NGM forecast period. These forecasts are prepared daily at approximately 0400 UTC and 1600 UTC for the preceding runs of the NGM.

NGM MOS PoP forecasts are presently available in alphanumeric format for 565 locations in the contiguous 48 states and for 60 locations in Alaska (National Weather Service 1995b). (However, in Alaska the 12-h PoP and QPF periods begin 6 hours after the model initialization instead of 12 hours after.) Forecasters at HPC also have access to gridded MOS PoPs on AWIPS grid #213 (95.25-km resolution); more general distribution of this product is planned (Dallavalle, personal communication).

In addition to the probabilistic forecast of .01 inch or more, MOS generates probabilities that the precipitation amount at the point of interest will exceed 0.10 inch, 0.25 inch, 0.50 inch and 1.00 inch in 6 and 12 hours, and 2.00 inches in 12 hours. The probabilities for these individual categories are available to HPC forecasters in gridded format and will become available to field forecasters in the future (Dallavalle, personal communication). However, a "best category" forecast, which is the highest category for which the probability exceeds a pre-determined threshold value, is part of the generally available MOS package. A MOS expected-value QPF (Antolik 1996) based on the probability of the precipitation amount in each category and the average amount of precipitation in that category, is presently available to HPC forecasters and will also become available to field forecasters at some future time (Dallavalle, personal communication).

B. AVN and MRF MOS

MOS packages have also been developed for the AVN (National Weather Service 1994a) and the MRF (National Weather Service 1993b), but they provide forecasts for fewer variables than NGM MOS. Forecasts are available for more than 225 locations in the contiguous United States, Alaska, and southern Canada, and are generated at approximately 0600 UTC and 1800 UTC for the prior AVN runs and at 0900 UTC for the MRF run. AVN MOS provides 12-h PoP forecasts from 12 to 72 hours, while MRF MOS PoPs are generated out to 192 hours (8 days). MRF MOS also provides 24-h PoPs beginning at 24 hours. These forecasts are also available in gridded format (AWIPS grid #202) to HPC forecasters only. MOS QPF is presently unavailable for either model, but a full set of probabilistic and categorical forecasts are planned for the AVN, and perhaps for the MRF out to a limited time range (Dallavalle, personal communication). MOS for the Eta model is also being considered (Dallavalle, personal communication), but current plans are to limit precipitation information to PoP forecasts.

C. Local AWIPS MOS Program (LAMP) QPF

Another MOS-related product currently being tested is the Local AWIPS (Advanced Weather Interactive Processing System) MOS Program (LAMP) QPF product (Charba et al. 1996a, b). The LAMP QPF is a specialization and extension of the basic LAMP model described by Unger et al. (1989). The basic model is a comprehensive package that decodes and analyzes conventional hourly observations; runs simple mean sea level pressure, advection, and moisture models; interpolates MOS forecasts to specific LAMP forecast sites and times; generates forecasts based on the observations and analyses, output from the simple models, and interpolated MOS; and creates graphic displays of these analyses and forecast fields.

The QPF model extends the LAMP concept in several ways. One is resolution: the input and output fields are on a 20-km grid covering the contiguous 48 states. Another is in the addition of new parameters pertinent to precipitation forecasting that help to produce meaningful detail at this scale. These include high-resolution topography, forecasted 850-mb u- and v-components of wind from the NGM (which are also used to generate fields of moisture convergence and of vertical velocity resulting from interaction with topography), and monthly precipitation amount climatology. Derived interactive predictor variables are used to introduce mesoscale detail into these synoptic-scale NGM 850-mb winds and MOS QPF forecasts. Finally, many of the derived predictor fields are transformed to enhance their effectiveness in the linear regression equations in this model.

The LAMP QPF module generates probability forecasts for various categories of precipitation amount: 0.00 to 0.09 inch; 0.10 to 0.24 inch; 0.25 to 0.49 inch; 0.50 to 0.99 inch; 1.00 to 1.99 inch; and 2.00 inches or greater. "Best category" and expected precipitation are also derived from the probability fields. All of these forecasts can be considered to be valid for any point within the 20-km grid box of interest. The LAMP QPF module--which can be run hourly if desired--generates forecasts for several time periods, including four 1-h periods in the 1-5 h range, two 3-h periods in the 4-10 h range. Two 6-h forecasts are also generated, covering the 7-19 or 10-22 h range, depending on the initialization time.

D. Radar-based precipitation estimates

Kitzmiller (1996) has developed and tested an algorithm for generating 0-1 h forecasts of rainfall within a single radar umbrella using an extrapolative-statistical method. The algorithm uses volumetric radar reflectivity information currently available from the Weather Surveillance Radar 1988 (Doppler), or WSR-88D, to produce forecasts on a 4-km grid. It is designed to alert forecasters to the threat of large 1-h rainfall amounts caused by intense and/or slow-moving convective systems.

The algorithm was developed by preparing a large number of extrapolation forecasts of reflectivity and vertically-integrated liquid (VIL) from digital radar archives. To generate the extrapolation forecasts, echo velocity was estimated by a lag-correlation pattern matching between the latest reflectivity image and earlier ones. The resulting reflectivity forecasts were converted to rainfall forecasts through the WSR-88D Z-R relationship, and regression equations were derived to relate the predictors to gridded rainfall estimates generated by the WSR-88D Stage III process. These rainfall estimates incorporate both radar and remote-reporting gauge data. This approach is similar to MOS in that the output of a theoretical model (here, extrapolation without radar echo growth or decay) has been calibrated with sensible weather observations. The use of Stage III data in development enables the algorithm to account for uncertainty due to extrapolation errors and echo development and decay; the incorporation of volumetric predictors yields an improvement on the information from single-level reflectivity alone, particularly for the higher rainfall categories.

In practice, the extrapolative-statistical procedure provides probabilistic forecasts for the 0-1 h period for the same categories as does the NGM MOS 6-h QPF system, and a "best category" forecast derived by comparing the probabilities to a set of present thresholds. An effort is now underway to extend this approach to 0-3 h prediction on both local and national scales, using local radar data, a national radar composite, and numerical model output as predictors for the regression relationships. Later versions will incorporate satellite data as well.

4. HPC'S CONTRIBUTION: NATIONWIDE MANUAL QPF PRODUCTS

HPC has produced manual QPF guidance for the 48 contiguous states since 1960 (Corfidi and Comba 1989; Olson et al. 1995). HPC forecasts (summarized in Table 3) combine information from numerous sources: Gridded QPF from EMC models, surface analyses and observations, radar-based precipitation estimates, estimates of past precipitation and briefings regarding potential future precipitation from Satellite Analysis Branch (SAB) forecasters, and HPC forecasters' knowledge of model behavior and of the relationships between synoptic features and the space-time distribution of precipitation typically associated with them. The latter is especially important since models typically forecast the position and configuration of synoptic features much more accurately than their associated precipitation fields. HPC manual guidance possesses significantly greater skill than unaltered EMC model gridded QPF--HPC "day 2" manual guidance generally has the same level of skill as "day 1" forecasts by EMC models.

HPC QPF forecast products consist of maps of the 48 contiguous states and adjacent portions of Canada and Mexico with isohyets representing areal average precipitation amounts, which are compatible with the basin average precipitation amounts used as input to the streamflow models used by the RFC's. With the exception of the 6-h QPF forecasts, these products are accompanied by text information explaining the reasoning behind the forecasts and describing the HPC forecasters' level of confidence.

Daily guidance for liquid-equivalent QPF from 1200 UTC to 1200 UTC is provided via a "day 1" 12-36 h forecast and a "day 2" 36-60 h forecast based on the 0000 UTC model runs. These products, which have AFOS headers of 94Q and 98Q respectively, are issued between 0930 and 1000 UTC. In addition, a preliminary 94Q is issued between 0500 UTC and 0600 UTC, and an update of the 98Q is issued between 1730 UTC and 1800 UTC based on the 1200 UTC model output. The isohyets on these maps are 0.25 inch, 0.5 inch, and every inch up to 6 inches. The discussion accompanying these products is issued under AFOS header QPFPFD.

HPC also provides 6-h manual QPF guidance with isohyets at 0.25 and 0.5 inch, with higher maximum amounts indicated with a labelled arrow. The 91E is a 0-6 h nowcast of precipitation issued every 6 hours beginning at 0000 UTC, and the 92E and 93E represent forecasts of precipitation for the 6-12 and 12-18 h time ranges. The latter two are issued at nearly the same time as the 91E during the 0600 UTC and 1800 UTC forecast cycles; for the other two cycles (0000 UTC and 1200 UTC), they are issued approximately 2 hours after the 91E.

In the future, a fourth 6-h period (probably 18-24 h) will be added to the HPC product suite. The forecast range of HPC QPF will also be extended: a "day 3" forecast will be issued with the afternoon update of the 98Q and a forecast of total precipitation from "day 3" to "day 7" is also planned. In conjunction with the trend toward probabilistic forecasting, the incorporation into the forecast products of some measure of confidence or estimate of probability is also being studied (Olson, personal communication).

HPC also provides an Excessive Rainfall Outlook under AFOS header 94E, with the discussion under header QPFERD (Excessive Rainfall Discussion). It is not a QPF product by a strict definition, but it does provide information about regions where precipitation amounts may exceed flash flood guidance values and/or 5 inches. A 24-h outlook for "day 1" is issued at 0600-0700 UTC. An update issued at 1400-1430 UTC covers the time period 1500 UTC to 1200 UTC, and the final update at 1800-1900 UTC covers the period 2100 UTC to 1200 UTC. Later updates are also issued if conditions warrant. A Special Rainfall Discussion narrative (header PQFSRD) can also be issued if necessary.

From mid-September to mid-May, HPC also provides a 6-18 h heavy snow forecast and an 18-30 h heavy snow outlook. They are issued every 6 hours beginning 0200 UTC (and thus are actually forecasts for 4-16 h and 16-28 h) under the AFOS headers 93S and 94S, respectively. Both are accompanied by a discussion under header QPFHSD (Heavy Snow Discussion). The graphics show isohyets of predicted snowfall at 4-inch intervals; areas of localized heavy snowfall (e.g. lake effect) are indicated by arrows.

5. THE WFO's CONTRIBUTION: LOCAL MANUAL QPF PRODUCTS

In the "end-to-end" forecast process that is the goal of the NWS, the WFO's receive the model QPF from EMC, MOS products from TDL, and the manual QPF guidance from HPC, and combine these with the WFO forecasters' knowledge of local conditions to provide "localized" QPF guidance for the RFC's. In practice, however, manual QPF production by the WFO's is relatively new, and has not yet been adopted by all of the WFO's. It was not until 1987 that forecasters at the WSFO in Charleston, West Virginia (CRW) began preparing local QPF for their area of responsibility; the practice has begun to spread to other offices since then (Zevin 1994).

Among those WFO's presently producing basin average QPF values (as opposed to point forecasts only), the predominant QPF tool at this time is WinQPF (Fenbers 1995). To prepare QPF using this product, the forecaster draws isohyets representing forecasts of mean areal precipitation values on a map on a computer screen. The computer interpolates these isohyets to produce gridded QPF on a 4.3-km polar stereographic grid in GRIB (GRIdded Binary) format, as well as forecasts of basin average precipitation in both graphic and ASCII format. (Basin average precipitation is used in the RFC's spatially lumped river stage forecast models, so it is the best forecast parameter for their needs.) These forecasts are prepared for the 0-24 h time period in 6-h subperiods, with the 24-h period beginning and ending at 1200 UTC (which is the beginning and ending of the "day" for hydrologic purposes). An update is issued each evening and whenever conditions make it necessary. The RFC's can then use a program called HASQPF to mosaic the gridded QPF products from the WFO's in their respective areas of jurisdiction and make appropriate changes.

The Interactive Computer Worded Forecast (ICWF) system (Calkins 1996; Ruth and Peroutka 1992), which is operational at three WFO's at this time with plans for nationwide use, contains a QPF-generating system that supercedes the abilities of WinQPF. To generate QPF, the ICWF is initialized with a "first guess" field from MOS (the midpoint of the "best" QPF category, or the bottom if it is the highest category), the Eta model, or the previous shift's forecast instead of model guidance. (Once the precipitation forecasting portion of LAMP becomes operational, it will replace MOS as an optional initial field.) If model guidance is used, it is interpolated onto the desired grid (a 4.3-km or 19-km Lambert projection grid can be selected) with a weighting scheme designed to account in part for local effects such as topography. The forecaster can then manipulate this field by modifying individual values or groups of values on the grid, or by modifying the contour field and having ICWF recompute the grid values accordingly. Once the field has been modified, it is converted to GRIB format for transmission to the appropriate RFC. The QPF-related forecast fields are 12-h probability of precipitation, 6-h precipitation amount, and 12-h snowfall amount. Forecasts are issued with a range of 72 hours, with the capacity to expand to 120 hours at the discretion of individual WFO's. It should be noted that this is beyond the range of Eta and MOS guidance; for such time periods, a field of zeroes is used for the initialized field (Peroutka, personal communication).

Both of these tools develop single-value precipitation forecasts, but a program developed by Krzysztofowicz et al. (1993), in conjunction with WSFO Pittsburgh (PIT), generates probabilistic QPF (PQPF) using a tool similar to WinQPF. They are issued in the form of three separate forecasts: the 75th exceedance fractile (an amount that has a 75% chance of being exceeded), the median value (50% chance of being exceeded), and the 25th exceedance fractile. When the isohyets of spatially averaged precipitation are drawn, each isohyet is assigned three different values, one for each exceedance fractile, and then basin average precipitation values are computed as with the scheme mentioned earlier. These 24-h forecasts are then disaggregated into 6-h periods by specifying the expected fraction of the total 24-h amount that will occur in each 6-h period. (This is the opposite approach of WinQPF, where four 6-h forecasts are generated individually and then aggregated into a 24-h forecast.) These fractions can be specified for each major basin (and assumed to be the same for all subbasins therein), or regions can be specified by drawing boundaries on a map; the expected fractions for basins that are in more than one region are a weighted average of the fractions for each portion of the basin. From these seven pieces of information (three exceedance fractiles and four expected fractions), four 6-hourly forecasts of precipitation amount for the three exceedance fractiles are prepared for each basin in the region.

This probabilistic approach is spreading to other WFO's that are presently producing QPF. In addition, a prototype probabilistic QPF system for ICWF is being developed based on the methodology of the Pittsburgh PQPF system (Ruth, personal communication). At present RFC river stage models do not directly handle probabilistic forecasts, though it is conceivable that contingency runs of the river stage models could be made according to the exceedance fractiles if conditions warranted it.

6. CONCLUSIONS

The incorporation of QPF into the flood and flash flood forecasting process has the potential to significantly increase the lead time available for the public to take appropriate action in the event of a disaster. This note summarizes all of the present and planned QPF products of the National Weather Service, and outlines the general flow of QPF forecast information among the various agencies involved in the forecast process. The integration of these contributions--NWP model QPF from EMC, MOS-type value added products from TDL, manual QPF from HPC--and the synthesis of these products by the WFO's into QPF that is ready to use by the RFC, will require increased communication between the involved meteorological and hydrological agencies to ensure a steady flow of products that are accurate and that are tailored to meet the needs of the various members of both communities.

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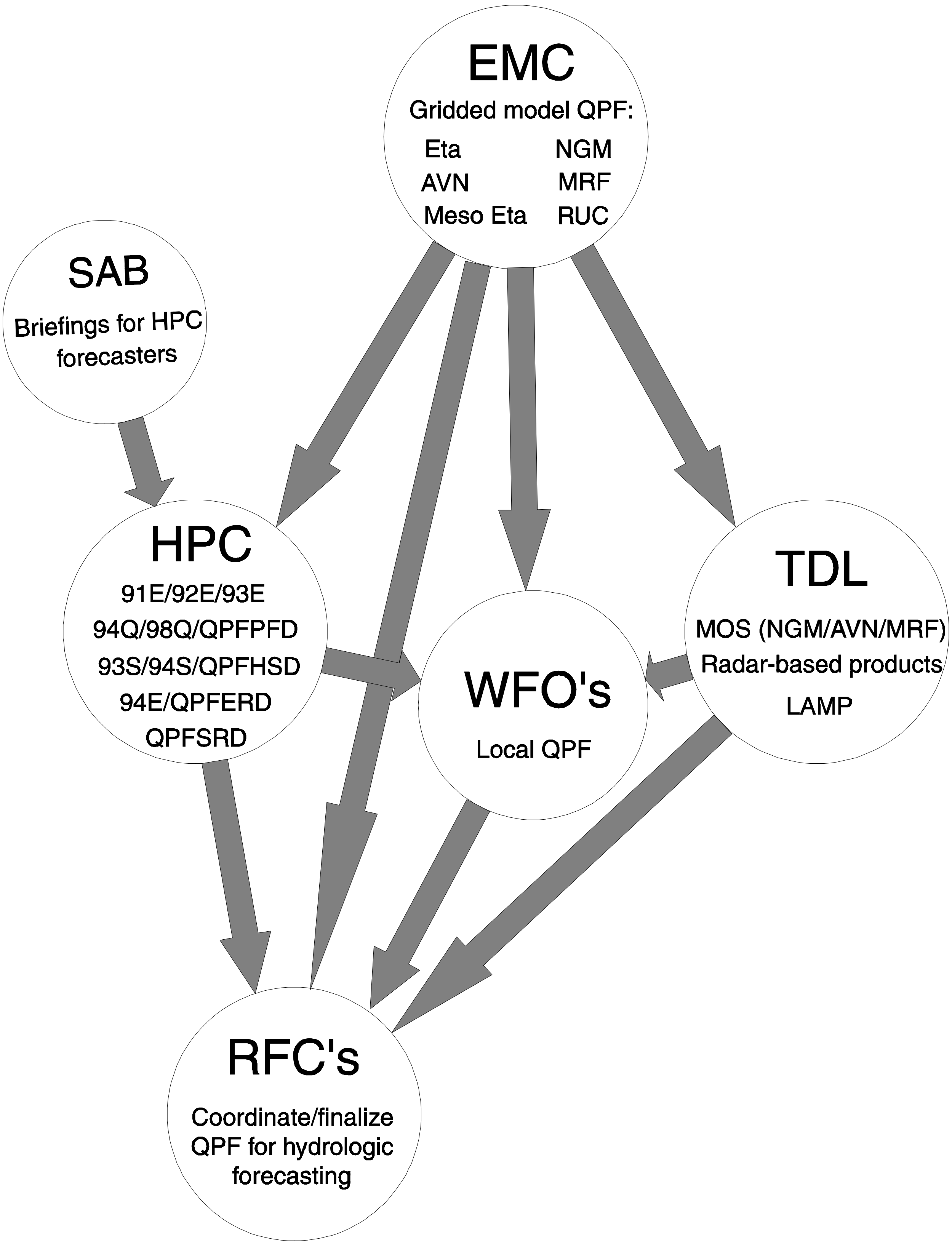

Figure 1. The flow of QPF information among NWS components.

Table 1a. Basic characteristics of the EMC numerical models.

Model	**Spatial Resolution (Native Model Grid)**	**Vertical Coordinate**	**Boundary Conditions**	**Convective Scheme**
Early Eta	48 km / 38 layers	Eta	Previous AVN run	Betts (1986) Betts-Miller (1986) Janjic (1994)
RAFS (NGM)	83-km inner grid / 16 layers	Sigma	Symmetric BC's at equator	Modified Kuo (1965)
AVN run of GSM	T126 (105 km) / 28 layers; RSM with 50-km nested region over N. America planned; T170 (78 km) / 42 layers planned	Sigma	None (global model)	Pan-Grell
MRF run of GSM	T126 (105 km) / 28 layers days 1-7, T62 (215 km) / 28 layers days 8-16			
Meso Eta	29 km / 50 layers; 10 km / 60 layer nest being tested	Eta	Current AVN run	Same as Eta
RUC	60 km / 25 layers; 40 km / 40 layers planned	Hybrid-b	Current NGM run (change to Eta planned)	Grell (1993)

Table 1b. Summary of the QPF products produced by the EMC numerical models.

Model	QPF produced	Update Frequency	Gridded QPF Format (Operational Product)
Early Eta	6-hour totals to 48 hours with grid-scale and convective components; 3-hour totals planned	Twice daily (Initialization time 0000/1200 UTC)	AWIPS grids #211 (80 km) and #207 (95 km / AK); AWIPS grids #212 (40 km) and #216 (45 km / AK) planned
RAFS (NGM)	6-hour totals to 48 hours	Twice daily (0000/1200 UTC)	AWIPS grids #202 (190.5 km), #207, #211, #213 (95.25 km)
AVN run of GSM	6-hour totals to 72 hours	Every 6 hours; only 0000/1200 UTC available for now	AWIPS grids #203 (190.5 km / AK), #211, #213
MRF run of GSM	12-h totals to 240 hours; 24-h categorical probabilities and "spaghetti charts" from ensembles planned	Daily at 0000 UTC	AWIPS grids #201 (381 km) and #213
Meso Eta	3-hour totals to 33 hours with grid-scale and convective components; hourly totals planned	Twice daily (0300 and 1500 UTC); four times daily planned	AWIPS grids #212 and #215 (20 km)
RUC	3-hour totals to 12 hours; hourly totals planned	Every 3 hours starting 0000 UTC; hourly planned	AWIPS grid #211; AWIPS grid #212 planned

Table 2. Summary of QPF products developed by TDL.

Product	**Precipitation-related parameters**	**Forecast Period**	**Update Frequency**	**Format**
NGM MOS	6/12-hour PoP and "best" QPF category (categorical probabilities produced but not disseminated); General distribution of 6/12-h expected-value QPF planned	6-60 hours every 6 h, 12-60 hours every 12 h	Twice daily (0000/1200 UTC) for corresponding NGM run	Point forecasts for 565 locations in contiguous U.S.; General distribution of gridded output on AWIPS grid #213 planned
AVN MOS	12-hour PoP; 6-hour PoP, categorical probabilities, "best" QPF category, and expected-value QPF planned	12-72 hours every 12 h; 6-72 hours every 6 h planned	Twice daily (0000/1200 UTC) for corresponding AVN run	Point forecasts for 225+ locations in contiguous U.S.; General distribution of gridded output on AWIPS grid #202 planned
MRF MOS	12/24-hour PoP; categorical probabilities, "best" QPF category and expected-value QPF planned	24-192 hours every 12/24 h (time range uncertain for planned QPF)	Once daily for 0000 UTC MRF run	Point forecasts for 225+ locations in contiguous U.S. General distribution of gridded output on AWIPS grid #202 planned
LAMP*	1-, 3-, 6-hour categorical probabilities, "best" category, and single QPF value	Hourly: 0-5 h, 3-hourly: 4-10 h, 6-hourly: 7-19 or 10-22 h	Hourly	20-km grid over contiguous U.S.
Radar-based products*	1-hour "best" category, probability of QPF exceeding certain thresholds	0-1 hours; 0-3 hours planned	Hourly	4-km grid (local); 40-km grid (contiguous U.S.) planned; eventual reduction to 12 km

* Product not yet operational

Table 3a. Summary of HPC QPF products.

AFOS Header	Description	Approximate Issuance Times
91E	0-6 hour liquid-equivalent QPF	Every 6 hours beginning 0000 UTC
92E	6-12 hour QPF valid 6 hours after the 91E	0200, 0600, 1400, and 1800 UTC
93E	12-18 hour QPF valid 6 hours after the 92E	
An additional 6-hour QPF product is planned		
94Q	QPF for 24 hours starting 1200 UTC "day 1"	Preliminary 94Q at 0500-0600 UTC; Final 94Q/Initial 98Q at 0930-1000 UTC; Updated 98Q at 1730-1800 UTC
98Q	QPF for 24 hours starting 1200 UTC "day 2"	
QPFPFD	Discussion accompanying the 94Q and 98Q	
A "day 3" QPF product accompanying the updated 98Q is planned		
A total QPF for days 3-7 is planned		

Table 3b. Additional HPC QPF-related products.

AFOS Header	Description	Approximate Issuance Times
94E	Rainfall potential exceeding flash flood guidance values and/or 5" for final 15, 21, and 24 hours of "day 1"	24-hour "initial" at 0600-0700 UTC; 21-hour "update" at 1400-1430 UTC; 15-hour "update" at 1800-1900 UTC; later updates if necessary
QPFERD	Excessive Rainfall Discussion accompanying the 94E	
QPFSRD	Special Rainfall Discussion	Issued as needed
93S	6-18 hour heavy snow forecast (4" contours) valid 4-16 hours after issuance time	Every 6 hours beginning 0200 UTC from mid-September to mid-May
94S	Heavy snow outlook valid 12 hours after the 93S	
QPFHSD	Heavy Snow Discussion accompanying the 93S and 94S	