15.1 ENHANCING PRECIPITATION ESTIMATION CAPABILITIES AT NATIONAL WEATHER SERVICE FIELD OFFICES USING MULTI-SENSOR PRECIPITATION DATA MOSAICS

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1. Introduction

The National Weather Service (NWS) provides hydrometeorological forecasts as part of its commitment to the preservation of life and property. The ability to monitor realtime precipitation rates using remote sensing techniques combined with actual observations is critical for the issuance of accurate meteorological and hydrological forecasts and warnings. While the NWS River Forecast Centers (RFCs) have computer applications for estimating observed rainfall such as the Multi-sensor Precipitation Estimator (MPE), the Weather Forecast Offices (WFOs), have comparatively few such applications. As WFOs have become more involved in short-term hydrologic forecasting, the need for more sophisticated precipitation analysis tools has grown.

To meet this need, the MPE application, a widely used tool for estimating precipitation at RFCs, has been modified and enhanced to be used at WFOs. This new application is based on a graphical user interface (GUI) which facilitates the manner in which the forecaster interacts with radar and rain gauge precipitation information, manages stored meteorological and hydrological data, and displays observed data.

In this paper, the origins and evolution of the MPE application and its component programs will be explored. This will be followed by a brief review of the concepts and techniques that support MPE precipitation processing. Then the functionality of the new version of MPE will be presented, followed by a summary of the important features of MPE and future enhancements.

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2. Origins and Evolution of the MPE Application

The MPE application was officially released to RFCs in December 2001 as part of Build 5.1.1 of the Advanced Weather Interactive Processing System (AWIPS), one of the primary systems for supporting operations at NWS forecast offices. It contained two distinct programs, MPE_FieldGenerator and MPE_Interactive. MPE_FieldGenerator created gridded precipitation estimates based on data from individual radar and rain gauge sites and mosaicked these estimates to cover the RFC area of responsibility. MPE_Interactive provided the forecaster with a means of displaying and interactively editing these mosaicked precipitation fields.

The MPE application has been used at RFCs for reviewing hourly precipitation amounts and quality controlling them to produce gridded estimates representative of actual conditions. The ultimate goal is to produce the most accurate rainfall estimates to use as input to hydrologic models. As WFOs have taken on a greater responsibility in short-term hydrologic forecasting, their need for a similar precipitation analysis application has manifested itself.

To address this need, the MPE application has been modified and enhanced to allow it to be used at WFOs as well as RFCs. In addition, MPE_Interactive has been merged with Hydroview, a component of the WFO Hydrologic Forecast System (WHFS) used for the real-time display and monitoring of hydrometeorological data. The combination of these two applications yields a new MPE_Interactive program which provides the ability to overlay both hourly rainfall data fields and observed hydrometeorological data in one display; the ability to compare Flash Flood Guidance (FFG) data with estimated rainfall amounts; the ability to display estimated rainfall totals over multiple hour intervals; and the ability to edit precipitation data and regenerate the rainfall mosaics to reflect the modifications.

The new MPE application will be provided to WFOs as part of the October 2002 release of AWIPS Build 5.2.2.

3. Concepts and Techniques Behind MPE Precipitation Processing

When the individual radar-estimated rainfall fields are mosaicked by MPE_FieldGenerator for subsequent display and editing in MPE_Interactive, an attempt is made to make the best automated quantitative precipitation estimate mosaic. The science behind this process is the subject of several Office of Hydrologic Development (OHD) research papers (Briedenbach et al., 2001a,b).

3.1 The Z-R relationship

The MPE application uses radar-derived rainfall estimates produced by the Weather Surveillance Doppler Radar (WSR-88D) Radar Product Generator (RPG) and distributed in the Digital Precipitation Array (DPA) product, a 131 x 131 array of grid boxes, using the national Hydrologic Rainfall Analysis Project (HRAP) grid. The HRAP grid uses a polar stereographic projection with roughly 4x4 km grid bins. The RPG calculates the DPA rainfall amounts by applying the Z-R relationship to a raw radar reflectivity field. The Z-R relationship is an equation which computes the precipitation rate as a function of radar reflectivity. While there are many different equations relating reflectivity to rain rate, the Z-R relationship utilized by the RPG is as follows:

$$Z = AR^B$$

where, Z is the reflectivity, R is the rate of precipitation, and A, B are coefficients used to adjust this relationship based upon the nature of the meteorological event and the season of the year. In MPE_Interactive, the Radar Mosaic data display represents the merged DPA rainfall estimates based on the Z-R relationship.

3.2 The Mean Field Bias Value

While the Z-R relationship provides a reasonable rain rate estimate for a given area, it sometimes is limited by the fact that the A, B coefficients can be different for different types of precipitation events and times of the year. To attempt to compensate for the Z-R relationship either underestimating or overestimating precipitation rates, observations are collected from rain gauges which are located within areas of radar estimated rainfall. Observations from rain gauges are treated as ground truth. The result of comparing the mean observed rain gauge value with the mean radar estimated rainfall amount for a collection of gauge locations over varying spans of hours for a single radar site results in a mean field bias value, which is a multiplicative value for that radar's estimated rainfall amounts. When the Z-R estimated precipitation amounts are multiplied by this bias or correction factor, the resulting precipitation estimates are closer to reality.

Field bias values are computed for each of the radars which contribute to the MPE precipitation mosaic. MPE_FieldGenerator then applies these bias values to the precipitation estimates from the DPA products received from the radar sites to produce the Field Bias Radar Mosaic. This mosaic then may be displayed in MPE_Interactive. Note that the process of applying the mean field bias values to the DPA products actually results in a field of unbiased rainfall estimates; that is, the radar-based biases which skew the rainfall estimates are being removed. The Field Bias Radar Mosaic is named as such to indicate that it is the result of the application of the mean field bias values to the raw radar values.

3.3 The Multi-sensor Precipitation Estimate

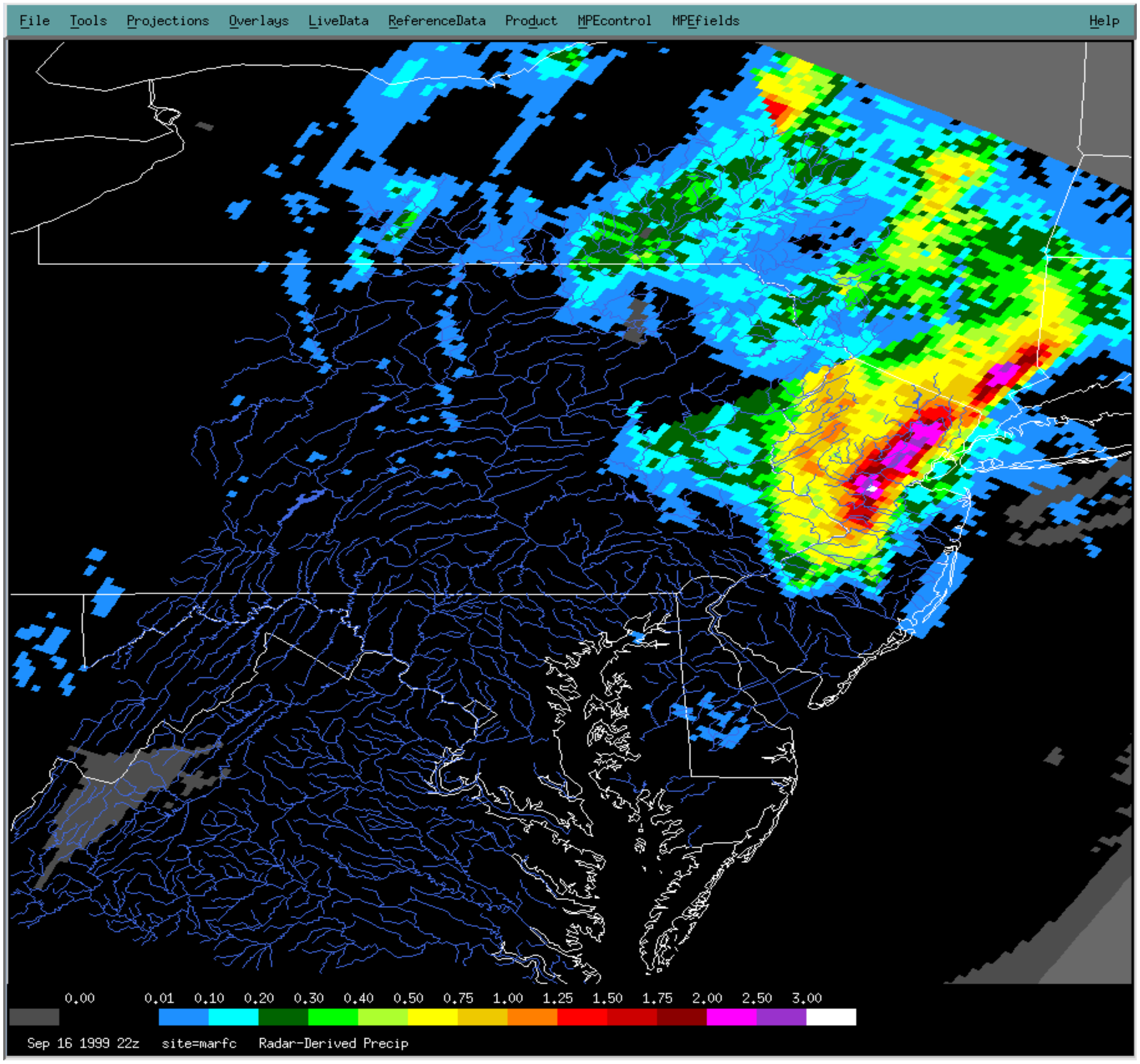


Figure 1. MPE_Interactive display of the September 16, 1999, 22Z radar-derived precipitation mosaic from a historical dataset. The remnants of Hurricane Floyd have deposited a swath of rainfall in excess of 2 inches during the past hour across north central New Jersey and extreme southeastern New York.

Once the Field Bias Radar Mosaic has been created, the last step in determining the best estimate quantitative precipitation amount is to incorporate rain gauge data. These data are used to fill in the portions of the precipitation mosaic where radar coverage was inadequate and to increment or decrement the Field Bias Radar Mosaic estimated rainfall amounts based on whether the corresponding rain gauge values are higher or lower. When the rain gauge values are applied to the Field Bias Radar Mosaic, the resulting product is the Multi-sensor Mosaic. By default, this mosaic is taken to be the Best Estimate QPE precipitation field.

4. MPE_Interactive Functionality

The MPE_Interactive program consists of a graphical user interface which allows the user to easily interact with and view hourly precipitation mosaics and hydrometerological data. The dominant feature on this interface is the map viewing area upon which the data are displayed, either as gridded image fields, station data plots, or some combination thereof. The

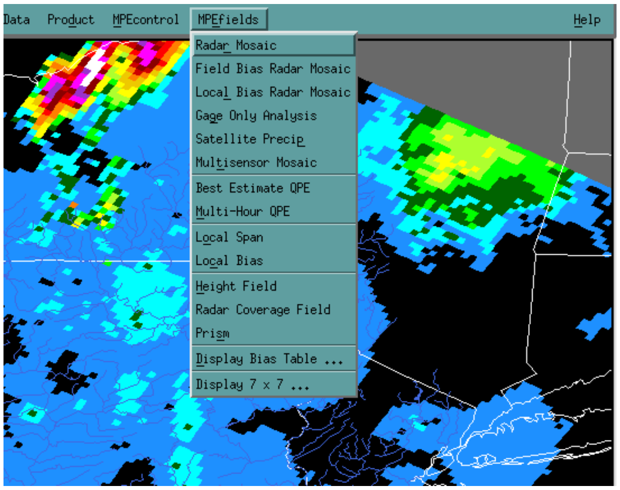


Figure 2. The precipitation mosaics, best estimate QPE fields, and reference data fields available in MPE_Interactive.

goal in the design of MPE_Interactive's interface was to maximize this viewing area to facilitate the analysis of data and to allow easy visual inspection and recognition of data patterns and trends, as shown in Figure 1.

4.1 Hydrometeorological Data Displays

As previously mentioned, the MPE_Interactive program also contains all existing functionality from Hydroview. This includes the display of station data in geographical, tabular, and timeseries form and the display of station reference data. It is not within the scope of this paper to discuss in depth this facet of MPE_Interactive.

4.2 Hourly Precipitation Mosaics

The core of the MPE_Interactive program revolves around the ability to display four mosaics of radar-based hourly precipitation estimates along with one analysis of hourly rain gauge values. As shown in the menu in Figure 2, the four different types of mosaics available in MPE_Interactive are: Radar Mosaic, Field Bias Radar Mosaic, Local Bias Radar Mosaic, and Multi-sensor Mosaic. The analysis of hourly precipitation "gage" values is the Gage Only Analysis. Throughout the remainder of this paper, these four mosaics and the "gage" analysis field will be collectively referenced as the Quantitative Precipitation Estimate (QPE) fields.

The Radar Mosaic represents the rainfall estimate as derived directly from the mosaic of DPA grids for each of the individual radar sites that provide coverage for the MPE area of responsibility. It represents the raw radar precipitation estimate.

The Field Bias Radar Mosaic is generated through the application of mean field bias values to the Radar Mosaic. As mentioned previously, a mean field bias is computed for each radar contributing precipitation data to the Radar Mosaic. This value is used for "unbiasing" the DPA estimates derived by the RPG, estimates which can easily be skewed by seasonal, meteorological, and mechanical effects on radar transmission.

The Local Bias Radar Mosaic is created by computing the bias for each grid bin of the HRAP grid that covers the MPE area. The resulting grid of local bias values is then applied to the Radar Mosaic to produce the Local Bias Radar Mosaic. By computing the bias for each HRAP grid bin, local climatological and geographical effects on rainfall can be better quantified.

The Multi-sensor Mosaic represents an attempt to obtain the most accurate precipitation estimate by adjusting the Field Bias Radar Mosaic using "ground truth" precipitation gauge observations.

As its name suggests, the Gage Only Analysis product represents the observed hourly precipitation as reported by precipitation "gages". In order to compensate for the generally large spacing between "gages", an objective analysis is performed to spatially smooth the precipitation around each "gage" point.

4.3 Best Estimate QPE Fields

MPE_FieldGenerator designates one of the five QPE fields mentioned earlier (i.e. the Radar Mosaic, Field Bias Radar Mosaic, Local Bias Radar Mosaic, Gage Only Analysis, or Multi-sensor Mosaic) as the Best Estimate QPE product. By

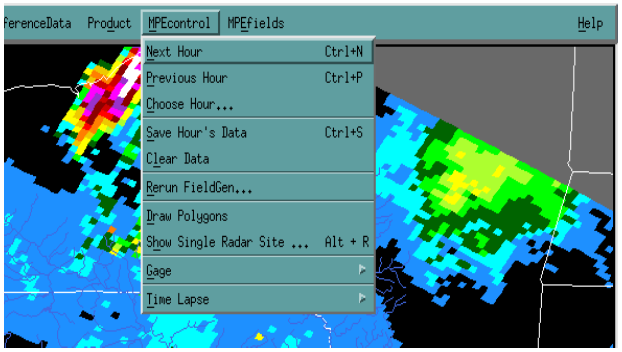


Figure 3. The MPE_Interactive control options which allow the user to easily manipulate the hourly precipitation data.

default it uses the Multi-sensor Mosaic. However, an application configurable parameter may be set to allow one of the other QPE fields be the Best Estimate QPE if so desired.

MPE_Interactive provides the ability to sum and display these Best Estimate QPE products over a user-specified duration of time which can range from 1 to 72 hours. This product allows the display of storm total precipitation estimates, and it provides the option of representing the precipitation amounts at a basin resolution scale.

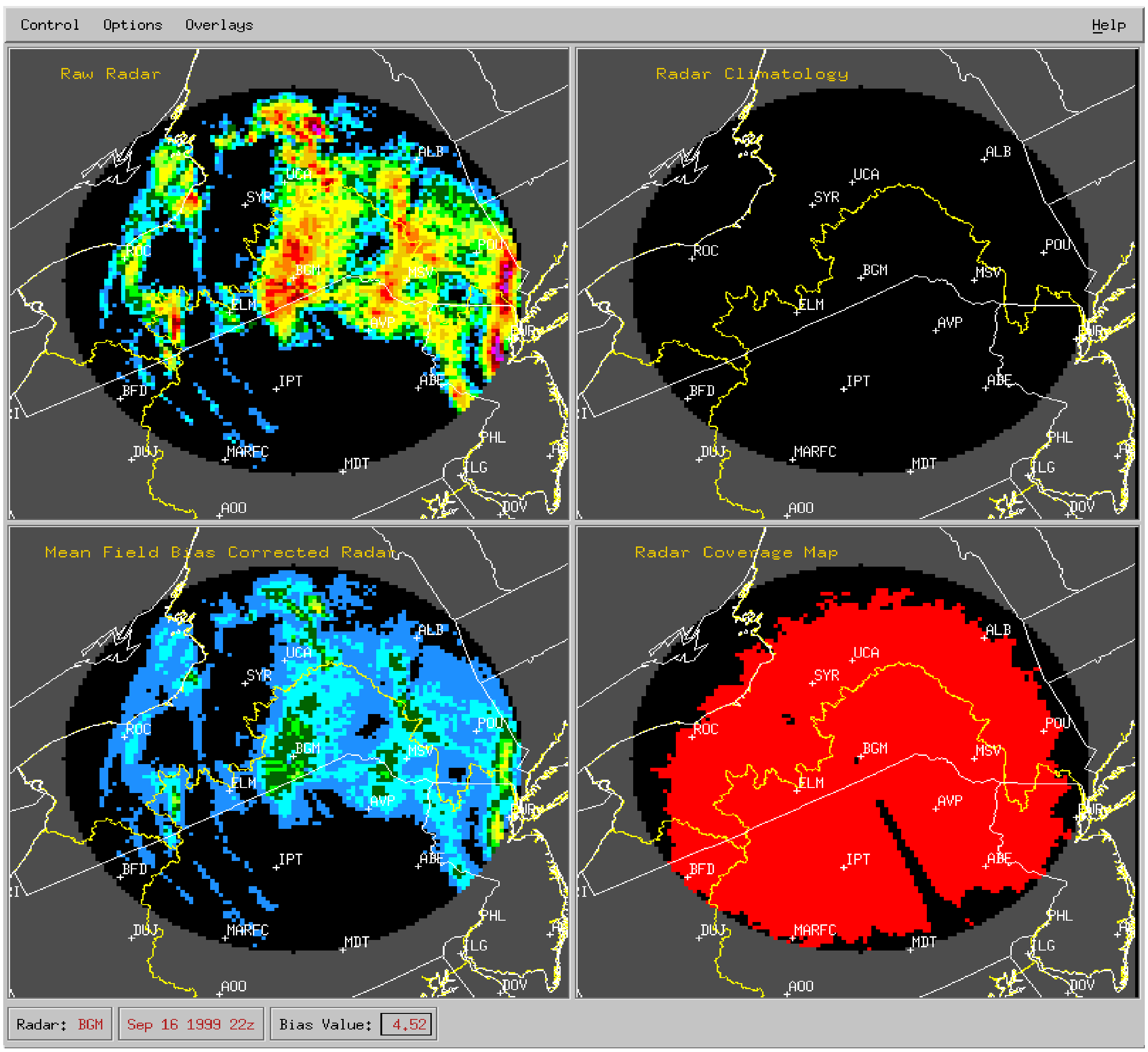


Figure 4. The Single Site Radar window displaying radar-derived precipitation and coverage data for the Binghamton, New York, radar site (BGM) for September 16, 1999 22Z from a historical dataset.

4.4 Reference Data Fields

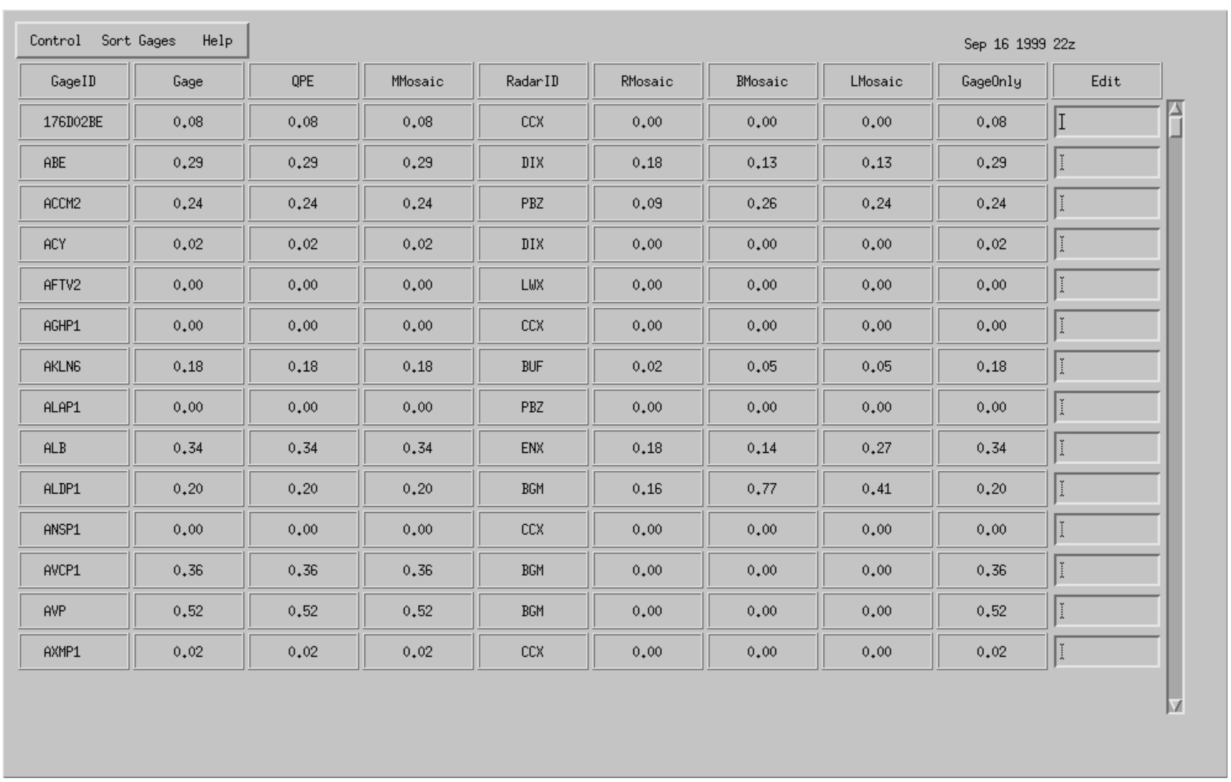
In addition to the QPE fields, MPE_Interactive provides five displayable data fields which allow the user to view the memory span, local bias, radar height, radar coverage, and climatological data which contribute to the derivation of the QPE fields. These reference data fields are the Local Span, Local Bias, Height Field, Radar Coverage Field, and the Parameter-elevation Regressions on Independent Slopes Model (PRISM) Field.

The Local Span data field displays the duration in hours of rain gauge and radar data used for computing the local bias of each of the bins in the HRAP grid which covers the MPE area. This duration, known as the memory span, is a means of creating discrete samples of rain gauge and radar value pairs. The average rain gauge value and average radar value computed from all of these pairs in the sample are used in the formulation of the bias value. There are 10 different memory spans available, ranging from under an hour to the amount of time that has elapsed since MPE operations began.

The Local Bias data field displays the local bias value for each of the HRAP bins contained within the MPE area. The Local Bias data field is used in combination with the Radar Mosaic in computing the Local Bias Radar Mosaic.

The Height Field displays the lowest available radar height that provides coverage for a particular HRAP grid bin in the MPE area. If a low elevation radar beam is blocked close to the radar transmitter, then the next higher elevation radar beam is selected to clear the obstacle. If, because of missing radars or ground obstacles, a grid bin has no coverage from any radar, then it is assigned a missing value.

The Radar Coverage Field displays which radar site is providing precipitation information for each of the HRAP grid bins in the MPE area. HRAP bins covered by more than one radar use the radar with the lowest elevation. If there is no radar



GageID	Gage	QPE	MMosaic	RadarID	RMosaic	BMosaic	LMosaic	GageOnly	Edit
176D02BE	0.08	0.08	0.08	CCX	0.00	0.00	0.00	0.08	
ABE	0.29	0.29	0.29	DIX	0.18	0.13	0.13	0.29	
ACCM2	0.24	0.24	0.24	PBZ	0.09	0.26	0.24	0.24	
ACY	0.02	0.02	0.02	DIX	0.00	0.00	0.00	0.02	
AFTV2	0.00	0.00	0.00	LWX	0.00	0.00	0.00	0.00	
AGHP1	0.00	0.00	0.00	CCX	0.00	0.00	0.00	0.00	
AKLN6	0.18	0.18	0.18	BUF	0.02	0.05	0.05	0.18	
ALAP1	0.00	0.00	0.00	PBZ	0.00	0.00	0.00	0.00	
ALB	0.34	0.34	0.34	ENX	0.18	0.14	0.27	0.34	
ALDP1	0.20	0.20	0.20	BGM	0.16	0.77	0.41	0.20	
ANSP1	0.00	0.00	0.00	CCX	0.00	0.00	0.00	0.00	
AVCP1	0.36	0.36	0.36	BGM	0.00	0.00	0.00	0.36	
AVP	0.52	0.52	0.52	BGM	0.00	0.00	0.00	0.52	
AXMP1	0.02	0.02	0.02	CCX	0.00	0.00	0.00	0.02	

Figure 5. The MPE_Interactive Gage Table indicating gage values as well as QPE fields and best estimate QPE values for the HRAP bin each gage is located in.

providing coverage for a particular HRAP bin, then this bin is assigned a missing value (Breidenbach et al., 1999).

The PRISM Field displays a monthly climatological precipitation average for each HRAP grid bin contained within the MPE area. It takes into account the localized effects of geography and local climatology on precipitation amounts. MPE_FieldGenerator incorporates the PRISM data into the construction of the Multi-sensor Mosaic field. This is especially useful for sites such as those located in the mountainous portions of the Western United States where radar coverage is inadequate and rain gauge networks tend to be sparse or non-existent

4.5 Display Control Options

MPE_Interactive offers three different ways of choosing the date and time for which to display a QPE or reference data field. The user is given the option to choose the previous or next hour's data field as well as the option to explicitly select data for a specific date and time (see Figure 3).

MPE_Interactive also allows the QPE fields, the Best Estimate QPE field, and all of the reference data fields except PRISM to be time-lapsed over a user-specified interval of time of up to 24 hours.

For the hour which the data are valid, the QPE field or Best Estimate QPE field being displayed and edited in MPE_Interactive may be saved as the new or modified Best Estimate QPE field. Through a set of configurable parameters, this field may be also saved in one or more of the following formats: netCDF, GIF, JPEG, and GRIB.

MPE_Interactive allows the DPA products contributing to the Radar Mosaic to be viewed on an individual radar basis. The Single Site Radar window (see Figure 4) displays the DPA estimated precipitation amounts, the mean field bias corrected radar precipitation estimates, and the radar coverage map. Through options available on the Single Site Radar window, MPE_FieldGenerator can be instructed to ignore the data from a particular radar site

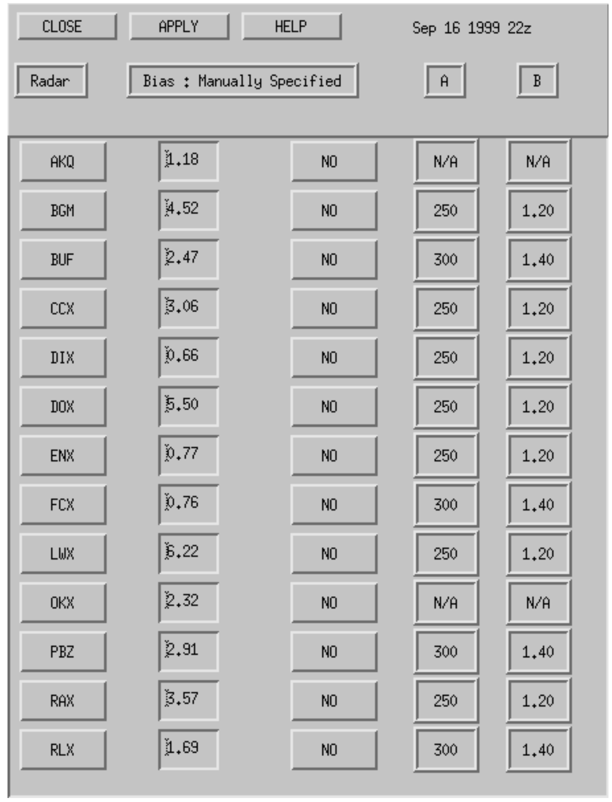


Figure 6. The MPE_Interactive bias table. Bias values for all of the individual radar sites used in producing the QPE fields can be viewed and edited here. Note that the A and B coefficients of the Z-R relationship used by the RPG in generating the DPA products are also shown.

when generating precipitation mosaics.

4.6 Tabular Data Displays

In addition to providing graphical displays, MPE_Interactive provides a means of viewing rain gauge and mean field bias information in a tabular, spread sheet style.

The Gage Table, shown in Figure 5, displays the hourly values for all of the precipitation "gages" reported within the MPE area. In addition to the actual "gage" amount, values taken from the QPE fields and the Best Estimate QPE product for the HRAP bin that the "gage" is located in are shown. The identifier of the radar site providing coverage for the "gage" site is also displayed.

The Gage Table also provides a means for editing individual "gage" values and performing quality control.

The Mean Field Bias Table, shown in Figure 6, displays the mean field bias values on an individual radar basis along with the coefficients used in the Z-R relationship when the RPG generated the DPA product. It also allows the editing of these mean field bias values. For each of the radars represented in this table, a separate table displaying the specific memory span information used in the computation of its mean field bias is available.

4.7 Editing Options

MPE_Interactive is a tool for displaying the hourly precipitation data grids generated by the MPE_FieldGenerator program. It also allows for the modification of the data grids by altering existing rain gauge values, adding user-defined pseudo-gauges, changing the mean field bias values, ignoring data from a particular radar site, and by drawing data substitution polygons on the data mosaics. These data manipulation options allow for the correction of inaccurate or erroneous precipitation data.

5. Data Sources

The data required by the MPE_Interactive program comes from two sources: disk files and the Interactive Forecast Hydrologic System (IHFS) relational database. The QPE fields, reference data fields, best estimate QPE data, and DPA data reside in disk files. The database contains metadata describing the data fields, radar biases and radar availability, and the hourly rain gauge reports.

A number of application configurable parameters enable the operations of MPE_Interactive to be tailored to the needs of the user.

6. Conclusion

The MPE application has traditionally been a tool used at RFCs for generating multi-sensor hourly precipitation estimates and allowing interactive quality control to make them as accurate as possible for use in hydrologic models. As WFOs perform an increasingly large role in short-term hydrologic forecasting, their requirement for a versatile precipitation analysis tool has come to light.

To satisfy this need, the key components of the MPE application, MPE_Interactive and MPE_FieldGenerator, have been enhanced to allow them to be utilized at WFOs. In addition to this, MPE_Interactive has been merged with Hydroview to produce a single, multi-purpose hydrological tool that not only provides hourly multi-sensor precipitation estimates, but also gives access to a plethora of hydrometerological data. It has also been given mouse controls mimicking those of AWIPS D2D so that individuals already familiar with the look and feel of D2D should have very little trouble adapting to MPE_Interactive.

Future enhancements to MPE_Interactive will include the implementation of satellite-based precipitation estimates and the eventual inclusion of this data into the multi-sensor precipitation mosaic. Like radar, a set of "local" bias values will need to be developed using rain gauges to ensure that these satellite precipitation estimates are as accurate as possible and take into account geographic and local climatological influences.

7. References

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