Quantile Mapping Using GEFSv12 Reforecasts for improving Probabilistic Precipitation Forecasts

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Introduction

Quantile mapping (QM) is a statistical post-processing technique currently used to calibrate precipitation forecasts for the NWS National Blend of Models (NBM).

The current QM procedure used by the NBM uses a short training data set comprised of the most recent 60 days of GEFS precipitation forecasts and analyses combined with data from "supplemental locations". The method provides forecasts with improved probabilistic skill and reliability relative to the raw guidance, but the use of supplemental locations to increase training data sample size also tends to reduce the amount of terrain-related precipitation detail in the western US.

On 20 September 2020, the National Oceanic and Atmospheric Administration's (NOAA's) Global Ensemble Forecast System, version 12 (GEFSv12) was implemented.
The GEFSv12 system:

- Provides 31-member real-time ensemble forecasts initialized at 06, 12, and 18 UTC to +16 days lead time. Once daily, from 00 UTC initial conditions, the forecasts are integrated to +35 days
- Accompanied by the production of a 20-year set of reanalysis and reforecasts covering 2000-2019, using a very similar data assimilation system as is used in real time. A five-member ensemble of reforecasts is available each day using the 00 UTC initial conditions. An 11-member ensemble forecast was generated once per week out to +35 day lead.

The new GEFSv12 reforecast data set provides a long time series that can be leveraged to improve upon the current QM technique used to produce probabilistic precipitation forecasts in the NBM.

Data

(a) GEFSv12 reforecasts from 1 Jan 2002 through 31 Dec 2019 covering a CONUS domain. Forecasts to +10 days (240 h) lead time from the 00 UTC are used, with accumulated precipitation saved every 6 h.

(b) A merged precipitation analysis, consisting of (i) Climatology-Calibrated Precipitation Analyses (CCPA) on the National Digital Forecast Database (NDFD) grid, a 2345 (x) ⨉ 1597 (y) grid on a Lambert-conformal projection with a grid spacing of approximately ~3 km inside the CONUS boundary, and (ii) interpolated Multi-Source Weighted-Ensemble Precipitation (MSWEP) analyses, version 2, originally on a 0.05-degree latitude-longitude grid, interpolated to the ~3-km NDFD grid for grid points outside CONUS and for missing CCPA data inside the CONUS.

(c) The results show the performance of the 31-member GEFS retrospective forecasts from Dec 2017-Nov 2019 generated from the pre-production of the GEFSv12 for the 00 UTC cycle.

Method

With the QM routine, cumulative distribution functions (CDFs) are determined from the 2002-2019 reforecast and analyzed climatologies, individually for each grid point, lead time (forecast), and time of day (analyzed). The CDFs are defined as follows, where A_f (A_a) are forecast and (analyzed) precipitation amounts, and X_f (X_a) are random variables of the precipitation forecast (analyzed).

Forecast CDF: $F_f(A_f) = P(X_f \le A_f)$

Analyzed CDF: $F_a(A_a) = P(X_a \le A_a)$

There is an inverse distribution function $F^{-1}_f(q)$, the quantile function, maps cumulative probability q back to a precipitation amount.

$$A_f = F_f^{-1}(q), \quad q \in [0, 1].$$

Quantile mapping is then defined as

$$A_{f \to a} = F_a^{-1}\left[F_f(A_f)\right].$$

CDFs used in the quantile mapping are generated by applying a cubic-spline fit to the cumulative hazard function (CHF) of positive precipitation amounts for locations providing a sufficient sample size of positive precipitation values. This CHF, defined here as H(p), provides a more linear relationship between precipitation and (transformed) cumulative probability, making CDF function-fitting more accurate after back transformation from the CHF to the CDF. Here, p denotes precipitation and $F_f(p)$ is the CDF.

$$H(p) = -\log[1-F_f(p)]$$

Once a new forecast arrives, which in this study come from the Dec 2017-Nov 2019 GEFS retrospective forecasts, the quantile individual grid point's member forecast is determined, and the bias-corrected forecast amount is determined from the analyzed amount at the same quantile.

Closest Member Histogram Weighting and Dressing

Closest-member histogram statistics provide data for an objective reweighting of the sorted ensemble of forecasts before determining the probabilities. They are estimated from the quantile-mapped training data during the 2002-2019 reforecast period.

Each histogram contains the statistics for three months of data during the 2017-2019 period of analysis for each lead time and mean precipitation amount ranging from light (0.1 mm / 6 h) to heavy (> 15 mm / 6 h).

Each member is subsequently dressed with a Gaussian probability distribution whose standard deviation depends on forecast amount.

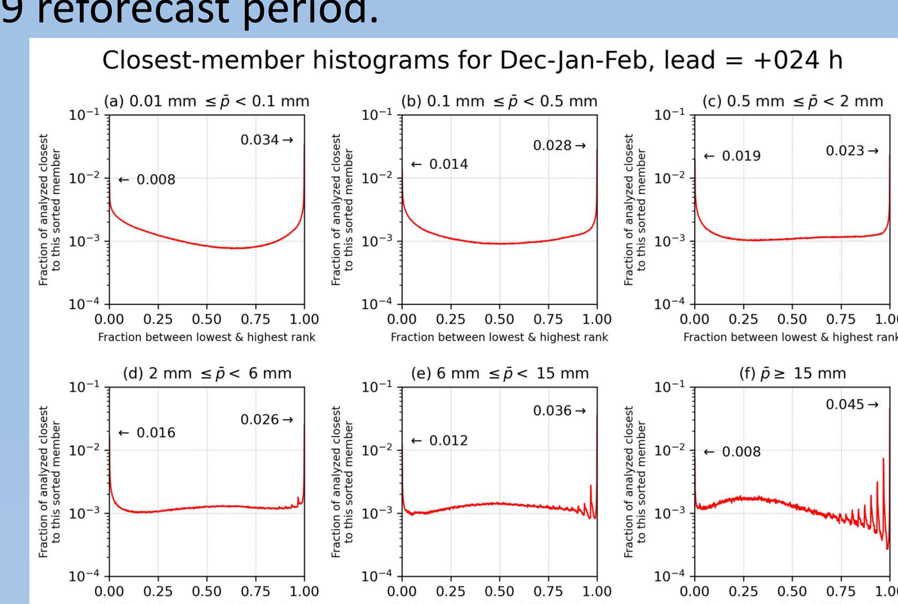
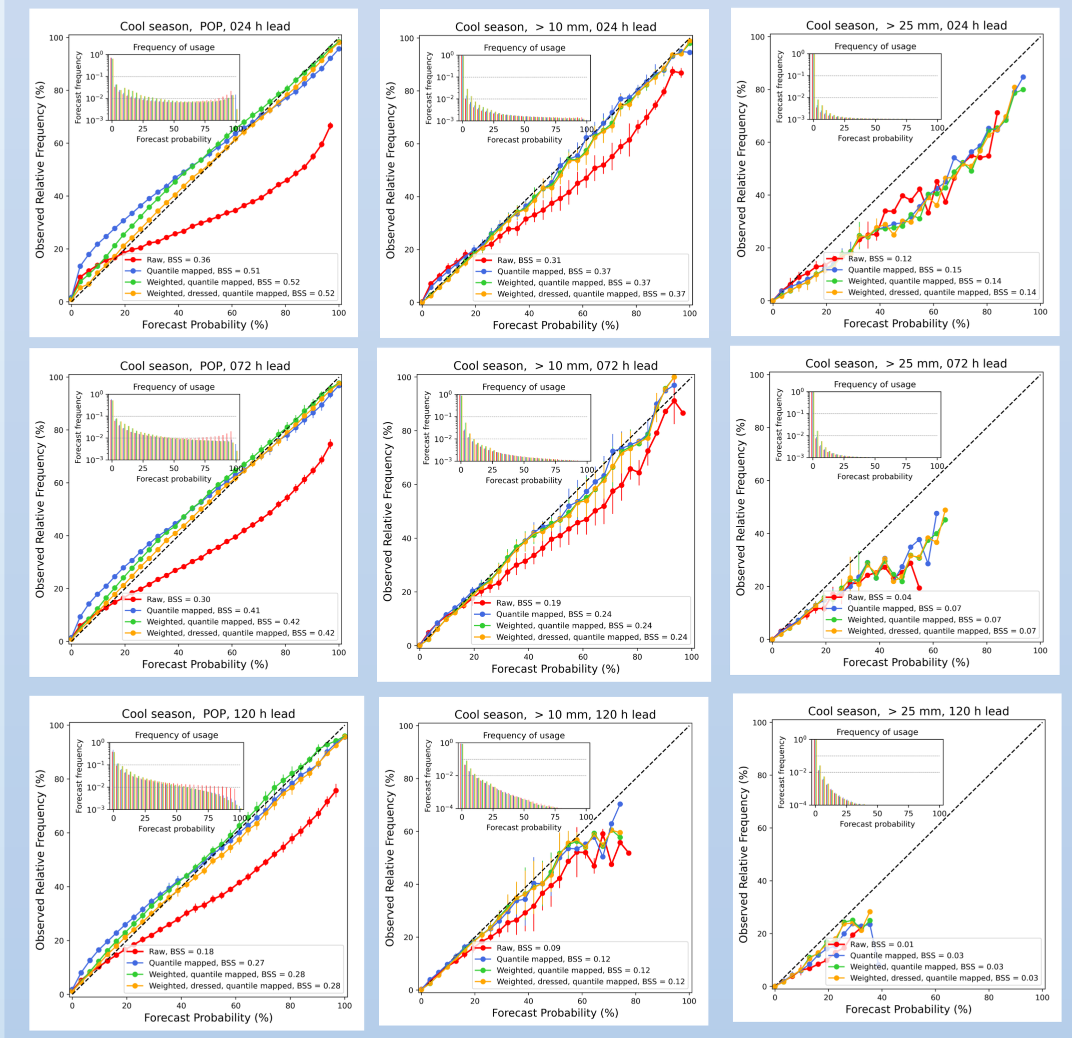


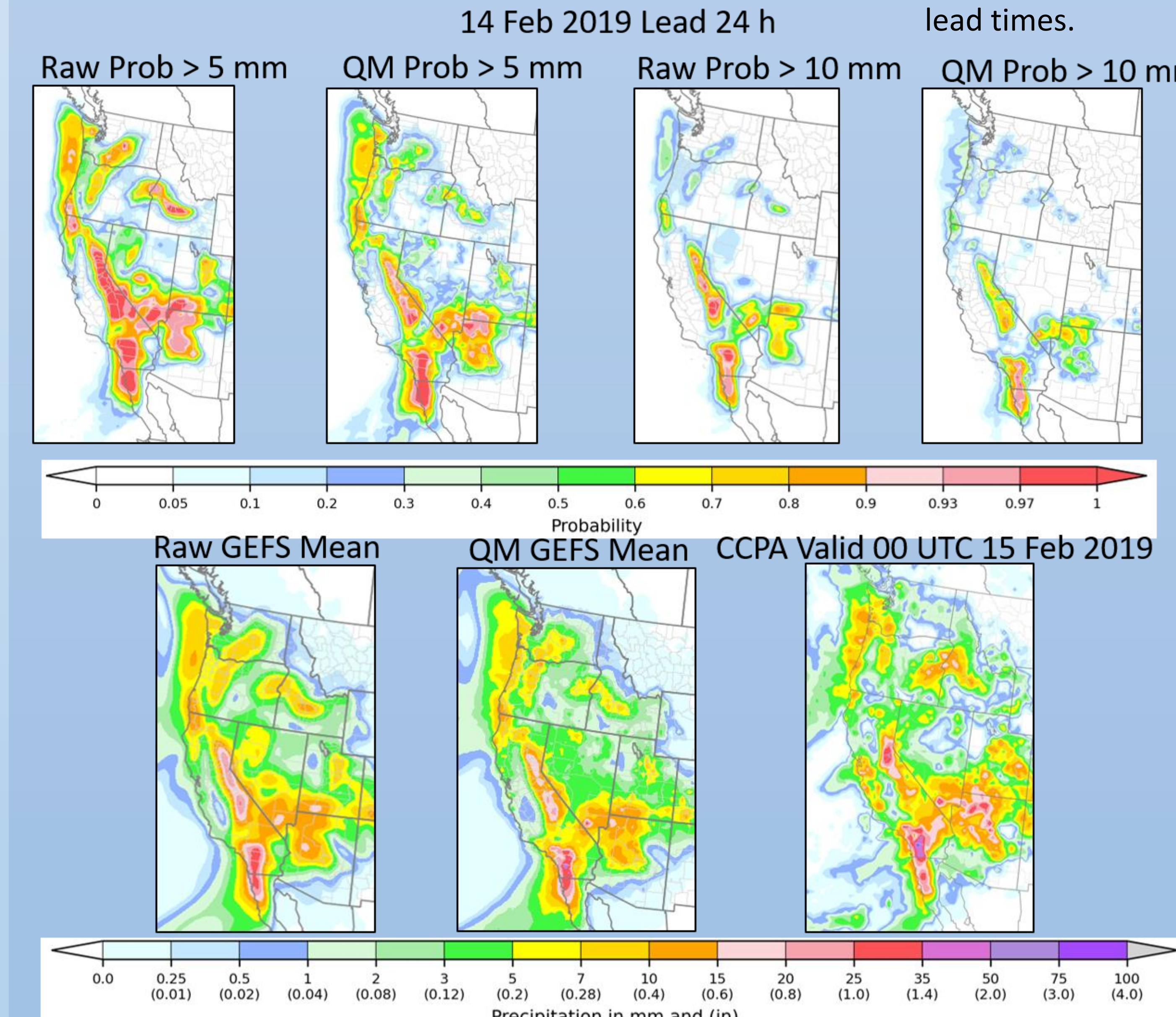
Figure 1: Closest-member histograms for the months Dec-Jan-Feb and 24 h lead time. The plots show general underdispersion and some amount-dependent bias.

Results



- **Quantile mapping, weighting, and dressing the GEFSv12 precipitation improves reliability and brier skill scores for probabilistic forecasts less than 25 mm / 6 h during cool season events (Oct – March) for the 24 h, 72 h, and 120 h lead times.**
- **Applying the closest-member weighting and Gaussian dressing to the QM especially improves POPs over the QM alone for probabilities less than 40%.**
- **Reliability and brier skills scores only slightly improve when the QM, weighting, and dressing is applied to the raw GEFS for forecasts >25 mm at the 72 h and 120 h lead times.**

Figure 2: Shown are reliability diagrams and brier skill scores (bottom-right inset) for cool-season probability of 6-h rainfall exceeding 0.254 mm (i.e., POP), 10 mm, and 25 mm for the 24 h (top row) and 72 h (middle row) and 120 h (bottom row) lead times.



The increased training data improves the QM so that terrain-related detail is added back into the probabilistic forecasts in the western US.

Figure 3: For an atmospheric river event, raw and quantile-mapped (non-weighted, undressed) probabilities for a 24 h lead time area shown for the 14 Feb 2019 00 UTC run. Shown below for the same run and lead time are the raw and quantile-mapped GEFS mean compared to the CCPA for matching lead time.

Additional Work

- **Publication in progress on the 2017-2019 results. Included in the results will be additional lead time analysis out to 240 h for cool season and warm season (Apr – Sept) events.**
- **Public website displaying the QM GEFS mean and precipitation exceedance probabilities out to + 240 h lead time. https://www.psl.noaa.gov/forecasts/GQM/**
- **Use QM GEFS-mean or probabilistic quantities as precipitation forcing in hydrologic models (e.g., Hydrologic Ensemble Forecast System, National Water Model) to assess the quality of the streamflow output.**