CORRESPONDENCE

Comment on "Bias Correction, Quantile Mapping, and Downscaling: Revisiting the Inflation Issue"

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Several papers in the *Journal of Climate* have discussed the use of inflation of regression estimates (e.g., Karl et al. 1990; von Storch 1999), a recent one being Maraun (2013). Generally, Maraun (2013, 2014) disparages the inflation concept and is very specific in Maraun (2014) where he states that ". . . inflation is appropriate for neither prediction nor simulation" (p. 1823). He also states, "In the early years of numerical weather forecasting, a tendency of the regression method to 'not forecasting the extremes as often as they are observed' (Klein et al. 1959) had been noted, basically because erroneously only the predicted mean *ax* had been considered for the forecast but not the distribution around it. As a 'correction' inflation has been suggested . . ." (p. 1823). I believe Maraun's statement (Maraun 2014) that the inflation procedure is "flawed" is unjustified and his statement that it is not appropriate for prediction is incorrect. Maraun's treatment of inflation may inhibit its use where it would be appropriate. His statement concerning the distribution around the mean implies probability forecasts, and that would be an excellent avenue to take, provided the users of the forecasts would accept them in lieu of a specific value forecast; however, since that is many times not the case, a specific value is imperative. My purpose here is not to justify inflation as the best way to achieve regression estimates of the more rare events, as Klein et al. (1959) long ago stated, but rather to indicate that it *can* be used successfully as one way.

Specifically, regression inflation relates to estimation of a weather variable (predictand) as a linear function of one or more predictors. The relationship between the predictand and the predictors is measured by the reduction of variance (RV), which is the square of the (multiple) correlation coefficient R. As R and RV being less than unity implies, the variance of the predicted value afforded by the regression equation is less than the variance in the dependent sample of the variable to be predicted. Inflation, here, is the division of the forecast departures from the dependent sample mean by R so that when combined with the mean this produces a predicted variance equal to the predictand variance on the dependent sample.[1]

Statistical postprocessing (of numerical model output) for weather prediction, to which this discussion relates, was in its infancy when Bill Klein and others first published the inflation adjustment. At that time, much less was known about statistical prediction than today, and even though Klein et al. (1959) state concerning inflation that ". . . it should not be construed that this is necessarily the best objective method of forecasting temperature classes" (p. 681), it seemed at the time that inflation was progressing into widespread use, and that the pitfalls of the procedure should be pointed out; that was the reason Roger Allen and I (Glahn and Allen 1966) wrote our brief note, which Maraun references in support of his statement that inflation is flawed.

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[1] Some papers, by virtue of assuming zero mean of the variables involved, do not make it abundantly clear that it is the *departures* from the mean that are inflated, and not the total regression estimate.

Klein et al. (1967, p. 218) show Klein's awareness of inflation's characteristics, but continued to use it.

Whether inflation is a good procedure or not depends critically on the intended use of the prediction. Discussions in the climate literature usually pertain to some form of climate prediction or climate simulation as stated by Maraun (2013), which generally differs in purpose from weather prediction on an hour-to-hour or day-to-day basis.

My and Allen's note (Glahn and Allen 1966) may have had a negative tone to it, but it was not intended to mean that inflation should never be used. We stated, ''When operational forecasts are being considered, the final judgement of the 'goodness' of these forecasts should be on the basis of their usefulness to the user'' (p. 126). Regression inflation is a technique that has some good features and, like any technique, some bad; does that make all of them ''flawed?'' Ed Epstein (Epstein 1967) provided comments on the Glahn and Allen (1966) and Klein et al. (1959) papers and states, ''It is my judgment that the considerations which led to the introduction of the inflation techniques are valid'' (p. 427). Then he went on to propose the use of a nonlinear scaling of the dependent variable such that the smaller deviations from the mean are changed less than inflation would change them and the larger deviations are changed more.

Weather forecasts must be useful to a user to justify their being made. I can cite a couple of situations where inflation has been used successfully. One is in the prediction of 10-m wind speed (Russo et al. 1964). Wind speed is essentially a continuous variable, but its distribution is highly nonnormal. It is bounded at the low end at zero. Values less than 10 knots (kt)[2] are not very predictable for various reasons, including instrument response, siting issues, and very small scale fluctuations, but are very numerous. A corporate user interested only in winds over 20 kt may find that regression just never forecasts winds that high, making the forecasts useless for that user. To make them useful, some method must be used to alert the user that 20-kt winds are more likely than at other times. Provided that there are some winds in the developmental sample greater than 20 kt, inflation will likely make some greater than 20 kt. Such forecasts can be verified by appropriate metrics, and the results of that verification provided to the potential users of the inflated forecasts. Strong winds can be perceived as a threat, and the threat score (TS) applies (Palmer and Allen 1949).[3] The TS generally rewards a system that produces as many forecasts of ''threats'' as occur.

One aspect of inflation is that not only more high forecasts are made, but also more low forecasts, and this means many very weak winds are forecast, even to being negative. Developers at the Meteorological Development Laboratory have used inflation for wind speed since 1975 (Schwartz and Carter 1982; Jacks et al. 1990; Su 2005; Rudack 2015), and the established practice now is to ''partially inflate,'' where the forecasts above the mean are inflated, but those below the mean are not (Su 2005; Rudack 2015).[4]

Another study where inflation was shown to be useful was in the prediction of cloud amount (Carter and Glahn 1976; Carter 1976). At some locations, the distribution is U-shaped; there are many clear days and cloudy days. Regression, where the amount of cloud (in octas or percent) is the predictand, will usually provide a great many forecasts of a few or some cloud, but a relatively few of clear and overcast. Inflation can spread the distribution to one that is nearer to the observed. Even though some measures of ''goodness'' will be worse with the inflation (e.g., RMSE), some will likely be better, possibly the Heidke skill score, TS, and the user's utility when the forecasts are scored with the users' specific utility matrix.

In summary, regression inflation should be considered one of the possible statistical techniques for weather forecasting, as long as its strengths and weaknesses are recognized, the characteristics of the forecasts are determined, and such information is furnished to the potential users.

[2] 1 knot (kt) = 0.51 m s^{-1}; kt is the unit of measurement used widely in the United States, especially by the aviation community.

[3] The threat score is the same as the critical success index (Donaldson et al. 1975; Schaefer 1990), widely used in evaluation of severe weather threats.

[4] The Meteorological Development Laboratory's home page (http://www.nws.noaa.gov/tdl/) states the partial inflation vice full inflation of the operational MOS wind speed forecasts started 20 June 2006.

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