Addressing model uncertainty through statistical post-processing

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statistical post-processing: the janitorial service of numerical prediction
Janitors’ preferred cleaning technique

- Old “reforecasts” (from stable modeling system)
- Old analyses or observations

> Synthesize information on forecasts, discrepancies

- Today’s real-time forecast
- Adjust today’s forecast
- Improved forecast guidance
Janitors’ preferred cleaning technique

This talk will be more about issues with the supporting data sets than on the specific post-processing techniques.
What can post-processing and reforecasts do that other model error corrections cannot?

• Provide context on how unusual today’s forecast event is, relative to other forecast events.
• Compensate for errors due to finite ensemble size.
• Provide extra “resolution” via statistical downscaling.
• Compensate for remaining systematic model biases not addressed through stochastic techniques, thereby increase reliability, increase forecast skill.
• Provide sufficient samples to quantify forecast errors for particular locations, hydrologic basins.
Disadvantages of post-processing

• Right answer perhaps, but for wrong reason? We prefer to directly improve the model in physically realistic ways.
  – Also, some errors are too complex to adjust via post-processing; for these, there is no substitute for improving the model.

• Additional computational and infrastructural burden to compute reforecasts and reanalyses, compile observation time series.
  – ECMWF’s (relatively sparse) weekly 5-member reforecast * 20 years = 100 extra members / week to compute.
  – Generally greater benefit the more years, more days, more members in reforecast, but proportionally more expensive.
  – Without high-quality, long observation time series, many of the benefits of reforecasts + statistical post-processing are lost.
  – Need to keep computing reforecasts with current model version, else improvements are temporary.

• If real climate or model-error statistics change significantly during reforecast period, decreased accuracy of post-processed estimates
Post-processing and reforecast advantages
Reforecast advantage: facilitates quantitatively assessing how unusual an event is (EFI)

EPS I-EFI 05@00+48/72h vt 07@00-08@00

The forthcoming Interactive EFI (I-EFI) can be used to identify areas where the ensemble forecast distribution is significantly different from the climatological distribution, and visualize the grid point distributions. This plot shows the I-EFI +48/72h forecasts issued on 5@00UTC and valid between 7@00UTC and 8@00UTC.

Weather anomalies predicted by EPS: Thursday 05 February 2009 at 00 UTC 3000 hPa Z ensemble mean (Saturday 07 February 2009 at 12 UTC) and EFI values for 24h TP, 10m wind gust and 2m temperature valid for 24 hours from Saturday 07 February 2009 at 00 UTC to Sunday 08 February 2009 at 00 UTC.

Wet and cold

Extreme hot and windy
Extreme Forecast Index
(needs accurate *forecast* climatology, such as provided by reforecasts)

\[ EFI = \frac{2}{\pi} \int_{0}^{1} \frac{p - F_f(p)}{\sqrt{p(1-p)}} \]

$p$ is the percentile of the cumulative distribution estimated from the ensemble; $F_f(p)$ is how the $p$-percentile of the climate record ranks in the EPS (0 the minimum, 1 the maximum). This “Anderson-Darling” version introduces a weighted statistic that gives more power in the tails of the distribution. $2/\pi$ is normalization factor to keep $-1 \leq EFI \leq 1$.

Ref: ibid
Imagine: your 20-member storm-scale ensemble (which is a calibrated system, truth consistent with a random draw from ensemble)

Your job: estimate reliable probabilities on the grid.

Adjusting for errors due to finite ensemble size.
Imagine: your 20-member storm-scale ensemble (which is a calibrated system, truth consistent with a random draw from ensemble)

Your job: estimate reliable probabilities on the grid.

Zero probability for this cell? Yes if you use ensemble relative frequency.
Kernel density estimation to produce smooth pdf from limited-size ensemble
Provide extra “resolution” via statistical downscaling

“resolution” here is used as in its definition in the Brier Score decomposition, the ability of a forecast model to successfully forecast deviations from the overall climatological probability.
Verified over 25 years of forecasts; skill scores use conventional method of calculation which may overestimate skill (Hamill and Juras, QJRMS, Oct 2006).
Reforecast vs. multi-model, $T_{sfc}$

ECMWF’s forecasts were corrected here using a blend of bias correction from the past 30 days of forecasts and a more sophisticated regression approach using reforecasts.

courtesy of Renate Hagedorn, ECMWF & DWD
Reforecast vs. multi-model precipitation over US, Jul-Oct 2010

Verification of 1-degree resolution forecasts against 1-degree precipitation analyses over CONUS.

The following forecasts are plotted: 20-member ECMWF forecasts (black); ECMWF, calibrated via logistic regression using 9 years of ECMWF 4-member weekly reforecasts (green); multi-model (blue) and multi-model, calibrated using the last 30 days of forecasts/analyses.

Reforecasts appear to provide most improvement at heavy precipitation thresholds, consistent with other previous results.
Sample reliability diagrams
ECMWF, reforecast-calibrated, multi-model

Reliability, Day +3 10.0mm

(a) ECMWF

(b) Reforecast-calibrated ECMWF

(c) Multi-Model Raw (including ECMWF)

BSS = 0.168

BSS = 0.246

BSS = 0.232

(more reliable)

(sharper)

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Reforecast advantage: permits quantifying forecast errors for particular locations, basins

TopLeft: Discharge Climatology Quantiles (30 day gliding mean) for the Verzasca basins obtained forcing the hydrological model PREVAH with COSMO-LEPS reforecasts (1971-2000).
TopRight: Observed daily discharge climatology (1989-2008)

Hydrologic Ensemble Prediction Experiment

Note that hydrologists envision a step to make sure that ensemble inputs to their hydrologic system are as reliable and sharp as possible.

from Schaake et al. 2007 BAMS article
Ref: D. Richardson, personal communication, ECMWF.
Reforecast / calibration disadvantages
Not all model deficiencies can be addressed easily through post-processing

An example from NSSL-SPC Hazardous Weather Test Bed, forecast initialized 20 May 2010

http://tinyurl.com/2ftbvgs

30-km SREF $P > 0.5''$

4-km SSEF $P > 0.5$ "

Verification

With warm-season QPF, comparatively coarse resolution and parameterized convection in operational SREF system produces forecast that is clearly inferior to the 4-km, resolved convection in SSEF. Calibration isn’t likely to provide nearly the improvement that the extra resolution will provide.
Computational burden

• Real-time ensemble: assume 50 members, 2x daily = 100/day = 700/week
• Minimal reforecast: 5 members, 20 years, 1x weekly = 100/week : 1/7 extra
• Moderate reforecast: 10 members, 30 years, 1x daily = 2100/week : 3x extra.
• Full reforecast: 50 members, 30 years, 2x daily = 21000/week : 30x extra!
Disadvantage: non-stationary forecast errors in reforecasts?

- If real climate or model-error statistics change significantly during reforecast period, decreased accuracy of post-processed estimates.

From Dee et al., QJRMS, 2011 article on ERA-Interim
Changing climate: today’s forecasts warmer than those in training data set?

If forecast today is warmer than any in the reforecast training data set, we’ll be “extrapolating the regression” when we apply statistical corrections.
Conclusions

• Statistical post-processing (using reforecasts) may complement other methods of addressing model uncertainty.
  – correct for model bias.
  – generally large improvements in forecasts of rare events.

• It’s not a solution for all problems, and it does increase system complexity, computational burden.

• Worth considering how these data sets may be leveraged to facilitate model uncertainty research.