International Journal of Forecasting 34 (2018) 477–496

Contents lists available at ScienceDirect

International Journal of Forecasting

journal homepage: www.elsevier.com/locate/ijforecast

Combining predictive distributions for the statistical post-processing of ensemble forecasts

Sándor Baran[a,*], Sebastian Lerch[b,c]

[a] Faculty of Informatics, University of Debrecen, Kassai út 26, H–4028 Debrecen, Hungary
[b] Heidelberg Institute for Theoretical Studies, Schloss-Wolfsbrunnenweg 35, D-69118 Heidelberg, Germany
[c] Institute for Stochastics, Karlsruhe Institute of Technology, Englerstraße 2, D-76128 Karlsruhe, Germany

ARTICLE INFO

Keywords:
Combining forecasts
Comparative studies
Density forecasts
Ensemble model output statistics
Precipitation
Weather forecasting
Wind speed

ABSTRACT

Statistical post-processing techniques are now used widely for correcting systematic biases and errors in the calibration of ensemble forecasts obtained from multiple runs of numerical weather prediction models. A standard approach is the ensemble model output statistics (EMOS) method, which results in a predictive distribution that is given by a single parametric law, with parameters that depend on the ensemble members. This article assesses the merits of combining multiple EMOS models based on different parametric families. In four case studies with wind speed and precipitation forecasts from two ensemble prediction systems, we investigate the performances of state of the art forecast combination methods and propose a computationally efficient approach for determining linear pool combination weights. We study the performance of forecast combination compared to that of the theoretically superior but cumbersome estimation of a full mixture model, and assess which degree of flexibility of the forecast combination approach yields the best practical results for post-processing applications.

1. Introduction

Nowadays, weather forecasts are typically based on the output of numerical weather prediction (NWP) models which describe the physical behavior of the atmosphere through nonlinear partial differential equations. Single deterministic predictions produced by individual runs of such models fail to account for uncertainties in the initial conditions and the numerical model. Thus, nowadays, NWP models are typically run several times with varying initial conditions and model physics, resulting in an ensemble of forecasts; see Gneiting and Raftery (2005) and Palmer (2002) for reviews. Examples of ensemble prediction systems (EPSs) include the 51-member European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble (Molteni, Buizza, Palmer, & Petroliagis, 1996), the eight-member University of Washington Mesoscale ensemble (UWME; Eckel & Mass, 2005), and the 11-member Aire Limitée Adaptation dynamique Développement International-Hungary Ensemble Prediction System (ALADIN-HUNEPS; Horányi, Kertész, Kullmann, & Radnóti, 2006) of the Hungarian Meteorological Service (HMS). The transition from individual deterministic forecasts to ensemble predictions can be seen as an important step towards probabilistic forecasting; however, ensemble forecasts are often underdispersive, that is, the spread of the ensemble is too small to account for the full uncertainty, and is subject to systematic bias. They therefore require some form of statistical post-processing. Fig. 1 illustrates the systematic errors of ensemble forecasts, with panel (a) showing UWME wind speed forecasts for Newport Municipal Airport (OR) and the corresponding observations for the first two weeks of October 2008, and panel (b) showing ALADIN-HUNEPS forecasts of the precipitation accumulation at Debrecen Airport and the corresponding observations for the first two weeks of December 2010. Both time

* Corresponding author.
E-mail address: baran.sandor@inf.unideb.hu (S. Baran).

https://doi.org/10.1016/j.ijforecast.2018.01.005
0169-2070/

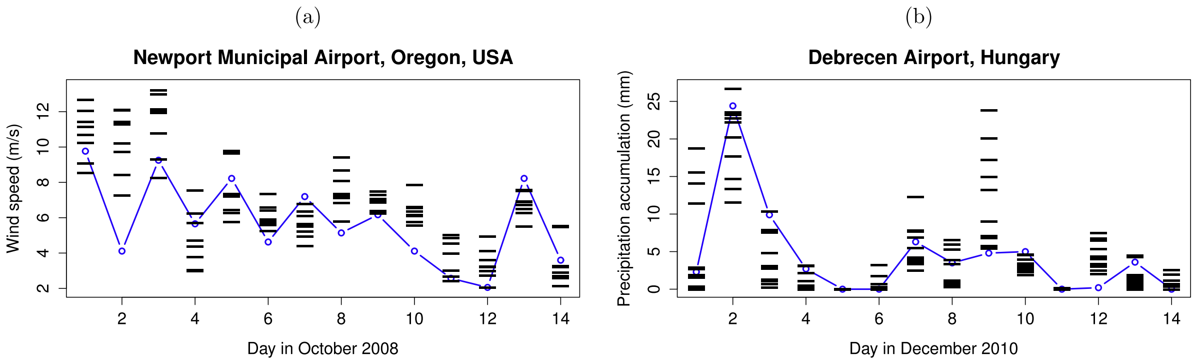

Fig. 1. (a) Wind speed observations (blue line) and the corresponding UWME forecasts (bars) for Newport Municipal Airport, Oregon, USA, for the first two weeks of October 2008; (b) observed precipitation accumulation (blue line) and the corresponding ALADIN-HUNEPS ensemble forecasts (bars) for Debrecen Airport, Hungary, for the first two weeks of December 2010. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

series illustrate the lack of an appropriate representation of the forecast uncertainty, as the verifying observations frequently fall outside the range of the ensemble forecasts.

Over the past decade, various different statistical post-processing methods have been proposed in the meteorological literature. In the Bayesian model averaging (BMA; Raftery, Gneiting, Balabdaoui, & Polakowski, 2005) approach, the forecast distribution is given by a weighted mixture of parametric densities, each of which depends on a single ensemble member, with the mixture weights being determined by the performances of the ensemble members over the training period. The present article builds on the conceptually simpler ensemble model output statistics (EMOS) approach proposed by Gneiting, Raftery, Westveld, and Goldman (2005), where the conditional distribution of the weather variable of interest given the ensemble predictions is modeled by a single parametric family. The parameters of the forecast distribution are connected to the ensemble forecast through suitable link functions. For example, the original EMOS approach models the temperature using a Gaussian predictive distribution, the mean of which is an affine function of the ensemble member forecasts and the variance of which is an affine function of the ensemble variance.

Over the last few years, the EMOS approach has been extended to other weather variables such as the wind speed (Baran & Lerch, 2015; Lerch & Thorarinsdottir, 2013; Scheuerer & Möller, 2015; Thorarinsdottir & Gneiting, 2010), precipitation (Baran & Nemoda, 2016; Scheuerer, 2014; Scheuerer & Hamill, 2015), and total cloud cover (Hemri, Haiden, & Pappenberger, 2016). To illustrate the EMOS approach to post-processing, Fig. 2(a) shows the observed wind speed, the corresponding UWME forecasts and the truncated normal (TN) and log-normal (LN) EMOS predictive distributions (for details, see Section 3.1) for Newport Municipal Airport for 2 October 2008. A different situation is shown in Fig. 2(b), where the observed precipitation accumulation, the corresponding ALADIN-HUNEPS ensemble forecasts and the estimated censored and shifted gamma (CSG) and censored generalized extreme value (GEV) EMOS predictive distributions (see Section 3.2) for Debrecen Airport for 12 December 2010 are plotted. In both examples, the spread of the ensemble forecasts is notably smaller than the spread of the post-processed forecast distribution.

The success of statistical post-processing relies on finding appropriate parametric families for the weather variable of interest. However, the choice of a suitable parametric model is a non-trivial task, and often a multitude of competing models are available. The relative performances of these models usually vary for different data sets and applications.

The regime-switching combination models proposed by Lerch and Thorarinsdottir (2013) partly alleviate the limited flexibility of single parametric family models by selecting one of several candidate models based on covariate information. However, the applicability of this approach is subject to the availability of suitable covariates. For some weather variables, full mixture EMOS models can be formulated where the parameters and weights of a mixture of two forecast distributions are estimated jointly (Baran & Lerch, 2016). However, such approaches are limited to specific weather variables, and the estimation is computationally demanding.

This article investigates the feasibility of an alternative, more generally applicable route to improving the forecast performance that has recently received some interest, and the further examination of which was called for by Yang, Sharma, Siddique, Greybush, and Mejia (2017), for example. Motivated by the recent promising results of Bassetti, Casarin, and Ravazzolo (2018) and Möller and Groß (2016), we study whether combining the predictive distributions of individual post-processing models is able to improve the forecast performance significantly. In a first step, individual EMOS models based on single parametric distributions are estimated. In a second step, the forecast distributions are combined by utilizing state of the art forecast combination techniques such as the (spread-adjusted) linear pool, the beta-transformed linear pool (Gneiting & Ranjan, 2013), and a recently proposed Bayesian, essentially non-parametric calibration approach (Bassetti et al., 2018). Further, we propose a computationally efficient 'plug-in' approach to determining combination weights in the linear pool that is specific to post-processing applications.

The main contribution of this article is the provision of an empirical assessment of the merits of combining