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Application of time-lagged ensemble approach with auto-regressive processors to reduce uncertainties in peak discharge and timing

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ABSTRACT

In spite of the popularity of ensemble streamflow predictions (ESP), data necessary to produce these predictions are still limited in many countries. This study developed an ensemble flood forecasting methodology for an urban catchment in Korea where only deterministic forecasts of three-hour rainfall accumulations are provided twice a day. The forecasted ensembles of rainfall were created using a time-lagged ensemble approach and used in a rainfall-runoff model to generate ensemble flood forecasts. An auto-regressive (AR) processor was then applied to the input and output ensembles to improve the accuracy of the flood forecasts.

The Jungrang catchment was selected to evaluate the performance of the proposed methodology. This is one of the urban areas vulnerable to flooding. From 1991 to 2010, there were 154 fatalities and 5,278 injured victims resulting from flooding.

An accuracy evaluation using observations from 2002 to 2009 found that the time-lagged ensemble approach alone produced significant bias but the AR processor reduced the relative error percentage of the peak discharge from 60% to 10% and also decreased the peak timing error from more than 10 h to less than 3 h, on average. The proposed methodology is easy and inexpensive to implement with the existing products and models and thus can be immediately activated until a new product for forecasted meteorological ensembles is officially issued in Korea.

1. Introduction

Ensemble streamflow prediction (ESP) is currently one of the most active research areas in hydrology. For example, more than 30 articles discussing ESP were presented at the oral program at the European Geophysical Union General Assembly in 2012. Notable review articles (e.g., Cloke and Pappenberger, 2009) and special journal issues (e.g., Georgakakos and Krzysztofowicz, 2001) are also currently available. First used as an acronym for extended streamflow prediction in the 1970s, ESP was a popular tool for long- and medium-range flow forecasting in the 1980s and 1990s. Its applications have been extended to short-range flood forecasting as more accurate meteorological ensemble forecasts have become available.

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A good example is the experimental Ensemble Forecasts System (XEFS) of the U.S. National Weather Service, which combines short-, medium-, and long-range streamflow forecasting procedures within a single system. Cloke and Pappenberger (2009) conducted a broad review of ensemble flood forecasting studies and practices, particularly in Europe, such as the EFFS (European Flood Forecasting System).

In Korea, ESP as ensemble streamflow prediction was first introduced in 2001 (Kim et al., 2001). Some successful results were obtained in Korea for probabilistic monthly streamflow forecasting using ESP theoretically (e.g., Jeong and Kim, 2009; Kang et al., 2010) and in practice (e.g., Kim et al., 2007). In particular, the Han River Flood Control Office in Korea began to publish "The Water Supply Outlook" every month in 2009 by using the ensemble approach. However, no studies or applications have been undertaken that focus on short-range flood forecasting. This study was the first effort that investigated the applicability of ESP for short-range (such as hourly) flood forecasting in Korea. Unlike the typical extended streamflow predictions, short-range ESP usually requires a forecasted meteorological ensemble. However, the Korea Meteorological Administration (KMA) does not officially issue such an ensemble (or scenario-based) format of forecasts. Rather, it only issues deterministic, single meteorological forecasts. Therefore, the first part of this study focused on how to create meteorological ensemble forecasts for short-range ESP from the current KMA forecasts. A time-lagged ensemble approach was used for this purpose.

The issue of uncertainty is very important in ESP. To reduce the uncertainties of ESP, pre- and post-processes are generally employed. The most popular processes include quantile mapping, optimal linear correction, and event bias correction; however, a majority of their applications have been limited to extended streamflow predictions (e.g., Hashino et al., 2006; Kang et al., 2010). The second part of this study proposed a post-processor with ESP for flood forecasting, which should be different from the well-known processors for extended streamflow predictions. For this second purpose, an auto-regressive (AR) processor was employed.

The proposed ESP approach was applied to the hourly flood forecasting for an urban catchment in Korea. In conclusion, it is worth noting that the proposed ESP approach improved not only the forecasting accuracy of the peak amount of flooding but also that of the peak timing of flooding. Few previous studies have investigated the use and effectiveness of ESP for flood timing forecasts.

The paper is organized as follows. The methodologies for uncertainty estimation and ensemble generation with the post-processor are described in Section 2. The proper time-lagged ensemble technique for the specific environment of Korea and the AR model as a post-processor are also described. In Section 3, these methodologies are applied to the Jungrang catchment of Korea, which has historically been vulnerable to flooding. Finally, in Section 4, the analysis results are discussed, which conclude that the ensemble technique with an AR model can provide reliable probabilistic flood information focusing on peak volumes and times.

2. Methodology

2.1. Short-range ensemble generation

The ensemble technique in hydrology is a method that creates various possible scenarios through a simulation model to capture various uncertainties that can occur during its simulation. Specifically, ESP generates possible streamflow ensemble scenarios that are simulated using a rainfall-runoff model with various input meteorological ensemble scenarios for a given initial soil moisture condition. For medium- and long-range ESPs, input ensemble data are usually constructed from "observed" meteorological data, assuming the future will be a repetition of the past.

In contrast, the "forecasted" meteorological ensemble data are generally used as input into a rainfall-runoff model for short-range ESPs, often because these numerical weather predictions provide reasonable information and uncertainty related to future weather conditions.

In Korea, the official short-range weather forecast product is called Regional Data Assimilation and Prediction System (RDAPS). RDAPS is produced by KMA from a regional forecast model. It runs with 191 × 171 grid points and a resolution of approximately 30 km. This system generates predictions twice a day, at 00 UTC and 12 UTC. Its time step is 3 h; thus, the RDAPS produces 3-h accumulations of rainfall every 12 h. However, RDAPS is a single, deterministic forecasts and thus, for this study, it was required to create an ensemble from the raw RDAPS data.

As described by Dietrich et al. (2008), different types of ensembles can be classified according to the mechanisms used to generate them. These types, for meteorological as well as for hydrological applications, are as follows:

- Single system ensembles: these consist of perturbation of initial and boundary conditions, different convection schemes (physically based ensembles), and perturbation of model parameters (e.g., Dietrich et al., 2008)
- Multi-model ensembles ("poor man ensembles"): combinations of simulations from different models (e.g., Georgakakos et al., 2004)
- Time-lagged ensembles: combinations of current forecasts with forecasts from earlier model runs (e.g., Hoffman and Kalnay, 1983).

In this study, the time-lagged ensemble method was selected. Hoffman and Kalnay (1983) proposed this method as an alternative to the Monte Carlo forecasting. In the selected method, the forecasts initialized at the current initial time