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Evaluation of real-time hydrometeorological ensemble prediction on hydrologic scales in Northern California

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SUMMARY

The paper presents an evaluation of real time ensemble forecasts produced during 2010–2012 by the demonstration project INFORM (Integrated Forecast and Reservoir Management) in Northern California. In addition, the innovative elements of the forecast component of the INFORM project are highlighted. The forecast component is designed to dynamically downscale operational multi-lead ensemble forecasts from the Global Ensemble Forecast System (GEFS) and the Climate Forecast system (CFS) of the National Centers of Environmental Prediction (NCEP), and to use adaptations of the operational hydrologic models of the US National Weather Service California Nevada River Forecast Center to provide ensemble reservoir inflow forecasts in real time. A full-physics 10-km resolution (10 km on the side) mesoscale model was implemented for the ensemble prediction of surface precipitation and temperature over the domain of Northern California with lead times out to 16 days with 6-hourly temporal resolution. An intermediate complexity regional model with a 10 km resolution was implemented to downscale the NCEP CFS ensemble forecasts for lead times out to 41.5 days. Methodologies for precipitation and temperature model forecast adjustment to comply with the corresponding observations were formulated and tested as regards their effectiveness for improving the ensemble predictions of these two variables and also for improving reservoir inflow forecasts. The evaluation is done using the real time databases of INFORM and concerns the snow accumulation and melt seasons. Performance is measured by metrics that range from those that use forecast means to those that use the entire forecast ensemble.

The results show very good skill in forecasting precipitation and temperature over the subcatchments of the INFORM domain out to a week in advance for all basins, models and seasons. For temperature, in some cases, non-negligible skill has been obtained out to four weeks for the melt season. Reservoir inflow forecasts exhibit also good skill for the shorter lead-times out to a week or so, and provide a good quantitative basis in support of reservoir management decisions pertaining to objectives with a short term horizon (e.g., flood control and energy production). For the northernmost basin of Trinity reservoir inflow forecasts exhibit good skill for lead times longer than 3 weeks in the snow melt season. Bias correction of the ensemble precipitation and temperature forecasts with fixed bias factors over the range of lead times improves forecast performance for almost all leads for precipitation and temperature and for the shorter lead times for reservoir inflow. The results constitute a first look at the performance of operational coupled hydrometeorological ensemble forecasts in support of reservoir management.

1. Introduction

The Integrated Forecast and Reservoir Management (INFORM) demonstration project was conceived to demonstrate increased water-use efficiency in Northern California water resources operations through the innovative application of climate, hydrologic and decision science (Georgakakos et al., 2005, 2000; Carpenter and Georgakakos, 2001; Yao and Georgakakos, 2001). The particular objectives of INFORM are to (a) implement an integrated forecast-management system for the primary Northern California reservoirs, both for individual reservoirs as well as system-wide; (b) demonstrate the utility of climate, weather and hydrologic forecasts through near-real-time tests of the integrated system with actual data; and (c) align the forecast component of INFORM to

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existing operational models and practices in the region to facilitate an eventual smooth transition to operations.

The Northern California river and reservoir system serves many vital water uses, including providing two-thirds of the state's drinking water, irrigating 7 million acres of the world's most productive farmland, and being home to hundreds of species of fish, birds, and plants. In addition, the system protects Sacramento and other major cities from flood disasters and contributes significantly to the production of hydroelectric energy. The Sacramento-San Joaquin Delta provides a unique environment and is California's most important fishery habitat. Water from the Delta is pumped and transported through canals and aqueducts south and west serving the water needs of many more urban, agricultural, and industrial users.

Fig. 1 shows the drainage basins of the region of interest in Northern California delineated by the U.S. National Weather Service (NWS) California Nevada River Forecast Center (CNRFC). The drainage basins are on the American, Yuba, Feather, Sacramento, and Trinity Rivers and their tributaries. The Folsom, Oroville, Shasta, New Bullards Bar and Englebright reservoirs on the Sacramento River tributaries are included in the INFORM system, together with the Trinity Reservoir (Clair Engle Lake) on the Trinity River. Forecasting of the precipitation and temperature in these drainage basins and of the resulting inflow into these reservoirs are part of the INFORM demonstration project activities.

INFORM meteorological-component forecast models use as input the operational ensemble forecasts of the National Centers for Environmental Prediction (NCEP) of the National Oceanic and Atmospheric Administration (NOAA). The INFORM models downscale these forecasts for the watersheds of the region of interest in real time to produce high resolution ensemble precipitation and surface air temperature forecasts and ensemble forecasts of reservoir inflows. The innovative aspects of the formulation aim to provide the ability to generate continuous dynamically-downscaled forecasts with high temporal and spatial resolution with lead times from 6 to 41.5 days.

In the present paper we summarize the formulations and procedures associated with the real-time ensemble predictions of basin-scale precipitation and temperature as well as of the ensuing reservoir inflows, and focus on the evaluation of their performance using observed data from the available real time databases. This evaluation of performance intends to illuminate the real time behavior of the forecast system that includes changes in the NCEP operational model output during the period of evaluation and a few missing forecasts due to real time connectivity problems. However, it is this type of evaluation that is useful for real time reservoir management as these are recurring problems with real time forecast systems.

Forecast lead times of interest in this work are from 6 h to 41.5 days and are pertinent to reservoir operations management. INFORM also produces longer lead-time forecasts (once a month out to 9 months with daily resolution) pertinent to reservoir operations planning but these are not evaluated herein (see relevant evaluations in Carpenter and Georgakakos (2001), and Yao and Georgakakos (2001), as well as in HRC-GWRI (2007, 2013)).

More complete descriptions of the activities, formulations, main findings and recommendations of INFORM are presented in HRC-GWRI (2007, 2013). Recent application of the INFORM formulations in climate change studies is in Georgakakos et al. (2012b,a). The present work complements the literature of operational forecast system evaluation that pertains to coupled hydrometeorological models, high resolution gridded ensemble precipitation and temperature forecasts in mountainous terrain with seasonal snow, and ensemble reservoir inflow forecasts used for improved multi-objective reservoir management worldwide (e.g., Collischonn et al., 2007; Olsson and Lindstrom, 2008; Vannitsem, 2008; McCollor and Stull, 2008; Renner et al., 2009; Cloke and Pappenberger, 2009; Janowiak et al., 2010; Achleitner et al.,

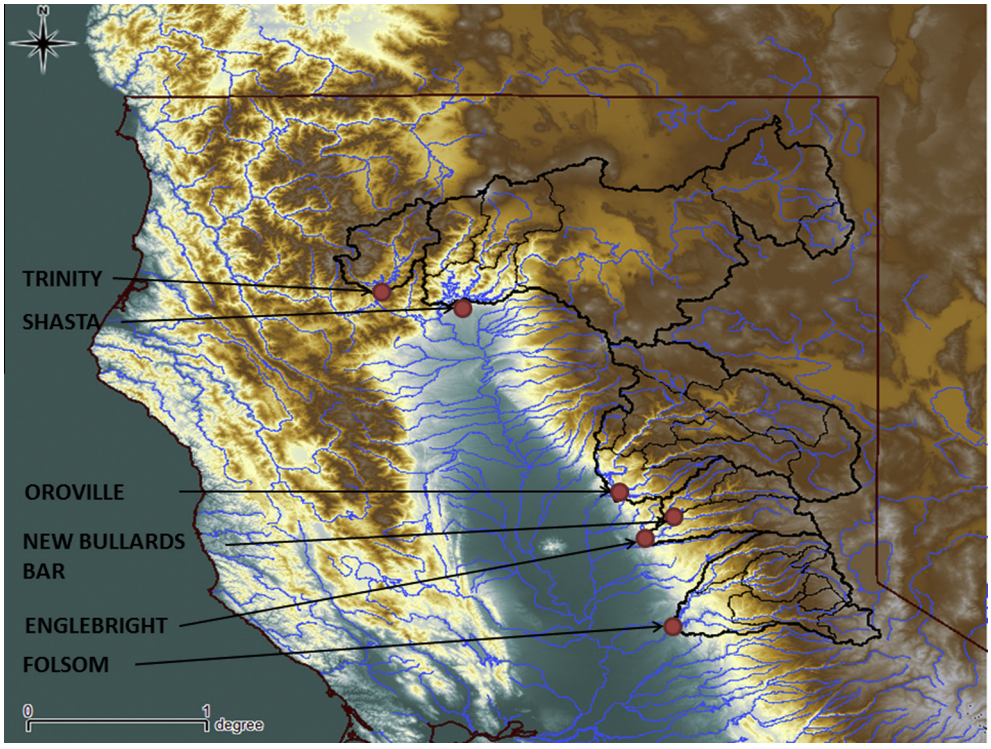

Fig. 1. Northern California hydrologic basins for the INFORM demonstration project. Watersheds draining into reservoirs are indicated by heavy black lines, subcatchments by thin black lines and main rivers by blue lines. The major reservoir locations and names are also indicated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)