**Project Progress Report for NWS Program Office (NWSPO)**
**Award Number: NA07NWS4620013**
Project Officer: Pedro Restrepo
Recipient Name: The Regents of the University of California, UCLA
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Title: Data Assimilation in Operational Watershed Models for Short and Long-term Hydrologic Forecasting
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## Project Objectives

The goal of this proposal is to formulate a parsimonious data assimilation framework capable of integrating streamflow, soil moisture and snow products into the current National Weather Service River Forecasting System (NWSRFS) in order to improve ensemble streamflow forecasting. The project involves development and testing of an Ensemble Kalman Filter (EnKF) method to update NWS hydrologic model states for snow dominated basins using streamflow and SNOTEL observations. Ensemble streamflow prediction hindcasting techniques will then be used to assess the potential impact of the automatic updating scheme on current operational forecast skill. Initial testing is proposed for the American River basin and the plan is to extend the project to other operational forecast basins in the Western U.S. Guidance for development of the data assimilation framework is being solicited from NWS personnel at all agency levels. The proposed system design is intended to be modular and transferable to any NWS River Forecast Center. The system will also provide some degree of user control to meet the requirements of specific operational forecast settings.

## Activities

Data Collection

The initial phase of this project involved extensive data collection, compilation and analysis. Progress has been made in collecting data from both the Natural Resources Conservation Service (NRCS) Snow Telemetry (SNOTEL) database and the California Department of Water Resources (CDWR) California Cooperative Snow Surveys Program. Data has been collected for several watersheds in the CNRFC forecast region (American and Carson River basins) as well as a variety of sites in the western United States. Initial calibration of the SNOW-17 model to various sites has also been undertaken (discussed below). In addition, a daily time series of high-resolution (1 km) remotely sensed potential evapotranspiration (PET) is being compiled based on a previously developed algorithm. We propose to integrate these spatial estimates of PET into the modeling-assimilation framework. Example images of daily PET are presented for specific winter and summer days over the DMIP2 study region of the American River (Figure 1).

Modeling

The SACramento Soil Moisture Accounting (SACSMA) and SNOW17 models were recoded into the Matlab platform and verified to facilitate this study. The recoded models were checked to assure consistency with NWSRFS source codes and evaluated at several watershed sites (both snow and non-snow systems). Several parameter sensitivity and estimation routines were also obtained and/or coded in Matlab and linked with the SNOW-17 and/or SACSMA, including the Regionalized Sensitivity Analysis (RSA), the Shuffle Complex

Evolution automatic calibration method and the Generalized Likelihood Uncertainty Estimator (GLUE). Parameter estimation and uncertainty studies were undertaken at both snow and non-snow basins, including an extensive study undertaken at MOPEX basins in the southeastern United States.

We are currently in the process of identifying suitable SNOTEL data sites within our selected watersheds (i.e. quality assuring data sources). Suitability will depend on length of the data record, quality of data, and accuracy of SNOW17 simulations using SNOTEL data. As a preliminary step, the SNOW17 was calibrated at 13 select SNOTEL sites throughout the western US with data records of at least five years (Figure 2). Only three primary parameters were calibrated (the snow correction factor, minimum melt factor and maximum melt factor). The SNOW17 model simulations were highly accurate at 11 of these sites, indicating the potential for use of these SNOTEL sites (and others) for the data assimilation study. Calibration of additional SNOW17 parameters may improve results further.

We are also in the process of linking the Ensemble Kalman Filter (EnKF) with the SNOW17 model. Initial work is being undertaken involving synthetic studies of state estimation and updating of SWE within the modeling framework. In addition, parameter estimation methods will be integrated to facilitate improved parameter estimates within the ensemble system.

**Dissemination of Results and Agency Collaboration**

During the reporting period of this project the investigators have communicated with key NWS personnel and hydrologists, including Rob Hartmann from the CNRFC and D.J. Seo and Yuqiong Liu at the NWS Hydrologic Research Laboratory (HRL) in Silver Spring, MD. The SACSMA-SNOW17 modeling and assimilation framework will be developed in direct collaboration with HRL and RFC scientists in order to facilitate ultimate integration into the proposed RFC ensemble forecasting systems. Investigators Hogue and Franz visited the NWS HRL in February to present ongoing related work and facilitate project collaboration with NWS researchers. In addition, the PIs have also presented various topics related to the objectives of this project at national meetings and invited seminars.

**Presentations related to current project:**

Hogue, T.S. and K. Franz, 2008: Hydrologic Tools and Products for Advancing Operational Forecast Systems, NOAA-NWS Hydrology Laboratory, March 2008.

Hogue, T.S., K. Franz and J. Barco, 2007: Performance and Probabilistic Verification of Regional Parameter Estimates for Operational Forecasting Models, AGU Fall National Meeting, December, 2007.

**Peer-reviewed Journal Articles related to current project:**

Kim, J. and T.S. Hogue, 2008: Evaluation of a MODIS-based Potential Evapotranspiration Product at the Point-scale, *in press, Journal of Hydrometeorology*.

Franz, K. J., T. Hogue, S. Sorooshian, 2008: Future challenges of applying an energy balance snow model for operational forecasting, *in review, Journal of Hydrology*.

Franz, K. J., T. Hogue, S. Sorooshian, 2008: Snow model verification using ensembleprediction and operational benchmarks, *in review, Journal of Hydrometeorology.*

Hogue, T.S., H.V. Gupta, and S. Sorooshian, 2006: A "User-Friendly" Approach to Parameter Estimation in Hydrologic Models, *Journal of Hydrology,* 320, 202–217.

**Figure 1**. Spatial estimates of PET derived from MODIS products (Kim and Hogue, 2008) for both a summer and winter day over the American River in northern California.

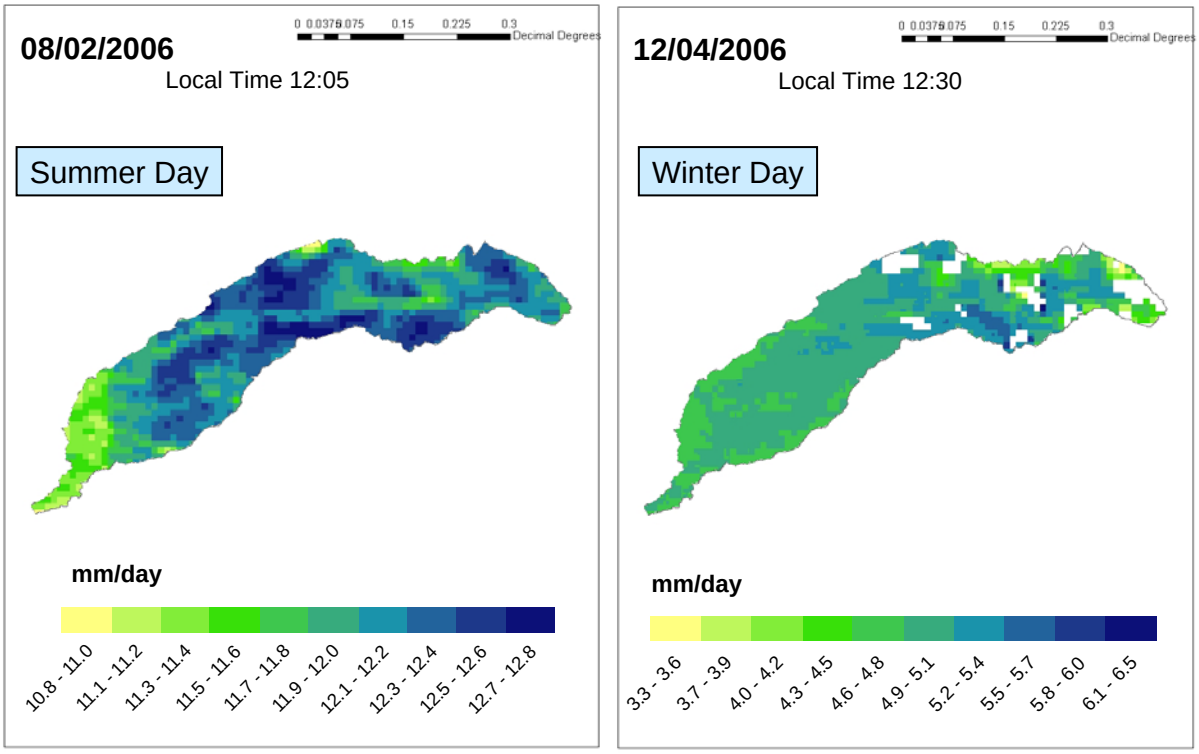


Figure 2. Nash Suttcliffe efficiency scores for SNOW17 simulated at 13 SNOTEL sites (point simulations) in the western United States. Perfect score = 1.