Assimilating SNOTEL Snow Water Equivalent Observations for Improved Streamflow Predictions

Yuqiong Liu[1,2], Minxue He[1,2], Dong-Jun Seo[3], Donald Laurine[4], and Haksu Lee[1,5]

[1]NOAA/NWS/Office of Hydrologic Development [2]Riverside Technology, inc., Fort Collins, Colorado

[3]University of Texas, Arlington [4] NOAA/NWS/Northwest River Forecast Center [5]University Corporation for Atmospheric Research

Introduction

The National Weather Service (NWS) River Forecast Centers (RFCs) currently uses a regression-based technique to produce areal snow water equivalent (SWE) data from point SWE measurements (e.g. from SNOTEL sites) for snow melt and streamflow forecasting in snow-impacted basins. While this method is parsimonious and easy to use in operations, it does not capitalize on the full capabilities offered by advanced data assimilation techniques to quantify, reduce, and propagate forecast uncertainty in a statistically and dynamically consistent fashion.

This study describes a preliminary application of assimilating point SNOTEL SWE observations and regression-based areal SWE estimates into the NWS operational snow model (SNOW-17), via direct insertion and an ensemble Kalman filter (EnKF). The performance of SWE assimilation strategies is evaluated for streamflow predictions using the Sacramento Soil Moisture Accounting model (SAC-SMA) at a snow-dominated basin in the service area of the Northwest River Forecast Center (NWRFC). Future work planned for improving the assimilation results is also discussed.

Science Questions

- How do SNOTEL SWE observations, model SWE simulations, and the areal SWE estimates derived from the regression technique compare to each other?
- How does the performance of EnKF compare to that of direct insertion in terms of streamflow prediction?
- How does the performance of assimilating point SNOTEL SWE observations compare to that of assimilating regression-based areal SWE estimates in streamflow prediction?

Study Area

In this study, we focus on the Stehekin River basin (Fig. 1) in the east of the Cascade divide in the Pacific Northwest of the United States. The basin has a drainage area of 321 square miles, with the maximum snow water equivalent exceeding 60 inches in most years. Snow and ice melt in the late Spring constitutes the major contributor to regional streamflow, which is highest during May through July when precipitation is lowest and air temperature is highest (Fig. 2).

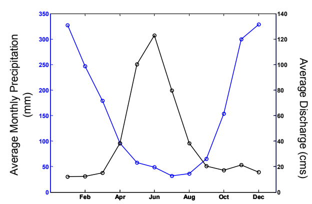


Fig. 2 Hydroclimatology of the basin

SWE measurements from the three SNOTEL sites in the basin (Fig. 1) for the period of 10/1/1983 ~ 9/30/2003) are used for data assimilation in this study.

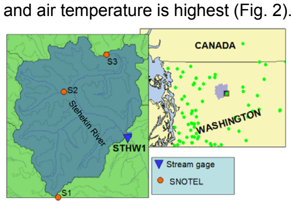


Fig. 1 The Stehekin river basin

Reference

Garen, D.C., Improved techniques in regression-based streamflow volume forecasting, J. Water Resour. Plann. Manage.,118, 654-670, 1992.

Koren, V., Parameterization of frozen ground effects: sensitivity to soil properties. In: Prediction in: Ungauged Basins: Promise and Progress (Proc. Of Symposium S7 at Foz do Iguacu, Brazil, April 2005), IAHS Publ. 303, 125-133, 2006.

Methods

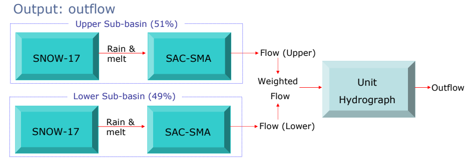
I. NWS Operational Models

a) Snow model: SNOW-17

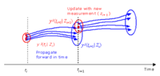
- Temperature-index (T_{air}>*PXTEMP*, snowfall; otherwise, rainfall)
- Input: T_{air} & Precip. (*SCF*×Precip.); Output: snowmelt & rainfall

b) Rainfall-Runoff model: SAC-SMA

- Two-layer, saturation runoff
- Input: snowmelt & rainfall (output from SNOW-17);
- Output: outflow



IV. EnKF



Step 1: Propagation

$$y_i(t) = A[\alpha_i, u_i(t), t];$$
$$y_i(t=t_0) = y_{0i}$$

Step 2: Updating

$$y_j^+ = y_j^- + K[z+\varepsilon_j - M_j(y_j^-)]$$
$$K = C_{yz}[C_{zz}+C_e]^{-1}$$
$$j = 1,2,...,N$$

Z: Flow measurement

y: Model states

N: Ensemble size

II. Regression

The principle component regression (PCR) technique presented in Garen (1992) is adopted here to estimate areal SWE estimates based on historical model simulations and SNOTEL SWE observations.

III. Direct insertion

1. Using point SNOTEL SWE observations

$$SWE_{update} = SWE_{model} * 0.5 + SWE_{snotel} * 0.5$$

2. Using PCR-based areal SWE estimates

$$SWE_{update} = SWE_{model} * 0.5 + SWE_{PCR} * 0.5$$

Results

In this preliminary study, we focus on SWE and streamflow predictions for Water Year 2003 (10/1/2002~9/30/2003). First, the SNOW-17 model is run for the period of WY1980~WY2002 to generate historical model SWE simulations. Daily SWE predictions for WY2003 are then generated from principle component regression using the historical SWE simulations and the SNOTEL SWE observations of WY1984~WY2002.

Table 1 Correlation Matrix between Model and SNOTEL SWE

	Model Upper	Model Lower	SNOTEL 1	SNOTEL 2	SNOTEL 3
Model Upper	1.0				
Model Lower	0.97	1.0			
SNOTEL 1	0.95	0.95	1.0		
SNOTEL 2	0.92	0.95	0.95	1.0	
SNOTEL 3	0.96	0.92	0.92	0.87	1.0

The correlation matrix (Table 1) shows that the SWE simulations for the upper and lower sub-basins are highly correlated with observations from all of the three SNOTEL sites; however, the climatology shown in Figure 3 indicates that the SWE observations from the third site are more representative of the upper sub-basin, while the first and second sites are more relevant to the lower sub-basin.

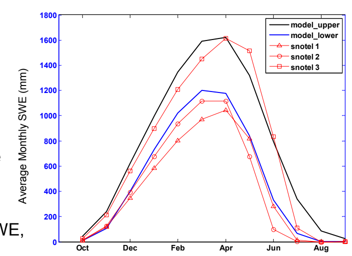


Fig. 3 Modeled SWE vs. SNOTEL SWE Observations

Hence, when assimilating point SNOTEL SWE, observations from the third site are used for updating the model SWE in the upper sub-basin, while the average SWE observations from the first and second sites are used for updating the lower sub-basin.

Streamflow predictions from direct insertion using both SNOTEL SWE observations and PCR-based areal SWE estimates, as compared to streamflow observations and the model simulations without updating, are presented in Fig. 4. The statistics of streamflow predictions are summarized in Table 2. Note that direction insertion is only applied during the period of January ~ May, as the SNOTEL SWE observations are considered to be more representative during this period due to the high forest cover percentage in the basin.

Table 2 Streamflow statistics from direct insertion of PCR-based SWE estimates and SNOTEL SWE observations

		RMSE (cms)	BIAS (cms)	NSE	R
Entire Year	default	17.1	18.4	0.77	0.96
	PCR	21.8	19.2	0.63	0.97
	SNOTEL	10.5	-1.8	0.91	0.96
Peak Period only	default	43.3	32.7	0.01	0.91
	PCR	60.9	48.4	-0.96	0.93
	SNOTEL	19.7	8.1	0.79	0.91

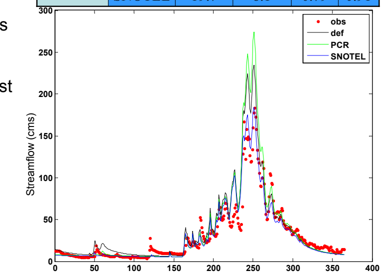


Fig. 4 Streamflow predictions from direct insertion of PCR-based SWE estimates or SNOTEL SWE observations

These results indicate that direct insertion of SNOTEL SWE observations has considerably improved streamflow predictions, especially during the peak flow period (days 230-270). However, direct insertion of PCR-based SWE estimates has led to somewhat deteriorated results compared to the default simulations, except for a marginal improvement on correlation. This is likely due to the fact that WY2003 is a dry year and PCR might be overestimating the areal SWE. The results from using EnKF are shown in Fig. 5 a) & b) for assimilating SNOTEL SWE and PCR-based SWE, respectively. In comparing to direct insertion, the EnKF results tend to outperform during low flow periods, but underestimating the peak flows in both cases.

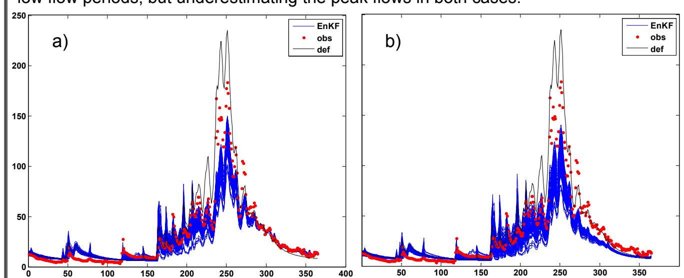


Fig. 5 Streamflow predictions from EnKF using a) SNOTEL SWE observations and b) PCA-based SWE estimates (ensemble size =100)

Summary and Future Work

Preliminary results indicate 1) EnKF outperforms direct insertion during low flow periods but not the perk flow period and 2) the PCA-based areal SWE estimates are less representative than the point SNOTEL SWE observations for dry years. Future work will focus on improving the EnKF technique by considering uncertainty in model states and exploring the sensitivity of EnKF performance to the ensemble size and the representation of errors in the different uncertainty sources. It would also be beneficial to use a new version of the SAC-SMA model that accounts for rainfall-runoff modeling with frozen soils (Koren, 2005) which are characteristic of the study basin. The performance of DA for wetter years will also be examined.

Contact: Kevin.He@noaa.gov