CALIBRATION OF A HYDROLOGIC AND DYNAMIC GLACIER MODEL TO THE NOOKSACK RIVER BASIN USING GRIDDED SURFACE CLIMATE DATA

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Abstract

The Nooksack River drains an approximately 2000 km² watershed in the North Cascades of Whatcom County, Washington (Figure 1) and is a valuable freshwater resource for regional Tribes, municipalities, industry, and agriculture, and provides critical habitat for endangered salmon species. Nooksack River streamflow is largely influenced by precipitation and snowmelt in the spring, and glacial melt throughout the warmer summer months when precipitation is minimal. Mt. Baker has the largest contiguous network of glaciers in the North Cascades, which have shown a significant retreat in recent decades (Polo and Brown, 2012: Figures 2 & 3). Concern has grown over the effects that climate variability and change might have on glaciers and water resources in general in the Nooksack basin. Regional climate projections through the end of the 21st century indicate an increase in average annual air temperature, a decrease in summer precipitation, and an increase in winter precipitation. We are investigating a publicly available statistically derived gridded surface data and numerical modeling techniques to simulate the effects of forecasted climate change on the Upper Nooksack River with an emphasis on summer low flow forecasts. Here, we focus on calibration and validation of the model for the North Middle, and South Fork Nooksack Basins.

1. Introduction

The Nooksack River drains an approximately 2000 km² watershed in the North Cascades of Whatcom County, Washington (Figure 1) and is a valuable freshwater resource for regional Tribes, municipalities, industry, and agriculture, and provides critical habitat for endangered salmon species. Nooksack River streamflow is largely influenced by precipitation and snowmelt in the spring, and glacial melt throughout the warmer summer months when precipitation is minimal. Mt. Baker has the largest contiguous network of glaciers in the North Cascades, which have shown a significant retreat in recent decades (Polo and Brown, 2012: Figures 2 & 3). Concern has grown over the effects that climate variability and change might have on glaciers and water resources in general in the Nooksack basin. Regional climate projections through the end of the 21st century indicate an increase in average annual air temperature, a decrease in summer precipitation, and an increase in winter precipitation. We are investigating a publicly available statistically derived gridded surface data and numerical modeling techniques to simulate the effects of forecasted climate change on the Upper Nooksack River with an emphasis on summer low flow forecasts. Here, we focus on calibration and validation of the model for the North Middle, and South Fork Nooksack Basins.

2. Project Objectives

Predict the effects of Pacific Northwest climate change on streamflow

Ultimately, the goals of our project are to assess the impacts of climate change on Nooksack basin hydrology using the Distributed Hydrologic Soil Vegetation Model (DHSVM) version 3.2 with an integrated glacier dynamics model, linked with downscaled future climate data developed using the multimodel ensemble constructed analogs method (MACA, Abatzoglou and Brown, 2011). The MACA downscaled data incorporates 20 global climate models of the CMIP5 using RCA4.5 and RCA6.0 forcing scenarios. Before simulating the hydrology and glacier response to climate change, we have to calibrate the DHSVM to the Nooksack basin using historical observed meteorological data. Due to a lack of spatially distributed long-term historical weather observations in the basin, we apply statistically available statistically derived gridded surface data developed by Livneh et al. (2013: Figure 6). The advantage of the Livneh data is that it was used to train the MACA data set that we will apply for future climate forcings.

Livneh Gridded Surface Data

The Livneh dataset was created by incorporating daily observations from National Weather Service Cooperative Observer stations across the USA and monthly precipitation from the Parameter-elevation Regressions on Independent Slopes Model (PRISM, PRISM Climate Group). Temperatures are adjusted with elevation using a 6.5°C/km lapse rate. The resulting data includes minimum and maximum temperature, precipitation, and wind speed from 1950-2011. For this project, the Livneh grids are disaggregated to 3-hr time-steps for use in the DHSVM.

3. Modeling Tools

Distributed Hydrologic Soil Vegetation Model

The DHSVM developed at the University of Washington and Pacific Northwest National Laboratory, uses meteorological and spatially distributed physical data to simulate a water and energy balance at the pixel scale of a digital elevation model (Figure 5, Wigmosta et al., 1994). The model predicts snowpack evolution, evapotranspiration, soil infiltration and storage, saturated subsurface flow, and surface runoff, for each pixel over a user-defined time step.

DHSVM Setup

Physical model inputs (Figure 6) to the DHSVM include a stream network and the following 50-meter resolution GIS data sets:

- Elevation Model (USGS)
- Soil Thickness (generated in ArcMap)
- Soil Type (STATSGO database)
- Landcover (NOAA Landcover)
- Stream Networks (generated in ArcMap)
- Solar/Shadow Map (generated in ArcMap)

4. Model Calibration

Calibration requires the adjustment of model parameters to achieve a reasonable comparison between predicted and observed values. The DHSVM is calibrated to observed 1) glacial mass balance and annual extent, 2) streamflow, and 3) snow-water equivalent (SWE) in the Nooksack basin (Figure 1). Calibration is performed for each of the three sub-basins separately in an effort to better capture local variability due to the complex topography of the Mt. Baker area. Here, we report the calibration to the North, Middle, and South Fork basins of the Nooksack River.

We are using processed meteorological data (see Project Objectives) from Livneh observational data grid points for the calibration. In addition, we are incorporating monthly (30-year normals) PRISM databases to capture the variable precipitation lapse rates at a higher resolution (800 m; PRISM Climate Group, 2004).

Statistical tests are used in addition to graphical comparisons to assess the accuracy of DHSVM results with respect to observations. The Nash-Sutcliffe (1970) model efficiency coefficient and R² test statistics are examined for each model run to assess the predictive capability of the DHSVM.

5. Preliminary Glacier Calibration Results

North Fork

Middle Fork

South Fork

6. Preliminary Hydrology Results

North Fork

Middle Fork

South Fork

Discussion and Further Modeling

Additional calibration is needed in the North and Middle Fork Nooksack basins, particularly with regard to glacier ice extent. Attempting to calibrate SWE, ice extent, and streamflow simultaneously has proved challenging as improving one often has a negative impact on the others. Initial ice extent adequately captures the estimated 3500 historical extent but additional calibration is needed to better simulate the observed change in glacier extent through the beginning of the 21st century. Modern day glacier coverage in the South Fork basin is minimal and does not contribute a significant amount of streamflow. Thus, model runs into the 21st century will not consider any glacier coverage in the South Fork basin. Glacier melt in the Middle and North Fork basins however, is a significant contributor to streamflow in the drier late summer months throughout the period of simulation.

South Fork hydrology has generally been well captured with the model but peak flows during large storm events are consistently underestimated, lowering the Nash Sutcliffe efficiency score significantly. In the Middle and North Fork basins, peak flow events are underestimated in the South Fork basin as the streamflow is generally underestimated as well. This is likely due, at least in part, to the glacier ice extent not being properly calibrated. Further calibration will likely focus on altering temperature lapse rates and soil conductivities to improve glacier and streamflow results respectively.

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