A SPATIALLY DISTRIBUTED ENERGY BALANCE SNOWMELT MODEL FOR APPLICATION IN MOUNTAIN BASINS

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ABSTRACT

Snowmelt is the principal source for soil moisture, ground-water recharge, and stream-flow in mountainous regions of the western U.S. Information on the timing, magnitude, and contributing area of melt under variable or changing climate conditions is required for successful water and resource management. A coupled energy and mass-balance model was used to simulate the development and melting of the seasonal snowcover in several mountain basins in California, Idaho, and Utah. Simulations were done over basins varying from 1 to 10,000 km^2, with simulation periods varying from a few weeks for the smallest basin, to multiple snow seasons for the larger basins. The model, ISNOBAL, is a spatially distributed form of the model SNOBAL, which was described in great detail by Marks, *et al.* (1998).

INTRODUCTION

ISNOBAL approximates the snowcover as two-layer system: a fixed-thickness active layer, and a lower layer that represents the rest of the snowcover. The model uses a set of energy balance equations to solve for the temperature, specific mass, and thickness of each layer (Marks 1988, Marks and Dozier 1992). It is driven by topographically corrected estimates of radiation, temperature, humidity, wind, and precipitation. The model runs over a digital elevation model (DEM) grid, and requires a 7-band initial condition image, and a specified number of 4-band precipitation images, and is then driven by a 6-band input image for each time-step. The model produces a 9-band energy and mass flux image, and a 10-band snow condition image for each output time-step. A detailed description of the structure, input, and output requirements of the model is presented by Marks, *et al.* (1998). The methods used to develop the initial condition and input-forcing images is described by Susong, *et al.* (1997).

DISCUSSION

The model has been tested over three alpine basins during the past five years. Each of these tests was at, or very near the limits of the capacity of a desktop computer workstation. The first test, in 1994, was over the Emerald Lake basin, an extensively instrumented experimental watershed in the Sierra Nevada of California. The basin is a small alpine cirque (1.2km^2), that is essentially a granite lysimeter allowing us to assume that daily snowmelt was equal to daily runoff from the basin. It was represented by a 5m DEM, containing 48,048 grid cells. The test was run for two 10-day periods at the beginning of, and then well into spring melt of the 1986 water year. The tests showed that the model accurately predicted snowmelt and runoff during both 10-day periods. The run required 120 M-bytes of input data, generated 200 M-bytes of output, and took 9.5 hours of CPU time on a Sun Sparc-2.

The second test, in 1996, was over the Boise River basin, just above the city of Boise, Idaho. The basin is large enough (2,151km^2) to be an important source of water and other natural resources in the region. The basin was represented by a 250m DEM, containing 34,411 grid cells. The basin contains six NRCS SNOTEL stations

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providing daily maximum and minimum air temperature, precipitation, and snow water equivalent (SWE). Input parameters were either simulated or derived from the SNOTEL data. SWE data were used to specify the initial condition of the snowcover, but not as input to the model. The test was run for the month of April, 1990. SWE data from the SNOTEL stations in the basin were the first direct validation of a model state variable. The test showed that the model was capable of accurate simulation of both the development and depletion of the snowcover over a large, complex basin, using only minimal available data. The run required 500 M-bytes of input date, generated 350 M-bytes of output data, and took 6.5 hours of CPU time on a Sun Sparc-10.

The third test, 1996, was over the Park City area, near Salt Lake City, Utah. This region is smaller than the Boise River basin (460km2), but was represented by 75m DEM containing 81,744 grid cells. The test was run for the last four months of two snow seasons (1994 and 1995). 1994 was a low-snow year, while 1995 was a very large-snow year. Again, only minimal data were available to drive the model, so inputs were either simulated or derived from SNOTEL or other nearby data collection sites. This test showed that the model is not only capable of accurate simulation of the development and depletion of the snowcover over large complex regions, but that these simulations can be done for long periods of time so that multiple snow seasons can be compared. This run required over 1.5 G-bytes of I data, generated SNOTELG-byte of output data, and took over 12 hours of CPU time on a Sun Sparc Ultra-170E for each water year.

RESULTS

Simulation results in all basins closely match independently measured snow water equivalent, snow depth, or runoff during both the development and depletion of the snowcover. The steady improvement in computer storage and processing capabilities has made application of this model possible over larger basins and for longer time-periods. Spatially distributed estimates of snow deposition and melt allow us to better understand the interaction between topographic structure, climate, and moisture availability in mountain basins of the western U.S. Application of topographically distributed models such as this will lead to improved water resource and watershed management.

REFERENCES

Marks, D., 1988. Climate, energy exchange, and snowmelt in Emerald Lake watershed, Sierra Nevada. Departments of Geography and Mechanical Engineering, University of California Santa Barbara, CA, Ph.D. Dissertation, 158 pp.

Marks, D., and J. Dozier, 1992. Climate and energy exchange at the snow surface in the alpine region of the Sierra Nevada: 2. Snow cover energy balance. Water Resources Research, vol. 28, no. 11, pp. 3043-3054.

Marks, D., J. Domingo, and J. Frew, 1998. Software tools for hydro-climatic modeling and analysis: Image Processing Workbench, USGS Version 2.0. Open File Report (in review) U.S. Geological Survey, Electronic Document http://quercus.ars.pn.usbr.gov/~ipw.

Marks, D., J. Kimball, D. Tingey, and T. Link, 1998. The Sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: A study of the 1996 Pacific Northwest flood. Hydrological Processes (in press).

Susong, D., D. Marks, T.E. Link, and D. Garen, 1997. Developing time-series climate surfaces to drive topographically distributed energy and water balance models. Abstract H12B-03, Eos, Transactions of the American Geophysical Union, vol. 78, no. 46, p. F209.