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GIS TOOL TO COMPARE SIMULATED AND REMOTELY SENSED SNOW-COVER OBSERVATIONS

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ABSTRACT

A GIS (geographic information system)-based Snow-Cover Comparison Tool (SCCT) is being developed for use by watershed modelers and other analysts to make comparisons between simulated and remotely sensed snow cover. In the past, watershed-model simulations have been calibrated almost entirely by comparison of simulated with observed streamflow variations. Watershed-model calibrations can be improved by verifying that snowpack distributions and conditions within the basin are simulated accurately, but this requires careful registration of observations to model land units. The SCCT facilitates these additional comparisons. NOAA's satellite-based snow-cover images on 1,101 meter grid cells are compared here with simulations, on 100-meter grid cells, of snowpacks in the Merced, American, and Carson Rivers of the Sierra Nevada on selected dates. Statistical analyses of disagreements between observed and simulated snow cover show a strong dependence of model error on altitude. Comparison maps, produced by the SCCT, make the spatial distributions of these errors easy to visualize.

INTRODUCTION

Recent watershed-modeling efforts in the Sierra Nevada have been hampered, in part, by limitations of data sets available for model calibrations and testing. Most models have been calibrated almost entirely by comparison of simulated and observed streamflow measurements at a single gage. Comparisons of simulated with observed snow cover could greatly improve the models and increase our confidence in their predictions.

In the past, there has been no easy method for testing the accuracy of simulated snowpack. Snow-cover observations from *in situ* measurements can be used but these observations, although generally accurate, are limited in areal extent. Snow-cover observations by remote-sensing methods provide the most widespread and complete coverage, but they are spatially coarse (about 1-kilometer grid cells) and can be inaccurate in areas of steep terrains or dense forest canopies.

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To combine the strengths and minimize the weaknesses of these different kinds of data, user-friendly tools for comparing a variety of snow-cover observations and simulations are needed. A geographic information system (GIS) Snow-Cover Comparison Tool (SCCT) is being developed to facilitate these comparisons. This tool will be useful to watershed modelers comparing simulated to remotely-sensed data and to other analysts who assess or compare areas covered by snow.

SNOW-COVER COMPARISON TOOL

The SCCT is designed to facilitate spatial comparisons between remotely sensed and simulated snow cover for arbitrary land units, such as model grids, altitude zones, political or watershed areas. Although SCCT is an evolving set of tools and procedures, it already is functional. The SCCT is written using ARC/INFO GIS software (from Environmental Systems Research Institute, Inc., Redlands, California). The data required by the SCCT are:

- Gridded georeferenced remotely sensed snow-cover observations.
- Georeferenced coverages of land units.
- Georeferenced coverage of the study area boundary.
- Lists of simulated snowpack-water equivalents within the land units on the day remotely sensed observations were made.

The user also must specify the land units for the comparisons, the boundary of the study area, the remotely sensed snow-cover imagery, and the simulated and remotely sensed snow-cover thresholds. These thresholds determine whether snow is considered present or not in a particular land unit. In this initial testing, snowpack-water equivalent was used as an indicator of simulated snow. The following thresholds were used:

- A land unit is assumed to be "simulated snow covered" if its simulated snowpack-water equivalent depth is greater than 12 inches.
- A land unit, as sampled from the remotely sensed data, is assumed to be "observed snow covered" if more than 50 percent of the land unit is covered by snow.

The SCCT produces two outputs:

- Tables listing the occurrences of snow cover per land units, for both the simulated and remotely sensed image.
- Maps showing the spatial distribution of simulated and remotely sensed snow cover.

EXAMPLES OF SNOW-COVER COMPARISONS

Sierra Nevada Snow Data

For the Sierra Nevada, snow-cover data from several sources are available for comparisons. Examples presented here use the SCCT to compare simulated snow cover in several river basins with remotely sensed data.

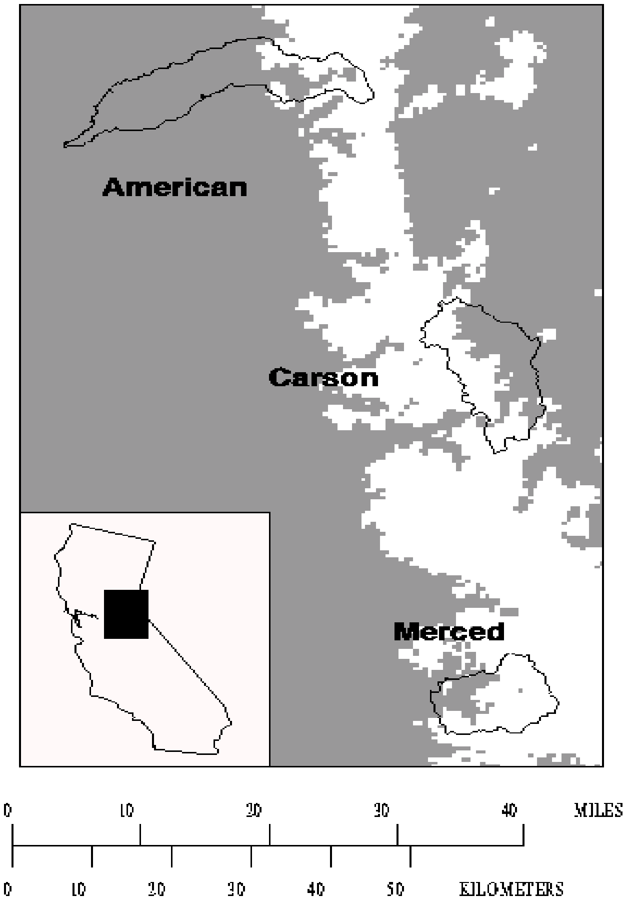


Figure 1. May 1996, snow-covered areas (white), no-snow area (gray) and three model boundaries. Image from NOAA's National Operational Hydrologic Remote Sensing Center (NOHRSC).

Remote sensing data. The NOAA National Operational Hydrologic Remote Sensing Center (NORHSC) has produced biweekly satellite-based snow-cover images (e.g., fig. 1) with 1,101-meter grid cells during winters and springs since 1990 (http://www.nohrsc.nws.gov). In addition, the NASA-funded Earth Sciences Information Partnership on Snowpack Hydrology in the Southwest, at Scripps Institution of Oceanography, soon will be offering a new generation of snow-cover products (Simpson and others, 1998) beginning with winter 1998 for use in future comparisons (http://landlub.ucsd.edu/projects/esip/esip.html).

Simulations. Simulations of snowpack and streamflow from existing watershed models of the Merced River, North Fork American River, and East Fork Carson River basins (Dettinger and others, 1999; Jeton and others, 1996) are used here. Snowpack-water equivalent and streamflow are simulated by applications of the USGS Precipitation-Runoff Modeling System (PRMS: Leavesley and others, 1983, 1996). The smallest land units represented in the models are "hydrologic-response units" (HRUs) which are developed and located on 100 meter grid cells. A HRU is an area of equal runoff response (including snowmelt) to a given meteorologic forcing. Snowpack in the watershed is simulated on a HRU-by-HRU basis and represents HRU-average snow properties at best. HRU properties include altitude, slope, aspect, vegetation cover, soils, geology and climate.

Other data**.** In addition to these resources, each winter and spring more than 250 monthly snow-course measurements and more than 100 continuously recording snowpack instrumentation arrays (SNOTELS) are operated in the Sierra Nevada by California State and local agencies (http://cdec.water.ca.gov/snow/). Although they are not used in the following examples, these observations provide another source of data for snow-cover comparisons.

Snow-Cover Comparisons for 1995

Using the SCCT, several PRMS simulations of snowpack in the Merced River basin were compared with corresponding NOHRSC snow-cover images. The hydrograph of the Merced River at Happy Isles Bridge (fig. 2) shows the fit of simulated to observed streamflow, and reflects snow accumulation and melt. The large overestimation of summer streamflow by the model suggests that the model carried too much snowpack into the spring and summer snowmelt period in 1995; the SCCT spatial comparisons verify this by showing broad (lower altitude) areas that, in simulation, are snow covered, in observations, are not (figs. 3A and 3B).

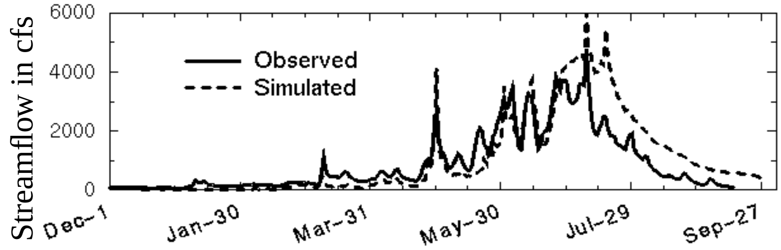
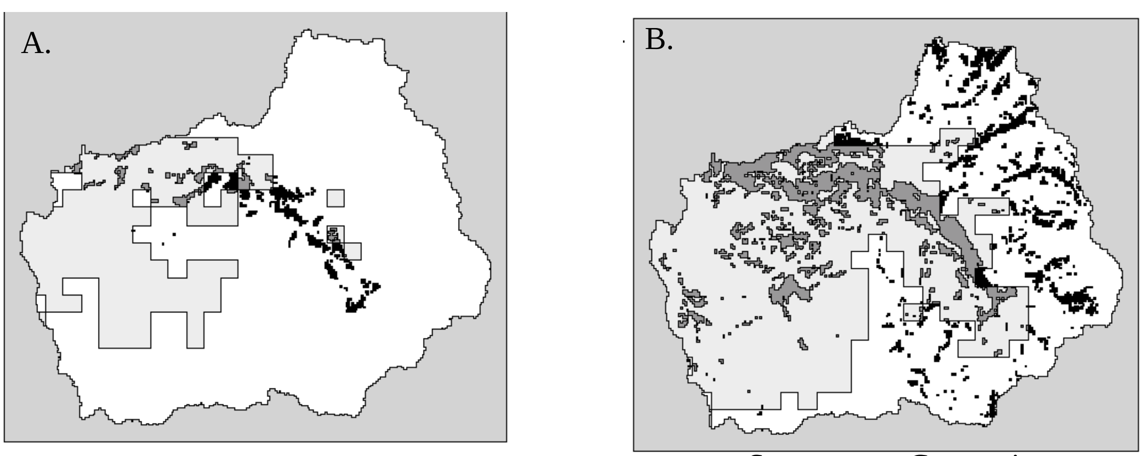


Figure 2. Simulated and observed streamflow in the Merced River at Happy Isles Bridge, Yosemite National Park, December 1994 through September 1995.

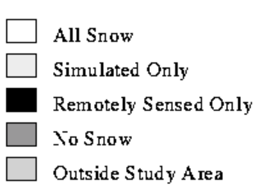
Statistical Comparisons for 1995

The snow-cover comparisons also can be analyzed statistically. Relations between land features -- such as slope, aspect, altitude, and vegetation-cover density -- and the spatial distributions of model errors are assessed here using a standard contingency-table analysis (Benjamin and Cornell, 1970, p. 511-512). Overall, in the three examples that follow, statistical analyses of disagreements between observed and simulated snow cover show strong dependence of model errors on altitude.



Snow-cover Comparison for May 29, 1995.

Snow-cover Comparison for July 6, 1995.



SIMULATED MODEL DATA Merced_6July1995			NOHRSC SNOWCOVER DATA s95187		
HRU	SNOW PRESENT	PACKWATER EQUIVALENT	HRU	SNOW PRESENT	PERCENT COVER
1	0	0.00	1	0	1
2	1	39.10	2	0	0
3	1	24.40	3	0	3
4	1	72.40	4	1	74
5	1	35.00	5	0	0
6	1	45.90	0	0	0
7	1	[illegible]	7	[illegible]	[illegible]

Figure 3. Snow-cover comparison maps of the Merced River basin for May 29, 1995 (A) and July 6, 1995 (B) and part of a snow-cover comparison table for July 6, 1995.

Merced River, May 29, 1995. Disagreements between remotely sensed and simulated snow-covered areas exist in one-fourth of the HRUs in this particular image (fig. 3A). The disagreements were highly significantly associated at a 99 percent confidence level, with HRUs at altitudes below 9,000 feet, which are the areas in the western third of the basin and along the dark zone from north central to southeast corners of fig. 3A. Statistically significant associations also exist for HRUs with vegetation-cover density (greater than 40 percent) and slope (greater than 33 percent), although these associations may be due to the relations of vegetation-cover density and slope to increasing altitudes in the basin. The association of HRU aspect with model errors was not statistically significant.

American River, May 17, 1993. No significant associations of model errors with altitude, vegetation-cover density, slope, or aspect were found, even at the 95 percent confidence level. Overall, however, the disagreements are restricted to the higher, eastern parts of the basin where the snow is located (fig. 4).

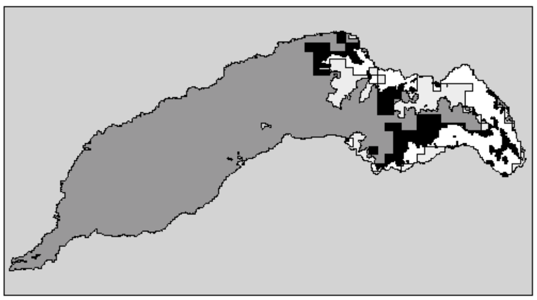


Figure 4. Snow-cover comparison map of the American River basin for May 17, 1993 (same shading as Fig. 3).

Carson River, May 21, 1998. Disagreements between remotely sensed and simulated snow cover in this image (fig. 5) are significantly associated with HRUs at altitudes below 8,000 feet, which are in the northeastern parts of the basin. Vegetation-cover density, slope, and aspect are not significantly associated with model errors.

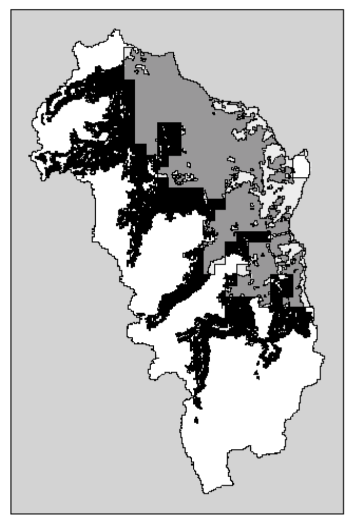


Figure 5. Snow-cover comparison map of the Carson River basin for May 21, 1998 (same shading as Fig. 3).

FUTURE WORK AND CONCLUSIONS

The SCCT is a user-friendly ARC/INFO tool that makes spatial comparisons between remotely sensed and simulated snow cover easier and more accessible than previous methods. Such comparisons have the potential to improve watershed models in snowpack-dominated river basins. The method was tested using simulations of the Merced, American, and Carson River basins of the Sierra Nevada and the NOAA NOHRSC snow-cover images. The examples of snow-cover comparisons shown here indicate some of the conditions under which existing PRMS simulations --which are generally successful at reproducing observed streamflow-- have deviated markedly from observed snowpack conditions.

The SCCT is an evolving set of tools and procedures. We expect that, in time, it will be expanded to include comparisons between simulated and remotely sensed snowpack-water equivalents (rather than just snow-covered areas), direct comparisons with *in situ* observations, more statistical tests, and an ArcView interface.

ACKNOWLEDGEMENTS

This tool is being developed with inputs from the NOAA NOHRSC snow-cover data sets and from California Department of Water Resources, Division of Flood Management, California Data Exchange Center. Any use of trade, product, or firm names in this report is for descriptive proposes only and does not imply endorsement by the U.S. Government.

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