SWE ESTIMATES IN THE HINDU KUSH AND THE SIERRA NEVADA USING PASSIVE MICROWAVE AND RECONSTRUCTION

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ABSTRACT: Accurate measurement of spatially distributed snow water equivalent (SWE) in mountain watersheds is perhaps the most significant problem in snow hydrology. We examine SWE measurements from two techniques. The first uses passive microwave estimates from the AMSR-E sensor aboard the Aqua satellite. Passive microwave (PM) has been used to estimate SWE for decades, and while it is subject to numerous problems, it is the only source of global SWE estimates. Recently, SWE reconstruction has been shown to be accurate at estimating basin-wide SWE in the Sierra Nevada and elsewhere. Reconstruction combines a melt model with snow covered area (SCA) measurements to retroactively build the snowpack, from disappearance back to its peak. Reconstruction can only be used retrospectively, so we examine prior reconstructed water years to better understand the strengths and weaknesses of PM SWE estimates. Our test case is California’s Sierra Nevada, where we have full natural flow estimates and a large network of SWE sensors for comparison. Our application area is Afghanistan’s Hindu Kush, where neither streamflow nor ground-based SWE measurements are available. In both regions, most of the runoff comes from snowmelt, and both experience occasional drought. In the Sierra Nevada, PM SWE estimates are an order of magnitude smaller than reconstructed SWE estimates and appear to suffer from biases caused by a dense canopy and a deep snowpack. In the Hindu Kush, PM SWE estimates are smaller than reconstructed estimates in basins with deep snow (> 250 mm SWE) but greater than reconstructed estimates in basins with shallow snow (< 90 mm). We hypothesize that AMSR-E underestimates the snowpack when the PM SWE signal saturates, and overestimates it when the snowpack has a significant depth hoar layer. To aid operational snow assessments in Afghanistan, we develop regression relationships to predict SWE using PM SWE and SCA as independent variables, and reconstructed SWE as the dependent variable.

KEYWORDS: SWE, microwave, reconstruction

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Snow water equivalent estimates in Afghanistan’s mountain watersheds using passive microwave and reconstruction

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ABSTRACT: Accurate measurement of spatially distributed snow water equivalent (SWE) in mountain watersheds is perhaps the most significant problem in snow hydrology. Via satellite SWE measurements from two techniques. The first uses passive microwave estimates from the AMSR-E sensor aboard the Aqua satellite. Passive microwave (PM) has been used to estimate SWE for decades, and while it is subject to numerous problems, it is the only source of global SWE estimates. Recently, SWE reconstruction has been shown to be accurate at estimating basin-wide SWE in the Sierra Nevada and elsewhere. Reconstruction combines a melt model with snow-covered area (SCA) measurements to reconstructively build the snowfield, then compare results back to its base. Reconstruction can only be used retroactively, so we examine prior reconstructed SWE using the data for mountain glaciers and estimate the SWE contributed by glaciers from the observed SWE contribution. We also develop an accurate SCA estimate for Afghanistan. We demonstrate our methodology and show the results for SCA estimates for the Afghanistan Hindu Kush, where similar sources of SCA data are unavailable. We also show a new relationship between SCA and normalized snow water equivalent (N) in Afghanistan to account for the effects of cloud cover on passive microwave measurements. In both regions, most of the snowfall comes from snowpack, and both experience occasional drought. In the Sierra Nevada, PM SWE estimates are an order of magnitude smaller than reconstructed SWE estimates and appear to suffer from biases caused by dense canopies and a deep snowpack. In the Hindu Kush, PM SWE estimates are smaller than reconstructed estimates in basins with deep snow (>250 mm SWE) but greater than reconstructed estimates in basins with shallow snow (<100 mm). We hypothesize that AMSR-E underestimates the snowpack when the PM SWE signal extrapolates, and overestimates it when the snowpack is shallow. We develop new methodologies to extract and model the snowpack SWE and glacier SWE contributions to the basin-wide SWE estimate. In this paper, we present and analyze the relationships to predict SWE using PM SWE and SCA as independent variables, and reconstructed SWE as the dependent variable.

Study Area

Table 1: List of basins and areas.

<table>
<thead>
<tr>
<th>Region</th>
<th>Name</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sierra Nevada</td>
<td>Nearch</td>
<td>63,956</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>Nearch</td>
<td>237,794</td>
</tr>
<tr>
<td>Afghan</td>
<td>37,001</td>
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<tr>
<td>Australian</td>
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<td>Pakhtoon</td>
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</tr>
<tr>
<td>Upper</td>
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</tr>
<tr>
<td>Lower</td>
<td>20,857</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>285,036</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Time series regression equations and correlation coefficients. For each equation, the dependent variable is the reconstructed SWE volume for the given year. The independent variables are: AMSR-E SWE, SCA, and AMSR-E SWE and SCA together. The time periods compared for each year are the basin mean peak SWE date through September 30th. The correlation coefficient r² is given in parenthesis.

Figure 1: (a) Sierra Nevada MUC 8 basins, gauges where I4 natural flow is measured, and elevation from the Shuey Radios Topography Mission. (b) Same area, but showing forest cover from the National Land Cover Database.

Figure 2: (a) Afghanistan basins, surrounding countries, and elevation from ASTER Global DEM. (b) Same area, but showing forest cover from Google Earth.

Figure 3: Modelled versus observed peak SWE estimates from locations in the Sierra Nevada shown as snow pillows; Rs=0.33. One-to-one dotted line also shown.

Figure 4: Sierra annual SWE estimates from four methods, compared to April to July Full Natural Flow (FNF). SWE is normalised by basin area. Regression coefficients and Rs values were computed for each method. Water years 2003-2011 were used.

Figure 5: Time series of observed and reconstructed modelled SWE for the Sierra Nevada. Time periods shown are basin mean peak SWE date through September 30th for each year.

Figure 6: Afghanistan annual SWE estimates from Reconstruction and AMSR-E. SWE is normalised by basin area. Regression coefficients and Rs values were computed for each method. Water years 2003-2011 were used.

Figure 7: Time series of observed and reconstructed modelled SWE for 8 basins in Afghanistan. Time periods shown are the basin mean peak SWE date through September 30th for each year.

Figure 8: Map of average April 1st SWE in Afghanistan from Reconstruction (a) and AMSR-E (b) for 2003-2011.