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

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ABSRACT: 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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Study Area

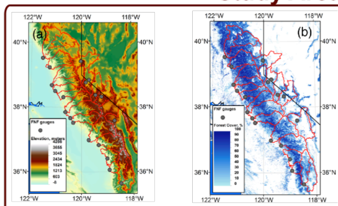

Figure 1 (a) Sierra Nevada HUC 8 basins, gauges where full natural flow is measured, and elevation from the Shuttle Radar Topography Mission. (b) Same area, but showing forest cover from the National Land Cover Database.

Region	Name	Area, km^2
Sierra Nevada	19 modified HUC8 basins	53,593
Afghanistan	Amu Darya	207,379
	Harirod-Murghab	77,891
	Helmand	201,102
	Upper Kabul	42,170
	Kunar	25,836
	Northern	70,891
	Western	85,350
	Upper Helmand	46,876

Table 1 List of basins and areas.

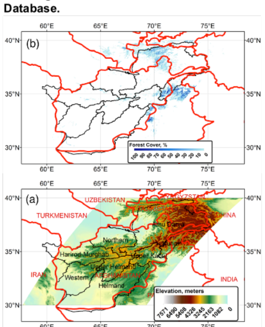

Figure 2 (a) Afghanistan basins, surrounding countries, and elevation from ASTER Global DEM. (b) Same area, but showing forest cover from Geocover.

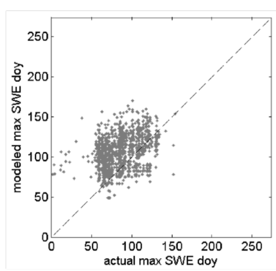

Figure 3 Modelled versus observed peak SWE date estimates from locations in the Sierra with snow pillows, R^2=0.33. One-to-one dotted line also shown.

Time series

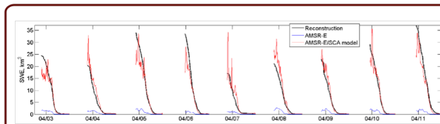

Figure 5 Time series of reconstructed and regression modelled SWE for the Sierra Nevada. Time periods shown are basin mean peak SWE date through September 30th for each year.

Area	AMSR-E	SCA	AMSR-E/SCA
Sierra Nevada, 19 modified HUC8 basins	0.720+11.321AMSRE (r=0.87)	0.057+1.338e-3SCA (r=0.93)	0.073+3.900AMSRE+9.809e-4SCA (r=0.95)
Afghanistan, Amu Darya	-10.135+3.689AMSRE (r=0.94)	-3.122+5.760e-04SCA (r=0.91)	-9.038+2.585AMSRE+1.964e-04SCA (r=0.95)
Afghanistan, Harirod-Murghab	-0.025+0.398AMSRE (r=0.70)	+0.039+5.682e-05SCA (r=0.70)	-0.002+0.223AMSRE+2.940e-05SCA (r=0.73)
Afghanistan, Helmand	+0.012+0.456AMSRE (r=0.72)	+0.117+7.912e-05SCA (r=0.74)	+0.056+0.209AMSRE+4.937e-05SCA (r=0.76)
Afghanistan, Upper Kabul	-0.191+2.080AMSRE (r=0.90)	+0.142+3.890e-04SCA (r=0.89)	-0.126+1.236AMSRE+1.806e-04SCA (r=0.92)
Afghanistan, Kunar	-1.146+3.485AMSRE (r=0.92)	-1.338+7.202e-04SCA (r=0.90)	-1.635+2.146AMSRE+3.336e-04SCA (r=0.95)
Afghanistan, Northern	-0.018+0.530AMSRE (r=0.87)	+0.029+7.662e-05SCA (r=0.80)	-0.013+0.433AMSRE+1.744e-05SCA (r=0.88)
Afghanistan, Western	-0.003+0.128AMSRE (r=0.38)	+0.007+3.547e-05SCA (r=0.70)	+0.007+0.000AMSRE+3.546e-05SCA (r=0.70)
Afghanistan, Upper Helmand	+0.003+0.495AMSRE (r=0.74)	+0.070+9.905e-05SCA (r=0.77)	+0.035+0.185AMSRE+6.861e-05SCA (r=0.79)

Table 2 Time series regression equations and correlation coefficients. For each equation, the dependent variable is the reconstructed SWE volume for the given area. 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 r is given in parenthesis.

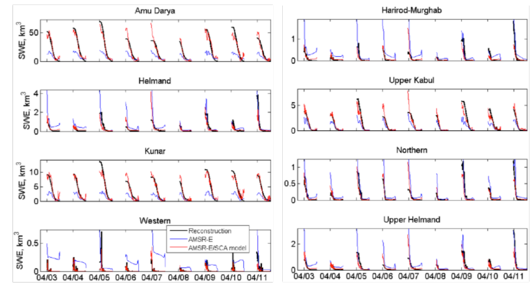

Figure 7 Time series of reconstructed and regression modelled SWE for 8 basins in Afghanistan. Time periods shown are the basin mean peak SWE date through September 30th for each year.

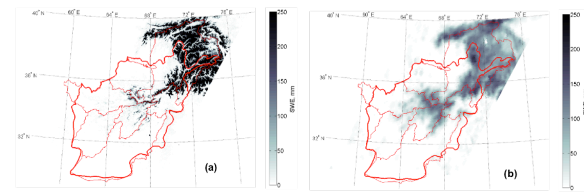

Figure 8 Map of average April 1st SWE in Afghanistan from Reconstruction (a) and AMSR-E (b) for 2003-2011.

Annual SWE

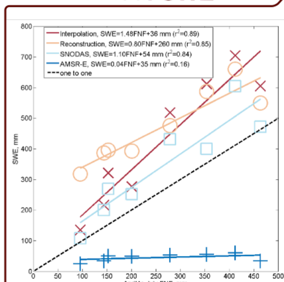

Figure 4 Sierra annual SWE estimates from four methods compared to April to July Full Natural Flow (FNF). SWE is normalized by basin area. Regression coefficients and R2 values were computed for each method. Water years 2004-2011 were used.

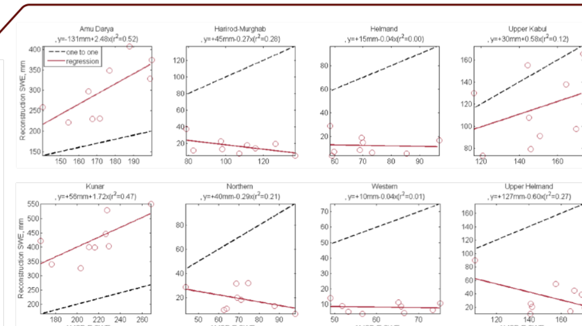

Figure 6 Afghanistan annual SWE estimates from Reconstruction and AMSR-E. SWE is normalized by basin area. Regression coefficients and R2 values were computed for each method. Water years 2003-2011 were used.

Forest cover bias

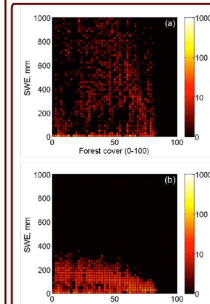

Figure 9 Two-dimensional histograms of maximum annual SWE vs. forest cover for (a) Reconstruction and (b) AMSR-E in the Sierra. Histograms are from annual maximum SWE values from 2003-2011.