Real Time Snow Water Equivalent (SWE) Simulation
May 15, 2013
Sierra Nevada Mountains, California

Introduction

We have developed a real-time SWE estimation scheme based on historical SWE reconstructions between 2000-2012, a near real time MODIS/MODSCAG image, and daily in situ SWE measurements for the Sierra Nevada in California (Molotch, 2009; Molotch and Margulies, 2008; Molotch and Bales, 2006; Molotch and Bales, 2005, Molotch, et. al., 2004 and Guan). Real-time SWE will be released on a weekly basis during the maximum snow accumulation/ablation period.

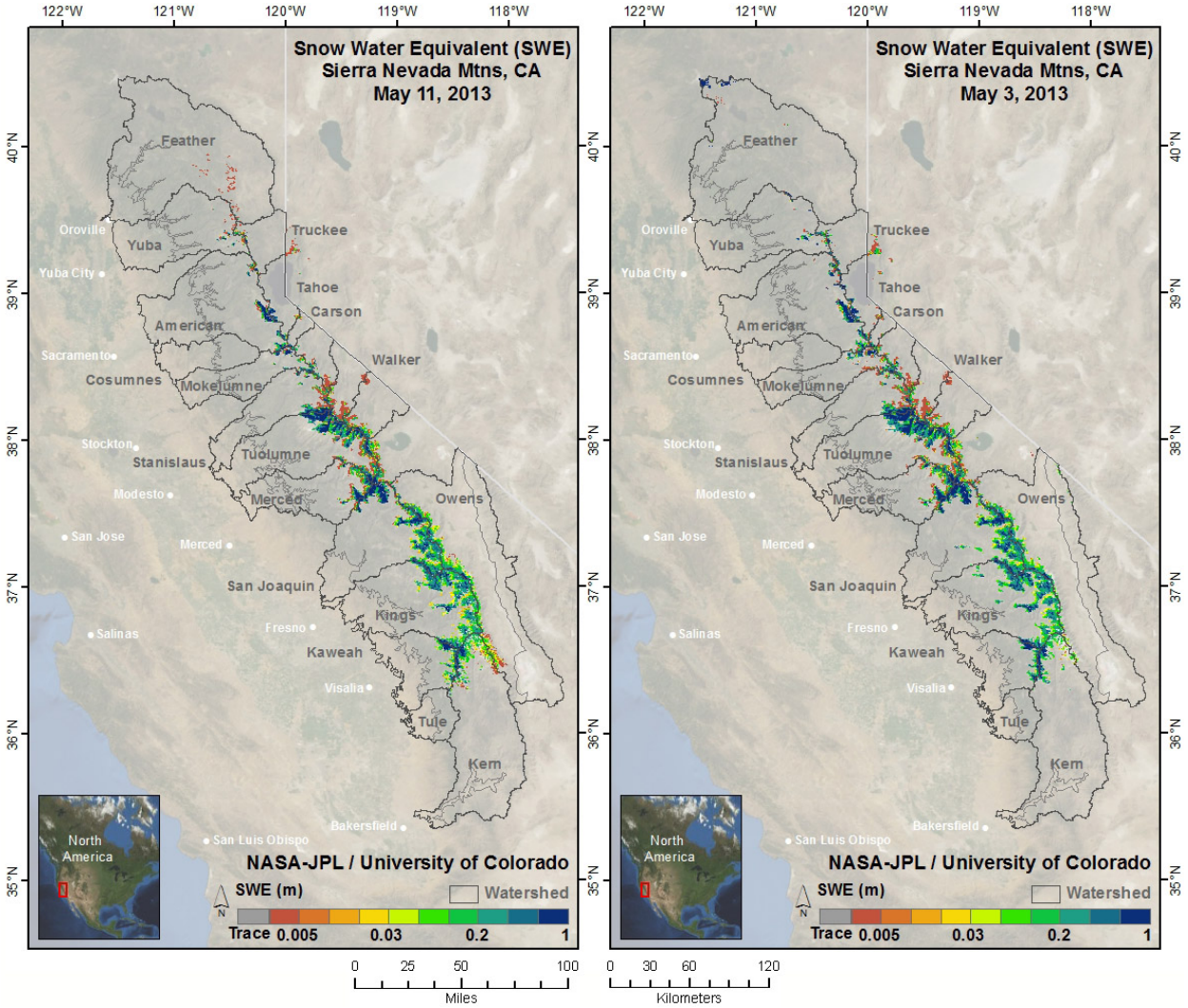

Figure 1. SWE amounts for May 11, 2013 are shown on the left and SWE amounts for May 3, 2013 are shown on the right.

Discussion

The most recent cloud-free MODIS/MODSCAG image available is for May 11, 2013. There was a multi-day snowstorm across the length of the Sierra between 5/5/13 and 5/7/13. Some sensors showed an increase of up to 1 inch of SWE. This Near Real Time SWE product showed an increase in SWE amounts in some watersheds in the upper elevations, see the tables for more details. Figure 1 shows SWE amounts for May 11, 2013 on the left and SWE amounts for May 3, 2013 on the right. On May 11, 2013, 22 snow sensors in the Sierra network were recording snow out of a total of 99 sensors. Note the locations of sensors that aren't recording snow (shown in yellow in Figure 3, left map) are mostly lower elevation than the remaining snowpack, so calculations from sensors alone do not accurately calculate SWE for each watershed. Figure 2 shows the percent of average SWE for May 11, 2013 for the snow-covered area on left and on the right is the mean percent of average for May 11, 2013 shown by watershed for all model pixels above 3000' (shown as gray elevation contour line on left map). Note that watershed averages are much lower than those calculated using snow sensors alone. Snow sensors produce a point value whereas the spatial SWE allows for areal calculations. Every square foot above 3000' in the watershed can be used to calculate the mean, therefore the mean value will be different than those calculated by snow sensor point data. Figure 3 shows the 13 year modeled average SWE for May 11th on the left with snow sensors shown in yellow that recorded no snow on May 11, 2013 and in red for sensors that recorded snow on May 11, 2013; and a banded elevation map on the right. Table 1 shows mean SWE and mean % of Average SWE for 5/11/2013, mean SWE for 5/3/2013, change in SWE between 5/3/2013 and 5/11/2013 summarized for each watershed above 3000'. Note that watershed averages are much lower than those calculated using snow sensors alone. Snow sensors produce several point values for each watershed whereas the spatial SWE allows for areal calculations. Every square foot above 3000' in the watershed can be used to calculate the mean, therefore the mean value will be different than those calculated by snow sensor point data. Table 2 shows mean SWE by elevation band inside each watershed for 5/11/2013, 5/3/2013, the percent of average for 5/11/2013 and the change in SWE between 5/3/2013 and 5/11/2013.

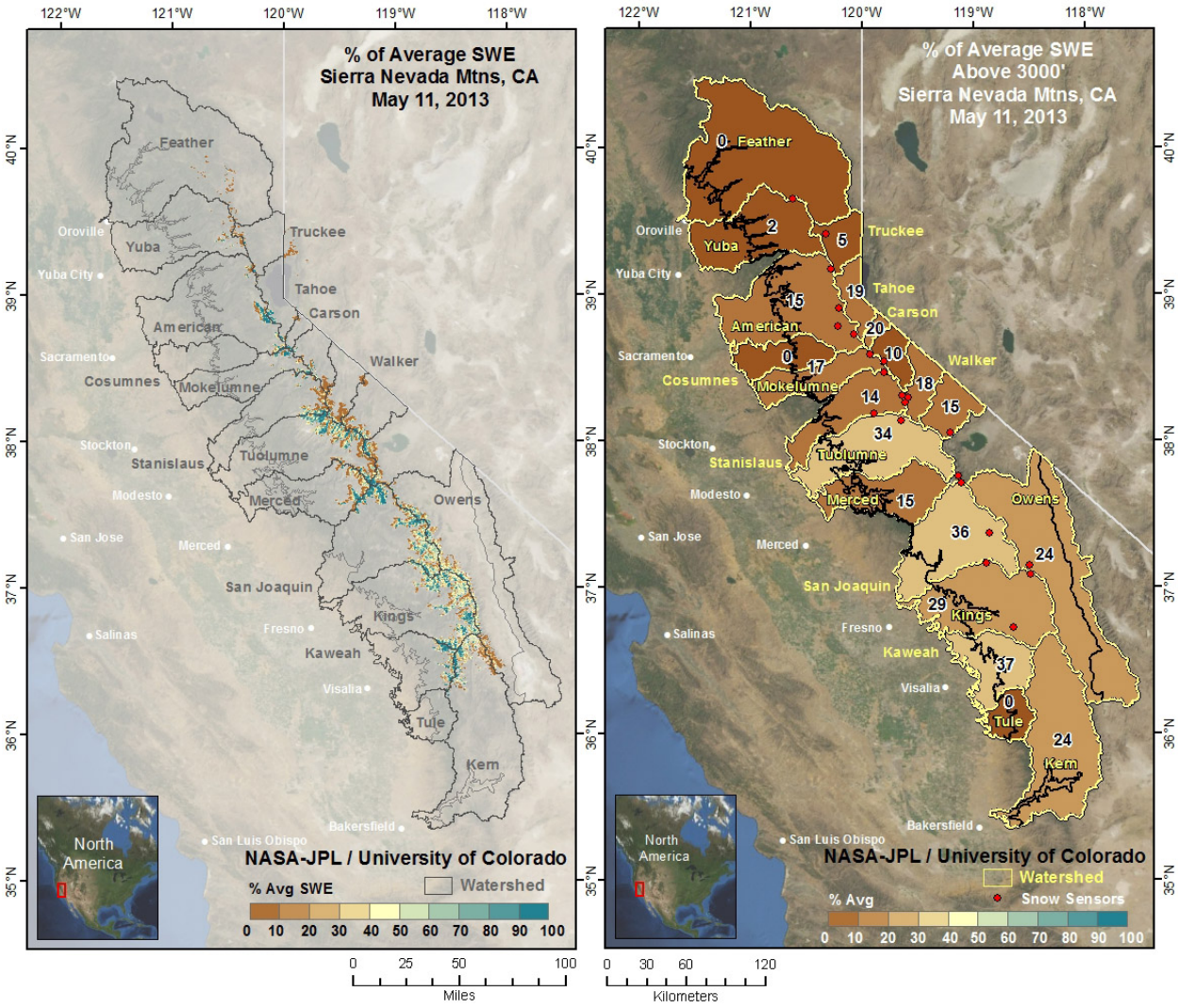

Figure 2. Percent of average SWE for May 11, 2013 for the entire Sierra (on left) and by watershed (on right). Watershed percentages are calculated for all model pixels above 3000' (shown as gray line on left map). SWE snow sensors that had snow on May 11th have been added to the map on the right.

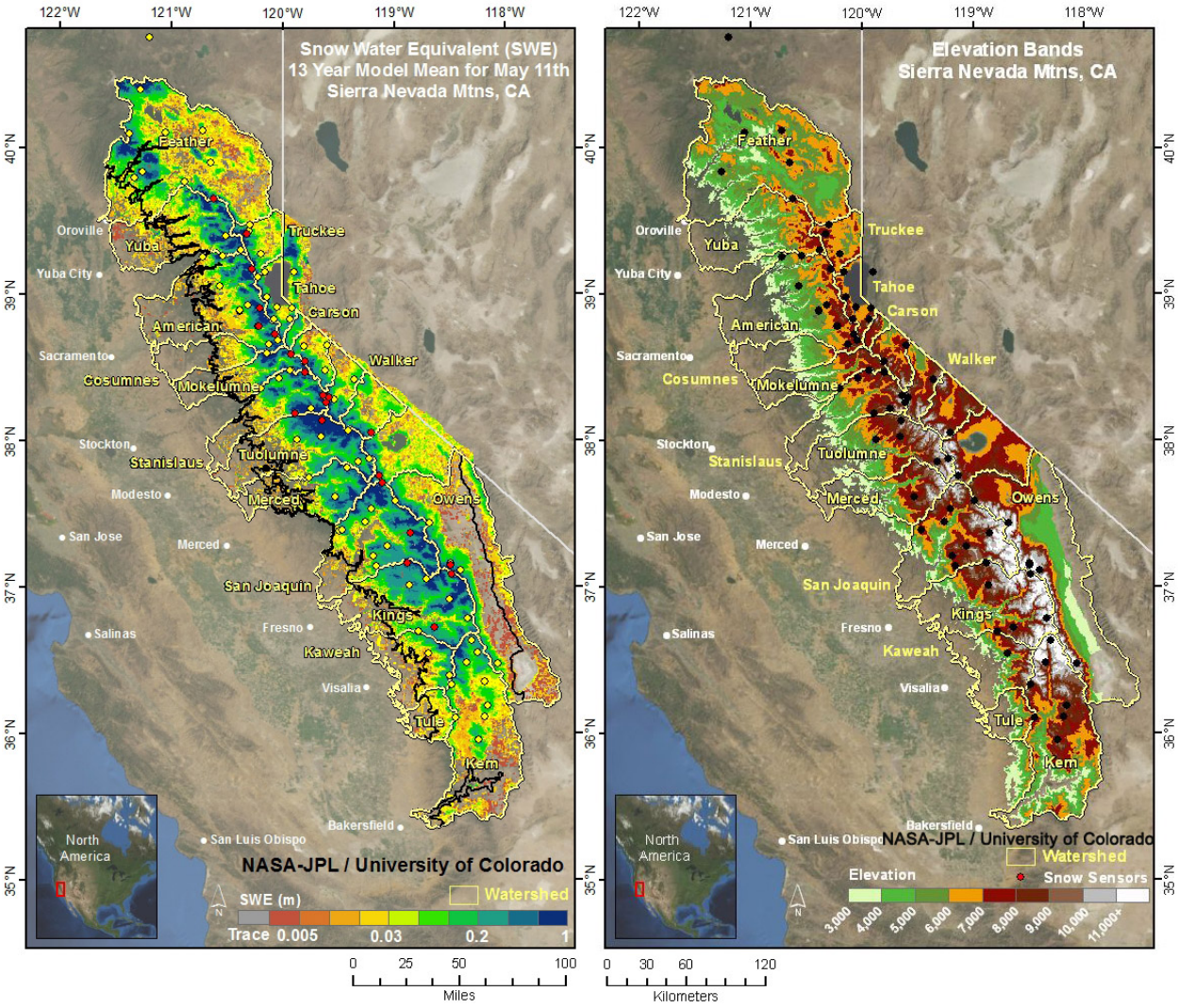

Figure 3. 13 year modeled average SWE for May 11th on the left with snow sensors shown in yellow that recorded no snow and in red for sensors that recorded snow on May 11, 2013; and a banded elevation map on the right.

Methods

Results for the date of May 11, 2013 are based on May 11, 2013 real-time data from 22 in situ SWE measurements distributed across the Sierra Nevada, one Moderate Resolution Imaging Spectroradiometer (MODIS)/Terra Snow cover daily cloud-free image which has been processed using the MODSCAG fractional snow cover program (Painter, et. al. 2009), a normalized reconstructed spatial SWE image for May 11, 2012, and an anomaly map based on 13 years of modeled SWE (2000-2012). Relative to snow stations and the NWS SNODAS product, the spatial reconstructed SWE product correlates strongly with full natural flow, especially late in the snowmelt season (Guan, et. al.).

Table 1. All calculations are for elevations above 3000', which currently contain many 0 value pixels thereby making the mean much lower than those calculated by snow sensors alone. Shown are mean SWE and mean % of Average SWE for 5/11/2013, mean SWE for 5/3/2013, change in SWE between 5/3/2013 and 5/11/2013 for each watershed.

Watershed	5/11/13 SWE (in)	5/11/13 % Avg to Date	5/3/13 SWE (in)	5/3 thru 5/11 Change in SWE (in)
AMERICAN	0.90	14.82	1.26	-0.36
FEATHER	0.01	0.13	0.48	-0.47
KAWEAH	1.27	37.47	1.29	-0.02
KERN	0.77	24.23	0.73	0.04
KINGS	2.93	28.93	3.28	-0.36
TAHOE	2.64	19.35	4.70	-2.07
MERCED	1.12	15.37	1.38	-0.26
OWENS	0.72	23.83	0.72	0.00
SAN JOAQUIN	4.10	35.86	4.67	-0.58
STANISLAUS	1.30	13.65	1.54	-0.25
TRUCKEE	0.39	4.61	1.04	-0.66
TUOLUMNE	3.40	33.88	4.12	-0.72
YUBA	0.14	2.09	0.29	-0.15
COSUMNES	0.00	0.00	0.00	0.00
MOKELUMNE	1.11	17.12	1.36	-0.24
TULE	0.00	0.00	0.00	0.00
WEST WALKER RIVER	1.58	18.22	1.98	-0.41
EAST WALKER RIVER	0.97	15.06	1.26	-0.29
WEST FORK CARSON RIVER	1.95	19.93	2.14	-0.19
EAST FORK CARSON RIVER	0.78	9.93	1.23	-0.45

Table 2. Mean SWE and mean % of Average SWE for 5/11/2013, mean SWE for 5/3/2013, change in SWE between 5/3/2013 and 5/11/2013, and area in square miles for each elevation band inside each watershed.

Watershed	Elevation	5/11/13 SWE (in)	5/11/13 % Avg to Date	5/3/13 SWE (in)	5/3 thru 5/11 Change SWE (in)	Area Sq Mi
AMERICAN	3000-4000'	0.00	0.00	0.00	0.00	191.9
	4000-5000'	0.00	0.00	0.00	0.00	249.3
	5000-6000'	0.00	0.00	0.00	0.00	294.8
	6000-7000'	0.04	0.29	0.47	-0.43	296.4
	7000-8000'	3.31	13.47	5.49	-2.18	175.7
	8000-9000'	13.18	40.51	16.19	-3.02	74.2
	9000-10,000'	26.84	65.77	28.19	-1.35	8.9
COSUMNES	3000-4000'	0.00	0.00	0.00	0.00	77.8
	4000-5000'	0.00	0.00	0.00	0.00	84.7
	5000-6000'	0.00	0.00	0.00	0.00	63.6
	6000-7000'	0.00	0.00	0.00	0.00	28.1
	7000-8000'	0.00	0.00	0.00	0.00	8.6
E CARSON	5000-6000'	0.00	0.00	0.00	0.00	32.7
	6000-7000'	0.00	0.00	0.00	0.00	77.7
	7000-8000'	0.11	2.09	0.13	-0.02	102.6
	8000-9000'	1.93	14.83	3.22	-1.30	96.5
	9000-10,000'	2.16	11.57	2.98	-0.81	29.7
	10,000-11,000'	0.99	4.84	1.38	-0.39	13.5
	> 11,000'	0.23	0.77	1.17	-0.94	0.3
E WALKER	6000-7000'	0.00	0.00	0.00	0.00	73.6
	7000-8000'	0.00	0.00	0.00	0.00	157.4
	8000-9000'	0.07	1.32	0.12	-0.05	154.9
	9000-10,000'	2.09	16.31	2.88	-0.79	63.1
	10,000-11,000'	5.85	27.01	7.36	-1.51	48.8
	> 11,000'	8.05	34.08	9.60	-1.55	7.8
FEATHER	3000-4000'	0.00	0.00	0.00	0.00	286.2
	4000-5000'	0.00	0.01	0.00	0.00	735.8
	5000-6000'	0.00	0.01	0.01	-0.01	1305.1
	6000-7000'	0.01	0.14	0.66	-0.65	871.3
	7000-8000'	0.11	0.61	8.07	-7.97	124.6
	8000-9000'	0.00	0.00	23.80	-23.80	5.2
KAWEAH	3000-4000'	0.00	0.00	0.00	0.00	74.4
	4000-5000'	0.00	0.00	0.00	0.00	64.8
	5000-6000'	0.00	0.00	0.00	0.00	60.9
	6000-7000'	0.01	0.34	0.00	0.01	63.1
	7000-8000'	0.19	3.50	0.00	0.19	63.5
	8000-9000'	1.47	14.33	0.93	0.54	56.3
	9000-10,000'	4.76	34.61	3.70	1.06	38.8
	10,000-11,000'	18.82	77.40	21.30	-2.48	36.6
	> 11,000'	22.06	75.33	22.79	-0.74	8.9
KERN	3000-4000'	0.00	0.00	0.00	0.00	175.2
	4000-5000'	0.00	0.00	0.00	0.00	221.9
	5000-6000'	0.00	0.00	0.00	0.00	273.6
	6000-7000'	0.00	0.00	0.00	0.00	391.9
	7000-8000'	0.01	0.56	0.00	0.01	334.9
	8000-9000'	0.05	1.30	0.00	0.05	308.7
	9000-10,000'	0.32	6.54	0.17	0.16	166.3
	10,000-11,000'	4.50	43.91	4.66	-0.16	149.7
	> 11,000'	7.32	38.42	6.85	0.47	142.5

KINGS	3000-4000'	0.00	0.00	0.00	0.00	83.1
	4000-5000'	0.01	0.40	0.00	0.01	92.8
	5000-6000'	0.01	0.20	0.00	0.01	95.0
	6000-7000'	0.01	0.20	0.00	0.01	136.0
	7000-8000'	0.08	0.82	0.03	0.05	170.0
	8000-9000'	0.39	2.98	0.35	0.03	209.9
	9000-10,000'	1.73	11.16	2.49	-0.76	187.6
	10.000-11.000'	9.89	47.43	11.28	-1.39	221.4
	> 11,000'	13.61	50.82	14.67	-1.07	199.5
MERCED	3000-4000'	0.00	0.00	0.00	0.00	138.3
	4000-5000'	0.00	0.00	0.00	0.00	88.7
	5000-6000'	0.00	0.00	0.00	0.00	72.9
	6000-7000'	0.00	0.00	0.00	0.00	78.3
	7000-8000'	0.00	0.00	0.03	-0.03	132.8
	8000-9000'	0.20	1.30	0.80	-0.59	124.1
	9000-10,000'	3.94	19.88	5.28	-1.33	76.2
	10.000-11.000'	11.63	37.51	13.19	-1.55	50.6
	> 11,000'	22.95	50.74	24.93	-1.98	13.5
MOKELUMNE	3000-4000'	0.00	0.00	0.00	0.00	83.3
	4000-5000'	0.00	0.00	0.00	0.00	87.2
	5000-6000'	0.00	0.00	0.00	0.00	84.0
	6000-7000'	0.00	0.00	0.03	-0.03	72.7
	7000-8000'	0.45	2.07	1.63	-1.18	85.9
	8000-9000'	8.74	34.65	10.11	-1.37	81.2
	9000-10,000'	17.72	59.04	15.37	2.35	7.8
	10.000-11.000'	43.67	125.12	39.94	3.72	0.1
OWENS	3000-4000'	0.00	0.00	0.00	0.00	184.1
	4000-5000'	0.00	0.00	0.00	0.00	428.5
	5000-6000'	0.00	0.00	0.00	0.00	254.6
	6000-7000'	0.00	0.01	0.00	0.00	255.2
	7000-8000'	0.00	0.03	0.00	0.00	302.6
	8000-9000'	0.30	4.98	0.42	-0.12	165.3
	9000-10,000'	1.12	13.67	1.25	-0.13	112.4
	10.000-11.000'	3.21	29.16	3.14	0.07	188.0
	> 11,000'	8.39	44.73	8.13	0.26	167.2
SAN JOAQUIN	3000-4000'	0.00	0.00	0.00	0.00	76.2
	4000-5000'	0.00	0.00	0.00	0.00	93.8
	5000-6000'	0.00	0.00	0.00	0.00	130.9
	6000-7000'	0.00	0.00	0.00	0.00	183.9
	7000-8000'	0.01	0.09	0.05	-0.04	214.5
	8000-9000'	1.28	8.21	2.37	-1.09	194.1
	9000-10,000'	6.33	31.01	7.69	-1.37	173.8
	10.000-11.000'	15.94	58.20	17.50	-1.56	188.0
	> 11,000'	17.02	56.02	18.53	-1.51	146.3
STANISLAUS	3000-4000'	0.00	0.00	0.00	0.00	61.6
	4000-5000'	0.00	0.00	0.00	0.00	100.0
	5000-6000'	0.00	0.00	0.00	0.00	105.7
	6000-7000'	0.00	0.00	0.00	0.00	142.3
	7000-8000'	0.16	0.97	0.29	-0.13	145.4
	8000-9000'	4.20	16.89	5.30	-1.10	121.9
	9000-10,000'	10.72	33.20	11.85	-1.13	47.1
	10.000-11.000'	13.32	33.15	15.40	-2.09	18.0
	> 11,000'	3.87	11.35	5.62	-1.75	0.7

TAHOE	6000-7000'	0.02	0.42	0.28	-0.25	103.2
	7000-8000'	2.06	12.21	6.15	-4.09	74.7
	8000-9000'	7.54	34.08	10.46	-2.92	51.3
	9000-10,000'	6.40	28.66	7.34	-0.94	12.1
	10,000-11,000'	0.51	2.46	0.25	0.27	0.9
TRUCKEE	5000-6000'	0.00	0.00	0.00	0.00	51.2
	6000-7000'	0.02	0.34	0.12	-0.10	254.6
	7000-8000'	1.19	6.83	3.17	-1.98	111.9
	8000-9000'	2.15	6.57	4.74	-2.59	14.1
TULE	3000-4000'	0.00	0.00	0.00	0.00	34.9
	4000-5000'	0.00	0.00	0.00	0.00	48.0
	5000-6000'	0.00	0.00	0.00	0.00	51.8
	6000-7000'	0.00	0.00	0.00	0.00	45.2
	7000-8000'	0.00	0.00	0.00	0.00	27.0
	8000-9000'	0.00	0.00	0.00	0.00	15.7
	9000-10,000'	0.00	0.00	0.00	0.00	5.8
TUOLUMNE	3000-4000'	0.00	0.00	0.00	0.00	122.4
	4000-5000'	0.00	0.00	0.00	0.00	149.9
	5000-6000'	0.00	0.00	0.00	0.00	172.8
	6000-7000'	0.00	0.00	0.00	0.00	149.0
	7000-8000'	0.20	1.33	0.98	-0.77	151.1
	8000-9000'	7.10	32.02	9.35	-2.25	170.9
	9000-10,000'	14.38	52.14	16.57	-2.19	152.7
	10,000-11,000'	14.09	45.89	16.54	-2.45	116.7
	> 11,000'	13.64	43.03	15.15	-1.51	28.8
W CARSON	4000-5000'	0.00	0.00	0.00	0.00	1.6
	5000-6000'	0.00	0.00	0.00	0.00	16.8
	6000-7000'	0.00	0.00	0.00	0.00	8.3
	7000-8000'	0.54	6.13	0.78	-0.24	35.6
	8000-9000'	4.87	34.32	5.10	-0.23	32.7
	9000-10,000'	2.91	16.10	3.35	-0.44	9.5
	10,000-11,000'	2.20	9.78	2.35	-0.15	2.3
W WALKER	5000-6000'	0.00	0.00	0.00	0.00	46.8
	6000-7000'	0.00	0.00	0.00	0.00	60.0
	7000-8000'	0.00	0.00	0.00	0.00	91.4
	8000-9000'	0.09	1.22	0.21	-0.12	93.8
	9000-10,000'	4.69	24.17	5.94	-1.25	73.3
	10,000-11,000'	6.82	25.48	8.31	-1.49	42.4
	> 11,000'	0.16	0.83	0.35	-0.19	2.6
YUBA	3000-4000'	0.00	0.00	0.00	0.00	168.8
	4000-5000'	0.00	0.00	0.00	0.00	202.8
	5000-6000'	0.00	0.00	0.00	0.00	188.0
	6000-7000'	0.31	1.62	0.60	-0.29	238.7
	7000-8000'	1.05	3.64	2.21	-1.15	123.0
	8000-9000'	1.86	4.77	4.48	-2.62	6.3

Location of Reports and Excel Format Tables
ftp://snowserver.colorado.edu/pub/fromLeanne/forCADWR/Near_Real_Time_Reports/

References
Guan, B., N. P. Molotch, D. E. Waliser, S. M. Jepsen, T. H. Painter, and J. Dozier. Snow water equivalent in the Sierra Nevada: Blending snow sensor observations with snowmelt model simulations. Submitted to *Water Resour. Res.*

Molotch, N.P., Reconstructing snow water equivalent in the Rio Grande headwaters using remotely sensed snow cover data and a spatially distributed snowmelt model, *Hydrological Processes*, Vol. 23, doi: 10.1002/hyp.7206, 2009.

Molotch, N.P., and S.A. Margulis, Estimating the distribution of snow water equivalent using remotely sensed snow cover data and a spatially distributed snowmelt model: a multi-resolution, multi-sensor comparison, *Advances in Water Resources*, 31, 2008.

Molotch, N.P., and R.C. Bales, Comparison of ground-based and airborne snow-surface albedo parameterizations in an alpine watershed: impact on snowpack mass balance, *Water Resources Research*, VOL. 42, doi:10.1029/2005WR004522, 2006.

Molotch, N.P., and R.C. Bales, Scaling snow observations from the point to the grid-element: implications for observation network design, *Water Resources Research*, VOL. 41, doi: 10.1029/2005WR004229, 2005.

Molotch, N.P., T.H. Painter, R.C. Bales, and J. Dozier, Incorporating remotely sensed snow albedo into a spatially distributed snowmelt model, *Geophysical Research Letters*, VOL. 31, doi:10.1029/2003GL019063, 2004.

Painter, T.H., K. Rittger, C. McKenzie, P. Slaughter, R. E. Davis and J. Dozier, Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. *Remote Sensing of the Environment*, 113: 868-879, 2009.