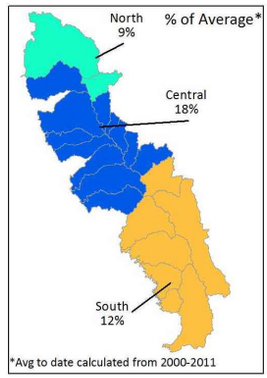
Applied Sciences Program
NASA Earth Science

Real-Time Spatial Estimates of Snow-Water Equivalent (SWE)

Sierra Nevada Mountains, California

May 18, 2020



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Summary of current conditions

The regional summary map above shows the mean SWE above 5000' elevation for three major regions of the Sierra Nevada. As of May 18, regional average SWE remained well below average across the Sierra, with percent of average SWE ranging from 9% to 18%. Detailed SWE maps (in JPG format) and summaries of SWE (in Excel format) by individual basin and elevation band accompany the report and are publicly available on our FTP site.

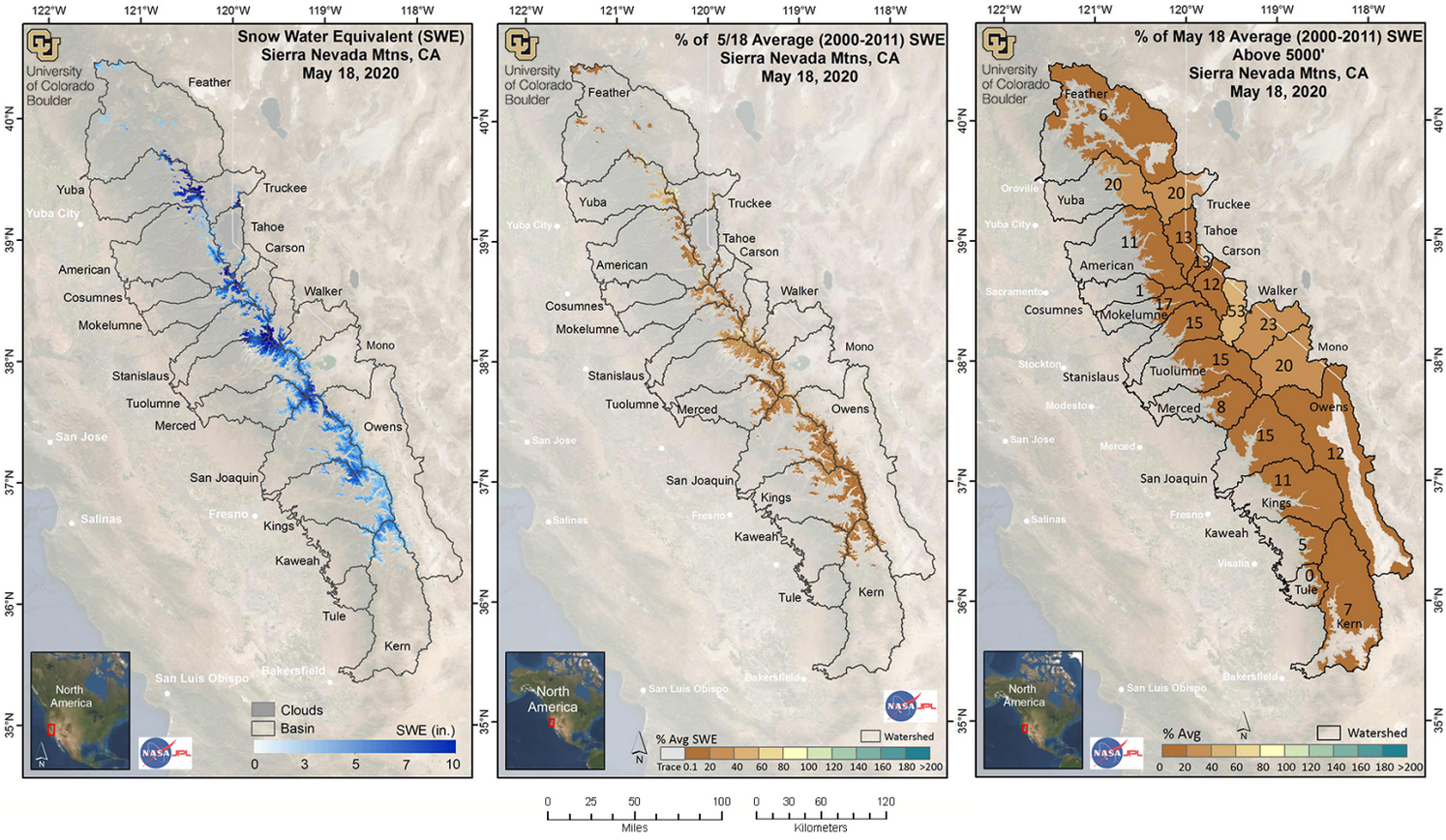

Figure 1. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts for May 18, 2020 (left), percent of average (2000-2011) SWE for May 18, 2020 for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

About this report

This is an experimental research product that provides near-real-time estimates of snow-water equivalent (SWE) at a spatial resolution of 500 m for the Sierra Nevada in California from mid-winter through the melt season. The report is released within a week of the date of data acquisition at the top of the report. A similar report covering the Intermountain West is available and is distributed to water managers in Colorado, Utah and Wyoming.

The spatial SWE analysis method for the Sierra Nevada uses the following data as inputs:

- In-situ SWE from all operational CA snow gage sensor sites and CoCoRaHS SWE values when available and applicable
- MODSCAG fractional snow-covered area (fSCA) data from recent cloud-free MODIS satellite images
- Physiographic information (elevation, latitude, upwind mountain barriers, slope, etc.)
- Historical daily SWE patterns (2000-2014) retrospectively generated using historical MODSCAG data and an energy-balance model that back-calculates SWE given the fSCA time-series and meltout date for each pixel

For more details on the estimation method see the *Methods* section below. Please be sure to read the *Data Issues / Caveats* section for a discussion of persistent challenges or flagged uncertainties of the SWE product.

Data availability for this report

101 snow gage sites in the Sierra Nevada network were recording SWE values out of a total of 114 sites, 13 were offline and 52 were recording zero SWE (shown in red and yellow, respectively, in Figure 6, left map).

The value of spatially explicit estimates of SWE

Snowmelt makes up the large majority (~60-85%) of the annual streamflow in the Sierra Nevada. The spatial distribution of snow-water equivalent (SWE) across the landscape is complex. While broad aspects of this spatial pattern (e.g., more SWE at higher elevations and on north-facing exposures) are fairly consistent, the details vary a lot from year to year, influencing the magnitude and timing of snowmelt-driven runoff.

SWE is operationally monitored at just over a hundred snow gage sensor sites spread across the Sierra Nevada, providing a critical first-order snapshot of conditions, and the basis for runoff forecasts from the CA DWR, NRCS, and NOAA. However, conditions at snow sensor sites (e.g., percent of normal SWE) may not be representative of conditions in the large areas between these point measurements, and at elevations above and below the range of the sensor sites. The spatial snow analysis creates a detailed picture of the spatial pattern of SWE using snow sensors, satellite, and other data, extending beyond the snow sensor sites to unmonitored areas.

Interpreting the spatial SWE estimates in the context of SNOTEL

The spatial product estimates SWE for every pixel where the MODSCAG product identifies snow-cover. Comparatively, snow sensor samples 8-20 points per basin within a narrower elevation range. Thus, the basin-wide percent of average from the spatial SWE estimates is not directly comparable with the snow sensor basin-wide percent of average. A better comparison might be made with the % of average in the elevation bands (Table 2) that contain snow sensor sites.

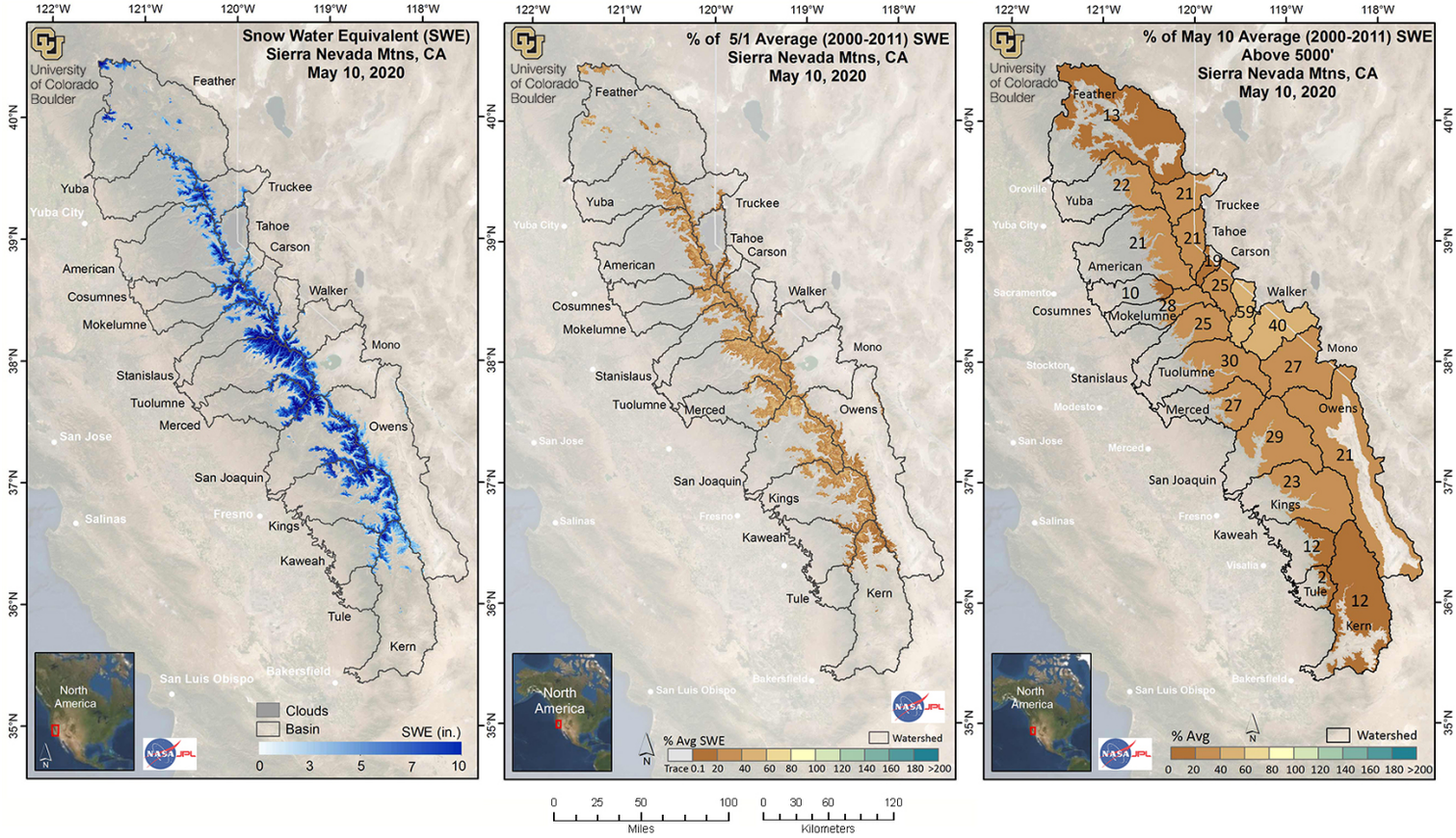

Figure 2. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts for May 10,2020 (left), percent of average (2001-2011) SWE for May 10,2020 for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

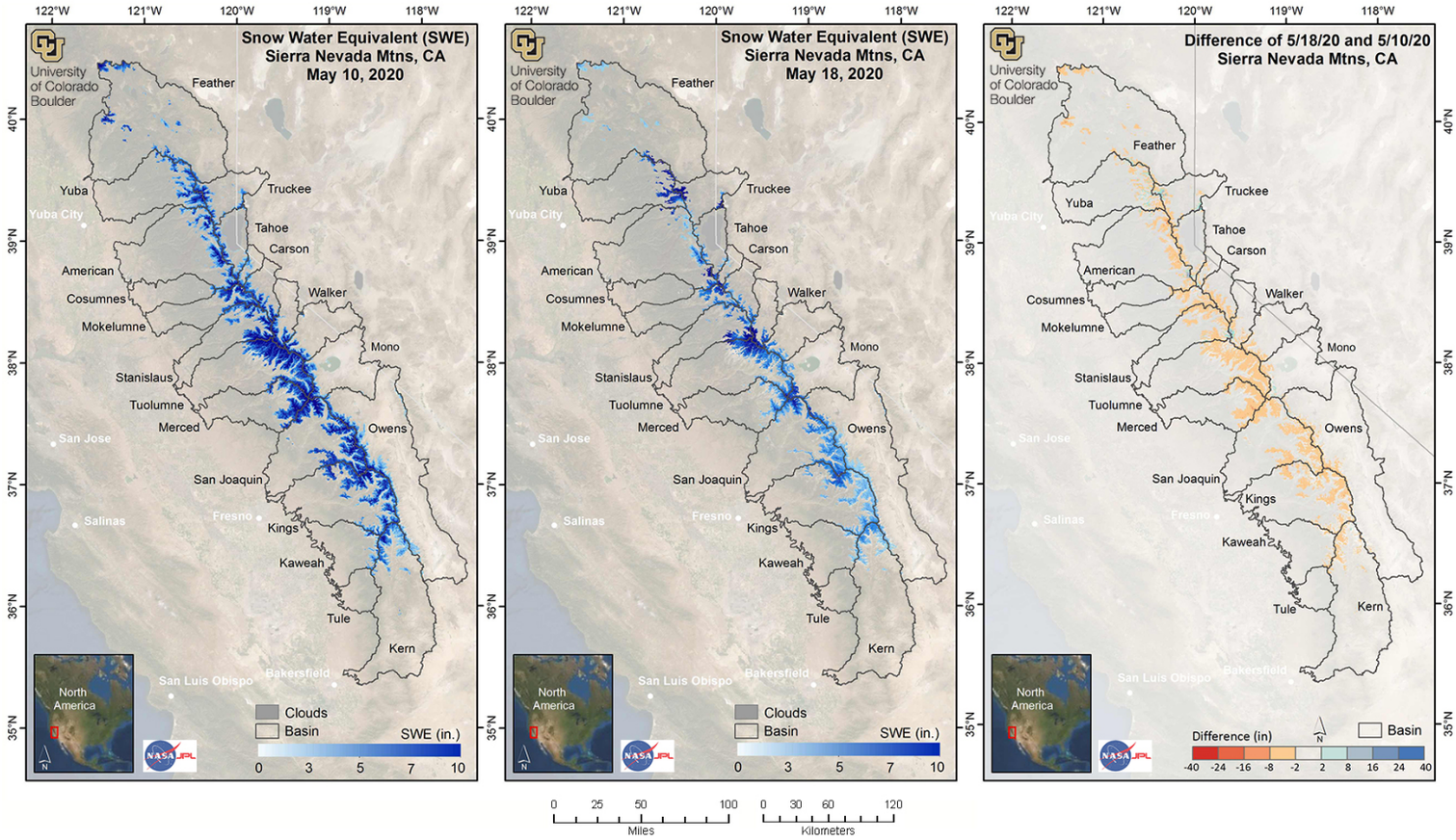

Figure 3. Estimated SWE across the Sierra Nevada, May 18, 2020. SWE amounts for May 10th (left), May 18th (middle) and the difference between May 18th and May 10th (right).

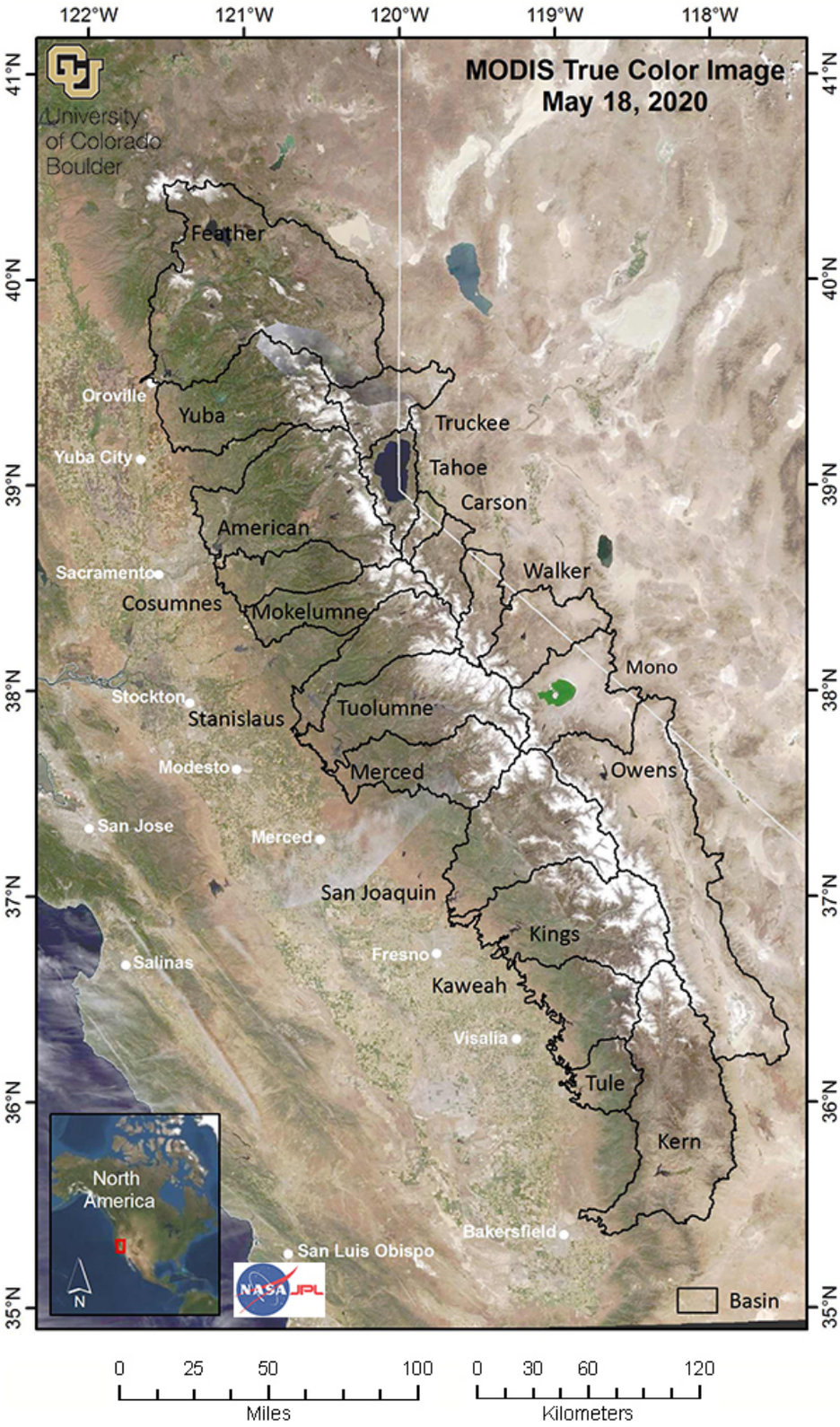

Figure 4. MODIS image, Sierra Nevada. A mostly cloud-free true color composite MODIS image, used for the May 18, 2020 regression model run.

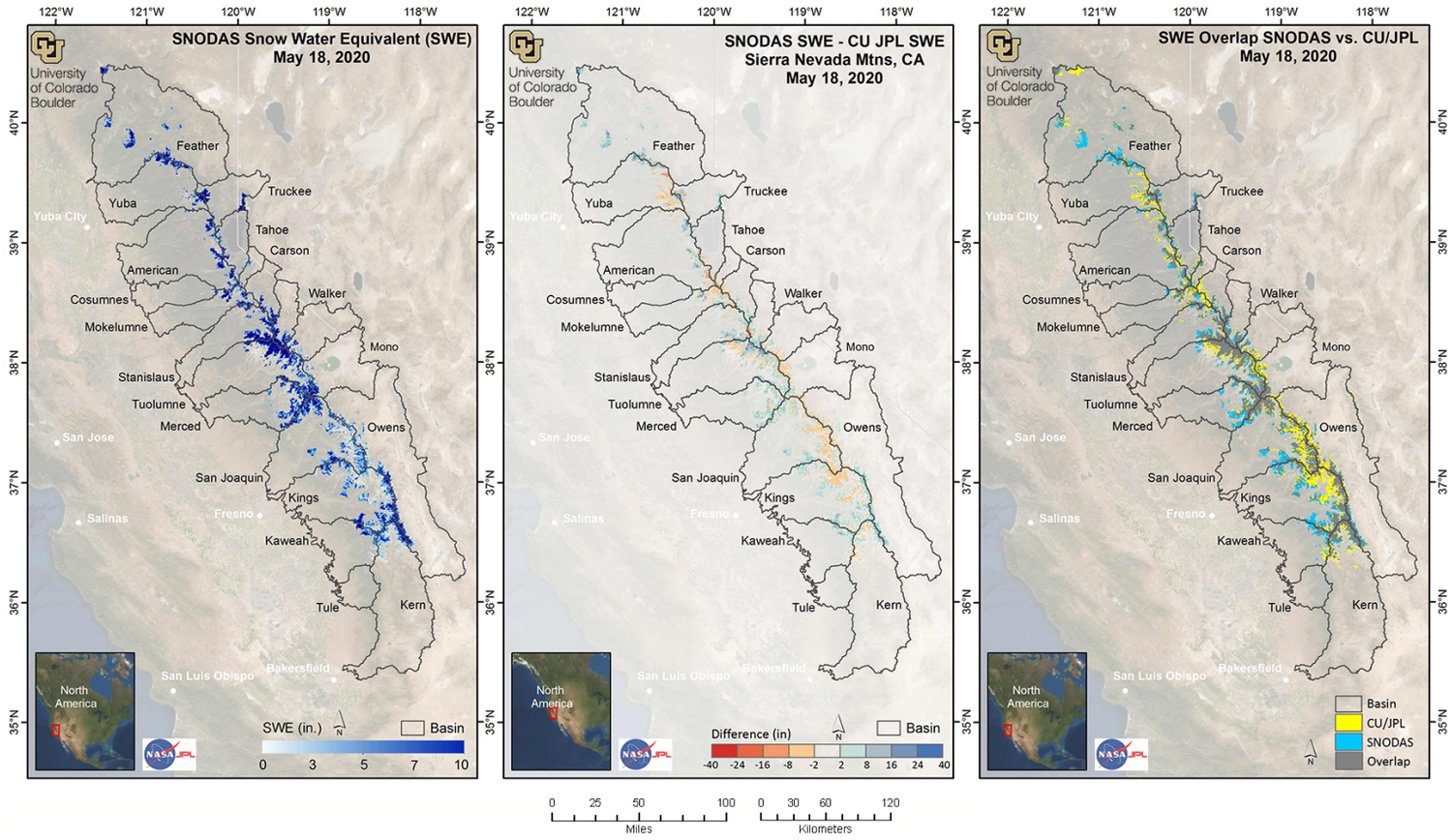

Figure 5. Comparison of CU/JPL regression SWE product and SNODAS SWE for the Sierra Nevada. The map on the left shows estimated SWE for May 18th from the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS). The middle map shows the difference between the May 18th SNODAS SWE estimate and CU/JPL regression SWE estimate. Red pixels denote areas where SNODAS SWE is less than CU/JPL SWE and blue pixels show areas where SNODAS SWE is higher than CU/JPL SWE. The map on the right shows the snow-cover extent of SNODAS and CU/JPL SWE estimates. Yellow pixels show where the location of CU/JPL snow extends beyond the location of the SNODAS snow extent. Blue pixels show where the SNODAS snow extends beyond the CU/JPL snow extent. Gray areas indicate regions where both products agree on the snow-cover extent.

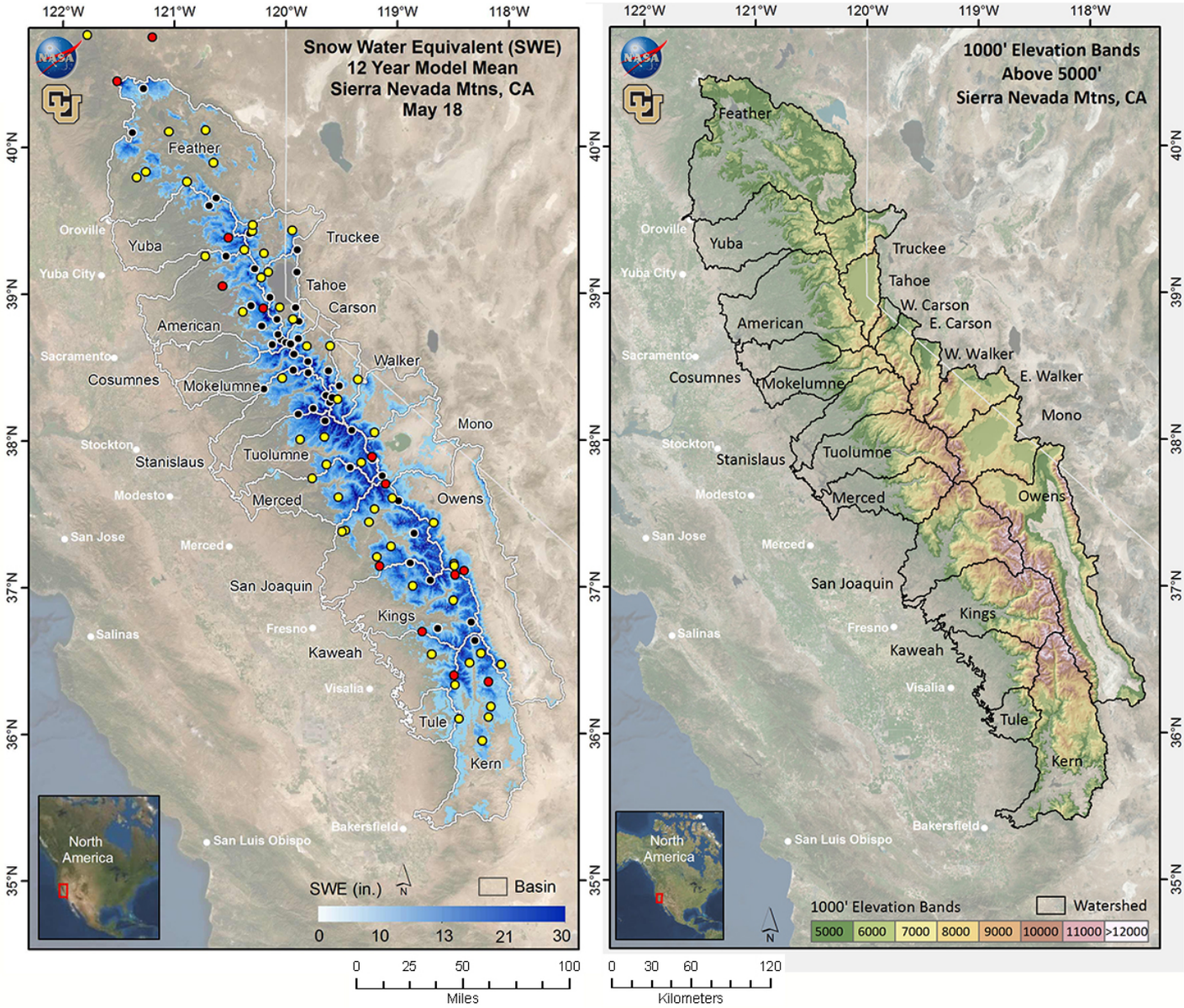

Figure 6. Historical average May 18th and Elevation Bands for the Sierra Nevada. Average SWE (2000-2011) for May 18th (left), and the Banded Elevation map (right) identifies basins used in this report (black boundaries) and 1000' elevation bands (colored shading) that match those used in Table 1 and Table 2. Map on left shows snow gage sensor sites recording SWE on May 18th (black), sites that were offline are shown in red and sites recording zero SWE are shown in yellow.

Methods

The spatial SWE estimation method is described in Schneider and Molotch (2016). The method uses linear regression in which the dependent variable is derived from the operationally measured in situ SWE from all online snow sensor sites in the domain. The snow sensor SWE observations are scaled by the fractional snow-covered area (fSCA) across the 500 m pixel containing that snow sensor site before being used in the linear regression model. The fSCA is a combination of a near-real-time cloud-free MODIS satellite image which has been processed using the MODIS Snow Cover and Grain size (MODSCAG) fractional snow-covered area algorithm program (Painter, et. al. 2009, snow.jpl.nasa.gov) and the Snow Today fSCA image when necessary (Rittger, et. al. 2019, https://nsidc.org/snow-today).

The following independent variables (predictors) enter into the linear regression model:

- Physiographic variables that affect snow accumulation, melt, and redistribution, including elevation, latitude, upwind mountain barriers, slope, and others. See Figure 2 in Schneider and Molotch (2016) for the full set of these variables.
- The historical daily SWE pattern (1985-2016) retrospectively generated using historical MODSCAG data, and an energy-balance model that back-calculates SWE given the fractional Snow-Covered Area (fSCA) time series and meltout date for each pixel. See Margulis, et. al., 2016 for details. (For computational efficiency, only one image from either the 1st or 15th of

each month during the 1985-2016 period that best matches the real-time SNOTEL-observed pattern is selected as an independent variable.)

The real-time regression model for this date has been validated by cross-validation, whereby 10% of the SNOTEL data are randomly removed and the model prediction is compared to the measured value at the removed SNOTEL stations. This is repeated 30 times to obtain an average R-squared value, which denotes how closely the model fits the SNOTEL data. During development of this regression method, the model was also validated against independent historical SWE data collected in snow surveys at 9 locations in Colorado, and an intensive field survey in north-central Colorado.

Data Issues/Caveats for* May 18, 2020 – *IMPORTANT – READ THIS!

- LIMITED SNOW PILLOW DATA – When snow at the snow pillow sites melts out, but remains at higher elevations, the model tends to underestimate SWE at the under-monitored upper elevations. This issue typically occurs late in the melt season, resulting in less accurate SWE prediction at higher elevations compared to earlier in the snow season.
- DENSE FOREST COVER – Dense forest cover at lower elevations where snow-cover is discontinuous can cause the satellite to underestimate the snow-cover extent, leading to underestimation of SWE.

List of All Known Data Issues/Caveats

- RECENT SNOWFALL – There are occasionally problems with lower-elevation SWE estimates due to recent snowfall events that result in extensive snow-cover extending to valley locations where measurements are not available. This scenario results in an over-estimation of lower- elevation SWE.
- LIMITED SNOW PILLOW DATA – When snow at the snow pillow sites melts out, but remains at higher elevations, the model tends to underestimate SWE at the under-monitored upper elevations. This issue typically occurs late in the melt season, resulting in less accurate SWE prediction at higher elevations compared to earlier in the snow season.
- CLOUD COVER – Cloud cover can obscure satellite measurements of snow-cover. While careful checks are made, occasionally the misclassification of clouds as snow or *vice versa* may result in the mischaracterization of SWE or bare-ground.
- LOW LOOK ANGLE – When a satellite does not pass directly over a region but the area is still included within the satellite sensor's field of view, this is referred to as a low "look angle". The resulting image has lower effective resolution – this "blurry" MODSCAG data still contains useful information but may lead to overestimation of SWE near the margins of the snow-cover extent.
- POOR QUALITY SNOTEL DATA – Although data QA/QC is performed, occasional SNOTEL sensor malfunction may result in localized SWE errors.
- ANOMALOUS SNOW PATTERNS – Anomalous snow years or snow distributions may cause SWE error due to the model design to search for similar SWE distributions from previous years. If no close seasonal analogue exists, the model is forced to find the most similar year, which may result in error.
- DENSE FOREST COVER – Dense forest cover at lower elevations where snow-cover is discontinuous can cause the satellite to underestimate the snow-cover extent, leading to underestimation of SWE.

Table 1. Estimated SWE by basin. *The basin-wide SWE values and averages, are across all pixels at elevations >5000'. Shown are May 10th percent of May 10th average SWE, May 18th percent of May 18th average SWE (between 2000-2011 as derived from the regression model), May 10th mean SWE, May 18th mean SWE, May 18th percent of snow-covered area, May 18th water volume (acre-feet), the change in SWE between May 10th and May 18th, the area (mi²) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), May 10th snow pillow data and May 18th snow pillow data for those areas collected, summarized for each basin. The last column shows May 18th mean SWE from SNODAS*.*

Basin	5/10/20 % 5/10 Avg.	5/18/20 % 5/18 Avg.	5/10/20 SWE (in)	5/18/20 SWE (in)	5/18/20 % SCA	5/18/20 Vol (af)	5/10 thru 5/18/20 Chg. in SWE (in)	Area (mi2) > 5000'	5/10/20 Pillows	5/18/20 Pillows	5/18/20 SNODAS* (in)
Feather	13	6	0.5	0.1	5.9	17,709	-0.4	2,251.5	0.0 (1)	0.0 (1)	0.5
Yuba	22	20	2.2	1.5	22.8	45,705	-0.6	555.5	NA	NA	1.7
American	21	11	1.8	0.8	19.2	36,461	-1.0	851.9	6.0 (9)	4.6 (9)	1.3
Cosumnes	10	1	0.4	0.0	0.9	162	-0.4	94.5	NA	NA	0.3
Mokelumne	28	17	3.0	1.6	32.2	28,250	-1.4	336.6	12.3 (1)	6.7 (1)	1.9
Stanislaus	25	15	2.7	1.4	21.8	43,340	-1.3	594.8	8.7 (6)	3.8 (6)	2.1
Tuolumne	30	15	3.5	1.6	32.6	83,898	-1.9	966.9	3.7 (7)	1.5 (7)	2.9
Merced	27	8	2.8	0.7	21.8	21,705	-2.1	565.0	1.0 (2)	0.3 (2)	2.0
San Joaquin	29	15	2.9	1.3	32.5	87,229	-1.6	1,262.1	1.3 (8)	0.1 (8)	1.4
Kings	23	11	2.3	1.0	33.1	66,439	-1.3	1,267.7	6.5 (6)	2.3 (6)	1.5
Kaweah	12	5	0.8	0.3	15.0	5,393	-0.4	326.7	0.0 (1)	0.0 (1)	1.2
Tule	2	0	0.1	0.0	1.0	70	-0.1	143.5	0.0 (1)	0.0 (1)	0.0
Kern	12	7	0.5	0.2	8.7	22,665	-0.3	1,733.2	1.2 (7)	0.6 (7)	0.4
Truckee	21	20	1.1	0.8	10.4	25,801	-0.3	592.4	4.5 (5)	4.4 (5)	1.2
Tahoe	21	13	1.7	0.9	12.1	15,468	-0.9	339.1	0.8 (5)	0.3 (5)	1.0
W Carson	19	13	1.4	0.8	17.3	5,672	-0.6	133.3	8.5 (2)	4.6 (2)	0.3
E Carson	25	12	1.6	0.7	15.7	15,010	-0.9	428.3	1.1 (4)	0.3 (4)	0.8
W Walker	59	53	3.6	2.8	15.5	30,774	-0.7	202.9	6.5 (5)	5.1 (5)	4.0
E Walker	40	23	1.2	0.6	6.8	11,703	-0.6	394.4	1.8 (1)	0.0 (1)	0.7
Mono	27	20	0.6	0.4	7.5	21,639	-0.2	990.8	9.5 (1)	7.6 (1)	0.3
Owens	21	12	0.6	0.3	12.5	37,008	-0.3	2,270.7	2.9 (5)	1.4 (5)	0.4

* This is a comparison to the SNODAS (SNOw Data Assimilation System) nationwide product from the National Weather Service.

Table 2. Estimated SWE by basin and elevation band. *Elevation bands begin at 5000' and extend past the highest point in the basin. Note that the area of the highest 2-5 bands is typically much smaller than the lower bands. Shown are May 10th percent of May 10th average SWE, May 18th percent of May 18th average SWE (between 2000-2011 as derived from the regression model), May 10th mean SWE, May 18th mean SWE, May 18th percent of snow-covered area, May 18th water volume (acre-feet), the change in SWE between May 10th and May 18th, the area (mi²) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), May 10th snow pillow data and May 18th snow pillow data for those areas collected, summarized for each 1000' elevation band inside each basin. The last column shows May 18th mean SWE from SNODAS*.*

Basin	Elevation Band	5/10/20 % 5/10 Avg.	5/18/20 % 5/18 Avg.	5/10/20 SWE (in)	5/18/20 SWE (in)	5/18/20 % SCA	5/18/20 Vol (af)	5/10 thru 5/18/20 Chg. in SWE (in)	5/18/20 Area (mi2)	5/10/20 Pillows	5/18/20 Pillows	5/18/20 SNODAS* (in)
Feather	5000-6000'	1	0	0.0	0.0	0.3	141	0.0	1,350.8	1.7 (1)	0.0 (1)	0.3
	6000-7000'	16	5	0.9	0.2	10.3	8,432	-0.7	770.4	0.3 (5)	0.1 (5)	0.7
	7000-8000'	25	13	3.1	1.3	39.1	8,535	-1.8	125.6	0.0 (1)	0.0 (1)	2.1
	8000-9000'	33	12	6.5	2.4	51.5	602	-4.1	4.7	NA	NA	4.7
Yuba	5000-6000'	1	0	0.0	0.0	0.6	133	0.0	203.9	NA	NA	0.4
	6000-7000'	18	12	2.0	1.0	17.0	12,131	-1.0	228.8	8.0 (3)	5.8 (3)	1.8
	7000-8000'	34	34	5.9	5.0	70.4	31,314	-0.9	118.2	NA	NA	3.3
	8000-9000'	36	38	8.8	8.8	95.4	2,126	0.0	4.5	NA	NA	14.3
American	5000-6000'	1	0	0.0	0.0	0.0	0	0.0	314.1	0.0 (2)	0.1 (2)	0.0
	6000-7000'	10	3	0.9	0.2	5.1	2,664	-0.8	281.9	8.3 (2)	5.3 (2)	0.2
	7000-8000'	27	10	3.8	1.2	44.7	10,878	-2.7	176.0	0.7 (4)	0.4 (4)	2.9
	8000-9000'	35	27	7.3	5.1	86.1	19,323	-2.1	70.6	11.5 (3)	9.6 (3)	7.2
	9000-10,000'	41	28	10.7	7.3	100.0	3,595	-3.5	9.3	NA	NA	6.1
Cosumnes	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	62.8	NA	NA	0.0
	6000-7000'	5	0	0.4	0.0	0.0	0	-0.4	24.8	NA	NA	0.3
	7000-8000'	28	4	4.0	0.4	12.0	162	-3.6	7.0	NA	NA	3.2
Mokelumne	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	88.3	NA	NA	0.0
	6000-7000'	4	0	0.3	0.0	0.3	30	-0.3	68.5	NA	NA	0.1
	7000-8000'	30	13	4.1	1.4	35.3	6,773	-2.7	90.9	NA	NA	2.9
	8000-9000'	34	25	6.7	4.4	84.1	18,767	-2.3	80.1	12.3 (1)	6.7 (1)	4.2
	9000-10,000'	37	25	8.8	5.7	98.4	2,680	-3.1	8.8	NA	NA	2.6
Stanislaus	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	112.4	NA	NA	0.0
	6000-7000'	3	0	0.2	0.0	0.0	0	-0.2	143.7	11.6 (1)	1.1 (1)	0.0
	7000-8000'	19	3	2.2	0.3	6.5	2,187	-1.9	152.5	7.4 (2)	1.9 (2)	0.6
	8000-9000'	31	19	5.3	2.8	49.0	17,648	-2.5	118.4	10.3 (3)	5.9 (3)	4.5
	9000-10,000'	38	27	8.4	5.8	90.1	16,713	-2.6	54.3	6.2 (1)	1.6 (1)	8.9
	10,000-11,000'	43	37	10.8	9.4	98.9	6,629	-1.4	13.3	NA	NA	10.3
	> 11,000'	43	45	10.8	11.0	100.0	163	0.1	0.3	NA	NA	7.8
Tuolumne	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	179.6	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	147.8	0.0 (1)	0.0 (1)	0.0
	7000-8000'	13	2	1.5	0.1	3.5	1,119	-1.3	159.3	0.2 (2)	0.0 (2)	0.5
	8000-9000'	31	14	4.8	1.9	36.7	17,929	-2.8	175.3	4.6 (3)	2.2 (3)	2.4
	9000-10,000'	36	20	7.1	3.6	70.0	35,599	-3.5	184.3	5.9 (2)	1.9 (2)	8.2
	10,000-11,000'	38	21	8.4	4.5	94.6	21,924	-3.9	91.6	NA	NA	7.3
	11,000-12,000'	39	22	8.7	4.6	98.4	6,463	-4.1	26.2	NA	NA	4.1
	> 12,000'	43	25	10.4	5.7	100.0	863	-4.8	2.9	NA	NA	5.1
Merced	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	75.0	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.1	0	0.0	82.4	NA	NA	0.0
	7000-8000'	5	0	0.5	0.0	0.4	32	-0.5	140.5	NA	NA	0.5
	8000-9000'	27	2	3.6	0.2	11.7	1,382	-3.4	124.9	1.0 (2)	0.3 (2)	1.9
	9000-10,000'	35	11	6.3	1.7	64.1	8,177	-4.5	88.8	NA	NA	5.8
	10,000-11,000'	41	18	9.0	3.8	94.8	8,111	-5.2	40.0	NA	NA	6.0
	11,000-12,000'	48	23	11.7	5.4	98.2	3,401	-6.2	11.7	NA	NA	5.8
	> 12,000'	54	27	14.9	7.0	100.0	601	-7.9	1.6	NA	NA	8.9

Basin	Elevation Band	5/10/20 % 5/10 Avg.	5/18/20 % 5/18 Avg.	5/10/20 SWE (in)	5/18/20 SWE (in)	5/18/20 % SCA	5/18/20 Vol (af)	5/10 thru 5/18/20 Chg. in SWE (in)	5/18/20 Area (mi2)	5/10/20 Pillows	5/18/20 Pillows	5/18/20 SNODAS* (in)
San Joaquin	5000-6000'	2	0	0.0	0.0	0.0	0	0.0	139.3	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	182.2	0.0 (3)	0.0 (3)	0.0
	7000-8000'	1	0	0.1	0.0	0.6	64	-0.1	218.1	0.9 (3)	0.0 (3)	0.2
	8000-9000'	20	4	1.8	0.3	11.8	3,097	-1.6	202.0	NA	NA	1.1
	9000-10,000'	32	14	4.7	1.9	51.2	20,641	-2.9	207.6	0.0 (1)	0.0 (1)	3.2
	10,000-11,000'	34	20	6.3	3.6	85.2	30,813	-2.8	162.6	7.7 (1)	0.6 (1)	3.1
	11,000-12,000'	37	21	7.8	4.1	95.7	26,505	-3.8	122.3	NA	NA	2.4
	> 12,000'	39	19	8.8	4.1	100.0	6,108	-4.7	28.2	NA	NA	3.9
Kings	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	102.7	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	137.5	NA	NA	0.0
	7000-8000'	0	0	0.0	0.0	0.0	0	0.0	177.1	NA	NA	0.0
	8000-9000'	9	1	0.7	0.1	3.9	923	-0.7	221.1	NA	NA	0.9
	9000-10,000'	21	7	2.6	0.8	28.5	9,117	-1.9	222.0	7.9 (3)	2.2 (3)	2.4
	10,000-11,000'	26	15	4.1	2.2	74.5	23,352	-1.9	196.0	5.1 (3)	2.4 (3)	2.0
	11,000-12,000'	33	17	6.1	2.9	94.4	24,110	-3.2	158.0	NA	NA	2.6
	> 12,000'	35	17	7.2	3.1	99.5	8,937	-4.1	53.4	NA	NA	5.7
Kaweah	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	61.9	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	60.9	0.0 (1)	0.0 (1)	0.0
	7000-8000'	0	0	0.0	0.0	0.0	0	0.0	62.7	NA	NA	0.1
	8000-9000'	4	0	0.3	0.0	3.3	79	-0.3	57.9	NA	NA	2.1
	9000-10,000'	13	5	1.6	0.5	33.3	1,192	-1.1	43.7	NA	NA	3.9
	10,000-11,000'	21	11	3.6	1.8	79.0	2,899	-1.8	30.9	NA	NA	2.7
	11,000-12,000'	27	14	5.2	2.6	95.2	1,191	-2.6	8.6	NA	NA	2.4
	> 12,000'	29	16	5.5	2.9	100.0	32	-2.6	0.2	NA	NA	4.7
Tule	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	55.3	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	41.8	NA	NA	0.0
	7000-8000'	0	0	0.0	0.0	0.0	0	0.0	27.1	0.0 (1)	0.0 (1)	0.0
	8000-9000'	1	0	0.1	0.0	1.0	3	-0.1	14.6	NA	NA	0.3
	9000-10,000'	14	2	1.8	0.2	24.6	60	-1.6	4.5	NA	NA	0.6
	10,000-11,000'	14	8	1.8	0.9	100.0	7	-0.9	0.1	NA	NA	0.0
Kern	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	259.7	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	349.2	NA	NA	0.0
	7000-8000'	0	0	0.0	0.0	0.0	0	0.0	328.0	0.0 (1)	0.0 (1)	0.0
	8000-9000'	0	0	0.0	0.0	0.0	0	0.0	326.0	0.0 (2)	0.0 (2)	0.0
	9000-10,000'	4	0	0.3	0.0	1.5	256	-0.3	193.5	0.0 (1)	0.0 (1)	0.0
	10,000-11,000'	14	5	1.8	0.6	28.5	4,281	-1.2	133.8	0.0 (2)	0.0 (2)	0.3
	11,000-12,000'	21	13	3.8	2.2	78.1	11,265	-1.6	96.8	8.5 (1)	4.5 (1)	2.5
	> 12,000'	22	15	4.6	2.8	91.7	6,862	-1.9	46.3	NA	NA	7.8

Basin	Elevation Band	5/10/20 % 5/10 Avg.	5/18/20 % 5/18 Avg.	5/10/20 SWE (in)	5/18/20 SWE (in)	5/18/20 % SCA	5/18/20 Vol (af)	5/10 thru 5/18/20 Chg. in SWE (in)	5/18/20 Area (mi2)	5/10/20 Pillows	5/18/20 Pillows	5/18/20 SNODAS* (in)
Truckee	5000-6000'	27	0	0.0	0.0	0.0	0	0.0	136.0	NA	NA	0.0
	6000-7000'	10	2	0.2	0.0	0.7	478	-0.2	264.7	5.7 (4)	5.5 (4)	0.1
	7000-8000'	24	18	2.5	1.5	21.1	11,128	-1.0	138.5	NA	NA	1.5
	8000-9000'	26	30	4.4	4.5	50.6	10,416	0.1	43.3	0.0 (1)	0.0 (1)	7.4
	9000-10,000'	24	35	5.1	7.0	94.2	3,567	1.9	9.6	NA	NA	16.2
	10,000-11,000'	26	39	6.6	9.5	100.0	212	2.9	0.4	NA	NA	17.2
Tahoe	6000-7000'	10	0	0.2	0.0	0.1	29	-0.2	133.7	0.1 (3)	0.0 (3)	0.0
	7000-8000'	19	5	1.5	0.3	13.2	2,023	-1.2	114.7	1.0 (4)	0.3 (4)	0.7
	8000-9000'	24	17	3.9	2.4	47.8	9,240	-1.5	72.9	0.0 (1)	0.2 (1)	2.2
	9000-10,000'	26	22	5.7	4.4	88.5	3,999	-1.3	17.0	NA	NA	4.4
	10,000-11,000'	24	18	5.6	4.0	91.7	177	-1.7	0.8	NA	NA	6.6
W. Carson	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	27.3	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	14.1	NA	NA	0.0
	7000-8000'	12	6	0.7	0.3	3.6	586	-0.4	42.4	NA	NA	0.1
	8000-9000'	21	15	2.8	1.7	30.9	3,325	-1.1	36.4	8.5 (2)	4.6 (2)	0.2
	9000-10,000'	23	15	4.5	2.6	76.6	1,643	-2.0	11.9	NA	NA	1.6
	10,000-11,000'	21	10	4.5	1.9	100.0	118	-2.7	1.2	NA	NA	5.7
E. Carson	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	69.5	NA	NA	0.0
	6000-7000'	2	0	0.0	0.0	0.0	0	0.0	96.8	0.0 (1)	0.0 (1)	0.0
	7000-8000'	13	3	0.5	0.1	1.6	423	-0.4	111.0	0.0 (1)	0.2 (1)	0.0
	8000-9000'	23	11	2.9	1.1	29.0	6,117	-1.8	103.4	1.4 (3)	0.4 (3)	0.6
	9000-10,000'	31	16	6.1	2.9	68.6	5,652	-3.2	36.4	NA	NA	5.0
	10,000-11,000'	36	20	8.7	4.7	94.2	2,739	-4.0	10.9	NA	NA	8.7
	> 11,000'	36	21	9.3	5.3	100.0	80	-4.0	0.3	NA	NA	7.8
W. Walker	5000-6000'	0	0	0	0	0	0	0.0	0.0	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	0.0	8.0	NA	NA	0.0
	7000-8000'	1	0	0.0	0.0	0.0	0	0.0	42.9	0.0 (1)	0.0 (1)	0.0
	8000-9000'	14	3	0.9	0.2	1.6	501	-0.8	52.0	3.4 (1)	0.1 (1)	0.8
	9000-10,000'	34	31	5.8	4.9	52.2	17,864	-0.9	68.0	9.8 (3)	8.5 (3)	7.1
	10,000-11,000'	38	34	8.8	7.4	87.6	11,566	-1.4	29.4	NA	NA	9.1
	> 11,000'	35	27	8.3	6.0	92.7	843	-2.4	2.7	NA	NA	6.3
E. Walker	5000-6000'	0	0	0.0	0.0	0.0	0	0.0	0.0	NA	NA	0.0
	6000-7000'	>300	0	0.0	0.0	0.0	0	0.0	61.2	NA	NA	0.0
	7000-8000'	1	0	0.0	0.0	0.0	0	0.0	122.3	NA	NA	0.0
	8000-9000'	5	1	0.1	0.0	0.4	107	-0.1	103.6	NA	NA	0.0
	9000-10,000'	23	12	2.5	1.1	21.1	3,557	-1.4	62.2	1.8 (1)	0.0 (1)	1.7
	10,000-11,000'	34	20	6.4	3.4	70.7	6,355	-3.0	35.6	NA	NA	3.5
	11,000-12,000'	33	17	7.2	3.3	82.8	1,632	-3.9	9.3	NA	NA	3.0
	> 12,000'	35	18	8.0	3.5	100.0	52	-4.5	0.3	NA	NA	4.1
Mono	6000-7000'	13	14	0.0	0.0	0.5	36	0.0	320.4	NA	NA	0.0
	7000-8000'	0	0	0.0	0.0	0.0	0	0.0	356.7	NA	NA	0.0
	8000-9000'	1	0	0.0	0.0	0.2	34	0.0	169.8	NA	NA	0.0
	9000-10,000'	17	14	1.5	1.0	23.2	3,527	-0.5	64.6	NA	NA	0.5
	10,000-11,000'	32	24	5.7	3.9	80.4	10,073	-1.8	48.7	9.5 (1)	7.6 (1)	3.2
	11,000-12,000'	34	24	7.5	4.7	93.1	6,587	-2.8	26.2	NA	NA	4.3
	> 12,000'	36	29	8.2	6.0	98.4	1,382	-2.2	4.3	NA	NA	5.7
Owens	5000-6000'	0	0	0	0	0	0	0.0	447.1	NA	NA	0.0
	6000-7000'	19	10	0	0	0	9	0.0	425.4	NA	NA	0.0
	7000-8000'	0	0	0.0	0.0	0.0	0	0.0	487.3	NA	NA	0.0
	8000-9000'	11	6	0.1	0.1	1.2	806	-0.1	271.5	NA	NA	0.0
	9000-10,000'	15	13	0.5	0.4	10.0	4,102	-0.1	199.1	4.5 (3)	2.4 (3)	0.1
	10,000-11,000'	17	10	1.4	0.8	33.9	8,219	-0.7	204.2	0.6 (2)	0.0 (2)	0.5
	11,000-12,000'	24	13	3.4	1.7	75.1	13,589	-1.7	153.1	NA	NA	2.2
	> 12,000'	26	15	4.7	2.3	92.7	10,283	-2.4	83.0	NA	NA	5.5

* This is a comparison to the SNODAS (SNOw Data Assimilation System) nationwide product from the National Weather Service.

Location of Reports and Excel Format Tables

ftp://snowserver.colorado.edu/pub/Sierras

References and Additional Sources

Margulis, S. A., Cortés, G., Girotto, M., & Durand, M. (2016). A Landsat-Era Sierra Nevada Snow Reanalysis (1985–2015). *Journal of Hydrometeorology*, 17(4), 1203–1221, doi:/10.1175/JHM-D-15-0177.1

Molotch, N.P. (2009). 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. (2008) 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. (2006). 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.

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

Molotch, N.P., T.H. Painter, R.C. Bales, and J. Dozier. (2004). 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. (2009) Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. *Remote Sensing of the Environment*, 113: 868-879.

Rittger, K., M. S. Raleigh, J. Dozier, A. F. Hill, J. A. Lutz, and T. H. Painter. 2019. Canopy Adjustment and Improved Cloud Detection for Remotely Sensed Snow Cover Mapping. Water Resources Research 24 August 2019. doi:10.1029/2019WR024914.

Schneider D. and N.P. Molotch. (2016). Real-time estimation of snow water equivalent in the Upper Colorado River Basin using MODIS-based SWE reconstructions and SNOTEL data. *Water Resources Research*, 52(10): 7892-7910. DOI: 10.1002/2016WR019067.