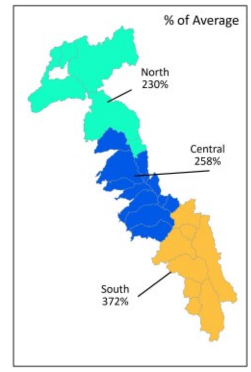
Real-Time Spatial Estimates of Snow-Water Equivalent (SWE)

Sierra Nevada Mountains, California
March 15, 2023



Team: Noah Molotch[1,2], Leanne Lestak[1], and Kehan Yang[1]
Institute of Arctic and Alpine Research, University of Colorado Boulder
[2] Jet Propulsion Laboratory, California Institute of Technology
Contact: Leanne.Lestak@colorado.edu

Summary of current conditions

The regional summary map above shows the mean SWE above 5000' elevation for three major regions of the Sierra Nevada, percent of average is calculated from a long-term average of 2001-2021. As of March 15, percent of average SWE is highest in the south (372%), then central (258%) and lowest in the north (230%). This snow year has produced sporadic percent of averages, especially in low-elevation areas, and will be higher than historical averages. **NEW this year, scroll down for comparison maps of CU SWE versus ASO SWE**. 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 website **[here](#)**.

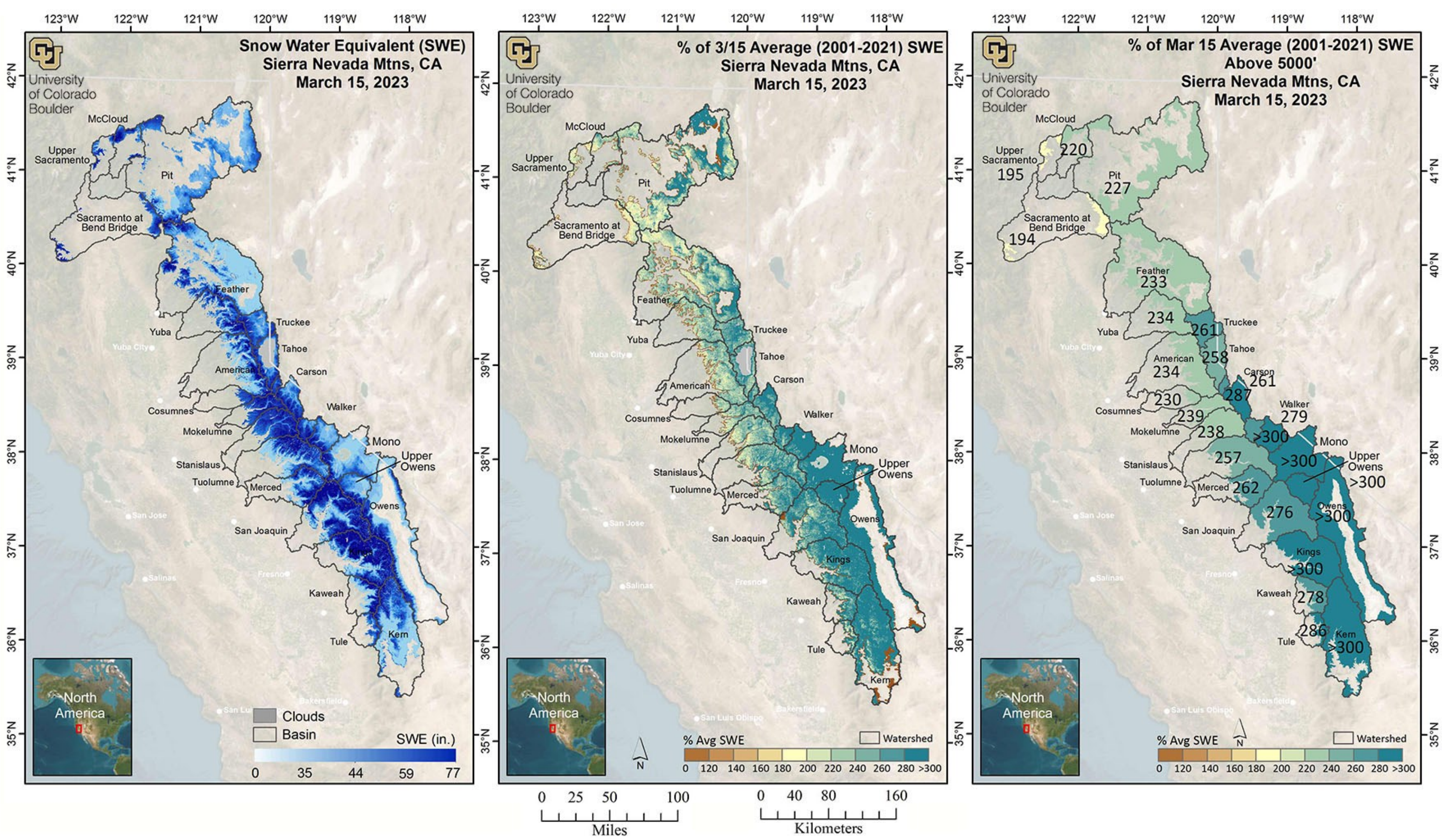


Figure 1. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts for March 15, 2023 (left), and percent of average (2001-2021) SWE for March 15, 2023 for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

Location of Reports and Excel Format Tables

https://www.colorado.edu/instaar/research/labs-groups/mountain-hydrology-group/sierra-nevada-swe-reports

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 typically 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 and NV snow pillow 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 (1985-2016) 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.
- Satellite-observed daily mean fractional snow-covered area (DMFSCA).

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

108 snow pillow sites in the Sierra Nevada network were recording SWE values out of a total of 127 sites, 20 were offline, and we used 16 CoCoRaHS measurements (shown in black, red and green, respectively, in Figure 5, 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 over a hundred and thirty snow pillow 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 pillow 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 snow pillows

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.

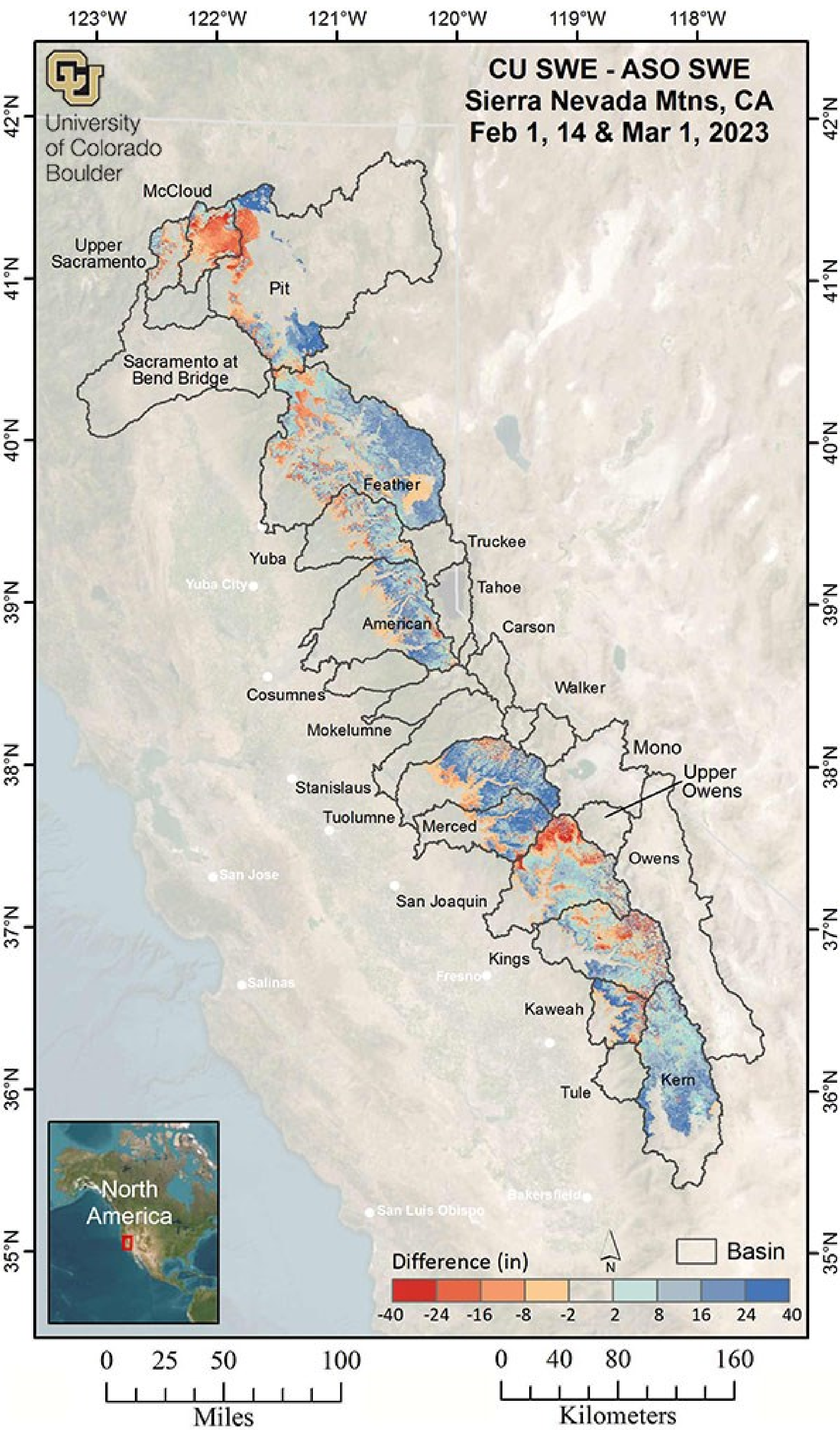


Figure 2. Comparison to ASO, Sierra Nevada. The difference in SWE amounts between the February 1, February 14, and March 1, 2023 CU SWE model run and Airborne Snow Observatories (ASO) lidar-derived SWE are shown for available basins. Red colors show where CU SWE is lower than ASO SWE and blue colors show where CU SWE is higher than ASO SWE. The CU SWE model runs are only for areas above 5000', so any snow imaged by ASO below 5000' will show up as light red colors. This map will be updated as new ASO data becomes available.

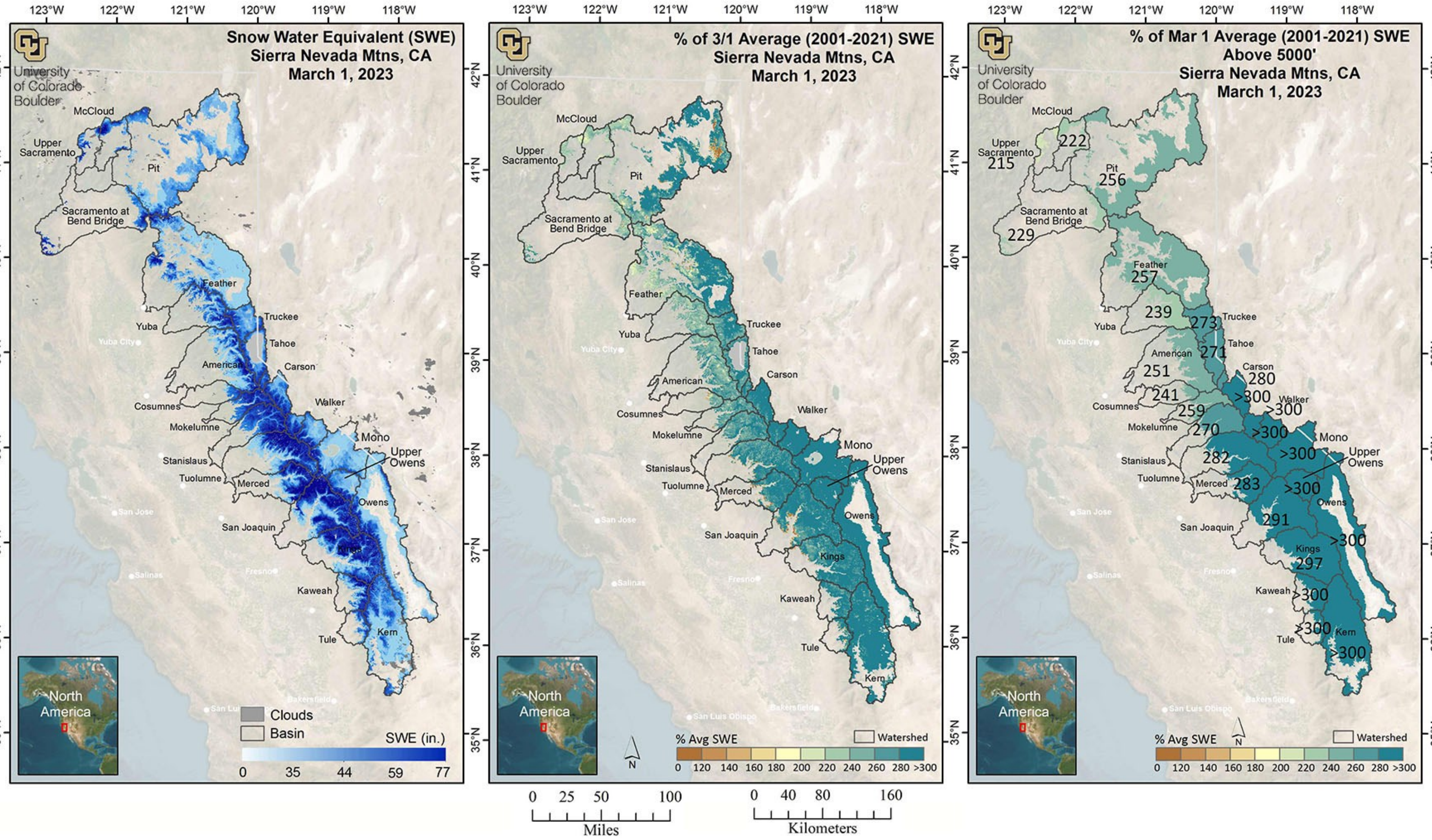


Figure 3. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts for March 1, 2023 (left), and percent of average (2001-2021) SWE for March 1, 2023 for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

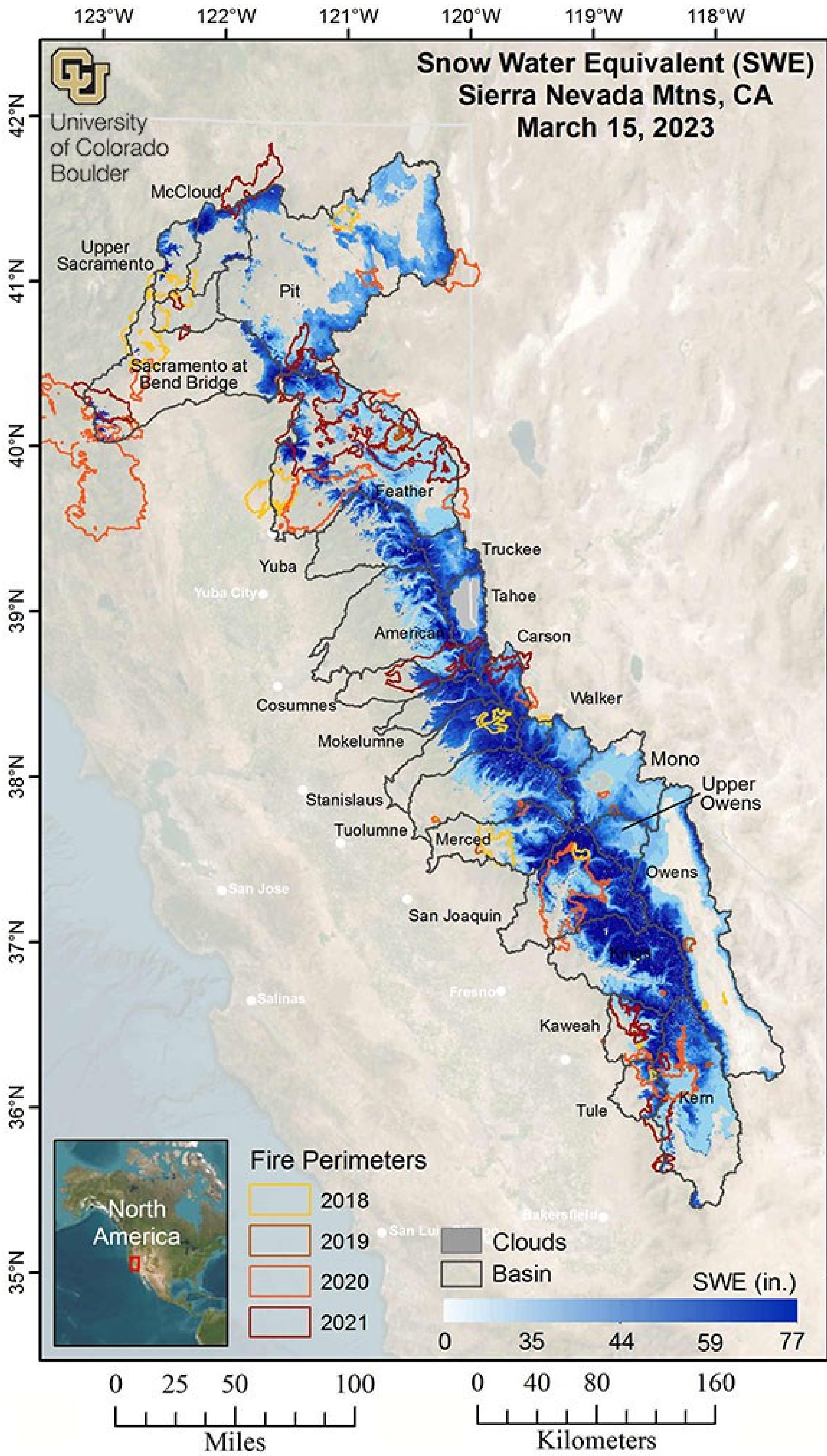


Figure 4. Estimated SWE with Fire Perimeters, Sierra Nevada. SWE amounts for March 15, 2023 are shown with fire perimeters from 2018-2021 (colored from yellow to red).

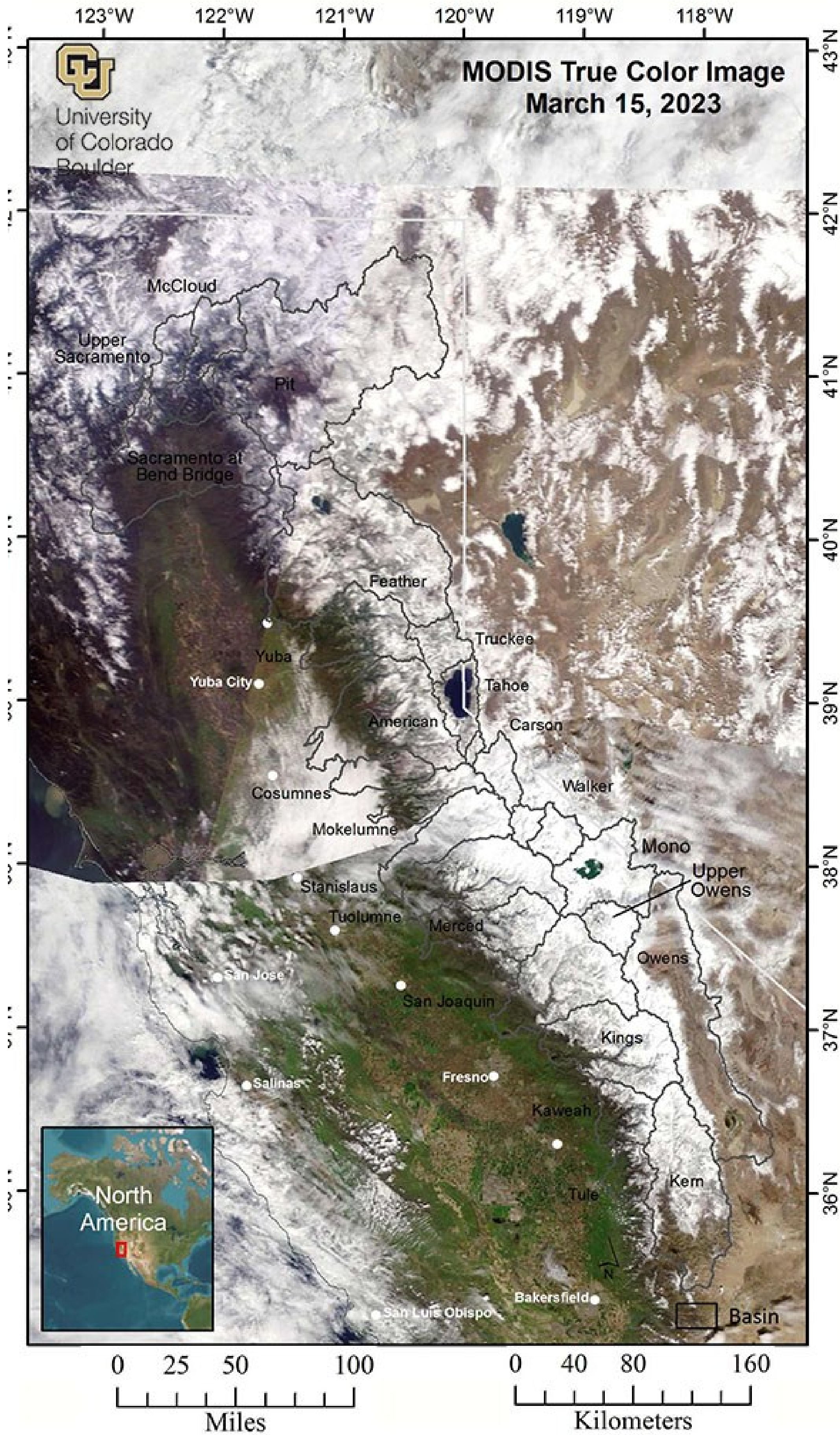


Figure 5. MODIS image, Sierra Nevada. A mostly cloud-free true color MODIS image, showing the image that was used for the March 15, 2023 regression model run.

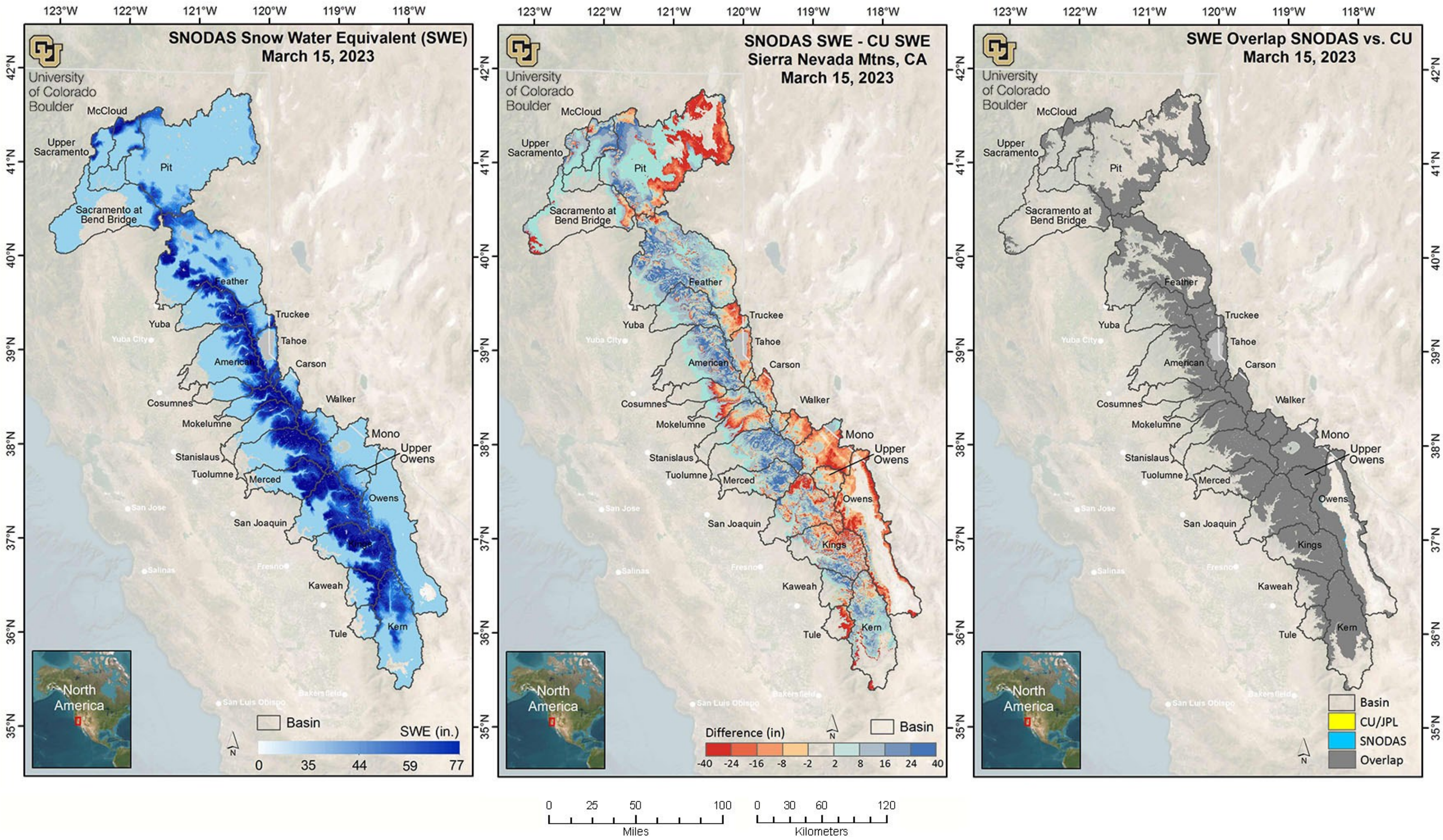


Figure 6. Comparison of CU regression SWE product and SNODAS SWE for the Sierra Nevada. The map on the left shows estimated SWE for March 15th from the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS). The middle map shows the difference between the March 15th SNODAS SWE estimate and CU regression SWE estimate. Red pixels denote areas where SNODAS SWE is less than CU SWE and blue pixels show areas where SNODAS SWE is higher than CU SWE. Light blue areas in low elevations are below 5000' where the CU SWE model doesn't calculate SWE estimates. The map on the right shows the snow-cover extent of SNODAS and CU SWE estimates. Yellow pixels show where the location of CU snow extends beyond the location of the SNODAS snow extent. Blue pixels show where the SNODAS snow extends beyond the CU snow extent. Gray areas indicate regions where both products agree on the snow-cover extent.

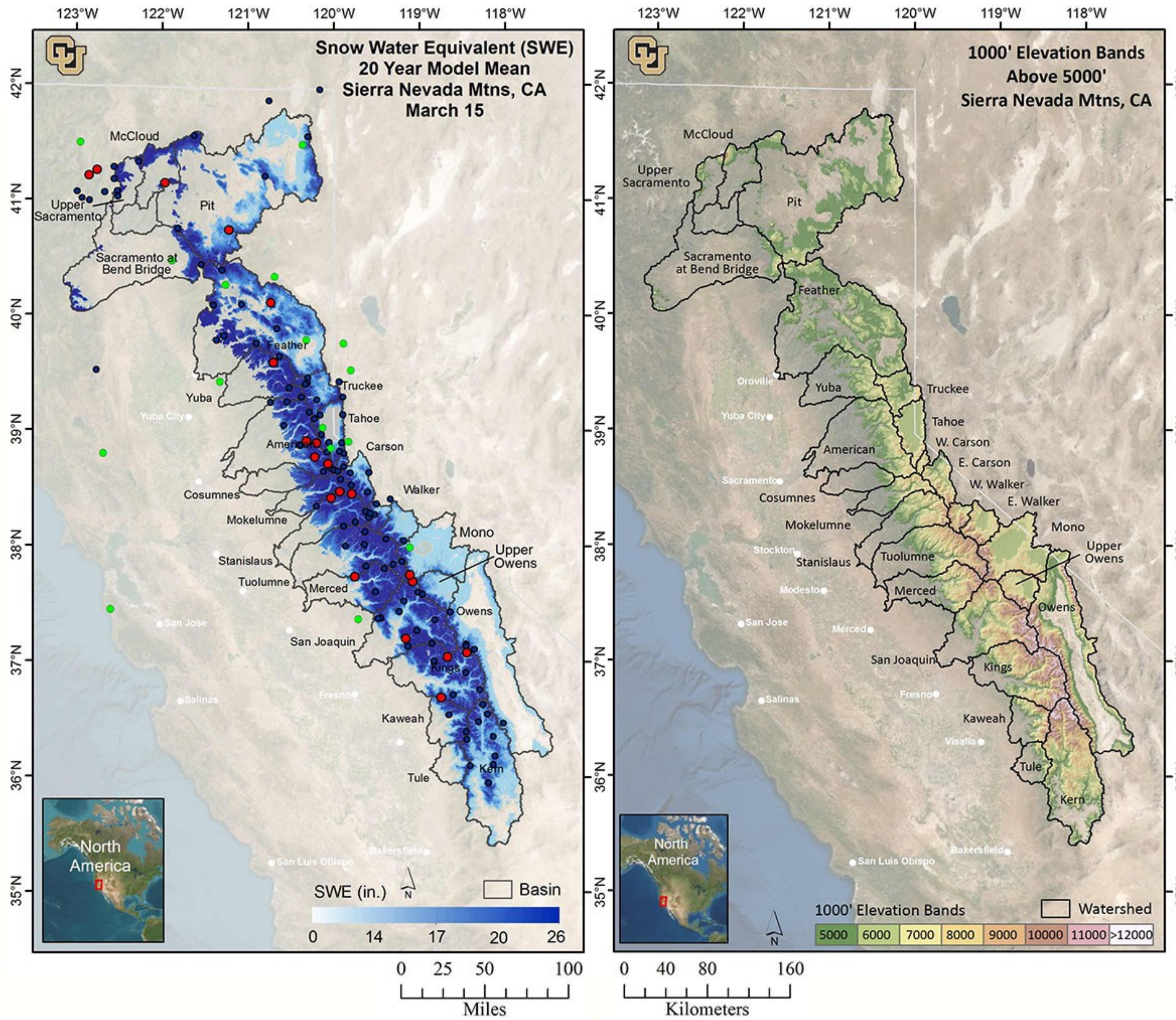


Figure 7. Historical average March 15th and Elevation Bands for the Sierra Nevada. Average SWE (2001-2021) for March 15th (left), and the Banded Elevation map (right) identifies basins used in this report (black boundaries) and 1000' elevation bands (colored shading) that match those used in Table 1 and Table 2. Map on left shows snow pillow sensor sites recording SWE on March 15th (black), sites that were offline are shown in red, and CoCoRaHS sites are shown in green.

Methods

The spatial SWE estimation method is described in Yang, et al. (2022) and 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 pillow sensor sites in the domain. The snow pillow sensor SWE observations are scaled by the fractional snow-covered area (fSCA) across the 500 m pixel containing that snow pillow 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) 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 Table 1 in Yang, et al. (2022) 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 during the 1985-2016 period that best matches the real-time snow pillow-observed pattern is selected as an independent variable.)
- Satellite-observed daily mean fractional snow-covered area (DMFSCA) derived from Rittger, et. al., 2019 data.

The real-time regression model for this date has been validated by cross-validation, whereby 10% of the snow pillow data are randomly removed and the model prediction is compared to the measured value at the removed snow pillow stations. This is repeated 30 times to obtain an average R-squared value, which denotes how closely the model fits the snow pillow 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 utilized to generate this report change to optimize model performance. To maintain consistency across the historical record, the percent of average values are based on our baseline algorithm and therefore there can be discrepancies between absolute SWE values and corresponding percent of averages.

Data Issues/Caveats for* March 15, 2023 *– IMPORTANT – READ THIS!

- 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.
- 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.
- 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.
- PERCENT OF AVERAGE CALCULATIONS - Data utilized to generate this report change to optimize model performance. To maintain consistency across the historical record, the percent of average values are based on our baseline algorithm and therefore there can be discrepancies between absolute SWE values and corresponding percent of averages.
- MODELING METHODS - We work to generate the best SWE estimates for each reporting date. Our methods can change from one report to another. Sometimes data changes between reports is an artifact of method changes.

List of All Known Data Issues/Caveats

- NEW AVERAGE CALCULATIONS – Average calculations are based on 2001-2021 model values, this includes the drought years (2012-2016) which brings our overall average SWE down considerably, thereby increasing percent of averages.
- 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 SNOW SENSOR DATA – Although data QA/QC is performed, occasional 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.
- MISSING SWE VALUES - Volume calculations for the Kings, Kaweah, Kern, and Tule basins are based on place-holder values for SWE in the lower elevations. Place-holder values are based on average SWE accumulation values at higher elevations where we have higher confidence in the SWE estimates.
- PERCENT OF AVERAGE CALCULATIONS - Data utilized to generate this report change to optimize model performance.

To maintain consistency across the historical record, the percent of average values are based on our baseline algorithm and therefore there can be discrepancies between absolute SWE values and corresponding percent of averages.

- MODELING METHODS - We work to generate the best SWE estimates for each reporting date. Our methods can change from one report to another. Sometimes data changes between reports is an artifact of method changes.

Table 1. Estimated SWE by basin. *The basin-wide SWE values and averages, are across all pixels at elevations >5000'. Shown are March 1st percent of March 1st average SWE, March 15th percent of March 15th average SWE (between 2001-2021 as derived from the regression model), March 1st mean SWE, March 15th mean SWE, March 15th percent of snow-covered area, March 15th water volume (acre-feet), the area (mi²) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), March 1st snow pillow data, and March 15th snow pillow data for those areas collected, summarized for each basin. The last column shows March 15th mean SWE from SNODAS*.*

Basin	3/1/23 % 3/1 Avg.	3/15/23 % 3/15 Avg.	3/1/23 SWE (in)	3/15/23 SWE (in)	3/15/23 % SCA	3/15/23‡ Vol (af)	Area (mi2) > 5000'	3/1/23 Pillows	3/15/23 Pillows	3/15/23 SNODAS* (in)
Upper Sacramento§	188	195	42.5	46.0	100.0	313,364	127.8	45.5 (2)	59.0 (2)	47.7
McCloud§	205	220	46.2	55.5	100.0	527,877	178.2	NA	NA	56.5
Pit§	235	227	26.1	31.7	99.2	3,887,963	2301.5	28.0 (4)	35.8 (4)	17.6
Sac at Bend Bridge	202	194	44.9	52.2	100.0	715,342	256.8	NA	NA	34.2
Feather§	235	233	22.3	27.1	100.0	3,286,295	2,273.4	44.6 (6)	58.3 (6)	34.2
Yuba§	222	234	39.7	47.0	100.0	1,393,960	555.7	56.9 (3)	74.2 (3)	55.8
American§	233	234	33.1	37.5	100.0	1,703,166	852.1	39.2 (10)	49.5 (9)	50.4
Cosumnes	220	230	40.9	51.0	100.0	256,702	94.4	NA	NA	38.7
Mokelumne	243	239	52.0	57.2	100.0	1,028,465	336.8	55.2 (1)	68.0 (1)	54.5
Stanislaus	>250†	238	52.1	55.9	100.0	1,765,140	591.6	53.4 (4)	66.7 (4)	52.0
Tuolumne§	>250†	>250†	46.2	41.9	100.0	2,149,372	961.5	53.5 (7)	66.9 (7)	56.0
Merced§	>250†	>250†	46.9	43.7	100.0	1,319,480	565.9	52.8 (3)	75.4 (2)	55.4
San Joaquin§	>250†	>250†	53.5	57.1	100.0	3,882,134	1,273.7	51.2 (8)	64.5 (8)	52.0
Kings§	>250†	>250†	49.9	59.3	100.0	3,986,132	1,261.0	54.9 (1)	68.0 (5)	56.5
Kaweah§	>250†	>250†	42.1	42.5	100.0	738,867	326.0	58.5 (1)	52.0 (2)	48.8
Tule	>250†	>250†	39.1	46.7	100.0	357,107	143.2	NA	NA	21.8
Kern§	>250†	>250†	26.2	25.1	85.8	2,342,880	1,746.9	33.7 (6)	49.3 (9)	28.3
Truckee	>250†	>250†	39.8	46.1	100.0	1,106,566	450.2	32.4 (5)	41.7 (5)	39.4
Tahoe	>250†	>250†	43.6	49.8	100.0	889,697	335.2	42.5 (7)	53.8 (7)	46.2
W Carson	>250†	>250†	51.3	55.9	100.0	209,050	70.2	48.7 (2)	61.1 (2)	54.0
E Carson	>250†	>250†	42.7	46.5	99.5	947,577	382.1	42.7 (5)	51.8 (5)	41.1
W Walker	>250†	>250†	50.4	53.6	100.0	547,043	191.4	51.8 (3)	65.2 (3)	56.1
E Walker	>250†	>250†	37.7	41.1	100.0	827,510	377.6	37.8 (1)	49.0 (1)	32.9
Mono	>250†	>250†	26.5	28.3	100.0	1,615,211	1,069.9	NA	NA	18.8
Upper Owens	>250†	>250†	37.4	39.6	100.0	839,680	397.7	68.5 (1)	88.0 (1)	33.6
Owens	>250†	>250†	22.5	24.4	73.6	2,429,391	1,866.9	33.9 (5)	45.3 (5)	14.1

§ Data in all ASO-collected basins have been bias-corrected using ASO data and therefore the SWE changes might not represent snowmelt but rather an update to the SWE estimates based on airborne data.

† Deep, and particularly low-elevation snow in areas that typically are snow-free can report exceptionally high percent of average for this date because the mean 2001-2021 regression-derived SWE for that area is low or 0.

‡ For volume totals above Shasta Lake add Upper Sac, McCloud and Pit volumes. For volume totals above Bend Bridge add Upper Sac, McCloud, Pit and Sac at Bend Bridge volumes.

* 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. *The basin-wide SWE values and averages, are across all pixels at elevations >5000'. 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 March 1st percent of March 1st average SWE, March 15th percent of March 15th average SWE (between 2001-2021 as derived from the regression model), March 1st mean SWE, March 15th mean SWE, March 15th percent of snow-covered area, March 15th water volume (acre-feet), the area (mi²) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), March 1st snow pillow data, and March 15th snow pillow data for those areas collected, summarized for each 1000' elevation band inside each basin. The last column shows March 15th mean SWE from SNODAS*.*

Basin	Elevation Band	3/1/23 % 3/1 Avg.	3/15/23 % 3/15 Avg.	3/1/23 SWE (in)	3/15/23 SWE (in)	3/15/23 % SCA	3/15/23‡ Vol (af)	3/15/23 Area (mi2)	3/1/23 Pillows	3/15/23 Pillows	3/15/23 SNODAS* (in)
Upper Sacramento§	5000-6000'	192	208	38.1	43.2	100.0	167,211	72.5	49.0 (1)	66.0 (1)	42.3
	6000-7000'	189	190	47.0	48.7	100.0	100,396	38.6	42.0 (1)	52.0 (1)	55.3
	7000-8000'	179	168	50.3	49.4	100.0	23,901	9.1	NA	NA	54.3
	8000-9000'	164	156	55.5	56.4	100.0	9,224	3.1	NA	NA	55.9
	9000-10,000'	158	148	55.7	57.4	100.0	6,407	2.1	NA	NA	55.0
	10,000-11,000'	171	160	57.0	58.9	100.0	3,945	1.3	NA	NA	49.5
	> 11,000'	158	144	35.5	36.0	100.0	2,279	1.2	NA	NA	43.6
McCloud§	5000-6000'	204	229	38.2	48.5	100.0	274,223	105.9	NA	NA	51.3
	6000-7000'	204	213	51.1	59.1	100.0	137,645	43.7	NA	NA	64.8
	7000-8000'	214	204	71.3	79.0	100.0	59,930	14.2	NA	NA	64.6
	8000-9000'	220	209	68.2	75.3	100.0	27,152	6.8	NA	NA	66.1
	>9,000'	221	213	65.1	71.0	100.0	11,884	3.1	NA	NA	63.3
Pit§	5000-6000'	>250†	250	22.7	28.5	98.8	2,398,794	1,578.6	43.9 (1)	56.6 (1)	13.1
	6000-7000'	208	199	31.4	36.4	100.0	1,088,869	560.1	23.9 (2)	31.0 (2)	25.3
	7000-8000'	210	196	39.8	45.0	100.0	335,228	139.6	20.4 (1)	24.4 (1)	35.3
	>8,000'	224	197	46.7	51.3	100.0	58,338	21.3	NA	NA	31.5
Sac at Bend Bridge	5000-6000'	198	192	40.6	43.2	100.0	437,024	169.9	NA	NA	28.4
	6000-7000'	203	194	50.1	53.6	100.0	198,658	65.3	NA	NA	42.2
	>7,000'	219	203	61.6	66.6	100.0	58,405	16.5	NA	NA	54.7
Feather§	5000-6000'	244	242	18.5	23.3	100.0	1,684,037	1,357.8	56.6 (1)	70.9 (1)	32.0
	6000-7000'	225	223	26.0	31.1	100.0	1,303,410	786.5	44.1 (4)	57.9 (4)	36.4
	7000-8000'	219	215	38.3	43.1	100.0	286,390	124.7	34.8 (1)	47.2 (1)	43.7
	8000-9000'	221	219	43.5	52.3	100.0	12,457	4.5	NA	NA	44.8
Yuba§	5000-6000'	216	224	27.9	32.7	100.0	355,935	204.1	NA	NA	42.4
	6000-7000'	224	241	40.8	49.5	100.0	605,342	229.5	48.5 (2)	62.9 (2)	59.0
	7000-8000'	227	235	56.7	66.1	100.0	414,698	117.6	73.7 (1)	96.8 (1)	71.6
	8000-9000'	221	220	67.7	75.6	100.0	17,985	4.5	NA	NA	84.6
American§	5000-6000'	229	223	16.8	19.0	100.0	317,485	313.9	27.5 (3)	34.0 (3)	33.1
	6000-7000'	233	238	31.0	35.7	100.0	535,933	281.4	37.9 (2)	52.1 (1)	50.7
	7000-8000'	237	239	49.4	55.7	100.0	526,005	176.9	44.9 (3)	57.1 (3)	69.4
	8000-9000'	239	239	66.2	74.0	100.0	279,377	70.8	49.4 (2)	60.1 (2)	74.6
	9000-10,000'	237	236	80.8	91.1	100.0	44,367	9.1	NA	NA	75.6
Cosumnes	5000-6000'	212	229	36.2	47.7	100.0	159,065	62.5	NA	NA	30.8
	6000-7000'	230	232	47.9	55.8	100.0	74,080	24.9	NA	NA	51.1
	7000-8000'	238	237	56.9	63.3	100.0	23,557	7.0	NA	NA	65.5
Mokelumne	5000-6000'	228	222	37.9	44.5	100.0	209,978	88.4	NA	NA	23.0
	6000-7000'	237	235	47.7	53.6	100.0	195,677	68.4	NA	NA	48.0
	7000-8000'	248	247	57.8	62.6	100.0	304,510	91.2	NA	NA	71.0
	8000-9000'	>250†	246	63.1	66.8	100.0	285,467	80.1	55.2 (1)	68.0 (1)	74.0
	9000-10,000'	246	233	67.5	71.2	100.0	32,834	8.6	NA	NA	71.7
Stanislaus	5000-6000'	243	220	37.1	42.0	100.0	250,862	112.0	NA	NA	21.0
	6000-7000'	245	235	46.0	50.7	100.0	382,079	141.4	42.5 (1)	52.9 (1)	45.5
	7000-8000'	>250†	245	54.5	58.4	100.0	474,092	152.2	NA	NA	61.8
	8000-9000'	>250†	244	61.6	64.5	100.0	407,883	118.6	60.8 (2)	76.1 (2)	66.8
	9000-10,000'	>250†	237	66.6	69.0	100.0	198,100	53.8	49.5 (1)	61.6 (1)	69.1
	10,000-11,000'	>250†	237	69.2	71.9	100.0	50,790	13.3	NA	NA	67.3
	> 11,000'	>250†	244	71.4	71.7	100.0	1,334	0.3	NA	NA	64.1

Basin	Elevation Band	3/1/23	3/15/23	3/1/23	3/15/23	3/15/23	3/15/23‡	3/15/23	3/1/23	3/15/23	3/15/23
		% 3/1 Avg.	% 3/15 Avg.	SWE (in)	SWE (in)	% SCA	Vol (af)	Area (mi2)	Pillows	Pillows	SNODAS* (in)
Tuolumne§	5000-6000'	246	243	12.9	16.5	100.0	158,168	179.6	NA	NA	18.9
	6000-7000'	>250†	239	26.7	27.7	100.0	217,279	147.2	33.4 (1)	43.6 (1)	43.4
	7000-8000'	>250†	>250†	46.6	45.5	100.0	381,785	157.4	60.8 (2)	75.2 (2)	63.9
	8000-9000'	>250†	>250†	63.2	57.0	100.0	526,132	173.2	55.5 (2)	69.2 (2)	71.2
	9000-10,000'	>250†	>250†	68.2	56.2	100.0	551,020	183.8	54.3 (2)	68.0 (2)	73.3
	10,000-11,000'	>250†	>250†	63.0	49.7	100.0	242,419	91.5	NA	NA	70.9
	11,000-12,000'	>250†	>250†	54.2	45.8	100.0	63,057	25.8	NA	NA	60.7
	> 12,000'	>250†	>250†	62.4	60.9	100.0	9,512	2.9	NA	NA	51.6
Merced§	5000-6000'	210	>250†	11.6	18.6	100.0	74,640	75.2	NA	NA	15.0
	6000-7000'	>250†	235	23.5	24.5	100.0	108,119	82.9	NA	NA	36.1
	7000-8000'	>250†	>250†	42.5	40.3	100.0	305,045	142.1	41.4 (1)	NA	61.7
	8000-9000'	>250†	>250†	61.8	57.1	100.0	379,778	124.7	58.5 (2)	75.4 (2)	69.7
	9000-10,000'	>250†	>250†	70.0	59.8	100.0	280,402	87.9	NA	NA	67.4
	10,000-11,000'	>250†	>250†	71.4	60.1	100.0	127,813	39.9	NA	NA	73.1
	11,000-12,000'	>250†	>250†	70.6	59.7	100.0	37,551	11.8	NA	NA	71.4
	> 12,000'	>250†	>250†	76.7	71.7	100.0	6,133	1.6	NA	NA	66.0
San Joaquin§	5000-6000'	226	>250†	16.1	23.0	100.0	177,056	144.4	NA	NA	17.2
	6000-7000'	>250†	>250†	29.5	31.2	100.0	311,259	187.0	49.6 (2)	59.9 (2)	37.0
	7000-8000'	>250†	>250†	45.2	47.0	100.0	557,053	222.3	52.6 (4)	67.2 (4)	56.5
	8000-9000'	>250†	>250†	66.0	68.4	100.0	740,415	203.1	NA	NA	62.4
	9000-10,000'	>250†	>250†	73.4	78.4	100.0	867,930	207.5	56.9 (1)	71.8 (1)	62.2
	10,000-11,000'	>250†	>250†	72.6	77.4	100.0	668,664	162.0	43.3 (1)	55.6 (1)	65.6
	11,000-12,000'	>250†	>250†	67.4	71.9	100.0	456,341	119.0	NA	NA	57.2
	12,000-13,000	>250†	>250†	63.6	68.8	100.0	98,995	27.0	NA	NA	44.5
	> 13,000	>250†	>250†	56.7	56.6	100.0	4,422	1.5	NA	NA	31.9
Kings§	5000-6000'	>250†	>250†	15.8	17.1	100.0	92,376	101.3	NA	NA	16.3
	6000-7000'	>250†	>250†	22.6	24.5	100.0	179,602	137.2	NA	NA	32.7
	7000-8000'	>250†	>250†	39.7	45.7	100.0	432,373	177.3	NA	NA	54.2
	8000-9000'	>250†	>250†	55.1	65.9	100.0	777,514	221.1	NA	65.3 (1)	66.3
	9000-10,000'	>250†	>250†	61.6	74.5	100.0	881,763	221.8	54.9 (1)	69.6 (2)	68.4
	10,000-11,000'	>250†	>250†	62.4	75.2	100.0	775,768	193.4	NA	67.8 (2)	68.1
	11,000-12,000'	>250†	>250†	64.1	77.4	100.0	642,005	155.6	NA	NA	62.7
	12,000-13,000	>250†	>250†	61.1	72.7	100.0	190,643	49.2	NA	NA	52.1
	>13,000'	>250†	>250†	55.6	64.2	100.0	14,088	4.1	NA	NA	41.8
Kaweah§	5000-6000'	>250†	>250†	22.8	8.0	100.0	26,082	61.4	NA	NA	11.0
	6000-7000'	>250†	>250†	20.9	17.9	100.0	58,102	60.8	NA	30.9 (1)	29.1
	7000-8000'	>250†	>250†	36.2	37.2	100.0	123,906	62.5	NA	NA	51.1
	8000-9000'	>250†	>250†	53.4	61.6	100.0	189,863	57.8	NA	NA	63.9
	9000-10,000'	>250†	>250†	64.5	73.2	100.0	170,696	43.7	58.5 (1)	73.1 (1)	77.1
	10,000-11,000'	>250†	>250†	72.8	80.6	100.0	133,058	31.0	NA	NA	82.5
	>11,000'	>250†	>250†	70.1	79.3	100.0	37,159	8.8	NA	NA	76.3
Tule	5000-6000'	>250†	>250†	28.2	38.0	100.0	111,995	55.2	NA	NA	6.6
	6000-7000'	>250†	240	38.9	45.3	100.0	101,123	41.8	NA	NA	16.3
	7000-8000'	>250†	>250†	49.2	54.5	100.0	78,038	26.8	NA	NA	36.7
	8000-9000'	>250†	>250†	56.2	63.4	100.0	50,005	14.8	NA	NA	52.3
	9000-10,000'	>250†	>250†	58.5	66.0	100.0	15,946	4.5	NA	NA	71.5
Kern§	5000-6000'	>250†	>250†	16.9	7.0	46.7	95,858	257.9	NA	NA	3.9
	6000-7000'	>250†	>250†	15.2	8.8	70.4	167,360	357.9	NA	NA	11.4
	7000-8000'	>250†	>250†	17.8	16.5	98.4	298,835	339.5	29.0 (2)	36.0 (2)	23.4
	8000-9000'	>250†	>250†	30.3	31.8	100.0	552,199	325.8	36.9 (2)	51.2 (3)	38.8
	9000-10,000'	>250†	>250†	37.3	43.5	100.0	448,473	193.2	NA	60.9 (1)	49.4
	10,000-11,000'	>250†	>250†	42.9	52.4	100.0	371,698	133.1	35.2 (2)	46.9 (2)	53.2
	11,000-12,000'	>250†	>250†	47.7	55.6	100.0	281,695	94.9	NA	63.2 (1)	55.3
	12,000-13,000	>250†	>250†	46.3	54.2	100.0	110,480	38.2	NA	NA	46.2
	>13,000'	>250†	>250†	42.0	48.1	100.0	16,281	6.3	NA	NA	33.4

Basin	Elevation Band	3/1/23 % 3/1 Avg.	3/15/23 % 3/15 Avg.	3/1/23 SWE (in)	3/15/23 SWE (in)	3/15/23 % SCA	3/15/23‡ Vol (af)	3/15/23 Area (mi2)	3/1/23 Pillows	3/15/23 Pillows	3/15/23 SNODAS* (in)
Truckee	5000-6000'	>250†	>250†	27.2	31.2	100.0	116,489	69.9	NA	NA	18.4
	6000-7000'	>250†	>250†	36.1	42.3	100.0	499,622	221.4	32.4 (5)	41.7 (5)	33.3
	7000-8000'	239	>250†	48.9	56.6	100.0	361,683	119.7	NA	NA	55.0
	8000-9000'	237	234	55.8	62.1	100.0	101,690	30.7	NA	NA	63.8
	9000-10,000'	243	219	56.4	60.6	100.0	25,716	8.0	NA	NA	65.7
	10,000-11,000'	246	208	58.8	61.2	100.0	1,365	0.4	NA	NA	62.5
Tahoe	6000-7000'	>250†	>250†	32.0	38.6	100.0	270,099	131.3	34.4 (2)	42.2 (2)	30.7
	7000-8000'	>250†	>250†	46.3	52.4	100.0	316,186	113.2	46.2 (4)	59.3 (4)	52.5
	8000-9000'	246	245	56.1	62.0	100.0	241,442	73.0	43.7 (1)	55.1 (1)	60.6
	9000-10,000'	246	234	60.2	65.1	100.0	59,119	17.0	NA	NA	61.8
	10,000-11,000'	>250†	240	63.9	69.7	100.0	2,851	0.8	NA	NA	51.7
W. Carson	5000-6000'	>250†	>250†	28.9	29.3	100.0	327	0.2	NA	NA	18.8
	6000-7000'	>250†	>250†	37.1	38.6	100.0	4,591	2.2	NA	NA	36.9
	7000-8000'	>250†	>250†	46.6	50.3	100.0	86,224	32.2	NA	NA	53.2
	8000-9000'	>250†	>250†	55.4	60.6	100.0	90,217	27.9	48.7 (2)	61.1 (2)	55.7
	9000-10,000'	250	>250†	61.5	68.3	100.0	25,653	7.0	NA	NA	57.2
	10,000-11,000'	244	214	57.0	60.9	100.0	2,038	0.6	NA	NA	51.9
E. Carson	5000-6000'	>250†	>250†	24.8	26.0	95.9	69,817	50.3	NA	NA	12.0
	6000-7000'	>250†	>250†	31.0	34.4	100.0	143,503	78.1	22.7 (1)	22.5 (1)	24.1
	7000-8000'	>250†	>250†	41.6	45.9	100.0	256,088	104.7	NA	NA	40.6
	8000-9000'	>250†	>250†	52.7	57.2	100.0	309,861	101.5	47.7 (4)	59.1 (4)	59.0
	9000-10,000'	>250†	248	61.0	65.3	100.0	127,115	36.5	NA	NA	64.1
	>10,000'	>250†	>250†	65.5	70.1	100.0	41,193	11.0	NA	NA	58.0
W. Walker	6000-7000'	>250†	>250†	29.1	31.3	100.0	13,022	7.8	NA	NA	23.7
	7000-8000'	>250†	>250†	33.1	35.9	100.0	78,032	40.7	32.1 (1)	40.0 (1)	32.2
	8000-9000'	>250†	>250†	45.9	49.6	100.0	127,221	48.1	43.2 (1)	53.9 (1)	55.3
	9000-10,000'	>250†	>250†	59.4	62.5	100.0	217,433	65.2	80.1 (1)	101.7 (1)	70.3
	10,000-11,000'	>250†	>250†	67.5	70.7	100.0	102,885	27.3	NA	NA	68.4
	> 11,000'	>250†	>250†	67.7	71.0	100.0	8,449	2.2	NA	NA	59.9
E. Walker	6000-7000'	>250†	>250†	21.8	23.9	100.0	76,939	60.5	NA	NA	20.4
	7000-8000'	>250†	>250†	28.0	31.0	100.0	198,539	120.2	NA	NA	20.3
	8000-9000'	>250†	>250†	38.0	41.9	100.0	214,706	96.2	NA	NA	32.7
	9000-10,000'	>250†	>250†	53.5	57.5	100.0	175,464	57.2	37.8 (1)	49.0 (1)	53.1
	10,000-11,000'	>250†	>250†	64.6	69.0	100.0	127,866	34.7	NA	NA	60.4
	>11,000'	>250†	>250†	67.8	72.0	100.0	33,996	8.9	NA	NA	54.6
Mono	6000-7000'	>250†	>250†	17.3	17.4	100.0	298,647	322.4	NA	NA	10.7
	7000-8000'	>250†	>250†	21.0	22.5	100.0	502,150	417.7	NA	NA	13.7
	8000-9000'	>250†	>250†	31.1	34.9	100.0	345,851	185.6	NA	NA	19.3
	9000-10,000'	>250†	>250†	48.1	51.4	100.0	177,909	64.9	NA	NA	40.5
	10,000-11,000'	>250†	>250†	61.7	66.0	100.0	170,806	48.5	NA	NA	62.0
	11,000-12,000'	>250†	>250†	68.9	73.0	100.0	102,639	26.4	NA	NA	58.1
	> 12,000'	>250†	>250†	68.5	73.4	100.0	17,209	4.4	NA	NA	50.3
Upper Owens	6000-7000'	>250†	>250†	21.8	22.3	100.0	78,374	66.0	NA	NA	17.7
	7000-8000'	>250†	>250†	28.6	30.1	100.0	244,679	152.7	NA	NA	27.9
	8000-9000'	>250†	>250†	41.6	43.9	100.0	187,735	80.3	NA	NA	36.9
	9000-10,000'	>250†	>250†	52.6	55.5	100.0	130,495	44.1	68.5 (1)	88.0 (1)	45.9
	10,000-11,000'	>250†	>250†	59.5	64.7	100.0	119,315	34.6	NA	NA	56.0
	11,000-12,000'	>250†	>250†	68.3	74.5	100.0	64,251	16.2	NA	NA	52.8
	> 12,000'	>250†	>250†	66.5	72.5	100.0	14,830	3.8	NA	NA	40.4
Owens	5000-6000'	>250†	>250†	3.9	1.1	19.6	27,164	446.8	NA	NA	0.4
	6000-7000'	>250†	>250†	12.8	9.3	66.3	177,758	359.5	NA	NA	4.7
	7000-8000'	>250†	>250†	19.2	20.1	95.4	358,934	334.6	NA	NA	10.8
	8000-9000'	>250†	>250†	23.1	27.9	100.0	281,861	189.2	NA	NA	17.2
	9000-10,000'	>250†	>250†	33.7	40.8	100.0	335,038	154.0	34.8 (3)	44.0 (3)	26.9
	10,000-11,000'	>250†	>250†	43.9	53.0	100.0	475,130	168.1	32.5 (2)	47.3 (2)	35.2
	11,000-12,000'	>250†	>250†	55.1	65.2	100.0	471,843	135.7	NA	NA	37.8
	12,000-13,000	>250†	>250†	60.8	72.0	100.0	260,894	67.9	NA	NA	31.5
	>13,000'	>250†	>250†	57.8	69.8	100.0	40,768	10.9	NA	NA	23.8

§ Data in all ASO-collected basins have been bias-corrected using ASO data and therefore the SWE changes might not represent snowmelt but rather an update to the SWE estimates based on airborne data.

‡ For volume totals above Shasta Lake add Upper Sac, McCloud and Pit volumes. For volume totals above Bend Bridge add Upper Sac, McCloud, Pit and Sac at Bend Bridge volumes.

† Deep, and particularly low-elevation snow in areas that typically are snow-free can report exceptionally high percent of average for this date because the mean 2001-2021 regression-derived SWE for that area is low or 0.

* 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

https://www.colorado.edu/instaar/research/labs-groups/mountain-hydrology-group/sierra-nevada-swe-reports

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.

Yang, K., K. N. Musselman, K. Rittger, S. A. Margulis, T. H. Painter and N. P. Molotch. (2022). Combining ground-based and remotely sensed snow data in a linear regression model for real-time estimation of snow water equivalent. *Advances in Water Resources,* 160, 2022, 104075. DOI: 10.1016/j.advwatres.2021.104075