Spatial Estimates of Snow-Water Equivalent (SWE)

Intermountain West Region

February 15, 2023

Team: Noah Molotch[1,2] and Leanne Lestak[1]
[1] Institute of Arctic and Alpine Research, University of Colorado Boulder
Report generation funded by: U.S. Bureau of Reclamation
Contact: Leanne.Lestak@colorado.edu

Summary of current conditions (as of 2/15/23)

As of February 15th, the modeled snow water equivalent (SWE) was in the range of 66% to 186% of the 2001-21 average across the Intermountain West (Figures 1 & 3). This is a time of year when percent of average values can be especially high in low-elevation areas as these values are quite sensitive to recent snowfall. Please note that the basin-wide percent of long-term average from the spatial SWE estimates is not directly comparable with the SNOTEL basin-wide percent of average. A better comparison might be made with the % average in the elevation bands (Table 2) that contain SNOTEL sites. 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. An additional table (not shown in this text report) containing summaries of SWE for the Colorado Basin River Forecast Center's basin zones is also available.

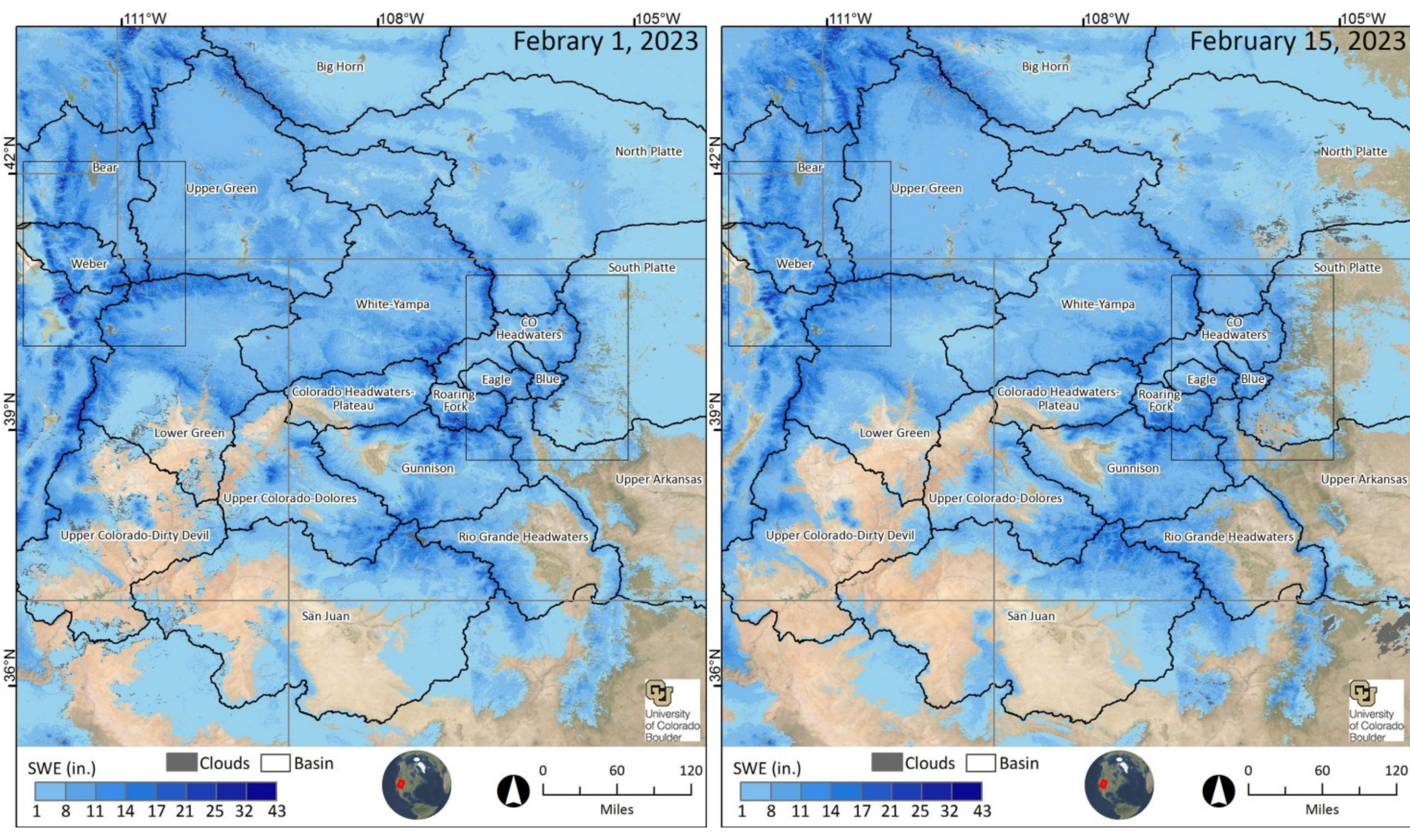


Figure 1. Estimated SWE amounts across the Intermountain West, for February 1st (left) and February 15th (right).

Data Issues/Caveats for **February 15, 2023**

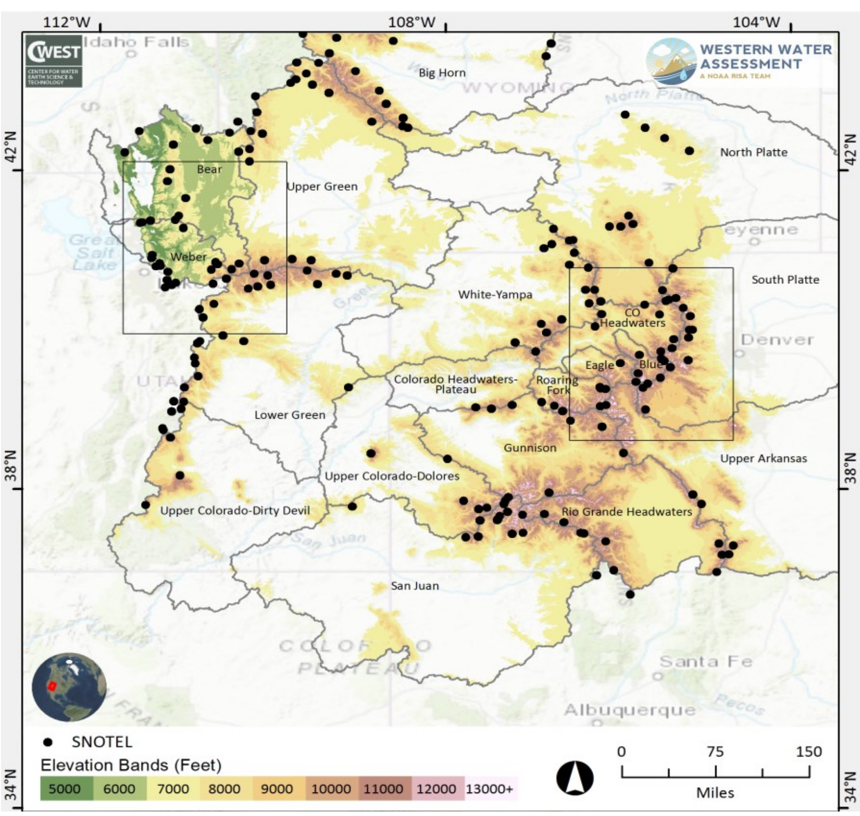
- DENSE FOREST COVER – Dense forest cover at lower elevations where snow-cover is discontinuous can cause the satellite to underestimate the snow-cover extent, leading to underestimation of SWE.
- CLOUD COVER – Cloud cover can obscure satellite measurements of snow-cover. While careful checks are made, occasionally the misclassification of clouds as snow or *vice versa* may result in the mischaracterization of SWE or bare-ground.
- 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.
- 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.
- 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.

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 Intermountain West region (Colorado, Utah, and Wyoming) 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 Sierra Nevada has been distributed to water managers in California since 2013-14.

The spatial SWE analysis method for the Intermountain West uses the following data as inputs:

- In-situ SWE from all operational NRCS SNOTEL sites and the CoCoRaHS network
- 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 (1985-2021) 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.

Figure 2. Intermountain West region. Location map identifies basins used in this report (gray boundaries), SNOTEL sites (black dots), and 1000' elevation bands (colored shading) that match those used in Table 1 and Table 2. The elevation bands below 7000' are shown only in the Bear and Weber basins. The Wasatch Front and Colorado Headwaters sub-regions are indicated by the small boxes.

Data availability for this report

307 SNOTEL sites in the Intermountain West network were recording SWE values out of a total of 313 sites; 0 were offline. 501 CoCoRaHs sites were also used for this report.

The value of spatially explicit estimates of SWE

Snowmelt makes up the large majority (~60-85%) of the annual streamflow in the Intermountain West. 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 hundreds of NRCS SNOTEL sites spread across the Intermountain West, providing a critical first-order snapshot of conditions, and the basis for runoff forecasts from NRCS and NOAA.
However, conditions at SNOTEL 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 SNOTEL sites. The spatial snow analysis creates a detailed picture of the spatial pattern of SWE using SNOTEL, satellite, and other data, extending beyond the SNOTEL 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, SNOTEL samples 8-20 points per basin within a narrower elevation range (Figure 2). Thus, the basin-wide percent of long-term average from the spatial SWE estimates is not directly comparable with the SNOTEL basin-wide percent of average. A better comparison might be made with the % average in the elevation bands (Table 2) that contain SNOTEL sites.

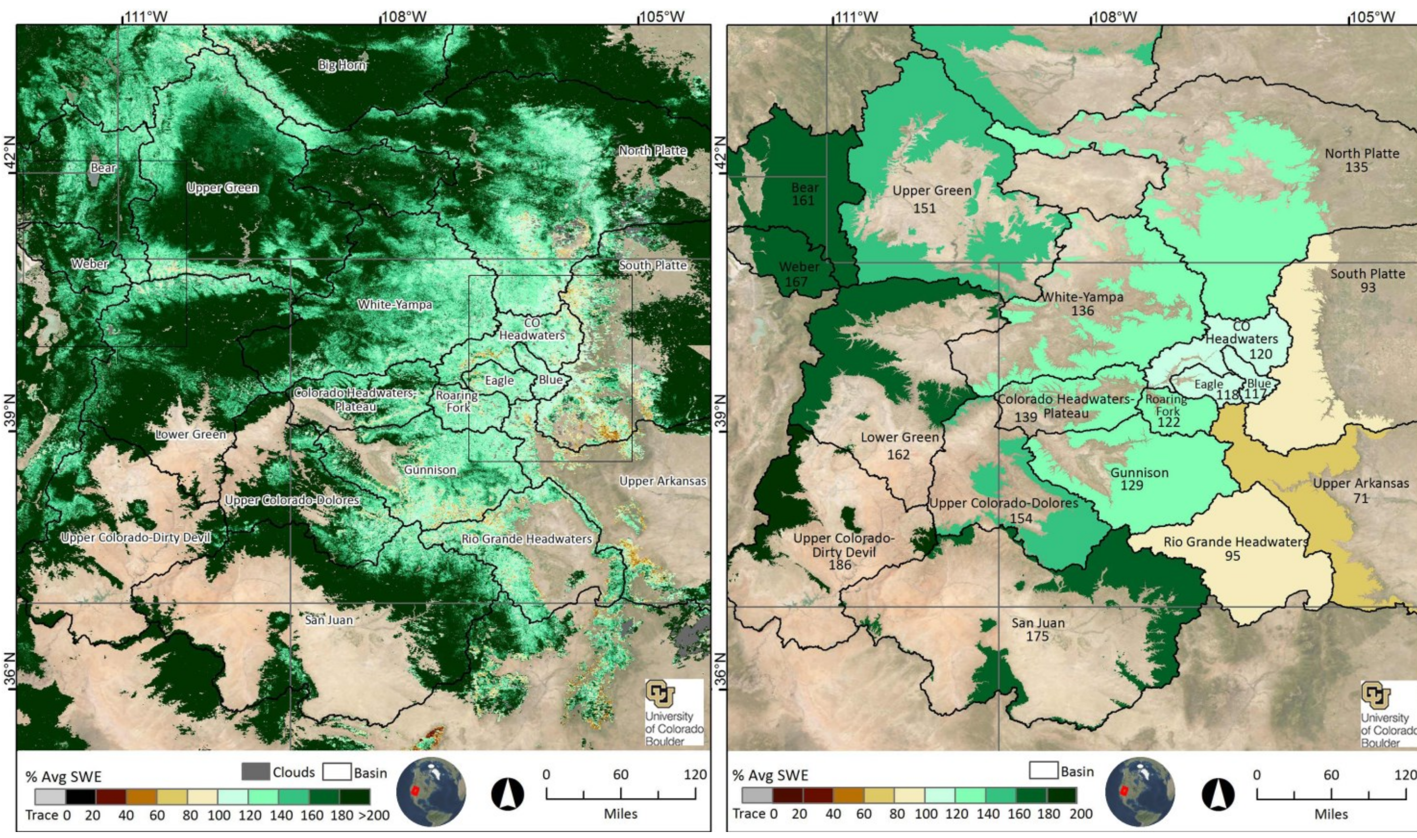


Figure 3**. **Estimated % of average SWE across the Intermountain West, February 15, 2023. Percent of long-term average (2001-2021) SWE for February 15, 2023 for the Intermountain West, calculated for each pixel (left) and basin-wide (right). Note that the basin-wide averages may reflect variable conditions across the elevation bands; see Table 2. Basin-wide percent of average is calculated across all model pixels >7000' elevation (>5000' elevation in the Bear River/Weber basins). This is a time of year when sporadic percent of average especially in low-elevation areas will be higher than historical averages.

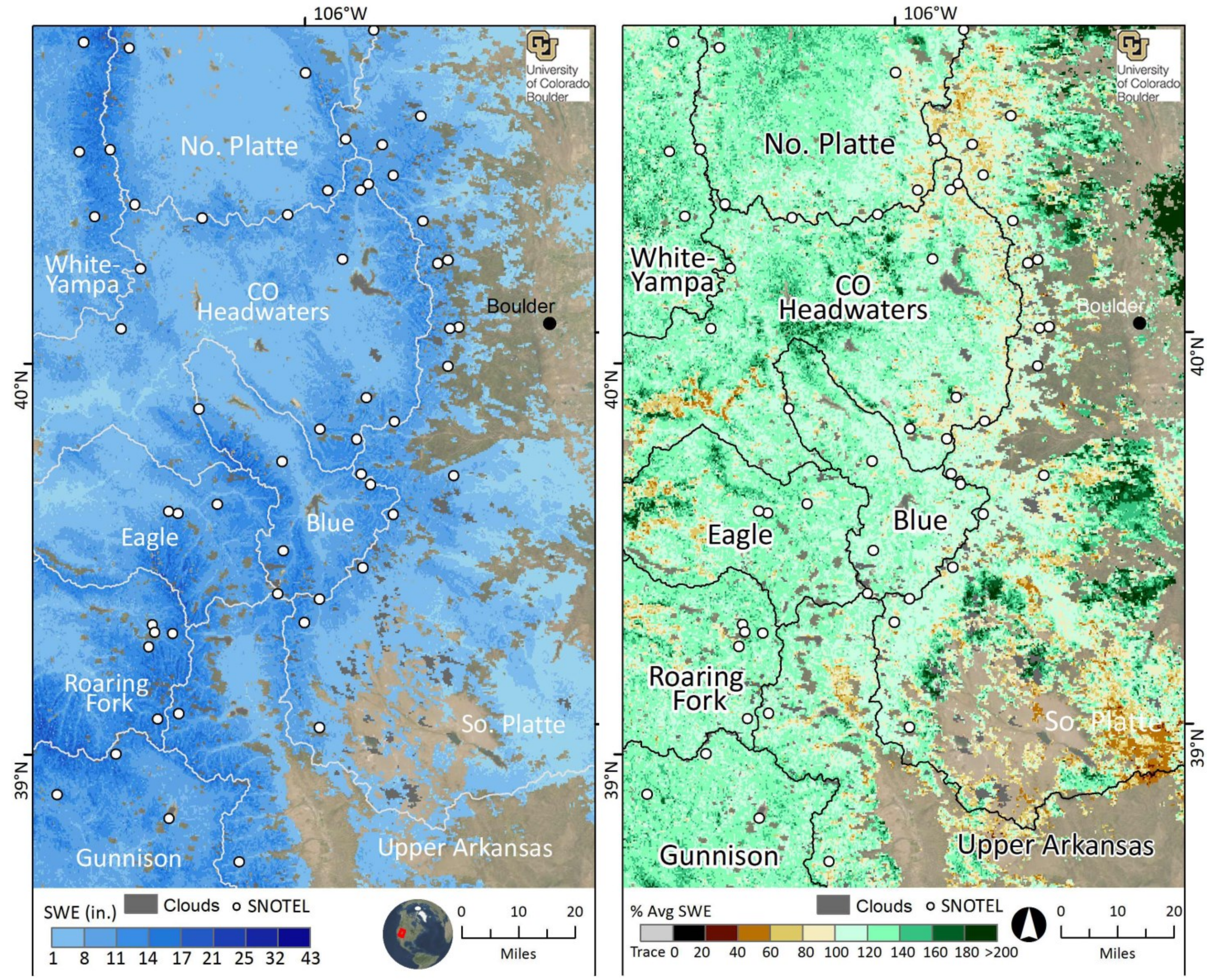


Figure 4. Estimated SWE across the Colorado Headwaters Sub-region, February 15, 2023. SWE amounts for February 15, 2023 (left), and the % of long-term average (2001-20201 SWE for February 15, 2023 for the snow-covered area (right). This is a time of year when sporadic percent of average especially in low-elevation areas will be higher than historical averages, hence the dark green shaded areas in the right map.

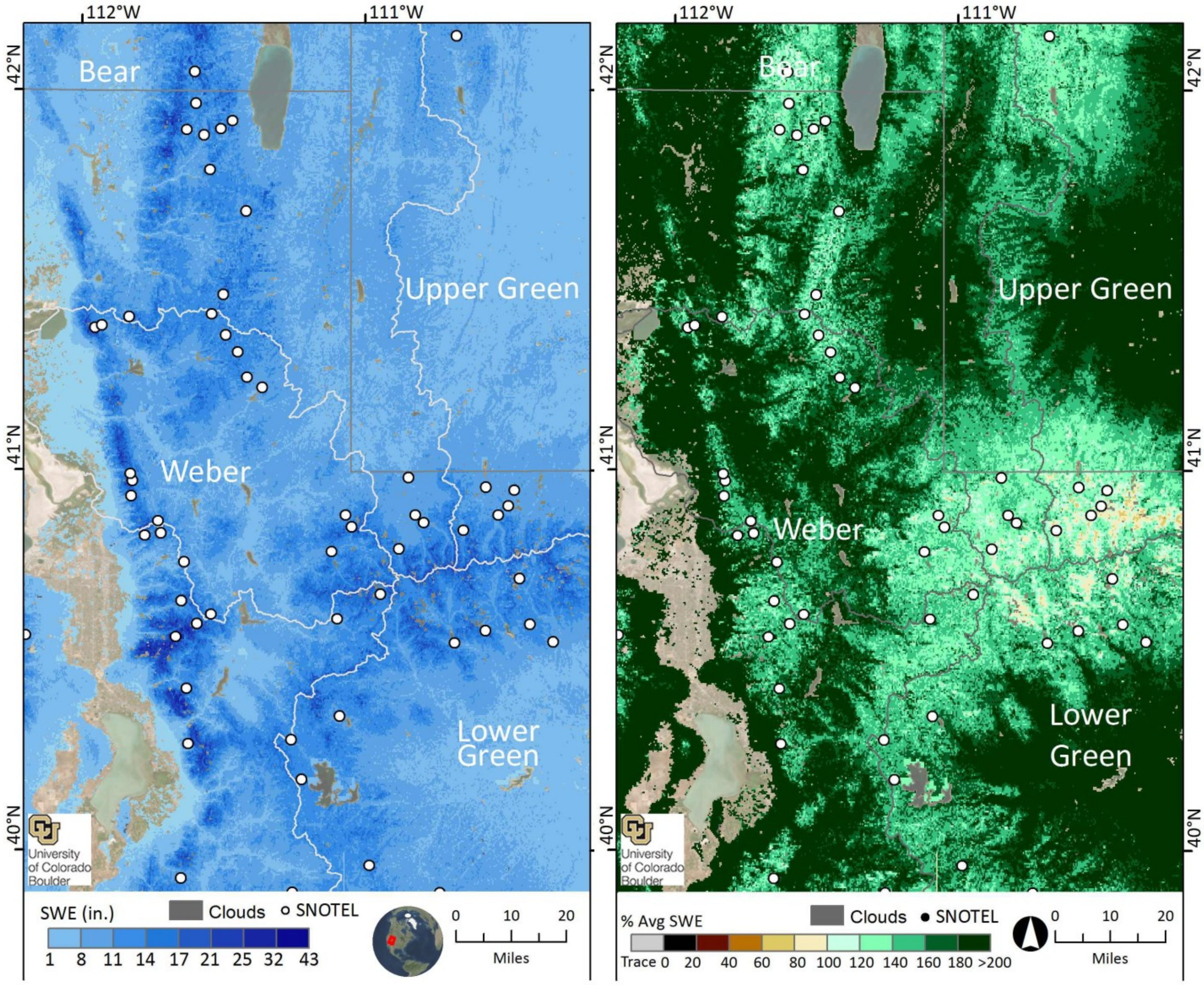


Figure 5. Estimated SWE across the Wasatch Front Sub-region, February 15, 2023. SWE amounts for February 15, 2023 (left), and the % of long-term average (2000-2020) SWE on February 15, 2023 for the snow-covered area. This is a time of year when sporadic percent of average especially in low-elevation areas will be higher than historical averages, hence the dark green shaded areas in the right map.

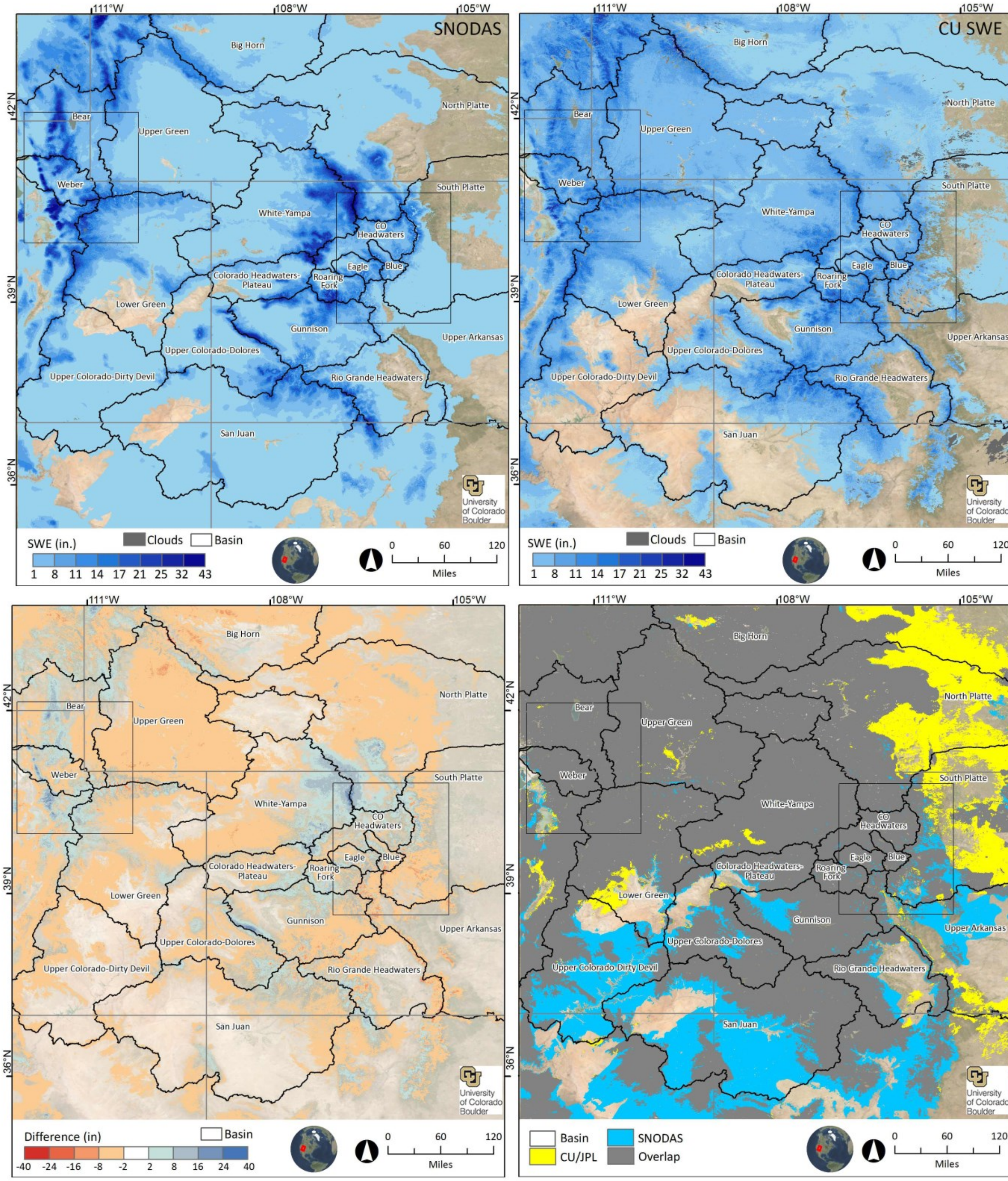


Figure 6. Comparison of the experimental CU SWE product and SNODAS SWE for the Intermountain West. The map in the upper left shows estimated SWE for February 15th from the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS). The upper right map shows experimental CU SWE estimated SWE amounts. The lower left map shows the difference between the February 15th SNODAS SWE estimate and the experimental CU 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. The map in the lower left 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.

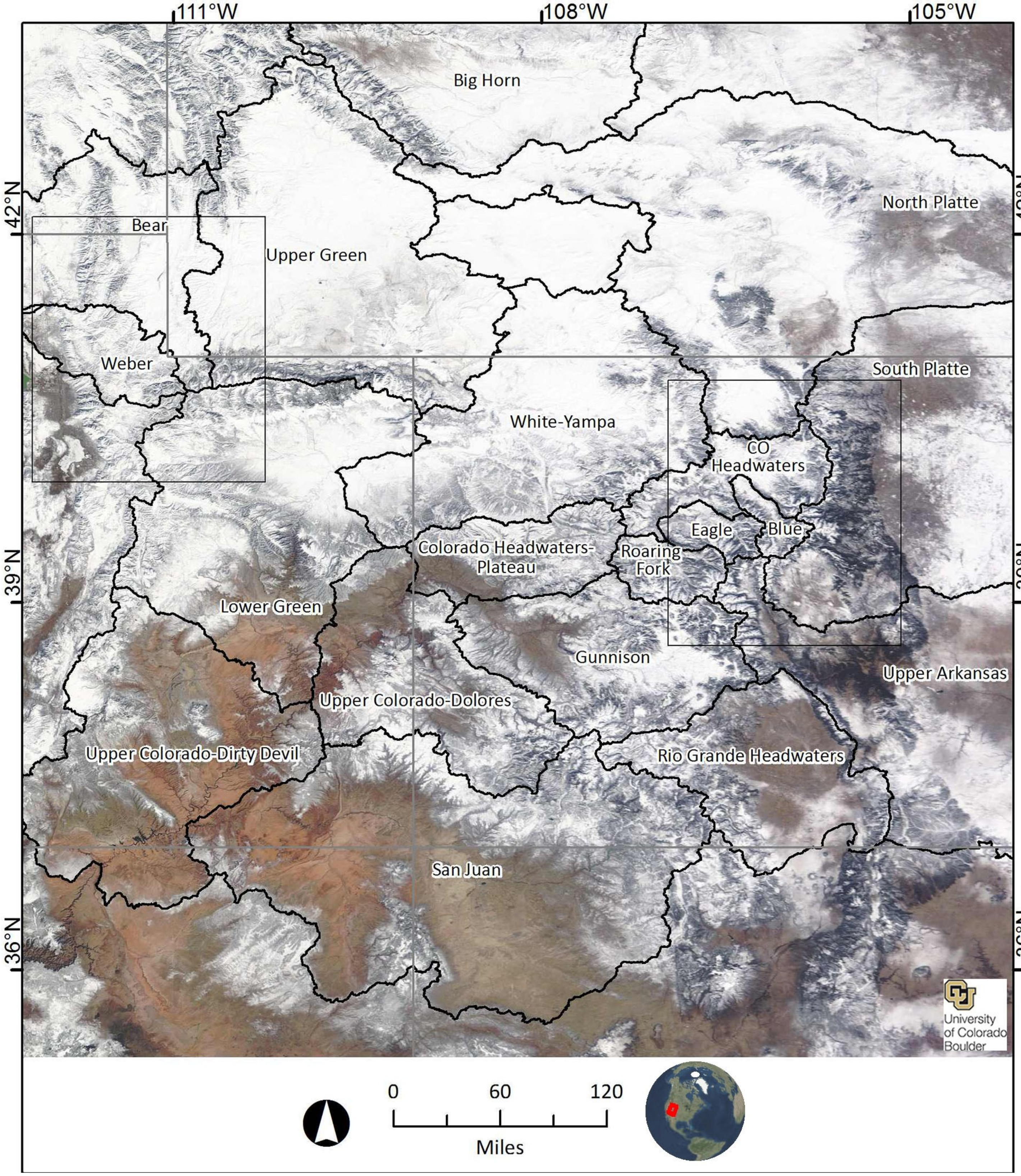


Figure 7. MODIS Image, Intermountain West. The February 15, 2023 cloud-free true color composited MODIS image showing the area that was used for the February 15, 2023 regression model run. 3 MODSCAG (MODIS Snow Covered Area and Grain-size) images were composited to create the model input fractional snow-covered area image.

Table 1. Estimated SWE by basin. The basin-wide SWE values and averages, and areas, for all pixels at elevations >7000', except for the Bear and Weber basins, which are >5000'. Shown are February 1st percent of February 1st average SWE, February 15th percent of February 15th average SWE (2001-21 as derived from the regression model), February 1st mean SWE, February 15th mean SWE, February 15th percent of snow-covered area, February 15th SWE volume (acre-feet), the area (mi^2) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), February 1st SNOTEL sensors, and February 15th SNOTEL sensors (the number of stations are in parentheses), for those areas collected, summarized for each basin. For comparison, the last column shows February 15th basin-wide mean SWE from SNODAS*.

Basin	2/1/23 % 2/1 Avg.	2/15/23 % 2/15 Avg.	2/1/23 SWE (in)	2/15/23 SWE (in)	2/15/23 % SCA	2/15/23 SWE Vol (af)	2/15/23 Area (mi^2)	2/1/23 Sensors (in)	2/15/23 Sensors (in)	2/15/23 SNODAS* (in)
Bear	165	161	10.2	10.1	96.9	3,509,000	6,525	15.5 (19)	16.3 (19)	10.0
Blue	130	117	10.0	10.0	97.6	379,386	711	11.5 (5)	12.3 (5)	8.5
Colorado Headwaters	130	119	8.2	8.6	97.8	1,376,505	3,014	12.4 (12)	13.1 (12)	9.4
Colorado Headwaters-Plateau	165	139	11.1	9.7	95.9	1,011,832	1,949	12.8 (1)	14.0 (1)	9.7
Eagle	132	117	9.6	9.5	96.3	501,322	987	11.6 (3)	12.2 (3)	9.3
Gunnison	133	129	8.7	9.5	96.1	3,464,698	6,832	13.2 (11)	14.8 (10)	8.5
Lower Green	182	162	11.4	10.6	97.5	3,477,485	6,163	13.4 (20)	13.7 (20)	10.0
North Platte	158	134	6.5	6.3	88.5	3,751,191	11,213	14.7 (20)	15.7 (19)	5.2
Rio Grande Headwaters	93	94	4.1	4.8	49.2	1,996,267	7,878	6.7 (13)	7.3 (14)	3.3
Roaring Fork	136	122	11.7	11.3	97.4	868,321	1,442	12.3 (7)	13.5 (7)	11.5
San Juan	161	174	6.6	7.8	91.0	2,796,999	6,700	15.0 (16)	17.3 (15)	6.8
South Platte	153	86	5.0	4.3	63.4	1,335,682	5,843	8.7 (20)	9.1 (20)	2.2
Upper Arkansas	97	66	3.4	3.2	42.8	1,056,900	6,194	4.8 (6)	5.4 (6)	1.4
Upper Colorado-Dirty Devil	195	186	8.6	8.5	90.8	1,254,294	2,779	9.6 (4)	10.5 (4)	5.9
Upper Colorado-Dolores	160	154	8.6	8.8	95.4	1,714,757	3,637	13.2 (7)	14.8 (7)	8.5
Upper Green	161	151	8.8	8.6	94.3	4,885,753	10,662	10.3 (21)	10.8 (20)	5.5
Weber	178	167	11.1	10.8	96.3	1,313,950	2,273	20.7 (14)	21.3 (14)	11.2
White-Yampa	155	136	9.8	9.0	96.1	3,114,921	6,509	18.7 (14)	19.8 (14)	11.2

* 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 7000’ and extend past the highest point in the basin, except for the Bear and Weber basins, which begin at 5000’. Note that the area of the highest 2-5 bands is typically much smaller than the lower bands Shown are February 1st percent of February 1st average SWE, February 15th percent of February 15th average SWE (2001-21 as derived from the regression model), February 1st mean SWE, February 15th mean SWE, February 15th percent of snow-covered area, February 15th SWE volume (acre-feet), the area (mi^2) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), February 1st SNOTEL sensors, and February 15th SNOTEL sensors (the number of stations are in parentheses), for those areas collected, summarized for each 1000’ elevation band within each basin. For comparison, the last column shows February 15th mean SWE for each 1000’ elevation band from SNODAS*.

Basin	Elevation Band	2/1/23 % 2/1 Avg.	2/15/23 % 2/15 Avg.	2/1/23 SWE (in)	2/15/23 SWE (in)	2/15/23 % SCA	2/15/23 SWE Vol (af)	2/15/23 Area (mi^2)	2/1/23 Sensors (in)	2/15/23 Sensors (in)	2/15/23 SNODAS* (in)
Bear	5000-6000'	194	199	8.3	8.1	96.2	366,793	846.2	NA	NA	6.9
	6000-7000'	173	172	9.1	9.1	95.2	1,367,334	2805.2	11.8 (3)	12.5 (3)	7.5
	7000-8000'	155	153	10.4	10.6	97.2	1,127,088	1985.8	14.2 (8)	14.9 (8)	11.5
	8000-9000'	149	138	14.1	13.3	99.2	458,059	644.5	20.5 (6)	21.6 (6)	18.2
	9000-10,000'	147	131	14.7	13.7	99.6	106,174	145.3	11.6 (2)	12.1 (2)	16.3
	10,000-11,000'	155	131	17.8	15.7	99.0	69,383	83.0	NA	NA	15.9
	11,000-12,000'	156	135	19.9	17.6	96.3	12,931	13.7	NA	NA	13.7
	12,000-13,000'	151	136	19.1	17.5	93.6	1,238	1.3	NA	NA	9.9
Blue	7000-8000'	132	139	4.4	6.1	97.8	11,759	36.0	NA	NA	6.0
	8000-9000'	131	118	6.3	6.8	99.3	39,094	107.1	NA	NA	5.6
	9000-10,000'	135	117	8.0	8.1	98.6	55,070	128.3	8.2 (1)	9.1 (1)	7.3
	10,000-11,000'	133	116	10.3	10.2	99.3	106,381	195.8	14.4 (2)	15.3 (2)	9.7
	11,000-12,000'	129	116	13.1	12.6	97.8	117,075	173.9	10.2 (2)	10.9 (2)	10.6
	12,000-13,000'	119	117	13.6	13.5	91.9	45,334	63.2	NA	NA	8.4
	13,000+	98	117	12.8	13.5	79.4	4,673	6.5	NA	NA	3.6
Colorado Headwaters-Plateau	7000-8000'	174	145	8.6	7.3	97.3	289,646	740.1	NA	NA	5.9
	8000-9000'	167	133	11.5	9.5	99.2	364,090	719.2	NA	NA	8.6
	9000-10,000'	149	139	12.7	12.8	99.9	174,808	256.4	NA	NA	14.6
	10,000+	158	142	15.6	14.7	99.9	177,963	226.4	12.8 (1)	14.0 (1)	19.1
Colorado Headwaters	7000-8000'	129	127	4.7	5.7	96.0	142,732	469.0	NA	NA	5.9
	8000-9000'	127	121	6.4	7.1	96.7	342,649	902.3	8.2 (3)	8.8 (3)	6.7
	9000-10,000'	130	123	8.1	8.9	98.4	369,138	777.0	10.1 (3)	10.6 (3)	9.6
	10,000-11,000'	134	117	11.5	11.0	98.8	355,083	606.8	16.2 (5)	17.1 (5)	14.7
	11,000-12,000'	131	107	14.0	12.1	95.9	146,566	228.0	12.8 (1)	13.5 (1)	13.0
	12,000+	113	106	12.8	12.1	89.1	20,180	31.2	NA	NA	7.1
Eagle	7000-8000'	126	121	4.6	5.7	99.6	52,376	172.0	NA	NA	3.7
	8000-9000'	129	117	7.4	7.7	99.6	80,080	196.2	9.7 (1)	10.4 (1)	6.3
	9000-10,000'	135	118	9.2	9.2	99.4	90,349	184.3	11.3 (1)	11.9 (1)	9.7
	10,000-11,000'	134	116	11.2	10.8	98.8	152,629	264.5	13.7 (1)	14.4 (1)	12.4
	11,000-12,000'	138	119	14.7	13.6	99.1	98,253	135.5	NA	NA	13.6
	12,000-13,000'	128	122	15.9	15.0	93.3	25,970	32.4	NA	NA	11.1
	13,000+	109	122	15.2	14.9	84.7	1,666	2.1	NA	NA	7.7
Gunnison	7000-8000'	142	144	5.2	6.3	97.5	364,738	1091.4	NA	NA	5.1
	8000-9000'	135	137	7.2	8.4	98.7	819,032	1829.1	16.0 (1)	17.5 (1)	7.7
	9000-10,000'	133	129	8.7	9.6	98.9	725,921	1413.3	17.4 (2)	18.7 (2)	9.1
	10,000-11,000'	131	122	10.3	10.8	98.5	880,433	1529.8	14.0 (5)	16.0 (4)	10.1
	11,000-12,000'	128	118	12.6	12.6	98.4	455,085	675.2	8.4 (3)	9.8 (3)	11.2
	12,000-13,000'	127	120	14.2	14.0	95.6	200,286	268.6	NA	NA	10.1
	13,000+	119	121	14.4	14.4	90.3	19,203	25.0	NA	NA	7.8

Basin	Elevation Band	2/1/23 % 2/1 Avg.	2/15/23 % 2/15 Avg.	2/1/23 SWE (in)	2/15/23 SWE (in)	2/15/23 % SCA	2/15/23 SWE Vol (af)	2/15/23 Area (mi^2)	2/1/23 Sensors (in)	2/15/23 Sensors (in)	2/15/23 SNODAS* (in)
Lower Green	7000-8000'	199	180	8.8	8.3	97.5	1,087,638	2459.3	8.4 (1)	8.5 (1)	6.9
	8000-9000'	182	163	11.5	10.8	99.3	1,100,152	1905.6	12.8 (9)	13.1 (9)	11.0
	9000-10,000'	173	151	13.8	12.7	99.7	597,412	881.2	15.4 (5)	15.9 (5)	13.6
	10,000-11,000'	164	140	15.5	13.8	99.0	494,123	670.0	13.1 (4)	13.3 (4)	13.4
	11,000-12,000'	157	141	16.0	14.9	96.0	164,508	207.4	15.2 (1)	15.6 (1)	11.6
	12,000-13,000'	150	145	16.3	16.1	95.1	32,392	37.7	NA	NA	8.3
	13,000+	141	145	16.4	16.9	91.9	1,261	1.4	NA	NA	3.7
North Platte	7000-8000'	176	146	5.7	5.2	92.4	1,909,583	6909.3	10.1 (3)	10.7 (3)	1.8
	8000-9000'	136	128	6.5	7.1	95.9	1,026,414	2709.9	10.3 (5)	11.1 (5)	8.0
	9000-10,000'	136	116	8.8	8.7	99.3	446,232	962.7	17.0 (7)	18.5 (6)	13.2
	10,000-11,000'	140	110	12.6	10.7	99.2	322,102	563.1	18.7 (5)	19.9 (5)	18.4
	11,000-12,000'	129	110	15.3	13.0	92.7	44,291	63.7	NA	NA	16.0
	12,000-13,000'	108	111	12.6	12.6	86.1	2,569	3.8	NA	NA	7.1
Rio Grande Headwaters	7000-8000'	11	7	0.2	0.1	5.8	13,747	2690.3	NA	NA	0.0
	8000-9000'	97	78	2.7	2.7	68.6	213,120	1494.9	NA	NA	0.9
	9000-10,000'	118	116	5.4	6.4	92.0	375,805	1108.9	5.7 (1)	6.6 (1)	3.7
	10,000-11,000'	116	115	7.5	8.5	95.6	649,800	1425.5	4.7 (7)	5.4 (7)	7.7
	11,000-12,000'	114	124	9.7	11.7	96.3	543,403	874.5	9.7 (5)	9.8 (6)	9.2
	12,000-13,000'	108	131	10.9	13.2	90.4	187,543	266.7	NA	NA	8.4
	13,000+	94	135	11.0	13.7	78.9	12,850	17.6	NA	NA	5.4
Roaring Fork	7000-8000'	120	125	5.4	6.6	98.8	75,402	215.0	NA	NA	4.1
	8000-9000'	130	117	8.3	8.3	99.4	122,052	276.3	7.0 (1)	7.6 (1)	7.5
	9000-10,000'	141	125	10.8	10.6	99.4	139,082	245.8	11.5 (2)	12.7 (2)	11.5
	10,000-11,000'	140	125	13.1	12.7	99.6	225,084	331.7	15.0 (3)	16.4 (3)	14.3
	11,000-12,000'	142	123	16.8	15.2	99.0	213,162	263.4	11.0 (1)	12.0 (1)	16.4
	12,000-13,000'	137	120	18.0	16.0	96.0	86,503	101.7	NA	NA	15.1
	13,000+	128	118	19.5	16.9	91.2	7,037	7.8	NA	NA	13.3
San Juan	7000-8000'	189	>200†	4.0	5.3	93.7	1,104,870	3878.9	NA	NA	3.5
	8000-9000'	154	169	6.9	8.4	98.0	494,881	1107.7	14.6 (2)	16.2 (2)	8.1
	9000-10,000'	146	151	9.3	10.4	98.6	299,244	541.2	10.6 (4)	12.8 (3)	11.0
	10,000-11,000'	140	138	12.3	12.8	98.1	368,300	538.9	15.5 (5)	17.5 (5)	14.4
	11,000-12,000'	129	138	14.2	15.5	95.3	356,785	431.4	18.2 (5)	20.2 (5)	15.7
	12,000-13,000'	116	133	15.2	16.0	86.8	160,209	187.7	NA	NA	14.1
	13,000+	113	132	16.5	16.8	82.9	12,709	14.2	NA	NA	11.3
South Platte	7000-8000'	>200†	113	3.3	2.1	90.0	169,284	1489.2	NA	NA	0.1
	8000-9000'	168	86	3.8	3.0	90.3	244,933	1542.6	5.9 (3)	6.0 (3)	0.7
	9000-10,000'	136	76	4.3	3.7	91.4	258,498	1301.6	10.4 (4)	10.7 (4)	1.7
	10,000-11,000'	118	90	7.2	6.7	93.4	312,477	869.0	9.3 (9)	9.8 (9)	5.8
	11,000-12,000'	118	103	10.1	9.8	96.1	240,360	460.1	7.6 (4)	8.2 (4)	6.7
	12,000-13,000'	112	110	11.0	11.3	90.6	96,380	159.5	NA	NA	6.2
	13,000+	99	109	11.4	12.0	80.3	13,751	21.5	NA	NA	3.6

Basin	Elevation Band	2/1/23 % 2/1 Avg.	2/15/23 % 2/15 Avg.	2/1/23 SWE (in)	2/15/23 SWE (in)	2/15/23 % SCA	2/15/23 SWE Vol (af)	2/15/23 Area (mi^2)	2/1/23 Sensors (in)	2/15/23 Sensors (in)	2/15/23 SNODAS* (in)
Upper Arkansas	7000-8000'	71	40	0.6	0.5	28.7	46,394	1854.7	NA	NA	0.0
	8000-9000'	70	32	1.6	1.0	42.4	87,562	1587.4	NA	NA	0.1
	9000-10,000'	102	62	3.6	3.0	73.5	198,323	1233.7	1.4 (1)	2.0 (1)	0.6
	10,000-11,000'	111	90	6.2	6.2	88.7	257,158	774.6	5.8 (3)	6.4 (3)	3.0
	11,000-12,000'	120	117	10.1	11.0	97.1	262,637	447.7	5.1 (2)	5.7 (2)	6.8
	12,000-13,000'	120	124	12.1	12.9	92.5	172,987	250.9	NA	NA	6.9
	13,000+	107	121	12.3	13.1	83.0	31,839	45.4	NA	NA	4.5
Upper Colorado-Dirty Devil	7000-8000'	>200†	>200†	5.5	6.1	88.2	389,483	1187.7	NA	NA	2.5
	8000-9000'	191	179	8.7	8.5	97.6	381,871	837.9	8.5 (1)	10.4 (1)	6.6
	9000-10,000'	180	152	12.1	10.7	99.0	227,485	399.5	11.5 (2)	11.8 (2)	9.0
	10,000-11,000'	175	150	14.5	13.2	99.2	202,236	288.0	7.0 (1)	7.9 (1)	12.1
	11,000-12,000'	164	157	14.6	15.0	99.9	53,220	66.3	NA	NA	11.9
Upper Colorado-Dolores	7000-8000'	177	181	6.0	6.6	98.5	526,091	1492.4	NA	NA	5.0
	8000-9000'	158	150	8.8	8.9	99.0	544,121	1143.7	11.8 (1)	12.6 (1)	8.3
	9000-10,000'	155	144	10.8	10.8	99.5	279,919	487.1	13.3 (3)	14.8 (3)	12.5
	10,000-11,000'	143	130	12.3	12.1	99.5	224,820	347.4	13.6 (3)	15.6 (3)	15.3
	11,000-12,000'	139	134	15.2	15.3	97.3	100,980	123.9	NA	NA	16.4
	12,000-13,000'	133	129	18.2	17.0	90.9	33,540	37.0	NA	NA	11.8
	13,000+	129	128	20.0	18.2	87.4	5,285	5.4	NA	NA	9.8
Upper Green	7000-8000'	176	163	7.6	7.3	93.5	2,796,964	7167.2	7.3 (1)	7.6 (1)	3.3
	8000-9000'	146	137	9.4	9.5	97.8	897,752	1774.3	10.9 (10)	11.4 (10)	7.8
	9000-10,000'	135	129	11.2	11.4	99.3	523,955	864.9	9.5 (8)	9.8 (7)	11.7
	10,000-11,000'	132	126	13.7	13.6	98.0	446,661	617.7	12.2 (2)	12.7 (2)	12.6
	11,000-12,000'	130	136	16.8	16.9	92.8	181,627	201.3	NA	NA	12.0
	12,000+	124	145	19.2	19.9	88.5	37,409	35.2	NA	NA	9.4
Weber	5000-6000'	>200†	>200†	8.3	8.3	96.7	131,498	298.4	NA	NA	6.8
	6000-7000'	189	181	9.5	9.3	97.8	410,883	826.6	13.8 (2)	14.1 (2)	7.4
	7000-8000'	167	159	11.6	11.6	98.8	461,493	749.1	24.6 (7)	25.5 (7)	13.0
	8000-9000'	163	144	15.0	13.9	99.5	192,847	260.8	16.1 (3)	16.7 (3)	19.1
	9000-10,000'	159	138	17.1	15.5	99.6	73,407	89.1	20.7 (2)	21.1 (2)	19.3
	10,000+	159	136	18.8	16.7	99.2	43,246	48.6	NA	NA	19.7
White-Yampa	7000-8000'	165	142	8.3	7.3	96.1	1,455,842	3722.9	12.3 (1)	13.0 (1)	7.1
	8000-9000'	144	130	9.9	9.6	98.6	803,499	1563.5	18.6 (5)	19.7 (5)	13.2
	9000-10,000'	144	131	12.4	12.3	99.4	429,778	657.2	16.1 (6)	17.3 (6)	18.4
	10,000-11,000'	149	130	15.5	14.1	99.1	362,290	482.8	30.0 (2)	31.4 (2)	23.5
	11,000-12,000'	152	118	18.3	14.4	97.5	63,422	82.6	NA	NA	22.1
	12,000-13,000'	129	105	14.6	12.0	93.5	89	0.1	NA	NA	18.0

† 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, Excel Format Tables, and JPG Maps
https://www.colorado.edu/instaar/research/labs-groups/mountain-hydrology-group/intermountain-west-swe-reports

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 NRCS SNOTEL sites in the domain and when applicable the CoCoRaHS SWE values. The SNOTEL SWE observations are scaled by the fractional snow-covered area (fSCA) across the 500 m pixel containing that SNOTEL site before being used in the linear regression model. The fSCA is 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 needed (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 (1985-2021) retrospectively generated using historical Landsat 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 Fang, et. al., 2022 for details. (For computational efficiency, only one image during the 1985-2021 period that best matches the real-time SNOTEL-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 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.

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 overestimate 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.
- 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.

References and Additional Sources

Hall, D. K. and G. A. Riggs. 2021. MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid, Version 61. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/MODIS/MOD10A1.061. Date Accessed May 10, 2022.

Fang, Y., Liu, Y. & Margulis, S.A. A western United States snow reanalysis dataset over the Landsat era from water years 1985 to 2021. Sci Data 9, 677 (2022). https://doi.org/10.1038/s41597-022-01768-7.

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.