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

Western United States Region

February 16, 2025

Team: Noah Molotch[1,2] , Karl Rittger[1], Leanne Lestak[1], Emma Tyrrell[1] and Kehan Yang[1]
[1] Institute of Arctic and Alpine Research, University of Colorado Boulder
[2] Jet Propulsion Laboratory, California Institute of Technology
Report generation funded by: U.S. Bureau of Reclamation
Contact: Leanne.Lestak@colorado.edu

Introduction

Figure 1 below displays estimated SWE amounts across the Western United States. 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 here. 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 percent of average in the elevation banded tables (linked below) that contain SNOTEL sites.

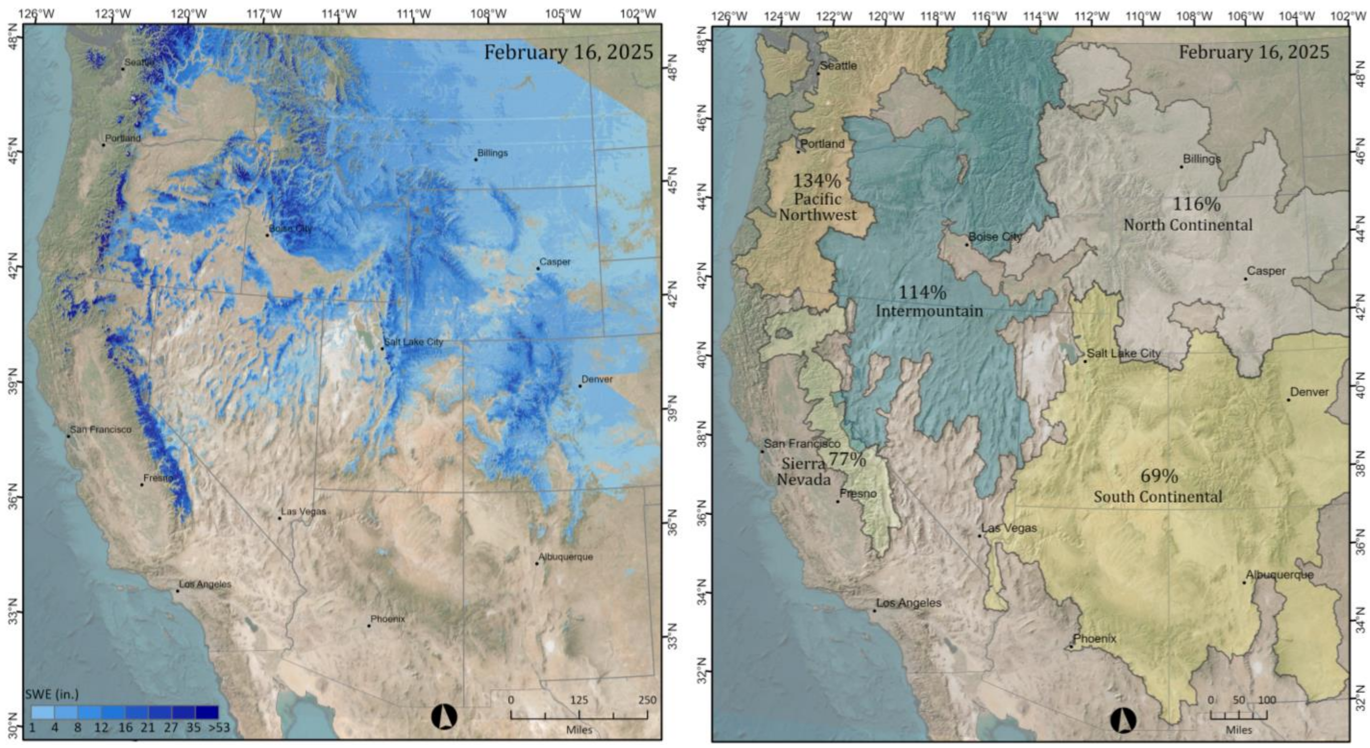


Figure 1. Estimated SWE and % of Average SWE across the Western U.S. SWE amounts across the entire Western region of the United States (left) and percent of long-term average (2001-2021) by five regions (right). Region boundaries are delineated based on Snowpack regimes of the Western United States (Trujillo and Molotch, 2014) and the Commission for Environmental Cooperation (CEC) Ecological Regions of North America, Level III [Commission for Environmental Cooperation, 2009, available at http://www.cec.org/north-american-environmental-atlas/terrestrial-ecoregions-level-iii/].

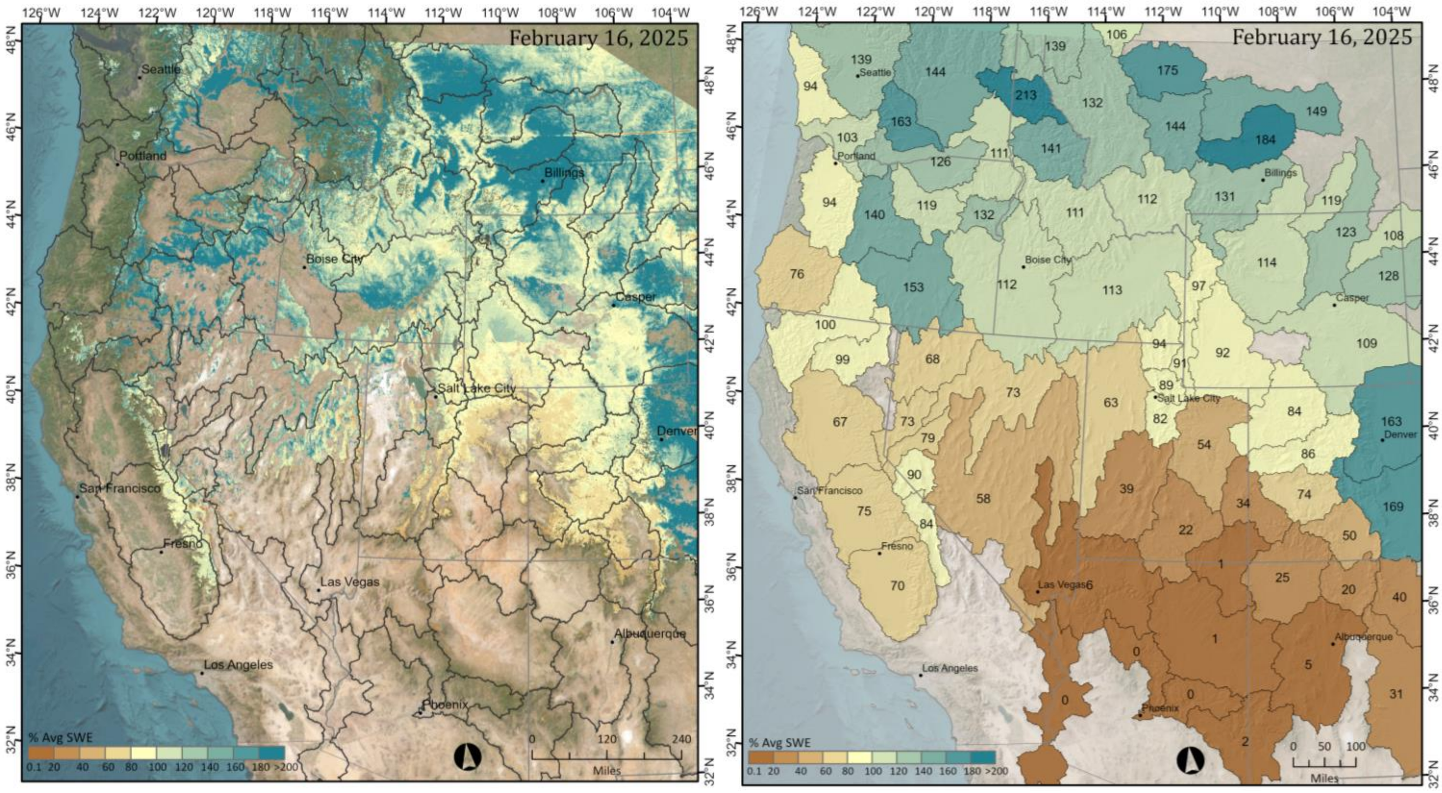


Figure 2. ***Estimated % of Average SWE across the Western U.S.*** Percent of long-term average (2001-2021) SWE calculated for each pixel (left) and by HUC-6 basin (right); integer within each watershed represents the percent of average SWE for the report date.

For detailed maps and tabular summaries of SWE and snowpack water storage volumes for specific regions and watersheds, click on the links below:

Pacific Northwest
North Continental
South Continental
Intermountain
Sierra Nevada
Elevation Banded SWE Tables

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 meters for the Western region of the United States 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 2012.

The spatial SWE data fusion (SWE-fusion) analysis method for the Western U.S. uses the following data as inputs:

- In-situ SWE from all operational NRCS and CDEC snow pillow sites, and the CoCoRaHS network when appropriate
- Fractional snow-covered area (fSCA) data from recent cloud-free satellite images
- Physiographic information (elevation, latitude, upwind mountain barriers, slope, etc.)
- Historical daily SWE patterns (1985-2021) retrospectively generated using historical fSCA 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 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-fusion product.

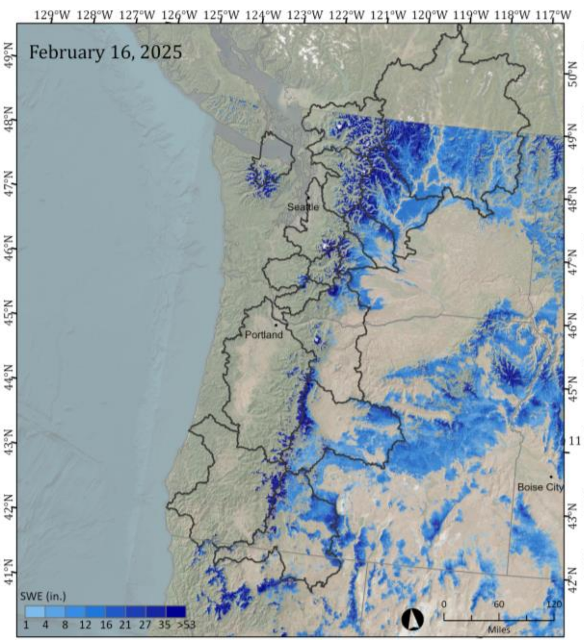
Data availability for reporting

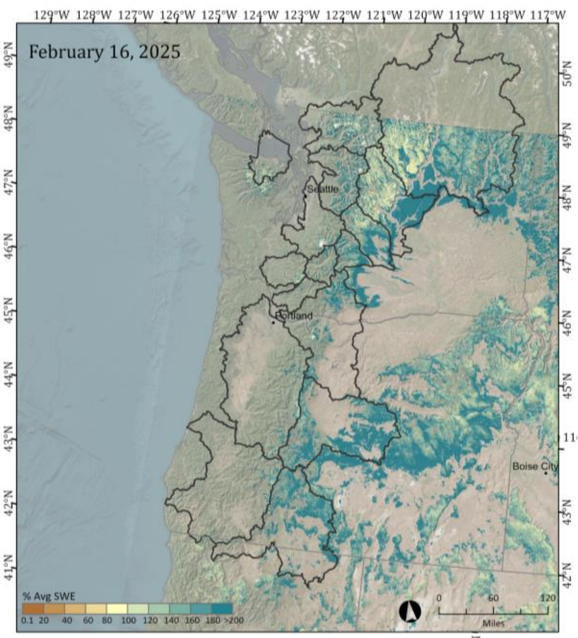
Snow pillows located throughout the Western U.S. region are input as the dependent variable in the SWE-fusion system. 799 Natural Resources Conservation Service (NRCS) Snow Telemetry (SNOTEL) sites and 131 California Department of Water Resources (CA-DWR) California Data Exchange Center (CDEC) are potentially available for each model run. In addition, the Community Collaborative Rain, Hail and Snow (CoCoRaHS, https://www.cocorahs.org/) network provides over 500 snow measurements across the modeling domain.

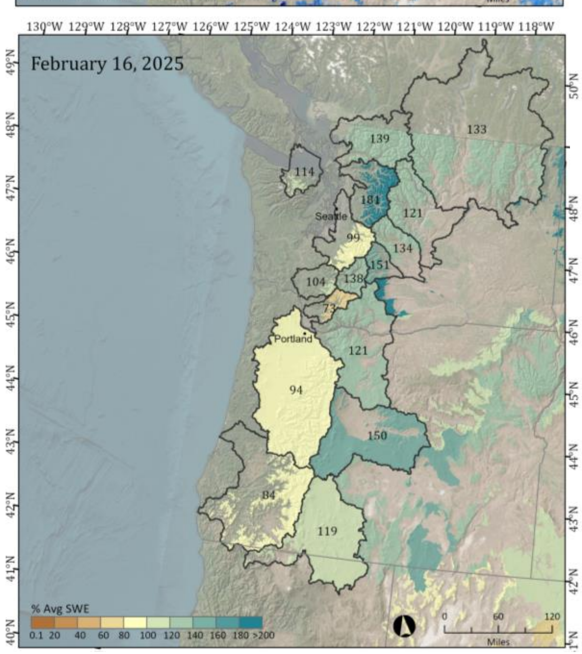
Maps and Tables by Region

Maps and tables for each of the five western regions (Figure 1b) are shown below. Note that the basin-wide averages may reflect variable conditions across the elevation bands; see banded-elevation tables (linked below). Basin-wide percent of average is calculated across all model pixels inside a given basin and base elevation. Basin base elevations vary anywhere between 2,000’ to 7,000’. Base elevations are dependent on long-term snow coverage. For example, a base elevation in the north could be lower as compared to a base elevation in the south.

Pacific Northwest







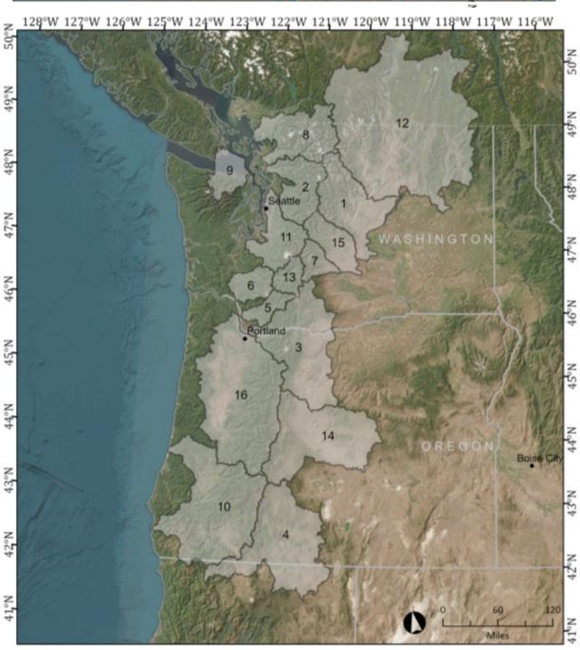


Figure 3. Estimated SWE and % of Average SWE across the Pacific Northwest Region. *SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left), and basin identification numbers that correspond to Table 1 below (lower right). The North Puget Sound and Upper Columbia basin portions that are inside Canada do not contain SWE-fusion model data due to lack of data availability needed to run the model in Canada.*

Table 1. SWE by watershed. Shown are percent of average SWE to date for the current date (2001-21 as derived from the regression model), mean SWE for the current report, current percent of snow-covered area, current 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), first of the month snow surveys, and current snow pillow sensors (the number of stations are in parentheses), for those areas collected, summarized for each basin. <u>*SWE tables by banded elevation are available below.*</u>

Pacific Northwest SWE Report for 2/16/2025

	% of Average		SWE (in)					Pillows	
Basin	2/1	2/16	2/1	2/16	SCA	Vol. (AF)	Area (mi. sq)	2/1	2/16
1. Central Columbia	113	121	13.8	17.6	81.3	2,004,417	2134.37	14.8 (7)	15.8 (7)
2. Central Puget Sound	168	181	8.1	12.2	52.6	804,610	1238.62	18.4 (4)	24.0 (5)
3. Hood-Sandy-Lower Deschutes	103	121	2.0	3.0	17.6	800,522	5079.08	12.5 (10)	17.2 (11)
4. Klamath	78	119	3.1	5.5	36.3	2,117,261	7197.14	11.9 (15)	19.6 (16)
5. Lewis	62	73	1.5	2.6	11.9	81,453	580.7	21.8 (7)	25.9 (7)
6. Lower Cowlitz	83	104	4.4	7.9	42.3	78,527	185.23	14.2 (2)	17.6 (2)
7. Naches	138	151	8.3	11.6	60.1	378,456	609.85	25.4 (4)	28.4 (4)
8. North Puget Sound	111	139	6.4	10.3	43.3	1,265,750	2312.17	22.1 (8)	24.0 (8)
9. Olympic	103	114	13.4	17.5	61.8	222,230	237.74	17.3 (3)	19.4 (3)
10. Rogue-Umpqua	66	84	2.0	3.3	12.3	589,104	3371.15	8.8 (6)	12.8 (6)
11. South Puget Sound	90	99	3.1	4.3	17.7	263,986	1147.59	13.3 (13)	15.5 (14)
12. Upper Columbia	118	133	10.1	13.1	80.8	3,829,678	5501.67	11.3 (7)	11.8 (7)
13. Upper Cowlitz	124	138	4.9	7.3	28.1	277,974	713.32	23.8 (3)	26.0 (3)
14. Upper Deschutes-Crooked	103	150	4.7	7.9	59.1	2,367,704	5606.69	19.7 (7)	22.3 (7)
15. Upper Yakima	122	134	9.5	12.6	70.4	696,096	1033.02	15.4 (3)	16.8 (3)
16. Willamette	77	94	0.7	1.2	4.8	708,158	11360.09	8.6 (18)	11.1 (18)

*Basin boundaries were derived from a combination of NRCS basins and HUC8 boundaries.

North Continental

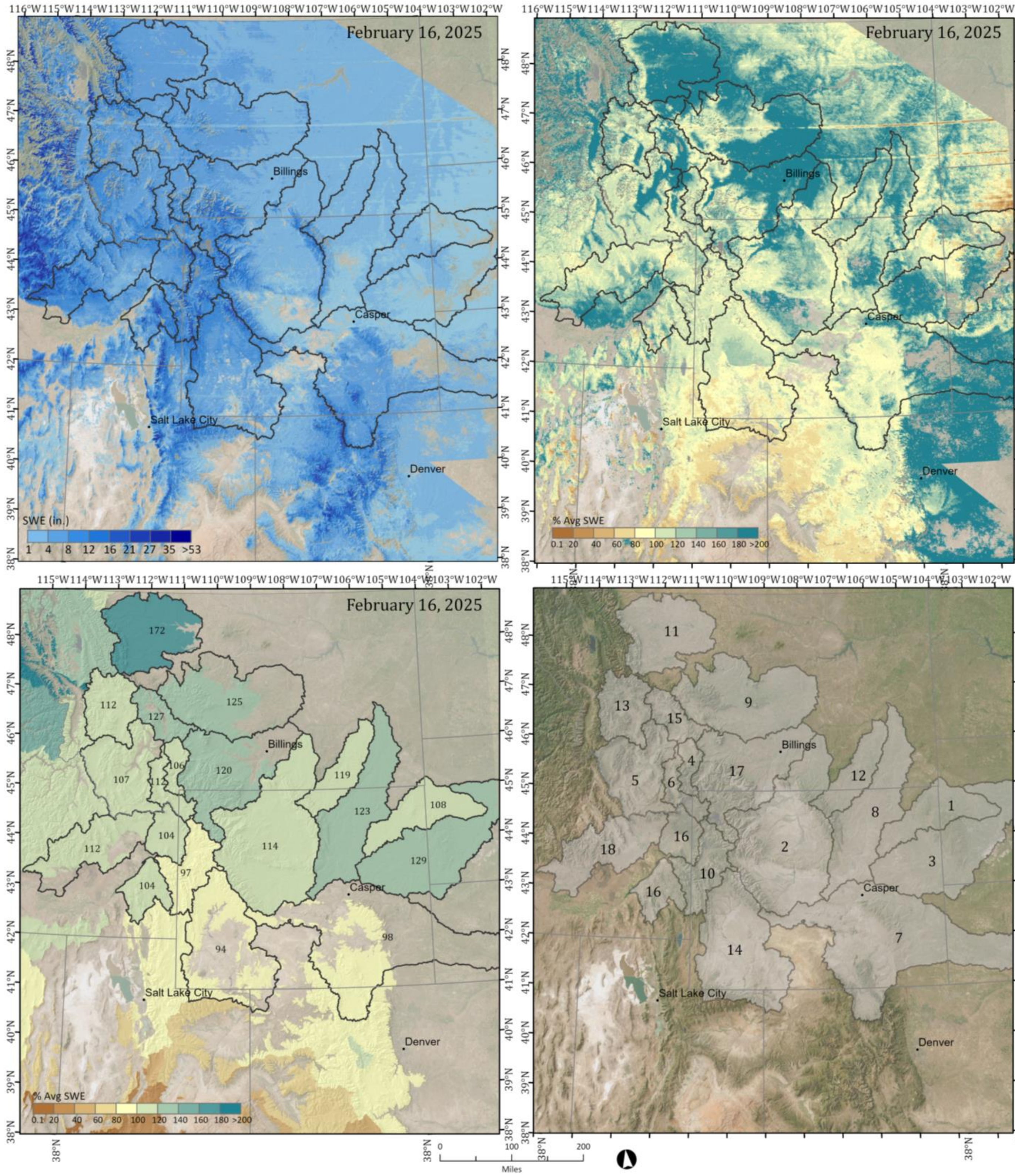


Figure 4. Estimated SWE and % of Average SWE across the Northern Continental Region. *SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left), and basin identification numbers that correspond to Table 2 below (lower right).*

Table 2. SWE by watershed. Shown are percent of average SWE to date for the current date (2001-21 as derived from the regression model), mean SWE for the current report, current percent of snow-covered area, current 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), first of the month snow surveys, and current snow pillow sensors (the number of stations are in parentheses), for those areas collected, summarized for each basin. *SWE tables by banded elevation are available below.*

North Continental SWE Report for 2/16/2025

	% of Average		SWE (in)					Pillows	
Basin	2/1	2/16	2/1	2/16	SCA	Vol. (AF)	Area (mi. sq)	2/1	2/16
1. Belle Fourche	89	108	1.7	2.3	71.4	900,962	7203.12	4.6 (1)	4.4 (1)
2. Bighorn	79	114	2.8	4.7	73.4	5,700,235	22740.55	5.8 (21)	8.4 (21)
3. Cheyenne	57	129	0.6	1.7	63.7	1,421,289	15348.04	4.2 (2)	4.4 (2)
4. Gallatin	75	106	4.3	7.1	80.5	694,415	1846.15	12.1 (4)	14.6 (4)
5. Jefferson	84	107	4.7	7.7	81.5	3,597,549	8788.26	6.4 (12)	8.7 (14)
6. Madison Headwaters in WY	77	112	4.6	7.9	83.0	1,055,749	2521.34	9.3 (7)	12.3 (7)
7. North Platte	90	98	6.0	7.5	86.8	4,103,045	10281.51	10.2 (22)	13.0 (22)
8. Powder	108	123	2.5	3.0	73.0	2,151,794	13384.42	4.3 (5)	4.6 (5)
9. Smith-Judith-Musselshell	96	125	3.8	6.3	90.4	2,781,566	8335.66	9.9 (8)	11.2 (9)
10. Snake	77	97	6.8	10.0	86.8	3,005,716	5624.93	10.4 (11)	15.7 (11)
11. Sun-Teton-Marias	123	172	2.8	6.8	95.3	3,792,508	10460.47	3.9 (5)	5.5 (5)
12. Tongue	112	119	3.0	4.0	93.5	1,152,826	5400.02	5.6 (6)	6.3 (6)
13. Upper Clark Fork	84	112	4.1	6.7	73.7	2,136,889	5982.85	6.2 (12)	8.3 (12)
14. Upper Green	76	94	5.3	7.7	86.1	3,921,186	9541.74	7.4 (21)	10.7 (21)
15. Upper Missouri	95	127	4.1	6.3	85.1	995,930	2950.01	4.4 (2)	5.7 (2)
16. Upper Snake Basins	81	104	5.5	7.8	80.9	2,857,315	6872.23	11.2 (10)	15.2 (11)
17. Upper Yellowstone	87	120	3.9	7.1	88.3	4,193,286	11070.03	8.0 (20)	11.1 (20)
18. Wood and Lost Basins	84	112	5.5	9.1	93.6	3,591,653	7420.69	7.1 (15)	10.9 (16)

*Basin boundaries were derived from a combination of NRCS basins and HUC8 boundaries.

South Continental

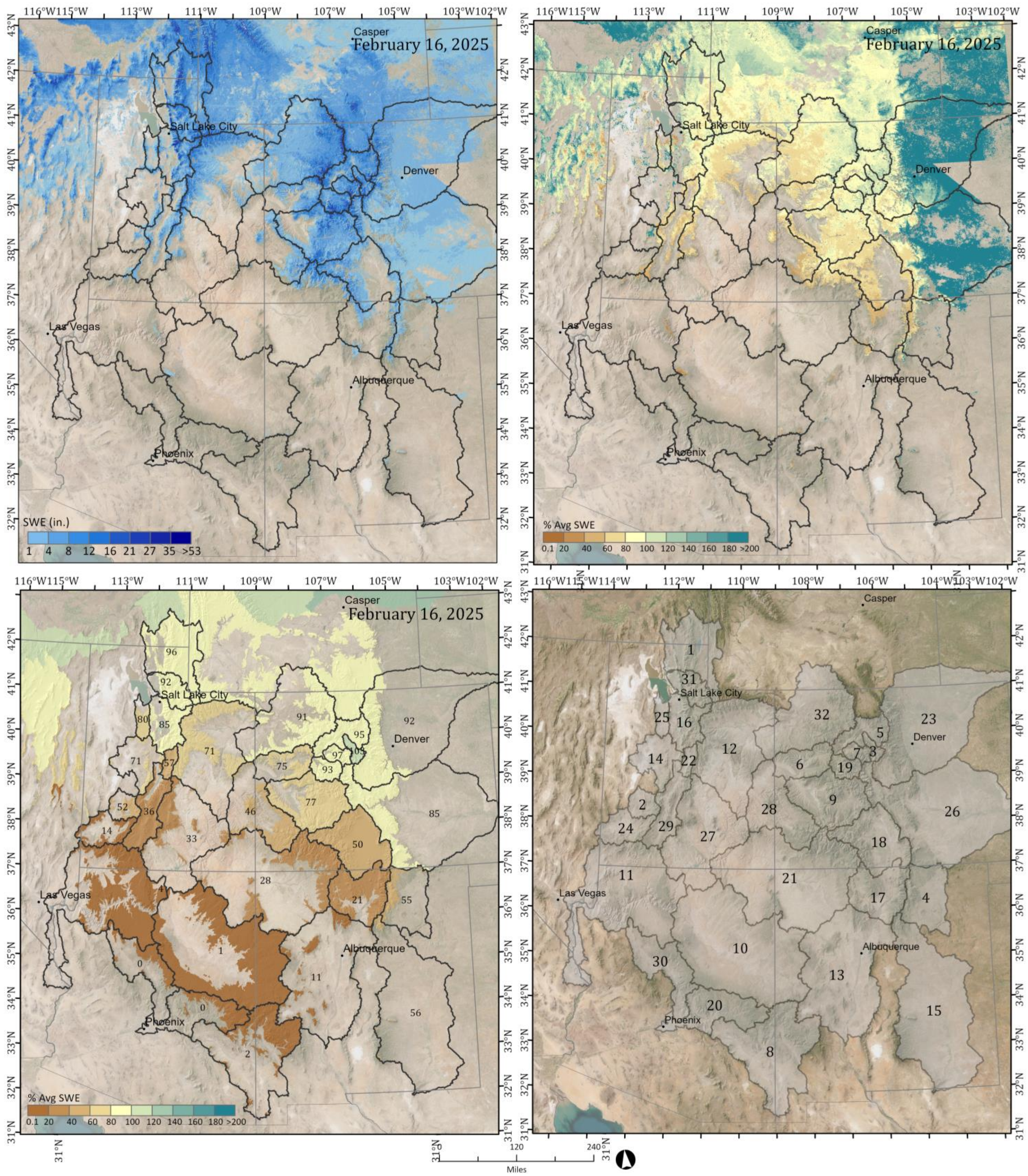


Figure 5. Estimated SWE and % of Average SWE across the Southern Continental Region. SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left), and basin identification numbers that correspond to Table 3 below (lower right).

Table 3. SWE by watershed. Shown are percent of average SWE to date for the current date (2001-21 as derived from the regression model), mean SWE for the current report, current percent of snow-covered area, current 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), first of the month snow surveys, and current snow pillow sensors (the number of stations are in parentheses), for those areas collected, summarized for each basin. *SWE tables by banded elevation are available below.*

South Continental SWE Report for 2/16/2025

	% of Average		SWE (in)					Pillows	
Basin	2/1	2/16	2/1	2/16	SCA	Vol. (AF)	Area (mi. sq)	2/1	2/16
1. Bear	75	96	5.5	7.8	79.2	2,562,396	6181.98	8.6 (18)	12.6 (18)
2. Beaver	30	52	0.6	1.5	26.0	68,251	835.62	6.4 (2)	7.8 (2)
3. Blue	89	103	7.1	9.4	79.8	333,668	668.73	10.3 (5)	12.3 (5)
4. Canadian	45	55	1.5	1.7	39.9	116,430	1265.26	3.7 (1)	4.2 (2)
5. Colorado Headwaters	88	95	6.6	8.2	79.6	1,256,654	2872.5	9.1 (13)	11.0 (13)
6. Colorado Headwaters-Plateau	74	75	4.6	6.2	70.5	599,479	1801.26	7.3 (1)	9.4 (1)
7. Eagle	81	97	5.9	8.6	79.0	424,952	921.34	8.2 (3)	10.7 (3)
8. Gila	1	2	0.0	0.0	0.6	2,091	4924.35	0.4 (5)	0.2 (5)
9. Gunnison	78	77	5.4	6.5	78.8	2,230,445	6433.62	7.7 (11)	9.5 (11)
10. Little Colorado	0	1	0.0	0.0	0.8	8,065	16380.09	1.4 (5)	2.9 (5)
11. Lower Colorado Mainstream	2	4	0.0	0.0	1.2	20,351	10695.42	1.7 (5)	3.4 (5)
12. Lower Green	56	71	3.7	5.8	71.0	1,747,004	5648.0	5.6 (24)	7.1 (23)
13. Lower Rio Grande	11	11	0.2	0.2	5.6	21,423	1794.8	1.9 (4)	1.7 (6)
14. Lower Sevier	43	71	1.3	3.5	55.0	167,267	896.82	5.1 (3)	6.6 (4)
15. Pecos	58	56	2.2	2.4	48.3	42,772	331.18	2.7 (2)	3.0 (2)
16. Provo-Utah Lake-Jordan	62	85	4.0	6.4	73.0	914,794	2680.71	9.4 (13)	14.5 (17)
17. Rio Chama-Upper Rio Grande	18	21	0.7	0.9	18.0	247,942	5206.68	3.1 (13)	3.6 (13)
18. Rio Grande Headwaters	48	50	2.2	2.6	42.9	1,059,008	7594.05	5.6 (14)	6.2 (14)
19. Roaring Fork	80	93	6.8	9.8	87.5	713,352	1358.6	8.9 (7)	11.1 (7)
20. Salt	0	0	0.0	0.0	0.4	673	2362.08	0.4 (8)	0.8 (6)
21. San Juan	27	28	1.3	1.5	19.0	523,598	6406.3	6.0 (15)	7.8 (15)
22. San Pitch	44	57	2.3	3.6	45.0	162,869	857.63	7.7 (6)	9.5 (6)
23. South Platte	87	92	3.8	4.8	64.2	1,453,294	5620.39	8.0 (21)	9.4 (21)
24. Southwestern Utah	9	14	0.2	0.3	5.1	19,484	1439.77	1.9 (5)	2.9 (4)
25. Toole Valley-Vernon Creek	46	80	1.3	2.6	45.1	124,181	906.47	7.0 (4)	9.2 (4)
26. Upper Arkansas	77	85	2.9	3.2	48.2	1,011,079	5876.67	5.6 (7)	6.1 (7)
27. Upper Colorado-Dirty Devil	28	33	1.1	1.7	26.9	228,881	2598.37	3.1 (7)	3.6 (7)
28. Upper Colorado-Dolores	45	46	2.4	2.9	45.6	534,684	3433.8	6.5 (7)	8.4 (8)
29. Upper Sevier	28	36	1.1	1.8	32.7	363,786	3758.51	3.7 (15)	4.9 (16)
30. Verde	0	0	0.0	0.0	0.8	768	1817.09	0.5 (7)	1.2 (7)
31. Weber-Ogden	71	92	5.5	8.2	84.5	890,314	2040.84	9.0 (16)	13.6 (17)
32. White-Yampa	85	91	6.2	8.0	81.4	2,525,086	5948.1	11.1 (14)	13.8 (15)

*Basin boundaries were derived from a combination of NRCS basins and HUC8 boundaries.

Intermountain

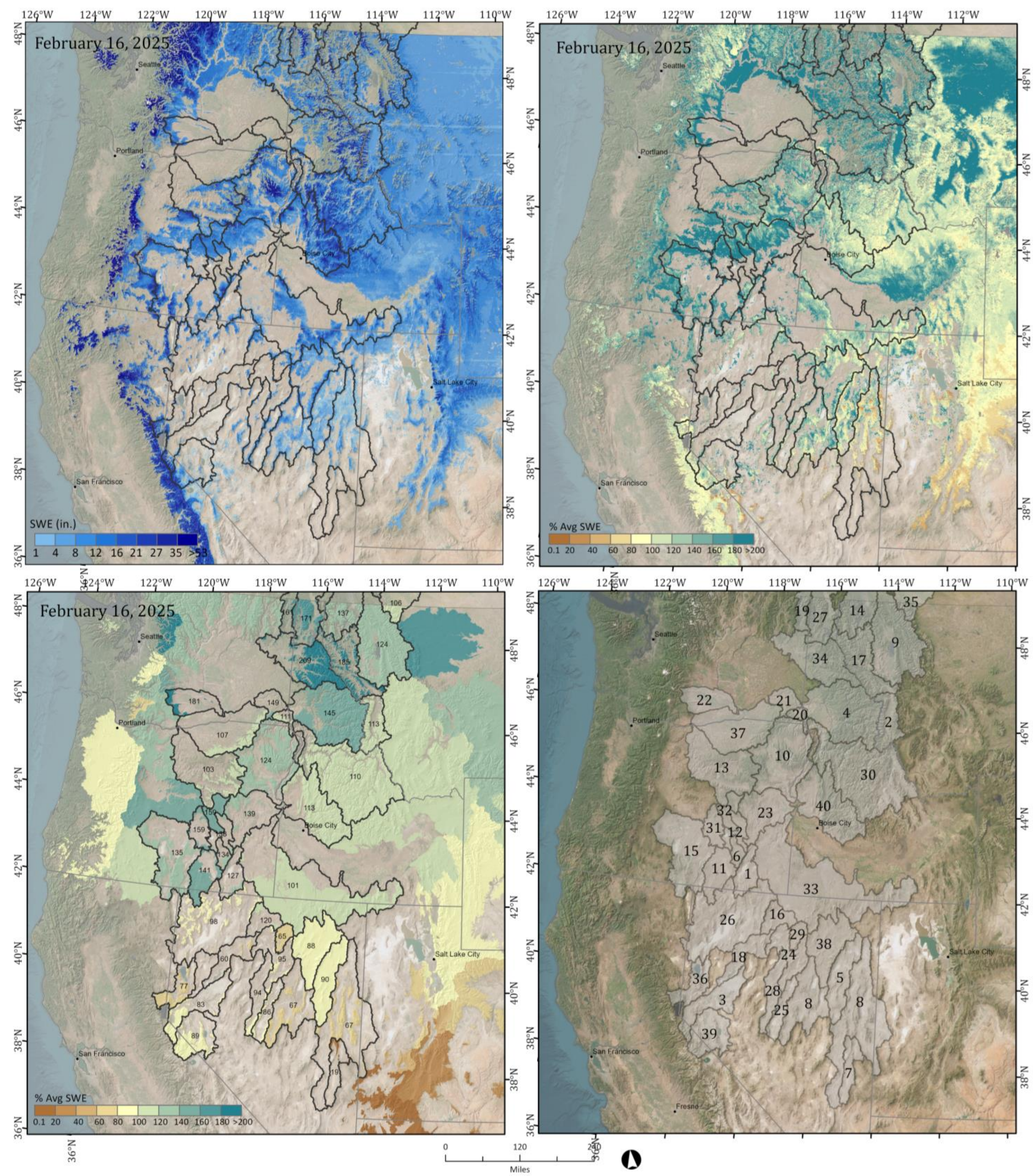


Figure 6. Estimated SWE and % of Average SWE across the Intermountain West Region. SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left), and basin identification numbers that correspond to Table 4 below (lower right).

Table 4. SWE by watershed. Shown are percent of average SWE to date for the current date (2001-21 as derived from the regression model), mean SWE for the current report, current percent of snow-covered area, current 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), first of the month snow surveys, and current snow pillow sensors (the number of stations are in parentheses), for those areas collected, summarized for each basin. <u>*SWE tables by banded elevation are available below.*</u>

Intermountain SWE Report for 2/16/2025

	% of Average		SWE (in)					Pillows	
Basin	2/1	2/16	2/1	2/16	SCA	Vol. (AF)	Area (mi. sq)	2/1	2/16
1. Alvord Lake	86	127	4.6	8.9	81.8	153,397	323.84	NA	NA
2. Bitterroot	92	113	5.1	7.9	64.0	821,965	1951.65	11.9 (4)	15.4 (4)
3. Carson	51	83	2.0	4.4	32.3	330,279	1405.03	9.5 (6)	14.9 (7)
4. Clearwater Basin	128	145	4.5	6.5	47.1	2,607,397	7488.26	17.4 (11)	20.8 (11)
5. Clover Valley and Franklin	47	90	1.2	2.7	53.2	580,460	4050.79	7.2 (2)	11.8 (2)
6. Donner und Blitzen	114	134	10.0	14.1	95.3	166,763	221.72	20.6 (2)	29.2 (2)
7. Dry Lake Valley	11	19	0.2	0.8	15.2	12,055	288.61	NA	NA
8. Eastern Nevada	41	67	1.3	2.8	41.9	642,505	4372.12	4.0 (8)	4.6 (8)
9. Flathead	93	124	2.5	5.1	42.8	2,027,419	7521.27	13.5 (11)	14.9 (13)
10. Grande Ronde-Burnt-Powder_Imnaha	105	124	6.9	10.0	74.8	2,846,795	5311.41	13.0 (10)	15.7 (10)
11. Guano	35	141	0.7	3.9	43.1	420,086	2038.62	NA	0.7 (1)
12. Harney-Malheur Lakes	100	138	4.7	7.1	65.4	104,965	275.58	NA	NA
13. John Day	94	103	5.5	7.9	58.8	630,351	1501.94	15.0 (2)	17.3 (2)
14. Kootenai	110	137	2.8	5.9	40.8	525,822	1672.88	12.9 (5)	14.6 (5)
15. Lake County-Goose Lake	86	135	3.7	6.8	51.7	1,313,957	3599.73	12.0 (2)	21.1 (2)
16. Little Humboldt	78	120	3.3	7.4	71.3	166,276	419.02	7.8 (3)	9.9 (3)
17. Lower Clark Fork	175	185	5.7	9.4	64.1	731,034	1465.26	22.0 (3)	24.9 (4)
18. Lower Humboldt	34	60	1.0	2.5	27.9	36,399	274.23	4.1 (1)	6.1 (1)
19. Lower Pend Oreille	130	161	8.3	12.7	68.7	87,563	128.96	17.5 (1)	17.7 (1)
20. Lower Snake-Asotin	89	111	2.8	4.3	40.8	76,043	328.28	4.0 (2)	5.6 (2)

*Basin boundaries were derived from a combination of NRCS basins and HUC8 boundaries.

Intermountain SWE Report for 2/16/2025									
	% of Average		SWE (in)					Pillows	
Basin	2/1	2/16	2/1	2/16	SCA	Vol. (AF)	Area (mi. sq)	2/1	2/16
21. Lower Snake-Tucannon	126	149	6.7	11.0	91.8	63,820	109.27	NA	NA
22. Lower Yakima	143	181	6.6	10.6	81.7	277,474	489.29	16.1 (2)	17.5 (2)
23. Malheur	114	139	7.3	10.2	83.5	539,141	992.38	11.1 (3)	14.6 (3)
24. Middle Humboldt	55	95	1.5	3.9	45.9	130,905	633.11	NA	NA
25. Northern Big Smoky Valley	53	86	1.8	4.4	50.7	134,776	569.69	NA	NA
26. Northern Great Basin	45	98	1.5	4.9	50.4	584,199	2226.94	4.6 (2)	6.5 (2)
27. Panhandle Basins	115	171	3.4	7.6	50.1	668,610	1643.35	19.1 (3)	21.0 (3)
28. Reese	57	94	2.1	5.4	56.9	141,204	491.03	7.9 (2)	9.4 (2)
29. Rock	34	65	0.8	2.6	27.3	113,743	834.75	8.4 (1)	12.1 (1)
30. Salmon Basin	93	110	7.2	10.1	79.9	6,396,312	11932.58	11.3 (11)	15.8 (11)
31. Silver	103	159	4.8	7.8	62.7	178,341	431.18	NA	NA
32. Silvies	119	159	6.2	9.3	82.5	654,304	1316.03	10.0 (2)	13.5 (2)
33. Southern Snake Basins	66	101	2.9	4.6	49.2	3,068,052	12500.93	7.4 (13)	9.3 (13)
34. Spokane	152	209	3.4	6.6	48.7	1,103,054	3145.86	12.2 (8)	13.9 (8)
35. St. Mary	78	106	4.0	8.0	75.9	275,519	648.17	4.6 (1)	6.4 (1)
36. Truckee	48	77	2.2	4.9	34.0	374,512	1420.37	9.7 (9)	17.3 (8)
37. Umatilla-Walla Walla-Willow	68	107	1.8	3.8	30.2	290,223	1433.69	12.3 (7)	15.1 (7)
38. Upper Humboldt	54	88	1.9	4.1	51.6	1,112,095	5032.84	7.1 (7)	11.1 (8)
39. Walker	50	89	1.8	4.2	53.8	433,648	1939.01	8.7 (6)	15.7 (7)
40. West Central Basins	94	113	8.9	12.8	90.3	3,842,030	5616.63	15.9 (13)	21.7 (14)

*Basin boundaries were derived from a combination of NRCS basins and HUC8 boundaries.

Sierra Nevada

There is a separate SWE report that has a stronger focus on the Sierra Nevada available **here**. This report takes additional vetting measures and bias corrects with Airborne Snow Observatory data. Below is a sample of the maps provided in this report.

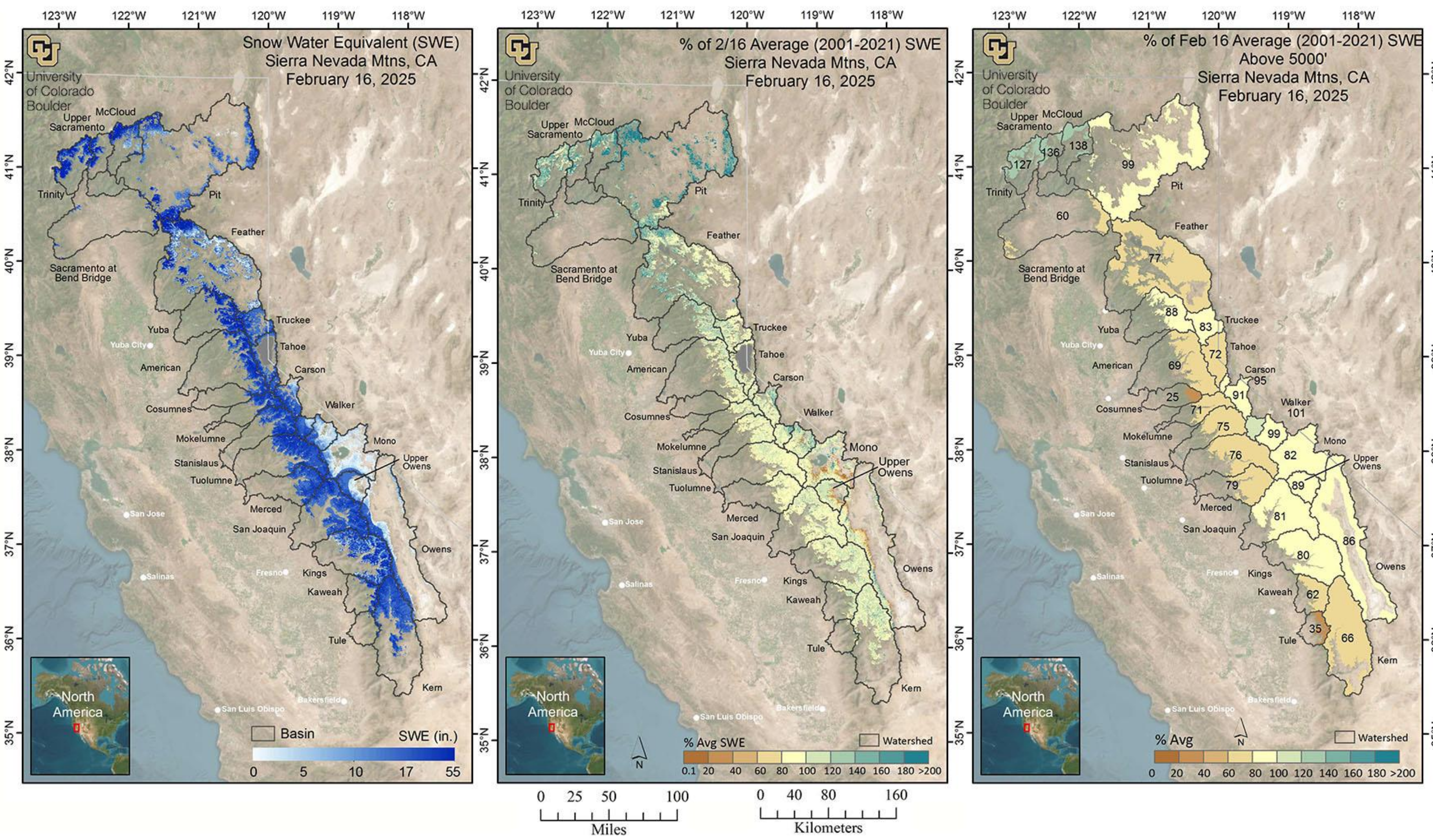


Figure 7. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts (left), and percent of average (2001-2021) SWE for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

Table 5. SWE by watershed. Shown are percent of average SWE to date for the current date (2001-21 as derived from the regression model), mean SWE for the current report, current percent of snow-covered area, current 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), first of the month snow surveys, and current snow pillow sensors (the number of stations are in parentheses), for those areas collected, summarized for each basin.

Sierra Nevada SWE Report for 2/16/2025

	% of Average		SWE (in)					Pillows		
Basin	2/1	2/16	2/1	2/16	SCA	Vol. (AF) ‡	Area (mi. sq)	2/1	2/16	SNODAS* (in)
Trinity	108	127	14.9	22.6	86.3	387,795	321.4	22.1 (4)	28.7 (4)	34.0
Upper Sacramento	95	136	12.4	22.5	78.7	137,992	115.2	21.3 (2)	33.7 (1)	29.3
McCloud	96	138	10.8	20.1	78.8	176,704	164.9	18.3 (1)	28.5 (1)	33.0
Pit	60	99	3.2	6.8	36.0	745,023	2064.7	13.0 (7)	21.3 (7)	8.4
Sacramento at Bend Bridge	36	60	3.0	7.5	26.9	95,481	239.6	NA	NA	12.2
Feather §	51	77	4.9	9.2	52.0	1,023,178	2086.6	17.6 (5)	23.7 (6)	12.2
Yuba	65	88	7.8	14.3	60.4	393,708	516.6	25.0 (5)	38.0 (5)	22.8
American	56	69	6.8	11.4	54.3	481,081	792.5	11.4 (10)	17.9 (10)	15.4
Cosumnes	20	25	1.6	2.9	16.7	14,126	91.9	NA	NA	5.7
Mokelumne	56	71	6.7	11.7	57.9	196,500	314.6	14.6 (3)	20.2 (3)	14.6
Stanislaus	55	75	6.3	12.4	65.3	367,879	557.3	12.1 (5)	23.5 (5)	13.2
Tuolomne	57	76	6.8	12.8	65.9	619,433	910.0	11.1 (7)	20.3 (7)	14.9
Merced	54	79	5.9	12.3	59.7	353,394	538.8	11.6 (2)	22.0 (2)	14.3
San Joaquin	52	81	6.1	13.0	67.2	838,534	1208.6	5.2 (7)	11.9 (7)	12.8
Kings §	46	80	5.6	12.7	62.9	818,627	1207.5	8.8 (6)	14.4 (7)	13.1
Kaweah	35	62	2.6	7.5	35.6	126,380	314.2	NA	13.7 (2)	9.7
Tule	18	35	0.7	2.1	11.2	15,635	137.6	NA	NA	3.2
Kern	27	66	2.2	7.6	40.9	683,893	1682.1	6.0 (5)	11.7 (6)	5.9
Truckee	56	83	5.8	13.1	71.8	287,332	412.0	10.6 (6)	17.9 (6)	15.8
Tahoe	55	72	6.3	11.5	63.9	188,194	307.0	10.0 (7)	18.4 (7)	13.5
W Carson	73	95	8.9	16.2	86.4	55,582	64.3	10.2 (3)	18.3 (3)	16.3
E Carson	61	91	5.3	11.5	73.5	216,411	354.3	8.9 (3)	12.3 (4)	10.6
W Walker	74	101	8.2	15.0	97.3	143,443	179.6	11.5 (3)	18.2 (4)	16.8
E Walker	63	99	3.2	7.3	85.7	137,233	351.1	6.2 (1)	12.6 (1)	8.0
Mono	40	82	1.4	3.7	67.9	200,733	1004.9	NA	NA	3.9
Upper Owens	46	89	2.9	8.0	74.0	160,452	374.6	12.8 (1)	27.3 (1)	6.9
Owens	37	86	1.3	3.8	37.5	361,150	1772.2	6.5 (4)	11.9 (5)	3.1

§ Data in all ASO-collected basins have been bias-corrected using ASO data and therefore the SWE changes might not represent snowmelt/accumulation 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.

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

Elevation Banded SWE Tables:

Due to the length of the banded elevation tables (tables 6-10), that data is being hosted on our GitHub repository. Direct links to all the tables are below. Access to the GitHub repository for the tables in both HTML and CSV formats is **here**.

- Pacific Northwest
- North Continental
- South Continental
- Intermountain, part 1
- Intermountain, part 2
- Sierra Nevada

The value of spatially explicit estimates of SWE

Snowmelt makes up the large majority (~60-85%) of the annual streamflow in the Western U.S. The spatial distribution of 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 and California DWR CDEC snow pillow sites spread across the Western U.S., 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 pillow sites. The spatial SWE-fusion creates a detailed picture of the spatial pattern of SWE using snow pillows, satellite, and other data, extending beyond the snow pillow sites to unmonitored areas.

Interpreting the spatial SWE estimates in the context of snow pillow sites

The spatial SWE-fusion product estimates SWE for every pixel where the fractional snow-covered area (fSCA) satellite product identifies snow-cover. Comparatively, snow pillow samples on average 8-20 points per basin within a narrower elevation range. Thus, the basin-wide percent of long-term average from the spatial SWE-fusion estimates is not directly comparable with the snow pillow basin-wide percent of average. A better comparison might be made with the % average in the elevation bands (elevation-banded tables 6-10) that contain snow pillow sites.

Location of Reports, Excel Format Tables, and JPG Maps

https://github.com/CU-Mountain-Hydrology/WestWide

Methods

The spatial SWE-fusion estimation method is described in Yang, et. al. (2022) and Schneider and Molotch (2016). The method uses a General Linear Model in which the dependent variable is derived from the operationally measured in situ SWE from all online NRCS SNOTEL and CDEC snow pillow sites in the domain and when applicable the CoCoRaHS SWE values. The snow pillow SWE observations are scaled by the satellite-based fractional snow-covered area (fSCA) across the 500 meter pixel containing that snow pillow site before being used in the linear regression model. The fSCA is a near-real-time cloud-free daily satellite image from the Snow Today fSCA image (Rittger, et. al. 2019, https://nsidc.org/snow-today) which uses the SPIReS algorithm (Bair, et al. 2021).

The following independent variables (predictors) enter 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 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 from Airborne Snow Observatory lidar data and from snow surveys at 10 locations in 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 SNOW SENSOR 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.
- EARLY SEASON FSCA ERRORS – The gap-filled fSCA requires some cloud-free images to determine fSCA amounts. Early in the season and if it has been particularly cloudy the algorithm hasn't had time to calculate fSCA amounts in some areas, typically in the Pacific Northwest and northern areas of the domain.

References and Additional Sources

Bair, E.H., T. Stillinger and J. Dozier (2021). Snow Property Inversion From Remote Sensing (SPIReS): A Generalized Multispectral Unmixing Approach With Examples From MODIS and Landsat 8 OLI. IEEE Transactions on Geoscience and Remote Sensing, 59(9): 7270-7284. DOI: 10.1109/TGRS.2020.3040328.

Commission for Environmental Cooperation (2009). Ecological regions of North America, Level 3, scale 1:4,000,000, Commission for Environmental Cooperation, Montreal, Quebec, Canada.

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 (2022). Sci Data 9, 677. 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.

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.

Trujillo, E., and N. P. Molotch (2014). Snowpack regimes of the Western United States, Water Resour. Res., 50, 5611–5623, doi:10.1002/ 2013WR014753.

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.