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

Western United States Region

April 6, 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.

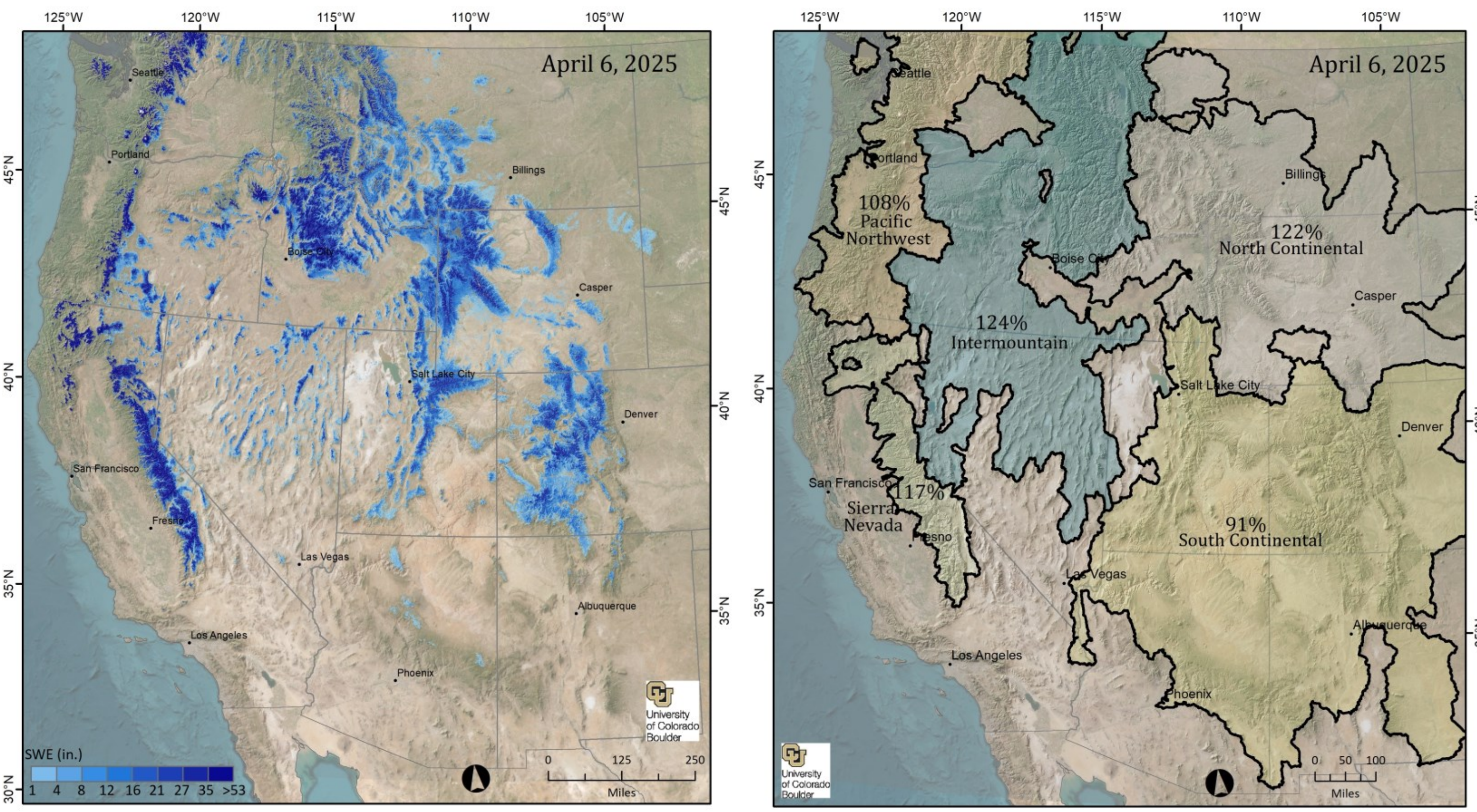

Figure 1. Estimated SWE and % of Average SWE across the Western U.S. SWE amounts across the entire Western region of the United States (left) and percent of long-term average (2001-2021) by five regions (right). Region boundaries are delineated based on Snowpack regimes of the Western United States (Trujillo 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/].

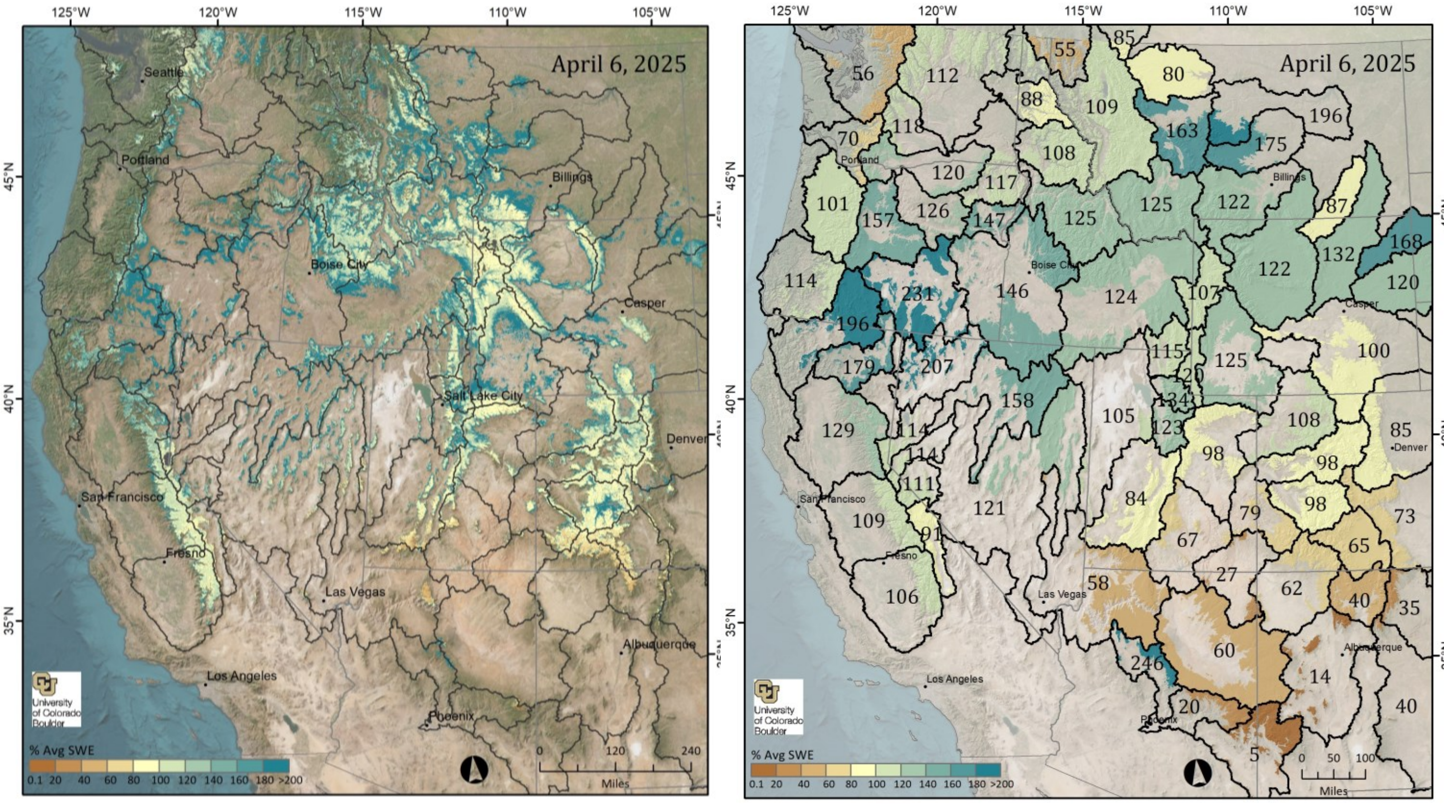

Figure 2. ***Estimated % of Average SWE across the Western U.S.*** Percent of long-term average (2001-2021) from the spatial SWE calculated for each pixel (left) and by HUC-6 basin (right); integer within each watershed represents the percent of average SWE for the report date. Shaded areas (right) correspond to the elevation bands used in the tables below.

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

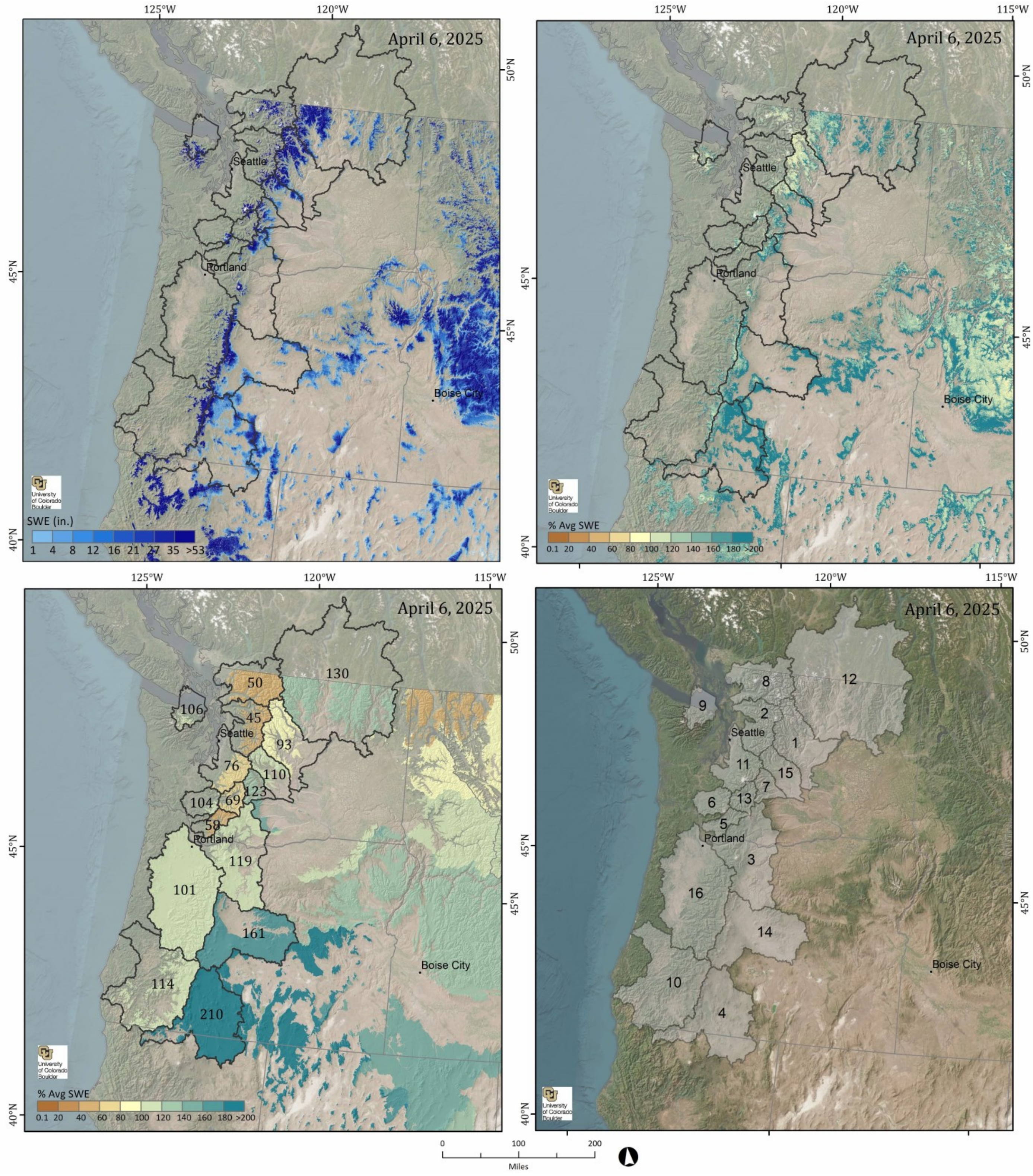

Figure 3. Estimated SWE and % of Average SWE across the Pacific Northwest Region. *SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left)* shaded areas correspond to the elevation bands used in the banded-elevation tables*, 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. *SWE tables by banded elevation are here.*

Pacific Northwest SWE Report for 4/6/2025

	% of Average		SWE (in)					Pillows	
Basin	3/31	4/6	3/31	4/6	SCA	Vol. (AF)	Area (mi. sq)	3/31	4/6
1. Central Columbia	76	93	14.9	19.1	53.6	2,170,484	2,134	20.4 (7)	20.0 (7)
2. Central Puget Sound	21	45	2.6	8.2	20.9	542,598	1,239	35.3 (5)	36.5 (5)
3. Hood-Sandy-Lower Deschutes	99	119	2.7	2.9	10.9	781,517	5,079	22.4 (11)	22.1 (11)
4. Klamath	191	210	5.8	5.4	31.9	2,076,752	7,197	21.7 (16)	21.4 (15)
5. Lewis	40	58	2.5	3.3	10.4	103,224	581	36.4 (7)	36.5 (7)
6. Lower Cowlitz	84	104	7.3	8.9	32.3	87,463	185	23.1 (2)	21.9 (2)
7. Naches	85	123	8.6	11.8	46.2	384,985	610	40.4 (4)	40.4 (4)
8. North Puget Sound	30	50	3.4	7.1	18.5	876,651	2,312	37.4 (9)	37.6 (9)
9. Olympic	77	106	18.1	24.6	61.5	312,020	238	31.7 (3)	31.4 (3)
10. Rogue-Umpqua	110	114	6.0	5.7	16.4	1,019,631	3,371	15.7 (6)	16.1 (6)
11. South Puget Sound	56	76	3.9	5.7	13.6	347,010	1,148	20.3 (14)	20.8 (14)
12. Upper Columbia	112	130	8.2	8.7	35.4	2,559,447	5,502	13.8 (7)	14.0 (7)
13. Upper Cowlitz	37	69	3.7	7.8	19.4	295,389	713	37.1 (3)	37.5 (3)
14. Upper Deschutes-Crooked	150	161	5.5	5.4	24.2	1,629,023	5,607	30.0 (7)	30.5 (7)
15. Upper Yakima	97	110	10.6	11.4	40.7	628,073	1,033	20.4 (3)	19.4 (3)
16. Willamette	92	101	1.7	1.7	5.1	1,047,829	11,360	15.5 (18)	15.5 (18)

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

North Continental

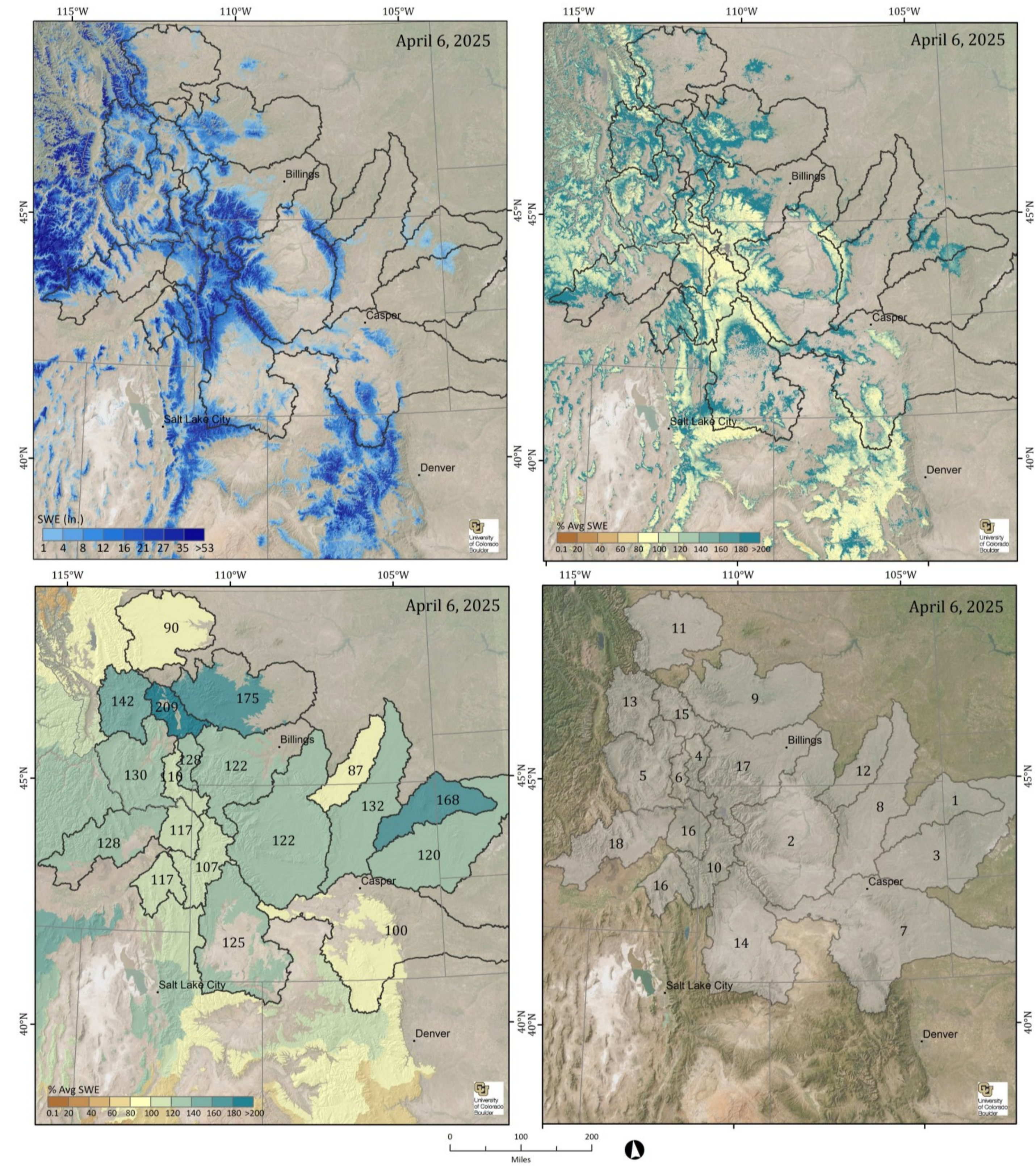

Figure 4. Estimated SWE and % of Average SWE across the North Continental Region. *SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left)* shaded areas correspond to the elevation bands used in the banded-elevation tables*, 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 here.*

North Continental SWE Report for 4/6/2025

	% of Average		SWE (in)					Pillows	
Basin	3/31	4/6	3/31	4/6	SCA	Vol. (AF)	Area (mi. sq)	3/31	4/6
1. Belle Fourche	24	168	0.2	0.3	11.5	127,951	7,203	4.4 (1)	5.8 (1)
2. Bighorn	97	122	2.6	3.2	24.3	3,829,519	22,741	12.0 (21)	12.4 (21)
3. Cheyenne	19	120	0.0	0.1	1.6	53,761	15,348	3.3 (2)	3.6 (2)
4. Gallatin	101	128	6.4	8.0	62.8	787,162	1,846	19.9 (4)	23.9 (3)
5. Jefferson	100	130	5.9	6.8	51.7	3,205,574	8,788	12.8 (14)	13.5 (14)
6. Madison Headwaters in WY	99	110	7.1	8.6	63.6	1,151,771	2,521	17.3 (7)	18.3 (7)
7. North Platte	65	100	3.3	4.2	39.0	2,298,650	10,282	17.9 (22)	19.0 (22)
8. Powder	63	132	0.4	0.6	7.8	439,423	13,384	6.3 (5)	7.0 (5)
9. Smith-Judith-Musselshell	89	175	2.5	3.8	41.3	1,681,640	8,336	14.6 (9)	15.8 (9)
10. Snake	110	107	12.9	14.0	88.7	4,189,882	5,625	21.8 (11)	22.6 (11)
11. Sun-Teton-Marias	63	90	1.0	1.7	13.4	964,150	10,460	7.4 (5)	8.1 (5)
12. Tongue	67	87	0.7	0.9	7.5	265,399	5,400	9.3 (6)	10.3 (6)
13. Upper Clark Fork	96	142	4.5	6.3	53.2	2,011,354	5,983	11.3 (12)	12.2 (12)
14. Upper Green	77	125	4.9	6.4	48.7	3,253,474	9,542	14.1 (21)	15.0 (21)
15. Upper Missouri	91	209	2.4	4.2	48.3	666,855	2,950	6.7 (2)	8.0 (2)
16. Upper Snake Basins	111	117	6.5	7.1	54.0	2,589,634	6,872	20.8 (11)	21.7 (11)
17. Upper Yellowstone	115	122	6.5	7.3	53.5	4,321,267	11,070	15.2 (20)	16.1 (20)
18. Wood and Lost Basins	102	128	5.5	6.4	41.2	2,541,508	7,421	12.9 (16)	13.2 (16)

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

South Continental

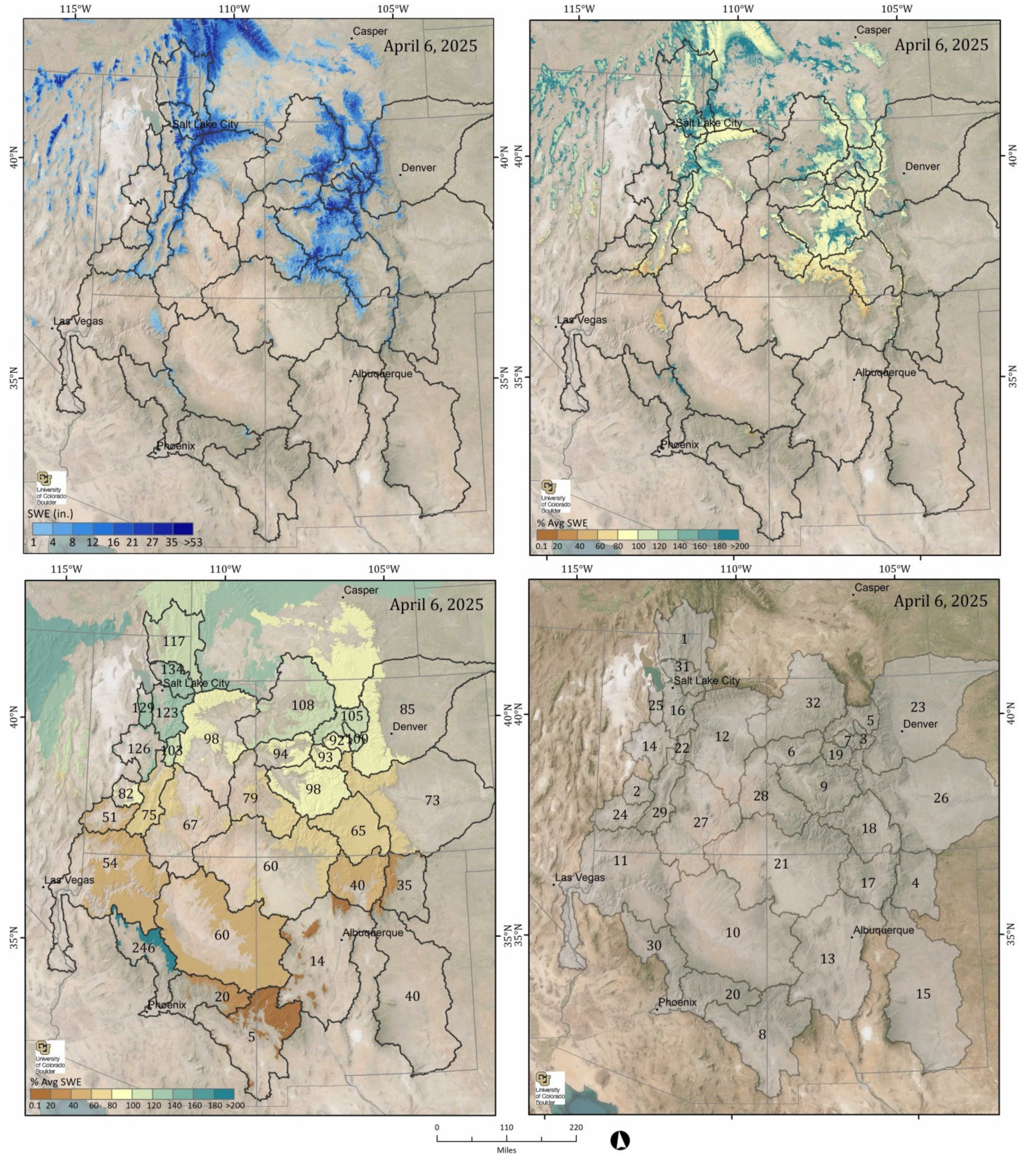

Figure 5. Estimated SWE and % of Average SWE across the South Continental Region. SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left) shaded areas correspond to the elevation bands used in the banded-elevation tables, 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 here.]()

South Continental SWE Report for 4/6/2025

	% of Average		SWE (in)					Pillows	
Basin	3/31	4/6	3/31	4/6	SCA	Vol. (AF)	Area (mi. sq)	3/31	4/6
1. Bear	93	117	5.3	6.1	44.4	2,005,143	6,182	16.3 (18)	17.4 (18)
2. Beaver	65	82	1.3	1.7	18.7	74,774	836	12.3 (2)	13.0 (2)
3. Blue	84	100	9.2	11.1	75.7	396,468	669	16.6 (5)	17.6 (5)
4. Canadian	15	35	0.3	0.4	7.7	30,366	1,265	0.1 (1)	1.4 (1)
5. Colorado Headwaters	88	105	7.7	8.6	63.7	1,314,439	2,873	15.3 (13)	16.3 (13)
6. Colorado Headwaters-Plateau	66	94	4.2	5.0	38.5	484,195	1,801	12.5 (1)	13.5 (1)
7. Eagle	80	92	7.7	8.6	56.5	420,147	921	12.3 (3)	13.7 (3)
8. Gila	0	5	0.0	0.0	0.0	365	4,924	0.0 (6)	0.0 (6)
9. Gunnison	66	98	4.8	7.0	61.5	2,412,090	6,434	11.1 (11)	12.1 (11)
10. Little Colorado	4	60	0.0	0.0	1.1	27,497	16,380	3.2 (5)	3.4 (5)
11. Lower Colorado Mainstream	21	54	0.1	0.2	5.6	112,804	10,695	4.0 (5)	4.1 (5)
12. Lower Green	69	98	5.1	6.7	53.0	2,013,784	5,648	9.4 (24)	10.3 (24)
13. Lower Rio Grande	6	14	0.0	0.1	1.0	6,652	1,795	0.7 (6)	1.1 (6)
14. Lower Sevier	67	126	1.5	3.4	38.2	164,205	897	11.7 (4)	13.4 (4)
15. Pecos	29	40	0.9	1.0	12.8	18,159	331	0.1 (2)	1.1 (2)
16. Provo-Utah Lake-Jordan	85	123	4.6	6.8	50.5	965,989	2,681	20.0 (18)	21.6 (18)
17. Rio Chama-Upper Rio Grande	25	40	0.5	0.7	11.0	202,282	5,207	2.9 (13)	3.3 (13)
18. Rio Grande Headwaters	45	65	1.6	2.3	24.6	911,863	7,594	6.6 (13)	6.9 (14)
19. Roaring Fork	80	93	9.1	10.7	66.3	774,601	1,359	14.0 (7)	15.3 (7)
20. Salt	1	20	0.0	0.1	3.4	13,231	2,362	0.0 (8)	0.0 (7)
21. San Juan	49	60	1.7	2.1	21.8	710,299	6,406	8.3 (15)	9.1 (15)
22. San Pitch	68	103	3.1	4.8	36.6	217,452	858	13.0 (6)	14.8 (6)
23. South Platte	64	85	2.6	3.3	28.4	987,092	5,620	12.6 (21)	13.4 (21)
24. Southwestern Utah	36	51	0.4	0.6	9.5	44,744	1,440	3.3 (5)	3.8 (5)
25. Toole Valley-Vernon Creek	91	129	1.4	2.0	18.4	95,387	906	12.7 (4)	13.8 (4)
26. Upper Arkansas	50	73	1.5	2.2	18.2	674,163	5,877	6.2 (7)	6.9 (7)
27. Upper Colorado-Dirty Devil	31	67	1.1	2.4	27.0	332,838	2,598	4.3 (7)	5.5 (7)
28. Upper Colorado-Dolores	45	79	1.9	3.2	39.0	583,752	3,434	9.4 (9)	10.6 (8)
29. Upper Sevier	43	75	1.4	2.6	33.0	531,173	3,759	6.2 (16)	7.4 (16)
30. Verde	3	246	0.0	0.3	8.9	25,110	1,817	0.7 (7)	1.1 (7)
31. Weber-Ogden	86	134	5.2	7.3	55.3	796,449	2,041	17.6 (17)	18.9 (17)
32. White-Yampa	83	108	5.9	6.6	50.0	2,101,950	5,948	17.9 (15)	19.2 (15)

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

Intermountain

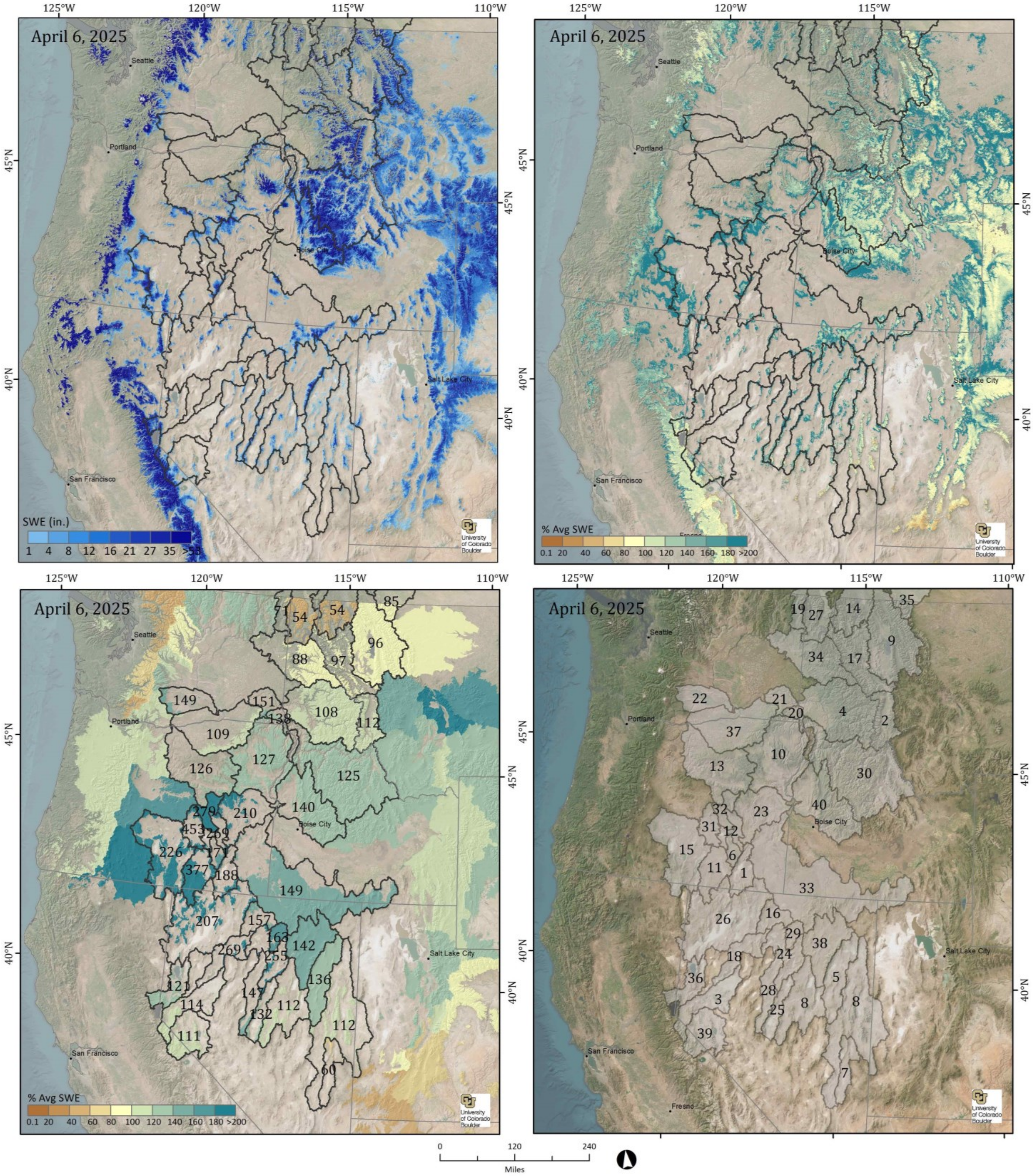

Figure 6. Estimated SWE and % of Average SWE across the Intermountain Region. SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left) shaded areas correspond to the elevation bands used in the banded-elevation tables, 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. *SWE tables by banded elevation are here.*

Intermountain SWE Report for 4/6/2025

	% of Average		SWE (in)					Pillows	
Basin	3/31	4/6	3/31	4/6	SCA	Vol. (AF)	Area (mi. sq)	3/31	4/6
1. Alvord Lake	176	188	5.4	6.0	39.4	103,782	324	NA	NA
2. Bitterroot	101	112	9.4	10.2	54.7	1,063,489	1,952	20.4 (4)	19.7 (4)
3. Carson	93	114	4.2	5.3	29.0	397,088	1,405	17.1 (7)	18.5 (7)
4. Clearwater Basin	100	108	6.1	7.0	32.9	2,775,665	7,488	29.5 (11)	28.4 (10)
5. Clover Valley and Franklin	86	136	0.7	1.1	11.9	234,148	4,051	19.9 (2)	21.3 (2)
6. Donner und Blitzen	145	171	12.5	14.9	85.9	175,808	222	38.1 (2)	39.1 (2)
7. Dry Lake Valley	46	60	0.6	0.9	11.2	13,699	289	NA	NA
8. Eastern Nevada	88	112	2.0	2.7	27.7	639,714	4,372	7.6 (8)	8.4 (8)
9. Flathead	71	96	3.6	6.1	36.3	2,453,254	7,521	21.1 (13)	23.0 (13)
10. Grande Ronde-Burnt-Powder_Imnaha	122	127	5.7	6.1	31.1	1,730,411	5,311	19.8 (11)	20.1 (11)
11. Guano	311	377	0.8	0.7	6.3	77,418	2,039	0.0 (1)	0.0 (1)
12. Harney-Malheur Lakes	248	269	3.1	3.1	26.1	46,248	276	NA	NA
13. John Day	121	126	5.9	6.0	36.5	484,564	1,502	20.0 (2)	19.9 (2)
14. Kootenai	40	54	2.1	3.1	17.5	280,653	1,673	20.8 (5)	21.4 (5)
15. Lake County-Goose Lake	190	226	5.6	5.8	39.4	1,106,333	3,600	22.0 (2)	23.2 (2)
16. Little Humboldt	106	157	2.2	3.9	29.5	87,399	419	14.0 (3)	14.9 (3)
17. Lower Clark Fork	89	97	6.8	8.2	42.9	642,691	1,465	38.9 (4)	40.1 (4)
18. Lower Humboldt	141	269	1.4	3.7	38.7	54,663	274	2.9 (1)	3.8 (1)
19. Lower Pend Oreille	48	71	4.4	6.6	29.1	45,598	129	26.5 (1)	27.7 (1)
20. Lower Snake-Asotin	122	138	1.6	1.8	13.4	30,840	328	6.5 (2)	6.6 (2)

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

Intemountain SWE Report for 4/6/2025

Basin	% of Average		SWE (in)		SCA	Vol. (AF)	Area (mi. sq)	Pillows	
	3/31	4/6	3/31	4/6				3/31	4/6
21. Lower Snake-Tucannon	148	151	6.1	6.4	43.7	37,117	109	NA	NA
22. Lower Yakima	135	149	5.6	4.3	23.8	111,016	489	21.1 (2)	21.4 (2)
23. Malheur	183	210	6.6	7.3	49.9	387,667	992	13.4 (3)	12.5 (3)
24. Middle Humboldt	94	255	0.8	2.7	28.8	91,869	633	NA	NA
25. Northern Big Smoky Valley	95	132	2.8	5.5	49.8	166,279	570	NA	NA
26. Northern Great Basin	108	207	1.1	2.5	21.4	291,145	2,227	5.3 (2)	6.2 (2)
27. Panhandle Basins	33	54	1.6	2.9	14.7	250,402	1,643	28.2 (3)	29.6 (3)
28. Reese	102	147	3.4	6.4	57.9	168,702	491	15.2 (2)	16.6 (2)
29. Rock	111	163	0.4	0.6	5.5	28,431	835	17.5 (1)	18.8 (1)
30. Salmon Basin	117	125	11.7	12.8	63.2	8,131,803	11,933	22.0 (11)	22.5 (11)
31. Silver	358	453	3.7	3.3	28.5	75,888	431	NA	NA
32. Silvies	239	279	3.0	3.4	29.7	238,918	1,316	13.9 (2)	13.1 (2)
33. Southern Snake Basins	107	149	1.5	2.0	14.7	1,314,047	12,501	12.2 (13)	13.0 (13)
34. Spokane	81	88	2.2	2.6	13.8	433,646	3,146	17.7 (8)	18.1 (8)
35. St. Mary	71	85	7.6	10.0	65.0	345,539	648	8.2 (1)	8.9 (1)
36. Truckee	90	121	4.9	6.9	37.1	523,387	1,420	19.9 (9)	21.3 (9)
37. Umatilla-Walla Walla-Willow	94	109	1.2	1.3	9.4	102,494	1,434	18.1 (7)	18.2 (7)
38. Upper Humboldt	103	142	1.5	2.0	14.5	541,103	5,033	14.8 (8)	15.6 (8)
39. Walker	89	111	3.3	4.3	31.4	448,480	1,939	18.7 (7)	19.9 (7)
40. West Central Basins	127	140	12.3	14.3	70.1	4,277,856	5,617	28.4 (14)	27.0 (15)

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

Sierra Nevada

There is a separate SWE report which also includes maps and tables that has a stronger focus on the Sierra Nevada, it is available **here**. The Sierra report incorporates additional vetting and can include bias-corrections with Airborne Snow Observatory data. Below is one of the maps from the current report.

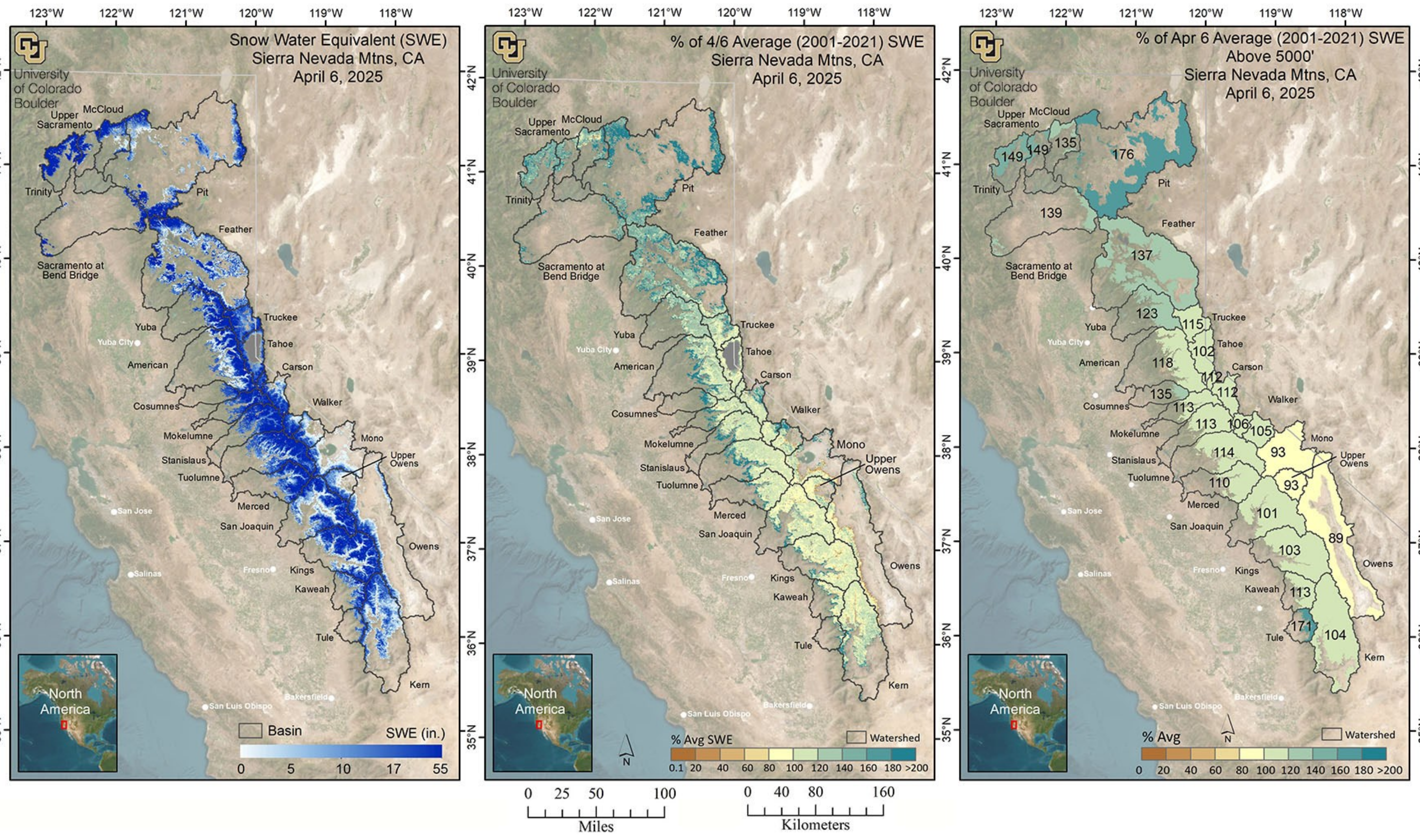

*Figure 7. **Estimated SWE and % of Average SWE across the Sierra Nevada.*** SWE amounts (left), and percent of average (2001-2021) SWE for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

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. [SWE tables by banded elevation are here.]

Sierra Nevada SWE Report for 4/6/2025

	% of Average		SWE (in)					Pillows		
	3/31	4/6	3/31	4/6	SCA	Vol. (AF)‡	Area (mi. sq)	3/31	4/6	SNODAS* (in)
Trinity	119	149	28.5	33.6	91.0	575,944	321.4	40.0 (4)	38.8 (4)	43.7
Upper Sacramento	115	149	23.9	30.1	86.2	184,641	115.2	30.0 (1)	33.4 (1)	38.7
McCloud	119	135	21.9	23.4	87.6	205,828	164.9	39.4 (1)	40.0 (1)	45.0
Pit	138	176	6.6	8.0	40.2	875,591	2063.1	25.7 (7)	27.5 (7)	9.0
Sacramento at Bend Bridge	88	139	11.6	17.9	58.1	229,210	239.6	NA	NA	18.7
Feather§	95	137	10.3	12.4	69.3	1,382,698	2085.6	30.9 (6)	33.0 (6)	14.9
Yuba§	95	123	19.9	20.3	81.3	559,528	516.1	48.4 (5)	52.9 (5)	32.7
American§	92	118	15.4	16.4	86.9	694,771	792.5	21.2 (11)	23.9 (11)	22.4
Cosumnes	76	135	8.5	16.7	84.1	81,745	91.9	NA	NA	10.1
Mokelumne	87	113	17.0	20.9	82.0	350,177	314.1	34.0 (2)	38.3 (2)	22.2
Stanislaus	89	113	17.2	20.9	84.3	620,760	557.1	29.2 (5)	33.6 (5)	20.4
Tuolumne§	92	114	16.4	19.3	85.6	934,506	909.4	25.8 (7)	28.7 (7)	22.8
Merced§	90	110	15.8	18.8	81.0	540,331	538.8	27.2 (2)	29.9 (2)	20.7
San Joaquin§	87	101	14.3	14.8	75.0	952,078	1207.1	18.0 (7)	19.8 (7)	16.8
Kings§	85	103	15.3	17.9	80.0	1,151,553	1207.0	18.9 (5)	20.7 (5)	17.6
Kaweah§	86	113	10.9	13.4	72.3	224,683	314.1	20.3 (2)	21.9 (2)	14.2
Tule	104	171	4.5	10.7	61.6	78,356	137.6	6.9 (1)	8.2 (1)	3.7
Kern§	74	104	4.7	6.7	46.6	600,074	1682.1	17.0 (6)	17.3 (6)	5.9
Truckee	91	115	13.1	18.0	86.1	396,276	411.7	20.9 (6)	21.8 (6)	18.3
Tahoe	90	102	15.0	17.0	80.5	277,312	305.5	20.8 (7)	24.6 (7)	16.7
W Carson	99	112	18.9	21.1	83.3	72,332	64.3	20.9 (3)	22.8 (3)	20.9
E Carson	92	112	10.7	13.6	67.7	257,004	354.3	14.2 (4)	15.3 (4)	13.1
W Walker	99	106	16.9	18.4	87.1	176,233	179.6	22.3 (4)	23.3 (4)	22.7
E Walker	93	105	6.2	7.8	52.6	144,973	350.7	15.4 (1)	17.5 (1)	8.6
Mono	80	93	3.0	3.4	28.4	183,179	1003.4	NA	NA	2.9
Upper Owens	81	93	6.1	7.6	52.1	151,558	373.8	38.0 (1)	39.8 (1)	5.3
Owens	74	89	2.9	3.8	26.3	362,895	1772.1	14.5 (5)	13.9 (5)	2.5

§ 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.

† Deep and recent snow in areas that typically are snow-free can report 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.

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 of the tables are below. Access to the GitHub repository for the tables in both HTML and CSV formats is **here**.

- Pacific Northwest (Table 6)
- North Continental (Table 7)
- South Continental (Table 8)
- Intermountain, part 1 (Table 9a)
  Intermountain, part 2 (Table 9b)
- Sierra Nevada (Table 10)

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

- SATELLITE FSCA - Recent snowpack accumulation particularly in the Arizona / NM region may be under-estimated due to issues with satellite-observed fSCA.
- GLACIER & NON-SEASONAL SNOW – SWE values on non-seasonal snow and glaciers need to be excluded before data analysis.
- 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.