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

Western United States Region

May 17, 2025

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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.

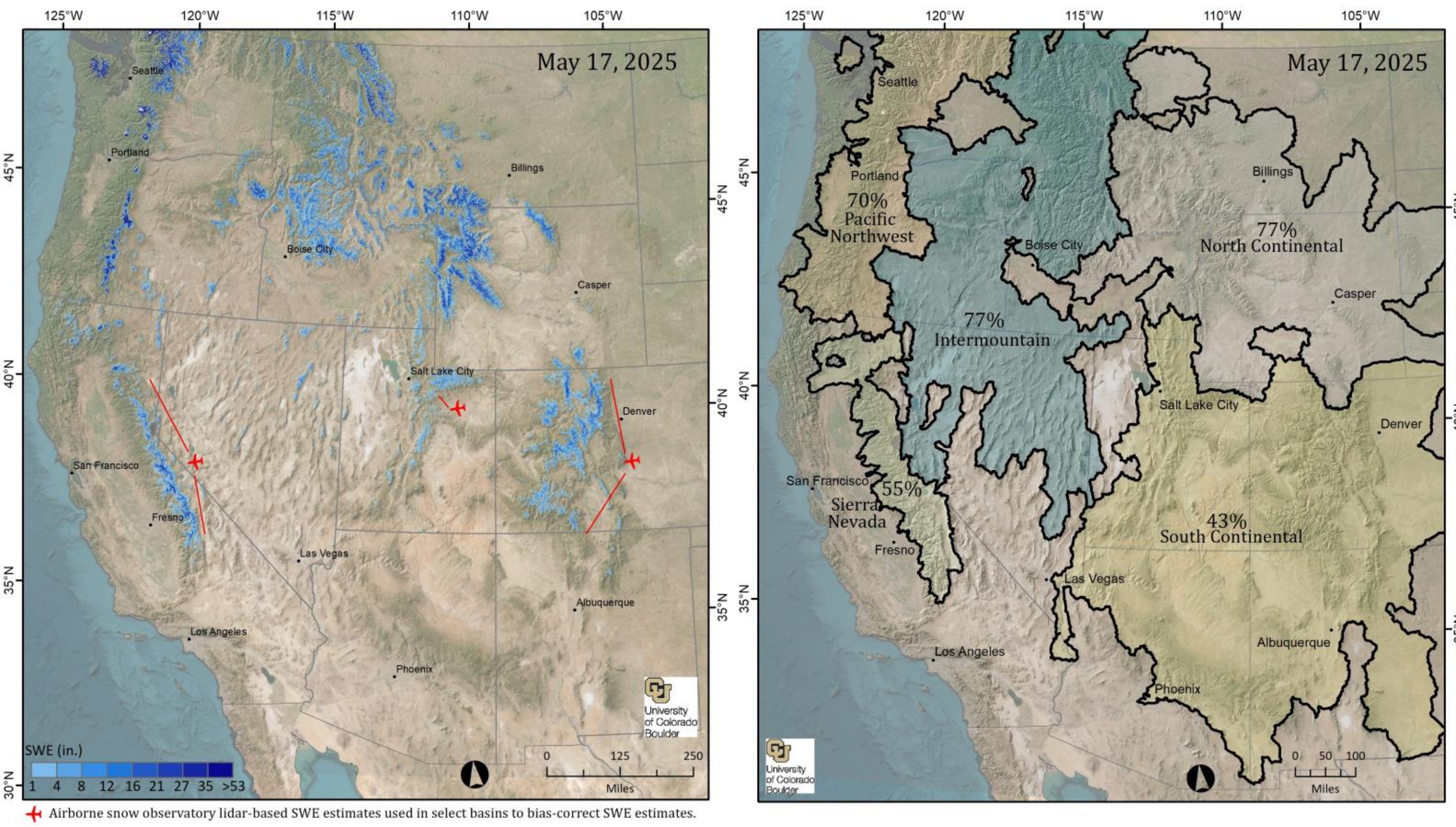

Figure 1. Estimated SWE and % of Average SWE across the Western U.S. SWE amounts across the entire Western region of the United States with red airplane markers indicating areas where the model was bias-corrected by Airborne Snow Observatory data (left) and percent of long-term average (2001-2021) by 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/].

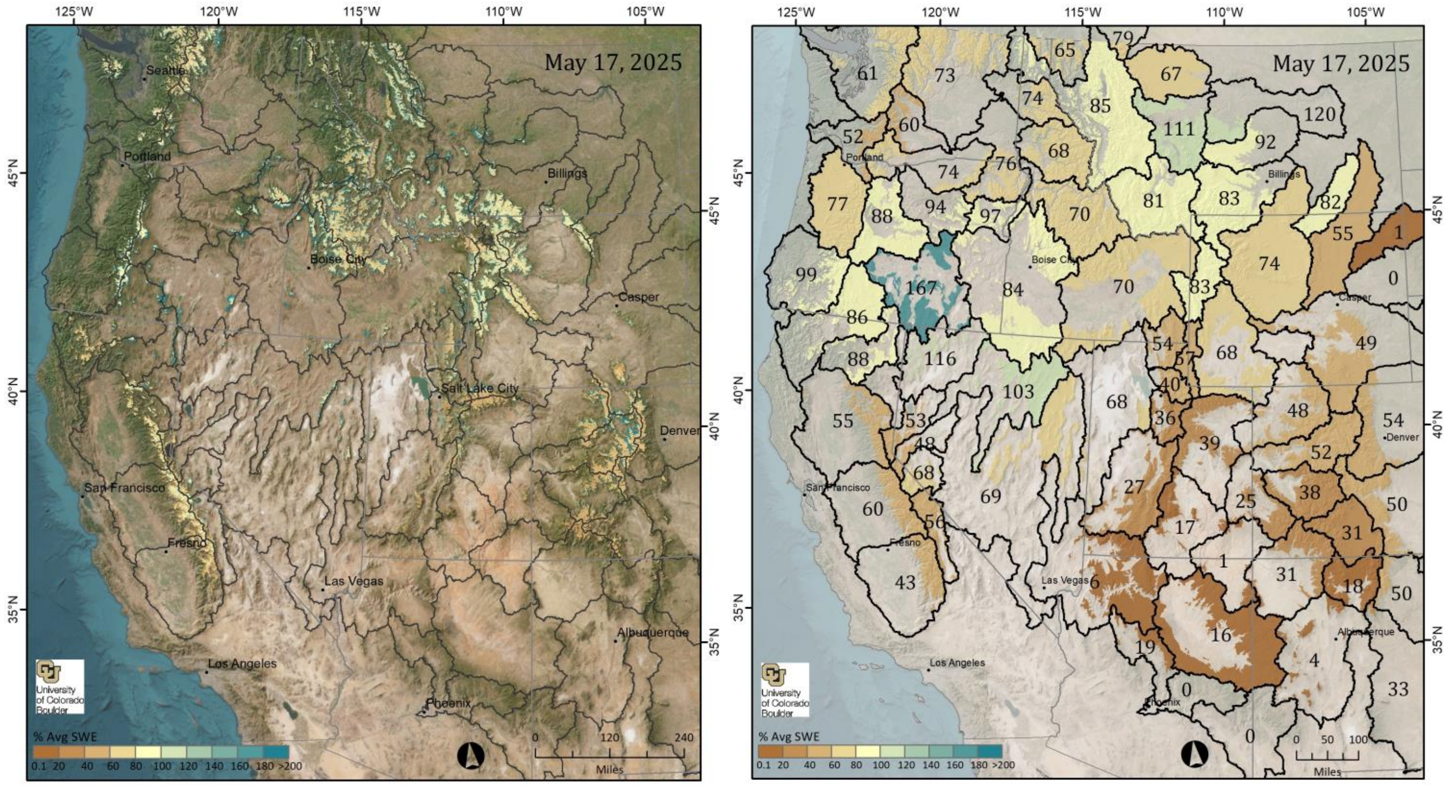

Figure 2. ***Estimated % of Average SWE across the Western U.S.*** Percent of long-term average (2001-2021) from the spatial SWE calculated for each pixel (left) and by HUC-6 basin (right); integer within each watershed represents the percent of average SWE for the report date. Shaded areas (right) correspond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

SWE input data available 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. When available and when appropriate SWE spatial data at 50-meter resolution from the Airborne Snow Observatory (Painter, et.al. 2016) is used to bias-correct model output.

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

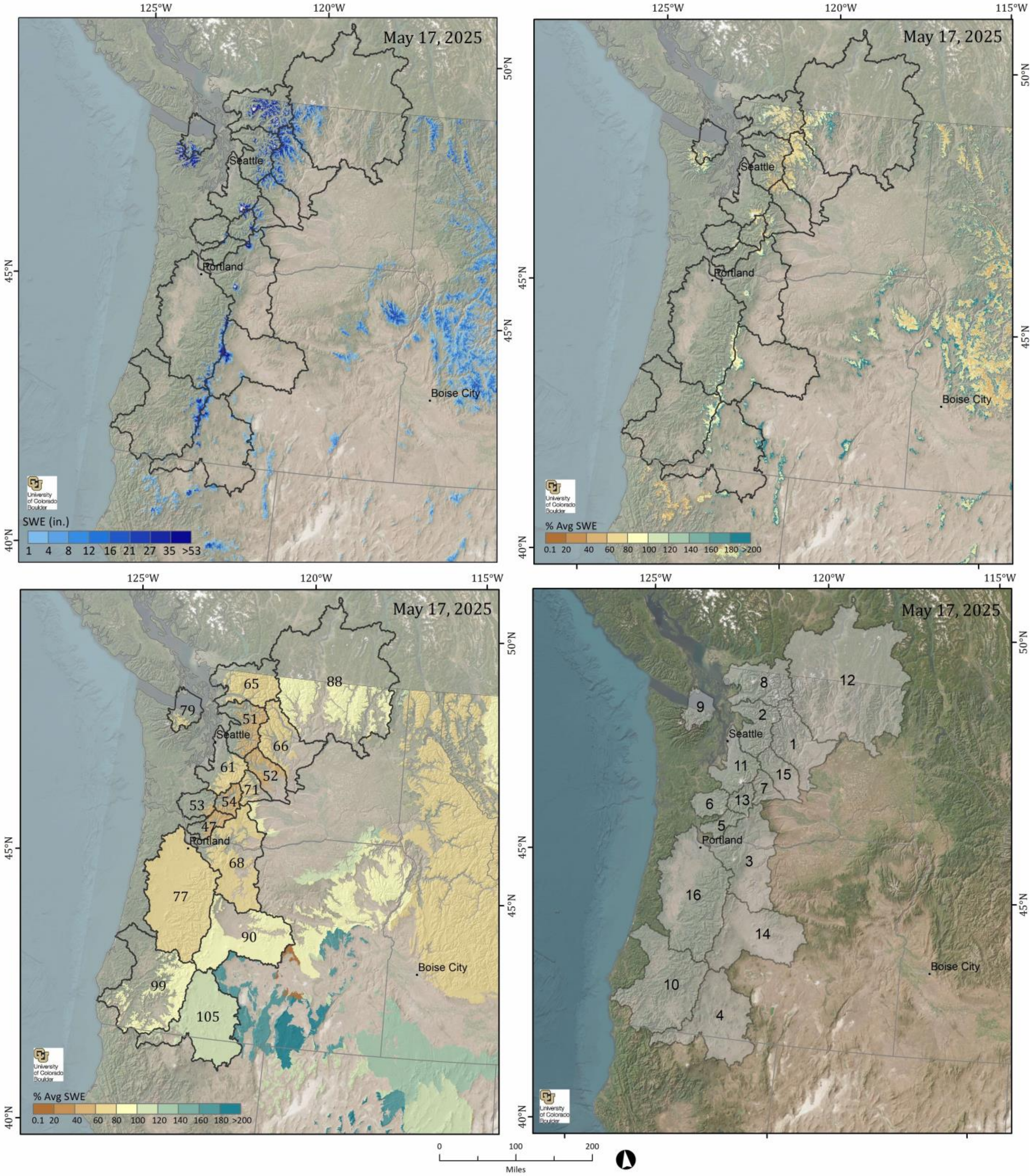

Figure 3. Estimated SWE and % of Average SWE across the Pacific Northwest Region. *SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left)* shaded areas correspond to the elevation bands used 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 5/17/2025									
	% of Average		SWE (in)					Pillows	
Basin	5/11	5/17	5/11	5/17	SCA	Vol. (AF)	Area (mi. sq)	5/11	5/17
1. Central Columbia	58	66	6.3	6.8	37.6	774,001	2,136	7.6 (7)	6.1 (7)
2. Central Puget Sound	56	51	6.3	6.1	32.6	406,100	1,238	17.3 (5)	14.7 (5)
3. Hood-Sandy-Lower Deschutes	60	68	0.6	0.6	4.1	171,521	5,080	9.3 (11)	9.3 (10)
4. Klamath	72	105	0.7	0.7	5.7	258,957	7,199	7.0 (14)	6.1 (14)
5. Lewis	41	47	1.2	1.3	6.5	40,991	581	24.9 (7)	26.8 (6)
6. Lower Cowlitz	52	53	1.9	1.8	9.1	17,995	185	13.8 (2)	12.5 (2)
7. Naches	55	71	2.6	3.4	23.7	112,272	610	24.7 (4)	20.9 (4)
8. North Puget Sound	64	65	6.4	6.6	29.8	808,033	2,313	26.3 (9)	23.9 (9)
9. Olympic	69	79	11.6	12.8	50.8	162,548	238	19.8 (3)	17.4 (3)
10. Rogue-Umpqua	71	99	1.8	1.9	12.2	345,395	3,371	3.5 (6)	3.4 (6)
11. South Puget Sound	61	61	2.4	2.7	12.6	164,976	1,148	10.6 (14)	9.7 (14)
12. Upper Columbia	75	88	1.5	1.5	10.3	443,561	5,502	3.9 (7)	3.6 (7)
13. Upper Cowlitz	53	54	3.7	3.9	19.2	149,590	714	16.8 (3)	13.3 (3)
14. Upper Deschutes-Crooked	74	90	1.2	1.2	7.2	346,273	5,608	5.4 (6)	4.1 (6)
15. Upper Yakima	50	52	2.3	2.4	16.7	132,897	1,033	1.5 (3)	0.0 (3)
16. Willamette	64	77	0.5	0.6	3.7	373,766	11,356	3.9 (17)	3.0 (17)

§ 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.

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

North Continental

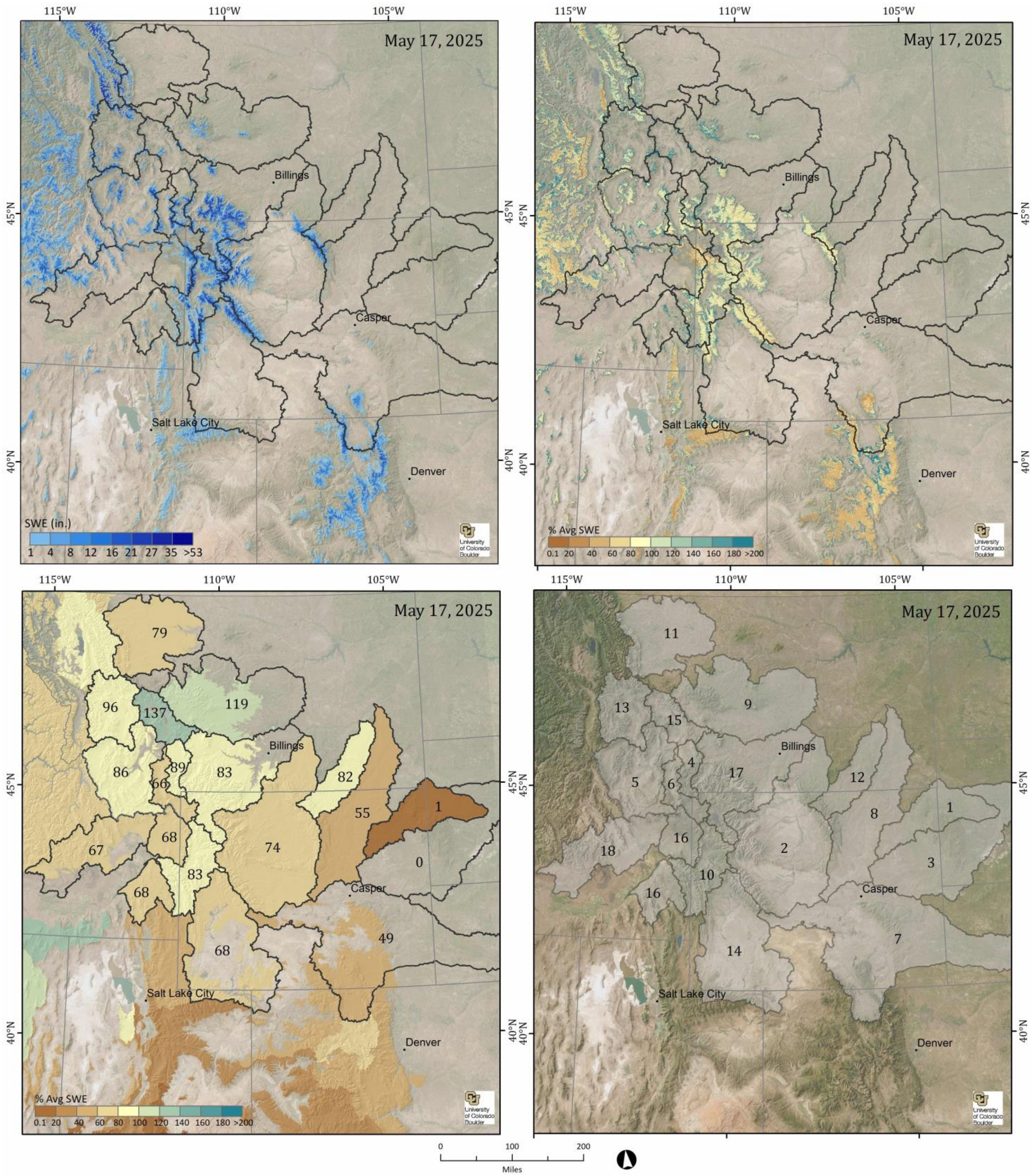

Figure 4. Estimated SWE and % of Average SWE across the North Continental Region. *SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left)* shaded areas correspond to the elevation bands used 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 5/17/2025

	% of Average		SWE (in)					Pillows	
Basin	5/11	5/17	5/11	5/17	SCA	Vol. (AF)	Area (mi. sq)	5/11	5/17
1. Belle Fourche	51	1	0.0	0.0	0.0	14	7,200	0.0 (1)	0.0 (1)
2. Bighorn	78	74	1.2	1.0	8.7	1,180,294	22,740	7.8 (21)	5.1 (20)
3. Cheyenne	10	0	0.0	0.0	0.0	0	15,348	0.0 (1)	0.2 (1)
4. Gallatin	81	89	2.8	2.8	24.2	274,547	1,846	18.9 (4)	17.8 (4)
5. Jefferson	70	86	1.3	1.5	18.1	711,324	8,788	7.6 (13)	7.6 (13)
6. Madison Headwaters in WY	62	66	2.5	2.4	22.8	317,117	2,524	11.1 (7)	9.8 (7)
7. North Platte	42	49	0.6	0.6	9.0	303,866	10,281	10.1 (22)	8.4 (22)
8. Powder	62	55	0.1	0.1	0.8	49,905	13,385	2.8 (5)	2.0 (5)
9. Smith-Judith-Musselshell	134	119	0.5	0.4	4.9	174,258	8,335	9.3 (9)	9.6 (8)
10. Snake	75	83	4.9	4.5	38.5	1,339,241	5,626	10.3 (11)	8.3 (11)
11. Sun-Teton-Marias	71	79	0.3	0.3	2.8	193,825	10,463	1.5 (5)	1.0 (5)
12. Tongue	81	82	0.5	0.4	4.5	123,163	5,400	7.7 (6)	4.9 (6)
13. Upper Clark Fork	80	96	1.2	1.2	11.3	387,101	5,981	6.3 (12)	6.1 (12)
14. Upper Green	66	68	1.6	1.3	12.4	663,693	9,539	6.1 (20)	4.8 (20)
15. Upper Missouri	105	137	0.4	0.4	4.2	58,681	2,951	0.1 (2)	0.1 (2)
16. Upper Snake Basins	53	68	1.0	1.1	14.1	402,915	6,875	6.3 (11)	5.2 (11)
17. Upper Yellowstone	80	83	3.3	2.9	22.0	1,701,223	11,070	11.0 (19)	10.0 (19)
18. Wood and Lost Basins	55	67	0.7	0.9	13.0	357,890	7,420	1.7 (16)	1.2 (16)

§ 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.

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

South Continental

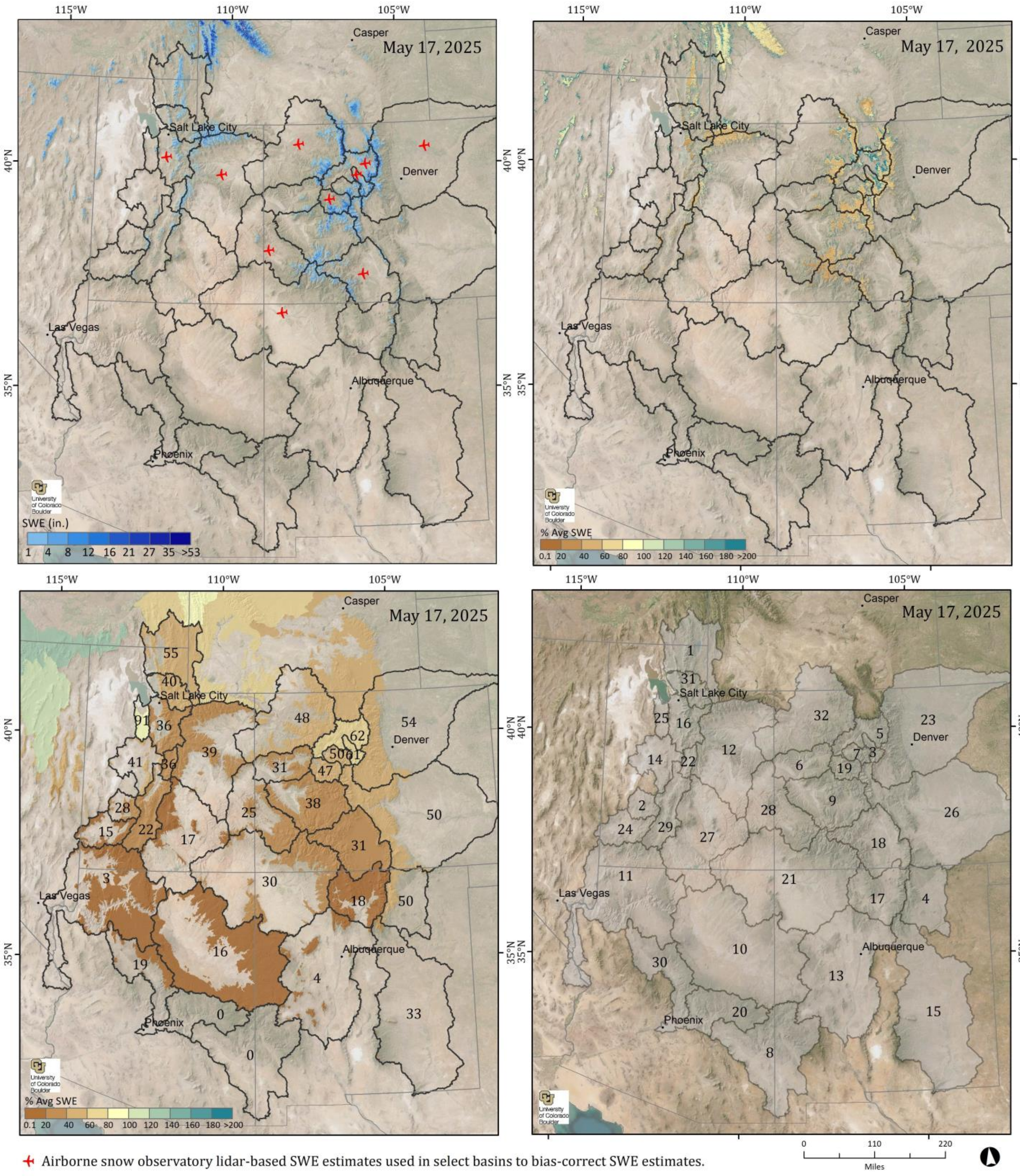

Figure 5. Estimated SWE and % of Average SWE across the South Continental Region. SWE amounts with red airplane markers indicating upper basin areas where the model was bias-corrected by Airborne Snow Observatory data (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (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 5/17/2025

	% of Average		SWE (in)					Pillows	
Basin	5/11	5/17	5/11	5/17	SCA	Vol. (AF)	Area (mi. sq)	5/11	5/17
1. Bear	43	55	0.6	0.6	11.8	190,485	6,181	4.7 (18)	3.5 (18)
2. Beaver	33	28	0.2	0.1	4.8	5,786	836	6.8 (2)	6.0 (2)
3. Blue§	44	61	4.1	4.2	45.7	149,239	670	12.1 (5)	10.4 (5)
4. Canadian	46	50	0.1	0.0	1.4	2,931	1,265	2.6 (2)	0.2 (2)
5. Colorado Headwaters§	43	62	2.1	2.2	28.6	335,160	2,874	9.5 (13)	8.0 (13)
6. Colorado Headwaters-Plateau	35	31	0.7	0.5	8.0	45,261	1,801	1.9 (1)	0.2 (1)
7. Eagle	40	50	2.1	2.0	25.0	100,418	921	0.1 (3)	0.0 (3)
8. Gila	0	0	0.0	0.0	0.0	0	4,924	0.0 (6)	0.0 (6)
9. Gunnison§	40	38	1.2	0.8	14.6	280,961	6,433	2.0 (11)	1.2 (11)
10. Little Colorado	33	16	0.0	0.0	0.0	281	16,379	0.5 (5)	0.4 (5)
11. Lower Colorado Mainstream	4	3	0.0	0.0	0.1	254	10,695	0.0 (5)	0.0 (5)
12. Lower Green§	37	39	0.8	0.6	11.4	169,668	5,647	1.7 (23)	1.2 (23)
13. Lower Rio Grande	31	4	0.0	0.0	0.0	83	1,795	0.6 (6)	0.0 (6)
14. Lower Sevier	22	41	0.1	0.1	3.0	2,937	897	2.1 (4)	0.2 (4)
15. Pecos	44	33	0.3	0.1	3.3	2,065	331	1.7 (2)	0.1 (2)
16. Provo-Utah Lake-Jordan§	35	36	0.6	0.4	11.0	63,031	2,681	5.4 (18)	4.4 (16)
17. Rio Chama-Upper Rio Grande	42	18	0.2	0.1	1.5	15,495	5,207	1.4 (13)	0.6 (13)
18. Rio Grande Headwaters§	53	31	0.9	0.3	6.5	135,242	7,595	2.3 (14)	0.6 (14)
19. Roaring Fork§	39	47	3.3	3.0	34.1	220,690	1,359	5.0 (7)	3.0 (7)
20. Salt	3	0	0.0	0.0	0.0	0	2,361	0.0 (7)	0.0 (6)
21. San Juan	43	30	0.6	0.3	6.1	102,000	6,406	2.1 (15)	1.4 (15)
22. San Pitch	38	36	0.6	0.4	10.0	18,123	857	2.3 (6)	1.2 (6)
23. South Platte§	54	54	1.2	0.9	12.8	265,853	5,620	9.3 (21)	7.7 (21)
24. Southwestern Utah	14	15	0.0	0.0	0.5	623	1,440	0.1 (5)	0.0 (5)
25. Toole Valley-Vernon Creek	48	91	0.1	0.1	3.3	7,175	906	2.5 (4)	1.8 (4)
26. Upper Arkansas	51	50	0.8	0.6	9.2	177,215	5,875	1.8 (6)	0.1 (6)
27. Upper Colorado-Dirty Devil	31	17	0.2	0.1	2.0	9,810	2,597	0.0 (7)	0.0 (7)
28. Upper Colorado-Dolores§	36	25	0.7	0.3	4.4	47,996	3,434	2.6 (7)	2.0 (8)
29. Upper Sevier	24	22	0.1	0.1	2.9	16,813	3,758	1.2 (16)	0.8 (16)
30. Verde	33	19	0.0	0.0	0.0	36	1,816	0.1 (7)	0.1 (7)
31. Weber-Ogden	34	40	0.5	0.5	13.7	51,119	2,041	2.7 (17)	1.9 (16)
32. White-Yampa§	42	48	1.3	1.2	16.5	378,376	5,948	6.6 (15)	5.4 (15)

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Intermountain

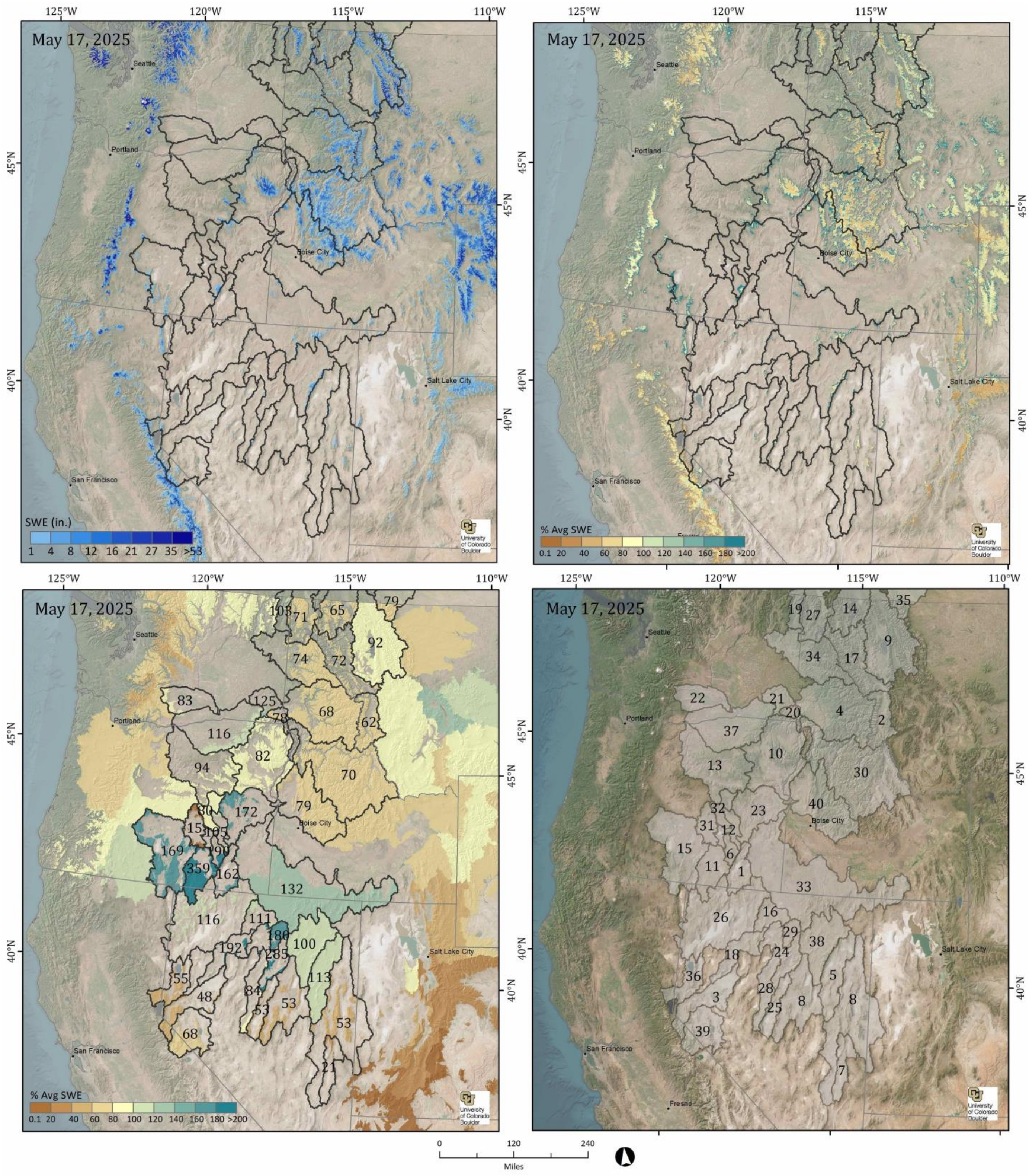

Figure 6. Estimated SWE and % of Average SWE across the Intermountain Region. SWE amounts (upper left), percent of long-term average (2001-2021) SWE calculated for each pixel (upper right), basin-wide percent of long-term average (lower left) shaded areas correspond to the elevation bands used in the 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 5/17/2025

	% of Average		SWE (in)					Pillows	
Basin	5/11	5/17	5/11	5/17	SCA	Vol. (AF)	Area (mi. sq)	5/11	5/17
1. Alvord Lake	131	162	0.6	0.7	9.8	11,992	324	NA	NA
2. Bitterroot	68	62	3.3	2.3	28.4	240,277	1,952	6.9 (4)	6.0 (4)
3. Carson	44	48	0.9	0.6	6.4	43,075	1,405	3.2 (7)	1.7 (7)
4. Clearwater Basin	70	68	2.6	1.8	19.9	717,066	7,488	16.1 (11)	13.9 (11)
5. Clover Valley and Franklin	74	113	0.1	0.1	2.7	27,226	4,048	1.2 (2)	0.2 (2)
6. Donner und Blitzen	146	190	2.9	3.4	47.1	40,598	222	18.4 (2)	18.3 (2)
7. Dry Lake Valley	15	21	0.0	0.0	0.2	128	289	NA	NA
8. Eastern Nevada	41	53	0.1	0.1	2.5	23,649	4,372	1.3 (8)	1.0 (8)
9. Flathead	83	92	3.0	2.9	21.3	1,147,144	7,526	15.8 (13)	11.6 (12)
10. Grande Ronde-Burnt-Powder_Imnaha	73	82	1.6	1.6	17.1	458,990	5,312	4.6 (10)	4.3 (10)
11. Guano	99	359	0.0	0.0	0.7	4,526	2,036	0.0 (1)	0.0 (1)
12. Harney-Malheur Lakes	69	105	0.0	0.0	0.4	405	276	NA	NA
13. John Day	70	94	1.0	1.0	11.7	80,717	1,502	0.0 (2)	0.0 (2)
14. Kootenai	67	65	1.9	1.6	16.6	141,898	1,673	11.1 (5)	8.8 (5)
15. Lake County-Goose Lake	78	169	0.4	0.5	7.5	89,068	3,602	12.3 (2)	10.6 (2)
16. Little Humboldt	59	111	0.1	0.1	2.1	2,508	419	3.4 (3)	1.8 (3)
17. Lower Clark Fork	77	72	3.4	2.6	27.2	203,423	1,465	32.5 (4)	29.9 (4)
18. Lower Humboldt	50	192	0.1	0.1	2.6	1,508	274	0.0 (1)	0.0 (1)
19. Lower Pend Oreille	90	103	4.2	4.2	46.6	28,703	129	15.2 (1)	13.6 (1)
20. Lower Snake-Asotin	80	78	0.2	0.1	1.9	2,377	328	0.0 (2)	0.1 (2)

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ǂ 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.

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

Intermountain SWE Report for 5/17/2025									
	% of Average		SWE (in)					Pillows	
Basin	5/11	5/17	5/11	5/17	SCA	Vol. (AF)	Area (mi. sq)	5/11	5/17
21. Lower Snake-Tucannon	132	125	1.0	0.9	14.4	5,038	109	NA	NA
22. Lower Yakima	55	83	0.4	0.5	6.4	13,880	489	4.7 (2)	2.6 (2)
23. Malheur	84	172	0.5	0.6	9.5	33,606	992	0.0 (3)	0.0 (3)
24. Middle Humboldt	21	285	0.0	0.0	0.7	1,009	633	NA	NA
25. Northern Big Smoky Valley	34	53	0.2	0.2	3.1	4,699	570	NA	NA
26. Northern Great Basin	70	116	0.1	0.1	1.3	8,069	2,226	0.0 (2)	0.0 (2)
27. Panhandle Basins	63	71	2.0	2.1	22.2	184,726	1,644	21.9 (3)	19.6 (3)
28. Reese	39	84	0.2	0.2	4.9	5,331	491	1.6 (2)	0.2 (2)
29. Rock	41	180	0.0	0.0	0.3	613	835	0.0 (1)	0.1 (1)
30. Salmon Basin	75	70	3.4	2.8	34.4	1,750,494	11,932	10.1 (11)	8.8 (11)
31. Silver	90	15	0.0	0.0	0.0	24	431	NA	NA
32. Silvies	53	80	0.1	0.0	0.6	2,985	1,316	0.1 (1)	0.0 (1)
33. Southern Snake Basins	54	132	0.1	0.2	2.7	101,301	12,500	1.7 (13)	1.3 (13)
34. Spokane	86	74	0.8	0.5	6.7	91,870	3,146	3.1 (8)	1.8 (8)
35. St. Mary	63	79	4.1	4.3	27.2	148,204	648	0.0 (1)	0.0 (1)
36. Truckee	42	55	0.9	0.7	8.5	51,844	1,420	10.0 (9)	8.9 (9)
37. Umatilla-Walla Walla-Willow	75	116	0.2	0.3	4.9	21,380	1,434	7.2 (7)	5.6 (7)
38. Upper Humboldt	78	100	0.3	0.3	5.0	84,013	5,032	4.0 (8)	3.3 (8)
39. Walker	60	68	1.0	0.8	7.8	79,110	1,939	9.6 (7)	8.1 (7)
40. West Central Basins	73	79	2.8	2.5	31.6	764,235	5,620	9.3 (15)	6.9 (15)

§ 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.

*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.

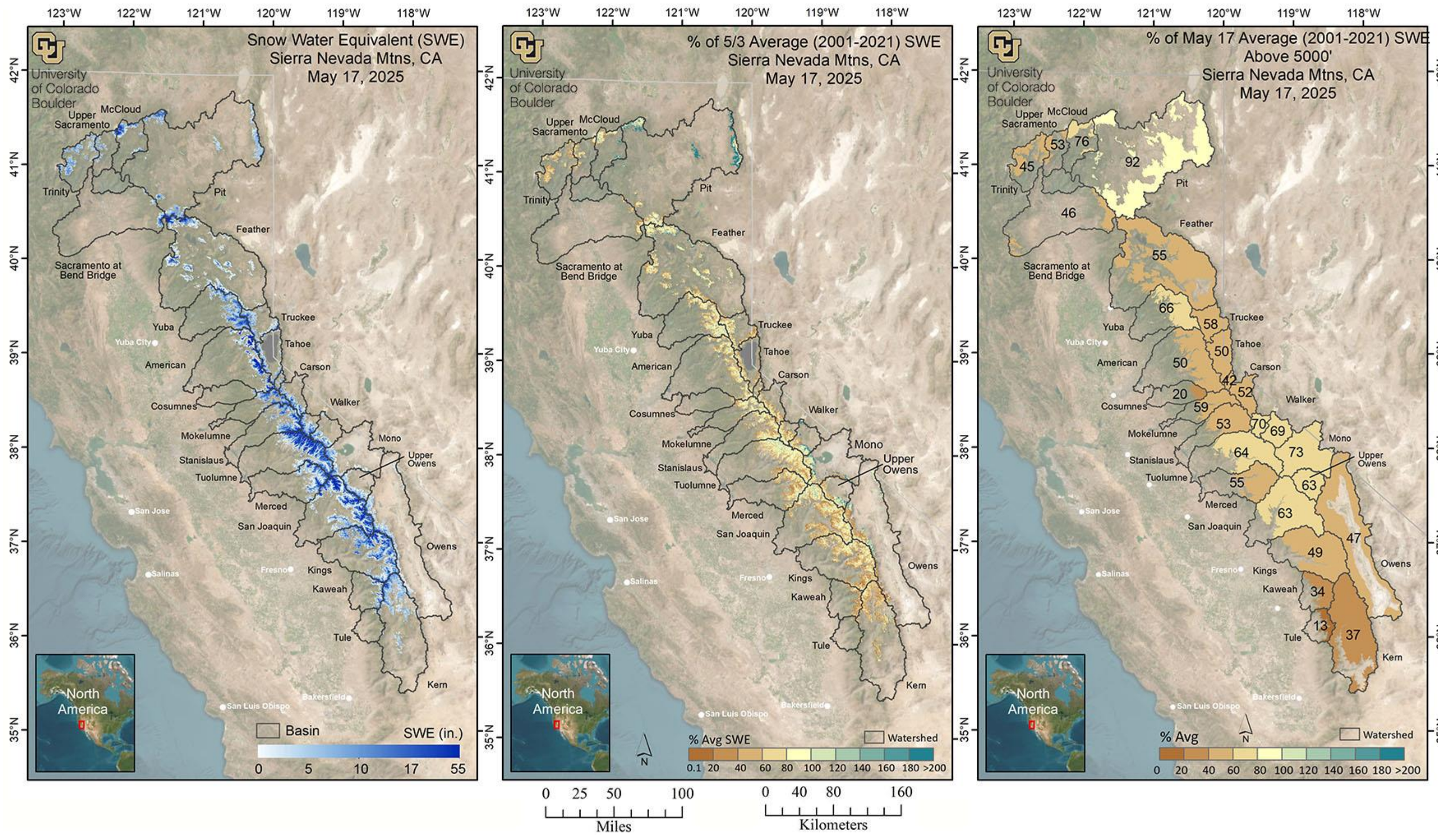

Figure 7. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts (left), and percent of average (2001-2021) SWE for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

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 5/17/2025

	% of Average		SWE (in)					Pillows		
	5/11	5/17	5/11	5/17	SCA	Vol. (AF)‡	Area (mi. sq)	5/11	5/17	SNODAS* (in)
Trinity	38	45	5.2	4.3	36.8	73,696	321.4	2.9 (4)	0.7 (4)	11.8
Upper Sacramento	48	53	5.9	4.7	33.1	28,996	115.2	0.0 (1)	0.0 (1)	10.6
McCloud	74	76	7.5	5.8	40.2	50,956	164.9	15.1 (1)	10.5 (1)	22.3
Pit	72	92	1.4	1.2	11.3	136,592	2065.9	5.1 (7)	4.0 (7)	1.1
Sacramento at Bend Bridge	36	46	2.3	2.0	16.6	26,060	239.8	NA	NA	3.3
Feather§	33	55	1.5	1.4	14.8	161,332	2087.7	3.8 (6)	2.5 (6)	2.2
Yuba	55	66	6.1	5.3	34.5	146,500	516.4	24.5 (5)	22.7 (5)	8.3
American§	45	50	4.6	4.6	19.8	196,664	795.3	5.0 (11)	3.4 (11)	3.4
Cosumnes	13	20	0.6	0.7	4.3	3,363	91.9	NA	NA	0.6
Mokelumne	56	59	6.3	5.0	23.5	84,204	315.1	18.7 (2)	15.5 (2)	5.2
Stanislaus	48	53	5.5	4.6	25.6	136,252	557.4	15.1 (5)	12.4 (5)	5.4
Tuolumne§	61	64	7.7	6.8	32.4	330,268	910.3	9.3 (8)	6.7 (8)	10.0
Merced§	49	55	5.7	4.2	27.5	120,961	538.8	7.8 (2)	0.4 (2)	6.2
San Joaquin§	56	63	6.8	6.3	33.2	406,759	1208.5	0.3 (6)	0.0 (6)	4.5
Kings§	49	49	6.2	5.0	30.5	319,995	1207.3	5.6 (4)	3.7 (3)	5.0
Kaweah§	36	34	3.7	2.7	18.7	45,358	314.1	0.0 (1)	0.0 (1)	5.7
Tule	11	13	0.3	0.3	3.0	2,063	137.6	0.0 (1)	0.0 (1)	0.3
Kern	33	37	1.7	1.4	9.6	129,021	1682.1	6.8 (6)	0.0 (4)	1.6
Truckee	43	58	3.4	3.3	22.6	71,852	412.0	10.1 (6)	9.2 (6)	4.8
Tahoe	46	50	4.5	3.7	25.5	60,913	306.0	4.0 (7)	1.3 (7)	2.9
W Carson	37	42	4.2	3.9	17.5	13,511	65.0	4.9 (3)	3.2 (3)	1.6
E Carson	50	52	3.9	3.0	19.0	57,279	354.3	1.9 (4)	0.6 (4)	3.0
W Walker	67	70	8.0	6.7	38.3	64,323	179.6	14.0 (4)	12.3 (4)	11.6
E Walker	62	69	2.8	2.5	17.2	46,593	351.0	10.0 (1)	7.8 (1)	3.9
Mono	63	73	1.3	1.2	8.2	63,043	1004.4	NA	NA	1.5
Upper Owens	57	63	2.6	2.4	16.4	47,752	374.5	29.6 (1)	26.6 (1)	1.4
Owens	48	47	1.3	1.1	8.3	103,549	1772.0	1.1 (4)	0.4 (5)	0.5

§ 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 (Painter, et.al. 2016) and from snow surveys at 10 locations in Colorado. Additionally, as a final step, when appropriate and when available, ASO data can be used to bias-correct model output.

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: 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. DOI: 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., D. F. Berisford, J. W. Boardman, K. J. Bormann, J. S. Deems, F. Gehrke, A. Hedrick, M. Joyce, R. Laidlaw, D. Marks, C. Mattmann, B. McGurk, P. Ramirez, M. Richardson, S. M. Skiles, F. C. Seidel, A. Winstral (2016). The Airborne Snow Observatory: Fusion of scanning lidar, imaging spectrometer, and physically-based modeling for mapping snow water equivalent and snow albedo. *Remote Sensing of Environment*, 184, 139-152, DOI: 10.1016/j.rse.2016.06.018.

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.