SPRING 2018 MODIS-BASED SPATIAL SWE PRODUCT FOR THE INTERMOUNTAIN WEST REGION: FEEDBACK FROM BETA TESTERS

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Cover photo: Heather M. Yocum

List of Abbreviations

ASO	Airborn Snow Observatory
CBRFC	Colorado Basin River Forecast Center
CoCoRaHS	Community Collaborative Rain, Hail and Snow Network
CONUS	Continental United States
CWCB	Colorado Water Conservation Board
CWEST	The Center for Water, Earth Science and Technology
ESP	Ensemble Stream Prediction
GIS	Geographic Information System
HUC	Hydrologic Unit Codes
INSTAAR	The Institute of Arctic and Alpine Research
JPL	Jet Propulsion Lab
MODIS	Moderate Resolution Imaging Spectroradiometer
MODSCAG	Snow Covered-Area and Grain size retrieval algorithm
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NRCS	National Resource Conservation Service
NWS	National Weather Service
RFC	River Forecast Center
SCA	Snow-covered area
SNODAS	Snow Data Assimilation System
SNOTEL	Snow Telemetry
SWE	Snow water equivalent
USDA	United States Department of Agriculture
WRF HYDRO	Weather Research and Forecasting Model -- Hydro

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INTRODUCTION AND METHODS

In a trio of Western Water Assessment (WWA) snowpack monitoring workshops in 2015, participants were introduced to retrospective maps of a MODIS-based spatial snow product for the Intermountain West, developed by WWA researcher Noah Molotch (INSTAAR and CWEST) and his research group. The keen interest of these workshop participants in the spatial snow information motivated a follow-on effort in spring 2018, when we worked with the Molotch group to produce and disseminate a near-real-time experimental product to provide estimates of snow-water equivalent (SWE) at a spatial resolution of 500 m for the Intermountain West region (Colorado, Utah, and Wyoming) through the spring.

The Molotch group had been producing a similar experimental product covering the Sierra Nevada mountains for water managers in California since 2013-14, but the report for the Intermountain West region would employ a new methodology, described in Schneider and Molotch (2016). The overall objectives of the project were to (1) test the feasibility of producing the spatial snow product and a user-focused report for the Intermountain West in a quasi-operational mode, and (2) gather feedback from users on the value and utility of the spatial snow information and the format for the report. This report focuses on the second item, feedback from users.

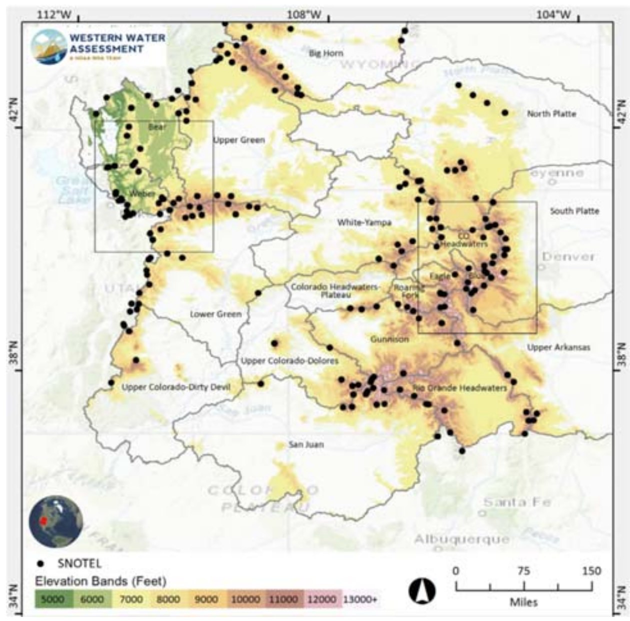

Figure 1. Image from the SWE report identifying the Intermountain West region, SNOTEL sites (black dots), and small boxes indicating areas shown in greater detail in the report.

The Molotch group, with support from WWA, produced four spatial snow reports (hereafter, the MODIS SWE report) for conditions as of March 13, April 3, April 18, and May 8. These reports were distributed to a select group of 18 "beta testers" in the region: 7 individuals with 6 water management organizations, 6 individuals with 5 boundary organizations and/or climate and weather information providers, and 5 snow and climate researchers (testers are listed by organization in the table in Appendix A). Additional data tables were also produced for the April 18 and May 8 reports, containing information on the SWE in the HUC 8 sub-basins (April 18 and May 8) and comparing the May 8, 2018 modeled SWE conditions for the 19 major basins in the region with the modeled SWE conditions for the same date in the 2000-2012 "climatology" (for May 8 only).

Semi-structured phone or in-person interviews were conducted with each of the beta testers to collect feedback on how to improve the report for future users. One beta tester from the research community was unable to provide feedback. This report summarizes the findings from these interviews.

This report is organized into the following sections:

1. Uses of Report
2. Most Useful and/or Compelling Information
    - 2.1. Maps
    - 2.2. Report Summary
    - 2.3. Tabular Information
3. Suggested Improvements
    - 3.1. Improving the Presentation of the Data and Report
    - 3.2. Frequency
    - 3.3. Creating an Online Archive
    - 3.4. Creating an Interactive Website
    - 3.5. Lower Elevation Snow
4. Verification and Validation of Model
5. Methodological Questions and Suggestions
    - 5.1. Discrepancies Between the MODIS SWE Report and Other Information
    - 5.2. Skill
    - 5.3. 2000-2012 Climatology
    - 5.4. Additional Suggestions
6. Sources of Snow Information

1. USES OF REPORT

All beta testers agreed that there was a need for the type of spatial information on snowpack contained in the MODIS SWE report. Water managers were most excited about the potential for spatial SWE information to improve seasonal streamflow forecasting, but also reported that it was useful for "ground truthing" gut feelings and anecdotal reports from on the ground, scenario planning, and comparing it to other sources of snowpack information in their area of interest (e.g., SNOTEL and snow courses[1]; SNODAS[2]).

Beta testers were also very interested in the potential for this product to shed light on the relative contribution of snow from different elevations to the overall water supply. The information in the MODIS SWE report on areas under-represented by SNOTEL, especially lower- and higher-elevation areas, was identified as a particularly important addition to existing information, especially in areas more reliant on lower-elevation snow.

Water managers also noted the potential uses for understanding how snowpack varies from year to year, and how climate change might impact snow at lower elevations, particularly during the early and late "shoulder" seasons.

The vast majority of the beta testers reported that they would use the information from the MODIS SWE report to complement their consultation of other snowpack information (e.g., SNOTEL, SNODAS, etc.) and water supply information (e.g., NOAA Colorado Basin River Forecast Center (CBRFC) streamflow forecasts, USDA Natural Resource Conservation Service (NRCS) streamflow forecasts, and National Center for Atmospheric Research's WRF-Hydro), but *not* to generate their own streamflow forecasts. Most do not have the technical capacity in-house to generate their own streamflow forecasts, and so rely on those generated by other organizations, such as the CBRFC. However, they did stress the importance of this type of spatial information for ground-truthing other information sources, to inform drought monitoring, as well as for use in scenario planning.

Only one person with a water management agency—the Colorado Division of Water Resources—reported that they might use this information in the future to generate their own streamflow forecasts. This would depend on how the MODIS SWE report information performed in any post-season verification, and would be used in conjunction with snowpack, runoff, and

[1] USDA National Resource Conservation Service (NRCS) Snow Telemetry (SNOTEL) and Snow Course Data and Products, available at: https://www.wcc.nrcs.usda.gov/snow/

[2] NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS), available at: https://nsidc.org/data/g02158

streamflow information from NRCS, CBRFC, and NCAR (e.g., the WRF-Hydro pilot activity in the Rio Grande Basin).

The beta testers from CBRFC reported that the NOAA RFCs cannot ingest any information into their streamflow forecast model unless it is fully operational by NWS standards[3]. The CBRFC did report that if the MODIS SWE report performs well in post-season verification over several seasons, it may be useful as a check on the modeled snowpack in their current model, i.e., identifying if they are under- or over-representing snowpack in particular areas.

2. Most Useful and/or Compelling Information

Beta testers found that the most helpful components of the MODIS SWE report were the following:

- Graphic/map representations of the snow-covered area, especially those which showed particular basins in greater detail, e.g., Figures 4 and 5 (see Appendix C)
- Summary of current conditions
- SWE information provided by elevation band in Tables 1 and 2
- Maps illustrating the change between the previous and current reports (Fig. 2 in report, shown as Fig. 2 below) after April 1 (e.g., peak SWE).

Water managers also appreciated the supplemental tables which provided the SWE for the HUC 8 sub-basins and which compared the May 8, 2018 modeled SWE conditions for the 19 major basins with the modeled SWE conditions for the same date from 2000-2012 (Appendix D).

2.1. Maps

Testers found the graphics to be both informative and compelling, and stated that they appreciated being able to toggle back and forth between the graphic and tabular information. Testers favorably compared the MODIS SWE report to both the NRCS SNOTEL reports and NOHRSC SNODAS product, appreciating the change maps (depicted in Figure 2 in the report; and as Figure 2 below), which they found to be more detailed than similar maps produced by NRCS. By using Figure 3 from the report (Figure 3 below), which showed the percent of average

[3] National Oceanic and Atmospheric Administration (2016) NOAA Administrative Order 216-105B: Policy on Research and Development Transitions. Available at: http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/NAO%20216-105B%20UNSEC%20Signed.pdf

SWE both pixel-by-pixel and basin-wide for the 19 primary basins, water managers said that they could identify approximate areas of interest (e.g., sub-basins) even if they weren't specifically identified. For Colorado users, the pixel-by-pixel map in Figure 3 of the report (Figure 3 below) was also preferred to the basin polygons in the Colorado Decision Support System SNODAS Tool[4] (from CWCB and Open Water Foundation, available here: http://snodas.cdss.state.co.us/app/index.html) (Figure 4 below).

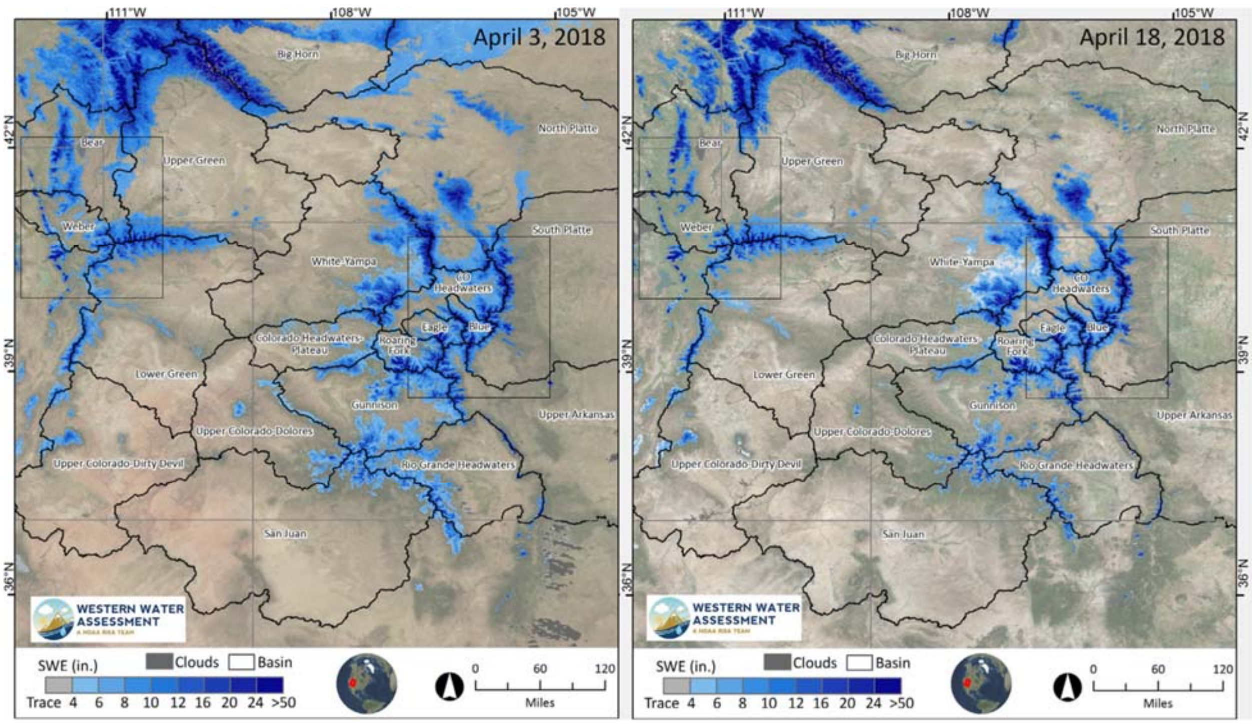

Figure 2. Showing Figure 2 from the SWE report. The "change map" comparing estimated SWE amounts across the Intermountain West from the previous report (left) and the most recent report (right) (April 3rd and April 18th, 2018 are shown here).

[4] The Colorado Water Conservation Board and Open Water Foundation's Colorado Decision Support System SNODAS Tool, available at: http://snodas.cdss.state.co.us/app/index.html.

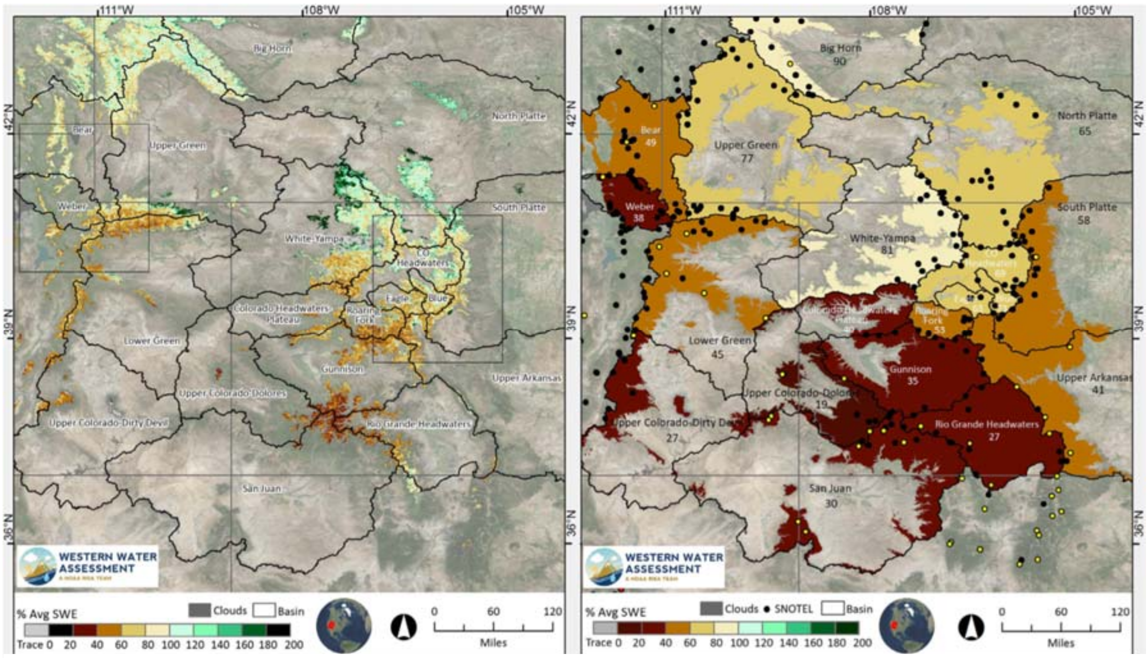

Figure 3. Showing Figure 3 from the SWE report. Estimated % of average SWE across the Intermountain West, April 18, 2018 (Figure 3 in the SWE Report). Percent of average (2000-2012) SWE for April 18, 2018 for the Intermountain West, calculated for each pixel (left) and basin-wide (right).

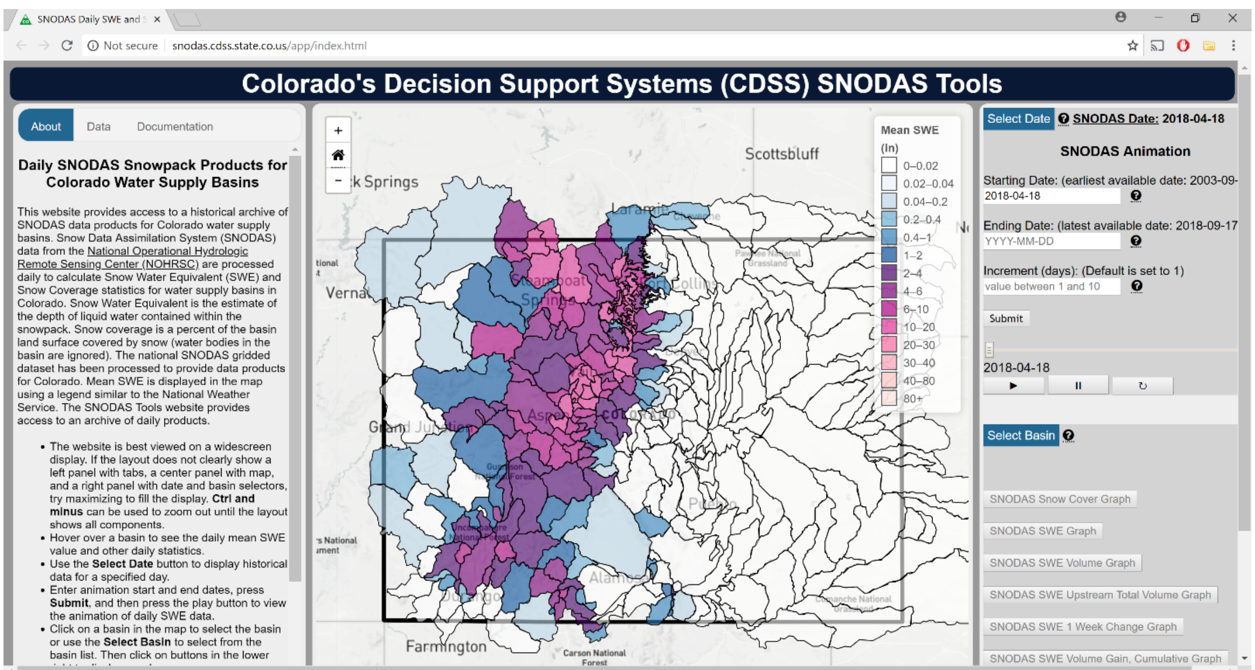

Figure 4. Screenshot of the Colorado Water Conservation Board and Open Water Foundation's Colorado Decision Support System SNODAS Tool for April 18, 2018, available at: http://snodas.cdss.state.co.us/app/index.html

2.2. Report Summary

Beta testers appreciated the initial summary of current conditions, and reported that it made the reports more digestible, providing a quick way for them to decide where they wanted to focus their attention. These summaries were cited as key for information users to be able to parse out relevant information in the face of increasingly large volumes of information to which they are exposed.

2.3. Tabular Information

Beta testers appreciated the information presented in the tables. In particular, they appreciated seeing the percent average and the area, in square miles, of each elevation band for the different basins. They reported that further breaking it down into HUC 8 basins was particularly helpful for understanding SWE in the sub-basins. The elevation band information was seen as useful for understanding melt patterns across space and time within the basins.

Basin	Elevation Band	4/3/2018 % 4/3 Avg.	4/18/2018 % 4/18 Avg.	4/3/18 SWE (in)	4/18/18 SWE (in)	4/3/18 thru 4/18/18 Change SWE (in)	Area (Sq Mi)	4/18/18 SNODAS* (in)
Bear	5000-6000'	5.1	0.0	0.2	0.0	-0.2	766.0	0.0
	6000-7000'	31.4	4.7	2.1	0.1	-2.0	2,692.2	0.4
	7000-8000'	64.0	43.3	6.7	3.2	-3.5	1,778.0	4.4
	8000-9000'	82.8	83.1	14.0	13.1	-0.9	578.2	16.7
	9000-10,000'	81.2	82.2	16.1	16.1	0.0	132.1	17.9
	10,000-11,000'	74.3	72.7	17.2	17.5	0.3	76.2	17.6
	11,000-12,000'	79.6	78.7	26.5	28.7	2.2	12.9	11.1
	12,000-13,000'	84.7	83.5	29.5	32.2	2.7	1.2	6.1

Figure 5. Showing an excerpt from Table 2 from the SWE report. Estimated SWE by basin and elevation band. Table 2 includes comparisons for the percent of average and total inches of SWE for the previous and current report (shown here are April 3 and April 18, 2018), A comparison with SNODAS is also included.

3. Suggested Improvements to increase usability

Best testers had a variety of suggestions and information requests which would improve the usefulness and usability of MODIS SWE report.

By far the most common request was for metrics showing how the MODIS SWE product performed relative to other available snowpack information and for information about how to use the MODIS SWE report information to add value to other snowpack information.

Additional suggestions and requests made by the beta testers are organized below into four sections:

1. Editorial suggestions to improve the presentation of the data and the report itself;
2. The frequency that the report is issued;
3. Suggestions for an expanded online archive of information; and
4. An interactive website with user-defined features and more refined geographic scale.

Suggestions and questions about verification/validation and model performance and methodology are discussed separately, below.

3.1 Improving the Presentation of the Data and Report

Editorial suggestions to improve the presentation of the data and the report itself included

- Move the summary of current conditions and the change map (Fig. 2) to the front page
- Bookmark within the PDF to facilitate faster navigation
- Add other identifying details to the maps (e.g., county-level boundaries, towns, roads, or river channels)
- Increase the size of the graphics, e.g., making maps fill an entire page, to make it easier to see details and ID area(s) of interest, particularly for the pixelated map, Fig. 3
- Circulate the summary of current conditions and the change map (Fig. 2) in the body of the email
- Create a name for the product.

Several water managers and researchers requested that a volumetric total (e.g., acre-feet of SWE) be included with the tabular information. Some noted the potential misuse of this number by lay-persons, but with the understanding that any volumetric number would not be equivalent to runoff, they still recognized this as an important step in verification of this MODIS-based SWE information.

Additional requests included:

- Extend the area covered in the report to include New Mexico, particularly the basins associated with the Rio Grande Compact (e.g., the Rio Grande and Conejos)

- Change the all-blue color scheme on the change map (Fig. 2) to make it easier to discern differences
- Add detailed maps for areas that have difficulties obtaining accurate SNOTEL and/or SNODAS information (e.g., Wind River basin)
- Add percent of area to basin area (e.g., 100 sq mi = X % of the basin) since it would make understanding the relative importance of the snow in that area to the total volume of snow in the area
- Identify the elevation/location of the SNOTEL sites in the elevation band tables
- Put the caveats as a more simplified warning label at the beginning; provide any additional detail later in the report
- Describe the product and the current conditions first; move the methodology to the end
- Move the definitions to the end
- Make raster files available so that the data can be used with GIS information tools
- Add comparisons with ASO, either graphically or in tables, for relevant areas

3.2. Frequency

Whatever the frequency of the report, beta testers placed very high importance on reliability, i.e., that the information/report be provided to them on the date(s) when they were expecting it. The majority of beta testers indicated that bi-weekly or monthly was an appropriate frequency for issuing the report. Additional suggestions included the following:

- Daily
- Weekly
- Monthly, but in the middle of the month to alternate with NRCS SNOTEL reports which come out at the beginning of each month.
- After every large snowstorm/snow event
- One time around the peak SWE (e.g. April 1 for West Slope; May 1 in east slope in WY)
- Around April 1 to get an idea of peak snowpack, but before the April 1 decision meetings begin (April 1 is an important decision point for determining “calls on river,” deliveries for various agreements (e.g., Yellowstone Compact), etc.).

3.3. Creating an Online Archive

One-third of the beta testers (n=6) requested an archive which would expand the information currently available on the FTP site[5] and contain all the tabular information and graphics for quick reference and provide a numerical and visual snapshot of evolution of SWE and snow-covered area during the accumulation and melt season. Beta testers suggested that the archive should include:

- A spreadsheet that includes the tabular information for the percent average and the actual inches of SWE for each report in adjacent columns
- Maps in Fig. 2 and Fig. 3 all adjacent to each other
- Archive of info from 2000-2012 "climatology" so that users can compare years and/or select their own analog years for comparison
- A time series of SWE for each pixel (e.g. for each pixel represented in Fig. 3) similar to the timeseries available for SNOTEL information
- The raw data available in an accessible format for users with the capacity to use it (e.g., raster files, KLM format, Excel files, etc.)

Some testers also suggested that the raw data from the report be included in the archive. As discussed above, many of the smaller water utilities/managers lacked the technical capacity or personnel who could make use of the raw data. However, for those that can use the GIS data (e.g., the Colorado Climate Center, NOAA CBRFC, Colorado River District, NRCS, and researchers), their interest in using it largely depends on ease of access, including if the format of the data is easily compatible with their current suite of tools. Suggested formats included Excel files, KML files for use with Google Maps, and/or raster files for other GIS-based software/tools. For example, NRCS wants to "extract the model's point value at SNOTEL sites" to do their own comparisons and to add the spatial distribution information to their presentations to stakeholders.

3.4. Creating an Interactive Website

Over two-thirds of the beta testers (n=13) requested that the MODIS SWE information be housed on an interactive website rather than distributed in a static PDF report. The primary driver of this request was the desire to precisely access data at finer spatial scales. Ideally, the website would include the archive as described above, along with interactive maps that would enable users to zoom in on their particular area(s) of interest, including ability to turn on/off geo-markers such as rivers, sub-basins, county boundaries, major roads, additional HUC levels, towns, etc.[6]

[5] ftp://snowserver.colorado.edu/pub/fromLeanne/forWWA/Near_Real_Time_Reports/

[6] However, after this year, NRCS SNOTEL is moving to an interactive map online instead of putting out static map in report, and both water managers and researchers that we spoke with had heard complaints from users of that

All beta testers wanted to be able to "zoom" in to their areas of interest. Almost universally, the testers appreciated the HUC 8 supplements to the report. The issue of scale, and being able to get information at finer scales (e.g., sub-basins), was important for many of the testers, especially the water managers. Some suggested showing HUC 12's, others cited particular sub-basins (see Table 1). One tester suggested that overlaying the HUC 8s (or smaller) boundaries onto the current, pixelated map in Fig. 4 would be one way to do this. Others requested more interaction and user-specified geo-markers, including the ability to turn on/off the various HUC levels, county boundaries, roads, towns, sub-basins, and rivers. They recognized the additional cost and effort associated with maintaining this type of interactive website, but stressed the importance of being able to zoom into their desired area of interest as key to making this information usable for water managers across various scales.

Specific areas of interest and preferences for scale from the beta testers included:

- 6-7 sub-basins of the Rio Grande and Conejos
- HUC 8 (by elevation if possible) especially for CO Plateau and East Taylor
- HUC 8 to HUC 12 (could overlay these onto the HUC 6 map)
- Sub-basins for Colorado as shown in the CWCB/Open Water Foundation SNODAS portal
- Willow Creek, Fraser, Upper Colorado above Granby
- The Wind River Indian Reservation area
- Down to 20 miles
- The Blue River above Dillon Reservoir on one complete map
- South Boulder Creek

3.5. Lower-elevation Snow

Testers also requested more analysis of the lower-elevation snowpack below SNOTEL sites. This includes identifying and understanding the discrepancies between the MODIS SWE report numbers and observations of SWE at low elevations, with the goal of gaining greater understanding about the contribution of snowpack at different elevation bands to the overall runoff, both of which are discussed below.

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information, not trusting their ability to generate similar maps to the previous static ones by themselves on the new website.

4. Verification and Validation of the Model

Testers from the water management sector and researchers requested post-season analysis of how the MODIS SWE product performed during the 2018 water year. Such retrospective verification and analysis is key for potential use by the CBRFC, and by extension, the multiple “downstream” water managers that rely on the stream flow forecasts from the CBRFC.

Testers identified three ways that this would be beneficial to them:

1. Understanding how well the MODIS SWE model performed in relation to observations of SWE (compared to observations from SNOTEL and snow courses, and perhaps measured indirectly via streamflow);
2. Understanding how the MODIS SWE product performed compared to other spatial estimates of SWE (e.g., SNODAS); and
3. Identifying the relative contributions of snowpack in different elevation bands to total basin water availability. This last point comes with the major caveat that the numbers from the MODIS SWE model would have to be fairly accurate in post-season analysis.

Specifically, regarding the first point, they requested retrospective analysis that compares the modeled SWE from the MODIS SWE report to the actual runoff from stream gauges and the stream flow forecasts from the CBRFC ESP, the NRCS streamflow forecasts, etc. Several testers suggested that it may be particularly helpful to compare peak modeled SWE with the observed volume of runoff, referencing an existing effort in Colorado by the CWCB to perform this type of retrospective snowpack-runoff analysis with SNODAS.

If the information in the MODIS SWE report was found to be accurate, beta testers suggested that the information from the MODIS SWE report could be digitized and then compared to the runoff data from NRCS (and elsewhere) and then they could get a better understanding of what fraction of SWE from different areas flows into streams, and what fraction goes elsewhere (e.g., groundwater, sublimation, etc.).

5. Methodological Questions and Suggestions

The central question expressed by the beta testers was how this product performs when compared to other products, including how this performance varies with *geography* (e.g., in different basins across the region), with *time* (early, mid-, and late-season; normal vs. anomalous years), and with *elevation* (e.g., snow above and below the range of the SNOTEL sites). Testers noted even if different products show similar SWE conditions in terms of percent of normal, the underlying absolute values of SWE could be very different.

5.1. Discrepancies Between the MODIS SWE Report and Other Information

One-third of the beta testers (n=6) specifically identified discrepancies between the information in the MODIS SWE report and SNOTEL or other on-the-ground observations at both high and low elevations. Some testers recognized that the differences in percent of average may be due to the different reference periods for the various products. Others suggested that the differences in lower-elevation snow numbers may be due to the skill of the model in estimating snow in forested areas, while discrepancies with higher- elevation snow could be in part due to the model's ability to account for dust on snow and/or sublimation (see Appendix A for email discussions). One individual from NRCS put together an analysis comparing the MODIS SWE report data and SNOTEL data for the April 18 beta report (compatible files available at: https://drive.google.com/drive/folders/1VxaIBxCKaJLBD0Invcbqihudt0go-kPB?usp=sharing; for associated maps and charts, contact heather.yocum@colorado.edu).

Discrepancies that were identified include:

- Over-representing low-elevation snow compared to SNOTELs (KW email; as of April 15 re: first beta report), including a higher percent of average than SNOTEL in Smith's Fork, WY (see also SW email in Appendix B; as of April 23 re: second beta report), and higher SWE in the Weber Basin (see also TB email in Appendix B) (as of end-April re: beta reports 1-3)
- Under-representing snow from 9,000'-12,000' (as of April 15 re: first beta report)
- Discrepancies in snow-covered-area at low elevations (as of end-April for reports 1-3; see also TB email in Appendix B)
- Discrepancies between MODIS SWE report and SNODAS in SWE at the highest elevations, where SNODAS decreases, but the MODIS SWE increases (see also TB email in Appendix B)
- Under-representing SWE from the Big Horn and Upper Green basins in WY compared to March 1 and April 1 SNOTEL and snow course data (SW email; as of April 23 re: second beta report)

Understanding the sources of these discrepancies is all the more important since many of the testers wanted to use the information in the MODIS SWE report to better understand snow at lower elevations.

5.2. Skill

Beta testers also want to understand the skill in different areas, as well as quantify the uncertainty for the model, and how skill and uncertainty may vary geographically, temporally, and by elevation. One suggested that the SWE information should be presented as probabilistic information including a +/- error, or similar to the way that CBRFC and NRCS presents their streamflow forecasts with the "most probable" (50th-percentile) forecast bracketed by the 10th and 90th percentile forecasts (https://www.cbrfc.noaa.gov/). Researchers also wanted to know how the model could be improved to deal with dust on snow, sublimation, and wind, as well as how the MODIS imagery could obtain more accurate snow-covered-area information for forested areas.

Many beta testers, especially the researchers, stated that it was important to understand how the MODIS SWE product performed compared to other information products both in terms of the (1) differences in the absolute SWE values provided in inches; and (2) differences in the percent of average, which in part may result from different periods of average for the various products (e.g., most SNOTEL analyses use 1981-2010). Testers noted that the second point might also make it difficult for some users to compare the percent of average information from different products directly, especially since those users might gloss over the different periods.

5.3. 2000-2012 Climatology

Several beta testers (n=7) wanted to know if there was a way to extend the 2000-2012 climatology to make it more directly comparable with the percent average numbers from SNOTEL and/or SNODAS, or if there was a way to control for the preponderance of drier years included in the 2000-2012 climatology. One concern with the short "climatology" period from 2000-2012 is that it might not be representative of a longer period, and so the percent average numbers may be skewed. Some testers recommended including the 2017 water year to provide a "bumper" snow year to compare, since overall the 2000-2012 period was unusually dry compared to the prior several decades. Another researcher questioned the utility of percent of average and comparisons to a climatological "average" in a changing climate, suggesting the past is not necessarily the best way to measure the present.

5.4. Additional Suggestions

Two additional tester suggestions to improve the methodology included:

- Find an alternative to the MODSCAG data to reduce dependence on that data if the team was unable to get a cloud free image and/or the site goes down (as it did twice during the 2018 season)
- Assess cost vs. performance of the MODIS SWE product relative to ASO and/or adding additional SNOTEL sites and snow courses.

6. Current Sources of Snow Information

The sources of snow information most often used by the beta testers were, first, NRCS SNOTEL and snow courses, followed by SNODAS, particularly the Colorado Decision Support System SNODAS Tool (from CWCB and Open Water Foundation's SNODAS-based tool, available here: http://snodas.cdss.state.co.us/app/index.html).[7] Boundary organizations (e.g., Colorado Climate Center) also got snow information from CoCoRaHS. Water managers also reported getting anecdotal information from snow plow operators and from ditch companies. The data from the Aerial Snow Observatory (ASO) from NASA JPL was also cited as an important source of information for those few areas in Colorado for which ASO data has been collected and made available.

Conclusion

Overall, the beta testers were excited to see the information presented in the MODIS SWE report, particularly as it pertains to potential future uses of the report to improve runoff forecasting. They found the information presented in the maps and the tables, particularly the elevation bands, to be very informative and accessible, and welcome this type of spatial information into the suite of available snow and water supply information they already use.

Beta testers emphasized the need to perform post-season verification to understand how the information in the report

many suggestions about next steps to verify the performance of the MODIS SWE information, potential uses of that information to understand the relative contributions of snow pack at different elevations to the overall water supply, and improvements in content delivery that would improve the usability of this information for stream flow forecasting, situational awareness, and scenario planning. Finally, the beta testers made suggestions that may motivate future research into comparing the MODIS SWE information with available snowpack information and how to evolve the model used to derive the information in the MODIS SWE product to expand potential uses.

[7] It should be noted that some users reported using SNODAS because it had reliable results in their area, while others (e.g., the CBRFC) reported that they consulted SNODAS but did not use the data because they either did not trust it and/or because they had gotten very inaccurate SNODAS numbers in the past.

Appendix A: Table 1 summarizing interview responses

Sector	Organization	Sources of snow information	Frequency of use	Uses for the report/spatial info	Use of GIS info	Most helpful	Report content and delivery	Methodology	Verification and validation	Scale
Boundary organization / information provider	Colorado Climate Center	SNOTEL CoCoRaHS		Potentially useful for drought monitoring b/c can watch progression of accumulation and melt	Depends on ease of access	Summary of current conditions Percent average SWE "Zoomed in" maps	Interactive website Email exec summary with link to full report so can chose what to drill down into Add bookmarks to report to aid navigation Add a map comparing peak snowpack from year-to-year that looks similar to Fig. 6 (e.g. is it early or late this year?) Time series of SWE at particular sites (e.g., similar to SNOTEL time series)		Post-mortem using streamflow data to see how critical low elevation snowpack is to the system ID contributions of different elevation bands to water supply (e.g., post-season validation/ verification with runoff #s)	Ability to zoom-in on areas of interest Add county-level boundaries to maps

Table 1., cont.

Sector	Organization	Sources of snow information	Frequency of use	Uses for the report/spatial info	Use of GIS info	Most helpful	Report content and delivery	Methodology	Verification and validation	Scale
Boundary organization / information provider	Colorado Climate Center, cont.						Archive of tabular information from all reports Include both percent of average and numerical average			
Boundary organization / information provider	Colorado Basin River Forecast Center (CBRFC)	SNODAS (but don't trust it)	Regularity is key Weekly and/or after every significant storm event	Ground-truth the snow/SWE in their ESP model	Yes, if in format compatib le with ESP model	Percent of average comparisons Concise report Graphics are helpful for visualization Understandab le for most users	Interactive website Must be reliable and fully operational before useful (per NWS definitions)	Extend period of average beyond 2000-2012 (e.g., include 2017/18) Make period of average the same to compare with SNOTEL and SNODAS	Retrospective analysis (esp. if data was available to users) ID cause of differences with SNOTEL #'s and SNODAS	Ability to zoom-in on areas of interest

Table 1., cont.

Sector	Organization	Sources of snow information	Frequency of use	Uses for the report/spatial info	Use of GIS info	Most helpful	Report content and delivery	Methodology	Verification and validation	Scale
Boundary organization / information provider	Natural Resource Conservation Service (NRCS) Colorado Snow Survey		Monthly in middle of month (to alternate with NRCS reports at beginning of month)	Compare with other (SNOTEL) data to get a more accurate picture of snowpack Provides data where SNOTEL is absent (e.g., small basins or high/low elevations) Could complement the monthly NRCS reports	Limited staff time to use; technical capacity is there Combine with SNOTEL data to make maps for presentations	HUC 8 information Percent of average (esp. by elevation band)	Interactive website Additional spatial references on map (e.g., roads, towns, rivers, etc.) Volumetric estimates included in tables	ID cause of differences with SNOTEL #'s and SNODAS	ID cause of differences with SNOTEL #'s and SNODAS	Ability to zoom-in on areas of interest Overlay HUC 8 boundaries on the current HUC 6 maps Add HUC 12 boundaries for individual users
Boundary organization / information provider	Natural Resource Conservation Service (NRCS) Utah Snow Survey				No	Tabular info Percent of average Elevation bands, esp. changes in late season				Ability to zoom-in on areas of interest

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Boundary organization / information provider	National Weather Service (NWS) Hydrologist	SNODAS		Monitor snow-covered area and spatial distribution of snowpack		Summary at beginning Explanation of caveats Comparison with SNODAS (esp. map) Elevation band information	Interactive website Add SCA to table and how compares to average SCA Add comparison to ASO Compare to RFC-modeled SWE (like in Sierras)	Extend period of average beyond 2000-2012 (e.g., include 2017/18) Describe skill in late-season snow Describe skill in picking up unusual snow distribution ID how blowing snow and sublimation impact high elevation SWE	Compare to runoff from SNODAS, RFC, and ASO to validate SWE #s ID cause of differences with SNOTEL #'s and SNODAS ID source of discrepancy between info sources at low elevations	Ability to zoom-in on areas of interest

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Water managers	Denver Water	SNODAS CWCB and Open Water Foundation's SNODAS-based tool SNOTEL Snow courses		Verifying anecdotal reports Ground-truthing other data	Yes, if raster files so they can create own maps	Figure 4 Tables with elevation band info and comparison with other data	Interactive website with ability to zoom in on area of interest Larger graphics (whole page) Archive with #s from individual years Finer resolution graphics Make raster files available	Extend period of average beyond 2000-2012 (e.g., include 2017/18)		Ability to zoom in on area of interest 20 –miles total? Similar to the scale of the SNODAS product from the CWCB and Open Water Foundation Blue River Basin above Dillon Reservoir on one complete map S. Boulder Creek

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Water managers	Northern Colorado Water Conservancy District	Snow courses CoCoRaHS, esp. in Grand County, in the valleys Anecdotal info from snow plow operators SNODAS SNOTEL	Once at peak SWE	Ground-truthing other data Understand year-to-year variation	Limited capacity to use	Summary of conditions (makes report skimmable) Map of previous vs current conditions Comparison with SNODAS (in map and tables) Tabular info elevation band Area of each elevation band	Interactive website with ability to zoom in on area of interest Scale down to include sub-basins Add a volumetric forecast		Compare SWE and volumetric forecast with other agencies (e.g., NRCS, CBRFC, etc.) ID source of difference with SNODAS at high elevations Verify by comparing peak SWE to actual runoff (similar to SNODAS verification)	Willow Creek Basin Fraser Basin Upper Colorado above Granby
Water managers	Colorado Department of Natural Resources – Water Resources	SNOTEL CBRFC ESP forecasts NCAR's WRF-HYDRO NRCS streamflow forecasts NASA JPL LiDAR / ASO		Augment SNOTEL info Potential uses in stream flow forecasting Compare with other sources (e.g., NRCS, CBRFC, NCAR) to see which is most accurate Inform own forecast	No	Interesting, but would only use as it pertains to/informs stream flow forecasting Elevation bands Visual representa-tion of data (maps) Pixel-by-pixel map	Include basins in NM Super-impose smaller basins onto the existing graphics Add a volumetric streamflow forecast			Include the sub-basins of the Rio Grande (including Conejos)

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Water managers	Wyoming State Engineers Office	SNOTEL SNODAS Reclamation	Biweekly, esp. April 1 thru melt Need in time for April decision meetings	May improve streamflow forecasting Monitor snow-covered area and spatial distribution of snowpack Ground-truthing other data Understand year-to-year variation Better estimate of April 1 (peak) snowpack and melt patterns Scenario planning Determine relative contribution of low elevation snow	No	Elevation bands, esp. changes throughout season Percent average Tabular data Information at lower elevations below SNOTELs	Interactive website with ability to zoom-in and out on areas of interest Show SNOTEL sites on maps and in relation to elevation bands Archive so can pick out and compare different years Clarify added value wrt to existing products ID analogue years Info at lower elevations below SNOTELS		Post-mortem of how our #'s related to runoff (e.g., CBRFC?) ID skill in different geographic areas and at different times in the season ID cause of differences with SNOTEL #'s and SNODAS	Ability to zoom-in on areas of interest

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Water managers	Colorado River District			Monitor snow-covered area and spatial distribution of snowpack (esp. distribution of SCA within basin)	Yes, if in KML format for Google Earth	Pixel-by-pixel map Distribution of SCA within basin (e.g., compared to SNODAS) Late season snow is well-represented in some areas (e.g., better than SNOTEL Visual representa-tion of data (maps) Elevation bands Table 2 data Map of previous vs current conditions Visuals/graph ics	Add elevation bands for smaller HUC's (e.g., HUC 8 between 9K and 10K) Summary could be more clear to direct attention to most important parts Blue color scale on Fig. 2 is difficult to read Need a name!	ID cause of differences with SNOTEL #'s and SNODAS	ID cause of differences with SNOTEL #'s and SNODAS ID skill in different geographic areas and at different times in the season; compare this with other products	HUC 8 (by elevation if possible) HUC 8 for CO Plateau, East Taylor

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Water managers	Salt Lake City Dept. of Public Utilities	SNOTEL Snow courses Own measurements CBRFC ESP forecasts		Additional info on shoulder seasons Impact of climate change on lower elevation snowpack	No; limited staff and technical capacity	Map of previous vs current conditions Having both maps and tabular data Elevation bands, esp. changes thru season	Clarify how it performs at low elevations compared Link it to water supply			Ability to zoom-in on areas of interest
Researcher	WWA/NOAA researchers					Comparison with SNOTEL and SNODAS "Zoomed in" maps of basins Basin averages Tabular information and elevation bands Visual representa-tion of SCA and other data	Need a name! Put the caveats ("warning labels) up front; simplify Too heavy on methodology up front Change all-blue color contours on Fig. 2 Add a volumetric estimate Bookmark the pdf	ID how #s compare with other info sources at high and low elevations	ID source of difference with SNODAS at high elevations ID how snow at lower and higher elevations influences water supply (if not significant, maybe the differences between products don't matter)	Wind River area

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Researcher	WWA/NOAA researchers	4-km CONUS-wide SWE product from U Arizona (Broxton et al.) National Water Model		Monitor accumulation and melt in space and time		Basin-wide summary combined with the pixel-by-pixel map Presenting SWE in both percent of average and inches Tabular information in elevation bands	Include the % of average for SNODAS as well (corrected for the same time frame) If the summary or captions include references to specific places on the map, put those places in the figures.	Mapping skill and uncertainty Present an "error bar" of estimate and a +/- range (e.g., probabilistic like CBRFC) Extend period of average beyond 2000-2012 (e.g., include 2017/18) Make period of average the same to compare with SNOTEL and SNODAS Does model need to be recalibrated every year when new data is available?	Different average years for comparable products	Ability to zoom-in on areas of interest
Researcher	WWA/NOAA researchers	Own measurement COCoRaHS								

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Researcher	WWA/NOAA researchers	NRCS maps SNODAS					Too general for water managers who want a runoff #, not specific enough for CBRFC to use Volumetric estimate to compare to CBRFC Resolve issues comparing point data to spatial data May need to change % of average and comparison to SNOTEL point-data (because spatial average)	ID how blowing snow and sublimation impact high elevation SWE ID how to deal with forest covered areas, and dust-on-snow ID how #s compare with other info sources at high and low elevations Impact of using different years for reconstructing SWE maps	Different periods for % average Uncertainty with performance above/below SNOTELs	Ability to zoom-in on areas of interest

Table 1., cont.										
Sector	**Organization**	**Sources of snow information**	**Frequency of use**	**Uses for the report/spatial info**	**Use of GIS info**	**Most helpful**	**Report content and delivery**	**Methodology**	**Verification and validation**	**Scale**
Researcher	WWA/NOAA researchers, cont.						Ability to zoom into graphics Add Wind River Reservation Pay attention to places that are underserved by SNOTEL, have unreliable SNOTEL data, and/or have discrepancies with SNODAS			

BETA test report – Do not distribute

Spatial Estimates of Snow-Water Equivalent (SWE)

Intermountain West Region

April 18, 2018

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About this report

This is an experimental research product that provides near-real-time estimates of snow-water equivalent (SWE) at a spatial resolution of 500 m for the Intermountain West region (Colorado, Utah, and Wyoming) from mid-winter through the melt season. The report is released within a week of the date of data acquisition at the top of the report. A similar report covering the Sierra Nevada has been distributed to water managers in California since 2013-14.

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

- In-situ SWE from all operational NRCS SNOTEL sites
- MODSCAG fractional snow-covered area (fSCA) data from recent cloud-free MODIS satellite images
- Physiographic information (elevation, latitude, upwind mountain barriers, slope, etc.)
- Historical daily SWE patterns (2000-2012) retrospectively generated using historical MODSCAG data and an energy-balance model that back-calculates SWE given the fSCA time-series and meltout date for each pixel

For more details on the estimation method see the *Methods* section below. Please be sure to read the *Data Issues / Caveats* section for a discussion of persistent challenges or flagged uncertainties of the SWE product.

Data availability for this report

310 SNOTEL sites in the Intermountain West network were recording SWE values out of a total of 312 sites; 67 were reporting but had zero SWE; and 2 were offline.

The value of spatially explicit estimates of SWE

Snowmelt makes up the large majority (~60-85%) of the annual streamflow in the Intermountain West. The spatial distribution of snow-water equivalent (SWE) across the landscape is complex. While broad aspects of this spatial pattern (e.g., more SWE at higher elevations and on north-facing exposures) are fairly consistent, the details vary a lot from year to year, influencing the magnitude and timing of snowmelt-driven runoff.

SWE is operationally monitored at hundreds of NRCS SNOTEL sites spread across the Intermountain West, providing a critical first-order snapshot of conditions, and the basis for runoff forecasts from NRCS and NOAA.

However, conditions at SNOTEL sites (e.g., percent of normal SWE) may not be representative of conditions in the large areas between these point measurements, and at elevations above and below the range of the SNOTEL sites. The spatial snow analysis creates a detailed picture of the spatial pattern of SWE using SNOTEL, satellite, and other data, extending beyond the SNOTEL sites to unmonitored areas.

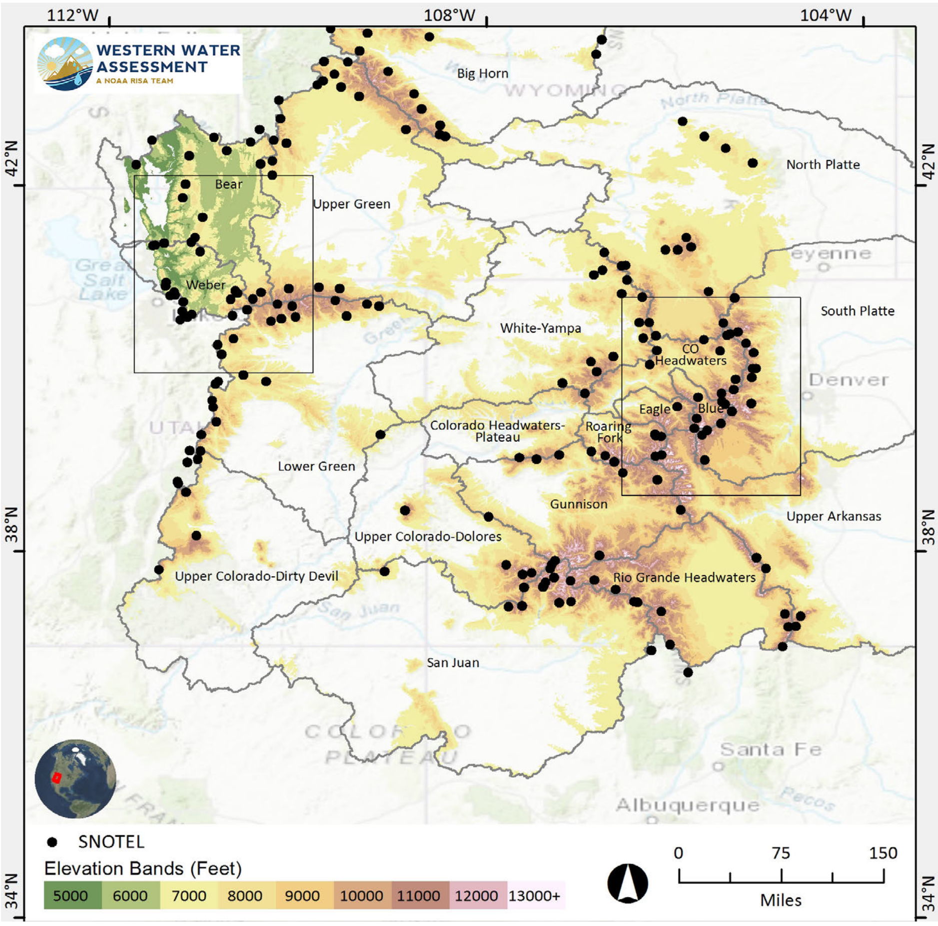

Figure 1. Intermountain West region. Location map identifies basins used in this report (gray boundaries), SNOTEL sites (black dots), and 1000’ elevation bands (colored shading) that match those used in Table 1 and Table 2. The elevation bands below 7000’ are shown only in the Bear and Weber basins.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

Interpreting the spatial SWE estimates in the context of SNOTEL The spatial product estimates SWE for every pixel where the MODSCAG product identifies snow-cover. Comparatively, SNOTEL samples 8-20 points per basin within a narrower elevation range (Figure 1). Thus, the basin-wide percent of average from the spatial SWE estimates is not directly comparable with the SNOTEL basin-wide percent of average. A better comparison might be made with the % average in the elevation bands (Table 2) that contain SNOTEL sites.

Summary of current conditions (as of April 18th)

The modeled snow conditions are much below the 2000-12 average across the model domain (Figures 2 & 3). Gains in modeled SWE at high elevations since April 3rd have been offset by SWE losses at lower elevations, and it appears that basin-wide SWE volumes are at or past the seasonal peak, as would be expected for mid-April (Figure 1; Tables 1 & 2). In southern Colorado and southern Utah, where the basin-wide SWE is only 20-40% of average, SWE has declined in nearly all elevation bands since April 3rd. There are limited areas in northwestern Colorado, northern Utah, and Wyoming, where recent storms left above-normal but temporary snow accumulations (dark green shades in Figure 3). In most basins, the modeled SWE at elevations below 9000' is further below normal than the SWE at elevations above 9000' (Table 2). This low anomaly compared to modeled average SWE conditions appears to be consistent with other observations.

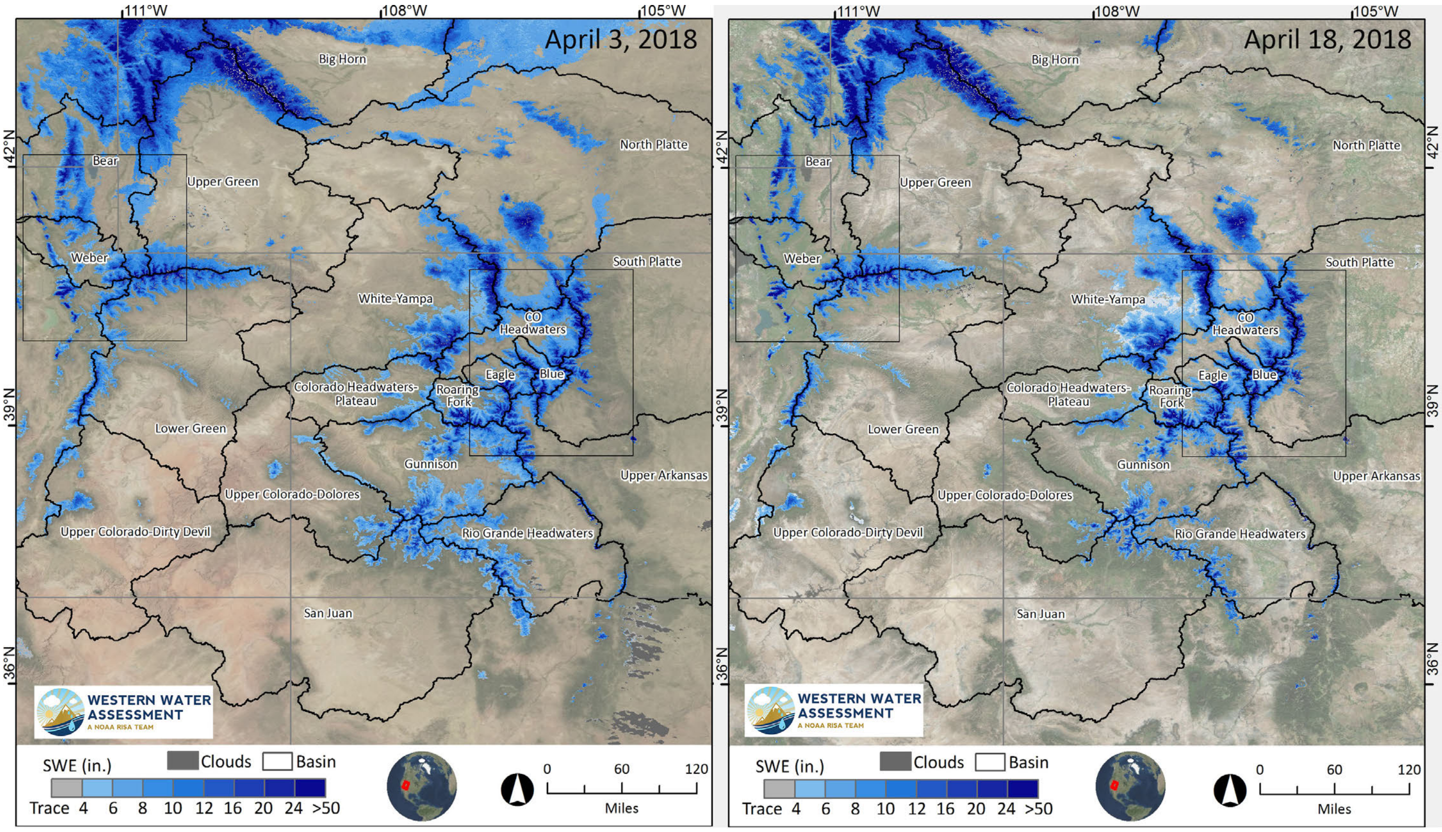

Figure 2. Estimated SWE amounts across the Intermountain West, April 3rd (left) and April 18th (right), 2018. While SWE amounts in northern Wyoming are typically higher than basins to the south in all years, that difference is visibly larger this season, and the gradient has strengthened over the last month, with unusually low amounts seen in the Gunnison, San Juan, Rio Grande, and southern Arkansas basins. Changes in SWE since April 3rd at high elevations (>10,000') are difficult to discern in the April 18th map, while the lower-elevation snow that was present on April 3rd has continued to melt out.

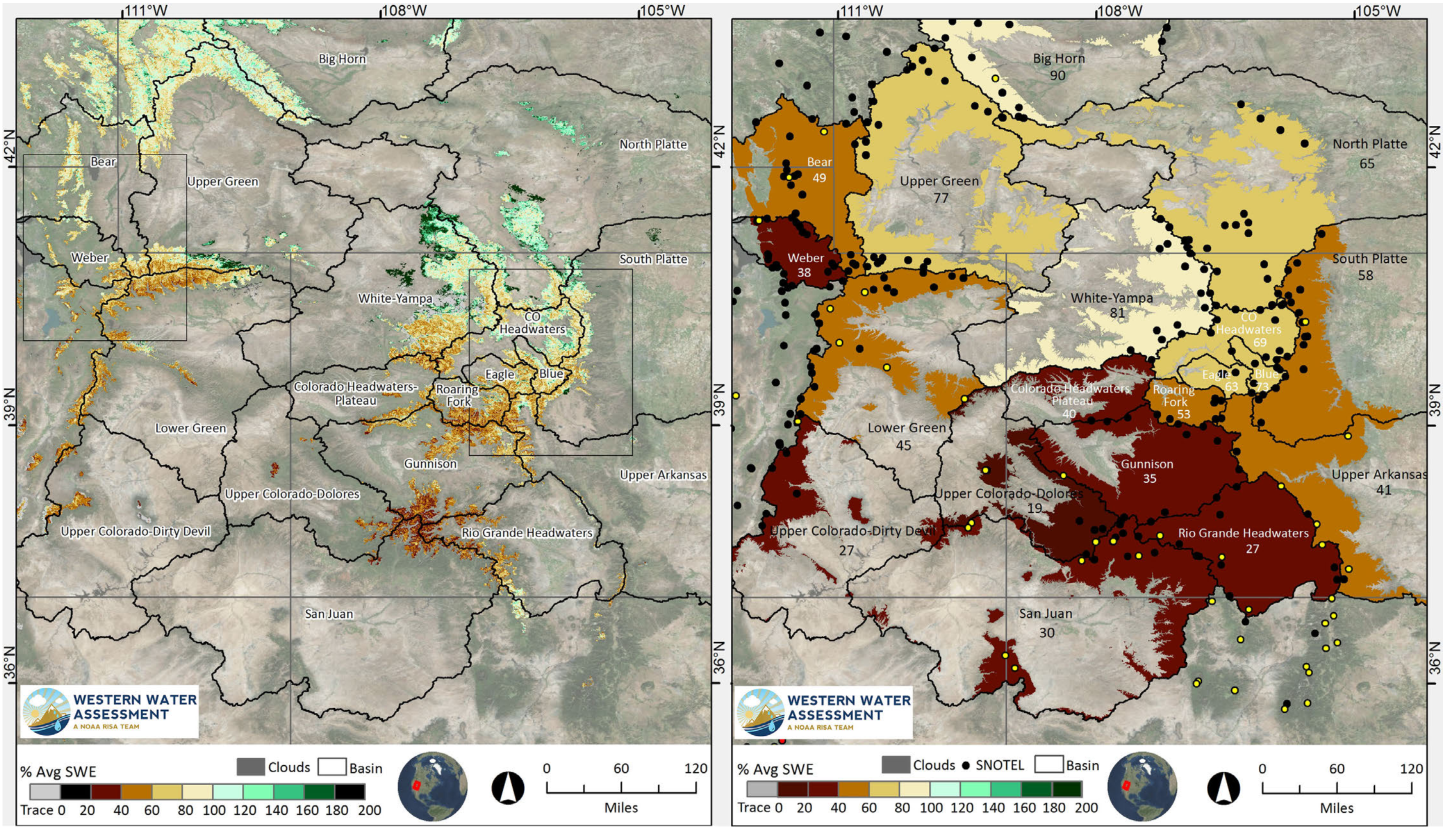

***Figure 3**. Estimated % of average SWE across the Intermountain West, April 18, 2018.* Percent of average (2000-2012) SWE for April 18, 2018 for the Intermountain West, calculated for each pixel (left) and basin-wide (right). Pixels below 60% of average (medium brown) are prevalent at the higher elevations across Utah (>8000') and Colorado (10,000'), with most pixels now below 40% (dark brown) in the San Juan Mountains. In Wyoming and in central and northern Colorado the basin-wide SWE values have held steady or increased since April 3rd , with current values between 50% and 80% of average, while the basin-wide SWE values in southern Colorado and Utah have generally declined since April 3rd, and are between 20% and 50% of average. Note that the basin-wide averages may reflect variable conditions across the elevation bands; see Table 2.

Basin-wide percent of average is calculated across all model pixels >7000' elevation (>5000' elevation in the Bear River/Weber basins). SNOTEL sites recording at least 0.1" SWE on April 18, 2018 are shown in black; sites that had zero SWE are shown in yellow, and sensors that are offline are shown in red.

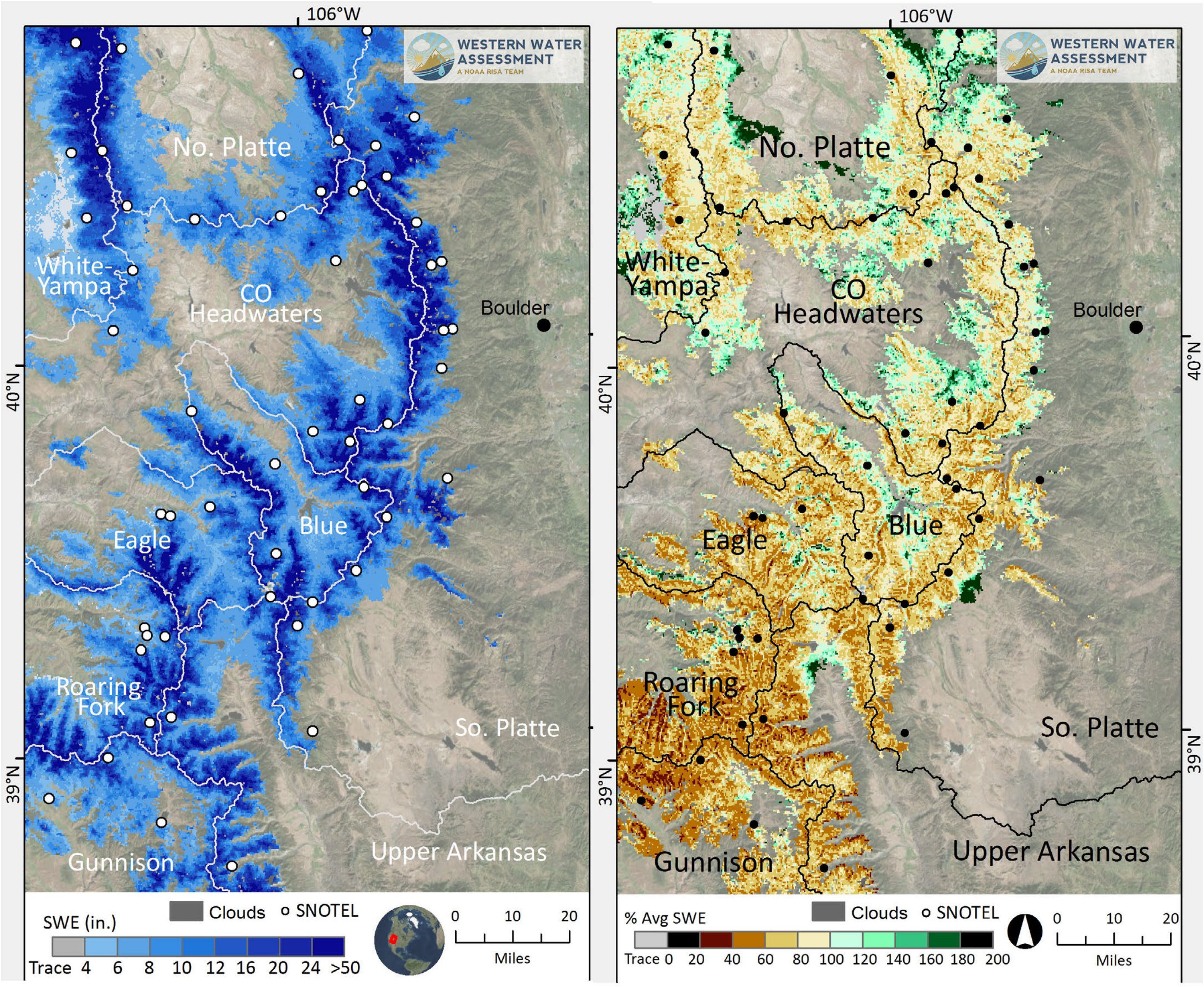

Figure 4. Estimated SWE across the Colorado Headwaters Sub-region, April 18, 2018. SWE amounts for April 18, 2018 (left), and the % of average (2001-2012) SWE for April 18, 2018 for the snow-covered area (right).

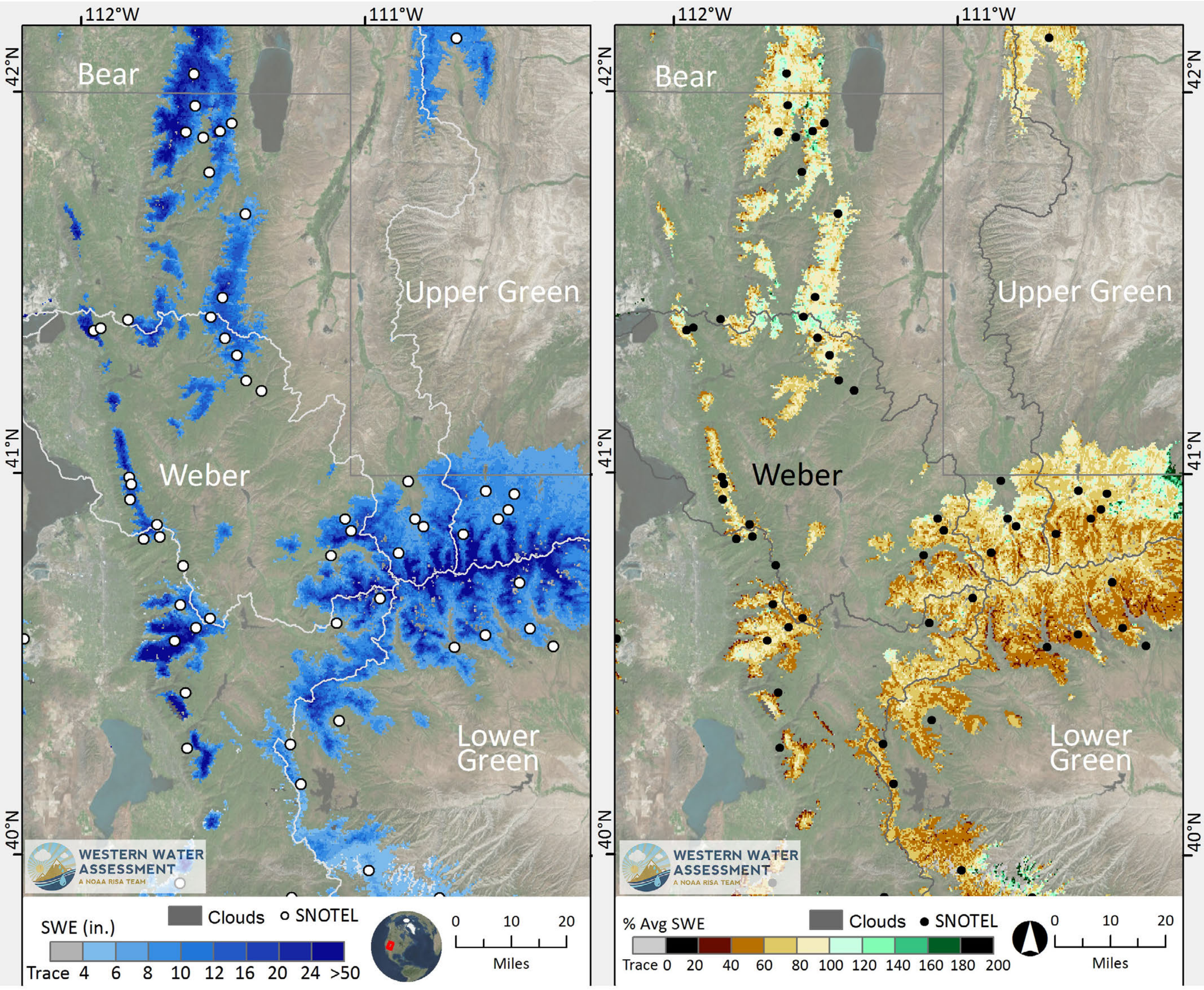

Figure 5. Estimated SWE across the Wasatch Front Sub-region, April 18, 2018. SWE amounts for April 18, 2018 (left), and the % of average (2000-2012) SWE on April 18, 2018 for the snow-covered area.

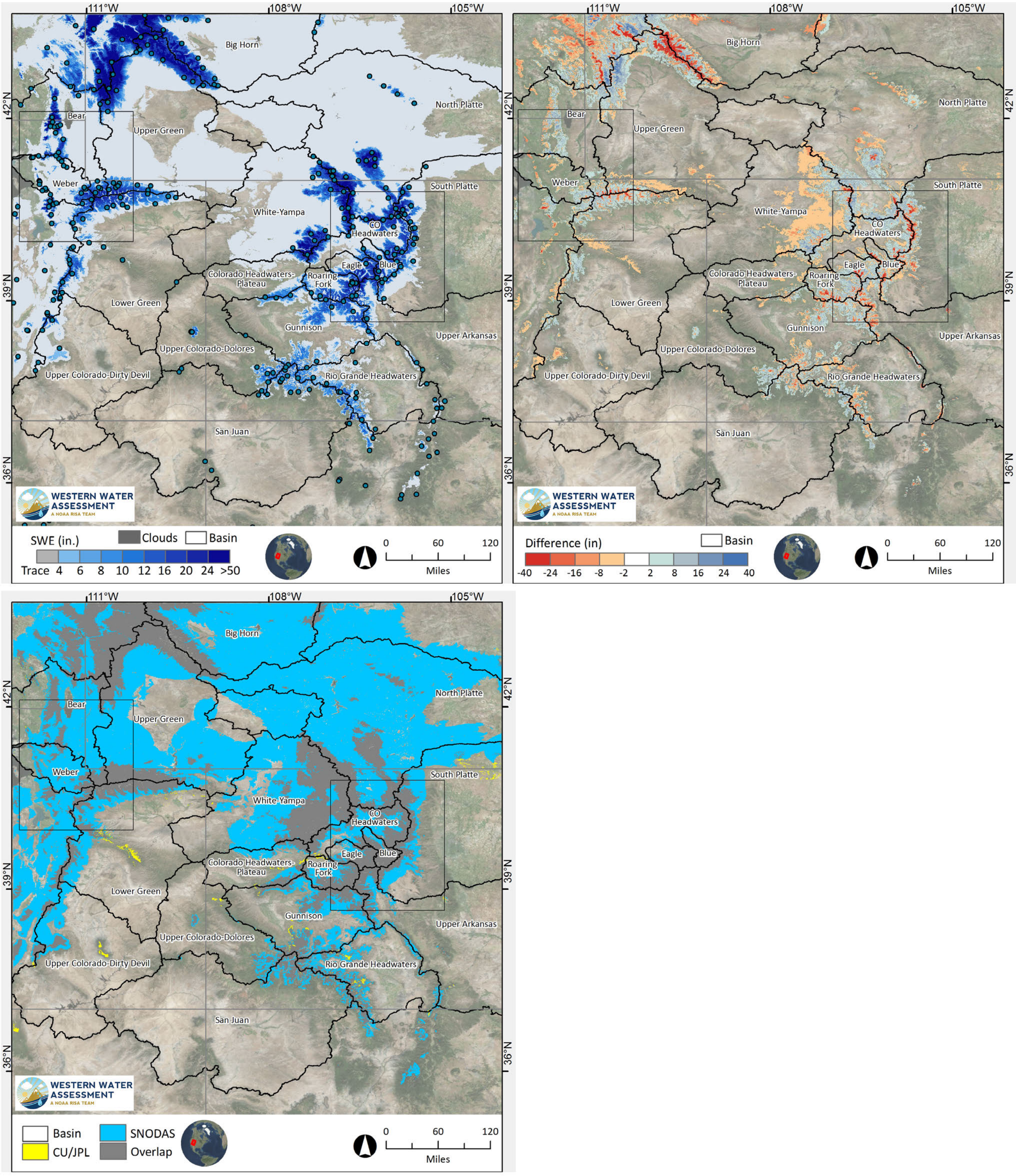

Figure 6. Comparison of the experimental (CU/JPL) SWE product and SNODAS SWE for the Intermountain West. The map in the upper left shows estimated SWE for April 18th from the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS). The upper right map shows the difference between the April 18th SNODAS SWE estimate and the experimental CU/JPL SWE estimate. Red pixels denote areas where SNODAS SWE is less than CU/JPL SWE and blue pixels show areas where SNODAS SWE is higher than CU/JPL SWE. The map in the lower left shows the snow-cover extent of SNODAS and CU/JPL SWE estimates. Yellow pixels show where the location of CU/JPL snow extends beyond the location of the SNODAS snow extent. Blue pixels show where the SNODAS snow extends beyond the CU/JPL snow extent. Gray areas indicate regions where both products agree on the snow-cover extent.

Table 1. Estimated SWE by basin. The basin-wide SWE values and averages, and areas, for all pixels at elevations >7000', except for the Bear and Weber basins, which are >5000'. Shown are April 3rd and April 18th percent of average (2000-12) SWE for those dates, and April 3rd and April 18th mean SWE value for each basin. Note that the basin-wide mean SWE values (in inches) are much lower than typical SNOTEL SWE values because of the extensive lower-elevation areas represented in the basin-wide SWE value. For comparison, the last column shows April 18th basin-wide mean SWE from SNODAS.

Basin	4/3/2018 % 4/3 Avg	4/18/2018 % 4/18 Avg	4/3/18 SWE (in)	4/18/18 SWE (in)	4/3/18 thru 4/18/18 Change SWE (in)	Area (mi^2)	4/18/18 SNODAS* (in)
Bear	54.5	49.0	5.0	3.0	-2.0	6,038	3.7
Big Horn	95.7	90.1	14.3	12.1	-2.2	2,703	8.9
Blue	70.7	73.4	10.9	10.6	-0.3	683	7.7
Colorado Headwaters	63.0	68.7	7.2	6.4	-0.8	2,812	6.5
Colorado Headwaters-Plateau	38.7	40.0	3.7	2.6	-1.1	1,809	2.1
Eagle	53.4	63.0	7.2	7.4	0.1	922	8.0
Gunnison	44.1	35.5	4.2	2.7	-1.6	6,457	2.8
Lower Green	40.8	45.2	3.7	3.1	-0.6	5,735	3.2
North Platte	55.9	65.0	4.2	3.1	-1.2	10,286	3.7
Rio Grande Headwaters	35.5	27.4	1.7	1.1	-0.7	7,609	0.9
Roaring Fork	50.7	53.2	7.9	7.6	-0.3	1,357	7.4
San Juan	30.4	29.6	1.4	1.0	-0.4	6,410	1.2
South Platte	42.3	58.3	2.8	2.7	0.0	5,629	2.4
Upper Arkansas	32.3	41.1	1.8	1.6	-0.2	5,861	1.1
Upper Colorado-Dirty Devil	28.4	26.7	1.3	0.8	-0.6	2,637	0.9
Upper Colorado-Dolores	25.2	18.8	1.4	0.7	-0.8	3,429	1.0
Upper Green	62.7	77.4	6.1	5.5	-0.6	9,620	5.2
Weber	46.5	37.9	4.2	2.4	-1.9	2,076	3.1
White-Yampa	55.3	80.5	5.4	5.6	0.2	5,939	5.0

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

Table 2. Estimated SWE by basin and elevation band. Elevation bands begin at 7000' and extend past the highest point in the basin, except for the Bear and Weber basins, which begin at 5000'. Note that the area of the highest 2-5 bands is typically much smaller than the lower bands. Shown are April 3rd and April 18th percent of average (2000-12) SWE for those dates, and April 3rd and April 18th mean SWE value for each 1000' elevation band within each basin. For comparison, the last column shows April 18th mean SWE for each 1000' elevation band from SNODAS.

Basin	Elevation Band	4/3/2018 % 4/3 Avg.	4/18/2018 % 4/18 Avg.	4/3/18 SWE (in)	4/18/18 SWE (in)	4/3/18 thru 4/18/18 Change SWE (in)	Area (Sq Mi)	4/18/18 SNODAS* (in)
Bear	5000-6000'	5.1	0.0	0.2	0.0	-0.2	766.0	0.0
	6000-7000'	31.4	4.7	2.1	0.1	-2.0	2,692.2	0.4
	7000-8000'	64.0	43.3	6.7	3.2	-3.5	1,778.0	4.4
	8000-9000'	82.8	83.1	14.0	13.1	-0.9	578.2	16.7
	9000-10,000'	81.2	82.2	16.1	16.1	0.0	132.1	17.9
	10,000-11,000'	74.3	72.7	17.2	17.5	0.3	76.2	17.6
	11,000-12,000'	79.6	78.7	26.5	28.7	2.2	12.9	11.1
	12,000-13,000'	84.7	83.5	29.5	32.2	2.7	1.2	6.1
Big Horn	7000-8000'	85.6	38.9	5.7	1.3	-4.4	916.1	1.2
	8000-9000'	93.9	74.2	10.5	6.2	-4.2	626.2	6.4
	9000-10,000'	97.5	93.8	15.0	13.8	-1.2	470.2	14.5
	10,000-11,000'	95.8	96.5	23.2	24.4	1.2	456.1	19.0
	11,000-12,000'	102.6	106.2	39.3	43.9	4.5	185.6	14.9
	12,000-13,000'	101.5	103.9	53.8	61.1	7.2	42.1	13.8
	13,000+	98.1	99.9	62.4	71.2	8.8	1.8	12.0
Blue	7000-8000'	0.2	0.0	0.0	0.0	0.0	36.9	0.1
	8000-9000'	47.2	26.6	3.6	1.0	-2.6	100.5	0.5
	9000-10,000'	74.0	83.5	7.0	5.6	-1.4	126.7	3.2
	10,000-11,000'	68.1	73.3	9.2	8.8	-0.4	183.0	10.4
	11,000-12,000'	72.9	72.1	16.4	17.3	0.9	165.8	13.9
	12,000-13,000'	81.6	80.6	24.6	27.0	2.4	63.4	9.0
	13,000+	88.5	87.6	26.5	29.3	2.8	6.4	3.3
Colorado Headwaters-Plateau	7000-8000'	4.3	0.4	0.2	0.0	-0.2	684.9	0.0
	8000-9000'	33.4	14.8	3.0	0.8	-2.2	662.3	0.4
	9000-10,000'	55.9	52.5	7.9	6.7	-1.2	237.6	5.0
	10,000-11,000'	61.5	60.3	11.7	11.3	-0.3	218.9	10.2
	11,000-12,000'	54.9	55.1	19.5	20.8	1.3	6.2	19.3
Colorado Headwaters	7000-8000'	1.7	0.8	0.1	0.0	-0.1	438.4	0.0
	8000-9000'	43.4	33.5	3.5	1.5	-2.0	853.7	1.0
	9000-10,000'	72.8	75.3	7.7	6.2	-1.5	715.4	8.0
	10,000-11,000'	70.3	73.2	11.2	11.2	0.0	564.3	15.3
	11,000-12,000'	77.4	77.5	20.9	22.6	1.8	211.8	13.0
	12,000-13,000'	86.3	86.8	29.0	32.4	3.3	30.1	5.8
	13,000+	82.3	82.8	31.9	36.0	4.1	0.2	3.9
Eagle	7000-8000'	1.8	3.5	0.1	0.0	-0.1	157.8	0.0
	8000-9000'	25.6	30.0	2.2	1.4	-0.8	180.4	0.8
	9000-10,000'	48.5	58.2	5.5	5.1	-0.4	169.9	6.0
	10,000-11,000'	58.3	67.0	8.8	9.3	0.5	249.0	14.2
	11,000-12,000'	67.9	67.4	17.1	18.2	1.1	130.0	17.9
	12,000-13,000'	72.6	72.1	27.6	30.5	3.0	32.1	10.0
	13,000+	80.4	79.7	30.5	33.9	3.4	2.1	4.3

Basin	Elevation Band	4/3/2018 % 4/3 Avg.	4/18/2018 % 4/18 Avg.	4/3/18 SWE (in)	4/18/18 SWE (in)	4/3/18 thru 4/18/18 Change SWE (in)	Area (Sq Mi)	4/18/18 SNODAS* (in)
Gunnison	7000-8000'	1.0	0.0	0.0	0.0	0.0	1,048.0	0.0
	8000-9000'	17.0	4.1	1.0	0.1	-0.9	1,708.9	0.2
	9000-10,000'	43.1	21.0	3.9	1.3	-2.6	1,329.6	1.6
	10,000-11,000'	55.7	36.4	6.8	3.9	-2.9	1,452.9	5.7
	11,000-12,000'	55.5	47.3	10.2	9.0	-1.2	636.4	8.7
	12,000-13,000'	55.4	50.8	14.3	14.4	0.1	256.7	6.8
	13,000+	53.6	48.7	14.6	14.9	0.3	24.2	4.3
Lower Green	7000-8000'	3.6	2.9	0.1	0.0	-0.1	2,299.7	0.1
	8000-9000'	24.4	23.5	2.1	1.3	-0.8	1,759.3	1.5
	9000-10,000'	53.9	47.1	7.0	5.3	-1.7	812.8	6.6
	10,000-11,000'	65.7	59.5	11.5	10.5	-1.0	630.8	12.3
	11,000-12,000'	68.6	64.3	17.9	18.2	0.4	196.6	9.8
	12,000-13,000'	78.7	74.3	22.9	24.3	1.4	35.2	5.3
	13,000+	84.9	79.6	25.6	27.5	1.8	1.2	2.4
North Platte	7000-8000'	27.1	14.8	1.5	0.3	-1.2	6,370.4	0.4
	8000-9000'	68.4	65.9	5.7	3.6	-2.1	2,456.1	3.9
	9000-10,000'	91.7	99.4	11.0	10.6	-0.3	877.0	14.9
	10,000-11,000'	89.0	93.3	17.3	18.4	1.1	519.0	23.4
	11,000-12,000'	85.6	88.2	29.8	33.3	3.5	59.8	13.6
	12,000-13,000'	87.6	88.9	32.7	35.9	3.3	3.5	5.6
Rio Grande Headwaters	7000-8000'	0.2	0.0	0.0	0.0	0.0	2,682.1	0.0
	8000-9000'	0.9	0.0	0.0	0.0	0.0	1,414.3	0.0
	9000-10,000'	8.3	1.8	0.4	0.0	-0.4	1,057.2	0.1
	10,000-11,000'	30.9	15.4	2.7	1.0	-1.7	1,357.1	1.9
	11,000-12,000'	51.5	35.7	7.2	5.0	-2.2	828.2	4.0
	12,000-13,000'	52.8	40.6	10.5	8.8	-1.7	252.6	4.0
	13,000+	60.9	40.8	13.4	10.0	-3.4	17.0	3.0
Roaring Fork	7000-8000'	2.4	0.0	0.1	0.0	-0.1	201.2	0.1
	8000-9000'	28.5	22.3	2.4	0.9	-1.4	258.3	1.0
	9000-10,000'	47.0	48.8	5.4	4.3	-1.1	228.6	5.8
	10,000-11,000'	52.5	53.4	8.2	7.8	-0.4	308.3	12.8
	11,000-12,000'	57.3	55.6	15.3	15.9	0.6	248.4	14.5
	12,000-13,000'	61.6	60.2	21.6	23.4	1.8	104.7	8.8
	13,000+	68.2	67.2	25.3	27.8	2.5	8.0	3.2
San Juan	7000-8000'	0.0	0.0	0.0	0.0	0.0	3,719.4	0.0
	8000-9000'	0.5	0.0	0.0	0.0	0.0	1,063.5	0.0
	9000-10,000'	12.3	1.8	0.8	0.1	-0.8	515.1	0.7
	10,000-11,000'	37.7	16.0	4.4	1.6	-2.7	510.0	4.7
	11,000-12,000'	48.7	38.5	8.8	7.3	-1.5	409.1	7.9
	12,000-13,000'	49.1	43.2	12.2	11.9	-0.3	179.5	7.2
	13,000+	53.8	48.9	15.0	15.4	0.4	13.5	4.8
South Platte	7000-8000'	1.9	0.1	0.1	0.0	-0.1	1,420.9	0.0
	8000-9000'	12.3	3.2	0.5	0.0	-0.4	1,477.4	0.3
	9000-10,000'	17.8	37.2	0.8	0.8	-0.1	1,282.0	1.5
	10,000-11,000'	48.3	63.7	5.1	5.3	0.3	824.6	7.2
	11,000-12,000'	72.5	71.6	13.4	13.7	0.3	438.2	8.6
	12,000-13,000'	83.7	82.1	20.2	21.8	1.6	161.2	7.7
	13,000+	91.9	89.3	22.6	24.6	2.1	25.7	4.2

Basin	Elevation Band	4/3/2018 % 4/3 Avg.	4/18/2018 % 4/18 Avg.	4/3/18 SWE (in)	4/18/18 SWE (in)	4/3/18 thru 4/18/18 Change SWE (in)	Area (Sq Mi)	4/18/18 SNODAS* (in)
Upper Arkansas	7000-8000'	0.0	0.0	0.0	0.0	0.0	1,745.5	0.0
	8000-9000'	0.1	0.0	0.0	0.0	0.0	1,492.1	0.0
	9000-10,000'	5.2	4.6	0.3	0.1	-0.2	1,168.1	0.1
	10,000-11,000'	24.5	22.9	2.1	1.5	-0.7	741.5	2.2
	11,000-12,000'	52.0	46.9	8.7	8.0	-0.7	423.8	7.6
	12,000-13,000'	68.1	63.6	16.5	16.8	0.3	245.2	5.8
	13,000+	76.7	72.1	19.6	20.5	1.0	45.7	3.0
Upper Colorado-Dirty Devil	7000-8000'	0.0	0.0	0.0	0.0	0.0	1,125.1	0.0
	8000-9000'	1.8	0.0	0.1	0.0	-0.1	795.5	0.3
	9000-10,000'	27.0	9.2	2.3	0.6	-1.7	377.6	1.1
	10,000-11,000'	54.1	36.5	6.9	4.4	-2.5	275.1	5.1
	11,000-12,000'	64.8	56.6	11.5	10.5	-1.0	62.7	6.0
Upper Colorado-Dolores	7000-8000'	0.0	0.0	0.0	0.0	0.0	1,408.0	0.0
	8000-9000'	8.0	0.5	0.4	0.0	-0.4	1,078.6	0.0
	9000-10,000'	30.7	3.4	2.6	0.2	-2.4	458.8	0.7
	10,000-11,000'	44.1	21.1	5.0	2.1	-2.9	326.7	6.4
	11,000-12,000'	46.1	36.2	8.6	7.0	-1.5	116.5	8.5
	12,000-13,000'	51.5	47.3	14.4	14.7	0.3	35.7	5.1
	13,000+	54.4	51.0	17.2	18.1	0.9	5.2	3.4
Upper Green	7000-8000'	26.9	24.5	1.5	0.5	-1.0	6,424.8	0.8
	8000-9000'	70.7	77.6	8.8	7.7	-1.1	1,591.9	10.5
	9000-10,000'	86.6	90.0	15.1	15.0	-0.1	787.4	16.0
	10,000-11,000'	94.1	96.4	25.6	27.4	1.8	592.2	19.9
	11,000-12,000'	97.1	98.9	40.2	45.0	4.7	192.3	14.5
	12,000-13,000'	96.7	98.1	45.2	51.0	5.7	33.2	10.0
	13,000+	94.3	96.1	58.4	66.5	8.1	1.0	11.7
Weber	5000-6000'	0.4	0.0	0.0	0.0	0.0	278.1	0.3
	6000-7000'	14.6	1.6	0.9	0.0	-0.9	754.3	0.6
	7000-8000'	52.5	21.4	5.3	1.5	-3.8	678.3	2.7
	8000-9000'	70.6	61.5	10.8	8.5	-2.3	237.6	8.9
	9000-10,000'	69.1	65.5	12.7	11.9	-0.8	81.5	15.9
	10,000-11,000'	74.4	73.5	18.1	18.6	0.5	46.1	16.6
	11,000-12,000'	73.9	74.8	24.4	26.3	1.8	0.6	13.6
White-Yampa	7000-8000'	26.4	87.0	1.6	2.0	0.3	3,381.5	0.5
	8000-9000'	64.9	79.2	6.7	6.1	-0.6	1,425.3	5.3
	9000-10,000'	75.3	80.9	12.1	12.3	0.2	604.4	13.8
	10,000-11,000'	76.0	78.9	17.5	18.7	1.2	448.7	23.0
	11,000-12,000'	72.1	72.7	25.7	28.2	2.5	77.2	18.7
	12,000-13,000'	65.1	64.0	20.7	22.3	1.6	0.1	18.3

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

Location of Reports and Excel Format Tables

ftp://snowserver.colorado.edu/pub/fromLeanne/forWWA/Near_Real_Time_Reports/

Methods

The spatial SWE estimation method is described in Schneider and Molotch (2016). The method uses linear regression in which the dependent variable is derived from the operationally measured in situ SWE from all online NRCS SNOTEL sites in the domain. The SNOTEL SWE observations are scaled by the fractional snow-covered area (fSCA) across the 500 m pixel containing that SNOTEL site before being used in the linear regression model. The fSCA is a near-real-time cloud-free MODIS satellite image which has been processed using the MODIS Snow Cover and Grain size (MODSCAG) fractional snow-covered area algorithm program (Painter, et. al. 2009, snow.jpl.nasa.gov)

The following independent variables (predictors) enter into the linear regression model:

- Physiographic variables that affect snow accumulation, melt, and redistribution, including elevation, latitude, upwind mountain barriers, slope, and others. See Figure 2 in Schneider and Molotch (2016) for the full set of these variables.
- The historical daily SWE pattern (2000-2012) retrospectively generated using historical MODSCAG data, and an energy-balance model that back-calculates SWE given the fractional Snow-Covered Area (fSCA) time series and meltout date for each pixel. See Guan, et. al., 2013 for details. (For computational efficiency, only one image from either the 1st or 15th of aa month during the 2000-2012 period that best matches the real-time SNOTEL-observed pattern is selected as an independent variable.)

The real-time regression model for this date has been validated by cross-validation, whereby 10% of the SNOTEL data are randomly removed and the model prediction is compared to the measured value at the removed SNOTEL stations. This is repeated 30 times to obtain an average R-squared value, which denotes how closely the model fits the SNOTEL data. During development of this regression method, the model was also validated against independent historical SWE data collected in snow surveys at 9 locations in Colorado, and an intensive field survey in north-central Colorado.

Data Issues/Caveats – IMPORTANT - READ THIS!

- 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.
- A known limitation of the model occurs late in the melt season when snow at the SNOTEL sites melts out, but snow remains at higher elevations. In this case, the model tends to underestimate SWE at these under-monitored upper elevations. Thus, late-season SWE prediction at higher elevations may be less accurate than earlier in the snow season.
- 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.
- Although data QA/QC is performed, occasional SNOTEL sensor malfunction may result in localized SWE errors.
- 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 at lower elevations where snow-cover is discontinuous can cause the satellite to underestimate the snow-cover extent, leading to underestimation of SWE.

References and Additional Sources

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Appendix C: Supplemental information distributed with May 8, 2018 report

Spatial Estimates of Snow-Water Equivalent (SWE) - Intermountain West Region - May 8, 2018

Supplemental Table 1b: SWE by HUC8 basin

The basin-wide SWE values and averages, and areas, for all pixels at elevations >7000',
except for HUC8s in the Bear and Weber basins, which are >5000'. Shown are May 8th percent of average (2000-12)
SWE for those dates, and May 8th mean SWE value for each HUC8 basin.

HUC2 Basin	HUC8 Code	HUC8 Basin Name	State	04-18-18 % 4/18 Avg.	5/8/2018 % 5/8 Avg.	4/18/18 SWE (in)	5/8/2018 SWE (in)	4/18/18 thru 5/8/18 Change SWE (in)	Area (mi^2)
Missouri	10080001	Upper Wind	WY	98	66	14.9	7.7	-7.1	1391
	10080002	Little Wind	WY	83	55	12.6	6.1	-6.4	341
	10080003	Popo Agie	WY	85	58	13.6	7.0	-6.6	384
	10080004	Muskrat	WY	0	0	0.0	0.0	0.0	5
	10080005	Lower Wind	WY	34	7	1.2	0.1	-1.0	147
	10080006	Badwater	WY	42	0	2.2	0.0	-2.2	120
	10080007	Upper Bighorn	WY	65	30	5.2	1.3	-3.9	214
	10080008	Nowood	WY	94	8	10.6	0.4	-10.2	99
	10180001	North Platte Headwaters	CO	73	46	5.3	2.1	-3.2	1424
	10180002	Upper North Platte	CO,	86	39	5.2	1.3	-3.9	2209
	10180003	Pathfinder-Seminoe Reservoirs	WY	6	0	0.2	0.0	-0.2	316
	10180004	Medicine Bow	WY	88	54	4.6	1.5	-3.1	750
	10180005	Little Medicine Bow	WY	41	3	0.9	0.0	-0.9	659
	10180006	Sweetwater	WY	32	22	1.4	0.4	-1.1	1196
	10180007	Middle North Platte-Casper	WY	40	4	2.4	0.1	-2.4	512
	10180008	Glendo Reservoir	WY	33	2	1.6	0.0	-1.6	196
	10180010	Upper Laramie	CO, WY	69	46	2.3	0.7	-1.6	2212

HUC2 Basin	HUC8 Code	HUC8 Basin Name	State	04-18-18 % 4/18 Avg.	5/8/2018 % 5/8 Avg.	4/18/18 SWE (in)	5/8/2018 SWE (in)	4/18/18 thru 5/8/18 Change SWE (in)	Area (mi^2)
Missouri, cont.	10180011	Lower Laramie	WY	13	0	0.3	0.0	-0.3	697
	10180012	Horse	WY, NE	3	0	0.1	0.0	-0.1	116
	10190001	South Platte Headwaters	CO	47	45	1.6	0.8	-0.8	1603
	10190002	Upper South Platte	CO	36	30	1.1	0.4	-0.7	1305
	10190003	Middle South Platte-Cherry Creek	CO	0	0	0.0	0.0	0.0	117
	10190004	Clear	CO	65	50	5.7	3.1	-2.6	446
	10190005	St. Vrain	CO	71	62	6.0	3.7	-2.3	474
	10190006	Big Thompson	CO	64	49	4.2	2.1	-2.1	439
	10190007	Cache La Poudre	CO	74	50	4.4	1.8	-2.6	918
	10190008	Lone Tree-Owl	CO	0	0	0.0	0.0	0.0	68
	10190009	Crow	CO, WY	0	0	0.0	0.0	0.0	121
	10190015	Upper Lodgepole	CO, WY, NE	7	0	0.1	0.0	-0.1	66
Arkansas-White-Red	11020001	Arkansas Headwaters	CO	49	45	3.0	1.9	-1.2	2911
	11020002	Upper Arkansas	CO	9	14	0.2	0.1	-0.1	907
	11020003	Fountain	CO	11	21	0.2	0.1	0.0	306
	11020004	Chinle	AZ, NM, UT	0	0	0.0	0.0	0.0	790
	11020006	Huerfano	CO	11	9	0.2	0.1	-0.2	837
	11020007	Apishapa	CO	3	0	0.0	0.0	0.0	143
	11020010	Purgatoire	CO, NM	23	17	0.4	0.1	-0.2	710

HUC2 Basin	HUC8 Code	HUC8 Basin Name	State	04-18-18 % 4/18 Avg.	5/8/2018 % 5/8 Avg.	4/18/18 SWE (in)	5/8/2018 SWE (in)	4/18/18 thru 5/8/18 Change SWE (in)	Area (mi^2)
Rio Grande	13010001	Rio Grande Headwaters	CO	27	25	2.5	1.4	-1.2	1381
	13010002	Alamosa-Trinchera	CO	24	14	0.5	0.2	-0.4	2536
	13010003	San Luis	CO	19	16	0.4	0.2	-0.2	1582
	13010004	Saguache	CO	13	7	0.3	0.1	-0.3	1343
	13010005	Conejos	NM, CO	48	24	2.7	0.8	-1.9	767
Upper Colorado	14010001	Colorado Headwaters	CO	69	45	6.4	2.8	-3.6	2812
	14010002	Blue	CO	73	59	10.6	6.5	-4.2	683
	14010003	Eagle	CO	63	49	7.4	4.2	-3.2	922
	14010004	Roaring Fork	CO	53	55	7.6	5.9	-1.6	1357
	14010005	Colorado Headwaters-Plateau	CO	40	25	2.6	0.8	-1.7	1809
	14020001	East-Taylor	CO	50	44	6.9	4.2	-2.7	768
	14020002	Upper Gunnison	CO	30	34	2.3	1.5	-0.8	2311
	14020003	Tomichi	CO	27	22	1.4	0.5	-0.9	1103
	14020004	North Fork Gunnison	CO	42	28	3.5	1.4	-2.1	770
	14020005	Lower Gunnison	CO	29	15	1.2	0.3	-0.9	797
	14020006	Uncompahgre	CO	31	48	2.0	1.9	-0.1	708
	14030001	Westwater Canyon	CO, UT	3	0	0.0	0.0	0.0	279
	14030002	Upper Dolores	CO	19	18	0.6	0.3	-0.3	1392
	14030003	San Miguel	CO	22	39	1.0	0.9	-0.1	1024
	14030004	Lower Dolores	UT, CO	13	8	0.5	0.1	-0.4	414
	14030005	Upper Colorado-Kane Springs	UT	15	11	0.3	0.1	-0.2	320
	14040101	Upper Green	WY	82	54	9.1	4.0	-5.1	2519
	14040102	New Fork	WY	94	69	13.2	7.7	-5.5	1187
	14040103	Upper Green-Slate	WY	0	0	0.0	0.0	0.0	336
	14040104	Big Sandy	WY	61	55	2.4	1.2	-1.2	879

HUC2 Basin	HUC8 Code	HUC8 Basin Name	State	04-18-18 % 4/18 Avg.	5/8/2018 % 5/8 Avg.	4/18/18 SWE (in)	5/8/2018 SWE (in)	4/18/18 thru 5/8/18 Change SWE (in)	Area (mi^2)
Upper Colorado, cont.	14040105	Bitter	WY	22	0	0.2	0.0	-0.2	1076
	14040106	Upper Green-Flaming Gorge Reservoir	UT, CO, WY	74	27	3.6	0.6	-3.0	1429
	14040107	Blacks Fork	UT, WY	65	33	5.4	1.6	-3.8	1163
	14040108	Muddy14040108	WY, UT	19	9	0.7	0.1	-0.6	513
	14040109	Vermilion	CO	29	0	0.3	0.0	-0.3	518
	14050001	Upper Yampa	CO	84	50	8.4	3.2	-5.2	1941
	14050002	Lower Yampa	CO	49	7	1.2	0.0	-1.2	464
	14050003	Little Snake	CO, WY	106	26	7.2	0.9	-6.3	1194
	14050004	Muddy14050004	WY	130	0	3.2	0.0	-3.2	355
	14050005	Upper White	CO	65	45	7.2	3.5	-3.7	897
	14050006	Piceance-Yellow	CO	5	0	0.1	0.0	-0.1	524
	14050007	Lower White	UT, CO	0	0	0.0	0.0	0.0	565
	14060001	Lower Green-Diamond	UT	62	24	4.0	0.7	-3.3	566
	14060003	Duchesne	UT	53	39	6.1	3.0	-3.1	1590
	14060004	Strawberry	UT	35	4	2.2	0.1	-2.1	896
	14060005	Lower Green-Desolation Canyon	UT	25	0	0.7	0.0	-0.7	708
	14060006	Willow	UT	0	0	0.0	0.0	0.0	527
	14060007	Price	UT	26	1	1.3	0.0	-1.2	784
	14060008	Lower Green	UT	0	0	0.0	0.0	0.0	46
	14060009	San Rafael	UT	45	23	4.0	1.2	-2.8	618
	14070001	Upper Lake Powell	UT	4	0	0.0	0.0	0.0	327
	14070002	Muddy14070002	UT	25	10	0.9	0.2	-0.8	390
	14070003	Fremont	UT	26	5	1.0	0.1	-0.9	1094

HUC2 Basin	HUC8 Code	HUC8 Basin Name	State	04-18-18 % 4/18 Avg.	5/8/2018 % 5/8 Avg.	4/18/18 SWE (in)	5/8/2018 SWE (in)	4/18/18 thru 5/8/18 Change SWE (in)	Area (mi^2)
Upper Colorado, cont.	14070004	Dirty Devil	UT	12	0	0.2	0.0	-0.2	10
	14070005	Escalante	UT	33	6	1.2	0.1	-1.1	549
	14070006	Lower Lake Powell	AZ, UT	0	0	0.0	0.0	0.0	96
	14070007	Paria	AZ, UT	28	0	0.0	0.0	0.0	172
	14080101	Upper San Juan	NM, CO	32	30	1.4	0.8	-0.5	1889
	14080102	Piedra	CO	24	20	1.0	0.5	-0.5	605
	14080103	Blanco Canyon	NM	0	0	0.0	0.0	0.0	691
	14080104	Animas	NM, CO	31	44	3.1	3.0	-0.1	925
	14080105	Middle San Juan	NM, AZ, CO	18	23	0.3	0.2	-0.1	301
	14080106	Chaco	NM	0	0	0.0	0.0	0.0	456
	14080107	Mancos	CO, NM	18	21	0.4	0.2	-0.1	270
	14080201	Lower San Juan-Four Corners	AZ, UT	0	0	0.0	0.0	0.0	191
	14080202	McElmo	CO, UT	0	0	0.0	0.0	0.0	64
	14080203	Montezuma	UT, CO	0	0	0.0	0.0	0.0	173
	14080205	Lower San Juan	AZ, UT	0	0	0.0	0.0	0.0	56

HUC2 Basin	HUC8 Code	HUC8 Basin Name	State	04-18-18 % 4/18 Avg.	5/8/2018 % 5/8 Avg.	4/18/18 SWE (in)	5/8/2018 SWE (in)	4/18/18 thru 5/8/18 Change SWE (in)	Area (mi^2)
Great Basin	16010101	Upper Bear	UT	43	30	1.9	0.7	-1.3	2021
	16010102	Central Bear	ID, WY	55	23	4.4	0.9	-3.5	824
	16010201	Bear Lake	ID, UT	47	18	3.1	0.6	-2.6	1275
	16010202	Middle Bear	UT, ID	46	18	2.5	0.5	-2.0	914
	16010203	Little Bear-Logan	UT	59	21	5.2	1.0	-4.3	760
	16010204	Lower Bear-Malad	UT, ID	17	2	0.6	0.0	-0.6	243
	16020101	Upper Weber	UT	37	25	2.3	0.8	-1.5	1171
	16020102	Lower Weber	UT	39	7	2.5	0.2	-2.3	906

Appendix C: Supplemental information distributed with May 8, 2018 report, cont.

Supplemental Table 1c: Comparison of modeled 2018 SWE to modeled 2000-2012 SWE on or around May 8th

RANKING OF 2018 vs 2000-2012, BY BASIN			
Basin	**YEAR**	**SWE (in.)**	**Date**
Big Horn	2011	23.5	20110506
	2008	16.1	20080508
	2005	13.7	20050510
	2009	12.1	20090508
	2006	10.6	20060508
	2003	10.4	20030508
	2010	9.7	20100507
	2007	7.3	20070508
	2001	6.9	20010501
	2018	5.9	20180508
	2004	4.6	20040508
	2000	4.6	20000508
	2002	4.6	20020508
	2012	3.5	20120508
Upper Green	2011	11.7	20110506
	2008	7.2	20080508
	2005	6.7	20050510
	2006	5.2	20060508
	2009	5.0	20090508
	2003	4.6	20030508
	2010	4.5	20100507
	2001	3.3	20010501
	2007	3.0	20070508
	2018	2.4	20180508
	2002	2.1	20020508
	2000	2.0	20000508
	2004	1.9	20040508
	2012	1.5	20120508
Bear	2011	10.7	20110506
	2008	6.1	20080508
	2005	4.1	20050510
	2009	3.9	20090508
	2006	3.5	20060508
	2010	2.4	20100507
	2003	2.4	20030508

RANKING OF 2018 vs 2000-2012, BY BASIN, cont.			
Bear, cont.	2001	1.5	20010501
	2002	1.0	20020508
	2007	1.0	20070508
	2000	0.8	20000508
	2018	0.7	20180508
	2004	0.5	20040508
	2012	0.4	20120508
North Platte	2011	7.0	20110506
	2008	5.4	20080508
	2010	3.1	20100507
	2003	2.7	20030508
	2009	2.2	20090508
	2001	2.2	20010501
	2005	2.0	20050510
	2006	1.7	20060508
	2007	1.2	20070508
	2018	0.9	20180508
	2000	0.9	20000508
	2004	0.7	20040508
	2002	0.5	20020508
	2012	0.3	20120508
White-Yampa	2011	12.1	20110506
	2008	7.2	20080508
	2003	5.0	20030508
	2005	4.6	20050510
	2009	4.5	20090508
	2010	4.5	20100507
	2006	3.8	20060508
	2001	3.7	20010501
	2007	2.4	20070508
	2000	2.0	20000508
	2018	1.8	20180508
	2004	1.6	20040508
	2002	1.2	20020508
	2012	0.5	20120508
Weber	2011	10.9	20110506
	2008	6.4	20080508
	2005	4.6	20050510
	2006	3.6	20060508
	2009	3.1	20090508
	2010	2.5	20100507
	2003	2.2	20030508

RANKING OF 2018 vs 2000-2012, BY BASIN, cont.			
Weber	2001	1.6	20010501
	2007	1.0	20070508
	2002	0.9	20020508
	2000	0.6	20000508
	2018	0.5	20180508
	2004	0.5	20040508
	2012	0.3	20120508
South Platte	2011	5.1	20110506
	2008	4.5	20080508
	2005	4.4	20050510
	2003	3.6	20030508
	2010	3.2	20100507
	2001	3.2	20010501
	2006	3.0	20060508
	2007	2.8	20070508
	2009	2.7	20090508
	2004	1.6	20040508
	2018	1.4	20180508
	2000	1.3	20000508
	2002	0.5	20020508
	2012	0.4	20120508
Lower Green	2011	9.7	20110506
	2005	8.6	20050510
	2008	7.1	20080508
	2006	4.6	20060508
	2003	3.8	20030508
	2010	3.6	20100507
	2001	3.4	20010501
	2009	3.0	20090508
	2007	2.1	20070508
	2000	1.3	20000508
	2004	1.3	20040508
	2018	1.1	20180508
	2002	1.1	20020508
	2012	0.5	20120508
Colorado Headwaters	2011	16.6	20110506
	2008	10.8	20080508
	2003	8.5	20030508
	2005	7.5	20050510
	2010	6.6	20100507
	2009	6.4	20090508
	2001	6.1	20010501

RANKING OF 2018 vs 2000-2012, BY BASIN, cont.			
olorado Headwaters, con	2006	5.9	20060508
	2007	4.4	20070508
	2000	2.9	20000508
	2018	2.8	20180508
	2004	2.7	20040508
	2002	1.4	20020508
	2012	0.8	20120508
Blue	2011	23.9	20110506
	2008	16.1	20080508
	2005	16.0	20050510
	2003	13.9	20030508
	2009	11.8	20090508
	2006	11.6	20060508
	2010	11.2	20100507
	2007	10.4	20070508
	2001	10.2	20010501
	2004	6.7	20040508
	2018	6.5	20180508
	2000	5.4	20000508
	2002	3.2	20020508
	2012	2.2	20120508
Colorado Headwaters-Plateau	2011	9.3	20110506
	2008	6.7	20080508
	2005	5.7	20050510
	2003	3.8	20030508
	2006	3.6	20060508
	2010	3.3	20100507
	2009	3.1	20090508
	2001	3.0	20010501
	2000	1.7	20000508
	2007	1.7	20070508
	2004	1.2	20040508
	2018	0.8	20180508
	2002	0.5	20020508
	2012	0.2	20120508
Eagle	2011	19.6	20110506
	2008	13.3	20080508
	2005	12.1	20050510
	2003	10.8	20030508
	2009	10.1	20090508
	2006	9.5	20060508
	2010	8.5	20100507

RANKING OF 2018 vs 2000-2012, BY BASIN, cont.			
Eagle, cont.	2001	7.8	20010501
	2007	6.9	20070508
	2004	4.6	20040508
	2018	4.2	20180508
	2000	4.1	20000508
	2002	2.5	20020508
	2012	1.3	20120508
Roaring Fork	2011	22.3	20110506
	2005	17.6	20050510
	2008	16.9	20080508
	2006	13.2	20060508
	2003	12.9	20030508
	2009	11.9	20090508
	2010	9.9	20100507
	2001	9.6	20010501
	2007	9.3	20070508
	2004	6.5	20040508
	2018	5.9	20180508
	2000	5.5	20000508
	2002	3.4	20020508
	2012	1.7	20120508
Upper Colorado-Dolores	2005	3.6	20050510
	2008	3.2	20080508
	2011	3.2	20110506
	2003	1.9	20030508
	2001	1.7	20010501
	2010	1.6	20100507
	2006	1.5	20060508
	2007	1.4	20070508
	2009	1.0	20090508
	2004	0.9	20040508
	2000	0.6	20000508
	2018	0.4	20180508
	2002	0.2	20020508
	2012	0.1	20120508
Upper Arkansas	2005	4.6	20050510
	2011	4.4	20110506
	2008	3.6	20080508
	2003	2.9	20030508
	2006	2.9	20060508
	2007	2.7	20070508
	2001	2.5	20010501

RANKING OF 2018 vs 2000-2012, BY BASIN, cont.			
Upper Arkansas, cont.	2010	2.5	20100507
	2009	2.1	20090508
	2004	1.6	20040508
	2000	1.2	20000508
	2018	1.0	20180508
	2002	0.4	20020508
	2012	0.3	20120508
Gunnison	2011	9.5	20110506
	2008	8.4	20080508
	2005	8.1	20050510
	2003	5.3	20030508
	2006	4.8	20060508
	2001	4.3	20010501
	2010	4.1	20100507
	2007	3.6	20070508
	2009	3.6	20090508
	2004	2.5	20040508
	2000	2.0	20000508
	2018	1.5	20180508
	2002	0.8	20020508
	2012	0.4	20120508
Upper Colorado-Dirty Devil	2005	4.4	20050510
	2011	2.9	20110506
	2008	2.6	20080508
	2006	1.9	20060508
	2010	1.4	20100507
	2001	1.4	20010501
	2003	1.2	20030508
	2007	0.7	20070508
	2009	0.5	20090508
	2004	0.4	20040508
	2000	0.3	20000508
	2012	0.1	20120508
	2002	0.1	20020508
	2018	0.1	20180508
Rio Grande Headwaters	2005	4.8	20050510
	2008	3.7	20080508
	2011	3.2	20110506
	2001	2.7	20010501
	2007	2.5	20070508
	2003	2.4	20030508
	2006	2.3	20060508

RANKING OF 2018 vs 2000-2012, BY BASIN, cont.			
Rio Grande Headwaters, cont.	2010	2.2	20100507
	2004	1.5	20040508
	2009	1.2	20090508
	2000	0.8	20000508
	2018	0.4	20180508
	2002	0.2	20020508
	2012	0.1	20120508
San Juan	2005	4.6	20050510
	2008	3.9	20080508
	2011	3.8	20110506
	2006	2.5	20060508
	2003	2.4	20030508
	2001	2.2	20010501
	2007	2.0	20070508
	2010	1.9	20100507
	2009	1.6	20090508
	2004	1.4	20040508
	2000	0.9	20000508
	2018	0.7	20180508
	2002	0.4	20020508
	2012	0.2	20120508

Appendix C: Supplemental information distributed with May 8, 2018 report, cont.

Supplemental Table 1c: Comparison of modeled 2018 SWE to modeled 2000-2012 SWE on or around May 8th, cont.

ANALOG YEARS, BY BASIN	
Basin	**Closest analog(s) to 2018**
Big Horn	2001
Upper Green	2002
Bear	2000
North Platte	2000
White-Yampa	2000, 2004
Weber	2004
South Platte	2000
Lower Green	2002
Colorado Headwaters	2000, 2004
Blue	2004
Colorado Headwaters-Plateau	2002
Eagle	2000
Roaring Fork	2000
Upper Colorado-Dolores	2000, 2002
Upper Arkansas	2000
Gunnison	2000
Upper Colorado-Dirty Devil	2002
Rio Grande Headwaters	2002
San Juan	2000