COMMUNITY SNOW OBSERVATIONS (CSO): A CITIZEN SCIENCE CAMPAIGN TO VALIDATE SNOW REMOTE SENSING PRODUCTS AND HYDROLOGICAL MODELS

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ABSTRACT: The ability to quantify seasonal water retention and storage in mountain snow packs has implications for an array of important topics, including forecasting and mitigation of snow avalanche and flood hazards, ecosystem function, water resources, climate modeling, and our economy. Runoff models, which typically rely on gridded climate data and snow remote sensing products, would be greatly improved if uncertainties in estimates of snow depth and snow water equivalence (SWE) in high-elevation complex terrain could be reduced. The NASA-funded Community Snow Observations (CSO) project recruits winter backcountry enthusiasts to help increase the temporal and spatial coverage of snow depth observations in high-alpine complex terrain. Crowdsourced snow observations in Thompson Pass started in 2015 with a small group of skiers and avalanche professionals, since then the number of CSO participants has increased dramatically, expanding across western North America, and engaging citizen scientists globally. Recruitment of citizen scientists takes place at winter festival events, avalanche safety workshops and classroom presentations, through news media coverage, social media, and via word of mouth. Participating citizen scientists use Mountain Hub, a multi-platform mobile and web-based crowd-sourcing application to record, submit, and instantly share geo-located snow depth, SWE, and measurement location photos. Snow depth observations submitted by citizen scientists are used to validate snow remote sensing products and snow depth distribution models produced by the CSO research team. CSO submissions during winters of 2016/2017 and 2017/2018 in Thompson Pass, south-central Alaska, were used as ground validation data that helped to improve snow remote sensing products, and as snow distribution model input, which greatly improved the accuracy of modeled snow depth and SWE for the area. CSO ambassadors are key to the success of our grassroots effort and include avalanche professionals, hydrologists, guides and recreationists who help promote the project in their local area. Thanks to their frequent use of the avalanche probe, CSO citizen scientists have not only contributed to snow science, they have also built on their own personal understanding of snow depth distribution in the mountains where they choose to recreate. As the CSO project moves forward, we will keep a data-driven approach to our selection of new study sites for the remote sensing and modeling work. We aim to broaden the pool of citizen scientists to ensure sustainable growth, collaborate with more snow and avalanche professionals to share critical results, and engage with other research groups to maximize the benefits of highly valuable crowd-sourced data.

KEYWORDS: Citizen Science, Crowd-Sourced Data, Snow Distribution, Snow Hydrology, Remote Sensing, Mountain Hub

1. INTRODUCTION

In mountainous areas around the globe, the arrival of winter focuses our attention on snow – its depth, distribution and surface characteristics – so that we can produce accurate avalanche forecasts, plan mitigation activities, or dream about our next recreational adventure. Snow delivers multiple environmental, social and economic benefits, serving as a natural reservoir of winter precipitation and source of runoff during the melt season. Fluctuations in the seasonal snowpack impacts water runoff and affects our drinking water supplies, agriculture, fishing industry and forests. Large amounts of snowfall

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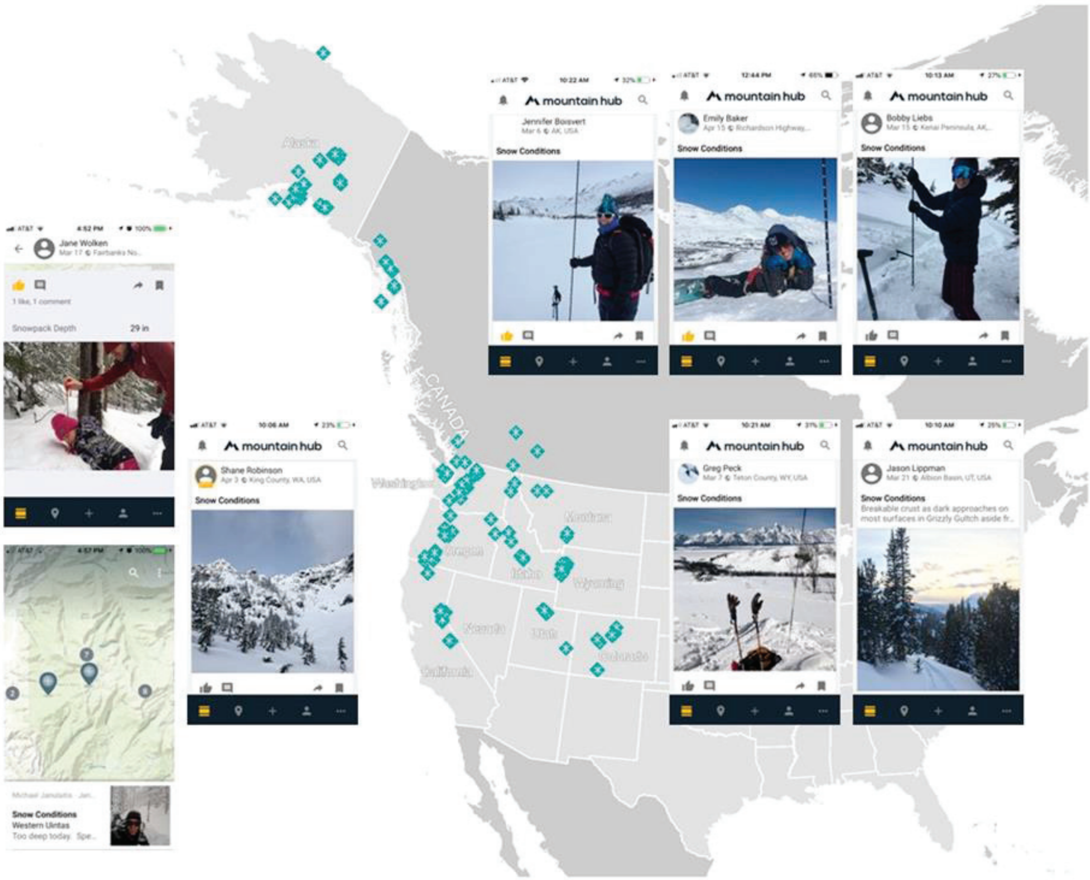

Figure 1. Geographical spread and example submissions of snow depth observations in Mountain Hub during 2017/2018 winter season.

and rapid snowmelt can cause natural hazards such as avalanches, landslides and floods, impacting communities and local economies.

Snow hydrology models provide an important mechanism to explore the linkages between physical and socioeconomic systems. However, modeling snowpack changes is complex and requires direct measurements of snow properties in order to calibrate simulations. Available information on the snowpack in the western United States vary in reliability, frequency, and spatial coverage. In the United States, data typically come from a combination of automated Snow Telemetry (SNOTEL) stations and snow courses. These are excellent sources of data, but they are limited in number due to resource constraints, and they tend to undersample complex topography and high elevations due to access constraints. Airborne and satellite assets are able to remotely sense the snowpack and overcome some of the spatial sampling issues of in-situ measurements. For example, NASA's Airborne Snow Observatory (Painter et al., 2016) uses lidar to measure snow depth and the MODIS sensor (Hall et al., 2002) on NASA's Terra satellite is able to measure snow covered area. However, these observations still lack the temporal and spatial resolution needed to accurately account for all patterns of seasonal snow behavior, for example snow depth changes after a large storm. Remote observations also require ground measurements for sensor calibration and validation.

The Community Snow Observations (CSO) project is a new NASA-funded project that aims to combine the activities of scientists and recreationists to broaden our understanding of snow. Since its launch in 2017 we have recruited winter backcountry enthusiasts and snow professionals to help improve the spatial and temporal coverage of snow depth observations in complex terrain. In partnership with Mountain Hub, creators of the outdoor oriented, community-fueled smartphone application, we have received more than 1500 snow depth measurements across the western United States and numerous others around the globe (Figure 1).

CSO data have already shown to be extremely valuable; the data have been used to improve estimates of snow water equivalence (SWE) in hydrological models, and to validate modeled snow depth distribution generated with remote sensing techniques. As the project enters its second year, we hope to recruit a more diverse pool of citizen scientists that include elementary school students, professional outdoor athletes and other research groups. We also plan to develop data sharing and visualization tools to help sustain long-term interest and engagement in this project.

2. BUILDING A CITIZEN SCIENCE COMMUNITY TO GATHER SNOWPACK DATA

Since the start of the CSO project we have focused on recruitment of citizen scientists from the winter backcountry community. Snow professionals and backcountry recreationists often travel long distances to high elevation areas that tend to be poorly represented by fixed observations (e.g. SNOTEL), providing an opportunity for sampling of remote snowpacks.

To maximize the success of the CSO project, our overriding priority was to remove as many obstacles to participation as possible. Specifically, we adopted the criteria that (i) measurements should require minimal equipment, (ii) measurements should be extremely fast and easy to make, and (iii) the flow of data from citizen scientist to project science team should be highly automated. To facilitate the data submission process and to reduce development cost, project spin-up time, and the ‘app clutter’ that overloads many phones, we partner with Mountain Hub, whose smartphone application (https://app.mountainhub.com) allows users to report and view outdoor-oriented information in real time. Through this partnership, the application was modified to accommodate input of snow depth and SWE data which are then sent in real-time to our web map service.

2.1 *Data Processing and Communication*

When a snow depth observation is submitted, the data point is available in real-time in our web map service (http://app.communitysnowobs.org/). Here we get immediate access to the data, and users can immediately view their observations on an interactive map. Our team relies on Amazon Web Services (AWS) to deploy web applications that can scale to respond to changing user requests at different times of year. As we continue to develop our Application Programming Interface (API) it will enable collaborators to subset any range of citizen science observations and compare these with other related snow datasets.

Most of our communication with participating and future citizen scientists occur online via our project website (http://communitysnowobs.org) and established social media channels (Facebook/Instagram @communitysnowobs; and Twitter @communitysnowob)

2.2 *Recruitment*

During the winter of 2017/2018, the number of CSO participants significantly increased with clusters of measurements submitted from south-central Alaska, Washington, Oregon and the Teton-area of Wyoming (Figure 1). The first two years of the CSO implementation phase have demonstrated that engaging citizen scientist may require different recruitment approaches depending on targeted crowd and locality of the campaign. Recruitment strategies include both intensive data collection campaigns with hands-on training, incentivized contests sponsored by industry partners, and regular encouragement through social media.

Together with Mountain Hub and industry partners, we design innovative approaches to incentivize community participation through our ambassador program and “Data for Good” campaigns. The program aims to retain a group of the most active or influential citizen scientists, each representing an area of our focus region. The ambassadors play an important role in promoting the project, influencing like-minded people to participate and they act as local CSO representatives who can share the scientific contributions of the project with pertinent institutions and agencies.

3. DATA ANALYSIS & APPLICATIONS

3.1 *Correction of snow water equivalence in hydrological models*

Crowd-sourced CSO data are extremely valuable for improving hydrological modeling. Hydrological models use meteorological observations, such as temperature and precipitation, to calculate surface mass and energy exchanges, and produce estimates of snow distribution and melt rates. In a subset watershed in Thompson Pass, Alaska, we found that the model significantly over-predicted snow in the test watershed, and that the CSO data could be used in the model to correct the output so that it better represented real conditions on the ground (See Figure 2).

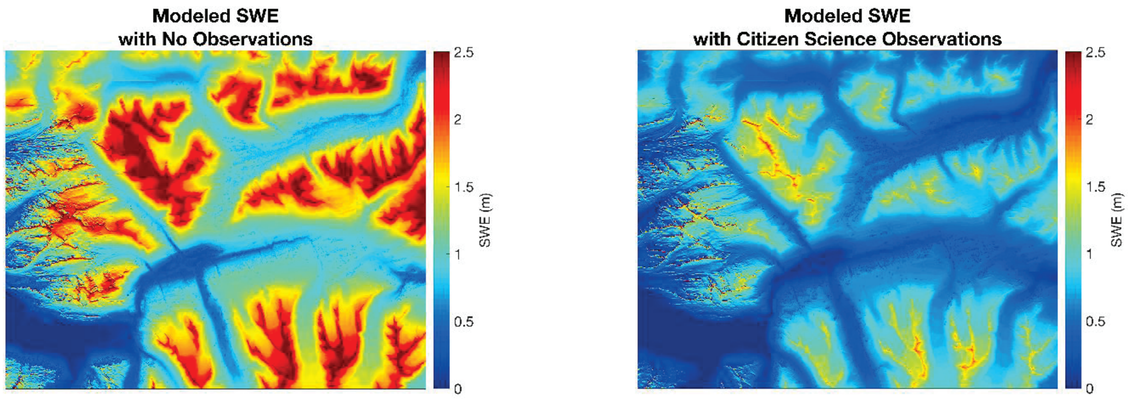

Figure 2. Modeled Snow Water Equivalent (SWE) depth without (left) and with (right) citizen science observations, on April 30th 2017 in Thompson Pass, Alaska

3.2 Validation of airborne remote sensing products

We use airborne photogrammetry and lidar to produce maps of snow depth distribution in various areas of Alaska. We use CSO data to validate patterns of wind-redistributed snow, and for quality assessment and to reveal systemic bias (Figure 4). Additionally, photogrammetric processing of snow-covered landscapes is often challenged with large, low contrast surfaces that lack distinctive texture, which can result in inaccurate surface modeling and generate artifacts in the final snow surface model. CSO observations provide valuable in-situ data that help us quantify uncertainties in these areas.

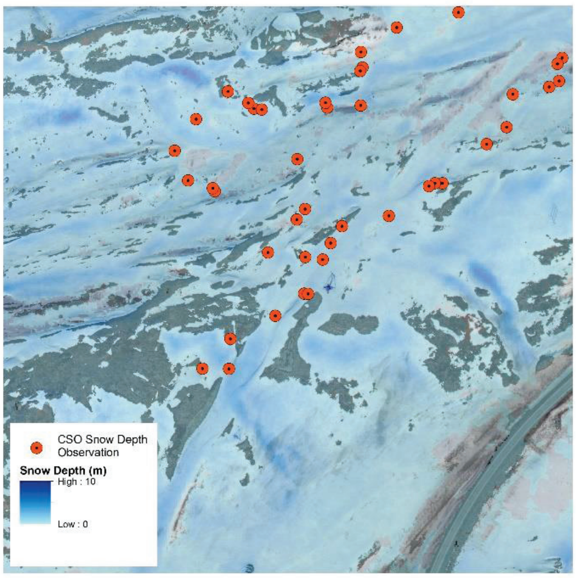

Figure 3. Snow depth distribution on 04/30/2017 in Thompson Pass, Alaska, retrieved with airborne structure-from-motion photogrammetry, and the locations of CSO snow depth measurements submitted the day after the survey.

4. HOW TO PARTICIPATE

Becoming a citizen scientist with CSO does not require any sign-up or membership. All the citizen scientist needs is:

- Undisturbed snow on the ground (avoid tree wells or spots where skiers and snowmachiners may have compressed the snow).
- A snow probe or measurement tape with graduated markings in metric (centimeters);
- A smartphone (iPhone or android) with the Mountain Hub app installed to submit a snow depth observation.

To account for small-scale snow cover variability we recommend the citizen scientist to record a snow depth that is an average of three measurements within a 1 m radius (Figure 4). We also recommend to submit a photo of the measurement location that we can use for data quality control. Because Mountain Hub accesses the GPS on the smartphone to geotag the observation with a location and a time, it is very important that the citizen scientist submits the observation exactly where the measurement was taken.

Figure 4. Community Snow Observations (CSO) tutorial flyer.

5. CROWD-SOURCED DATA: CHALLENGES & BENEFITS

Citizen science as a paradigm brings with it a unique set of opportunities and challenges. By its very nature, citizen science is decentralized and unstructured. Observations are opportunistic and depend upon decisions (routes taken, days traveled, etc.) made by the citizen scientists themselves. Another challenge has to do with data quality control of the submitted observations. Quality control in CSO is both automated and performed manually by the research team. However, we have to accept that observations are coming from a diverse body of contributors with differing levels of experience in data collection. On the other hand, a key advantage is that individual observations are zero cost. They come from volunteers who possess the resources and skills to travel to the field, collect the data, and transmit it to the project team. Further, there is some evidence (e.g., Garbarino and Mason, 2016; Bonney et al., 2016) that citizen science democratizes access to science and encourages scientific literacy in the greater public. Because, importantly, not only does the scientific community benefit from involving citizen scientists, participants with CSO have explicitly stated that they have increased their personal understanding of snow depth distribution in the mountains by submitting snow depth observations while travelling in the backcountry.

ACKNOWLEDGEMENT

We would like to thank all of our citizen scientists, Mountain Hub, NASA Citizen Science for Earth Science Program, and our industry partners and research collaborators for supporting the project.

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