Remote Sensing of Snow Data

Rebecca Pappas

GPHY 426
Spring 2017

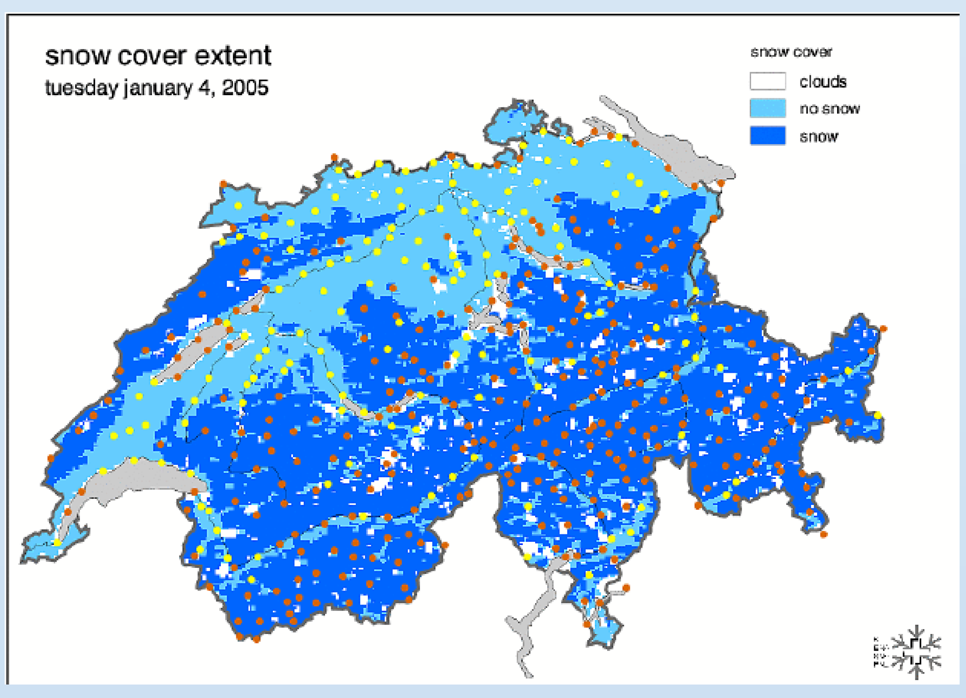
Remote Sensing of snow and ice data is an important and growing application within the fields of hydrology, snow science and climate change. As remote sensors onboard satellites, aircraft, and unmanned aerial vehicles (UAV) evolve to meet growing demands, the scientific studies that can be conducted using this data have become more advanced. Recent decades have seen major advancements in the study of land cover classification and vegetation indices, as well as soil, mineral, and geologic classification. The drive for mineral and geologic classification comes from the oil and gas industries, while the advancements in land cover classification benefit a variety of industries, including agriculture, forestry, urban and transportation development, conservation groups, and government officials. While advancements have been made in the remote sensing and classification of snow, they have not moved nearly as fast as in other disciplines. The need for advancements in the remote sensing of snow and ice data to light recently with the added emphasis governments and scientists are placing on climate change. In our increasingly globalized, politicized, and industrialized world, the need for accurate and timely climate data has increased the amount of work being conducted in the field of remote sensing of snow and ice.

Winter 2013-2014: Animation showing the change in extent of snow cover, as well as ice cover on the Great Lakes, in North America during the winter of 2013-2014. Source: NASA Scientific Visualization Studio https://svs.gsfc.nasa.gov//cgi-bin/details.cgi?aid=4256

SnoTel site south of West Yellowstone, Montana. December 2012. Photo courtesy of USDA Natural Resources Conservation Service. https://nrcs-photogallery-mt.smugmug.com/keyword/snotel;winter/

The single largest contributing variable hydrologists look at when studying the amount of water available in a drainage basin in a mountainous region is snow water equivalent (SWE). SWE is the amount of water (typically reported in inches in the U.S.) contained within a snowpack. It is the depth of water, if the snowpack melted instantly. SWE is calculated by multiplying the snow depth by the snow density. While the snow density can be estimated for a given area based upon type of snowpack, time of year, remote sensing of the area, etc., the depth of the snowpack is much harder to determine without physically going to the site and measuring the depth.

Snow depth has proven to be the most frustrating measurement to achieve through remote sensing. Most remote sensors cannot detect snowpack depths greater than 25 cm (10 inches). When snow depth is measured, it is typically measured by subtracting surface elevations obtained during times of no snow, from snow surface elevations. Snowpack telemetry (SnoTel) sites have been established across the western U.S. and Canada to address this problem. These sites consist of a variety of sensors that measure snow and weather data and relay this information back to the USDA offices in real time via meteor burst communications technology. These sites are located in remote yet accessible locations that are assumed to be indicative of the surrounding area. This allows the information gathered at each site to be extrapolated to the surrounding drainage basin. SnoTels have ultrasonic sensors to measure snowpack depth, as well as snow pillows, a device that is specifically designed to measure SWE. The question for hydrologist and snow scientists has always been, "Are these SnoTel sites truly representing the surrounding areas?" Many attempts have been made to verify the values obtained though extrapolation with remote sensing, but the inability of remote sensors to detect snowpack depths greater than 25 cm make this an impossibility in most locations.

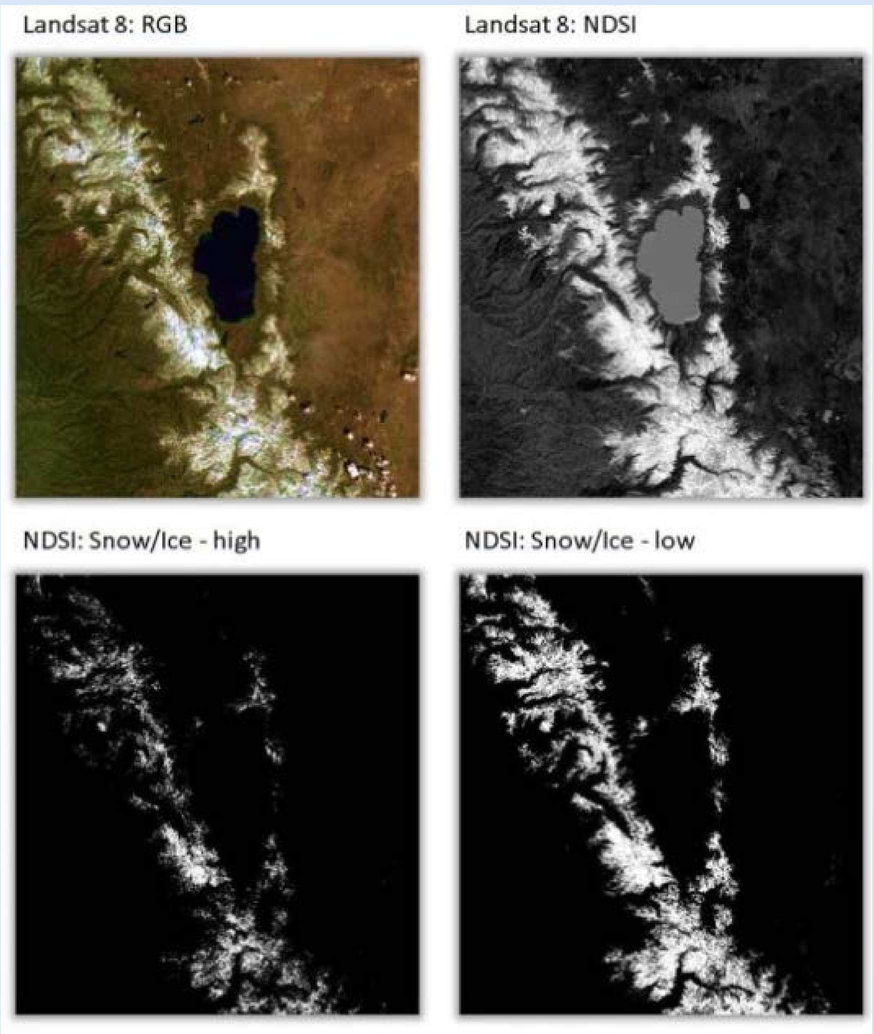


Binary Snow Cover Map. Map shows snow cover extent over Switzerland. A binary map maps areas as either snow or no snow. Source: ResearchGate https://www.researchgate.net/figure/242166845_fig3_Figure-3-Binary-snow-cover-map-using-a-threshold-of-15-snow-cover-fraction-The-virtual

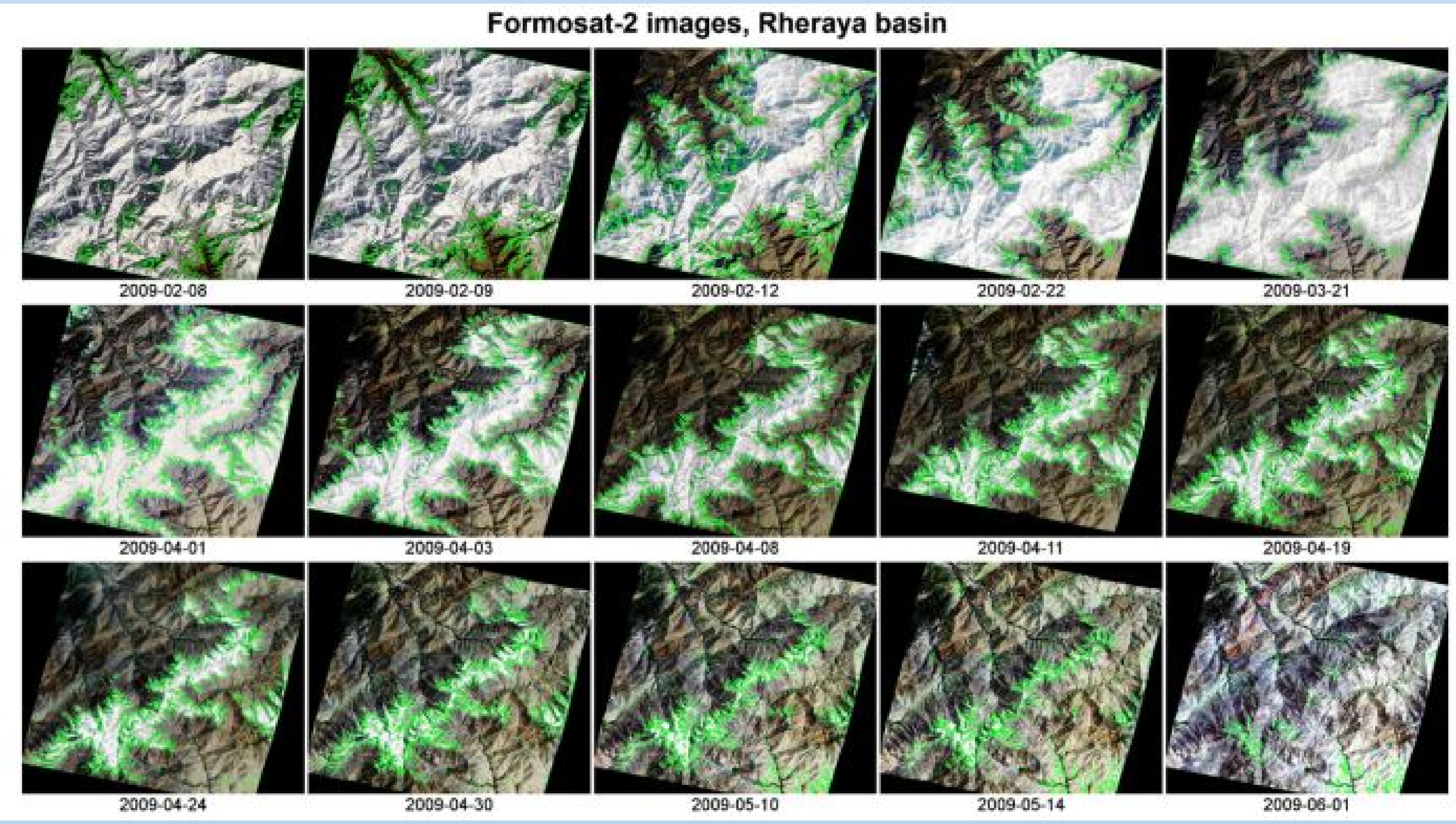
$$NDSI = \frac{Red - NIR}{Red + NIR}$$

Above: NDSI Equation. Red refers to a band in the red portion of the visible spectrum, approximately 650 nm. NIR refers to the near infrared portion of the spectrum, approximately 700-1000 nm.

Left: NDSI Images. NDSI images derived from Landsat-8 images of Lake Tahoe. Low and High refer to confidence level. NDSI is a ratio used to differentiate snow from clouds, water bodies, and land. https://hyspeedblog.wordpress.com/2014/10/14/enhancing-the-landsat-8-quality-assessment-band-detecting-snowice-using-ndsi/



Since snow depth, and therefore SWE, is hard to determine using remote sensing, most remote sensing of snow and ice data focuses on extent, as well as spatial and temporal changes. Although the sensors cannot penetrate very deep into the snowpack, they do a wonderful job at determining where the snowpack is located and when. The Moderate Resolution Imaging Spectroradiometer (MODIS) has become the go to sensor for snow cover extent data. This is due to the quality of images produced by MODIS, as well as the number of bands MODIS senses. Many snow mapping algorithms and products have been developed for use with the MODIS images that cover a variety of spatial and temporal resolutions. There are three main snow products for use with MODIS that are widely used. The first snow product is the binary global snow maps that were an initially a standard MODIS product. This binary product maps the image as snow or no snow, with each pixel receiving one if the two designations. If a pixel is snow covered, but contains a forest with a dense evergreen canopy, then that pixel will most likely be mapped as no snow. These mixed pixels will result in underestimation of snow cover at lower elevations and overestimation of snow cover at higher elevations. The second and third snow products developed for use with MODIS are both fractional snow products, with both of these models using an empirical relationship between snow cover and the normalized-difference snow index (NDSI). The NDSI is similar to the normalized-difference vegetation index (NDVI), in that it is a ratio comparing ideal bands for what it is looking at. The NDSI compares a band in the visible spectrum (where snow is bright), typically a red band, with a band in the near infrared spectrum (where snow is dark). Once the NDSI is applied, an image can be reclassified to locate all pixels containing snow. Map geometry can then be used on this reclassified image to determine the area covered by snowpack. Snow and ice cover extent data is being used more and more these days in conjunction with climate change research and education. These up-to-date images of snow cover extent are a powerful medium for climate change education. As they say, a picture is worth a thousand words.

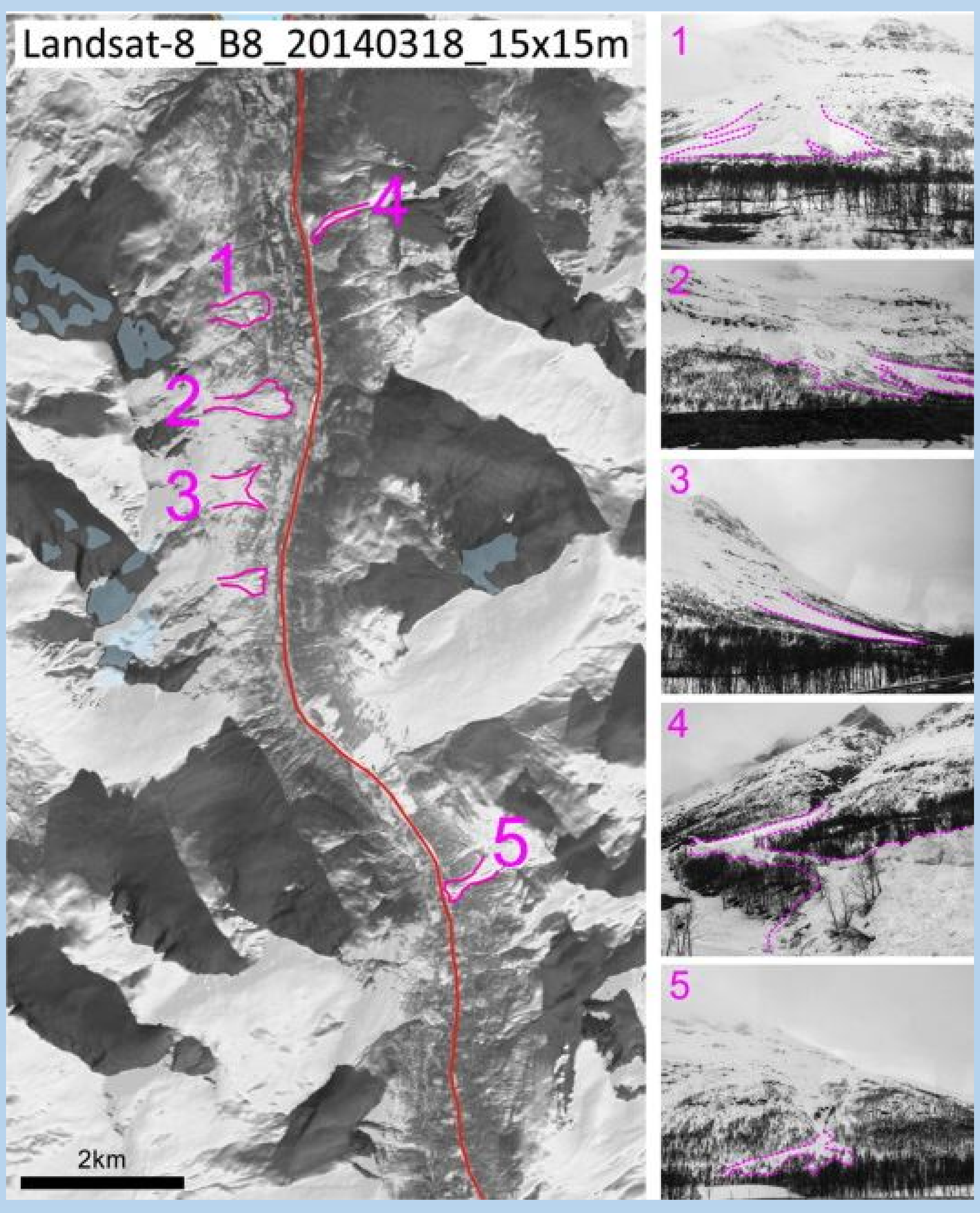


Temporal Changes in Snow Cover Extent in the Rheraya Basin, Marrakech. The green lines form the borders of polygons that indicate the snow cover extent. Images such as this can employ map geometry to determine the geographical area covered by snow. http://ac.els-cdn.com/S0034425715000115/1-s2.0-S0034425715000115-main.pdf?_tid=6405caaa-22c0-11e7-8f44-00000aacb361&acdnat=1492359716_12a86dd5c7d02fa39f2546d01813e891

If a picture is worth a thousand words, then a time series of pictures must be worth all of the English language. The most productive use of MODIS snow cover extent images is to create a time series of images of the same location that shows temporal changes in the snowpack. Not only can images be compared through out a season to determine seasonal changes, but images can be compared over years, even decades, to obtain a climate record for the area. Historic images of peak snow cover extent can be archived and time stamped. These images can be referenced to see information such as if peak extent is shrinking or growing, or if the date of peak extent is shifting to either earlier or later in the season. These dates and data are incredibly valuable to hydrologists and climate change scientists studying the amount of water available in a drainage basin. The most useful application of remote sensing in the world of snow science is the ability to study temporal changes in the extent of the snowpack through images.

Another use for remote sensing in the snow sciences is in the study of avalanches. Remote sensors have recently reached the resolution required to pinpoint avalanches and avalanche paths in remotely sensed imagery. Landsat-8 panchromatic images are of high enough resolution to see avalanches, and the bands on the sensor give it the ability to differentiate between clouds and snow, as well as between snow and ice. These high resolution images allow snow scientists to study avalanches in remote, dangerous areas, without having to leave the comfort of their offices. Map geometry can be applied to these images to determine total area within the slide path, as well as estimate the volume of material moved in the slide.

Many locations, such as the Milford Road in New Zealand, lie within the zone of an avalanche path, but cannot directly see the start zone of the avalanches. Remote sensing of active avalanche paths and start zones in the area can help convey the avalanche risk to locals. If images of wind loaded cornices and active avalanches can be provided in a timely manner, perhaps the locals will realize the necessity of road closures and start believing the avalanche forecasters when they say conditions are serious.



Remote Sensing of Avalanches. March 18, 2014 Landsat-8 image of Northern Norway. Six avalanches have been pinpointed using the Landsat image. Of these six , five avalanches (shown in pink) were confirmed in the field.
Source: Eckerstorfer et al. 2015.
http://www.sciencedirect.com/science/article/pii/S0165232X15002591

Milford Road, New Zealand. Source: Leisure Tours https://www.leisuretours.co.nz/day_tour/milford-sounds-day-tour-with-nature-cruise-lt-96b/

Milford Road, NZ. Photo Courtesy of Dr. Jordy Hendrikx, MSU

References

Computing, HySpeed. "Enhancing the Landsat 8 Quality Assessment band – Detecting snow/ice using NDSI." *HySpeed Computing Blog*. N.p., 14 Oct. 2014. Web. 3 Apr. 2017.

Dietz, Andreas Juergen, Claudia Kuenzer, and Christopher Conrad. "Snow-cover variability in central Asia between 2000 and 2011 derived from improved MODIS daily snow-cover products." *International Journal of Remote Sensing* 34.11 (2013): 3879-902. *Taylor & Francis Online*. Web. 2 Apr. 2017.

Eckerstorfer, Markus, Yves Bühler, Regula Frauenfelder, and Eirik Malnes. "Remote sensing of snow avalanches: Recent advances, potential, and limitations." *Cold Regions Science and Technology* 121 (2016): 126-40. *ScienceDirect*. Web. 4 Apr. 2017.

Foppa, Nando, Andreas Stoffel, and Roland Meister. "SNOW DEPTH MAPPING IN THE ALPS: MERGING OF IN SITU AND REMOTELY-SENSED DATA." *EARSeL eProceedings* 4.1 (2005): 119-29. *ResearchGate*. Web. 5 Apr. 2017.

Marchane, A., L. Jarlan, L. Hanich, A. Boudhar, S. Gascoin, A. Tavernier, N. Filali, M. Le Page, O. Hagolle, and B. Berjamy. "Assessment of daily MODIS snow cover products to monitor snow cover dynamics over the Moroccan Atlas mountain range." *Remote Sensing of Environment* 160 (2015): 72-86. *ScienceDirect*. Web. 2 Apr. 2017.

NASA. NASA Scientific Visualization Studio, n.d. Web. https://svs.gsfc.nasa.gov 5 Apr. 2017.

Rittger, Karl, Thomas H. Painter, and Jeff Dozier. "Assessment of methods for mapping snow cover from MODIS." *Advances in Water Resources* 51 (2013): 367-80. *ScienceDirect*. Web. 1 Apr. 2017.