COLORADO STATE UNIVERSITY

WR575 Snow Hydrology Field Methods

Instructor:
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Graduate Teaching Assistant: N/A *Office Hours*: N/A
Tentative Dates and Times: Spring 2020, Wednesday (Jan 15), Saturdays (Feb 1, May 2), and Apr 3-6/7 (depart at 1530).
Prerequisites: none *Credit*: One
Location: various field sites, including near Cameron Pass, Dry Lake, and Rabbit Ears Pass

Textbooks: none required for purchase. A course primer will be distributed. Articles and other materials will be provided through Canvas or on the OneDrive. It is recommended that you use a Rite-in-the-Rain waterproof field book sold at the CSU bookstore or Hixon Mfg. & Supply (not the Elan water resistant books).

Warning: Safety is of upmost importance, including getting to/from the field sites, and in the field. This course will be physically demanding, requiring winter backcountry travel using skis or snowshoes and digging snow pits (up to 2 m deep) at elevations above 3000 m. At these high elevations, the oxygen levels are substantially lower than in Fort Collins and thus activities require more exertion. At this decreased atmosphere, the incoming solar radiation is more, especially in the UV portion of the spectrum, which will increase the potential for sunburn. As well, the snowpack has a high albedo, especially fresh snow, so reflected solar radiation can be at an intensity almost as high as incoming.

Motivation: Snow is an important component of the global water cycle, contributing 50-90% of the annual streamflow in mountainous regions, and is very relevant for the global energy balance. Snow has a very important direct link to tourism: the ski and snowboard industry is currently worth ~$4.5 billion in Colorado economy, and snowmobile tourism is worth ~$1.5 billion. Indirect snowmelt generated streamflow drives whitewater tourism. Finally, snow is a hazard (avalanches, blowing snow, snowmelt flooding) that requires prevention or mitigation. This course provides hand-on experiences in the snow.

Course Objectives: A successful student will

- learn how to measure the snowpack properties,
- understand the nature of snowpack properties, including i) water-based (depth or d_s, snow water equivalent or SWE, density or ρ_s), ii) structure (layer characteristics specifically grain shape and size), iii) energy-based (albedo or α_s, e-folding depth or XX, aerodynamic roughness length or z_0), and iv) melt components (liquid water content or θ_s, soil volumetric water content or VWC)
- understand the scales of spatial and temporal variability in snowpack properties
- learn data protocols, including metadata, archiving, and presentation of results. [Note that most funding agencies, scientific organizations, and journals require the public dissemination of all data collected using government funding and that have been used in publications.]

Meetings and Field Exercises: Note that the instructor reserves the right to postpone or change field dates due to weather. With the exception of the Steamboat Springs trips, we will decide the day before the activity if the field exercise needs to be postponed.

1) Wednesday January 15 – field work near Cameron Pass
    - Initially: discuss course objective, plan, and logistics
    - Goals: i) field site evaluation, ii) sensor installation
    - Tools: Blue Maestro temperature/relative humidity sensors and the Tempo Utility app.
    - Outcomes: i) install temperature/relative humidity sensors, ii) download sensor data for a research project
2) Saturday Feb 01 07:30 – meet in Forestry Parking Lot, field work south of Zimmerman Lake parking lot on CO Hwy 14 near Cameron Pass (may stop at Big South to view spatial difference in layers and SWE)
    - Goals: i) measurement tools and snowpack properties, ii) operational snowpack measurement (SNOTEL), iii) bulk ρ_s variation over space, iv) surface roughness measurement with snow boards in the forest vs. alpine/sastrugi
    - Tools: shovels, Federal Sampler, Snow Hydro sampler, wedge cutter and pit kit, crystal cards, hand lenses, camera, field book and pencil, depth probe, GPS, 1-m long black roughness board, two folding tapes
    - Outcomes: i) layer profiles of interval, grain shape and size range (at ZLM and BS), ii) ρ_s profile, iii) temperature profile, iv) hand hardness and force gauges reading per layer, v) various bulk SWE and ρ_s measurements, vi) summary of ρ_s measurements with location, vii) comparison of surface characteristics plus photographs
    - Citations: Doesken and Judson (1997); Boon et al. (2009); Fassnacht et al. (2009a; 2009b; 2010); Dixon and Boon (2012); López-Moreno et al. (2013); American Avalanche Association (2016); Proksch et al., (2016); Pirazzini et al., (2018); López-Moreno et al. (in review)
3) Friday, Apr 03 19:00 to Apr 06 15:00 – meet in Steamboat Springs on 4/3, return to Fort Collins 4/6; field work at Dry Lake (Routt County Road 38) and Rabbit Ears Pass along Hwy 40 (west side and Dumont or Muddy Pass) * Note that this fieldwork is still being planned and may include a day
    - Goals: i) light penetration into the snowpack (e-folding depth) (4/3 evening @ cabin), ii) spatial variability in temperature (4/4 all day @ Dry Lake), iii) snowmelt lateral flow, snowpack liquid water content (4/5 all day @ Dry Lake), iv) snowmobile compaction of the snowpack (4/6 morning @ west side Rabbit Ears Pass and Dumont or Muddy Pass)
    - Tools: shovels, GPS, Federal Sampler or Snow Hydro sampler, TDR, hand-held meteorological station, camera, field book and pencil, GPR (McGrath/Bonnell), snowpack water content/Denoth meter (McGrath/Bonnell), possibly iButtons/BlueMaestro temperature sensors, lasers and pyranometers, force gauges with variable disk sizes, ram penetrometer (if available)
    - Outcomes: i) spatial temperature variability plot(s), ii) photographs and e-folding depth estimates, iii) snowpack water content, SWE and TDR data, iv) hardness, ram resistance profiles
    - Citations: Libois et al. (2013); Fassnacht et al. (2018a); Webb et al. (2018a; 2018b)
4) Saturday, May 02 07:30 – meet in Forestry Parking Lot, field work around the Joe

Wright snow telemetry (SNOTEL) station

- Goals: i) spatial variability of snow depth, ii) add to an existing decade-long dataset
- Tools: depth probe, pre- and post-survey questionnaires, datasheet, clipboard, elastic band for clipboard, GPS, pencil
- Outcomes: i) measure, record, and digitize data, ii) pre- and post-survey questionnaires, iii) GPS and phone data [phone data will only be recorded if heart rates monitors are used]
- Citations: López-Moreno et al. (2011); Meromy et al. (2013); Fassnacht et al. (2017; 2018b)

Grading: Field participation is expected. Grades are based a simple presentation or analysis of the collected field data. Submissions will include data, metadata, and relevant graphs. Methods and write-ups are not required. For each field exercise, one assignment will be submitted per group of 2-4 students, except the reflection and the spatial snow depth, which will be an individual submission.

1) Reflection – at the end of the semester, each student will write a brief reflection of the course – due May 8
2) Tools and Properties – due February 1
3) Density Variation and Snow Surface Roughness – due March 1
4) a. Temperature Variability, b. E-Folding Depth, c. Snowpack Water Content and Soil Moisture, d. Snowmobile Impacts on Snowpack Hardness – due April 15
5) Spatial Snow Survey – due May 08

References:

American Avalanche Association, 2016. *Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States* (3rd.). The American Avalanche Association, Pagosa Springs, Colorado, 136pp. Available online at <https://www.americanavalancheassociation.org/swag/>.

Dixon, D., and S. Boon, 2012. Comparison of the SnowHydro snow sampler with existing snow tube designs. *Hydrological Processes*, 26, 2555-2562, [doi: 10.1002/hyp.9317].

Doesken, N.J., and A. Judson, 1997. *The Snow Booklet: A guide to the science, climatology, and measurements of snow in the US*. Colorado Climate Center, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, 87 pp. Available online at <http://climate.colostate.edu/pdfs/snowbook.pdf>.

Fassnacht, S.R., J.D. Stednick, J.S. Deems, and M.V. Corrao, 2009a. Metrics for assessing snow surface roughness from digital imagery. *Water Resources Research*, 45, W00D31, [doi:10.1029/2008WR006986].

Fassnacht, S.R., M.W. Williams, and M.V. Corrao, 2009b. Changes in the surface roughness of snow from millimetre to metre scales. *Ecological Complexity*, 6(3), 221-229 [doi:10.1016/j.ecocom.2009.05.003].

Fassnacht, S.R., C.M. Heun, J.I. López-Moreno, and J.B.P. Latron, 2010. Variability of Snow Density Measurements in the Rio Esera Valley, Pyrenees Mountains, Spain. *Cuadernos de Investigación Geográfica (Journal of Geographical Research)*, 36(1), 59-72.

Fassnacht, S.R., D. Wyss, and S.M. Heering, 2017. Räumliches Denken – ein Beispiel im Schnee / A Spatial Thinking Research-Didactic Example in Snow. Geoöko, 37(3-4), 231-247.

Fassnacht, S.R., J.T. Heath, N.B.H. Venable, and K.J. Elder, 2018a. Snowmobile Impacts on Snowpack Physical and Mechanical Properties. *The Cryosphere*, 12, 1121-1135, [doi:10.5194/tc-12-1121-2018].

Fassnacht, S.R., K.S. Brown, E.J. Blumberg, J.I. López Moreno, T.P. Covino, M. Kappas, Y. Huang, V. Leone, and A.H. Kashipazha, 2018b. Distribution of Snow Depths Variability. *Frontiers of Earth Science*, 12(4), 683-692, [doi: 10.1007/s11707-018-0714-z].

Kinar, N.J., and J.W. Pomeroy, 2015. Measurement of the physical properties of the snowpack. *Review in Geophysics*, 53, 481-544, [doi: 10.1002/2015RG000481].

Libois, Q., G. Picard, J.L. France, L. Arnaud, M. Dumont, C.M. Carmagnola, and M.D. King, 2013. Influence of grain shape on light penetration in snow. The Cryosphere, 7, 1803-1818, [doi: 10.5194/tc-7-1803-2013].

López-Moreno, J.I., S.R. Fassnacht, S. Beguería, and J.B.P. Latron, 2011. Variability of snow depth at the plot scale: implications for mean depth estimation and sampling strategies. *The Cryosphere*, 5, 617-629, [doi:10.5194/tc-5-617-2011].

López-Moreno, J.I., S.R. Fassnacht, J.T. Heath, K. Musselman, J. Revuelto, J. Latron, E. Morán, and T. Jonas, 2013. Spatial variability of snow density over complex alpine terrain: implications for estimating snow water equivalent. *Advances in Water Resources*, 55, 40-52, [doi, 10.1016/j.advwatres.2012.08.010].

López-Moreno, J.I., L. Leppänen, B. Luks, L. Holko, G. Picard, A. Sanmiguel-Vallelado, E. Alonso-González, D.C. Finger, A. Nadir-Arslan, K. Gillemot, A. Sensoy, A. Sorman, M. Cansaran Ertaş, C. Fierz, S.R. Fassnacht, and C. Marty, *in review*. Comparison of manual measurements of snow density and water equivalent of the snow cover: instrumental bias and variability induced by observers. Submitted to *Water Resources Research*.

Meromy, L., N.P. Molotch, T.E. Link, S.R. Fassnacht, and R. Rice, 2013. Subgrid variability of snow water equivalent at operational snow stations in the western United States. *Hydrological Processes*, 27(17), 2383-2400, [doi, 10.1002/hyp.9355].

Pirazzini, R., L. Leppänen, G. Picard, J.I. Lopez-Moreno, C. Marty, G. Macelloni, G. Kontu, A. von Lerber, C. Melih-Tanis, M. Schneebeli, P. de Rosnay, and A. Nadir-Arslan, 2018. European in-situ snow measurements: Practices and purposes. *Sensors*, 18 (7), 2016, [doi: 10.3390/s18072016].

Proksch, M., N. Rutter, C. Fierz, and M. Schneebeli, 2016. Intercomparison of snow density measurements: bias, precision, and vertical resolution. *The Cryosphere*, 10, 371-384, [doi: 10.5194/tc-10-371-2016].

Library & Research Help

The CSU Libraries Help Desk provides research and technical assistance either in person at Morgan Library or by phone at 970-491-1841. Jocelyn Boice is the librarian supporting this course. Contact her by email at jocelyn.boice@colostate.edu or by phone at 970-491-3882 to ask questions or set up an appointment for in-depth research help.

Referencing

It is crucial to provide all the necessary information and it is important to be consistent with formatting of references. Various disciplines use difference styles, such as MLA. Journals in the same discipline use different formatting, and even journals from the same publisher can use different styles. It is recommended that the student go to the "author guide" for a particular journal (from one of the papers they retrieve) and adopt that referencing format for this course. For example, the following is taken from the *American Geophysical Union* (AGU) (accessed 2017-09-27): < https://publications.agu.org/brief-guide-agu-style-grammar/#reference>

AGU follows APA reference style as found in the Publication Manual of the APA, Sixth Edition. Please note that all sources cited in text, tables, and figures must appear in the reference list, and all entries in the reference list must be cited in text. Responsibility for the accuracy of bibliographic citations lies entirely with the authors.

Text citations. In-text should be cited using author surname(s) and the date of publication: "in earlier studies (Johnson and Smith, 2009)" or "…as given by Johnson and Smith (2008)" or "In 2012, Johnson and Smith's study showed that…."

Journal abbreviations source

Journal names should be abbreviated according to the List of Title Word Abbreviations: http://www.issn.org/2-22661-LTWA-online.php.

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