

Keith N. Musselman, Ph.D.

CONTACT INFORMATION

Email: keith.musselman atcolorado.edu
Web: www.keithmusselman.com

EDUCATION

University of California Los Angeles Los Angeles, California

Doctor of Philosophy in Civil Engineering 2012

Minor in Atmospheric Sciences

- Emphasis in Hydrology & Water Resources
- Dissertation: “Estimating the Spatial and Temporal Distribution of Snow in Mountainous Terrain”

University of Arizona Tucson, Arizona

Master of Science in Hydrology 2006

- Emphasis in Surface Hydrology
- Thesis: “Quantifying the effects of forest vegetation on snow accumulation, ablation, and potential meltwater inputs, Valles Caldera National Preserve, NM.”

University of Vermont Burlington, Vermont

Bachelor of Science in Geology 2003

- Emphasis in Surface Hydrology
- Senior research project: “Analysis of spatial variability of precipitation and snow accumulation on Mount Mansfield, Stowe, VT.”

PROFESSIONAL EXPERIENCE.

Institute of Arctic and Alpine Research, Boulder, Colorado
University of Colorado Boulder

Research Associate

October 2017 – Present

40 Hours/Week

- Lead Principle Investigator on \$3M collaborative project with NCAR and USGS scientists (Alaska; Denver offices) to the National Science Foundation Navigating the New Arctic program to strengthen understanding of terrestrial hydrologic change in the Arctic and the potential impacts on rivers, fisheries, and Indigenous communities.
- Supervise and mentor three graduate students. Analyze the agricultural water supply-demand imbalance during the unprecedented California drought using NASA satellite data, snow models, and Airborne Snow Observatory measurements. Assess the hydrologic conditions that lead to the 2017 Oroville Dam disaster. Oversee real-time production of operational snowpack reports to California DWR and stakeholders.
- Published high impact paper in *Nature Climate Change* on future rain-on-snow flood risk. Interviews carried by 11 news outlets, 250+ Tweets, and three blogs.

National Center for Atmospheric Research
Advanced Study Program Postdoctoral Fellow
October 2015 – October 2017
40 Hours/Week

Boulder, Colorado

- Independently pursued research that collaboratively leveraged NCAR's climate modeling capacity and multidisciplinary hydrologic team expertise. Analyzed results and first-authored a high-impact paper in *Nature Climate Change* that altered conventional thought of how snow water resources may respond to climate change.
- Advanced the capability of hydrologic models to simulate dominant cold region processes in Alaska. As a member of a collaborative team, built propensity for research techniques using a model for multiple working hypotheses to achieve the Mission's goal of advancing cold region hydrological model accuracy and capacity.

University of Saskatchewan
Postdoctoral Fellow
October 2012 – October 2015
40 Hours/Week

Kananaskis, Alberta

- Developed new parsimonious model capacity of snow and forest hydrology to evaluate cold region process sensitivity to changes in land cover and climate. Creative use of technology (computational fluid dynamics, ray tracing) in solutions of challenging problems related to fine-scale numerical modeling of Earth System processes.
- Designed and supervised a large field campaign to evaluate how forest vegetation structure and disturbances influence water and energy availability. Mentored and developed graduate students, student interns, and supervised two technicians.

University of California Los Angeles
NASA Earth System Science Graduate Fellow
September 2008 – September 2012

Los Angeles, California

- Developed a proposal that garnered full financial support to conduct independent research using field measurements and numerical modeling to analyze snow accumulation and melt dynamics in a forested and alpine region of the Sierra Nevada.
- Designed and supervised ten basin-scale snow surveys with five or more researchers including undergraduate and graduate students in the remote Sierra Nevada, California.
- Build future capabilities leveraging state-of-the-art lidar technology to estimate high-resolution solar radiation beneath a forest canopy in Sequoia National Park with a novel approach that remains an example of technical excellence.

CLASSROOM
TEACHING
EXPERIENCE

University of Colorado Boulder
Lecturer
January 2019 – May 2019

Boulder, Colorado

- Lecture three days per week a class of 160 undergraduates in the Geography course *Environmental Systems: Landscapes and Water*; plan field excursions, design lectures, homework, and exams. Supervise three teaching assistants who hold weekly labs.

University of California Los Angeles

Los Angeles, California

Teaching Assistant (TA)

September, 2009 – December, 2009

Lead weekly discussion sessions, designed homework, and held open office hours for class of 100+ students in CEE 150 “Introduction to Hydrology”. Professor: Steve Margulis.

WORKSHOPS &

FIELD COURSES

TAUGHT

- NSF-funded workshop LiDAR Applications in Critical Zone Sciences (2014)
- TA for *Advanced Field Methods in Snow Science*, Prof. Noah Molotch(2011)
- TA for *Snow Hydrology and Field Camp*, Prof. Paul Brooks (2006)

FUNDING

- (Awarded) **NSF, Navigating the New Arctic** 2020-2024
“Climate sensitivity of Alaskan rivers, fish and communities: Developing storylines of Arctic transformation” (role: **PI, \$3M**)
- (Awarded) **NOAA, Climate Program Office** 2019-2021
“Assessing the predictability and probability of 21st century rain-on-snow flood risk for the conterminous U.S.” (role: **PI, \$200K**)
- (Awarded) **NASA, GEO, supplemental funding** 2019
“Optimizing the Indus Basin Irrigation System and reservoir operations using remotely sensed snow surface properties in the ParBal model” (role: **co-I, \$20K**)
- (Awarded) **National Science Foundation, Hydrologic Sciences** 2018-2020
“Extending the vadose zone: characterizing the role of snow for liquid water storage and transmission in streamflow generation” (role: **co-I, \$142K**)
- (Awarded) **University of Colorado Outreach Award** 2019-2020
“Past, Present, Future: Exploring Boulder’s Natural Environment” (role: **co-I, \$24K**)
- (Pending) **Department of Energy, Subsurface BioGeoChem Research** 2019-2022
“Consequences of winter perturbations on hydro-biogeochemical connectivity in contrasting ecosystems” (role: **co-I, \$60K**)
- (Past Award) **NCAR Advanced Study Program Fellowship** 2015-2017
“Slower snowmelt in a warmer world” (**\$136K**)
- (Past Award) **NASA Earth and Space Science Fellowship Program** 2008-2012
“Remote Sensing and Ground Data Assimilation Using A Basin-Scale Snow Water Equivalent Reconstruction Method” (**\$90K**)

STUDENT

MENTORSHIP

Ph.D. Committee Member

Kehan Yang, University of Colorado, Boulder

Hamideh Safa, University of Nevada, Reno

AWARDS

RECEIVED

Best Presentation

Western Snow Conference Annual Meeting, Reno, NV 2019

- Reconsidering the utility of the April 1st Snow Water Equivalent Metric for Water Resource Applications

Best Student Poster Presentation

Eastern Snow Conference Annual Meeting, Montreal, Quebec 2010

- The use of hemispherical photos to estimate radiation beneath a forest canopy improve results from a physically based snow model

Graduate College Fellowship Award

University of Arizona 2005 and 2006

- Merit-based (GPA) cash award through Dean's office of the College of Engineering to recruit and retain top graduate students

David Hawley Undergraduate Research Scholarship

University of Vermont 2003

- Financial support for an independent research project studying the spatial variability of precipitation on a paired watershed.

REFEREED PUBLICATIONS

In Review

Henn, B., **K.N. Musselman**, L. Lestak, F.M. Ralph, and N.P. Molotch, Extreme runoff generation from atmospheric river driven snowmelt during the 2017 Oroville Dam spillways incident. *In Review* at Geophysical Research Letters.

Rasmussen, R., K. Ikeda, C. Liu, F. Chen, M. Barlage, A.J. Newman, E. Gutmann, J. Dudhia, D. Gochis, A. Dai, C. Luce and **K.N. Musselman**, Projected Future Changes in Snowfall and Snowpack in the Western U.S. as Captured by a Convection Resolving Climate Simulation: Mesoscale and Microphysical Factors. *In Review* at Journal of Climate.

Uecher, T.M., S.D. Kaspari, S.M. Skiles, and **K.N. Musselman**, The post-wildfire impact of burn severity and age on black carbon snow deposition and implications for snow water resources, Cascade Range, Washington, USA. *In Review* at Journal of Hydrometeorology.

Mendoza, P.A., **K.N. Musselman**, J.S. Deems, J.R. Revuelto, I. Lopez-Moreno, and J. McPhee, Seasonal and annual variability of snow depth fractal behavior in a sub-alpine catchment. *In Review* at Water Resources Research.

Published

[20] **Musselman, K.N.**, F. Lehner, K. Ikeda, M.P. Clark, A.F. Prein, C. Liu, M. Barlage and R. Rasmussen (2018), Projected increases and shifts in rain-on-snow flood risk over western North America. *Nature Climate Change*, 8, 808-812.

[19] Isabelle, P.E., D.F. Nadeau, M.H. Asselin, R. Harvey, **K.N. Musselman**, A.N. Rousseau, F. Anctil (2018), Solar radiation transmittance of a boreal balsam fir canopy: Spatiotemporal variability and impacts on growing season hydrology, *Agricultural and Forest Meteorology*, 263, 1-14.

- [18] **Musselman, K.N.**, M. P. Clark, C. Liu, K. Ikeda and R. Rasmussen (2017), Slower snowmelt in a warmer world. *Nature Climate Change*, 7(3), 214-219.
- [17] **Musselman, K.N.**, N.P. Molotch, and S.A. Margulis, Snowmelt response to simulated warming across a large elevation gradient, southern Sierra Nevada, California. (2017) *The Cryosphere*, 11(6) 2847-2866.
- [16] López-Moreno, I., S. Gascoïn, J. Herrero, E. Spoles, M. Pons, E. Alonso, J. Sickman, **K.N. Musselman**, A. Boudhar, L. Hanich, N. Molotch, J. Pomeroy (2017), Different sensitivities of snowpack to warming in Mediterranean climate mountain areas. *Environmental Research Letters*, 12(7), p.074006.
- [15] **Musselman, K.N.** and J.W. Pomeroy (2017), Estimation of needleleaf canopy and trunk temperatures and longwave contribution to melting snow. *Journal of Hydrometeorology*. 18, 555-572, DOI: 10.1175/JHM-D-16-0111.1.
- [14] **Musselman, K.N.**, J.W. Pomeroy, R. Essery, and N. Leroux (2015), Impact of windflow calculations on simulations of alpine snow accumulation, redistribution and ablation. *Hydrological Processes*, 29(18) 3983-3999.
- [13] **Musselman, K.N.**, J.W. Pomeroy, and T.E. Link (2015), Variability in shortwave irradiance caused by forest gaps: Measurements, modelling, and implications for snow energetics. *Agricultural and Forest Meteorology*, 207, 69:82.
- [12] Harpold, A.A., J.A. Marshall, S.W. Lyon, T.B. Barnhart, B. Fisher, M. Donovan, K.M. Brubaker, C.J. Crosby, N.F. Glenn, C.L. Glennie, P.B. Kirchner, N. Lam, K.D. Mankoff, J.L. McCreight, N.P. Molotch, **K.N. Musselman**, J. Pelletier, T. Russo, H. Sangireddy, Y. Sjöberg, T. Swetnam, N. West (2015), Laser Vision: LiDAR as a Transformative Tool to Advance Critical Zone Science. *Hydrology and Earth System Sciences*.
- [11] Meromy, L., N.P. Molotch, M. Williams, **K.N. Musselman**, L. Kueppers (2015), Snowpack-climate manipulation using infrared heaters in subalpine forests of the Southern Rocky Mountains, USA. *Agricultural and Forest Meteorology*, 203, 142- 157.
- [10] Harpold, A.A., N.P. Molotch, **K.N. Musselman**, R.C. Bales, P.B. Kirchner, M. Litvak, and P.D. Brooks (2014), Snowmelt infiltration in mixed conifer subalpine forests. *Hydrological Processes*, doi: 10.1002/hyp.10400
- [9] Harpold, A.A., Q.Guo., N. Molotch, P.D. Brooks, R. Bales, J.C. Fernandez- Diaz, **K.N. Musselman**, T.L Swetnam, P. Kirchner, M. Meadows, J. Flanagan, and R. Lucas (2014), LiDAR-derived snowpack datasets from mixed conifer forests across the Western U.S., *Water Resources Research*. 50, doi:10.1002/2013WR013935.
- [8] **Musselman, K.N.**, S.A. Margulis, and N.P. Molotch (2013), Estimation of solar direct beam transmittance of conifer canopies from airborne LiDAR. *Remote Sensing of Environment*. 136, 402-415.

- [7] Perrot, D.O., N.P. Molotch, **K.N. Musselman**, and E.T. Pugh (2013), Modeling the effects of the Mountain Pine Beetle on snowmelt rates in a subalpine forest. *Ecohydrology*. DOI: 10.1002/eco.1329
- [6] Huang, C., S.A. Margulis, M.T. Durand, and **K.N. Musselman** (2012), Assessment of snow grain-size model and stratigraphy representation impacts on snow radiance assimilation: Forward Modeling Evaluation, *IEEE Transactions on Geoscience and Remote Sensing*. 50 (11) 4551 – 4564. ISSN 0196-2892.
- [5] López-Moreno, J.I., S.R. Fassnacht, J.T. Heath, **K.N. Musselman**, J. Revuelto, J. Latron, E. Morán-Tejeda, T. Jonas (2012), Small scale spatial variability of snow density and depth over complex alpine terrain: Implications for estimating snow water equivalent, *Advances in Water Resources*, ISSN0309-1708, doi:10.1016/j.advwatres.2012.08.010.
- [4] **Musselman, K.N.**, N.P. Molotch, S.A. Margulis, M. Lehning, and D. Gustafsson (2012), Improved snowmelt simulations with a canopy model forced with photo-derived direct beam canopy transmissivity, *Water Resour. Res.*, 48, W10509, doi:10.1029/2012WR012285
- [3] **Musselman, K.N.**, N.P. Molotch, S.A. Margulis, P.B. Kirchner, and R.C. Bales (2012), Influence of canopy structure and direct beam solar irradiance on snowmelt rates in a mixed conifer forest. *Agricultural and Forest Meteorology*, 161, 46 – 56, doi: 10.1016/j.agrformet.2012.03.011.
- [2] Molotch, N.P., P.D. Brooks, S.P. Burns, M. Litvak, R.K. Monson, J.R. McConnell, and **K.N. Musselman** (2009), Ecohydrological controls on snowmelt partitioning in mixed-conifer sub-alpine forests, *Ecohydrology*, 2, 129– 142, doi:10.1002/eco.48.
- [1] **Musselman, K.N.**, N.P. Molotch, and P.D. Brooks, (2008), Effects of vegetation on snow accumulation and ablation in a mid-latitude sub-alpine forest, *Hydrological Processes*, Vol 22, doi: 10.1002/hyp.7050.

CONFERENCE
PROCEEDINGS
(LAST 3 YEARS)

Musselman, K.N., N. Addor, J. Vano, and N. Molotch, (2019) Reconsidering the utility of the April 1st snow water equivalent metric for water resource applications. Oral presentation at the Western Snow Conference, Reno, NV.

Yang, K., **K.N. Musselman**, K. Rittger, N.P. Molotch (2019), Bias correction of SWE estimates with the NASA Airborne Snow Observatory SWE data. Oral presentation at the Western Snow Conference, Reno,

Musselman, K.N., B. Henn, F.M. Ralph, L. Lestak, and N.P. Molotch (2018), The role of atmospheric river precipitation intensity, rain-snow height levels and antecedent snowpack in the 2017 Oroville Dam crisis. Oral presentation at the American Geophysical Union Fall Meeting, Washington, DC.

Yang, K., **K.N. Musselman**, D. Schneider, T.H. Painter, S.A. Margulis, K. Rittger, N. Bair, N.P. Molotch (2018), An inter-comparison of five snow

water equivalent estimation methods in the Sierra Nevada Mountains, California. Poster presentation at the American Geophysical Union Fall Meeting, Washington, DC.

Musselman, K.N., B. Henn, F.M. Ralph, L. Lestak, and N.P. Molotch (2018), The role of atmospheric river rain-snow levels and antecedent snowpack in the 2017 Oroville Dam crisis. Oral presentation at the American Meteorological Society Mountain Meteorology Conference, Santa Fe, NM.

Musselman, K.N., N. Addor, J. Vano, J. Berggren, and N. Molotch, (2018) Reconsidering the utility of the April 1st snow water equivalent metric. Oral presentation at the Eastern Snow Conference, College Park, MD.

Mendoza, P.A., **K.N. Musselman**, I. López-Moreno, R. Essery, N.P. Molotch, and J. McPhee, (2018), The effects of geospatial decisions on the accuracy of a distributed blowing snow model, Oral presentation at the European Geophysical Union General Assembly, Vienna, Austria.

Musselman, K.N., F. Lehner, K. Ikeda, M.P. Clark, A. Prein, C. Liu, M. Barlage and R. Rasmussen (2018), Projected increases and shifts in rain-on-snow flood risk over western North America. Oral presentation at the Western Snow Conference, Albuquerque, NM.

Henn, B., **K.N. Musselman**, F.M. Ralph, L. Lestak, and N.P. Molotch (2018), The role of atmospheric river rain-snow levels and antecedent snowpack in the 2017 Oroville Dam crisis. Oral presentation at the Western Snow Conference, Albuquerque, NM.

Musselman, K.N., M.P. Clark, B. Nijssen and J. Arnold (2017), Challenges in land model representation of heat transfer in snow and frozen soils. Oral presentation at the American Geophysical Union Fall Meeting, New Orleans, LA.

Musselman, K.N., F. Lehner, K. Ikeda, M.P. Clark, A. Prein, C. Liu, M. Barlage and R. Rasmussen (2018), Large projected increases in rain-on-snow flood potential over western North America. Oral presentation at the American Geophysical Union Fall Meeting, New Orleans, LA. Invited.

Musselman, K.N., F. Lehner, K. Ikeda, M.P. Clark, A. Prein, C. Liu, M. Barlage and R. Rasmussen (2017), Projected increases in rain-on-snow flood potential over western North America. Annual Meeting of the Rocky Mountain Hydrologic Research Center, Boulder, Colorado.

Musselman, K.N., M.P. Clark, Changhai Liu, Kyoko Ikeda, and R. Rasmussen (2017), Slower snowmelt in a warmer world. Oral presentation at the European Geophysical Union General Assembly, Vienna, Austria.

Musselman, K.N., M.P. Clark, A. Endalamaw, W.R. Bolton, B. Nijssen and J. Arnold (2017), Assessing the effects of modeling decisions on cold region hydrologic model performance. Interactive Poster presentation at the European Geophysical Union General Assembly, Vienna, Austria.

- NASA Terrestrial Hydrology
- NASA Applied Sciences Program

Manuscript Reviewer:

- Advances in Water Resources
- Agricultural and Forest Meteorology
- Arctic, Antarctic, and Alpine Research
- Earth System Science Data
- Ecohydrology
- Frontiers of Earth Science
- Geophysical Research Letters
- Hydrological Processes
- Hydrology Research
- Journal of Advances in Modeling Earth Systems
- Journal of Applied Meteorology and Climatology
- Journal of Geophysical Research – Atmospheres
- Journal of Hydrology
- Journal of Hydrometeorology
- Remote Sensing of Environment
- Science Advances
- The Cryosphere
- Water Resources Research

Discussion Panelist

- The Future of Skiing: The Science Behind Snow; sponsored by Arapahoe Basin and Protect Our Winters. Arapahoe Basin, CO

Society Member:

- American Geophysical Union
- Canadian Geophysical Union
- European Geophysical Union
- American Meteorological Society
- USGS Rocky Mountain Hydrologic Research Center
- Sigma Gamma Epsilon Earth Sciences Honor Society
- Changing Cold Regions Network

Committee Member:

- Executive Board Member, Western Snow Conference, South Continental Region Leader

FIELDWORK EXPERIENCE

2019	Snowmelt pathway study, Niwot Ridge Long Term Ecological Observatory, Colorado
2017	NASA SnowEx field campaign, Grand Mesa, Colorado
2016	Photogrammetric monitoring of SNOTEL sites snow depth dynamics, Colorado
2013 - 2015	Terrestrial laser survey of 4-D snowpack dynamics, Rocky Mountains, Canada
2012 - 2015	Hydrometeorological impacts of forest clearings, Kananaskis, Alberta, Canada
2011	NASA Goddard grain size measurement campaign, Steamboat Springs, Colorado
2010	NASA JPL vegetation biomass survey, Grand Mesa, Colorado

2010 Basin scale variability of snow properties, Pyrenees, Spain and France
2007 - 2009 Plot and basin scale snow surveys, Sequoia National Park, California
2005 - 2006 Snow-vegetation interactions, Valles Caldera, NM
2002 - 2003 Precipitation gauge deployment and maintenance, Stowe, VT

GUEST

LECTURES

(LAST 6 YEARS) Title: *Snow water resources in a warmer American West*
Rocky Mountain Association of Professional Geologists, Fall 2018
Denver, Colorado

Title: Climate change impacts on snow water resources
Mountain Meteorology, ATOC 4550, Fall 2018
Department of Atmospheric & Oceanic Sciences
University of Colorado, Boulder, CO

Title: *Snow water resources in a warmer American West*
Rocky Mountain Association of Professional Geologists, Fall 2018
Denver, Colorado

Title: *Reanalysis of the Feb. 2017 Oroville Dam Atmospheric River Event: the role of rain-on-snow.*
Earth System Research Laboratory, Spring 2018
NOAA, Physical Sciences Division
Boulder, Colorado

Title: *The science of snow and snow-cover persistence*
Cross Country Ski Area Association, Spring 2018
Snow Mountain Ranch, Granby, Colorado

Title: *Applications in mountain and forest hydrology: Observation, models and advances*
Engineering Hydrology CVEN 4333, Fall 2017
Dept. of Civil, Environmental & Architectural Engineering
University of Colorado, Boulder

Title: *Slower snowmelt in a warmer world: Using observations and modeling to develop a new theory of hydrologic change*
Hydrology & Water Resources Seminar, Winter 2017
Dept. of Civil, Environmental & Architectural Engineering
University of Colorado, Boulder

Title: *Slower snowmelt in a warmer world*
Geology Visiting Lecture Series, Winter 2016
University of Vermont

Title: *LiDAR: a transformative tool for hydrological sciences* Canadian Society for Hydrological Sciences, Short Course Principles of Hydrology, Winter 2015

University of Saskatchewan
Held in the Canadian Rockies, Alberta

Title: *Snow Measurements*
Canadian Society for Hydrological Sciences, Short Course
Principles of Hydrology, Winter 2014
University of Saskatchewan
Held in the Canadian Rockies, Alberta

Title: *Hydrology and Landscape Processes in Kananaskis*
Ecology 413: Field Ecology. Summer 2013
University of Calgary, Alberta, Canada

Title: *Snow and Forest Hydrology*
4th-year Ecology course. Spring 2013
University of Calgary, Alberta, Canada