Water storage studies

Stephanie A. Ewing

Director, Montana Water Center

Land Resources & Environmental Sciences, Montana State University

WPIC presentation

March 26, 2026

Montana Water Center

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www.montanawatercenter.org

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Associate Director
Montana Bureau of Mines & Geology

Water Resource Research Institutes (WRRI)

Section 104 of the Water Resources Research Act of 1984 authorized the **Water Resources Research Act Program**, as a Federal-State partnership that plans, facilitates, and conducts research to aid in the resolution of State and regional water problems.

The Montana Water Center is one of 54 state **Water Resources Research Institutes (WRRI)** funded by the WRRA program, which comprise the **National Institutes for Water Resources (NIWR)**.

NIWR THE NATIONAL INSTITUTES FOR WATER RESOURCES

USGS science for a changing world

Montana American Water Resources Association Annual Meeting 2025

Groundwater – Surface Water Interactions: Implications for Water Management and Water Quality in Montana

Stephanie Ewing
Director, Montana Water Center
Professor, Land Resources & Environmental Sciences
Montana State University

Great Falls, Montana
8-10 October 2025

Judith River Watershed, 2023

Montana Water Center

Turning Science into Solutions

Mission: Resolve Montana's water resource issues through research, collaboration, and education

$147,000
The amount of annual base funding awarded to each water research institute from the United States Geological Survey (U.S. Department of Interior).

94
Water faculty at seven institutions across Montana doing local water research.

54
Water research institutes are receiving annual base funding from the United States Geological Survey (U.S. Department of Interior) in 2026.

1,100
Approximate number of individuals reached in the last three years through trainings, conferences, and education and outreach events supported by the Montana Water Center.

43
Early-career faculty and graduate students at five institutions supported by the Montana Water Center over the last three years.

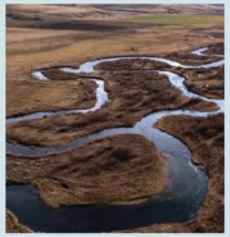
$440,000
Non-federal funds leveraged in the last three years by the Montana Water Center.

Funded Research Projects

Each year the Montana Water Center funds Faculty Seed Grants and Graduate Student Fellowships to faculty and students across the Montana University System.

Over the past three years, $214,000 has been provided in project funding, supporting 13 faculty and 30 graduate and undergraduate students.

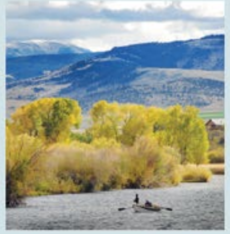
Project Focal Areas



Industry and water quality
5 projects

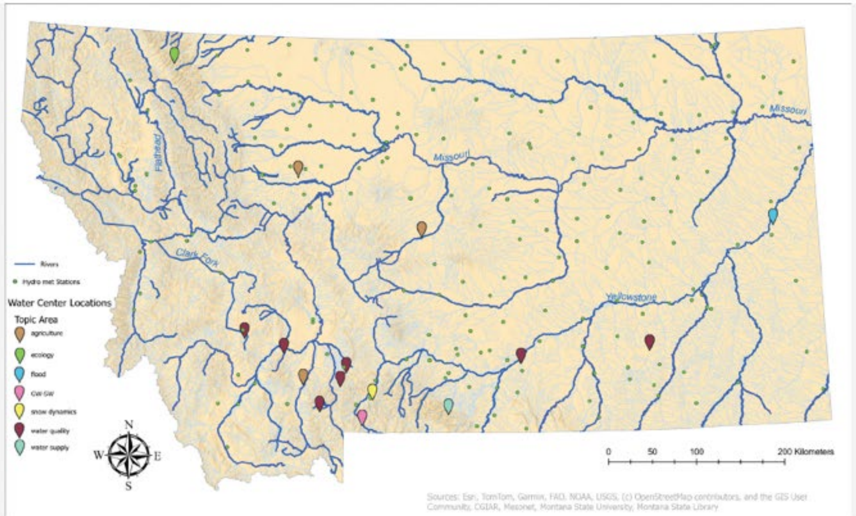
Managing agricultural water
6 projects

Urbanization and human health
3 projects

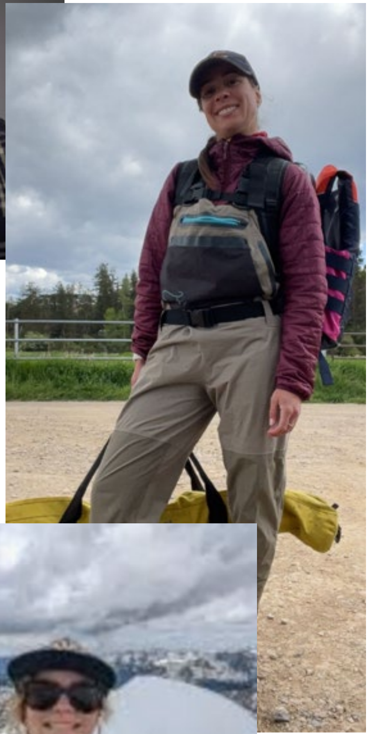


Drought and river health
5 projects

Snapshot of Project Locations



2024-2025 Graduate Student Grantees



Safal Adhikari (Sapkota, MSU) *UAS-derived CWSI and ET for irrigation scheduling in wheat in Montana*

Brooke Bannerman (Ballantyne, UM) *Fire on the mountain: paleolimnological investigation of lake productivity*

Marina Barbosa Santos (Wilcox, UM) *Understanding Hydrologic Connectivity in Gravel-Bed Rivers: Integrating UAV and SWOT Observations to Analyze Connectivity Dynamics*

Bridger Creel (Colman, UM) *A bird's eye view: Using tree swallows (Tachycineta bicolor) to assess the effects of aquatic metal contamination on riparian insectivores in the Upper Clark Fork River Superfund site*

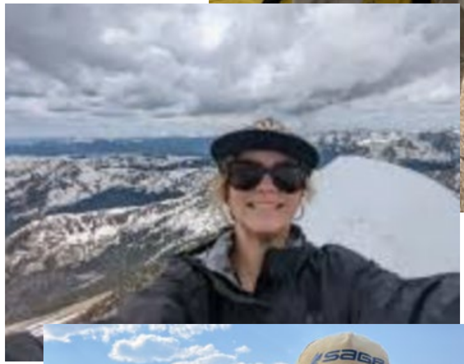
Josie Grigsby (Gammons/Shaw, MTech) *Hydrology and geochemistry of natural acid rock drainage at the headwaters of the South Boulder River, Tobacco Root Mountains, Montana*

Riley Henson (Wilcox, UM) *Quantifying geomorphic resilience in rivers to hydroclimatic extreme events*

Nick Hudson (Cline, MSU) *Evaluating Effects of Flow on Juvenile Trout Production and Survival in Southwest Montana Watersheds*

Megan Robinson (Sigler, MSU) *Assessing water and nitrogen use efficiency in irrigated fields*

Cora Steinbach (Hall, UM) *Green ribbons in a blue-ribbon fishery: predicting nuisance algal blooms using river metabolism*



2024-2025 MWC faculty grants


Nick Hagerty, Sungmin Cheu
MSU, Agricultural Economics

Muchen Sun
Montana Tech
Geological Eng


Andrew Felton & Anna Schweiger
MSU, Land Resources & Env Sci.

John Kimball
U of Montana
Forestry

Payton Gardner
U of Montana
Earth Sci

Kayhan Ostovar
MSU Billings

Hagerty & Cheu: *Economic Modeling of Irrigation Water Demand for Watershed Planning*

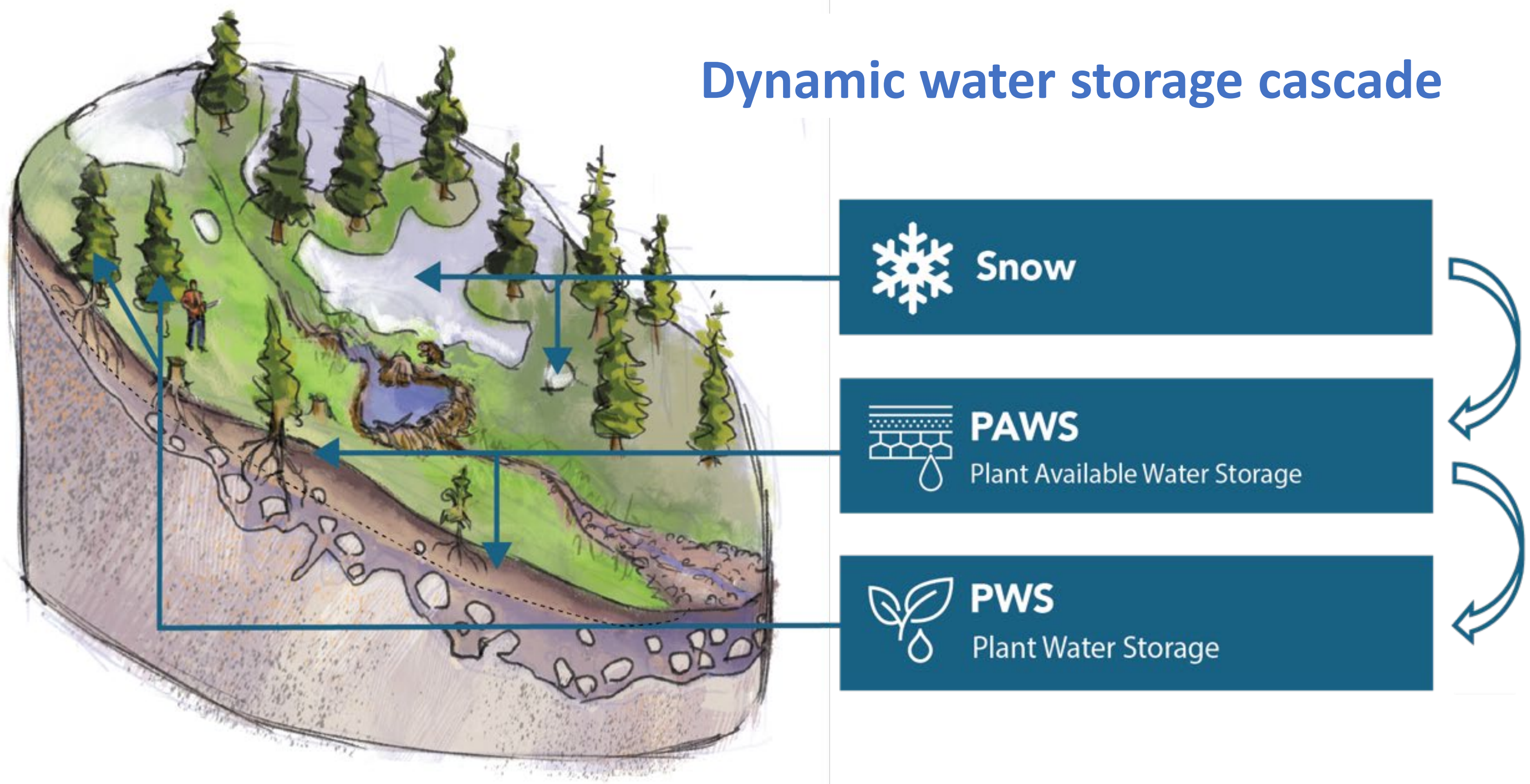
Sun: *Using ambient noise tomography and machine learning techniques to track groundwater*

Felton, Schweiger & Kimball: *From probes to pixels: scaling-up soil water content monitoring*

Gardner: *Environmental tracers of groundwater in the Upper Clark Fork River watershed*

Ostovar: *Freshwater Species of Concern as Bio-Sentinels of PFAS Contamination*

Dynamic water storage: "Goldilocks zone" between short to long water residence times where storages fill and drain at intervals that are coupled to ecohydrological process and function



Modified from original illustration by Eric Parrish; Tague et al., 2025

REVIEW ARTICLE OPEN ACCESS

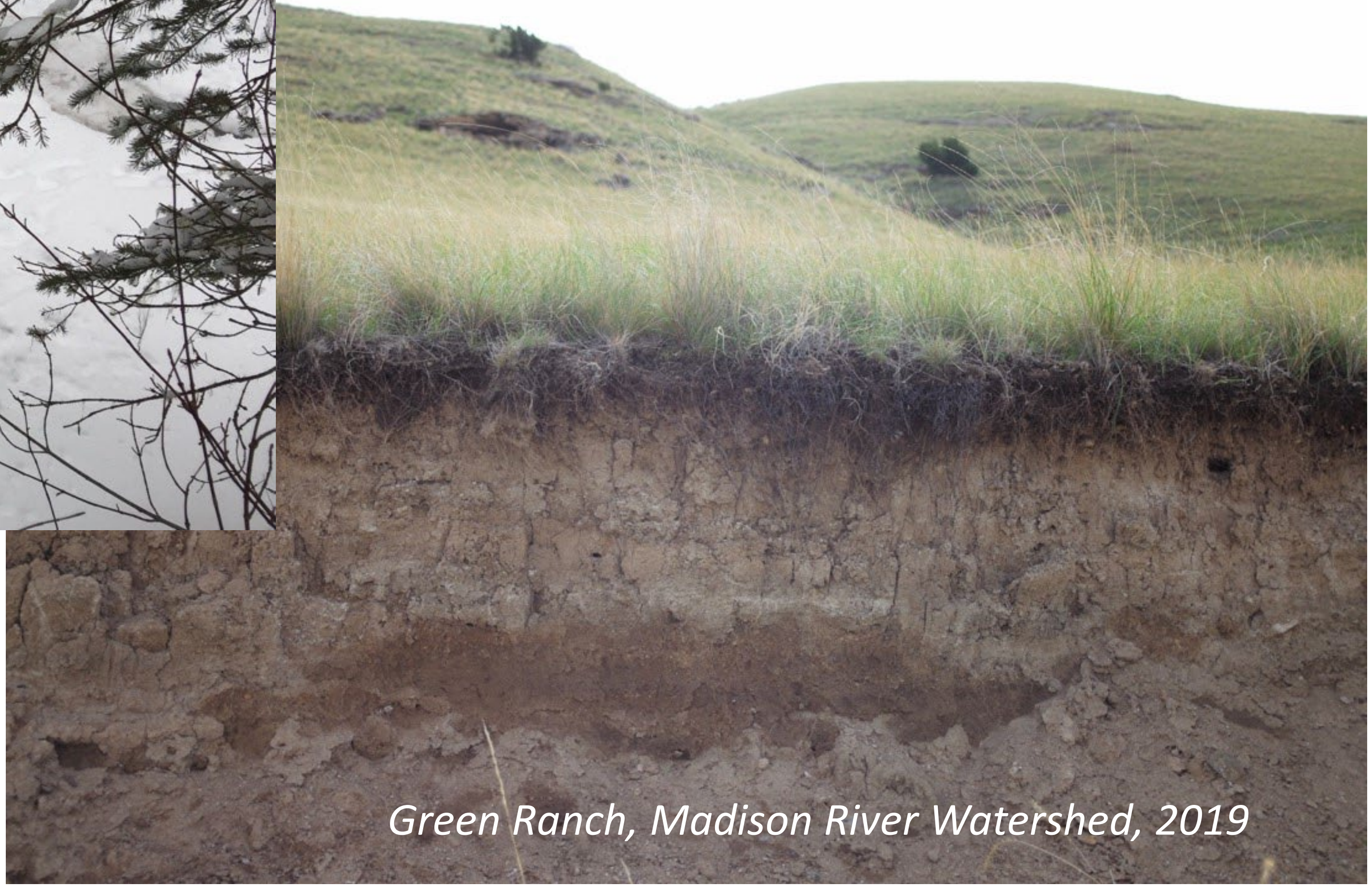
James Buttle Review: Dynamic Water Storage Shapes Critical Zone Function in Snow-Dominated Mountain Watersheds

Christina Tague[1] | Holly R. Barnard[2] | Adrian A. Harpold[3] | Christopher J. Heckman[4] | Keira Johnson[5] | John F. Knowles[6] | Katherine B. Lininger[7] | Lauren E. L. Lowman[4] | Alexis Navarre-Sitchler[8] | Eric Parrish[7] | Kamini Singha[9] | Pamela L. Sullivan[5] | Sara Warix[10]

John Knowles, MSU

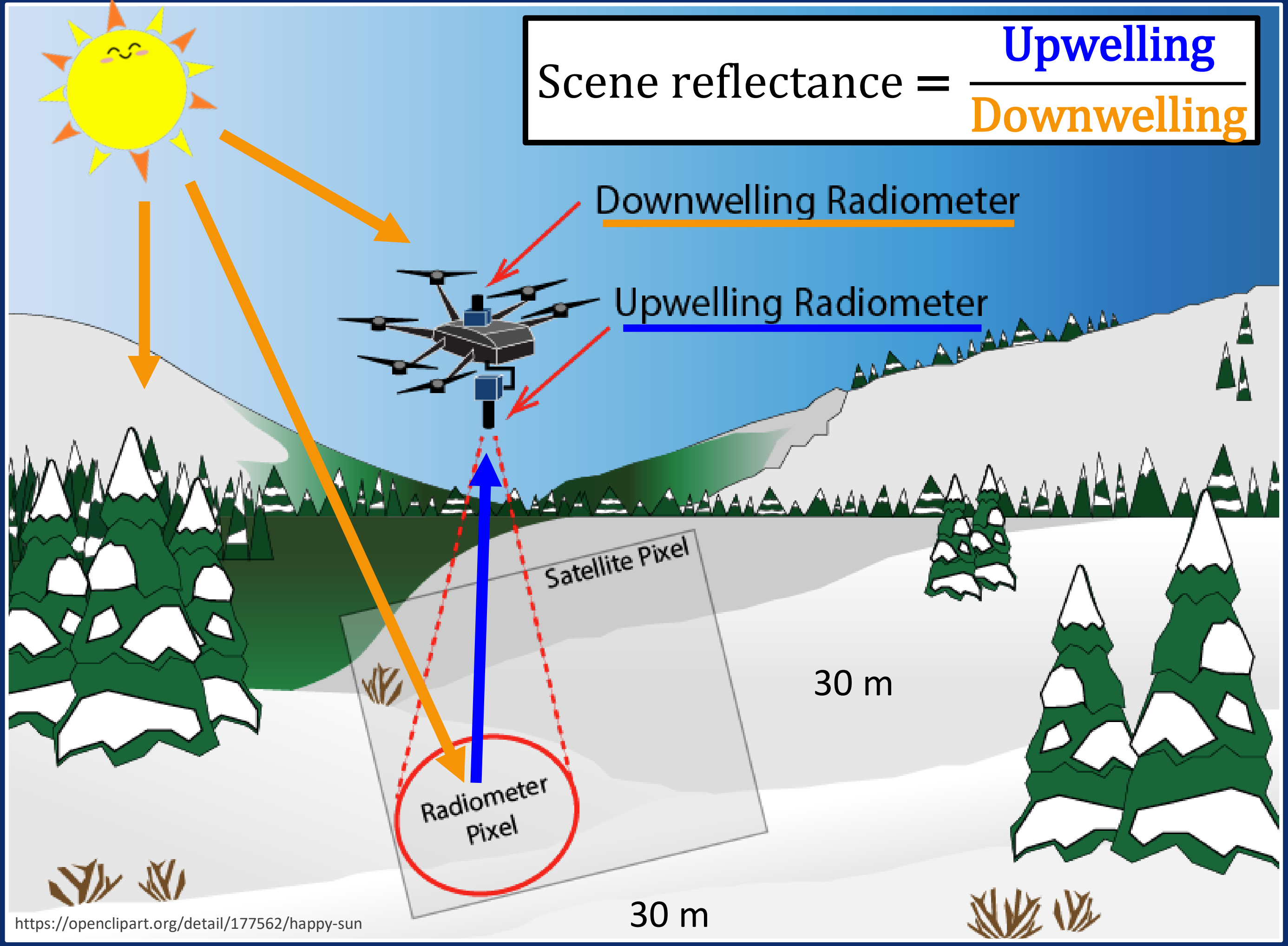
Water storage in snow and soils


upper Sourdough Canyon, 2017

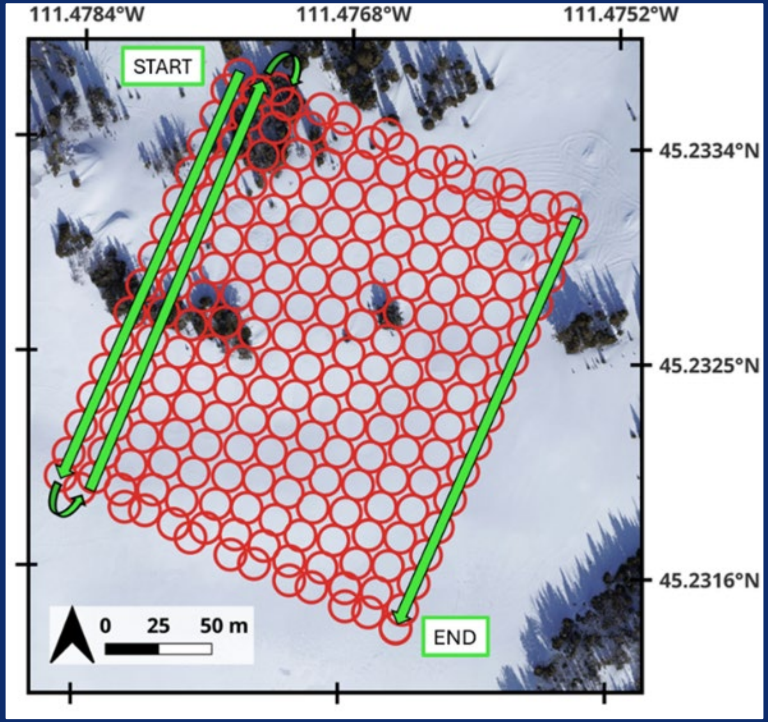

Green Ranch, Madison River Watershed, 2019


UAV-based measures of snow

UAV-Based Radiometer for Validating Satellite Snow Products



Namaste Valley, southwest Montana

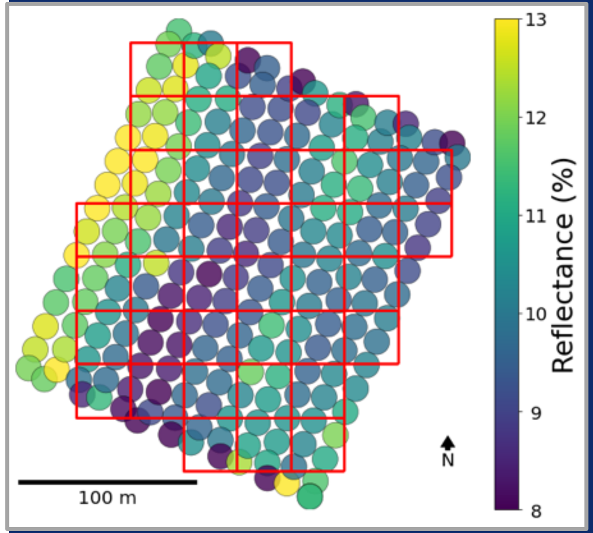


- Custom short-wave infrared radiometer for validating snow products from Landsat 8/9 Band 7 and Sentinel Band 12
- Field campaigns at Namaste Valley in March and April of 2025 in alignment with satellite overpasses

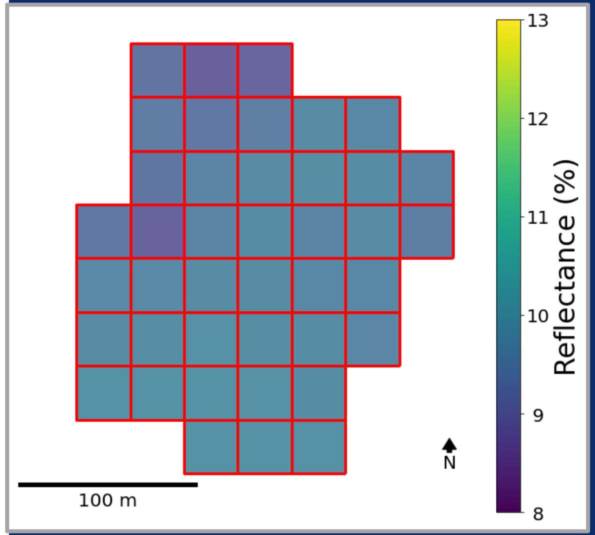
S. M. Hamp, R. D. Logan, E. A. Sproles, J. A. Shaw, "Short-wave infrared radiometer for airborne validation of satellite snow products," J. Appl. Rem. Sens. 20(1): 017501 (January 2026).

UAV-Based Radiometer for Validating Satellite Snow Products

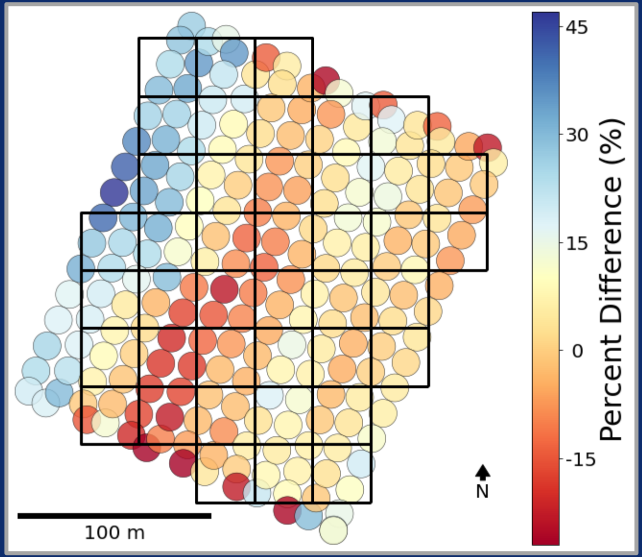
Radiometer Reflectance

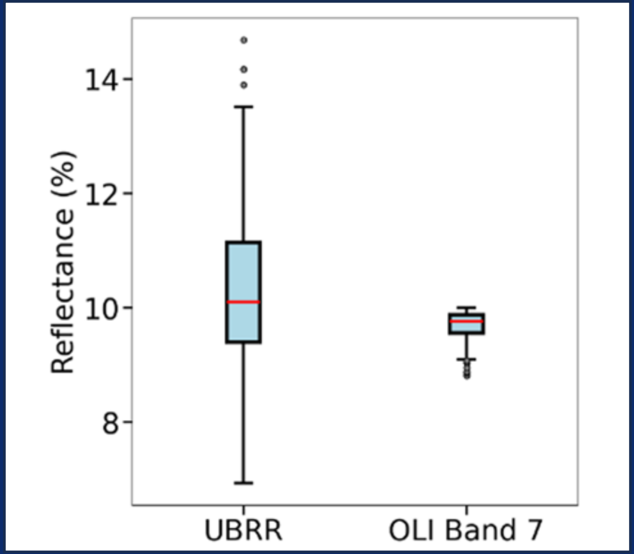


Landsat OLI Band 7 Reflectance

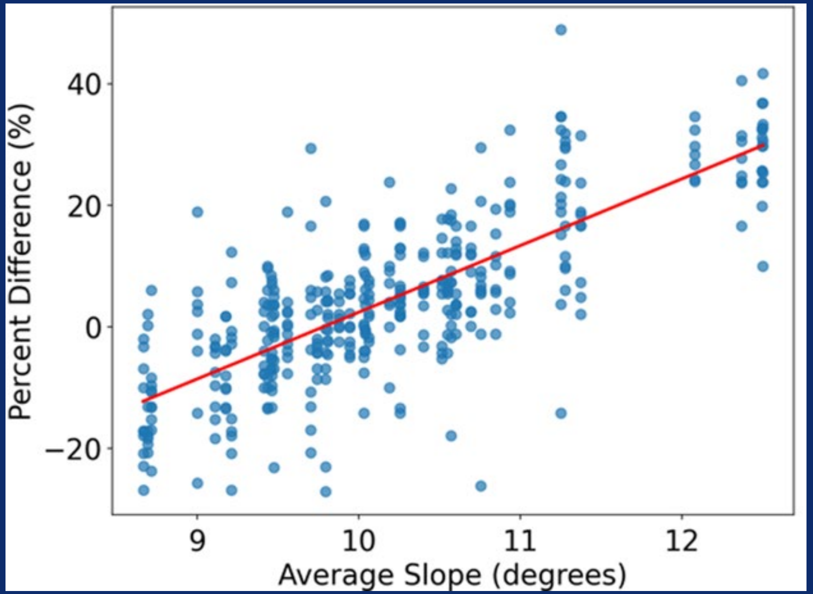


Percent Difference Between Radiometer and Satellite Measurements





Percent Difference Between Radiometer and Satellite Reflectance with Respect to the Average Slope Angle

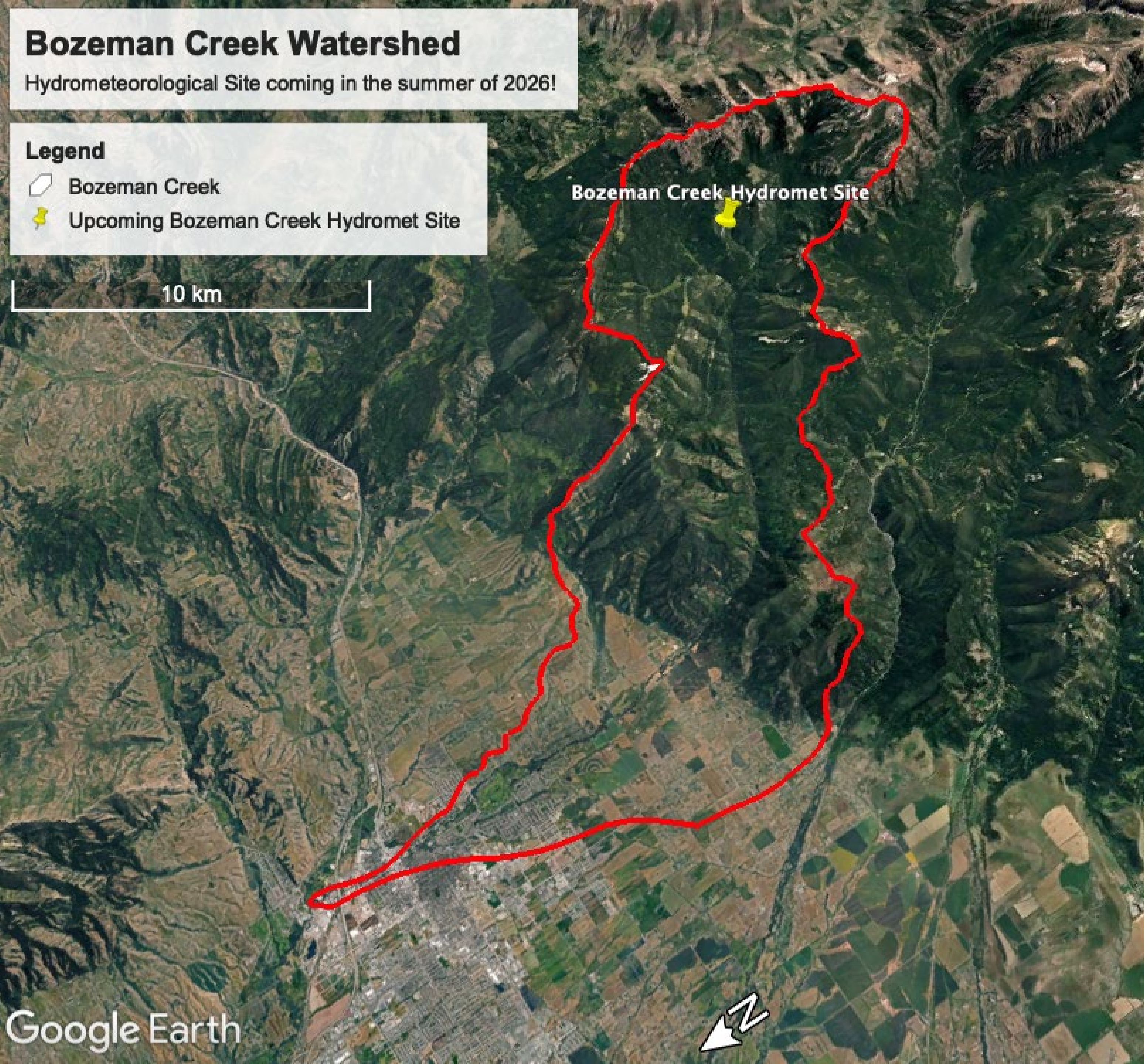


Pearson Correlation Coefficient: 0.9651

P-value < 0.001

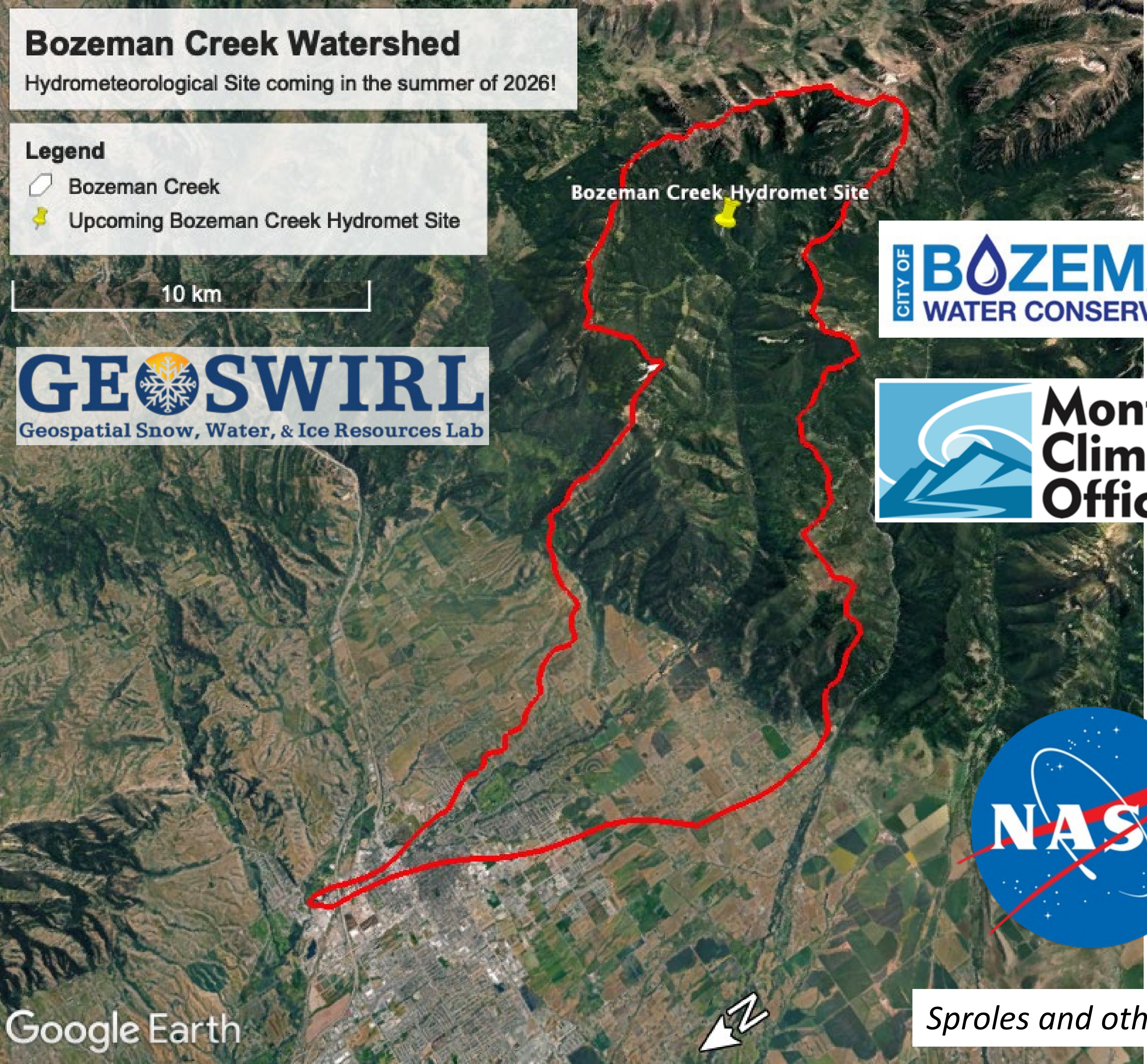
- The difference between UAV- and satellite-based surface reflectance values relate to surface topography

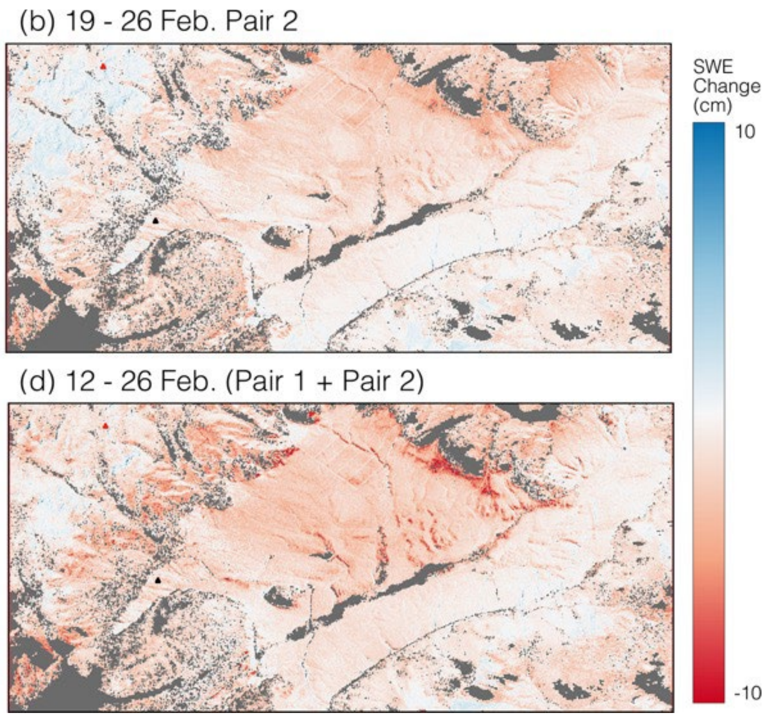
M. Hamp, R. D. Logan, E. A. Sproles, J. A. Shaw, "Short-wave infrared radiometer for airborne validation of satellite snow products," J. Appl. Rem. Sens. 20(1): 017501 (January 2026).



40% of Bozeman's water comes from Bozeman Creek, but there are no measures of snowpack or precipitation within the watershed.

Sproles and others

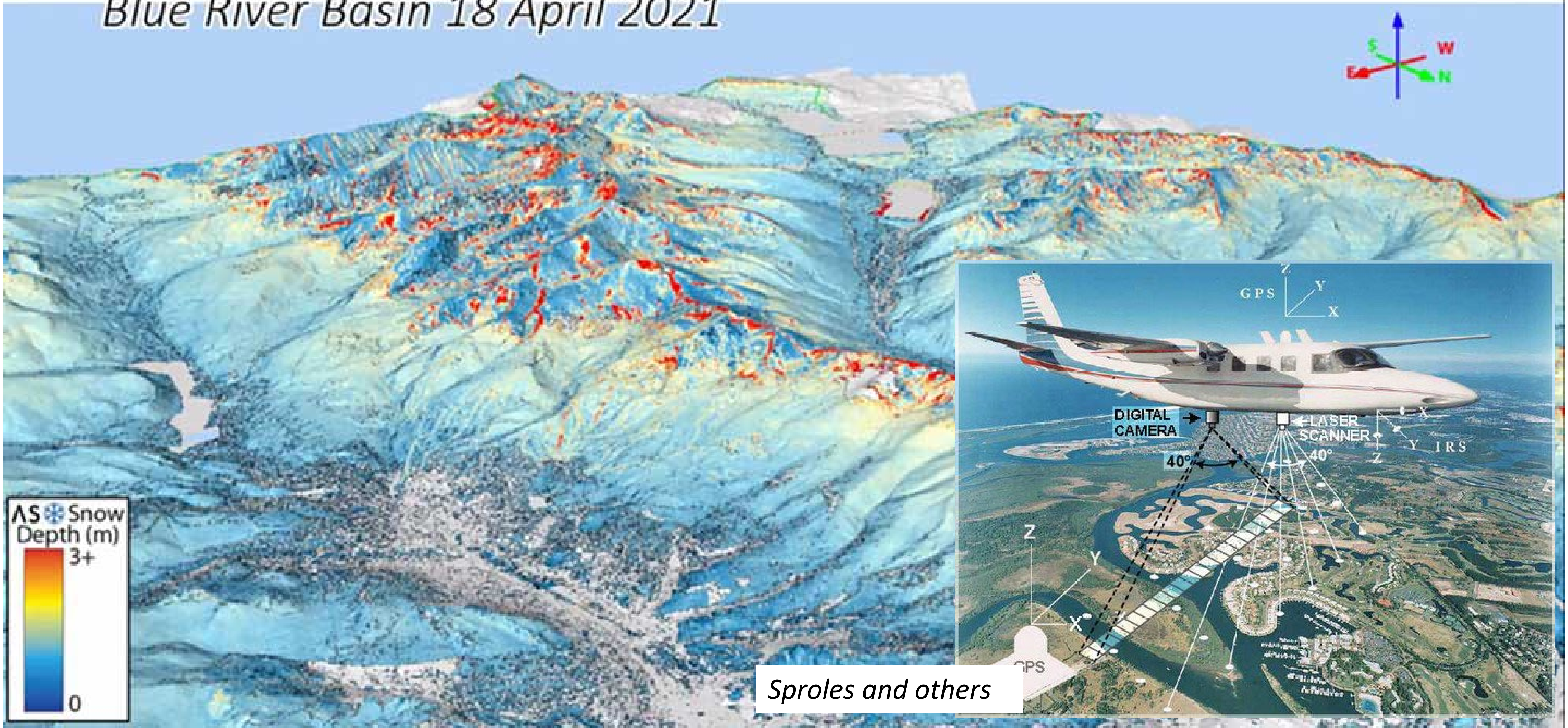




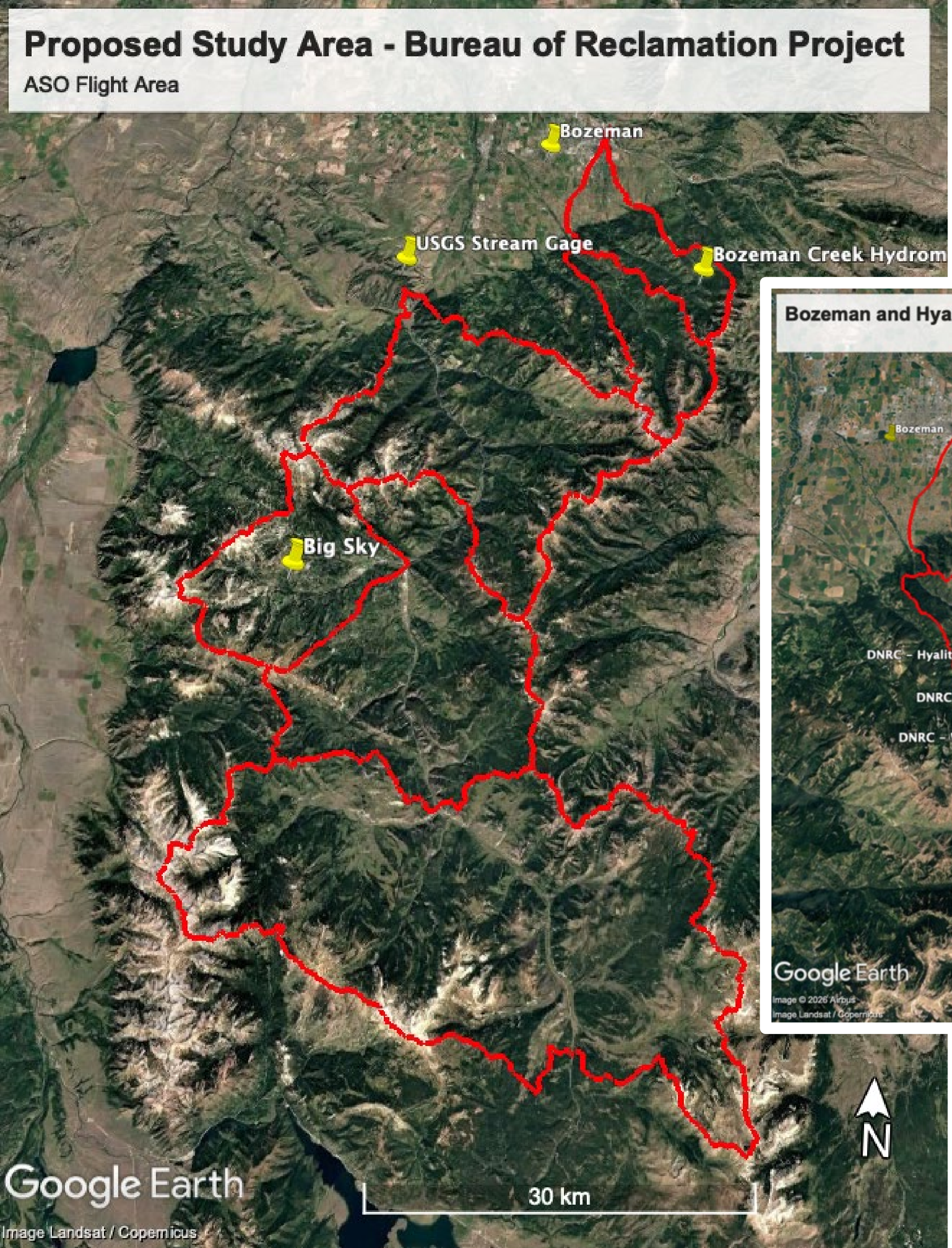
Sproles and others

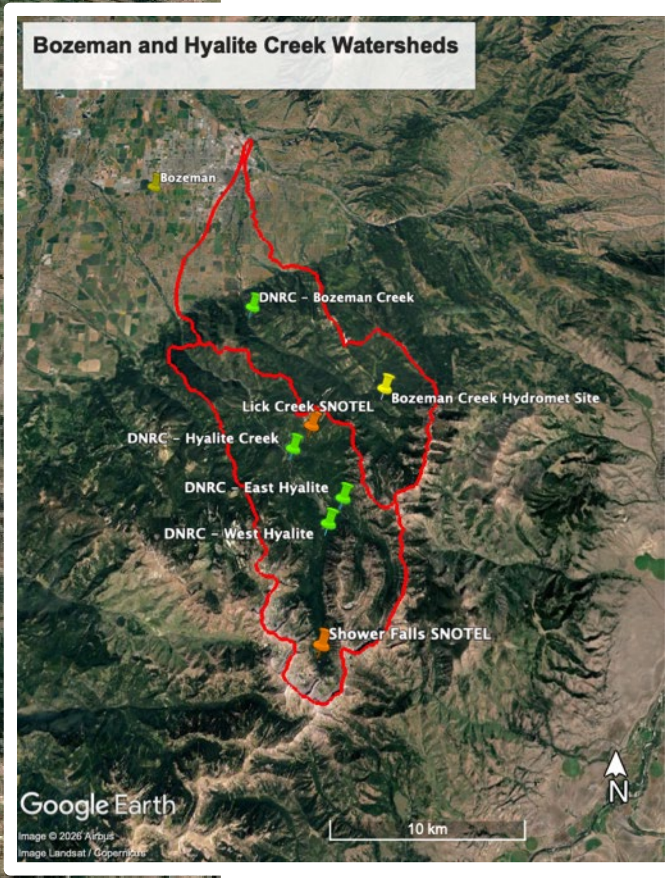
Airborne Snow Observatory

Blue River Basin 18 April 2021



Sproles and others





Proposed…

- Three winters
- Two to three overpasses per winter
- Snow depth, water storage (SWE), and reflectance
- Capture accumulation, peak SWE, and melt
- Integrated into forecasts and model improvements

MONTANA DNRC

GEOSWIRL
Geospatial Snow, Water, & Ice Resources Lab

CITY OF BOZEMAN WATER CONSERVATION

BUREAU OF RECLAMATION

Montana Climate Office

Sproles and others

Stubble Management and Soil Water Storage, Central and Southwest Montana, USA

Jack Poole (MS), Stephanie Ewing, Perry Miller,
Eric Sproles, Simon Fordyce

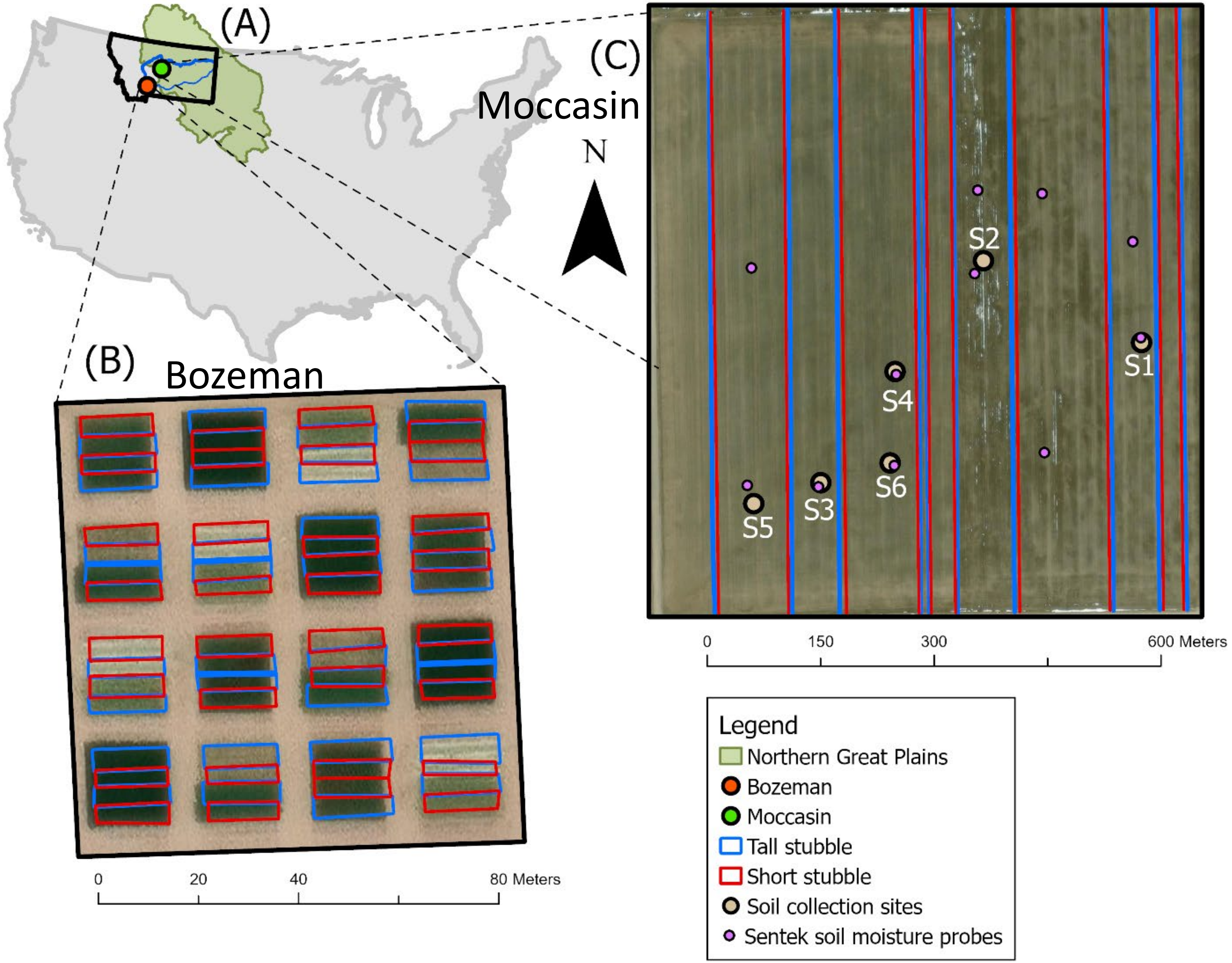
Farm partner: Jeremy Grove

Photo: Shelbourne Reynolds

Stubble height management influences soil water storage and can benefit subsequent pulse crops.

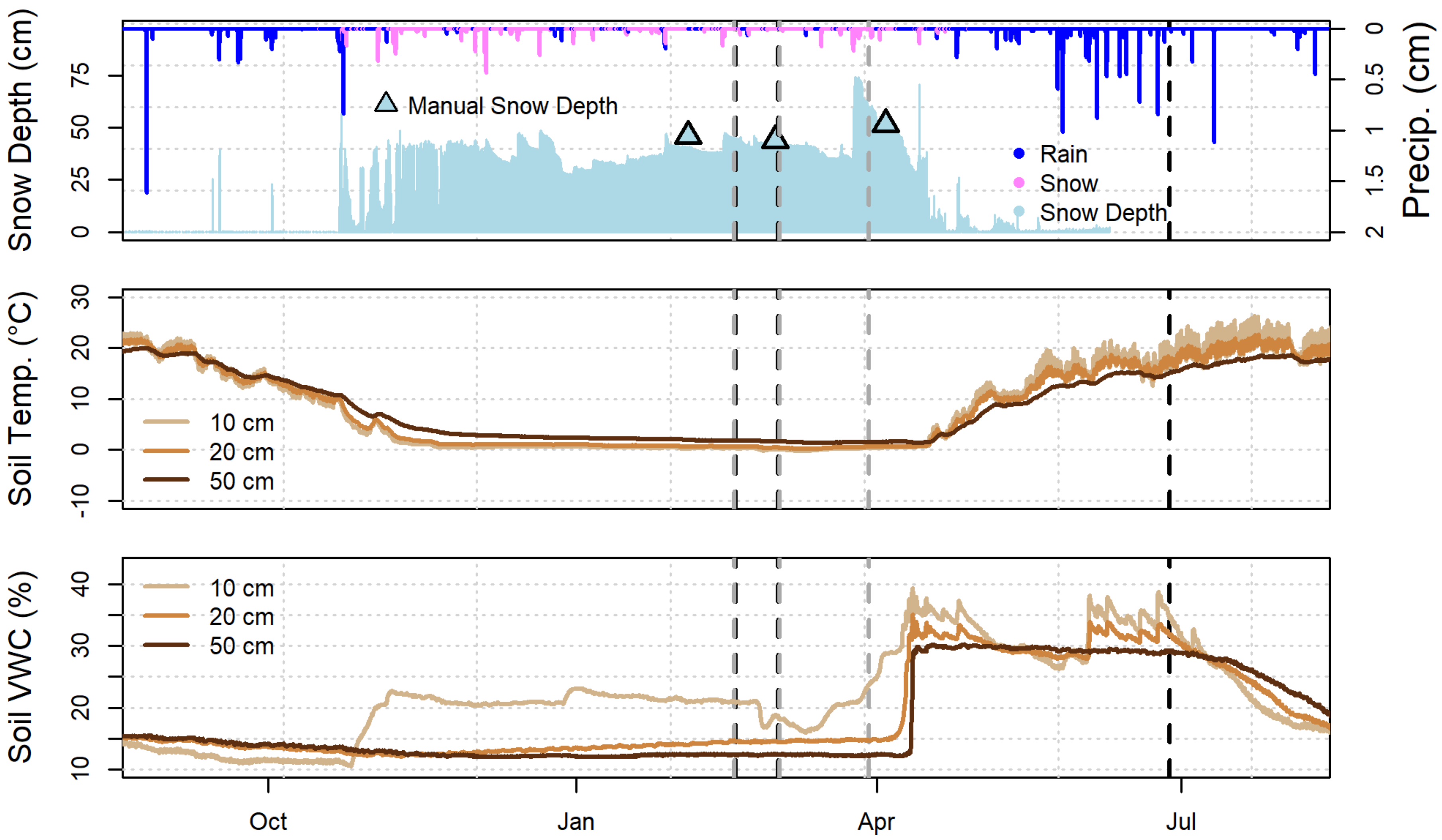
Field pea
in winter
wheat
stubble

Grove farm
Moccasin, MT
June 2024

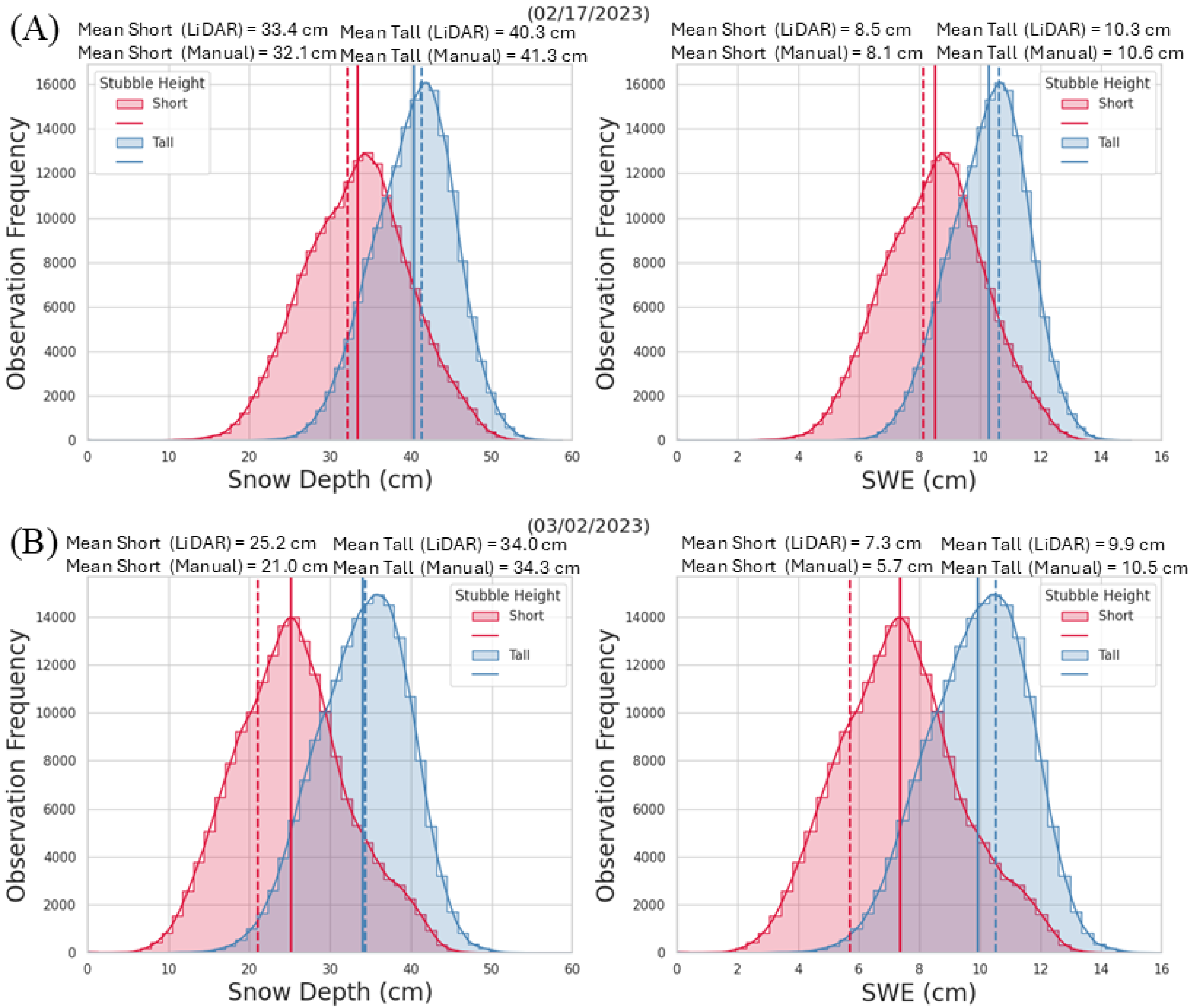


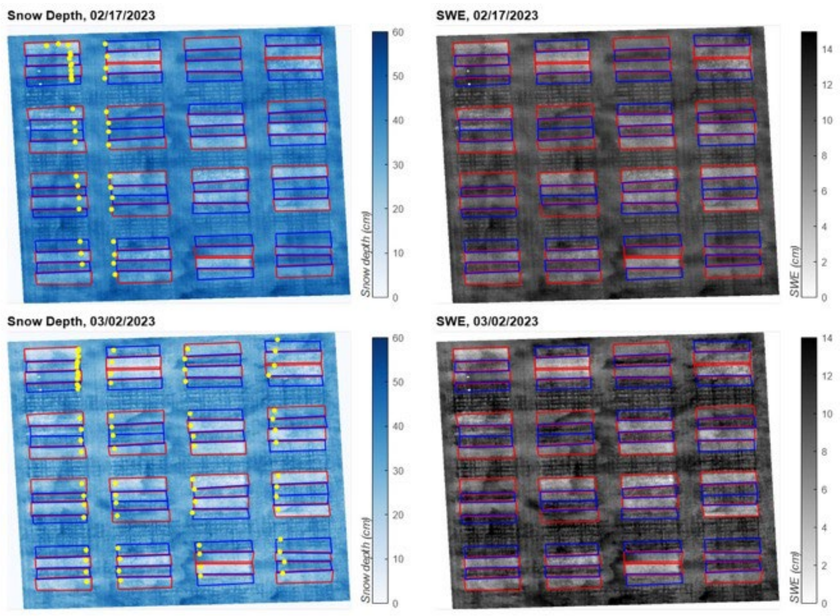
(A)
(B)
Bozeman
0
20
40
80 Meters
(C)
Moccasin
N
S1
S2
S3
S4
S5
S6
0
150
300
600 Meters
Legend
Northern Great Plains
Bozeman
Moccasin
Tall stubble
Short stubble
Soil collection sites
Sentek soil moisture probes

Bozeman, MT (2022-2023)



LiDAR derived snowpack analysis: Bozeman, Feb-March 2024





- tall stubble clearly holds more snow (about 2 cm more water on each date)
- continuous histograms show detailed distribution of snow depth and snow water equivalent (SWE)
- mean reflects >300,000 point observations
- field scale needed for understanding stubble height effects

The 'snowflake' design

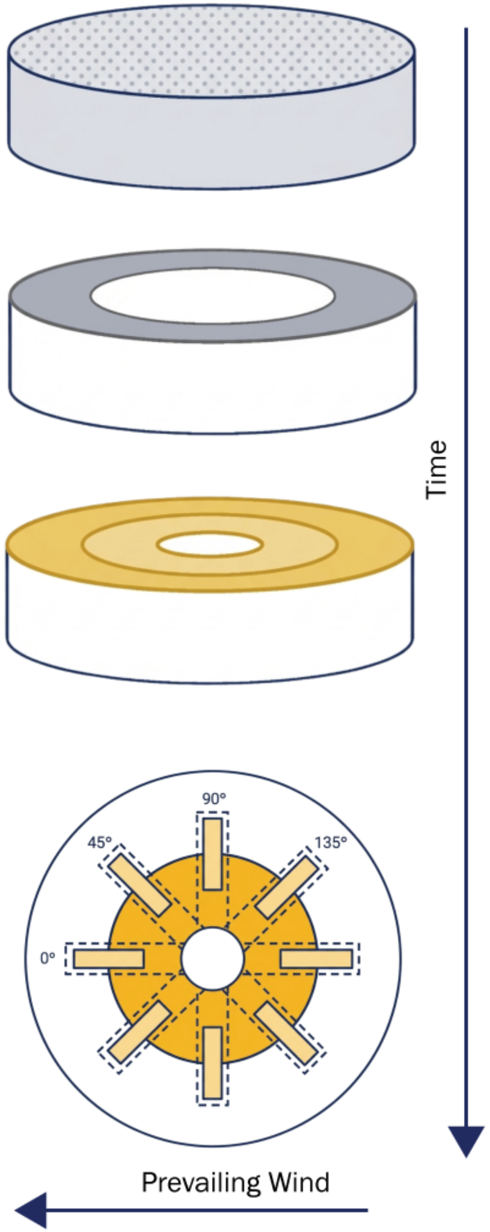
Study design: Radial plot layout to manipulate surface roughness and snow capture over a small area (20 m radius)

Fall 2024:
Tall & uniform crop stubble

Spring 2025:
Short & uniform crop stubble encompassing tall & uneven crop stubble

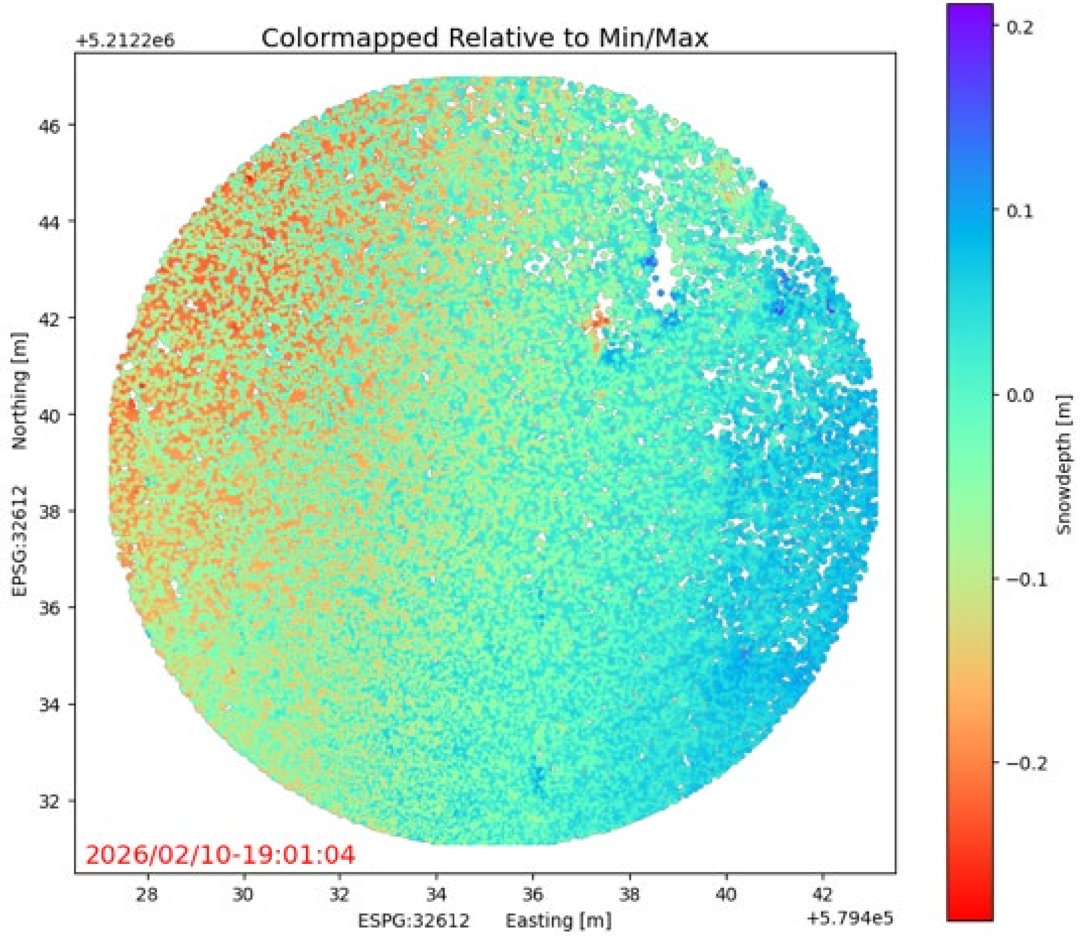
Fall 2025:
Assessment of fall-planted (winter) wheat established in two stubble environments (stubble & bare ground).

Spring 2026:
Assessment winter wheat mortaility and spring wheat performance in four transects (varying in orientation to prevailing wind) across two stubble environments (stubble & bare ground).



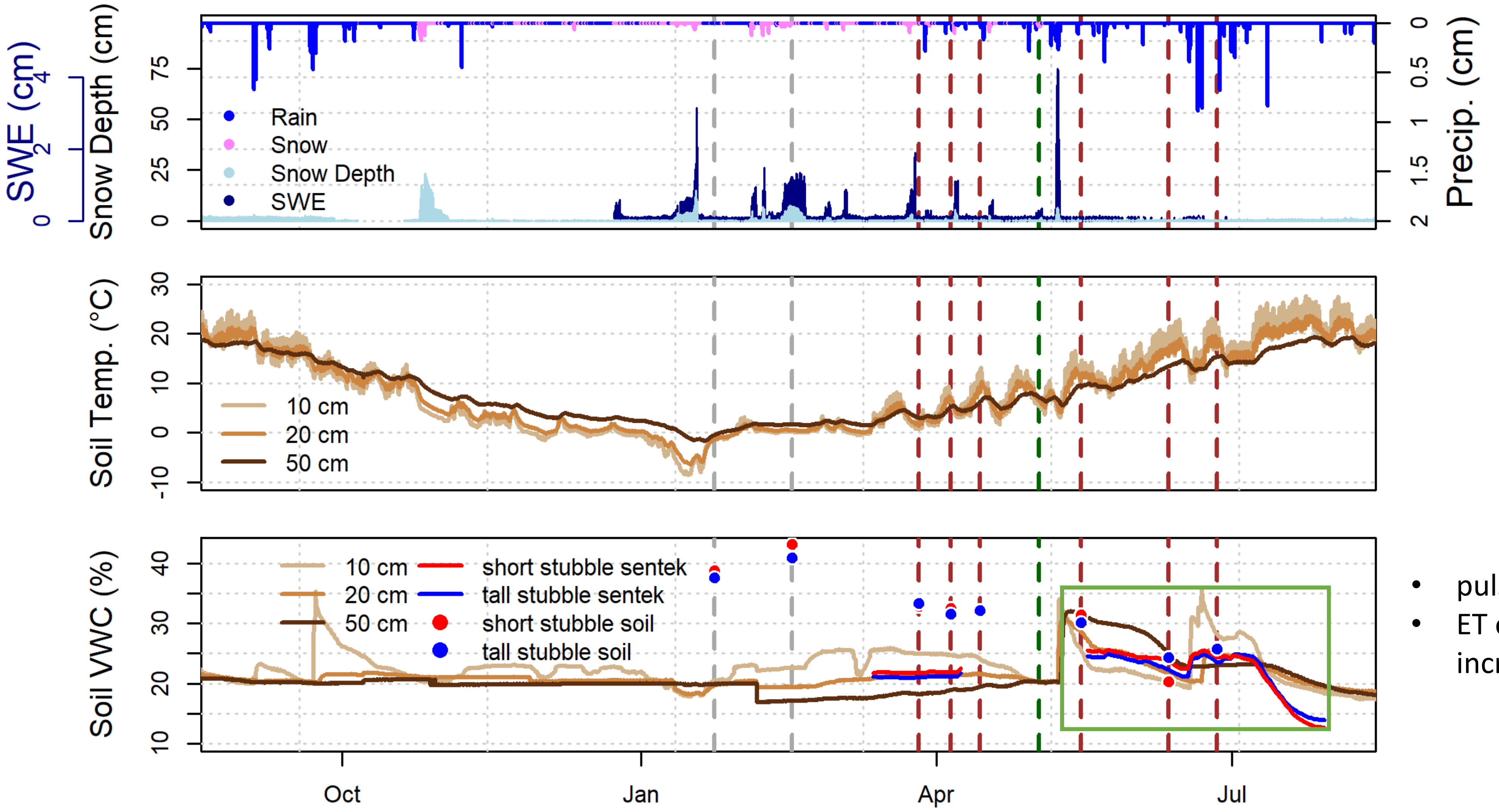
Simon Fordyce, CARC

Tower LiDAR for frequent snow depth maps



Simon Fordyce, CARC

Moccasin, MT (2023-2024)

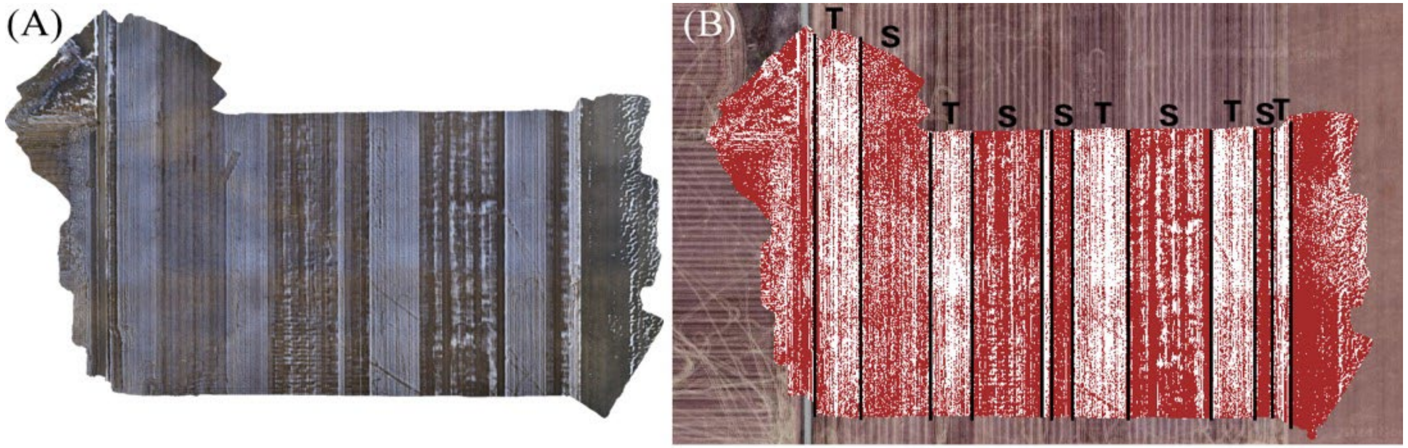


- pulse seeded 2 May
- ET evident in June, increasing in July

Ewing & others

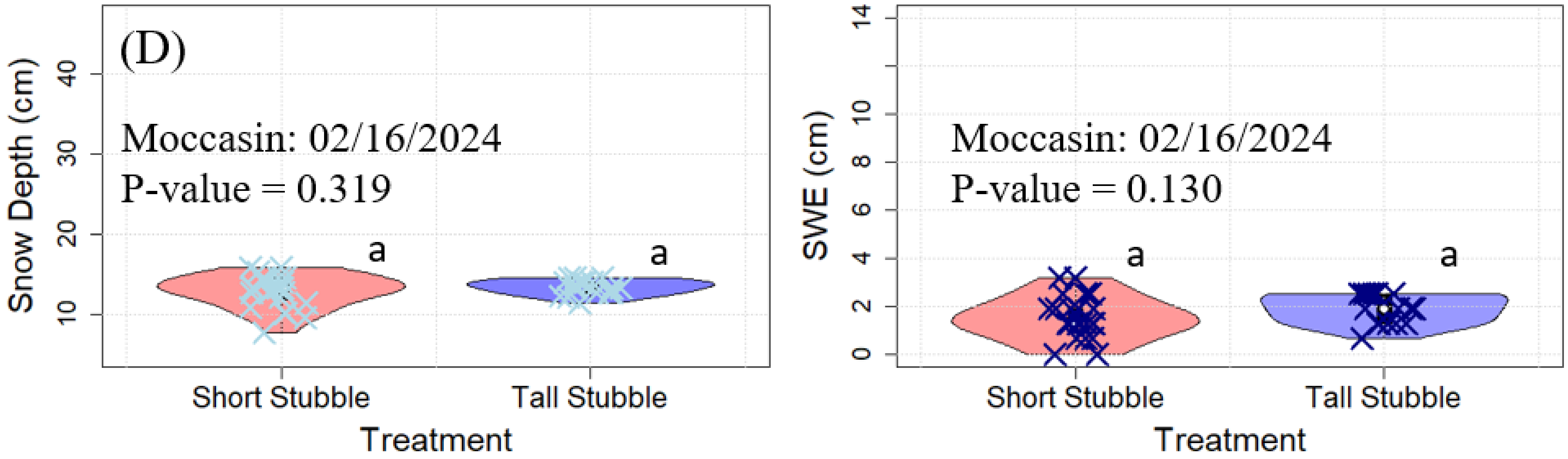
Moccasin snowpack assessment 2024

Snow presence/absence January 23rd



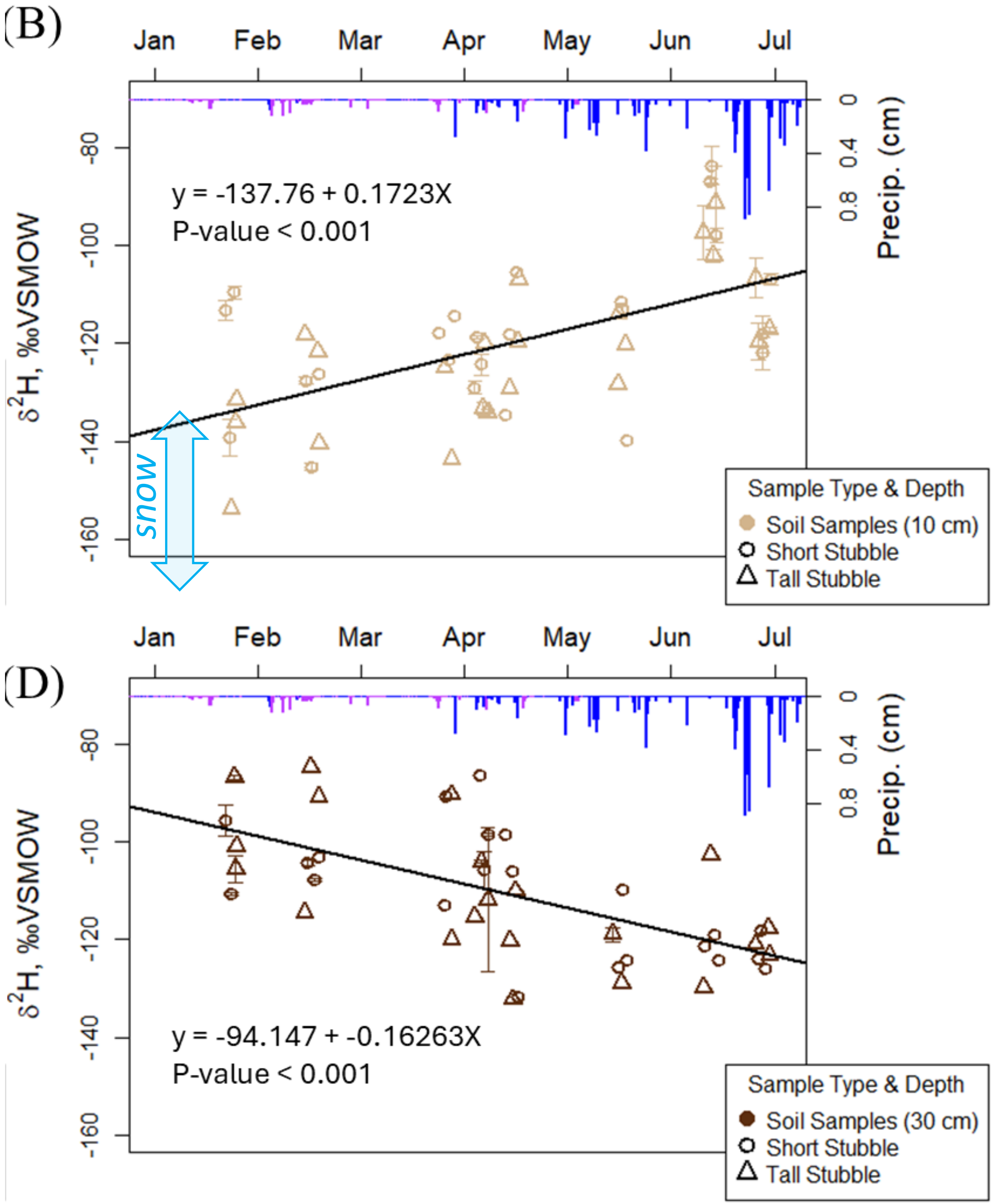
- Less snow overall during the winter of 2023-2024
- January image: Increased presence of snow in tall stubble (LiDAR unsuccessful due to limited snow)
- February sampling: More variable/patchy snow in short stubble; same average snow accumulation

Manual snow assessment February 16th



Ewing & others

Snowmelt additions to soil water

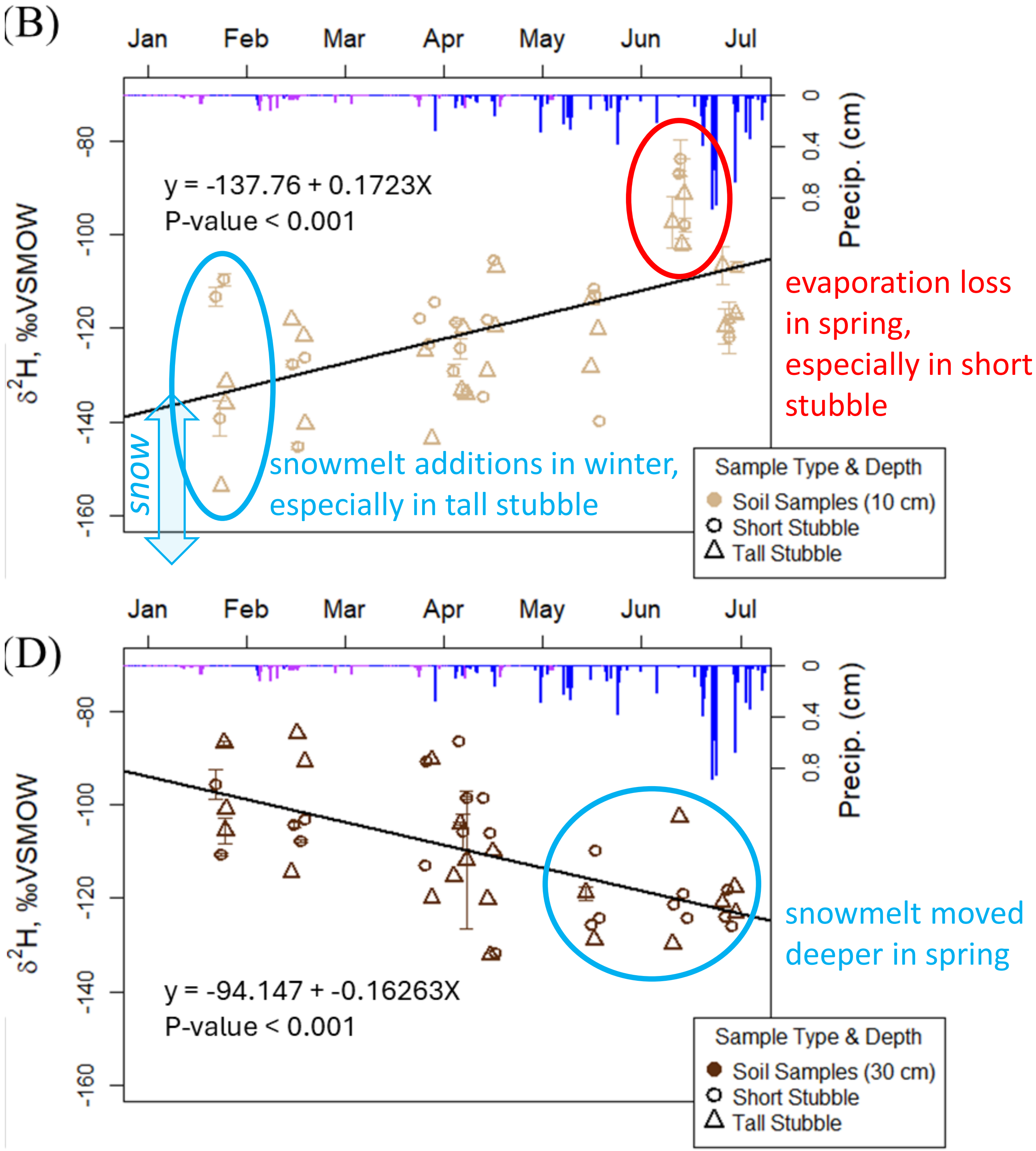


shallow soil
0-4 inches
(0-10 cm)

deeper soil
8-12 inches
(20-30 cm)

Ewing & others

Snowmelt additions to soil water



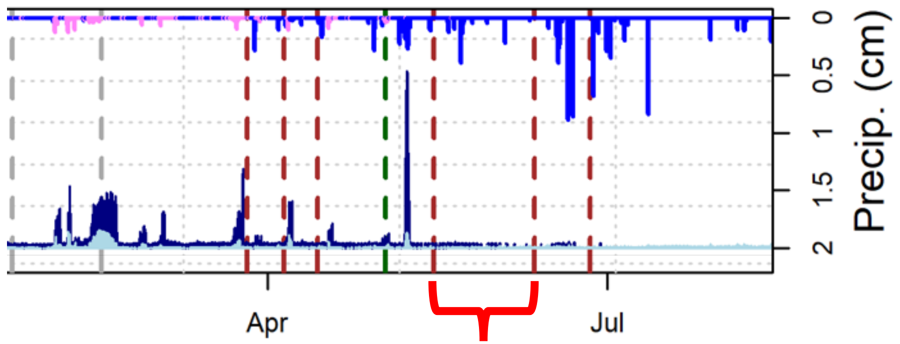
shallow soil
0-4 inches
(0-10 cm)

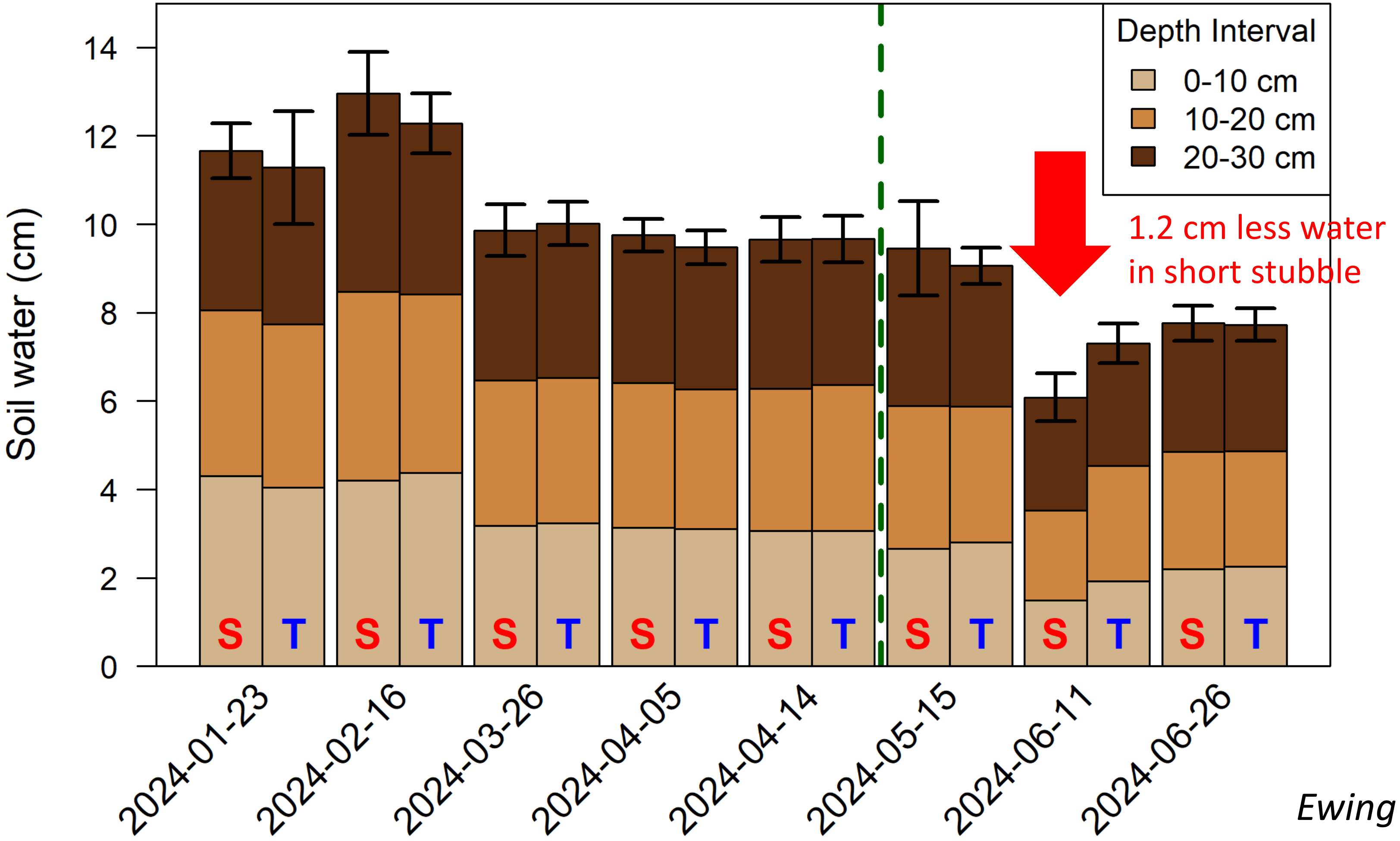
deeper soil
8-12 inches
(20-30 cm)

Ewing & others

Soil water storage

- After planting (May 2) transpiration and evaporation outpace precipitation inputs
- More evaporation loss from short stubble soil on June 11 and 1.2 cm (0.6 inch) less water despite precip added





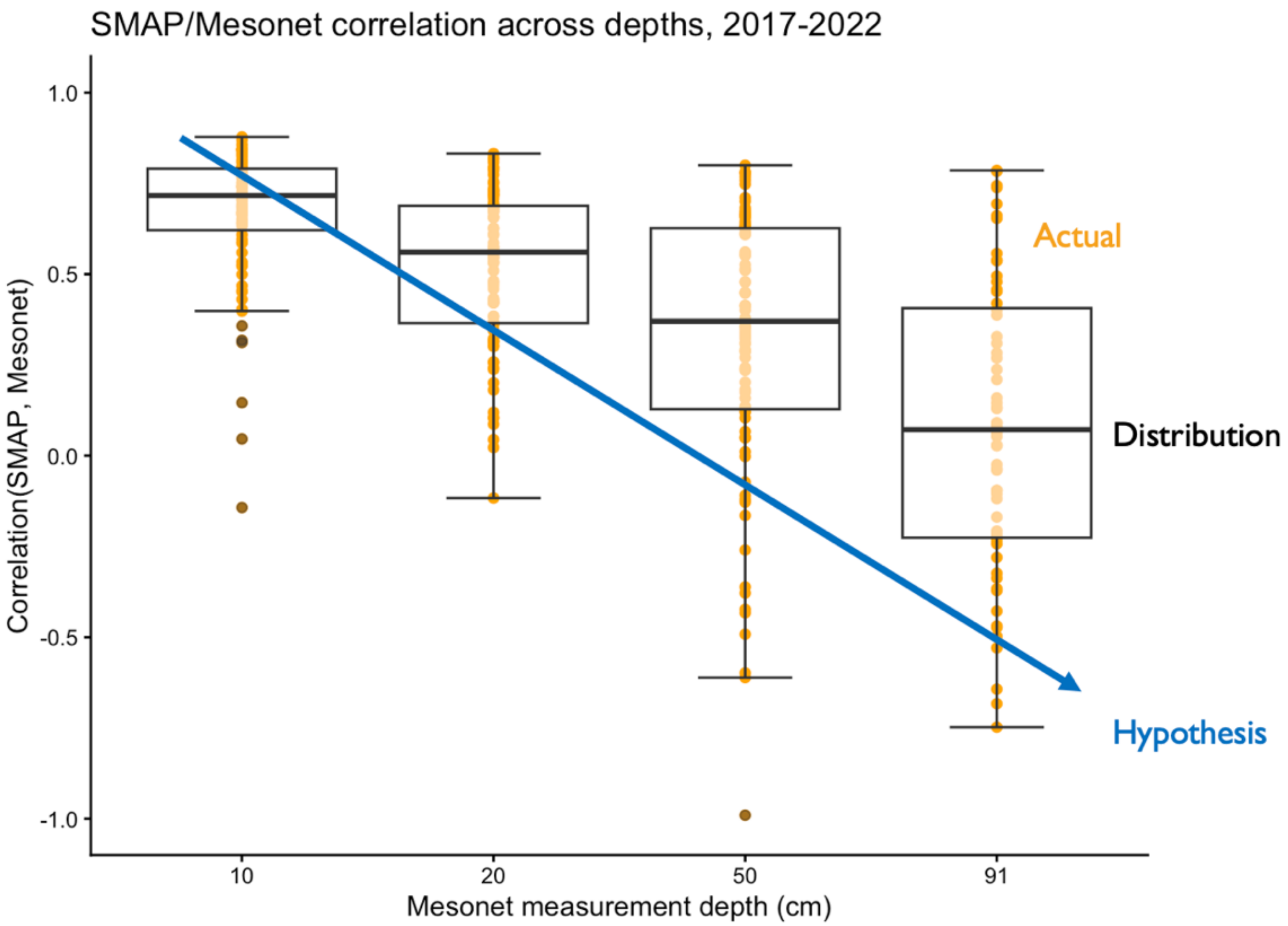
Ewing & others

From Probes to Pixels: Downscaling soil water content maps for drought monitoring

Carson Williams, MS student;
Advisor: Andrew Felton

My work is supported by a Montana water center seed grant awarded to Andrew Felton and Anna Schweiger, which is now being used to motivate a Step-1 that was submitted to the NASA-ROSES NISAR-25 call.

Carson Williams



Early takeaway: as expected, NASA's SMAP satellite generally contains less information about soil moisture as depth below the soil surface increases. But can factors like climate and soil characteristics help us explain the outliers here, where SMAP is well-correlated with deeper root zone soil moisture, and where SMAP is not well-correlated even with surface soil moisture?

Water storage in soils and groundwater

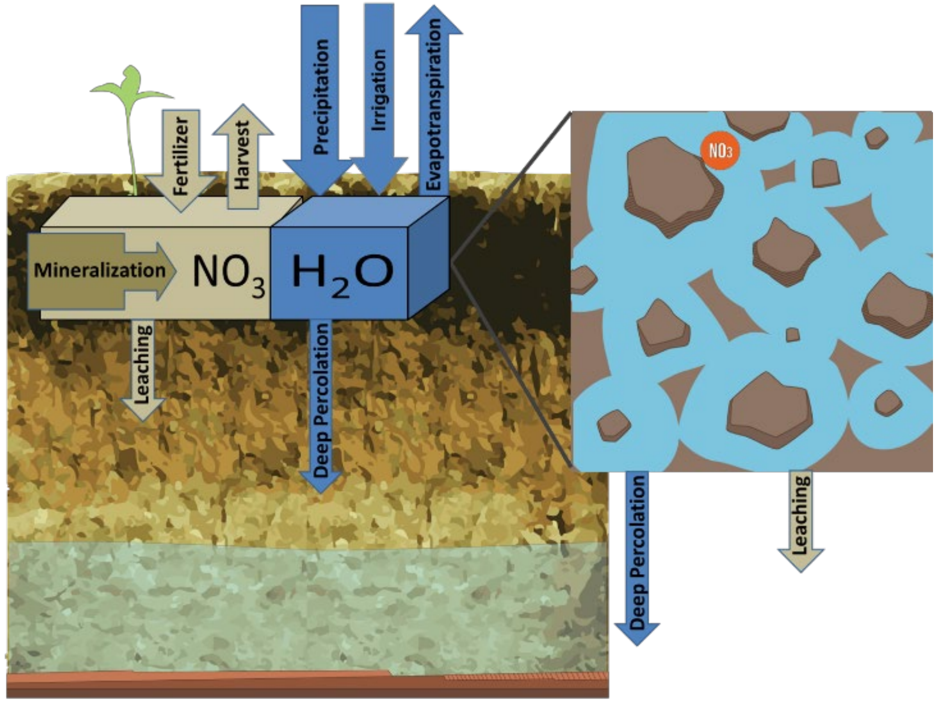
Upper Yellowstone Watershed

Payton Gardner, Deer Lodge Valley

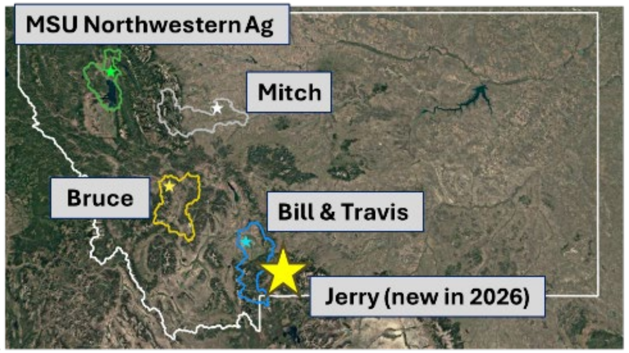
Water and Nitrogen Use Efficiency under Irrigated Cultivation

Adam Sigler – MSU Extension

1.5 m
(5 feet)



Mitch Konen - Fairfield



Bruce Thomas – Gold Creek

Bill Lee - Churchill

Funding
MT Fertilizer Advisory Committee
MSU College of Agriculture
MSU Extension

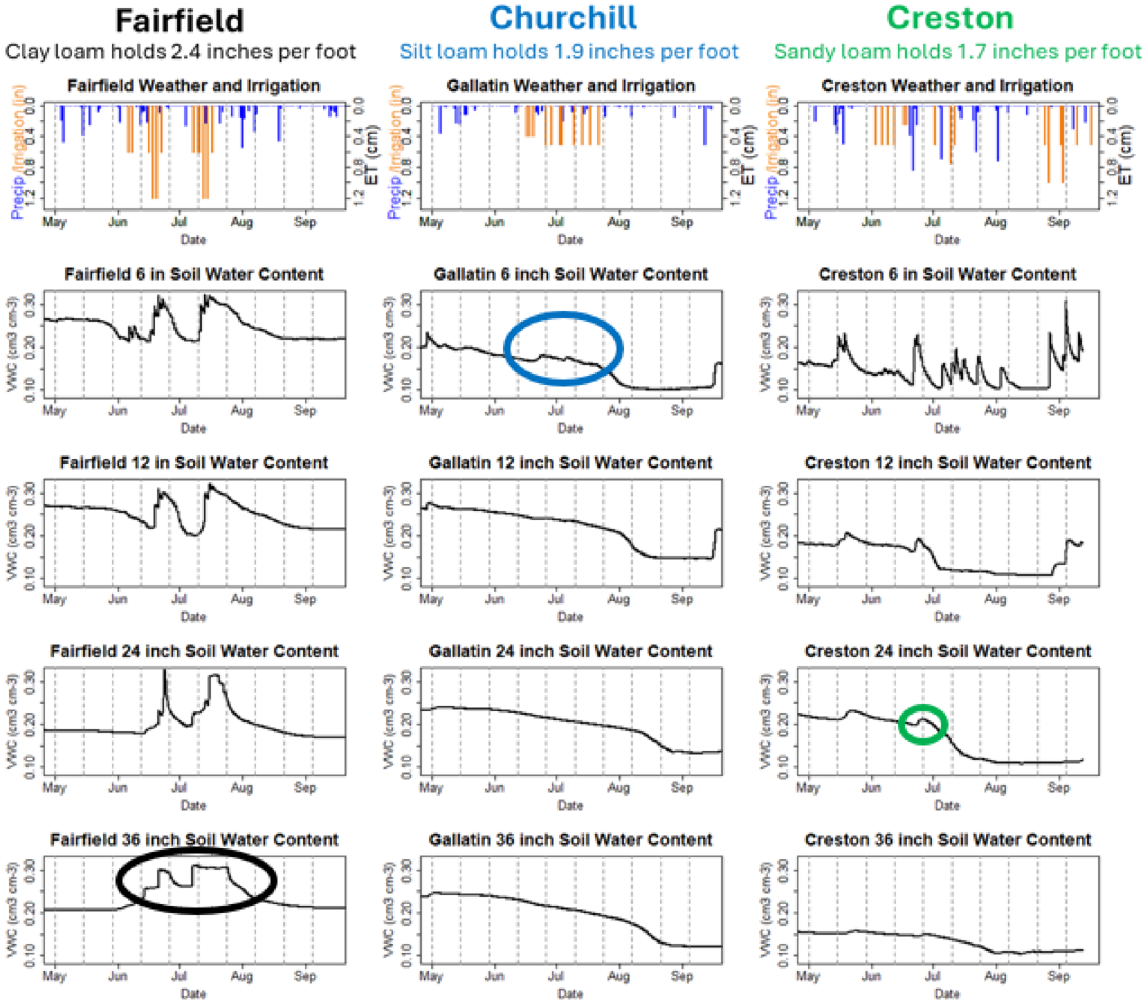
Sigler & others

Field Methods

Sigler & others

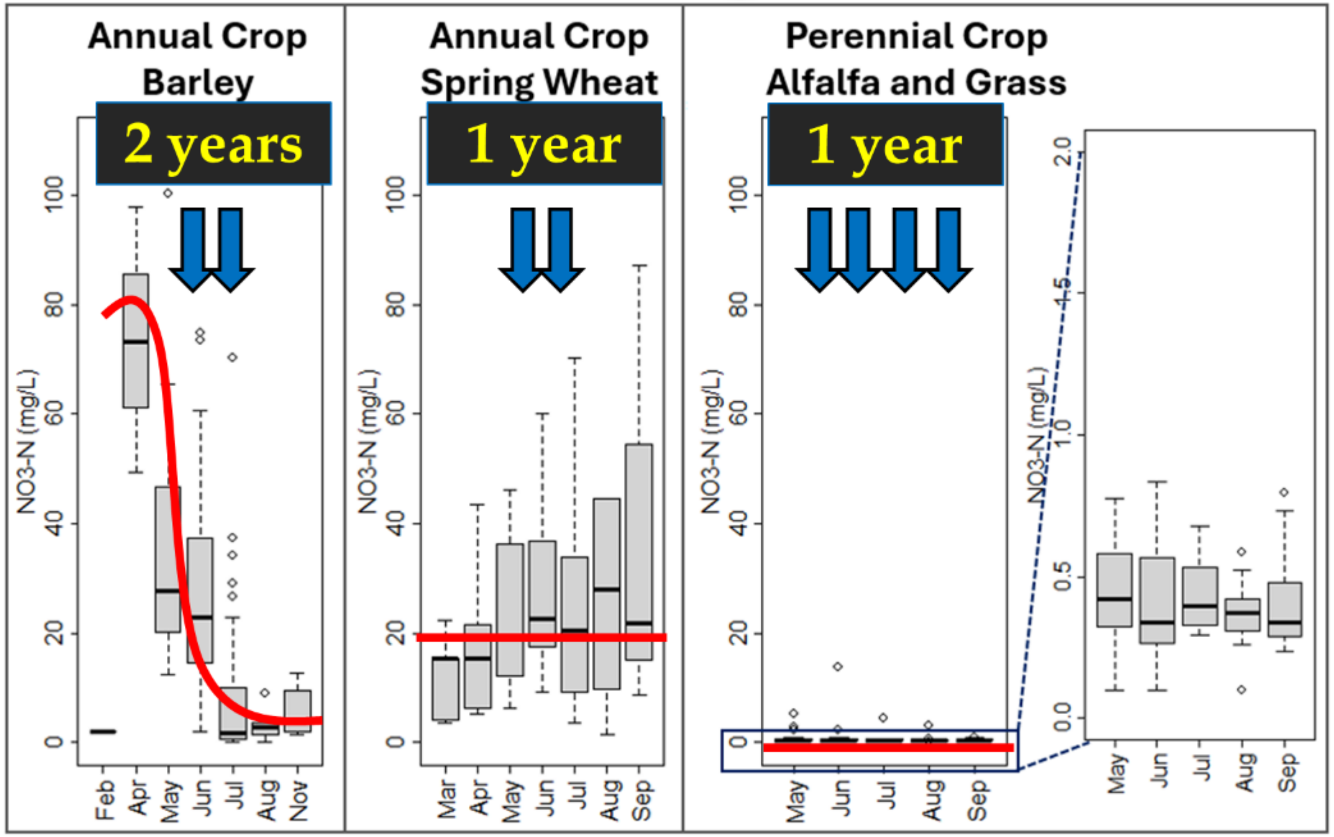
Results

Water



Water moves deepest in clay, shallowest in silt.

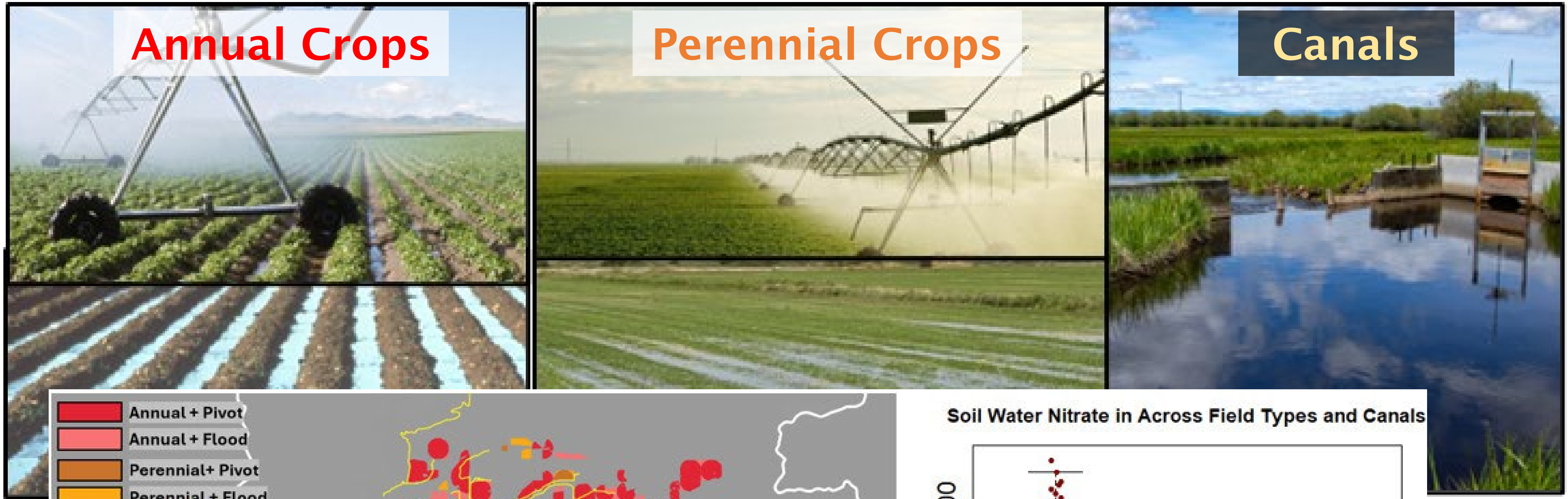
Nitrogen

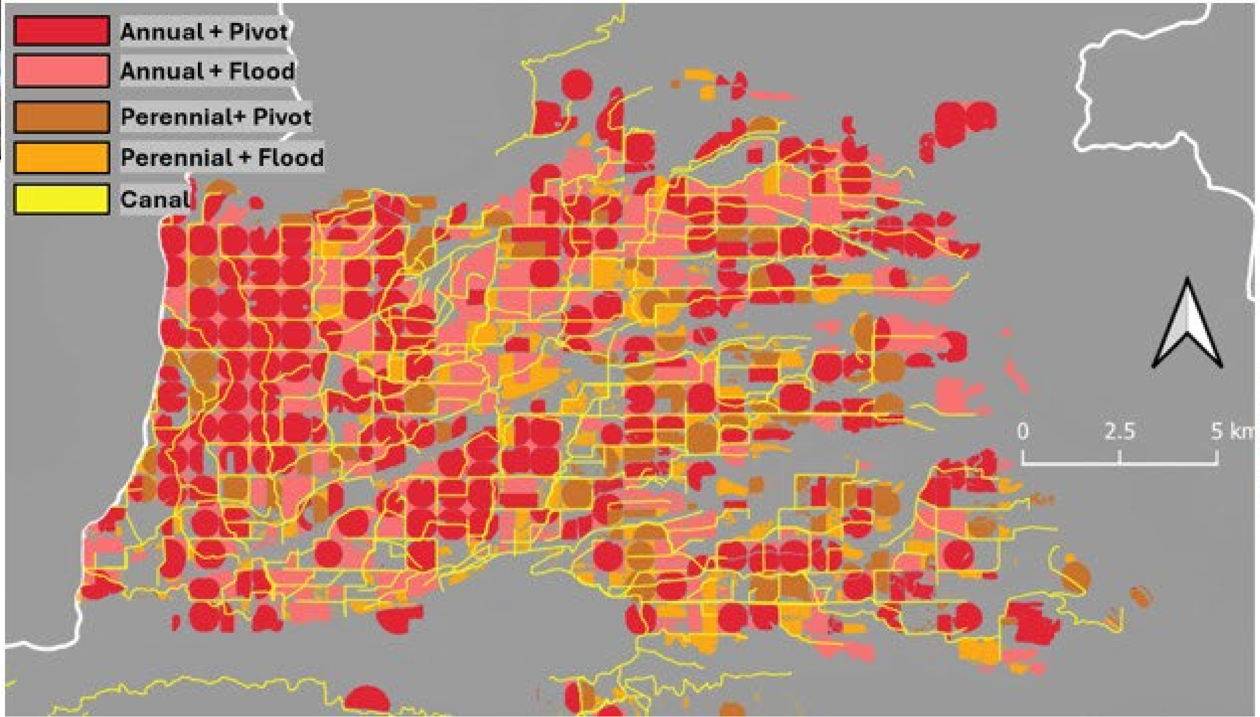


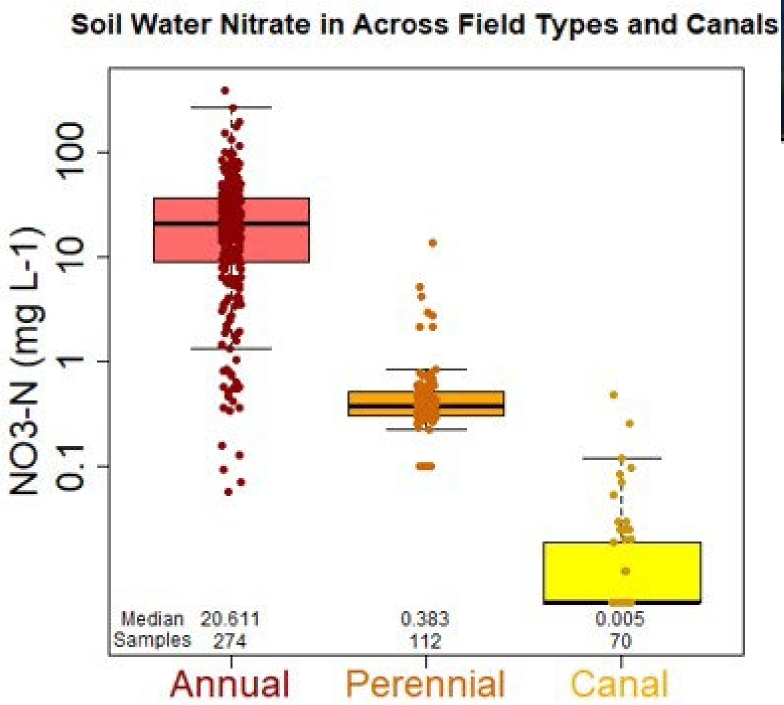
Soil nitrate depends on crop and N management.

Sigler & others

Irrigation plays a key role in recharging groundwater







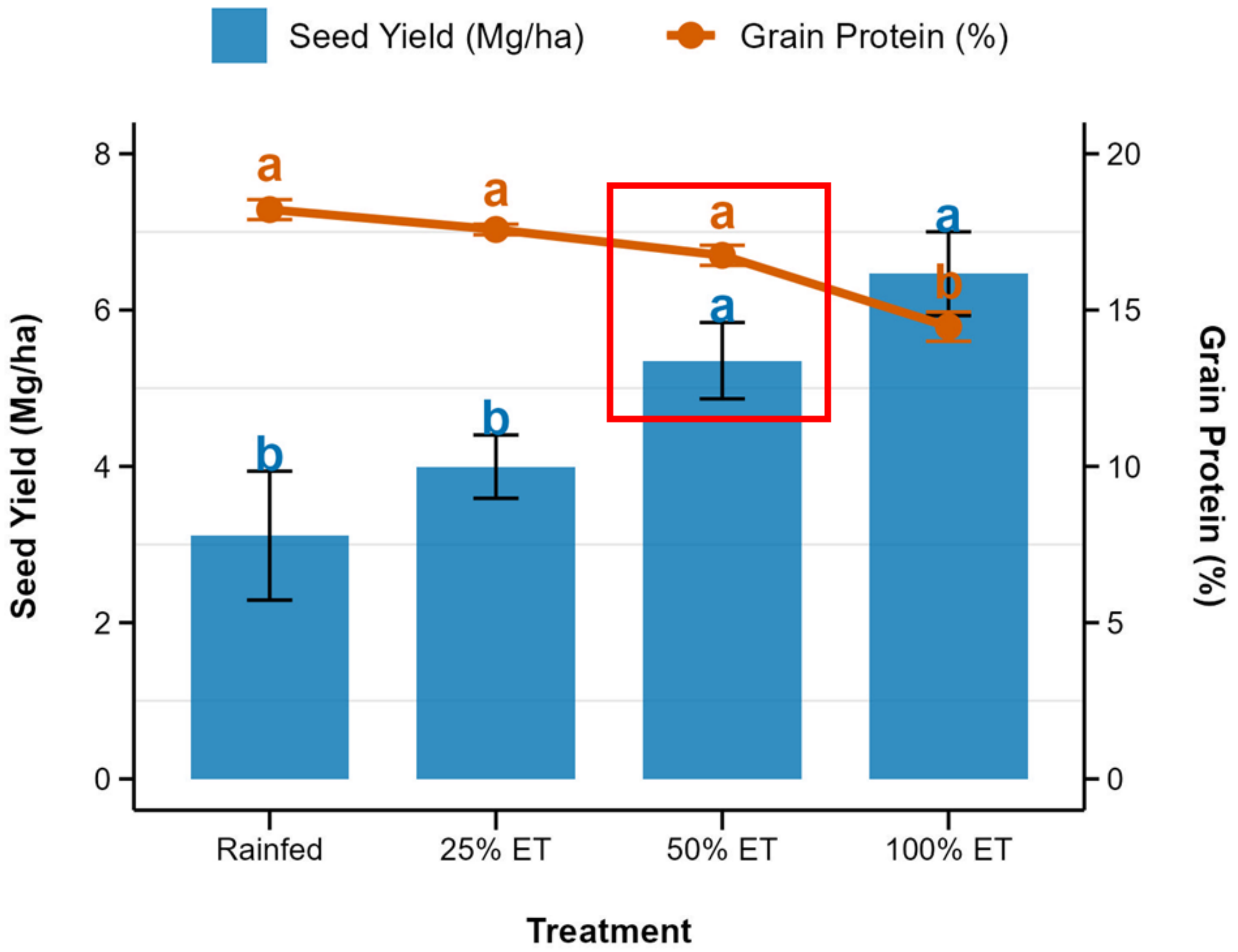
Sigler & others

Precision Crop, Soil, and Water Management Group

PI: Anish Sapkota, PhD
Assistant Professor, Precision Agriculture
Dept. of Land Resources and Environmental Sciences
Montana State University, Bozeman
anish.sapkota@montana.edu

MONTANA
STATE UNIVERSITY

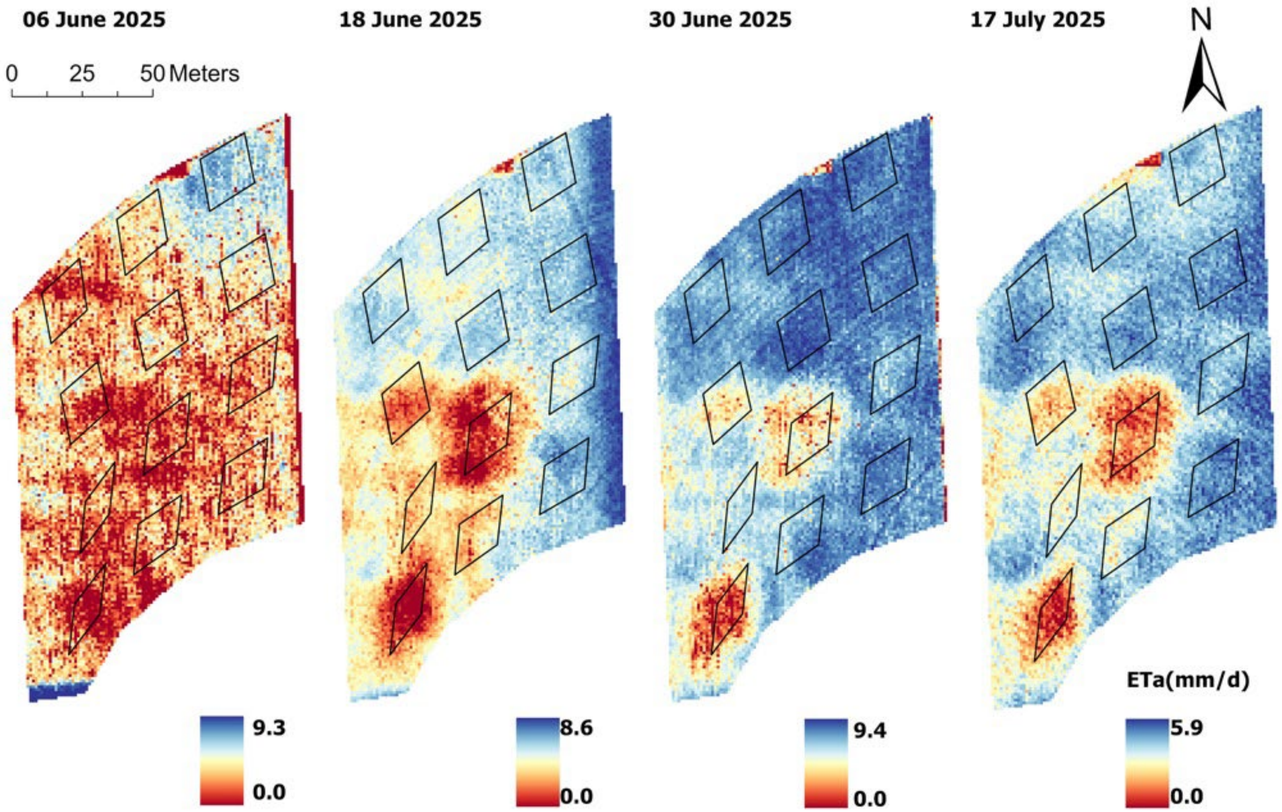
Deficit irrigation in spring wheat for water conservation

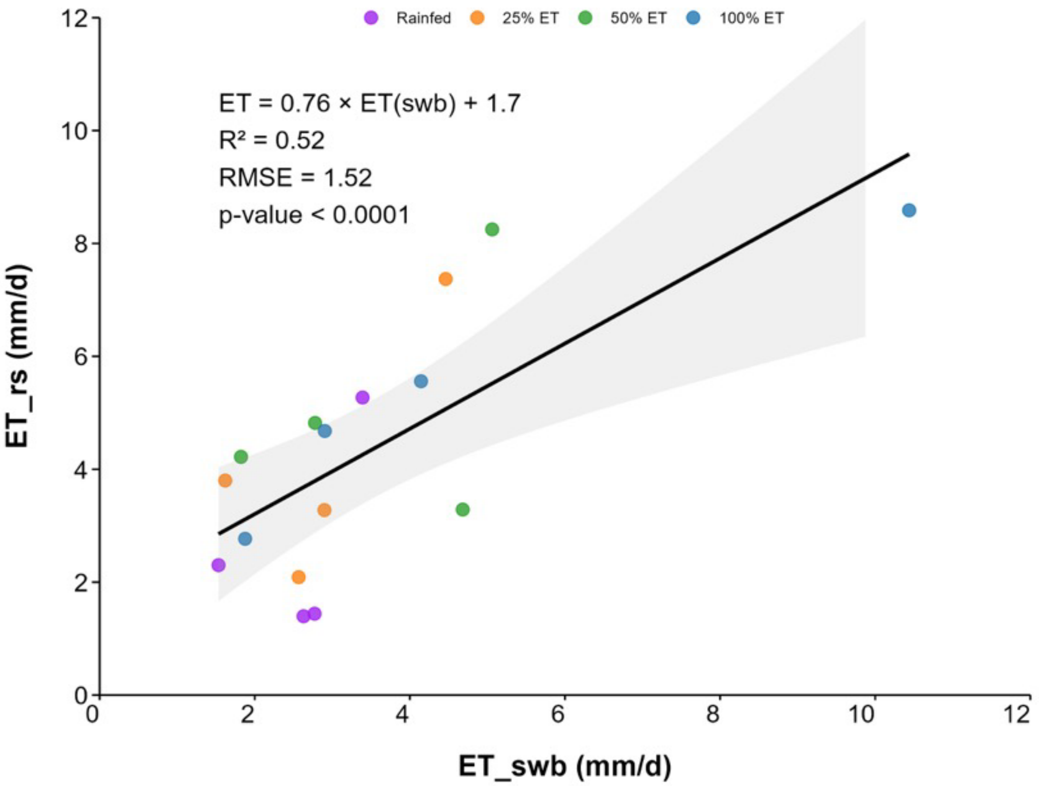


Funded by College of Agriculture, Montana State University
Lead: Sapkota
Collaborator: Torrion and Dalen
Student: Safal Adhikari [Partially supported by Montana Water Center]

Sapkota & others

Estimating actual evapotranspiration (ET_a) using remote sensing for precision irrigation



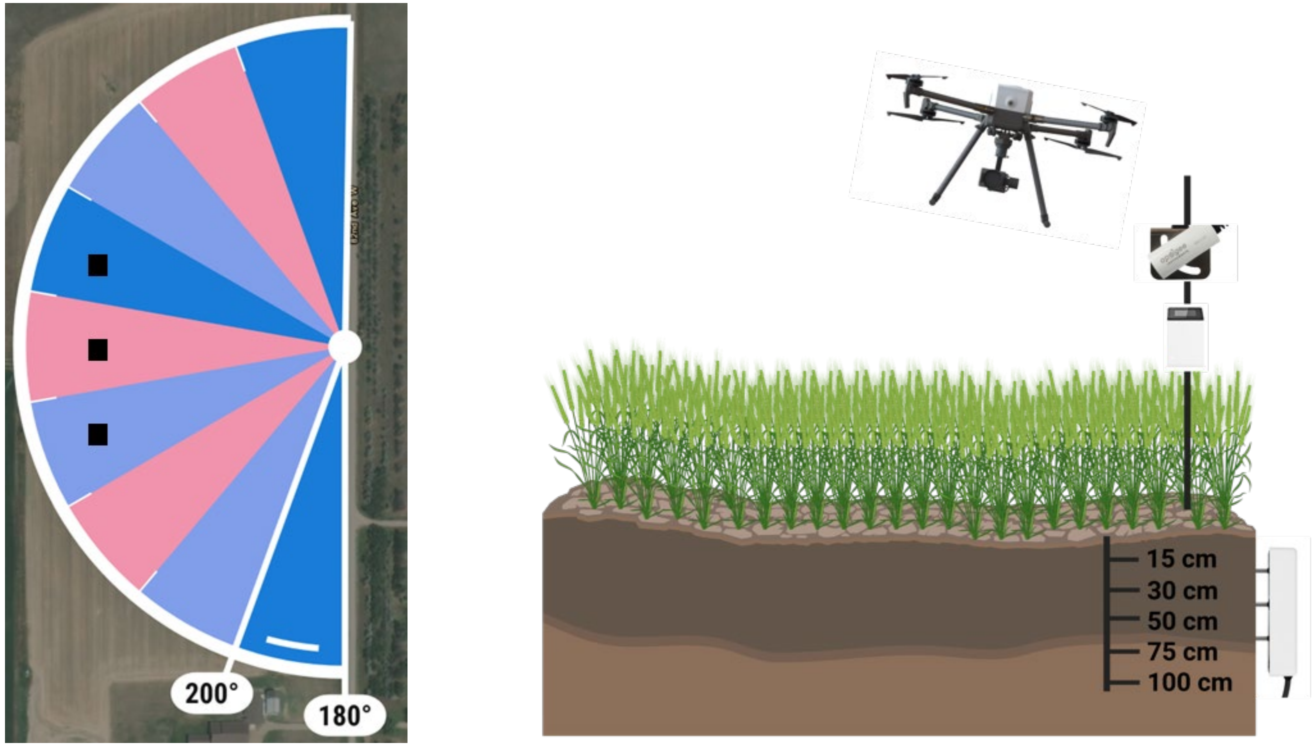


ET_a estimated using multispectral and thermal images from UAS were validated using soil water balance (SWB)

Sapkota & others

Funded by College of Agriculture, Montana State University
Lead: Sapkota
Collaborator: Torrion and Dalen
Student: Safal Adhikari [Partially supported by Montana Water Center]

Potential of OpenET for precision irrigation and water conservation



Thematic layout of the experimental field with an instrumentation plan

$$ET = P + I - R - D - \Delta S$$

ET = evapotranspiration
P = precipitation
I = Irrigation
R = Runoff
D = deep percolation
ΔS Change in soil water storage

A comparative analysis of irrigation based on OpenET data and scheduling based on reference evapotranspiration (ET) from a nearby weather station will be conducted to evaluate OpenET's potential for irrigation scheduling.

Project in progress; funded by Montana NASA EPSCoR
Lead: Sapkota
Collaborator: Pinto

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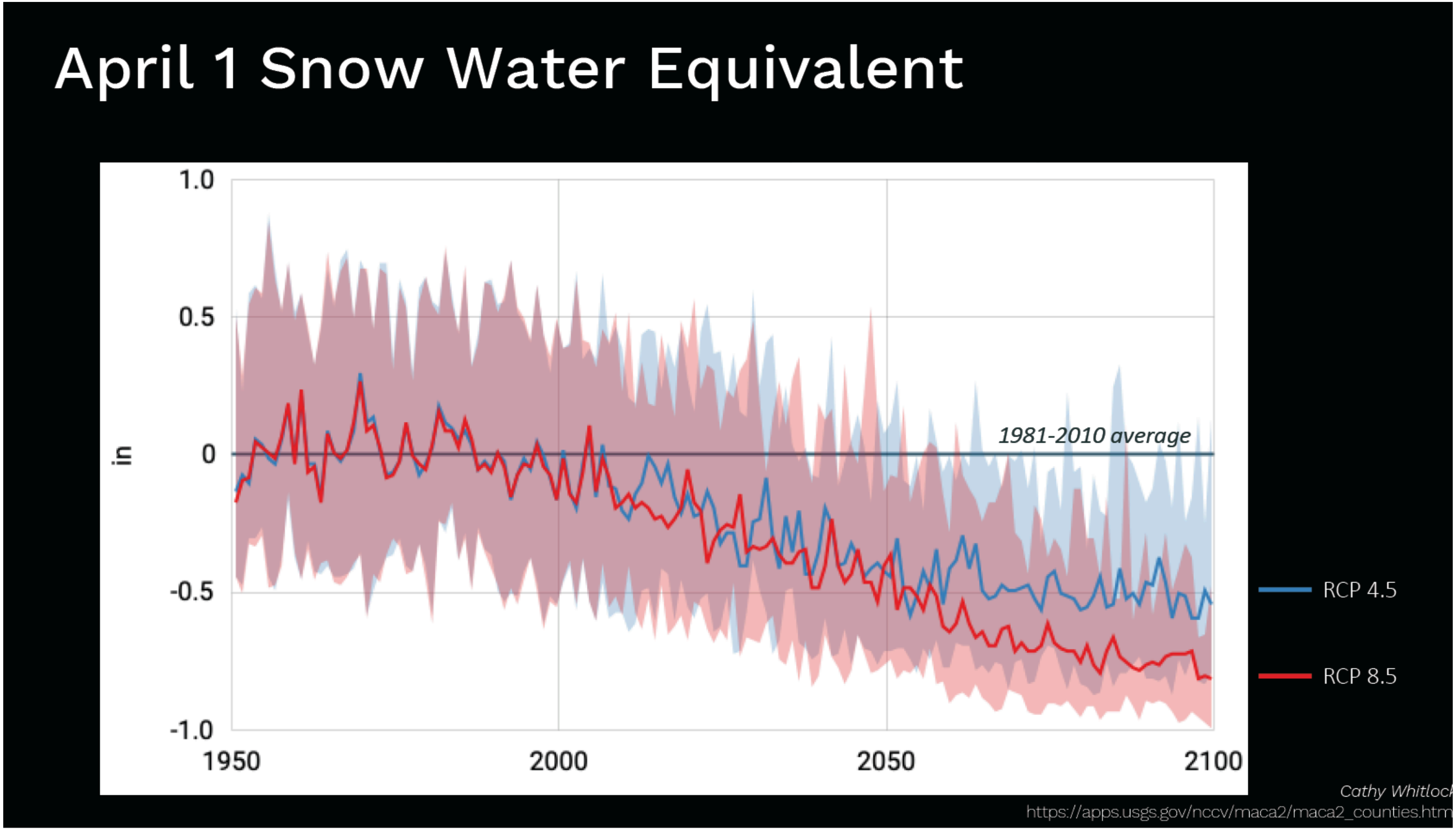
Storage of declining snowpack in groundwater



Modeled Changes in SWE and Mountain Aquifer Recharge in west-central Montana

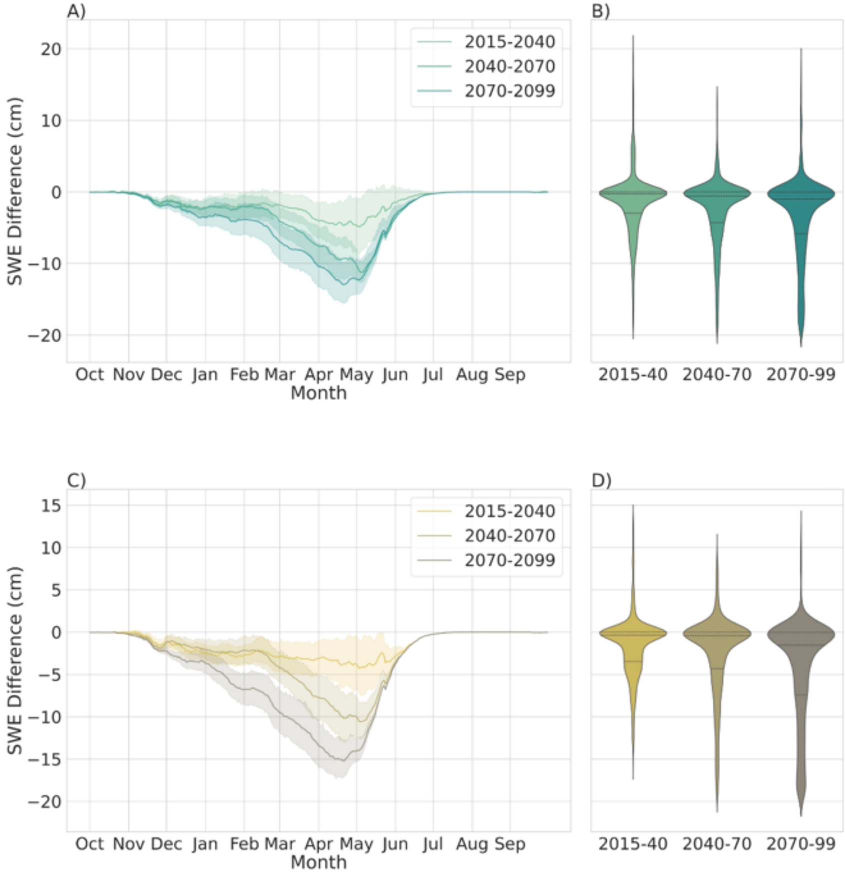


Figure 9: Difference from historical SWE for each day of the year separated by time interval for A)SSP245 and C)SSP370 emission scenario. Dark line is the mean and shaded area is the 95% confidence interval. Violin style box plots for each time interval, with mean SWE and quartiles (C & D).

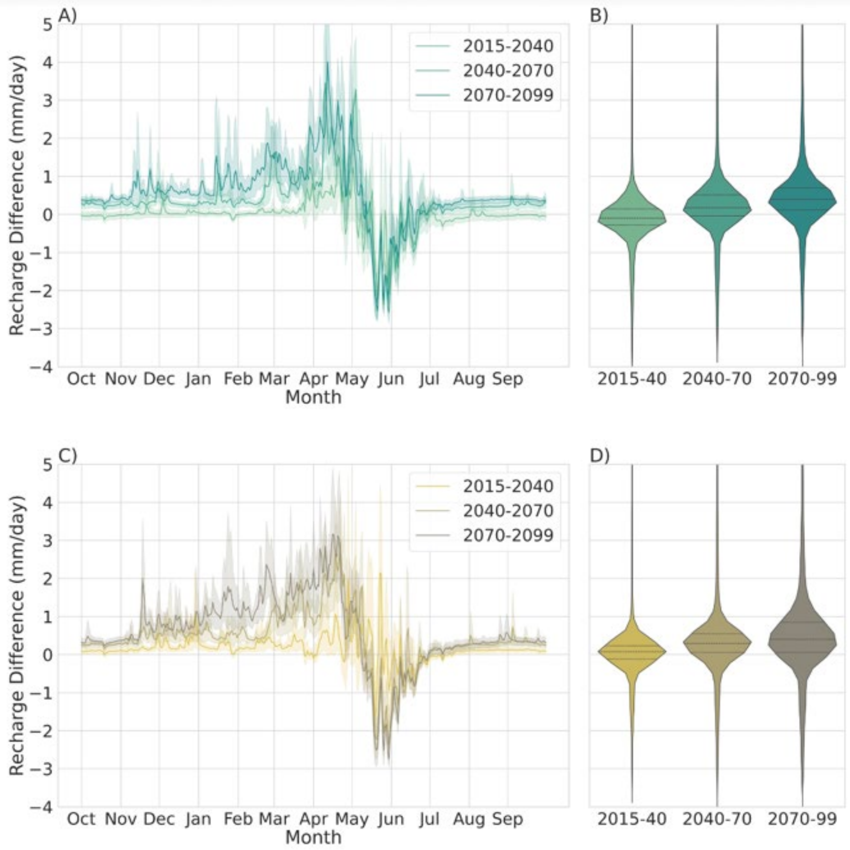


Figure 15: CW difference from historical recharge for each day of the year separated by time interval for A)SSP245 and C)SSP370 emission scenario. Dark line is the mean and shaded area is the 95% confidence interval. Violin style box plots for each time interval, with mean recharge and quartiles (C & D).

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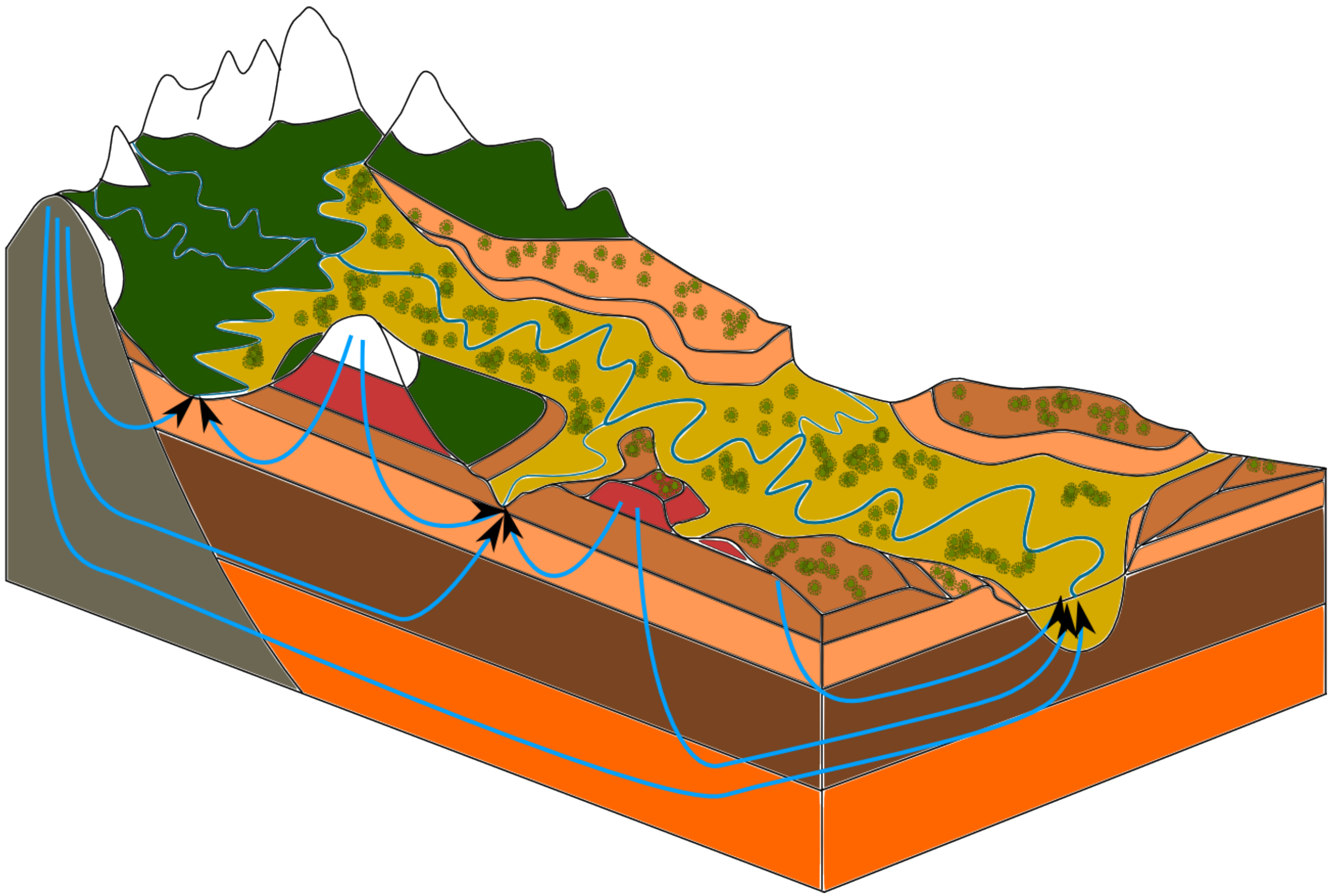
Stream chemistry as window to the surrounding groundwater system



- The vast majority of stream water has spent some of its flow path underground
- Groundwater contributes a large proportion of stream flow for the entire year
- Stream flow integrates all water sources in the basin, including all groundwater flow paths
- The river is a means to sample the groundwater composition in the basin
- Chemical separation techniques can show the source of streamflow and quantity of groundwater
- Combining geochemical methods and groundwater modeling can reveal the interaction between streams and groundwater.

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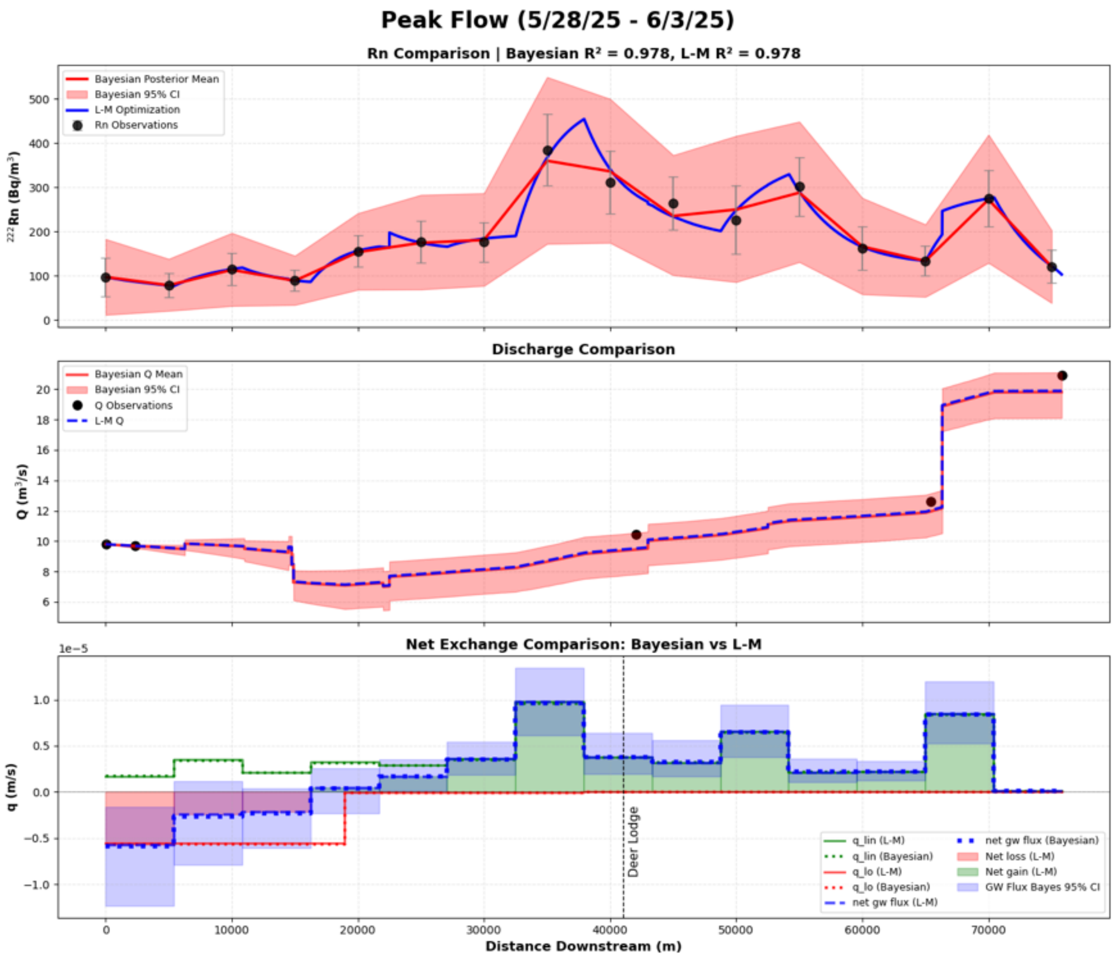
Upper Clark Fork – Estimating Groundwater Net Exchange Using Enivronmental Tracers



- Use radon concentration and discharge to solve for net exchange along the reach.
- Map and quantify the gaining and losing portions of the stream.

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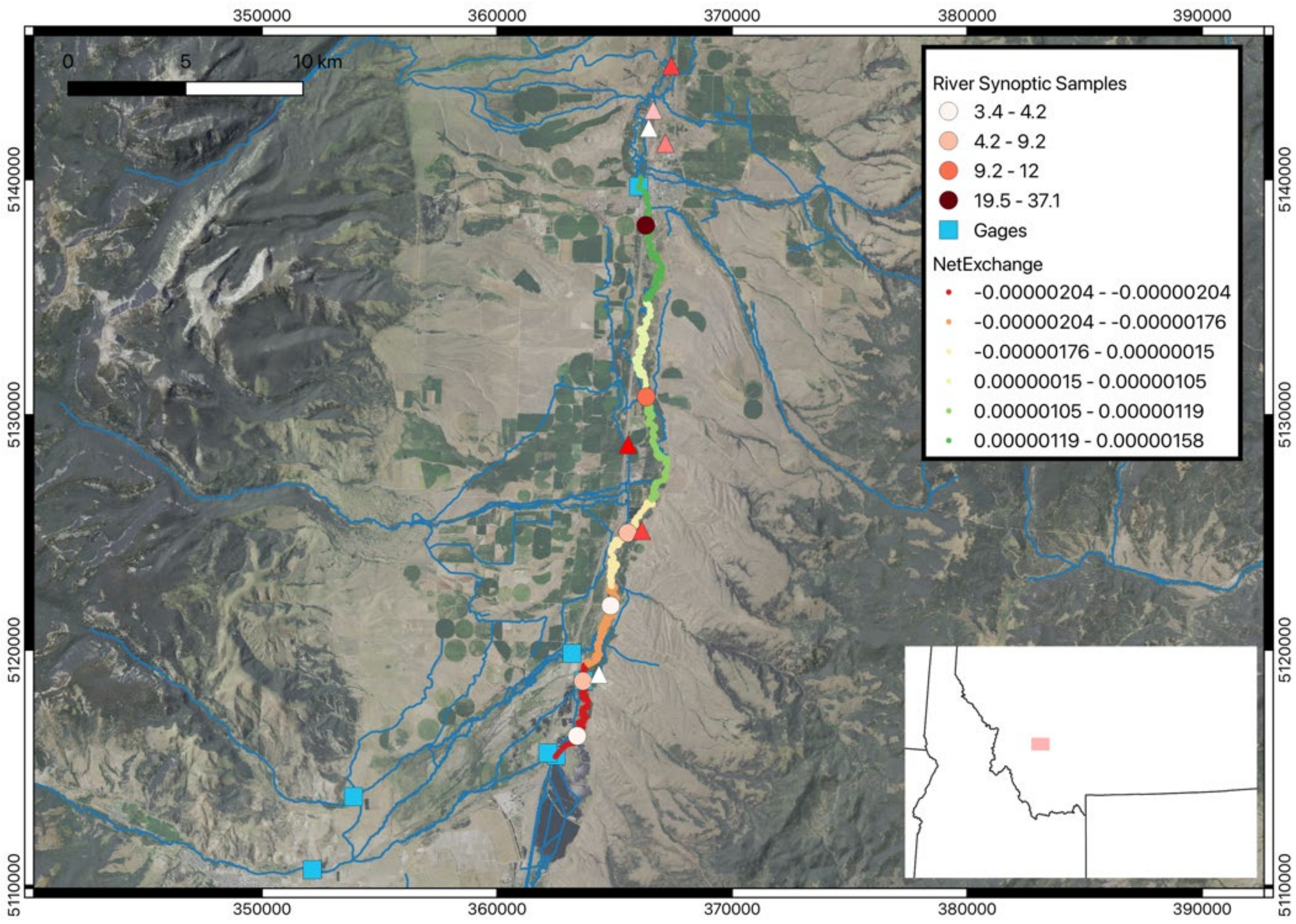
Upper Clark Fork – Estimating Groundwater Net Exchange Using Enivronmental Tracers



- Use radon concentration and discharge to solve for net exchange along the reach.
- Map and quantify the gaining and losing portions of the stream.

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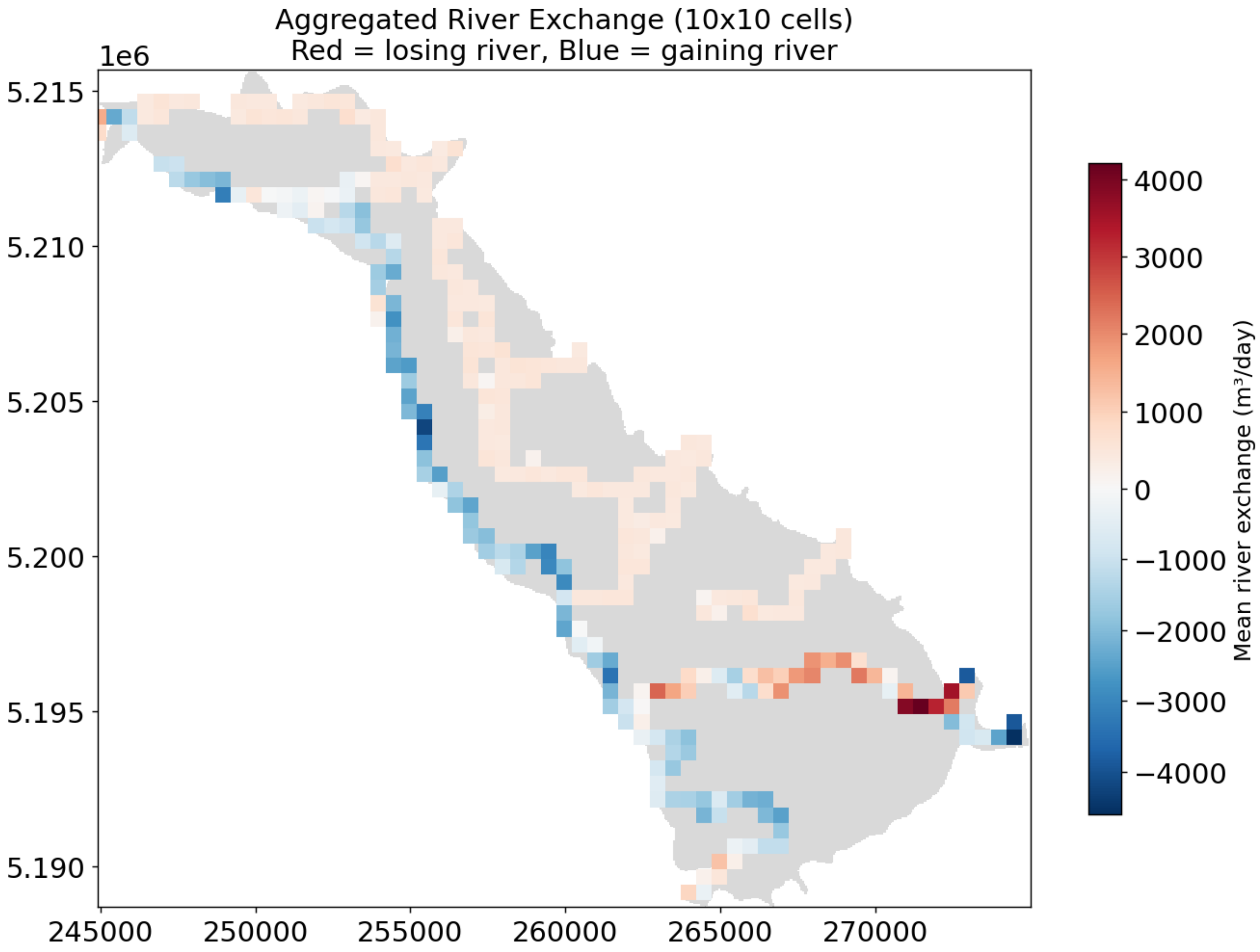
Clark Fork Near Missoula – Modeling Groundwater Exchange



- Modeling Missoula aquifer water nalance
- Missoula Valley is a net groundwater exporter to stream
  - More stream gain than loss
- Streams lose when the enter the valley and gain when they leave
- Mountain block recharge is a major component of the valley aquifer budget

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