Understanding ecosystem processes in the subalpine forests of Wyoming and Colorado under synergistic disturbances from bark beetles, wildfire, and climate change

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Introduction

In the Rocky Mountains, increasing disturbance under climate change affects landscape-scale water and carbon cycles. These ecosystems house the headwaters of many of the United States' most significant watersheds, highlighting a need to anticipate these changes.

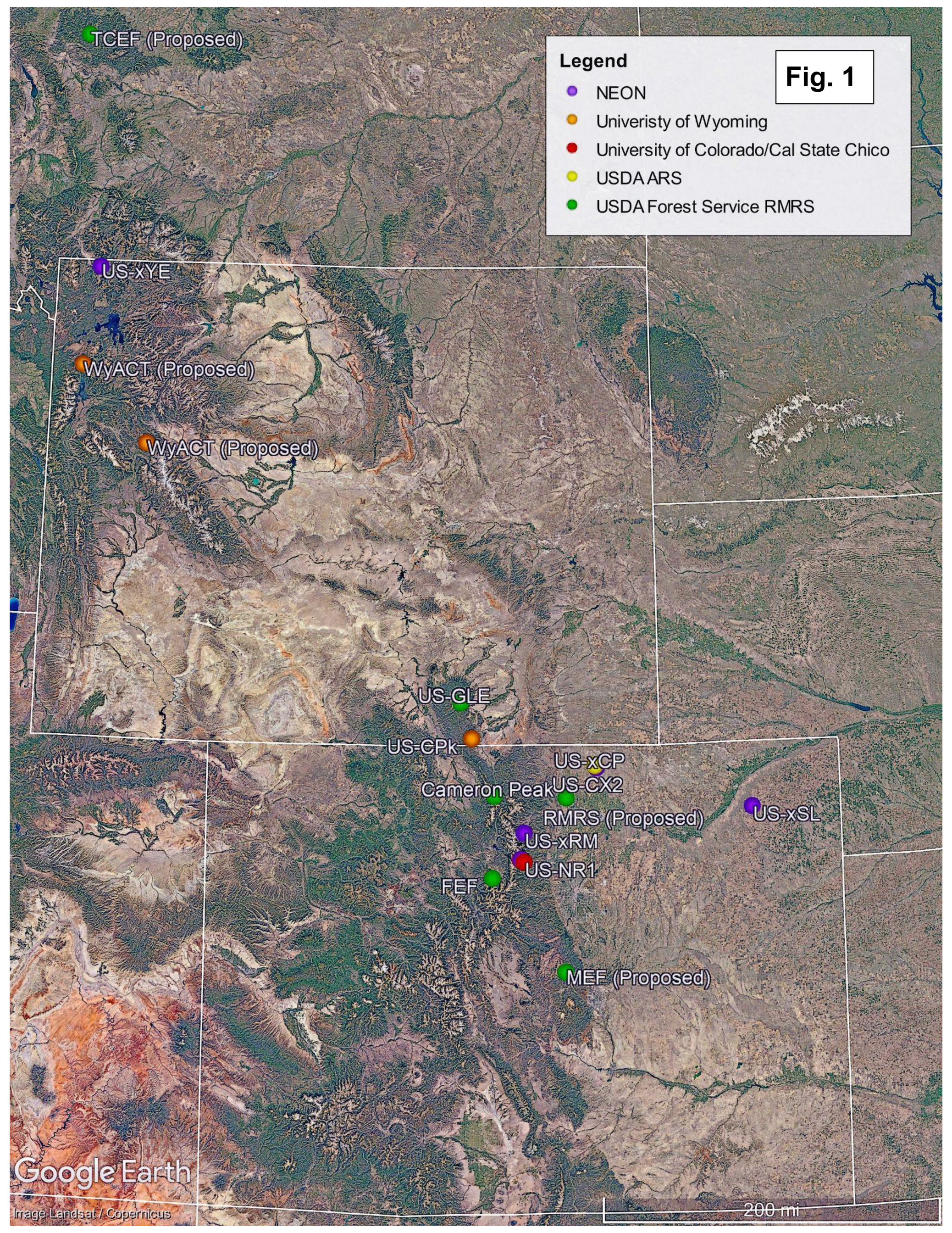
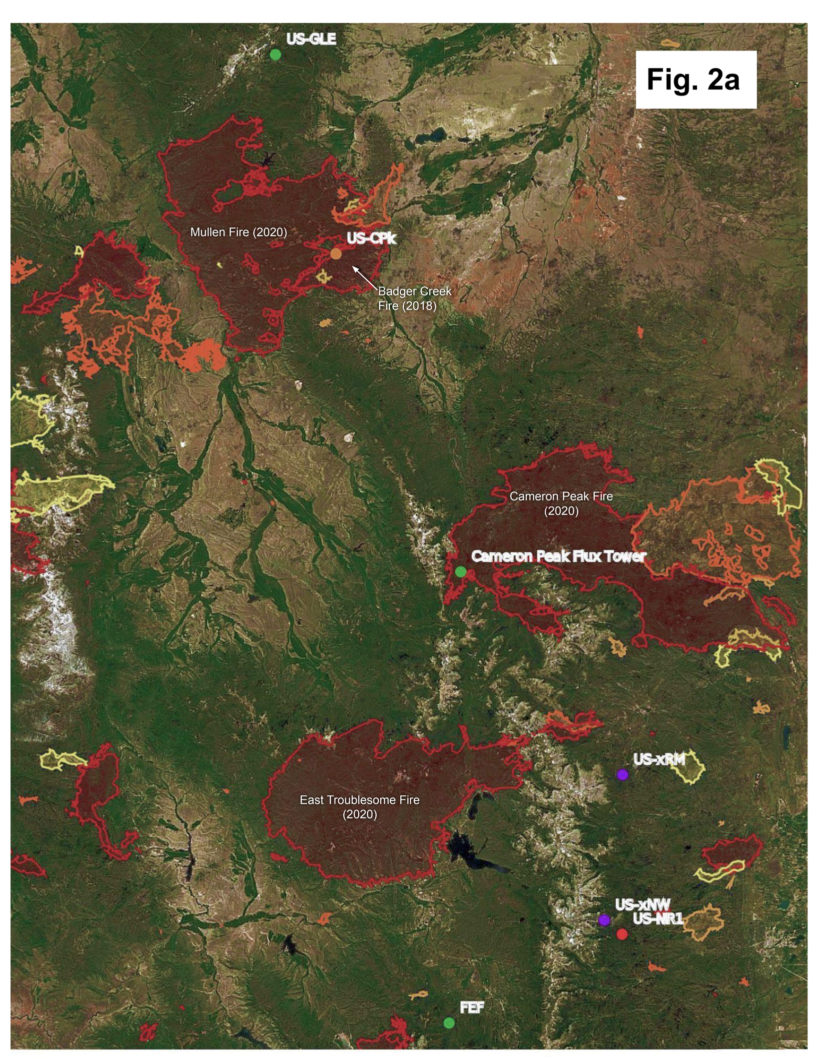


Fig. 1: The currently known active and proposed flux towers in the Wyoming and Colorado Rockies. Additional sites near Niwot Ridge (US-NR3, US-NR4, US-xNW) and the Central Plains Experimental Range (US-CX1) are obscured.



Cameron Peak Flux Tower

In 2020, three unprecedented fires burned in the front range of CO/WY: Cameron Peak (84,000 ha, largest in CO history), East Troublesome (78,000 ha), and Mullen (72,000 ha) (Fig. 2a)

In Nov 2021, a flux tower was installed in a high-altitude, severe-burn region of the Cameron Peak Fire (Fig. 2b). The Cameron Peak site has similar elevation (3090 m) and forest composition (spruce-fir-lodgepole pine) to the unburned Niwot Ridge and GLEES sites

The site will be studied to understand the processes that control forest regeneration following stand-replacing fire during a time of climate change

Fig. 2a (Top): Recent fires in the WY/CO rocky mountains, along with flux towers. The Cameron Peak tower is indicated in the center.
Fig. 2b (Bottom): Nearly two years after the fire, minimal plant recovery has occurred in this high-elevation subalpine forest

Chimney Park (US-CPk)

In 2018, the US-CPk sitw (2740m, lodgepole pine) was destroyed by the Badger Creek Fire (Fig. 2a). The site had previously been used to study the impacts of mountain pine beetle epidemics on subalpine forest.

In 2019, the site was rebuilt and expanded to include three additional understory flux towers representing different disturbance types: bark beetle mortality followed by understory fire, lower bark beetle mortality followed by no fire, and bark beetle mortality followed by a stand-replacing fire.

This site provides an opportunity to study interactions between bark beetle outbreaks and fire, and their effects on post-disturbance recovery.

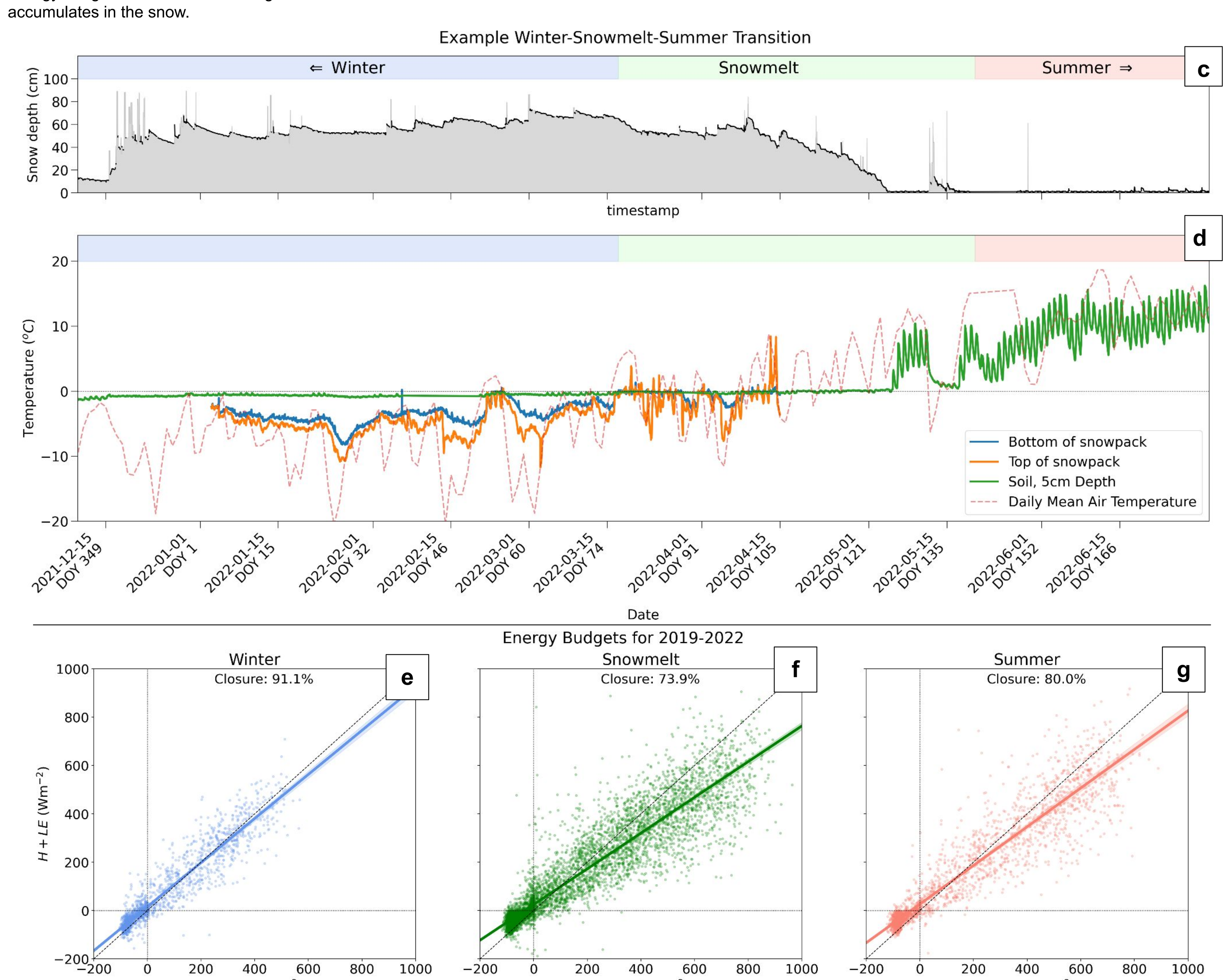
Fig 3: (a) The main 17m tower at US-CPk in 2020
(b) One of the three understory towers at US-CPk, which are deployed in unburned, severely burned, and understory-burned sites
(c,d) Example timeseries showing the progression from winter (persistent snowpack, zero soil heat flux, below-freezing air temperatures) to snowmelt (isothermal/unstable snowpack, near-freezing air temperatures) to summer (no snow, fully thawed soil, warm air temperatures). Summer ends at first snowfall, winter begins at first persistent snowpack.
(e,f,g) Energy budget plots using data from 2019 - 2022. Energy budget closure suffers during snowmelt as latent heat accumulates in the snow.

Heat Storage in Melting Snow

At US-CPk, snowpack can be present from December-June. The snowmelt period at snow-dominated ecosystems, beginning when the snowpack becomes isothermal, is crucial for understanding ecosystem function. Here, this period typically begins in March and lasts for 2-3 months.

Ecosystem composition can interact with the timing of snowmelt: understory-dominated ecosystems may not become active until late spring when they are uncovered, whereas tree-dominated ecosystems can become active much earlier. There is a clear need for accurate flux measurements during this time period.

The melting snow introduces new energy dynamics that are difficult to measure and easy to miss. As a multiphase system, an isothermal snowpack can store large amounts of energy as latent heat without transmitting it into the ground or atmosphere. **This can result in large imbalances in calculated energy budgets that we need to account for with improved snowpack profile monitoring.**



Niwot Ridge (US-NR1)

To estimate forest water content at the US-NR1 site, a pair of GPS receivers was added, one above and one below the canopy. Signal differences between these two units caused by moisture can be used to find the amount of intercepted water/snow in the canopy at 30min intervals (Humphrey & Frankenberg, 2022).[1]

To supplement the canopy interception determined by the GPS units, tree sway sensors estimate the canopy snow interception by snow (Raleigh et al., 2022).

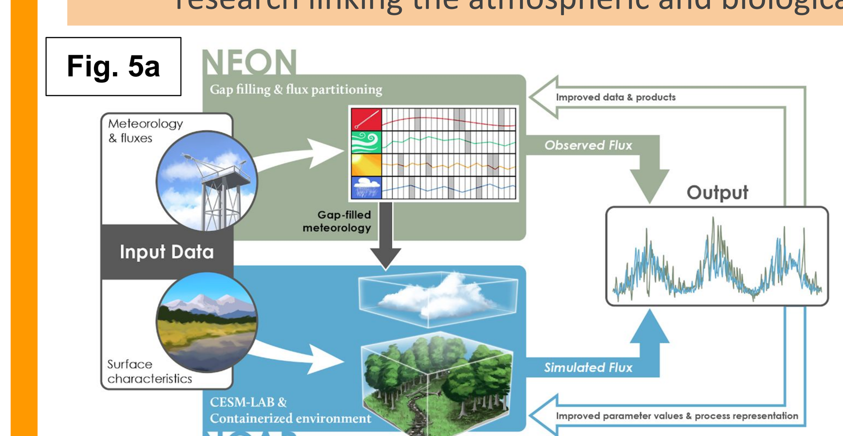
To facilitate model development and testing, a 120m-long track-mounted tram system was built near the site. The tram travels from a mixed conifer forest (with thin rocky soils) to a grass-dominated perennial wetland (with deep, organic-rich soils). The tram carries a modular suite of meteorological sensors, a high-precision inertial/GPS unit, a downward-looking hyperspectral camera, a forward-looking camera for producing 3D structure data, and an upward-looking visible camera with a hemispherical lens that provides fine-scale characterization of plant structure and phenology. The tram will run from snowmelt through the growing season to yield novel data on the spatial water, energy, and vegetation phenology gradients throughout the growing season.[2]

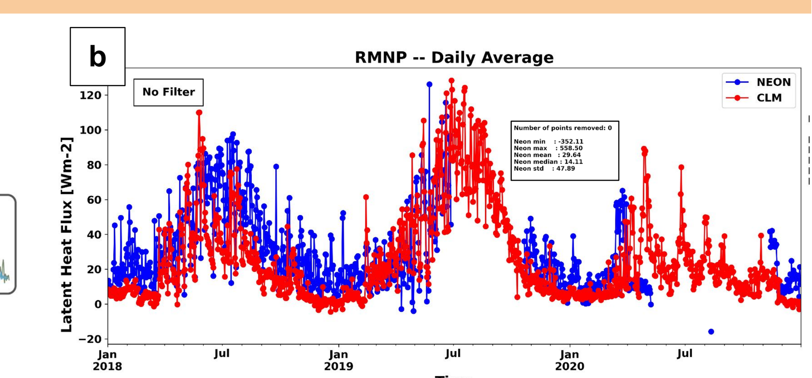
Fig. 4a. GPS units are placed above and below the canopy. Signal differences can be used to infer water interception.
Fig. 4b. Tram-mounted instrument system runs between a mixed conifer forest and a perennial wetland

[1]This work is done with support from UNAVCO and in collaboration with Vincent Humphrey (Cal Tech + University of Zurich), Kristine Larson (CU, retired), Ethan Gutmann (NCAR), and Mark Raleigh (Oregon State).
[2]This work is done in collaboration with Keith Musselman and Nicolas Tarasewicz.

NEON-NCAR Model-Data Integration

- NCAR, PI: Gordon Bonan
- NEON, co-PIs: Mike SanClements, David Durden, Dawn Lenz
- Data CI Pilot: NCAR and NEON cyberinfrastructure collaborations to enable convergence research linking the atmospheric and biological sciences





NEON Data used in CLM simulations:

- *Tower Meteorology*: Temperature, precipitation, pressure, humidity, windspeed
- *Vegetation characteristics*: Dominant plant species
- *Soil characteristics*: Depth, sand and clay fractions, organic content
- *Fluxes for model evaluation*: Latent and sensible heat fluxes, GPP, NEE, net radiation

https://www.neonscience.org/ncar-neon-community-collaborations

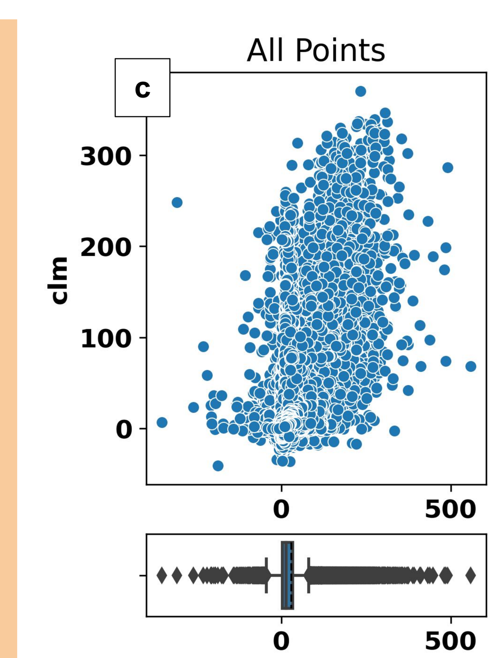


Fig 5: (a) Conceptual diagram of NEON-NCAR Data assimilation
(b) Daily ET in RMNP from NEON and CLM
(c) CLM-NEON validation plot