The impacts of cold-air pooling on Northeastern Temperate Forest structure & function

C. Adair, A. D'Amato, M. Pastore, J.R. Foster, A.T. Classen, M.E. English, M. Landsman-Gerjoi, K. Rand

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Project overview

Cold-air pooling, the accumulation of cold dense air in low-lying areas, is not well understood, but may have large impacts on forests, especially as the climate warms[1]. Cold-air pooling occurs when radiative surface cooling forms dense, cold air that drains downslope and pools in low-lying areas, creating temperature inversions with the lowest temperatures at valley bottoms, where it would typically be warmer. These inversions likely regulate other key environmental conditions, such as soil temperature, soil moisture, humidity, frost frequency, and winter dynamics[2-7]. Because local climate patterns in areas prone to cold-air pooling are decoupled from regional climates, they may be buffered from macroscale climate change[2] and therefore serve as microrefugia for species and ecosystem functions[1].

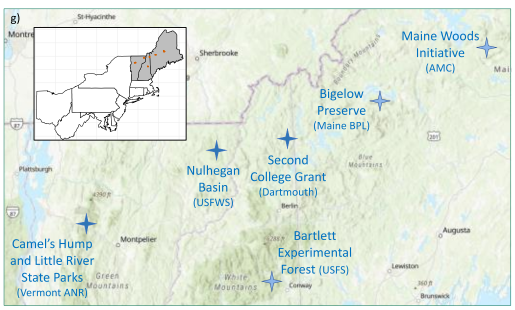

Figure 1. Sites in VT, NH, and ME. Dark and light blue sites (3 transects/site) were established in 2021 and 2022, respectively.

To characterize cold-air pooling across northeastern temperate forests and link cold-air pooling to forest structure and function, we established a unique, cross-scale sensor network in 2021-22 (6 sites, 3 elevational transects per site, 100 plots; Fig. 1). FEMC funding allowed us to continue collecting data from this network (2023-24) and begin analyzing existing and incoming data to **(1)** Characterize the seasonality of cold-air pooling dynamics in northeastern forests and advance our understanding of **(2)** how cold-air pooling dynamics affect forest composition and function and **(3)** if and how cold-air pooling buffers forests from regional climate change.

Completed activities

In April through August 2023, our research team visited each of our 6 sites and downloaded or replaced (when necessary) sensors along each transect. We also trained local partners, including the Appalachian Mountain Club to help us collect sensor data in future years. During the Fall-Winter 2024, we QA/QC'ed sensor data and determined inversion frequency at all 6 sites (see preliminary results). During the summer of 2024, the research team, including several undergraduate research technicians, visited all 6 sites to download data, train with new local partners, and replace iButtons in remote locations with more reliable and longer-lasting temperature sensors. We also had the opportunity to engage with new and existing local partners on project management and longevity. We compiled data sets that characterize forest structure and function at each site and plot, including forest composition, soil carbon, and decomposition (via the and the teabag method[8]).

Preliminary results

As noted in our proposal, we have evidence from three of our sites that cold-air pooling frequency impacts forest composition (Fig. 2). This proposal supported the publishing of this work in *Ecology and Evolution*[9]. In this publication, we found that cold-air pooling was frequent in three of our sites, during all times of day and year and that when cold-air pooling was frequent, cold loving species (e.g., conifers) were at low elevations in valleys, while warm loving species were at higher elevations (e.g., hardwoods).

This year, analyses revealed that cold-air pooling is frequent across all six of our sites, regardless of time of day or season, but is variable across our sites (Fig. 3), and only affects forest composition when cold-air pooling is both frequent and strong.

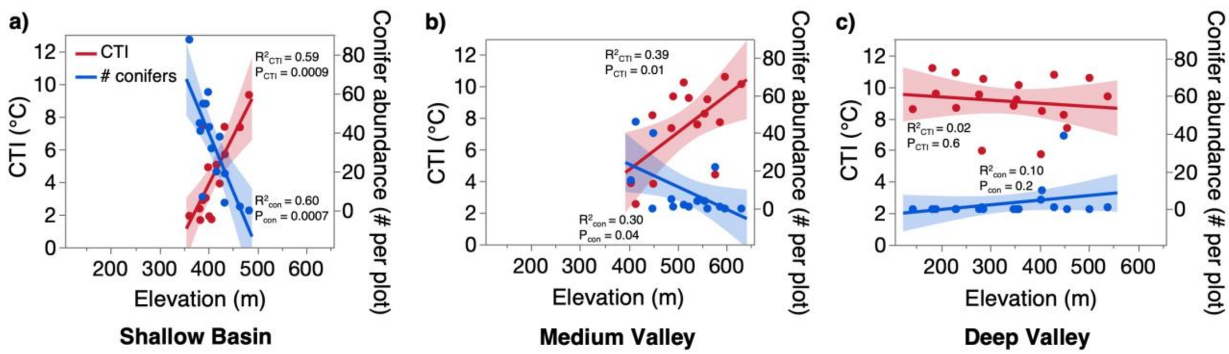

Figure 2. Forest community composition change with elevation is opposite to what is expected at Second College Grant and Nulhegan, where cold-air pooling is frequent: community temperature index (CTI; community weighted mean of species' preferred temperature) increases with elevation, indicating warm-loving species increase with elevation; conifers decline with elevation. Shaded areas = 95% CI of linear regressions. From Pastore et al. (2024)

Further, a comparison of our below-canopy temperature sensor data to above-canopy MODIS land surface temperature data (Daily products MOD21A1D.061 , MYD21A1D.061, MOD21A1N.061, MYD21A1N.061) found that, while our below-canopy sensors found similar frequencies of night-time cold-air pooling events as MODIS data, our below-canopy sensors found frequent day-time inversions; as high as 25-50% of day-time hours for some watersheds. This work was presented at the American Geophysical Union Annual Meeting in December 2023. Submission of this work to *Agricultural and Forest Meteorology* is planned for early 2025.

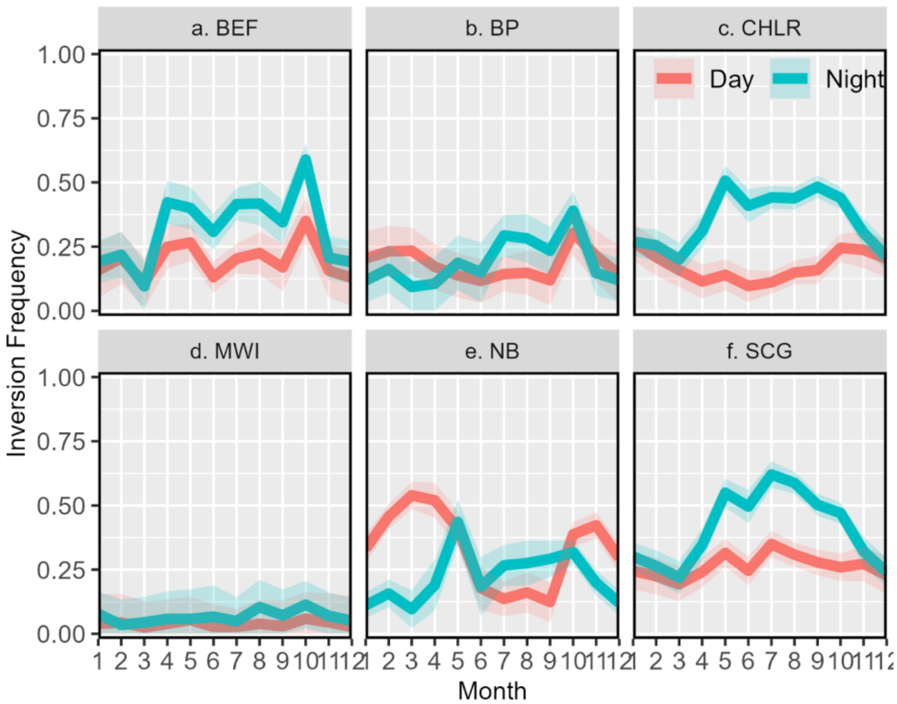

Figure 2. Monthly frequency of day- and night-time temperature inversions (i.e., cold-air pooling) under all-sky conditions identified from below-canopy microclimate transects measuring air temperature at six watersheds in Vermont, New Hampshire, and Maine from 2021-2023: Camel's hump (CHLR), Nulhegan Basin, VT (NB), Second College Grant, NH (SCG), Bigelow Preserve, ME (BP), Bartlett Experimental Forest , NH (BEF), and Maine Woods Initiative. ME (MWI). Day is defined from sunrise to sunset.

Continuing work

We are continuing to work uploading datasets to our FEMC project page (see below) as ongoing data is cleaned and analysed. We submitted an NRCS proposal to continue funding our microclimate data collection (see below) and we continue to work with our partners on maintenance of microclimate transects and data collection. We have also completed soil carbon analyses and are beginning analyses investigating relationships among ecosystem process and cold-air pooling.

Products/Outcomes

Foster, J., M. Pastore, K. Rand, M. English, A.T. Classen, D. King, D. Lutz, S. Nelson, A.W. D'Amato, E.C. Adair. *In Prep.* Climatology of cold-air pooling and thermal belt formation in montane watersheds and forests of the Northeastern US from MODIS data.

Pastore, M., A.T. Classen, A. D'Amato, M.E. English, K. Rand, S. Frey, J.N. Perdrial, E.C. Adair. *2024. Ecology and Evolution.* Frequent and strong cold-air pooling drives temperate forest composition.

Pending grant proposal: Quantifying the Impact of Forest Canopy Structure on Dynamic Thermal and Hydrologic Soil Properties in Eastern U.S. Forests. USDA NRCS. $494,758. 2024-2027. Co-PI with A.W. D'Amato and others.

Webinar: Pastore, M., A.T. Classen, A. D'Amato, M.E. English, K. Rand, S. Frey, J.N. Perdrial, E.C. Adair. A breath of cold air: Do temperature inversions cause forest composition inversions? Northeast Network of Mountain Observatories. June 22, 2023. Monthly Webinar. Presented by M. Pastore.

Poster presentation: Foster, J., M.A. Pastore, K. Rand, M.E. English, E.C. Adair, A.T. Classen, A.T. D'Amato. December 2023. Below-canopy Temperature Inversions More Common and Persistent in Temperate Forests Than Land Surface Temperatures Suggest. American Geophysical Union Annual Meeting.

Seminar: Pastore, M., A.T. Classen, A. D'Amato, M.E. English, K. Rand, S. Frey, J.N. Perdrial, E.C. Adair. A breath of cold air: Do temperature inversions cause forest composition inversions? University of New Hampshire, April 6, 2023. Earth Systems Research Center Spring Seminar. Presented by M. Pastore.

Oral presentation: S. Hanson & G. Wang. Cold-air pooling perennial internship results. Fall Internship & Research Slam. RSENR, UVM. October 2024.

FEMC Project page: https://www.uvm.edu/femc/data/archive/project/cold-air-pooling

Selected press coverage:

- Radio: https://www.vermontpublic.org/local-news/2024-05-03/how-pockets-of-cold-air-in-new-england-may-help-plants-survive-a-changing-climate
- Nautilus Magazine: https://nautil.us/a-buffer-zone-for-trees-583899/?_sp=64a8e079-dee9-4296-911c-f2209b3fc7ed.1715357137972

Next steps

In the coming months we will continue finalizing and analyzing existing temperature and moisture data sets from our in-situ sensors, as well as data sets that describe forest structure and function. We will update datasets on our FEMC project page.

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