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Editorial: Resolving atmospheric flow in complex environments: recent experiments in terrain and forest canopies

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Editorial on the Research Topic
Resolving atmospheric flow in complex environments: recent experiments in terrain and forest canopies

1 Introduction

The characterization of atmospheric flows in complex environments, which may include steep terrain slopes and heterogeneous vegetation and/or forest cover, is a long-standing challenge in boundary-layer meteorology. Atmospheric observations are complicated by the presence of transient, terrain-induced flow features, forest-canopy-atmosphere interactions, and atmospheric stability effects, not to mention the logistical hurdles involved with instrument deployment, data analysis, and quality control. Furthermore, challenges in atmospheric modeling arise due to numerical errors associated with complex terrain flows, as well as reliance on simplified parameterizations for unresolved processes such as turbulent mixing and land-surface or forest-canopy-atmosphere interactions. These modeling challenges are exacerbated in the so-called “gray zone,” wherein features of interest have length scales that are similar to the model grid spacing, or when the principal flow layer is smaller than the grid spacing (e.g., slope flows).

Despite these difficulties, recent advances in measurement and modeling approaches have enabled innovative research. As summarized in Figure 1, this special Research Topic includes seven studies spanning different application areas (from complex terrain to forests) and research approaches (including field observations, modeling, and laboratory experiments). Here, we summarize each study and place it in the context of the challenges discussed above. First, we discuss scientific process studies, which are

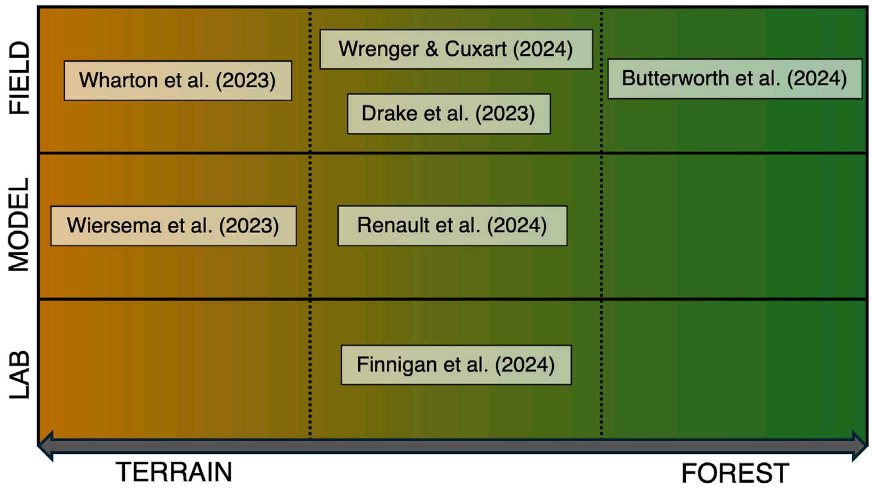

FIGURE 1
A graphical summary of the contributions to this Research Topic grouped by focus area (spanning complex terrain to forests) and primary research method (spanning field observations, modeling, and laboratory experiment).

generally focused on forest–canopy-atmosphere interactions, including terrain effects. Second, we discuss applied studies in the presence of complex terrain or vegetated canopies.

2 Scientific process studies

Four studies in this Research Topic use observational or experimental approaches to characterize forest-canopy-atmosphere interactions; two focus on spatially varying forest processes and two others consider canopy effects on wind flows. Butterworth et al. used multi-tower eddy covariance (EC) to study the surface energy budget over a forested area that is interspersed with open water surfaces and wet meadows, as part of the Chequamegon Heterogeneous Ecosystem Energy-balance Study Enabled by a High-density Extensive Array of Detectors 2019 (CHEESEHEAD19). They found that imbalances in the measured surface energy budget varied spatially, highlighting the effects of forest heterogeneity, particularly in terms of canopy height. The dense experimental setup also allowed Butterworth et al. to test the effectiveness of spatial EC, an emerging technique that uses spatial averaging rather than temporal averaging (as in traditional EC) to calculate fluctuating quantities.

Drake et al. also used multi-tower EC, but to characterize evaposublimation processes in a montane conifer forest. The novel experimental design, which included five towers deployed over three consecutive winters, enabled flux measurements over a range of canopy densities (including an open meadow), snow cover, and meteorological conditions. Furthermore, to alleviate the difficulty in measuring subcanopy evaposublimation, Drake et al. created an environmental response function to generalize their measured results over a wider region.

While the previous two studies deployed multiple meteorological towers, Wrenger and Cuxart used a three-dimensional sonic anemometer mounted on an unmanned aerial vehicle (UAV) to measure vertical profiles of wind, temperature, and turbulence at multiple locations in a sloping, forested region. By comparing in-forest observations to those in a nearby clearing, they inferred the effect of the canopy on katabatic (i.e., downslope) flows. Additionally, they observed seasonal differences in flow profiles related to leaf area density.

Finnigan et al. also investigated the effects of sloping terrain and canopy on wind flows. However, unlike the aforementioned field studies, they used a novel laboratory setup to characterize the physical mechanisms governing the flow. In particular, Finnigan et al. measured gravity currents that were generated by cooling within the canopy layer and showed that they can propagate away from the genesis topography. This result could have important implications for real world measurements; for example, gravity currents generated by non-local topography could still affect surface-atmosphere interactions at “flat” terrain sites.

3 Applied studies

Three additional studies in this Research Topic focus on meteorological applications for complex terrain, with and without forest cover. Two of these are associated with the Nevada National Security Site Meteorological Experiment (METEX21), a large-scale field campaign focused on plume transport and dispersion over complex terrain. Wharton et al. describes the experimental setup, which included a variety of atmospheric instrumentation such as EC towers, three-dimensional sonic anemometers, profiling Doppler lidars, scanning Doppler lidars, and a tethered balloon system. Smoke tracer releases were also measured with cameras, aerosol sensors, and lidar backscatter. Wharton et al. present examples of synoptically driven periods, with relatively narrow plumes, and locally driven periods, during which complex terrain flows lead to more variable plume dynamics.

In a related study, Wiersema et al. use METEX21 observations to evaluate a multiscale modeling approach that bridges the meso- and micro-scales using the Weather Research and Forecasting

(WRF) model. They demonstrate that the subgrid-scale turbulence parameterization influences modeled plume behavior, especially during locally driven periods. As noted by Wharton et al., a main finding of METEX21 was the effectiveness of scanning Doppler lidars in measuring plume behavior, and Wiersema et al. used virtual lidar output to compare model predictions with these measurements.

As a fast-running alternative to the full multiscale approach adopted by Wiersema et al., Renault et al. added a canopy wind solver to the Quick Urban and Industrial Complex (QUIC-URB) model. Their model can represent spatially heterogeneous canopies over weakly complex terrain, and can downscale WRF output to the meter scale for operational applications that prioritize computational efficiency.

4 Conclusion

In summary, this special Research Topic comprises seven studies that use a variety of approaches to improve our understanding of atmospheric boundary-layer dynamics in regions with complex terrain and forest cover. Several themes emerge, including the need for novel field deployments to capture spatial heterogeneity, as well as the need for process-level understanding that can be used to extend knowledge beyond particular study areas. Furthermore, modeling approaches can be tailored to different applications by treating land-surface and forest-canopy-atmosphere interactions with an appropriate level of fidelity. We believe that this Research Topic provides a valuable snapshot of recent advancements in characterizing atmospheric flow in complex environments, and hope that it serves to guide future research efforts.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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