Analysis of urban greenhouse gas dispersion for downtown Montréal using computational fluid dynamics

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In order to better quantify the impacts of urban greenhouse gas (GHG) emissions on climate, precise knowledge of their spatial and temporal variability is necessary. The highly complex built environment of cities leads to strongly local dispersion characteristics, significantly affecting the distribution of GHGs. These emissions also impact human health, with byproducts from fossil fuel usage substantially reducing air quality. This study uses computational fluid dynamics (CFD) in conjunction with a robust field measurement campaign to simulate and investigate the distribution of GHGs in the downtown region of Montréal, Canada, for the day of February 21, 2024. CFD is uniquely advantaged in its ability to provide GHG concentrations at every location in an area of study, especially important in urban environments. Incompressible and compressible Reynolds-averaged Navier-Stokes simulations and large eddy simulations are carried out using the open-source CFD software OpenFOAM to investigate the effects of stability and turbulent flow on the dispersion of GHGs across the city. Radiosondes, drones, GHG sensors, a Doppler lidar, and aircraft measurements are used to initialize model components such as wind velocity and background GHG concentration profiles, as well as to validate the simulation results. Two main GHGs are considered, carbon dioxide and methane, due to their frequent emissions in cities. The computational domain, which is centered on the campus of McGill University, is created in accordance with best practice guidelines to ensure the quality of the results. Significant changes in wind direction with height require a novel process of assigning boundary conditions. The primary source of GHG emissions come from McGill's central heating plant, while other sources in the model include traffic emissions and large government buildings nearby. The resulting wind fields and GHG distributions are then analyzed. The concentrations of the various GHG species are found to be highly heterogeneous based on the local wind conditions. As such, the most optimum locations for GHG monitoring stations can be identified to either allow for more representative sampling of citywide emissions or to specifically investigate local areas of anomalously low or high concentrations. Simulation results such as these can also be used for satellite source inversion modelling, allowing for better estimations of urban GHG emissions. Further, the spatiotemporal variation in GHG concentrations has the potential to alter the Earth's energy budget, and the effects of the city's emissions on climate are discussed.

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