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Computational fluid dynamics (CFD) simulation of CO_2 emission from a thermal power plant in an urban environment.

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Climate change, a societal challenge for the European Union, is affecting all regions in Europe and has a profound impact on society and environment. It is now clear that the present global warming period is due to the strong anthropogenic greenhouse gas (GHG) emission, occurring at an unprecedented rate. Therefore, the identification and control of the greenhouse gas sources has a great relevance. Since the GHG emissions from cities are the largest human contribution to climate change, the present investigation focuses on the urban environment. Bottom-up annual emission inventories are compiled for most countries. However, a rigorous approach requires to perform experimental measurements in order to verify the official estimates. Measurements of column-averaged dry-air mole fractions of GHG (XGHG) can be used for this. To comprehensively detect and quantify GHG emission sources, these punctual column data, however, have to be extended to the surrounding urban map, requiring a deep understanding of the gas transport. The resulting emission estimation will serve several practical purposes, e.g. the verification of official emission rates and the determination of trends in urban emissions. They will enable the administration to make targeted and economically efficient decisions about mitigation options, and help to stop unintentional and furtive releases.

With this aim, this investigation presents a completely new approach to the analysis of the carbon dioxide (CO_2) emissions from fossil fuel thermal power plants in urban environments by combining differential column measurements with computational fluid dynamics (CFD) simulations in order to deeply understand the experimental conditions. The case study is a natural gas-fueled cogeneration (combined heat and power, CHP) thermal power plant inside the city of Munich (Germany).

The software used for the simulations (OpenFOAM) was modified in order to use the most advanced RANS turbulence modeling (i.e. Durbin) and parametrization for the fluid flow, and to consider the turbulent eddy dissipation for gas transport and diffusion. Turbulence and gas transport and diffusion modeling are initially validated by reproducing a wind-tunnel benchmark case.

The full-scale simulation results are compared with the Gaussian plume model, and an improvement of such model is suggested for being used in the urban environment. CFD resolves the turbulent eddy dissipation phenomena that enhance the gas diffusion close to building roofs, which is not considered by the Gaussian model.

The results are also compared with experimental measurements of XCO_2 on the site. The XCO_2 is calculated from the simulation results both considering a vertical column and the real axis of measurement at that time. The results show that the XCO_2 values expected for a vertical column are less representative for the measurement, but the real measurement axis angle needs to be considered. These results help to design experimental strategies in future campaigns.

In addition, CO_2 concentration maps for the city are obtained from the simulations. These concentration maps are presented and the CO_2 spatial distribution is analyzed.