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Modeling The Anthropogenic CO_2 Footprint in Europe Using a High Resolution Atmospheric Model

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The localized nature of most fossil fuel emission sources leaves a distinct footprint on atmospheric CO_2 concentrations, yet to date, most studies have used relatively coarse atmospheric transport models to simulate this footprint, causing an excess amount of spatial smoothing. In addition, most studies have considered only monthly variations in emissions, neglecting their substantial diurnal and weekly fluctuations. With the fossil fuel emission fluxes dominating the carbon balance in Europe and many other industrialized countries, it is paramount to simulate the fossil fuel footprint in atmospheric CO_2 accurately in time and space in order to discern the footprint of the terrestrial biosphere. Furthermore, a good understanding of the fossil fuel footprint also provides the opportunity to monitor and verify any change in fossil fuel emission.

We use here a high resolution (7 km) atmospheric model setup for central Europe based on the operational weather forecast model COSMO and simulate the atmospheric CO_2 concentrations separately for 5 fossil fuel emission sectors (i.e., power generation, heating, transport, industrial processes, and rest), and for 10 different country-based regions. The emissions were based on high-resolution emission inventory data (EDGAR(10km) and MeteoTest(500m)), to which we have added detailed time functions for each process and country. The total anthropogenic CO_2 footprint compares well with observational estimates based on radiocarbon (C14) and CO for a number of sites across Europe, providing confidence in the emission inventory and atmospheric transport. Despite relatively rapid atmospheric mixing, the fossil fuel footprint shows strong annual mean structures reflecting the point-source nature of most emissions. Among all the processes, the emissions from power plants dominates the fossil fuel footprint, followed by industry, while traffic emissions are less distinct, largely owing to their spatially more distributed nature. However, on shorter time-scales, atmospheric transport leads to strong plume-like patterns, causing a high degree of variability on the mesoscale and up to synoptic scales. This variability is enhanced through the temporal variability of the emissions. The time-variations in the emissions also cause an annual mean reduction in the near surface atmospheric CO_2 concentration of several ppm relative to a simulation with time-invariant emissions, owing to a diurnal "rectification" effect with atmospheric transport and mixing. Finally, we also conducted a few ensitivity analyses to check how well regional reductions of fossil fuel emissions can be detected by various atmospheric CO_2 observing systems, including satellites. Our results suggest that the fine-scale spatiotemporal pattern of the fossil fuel footprint offer specific opportunities for detection beyond the changes in annual mean atmospheric CO_2.