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Impacts of COVID-19 lockdown restrictions on urban NO_2 and O_3 level in Germany with consideration of meteorological impacts and seasonal variation

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In 2020, the entire world population has witnessed an unprecedented virus outbreak in terms of COVID-19, which led to restrictions in human activities across the world. Strict measures in Germany started on March-21, 2020 and ended on April-30, 2020, while more relaxed measures continued until July 2020. Vehicle traffic volume and industrial activities were drastically reduced, and, as a result, pollutant emission rates were expected to be reduced. Changes in atmospheric pollutant concentrations are an indicator for changes in emission rates although they are not directly proportional as concentrations are heavily influenced by meteorological conditions and as atmospheric photochemical reactions can be non-linear. Without accounting for the influence of meteorology and atmospheric photochemical reactions, a simple comparison of the lockdown period pollutant concentration values with pre-lockdown only to estimate emissions could be misleading. To normalize the effects of meteorological conditions and atmospheric chemical transformation and reactions, we adopted a method of comparing the predicted Business As Usual (BAU) NO_2 and O_3 concentrations, i.e., the expected value of NO_2 and O_3 concentration for 2020 meteorological conditions without lockdown restrictions, with the observed NO_2 and O_3 concentrations. BAU NO_2 and O_3 concentrations corresponding to 2020 meteorological conditions were predicted based on wind speed and sunshine duration (and season of the day) using the previous year NO_2 and O_3 concentrations as the references. Compared to BAU levels, big metropolitan cities in Germany show a decline in observed NO_2 level (-24.5 to -37.7 %) in the strict lockdown period and rebound to the BAU level at the end of July 2020. In contrast, there is a marginal change in O_3 level (+9.6 to -7.4 %). We anticipate that the imbalanced changes in precursors emission (decrease in NO_X and increase in volatile organic compounds (VOCs) emission) are attributed to the marginal changes in observed O_3 level compared to BAU level; decreased NO_X would decrease the O_3 concentration due to NO_X-limited conditions, and increased VOCs would increase the O_3 concentration. These results imply that the balanced emission control

between the VOCs and NO_X are required to limit the secondary pollutant (O_3) formation.