Supplement of

Satellites reveal a 28% drop in Ukraine's Nitrogen oxides emissions during the Russia-Ukraine war in 2022

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- Supplemental texts S1
- Figures S1 to S15
- SI References

Supplemental Texts

Text S1: NO_x Emissions During the Pandemic

The impact of the 2020 epidemic on NO_x emission reductions in Ukraine was relatively modest and transient compared to the effects of the war. The widespread outbreak of the coronavirus disease in Ukraine in 2020 commenced in April (Malarvizhi et al., 2023) and was accompanied by a notable reduction in emissions, followed by a comparatively smaller decline in emissions observed in May. The industry sector was the most affected during the 2020 pandemic, although to a lesser extent than during the war. A 15% (±3.3%) reduction was observed between April and December. Transportation was the second-most affected sector during the pandemic, exhibiting a greater decline than housing and agriculture. Energy consumption data from SSCU indicate that Ukraine's coal and oil consumption in 2020 decreased by 6% and 3%, respectively, compared with those in the baseline year. This also corroborates the impact of the pandemic on Ukrainian industry and transportation. The seasonal fluctuations observed in the industrial and transportation sectors were more pronounced, with notable declines in emissions occurring in April and June (Figs. S7, S8). In contrast, both the agricultural and residential sectors exhibited a return to similar levels of emissions as those observed in regular years following a significant decline in April.

The NO_x emissions in Ukraine during the pandemic exhibited a stronger decrease in the western regions, although the relative difference was not as significant as that in 2022 (Fig. S13–S15). The observed changes in emissions across all sectors in the Eastern Ukraine and Western Ukraine were smaller than those observed in 2022; however, the reduction in transport emissions during the Western Ukraine epidemic was comparable to that observed during the war. This can be attributed to the fact that the epidemic did not result in a significant loss of population, and that the home quarantine policy implemented during the epidemic reduced transport emissions while suppressing the reduction in agricultural and residential emissions. Compared with that of 2022, the impact of the 2020 epidemic appears to have been more evenly distributed across the different regions of Ukraine. Emissions from the industrial sector remained the most affected but decreased by slightly over 10% in both the Eastern Ukraine and Western Ukraine. This is partly because the industrial sector is the largest source of NO_x

emissions in Ukraine, and partly because of the challenges posed to industrial production by both epidemic and war.

Supplemental Figures

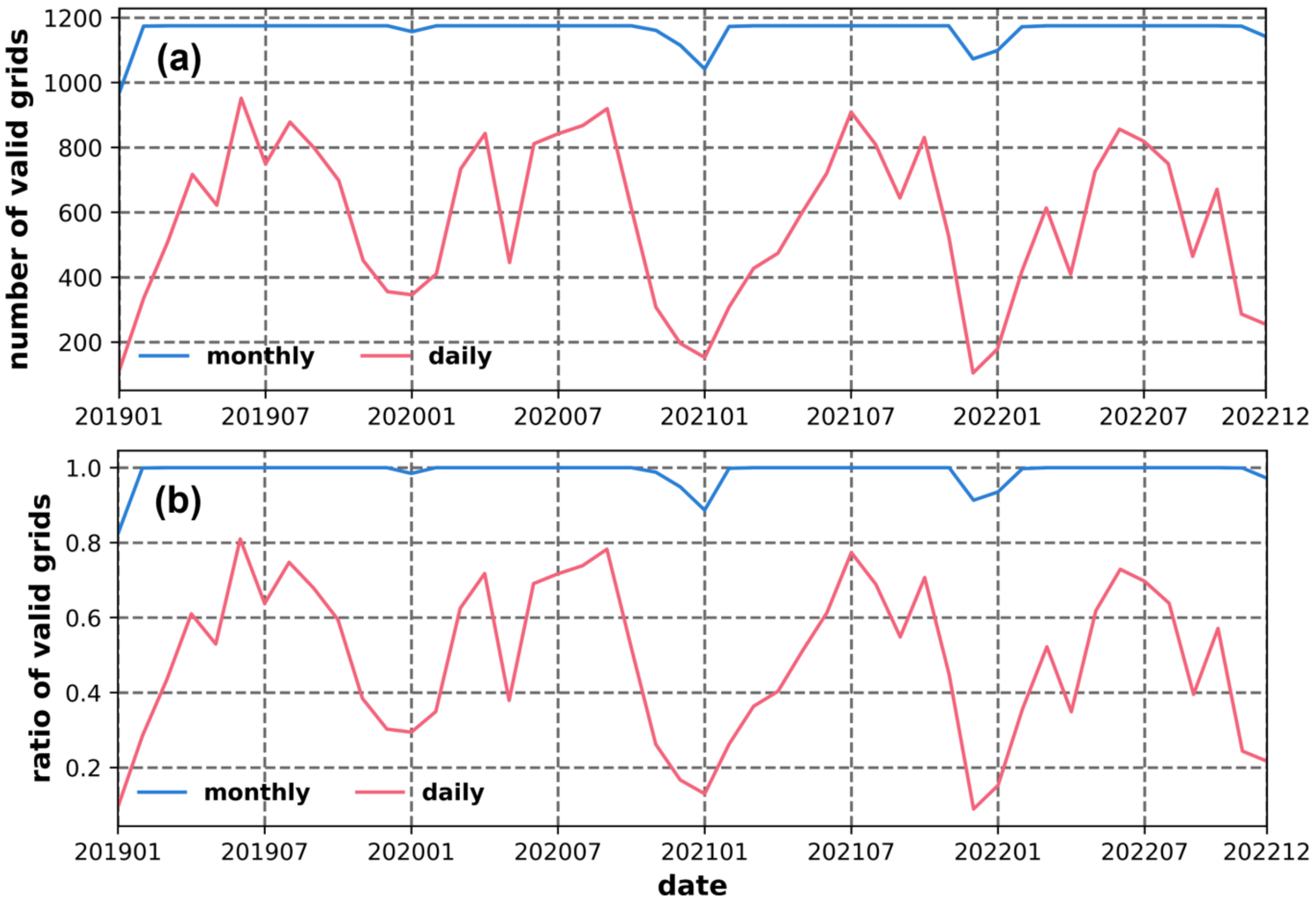

Fig. S1. (a) Number monthly averages of daily (red) and monthly-scale (blue) valid observation grids of TROPOMI in Ukraine in 2019~2022. (b) Ratios of monthly averages of daily (red) and monthly-scale (blue) valid observation grids of TROPOMI to the total number of grids in Ukraine in 2019~2022.

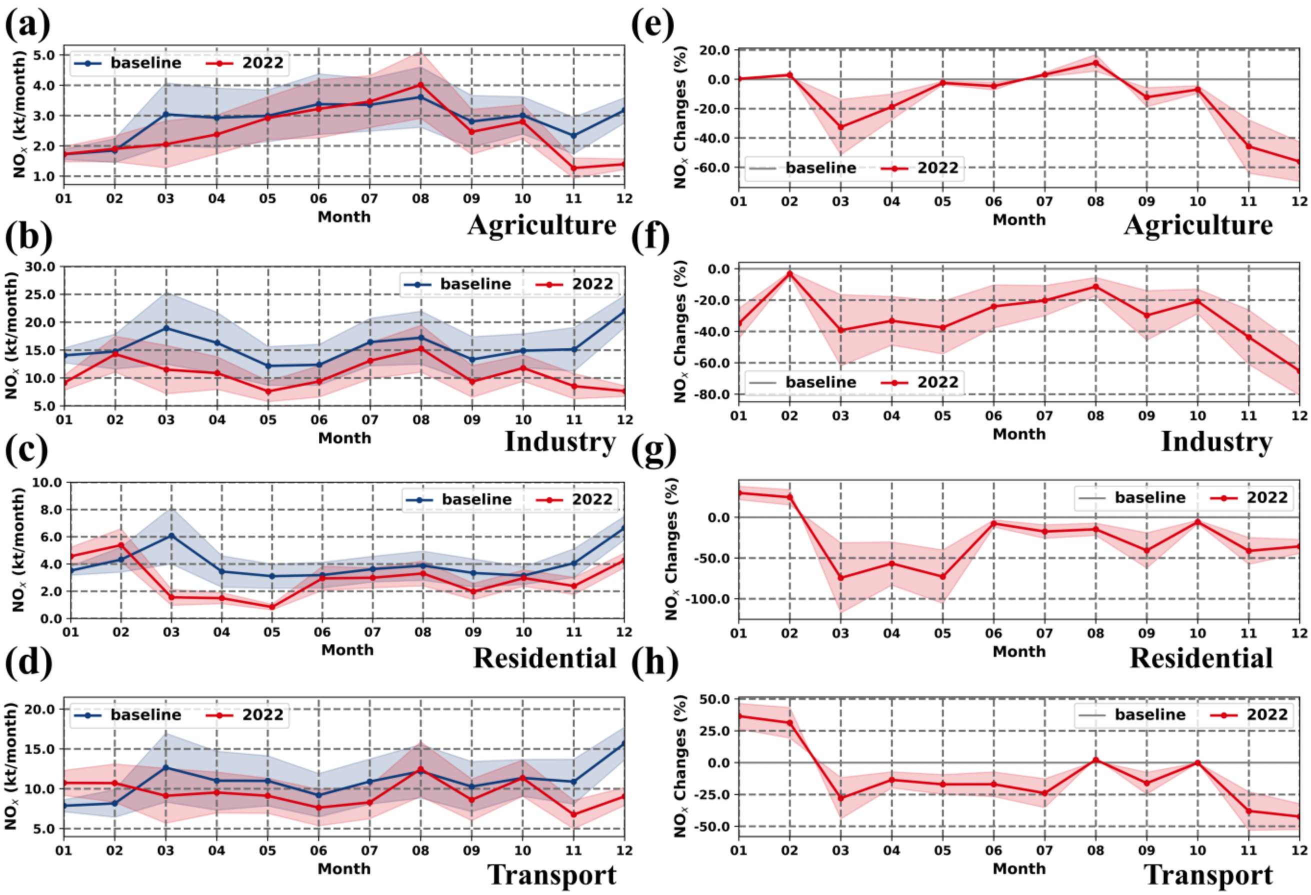

Fig. S2. Seasonal changes of sectoral NO_x emissions in Ukraine in 2022, and the relative changes with baseline year.

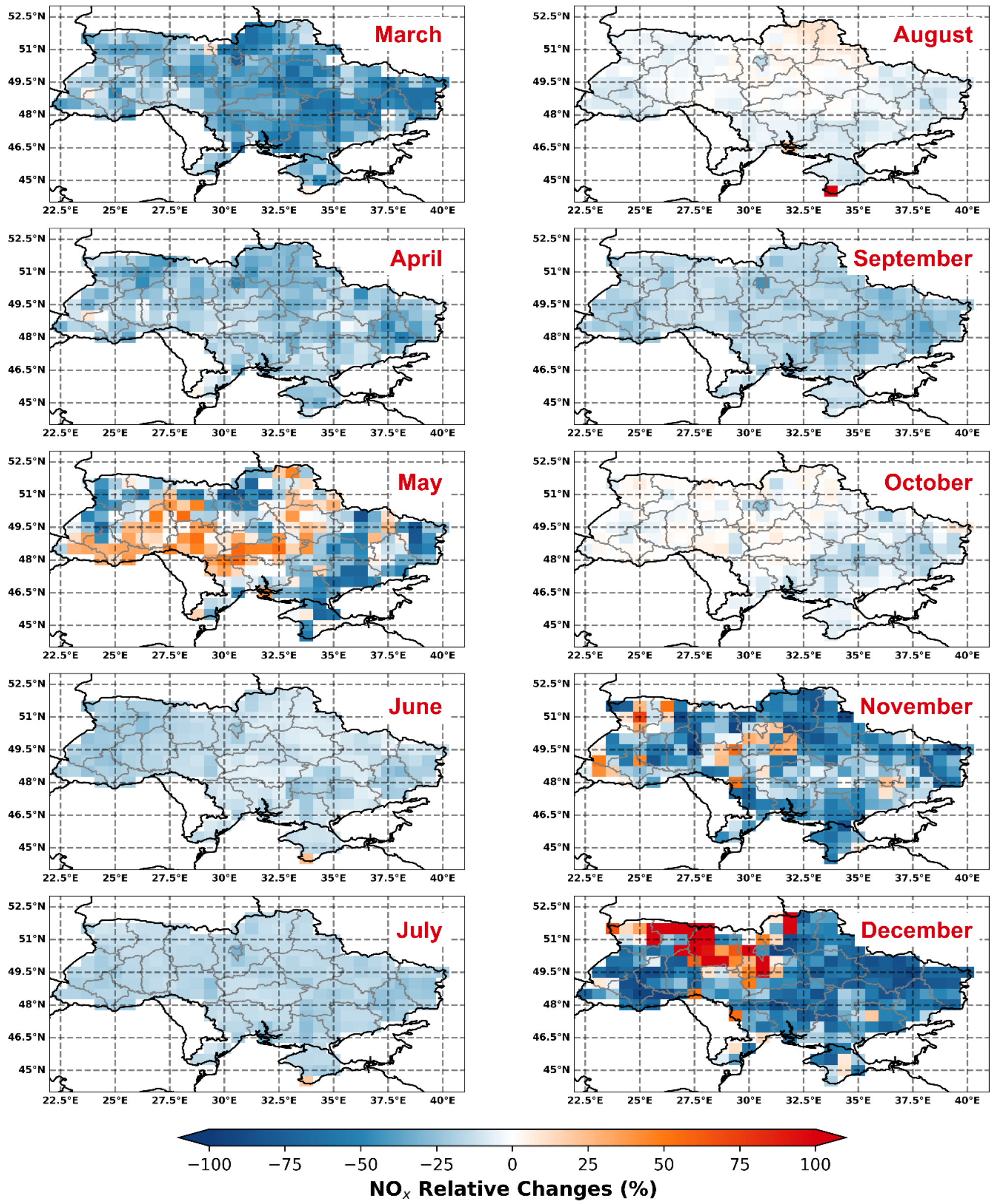

Fig. S3. Spatial distribution of monthly NO_x emission changes during the war (March to December) in 2022 relative to the baseline year.

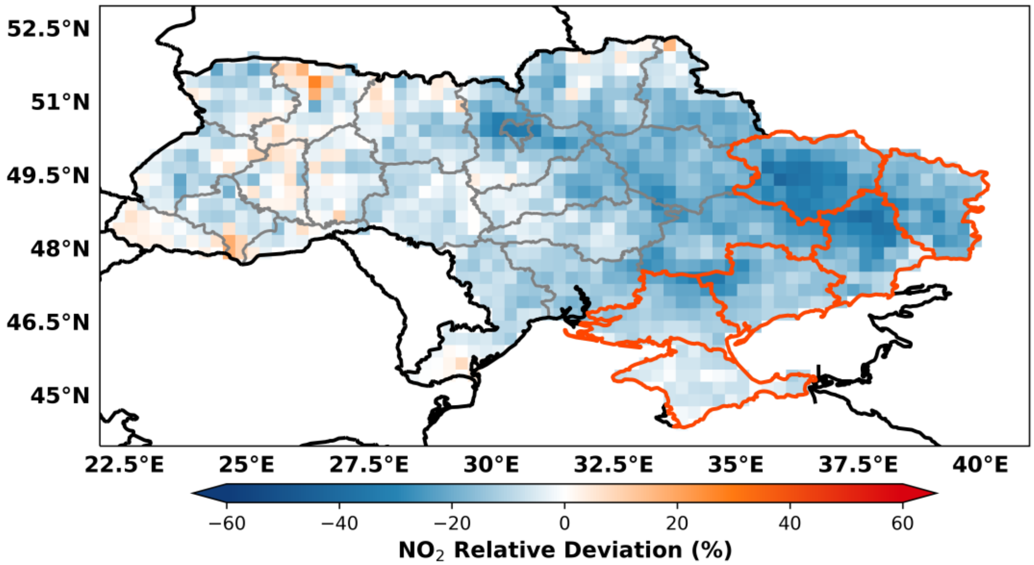

Fig. S4. The Spatial changes in satellite-observed NO_2 VCDs are illustrated during the war (March to December) in 2022 relative to the baseline year.

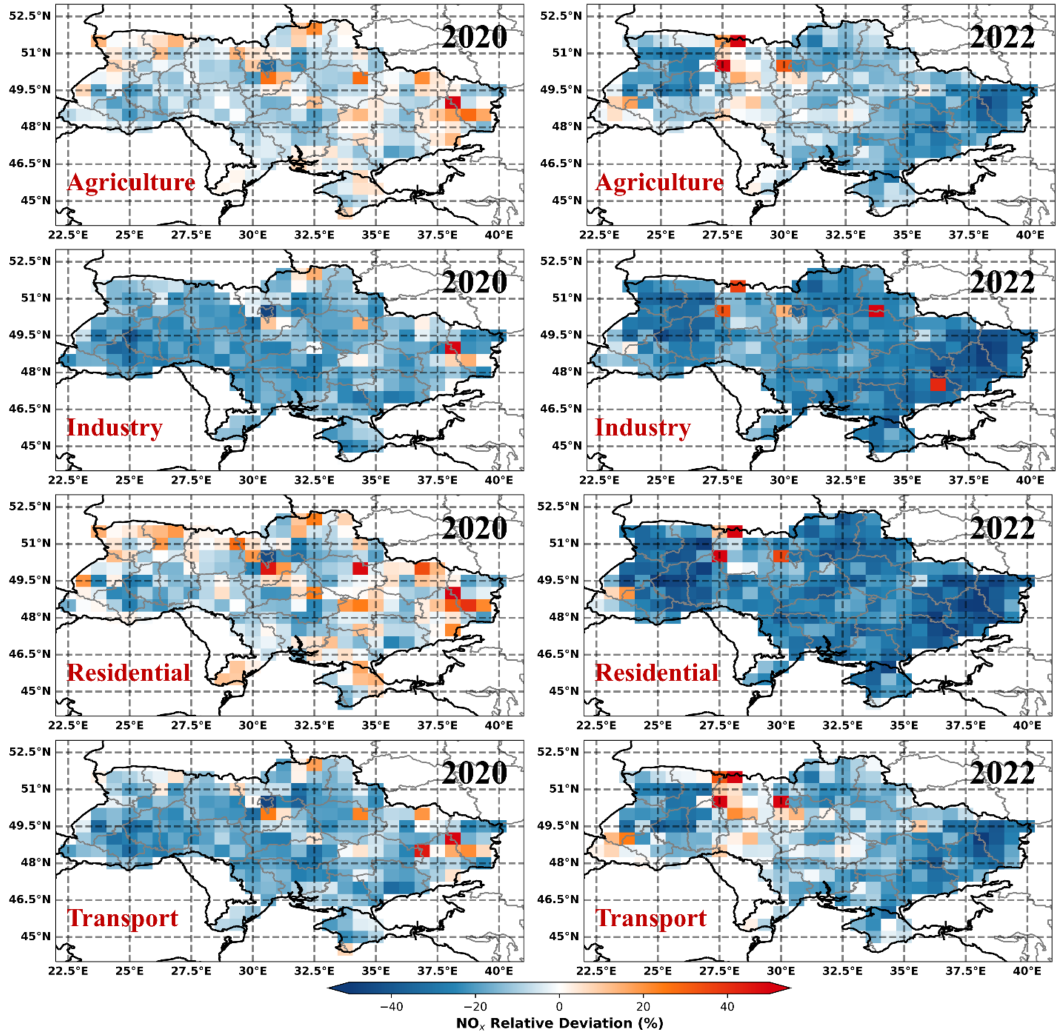

Fig. S5. Spatial variation of sectoral NO$_x$ emissions in Ukraine during COVID-19 epidemic (April to December) in 2020 and war (March to December) in 2022.

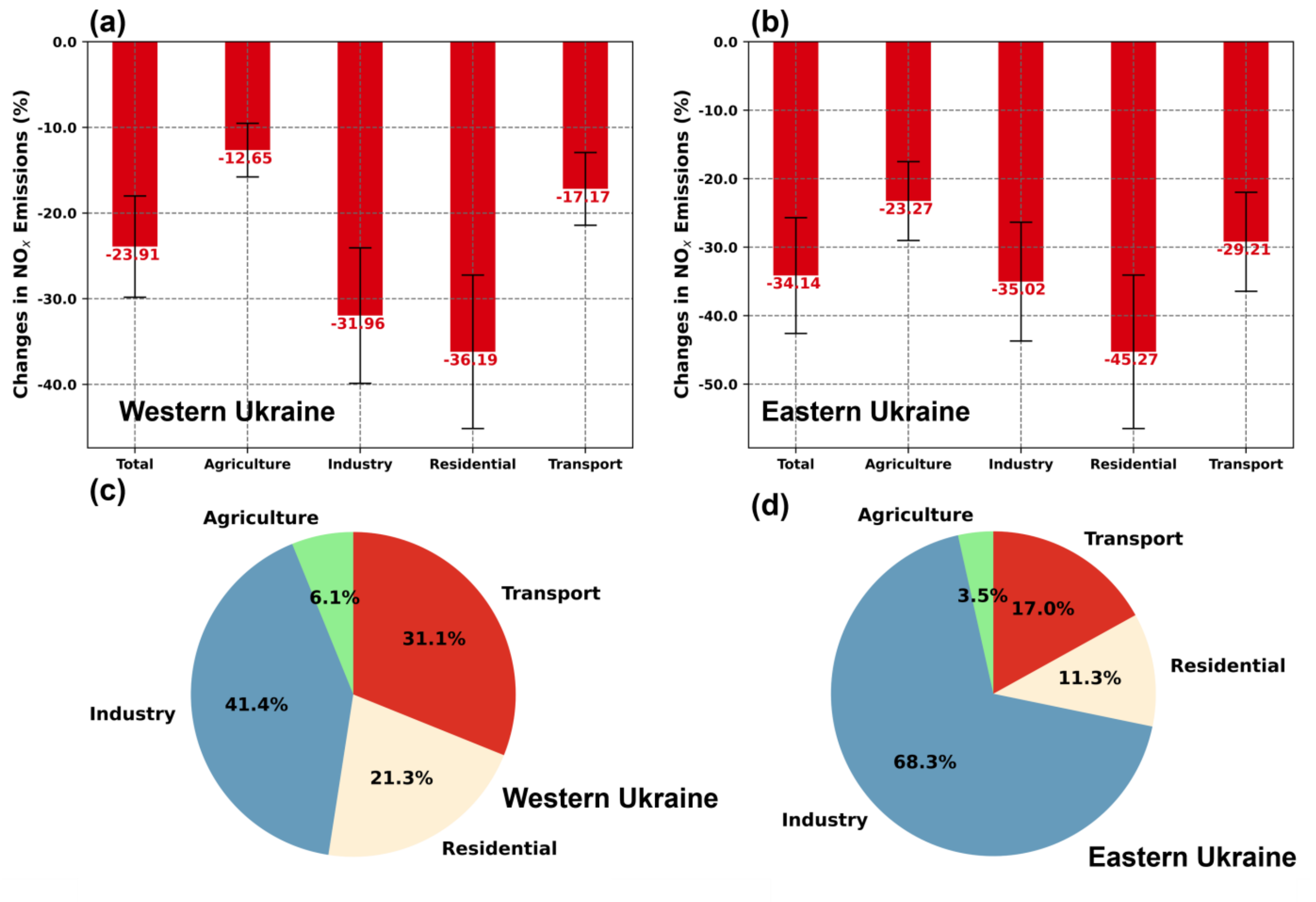

Fig. S6. Changes in sectoral emissions during war. Relative changes in (a) Western Ukraine and (b) Eastern Ukraine sectoral emissions in March to December of 2022 relative to the baseline year; and (c) Western Ukraine and (d) Eastern Ukraine sectoral contributions to the decline in emissions in March to December of 2022.

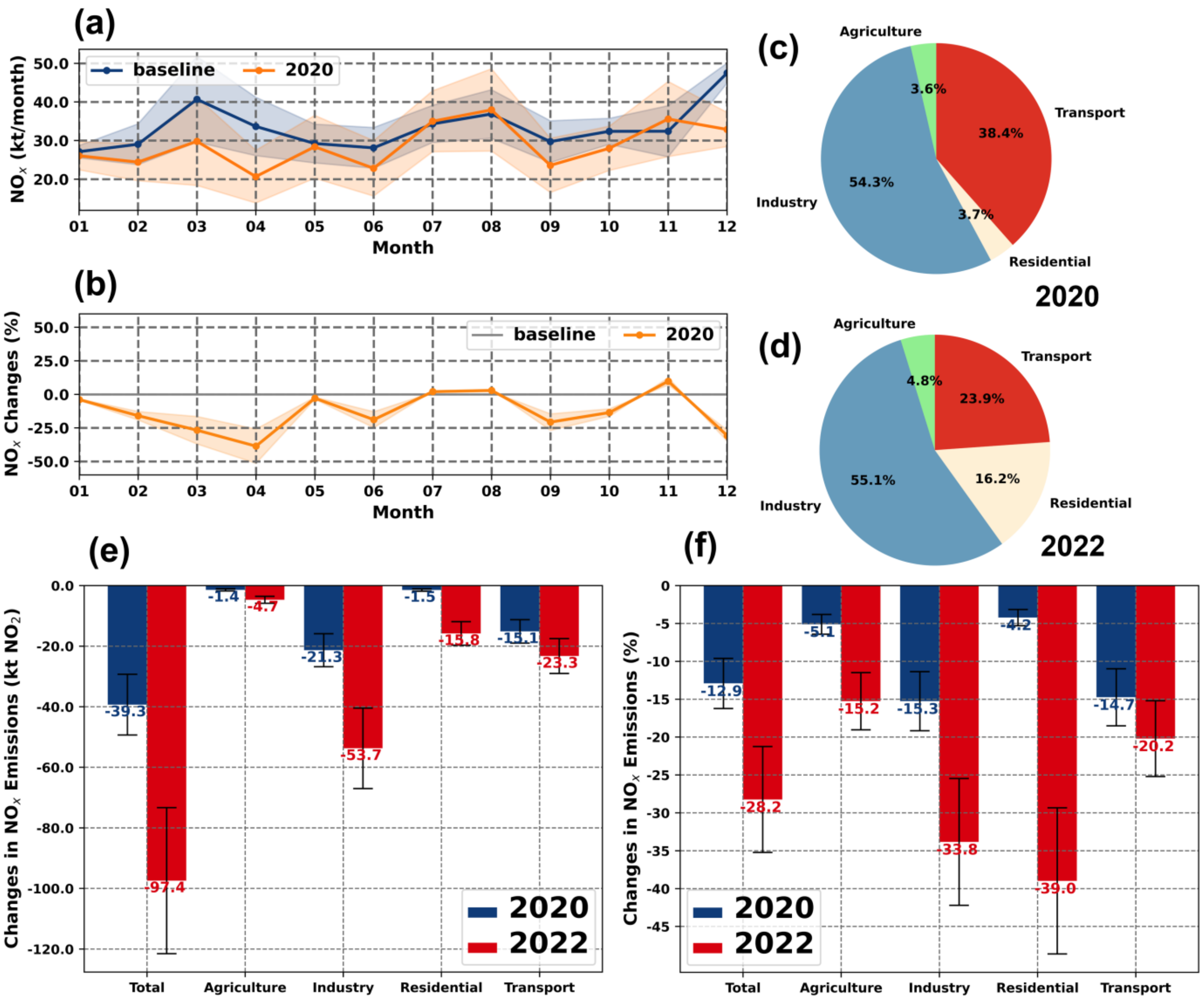

Fig. S7. Seasonal and sectoral NO_x emission changes in Ukraine in 2020. (a) Monthly NO_x emissions in 2020 and the baseline year, (b) relative changes in monthly emissions in 2020 and 2022 compared to the baseline year. contribution of different sectors to the decrease in emissions during COVID-19 epidemic (April to December) in (c) 2020 and war (March to December) in (d) 2022; and actual (e) and relative (f) changes in different sectors during COVID-19 epidemic of 2020 and war 2022 compared to the baseline year.

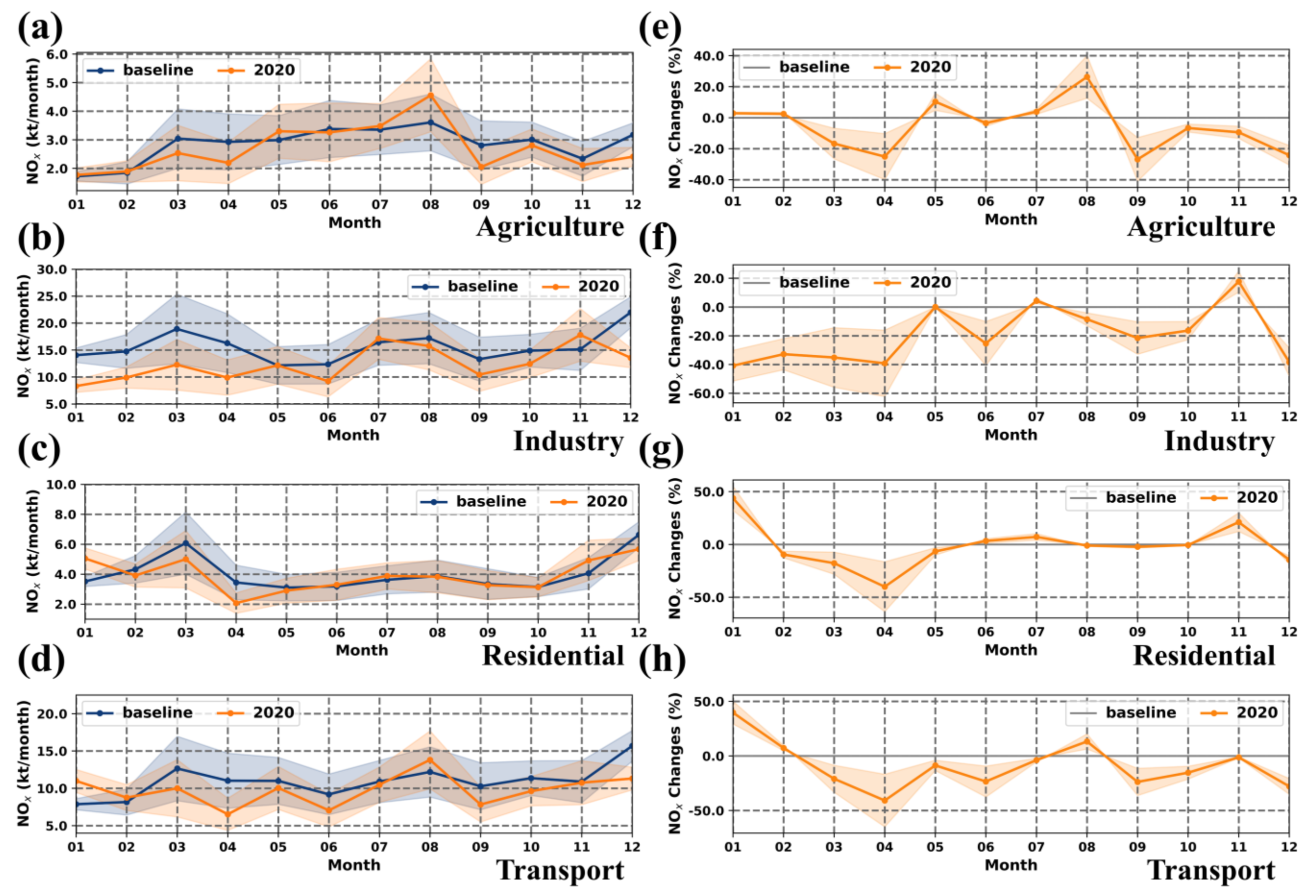

Fig. S8. Seasonal changes of sectoral NO_x emissions in Ukraine in 2020, and the relative changes with baseline year.

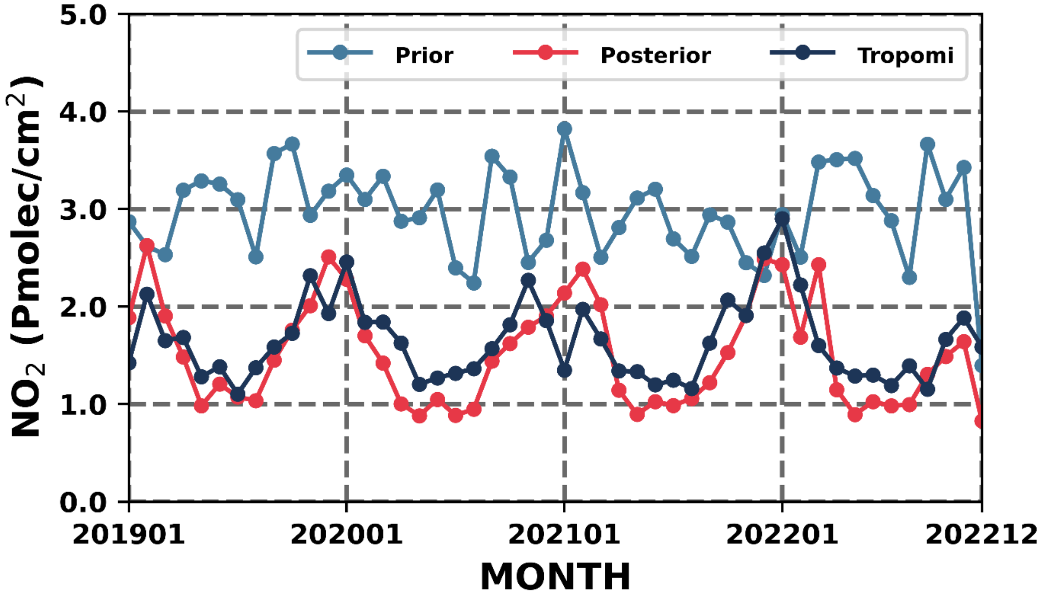

Fig. S9. Monthly average NO_2 VCDs estimated from the prior and posterior emission inventories versus satellite-observed NO_2 VCDs seasonal changes from 2019 to 2022.

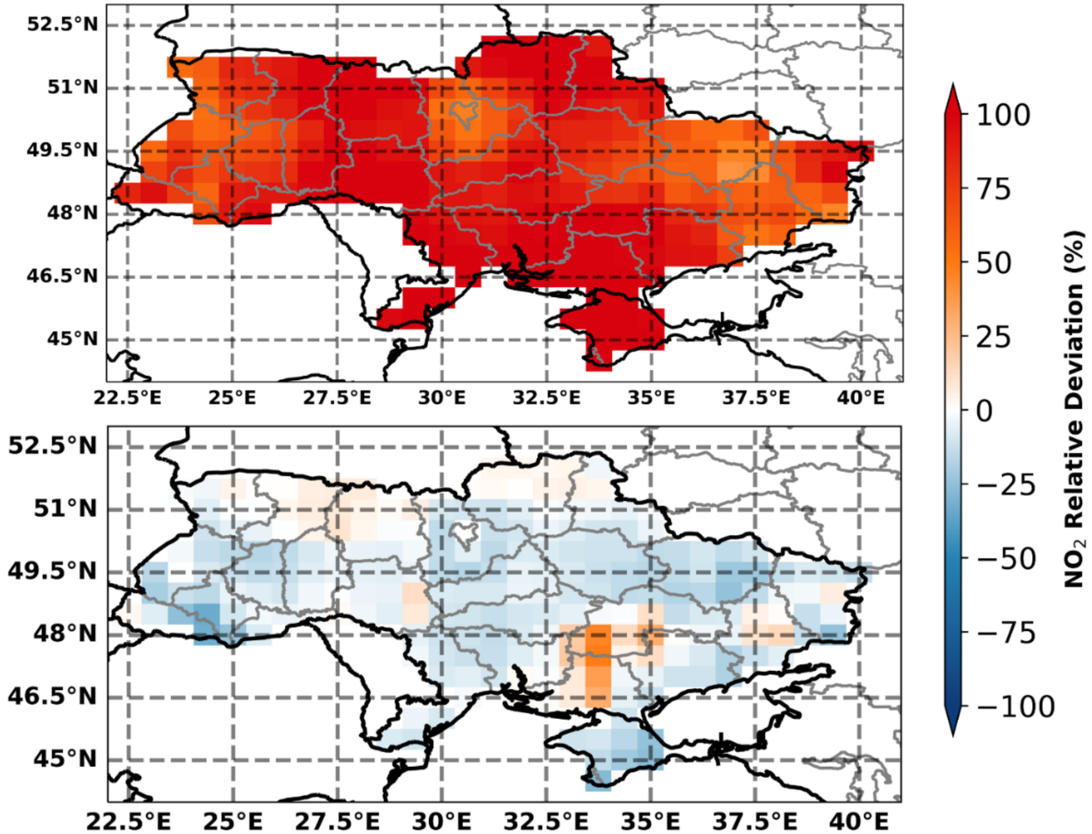

Fig. S10. Spatial distribution of relative deviations between the prior emissions and inverted the posterior emissions modeled NO_2 VCDs and satellite observations.

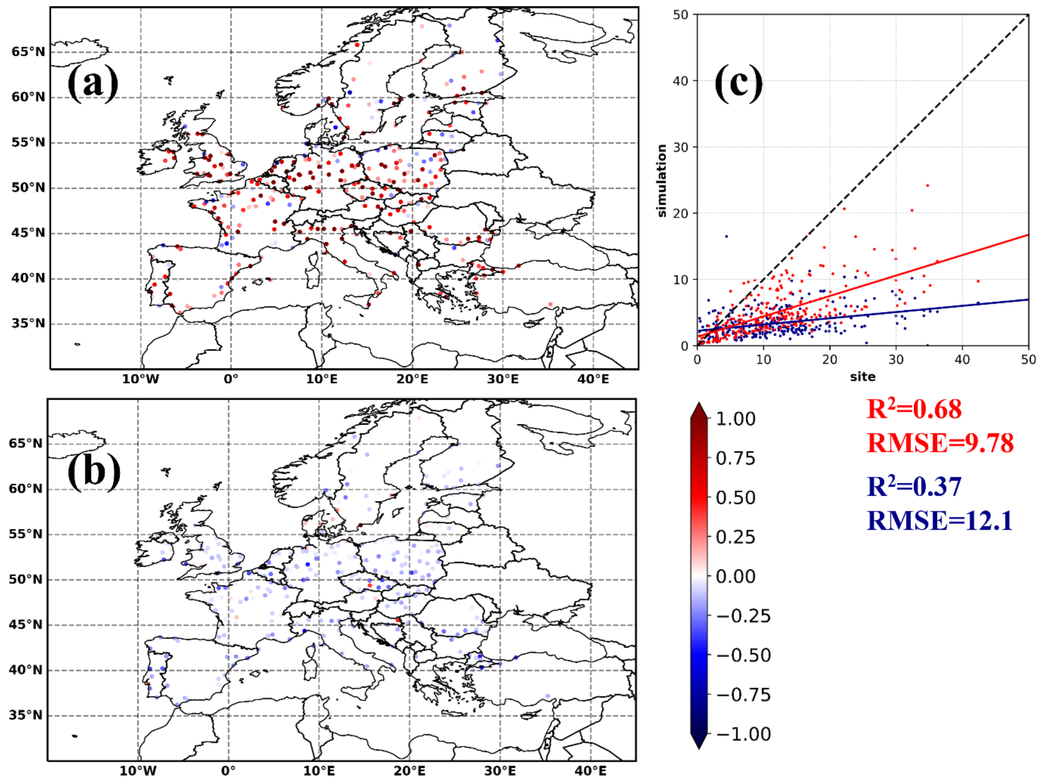

Fig. S11. Accuracy of priori and posteriori emission simulated surface concentration with in-suit observations. (a) Relative change in R2 of the time series of in-suit observations to the posterior versus prior simulated surface concentration in the corresponding grids (($R^2_{posterior}$- R^2_{prior})/R^2_{prior}); (b) Relative change in RMSE of the time series of in-suit observations to the posterior versus prior simulated surface concentration in the corresponding grids (($RMSE_{posterior}$- $RMSE_{prior}$)/$RMSE_{prior}$); (c) Scatterplot of the linear fit of the time-averaged values of in-suit observations to the priori (blue) and posterior (red) simulated concentrations of the corresponding grids.

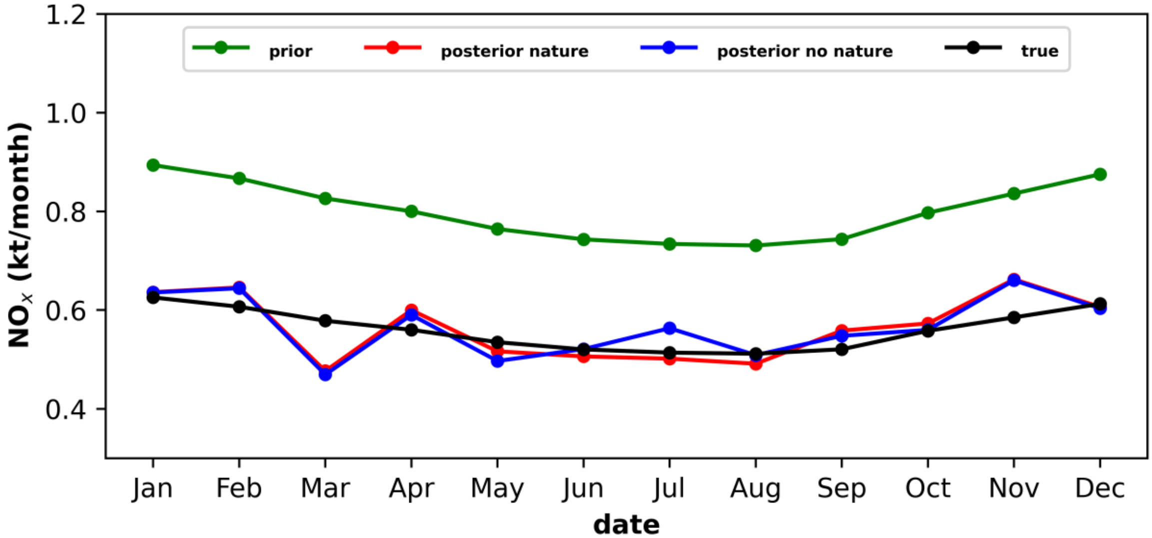

Fig. S12. Seasonal changes of posterior Ukrainian anthropogenic NO$_x$ emissions considering natural source emissions (red) versus those without natural source emissions (blue) with pseudo-true values (black) and prior (green) emissions in the OSSE test in 2022.

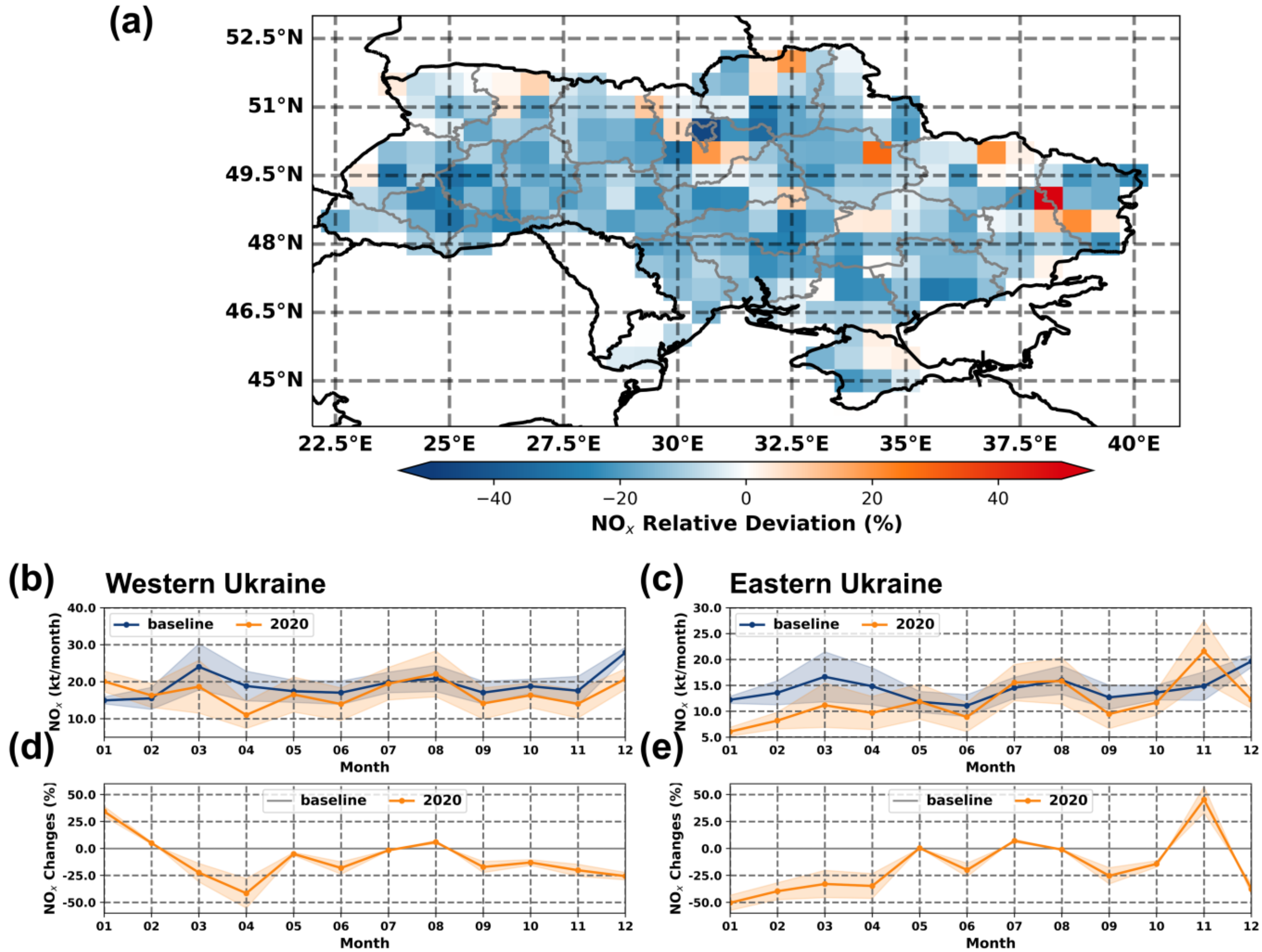

Fig. S13. Spatial variation of NO_x emissions in Ukraine during the epidemic in 2020. (a) Spatial distribution of changes in total emissions in Ukraine during the epidemic in 2020 relative to the baseline year. And (b) Western Ukraine 's and (c) Eastern Ukraine 's Monthly NO_x emissions in 2020 compare with the baseline year, and changes in monthly NO_x emissions in 2020 relative to the baseline year for (d) Western Ukraine and (e) Eastern Ukraine.

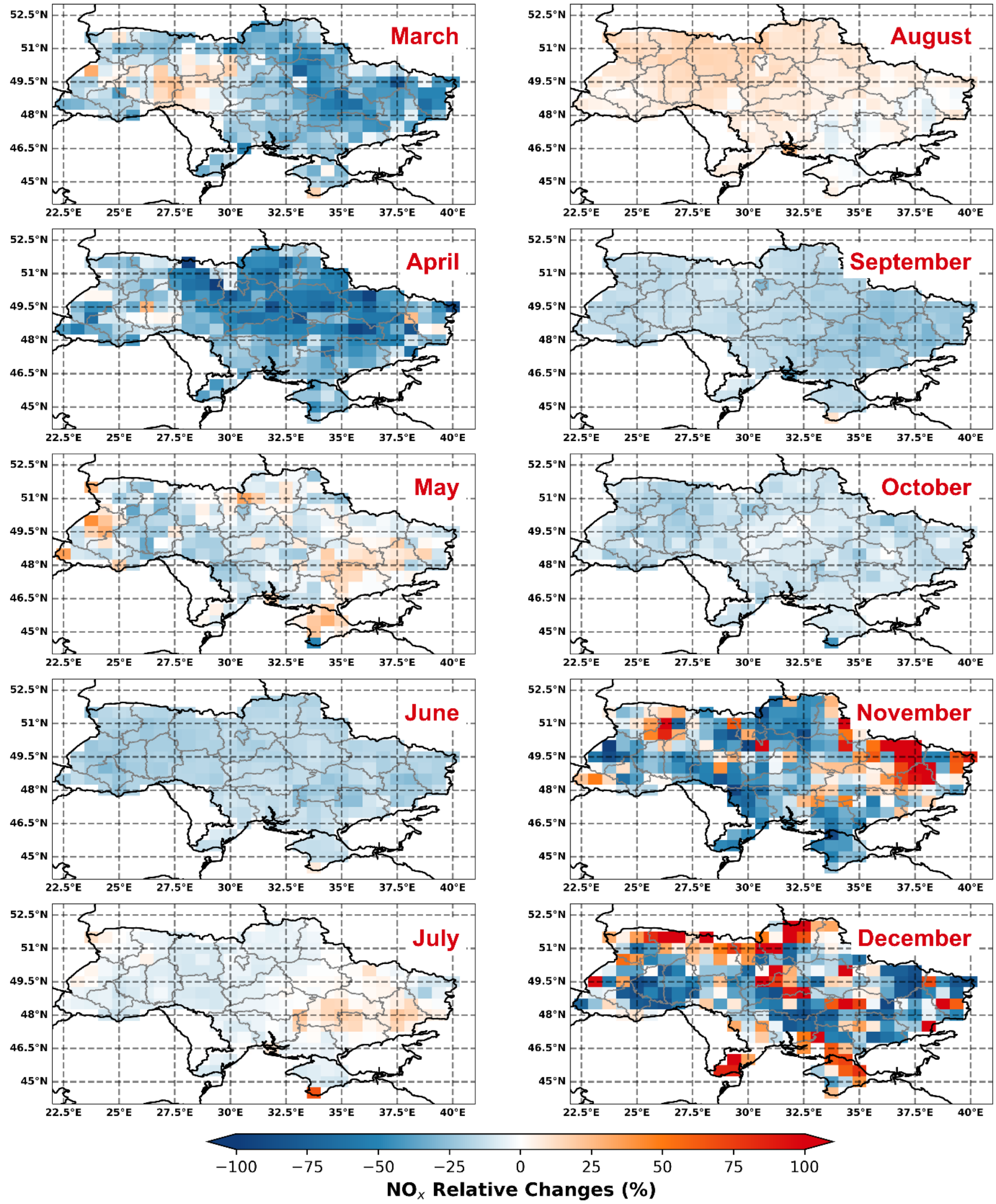

Fig. S14. Spatial distribution of monthly NO$_x$ emission changes in March to December of 2020 relative to the baseline year.

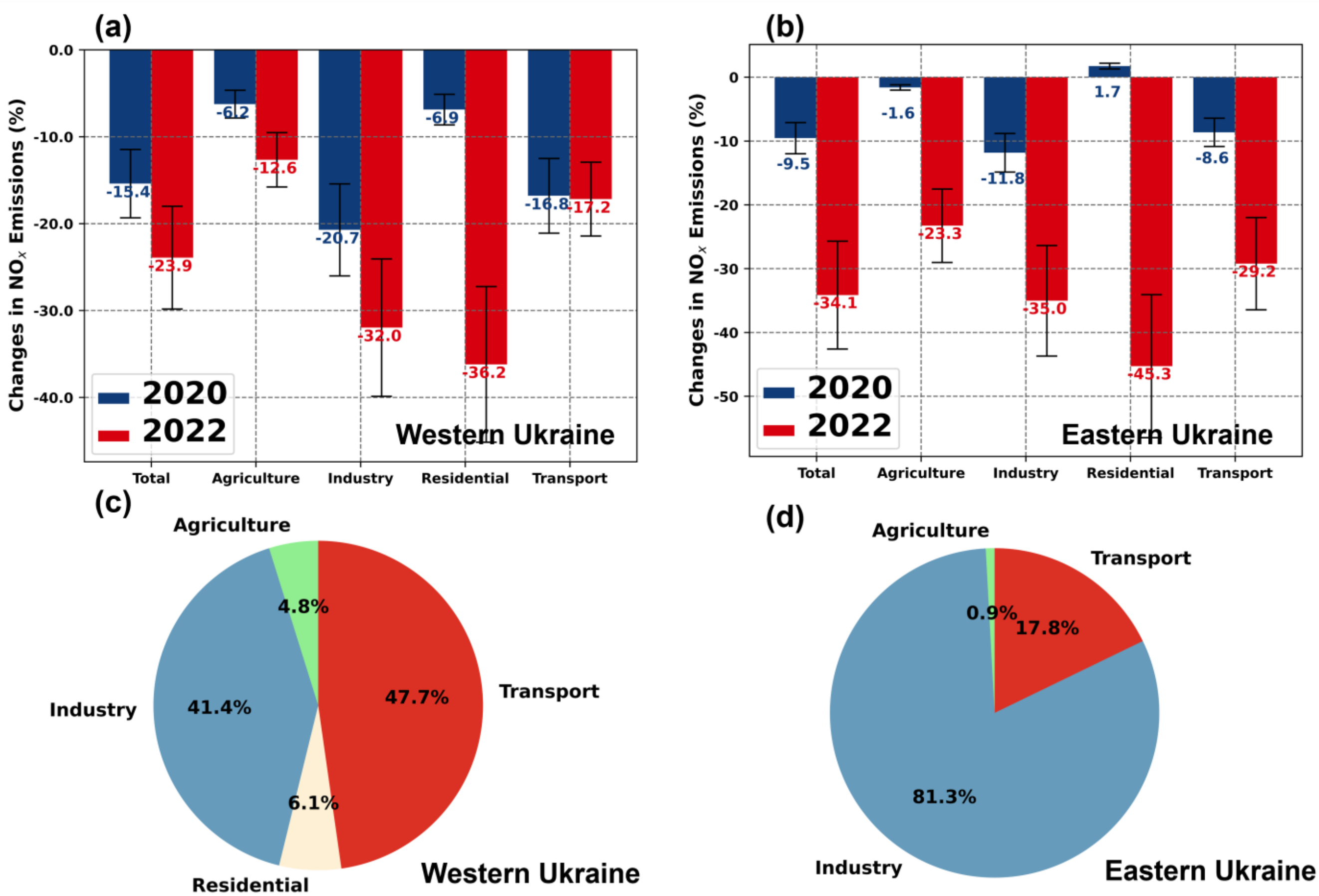

Fig. S15. Changes in sectoral emissions during the epidemic of 2020. Relative changes in (a) Western Ukraine and (b) Eastern Ukraine sectoral emissions during the epidemic in 2020 relative to the baseline year; and (c) Western Ukraine and (d) Eastern Ukraine sectoral contributions to the decline in emissions during the epidemic in 2020.

SI References

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