TROPOMI NO_2 and SO_2 Temporal Changes over Large Point Sources and Their Relationship with Electricity Production

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Abstract. This study focuses on the spatial distribution and temporal changes of NO_2 and SO_2 pollution over large point sources using high-resolution TROPOMI retrievals, and aims to find a correlation between the retrievals and electricity production. SO_2 retrievals showed highest signals over power plants, whereas NO_2 retrievals showed highest signals over large cities. Daily and monthly time series of NO_2 and SO_2 for the selected nine coal power plants were compared with electricity production for two years. Correlations between NO_2, SO_2, and electricity production were calculated for daily and monthly averages for every power plant. Then, the monthly averages with more than 23 days data (~75%, May-October) were used for correlation analysis. Highest correlations were observed for lignite-fired Afsin Elbistan Power Plant with highest total capacity in Turkey. The monthly correlations for May-October were found as 0.71 for NO_2, 0.84 for SO_2 for Afsin Elbistan Power Plant, as 0.45 for NO_2 and 0.43 for SO_2 for all selected power plants. Temporal changes in electricity production can be captured on monthly-basis, however, the correlations were lower on daily-basis. Point sources located close to land-sea boundaries and multiple sources located in the same region were poorly captured using satellite retrievals.

Keywords: TROPOMI, power plants, NO_2, SO_2, temporal distribution

1. Introduction

Remote sensing of atmospheric gases and particles provides a large spatial coverage with reasonable temporal resolution. Satellite retrievals remarkably helpful for capturing large point sources, whereas ground-based observations have limitations due to meteorological and topographical factors. Moreover, using satellite retrievals capture the yearly changes in the pollution levels over large region.

TROPOspheric Monitoring Instrument (TROPOMI) retrievals were used to investigate tropospheric NO_2 over Siberia with significant NO_2 emissions due to natural gas pipelines and gas compressor stations (Van der A. et al., 2020). Results showed that the compressor stations have almost medium-size coal power plant (PP) NO_x emissions and retrievals can be obtained over snow cover lands if clouds coverage are low. The relationship between surface NO_2, weekly cycles and temperature over the U.S. showed large point sources such as oil & gas operations having five times higher NO_2 concentrations than rural areas (Goldberg et al., 2021). For India, from April 2019 to April 2020 during the COVID-19 lockdown period, TROPOMI retrievals indicated that NO_2 pollution from coal PPs decreased by ~24% (Biswal et al., 2021). Similarly, 40% decrease in NO_2 pollution were found for 3 months of 2019 compared to 2020 for China (Ding et al., 2020).

Approximately 500 point sources were identified, and a global SO_2 catalog was created with Ozone Monitoring Instrument (OMI) (Fioletov et al., 2016). Half of the total anthropogenic SO_2 emissions were detected with OMI, emissions <30 ktons/year could not be observed due to the lower spatial resolution. In another similar study, half of the anthropogenic emissions (400 point sources) were detected using OMI (Liu et al. 2018). A more recent comparison using OMI, Ozone Mapping and Profiler Suite (OMPS), and TROPOMI instruments showed similar global distributions, indicating 278 point sources some of which were located in Turkey (Fioletov et al., 2020).

Growing population entails an increase in energy production across the globe. Types of energy production differ according to the energy policies of the governments. 31 coal PPs (>50 MWh) are currently operating in Turkey, 19 of which use lignite coal, while others use export/hard/asphaltite coal (EPIAS 2021). Domestic lignite has more sulfur content, thus emits more SO_2 compared to other coals. Firatli and Kaynak (2015) studied SO_2 pollution over large coal PPs in Turkey using OMI retrievals for 2005-2014. Akyuz and Kaynak (2019) indicated the SO_2 transport from coal PPs in Canakkale can be observed using OMI retrievals, where ground-based observations cannot capture. They also reported high correlations (R^2=0.71) between 18 Mart Can electricity generation and annual SO_2 pollution.

Identifying the contribution and spatiotemporal distribution of the pollution from large point sources is important for policymakers. The aim of this study is to determine NO_2 and SO_2 pollution from the selected PPs, the spatial distribution, and the temporal changes for 2019 and 2020. The study interval covers some of the coal PP shutdowns due to technical deficiencies. This is the first time that NO_2 and SO_2 temporal changes were investigated over large point sources in Turkey using high-resolution TROPOMI retrievals (7×3.5 km^2).

2. Methodology

Satellite Retrievals. Sentinel-5P TROPOMI Level 2 (L2) NO_2 and SO_2 retrievals downloaded (NASA 2021) over Turkey for two years (2019-2020) were processed. SO_2 retrievals were filtered according to quality criteria; cloud fraction <0.3, solar zenith angle (SZA) <60°, snow ice flag <0.5, qa (quality assurance) value >0.5, sulfur dioxide total air mass factor polluted >0.1, sulfur dioxide total vertical column >-0.001 mol/m^2 (ESA, 2021), NO_2 data were filtered for qa value >0.5 (ESA, 2021). A domain covering Turkey with 1×1 km^2 grid resolution was used for spatial averaging (Figure 1). Gridded monthly NO_2 and SO_2 column concentrations were calculated for this domain with spatial matching. Oversampling method (Fioletov et al. 2016) with 10 km radius was applied for SO_2 for smoothing. For power plants, NO_2 scan centers within 6 km, SO_2 scan centers within 10 km of the powerplant locations were selected to represent their pollution impact.

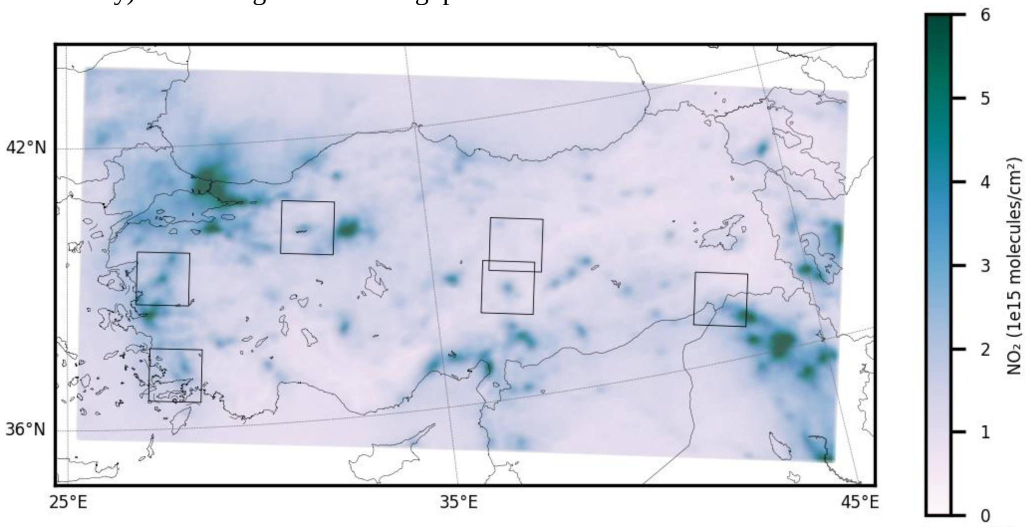
Monthly distribution maps and statistics were calculated for both NO_2 and SO_2 retrievals. The fall-winter months (November-February) showed significant data gaps and high noise. The pollution can be clearly observed in the other months, with highest SO_2 values observed in October 2020 (Figure 1).

Power Plants. The large capacity power plants (PP) with significant emissions were selected for investigation (Table 1). The hourly electricity production (EP) statistics were downloaded (EPIAS 2021), daily and monthly total electricity productions were calculated for the selected power plants. 2018 EMEP NO_x and SO_x emissions were also given in Table 1. The locations were identified with black squares in Figure 1.

Table 1. Summary of the selected power plants with capacity, fuel type, emissions (EMEP 2020), and EP.

Power plant	Capacity (MW)	Fuel Type	Emissions (Mg) NO_x	Emissions (Mg) SO_x	EP (10^3 MWe) 2019	EP (10^3 MWe) 2020
Afsin Elbistan A-B	2795	Lignite	48160	289599	4671	4552
Kangal	457	Lignite	4690	33286	2588	188
Yatagan	630	Lignite	17645	73823	3764	3835
Yenikoy	630	Lignite	5965	30949	2997	3240
Kemerkoy	420	Lignite	9908	45366	4128	3504
Mugla Total	*1680*		*33518*	*150137*	10889	10578
Silopi	405	Asphaltite	2172	8470	2324	2223
Cayirhan	620	Lignite	6269	44490	4312	2893
Soma A-B	1034	Lignite	10181	72259	5059	3866
Soma Kolin*	510	Lignite	-	-	2527	3247
Manisa Total	*1544*		*10181*	*72259*	7586	7113

* started to produce electricity as of 2019.



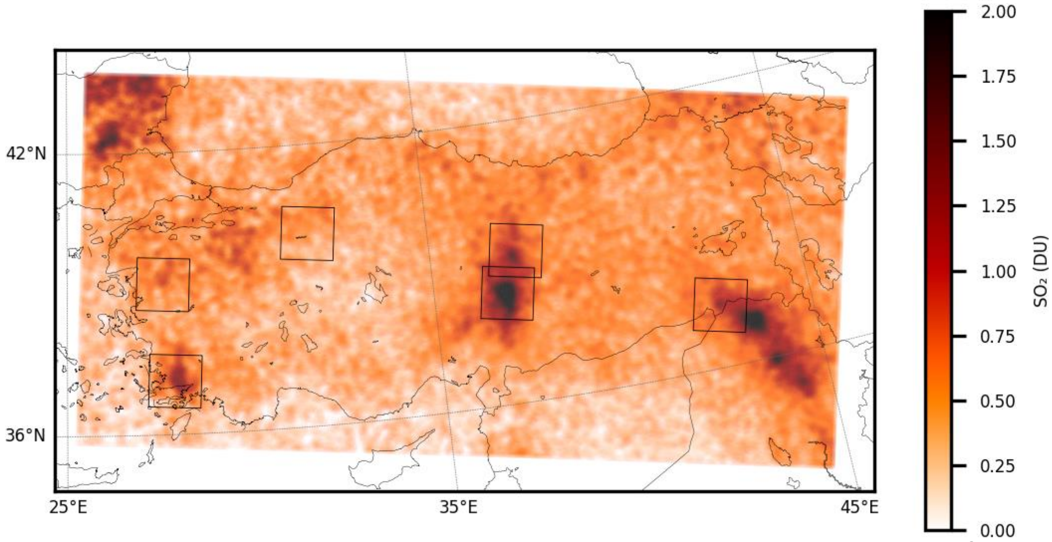


Figure 1. The monthly average (October-2020) NO_2 *(upper)* and SO_2 *(lower)* with 1×1 km^2 resolution.

3. Results and Discussion

The overall pollution over Turkey and the spatiotemporal distribution of the NO_2 and SO_2 pollution were identified for the years of 2019 and 2020. Due to high spatial resolution of TROPOMI, a more detailed distribution can be observed than the previous instruments. When the monthly averaged maps were investigated, the seasonal changes were observed. The month with cleanest signals (October-2020) for both pollutants was shown to represent the spatial distribution (Figure 1). Results indicated highest NO_2 values in November-February and over the highly populated urban areas such as metropolitan cities of Istanbul, Ankara, and Izmir. However, the selected PP signals were also visible in most of the months.

SO_2 on the other hand did not indicate significant changes in maximums for seasons. There were very limited data for December-January, and some data gaps in other months due to the limitations of the SO_2 retrievals. Even though oversampling with 10 km was performed, the smoothing could not be achieved in some of the months. The maximum signals were over large coal PPs, with the highest signal observed over Afsin Elbistan Power Plant (AEPP), which is similar to previous studies with OMI SO_2 (Kaynak and Firatli, 2016). Secondly, three plants located in Mugla (Yatagan, Yenikoy, Kemerkoy) showed high signals.

For each selected PPs (Table 1), daily and monthly average NO_2 and SO_2 values were estimated and compared with EP values using time series and correlation matrices. The highest correlations with NO_2, SO_2 and EP were found for AEPP.

Some of the coal PPs of which AEPP (Unit A-1355 MWe), Kangal and Soma PPs are within, were fully or partially shut down on December 31, 2019 in Turkey. They were opened around June 2020, which can also be seen in EP statistics.

There was a period for AEPP; April-May 2020 where there was no electricity production where Unit-B also was not producing electricity (Figure 2). That period was also associated with lowest NO_2 and SO_2 levels as well. Overall, the timeseries of SO_2 showed similarities with EP, indicating higher SO_2 levels, especially with a sharp increase after the reopening of Unit-A in June 2020. This increase was also observed in Kangal, however not observed in Soma PP which was only partly closed.

The correlation of daily average SO_2 and daily total EP was moderate (R=0.44); whereas the correlation of NO_2 and EP was low (R=0.27) for AEPP. However, one should note that the uncertainty in some of the months were high and averages were obtained with limited number of scans. The correlation between NO_2 and SO_2 was strong (R=0.69) indicating they could be dominantly impacted from the same source.

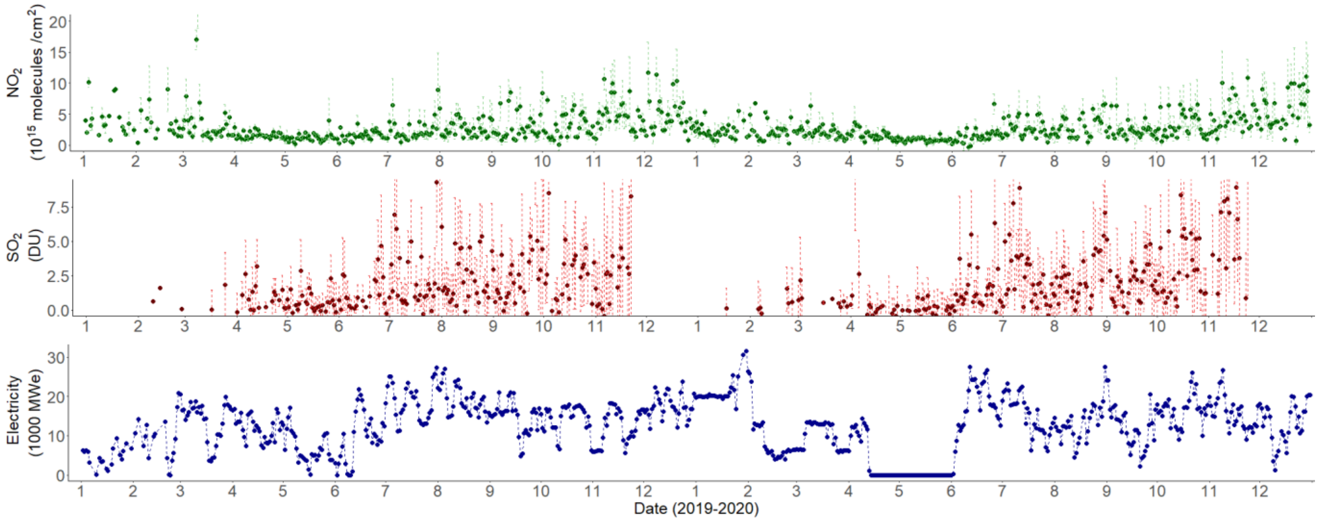


Figure 2. The daily average NO_2 *(upper)*, SO_2 *(middle), and* EP *(lower)* of AEPP and their correlation.

For the correlations, monthly averages of NO_2 and SO_2 retrievals for selected PPs for all 24 months indicated very low counts in some of the months, especially for SO_2. Thus, the monthly averages composed of more than 23 days (~75%) for all selected PPs were selected. These months were May-October for both years (6-month season) with more cloud-free scans and higher data completeness and quality. Selecting these months also eliminated the impact of the residential heating on the pollutant concentrations, which can be significant in Turkey.

The daily correlations for AEPP for the selected 6-month season were increased for NO_2-EP (R=0.39), with minor increase in others (Figure 3). Monthly comparisons showed very strong correlation for AEPP with minimum of 0.71 between NO_2 and EP (Figure 3).

Table 2. Pearson Correlation Coefficients (R) for selected power plants for NO_2, SO_2 and EP.

Power plant	NO_2 vs SO_2	NO_2 vs EP	SO_2 vs EP
Afsin Elbistan	**0.96***	**0.71***	**0.84***
Kangal	**0.62**	**0.66**	0.32
Yatagan	**0.70***	0.24	0.24
Yenikoy	**0.69**	*-0.45*	*-0.27*
Kemerkoy	**0.79***	*0.01*	*-0.05*
Silopi	**0.66**	**0.57**	**0.63**
Cayirhan	**0.83***	**0.54**	**0.59**
Soma	**0.71***	**0.55**	0.33
Soma Kolin	**0.72***	0.25	0.05

Other selected PPs showed a range of different correlations (Table 2). Two PPs with high SO_2 signal in Mugla (Yenikoy, Kemerkoy) showed negative correlations between SO_2 and EP. These plants are within 12 km distance and one located at the coast with complex terrain. The monthly SO_2 maps over Mugla region indicated pollution transport with maximum signals at the central region of these three PPs.

All selected PPs -indicated with different colors- showed moderate correlation between EP and both pollutants (R=0.45-0.43) (Figure 3). Low correlation between NO_2 and SO_2 was observed, even though individual correlations were consistently higher (R<0.62) (Table 2).

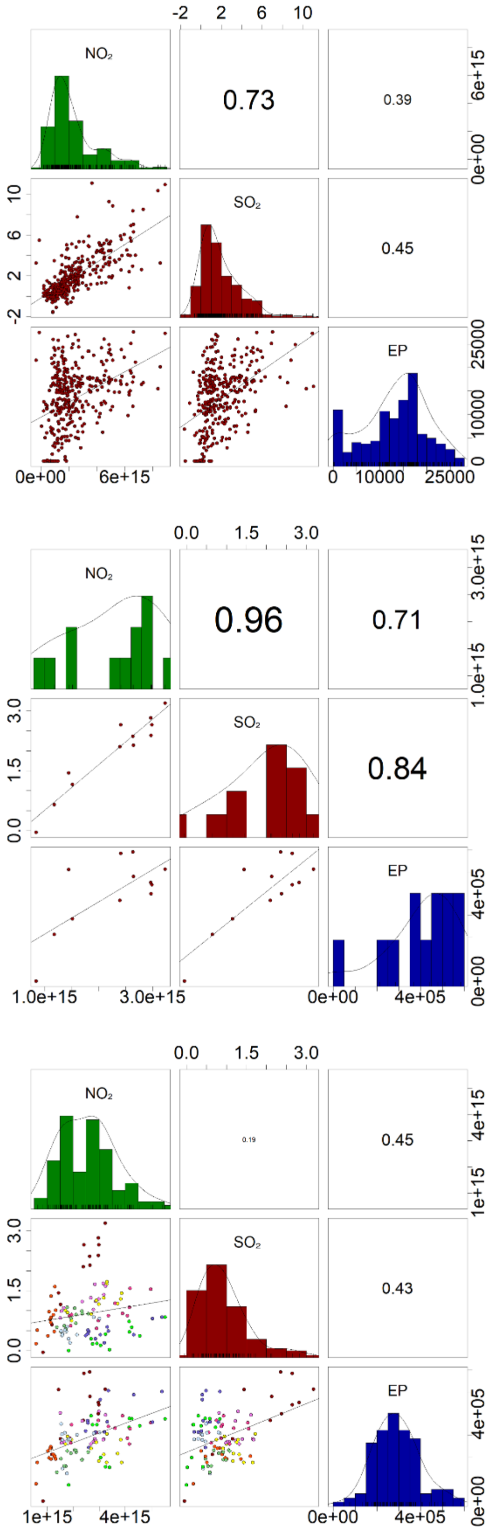


Figure 3. Distributions and scatter plots for daily NO_2, SO_2 and EP for AEPP *(upper)*, monthly NO_2, SO_2 and EP for AEPP *(middle)* and all selected power plants *(lower)* for May-October (2019-2020).

4. Conclusion

The preliminary findings shown here indicated the temporal changes in electricity production can be captured using TROPOMI SO_2 and NO_2 retrievals on monthly-basis, however, there are still limitations on daily-basis due to the quality and quantity of the data.

The pollution transport in land-sea boundaries are harder to capture using satellite retrievals. A revised spatial matching is necessary for quantifying the cumulated impact of multiple plants within a region, because current search radius cannot be representative in such cases.

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