Assessing Spatiotemporal Variability in NO_2 and O_3 Along the Korean Peninsula Using Remote Sensing and Ground-Based Observations

Reina Li[1], Owen Parker[2], Maria Tzortziou[2]

[1]Computer Science, New York City College of Technology, CUNY

[2]Department of Earth and Atmospheric Sciences, The City College of New York, CUNY

Abstract

Using ground-based data from the Pandora spectrometers and satellite observations from the Ozone Monitoring Instrument (OMI) on the satellite Aura, we examined variability in atmospheric NO_2 and O_3 along the Korean Peninsula from 05/18/16 to 06/02/16. Assessing nitrogen dioxide and ozone variability is crucial for the local and regional environmental degradation, human health, and vegetation. By applying statistical transformations to the ground-based and satellite data, we are able to use GIS (Geographic Information System) to map and quantify spatial and temporal variability of total column amounts of NO_2 and O_3 along the Korean Peninsula. Results are shown for eight sites where different Pandora instruments were used. There was a notable difference in $TCNO_2$ in which the variability correlates to the population and land use.

Introduction

Seoul and Busan are the two most populated cities in South Korea, with around 10 million and 3.5 million people in each city, respectively. Nationally, oil, coal and natural gas account for 36%, 31% and 16.2% of their energy supply (IEA 2012). Consequently, nitrogen dioxide (NO_2) – which is a combustion product of fossil fuels - concentration in the local environment is expected to be high, and a concern for human health. Additionally, high tropospheric NO_2 can provide nitrogen input into local ecosystems. Ozone (O_3) is also a concern. While stratospheric ozone protects us from ultraviolet rays, ground-level O_3 poses a risk for health and vegetation. Examining both NO_2 and O_3 is essential to healthier environments and people. Since Aura-OMI provides only 1-2 measurements of wide spatial coverage per day, the satellite cannot capture the strong diurnal variability in NO_2 and O_3, whereas usage of the Pandora spectrometers offers us detailed local coverage and temporal variability, and continuous measurements of NO_2 and O_3. Deployment of boat-mounted Pandora sensors also allows us to gain valuable insight into off-shore behavior of trace gases.

Methodology

- Use satellite observations and measurements from past and ongoing air-quality and oceanographic field campaigns (Pandora ground-based network and shipboard observations, and Aura-OMI satellite data).
- Gather continuous measurements of $TCNO_2$ and TCO_3 over land and over the ocean from the ground-based Pandora spectrometers.
- Collect satellite observations of $TCNO_2$ and TCO_3 from the OMI instrument on the Aura satellite.
- Use of MATLAB/GIS software to conduct statistical transformations, GIS analysis, and formatting

Results

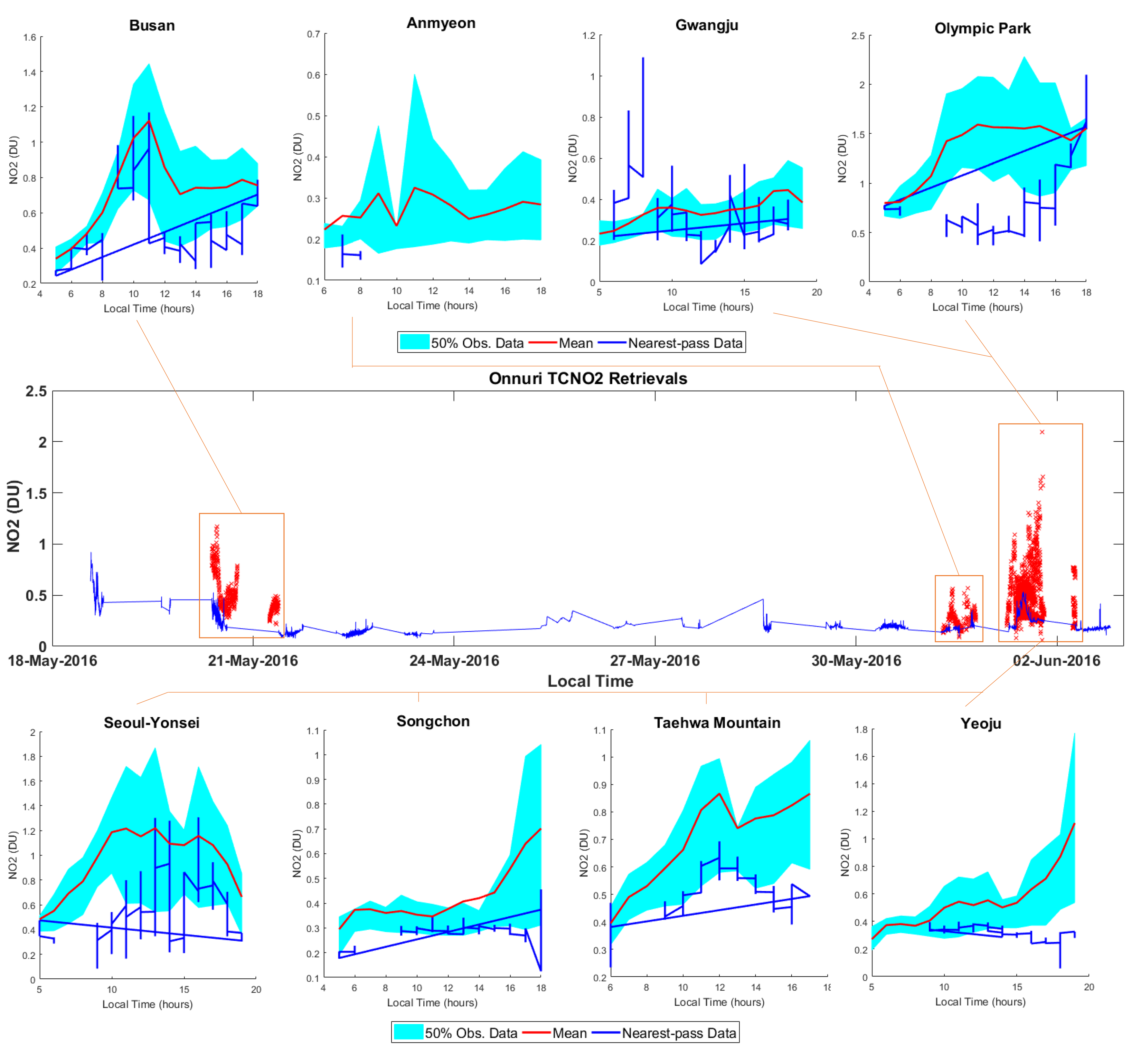

Fig. 1 Time series of $TCNO_2$ measurements taken from ship-board Pandora deployed on the Onnuri research vessel (May 18, 2016 to June 2, 2016) and $TCNO_2$ diurnal variability for the eight ground sites for when the Onnuri was closest

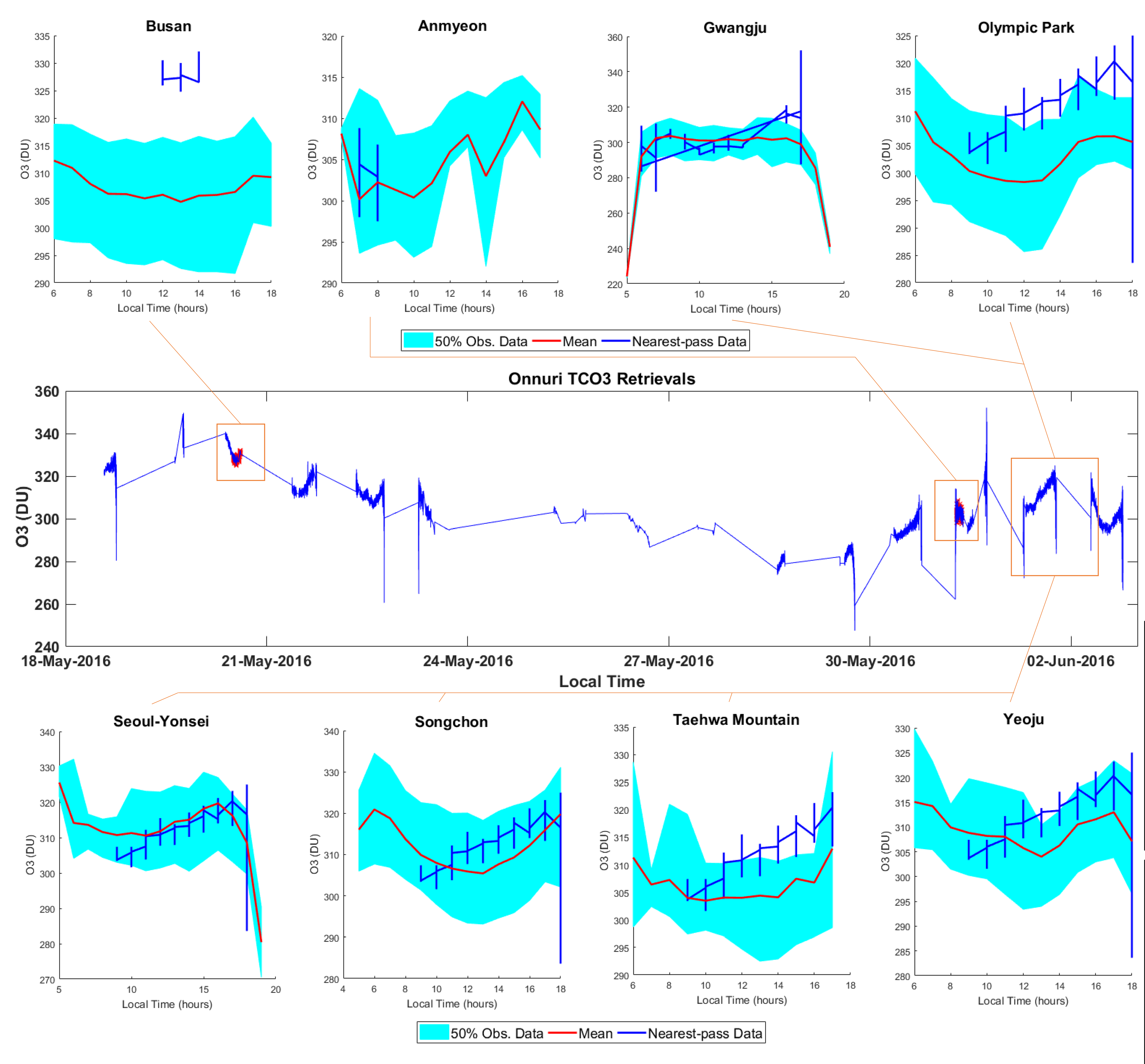

Fig. 2 Time series of TCO_3 measurements taken from ship-board Pandora deployed on the Onnuri research vessel (May 18, 2016 to June 2, 2016) and TCO_3 diurnal variability for the eight ground sites for when the Onnuri was closest

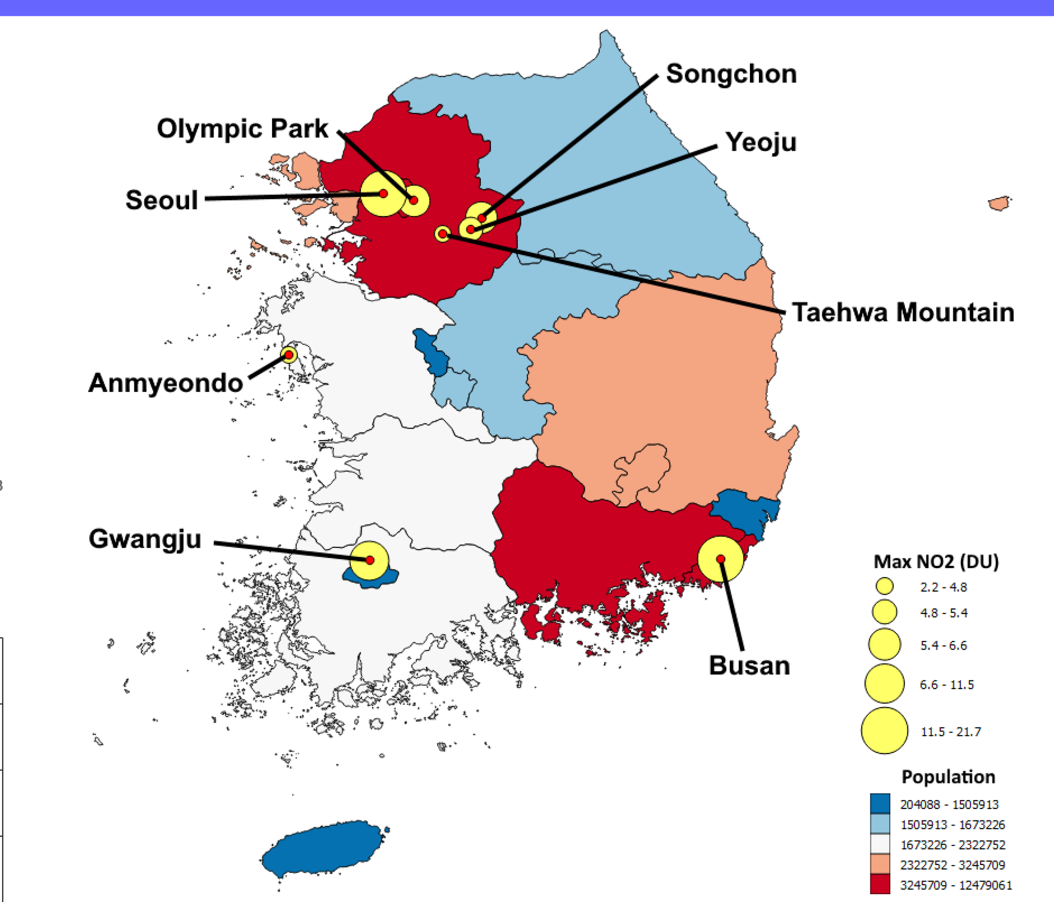

Fig. 3 South Korea population with $TCNO_2$ peak values at eight ground sites where Pandora spectrometers are located

Pandora Onnuri Observations: Nitrogen Dioxide, Campaign Day									
Timeline	**Mean (DU)**	**Median (DU)**	**Min (DU)**	**Max (DU)**	**Variance (DU)**	**SD (DU)**	**CoV (DU)**	**MMS**	**Avg. Dist (m)**
Day 1	0.30	0.31	0.15	0.53	0.01	0.08	25%	Busan	2.60E+06
Day 2	0.13	0.13	0.08	0.22	0.00	0.02	17%	Anmyeondo	1.08E+06
Day 3	0.15	0.14	0.09	0.27	0.00	0.02	16%	Gwangju	3.82E+06
Day 4	0.12	0.12	0.08	0.16	0.00	0.01	7%	Busan	5.54E+06
Day 6	0.25	0.24	0.17	0.35	0.00	0.05	19%	Gwangju	5.22E+06
Day 7	0.20	0.20	0.17	0.25	0.00	0.02	10%	Gwangju	3.69E+06
Day 8	0.20	0.19	0.17	0.29	0.00	0.03	15%	Anmyeondo	2.07E+06
Day 9	0.19	0.18	0.13	0.46	0.00	0.04	19%	Gwangju	1.01E+07
Day 10	0.19	0.19	0.16	0.25	0.00	0.01	7%	Yeoju	1.54E+06
Day 11	0.19	0.19	0.15	0.27	0.00	0.02	8%	Yeoju	7.86E+05
Day 12	0.17	0.17	0.09	0.36	0.00	0.03	17%	Anmyeondo	4.51E+06
Day 13	0.29	0.26	0.14	0.53	0.01	0.09	31%	Busan	2.59E+06

Pandora Onnuri Observations: Ozone, Campaign Day									
Timeline	**Mean (DU)**	**Median (DU)**	**Min (DU)**	**Max (DU)**	**Variance (DU)**	**SD (DU)**	**CoV (DU)**	**MMS**	**Avg. Dist (m)**
Day 1	333.33	333.05	326.00	340.80	15.10	3.89	1%	Busan	2.61E+06
Day 2	315.65	314.40	309.40	326.90	13.52	3.68	1%	Anmyeondo	1.08E+06
Day 3	309.63	309.70	260.60	318.80	9.95	3.15	1%	Gwangju	3.81E+06
Day 4	305.61	304.80	264.80	319.30	28.80	5.37	2%	Busan	5.55E+06
Day 6	302.15	302.30	297.60	305.90	4.71	2.17	1%	Gwangju	5.01E+06
Day 7	295.62	295.70	286.70	302.50	14.41	3.80	1%	Gwangju	3.65E+06
Day 8	295.36	295.70	292.30	298.20	2.42	1.55	1%	Anmyeondo	2.03E+06
Day 9	279.94	280.50	273.70	285.20	5.62	2.37	1%	Gwangju	1.01E+07
Day 10	282.29	283.60	247.50	289.20	27.44	5.24	2%	Yeoju	1.56E+06
Day 11	295.11	294.60	278.30	311.30	10.78	3.28	1%	Yeoju	7.86E+05
Day 12	303.52	302.10	262.20	352.10	67.14	8.19	3%	Anmyeondo	4.50E+06
Day 13	310.77	311.00	272.10	325.00	32.39	5.69	2%	Busan	2.58E+06

Fig. 5 Campaign Day $TCNO_2$ and TCO_3 Pandora Onnuri Observations

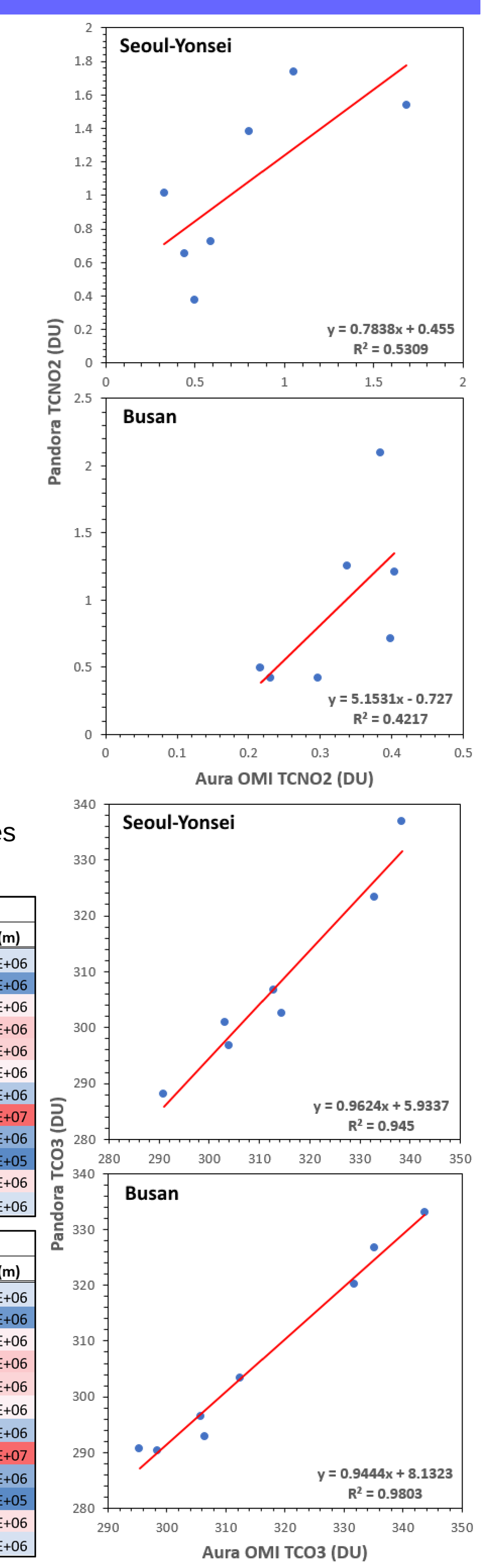

Fig. 4 Comparison in $TCNO_2$ and TCO_3 data retrievals between Aura-OMI and Pandora at the Seoul-Yonsei site and the Busan site

Discussions

- Local maxima in NO_2 levels in Onnuri data reflect proximity to Busan and Seoul metropolitan areas.
- No observed twice-daily "rush hour" increase in NO_2 levels. Instead, NO_2 generally rises over the course of the day.
- Rapid increases in evening may be an artifact from high-zenith observations, or may reflect real phenomenon.
- NO_2 levels seem to be highly dependent on proximity to centers of industry and transportation.
- O_3 data from the Onnuri seems flatter. This is expected, as O_3 production is not as strongly linked to anthropogenic activity.
- Daily variations in O_3 is less dramatic. Extremely low levels of O_3 at sunrise/sunset may be artifacts, or real phenomena.
- Close agreement was found between Aura OMI and ground-based measurements of TCO_3. Conversely, NO_2 measurements had lower correspondence.

Conclusions

- Diurnal variability illustrates complex $TCNO_2$ and TCO_3 emission patterns.
- Onnuri transects demonstrate presence of off-shore plumes.
- Diurnal $TCNO_2$ variability corresponds with human activity.
- Population correlates to increased $TCNO_2$, with more populated cities exhibiting higher NO_2 peak values.
- Variability in NO_2 levels corresponds with importance of anthropogenic activity on NO_x production.
- Agreement/Disagreement between OMI and Pandora sensors for NO_2 and O_3 demonstrates importance of ground-based sensors in validation.

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