Title of dissertation			
Analysis of tropospheric ozone formation sensitivity in metropolitan Jakarta Greater Area using combined surface measurements and satellite observations			
RONPAKU Fellow			
Name	**Sheila Dewi Ayu KUSUMANINGTYAS**		
Position	Middle career researcher	ID No.	R12007
Department	Air Quality Division, Center for Applied Climate Information Services		
Institution	Agency for Meteorology, Climatology, and Geophysics of Republic of Indonesia (BMKG)	Nationality	Indonesia
Japanese Advisor			
Name	Kenichi TONOKURA		
Position	Professor	Institution	The University of Tokyo

Introduction

The Jakarta Greater Area (JGA), the largest urban agglomeration in Indonesia, comprises Jakarta megacities and overlaps with neighboring cities or municipalities (the inner suburbs), such as Bogor, Depok, Tangerang, and Bekasi, experience a rapidly expanding urban region, faces pressing air quality challenges, with surface ozone (O_3) emerging as a major concern. As the third largest contributor to greenhouse radiative forcing, O_3 not only harms human health but also threatens ecosystems. Since the early 2000s, O_3 concentrations in Jakarta have frequently surpassed national air quality standards[1,2]. The complex, nonlinear process of O_3 formation, driven by interactions between nitrogen oxides (NO_X) and volatile organic compounds (VOCs), is further complicated by local meteorological conditions. The implementation of emission control measures and O_3 reduction strategies in urban areas varies geographically depending on local emission characteristics and meteorological conditions. Thus, a comprehensive assessment of tropospheric O_3 with respect to meteorological influences and formation sensitivity to the precursors is essential for establishing practical O_3 abatement efforts and remains a scientific challenge that must be addressed. However, addressing O_3 pollution is hindered by sparse surface measurements across the region.

Methods

This thesis combined the surface in-situ O_3 measurement to assess meteorological influences on O_3 levels and the satellite-based tropospheric column of Nitrogen Dioxide (NO_2) and formaldehyde (HCHO) from the Ozone Monitoring Instrument (OMI) to investigate its formation sensitivity. Meteorological parameters such as hourly maximum temperature (Tmax), relative humidity (RH), wind speed mean (WS_mean) are obtained from meteorological and air quality monitoring stations (AQMS) (Fig.1); while other meteorological parameters, such as the Boundary Layer Height (BLH), Surface Pressure (SP), and downward ultraviolet radiation (UVB), were downloaded from the European Center for Medium-Range Weather Forecasts Reanalysis (ECMWF ERA5). Meteorological influences on O_3 variations are resolved using the Stepwise Multi Linear Regression (MLR) model. The long-term surface O_3 is analyzed using Quantile Regression (QR).

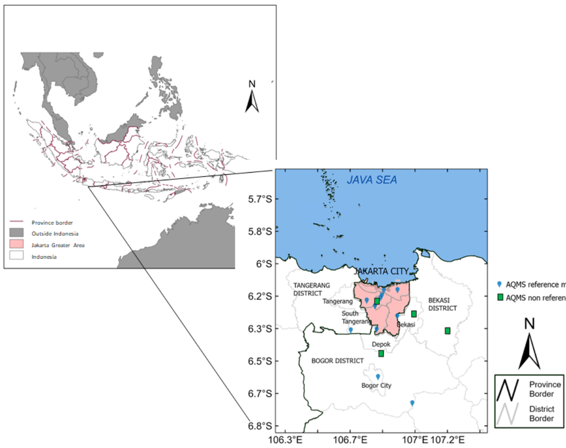

Fig. 1 1Map of Jakarta Greater Area (JGA). The pink shade represents Jakarta city.

The tropospheric O_3 is also affected by precursors changes. A common approach involves using satellite measurements of HCHO to NO_2 ratio (FNR) to study O_3 Formation Sensitivity (OFS). The OFS can be classified into VOCs-limited (or NO_X-saturated), whenever O_3 increases with increasing VOC in relatively low VOC/NO_X ratios; NO_X-limited (mainly affected by the increase of NO_X and largely insensitive with VOC and in higher VOC/NO_X ratios); and transitional regime (when a reduction in either NO_X or VOCs can lead to less O_3 production)[3]. The threshold to differentiate the chemical regime varies in different regions. Therefore, this research also compares the FNR value found in Jakarta with other megacities in the world.

Results and Analysis

Between 2010 and 2019, 41% of 1-hour O_3 measurements in Jakarta exceeded national thresholds, while rural Bogor, an adjacent area closes to Jakarta, recorded only 0.1% exceedance over three years of measurement. Anomalies in the maximum daily 8-hour O_3 averages (MDA8) showed a downward trend in Jakarta, contrasting with rising levels in Bogor, indicating enhanced precursor activity in rural areas (Fig.2). Anthropogenic drivers accounted for 70% of O_3 variability in Jakarta, while meteorologically contributes as much as 30% with ultraviolet radiation (UVB), WS_mean, Tmax, and RH as the significant contributors (Fig.3a and 3b).

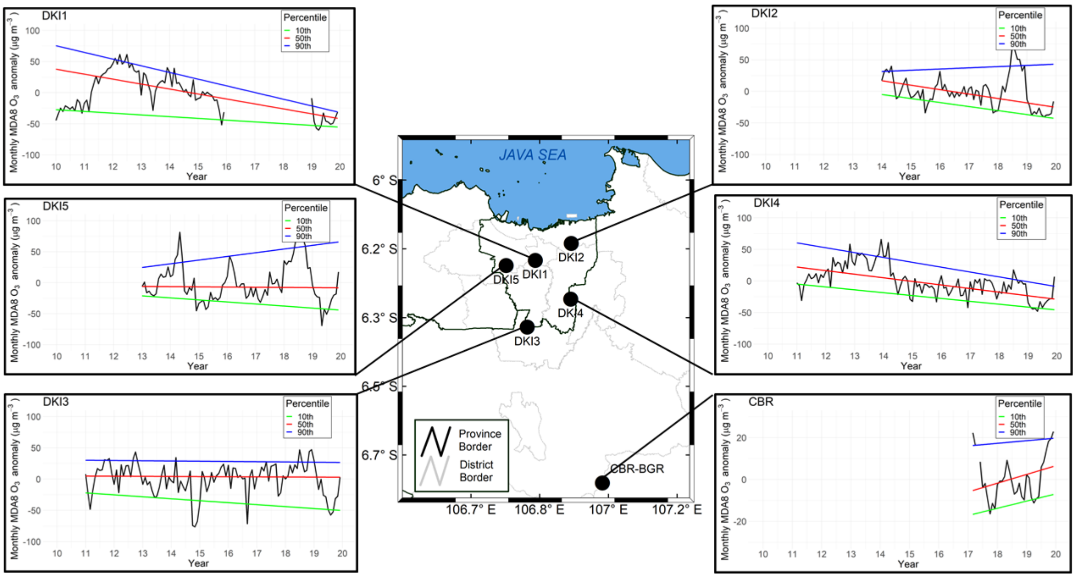

Fig.2 Map of the study area and the time series of the monthly mean anomaly of O_3 maximum daily 8-h average (MDA8 O3) during the study period at Jakarta and Bogor sites.

Temporal agreement (R>0.5) occurred between space-based NO_2 tropospheric columns with surface measurement, confirmed its reliability for long-term analysis. The NO_2 tropospheric column averaged 3.92×10^{15} molecules cm^{-2} over 14 years, lower than the HCHO column at 12.75×10^{15} molecules cm^{-2}. Emission inventory estimates suggest comparable contributions from non-methane volatile organic compounds (NMVOCs) and NO_2, primarily from road transport. Trend analyses show a strong and high certainty of declining NO_2 in all areas in JGA while depicting a stable HCHO. The implementation of control policies for vehicle emission and the use of clean energy for cooking has proven to decrease NO_2 and subsequently decrease O_3. OMI HCHO reveals a higher value by a factor of 3 compared to NO_2 showing the domination of VOC emission thus delivering high FNR value compared to other megacities in the world. The sensitivity analyses show an increasing trend of FNR in Jakarta megacity from 2006 to 2019 with an average of 3.51 towards a NO_X-limited regime (Fig. 4). This result suggests that the reduction of OMI NO_2 and stagnant HCHO affect the O_3 concentration reduction as O_3 is more sensitive to NO_2.

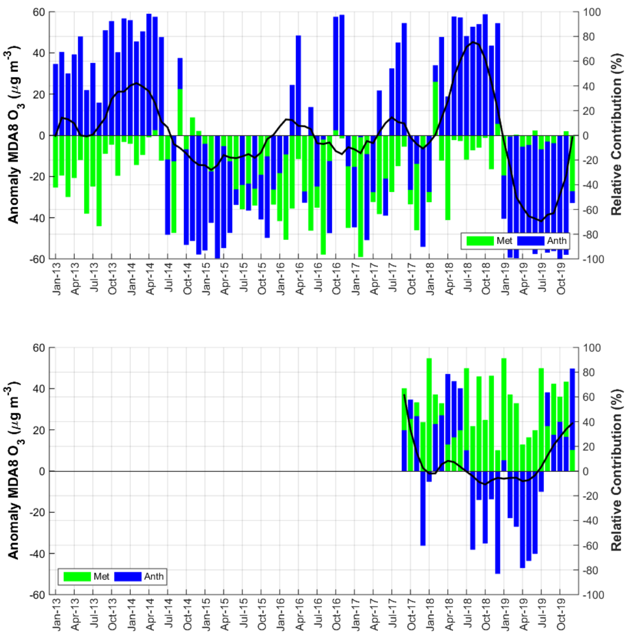

Fig.3 Contribution of meteorological (green bar) and anthropogenic factor (blue bar) to observed MDA8 O3 anomalies (black line) in (a) Jakarta and (b) Bogor.

Summary of research findings

The thesis demonstrates the application of surface air quality measurement, satellite observation, and statistical techniques to determine trends and contribution of meteorological drivers, and to interpret the formation sensitivity. This thesis contributes to a deeper understanding of O_3 dynamics in JGA, providing valuable insights for policymakers to develop effective O_3 mitigation strategies.

Recommendations for future research

There is an urgent need for ambient in-situ VOC speciation measurements and source identification in Jakarta considering high HCHO compared to NO_2 as measured by OMI. Utilization of finer spatial resolution of satellite products such as Tropospheric Monitoring Instrument (TROPOMI) will deliver better results. There could be a shift of regime classification threshold for Jakarta. Research on the derivation of O_3 chemical regime threshold is important to verify our findings, both observation and modelling simulation can be done.

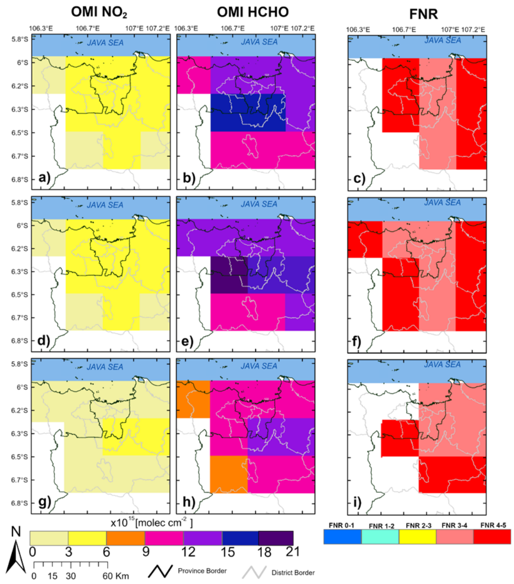

Fig.4 Map of the average (a) OMI NO2 tropospheric column, (b) OMI HCHO vertical column, and (c) FNR value from 2010-2019 for all seasons; (d), €, and (f) for dry seasons; and (g), (h), and (i) for the wet season.

References

1. Permadi, D.A.; Kim Oanh, N.T. Episodic Ozone Air Quality in Jakarta in Relation to Meteorological Conditions. Atmos. Environ. 2008, 42, 6806–6815, doi:10.1016/j.atmosenv.2008.05.014.

2. Syuhada, G.; Akbar, A.; Hardiawan, D.; Pun, V.; Darmawan, A.; Heryati, S.H.A.; Siregar, A.Y.M.; Kusuma, R.R.; Driejana, R.; Ingole, V.; et al. Impacts of Air Pollution on Health and Cost of Illness in Jakarta, Indonesia. Int. J. Environ. Res. Public Health 2023, 20, doi:10.3390/ijerph20042916.

3. Jin, X.; Holloway, T. Spatial and Temporal Variability of Ozone Sensitivity over China Observed from the Ozone Monitoring Instrument. J. Geophys. Res. Atmos. 2015, 120, 7229–7246, doi:10.1002/2015JD023250.

Photos

第18955号

学　位　記

Sheila Dewi Ayu Kusumaningtyas

1985年 3 月20日生

本学に博士の学位論文を提出しその
審査および試験に合格し、かつ、所定の
学力を有するものと認める

東京大学大学院新領域創成科学研究科長

徳永明祥

上記研究科長の認定により博士（環境学）
の学位を授ける

令和 7 年 3 月 5 日

東京大学総長　藤井輝夫

Sheila Dewi Ayu KUSUMANINGTYAS Diploma