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Greenhouse gases and air pollutants monitoring project around Jakarta megacity

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Abstract. National Institute for Environmental Studies (NIES) has been implementing a joint monitoring project of greenhouse gases (GHGs) and air pollutants in Indonesia with Bogor Agricultural University (IPB), Agency for the Assessment and Application of Technology (BPPT), and Meteorological, Climatological, and Geophysical Agency (BMKG). To estimate the amount of anthropogenic emissions from Jakarta megacity (Jabodetabek) and compare with city activities, we developed a ground-based comprehensive monitoring system of GHGs and air pollutants and installed it at Bogor (center of Bogor city) in March 2016, Serpong (Jakarta suburb) in August 2016, and Cibereum (mountainous area, background-like site) in March 2017. The monitoring system consists of data acquisition/control units and the instruments for continuous measurements of CO₂, CH₄, CO, NO_x, SO₂, O₃, aerosol concentrations (PM_{2.5}, PM₁₀, BC) and the chemical components, and meteorological parameters. Flask sampling of air is also done to analyze N₂O, SF₆, and carbon isotopes (¹³C, ¹⁴C) in CO₂ and to validate the continuous measurement data. The result shows that CO₂ mole fractions observed at three sites have clear diurnal variations representing the minimum values from 12 to 15 local time while the values at Bogor and Serpong are 6.8 and 7.1 ppm higher than Cibereum, respectively.

Keywords : CO₂, CH₄, CO, NO_x, SO₂, O₃, aerosol.

1. Introduction

Megacities, being hotspots of human activity, have emitted large quantities of greenhouse gases (GHGs) and air pollutants into the atmosphere with distinct climate effects [1]. Jakarta, the capital and largest city of the Republic of Indonesia, including suburban cities (Bogor, Depok, Tangerang, South Tangerang, and Bekasi; locally known as “Jabodetabek”), has a population of 32 million people and has been listed as the second largest megacity in the world and the largest megacity in Southeast Asia [2]. The increasing GHGs and air pollutants emissions from the megacity in developing country such as



Jakarta due to rapid economic growth in recent years have been recognized as one of the important issues to be solved [3]. Since reduction strategies of GHGs and air pollutants emissions in developing countries have been relatively insufficient compared to developed countries, further urbanization will lead to further increase of GHGs and deterioration of air quality. Urban climate change-related risks, such as heat stress, extreme precipitation, inland and coastal flooding, and air pollution, are increasing with widespread negative impacts on people (and their health, livelihoods, and assets) and on local and national economies and ecosystems [4]. Hence new interdisciplinary research studies have been needed to increase our current understanding of the interactions between emissions, air quality, and regional/global climates taking place in megacities [1].

Several urban air quality monitoring studies in Indonesia were conducted in Jakarta [5, 6, 7, 8], Serpong [8, 9], Bandung [8, 10, 11], and Makassar [12]. However, highly accurate and continuous monitoring has been insufficient due to the limitations of environmental monitoring budgets and experts [3, 6]. Such situations may not promote better understanding of GHGs and air pollutants variability in Indonesia, which is considerably important for making quick actions for global warming mitigation.

National Institute for Environmental Studies (NIES) has been implementing a joint monitoring project of GHGs and air pollutants in Indonesia with Bogor Agricultural University (IPB), Agency for the Assessment and Application of Technology (BPPT), and Meteorological, Climatological, and Geophysical Agency (BMKG). To estimate the amount of anthropogenic emissions from Jakarta megacity (Jabodetabek) and compare with city activities, we developed a ground-based comprehensive monitoring system of GHGs and air pollutants and installed it at three sites around Jakarta. In this paper, we introduce the monitoring system and the initial results obtained at three monitoring sites.

2. Monitoring system

We developed a ground-based comprehensive monitoring system of GHGs and air pollutants. By monitoring both GHGs and air pollutants, it will be possible to gain a greater understanding of the complex relationships between these species during different seasons and times of day as a result of emissions from anthropogenic and natural sources as well as secondary atmospheric chemical reactions [13]. After developing the monitoring system in NIES, we transferred it from Japan to Indonesia and then installed it at Bogor (center of Bogor city) in March 2016, Serpong (Jakarta suburb) in August 2016, and Cibereum (mountainous area, background-like site) in March 2017 (Figure 1, Table 1).

The monitoring system consists of data acquisition and system control units (GSCT-14, Kimoto) and the instruments for continuous measurements of carbon dioxide (CO_2), methane (CH_4) (G2301, Picarro), carbon monoxide (CO) (CO-30r, Los Gatos Research), nitrogen oxides (NO_x) (Model 42i-TL, Thermo), sulfur dioxide (SO_2) (Model 43i-TLE, Thermo), ozone (O_3) (OA-787, Kimoto), aerosol concentrations (particulate matter ($\text{PM}_{2.5}$, PM_{10}), black carbon (BC)) and the chemical components of $\text{PM}_{2.5}$ and PM_{10} (nitrate ion (NO_3^-), sulfate ion (SO_4^{2-})) (ACSA-14, Kimoto), and meteorological parameters (WXT520, VAISALA) (Table 2). Flask sampling of air has also been done automatically at 1:30 PM in local time once a week to analyze nitrous oxide (N_2O), sulfur hexafluoride (SF_6), and carbon isotopes (^{13}C , ^{14}C) in CO_2 in NIES and to validate the continuous measurement data of CO_2 , CH_4 , and CO (these flask sampling data are not shown in this paper). Figures 2 and 3 show the framework and schematic diagram of the monitoring system, respectively. Also Figures 4 and 5 express the appearance of the system installed at IPB in Bogor. This system allows us to control remotely not only all instruments but also peripheral devices (e.g., pumps, valves) through the IPsec virtual private network constructed between three monitoring sites and NIES. The system also has an automatic operation function for power failures because electric power supply is sometimes unstable due to high lightning activity in Indonesia. Moreover, the system is corresponding to redundant operation for any device failures (i.e., there are dual air sampling lines, dual dust filters, dual sampling pumps, etc.; Figure 3). For instance, if any problems occur in one sampling pump, we can change the pump to alternative one remotely. To minimize missing data by any instrument and/or program errors, the system has an e-mail alert function to send alert mails on errors and also has a status mail function to send a status mail every morning. The monitoring data obtained from each measuring instrument and sensor, such as flow meters, pressure sensors, and temperature sensors, are visualized on the monitoring display (Figure 6) in real-time and recorded every

1 minute in unified data format with GPS time stamps. These data files are transferred to a cloud server at regular intervals.

For highly accurate measurements, the observed values of CO₂, CH₄, CO, NO_x, and SO₂ mole fractions have been automatically calibrated with standard gases periodically. We have utilized 9 standard gas cylinders in Bogor and Cibeureum and 6 standard gas cylinders in Serpong (4 concentrations of CO₂/CH₄, 3 concentrations of CO, 1 concentration of NO, and 1 concentration of SO₂). These standard gases of CO₂, CH₄, and CO were calibrated with NIES-09, NIES-94, and NIES-09 scales, respectively [14], in advance of the shipment from NIES. As for calibration for NO_x and SO₂, we used commercially available NO and SO₂ standard gases which had higher concentrations (e.g., ppm level). Such gases were diluted by zero gas (i.e., NO_x and SO₂ free air) to make span gases for the analyzers.

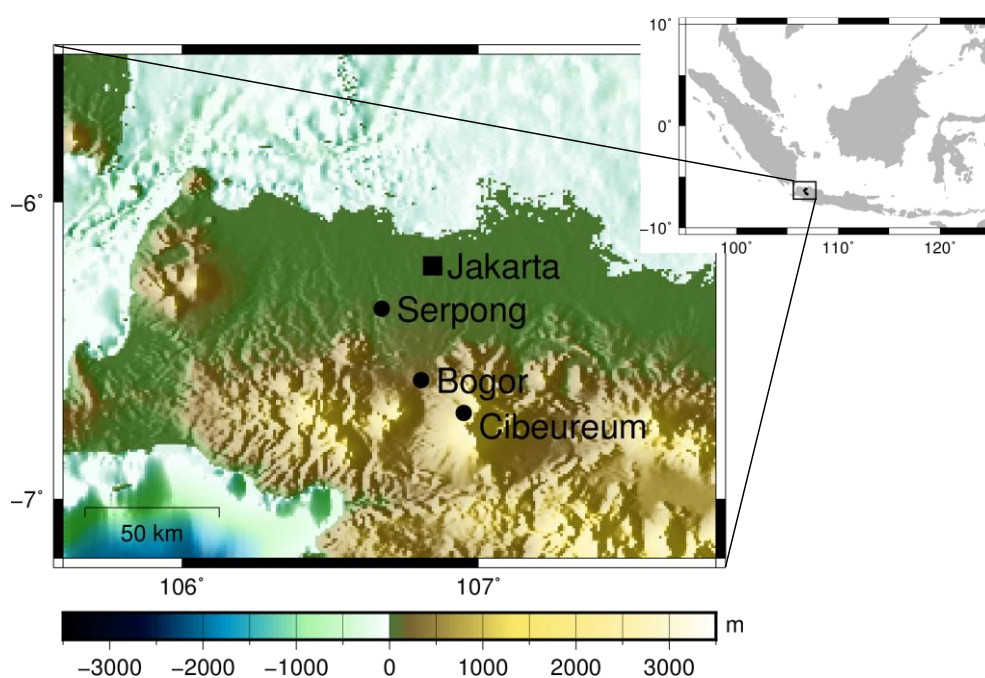


Figure 1. Map of the monitoring sites.

Table 1. Location and affiliation of the monitoring sites and monitoring starting date.

Location	Affiliation	Latitude	Longitude	Altitude	Starting date
Serpong (<i>Jakarta suburb</i>)	Geotech Laboratory, Agency for the Assessment and Application of Technology (BPPT) Center for Climate Risk and Opportunity Management in Southeast Asia Pacific,	6.36°S	106.67°E	63 m	26 Aug 2016
Bogor (<i>center of Bogor city</i>)	Bogor Agricultural University (IPB CCROM-SEAP)	6.60°S	106.81°E	266 m	1 Jun 2016
Cibeureum (<i>mountainous area</i>)	Meteorology Station Cibeureum, Meteorological, Climatological, and Geophysical Agency (BMKG)	6.71°S	106.95°E	1160 m	10 Mar 2017 (O ₃ , PM) 6 Jun 2017 (all)

Table 2. Monitoring species and instruments.

Species	Characteristics	Monitoring instrument	Serpong	Bogor	Cibeureum
CO ₂ CH ₄	GHG	CO ₂ /CH ₄ /H ₂ O analyzer (G2301, Picarro)	√	√	√
CO	Air pollutant	CO analyzer (CO-30r, Los Gatos Research)		√	√
O ₃	GHG, air pollutant	O ₃ analyzer (OA-787, Kimoto)	√	√	√
PM _{2.5} , PM ₁₀ NO ₃ ⁻ SO ₄ ²⁻ Black carbon	Air pollutant, radiation related material	Continuous dichotomous aerosol chemical speciation analyzer (ACSA-14, Kimoto)		√	√
NO _x	Air pollutant, converted to NO ₃ ⁻	NO _x analyzer (Model 42i-TL, Thermo)	√	√	√
SO ₂	Air pollutant, converted to SO ₄ ²⁻	SO ₂ analyzer (Model 43i-TLE, Thermo)	√	√	√
CO ₂ , CH ₄ , N ₂ O, SF ₆	GHG				
CO	Air pollutant				
CO ₂ stable isotope (¹³ C and ¹⁸ O)	CO ₂ indicator	Automatic flask sampler (S-KM-IS, Koshin-RS) and analysis in NIES	√	√	√
CO ₂ radiocarbon (¹⁴ C)					
Temperature Relative humidity Wind direction Wind speed Rain, Pressure	Meteorology	Weather sensor (WXT520, VAISALA)	√	√	√

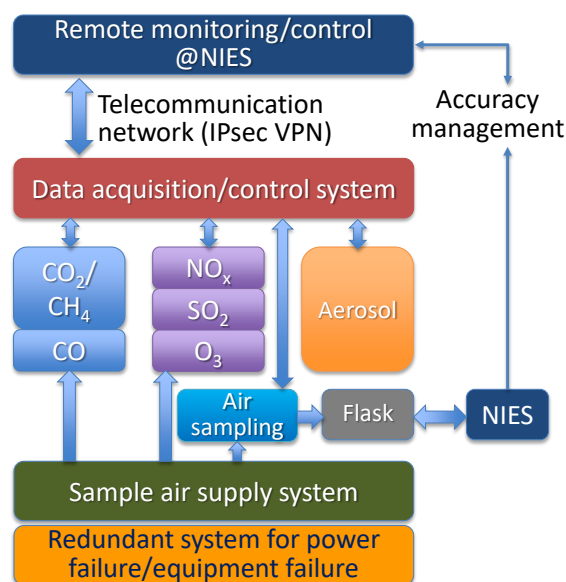


Figure 2. Framework of the monitoring system.

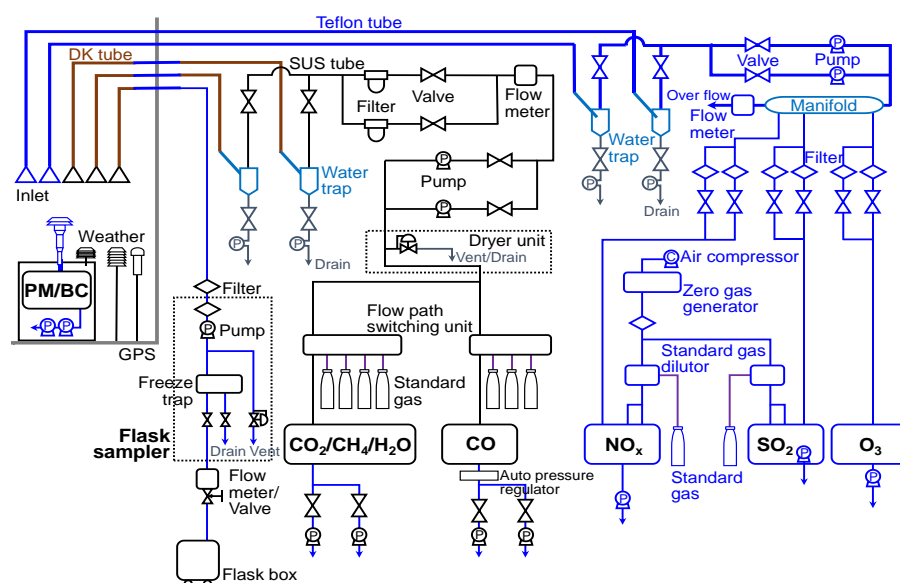


Figure 3. Schematic diagram of the monitoring system.

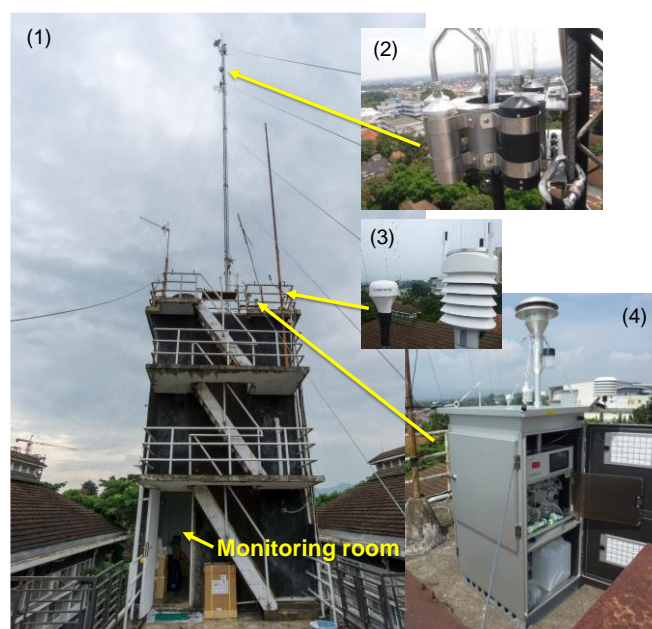


Figure 4. Appearance of the monitoring site at Bogor. (1) Monitoring room and tower, (2) inlets on the tower (35 m above the ground), (3) GPS antenna and weather sensor (WXT520, VAISALA), (4) continuous dichotomous aerosol chemical speciation analyzer (ACSA-14, Kimoto).

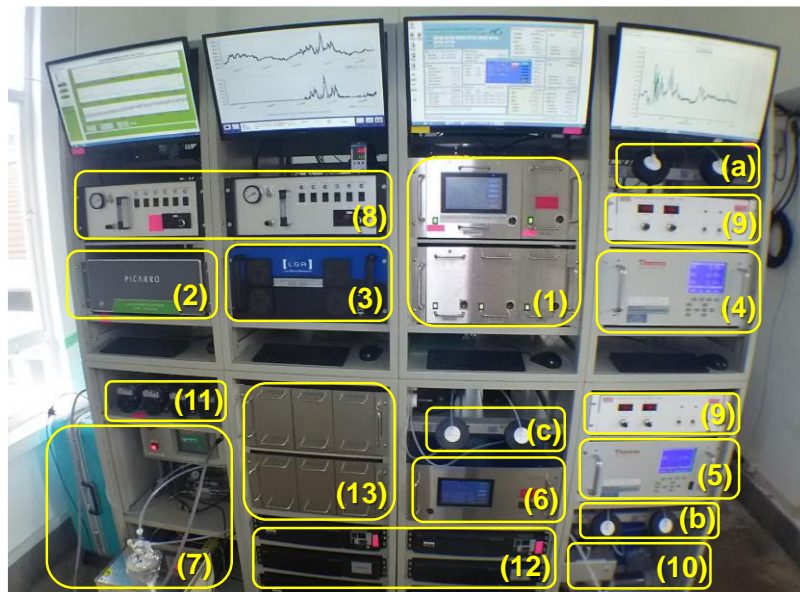


Figure 5. Monitoring system in the monitoring room at Bogor site. (1) Data acquisition and system control units (GSCT-14, Kimoto), (2) CO₂/CH₄/H₂O analyzer (G2301, Picarro), (3) CO analyzer (CO-30r, Los Gatos Research), (4) NO_x analyzer (Model 42i-TL, Thermo), (5) SO₂ analyzer (Model 43i-TLE, Thermo), (6) O₃ analyzer (OA-787, Kimoto), (7) automatic flask sampler (S-KM-IS, Koshin-RS), freeze trap, and flask box, (8) flow path switching units for CO₂/CH₄/H₂O and CO analyzers (GBJT-2001-01, Glovebox Japan), (9) standard gas dilutors for NO_x and SO₂ analyzers (103S, Nippon thermo), (10) zero gas generator for NO_x and SO₂ analyzers and exhaust pump for NO_x analyzer, (11) exhaust pumps for CO₂/CH₄/H₂O and CO analyzers, (12) uninterruptible power supplies, (13) power supply units for GSCT-14. There are three sets of dust filters for NO_x (a), SO₂ (b), and O₃ (c) analyzers.

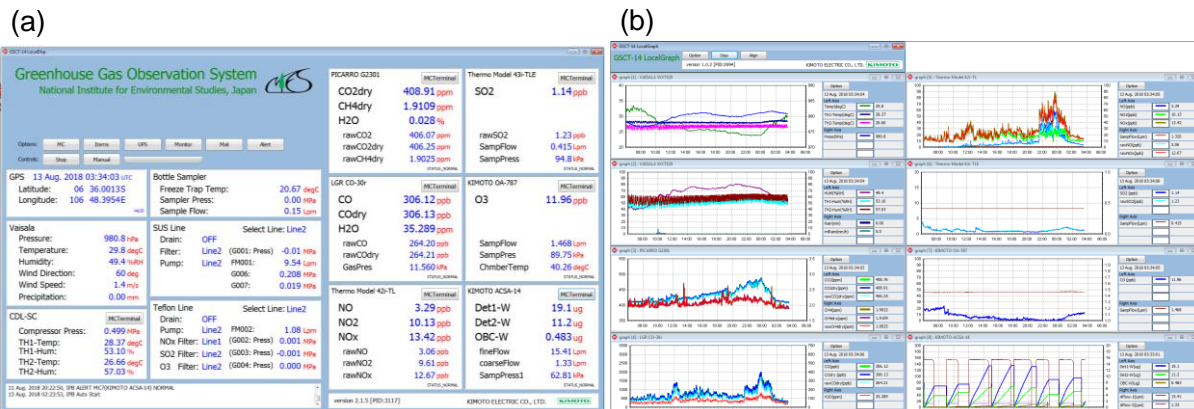


Figure 6. (a) Monitoring and controlling program for the monitoring system, (b) real-time monitoring data visualization program.

3. Monitoring data

We report the initial results obtained at Serpong, Bogor, and Cibereum.

3.1. CO₂, CH₄, and CO

Figure 7 shows the temporal variation of hourly averaged CO₂, CH₄, and CO mole fractions observed at Serpong, Bogor, and Cibereum from 1 June 2016 to 11 March 2018. The mole fractions of CO₂ and CH₄ at Serpong and Bogor and of CO at Bogor are relatively high value compared with those at Cibereum. In particular, very high mole fraction (3–5 ppm) of CH₄ were observed at Serpong from

evening to early morning as well as CO₂ at Serpong (Figure 7, 8). Figure 9 shows the diurnal variations of CO₂ mole fractions (hourly median) observed at three sites from 1 June 2017 to 28 February 2018. They have clear diurnal variations representing the minimum values at 3 sites during early afternoon (12–15 local time) and the maximum values at Serpong and Bogor during early morning and at Cibereum during midnight. Hence we computed daytime values of CO₂ mole fractions at each site using three hours averages from 12 to 15 local time (Figure 10). The daytime values at Bogor and Serpong are 6.8 and 7.1 ppm higher than Cibereum in average between June 2017 and March 2018, respectively. These results indicate that the mole fractions of CO₂ at Serpong and Bogor and of CO at Bogor have been affected by anthropogenic emission originating from fossil fuel combustion and industrial processes in the urban area. Meanwhile, those values observed at Cibereum indicate that they have background-like characteristics. Furthermore, we need to survey the reason of the high concentration of CH₄ and CO₂ at Serpong and also any effects of vegetation and anthropogenic emissions around three sites using carbon isotopes obtained from flask samplings.

The daytime values at Bogor and Serpong in December and January are 5–10 ppm lower than the other months. We also observed no frequent night-time enhancements of CO₂ and CH₄ mole fractions at Serpong in December and January. The wind rose diagrams of the three sites in April, July, and October 2017 and January 2018 in Figure 11 show that most of winds in January (mid-rainy-season around Jakarta) blow from westerly direction obviously, which is relatively strong wind compared with the other months. There are no large source in the west of Serpong and Bogor. Thus we estimate that the lower values of CO₂ mole fractions in December and January are caused by such distinctive westerly and relatively strong wind.

3.2. NO, NO₂, SO₂, and O₃

Figure 12 shows the temporal variations of hourly NO, NO₂, SO₂, and O₃ mole fractions observed at Serpong, Bogor, and Cibereum from 1 June 2016 to 11 March 2018. The mole fractions of NO, NO₂, and SO₂ at Serpong and Bogor tend to be higher than those at Cibereum. While the NO mole fractions at Cibereum almost stayed at low level (1–2 ppb), the NO mole fractions at Serpong and Bogor sometimes exceeded 40 ppb. This result indicates that there are many anthropogenic emission sources around Serpong and Bogor while there are few sources around Cibereum. The clear diurnal variations of O₃ mole fractions are recognized at three sites. Although the peak values of the O₃ mole fraction in the afternoon observed at three sites were almost same level, the values of O₃ mole fraction at Cibereum during night-time were 10–20 ppb higher than Serpong and Bogor. Moreover, the mole fractions of NO₂, SO₂, and O₃ at three sites decreased in December and January as well as CO₂ and CH₄.

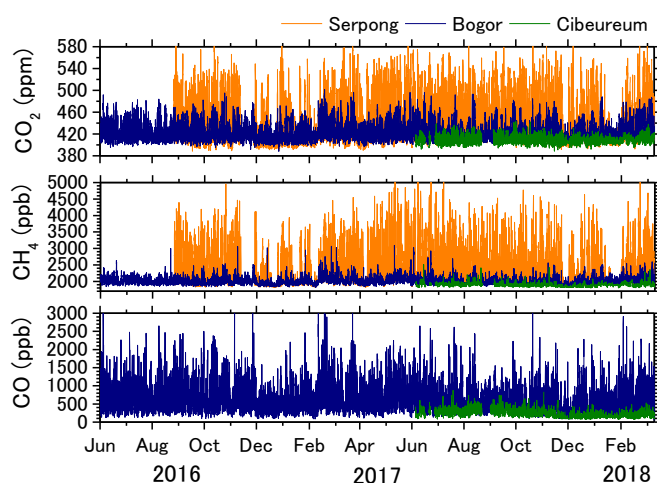


Figure 7. Temporal variation of hourly CO₂, CH₄, and CO mole fractions observed at Serpong, Bogor, and Cibereum from 1 June 2016 to 11 March 2018.

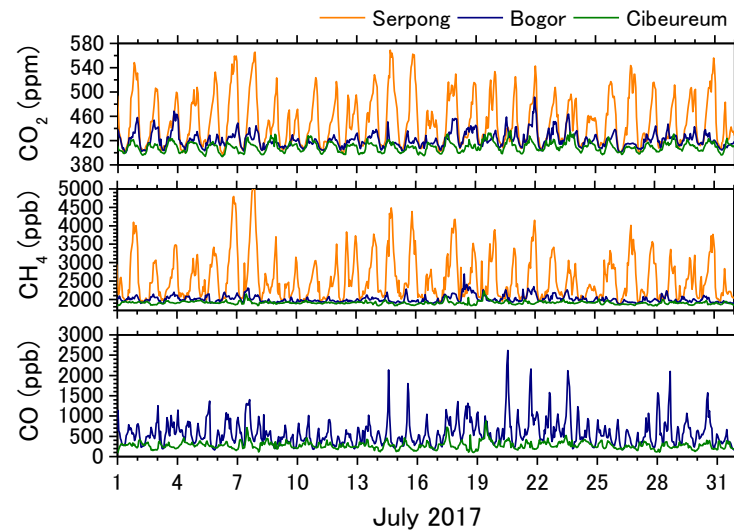


Figure 8. Temporal variation of hourly CO_2 , CH_4 , and CO mole fractions observed at Serpong, Bogor, and Cibeureum in July 2017.

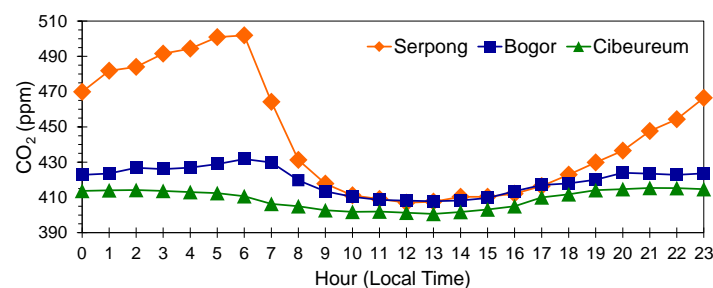


Figure 9. Diurnal variation of hourly CO_2 mole fractions observed at Serpong, Bogor, and Cibeureum from 1 June 2017 to 28 February 2018.

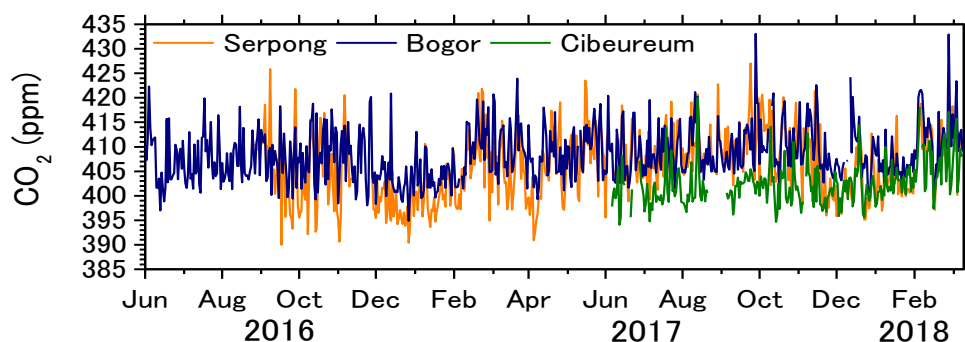


Figure 10. Daytime value (average from noon to 3 PM) of CO_2 mole fraction observed at Serpong, Bogor, and Cibeureum from 1 June 2016 to 11 March 2018.

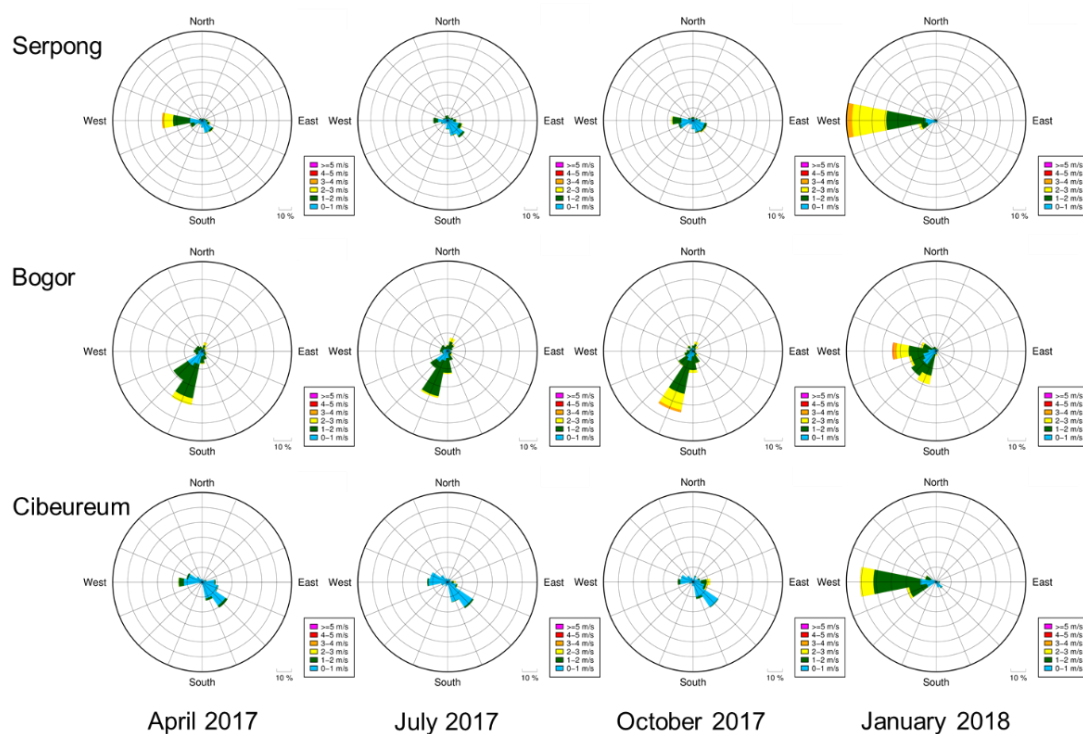


Figure 11. Wind rose diagrams of Serpong, Bogor, and Cibereum in April, July, and October 2017 and January 2018.

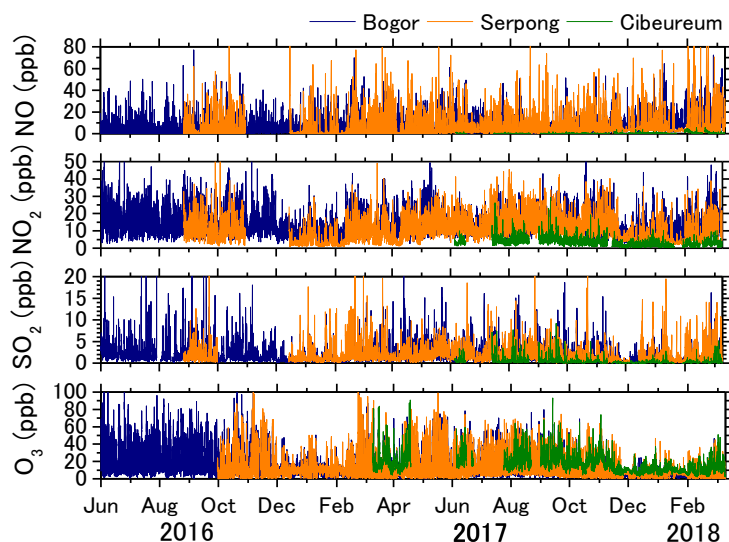


Figure 12. Temporal variations of hourly NO, NO₂, SO₂, and O₃ mole fractions observed at Serpong, Bogor, and Cibereum from 1 June 2016 to 11 March 2018.

3.3. PM_{2.5}, PM_{10-2.5}, and BC

Figure 13 shows the temporal variation of PM_{2.5}, PM_{10-2.5}, and BC concentrations observed at Bogor and Cibereum from 1 June 2016 to 11 March 2018. The measurement interval is 3 hours to extend the replacement interval of filter tape and chemical reagents for the chemical component analysis of PM_{2.5} and PM_{10-2.5}. The average values of PM_{2.5} observed at Bogor and Cibereum during dry season,

approximately from May to October, are 2.0 and 2.7 times higher than those of wet season, from November to April, respectively. While the seasonal trend of $PM_{2.5}$ at Bogor is similar with Cibereum, the average $PM_{2.5}$ at Bogor is 1.8 times larger than Cibereum. The difference of $PM_{10-2.5}$ and BC between Bogor and Cibereum is large, compared with $PM_{2.5}$, and the average values of $PM_{10-2.5}$ and BC observed at Bogor is 2.8 and 4.2 times larger than Cibereum, respectively. These results suggest that the $PM_{2.5}$, $PM_{10-2.5}$, and BC at Bogor is affected by peripheral anthropogenic emissions compared with Cibereum.

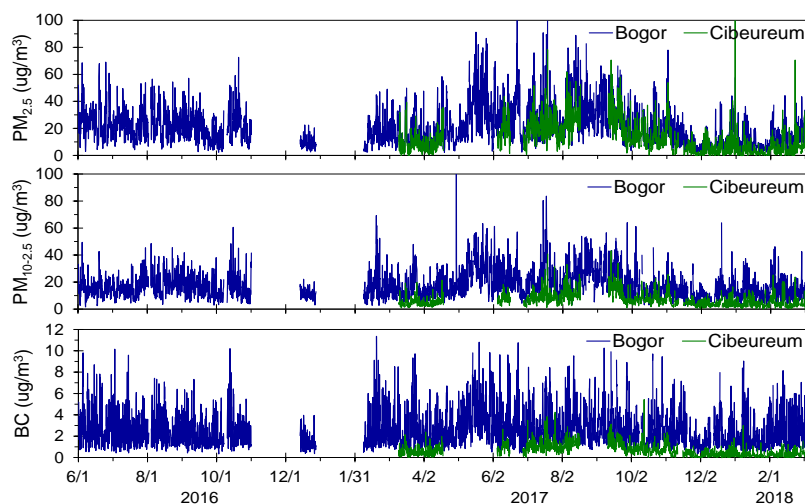


Figure 13. Temporal variation of $PM_{2.5}$, $PM_{10-2.5}$, and BC concentrations observed at Bogor and Cibereum from 1 June 2016 to 11 March 2018. The measurement interval is 3 hours.

4. Summary

We developed a ground-based comprehensive monitoring system of GHGs and air pollutants specialized for remote automatic operation in Indonesia and installed it at Bogor, Serpong, and Cibereum in 2016–2017 to estimate the amount of anthropogenic emissions from Jakarta megacity and compare with city activities. The monitoring results indicate that the mole fractions of CO_2 at Serpong and Bogor and of CO at Bogor have urban characteristics affected by anthropogenic emission from the urban area while those values at Cibereum have background-like characteristics. This characteristics are also recognized in the other species, NO_x , SO_2 , $PM_{2.5}$, $PM_{10-2.5}$, and BC. Moreover, we found diurnal and seasonal characteristics. We need to continue the GHGs and air pollutants monitoring in Indonesia for a long time to observe the variability and to predict future local and global environment.

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