Peer-reviewed version available at Atmosphere 2018, 9, 367; doi:10.3390/atmos9100367

Article)

Diurnal and seasonal variations of carbon dioxide (CO_2) concentration in urban, suburban and rural areas around Tokyo-city

Ryoichi Imasu [1,*] and Yuka Tanabe [1]

[1] Atmosphere and Ocean Research Institute, The University of Tokyo ; imasu@aori.u-tokyo.ac.jp
* Correspondence: imasu@aori.u-tokyo.ac.jp; Tel.: +81-4-7136-4410

Abstract: Site environments and instrumental characteristics of carbon dioxide (CO_2) measurements operated by local governments in the Kanto Plain, the center of which is Tokyo were summarized for this study. The observation sites were classified into environments of three types: urban, suburban, and woodland. Based on a few decades of accumulated hourly data, the diurnal and seasonal variations of CO_2 concentrations were analyzed as a composite of anomalies from annual means recorded for each site. In urban areas, the highest concentrations appear before midnight in winter. The second peak corresponds to the morning rush hour and strengthening of the inversion layer. Suburban areas can be characterized as having the highest concentration before dawn and the lowest concentration during the daytime in summer in association with the activation of respiration and photosynthesis of vegetation. In these areas, concentration peaks also appear during the morning rush hour. Woodland areas show background features, with the highest concentration in early spring: higher than the global background by about 5 ppmv.

Keywords: CO_2; Carbon dioxide; mega-city; diurnal cycle; CO_2 emission; GOSAT

1. Introduction

Since the 1990s, studies of CO_2 emissions and uptake using global scale inverse models [1] have been conducted based on in situ measurements to monitor background levels using data from global meteorological networks [2-4]. Source/sink strengths have been evaluated by these studies as a time series on sub-continental scales [e.g., 5]. However, because the number of observation sites are limited particularly over the ocean, satellite observation of CO_2 has been sought for a long time for more accurate evaluation of phenomena. Responding to this demand, earth observation satellites such as the Greenhouse gases observing satellite (GOSAT) and Orbiting Carbon Observatory-2 (OCO-2) were launched. Ever since, they have been provided global observations [6,7]. Source/sink invers analyses have also been conducted [e.g., 8]. Recently, regional through city-scale emissions assessment has attracted attention as a target of satellite observations [e.g., 9,10,11].

In the context of general interest in the global environment, local governments have conducted CO_2 observations in each prefecture of Japan. Although it has been expected that these data shall be used to estimate CO_2 emissions from large cities in conjunction with satellite data, characterizations of observation sites and data have not been studied synthetically, except for a few studies, despite more than a decade that datasets have been available to researchers [12].

This study summarizes site locations and instrumental characteristics of CO_2 measurements conducted by local governments in the Kanto Plain, Japan. These are the only data officially available in digital format to researchers for the region. Based on data observed during more

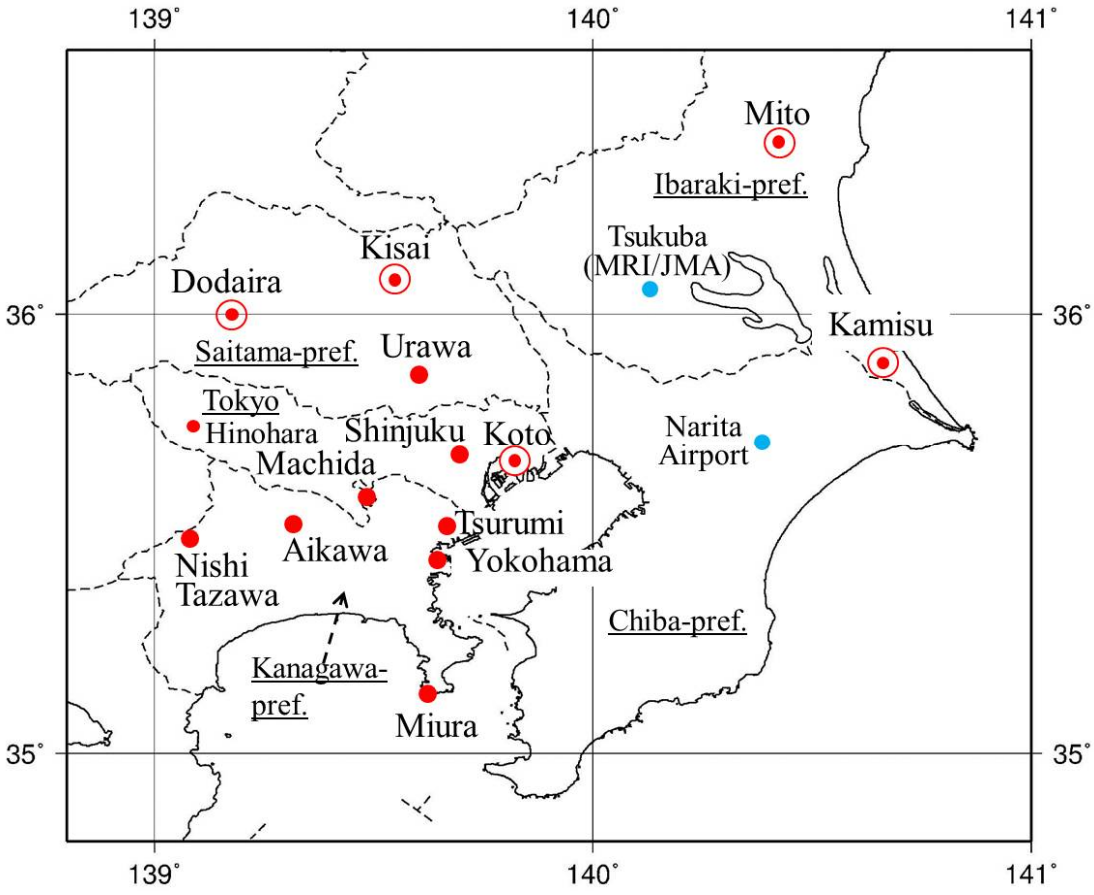

Figure 1. Locations of observation sites. Closed red circles with an open circle represent sites for which hourly data are available. Closed red circles represent older sites. Closed blue circles denote the locations of MRI/JMA and Narita Airport, where tower data and vertical profiles of CO_2 concentration are available, respectively. Names of prefectures are underlined.

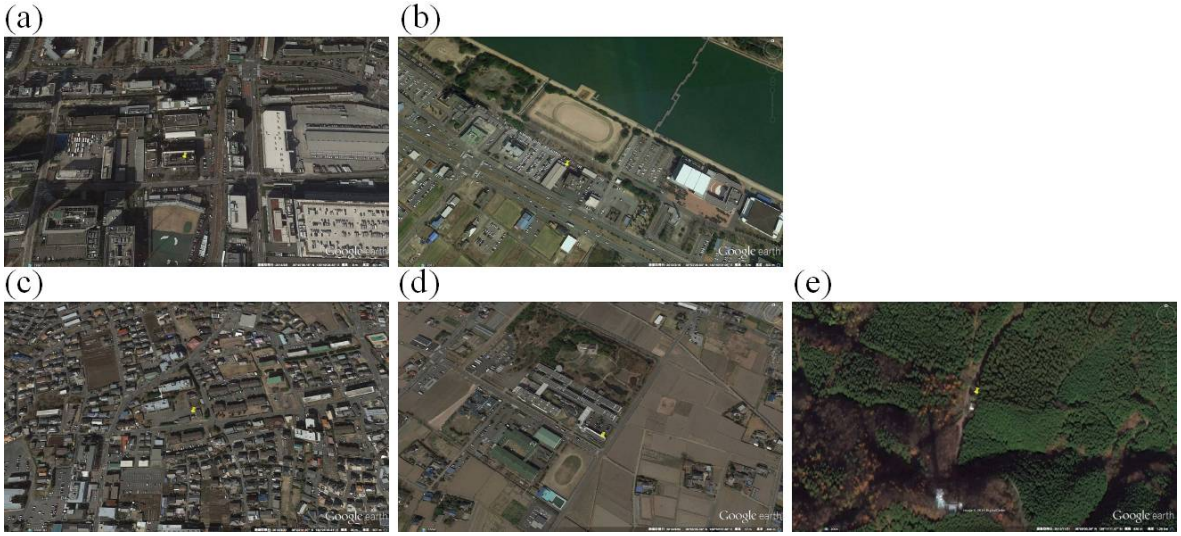

Figure 2. Aerial photographs of (a) Koto (Tokyo), (b) Kamisu (Ibaraki), (c) Mito (Ibaraki), (d) Kisai (Saitama), and (e) Dodaira (Saitama). Images are based on Google Earth (https://www.google.co.jp/intl/ja/earth/).

Table 1. Site characteristics and instruments.

Site name (Prefecture)	Latitude Longitude Altitude (m)	Classification	NDIR Model No.	Dehumidifier temperature (℃)	Filter pore size (μm)	Operational period
Koto (Tokyo)	35°40'07"N 139°49'27"E 8 (Inlet:+25)	Urban (dense city near Tokyo bay)	Shimadzu URA-207	+2	0.045	1993.1-2015.8
Kamisu (Ibaraki)	35°53'20"N 140°39'58"E 5 (Inlet: -)	Urban (industrial district)	Horiba VA-3000	-	-	2000.1 - present
Mito (Ibaraki)	38°23'32"N 149°25'35"E 36 (Inlet: -)	Suburban (residential)	AIC-500 →Horiba VA3001 (after 2008)	+2.5	0.3	2000.1 - present
Kisai* (Saitama)	36°05'04"N 139°33'38"E 17 (Inlet:+20)	Suburban (paddy field, residential)	Horiba VIA-510R	+5, -30, -65	5, 1, 0.0	2000.5 - present
Dodaira* (Saitama)	36°00'02"N 139°11'09"E 831 (Inlet:+20)	Woodland	Horiba VIA-510R	+5, -30, -65	5, 1, 0.01	1992.4 - present

*WDCGG site

than a decade, diurnal and seasonal variation of CO_2 concentrations were analyzed to characterize site environments of each class.

2. Observation sites, instruments, and analysis

Figure 1 portrays the locations of the observation sites operated by local governments or government-funded research institutes. Names of prefectures are underlined in the figure. Closed red circles with an open circle represent sites for which hourly data are available as digital data for all observation periods. Site information, instrumentation, and results of data analyses are presented for these five sites in this report. Closed red circles represent older sites for which data are no longer provided in digital files. One closed blue circle in Figure 1 denotes the location of the Meteorological Research Institute of the Japan Meteorological Agency (MRI/JMA) where there was a 200 m high tower and where CO_2 concentrations had been measured at 1.5 m, 25 m, 100 m, and 200 m heights during 2000–2010 [13]. Another closed blue circle in the figure shows the location of Narita Airport, where vertical profiles of CO_2 concentration have been measured by passenger aircraft in conjunction with a the Japan Airlines project: Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL) [14,15].

Figure 2 presents aerial photograph of five sites: (a) Koto (Tokyo), (b) Kamisu (Ibaraki), (c) Mito (Ibaraki), (d) Kisai (Saitama), and (e) Dodaira (Saitama). For these sites, hourly data are available as digital data. Judging from photographs and field surveys conducted by the authors, these five sites are classified into environments of three types: urban, suburban, and woodland. Information related to these five sites and instruments is presented in Table 1.

Regarding the Tokyo metropolitan government, the Tokyo Metropolitan Research Institute for Environmental Protection has conducted CO_2 measurements. Koto is the only site in Tokyo. Measurements there continued through August 2015. Because the site is located in an industrial area near Tokyo Bay, it is classified as an urban area. The measurement system is placed in an upper level of the institute building. The inlet for air sampling is placed at the top of the building. Other observation sites in Tokyo are presented in Figure 1. The measurements were conducted at Shinjuku and Machida during 1993–1998. Hinohara site was used during 2000–2001.

One site in Ibaraki prefecture, Kamisu, is an urban site located in the Kashima coastal industrial zone. The observation shed is placed in an area used for a fire station. The other site in Ibaraki prefecture is in Mito city. The site is located in a residential area, but the area is only a few kilometers, surrounded by rice paddy fields with some woods. This site can be regarded as suburban. Measurements at these two sites are conducted by the Ibaraki Prefectural Government, but operations have been consigned to a private company.

Table 2. Calibration gas and frequency.

Site name (Prefecture)	Gas type	CO_2 concentration (ppmv) Reference gas	Span gas	Accuracy (ppmv)	Calibration frequency
Koto (Tokyo)	Commercially sold gas (Sumitomo Chemical)	480	340	1	Every 13 hours
Kamisu (Ibaraki)	Commercially sold gas (Sumitomo Seika Chemical)	450	0 (N_2)	1	Every week
Mito (Ibaraki)	Commercially sold gas (Sumitomo Seika Chemical)	450	0 (N_2)	1	Every week
Kisai (Saitama)	Calibrated by JMA* secondary gas	390,410,430,450	380	0.1	Every 2 hours
Dodaira (Saitama)	Calibrated by JMA* secondary gas	390,410,430,450	380	0.1	Every 2 hours

* Japan Meteorological Agency

Kisai in Saitama prefecture is another suburban site. It is surrounded mainly by rice paddy fields, with houses studding the fields. Dodaira site is located almost at the top of Dodaira Mountain, which is located at the west end of the Kanto Plain. The site is in a woody area with evergreen conifers. Its altitude is 831 m, the highest among the sites. Both sites, Kamisu and Dodaira, have been registered with the World Data Centre for Greenhouse Gases (WDCGG) [4]. Earlier, there was a site at Urawa. It was used during 1991–2002 before measurements started at the Kisai site.

In Kanagawa prefecture, there is no observation site for which data are available now, but there were five sites, at Tsurumi (operated in 1992–2006), Yokohama (1992–2006), Miura (1992–2006), Nishitanzawa (2000–2006), and Aikawa (2002–2006). During March 1998 through May 2000, measurements using a helicopter were conducted seven times to observe the three-dimensional distribution of CO_2 over the cities in Kanagawa prefecture. We investigated official reports and newsletters published by the local government, but no record of CO_2 observations exists for Chiba prefecture.

For measuring CO_2, the Non-dispersive Infrared absorption (NDIR) system is used at all sites. The model numbers are presented in Table 1. The most important factor affecting its measurement accuracy is calibration of the instrument. Gas types used for calibration, CO_2 concentration of the reference and span gases, their accuracy, and frequency of calibration are presented in Table 2. In Saitama prefecture, the secondary gases calibrated by the JMA and their accuracy are evaluated as 0.1 ppmv. They are used for calibrating reference gases. By calibrating the system every 2 hour, the representability of measurements is estimated as better than 0.2 ppmv (T. Muto, personal communication, 2014). In other prefectures, commercially sold gases are used for the calibration. Their concentration accuracy is labeled as 1 ppmv. The calibration frequency is every 13 hour at Koto, and one week at Kamisu and Mito. Also affecting the measurement accuracy are the dehumidifier and aerosol filter. Their dew point temperature and filter pore size are presented in Table 1. Although we visited Kamisu site and read all documents related to the system configuration kept at the office of Ibaraki Prefectural Government, we found no description of the dehumidifier component and aerosol filter of the system.

From all sites, hourly data were distributed to users upon request for disclosure except for the data of Saitama prefecture, which are obtainable from the WDCGG website. For this study, hourly data are simply averaged to obtain daily mean values as far as more than 50% of data are valid data. Monthly mean values are obtained using the same manner of averaging.

3. Results

Monthly mean CO_2 concentrations for all sites in the Kanto Plain are shown as a function of time in Figure 3. At all sites, concentrations have increased almost constantly, showing the seasonal cycle clearly. The growth rates are uniformly about 2 (ppmv/year). The annual mean value is highest

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 20 April 2018 doi:10.20944/preprints201804.0265.v1

Peer-reviewed version available at Atmosphere 2018, 9, 367; doi:10.3390/atmos9100367

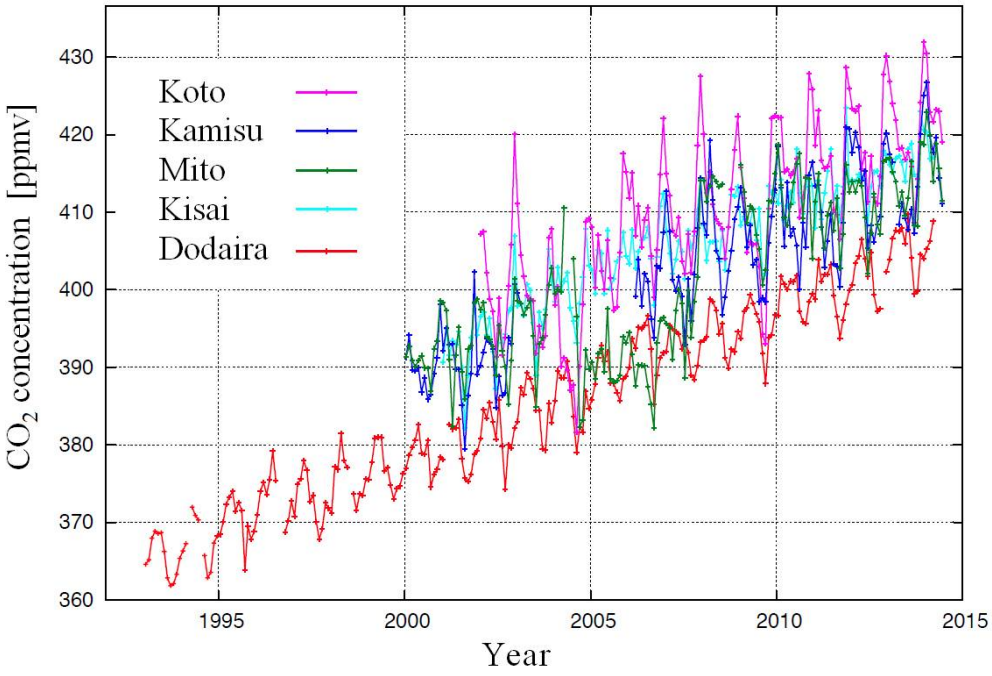

Figure 3. Monthly mean CO_2 concentrations observed at five sites.

at Koto (Tokyo) and lowest at Dodaira (Saitama). It is recorded that CO_2 concentrations decreased drastically for a few months immediately after the Great East Japan earthquake in 2011. At the Mito (Ibaraki) site, the values in 2004-2007 are remarkably smaller than those expected from the trend line compared with other years. Reportedly, the measurement system was replaced in 2004. The system was not well calibrated during the period.

To extract the diurnal and seasonal variations of CO_2 concentration at each site, anomalies of hourly data from annual means centered at each time are composited for each site. The results for all observation periods up to 2014 are presented in Figure 4.

At the Koto site, the highest concentration appears before midnight in winter; the second peak appears at 7–10 A.M. in all seasons [Figure 4(a)]. The daily minimum appears at around 3 P.M. in all seasons, and their lowest concentration has been recorded in September. Kamisu (Ibaraki) is another site classified as an urban area showing similar features to those of the plot for the Koto site [Figure 4(b)]. However, the highest concentration before midnight in winter is lower than that at the Koto site. Furthermore, the minimum value in August is lower.

Mito (Saitama) and Kisai (Saitama), which are classified as suburban areas, show mutually similar features [Figure 4(c) and 4(d)]. These areas can be characterized having the highest concentration before dawn and the lowest concentration in the daytime during summer. At the Mito site, an increase of concentration appeared before midnight, as in urban areas in winter.

Dodaira (Saitama) site is a woodland area. The features of diurnal and seasonal variation differ from those of other sites [Figure 4(e)]. The daily average is highest in springtime and lowest in late summer. Although the scale range of presented values is expanded for the Dodaira site to emphasize the relative variation, the variation amplitude is two or three times lower than those of urban and suburban areas.

4. Discussion

As presented in Section 2, the measurement accuracy differs among prefectures. In Saitama prefecture, the accuracy and representativity are about 0.2 ppmv using officially released calibration

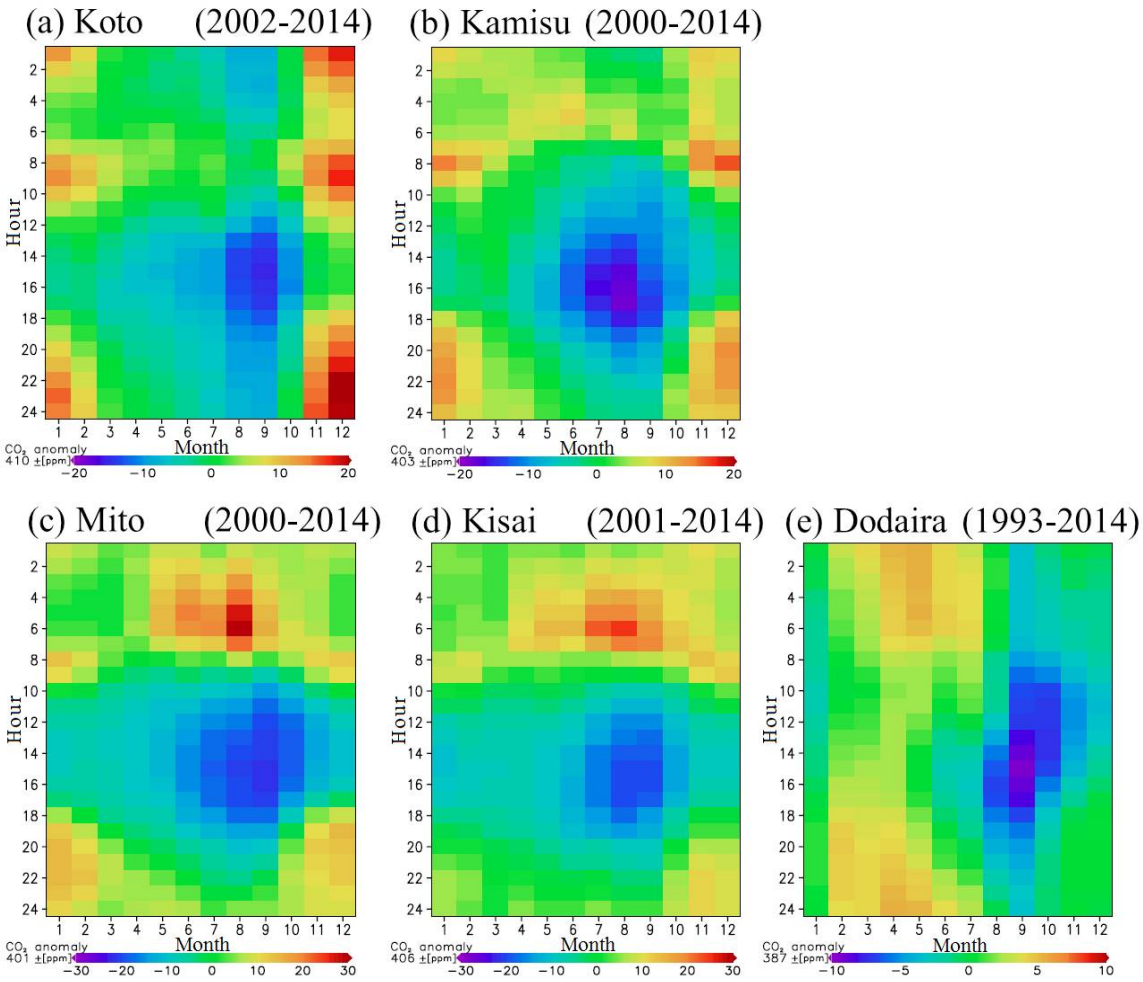

Figure 4. Diurnal–monthly anomalies of CO_2 concentration for five sites. Anomalies are calculated as composites of differences between hourly data and annual mean values calculated using the running mean centered at each hourly datum with a one year window. Observational periods used for calculations are shown in the respective plots.

gases. Data screening criteria follows that recommended by WDCGG. On the other hand, the accuracies can be about a few parts per million by volume (ppmv) for data observed in Ibaraki prefecture and Tokyo city, mainly because of the low accuracy of calibration gases and low frequency of calibration operation, particularly in Ibaraki prefecture where the calibration frequency is only once per week. However, the room temperature and dehumidifier temperature are kept constant. As it is expected that the measurement systems have not been unstable, measurement accuracies can be on the order of a few parts per million by volume. As a consequence, measurement accuracy of a few parts per million by volume is achieved and is sufficiently accurate to represent the diurnal and seasonal variations presented in Section 3 because the amplitude of the variation is about 10 times greater than the measurement accuracy.

Many studies have been made to characterize the CO_2 concentration or flux in areas of various types classified in the same way as we described as a result of this study [5,16-27]. Although many of them are made based on CO_2 flux measurements using the eddy covariance method, the characteristics of concentrations and fluxes can show almost identical features because the concentration is strongly affected by the flux (emission/up take) in a limited spatial and temporal scale.

Results of this study demonstrated that urban areas are characterized by high concentrations before midnight in winter and in the morning during all seasons. Many studies conducted for urban areas show similar features. One can infer that the former is attributable to emissions from private

household, heating, or from businesses [21]. The latter is attributable to emissions corresponding to the rush hour [19,28,29]. Some reports [e.g., 12] describe that the increase in CO_2 concentration derives from an increase of atmospheric stability during nighttime. If that is true, then the concentration can be expected to increase constantly up to the time of sunrise. However, the actual concentration shows a decrease once immediately after the midnight; then it increases again until sunrise. Therefore, it can be concluded that the increase of CO_2 concentration before midnight is mainly attributable to the increase of CO_2 emission in this area. The minimum concentration appearing in the daytime in summer at Kamisu is lower than that at Koto because the Kamisu site is surrounded by more vegetation than the Koto site is, and CO_2 uptake by vegetation around Kamisu site is stronger than that around Koto.

High and low concentrations were respectively found during nighttime and daytime in suburban areas in summer as reported by some studies for the Mito and Kisai sites [18,30]. They correspond to the respiration and photosynthesis of vegetation in the area.

Smaller amplitude of variation and the highest concentration in spring time are the characteristics of the background concentration of CO_2 [2,31]. At the Dodaira site, diurnal and seasonal variations are similar to those of the background, but the average level is higher than the global background by about 5 ppmv [4]. At the Dodaira site, high concentrations of CO_2 before drawing have not been observed in spite of the existence of vegetation in the area because the inversion layer near the surface is not easily formed near a mountain top.

To estimate the total amounts of CO_2 emissions and uptake precisely, numerical simulation models used for estimation should be able to represent the nature of CO_2 concentration not only spatially but also temporally, as observed. From this perspective, characteristics of the diurnal and seasonal variation of CO_2 concentration presented by this study for urban, suburban, and woodland areas around Tokyo can be the standard features to be presented by the models. This study also showed that CO_2 concentration characteristics vary depending on the type of the surrounding environment. Measurements must be made operationally for every environment. Nevertheless, measurements at the Koto site stopped in August 2017; no official observation site exists in Tokyo anymore. Because the reduction of CO_2 emissions from the city has recently attracted great attention, CO_2 measurements are expected to begin again in Tokyo.

5. Conclusions

CO_2 measurement sites operated the local governments in the Kanto Plain have been classified as urban, suburban and woodland. Characteristics of diurnal and seasonal variation of CO_2 concentration have been presented for the environments of three types. Although the measurement accuracy varies among prefectures depending on the types of calibration gases and frequency of calibration operation, it is by no means accurate enough to represent the diurnal and seasonal variations presented in this study. This study demonstrated clearly that continuous measurements at fixed observation sites can elucidate the effects of CO_2 emissions and uptake around the site. On the other hand, satellite instruments can target arbitrary locations. However, because the observation times are generally limited to around noon, the diurnal cycle of CO_2 emission is difficult to observe by satellites. Therefore, it can be inferred that satellite measurement data should be used synergistically with ground-based measurements to estimate CO_2 emissions and uptake from a city effectively.

Acknowledgments: CO_2 data used for this study were provided by The Tokyo Metropolitan Research Institute for Environmental Protection, Ibaraki prefectural government, and WDCGG. The authors specially thank Mr. Yosuke Muto of The Center for Environmental Science in Saitama (CESS) for his valuable comments related to measurement techniques and data analyses.

Author Contributions: Ryoichi Imasu conducted the research and wrote the manuscript; Yuka Tanabe carried out the field research and analyzed the data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gurney, K.R.; Law, R.M.; Denning, A.S.; Rayner, P.J.; Baker, D.; Bousquet, P.; Bruhwiler, L.; Chen, Y.H.; Ciais, P.; Fan, S.M., *et al.* Transcom 3 CO_2 inversion intercomparison: 1. Annual mean control results and sensitivity to transport and prior flux information. *Tellus Series B-Chemical and Physical Meteorology* **2003**, *55*, 555-579.
2. Conway, T.J.; Tans, P.P.; Waterman, L.S.; Thoning, K.W. Evidence for interannual variability of the carbon-cycle from the national-oceanic-and-atmospheric-administration climate-monitoring-and-diagnostics-laboratory global-air-sampling-network. *J. Geophys. Res.* **1994**, *99*, 22831-22855.
3. Andrews, A.E.; Kofler, J.D.; Trudeau, M.E.; Williams, J.C.; Neff, D.H.; Masarie, K.A.; Chao, D.Y.; Kitzis, D.R.; Novelli, P.C.; Zhao, C.L., *et al.* CO_2, co, and ch4 measurements from tall towers in the noaa earth system research laboratory's global greenhouse gas reference network: Instrumentation, uncertainty analysis, and recommendations for future high-accuracy greenhouse gas monitoring efforts. *Atmospheric Measurement Techniques* **2014**, *7*, 647-687.
4. Tsutsumi, Y.; Mori, K.; Ikegami, M.; Tashiro, T.; Tsuboi, K. Long-term trends of greenhouse gases in regional and background events observed during 1998-2004 at yonagunijima located to the east of the asian continent. *Atmospheric Environment* **2006**, *40*, 5868-5879.
5. Baker, D.F.; Law, R.M.; Gurney, K.R.; Rayner, P.; Peylin, P.; Denning, A.S.; Bousquet, P.; Bruhwiler, L.; Chen, Y.H.; Ciais, P., *et al.* Transcom 3 inversion intercomparison: Impact of transport model errors on the interannual variability of regional CO_2 fluxes, 1988-2003. *Global Biogeochemical Cycles* **2006**, *20*.
6. Crisp, D.; Team, O.C.O. Measuring atmospheric carbon dioxide from space with the orbiting carbon observatory-2 (OCO-2). In *Earth observing systems xx*, Butler, J.J.; Xiong, X.; Gu, X., Eds. 2015; Vol. 9607.
7. Yoshida, Y.; Ota, Y.; Eguchi, N.; Kikuchi, N.; Nobuta, K.; Tran, H.; Morino, I.; Yokota, T. Retrieval algorithm for CO_2 and CH_4 column abundances from short-wavelength infrared spectral observations by the greenhouse gases observing satellite. *Atmospheric Measurement Techniques* **2011**, *4*, 717-734.
8. Takagi, H.; Houweling, S.; Andres, R.J.; Belikov, D.; Bril, A.; Boesch, H.; Butz, A.; Guerlet, S.; Hasekamp, O.; Maksyutov, S., *et al.* Influence of differences in current gosat xco2 retrievals on surface flux estimation. *Geophysical Research Letters* **2014**, *41*, 2598-2605.
9. Bovensmann, H.; Buchwitz, M.; Burrows, J.P.; Reuter, M.; Krings, T.; Gerilowski, K.; Schneising, O.; Heymann, J.; Tretner, A.; Erzinger, J. A remote sensing technique for global monitoring of power plant CO_2 emissions from space and related applications. *Atmospheric Measurement Techniques* **2010**, *3*, 781-811.
10. Hakkarainen, J.; Ialongo, I.; Tamminen, J. Direct space-based observations of anthropogenic co2 emission areas from oco-2. *Geophysical Research Letters* **2016**, *43*, 11,400-411,406.

11. Kort, E.A.; Frankenberg, C.; Miller, C.E.; Oda, T. Space-based observations of megacity carbon dioxide. *Geophysical Research Letters* **2012**, *39*, n/a-n/a.
12. Muto, Y. Atmospheric carbon dioxide concentration in saitama area iii. *Newsletter of The Center for Environmental Science in Saitama* **1996**, *23*, 1-5.
13. Inoue, H.Y.; Matsueda, H. Measurements of atmospheric CO_2 from a meteorological tower in tsukuba, japan. *Tellus Series B-Chemical and Physical Meteorology* **2001**, *53*, 205-219.
14. Machida, T.; Matsueda, H.; Sawa, Y.; Nakagawa, Y.; Hirotani, K.; Kondo, N.; Goto, K.; Nakazawa, T.; Ishikawa, K.; Ogawa, T. Worldwide measurements of atmospheric CO_2 and other trace gas species using commercial airlines. *Journal of Atmospheric and Oceanic Technology* **2008**, *25*, 1744-1754.
15. Matsueda, H.; Machida, T.; Sawa, Y.; Nakagawa, Y.; Hirotani, K.; Ikeda, H.; Kondo, N.; Goto, K. Evaluation of atmospheric CO_2 measurements from new flask air sampling of jal airliner observations. *Papers in Meteorology and Geophysics* **2008**, *59*, 1-17.
16. Hirano, T.; Sugawara, H.; Murayama, S.; Kondo, H. Diurnal variation of CO_2 flux in an urban area of tokyo. *Sola* **2015**, *11*, 100-103.
17. Feng, S.; Lauvaux, T.; Newman, S.; Rao, P.; Ahmadov, R.; Deng, A.; Diaz-Isaac, L.I.; Duren, R.M.; Fischer, M.L.; Gerbig, C., *et al.* Los angeles megacity: A high-resolution land-atmosphere modelling system for urban co2 emissions. *Atmospheric Chemistry and Physics* **2016**, *16*, 9019-9045.
18. George, K.; Ziska, L.H.; Bunce, J.A.; Quebedeaux, B. Elevated atmospheric CO_2 concentration and temperature across an urban–rural transect. *Atmospheric Environment* **2007**, *41*, 7654-7665.
19. Gurney, K.R.; Razlivanov, I.; Song, Y.; Zhou, Y.Y.; Benes, B.; Abdul-Massih, M. Quantification of fossil fuel CO_2 emissions on the building/street scale for a large us city. *Environmental Science & Technology* **2012**, *46*, 12194-12202.
20. Lac, C.; Donnelly, R.P.; Masson, V.; Pal, S.; Riette, S.; Donier, S.; Queguiner, S.; Tanguy, G.; Ammoura, L.; Xueref-Remy, I. CO_2 dispersion modelling over paris region within the co2-megaparis project. *Atmospheric Chemistry and Physics* **2013**, *13*, 4941-4961.
21. Matese, A.; Gioli, B.; Vaccari, F.P.; Zaldei, A.; Miglietta, F. Carbon dioxide emissions of the city center of firenze, italy: Measurement, evaluation, and source partitioning. *Journal of Applied Meteorology and Climatology* **2009**, *48*, 1940-1947.
22. Moriwaki, R.; Kanda, M. Seasonal and diurnal fluxes of radiation, heat, water vapor, and carbon dioxide over a suburban area. *Journal of Applied Meteorology* **2004**, *43*, 1700-1710.
23. Song, T.; Wang, Y. Carbon dioxide fluxes from an urban area in beijing. *Atmospheric Research* **2012**, *106*, 139-149.
24. Velasco, E.; Pressley, S.; Grivicke, R.; Allwine, E.; Coons, T.; Foster, W.; Jobson, B.T.; Westberg, H.; Ramos, R.; Hernandez, F., *et al.* Eddy covariance flux measurements of pollutant gases in urban mexico city. *Atmospheric Chemistry and Physics* **2009**, *9*, 7325-7342.

25. Velasco, E.; Roth, M.; Tan, S.H.; Quak, M.; Nabarro, S.D.A.; Norford, L. The role of vegetation in the co₂ flux from a tropical urban neighbourhood. *Atmospheric Chemistry and Physics* **2013**, *13*, 10185-10202.
26. Ward, H.C.; Kotthaus, S.; Grimmond, C.S.; Bjorkegren, A.; Wilkinson, M.; Morrison, W.T.; Evans, J.G.; Morison, J.I.; Iamarino, M. Effects of urban density on carbon dioxide exchanges: Observations of dense urban, suburban and woodland areas of southern england. *Environ Pollut* **2015**, *198*, 186-200.
27. Yi, C.; Davis, K.J.; Bakwin, P.S.; Berger, B.W.; Marr, L.C. Influence of advection on measurements of the net ecosystem-atmosphere exchange of CO_2 from a very tall tower. *J. Geophys. Res.* **2000**, *105*, 9991-9999.
28. Coutts, A.M.; Beringer, J.; Tapper, N.J. Characteristics influencing the variability of urban CO_2 fluxes in melbourne, australia. *Atmospheric Environment* **2007**, *41*, 51-62.
29. Rao, P.; Gurney, K.R.; Patarasuk, R.; Song, Y.; Miller, C.E.; Duren, R.M.; Eldering, A. Spatio-temporal variations in on-road CO_2 emissions in the los angeles megacity. *Aims Geosciences* **2017**, *3*, 239-267.
30. Crawford, B.; Grimmond, C.S.B.; Christen, A. Five years of carbon dioxide fluxes measurements in a highly vegetated suburban area. *Atmospheric Environment* **2011**, *45*, 896-905.
31. Murayama, S.; Saigusa, N.; Chan, D.; Yamamoto, S.; Kondo, H.; Eguchi, Y. Temporal variations of atmospheric CO_2 concentration in a temperate deciduous forest in central japan. *Tellus Series B-Chemical and Physical Meteorology* **2003**, *55*, 232-243.