Long range transport of air pollutants (trace gases) related with meteorological process in Asia (subregion)

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Abstract

This research focused on the air quality monitoring data analysis of Ulaanbaatar sites and some Asian sites which include EANET to determine seasonal diurnal variation and comparison of O₃, NO₂ and CO. Main purpose were an explanation of high concentration of trace gases related with local and regional air mass transport in the Asian region. Air quality monitoring data of Ulaanbaatar sites (July 2010 to June 2011) are indicated general air pollution trend of Ulaanbaatar city. There are big seasonal (high concentration in summer July, min-Jan) diurnal variation of ozone (maximum in summer), NO₂, CO (high concentration in winter Feb) and depending emission sources and meteorological condition. There is long range transport from neighbor countries (from Russia and China), but city pollution is dominated in Ulaanbaatar.

Key words: Trace gases, Air quality, Air pollutants, Transport

1. Introduction

Air pollutants are classified according to the manner in which they reached the atmosphere, namely primary pollutants, which emitted directly from sources and secondary pollutants which formed in the atmosphere by chemical interactions among primary pollutants and normal atmospheric constituents. The atmospheric distribution of nitrogen oxides is highly non-uniform. Although about ninety percent of nitrogen oxides in the earth’s atmosphere are estimated to be produced by natural bacterial action, localized urban concentrations may far exceed clean air background concentrations. The oxides of nitrogen, NO, NO₂ play an important role in the air pollution chemistry. Most of the NOx formed in fossil fuel combustion. However, NO dominates the NOx. NO₂ is formed to some extent from NO in combustion exhaust gases by \(2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2\). (1)

When NO and NO₂ are present in sunlight, ozone formation occurs as a result of the photolysis of NO₂.
\[ \text{NO}_2 + \text{hv} \rightarrow \text{NO} + \text{O} \quad (2) \]
\[ \text{O} + \text{O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M} \quad (3) \]

Where M present N₂ or O₂ or another third molecule that absorb the excess vibrational energy and thereby stabilizes the O₃ molecule formed (John, 1986).

Ground-level ozone- what we breathe- can harm our health. Even relatively low levels of ozone can cause health effects. People with lung disease, children, older adults, and people who are active outdoors may be particularly sensitive to ozone. Children are at greatest risk from exposure to ozone because their lungs are still developing and they are more likely to be active outdoors when ozone levels are high, which increases their exposure. Children are also more likely than adults to have asthma. (http://www.epa.gov/air/ozonepollution/)

There is no significant source ozone in an atmosphere other than reaction \( \rightarrow (3) \). Once formed O₃ react with NO to regenerate NO₂.

\[ \text{O}_3 + \text{NO} \rightarrow \text{NO}_2 + \text{O}_2 \quad (4) \]

The photolysis of NO₂ is a key atmospheric reaction.

Also, ozone photolysis to produce both ground state (O) and excited single (O(‘D)) oxygen atoms. Oxygen atom just can react with O₂. However, O(‘D) collides with H₂O and produces two hydroxyl radicals.

\[ \text{O(‘D)} + \text{H}_2\text{O} \rightarrow \text{2HO} \]
\[ \text{CO+OH} \rightarrow \text{CO}_2 + \text{H} \quad (5) \]

There is too complex reaction in the atmospheric system of NO, NO₂ and CO (John, 1986).

Meteorological conditions are a crucial factor contributing to poor air quality, in addition to the two other factors of emissions and atmospheric chemistry. Many studies are shown that very different local and regional meteorological influences can be dominant in various settings (Nelson and Sara, 1998).

In East Asia, especially China, emission of O₃ precursors have increased greatly since 2000 (Ohare et al. 2007), (Zang et al., 2007). Tanimoto, Ohara and Uno (2009) noted that the anthropogenic emission became dominant contribution, showing Mt. Hoppo site of Japan to be an ideal location for detecting rapid changes in anthropogenic emissions in East Asia. This research focused on the air quality monitoring data analysis of Ulaanbaatar sites and some Asian sites which include EANET to determine seasonal diurnal variation and comparison of O₃, NO₂ and CO. Main purpose were an explanation of high concentration of trace gases related with local and regional air mass transport in the Asian region.

2. Method

2.1 Data and monitoring sites

Fifteen min averaged raw data of mixing ratios and concentrations of O₃, NOₓ from June 2010 to July 2011 of Air quality monitoring sites of Mongolia and daily average data of EANET sites of Russia (Mondy), Japan (Ochiishi, Rishiri, Tappi, Sado-Seki) from ACAP used in this work. We converted 15 min concentration to 1-hour average and the same unit. A few days mixing ratio of the gases was extremely high from other days and we discharged such data for estimation diurnal and annual variations. But the extreme data’s used for trajectory analysis.
<table>
<thead>
<tr>
<th>Data type</th>
<th>Sites</th>
<th>Parameters</th>
<th>Period</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Air quality monitoring data</td>
<td>UB01 (industrial)</td>
<td>O₃, NO₂, NO, NOₓ, CO, temperature, wind direction, wind speed, pressure for every 15 min</td>
<td>July 2010-June 2011</td>
<td>(ACAP from CLEM)</td>
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<tr>
<td></td>
<td>UB04 (urban)</td>
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<td></td>
<td>UB05 (urban)</td>
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<td></td>
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<td></td>
<td>UB08 (background)</td>
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<td></td>
<td>Ulaanbaatar, Mongolia</td>
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<tr>
<td>2. Air quality monitoring data</td>
<td>(UB02 (road-site))</td>
<td>(NO₂, CO, NO, NOₓ, temperature, wind direction, wind speed, pressure ), (15 min)</td>
<td>July 2010-June 2011</td>
<td>ACAP from CLEM</td>
</tr>
<tr>
<td>3. Air quality monitoring data</td>
<td>Mondy (remote-51.39N 100.55E ), Russia</td>
<td>O₃ (daily average)</td>
<td>2010-2012</td>
<td>ACAP</td>
</tr>
<tr>
<td>4. Air quality monitoring data</td>
<td>Ochiishi(43.09.43N 145.29.5E)</td>
<td>NO, NO₂, NOₓ, O₃</td>
<td>2010-2012</td>
<td>ACAP</td>
</tr>
<tr>
<td></td>
<td>Rishiri(45.07.11N, 141.12.33E)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tappi (41.15.06N, 140.20.59E)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sado-Seki(38.14.59 N, 138.24E)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Short time observation</td>
<td>Sainshand, Mongolia</td>
<td>O₃</td>
<td>2010 (9-22Aug)</td>
<td>Russian-Mongolian expedition,</td>
</tr>
</tbody>
</table>

2.2 Location of sites

Ulaanbaatar city is located in the valley of the mountains. There are 6 automatic monitoring (Figure 1) sites based on influencing emission sources and activities: roadside (UB02), urban (UB04, UB05), industrial (UB01, UB07) and background (UB08). Remote sites were selected from EANET (Russia (Mondy)), (Japan (Ochiishi, Tappe, Sado-Seki, Rishiri)) in order to compare mixing ratios and determine long-range transport.
2.3 Trajectory model

Hysplit trajectory model (http://ready.arl.noaa.gov/hypub-bin/trajtype.pl) has been used for identifying the origin of the air masses arriving at high concentration region in Asian subregion and long range transport, isobaric air mass trajectory used for high concentration O₃ days. Trajectories were calculated one a day with the initial level at 0, 500 and 1,500 m from ground level.

3. Results and discussion

3.1 Annual and diurnal variation of O₃ and NO₂

3.1.1 Data comparison of Ulaanbaatar city sites

The sources of tropospheric ozone are an influx from the stratosphere and generation by photochemical reactions in the troposphere. The influx of ozone from the stratosphere takes place mainly in
middle and high latitudes and is most active in early spring. The generation of ozone in the troposphere is most active in summer since it is caused by photochemical reactions involving nitrogen oxides (NO\textsubscript{x}), carbon monoxide (CO) and volatile organic compounds (VOCs) (http://www.acap.asia/publication/pdf/ozone1.pdf).

Therefore, we analyzed ground level O\textsubscript{3} data and its precursor’s such NO\textsubscript{2} and CO. Before analysis, all measured 15 min data were converted to hourly averaged data. The comparing of daily averaged ozone and NO\textsubscript{2} data of Ulaanbaatar sites was shown on Figure 3, 4 and other Asian stations data’s on Figure 5.

The daily averaged mixing ratios of O\textsubscript{3} were higher in summer lower in winter (Figure 3) and NO\textsubscript{2} lower in summer higher in winter (Figure 4) in Ulaanbaatar Mongolia. The highest mixing ratio of NO\textsubscript{2} measured at the road site (UB02).

![Figure 3. Annual variation of O\textsubscript{3} at Ulaanbaatar sites, Mongolia.](image)

During summer, the daily averaged mixing ratios of ozone were exceeded the national air quality standard level (8 hour average) at UB01 site and UB08 on some days. In winter, the mixing ratios were under national air quality standard, lowest observed at Urban residential area (UB05 site) (Figure 3).
Figure 4. Annual variation of NO₂ at Ulaanbaatar sites, Mongolia.

The highest mixing ratio of NO₂ was measured at UB02 (central cross roadside), it was higher than air quality standard during the year. In the winter season, NO₂ was exceeded air quality standard at all sites of Ulaanbaatar. It emits from a residential area which is coal burning for heating.

Figure 5. The daily average concentration of O₃ at different sites.

The daily averaged mixing ratio of O₃ was higher than other sites at Sado-Seki site of Japan during the year, lowest in Ulaanbaatar Mongolia every season from selected sites (Figure 5). The maximum mixing ratio was measured in July at Mondy of Russia and Ulaanbaatar (UB08) Mongolia. But it was observed in April and May in sites of Japan (Figure 5). In most of the Japan, the rainy season lasts from the beginning of
June to mid-July.

3.2 Transport of ozone

3.2.1 Local transport of ozone

Ozone is likely to reach unhealthy levels on hot sunny days in urban environments. Ozone can also be transported long distances by the wind. For this reason, even rural areas can experience high ozone levels (http://www.epa.gov/air/ozonepollution/). The reason we have selected background site UB08 of Ulaanbaatar city. Average mixing ratios of gases were estimated by 16 wind direction at background site by hour and season.

At background site of Ulaanbaatar (UB08) has dominated 2 main wind direction Nigh time from East Southeast-East south (110-135), daytime West and West northwest (270-290). In winter time, highest concentration dominated when there wind direction from 270-340 and 110-135. In summer season higher concentration occurred with the (110-135) wind. It means NO\textsubscript{2} transported from residential area (270-340) and main central road 110-135) (Figure 7). The concentration of CO was shown similar. But it was higher when wind direction from near village such Khonkhkhor and Nalaikh district (Figure 8).

Figure 6. Annual variation of O\textsubscript{3} (a.) and NO\textsubscript{2} at selected sites of Asia.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>O\textsubscript{3} Ochiishi, Japan</th>
<th>O\textsubscript{3} Monday, Russia</th>
<th>O\textsubscript{3} UB08, Mongolia</th>
<th>O\textsubscript{3} Rishiri, Japan</th>
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<tbody>
<tr>
<td>2010</td>
<td>Jan</td>
<td>70</td>
<td>60</td>
<td>50</td>
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<tr>
<td>2011</td>
<td>Feb</td>
<td>60</td>
<td>50</td>
<td>40</td>
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<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>NO\textsubscript{2} Ochiishi, Japan</th>
<th>NO\textsubscript{2} Rishiri, Japan</th>
<th>NO\textsubscript{2} Sado-seki, Japan</th>
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<tbody>
<tr>
<td>2010</td>
<td>Jan</td>
<td>25</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>2011</td>
<td>Feb</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>
Figure 7. Frequency of wind direction (blue) and average concentration of NO₂ (purple) in winter and summer.

Figure 8. Frequency of wind direction (blue) and average concentration of CO (black) in winter and summer.
Figure 9. Frequency of wind direction (blue) and average concentration of O₃ (red) in winter and summer.

Higher concentrations of O₃ were the same direction with NO₂. But it was high in summer (Figure 9). It indicated that background site of Ulaanbaatar is located under the influence of city and major East road pollutants. There is local transport from the residential area of Ulaanbaatar city usually daytime and main road nighttime.

3.2.2 Regional transport of ozone

We have compared daily average data of Mondy site and Ulaanbaatar sites. It was shown a higher concentration of O₃ measured at sites of Ulaanbaatar after 2-3 days Monday (Figure 10).

Figure 10. Summer mixing ratio of O₃ at Monday and Ulaanbaatar sites.
We have selected high mixing ratio of O₃ observed days and used 24 hours continuously meteorological parameters such temperature pressure, wind direction and speed and weather maps.

Figure 11. The time series of meteorological parameters during high O₃ episode days (7-9 and 14-15 July).

We selected 2 cases for 7-9 July and 14-15 July. The 2 cases, air temperature and pressure going down and up, the wind speed was unstable. It means weather front was crossing.
On 9 July 2010, the weak cyclonic system was found northern Mongolia. The same time deep strong cyclone was located on the Eurasian continent. Pakpong Pochard and Hajime Akimoto (2003) mentioned EU air masses are those originating in or passing through Europe before arriving on Monday. We would like to explain similar processing (Figures 12, 13) the high concentration of O₃ at Monday before 1-2 days Ulaanbaatar.
At the same day (12 and 17 August 2010) high concentration ozone was measured at Sainshand and Ulaanbaatar background station (Figure 14). We used weather maps and hysplit model to explain the cyclonic process related to the higher concentration. The day’s cyclone was lying on the territory of Mongolia (Figure 15). It is possible to mix northern and southern air in the area. Hysplit model was shown the similar trajectory from northern and southern (Figure 16). The highest concentration of O$_3$ measured at Sado-Seki site of Japan on 14 and 19 April 2011.
Figure 16. Air mass transport patterns arriving at Ulaanbaatar and Sainshand (Southeast Mongolia) by Hysplit model (NOAA) August 2010.

Figure 17. Daily average mixing ratio of O₃ at sites of Japan, Russia, Mongolia (July 2010-June 2011).
The during days with high concentration ozone, the Hysplit model results are shown air mass transport from the west side such China and Korea. But main ozone precursor NO₂ was very low.

5. Conclusion

- Air quality monitoring data of Ulaanbaatar sites (July 2010 to June 2011) are indicated general air pollution trend of Ulaanbaatar city. There are big seasonal (high concentration in summer July, min-Jan) diurnal variation of ozone (maximum in summer), NO₂, CO (high concentration in winter Feb) and depending emission sources and meteorological condition.
- The UB08 site is not background station. It is under the influence of city pollution (270-320WNW) and main (ESE 110-135) road pollution (Maybe from Nalaikh district).
- Highest mixing ratio of O₃ observed at Sedo-Seki site, Japan (it may be transported from South East Asia because NO₂ is lower than 1ppbv in Japan remote sites)
- There is long range transport from neighbor countries (from Russia and China), but city pollution is dominated in Ulaanbaatar.

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