Seasonal-yearly variation of ozone in the lower and middle troposphere over east Asia: An analysis of ozonesonde observations

Chenhong Zhou

Feb-24-2012
Outline

• Objectives

• Data and methodology

• Preliminary results

• Summary and conclusions

• On-going and future work
Objectives

• To quantify seasonal and long-term variations in lower/middle tropospheric ozone over East Asia

• To determine the relative importance of tropospheric photochemical production and stratospheric intrusion in the seasonal variation

• To classify the synoptic patterns associated with the peak O$_3$ in the lower/middle troposphere
• Three observational sites:

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Observation</th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>22.3° N, 114.7° E</td>
<td>2000-2010 (2002, 2003)</td>
<td>432</td>
<td></td>
</tr>
<tr>
<td>Sapporo</td>
<td>43.1° N, 114.7° E</td>
<td>2000-2010</td>
<td>477</td>
<td></td>
</tr>
<tr>
<td>Hilo</td>
<td>19.7° N, 155.1° E</td>
<td>2000-2010</td>
<td>497</td>
<td></td>
</tr>
</tbody>
</table>

• Variables: Pressure, O$_3$ partial pressure, temperature, Wind speed, Wind direction, Geo-potential height, Relative humidity
Observational Sites

Sapporo (JPN 43.1° N, 141.3° E)

HK (22.31° N, 114.71° E)

Hilo (19.72° N, 155.07° E)
1) According to Dalton’s law, ozone mixing ratio (ppb) is calculated by

\[ C_x = \frac{P_x}{P} \]

where \( P_x \) is partial pressure of gas x (O\(_3\) here), \( P \) is the total pressure. Both \( P_x \) and \( P \) are obtained from ozone sounding measurements.

2) \( O_3 \), RH are linearly interpolated from the measured heights to the fixed level at vertical resolution of 20 m.
Month-Height Cross Section of $O_3$ at HK

$O_3$ averaged from year 2000 to 2010 for HK

$O_3$ (ppbv)
Linking to monthly variation of surface O₃ at HK

Monthly variation pattern of O₃ in 2010

(Source: Hong Kong EPD's report)
Month-Height Cross Section of $O_3$ at Hilo

$O_3$ averaged from year 2000 to 2010 for Hilo

$O_3$ (ppbv)
Month-Height Cross Section of O$_3$ at Sapporo

O$_3$ averaged from year 2000 to 2010 for Sapporo

O$_3$ (ppbv)
Seasonal and yearly variations of $O_3$

Averaged over the year 2000 to 2010 at a) Hong Kong, b) Sapporo, and c) Hilo.
Long term trend: Surface O₃ in HK

Source: Hong Kong EPD
Yearly variation of O$_3$ at HK

![Yearly variation of O$_3$ at HK](image)

- Graphs showing the yearly variation of ozone (O$_3$) at HK from 2000 to 2010.
- Data are represented in parts per billion by volume (ppbv).
- Color-coded lines indicate ozone levels for different years.
Yearly variation of O₃ at Hilo
Yearly variation of $O_3$ at Sapporo
Spring/fall variation of O$_3$ at HK

Spring variation of O$_3$ at HK

Fall variation of O$_3$ at HK
Spring/fall variation of O₃ at Hilo

Spring variation of O₃ at Hilo

Fall variation of O₃ at Hilo
Spring/fall variation of O$_3$ at Sapporo

Spring variation of O$_3$ at Sapporo

Fall variation of O$_3$ at Sapporo
Spring O3-T-RH Plot of HK

(a)

Summer O3-T-RH Plot of HK

(b)

Fall O3-T-RH Plot of HK

(c)

Winter O3-T-RH Plot of HK

(d)
<table>
<thead>
<tr>
<th>Types</th>
<th>Dominant Surface Pressure Patterns</th>
<th>Major Flow Patterns and Surface Winds in Hong Kong</th>
<th>Weather and Atmospheric Conditions</th>
<th>Period of Frequent Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northerly (N)</td>
<td>continental anticyclone over northwestern China</td>
<td>straight northerly anticyclonic flow from Mainland China as north or northeast winds</td>
<td>dry, clear sky and occasionally cold and strong wind</td>
<td>Dec. to March</td>
</tr>
<tr>
<td>Weak northerly (WN)</td>
<td>moderate or weak continental anticyclone over northwestern China</td>
<td>weak and straight northerly anticyclonic flow from Mainland China as weak north or northwest wind</td>
<td>dry and clear sky</td>
<td>Oct. to early Dec.</td>
</tr>
<tr>
<td>North-easterly (NE)</td>
<td>continental anticyclone over northeastern China, East China Sea, and southern Japan</td>
<td>northeasterly anticyclonic flow from East China Sea and Taiwan Straits as northeast and east winds</td>
<td>dry, clear sky and long sunshine hours</td>
<td>Late Sept. to mid. Mar.</td>
</tr>
<tr>
<td>Easterly or southeasteprly (E)</td>
<td>anticyclone centered east of 130°E and north of 20°N</td>
<td>easterly or northeast anticyclonic flow as east or southeast winds</td>
<td>fairly long sunshine hours</td>
<td>Mid. Apr. to mid May</td>
</tr>
<tr>
<td>Trough (T)</td>
<td>low-pressure trough with axis extending approximately east-west over south China</td>
<td>northerly anticyclonic flow to the north of trough and easterly cyclonic flow to the south; wind is variable</td>
<td>low wind and stagnant atmosphere</td>
<td>Late May to early Jun; mid. Aug. to mid. Sept.</td>
</tr>
<tr>
<td>Southerly or southwesterly (S)</td>
<td>Quasi-stationary low-pressure area over Asian continent</td>
<td>cyclonic flow from the South China Sea as south or southwest wind</td>
<td>high temperature and strong solar radiation</td>
<td>June. to Aug.</td>
</tr>
<tr>
<td>Pacific ridge (P)</td>
<td>ridge of Pacific high-pressure extending to Taiwan and southeastern China</td>
<td>straight flow from the Pacific Ocean as east or southeast winds</td>
<td>high temperature and strong solar radiation</td>
<td>June. to Aug.</td>
</tr>
<tr>
<td>High-pressure cell (H)</td>
<td>weak high pressure cell over south China</td>
<td>weak anticyclonic flow with weak surface winds</td>
<td>clear sky, long sunshine hours and low wind</td>
<td>Early Sept.; late April to late May</td>
</tr>
<tr>
<td>Cyclone (C)</td>
<td>Hong Kong within circulation of a traveling cyclone</td>
<td>cyclonic flow as north or northwest winds</td>
<td>low-level inversion, hot, clear sky, and long sunshine hour</td>
<td>May to early Dec.</td>
</tr>
</tbody>
</table>

Source: Y. Chan and L. Y. Chan, 2000
synoptic patterns
• Light winds on 25 May correlated to the presence of a weak high pressure system over the southern part of China. Well-defined boundary layer, light winds, high solar radiation, such conditions promote photochemical \( \text{O}_3 \).

• Large-scale weak northerly winds were deflected at Victoria Harbor to a northwesterly or westerly direction. This helps transport of the pollutants emitted from both sides of the harbor and possibly from areas farther north of Kowloon to the HK island.
Summary and conclusions

• Consistent with other studies, in spring, especially March and April, high ozone center (yearly average of 70~80 ppb) occurs around 2~4 km AGL in HK. But our analysis shows the stratospheric intrusion plays the most important role in the spring ozone enhancement in the lower troposphere, which is different from the finding in some other studies.

• An interesting finding is that high ozone concentrations are also observed in the atmospheric boundary layer (< 2km) in autumn at HK. This is mainly related to local photochemical production and regional transport from the PRD region (anthropogenic contribution). This phenomenon is not observed at Hilo and Sapporo sites.
• The seasonal variation in HK is more evident than other two sites. In HK, the O$_3$ max season in the lower to middle troposphere is different from that at the surface. The max O$_3$ occurs in spring for in the upper level whereas the O$_3$ max season is fall at the surface. This is not observed in Hilo and Sapporo. In Hilo, the max O$_3$ extends through from the surface to the upper level and the min O$_3$ season is summer. However, in Sapporo, the min O$_3$ season is winter.
Surface $O_3$ shows a steady increasing trend over the past 20 years. However, this trend is not clear in the lower to middle troposphere. There are two reasons for this. First, it probably is due to insufficient ozone sounding data (weekly sampling may be not enough to resolve this). Second, the surface contribution is not competitive with the contribution from the upper levels (e.g., stratospheric intrusion).
On-going and future work

• Further analysis of ozone sounding data: Necessary
• Classification of weather charts associated with ozone peak cases in the lower atmospheric layer (2~4km) in spring and in Hong Kong: sort out the cases and download surface, 850 hpa, 700 hpa weather charts and then to see whether they can be classified.
• Combing observational analysis with numerical model, WRF/Chem to better understand the processes or mechanism causing the spring peak ozone cases in HK.
Thank you !!!