Relationship of aerosol size distribution and visibility in a sea fog

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Research background
Sea fog (marine fog) occurs frequently in China coastal areas. Foggy month shifts northward with time.

Fog days in Qingdao is about 51.5 days on a 30-year average, and the maximum is in July, it’s about 10.5 days (Jiang et al. 2008).
Many research on circulation background, meteorology conditions and numerical simulation of Qingdao sea fog episode has been done (Wang, 1983; Zhou et al., 2004; Fu et al., 2004, 2006, 2008; Gao, 2007; Zhang et al., 2008).

There were only two sporadic reports about the micro-physical observation of Qingdao sea fog (Yang, 1985; Xu et al., 1994). Tri-purpose droplet spectrometer was adopted to find the fog droplet information. We still have knowledge on the aerosol size distribution and its induced extinction.

It was found in guangzhou and other inland cities that anthropogenic induced increase of fine particles in atmosphere make the fog last longer time and visibilities deteriorate (Wu et al., 2007; Shi et al., 2008).
• Atmospheric aerosol in coastal city was determined by prevailing wind direction and wind speed (Kim et al. 1995; Zielinski et al., 1997; Zielinski et al. 2005).
• The shift of Sea land breeze influence the size distribution (Moorthy et al. 2003).
• **hygroscopic growth** of accumulation mode particles contribute to CCN number and the formation of fog and haze (Johnson et al. 2005; Swietlicki et al. 2008; Liu et al., 2008; Moon et al. 2007).

**Our aim**

Analyze the variation of aerosol size distribution, and its impact on the visibility during the forming, maintaining and enhancing stage of the fog.
Data source

- GOOS (Global Ocean Observing System) — daily average sea surface temperature
- NCEP FNL — global reanalysis data
- MTSAT-1R — visible satellite cloud map
- SCRTWP-01 — wind profile radar. Resolution: 5min, 120m
- GFE(L)1, GTS1 — radiosonde, two times per day
- FD12 — visibility meter, Resolution: 15s
- GRIMM 180 — particulate monitor, 32 intervals, frequency: 5min

WRF model
- Fog evolution
- Wind variation
- Temperature humidity
- Visibility
- Aerosol size distribution
Sketch map of the observation site and instrument

- wind profile radar
  - (120°14'E, 36°20'N)

- Radiosonde
  - (120°14'E, 36°20'N)

- GRIMM 180
  - (120°20'E, 36°04'N)

- FD12
Formation and evolution of the fog
1. Measurement result

Visibility change from Jul.7 to 9. 2008

Fog duration time
- Jul.7: 12:51-19:20
- Jul.8: 21:51-23:44
- Jul.9: 9:28-12:51
  20:37-23:55
  6:58-19:52

Visibility duration fog
- Jul.7: 168-1140m
- Jul.8: 347-1083m
- Jul.9: 125-1192m
MTSAT-1R satellite images (Beijing Time)
2. Meteorology condition

The fog frequency is high in upwelling area, where the sea water temperature is low and air-sea temperature difference is large. (Leipper et al., 1994; Cho et al., 2000; Tokinaga et al., 2009)
7月7日14时
副高西伸北抬
海风明显

7月8日14时
副高西伸北抬
海风明显
Fog layer: >90%RH
wind speed
Relationship of atmospheric aerosol concentration and horizontal visibility
Good relationship was found between the occurring time of low visibilities and number concentrations of coarse mode particles in the 1-5µm size range.
An inverse correlation was identified between the visibility and the number concentration of the particles in 1–2.5 μm. The visibility was much lower and the dense fog would last much longer when the number concentration of the particles in 1–2.5 μm was large.

<table>
<thead>
<tr>
<th>Duration</th>
<th>Fog</th>
<th>Strong fog</th>
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<tbody>
<tr>
<td></td>
<td>number concentration(cm$^3$)</td>
<td>averaged visibility(m)</td>
</tr>
<tr>
<td>&lt;1μm</td>
<td>1~2.5μm</td>
<td>2.5~5μm</td>
</tr>
<tr>
<td>12:51~19:20</td>
<td>5548.71</td>
<td>13.14</td>
</tr>
<tr>
<td>13:00~19:00</td>
<td>5364.93</td>
<td>13.89</td>
</tr>
<tr>
<td>13:00~19:00</td>
<td>5364.93</td>
<td>13.89</td>
</tr>
<tr>
<td>21:51~23:44</td>
<td>14798.71</td>
<td>22.15</td>
</tr>
<tr>
<td>22:05~23:15</td>
<td>15067.43</td>
<td>27.65</td>
</tr>
<tr>
<td>22:05~23:15</td>
<td>15067.43</td>
<td>27.65</td>
</tr>
<tr>
<td>23:00~23:55</td>
<td>4092.32</td>
<td>12.38</td>
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<tr>
<td>23:55~23:55</td>
<td>4846.88</td>
<td>69.73</td>
</tr>
<tr>
<td>23:55~23:55</td>
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<td>69.73</td>
</tr>
<tr>
<td>0:37~23:55</td>
<td>5137.85</td>
<td>62.17</td>
</tr>
<tr>
<td>3923.92</td>
<td>13.99</td>
<td>1.55</td>
</tr>
</tbody>
</table>

The number concentration of 1~2.5μm particles was above 11.79/cm$^3$ during the fog.
• During the visibility degradation (from 10 km to 1 km) process, the number concentration of the submicron particles less than 0.5 μm increased more quickly, while those in 0.5–1 μm increased slowly.

• Onset of the fog (visibility less than 1 km) was concurrent with the abrupt increase of the number concentration of the coarser particles in 1–5 μm, when the number concentration of the particles in the Atken nuclei range and the accumulation range (diameter less than 1 μm) started to decrease.
Size distribution of the atmospheric aerosol
When the fog is forming, density of fine particles below 1μm decrease continuously, however number concentration of particles in 1-2.5μm size range had a trend of fluctuating growth, and its change period is about 2.5h.

During the fog strengthening stage, the number concentration of particles below 1μm diameter was on a declining trend, whereas the number concentration of particles above 1μm diameter had a increasing tendency.

When close to the fog decay time, there was fast decrease of 0.5μm-5μm particles.
When the fog was enhanced, particles above 1μm increased with the decrease of particles less than 1μm. But there was bi-modal distribution in the submicron size particles, 0.3-0.5μm particles decrease, and 0.5-0.7μm particles increase, showing the tendency of size shift from condensation mode to droplet mode.

Compared with non-fog days, the common feature in fog days is, number of particles below 0.5μm decrease, 1-5μm increase, and particles above 5μm was mostly removed.
Meteorology data was analyzed to find the reason of variation of aerosol size distribution. The main factors are

- Temperature
- Humidity
- Wind speed
- Wind direction
Number concentration of particles below 1μm was larger in high temperature and low humidity conditions (Jul.5-Jul.7 and Jul.11) than that in low temperature and high humidity conditions (Jul.8-Jul.10).

The number concentration of the particles corresponded very well with the specific humidity.
If the specific humidity increased continuously, the number concentration of the particles larger than 1 μm would increase with high speed and large amplitude, which would impact the visibility much stronger. On the contrary, if the specific humidity decreased continuously, the number concentrations of the particles in 1–2.5 μm would reduce accordingly, and the visibility would become better.

It seems that the number concentration of the particles in 1–5 μm and the specific humidity were two factors which play important roles in visibility degradation and fog evolution.
Effect of wind

- Sea breeze brings coarse particles. The predominant modes of aerosols from the sea was mostly in the 0.8-5μm size range in this sea fog.
- When there is wind shift from land to sea, there is abrupt increase of particles in 1-2.5μm size range, which may caused by the hygroscopic growth of polluted land particles when meeting water vapor and sea aerosol.

Size distribution and wind profile on Jul.9
summary

◆ The sea fog happened on July 7-9, 2008 in Qingdao was caused by the co-effect of the Northeast cold vortex and subtropical high.

◆ The fog easily formed in the layer with RH $\geq 90\%$, and wind speed $\leq 3$ m/s. It may arrive 530m altitude under the help of sea breeze.

◆ An inverse correlation was identified between the visibility and the number concentration of the particles in 1–2.5µm. The number concentration of 1-2.5µm particles was above 11.79/cm$^3$ during fog.

◆ Different size particles have different change patterns during the different stage of the fog.

◆ It seems that the number concentration of the particles in 1–5µm size range and the specific humidity were two factors which play important roles in visibility degradation and fog evolution.
Thanks for your attention