Observations of Relative Humidity Effects on Aerosol Light Scattering in the Yangtze River Delta of China

Zhang Lu¹, Sun Junying¹, Shen Xiaojing¹, Zhang Yangmei¹, Che Haochi¹, Ma Qianli², Zhang Yiwen¹, Zhang Xiaoye¹, John A. Ogren³

¹ Key Laboratory of Atmospheric Chemistry, Institute of Atmospheric Composition, Chinese Academy of Meteorological Sciences, Beijing100081, China
² LinAn Regional Atmosphere Background Station, LinAn 311307, China
³ Earth System Research Laboratory, NOAA, Boulder, CO, USA
Questions

1. What are the hygroscopic enhancement factors for scattering properties “f(RH)” in Yangtze River Delta?
2. Which chemical species are the main factors that determine f(RH)?
3. What is the influence of f(RH) on aerosol direct radiative forcing?
-0.3 ± 0.013 km/yr  
(Zhang et al., 2012)

**Visibility**

**Haze-fog**

-0.3 ± 0.013 km/yr  
(Zhang et al., 2012)

**Yangtze River Delta:**

**Economy**
**Population**
**Vehicles**
**Emissions of NO_x, SO_2, VOC...**
LinAn Regional Atmosphere background station

- WMO/GAW regional station
- 30.3° N, 119.73° E, 138 m a.s.l.

- bamboo forests and paddy rice fields
- represents the background conditions of the Yangtze River Delta
Sulfate Nitrate Ammonium Chloride Organics (D<1μm)

PM$_{10}$ → Dryer → Splitter → Size distribution

Humidification system

Light scattering as f(RH)

Dry aerosols

Porous PTFE tube

Water

Humidified aerosols

Heater
The humidification system

\[ f(RH) = \frac{\sigma_{sp}(RH, \lambda)}{\sigma(dry, \lambda)} \]

Example of recorded data on 17 March 2013

Sample humidogram
Time series and average hygroscopic enhancement factor

<table>
<thead>
<tr>
<th>RH(%)</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>85</th>
</tr>
</thead>
<tbody>
<tr>
<td>f(RH)</td>
<td>1.07</td>
<td>1.14</td>
<td>1.24</td>
<td>1.43</td>
<td>1.58</td>
</tr>
</tbody>
</table>
The Relationship of $f(RH)$ and Chemical Composition

- $f(RH)$ increases with inorganic mass fraction, but decreases with organic mass fraction.
- $f(RH)$ shows clearer relation with Nitrate fraction than sulfate fraction.

(a) and (b) colored by sulfate

(c) and (d) colored by nitrate

✓ $f(RH)$ increases with **inorganic mass fraction**, but decreases with **organic mass fraction**
✓ $f(RH)$ shows clearer relation with **Nitrate** fraction than sulfate fraction
Importance of Nitrate

Nitrate plays a more important role than sulfate in the determination of the magnitude of $f(85\%)$ at LinAn. Compared with Quinn et al. (2005)

\[ \gamma = \ln f(85\%) / \ln((100-40)/(100-85)) \]
Steepness index $\eta$

$$\eta = \frac{f'(80\%)}{f'(60\%)} - 1$$

- $\eta = (4/3)^{b-1} - 1$
- $\eta$ only matters with $b$, $f(RH)=1+a \cdot RH^b$
- An indicator of the steepness of humidograms
- $\eta$ decreases with the increase of $NO_3^-$

Nitrate also plays an important role in the steepness of humidograms in our study at LinAn.

The Red lines represent the regression line, the fitting equation was $f(RH)=1+a \cdot RH^b$
The Blue lines represent the tangent line at RH 60% and 80%.
Classified by trajectory

<table>
<thead>
<tr>
<th></th>
<th>( f(85%) )</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locally-polluted(^a)</td>
<td>1.53</td>
<td>1.24</td>
<td>5.46</td>
</tr>
<tr>
<td>Northerly-polluted(^b)</td>
<td>1.65</td>
<td>1.20</td>
<td>3.90</td>
</tr>
<tr>
<td>Dust-influenced</td>
<td>1.49</td>
<td>1.02</td>
<td>4.51</td>
</tr>
</tbody>
</table>

Fitting equation:

\[ f(RH) = 1 + a \cdot RH^b \]

Inorganics & nitrate largest

Dust?
The dependence of TOA radiative forcing on relative humidity for various periods.

The increasing pattern of the dependence of TOA radiative forcing on relative humidity basically follow the increase of f(RH)

At 85% RH, the TOA radiative forcing increased by 47% compared to that at dry conditions;

The sensitivity of the direct radiative forcing of different aerosols to f(RH)
Summary

1. On average, aerosol light scattering in March in LinAn was 58% higher at 85% RH.

2. Aerosol uptake of water decreased with increasing organic mass fraction.

3. Nitrate played an important part in both the magnitude and shape of f(RH) during our study.

4. At 85% RH, the direct radiative forcing increased by as much as 47% due to the aerosol hygroscopicity.
Acknowledgments

This work was supported by

- National Basic Research Program of China (2011CB403401),
- National Natural Science Foundation of China (41175113),
- China International Science and Technology Cooperation Project (2009DFA22800),
- key project of CAMS (2013Z007, 2013Y004)
- the CMA Innovation Team for Haze-fog Observation and Forecasts.
Thanks!
In order to estimate the sensitivity of the forcing to different RHs for various aerosol types (locally-polluted, northerly-polluted and dust-influenced aerosols), the ratio of direct aerosol radiative forcing \( \Delta F_R \) at a defined RH to that at dry condition was calculated:

\[
\frac{\Delta F_R(\text{RH})}{\Delta F_R(\text{dry})} = \frac{(1 - \alpha_s)^2 \beta(\text{RH}) \alpha_s f(\text{RH}) - 2 R_s \alpha_s}{(1 - \alpha_s)^2 \beta(\text{dry}) \alpha_s f(\text{dry}) - 2 R_s \alpha_s} \quad (8)
\]

Parameters used in Eq. (8) were \( R_s = 0.15 \), and \( \alpha_s = 0.3 \text{ m}^2\text{ g}^{-1} \) (Wang et al., 2012; Hand and Malm, 2007). The mass scattering efficiency \( \alpha_s \) is 2.76 m\(^2\) g\(^{-1}\), which is derived from the slope of a linear regression of the measured scattering coefficients and the calculated PM\(_{10}\) mass concentrations based on TDMPS and APS measurement (see Fig. 13); the high mass scattering efficiency is explained by the high ratio of PM\(_1\) to PM\(_{10}\) mass at this site (average 0.81). The average upscatter fraction \( \bar{\beta} \) was calculated as \( \bar{\beta} = 0.0817 + 1.8495b - 2.9682b^2 \) (Delene and Ogren, 2002). The sensitivity of direct radiative forcing to RH for various aerosol types were shown in Fig. 14. As is shown in the figure, the variation of \( \Delta F_R(\text{RH})/\Delta F_R(\text{dry}) \) with RH was in accordance with the variation of humidograms. The \( f(\text{RH}) \) was the largest during the northerly-polluted period, correspondingly, the effects of RH on aerosol radiative forcing during this period was the largest. The same was true for the locally-polluted period and the dust-influenced period. Since \( b \) decreases with increasing RH, this correspondence also demonstrated the vital role \( f(\text{RH}) \) played in direct forcing enhancement. At 85% RH, the average ratio was 1.47, i.e. the direct radiative forcing