Measurements and Parameterization of Atmospheric Ice Nuclei in Different Regions in China

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Fig. 1. Schematic diagram of the effect of ice nuclei from various possible aerosol sources on midlevel precipitating clouds and cirrus ice clouds. The likely but uncertain change in the magnitude of the general cooling impact (blue arrows) of midlevel clouds and warming impact (red arrows) of high cirrus clouds in response to increases in the relative number concentrations of IN is indicated (see text for further description).
Microphysical Pathways

Warm processes

- Droplets
  - condensation
  - collision-coalescence
  - coalescence/breakup
  - sedimentation
  - washout
- Drops
  - precipitation
- Aerosol
  - nucleation
  - riming
- Ice crystals
  - aggregation
  - melting/collection

Cold processes

- Snow
  - melting/collection
- Precipitation
  - melting/freezing
  - collection

IN

Activation
Locations of the measurements

- Xinjiang: a desert station
- Nanjing: urban
- Huangshan: mountains
INSTRUMENTATION

(a) 5L Mixed chamber
INSTRUMENTATION

Mixed chamber

IN sampler
Static Diffusion Chamber

(a) [Diagram of static diffusion chamber]

(b) [Image of static diffusion chamber setup]

(c) [Image of setup with tubes and wires]

(d) [Image of a grid with patterns]
IN concentration as a function of temperature

\[ N = N_0 e^{bT_a} \]
Huangshan (The Yellow Mts.)

- Natural lab for clouds
  - 1840 m above m.s.l
  - Frequent cloud/fog occurrence during April to July
The locations for measurements on the Huangshan Mt.
# IN at the Mt. Huangshan

Table 1 the statistic values of atmospheric IN concentration in different seasons (the unit of ice nuclei concentration is L$^{-1}$)

<table>
<thead>
<tr>
<th>Nucleation mechanisms</th>
<th>Statistic value</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concentration of total ice nuclei</strong> (T=-20°C)</td>
<td>Average</td>
<td>22.764</td>
<td>11.346</td>
<td>15.724</td>
<td>16.611</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1.282</td>
<td>0.636</td>
<td>0.753</td>
<td>0.890</td>
</tr>
<tr>
<td></td>
<td>maximum</td>
<td>1.667</td>
<td>1.45</td>
<td>1.642</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>minimum</td>
<td>0.942</td>
<td>0.142</td>
<td>0.192</td>
<td>--</td>
</tr>
<tr>
<td><strong>IN(S$_w$=5%)/IN(total)</strong></td>
<td>Percentage</td>
<td>5.63%</td>
<td>5.60%</td>
<td>4.78%</td>
<td>5.36%</td>
</tr>
<tr>
<td><strong>Concentration of ice nuclei</strong> (T=-20°C, S$_w$=5%)</td>
<td>Average</td>
<td>0.195</td>
<td>0.038</td>
<td>0.082</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>maximum</td>
<td>0.833</td>
<td>0.1</td>
<td>0.242</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>minimum</td>
<td>0.008</td>
<td>0.017</td>
<td>0.042</td>
<td>--</td>
</tr>
<tr>
<td><strong>IN(S$_i$=5%)/IN(total)</strong></td>
<td>Percentage</td>
<td>0.86%</td>
<td>0.33%</td>
<td>0.52%</td>
<td>0.63%</td>
</tr>
</tbody>
</table>
### IN-temperature

<table>
<thead>
<tr>
<th>Location</th>
<th>Equation</th>
<th>Parameterization Equations</th>
<th>Temperature Range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meyers</td>
<td>$N = 0.06 \times \exp(-0.262 \times T)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooper</td>
<td>$N = 0.005 \times \exp(-0.304 \times T)$</td>
<td></td>
<td>$-40 \degree C \sim 0 \degree C$</td>
<td>(Cooper, 1980)</td>
</tr>
<tr>
<td>Fletcher</td>
<td>$N = 10^{-5} \times \exp(-0.6 \times T)$</td>
<td></td>
<td>$-27 \degree C \sim 0 \degree C$</td>
<td>(Fletcher, 1962)</td>
</tr>
<tr>
<td>Ardon-Dryer</td>
<td>$N = 3 \times 10^{-7} \times \exp(-0.66 \times T)$</td>
<td></td>
<td>$-26 \degree C \sim 19 \degree C$</td>
<td>(Ardon-Dryer et al., 2011)</td>
</tr>
<tr>
<td>Mts. Huangshan</td>
<td>$N = 0.0038 \times \exp(-0.286 \times T)$</td>
<td></td>
<td>$-10 \degree C \sim 25 \degree C$</td>
<td>deposition, condensation freezing</td>
</tr>
<tr>
<td></td>
<td>$N = 7 \times 10^{-6} \times \exp(-0.531 \times T)$</td>
<td></td>
<td></td>
<td>deposition</td>
</tr>
</tbody>
</table>

Table 3: The comparison of ice nuclei concentration (std/L) for different locations with different water saturation (S_w) and iodine content (S_i).
IN concentration at different height

(a)

(b)

IN($S_w = 5\%$) (L$^{-1}$)

$T(\degree C)$

- the bottom of Mts. Huangshan
- the mountainside of Mts. Huangshan
- the peak of Mts. Huangshan
<table>
<thead>
<tr>
<th>Observation sites</th>
<th>Observation time</th>
<th>Volume of the chamber (L)</th>
<th>Average concentration of IN (L⁻¹)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baicheng in Jilin</td>
<td>April to May 1964</td>
<td>2</td>
<td>5.8</td>
<td>(Wang et al., 1965)</td>
</tr>
<tr>
<td>Beijing</td>
<td>March to April 1963</td>
<td>3.34</td>
<td>4.8</td>
<td>(You and Shi, 1964)</td>
</tr>
<tr>
<td>Beijing</td>
<td>March to April 1995</td>
<td>3.34</td>
<td>78.9</td>
<td>(You et al., 2002)</td>
</tr>
<tr>
<td>Henan county in Qinghai</td>
<td>August 2001</td>
<td>3.05</td>
<td>31.3</td>
<td>(Li et al., 2003)</td>
</tr>
<tr>
<td>Henan county in Qinghai</td>
<td>October 2003</td>
<td>3.05</td>
<td>47.4</td>
<td>(Shi et al., 2006)</td>
</tr>
<tr>
<td>Nanjing</td>
<td>May to September 2011</td>
<td>5.0</td>
<td>20.112</td>
<td>(Yang et al., 2012)</td>
</tr>
<tr>
<td>Mts. Huangshan</td>
<td>May to September 2011</td>
<td>5.0</td>
<td>16.6</td>
<td>This article</td>
</tr>
</tbody>
</table>
FRIDGE-NUIST
IN in Nanjing & YM

![Graph showing IN concentration vs. temperature](image)

- **Mt. Huangshan**
- **Nanjing**

**Y-axis:** IN concentration (L$^{-1}$)

**X-axis:** Temperature (°C)
Dust weather

The graphs show the concentration of aerosols in different size ranges over a period from 2014-05-13 to 2014-05-23. The graphs are labeled as follows:

1. **IN concentration (L⁻¹)**
   - Different colors represent temperatures of -20°C, -18°C, -16°C, and -14°C.

2. **Wind speed (m/s)**

3. **Concentration of aerosols in size of 0.5-20μm**
4. **Concentration of aerosols in size of 0.1-0.5μm**

The data points indicate variations in concentration over time, with significant increases in certain periods.
IN concentration (RH=100%, T=-20°C) vs. the concentrations of aerosol particles.
Comparison of IN concentration from different locations

\[ N_{\text{IN}} = 0.0172c^{-0.386T} \quad (\text{RH}=100\%) \]

\[ N_{\text{IN}} = 0.0215c^{-0.311T} \]

\[ N_{\text{IN}} = 0.0397c^{-0.258T} \]

\[ N_{\text{IN}} = 0.0252c^{-0.311T} \]
Parameterization:

Flecher et al. (1962):

\[ N = A \exp(-b \times T) \]

Meyers et al. (1992):

\[ N = \exp(a + b \times S_i) \]

DeMott et al. (2010):

\[ N = a(-T)^b (n_{aer,0.5})^{c(-T)+d} \]
Parameterization:

This study:

\[ N = A(-T)^B (S_i)^C N_{\text{Aer,0.5}}^{(-aT+bS_i+c)} \]
Xinjiang:

\[ N = 5.7 \times 10^{-7} (-T)^{3.745} (S_i)^{1.31} N_{\text{Aer,0.5}} (-0.018T - 0.007S_i + 0.342) \]

\[ R^2 = 0.915 \]
Mts Huangshan:

\[ N = 4.7 \times 10^{-8} (-T)^{4.2} (S_i)^{1.852} N_{Aer,0.5} (-0.027T - 0.013S_i - 0.154) \]
Combined:

\[ N = 2.47 \times 10^{-8} (-T)^{4.91} (S_i)^{1.144} N_{Aer,0.5} (0.019T + 0.913) \]

\[ R^2 = 0.79 \]
Summary

- The concentrations of ice nuclei (IN) in selected regions in China, including a relatively polluted urban site, a relative clean remote mountainous site, and a desert meteorological station in northwest China, were measured and analyzed by using a newly built static vacuum water vapor diffusion chamber.
- The concentrations of IN vary with temperature, supersaturation, and the relationship with the concentration and size distribution of aerosol particles under different background conditions.
- Parametrization schemes are proposed to calculate IN concentration by considering temperature, supersaturation, and the concentration of aerosol particles.
For more details:


Thank you for your attention!