Laboratory measurements and modelling of the scattering properties of hollow and solid ice crystals

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Why Ice Clouds?

- IPCC concluded that clouds are the biggest uncertainty in predicting climate change (2013)
- Ice clouds have a large range of crystal shapes and sizes
- Global coverage of ~30%

Ice Crystal Habits

Ice Particles In Scattering Models

- Real ice particles represented by simplified models
- Habit mixture models are commonly used, including hollow particles
- Featureless phase functions are sought

The Manchester Ice Cloud Chamber

Diagram showing the layout of the Manchester Ice Cloud Chamber, with labels for Droplet Gun, Nucleator, Temperature probes, Vapour Input, Scattering Chamber, CPI 1.0, Mezzanine, 2nd Floor, 1st Floor, and Basement.
What we measure

• We are measuring the intensity of the scattered light from an *ensemble* of particles
• We measure between $0^\circ$ and $150^\circ$
• To get the *phase function*, we need to know the full $0^\circ$-180$^\circ$ range
• We use suitable modelled data to ‘fill in the gap’ – data is then normalised to get $P_{11}$
• The normalised data is used to find the *asymmetry parameter*, $g$
Cloud monitoring

• The Cloud is monitored using a Cloud Particle Imager (CPI)

• Formvar replicas are also taken throughout the course of the experiment, giving additional insight into internal structure
Findings from the Formvar Replicas

- Different internal structures found at -7°C and -30°C
- ‘warm’ structure similar to current particle models
- ‘cold’ structure more complex
Particle models

- ‘Warm’ column cavity represented by hexagonal based pyramid
- ‘cold’ column cavity represented by a series of hexagonal stepped intrusions
- Hollow plates also represented using the ‘cold’ column intrusion
Theoretical results

Ray tracing predicts a significant decrease in asymmetry parameter for both hollow crystals.

\[ g(\text{solid}) = 0.7695 \]
\[ g(\text{warm}) = 0.6337 \]
\[ g(\text{cold}) = 0.6094 \]

Ray tracing predicts an increase in asymmetry parameter for the ‘warm’ column, but a decrease for the ‘cold’ column.

\[ g(\text{solid}) = 0.8085 \]
\[ g(\text{warm}) = 0.8100 \]
\[ g(\text{cold}) = 0.7927 \]

Acknowledgements: with thanks to Evelyn Hesse for RTDF calculations.
Measured results -7°C solid columns

\[
g(\text{red}) = 0.7623 \\
g(\text{blue}) = 0.7698 \\
g(\text{RTDF red}) = 0.7718 \\
g(\text{RTDF blue}) = 0.7797 \\
g(\text{RT red}) = 0.7733 \\
g(\text{RT blue}) = 0.7615
\]
Measured results -7°C hollow columns

\[
\begin{align*}
g(\text{red}) & = 0.7746 \\
g(\text{blue}) & = 0.7825 \\
g(\text{RTDF red}) & = 0.8141 \\
g(\text{RTDF blue}) & = 0.8229 \\
g(\text{RT red}) & = 0.6875 \\
g(\text{RT blue}) & = 0.6755
\end{align*}
\]
Measured Results -15°C solid plates

- $g(\text{red}) = 0.8148$
- $g(\text{blue}) = 0.8243$
- $g(\text{RTDF red}) = 0.8250$
- $g(\text{RTDF blue}) = 0.8362$
- $g(\text{RT red}) = 0.8413$
- $g(\text{RT blue}) = 0.8317$

![Graph showing scattering angle vs. $P_{11}$](image)
Measured Results -15°C hollow plates

$g(\text{red}) = 0.7779$
$g(\text{blue}) = 0.7851$
$g(\text{RTDF red}) = 0.7844$
$g(\text{RTDF blue}) = 0.7892$
$g(\text{RT red}) = 0.7468$
$g(\text{RT blue}) = 0.7394$
Measured Results - $-30^\circ\text{C}$ hollow columns/plates

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTDF red</td>
<td>0.7320</td>
</tr>
<tr>
<td>RTDF blue</td>
<td>0.7464</td>
</tr>
<tr>
<td>RT red</td>
<td>0.7582</td>
</tr>
<tr>
<td>RT blue</td>
<td>0.7687</td>
</tr>
</tbody>
</table>

Scattering angle $\theta, ^\circ$

- Measured data 635nm
- Measured data 405nm
- RTDF 635nm
- RTDF 405nm
- Ray Tracing 635nm
- Ray Tracing 405nm
What can we conclude from this?

• Both RT and RTDF predict accurate asymmetry parameters for solid particles – however, differences are seen in the phase functions.
• RT deviates largely from measured results for hollow particles (both ‘warm’ and ‘cold’ geometries).
• RTDF fits closely to measured results for both solid and hollow columns.
• This suggests a decrease in asymmetry parameter for hollow particles with the ‘cold’ cavity.
Difficulties

• Due to the inhomogeneous cloud chamber environment, relative humidity (and supersaturation) is difficult to measure.

• Impossible to separate the effects of hollowness and roughness – both linked with supersaturation.

• Currently unable to measure roughness.

• A comparison of RT and RTDF highlights the limitations of geometric optics for hollow particles.
Difficulties - Roughness

Surface on the sample may be artefacts - suggesting collection technique.
Looking forward

• Work is still on-going
• Current set up has been modified to measure $P_{12}$
• Need to test models ability to adequately treat cavities and polarization