In-situ Observations of Ice Crystal Habits, Their Crystal Complexity and Light Scattering Properties During ACRIDICON-CHUVA

ACRIDICON-CHUVA Workshop, Ilhabela

Emma Järvinen¹, C. Mahnke², M.O. Andreae³, H. Schlager⁴, R. Weigel², B. Weinzierl⁵, M. Wendisch⁶, and M. Schnaiter¹

¹Karlsruhe Institute of Technology, ²Johannes Gutenberg-Universität, ³Max Planck Institute for Chemistry, ⁴Deutsches Zentrum für Luft- und Raumfahrt, ⁵Ludwig-Maximilians-Universität, ⁶University of Leipzig
Ice crystal complexity

Large-scale complexity

Small-scale complexity

Connolly et al. (2005)

Ulanowski et al., ACP, 2014

Karlsruhe Institute of Technology (KIT) Institute for Meteorology and Climate Research (IMK-AAE)
Scattering phase function of ice particles depend on their shape and complexity (aggregation, polycrystals, surface roughness, hollowness, etc.)

- Polycrystal and roughened ice particles show a **featurless scattering function**
Ice Crystal Complexity Increases Back Reflection

Lab and modeling studies show that roughness reduces the asymmetry parameter 2 times higher back reflection
PHIPS / SID-3 Package on-board HALO

HALO (High Altitude and Long Range Research Aircraft)
PHIPS/SID-3 Instrument Package

**PHIPS-HALO**
- Polar light scattering function (1° to 170°) of single ice particles
- Simultaneous stereoscopic (3D) imaging of the same particle
- **Large-scale complexity** (50 µm – 1 mm)

**SID-3**
- Spatial light scattering (diffraction) pattern in forward direction (6° to 25°)
- Shape information especially for small particles (5 - 50 µm)
- **Small-scale complexity**
Large-Scale Complexity

\[ C' = \frac{A}{\sqrt{a r P^2}} \]

Schmitt & Heymsfield (2014)

- aggregates
- single crystals

Complexity

- 0.15
- 0.20
- 0.25
- 0.35
- 0.45

Emma Järvinen – ACRIDICON-CHUVA Workshop, Ilhabela
Small-scale Ice Crystal Complexity

Crystal complexity leads to spatially randomized light scattering. The shape distinct diffraction features will disappear.

Pristine column

Roughened or distorted column
Quantification of Small-scale Complexity through $k_e$

$\sigma$: 0, 0.05, 0.1

$\sigma \sim k_e$

$\sigma$: 0.3, 0.4

$k_e$: 4.05, 4.09, 4.11

$\sigma \sim k_e$

Schnaiter et al., *ACPD*, 2015

Emma Järvinen – ACRIDICON-CHUVA Workshop, Ilhabela
Ice Crystal Habits
Particle Habit Classification: in-situ vs outflow

**In-situ cirrus**

**Outflow cirrus**

Emma Järvinen – ACRIDICON-CHUVA Workshop, Ilhabela

Karlsruhe Institute of Technology (KIT)
Institute for Meteorology and Climate Research (IMK-AAE)
Particle Habit Classification: in-situ vs outflow

Connolly et al. (2015)
Particle Habit Classification: in-situ vs outflow

In-situ cirrus

Lawson et al. (2006)

Connolly et al. (2005)
Ice particles imaged with PHIPS-HALO instrument were classified to plates, columns, bullet rosettes, small ice particles and (plate) aggregates.
Large-scale complexity
Flight Overview

Outflow flights

<table>
<thead>
<tr>
<th>Flight</th>
<th>Aerosol concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC11</td>
<td>490 cm$^{-3}$</td>
</tr>
<tr>
<td>AC15</td>
<td>1100 cm$^{-3}$</td>
</tr>
<tr>
<td>AC16</td>
<td>2000 cm$^{-3}$</td>
</tr>
<tr>
<td>AC20</td>
<td>2000 cm$^{-3}$</td>
</tr>
</tbody>
</table>

In-situ cirrus
AC12

Outflow anvils were probed at different altitudes and some anvils with different distances to the core.
Outflow Southwest of Manaus

Figure by Ramon Braga

Photo by courtesy of Manfred Wendisch
Outflow Southwest of Manaus

Photo by courtesy of Manfred Wendisch

Emma Järvinen – ACRIDICON-CHUVA Workshop, Ilhabela
Outflow Southwester of Manaus

Outflow well mixed up to the upper edge
Dimensions of the Complex Particles

CRYSTAL-FACE

AC20

Outflow AC20

- Aggregates
- Single habits

Dimensions of the Complex Particles

- C
- Particle maximum dimension (μm)

- Single habits
- Complexity parameter c

- Maximum dimension [μm]
Dimensions of the Complex Particles

In-situ AC12

Outflow AC15

Outflow AC16

Outflow AC20

Aggregates

Single habits

AC12

AC15

AC16

AC20
Dimensions of the Complex Particles

Temperature [°C] vs. Fraction of Aggregates

Temperature [°C] vs. $D_{50} [\mu m]$ for large-scale complexity
Large-Scale Complexity

CRYSTAL-FACE

ACRIDICON-CHUVA

Emma Järvinen – ACRIDICON-CHUVA Workshop, Ilhabela
The Liquid Origin of Outflow Ice Particles

- Plates formed at temperatures above -40°C
- Riming observed

AC20 rimed plates
Small-scale complexity
Flight Overview

Outflow flights

<table>
<thead>
<tr>
<th>Flight</th>
<th>Aerosol concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC11</td>
<td>490 cm⁻³</td>
</tr>
<tr>
<td>AC15</td>
<td>1100 cm⁻³</td>
</tr>
<tr>
<td>AC16</td>
<td>2000 cm⁻³</td>
</tr>
<tr>
<td>AC20</td>
<td>2000 cm⁻³</td>
</tr>
</tbody>
</table>

In-situ cirrus

AC12

- Outflow anvils were probed at different altitudes and some anvils with different distances to the core
Outflow Southwest of Manaus

PSD from SID-3 + CDP + CIP + PIP

Particle Number Concentration [cm⁻³]

Diameter [μm]

Photo by courtesy of Hans Schlager
Outflow North of Manaus

PHIPS Classified Images AC11 FL300

780 Classified ice particles

Fraction

0
0.1
0.2
0.3
0.4
0.5

Column
Plate
Frozen droplet
Bullet rosette
Small irregular
Irregular
Aggregate
Bullet rosette aggregate
Plate aggregate
Shattered plate aggregate
Shattered aggregate

Photo by courtesy of Hans Schlager
Outflow North of Manaus

Z. Ulanowski, ICCP, 2004

PHIPS Images of Frozen Droplets

SID3 Diffraction Patterns

20 µm
Ice Crystal Complexity

AC12 in-situ cirrus
Fraction of complex particles: 0.74

AC20 polluted outflow
Fraction of complex particles: 0.67

AC11 “clean” outflow
Fraction of complex particles: 0.82
PHIPS-HALO

Phase Function

Scattering Angle

In-situ
Outflow
Outflow
Outflow
Outflow
AIDA
Lampert et al. (2009)

SID-3

Complex

Ke

In-situ
Outflow
Outflow
Outflow
Outflow
AIDA
Take-Home Message

- Verified a method to study large-scale complexity from PHIPS-HALO images
- Outflows well mixed
- High degree of crystal complexity is observed in all sizes, shapes and formation pathways
  - This leads to uniform angular light scattering behaviour