Observations and simulations of wintertime orographic mixed-phase clouds

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Acknowledgements:
Alexander Beck, Olga Henneberg and Jan Henneberger

University of Bern, 20.4.2017
Hail frequency in Switzerland

Average number of hail days between April and September (Nisi et al., 2016)
What do we know about mixed-phase clouds?

Lohmann et al., 2016
How to observe mixed-phase clouds?
Using the HOLographic Imager for Microscopic Objects (HOLIMO 3G)

Weight ~ 20 kg
Size Range 6 µm - mm
Sample Volume 17 cm³
Sample Volume ~ 100 cm³ s⁻¹
Rate

Beck et al., AMT, 2017
Orographic clouds at the Jungfraujoch

Photos: Jan Henneberger
**Shapes of ice crystals at Jungfraujoch**

<table>
<thead>
<tr>
<th>Ice Crystal Shape</th>
<th>Case study 16/17.02.2015 (-16.5 to -12 °C, 2-10 m/s, wind from SE to N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>29 %</td>
</tr>
<tr>
<td>Needle</td>
<td>14 %</td>
</tr>
<tr>
<td>Irregular</td>
<td>57 %</td>
</tr>
</tbody>
</table>

![Image of ice crystal shapes](image-url)

Jan Henneberger, ETH/AC
Shapes of ice crystals at Jungfraujoch

<table>
<thead>
<tr>
<th>Ice Crystal Shape</th>
<th>Case study 13/14.02.2015 (-17 to -13 ºC, 4-14 m/s wind from SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>6 %</td>
</tr>
<tr>
<td>Needle</td>
<td>20 %</td>
</tr>
<tr>
<td>Irregular</td>
<td>74 %</td>
</tr>
</tbody>
</table>

Jan Henneberger, ETH/IAC
While we can detect rimed particles, particles already as large as 1 mm are rare in wintertime orographic clouds.
Ice fraction at Jungfraujoch

Lohmann et al., GRL, 2016
Ice fraction: South-East vs. North-West

North-West

South-East

Jan Henneberger, ETH/AC
Is the difference due to ice nucleating particles?

→ Differences in INP concentrations between SE and NW wind cases are small

→ Are there other microphysical reasons or is it due to dynamics?

Boose et al., 2016
Ice crystals vs. INP at Jungfraujoch: what causes the discrepancy?

Concentration [L^{-1}] vs. Temperature [°C]

- Ice crystals
- Ice nucleating particles

Seeder-feeder process

Primary nucleation

Ice multiplication

Surface-based sources
Ice crystal concentration near the surface

Blowing snow could be an important contributor
Can we infer the importance of dynamics from COSMO model simulations?

- 1 km resolution; \( \Delta t = 10 \) s
- 350 x 400 grid points
- Seifert and Beheng (2008) two moment cloud microphysics scheme
- Phillips et al. (2008) for deposition nucleation and condensation freezing
- Prescribed CCN and INP concentrations

Henneberg et al., 2017
Importance of updraft velocities at Jungfraujoch

NW wind cases

SE wind cases

→ Updraft velocities are much higher during NW wind cases

Lohmann et al., 2016
Different cloud regimes at Jungfraujoch

Microphysics regime
- Liquid
  - Droplet condensation
- Mixed-phase
  - Primary ice nucleation
  - Growth by diffusion: Wegener-Bergeron-Findeisen process
- Glaciated
  - Pockets of pure ice and liquid water

Dynamics regime
- Liquid
  - Droplet condensation
- Mixed-phase
  - Primary ice nucleation
  - Simultaneous growth of droplets and ice crystals
- Glaciated
  - Ice enhancement:
    - Seeder-feeder process
    - Rime splintering
    - Collisional break up
    - Uplift of ground ice/snow particle

Aerosols

Weak forcing

Stronger turbulence enhances:
- Riming
- Aggregation
- New droplet formation

Strong forcing

Larger optical depth

Delayed but stronger precipitation

Lohmann et al., 2016
Simulations of orographic MPCs

Frontal case

Cold case

The mixed-phase region is much larger in the frontal case

Henneberg et al., 2017
HoloGondel platform:

Battery cases

Sonic

Temp/RH

HOLIMO 3G

Beck et al., AMT, 2017
How homogeneous are MPCs?

Spatial Distribution:

Undiluted cloud volume

a) 2600 m

Strongly diluted cloud volume

b) 2300 m

Beck et al., AMT, 2017
Conclusions

- Mixed-phase clouds are persistent in the Alps given a strong dynamic forcing

- The sources of ice crystals in our observed mixed-phase clouds remain uncertain

- Our in-situ measurements can help to validate remote sensing algorithms of mixed-phase clouds
Thank you for your attention
Air parcel trajectories on their way to the JFJ

Frontal case
(Henneberg et al., 2017)
Air parcel trajectories on their way to the JFJ

Height of air parcels

Temperature

Liquid water content

Cloud ice water content

Snow category

Graupel category

Cold case
(Henneberg et al., 2017)