Investigations of Mixed-phase Clouds at Ny-Ålesund, Svalbard with SPEC Micro-COPP

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“Clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the Earth’s changing energy budget.”

Need in–situ cloud measurements:
- Ground truth for remote sensing (Satellite & Radar)
- Better understand cloud processes and interactions
- Improved parameterization for models
Cloud Probes

(1) **FCDP / FSSP**: Forward Scattering Probe measures size distribution and concentration of cloud droplets from 2 to 50µm.

(2) **2D-S / CIP**: Optical Array Probe measures size distribution, concentration, and area/extinction of cloud droplets, precipitation and ice crystals with 10 to 25 µm pixel resolution.

(3) **CPI (Cloud Particle Imager)**: High-resolution (2.5 µm pixel) digital camera up to 400 frames per second, with auto cropping of ROI’s.
Globalhawk with SPEC Hawkeye Cloud probe

Hawkeye Probe:
• 70 lbs
• 36.5” x 16” x 6.5”
• 2000 watts (heaters & electronics)

Data system:
• 40 lbs
• 19” x 20” x 7”
• More power
Micro-COPP

- 5.5 lbs
- 90 Watts
- 9-36 Volts Operating Voltage
- Optional Heaters 150 Watts

- Forward Scattering Measurement
  - 1-50 µm
  - 20 bins
- CCD Camera
  - 5µm-1mm Measurement Range
  - 1 µm- Resolution
  - Auto Cropping of ROI’s
  - Up to 20 Frames per second 8 bit Gray Scale
- 128 Element Photodiode Array
  - 25 µm-3.2 mm Measurement Range
  - 25 µm – Resolution (optional 5 or 10 µm)

Measurement: Concentration, area, & mass size distributions, extinction, water content over 1 µm – 3.2 mm, particle phase, shape, habit, & morphology up to 1 mm
UAV Flying in Clouds

• Lots of Restrictions
• Clouds are defined by the type of air space
• 100’ below, 2000’ horizontal, and 3 miles visibility
• In US can only fly UAV’s in clouds within restricted airspace
• Or have a detect and avoid system as well as a waiver.

• Find a country or area with less restrictive rules
• Ny-Ålesund has restricted airspace
• But need Norwegian UAV Pilot license.
The Arctic is a region of particular sensitivity to climate change.

Annual average temperature over the Northern high latitude land surface has increased at almost twice the rate of the global average.

Clouds represent the primary factor influencing irradiances in the Arctic, and thus the rate of warming and ice melt.

Ice crystal shape impacts cloud optical properties and irradiance, so long-term in situ measurements of arctic cloud properties are needed to obtain information about their inherent optical properties.

Coupled Interactions between sea ice, snow cover, artic clouds which can Persistant mix - phase clouds
Tethered Balloon System (TBS)

Payload
- Aspirated $\mu$-COPP
- Cloud Condensation Nuclei counter
- Three channel Optical Particle Counter
- Cryogenic Frost point Hygrometer
- Ice Nuclei Filter
- Reverse Flow Temperature
- Humidity
- Anemometer

System Features
- 73 m$^3$ balloon
- Maximum altitude 7000 ft
- Automatic emergency cut down device
Penguin with μ-COPP

- Customized UAV Factory Penguin B
- Carries 5.5 lb version of the μ-COPP
- Reverse Flow Temperature Probe
  - Humidity Probe
- 350 Watts Payload Power
  - Piccolo Auto Pilot
- 4 Watts Silvus Stream Caster Radio
# Balloon Flights

<table>
<thead>
<tr>
<th>Flight</th>
<th>Date</th>
<th>Start (UTC)</th>
<th>End (UTC)</th>
<th>Max GPS Alt (m AGL)</th>
<th>Min Pressure (mbar)</th>
<th>Temp Range (°C)</th>
<th>Notes / cloud type</th>
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<tr>
<td>1</td>
<td>1-May</td>
<td>7:43</td>
<td>9:46</td>
<td>1909</td>
<td>799</td>
<td>3.9 to -10.5</td>
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<td>2-May</td>
<td>13:40</td>
<td>15:08</td>
<td>1387</td>
<td>855</td>
<td>4.3 to -7.9</td>
<td>Clear air</td>
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<tr>
<td>3</td>
<td>7-May</td>
<td>4:08</td>
<td>5:18</td>
<td>358</td>
<td>954</td>
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<td>Clear Air CCN no uCOPP</td>
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<td>8-May</td>
<td>12:58</td>
<td>14:37</td>
<td>997</td>
<td>882</td>
<td>2.4 to -7.1</td>
<td>Liq. Cloud (park &amp; profile)</td>
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<td>9-May</td>
<td>4:45</td>
<td>7:02</td>
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<td>883</td>
<td>0.7 to -7.8</td>
<td>Liq. Cloud</td>
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<td>9-May</td>
<td>10:32</td>
<td>11:31</td>
<td>1051</td>
<td>880</td>
<td>1.0 to -6.4</td>
<td>Mixed phase cloud</td>
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<td>10-May</td>
<td>10:32</td>
<td>11:31</td>
<td>1051</td>
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<td>1.0 to -6.4</td>
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<td>1150</td>
<td>872</td>
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<td>5:01</td>
<td>5:48</td>
<td>1092</td>
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<td>5.7 to -3.3</td>
<td>Aerosol Profile / clear air</td>
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<td>-0.2 to -4.5</td>
<td>CCN</td>
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<td>11:26</td>
<td>12:49</td>
<td>907</td>
<td>903</td>
<td>0.5 to -6.5</td>
<td>CCN with small cloud</td>
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</table>
Mixed Phase Cloud (Flight 8)

- Altitude
- Pressure
- Temperature
- μFCDP Concentration

Example μCPI Images for a region of mixed phase (ice columns and water droplets) from a Balloon flight in Svalbard 2018.
Quantitative data from μFCDP and μ2D instruments in the mixed phase region indicates that the concentration (left) and mass (right) size distributions are dominated by small water droplets.
Current Activities

- Lots of Data to analyze from Ny-Ålesund.
- Separate data into different temperature regions, and ice crystal habits.
- Correlate data with other on-site measurements (Lidar and Radar)
- Analyze the aerosol data.
- Aircraft issues prevented us from capturing data with the UAV Micro-COPP.
- Smaller, lighter probe development
**Micro-FCDP**

- Forward Scattering
- 1-50 µm Measurement Range
- 2 µm Resolution
- Continuous Sampling
- 1 kg Weight
- 20 Watts Power
- 9-36 Volts Operating Voltage
- Optional Heaters 50 Watts

**Nano-COPP**

- Forward Scattering (1-50 um)
- CCD Camera triggered by scattering system
- 5µm-1mm Measurement Range
- 1 µm- Resolution, 8 bit Gray Scale, 20 fps
- Auto Cropping of ROI’s
- Provides phase (liquid/ice), shape, and habit
- 2 kg Weight
- 25 Watts Power
- 9-36 Volts Operating Voltage
- Optional Heaters 75 Watts
Sharkeye

- FCDP
- CPI
  - Sub Micron Pixel resolution
  - 100 frames per second

- 2D-Gray OAP
  - High Resolution (5 μm)
  - Black, white and two gray levels

- Improved ice / water differentiation
- Improved resizing of out-of-focus drops
- Imaging Volcanic ash & other large aerosols including organic materials and pollen
- Allows for more accurate understanding of radiative properties through imaging of surface roughness on aerosol and ice particles

- Allows for clear phase distinction for large out-of-focus ice crystals (example with Rosettes on left).
- In Mono-scale, complex ice crystal shapes may be confused with spherical droplets, but the crystal structure is evident in gray scale images.
- Improved sizing with highest resolution commercially available OAP
- Improved estimates of cloud water content
Take Home

• Huge need for better cloud characterization and for increased understanding of cloud / aerosol interactions.
• UAV’s & TBS provide a great, relatively inexpensive platform for cloud research.
• Need more opportunities for cloud sampling with UAV’s.
• Shown that micro-COPP can provide full spectrum of cloud droplet / ice crystal measurements.
• Useful for Icing studies

Thank You
Penguin (UAV Factory) vs. Others

UAV Factory Penguin B
- 10 kg Payload
- 5 km ceiling
- 80 Watts Payload Power
- 20 + hours Flight Time
- 3.3 m Wing Span
- 26 knot stall speed

BlackSwift S2
- 2.3 kg Payload
- 6 km ceiling
- 50 Watts Payload Power
- 110 minute Max Flight Time
- 6.6 kg MTOW
- 3 m Wing Span

Skywalker X8
- 1.5 kg Payload
- 4 km ceiling
- 5 kg MTOW
- 2.1 m Wing Span
Motivation

Determining particle concentration, extinction, phase, and ice type is essential for modeling of clouds, particularly in cold clouds dominated by ice crystals. Ice crystal habits are extremely sensitive to temperature and relative humidity and can change rapidly over the range of a few degrees (or few hundred meters).

**Top and Right Panels:** Evolution of ice particle habits with altitude and temperature in cloud.

- Ice Crystal Habit is difficult to determine for small or freshly nucleated crystals. The high resolution µCPI is ideal for this purpose.

- Ice Crystal Habit determines radiative properties and accretion rates for cloud parcels.

- Profiling ice crystal habits in cloud with altitude is difficult with large aircraft, and is ideal for small UAV and balloon systems.