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

Chris Roden, R. Paul Lawson, Nick Krause

Sebastian Schmidt, Matthew Norgren

Greg Roberts,

Ted Fisher, Ben Kamen

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

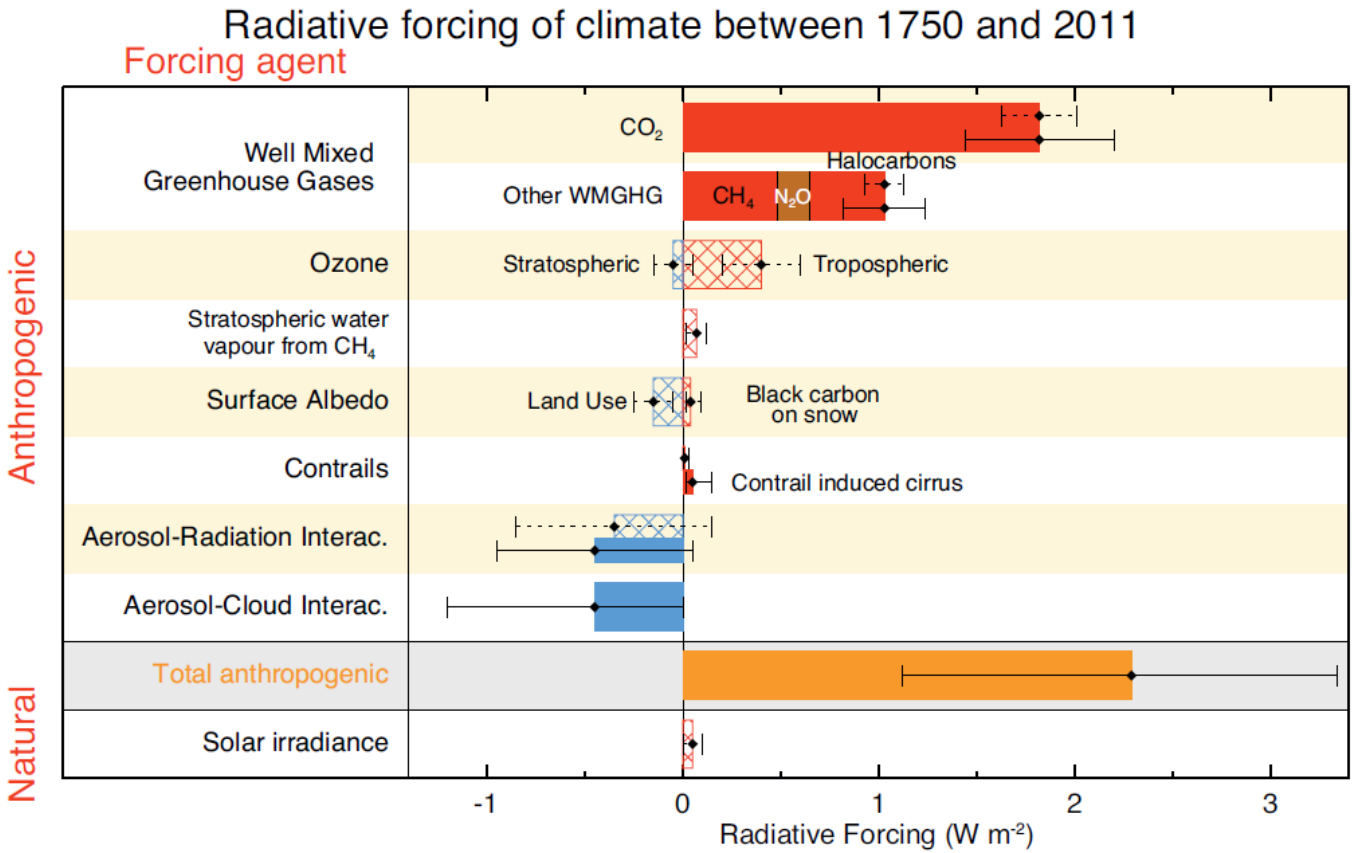


Figure 8.15 | Bar chart for RF (hatched) and ERF (solid) for the period 1750–2011, where the total ERF is derived from Figure 8.16. Uncertainties (5 to 95% confidence range) are given for RF (dotted lines) and ERF (solid lines).

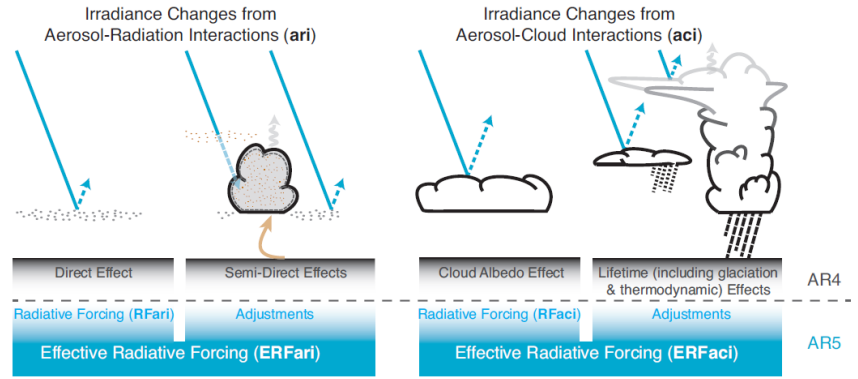


Figure 7.3 | Schematic of the new terminology used in this Assessment Report (AR5) for aerosol–radiation and aerosol–cloud interactions and how they relate to the terminology used in AR4. The blue arrows depict solar radiation, the grey arrows terrestrial radiation and the brown arrow symbolizes the importance of couplings between the surface and the cloud layer for rapid adjustments. See text for further details.

Need in–situ cloud measurements:

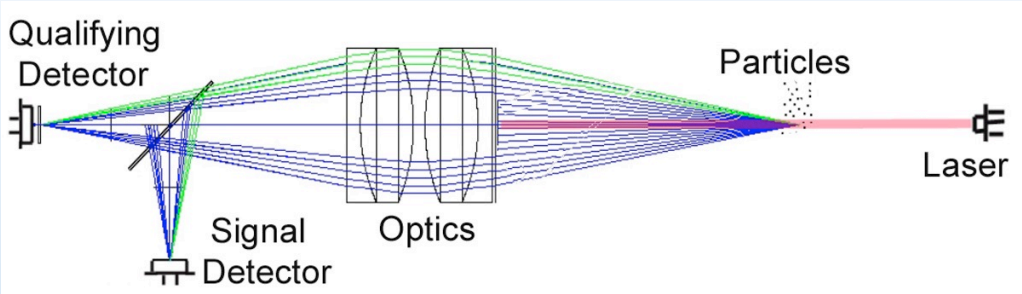
- Ground truth for remote sensing (Satellite & Radar)
- Better understand cloud processes and interactions
- Improved parameterization for models

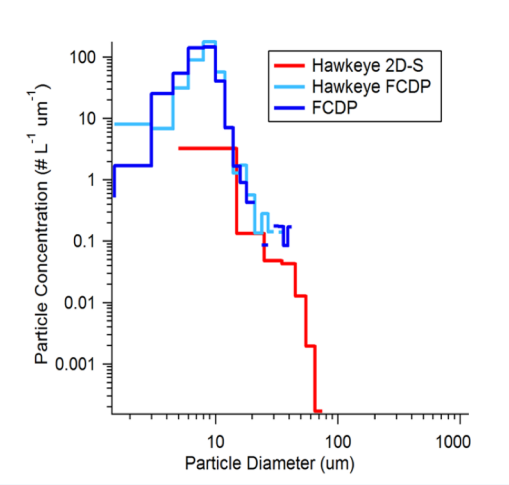
Cloud Probes

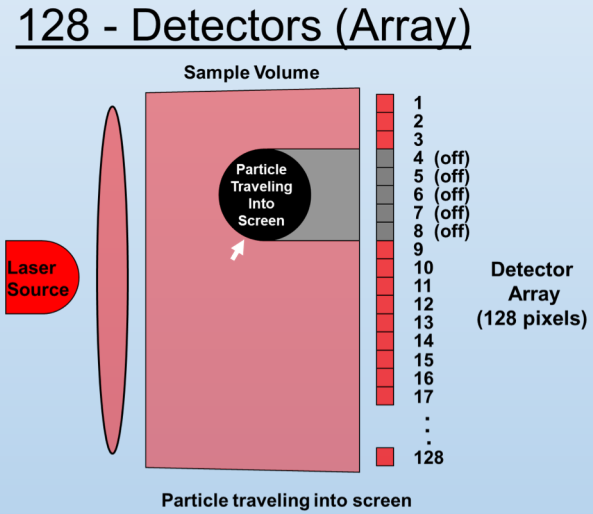
(1) <u>FCDP / FSSP</u> : Forward Scattering Probe measures size distribution and concentration of cloud droplets from 2 to 50µm

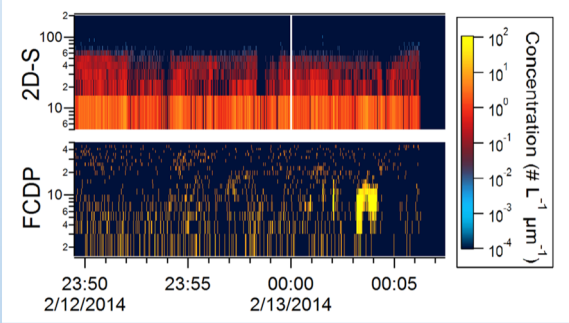
(2) <u>2D-S / CIP</u> : Optical Array Probe measures size distribution, concentration, and area/extinction of cloud droplets, precipitation and ice crystals with 10 to 25 µm pixel resolution.

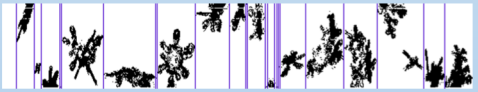
(3) <u>CPI (Cloud Particle Imager)</u> : High-resolution (2.5 µm pixel) digital camera up to 400 frames per second, with auto cropping of ROI's











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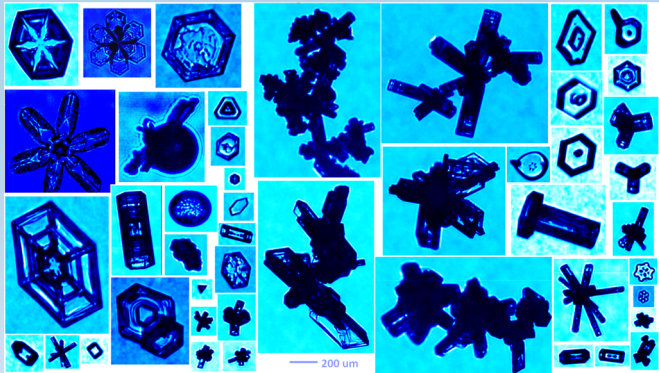


SPEC inc. Cloud Physics and Instrumentation

Globalhawk with SPEC Hawkeye Cloud probe

Hawkeye Probe:

- 70 lbs
- 36.5” x 16” x 6.5”
- 2000 watts (heaters & electronics)

Data system:

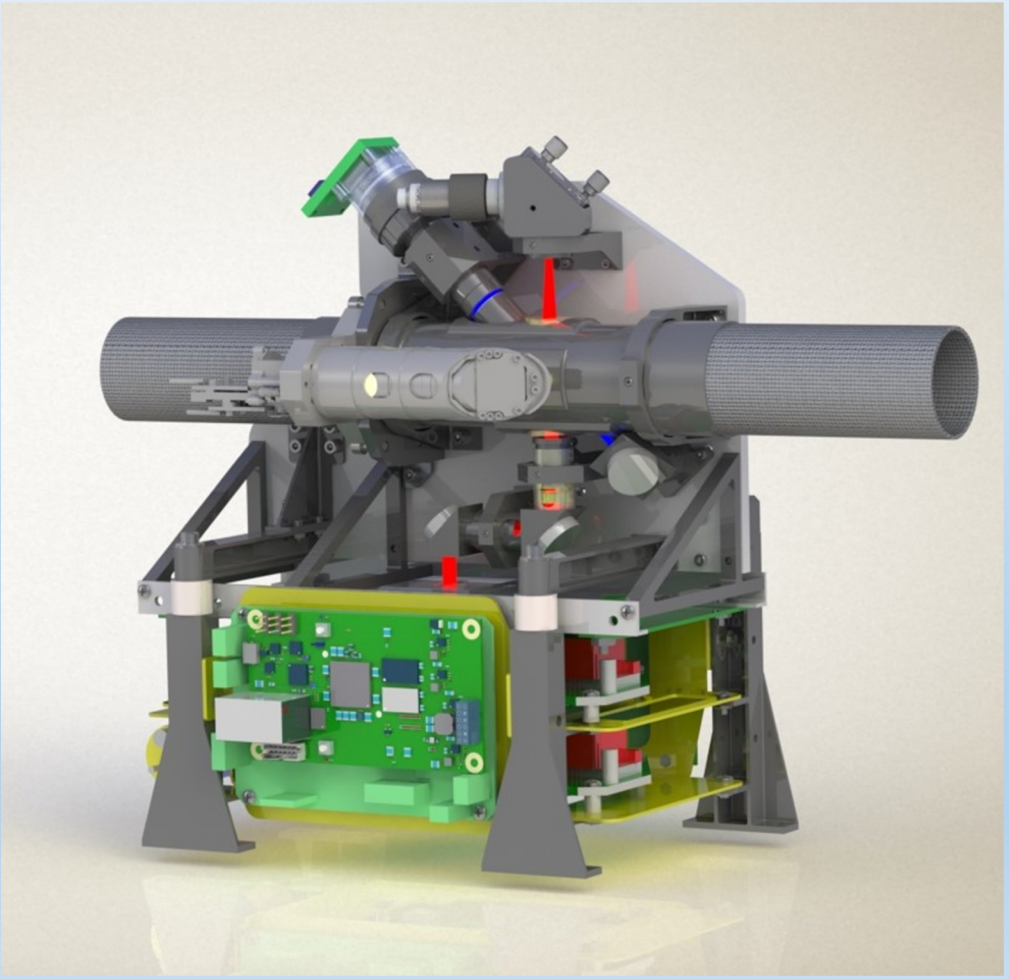
- 40 lbs
- 19” x 20” x 7”
- More power

Micro-COPP

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

- 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)



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.

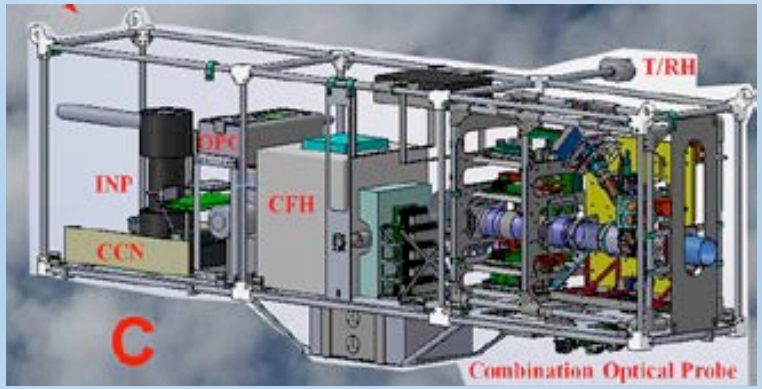
Arctic Clouds : Ny-Ålesund, Svalbard

- 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 Persistent mix - phase clouds

Tethered Balloon System (TBS)

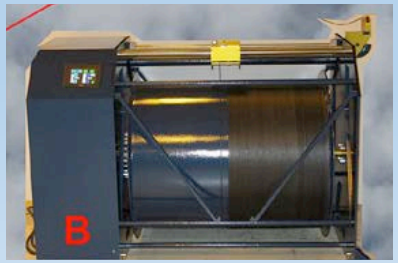
Payload

- Aspirated μ-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 (UAV Factory)

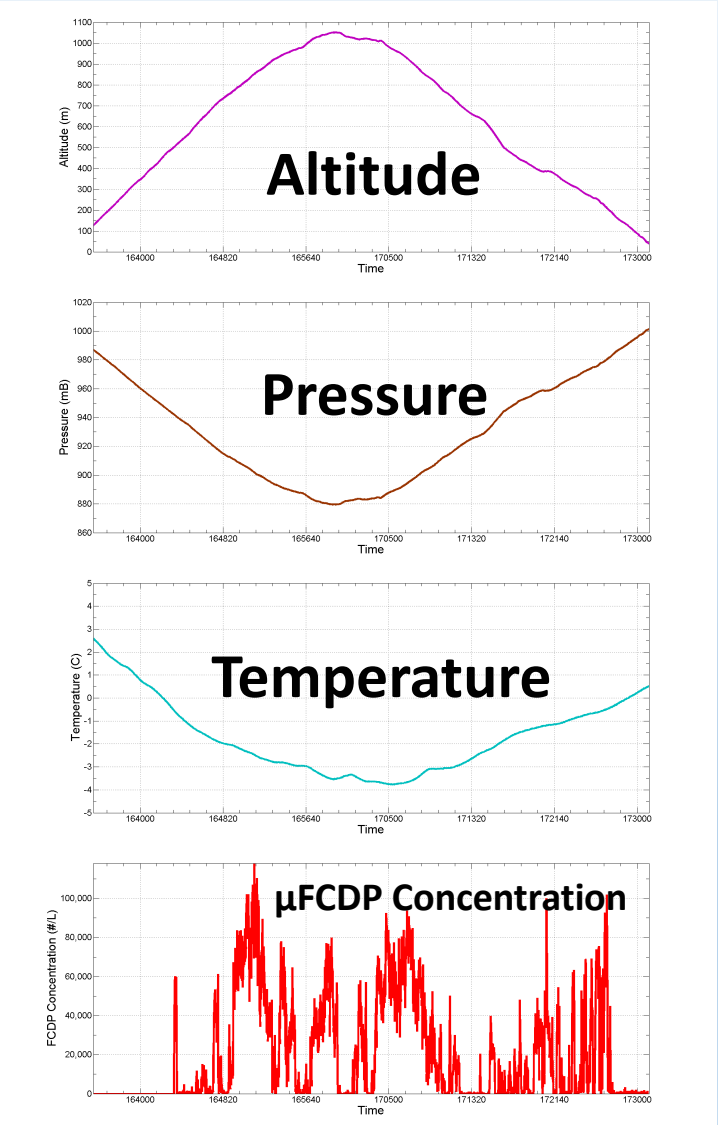
Penguin with µ-COPP

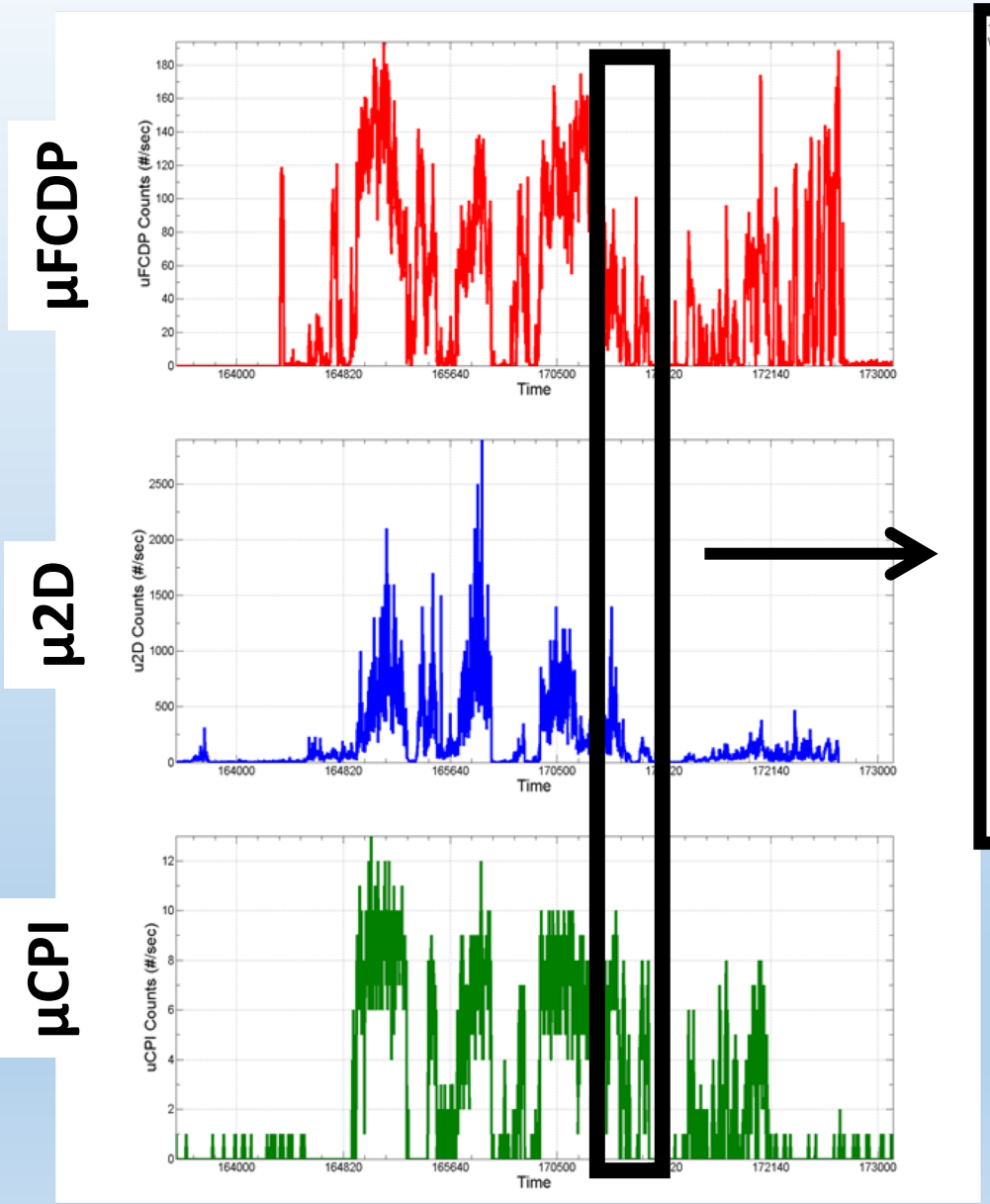
- Customized UAV Factory Penguin B
- Carries 5.5 lb version of the µ-COPP
- Reverse Flow Temperature Probe
- Humidity Probe
- 350 Watts Payload Power
- Piccolo Auto Pilot
- 4 Watts Silvus Stream Caster Radio

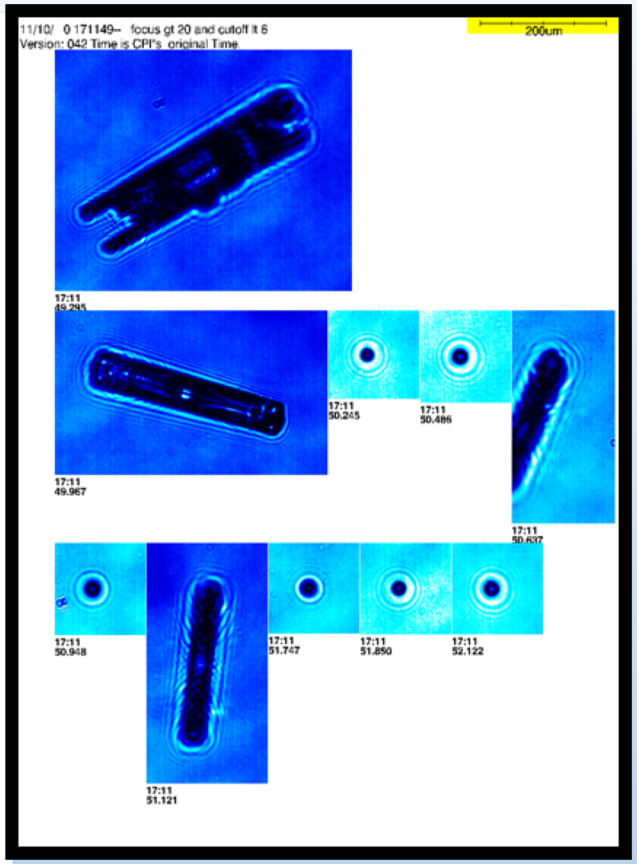
Balloon Flights

Flight	Date	Start (UTC)	End (UTC)	Max GPS Alt (m AGL)	Min Pressure (mbar)	Temp Range (C)	Notes / cloud type
1	1-May						test
2	2-May	7:43	9:46	1909	799	3.9 to -10.5	Mixed Cloud / No asp fan
3	2-May	13:40	15:08	1387	855	4.3 to -7.9	Clear air
4	7-May	4:08	5:18	358	954	2.2 to -2.6	Clear Air CCN no uCOPP
5	8-May	12:58	14:37	997	882	2.4 to -7.1	Liq. Cloud (park & profile)
6	9-May	4:45	7:02	1036	883	0.7 to -7.8	Liq. Cloud
7	9-May	7:24	8:37	877	900	1.2 to -5.9	Aerosol Profile
8	10-May	10:32	11:31	1051	880	1.0 to -6.4	Mixed phase cloud
9	10-May	17:53	19:38	1150	872	0.3 to -7.6	Liquid Cloud multi-profile
10	11-May	5:01	5:48	1092	880	5.7 to -3.3	Aerosol Profile / clear air
11	11-May	7:05	7:56	412	960	2.4 to -3.0	4pi no cloud
12	12-May	5:42	7:05	777	912	-0.1 to -5.0	Ice then liquid
13	12-May	7:14	7:48	591	936	-0.2 to -4.5	CCN
14	12-May	11:26	12:49	907	903	0.5 to -6.5	CCN with small cloud

Mixed Phase Cloud (Flight 8)



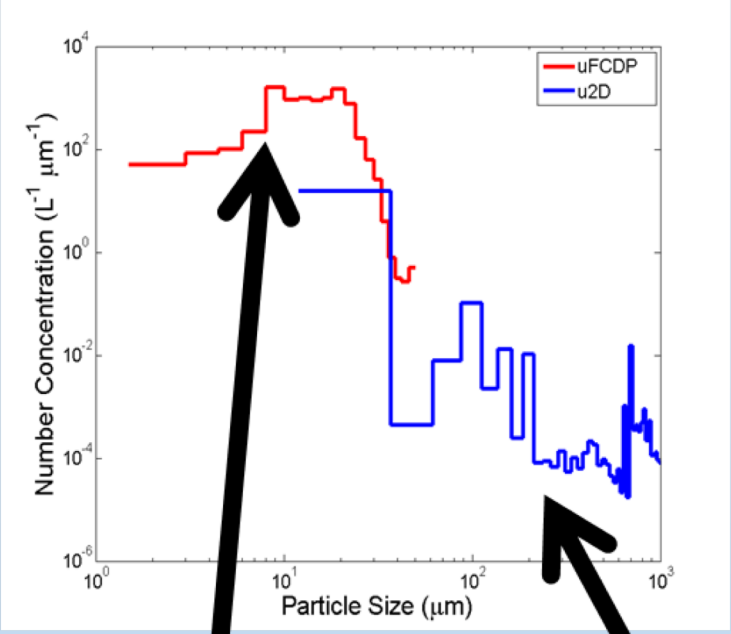




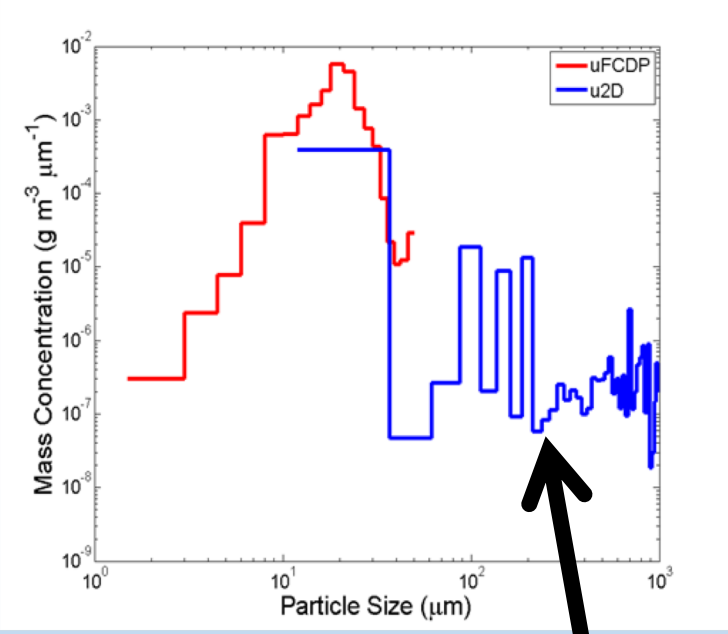
Example µCPI Images for a region of mixed phase (ice columns and water droplets) from a Balloon flight in Svalbard 2018.

Mixed Phase Cloud (Flight 8)

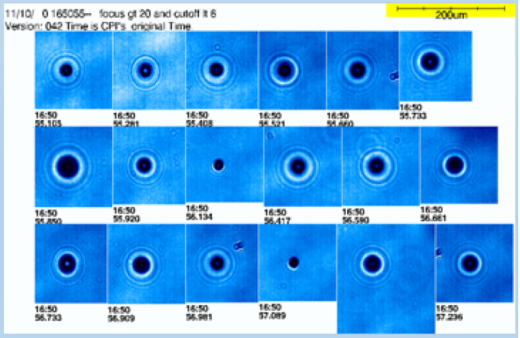
Number Conc



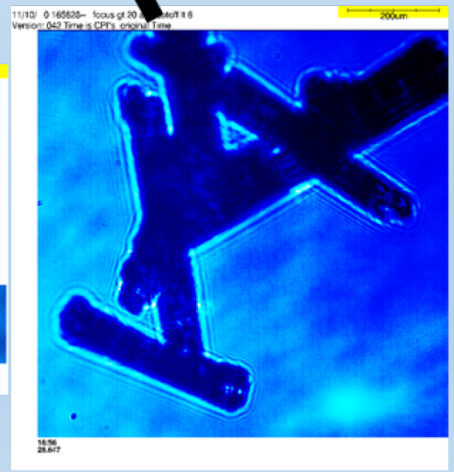
Mass Conc



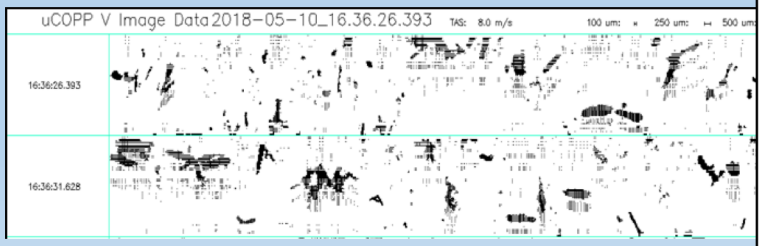
Quantitative data from µFCDP and µ2D instruments in the mixed phase region indicates that the concentration (left) and mass (right) size distributions are dominated by small water droplets.

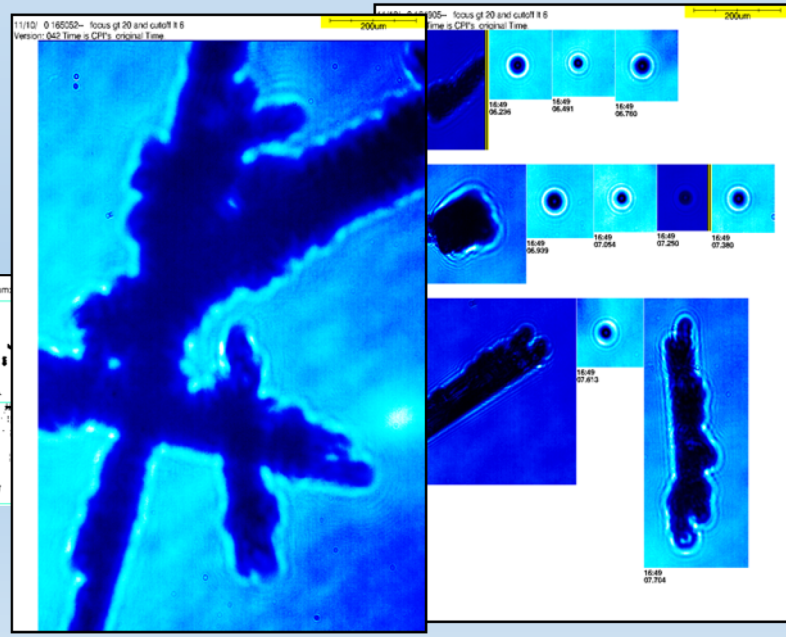


Cloud Droplets



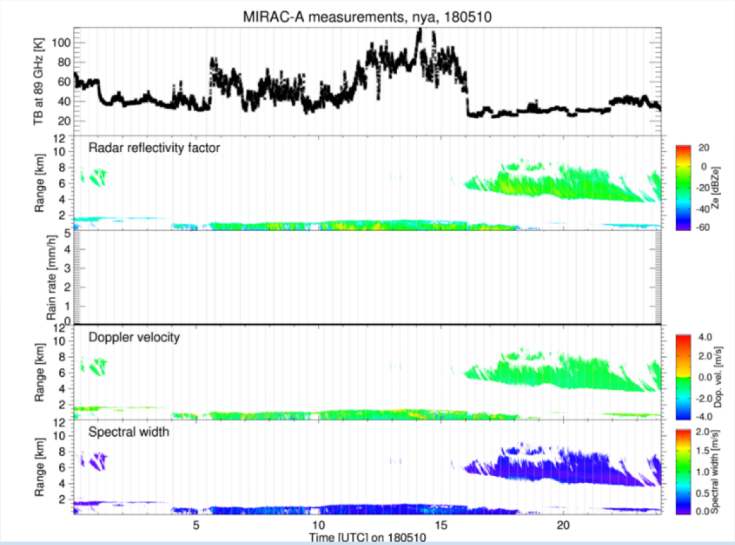
Large Ice Aggregates



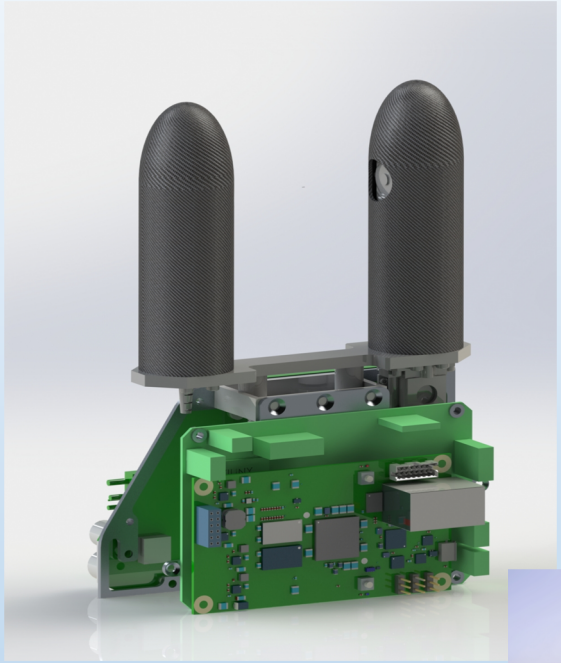


Current Activities

- 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

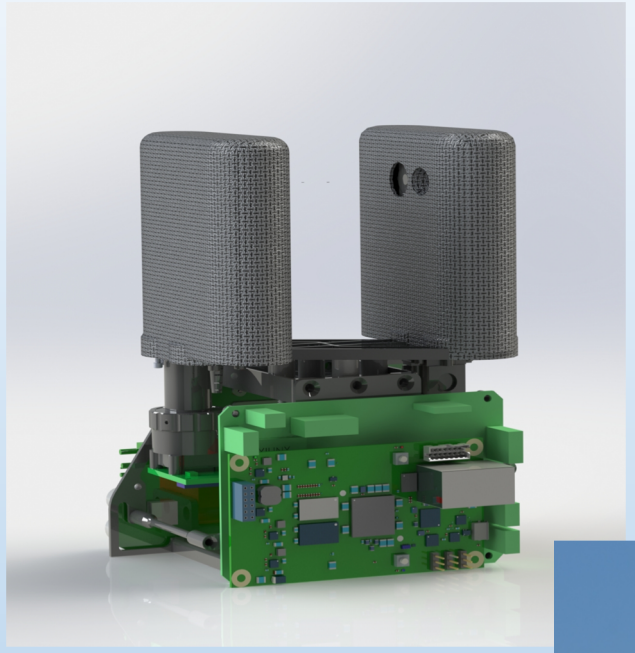


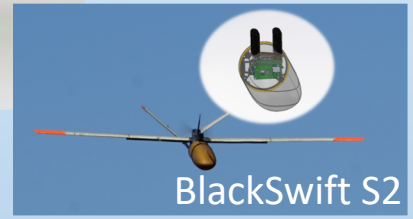
Micro-FCDP



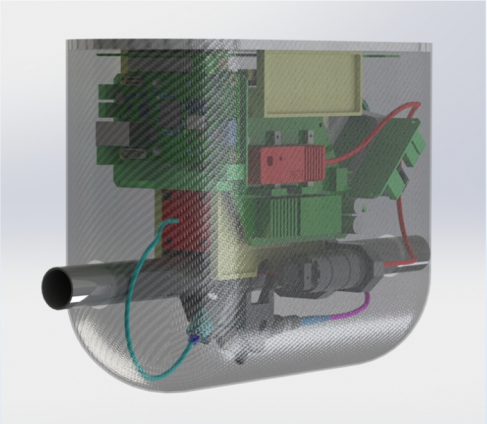
- Forward Scattering
- 1-50 µm Measurement Range
- 2 µm Resolution
- Continuous Sampling
- 1 kg Weight
- 20 Watts Power
- 9-36 Volts Operating Voltage
- Optional Heaters 50 Watts

Nano-COPP



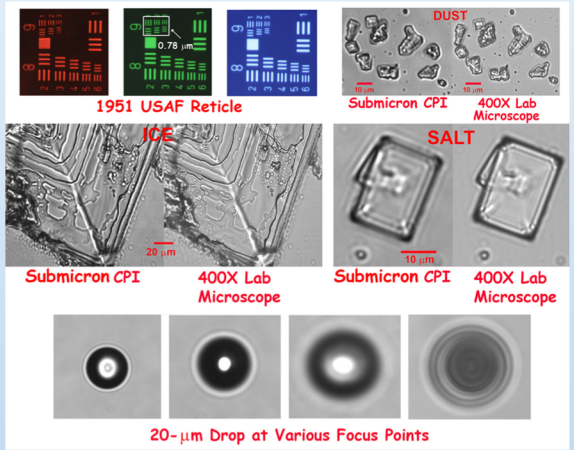


- Forward Scattering (1-50 um)
- CCD Camera triggered by scattering system
- 5µm-1mm Measurement Range
- 1 µm- Resolution, 8 bit Gray Scale, 20 fps
- Auto Cropping of ROI's
- Provides phase (liquid/ice), shape, and habit
- 2 kg Weight
- 25 Watts Power
- 9-36 Volts Operating Voltage
- Optional Heaters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



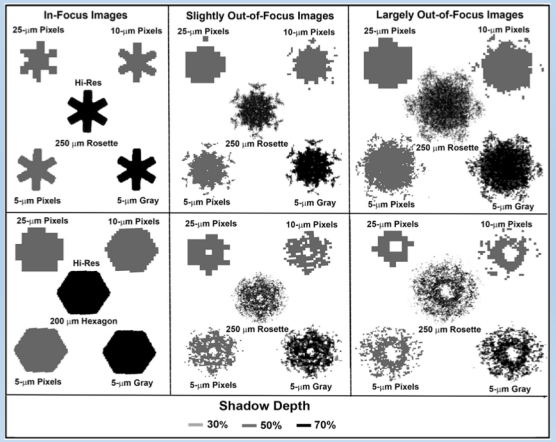
Sharkeye

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



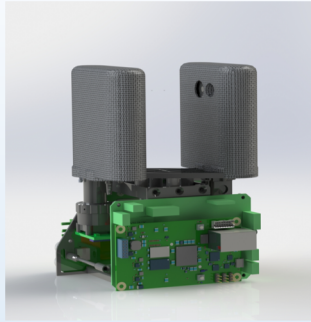
- Improved ice / water differentiation
- Improved resizing of out-of-focus drops
- Imaging Volcanic ash & other large aerosols including organic materials and pollen
- Allows for more accurate understanding of radiative properties through imaging of surface roughness on aerosol and ice particles

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



- 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

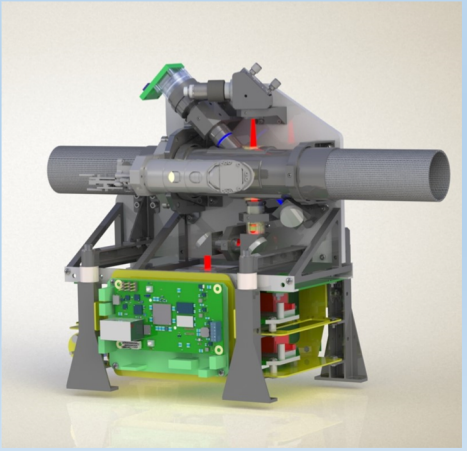
Take Home



- 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

SPECinc
Cloud Physics and Instrumentation

Thank You

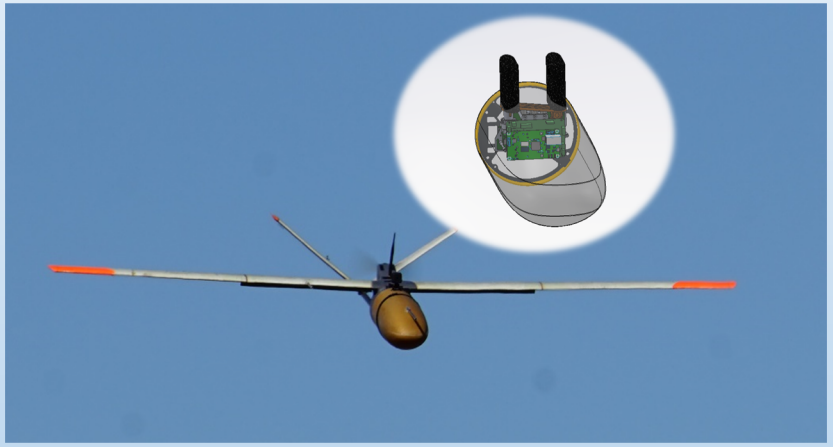


Penguin (UAV Factory) vs. Others

UAV Factory Penguin B

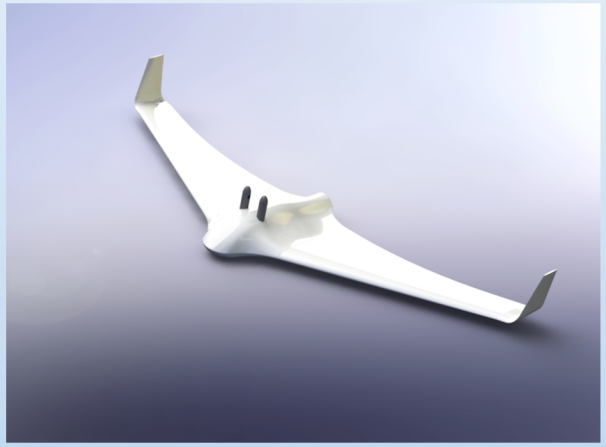
- 10 kg Payload
- 5 km ceiling
- 80 Watts Payload Power
- 20 + hours Flight Time
- 3.3 m Wing Span
- 26 knot stall speed

BlackSwift S2



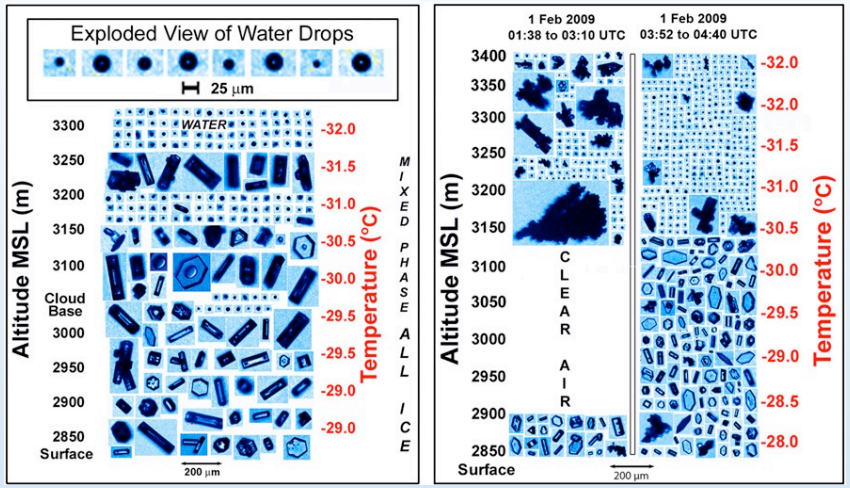
- 2.3 kg Payload
- 6 km ceiling
- 50 Watts Payload Power
- 110 minute Max Flight Time
- 6.6 kg MTOW
- 3 m Wing Span

Skywalker X8



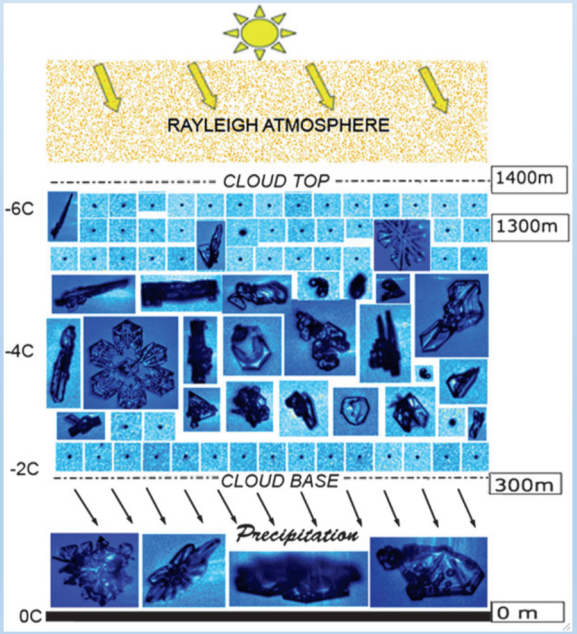
- 1.5 kg Payload
- 4 km ceiling
- 5 kg MTOW
- 2.1 m Wing Span

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.