Project Description

Title: ACLOUD – $(AC)^3$

Arctic **Cl**oud **O**bservations **U**sing airborne measurements during polar **D**ay
as part of the Transregional Collaborative Research Centre TR 172 ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms $(AC)^3$

Time:	22. May – 28. June 2017
Aircraft:	Polar 5 & 6
Airport:	Longyearbyen/Svalbard (Svalbard lufthavn, LYR)
Area of Activities:	Greenland Sea, North polar ocean 75° - 85° N, 10° W - 30° E

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Summary of the Project Description

ACLOUD is a joint project of different German universities and research institutes (listed below) embedded in the Transregional Collaborative Research Centre TR 172:

ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms (AC)³

The involved institutes are:

LIM	Leipzig Institute for Meteorology, University of Leipzig, Germany
IGM	Institute for Geophysics and Meteorology, University of Collogne, Germany
AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven and Potsdam, Germany
TROPOS	Leibniz Institute for Tropospheric Research, Leipzig, Germany
IPA	Institute for Atmospheric Physics, Johannes Gutenberg University Mainz, Germany
MPI-C	Max Planck Institute for Chemistry, Mainz, Germany
KIT	Karlsruhe Institute for Technology, Germany
LaMP	Laboratoire de Météorologie Physique, Clermont-Ferrand, France

The general goal of ACLOUD is to obtain a comprehensive data set of a diversity of atmospheric parameters that will be used to understand and quantify specific physical processes in, above, and below Arctic clouds. The analysis of the measurement data will, in combination with different kinds of atmospheric models, be used to estimate the role of Arctic clouds for the amplified climate change in Polar Regions.

ALOUD employs two research aircraft, Polar 5 & 6, operated by the Alfred Wegener Institute for Marine and Polar research. The research flights aim to measure properties of cloud and aerosol particles, trace gas concentration, the energy fluxes in the atmospheric column including radiative fluxes as well as fluxes of sensible and turbulent latent heat. In situ measurement techniques and remote sensing instruments will be applied.

The flights will be performed simultaneously with both aircraft. In total, 80 flight hours for each aircraft within 5 1/2 weeks (22. May – 28. June 2017) are planned. Polar 5 & 6 will approach the ice-pack mainly in altitudes of 3,000 m (10,000 ft). Then flights will be performed in different levels above, in and below clouds if visibility conditions are sufficient. The lowest possible flight level is at 60 m (200 ft) above ground which is needed to characterize turbulent fluxes in the lower part of the atmospheric boundary layer and the surface reflectivity.

The base for the aircraft operation will be Longyearbyen, (Svalbard lufthavn, LYR). We strive to minimize the environmental impact of our research activities. Flights at low altitude will not be performed over land, over bird sanctuaries, or wherever marine mammals are spotted by the aircraft crew. To our best knowledge, the environmental impact of our activities will be limited to (a) aircraft noise, (b) aircraft exhaust fumes, and (c) 100 meteorological probes released from the aircraft.

The airborne observations will be closely coordinated with surface based observations at the AWIPEV station (Ny Ålesund) and with surface based observations from an ice camp around RV Polarstern that will be drifting in sea ice north of Svalbard during the period of the aircraft campaign. Some flights will be performed also while the ship is sailing in the Fram Strait along its way to the final position in the ice pack.

Summary of the Proposed Development

Purpose

The research activities of ACLOUD combine investigations of clouds, atmospheric aerosol, trace gases, and of turbulent and radiative fluxes in cloudy and clear-sky conditions. The main aim of the cloud studies is to improve the understanding of the cloud-related processes in the Arctic atmosphere and to obtain data which can be used for testing the performance atmospheric models in the Arctic ranging from small-scale (LES) to regional and global climate models. Data will be used also for a test of parameterizations (e.g. radiation and turbulence). ACLOUD will characterize the cloud microphysical properties (cloud particle size, concentration, thermodynamic phase and shape), cloud radiative properties and aerosol properties to estimate the impact of cloud-aerosol interactions on the characteristics of the clouds. ACLOUD will focus on low level clouds within the lowest 10,000 ft of the atmosphere and especially on the atmospheric boundary layer clouds. These clouds strongly interact with the Arctic surface and potentially change the surface energy budget in sea ice and ice free areas. Therefore, ACLOUD aims to characterize cloud-surface interaction including turbulent and radiative fluxes, precipitation of snow and rain.

Framework

ACLOUD is embedded in a major research effort of the German Transregio SFB TR172. The activities include intense ground-based and ship borne observations. The German research vessel Polarstern will sail into the central Arctic north of Svalbard, where a three week ice camp is planned. Ground-based measurements will be performed at the same time at Ny Alesund / Svalbard. The aircraft activity of ACLOUD will connect these to stationary observatories by flying transects between Polarstern and Ny Alesund.

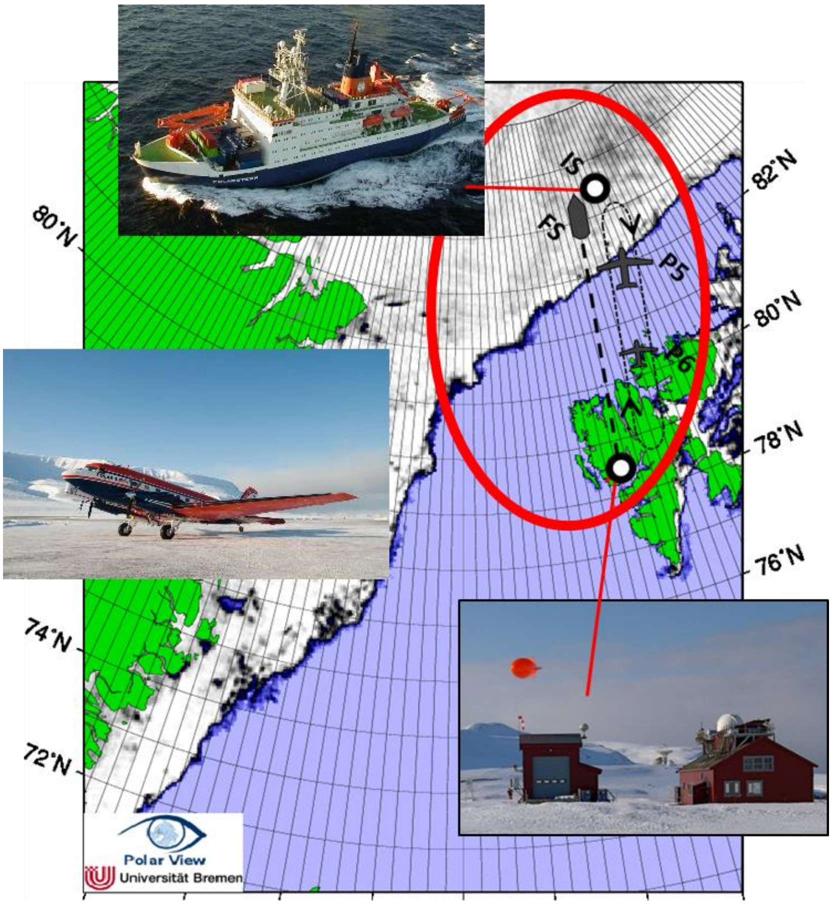


Fig. 1: Map of the areas for aircraft operation illustration the coordination activities at Polarstern and Ny Alesund.

Location

The operation area of Polar 5 & 6 will be adjusted to the position of Polarstern. Polarstern is expected to sail along the west coast of Svalbard north into the sea ice. The ice station is supposed to be initially at about 82.5° N and 15° E and is expected to drift towards south-west.

The Polar 5 and Polar 6 aircraft will perform multiple science flights from Longyearbyen airport, Svalbard. Permission is requested to operate the aircraft in a sector defined by four points (A, B, C, D). See Figure 1.

A	85° N / 28° E
B	75° N / 28° E
C	75° N / 10° W
D	85° N / 30° W

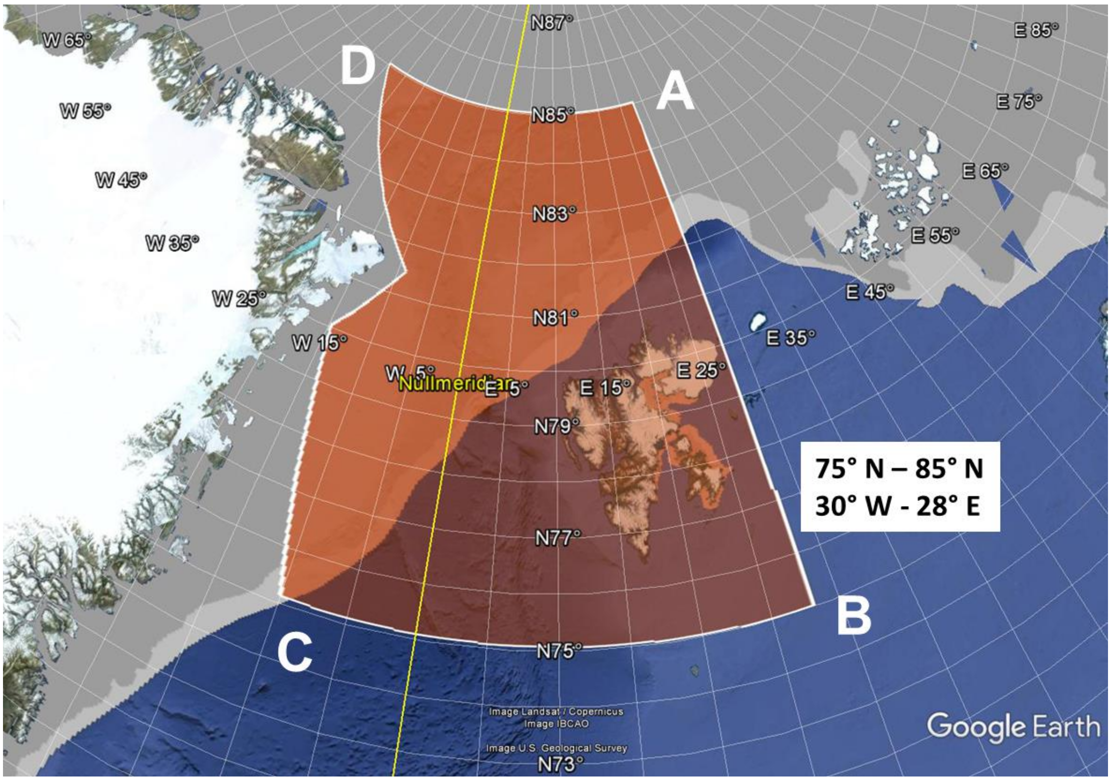


Fig. 2: Map of areas for which we ask for permission to operate Polar 5&6 aircrafts.

Our research target will be cloud fields (in particular, mixed-phase, ice and liquid water stratiform clouds in the boundary layer) which can appear anywhere within the range of our aircraft. The maximum distance from Longyearbyen is 750 km, or 400 nautical miles. The exact flight tracks will depend on the current weather situation, in particular on the occurrence of cloud fields and wind direction since the ideal flight pattern will be performed parallel to the mean wind.

Time Schedule

The research flights are scheduled in coordination with the Polarstern activities.

Polarstern Schedule:	26.5. – 04.6. 2017	Ferry BHV - Arctic
	04.6. – 18.6. 2017	**Ice Station**
	18.6. – 22.6. 2017	Ferry Arctic – LYR

To cover all Polarstern activities, the research flights with Polar 5 & 6 will be conducted between:

Polar 5 & 6 operation: **22 May and 28 June 2017.**

A total of 80 flight hours for each of the two aircraft (Polar 5 and Polar 6) is planned for the flight activities. The exact times and dates of the flights within that time frame will depend on the current weather situation. An average flight duration of 5 hours is estimated resulting in about 16—20 flight days within the entire period.

Infrastructure Requirements

The infrastructure required for our activities are: Svalbard lufthavn, LYR, UNIS, general facilities (hotels etc.) within the town of Longyearbyen.

Fuel requirements

The aircraft will be routinely fuelled at Svalbard lufthavn, LYR.

Scientific Rationale

The main motivation for this project is the pressing need to improve the understanding of the physical processes in Arctic clouds and their contribution to the current changes in the polar environment. Current studies have shown that depending on their properties clouds may act warming or cooling in arctic environments. General assumptions about these clouds lead to uncertainties in regional and global model simulations that are an important tool for the prediction of future weather and climate. Airborne observations are a valuable method to verify and to improve those assumptions and to reduce the uncertainties in the climate models for the Arctic. However, airborne measurements are limited in time. Therefore, the aim of ACLOUD is to combine the airborne observations with ground- and ship-based long term observations at Ny Alesund and on board of the research vessel Polarstern.

The cloud properties, such as cloud phase, particle size, horizontal and vertical variability, amount and phase of precipitation on the other side strongly interact with the turbulent, radiative fluxes and the concentration and composition of aerosol particles inside, below and above the cloud layer. While fluxes influence the dynamics of clouds, aerosol particles may effect cloud and precipitating particles. As fluxes and aerosol particles are hard to observe form satellite instruments, again airborne measurements are the key to improve our understanding of cloud dynamics and cloud-aerosol interactions.

<u>Cloud Studies:</u> Arctic clouds are often mixed-phase clouds which means that they simultaneously contain liquid water droplets and ice crystals. Physically, this can happen at all temperatures between 0°C and –40°C (between +32° and –40°F). The impact of these clouds on the energy budget of the Arctic (and thereby on the Arctic climate change and sea ice melt) strongly depends on the distribution between ice and liquid water in the cloud volume. This study will characterize Arctic clouds by (A) in situ measurements of cloud microphysical properties (concentration and size of droplets and ice crystals) and (B) by remote sensing of the cloud optical properties. The combination of both methods will help to quantify the impact of the clouds' microphysical properties on the radiative transfer (reflection, absorption of solar and terrestrial radiation) and to improve our understanding of the Arctic energy budget.

<u>Aerosol and Trace Gas Studies</u>: Aerosol particles potentially affect climate both directly by changing the radiation balance and indirectly by modifying cloud microphysical properties. E.g. the fraction of ice crystals in Arctic mixed-phase clouds may change depending on the particle composition. Different sources contribute to the total aerosol particle concentration in Arctic areas. Sea salt from the ocean is one major source in sea ice free conditions. Other aerosol particles are transported from lower latitudes and may contain sulfur, nitrogen

compounds or soot. Especially soot is a critical component in assessing the climate impact of aerosols and cloud processes. Simultaneous trace gas measurements can indicate which of these transport paths dominate the origin of the observed aerosol particles. Over the Arctic, little information is available for the distribution of atmospheric aerosols, and the impact of aerosol particles on the environment is not well known. This study will measure aerosol particles quantified by number concentration, size distribution and composition to improve our understanding of direct aerosol radiative forcing and indirect aerosol-cloud processes in the Arctic.

Studies of Radiative and Turbulent Fluxes:
Atmospheric fluxes strongly depend on clouds and on the surface characteristics such as the sea ice concentration. So, the surface radiative fluxes will differ between sea ice covered and sea ice free areas due to the different surface albedo and surface temperature of open water and sea ice. The latter difference is larger during winter. Nevertheless, we will quantify its (weaker) influence during the time of our campaign. Surface turbulent fluxes vary also with changing surface roughness and fluxes of latent heat depend on the availability of water vapor that are both linked to the presence of different sea ice regimes (marginal sea ice zone with small floes, sea ice with leads (channels in pack-ice), and closed pack ice). In the cloud layer the radiative and turbulent fluxes will be affected by cloud properties such as cloud optical thickness, cloud phase, cloud top cooling and entrainment processes. Due to the different impact of clouds and surface characteristics often a 2-layer structure develops in the ABL with strongly different turbulent fluxes in both layers. Thus the airborne observations will help to A) characterize the horizontal variability of the different fluxes in the Arctic and B) understand the vertical profile of fluxes including the 2-layer structure by linking measurements in different altitudes between surface and cloud top.

Methods – Instrumentation

The Polar 5 research aircraft is a Canadian Basler BT–67 (call sign C–GAWI) and will operate as a remote sensing aircraft. It will be equipped with the following instruments: SMART-Albedometer (measurement of the solar radiation spectrum), AISA Eagle and AISA Hawk (hyperspectral cameras), MiRAC (microwave radiometer and cloud radar), nose boom for turbulent fluxes, broadband sensors for solar and infrared radiation, AMALi lidar system, AIMMS-20 (winds and turbulence), sun photometer (optical thickness of aerosol column), digital video cameras, drop sonde system and meteorological sensors.

The remote sensing instrumentation for the observations (SMART-Albedometer, AISA Eagle/Hawk, MiRAC Sun Photometer, AMALi) is almost entirely located inside the under-floor compartments of the aircraft, which are closed by roller doors when not operated. Only the sun photometer and parts of the SMART-Albedometer are mounted on the roof of the aircraft: While the sun photometer is installed within the large glass dome, the SMART-albedometer optical inlets are mounted at the view port close to the door. The radar of MiRAC will be deployed in a belly-pod below the fuselage of Polar 5.

AMALi, the lidar system, can also be configured to measure in zenith direction, for which a second viewport on top of the fuselage is used. The lidar system will be operated in nadir

direction only above altitudes of 9,000 feet. In zenith configuration it will be operated at all altitudes.
The nose boom will be equipped with a new de-icing system that allows flights in cloudy environment.

Tab. 1: Instrumentation of Polar 5 for remote sensing and turbulent flux observations.

Instrument	Institution	Products
SMART-Albedometer	LIM	Spectral radiance I (nadir), irradiance F (up and down) 300-2200 nm; cloud albedo, cloud optical depth and effective radius, ice indices
AISA Eagle	LIM	Spectral radiance I in 512 pixel (36° swath), 300-1000 nm; cloud optical thickness
AISA Hawk	LIM	Spectral radiance I in 256 pixel (36° swath), 1000-2500 nm; cloud phase, cloud effective radius
MiRAC	IGM	Passive microwave radiometer; 6 channels at 183 GHz + 243 and 340 GHz, water vapor profiles, LWP, IWP
		Cloud radar 95 GHZ (Doppler), cloud geometry, precipitation, 89 GHz for LWP estimation
AMALi	AWI	Particle extinction coefficient, cloud-top height
Nose Boom	AWI	3D wind vector, temperature and humidity, turbulent fluxes
Sun-Photometer	AWI	Aerosol optical depth
AVAPS drop sondes	AWI	Profiles of air pressure, humidity, temperature, and wind
180° Fish-Eye Camera	AWI / LIM	BRDF, cloud phase function, Photo documentation
Basis Intrumentation		
AIMMS-20	AWI	Temperature, pressure, humidity, wind vector, aircraft attitude
Broadband radiometers	AWI	Solar and terrestrial broadband irradiance, up- and downward
KT-19 radiation thermometer	AWI	Cloud-top or surface temperature
Laser altimeter LDM301	AWI	Ground altitude
Up- and downward looking digital Video	AWI	Video imagery
Inertial Reference System	AWI	Aircraft attitude
Air Data Computer	AWI	Avionics
Flight Management System	AWI	Avionics

The Polar 6 research aircraft is a Canadian Basler BT–67 (call sign C–GHGF) and will operate as in situ aircraft for cloud, aerosol, trace gas and turbulent flux observations and will be equipped with the following instruments: nose boom (also with a de-icing system) for turbulent fluxes, fast cloud droplet probe FCDP (cloud particle size distribution), 2D-S (stereo) probe (droplet and ice particle size and shape), precipitation imaging probe PIP (drizzle droplets, snow sampling), Small Ice Detector SID-3 (characterization of ice particles

in clouds), PHIPS (cloud particle scattering phase function, stereo particle imaging), CVI (counterflow virtual impactor inlet), Aerosol sensors (CPC, OPC, UHSAS, PSAP, SP2 for aerosol and cloud residual number concentration, size distribution and soot content), AMS (aerosol particles mass spectrometer), CO, CO_2 and O_3 sampler, AIMMS-20 (winds and turbulence), broadband sensors for solar and infrared radiation, digital video cameras, and meteorological sensors.
The cloud particle probes will be installed in standard PMS canisters under the wings (2x doubly pylons). The particle characterization is realized by an aerosol inlet that guides air into the cabin to the instruments (ALABAMA, UHSAS, SP2, OPC, CPC). A CVI inlet is used to allow measurements of ambient and cloud residue aerosol particles. The trace gas instruments will use a different inlet to suck air into the cabin. All three inlets are installed on the top of the aircraft.

Tab. 2: Instrumentation of Polar 6 for turbulent fluxes, cloud, aerosol and trace gas in situ observations.

Instrument	Institution	Products
FCDP	LaMP	Cloud particle size distribution
2D-S or PIP	LaMP	Precipitating particle size distribution and shape
SID-3	KIT	Cloud particle shape and size
PHIPS	KIT	Cloud particle scattering phase function, stereo particle images
Nevzorov Probe	AWI	Liquid and Total Water Content
CVI	TROPOS	Cloud particle residual sampling
CPC, UHSAS, OPC, PSAP	TROPOS	Particle number and size distribution, soot content
SP2	AWI	Soot content
ALABAMA	MPI-C	Particle chemical composition
CO, CO2, H20, O3 sensors	IPA	CO, CO2, O3 concentration and humidity
	Basis Intrumentation	
AIMMS-20	AWI	Temperature, pressure, humidity, wind vector, aircraft attitude
Broadband radiometers	AWI	Solar and terrestrial broadband irradiance, up- and downward
KT-19 radiation thermometer	AWI	Cloud-top or surface temperature
Up- and downward looking digital Video	AWI	Video imagery
Inertial Reference System	AWI	Aircraft attitude
Air Data Computer	AWI	Avionics
Flight Management System	AWI	Avionics

Methods – Flight Pattern

We will perform airborne measurements with two aircraft, the Polar 5 and Polar 6 owned by Alfred-Wegener Institute for Polar and Marine Research, Germany, and operated by Kenn

Borek Air, Canada. In general, the aircraft will not fly at low altitudes until it is safely away from the coast. No landing of the aircraft will take place during each mission. The aircraft will avoid bird/wildlife sanctuaries. The crew on board the aircraft will look for marine mammals on the sea ice, and if encountered during low altitude flight, the aircraft will change course to avoid them.

The target of our cloud studies will be low-level stratiform clouds over sea ice and open water (typically cloud altitude between 1000–6000 ft / 300–2000 m). The scientific objective is to observe (from above) and probe (from inside) those clouds. To this purpose, two kinds of flight strategies are required, one for “remote sensing” (passive solar, microwave, active radar, lidar) and one for “in-situ probing” of the cloud particles (concentration, size, phase, shape), respectively. Having two aircraft each aircraft is dedicated for one of the two flight strategies, Polar 5 doing “remote sensing” and Polar 6 “in-situ probing”. Synchronizing and collocating the flight tracks of both aircraft allows us to simultaneously sample inside the clouds and do the remote sensing, which is a key improvement in our research. In addition turbulent and radiative fluxes will be measured on both aircraft. Part of the flight strategy will include profiling the atmosphere by both aircraft in an area of intense observations close to the Polarstern position.

When Polarstern is at the ice station both Polar 5 and 6 will first ferry to the location of Polarstern (Ferry 1). At Polarstern, an area of intense observations will be defined and investigated in Pattern A. Ideally, when time allows, a second area located along the mean wind direction with intense observations will follow right after with a similar or alternative flight pattern (Pattern B, C, and D). Afterwards, both aircraft will ferry back (Ferry 2).

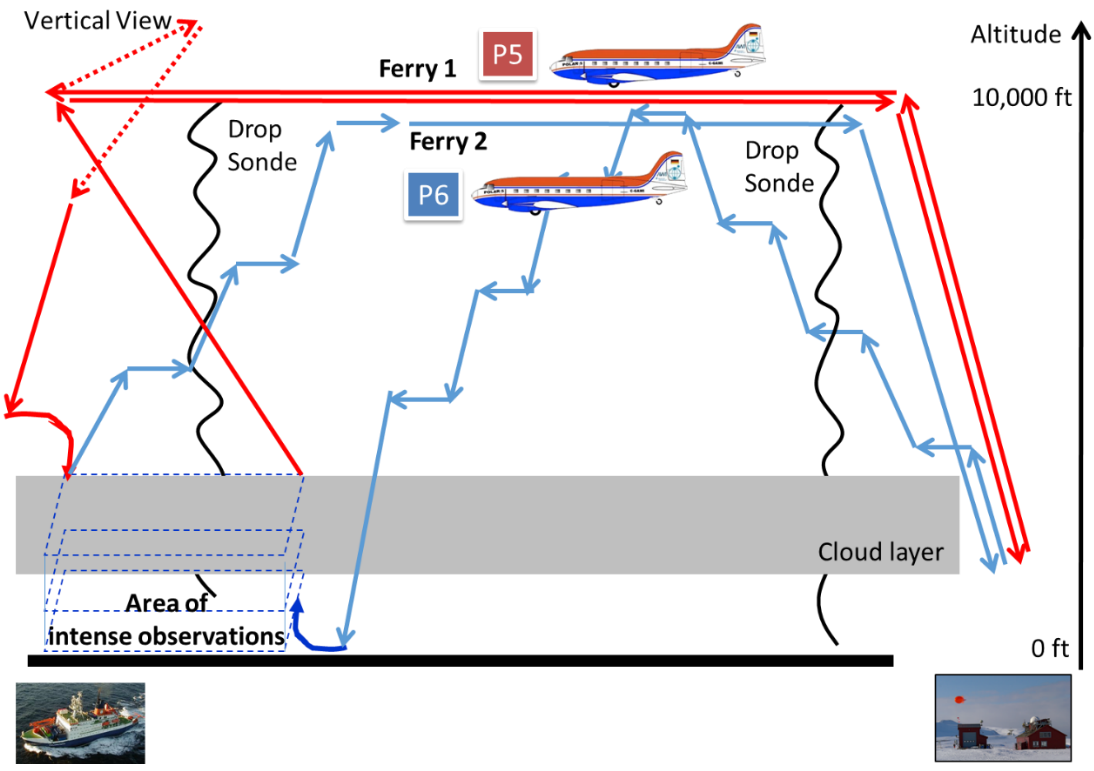


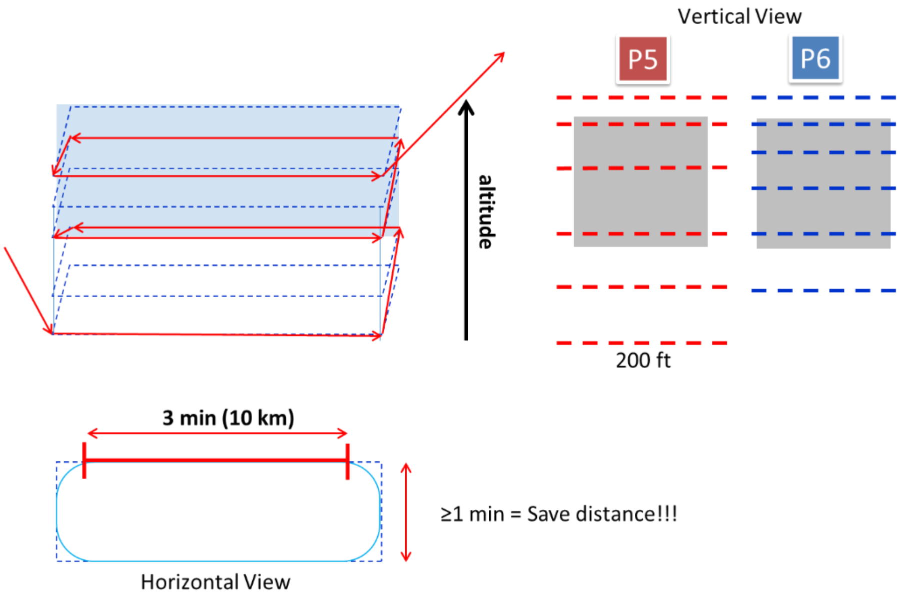
Fig. 3: General flight pattern of Polar 5 and 6 including Ferry 1&2 and observation in an area of intense observations as propose for the ACLOUD mission.

Ferry 1: During this ferry Polar 5 will perform remote-sensing observations (see Figure 3) at a constant altitude above the cloud top, typically near the maximum aircraft altitude; 10,000 ft / 3,000 m. These legs are straight lines if possible coordinated with satellite overpasses. To allow the launch of drop sondes, Polar 5 will fly behind Polar 6. The synchronization of Polar 5 and 6 can be realized by adjusting the aircraft speeds or performing holding pattern. The drop sondes are used to determine the vertical structure of the atmosphere and will be launched only at 10,000 ft (3 km) and only over uninhabited areas. Polar 6 will sample aerosol and trace gases in different altitudes during the ferry. Therefore, Polar 6 will stepwise climb in the beginning and stepwise descend at the end of the ferry. When the lidar on Polar 5 indicated specific interesting aerosol layers we will guide Polar 6 at this specific altitude during the ferry.

Ferry 2: The ferry back to LYR will be performed in a pattern similar to Ferry 1. However, Polar 6 may choose higher altitudes if fuel allows. To cover aerosol particles and trace gases transported from long distances in higher altitudes we will increase the maximum flight height to 15,000 ft for short sequences (<30min).

Pattern A:
The area of intense observation (AIO) will be approximately a 20 km x 20 km box. In the area of intense observation, Polar 5 will first perform a cross flight pattern to sample the area from above in both directions. The legs will extend the AIO (about 40 km) to characterize the representativeness of the clouds in the AIO.

In the AIO horizontal legs of 3 min (10 km) will be used to characterize the vertical profile of the clouds and the boundary layer. The legs will be oriented along the main wind direction. To optimize the sampling time, legs at different altitudes will not be flown at a fixed location (see Fig. 4). After each leg a perpendicular leg will be used to climb and separate the straight legs. About 1 min or more are estimated for this perpendicular leg to separate the straight legs in save distance. In this way different levels of the cloud and boundary layer will be sampled. We intend to start the profiling at the lowest level. This allows to first penetrate the cloud fast without a lot of icing if icing is present. The legs at cloud top where icing of present might be strongest will be at the end of the profile allowing to escape the cloud to the top. The final leg will be flown above cloud top to characterize out-cloud aerosol and trace gas conditions.
This profiling will be started by Polar 6 which is already at cloud altitude at the end of Ferry 1. Polar 5 will follow. The flight pattern straight legs separated horizontally and vertically will allow to have both aircrafts in the AIO at the same time.
The altitudes at which the profiles will be performed will be defined during the flight, depending on cloud top altitude and cloud base altitude. Polar 6 will spend more legs in the cloud to increase the sampling statistics of cloud particles, while Polar 5 will additionally add one leg at lowest altitude (200 ft) to sample the surface radiative and turbulent fluxes (See Fig. 4). The number of straight legs and the corresponding time needed to complete this pattern are given in Figure 4.



Legs	Time (min)
5	25
6	30
7	35
8	40
9	45
10	50

Fig. 4: Flight pattern of Polar 5 and 6 within the area of intense observation performing legs in a box pattern at different altitudes.

Pattern B (Alternative – Repeat Pattern A):
Here we intend to repeat the observations of Part A but at a different location. The second IOA will be located about 50 km upwind of the first AIO.

Pattern C (Alternative – Satellite Overpass):
Coordination with satellite observations. This pattern will be flown on a straight leg along the satellite overpass. Polar 5 will perform remote sensing at 10 000 ft altitude while Polar 6 will fly inside the cloud layer to observe cloud microphysical properties. The total length of the leg may range about 60 nm, about 15 min before and 15 min after the satellite overpass.

Pattern D (Alternative – Cloud layer properties):
To measure radiative fluxes above and below the cloud layer and study their horizontal variability, long straight legs ~60 NM will be flown. While Polar 5 will fly above cloud top, Polar 6 will fly below the cloud layer. This allows to calculate the divergence within the cloud layer. Cloud remote sensing can be applied all the leg. Additionally cloud precipitation will be measured over a longer time with enhanced sampling statistics.

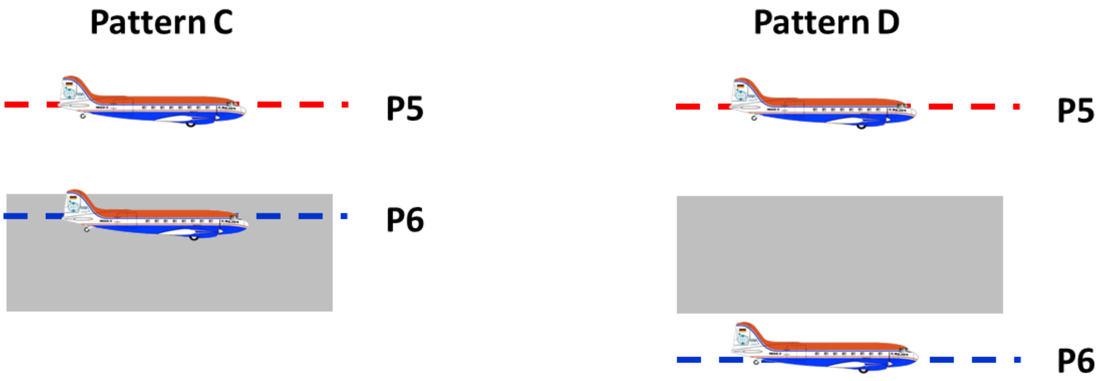


Fig. 5: Flight pattern of Polar 5 and 6 proposed for Pattern C and D.

Environmental Overview

This aircraft study will be conducted away from all wildlife areas. We expect very little anticipated impact on the environment.

Anticipated impacts

There will be minimal impact on the environment as a result of this project. All atmospheric samples will be taken from aircraft which will take off and land at Longyearbyen airport only. The aircraft will not fly at altitudes lower than 200 ft. Flights at low altitudes between 200-1000 ft will occur only over sea ice far from Svalbard. 50 to 70 meteorological probes (drop sondes) will be released during flights at high altitude (only over uninhabited areas outside bird and wildlife sanctuaries), descend through the atmosphere with a parachute, and remain at their landing site. The release of meteorological probes (drop and radio sondes) is a standard procedure in environmental studies of the atmosphere and no harmful impact on the environment is known. The sondes' weight is 350 g, they are 41 cm long and 7 cm wide in diameter.

Mitigation of Impacts

When flying at low altitudes (minimum 200 ft), the aircraft will fly exclusively over sea ice or open water. No low-level flights will be performed over land areas. All sensitive wildlife areas will be avoided. Crew on the aircraft will look for marine mammals on the sea ice and avoid areas where they are seen. All marine mammals spotted will be logged and mentioned in the final report.

Emergency Response Plan

Staff trained in Emergency First Aid will be travelling with the aircraft at all times. In case of an emergency off-strip landing, there will be emergency camp gear, rations, and first aid equipment on board at all times. The aircraft is equipped with both radio and satellite communications. Should an emergency arise, the aircraft personnel will communicate with air traffic controllers and emergency services and will be used for transport to the nearest emergency care facility.