Project Description

Title: AFLUX – *(AC)³*

Airborne measurements of radiative and turbulent FLUXes of energy and momentum in the Arctic boundary layer

as a part of the Transregional Collaborative Research Centre TR 172 ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms *(AC)³*

Time:	15 March – 16 April 2019
Aircraft:	Polar 5
Airport:	Longyearbyen/Svalbard (Svalbard lufthavn, LYR)
Area of Activities:	Greenland Sea, North Polar Ocean 75° - 85° N, 10° W - 30° E

Primary Contact:

Dr. Christof Lüpkes
Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (AWI)
Am Handelshafen 12
27568 Bremerhaven
GERMANY
Tel.: +49 (0)471 4831 1786
Fax: +49 (0)471 4831 1797
Email: christof.luepkes@awi.de

Lead Researchers:

Christof Lüpkes – Alfred Wegener Institute, Germany (Email: christof.luepkes@awi.de)
André Ehrlich – University of Leipzig, Germany (Email: A.Ehrlich@uni-leipzig.de)
Manfred Wendisch – University of Leipzig, Germany (Email: M.Wendsich@uni-leipzig.de)

Summary of the Project Description

AFLUX is a joint project of different German universities and research institutes and of one French university (listed below). It is 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:

AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven and Potsdam

LIM Leipzig Institute for Meteorology, University of Leipzig
IGM Institute for Geophysics and Meteorology, University of Cologne
LaMP Laboratoire de Météorologie Physique, Clermont-Ferrand, France
DLR Deutsches Zentrum für Luft- und Raumfahrt

The general goal of AFLUX is to obtain a comprehensive data set of atmospheric parameters in the polar cloud-covered and cloud-free atmospheric boundary layer (ABL) over sea ice. Flights will be arranged in a way that the data can serve to improve our understanding of boundary layer processes dependent on the dominating impact factors such as clouds, sea ice cover, surface temperature and wind. The combined analysis of the measurement data and of suitable modeling results will be used to estimate first of all the role of Arctic clouds and of surface heterogeneities for the amplified climate change in polar regions. Special emphasis is on the comparison of results during this winter/early spring campaign with the ACLOUD – $(AC)^3$ campaign carried out during late spring/early summer in the same region in 2017.

AFLUX will employ one research aircraft, Polar 5, operated by the Alfred Wegener Institute. To reach the goals described above the research flights aim to measure turbulent and radiative fluxes of energy depending on the properties of low-level clouds and aerosol particles, as well as on trace gas concentration. To that aim both in situ measurement techniques and remote sensing instruments will be applied.

80 flight hours are planned within about 4 weeks (15 March – 16 April 2019). Polar 5 will approach the ice-pack mainly in altitudes of 3,000 m (10,000 ft). Then, flights will be performed in different levels above and below clouds if visibility conditions are sufficient. During descend clouds will be probed under suitable conditions with only very weak icing. If conditions allow, also short horizontal flight legs are planned in clouds. Such conditions might be found in shallow stratocumulus over sea ice where humidity is lower than at the sea ice edge. 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 below clouds as well as to measure the surface temperature 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) 60 meteorological probes released from the aircraft.

The airborne observations will be closely coordinated with surface-based observations at the AWIPEV station (Ny-Ålesund).

Summary of the Proposed Campaign

Purpose

The research activities of AFLUX are similar to those of the previous ACLOUD campaign (Wendisch et al., 2018). We aim to elaborate the differences to the more summerly conditions. As during ACLOUD we combine investigations of clouds, atmospheric aerosol, trace gases, and of turbulent and radiative fluxes in cloudy and clear-sky conditions. The main aims are to improve the understanding of the cloud-related processes in the Arctic atmosphere and to obtain data, which can be used to test the performance of atmospheric models in the Arctic. These may range from small-scale Large Eddy Simulations to regional and global climate models. Data will be used also for a test of parametrizations, e.g., of surface albedo and turbulence. AFLUX will characterize the cloud microphysical properties (cloud particle size, concentration, thermodynamic phase and shape) and cloud radiative properties to estimate the impact of boundary layer fluxes on the cloud characteristics. The focus will be on low-level clouds within the lower 10,000 ft of the atmosphere and especially on the ABL clouds. These clouds strongly interact with the Arctic surface and potentially change the surface energy budget in sea ice and ice free areas. Therefore, AFLUX aims to characterize cloud-surface interaction including turbulent and radiative fluxes, precipitation of snow and rain. During late winter/early spring we expect a much stronger impact of the surface heterogeneity than during ACLOUD with late spring/early summer conditions since the surface temperatures between open water and sea ice amounts to up to 40 K during early spring. Thus flight patterns will be arranged in a way to account for the impact of the surface heterogeneity and to separate this impact from the cloud impact.

Framework

AFLUX is embedded in a major research effort of the DFG-funded Transregio SFB TR172. The activities include also intense ground-based observations performed at the same time at Ny-Ålesund / Svalbard. The aircraft measurements of AFLUX will connect the observatory data with the airborne data by arranging the transect flights to the ice pack as close as possible over Ny-Ålesund.

Location

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

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

Individual flights will be located within this sector but in a smaller sub-region depending on the aircraft's range (payload), on the sea ice conditions and on weather. In the last decade sea ice cover was highly variable in the highlighted region shown in Figure 1. The variability concerns especially the position of the pack ice edge North and West of Svalbard and the sea ice cover on Storfjorden (SouthEast of Spitzbergen).

During each flight we will try to reach the ice edge with a reasonable reserve for flight patterns also beyond the sea ice edge over the sea ice covered part.

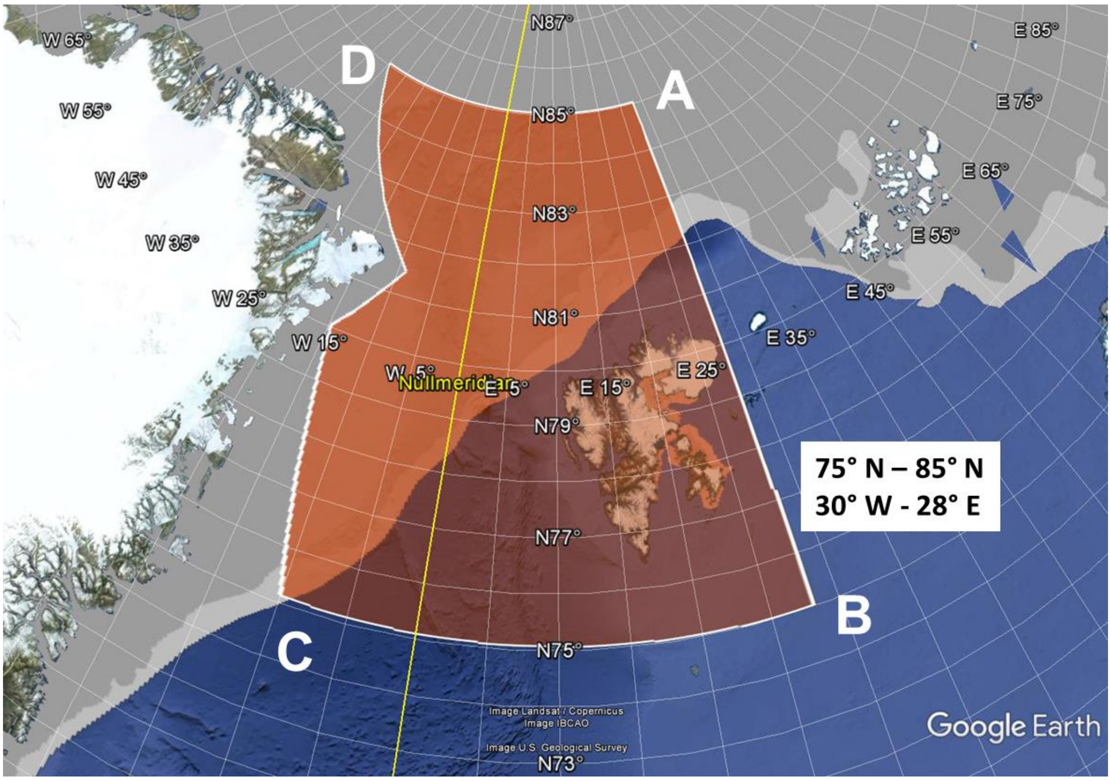


Fig. 1: Map of area, for which we ask for permission to operate Polar 5&6 aircrafts.

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. As a reference, also flights in clear-sky condition over the same area are envisioned. 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, the sea ice cover, and wind direction since the ideal flight pattern will be performed parallel to the mean wind.

Time Schedule

The research flights are scheduled for **15 March until 16 April 2019.**

A total of 80 flight hours 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 12-16 flight days within the entire period.

Infrastructure Requirements

The infrastructure required for our activities are: Svalbard lufthavn, LYR, general facilities (hotels etc.) within the city of Longyearbyen, a meeting room in the Spitsbergen Hotel (Funken).

Fuel requirements

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

Science

The main motivation for this project is the pressing need to improve the understanding of the physical processes in Arctic clouds, their interaction with the sea ice cover, and their contribution to the current changes in the polar environment. Especially the interaction with the ice surface is not well represented in models, which is due to the small scales involved.

Current studies have furthermore shown that depending on their properties clouds may act as a warming or cooling factor in the arctic environment. However, parameterizations and general assumptions about clouds lead to uncertainties of the representation of these cloud effects in regional and global weather prediction and climate models. Airborne observations are a valuable method to verify and to improve those assumptions and to reduce the model uncertainties. However, airborne measurements are limited in time. Therefore, one aim of AFLUX is also to combine the airborne observations with ground-based long term observations at Ny-Ålesund.

<u>Studies of Radiative and Turbulent Fluxes:</u>

The cloud properties such as cloud phase, particle size, horizontal and vertical variability, amount and phase of precipitation strongly interact with the turbulent and radiative fluxes inside, below and above the cloud layer. Since turbulent fluxes cannot be observed from satellite, airborne measurements are the key to improve our understanding of cloud dynamics and their interaction with cloud-aerosol. Both radiation and turbulent fluxes strongly depend on the clouds but also on the surface characteristics such as the sea ice concentration. Surface radiative fluxes as well as the turbulent 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. Especially leads (channel-like openings in the ice pack) play an important role for the turbulent fluxes and in case of large leads also for related clouds. Fluxes of latent heat depend on the availability of water vapor which is linked to the presence of different sea ice regimes (marginal sea ice zone with small floes, sea ice with leads, and closed pack ice). Although we can measure the lead impact on turbulent fluxes only in case of wide leads when the fluxes reach to the measurement height of 200 ft, we can estimate the impact of lead ensembles by (vertical) profile flights (or drop sondes) upstream and downstream of lead ensembles.

Cloud top cooling and entrainment processes contribute strongly to the energy budget of the boundary layer also in conditions without leads. We will measure the impact of clouds on the fluxes with special emphasis on cloud top generated cooling, entrainment and on the cloud's impact on the ABL turbulence structure. The latter is often characterized by the existence of a shallow surface dominated layer and of a cloud dominated layer. Fluxes differ strongly from each other in both layers. This phenomenon has been investigated already during summer (e.g. ACLOUD) but for winter conditions it is not yet documented in much detail. Thus the airborne observations will help to A) characterize the horizontal variability of the different fluxes in the Arctic and B) understand the vertical profiles of fluxes including the 2-layer structure by linking measurements below and in clouds.

<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°F and –40°F). The impact of these clouds on the energy budget of the Arctic (and thereby on the Arctic climate change) strongly depends on the distribution between ice and liquid water in the cloud volume.
AFLUX will characterize Arctic clouds by (A) in situ measurements **(as far as flight conditions allow)** 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.

Methods – Instrumentation

The Polar 5 research aircraft is a Canadian Basler BT–67 (call sign C–GAWI). It will be equipped with the following instruments: nose boom and AIMMS-20 for turbulent fluxes, broadband radiometers for solar and terrestrial radiation, SMART-Albedometer (spectral solar radiation), AISA Eagle and AISA Hawk (solar hyperspectral cameras), MiRAC (microwave radiometer and cloud radar), AMALi lidar system, sun photometer, four cloud in situ probes, digital video cameras, drop sonde system, and meteorological sensors.

The nose boom will be equipped with a de-icing system that allows **short** flights in cloudy environment.
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.

Four in situ probes for cloud microphysical measurements will be mounted below the wings of Polar 5. The Polar nephelometer and the 2D stereo probe (2D-S) are combined in one twin carrier, the Cloud, Aerosol, and Precipitation Spectrometer (CAPS) and the Precipitation Imaging Probe (PIP) in a second carrier.

Tab. 1: Instrumentation of Polar 5 for turbulent and radiative flux measurements and in situ and remote sensing clouds observations.

Instrument	Institution	Products
In Situ Instrumentation		
Nose Boom	AWI	3D wind vector, temperature and humidity, turbulent fluxes
AVAPS drop sondes	AWI	Profiles of air pressure, humidity, temperature, and wind
Polar-Nephelometer	LaMP	Cloud particle scattering phase function
2D-S	LaMP	Cloud particle shape and size
CAPS	DLR	Cloud particle shape and size
PIP	DLR	Precipitating particle size distribution and shape

Nevzorov Probe	AWI	Liquid and Total Water Content
Remote Sensing Instrumentation		
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; 7 channels at 60GHz oxygen absorption for T-profiles
		Cloud radar 95 GHZ (Doppler), cloud geometry, precipitation, 89 GHz for LWP estimation
AMALi	AWI	Particle extinction coefficient, cloud-top height
Sun-Photometer	AWI	Aerosol optical depth
180° Fish-Eye Camera	AWI / LIM	BRDF, cloud phase function, Photo documentation
Basis Instrumentation		
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

Methods – Flight Pattern

We will perform airborne measurements with the Polar 5 owned by Alfred Wegener Institute Helmholtz Centre for Polar und 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 outside Longyearbyen 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 the research flights is the sea ice covered area. Flights will be performed there in cloud covered, but also in cloud free conditions. The latter need to be investigated in order to compare the turbulent and radiative fluxes with those measured in the cloudy areas. Part of the flight strategy will include profiling the atmosphere, again in both cloud covered and cloud free regions.

To characterize the cloudy boundary layer, we aim to probe 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 those clouds from above and to probe the atmosphere below and inside the 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 turbulent fluxes and individual cloud particles (concentration, size, phase, shape). These different strategies can be realized by Polar 5 either by combining flight sections for remote sensing with in situ sections during individual flights or by realizing only one strategy, e.g.

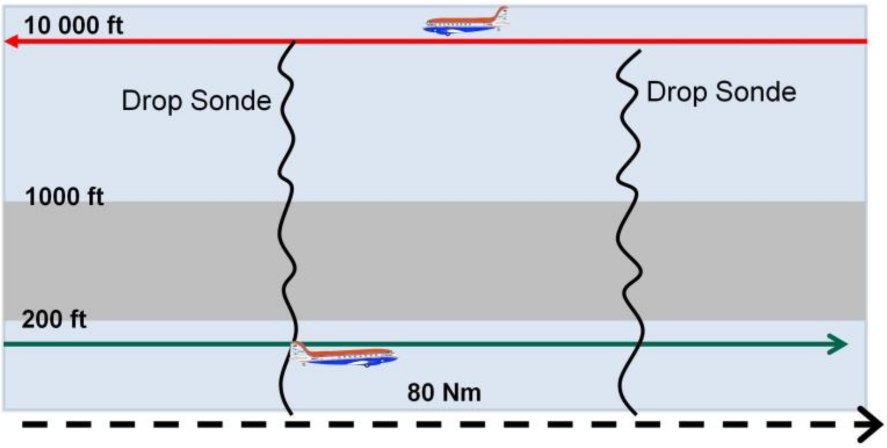
remote sensing, during some flights. In situ and remote sensing flight section should be collocated on the same flight tracks (following the same track but in different heights). This is essential for our research strategy during most of the flights to reach our research goals.

Possible flight patterns are explained below in more detail. There, we distinguish between the ferry flights to/from the locations of main measurements and the patterns at these locations/regions

Ferry 1: Polar 5 will perform remote-sensing observations (see Figure 3) typically 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 and are sometimes coordinated with satellite overpasses. Some drop sondes will be launched at 10,000 ft (3 km) to determine the vertical structure of the atmosphere but only over uninhabited areas.

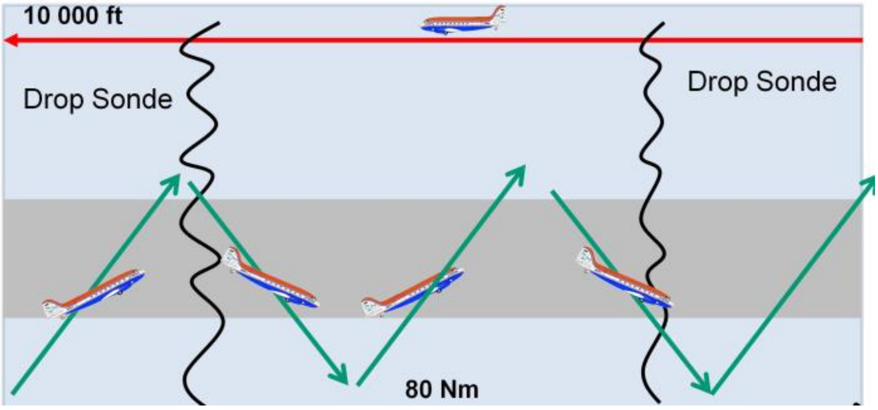
Ferry 2: If the endurance allows, ferries back home can be used to repeatedly probe the boundary layer by consecutive saw tooth pattern (climbing-descending, see Pattern B) in low altitude.

Pattern A:



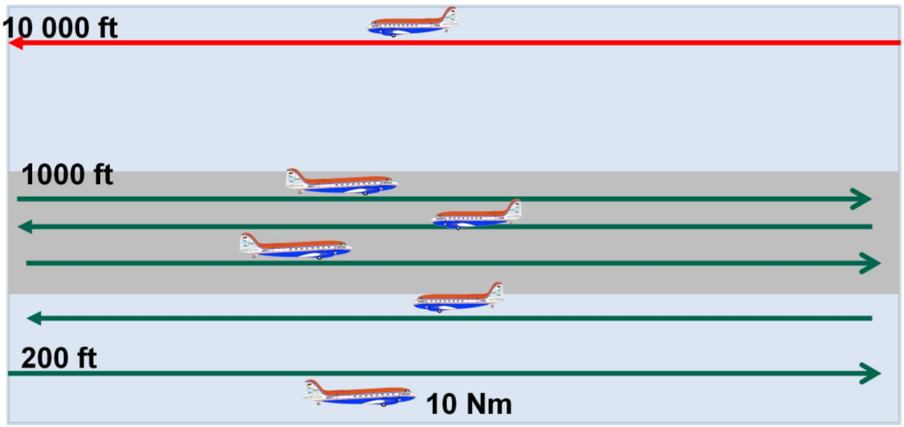
The area of intense observation (AIO) will be approximately over sea ice. Polar 5 will arrive at the pack ice edge and will then go down with a fast descend rate of 1000 ft/ min to reach 200 ft above the surface. A horizontal distance of 80 Nm is flown parallel to the mean wind at this height. A fast ascend will follow to 10.000 ft. At this level the aircraft flies back while releasing a series of drop sondes. This basic pattern can be varied with respect to heights and lengths of the tracks.

Pattern B:



This patterns consist basically of a saw tooth pattern over the ice and cloud covered region. Ascend and descend rates as well as the number of saw teeth can be varied. But a typical climbing rate should be 200 ft /min. This allows to measure turbulent and radiative fluxes as well as cloud particles sufficiently accurate.

Pattern C:



This pattern serves as the basic pattern to measure vertical profiles of fluxes and particles. A large number of horizontal flight legs (e.g., 10) should be flown to achieve a high vertical resolution. If flight time allows, the pattern should be repeated at different positions preferably on the downwind and upwind side of leads or in a region with a section characterized by very homogeneous sea ice cover. Lengths of legs and heights must be varied according to the cloud and sea ice conditions. Such a pattern is also helpful when no clouds are present.

Pattern D (Alternative – Satellite Overpass):
Coordination with satellite observations. This pattern will be flown on a straight leg along the satellite overpass. Polar 5 will perform mostly remote sensing at 10 000 ft altitude with a few sections in the cloud if icing conditions will allow this. The total length of the leg may range about 60 nm, about 15 min before and 15 min after the satellite overpass.

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, but this low height occurs 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.

References

Wendisch, M. et al., 2018, Multi-Platform Observations of Arctic Mixed-Phase Clouds and Aerosol Particles during the Combined ACLOUD/PASCAL Field Campaigns, submitted to Bull. Am. Meteorol. Soc.