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MOSAiC Expedition: Airborne Surveys with Research Aircraft POLAR 5 and POLAR 6 in 2020

Edited by

Andreas Herber, Sebastian Becker, Hans Jakob Belter, Jörg Brauchle, André Ehrlich, Marcus Klingebiel, Thomas Krumpen, Christof Lüpkes, Mario Mech, Manuel Moser, and Manfred Wendisch

HELMHOLTZ

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Titel: Blick aus dem Forschungsflugzeug Polar 6 auf Polar 5 (Foto: T. Krumpen, AWI)

Cover: View from Research Aircraft Polar 6 to Polar 5 (Photo: T. Krumpen, AWI)

MOSAiC Expedition: Airborne Surveys with Research Aircraft POLAR 5 and POLAR 6 in 2020: Atmospheric Airborne Observations in the Central Arctic (ACA) and Sea Ice Measurements (IceBird)

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MOSAiC-Accompanying Airborne Measurements with *Polar 5* and *Polar 6* in August/September 2020: Atmospheric Airborne Observations in the Central Arctic (ACA) and Sea Ice Measurements (IceBird)

17 August 2020 – 17 September 2020

Longyearbyen, Spitzbergen

Chief scientist
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Coordinator
Daniel Steinhage

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1. ÜBERBLICK

Ein allgemeines Ziel der Flugzeugmesskampagnen ACA (Atmospheric Airborne observations in the Central Arctic) und IceBird (Sea Ice surveys) mit den AWI Forschungsflugzeugen *Polar 5* und *Polar 6* bestand darin, die lokalen Messungen, die während der MOSAiC-Drift über den Arktischen Ozean mit dem Forschungsschiff *Polarstern* gewonnen wurden, in einen regionalen Kontext zu stellen. Die beiden unterstützenden Flugzeugkampagnen ACA und IceBird lieferten somit zusätzliche luftgestützte Beobachtungen für die MOSAiC-Expedition.

ACA war auf den atmosphärischen Teil des gemeinsamen Messprogramms fokussiert. Sie ist in den von der DFG geförderten transregionalen Sonderforschungsbereich TR 172 eingebettet und Teil des Gemeinschaftsprojekts verschiedener deutscher Universitäten und Forschungsinstitute $(AC)^3$ „ArctiC Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms" (www.ac3-tr.de), das von der Universität Leipzig koordiniert wird. Ein konkretes Hauptziel von ACA war, Unterschiede in Wolkeneigenschaften und deren Wirkung auf die Energiebilanzen (Strahlung, Turbulenz) über Meereis und offenem Ozean zu charakterisieren. Die IceBird-Kampagne des AWI ist Teil eines langfristigen Monitoringprogramms zur Erfassung von Messungen der Meereisdicke und des Oberflächenzustands in der Arktis. Sie wird vom AWI mit Beiträgen verschiedener externer Partner finanziert.

Ursprünglich waren während der MOSAiC-Expedition vier Flugzeugkampagnen geplant – zwei im Frühjahr und zwei weitere im Sommer. Aufgrund der Coronavirus-Pandemie mussten die Frühjahrskampagnen jedoch abgesagt werden, da Spitzbergen für ausländische Besucher komplett gesperrt war. Die beiden MOSAiC Flugzeugkampagnen (ACA und IceBird) fanden im Sommer vom 17. August bis 17. September 2020 statt. Die ersten Messflüge waren aber durch die notwendigen Quarantänemaßnahmen in Norwegen auf Grund der Coronavirus-Pandemie erst ab dem 30. August 2020 möglich. Als Operationsbasis für die Flugzeugmessungen diente Longyearbyen, Spitzbergen (78°13‘ N, 15°38‘ E). In Abbildung 1.1 ist eine Übersicht über die Messflüge während der MOSAiC-Flugzeugkampagnen ACA (neun Messflüge) und IceBird (sieben Messflüge) dargestellt. Die Gesamtflugstundenzahl für die Flugzeugoperation der *Polar 5* und der *Polar 6* betrug 126,8 h. Abbildung 1.2 zeigt die Teilnehmer der MOSAiC Flugzeugkampagnen ACA und IceBird vor der *Polar 5*.

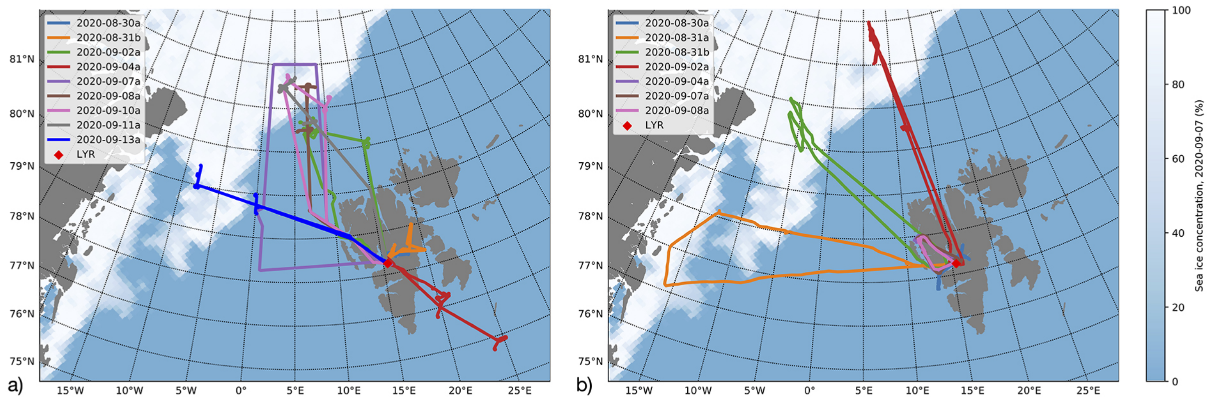

Abb.1.1: Übersicht über die Messflüge während ACA a) und IceBird (b); siehe https://doi.pangaea.de/10.1594/PANGAEA für eine Darstellung des master tracks

Fig. 1.1: Overview on the flight activity during ACA (a) and IceBird (b); see https://doi.pangaea.de/10.1594/PANGAEA to display the master track

SUMMARY AND ITINERARY

The airborne campaigns ACA (Atmospheric Airborne observations in the Central Arctic) and IceBird Summer (Sea Ice surveys) with the AWI research aircraft *Polar 5* and *Polar 6* aimed to complement the measurements obtained during the MOSAiC drift across the Arctic Ocean with the German research vessel *Polarstern*. The major aim of the Airborne operation during MOSAiC was to support the year-round surface-based measurements of atmospheric processes and sea ice state in the vicinity of *Polarstern* by aircraft measurements covering a wide geographic area ranging from the open ocean to sea ice covered regions. The two assisting aircraft campaigns ACA and IceBird thus provided additional airborne observations to the MOSAiC expedition. ACA is embedded in the Transregional Collaborative Research Centre TR 172 project "ArctiC Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms" (AC)^3, which is a joint project of different German universities and research institutes coordinated by University of Leipzig. The AWI IceBird campaign is part of a long-term monitoring programme to collect measurements of sea ice thickness and surface state in the Arctic. The IceBird monitoring programme is funded by AWI with contributions of various external partners.

Originally, four airborne campaigns were planned during the MOSAiC expedition – two in spring, and another two in summer. Due to the coronavirus pandemic, the spring campaigns had to be cancelled. The two MOSAiC aircraft campaigns in summer (ACA and IceBird) took place from 17 August to 17 September 2020. However, first measurement flights were possible only from 30 August 2020, due to the necessary quarantine measures in Norway as a consequence of the coronavirus pandemic. Longyearbyen, Spitsbergen (78°13' N, 15°38' E) served as the base of the airborne operations. Fig. 1.1 gives an overview of the airborne activity during the MOSAiC aircraft campaigns ACA (nine measurement flights) and IceBird (seven measurement flights). The total flight hours for the *Polar 5* and *Polar 6* operation were 126.8 h. Fig. 1.2 shows the participants of the MOSAiC aircraft summer campaign in front of the *Polar 5*.

Grant-No. AWI_PS122_00

Abb. 1.2: Teilnehmer der MOSAiC Flugzeugkampagnen ACA und IceBird vor Polar 5
(Bild: Esther Horvath, AWI)

Fig. 1.2: Participants of the MOSAiC Airborne Campaigns ACA and IceBird in front of Polar 5
(picture: Esther Horvath, AWI)

2. OBJECTIVES OF MOSAIC AIRBORNE

2.1 Atmospheric Campaign ACA

For the Alfred Wegener Institute Helmholtz Center for Polar and Marine Research (AWI) atmospheric programme the *Polar 5* was equipped with remote sensing systems, like Lidar, Sun photometer, Hyperspectral Camera, spectral solar radiometer, and a cloud radar system as well as standard meteorological sensors, including drop soundings and nose boom for turbulence measurements. In the focus of the atmospheric airborne operation in August and September 2020, measurements characterizing the atmospheric and Arctic Boundary Layer (ABL)-processes were mainly involved, such as ocean-atmosphere interaction, clouds, radiation, and aerosols. The typical main flight pattern for survey flights with *Polar 5* – atmospheric study – is visualized by Fig. 2.1 (left side).

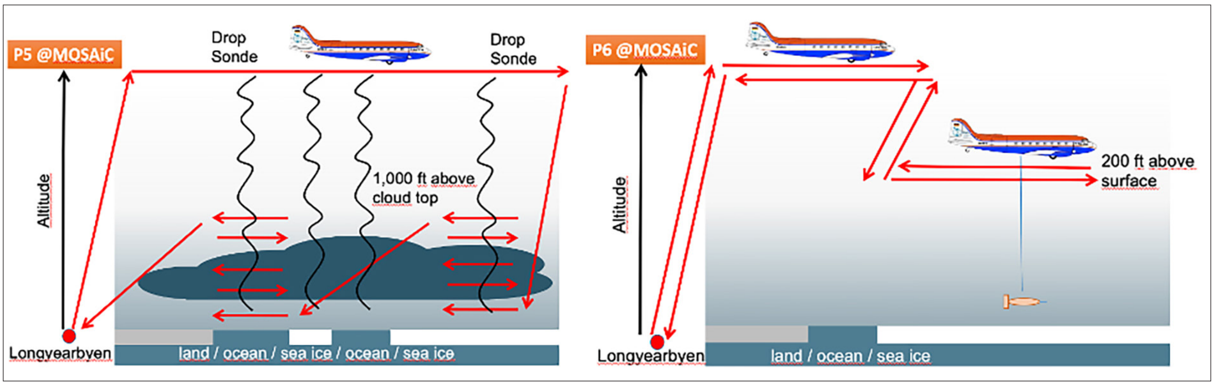

Fig. 2.1: Typical main flight pattern for both activities during the campaign; atmospheric study ACA with Polar 5 (left side) and sea ice study IceBird with Polar 6 (right side)

The MOSAiC ACA 2020 summer airborne campaign also aimed to complement earlier atmospheric surveys made, e.g., during the AC³ campaigns ACLOUD 2017 (May/June) and AFLUX 2019 (March/April) in the area of Svalbard during different seasons. The following research questions were investigated:

1. Spatial and seasonal variability of ABL processes as a function of large-scale flow, sea ice characteristics, and clouds.
   For this purpose, the aircraft was equipped with measuring systems to collect data on mean meteorological variables but also on radiation and turbulent fluxes of heat, humidity, and momentum. The measurements aimed to better understand the cloud impact on the ABL structure and mixing processes in the ABL over the open ocean, Marginal Sea Ice Zone (MSZ), and over the sea ice covered Arctic Ocean.

2. Surface property maps (albedo/surface reflection properties, bidirectional reflectivity distribution function, BRDF) to identify typical scales and distributions of the surface variability in the Arctic.

For this purpose, we carried out intensive measurements on the DF, including information on the albedo over open ocean, over the MSZ and over the sea ice covered Arctic Ocean.

3. Influence of macro-physical and microphysical cloud properties on precipitation and the Arctic radiative energy budget.
   The aim was to investigate the cloud formation and interaction, based on measurements of Arctic cloud parameters, like size distribution and particle shape as well as ice and liquid water content.

4. Investigation of air mass intrusion into the Arctic by combining model-based quasi Lagrangian tracking with airborne observation.
   The aim was to study the processes along the air parcel trajectories moving over the open ocean and the sea ice on the basis of the LES data, based on cases observed along aircraft *Polarstern* linking trajectories, driven by profile measurements from aircraft and *Polarstern* as beginning and ending point of the trajectories.

2.2 Sea Ice Campaign IceBird

The AWI IceBird programme (IceBird Project Page) consists of a series of airborne surveys to collect measurements of sea ice thickness in the Arctic. The programme is a continuation of earlier campaigns (TIFAX, PAMARCMiP) made north of Svalbard, Greenland, and Canada. Airborne surveys provide insight into composition and properties of the ice in general and how it changes over time. The AWI IceBird campaigns usually take place twice a year: In summer (August) and winter (March/April), when sea ice extent and thickness are at their minimum and maximum, respectively. Fig. 2.1 (right side) shows the typical main flight pattern for survey flights with *Polar 6* – sea ice study.

The aim of the MOSAiC IceBird 2020 campaign was to complement earlier sea ice surveys made in Fram Strait area between 2001 and 2018. The focus was on the following research questions:

1. Are thickness and surface state of the sea ice surveyed in the surrounding of *Polarstern* exceptional or in agreement with historical observations made in Fram Strait?
   To answer this question, we compare the long-term time series of sea ice thickness and surface state obtained during previous surveys with MOSAiC IceBird data and ground-based EM (GEM) measurements. First results were published recently in Belter et al. (2021).

2. How did the MOSAiC ice floe and the Distributed Network (DN) develop after *Polarstern* left the floe in later July?
   For this, parts of the MOSAiC Distributed Network were revisited. A comparison of those airborne surveys with data collected shortly prior *Polarstern* left the floe will provide an insight into processes occuring on the ice cover in Fram Strait area.

3. What are the processes driving interannual variability of sea ice thickness and surface state in Fram Strait region?

4. Applicability of the MACS/DLR camera to assist long-term sea ice monitoring programmes like IceBird.
   A fourth aim was to test the MACS/DLR camera over sea ice. The images provided continuous informations along flight track about the surface state of sea ice like melt ponds, floe size, etc. Moreover, after the campaign the images will be used to construct high resolution Digital Elevation Models (DEMs).

3. LOGISTIC OVERVIEW

Originally, four airborne campaigns were planned during the MOSAiC expedition – two in spring, and another two in summer. The challenging preparation of the four campaigns including both aircraft was in a good status at the beginning of 2020. Freight containers had arrived in Longyearbyen already, accommodation etc. was arranged. However, due to the coronavirus pandemic, the spring campaigns had to be cancelled, while, fortunately, the summer measurements were realized. The two MOSAiC aircraft campaigns in summer, ACA and IceBird, then took place from 17 August to 17 September 2020. Longyearbyen, Spitsbergen (78°13' N, 15°38' E) served as the base of the airborne operations. Nevertheless, we had to overcome huge difficulties in preparing the campaigns and travelling to Longyearbyen, Spitzbergen in these challenging times of the pandemic. Eventually, the two summer campaigns became possible only because of the support by both, the Government of Norway and the Governor of Svalbard. For our Canadian aircraft crews, the campaign began already ten days earlier than for other participants because all crew members had to endure a ten days quarantine in Oslo, before they were allowed to fly with the *Polar 5* and *Polar 6* aircraft to Svalbard on 28 August 2020. The scientific crew had to leave Germany two days earlier than planned to avoid new regulations prescribing ten days of quarantine also for Germans in Oslo because of a recent increase of the number of corona-infected people in Germany. However, the first measurement flights were only possible from 30 August 2020, due to the necessary quarantine measures in Norway as a consequence of the coronavirus pandemic.

During the MOSAiC-Airborne campaigns we used both AWI aircraft *Polar 5* and *Polar 6* from aircraft type Basler BT-67. Both aircraft are operated by the Canadian Company Kenn Borek Air Ltd. Calgary. The home base is the international airport in Bremerhaven, Germany. The Basler BT-67 is a modern version of the Douglas DC-3, which is equipped with modern avionics, turbo-prop engines and a combined ski-wheel gear. This allows landing and take-off from paved, gravel or snow-covered surfaces. The fuselage provides space for a variety of scientific installations, which can be adapted to the different scientific programmes. Loading capacity and cabin volume allow efficient logistic activities. The passenger transport capacity of the aircraft is 18 passengers up to maximum of 2,000 kg. Modifications to the "standard" Basler BT-67 for AWI include large belly retractable doors, several large openings in the cabin, wing stations for antennas and probes, and more powerful generators for 15.4 KVA of electrical power. This allows more extensive and flexible scientific systems relative to earlier polar research aircraft. Both aircraft have an operational range of more than 2,500 km. Scientific equipment is mounted either inside the aircraft or on the wings to investigate the lithosphere, the atmosphere and the cryosphere in the Arctic and Antarctica (Wesche et al., 2016).

4. GENERAL WEATHER INFORMATION

The feasibility of flights during a campaign on Svalbard depends strongly on the weather conditions, not only in the operation area but also at the airport Longyearbyen. The conditions in the first week were governed by a surface low pressure system that was almost stationary at the western coast of Svalbard and moved only very slowly causing a multitude of clouds in all vertical levels, very humid air and rain. Hence, flight activities during the first week were limited to an area nearby Longyearbyen. However, this period was used for short tests and survey flights.

In the second part of the campaign the synoptic situation was governed by a strong low-pressure system south of Svalbard, which only slowly moved eastwards. The low caused easterly wind over Svalbard and northerly wind over Fram Strait for some days. Later in the week, there was a significant variability in the local wind direction around Longyearbyen causing much uncertainty for the flight planning. Thus, the predictability of the weather situation especially at the airport was highly sensitive ranging from perfect conditions to no-go situations with very low clouds and rain showers over the airport. Another difficulty was caused by a front approaching from the North, which allowed only one low-level flight with *Polar 5* over sea ice north of Svalbard, and no flight with *Polar 6* for sea ice thickness surveys in this region.

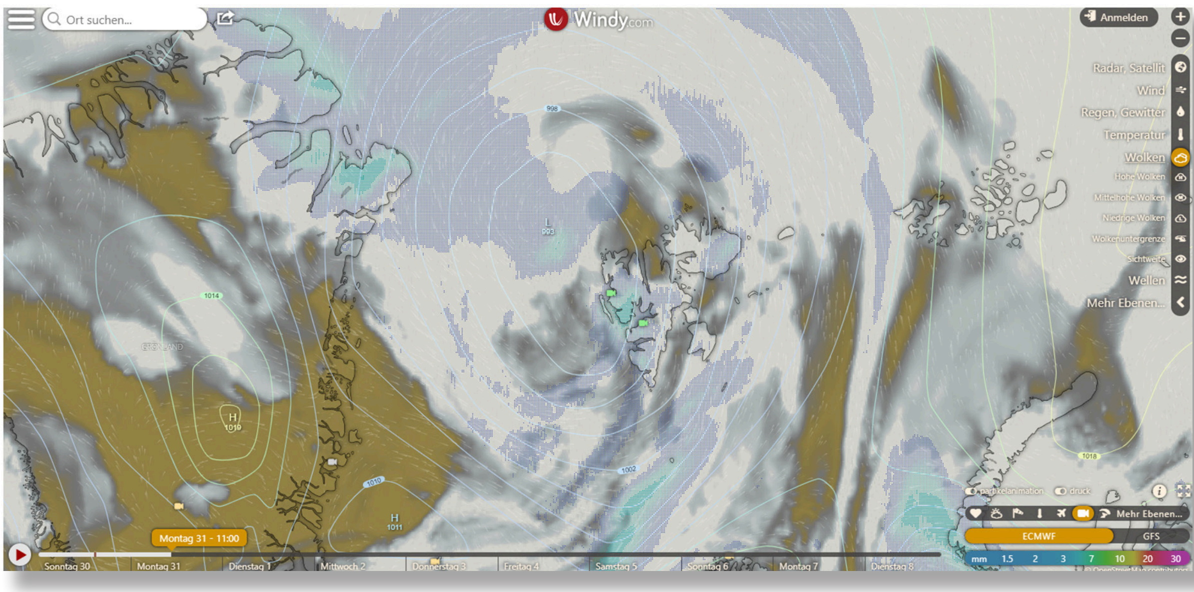

Fig. 4.1: Example for the weather charts during the first part of the campaigns; the air pressure map gives a typical view on the general weather situation in the Arctic (https://www.windy.com).

5. SYSTEMS ON BOARD OF POLAR 5 AND POLAR 6 AND THEIR STATUS DURING THE CAMPAIGN

On *Polar 5* basic atmospheric measurements were obtained by a set of instruments. Mean wind and turbulent fluxes of momentum were derived from high frequency measurements of a five-hole probe mounted at the noseboom. A fast temperature sensor was installed to obtain also fluxes of sensible heat. Dropsondes contributed to study the vertical profiles of the atmospheric state. In situ measurements of cloud particles were obtained by the 2-dimensional-stereo (2D-S) cloud probe, the cloud combination probe (CCP), the polar nephelometer (PN), and the precipitation imaging probe (PIP). The cloud and surface remote sensing instrumentation of *Polar 5* combined the Microwave Radar/radiometer for Arctic Clouds (MiRAC, including an active cloud radar and a passive microwave radiometer HATPRO), the Airborne Mobile Aerosol Lidar (AMALi) system, the Spectral Modular Airborne Radiation measurement sysTem (SMART Albedometer), the Airborne Imaging Spectrometer for Applications (AISA) Eagle/Hawk, and a digital 180° camera (NIKON).

Polar 6 was equipped with a towed electromagnetic (EM) sensor system that measures the combined thickness of the sea ice and its snow layer. The measurement principle is based on electromagnetic induction sounding at a frequency of 4 KHz. In addition, an airborne laserscanner provide high-resolution information of the sea ice surface topography. This information is used to estimate the roughness of the sea ice surface as well as freeboard, a crucial parameter for remote sensing of sea ice thickness. In addition to the laser scanner, the DLR MACS camera provides photos of the sea ice surface state (e.g., melt pond distribution) along the survey line of the aircraft. Table 5.1 provides an overview of the sensors installed on *Polar 5* (ACA configuration) and *Polar 6* (Icebird configuration).

Tab. 5.1: Configuration of *Polar 5* and *Polar 6* during the campaign (Instrumentation of *Polar 5* is described in detail by Ehrlich et al. (2019).

Instrument	**Institute**	***Polar 5***	***Polar 6***
Spectral Imager AISA Eagle/Hawk	Leipzig	X	
MIRAC Radar	Uni Köln	X	
Launcher for CALIB ice buoys	AWI		X
2D-S cloud probe	LaMP	X	
PIP cloud probe	DLR-IPA	X	
MIRAC HATPRO	Uni Köln	X	
PN2 cloud probe	LaMP	X	
PLANET Communication Tool	AWI	X	
GPS Sensor	AWI	X	X
Basic meteorology sensors	AWI	X	X

Instrument	Institute	*Polar 5*	*Polar 6*
Spectral Albedometer	Uni Leipzig	X	
Turbulence Nose Boom, 5-hole probe	AWI	X	
CR2 Hygrometer	AWI	X	
Aerosol LIDAR AMALI	AWI	X	
Sun photometer	AWI	X	
Drop-sonde system (AVAPS lite)	AWI	X	
Nevzorov probe for water content	AWI	X	
EM-Bird for sea-ice measurements	AWI		X
Adjustable nadir video camera	AWI		X
Laser scanner Riegl VQ580	AWI		X
Basic data acquisition system	AWI	X	X
Infrared radiation thermometer KT19	AWI	X	X
Kipp&Zonen CMP22/CGR4, 2 each	AWI	X	X
CCP cloud probe	DLR-IPA	X	
Nikon D5-A, nadir mounted	Uni Leipzig	X	
MACS – camera system	FU Berlin		X

Status of the systems during the campaign

Polar 5: It turned out that the fault in the 115V/400Hz science inverter had not been resolved yet, further investigation revealed the actual cause and a provisional fix could be found. Flight operations were not affected, and the heaters remained fully operational. Temporary problems existed during the campaign by following systems, like broadband radiation sensor, spectrometers of SMART, Hyperspectral camera Eagle/Hawk. Additionally, the Nikon wide-angle lens was exchanged for a fish-eye lens during the campaign on 09 September 2020. During the flight on 07 September 2020 the Sun photometer SPTA failed, the microcontroller was down. A replacement during the campaign was not possible. For following systems existed no problems during the campaign, like all cloud probes (DLR CCP and PIP, LAMP 2DS and PN), MiRAC radar, HATPRO radiometer, Lidar AMALi, KT19, and also for the nose boom instrumentation (see the flight logs in Appendix 4.1)

Polar 6: There were no fundamental problems with the sensor systems installed on board. On one flight, the aircraft INS did not initialize (see flight log for details). As a consequence, laser scanner data from this flight require post-processing with attitude data from different sources. In addition, intermittent glitches affecting the zenith video were reported on three flights (see the flight logs in Appendix 4.2).

6. OVERVIEW ON THE FLIGHT ACTIVITY OF POLAR 5 AND POLAR 6

A total of 16 survey flights were conducted during the MOSAiC Airborne campaign. Nine of these flights were part of the ACA programme run with *Polar 5* (a detailed composition of the flight hours is given in Table 6.1). The IceBird programme conducted seven flights with *Polar 6* (flight hours given in Table 6.2). Detailed information on the flight activity of *Polar 5* and *Polar 6* is given in Appendix A 4.1 (atmospheric survey flights) and Appendix A 4.2 (sea ice survey flights).

Tab. 6.1: Overview on the flight activity during MOSAiC Airborne, whereby *Polar 5* is equipped for the atmospheric program ACA

Date	Subject *Polar 5*	Air time	Flight time
06 Aug 2020	Test flight in Bremerhaven	2.3	2.5
17 Aug 2020	Ferry from Bremen to Oslo	2.6	2.7
28 Aug 2020	Ferry from Oslo to Longyearbyen	6.5	6.8
30 Aug 2020	Test flight (final check of systems)	0.9	1.3
31 Aug 2020	Certification flight for PMS probes	0.7	0.8
31 Aug 2020	Wing by wing flight with *Polar 6*	2.3	2.4
02 Sep 2020	Calypso satellite over flight path	5.5	5.6
04 Sep 2020	ABL structure and fluxes	5.5	5.6
07 Sep 2020	Remote sensing measurements of clouds	5.7	5.9
08 Sep 2020	ABL structure and fluxes	6.1	6.2
10 Sep 2020	Cloud properties over sea ice/open water	6.2	6.4
11 Sep 2020	Cloud properties over sea ice/open water	5.7	5.8
13 Sep 2020	ABL structure and fluxes	5.8	5.9
16/17 Sep 2020	Ferry to Bremen via Trondheim	9.1	9.5
Total flight hour		**64.9**	**67.4**

Date	Subject *Polar 6*	Air time	Flight time
05 Aug 2020	Test flight in Bremerhaven	3.6	3.9
17 Aug 2020	Ferry from Bremen to Oslo	2.6	2.8
28 Aug 2020	Ferry from Oslo to Longyearbyen	6.5	7.0
31 Aug 2020	Wing by wing flight with *Polar 5*	3.1	3.4
02 Sep 2020	Overflight over MOSAiC DN remains and active buoys	6.5	6.8
07 Sep 2020	EM Bird survey, MACS calibration	5.7	5.9
08 Sept 2020	EM Bird survey, deploy CALIB buoys, calibration of radiation sensors	6.0	6.3
10 Sep 2020	MACS operation over Ny-Ålesund	5.8	6.1
11 Sep 2020	MACS operation over Ny-Ålesund	4.4	4.7
13 Sep 2020	MACS operation over Ny-Ålesund	2.7	3.0
16/17 Sep 2020	Ferry to Bremen via Trondheim	9.1	9.5
Total flight hour		**56.0**	**59.4**

7. PRELIMINARY (EXPECTED) RESULTS

7.1 Atmospheric Study

Cloud impact on mean ABL structure, turbulence and radiation

Several flights aimed to measure the atmospheric boundary layer (ABL) structure over both sea ice and open ocean. The focus was on the impact of clouds on the ABL structure. Mean meteorological quantities (wind, temperature, humidity) were measured but also radiation fluxes. Also, high frequency measurements of wind (5-hole probe) and temperature were obtained to derive turbulent quantities such as the turbulent kinetic energy (*tke*) and fluxes of sensible heat and momentum. Dropsondes were released, which helped to detect the mean vertical ABL structure while the aircraft remained in high altitude, in order to avoid e.g. icing zones in clouds.

An example of measurements derived from the high frequency measurements is given in Fig. 7.1.1. It shows profiles of potential temperature, wind speed and of *tke* obtained on 08 September 2020 northwest of Svalbard (at about 81.5°14N, 7.5° E). The profile of potential temperature hints to strong mixing in the upper cloud, also confirmed by the high-resolution wind profile, which indicated an increased wind variability above 1.2 km height. The increased turbulent kinetic energy proves finally that the turbulence in this mid-level cloud was more intense than in the near-surface cloud. Reasons for this feature will be investigated later by considering the radiation flux profiles in addition to other turbulent quantities.

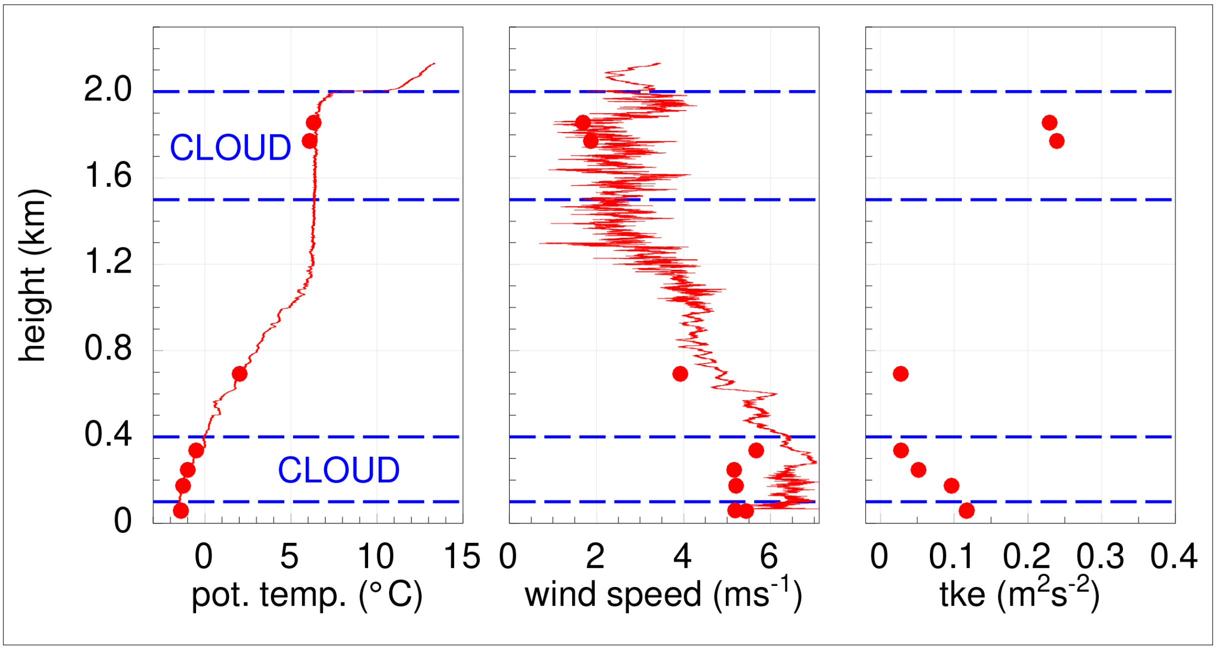

Fig. 7.1.1: Profiles of potential temperature, wind and turbulent kinetic energy (tke) measured on 08 September 2020 northwest of Svalbard over the ice free Fram Strait. Solid lines were obtained during a descent of Polar 5, while bullets mark results from horizontal flight legs.

The ABL structure seen in Fig. 7.1.1 is confirmed by the dropsondes released on this day as depicted in Fig. 7.1.2. Sondes have been launched along the flight following roughly longitude 7° E. Obviously, the well-mixed layer between 1.2 and 2 km height persisted along the whole distance at 7° E. This strong impact of the cloud leading to two ABL layers with different properties might be characteristic for summer conditions where the surface forcing is weak. This will be investigated in more detail in the future.

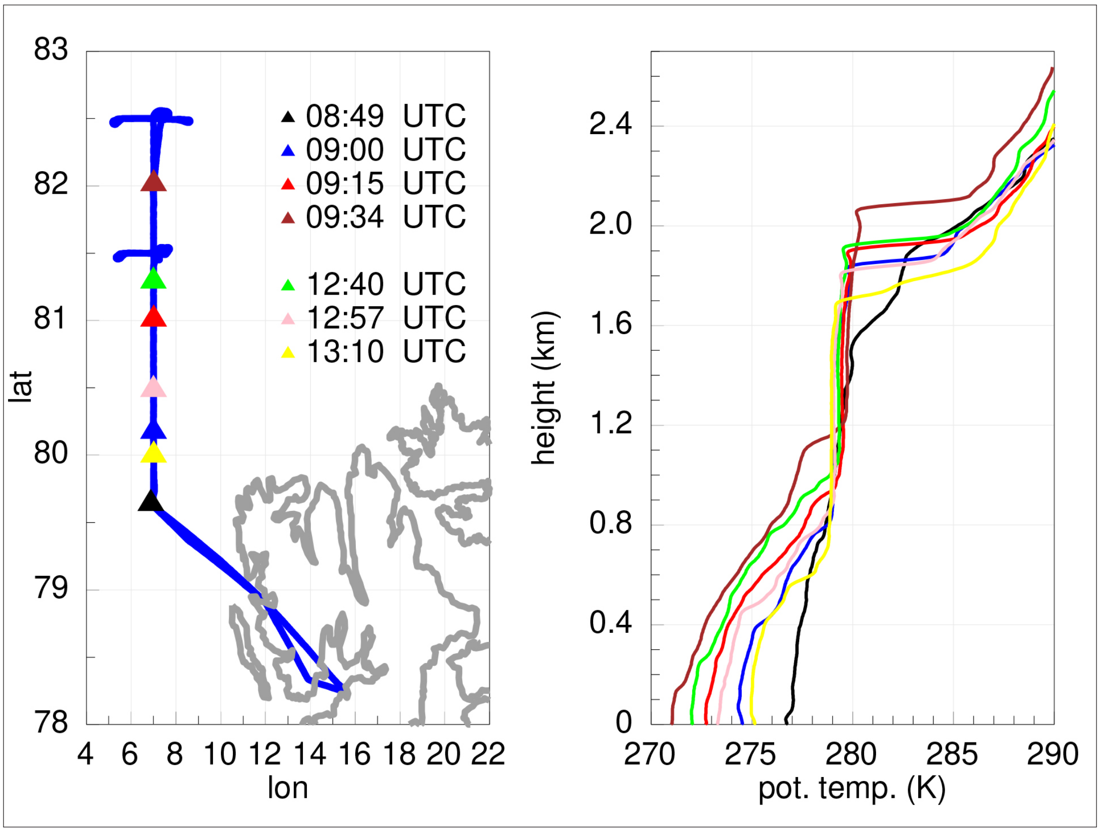

Fig. 7.1.2: Flight track and dropsonde positions (left) and measured potential temperature (right) during a flight on 08 September 2020. Colors of profiles refer to the corresponding colors of dropsonde positions.

For the characterization of the radiative flux profiles and the radiative energy budget, *Polar 5* was equipped with two pairs of broadband radiometers. One pair of pyranometers measured the solar irradiance in the wavelength range between 200 and 3,600 nm. The other pair was formed of pyrgeometers measuring the irradiance in the terrestrial part of the spectrum ranging from 4.5 to 42 μm. Each pair consisted of one instrument installed at the top of *Polar 5* and another one installed at the bottom to measure the downward and upward irradiances, respectively.

Fig. 7.1.3 shows a time series of the broadband irradiances measured during the research flight performed on 8 September. The two low-level legs, dedicated to assess the surface energy budget, are highlighted in grey (over the MIZ) and blue (over open ocean). A time series of the flight altitude is shown in Fig. 7.1.3b together with the sea ice fraction measured during the low-level sections. During the rest of the flight, the satellite-derived sea ice fraction is plotted. Fig. 7.1.3a makes it obvious that the upward solar irradiance (orange line) is larger and more variable over the MIZ than over open ocean. Fig 7.1.3c shows a frequency distribution of the solar upward and downward irradiance. It shows that the solar upward irradiance over open ocean is less than 10 W m^{-2} because of the low albedo of ocean water. In contrast, over the MIZ, the solar upward irradiance covers a wide range between about 20 and 50 W m^{-2}, which is due to the very inhomogeneous distribution of sea ice and open water surfaces (compare blue line in Fig. 7.1.3b). The differences of the downward solar irradiances (yellow line in Fig. 7.1.3a) between the surface types are less, although this quantity is smaller over open ocean (57 W m^{-2} on average), partly due to the reduced multiple scattering between surface and cloud over open ocean compared to the MIZ (78 W m^{-2} on average). The higher opacity of the clouds over open ocean (not shown) further contributes to that effect. However, the downward solar irradiance over both surfaces is highly variable, which indicates variability in the optical thickness of the cloud above.

A frequency distribution of the terrestrial irradiances is displayed in Fig. 7.1.3.d. They show less variability throughout the time interval, especially for the upward component (red line in Fig. 7.1.3.1a), indicating that the surface temperature is fairly constant during the respective low-level section. The higher upward terrestrial irradiance over open ocean (about 315 W m^{-2}) indicates larger surface temperatures than over the MIZ (305 W m^{-2}). The downward irradiance (black line in Fig. 7.1.3a) again shows higher variability because of the inhomogeneity in cloud properties and is larger over open ocean (299 W m^{-2} on average) than over the MIZ (293 W m^{-2} on average), which means that the clouds are either warmer or more emissive (optically thicker) over open ocean.

Finally, Fig. 7.1.3e shows a frequency distribution of the total (solar plus terrestrial) net irradiance, which indicates that the ocean surface (38 W m^{-2} on average) warms more than the MIZ (25 W m^{-2} on average), mostly because of its lower albedo.

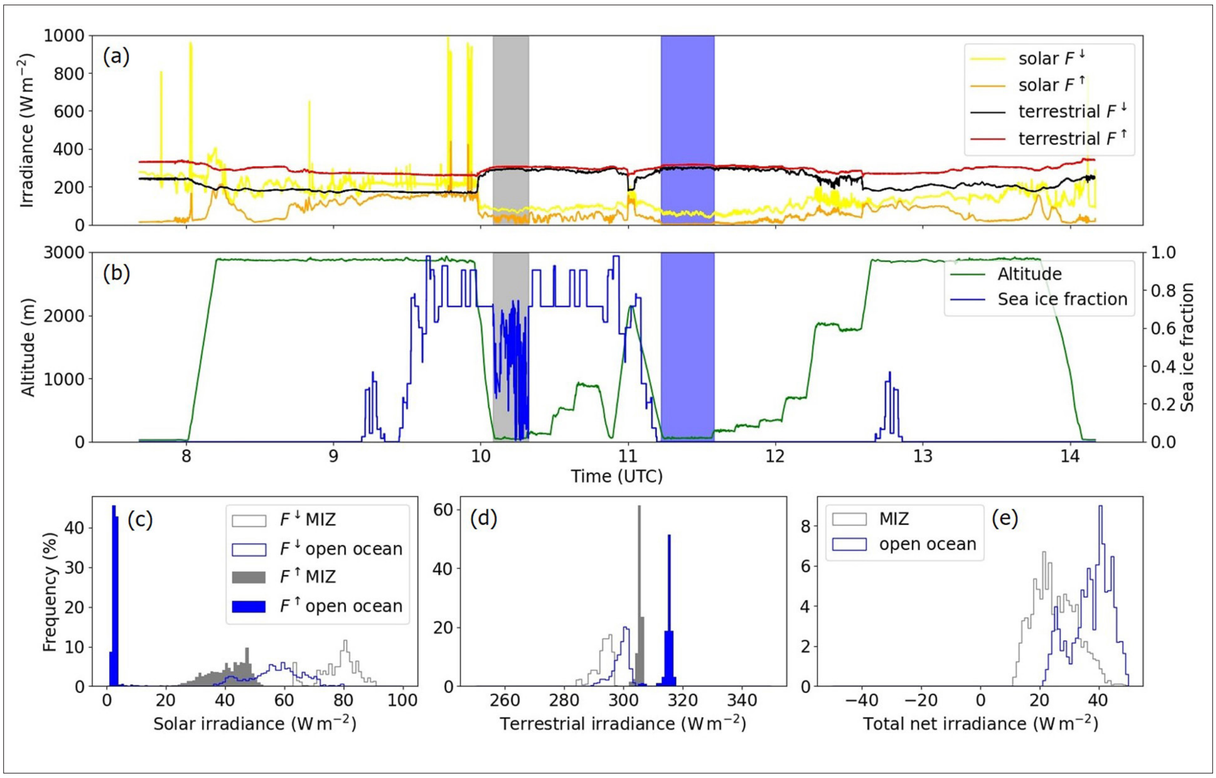

Fig. 7.1.3: (a) Time series of the solar and terrestrial upward and downward irradiances measured during the flight on 08 September 2020. (b) Time series of the flight altitude and the sea ice fraction observed by a digital camera (during low-level legs) and by satellite. The low-level sections over the MIZ and the open ocean are highlighted in grey and blue, respectively in (a) and (b). Histograms of the upward and downward solar (c) and terrestrial (d) and total net (e) irradiances obtained from the measurements during the low-level sections.

Variability of Arctic cloud properties during summer conditions from airborne spectral solar remote sensing

For cloud and surface remote sensing, *Polar 5* was equipped with the Spectral Modular Airborne Radiation measurement system (SMART), (Wendisch et al. 2001), to measure upward and downward spectral solar irradiance, and two spectral imagers, the AISA Hawk (Pu 2017, Ehrlich et al., 2019; Ruiz-Donoso et al., 2020) and the AISA Eagle (Schäfer, 2015). Both imagers consist of a downward-viewing push-broom sensor aligned across the flight track to measure 2D fields of upward radiance. The push-broom sensors of the AISA Eagle and the AISA Hawk instruments contain 1,024 and 384 across-track-pixel, respectively. Each pixel of the AISA Eagle performs spectral measurements between 400 nm and 970 nm with 488 channels. The AISA Hawk instrument covers larger wavelengths, between 930 nm and 2,550 nm in just 288 channels. Both instruments have a field of view of roughly 36° and a sampling frequency of 20–30 Hz.

A measurement example of AISA Eagle and AISA Hawk is given in Fig. 7.1.4, which shows approximately one minute of measurements during the *Polar 5* flight on 10 September 2020. During this flight section, the edge of a boundary layer cloud was sampled with both instruments. This cloud edge is visible in Fig. 7.1.4a and 7.1.4b between 10:15:30 UTC and 10:15:50 UTC. To demonstrate the capabilities of the spectral imagers, Fig. 7.1.4c shows two combined AISA Eagle and AISA Hawk spectra for the center pixels marked by the blue and orange rectangles in Fig. 7.1.4a and 7.1.4b. The spectra show higher radiance over the boundary layer cloud (blue rectangle) and lower radiance over a thinner cloud (orange rectangle). The spectra sampled by the AISA Hawk instrument (between 930 nm and 2,550 nm) look smoother than from AISA Eagle because it has a lower number of spectral channels.

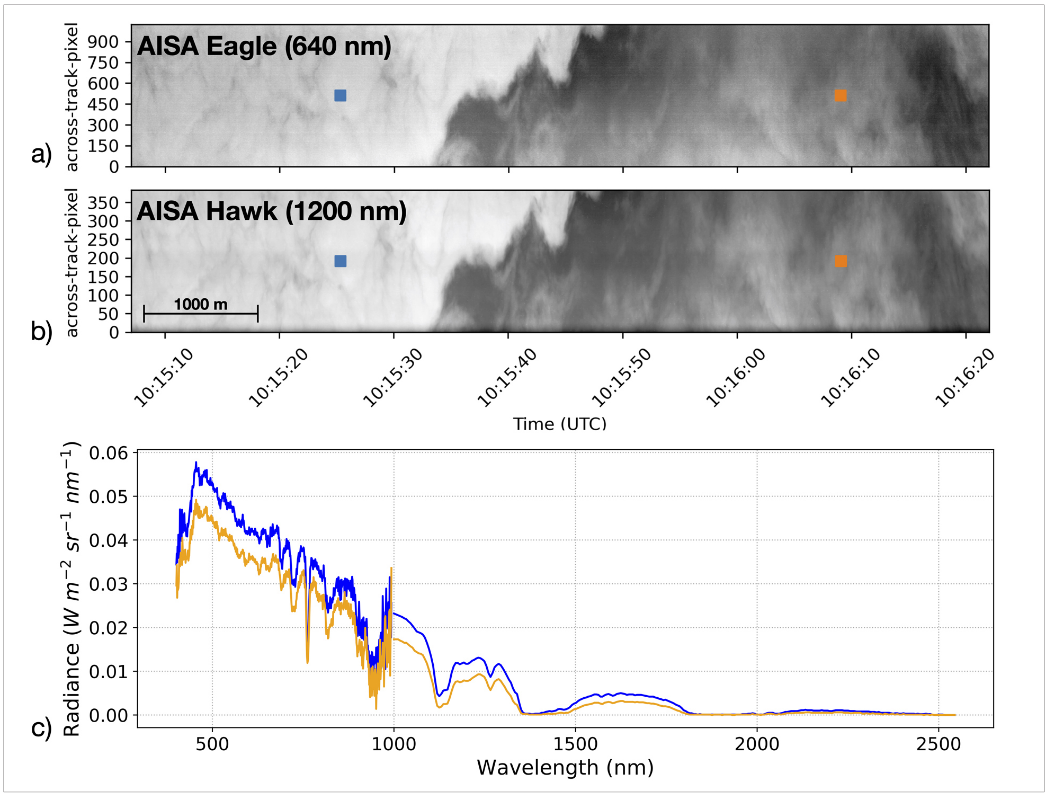

Fig. 7.1.4: 2D fields of upward radiances, sampled by the AISA Eagle (a) and AISA Hawk (b) instrument. Spectral radiances at the locations marked with the blue and orange rectangle in (a) and (b) are given in panel (c) and show a combination of both instruments.

The data from the spectral imagers, collected during MOSAiC-ACA, will be used in combination with SMART and with radiative transfer simulations to identify cloud parameters (e.g., optical depth, effective radius and liquid water path) and to study their differences over open ocean and Arctic sea ice.

Airborne *in-situ* observations of Arctic clouds particle in summer above sea ice and the open ocean

Additionally, the *Polar 5* was equipped with an advanced *in-situ* cloud payload on both wings including a combination of scattering (CDP) and 2-dimensional imaging probes (CIP, 2DS and PIP). The cloud probes cover the size range of arctic cloud hydrometeors from 0.5 µm to 6.2 mm and measure the particle number concentration and the particle size distribution. The phase function of aerosol and hydrometeors was measured with a polar nephelometer. In addition to the wing instruments, a Nevzorov bulk probe installed on the front part of the fuselage measured liquid and total water content of the arctic clouds.

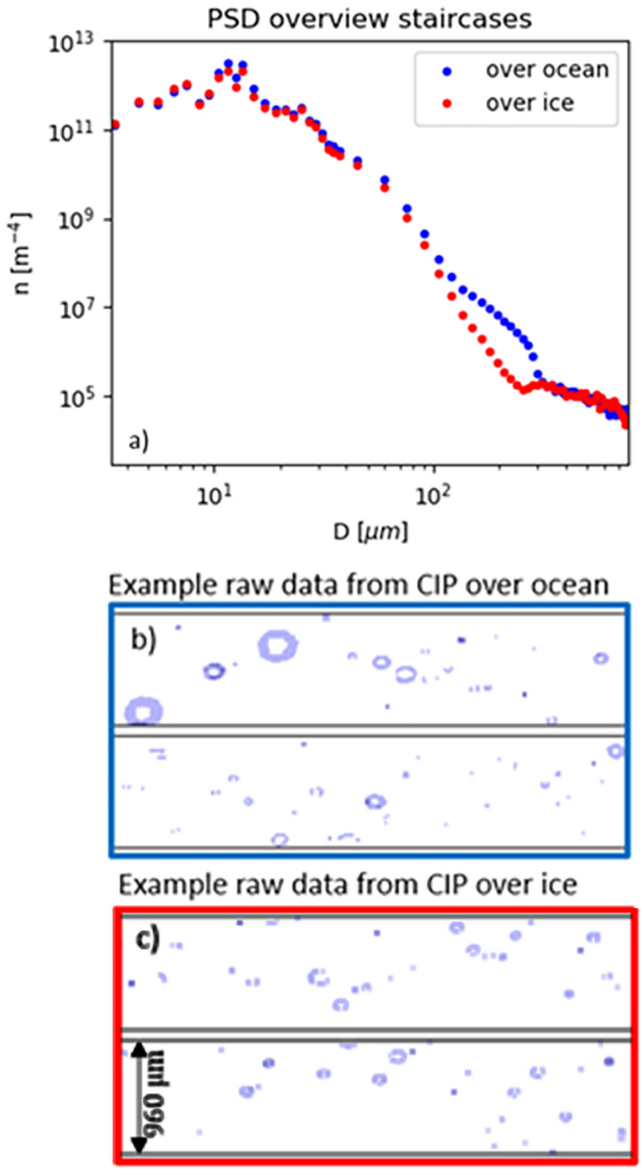

Fig. 7.1.5: a) Particle size distribution from all data during staircase patterns over ice (red) and over the open ocean (blue); b and c) example of raw hydrometeor images recorded with the CIP over the open ocean and the sea ice

Fig.7.1.5 shows an overview of the particle measurements obtained with the DLR particle measurement system (CDP, CIP and PIP). All cloud datasets measured during staircase patterns over the sea ice (red) and the ocean (blue) were compiled into average particle size distributions (Fig. 7.1.5a). The cloud particle size distributions over the open ocean showed larger particle sizes, which was most evident for the size between 90 µm and 310 µm. Also, mean particle number concentrations tended to be slightly higher for the open ocean case compared to the ice surface.

Further analysis will aim to explore the difference of microphysical properties of clouds formed over the sea ice and the open ocean at different altitudes and will include their seasonal variability by comparison to data sets from previous campaigns.

7.2 Sea Ice Thickness Surveys

Sea ice thickness is derived from an electromagnetic (EM) sensor towed behind the plane, the EM-Bird, and from an on-board laser scanner system (Fig. 7.2.1). An overview of all sea ice thickness surveys conducted during MOSAiC IceBird Summer is given in Fig. 7.2.2. Specific survey locations were marked by CALIB buoy drops. For details we refer to the flight logs in the Appendix A.4.2.

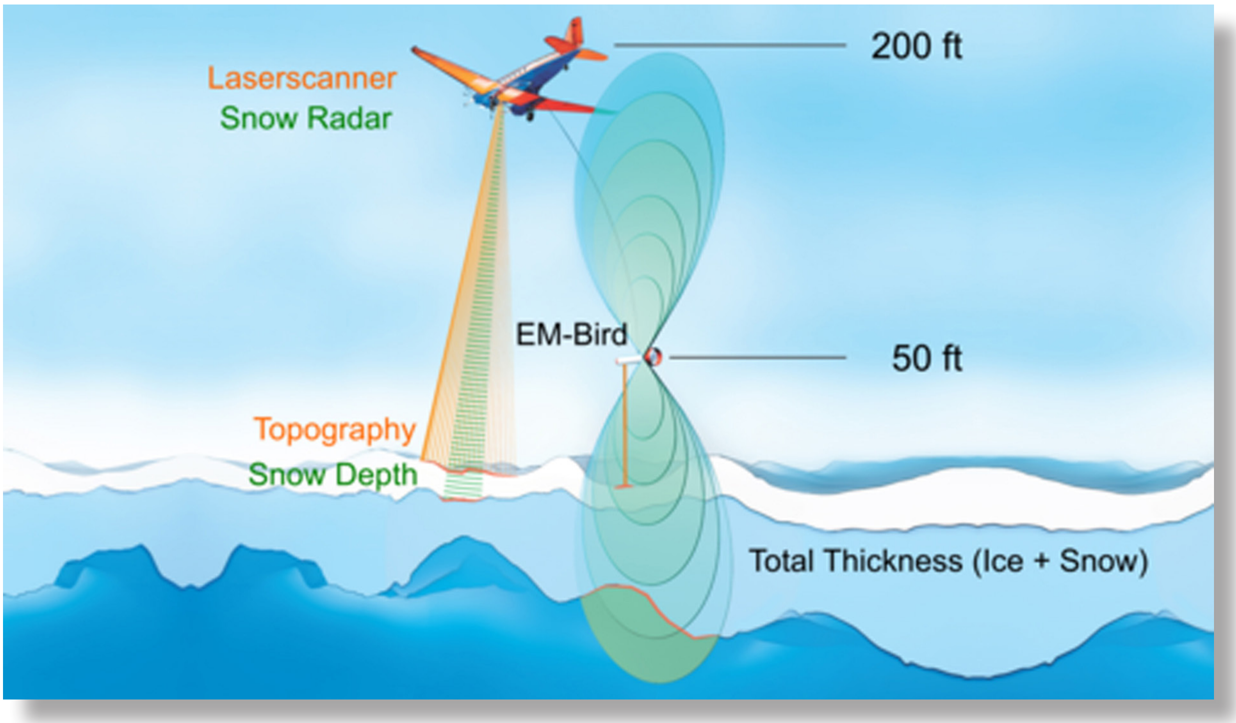

Fig. 7.2.1: Different sensors on board of the aircraft to derive total (ice- and snow-) sea ice thickness; note that the snow radar system is operated in winter only.

EM thickness measurements

EM ice thickness measurements utilize the contrast of electrical conductivity between sea water and sea ice to determine the distance of the instrument to the ice-water interface (Haas et al. 2009). The accuracy of the EM measurements is in the order of ± 0.1 m over level sea ice (Pfaffling et al. 2007). The AEM thickness data enable us to determine the general thermodynamic and dynamic boundary conditions of ice formation (Maykut, 1985). The ice thickness occurring most frequently, the mode of the distribution, represents level ice thickness and is the result of winter accretion and summer ablation. We assume the bias that arises from the unknown snow thickness to be negligible, since temperatures above freezing had certainly caused a significantly reduced snow cover or no snow cover at all. More details about sensor footprint and frequency are given in Table 7.2.1. For details about data processing and handling we refer to Haas et al. (2009) and Krumpen et al. (2016).

Tab. 7.2.1: EM-Bird specifications

Parameter	Value
Method	Frequency-domain electromagnetic induction (FDEM)
EM Frequency	4.060 Hz
Sampling Rate	10 Hz (4–5-meter point spacing at 120 kt)
EM Footprint	40–50 m
Uncertainty	10 cm (level sea ice)
Laser Altimeter	Jenoptik LDM 301

A detailed analysis of the EM ice thickness data collected during MOSAiC IceBird is given in Belter et al. (2021). Fig. 7.2.2 shows preliminary results from the three survey flights made with the EM-Bird over sea ice (02 September, 07 September and 08 September 2020, see flight logs in the Appendix A 4.2). On average, sea ice in the survey area was 1.44 m thick. The modal (most frequent) ice thickness was 0.93 m. The survey flight carried out on 02 September included flights over buoys from the MOSAiC Distributed Network (DN, compare Fig. A.4.1.4 and Table A.4.1.1 in the Appendix). Note that in parallel to the MOSAiC airborne campaign, sea ice and oceanographic surveys were carried out by the RV *Kronprins Haakon* (KPH) from the Norsk Polar Institute (NPI) in Fram Strait (cruise leader Dmitry Divine). An overflight of KPH with *Polar 6* took place on 02 September 2020.

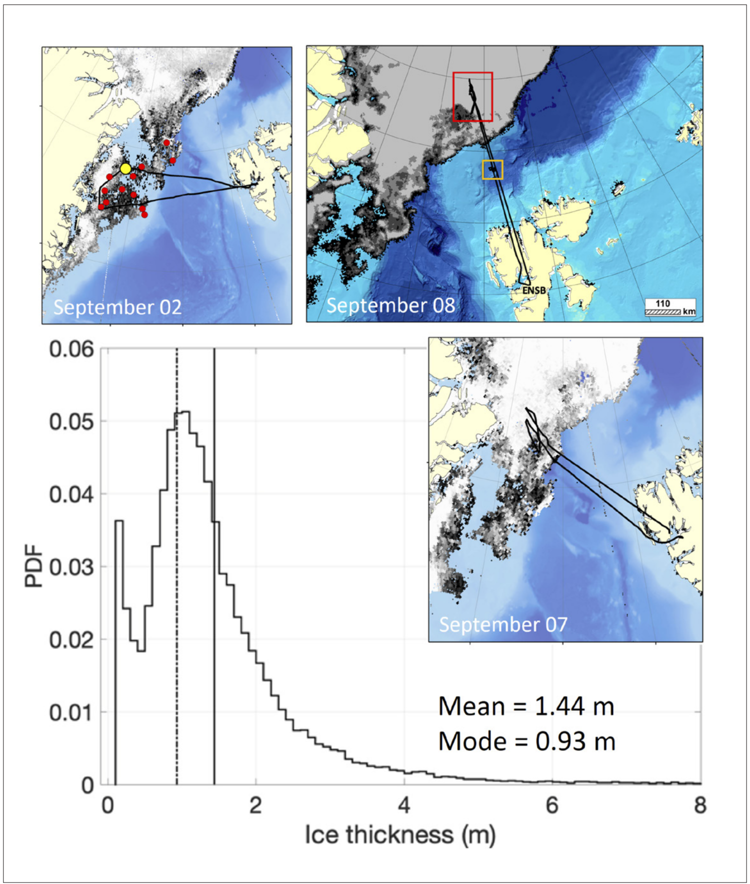

Fig. 7.2.2: Overview of survey flights carried out in September 2020 (02, 07, 08) with the EM-Bird; the histogram shows the distribution of sea ice thickness (0.1 m bin width) with mean and modal thickness marked by a dashed and solid vertical line.

The laser scanner model installed in *Polar 6* is a Riegl VQ-580. The scanning mechanism is realised with a rotating mirror resulting in linear and parallel scan lines. Its specifications are given in the Table 7.2.2 below (from Riegls Q580 data sheet):

Tab. 7.2.2: Laser scanner specifications

Parameter	Value
Field of View	+/- 30 deg
Angle Measurement Resolution	0.001°
Scan Speed (selectable)	10–150 lines per second
Laser Pulse Repetition Rate	50–380 kHz
Accuracy	25 mm
Precision	25 mm
Wavelength	Near infrared (1.064 nm)

The scanner needs to be configured for the specific flight profile and two configurations are required for the sea ice low (EM-Bird) and sea ice high (return leg) flight altitudes. Its nominal settings are described in the Table 7.2.3 below.

Tab. 7.2.3: Laser scanner setup at different survey altitudes

Parameter	Sea ice Low Mission Profile	Sea ice High Mission Profile
Altitude AGL	600 ft	1.600 ft
Ground Speed	120 kt	160 kt
Scan Mode	Line	Line
Measurement Programme	300 kHz	200 kHz
Monitor Step Multiplier	36	24
Line Start/Stop	60 deg	60 deg
Line Distance	0.4112 m	0.7020 m
Point Distance	0.2297 m	0.7081 m
Swath Width	211 m	563 m

MACS camera survey

During sea ice measurements the optical instrument "MACS-Polar20" was operated on *Polar 6*. This is an aerial camera developed by DLR (Brauchle et al. 2018). It is equipped with three different nadir looking sensors acquiring images in various spectral bands: human-visible (red-green-blue, RGB), near-infrared (NIR) and thermal infrared (TIR). The area scan images are taken synchronously at a frequency up to 4 frames per second. Every image is geometrically calibrated and tagged with absolute time, geographical position and attitude information. Thus, image triplets, MOSAiCs ground elevation models and classification can be derived, such as automatically analyzed information about melt ponds, floe size and leads. Technical parameters are given in the following Table 7.2.4. This instrument was operated over sea ice area for the first time.

Tab. 7.2.4: MACS-Polar20 specifications

Parameter	Value
Croma NIR	700–1.000 nm
Croma RGB	450–750 nm
Croma TIR	7.5–14 µm
Resolution NIR / RGB	16 MPix
Resolution TIR	1.024*768 Pix
Field of view NIR / RGB	40° x 27°
Field of view TIR	32° x 25°
Ground sampling distance @ 3.300ft / 300 ft AGL (NIR and RGB)	15 cm / 1.5 cm
Swath width @ 3.300 ft / 300 ft AGL	700 m / 66 m
Points per m² @ 3.300 ft / 300 ft AGL	43 / 4.350
Frame rate max.	4 fps
Image bit depth	~11.5 Bit
INS	Built in L1/L2 + IMU
Image overlap along-track @ 300 ft AGL	60 %

The system was continuously operated while flying over sea ice, including periods and altitudes with activated EM-Bird. Acquired imagery is collected in the following Table 7.2.5. Exemplarily, two different outputs are shown in Fig. 7.2.3 and 7.2.4, which are accessible instantly.

Tab. 7.2.5: MACS-Polar20 acquired raw data

Day	#Images / Triplets (RGB+NIR+TIR)	Size raw images
2020-09-02	119.331 / 39.777	1.24 TB
2020-09-07	120.152 / 40.050	1.30 TB
2020-09-08	87.352 / 29.117	1.08 TB
Total	326.835 / 108.945	3.62 TB

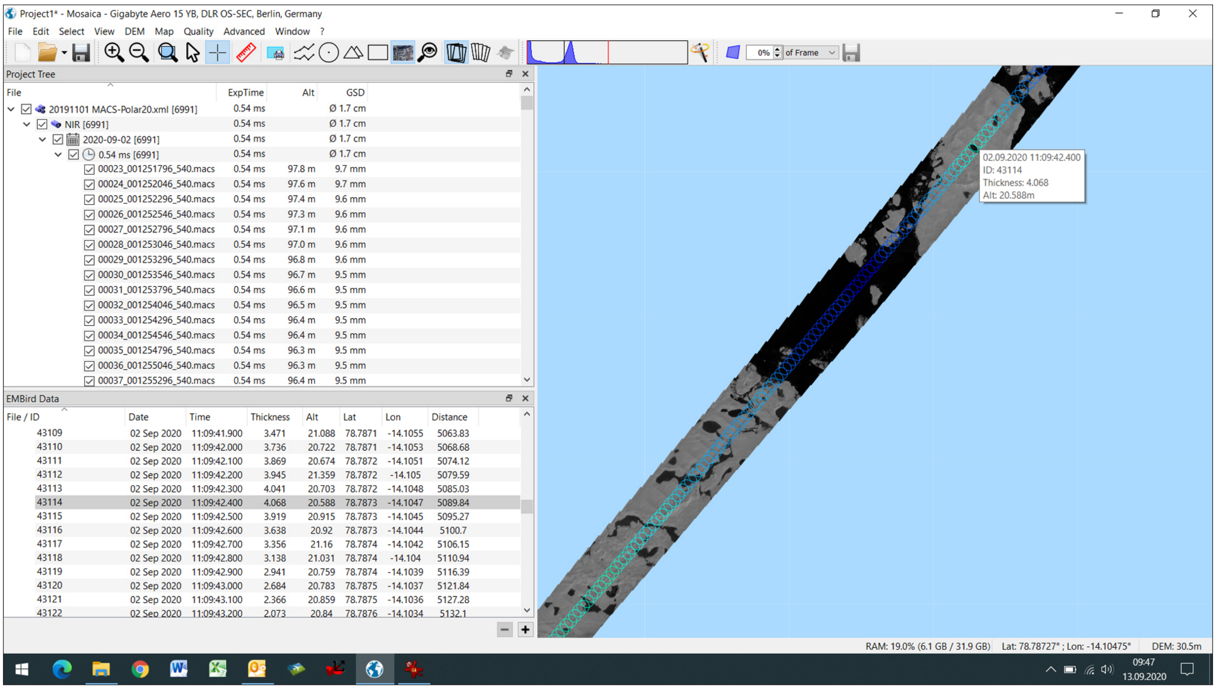

Fig. 7.2.3: MACS-imagery overlay with colour-coded EM-Bird ice thickness measurements acquired at the same time

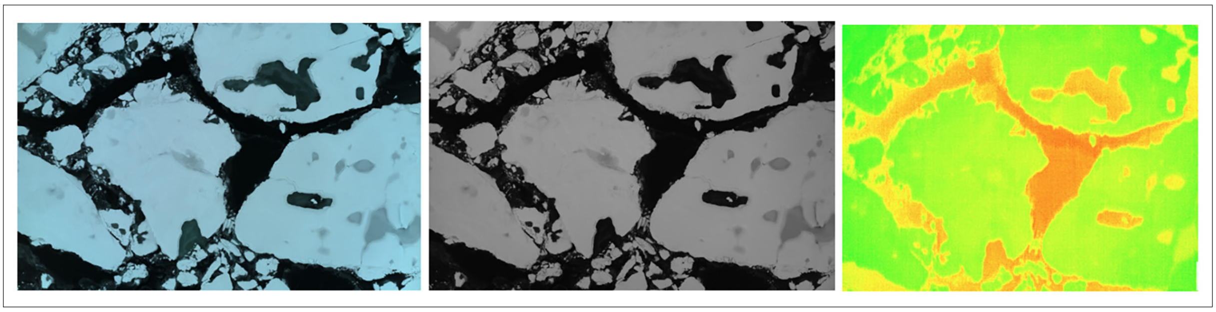

Fig. 7.2.4: Example of a MACS sea ice image triplet consisting of RGB left, NIR middle and TIR right; as a preview, such triplets are visually available for the aircraft Operator to monitor the system. Raw imagery is stored on the camera system.

8. DATA MANAGEMENT

All data are archived in the MOSAiC Central Storage (MCS) and will be available on PANGAEA after finalisation of the respective datasets according to the MOSAiC data policy.

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise. By default the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

In all publications, based on this cruise, the Grant No. AWI_PS122_00 will be quoted and the following *Polar 5* / *Polar 6* research aircraft article will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2016) Polar aircraft Polar 5 and Polar 6 operated by the Alfred Wegener Institute. Journal of large-scale research facilities, 2, A87, http://dx.doi.org/10.17815/jlsrf-2-153

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APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

A.3 BESATZUNG POLAR 5 & POLAR 6 / CREW POLAR 5 & POLAR 6

A.4 FLIGHTLOGS FOR MOSAIC AIRBORNE

A.4.1 ATMOSPERIC CAMPAIGN

A.4.2 SEA ICE CAMPAIGN

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

Institution	Address
DE.AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Postfach 120161 27515 Bremerhaven Germany
DE.DDV	DDV Mediengruppe GmbH & Co. KG Sächsische Zeitung Ostra-Allee 20 01067 Dresden Germany
DE.DLR1	Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) Institute of Atmospheric Physic Muenchener Str. 20 82234 Wessling Germany
DE.DLR2	Deutsches Zentrum für Luft- und Raumfahrt Institut für Optische Sensorsysteme Rutherfordstr. 2 12489 Berlin-Adlershof Germany
DE.IGM	Institute for Geophysics and Meteorology University of Cologne Pohligstr.3 50969 Cologne Germany
DE.LIM	University of Leipzig Leipzig Institute for Meteorology (LIM) Stephanstr. 3 04103 Leipzig Germany
DE.Mainz	Johannes-Gutenberg-Universität Institut für Physik der Atmosphäre Johann-Joachim-Becher-Weg 21 55128 Mainz Germany

Institution	Address
DE.MPI	Institute for Meteorology MPI Hamburg Bundesstr. 53 20146 Hamburg Germany
DE.UFA	UFA Sh & Factual GmbH Siegburger Straße 215 50679 Köln Germany
FR.LAMP	Laboratoire de Météorologie Physique (LaMP) UMR6016 Université Clermont Auvergne 4 Avenue Blaise Pascal, TSA 60026 CS 60026 63178 Aubière Cedex France

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

Name / Last name	Vorname / First name	Institut / Institute	Beruf / Profession	Fachrichtung / Discipline
Becker	Sebastian	LIM Leipzig	PhD-Student	Meteorology
Belter	Jakob	AWI Bremerhaven	PhD-Student	Sea Ice Physics
Brauchle	Jörg	DLR Berlin	Scientist	Physics
Ehrlich	André	LIM Leipzig	Scientist	Meteorology
Gehrmann	Martin	AWI Bremerhaven	Engineer	Aircraft operation
Gollin	Clemens	AWI Bremerhaven	Engineer	Aircraft operation
Gregor	Reinbold	UFA Potsdam	Photographer	Media
Grieß	Philipp	UFA Potsdam	Journalist	Media
Hahn	Valerian	JGU Mainz/DLR	PhD-Student	Physics
Hartmann	Jörg	AWI Bremerhaven	Scientist	Meteorology
Herber	Andreas	AWI Bremerhaven	Chiefscientist	Physics
Horvath	Esther	AWI Bremerhaven	Photographer	Media
Jansen	Friedhelm	MPI Hamburg	Engineer	Meteorology
Klingebiel	Marcus	LIM Leipzig	Scientist	Meteorology
Krumpen	Thomas	AWI Bremerhaven	Scientist	Sea Ice Physics
Lüpkes	Christof	AWI Bremerhaven	Scientist	Meteorology
Mech	Mario	IGM Köln	Scientist	Meteorology
Meierdierks	Markus	AWI Bremerhaven	Management Assistant	Logistic
Moser	Manuel	JGU Mainz/DLR	PhD-Student	Physics
Probst	Hannes	AWI Bremerhaven	Engineer	Aircraft operation
Sans Coll	Cristina	AWI Bremerhaven	Engineer	Aircraft operation
Schäfer	Michael	LIM Leipzig	Scientist	Meteorology
Schön	Stephan	SZ Dresden	Journalist	Media
Wendisch	Manfred	LIM Leipzig	Scientist	Meteorology

A.3 BESATZUNG POLAR 5 & POLAR 6 / CREW POLAR 5 & POLAR 6*

No.	Name	Rank
1	William Houghton	Chief Pilot *Polar 5*
2	Michelle Lacey	Co-Pilot *Polar 5*
3	Lucius Cirtwill	Mechanic *Polar 5*
4	Alan Gilbertson	Chief Pilot *Polar 6*
5	Benjamin Guinan	Co-Pilot *Polar 6*
6	Ryan Schrader	Mechanic *Polar 6*

** The crews are employers of Kenn Borek Air Ltd. (KBAL) Calgary, Canada*

A.4 FLIGHT LOGS FOR MOSAIC AIRBORNE

A.4.1 Atmospheric Campaign

MOSAiC ACA FLIGHT #02 – 30 AUGUST 2020
2020_08_30_Flight_02_MOSAiC_ACA

MOSAiC ACA FLIGHT #04 – 31 AUGUST 2020
2020_08_31_Flight_04_MOSAiC_ACA

MOSAiC ACA FLIGHT #05 – 2 SEPTEMBER 2020
2020_09_02_Flight_05_MOSAiC_ACA

MOSAiC ACA FLIGHT #06 – 4 SEPTEMBER 2020
2020_09_04_Flight_06_MOSAiC_ACA

MOSAiC ACA FLIGHT #07 – 7 SEPTEMBER 2020
2020_09_07_Flight_07_MOSAiC_ACA

MOSAiC ACA FLIGHT #08 – 8 SEPTEMBER 2020
2020_09_08_Flight_08_MOSAiC_ACA

MOSAiC ACA FLIGHT #09 – 10 SEPTEMBER 2020
2020_09_10_Flight_09_MOSAiC_ACA

MOSAiC ACA FLIGHT #10 – 11 SEPTEMBER 2020
2020_09_11_Flight_10_MOSAiC_ACA

MOSAiC ACA FLIGHT #11 – 13 SEPTEMBER 2020
2020_09_13_Flight_11_MOSAiC_ACA

A.4.1.1 MOSAiC ACA Flight #02 – 30 August 2020

Objectives

- Test of instrumentation, procedures and communication during flight
- Wing by wing flight with *Polar 6* for instrument intercomparison
- Five-hole nose boom calibration pattern
- Microwave radiometer calibration, radiation pattern
- Check micro-physical probes

Crew

Tab. A.4.1.1: Crew and Operator during the research flight on 30 August 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART/Eagle Hawk	Michael Schäfer
Basis Data Acq.	Martin Germann
Cloud Probes	Manuel Moser
MiRAC	Mario Mech
SZ Dresden	Stephan Schön
Mission-PI	Manfred Wendisch

Flight times

Tab. A.4.1.2: Flight time during the research flight on 30 August 2020

Polar 5	
Take off	10:14 UTC
Touch down	11:07 UTC
Air time	0.9 h
Flight time	1.3 h

Overview

This test flight served to check the instrumentation, train, the turn-on and shutdown procedures for the instruments, practice communication between crew and pilots during the flight, and perform some special calibration maneuvers. Furthermore, we had planned to fly wing by wing with *Polar 6* for instrument intercomparison. The weather conditions were extremely challenging, clouds in all vertical levels with icing prevailed. Thus, we tried to find some way in between the clouds until reaching about 7,000 ft where we started one of the special flight patterns to calibrate the nose boom. We actually managed to find a straight flight path at constant altitude along the wind direction, as desired. However, after finishing this 20 nmi flight path in wind direction and returning to fly in opposite direction, clouds had moved into that pathway. Therefore, we had to discontinue the flight after about one hour. The originally planned flight pattern could not be completed. Nevertheless, parts of the objectives (check instrumentation, practicing procedures and communication during the flight) could be reached.

Weather

The weather at Svalbard was dominated by an almost stationary low-pressure system west of the island. The low caused a multitude of clouds in all vertical levels. The wind at the ground was from southeast (20–35 kt) with decreasing tendency during the day. Clouds base: SCT/BKN 2,000 – 4,000 ft southern part, SCT FL080 – 100 northern part. Clouds top: FL080 – 100 southern part, FL180 northern part. Precipitation: Scattered rain part. 0° C-isotherm: 3,000 ft.

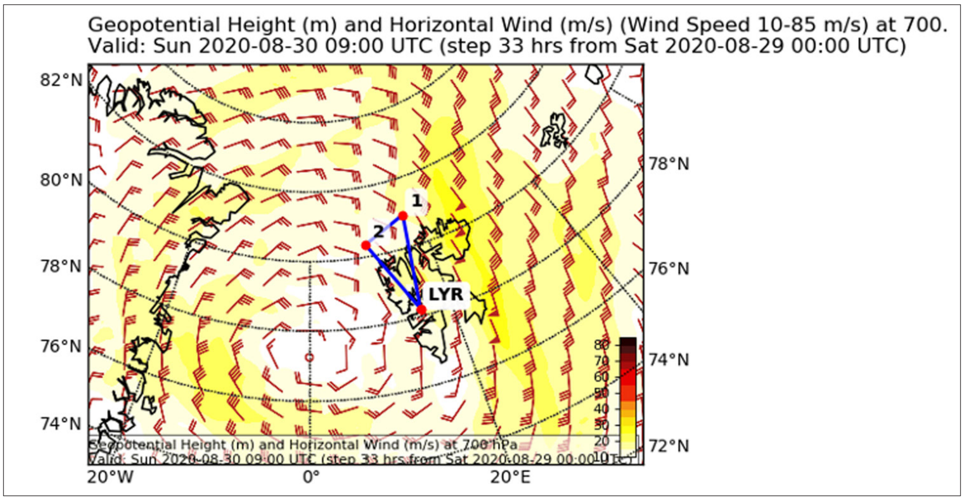


Fig. A.4.1.1: 700 hPa wind vectors as predicted by ECMWF showing the low west of Svalbard

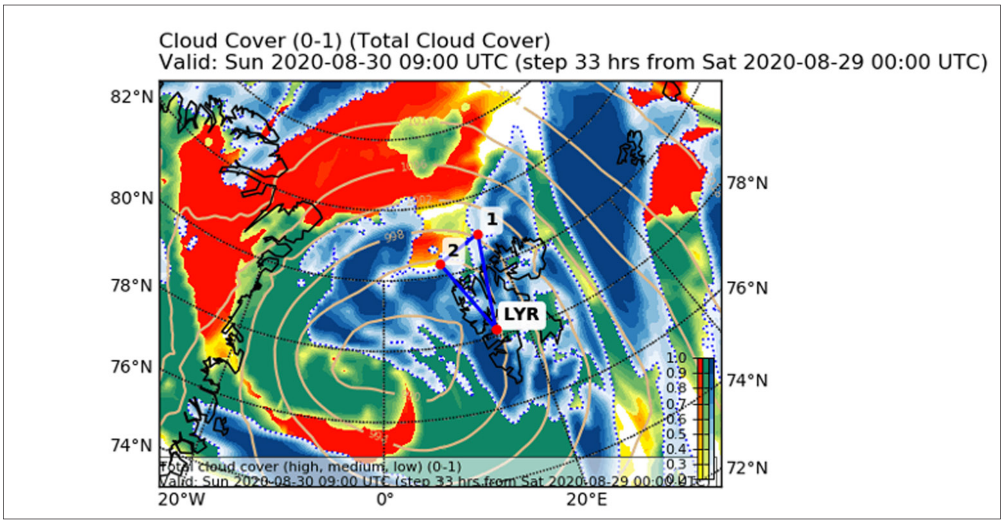


Fig. A.4.1.2: Clouds in all altitudes as predicted by ECMWF. Blue indicates high, green mid-level, and green low-level clouds.

Flight description

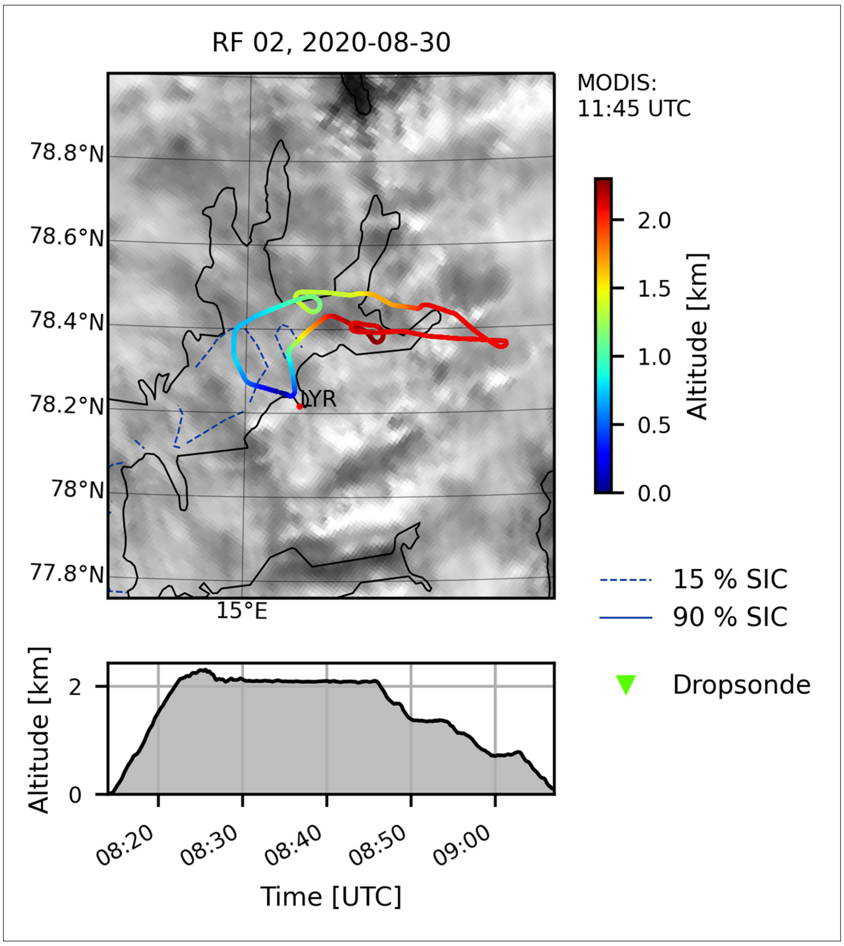


Fig. A.4.1.3: The map shows the flight pattern of Polar 5 on 30 August (upper part: flight track; lower part: height line)

Instrument Status

The radiation instruments worked okay, radar and MW radiometer also. The polar nephelometer did not work, the lidar was not switched on.

Tab. A.4.1.3: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC-A	Operated
MiRAC-P	Operated
AMALi	Not operated
SMART	Operated
Eagle/Hawk	Operated
Sun Photometer	Operated
Polar Nephelometer	Not operated
2D-S	Not operated
CAPS	Not operated
PIP	Not operated
Dropsondes	None launched

A.4.1.2 MOSAiC ACA Flight #04 – 31 August 2020

Objectives

- Joint *Polar 5* and *Polar 6* operation close to Longyearbyen and test flight for *Polar 5* instruments (nose boom calibration)

Crew

Tab. A.4.1.4: Crew and Operator during the research flight on 31 August 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART / Eagle Hawk	Sebastian Becker
Basis Data Acq.	Clemens Gollin
Basis Data Acq. II	Martin Gehrmann
MiRAC / AMALi	Friedhelm Jansen
Media, SZ Dresden	Stephan Schön
Mission-PI	André Ehrlich

Flight times

Tab. A.4.1.5: Flight time during the research flight on 31 August 2020

Polar 5	
Take off	12:40 UTC
Touch down	14:55 UTC
Air time	2.3 h
Flight time	2.4 h

Overview

From the certification flight in the morning, some issues with the heating of the nose boom were reported. Due to this uncertainty, we decided not to fly into clouds during the entire flight. The PMS cloud probes were not operated during the flight. The first part of the flight was a joint flight with *Polar 6* for the film teams on both aircraft. We operated in the close vicinity of the airport in different altitudes. Instrument tests were already started during this part. Due to the strong southerly flow, the orography of the island caused some cloud gaps in the eastern part of the Island. However, the low clouds were thicker than expected. Therefore, we could not aim for the intended area of observations left to Svalbard. Instead, we climbed through a cloud gap eastward and started a first calibration leg for the nose boom. The calibration was not flown with fixed waypoints. *Polar 5* used a constant heading, east-west and north-south. Therefore, the flight track was affected by the southerly winds and the forth and reverse legs did not match perfectly. However, we could finish both calibration legs without flying in clouds. Some clouds could be sampled by the remote sensing instruments, although, over the island the cloud situation was rather complex. Afterwards, we continued with the instrument tests and returned to the airport.

Weather

A low pressure was located close to the north western tip of Svalbard. This position was very stable and lead to a southerly flow over Svalbard associated with a low and mid-level cloud layers present over the Isfjord. West of Svalbard only low clouds were expected as visible on the satellite image below. This was the area we aimed to fly for testing the remote sensing instruments and calibrating the nose boom.

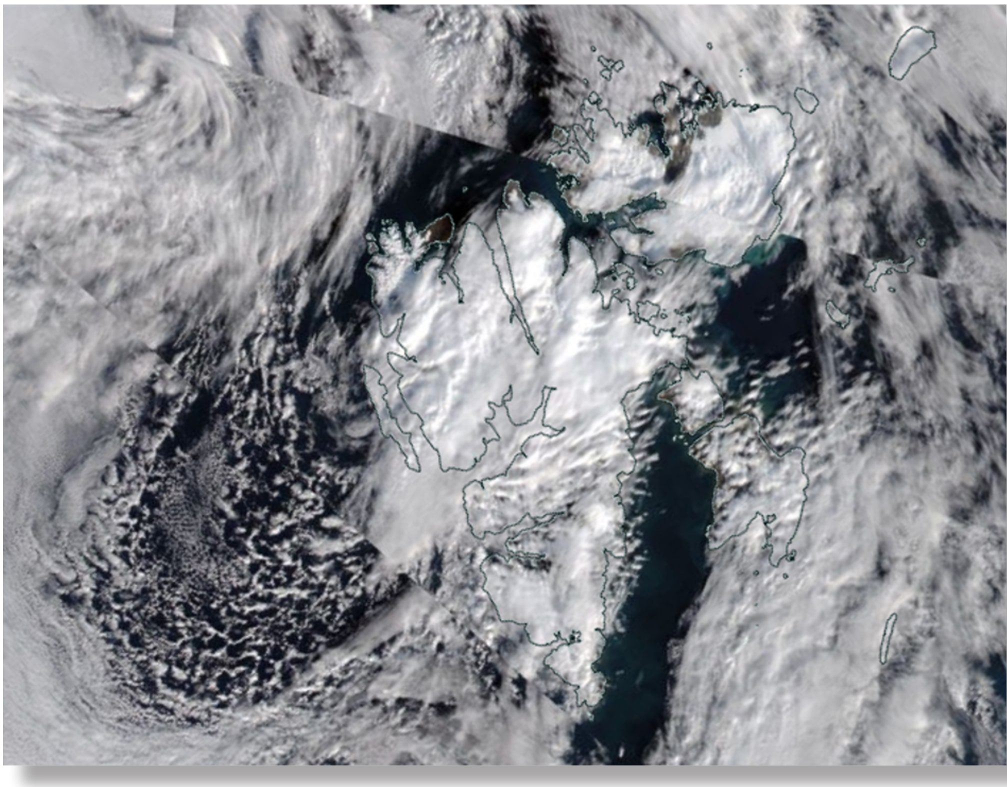


Fig. A.4.1.4: Satellite picture from 31 August 2020

Flight description

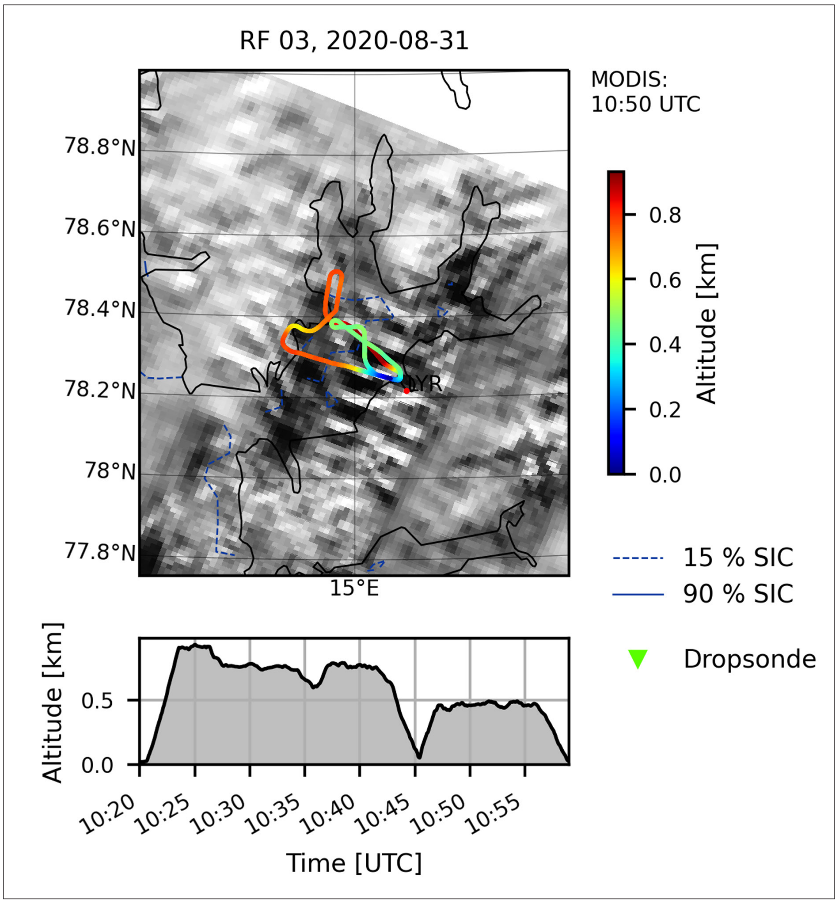


Fig. A.4.1.5: The map shows the flight pattern of Polar 5 on 31 August (upper part: flight track; lower part: height line)

Details during the flight

12:38 Overcast with low- and mid-level clouds. Some showers over the fjord

12:40 Take Off

12:46 Broken low clouds, some cirrus

12:48 Roller door open

13:42 Start leg West → East

13:44 Restart HAWK/Eagle – GPS; changed data storage of Eagle to disk 2

13:53 Turn back East → West (little head wind); we did fly heading direction and did not follow the way points

14:05 Start leg South → North

14:16 Turn back North → South; thin clouds over land

14:26 End of leg but continue for nose boom

14:34 End of leg

14:35 Finish Eagle/Hawk recording

14:55 Touch down

Instrument Status

Cloud *in-situ* probes have not been operated. The radiation instruments worked okay, radar and MW radiometer too. The polar nephelometer did not work, the lidar was not switched on.

Tab. A.4.1.6: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC-A	Operated
MiRAC-P	Operated
AMALi	Operated
SMART	Operated
Eagle/Hawk	Operated
Sun Photometer	Operated
Polar Nephelometer	Not operated
2D-S	Not operated
CAPS	Not operated
PIP	Not operated
Dropsondes	None launched

A.4.1.3 MOSAiC ACA Flight #05 – 02 September 2020

Objectives

- Main objective was a co-located flight with the A-Train satellites north of Svalbard. Second objectives where nose boom, radiation, and microwave radiometer calibration.

Crew

Tab. A.4.1.7: Crew and Operator during the research flight on 02 September 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART/Eagle Hawk	Michael Schäfer
Basis Data Acq.	Clemens Gollin
Basis Data Acq. II	Martin Gehrmann
MiRAC / AMALi	Friedhelm Jansen
Cloud Microphysics	Valerian Hahn
Mission-PI	Mario Mech

Flight times

Tab. A.4.1.8: Flight time during the research flight on 2 September 2020

Polar 5	
Take off	06:52 UTC
Touch down	12:23 UTC
Air time	6.5 h
Flight time	6.8 h

Overview

Major target of the flight was meeting the A-Train satellites in the north of Svalbard. Meeting time on swath was 8:21 at W1. After take-off we climbed to 10,000 ft and stayed at this altitude towards W1. After reaching the open ocean north of Svalbard, a dropsonde has been launched. At W1 we arrived 25 min early. Since there were no cirrus above, we decided to perform a radiation calibration square. From W1 to W2 we stayed on the path of the satellite in 10,000 ft with clouds below with tops at 5,000 to 5,500 ft. Some of them were connected to precipitation as indicated in the radar, especially in the eastern part of the under flight. Approaching W2, clouds thinned. On the path between W1 and W2, three dropsondes have been launched. After passing W2, we turned around and made a descent to 200 ft with 1,000 ft/min for testing the clouds for the stag pattern reaching the lowest level at W3 (located 10 % of the distance to W1). Once at 200 ft we turned again towards W2 and stayed at 200 ft for 5 mins. Next legs at 1,000 and 2,000 ft. Since there was no cloud at 3,000 and 4,000 ft, we climbed to 4,200 ft being at clouds base and stayed at this altitude for 5 mins. Last leg at cloud top between 5,400 and 5,000 ft. At W3 we climbed again to 10,000 ft and started the calibration cross for the nose boom: legs aligned with the wind towards and with and twice perpendicular in opposite directions. In the two most northern positions we could see the ice edge to the North at approx. 82°N. Heading towards South direction W4. After 20 min we dropped sonde number 5. As we got visual of Svalbard, we saw a clear sky area ahead of us. This area we followed for three minutes and dropped a sonde for the radiometer calibration. Afterwards we followed the path to W4. Between W4 and W5 we were flying over the fjord in Ny-Ålesund, overpassing the AWIPEV observatory. Unfortunately, there were clouds in our flight altitude of 10,000 ft. Since the cloud top seemed too high to climb above, we decided to stay in and collect the particles around. After W5 we started the descent to Longyearbyen.

Weather

For take-off, there were scattered clouds in mid-level predicted that should offer some holes to get through. For the satellite constellation under flight in the North, low- to mid-level clouds with precipitation in the eastern part were predicted. The day before, the arrival of the frontal system was predicted for 14:00 LT which changed in the forecast of the same day to 17:00 LT. The cloud situation as observed during the flight was very well predicted. The arrival of the front at Longyearbyen airport was around 16:00 LT.

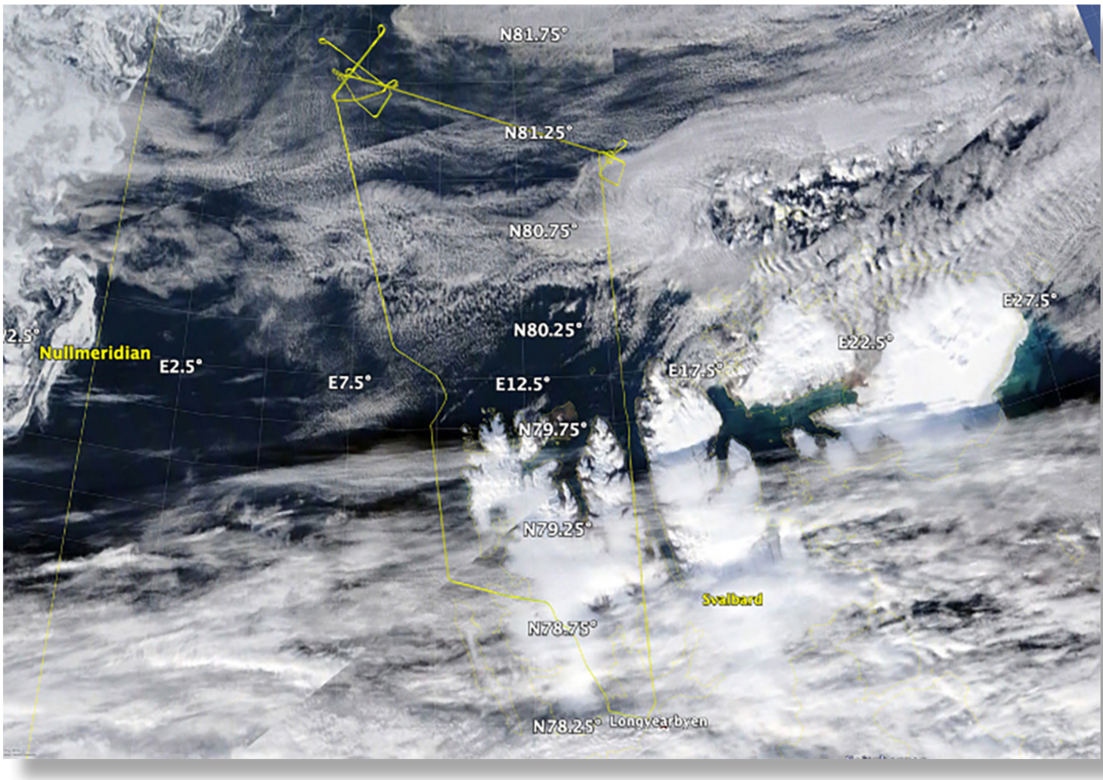


Fig. A.4.1.6: MODIS satellite image of 02 September 2020

Flight description

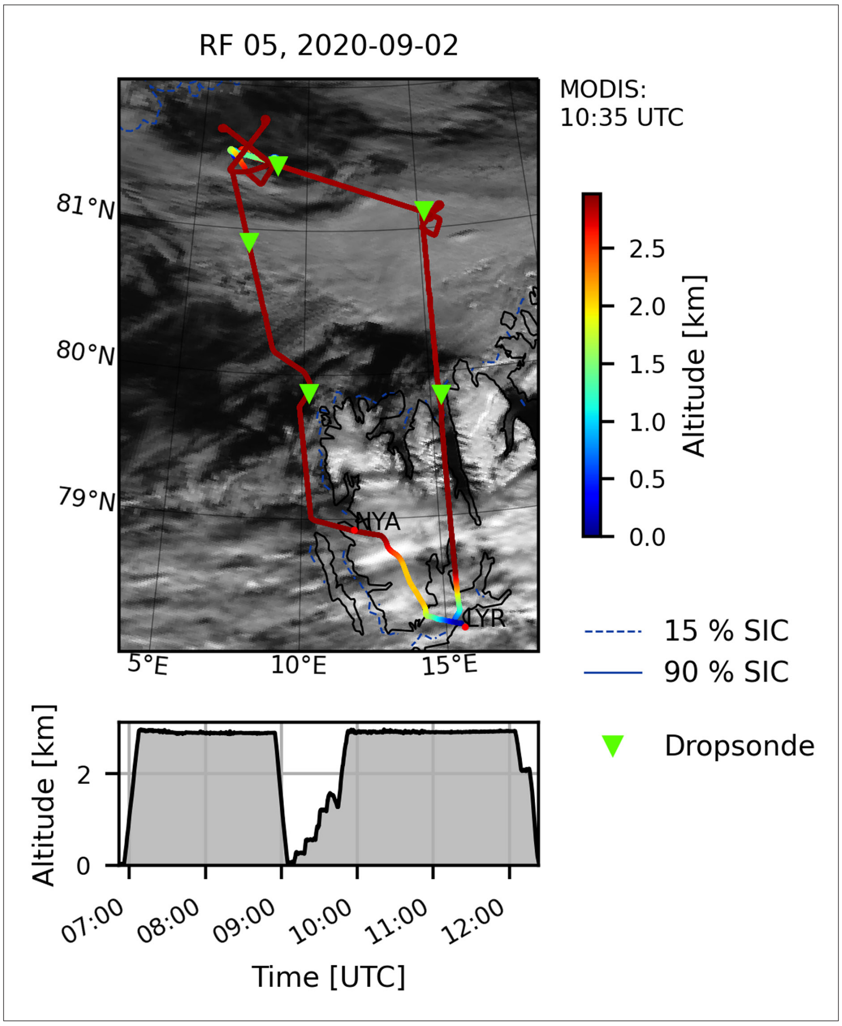


Fig. A.4.1.7: The map shows the flight pattern of Polar 5 on 02 September 2020 (upper part: flight track; lower part: height line).

Details during the flight

6:52	Taxi
6:55	Take off
7:07	At 10,000 ft, clouds above
7:18	Isfjord ice free
7:31	DS1 launched
7:42	Precipitation in radar
7:57	Reached W1
7:58	Start of radiation square
8:08	Radiation square done

8:20	DS2 launched
8:30	No precipitation anymore
8:37	DS3 but without GPS
8:39	In cloud at 10,000 ft
8:42	Left cloud
8:43	Clouds to ground
8:48	DS4
8:54	W2 → start descent after turn to 200 ft with 1,000 ft/min
8:59	Cloud top at 5,400 ft
9:04	Leg at 200 ft from W3 to W2
9:13	Leg at 1,000 ft
9:22	Leg at 2,000 ft
9:30	Leg at 4,200 ft in lowest part of cloud
9:39	Leg at 5,400 ft in upper part of cloud → down to 5,200 ft since tops decrease
9:44	Climb to 10,000 ft
9:58	Starting nose boom calibration against the wind
10:08	Reverse course to fly with the wind
10:11	Reverse leg start
10:27	Starting cross leg
10:39	And reverse leg
10:47	End nose boom
10:53	Towards W4 at 10,000 ft
11:01	DS5
11:28	Over clear ocean → starting radiometer “calibration”
11:29	DS6
11:32	End clear sky
11:42	Clouds in 10,000 ft over Ny-Ålesund visible
11:46	Melting layer in 1,200 ft
11:52	Turn at W4 on leg over Ny-Ålesund → stay in cloud, since top too high
11:59	Over AWIPEV
12:03	W5 → start descent to Longyearbyen
12:23	Touch down

Instrument Status

Inverter problems in the beginning; radar needed 8 restarts of the software; one dropsonde had no GPS signal; hawk did not measure properly

Tab. A.4.1.9: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC-A	Operated
MiRAC-P	Operated
AMALi	Operated
SMART	Operated
Eagle/Hawk	Not operated
Sun Photometer	Operated
Polar Nephelometer	Operated
2D-S	Operated
CAPS	Operated
PIP	Operated
Dropsondes	6 launched, one sonde had no GPS signal

A.4.1.4 MOSAiC ACA Flight #06 – 04 September 2020

Objectives

- Study the atmospheric structure along the transition from a cloud-free region to a cloudy region during warm air intrusion.

Crew

Tab. A.4.1.10: Crew and Operator during the research flight on 04 September 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART / Eagle Hawk	Marcus Klingebiel
Basis Data Acq.	Hannes Probst
Basis Data Acq. II	Martin Gehrmann
MiRAC / AMALi	Friedhelm Jansen
Cloud Microphysics	Valerian Hahn
Mission-PI	Christof Lüpkes

Flight times

Tab. A.4.1.11: Flight time during the research flight on 4 September 2020

Polar 5	
Take off	12:12 UTC
Touch down	17:30 UTC
Air time	5.5 h
Flight time	5.6 h

Overview

During southerly flow two staircase patterns were flown south of Svalbard over the open sea. Two (sometimes three) cloud layers occurred in the northern part of the flight and cloud free conditions in the southern part. The flight to the southernmost positions was at 10,000 ft while staircase patterns have been flown on the way towards north.

Weather

The warm air intrusion developed due to the formation of a low-pressure ridge between a strong low-pressure system near Iceland and a small low on the western side of Svalbard as shown in the Figure below. The surface analysis map (not shown here) showed two fronts, one on the western side of Svalbard (southwest-northeast orientation) and an occlusion southeast of Svalbard. The latter had to be passed during our track towards South.

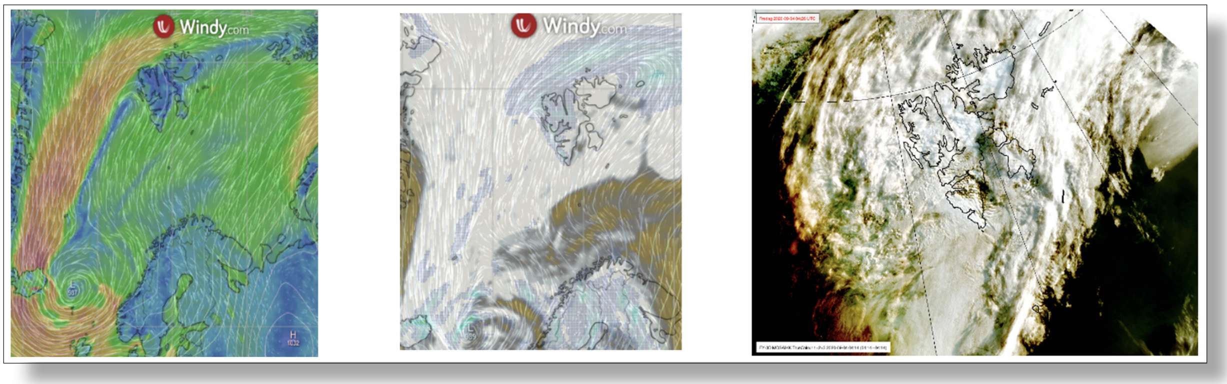


Fig. A.4.1.8: Predicted (24 hour forecast) near-surface wind (left), clouds and precipitation (middle) (ECMWF, Windy) and satellite image of 04 September 2020 (right)

Flight description

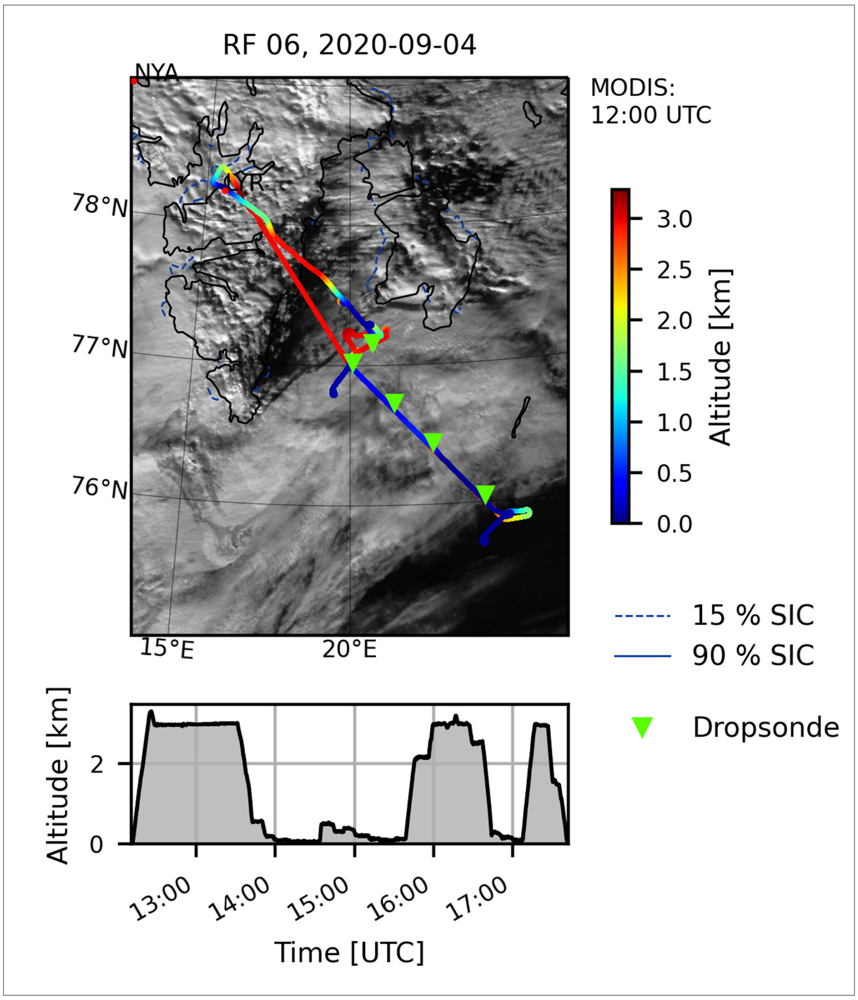


Fig. A.4.1.9: The map shows the flight pattern of Polar 5 on 04 September 2020 (upper part: flight track; lower part: height line).

Details during the flight

The track from LYR to W1 was flown in 10.000 ft. On the way to W1 three cloud layers were visible, low clouds, mid-level clouds (tops below us) and some cirrus clouds. Between W1 and W2 we crossed the clouds belonging to the occlusion because the tops of the mid-level clouds were higher than 10.000 ft for a distance of about 10 nmi. To avoid icing we changed altitude to reach a lower level (3,000 ft) between the mid-level and low clouds while approaching W2. We crossed the cloud edges and reached then W2 in a cloud free region as predicted. After a staircase pattern was flown at W2, our plan was to go to W1 in 200 ft. However, this could not be carried out because of thick surface-based clouds (fog) before we reached W1. Thus, we changed to a level slightly above cloud top. At W1 another staircase pattern was flown with the highest level at 600 ft. The lowest one had to be flown at 300 ft because visibility was too bad for a lower altitude. Instead of this level the 400 ft leg was repeated. After the low-level staircase pattern at W1 we ascended to about 6,000 ft and flew one leg slightly above the base of a mid-level cloud (white arrow in the above Figure). Another one 300 ft higher had to be interrupted due to icing. Thus, another leg followed at 10,000 ft above this cloud. After some maneuvering (waiting for a dropsonde and navigation issues) we flew another low-level staircase at the position of the red arrow. Turbulence: No turbulence was felt during the staircase at W1 and only weak turbulence at W2. However, much turbulence occurred while the mid-level cloud was probed (white arrow). During the lowest leg at the position of the red arrow (third staircase) turbulence occurred too. Sea ice and cloud conditions: No sea ice was observed. Mid-level cloud layer between LYR and W1.

Instrument Status

Four dropsondes have been thrown between W1 and W2 and another one at W1 and one near the position of the red arrow. At least, two further ones were released but they did not work properly.

Tab. A.4.1.12: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC	Operated
AMALi	Operated
SMART	Operated
Eagle/Hawk	Operated
Cloud Particle Probes	Operated
Sun Photometer	Operated
Polar Nephelometer	Operated
2D-S	Operated
CAPS	Operated
PIP	Operated
Dropsondes	8 launched, two sondes worked not properly

A.4.1.5 MOSAiC ACA Flight #07 – 07 September 2020

Objectives

- The aim was to concentrate on remote sensing of clouds in different regimes (single layer, multi-layer clouds, over sea ice, over open ocean). Dropsondes were released in regular distances to characterize the thermodynamic structure of the atmosphere and the wind field

Crew

Tab. A.4.1.13: Crew and Operator during the research flight on 07 September 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART / Eagle Hawk	Michael Schäfer
Basis Data Acq.	Clemens Gollin
Basis Data Acq. II	Martin Gehrmann
MiRAC / AMALi	Mario Mech
Cloud Microphysics	Manuel Moser
Mission-PI	André Ehrlich

Flight times

Tab. A.4.1.14: Flight time during the research flight on 07 September 2020

Polar 5	
Take off	08:22 UTC
Touch down	14:03 UTC
Air time	5.7 h
Flight time	5.9 h

Overview

The flight started with a 15 min. delay due to a failure of the aircraft inverter, which could be solved temporarily. Climbing above the clouds in the Isfjord was not a problem and we could climb to 10,000 ft way before overpassing Ny-Ålesund. At Ny-Ålesund the clouds were rather thick and could not be penetrated by the Lidar. Afterwards, we followed the track in survey altitude releasing dropsondes about every 60 nmi. On the way north, the clouds showed different layers. Sometimes the upper layer showed precipitation into the lower layer. Cloud top altitude increased continuously, so that we ascended up to 11,000 ft for save operation of AMALi. The marginal sea ice zone was reached at about 82° 20’ N indicated by the microwave radiometer. Visually, the sea ice was not visible as the clouds were optically thick. On the western leg south, the sea ice lasted until about 81° 30' N. The western leg showed different cloud characteristics. Low cloud layer became thinner and later broken and scattered. For a long time, a thick cirrus was located over the flight patch dimming the sun very significantly. Later a mid-level cloud appeared in about flight altitude. The particle probes sampled some ice crystals at cloud base or precipitating particles below cloud base. To ensure a good operation of AMALi and MiRAC, we decided to descend back to 10,000 ft. At the southern end of the leg, about 80°N, a cloud free area was close by the flight track. We did a short detour to release a dropsonde into this cloud free spot for calibration of the microwave radiometer. A second cloud free spot was observed shortly before W4. The flight eastward back to Svalbard was characterized by a change in cloud cover. Closer to the island, a more convective cumulus with heavy precipitation was observed. The island itself was partly cloud-free due to orographic effects.

Weather

After the weak cold air outbreak on Sunday, the northerly flow became weaker. A low-pressure system was located far east of Svalbard. Still, it caused a cyclonal flow around the island. This is reflected in the temperature map showing a cold air mass moving south-east west of Svalbard. Due to the low winds and different wind directions, the forecasted cloud field was very heterogeneous. The vertical extend of the clouds west of Svalbard were predicted to be rather thick indicating that different cloud layers should be present. This was confirmed by the observations. Also, the predicted increase of cloud top altitude was observed. Further west, where the colder air mass moved eastward, less low-level cloud cover was forecasted. In the flight, we saw the reduced cloud cover with partly only scattered cumulus fields and cloud free sections. The ECMWF showed a thick field of cirrus reaching to 5°E at 12 UTC. This field was also present during the research flight significantly reducing the solar radiation and shadowing the lower clouds.

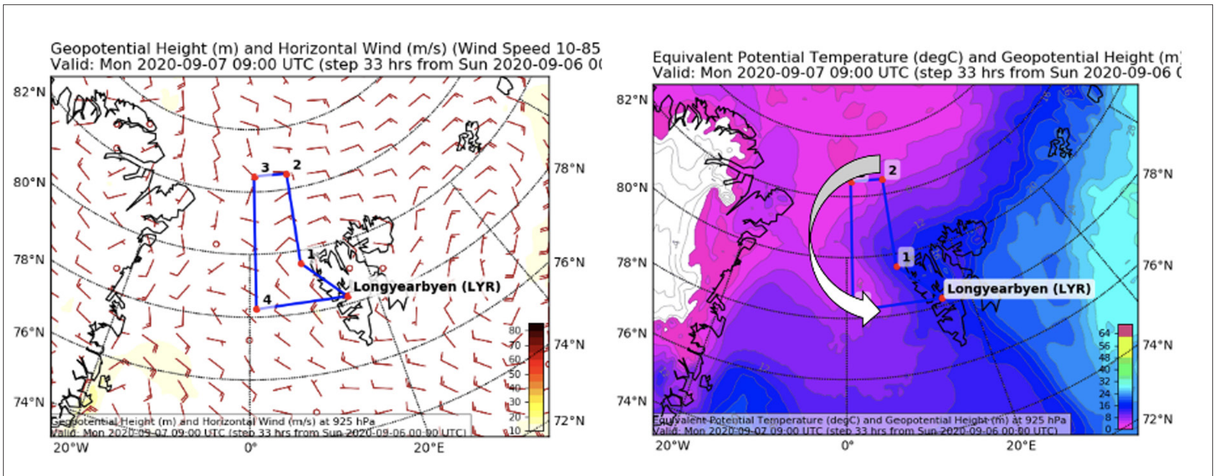


Fig. A.4.1.10: ECMWF wind field and equivalent potential temperature in 925 hPa

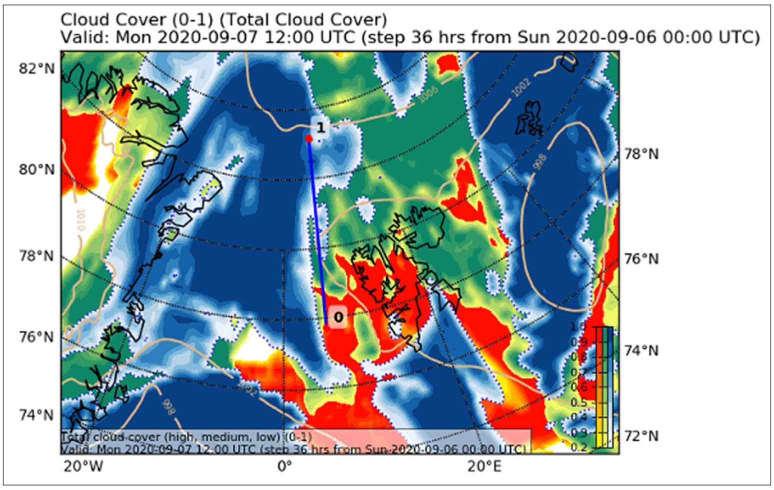


Fig. A.4.1.11: Total cloud cover as forecasted by ECMWF

Flight description

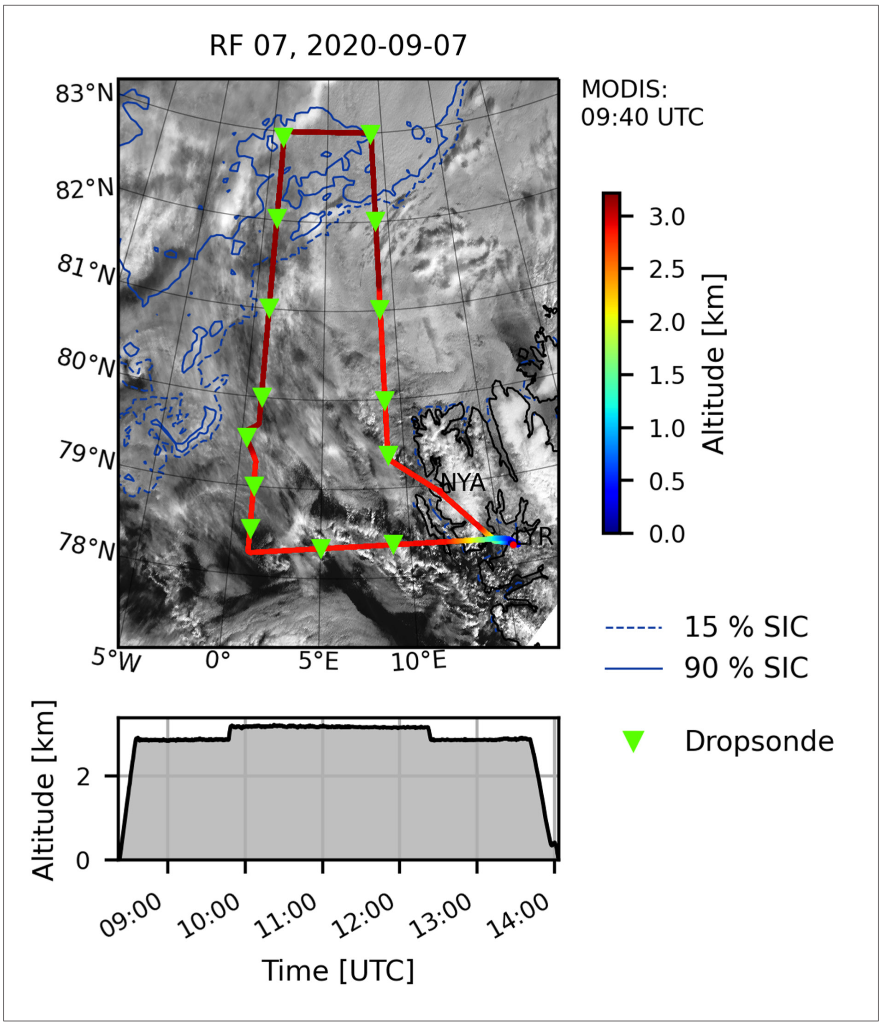


Fig. A.4.1.12: The map shows the flight pattern of Polar 5 on 7 September (upper part: flight track; lower part: height line)

Details during the flight

07:53	Overcast at the airport
08:02	Inverter problem → delay of 15 min.
08:22	Take-off
08:24	At cloud base
08:25	Above first cloud layer, was quite thin
08:28	At cloud top of second layer, little icing
08:35	At 10,000 ft: No cirrus, low clouds all over the place
08:42	Some high clouds North West
08:48	Crossing Ny-Ålesund
08:50	Over the open ocean clouds look more convective / westwards: thick high clouds – cast shadow and seem to affect the low cloud layer
08:58	Ahead: mixture of convective and thin layers of clouds
09:05	WP1 – turn and dropsonde – DS#1
09:06	Low clouds with homogeneous cloud top
09:12	Intermediate change of low clouds: looks like a cloud gap but was likely a second thin layer
09:19	DS#2 - before low clouds did change
09:30	Very homogeneous low clouds / some cirrus clouds ahead (thin stripes which are also visible as a shadow on the lower cloud layer)
09:40	Cirrus causes shadows on low cloud layer
09:42	DS#3
09:43	Cirrus clouds became more frequently
09:47	Climb to 11,000 ft due to increasing cloud top altitude
09:51	More cirrus and more shadows
09:55	Cloud top still climbing
10:00	Still large areas with shadows but will end soon
10:04	DS#4
10:10	Cirrus less and only very thing → no shadows anymore
10:10	Over the sea ice approx. 82° 20’N
10:26	DS#5 - and turn at WP2

10:34	Homogeneous low clouds everywhere
	Cirrus ahead to the west
10:39	Approaching cirrus – broad homogeneous field of cirrus
10:47	Turn at WP3
10:52	DS#6 - Very thick cirrus → becoming thicker further south
11:15	DS#7- Getting almost dark due to the thick cirrus
11:23	Autopilot on → slight roll/yaw movements
11:27	End of the marginal sea ice zone at about 81°30’ N
11:39	DS#8
11:40	Still thick cirrus ahead / low clouds are in shadow
	Further ahead low clouds seem to get thinner (or it is a change of the shadow)
11:50	Low clouds with less structure of the cloud top
	May be: cirrus → less cloud top cooling → less turbulence → less structure
11:55	No low clouds east of the flight track + thin sea ice visible in this area
	Ahead still low clouds and cirrus far ahead less cirrus
12:04	DS#9
12:09	Short cloud free area ahead
12:18	Detour to overpass the cloud free area for calibration of the microwave radiometer/
	DS#10 in cloud free gap
12:19	Mid-level clouds in flight level – *Polar 5* at cloud base – little precipitation
12:21	Descent to 10,000 ft to avoid the mid-level clouds
12:26	Back on track after detour
12:32	DS#11- Scattered low clouds, no cirrus, just some further south
12:40	Cloud gap, only tiny thin cumuli
12:43	DS#12: almost clear sky below
12:49	Scattered low clouds, further south cloud-free
12:50	WP4 and turn
12:51	Ahead eastwards: first scattered low clouds → getting thicker soon
13:05	Low clouds became more complex, mixture of stratiform layers and cumuli
13:08	DS#13
13:26	DS#14: maybe into a cloud gap
13:28	Clouds up to the coast / at the coast some parts are cloud-free

13:41 Start to descend

14:03 Touch down

Instrument Status

The Hawk camera still suffered from condensation of moisture on the window. All dropsondes were successful, except #10 which did not have GPS signal and therefore no wind measurements.

Tab. A.4.1.15: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC-A	Operated
MiRAC-P	Operated
AMALi	Operated
SMART	Operated
Eagle/Hawk	Not operated
Sun Photometer	Operated
Polar Nephelometer	Operated
2D-S	Operated
CAPS	Operated
PIP	Operated
Dropsondes	14 launched, one without GPS signal

A.4.1.6 MOSAiC ACA Flight #08 – 08 September 2020

Objectives

- Study differences in the atmospheric structure over sea ice and open ocean

Crew

Tab. A.4.1.16: Crew and Operator during the research flight on 08 September 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART/Eagle Hawk	Marcus Klingebiel
Basis Data Acq.	Hannes Probst
Basis Data Acq. II	Martin Gehrmann
MiRAC / AMALi	Friedhelm Jansen
Cloud Microphysics	Valerian Hahn
Mission-PI	Christof Lüpkes

Flight times

Tab. A.4.1.17: Flight time during the research flight on 08 September 2020

Polar 5	
Take off	08:10 UTC
Touch down	14:15 UTC
Air time	6.1 h
Flight time	6.2 h

Overview

During near-surface easterly flow over Svalbard and northeasterly flow north of 80° N a transect was flown along 7°E between 79° and 82.5° N with two staircase patterns included, one over sea ice and one over the open ocean. Several cloud layers occurred at both staircase positions and again – as during Flight #6 (south of Svalbard) – the strongest turbulence occurred in the uppermost mid-level cloud. The flight to the northernmost positions was at 10,000 ft. Ny-Ålesund was on the flight track and two times overflown, first on the way towards North and second on the way back to Longyearbyen.

Weather

The synoptic situation was governed by a strong low-pressure system south of Svalbard, which only progressed slowly during the day. It caused easterly, near-surface wind over Svalbard and over the eastern part of Fram Strait. However, at 850 hPa the opposite wind direction was predicted. The easterly wind caused a cloud free region along the western coast of Svalbard while almost complete StCu cover existed between waypoints 1 and 2 (see below). The strong change of wind direction with height was confirmed by the wind measurements as can be seen in the nose boom data. They show wind from northeast in the low-level legs and wind from south at 10,000 ft.

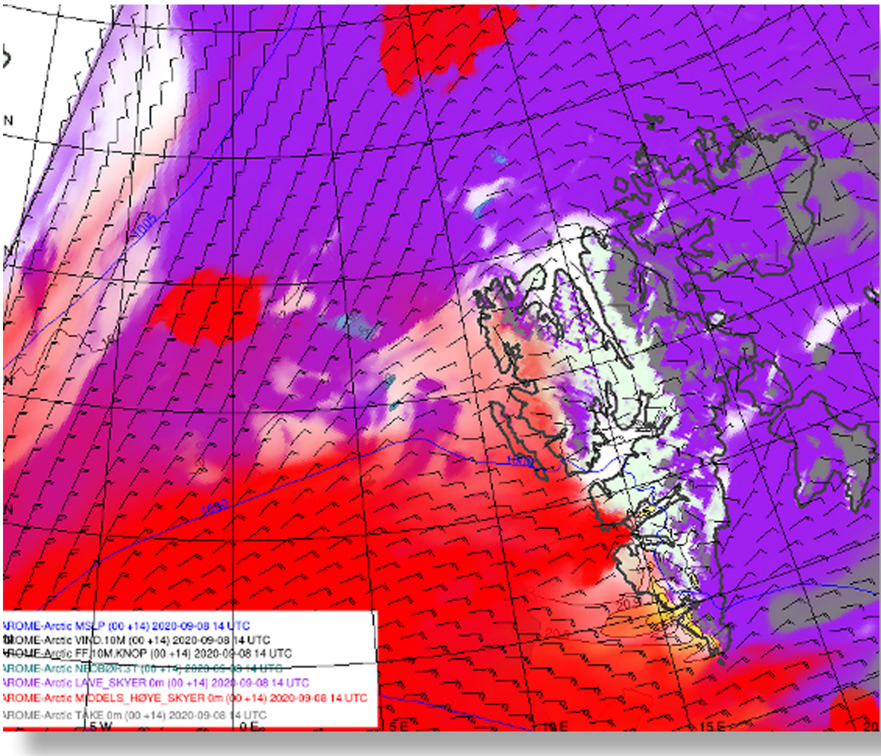


Fig. A.4.1.13: The AROME prediction for 14 UTC reflects well the situation found with different wind and cloud regimes in the North and on the western side of Svalbard (but almost no clouds were found along the coast west of Svalbard, light reddish area). The red color marks high clouds caused by the related frontal systems approaching from south.

Flight description

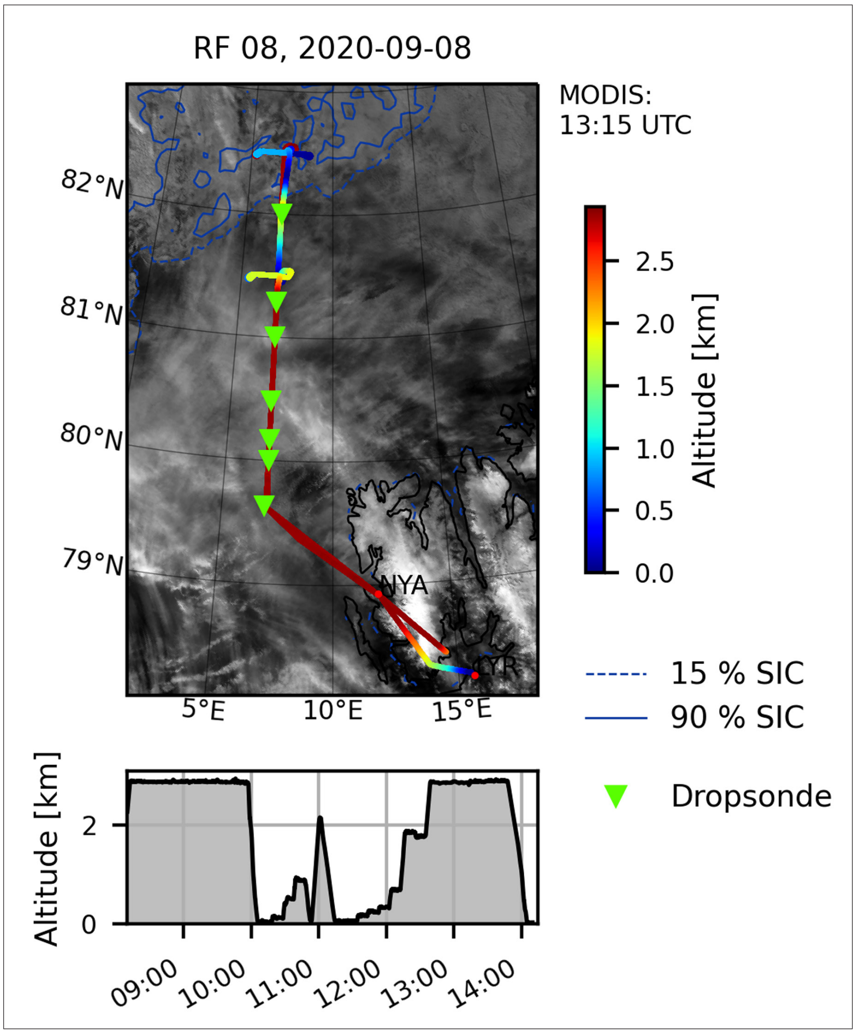


Fig. *A.4.1.14: The map shows the flight pattern of Polar 5 on 08 September 2020 (upper part: flight track; lower part: height line).*

Details during the flight

Northern staircase: A staircase pattern followed between W2 and W3 with the highest leg at 10,000 ft and the lowest one in 200 ft. The latter leg position was reached during descent from W3 to W2. During this descent we crossed a complex cloud structure with clouds occurring in four layers. However, clouds were not homogeneous with respect to coverage, cloud base and cloud tops, which varied strongly along the horizontal legs. Cloud base of the lowest (convective) clouds was in general at 300 ft, so that visibility during the 200 ft leg allowed mostly a clear view on drifting floes (see below). However, over leads some clouds were also surface based. After the near-surface leg a leg in the lowermost cloud layer followed and then two further legs in the upper cloud layers, but due the variability of the clouds, not the complete legs were either in or outside clouds.

Transect: A transect from W2 to W4:A sawtooth was flown towards W4 with top at 7,000 ft. We crossed two cloud layers, the lowermost and mid-level clouds with tops around 6,500 ft. But the uppermost cirrus was not reached. After the following descent, we reached already position W4 at 200 ft below the lowest cloud layer whose base was at 300 – 400 ft.

Southern staircase: Two 200 ft legs were flown in opposite direction, the next one at 500 ft, thus above cloud base, and then the next one at 750 ft, and finally at 2,000 ft, which was slightly above cloud top. Outside clouds we climbed up to reach the mid-level cloud and measured clearly above cloud base at 5,400 ft and the next one in 5,100 ft at cloud base, and sometimes slightly below. The 5,100 ft leg was the one with the strongest turbulence.

Turbulence: Turbulence during all low legs was weak or moderate, while it was stronger at the southern staircase in the two uppermost flight legs (in mid-level clouds). This corresponds to the structure of the potential temperature profiles with a well-mixed layer in this level.

Sea ice: The northernmost staircase was over sea ice, where drifting floes were observed with an estimated sea ice concentration of 70 – 90 % (in agreement with the satellite image obtained by the AWI Sea ice group). The sea ice edge could not be observed because of clouds. It probably occurred near 82°N, where the staircase was flown. No sea ice occurred at the position of the southern staircase.

Instrument Status

Four dropsondes have been thrown between W1 and W2 and another three ones during the way back towards South.

Table A.4.1.18: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC	Operated
AMALi	Operated
SMART	Operated
Eagle/Hawk	Operated
Cloud Particle Probes	Operated
Sun Photometer	Operated

Polar 5	
Polar Nephelometer	Operated
2D-S	Operated
CAPS	Operated
PIP	Operated
Dropsondes	7 launched

A.4.1.7 MOSAiC ACA Flight #09 – 10 September 2020

Objectives

- Investigate cloud evolution along the wind direction and compare the clouds over sea ice and open water
- Collect data for comparison with models (11 dropsondes were released during the flight)
- Evaluate lee effects from Svalbard

Crew

Tab. A.4.1.19: Crew and operator during the research flight on 10 September 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART/Eagle Hawk	Marcus Klingebiel
Basis Data Acq.	Hannes Probst
Basis Data Acq. II	Clemens Gollin
MiRAC / AMALi	Mario Mech
Cloud Microphysics	Manuel Moser
Mission-PI	Manfred Wendisch

Flight times

Tab. A.4.1.20: Flight time during the research flight on 10 September 2020

Polar 5	
Take off	08:29 UTC
Touch down	14:45 UTC
Air time	6.2 h
Flight time	6.4 h

Overview

During this flight, the differences of cloud properties over sea ice and open water were successfully observed along the wind direction. The synoptic situation was such that there was no other choice than to go to the North; in western direction mid-level clouds were too high. These mid-level clouds resulted from an occlusion south of Spitzbergen (see synoptic overview below). On the way to the North and backward plenty of clouds with different vertical structures, partly including precipitation, were observed by the active and passive remote sensing instruments onboard *Polar 5*. We encountered heavy cirrus above the maximum flight level (FL130), other parts of the flight track were cirrus-free. We even had a short portion of the flight track in cloud-free sky, when sampling the area north of Svalbard influenced by the lee effect of the island. After arriving at the northern part of the flight track at 82.5°N and 3°E we were visibly over sea ice. We probed a low-level cloud sheet touching the ground (top height about 1,800 – 1,700 ft) and a second (maybe rather synoptically formed, possibly remaining from the occlusion of the previous day) mid-level cloud (layer between about 8,500 – 9,000 ft). We performed vertically stacked horizontal flight patterns (about 5 minutes long corresponding to a distance of 10 nmi, altogether 6 height levels): two in the lower cloud layer, one between the upper and the lower cloud, another one in the upper cloud and two above the upper cloud. Both clouds were rather homogeneous, only little turbulence was noticeable. The lower cloud layer consisted of liquid water droplets. The upper cloud was an ice cloud. After completing the stacked flight pattern, we arrived at FL100, stayed at this altitude heading against the wind in southeastern direction until reaching open water, where we repeated the stacked horizontal flight pattern, this time in seven altitudes. We did not observe a gap in the low-level cloud deck on our way from the sea ice to the open water. Thus, cloud properties could probably be linked between the two places, also taking into account that we had followed the opposite wind direction. The clouds over the open water appeared bumpier and more heterogeneous compared to the one over sea ice. The synoptically driven mid-level cloud did not show up over sea ice, although high cirrus was omnipresent in this area. Then we returned to the south at FL100. We had to climb even higher to allow the remote sensing instruments to operate safely (lidar). We experienced an increasing ceiling of the mid-level clouds on our way to the south, and we partly probed the upper level of them. Eventually we received some icing and decided to climb even higher exceeding the cloud top to get rid of a little accumulated ice. We returned home safely.

Weather

The weather in the area around Svalbard was determined by a low-pressure system in the south-east of the island. A respective occlusion caused a multitude of clouds at different levels in the south and the eastern directions of Svalbard. Therefore, the only direction that was possible for a research flight on this day was into the north. Surface winds in the area northeast of the island (our target area) were from the southeast. Low-level clouds were omnipresent, the lee effect of the island caused some cloudless spot. A respective satellite image is shown in Fig. A.4.1.18, already including the flight path.

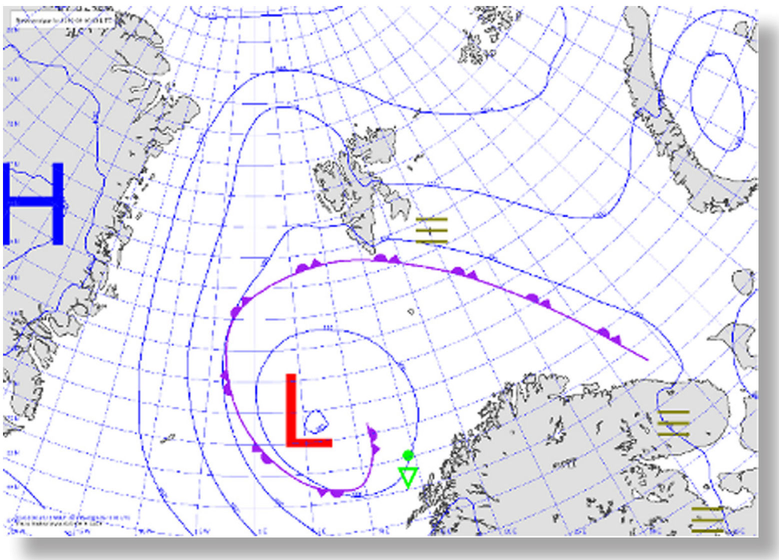


Fig. A.4.1.15: Surface weather map from 10 September 2020, 03 UTC

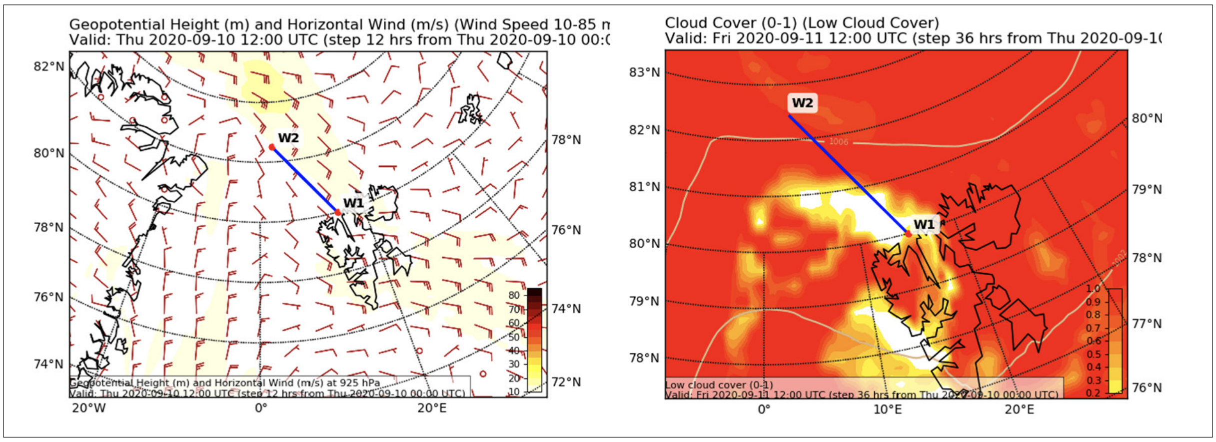


Fig. A.4.1.16: Wind at 925 hPa (left panel), and low-level cloud distribution (right panel) from ECMWF forecast

Flight description

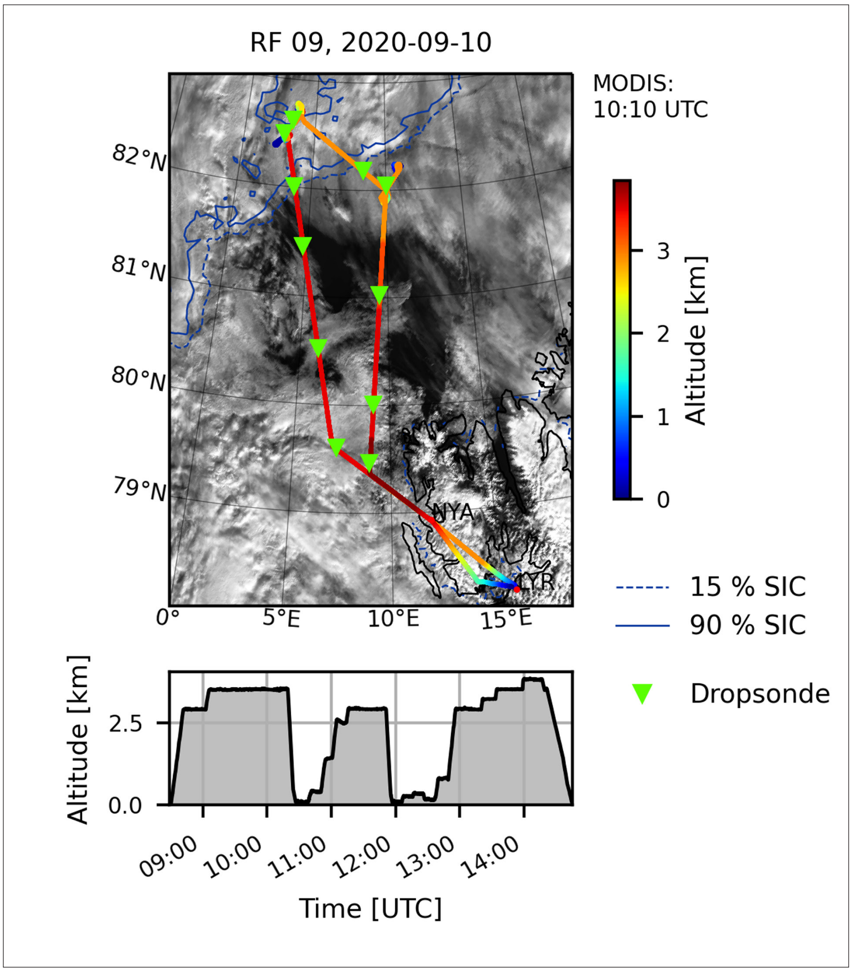


Fig. A.4.1.17: The map shows the flight pattern of Polar 5 on 10 September (upper part: flight track; lower part: height line).

Waypoints

LYR	78° 14,7‘	15° 28,9‘
NY	78° 55,4‘	11° 55,4‘
W1	79° 37,8‘	7° 00,0‘
W2	82° 30,0‘	3° 00,0‘
W3	82° 39,0‘	3° 45,6‘
W4	82° 00,0‘	10° 00,0‘
W5	82° 09,0‘	10° 45,0‘
W6	79° 22,2‘	8° 56,4‘

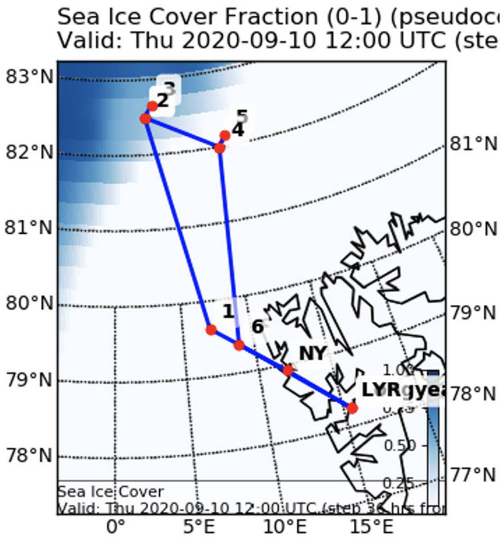


Fig. A.4.1.18: Overview on the way points (position) during this flight

Details during the flight

08:04	Props and science power on
08:24	Taxi
08:29	Take off
08:35	Heading to Ny-Ålesund, clouds everywhere, ascending
08:42	Reaching FL100
08:44	Cloud penetration, some turbulence, -6° C
08:52	Over Ny-Ålesund
08:59	Nice Sc below, just few clouds above flight level
09:03	A mid-level cloud ahead of us, we climb to FL120 to stay above it, almost no Cirrus
09:15	Dropsonde (DS) number 1 (DS1) released, Mario reports precipitation
09:16	Reaching W1, we stay above a thick cloud, no cirrus above
09:21	DS1 reaches ground, clouds below flight path become more scattered towards the North, we stay at FL120
09:25	Cloud gaps below
09:29	Again increasing cloud amount below, no cirrus above
09:33	DS2 released
09:38	DS2 touches ground, clouds become thinner, heterogeneous
09:45	Almost cloud-free below

09:50	DS3 released into cloud-free region
09:55	DS3 arrives at ground, reports temp at surface of roughly 2° C
09:59	Again more clouds, DS4 launched
10:05	Cloud penetration
10:09	Circle to have time to adjust to W2
10:15	DS5 launched
10:19	Reaching waypoint 2 (W2), start with the first leg of the horizontal stacked profile within cloud
	W2 → W3 at 12,000 ft
	W3 → W2 descending from 12,000 ft → 300 ft
	W2 → W3 at 300 ft (in cloud, liquid water)
	W3 → W2 at 1,300 ft (in cloud, liquid water)
	W2 → W3 at 5,000 ft (in cloud-free condition, between lower and upper cloud)
	W3 → W2 at 8,600-8,900 ft (in cloud, partly, patchy, ice)
	W2 → W3 at 10,000 ft
	Partly further clouds above flight level
	DS6 released at FL100 between W2 and W3
11:23	We leave W3, stay at FL100 on our way to W4, nice clouds below
11:31	Nice clouds below, Cirrus above, DS7 between W3 and W4
11:47	We arrive at W4, procedure turn, cirrus above, low level clouds below, we start again with the stacked profile pattern
11:51	W4 → W5 descending from 10,000 ft → 300 ft
12:00	W5 → W4 at 300 ft (fully in cloud)
12:10	W4 → W5 at 800 ft (cloud gap at the end)
12:20	W5 → W4 at 1,100 ft (with some cloud gaps)
12:30	W4 → W5 at 500 ft (fully in cloud)
12:40	W5 → W4 at 3,000 ft (above cloud, cirrus above)
12:59	W4 → W5 at 10,000 ft (above cloud, cirrus above)
13:06	W5 → W4 at 10,000 ft (above cloud, cirrus above)
13:09	Launch of DS8 at W4
13:20	Climb to FL110, because we need a distance to increasing cloud top of 1,200 ft for the lidar, Cirrus above

13:31 DS9, no cirrus above, we climb further to FL120 (lidar requirement)

13:45 No more cirrus above, below thick mid-level clouds

13:52 DS10

13:54 We encounter cloud top, some icing starts, therefore, we go up to FL130 out of cloud.

14:04 DS11

14:05 We reach W6, thick cloud below, almost no cirrus above

14:20 Passing Ny-Ålesund

14:45 Landing

Instrument Status

All instruments except the sun photometer worked fine throughout the whole flight with some minor outages of the PIP.

Tab. A.4.1.21: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC-A	Operated
MiRAC-P	Operated
AMALi	Operated
SMART	Operated
Eagle/Hawk	Operated
Sun Photometer	Not operated
Polar Nephelometer	Operated
2D-S	Operated
CAPS	Operated
PIP	Operated
Dropsondes	11 launched

A.4.1.8 MOSAiC ACA Flight #10 – 11 September 2020

Objectives

- Characterize the lee effect of Svalbard on atmosphere and cloud conditions in south-easterly wind conditions by dropsondes and remote sensing. Profile multi-layer clouds over sea ice and over open ocean by *in situ* observations in different altitudes.

Crew

Tab. A.4.1.22: Crew and Operator during the research flight on 10 September 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART/Eagle Hawk	Marcus Klingebiel
Basis Data Acq.	Cristina Sans Coll
Basis Data Acq. II	Clemens Gollin
MiRAC / AMALi	Friedhelm Jansen
Cloud Microphysics	Valerian Hahn
Mission-PI	André Ehrlich

Flight times

Tab. A.4.1.23: Flight time during the research flight on 10 September 2020

Polar 5	
Take off	08:19 UTC
Touch down	13:59 UTC
Air time	5.7 h
Flight time	5.8 h

Overview

During this flight, the differences of cloud properties over sea ice and open water were successfully observed along the wind direction. The synoptic situation was such that there was no other choice than to go to the North; in western direction mid-level clouds were too high. These mid-level clouds resulted from an occlusion south of Spitzbergen (see synoptic overview below). On the way to the North and backward plenty of clouds with different vertical structures, partly including precipitation, were observed by the active and passive remote sensing instruments onboard *Polar 5*. We encountered heavy cirrus above the maximum flight level (FL130), other parts of the flight track were cirrus-free. We even had a short portion of the flight track in cloud-free sky, when sampling the area north of Svalbard influenced by the lee effect of the island. After arriving at the northern part of the flight track at 82.5°N and 3°E we were visibly over sea ice. We probed a low-level cloud sheet touching the ground (top height about the flight started with crossing Svalbard to reach W1. The island was partly covered by low clouds. One higher second cloud layer required us to climb to 11,000 ft. North of Svalbard a large cloud gap in the lee was observed. From W1 we headed north-west. We started with releasing dropsondes in the cloud free area. To cover the atmospheric change in the transition from cloud-free to cloudy, we increased the frequency of dropsonde releases (max. each 15 min.). The cloud remote sensing could document the change in cloud properties. Further north, a second thin cloud layer started. Close to the area for the stacked pattern in the north-west, the clouds visually became denser and mightier. The second cloud-layer ended in western direction close to the cloud track. Therefore, the coordinates for the first stack were adjusted, placing the stack pattern more into the east where the cloud fields looked rather homogeneous. During the descent we could observe two cloud layers, one very low, the other in about 9,000 ft. Above another cloud layer was visible now very high above *Polar 5*. All layers were homogeneous between the two waypoints which makes this stack a good dataset for analysis. Returning to location of the second stack, we descended to 200 ft and started a saw tooth pattern to sample the low cloud repeatedly as often as possible to obtain good statistics but also for following the changes of cloud properties. Other than expected, the cloud top altitude increased towards South. These clouds always reached the ground (first sea ice, then open ocean). During this leg, also mid-level and cirrus was present. The altitudes of the saw tooth pattern are illustrated below. At the location of the second stack only one low cloud layer was present, except of high cirrus. A mid-level cloud was not visually obvious but was discovered later, when climbing to 10,000 ft. This stack was compiled of four different legs. The low cloud layer was significant thicker than in the north but also reached the ocean surface. The stack is illustrated below. After the second stack, the flight turned south flying at 11,000 ft altitude. Three dropsondes were released. The last in the still existing cloud free area due to the lee effect.

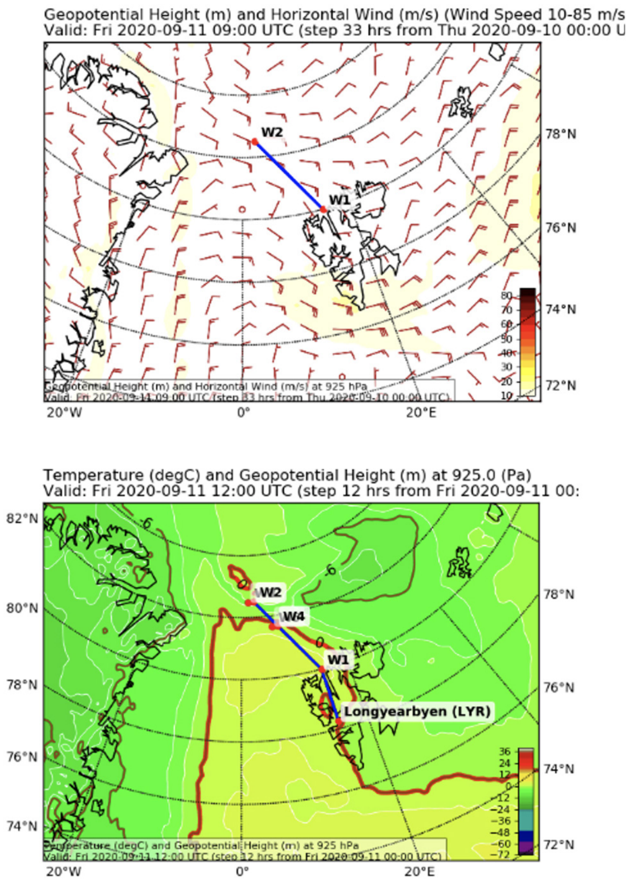


Fig. A.4.1.19: ECMWF Wind field and temperature in 925 hPa

Weather

Low pressure south of Svalbard caused a south-easterly flow around the island. A long front was still located west of Svalbard. This trough also generated a kind of front close to the west coast of Svalbard which was avoided in the flight plan. Similar to the day before, north of Svalbard a strong lee effect caused a cloud free area orientated in north-west direction. In this area also rather, warm temperatures were predicted. North of the cloud-free lee hole, low clouds were forecasted by ECMWF and ICON. During the day, the cloud-free lee hole was predicted to narrow and close. This cloud free area was observed at its place but during both crossings. We could not identify a closing. The low clouds were observed always with clouds bases touching the ground, both over sea ice and over the ocean. This low cloud was more clearly forecasted by ICON, while ECMWF did show an elevated cloud base (model vertical resolution). Temperatures were observed as forecasted with often above freezing level. Only in the mid-level clouds slight icing was observed. Both models had mid-level at the northern edge of the flight track, but in different altitudes. High clouds were forecasted at the eastern and western end of the track. This complex situation was also observed during the flight. Even the end of mid-level clouds was just west of the flight track. However, the observed mulit-layer structure and altitudes of the different cloud levels varied from the forecasts.

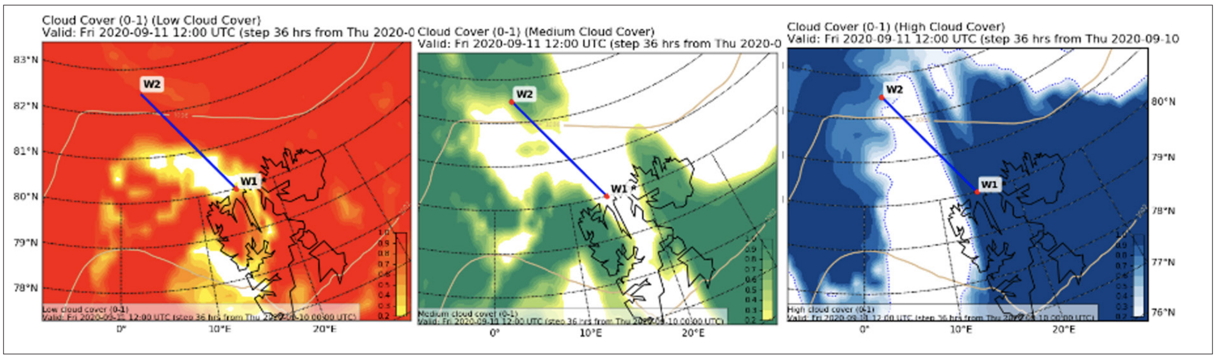


Fig. A.4.1.20: ECMWF Low, mid-level and high cloud cover

Flight description

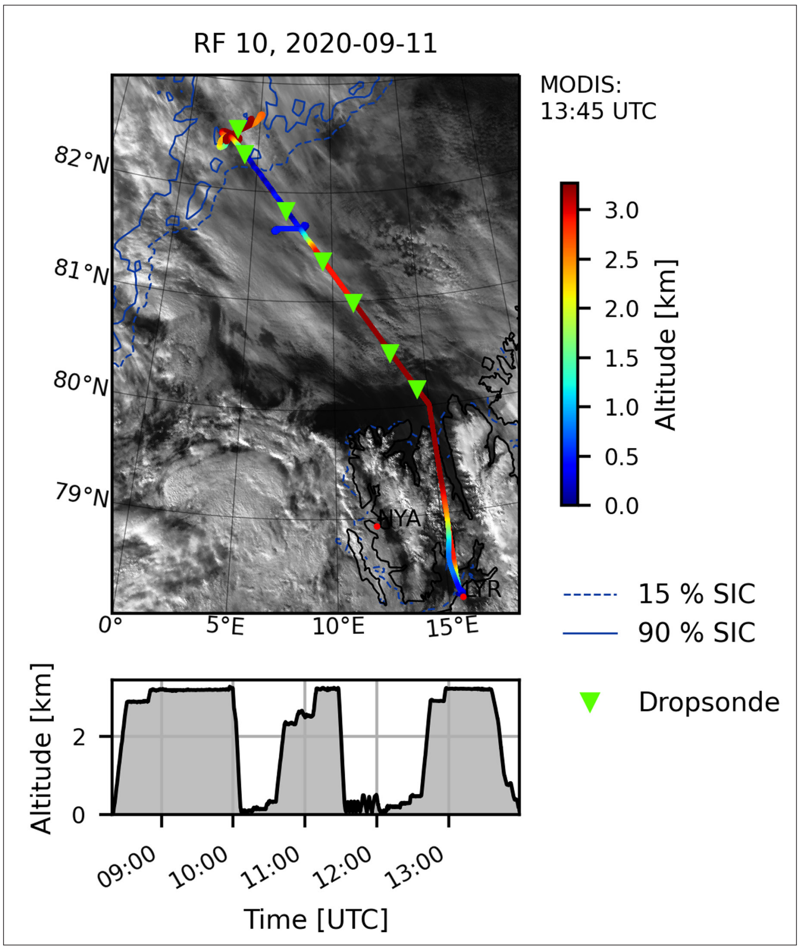


Fig. A.4.1.21: The map shows the flight pattern of Polar 5 on 11 September 2020 (upper part: flight track; lower part: height line).

Details during the flight

08:19 Take Off

08:22 Roller doors open

08:24 Cloud top of the first layer ~4,000 ft

08:26 Second cloud layer with cloud top ~6,000 ft, Many other thin layers visible

08:28 Now over the top of all lower clouds with cloud top ~8,000ft

08:31 Broken clouds over the island, cloud fraction 50 %

08:38 Some mid-level clouds and cirrus ahead

08:49 Now over mid-level cloud, cloud top very close to aircraft with about 2,800 ft cloud top → ascent to 11,000 ft

08:54 Now cloud free in the lee of Svalbard

09:01 WP1 – WP2: DS#1; cloud free in the center of the lee cloud hole

09:10 DS#2 at the edge of the cloud hole

09:15 Stratiform clouds below

09:19 DS#3 same conditions

09:29 DS#4 still Stratus below, very thin / lot of cirrus, almost homogeneous

09:35 Still one single thin cloud layer

09:38 DS#5 thin second cloud layer below / Some precipitation from a layer above

09:42 Ahead the low cloud layers become bigger and more structured at cloud top (like convection) / lot of thick cirrus or higher mid-level clouds (as was forecasted) / DS#6

10:25 Cloud hole

10:35 Nice two layers cloud: not a very large field, but homogeneous between W2 and W3

10:44 Second layer only before W2: not a nice cloud base, some patches also below

10:57 Also a thick Cirrus above

11:02 More turbulence in higher cloud top / little icing

11:09 Thick cloud above (rather mid-level than cirrus)

11:31 Still sea ice below clouds

11:35 Second cloud layer is gone but still cirrus above

11:59 Stratiform low cloud, no second layer, lot of altostratus + cirrus

12:30 Low clouds are not illuminated by the Sun → thick Cirrus / low clouds look dark

12:36 Finish second stack

12:44 Again second cloud layer between 8,000 – 9,000 ft, cirrus above

12:47 DS#8

12:58 Second cloud layer ends

13:04 DS#9 one cloud layer below getting thinner and becomes broken

13:13 Low cloud layer almost ends

13:15 Lee effect visible on the sea surface, no waves in lee

13:19 DS#10 / cloud free, some cirrus above

13:35 Start descent

13:59 Touch down

Instrument Status

SMART had a software failure, but could be reinitialized. About 90 min. data was lost. The CDP of the CCP had a storage problem in one of the legs of the first stack. Some minutes of data are lost. The Nikon Camera was operated only with fixed settings. Changes of shutter time, etc. could not be applied due to software issues.

Tab. A.4.1.24: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC-A	Operated
MiRAC-P	Operated
AMALi	Operated
SMART	Partly not operated
Eagle/Hawk	Operated
Sun Photometer	Not operated
Polar Nephelometer	Operated
2D-S	Operated
CAPS	Partly not operated
PIP	Operated
Dropsondes	10 launched

A.4.1.9 MOSAiC ACA Flight #11 – 13 September 2020

Objectives

- Study differences in the atmospheric structure over sea ice and open ocean

Crew

Tab. A.4.1.25: Crew and Operator during the research flight on 13 September 2020

Polar 5	
Pilot	William Houghton (Kenn Borek Air)
Co-Pilot	Michelle Lacey (Kenn Borek Air)
SMART/Eagle Hawk	Michael Schäfer
Basis Data Acq.	Hannes Probst
MiRAC / AMALi	Friedhelm Jansen
Cloud Microphysics	Manuel Moser
Mission-PI	Christof Lüpkes

Flight times

Tab. A.4.1.26: Flight time during the research flight on 13 September 2020

Polar 5	
Take off	08:20 UTC
Touch down	13:26 UTC
Air time	5.8 h
Flight time	5.9 h

Overview

During northerly flow over Fram Strait a transect was flown from LYR over Ny Ålesund in westerly direction towards Greenland with two staircase patterns included, one over sea ice and one over the open ocean. The western staircase was characterized by inhomogeneous cloud conditions, parts of the legs were outside clouds. More clouds were present at the eastern staircase position and all legs were flown below and in the lowermost cloud layer. A sawtooth pattern was included on the way back from the western to the eastern staircase with some low-level horizontal legs included. Ny Ålesund was on the flight track and was crossed two times.

Weather

The synoptic situation was governed by two low-pressure systems, one west of Norway and one northeast of Svalbard causing a thick cloud layer with precipitation north of Svalbard (see Fig. A.4.1.22).

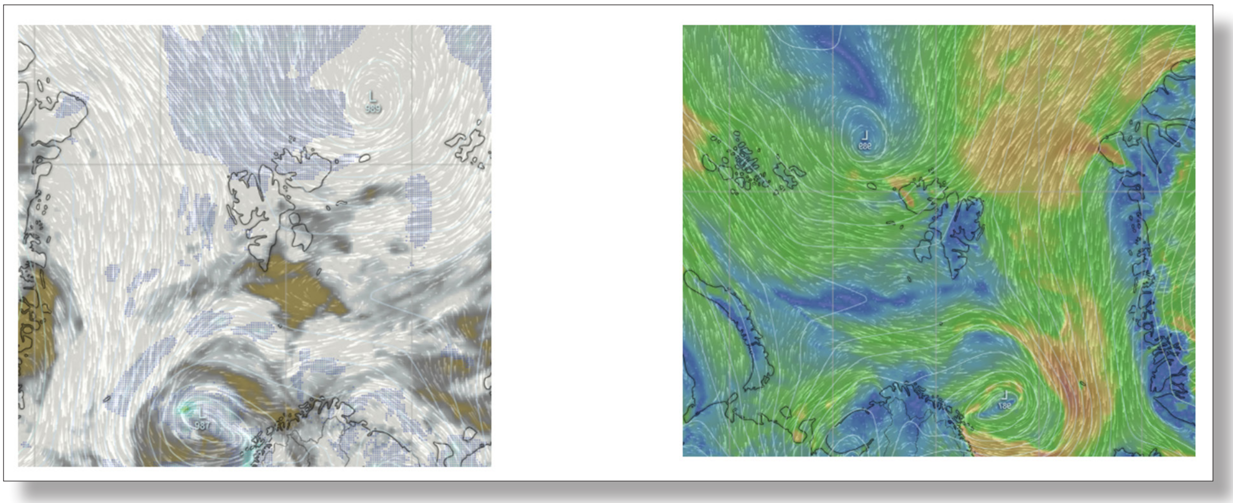


Fig. A.4.1.22: Twelve hour ECMWF forecast for 13:00 local for cloud cover and precipitation (left) and wind (right)

Flight description

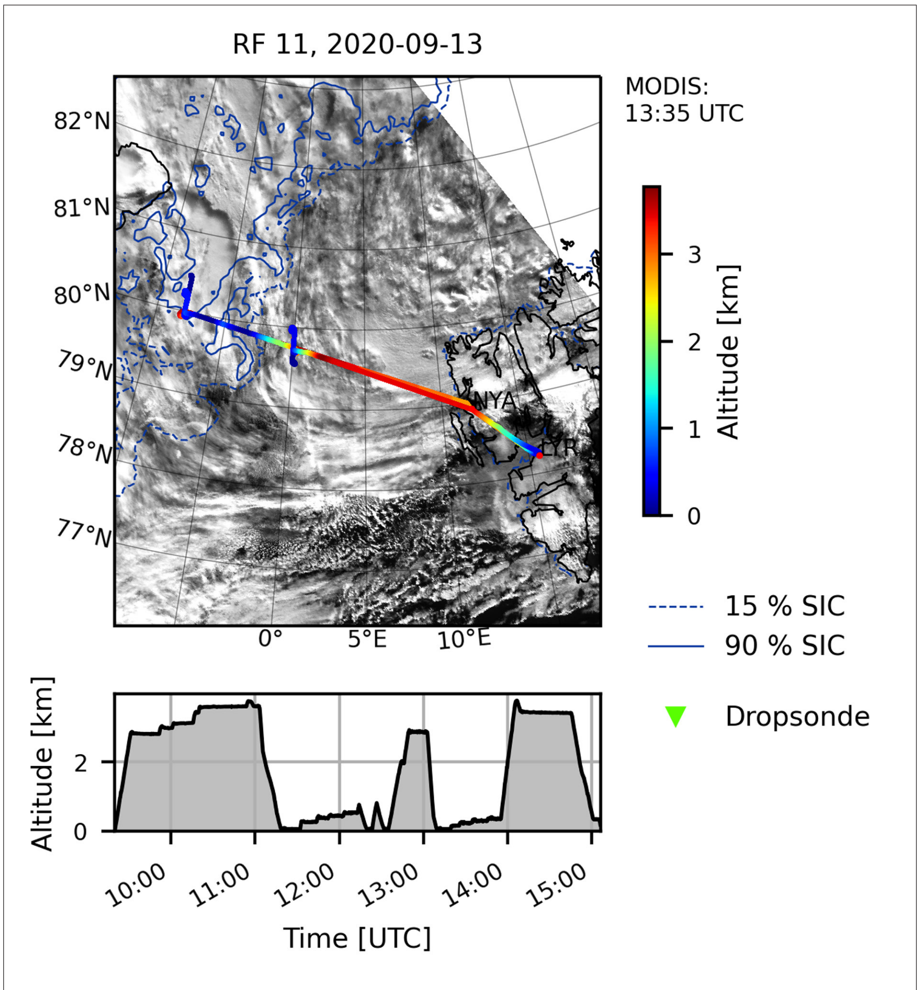


Fig. A.4.1.23: The map shows the flight pattern of Polar 5 on 08 September 2020 (upper part: flight track; lower part: height line).

Details during the flight

During the flight from LYR towards west we had to increase the flight altitudes several times to stay well above the clouds. The highest altitude of about 13,000 ft was necessary between the positions of both staircase flights.

Western staircase: We had to skip the first planned leg at 10,000 ft because of icing so that the first step was to descend to 200 ft. This altitude was reached at the northern end of the staircase. Then, horizontal legs followed in 200 ft, 850 ft (cloud base), 1,300 ft, 1,500 ft, 1,700 ft (cloud top).

Transect from western staircase to eastern staircase: A sawtooth pattern was flown towards the eastern staircase position with tops at 2,500 ft in the first two saw teeth. Then, low-level legs at 200 ft followed to measure the change of surface fluxes towards the open ocean. The first one of these legs was still over the MIZ but a large lead was also passed. The second leg crossed the ice edge (strong decrease of sea ice concentration, but still some drifting floes) at longitude 3.5° W. The following ascent was carried out until 9,400 ft to reach the top of the mid-level cloud layer at that position. But during the further horizontal flight, we crossed once more clouds and started then the descent to 200 ft at the eastern staircase position.

Eastern staircase: After the descent, our position was several miles away from the planned starting point of the legs. We approached to this position in 200 ft. This was below cloud base, but we saw also clouds reaching to the surface (in agreement with the signals from the cloud radar, which had shown surface based clouds). After arrival at the originally planned starting point of the staircase we ascended to 500 ft (mostly already in the cloud or slightly below cloud base). The next legs followed at 1,200 ft, 1,400 ft, 1,700 ft.

Transect to LYR: After the staircase patterns we ascended to about 11,000 ft, which was for some distance still in clouds but the radar lost surface contact at higher altitudes so that we did not go higher. We were outside of clouds over Ny-Ålesund.

Turbulence: Turbulence during all low legs was weak or moderate, this time with more turbulence during the legs over sea ice than over open water.

Sea ice: The western staircase was over drifting sea ice floes of about 90 % concentration. The sea ice was visible already from 10,000 ft while we approached the planned staircase position.

Clouds: After leaving the western coast of Svalbard we crossed a mid-level cloud layer with tops around 13,000 ft so that we had to ascend to 13,500 ft. However, although their vertical extent was high these clouds were most often thin.

Instrument Status

Four dropsondes have been thrown on the way towards West and three ones on the way back

Tab. A.4.1.27: Instrument status as reported after the flight for all instruments on *Polar 5*

Polar 5	
Basis data acquisition	Operated
Nose Boom	Operated
MiRAC	Operated
AMALi	Operated

Polar 5	
SMART	Operated
Eagle/Hawk	Operated
Cloud Particle Probes	Operated
Sun Photometer	Not operated
Polar Nephelometer	Operated
2D-S	Operated
CAPS	Operated
PIP	Operated
Dropsondes	7 launched

A.4 FLIGHT LOGS FOR MOSAiC AIRBORNE

A.4.2 Sea Ice Campaign

MOSAiC ICEBIRD Flight #02 – 31 August 2020
2020_08_31_Flight_02_MOSAiC_IceBird

MOSAiC ICEBIRD Flight #03 – 02 SEPTEMBER 2020
2020_09_02_Flight_03_MOSAiC_IceBird

MOSAiC ICEBIRD Flight #04 – 07 SEPTEMBER 2020
2020_09_07_Flight_04_MOSAiC_IceBird

MOSAiC ICEBIRD Flight #05 – 08 SEPTEMBER 2020
2020_09_08_Flight_05_MOSAiC_IceBird

MOSAiC ICEBIRD Flight #06 – 10 SEPTEMBER 2020
2020_09_10_Flight_06_MOSAiC_IceBird

MOSAiC ICEBIRD Flight #07 – 11 SEPTEMBER 2020
2020_09_11_Flight_07_MOSAiC_IceBird

MOSAiC ICEBIRD Flight #08 – 13 SEPTEMBER 2020
2020_09_13_Flight_08_MOSAiC_IceBird

A.4.2.1 MOSAiC ICEBIRD Flight #02 – 31 August 2020

Objectives

- Test of instrumentation, procedures and communication during flight
- Wing by wing flight with *Polar 5* for instrument intercomparison
- EM-Bird test over open water
- MACS camera system test near ENSB

Crew

Tab. A.4.2.1: Crew and Operator during the research flight on 31 August 2020

Polar 6	
Pilot	Alan Gilbertson (Kenn Borek Air)
Co-Pilot	Ben Guinan (Kenn Borek Air)
EM-Bird	Jakob Belter
Basis Data Acq.	Cristina Sans Coll
UFA	Phillip Grieß
UFA	Gregor Reinbold
Mission-PI	Thomas Krumpen

Flight times

Tab. A.4.2.2: Flight time during the research flight on 31 August 2020

Polar 6	
Take off	12:47 UTC
Touch down	15:51 UTC
Air time	3.1 h
Flight time	3.4 h

Overview

The test flight was done in parallel with *Polar 5*. Aim was to test performance of various systems, communication and turn-on and shutdown procedures. Furthermore, a wing by wing flight with *Polar 5* for instrument intercomparison was made.

Weather

The weather at Svalbard was dominated by an almost stationary low-pressure system west of the island. The low caused a multitude of clouds in all vertical levels. Hence, flight activity was limited to an area nearby ENSB.

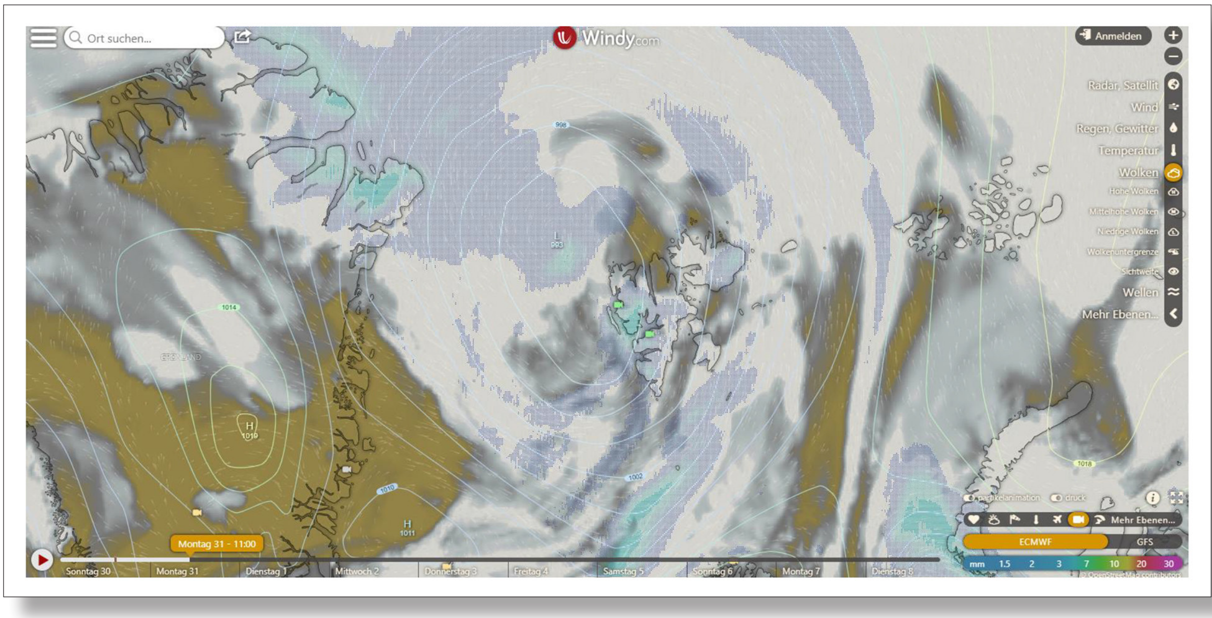


Fig. A.4.2.1: ECMWF forecast for 31 August (11 UTC): Cloud coverage and surface level pressure (source: Windy.com)

Flight description

After take-off in ENSB (Fig. A.4.2.2, red point), a wing by wing flight was performed together with *Polar 5* (A). Hereafter, the EM-Bird was deployed and a short flight at low altitude over open water in a nearby Fjord was made (B). The EM-Bird test was followed by an AIMMS-20 calibration pattern (C) and a MACS camera aerial survey in a valley near Longyearbyen (D).

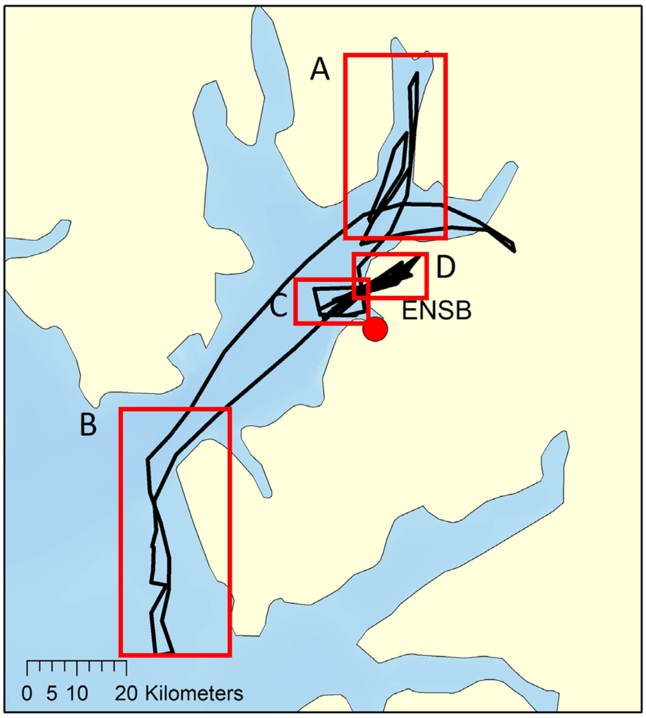


Fig. A.4.2.2: The map shows the flight pattern of Polar 6 on 31 August.
The red boxes (A-D) indicate different test sites:
A – wing by wing flight,
B – EM-Bird testing,
C – AIMMS-20 calibration,
D – MACS testing

CALIB Buoys

No CALIB buoys were deployed along the flight track.

Instrument Status

All instruments were turned on and working during the flight.

A.4.2.2 MOSAiC ICEBIRD Flight #03 – 02 SEPTEMBER 2020

Objectives

- Survey over areas with active buoys from the MOSAiC Distributed Network (around 77° N)
- Fly over *RV Kronprins Haakon (KPH)*
- Support of NPI with sea ice thickness and surface surveys in the vicinity of *KPH*
- Test of MACS camera operating over sea ice

Crew

Tab. A.4.2.3: Crew and Operator during the research flight on 02 September 2020

Polar 6	
Pilot	Alan Gilbertson (Kenn Borek Air)
Co-Pilot	Ben Guinan (Kenn Borek Air)
EM-Bird	Jakob Belter
Basis Data Acq.	Cristina Sans Coll
MACS	Jörg Brauchle
KM/camera system	Esther Horvath
Mission-PI	Thomas Krumpen

Flight times

Tab. A.4.2.4: Flight time during the research flight on 02 September 2020

Polar 6	
Take off	07:49 UTC
Touch down	14:23 UTC
Air time	6.5 h
Flight time	6.8 h

Overview

The aim of the flight was to survey sea ice in an area with active buoys from the MOSAiC Distributed Network. In August 2020, those buoys got trapped in an area of higher ice concentration near the Greenland coast (at 77° N, compare Table A.4.2.5). All other remaining active buoys were located further south at the time when the flight was made.

A second aim was to assist sea ice and oceanographic work carried out by the *RV Kronprins Haakon (KPH)* in Fram Strait (cruise leader Dmitry Divine, NPI). The NPI was performing sea ice surveys using a similar EM-Bird System towed by a helicopter one day earlier. At the time when overflights were made, satellite acquisitions were taken and people were working actively on the floe next the vessel.

A third aim was to operate the DLR MACS camera over sea ice for the first time ever. The instrument consists of down looking cameras acquiring three spectral bands (human-visible, near-infrared and thermal infrared). While RGB and NIR were used during past AWI permafrost campaigns, TIR was incorporated as a potentially new source of information. A first dataset should be acquired to analyze basic handling aspects, illumination conditions and the potential value for sea ice applications.

Weather

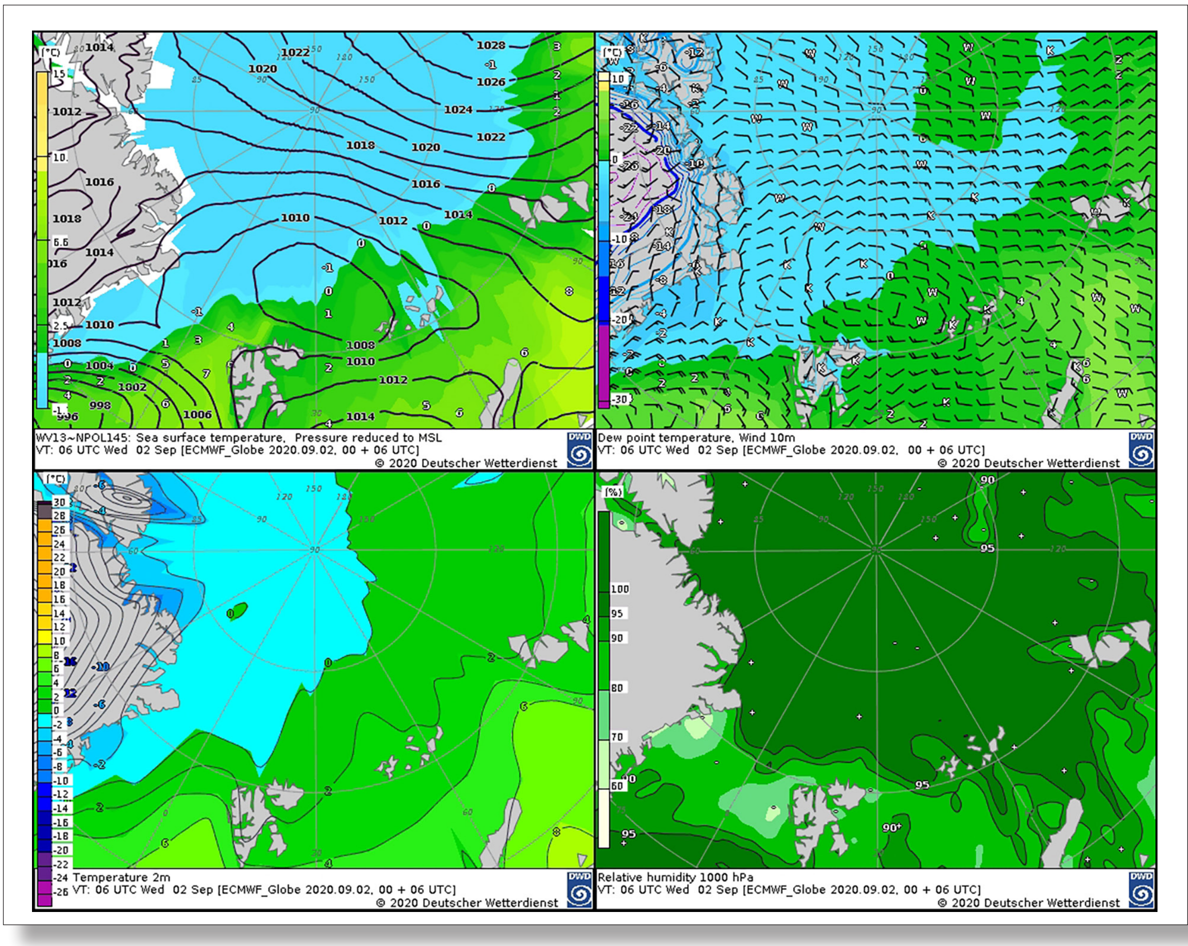


Fig. A.4.2.3: ECMWF forecast (source DWD) for 02 September, 06 UTC.
Low relative humidity at surface level in the surveying area provided good conditions.
Light winds, high visibility and absence of clouds were reported by KPH prior take-off.

Flight description

Ferry flight from ENSB towards southernmost first waypoint (WP1: 79° N, 15° W) was performed at high altitude. The first waypoint was positioned in closed ice cover (see Fig. A.4.2.4). From here on, EM-Bird surveys were carried out towards North until *KPH* was reached at 79.05° N, 12.03° W (yellow point). A list of active MOSAiC buoys in the survey area is provided in Table A.4.2.5. After flying over *KPH*, survey continued eastward until the ice edge was reached. Flight back to ENBS was made at higher altitude.

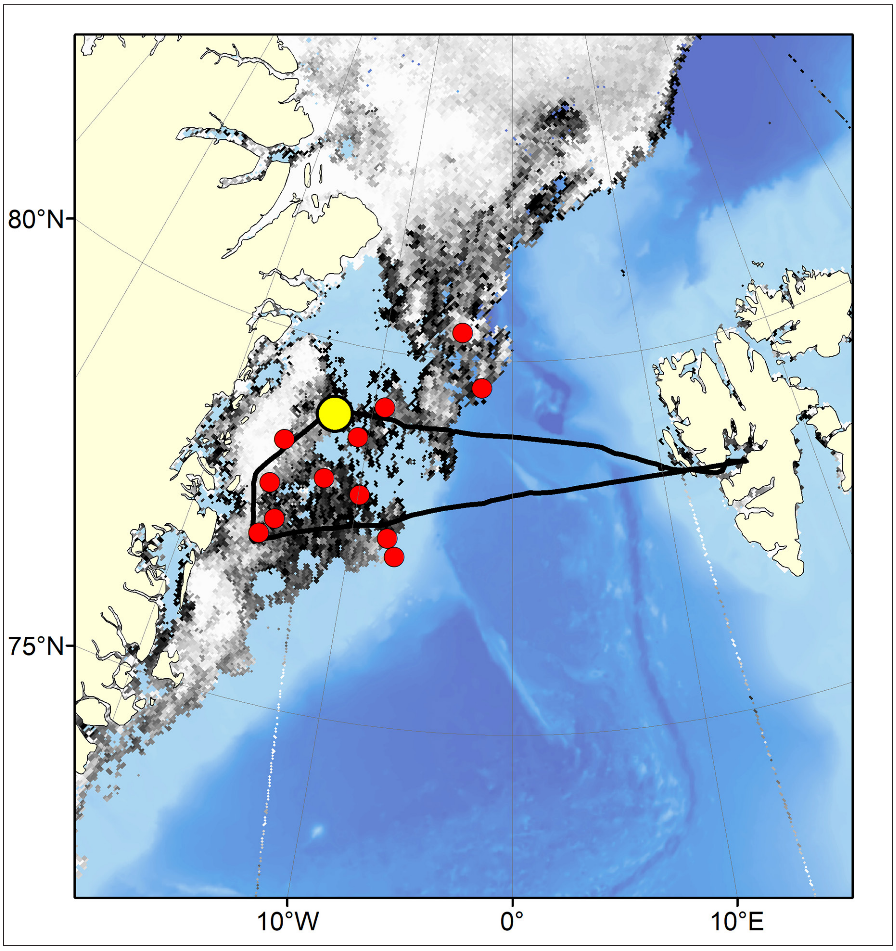


Fig. A.4.2.4: The map shows the flight path of Polar 6 on 02 September. The red dots indicates the position of active buoys from the MOSAiC Distributed Network (see Tab. A.4.2.5). The yellow dot indicates the position of KPH.

Tab. A.4.2.5: List of active MOSAiC buoys along the survey track and their position (Lat/Lon) on 02 September (see: https://www.meereisportal.de)

Buoy ID	Latitude	Longitude
2019P103	78.54	-15.56
2019P127	77.28	-7.20
2019P151	77.24	-15.55
2019P152	79.63	-2.27
2019P155	80.36	-3.99
2019P158	76.18	-12.95
2020P185	77.93	-15.73
2019P192	78.63	-2.10
2019P197	78.79	-10.69

Buoy ID	Latitude	Longitude
2019P206	79.24	-9.20
2020P211	77.51	-7.76
2020P214	78.16	-12.38
2020P219	78.03	-9.91
2020S97	77.48	-14.84

CALIB Buoys

No CALIB buoys were deployed along the flight track

Instrument Status

All instruments were turned on and working during the flight. On the transit out to the first waypoint, the EM-Bird went off a couple of time. Issues may be related to statics. During survey, no failures were observed.

A.4.2.3 MOSAiC ICEBIRD Flight #04 – 07 SEPTEMBER 2020

Objectives

- EM-Bird survey over areas with high sea ice concentration (north of 81° N)
- MACS camera survey over sea ice

Crew

Tab. A.4.2.6: Crew and Operator during the research flight on 07 September 2020

Polar 6	
Pilot	Alan Gilbertson (Kenn Borek Air)
Co-Pilot	Ben Guinan (Kenn Borek Air)
EM-Bird	Jakob Belter
Basis Data Acq.	Cristina Sans Coll
MACS	Jörg Brauchle
KM/camera system	Esther Horvath
Mission-PI	Jakob Belter, Thomas Krumpen

Flight times

Tab. A.4.2.7: Flight time during the research flight on 07 September 2020

Polar 6	
Take off	08:27 UTC
Touch down	14:09 UTC
Air time	5.7 h
Flight time	5.9 h

Overview

The aim of the flight was to conduct sea ice thickness surveys on a transect from the Southeast to the Northwest across the northern Fram Strait. The area was selected as sea ice concentrations were high and ice cover seemed less loose than it was during the first EM-Bird survey further south (02 September). The reference waypoint was selected to be at the ice edge (81° N and 1.5° W).

A second aim was to operate the DLR MACS camera to gather important data over sea ice that could be combined to EM ice thickness data. The flight was also used to further understand challenges of operating the camera and improve the settings for flights over sea ice.

Weather

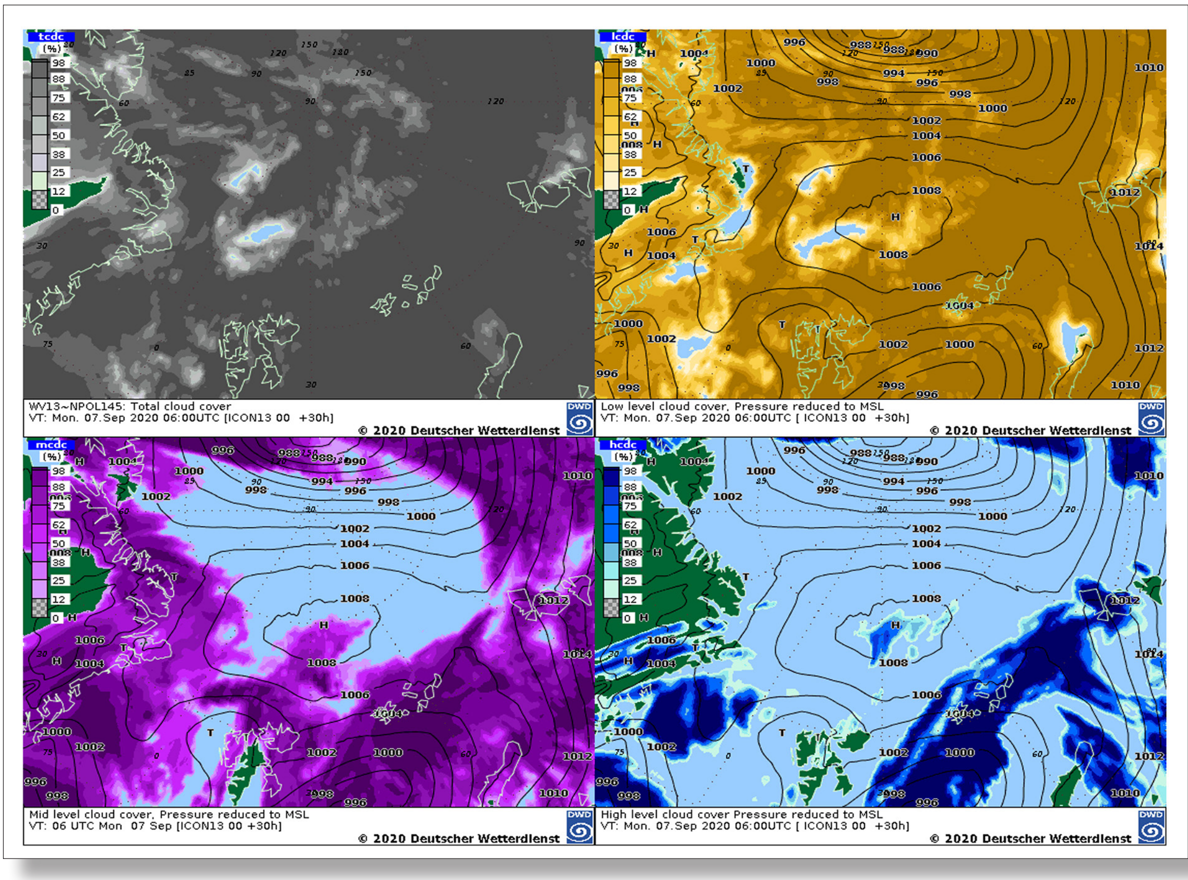


Fig. A.4.2.5: ICON forecast (source DWD) for 07 September, 00 UTC;
gaps in the low-level cloud over the planned survey area provided promising conditions.

Flight description

Ferry flight from ENSB towards the main reference waypoint (WP1: 81° N, 1.5° W) was performed at high altitude (compare Fig. A.4.2.7). The first waypoint was positioned at the ice edge in closed ice cover (see red dot in Fig. A.4.2.6). It was planned to pass the waypoint and continue towards northwest to find a suitable survey area for the return flight. However, due to difficult weather conditions and low clouds at calibration altitude it was decided to start the surveys early (altitude profile in Fig. A.4.2.7). A total of 4 surveys was conducted wherever cloud cover permitted it. The MACS cameras (visible, near-infrared and thermal infrared) recorded throughout the entire time *Polar 6* was passing over sea ice and over Svalbard. Flight back to ENBS was made again at higher altitude.

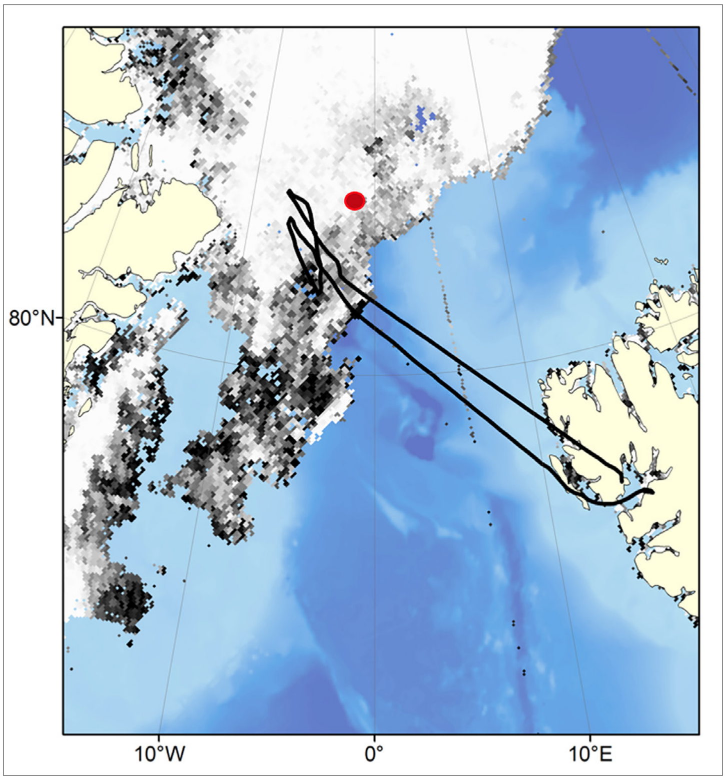


Fig. A.4.2.6: The map shows the flight path of Polar 6 on 07 September. Longyearbyen, Svalbard was the start and end point of the flight. The main reference and first waypoint were selected at the ice edge (red dot, 81° N, 1.5° W). EM-Bird surveys were only conducted over sea ice (AMSR-2 sea ice concentration visible in the background).

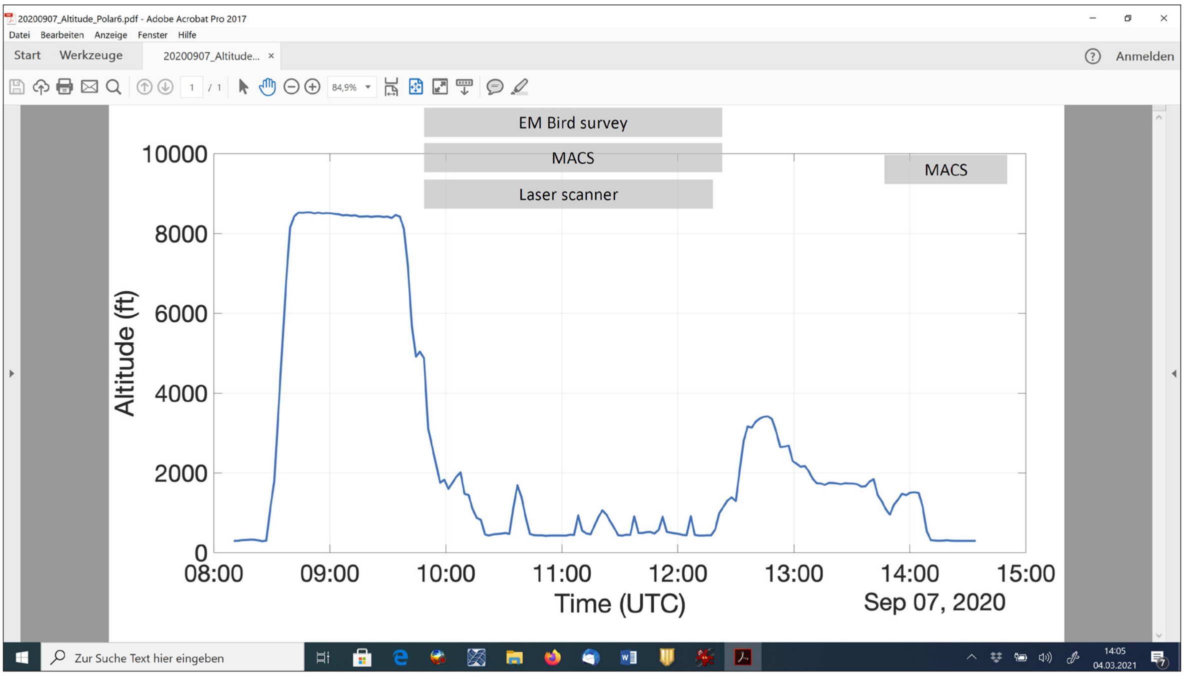


Fig. A.4.2.7: Altitude of Polar 6 during survey on 07 September with event description

CALIB Buoys

No CALIB buoys were deployed along the flight track.

Instrument Status

All instruments were turned on and working during the flight. After the start it was discovered that the INS was not working properly. It was decided to continue with the flight towards the ice. After return to Longyearbyen the INS was tested and worked properly. DLR NIR camera showed milky images during the flight. Camera had recorded properly but the quality of the images was impaired.

A.4.2.4 MOSAiC ICEBIRD Flight #05 – 08 SEPTEMBER 2020

Objectives

- EM-Bird sea ice thickness surveys over areas with high sea ice concentration (reference coordinates 83° N, 9° E)
- MACS camera survey over sea ice
- Deployment of two CALIB buoys over sea ice
- Calibration of upward-looking pyranometer to determine angle of the instrument relative to the plane

Crew

Tab. A.4.2.8: Crew and Operator during the research flight on 08 September 2020

Polar 6	
Pilot	Alan Gilbertson (Kenn Borek Air)
Co-Pilot	Ben Guinan (Kenn Borek Air)
EM-Bird	Jakob Belter
Basis Data Acq.	Clemens Gollin, Cristina Sans Coll
MACS	Jörg Brauchle
KM/camera system	–
Mission-PI	Jakob Belter

Flight times

Tab. A.4.2.9: Flight time during the research flight on 08 September 2020

Polar 6	
Take off	08:32 UTC
Touch down	14:28 UTC
Air time	6.0 h
Flight time	6.3 h

Overview

Aim of the flight was to survey sea ice in an area of high sea ice concentration. A transit to the ice (waypoint 83°N, 9°E, red area in Fig. A.4.2.9) was planned and to use the EM-Bird on a north-bound survey after reaching the ice. Gathering these data would provide important data in order to compare them to those that were sampled during IceBird campaigns in previous years. Although this year's campaign takes place later in the season, measurements of sea ice thickness can still provide an insight into areal distributions and allow an estimation of the sea ice-state earlier in the year. Observations during previous flights showed that sea ice was freezing up again. Although a lot of new ice was already forming further south, larger open water areas were still existent. Surveying further north would allow the investigation into different grades of freeze-up.

The second aim was to operate the DLR MACS camera over sea ice to complement the first available data sets and improve further understanding of basic handling as well as illumination conditions.

The third aim was to deploy two CALIB buoys on the return flight. These buoys are an important reference for sea ice drift patterns. This flight to the north provided the opportunity to deploy those buoys in an area specifically north of the Fram Strait where satellite sea ice motion products show the largest uncertainty. The buoys will provide a detailed picture of sea ice drift all along the variable Fram Strait.

Fourth goal was to calibrate the upward-looking pyranometer by flying two radiation-rectangles. This calibration allows the determination of the instrument's angle relative to the plane. Knowing this angle is vital for the correct interpretation of the recorded radiation data.

Weather

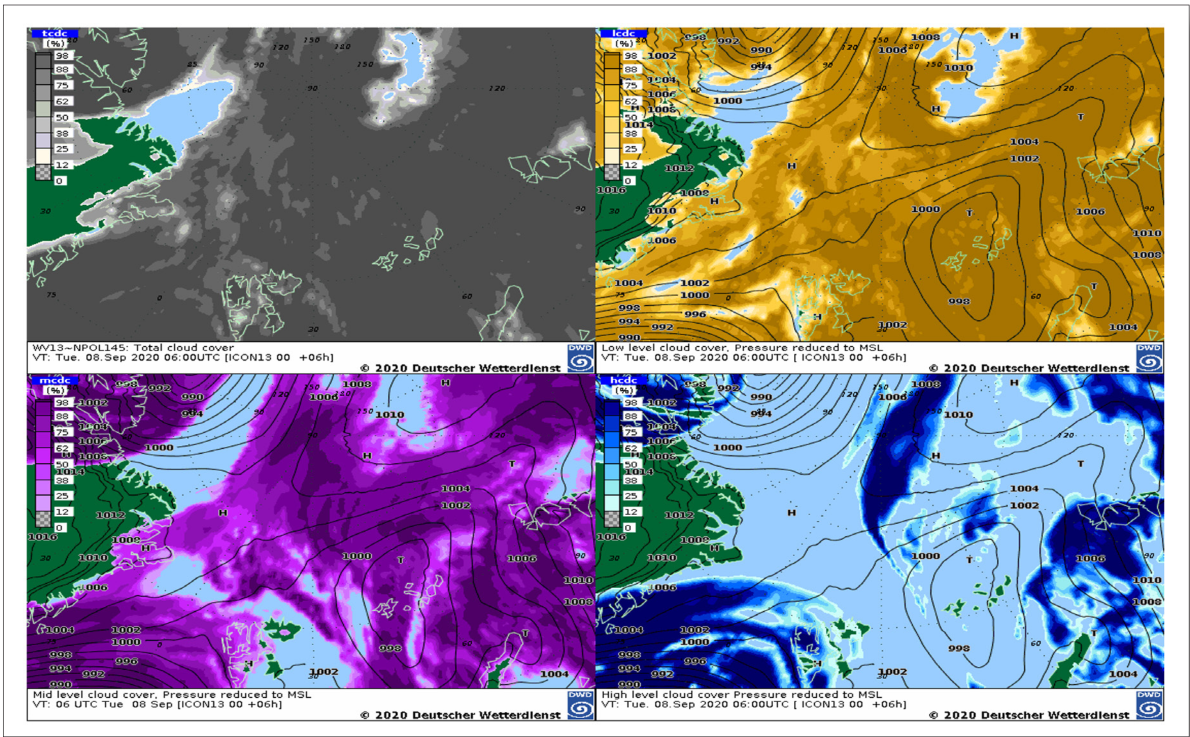


Fig. A.4.2.8: ICON forecast (source DWD) for 08 September. Prediction of a gap in the low cloud cover combined with relative humidity below 80 % indicated promising conditions over the survey area. Additional satellite images also suggested a break in the clouds.

Flight description

Ferry flight from ENSB towards the main reference waypoint (WP1: 83°N, 9°E) was performed at high altitude. The first waypoint was positioned at the ice edge in close ice cover. Upon reaching the waypoint we descended and selected a suitable channel between the low clouds to survey. EM-Bird survey was started from North to South (Fig. A.4.1.9). The second survey was conducted in the opposite direction. As weather conditions worsened, EM-Bird surveys were stopped. After the EM-Bird was retrieved two floes were selected for CALIB buoy deployments (Table A.4.2.9, Fig. A.4.2.9). Flight back to ENBS was made at higher altitude and during that flight two pyranometer calibration rectangles were flown (Fig. A.4.2.11 and Fig. A.4.2.9). The rest of the flight to ENBS was made at higher altitude. The full *Polar 6* altitude profile can be seen in Fig. A.4.2.10.

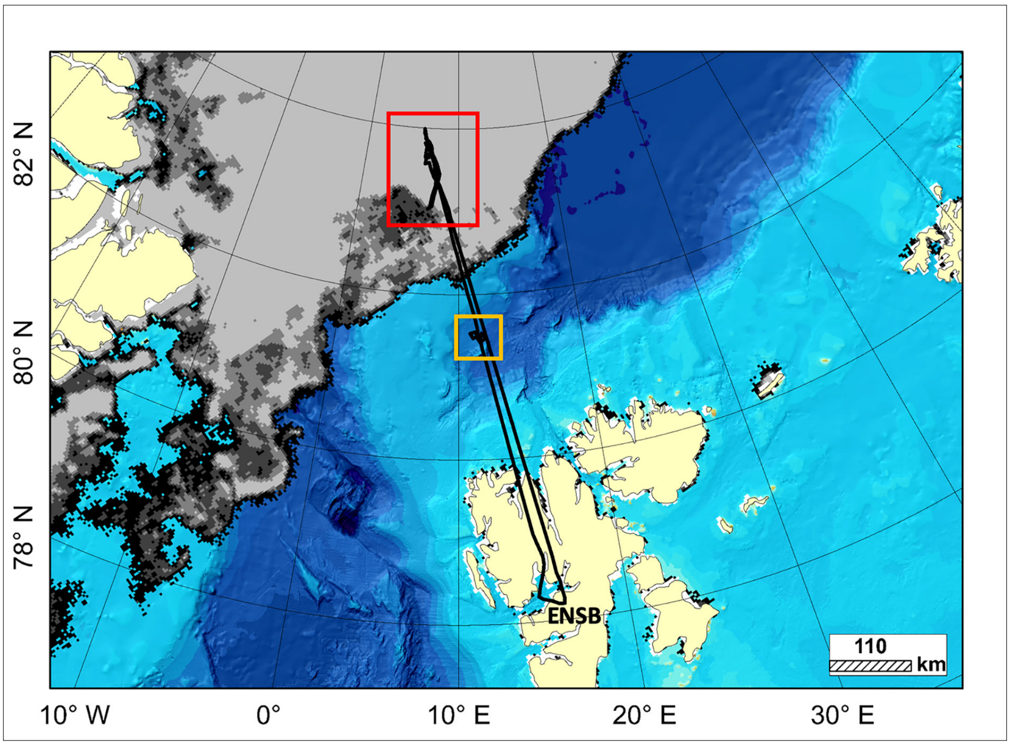


Fig. A.4.2.9: The map shows the flight path of Polar 6 on 08 September 2020. The area enclosed in red shows the EM-Bird survey area. CALIB buoys were deployed in the same area (www.meereisportal.de). Enclosed area between Svalbard and the ice edge (yellow) shows position of the pyranometer calibration rectangles.

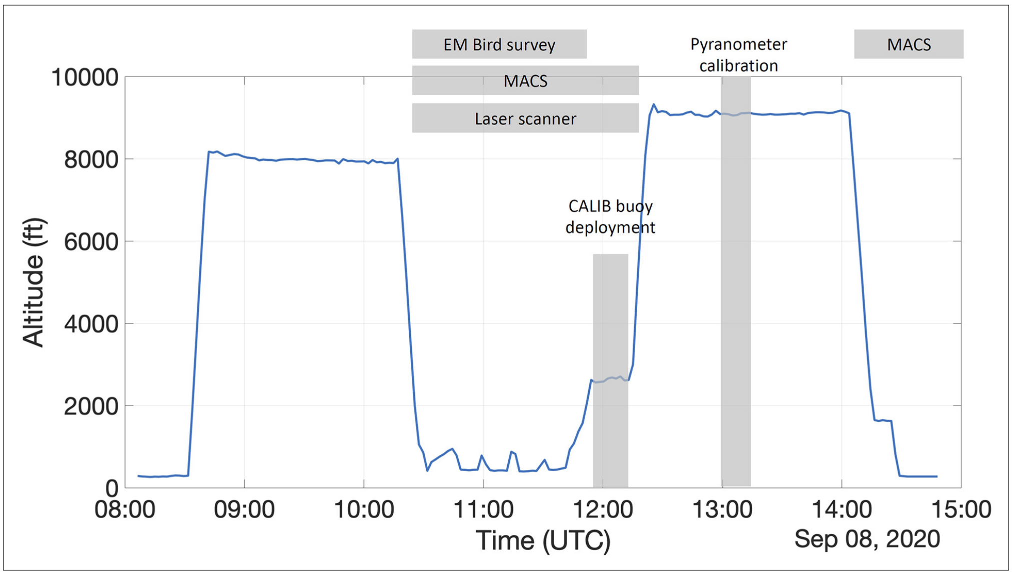


Fig. A.4.2.10: Altitude of Polar 6 during survey on 08 September with event description

CALIB Buoys

Tab. A.4.1.10: Details about two CALIB buoys that were deployed along the flight track

IMEI	**300234066898220**	**300234066890260**
Date	08.09.2020	08.09.2020
Time	12:02:20 UTC	12:13:00 UTC
Latitude	83°34.418 N	83°16.167 N
Longitude	6°25.464 E	8°05.326 E

Pyranometer calibration

Two rectangular flight patterns were selected to determine the installation error of the upward-looking pyranometer integrated into the plane. Each rectangle consisted of 4 legs. Fig. A.4.2.11 shows the setup of the calibration rectangles (positions of the rectangles visible in Fig. A.4.2.9). Each leg was 1 min and 5 s long, with legs 1 and 5 facing the sun. The plane flew over the clouds to avoid cloud cover above the instrument. Leg 1 started at 12:56:25 UTC (81°30.874 N, 11°36.893 E) and leg 8 ended at 13:11:30 UTC (81°31.759 N, 11°53.049 E).

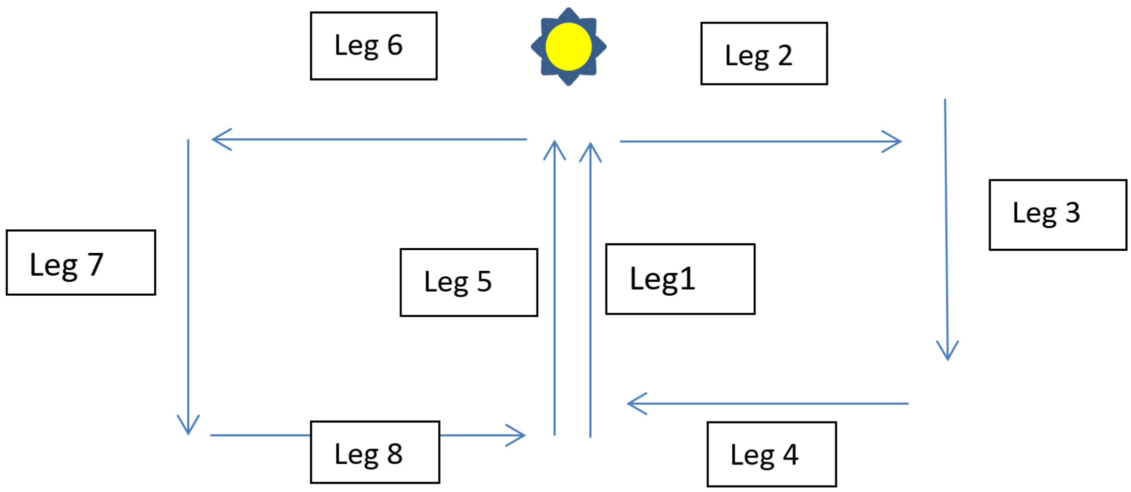


Fig. A.4.2.11: Flight patterns for pyranometer calibration

Instrument Status

All instruments were turned on and working during the flight. The upward-looking camera stopped during the flight and was not recording during the radiation calibration rectangles. DLR NIR camera problems discovered during the flight on 07 September did not occur this time and high-quality images were recorded with all cameras of the MACS system.

A.4.2.5 MOSAiC ICEBIRD Flight #06 – 10 SEPTEMBER 2020

Objectives

- MACS camera surveys over Ny-Ålesund
- Laser scanner calibration flight over the landing strip in Ny-Ålesund
- Additional EM-Bird testing

Crew

Tab. A.4.2.11: Crew and Operator during the research flight on 10 September 2020

Polar 6	
Pilot	Alan Gilbertson (Kenn Borek Air)
Co-Pilot	Ben Guinan (Kenn Borek Air)
EM-Bird	Jakob Belter
Basis Data Acq.	Cristina Sans Coll
MACS	Jörg Brauchle
KM/camera system	–
Mission-PI	Jakob Belter

Flight times

Tab. A.4.2.12: Flight time during the research flight on 10 September 2020

Polar 6	
Take off	07:58 UTC
Touch down	13:49 UTC
Air time	5.8 h
Flight time	6.1 h

Overview

The goal of the flight was to conduct a detailed DLR MACS camera survey for parts of the SPLAM-aero20-project (Uni Münster et al.) over Ny-Ålesund and the wider area. Multiple survey areas were selected in advance (Fig. A.4.2.13) and the overarching goal was to achieve sufficient image overlap to later 3D model the area. One additional survey was planned for the previously targeted area north of Longyearbyen on 31 August. Flying over this area for a second time will provide important data for the comparison and will also indicate improvements and adjustments that were made during the MACS camera flights conducted so far during this expedition.

The second aim was to use the exact knowledge of the position of the landing strip in Ny-Ålesund to conduct a calibration survey for the laser scanner.

Weather

On the day of the flight meteorological measurements from Ny-Ålesund were analyzed and the colleagues on the ground were contacted for a final estimate of the conditions. Cloud ceiling at about 2,500m, comparably high temperatures of 8° C and low relative humidity of 71 % indicated favorable conditions for the planned surveys. The ceilometer data from Ny-Ålesund show that the cloud ceiling was high enough for the camera flights (Fig. A.4.2.12).

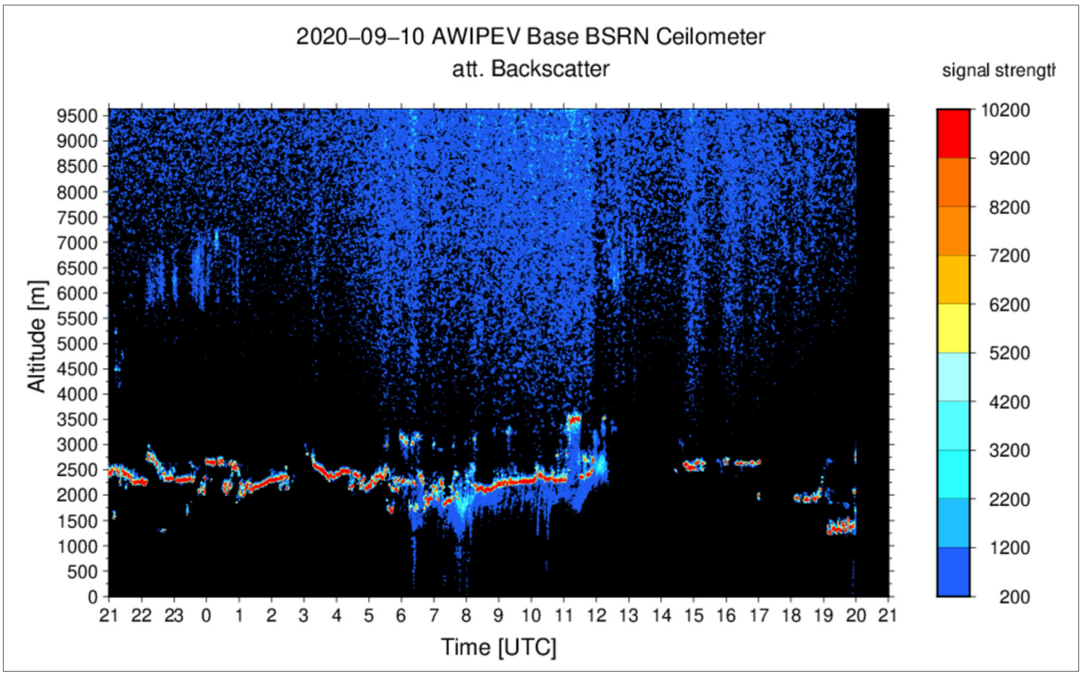


Fig. A.4.2.12: Ceilometer measurements from AWIPEV Base in Ny-Ålesund

Flight description

Prior to departure flight plans and local weather conditions were coordinated with the AWIPEV engineer. Ferry flight from ENSB towards the main reference waypoint (WP1: 83°N, 9°E) was performed at high altitude. Upon arrival in Ny-Ålesund the calibration flight for the laser scanner was conducted over the runway at the airport (blue enclosed area in Fig. A.4.2.14). Calibration was conducted at an altitude of 1,800 ft (Fig. A.4.2.15) and with an indicated speed of 115 kt. The laser scanner was turned on and the first overflight followed the runway from northwest to southeast (along the runway). The second along-runway pass was conducted from southeast to northwest. Following the two along-runway passes the across-runway transects started with a pass from north to south followed by another across-runway pass from south to north. Times and positions of start and end point of each one of the four passes was recorded in the logbook. We then proceeded to target area 3 (Ny-Ålesund East, Fig. A.4.2.13). After passing all lines of the survey block, we continued on to target area 2 (Ny-Ålesund West, Fig. A.4.2.13). Altitudes and passing speed are indicted for each target area in Fig. A.4.2.15. Due to a descending cloud cover the survey block in target area 4 was cancelled. We went back to target area 3 to close single gaps and provide complete coverage of the area (three additional passes at higher altitudes). *Polar 6* followed the western coastline of Svalbard back south. During the transit to MACS target area 1 a short EM-Bird test was conducted. The EM-Bird was deployed and two test files were recorded before the EM-Bird was retrieved again. Upon arrival at target area 1 clouds had descended too low to allow safe surveying. The revisit of target area 1 was therefore cancelled and *Polar 6* returned to ENSB.

Fig. A.4.2.13: Map of the Ny-Ålesund area shows three exact target areas and flight patterns for the DLR MACS camera surveys (targets 2-4). An additional survey was planned just north of Longyearbyen (target 1).

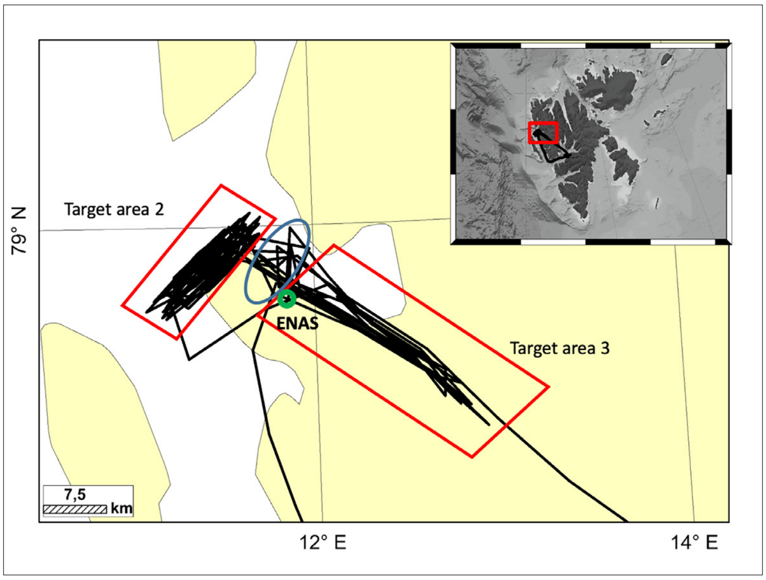


Fig. A.4.2.14: The map shows the flight path of Polar 6 on 10 September (top right) and an enlarged map of the Ny-Ålesund region. Areas enclosed in red indicate MACS survey areas, while the blue area shows where laser scanner calibration took place.

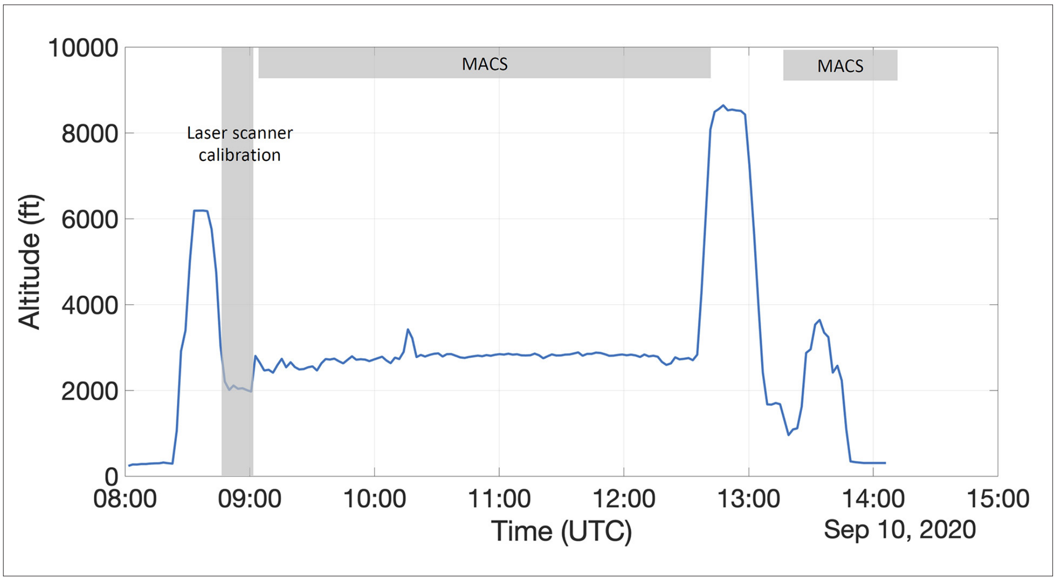


Fig. A.4.2.15: Altitude of Polar 6 during survey on 10 September with event description

CALIB Buoys

No CALIB buoys were deployed.

Instrument Status

All instruments were turned on and working during the flight. The laser scanner was only turned on and used during the calibration flight over the Ny-Ålesund runway.

A.4.2.6 MOSAiC ICEBIRD Flight #07 – 11 SEPTEMBER 2020

Objectives

- MACS camera surveys over Ny-Ålesund and north of Longyearbyen

Crew

Tab. A.4.2.13: Crew and Operator during the research flight on 11 September 2020

Polar 6	
Pilot	Alan Gilbertson (Kenn Borek Air)
Co-Pilot	Ben Guinan (Kenn Borek Air)
EM-Bird	Jakob Belter
Basis Data Acq.	Martin Gehrmann, Hannes Probst
MACS	Jörg Brauchle
KM/camera system	Esther Horvath
Mission-PI	Jakob Belter

Flight time

Tab. A.4.2.14: Flight time during the research flight on 11 September 2020

Polar 6	
Take off	09:04 UTC
Touch down	13:28 UTC
Air time	4.4 h
Flight time	4.7 h

Overview

The goal of the flight was to finish DLR MACS camera surveys previously conducted over Ny-Ålesund and the wider area. Target area 4 (Ny-Ålesund, Fig. A.4.2.16) was of specific interest. The flights will provide a continuation of the survey flights conducted on 10 September and will support the overarching goal of creating 3D models of the Ny-Ålesund area. One additional survey was planned for the area north of Longyearbyen previously targeted for 31 August. Due to low cloud cover a second survey of this this area was cancelled during the flight on 10 September.

Weather

On the day of the flight meteorological measurements from Ny-Ålesund were analyzed and the colleagues on the ground were contacted for a final estimate of the conditions. An observed cloud ceiling at about 4,000 m indicated favorable conditions for the planned surveys.

Flight description

Shortly after take-off ENSB we surveyed target area 1 with the MACS camera system (Fig. A.4.2.16, Fig. A.4.2.17). After finishing target area 1 we continued on towards Ny-Ålesund. Upon arrival in Ny-Ålesund it was discovered that the cloud ceiling was too low for the planned survey flight at 8,200 ft over target area 4 (Fig. A.4.2.16). We therefore surveyed again target area 3 to achieve even more overlap between the images which is vital for the 3D modelling of the area (Fig. A.4.2.17). After finishing target area 3 we followed the coastline in a southward direction and to sample another area south of Ny-Ålesund (Pingo in A.4.2.17). We returned to ENSB at an altitude of about 2,000 ft (Fig. A.4.2.18).

Target 1: LYR North

GS: ca. 140 kn

Altitude: 3,300 ft

Line count: 6

Time on lines: 10 min

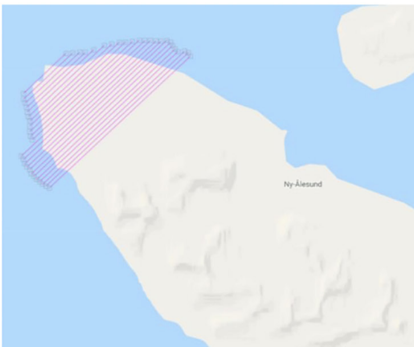
Target 2: Ny Alesund west

GS: <120 kn

Altitude: 2,300 ft

Line count: 23

Time on lines: 40 min



Target 3: Ny Alesund east

GS: <120 kn

Altitude: 2,300 ft

Line count: 6

Time on lines: 25 min

Target 4: Ny Alesund

GS: ca. 140 kn

Altitude: 8,200 ft

Line count: 13

Time on lines: 120 min

Fig. A.4.2.16: Map of the Ny-Ålesund area showing the three exact target areas and flight patterns for the DLR MACS camera surveys (targets 2-4). An additional survey was planned specifically north of Longyearbyen (target 1).

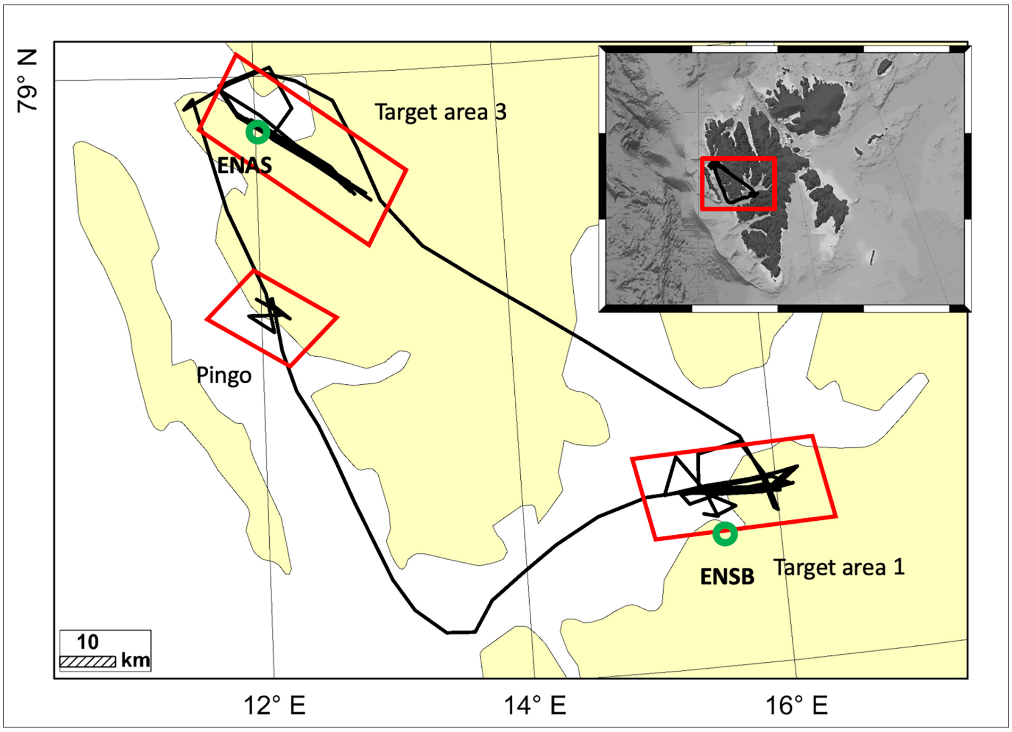


Fig. A.4.2.17: The map shows the flight path of Polar 6 on 11 September. Enclosed are MACS camera survey areas.

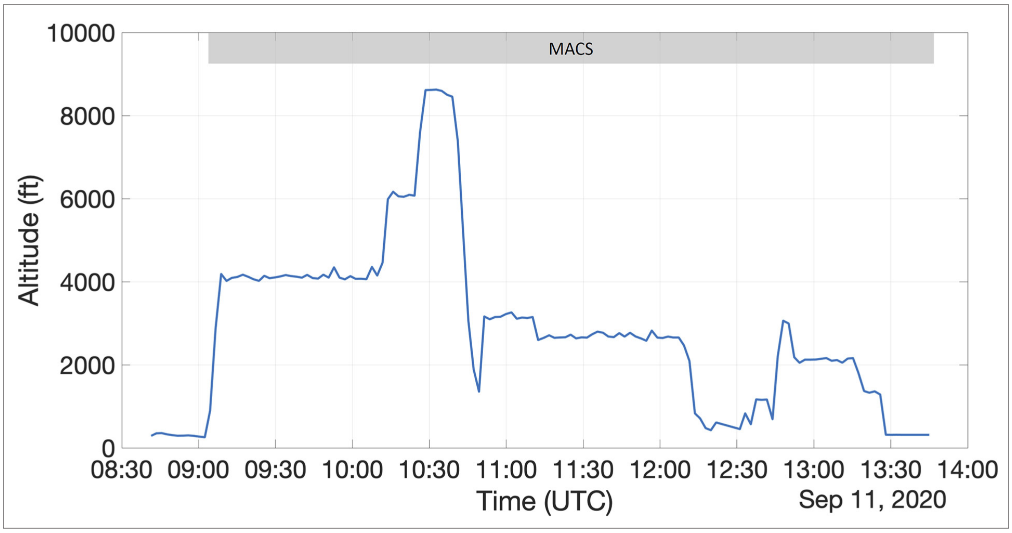


Fig. A.4.2.18: Altitude of Polar 6 during survey on 11 September with event description

CALIB Buoys

No CALIB buoys were deployed.

Instrument Status

All instruments were turned on and working during the flight. Due to the strict radio silence over Ny-Ålesund the EM-Bird was only running during the transit flights and tests. The laser scanner was not used.

A.4.2.7 MOSAiC ICEBIRD Flight #08 – 13 SEPTEMBER 2020

Objectives

- MACS camera surveys over Ny-Ålesund and the wider area and pingo surveys over Svea

Crew

Tab. A.4.2.15: Crew and Operator during the research flight on 13 September 2020

Polar 6	
Pilot	Alan Gilbertson (Kenn Borek Air)
Co-Pilot	Ben Guinan (Kenn Borek Air)
EM-Bird	Jakob Belter
Basis Data Acq.	Cristina Sans Coll
MACS	Jörg Brauchle
KM/camera system	–
Mission-PI	Jakob Belter

Flight time

Tab. A.4.2.16: Flight time during the research flight on 13 September 2020

Polar 6	
Take off	09:59 UTC
Touch down	12:43 UTC
Air time	2.7 h
Flight time	3.0 h

Overview

The primary aim of the flight was to collect aerial imagery of a permafrost scenery close to the airport in Ny-Ålesund for AWI-Potsdam (Julia Boike et al.). The acquisition is part of the SPLAM-aero20 project. A digital elevation model with a ground resolution of 12 cm per pixel will be processed to evaluate changes compared with previous elevation models.

The secondary aim was to collect aerial imagery of a pingo which is a debris-covered ice core. The permafrost-related field of pingos is relevant in planetology analogy research particularly with respect to Mars. A pingo south of Ny-Ålesund was acquired with a ground resolution of 18 cm per pixel. This VIS-NIR-TIR dataset will be used as an example to evaluate whether mid-resolution aerial imagery can be used to derive relevant information about the structure and development of pingos. This research is a collaboration between DLR Institute of Planetary Research and Nikita Demidov, Russian Arctic and Antarctic Research Institute (AARI) et. al.

Weather

On the day of the flight meteorological measurements from Ny-Ålesund were analyzed and the colleagues on the ground were contacted for a final estimate of the conditions. An observed cloud ceiling at about 4,000 m indicated favorable conditions for the planned surveys.

Flight description

The ferry flight to Ny-Ålesund was performed at high altitude (Fig. A.4.2.20). Upon arrival we descended to 2,700 ft for the survey of the permafrost observatory close to the Ny-Ålesund airport (Fig. A.4.2.19). After finishing that survey, we continued on to the pingo south of Ny-Ålesund that was only briefly surveyed on 11 September. After an extensive survey of the pingo area (Fig. A.4.2.19) we returned south to survey the region around Svea. However, the cloud cover was much lower over Svea and the plan to survey there was abandoned. We therefore returned to ENSB.

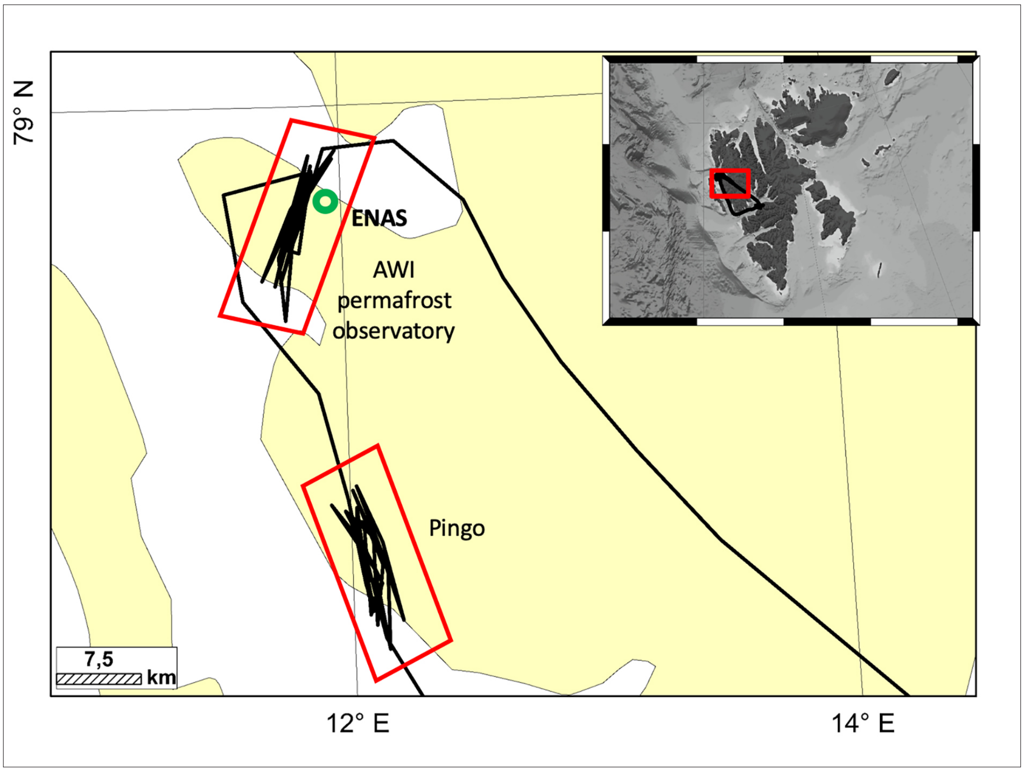


Fig. A.4.2.19: The map shows the flight path of Polar 6 on13 September. Enclosed areas indicate MACS camera survey areas.

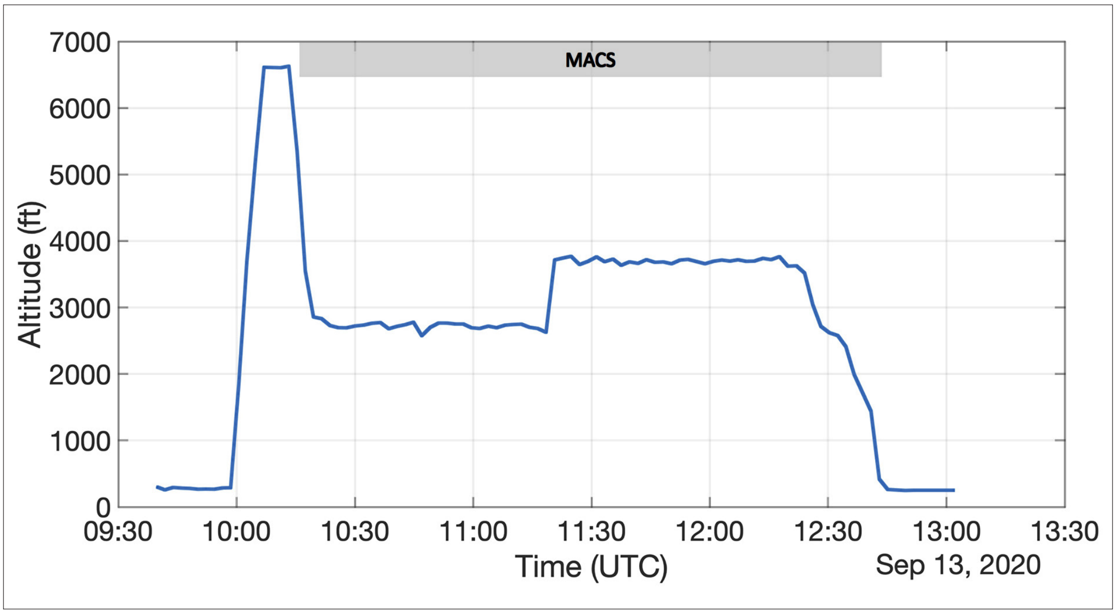


Fig. A.4.2.20: Altitude of Polar 6 during survey on 13 September with event description

CALIB Buoys

No CALIB buoys were deployed.

Instrument Status

All instruments were turned on and working during the flight. Due to the strict radio silence over Ny-Ålesund the EM-Bird was only running during the transit flights. The laser scanner was not used.

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