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Supplement of

A comprehensive in situ and remote sensing data set from the Arctic CLoud Observations Using airborne measurements during polar Day (ACLOUD) campaign

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ACLOUD Flight #04 – Polar 5 – 2017/05/23

Objectives:

The main goal of the flight was a study of the cloud development during a cold air outbreak over the Northern Fram Strait. Secondary goal: Nose boom calibration.

Mission PI P5:

Christof Lüpkes

Polar 5 Crew	
Mission PI	Christof Lüpkes
Basis Data Acq.	Christoph Petersen
SMART	Johannes Stapf
Eagle/Hawk	Elena Ruiz
MiRAC	Tobias Doktorowski
AMALi	Friedhelm Jansen

Flight times:

Polar 5	
Take off	09:08 UTC
Touch down	14:20 UTC

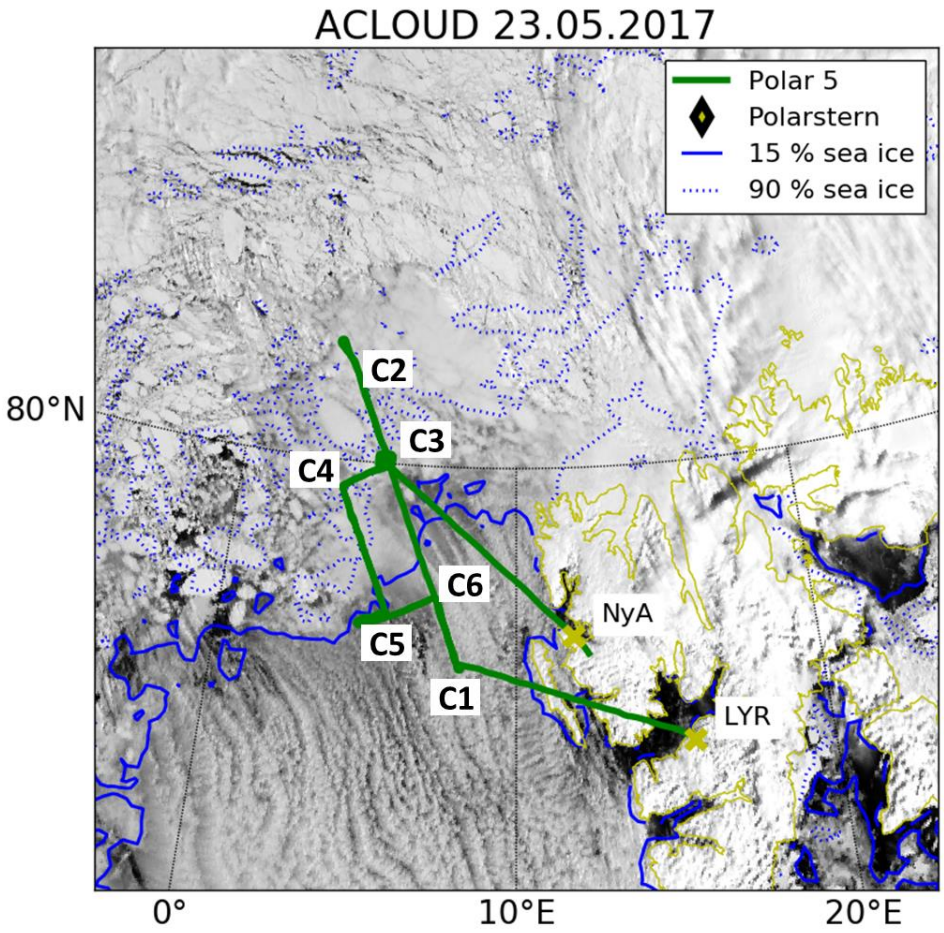


Fig. S4.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

The weather was characterized by a weak cold air outbreak with wind from northeast as seen in the figure S4.2 showing the 3 hour GFS forecast for 9 Z (wind and low clouds).

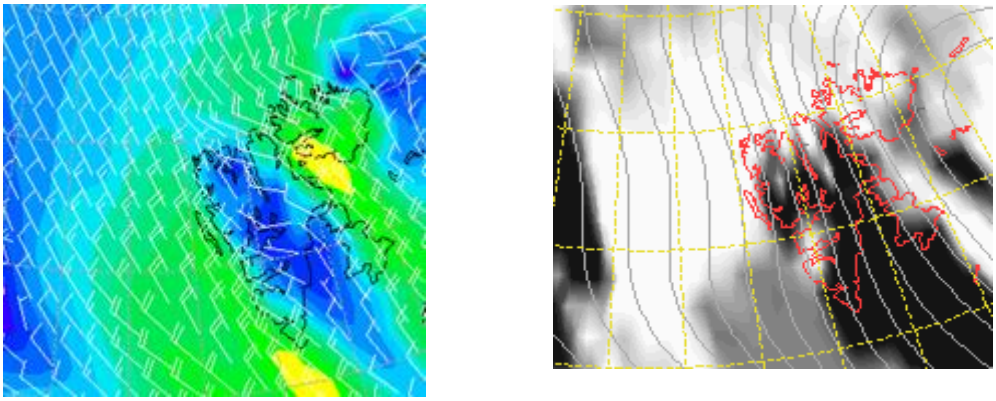


Fig. S4.2: 10 m wind (left) and low clouds (right) for 9 UTC GFS 3 hr prediction (www.wetterzentrale.de, Georg Müller).

The predicted wind direction agreed well with the (visual) observation (based on wave orientation in leads) during the flight. Over sea ice the observed cloud cover was smaller than predicted (see below).

Overview:

The flight strategy was to measure the cloud structure by the remote sensing instrumentation (Lidar, Eagle Hawk, Mirac), the inflow profile of wind and temperature over sea ice at the northernmost position, and near-surface turbulent fluxes along several flight legs over the sea ice covered part and over open water.

Flights should be performed in 10.000 ft from C1 to C2.

At 200 ft: C2→ C3 →C4 → C5→C6

Then in 10.000 ft: C1 → C6→ C5→C4 → C3 → Ny Alesund

Due to icing conditions (precipitating clouds), the low level flight sections had to be aborted close to C5. Some problems occurred with the Eagle/Hawk and Smart Albedometer. They were working only during parts of the flight. The shortening of the low-level flight section (no low-level leg C5→ C6) allowed later a high altitude calibration pattern for the noseboom.

Clouds

Although convection rolls could be seen in the satellite image, during the whole flight section from C1 to C2 clouds appeared to be homogenous (complete cloud cover; stratus and stratocumulus). Only over the sea ice part close to half the way between C3 and C2 convection rolls were visible.

Fig. S4.3: Photograph taken from Polar 5 between C1 and C3.

Cloud cover decreased considerably a few miles south of C2. The reduction was stronger than expected based on the GFS and ECMWF model forecast.

During the low-level flight from C2 to C3 low cloud cover increased from about 30 % at C2 to 100 % at C3. Cloud tops at C2 were in about 1200 ft, cloud base in 600 ft. Towards C3 cloud base decreased more and more and some clouds over leads were surface based. Between C3 and C4 low cloud cover was 100 %, we crossed one shower (snow). Close to C5 a shower was that strong that the pilots had first to interrupt the straight line of the track (turning more to the west) and afterwards they decided to go up above the cloud top. An attempt was made to fly 200 ft below cloud top (roughly 4500 ft) between C5 and C6. However, also this had to be aborted due to icing.

Maneuvers

Two noseboom calibration patterns were flown. The first one (between C2 and C3) consisted of acceleration and deceleration legs staying at the same height (200ft). The second one (at C3) consisted of 3 squares with 3 Nm edge length flown with different speed (100, 120, 145 kn) in 10.000 ft .

Sea ice conditions

Sea ice was visible only during the low level sections C2→C3→C4→C5. At C2 there was 95% sea ice cover with open small leads (no nilas visible) and polynyas (estimated width 100 – 200 m).

Fig. S4.4: Photograph taken from Polar 5 at C2.

Further south, the number and width of leads increased (see Fig. S4.5).

Fig. S4.5: Photograph taken from Polar 5 between C2 and C3.

Between C4 and C5 sea iced opened more and more and the typical ice floe structure of a marginal sea ice zone developed.

Fig. S4.6: Photograph taken from Polar 5 half the way between C4 and C5.

The ice edge was reached at about 79 N 5 E (see Fig. S4.7).

Fig. S4.7: Photograph taken from Polar 5 close to the sea ice edge.

Fig. S4.8: Photograph taken from Polar 5 close to C5.

But close to C5 there were still some drifting ice fields (see Fig. S4.8). The photo has been taken shortly before the low-level section had to be terminated.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Drop Sondes	

Table. S4.1: Instrument status as reported after the flight for all instruments on Polar 5.

Comments:

Eagle/Hawk: Some problems occurred due to a broken cable. SMART: Connection sometimes interrupted for unknown reason. Dropsondes system was not working, reason unknown.

ACLOUD Flight #05 – Polar 5 – 2017/05/25

Objectives:

Remote sensing of clouds in different regimes and different surfaces (sea ice/open ocean) within a weak cold air outbreak.

Mission PI P5:

André Ehrlich

Polar 5 Crew	
Mission PI	André Ehrlich
Basis Data Acq.	Christoph Petersen
SMART	Michael Schäfer
Eagle/Hawk	Elena Ruiz-Donoso
MiRAC	Mario Mech
AMALi	Tatiana Nomokonova

Flight times:

Polar 5	
Take off	08:18 UTC
Touch down	12:40 UTC

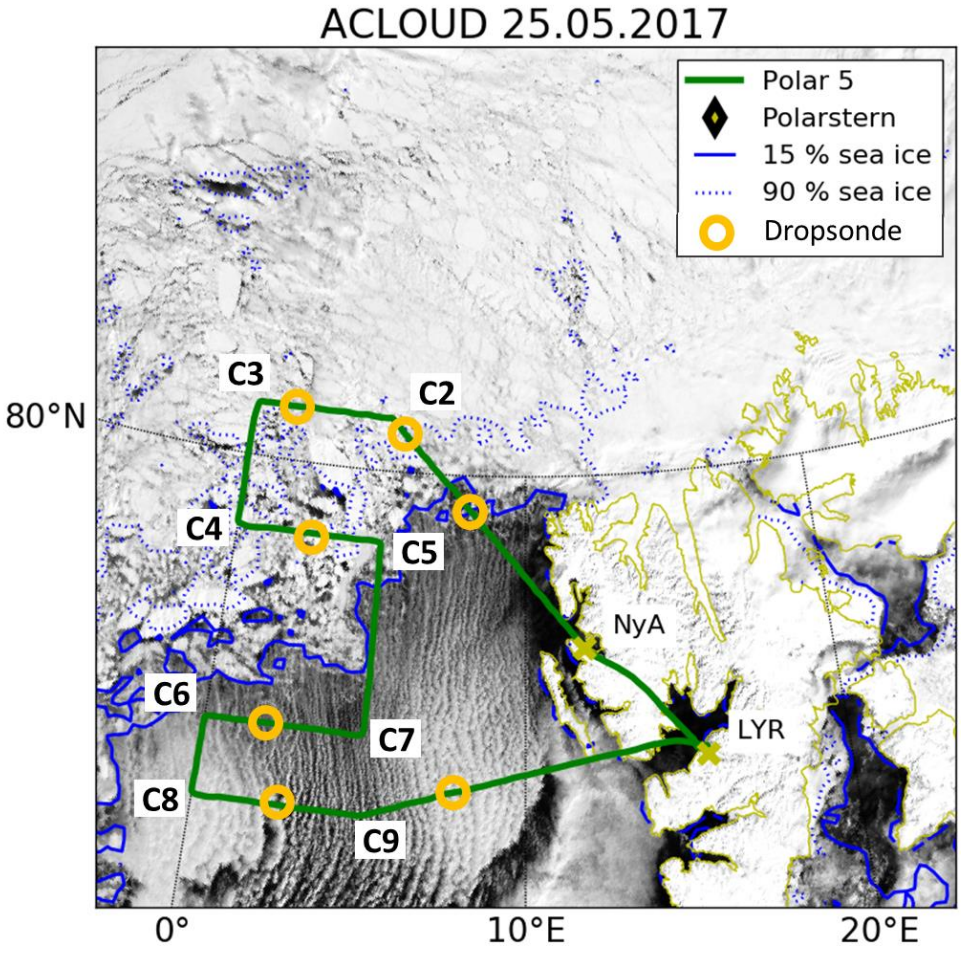


Fig. S5.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

The weather situation was very similar as predicted. A low pressure system north east of Svalbard caused a northerly flow of relative cold air masses. This air mass was channeled west of Svalbard. The island itself disturbed the flow and affected the cloud cover. Over Svalbard almost no low level clouds were present. Only tiny cloud even with light precipitation we could observe before take-off over the Isfjorden. The predicted cirrus was widespread over Svalbard but did only affect the measurements in the eastern and north-easterly part. West of the island low level clouds were present with different cloud cover. Higher cloud cover was observed with increasing distance to the sea ice edge. Over sea ice thin cloud layers and cloud streets were generated by the open leads. One cloud field close to waypoint C2 over dense sea ice showed different characteristics. Here the clouds occurred denser and homogeneous, with a very smooth cloud top.
The sea ice edge was not a fixed line, the ice fraction rather decreased continuously from almost close sea ice at 80°N, to packed small broken ice floes to single bands of ice floes at 78°N.

Overview:

Due to the absence of low level clouds the cross pattern planned for the overflight of Ny Alesund was skipped. Therefore, Polar 5 did fly a first leg in low altitude, 1000 ft above ground, over the glacier Sveabreen. These measurements can be used for surface albedo characterization. Before passing Ny Alesund Polar 5 ascended to 10 000ft and stayed in this level for the entire flight. Half the way to waypoint C2 a dropsonde was launched to test the dropsonde system, which was not operating before. The dropsonde launch succeeded. Therefore, the optional descent and ascend planned between waypoints C2 and C3 was omitted. Atmosphere profiles were sampled by dropsondes instead. In total 7 dropsondes were launched in different locations. 4 sondes on the east-west legs in different latitudes. And 3 sondes at about 8.5° E also in different latitudes.

Fig. S5.2: Photographs taken from Polar 5. Left (LYR-NyA): Sveabreen Glacier. Right (NyA-C2): Edge of cloud cover west of Svalbard.

Fig. S5.3: Photographs taken from Polar 5. Left (NyA-C2): Denser clouds over water. Right (close to C2): Dense clouds over sea ice.

Fig. S5.4: Photographs taken from Polar 5. Left (C2-C3): Thin cloud layers and small cloud streets produced by leads. Right (C3-C4): Larger leads produce larger clouds.

Fig. S5.5: Photographs taken from Polar 5. Left (C5-C6): Cloud streets become more organized with decreasing sea ice cover. Right (C5-C6 further south): compare to left image.

Fig. S5.6: Photographs taken from Polar 5. Left (C6-C9): Dense cloud fields over open water. Right (C6-C7): Cloud tops are oscillating.

Fig. S5.6: Photograph taken from Polar 5 between C9-LYR showing some larger cloud gaps. These gaps look somehow hazy.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	8 launched 1 failed

Table S5.1: Instrument status as reported after the flight for all instruments on Polar 5.

Comments: SMART and Eagle/Hawk had only one short stop in the measurements. Eagle suffered little by drop frames what could be avoided by reducing the frame rate. One dropsonde failed, because the connection to the receiver did not work properly.

Detailed Flight Logs:

André Ehrlich (times UTC)

08:17 almost clear sky in low levels with some patchy cumuli, but cirrus above
08:26 above glacier, mountains may affect measurements, some cirrus above
08:?? Start to climb to 10 000ft
08:45 SMART spectrometer crashed, before some strange values were recorded (higher counts than in clear sky). Restart of the spectrometer box could solve the problem. Failed at the same time Eagle failed… coincidence?
08:49 leaving the island, wide cloud field to the west. No sea ice jet.
08:53 lot of cirrus. Downward radiance fluctuates quite a lot
09:03 P5 above clouds now
Patchy sea ice north-east
Hazy and cirrus north-east
Cirrus also above
Clear sky to the west
09:09:30 DS #1
09:11 more and more sea ice visible
09:13 cloud top at about 600 m
09:22 clouds become denser
More sea ice
09:26 DS#2
09:30 C2
No cirrus
West of us clouds are less and only patchy
09:37 again some more clouds to the west
Dense sea ice
09:50 C3
Thin low level clouds
Ice cover 90%
No cirrus above
09:55 two thin cloud layers visible in some patches
10:05 sea ice 80%
Some leads are refrozen
Cloud streets over leads
Clouds getting thicker
10:07 C4
70% cloud cover
No cirrus
10:17:30 DS#4 → showing many layers
Inhomogeneous low clouds
Some larger leads
10:19 two cloud layers visible
10:24 more broken ice floes in south
10:26 – 10:36 over cloud streets

Sea ice only in form of single broken floes densely floating beside each other
Sea ice concentration further decreasing
Some precipitation visible by MiRAC

10:41 less and less sea ice
Clouds sometimes seem to precipitate (MiRAC)

10:44 some cirrus in East, but not in front of the Sun
Cirrus above → Downward radiance is fluctuating
Cirrus not in front of Sun → Downward irradiance stable

10:47 In westerly direction: change in cloud structure visible → photos
Still some ice floe fields
No single cloud street any more visible → structured cloud field

10:54 C6
Almost no sea ice left
Dense cloud field

11:05 DS#5 failed

11:08 DS#6 wide cloud field, only some little gaps visible when looking downward
Loose ice floes 10% ice cover

11:14 20% sea ice cover

11:24 dense cloud fields
Westerly direction: some convective cloud tops shooting atop the inversion visible

11:28 No cirrus
Over sea ice??? → Satellite image tells No Sea Ice! Just dense clouds

11:32 Change in cloud structure close ahead visible: dense clouds → structured rolls with gaps

11:40 DS#7 clouds more inhomogeneous, different phases???

11:50 C9 clouds inhomogeneous
No sea ice
No cirrus

11:57 ahead cloud field look homogeneous again
Otherwise no significant changes

12:09 DS#8 clouds everywhere

12:20 cloud gap generated by Prinz Karls Land

ACLOUD Flight #06 – Polar 5 – 2017/05/27

Objectives:

Meet with CLOUDSAT, collect data for remote sensing of different clouds and above different surfaces (sea ice/open ocean) formed in a weak cold air outbreak.

Mission PI P5:

Manfred Wendisch

Polar 5 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Christoph Petersen
SMART	Johannes Stapf
Eagle/Hawk	Elena Ruiz
MiRAC	Mario Mech
AMALi	Tobias Doktorowski

Flight times:

Polar 5	
Take off	07:58 UTC
Touch down	11:23 UTC

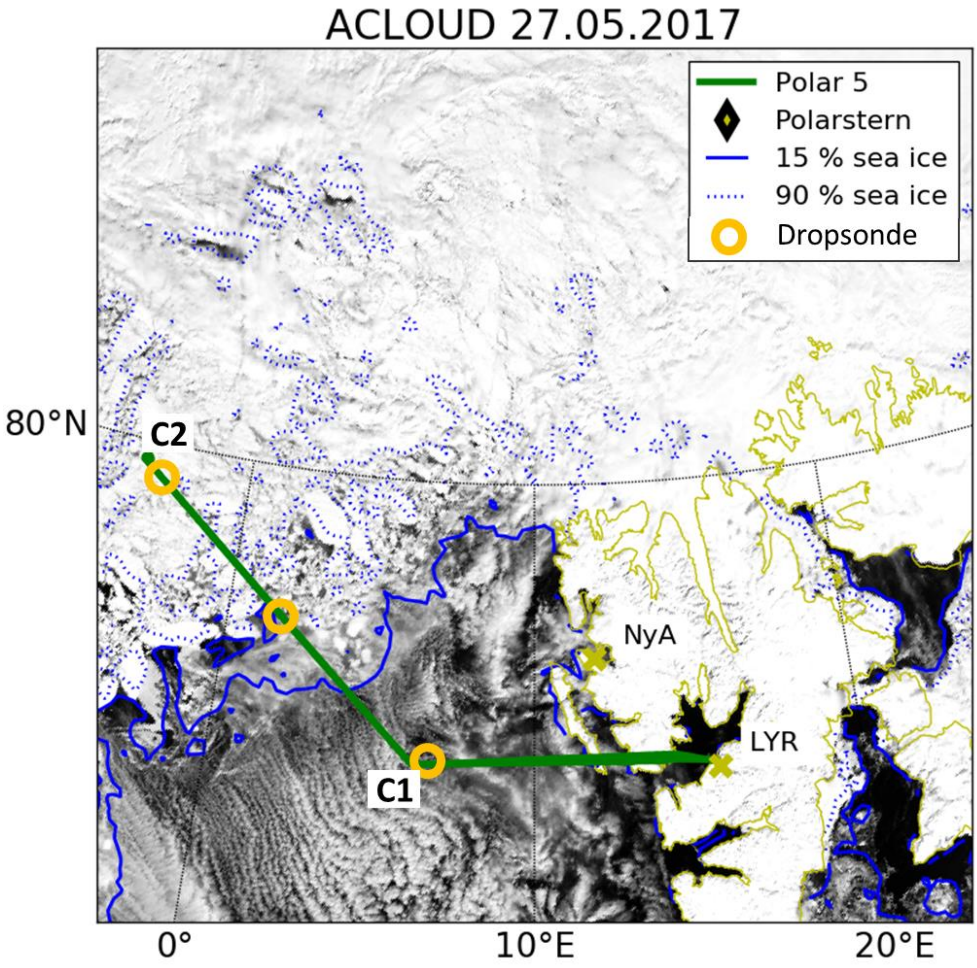


Fig. S6.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

Clouds at different altitudes were predicted by both ECMWF and GSF, and actually also showed up during the flight, see figures below. There were Northeasterly winds at 850 hPa which were well predicted, see figures below.

ECMW prediction of clouds—horizontal

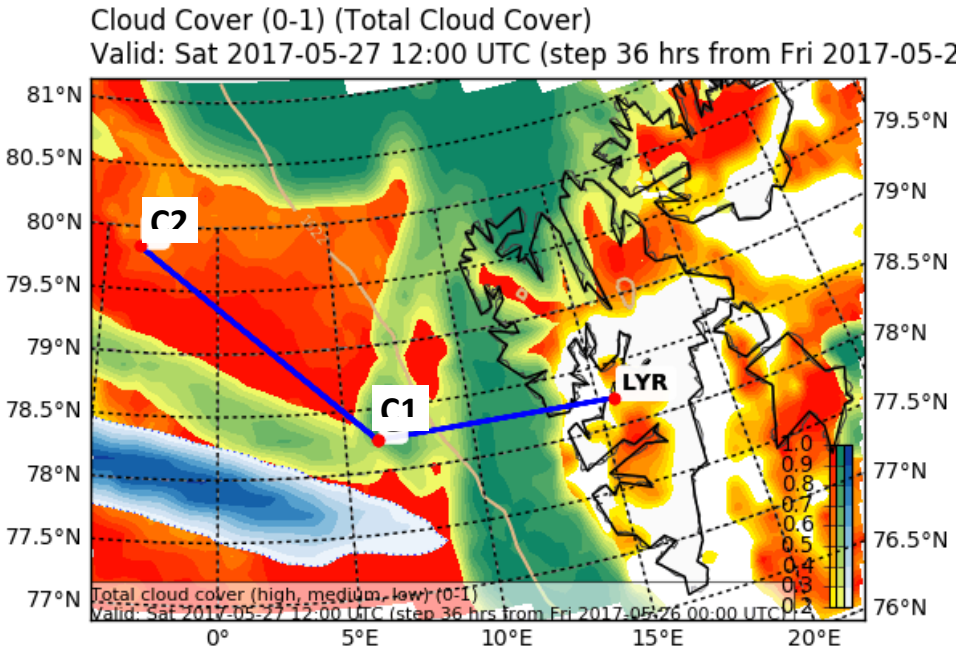


Fig. S6.2: ECMWF forecast of cloud cover of low, mid-level, and high clouds (Rautenhaus et al. 2012).

ECMW prediction of clouds—vertical

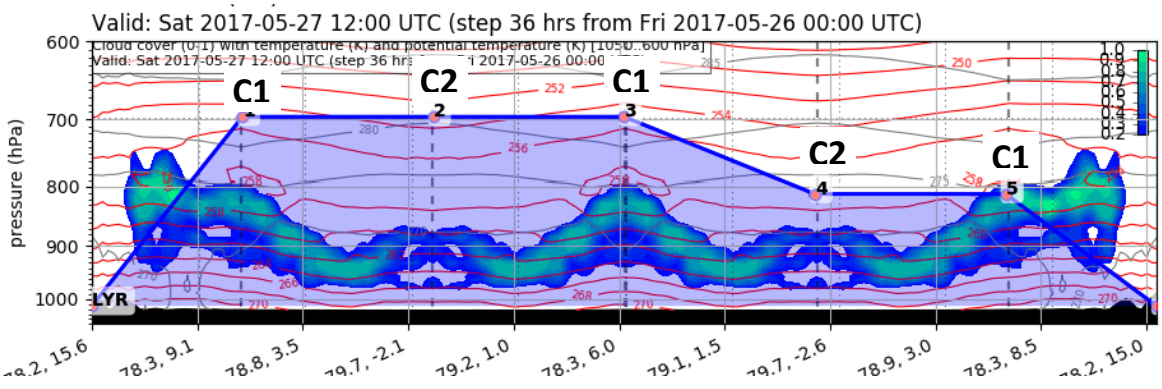


Fig. S6.3: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

ECMW prediction of wind 850 hPa

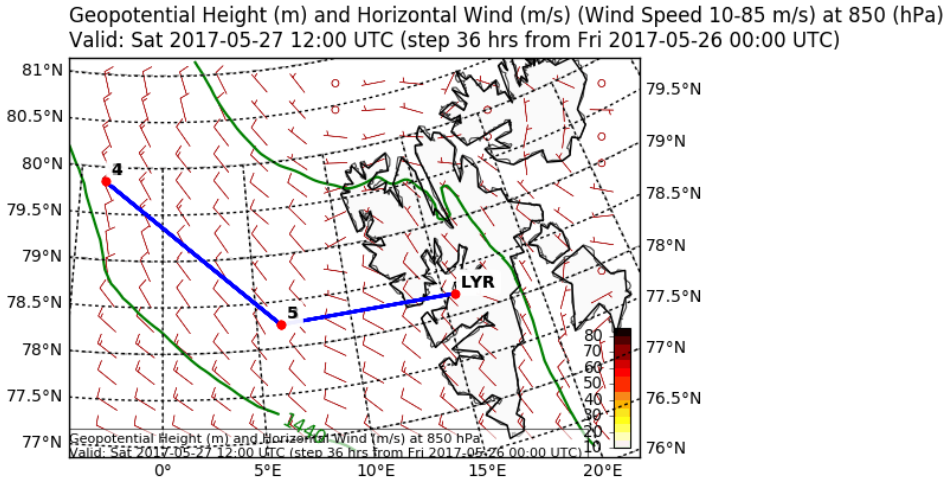


Fig. S6.4: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Overview:

LYR – C1 climb and stay at ≈10,000 ft: **115 NM @ 140kn** **45 min**

- 07:55 Taxi, all instruments okay
- 07:58 Takeoff
  - Almost cloudless, some scattered Cu
- 08:08 Start climbing to 10,000 ft in the direction of C1
  - Cloud penetration, thin cloud
  - At 10,000 ft cloud below aircraft
- 08:12 Nice clouds below and ahead of us, no cirrus above, see photo

Fig. S6.5: Photograph taken from Polar 5.

- 08:24 More scattered clouds below

Fig. S6.6: Photograph taken from Polar 5.

- 08:26 Rather thin clouds
- 08:28 Climbing somewhat higher than 10,000 ft to reach the cloud tops.

- 08:45 We reach C1, thick clouds below, multilayer

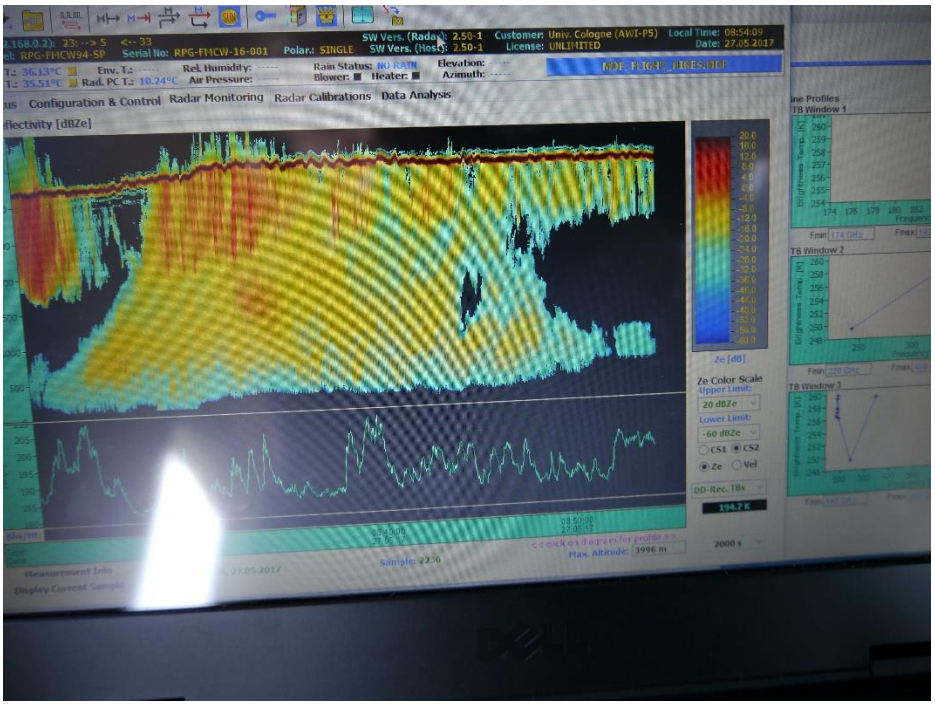


Fig. S6.7: Photograph taken from Polar 5.

C1 – C2 at 10,000 ft: **147 NM**

- 08:50 Inhomogeneous cloud below, no cirrus above, some sea ice
- 09:03 Cloud top about 700 m, quite low, more sea ice below
- 09:08 Clouds getting thicker, no cirrus
- 09:23 Scattered clouds, but no cirrus above, cloud top at 1 km, more sea ice below

Fig. S6.8: Photograph taken from Polar 5.

Fig. S6.9: Photograph taken from Polar 5.

- 09:45 We pass C2, turn with a circle
- 09:49 View into direction of C1

Fig. S6.10: Photograph taken from Polar 5.

C2 – C1 at 10,000 ft: **147 NM**

Objective: Release three drop sondes at C2, Satellite meeting, and C1

Meet satellite at: **79° 4.044' N, 1° 47.434' E**

10:27:00 UTC

- 09:54 First drop sonde, close to C2, Aircraft slows down, to adjust the meeting to the satellite, pitch about 5°, sonde landed on ice

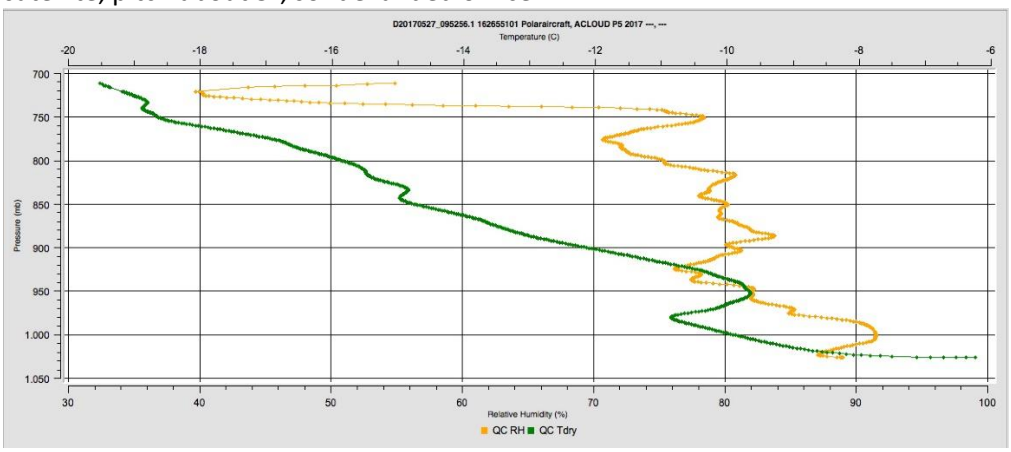


Fig. S6.11: Temperature and humidity profile measured by a the dropsonde.

Fig. S6.12: Photograph taken from Polar 5.

-
- 10:22 Satellite point is reached
- 10:23 Second drop sonde is released, landed in the water

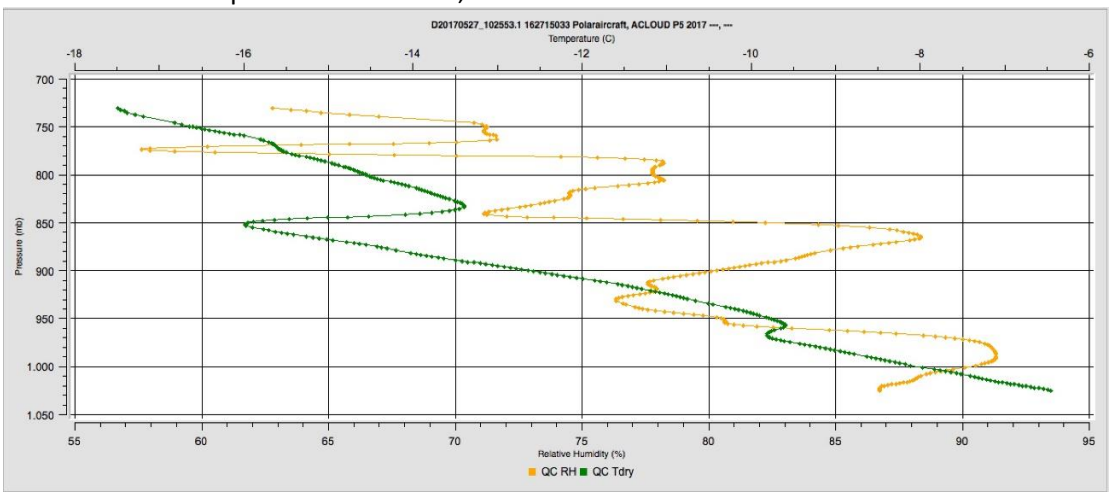


Fig. S6.13: Temperature and humidity profile measured by a the dropsonde.

Fig. S6.14: Photograph taken from Polar 5.

- 10:27 CALIPSO flies over us, we met the satellite a little more to the south, as originally planned
- 10:27 Some problems with SMART, data loss for about 10 minutes
- 10:45 We reach C1 again, third dropsonde released, has landed in water

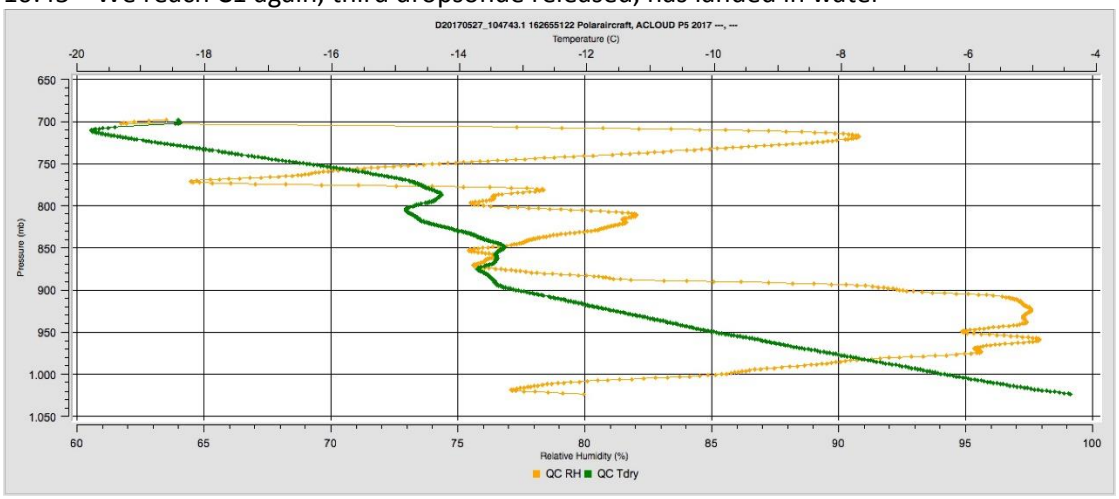


Fig. S6.15: Temperature and humidity profile measured by a the dropsonde.

C1 – LYR **115 NM**

- 10:50-10:55 Glories observed all the flight back
- 11:23 Touch down

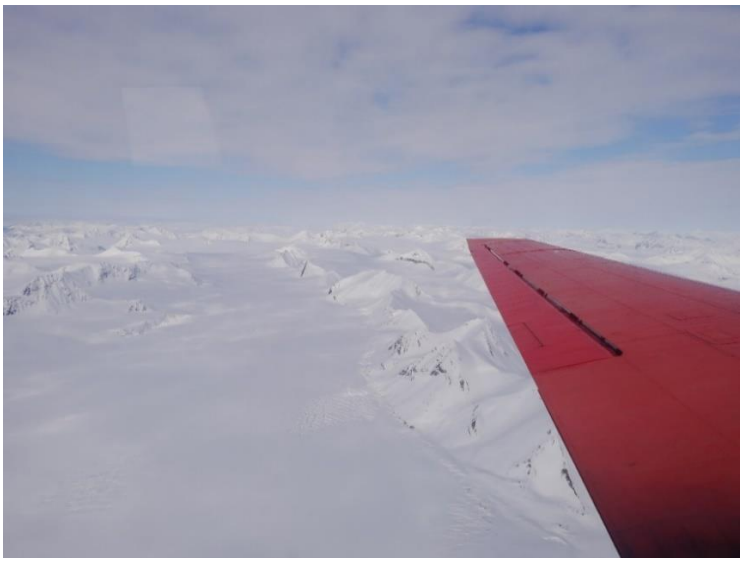


Fig. S6.16: Photograph taken from Polar 5.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	3 launched

Table S6.1: Instrument status as reported after the flight for all instruments on Polar 5.

Comments:

SMART had a short stop in the measurements, 10 minutes of data were lost. Eagle and Hawk worked fine, also the radar and microwave worked well. No problems with drop sondes.
No cirrus at all during the whole flight.

- This flight should ideally work to do a detailed comparison with CloudSat. We had thick and thin clouds, the cloud radar covered it well.

ACLOUD Flight #07 – Polar 5&6 – 2017/05/27

Objectives:

Repeating the identical flight track of flight #06 few hours ago and investigating potential changes of the cloud properties within this short time span. Coordinated flight of Polar 5 and 6 to characterize clouds in different regimes and different surfaces (sea ice/open ocean) within a weak cold air outbreak. Polar 5 remains at 10 000ft altitude for continuous remote sensing, while Polar 6 sampled the low-level cloud, analyzed aerosol below and above the cloud adding a vertical profile to 10000 ft altitude.

Mission PI P5:

Manfred Wendisch

Polar 5 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Christoph Petersen
SMART	Michael Schäfer
Eagle/Hawk	Evelyn Jäkel
MiRAC	Tatiana Nomokonova
AMALi	Friedhelm Jansen

Mission PI P6:

Johannes Schneider

Polar 6 Crew	
Mission PI	Johannes Schneider
Basis Data Acq.	Martin Gehrmann Daniel Damaske
ALABAMA	Hans-Christian Clemen
CVI	Stephan Mertes
Gas/AWI-Aerosol	Heiko Bozem
PMS	Emma Järvinen Christophe Gourbeyre

Flight times:

Polar 5	
Take off	13:02 UTC
Touch down	16:21 UTC

Polar 6	
Take off	13:02 UTC
Touch down	16:27 UTC

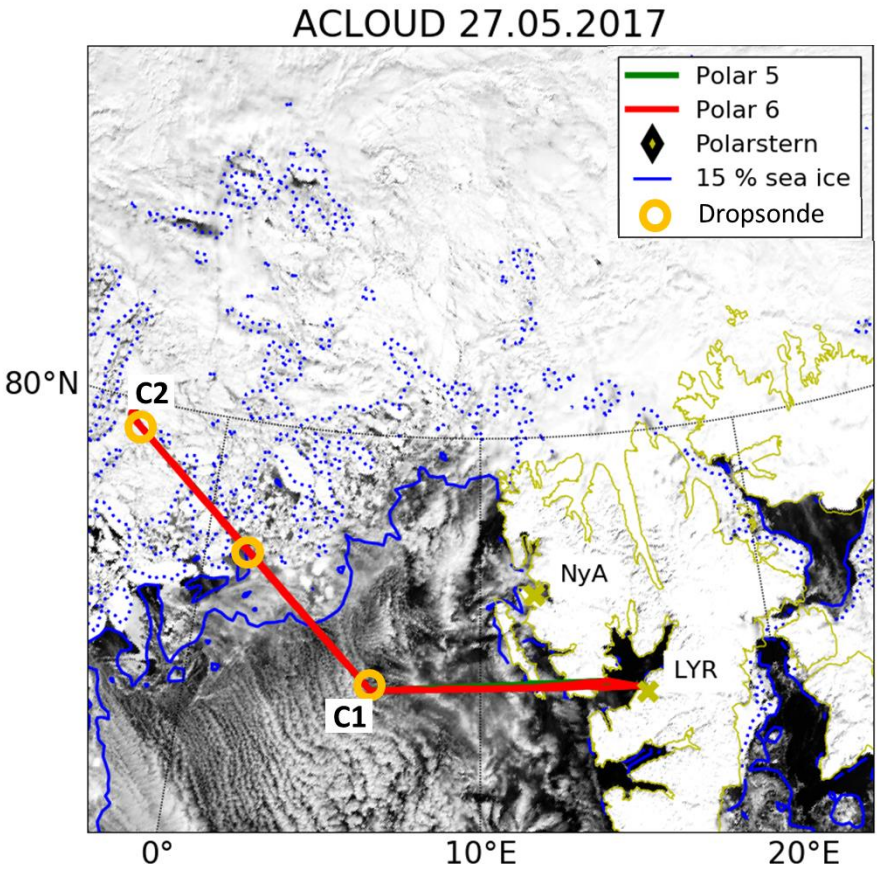


Fig. S7.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

No significant changes to flight #06 on the morning of 27 May 2017. See also flight report of flight #06. Cloud situation was still similar to forecast: cloud top higher at C1 and lower towards C2. Cloud base was between 400 ft and 600 ft, lower over the sea ice compared to open water, also as predicted. The clouds were mainly liquid, but occasionally ice was observed. Little precipitation was observed below the clouds.

Overview:

Flight pattern was flown as planned. Polar 6 approached to C1 at 6000 ft (briefly passing though clouds), then cloud profiling between C1 and C2 as sketched below:

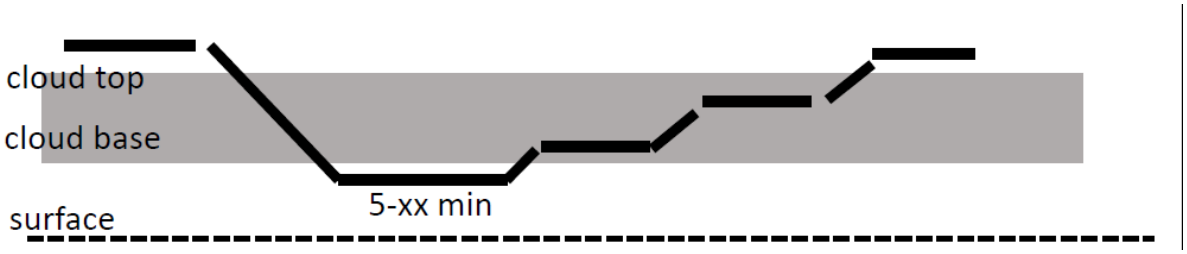


Fig. S7.2: Proposed flight pattern of Polar 6 to sample the clouds in different altitudes.

On the return between C2 and C1 three cloud levels and one leg below the clouds were flown by Polar 6. Between C1 and LYB ascent to 5000 ft, short level, then ascent to 10000 ft, then descent to LYB.

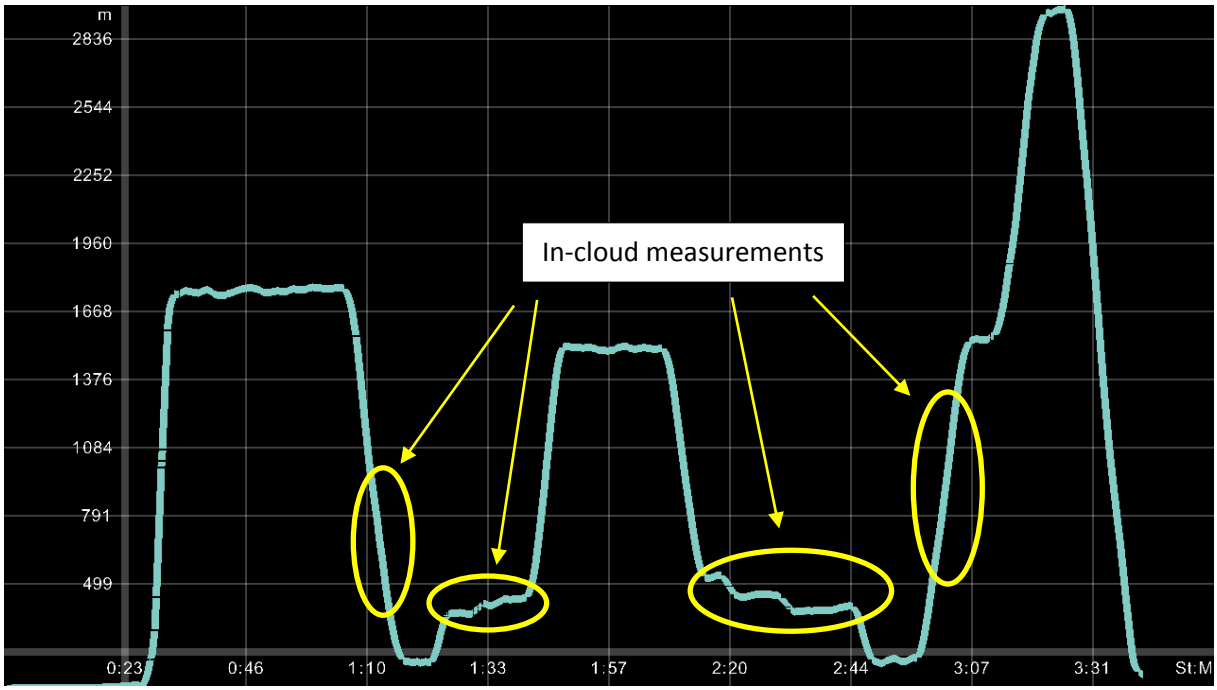


Fig. S7.3: Flight altitude of Polar 6 during the flight. Yellow circles indicate the location of in-cloud measurements.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	3 launched

Table. S7.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table. S7.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

No instrumental problems were reported.

Detailed Flight Logs:

Polar 5: Manfred Wendisch (all times UTC)

LYR – C1 climb and stay at ≈10,000 ft: **115 NM @ 140kn 45 min**

- 13:02 Taxi, all instruments okay
- 13:04 Takeoff
- 13:06 We are below a cloud deck, as we were in the morning flight
- 13:10 Very scattered clouds at the beginning
- 13:14 Sun glint below us, also snow, kind of mixed clouds
- 13:17 Cloud penetration from below, no cirrus above

Fig. S7.4: Photograph taken from Polar 5.

- 13:24 Thin clouds beneath us
- 13:27 We slightly climb to get over the cloud top
- 13:32 More thick clouds, and lower

Fig. S7.5: Photograph taken from Polar 5.

- 13:49 We reach C1 at an altitude of 10,750 ft

C1 – C2 at 10,000 ft: **147 NM**

- 13:50 Clouds below, nothing above flight altitude

Fig. S7.6: Photograph taken from Polar 5.

Fig. S7.7: Photograph taken from Polar 5.

- 14:00 Scattered low level clouds below flight altitude, cloud top estimated at 500 m, radar doesn't see much

Fig. S7.8: Photograph taken from Polar 5.

- 14:15 No cirrus observed so far on this flight
- 14:20 More thick clouds, better for radar, however still quite low

Fig. S7.9: Photograph taken from Polar 5.

- 14:38 Polar 6 can be seen beneath us

Fig. S7.10: Photograph taken from Polar 5.

- 14:50 C2 is reached, P6 just ahead of us

C2 – C1 at ≈10,000 ft: **147 NM**

- 14:54 P6 enters the cloud, can be seen from above from P5
- 14:55 First drop sonde released

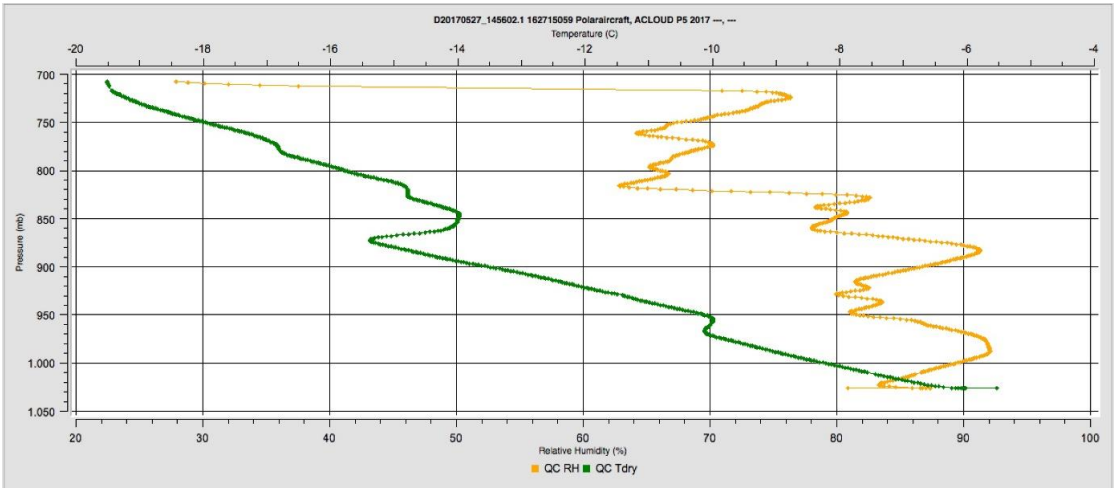


Fig. S7.11: Temperature and humidity profile measured by a the dropsonde.

- 14:55 Glory
- 15:02 First dropsonde landed on the ice (-5.7 °C)

Fig. S7.12: Photograph taken from Polar 5.

- 15:05 Glories all the time

Fig. S7.13: Photograph taken from Polar 5.

- 15:14 Altitude still ≈10,800 ft

Fig. S7.14: Photograph taken from Polar 5.

- 15:25 Second drop sonde released

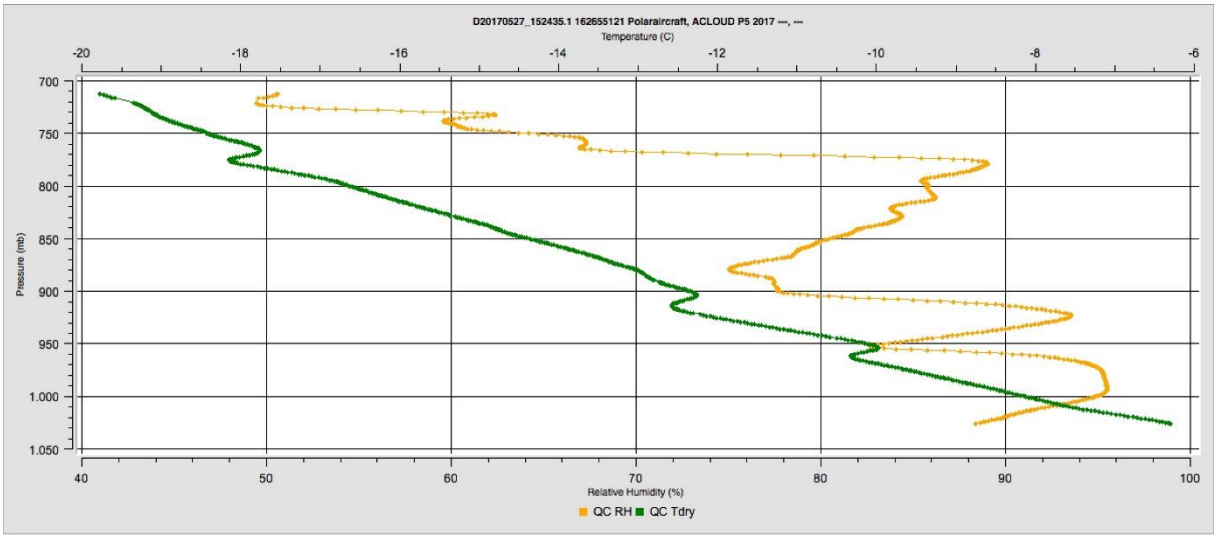


Fig. S7.15: Temperature and humidity profile measured by a the dropsonde.

- 15:45 C1 is reached again

C1 – LYR **115 NM**

- Third sonde

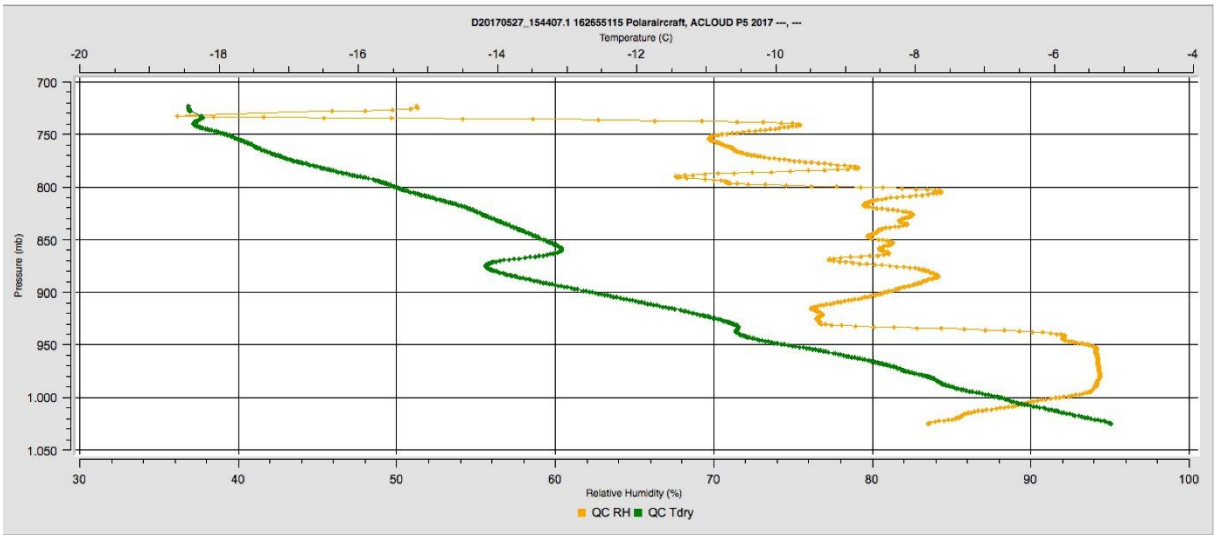


Fig. S7.16: Temperature and humidity profile measured by a the dropsonde.

Fig. S7.17: Photograph taken from Polar 5.

- 16:23 Touch down

Polar 6: Johannes Schneider (all times UTC)

13:02	Take off
	climb to 6000 ft, 160 knots
13:24	slow to 150 knot to allow P5 to approach
13:28	above clouds
13:30	again in clouds, T = -11°C
13:33	between mid and low clouds, CVI residuals decrease
	135 knots
	140 knots
13:47	turn
13:48	descent (500 ft/min) starts
13:54	cloud top (3300 ft)
13:58	cloud base (400 ft)
13:59	200 ft (stay for 5 min) below clouds
14:01	ice edge
14:08	climb into cloud (cloud base 600 ft)
14:09	1000 ft (in cloud)
14:16	1200 ft (in cloud) 150 knots
14:22	Emma reports ice in clouds
	Pilots: Ice on PMS probes
14:26	go above cloud
14:31	5000 ft
	Continue to C2, then turn, then try cloud profile in 3 levels
14:50 – 53	descend (500 ft/min)
	Try 3 cloud levels
	Some mid-level clouds at 3500 ft
15:00	1500 ft (stay 5 min), over sea ice
15:05	go down to 1200 ft (175 knots ground speed)
15:12	to 1000 ft (around cloud base, but mainly inside)
	Emma: ice in this cloud
	(10 more minutes, -6°C)
15:30	go below cloud
15:33	200 ft, stay until C1
15:45	C1
	Climb to 5000 ft
	Cloud base at 1300 ft
	Cloud top at 4800 ft
15:53	5000 ft, stay for a few minutes
16:00	start ascent to 10000 ft
16:13	start descent (fast)
16:27	Touch down

ACLOUD Flight #08 – Polar 5&6 – 2017/05/29

Objectives:

The main goal of the flight was a study of the cloud development during a cold air outbreak over the Northern Fram Strait with both aircraft coordinated. Secondary goal: Nose boom calibration.

Mission PI P5:

Christof Lüpkes

Polar 5 Crew	
Mission PI	Christof Lüpkes
Basis Data Acq.	Christoph Petersen
SMART	Johannes Stapf
Eagle/Hawk	Evelyn Jäkel
MiRAC	Tatiana Nomokonova
AMALi	Tobias Doktorowski

Mission PI P6:

Johannes Schneider

Polar 6 Crew	
Mission PI	Johannes Schneider
Basis Data Acq.	Daniel Damaske
ALABAMA	Hans-Christian Clemen
CVI	Stephan Mertes
Gas/AWI-Aerosol	Heiko Bozem
PMS	Delphine Leroy

Flight times:

Polar 5	
Take off	04:54 UTC
Touch down	08:50 UTC

Polar 6	
Take off	05:11 UTC
Touch down	09:16 UTC

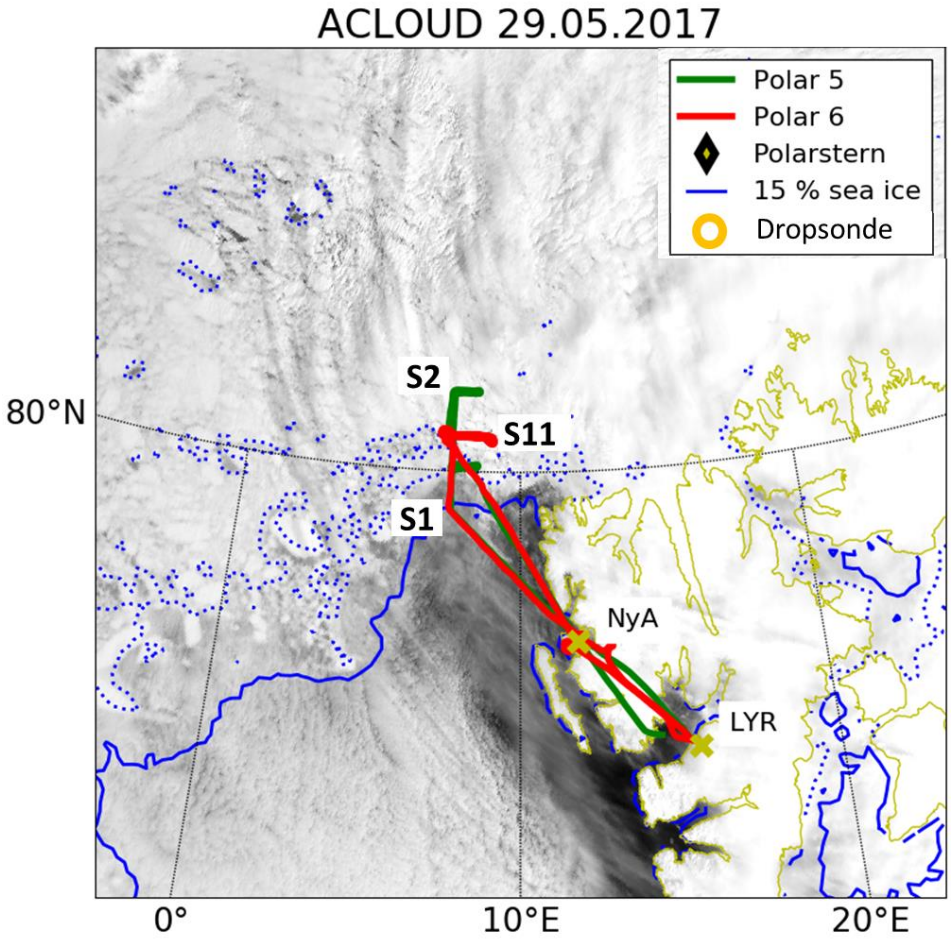


Fig. S8.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

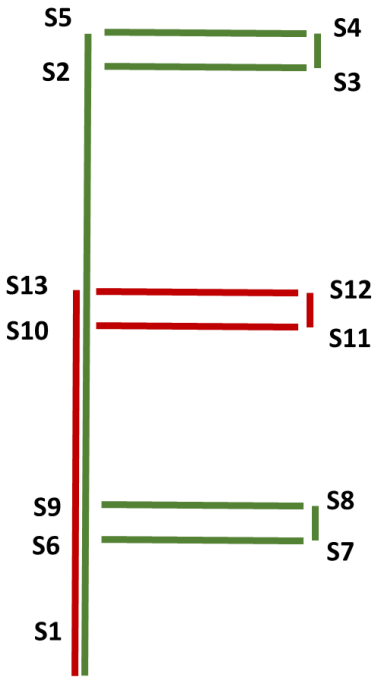


Fig. S8.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

Still, cold air was flowing off the sea ice in southerly direction (see Figure below) with wind from northeast as seen in the figure below showing the 3 hour GFS forecast for 9 UTC (wind and low clouds). The flight was carried out early due to an approaching front from east across the entire Svalbard region.

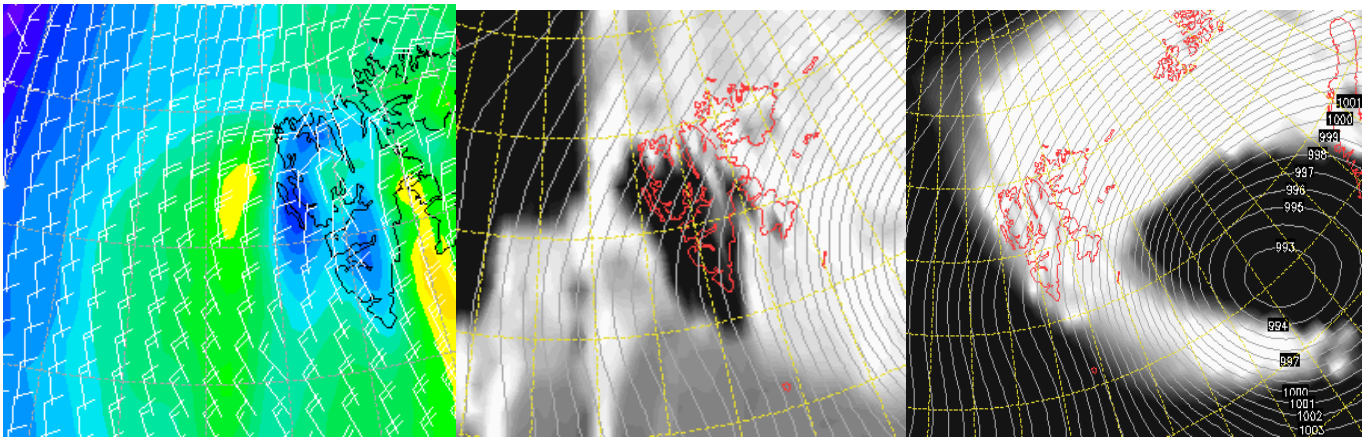


Fig. S8.3: 10 m wind (left), low clouds (middle) and high clouds (right) from 9 UTC GFS 3 hr prediction (www.wetterzentrale.de, Georg Müller).

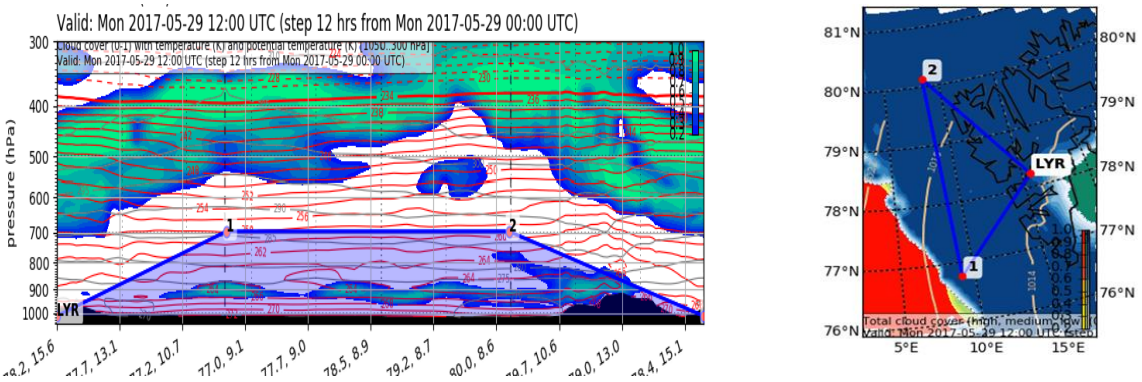


Fig. S8.4: left: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast. Right: ECMWF forecast of cloud cover of low, mid-level, and high clouds (Rautenhaus et al. 2012).

Low clouds were predicted for the ice free part of the Fram Strait and the marginal sea ice zone (see Figure above). The observed situation agreed well with the prediction clouds were sometimes surface based at the position of the northernmost box.

Over the ice where rectangle pattern (S10-S11-S12-S13) was conducted clouds were between 800 ft and 300 ft, thus thicker than expected. At the beginning if the flight (after Ny Alesund overpass clouds where around 1500 ft, but below 3000 ft. Some high level cloud were observed as predicted.

Overview:

The flight strategy was to measure the cloud structure by the remote sensing instrumentation (Lidar, Eagle Hawk, MiRAC), the inflow profile of wind and temperature over sea ice at the northernmost position, and near-surface turbulent fluxes along two boxes over sea ice with Polar 5 (S2-S3-S4-S5 and S6-S7-S8-S9). Another box (S10-S11-S12-S13) should follow with Polar 6 flown between the northern and southern box of Polar 5.

Horizontal legs should be flown in the boundary layer in different heights. The rectangle pattern (S10-S11-S12-S13) was flown by Polar 6 in legs of 200, 400, 600, 1000, 1200, 3000, 3300, 3600 ft, with two layers (1000 and 1200) in clouds. The noseboom calibration square was flown (due to a misunderstanding during the flight) over Ny Alesund at 10000 ft altitude with 100, 120, 150 and 100 knots. The highest altitude of Polar 6 was 12000 ft.

With Polar 5, snow albedo measurements were planned over the glacier between Longyearbyen and Ny Alesund at 1000 ft and in the region of the boxes.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	None launched

Table S8.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S8.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments: Noseboom on Polar 5 was working only at the northern boxes due to strong icing (as seen after the flight). On Polar 6, PHIPS and SID not operational due to inverter problems.

Detailed Flight Logs:

Polar 5: Christof Lüpkes (all times UTC)

Clouds

As predicted, there were only cirrus clouds over Svalbard increasing in thickness towards East (see photo below taken over the glacier).

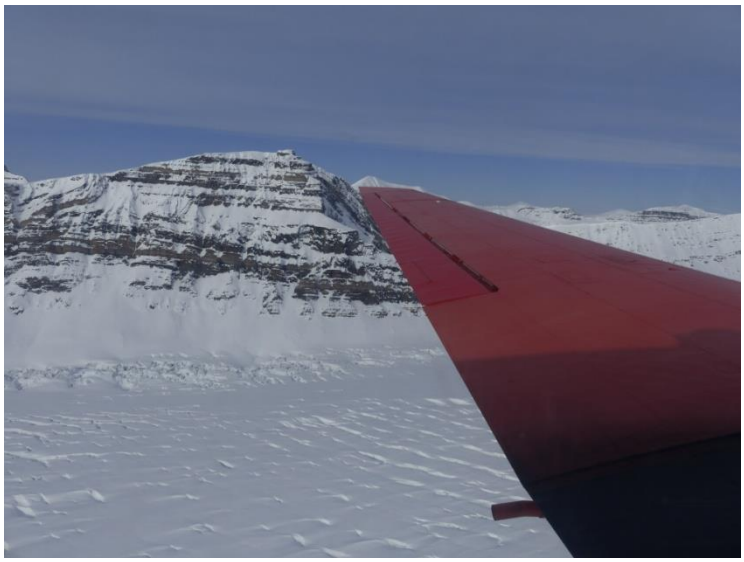


Fig. S8.5: Photograph taken from Polar 5 (7:06 UTC).

Cloud situation over Fram Strait

Cloud cover increased considerably over Fram Strait with typical cold-air stratocumulus rolls.

Fig. S8.6: Photograph taken from Polar 5 (7:40 UTC).

Over the northern box, low cloud was still high (7/8 - 8/8). Some clouds were surface based causing bad visibility at 200 ft.

Clouds in the region of the boxes and boundary layer

Fig. S8.7: Photograph taken from Polar 5 during the first 200/400 ft leg at northern box.

Fig. S8.8: Photograph taken from Polar 5 during the first 200/400 ft leg at northern box.

Quicklook of temperature profile (noseboom)

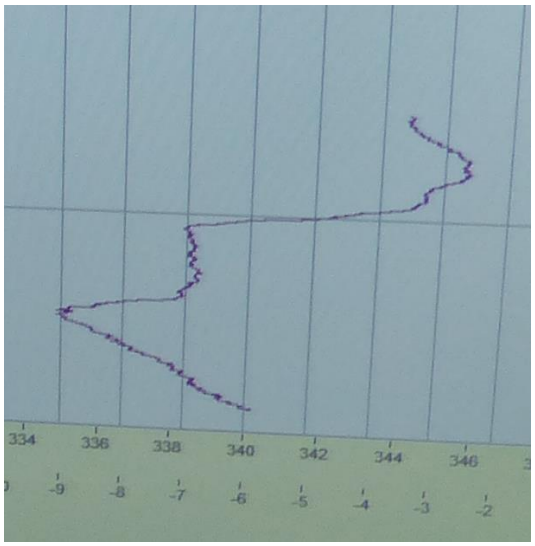


Fig. S8.9: Temperature profile measured by the noseboom on Polar 5. The lowermost inversion base is at 1500 ft. The secondary inversion base at 3000 ft (height marked by horizontal grey line).

About 90 % cloud cover (low clouds) has been observed at the position of the northern box. Some clouds were surface based, visibility was very low (about 1 km and less). Cloud tops were at 1500 ft (north) and 1300 ft at the southern box. Cloud base increased significantly on the way towards south to about 800 ft at the southern box. As shown in the Figure above, there were multiple inversions, the lowermost in 500 ft, but clouds extended up to 1300-1400 ft.

Maneuvers

The northern boxes consisted of four flight sections in different heights. The first one was started at 200 ft, however, the leg had to be interrupted due to decreasing visibility along the flight leg. The remaining leg was flown in 400 ft. The other legs followed in 700, 1000 and 1300 ft. The latter was 100, 200 ft below cloud top.

A low-level leg at 200 ft followed on the way towards south (S2 → S6). There, the visibility increased significantly and clouds were not any more surface based.

The southern box at S6 was flown in 4 levels 200 ft, 400 ft, 800 ft, and 1200 ft. The last base had to be interrupted due to strong icing and vibrations during the flight.

Sea ice conditions

Fig. S8.10: Photograph taken from Polar 5 during the 200 ft leg between S2 and S6.

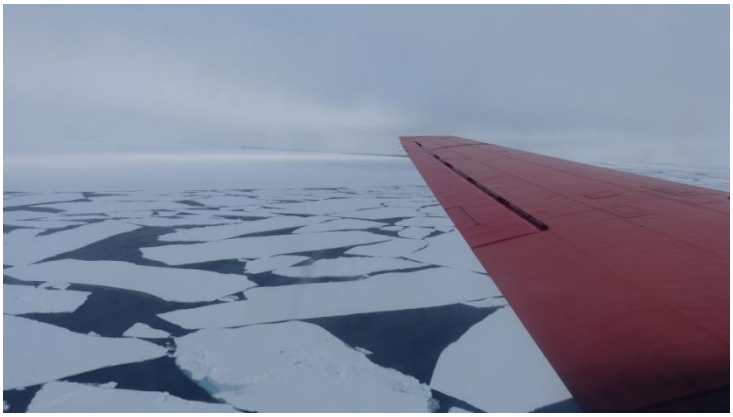


Fig. S8.11: Photograph taken from Polar 5 during the 200 ft leg between S6 and S7.

There was large sea ice cover, but several ice free small polynyas and leads occurred along the tracks. At the southern box (between (S6 and S7) also drifting floes were observed during the first third of the leg.

Polar 6: Johannes Schneider (all times UTC)

05:11:20	Take off
	climb to 4000 ft, fly over fjord toward Ny Alesund, over glacier. Some cirrus above, otherwise cloud-free
05:35 – 40	fly over fjord near Ny Alesund at 1500 ft
05:41	start descent to 200 ft
05:43	ship overpass, have to stay higher than 200
05:44:30	reach 200 ft, flowmeter aerosol 50 l/min
05:49:30	start ascent to 1500 ft
05:53:20	at 1500 ft into clouds
05:58:00	climb above clouds (inversion, ambient T -2°C)
06:00	3000 ft
06:06:30	S1, start descent to 200 ft, through clouds. Below clouds we are over ice
06:17	leave track to the right to start turn toward leg S10-S11
06:21:37	S10, start rectangle pattern, 200 ft
06:27:20	S11, turn and climb to 400 ft
06:29:30	reach 400 ft
06:31:55	S12, start 400 ft leg
06:37:16	S13, climb to 600 ft
06:42:15	S10, start 600 ft leg
06:48:50	S11, climb to 1000ft
06:53:44	S12 (in clouds), start 1000 ft leg
06:59	S13, climb to 1200 ft
07:04:10	S10, start 1200 ft leg, in clouds
07:09:59	S11, climb to get above cloud, have to go to 3000 ft
07:15:55	S12, start 3000 ft leg. Very low aerosol concentration so close above cloud!
07:25:55	S10, start 3000 ft leg
07:31:40	S11, climb to 3600 ft
07:36:40	S12, start 3600 ft leg
07:41:15	S13, end of rectangle pattern, turn towards Ny Alesund, climb to 10000 ft, then to 12000 ft
08:00:00	12000 ft
08:05:00	start descent to 10000 ft
08:17	start noseboom calibration square, 100 knots, 1st square
08:28	start 2nd square, 220 knots
08:38	start 3rd square, 150 knots
08:41	start 4th square, 100 knots
	2 more minutes at 10000 ft
	Descent to 5000 ft (3 minutes)
	Approach to LYB
09:16:41	Touch down

ACLOUD Flight #09 – Polar 6 – 2017/05/30

Objectives:

Cloud probing, measurements in the exhaust plume of Polarstern and Aerosol and trace gas vertical profile near Polarstern for intercomparison.

Mission PI P6:

Heiko Bozem

Polar 6 Crew	
Mission PI	**Heiko Bozem**
Basis Data Acq.	**Daniel Damaske**
ALABAMA	**Hans Clemen**
CVI	**Stephan Mertes**
Gas/AWI-Aerosol	**Johannes Schneider**
PMS	**Emma Järvinen, Christophe Gourbeyre**

Flight times:

Polar 6	
Take off	**09:17 UTC**
Touch down	**13:30 UTC**

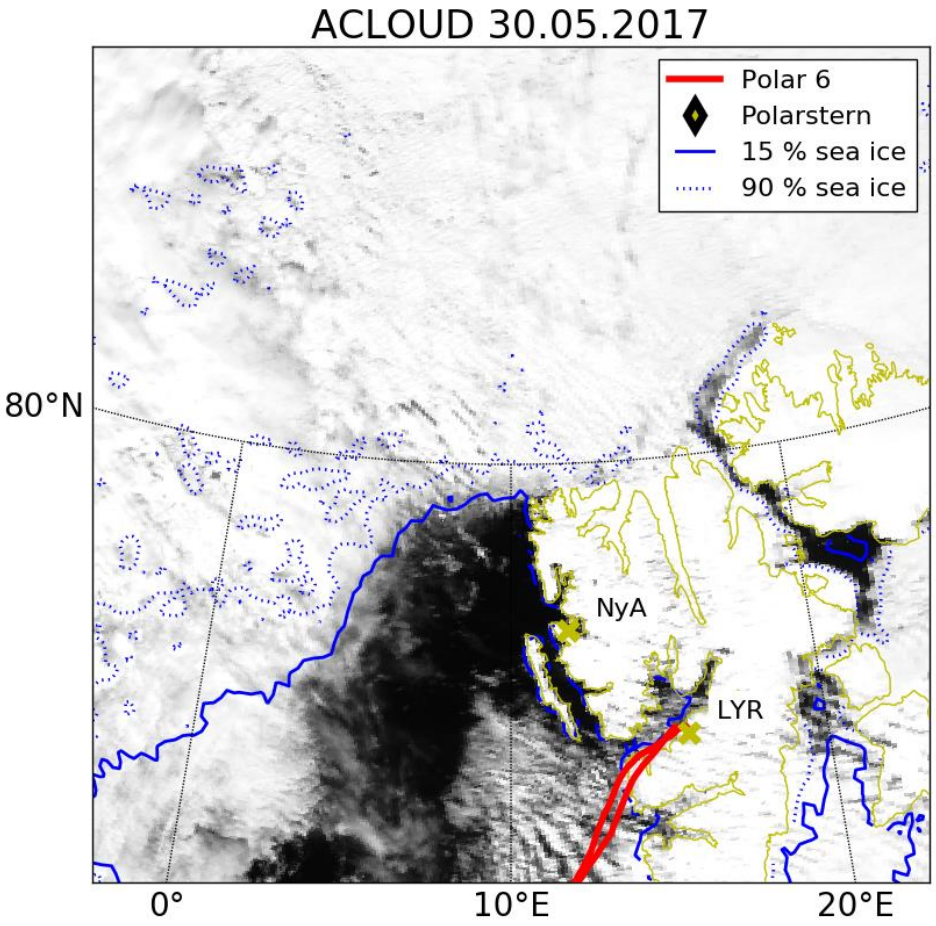


Fig. S9.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

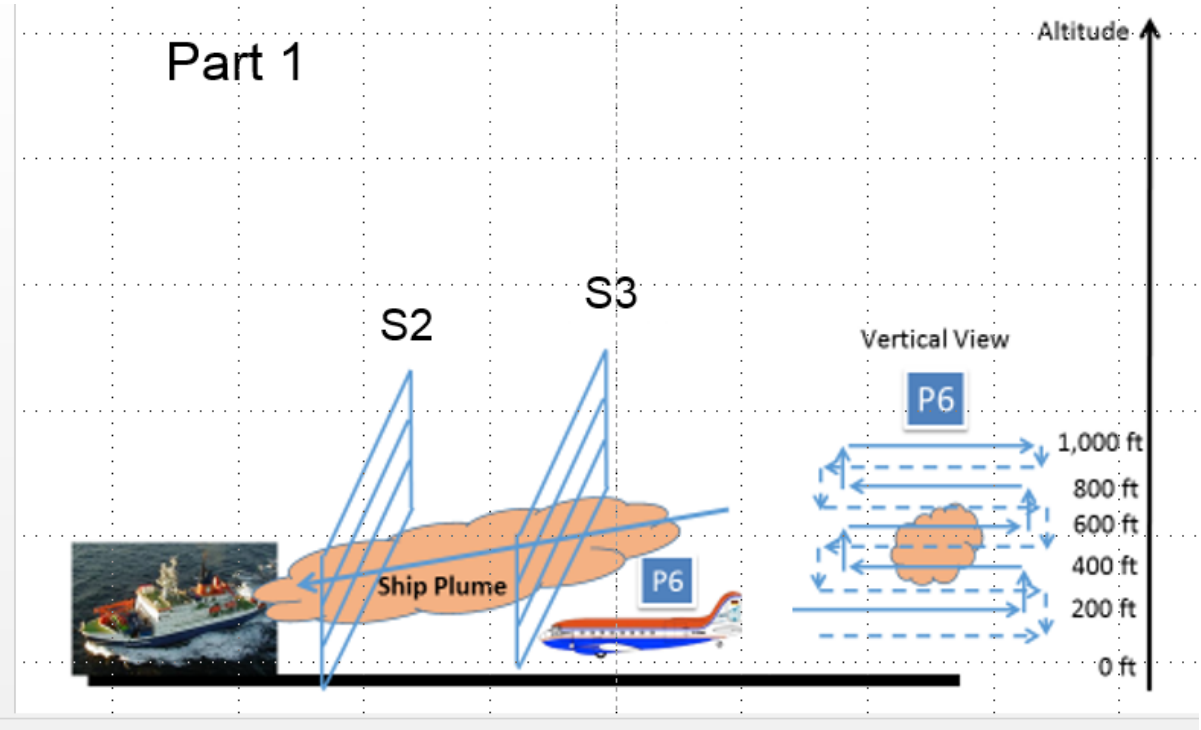


Fig. S9.2: Detailed flight pattern in the main observation area in low altitudes close to Polarstern.

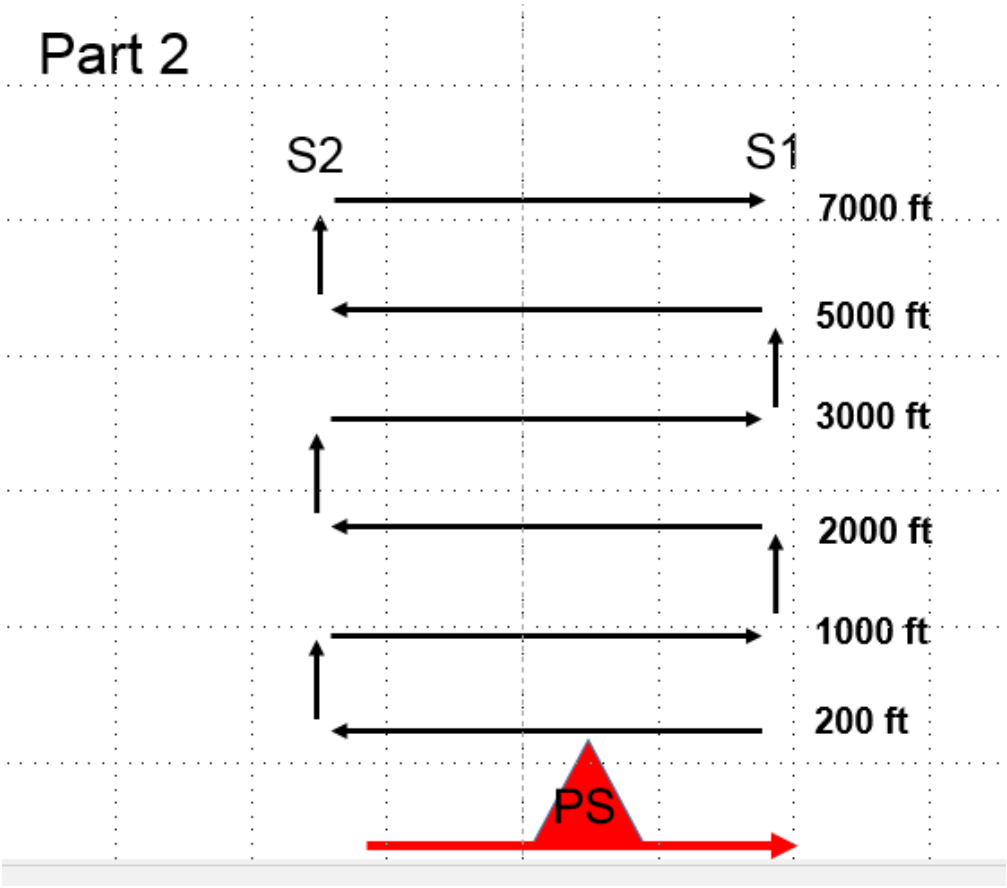


Fig. S9.3: Detailed flight pattern in the main observation area in high altitudes over Polarstern.

Weather situation as observed during the flight (compare to forecast):

A mix of mid and high level clouds observed as forecasted. Cloud situation on the way to Polarstern: very patchy clouds, thin in vertical and horizontal extend. Cloud layer above 10000 ft. On the way back from Polarstern “haze layer” at 10000 ft. and again patchy clouds below. Mostly cloud free over Longyearbyen.

Overview:

The main objectives of the flight were to probe clouds on the way to Polarstern, then sample the exhaust plume of Polarstern at different horizontal distances behind the ship and afterwards to perform a vertical profile with different levels between 200 and 10000 ft behind the ship (levels: 2000 ft, 3000 ft, 5000 ft, 7000 ft, 10000 ft). The idea for plume sampling was to do a vertical “slice” behind the ship at a distance of ~10 nm for sampling the exhaust. With levels of 200 to 1400 ft with 200 ft altitude steps the vertical extent of the plume should be characterized. A second slice at a distance of 2-3nm behind the ship should help to identify the dispersion of the plume.

The flight pattern worked quite well for the plume and the plume could be identified with the most intensive signals between 400 and 800 ft in altitude. Also the vertical profile nearby Polarstern up to 10000 ft worked well. On the way to Polarstern only midlevel patchy clouds could be observed. With probing the cloud for only a few seconds no proper cloud measurements were possible. On the way back from Polarstern a haze layer containing large ice particles could be probed for 15 min at an altitude of 10000 ft.

Instrument Status:

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table. S9.1: Instrument status as reported after the flight for all instruments on Polar 6.

Comments: None

Detailed Flight Logs:

Heiko Bozem (times UTC)

9:17:54 Takeoff and ascent to 5000 ft

9:34 fly through fields of patchy clouds at 5000 ft, very thin in horizontal and vertical extent. Cloud layer above at an altitude > 12000 ft

Fig. S9.4: Photograph taken from Polar 6.

9:41 29 min to Polarstern. Weather at Polarstern: good visibility and wind from 030°, 10 kt.

9:54 still flight at 5000 ft through thin patchy cloud field not well suited for probing.

10:04 start descent to Polarstern

10:11 cloud crossing at 2500 ft

10:16 start of “slice” pattern 5nm behind the ship at 200 ft

10:18 CPC signal of ship plume

10:21 next level at 400 ft

10:22 CPC signal of ship plume

10:25 next level 600 ft

10:27 CPC and SP2 plume signal

10:29 next level 800 ft

10:31 CPC peak

10:32 second CPC peak

10:35 next level 1000 ft

10:37 CPC peak

10:39 CPC peak

10:40 next level 1200 ft

10:43 CPC peak

10:44 CPC peak

10:46 next level 1400 ft

10:49 CPC peak

10:51 CPC peak

10:58 circles to wait for radiosonde on Polarstern to be launched
11:05 next slice 3nm behind ship starting at 200 ft
11:07 CPC peak
11:12 CPC peak at 400 ft
11:13 second CPC peak but not as large as first one
11:17 CPC peak at 600 ft
11:20 CPC peak at 800 ft
11:26 CPC peak at 1000 ft
11:32 CPC peak at 1200 ft
11:40 approach of Polarstern from behind within the plume
11:57 start of vertical profile at different layers behind the ship
12:01 start first leg at 2000 ft
12:06 turn and ascent for next leg at 3000 ft
12:10 turn and ascent for next for leg at 5000 ft
12:16 turn and ascent for next for leg at 7000 ft
12:23 turn and ascent for next for leg at 10000 ft
12:28 finished vertical profile and heading back to LYR
12:36 entering haze layer at 10000 ft, large ice particles within cloud

Fig. S9.5: Photograph taken from Polar 6.

12:44 41 min to LYR haze layer gets thinner and flight in and out of layer
12:58 exiting cloud layer
13:01 thin cloud for 1 min
13:10 descent for final approach
13:29 Touchdown

ACLOUD Flight #10 – Polar 5&6 – 2017/05/31

Objectives:

Low level clouds above sea ice in the proximity of Polarstern: Polar 5 aimed for sea ice albedo and turbulence measurements below clouds, radiation profiles and remote sensing above cloud top. Polar 6 planned to perform vertical profiles up to 12000 ft around Polarstern. Calibration of the microwave radiometer on Polar 5 and the nose boom on Polar 6.

Mission PI P5:

André Ehrlich

Polar 5 Crew	
Mission PI	André Ehrlich
Basis Data Acq.	Christoph Petersen
SMART	Michael Schäfer
Eagle/Hawk	Evi Jäkel
MiRAC	Tatiana Nomokonova
AMALi	Roland Neuber

Mission PI P6:

Johannes Schneider

Polar 6 Crew	
Mission PI	Johannes Schneider
Basis Data Acq.	Daniel Damaske
ALABAMA	Hans-Christian Clemen
CVI	Stephan Mertes
Gas/AWI-Aerosol	Heiko Bozem
PMS	--
Nevzorov	Dmitry Chechin

Flight times:

Polar 5	
Take off	15:05 UTC
Touch down	18:57 UTC

Polar 6	
Take off	14:59 UTC
Touch down	19:03 UTC

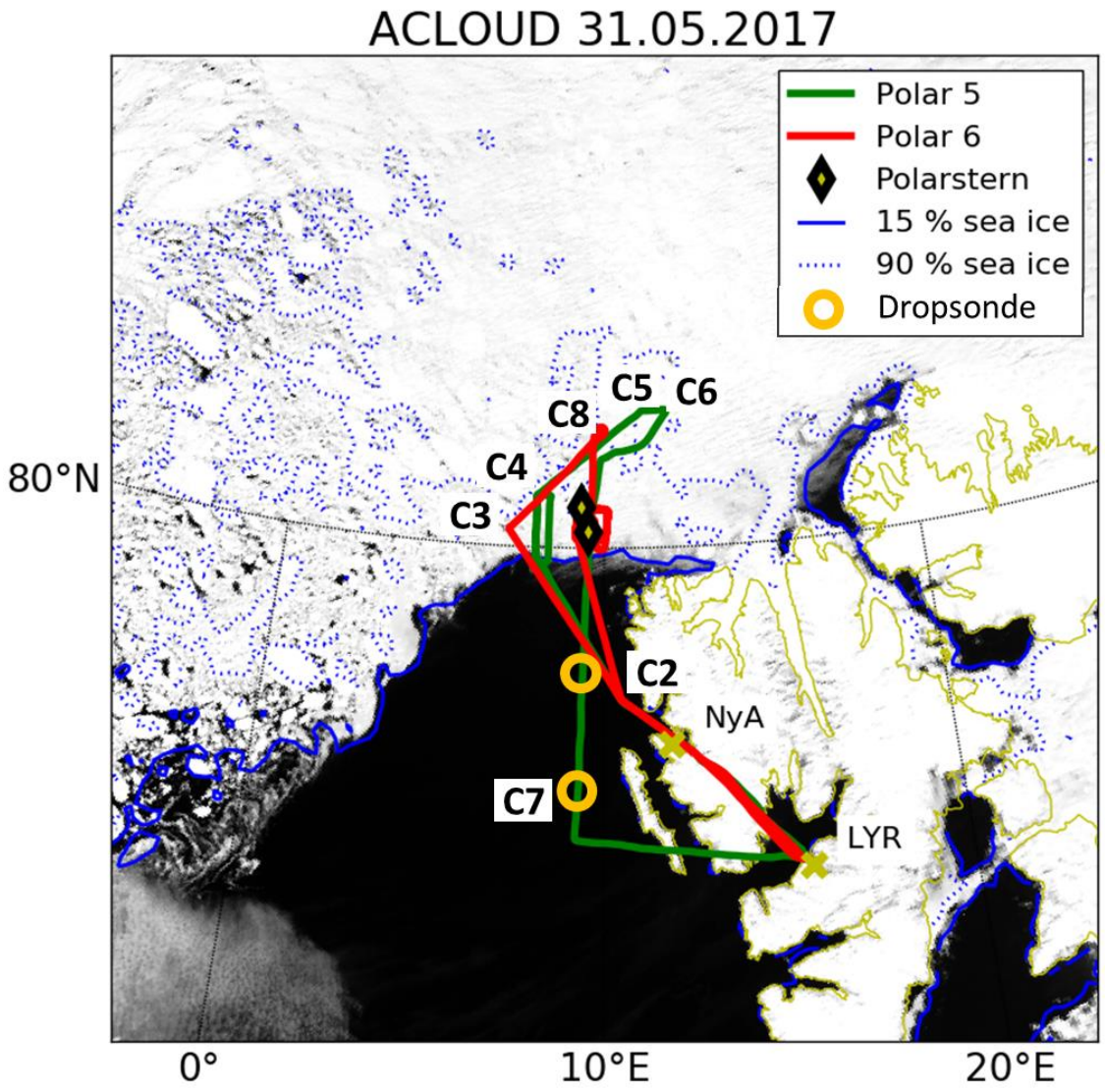


Fig. S10.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

The initial plan of the flight was to map sea ice in cloud free conditions. A strong lee effect with easterly winds produced a large cloud hole west of Svalbard. Subsidence in a high pressure system was supposed to spread the cloud free area towards north over the sea ice, where the Polarstern position was predicted.

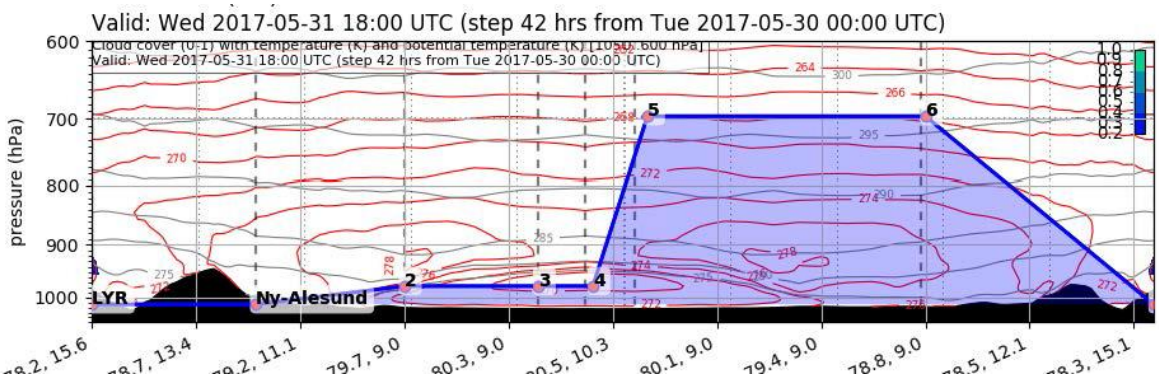


Fig. S10.2: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

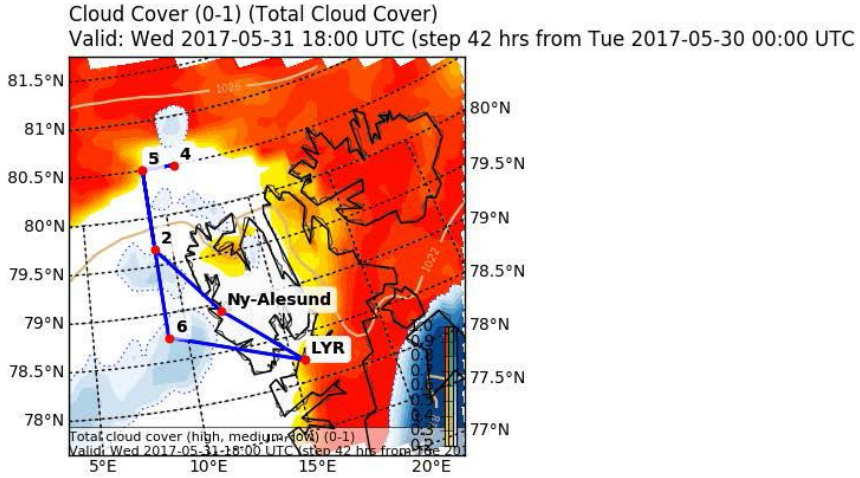


Fig. S17.3: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

The cloud situation observed by satellite images during 31 May 2017 showed a different picture compared to the forecast. A larger cloud free area was observed in north-westerly direction already in the morning. North of Svalbard, a strip of clouds moved with the north-easterly flow into the observation area. These clouds did not dissolve during the late afternoon. Therefore, low level clouds were present during the entire flight. The clouds started some NM south of the sea ice edge. Around that area low level clouds had formed with cloud base between about 300 and 600 ft. Partly, cloud streets were observed. These low clouds were partly broken with sunny spots. Also a strong inversion layer with temperatures up to about 10°C was present. The sea ice edge was much sharper during this flight as observed before. In the north-easterly box clouds were thicker compared to the location of Polarstern closer to the sea ice edge.
Cirrus fields were present mostly over Svalbard but not over the open ocean and the measurement area over the sea ice.

Overview:

Polar 5: The first part of the flight worked as planned including a long 1000 ft above ground overflight of the Sveabreen for albedo measurements and a low flyby of Ny Alesund along the fjord in 1000 ft above the water for the lidar comparison. Towards the ice edge still cloud free conditions were present, which allows to measure the surface albedo of open water. Close to the sea ice edge a

field of low level clouds started and no cloud free spot was visible over the sea ice. Therefore, we changed the plan for the first box slightly. Surface albedo was measured below the clouds with cloud base reaching 300ft altitude or sometimes also the surface. The clouds partly were broken and the Sun could shine through. The sea ice cover was about 80% with larger floes but also many leads. The leg was flown twice below the clouds and a third leg at 3000 ft above the clouds for remote sensing of the clouds. All legs should give a good picture of the inhomogeneous scene with both sea ice and cloud inhomogeneities.
After the box Polar 5 descended below the clouds again and performed the calibration pattern (different flight speed) for the nose boom. Having the calibration finished, we climbed above the cloud to search for a cloud free area but did not see any. Therefore, we stuck to the flight plan and tried to sample cloud profiles in Box 2, performing continuous descends and ascends. The clouds in Box 2 have been thicker without gaps. Therefore, also icing was stronger and only one profile could be flown. We then cancelled the pattern in Box 2 and headed for Polarsten which was further south than expected. At Polarstern the cloud cover was again more broken with only thin clouds ranging from roughly 300 ft to 800 ft altitude. Parallel to Polarstern 5 legs with ~5min length were flown in different altitudes, 200/500/800/1500/3000ft. This data can be used for comparing the Polarstern measurements and also for studies of thin low level clouds.
The last part of the flight was flown in 10 000ft to perform a calibration of the microwave radiometer over open water and a cloud free area including two dropsonde releases.

Polar 6: Flight started with 1500 ft overpass over Ny Alesund fjord, then we started low level boundary layer profiling, including cloud penetration at around 600 ft. After C3 nose boom calibration pattern was performed in the assumed direction of the Polarstern. After completing this pattern, we learned that Polarstern was 30 miles to the south, so we turned to reach Polarstern. There the 10-miles square was flown in 6 altitudes (200, 1000, 3000, 5000, 7000, 10000 ft). A thin patchy cloud layer was observed between 600 and 900 ft. After that we ascended to 12000 ft, then descended to 10000 and 5000 ft before LYR.

Fig. S10.4: Photographs taken from Polar 5. Left: Sun glint over open water with relative low Sun due to the late start. Right: Sea ice edge seen below clouds. Edge was much sharper than before.

Fig. S10.5: Photographs taken from Polar 5 showing thin low clouds over sea ice as observed in Box 1. The two images had been made in almost the same area only into different directions. Left: Towords the Sun. Right: aways from Sun. This illustrates, that the Sun still influences the radiative field below the thin cloud layer.

Fig. S10.6: Photographs taken from Polar 5 showing the same clouds presented in Fig. S10.5 as seen from above (left) and just at cloud top (right). The cloud top structure is very smooth.

Fig. S10.7: Photographs taken from Polar 5 showing the thin cloud layer in the area of the Polarstern meeting.

Fig. S10.8: Photographs taken from Polar 5 showing some precipitating?? clouds little south of Polarstern.

Fig. S10.9: Photographs taken from Polar 6 showing Polarstern in about 5-mile distance during a square pattern at 1000 ft.

Fig. S10.10: Photographs taken from Polar 6 showing Polarstern observed from 5000 ft altitude (17:41:25 UTC), ca. 5 miles' distance.

Fig. S10.11: Photographs taken from Polar 6 showing cloud streets observed from 5000 ft altitude (17:37 UTC).

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	Pointing zenith
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	2 launched

Table S10.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	not installed
SID-3	not installed
CIP	not installed
PIP	not installed
CDP	
Trace Gases	

Table S10.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments: No instrumental problems were reported. PMS probes were not installed for intended clear sky flight.

Detailed Flight Logs:

Polar 5: André Ehrlich (all times UTC)

14:42 Cirrus at the airport
15:06 Still cirrus above
15:18 Glacier overpass: in center of some cirrus
15:22 Summit of glacier, cirrus ahead
15:27 C1 still cirrus. 6.5km altitude indicated by AMALi
15:31 strong sun glint
15:33 no cirrus ahead of us

→ AMALi does not see cirrus anymore

15:38 C2: cloud free

15:40 AMALi: cirrus band at 7km altitude

15:45 low clouds ahead

→ climb → later descend below clouds

15:59 sea ice edge

16:00 C3: now below clouds

16:05 thin broken clouds

16:09 to north-east clouds get thinner

16:12 turn 4 NM to east

→ then go back south until sea ice edge

16:20 clouds sometimes touching the surface

Clouds still thin and broken

16:22 perfect 3D World: 2D sea ice + 3D thin cloud layer

16:25 end of sea ice

→ climb above clouds

→ climb was unfortunately flown in a turn

16:34 in 3000 ft altitude, above low level clouds: cloud top estimated at 800 ft

16:38 C4: descend to 200ft

16:41:40 100kn

16:43:30 120kn

16:45:40 140kn

16:47:35 160kn

16:49:30 140kn

16:51:30 120kn

16:53:15 100kn

→ climb above clouds → dense cloud field

→ go to C5

→ one single dive through cloud layer → icing → turn to Polarstern

→ ferry below clouds

17:20 200ft below clouds, 10 NM to PS

→ cloud layer getting thinner

17:25 PS on left. P6 at 200 ft

Scattered clouds, some touching the ground

17:28 turn → 500 ft

17:36 turn → 800 ft already on top of clouds

17:39 turn → 1500 ft

17:42 clouds look thin and with a lot of gaps

17:45 turn → 3000 ft

17:49 at PS still scattered low clouds

No cirrus

17:53 climb to 11 000ft heading to C7

18:03 at 11 000ft

18:08 looks moist in low levels looking towards west

18:11 DS#1

18:17 all clear air and no sea ice

Some cirrus over Svalbard and in south
18:21 DS#2
18:27 turn → go home

Polar 5: Roland Neuber (all times UTC)

15:13 AMALi Start 15:13
15:29 Ny-Aalesund passing by
15:45 start climbing above low level clouds
15:53 Down to FL 200 ft , below clouds
16:01 HV reduced to 550 V
16:11 C4, turning towards east for first block pattern
16:13 turning right, bank 30°, return to C3
16:23 C3, start climbing above clouds
cloud top at ca. 1000 ft, ascending to 3000 ft,
patchy, very thin cirrus at high altitude
HV increased
16:31 on the way N again C3 - C4
16:37 C4, start heading for C5 for 200 ft
16:39 HV adjusted for below cloud run
16:40 for ca. 10 min various speeds for calibration purpose
16:53 start climbing above clouds again
HV adjusted for flying above low level clouds
C5 descending again, diving through thin clouds; rain!
17:01 HV reduced
17:03 above clouds, turning from the N towards RV PS
17:13 approaching PS
17:25 passing PS at 200 ft
17:27 turn, ascending to 500 ft for 2nd pass by
17:35 return again, level 800 ft, just above clouds
17:37 HV increased for flight over clouds
17:45 returning at 3000 ft
17:51 start southbound leg for calibration, climbing
18:11 Drop Sonde 1
10 min after DS 1 follows DS 2
thereafter return directly to LYR, slowly descending
18:39 final HV adjustment perp channel

Polar 6: Johannes Schneider (all times UTC)

14:59:18 Take off
climb to 4500 ft, fly over fjord toward Ny Alesund, over glacier.
15:17 Overpass meteorological station on glacier
15:18 C1
15:20 overpass Ny Alesund fjord at 1500 ft
15:30 C2, start descent to 200 ft
15:33 reach 200 ft

15:38 climb to 1000 ft
15:41 reach 1000 ft
15:43 over clouds (approx. 600 ft)
15:46 descent into clouds, to 500 ft. T = -1°C
15:53 descent to 200 ft
15:56 climb above clouds
15:52:20 reach cloud top (900 ft), remain until C3
15:59:09 C3. Turn and descent to 200 ft
Start Noseboom calibration pattern:

16:02:20 – 16:03:20 100 kn
16:04:08 – 16:05:08 110 kn
16:05:36 – 16:06:36 120 kn
16:07:04 – 16:08:04 130 kn
16:08:23 – 16:09:23 140 kn
16:09:50 – 16:10:50 150 kn
16:11:12 – 16:12:12 160 kn
16:12:33 – 16:13:33 150 kn
16:13:48 – 16:14:48 140 kn
16:15:04 – 16:16:04 130 kn
16:16:21 – 16:17:21 120 kn
16:17:41 – 16:18:41 110 kn
16:19:04 – 16:20:04 100 kn

16:20:30 ascent to 1000 ft, 140 kn
16:14 turn to reach actual Polarstern position
16:27 ascent to 1500 ft, 140 kn
16:28 reach 1500 ft
16:37 see Polarstern, descent to 200 ft
16:42 through clouds
16:46:33 1st way point, start square around Polarstern 200 ft, 1st leg northbound
16:51:20 2nd leg (westbound)
16:55:13 3rd leg (southbound)
16:59:30 4th leg (eastbound), climb to 1000 ft
17:01:10 reach 1000 ft
17:03:48 1st leg (north)
17:07:50 2nd leg (west)
17:11:16 3rd leg (south)
17:15:02 4th leg (east), climb to 3000 ft
17:18:32 reach 3000 ft
17:20 1st leg (north)
17:23:50 2nd leg (west)
17:27:20 3rd leg (south)
17:30:30 4th leg (east), climb to 5000 ft
17:35 north
17:39 west
17:42:30 south

17:46:07	east, climb to 7000 ft
17:50:20	north (T = +6°C)
17:54:23	west
17:57:30	south
18:00:42	east, climb to 10000 ft (cross several aerosol layers during ascent)
18:05:07	north
18:08:40	west
18:11:50	south
18:15:14	turn towards C2
18:15:40	climb to 12000 ft
18:19:30	reach 12000 ft
18:25:00	descent to 10000 ft
18:29:00	reach 10000 ft
18:32:40	C2, descent to 5000 ft, turn towards C1
18:41:40	5000 ft
18:43:00	C1, turn to LYB
19:02:48	Touch down

ACLOUD Flight #11 – Polar 5&6 – 2017/06/02

Objectives:

Characterize horizontal and vertical variability of cloud properties observed by remote sensing measurements on Polar 5 and in situ cloud microphysical measurements on Polar 6. Investigate how both data sets relate to each other. Vertical cloud profiles are analyzed over Polarstern.

Mission PI P5:

Susanne Crewell

Polar 5 Crew	
Mission PI	Susanne Crewell
Basis Data Acq.	Christoph Petersen
SMART	Johannes Stapf
Eagle/Hawk	Elena Ruiz
MiRAC	Mario Mech
AMALi	Friedhelm Jansen

Mission PI P6:

Emma Järvinen

Polar 6 Crew	
Mission PI	Emma Järvinen
Basis Data Acq.	Daniel Damaske
ALABAMA	Hans Clemen
CVI	Stephan Mertes
Gas/AWI-Aerosol	Heiko Bozem
PMS	Delphine Leroy
Nevzorov	Dmitry Chechin

Flight times:

Polar 5	
Take off	08:13 UTC
Touch down	13:55 UTC

Polar 6	
Take off	08:27 UTC
Touch down	14:09 UTC

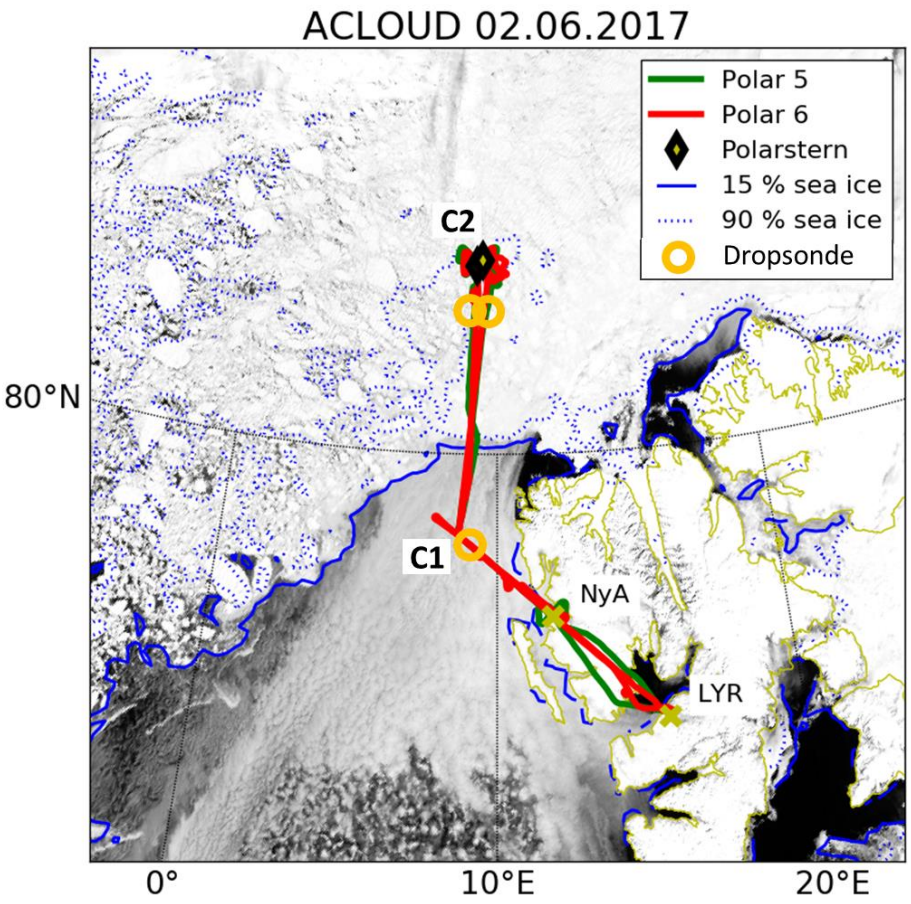


Fig. S11.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

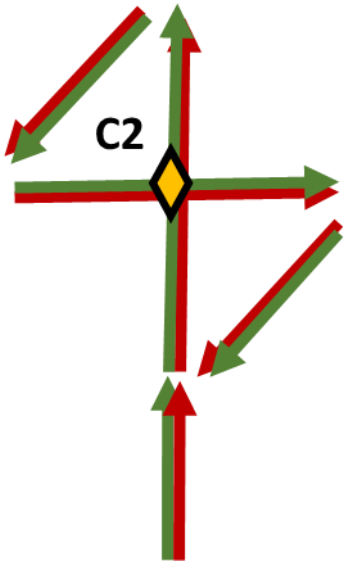


Fig. S11.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

The last days were dominated by a northeasterly wind flow caused by a low-pressure system over northern Russia combined with a high-pressure system north of Svalbard. This circulation changed as predicted to a southwesterly flow associated with a high pressure system south of Spitsbergen. As predicted by IFS low clouds formed in this air mass which persisted during the whole flight and no view on the surface was possible. The GFS failed to predict these clouds. Cloud top was at about 2800 ft at Ny Alesund and decreased to roughly 1300 ft in the area of the Polarstern where the mid atmosphere was much drier. The cloud base was found at 1600 ft in Ny Ålesund and at 300 ft near Polarstern. Due to the lee effect Longyearbyen was still mainly cloud free and low level clouds only started to appear on top of the glacier when flying toward Ny Alesund. Some thin cirrus above was evident in the on the way to Polarstern.

Overview:

Polar 5: As usual Polar 5 did fly a first leg in low altitude, 1000 ft above ground, over the glacier Sveabreen. for surface albedo characterization and when ascended to 10.00ft which was the flight altitude over the whole flight. At Ny Alesund a loop similar as an 8 was flown 2.5 times while P6 ascended through the cloud from below above the runway to get a microphysical profile. Afterwards P5 continued along track to C1 for a Cloudsat underflight. We met the satellite at 9:49 roughly between Ny Alesund and C1 while P6 flew in a saw tooth pattern for microphysical profiles. About five minutes later we encountered 3 short power interruptions in a row - after 10:40 all instruments were back in operation. At that time, we had reached the Polarstern (C2) area and droped a sonde. A coordinated double-triangular pattern with P6 below was flown for about 2 hours. The clouds were quite homogeneous and not optically thick. The lidar saw some enhanced backscatter in a coherent spatial structure confined to a region below 1800 m which coincided with a small inversion (see dropsondes). After dropping a sonde we headed back to Longyearbyen via C1 and Ny Alesund. Cloud topped boundary layer increased on the way towards the Island and we could sense the clouds over Ny Alesund which showed a rapid change around 11 UTC with a transition from a more liquid dominated type to very light snowfall.

Polar 6: Polar 6 (P6) flew the first leg to Ny Ålesund at an altitude of 4000 ft before starting the descent. Since clouds were present above the Ny Ålesund airport the approach had to be made from the sea towards the fjord. P6 descended below the cloud deck (1600 ft), turned in the fjord and aligned with the Ny Ålesund airport runway. Above the runway, we ascended back in the cloud and did first straight leg at 2200 ft. The second leg at 2700 ft had to be interrupted because of icing problems. Looking back, it would be recommended to perform a faster and continues ascent though the clouds to get a more localized vertical profile.

After sampling clouds at 2200 ft, 2700 ft and 2800 ft a saw tooth pattern was started on the way to C1. One ascent and descent were made, in which time C1 was passed. Above the cloud top P6 turned around to be co-located with P5 and to meet the satellite at C1 at 09:50 UTC. This time the P5 had encountered some technical problems, so that the co-location was possible only after the satellite had passed. From C1 to C2 P6 continued the saw tooth patterns inside the clouds as P5 measured above. Over Polarstern (PS) P6 and P5 performed four coordinated double-triangle patterns, P5 in

one altitude and P6 changing altitudes after every co- and cross-wind leg. The patterns were performed at 300 ft (below the clouds), 800 ft, 1000 ft and at 1300 ft, which was right at the cloud top. One leg was 15 miles long and took approximately 7 minutes. To get a better vertical profile of the cloud, it would have been possible to change altitude after every leg.

After PS P6 did a horizontal profile that was supposed to be flown in one level to C1. We started at 1000 ft but as the cloud base rose towards the open ocean, we had to adjust the height to 1500 ft. Keeping one representative level in clouds over such a large distance was proven challenging and it is advised to perform saw tooth patterns for the horizontal variability instead of single straight leg. From C1 to LYR an aerosol profile with altitudes at 6000 ft and 12000 ft was flown before landing.

Fig. S11.3: Photographs taken from Polar 5. Left (LYR-NyA): Sveabreen Glacier. Right (LYR-NyA, 08:48 UTC): Start of low level clouds.

Fig. S11.4: Photographs taken from Polar 5. Left (NyA – loop C2): Clouds over Ny Alesund at 9:31 UTC. Right (C1 - C2): Low clouds with few cirrus above at 11:30 UTC.

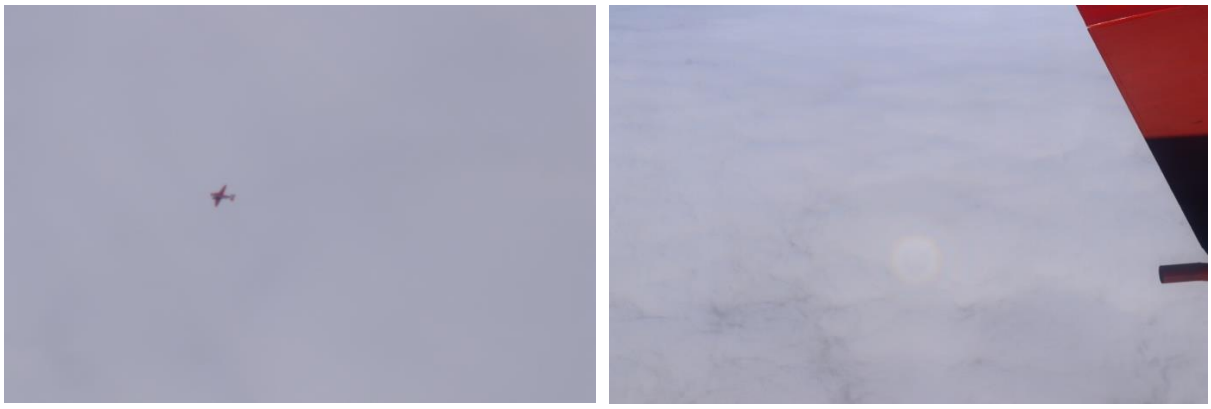


Fig. S11.5: Photographs taken from Polar 5. Left (at C2): Coordination with Polar 6 around Polarstern. Right (at C1): Heading back to Longyearbyen.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	5 launched 1 failed

Table S11.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S11.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

Due to three short power breaks on Polar5 between 9:55 and 10:35 some data losses occurred for those instruments needing 230 V. Gaps are a few minutes for cloud radar around more than 10 min for lidar and about 1,5 hours for MiRAC passive. In addition, the first dropsonde launched at 9:49 only transmitted data down to about 1800 m. One dropsonde did not found a GPS signal. PIP lost connection during saw tooth profiles but worked again later in flight. SP2 stopped working during the vertical profiles over Polarstern.

Detailed Flight Logs:

Polar 5: Johannes Stapf (all times UTC)

08:31:04 in the air
08:31:50 water, closed cloud deck above
08:36:25 albedometer down
08:41:46 hazy but clear above
08:41:53 glacier below
08:46:28 cirrus in front of us
08:47:58 overcast clouds
08:49:54 only mountain tops look out
08:50:30 starting to climb
08:55:15 starting loop for the pattern over Ny Alesund see right
09:07:49 glory
09:10:33 some ci near horizon
09:29:25 after second loop we had for a half loop before starting off on the satellite track at 9:39
09:52:21 dropsonde is out
09 55:00 crash of the 230 V system - MiRAC, dropsonde and lidar
10:12:46 polar 6 down on the left side
10:13:02 we are a few km of track, turn and about 20 min to C2
10:17:38 power is down, everything restarted
10:29:02 power is off again
10:29:51 some roll structures - photo
10:32:15 15 miles to Polarstern
10:33:32 clouds get thinner, could see some ice flows below
10:34:46 P6 can be seen over clouds
10:36:16 some ci above and nice clouds below
10:47:30 starting double triangular pattern for first time
10:56:23 clouds have still some roll structures
11:13:04 20 min ago the heating started to work again

11:31:14 restarted smart spectrometer
11:27:48 finishing pattern to go back to c1
12:34:37 dropsonde died at 1000m and prepare new one
12:55:19 approaching again the ice edge probably
13:22:17 reaching C1
13:37:40 descending
13:40:32 glacier full with clouds
13:55:30 landing

Polar 6: Emma Järvinen (all times UTC)

08:27	Take off • 4000 ft towards Ny Ålesund • clouds over the glacier, solid cloud deck • almost no cirrus above
08:52	Start decent to Ny Ålesund, 500 ft/min
08:54	In cloud • cloud top was at 3000 ft • Temperature +1°C • Liquid cloud
08:56	Underneath the cloud at 1400 ft • No precipitation
	Ny Ålesund Cloud Profile
09:07	Centered with the Ny Ålesund runway • Cloud base at 1600 ft
09:07	2200 ft • Temperature 0°C • CIP: ice particles • SID3: small droplets • PHIPS: needles
09:15	2700 ft
09:17	Out of the cloud to 3100 ft due to icing problems
09:18	Climbing to 4000 ft to de-ice at +8°C
09:23	Cloud probes ice free, start descent into clouds
09:25	At 2800 ft in cloud top • Ice particles observed
	Saw Tooth Cloud Horizontal Profile
09:27	Saw tooth ↓ 100 ft/min • First profile over open ocean • Icing on SID-3 • Droplets get smaller as descending
09:34	Underneath the cloud at 1200 ft • No precipitation
09:41	Saw tooth ↑ 200 ft/min • Both ice particles and droplets (mixed-phase) • Cloud profile past C1
09:47	Cloud top at 2500 ft

09:50	180° turn to head back to C1
09:52	Saw tooth ↓ 200 ft/min
09:59	Underneath the cloud at 1000 ft • Delphine: problems with the PIP probe
10:06	Saw tooth ↑ 200 ft/min
10:10	Cloud top at 2000 ft
10:12	Saw tooth ↓ 200 ft/min • Both ice particles and droplets (mixed-phase)
10:20	Underneath the cloud at 300 ft • Sea ice visible • Cloud base lower, almost reaching the surface
10:21	Change altitude to 200 ft
10:24	Saw tooth ↑ 200 ft/min
10:26	Change to 500 ft/min
10:27	Cloud top at 1700 ft
10:33	360° turn
10:35	Saw tooth ↓ 200 ft/min • Cloud top at 1300 ft • PHIPS: ice needles, more ice observed as in the first profiles
10:36	Underneath the cloud • precipitation
	Double Triangle (Vertical Profile) over Polarstern
10:50-11:08	Level 300 ft (below cloud) • precipitation (ice needles with sizes >700 µm) • 13:07 encountered PS or P6 plume
11:18-11:35	Level 800 ft (inside cloud) • SID-3: small droplets • PIP: large ice needles
11:44-12:01	Level 1000 ft (inside cloud) • 0°C • some icing on SID-3 • ice and small droplets
12:09-12:28	Level 1300 ft (right at the cloud top) • mostly liquid cloud top and some ice particles • 14:10 out of cloud due to icing • 14:18 descent back to cloud
12:28	End of double triangle and out of cloud to de-ice • de-icing at +8°C
	Horizontal Straight Leg towards C1
12:32	In cloud 1000 ft • small cloud particles
12:58	Out of the cloud for de-icing • cloud top at 1800 ft
12:57	Back in cloud
12:59	Cloud base at 1200 ft • Still sea ice below
13:00	Level 1500 ft • Small particles, SID-3 records one mode • PHIPS: big droplets
13:11	Ice free water below

13:12	Ascent to 1700 ft
13:19	C1 • Climb to 6000 ft • Cloud top at 2800 ft
13:26	6000 ft
13:29	Climb to 12000 ft
13:37	12000 ft
13:40	Leave 12000 ft
14:09	TOUCH DOWN

ACLOUD Flight #12 – Polar 6 – 2017/06/04

Objectives:

Study the horizontal and vertical variability of cloud microphysical properties by in-situ observations along an overpass of the A-Train satellites. The second part of the flight aimed to characterize the vertical cloud profile over Polarstern.

Mission PI P6:

Emma Järvinen

Polar 6 Crew	
Mission PI	**Emma Järvinen**
Basis Data Acq.	**Daniel Damaske**
ALABAMA	**Hans Clemen**
CVI	**Stephan Mertes**
Gas/AWI-Aerosol	**Heiko Bozem**
PMS	**Martin Schnaiter, Christophe Gourbeyre**

Flight times:

Polar 6	
Take off	**08:06 UTC**
Touch down	**13:39 UTC**

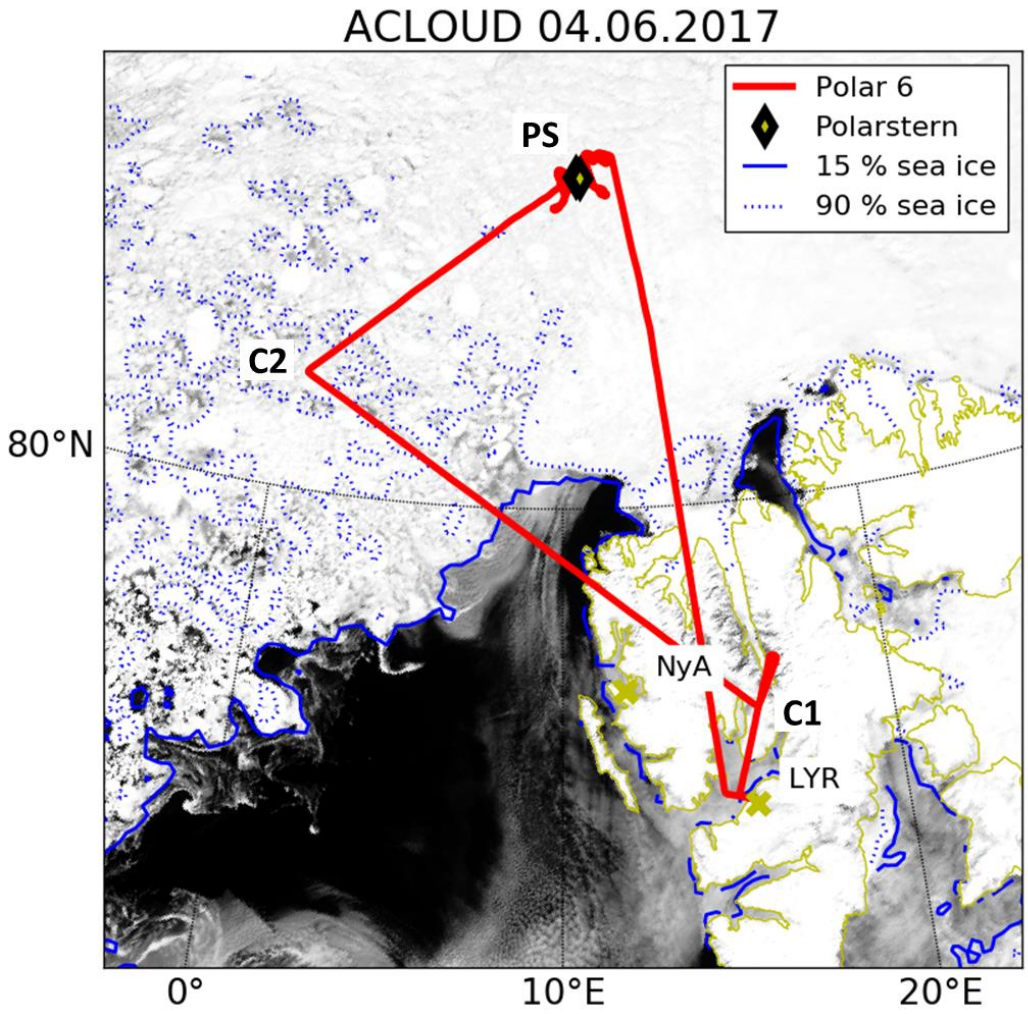


Fig. S12.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

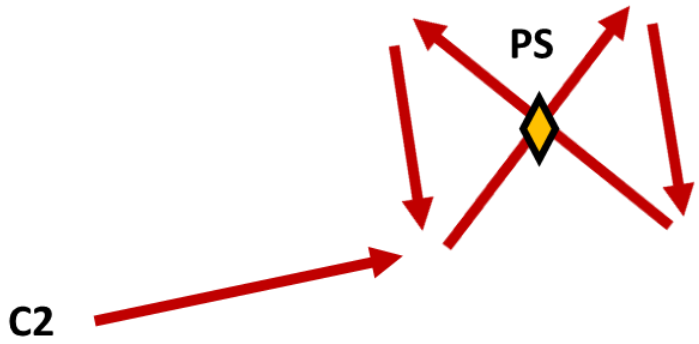


Fig. S12.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

The high-pressure system on that day located west of Svalbard bringing northerly flows over the open water. Low-level clouds were predicted north of Longyearbyen stretching all the way to Polarstern. As predicted a relative uniform cloud layer was observed from Longyearbyen to Polarstern. Near Svalbard the cloud top was found at 1600 ft and at Polartern at 1300 ft.

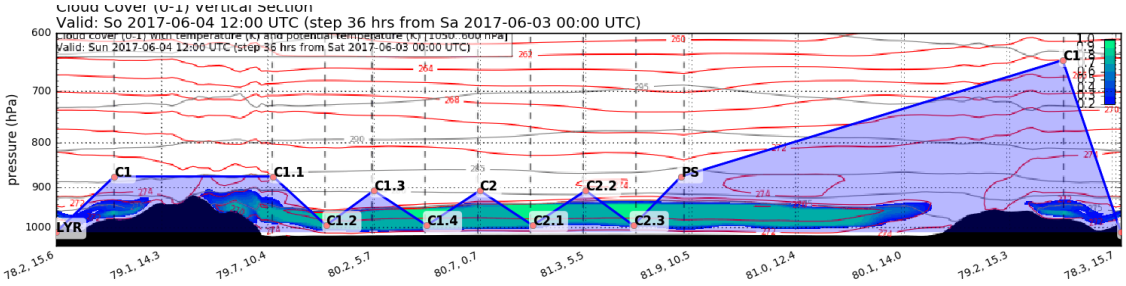


Fig. S12.3: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

Overview:

Due to problems with the Polar 5, Polar 6 headed alone to the planned satellite overpass towards C1. On the way to C1 an aerosol profile was performed with legs at two heights: 10 000 ft and 5 000 ft. At this part of the flight it was discovered that the INS did not align before take-off and, therefore, was not working during the flight. C1 was reached ahead of the schedule so a loop was performed to leave C1 planned at 09:38 UTC. The part of the satellite overpass over continent was flown above the clouds at 5000 ft and the saw tooth pattern in the clouds was started over the open ocean. The first descent was performed over open ocean. The cloud consisted of only liquid droplets with sizes below 100 µm. Below the cloud sea ice started to appear and the next ascent was performed over broken sea ice. Now, some ice was detected in the clouds with increasing ice particle concentration towards the cloud top. The dominant ice particle shape was needles. In the second descent the satellite was met at a height of 600 ft – in the mid of the mixed-phase cloud. The saw tooth profile was continued to C2 and from there to Polarstern. In all of the profiles both ice and liquid droplets were measured.

Fig. S12.4: Photograph taken from Polar 6. Left: Cloud top at 09:00 UTC. Right: Cloud base at 09:38 UTC.

Near Polarstern three double-triangle patterns were performed starting below the cloud at 100 ft. The cloud base was found at 300 ft. After each co- and cross-leg the altitude was changed. The legs inside the cloud were performed at 400 ft, 600 ft, 800 ft, 1000 ft and at 1200 ft. The cloud top was found at 1300 ft. After the leg at 800 ft P6 faced some icing problems, so it was decided to spend the transitions between the legs above the clouds to de-ice. The cloud was found to be mixed in all layers with relative high concentrations of ice of several counts per liter.

After the double-triangle patterns an aerosol race-track was performed near the double-triangle. A continuous climb with 800 ft/min with 1 minute legs was done until 12000 ft was reached. During the climb a pollution layer was observed at 11000 ft. P6 descended to the pollution layer and followed it towards Longyearbyen for about 20 minutes before free speed and height was given to the pilots for the rest of the flight.

Fig. S12.5: Photograph taken from Polar 6 showing Polarstern.

Instrument Status:

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S12.1: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

Aircraft INS did not work.

Detailed Flight Logs:

Emma Järvinen (times UTC)

08:06	Take off
08:12	At 6000 ft
	Aerosol Profile C1
08:24	At 10 000 ft
08:27	Check aerosol inlet heating by turning on and off
08:30	INS Problem noticed: INS did not align at the airport. Decision to continue to flight without INS.
08:37	C1
08:46	Start descending
08:56	At 5000 ft (+5°C)
	Saw Tooth Cloud Horizontal Profile C1-PS
09:07	Saw tooth ↓ 100 ft/min
09:12	Cloud top at 1600 ft • +1°C • SID3: stable counts (3000 1/s), Dp<100 µm, all liquid cloud • Some patches in cloud
09:23	At 200 ft -> cloud reaches the ground • Ice sheets appearing below
09:26	Saw tooth ↑ 200 ft/min • Few ice particles
09:29	Cloud top at 1200 ft • More ice on cloud top (PHIPS: needles)
09:31	Saw tooth ↓ 200 ft/min
09:33	Cloud top at 1300 ft • Large droplets and big ice crystals at the cloud top
09:38	Satellite overpass, P6 at 600 ft
09:39	Martin: only ice (needles), temperatures around 0°C
09:40	Cloud base at 200 ft • Steady ice counts
09:45	Saw tooth ↑ 200 ft/min
09:47	Droplets and ice, about 50/50
09:49	Low number and size of ice, PHIPS sees no ice
09:50	Cloud top at 1600 ft
09:54	Saw tooth ↓ 200 ft/min • Cloud top at 1700 ft • Ice in all sizes and in all levels in the cloud
09:59	Turn to C2 (almost below the cloud)
10:01	Mostly ice observed (needles and aggregates of needles)
10:02	At 200 ft -> cloud down to ice
10:07	Saw tooth ↑ 200 ft/min
10:11	Cloud top at 1600 ft
10:15	Saw tooth ↓ 200 ft/min
10:16	Cloud top at 1600 ft • Ice in the cloud top

10:24	Cloud base at 400 ft
10:26	At 200 ft • precipitation
10:31	Saw tooth ↑ 200 ft/min
10:35	Cloud top at 1300 ft
10:40	Saw tooth ↓ 200 ft/min • cloud top at 1300 ft
10:46	At 300 ft
	Double Triangle (Vertical Profile) over Polarstern
10:53-11:00	Cross-wind at level 100 ft (below the cloud)
11:04	Level 400 ft
11:06-11:10	Co-wind at level 400 ft (inside the cloud) • mainly droplets but also some ice particles
11:11	Sampled PS plume
11:11	Balloon launch from PS
11:12	Level 600 ft
11:15-11:21	Cross-wind at level 600 ft (inside the cloud) • droplets somewhat larger and have a steady concentration • ice with same concentration as in level 400 ft
11:25	Level 800 ft
11:26-11:31	Co-wind at level 800 ft (inside the cloud) • bigger droplets and stable N_tot • ice particles -> rimed needles
11:32	Out of the cloud due to icing
11:38	Descent into the cloud • cloud top at 1300 ft
11:41-11:48	Cross-wind at level 1000 ft (inside the cloud) • N_tot the same but some tendency towards bi-modal size distribution • Low concentration of ice
11:50	Procedure turn to de-ice above the cloud
11:54	Descent into the cloud
11:58-12:05	Co-wind at level 1200 ft • Bi-modal droplet spectrum • Some small ice particles
	Aerosol race track
12:06	Start climbing with 800 ft/min and free speed
12:07	Right turn at 2300 ft
12:09	Right turn at 4300 ft
12:14	Right turn at 8000 ft
12:17	Right turn at 11 000 ft
12:19	At 12 000 ft • Pollution layer observed at 11 000 ft
12:24	Start descent
12:29	Pollution layer at 10 300 ft -> stay in this level
12:32	Ascent to 10 500 ft to follow the pollution layer
12:37	To 11 000 ft
12:48	Aerosol layer at 9000 ft
12:58	At 10 000 ft -> above the pollution layer
13:05	At 9000 ft
13:39	TOUCH DOWN

ACLOUD Flight #13 – Polar 5&6 – 2017/06/05

Objectives:

Collect data for remote sensing of different clouds above sea ice. Collocate flight jointly with P6 (in-cloud profile measurements) and the balloon at the ice camp near PS. Perform measurements over PS in different altitudes profiling the low level clouds and boundary layer structure.

Mission PI P5:

Manfred Wendisch

Polar 5 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Christoph Petersen
SMART	Michael Schäfer
Eagle/Hawk	Elena Ruiz
MiRAC	Mario Mech
AMALi	Tobias Doktorowski

Mission PI P6:

Johannes Schneider

Polar 6 Crew	
Mission PI	Johannes Schneider
Basis Data Acq.	Martin Gehrmann
ALABAMA	Hans-Christian Clemen
CVI	Udo Kästner
Gas/AWI-Aerosol	Heiko Bozem
PMS	Delphine Leroy Martin Schnaiter

Flight times:

Polar 5	
Take off	10:48 UTC
Touch down	14:59 UTC

Polar 6	
Take off	10:43 UTC
Touch down	14:44 UTC

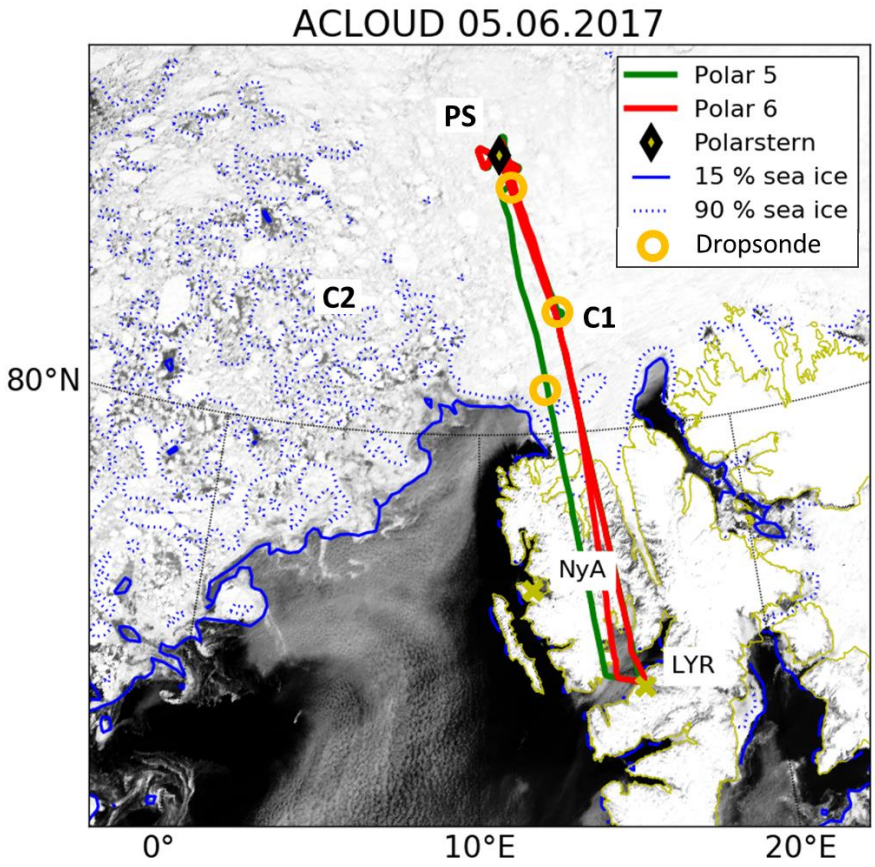


Fig. S13.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

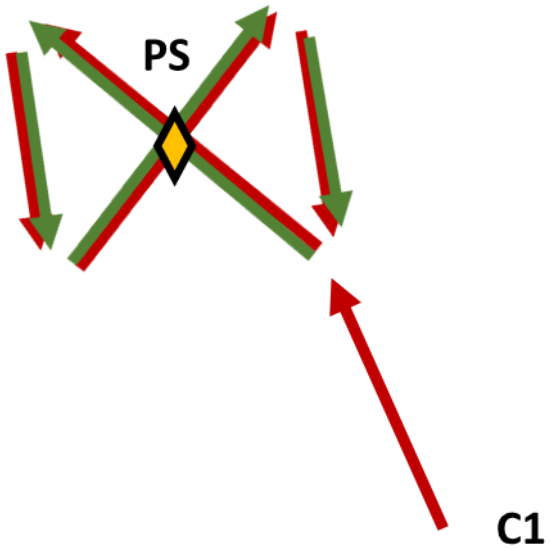


Fig. S13.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

The original plan was to meet CLOUDSAT and to perform a coordinated flight jointly with P6 and the tethered balloon close to Polarstern. However, the cloud base in LYR was way too low to take off on time. Therefore, we had to postpone the take-off several times and missed the satellite overpass. As a consequence, we have shortened the flight path. We basically flew north to Polarstern, sampled there, and returned to LYR.

Over the island, scattered clouds in lower levels and some cirrus (not much) were observed. Over the sea ice a persistent low-level cloud deck was detected with different levels of horizontal heterogeneity. Only few cirrus was observed over most of the flight. Both features were well predicted by the ECMWF cloud forecast, see figures below.

ECMW prediction of clouds—horizontal

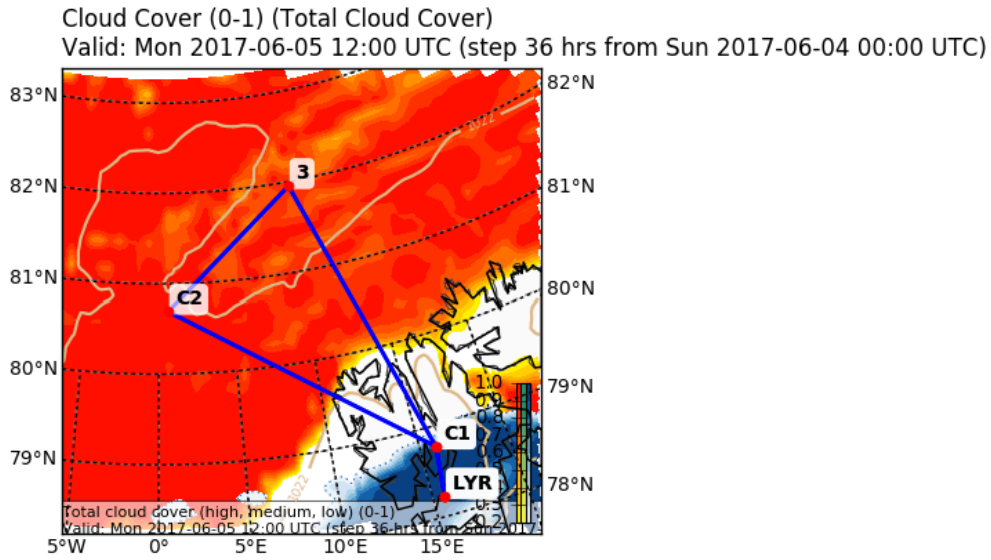


Fig. S13.3: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

ECMW prediction of clouds—vertical

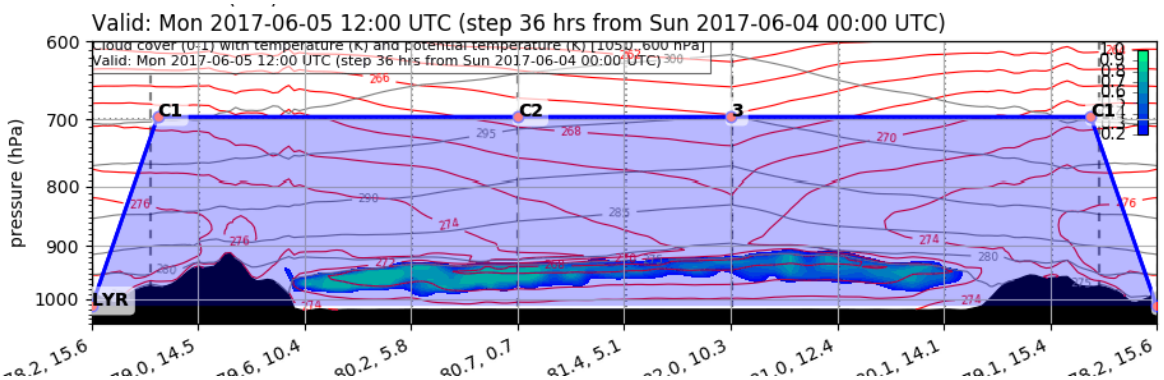


Fig. S13.4: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

ECMW prediction of wind 950 hPa

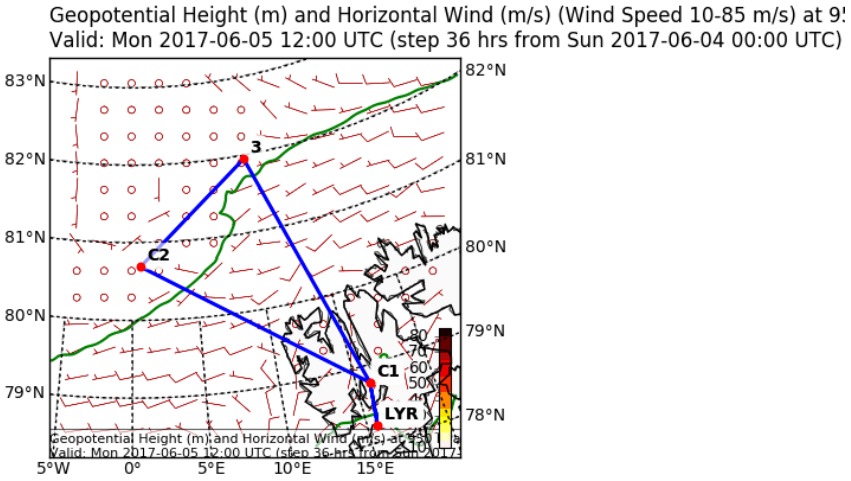


Fig. S13.5: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Overview:

Flight started with delay of 3 hours due to low clouds at Longyearbyen airport. Therefore, the satellite meeting was not possible and the flight track was modified (waypoint C2 was cancelled).

Polar 5: After start, Polar 5 climbed to 10000 ft altitude for remote sensing observations along the track to Polarstern. During the coordinated flight at Polarstern, Polar 5 remained in that altitude. Two dropsondes were released, one on the ferry to Polarstern and one close to Polarstern. After the coordinated flight, Polar 5 descended to characterize the turbulent and radiative fluxes below the cloud base. The second part of the leg back to Longyearbyen was flown at 10000 ft again. One additional dropsonde was released.

Polar 6: After start P6 climbed to 5000 ft, after a 5 min level to 10000 ft. The we descended to reach cloud level over ice and started cloud profiling. Cloud top was at 1400 ft, cloud base around 200 ft. Three cloud profiles were conducted until Polarstern. At Polarstern "double-triangle" pattern at 200, 800, 1000, 1200, 1700, and 1300 ft. 1700 was above cloud top. After finishing the pattern, we stayed at 2500 ft for de-icing, then did two more cloud profiles on the way back, then ascended to 12000 ft, descended to 9000 ft before landing at LYB. During return weather forecast for Longyearbyen airport predicted low clouds and fog, landing occurred under foggy conditions.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	3 launched

Table. S13.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table. S13.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

The cloud radar had a software problem and could not measure during this flight. One dropsonde did not found a GPS signal.

Detailed Flight Logs:

Polar 5: Manfred Wendisch (all times UTC)

LYR – C1 **158 NM @ 140 kn** **68 min**

- 10:00 Start motors
- 10:05 Problems with MIRAC, no data connection between data acquisition and the instrument, P6 also had a computer issue.
- 10:38 Taxi
- 10:48 Take-off into eastern direction, we turn West and then North after take-off, ascending to 10,000 ft

- 10:48 Thin, scattered cloud deck over the fjord, little cirrus above, see photo below.

Fig. S13.6: Photograph taken from Polar 5.

- 10:56 Flight over land: Only scattered louds below, cirrus above, low clouds and cirrus decreasing (becoming almost cloudless) towards the coastline.

Fig. S13.7: Photograph taken from Polar 5.

- 11:28 After passing the coastline, a thick low-level cloud layer was observed beneath of us, No cirrus above, over sea ice
- 11:37 Clouds below get even thicker

Fig. S13.8: Photograph taken from Polar 5.

- 11:42 We reach C1
- 11:43 *Dropsonde #1*

C1 – PS **73 NM @ 140 kn 31 min**

- 11:46 Northward, on our way to Polarstern, helicopter and balloon are in the air
- 12:06 Much more homogeneous clouds below

Fig. S13.9: Photograph taken from Polar 5.

- 12:07 *Dropsonde #2*
- 12:10 Still 10 miles to PS
- 12:14 We reach Polarstern
- 12:20 **First** horizontal double triangle at 10,000 ft: 12:20-12:37

- 12:40 **Second** horizontal double triangle at 10,000 ft: 12:40-12:57
- 12:55 Balloon can be seen from Polar 5, it operates at 3000 ft, the pilots can see it on their instruments, I can see the balloon by eye (just a small black spot)
- 13:00 **Third** horizontal double triangle at 10,000 ft: 13:00-13:17

PS – LYR **240 NM @ 140 kn 103 min**

- 13:20 Start descending
- 13:30 Cloud penetration through the cloud from atop, stay horizontal below the cloud for 10 minutes at 500 ft altitude, photo below was taken below the cloud

Fig. S13.10: Photograph taken from Polar 5.

- 13:40 Go through the cloud again from below, stay just above the cloud top for 10 minutes, photo below was taken just above cloud

Fig. S13.11: Photograph taken from Polar 5.

- 13:45 We receive a call from the weather station at LYR, conditions becoming poor at LYR, we climb to 6000 ft and head home as fast as possible
- 13:45 Thick and homogeneous clouds below the aircraft
- 14:02 *Dropsonde #3*
- 14:14 We reach the coastline again

Fig. S13.12: Photograph taken from Polar 5.

- 14:15 Almost cloud-free over land

Fig. S13.13: Photograph taken from Polar 5.

- 14:59 Landing in very hazy/foggy conditions at LYR, fog just in the fjord

Polar 6: Johannes Schneider (all times UTC)

10:43:34	Take off
	climb to 5000 ft
10:50:35	reach 5000 ft, stay for 5 min
10:55:46	climb to 10000 ft
11:06:08	reach 10000 ft
11:12:15	start descent
11:16	closed sea ice below, clouds observed in front below us
11:16	2500 ft, 5°C, still above clouds
11:28:20	start cloud profile with 200 ft/min descent rate, 140 kn
	Cloud top 1400 ft
	PMS reports some ice, but mainly droplets
12:32	+1°C
11:33	cloud base is very low
11:34:18	200 ft cloud base
	PMS: some small ice crystals and larger columns below cloud
11:43:30	C1, start ascent through cloud
11:46:25	cloud base
11:49:30	cloud top (1800 ft)
11:54:45	next descent
11:56:20	1700 ft, cloud top
	PMS: ice in upper layer
12:01:16	big ice particles (lower edge of cloud)
12:04	cloud base
	PMS: ice precipitation continues
	Stay here until Polarstern (7 minutes)
12:06:10	200 ft
12:12:15	turn right
12:13:00	see Polarstern on left side
12:19:30	start 1st leg of "double triangle" at 200 ft, 120 kn
12:22:00	Polarstern on right side
12:25:30	end of line, turn and climb
12:28:40	800 ft
12:29:42	turn and start 2nd leg (in cloud), 800 ft, close to cloud base
12:35:50	turn
12:37:20	climb to 1000 ft
12:39:57	turn and start 3rd leg,
	PMS: more large droplets
	ALABAMA: hit rate increases
12:45:50	turn and climb to 1200 ft
12:50:15	start 4th leg at 1200 ft, close to cloud top
12:56:00	end, turn, climb to 1700 ft -> above cloud, >0°C, de-ice
	5th leg above cloud
13:05:50	turn and descend to 1300 ft, try to do 6th leg just below cloud top
13:07:40	reach cloud top, start 6th leg
13:16:00	turn and climb to 2500 ft to de-ice

13:26:00	descent for profile through cloud, 200 ft/min, free speed
13:27:40	cloud top
13:31	cloud base at 800 ft
13:34:50	200 ft, level for 5 min
13:39:50	start next ascent 200 ft/min
13:42:15	cloud base
	Call from LYB, weather conditions become worse, have to stop cloud profiling and go back to LYB fast
	Ascent to 12000 ft
13:56	aerosol layer around 1000 ft
14:01	12000 ft
14:12	start descent to 9000 ft
14:44	touch down (approximate time)

Pictures:

Fig. S13.14: Photograph taken from Polar 6 showing low clouds close to LYB after take-off.

Fig. S13.15: Photograph taken from Polar 6 at 200 ft flight level close to Polarstern.

Fig. S13.16: Photograph taken from Polar 6 during the highest leg in clouds (1300 ft), just below cloud top (13:13 UTC).

Fig. S13.17: Photograph taken from Polar 6 showing fog over LYB shortly before landing.

ACLOUD Flight #14 – Polar 5&6 – 2017/06/08

Objectives:

Study thin broken clouds over sea ice and the transition from open ocean to closed sea ice. The flight was coordinated with an A-Train overpass and with Polarstern. Over Ny-Ålesund a flight leg was flown to compare ground-based and airborne remote sensing observations.

Mission PI P5:

Mario Mech

Polar 5 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Christoph Petersen
SMART	Michael Schäfer
Eagle/Hawk	Evelyn Jäkel
MiRAC	Tatiana Nomokonova
AMALi	Friedhelm Jansen

Mission PI P6:

Emma Järvinen

Polar 6 Crew	
Mission PI	Emma Järvinen
Basis Data Acq.	Daniel Damaske
ALABAMA	Hans Clemen
CVI	Udo Kästner
Gas/AWI-Aerosol	Heiko Bozem
PMS	Delphine Leroy
Nevzorov	Dmitry Chechin

Flight times:

Polar 5	
Take off	07:36 UTC
Touch down	12:51 UTC

Polar 6	
Take off	07:30 UTC
Touch down	13:12 UTC

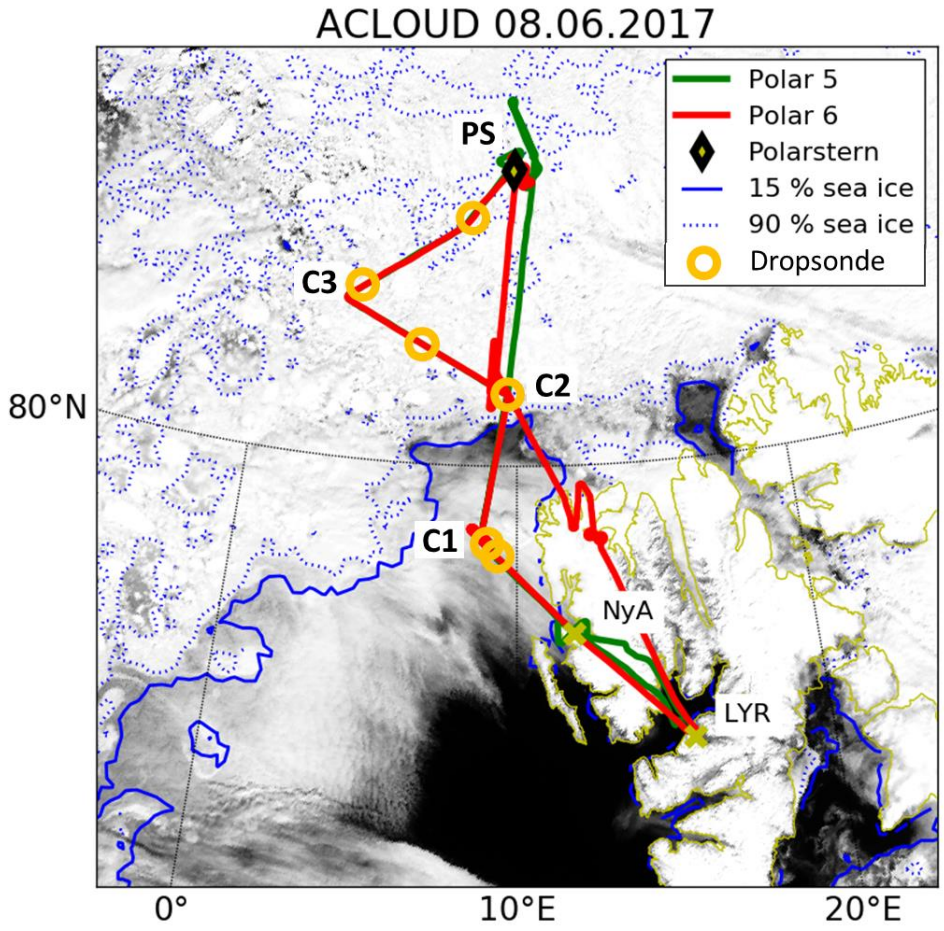


Fig. S14.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

The weather forecast predicted slow wind speeds and a layer of broken low clouds in the west and north of the archipelago. The mid- and high-level clouds were predicted to have cleared from the past days. As predicted, low-level clouds were found from Ny Ålesund to Polarstern with only occasional mid- and high-level clouds. The cloud deck was found to be solid until few tens of nautical miles before Polarstern and near Polarstern only a weak and broken cloud layer were observed. Towards the afternoon, the clouds cleared over the open sea.

Overview:

Polar 5: We took off in Longyearbyen, made a loop because we saw a whale and headed towards Ny ALesund over the Sveabreen glacier in low altitude. At the top of the glacier we climbed to be at 10000 ft over Ny Alesund. Underneath us there were several cloud layers. Once at C1 we had to perform a race pattern since we were ahead of time to co locate with Polar 6 and to meet the

satellite later on. Turned towards North to C2 where we hit the satellite track. From C2 to C3 underneath the satellite in 10000 ft. At C3 turn into direction towards Polarstern. Cross pattern over Polarstern were performed before descending and flying legs below and above the clouds. Afterwards back to 10000 ft and direction C1. At C1 turn to NyA and cross pattern over NyA and back to Longyearbyen.

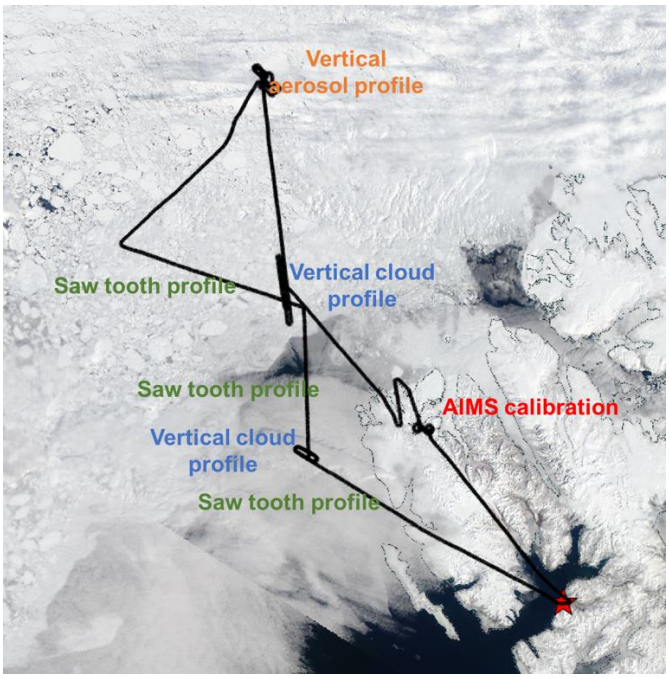


Fig. S14.2: MODIS RGB composite overlaid with the flight manoeuvres of Polar 6.

Polar 6: Polar 6 (P6) started before the Polar 5 (P5) and headed towards Ny Ålesund and C1 at an altitude of 4000 ft. The cloud deck began 10 minutes before arriving to Ny Ålesund and to avoid flying in the clouds above terrain, P6 ascended to 4500 ft. Although the first saw tooth pattern was planned to start at C1, it was decided to probe the clouds over the open ocean 10 minutes after passing Ny Ålesund. Before arriving to C1, P6 did one decent through clouds with 200 ft/min. The cloud top was found at 4400 ft and cloud base at 1000 ft. Temperatures were few degrees in positive, which resulted in all-liquid cloud phase.

Fig. S14.3: Photograph taken from Polar 6 showing the ice edge seen below the cloud layer.

At C1 the P5 was approximately 10 minutes behind, so while waiting to be co-located P6 decided to perform a race track with 2 minute legs at C1. The levels probed were 1800 ft (cloud base at 1700 ft), 2500 ft, 3000 ft and 3400 ft. The cloud was found to consist of multiple layers and the level 3000 ft was located in between cloud layers. Temperatures were +2°C and the cloud composed of ~10 µm droplets. After the race track P6 and P5 co-located and headed towards C2 at 08:59 – one minute later than planned.

Fig. S14.4: Photograph taken from Polar 6 showing patchy clouds near Polarstern.

Between waypoints C1 and C2 P6 flew saw tooth pattern. The first descent was with 400 ft/min and the cloud top and base

were at 3900 ft and 2600 ft, respectively. Below the cloud base were thin lower clouds approximately at 700 ft. P6 continued to descent to 200 ft. Below the cloud base P6 sampled boundary layer. The ice edge was crossed before the next saw tooth ascent. The next saw tooth pattern was performed over sea ice. The cloud base was at 700 ft and top at 1400 ft. Within this penetration also ice crystals were observed at temperatures around -3°C. The clouds above the sea ice were colder than above open ocean but this day the strong inversion layer was missing. Temperatures above the cloud top were around 1.5°C. During the next attempt to descent through the cloud the pito-tube started vibrating and the pilots pulled the P6 back up. The reason for the vibration was icing on the pito-tube structures. Altogether 6 minutes were spent above the cloud top to get rid of the ice. During this time, the satellite overpass was missed. After de-icing one more saw tooth descent and ascent were made, which resulted into increasing buildup of ice on aircraft structures and cloud probes. To avoid unnecessary icing the saw tooth pattern was stopped and way to Polarstern was made in clear air at 1200 ft.

At Polarstern the clouds were broken and thin, so instead of performing a cloud race track near Polarstern we performed an aerosol race track with 1-minute legs and constant ascent with 800 ft/min. The race track started at 200 ft and ended at 12000 ft. After sampling the ceiling altitude 3 minutes, P6 headed towards C1 with a constant ascent.

The cloud deck turned more solid in between Polarstern and C1 and the solid cloud layer offered the change to perform the cloud race track near C2. The cloud top was observed to be at 1400 ft and the cloud base was located at 400 ft. The race track was performed as 8-minute legs with first leg below the cloud base (200 ft), the second at 600 ft and the third at 800 ft. During the third leg, the vibrations in the pito-tube occurred again and weren't avoided even after de-icing above the cloud deck. To avoid damaging the pito-tube the cloud profile was stopped and the coordinates were set to LYR. On the way back P6 sampled the vertical distribution of aerosol by ascending to 12000 ft and maintaining that level for 2 minutes before descending to 8000 ft. At 8000 ft a calibration pattern for the AIMS was performed with jaws at different speeds and circles with different banks.

Fig. S14.5: Photograph taken from Polar 6 showing a solid cloud deck, which started before C2.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	6 launched

Table S14.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S14.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

No instrumental problems were reported.

Detailed Flight Logs:

Polar 5: Mario Mech (all times UTC)

07:36 take off
07:46 low clouds just over glacier
07:52 start of climb to 10000 ft
no cirrus above
07:53 in clouds between 3300 and 3600 ft
07:56 1500 ft above clouds to gain of the better resolution in the near field of the radar

08:02 further climb to 10000 ft
08:07 lidar on
08:14 two cloud layers
08:19 no broken clouds in radar visible even though present
08:26 at C1 race pattern to co-locate
08:28 DS - bad dropsonde, no GPS
08:29 DS1
08:31 edge of higher clouds the left - no cirrus
08:37 co-locate 2 min behind the schedule
08:40 pitch to 0° for testing purposes; directly back to 2°
08:41 cirrus ahead
08:43 whole in upper cloud layer ahead
08:48 broken clouds
08:49 still over open ocean
08:50 ice edge ahead
08:58 DS2
08:59 on satellite track
09:04 clouds in 2500 ft not visible for the radar
09:13 DS3 launched at satellite overpass
09:20 P6 reports400/800 to 1300 ft (?) clouds
09:23 P6 clouds in 200 to 1200 ft
09:30 cloud free areas to the North
09:32 DS4
09:32 C3
09:37 cloud wholes getting bigger
09:42 P6 icing
09:42 very thin clouds
10:33 200 ft with clouds at 300 ft
10:27 hazy
10:30 turn to climb out of the clouds
10:32 300 ft in clouds with 200 ft extend
10:41 1600 ft inversion seen in dropsonde
10:43 2800 ft
11:15 still over sea ice; very thin low clouds
11:25 closed cloud deck
11:35 DS6 - might be bad dropsonde
11:45 closed cloud deck
11:53 DS7 at C1
12:01 clouds over NyA
12:10 passed NyA and started pattern
12:51 touch down

Polar 6: Emma Järvinen (all times UTC)

07:30	Take off • 4000 ft and 140 kn towards Ny Ålesund
07:48	Cloud deck begins
07:51	Ascent to 4500 ft to avoid clouds • some mid-level clouds in sight
07:57	Ny Ålesund • cloud top almost at 4500 ft
07:59	To 4600 ft
08:01	Patchy mid-level clouds above
	Saw Tooth Profile in Clouds
08:05	Saw tooth ↓ 300 ft/min • Cloud top at 4400 ft (+2°C) • mid-level clouds were above
08:10	Change to 500 ft/min
08:14	Cloud base at 1000 ft
08:14	At 500 ft • no precipitation
	C1 Cloud Race Track (2 min legs)
08:18	Climbing to cloud level with 500 ft/min
08:21	Cloud base at 1700 ft
08:21	Level 1800 ft
08:25	Right turn, climb to 2500 ft
08:26	Level 2500 ft • small droplets around 10 µm
08:29	Right turn, climbing to 3000 ft
08:30	Level 3000 ft • Between cloud layers
08:32	Level 3400 ft (without turn)
08:33	Back in cloud • Cloud droplets small, around 10 µm
08:35	C1: Climb out of the cloud
	Saw Tooth Profile
08:36	Above the clouds at 4000 ft • Some mid-level cloud right above
08:41	Saw tooth ↓ 400 ft/min • Cloud top at 3900 ft
08:44	Cloud base at 2600 ft • Some lower thin clouds ahead (+4°C)
08:47	Top of the boundary layer at 1500 ft
08:49	Thin cloud layer at 700 ft
08:51	At 200 ft • Ice edge ahead
08:55	Saw tooth ↑ 200 ft/min
08:57	Cloud base at 700 ft • Ice crystals, needles at -3°C • Droplet sizes around 18 µm
09:01	Cloud top at 1400 ft • No ice at the top

	• Temperature in the inversion layer 1.5°C
09:05	Saw tooth ↓ 200 ft/min • Cloud top at 1500 ft (-4°C) • Big droplets around 25 µm
09:09	Back up due to vibrations • De-icing at 2200 ft (1°C)
09:15	Saw tooth ↓ 200 ft/min • Cloud top at 1300 ft (-4.8°C)
09:21	Some ice crystals
09:22	Cloud base at 700 ft • Some precipitation ice but also droplets -> cloud base not clear
09:30	C3
09:31	Saw tooth ↑ 200 ft/min • Cloud base at 250 ft
09:36	Cloud top at 1300 ft • No ice in the cloud top • Clouds start to form patchy
09:43	End of saw tooth, heading to Polarstern at 1200 ft
09:57	Descent to Polarstern -> only thin and patchy clouds
	PS Aerosol Race Track
10:14	Start race track at 100 ft
10:19	PS plume
10:32	12000 ft
10:35	Head to C1
10:40	Start descent
	Solid cloud deck ahead that ends to sea ice border
	Cloud Race Track, 8 min legs
10:01	Cloud top at 1400 ft
10:03	Cloud base at 400 ft
10:04-11:10	Level 200 ft • No precipitation
11:10	Turn near ice edge -> clouds getting thinner
11:15-11:23	Level 600 ft • Small droplets around 10 µm • Cloud base lowered towards end of the leg
11:23	Turn and climb to 800 ft
11:24	Level 800 ft • Only liquid at -4°C
11:25	Out of cloud due to vibrations
11:35-11:40	Level 800 ft
11:40	Stop race track due to vibrations
12:06	Level 12000 ft
12:08	Level 8000 ft
	AIMS Calibration
12:14	Jaws 100 kn
12:15	Jaws 120 kn
12:17	Jaws 140 kn
12:18	Jaws 160 kn
12:19	Bank 160 kn
12:22	Jaws 160 kn

12:23	Jaws 140 kn
12:24	Jaws 120 kn
12:26	Jaws 100 kn
12:28	360° turn, 15° bank, right turn
12:31	360° turn, 30° bank, right turn
12:33	360° turn, 45° bank, right turn
12:35	360° turn, 15° bank, left turn
12:38	360° turn, 30° bank, left turn
12:40	360° turn, 45° bank, left turn
12:43	Head to LYR
13:12	TOUCH DOWN

ACLOUD Flight #15 – Polar 5&6 – 2017/06/09

Objectives:

Coordinated flight leg in short distance between Polar 5 and Polar 6 to compare and cross calibrate instruments which are operated on both aircraft.

Mission PI P5:

Christof Lüpkes

Polar 5 Crew	
Mission PI	Christof Lüpkes
Basis Data Acq.	Martin Gehrmann
SMART	Johannes Stapf
Eagle/Hawk	Elena Ruiz
MiRAC	Tobias Doktorowski
AMALi	Tobias Donth

Mission PI P6:

Johannes Schneider

Polar 6 Crew	
Mission PI	Johannes Schneider
Basis Data Acq.	Daniel Damaske
ALABAMA	Hans-Christian Clemen
CVI	Stephan Mertes
Gas/AWI-Aerosol	Heiko Bozem
PMS	Delphine Leroy

Flight times:

Polar 5	
Take off	08:05 UTC
Touch down	09:25 UTC

Polar 6	
Take off	07:56 UTC
Touch down	09:18 UTC

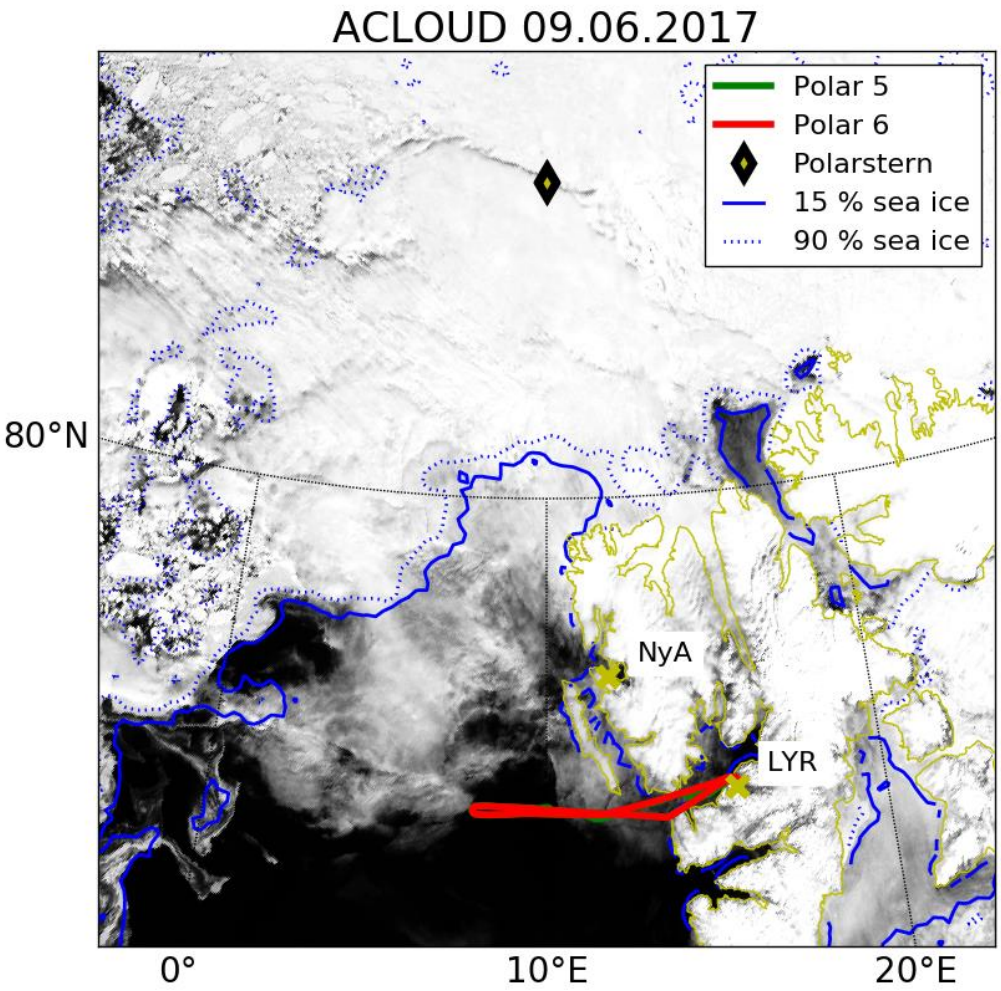


Fig. S15.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

The wind direction was predicted to be variable over Svalbard. Over Framstrait wind from south was expected. Only few cirrus clouds were observed over the airport, but increasing cloud cover towards west due to an approaching front. During the flight, this prediction was confirmed, clouds were observed in different layers. A layer with thin low clouds was sometimes present over Framstrait as predicted. An unexpected thin layer of mid-level clouds occurred at 10.000 ft over Fram Strait.

Overview:

Due to risk of fog the flight was restricted to a distance of 30 minutes to LYB. The strategy was to fly with both aircraft closely collocated (wing-by-wing) in a horizontal distance of 2000 ft to obtain a comparison especially of the noseboom measurements, the CO2 instruments Licor, and the INS. The strategy was to climb up to 10.000 ft, interrupted by horizontal flight sections at 5000 ft and 8000 ft

of 3 min duration. At 10000 ft two flight speeds (120 and 160 kn) were flown for 10 minutes. After the westernmost position was reached, the track was flown in opposite direction with a higher speed.

Fig. S15.2: Photograph of Polar 5 taken from Polar 6 during a flight in close formation. The clouds above were at about 10000 ft and were penetrated later during the flight.

Fig. S15.3: Photograph of Polar 6 between the two cloud layers over Fram Strait taken from Polar 5.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	None launched

Table S15.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S15.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

Computer froze during attempt to connect to LAMP PMS probes, but probes worked.

Detailed Flight Logs:

Polar 6: Johannes Schneider (all times UTC)

07:56:30	Take off
08:05	P5 appears on our right side
08:12 - 08:15	level at 5000 ft, 140 kn
08:15:10	start climb to 8000 ft (estimated distance to P5 3000 ft)
08:10	Heiko: CO2 decreases
08:21:30	8000 ft
08:22:56	low level clouds below us
08:24:30	reach 10000 ft
08:25	Heiko: CO2 very low
08:29	penetrate clouds at cloud base (but at constant altitude), only shortly
08:31	start 120 kn at 10000 ft
08:40:34	end of 10 minutes, turn
08:44	start way back
08:44:24	10000 ft, 160 kn, P5 coming on right side behind us
08:52 – 08:53	again through clouds, from cloud base to cloud top at constant altitude
08:54	end of 10 minutes at 160 kn,
08:55	start descent, meet P5 again below clouds
08:56	reach cloud base
08:56:30	descent with 500 ft/min 150 kn, P5 was further away due to cloud passage
08:50	end of low cloud field below us
09:00	P5 is close again
09:18:14	Touchdown

ACLOUD Flight #16 – Polar 5&6 – 2017/06/13

Objectives:

Calibrate the nose boom of both aircraft (Polar 5 and Polar 6) and collect in situ data of aerosol and cloud particles over the open sea West of Spitzbergen. Joint flight was partly collocated to repeat the comparison of measurements on Polar 5 and 6.

Mission PI P5:

André Ehrlich

Polar 5 Crew	
Mission PI	André Ehrlich
Basis Data Acq.	Lukas Kandroa
SMART	Elena Ruiz
Eagle/Hawk	Tobias Donth
MiRAC	Mario Mech
AMALi	Marek Jacob

Mission PI P6:

Manfred Wendisch

Polar 6 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Cristina Sans i Coll
ALABAMA	Udo Kästner
CVI	Franziska Köllner
Gas/AWI-Aerosol	Oliver Eppers
PMS	Delphine Leroy

Flight times:

Polar 5	
Take off	14:56 UTC
Touch down	16:55 UTC

Polar 6	
Take off	14:57 UTC
Touch down	17:16 UTC

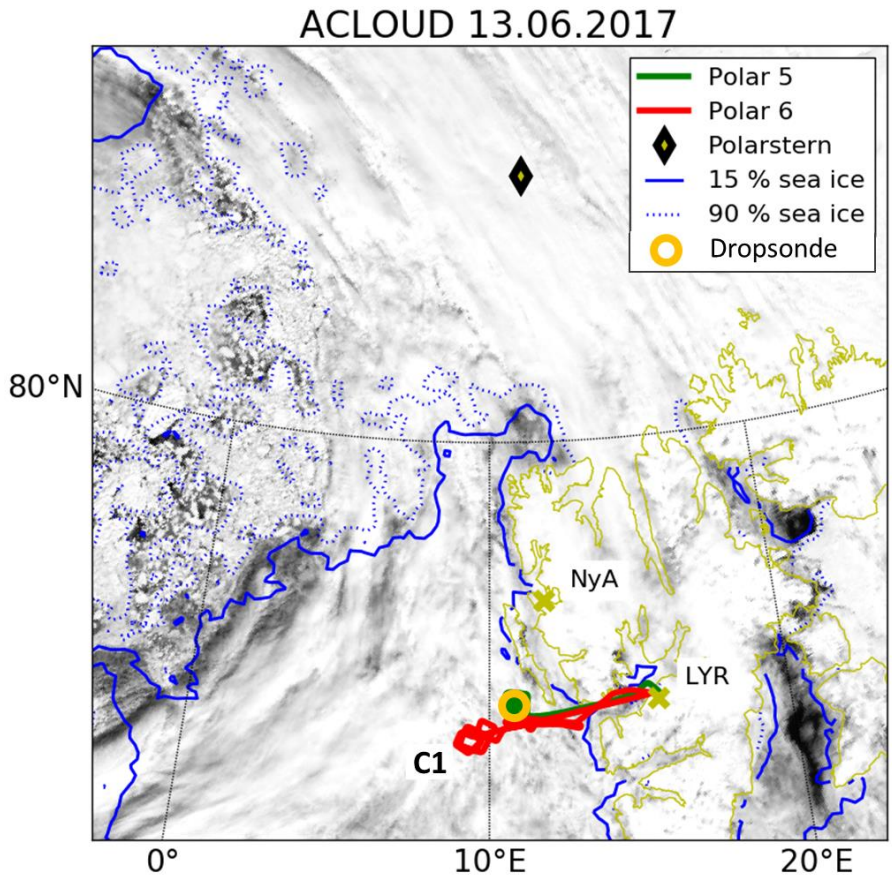


Fig. S16.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

We had drafted two flight plans, one extended version (to Polarstern, point 5 in the graphs below), and a second flight plan was filed just to the west (short flight, to point 1 and back). We opted for the short version because the weather conditions at LYR airport were unsure to some degree with a significant danger of low-hanging clouds and fog.

A low pressure system in high altitudes west of Svalbard and an occlusion north east of Svalbard were approaching towards the island. Low level clouds were predicted all over the place, mid-level associated with the pressure systems. The fog of the last days almost disappeared but the cloud base was not higher than 1000 m. This did not allow a flight in the morning for the initially planned flight pattern towards Polarstern. The situation improved over the day with increasing cloud base and some gaps in the lowest cloud layer.
Finally, a shortened flight towards west of Svalbard was conducted. In this area a multilayer cloud field was observed. Some convective clouds close to the coast, low stratiform clouds, partly alto stratus clouds and further west a thick cirrus. Temperatures in the low clouds had been above zero.

We mostly flew in between two extended cloud layers, one above (mid-level), the other one below the aircraft. The lower clouds (top heights between 2000-3000 ft) were partly quite homogeneous and extended, the upper clouds were mostly inhomogeneous.

ECMW prediction of clouds—horizontal

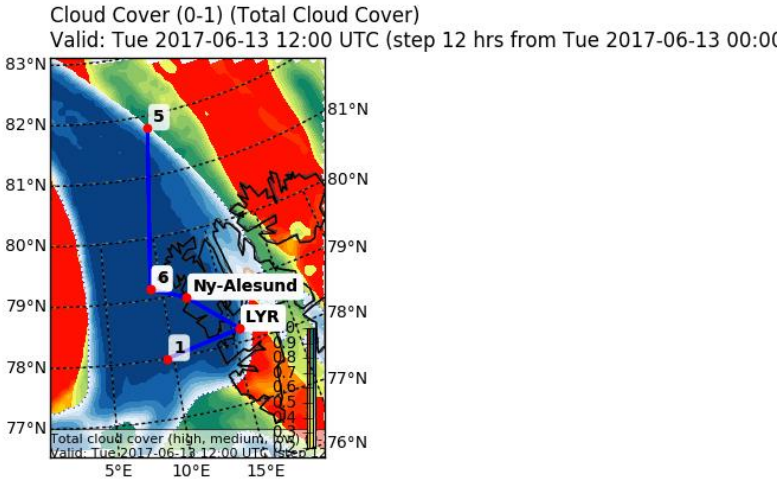


Fig. S16.2: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

ECMW prediction of clouds—vertical

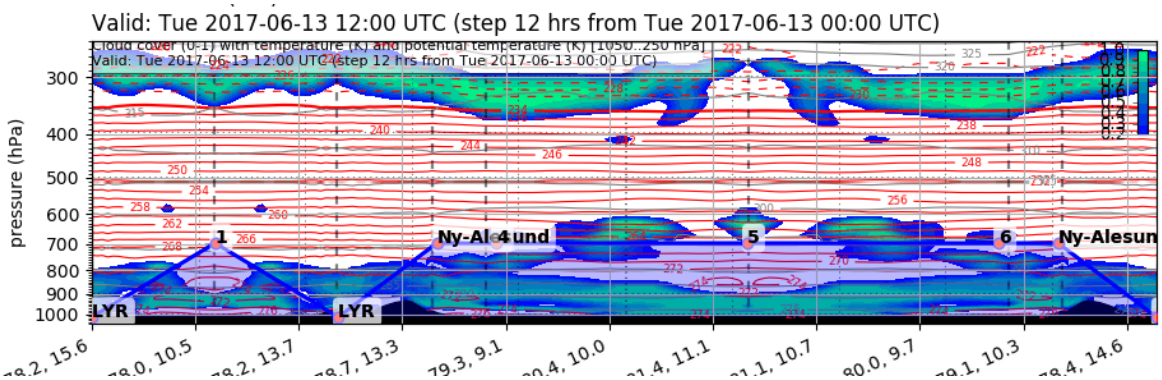


Fig. S16.3: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

ECMW prediction of wind 950 hPa

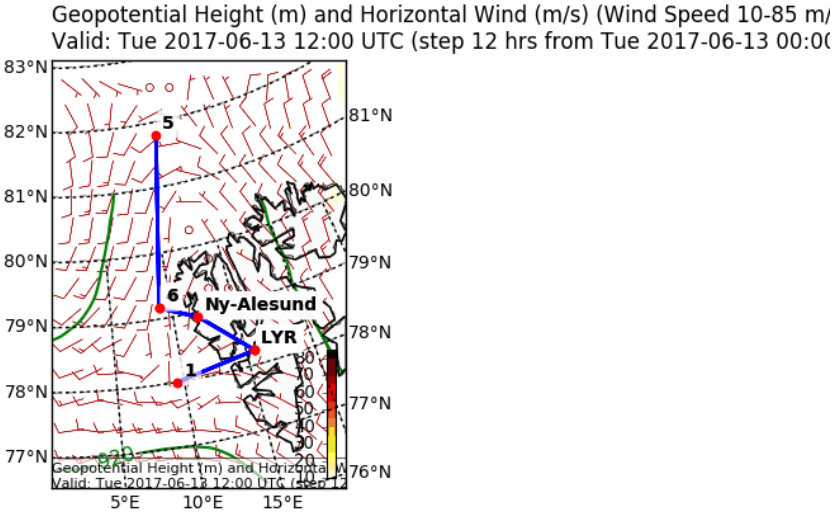


Fig. S16.4: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Overview:

Polar 5: The start of Polar 5/6 was synchronized to allow a climb in close horizontal collocation being in the same altitude at the same time. This worked out until 10 000 ft and allows a detailed comparison of the P5/P6 instrumentation. Some cloud layers were crossed during the ascent. For the lowest leg, the roller doors and the albedometer likely were not opened before entering the cloud (low cloud base). Some clouds exceeded 10 000 ft altitude. To allow reasonable RADAR measurements, the flight level was slightly adjusted to 11 000 ft. Before reaching C1, we started with the calibration square, 2 min legs, and four different speeds. In this area a low level clouds was detected by the radar. During the squared, we noticed some turbulence by motion of the aircraft. Also the radar observed some clouds which Polar 5 penetrated even when the pilots could not identify a "solid" cloud layer. Therefore, we added a second calibration square, 1 min legs, after finishing the first. Before ending the final box, we released one drop sonde. The second was flown in 8 000 ft altitude. Here, much calmer conditions were observed. After the second box Polar 5 returned to LYR staying in 10 000 ft as long as possible.

Fig. S16.5: Photograph taken from Polar 5 west of Svalbard showing the multi-layer structure of the clouds.

Fig. S16.6: Photograph taken from Polar 5 west of Svalbard showing the multi-layer structure of the clouds.

Fig. S16.7: Photograph taken from Polar 5 close to the west coast of Svalbard more convective cloud tops.

Polar 6: We climbed to 10,000 ft at C1. Close to C1 we performed four square patterns at 9,000 ft, with four speeds of 100 kn, 120 kn, 145 kn, 100 kn for each of the squares. This pattern was flown to calibrate the nose boom. On our way back we performed three downward and three upward (3 times a saw tooth) pattern through the lower cloud.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	1 launched

Table S16.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S16.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

No instrumental problems were reported.

Detailed Flight Logs:

Polar 5: André Ehrlich (all times UTC)

14:33 Almost overcast at the airport, cloud base at top of the mountains.
15:02 Mid- and low-level clouds
15:10 Different cloud layers, low, mid and high
15:12 within a cloud layer
15:14 climb above mid-level clouds
15:16 stratiform mid-level cloud above
15:18 two cloud layers, low and high cirrus
15:20 start first box of calibration pattern
15:21 SMART stabilization still spikes in roll and pitch analog channels
15:22 Thick cirrus with a halo visible.
15:30 End of first box
15:36 still multi-layer clouds
15:42 End of second box
15:46 quite turbulent
15:48 cloud conditions unchanged: cirrus above and multi-layer below
15:53 ½ of the legs are in clouds with respect to the radar
15:54 start of 4th box
16:03 Dropsonde #1
16:07 End of 4th box
→ Descend to 8 000 ft
16:11 start of 1st box

16:13 much calmer in the flight level
16:17 start of 2nd box
16:23 start of 3rd box
16:25 cloud conditions unchanged, much smoother at 8 000 ft
16:30 start of 4th box
16:37 end of calibration box pattern
→ Climb to 10 000ft
16:44 clouds in all altitudes
16:47 inside some convective cloud tops
16:48 start descent

Polar 6: Manfred Wendisch (all times UTC)

LYR – C1 **80 NM @ 160 kn 30 min**

- 14:15 Start of motors
- 14:52 Taxi
- 14:56 Take off
  We fly through a mixture of clouds in different levels, during the whole flight there are some clouds in higher altitudes above flight level
- 15:06 Above cloud, 6,000 ft
- 15:10 P5 appears on our right side
- 15:12 We reach 10,000 ft
- 15:13 Cloud penetration, we change between 11,000 ft and 9,000 ft
- 15:19 9,000 ft, this is below a high and above low clouds, CPC with 400 cm^{-3}
- 15:26 We reach C1

C1 Calibration Pattern (9,000 ft) **different speeds 48 min**

- 15:28 Begin 1st square 100 kn
- 15:39 Begin 2nd square 120 kn
  (ice crystals are reported, falling from above)

Fig. S16.8: Photograph taken from Polar 6.

- 15:52 Begin 3rd square 145 kn
- 16:04 Begin 4th square 100 kn
  CPC with 300 cm^{-3}
- 16:16 End of last (4th) square

C1 – LYR Saw Tooth **different speeds** **58 min**

First saw tooth

- 16:18 We descend (partly with 1000 ft/min), trey saw tooth, orbit to get faster down
- 16:21 6,000 ft
- 16:25 Begin downward saw tooth, enter cloud, +2°C, rain
  There are two clouds, a higher one (3000 ft), a lower one (2000 ft)

Fig. S16.9: Photograph taken from Polar 6.

- 16:29 We reach the lowest level at 500 ft below cloud, stay at this altitude for 2 min

Fig. S16.10: Photograph taken from Polar 6.

- 16:30 Start climbing with 800 ft/min, 1°C, go through cloud
- 16:32 Reach cloud top

Fig. S16.11: Photograph taken from Polar 6.

- We return (off the coast) to have another saw tooth.

Second saw tooth

- 16:35 Begin descending into cloud

Fig. S16.12: Photograph taken from Polar 6.

- 16:41 Reach cloud base at 500 ft
  Stay below cloud
- 16:42 Begin ascend into cloud
- 16:48 Reach cloud top (3000 ft)
- We return (towards the coast) to have another saw tooth

Third saw tooth

- 16:51 Begin descending into cloud, start from 3000 ft (descend rate 500 ft/min)
- 16:57 Reach cloud base between 900 ft and 500 ft
  Stay 1 min below cloud
  Many salt particles reported
- 16:58 Begin ascent into cloud from below (500 ft)
- 17:01 Reach cloud top (2300 ft)

Fig. S16.13: Photograph taken from Polar 6.

Fig. S16.14: Photograph taken from Polar 6.

Fig. S16.15: Photograph taken from Polar 6.

- Go home at 4000 ft, thick cloud below
- 17:16 Touch down
- 17:18 Parking
- 17:28 Motors off

ACLOUD Flight #17 – Polar 5&6 – 2017/06/14

Objectives:

The main goal of the flight was a study of the boundary layer structure and energy fluxes in the environment of RV Polarstern. The focus was on the profiles of vertical fluxes of heat, humidity, and momentum as well as radiation.

Mission PI P5:

Christof Lüpkes

Polar 5 Crew	
Mission PI	Christof Lüpkes
Basis Data Acq.	Lukas Kandora
SMART	Johannes Stapf
Eagle/Hawk	Tobias Donth
MiRAC	Tobias Doktorowski
AMALi	Ana Radovan

Mission PI P6:

Manfred Wendisch

Polar 6 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Cristina Sans i Coll
ALABAMA	Udo Kästner
CVI	Franziska Köllner
Gas/AWI-Aerosol	Oliver Eppers
PMS	Guillaume Mioche

Flight times:

Polar 5	
Take off	12:48 UTC
Touch down	18:50 UTC

Polar 6	
Take off	12:54 UTC
Touch down	17:37 UTC

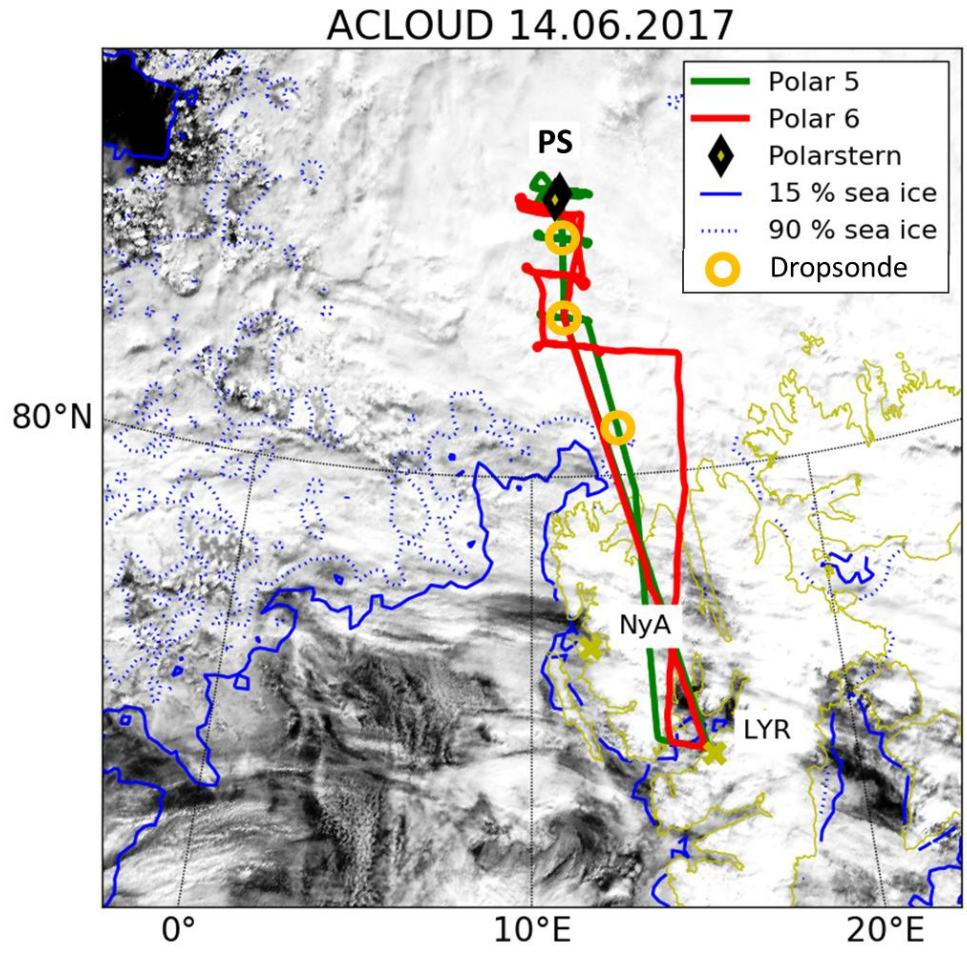
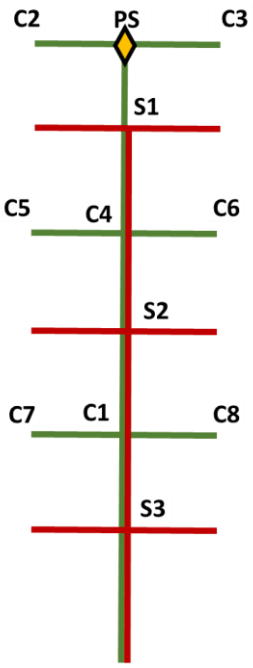


Fig. S17.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).



The planned flight track is shown in the Figure S17.2. Waypoints C1-C8 refer to the Polar 5 flight, while S1, S2, S3 and white lines refer to the Polar 6. C1---C4 was flown in 10.000 feet, while the 'flux tracks' where flown orthogonal to this direction. Each of them lasted 8 minutes corresponding to 16 Nm. Between PS and C4 as well as between C4 and C1 Polar 5 performed measurements in 200 ft.

Dropsondes were released at C1, C4 (outbound) and south of S3 (inbound flight).

Fig. S17.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

An occlusion front was approaching from north east towards Svalbard. Ahead northerly winds and multi-layer clouds with a defined low-level cloud dominated the area close to Polarstern. This situation was used to extensively probe the boundary layer along the northerly flow at different latitudes. Measurements were carried out north of Svalbard during predicted northerly flow of roughly 10 Kn (below: 12 UTC prediction of GFS). In the measurement region an elevated layer of low clouds was predicted as well as high clouds. Mid-level clouds had been expected for the region between Longyearbyen and the northern coast of Svalbard.

The observed cloud features agreed roughly with the prediction. The main difference: many clouds appeared to be surface based in reality. This differed from the prediction of an elevated cloud layer.

ECMW prediction of clouds—horizontal

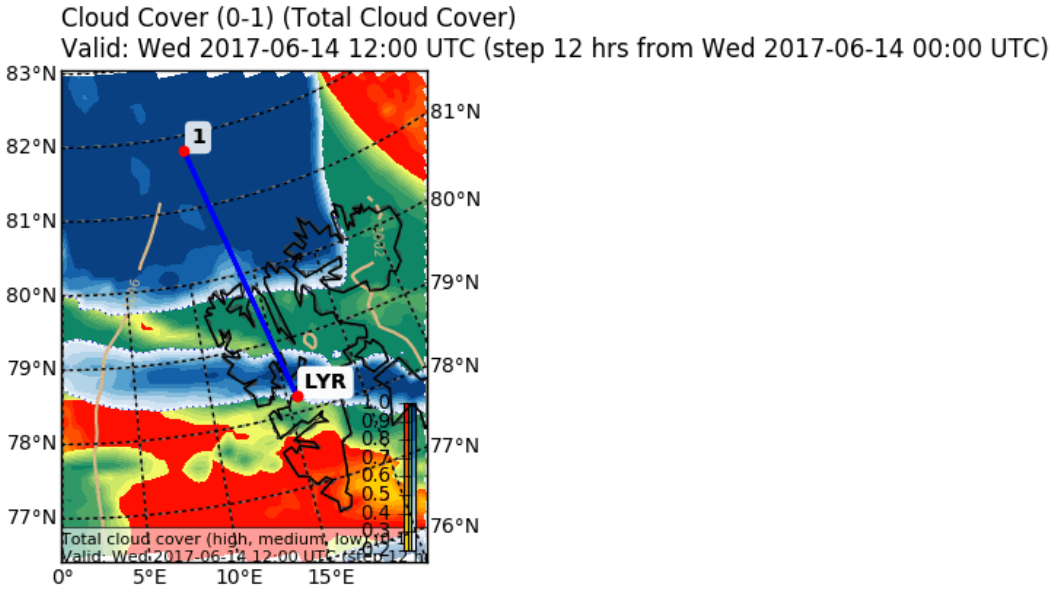


Fig. S17.3: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

ECMW prediction of clouds—vertical

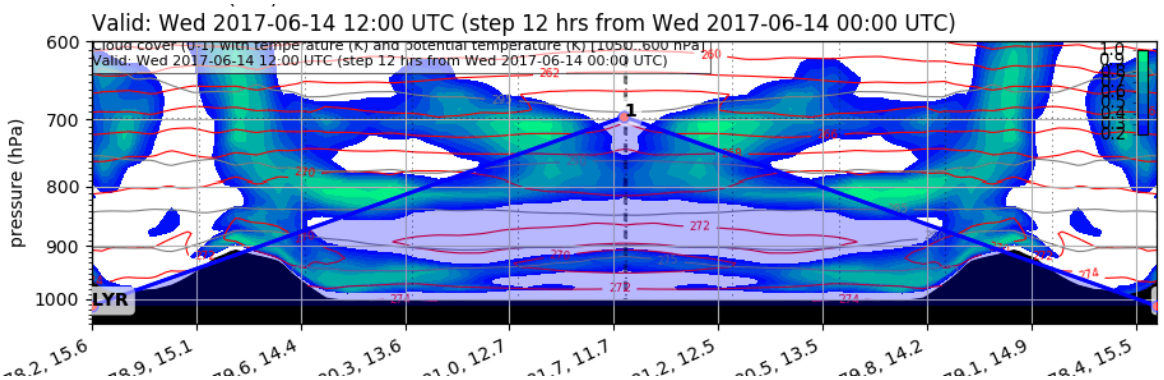


Fig. S17.4: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

ECMW prediction of wind 950 hPa

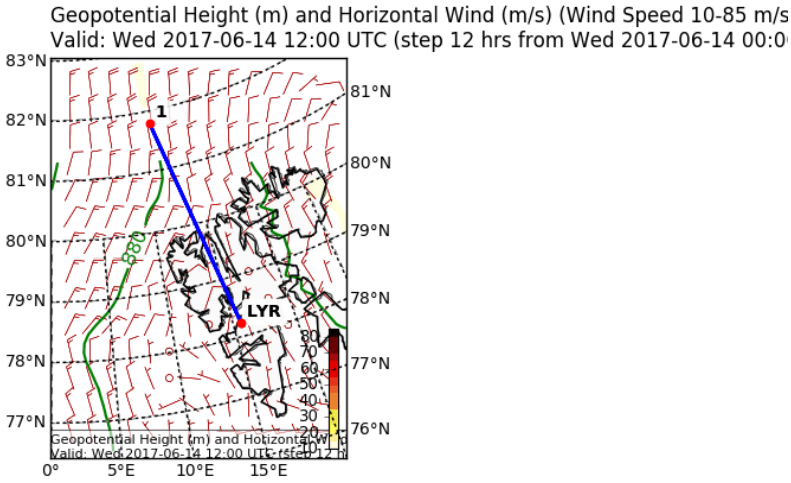


Fig. S17.5: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Overview:

Polar 5: The flight strategy was to measure first the cloud structure by the remote sensing instrumentation (Lidar, Eagle Hawk, Mirac) flying at 10.000 ft in northerly direction from C1 to Polarstern. Then the inflow profiles of wind and temperature were obtained during a fast descend reaching Polarstern in 200 ft. Fluxes were measured then along flights in five different heights between 200 ft and cloud top at three positions. The flight was performed in close collocation with Polar 6 measuring e.g. fluxes at further positions along the Polar 5 track. At the end of the flight the last horizontal flight leg had to be finished a little earlier than planned due to sudden icing. Also several dropsondes had been launched.

Polar 6: The flight was very successful although problems with the heating system of the CVI inlet occurred after 2/3rd of the flight. In total, the cloudy boundary layer was profiled at 5 locations what was only possible by operating Polar 5 & 6 jointly and because both were equipped with identical noose booms using the new heating systems that allowed longer flights in cloud layers. At the same time balloon borne measurements of turbulent and radiative flux profiles were conducted on the ice floe close to Polarstern.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	3 launched

Table S17.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S17.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

Problems with the CVI heating, otherwise no instrumental problems were reported.

Detailed Flight Logs:

Polar 5: Christof Lüpkes (all times UTC)

Clouds: As it was predicted, there were two cloud layers (high and low) as shown in Fig. S16.6.

Fig. S17.6: Photograph taken from Polar 5 at a position between S1 and C4.

Further north the fraction of the low clouds decreased as shown in Fig. S16.7.

Fig. S17.7: Photograph taken from Polar 5 not far from Polarstern.

During all legs the altitudes of cloud base and cloud top were rather nonhomogeneous. For example, on the leg C2 C3 close to Polarstern clouds were surface based while farer away on the same leg, they were elevated from the surface. The thinner clouds had tops in 1200-1300 ft while other cloud tops were at least 200-300 ft higher (estimated values since we did not fly at the level of the higher cloud tops). Towards south, the cloud tops were on average at higher altitudes (around 1400 ft) but also this value is an estimate due the strong inhomogeneity.

Some further photos of the cloud situation are added in the following:

Fig. S17.8: Photograph taken from Polar 5 showing an example of large (low) cloud cover.

Fig. S17.9: Photograph taken from Polar 5 showing that some parts of the flight legs were almost free of low clouds.

Fig. S17.10: Photograph taken from Polar 5 showing an example of surface based clouds.

Sea ice conditions

There was a slight North South gradient in sea ice cover with higher sea ice concentration and larger floes in the North and lower sea ice cover and smaller floe diameters in the South. However, along the 16 Nm leg (C7 C8) the sea ice (cover, floes, ridges) looked over some miles very similar to the situation found in the North close to Polarstern.

Fig. S17.11: Photograph taken from Polar 5 showing an example of small sea ice floes.

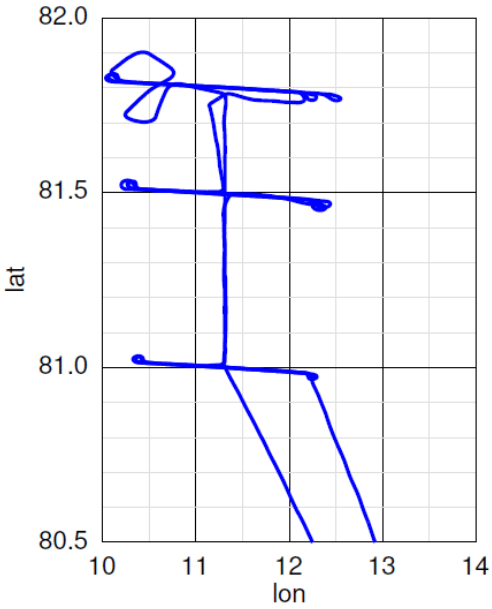
Fig. S17.12: Photograph taken from Polar 5 showing an example of large ice floes between C5 and C6.

There were indications for melting. We observed grey, dark snow patches, but only very few melt ponds were clearly identified. Most pond-like structures seemed to be flooded ice floes in the vicinity of ice ridges.

Detailed notes during the flight, heights of flight legs:

S3→C1: 8/8 low clouds, 6/8 cirrus clouds
C2→ C3: legs in 200 ft, 400 ft, 600 ft, 800 ft, 1200 ft (cloud top, and inversion base)
1200 ft leg, mostly at cloud top, but sometimes still within clouds
PS→ C4 mostly good visibility
C5→C6,: legs in 200 ft, 400 ft, 600 ft, 850 ft, 1200 ft. More indications for melting, in the eastern part of the leg initially less open water, at the end again more open water. Clouds elevated from the surface with a very variable base, the 400 ft leg sometimes at cloud base, sometimes below.
C4 → C1 in 200 ft, initially in clouds, later elevated clouds.
C7→C8: legs in 200 ft, 400 ft, 600 ft, 800 ft, 1300 ft. The last leg had to be aborted due to strong icing.

Maneuvers



The position of Polarstern was a few Nm West of the expected one, so that the position of the northernmost leg (C2-C3) was slightly shifted. (The goal of this maneuver was to have Polarstern in the center of the leg).

A dropsonde that was planned for C1 had to be launched later (between S1 and Svalbard) due to GPS alignment problems.

Fig. S17.13: Flight track of Polar 5 showing three legs to profile the atmospheric boundary layer.

Polar 6: Manfred Wendisch (all times UTC)

12:28 Motor on
12:35 CVI ready
12:38 Alabama ready
12:40 Trace gas and Aerosol ready
12:40 Taxi
12:54 Take off

LYR –> C1 10,000 ft 175 Nm, 160 kn 63 min

Fig. S17.14: Photograph taken from Polar 6.

13:00 We reach 4500 ft, cloud mixture, mid and low level clouds all over the place
13:04 8000 ft
13:05 Cloud penetration
13:06 9000 ft, very hazy
13:08 10,000 ft
13:15 We are inside clouds, some icing, we climb further to get rid of the ice
13:21 We are below a low-level cloud, ice vanishes

Fig. S17.15: Photograph taken from Polar 6.

13:24 Out of cloud, still mostly below a cloud, precipitation from above, PMS records ice particles
13:28 Several cloud encounters, it is quite turbulent, many droplets
13:30 Cloud patches
13:32 Less clouds, still scattered, kind of messy
13:40 Cloud encounters
13:45 Nice low-level clouds, just little clouds above
13:50 Little cirrus above, nice clouds below

Fig. S17.16: Photograph taken from Polar 6.

13:55 We reach C1

C1 – > S1 40 Nm, 160 kn 15 min

13:56 Descend with 500 ft/min
14:00 9000 ft
14:02 8000 ft, almost mid-level cloud top, we start penetrating through a mid-level cloud
14:04 We reach mid-level cloud base at roughly 6000 ft
14:12 We reach the top of lower cloud (1200 ft)
14:13 We reach S1

at S1 5 staggered legs 8 min length 120 kn 60min

14:18-14:25 Leg below cloud, 200-300 ft, below cloud base, partly in clouds, partly out of clouds, 15 cm^{-3} particle number concentration

Fig. S17.17: Photograph taken from Polar 6.

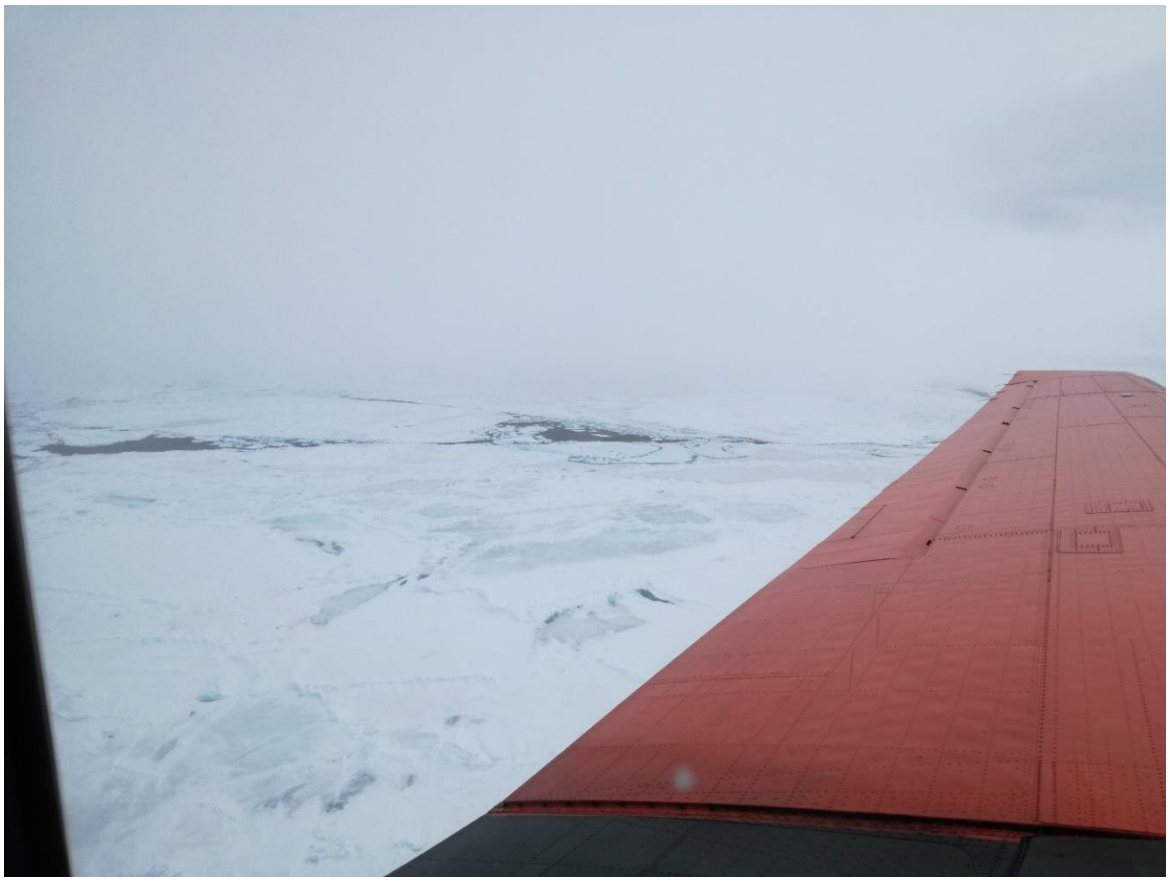


Fig. S17.18: Photograph taken from Polar 6.

Fig. S17.19: Photograph taken from Polar 6.

14:27-14:37 Leg through the middle of the cloud, 600 ft

14:40-14:48 Leg through cloud top, 900 ft, partly out of cloud, some icing, traces of ice at the wings, -0 °C

14:50-14:58 Leg above cloud, 1500 ft, mostly out of cloud, icing not gone, is an issue

S1 – S2 saw tooth 24 Nm, 120 kn 12 min

15:00 Go through cloud from above

15:03 Below cloud, we go at 200 ft below the cloud to the south into the direction of S2, we get rid of the ice.

at S2 5 staggered legs 8 min length 120 kn 60min

15:09-15:17 Leg at 200 ft, mostly below the cloud, icing is gone, melted away, sometimes in cloud, +0 °C

15:19-15:27 Leg at 600 ft, within cloud all the time during this leg, again icing, accumulating, at the end of the leg heating of CVI does not work anymore, Because of the CVI heater problem, the inverter was affected as well and it might be that the heating of the noseboom was off. After flight preliminary data analysis showed that the noseboom was not affected, data seemed okay.

15:28-15:42 We go to 4000 ft to get rid of the iced CVI inlet

S2 –> S3 40 Nm, 120 kn 20 min

15:43-15:46 We go below cloud again

at S3 3-5 staggered legs 8 min length 120 kn 36- 60 min

15:54-16:02 Leg at 200 ft, repeated in backward direction

16:06-16:14 We stay at 200 ft

S3 --> LY 10.000 ft 160 kn 60 min

16:15 Start climbing to 4500 ft, inverter switched on again.

16:35 Reaching 4500 ft, we stay 6 mins at this altitude, then go to 10,000 ft, then to 8000 ft

Fig. S17.20: Photograph taken from Polar 6.

16:42 We encounter a heavy pollution plume, which we sample.

Fig. S17.21: Photograph taken from Polar 6.

16:52 Partly in clouds

17:13 Enter mid-level cloud, we stay in this cloud almost until landing

17:19 Start descending

Fig. S17.22: Photograph taken from Polar 6.

17:37 Touch down

17:41 Parking

ACLOUD Flight #18 – Polar 5&6 – 2017/06/16

Objectives:

The flight aimed to study a low level cloud field close to Polarstern. The flight was coordinated with two subsequent overpasses of the A-Train satellites. Both overpasses were close to Polarstern. While Polar 5 followed a straight path along the satellite track, Polar 6 measured the vertical cloud profile at two locations in the center of these straight legs. On the return to Longyearbyen, Ny Alesund was overflown.

Mission PI P5:

Mario Mech

Polar 5 Crew	
Mission PI	Mario Mech
Basis Data Acq.	Lukas Kandera
SMART	Johannes Stapf
Eagle/Hawk	Elena Ruiz
MiRAC	Tobias Doktorowski
AMALi	Marek Jacob

Mission PI P6:

Emma Järvinen

Polar 6 Crew	
Mission PI	Emma Järvinen
Basis Data Acq.	Cristina Sans i Coll
ALABAMA	Franziska Köllner
CVI	Stephan Mertes
Gas/AWI-Aerosol	Oliver Eppers
PMS	Guillaume Mioche

Flight times:

Polar 5	
Take off	04:45 UTC
Touch down	10:01 UTC

Polar 6	
Take off	04:40 UTC
Touch down	12:31 UTC

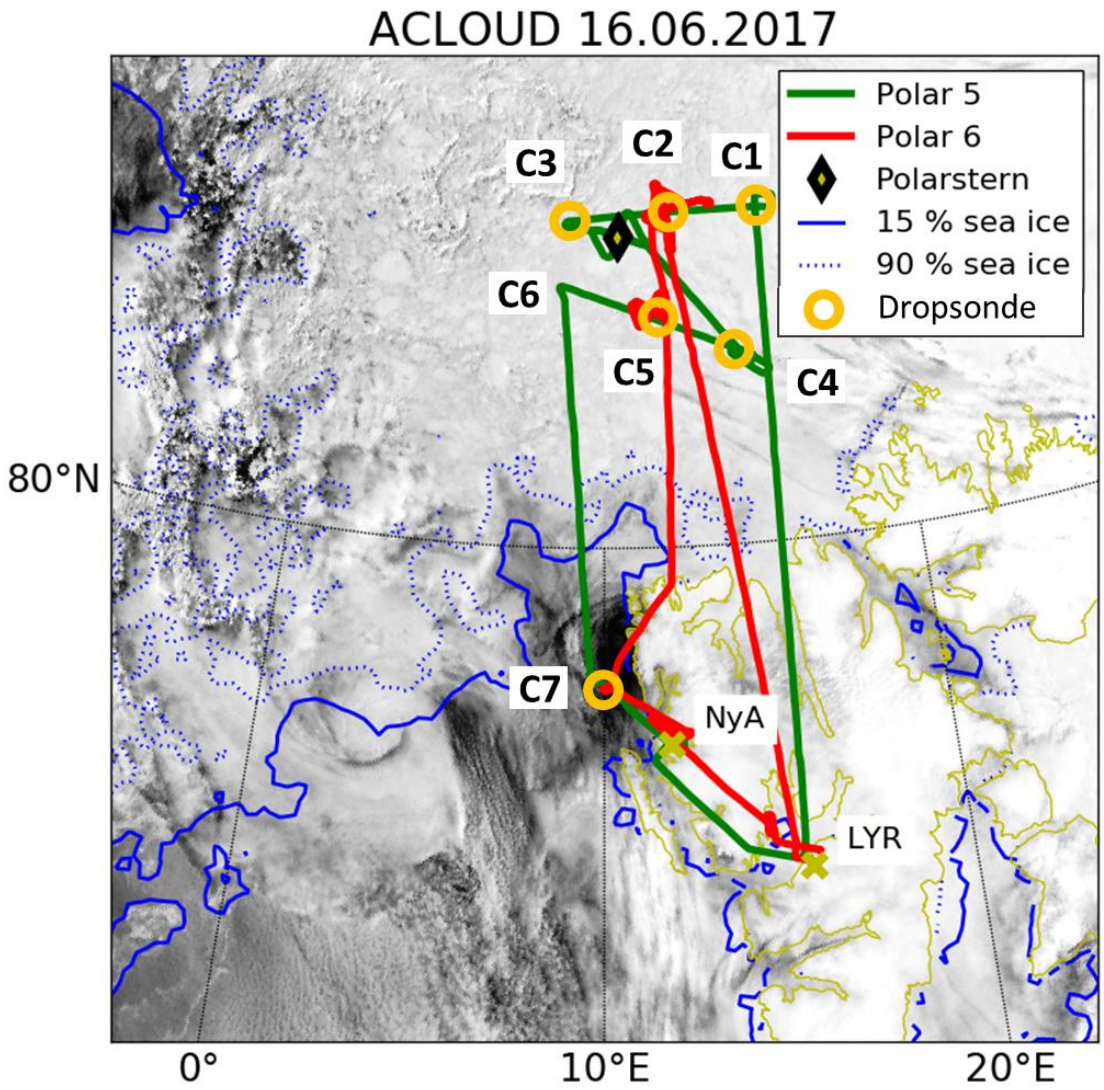


Fig. S18.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

The flow direction on the flight day was from the north bringing colder air north and west of Svalbard. For the flight day a high cloudiness was predicted. In the area west and north west of Svalbard the GFS model predicted low level clouds and the ECMWF model both low and medium level clouds. During the flight a solid cloud deck was observed that continued unbroken from Longyearbyen to Polarstern (PS). The cloud top after Longyearbyen was found at 7000 ft and at PS around 3000 ft. Unlike predicted, the clouds were more uniform and mainly in one layer. Some brokenness was observed in the lower parts of the cloud layer. Below 2000 ft only thin and broken clouds were seen. The solid cloud deck began to dissipate in the west coast of Svalbard but over Ny Ålesund still a thinner cloud layer from 4500 ft to 5000 ft existed.

Overview:

Polar 5: The flight has been performed as planned. Taking of in Longyearbyen and heading North towards the starting point of the first satellite overpass. Once there, we realized that we were early and performed a holding pattern. From C1 to C2 the A-train has been under flown before heading to Polarstern. Since there was again time, a double triangle over Polarstern has been performed as well as another holding pattern over C3. After 20 min on satellite track we headed straight South to fly after C5 towards Ny Alesund along the valley axes. Directly after C5 we turned slightly a bit towards East to have a small section over open water without clouds underneath. Shortly before a dropsonde has been launched. Over Ny Alesund a half triangle was included.

Fig. S18.2: Photograph taken from Polar 5 showing the cloud deck before the second double triangle profile.

Fig. S18.3: Photograph taken from Polar 5 showing the cloud base after the second double triangle profile. Some thin clouds below the cloud deck.

Polar 6: On the way to the first satellite overpass P6 measured aerosols at 7000 ft, 12000 ft, 9000 ft and 6000 ft. In the first attempt to decent below the cloud base, pilots observed vibrations in the pito-tube due to icing and had to interrupt the descent and ascent above the cloud layer. The inversion layer above the cloud deck was around zero degrees and so the deicing of the aircraft structures was slow. In the second attempt the same problem occurred again, so it was decided to perform the planned double triangle patterns at C1 above the cloud and only in the top cloud layers. The first legs were made at 8000 ft, 6000 ft and 5000 ft before P6 descended in the uppermost cloud layer (between 2800 ft and 3000 ft) for the satellite overpass. During the legs in cloud the instruments gathered ice and the transitions between the straight legs were spend above the clouds to de-ice. The next level was at 2600 ft and since the pito-tube was not causing problems, the last leg was made at the level 2300 ft. After this, P6 headed to the second satellite overpass position at C2.

P6 was well ahead the schedule and at arrival to C2 the satellite overpass was 40 minutes away. It was decided to start the double triangles again above the cloud at levels 6000 ft, 5000 ft and 4000 ft before descending to the cloud top for a leg at 3100 ft. Between the first legs in the cloud top, P6 ascended above the clouds to de-ice. The next levels were made inside the cloud at 2600 ft and at 2300 ft. After the leg at 2300 ft, the icing problem seemed to have settled and the time between the legs were spend in cloud. Since P6 was ahead of the schedule an extra double triangle pattern was made at levels 2000 ft (in the cloud base) and at 1200 ft (below the cloud).

Fig. S18.4: Photograph taken from Polar 6.

Cloud base at Ny Ålesund.

After the double triangles, it was decided to head to Ny Ålesund for a cloud profile. On the way to Ny Ålesund, aerosol profiles were measured at 200 ft, 5000 ft, 8000 ft and 12000 ft. Ny Ålesund was approached from the sea and P6 turned under the cloud base in the fjord to align with the Ny Ålesund runway. Above the runway P6 ascended one through the cloud. The cloud base was at 4500 ft and top at 5000 ft. After the last profile P6 heated back to Longyearbyen.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	7 launched

Table S18.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S18.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

Two power outages of 230 V on Polar 5 in the beginning during transfer to first satellite meeting. On Polar 6 the CVI heating did not work, which caused inlet freezing inside clouds. One dropsonde did not found a GPS signal.

Detailed Flight Logs:

Polar 5: Mario Mech (all times UTC)

04:45 take of
04:47 1000 ft in clouds
04:53 aboce clouds in 6000 ft
04:54 cirrus to the West
05:05 power outage 230 V
05:11 power outage 230 V
05:23 since breaking through clouds, strato cumulus 4000 ft below us
05:38 halo to the West
05:54 thin cirrus aboce to the West
a lot of cirrus to the East
06:00 cloud top at 4500 ft
06:23 C1 circle clockwise to be at C1 at 6:31
06:31 DS1 at C1
06:34 120 kt
06:46 DS2
07:02 DS3 after C3
07:12 cross pattern over Polarstern
clouds with precip over Polarstern
08:09 DS4
08:24 DS5
08:38 DS6 but no GPS
09:05 broken clouds
09:13 satellite showed whole West of Svalbard
09:18 C7 very few clouds
09:21 DS7
2 min clear leg after DS7
09:31 loop over NyA
09:45 start descend
09:48 6300 ft cloud top
09:56 2900 ft cloud base
patchy clouds below
09:58 1300 ft cloud base
12:01 touch down

Polar 6: Emma Järvinen (all times UTC)

04:40	Take off
04:42	Ascent through cloud • Multi-layer cloud
04:50	7000 ft just above the clouds
05:08	12 000 ft • No cirrus above • Cloud deck solid but more uneven than in first half of the campaign
05:16	Start descent to 9000 ft
05:29	Start descent to 6000 ft
05:34	6000 ft
05:40	Start descent to 3000 ft • Cloud deck at 4000 ft
05:45	Vibrations in the pito-tube -> back above the cloud
05:59	New try to descent into the cloud -> again vibrations
	Double-triangle C2
06:13	Reached 8000 ft • Some cirrus above
06:16 – 06:20	1st leg at 8000 ft (above cloud)
06:25 – 06:29	2nd leg at 6000 ft (above cloud)
06:34 – 06:38	3rd leg at 5000 ft (above cloud)
06:43 – 06:48	4th leg at cloud top at 2800-3000 ft
06:46	Satellite overpass
06:52 – 06:57	5th leg at 2600 ft (inside cloud) • Few ice particles in CIP, nothing in PHIPS • Droplets around 18 µm
07:09 – 07:16	6th leg at 2300 ft (inside cloud) • CVI iced • Droplets around 16 µm • Some ice (rimed aggregates in PHIPS)
	Double-triangle C5
07:33 – 07:37	1st leg at 6000 ft (above the cloud)
07:41 – 07:46	2nd leg at 5000 ft (above the cloud)
07:50 – 07:55	3rd leg at 4000 ft (above the cloud)
08:00 - 08:05	4th leg at cloud top at 3100 ft • Droplets around 22-26 µm, sometimes 2 modes • At one point CIP recorded ice particles, whereas no ice in the PHIPS • -5°C
08:11 – 08:16	5th leg at 2600 ft (inside the cloud) • -3°C • Droplets around 18 µm and LWC 0.2 g/m^3 • Few ice particles in CIP, nothing in the PHIPS
08:18 – 08:24	6th leg at 2300 ft (inside the cloud) • -3°C • sometimes ground can be seen through • droplets around 16-18 µm and sizes varying a lot • LWC 0.15 g/m^3 • Ice in both CIP and PHIPS -> graupel, riming and needles
08:28 – 08: 32	7th leg at 2000 ft (the lowest level of the cloud)

	• Cloud sometimes patchy, maybe in between cloud layers but no clear separation • Droplets around 12 µm • Some ice particles • Patchy and small low level clouds below
08:37 – 08:42	8th leg at 1200 ft (under the cloud) • Mostly no precipitation but sometimes smaller burst of ice appears • At times inside patchy low level clouds
	Cloud penetration and Aerosol Profile
08:44 – 08:53	At level 200 ft • No precipitation
08:53	Climb to 4000 ft
08:56	Cloud base at 2500 ft • Some small cloud below • Droplets 13-14 µm • Some ice
08:58	Cloud top at 4000 ft
08:59 - 09:06	5000 ft
09:10 – 09:16	8000 ft
09:22 – 09:28	12 000 ft
09:28	Start descent
	Ny Ålesund Cloud Profile
09:39	Cloud base around 3500 ft but decreasing towards Ny Ålesund
09:44	Clouds down to 1000 ft
09:48	500 ft over Ny Ålesund
09:49	Start climbing
09:33	Cloud base at 4500 ft
09:54	Cloud top at 5000 ft • Cloud all liquid • Below cloud base some ice
09:55	7000 ft towards LYR
10:31	TOUCH DOWN

ACLOUD Flight #19 – Polar 5&6 – 2017/06/17

Objectives:

The coordinated flight with both aircraft, Polar 5 and Polar 6, aimed measuring cloud properties by in situ and remote sensing techniques above sea ice, in the transition zone between sea ice and open water and over sea. The purpose was to identify the influence of the surface on the cloud properties and to investigate cloud properties developing over sea ice, and to follow their transition to the open sea.

Mission PI P5:

Manfred Wendisch

Polar 5 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Lukas Kandora
SMART	Elena Ruiz
Eagle/Hawk	Tobias Donth
MiRAC	Mario Mech
AMALi	Pavel Krobot

Mission PI P6:

Dmitry Chechin

Polar 6 Crew	
Mission PI	Dmitry Chechin
Basis Data Acq.	Cristina Sans Coll
ALABAMA	Franzisca Kollner
CVI	Stephan Mertes
Gas/AWI-Aerosol	Oliver Eppers
PMS	Guillaume Mioche

Flight times:

Polar 5	
Take off	09:55 UTC
Touch down	15:25 UTC

Polar 6	
Take off	10:10 UTC
Touch down	15:55 UTC

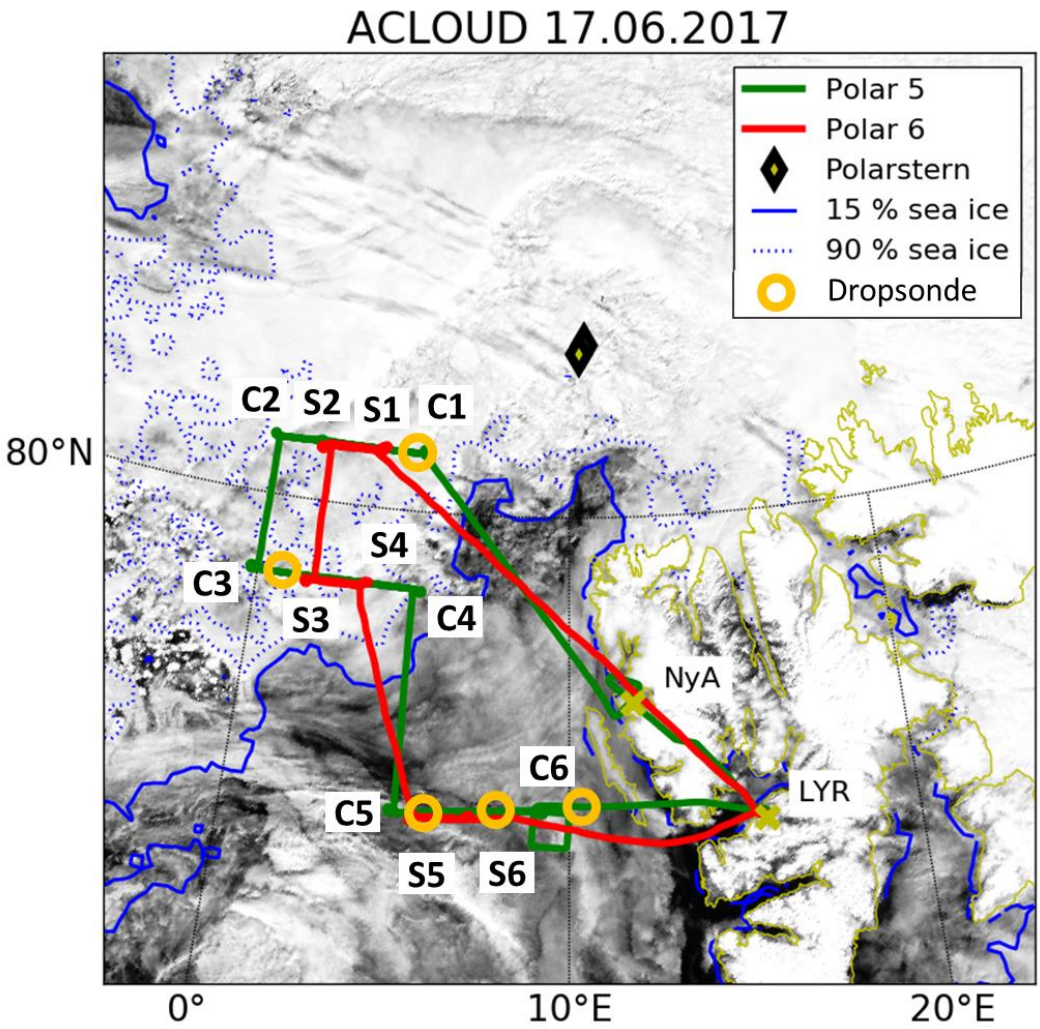


Fig. S19.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

Good agreement with the ECMWF forecast with respect to the location and timing of the cloudy areas. Clouds were in the northern part of the domain (S1-S2) as well as in the southern (S5-S6), with thicker clouds to the east (S2 and S6). Over the MIZ there were only thin clouds. Clouds were spatially strongly inhomogeneous, often with several layers. The thickest clouds were found over the open water in the eastern part of the track S5-S6 and on the way back to Svalbard (S6-LYR), as also predicted by the ECMWF.

Over the ice at S1-S2 we observed showers with presence of ice crystals. They looked like foggy areas reaching the ice surface. Above these showers there was a stratocumulus layer with sometimes another stratus layer right above the first one.

ECMW prediction of clouds—horizontal

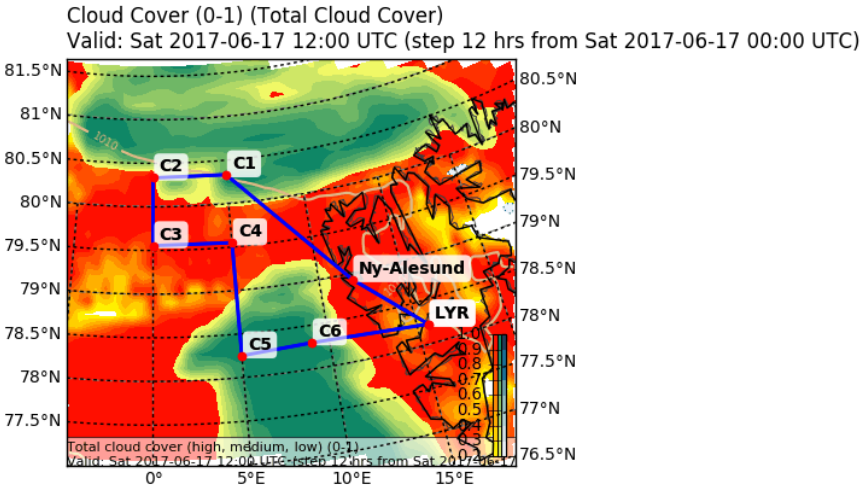


Fig. S19.2: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

ECMW prediction of clouds—vertical

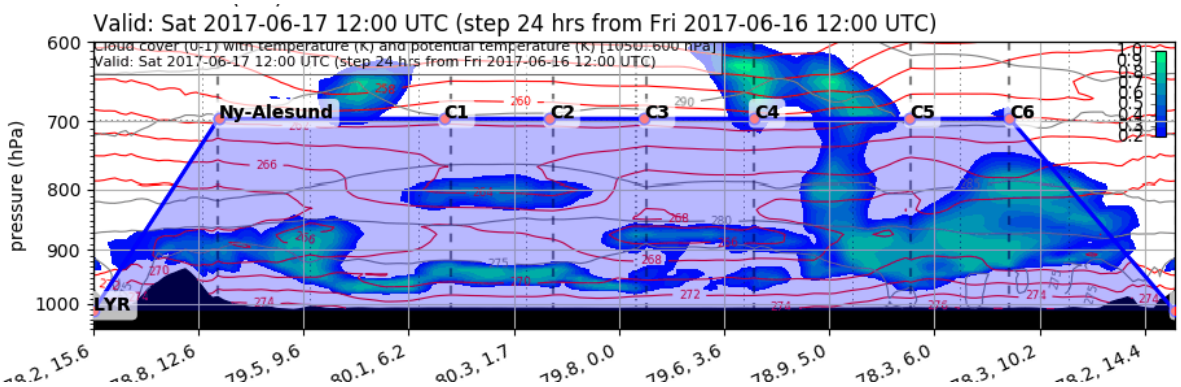


Fig. S19.3: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

ECMW prediction of wind 950 hPa

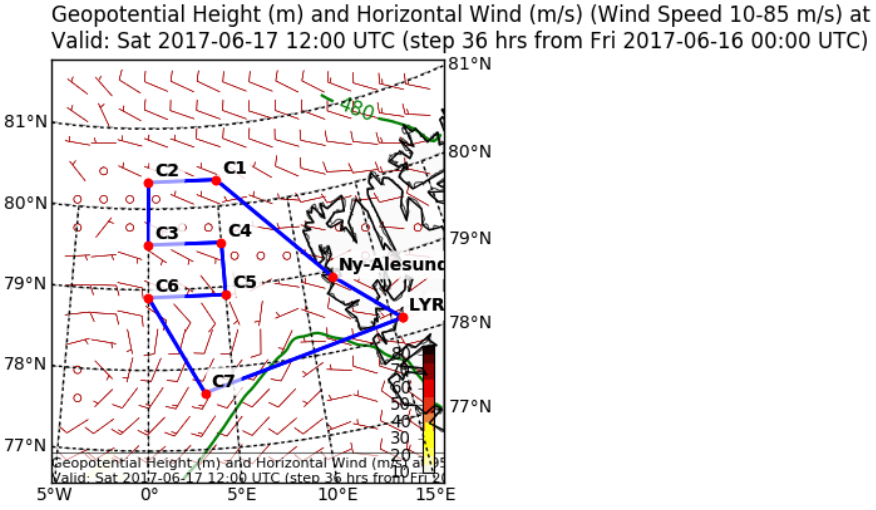


Fig. S19.4: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Overview:

Polar 5: We had mostly too cloud layers, one low-level cloud and another mid-level cloud, which we succeeded to observe from above. Above the aircraft there was no cirrus during almost all of the flight. The cloud situation was such that we had to fly high above the observed **mid-level** clouds with Polar 5 (we had to use oxygen supply), while Polar 6 sampled the clouds in situ and closely coordinated with P6. The flights went very well, and we collected promising data.

Polar 6: Aerosol profile on the way to S1. Two racetrack patterns over the ice: S1-S2, S3-S4 with 5 legs 15NM each at different heights. The cloud saw-tooth pattern on the way south to S5 crossing the marginal sea ice zone. Third racetrack pattern S5-S6 over open water also consisting of 5 legs 15NM each at different heights.

Flight levels during each racetrack had to be adjusted according to the current cloud base and cloud top heights. Lowest level was always at 200 f. However,

Cloud base and top heights were spatially inhomogeneous and varied strongly even across the 15NM legs. Clouds were multilevel, with stratus layers above the more mixed lower layer. Thus, it was not easy to define the cloud top and plan the flight levels.

We still had the earlier encountered problem with the heating of the CVI inlet. The CVI inlet functioned well on the way to S1, but after some time in the clouds at S1-S2 it stopped working due to icing. On the way between S4 and S5 over warmer open ocean the ice on the CVI inlet melted away. This allowed us to continue the CVI-related measurements outside of the clouds, but not in clouds. All other instruments worked well.

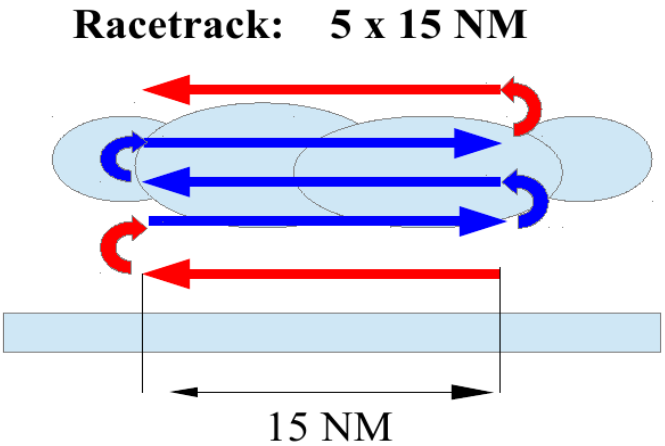


Fig. S19.5: Flight pattern of a vertical stack as flown at S1-S2, S3-S4 and S5-S6 to obtain profiles of turbulent and radiative fluxes.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	5 launched

Table S19.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S19.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

On Polar 6, the CVI inlet heating was not working. When the inlet freezes it does not operate at its full functionality. It got frozen during the first racetrack (S1-S2) but got unfrozen later on the way to S5-S6 and operated with limited functionality (only outside of clouds measurements were possible).

Detailed Flight Logs:

Polar 5: Manfred Wendisch (all times UTC)

LYR—NyA—C1 Ascend to 10,000 ft **174 NM @ 160 kn** **65 min**

09:30 Motor on, problems with GPS reported by Lukas

09:52 Taxi

09:55 Take off

Mixed clouds

We are heading to the glacier

09:58 We are below a cloud, Wale on left side

Fig. S19.6: Photograph taken from Polar 5.

10:05 We fly over the glacier

Fig. S19.7: Photograph taken from Polar 5. Left: Begin of the glacier. Right: Rough surface of the glacier

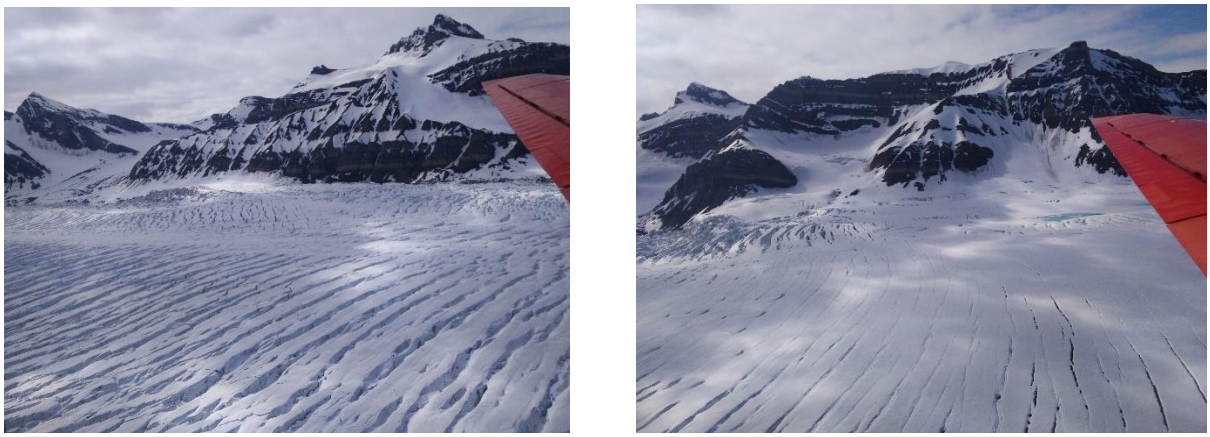


Fig. S19.8: Photograph taken from Polar 5. Left: Center of the glacier. Right: Snow filled glacier rifts.

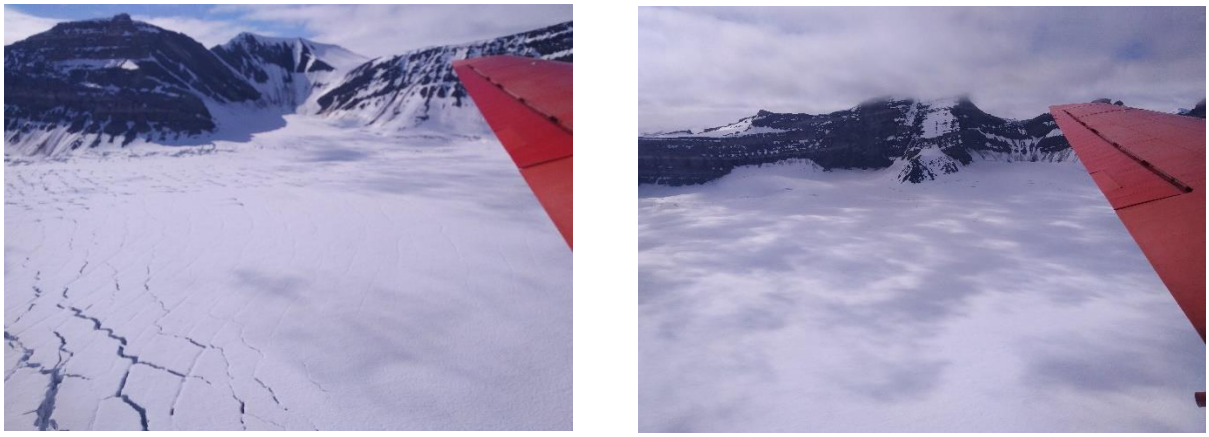


Fig. S19.9: Photograph taken from Polar 5. Left: End of the rift area. Right: Entire smooth glacier surface.

10:13 7000 ft, we ascend further, low-level cloud below, also mid-level cloud
10:16 9000 ft
10:18 10,000 ft
10:22 11,500 ft, we are above a mid-level cloud, no cirrus above
10:24 12,000 ft
10:25 We cross Ny Ålesund and do the cross pattern
10:35 Heading North to C1, 12,200 ft, 150 kn
10:44 Very nice cloud cover below

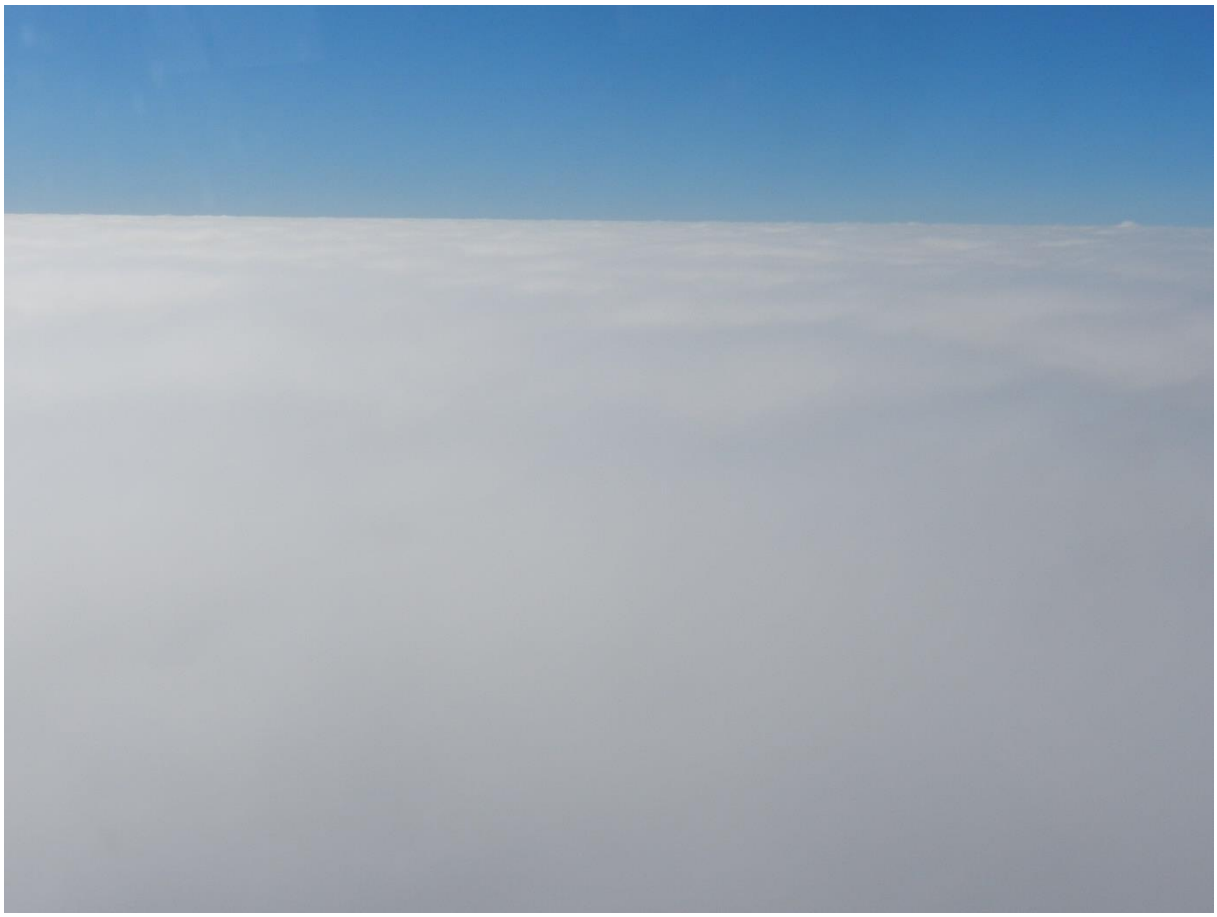


Fig. S19.10: Photograph taken from Polar 5.

10:53 Clouds actually change, we cross the ice edge, we still stay at 12,200 ft
11:12 Thick clouds beneath us, still at 12,000 ft
11:20 We reach C1, dropsonde **DS1** launched

C1—C2 3 times, back & forth **50 NM @ 150 kn** **60 min**

All the time a thick cloud below us, no cirrus above, we fly in 12,000 ft

11:19-11:28 First leg: C1 → C2
11:41-12:00 Second leg: C2 → C1
12:02-12:22 Third leg: C1 → C2

C2—C3 **46 NM @ 150 kn** **20 min**

12:25 We climb to 13,000 ft, because we want to be above cloud
12:38 We arrive at C3, drop sonde **DS2**

C3—C4 3 times, back & forth **54 NM @ 150 kn** **60 min**

We go much higher, > 17,000 ft, we use oxygen mask, see glory, we are always 100 m above cloud top (radar)

Fig. S19.11: Photograph taken from Polar 5.

Fig. S19.12: Photograph taken from Polar 5.

12:39-12:53 First leg: C3 → C4
12:55-13:13 Second leg: C4 → C3
13:15-13:30 Third leg: C3 → C4

C4—C5 **78 NM @ 150 kn** **32 min**

13:38 Begin our way to C5
13:42 We cross the ice edge, clouds seem different after crossing the ice edge, we are at 14,500 ft to be 100 m above cloud
13:54 We reach C5 at 14,500 ft

C5—C6 3 times, back & forth **49 NM @ 150 kn** **60 min**

13:51-14:08 First leg: C5 → C6 nice glory

Fig. S19.13: Photograph taken from Polar 5.

14:10-14:28 Second leg: C6 → C5 14:23 **DS3** released
14:30-14:44 Third leg: C5 → C6 14:40 **DS4** released
14:45 We reach C6

C6—LYR **81 NM @ 160 kn** **30 min**

15:03 **DS5** released
15:08 Start descending
15:25 Touch down
15:28 End taxi

Polar 6: Dmitry Chechin (all times UTC)

At height of about 10500-11500ft there was a thin alto-cumulus/stratus layer almost during the whole flight. Rarely we had sunnier conditions when this layer was, perhaps, absent. We penetrated this layer twice during the aerosol profile up to 12000ft on the way LYR-S1 (10:10 – 11:10 UTC).

Over the open water on the way to S1: looking from above we observed the stratocumulus deck, not very homogeneous.

Approaching to S1: descent to 200ft. Cloud top is between 2500 and 1700ft. At 2300f we were between the two layers of clouds. Cloud base is at 1000ft. But below the cloud base we observe showers over the sea ice which touch the surface.

11:18-12:15: First racetrack pattern S1-S2

Leg #1 @ 200ft: flying in a shower for about 4 min. Inhomogeneous cloud conditions: shower (or fog/cloud) / no shower

Leg#2 @ 700ft: patchy-foggy mixed-phase showers, but more abundant than on 200ft; sampling ice crystals; below the main cloud deck; turbulence is variable

Leg#3 @ 1200ft: in cloud all the time; sometimes we sample ice

Leg#4 @ 3500ft: upper leg above the cloud top (to deice before the last cloud leg); cloud top is inhomogeneous; another stratus layer (sometimes 2 layers) right above the main low-level deck;

Leg#5 @ 1700ft → 1200ft: flying at the cloud top, sometimes sampling air from above the cloud; descend to 1200ft following the cloud top.

Closer to the end of the first racetrack CVI inlet got frozen and stopped working.

From S2 to S3 flying at 2500ft above low-level clouds; still altocumulus above us. Clouds below become thinner, more inhomogeneous, broken.

Descending to S3. Cloud top is at 1000ft. Approaching S3 at 200ft.

12:32 – 13:30: Second racetrack pattern S3-S4

Leg #1 @ 200ft: It looks calm, no wind over leads. Larger ice floes to the west, smaller to the east.

Leg#2 @ 500ft: we are flying below very thin inhomogeneous, broken layer of clouds

Leg#3 @ 700ft: we are flying through those thin, broken clouds, sampling them

Leg#4 @ 1500ft: at S4 we encountered stratus layer; droplets 25 micron

Leg#5 @ 2000ft → 3200ft we started at 2000ft but went higher after first half of the leg, trying to sample something that looked like a cloud; but it turned out that it was not really a cloud. It looked hazy through the window.

13:30 -14:00 UTC: From S4 to S5 saw-tooth pattern. We started almost in cloud-free conditions at low levels (but still Ac high above us). Then we reached the cloud with cloud top at 1500ft. Second profiling: cloud top still at 1500ft. As we went closer to S5, clouds started to thicken: second layer appeared at 2300f. In the lower levels it is more turbulent, looks like langmuir circulations in the ocean. Cloud base got also lower as we approached S5. In warmer air CVI inlet deiced and started working.

<u>14:00 – 15:00: Third racetrack pattern S5-S6</u>

Leg #1 @ 200ft cloud base is higher in the eastern part of the leg

Leg #2 @ 1000ft in the lower part of the cloud; 12 micron droplets;

Leg#3 @ 1300ft In the cloud; quite homogeneous; some turbulence;

Leg#4 @ 1600ft in the cloud;

Leg#5 @ 2500ft → 3000ft between two cloud layers, but then got into the top of the cloud in the western part and sampled it.

Ascent at S6 around 15:00 UTC. Found cloud top at 4000ft.

Halfway to LYR descended to the level below the clouds. More turbulent, waves.

ACLOUD Flight #20 – Polar 5&6 – 2017/06/18

Objectives:

The objectives were the same as on the previous flight #19, but this time there was no mid-level cloud (no contamination by synoptic system). The coordinated flight with both aircraft, Polar 5 and Polar 6, aimed measuring cloud properties by in situ and remote sensing techniques above sea ice, in the transition zone between sea ice and open water and over sea. The purpose was to identify the influence of the surface on the cloud properties and to investigate cloud properties developing over sea ice, and to follow their transition to the open sea.

Mission PI P5:

Manfred Wendisch

Polar 5 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Lukas Kandora
SMART	Elena Ruiz
Eagle/Hawk	Tobias Donth
MiRAC	Tobias Doktorowski
AMALi	Marek Jacob

Mission PI P6:

Dmitry Chechin

Polar 6 Crew	
Mission PI	Dmitry Chechin
Basis Data Acq.	Cristina Sans Coll
ALABAMA	Franzisca Kollner
CVI	Stephan Mertes
Gas/AWI-Aerosol	Oliver Eppers
PMS	Guillaume Mioche

Flight times:

Polar 5	
Take off	12:04 UTC
Touch down	17:44 UTC

Polar 6	
Take off	12:25 UTC
Touch down	17:50 UTC

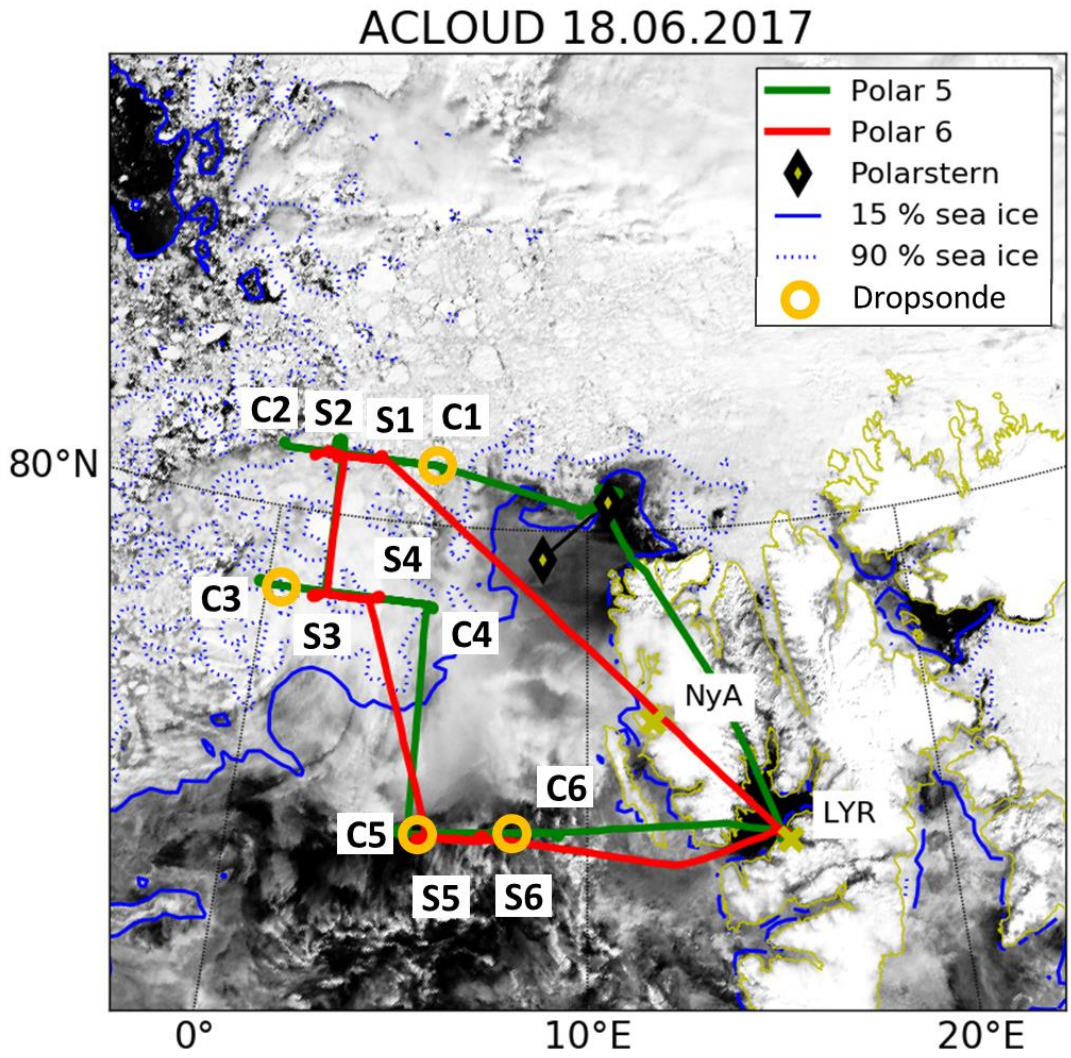


Fig. S20.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

Low-level clouds were predicted all over the measurement area by ECMWF, with mid-level clouds dissipating during the day. Weak-gradient pressure field with low wind speed was predicted.

Indeed, there was a mid-level cloud in the first half of the flight, with low-level clouds below. The upper cloud was at 6500-7000 ft. Low-level clouds over the ice were in the layer 100-650 ft during the northernmost track (C1-C2). Over the open water there was a thin layer of stratocumulus with strong convective clusters penetrating through it from below. Convective clusters were separated from each other by large distances of order of 10km. There was a distinctive difference between cloud cover over the ice and water.

ECMW prediction of clouds—horizontal

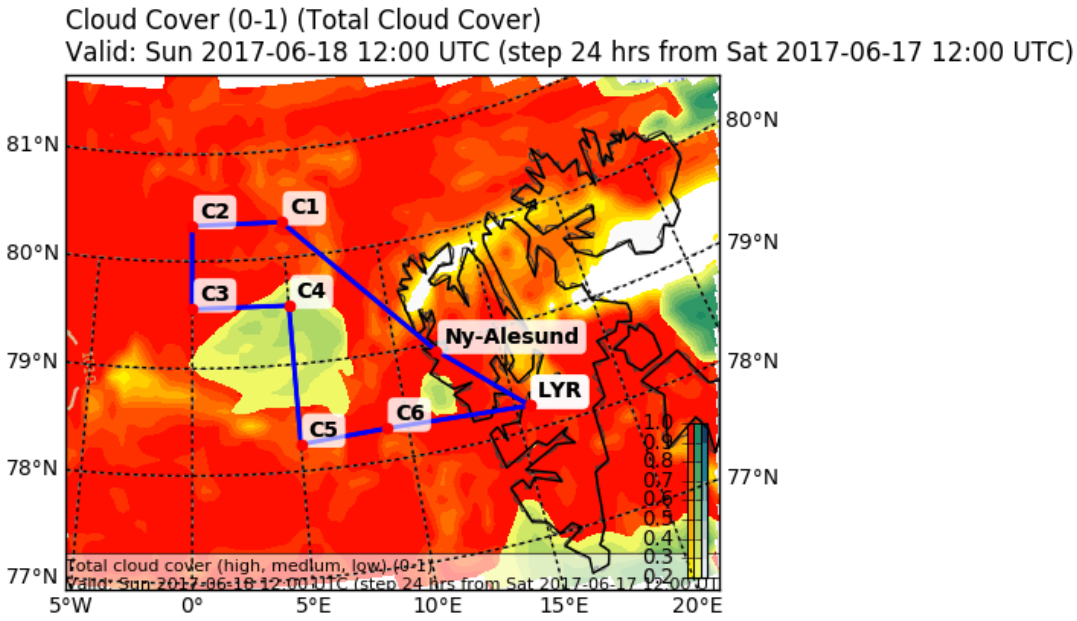


Fig. S20.2: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

ECMW prediction of clouds—vertical

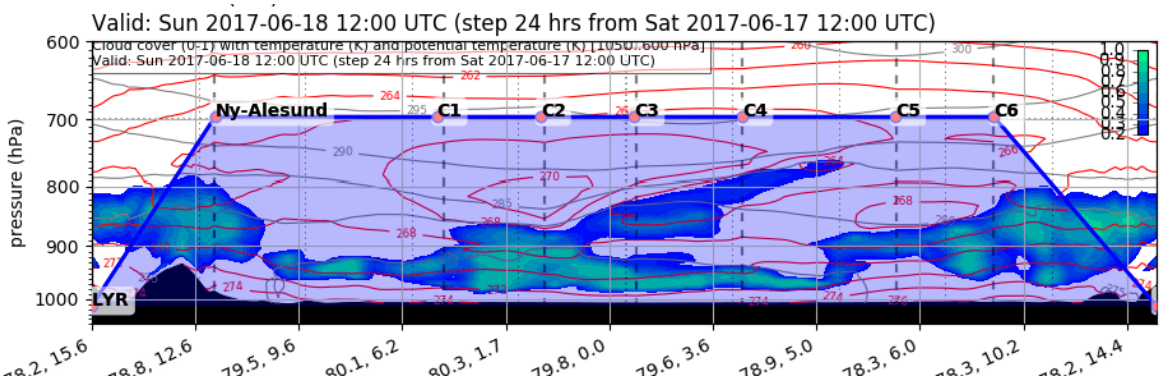


Fig. S20.3: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

ECMW prediction of wind 950 hPa

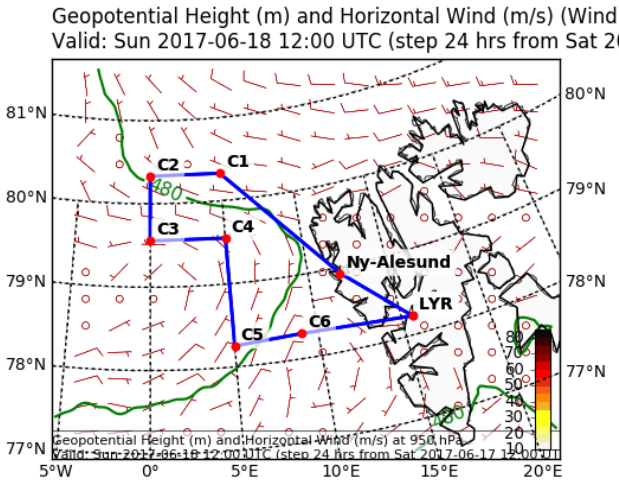


Fig. S20.4: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Overview:

Polar 5: The plan was the same as for the previous flight #19. The cloud situation was such that there was one extended cloud layer. Polar 5 should stay at 10,000 ft all the time. Between C1 and C2, C3 and C4, C5 and C6 we went back and forth (three times) and the Polar 6 sampled the clouds in a collocated way by going back and forth between the way points of Polar 6. We had mostly one layer of low-level cloud, which we succeeded to observe from above. Above the aircraft there was no cirrus during almost all of the flight. The cloud layer was different over sea ice and open water: more homogeneous over sea ice, more turbulent over open water. These clouds were not contaminated by synoptic systems, the were mostly driven by local surface properties (sea ice, open water).

Polar 6: The main goal of the flight was to sample low-level clouds over the ice and open water to study the difference.

Aerosol profile was made on the way to S1 with legs at 12000 ft and 8000 ft. Two racetrack patterns over the ice: S1-S2, S3-S4 with 5 legs 15NM each at different heights. The cloud saw-tooth pattern on the way south to S5 crossing the marginal sea ice zone. Third racetrack pattern S5-S6 over open water also consisting of 5 legs 15NM each at different heights.

Flight levels during each racetrack were adjusted according to the current cloud base and cloud top heights. Lowest level was always at 200 ft and highest – above the cloud top.

The northernmost racetrack pattern over the ice was shifted 5 miles to the west in a way that eastern 10 miles are in the low-level homogeneous stratocumulus with no upper cloud above and western couple of miles are below the upper cloud in less homogeneous and thinning stratocumulus cloud.

Over the open water we sampled a large convective cluster. It was snowing below it and we were flying several times through the precipitating snow and through the cloud.

CVI inlet got frozen during the patterns over the ice but deiced over warmer water in the southern part of the flight.

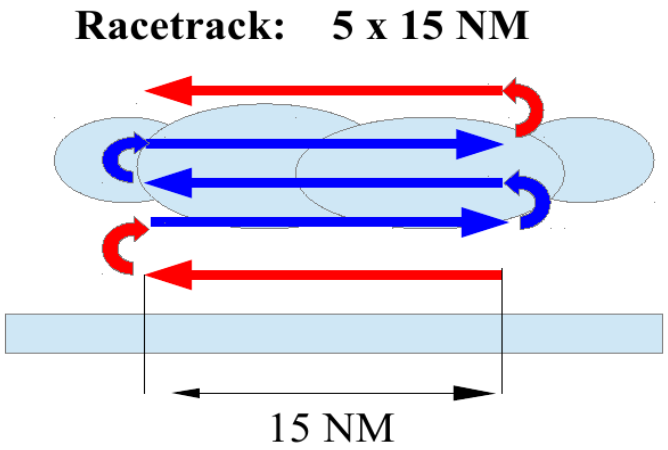


Fig. S20.5: Flight pattern of a vertical stack as flown at S1-S2, S3-S4 and S5-S6 to obtain profiles of turbulent and radiative fluxes.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	4 launched

Table S20.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S20.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

On Polar 6, the CVI inlet heating was not working. When the inlet freezes it does not operate at its full functionality. It got frozen during the first racetrack (S1-S2) but got unfrozen later over the open water and during the S5-S6 racetrack observations were made also in clouds.

Detailed Flight Logs:

Polar 5: Manfred Wendisch (all times UTC)

LYR → PS → C1 Ascend to 10,000 ft **200 NM @ 160 kn** **95 min**

11:32 Motor on
Problems with SMART, are solved after a while, that's why the take-off is delayed.
12:02 Taxi
12:04 Take off
12:07 Little clouds during take-off, ascending to 9200 ft, beautiful clouds ahead of us, no cirrus above
12:15 We reach 9200 ft, lidar switched on, just one layer of clouds, radar sees not much of it
12:33 Awesome clouds below, no cirrus above. We can see the edge of the sea ice in the clouds ahead of us, clouds distinctly stop at the ice edge.
12:42 We reach Polarstern in 100-200 ft

Fig. S20.6: Photograph taken from Polar 5. Left: First passage of Polarstern. Right: Second passage.

12:50 Surface albedo measurements in cloudless conditions close to Polarstern, partly over sea ice, partly over open water
13:05 We leave Polarstern
13:06 We start climbing
13:11 Partly cloudless
13:12 We reach 7000 ft
13:18 10,000 ft, nice clouds below
13:26 We reach C1, drop sonde **DS1**

C1—C2	3 times, back & forth		**50 NM @ 150 kn** **60 min**
13:28-13:43	C1 → C2	10,000 ft	some cloudless spots, 13:38 many clouds below, first thin, but then getting thicker
13:49-14:03	C2 → C1	10,000 ft	clouds below us, not thick but okay, one can partly see sea ice, Marek distributes cake


Fig. S20.7: Photograph taken from Polar 5.

14:05-14:22	C1 → S2	10,000 ft	many clouds in the south, we see two layers, below the shadow of the upper layer, the lower one disappears quite sharply.

We circle around S2 and wait for P6 to arrive at S2, cirrus above
Cirrus above
14:26 We go to the south

S2 → S3 **46 NM @ 150 kn** **20 min**

14:38-14:58 More thick clouds ahead of us, they seem different from those sampled between C1—C2. Very nice clouds below of us, nothing above, kind of hazy. Cloud top at about 1.5 km altitude. Radar doesn't see much from those low-level-shallow clouds. But they look highly reflective with probably many small droplets

Fig. S20.8: Photograph taken from Polar 5.

S3—C4 3 times, back & forth **54 NM @ 150 kn** **60 min**

14:45-14:58	S3 → C4	10,000 ft	very nice clouds below, no cirrus above, at the end of the leg clouds get thinner, party sea ice can be seen
15:02-15:17	C4 → C3	10,000 ft	clouds become always thicker in eastern direction, very nice clouds
15:21-15:39	C3 → C4	10,000 ft	**DS2** (15:20), nice clouds below, nothing above, again clouds get thinner towards C4 (eastern direction). At the end of the leg there is a cloudless spot below.

C4 → C5		10,000 ft		**78 NM @ 150 kn**	**32 min**
15:40-16:10	at the beginning cloudless below and some patchy clouds, however, clouds start roughly at 15:42, very nice extended layer, although thin, we can see the remaining of some mid-level clouds ahead of us, these were predicted by ECMWF a day before, impressive, seems an endless, low-level cloud layer After a while the ice edge is reached, (at least at 16:04), glory				

Fig. S20.9: Photograph taken from Polar 5.

C5 – C6	3 times, back & forth	10,000 ft		**49 NM @ 150 kn**	**60 min**
16:11-16:26	C5 → C6	10,000 ft	clearly different clouds compared to over sea ice, that's for sure, clouds getting more and more convective towards the East (similarly to the northern paths), some problems with catching GPS by the dropsonde, glory		
16:28-16:44	C6 → C5	10,000 ft	seems we observe specular reflection, might also be from the ground, **DS3** at 16:41		
16:47-17:03	C5 → C6	10,000 ft	very nice clouds below, nothing above, **DS4** at 16:59		

C6 → LYR		**81 NM @ 160 kn**	**30 min**
17:05	Heading home, very nice clouds towards LYR, we will try a "star track" for Elena's calibration of Hawk.		
17:11	Start descending toward LYR, lidar switched off		
17:20	Cloud penetration, maybe 5 min in cloud, cloud base about 3000 ft		
17:30-17:38	Star pattern for Elena (Boresight calibration)		

17:44 Touch down
17:46 End of taxi
17:53 Motor off

Polar 6: Dmitry Chechin (all times UTC)

Soon after take-off ascending through the cloud layer over LYR (cloud top at 4000 ft).

We are making aerosol profile over Svalbard with legs at 12000 ft and 8000 ft.

12:58: Leg at 8000 ft, above the top of an altocumulus (or strato-) layer. Further we descent through it: cloud top 7200 ft and cloud bottom is at 6500 ft. But this cloud ends soon ahead of us.

13:17: We descent further and reach the ice edge. Over open water there were inversions at heights 1200 and 400m. We observe large leads.

13:22: We reach and enter low-level clouds flying at 200 ft. It's bottom is probably at 60-80 ft or touching the ground and its top is at 450 ft but might vary.

13:30: We approach S1. Above us there is blue sky and no mid-level cloud, below us – homogeneously turbulent stratocumulus.

13:30-14:30: First racetrack S1-S2:

#1 @ 700 ft--> 800 ft (S1-S2): we fly above the low-level stratocumulus to check the situation along the racetrack. We have to change height to 800 ft to avoid rising cloud top. Approaching S2 we clearly observe the mid-level cloud ahead and, importantly, low-level stratocumulus below the mid-level cloud breaks and disappears. Thus, we decide to shift our lower-level legs 5 miles to the west, to capture this transition.

#2 @ 200 ft: at S2 low-level cloud is broken and thin, this is where we start our leg. We fly ¼ of our leg in clear air and then enter the stratocumulus deck.

#3 @ 400 ft: when we are above S2 stratocumulus deck starts to be broken and patchy.

#4 @ 500 ft: the whole leg is in the upper part of the cloud. Only liquid, no ice.

#5 @ 300 ft: in the west the cloud is thinner, in the east – thicker,

The mid-level cloud above S2 started dissipating while we were flying our pattern. CVI inlet got frozen during the first race track.

14:26: We start from S2 to S3. We get again below the mid-level cloud. Low-level clouds become patchy.

14:35: We go through a stratus cloud with bottom at 1500 ft and top at 2000 ft.

14:44: We are at S3 starting second racetrack pattern.

14:44-15:40: Second racetrack S3 -->S4

#1 @ 2500 ft: first leg is above the clouds. We observe a cloud-free spot to the east of S4. Large leads are observed.

#2 @ 200 ft: during this leg we observe that at S3 cloud base is much lower than at S4: almost at 200-300 ft

#3 @ 700 ft: this leg is aiming to catch low-level clouds which are observed over S3, flying through them. As we approach S4, cloud base rises. We see much more open water than the day before.

#4 @ 1200 ft: we enter the cloud at S4 and fly in the lowermost part of the cloud; but as we approach S3 we get into a proper cloud and fly there for about 2:30 min.

#5 @ 1600 ft: the whole leg was completely in the cloud. Only exited it at S4.

We start to go in the direction of S5, doing the saw-tooth pattern.

We descent through a hole in the clouds to deice. Cloud top is at about 1900 ft and cloud base is at about 1300-1500 ft.

15:53: we meet low-level clouds with cloud base at 200 ft; we are over the transition to open water – separate floes below us.

15:56: cloud base is at 300-400 ft, we are ascending.

15:58: we still see the surface being at 700 ft; at 900 ft we feel turbulence in the cloud.

16:00: we are at 1200 ft in the cloud, it becomes more turbulent; at 2000 ft it is even more turbulent.

At height 2200 ft we cross the cloud top. Around us we see holes in the cloud field. Perhaps, the latest ascent was through a convective structure. Those ones are found later over the open water.

Third racetrack pattern S5-S6

#1 @ 200 ft: we fly across the elongated cloud structures. Passing by a shower to the right of us. At S6 we get into precipitation, it is snowing, large crystals.

#2 @ 1500 ft: there small pieces of clouds below us. At 18:24 we get out of the cloud, as the cloud base rises closer to S5

#3 @ 3000 ft → 2700 ft: we are in the layer of mid-level clouds; it feels turbulent; and more turbulent around S6;

#4 @ 4000 ft: we see that convective cloud tops pop up from the stratocumulus deck here and there

#5 @ 900 ft: there are no clouds at this height close to S5; but we get into the shower as we approach S6.

We make ascent through this precipitating convective cluster at S6 (seen at the satellite image). There is ice in this cloud all the way through the ascent. Cloud top is at about 3500-4000 ft.

We ascent to 8000 ft doing aerosol profile and find a dirty polluted layer there.

On the way to Svalbard everywhere around we see convective cloud tops penetrating through the stratocumulus. We descent to LYR. Cloud top is at 4300 ft, cloud base at 3600 ft.

17:50: landing

ACLOUD Flight #21 – Polar 5&6 – 2017/06/20

Objectives:

The main goal of the flight was a study of the boundary layer structure and energy fluxes over the Fram Strait. The focus was on the profiles of vertical fluxes of heat, humidity, momentum and on radiation fluxes. The profiles were measured at six locations with different distance to the sea ice edge.

Mission PI P5:

Christof Lüpkes

Polar 5 Crew	
Mission PI	Christof Lüpkes
Basis Data Acq.	Lukas Kandora
SMART	Johannes Stapf
Eagle/Hawk	Tobias Donth
MiRAC	Tobias Doktorowski
AMALi	Erlend Knudsen

Mission PI P6:

Mario Mech

Polar 6 Crew	
Mission PI	Mario Mech
Basis Data Acq.	Cristina Sans i Coll
ALABAMA	Franziska Köllner
CVI	Stephan Mertes
Gas/AWI-Aerosol	Oliver Eppers
PMS	Guillaume Mioche
Nezvzorov	Dmitry Chechin

Flight times:

Polar 5	
Take off	07:30 UTC
Touch down	13:55 UTC

Polar 6	
Take off	07:37 UTC
Touch down	13:27 UTC

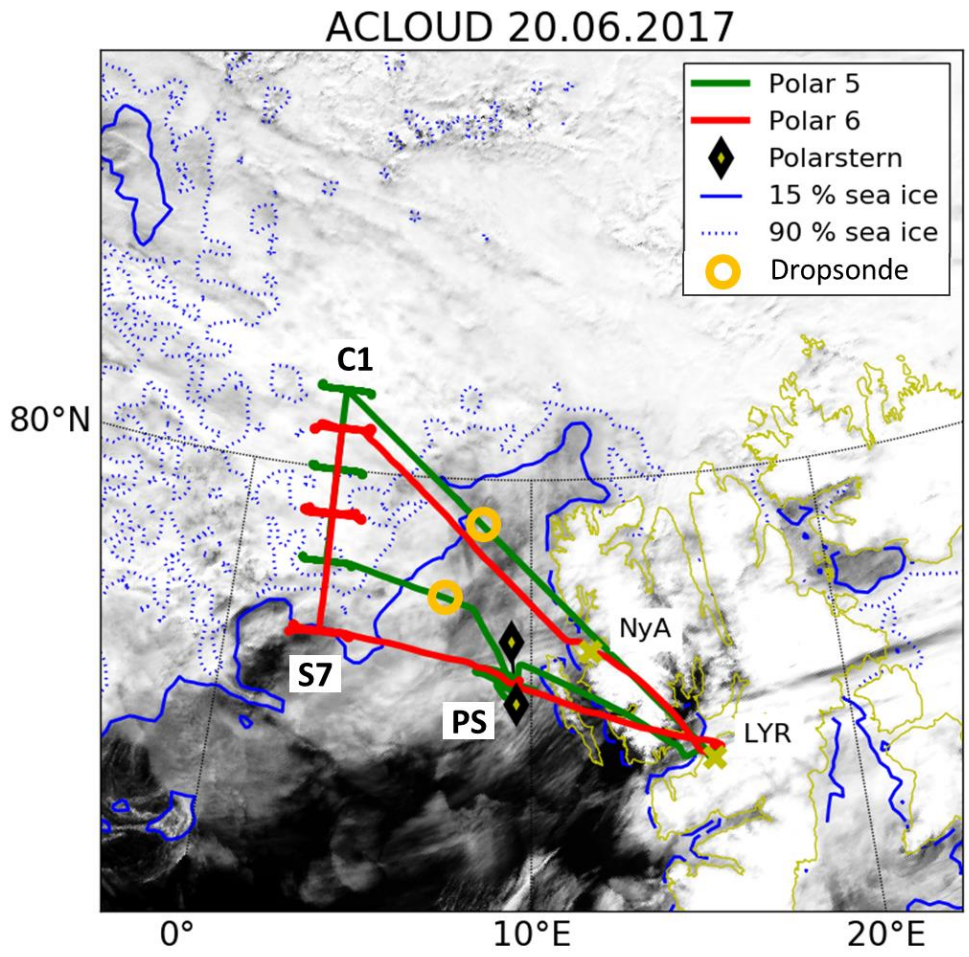


Fig. S21.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

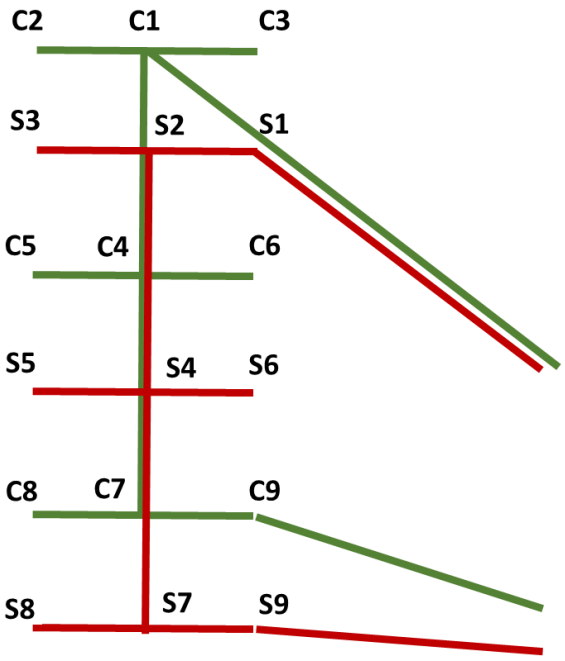


Fig. S21.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

GFS and ECMWF predicted northerly winds in the measurement region over Fram Strait west of Svalbard. This flow was caused by a weak high pressure system that had been developing over the sea ice covered region between Svalbard and Greenland with a center at 78.5°N and 3° W. Clouds were predicted by ECMWF as a low-level layer reaching to about 300 ft above the surface and as a layer of high clouds. The Figure S21.2 shows the 36h forecast of ECMWF (note that the measurements were carried out in a North-South section along 3° E; the Figure shows only three of 18 waypoints over sea ice.)

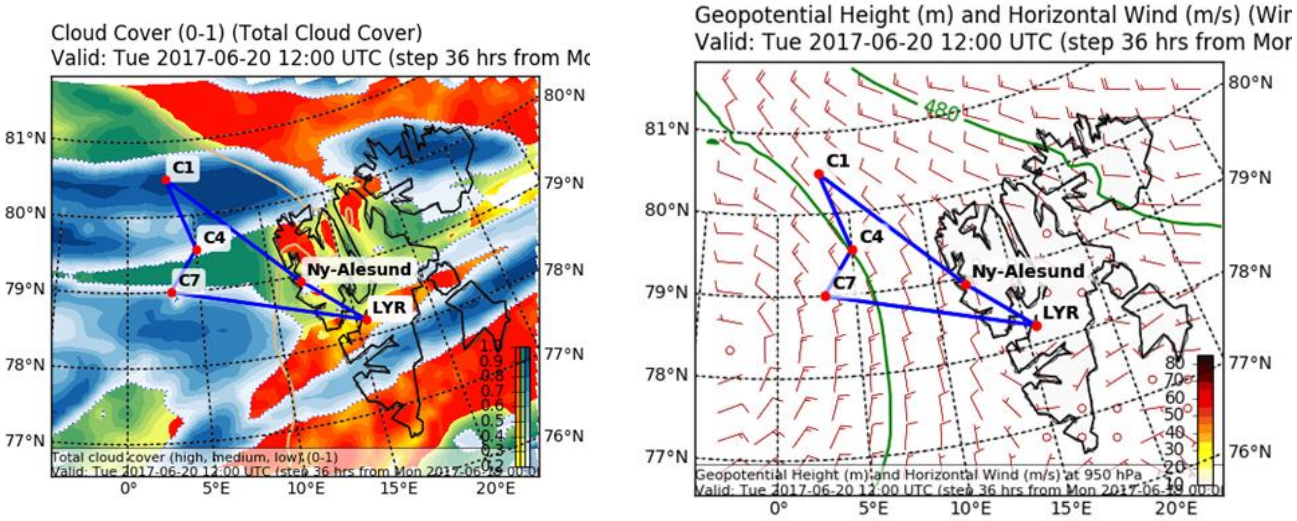


Fig. S21.3: left: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line. Right: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Actually, we observed a westerly flow as would have been expected from the forecast only further to the west. The observed cloud fields agreed roughly with the prediction (see also below in the description of clouds).

Overview:

The flight strategy was the same as on 14 June during a mission also focusing on the ABL. This means that along the main flight direction horizontal sections (series of 5 cross legs) were flown for the determination of fluxes and the detection of horizontal non-homogeneity. Both aircraft finished three profiles separated by 30 NM. The last profile of Polar 6 has been shifted further South to get a chance of being completely over open water. This didn't succeed to 100%. There was still some ice remaining.

Polar 5 did not fly with the planned measurement speed of 120 kn but with 130 kn (information of the pilot) so that the Polar 5 pattern was finished earlier than expected. Thus there was enough time at the end to visit once more RV Polarstern. This time parts of the visit were flown very closely

collocated with Polar 6. However, a planned overflow of Ny Alesund on the way back to Longyearbyen was skipped. Over Longyearbyen a calibration pattern followed for EAGLE/HAWK.

Two dropsondes have been released, one on the track from Ny Alesund to C1 (at 79.5°N, the other one on the way back from S9 to Longyear (at 79.25°N).

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	2 launched

Table S21.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S21.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

CVI inlet heating is not working. When the inlet freezes it does not operate at its full functionality.

Detailed Flight Logs:

Polar 5: Christof Lüpkes (all times UTC)

Clouds

As predicted, there was a sector with almost no high-level clouds in a section west of Ny Alesund. This is shown in Fig. S21.4.

Fig. S21.4: Photograph taken from Polar 5.

Further north a closed layer (8/8) of high clouds was found which agreed also with the prediction. Furthermore, at around 79.5° N a we reached at 2050 m the top of a mid-level cloud layer which was not seen in the ECMW prediction. Near cloud top there was a section with distinct turbulence. The base of these clouds was found in 1550 m.

In the region of the measurements clouds were very nonhomogeneous with respect to cloud depth, basis, top and visibility in the clouds. Sometimes, they were surface based but, for example, along the section C1-C4 they were clearly elevated from the surface. Some typical photos are given below in the section with detailed notes.

Sea ice conditions

The sea ice cover was about 95 % showing the typical features of the marginal sea ice zone with drifting ice floes. The estimated diameters of the dominating floes were in the range of 100 – 200 m with very small floes between the large ones. The sea ice surface showed also clear signs of melting with increasing number of melt ponds. Nevertheless, only the initial stage of melting is reached.

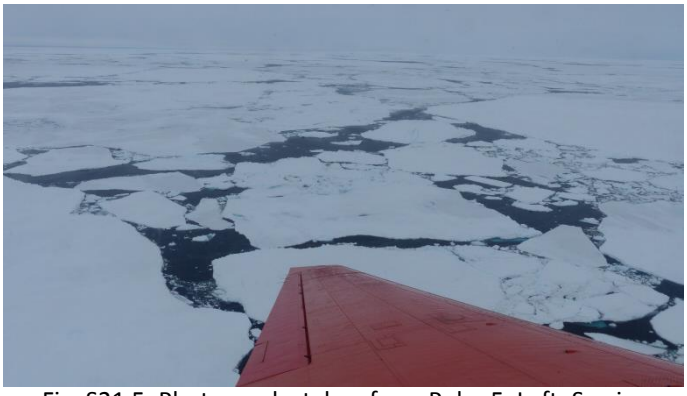
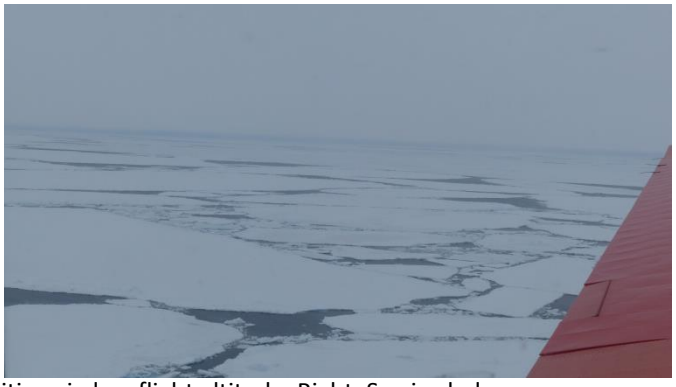



Fig. S21.5: Photographs taken from Polar 5. Left: Sea ice conditions in low flight altitude. Right: Sea ice below clouds.

Detailed notes during the flight, heights of flight legs:

NY –>C1: At the latitude of S5, stronger turbulence occurred near the top of a midlevel cloud layer.

Leg heights at the northernmost position (C2-C3) were 200, 300,400,500,600 ft. The first one was mainly below the clouds the highest one was clearly above the cloud top (see photo below). Boundary layer height was at roughly 400 ft.

Fig. S21.6: Photograph taken from Polar 5 showing the cloud situation during the 200 ft leg C2-C3.

Fig. S21.7: Photograph taken from Polar 5 above cloud top between C2 and C3.

Leg C1—C4: At the beginning bad visibility, but after some miles increasing visibility (see Fig. S21.8).

Fig. S21.8: Photograph taken from Polar 5 during Leg C1 - C4.

Diameter of open water patches increased further in the southern part of the leg.

C5-C6. Leg heights at these positions were 200, 300,400,550,700 ft. Leg 1 was flown clearly below clouds with good visibility. The 400 ft leg was at the beginning at cloud base, but he latter seemed to be variable. At C5 cloud base was clearly higher than 550 ft. The 700 ft leg seemed to be roughly in the center of the clouds. For this reason, at the end (from C6 to C4) an additional (half) leg was flown in 900 ft.

C4 to C7: bad visibility within the first few miles but then visibility increased significantly. While approaching C7, it becomes more turbulent.

The top of the ABL was now lower (at 350 ft), so the leg heights were 200, 250, 300, 350, 500 ft. Conditions during the legs were very variable, parts were in light clouds, even light snowfall occurred. It was not possible to clearly identify the cloud base and top.

Fig. S21.9: Photograph taken from Polar 5 Between C4 and C7, where the polynya size increased.

Maneuvers

On the way back Polarstern was overflown together with P6 not far from Ny Alesund.

Fig. S21.10: Photographs taken from Polar 5 close to Polarstern.

At the end, a calibration pattern followed for EAGLE/HAWK over Longyearbyen airport.

Polar 6: Mario Mech (all times UTC)

07:37: take off
07:44: heading towards glacier Sveabreen in 1500 ft
07:45: closer to the glacier it is getting turbulent
07:51: patchy cirrus ahead, very few mid-level clouds
07:53: top of glacier
07:57: over NyA fjord
07:58: mountain tops in clouds ~1200 ft
08:01: over NyA
08:05: 200 ft - stratocumulus mid-level
08:10: strong head wind
08:14: patchy low level clouds 500 ft
08:19: getting less patchy
08:21: 220° 16 kt wind just before transition zone
08:22: sea ice starts
08:23: cloud base lowering to 300 ft
08:26: very thin clouds in flight altitude
08:27: sea ice gets more closed
08:28: more particles (aerosol) in the transition zone than over open water
08:30: sea ice almost closed
08:34: climb to 5000 ft
08:35: cloud base at 1500 ft
08:37: snow recorded at 2700 ft
08:40: at 5000 ft in clouds
precipitation from above but ground still visible
08:43: visibility getting worse
08:44: start descend to S1 at 700 ft/min - legs at 200, 300, 400, 500, and 700 ft
08:52: S1 - 200 ft 125 kt
08:54: many leads visible
09:00: S3 climb to 300 ft 120 kt
09:02: S3 to S1
09:05: hazy due to precipitation
09:09: still precipitation but very low concentration
09:10: S1 with climb to 400 ft
09:12: hazier with a lower cloud base to the North
09:15: S1 to S3
09:23: climb to 550 ft
09:25: S3 to S1
09:27: getting bright
09:27: ice precipitation in PMS
09:36: S1 to S3 in 700 ft
09:41: precipitation ahead
09:43: PMS reports ice precipitation
09:45: S3
09:46: to S2 going down to 200 ft and start saw tooth up to 2500 ft
09:48: S2

09:50: start of saw tooth
09:53: precipitation in PMS at 2000 ft
09:54: descend from 2500 ft back to 200 ft
09:57: reddish horizon to the South-East
09:59: back at 200 ft - levels for the next legs at 200, 300, 400, 550, and 700 ft - BL at 600 ft
10:04: S4
10:05: large lead (whale)
10:10: at S5 in 200 ft
10:18: at S6 climb to 300 ft
10:25: 5 kt wind
10:29: decrease in cloud
10:31: S5
10:39: S6 550 ft
10:50: into cloud
10:53: S5 PMS reports snow
10:57: S5 to S6 in 700 ft
11:02: S6
11:07: hazy/cloudy stuff to the West comes closer
11:11: out of clouds again
11:17: start climb to saw tooth
11:19: st 2500 ft no clouds
11:27: at new S7 heading to S81 (moved pattern to South due to sea ice coverage; idea was to have the last legs over open water)
11:29: mid/high level broken clouds
11:34: levels for this legs: 200, 300, 400, 550, and 700 ft
11:34: 200 ft S81 to S71
11:44: turbulent at S71 - 300 ft
11:56: S81 - 400 ft
12:05: S71 - 550 ft
12:18: S81 - 700 ft
12:28: S71 climb to 2000 ft and head for Polarstern
12:33: left the transition zone
12:40: turbulent
12:45: climb to 12000 ft
13:01: 5700 ft cloud base
13:02: 6750 ft cloud top
13:04: cirrus above, therefore no radiation square
13:06: 9800 ft cloud
13:13: descend
13:27: touch down

ACLOUD Flight #22 – Polar 5&6 – 2017/06/23

Objectives:

Flight over and in the vicinity of Ny Ålesund, dedicated to the columnar comparison over Ny Ålesund. Polar 5 would probe the clouds from above, whereby Polar 6 would collect in situ measurements in different altitudes along the Kongsfjord.

Mission PI P5:

Manfred Wendisch

Polar 5 Crew	
Mission PI	Manfred Wendisch
Basis Data Acq.	Lukas Kandora
SMART	Johannes Stapf
Eagle/Hawk	Elena Ruiz
MiRAC	Pavel Krobot
AMALi	Marek Jacob

Mission PI P6:

Mario Mech

Polar 6 Crew	
Mission PI	Mario Mech
Basis Data Acq.	Cristina Sans i Coll
ALABAMA	Franziska Köllner
CVI	Stephan Mertes
Gas/AWI-Aerosol	Oliver Eppers
PMS	Guillaume Mioche

Flight times:

Polar 5	
Take off	10:57 UTC
Touch down	14:39 UTC

Polar 6	
Take off	10:37 UTC
Touch down	14:52 UTC

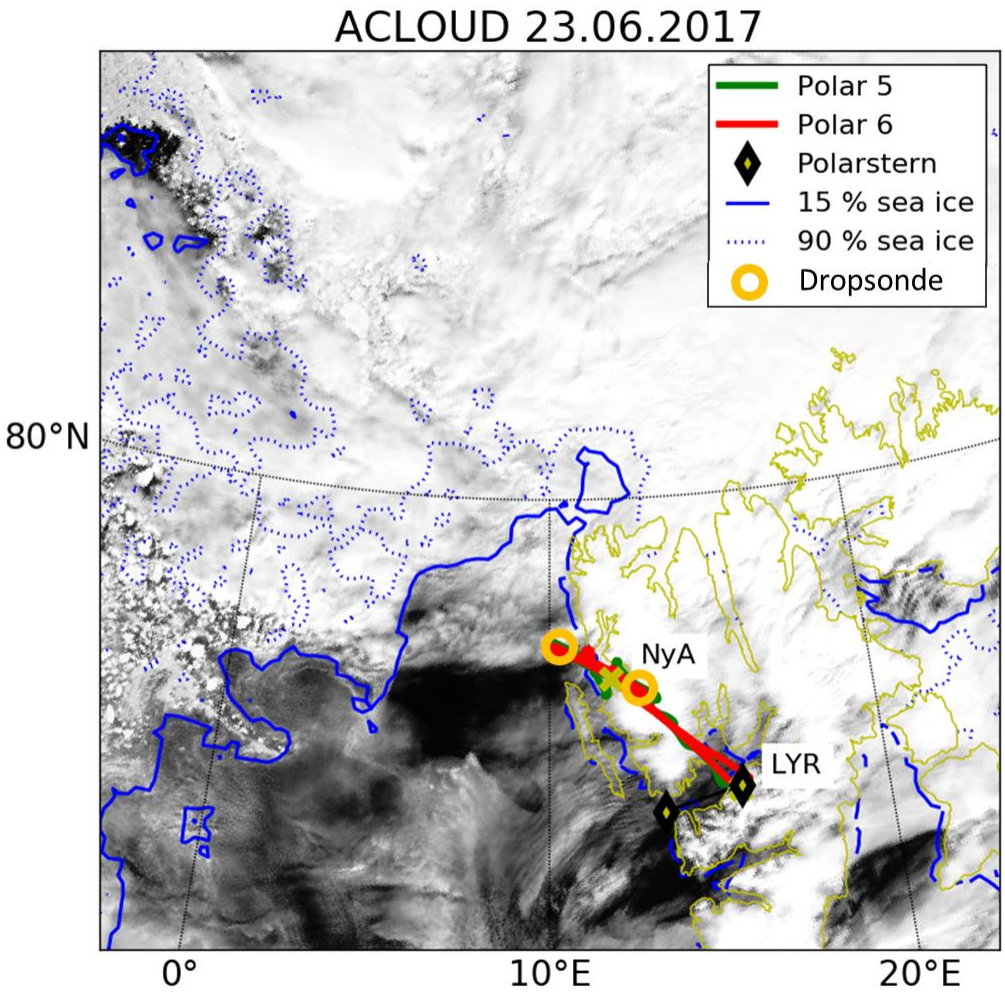


Fig. S22.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

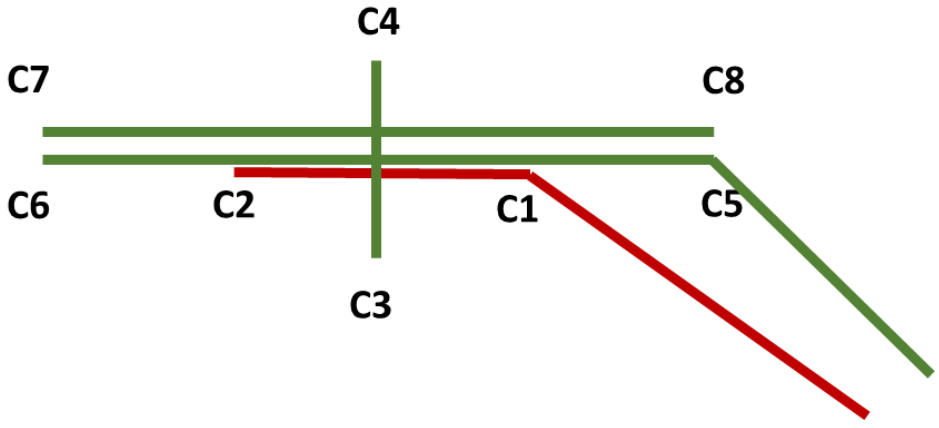


Fig. S22.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

Mid-level and low-level clouds were encountered during the flight. The structure of the clouds changed quite quickly which might it hard to sample them in different layers. In the first half of the flight Polar 5 flew in between, then it ascended to 14,500 ft to be above all the clouds (no cirrus above). The observed clouds were almost exactly the same as predicted by ECMWF, see below.

ECMW prediction of clouds—horizontal

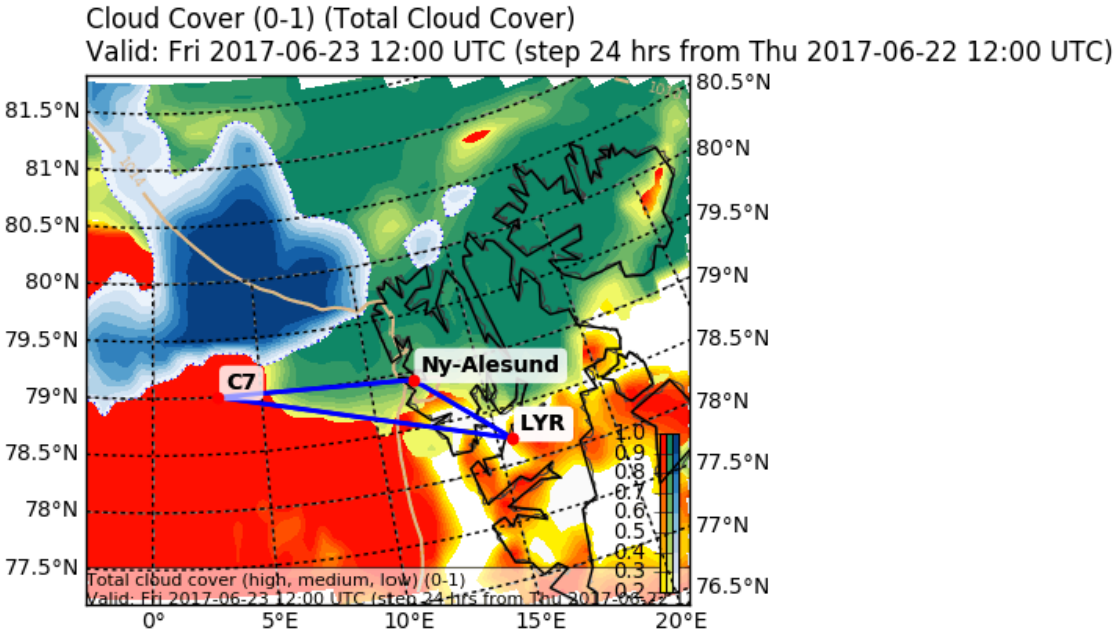


Fig. S22.3: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

ECMW prediction of clouds—vertical

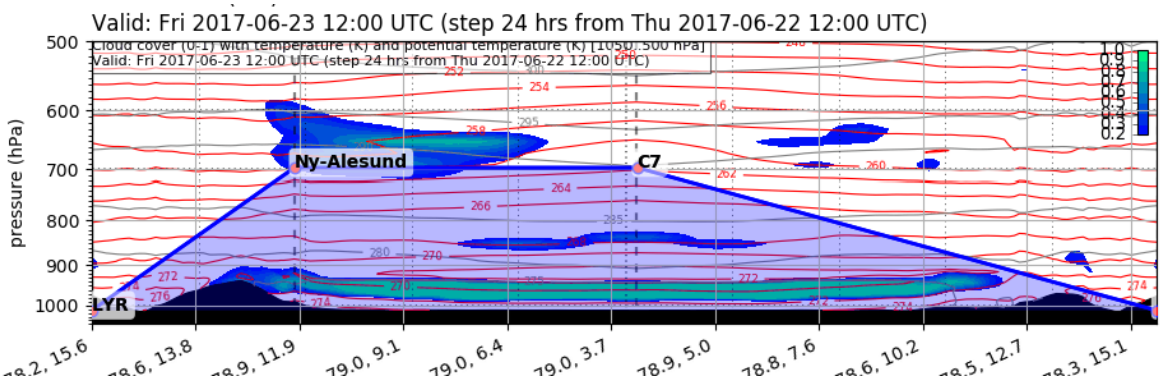


Fig. S22.4: Vertical cross section of liquid water content along the flight track as predicted by the ECMWF forecast (Rautenhaus et al. 2012).

ECMW prediction of wind 950 hPa

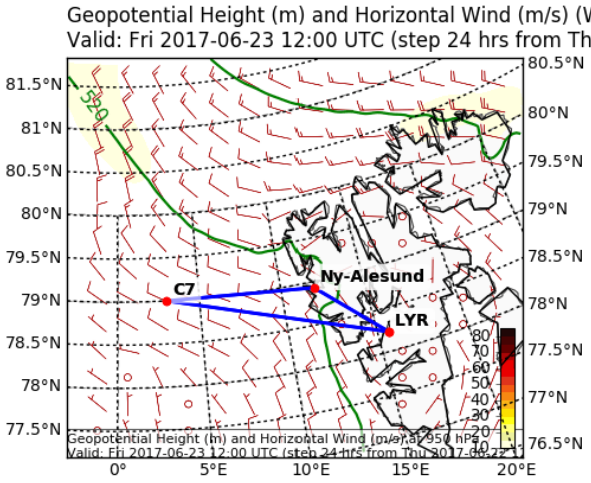


Fig. S22.5: ECMWF forecast of geopotential height and horizontal wind speed (Rautenhaus et al. 2012).

Overview:

After taking off in Longyearbyen and the ascend over the glacier Sveabreen we entered the airspace over Ny Alesund. Since the cloud structure allowed us to do so, we started by descending down to lower levels in the fjord to get an idea of the clouds. Once being in lower levels and having an idea we started be sampling different clouds in different levels up to the uppermost layers just below Polar 5. This has been done by flying in and out of the fjord passing over Ny Alesund. In the end after several legs we performed a spiral from 200 ft up to cloud top over the Ny Alesund station. Thereby we drifted due to the wind which has been corrected for in upper levels.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	4 lauched

Table S22.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S22.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

CVI inlet heating is not working. When the inlet freezes it does not operate at its full functionality. One dropsonde did submit data until the surface and stopped recording at 100 ft altitude.

Detailed Flight Logs:

Polar 5: Manfred Wendisch (all times UTC)

LYR—C1 **51 NM @FS 30 min**

10:35 Motor on
Some issues with SMART level stabilization, solved
10:54 Taxi
10:57 Take off
Scattered clouds, we climb to 10,000 ft in the direction of C1, low- and mid-level clouds all over the place
11:03 5300 ft
11:04 7000 ft
11:08 9500 ft, lidar switched on
11:09 11,000 ft
11:09 We enter a cloud from below, 11,000-12,500 ft cloud thickness

Fig. S22.6: Photograph taken from Polar 5.

Fig. S22.7: Photograph taken from Polar 5.

11:11 Arrival at 12,000 ft, above cloud top, nearly no cloud above, just patches of cirrus

11:19 We reach C1

Cross pattern over Ny Ålesund:

C1-C2 **16 NM** **8 min**

11:19 We climb to 12,300 ft for the radar, to reach sufficient distance to cloud top, nice cloud below

11:22 We are just above Ny Ålesund

11:26 We reach C2, nice cloud below, almost nothing above, just some ci patches

Fig. S22.8: Photograph taken from Polar 5.

C2-C3 **10 NM** **5 min**

11:28 Only little patches of ci above

11:31 We go a little higher to 12,500 ft for the radar, we start taking oxygen

11:32 Arrive at C3

C3-C4 **10 NM** **5 min**

11:32-11:37	C3 → C4	12,500 ft	no clouds above, nice clouds below

C4-C5 **10 NM** **8 min**

11:38-11:44	C4 → C5	12,500 ft	no clouds above, nice clouds below
11:40	We drop a sonde **DS1** (over land, accidentally)		

Long legs pattern (three times)

---1st time

C5-C6 **40 NM 20 min**

11:48-14:07 C5 → C6 12,500 ft no clouds above, nice clouds below

Fig. S22.9: Photograph taken from Polar 5.

12:00 clouds above us

12:01 **DS2** just before we reach C6

C6-C7 **1.5 NM 2 min**

Curve

C7-C8 **40 NM 20 min**

12:07-12:27 C7 → C8 12,500 ft partly clouds above, nice clouds below,

Most of the track is below a cloud, some parts (12:21) nothing above, perfect conditions (cloudless above) between 12:21-12:25.

C8-C5 **1.5 NM 2 min**

12:27 turn to next leg (slightly shifted to the sea)

---2nd time

C5-C6 **40 NM 20 min**

12:28-12:48 C5 → C6 12,500 ft

First part ideal, nothing above, nice cloud below

Second part (starting 12:33) high-level cloud above, nice cloud below, we are in the middle of the two

Fig. S22.10: Photograph taken from Polar 5.

Turbulent in between the two clouds, lower clouds partly just patchy
We decide, for the next leg to go above cloud

12:41 Just before C6 we drop dropsonde **DS3**

C6-C7 **1.5 NM 2 min**

We climb to 14,300 ft (all take oxygen), before we switch off the lidar, we are now above all clouds, nothing above

12:49-12:51 We are inside the cloud, 3700-4000 m base and top of cloud

C7-C8 **40 NM 20 min**

12:51-13:06 C7 → C8 14,300 ft
We are above all clouds now.

Fig. S22.11: Photograph taken from Polar 5.

P6 suggest by radio to have a third pair of long legs, we happily agree!

The radar people summarize the two clouds layers below us as:

1st cloud: 1500-3000 m

2nd cloud: 3500-4200 m above ground

C8-C5 **1.5 NM 2 min**

Turn, at 14,400 ft

---3rd time

C5-C6 **40 NM 20 min**

13:08-13:27 C5 → C6 14,400 ft

No clouds above, all clouds below

Fig. S22.12: Photograph taken from Polar 5.

	Radar works great, we are always 200 m above the cloud for the radar	
13:25	**DS4** released	
	It is incredible how ECMWF has predicted the actually observed mid-level and low-level clouds	
C6-C7		**1.5 NM 2 min**
13:28-13:29	C6 → C7	14,500 ft
C7-C8		**40 NM 20 min**
13:29-13:44	C7 → C8	14,500 ft
	Impressive glory, almost all of the leg, two rings	

Fig. S22.13: Photograph taken from Polar 5.

C8-C7		**40 NM 20 min**
13:46-14:03	C8 → C7	descend from 14,500 ft → 200 ft
	First cloud from 4100 m to 3650 m	
	Below this cloud it is kind of hazy, patchy clouds	
	Second cloud from 4900 ft to 3500 ft, very thin, similar to haze	
	Lowest level at 200 ft	
	We stay at 200-300 ft for a couple of minutes	

C7—LYR		**45 NM @fs**	**30 min**
14:10	Overflight Ny Ålesund at 500 ft		
14:15-14:30	Several glaciers		

Fig. S22.14: Photograph taken from Polar 5.

14:39	Landing
14:42	End taxi
14:55	Motors off

Polar 6: Mario Mech (all times UTC)

10:37: take off
10:42: first cloud at 1000 ft 300 ft thick
10:51: 11000 ft liquid clouds in PMS detected
10:52: 11000 ft cloud top
10:53: 12000 ft no radiation square due to cirrus
10:56: closed cloud deck
11:03: NyA
11:06: start descent to check cloud structure
11200 ft in liquid clouds but some crystals present
10700 ft cloud base
6400 ft cloud with very low vertical extend
11:29: cloud hanging over mountain in 1900 ft
11:32: cloud in 1500 ft

11:34: climb
11:39: cloud base 4800 ft after turn at C2
in cloud at 5200 ft - mixed phase with droplets and crystals
11:51: 9000 ft snow flakes
11:57: cloud cover in the fjord changes quite quickly
11:58: thick cloud below and thin above us; we are at 9000 ft
12:04: turbulent at 10300 ft
12:06: 11000 ft droplets, drizzle
12:08: crystals
climb above the clouds at 11500 ft towards C2
12:19: descending
12:23: cloud top 8600 ft, cloud base 7500 ft
in lower part of cloud to C1
lot of droplets and few ice crystals
12:32: back to C2 in 8250-8400 ft
12:36: only liquid and very few crystals
higher LWC than in the lower leg
12:37: icing starts
12:45: no low level clouds - climb back to 7800 ft
12:48: ice and liquid below the clouds; in the clouds only liquid
12:56: 5500 ft nothing
12:57: droplets in 8100 ft
13:09: small droplets
13:14: climb to highest layer
13:20: liquid and ice in high level cloud
13:29: leg above top layer in 13700 ft
13:35: 13600 ft droplets and ice
12000 ft no more liquid, only ice precipitation
13:43: 12200 ft large ice crystals
13:49: no more droplets only ice
13:52: 7300 ft droplets - going down to 500 ft
14:05: spirals over NyA starting at 500 ft with 700 ft/min, speed 120 kt, and 20° bank angle
7200 ft droplets
7800 ft out of cloud
9400 ft liquid droplets
horizontal drift, corrected for between 11000 and 12000 ft
droplets and ice at 12300 ft
cloud top at 13500 ft
14:20: heading back home
14:52: touch down

ACLOUD Flight #23 – Polar 5&6 – 2017/06/23

Objectives:

The main goal of the flight was a study of the boundary layer structure and energy fluxes north from Svalbard during warm air advection. The focus was on the profiles of vertical fluxes of heat, humidity, momentum and on radiation fluxes.

Mission PI P5:

Christof Lüpkes

Polar 5 Crew	
Mission PI	Christof Lüpkes
Basis Data Acq.	Martin Gehrmann
SMART	Johannes Stapf
Eagle/Hawk	Tobias Donth
MiRAC	Tobias Doktorowski
AMALi	Pavel Krobot

Mission PI P6:

Mario Mech

Polar 6 Crew	
Mission PI	Mario Mech
Basis Data Acq.	Cristina Sans i Col
ALABAMA	Franziska Köllner
CVI	Stephan Mertes
Gas/AWI-Aerosol	Oliver Eppers
PMS	Dmitry Chechin

Flight times:

Polar 5	
Take off	11:09 UTC
Touch down	17:30 UTC

Polar 6	
Take off	11:03 UTC
Touch down	16:56 UTC

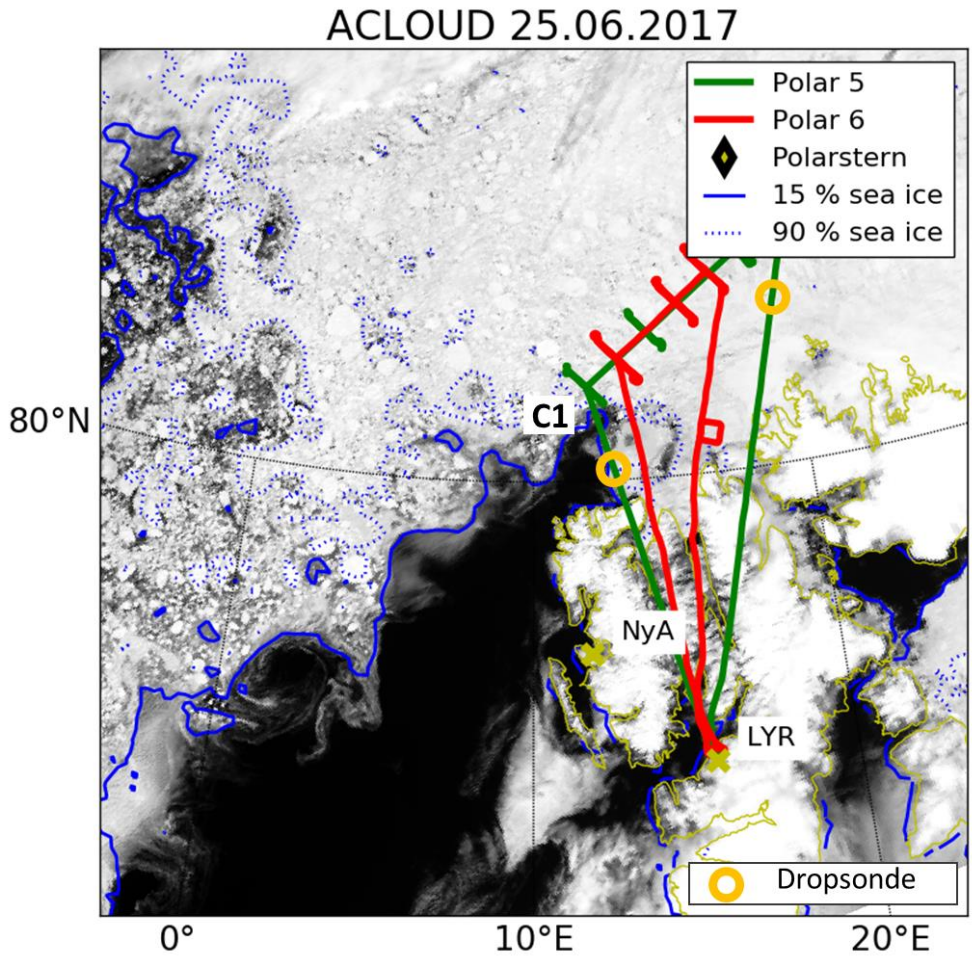


Fig. S23.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

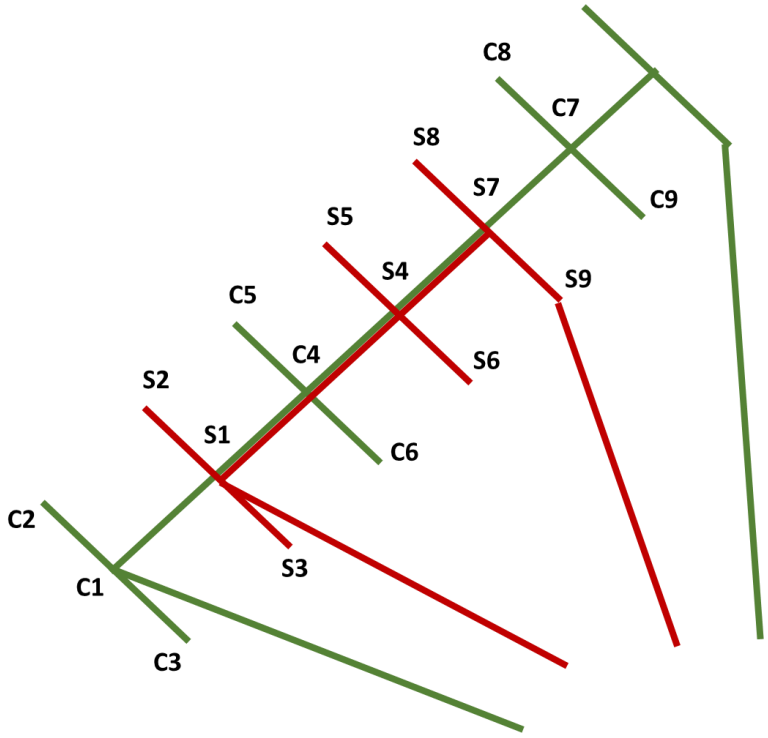


Fig. S23.2: Detailed flight pattern in the main observation area.

Weather situation as observed during the flight (compare to forecast):

GFS and ECMWF predicted winds from southeast in the measurement region north of Svalbard while the cloud prediction differed. GFS predicted no clouds, ECMWF predicted high low cloud cover.

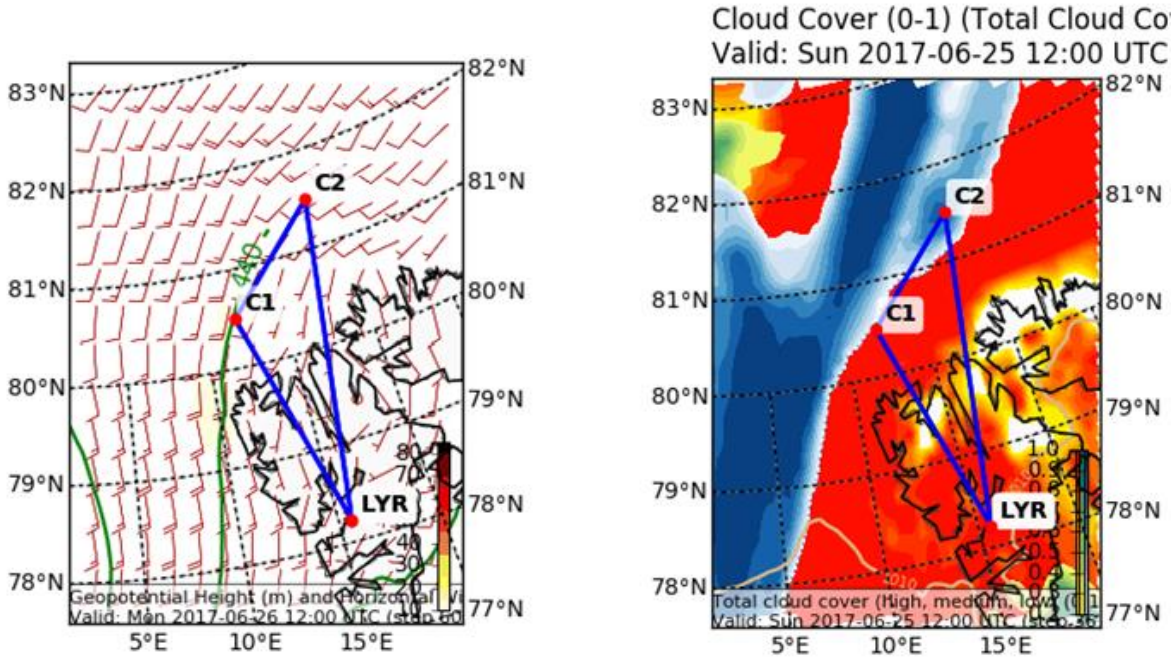


Fig. S23.3: left: ECMWF forecast of geopotential height and horizontal wind speed. Right: ECMWF forecast of cloud cover of low, mid-level, and high cloud cover. The planned flight track is indicated by the blue line (Rautenhaus et al. 2012).

This time, GFS was closer to reality since an ideal clear sky situation was found in the measurement region.

Overview:

The flight strategy was the same as on 14 June (flight #17) and 20 June (flight #21) during missions also focusing on the atmospheric boundary layer. Along the main flight direction series of 3-5 cross-legs were flown for the flux determination.

This case was characterized by a very stable stratification in the atmospheric boundary layer due to advection of an air mass with a temperature of +5-7° C in about 400 m height. Thus there was a surface based inversion at the position of the westernmost legs. Along the mean flow the inversion was found to be to be elevated and was at 120 m at the northernmost position.

The ideal clear-sky conditions allowed some patterns for the determination of the sea ice surface albedo.

Two dropsondes have been released, both over sea ice between the northern coast of Svalbard and the main flight track during the flux pattern (see below).

For Polar5, it was planned to fly 5 cross-wind legs for the flux determination at 3 positions as in the previous flights with similar mission plans. However, due to the extremely shallow ABL only three cross-wind legs were flown at the first two positions so that there was time left for Polar 5 to add another (4th) cross-wind leg extending the flight pattern into north-east.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	2 launched

Table S23.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S23.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

CVI inlet heating is not working. When the inlet freezes it does not operate at its full functionality.

Detailed Flight Logs:

Polar 5: Christof Lüpkes (all times UTC)

Clouds

Over the southern part of Svalbard, there was a closed layer with low clouds as shown in Fig. S23.4. However, these clouds disappeared more and more in the northern part and in the measurement region ideal clear-sky conditions were found almost during the whole flight pattern.

Fig. S23.4: Photograph taken from Polar 5.

Fig. S23.5 and Fig. S23.6 show a photographs towards Southwest during the first cross-wind leg, where only some very thin cirrus clouds were present. This situation did not change until the third position with cross-legs was reached. About 20 -30 Nm north of the track a layer with low clouds was present as shown below. This layer became clearly visible on the foto only after adjustment of the colours and during the flight it was difficult to identify these clouds.

Fig. S23.5: Photograph taken from Polar 5.

Fig. S23.6: Photograph taken from Polar 5.

Sea ice conditions

The sea ice cover was about 90 -95 % with open water patches whose diameters varied strongly. Also the diameter of floes was variable with floes ranging from 30 m to 1 km diameter.

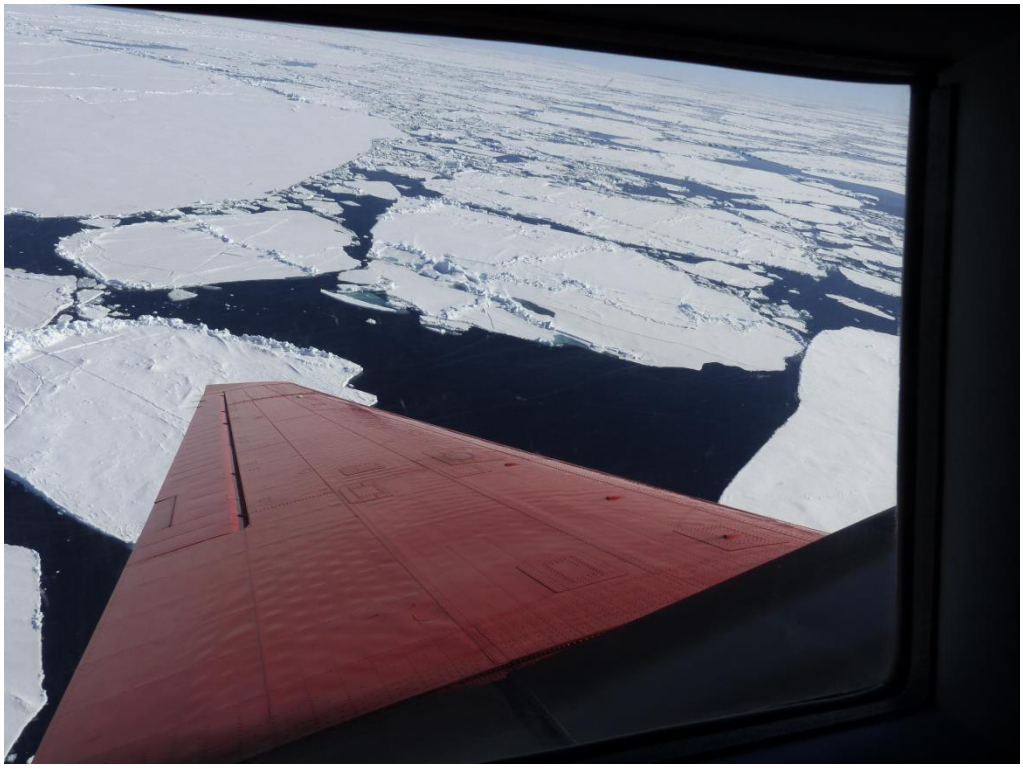


Fig. S23.7: Photograph taken from Polar 5.

At some locations individual floes could not be identified any more (Fig. S23.8).

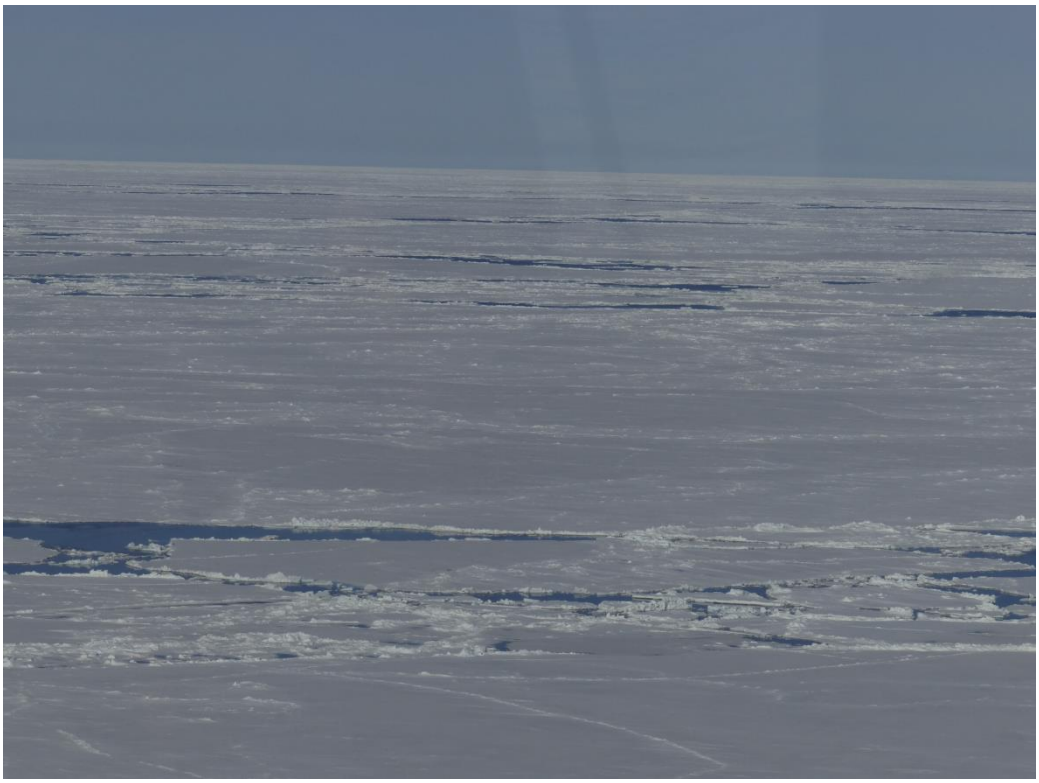


Fig. S23.8: Photograph taken from Polar 5.

Fig. S23.9: Photograph taken from Polar 5 showing the largest open water patches, which had already lead character as shown below.

Detailed notes during the flight, heights of flight legs:
NY –>C1: During descend to C1 the temperature maximum amounted to +7°C at 500 m height. The stable ABL was found to be surface based. For this reason we decided to fly only 3 legs C2-C3 at heights of 200, 300 and 400 ft.

The situation did not change at C4, thus also gere only three lges followed, this time at 200, 250 and 300 ft. During these legs only little turbulence was felt in the aircraft, but turbulence increased on the 200 ft leg towards C7. There, the ABL height increased to about 100-120 m and we decided for leg height between C8 and C9 of 200, 250, 300, 350 and 500 ft. At the last position of cross-legs levels were flown at 200, 250,300, 400, and 500 ft. This last leg became possible by the reduced number of legs at C1 and C4, but also by increasing the speed between positions C3 and C1 after leg 3 and between C6 and C4 on the way to the next 200 ft leg towards north-east.

Maneuvers
Several circles have been flown for the albedo detection. The last one with most ideal conditions with respect to sea ice (large floe) was done after the last cross-leg was flown at the northernmost position.

Drop sonde
Drop sondes were thrown over Whalers Bay polynya at 80 3’ N on the track to C1 and oanother one on the way back between at 81° 6’N and 19° 41’ E.

Polar 6: Mario Mech (all times UTC)
11:03: take off
11:04: windy during take off
11:20: 12000 ft
11:33: only few low level clouds ahead
11:38: descend to 200 ft
11:53: no low and mid-level clouds; some cirrus present
11:57: BL at 600 ft
12:01: climb to 2000 ft for temp - levels will be flown on 200, 250, 300, 400, and 500 ft
12:02: descend to 200 ft
12:09: 200 ft leg S2 to S3
12:21: 250 ft S3 to S2
12:23: polar bear
12:32: 300 ft S2 to S3
12:44: 400 ft S3 to S2
12:54: 500 ft S2 to S3
13:11: at S1 starting saw tooth to 2500 ft at 5000 ft/min
13:15: 2500 ft and down
13:23: climb to 2000 ft for temp - levels will be flown on 200, 250, 300, 350, and 400 ft
13:30: 200 ft S5 to S6
13:41: 250 ft S6 to S5
13:52: 300 ft S5 to S6

14:04: 350 ft S6 to S5
14:08: hazy to the West
14:18: 400 ft S5 to S6
14:30: climb to 2000 ft for temp - levels will be flown on 200, 250, 300, 350, and 400 ft - BL at 300 ft
14:36: 200 ft S8 to S9
14:50: sea ice cover seems to be more closed
14:56: 250 ft S9 to S8
14:58: more cirrus appears to be North
15:06: 300 ft S8 to S9
15:17: 350 ft S9 to S8
15:28: 400 ft S8 to S9
15:37: heading home
15:39: saw tooth to Svalbard up to 2000 ft
15:49: climb to 6000 ft for radiation pattern
15:52: clouds in 2000 ft ahead
15:57: start of radiation pattern
16:12: radiation pattern done
16:56: touch down

ACLOUD Flight #24 – Polar 6 – 2017/06/26

Objectives:

Different calibration pattern for AIMMS-20 turbulence probe and a radiation square for the broadband radiometers.

Mission PI P6:

Mario Mech

Polar 6 Crew	
Mission PI	**Mario Mech**
Basis Data Acq.	**Cristina Sans i Col**
ALABAMA	**Franziska Köllner**
CVI	**Stephan Mertes**
Gas/AWI-Aerosol	**Oliver Eppers**
PMS	**Regis Dupuy, Mathias Schulze**

Flight times:

Polar 6	
Take off	**8:33 UTC**
Touch down	**10:39 UTC**

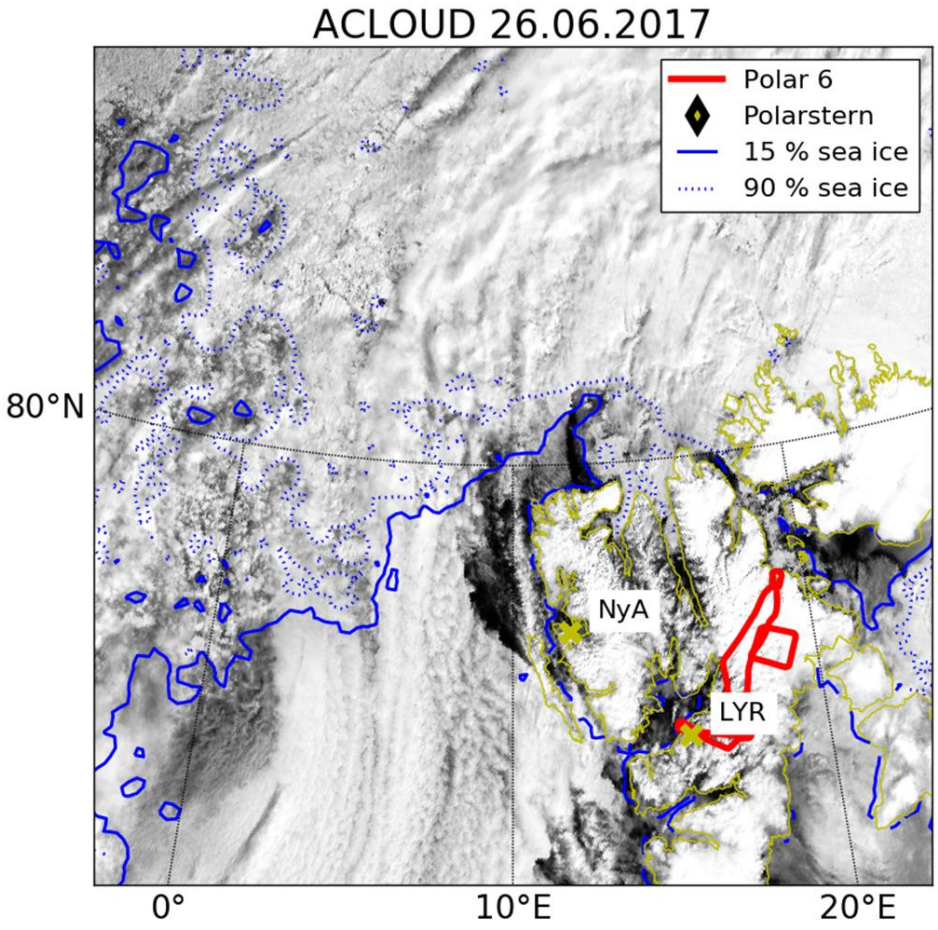


Fig. S24.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

Around the airport broken clouds were present. These have been observed over the island as well. To the East and North, the cloud cover was lower. During flight we could see that to the North over the ice shield no lower clouds were present. In higher levels hardly any cirrus was present. During the landing procedure we had to cut through a moderate thick cloud layer, which we didn't succeed with.

Overview:

After take-off towards West we turned around to stay over land and climbed to 10000ft. There we started the calibration of the AIMMS-20. This contains yaw maneuver while heading towards true North and true South. Afterwards conditions where appropriate for a radiation calibration. This has been performed a bit further North more central over Svalbard. After finishing the radiation calibration, we headed a bit further North to inspect the ice condition over the North Eastern coast.

Instrument Status:

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S24.1: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

CVI inlet heating is not working. When the inlet freezes it does not operate at its full functionality.

Detailed Flight Logs:

Mario Mech (times UTC)

08:33: take off
08:39: above clouds
08:51: heading true North
08:56: heading true South
09:26: radiation square
10:30: aborted landing approach
10:39: touch down

ACLOUD Flight #25 – Polar 5&6 – 2017/06/26

Objectives:

The main goal of the flight was a study of the boundary layer structure and energy fluxes north from Svalbard during warm air advection. The focus was on the profiles of vertical fluxes of heat, humidity, momentum.

Mission PI P5:

Christof Lüpkes

Polar 5 Crew	
Mission PI	Christof Lüpkes
Basis Data Acq.	Lukas Kandora
SMART	Elena Ruiz Donoso
Eagle/Hawk	Tobias Donth
MiRAC	Ana Radovan
AMALi	Pavel Krobot

Mission PI P6:

Mario Mech

Polar 6 Crew	
Mission PI	Mario Mech
Basis Data Acq.	Martin Gehrmann
ALABAMA	Franziska Köllner
CVI	Stephan Mertes
Gas/AWI-Aerosol	Oliver Eppers
PMS	Dmitry Chechin

Flight times:

Polar 5	
Take off	12:32 UTC
Touch down	14:48 UTC

Polar 6	
Take off	13:02 UTC
Touch down	16:27 UTC

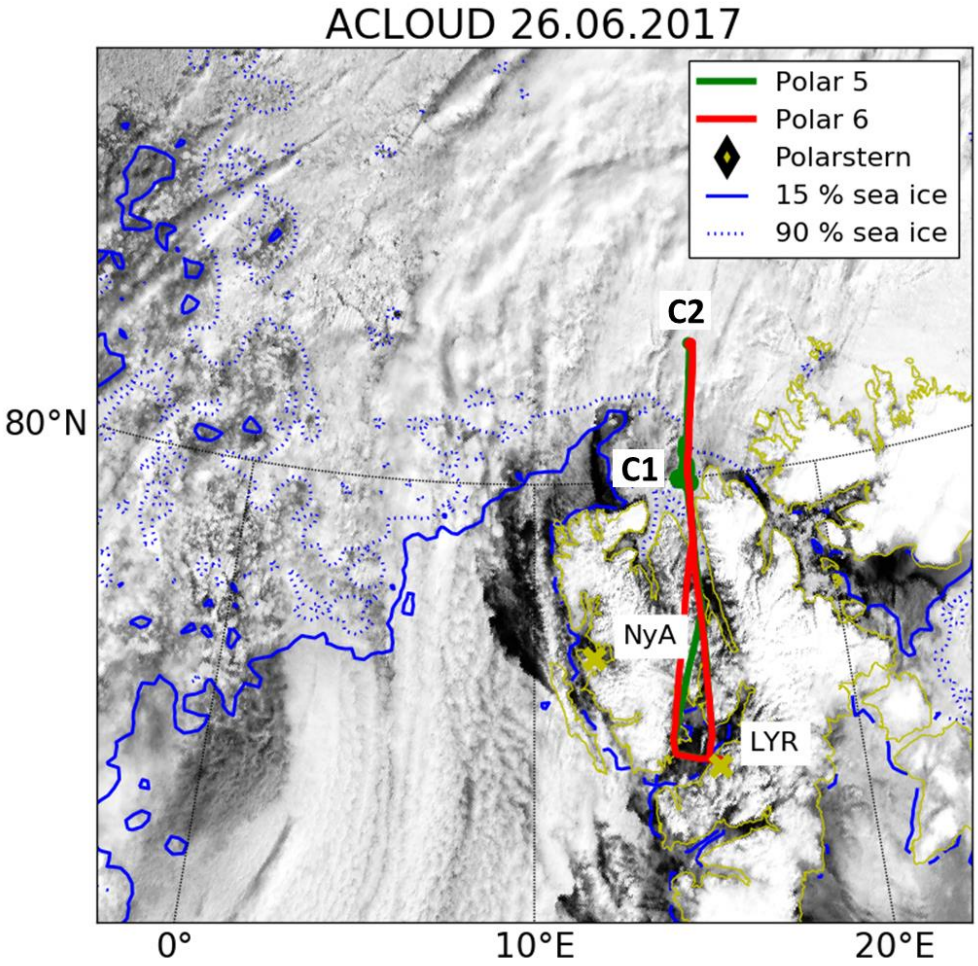


Fig. S25.1: MODIS RGB composite satellite image and sea ice fraction observed by the Advanced Microwave Scanning Radiometer (AMSR2) by the University of Bremen (Spreen et al., 2008).

Weather situation as observed during the flight (compare to forecast):

GFS predicted winds from south to southeast in the measurement region north of Svalbard. Low clouds were predicted over, west and north of Svalbard with a small, almost cloud free part in the measurement region. This situation agreed very well with the situation observed.

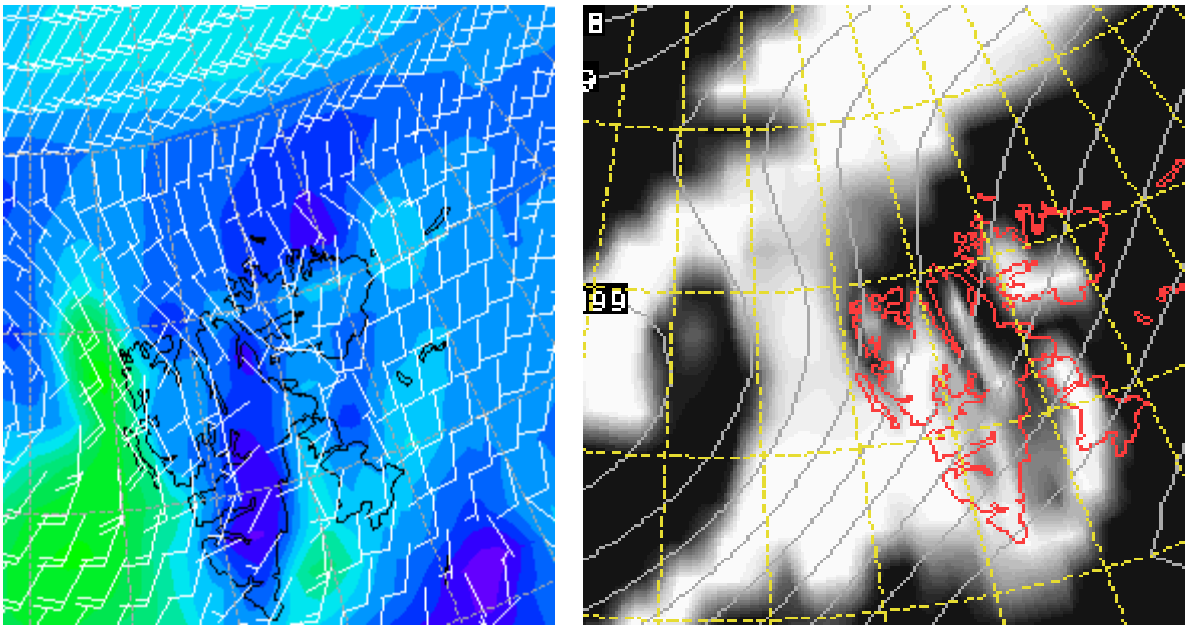


Fig. S25.2: 10 m wind (left) and low clouds (right) for 9 UTC GFS 3 hr prediction (www.wetterzentrale.de, Georg Müller).

Overview:

The main idea of this flight was to go once more in the same region as on the day before (25th June) to investigate the change in boundary layer properties. Due to restricted remaining flight time another flight pattern was performed. This time, only two legs were flown by Polar 5 and 6 and also closely collocated with a horizontal distance of 2000 ft and a vertical distance of 100 ft.

It was found that the boundary layer was indeed higher on this day reaching about 120 m in a region where it seemed to be surface based on the day before. Still +7°C was found in 400 m height, so that the elevated ABL was probably due to an increase in wind speed.

Flight track and pattern:

The ABL measurements were obtained in the region north of 80° flying with Polar 5 in the levels 200 ft on the way towards north and in 400 ft on the way back to south. Polar 6 did the same tracks, but in 300 ft and 500 ft.

At the end of this pattern Polar 5 flew a calibration for the AIMMS20 at a height of 10.000 ft (circles at about 80°N.

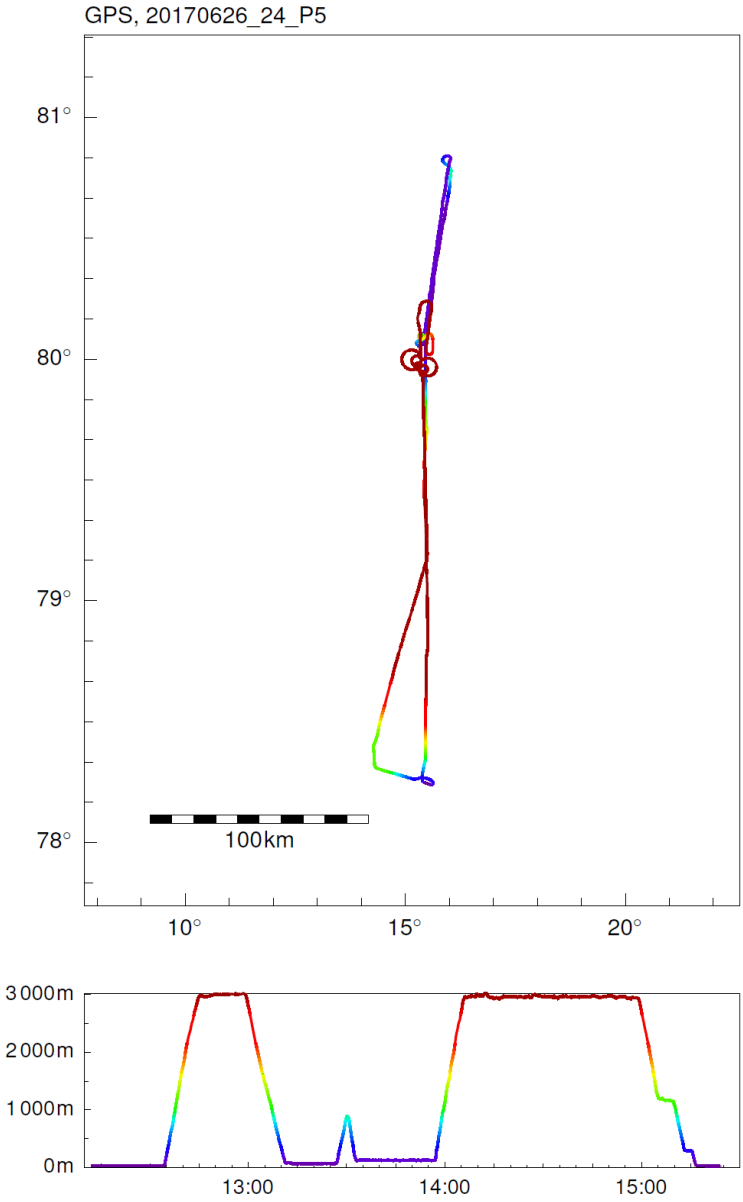


Fig. S25.3: Flight track (upper panel) and altitude profile (lower panel) flown with Polar 5.

Instrument Status:

Polar 5	
Basis data acquisition	
Nose Boom	
MiRAC	
HATPRO	
AMALi	
SMART	
Eagle/Hawk	
Sun Photometer	
Drop Sondes	none launched

Table S25.1: Instrument status as reported after the flight for all instruments on Polar 5.

Polar 6	
Basis data acquisition	
Nose Boom	
CVI	
CVI UHSAS	
ALABAMA	
AWI SP2	
AWI UHSAS	
PHIPS	
SID-3	
CIP	
PIP	
CDP	
Trace Gases	

Table S25.2: Instrument status as reported after the flight for all instruments on Polar 6.

Comments:

CVI inlet heating is not working. When the inlet freezes it does not operate at its full functionality. Cloud probes were not operated due to the flight objectives.

Detailed Flight Logs:

Polar 5: Christof Lüpkes (all times UTC)

Clouds

As the day before, over the southern part of Svalbard, there was a closed layer with low clouds leading to slight precipitation in Longyearbyen and in Ny Alesund. The cloud cover reached further north than on the day before and during descend we found the clouds between about 1700 and 2100 ft.

Fig. S25.4: Photograph, taken from Polar 5 during the descend after crossing the northern coast of Svalbard, showing, that also Cirrus clouds and high stratus were present

Fig. S25.5: Photograph, taken from Polar 5 showing, that the further way north the high clouds observed in Fig. S25.4 disappeared.

Later- while approaching the end of the northbound leg - the cloud cover (mid-level clouds) increased. We did not reach them in 3000 ft (top of the temp). This is illustrated in Fig. S25.6.

Fig. S25.6: Photograph, taken from Polar 5.

Sea ice conditions

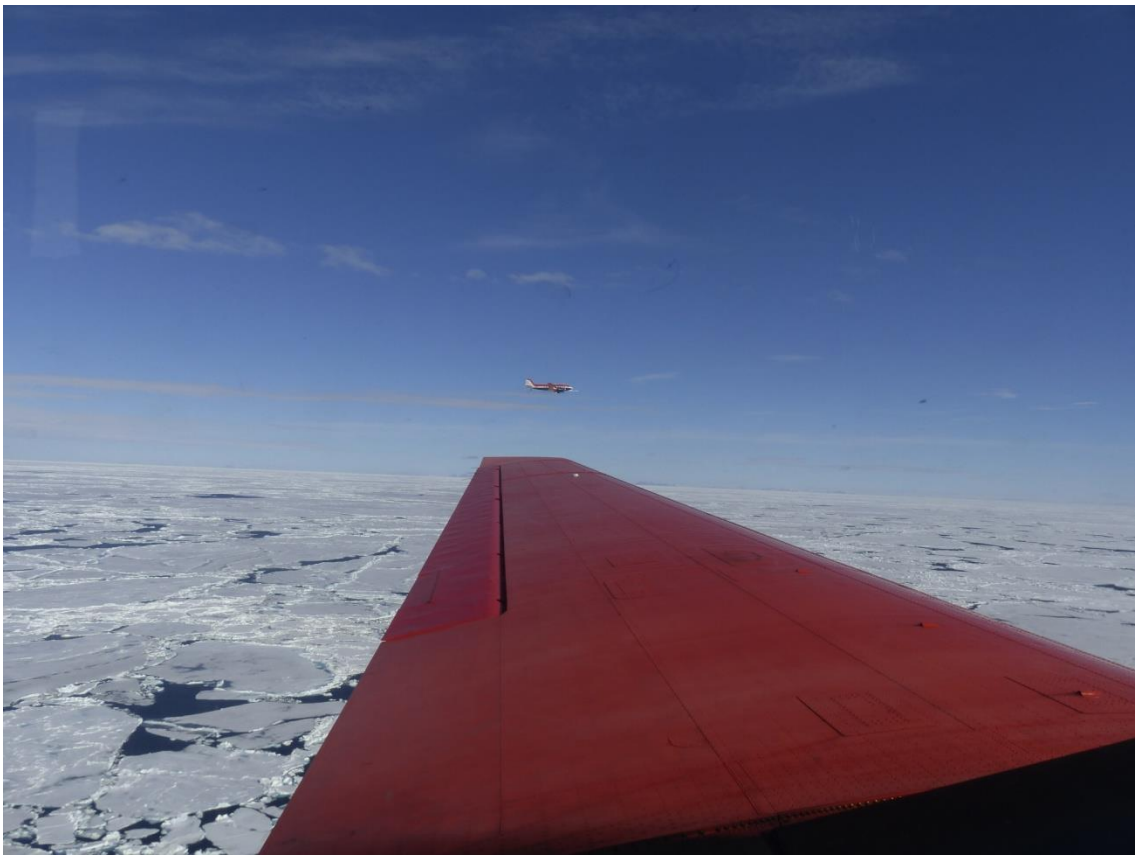


Fig. S25.7: Photograph, taken from Polar 5 showing the typical sea ice cover observed on the southbound leg.

Our impression was that the melt pond cover has now increased. Examples of melt ponds are shown in Fig. S25.8.

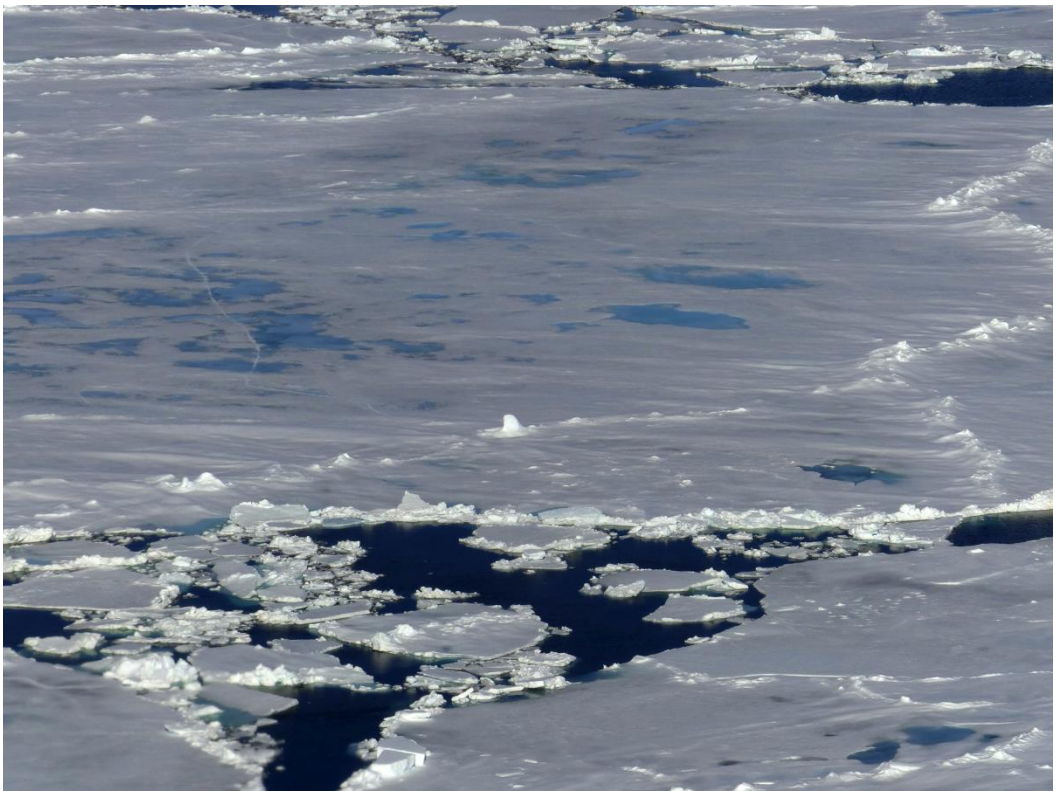


Fig. S25.8: Photograph, taken from Polar 5.

Detailed notes during the flight, heights of flight legs:
In the cloud layer we noticed turbulence. The turbulence was also clearly felt in the lowest levels approaching the starting point of the low-level leg at 80° 3'N and 15° 24'E. Going further to the north the turbulence decreased but was still more dominant than during all flight legs on 25th June.

Maneuvers
A detailed pattern has been flown for the AIMMS20 calibration.

Polar 6: Mario Mech (all times UTC)

12:32: take off
12:35: scattered clouds
12:38: cloud top at 4800 ft
12:41: cloud at 7700 ft
12:42: at 10000 ft
12:58: change of heights for the pattern as proposed by Christof P6 200 and 300 ft
12:58: started descent with 700 ft/min
13:03: 5800 ft clouds for the next 600 ft
13:07: no low level clouds present

13:09: 1500 ft turbulence present
13:11: 200 ft – BL at 600 ft
13:13: climb to 300 ft – quite some turbulence
13:24: clouds closed above
13:27: climb to 3000 ft
13:30: 3000 ft
13:34: 500 ft leg C2 to C1
13:58: heading home
14:08: above clouds at 6000 ft
14:48: touch down

Reference list of the supplement:

Rautenhaus, M., Bauer, G., and Doernbrack, A.: A web service based tool to plan atmospheric research flights, Geosci. Model Dev., 5, 55-71, doi:10.5194/gmd-5-55-2012, 2012.

Spreen, G., Kaleschke, L., and Heygster, G.: Sea ice remote sensing using AMSR-E 89-GHz channels, J. Geophys. Res.-Oceans, 113, https://doi.org/10.1029/2005JC003384, 2008