



# VILLUM

## RESEARCH STATION, Station Nord

2017 ANNUAL REPORT



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Flade Isblink. Jørgen Bendtsen

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VILLUM RESEARCH STATION,  
Station Nord



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# INTRODUCTION



## INTRODUCTION

Kangerlussuaq in 2017. Measurements of surface morphology with a LIDAR on board a Penguin B drone were carried out as a performance test close to the Greenland Inland Ice. The tests were successful so in 2018, the drone will be in use for the first time at VRS. Ceilometer measurements of cloud height has been performed for some years, while vertical wind profiles are measured with a wind coupe LIDAR. The last instrument, a multi axial differential optical absorption photometer, to measure the vertical distribution of bromine oxyl – and iodine oxyl – radicals was installed in the spring 2017 and it is very interesting what the measurements will tell us.

The Atmospheric Laboratory, August 2015.

Photo: Henrik Skov

### Dear Reader

Welcome to the yearly report of The Villum Research Station 2017. This is the third time I welcome to the yearly report for the activities at Villum Research Station, Station Nord (VRS). Many different activities have been carried out at the station and it is a great pleasure for me to see that the annual report addresses on multidisciplinary and divers topics. There are articles covering activities spending from aquatic science over geology to atmospheric chemistry and physics. In 2017, the last part of the VRS infrastructures were purchased and installed, so the construction of VRS is now completed. Therefore, there is a small article on the finalization of VRS.

Most activities were carried out at the Base Station of Villum Research

Station, but in 2017, VRS also served as logistic hub and supported activities in "Sirius Passet" (rich in fossils from the Cambrian explosion) and Krøyers Holme (important Bird colonies are expected to be found there).

Projects financed through the Interact program have been running at VRS, activities that otherwise would have been impossible to carry out. The program has thus shown its great value by opening the opportunity for scientists to use VRS for their research, who otherwise had difficulties rising sufficient funding for travel and stay at VRS. Furthermore, Interact selection procedure ensured that the projects were of high scientific quality.

The first tests flights with a larger drone on Greenland took place at

The Base Station has now been in use for three years and it has really shown its usefulness and robustness. Many studies have been made from the Researchers house and at the Atmospheric Laboratory. It is an extraordinary pleasure for me finally to see the three parts of the VRS in function; base station, Mobile Station and Air Station.

Last but not least I will send a warm thank to the Villum Foundation that supported the construction of VRS. I am very proud of what we have obtained and I am convinced, the result shows that we are worthy of the trust the Foundation gave us by awarding the large grant.

*Best regards*

*Henrik Skov, Scientific Head of Villum Research Station, Station Nord*

Researchers House, garage and solar cell plant, August 2017.  
Photo: Poul Friis Jørgensen



# VILLUM RESEARCH STATION, STATION NORD INFRASTRUCTURE IS COMPLETED

By Henrik Skov, Scientific Head  
of Villum Research Station,  
Station Nord

## INFRA- STRUCTURE

In February 2013, Aarhus University received an infrastructure grant from Villum Foundation of 70.5 mill. DDK (~9.5 mill €) for building a new modern Research Station at Station Nord in the most northern part of Greenland. The aim of the initiative was to establish a unique state-of-the-art research infrastructure in the high Arctic for investigating climate changes and their impacts on atmospheric, oceanographic, biological and geological conditions and processes in the Arctic. The station consists of three parts:

1. The Base Station located at Station Nord consists of two buildings with living quarters, laboratories storage rooms, and a garage. It provides a platform for joint studies of air pollution, climate, geology, and biological processes in ecosystems in the neighborhood of Station Nord. The Base Station has accommodation for 14 scientists and it is open year round.

2. The Mobile Station includes mobile laboratories and living quarters consisting of tents and vehicles. The Mobile Station makes it possible to do atmospheric, terrestrial, sea-ice and marine research at long distances away from Station Nord.

3. The Air Station consists of drones and ground based remote sensors that makes it possible to study vertical profiles of the atmosphere to an altitude of up to five kilometers, and to make aerial observations of snow, sea-ice and the terrestrial landscape by remote sensing. The Air Station can be moved and operated at different places, e.g. as part of the Mobile Station.

The grant was the initiation of four extremely busy years for my colleagues and me. The work with the construction started very intensely from day one. The sketches of the stations in the application had to be converted into official draw-

ings including much more details, preparation of call for tenders and obtaining building permissions. The situation was further complicated by the fact that it is only possible to build houses at Station Nord during 6 weeks in the summer period. Very quickly I got a very strong team consisting of John Lau Hansen, Morten Rasch, Ioanna Miclaus and Bent Lorenzen, whom I will special acknowledge for their enormous commitment and professionalism in the early stages of the construction of the research infrastructure. After his Highness Crown Prince Frederik took the first shot, we succeeded to get the foundation built in summer 2013 and the two houses and a garage were completed in summer 2014. The Greenlandic authorities showed a large degree of flexibility and high efficiency, so we got all permissions in very short time. POLOG and Venslev Byg, which showed an incredible efficiency in the building process, flew in building materials, in total 250 tons, from Longyearbyen on Svalbard.

Researchers house and garage as  
seen from apron.

Photo: Henrik Skov



I cannot express the feeling I had when I landed in late August 2014 and saw the buildings standing there and John Lau showed me around at the new Station. A documentary about the building process and the vision for the station was produced during 2014 (see VRS homepage [www.villumresearchstation.dk](http://www.villumresearchstation.dk)). In 2015, we had the official opening of VRS. Her Royal Highness Queen Margrethe II should have participated as well in the opening ceremony but was delayed due to weather conditions and arrived a few days after the ceremony. We had to have the ceremony without Her Majesty due to other logistic constraints.

Chairman of the Counsel for the Villum Foundation, Jens Kann Rasmussen held the opening speech. In the inauguration, Professor Niels Christian Nielsen, Dean of the Faculty for Science and Technology, and Professor Carsten Suhr Jacobsen, Head of Department of Environmental Science both at Aarhus

University were also among the participants.

In the following months, the station was equipped with traditional laboratory equipment for hosting a wide variety of natural science disciplines. At the same time, more advanced equipment was tested in Denmark as e.g. Proton Transfer Reaction time of flight mass spectrometers, soot particle aerosol mass spectrometer, and a Hygroscopicity Tandem Differential Mobility Analyzer.

The first large international campaign was accomplished within the Arctic Science Partnership (<http://www.asp-net.org/>) in 2015. This was the first real test of how well the station fits to the researchers demands. We asked each participants to fill in a questionnaire, and we were happy to see that visitors in general were happy about the facilities; however, there were also some points to improve. A simple thing was for example that the py-

rolysis toilets did not work and we had to replace them all.

After the first year of very intense work constructing the Base station followed 2016 and 2017, where the mobile Station and the Air station were established. The building of these two sub-stations appeared to be equally challenging, especially the Air Station because this was a complete new area. We had to select the right drones and equipment to be operated on the drones. We benefitted from a very good collaboration with professor René Forsberg from DTU SPACE and Director Michael Thorsen from INTEGRAL. It was a pleasure for me to see the first report on the use of a VRS drone for measuring surface morphology on Greenland to appear in this report.

We have three more drones Prion Mark 3 from UAVE that have been through the first tests, they will be operated at VRS in 2018/2019 for the first time. They are equipped



with instruments to measure black carbon (soot) and particle number concentrations.

Finally, yet importantly, it is always a dilemma carrying research at remote locations as at VRS in high Arctic. The transport and stay consume large amount of energy. Therefore, we optimize the flights in order to limit the number. Furthermore, the last part of the construction at VRS was the installation of solar cells in 2017. After installation, we observed a production as high as 15 kW, which could cover all the needed power consumption at that given time. In 2018, we will see how large part of our yearly energy-need we can cover through solar energy after a whole year of use. Acknowledgement:

A special thank is to the Royal Family for supporting the Villum Research Station. Your presence and support has been of great value for the entire project and contributed to lift the celebrations to be something extraordinary.

Villum Foundation is acknowledged for the large grant making it possible to build the new research station at Station Nord. The Danish Environmental Protection Agency and the Danish Energy Agency financially supported the monitoring work within the AMAP program with means from the MIKA/DANCEA funds for Environmental Support to the Arctic Region and this support is the backbone for our presence at Station Nord. Integrated Carbon Observation System (ICOS) a NUI project. Interact is acknowledge for support of visiting scientists at the Station. The Royal Danish Air Force is acknowledged for providing free transport to Station Nord, and the staff at Station Nord is especially acknowledged for excellent support.







A. Building modules ready for shipment.  
Photo: Henrik Skov

B. Modules loaded on truck.  
Photo: Henrik Skov

C. The fundament of Researchers House.  
Photo: Jørgen Nielsen from Venslev

D. Researchers House under construction.  
Photo: Jørgen Nielsen from Venslev

E. External plates are being mounted on Researchers House.  
Photo: Jørgen Nielsen from Venslev



# THE VILLUM STATION NORD DRONES – FIRST TEST FLIGHTS WITH LASER SCANNING

By Rene Forsberg and Eric Haase;  
Technical University of Denmark

As part of the VRS grant, an “Air Station” of several small to medium range drones has been purchased, for use as an infrastructure for environment observations, including atmospheric monitoring (AU), measurement of cryosphere changes (DTU Space), and general monitoring of geomorphology, terrain height, living resources etc. As the first of the batch of the longer-range drones, a “Penguin-B” drone has now gone through a major testing program in Denmark and Greenland, and is ready for extended tests for precision snow and ice mapping. The drone and its sensors systems have been developed in a close cooperation with Integra A/S, DTU and AU.

The gasoline-driven Penguin-B drone is manufactured by UAV Factory, Estonia, has a 3.3 m wingspan, a (theoretical) payload of 10 kg and a potential endurance of 10 hours, depending on payload. The Penguin-B drone belongs to the class of drones below 25 kg total weight, where it is relatively easy to get dispensation for operations in Denmark or Greenland air space. The flight instrumentation, implemented and tuned by Integra A/S, include an autopilot/flight control computer, an altimeter, and an Iridium modem allowing the communication with the drone beyond visual line of sight (BVLOS).

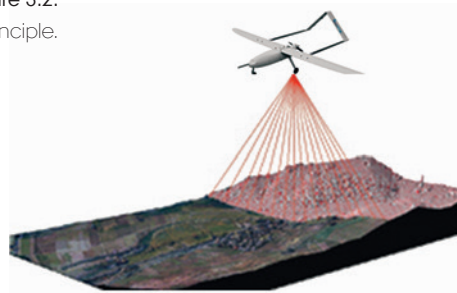
## FIRST DRONE

Figure 3.1.  
Drone in Kangerlussuaq, with the DTU/Integra team.  
Photo: Eric Haase, DTU Space



Separate from the avionics system, DTU Space has implemented a “science payload” consisting of a precise GPS, an inertial navigation system, nadir-looking camera and a control computer. The GPS/IMU form an inertial navigation system (INS) which allow drone positioning at 5 cm accuracy in all three dimensions. The precision laser scanning system allows the continuous measurement of a wide “point cloud” below the drone along the flight path. The first laser system implemented has a maximal range of 100 m, and features 16 simultaneous laser beams, pointing at different angles to nadir, all rotating

Figure 3.2.  
Lidar principle.



across-track to provide the continuous “swath” of data, at a horizontal resolution at a fraction of a meter, a vertical accuracy of few cm in height.

The major constraint for the drone lidar is determination of the drone flight altitude and attitude (roll, pitch and heading) sufficiently accurately. Even though the lidar system is lightweight (total science package weighs currently 2.3 kg), and the use of much cheaper sensors than for traditional airborne lidar, flight tests at Odense airport have demonstrated an accuracy of 5 cm compared to surface GPS surveys of the runway. This is a highly satisfactory result, giving similar accuracy as aircraft lidar systems, and building upon the long experience of DTU Space in flying airborne lidar and other sensors in small aircrafts, primarily in Greenland and Antarctica, in support of cryosphere change monitoring and satellite validation projects.

A first application of the drone lidar in Greenland was done in Kangerlussuaq, West Greenland, in the period Oct 27-Nov 4, 2017. Flights were made over the main runway, and then 30 km away from a frozen lake in front of the Russel glacier, a spur of the Greenland ice sheet. The Kangerlussuaq flights served as a first operational test for cold weather operations, including use of skis, rather than wheels on the drone. Though the data is not post-processed to the final level, the initial results from Greenland confirmed a 5-10 cm point cloud accuracy, as well as a few practical problems, to be addressed before the upcoming Station Nord test flight program, planned for April 28-May 5, 2018.

Figure 3.3. Point cloud of H C Andersen airport in Odense, heights in meter above WGS84 – dark lines are GPS “ground truth” data along the runway.

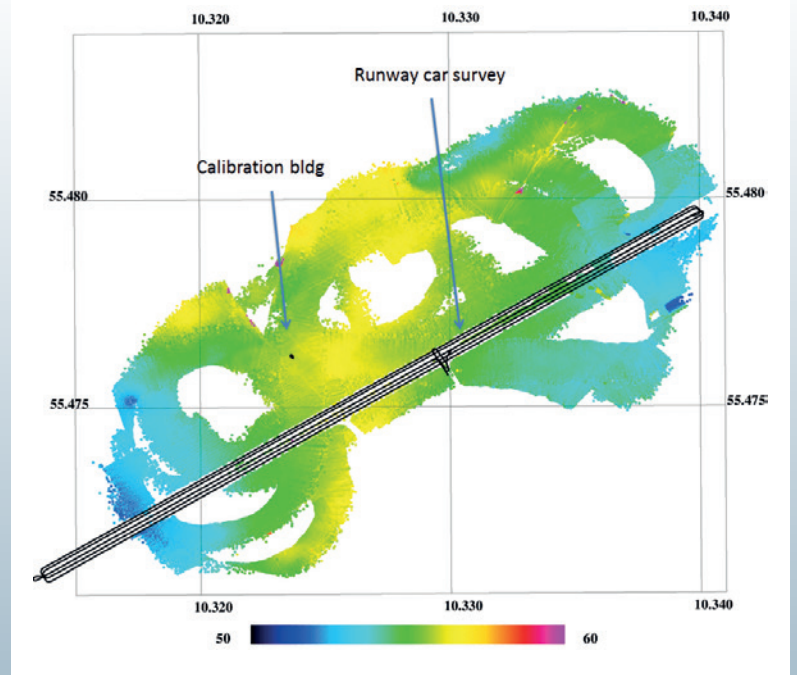


Figure 3.4. Penguin B drone over the Russel Glacier. Photo: Eric Haase, DTU



# OPEN WATER INVESTIGATIONS AROUND VILLUM RESEARCH STATION

Figure 4.1.

Image of the tidewater outlet glacier from Fladen Isblink glacier. The tidewater outlet glacier is seen in the background. It is ~4-6 m high and the surface is covered with dust. The large ice berg in foreground has calved from the glacier.

Photo: Jørgen Bendtsen

TIDEWATER  
FROM GLACIER

By J. Bendtsen; ClimateLab

In August 2015 a team of scientists investigated the marine conditions around Villum Research Station (VRS) from small inflatable boats. This was the first “sailing” oceanographic investigations in the area and it was made possible because of the warm summer this year and the relatively open water around the research station. Although the area in front of the station was relatively ice free, we experienced that sea ice could rapidly cover the small strait between Princess Dagmar Island and the VRS because of changing winds or tidal flow. This caused many hours of delay with slowly maneuvering between thick sea ice floes and it made planning of the field work difficult. After a few days it was, therefore, decided to move the small and temporary “harbor” near Villum Research Station a few kilometers north of the

station. Here, the boats had a relatively free access to the bay located east of the station and it was also near the tidewater outlet glacier from Flade Isblink. The following weeks measurements were made in the bay and close to the terminus of the glacier. Transects were also made between Princess Dagmar Island and the multi-year ice north of the area when it was ice-free.

### Is the tidewater outlet glacier floating or grounded?

Part of the investigations were focused on understanding the conditions near the terminus of the tidewater outlet glacier from Flade Isblink Ice Cap. The terminus of the outlet glacier form the eastern side of the bay and it has been retreating several kilometers in the last decades. However, very little was known about the physical conditions of the terminus and, in particular, to what extent warm ocean water was influencing the melt of the glacier. Several transects were made close to the terminus, i.e. within a few meters from the glacier ice, and along hydrographic transects perpendicular to the terminus. Results from these investigations are published in Nature Scientific Reports (Bendtsen *et al.*, 2017) and are summarized below.

The terminus was typically about 4 to 6 m high above sea level and calved icebergs (~40 m deep) were floating or grounded close to the glacier. Observations very near the glacier showed that a 5-10 m deep ice foot extended up to ~40 m out from the glacier. The ice foot was seen on the echo sounder and also observed when the instruments were lowered close to the glacier where they hit the glacier surface. When the instruments were lowered outside the ice foot, they slid along the glacier and landed on the soft bottom at 60-80 m depth. Temperature, salinity measurements and their water mass characteristic very close to the terminus indicated that it was a floating ice shelf along this section of the tidewater outlet glacier, and this was additionally supported by ice surface elevation data inferred from satellite observations. Temperatures near the glacier between 20-80 m depth were relatively constant and near the freezing point of seawater (-1.75 °C) and the salinity was typically between 31-33. Some observations near the glacier below 20 m was super-cooled or very near the freezing point and this indicated that net subsurface freezing took place at the glacier-ocean interface below. In contrast to this



subsurface freezing, relatively high temperatures were measured in the ~10 m deep surface layer. Here, temperatures were typically between 0-2 °C and, thereby, 2-4 degrees higher than the freezing temperature. The high surface temperature would cause melting of the upper part of the outlet glacier and this could explain the observed ice foot described above.

#### **Annual melt and retreat of Flade Isblink outlet glacier**

Observations of temperature and salinity was also made in the area between Villum Research Station and Princess Dagmar Island. The surface average salinity in the upper 10 m was ~20, corresponding to a freshwater layer of 3-4 m when compared with the deeper salinity of ~30.6. These measurements from August was compared with measurements from the April 2015-campaign where freshwater content in the upper 10 m was only ~1.6 m. Thus, seasonal melt of snow, ice and runoff from land cause a large increase in the freshwater content of more than 2 meter in the whole out-flowing region around the Villum Research Station.

A CTD (measuring salinity, temperature and depth) was deployed off

Villum Research Station at about 13 m depth and measured pressure, temperature and salinity from May 2015 to April 2016. Heating of the upper surface layer during the season was calculated from this record and, together with the measurements made near the terminus; an energy balance was made of the annual melt of the glacier. This analysis showed that the short open-water period near the terminus has a large impact on the annual melt of glacier ice because of the increased solar heating of the ice-free surface layer. Increased heating of the surface layer may also explain the observed retreat of this tidewater outlet glacier from Flade Isblink during the last decades. Earlier sea ice breakup and reduced sea ice cover in front of the tidewater outlet glacier can, therefore, lead to further retreat of the outlet glacier from Flade Isblink Ice Cap and similar response may also be expected from other tidewater outlet glaciers along the north coast of Greenland.

Figure 4.2.

Approaching the tidewater outlet glacier from Flade Isblink. The investigation along the tidewater outlet glacier was carried out from small boats equipped with CTD's and light-weight marine instruments for profiling and collection of water samples.

Photo: Jørgen Bendtsen

#### **Reference**

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#### **Sea ice breakup and marine melt of a retreating tidewater outlet glacier in northeast Greenland.**

Scientific Reports, 7: 4941, doi:10.1038/s41598-017-05089-3, 2017.

## AQUATIC ECOLOGY

LAKE ECOLOGY AND MONITORING  
AT THE VERY NORTH

## YEAR-ROUND MEASUREMENTS OF LIFE CONDITIONS IN LAKES

By Kirsten Seestern Christoffersen;  
Freshwater section, Department of  
Biology, University of Copenhagen

HIGH ARCTIC  
LAKE  
MONITORING

Lakes in the high Arctic region are nutrient poor and covered by ice for 9-10 month, so intuitively we may think, that such ecosystems are extremely little productive, host very few biota and can hardly play any role in the overall performance of the high Arctic ecosystem. These aquatic waterbodies are indeed low-productive when compared to temperate systems but are not at all inactive – even not during the long ice-cover.

Long term monitoring of lakes takes place in different place in Greenland as part of the GEM-program (Greenland ecosystem monitoring; <http://g-e-m.dk/>) that runs in Zackenberg and Kobbefjord as well as at Disko Island. These stations form a climate gradient going from the high Arctic to the low Arctic zone which is essential to be able to perform evaluations of the effect of global warming. However, monitoring of lake ecosystems in Greenland has not been done north of 74°N.

The newly established Villum Research Stations at Station North provides infrastructures and facilities that allows for moving the monitoring activities further North. A pilot limnology project was performed late in 2017 (November/December) to get basic measurement of water chemistry and to launch con-

tinuous recording equipment in two lakes near the station.

“Vandsøen” is just 2 km from the stations and close to the atmospheric monitoring facilities (Flygers hut and Air Observatory). The lake is 6 m deep and serves as the year-round drinking reservoir for Station Nord and the Villum Research Station. The water has been tested prior to human consumption and is nice and clear. Some macro-size rubbish from earlier station-life is present at the bottom. The other lake is “Fiskesøen” which is situated some 8 km South-East of Station Nord. It is around 10.5 m deep and holds a population of fish (Arctic charr; *Alpinus salvenius*). This lake is far enough away from any human disturbance although popular as recreative fishing spot for the personnel at Station Nord.

These lakes are ideal for monitoring purposes as being typical Arctic lakes and within driving distance using snow scooters or an all-terrain vehicle during the snow-cover season as well as in walking distance during summer. To initiate a

minimum all-year monitoring program a set of data-loggers were deployed in the lake at the deepest part. These loggers will record light, temperature, oxygen and conductivity every 2 hour. The battery power consumption is minimal and will allow for data collection for approximately one year. However, the plan is to retrieve all data loggers during summer 2018 (using a dingy) for reading out data and redeployment.

The lakes were visited using an all-terrain vehicle during the first days in December. The approximately mid-lake position was detected using GPS as the lakes were not easily distinguished from the surrounding due to deep snow and darkness. Holes (50×50 cm) were made through the ice using a powered drill and an ice-saw (see figure 5.1) and the data logger-stations (see figure 5.2) were successfully deployed at the bottom.

Further analyses of micro-organism (plankton), nutrients and dissolved carbon is done at our lab in Copenhagen.

Some basic winter conditions in the lakes:

Lake / Parameter	Ice thickness	pH	Conductivity
Vandsøen	72 cm	7.86	169 µSi
Fiskesøen	58 cm	7.35	200 µSi



Figure 5.1.  
Preparing holes  
in the ice at  
Vandsøen.  
Photo: K.S.  
Christoffersen,  
December 2018.



Figure 5.2.  
The data-logger  
station ready to  
be deployed at  
Fiskesøen.  
Photo: K.S.  
Christoffersen,  
December 2018.

# TRANSGREEN ACTIVITIES AT VILLUM RESEARCH STATION IN 2017

By Ole Humlum, Wesley Randall Farnsworth, and Sarah Marie Strand; The University Center in Svalbard (UNIS).

## Background

In August 2018, a three-person field team from UNIS conducted fieldwork on the Princess Ingeborg Peninsula. The team was based in the Villum Research Station (81°36' N, 16°40' W), and financially supported by the INTERACT initiative.

## QUATERNARY AND GEOMORPHOLOGICAL MAP

The main aim of the TRANSGREEN research project at Villum Research Station is the production of a Quaternary and geomorphological map of the Princess Ingeborg Peninsula, to supplement the pioneering work done by Petersen in 1988. Such a map showing the main landforms and sediment types may form an important basis for a range of other research projects using the Villum Research Station.

The fieldwork during August 2017 focused on field mapping of landforms and sediment deposits related to ice cover during the last glacial maximum and the subsequent Holocene interglacial. The combination of raised marine sediments (✓beach ridges) and occasional boulders with glacial striae covering the northernmost part of the Princess Ingeborg Peninsula suggests that at some point in

Large-scale patterned ground shortly west of Flade Isblink. This periglacial landform is diagnostic for the presence of permafrost. Photo: Ole Humlum







Intersecting linear depressions (partly water-filled) suggesting the presence of very large ice-wedges about 2 km SW of lake Fiskesøen. Photo: Ole Humlum

the past the area was covered by warm-based ice, not frozen to the bed. The field team surveyed and collected observations contributing to the Princess Ingeborg Peninsula sea level history outlined by Funder *et al.* (2011).

The field campaign additionally focused on maintenance and downloading data from two 20 m deep permafrost boreholes. These boreholes were established in summer 2014 about 2 km south of the station, as part of the monitoring programme at Villum Research Station, in cooperation with the University Centre in Svalbard (UNIS).

#### Field Mapping

During the field mapping, attention was directed towards the margins of retreating ice bodies, such as the large ice cap Flade Isblink and also smaller wind-controlled firn areas. Recent ice marginal retreat in areas of cold based and/or slow flowing

ice can expose undisturbed vegetation and moss that lived at a time when the ice bodies were even less extensive than today. Radiocarbon ages of such vegetation can provide an understanding of the timing of ice expansion in the area, which may relate to a decrease in summer temperatures, an increase in winter precipitation, enhanced winter snow drifting by wind, or some combination of all factors.

Raised beach ridge sediments were surveyed for driftage, which upon radiocarbon dating can be used to reconstruct a Holocene sea level curve. Relative sea level curves provide projections of the rate of post glacial uplift, timing of local sea level regression as well as relative sea ice distribution (Häggblom, 1982; Funder *et al.*, 2011). Relative sea level data is critical for getting a holistic understanding of the Holocene history of the region around the Villum Research Station and has large

implications for the ground thermal regime (permafrost).

The northernmost part of the Princess Ingeborg Peninsula is entirely covered by raised beach ridges, extending up to an upper marine limit located about 67 m above the modern sea level. This old coastal landscape extends east right up to the modern margin of an outlet glacier from Flade Isblink, demonstrating that this outlet of the ice cap was not as extensive at the time of formation of the beach ridges. A detailed geomorphological mapping of the beach ridges can provide information of past wave and wind activity, and potentially also information on the presence or absence of sea ice along the past coastlines. Today, 1 m high ice-pushed ridges formed by the landward movement of floating sea ice is frequent along the modern shore but is apparently not found in connection with the raised coastlines.



### Permafrost

The modern mean annual air temperature at Villum Research Station is around  $-14^{\circ}\text{C}$ , and the mid-winter average (DJF) is usually around  $-26^{\circ}\text{C}$ . The entire Princess Ingeborg Peninsula is therefore expected to be underlain with thick, continuous permafrost. The winter snow cover, however, has a long duration and is often quite thick ( $> 1\text{m}$ ), which prevents the ground temperatures from fully reflecting the low winter air temperatures. For that reason, permafrost in the area may be somewhat shallower than suggested by the air temperatures alone. The mean annual ground temperature at 20 m depth was  $7.9^{\circ}\text{C}$  and  $7.1^{\circ}\text{C}$  at the two boreholes, respectively, from 20 August 2016 to 19 August 2017. The borehole with the slightly warmer 20 m temperature ( $7.1^{\circ}\text{C}$  at Site 2) routinely has thicker snow cover than the other borehole and thus has a greater buffer from winter air temperatures. Investigating the relationship between air temperature and winter snow cover in this part of high Arctic Greenland was part of the motivation for establishing the two permafrost boreholes in 2014.

Permafrost landforms are widespread in the entire Princess Ingeborg Peninsula; mainly in the form of large-scale patterned ground and ice-wedges. Ice-wedges form by thermal contraction cracks forming mid-winter in the uppermost permafrost, and the subsequent seepage of rain or snow meltwater into the cracks during spring and summer, forming a thin ice vein filling the permafrost crack. By repeating this crack-and-fill process over centuries, vertical meter-thick ice-wedges may form in the uppermost 2-7 m of the permafrost. By investigating individual vertical ice layers (exposure dating, C14 or by oxygen isotopes) ice wedges may yield detailed information about the paleoenvironment. The

detailed chemistry of the accumulated ice layers may potentially provide information of past atmospheric chemistry.

### Extraordinary large ice-wedges

Ice-wedges are found in many parts of the Princess Ingeborg Peninsula, typically having a cross dimension of 1-3 m, roughly indicating the width of the underlying ice-wedge. This dimension is typical for Holocene ice wedges in many modern permafrost areas, such as Svalbard 400 km to the east. In eastern Princess Ingeborg Peninsula, however, extraordinarily large ice wedges (up to 20 m wide) were identified covering an area of at least 1 km<sup>2</sup>, about 2 km SW of lake Fiskesøen.

It is unknown what causes these supposed ice wedges to be an order of magnitude larger than most other studied ice wedges. It is possible that the massive size of these features may be influenced by a development over long time, suggesting the ice wedges may not just be Holocene in age, but may have formed at an earlier interglacial time. If so, the apparently survived glaciation(s) below glaciers with limited erosion capability and were finally re-activated during the Holocene.

A. Sampling dead mosses for dating at the lower rim of elongate firn located along the northeastern side of Knuth's Field.

B. Linear depression (10-15 m wide) suggesting the presence of a very large ice-wedge a few km's SW of lake Fiskesøen. The narrow water-filled crack is probably located over the central part of the ice-wedge.

C. Linear depression suggesting the presence of an ice-wedge of 'normal' dimension (1-2 m wide) shortly east of the Villum Research Station.

Photos: Ole Humlum



# SEARCHING FOR NOVEL PHOTOSYNTHETIC BACTERIA IN THE HIGH ARCTIC

## HAVE THE UNIQUE LIGHT AND NUTRIENT CONDITIONS IN NORTHERN GREENLAND LED TO THE EVOLUTION OF NOVEL PHOTOSYNTHETIC BACTERIA THAT ARE AWAITING DISCOVERY?

By Yonghui Zeng, Louise Feld and Lars Hestbjerg Hansen

We are living on a microbial planet dominated by tiny but mighty microorganisms. The barren high Arctic with little vegetation is no exception. Microbes are found in any corner of northern Greenland, no matter it is snow, ice or permafrost soil, even up in the air and down onto the rock surfaces. They play a significant role in maintaining a healthy Arctic ecosystem and mitigating the consequences of global climate change.

Among the extremely diverse microbial members, we are particularly interested in photosynthetic bacteria and their presence in the terrestrial environments of high Arctic. Photosynthetic bacteria are a

group of microorganisms that can harvest sunlight and convert solar irradiation to chemical energy to drive cellular activities. In relatively warm climates, these bacteria have demonstrated a growth advantage over their non-photosynthetic relatives when competing for resources. But we know very little about their prevalence, distribution and diversity in high Arctic regions. Compared to low latitude regions, the high Arctic is characterized by very low levels of nutrient available to phototrophic lives, low intensity of light at visible spectra, and long periods with either sleepless continuous sunshine or hopeless complete darkness. Such unique light and nutrient conditions could have fostered the development of new photosynthetic bacterial species that are awaiting discovery.

### PHOTO-SYNTHETIC BACTERIA

In the summer of 2017, we set out to try the isolation of photosynthetic bacteria from environmental samples of Greenland and Svalbard. These included snow and ice samples collected by Niels Bohse Henriksen from the Knuth Fjeldet that is close to the Villum Research Station (Fig. 7.1), lake surface waters from Nuuk and Kangerlussuaq, streams and river surface sediments from Zackenberg Research Station (collected by Naicheng Wu), and permafrost soil from Svalbard (provided by Ebbe Norskov Bak).

When samples arrived in our laboratory of Environmental Microbiology and Biotechnology in Roskilde in September 2017, we plated them on 1/5 strength nutrient-poor R2A agar until visible colonies appeared after 2-8 weeks. We assembled a

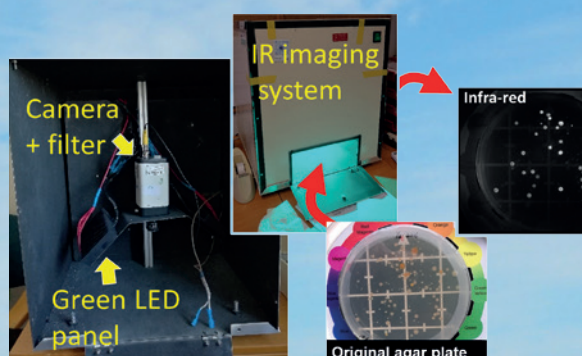


Figure 7.2.

A homemade infrared imaging system for rapid identification of colonies of photosynthetic bacteria grown on agar plates.

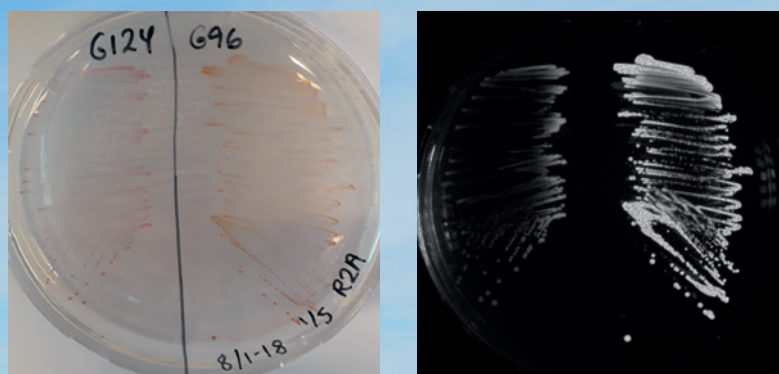


Figure 7.3.

Photographs of two new photosynthetic bacterial species (strains G124 and G96 with brown colored colonies) found at the Villum Research Station. Left, original plate with colonies grown on 1/5 strength R2A agar in a 90 mm-diameter petri dish; Right, the same plate after infrared imaging showing strong IR signals coming from photosystems when the plate was shined with green light.



Figure 7.1.

Sampling of snow and ice at the Knuth Fjeldet accessed from the Villum Research Station was done by Niels Bohse Henriksen. Photo: Ole Humlum

self-designed infrared (IR) imaging system for rapid identification of photosynthetic colonies grown on agar plates (Fig. 7.2 and 7.3). The detection principle is that, photosystems embedded in the cell membrane of photosynthetic bacteria absorb green and blue light; the absorbed energy is passed to the main photosynthetic pigments – bacteriochlorophylls, which get excited and then emit infrared irradiation; eventually, our IR imaging system captures these infrared signals. Since bacteriochlorophylls have been found only in photosynthetic bacteria, this IR imaging system was proven to be a very reliable and efficient tool for identifying photosynthetic species.

By February 2018, we have identified more than 200 photosynthetic

bacterial isolates from these Arctic environmental samples, including 41 from the Villum Research station. The 16S rRNA gene sequences of these 41 isolates show that they cover 13 genera, 2 of which are for the first time found to have phototrophic members. In total, we found 11 new phototrophic genera from all investigated samples, suggesting that there is a hidden, photosynthesizing world present in the high Arctic, awaiting further discovery. We expect the ongoing work on genome sequencing of these isolates will even bring more surprises to us in the near future, in terms of how these photosynthetic microbes evolved in the high Arctic and how they thrive in such harsh environments.

# CLOUD FORMING POTENTIAL OF ARCTIC AEROSOLS

## AEROSOL PARTICLES THAT FORM CLOUDS GREATLY INFLUENCE THE MAGNITUDE OF WARMING IN THE HIGH ARCTIC

By Robert Lange and Andreas Massling

### Introduction

At the Villum Research Station (VRS) we have the rare opportunity to study how atmospheric aerosol particles influence the climate in a high Arctic environment.

Aerosol particles are ubiquitous in the earth's atmosphere. They function as the seeds upon which cloud droplets grow, and as such are critical for the formation of clouds. Clouds in turn influence the radiation balance; where energy from incoming sunlight is input and where energy from outgoing infrared radiation is output from the Earth's climate system. Consequently, the concentration of aerosol particles determine the radiative properties of clouds (IPCC, 2013).

When aerosol particles facilitate the formation of cloud droplets, they are called cloud condensation nuclei (CCN). The Arctic radiation balance has proven to be sensitive to increases in the CCN concentration,

as the Arctic atmosphere is limited in CCN. This means that an increase of CCN, be it from human or natural sources, will have a comparably large effect on the Arctic radiation balance (Mauritsen, 2011).

Atmospheric supersaturation (SS) occurs when air rises, expands and cools. This decreases the capacity of the air to contain water vapor. Eventually the air becomes supersaturated and the water will condense on to the CCN, and cloud droplets form. These concepts are summarized in fig. 8.1.

### Our studies

We measured the concentration of CCN at the VRS during two field studies in 2016. The first was during springtime in April-June, while the second took place during August-September. The used instrument, a CCN counter by DMT, creates artificial supersaturations and detects the concentration of CCN. Thereby elucidating how many CCN would be available for cloud droplet formation at different SS scenarios.

### ARCTIC AEROSOLS

The process of cloud droplet formation is called CCN activation, and this activation depends on the aerosol particle size and their chemical composition. The efficiency of a certain type of aerosol to undergo CCN activation is summarized in the  $\kappa$  (kappa) parameter value. Thus, the higher the  $\kappa$ -value, the more efficient is CCN activation, and consequently, the more available CCN at a given aerosol concentration.

When we measure the concentration and sizes of the present ambient aerosol particles alongside the CCN measurements, we gain additional insights about the CCN.

Hereby we can determine the actual size of the CCN particles, and their associated  $\kappa$ -value.  $\kappa$ -values below 0.1 signify low CCN activity and  $\kappa$ -values above 1.0 means that particles are very efficient CCN. When these parameters are known, we can draw conclusions about the chemical composition of the particles.

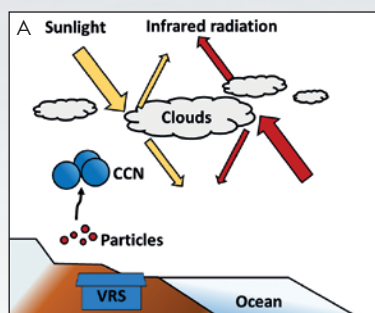


Figure 8.1.

A. conceptual drawing of CCN on the radiation balance. Particles raise in altitude, and eventually become CCN. They influence cloud formation, and the clouds absorb, scatter and transmit incoming solar light, and outgoing infrared radiation.

B. Photograph showing cloud layers near VRS.

## Results

We observed a higher concentration of CCN during the spring field study, than in the summer. Contrary to that, the  $\kappa$ -values are comparable between the two seasons. The CCN concentrations are much lower, than one would observe in mid-latitude populated areas as in e.g. central Europe. The average  $\kappa$ -values were in the range 0.32-0.45 during both seasons, which is high compared to mid-latitude continental aerosol (Levin, 2012; Chang, 2010). It is interesting to note, the  $\kappa$ -values appear more stable in the summer, than in the spring study. Additionally, a strong decrease in CCN concentration is observed between 21-05-2016 and 31-05-2016. Even as less CCN are available for cloud formation in summer, the aerosol is just as efficient in forming cloud droplets. This is significant, as the spring aerosol is strongly influenced by human air pollution that has been transported into the Arctic. The summer aerosol is derived from natural sources within the Arctic. The CCN concentrations and  $\kappa$ -values from the two field studies are shown in fig. 8.2.

## Conclusion

These results help shed light on the climate driving processes in the high Arctic. The aerosols at VRS are efficient CCN. Changes in CCN concentration due to changed aerosol sources, be they from pollution or natural, potentially have strong impacts on the cloud properties. Extensive measurements, or optimally, an ongoing CCN monitoring program would clarify the CCN dynamics further. We have, by performing these field studies paved the way for more CCN measurements at VRS.

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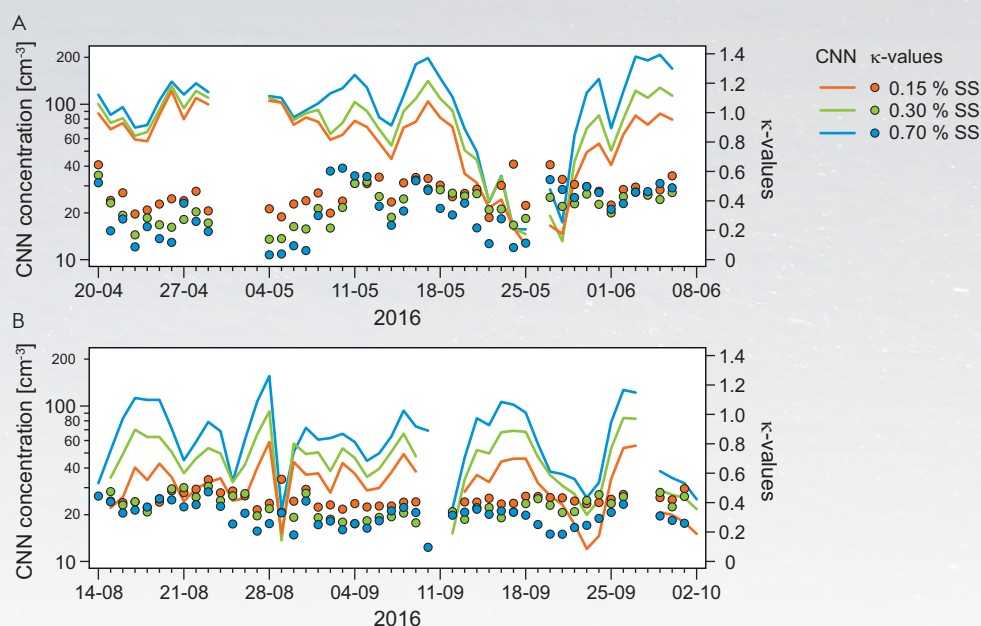


Figure 8.2.

A. April-June.

B. August-September study.

Lines show the measured CCN concentrations at different SS, values can be read at the left y-axis. Dots show calculated  $\kappa$ -values at different SS, values can be read at the right y-axis.

# SIRIUS PASSET, NORTHERN GREENLAND: ANCIENT FOSSILS FROM THE DAWN OF ANIMAL LIFE

By Arne Thorshøj Nielsen, Department of Geoscience and Natural Resource Management, University of Copenhagen

## FOSSILS

In 1984 geologists found a locality with fossiliferous shales, some 520 mill. years old, close to J.P. Koch Fjord in north western Peary Land. The discovery was a sheer stroke of good luck, made in connection with geological mapping of the area. An eye-catching sharp contact between black shales and white limestone at this site can be seen from far away and the geologists decided for a short landing with

Jakob Vinther and Arne Thorshøj Nielsen searching for fossils.

Photo: Arne Thorshøj Nielsen

helicopter in order to investigate the outcrop. The geologists noted that the black shales contained fossils (so-called trilobites) and they collected a few samples with the intention of getting the fossils determined. This is a method to date the rocks and knowing the age of the strata is important for mapping. However, what the two mapping geologists did not know was that they incidentally had stumbled over a unique fossil locality of a kind unknown from anywhere else in Greenland.

Back home in Copenhagen the palaeontologist John Peel, working

at the Geological Survey of Greenland, discovered that the samples in addition to the trilobites also contained less conspicuous fossils, reminding of the world famous "soft bodied" fossils from the Burgess Shale in western Canada. But! The Greenlandic fossils were c. 15 mill. years older than the acclaimed fossils from the Burgess Shale, and John Peel instantly realized that he had a potential world sensation at hand. However, only a sparse fossil material had been collected. In the following years several expeditions to Sirius Passet were then organized, and gradually a rich fossil material was collected, predominantly





Trilobites from Sirius Passet.  
Photo: Jakob Vinther



deriving from the scree below the main exposure of steeply sloping shales. For unknown reasons the early expeditions arrived at the conclusion that the soft bodied fossils only became visible after slight weathering of the shale surface. A total of c. 3000 slabs with fossils were collected during these early expeditions. Literally every loose slab in the scree was turned over and searched for fossils – and then stacked in small heaps that are still visible at the site today.

During the 90'ties several new species of fossils were described from Sirius Passet. One of the earliest described was the enigmatic *Halkieria evangelista* – now interpreted as a mollusc (i.e. a relative of bivalves, gastropods, squids etc.). This fossil has become an icon for the Sirius Passet fauna. The genus *Halkieria* was originally described from coeval strata on Bornholm and named in honour of the photographer at the Geological Museum, Christian Halkier. But up until the finding of

complete specimens at Sirius Passet only mm-sized isolated skeletal parts were known and nobody had a clue what kind of animal it was.

New expeditions to Sirius Passet undertaken by researchers at the University of Copenhagen in 2009 and 2011 discovered that fossils also are extractable from the unweathered “in situ” shales forming the bedrock at the site. In fact, the fossils are better preserved on the fresh surfaces than in the more or



less weathered loose slabs and several new types of fossils, preserved only as thin coalified films, were discovered. It is, however, a major enterprise to collect fossils from shale that first has to be "quarried" so the two rather short expeditions in 2009 and 2011 could not undertake an exhaustive investigation of the site.

Each new expedition to Sirius Passet has added new findings of hitherto unknown fossil species. Under normal circumstances, only organ-

isms with hard parts are preserved as fossils, but occasionally, given the right circumstances, organisms without hard skeletal parts may be preserved, although it happens very rarely. Such sites with exceptional preservation are called lagerstätten and these rare localities provide a unique insight into the true biodiversity in the ancient environments – under normal circumstances only some 10-15 % of the animals would have been fossilized and preserved for posterity. As the first expeditions

to Sirius Passet were supported economically by the Carlsberg Foundation it became a common joke among palaeontologists: "Sirius Passet, probably the best lagerstätten in the world" referring to Carlsberg's well-known commercials.

The Sirius Passet animals lived in rather deep water in a tropical sea close to Equator some 520 mill. years ago. This is, as the geologists would put it, "only" 20 mill. years after origin of the first animals with



View across Sirius Passet to J.P. Koch Fjord.  
Photo: Arne Thorshøj Nielsen



The participants in the Sirius Passet expedition: Ji-Hoon Kim (KOBRI, South Korea), Jakob Vinther (University of Bristol, UK), Tae-Yoon Park (KOBRI, South Korea) and Arne Thorshøj Nielsen (University of Copenhagen). Photo: Arne Thorshøj Nielsen

hard skeletal parts. This important biological innovation was followed by the most spectacular and rapid evolution of animals that ever has occurred, the so-called “Cambrian Explosion” (the Cambrian, 542-485 mill. years ago, is the first geological time period with skeletal life). This is the reason why the fossils from Sirius Passet have received so much international attention: the spectacular preservation provides a “window” into the early Cambrian marine realm showing how diverse life in fact was so relatively short time after onset of the “Cambrian Explosion”.

Life in the early Cambrian sea was quite unlike modern marine life and the Cambrian fauna includes several so-called stem forms – by laymen commonly referred to as “missing links” and all long gone. The fossils from Sirius Passet thus contribute to unravelling the earliest marine life on Earth. And the conservation is so spectacular that even intestines, legs, antennae, muscle tissue, nerves etc. occasionally are preserved.

It has been a challenge to study the locality to the degree of detail it de-

serves, first and foremost because it is so exceptionally expensive to get to this remote place, but this is now resolved. Expeditions during the summers of 2016-17 undertaken by the Korean Polar Research Institute (KOPRI) in corporation with the universities in Bristol and Copenhagen managed to recover a large material of fossils and the investigations are planned to continue in 2018 and 2019. The 2017 expedition was the first one carried out in corporation with the VRS.

Registration and preliminary identification of the extensive new material from Sirius Passet are very time consuming, but well under way. As a first scientific result of the new phase of investigation a paper on the brain and nerve system in the lobopod *Kerygmachela kirkegaardii* (a distant relative of the extant “velvet worm”) is recently published in Nature Communications.

This species, named in honour of the Danish philosopher Søren Kirkegaard, is known only from Sirius Passet. One can then speculate about how Kirkegaard would have reacted to that honour, considering his somewhat strained attitude to-

wards natural science. In 1846 he thus wrote: “The researcher immediately begins to distract us with his particular projects — now to Australia, then to the moon, then into an underground crevice, then the devil knows where — looking for an intestinal worm. Now we use the telescope — now the microscope. Who in the devil can stand that!”<sup>1</sup>

The new investigations of the Sirius Passet locality aim at systematic collections of fossils bed-by-bed with the intention of analysing the variable composition of the fossil assemblage through the fossiliferous succession. In this way changes in the depositional environment can be charted. It appears for instance that there were changing but generally low oxygen levels at the sea floor (and the low oxygen content is likely one of the reasons for the spectacular preservation). Maybe the new data can also shed light on the marine community structure in the early Cambrian sea. Last but not least it is also the hope that new spectacular fossils turn up as more shale is investigated. Early chordates (animals with kind of a spine, our distant ancestors) are ranked high on the “wish list”. It is also planned to search for additional localities in the area with similar spectacular preservation which, in case, could be targeted by future expeditions.

<sup>1</sup> Original Danish: “Man staaer der værgeløs og kan aldeles ikke kontrollere. Forskeren begynder strax at adspredde med sine Enkeltheder, nu skal man til Australien nu til Maanen, nu ned i en Hule under Jorden, nu Fanden i Vold i Røven – efter en Indvoldsorm; nu skal Teleskopet bruges, nu Mikroskopet: hvo Satan kan holde det ud!”

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# CONFERENCE CONTRIBUTIONS & OUTREACH

## CONFERENCE CONTRIBUTIONS

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OUTREACH

**Villum Research Station – Station Nord – 2016 Annual Report.**

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