Annual report

SUMMER CAMPAIGN

2019 2020

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INFORMATION:
This English version of the activity report is shorter than the French version.

All photos without author's names belong to the French Polar Institute and were taken by the Institute's teams during their missions.

A mixed year of joys and hardships

EDITORIAL

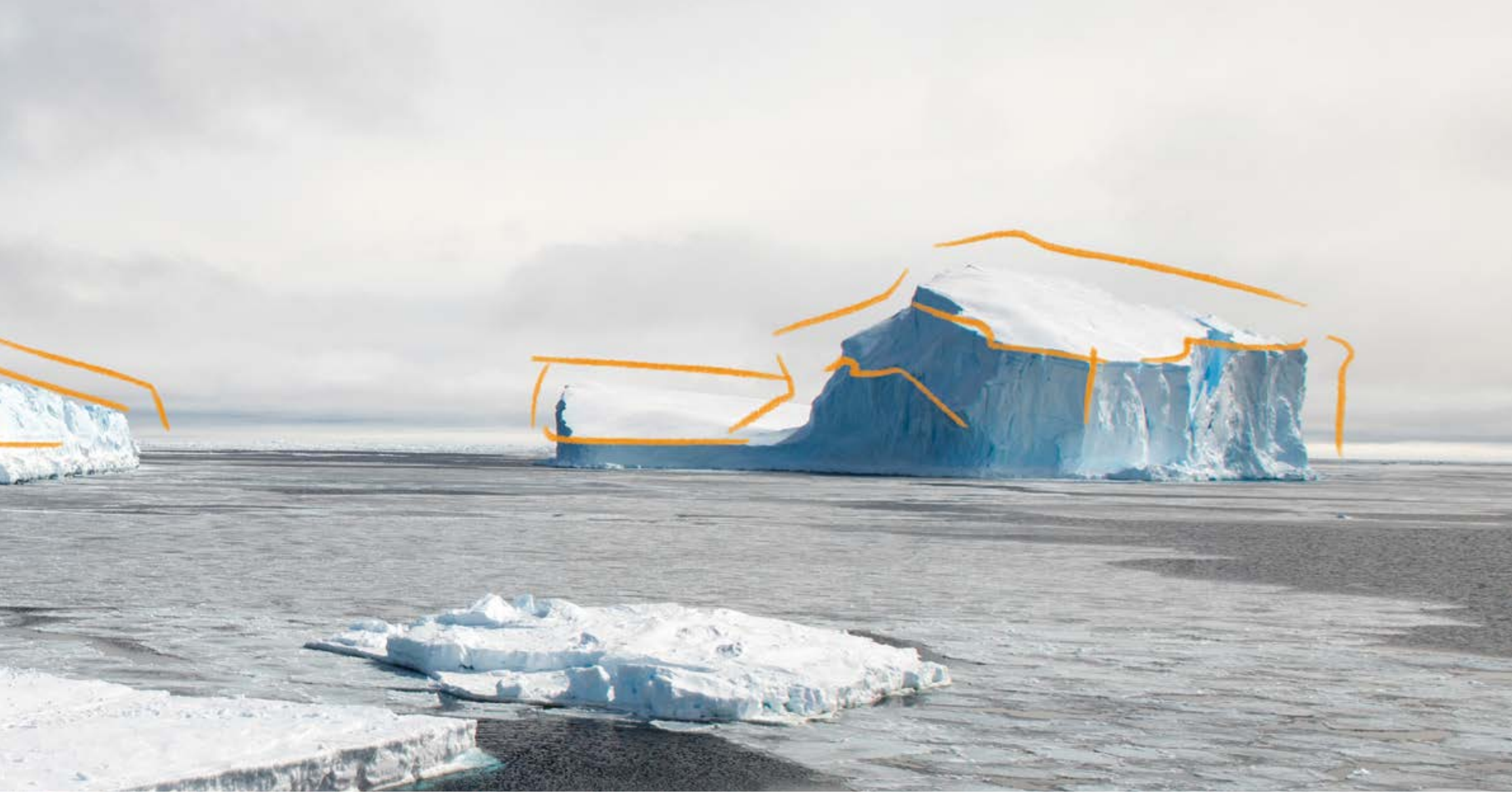
The time has come to present the new activity report for the French Polar Institute, which covers the 2019 calendar year as well as the 2019-2020 austral summer campaign. The results are mixed, with both highs and lows.

Author

Jérôme **CHAPPELLAZ**
Director of the
French Polar Institute

Let's start with the high points, the ones that will remain in the Institute's history because, fortunately, memories are selective and tend to remember the positive. The spotlight is on the research projects, the "raison d'être" of the Institute that supports them. Among the ongoing 74 projects and 108 field campaigns in the various Arctic, Subantarctic and Antarctic regions, three of them, which much more ambitious than usual, were implemented in the southern hemisphere this fiscal year. First we have the French-Norwegian PALAS 2 project in the Subantarctic area, which plans to collect sediment cores in several lakes that are quite difficult to access, located in the western sector of the Kerguelen Islands. Second, in Antarctica, glaciology took centre stage with the setting up of a core drilling camp at the Little Dome C site (located roughly 40 km from the Concordia station) for the new European Beyond EPICA project. And third, the EAIIST scientific traverse into the unexplored sector separating Concordia from the South Pole.

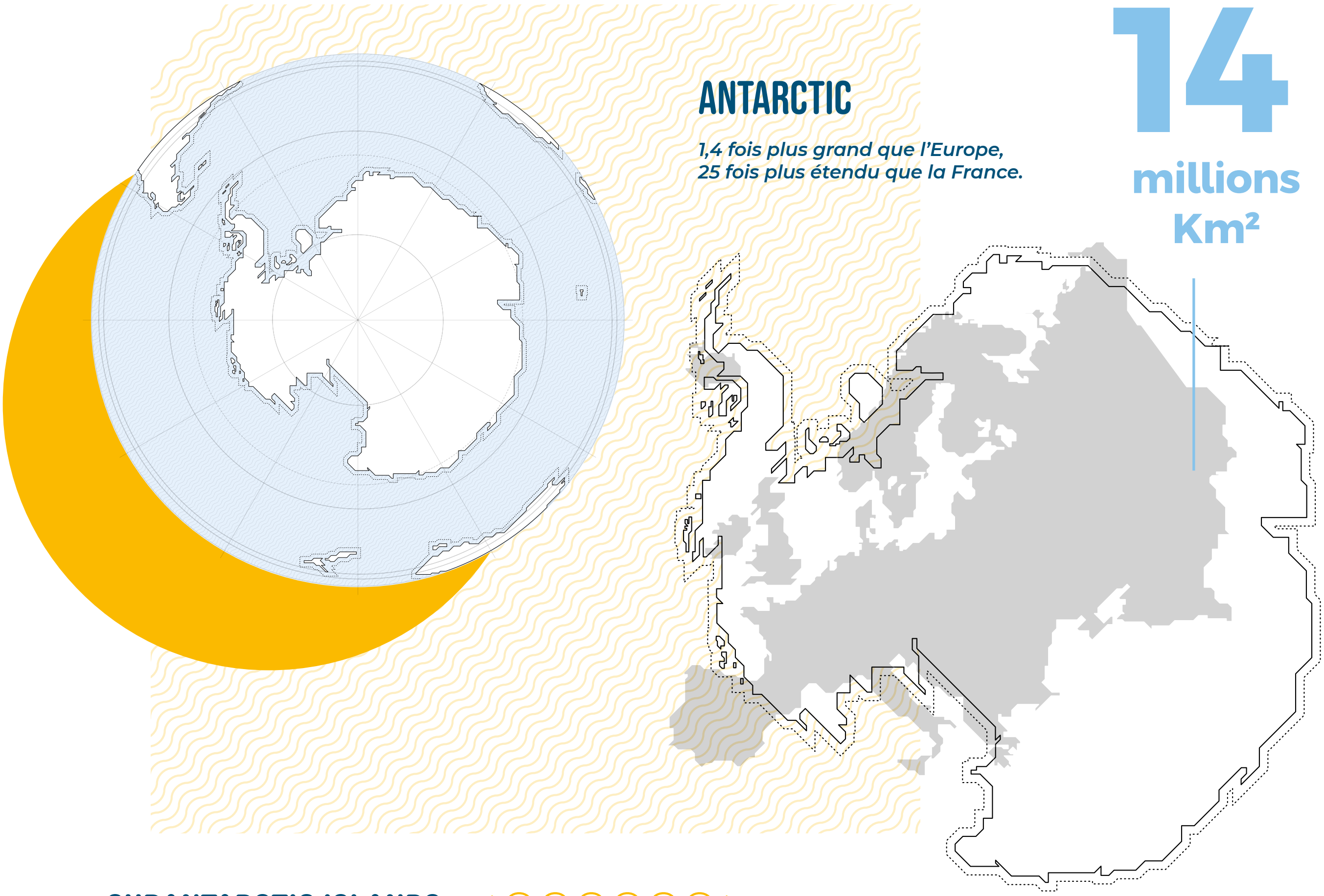
In all three cases, the missions were a complete success. The PALAS 2 team managed to extract a total of 127 m of lake cores, obtained from 6 different lakes and 14 coring sites. Their analyses will provide an exceptional look at the climatic and environmental evolution of this poorly documented sector of the planet. For the Beyond EPICA project, it was possible to install the main elements of the camp. This is an immense logistical challenge because it must be possible for a team of approximately fifteen people to live there and to be completely self-sufficient during close to 60 consecutive days each season and for 5 consecutive summer campaigns, one after the other. Last, the EAIIST scientific traverse continued to help revive the great scientific exploration expeditions in the best way possible; the Polar Institute had received equipment for this in the early 2010s. This was the fourth expedition of its kind for the Institute, and it was possible to travel more than 1300 km into unknown territories, to the centre of the Antarctic plateau consisting primarily of megadunes and "glazed" surfaces. Through the numerous fieldwork projects, it was possible to collect close to 1000 m of accumulated snow and ice cores, which will enable researchers to better understand the origin of these unique structures on Earth as well as to quantify the contribution of this large Antarctic sector to global sea level changes. For both the PALAS 2 project and the EAIIST project, the 2019-2020 activity report includes a detailed scientific focus, written by their scientific coordinators as soon as they got back from the field. I would like to thank them very much for this.



In addition, one of the high points of this past fiscal year was to have been able to bring the Minister of Research, Frédérique Vidal, as well as the CEO of the CNRS, Antoine Petit, to discover the mythical white continent and some of our infrastructures. This was a first for a Minister in charge as well as for the head of the flagship of French research. On this occasion, an action plan was discussed in favour of research, infrastructures and national logistics at the poles. I hope that this will become a reality in the coming months because the Institute is currently understaffed, placing a burden on French aspirations.
2019 was also a year of internal and external initiatives. A few examples of this include: the development of a 'Forward-looking management of jobs and skills' solution and a review of the functionality of the Institute, the creation of an innovation department that made it possible to initiate numerous industrial contacts as well as to launch the Institute's 'Carbon footprint©' programme (a first for a polar operator), the application of the new graphic charter and the creation of new institutional films, in addition to the management of the Archipôles national archives platform, the establishment of a bilateral scientific committee for Concordia as well as a tripartite managerial committee with the European Space Agency, and the organization of the general assembly of the European Polar Board in Brest.

The main setback was the damage caused to the L'Astrolabe, discovered by the ship - the French Navy - in mid-November 2019 when it was leaving Hobart in Tasmania to carry out its first mission to support our Antarctic logistics. The ship ended up being sent to an Australian shipyard for repairs, and we are grateful to the Australians who stepped in and saved the Polar Institute's campaign and our two Antarctic stations at the same time: our counterparts from the Australian Antarctic Division agreed, at a moment's notice, to provide their own icebreaker to ensure the supply run, delaying their own campaign by two weeks. A tremendous display of solidarity among polar operators! The fact that the collateral damage caused by this technical mishap was as limited as possible is also due to our highly skilled operational teams: they were able to reorganize several hundred tons of freight within a few hours, they immediately changed the routes for personnel, they organized three lightning-fast rotations for the Astrolabe in the second half of the season once the ship had been repaired, etc. However, international solidarity and the skills of our agents were not enough. Against this exceptional background, the Polar Institute fortunately had its fair share of good luck with the exceptionally good weather and sea ice conditions during the stopovers at Dumont d'Urville. Obviously, this is not something that can be counted on each year.

In June 2021, France will chair the annual meeting of the Antarctic Treaty in Paris, 32 years after the last time. It is my personal hope that with this geopolitical perspective, we will be able to collectively inspire a new national momentum in favour of research in polar environments. Anyone who reads the following pages should be convinced that this is a necessity because France should be very proud of the work we're carrying out there. As it stands, in the words of former minister Hervé Gaymard, France will not remain a 'polar power' unless our decision-markets engage in strong and long-lasting commitments.



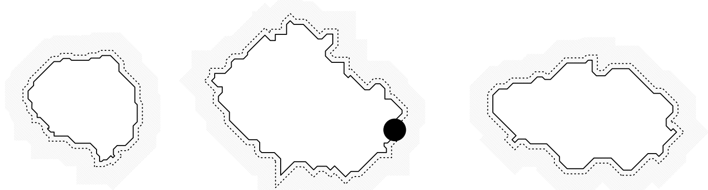
ANTARCTIC

1,4 fois plus grand que l'Europe,
25 fois plus étendu que la France.

14
millions
Km²

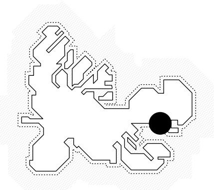
SUBANTARCTIC ISLANDS

ARCHIPEL DE CROZET



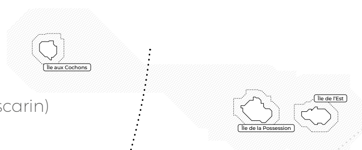
Île aux Cochons *Île de la Possession* *Île de l'Est*

ARCHIPEL DE KERGUELEN



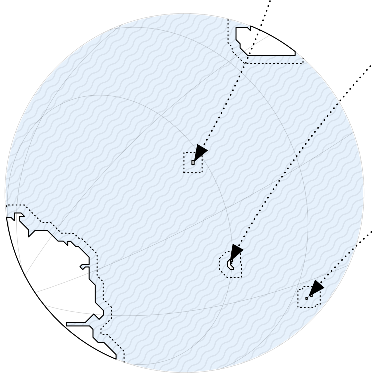
Base Alfred Faure

46°25'S – 51°51'E
934 m d'altitude (Pic du Mascarin)
1er hivernage en 1962
Environ 25 hivernants
et jusqu'à 50 personnes en été

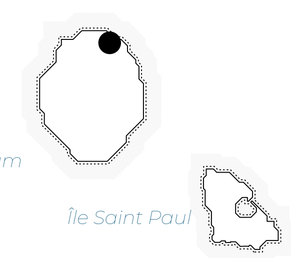


Station de Port-aux-Français

48°27 -50°00 S, 60°27'-70°35'E
1800 m d'altitude (Mont Ross)
1er hivernage en 1949
Environ 50 hivernants
et jusqu'à 100 personnes l'été



ÎLES AMSTERDAM ET SAINT PAUL

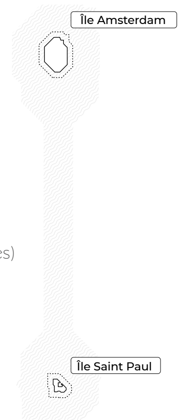


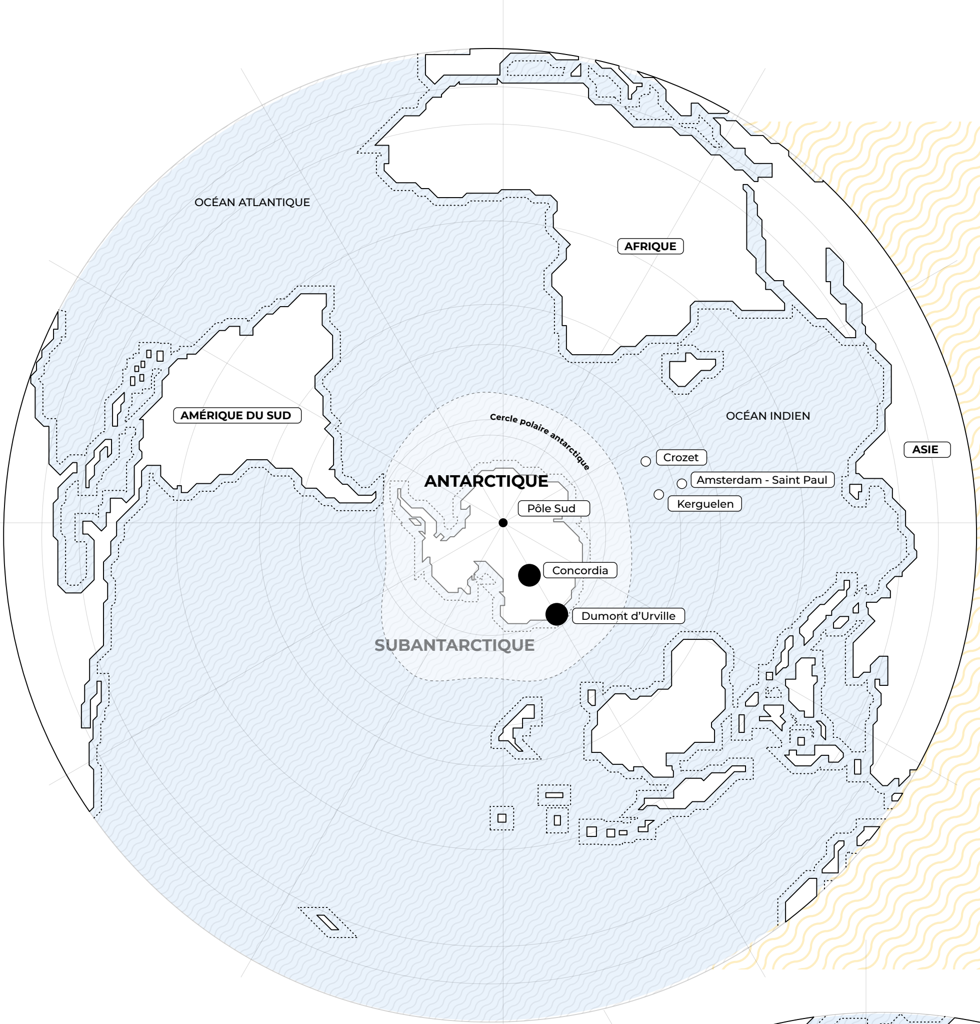
Île Amsterdam

Île Saint Paul

Base Martin-de-Viviès

37°50'S – 77°32
881 m d'altitude (Mont de la Dives)
1er hivernage en 1950
Environ 25 hivernants
et jusqu'à 50 personnes en été





ANTARCTIC SUBANTARCTIC

Station Concordia

75°06'S – 123°21'E
3200 m d'altitude
1er hivernage en 2005
12 à 15 hivernants
et de 50 à 70 personnes en été

Station Dumont d'Urville et la station annexe de Cap Prud'homme

66°40'S – 140°01'E
20 m d'altitude
1er hivernage en 1952
25 à 35 hivernants
et jusqu'à 100 personnes en été

ARCTIC

Station arctique AWIPEV

Position (79°N – 12°E)
Températures moyennes :
en été : + 4°C
en hiver : – 12°C

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SCIENTIFIC PROGRAMMES SUPORTED

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PARTNER

A year in the Field

SUPPORT FOR SCIENTIFIC PROJECTS

Author
Dominique FLEURY

The Institute provided support for 10 French scientific projects in marine biology, ornithology, glaciology, ionospheric science and atmospheric physical chemistry.

Installation of the electric winch on the *Jean Floc'h* vessel:

The winch and hydraulic crane on the *Jean Floc'h* are quite often used for all operations at sea. This combination is very practical for putting somewhat heavy loads to sea, but lacks flexibility and speed for small sensors or light sampling systems. As it has already been shown that the electric winch on AWIPEV's second boat is perfect for this use, the same model was installed on the *Jean Floc'h*. As a result, we now have two winches and a more suitable profile speed for the body of water. The lower units of the outboard engines were brought back at the end of the season for a complete overhaul by a professional in Brest.

Installation of a stabilization ballast on the Goupil electric vehicle:

After a few years of use of this vehicle, the Goupil has a better grip on the ice and snow when loaded. As a result, ballast was placed on the chassis of the vehicle to improve passenger safety during use.

Installation of a compressed air system in the scooter garage workshop:

The general mechanical workshop called the 'scooter garage' now has a compressed air system equipped with a 150L compressor (to clean mechanical parts, inflate tyres, etc.). It also has a bench grinder and a welding machine (TIG steel/stainless steel/aluminium and coated electrodes).

CORBEL BASE

Installation of a new load regulation system for the Corbel wind turbine

In 2018, a new wind turbine was installed at the Corbel station. It worked for several months on the old battery electric charging regulation system. But at the beginning of this year, the system broke down. Therefore, a new charging system was purchased from the manufacturer of the wind turbine and installed during the fall campaign.

Creation of a special window and installation of a staircase

This year, the researchers wanted to install scientific equipment to measure the auroral radiation at the Corbel station. Given that this equipment is very sensitive to stray light (extraneous light), the Corbel site in winter is an ideal location as there is no light pollution. In order to install this equipment, a window had to be created in the laboratory/workshop building. It is tilted towards the sky and has optical quality glass with an anti-frost system.
An external staircase was also manufactured so as to be able to reach the roof platform safely in order to take a series of measurements using the 360° instrument.

SCIENTIFIC AND TECHNICAL ACTIVITIES IN ANTARCTICA

Authors
Gaëlle SELLIN, Doris THUILLIER

At the start of the season, this 2019-2020 summer campaign was generally characterized by good environmental conditions with mild weather and negotiable pack ice less than 35 km from Dumont d'Urville. The first air arrivals to Dumont d'Urville and Dome C landed on the agreed-upon dates, 2-8 November, which meant that the stations could be opened and the EAIIST and logistics traverses were able to depart on time.

However, the weather changed for the worse starting in January with 16 days of snowfall, two times the normal seasonal values, making it much more dangerous to carry out all of the operations.

The major difficulty encountered this season was the damage to the submerged bearings of the *Astrolabe*'s shaft lines right before the first rotation (R0). This breakdown had a long-lasting impact on the summer campaign and meant that all arrivals and departures as well as logistical and technical provisional schedules had to be reorganized.
Fortunately, the chartering of the polar vessel *Aurora Australis* on December 11 to Dumont d'Urville and the three express rotations of the repaired *Astrolabe* organized between late January and early February made it possible to deliver the priority cargo, i.e. food, spare parts, fuel and the essential fluids needed to maintain the stations.

In addition to the impact on the scientific programmes, the damage to the *Astrolabe* resulted in significant repercussions on several logistical and technical positions.

With regards to energy, it was not possible to deliver 300 m3 of SAB fuel (Special Antarctic Blend, the fuel used in Antarctica). Stations will still be able to be self-sufficient up until early January 2021, however the safety stock was not built up. There was a shortage of 30 m^3 of aircraft fuel, i.e. the overall supply contained 23% less fuel. One of the direct results of this shortfall this season was that the Icecap airborne project was discontinued in order to save energy. And last, 50% of the fuel supply for the vehicles could not be delivered. Broadly speaking, all of the stations' SAB fuel safety stocks were used to cover the consequences of the *Astrolabe* damage.

With regards to the work projects, the repair of the Concordia supply store and the work on the southern helipad field camp had to be postponed because the equipment could not be delivered. Because the equipment needed to repair the cladding on machinery hangar No. 57 at Dumont d'Urville was only delivered during R4, this project had to be postponed. In addition, work on the Prud'homme store (covering it with cladding), was also postponed until later in the season.

Aurora Australis unloading on sea ice

Following the cancellation of R0, and thus the arrival of the scientific personnel, the technical team had to help out with the scientific work during the month of November and in early December. As a result, certain work projects were slowed down.

The handover between inbound and outbound wintering personnel took place in one and a half days instead of 7 days (the average). Certain more specific handovers requiring more time (telecommunication-radio, glaciology, power plant), which normally take place over a one-month period, did not happen. This meant that the handover of the necessary information needed for the incoming team was less efficient. This made it more difficult for incoming personnel to take up the post and the on-site handover (polar environment) was limited.

The Institute operated with the new helicopter company (Canadian Helicopters - HNZ) that won the tender last year. A helicopter was on-site throughout the entire season and a second machine arrived with the Aurora Australis vessel to facilitate the unloading as well as the R4 rotation. The collaboration with this company is highly satisfactory and it was shown that the investment in the company's equipment was worthwhile.

DUMONT D'URVILLE

REPAIR/IMPROVEMENT WORKS AND LOGISTICS

Despite the delay in deliveries, it was possible to carry out repair work at the station and at Cap Prud'homme using materials that had been delivered during the previous campaign. The main project was to completely cover the spare parts store for the Cap Prud'homme traverse.

The campaign also included numerous projects that were smaller in scope but still quite important as they ensured the proper technical management of the site: the sides of building 25 laboratory No. 1 were covered, the boiler room in building 31 living room-recreation room was renovated, the tunnel under the road used to pass pipes and electric cables was replaced in the southern end of Pétrels Island.

TRAVERSE: DUMONT D'URVILLE/ CONCORDIA CONVOYS

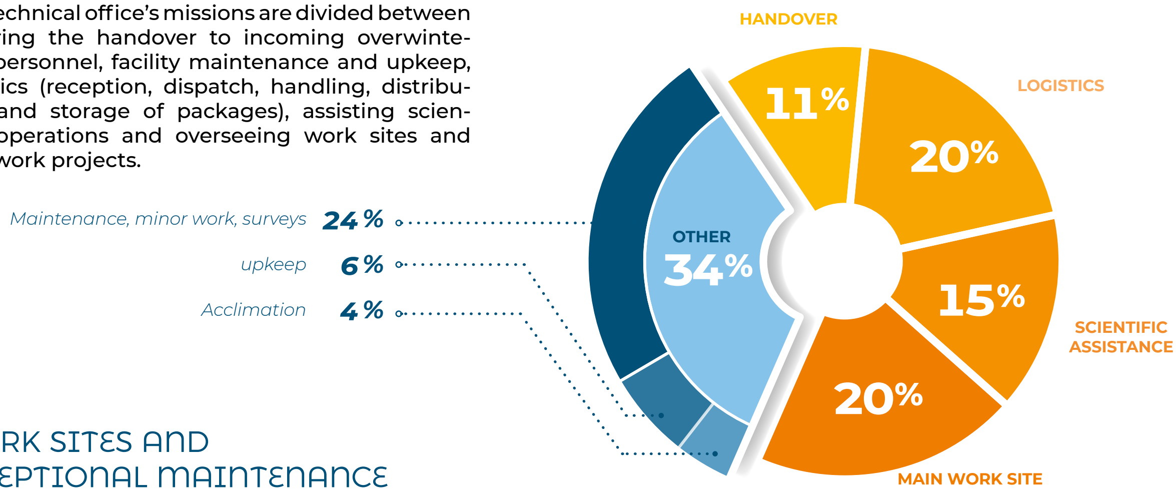
Despite the disruptions during this season, the 5 logistical and scientific traverses (EAIIST, Samba) left on time. It was possible to carry out the planned maintenance or specific projects, such as covering the exterior of the store with cladding.

Although the temperatures were relatively high, adverse weather affected air links with delays up to 10 days at times.

FRENCH-ITALIAN CONCORDIA STATION

SEASONAL OVERVIEW

The technical office's missions are divided between ensuring the handover to incoming overwintering personnel, facility maintenance and upkeep, logistics (reception, dispatch, handling, distribution and storage of packages), assisting scientific operations and overseeing work sites and new work projects.



WORK SITES AND EXCEPTIONAL MAINTENANCE

Some of the first major projects of the year were to repair the flat base of the noisy tower, to overhaul the grey water treatment unit (GWTU) and to cover the exterior of the general store with cladding.

Overall, the work carried out to support scientific programmes went very well. Collaboration between the scientific coordination and the technical coordination beforehand, as well as in the field, made it possible to synchronize and smooth the workload.
A major challenge was to provide assistance to the Beyond Epica (BEOI) project, which took up more than half of the technician time allocated to science.

The EAIIST traverse required significant support during their two visits to Concordia; however, the work orders had been anticipated. Last, the Subglacior project also figured predominantly during the first part of the season.

LOGISTICS IN THE SUBANTARCTIC ISLANDS

The main mission of the French Polar Institute in the southern islands is to ensure the scientific and logistical organization for the winter camps and summer campaigns. Due to weather conditions, these field missions are deployed between the months of November and March.

Authors
Yann LE MEUR , Romuald BELLEC

DELIVERING SUPPLIES TO THE FIELD CAMPS

Specifically, the French Polar Institute provides supplies and maintenance to the field camps, 50 potential sites, where scientists and civic service volunteers stay throughout the year. Primarily helicopters and barges are used to drop off scientific materials, food and equipment at the sites.
In 2019, supplies were delivered via helicopter during the Marion Dufresne's November and December rotations. Scientific equipment and tools (logistics) are recovered during the March-April rotation (OP1).

By the end, the logistics team from the French Polar Institute replenished the food, energy and scientific equipment supplies at the following field camps and isolated sites:

CROZET: La Pérouse, Baie américaine, Pointe basse
KERGUELEN: Pointe Suzanne, Estacade, Ratmanoff, Pointe Morne, Val Studer, Baie Charrier, Cap Noir, Cap Cotter, Cataractes, Sourcils noirs, Phonolite, Bossière, Port Elisabeth, Gazelle, Port Couvreux. Mortadelle and the 6 isolated sites of the PALAS project (north of Kerguelen)

AMSTERDAM : Entrecasteaux and Del Cano

WORK PROJECTS AT REMOTE SITES

CROZET

During the 2019 campaign, a logistics team was deployed to carry out a renovation project at the Pointe Basse field camp. The main objective of the project was to repair the ageing parts of the structure so as to ensure the safety of users and the durability of the structure in particular. The most important part involved reinforcing the structure of the raft foundation, which supports the field camps, and the traffic zones. The storage and work spaces in the red French Arbec Hut, located next to the field camp, were reorganized, maximizing the available space.

The Baie Américaine field camp was inventoried this year in anticipation of a renovation project in the next few years. However, some improvements were made such as temporarily securing the awning and routine maintenance, as well as sorting out and fully cleaning the field camp.

KERGUELEN

The interior of the Estacade field camp has been renovated so that a team of 4 scientists can live there over long periods of time with, in particular, the installation of solar panels so that the field camp is now self-sufficient in energy. In addition, the field camp was furnished with 4 beds, a kitchenette and a workshop for scientific activities.

The Pointe Morne field camp was completely renovated with the installation of exterior cladding over the entire refuge and the installation of a new roof. Rainwater collection systems and autonomous photovoltaic solar systems were also installed.

Continuation of the multiannual project at the Studer field camp: after having thoroughly cleaned up this site, which dates back to the 1980s, and furnishing the inside with sleeping and storage fixtures, major work was carried out to solidify the foundations and to maintain the field camp.

The old scientific workshop at the Ile Verte field camp was demolished and fully cleaned up. A new module was brought to the island by helicopter and set up by the logistics team.

Estacade field camp

Workshop for the Île Verte field camp

Pointe Morne field camp

Restoration of the raft foundation for the Studer field camp

The Korrigan Field camp was prepared for winter because there are no plans for personnel to overwinter there in 2020.

The two Fillods (prefabricated metal constructions) for the Mortadelle field camp were given a waterproof coating in order to make the field camp permanent. The weather station was inspected by civic service volunteers from the Polar Institute's IT department and data were sent for an IGE science project.

On the nearby glacier, the forward base for the Mortadelle field camp was dismantled and then evacuated during Marion-Dufresne's OP1 (port operation 1) because it was no longer in use.

New remote sites were established so that scientific projects could be set up on new sites:

For the Palas scientific project (see insert below), a total of 6 drop-off sites for scientific and living equipment were used: 5 wooden living and sleeping modules, 5 wooden sleeping and storage boxes and 4 tents and coring equipment.

For Talisker, a camp with 2 modules that can be transported by helicopter was positioned in the northern Presqu'ile de la société de Géographie area..

Port Cenis field camp

WORK SITES AT THE STATIONS

CROZET, ALFRED FAURE

The main activity of the Polar Institute teams is still to provide support for science projects during the summer campaign. Specific maintenance projects are also being carried out to upkeep the base's logistical and scientific structures.

This year, a team was sent to the Crozet station to start reorganizing the Biomar laboratory in order to make it more operational and functional.

The Science de l'Univers field camp has now been freed up with the transfer of the servers to Biomar. This room is now being used as a long-term storage area for logistics and scientific equipment.

KERGUELEN, PORT AUX FRANÇAIS

The B17 logistics platform of the French Polar Institute at the Port-aux-Français station received a new roof and by moving and re-installing the equipment it was possible to tidy up, sort and reorganize the workshop.

For the Palas project, in addition to ordering the large modules, 2 small storage modules were manufactured in wooden box format to be transported by helicopter.

SUPPORTS AND SPECIFIC MEANS OF SUPPORT FOR SCIENTIFIC ACTIVITY:

Over the past few years, in a joint charter with TAAF, the Polar Institute has been deploying a 25 m vessel, La Curieuse, to carry out both scientific projects and prospecting activities and to maintain remote coastal sites over the entire Kerguelen district.

This year, La Curieuse enabled numerous scientific missions to be carried out around Kerguelen. The vessel was on-site during the first period of the year from January 1 to January 24 and then from November 26 to December 31, 2019.

It ensured a security support mission for the Palas mission and enabled the deployment of the land missions across Kerguelen for the Enviker, Bingo, Talisker, Cycleleph, Salmevol, Subanteco projects as well as the monitoring of the marine environment with the Proteker project which involves scuba diving around Kerguelen and in the Gulf of Morbihan.

As part of the ten-year maintenance plan for the Superdarn Project, a certified observation project, an 18 m articulated boom lift was installed in 2019 and enabled the scientific teams to carry out the rejuvenation plan and guarantee the operational continuity of this tool.

Guynemer Site

PALAS 2 PROJECT:

During this 2019 campaign, the logistics team set up the Paleoclimate from Lake sediments on Kerguelen Archipelago 2 (Palas 2) project in the northern part of the Kerguelen Archipelago. The objective was to collect lake sediment samples in order to reconstruct past climatic fluctuations at high resolution.
Its deployment around the glacier lakes in the northern area of Kerguelen required a substantial logistical investment on a scale that has never been seen in the past two decades!

• A self-sufficient mission was set up for a team of 8 scientists comprised of 4 French and 4 Norwegians over a period of one month. In order to guarantee the safety of the mission, new communication procedures were used with GPS allowing messages to be sent even if there is no network coverage.

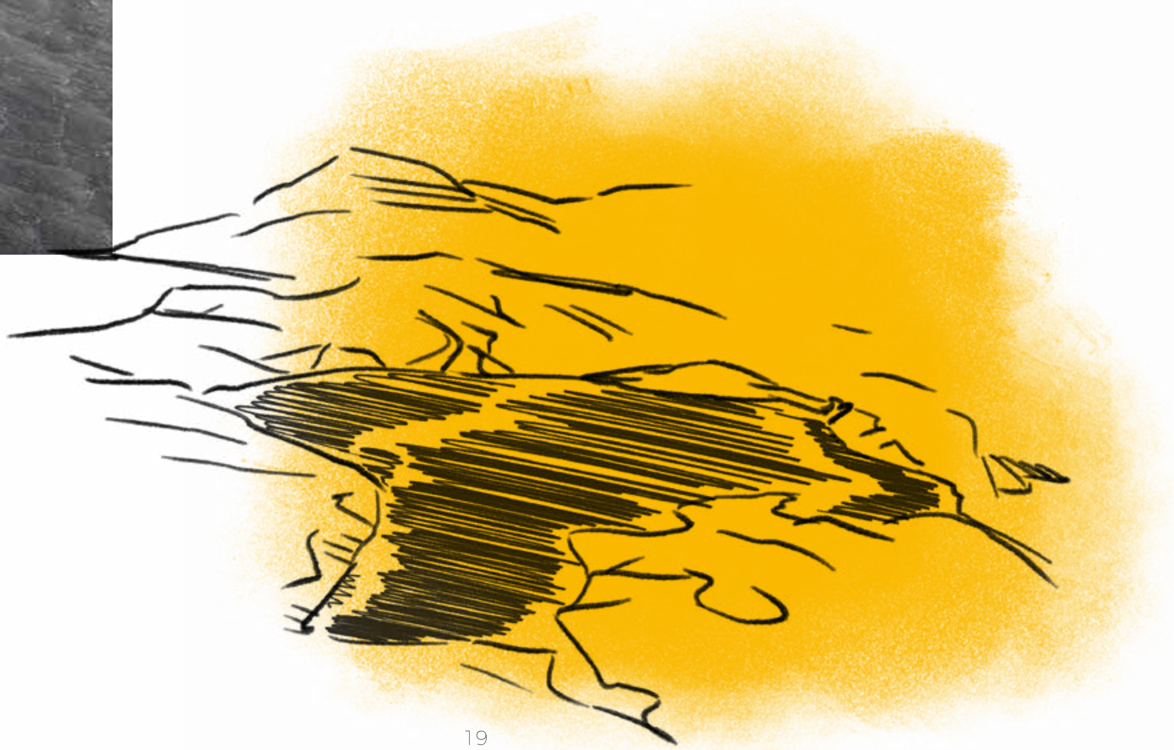
• New field camps were installed at 6 remote sites near the lakes selected to carry out lake coring operations. These field camps were built, furnished and then temporarily set up on site for the duration of the mission.

In total, the logistics (field camps, food, energy, etc.) and scientific (coring barge, sonar, etc.) equipment weighed 17 tonnes: 31 helicopter loads. This required the exceptional deployment of a B3-type Écureuil (or Squirrel) helicopter for the recovery.

In particular, the main difficulty of this operation was that there was only a very short operational window available to install the personnel, samples and equipment during OP3, and then to recover everyone and everything during OP4 over a large geographical area: Approximately 3 days of helicopter time (roughly 10 hours/day) were needed: 1.5 days for drop-off + 1.5 days for recovery. This duration is equivalent to or greater than that needed to deploy an operation at Crozet or Amsterdam, all operations combined (TAAF, French Polar Institute, Nature Reserve) during the Marion Dufresne's supply rotations.
A lot of preparation was needed beforehand between the scientific and logistics team to complete this project.

IT WAS POSSIBLE TO COLLECT SAMPLES FROM THE 6 SELECTED LAKES IN UNDER ONE MONTH OF THE CAMPAIGN. THIS REPRESENTS 14 SAMPLING POINTS FOR A TOTAL OF MORE THAN 120 METERS OF SEDIMENT CORES.

Science



Mission PALAS 2019

PALAEOCLIMATE FROM LAKE SEDIMENTS ON THE KERGUELEN ARCHIPELAGO

Authors

Charline GIGUET-COVEX, Philip DELINE, Ludovic RAVANEL, Pierre SABATIER et Fabien ARNAUD

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ABSTRACT

The Kerguelen Archipelago is located in the Southern Hemisphere westerly wind belt (SWW), which plays a critical role in regulating the Earth's climate system. Almost as large as Corsica, it is characterized by numerous glacial lakes. Sediments deposited at the bottom of these lakes constitute valuable records of past climatic and environmental changes. During the PALAS 2019 field work, sediments found in six of these lakes, located between the Cook Ice Cap and the Presqu'île de la Société de Géographie, were cored. Using cores measuring 5 to 10 m long, we hope to cover several thousand years of history in these environments. Glacial landforms close to the lakes were also mapped and sampled. As part of the 'Southsphere' project, led by Jostein Bakke from the University of Bergen (Norway), 'classic' sedimentological and geochemical analyses will be performed on the cores. Emerging methods, such as 3D tomography, analyses of lake sediment DNA or even temperature-dependent bacterial membrane lipid compounds will also be used. Cosmogenic isotopes from the rock samples will be used to date moraines, erratic boulders and roches moutonnées. This set of unprecedented results can be used to reconstruct the glacier fluctuations during the Holocene and the climatic changes that controlled them, which are still poorly known in this very remote region.

flour

Glacial flours are composed of fine clayey particles that are formed by glacial abrasion on rock surfaces.

Cosmogenic

Cosmogenic isotopes are formed when high-energy cosmic radiation interacts with atomic nuclei. They are produced in the atmosphere and, in some cases, in rocks and soils exposed to this radiation.

INTRODUCTION

The Kerguelen Archipelago is located at 49°S, i.e. in the Antarctic Polar Front Zone which separates the cold polar waters from the temperate waters of the Subantarctic regions. Today, this zone, also known as the 'Antarctic Convergence', oscillates between a latitude of 48° and 61° depending on the season. It is characterized by very strong westerly winds that are found in the northern hemisphere. In the southern hemisphere, these winds are particularly violent given that there are no continents to slow them down (Figure 1). Navigators call these strong winds the famous 'roaring forties' and 'furious fifties'; for climatologists, they require special study because of the essential role they play in regulating the Earth's climate. They isolate Antarctica from the warmth of the lower latitudes, stimulate global ocean circulation via the Antarctic circumpolar current (ACC) system and regulate the absorption of CO_2 in the Southern Ocean. This position in the Antarctic Convergence Zone makes the Kerguelen Islands a key site for understanding the global climate system and its evolution.

Even though this band of latitudes plays a major role in regulating the climate on a global scale, we have very limited knowledge about past climate changes. This is explained by the high proportion of ocean compared to continents, making it difficult to acquire climate records. A few records have been obtained via marine cores, as well as from continental records, primarily in Patagonia followed by Tasmania, New Zealand and South Georgia[1]. In the French Southern and Antarctic Lands (TAAF), the first studies on the continental records are quite recent. At Amsterdam, for example, analysis of the flux and origin of dust trapped in peat has made it possible to reconstruct the past dynamics of westerly winds over the past 6,600 years. In particular, it highlights alternating phases of strengthening and/or shifting winds towards the equator and phases of weakening and/or shifting winds towards the poles[2]. A study carried out on the geomorphology of glaciers on Kerguelen have allowed us to track major glacier fluctuations over the past 24,000 years[3]. In addition, using a modelling approach (integrating instrumental data from the Port-aux-Français station), this same team showed that the poleward shift towards the polar front, which resulted in decreased precipitation on Kerguelen, explained to a large extent the dramatic retreat of the Cook Ice Cap since the 1960s[4]. Thus, there is a relationship between polar front fluctuations and the westerly winds, and the fluctuations of the Kerguelen glaciers, via precipitation.

The PALAS 2019 mission was designed to improve our knowledge about past glacial and climatic fluctuations in this region of the world. To do this, the goal was to collect as many lake sediment records in connection with the Cook Ice Cap as possible (Figure 2), so as to be able to indirectly study (i.e. via glacial processes) the dynamics of the westerly winds. Lakes fed by glaciers have a high potential for recording the glacial signal over time, since a large part of their sedimentation comes from the production of glacial flour[5]. In order to validate these reconstructions and to better constrain them in space, the moraines and other glacial landforms around the lakes were mapped and sampled during the mission for cosmogenic isotope dating purposes.

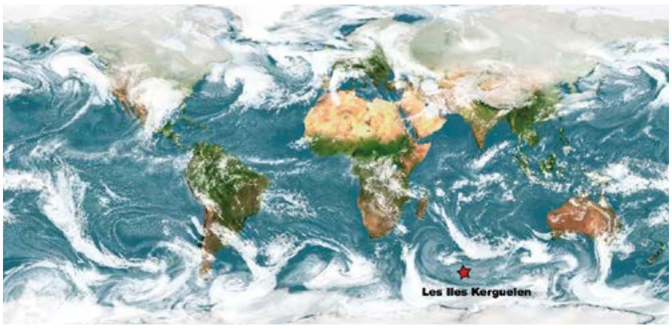
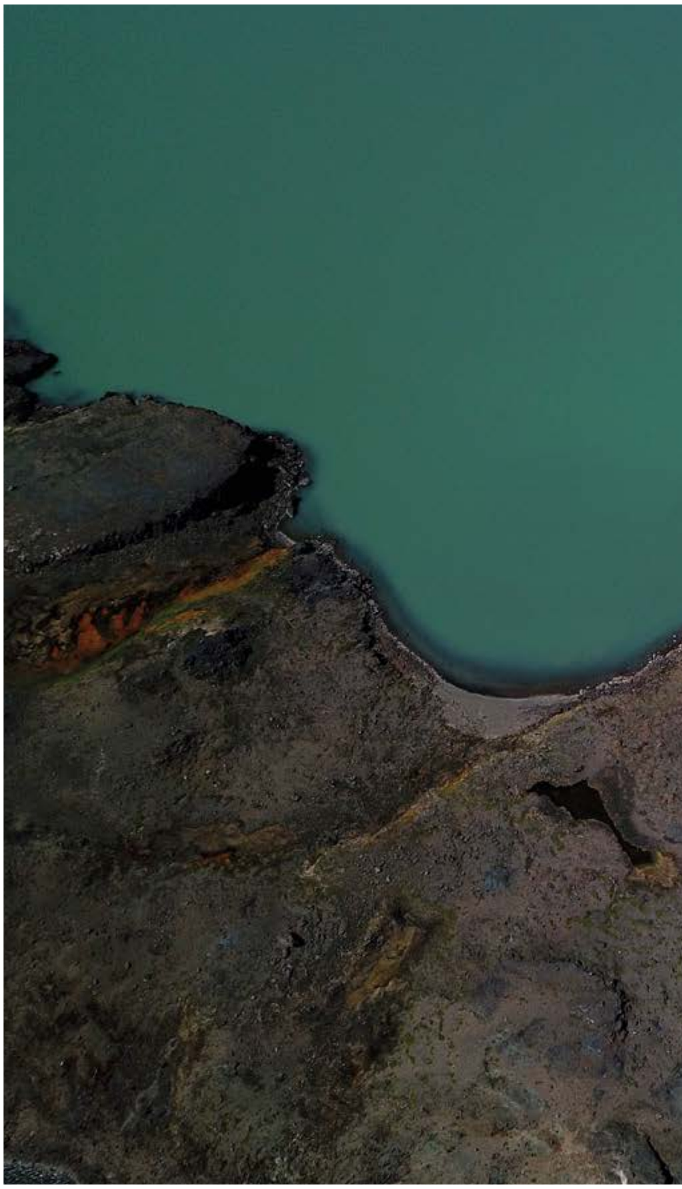


Figure 1. **Illustration of the atmospheric circulation** (source : Nasa) : the changes in circulation over time can be viewed here : https://svs.gsfc.nasa.gov/3723

[1] Dätwyler et al., 2018; Fletcher et Moreno, 2011; Kilian et Lamy, 2012; Oppedal et al., 2018; Saunders et al., 2012; Shulmeister et al., 2004
[2] Li et al., 2020
[3] Jomelli et al., 2017
[4] Favier et al., 2016
[5] Nesje et al., 1991

Furthermore, to determine the role of temperature and precipitation in the Cook Ice Cap fluctuations, a multi-indicator approach will be used on cores as part of the 'Southsphere' project, led by Jostein Bakke from the University of Bergen (Norway). The target indicators are hydrogen isotopes for tracking precipitation and lipid biomarkers for temperature. Sedimentological and geochemical analyses will be used to track glacier fluctuations. Analyses will also be performed on terrestrial plant remains, pollen and plant DNA to study fluctuations in plant cover, in terms of extent and composition, in relation to climate change. If exotic pollens are found, they can be used as indicators of changes in the position of the westerly winds. Finally, at Lake Cartographie (Figure 2), around which a large number of rabbits could be observed during the mission, it is planned to carry out DNA analyses of mammals and plants in order to track the dynamics of invasive species and their impact on the environment in this area which is actually quite far from their point of introduction.



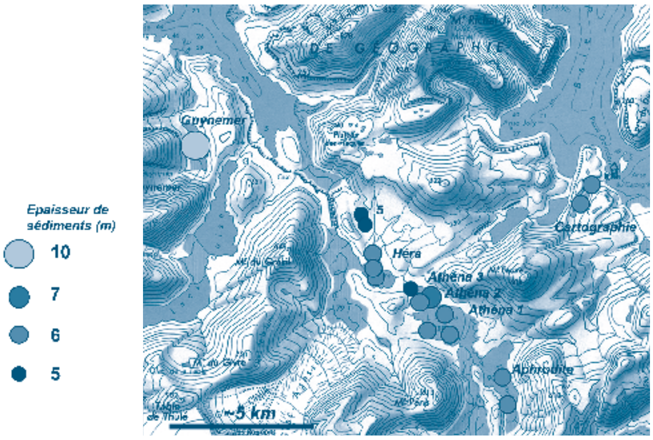
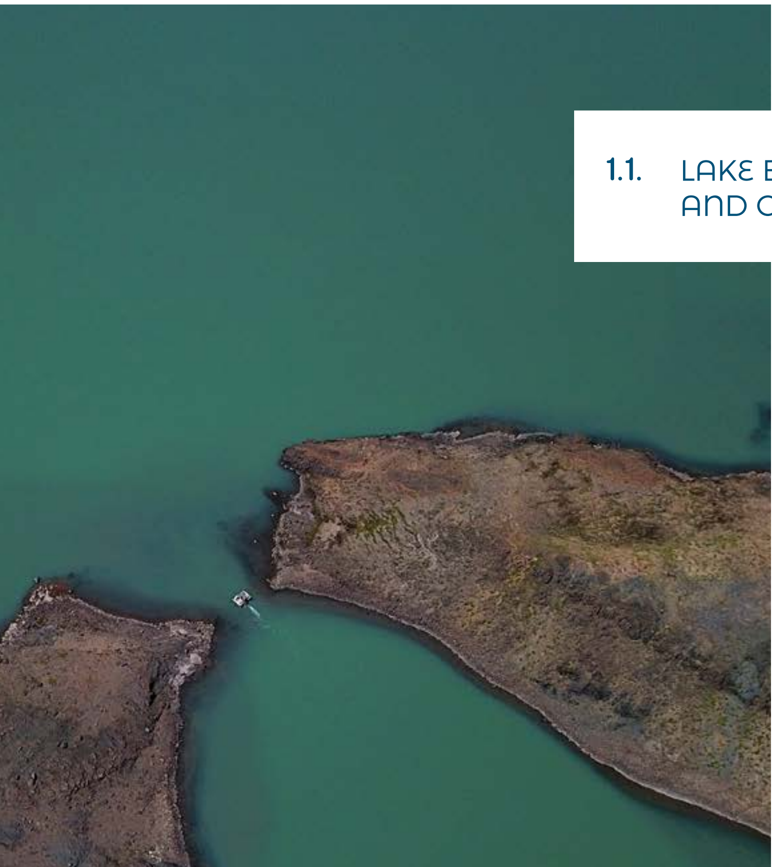


Figure 2. **Distribution of the coring sites and lengths of the core sampled during the PALAS 2019 mission.**

Figure 3. **Illustration of the applied coring techniques.**
A) Photos of the coring platform used at Guynemer and one of the core samples collected using the Nesje corer. The corer diagram illustrates the piston corer system developed by Niederrieter and used at Guynemer as well as Athena to collect cores > 6 m long (in sections measuring 2 or 3 m).
B) Core diagram provided by the Corebook application. When this application is used in the field, it is possible to enter the coordinates of the cores and to mark the position of each section in real time. This makes it possible to assess how much sediment is lost and thereby helps the person sampling the cores to obtain the entire sediment infilling sequence (i.e. a recovery rate of 100% between the sections).
https://svs.gsfc.nasa.gov/3723

biomarkers

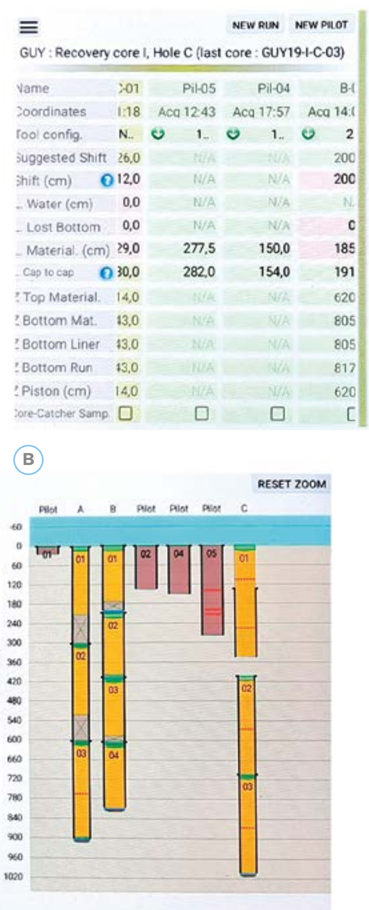
Lipid biomarkers are specific organic molecules that can be used to identify the origin of organic matter.



1. METHODS

1.1. LAKE BATHYMETRY, SEDIMENTARY INFILLINGS AND CORE ASSESSMENT

In order to determine the zone(s) where sediment core samples will be taken, it is necessary to know the lake bathymetry. In addition to the morphology of the lake basin, it could be interesting to determine the thickness of the sedimentary infilling and to study how the deposits are organized. In order to do this, sedimentologists use seismic reflection equipment which, through the various propagation speeds of the waves based on the materials encountered, makes it possible to show the layers of sediment. Palaeo-environmentalists/climatologists often prefer the deeper, flat and remote areas of deltas. In fact, these areas are the least affected by sublacustrine landslide deposits coming from the slopes of the basin. These instantaneous deposits may be quite thick and may have eroded some of the previous deposits. In addition, these areas have reduced sediment accumulations, which allows to maximize the temporal depth covered by the record.



During the PALAS 2019 mission, three different core drilling techniques were used. On each of the lakes, 'short' gravity cores (UWITEC core drill), mostly involving hammering so as to increase the thickness of the sediment collected, were sampled. This coring technique is used to take sediment samples without disturbing the interface and therefore provides essential records that can be used to properly document the recent sedimentation. In Lake Guynemer, the objective was to sample the longest sequence possible. In order to do this, we used a platform and an UWITEC stationary piston corer developed by Richard Niederrieter (uwitec.at). This type of corer (Figure 3A) can be used to sample the sediment in sections measuring 2 (90 mm Ø) or 3 m long (63 mm Ø). The principle consists of lowering the corer from the platform to the desired depth and then locking the piston in order to be able to start the coring by hitting it using hammers. Once the 2 or 3 m tube is filled with sediment, the corer is raised to the surface using winches and the core is recovered. Then, the corer is sent 2 or 3 m further down in order to sample the next section and so on. A hydraulic core catcher system or an orange peel is installed at the base of the corer to prevent the loss of sediment while raising the core. Even if these systems work correctly, sediment corresponding to the space taken by the stationary piston is lost between each section. In order to make up for this loss and obtain 100% of the sedimentary sequence, a second core(Hole B, Figure 3B), offset in depth, is sampled right next to the first (Hole A). The core diagram is built in real time in the field using the Corebook application developed at the EDYTEM Laboratory (Figure 3B). The third coring system used is the one developed by Atle Nesje[6]. This is also a stationary piston system that is used to collect samples by hammering up to 6 m of sediment at once. It has been used in all of the lakes.

[6] Nesje, 1992

1.2. GEOMORPHOLOGICAL MAPPING AND SAMPLES TAKEN FOR DATING ANALYSES

MAPPING

Past glacier extensions are identified through a combination of observations and the mapping of glacial landforms and formations. Observations are carried out at several spatial and temporal scales. Prior to the field mission, satellite imagery is used to perform these observations. Since 2017, the resolution of the images available on Google Earth have been satisfactory, however the easternmost part of our study area (Guynemer Peak) is completely whited-out because it is covered by an image from August 2006. This resource made it possible to identify several moraines that have been there for a while but only recently became more visible, especially in the Guynemer sector. Given the cloudy and snowy conditions in this region, we only acquired Pléiades tri-stereo coverage on January 16, 2019, almost one year after it was ordered from Airbus DS as part of the ISIS programme (Access to SPOT images for Science/Incitation à l'utilisation Scientifique des Images SPOT). Thus, from this perspective, the postponement of the PALAS mission by one year to the 2019 OP3 was welcomed: the DEM (digital elevation model) and orthophotography produced from these satellite images helped us with our preliminary observations for the mission. Numerous moraines were identified, as well as areas with roches moutonnées with their abundant erratic boulders, and potential glacial drainage channels, which helped guide the organization of the field mission. Given that this area does not have any footpaths whatsoever and is also characterized by numerous rivers that cannot be crossed on foot, these images were used to identify possible routes in the field. In fact, this geomatic resource formed the basis of the Geographic Information System (GIS) in which the field observations were reported daily as a geomorphological map (see Inset 1) — which also incorporated very high-resolution images acquired by drone in several sectors.

The goal of geomorphological mapping is to create a spatial reconstruction of the Holocene or even Tardiglacial glacial extensions[7]. The frontal and lateral moraines illustrate the 2D geometry of the glacier (and its temporal variations). It was possible to model the volume of this glacier from this geometry as well as from the derived glaciological parameters — therefore, the altitude of the glacial equilibrium line and its evolution are palaeoclimatic indicators. A roches moutonnées sector indicates minimal extension of the glacier in terms of length and altitude; an erratic boulder, one position of the glacier during a retreat phase.

DEM

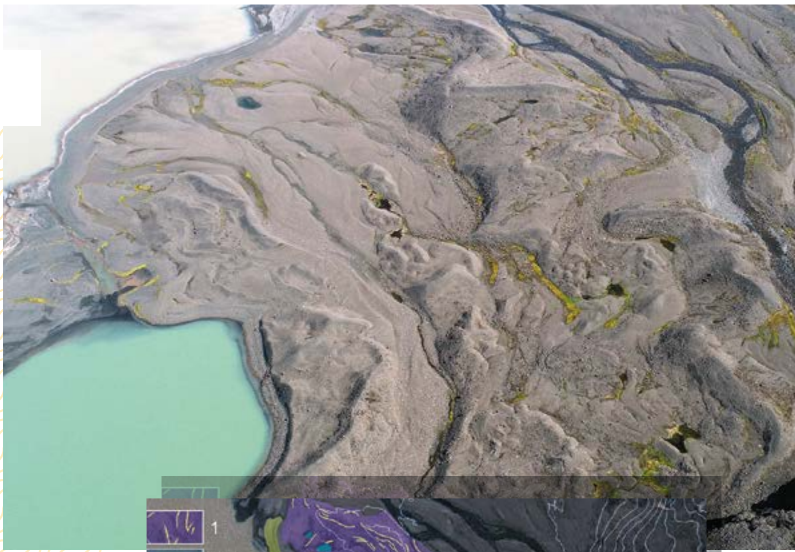
The DEM (Digital Elevation Model) is a representation of topography. Orthophotographs are images of the earth's surface (satellite or aerial) whose geometry has been rectified so that they can be superimposed on a flat map.

[7] Jomelli et al., 2017

Inset 1.

GEOMORPHOLOGICAL MAPPING

The principle of this mapping is to represent all landforms (e.g. moraine, scree, etc.) and formations (e.g. till, glacial-lacustrine infilling, etc.) found within a study sector, by associating them to the processes that generated them (e.g. glacial, periglacial processes, etc.) while integrating the chronology (at least relative) of their establishment.
The topic of our study explains that emphasis was placed on geomorphological markers of glacial dynamics — only a few non-glacial forms/formations have been mapped when they can be used to recognize/identify glacial forms (e.g. gullying and associated deposition affecting a moraine, or an abutting rockfall deposit).



This figure shows part of the moraine complex of the Agassiz glacier. Three sets of moraines can be distinguished in the photo taken by the drone (top; authorization 2019-158). By cross-checking satellite (bottom) and drone images with field observations and photos, it was possible to map these moraines in detail as seen by the large number of ridges (N.B.: the moraines are not listed in order based on their sizes). The footprint and distribution of the wide drainage channels provide evidence for the extensive reworkings that have affected this moraine complex on at least two occasions. The wind fetch induced by the size of the lakes, which see frequent and intense winds, and the seasonal variations in their water level explain the development of beaches on their shores.

1: moraine and moraine ridg ; 2: drainage channels ;
3 : lake beach (N.B. : the other represented landforms are not explained here). The dotted white line indicates the position of the glacier front in 1963.
Isohypse contour interval: 50 m
Orthophoto: Pléiades satellite, 16/01/2019

dendrochronology

Dendrochronology is a dating method based on counting and analysing the morphology of growth rings in trees.

fetch

Fetch is the time and unobstructred distance travelled by wind over a body of water. At the end of this 'momentum' zone, the water will rise to form a wave: the greater the fetch, the higher the wave.

SAMPLES COLLECTED FOR COSMOGENIC DATING

This spatial dimension of the palaeo-glaciation shown by the map must be combined with a relative and absolute chronometric calibration. In most mountain massifs, the presence of wood layers in the moraines has made it possible to establish chronologies for the glacial fluctuations using dendrochronology and radiocarbon dating[8]. As there are no trees on Kerguelen, dating using in situ cosmogenic isotope (see Inset 2) products was used[9] (see Inset 2). For this, samples were taken from the moraine complexes, in areas with roches moutonnées and on erratic boulders. It will also be possible to use these dates to track the past dynamics of the various glaciers (Guynemer, Agassiz and Chamonix).

In total, two glacial deposits, 10 roches moutonnées surfaces, 23 erratic boulders and 75 boulders on moraines were sampled using an angle-grinder and a hammer and chisel (Figure 4). These 110 samples, weighing 1 to 2 kg, were collected from basalts (100), in which 36Cl is produced from calcite, and from quartz veins and geodes (10) in order to measure the ^{10}Be concentration.

Inset 2.

DATING BY IN SITU-PRODUCED COSMOGENIC ISOTOPES

Primary cosmic radiation interacts with components of the atmosphere creating cosmogenic nuclides which then adsorb onto the surface of the minerals in the rocks, resulting in nuclear reactions. As a result, cosmogenic nuclides (14C, 26Al, 36Cl, 10Be) then start to be produced there, in situ. The measurement of their concentration provides an estimate of how long the rocky surface has been exposed, taking into account the nuclide production rate (which depends on time, altitude, etc.), the local topography (shielding) and the rate of possible erosion of this surface. Cosmogenic nuclide surface exposure dating requires collecting samples with a maximum thickness of 3-5 cm, preferably at the centre of large flat boulders or on the ridge for moraines, and as stable as possible, and recording their dimensions, their altitude and the topographic shielding (Figure 4). The sample then undergoes mechanical preparation followed by geochemical preparation in the laboratory, which takes a long time for 10Be: the steps include grinding and sieving, purification, separation and dissolution with hydrofluoric acid (HF), then substitution of HF and, last, beryllium oxide (BeO) extraction — a much faster preparation for 36Cl. The isotope ratio can then be measured by Accelerator Mass Spectrometry (AMS), in France, on the national ASTER instrument (LN2C, CEREGE). This ratio is then converted into a concentration, from which an exposure age is calculated using an online calculator, along with an uncertainty (analytical and on the production rate) that is generally < 5% except for very young surfaces (past few centuries).

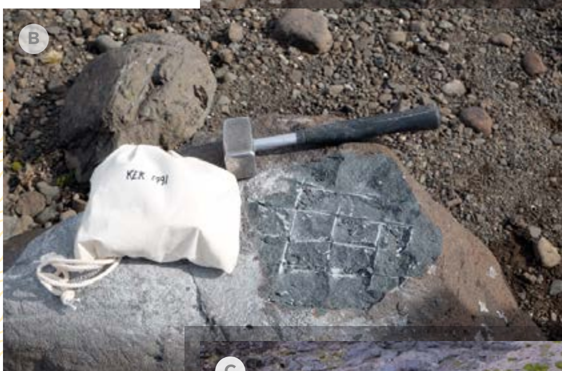


Figure 4. **Collecting basalt samples** for surface exposure dating using 36Cl. a: collecting samples on an erratic boulder located in the upper western flats of the Guynemer Basin (325 m altitude) ; b: sample Ker 1991 collected from a boulder on lateral-frontal moraine Ma-1 (the outermost) of the Agassiz complex (70 m); c: shielding sample and measurement on a boulder on frontal moraine Ma-3 of the Agassiz complex (75 m); d: sample taken from a roche moutonnée on Mont Fauve (515 m).

2. RESULTS

2.1. BATHYMETRY AND SEDIMENTARY INFILLING

The bathymetry of Lake Guynemer is relatively simple as there is a single basin that is quite deep (90 m). Conversely, the bathymetry of Lake Hera and the other Mythos lakes is much more complex as they are made up of several basins and sometimes contain ‘hummocky’ structures that can be seen on the seismic profiles (Figure 5A). This complexity is probably related to sediment inputs from the various glaciers (Agassiz, Chamonix and Pointu) connected to the lakes in the past and to subaqueous slides. Within this sedimentary context, we understand why seismic equipment is needed to identify the most appropriate coring areas, i.e. areas with undisturbed sedimentation (preservation of the chronological order of the deposits and without hiatus), and thus to be able to address our scientific question.

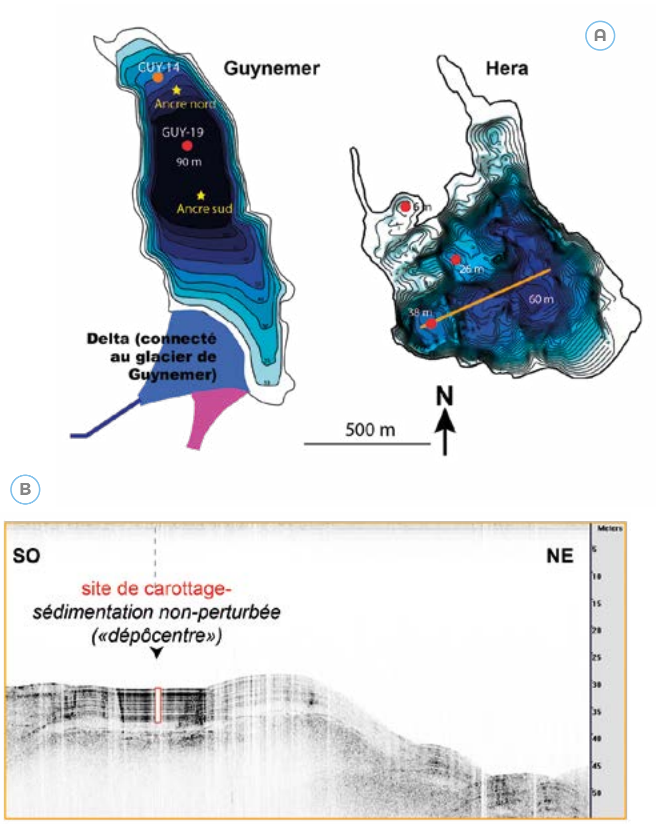
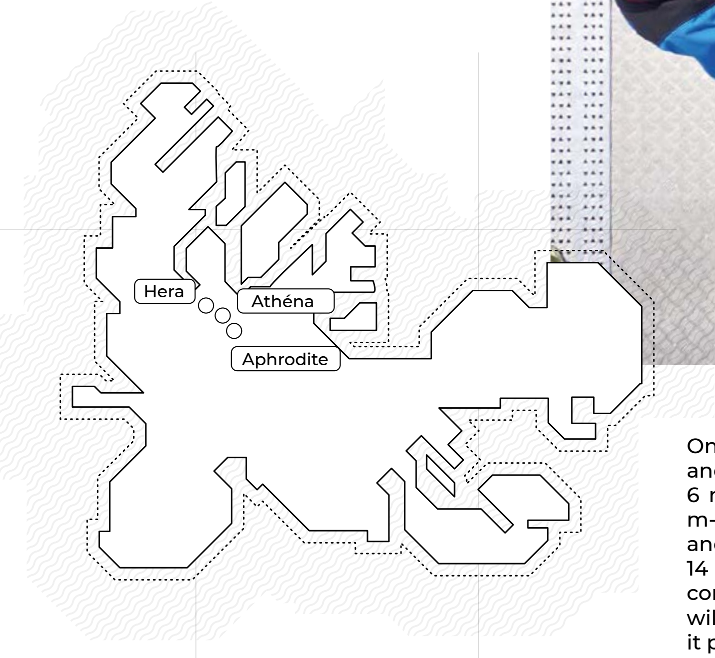


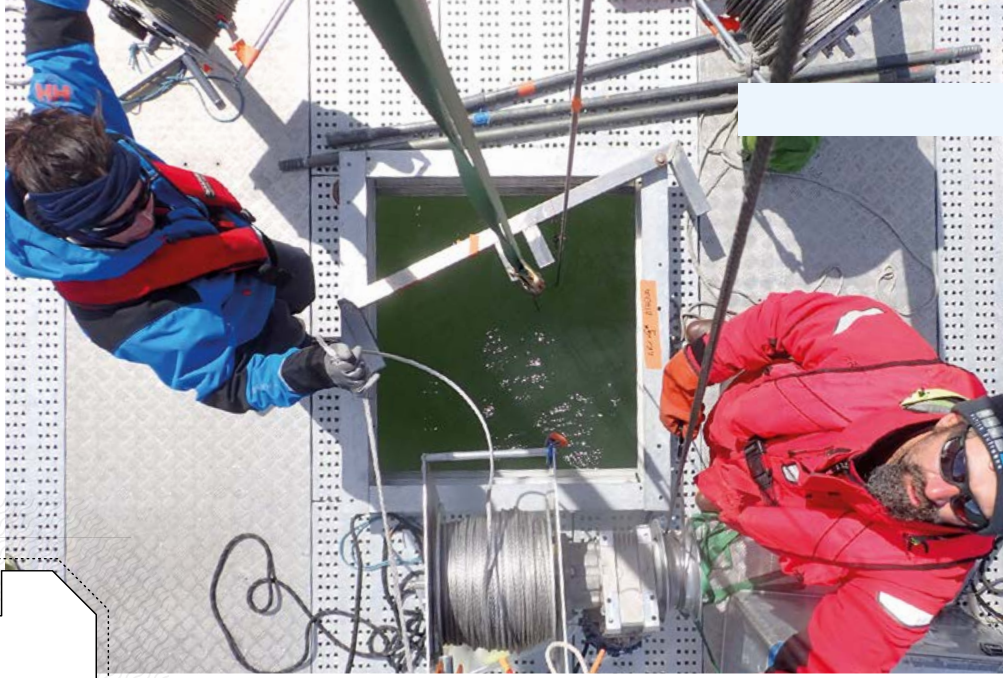
Figure 5. **Bathymetry and seismic profile.**
A) Bathymetric maps of Guynemer Lake and Lake Héra illustrating the various underwater topographies encountered on the lakes located north of the Cook Ice Cap. The 2014 and 2019 coring areas are indicated by orange and red dots, respectively. The positions of the north and south anchors, installed to stabilize the platform during coring, are indicated by yellow stars. B) Seismic profile corresponding to the SW-NE transect in orange on the bathymetric map of Héra. In particular, it highlights a small perched basin with undisturbed sedimentation (unlike the deeper zone) and in which a 6 m core was sampled using a Nesje corer (Nesje, 1992). In the northeastern part of the transect, ‘hummocky’ structures appear.

2.2. OVERVIEW OF THE SAMPLES, FIRST RESULTS AND OUTLOOK

At Guynemer Lake, 10 m of sediments in 3 m-long sections and from 3 holes (A, B and C) were collected (Figure 3B). In addition, three other cores measuring 1.40 to 2.90 m in length were collected using the Nesje coring system. The cores will be studied in Bergen and Chambéry starting in June 2020. However, it was already possible to make a few observations. As an example, approximately fifteen centimetres of well-preserved and laminated sedimentation was brought up on the anchors used to stabilize the core drilling platform when the anchors were removed (Figure 6). These sediments clearly show a colour change marking a recent change in the type of sedimentation. In the southern anchor, at the foot of the delta formed by glacial inputs from Guynemer Peak (1088 m), it was possible to observe a deposit that had slid and rolled up on itself, something that is typical of sub-lacustrine landslide sediments. At the other end of the lake, an atypical deposit containing high amounts of plant debris was also observed in the sediments brought up with the anchor, whereas the water depth (80 m) is too shallow for the in situ development of aquatic plants. Future studies will enable researchers to determine if these deposits are synchronous and to determine their origin. One hypothesis could be that an earthquake triggered a destabilization in the aquatic part of the delta, causing a tsunami at the other end of the lake. Such evidence of recent seismic activity would be an important discovery, as Kerguelen is not known to be a very seismically active area. This would complement a recent study carried out by our team, which studied sediments from Lake Armor and found deposits linked to 8 major volcanic eruptions that took place on the Rallier du Baty Peninsula over the past 11,000 years[10].

[8] e.g., Le Roy et al., 2015
[9] e.g., Le Roy et al., 2017
[10] https://eartharxiv.org/5jnu6/





On the so-called 'Mythos' lakes (i.e. Héra, Athena, 5 and Aphrodite) and one of the 'Cartographie' lakes (Figure 2), cores measuring 5 to 6 m long were collected using the Nesje system. At Athena 2, a 7 m-long core was also taken with the Nesje system up to 6 m long and then with the 'Niederrieter' system up to 7 m long. A total of 14 sites were cored on the six lakes, representing a total of 127 m of cores (Figure 2). Among other analyses, lake sediment DNA analyses will be performed to track past climate changes. They will also make it possible to address palaeoecological questions such as the interactions between an invasive species, the rabbit, and the environment (see: Inset 3).

As with all records, dating analyses are essential in order to obtain palaeoclimatic and palaeoecological reconstructions. For lake sediments spanning several thousand years, the main step is based on radiocarbon (14C) analyses of plant macro-remains. However, in glacial environments, it can be difficult to find plant remains in the cores. Chronologies of volcanic eruptions, recently established by our team using sediments from Lake Armor[11], could be used to provide additional dating information.

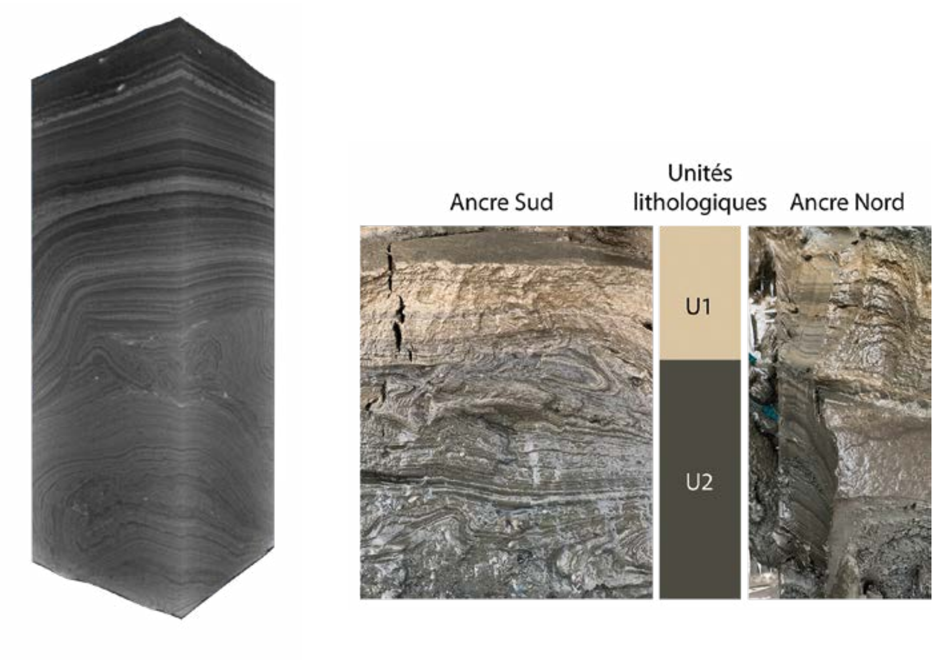


Figure 6. **Illustration of the sedimentation in Lake Guynemer.**
The left part of the figure shows a 3-dimensional tomographic image (CT-scan) of the sediment core collected from the anchor located on the southside of the lake. It highlights denser clay sediments (in black), less dense silts and sands (in white) and highlights the 3-dimensional deformations caused by a subaqueous slide. The right part shows photos taken in the field of the sediments brought up from the south and north anchors and their division into lithological units.

[11] Arnaud et al., 2020

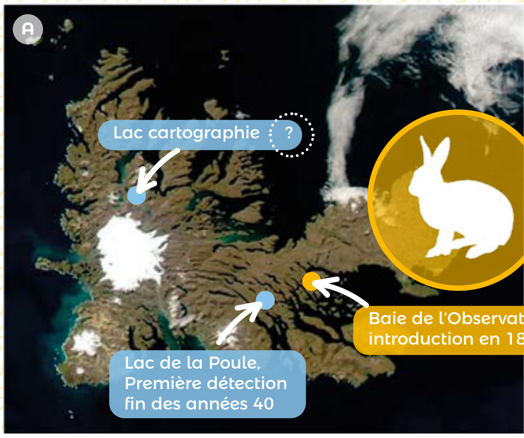
Inset 3.

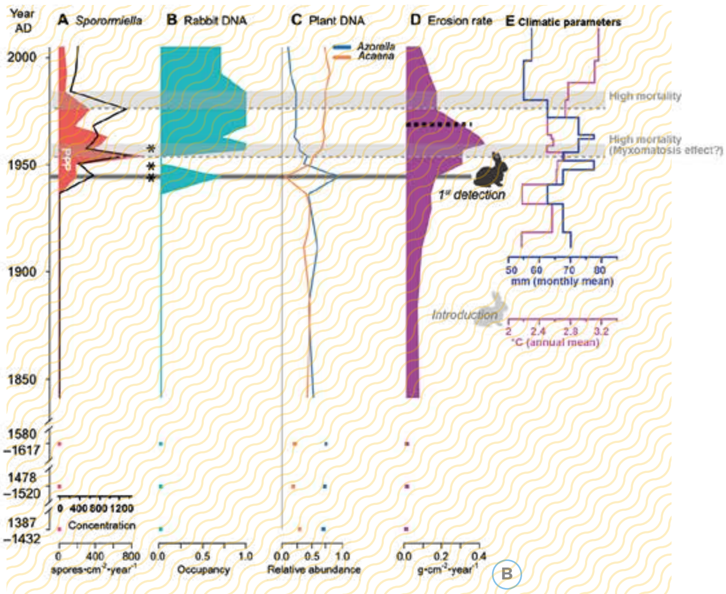
HISTORY OF THE RABBIT INVASION ON KERGUELEN AND ECOLOGICAL IMPACT

Rabbits were introduced to Observatory Bay in 1874 by British navigators from the HMS Volage. This was done in order to ensure a food resource on this mammal-free island, especially in the event of a shipwreck. The introduction was successful in the sense that the rabbits proliferated. However, it also resulted in a major ecological crisis. During the subsequent scientific missions, the very first signs of this crisis were seen on the endemic flora, with the almost-complete disappearance of the Kerguelen cabbage (Pringlea antiscorbutica), followed by the replacement of the Azorella Selago carpets with Acaena Magellanica, and then the effect of plant cover degradation on soil erosion. Even though the impacts of the introduction of this invasive species have been described many times, we still only have limited knowledge about the temporal dynamics of the invasion and ecosystem responses. Lake sediment records are the only way to go back in time to retrace these dynamics.

During the previous PALAS mission in 2014, sediments from a core sample taken from Lac de la Poule were subjected to plant and mammal DNA analyses (Fig. A). These analyses have made it possible to pinpoint the arrival of rabbits in the watershed towards the late 1940s, i.e. approximately 70 years after they were introduced on the island, roughly ten kilometres away as the crow flies (Fig. B). This presence is confirmed by the observation of coprophilic fungi spores (Sporomiella sp.) that grow on herbivore faeces. The rabbit invasion very quickly caused an erosion crisis that lasted until the mid-1960s. Although erosion has become less of a problem since the 1960s, the change in the plant community, i.e. the gradual disappearance of Azorella in favour of Acaena, still exists today. Given that the Azorella population started to decline as soon as the rabbits arrived can most likely be explained by the massive degradation of these cushion plants due to the construction of burrows (and then the rains could easily move the plant fragments). In the mid-1950s, the high rabbit mortality suggested by the data (decreased sporomiella concentration and DNA spike due to cadavers), may reflect the introduction of myxomatosis in 1955-1956.[12] . A second phase of significant mortality was recorded in 1975. This could have been caused by the virus, decreased food resources or another reason. It is interesting to note that the decrease in erosion occurs before this significant decline in the rabbit population, but it is concurrent with the decrease in precipitation. The erosion crisis observed when the rabbits arrived could also have been exacerbated by the increase in rainfall (Fig. B).

Around Guynemer Lake and the Mythos lakes, only a few living or dead rabbits were observed during our PALAS 2019 mission. Kerguelen cabbage is still relatively abundant there and so are Azorella cushions. However, near the Cartographies lakes or on the coast of the Baie du Repos, further away from the Cook Ice Cap, we were able to observe large rabbit populations. How long did it take for the rabbits to colonize this very remote area of Observatory Bay? What is the scale of the impact on erosion and vegetation? What are the temporal dynamics of the responses of the ecosystem as well as the rabbit populations (are we in a phase of decline as around Lac de La Poule?)? The use of DNA analyses on the sediments of Lake Cartographie will provide answers to these questions.





A) Location 1) the lakes targeted to study the rabbit invasion and its effects on the ecosystem (in yellow) and 2) Observatory Bay where the rabbits were introduced (in red).

B) Temporal evolution of Sporomiella spores (A), rabbit DNA (B). Acaena and Azorella (C) and the rate of erosion in the sediment core from Lac de La Poule Lake (D)[13] . The curves (E) represent the changes in temperature (annual average) and precipitation (monthly average) since 1912 (interpolated using data collected from weather stations worldwide from the University of Delaware[14]).

[12] Chappuis et al., 1995
[13] Ficetola et al., 2017
[14] Nickl et al., 2014

2.3. MAPPING THE MORAINES AND TAKING SAMPLES FOR DATING: PRELIMINARY RESULTS ON THE GUYNEMER PROGLACIAL MARGIN

The current Guynemer Glacier is divided into four unequal parts, with a total surface area close to 1.4 km². The two lower sectors (0.25 km²) are found 100 to 250 m below the upper sectors from which they are separated by non-glaciated walls; their fronts descend to an altitude of 340 and 395 m.
The part of the Guynemer moraine complex located upstream from the cone-delta is quite complex: in addition to the three main lateral-frontal moraines (Mg-4 to 6) downstream from the upper lake, between which less-continuous ridges are found, numerous ridges surround this lake, especially on its north shore, marking the glacial retreat since 1963; the inner flank of the largest of these moraines, the visible part of which overlooks the 30 m lake, is subject to active runoff (Figure 7a). A few perched ridges > 300 m on the south shore are possibly connected to the Mg4-6 set.

Three moraines are present around the lower Lake Guynemer: Mg-3 on the intermediate bench on the west shore, between 165 and 200 m in altitude, Mg-2 at its northern end, a few m above the lake, and Mg-1 on a bench on the east shore, at an altitude of 190 m.
Forty samples were collected to carry out cosmogenic dating on Mg-1 (2), Mg-2 (3), Mg-3 (3), Mg-4 (7), Mg-5 (8), Mg-6 (5) and on 12 erratic boulders distributed at various altitudes (max: 305 m) around the lower lake including at the limit, at an altitude of 150 m, between Lake Louise and Guynemer Lake.
The same mapping and sampling approach was applied in the proglacial margins of Agassiz (Figure 7b) and Chamonix. Samples were also taken from roches moutonnées and boulders along a 500 m altitudinal transect between Lake Athena 2 and the summit of Mont Fauve (Figures 2 and 7c). This work will help document the extension phases of the Agassiz and Chamonix glaciers.

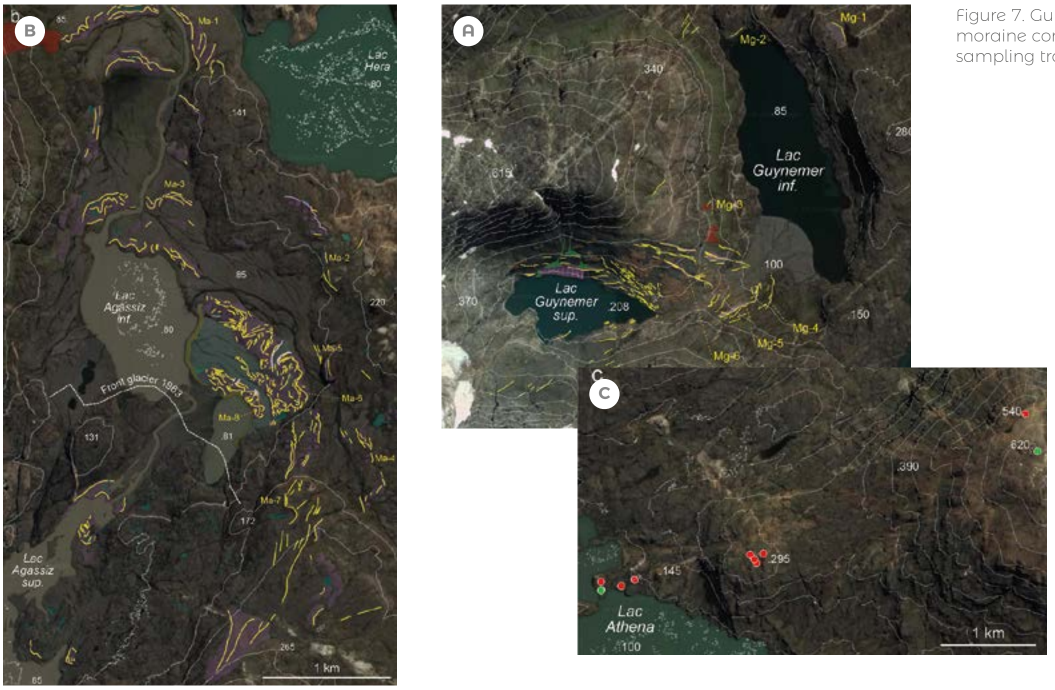


Figure 7. Guynemer (a) and Agassiz (b) moraine complexes, and Mont Fauve sampling transect (c).

CONCLUSION

The work of the five core cutters and three geomorphologists during a one month period in the field and the logistics put in place by the French Polar Institute meant that an incredible amount of samples could be collected: 127 m of sediment and 110 rock fragments.

The preliminary results of this mission have already resulted in a map of the glacial formations in the study area, located between the Cook Ice Cap and the Presqu'île de la Société de Géographie. The first analyses performed on two short cores from Lake Guynemer already show recent changes in the sedimentation dynamics and raise questions about the potential recording of seismic activity linked to volcanism. Answers to these questions will be found by dating these cores. Cosmogenic isotope analyses to date the ice formations are currently underway and the study on the remaining cores will begin in June 2020. Therefore, we will soon have the reconstructions of the glacier and palaeoclimatic fluctuations.

ACKNOWLEDGEMENTS

The entire PALAS team would like to thank the Polar Institute as the PALAS 2019 campaign simply could not have even been imagined without it. In particular, the subantarctic logistics team provided us with support from the very start in the design stage of the campaign. The professionalism and total dedication of the Institute in the field, in the name of science, undoubtedly made possible what seemed to many people as impossible.

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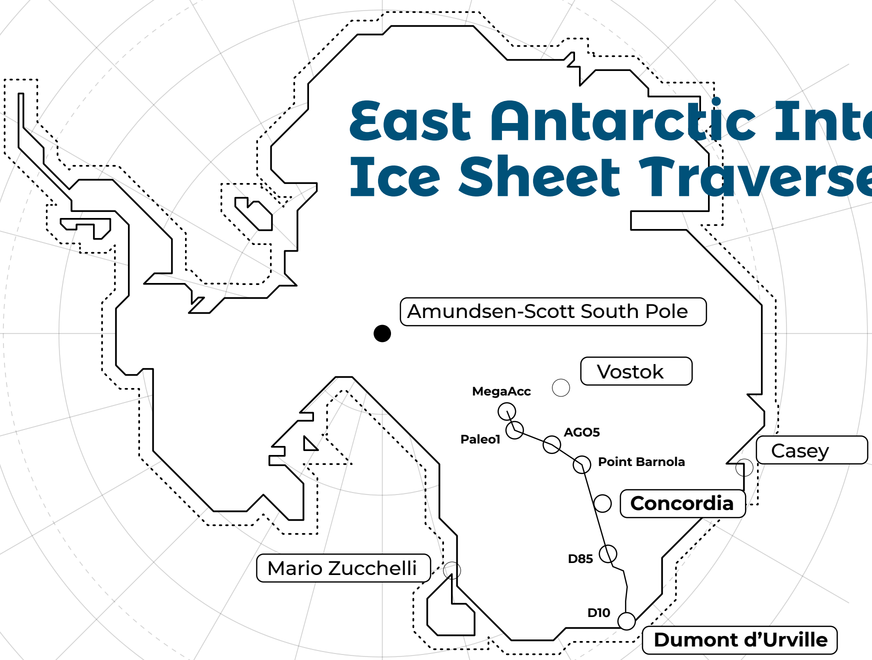
EAIIST



East Antarctic International Ice Sheet Traverse

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INTRODUCTION

A SHORT AND RATHER INCOMPLETE HISTORY OF LAND TRAVERSES IN ANTARCTICA.

Honour where honour is due. The first person to have ever envisioned, designed, organised and attempted a land traverse on continental Antarctica was the incomparable Ernest Henry Shackleton. The aim of the 1914 Imperial Trans-Antarctic Expedition – better known as Endurance, the ship that was swallowed up by pack ice – was to make a crossing of Antarctica from the Weddell Sea to the Ross Sea via the South Pole. Shackleton's crew used dog sleds and counted on the support of a second logistics team deployed in the Ross Sea, whose mission was to lay depots for the last leg of the journey. This they did, although three members of the team died.

All ‘Polar’ people know the incredible story of the Endurance, this epic monument to survival in a hostile polar environment, and the unbelievable crossing by boat between the inhospitable and ice-covered Elephant Island and South Georgia. This journey was a feat (an inspiring story of survival under Shackleton’s command) within a failure (the Antarctic crossing itself never took place).

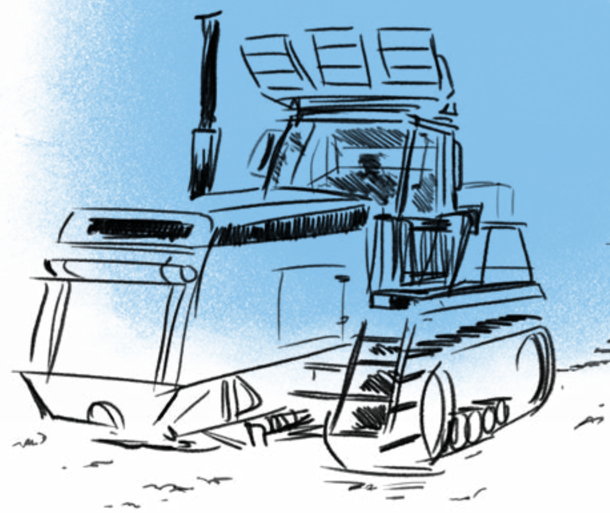
It was almost fifty years later and during the third International Polar Year (1957-1958) that the first overland traverse of the Antarctic continent would take place over 99 days and 3500 km. The British explorer Vivian Fuchs and his team set out from the Weddell Sea on Tucker Sno-Cat and Bombardier Muskeg vehicles and became the first to cross Antarctica. Their support team was led by the illustrious Sir Edmund Hillary, who mapped out the final section of the journey between the Ross Sea and the South Pole.

Two years later, after overwintering at Charcot station in 1957, the French glaciologist Claude Lorius – invited by an American team for the Victoria Land Traverse – carried out a mechanised traverse and co-discovered a mountain range that was not mentioned in the topographical surveys of the time. On the strength of his polar experience, Claude Lorius pioneered the International Antarctic Glaciological Project (IAGP) with Russian, American, Australian and British colleagues. This glaciology programme, which ran from 1969 to 1980, aimed to study and understand the history, evolution, flow, surface and bedrock topography of the East Antarctic polar ice cap through overland traverses and airborne soundings[1]. This programme was the first to use overland traverses as a research rather than an exploration tool, with a complete scientific programme including geodesy, geophysics, seismology, analysis of the physical and chemical properties of ice, and a drilling programme. The data acquired during the IAGP determined, among other things, the location of the deep drill holes at D47 and Dome C (drilling Dome C 78, EPICA) and consequently the location of the Concordia research station.

Many traverses followed, not all of which will be detailed here, but it is worth noting that 10 years after the end of the IAGP programme, the International Trans-Antarctic Scientific Expedition (ITASE) initiative was relaunched in France, Grenoble, bringing together 20 nations. This international programme, which lasted until 2010, enabled several scientific traverses to be carried out that aimed to spatialize climatic, meteorological, geophysical and chemical data.

It is within the ITASE framework that France resumed scientific traverses. With the benefit of 20 years of experience in logistical traverses supplying the Concordia research station and following the renewal of part of its vehicle fleet, the French Polar Institute Paul-Emile Victor (IPEV) had gained new capacities for scientific traverses. It now had, 30 years after the IAGP programme, a life caravan, energy caravan, mobile laboratories and sleds. This means that since 2010, scientists have been able to carry out scientific traverses such as the VANISH programme (Concordia-Vostok round trip traverse), ABN (French-Australian Dumont d’Urville-Aurora Basin North traverse) or ASUMA (coastal traverse around Dumont d’Urville). All have more or less followed an identical scientific programme close to IAGP’s recommendations. A scientific traverse, although less expensive than an oceanographic or airborne campaign, still represents a considerable financial cost, so everyone strives to maximize the scientific experience gained in order to make the most of the investment. The EAIIST traverse of the 2019-2020 summer campaign was not immune to this constraint. Here is the story.

[1] Zumberge, 1974 #7940



PREPARATIONS

CONSTRUCTION PHASE OF THE PROJECT AND FINANCING

In line with previous projects and in the absence of surface data on a section of Dome C-South Pole, which corresponds to the shift in the ice flow towards the western part of Antarctica, the idea arose to conduct a scientific traverse in this section. While visiting McMurdo station in 2012, I spoke with the then director of the National Science Foundation's (NSF) glaciology programme, Julie Palais, to see what she thought about a Dome C-South Pole traverse in collaboration with American teams. With her encouragement, the first contacts were established with Italian and American teams and later with Australian researchers.

A first workshop was organised in Grenoble in September 2014, followed by the drafting of a white paper which included scientific questions, participants, route, financial plan and a planned timetable. Given the distances to be covered in a two-month traverse, this journey (3300 km round trip) could only be completed in two seasons: Dome C-South Pole in year n with winter storage of vehicles at the South Pole and the return journey in year n+1. This set-up was the best match for the distance that needed to be covered, with the double benefit of crossing specific topographic structures such as megadunes or 'glazed' surfaces, and it enabled us to set up a series of experiments on the visited sites that could be recovered the following year when returning to Concordia. Therefore, logistical support was needed (fuel, winter storage of vehicles, maintenance) from the South Pole station. Unfortunately, a major difficulty that is common in this type of project very quickly emerged: coordinating the logistical and financial support from several nations who all have different means, procedures and structures for financing their polar research.

megadunes

Surface undulation with an amplitude of a few tens of meters for a wavelength of a few km. Structure formed by the combined effect of wind, accumulation and slope of the surface.

glazed

Wind-hardened surface with very little surface relief, which does not allow snow to be deposited

Over time, for internal reasons, the NSF became increasingly reluctant to host the South Pole traverse. Moreover, the American project systematically received poor assessments from the project selection committee on which the NSF relies for funding. This resulted in a long process of application submission and rejection for the Americans that finally led to the withdrawal of the US teams in 2018 and the participation of the Australians but with no involvement on the ground. With the Italians having obtained funding through their National Antarctic Research Programme (PNRA) and the French from the National Research Agency (ANR), the BNP-Paribas Foundation and French Polar Institute Paul-Emile Victor (IPEV), two workshops in October 2018 and 2019 and numerous exchanges with the polar institutes laid the traverse's foundations: the route (round trip to the Mid Point Concordia-South Pole), research activities and traverse participation.

SCIENTIFIC OBJECTIVES

During the first meetings, three scientific questions were identified.

The first was the mass balance in Antarctica, which directly affects sea level rise. Projections from the IPCC's Special Report on the Ocean and Cryosphere[2] indicate a sharp rise in sea levels of between 20 and over 100 cm by 2100. This wide range is largely due to uncertainty about the mass balance in Antarctica. However, if coasts continue to lose increasing amounts of ice, the question arises of what fate awaits the Antarctic Plateau. In a warmer climate, the atmosphere will contain more moisture and snowfall is expected to increase on the Antarctic continent, which, if not reversed, could slow down the rate of sea-level rise. A 1% loss of mass from the Antarctic continent represents a 70 cm rise in sea level. With 10% of the world's population living less than 10 m above sea level, the consequences would be catastrophic for societies and marine biodiversity. It is therefore essential to measure the evolution of snow accumulation rates over the central parts of

[2] Pörtner, 2020 #7934

Antarctica and to place them in a historical context over the last few thousand years in order to obtain the best possible future projections.

The second question concerns the quality of the glaciological record contained in the ice. At deep drilling sites such as Vostok or Concordia, the accumulation of snow during the ice ages was about half of the levels in warm periods. In the hyper-arid zones of Antarctica, however, very specific surface structures can form. These include megadunes, where snow accumulation is highly variable (loss on the leeward and gain on the windward side of the dune) and can lead to biases in the recording of climatic and chemical signals. Going to study these areas of megadunes and other surfaces where snow accumulation has been impacted by ablation processes enables us to set foot on a terrain similar to what might have happened during an ice age at Vostok or Concordia and to see how the signals are recorded.

The final issue addressed by EAIIST concerns the representative nature of the measures currently being taken near research stations such as Concordia. The activity of a station running on fuel-based power inevitably generates local snow pollution, the consequences of which are sometimes difficult to assess: contamination of the snow, thermal structure of the snowpack, redistribution of the snow by wind, lack of zone marking for sampling areas, passage of non-listed vehicles, and so on. Conducting experiments in virgin ground makes it possible to assess the impact and biases that a station's activity can generate.

Finally, EAIIST is now YOPP (Year of Polar Prediction) endorsed. YOPP is an international initiative coordinated by the World Meteorological Organization to promote international cooperative research for the development of improved meteorological and environmental prediction services for the polar regions, on time scales ranging from hours to seasons. EAIIST therefore plans to make all of its meteorological data available to the community.

The project has brought together around twenty

THE CONSORTIUM

teams, with the participation of the Laboratory of Climate and Environmental Sciences (LSCE), European Centre for Research and Teaching in Environmental Geoscience (CEREGE), Strasbourg Institute for Earth Physics (IPGS) and Institute of Environmental Geosciences (IGE) for France, the National Institute of Geophysics and Volcanology (INGV), National Research Council of Italy (CNR), Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), and the universities of Venice, Bologna and Florence for Italy, and the Australian Antarctic Division (AAD) for Australia. To these we must, of course, add the French Polar Institute Paul-Emile Victor (IPEV) and the National Antarctic Research Programme (PNRA) for the logistical aspects. The traverse participants will be selected from these teams.

THE CHOSEN ROUTE

Having adjusted for the fact that the Americans were no longer project participants, a new route was defined with the constraint of having to make the round trip in the same season since there was no longer any support available at the South Pole. Seeking to protect the project's initial objectives, it was finally decided to travel as far as the megadunes areas, around 640 km from Concordia. The distance of this round trip meant that it could be made in one season, but it also meant that it was possible to recover, by air or over land, some of the scientific equipment that the traverse had left on site to cover a full year's worth of recordings. On the basis of the scientific questions and satellite maps, five locations were defined (Table 1).

	POINT BARNOLA	AGO5	PALÉO	WIND	MEGA accumulation	MEGA érosion
Contact.	75°42'33"S 123°15'30"E	77°14'17"S 123°28'35"E	79°38'47"S 126°8'15"E	80°47'58'S 122°10'38"E	80°34'15"S 121°38'33"E	80°34'39"S 121°47'58"E
Distance Concordia / km	68	239	512	637	613	612
Relevance	Close to Concordia, no pollution	American geophysical station, uniform accumulation area	Uniform accumulation area	Glazed surface, probably ablated	Megadune accumulation area	Megadune erosion area

table 1 . **Locations defined for extended 'science' stops.**

SCIENTIFIC PROGRAMME

As mentioned above, the organisation of a scientific traverse in a hostile, isolated environment that is restrictive for both machines and people, involves significant costs that have to be optimized by maximising the possible scientific returns, while at the same time answering scientific questions. In accordance with this principle, the planned scientific activities were as follows:

SNOW PHYSICS

- **SPECTRAL ALBEDO** for energy budget
- **SNOW STRUCTURE AND SURFACE ROUGHNESS** for energy budget and comparison with satellite microwave measurements
- **SNOW DENSITY** for energy and accumulation budgets
- **THERMAL GRADIENTS AND LIGHT PENETRATION INTO THE SNOWPACK** for energy budget
- **DEPLOYMENT OF BEACONS** to measure accumulation

SNOW CHEMISTRY

- **SNOW PITS** for measuring surface glaciological records
- **SURFACE SNOW** for spatial variability of the records
- **DRILLING** for accumulation measurements and spatial and historical variability of the records

GEOPHYSICS

- **SURFACE RADAR** to determine snowpack layers and to spatially monitor accumulation changes
- **SEISMIC STATIONS** to make soundings of glacier movements and thickness
- **GPS STATIONS** to determine flow directions and speeds

ATMOSPHERIC PHYSICS

- **TEMPERATURE, HUMIDITY, PRESSURE, WIND SPEED AND DIRECTION, SOLAR RADIATION, ACCUMULATION** pour le bilan de masse et la météorologie

ATMOSPHERIC CHEMISTRY

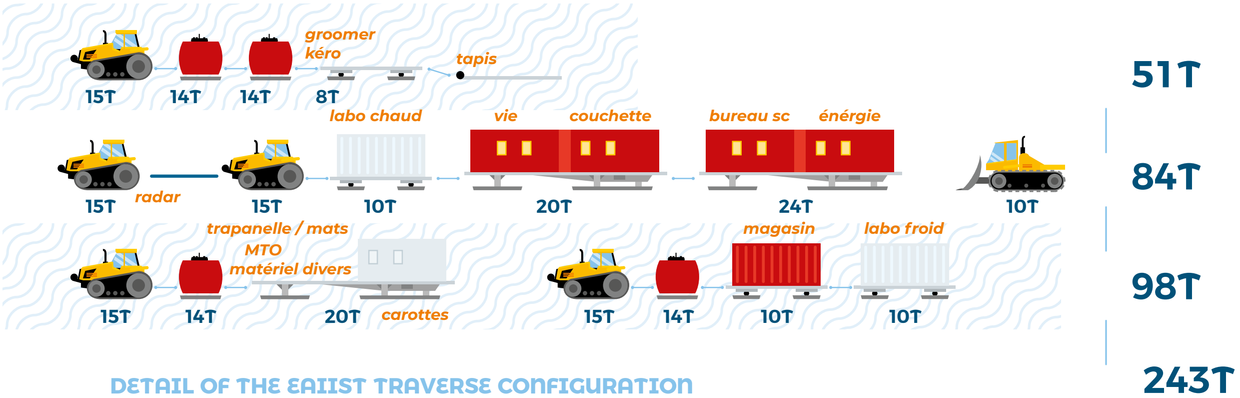
- **WATER VAPOUR ISOTOPES** for air-snow transfer functions
- **MASS AND SIZE DISTRIBUTIONS OF AEROSOLS** for comparison with Concordia and for air mass transport
- **AEROSOL COLLECTION** for comparison with Concordia and air-snow transfer functions
- **NITROGEN OXIDES** for comparison with Concordia and air-snow transfer functions

All these tasks are unevenly distributed depending on the site visited

ORGANISATION

On the strength of this scientific programme, different working meetings made it possible to establish a chronogram, the configuration of the traverse, allocation of tasks and staff rotation. A season on the Antarctic plateau corresponds to only around sixty days of scientific activities in summer. Taking into account the necessary preparations, fifty traverse days were finally available to carry out EAIIST. On top of these fifty days on the Antarctic plateau, 2 x 10 days of driving were required to bring the vehicles from the coast to Concordia and back down again. In order to allow all the scientific experiments to be carried out, there was a staff rotation system for the megadunes area which meant that 15 people could participate, even though the traverse has only 10 beds. The convoy set-up was designed by the Polar Institute to accommodate staff, ensure a high level of security and be capable of transporting all the equipment.

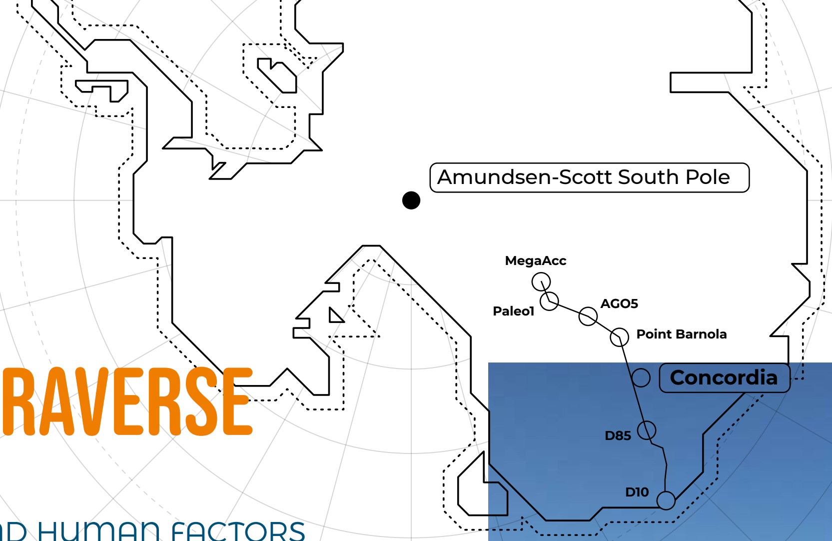
SHOWS ITS CONFIGURATION



DETAIL OF THE EAIIST TRAVERSE CONFIGURATION

There are five Challenger C65 tractors, sleds, fuel tanks, a snow groomer, life caravan (kitchen, office, beds, communication), energy caravan (mechanical workshop, bathroom facilities, shower, generator, food supply) and two CLIMCOR mobile laboratories (one hot, one cold). Because, in previous years, the transport of equipment and staff had come up against difficulties caused by sea ice-related hazards, the shipment of heavy equipment was brought forward to year n - 1. This turned out to be a critical choice. Beyond gaining flexibility and being able to work independently of the sea ice conditions, the damage to the Astrolabe vessel at the beginning of the 2019 season would have dealt a fatal blow to the traverse project now considering the COVID-19-related issues that also arose.

THE FIVE CHALLENGER TRACTORS, THE GROOMER AND THE DIFFERENT TOWED LOADS ARE SHOWN. THE CONVOY CONSISTS OF THE HOT LAB AND THE LIFE AND ENERGY CARAVAN. THIS ASSEMBLY MADE IT POSSIBLE TO KEEP THE LABORATORY AND THE LIVING AREAS WARM DURING THE DRIVING PHASES, WITH THE ENERGY CARAVAN'S GENERATOR KEPT RUNNING DURING THE TRIPS.



THE TRAVERSE

THE TEAM AND HUMAN FACTORS

Selecting a team for an isolated traverse in quasi autonomy is not a task to be taken lightly. While it is always difficult to predict the dynamics of a group that will be living in very close quarters, it is worth attending to this aspect before setting out. The initial requirement was to have on board a competent and experienced technical team consisting of a traverse leader, two mechanics and a doctor. That left six places for scientists, who needed to be experienced and familiar with the terrain and its difficult conditions, adaptable and able to multi-task. There also had to be both French and Italian contingents in the traverse. I also wanted as many women as possible to be involved so as to have varied and complementary viewpoints on subjects that may arise during the 70 days of voluntary confinement.
The technical team was established by the French Polar Institute. It was composed of Anthony Vendé, traverse leader, Alexandre Leluc and Quentin Celle, mechanics, and Nicolas Rombauts, part-time emergency physician and designated cook.

As for the scientists, the various meetings had made it possible to compose a complementary and experienced team consisting of Joël Savarino (IGE), scientific coordinator and chemist, Nicolas Caillon (IGE), chemical engineer, Pete Akers (IGE), post-doctoral chemical researcher, Mathieu Casado (AWI), post-doctoral chemical researcher, Andrea Spolaor (U. Venice), chemical researcher, Graziano Larocca (INGV), geophysics engineer, Emmanuel Le Meur (IGE), geophysics senior lecturer, Fanny Larue (IGE), post-doctoral researcher and physicist (the only woman, much to my regret), Vincent Favier (IGE), observatory physicist, Laurent Arnaud (IGE), geophysics engineer, Ghislain Picard (IGE), professor in geophysics and Philippe Possenti (IGE), design engineer, driller.

Everybody had years of polar experience in every configuration possible (working in research stations, isolated camps, traverses, alpine environments) with scientific specialities that were purely polar. As already mentioned, although it is difficult to predict group dynamics, I feel that everybody got on extremely well. Each person added their own identity and complementary perspective to the group. There was hardly any tension between us as everybody made an effort to be as accommodating as possible in a spirit of warmth, conviviality and kindness. As coordinator, I received almost no complaints, and the very few I did receive were incidental. Encounters with the logistics traverse supplying the Concordia research station on the shared road sections were some of the high points of the traverse. This is not really a place where you think you'll bump into somebody along the road. Some of the most memorable moments of the traverse were getting together in such a cordial and friendly atmosphere, in the middle of nowhere, having a drink, enjoying a meal with the 'science bods' and 'techies', and staff changeovers at the megadunes.

1 · **Nicolas Rombauts**, notre doc
2 · **Graziano Larocca**, dépose des sismomètres
3 · **Anthony Vende**, chef de raid
4 · **Emmanuel Le Meur**, radar de surface
5 · **Ghislain Picard**, propriétés physique et optique de la neige
6 · **Quentin Celle**, mécanicien
7 · **Andrea Spolaor**, chimiste de la neige
8 · **Philippe Possenti**, foreur
9 · **Vincent Favier**, données météo et accumulation de neige
10 · **Laurent Arnaud**, ingénieur instrumentaliste
11 · **Alexandre Leluc**, mécanicien
12 · **Nicolas Caillon**, ingénieur chimiste
13 · **Pete Akers**, géochimiste
14 · **Joel Savarino**, coordinateur scientifique et chimiste atmosphère et neige
15 · **Fanny Larue**, propriétés physique et optique de la neige
16 · **Mathieu Casado**, climat et isotopes de l'eau

THE JOURNEY

The EAIIST traverse took place from 23 November 2019 to 5 February 2020. The journey, based on the analysis of satellite maps, was made up of 34 days of driving (including time to get vehicles to the departure point) at an average speed of 12 km/h, 19 days of technical stops at Cap Prud'homme and Concordia and 26 days of 'scientific' stops.

Figure 2 shows the GPS track of the route followed by the EAIIST traverse with the evening stops and the visited sites (Table 1). We were able to follow the planned route exactly. Staff changeovers were seamless and took place on the agreed days. The traverse went almost without a hitch. The only real technical problems encountered were the malfunctioning of a hydraulic power station, which had no impact on the traverse, and an engine failure on a Challenger that required the loads to be redistributed. Fortunately, this happened on the return journey and only 100 km from Concordia. If it had happened earlier it would have caused serious problems. Some other incidental issues that were taken care of without delaying the traverse's progress were a broken tiller, the replacement of a sled runner axle, breakage of a snow groomer's window, as well as other mechanical problems. The positive atmosphere that prevailed throughout the traverse was also the result of this excellent progress. Returning to the coast with no pressure and ahead of schedule, we made a detour to a site visited by the ASUMA traverse in 2017 to repair a broken weather station.

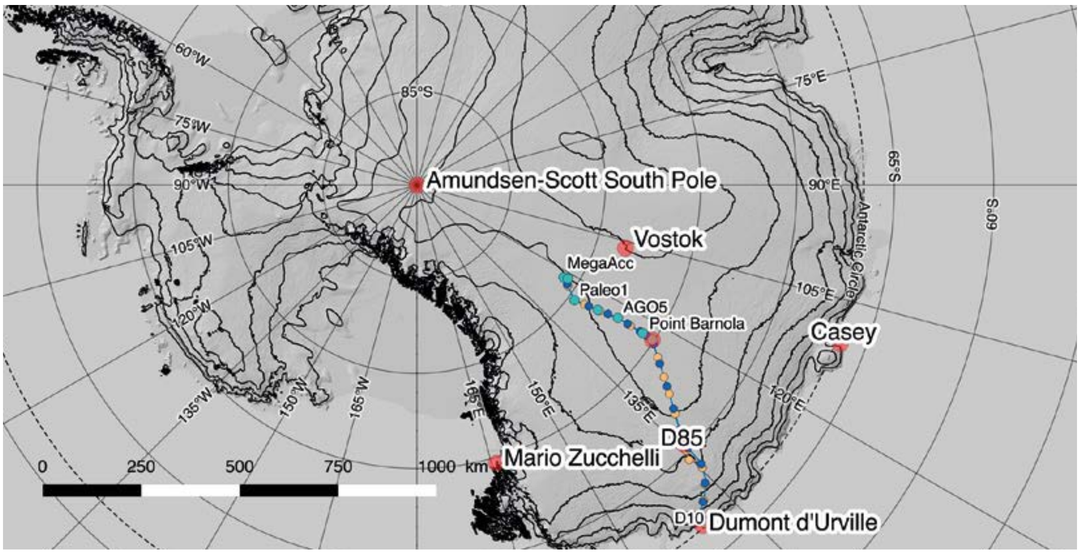
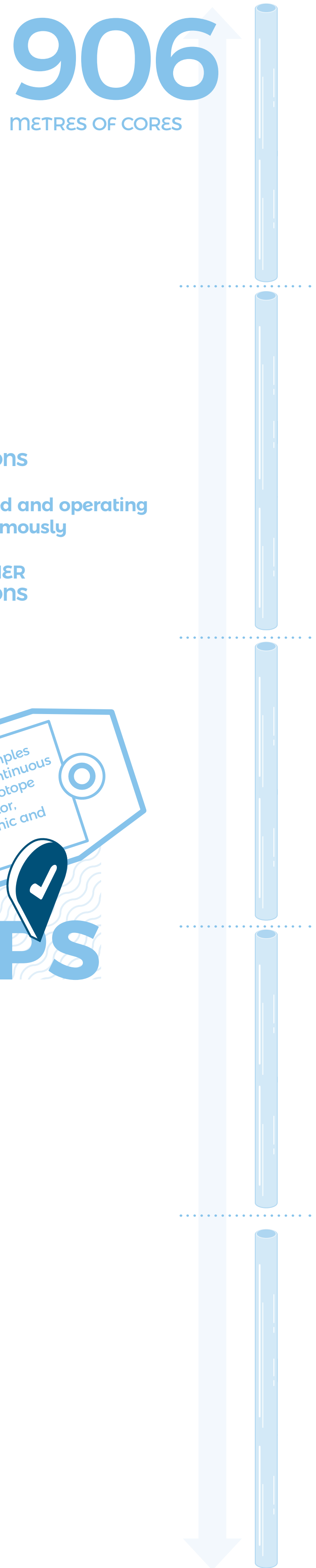
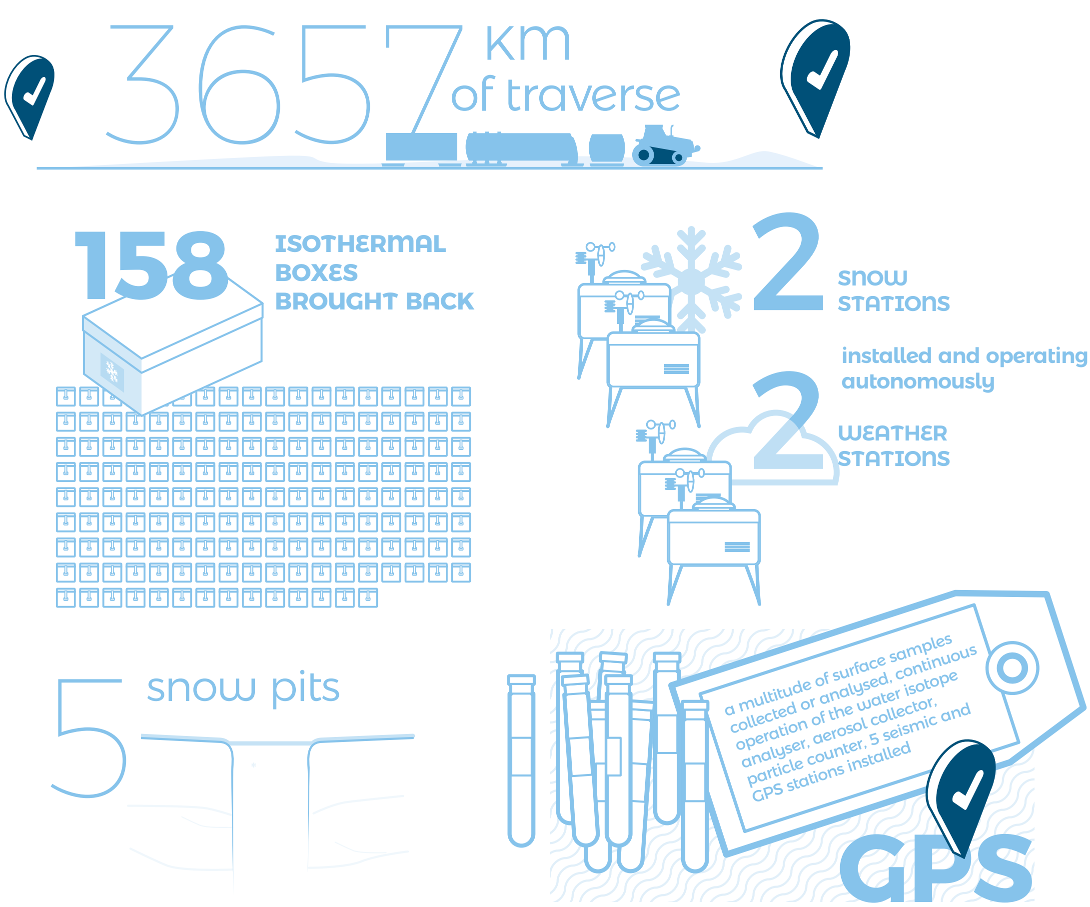


Figure 2. **EAIIST traverse route** (approx. 3700 km in 70 days with the various long science stops and short night stops. Except at the exit of the Concordia station, the vehicles found load-bearing terrain along the entire route which meant that the only time they got stuck was the first day of the traverse when leaving Concordia. .



THE MISSION



All of the cores could be taken. No major problems threatened the smooth execution of the scientific programmes. Once again, like the logistics, the science had only minor problems to deal with that had no consequences for the experiments. For example, a malfunction of the particle counter caused by very low temperatures led to no data being obtained during the Prud'homme - Dôme C pre-routing. Once transferred inside the CLIMCOR hot laboratory, however, the counter worked without a hitch. The loading of the NOx monitor on the Prud'homme - Dome C portion ensured a minimum of data for this task. Unfortunately, an on-site breakdown of the UV lamp at Concordia prevented us from taking it on the EAIIST traverse as the replacement UV lamp did not arrive until the end of the summer season.

Given the difficulty of operating the FELICS core drill in the CLIMCOR cold laboratory by staff without the proper experience, it was decided to take on board a master driller (Philippe Possenti) at the start of the expedition. This turned out to be a decisive choice for the success of the drilling programme. The rapid execution of some of the drillings saved precious time. Each project manager's experience was deployed in the field and they will all now have something to work on (Table 2). We can be confident that the data collection will lead to first-class publications. The analysis of this body of experience will take time and at this stage, it has not yet been possible to present concrete results that answer the scientific questions posed at the start of the project.

By way of illustration, Figure 3 shows the first meteorological data transmitted by the megadune station and analysed by Laurent Arnaud. In view of the results of the data and samples acquired, I consider that all the scientific objectives set for the traverse have been achieved and even, in some cases, exceeded.

	Ancillary activities	Continuous measurements	Fixed and ad hoc devices	Drilling	Pits	Surface	Problems (Pb) Repairs (Rep)
PREPARATION	Loading of material	Putting the isotope monitor and aerosol collector into operation					Pb Particle counter
PRUD-DC	ASUMA beacon data collection	· Water isotope · Aerosol collection		At each stop · 1 core 1.3m	At each stop · 1 snow sample at 1m	At each stop · 1 snow sample isotope · 1 snow sample chemistry	Pb Particle counter
DC	· Loading of material · Core drill test · Staff changeovers	· Water isotope · Aerosol collection · Particle counter					Pb FELICS core drill Counter repair
DC-AGO5		· Water isotope · Aerosol collection · Particle counter · Surface radar · Roughness measurement	Point Barnola · Seismic station FR · GPS station	Every 20kms · 2 cores 1.5m · 1 snow sample	At each stop · 1 snow sample at 1m	At each stop · 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo · Grain size	
AGO5	· Installation of core drills · Aircraft runway	· Water isotope · Aerosol collection · Particle counter · Surface radar transect · Roughness measurement · Spectral Albedo	· Seismic station IT · Sastrugi orientation	· 2x48m · 2x18m · 2x8m · Density/size 8m · Temperature 10m · Conductivity measurement 8m	· 2m chemistry · 1m isotope Π	· 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo Grain size	
AGO5-PALEO		· Water isotope · Aerosol collection · Particle counter · Surface radar · Roughness measurement	Mid Point · Seismic station FR · GPS station · Aldebo spectral measurement · SOLAB Transect	Tous les 20kms · 2 carottes 1.5m · 1 éch neige	At each stop · 1 snow sample at 1m	At each stop · 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo · Grain size · Photogravimetry	
PALEO	· Installation of core drills · Aircraft runway	· Water isotope · Aerosol collection · Particle counter · Surface radar transect · Roughness measurement · Spectral Albedo	· Sismo station IT · GPS station · Sastrugi orientation	· 2x48m · 1x18m · 2x8m · Density/size 8m · Temperature 10m · Conductivity measurement 8m	· 2m chemistry · 1m isotope Π	· 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo · Grain size · Multiphoto	Pb: GPS on SOLAB Pb: wind when drilling
PALEO-WIND		· Water isotope · Aerosol collection · Particle counter · Surface radar · Roughness measurement		Every 20kms · 2 cores 1m · 1 snow sample	At each stop · 1 snow sample at 1m	At each stop · 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo · Grain size	
WIND	· Italian radar test · Installation of core drills · Aircraft runway	· Water isotope · Aerosol collection · Particle counter · Surface radar transect · Roughness measurement · Spectral Albedo	· Seismic station IT · GPS station · CMP borehole radar · Installation of the accu beacon	· 2x50m · 2x20m · 2x8m · Density/size 8m · Temperature 10m · Conductivity measurement 8m	· 2m chemistry · 1m isotope Π	· 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo · Grain size · Multiphoto	Pb: ForPossum corer
MÉGAACC	· Staff changeovers · Installation of core drills · Aircraft runway	· Water isotope · Aerosol collection · Particle counter · Surface radar transect · Roughness measurement · Spectral Albedo	· Seismic station FR · GPS station · CMP borehole radar · Snow station · Weather station	· 1x162m · 1x50m · 1x20m · 2x8m · Density/size 8m · Temperature 10m · Cutting IC 8m	· 2m chemistry · 1m isotope Π	· 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo · Grain size · Multiphoto	Conductivity abandoned and replaced by IC cut-out Rep: ForPossum drum
MégaEro	· Staff changeovers · Installation of core drills	· Water isotope · Aerosol collection · Particle counter · Surface radar transect · Roughness measurement · Spectral Albedo		· 1x50m · 1x20m · 2x8m · Density/size 8m · Temperature 10m · Cutting IC 8m	· 2m chemistry · 1m isotope Π	· 1 snow sample isotope · 1 snow sample chemistry · Spectral Albedo · Grain size	
MégaEro-PALEO		· Water isotope · Aerosol collection · Particle counter	· GPS Station recovery		At each stop · 1 snow sample at 1m	At each stop · 1 snow sample isotope · 1 snow sample chemistry	

table 2 . **all the experiments conducted at different points during the EAIIST traverse.**

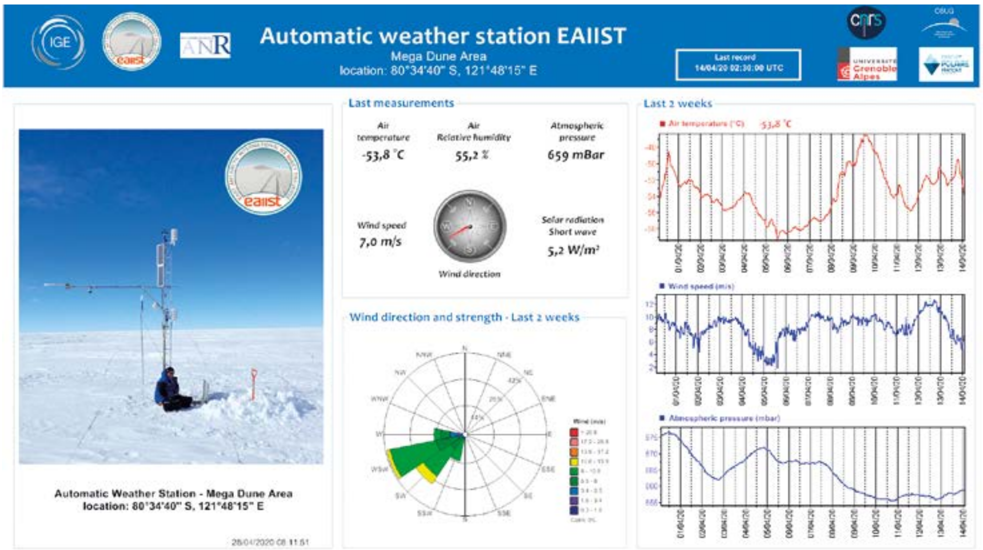


Figure 3. **Readings from the automatic weather station** installed in the megadunes area, located 610 km from Concordia. The stations are operated by solar panels and batteries. The data are sent by the Iridium satellite constellation on a daily basis.

CONCLUSIONS
AND PROSPECTS

Taking stock of such an operation, a great deal of scientific work remains to be done, but it is evident that the amount of effort that was needed on all levels is astounding. Nearly 8 years of preparation were necessary, a period marked by countless meetings, failures, exchanges, and also crises (an emotional experience). Yet, despite the meticulous preparation, there is also a certain amount of luck involved. Had the engine breakdown occurred in the middle of the scientific programme, it would have been a completely different story. And what about the emergence of a pandemic, the type the world has not witnessed since the Spanish flu? The need to prepare this type of complex project well in advance goes without saying because of the type of terrain, how the scientific programme is structured, and the safety of all staff involved. However, luck must also be on your side. What this experience has shown is that long and meticulous preparation work carried out well beforehand and by seasoned and experienced staff is a sine qua non for the success of such an undertaking. Yet this is not enough, as even though it reduces the risks, it cannot eliminate them. I am also aware of the sheer effort and amount of work required to prepare for and to implement such a traverse. The interdependence of people with different profiles is probably what best embodies this type of project.

Finally, on a more forward-looking aspect, scientific tractor traverses are still fantastic exploration tools, but are also heavy infrastructures that are not very agile, and lack flexibility and adaptability. While this approach is perfectly suited to traverses where scientific operations require a large payload, their 'heaviness' can also become an impediment. The Institute is currently working with scientists to find ways of providing a lighter infrastructure capable of covering large areas in a short space of time while guaranteeing safety and autonomy. Having such an infrastructure would make a significant contribution to the study of the strong gradients of altitude, accumulation, temperature, wind, humidity and flow observed along the Dumont d'Urville - Concordia axis.

Finally, it was a shame that there was no film crew on the traverse as initially planned to make a EAIIST documentary, as this will now have to be done with amateur footage and with a different form of narration.

Nevertheless, with luck on our side (favourable weather, good snow, few worries), EAIIST remains a great success both scientifically and logistically and is fully in keeping with the IAGP approach.