Low-cost and low-disturbance science in extreme environments

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Abstract

In this article we will develop how and why small sailing vessels offer unique research opportunities in the study of environmental sciences. We will give a brief description of the design of a small arctic sailing vessel and provide an overview of research activities from 2015-2018. These can be considered as representative of small size and small budget arctic research activities.

Keywords: Polar science, Arctic logistics, proof of concept, small vessel

Article

Human curiosity has driven mankind to the highest summits, the deepest rifts and even into space. The curiosity to go beyond frontiers of the known has given opportunity to mankind to settle and develop on all continents and make life possible where only wildlife prospers.

Of course, this has been due to courage and determination of explorers, but also is closely related to technological progress. Expeditions to remote places have become feasible due to vessels capable of crossing big distances with reasonable chances of success. It has to be kept in mind, that almost 100% of coastlines have been explored and charted from expeditions at sea.

High latitudes and more generally the Polar Regions have resisted exploration for a long time. One of the first expedition reports dates back to Barents in 1596[1] and whalers could

[1] On June 16, 1596, a Dutch expedition led by Willem Barentsz reaches the latitude 79° 49′ N.

sail far into uncharted arctic waters. But the steam engine was one of the major inventions to make arctic exploration possible. One of the very first steamers was the «Palmipede» in 1776, but it relied on paddle wheels that would have been completely incompatible with sailing through ice. One of the very first propellers was to fit the «SS Archimedes»[2] in 1839. Steamers played an essential role in commerce and globalization (1870-1913) and contributed in a historic increase of international trade (Pascali, 2017). Sailing through packed ice only became possible with modern steam engines associated with immersed propellers, since there is no means of reasonably manoeuvring and breaking through ice solely relying on the force from wind. Thus stronger engines and heavier vessels meant higher capacity to push exploration even further. The dramatic «Jeannette» expedition between 1879 and 1881 provided essential scientific knowledge on the arctic environment (De Long and De Long, 1885). Fridthof Nansen's expedition to the North Pole in 1893–1896 on the «Fram» demonstrated the feat of then modern technology (Nansen, 1897). Fridthof Nansen's «Fram» is nowadays considered the precursor of contemporary passive building, making massive use of thermal insulation and triple glazing to provide comfort in the most extreme arctic environments as far back as the late 19th century. A powerful engine and an ingenious lifting propeller were part of Nansen's success.

The invention of «lighter than air» craft such as Andrée's ill-fated «Örnen» allowed for the disastrous attempt to reach the pole with a hydrogen-filled balloon in 1897 (Andrée et al., 1930); but also to fly the Italian designed, built and piloted airship «Norge» that crossed the Pole on May 12, 1926, safely landing in Alaska. Over the following decade, airplanes accomplished successful Arctic flights, including the relevant near-pole airlift of Soviet operation Северный полюс-1 (North Pole-1), led by explorer Ivan Papanin on May 21, 1937.[3] These accomplishments opened even new perspectives of exploration where surface vessels would have had no chance of success, yet. The first artificial satellite, «Sputnik 1», was sent into orbit by the Soviet Union on October 4, 1957, opening an all new era of remote sensing. Satellites, making use of centrifugal force to remain orbiting at very high altitude, nowadays offer a most remarkable means of observation using

[2] SS : steam ship.

[3] Accompanied by three scientists, Ernest Krenkel, Yevgeny Fedorov and Piotr Chirchov, Ivan Papanin landed on the drifting Arctic sea ice in a plane piloted by Mikhail Vodopianov. For 234 days, Papanin's team conducted a wide range of scientific observations in a near-polar area before being recovered by icebreaker «Taimyr» and «Murman»

remote sensing equipment such as surface radars, IR imagery, spectrometers and many other instruments. Nevertheless, they still heavily rely on ground stations and calibration measurements on the ground, which implies that ground observations will remain crucial for accurate remote sensing. In fact, they are complementary.

All these expeditions have yielded invaluable scientific knowledge and have set landmarks to the understanding of climate change that is most visible in the also most inhospitable and inaccessible regions of high latitudes.

All these means of observation have one point in common; they use considerable amounts of resources for construction, deployment and operation and hence have a high environmental impact. Since environmental impacts related to Arctic scientific expeditions are not negligible, they are likely to impact the monitoring itself due to own pollution from the vessels, machinery and equipment (e.g. gen-sets, vehicles, heating, waste …).

Things, however, tend to change.

On the one hand, one can compare the first ascent of Mt. Everest by Hillary and Norgay in 1953, with a team of 20 and hundreds of porters, making heavy use of equipment and oxygen, known as the «Himalayan style». Speed climbers succeed in roughly a day with ultra-light equipment and without oxygen half a century later, this being called the «Alpine style», such as the unofficial Marc Batard ascent on September 26, 1988, in 22 hours 30 minutes and Kazi Sherpa climb on October 17, 1998, in 20 hours 24 minutes. This is much more than an evolution, it is a change of paradigm; it matters less what we do, but how we do things and this also applies to exploration, including scientific expeditions. This paradigm in style could be summarized as follows:

a) Himalayan style: big budget, big team, inertia, planning, overdimension.

b) Alpine style: small budget, small team, speed, adaptation, go with the essential (no place for anything useless).

On the other hand, if one observes the incredible miniaturization and ever greater efficiency of scientific instruments that make it now possible to deploy science in a much more cost efficient and proficient way, new perspectives for «doing science» can be assumed. Whilst in the past scientific equipment was bulky and heavily relied on energy and resources, recent developments often allow light weight, rugged, self-contained and smart solutions that could fit into a back-pack or even a wrist watch.

This does not mean that heavy ice-breakers and hydrographic vessels are obsolete; they will still be a useful and necessary support to polar science. But in many cases light weight expeditions can advantageously substitute what formerly required heavy equipment and costly logistics for deployment in remote areas.

There is a strong relationship between budget and how much resources can be involved in a project. And there is a strong correlation between involved resources and environmental impact. This means that, in many cases, there is causal relation between cost and impact. Therefore, making Arctic science affordable also means reducing environmental impact. It suggests, moreover, that Arctic research may become more accessible, which is more than welcome at the time being where an in-depth understanding of the effects of climate change and, in a wider scope, of human activities, is most essential.

Much of the research work of the next decades depends on having polar vessel support in partially and fully ice-covered seas (National Research Council, 2011).[4] Examples of such vessels are German ice-breaker «Polarstern» (120 m), U.S. Coast Guard icebreaker «Healy» (130 m), Russian (Lukoil, Ltd.) icebreaker «Varandey» (100 m), French «Astrolabe» (72 m) or the much smaller intermediate size schooner «Tara» (36 m). These are representatives of the «Himalayan expedition» style: they rely on big budgets and imply massive use of resources.

Hence, some of the proposed research activities could be light weighted. In the following lines an illustration of light weight arctic exploration in the «Alpine style» and activities conducted on board of a small sailboat shall be discussed as proof of concept.

«Nanuq», named after the polar bear in Inuit language, is a 60 foot[5] polar exploration sailboat designed to accommodate a crew of 2 to 6 persons to live and work over long periods of time in conditions of severe cold.[6] During the Arctic summer, crew can be as numerous as 10 to 12. Even though a reliable engine is a prerequisite for safe polar navigation, big distances have to be crossed before running into ice and so «Nanuq» is also an efficient blue water ocean-cruiser. During the winter 2015-2016 the boat was

[4] See https://www.nap.edu/read/13169/chapter/12#chapter_Split19x-a35 .

[5] 18 metres.

[6] Self-sufficiency with a permanent crew of 4: 1 year.

frozen into the ice in north-western Greenland[7] during a 10 months wintering period to demonstrate her capability to withstand extreme winter temperatures (record temperatures below -40° C) and ice (growing to almost two metres in thickness) whilst being self-reliant and resource efficient. Monitoring was carried out over the period, providing objective evidence that it is possible to design and build a safe, comfortable and almost independent habitat to live and work while keeping technology simple, fair and affordable, even in the Arctic climate.

This goal was achieved by implementing the following features developed with the aim to reduce heating energy demand. That is a major challenge in terms of costs, self-reliance, atmospheric pollution reduction and environmental impact. The adopted solutions, beyond a massive decrease, of carbon footprint (up to 90%), can keep local pollution to a minimum, an aspect that may be critical when monitoring environmental parameters.

The living quarters of the boat are organised in a so-called igloo.[8] The overall thermal insulation consists of a structural core made of specially formulated high density polystyrene foam. The foam is sandwiched between two fiberglass and epoxy resin skins, thus constituting both a structural and an insulating compound without thermal bridges. The thermal transmittance U value of this sandwich is 0.12 $W/(m^2K)$,[9] a strict minimum in terms of thermal performance and a strict maximum in terms of habitability (space use) that is particularly constrained on a small vessel. While the immersed hull acts as a passive heat exchanger in the “warm” unfrozen seawater,[10] a division of the boat’s interior in thermal zones allow intermediate spaces with reduced thermal requirements to act as additional insulating layers[11] around the igloo.

The windows meet a compromise of appropriate visibility when sailing during summer and autumn, when weather is warm, and optimal thermal performance to reduce heat losses during the cold winter. Despite their state of the art performance with a thermal transmittance U value of only 0.5 $W/(m^2K)$, their performance is four times less than the surrounding walls. Therefore, during the extremely cold and dark wintering months, the windows were covered with snow, acting as an additional insulation layer. Glazing consists

[7] 77° 30’ N 66° 33’ W.

[8] Igloo from ‘illu’, the Inuit word for house.

[9] The thermal performance is close to Fridthof Nansen’s «Fram».

[10] -1 to -2° C.

[11] Buffer zones.

of a triple glazing with two low-e layers and an inert gas filling; windows must also withstand high mechanical stress and impacts during navigation, and have a bonding that is qualified for extreme cold, below -30°C.

An appropriate ventilation system allows for healthy air while keeping the heat inside and preventing the cold to flow inside. In order to overcome this paradox a heat exchanger is used to recover heat from the extracted air to preheat the fresh air. A counter-flow plate heat exchanger that has been especially designed for use in the marine environment was used. Particular precautions ensured its smooth operation despite the extreme cold where a conventional heat exchanger would have become frosted, clogged and useless in a short time. These precautions included a system making use of the "warm" water from below the ice-shelf to preheat incoming fresh air and a microcontroller-equipped defrosting bypass.

These features are completed by a strict waste management system and composting unit, especially for the toilet that could have potentially contaminated the natural environment in the close surrounding area of the boat while she was remaining stationary for long periods (10 months). The maximum possible amount of environmental resources (wind and sun) were used to supply energy for on-board electricity, instruments, cooking and auxiliary heating. The long Arctic night, however, can be challenging since solar energy is unavailable for several months, and so appropriate power management is also necessary.

In general, the aforementioned specific features not only demonstrate the potential of passive design and an all-embracing use of environmental energies as response to rarefaction of natural resources and as a step forward in reducing carbon footprint. Indeed, they also provide an ideal base camp for environmental sciences in the Arctic remote and fragile natural environments. One's own pollution potentially reduces the quality and possibility of collecting relevant environmental data.

As it has been pointed out, relying solely on wind force for propulsion is impossible while pushing through ice. But due to an optimised hull design even cruising on engine implies, for Nanuq, a specific fuel consumption of only 3 litres per hour and can be further reduced by a factor 2-3 by extensive use of sail force. In place of a helicopter, small electric drones provide inestimable support to navigation allowing for reconnaissance missions and science. This is possible thanks to their increasing capability of transporting small but powerful sensors to otherwise inaccessible or risky places. The same applies to nowadays available pocket size surface and underwater drones.

Of course, small vessels have downsides, such as restricted availability of space and energy. This can be a handicap and exclude experiments that rely on heavy and resource-intensive probes. But in some cases these constraints can also boost technological innovation: rather than adapt logistics to instruments, instruments may be adapted, to some extent, to specific requirements of available logistics (the «Alpine style»), thus powering technological innovation to make equipment more portable and self-reliant. This has been demonstrated with the PolarqeEEEst cosmic ray detector that was custom-designed and built to fit specifications (Nania and Pinazza, 2018). The newly gained portability now opens new perspectives allowing for deployment in so far unreachable remote locations.

An outline of projects conducted on board of the small sailing vessel «Nanuq» over the 4 season's period from 2005 to 2018 are summarized hereafter. It demonstrates some possibilities and typical applications. Due to the flexibility offered in doing research from a sailboat, several projects have been conducted in collaboration with various institutes and laboratories: atmospheric measurements (LCME, Université de Savoie, France); it was a unique opportunity to measure atmospheric PCB concentration, without the risk of air contamination by ship equipment (Lohman et al., 2004). A passive polyurethane foam sampler was used to measure PCBs concentration all along a longitudinal and a latitudinal transect during the crossing from Europe to Greenland in 2015 and the return voyage in summer 2016. PCB concentration was also measured in the Greenland air during winter 2015-2016 in the Qaanaaq region, north-western coast of Greenland (Cottin et al. 2017), far from any primary PCB source. Another probe was installed in Spitsbergen, Svalbard, for a long term monitoring project. Impacts of climate change on Arctic maritime ecosystems have been studied by investigating the spatial distribution and the phytoplanctonic diversity of microorganisms and nutrient and trace element distribution (CNRS, Université de Brest, France). Microplastics samplings have been made in Greenland and Iceland during the 2016-2017 campaign and all around the Svalbard archipelago and up to 82° N during the 2018 campaign. Plastics degrade slowly, often over hundreds if not thousands of years. This increases the probability of microplastics being ingested and incorporated into, and accumulated in, the bodies and tissues of many organisms. The entire cycle and movement of microplastics in the environment is not yet well understood, but research is currently in progress to investigate this issue. Sampling of microplastics in Arctic waters is particularly demanding due to cold and ice. Analysis is done by IFREMER (France) and CNR-ISMAR (Italy). Geographical mapping of several sites of historic interest have been conducted in 2018 while demonstrating the capability of commercial drones to operate in high latitudes. In addition detailed 3D models of glacier fronts were made (GREAL, Italy). PolarQuEEEst extreme energy events aimed at the study of cosmic rays at different latitudes, including the high Arctic (Centro Fermi, Italy and CERN, Switzerland). In 2018 a search mission for the remains of the airship «Italia» lost off Nordaustlandet, Svalbard, in 1928 was conducted as part of the Polarquest2018 expedition. A useful by-product included the partial mapping of still poorly or uncharted waters north of the archipelago. On the way, several micro-projects were conducted, such as retrieving sensors[12] or stranded drifting buoys[13] that would have been too costly to recover otherwise. In 2015 several ocean drifter buoys used in the global weather and climate observation network were deployed on behalf of METEOFRANCE (France).

Experience gathered during five seasons of Arctic expeditions and science shows that experiments must be thoroughly prepared and fool-proofed; laboratory conditions on board of a small vessel are particularly constrained and equipment in the Arctic is exposed to most severe conditions. Operations in remote regions implies that there is no easy back-up or means of repair for damaged equipment. This problem also includes communications since, even if data transfer via satellite is operational, the available bandwidth is narrow and communication protocols must be adapted accordingly.

Conclusion

Science on board of small vessels is not only possible but also complementary to traditional big budget expeditions. In the future it may provide innovative approaches to knowledge that may be inaccessible to conventional research methods since low budgets allow funding of more and longer observation and monitoring campaigns.

While small craft do not have the capacity to break through heavy ice, they are inherently flexible and capable of sailing into uncharted and shallow waters that are inaccessible to

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[12] Temperature probes in Troll springs, Woodfjord, Svalbard.

[13] CNRS ice thickness buoy 'Ringo', Storoya, Svalbard.

other vessels of any kind. Since expedition funding is much easier, small vessels can also reach out over much longer periods of time and still provide self-sufficiency beyond 1 year in the remotest areas.

Light weight, «Alpine» style expeditions in the field of environmental science have gained recognition. At the Polarquest2018 restitution conference in Rome on November 27, 2018, prof. Andrea Riggio, President of the Associazione dei Geografi Italiani (AGeI, or Association of Italian Geographers), was positively impressed with the demonstration, given by «Nanuq», of a different paradigm for future research vessels in the Arctic. The 2018 expedition[14] reached 82° Lat. N and successfully conducted several innovative scientific projects.

Never, before, monitoring and observation have been as small and smart as today. Micro-science definitely adds new ways of monitoring and gives new and unique insights into environmental science. Light weight expeditions may develop into an ideal approach to numerous fields in environmental science, while maintaining the activities' carbon footprint to a minimum. Less weight also means – most of the time - smaller budgets that make science in remote places far more accessible. Small sailing vessels are now robust, safe, self-reliant. They are an efficient alternative or at least a very complementary means to conventional logistics in polar science and, more generally, in remote waters.

[14] PolarQuest2018; Project manager: Paola Catapano, Expedition leader: Peter Gallinelli.

Illustrations

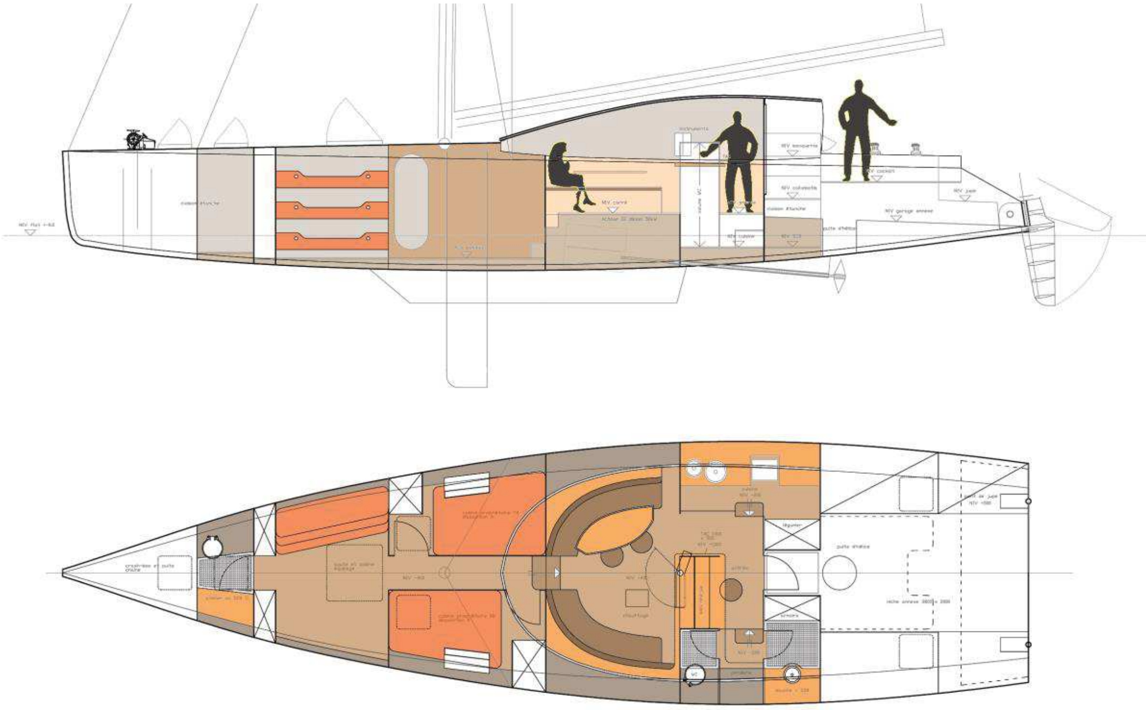

Figure 1. «Nanuq», a scientific base camp and logistical support to science in remote areas, is a 60-foot expedition sail vessel dedicated to research in the Arctic and remote waters. She has a capacity to support a crew for long periods, up to 1 year.

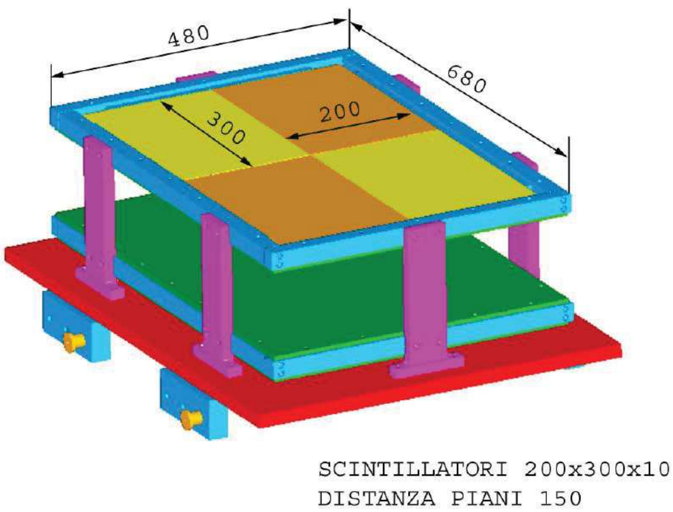

Figure 2. The PolarqEEEst cosmic ray detector that has been especially developed by Centro Fermi based-on specifications of space and energy footprint (12W), for use onboard Nanuq during the Polarquest2018 expedition.

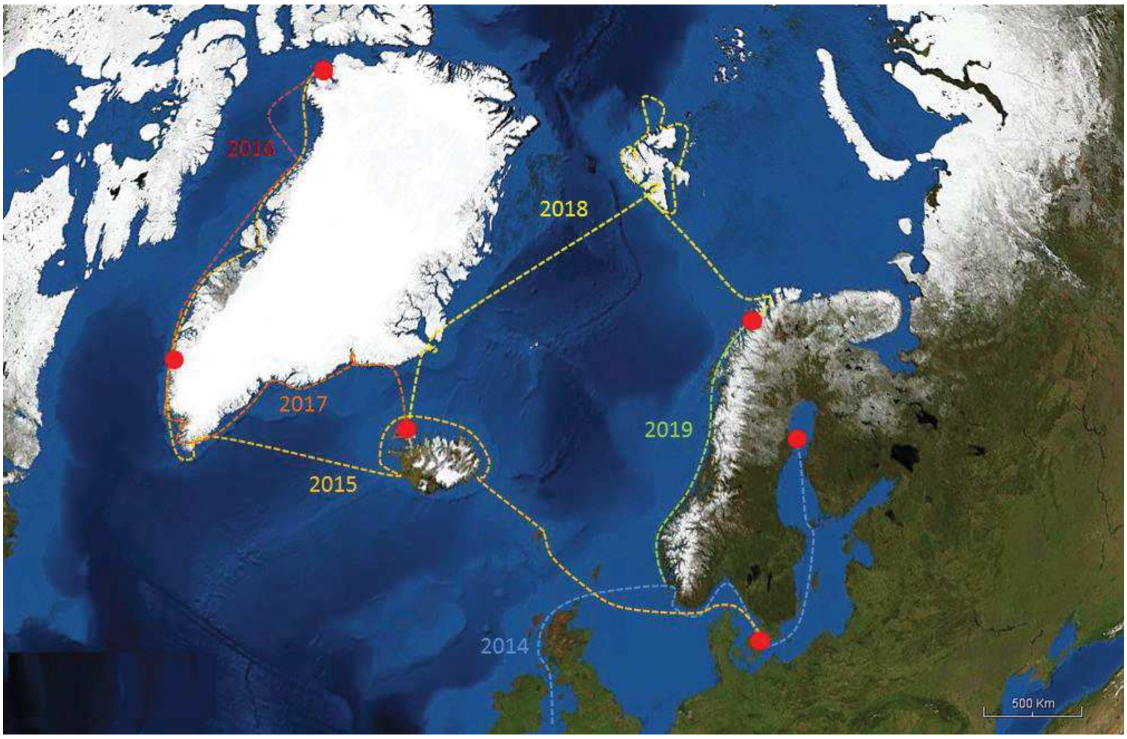

Figure 3. «Nanuq», routes and missions conducted between 2015 and 2018. Red spots mark wintering locations

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