Polar rover mission :

Preliminary concept study

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Introduction :

As part of their development towards the deployment of an autonomous lunar rover, EPFL Xplore is looking to build and deploy a more polar-focused model in the coming years. The objective of this document is to serve as a preliminary concept study to ease the future development of a rover and its deployment in a polar environment for scientifically oriented missions. It will go through the general environmental and high-level technical requirements that the rover needs to fulfill as well as some logistical steps that need to be taken into account for the deployment and operation of the rover. This document also provides some mission and design proposals.

Assumptions :

To develop the logistical part of this document, we assume that a rover has been built at EPFL by Xplore and that a scientific partner is willing to use it for a specific polar mission. We therefore also assume that it can conduct the mission experiments and fulfills all stated requirements.

As a way to prove the ability of the rover to overcome some of the most challenging conditions found on earth, and due to its environmental similarities with the Moon and Mars surfaces, we assume that the rover will be deployed on the Antarctic continent in the vicinity of a scientific station. Deployment is planned during the summer period (anywhere from November to February) as this is the most active period on the continent.

Notes on the current situation :

For over a year now, most of the Antarctic stations are operating with minimum personnel because of the Covid-19 pandemic and most missions have been put on hold. This means that when the situation improves there will be a considerable waiting list to go through before new proposals could be approved. A two to three years waiting period is thus to be expected and planning an expedition before 2024 is not advised.

Regarding the current state of research on Antarctica, the Scientific Committee on Antarctic Research (SCAR) made a horizon scan in April 2014 identifying the main topics to be addressed in the coming decades. The exercise was expected to be repeated around 2020 but no signs of it have been announced yet. It may take place in the coming years, leading to a fresh update of the research needs, and thus new potential missions may arise.

Why taking a rover to Antarctica :

Such an endeavor can be considered unnecessary and prohibitively costly at first glance, but it is undeniable that a rover possesses some advantages compared to manned deployments when taking, for example, the harsh environment into account. A more detailed pros and cons list is given here in table 1.

Pros	Cons
Creates less/no wastes and requires less resources than humans.	Needs specialized maintenance and handling for mission preparation.
Requires less logistics to perform a mission than humans.	May have to make critical decisions with a limited view of the situation.
Can operate in more challenging environments than humans and where accessibility is low.	Prone to simple failures if unforeseen situations arise.
Does not suffer from loss of concentration or patience.	Energy autonomy is challenging for long traverses and operations.
More flexible than a manned operation. (Smaller size and manoeuvrability)	Less flexible than a manned operation. (Less adaptability and minimal equipment)
Can be used when a full manned traverse is not justified.	
Can support manned traverses by taking the risks in place of humans.	
Can support manned traverses by performing side tasks.	
Does not need immediate rescue in case of failure.	
Can operate during polar nights without support or the psychological stress that the lack of light causes to humans.	
Can make long and slow measurements.	
The lower ferromagnetic mass and electronic activity benefits some	

observations.	
Leaves minimal pollution and contamination on its path.	
Can capture public interest.	

Table 1 : Advantages and disadvantages of using a rover for missions in Antarctica.

These general statements lead to a great variety of tasks that could be improved by the use of a rover. As stated during the workshop on Antarctic Autonomous Scientific Vehicles and Traverses held at the National Geographic Society in 2001 (Carsey et al., 2001, p.2-3), rovers are uniquely valuable for such tasks as :

- Data taking on tedious or repetitive routes.
- Traverses in polar night.
- Data acquisition on difficult or hazardous routes.
- Surveys in extremely remote regions.
- Traverses requiring only simple instrumentation.
- Traverses that must be conducted at low speed.
- Augments of manned traverses.
- Procedures incompatible with the presence of humans or combustion engines.

In addition to those benefits to the research community, the south polar plateau presents environmental conditions reasonably similar to the ones found on Mars and thus provides an excellent test ground for Mars or other planetary rovers development, as demonstrated by the NASA experiments with the NOMAD rover (Apostolopoulos et al., 2001).

"The testing of autonomous long-range planetary exploration systems in Antarctica can logically be planned as a long-range traverse similar to those performed for ice sheet science." (Carsey et al., 2001, p.2)

Rovers :	AUVs	UAVs	Other
- NOMAD - Cool Robot - Yeti - GROVER - CIC rover	- Theseus - Autosub - IceFin - BRUIE	- DataHawk - SUMO	- Tumbleweed

Table 2 : Non-exhaustive list of polar autonomous vehicles.

Polar autonomous vehicle research :

First seen mainly as a testing ground for space exploration, Antarctica has seen during the last couple of decades the development of vehicles intended for glaciological science only. The first two autonomous battery-powered polar science rovers; the Cool Robot (Lever et al., 2006, and Ray et al., 2007) and the Yeti rover (Lever et al. 2013); were designed for pulling a ground-penetrating radar for internal ice structure imagery. This method is both useful to map ice layers and to detect bridged crevasses in front of manned traverses. Later, NASA built the GROVER to image the near-surface firn of glaciers similarly and better understand snow accumulation and firn processes (Robertson et al., 2013). The unconventional "Tumbleweed" rover from NASA (Behar et al., 2004) relied on near-surface wind alone to transport itself across the ice sheet. Its instrumentation was focused mainly on monitoring its own movement efficiency and not intended for glaciological science. The most recent CIC rover (Hoffman et al., 2019) attempts to correct the main weaknesses of its predecessors with its low cost, high versatility, and potential for group deployment. Note that the schematics and code for building it are freely available.

"None of the aforementioned rovers have been deployed on missions beyond their original project scope (crevasse detection and mapping of internal layers with radar), and the cost to design and deploy polar rovers has remained much higher than the number of equivalent person-hours required to conduct the same volume of work, as the rovers themselves often require the support of crewed camps." (Hoffman et al., 2019, p.2)

The addition of a structure-from-motion camera during its field tests allowed it to map the surface with photogrammetry while the "traditional" ground-penetrating radar mapped the internal layers. The CIC model encompasses the state of the art regarding polar rover research as the previously cited models were hardly used beyond the personnel involved in their original design and are for the most part out of activity for more than half a decade.

Another field of autonomous vehicles that received increased attention is underwater vehicles (AUVs). The need for undersea ice studies increased for understanding the exchanges between the Antarctic atmosphere, the ice sheet mass loss, and the Southern ocean. This encouraged the development of AUVs such as the Autosub (McPhail, 2009) or the IceFin (Spears et al., 2016). The more recent BRUIE from NASA is more focused on the search for life under the sea ice (Samuelson, 2019).

The strong Antarctic winds make UAVs' use challenging, but some designs are still being used to gather atmospheric data, like the DataHawk (Lawrence et al., 2013) or the SUMO (Reuder et al., 2009, and Cassano et al., 2021).

Stakeholders :

The principal stakeholders regarding the rover deployment are shown in table 3, along with a brief overview of the mutual benefits. The major stakeholders are Xplore, the EPFL, the SPI, the chosen Station, and the scientific community. The main interaction with them is described in more detail below.

Xplore :

The association in itself will not be solely centered on the polar rover project and thus balance with other works within the group will be an important component of the project development. The funds, workforce, and workspace repartition will be part of the concern.

EPFL :

Although EPFL will not likely be much involved during the development of the project, it remains Xplore's parent university and one of the main monetary contributors to the association. EPFL provides the project team its premises and most of the association's members and potential partner laboratories come from it.

Swiss Polar Institute :

The SPI will be a major partner in ensuring the project's successful development. It possesses many valuable contacts and considerable expertise in organizing field tests the likes of which are planned with this project, and it could provide complementary funding through its Technogrants program.

Station :

The station and its personnel will be the team's hosts during the several weeks of testing. Having a well-established contact on site will be essential for coordinating outside trips and refining requirements based on their unique experience with the local conditions. If future commercial opportunities open themselves, the station could be interested in purchasing a rover for future missions.

Scientific partner and community :

Having a partner laboratory of some sort will allow refining the requirements regarding the rover equipment, tasks, and its further deployment in specific interest regions. Similar to the station, there is potential for future rover sales if it performs well enough and gets enough visibility in the community.

to / Provides	Xplore	EPFL	SPI	Station	Governmental institution	Scientific partners	Service Providers	Scientific community	Public
Xplore		Project proposal Public interest	Project proposal Public interest	Contract Future rover support	Project proposal	Field data Payload space	Contracts	Science and technical progress Research	Entertaining technology deployment
EPFL	Renown Project approval Infrastructure Funding Skilled workforce		Skilled partners	Skilled partners	Policy support	Skilled workforce		Policy support Skilled workforce Research	Technology development
SPI	Project approval Contacts Logistics Funding	Partnership opportunities		Partnership	Policy support	Contacts		Policy support Research	Entertaining technology deployment
Station	Base of operations, supplies and logistics Future partnership	Access to Antarctica	Access to Antarctica		Physical scientific presence in Antarctica	Base of operations	Contracts		
Governmental institution	Project approval			Economic support		Economic support		Policy support Economic support	
Scientific partners	Requirements Policy support Future partnership Future funding	Rewarding employment	Partnership opportunities					Science and technical progress Research	
Service Providers	Transport, supplies			Supplies					
Scientific community	Science systems Policy support Knowledge	Policy support Rewarding employment Knowledge	Policy support Knowledge	Policy support Knowledge	Policy support	Policy support Knowledge			Technology development
Public	Rewarding interest Policy support	Interest	Interest	Interest	Public opinion	Interest		Interest	

Color legend : Policy/Opinion | Goods & Services | Money | Knowledge/Information | Employment

Table 3 : Stakeholders and the benefits provided between them. The benefit type is color coded.

Authorizations :

Before deployment, the project must acquire authorization from the national Antarctic program specific to the station or stations involved. Switzerland does not have an independent activity on the continent so contact must be made with foreign-held stations. They can be approached independently but the Swiss Polar Institute may provide valuable contacts as well as facilitate the development of incoming logistics.
Although not necessary, approval by the SPI is recommended as they can provide insight on some mission details and the refining of the logistical part of the project. By making a project proposal through their Technogrants program, open for submissions from August to mid-October, potential complementary funding can also be acquired.

To facilitate the approval process for an Antarctic mission, it is important to precise why this location has its importance and why the project could not take place somewhere else with similar conditions, as such endeavor will engage a lot of logistics and costs that need to be justified and will also have a non-negligible carbon footprint. See the "Why taking a rover to Antarctica" section as a starting point.

As a general note, the project must also be compliant with the Antarctic Treaty and should follow the operational guidelines of the Council of Managers of National Antarctic Programs (COMNAP) if applicable.

Transport and Costs :

Access to the continent is not easy due to its evident remoteness. The main entry points are South America, South Africa, and Australia. From there, there usually is a first transport either by plane or cargo to a station near the coast and eventually a second inland flight to another station deeper in the continent.
The costs vary greatly depending on the chosen station and its operator, its position on the continent, the length of stay, specifics of the mission, etc. To get a rough estimate, this section provides an example for a stay at the Belgian Princess Elisabeth Antarctica Research Station. This specific station has been chosen because of the frequent partnership with SPI and its focus on offering a solid logistics backbone for international science programs.
The transport from Europe to Princess Elisabeth station (PEA) involves a stopover at Cape Town (CPT) and another at the Russian Novolazarevskaya Station (Novo). Table 4 gives an estimate of the costs for one person with scientific equipment.

Europe - CPT roundtrip	CHF 1,000
Stay and services at Cape Town	CHF 3,000
CPT - Novo flight roundtrip	CHF 13,000 - 15,000
CPT - Novo cargo	CHF 15/Kg per way
Novo - PEA feeder flight	CHF 6,000
Stay and food at PEA	CHF 100/day
Overheads	15%

Table 4 : Deployment costs breakdown for one person with scientific equipment.

In summary, a one-month stay at PEA with services and transport of scientific equipment goes roughly around 35’000 to 50’000 CHF per person. Figure 1 illustrates the location of both Novo and PEA on the continent.

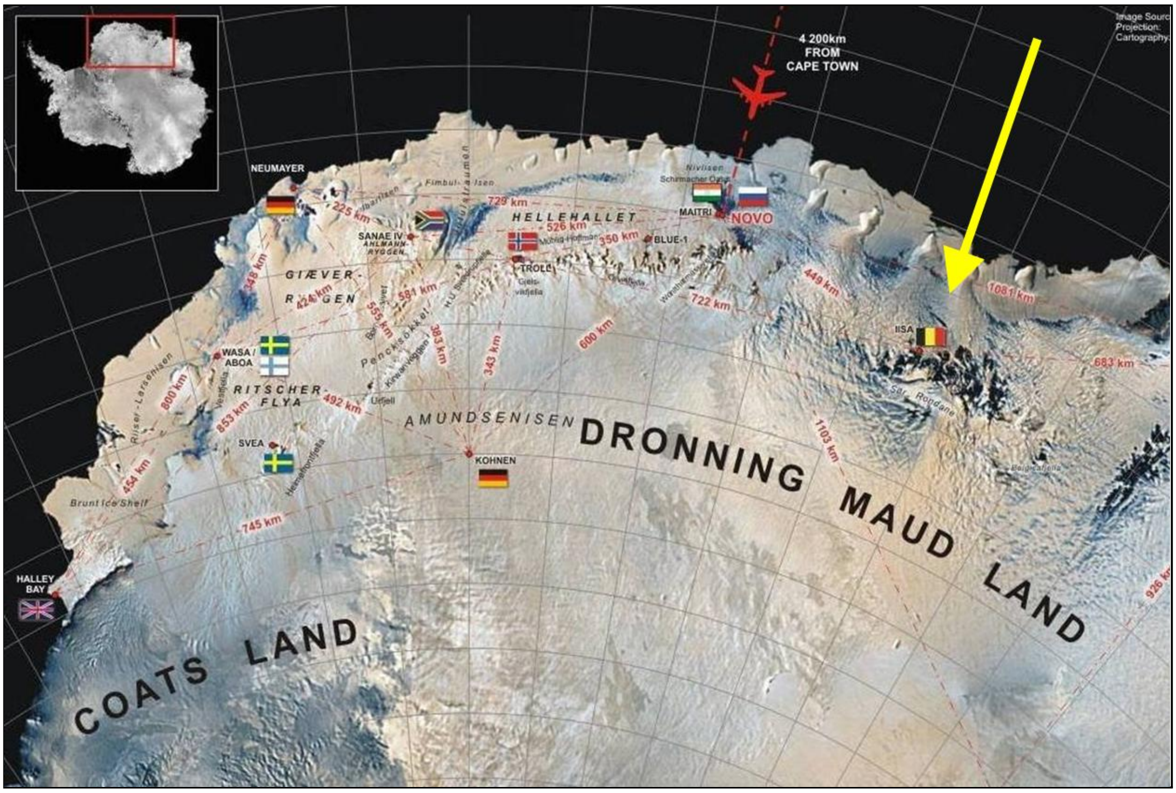


Figure 1 : The PEA station is located under the Belgian flag, under the yellow arrow. The Novo station can be seen under the red plane symbol. (Gonçalves, M. R., 2010)

Mission proposals :

Here is a list, in no particular order, of potential tasks for which an autonomous vehicle could be used. It has been selected in the gathering of general tasks and research proposals from both the 2001 workshop on Antarctic Autonomous Scientific Vehicles and Traverses (Carsey et al., 2001) and the 2014 SCAR horizon scan (Kennicutt et al., 2014).

Scouting manned parties :

Crevasses are a common occurrence in the desert plains of Antarctica and the snow easily bridges over and conceals them to advancing parties. A rover with a sounding radar can detect them with minimal risks and warn a manned party.

Ice Sheet Mass Balance measurements :

The mechanisms behind ice flow and its links to surface and bed topography are poorly understood and research to uncover how, where and why ice sheets lose mass lacks field data. Mapping of the surface, the snow and ice accumulation layers, and the bed topography with a ground-penetrating radar is a slow and repetitive task, physically and mentally taxing for manned parties. This kind of survey also requires periodic measurement missions along established paths, which is an ideal task for rover deployment. This is generally the mission performed by the existing rovers.

Heat and Momentum Exchanges Through Sea Ice measurements :

The interaction between the atmosphere, the southern sea, and the Antarctic sea ice is a system highly sensitive to climate change and the heat, momentum, and gases exchange through the sea ice are strongly affected by its formation and melt. A lightweight buoyant rover could be used to take induction or acoustical measurements of sea ice and snow cover thickness.

Small-Scale Geophysical Structures mapping :

Geophysical structures are mapped either during linear manned traverses or with airborne platforms insensitive to small-scale phenomena. Local two-dimensional datasets taken with gravimeters and magnetometers from a slow-moving rover would be a solution to the current methods' defects.

Snow Surface Chemical Processes measurements :

During the late polar night, human investigations are difficult to support. It is also the time at which the complex chemical exchange between the atmosphere and snowpack is at its peak and ideal to measure. Due to the small concentration of chemicals, the presence of humans and combustion engines also comes with a great risk of contamination, whereas a rover suited for late polar night deployments would be able to make those measurements safely. Polar night data is something that is also generally lacking in the other fields of research and a modular rover could help tremendously to reduce this information gap.

Mission example :

Goal :

Looking at the current needs of the scientific community and the current state of rover research in polar regions, the missions a rover is most likely to perform will inevitably involve long-distance travel, be it to reach isolated points of interest or for mapping needs, and it will generally be tasked with pulling or pushing most of its scientific payload rather than carrying it onboard. As to keep this document generic and because it will probably be the first test mission carried out after reaching the station, the proposed mission is a simple demonstration of those two abilities with the use of already established instruments.

Path and instrumentation :

The mission will take place near the PEA station. The small test of endurance will be a ~9 km trip around the station and the adjacent mountain, with a small mapping exercise at the foot of the Nunatak and a manual remote test drive. The rover will be towing a typical ground-penetrating radar system (less than 80kg) placed on a low friction plastic sled and it will be equipped with an additional DSLR camera. This equipment and its use are largely inspired by previous deployments of both the Yeti and CIC rovers.

The expected speed of the rover in these circumstances depends on its design but could be about 0.5m/s, which leads to an approximative 5 hours long mission with an additional 30 minutes of mapping and 20 minutes of manual remote driving.

The camera can be used in combination with the GPS receiver to build a surface elevation map with structure-from-motion photogrammetry while the radar images the internal ice structure and maps the snow stratigraphy. As mentioned in the "Mission proposals" section, this data can be used in surveys to study for example the interaction between surface and bed topography and ice flow, to better understand sastrugi evolution or to better understand the influences of surface topography on snow densification.

The mapping exercise consists of a 40m by 80m area over partially snow-covered ice. With a scanning width of around 5m, the total mapping path will take under 30 minutes to complete, which is enough for a simple mapping test. Figure 2 illustrates the mission path, and figure 3 gives a better view of the station.

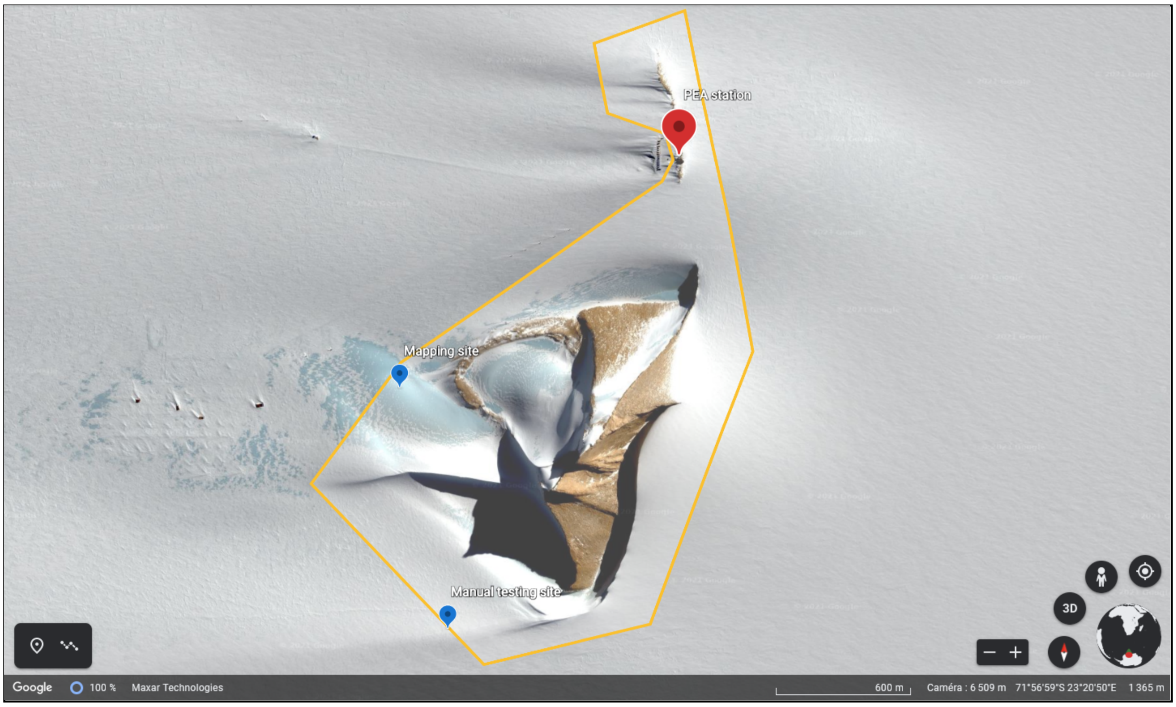


Figure 2 : Suggested path around the PEA station and the nearby mountain, with markers for the station, the mapping site, and the manual testing site. The total path is about 9km long.
Screenshot taken from Google Earth.

Figure 3 : Image of PEA station next to the Utsteinen Nunatak and with the Sør Rondane Mountains in the background. (International Polar Foundation, 2021)

ConOps of logistics :

The logistics ConOps assume that the rover is already built or is at least fully conceptualized a year before the first deployment in Antarctica. This approach is conceivable since, as stated earlier, the design should not be instrument-dependent but rather made to pull its payload on a sled. The time T used in the ConOps of logistics in table 5 is the arrival at PEA station, preferably around the end of December to have the best meteorological conditions. It is to note that the evaluation results from the SPI Technogrants are sent at the latest 4 months after the October deadline. If a positive answer comes fast enough, the mission can begin the same year as the proposal, otherwise, it may have to wait until the next December.

T - 1 Year	- Contact scientific partners that could be interested in missions. - Start definition of project specifics. - Finish rover assembly if needed to have enough time for testing. - Get in touch with SPI and get contacts at PEA. - Contact PEA for project approval.
T - 4 Months	- Make the (hopefully successful) mission proposal to SPI through Technogrants.
T - 1 Month	- Finalize logistics with the help of SPI and PEA.
T - 1 Week	- Departure to CPT. Flights to NOVO and PEA highly depend on the weather. Expect up to a week to reach PEA.
T	- Arrival at PEA, unpacking.
T + 1 Day	- Finish installations and start preliminary tests.
T + 3 Days	- First mission around PEA and Utsteinen Nunatak.
T + 1 Week	- Perform partner missions and data analysis.
T + 1 Month	- Return to Switzerland by NOVO and CPT.

Table 5 : ConOps of logistics. Time T is around the end of December.

ConOps of mission :

The following ConOps is based on the rover constantly moving at an average speed of 0.5 m/s on compact snow, but its movement speed can be highly affected by the snow conditions on the path. The travel times are only overestimated by 5% to 10% and do not hold if the area were to be covered by fresh and soft snow, which would hinder its movement. Time T in table 6 is set at 9 am, but it is an arbitrary decision since the sun is in the sky all day.

T	- Departure from the station.
T + 55min.	- Start of ice mapping at the foot of the Nunatak.
T + 1h30min.	- Resume autonomous path following.
T + 2h15min.	- Request manual control
T + 2h35min.	- Resume autonomous path following.
T + 5h50min.	- Arrival at the station.

Table 6 : ConOps of mission example. Time T is around 9 AM.

Design constraints and opportunities :

Environmental conditions :

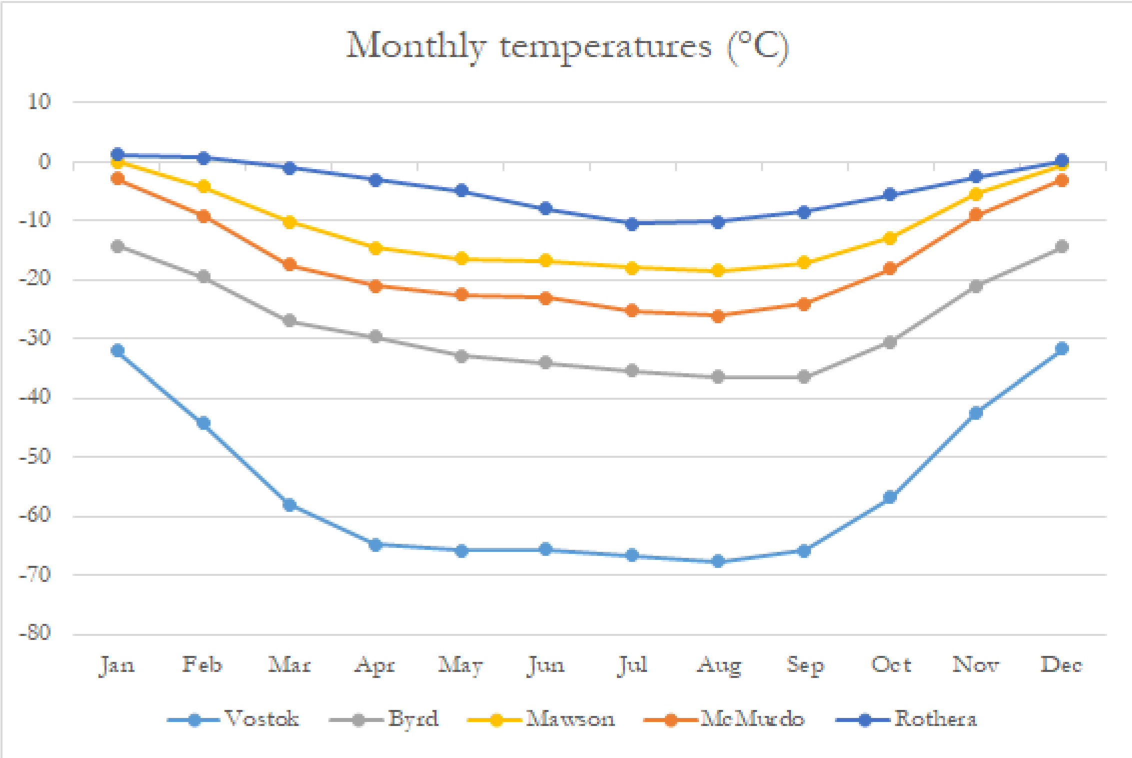
Antarctica is a large continent, and its climate varies greatly from region to region. It is subject to more extreme conditions than the Arctic, notably due to its altitude and the strong katabatic winds created by the thick glaciers that cover its surface. It is hard to find complete data for every region, but table 7 provides an overview of different locations and should give a rough idea of the overall environmental conditions. Monthly winds and temperatures can be found in figures 4 and 5.

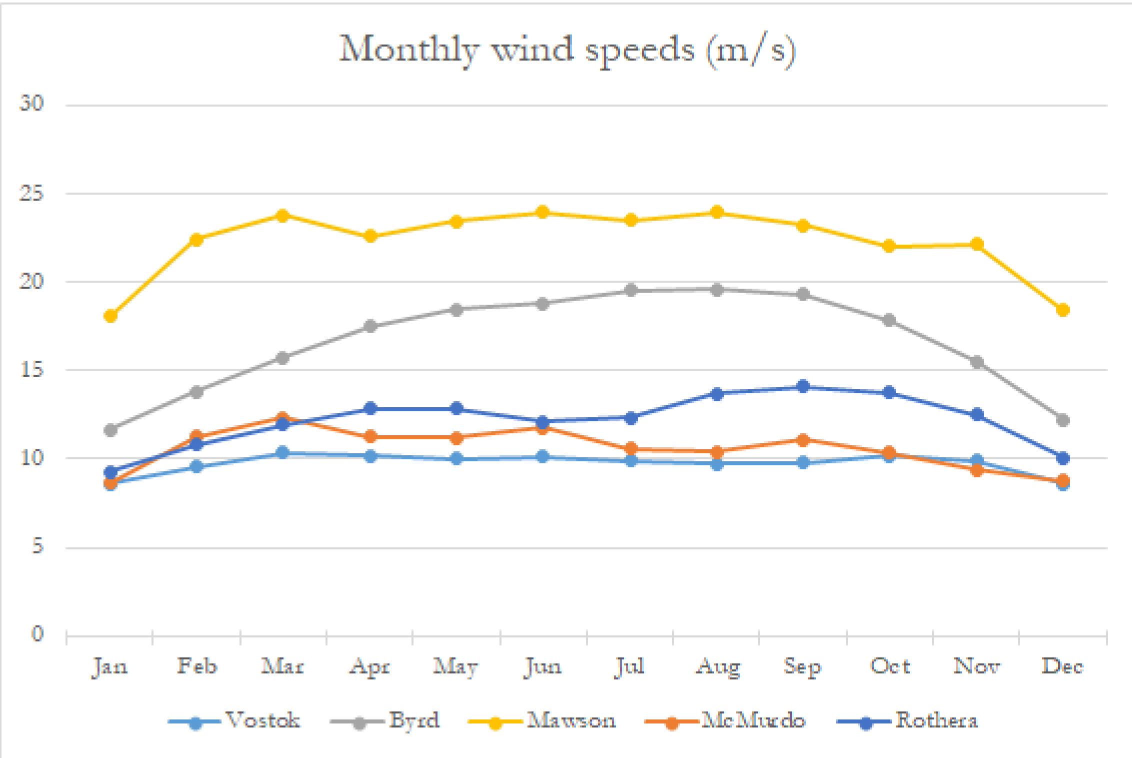
	Continental high plateau (Vostok, 3490 m.)	Continental low plateau (Byrd, 1515 m.)*	Continental low latitude coast (Mawson, 16 m.)	Continental high latitude coast (McMurdo, 24 m.)	Antarctic Peninsula (Rothera, 32 m.)
Avg. Temperature (°C)	-36.8 (5.6)	-17 (3.2)*	-2.6 (2.2)	-5.6 (3)	-0.1 (1.3)
Min. Temperature (°C)	-44.3 (5.7)	-21 (3)*	-5.1 (2.1)	-8.7 (3)	-2.4 (1.2)
Avg. Pressure (hPa)	630 (3.9)	812.9 (4.5)*	985.4 (3.3)	986.2 (4.4)	985.5 (4.3)
Avg. Wind speed (m/s)	9.1 (1.4)	13.4 (1.7)*	21.4 (3.2)	8.8 (1.1)	10.9 (1.8)

Table 7 : All values are averaged over the last 20 years and cover only the Antarctic summer (November to February). The standard deviation is given in parenthesis. * Byrd's values are outdated (dating from 1957 to 1970) since the station was abandoned, but modern data should not be too different. Data recovered from the SCAR READER project, from November 2000 to February 2021.

In general, the inland regions, in altitude, are the coldest but the coast is subject to the greatest winds as the cold air travels down from the high plateau.

Due to the overall coldness of the environment, the absolute humidity is very low, much like a desert. The high winds however lift a vast quantity of snow from the ground which can infiltrate easily and, in insulated areas, the internal heat of a system may lead the snow to melt and liquid water to infiltrate. Good protection against snow infiltration is thus needed to safeguard the sensitive elements.





Figures 4 and 5 : Monthly temperatures and wind speeds averages of 5 different stations. Once again, Byrd's values are outdated, but help get an idea of the continental low plateau conditions. All values were calculated using the SCAR READER project records.

The blizzard can sometimes lead to really poor visibility conditions and snow can build up in front of sensors. The winds can have enough force to slow a rover down, which would increase the power consumption and travel times, and cause drifts or even overturns.

The ground itself is relatively flat, mostly covered by snow or ice, and soil can be found near mountains and on part of the coast. In general, the incline expected to be traversed should not exceed 30°, which is a slope only found on larger sastrugi. The sastrugi are small-scale wave structures carved in the snow by the blowing winds and are frequent all over the continent. They typically are under 30cm peak-to-trough at 2m wavelengths. Unlike sand dunes, they are hard and resilient, easily deflecting skis and tracks of their course and can, as they extend for tens of kilometers, increase the travel distance and power consumption. In high-wind regions and near topographic features, this phenomenon grows in size and severely hinders movement. Fortunately, these more extreme zones can generally be avoided during planning and can be detected by remote sensing. Some crevasses can also be expected but rarely away from mountains and ice streams. Generally bridged by snow, most can be crossed safely by a lightweight vehicle (< 100kg).

Although during summer the snow is firm most of the time and suited for low-pressure tires, temperatures, recent precipitation, and topography can greatly affect snow density and thus rover mobility.

"*Building a polar rover capable of driving long distances over an ice sheet requires a careful ledger of total traction and resistance associated with driving in snow. The drive mechanics originally developed for extraterrestrial rovers have been adapted for use in other polar rover designs to ensure platform mobility and efficiency on snow." (Hoffman et al., 2019, p.3)*

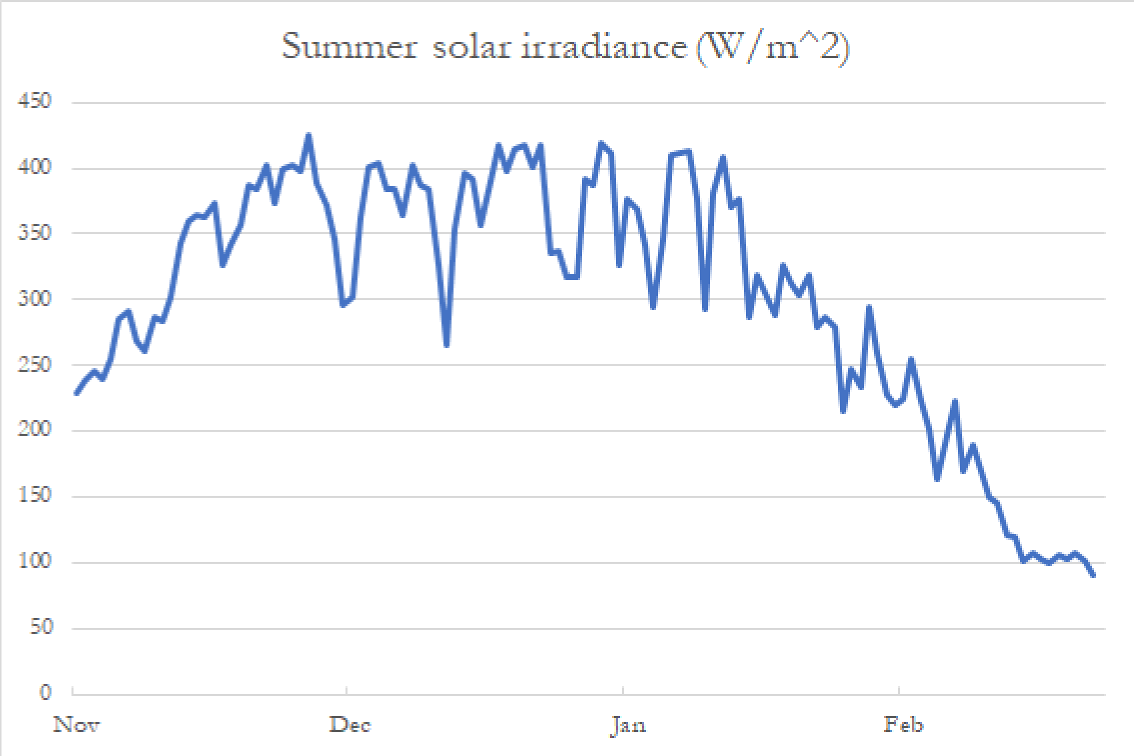
The Bekker locomotion theory was successfully used on the CIC rover to predict wheel traction and resistance as it compresses the snow, assuming it to act as a nonlinear spring under the applied pressure. In table 8 are the cohesion parameters of dry, low-density polar snow found after large snow-fall events which should be the worst case encountered by a rover.

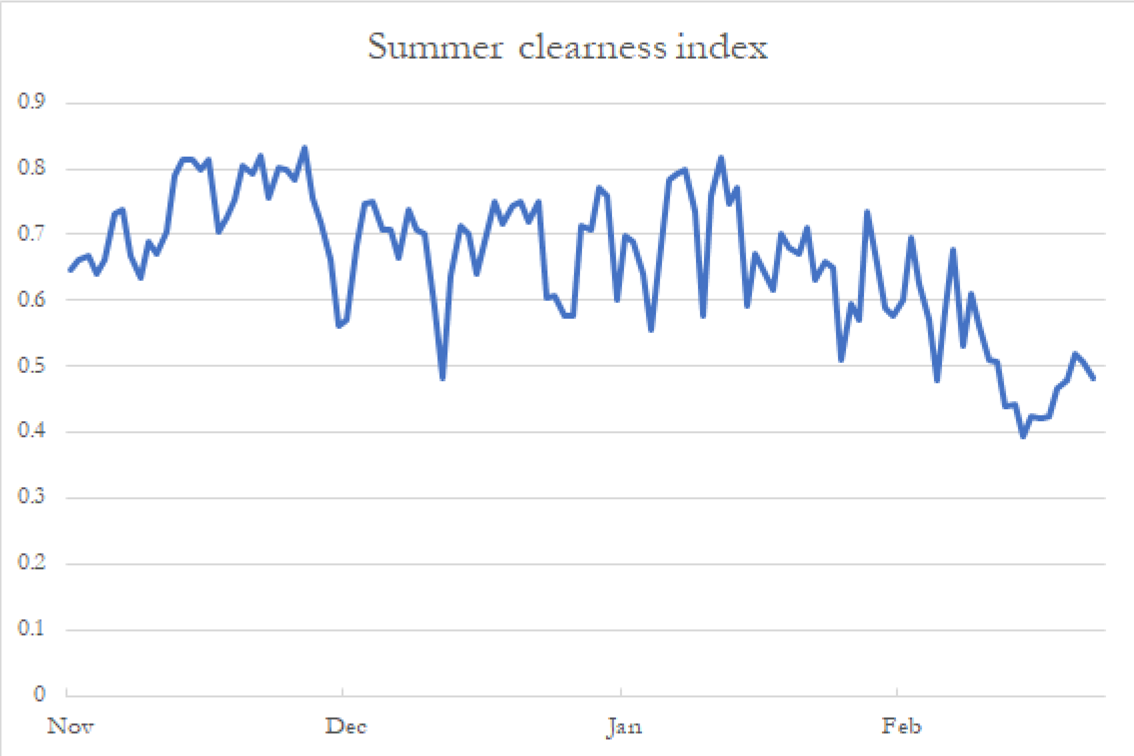
Parameter	Description	Typical value
k_1	Modulus of snow cohesion	$0.2\ N/cm^{n+1}$
k_2	Modulus of snow friction	$0.1\ N/cm^{n+2}$
l	Width of wheel *	12.7 cm
z_0	Total depth of sinkage *	1.3 cm
n	Pressure sinkage exponent	0.9-1.2
D	Diameter of wheel *	37 cm
c_f	Internal friction coefficient	0.05-0.10
ϕ	Snow wheel friction angle	30-60°
s	Wheel slip ratio	0.02

Table 8 : Parameters for Bekker locomotion equations used by the CIC rover.
The parameters marked by a * are rover specific values (Hoffman et al., 2019, p.3).

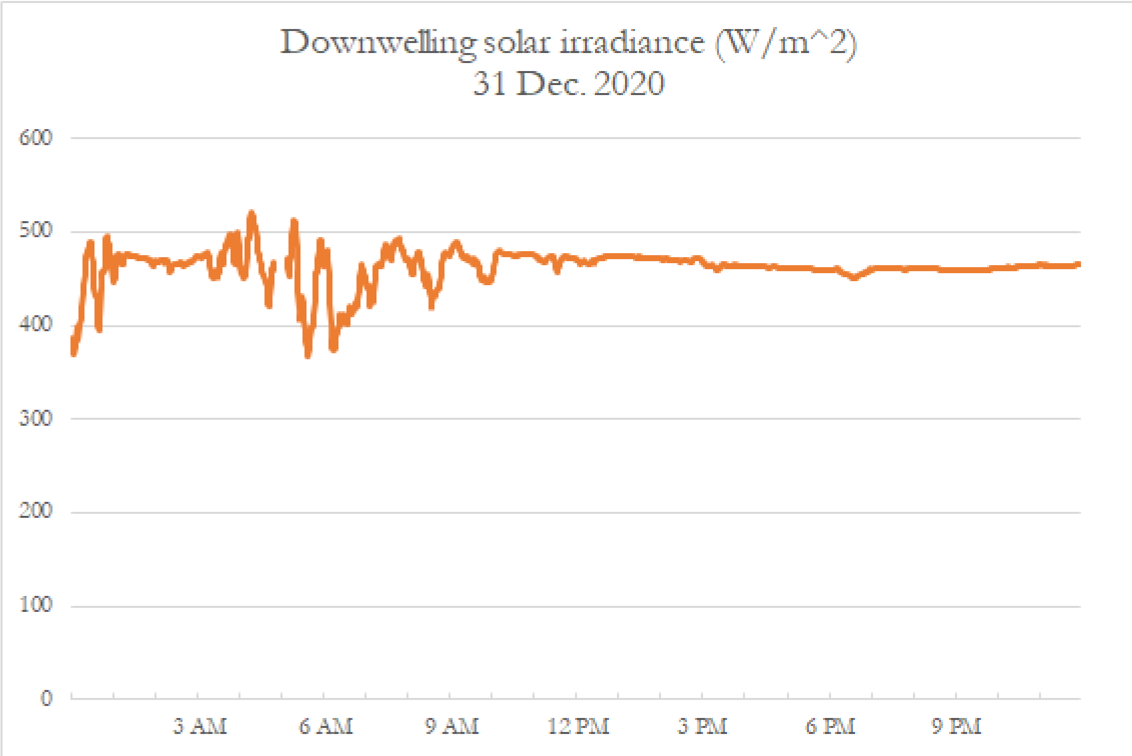
During the better part of the Antarctic summer, the sun stays above the horizon for the entire day. The closer a region is to the pole, the longer its period of full daylight is, with the south pole itself having a close to 6 months long uninterrupted daylight period. Because the precipitation is also almost non-existent, there is a high potential for solar energy usage. It is also to note that, due to the white snow covering, a non-negligible amount of solar radiation is reflected from the ground and can also be harvested (Lever et al., 2006). See figures 6 to 9 for estimates of solar irradiance and clearness index through the summer and a typical day.

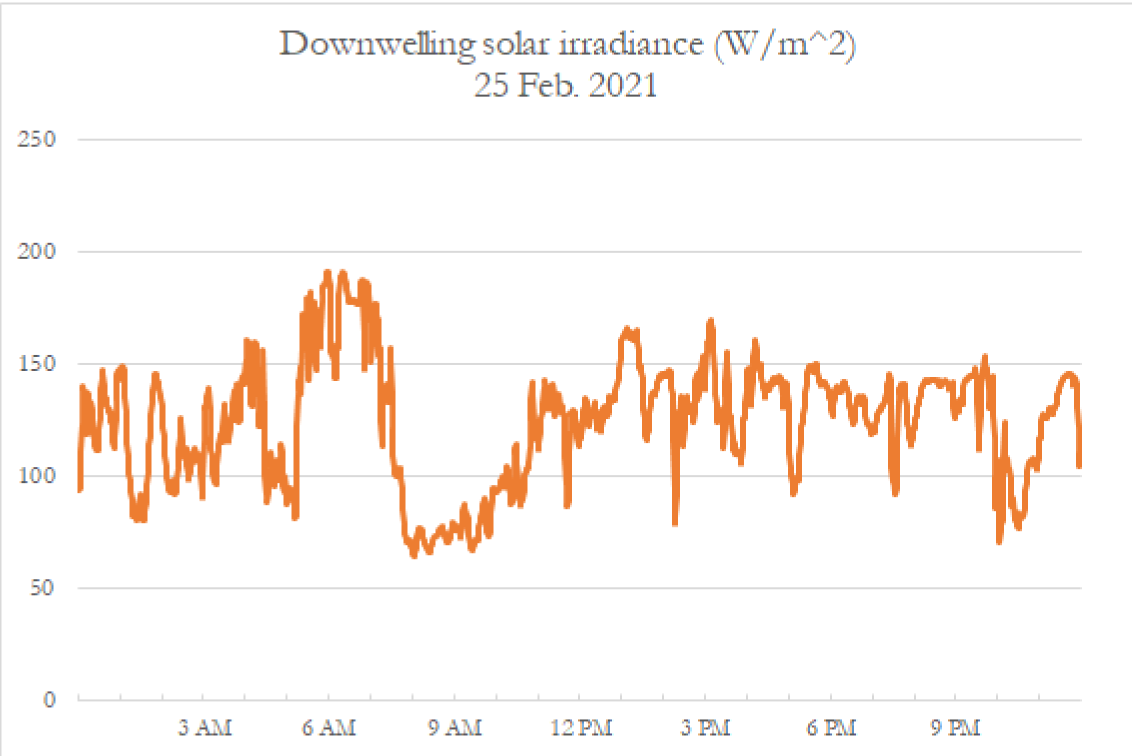
An alternative for solar panels, if planning to deploy the rover for polar night missions for example, would be to utilize wind turbines to generate power. This approach has not been explored much and could be a field of research in itself, as demonstrated by Liu et al. with their multifunctional wind energy unit (2014).





Figures 6 and 7 : Plot of average solar irradiance and clearness index over the Antarctic summer in the South Pole. Average over the last 5 years. These data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program.





Figures 8 and 9 : Examples of the daily evolution of solar irradiance on the 31st of December 2020 and the 21st of February 2021. These measurements come from the American Amundsen-Scott South Pole Station (Global Monitoring Laboratory, 2004).

Other design constraints :

Here is a list of other design constraints and recommendations that do not come from Antarctica's environment but the logistical and instrumentation constraints.

Shipping material to Antarctica is expensive. Cargo space is limited and usually paid for by the kilo. In addition to that, transport via helicopter or ground vehicles to deployment sites is common and the size and mass of equipment can be limiting. A rover under 100 kg and 1 m^3 should accommodate most of those constraints, and the mass limitation also complies with the traverse of bridged crevasses. Not required but desirable is the ability to easily separate the rover into subparts, which would considerably help with storage and handling. Replacement parts can take months to come from outside the continent, so special care must be taken for the possibility to repair or rebuild a good part of the rover elements easily with the standard workshop equipment available on the station.

As stated earlier, the instrumentation will mostly be towed behind the rover, which means it will need to have an attachment for sleds and enough force to pull its payload and itself, even on inclines. A pulling force over 250 N should be more than enough to move a ground-penetrating radar in most snow conditions.

It is hard to state a requirement on the rover speed. The Yeti rover, which is the most used model to date, can move at an average speed of 1.5m/s and a top speed of 2.2m/s. This allows it to conduct large surveys rapidly and scout in front of parties without impeding its progress too much. This comes at the cost of battery time and mission range reduction. The CIC rover on the other hand is suited for longer-range missions but has a limited speed of 0.8m/s. This will eventually depend on design focus choice, but a target speed of 1 m/s could be a good middle ground, with a battery duration of 6h and a range greater than 20km. If choosing to add solar panels or wind turbines to recharge batteries during deployment, the range requirement must obviously be upscaled. A 1'000 km range would meet the same requirements as the Cool Robot, which is entirely covered with solar panels.

In regards to handling and operating, the current lack of widespread use of rovers means external personnel is unlikely to be able to reconfigure them easily. The ability to be equipped effortlessly for a variety of missions and a user-friendly interface should help lower the barrier to use, which is a necessary step if planning a long-term partnership with the stations' personnel.

To follow a predetermined path and to map data effectively on the evermoving ice of the continent, it is essential to have a GPS receiver able to pinpoint the rover location with a better than 5m accuracy. A good route selection and decision-making algorithm working in tandem with a crevasses/sastrugi detection and avoidance system are recommended for mission completion reliability. A manual remote control mode could be envisioned in case of emergencies.

Research stations in Antarctica don't have a lot of funding to spend on a rover. Although the most limiting cost is related to shipping, the vehicle itself should not exceed the ~20'000 USD required for the construction of existing rovers without a significant performance or feature improvement, like the ability to conduct extended missions autonomously during polar nights. On the other end of the spectrum, the CIC rover was able to lower the cost down to 3'000 USD with relative performance drops.

Table 9 provides a summary of some of the most general design constraints. The proposed concept is a middle ground between the specialized expensive models and the low-cost CIC model. Some parameters may have to be tweaked if planning for extreme long-range or polar night deployments.

Parameter	Value
Rover mass (kg)	< 100
Dimension (m^3)	< 1
Pulling force (N)	250
Speed (m/s)	1
Run time ($hours$)	> 6
Range (km)	> 20 (1000)
Path tolerance (m)	± 5
Min. temperature ($°C$)	-30
Cost (USD)	< 20'000

Table 9 : Summary of general, quantifiable design constraints.

Summary :

There is a true potential for rover research in the polar regions, especially in Antarctica, where the harsher conditions are better left to autonomous vehicle deployments rather than manned expeditions. Only a few models have yet been deployed, with the more established ones being underutilized due to a lack of versatility and a prohibitive price, while the more recent CIC rover is limited in performance by its aim at a cheap fabrication. The rover research domain is still at its debut, but there is sufficient data available to build a new platform, combining efficiency and reasonable costs or significant capabilities improvements for a higher price. The harnessing of wind power and the deployment of rovers during polar nights are two almost unexplored fields, and innovating in these domains could set a new generation of rovers that allows new tasks to be accomplished. More broadly, despite the variety of advantages they propose, it remains to firmly establish the use of rovers in Antarctic and polar research methods outside of specific circumstances.

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