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Annex A to the WP presented by Italy

In progress
Comprehensive Environmental Evaluation

Proposed construction and operation of a gravel runway in the area of Mario Zucchelli Station, Terra Nova Bay, Victoria Land, Antarctica

April 2015

Rev. 0

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Non-technical summary

I Introduction

This "*In Progress Draft*" of the Comprehensive Environmental Evaluation (CEE) has been prepared for the construction and operation of a new gravel runway in Terra Nova Bay (TNB) pertinent to "Mario Zucchelli" Station (MZS), Antarctica.

The document has been prepared by ENEA which is in charge for the implementation of the Italian Antarctic expeditions, logistics and maintenance of the stations.

The CEE describes the proposed activity, the alternatives in terms of different sites and logistical configuration, the local environmental and the predicted environmental impacts, in accordance with Annex I of the Protocol on Environmental Protection to the Antarctic Treaty (1998) and the Guidelines for Environmental Impact Assessment in Antarctica (Resolution 4, XXVIII ATCM, 2005). Actions to mitigate the impact of infrastructures are proposed to reduce the assessed risks.

The WP-CEE describes the following contents:

- Purpose and description of the proposed activity;
- Analysis of the alternatives to the proposed activity;
- Site selection and initial environmental reference;
- Construction, operation and maintenance of the new gravel runway;
- Analysis of potential environmental impacts during construction and operation phase;
- Prevention and mitigation measures to minimize environmental impacts;
- Gaps in knowledge and uncertainties.

Considering the past studies reported in Information Papers (XXV, XXXVI, XXXVII ATCMs, respectively IP041, IP080, and IP57), the location of the gravel runway, at Boulder Clay (74° 44'45''S, 164° 01'17''E, 205 m a.s.l.), was chosen in convenience the construction/operation impacts and logistical advantages, through an evaluation process of two candidate sites (Boulder Clay and Campo Antenne) and after the past unsuccessful attempt of a permanent ice sheet runway (Nansen Glacier).

The gravel runway will operate as a long term solution facility for personnel and materials transportation of PNRA, having also in mind that it would become an important common facility for the international network of Antarctic Programs established in Ross Sea region as well.

The PNRA is trying to meet the international guidelines related to the reduction of logistical costs in favour of research activities funding. The project for the realization of an international transport hub in the Ross Sea area has already been officially supported by German BGR, but also KOPRI, IPEV and ANZ showed interest, opening to future agreements.

From a multinational feature of such facility it would benefit the costs cutting and the environmental impact reduction in Antarctica, as Concordia Station and Dromlan Air Network are already testifying. A joined airstrip in TNB could likely reduce naval activities and increase safety, being adopted as an alternate airstrip for McMurdo air operations and an emergency way in winter for the near Korean Jang Bogo Station.

Two locations (Figure A) were deeply investigated for the airstrip realization, "Campo Antenne" and "Boulder Clay" (unofficial place names), and, keeping in consideration the minor environmental impact of the activity in terms of moved rock volume, the second one has been chosen as most suitable location for the proposed gravel runway.

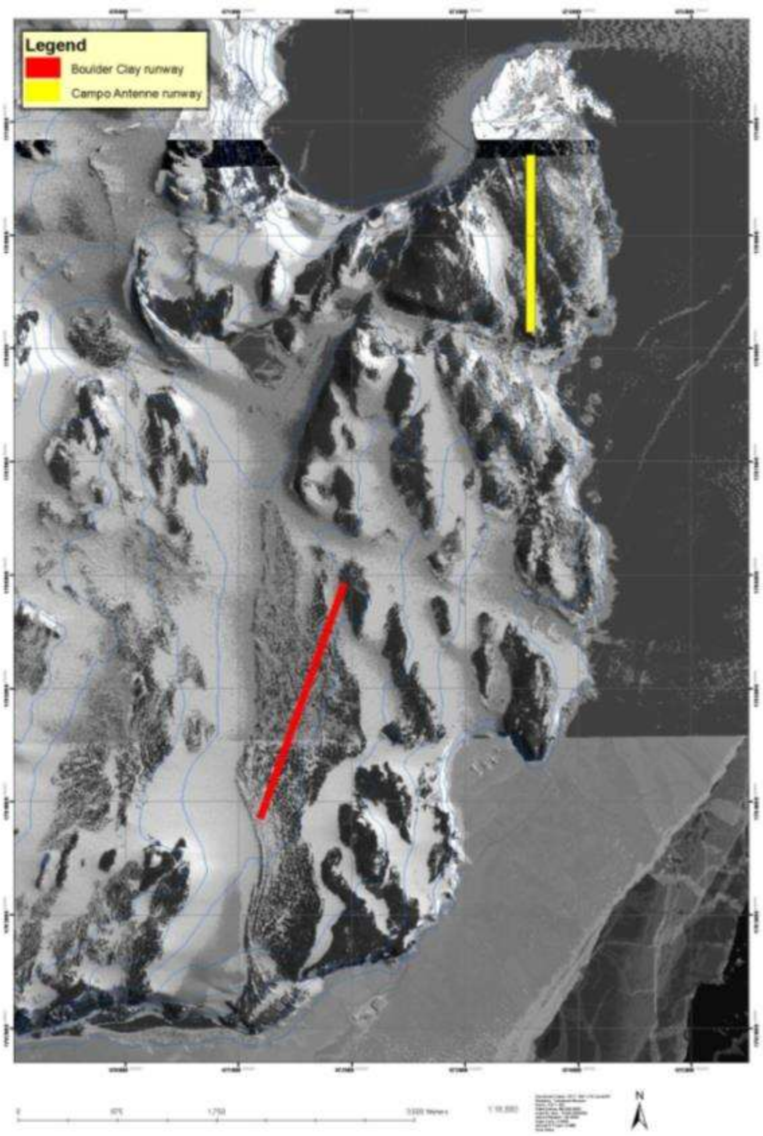


Figure A: Map of the area around MZS, with the two locations investigated for the gravel airstrip realization, Campo Antenne and Boulder Clay Moraine (yellow and red line respectively).

II Description of Proposed Activities

The proposed site for the runway is located in the Northern Foothills, about 6 km south of the Italian Antarctic Research Station Mario Zucchelli. The site, named Boulder Clay (74°44'45''S, 164°01'17''E, 205 m a.s.l.) is an ice-free area located on a very gentle slope (5°) with south-eastern exposure. The proposed site for the airstrip is far about 13 km from Gondwana Station and 15 km from Jang Bogo Station, about 16 km from the proposed new Chinese station at Inexpressible Island, and about 400 km from McMurdo Station and Scott Base (Figure B).

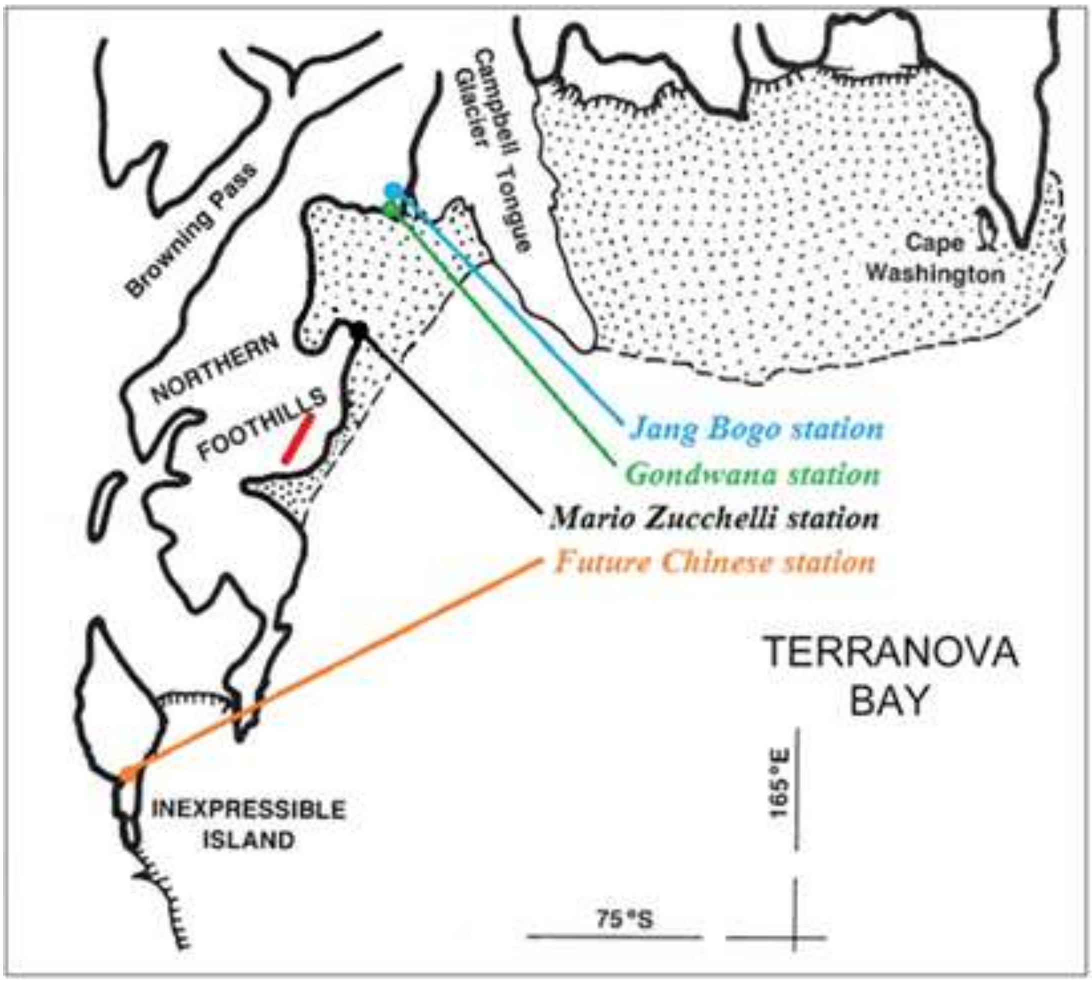


Figure B: The locations of proposed runway (red line) and Research Stations at Terra Nova Bay.

The activities described in this CEE concern construction and operation of the airstrip and use of machineries and temporary facilities on site during the construction.

The construction is planned to start as soon as the CEE will be approved by the CEP and to last for 3-4 austral summers (3 months each). The runway will likely begin to operate in early 2020-21.

The included facilities are the gravel runway, the apron for 2 aircrafts, the taxiways, a parking area for vehicles, a tank and a pipeline for supplying and storing aviation fuel, a removable building as office with a lounge for arrival and departure passengers and a power generator. The total occupied surface in the area will be approximately 0.15 km^2.

The opera has been designed to require only an annual snow removing and small levelling adjustment, and it's planned to be used with no major adjustments at least for 20 years.

The detailed project consists of the realization of a gravel embankment runway, 2,200 m long and 60 m wide (45 m of runway + 7.5 m shoulder on each side), located at about 6 km south from MZS, as shown in Figure B.

The longitudinal centreline of the entire embankment runs in the direction NNE-SSW, at an elevation of about 200 m a.s.l.

Referring to the centreline of the longitudinal profile, the existing ground level shows a maximum elevation difference of about 6 m (205.62 m at CH 1+500 and 200 at CH 2+200), while transversally the slope is more pronounced, with a maximum elevation difference of 4 m over a distance of 70 m. This variation is consequent to the south-eastern exposure slope of the Boulder Clay moraine and, to reduce the environmental impact of the construction, the embankment will have a transversal thickness of 0.6 m on the high side and a maximum of about 5 m on the low side. The embankment side slope will be designed with a 1V:1.5H geometry and made of rock blocks.

The runway has been designed for 0% transversal slope and a very limited longitudinal slope (below 0.8%).

The proposed gravel runway will be based on a subgrade corresponding to an ice core moraine that overlies a body of dead glacier or buried glacial ice. The till matrix is generally silty-sand while the surface is dominated by granitic pebbles and gravel, together with boulders. The ice is highly variable in composition, typically foliated and containing fine sediment layers. On the moraine several Lake Ice Blisters are present.

The runway embankment is intended to be constructed mainly using the material available in the nearby area.

The seasonal surveys of the well-known area of Boulder Clay, the meteorological data acquired on site in the last years, the accurate determination of the behaviour of long term moraine ice shifts by means of interferometric satellite data (Figure C) and the specific design of the opera, allow to assess that only a minor annual snow removing and small levelling adjustments are required, considering an approximated mean shift of less than 20 mm per year.

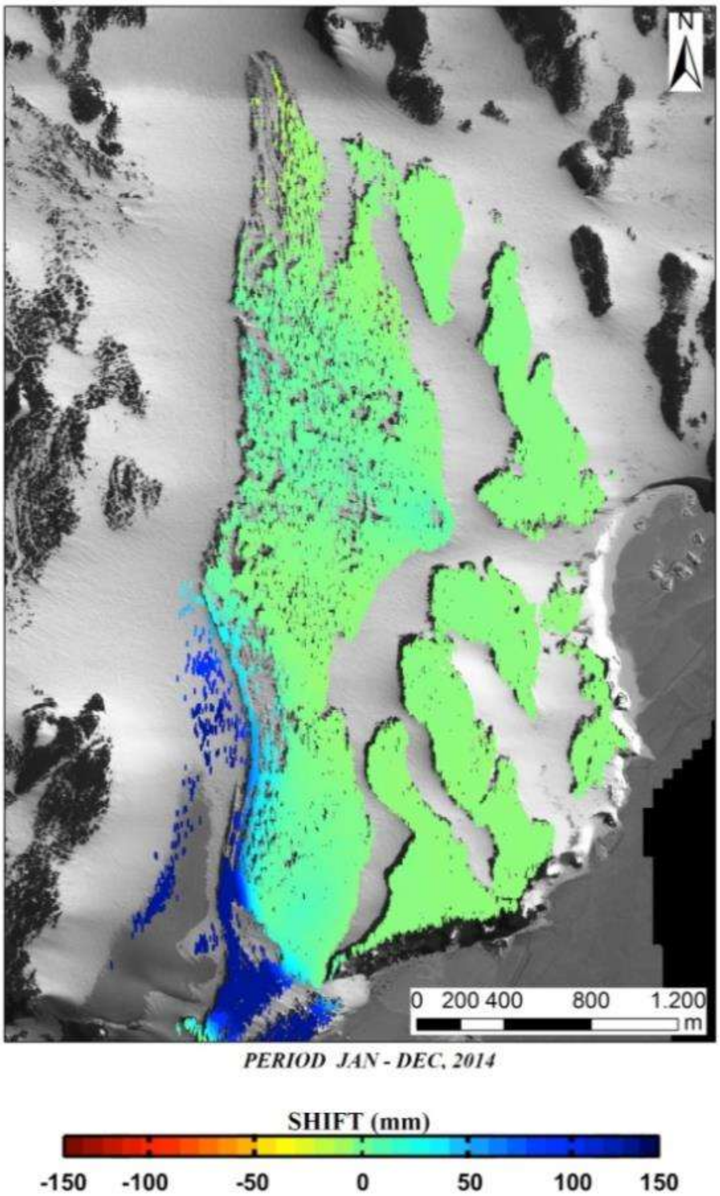


Figure C: Colour-coded drifting velocity of the moraine surface as obtained by satellite interferometric data (CosmoSkyMed) for the period January - December 2014.

Further facilities alongside of the gravel runway are planned: an apron for 2 Hercules L100/30 aircrafts, a taxiway in the head of the airstrip, a parking area for vehicles and a removable tank for avio fuel. For future development of the flying activity, and for safety reasons the construction of a pipeline from MZS tanks is also taken in account.

The reduction of the environmental impact of the activity was taken into full consideration also on the aspect of the offices dedicated to the air traffic control and to the passengers lounge, planned to consist of removable buildings provided with their own renewable energy resources. The maintenance and management of the entire facility, including the waste treatment, recycling and water utilization, and the mitigation of operative environmental impact will gain great advantage from the vicinity of MZS, which all the waste treatment and staffs supply will be demanded to.

III Alternatives to the proposed activities

The Boulder Clay site has been chosen for its environmental and logistical characteristics. Several runway orientation have been tried with the aim to increase efficiency and safety in relation with wind direction and to reduce the volume of gravel for the embankment.

Two alternative locations have been studied in years (Nansen Glacier and Campo Antenne), also the no action possibility has been considered.

Campo Antenne (namely field of antennas) site requires a huge amount of blasting work in consideration of the bedrock soil, an extended volume of material movement (around 1,000,000 m^3), with the result of a runway of limited length (1,700 m), which implies strong limitations in aircraft's dimension that can land in it. In addiction Campo Antenne is the location, close to MZS, chosen for the installation of most of the larger antennas used for the scientific observatories and logistic activities during summer and winter. The realization of a runway on site entails a repositioning of the entire facility to a different suitable location, still close to the station.

Nansen Glacier site has been considered in past, a blue-ice airstrip has been prepared and utilized few times for Hercules L100/30 landing. The endeavour was partially unsuccessful due to several reasons: the site is over 50 km away from the operative area of Mario Zucchelli Station and the available route to the runway area crosses for few kilometres a crevassed glacier, and the flatness of the place was continuously degraded year by year by the climate changes in the area.

The non-proceeding possibility, maintaining the fast ice runway at the beginning of the summer season and using a ship every year for the transport of persons more than materials was also considered. Such a solution resulted, on long-term perspective, more expensive and much less effective with respect to the realization of the gravel runway.

IV Initial Environmental Reference State of the Region

The location interested by the construction of the runway is characterized by the presence of several typical Antarctic species like Antarctic skuas and Adélie penguins. However, there are no colonies or habitats of any species within 1.8 km with respect to the borders of the proposed facility.

The Adélie penguins colony is about 1.8 km south from the runway end, at Adelie Cove site. The skuas are often seen in the area due to the penguin colony presence, but no evidence of nests was found in the area in the last decade.

As already mentioned, several perennially frozen lakes are widespread along the Boulder Clay area and in many cases are characterized by the occurrence of another permafrost feature: the icing blisters. Among them just one will be marginally interested by the runway. More recently, during the summer 2013-2014, for the first time, it was observed in the monitoring activities, a partial melting of some of these lakes. The presence of biological life (bdelloidea rotifers, protists and platyhelminthes) in water sampled in these lakes was confirmed during the same summer campaign.

Main research activities in the Boulder Clay area, along the projected line of the airstrip, consist of a CALM (circumpolar active layer monitoring) grid of 100x100 m, this monitoring grid was established in 1999 and represents a near continuous data series of permafrost and active layer temperature in Antarctica. In addition less than 100 m far from the grid, there is a shallow permafrost borehole with temperature monitoring records. The monitoring network will be interested by the proposed activity. Actions will be planned to evaluate and reduce the impact. Within the grid, as in general in the Boulder Clay area, vegetation is very scarce (less than 5% of the surface is covered by vegetation), composed mainly of patches of mosses and epilithic lichens.

V Identification and Prediction of Environmental Impact, Assessment and Mitigation Measures of the Proposed Activities

The main potential environmental impacts to be monitored during the construction and operation of the gravel runway were identified in:

- Atmospheric pollutants from fuel consumption;
- Risks of fuel and oil spills from fuel transfer and refuelling process as well as the leakage of fuel pipelines and tanks;
- Change in landscape layout;
- Noise construction activities, landing and take-off of aircrafts;
- Minimal/medium disturbance to the local ecosystem of both marine and land bio-species (e.g., penguins, skuas, mosses and lichens).

The impact mitigation during the construction and operation of the airstrip will mainly consist of the following measures:

- Mono fuel JA1 will be used for every vehicles or machinery;
- All vehicles and mechanical equipment must be energy efficient, they will be maintained under best condition and their use will be reduced as much as possible;
- Fuel spills will be prevented by using double-skinned fuel tanks posed on confined structures made of impermeable layer. Suitable absorbent mats will be considered in underlying layer in the project phase of the pipeline;
- Use of low noise machines and vibration-reduction technologies will be considered, including noise-absorbing materials in power generators, in order to minimize any possible impact of noise on the colonies of penguins and on skuas;
- Aircraft flight path for landing and taking-off will be kept off the Adelie Cove area, in addition to important limitations in height and space flight in overpasses of ASPA n°161 area.

VI Environmental Management and Environmental Impact Monitoring Plan

The environmental impact is predicted to be more than minor. However, both an Environmental Management Plan (EMAP) and an Environmental Monitoring Plan (EMOP) will be developed to evaluate and manage environmental impact on to the runway construction and operation.

Research projects in the Boulder Clay area, as well as research project on penguins and skuas in Adelie Cove site, will be enhanced, to analyse the life response of the birds community to any possible interference from the airstrip construction and activity.

VII Gaps in Knowledge and Uncertainties

To prepare a runway over a glacier moraine is a challenging project, even if the stability of the moraine has been deeply investigated during the last campaigns by means of several instruments and techniques, obtaining encouraging results. In situ tests will be continued during the next summer campaign to acquire further information. Identified gaps in knowledge and uncertainties for the construction and operation of the new gravel airstrip include:

- Long-term climate change, usage time as function of favourable atmospheric condition, winter snow accumulation on the pathway;
- Long-term maintenance;
- Uncertainties in the knowledge of long-term moraine behaviour changes;
- Changes in future perspectives of research projects in the area.

VIII Conclusion

The runway will potentially be a logistic hub for many Antarctic Programs in the region, gaining a more flexible turnover in Antarctica for Italian and foreign scientists, so contributing to develop international and multidisciplinary research activities.

The impact of the construction and operation of the gravel runway at Boulder Clay on the environmental and on the ecosystem will be minimized applying appropriate mitigation and monitoring measures.

The result of CEE suggests that the benefits that will be obtained from the permanent runway will grossly outweigh the “more than a minor or transitory” impacts of the runway on the environmental and on the ecosystem.

On these basis, the establishment of the proposed facility is highly recommended.

1. Introduction

1.1. History of PNRA activities and logistic structures at MZS

In 1981 the Italian government signed the Antarctic Treaty and the National Program for Research in Antarctica (PNRA) was created in 1985. PNRA is directed by the Ministry of Education, Universities and Research through three national bodies: the National Scientific Committee for Antarctica (CSNA) for long term objectives and strategies, the National Research Council (CNR) for the coordination of scientific research and the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) for the implementation of the Antarctic expeditions, logistics and maintenance of the Stations. At present ENEA acts trough the Technical Antarctic Unit (UTA).

Up to now, 30 national scientific campaigns were successfully concluded and two permanent Stations were built: the seasonal Mario Zucchelli Station in Terra Nova Bay (1986-1987) and the all year round Concordia Station (1999-2005), co-managed with France on the Antarctic plateau. Valuable results were achieved by Italian scientists in the last 30 years with a significant amount of international publications. A summary of the main scientific area of interest, overviewing the large research production of Italy in the Terra Nova Bay area, was presented during the last Antarctic Treaty Consultative Meeting (IP 90/XXXVII ATCM).

Close to MZS are located the German Gondwana Station and the new Korean Jang Bogo Station, opened in 2014; China already proposed the construction of a new Station at Inexpressible Island, about 16 km south-east of MZS.

MZS is usually opened from late October to mid February to host important researches in the Victoria Land and in the Ross Sea region, in the fields of earth sciences (geology, geophysics and glaciology), oceanography, marine biology, chemistry and atmospheric physics; besides, MZS serves as essential base for the air traffic to support the Concordia Station research activities.

For the intercontinental transportation of personnel and freights, PNRA relies on two transportation methods: flights and the multipurpose ice class ship Italica, which is rent every two years and it is used both to refuel the Station and for the oceanographic research campaigns.

International cooperation with NSF-USAP, IPEV, KOPRI, AntNZ and AAD also provide an essential support to the PNRA logistics.

Since beginning of 90’s, PNRA chose to operate an ice runway, which is prepared on the fast ice of Gerlache Inlet, in front of MZS, at the beginning of the Summer campaign. This runway is generally operated between late October and late November, depending on fast ice conditions, for wheeled aircrafts landing (Hercules L100/30) and holds a crucial role to carry out most of the

Italian scientific activities in Antarctica, allowing an earlier opening of MZS (mid-October) compared to the later opening by vessel (late December).

PNRA also use other blue ice runways in the MZS area, for operations with smaller aircrafts, like Twin-Otter and Basler, to support scientific and logistic activities in MZS, in several sites around Terra Nova Bay / Victoria Land and for connecting MZS with McMurdo Station, Concordia Station and Dumont d'Urville Station. Twin-Otter aircrafts play also a key role for providing the needed capacity of search and rescue operations.

Since 90's the use of airplanes was remarkably increased, thanks to its effectiveness in supporting both logistic and scientific activities, thus allowing an important increase in quantity and quality of the scientific production related to PNRA activity.

A detailed description of all the PNRA skyway operations in MZS will be found in the following Chapter 3.1.

1.2. Necessity of a new gravel airstrip and site selection work (IPs)

Although the effectiveness of PNRA in supporting the research in MZS was continuously increasing in the last decade, recently it suffered of hard logistic difficulties. They were mainly related to a late delivery of the scientific material and a late arrival of the personnel, caused by delays and cancellations of planned flights due to an unpredictable fast deterioration of the ice runway. Actually a significant environmental variability of the fast ice thickness and temperature in Gerlache Inlet was observed in the last years and the reason was identified in the abrupt reduction of Campbell Ice Tongue extension in Terra Nova Bay in 2005.

The result of such variability was a strong prejudice over the realization of some of the planned scientific activities and a long term solution to this problem for the next future is requested, in order to assure a timely and improved support to scientific researches in Antarctica through aircraft operations.

At this moment the situation is quite critical, because several important scientific proposals, related to Antarctic researches, cannot be funded due to present PNRA lack in assuring them the necessary logistic support, a lack actually caused by the impossibility of a clear schedule of personnel and staff movements in/out at MZS. In addition, there is the necessity, recurring year by year, to request transport services to NSF-USAP to permit personnel rotation during the part of the season when the ship is not available and the ice runway cannot be used.

It must be pointed out that, to overcome these problems, diverse landing ice airstrips were considered and became matter for several Information Papers (IP) presented in the last years during ATCM meetings. The main tentative, described in detail in Chapter 3.3.2, was the blue ice runway on Nansen Ice Sheet (IP 71/XXX ATCM), used just once and then considered not enough safe, due to the ice degradation in summer with dangerous presence of temporary fresh water puddles and streams during warmer months in late season. Other attempts (IP 42/XXIX ATCM) were more successful but limited to small aircraft operations.

Nowadays, without the US logistic support for the air operations, the most recent PNRA scientific activities, already reduced, would be even more seriously affected. So at this moment PNRA has to confide in the support of foreign Antarctic programs for moving personnel and stuffs in/out of Antarctica, especially when the Italica vessel is not chartered. Specifically from the air operation point of view, important agreements with USAP lead to operational help by their aircraft operations, although bringing personnel and stuffs from MZS to McMurdo airport (> 400 km trip) by Twin Otter or helicopter appears a very costly and inefficient operative way. A most effective way comes from the agreement with the Korean Antarctic program KOPRI, that lead to a help to PNRA operations by means of the Araon vessel, usually reaching the close Jang Bogo Korean station every year in late austral summer.

Indeed it should be here highlighted that all these operative ways, although very useful, are obviously strictly depending on the real possibility of support at that moment by the partners, and are necessary enslaved to their own priorities, leading anyway to a large difficulty in an effective schedule of all the required operational supports for the scientific projects.

It is quite clear that PNRA needs a long term solution to the problem, to increase the reliability of the air support for both the Italian Stations, in terms of adequate arrival of personnel and delivery of materials, greater effectiveness of scientific researches in Antarctica and easier multi-year programming.

So the proposed solution has to be considered the final step of a long study process, solicited by PNRA, started several years ago with the already mentioned blue ice runway on Nansen Ice Sheet and continued in the recent past with geological and aeronautical investigations devoted to find the best way and site for the construction of a gravel runway close to MZS (IP 41/XXXV ATCM, IP 80/XXXVI ATCM, IP 57/XXXVII ATCM).

The proposed gravel runway, object of the present CEE, would become an important permanent infrastructure, to be shared with other Antarctic National Programs, leading to a better management of the Italian program, increasing partnerships, facilitating science, allowing the air transportation of personnel at the end of the season, minimizing the need of a chartered vessel and finally reducing the overall environmental impact of the Italian expeditions.

In February 2014 the Korean Polar Research Institute KOPRI successfully inaugurated its new permanent Jang Bogo Station (JBS) in Terra Nova Bay. JBS is located at a distance of 10 km away from the Italian Mario Zucchelli Station (MZS). It is foreseen that the proposed airstrip could became an important hub for KOPRI air operations and would increase the safety of all the operations in the area and particularly during winter for JBS. KOPRI already expressed a favourable opinion about the project offering help to PNRA, in terms of machineries and transport.

It is unquestioned that sharing such a facility with other Antarctic programs will favour cooperation between Nations, diminishing overall logistic costs and increasing resources dedicated to science, in full accordance with the Antarctic Treaty feeling. With this aim PNRA is ready to establish fruitful cooperation with other National Antarctic programs interested in the proposed facility.

1.3. Preparation and submission of the Draft CEE

The Comprehensive Environmental Evaluation (CEE) has been prepared by the Antarctic Technical Unit (UTA) of ENEA. The reviewing process is still in progress and will also gather comments and inputs from the Italian institutions involved in the governance of the PNRA and of the Antarctic Treaty before the publication of the Final CEE. Besides, contributions were and will be provided by Italian scientific community on specific critical aspects.

The present document is defined as "In Progress Draft CEE", highlighting the advancement status on April 14th, 2015. This document is currently digitally available on PNRA website, while a paper copy will be circulated to each Contracting Party via diplomatic channels in April, and submitted as a Working Paper and Information Paper to Antarctic Treaty Consultative Meeting (ATCM) XXXVIII (1 June 2015, Sofia, Bulgaria) and the Committee for Environmental Protection (CEP) XVIII.

This work should be considered as pre-final step of a process started several years ago, consisting of subsequent IPs drawn to the attention of the Antarctic Treaty parties as soon as aeronautical and geological studies, conducted to analyse possible solutions and suitable locations, were providing clear indications to the best route to follow for a definitive solution to the skyway operations at MZS.

The document aims to provide the rationale for such solution, consisting of the construction of a gravel runway on the Boulder Clay moraine at Terra Nova Bay. The document has been developed in conformity with the guidelines of Annex I to the Protocol on Environmental Protection to the Antarctic Treaty and Guidelines for Environmental Impact Assessment in Antarctica (Resolution 4, XXVIII ATCM, 2005).

1.4. Laws, standards and guidelines

During the preparation of the Draft CEE, full reference will be given to the Antarctic Treaty System and Italy's relevant laws and regulations. The guidelines and documents for environmental impact assessment developed by the COMNAP and SCAR have been followed as well.

Italy acceded to the Antarctic Treaty in 1981 and became a Consultative party to the Antarctic Treaty in 1987. Another milestone was Italy becoming a full member of the Scientific Committee on Antarctic Research (SCAR) in 1988. Since joining SCAR, Italy has contributed to the growth of SCAR and benefitted from SCAR's international network of Antarctic nations.

Italy ratified the Environmental Protocol in 1995. The Environmental Protocol set out environmental principles, procedures and obligations for the comprehensive protection of the Antarctic environment and its dependent and associated ecosystems.

The COMNAP and the SCAR are two international organizations involved in the Antarctic affairs. Their guidelines and documents regarding the activities in Antarctica has made reference for the CEE, particularly the Environmental Monitoring Manual in Antarctica (COMNAP, 2000), The Technical Standards for Environmental Monitoring in Antarctica (COMNAP, 2000), the Practical Guidelines for the Development and Design of Environmental Monitoring Programs (COMNAP, 2005b) and the Guidelines for EIA in Antarctica (COMNAP/ATCM, 2005a).

The construction and operation of new proposed airstrip will enforce strictly relevant domestic environmental laws and guidelines for Environmental Impact Assessment.

1.5. Project management system

Under the direct PNRA leadership of MIUR, and with the support from the Ministry of the Environment, the Ministry of Foreign Affairs, ENEA UTA takes responsibility for coordinating the design, construction and operability of the proposed gravel runway.

Supported by its long experience in operating ice airstrips in MZS, ENEA UTA has broadly analysed and tested alternatives to the proposed facility, compared and studied various modes of construction, conducted on-site investigations in several locations, accepted comments and recommendations from specialists in scientific research, environmental impact and aircraft logistics and management. The design and location of the airstrip facility gives priorities to the environmental protection, safety and impact mitigation.

The project and CEE will be both further developed along 2015, making use of results and data arising from more tests and analysis. Monitoring program of environmental impact and mitigation actions will be enlarged and improved.

The construction of the gravel airstrip is expected to be finished in 2020-21 and then it will go into trail operation. ENEA UTA is responsible for the management and maintenance of the facility, along with the implementation of the follow-up supporting facilities and the environmental management.

2. Description of the Proposed Activity

2.1. Scope

For intercontinental transportation of personnel and freights, the Italian Program relies on two transportation methods: flights and a multipurpose ice class ship, which is used also to refuel the station and for the oceanographic campaigns. International cooperation provides also an essential support.

Flights are currently operated chartering an Hercules aircraft and realizing a fast ice runway at the beginning of the summer campaign in the Gerlache Inlet (Figure 2.1). This ice runway is of crucial importance for the execution of the Italian scientific activities allowing an earlier opening of MZS than would be possible chartering only a ship. In the last years however, a significant environmental variability was observed and resulted in an premature closing of the fast ice runway, and related logistic difficulties affecting the scientific activity.

Other landing possibilities on ice were considered. A blue ice area on the Nansen Ice Sheet, at about 30 km north of the Station, was investigated in 2004/05. The runway was built in 2006 in the selected site and some test flights were carried out with positive result. Starting from 2009 the area was no more suitable because the surface of the glacier was crossed from deep ruts caused by increased water streaming (see in Paragraph 3.3.2).

Figure 2.1: The Hercules aircraft landing at the Gerlache Inlet fast ice runway.

In addition, without the US NSF support, our scientific activities would be seriously affected as the Italian National Antarctic Program is strongly dependent upon the establishment of cooperation agreements especially when the multipurpose ice class ship is not chartered.

The driving force of the proposal is the need of PNRA to have a long term solution for the adequate transportation of personnel and materials, considering the climatic changes experienced during last years that strongly affected operations and allowing greater effectiveness of scientific research and a more reliable multi-year programming.

A gravel runway would be an important permanent infrastructure to share with other Antarctic National Programs that could change the management of the Italian Program, increasing partnerships, facilitating science, allowing the air transportation of personnel at the end of the season and reducing to the minimum the need to charter a vessel from Italy, thus lowering the overall human footprint and the logistical cost of the expeditions.

2.2. Location of the activity

The Boulder Clay Glacier (74°44'S, 164°02'E) is a glacier belonging to the Northern Foothills area (Terra Nova Bay, Victoria Land, Antarctica) that represents a low coastal range comprised between Cape Russel (74°54' S), Mt. Browning (74°36' S) and the Campbell (164°27' E) and Priestley (163°31' E) Glaciers [2.1]. This area was described in the past by several authors, from 1914 [2.2] to nowadays [2.3] especially under the geological, glaciological and geomorphological aspects. The area is mainly an ice-covered landscape and the ice-free areas are few, the main landforms are controlled by the structural trend and by glacial erosion while the periglacial processes actively drive the evolution of the subaerial landforms.

The Boulder Clay Glacier is parallel oriented to the coast, elongated for about 6 km from south to north (about 1.5 km wide). It ranges between Adelie Cove and Enigma Lake, a small frozen lake, and it is supposed to be dry based. Besides, it is partially covered by a heterogeneous debris size ice-cored moraine that occupies more than half of its surface (Boulder Clay Moraine).

The Boulder Clay Moraine consists in a discontinuous sheet of glacial sediment locally ice-cored and widely affected by ice-wedge polygons. In particular there is an ablation till, 0.4 - 1.0 m thick, that overlies a body of dead glacier or buried glacial ice (thick greater than 60 m). In the upper part the ice is highly variable in composition, typically appearing foliated and containing fine sediment layers.

The site, in its snow covered area, is currently used as an emergency landing site for Twin Otters in case of strong winds.

The permafrost conditions present at Boulder Clay have been monitored on since December 1996 and it results the presence of an active layer thickness of a few tens of centimetres. On the moraine, several small frozen lakes (known in the literature as Lake Ice Blisters) are also present. The fluvial processes are relatively unimportant in the Northern Foothills and the stream channels are extremely rare. The observations carried out on the Boulder Clay moraine indicate limited groundwater movement.

An Adélie Penguin colony is located in the south coast respect to the proposed area, at Adelie Cove. The colony site is also interested by the presence of Antarctic skuas, without nest evidence. This fauna, considering the altitude difference and about 1.8 km distance will not be directly involved by the construction activity and aviation operations of the airstrip.

Boulder Clay is bordered east and south with ASPA n°161 Antarctic Special Protected Area. A coastal marine area of 29.4 km^2, encompassing Adelie Cove, is proposed as an Antarctic Special Protected Area (ASPA) promoted by Italy on the grounds that it is an important littoral area for well-established and long-term scientific investigations. The Area is confined to a narrow strip of waters extending approximately 9.4 km in length immediately to the south of the Mario Zucchelli Station (MZS) and up to a maximum of 7 km from the shore (Figure 2.2).

The human impacts within the area are believed to be minimal and confined to those arising from the nearby Mario Zucchelli Station, the proposed activity and scientific work conducted within the area.

An atmospheric monitoring facility (locally referred to as 'Campo Icaro') is located approximately 650 m north of the northern boundary of the area and 150 m from the shore: no wastes are produced and discharged from this facility.

To preserve as pristine as possible the characteristics of the two sites, particular attention will be carried on aircraft flight path, not permitting the flight on the colony, except for safety reasons, and fixing limitations in height and space on ASPA n°161 area.

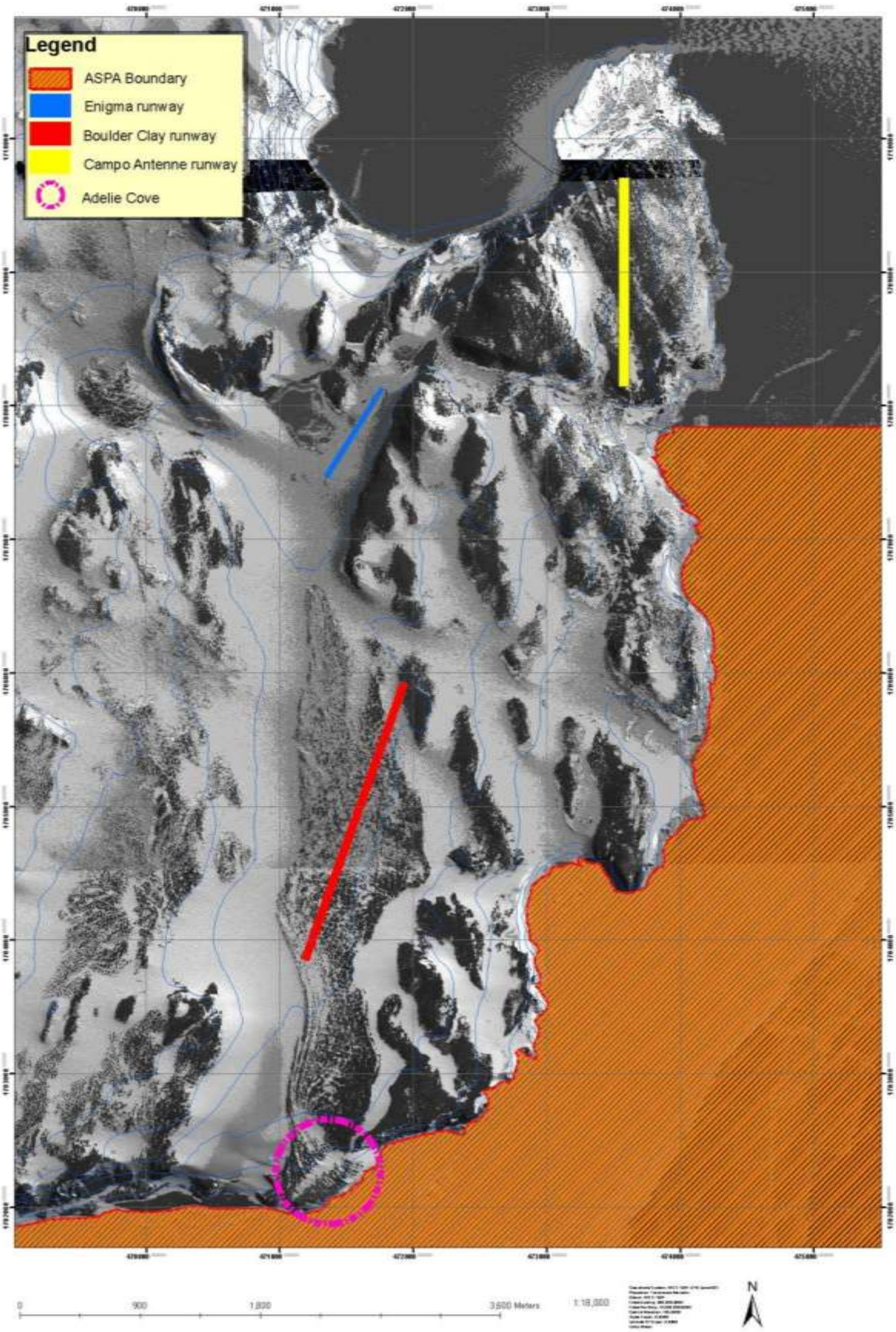


Figure 2.2: Evidence of ASPA n°161 and Adelie Cove respect Boulder Clay runway, Enigma airstrip and the alternative site of Campo Antenne.

2.3. Airstrip design

2.3.1. General specifications

In the Antarctic regions soils are often frozen at considerable depths year round. Seasonal thawing and refreezing of the upper layer of permafrost can lead to severe loss of bearing capacity and/or differential heave. The construction of engineering structures, such as road and airfield embankments, changes the thermal regime of the ground, and may lead to permafrost degradation under or adjacent to such structures. This occurs because of changes of the ground-surface energy balance, which is a complex function of seasonal snow cover, solar and long wave radiation, moisture content and atmospheric air temperature. All these factors contribute to produce the mean annual surface temperature, which may differ substantially from the mean annual air temperature.

In general the construction of an embankment results in an increased mean annual surface temperature, which will increase the thawing of permafrost [2.4]. Therefore, in area with continuous high-ice-content permafrost at shallow depths, satisfactory pavements are best ensured by restricting seasonal thawing to the pavement and to a non-frost susceptible base course. This approach is intended to prevent degradation (thawing) of the permafrost layer.

Gravel surfaced pavements are rather common in permafrost areas and generally will provide satisfactory service. These pavements often exhibit considerable degradation but are rather easily reconditioned, maintenance and repair are considered in the design.

2.3.2. Project description

The layout of the runway was based on a topographic survey performed at the Boulder Clay site with a laser scanner technique during the XXVIII Italian Antarctic Expedition.

The project comprises the realization of a gravel embankment runway 2,200 m long and 60 m wide (45 m of runway + 7.5 m shoulders on each side), as shown in Figure 2.5. The embankment is forecasted to be subdivided into four construction phases:

- Phase 1 of 400 m length from CH 0+000 to CH 0+400
- Phase 2 of 400 m length from CH 0+400 to CH 0+800
- Phase 3 of 1000 m length from CH 0+800 to CH 1+800
- Phase 4 of 400 m length from CH 1+800 to CH 2+200

The embankment longitudinal centreline runs in direction NNE-SSW, at an elevation of about 200 m a.s.l.. With reference to the centreline of the longitudinal profile, the existing ground level shows an elevation difference of about 6m (205.6m at CH 0+700 and 200 at CH 0+000) while transversally the slope is significant, with a maximum elevation difference of 5m. This variation is in agreement with the south-eastern exposure slope of the Boulder Clay moraine, and for this reason the embankment will have a minimum thickness of 0.6 m on the high side and a maximum thickness of about 5 m on the low side. The embankment side slope will be sloped with 1V:1.5H geometry and made of rock block.

The runway has been designed for 0% transversal slope and very limited longitudinal slope (up to 0.8%). The runway layout has been designed to avoid the superimposition on the lake ice blisters present in the moraine. The runway embankment is intended to be constructed using the material available from the nearby area.

Figure 2.3 and Figure 2.4 show the moraine and the lake ice blister, respectively.

Figure 2.3: Boulder Clay Moraine (11 November 2014)

Figure 2.4: Lake ice blister at Boulder Clay Site (11 November 2014)

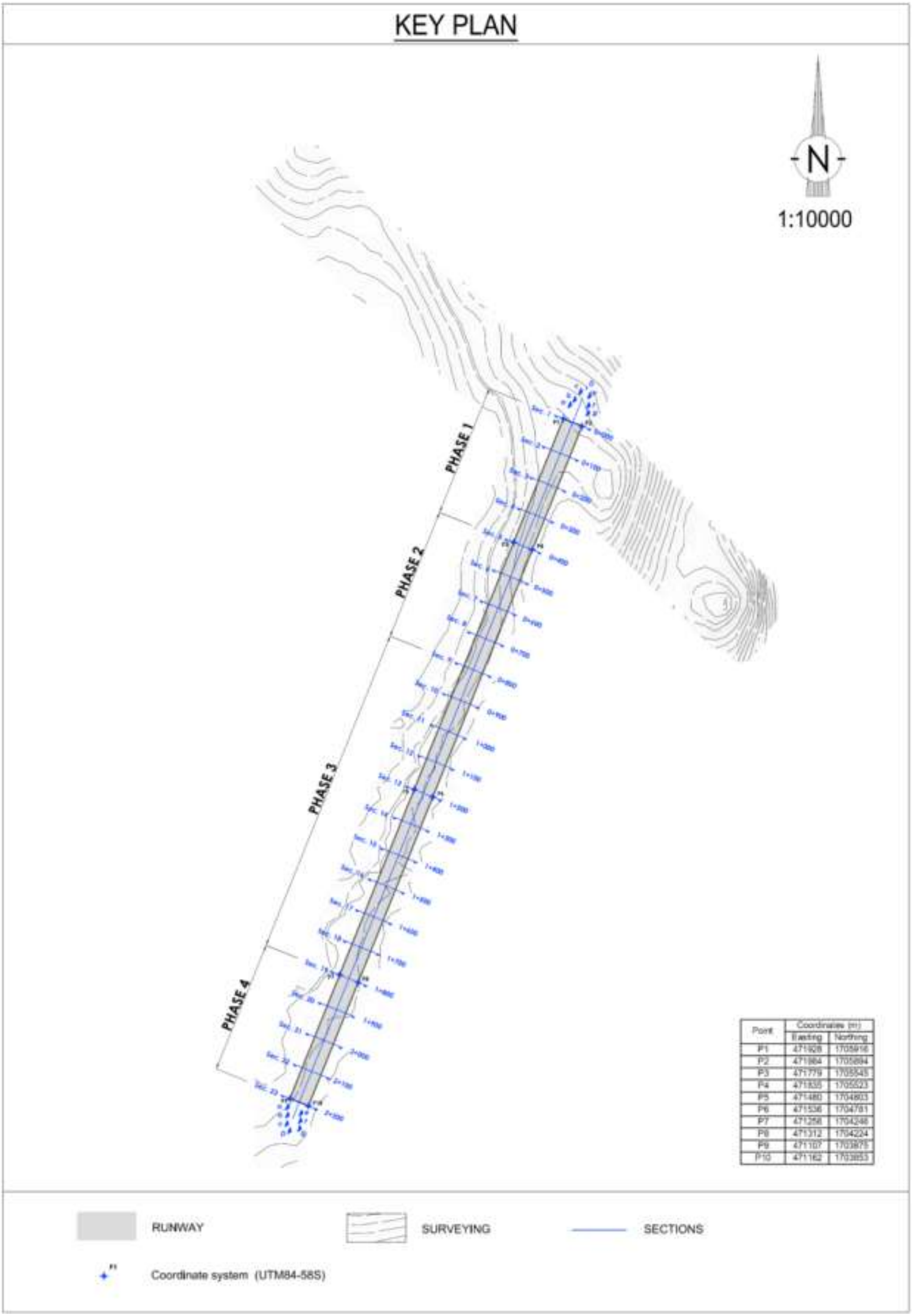


Figure 2.5: Runway layout with the four construction phases

2.3.3. **Runway facilities**

The areas of interest of the runway may thus be identified (Figure 2.6):

- landing area: consist of the runway (including thresholds) intended for landing and for take-off of aircraft;
- transit surfaces: consist of the taxiways that connect the parking areas to the runways;
- apron: destined for refuelling, for boarding/disembarking passengers, for the loading/unloading of goods and to overhaul and repair aircrafts;
- service area: which includes the area occupied by the terminal.

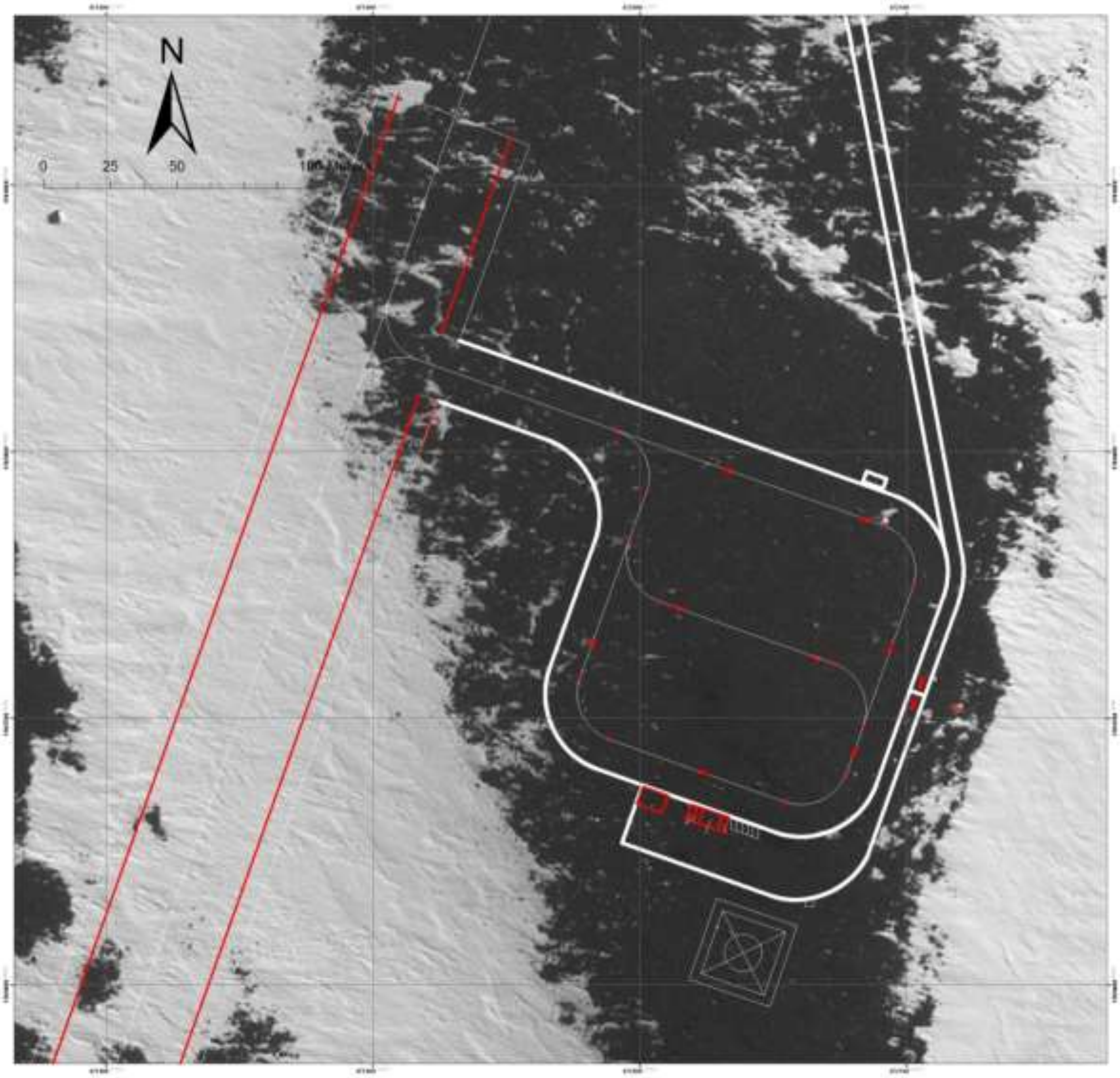


Figure 2.6: Runway facilities: Apron, taxiways, fuel tank, helipad, and vehicle access road.

Taxyway

The traffic routes in question consist of a single way connecting the apron to the runway; it has an orthogonal axis with the runway and accordingly it is defined as connecting link.

Apron

The apron is intended for aircraft parking and preparation for their operational tasks, and for the first and second maintenance level, including periodic inspections of the aircraft; in particular, it provides for the stationing of two Hercules aircraft and, considering the overall dimensions and the related safety clearances, a surface of 130x134 m is required.

In addition to this surface, in order to minimize FOD problems, 3 m in width, for fixed wing shoulders must be provided. The entire perimeter of the apron should be made of compacted soil and levelled.

Due to the orography of ground and low number of aircrafts present at the same time (less than 10) only one access point for mass parking and one individual parking platform are required. Besides, an helipad is designed to provide an emergency use for operational redundancy.

Fire service

The rules establish the minimum extinguishing potential in terms of quantity and quality of the agents used, as well as fire-fighting vehicles which must be operationally available, classifying airports in nine categories, depending on the maximum size of the aircraft; on the basis of this definition the airstrip of this project is classified in category 6 (length of the aircraft between 28 and 39 m, and width of the fuselage below 5 m). It follows that for operations the airstrip must be equipped with at least 2 independent fire fighting vehicles.

Similarly, it is identified the minimum extinguishing potential in terms of quantity and quality of the agents used (proteinaceous foam agents or filming agents); in particular the runway must be equipped with:

- at least 11,000 litres of water and proteinaceous foam disbursed through a discharge capacity of at least 6,000 litres per minute; as an alternative to proteinaceous foam, at least 7,900 litres of water and filming agents or fluoro-proteinaceous foam disbursed through a discharge capacity of at least 4,000 litres per minute;
- in addition, it should be added an amounts of complementary agents to the foam, in particular: 225 kg of chemical powder or 450 kg of CO_2.

The operational area is provided with a garage to recover at least three fire trucks; this will ensure the minimum provision also in case one is unavailable.

The structure for the shelter of the fire trucks will be made of steel or at least in a non-combustible material; it provides an area designated for the parking of fire-fighting trucks (not less than 7x14 m^2) positioned so as to be ready for use, an area for materials storage, an area for storage of the extinguishers and one used for office; the structure has exits of adequate width for the simultaneous passage of at least two fire-fighting vehicles and one or more independent exits for the staff.

Fuel Deposit

The fuel tanks in the base and in the operational areas (main deposit of Mario Zucchelli Station, fuel tank of Enigma Lake skiway and fuel tank of Boulder Clay), will be connected through a pipeline of small diameter with a transfer capacity of about 20,000 l of fuel in 24 hours. The route of this pipeline will be, as long as possible, beside the road that connects MZS and the operational areas. The supporting line of the pipeline will be used to pass other service lines (electricity, telephone network, etc.).

The solution of a pipeline of small diameter is the one that most reduces the environmental risks because, while eliminating the risks associated with the traffic of the road tankers, reduces the flow of fuel transferred, making less impact the outcome of a hypothetical oil spill.

Operations room

It is planned to install an operations room close to AWS Rita, at 265 m a.s.l. respect to, the 205 m a.s.l., proposed gravel runway. This operations room would serve as well the two skiways at Enigma Lake. These skiways have been existing for almost 10 years, but their traffic is even now managed by radio, without a direct control, from the Operations Room of MZS.

The facility, conceived as an ISO-20 equipped container, will be located on the top of a hill in order to allow an unobstructed view over the three runways and the entire operational area.

Electrical power

It is planned to install a 68 kW generator in the services area to supply electricity to the apron and runway and a 28 kW generator for the operations room, to be installed in its vicinity, downwind. Subsequently it is planned to connect the Boulder Clay area, the Enigma skiways area, and the operations room close to AWS Rita with the network of MZS by passing the cables along the pipeline.

2.3.4. Mechanical properties of soil

The definition of geotechnical parameters is based on the results of the ground investigations, carried out during the XXVIII, XXIX and XXX Antarctica expeditions. The soil samples collected during the XXIX Antarctica expedition were examined at *2° Reparto Genio Areonautica Militare – Laboratorio Principale Prove e Materiali Edili,* while the samples collected during the XXVIII Antarctica expedition were examined at the *Laboratory of Applied Geology of the Sapienza University of Roma*.

The site investigation consisted of a series of Clegg Hammer compaction tests and a series of dynamic Light Weight Deflectometer (LWD) tests, while the laboratory tests carried out as part of the ground investigation were a series of sieve analyses, a Modified Proctor test and a Standard Proctor test.

Figure 2.7 shows the location of the ground investigations of the XXIX and XXVIII expeditions: the blue labels refers to the XXIX Antarctica expedition and the green labels to the XXVIII Antarctica expedition.

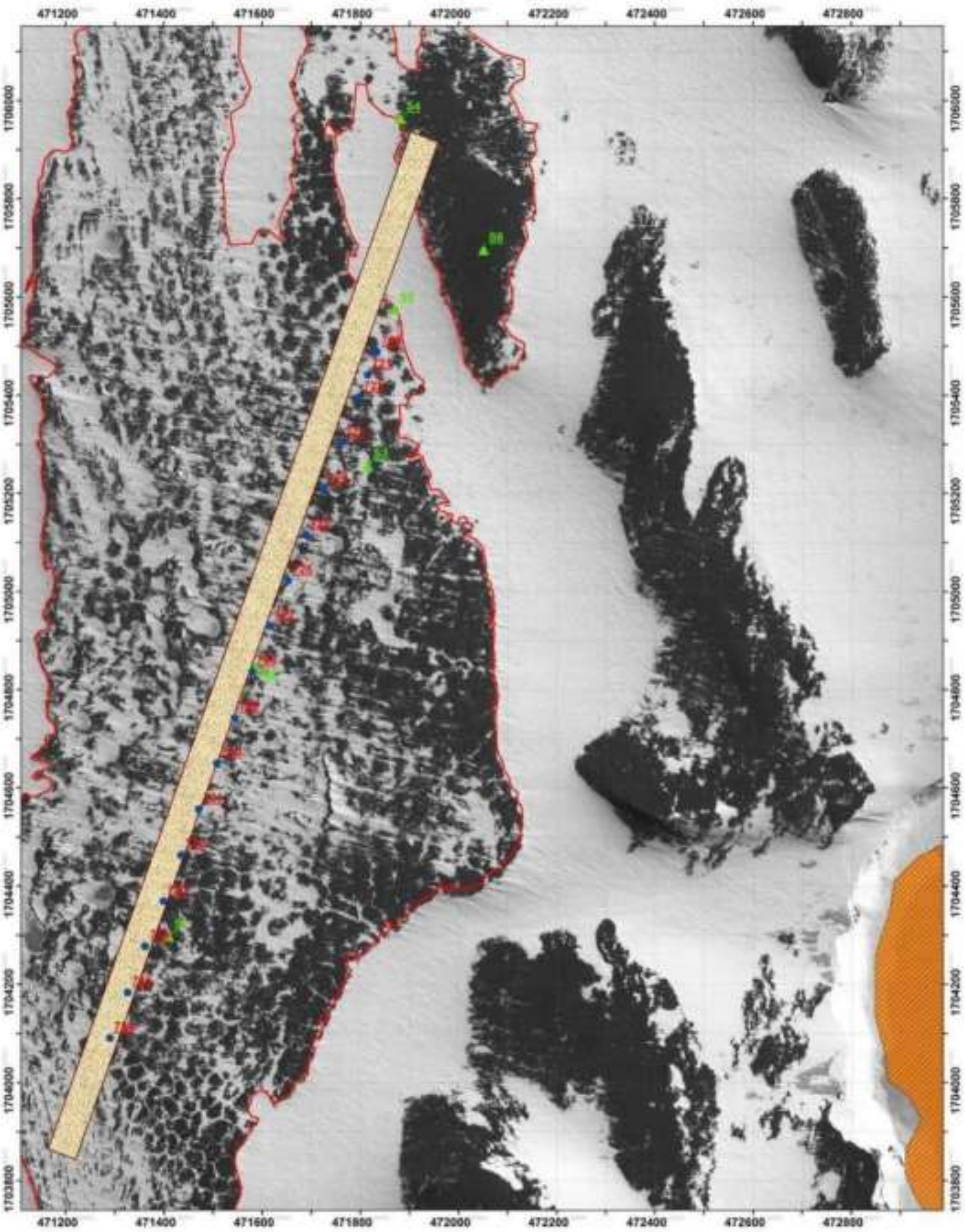


Figure 2.7: Ground investigations location (blue labels =XXIX Antarctica expedition, green labels = XXVIII Antarctica expedition)

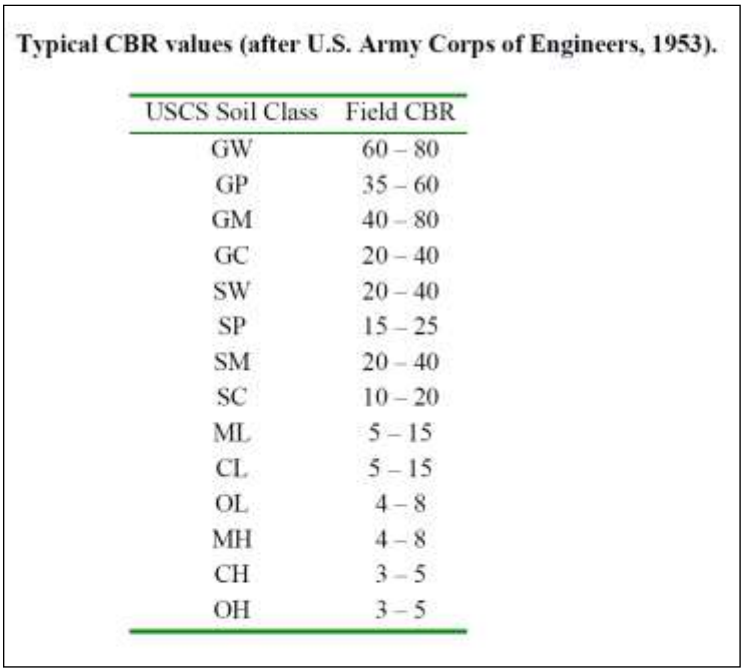
The site investigations carried out with the Clegg Hammer tests on late November 2013 reported a CBR ranging from 36% to 43% with an average of 39.5%, in agreement with the site investigation carried out with the LWD in the same period, which reported a CBR ranging from 20% to 58% with an average of 38.0%. Based on the available temperature data, these values are considered representative for the period of the year ranging from February to November, when the registered temperatures are equal or below those at which the site tests were carried out.

Typically CBR values are correlated to the type of soil units, as shown in Figure 2.8 [2.5]. Accordingly, site investigation results classify the soil (according to USCS Soil Class) ranging from well-graded with small silt content (SM) or clean (SW) Sands and Sandy soils to well graded with small silt content gravel/sand mixtures (GM).

Clegg Hammer test carried out in December 2013, January, November and December 2014 give CBR values ranging from 2% to 37%. Average values are as follows:

- 26% on the second week of November 2014;
- 25% on the third week of November 2014;
- 18% on the first week of December 2014;
- 4% on the second week of December 2013;
- 4% on the third week of January 2014.

These results are in agreement with the seasonal thawing the moraine is subjected to, and correspond to a reduced CBR value during the summer time.


Typical CBR values (after U.S. Army Corps of Engineers, 1953).

USCS Soil Class	Field CBR
GW	60 – 80
GP	35 – 60
GM	40 – 80
GC	20 – 40
SW	20 – 40
SP	15 – 25
SM	20 – 40
SC	10 – 20
ML	5 – 15
CL	5 – 15
OL	4 – 8
MH	4 – 8
CH	3 – 5
OH	3 – 5

Figure 2.8: Typical CBR values [2.5].

The range and frequency distribution of particle sizes, shown in Figure 2.9 and Figure 2.10, classify the soil as a moraine deposits with its typical spread grain size distribution curve that ranges from clay to cobbles. Figure 2.11 and Figure 2.12 show photos of the material representing the composition of the moraine at Boulder Clay site, the coarse bulky particles being sub-angular to angular shaped.

Although cobbles and boulders are present on site, as shown in Figure 2.13, prior to the sieve analysis grain size greater than 60 mm were removed from the specimens and they are not reported in the grain size distribution.

Further, it is noted that the percentage of the fine-grained soils (silt and clay) is very low, ranging from 5% to 20% with an average of 10%. This result is in agreement with the extreme site condition that is affected by strong wind during winter responsible for transporting away the smaller sediments from the superficial strata.

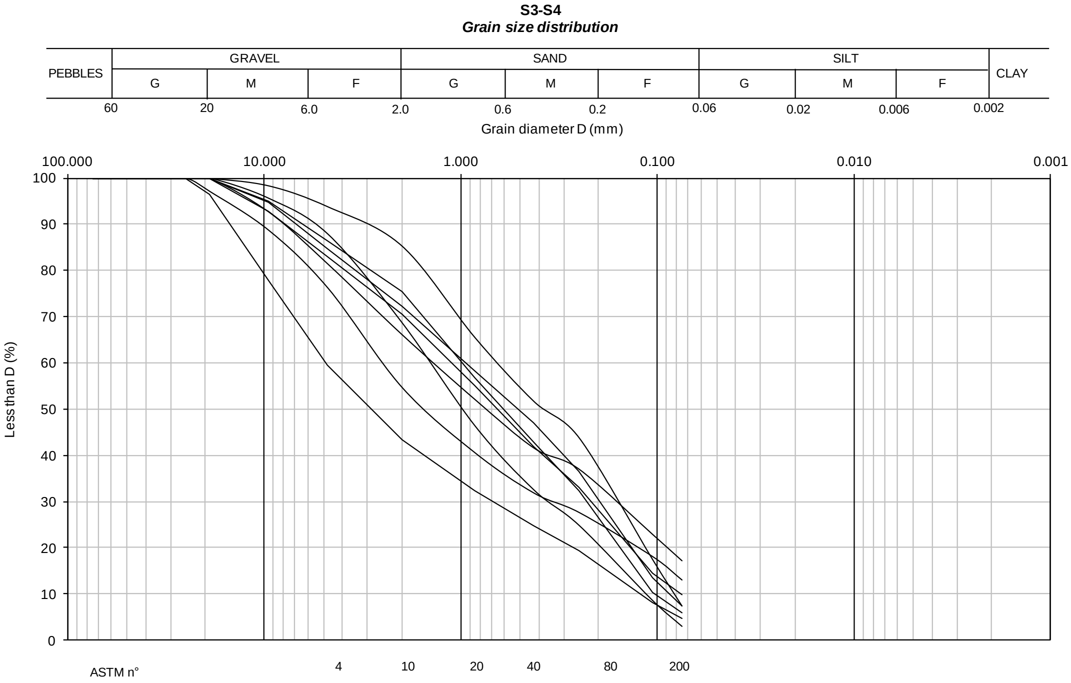


Figure 2.9: Grain size distribution (XXIX Antarctica expedition).

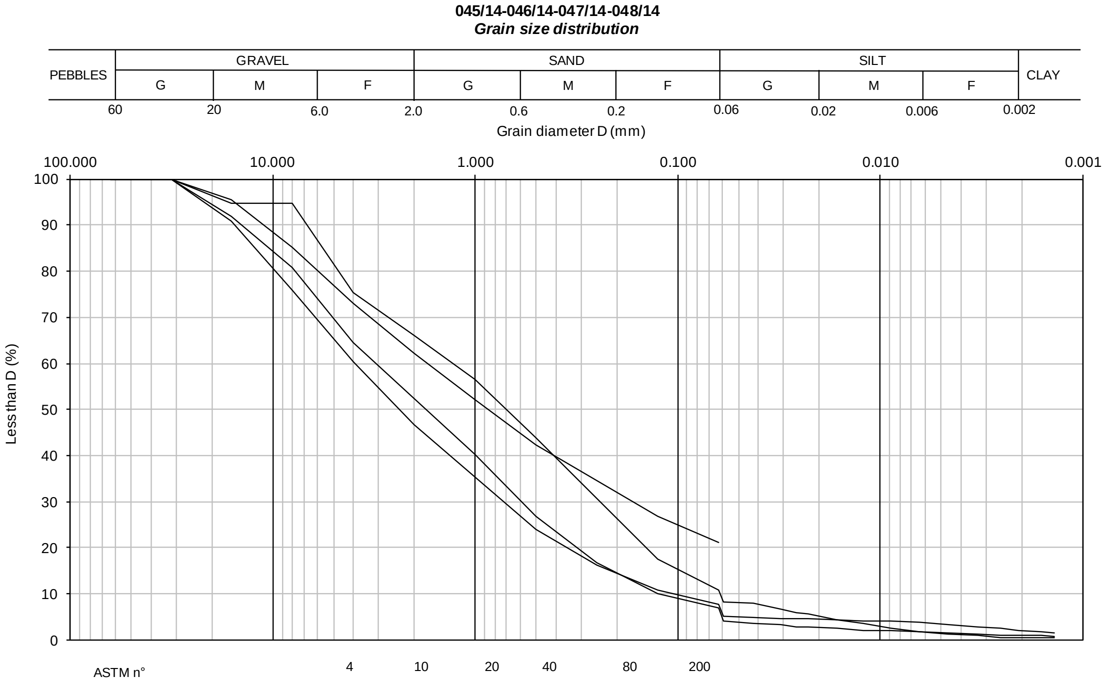


Figure 2.10: Grain size distribution (XXVIII Antarctica expedition).

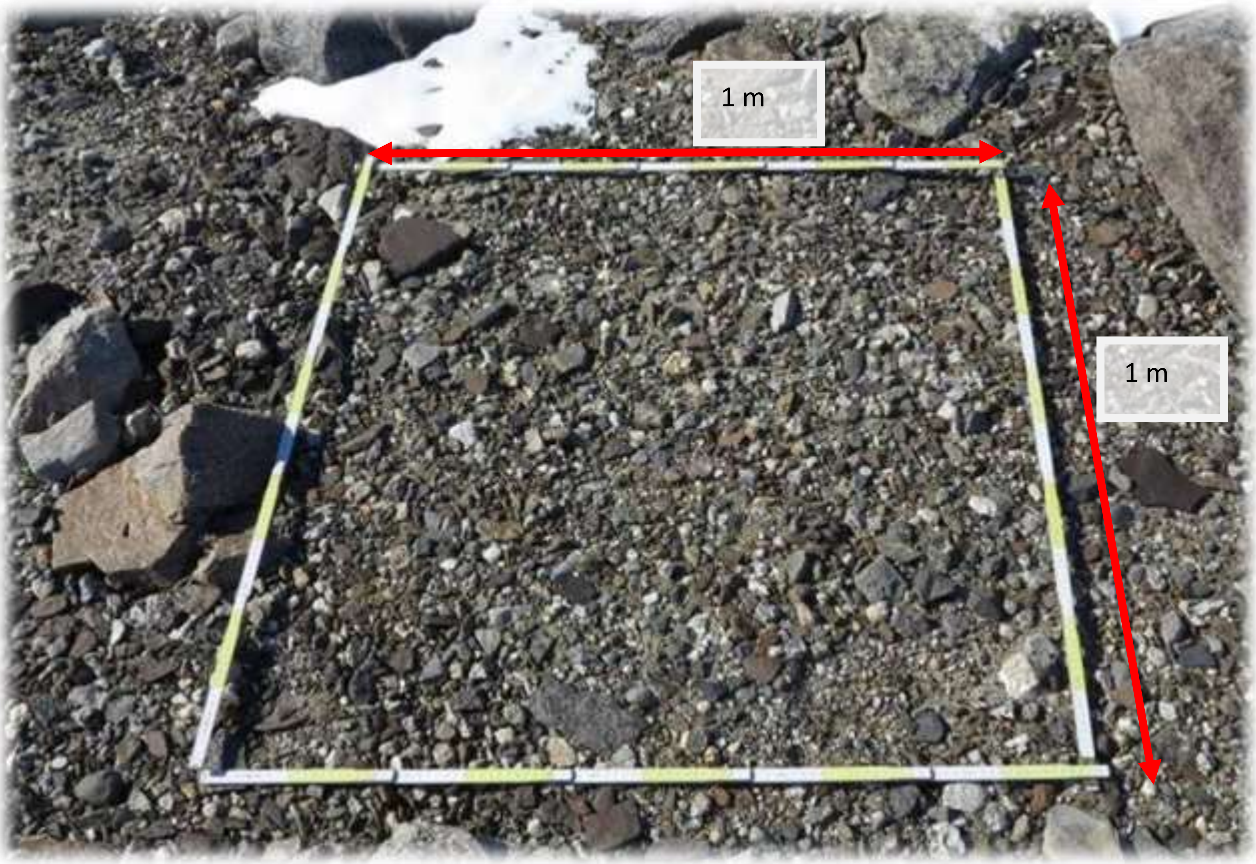


Figure 2.11: Moraine material at Boulder Clay site in a square meter (12 November 2014).

Figure 2.12: Moraine material at Boulder Clay site (12 November 2014).

Figure 2.13: Boulders and cobbles at Boulder Clay site (12 November 2014).

One Standard Proctor test was carried out according to ASTM D698-07 at the *Laboratory of Applied Geology of the Sapienza University of Roma*, on a sample collected during the XXVIII Antarctica expedition. A second compaction test was carried out according to AASHTO T180 (modified Proctor) at the *2° Reparto Genio Aeronautica Militare - Laboratorio Principale Prove e Materiali Edili* on a sample collected during the XXIX Antarctica expedition.

Typically, maximum dry unit weight and optimum moisture content are correlated to soil type as shown in Figure 2.14 [2.5]. The obtained relevant result is in agreement with the sieve analysis and classify the soil as well graded with small silt content gravel/sand mixtures (GM).

Soil Description	USCS Class	Compacted Dry Unit Weight		Optimum Moisture Content (%)
		(lb/ft³)	(kN/m³)	
Gravel/sand mixtures:				
well-graded, clean	GW	125-134	19.6-21.1	8-11
poorly-graded, clean	GP	115-125	18.1-19.6	11-14
well-graded, small silt content	GM	119-134	18.6-21.1	8-12
well-graded, small clay content	GC	115-125	18.1-19.6	9-14
Sands and sandy soils:				
well-graded, clean	SW	109-131	17.2-20.6	9-16
poorly-graded, small silt content	SP	94-119	15.7-18.6	12-21
well-graded, small silt content	SM	109-125	17.2-19.6	11-16
well-graded, small clay content	SC	106-125	16.7-19.6	11-19
Fined-grained soils of low plasticity:				
silts	ML	94-119	14.7-18.6	12-24
clays	CL	94-119	14.7-18.6	12-24
organic silts	OL	81-100	12.7-15.7	21-33
Fine-grained soils of high plasticity:				
silts	MH	69-94	10.8-14.7	24-40
clays	CH	81-106	12.7-18.6	19-36
organic clays	OH	66-100	10.3-15.7	21-45

Figure 2.14: Typical compacted densities and optimum moisture contents [2.5].

In order to achieve more information about the till moraine several geophysical and topographical activities were carried out during the 2013-2015 surveys. In particular, Ground Penetrating Radar (GPR) survey, activities were initialized focusing on a comprehensive evaluation of the site condition with the following main goals:

- Average thickness of debris along the till moraine;
- Bedrock morphology in the Boulder Clay area;
- Lake-ice blisters present in the area.

Due to the extension of the surveyed area, both airborne and on-ground GPR measures were collected. Figure 2.15 reports the map of the averaged thickness data recorded by the airborne survey. As it is shown, in the area of interest, the till moraine thickness varies between 0.4 to 1.0 m, with an average thickness of about 0.8 m.

Based on the available information it can be concluded that the material available on site can be considered a satisfactory subgrade for the embankment and a good to excellent material to be used for the construction of the embankment.

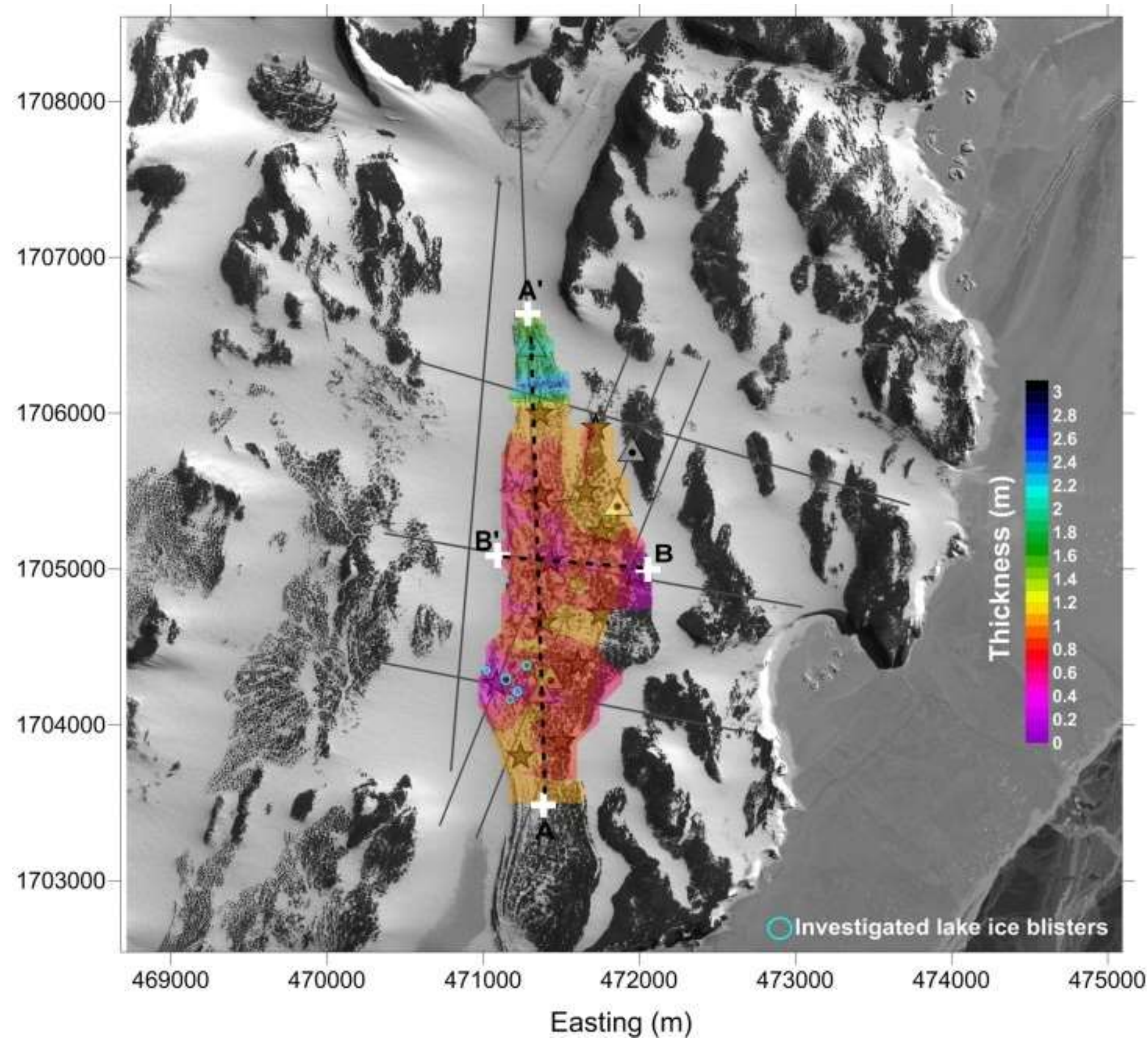


Figure 2.15: Representative map of debris thickness.

2.4. Airstrip construction and operation plan

2.4.1. **Engineering design**

In general the structural design of airport pavements consists of determining both the overall pavement thickness and the thickness of the component parts of the pavement. The factors that influence the required thickness of pavement are the following:

- magnitude of the airplane loads;
- volume of traffic;
- strength of the subgrade soil;
- quality of materials that make up the pavement structure.

Due to particular environmental Antarctic conditions the embankment design has been designed taking in account two requirements, discussed in the following:

- Permafrost protection.
- Geotechnical aspects, according to U.S. Department of Transportation [2.6] and Transport Canada [2.7].

2.4.2. **Embankment design**

Permafrost Protection

The design adopted for the proposed airstrip follows the Air Convection Embankments (ACE) technique. These embankments are constructed of poorly-graded open aggregate with a low fine content, resulting in very high air permeability. Unstable air density gradients that develop within the embankment during winter result in buoyancy-induced pore air convection (dense cool air moves downward pushing warm air upward). This convection increases the heat flux out of the embankment and foundation material during winter months. During summer, the air density gradient is stable and convection does not occur (warm air at the top and cold air at the bottom). The net effect is an increase in winter cooling without a corresponding increase in summer warming, so that thawing is reduced in the permafrost layer beneath the embankment [2.8].

The embankment will be therefore constituted by graded filters, which consists of layers of granular material that prevent the movement of particles subjected to erosion. Successively more permeable and coarse-grained soils are placed, such that the fine constituents of each layer cannot be washed into the voids of the succeeding layer.

As a preliminary indication, to be revised after the results of a trial embankment that will be carried out on site, Figure 2.16 and Table 2.1 summarize the three grain size distribution ranges corresponding to the surface, the base course, and the sub-base respectively. In particular, the first sub-base layer will be composed by crushed rock and coarse gravel; the base course will be composed by coarse to medium gravel; the surface layer by coarse to fine gravel.

Furthermore, the surface temperature can be reduced by a light colour material, such as crushed granite (first 5 cm), which will increase the albedo of the surface and thereby lead to a reduced thickness of the active layer in permafrost areas underneath embankments.

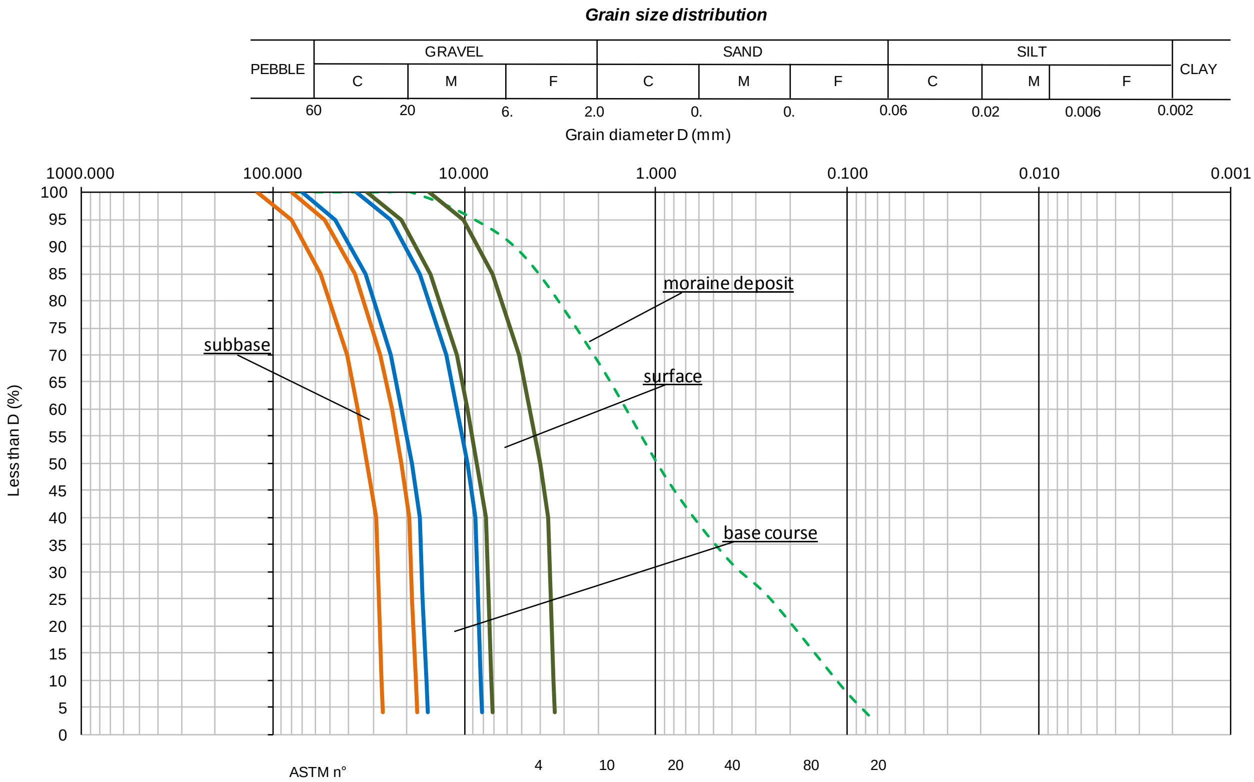


Figure 2.16: Sub-base, base course, surface Grain size distribution and relative layers.

Table 2.1: Grain Diameter less than values (mm)

passing (%)	Sub-base		Base course		Surface	
100	120.0	80.0	70.6	36.4	32.1	15.2
95	80.0	53.3	47.1	24.2	21.4	10.1
85	56.0	37.3	32.9	17.0	15.0	7.1
70	41.0	27.3	24.1	12.4	11.0	5.2
60	36.0	24.0	21.2	10.9	9.6	4.5
50	32.0	21.3	18.8	9.7	8.6	4.0
40	29.0	19.3	17.1	8.8	7.8	3.7
25	28.0	18.7	16.5	8.5	7.5	3.5
10	27.0	18.0	15.9	8.2	7.2	3.4
4	26.5	17.7	15.6	8.0	7.1	3.3

Embankment design: geotechnical aspects

In order to determine the minimum embankment thickness the following assumptions have been made:

- flexible pavement based on CBR method of design;
- reduced subgrade strength providing adequate load carrying capacity during the frost melting period.

The design of a flexible pavement is based on the empirical CBR design method. Gear configurations are considered using theoretical concepts as well as empirically developed data. FAA (Federal Aviation Administration) provide guidance to determine the required total thickness of flexible pavement (surface, base, and sub-base) needed to support a given weight of aircraft over a particular subgrade.

Consideration should be given on the choice of adopting the "reduced subgrade strength method". As stated in AC150/5320-6E U.S. Department of Transportation, the protection of pavements from the adverse seasonal frost and permafrost effects may be based on either of two approaches. The first approach is based on the control of pavement deformations resulting from frost action. In this case, sufficient combined thickness of pavement and non-frost-susceptible material must be provided to eliminate, or limit to an acceptable amount, frost penetration into the subgrade and its adverse effects. The second approach is based on providing adequate pavement load carrying capacity during the critical frost melting period. This second approach provides for the loss of load carrying capacity due to frost melting but ignores the effects of frost heave.

Three design procedures that encompass the approaches have been developed and they are shortly reported below for comprehensiveness.

Complete Frost Protection (1). Complete frost protection is accomplished by providing a sufficient thickness of pavement and non-frost-susceptible material to completely prevent frost/thaw penetration. The method can be based respectively on the thaw penetration or frost penetration depth which are determined in similar empirical ways. The depth of thaw penetration is based on the air thawing index, average wind speed during the thaw period, pavement type, and density of the permafrost layer. The thawing index used for design should be based on the three warmest summers in the last 30 years of record or the warmest summer in the last 10 years. The difference between the determined depth of seasonal thaw and the thickness needed for structural support is the amount of non-frost-susceptible material that must be provided to fully contain the depth of seasonal thaw. Complete frost protection method applies to FG-3 and FG-4 soils (see Table 2.2 for soil frost group definitions), which are extremely variable in horizontal extent. These soil deposits are characterized by very large, frequent, and abrupt changes in frost heave potential.

FROST GROUP	KIND OF SOIL	PERCENTAGE FINER THAN 0.02 mm BY WEIGHT	SOIL CLASSIFICATION
FG-1	Gravelly Soils	3 to 10	GW, GP, GW-GM, GP-GM
FG-2	Gravelly Soils Sands	10 to 20 3 to 5	GM, GW-GM, GP-GM, SW, SP, SM, SW-SM, SP-SM
FG-3	Gravelly Soils Sands, except very fine silty sands Clays, PI above 12	Over 20 Over 15 -	GM, GC SM, SC CL, CH
FG-4	Very fine silty sands All Silts Clays, PI = 12 or less Varved Clays and other fine grained banded sediments	Over 15 - - -	SM ML, MH CL, CL-ML CL, CH, ML, SM

Table 2.2: Soil Frost Groups [2.6].

Limited Subgrade Frost Penetration (2). The limited subgrade frost penetration method is based on holding frost heave to a tolerable level. Frost is allowed to penetrate a limited amount into the underlying frost susceptible subgrade. Sixty-five percent of the depth of frost penetration is made up with non-frost-susceptible material. Use of the method is similar to the complete protection method. Additional frost protection is required if the thickness of the structural section is less than 65 % of the frost penetration. The limited subgrade frost penetration method allows a tolerable amount of frost heave. This design method should be used for FG-4 soils but can be applied to soils in frost groups FG-1, FG-2, and FG-3 (see Table 2.2 for soil frost group definitions).

Reduced Subgrade Strength (3). The reduced subgrade strength method is based on the concept of providing a pavement with adequate load carrying capacity during the frost melting period. Use of the reduced subgrade strength method involves assigning a subgrade strength rating to the pavement for the frost melting period. The various soil frost groups should be assigned strength ratings as shown in Table 2.3. This method is recommended for FG-1, FG-2, and FG-3 subgrades, which are uniform in horizontal extent (see Table 2.2 for soil frost group definitions).

Frost Group	Flexible Pavement CBR Value	Rigid Pavement *k*-value
FG-1	9	50
FG-2	7	40
FG-3	4	25
FG-4	Reduced Subgrade Strength Method Does Not Apply	

Table 2.3: Reduced Subgrade Strength ratings [2.6].

Both Complete Frost Protection (1) and Reduced Subgrade Strength (3) methods have been considered for the design of the runway embankment. It was preferred to proceed adopting the Reduced Subgrade Strength method for the following two reasons:

1. In order to satisfy the convection embankment technique requirements, the embankment is designed with non-frost susceptible material as shown in Figure 2.16. The method (1) based on the freezing/thaw index determine the amount of non-frost-susceptible material

that must be provided to contain the depth of seasonal thaw/frost which in this case results already fulfilled.

2. The natural thermal regime of the ground comprises seasonal thawing and refreezing of the upper layer of the permafrost that lead to a loss of bearing capacity. By preventing the degradation of the permafrost layer seasonal thawing should remain constant (or follow its natural course) and it is therefore important to base the pavement design on a reduced subgrade strength that will capture this condition.

FAA suggests different reduced subgrade strength ratings in function of the frost group material and the type of pavement (flexible Vs rigid). In the present case a CBR value of 8 was assumed, according to the above mentioned guidelines. However, based on site test results, a CBR value of 6 and 4 have also been investigated.

The base course represents the principal structural component with the major function of distributing the imposed wheel loadings to the subgrade. In general, the base course must be of such quality and thickness to prevent failure in the subgrade, withstand the stresses produced in the base itself, resist vertical pressure tending to produce consolidation and resulting in distortion of the surface course, and resist volume changes caused by fluctuations in its moisture content. The quality of the base course depends upon composition, physical properties and compaction. Many material and combinations thereof have proved to be satisfactory as base course, Figure 2.17 reports a list of material suggested by the U.S. Department of Transportation [2.6].

(1) Item P-208 – Aggregate Base Course[1]
(2) Item P-209 – Crushed Aggregate Base Course[2]
(3) Item P-211 – Lime Rock Base Course
(4) Item P-219 – Recycled Concrete Aggregate Base Course
(5) Item P-304 – Cement Treated Base Course
(6) Item P-306 – Econocrete Subbase Course
(7) Item P-401 – Plant Mix Bituminous Pavements
(8) Item P-403 – HMA Base Course

Figure 2.17: Materials for use of Base Course [2.6].

A sub-base is included as an integral part of the flexible pavement structure in all pavements except those on subgrade with a CBR value of 20 or greater (usually GW or GP type of soils). The function of the sub-base is similar to that of the base course and any material suitable for use as base course can also be used on sub-base.

In general the subgrade soil are subjected to lower stresses than the surface, base and sub-base courses. Subgrade stresses attenuate with depth, and the controlling subgrade stress is usually at the top of the subgrade, unless unusual conditions exist. FAA indicates depths below the subgrade surface to which compaction control apply for construction and density control of subgrade soil, depending on the design aircraft.

FAARFIELD (FAA Rigid and Flexible Iterative Elastic Layered Design) software, version 1.305, was used to determine the minimum layer thickness. The software is the Standard Thickness Design Software accompanying the [2.6] Airport Pavement Design and Evaluation.

The obtained thicknesses are shown in Figure 2.18 to Figure 2.20 for the three reduced CBR values considered for the subgrade.

According to these values, a minimum thickness of 0.6 m has been adopted in the design, corresponding to a reduced CBR value of 8%, adopted in accordance with the [2.6] and in correspondence with the weakened condition due to frost melting.

However, the above mentioned reduced value does not reflect the worst condition corresponding to a CBR value of 4%. This degradation of the subgrade takes place during a very limited period of the year and it was thus decided not to penalize the design prescribing a minimum thickness of 0.78 m in order to optimize costs and material requirements.

In this respect it should be noted that the average thickness of the embankment is more than 1.0 m and localized area might require greater maintenance intervention during the month of January.

Further, individual thicknesses where determined for the three layers having the following geometry and minimum CBR: 25 cm of surface layer with CBR=21.5%, 16 cm of base course layer with CBR=24%, and 19 cm of sub-base layer with CBR=33%.

The CBR values of the base course and sub-base layer corresponds to the lower bound of the typical CBR values correlated to the type of soil units as shown in Figure 2.8 [2.5]. The CBR value of the surface layer is based on unpaved surface requirements for shear strength, as discussed in the sequel.

The runway is designed with an unpaved surface according to Unpaved Runway Surfaces [2.7].

Gravel surfaces deteriorate with time and under repeated traffic loadings. The most common defects occurring with gravel surfaces are frost heaves, depressions, soft spots and loss of aggregates. Periodic grading, compaction and addition of new material are required to maintain the integrity of the gravel surface and to ensure the safe operation of aircraft.

The shear strength of gravel surfaces depends on the interlock of aggregates and internal friction. The surface shear strength also depends on the properties of the surface materials under the influence of moisture. This results in the surfaces of unpaved runways being susceptible to shear failures, in particular in wet conditions.

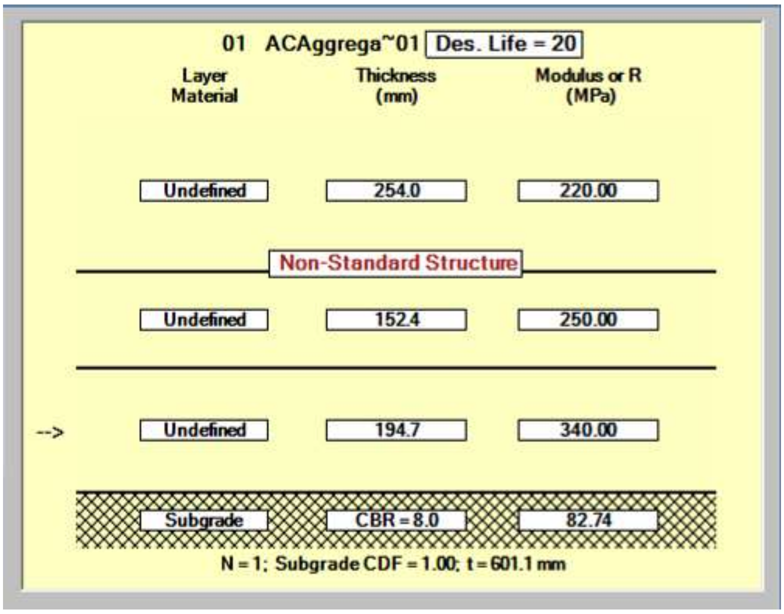


Figure 2.18: FAARFIELD software results for a subgrade with a reduced CBR=8% [2.6].

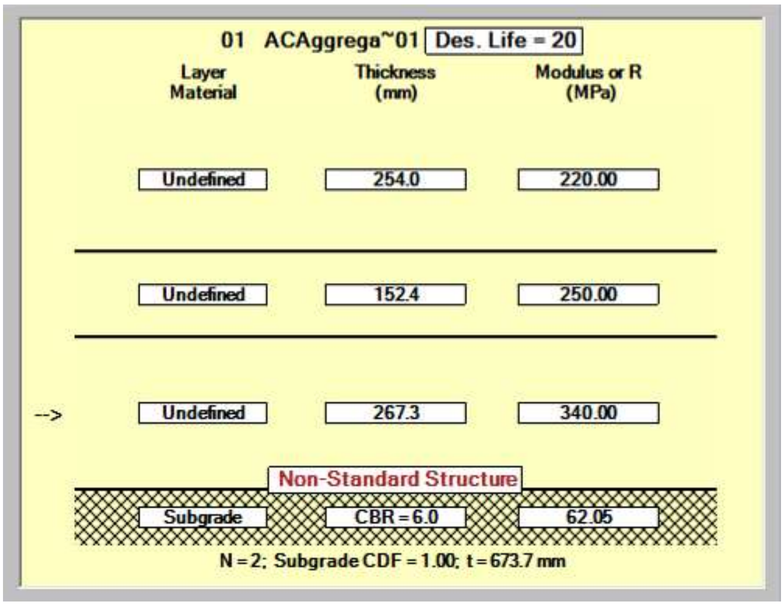


Figure 2.19: FAARFIELD software results for a subgrade with a reduced CBR=6% [2.6].

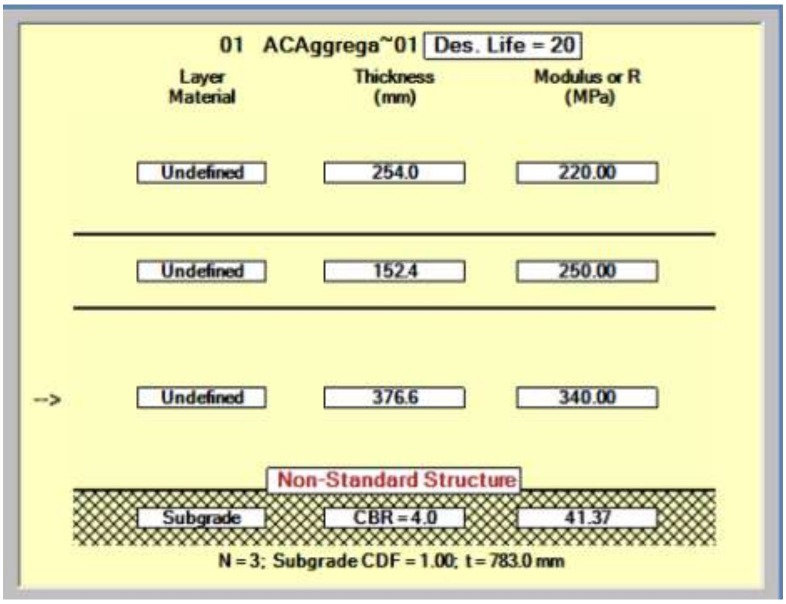


Figure 2.20: FAARFIELD software results for a subgrade with a reduced CBR=4% [2.6].

The surface shear strength of unpaved runway is usually expressed in terms of CBR value. In particular, AC 300-004 [2.7] correlates the maximum tire pressure depending on the CBR value measured with Boeing Penetrometer, as shown in Figure 2.21. The curve indicates that a runway has sufficient surface strength for aircraft operations provided the tire pressure in psi is less than or equal to 5 times the CBR as measured with the Boeing High Load Penetrometer, which corresponds to a CBR minimum of 21.5% for the design under consideration.

The Boeing High Load Penetrometer consists of a hydraulic cylinder with a cone point test probe mounted at the rod end. The hydraulic cylinder is normally positioned against the frame of a heavy vehicle which serves as a reactive load. In the test procedure, the probe is driven at a steady rate to a 100 mm (4 inch) depth into the surface by the application of pressure through a hand pump.

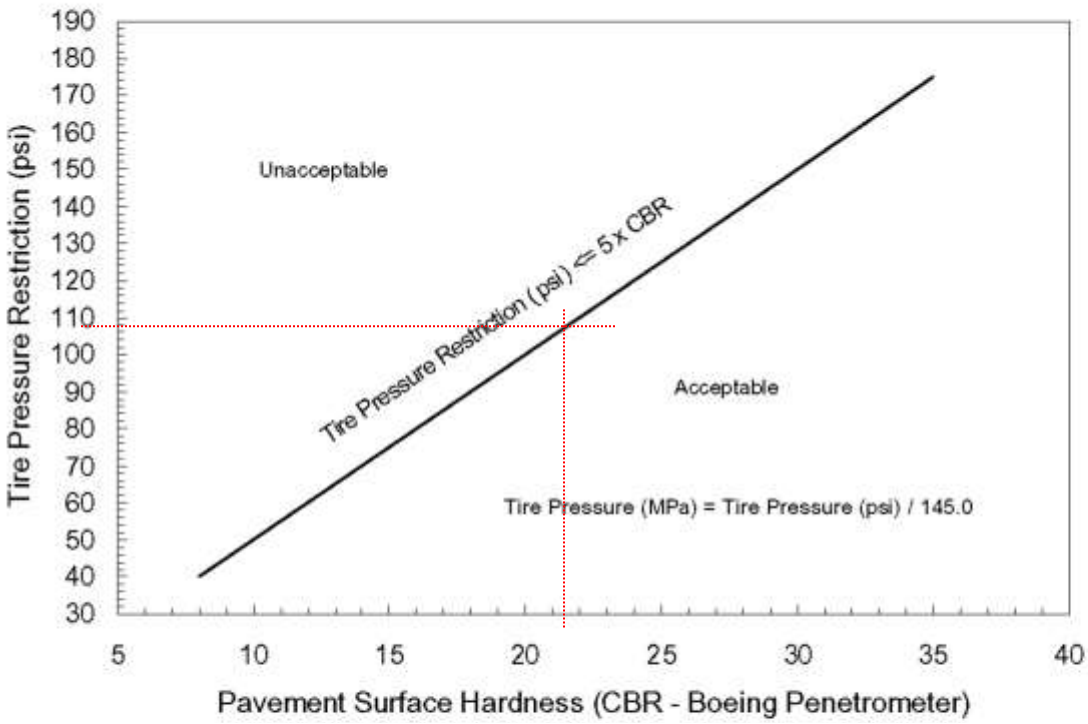


Figure 2.21: Tire Pressure Restriction vs CBR Measured with Boeing Penetrometer [2.7].

The convection embankment design has been summarized by detailed drawings as stated below:

- Figure 2.22: example of longitudinal profiles;
- Figure 2.23: embankment transverse section with details;
- Figure 2.24: construction phases.

As it is shown in Figure 2.23 the thickness of the surface and base course layer are kept constant as determined, while the sub-base layer has a variable thickness in order to adapt to the slope of the ground level. In this respect, where the sub-base layer should be more than 30 cm, the additional amount of material could be obtained as moraine, as it is found in place. In addition, the scope of the shoulders of the embankment is to protect the structure from adverse erosion condition. In order to combine this requirement with the use of the existing material on site it is advisable to form the shoulders with pebbles and crushed fragments having diameter ranging from 10 to 50 cm.

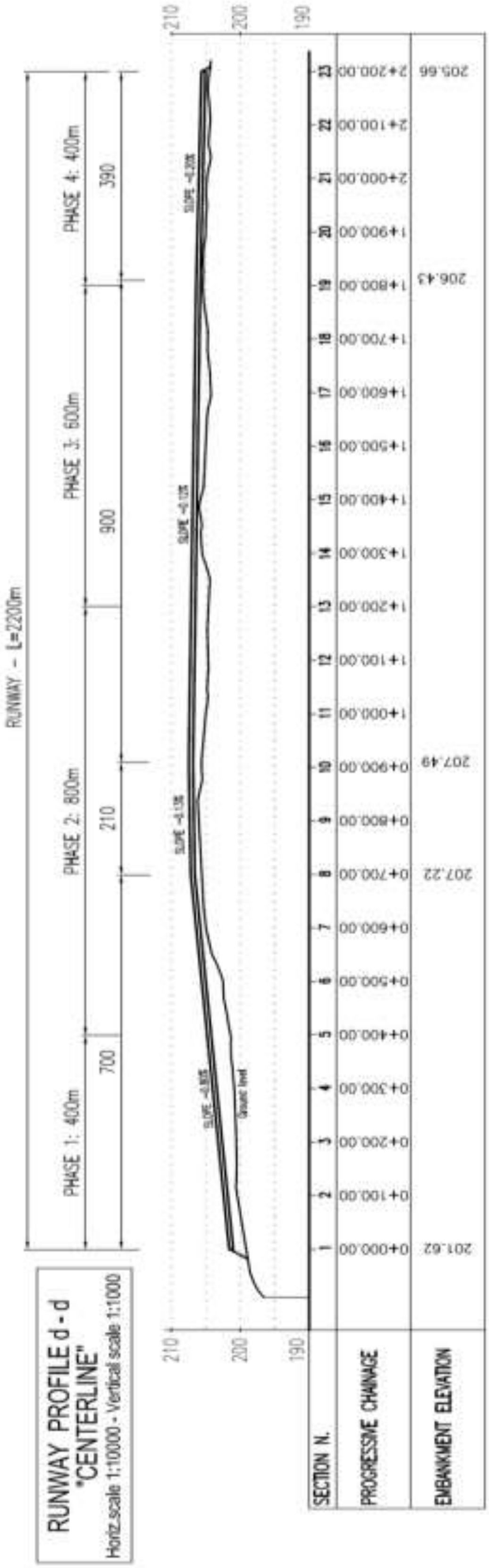


Figure 2.22: Runway profile d-d (centreline).

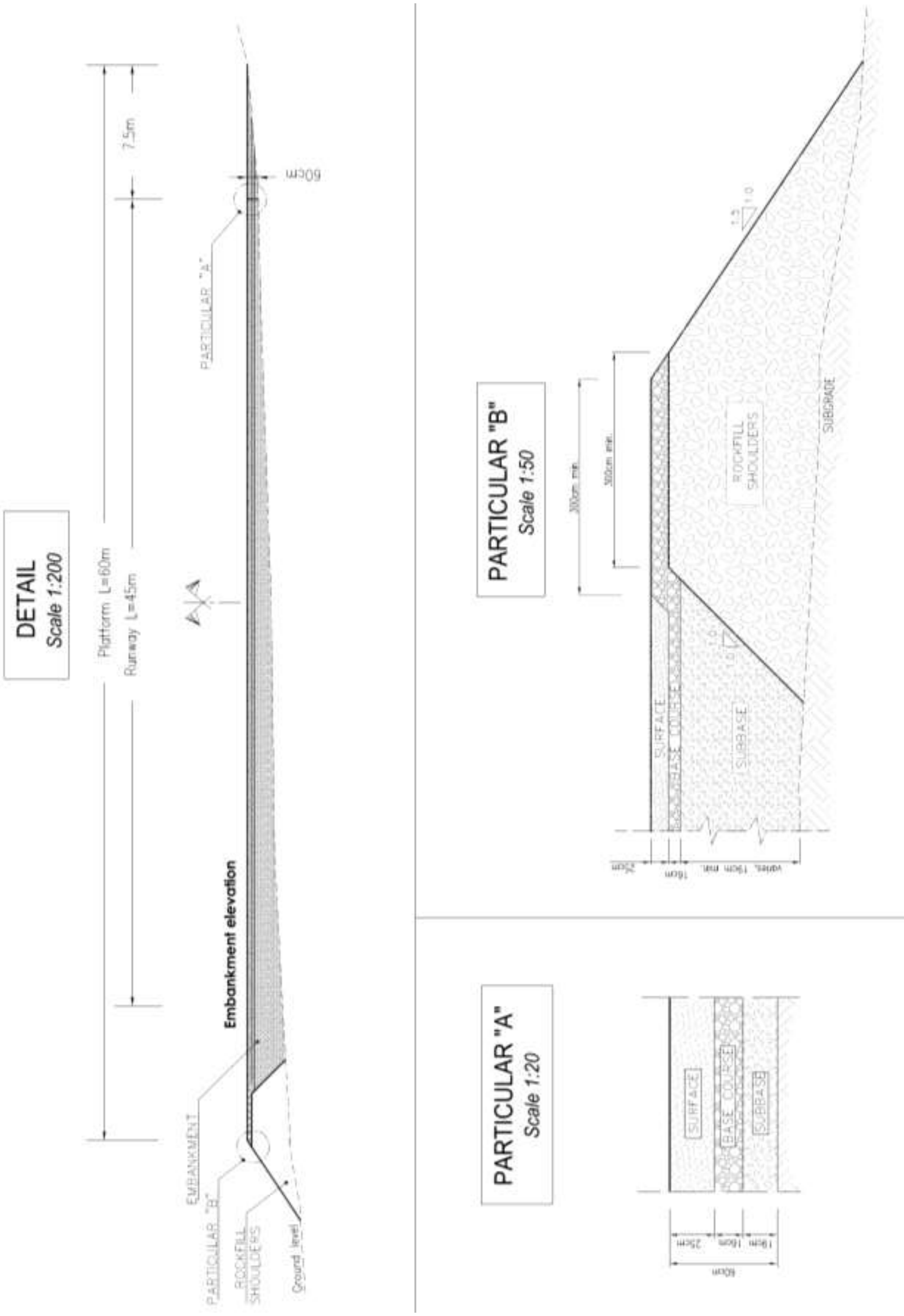


Figure 2.23: Detail of Runway section, with embankment and shoulders profile.

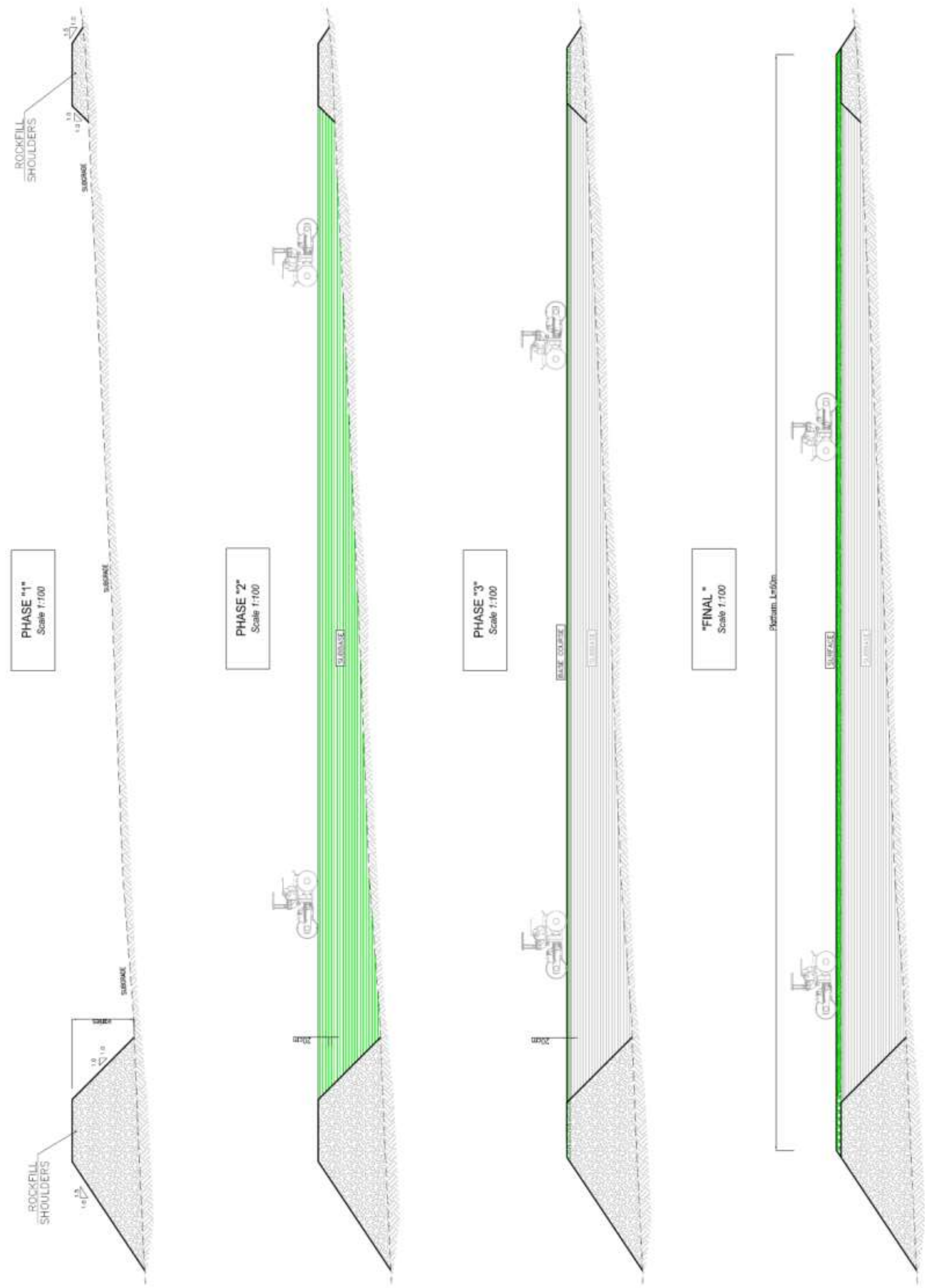


Figure 2.24: Construction phases.

2.4.3. Numerical modelling

A series of preliminary thermal models of the embankments were carried out in order to test the effectiveness of the design theory as well as to optimize the test-site embankment.

The modelling was carried out with the finite element software TEMP/W in combination with SEEP/W-AIR/W from GEO-SLOPE International Ltd. TEMP/W is a finite element software that models thermal changes in the ground due to different causes.

In the present case, the key modelling assumption made in the analyses is that the moisture content of the ground is constant through the process. In addition, frost heave or any volumetric changes are not predicted, because the modelling is aimed at forecasting only heat conduction processes.

To establish the initial pore-water/pore-air and temperature conditions, a steady-state SEEP/W-AIR/W and TEMP/W analysis is first required. Then, TEMP/W uses the liquid water and air fluxes to compute and assemble the advective heat transfer terms into the global finite element equations.

The model geometry is represented in Figure 2.25 and corresponds to a section (phase 4), as reported in Figure 2.23. As it is shown the mesh is formed by quadrilateral and triangular elements with increased density within the embankment. The model has been simplified and 3 different materials have been defined: subgrade, surface and sub-base. As it can been seen in Figure 2.25 the sub-base material has been used to model the side shoulders and the base-coarse layers.

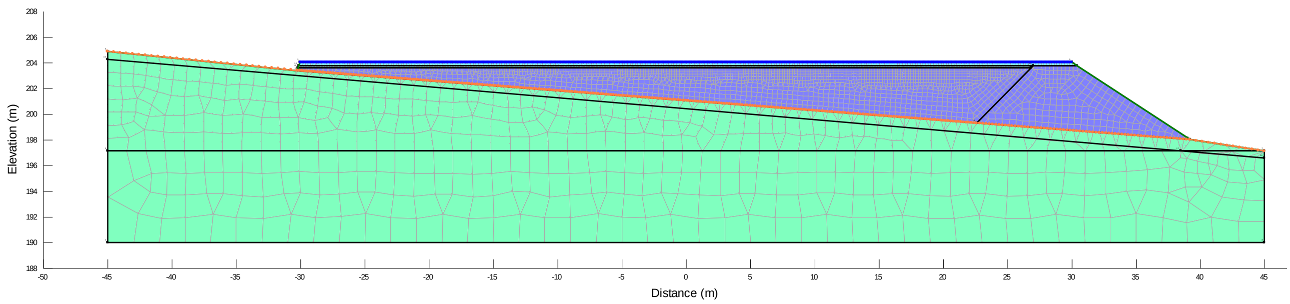


Figure 2.25: Model geometry.

The boundary conditions are as follows:

1. Initial Conditions: Steady-state analyses

The SEEP/W-AIR/W analysis was performed by applying a null hydraulic pressure at the original ground surface and a zero pore-air pressure at the top of the embankment. These boundary conditions result in hydrostatic pore-air and pore-water distributions.

2. Transient Convective Heat Flow Analyses

A total head of 0 m was applied to the entire domain throughout the duration of the SEEP/W transient analysis. This boundary condition ensures that the water remains hydrostatic, despite the fluctuation in air pressure.

Three harmonic temperature functions representing the temperature fluctuation with time were applied to the existing ground level (outside the embankment), to the side-slope and top of the embankment, and to a depth of 60 cm below the ground surface. These functions are defined over 365 days, based on available temperature data for the site. Ultimately a geothermal ground heat flux of 5.2 $kJ/day/m^2$ was applied to the bottom of the domain.

The geotechnical, hydraulic and thermal material properties used for the models are summarized in Table 2.4. These parameters are based on available literature data [2.9] and [2.10].

Table 2.4: Material Properties adopted in the numerical analyses

	Units	Subgrade	Subbase & Base Course & shoulders	surface
Hydraulic Conductivity	(m/day)	1	50	1
water content	(%)	0.3	0.01	0.1
Frozen Heat Capacity	($kJ/m^3/°C$)	2,079	2,079	2,191
Unfrozen Heat Capacity	($kJ/m^3/°C$)	3,150	3,150	3,061

The harmonic temperatures distribution were simulated cycling for 5 years using time steps of 1 day with adaptive time stepping having a minimum and a maximum allowable time step of 0.25 day and 1 day, respectively.

Results are showed in Figure 2.26 and in Figure 2.27. As expected, during the summer months, the air density gradient is stable and the air fluxes are negligible (warm air at the top and cold air at the bottom). Conduction dominates the heat transfer process and temperature contours are relatively horizontal within the embankment.

During winter or when the temperature at the surface is lower than the temperature at the base of the embankment, convective cells develop within the embankment, as shown in Figure 2.26 and in Figure 2.27 for different time step. The air convection develops through the entire embankment, even if it is noted that distinctive big convection cells develop close to the shoulder of the embankment and not along the entire thicknesses.

Sensitivity analyses were also carried out by considering different values of air hydraulic conductivity and the results obtained are consistent with those above shown.

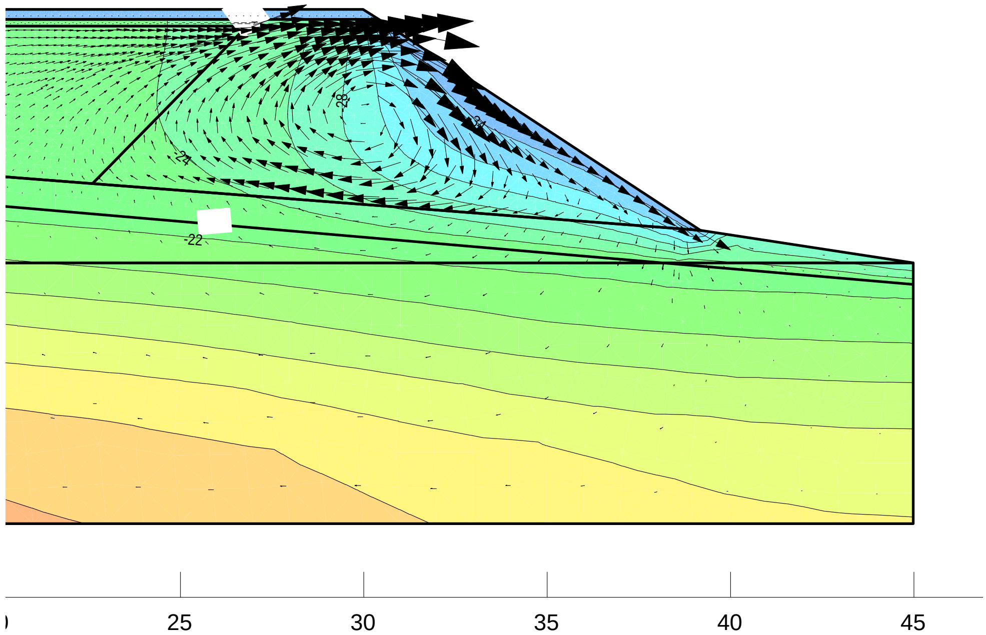


Figure 2.26: Numerical result – convective cells and temperatures (Day 220).

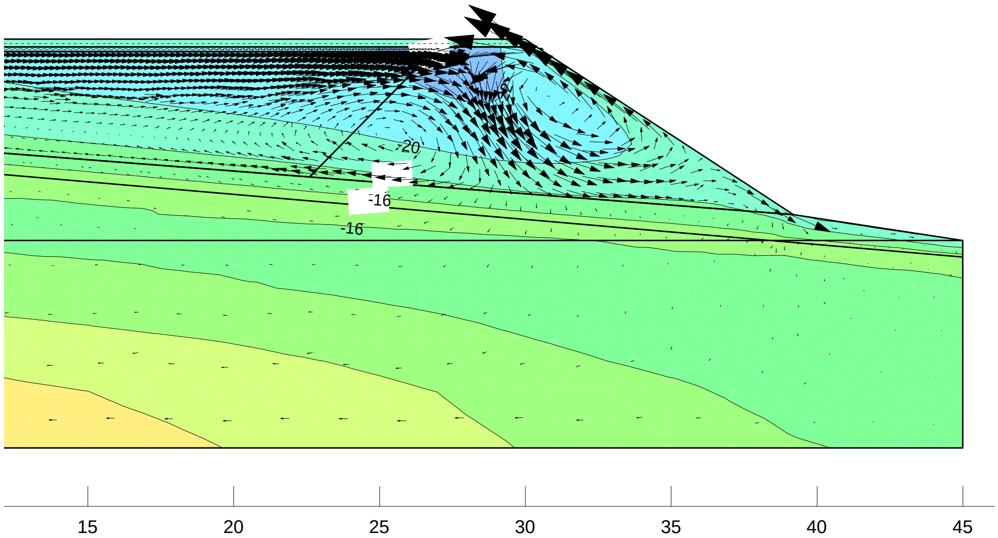


Figure 2.27: Numerical result – convective cells and temperatures (Day 270).

It must be outlined that the scope of the analysis herein presented is to have a basis for the design by assessing the development of natural convection of the pore air in the gravel embankment due to temperature gradients. However, the model will be furthermore detailed once a test-site embankment will be carried out. The reason is that, because of complex and adverse ambient conditions, it is necessary to base many aspects on a back analysis of collected experimental data, such as ground temperature within, below and outside the embankment, in addition to the already available air temperature. The preliminary analyses are considered satisfactory for the purpose.

2.4.4. Material requirements and quarries

On the basis of the available survey, the discussed layout and the embankment profile it was estimated the material volume required to form the embankment. Figure 2.23 shows the typical cross section of the runway. Table 2.5 summarizes the volume required in details per each phase for the construction of the embankment and the rockfill shoulders.

The runway will be constructed by using essentially the material that will be collected all around the layout the road to access the site, reported in Figure 2.28, using heavy equipment. If necessary, the remaining required material will be obtained by means of blasting of the surrounding granite bedrock.

Table 2.5: Volume of material required to realize the embankment

		Volume (m^3)			
	L (m)	Main platform of the embankment	Rockfill shoulders West side	Rockfill shoulders East side	Embankment
Phase 1	400	50,230	11,600	1,170	63,000
Phase 2	800	39,850	10,170	380	50,400
Phase 3	600	99,820	19,170	1,410	120,400
Phase 4	400	26,520	3,590	190	30,300
	Total	216,420	44,530	3,150	264,100

The intention is to use many small quarries that have been visually identified along the road to access the site. In more details, an outcrop of granite has been identified near to the east side of chainage 0+000 and this would provide about 16,000 m^3. Figure 2.29 shows in magenta colour the available small quarries that could be used along the road to access the site.

The material collected from the small quarries could also be extracted by means of blasting that might be performed with traditional explosive or with the use of low-water content explosive depending on the temperature. The explosive normally used are suitable for up to about -5 degrees Celsius, while for temperature that reaches -45 degrees, the explosive should be composed of granular powder not to damage the dynamite material itself.

A separate study of the blasting methods will establish a distance between the drilling holes in accordance to the grain size diameters required for the different embankments layers. The extracted material will be then removed using excavators and dumpers, then transported to the screening/crusher, where it is shredded and screened according to the grain size indicated in the project.

In order to crush and select the necessary rock bed for the construction of the airstrip the following equipment, or others having similar characteristic, have been selected:

- Atlas Copco Powercrusher PC 1055 J for crushing
- Atlas Copco Powercrusher HSC 3715 IT to select according to the requested grain diameter.

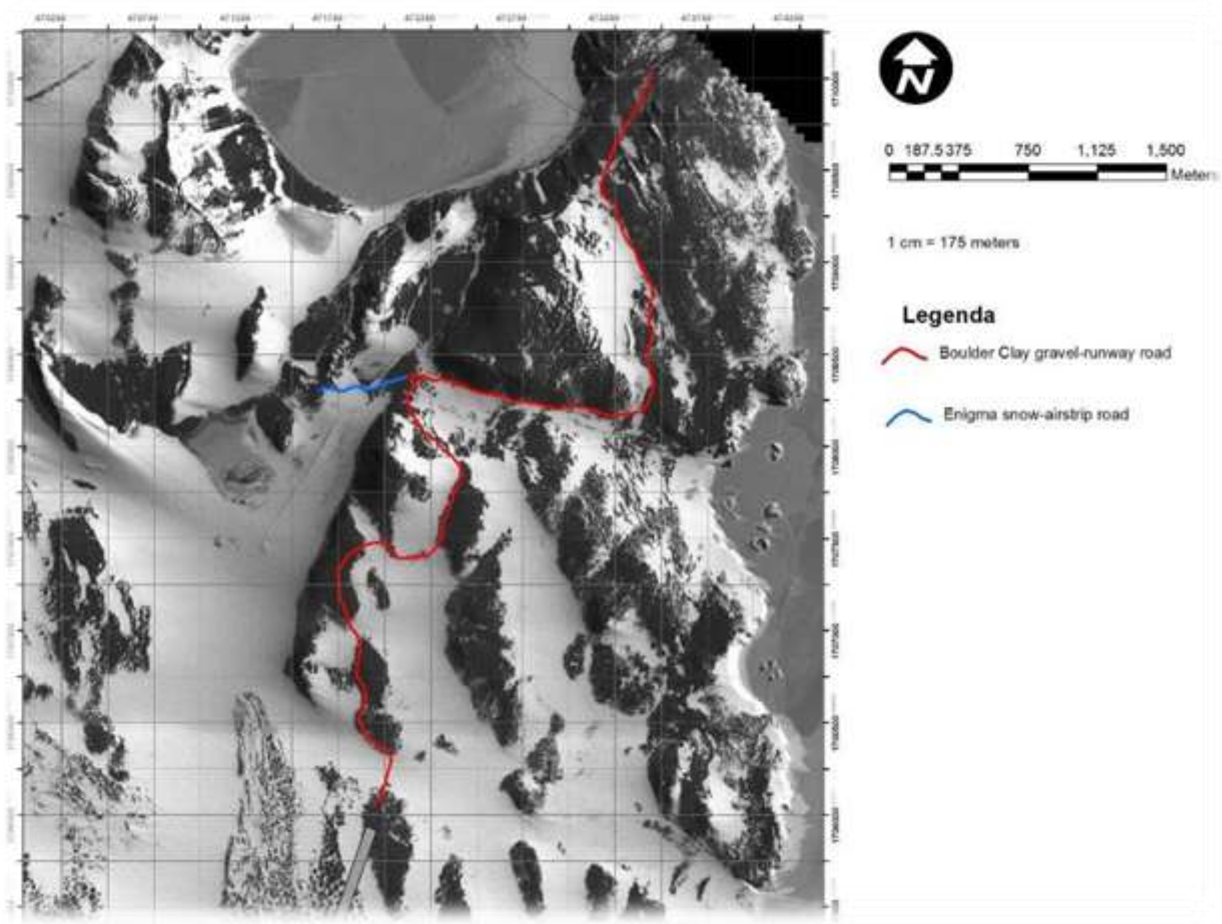


Figure 2.28: Roads to access the runway site, Boulder Clay.

Figure 2.29: Hypotetical quarries location (in magenta).

2.4.5. Construction Method

Before beginning excavation the area should be completely cleared from cobbles and rock fragments having dimension greater than 15 cm approximately.

The suitability of material to be placed in embankments shall be subject to prior qualification.

Excavation: Excavation should be performed only locally where ridge formations have been recorded and to follow the design profile reported in the present document. All suitable excavated material shall be used in the formation of embankment, or subgrade in areas where there is no moraine deposit.

Compaction requirements: The subgrade under areas to be paved shall be compacted to a target depth of 30 cm and to a density of not less than 95% of the maximum density as determined from ASTM D1557. Achieved performance will be controlled by field density tests according to ASTM D 1556 (preferably) or ASTM D 6938 (to be considered with care, taking into account the coarse grain size of the material). The material to be compacted shall be within +/- 2 of optimum moisture content before rolling to obtain the prescribed compaction. The finished grading operations, conforming to the typical cross section, shall be completed and maintained at least 100 m ahead of the paving operations.

Where blasting is planned to be implemented, a vibration consultant should be consulted, to advise on explosive charge weights per delay and to analyse records from seismograph recordings. The seismograph shall be capable of producing a permanent record of the three components of the motion in terms of particle velocity, and in addition shall be capable of internal dynamic calibration.

A record of each blast fired, its date, time and location should be kept; the amount of explosives used, maximum explosive charge weight per delay period, and, where necessary, seismograph records identified by instrument number and location.

Formation of embankments: Embankments shall be formed in successive horizontal layers of not more than 12 inches or 30 cm in loose state for the full width of the cross section.

The grading operations shall be conducted, and the various soil strata shall be placed, to produce a soil structure as shown on the typical cross section.

Operations on earthwork shall be suspended at any time when satisfactory results cannot be obtained because of unsatisfactory conditions of the field.

The material of the layers shall be within +/-2 of optimum moisture content before rolling to obtain the prescribed compaction.

Rolling operations shall be continued until the embankment is compacted to not less than 95% of maximum density as determined by ASTM D 1557.

The in-place field density shall be determined in accordance with ASTM D 1556 (preferably) or ASTM D 6938.

Compaction areas shall be kept separate, and no layer shall be covered by another until the proper density is obtained.

In the construction of embankments, layer placement shall begin in the deepest portion of the fill; as placement progresses, layers shall be constructed approximately parallel to the finished pavement grade line.

Finishing and protection of subgrade: After the subgrade has been substantially completed the full width shall be conditioned by removing any unstable material which will not compact properly. The resulting areas and all other low areas, holes or depressions shall be brought to grade with suitable selected material. Scarifying, blading, rolling and other methods shall be performed to provide a thoroughly compacted subgrade shaped to the lines and grades shown on the plans.

In summary, the site work operation mainly comprise: scraping, grading, transporting and compacting operations.

The heavy equipment currently available at Mario Zucchelli Station are listed below:

- 2 Excavator;
- 1 Dumper;
- 2 Dozer;
- 3 Wheel Loader;
- 1 Motor Grader;
- 1 Vibratory Roller.

In addition, heavy equipment that will be purchased, or rented, to carry out the construction are listed below (the brand type is here only an indication, and comparable models are available by many different construction equipment manufactures):

- 1 Excavator;
- 1 Track Loader;
- 1 Dozer with Ripper;
- 3 Dumper;
- 1 Motor Grader;
- 1 Screener unit.

The timeline estimate has been based on a work schedule of 4 years with 2 periods per year: Period 1 November-December, Period 2 January-February. This division was made to account for the more difficult weather related ground conditions, such as excavating the frozen ground, that exists in Period 1, by assuming reduced capacities for the operating machines.

The construction site is planned to be divided into 3 major areas. One area will be designated for the powercrusher to crush/screen the material and store the material that will be used to form the embankment. The second one is formed by the area where the collecting of the material will take place by means of scraping or blasting. The third area is represented by the layout of the embankment itself. The material will therefore be transported between the 3 major areas by 4 dumpers.

The heavy machines intended to be used to collect the material are the following:

- Excavator
- Wheel loader
- Tracked loader
- Dozer D7

While, the heavy machines intended to be use to form the embankment are:

- Excavator
- Wheel loader
- Tracked loader
- Dozer D5
- Roller
- Grader

The construction timelines has been based on the assumptions listed below:

- Excavator bucket capacity = 1 m^3
- Blade capacity = 2 m^3
- Average distance that the dumper will cover = 1 km
- Average manoeuvre distance for the blade = 75 m
- Worked time per hour = 50/60 (= 0.83)
- Medium experience workers
- 2 shifts of 10 hours each for a total of 20 hours per day (24 h sunlight)
- 1 operator per machine
- 1 personnel on the site per shift
- Working period per personnel: 25 days/30 days

2.4.6. **Maintenance and Repair of Surface Layer**

Gravel pavement surface maintenance primarily involves periodic grading to remove the surface irregularities developing with time and to re-establish grades. Occasionally, new gravel has to be added to replace lost material. Dust suppression measures may also be needed during the summer months.

In the following the indications given in Unpaved Runway Surfaces [2.7] are reported.

Gravel Replacement

Material is gradually lost from gravel surfaces due to grading operations and the erosion effects of traffic and wind, and thickness may be lost from contamination by the subgrade soil. As a rule of thumb and depending on the number of aircraft movements and the type of traffic, runways surfaced with uncrushed gravel lose thickness at an average rate of 25 mm (1 inch) per year and runways surfaced with crushed gravel lose material at about half that rate.

Depending on the conditions and rate loss, the periodic addition of new material to the gravel surface is required to replace granular material that has been worn, blown, eroded or driven into the subgrade soil.

The repair materials should be mixtures of gravel, stone, and soil proportioned to meet the requirements specified. The aggregate should consist of clean, hard and durable particles of crushed or uncrushed gravel, stone, and be free from soft, thin elongated or laminated particles or other deleterious substances.

Grading and Compaction

Gravel surfaces should be graded and compacted as soon as conditions permit following the summer thaw in preparation for autumn/winter operations.

Maintenance of gravel surfaces should include grading at intervals sufficient to maintain pavement smoothness as well as the longitudinal and transverse slopes.

Surface grading should not cause any abrupt changes to the gradient and every effort should be made to maintain grades as close to the original design as possible.

Grading operations should eliminate surface depressions and soft spots. During normal grading operations, the surface is scarified to the depth of these depressions and the material blended and re-compacted. The amount of surface material removed by the grader should be minimal.

New material, when added during the grading operation, should be incorporated into a loosened surface and the resulting mixture compacted in 50 to 75 mm (2 to 3 inch) homogeneous lifts. This method is preferred because it ensures bonding between layers, as opposed to simply adding new material to an existing surface. The addition of fresh gravel should replace lost fines and fill local depressions such as those frequently experienced in aircraft run-up areas near the runway threshold.

Following grading operations or graveling and grading, the surface should be compacted using a roller when the surface is at its optimum moisture content.

Following compaction, the surface should be smooth, close to line and grade when measured with a 5 meter (16.4 ft) straight edge and free of loose stones greater than 25 mm (1 inch). Depressed areas, which occur during the rolling operations, should be lightly loosened, new material added and compacted.

2.4.7. **Case Histories**

In the sequel a list of successful case histories regarding convection embankment or unpaved gravel runway is reported.

Tasiujaq Airport

The village of Tasiujaq is located in the south-western part of Ungava Bay at 58°71' N and 69°82' W. Due to an increase of the mean annual air temperature the existing runway embankment suffered depressions along the shoulders caused by an accelerated thaw of the permafrost underneath and adjacent to the runway. A test-site of 200 m was constructed to investigate the air convection embankment method.

Fairbanks Test Site

An experimental Air Convection Embankment was designed during the winter of 1992-93 and constructed at Brown's Hill Quarry near Fairbanks, Alaska, during the summer and fall of 1993. Construction was carried out by placing 5-8 cm diameter of crushed rock. A total of 44 thermistors temperature sensors were installed in the embankment with four more installed beneath the original grade. The results presented indicate that air convection embankment should be effective at limiting or eliminating thaw of permafrost.

Nunavik airfields

Permafrost degradation is affecting the integrity of some transportation infrastructures in Nunavik, Québec. In 2005 and 2006 studies initiated by the MTQ (Ministère des Transports du Québec) were carried out in order to identify possible mitigation methodologies to be implemented. Air convective embankment was chosen as a protection technique to mitigate permafrost degradation under transportation infrastructure in recently paved access roads.

Leismer Airport

Leismer Airport (CET2) is located in Alberta, Canada. APMS (Airfield Pavement Management Systems, Velsen-Suid, the Netherlands) executes test procedure and calculations with respect to the assessment of the successful usability of unpaved gravel runways for aircraft operations.

2.5. Aeronautic characteristics

2.5.1. **Runway geometric characteristics**

The aeronautic design of the runway has been made with the support of ENAV, which is the Italian State delegates the management and control of civilian air traffic in Italy, according to the ICAO criteria:

- The apron will be located at 4.8 km from Mario Zucchelli Station, direction 204°.
- The orientation of the runway in flight approach and take off (GEO) is: 23.2° 203.2°.

- Considering the TRUE angle, the runway designation (rounded up to the next 10°) results to be: (023.2°) 02 / (203.2°) 20

The extremities of the runway, defined for both runway directions, identify the runway thresholds. The threshold (THR) is the beginning of that portion of the runway usable for landing. Begin and runway end are both coincident with the position of the THR.

Indeed, the positions of these points related to the centreline axis identify the following characteristic points:

Table 2.6: Runway characteristic point.

Designation NR RWY	THR Coordinates	RWY END Coordinates
02	74°45'06.2762" S 164°01'07.1530" E	74°43'59.8126" S 164°02'41.8436" E
20	74°43'59.8126" S 164°02'41.8436" E	74°45'06.2762" S 164°01'07.1530" E

The elevation of THR 02 is 203.5 m and the elevation of THR 20 is 201.0 m a.s.l.. The length of a runway defines its classification; it refers to the aircraft that requires greater length for the operations of take-off and landing.

The ICAO has developed a classification based on two codes: numeric (1 to 4) and alphabetic (A to F); the first symbol refers to the characteristic length of the runway "L", which represents the minimum distance request for the take-off by the plane at the maximum load, at sea level, in the absence of wind and standard atmospheric conditions (15° C) with no longitudinal slope; the second symbol regards the requirements to manoeuvre the aircraft in the critical stages of taxiing and parking, this is represented by the wingspan "R"; on the basis of these considerations the runway in question is classified as 4 (runway ≥ 1,800 m) D (wingspan ≥ 36 and < 52).

The runway is constituted by a single structure in mix crushed and compacted aggregate, with a length of 2,200 m and a width of 45 m. The available strip is 60 m large and it is possible to use exceeding meters to define a RWY shoulder of 7.5 m for each side of the runway.

The longitudinal slopes have been designed within the limits reported in the ICAO ANNEX 14 and they have the following characteristics:

- The first segment starts at 0 m up to 300.120 m and has a slope of 0.50%
- The second segment is 600.234 m long, it starts at 300.120 m up to 900.354 m and has a slope of 0.08%
- The third segment is 500.195 m long, it starts at 900.354 m up to 1,400.549 m and has a slope of 0.36%
- The highest slope of 0.79% is associated to the last segment which is long 803.310 m and goes from 1,400.549 m up to the end of the RWY.

In the following picture it is possible to see an example of the runway profile. The cross slope of this runway is 0.0%.

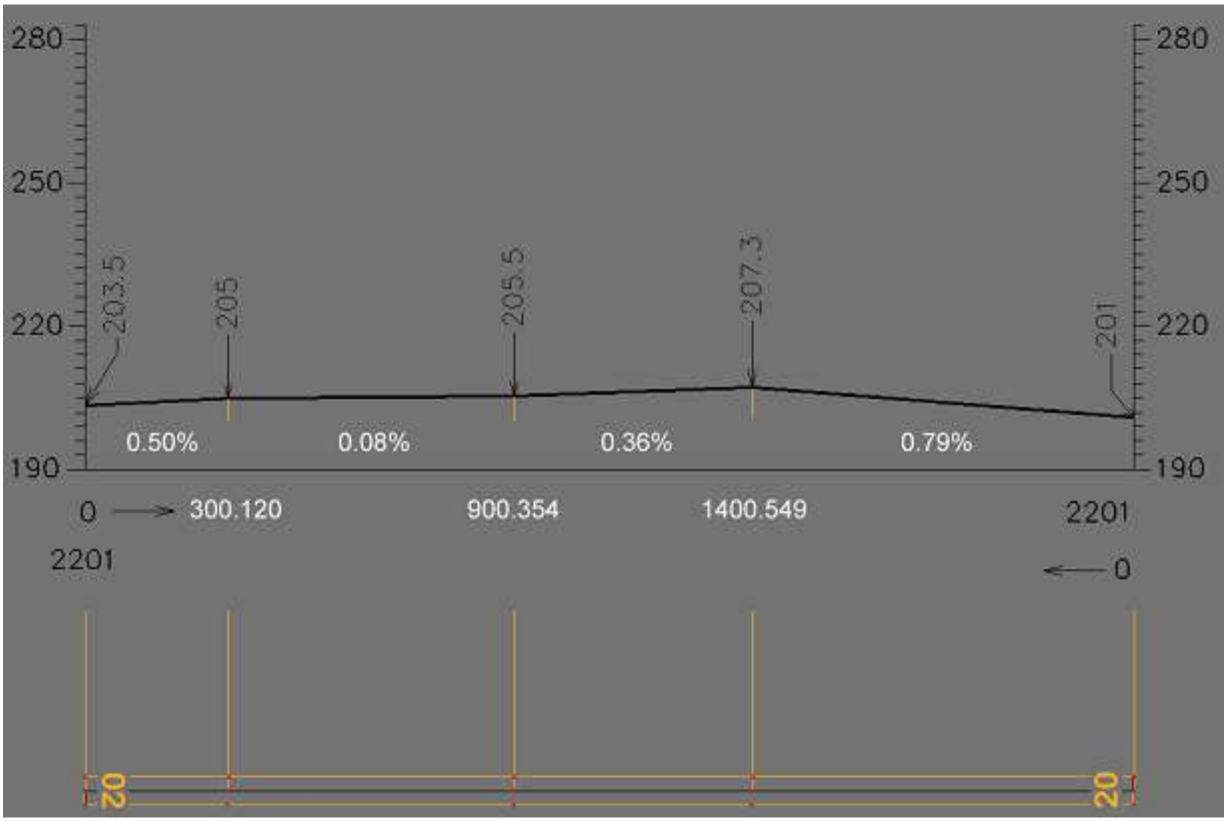


Figure 2.30: Runway longitudinal slopes.

The following aircrafts have been considered for the airstrip design at Boulder Clay site:

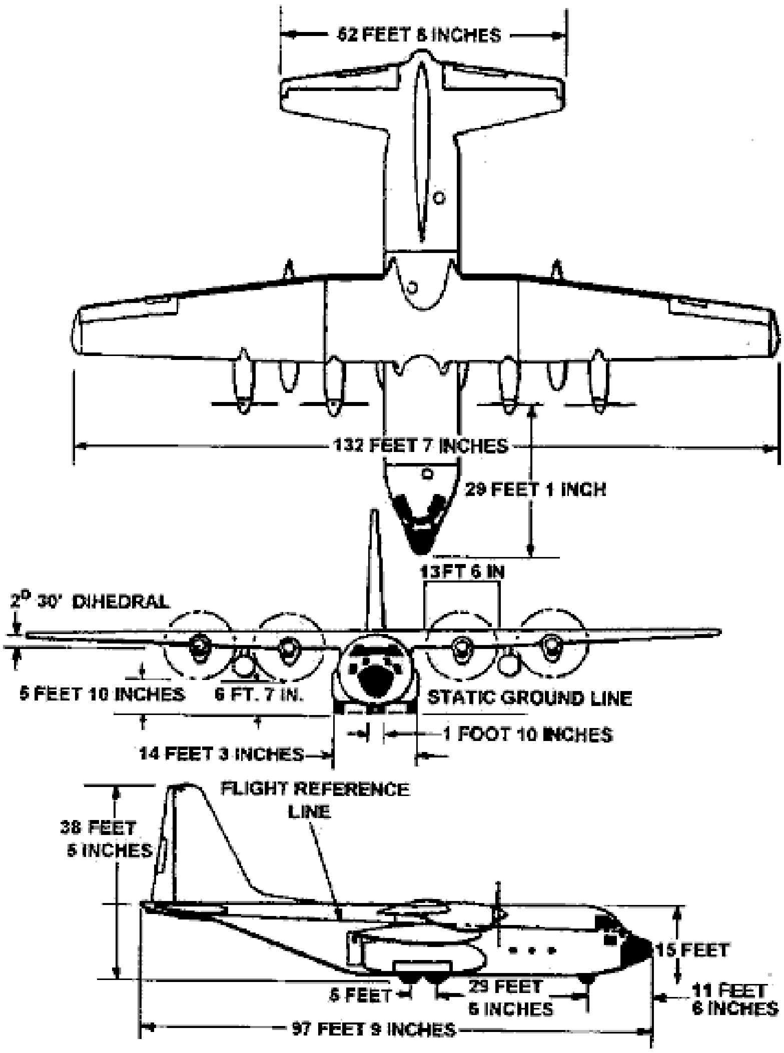
- L100/30;
- C130/J.

Aircraft characteristics are summarized in Table 2.7. Figure 2.31 shows a typical layout of a C130 cargo aircraft.

Table 2.7: Design Aircrafts

Aircraft	Gear Type	Equivalent single gear load (kg)	Tire pressure (MPa)	Maximum Takeoff Weight (lbs)	Maximum Takeoff Weight (kg)
L100/30	dual	26,400	0.74	156,000	70,600
C130/J	dual	29,600	0.67	175,050	79,400

*The average annual departures was based on the past 3 years flight activities



Airplane dimensions

Figure 2.31: Typical C130 Cargo dimension.

2.5.2. **Runway Considerations**

The ARP (Aerodrome Reference Point) coordinates of Boulder Clay runway are:

ARP Coordinates WGS84:	LAT 74°44'33"S LON 164°01'55"E
AD Elevation:	668FT
Geoid Undulation	-187.4FT
Variazione Magn. / Var. annua	NIL/NIL

Table 2.8: Runway characteristics

The runway code respect Annex 14 results "4D":

- "4" number related to the length (≥1,800m)
- "D" letter related to the wingspan (36 ≤ wingspan <52)

2.5.3. **Flight approach and take off**

ENAV conducted a study of the suitability of the site for a runway. The method used to evaluate the impact of each foreseen and existent obstacle inside the airfield is defining the slopes and the dimensions of the Obstacle Limitation Surfaces (OLS).

The surfaces are listed below:

- Take Off Climb Surface - TOCS
- Approach Surface - AS
- Transitional Surface – TS
- Inner Horizontal Surface - IHS
- Conical Surface - CS

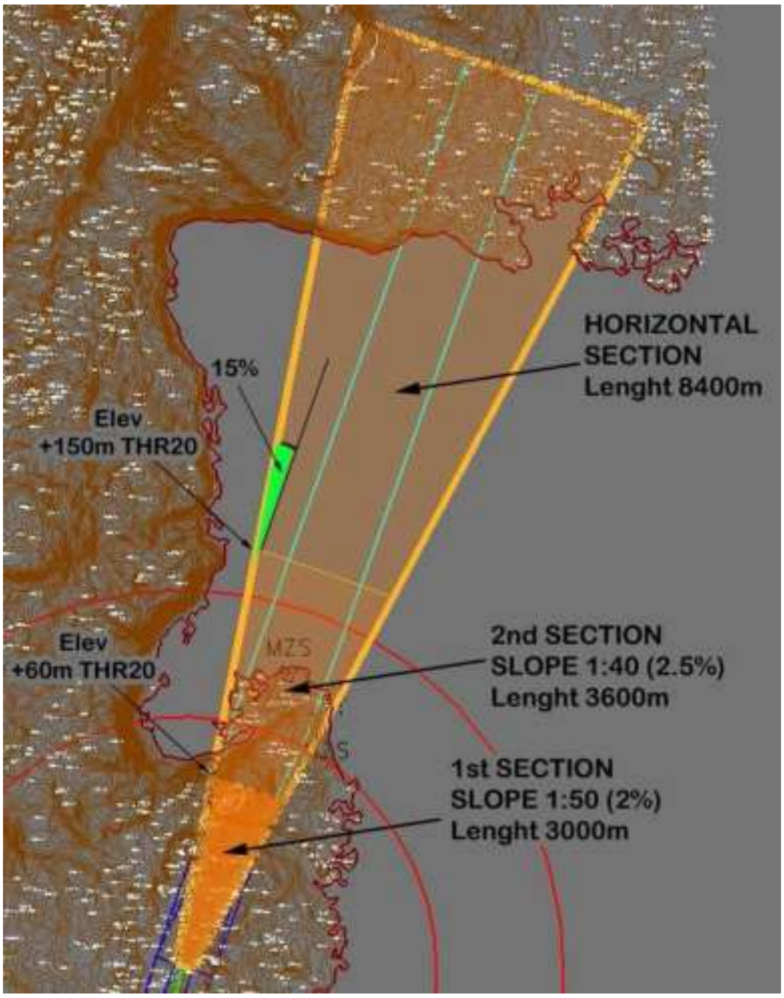


Figure 2.32: Approach Surface RWY20 (AS RWY20).

As conclusions of OLS analysis ENAV remarked that all the Obstacle Limitation Surfaces are penetrated by the terrain surrounding Boulder Clay aerodrome. However no particular implication is identified on defining approaches and departures operations for a single runway direction (north bound).

The terrain penetration, for what concern RWY 20, can be mitigated increasing the slope of section 1 up to 3.33% (1:30). The length of the second section can be increased in order to avoid the orography located at 14 km.

2.6. Future air operations and International profits

Having a permanent runway will allow intercontinental air operations to be distributed throughout the entire season. This will make all planning more reliable and will mean a much more efficient use of the stations and their infrastructures. In addition timely scheduled exchange of personnel would be possible with the assurance of a permanent runway. This would avoid the overpopulation that often occurs at the stations and simplify their logistic needs.

A reduction in the length of occupancy time could be achieved. So that, more science could be accomplished as more personnel will be rotated through Antarctica. With this reduction in the mean staying time for the scientists in Antarctica by an efficient redistribution of the occupancy in the stations, science would benefit, because more scientists could have access to Antarctica for their research needs (typically it would allow the increase of activities of "scientific observatory"), which usually requires limited and specific times for their management and often have a need to be repeated seasonally.

A permanent runway will increase the safety of all personnel by having a reliable site for air evacuations along with a place to land vital equipment, either medical or technical.

The importance of being able to manage medical emergencies does not need to be stressed. It is obvious. Having the possibility to manage technical emergencies makes the planning of expeditions easier and more reliable, because it will prevent the termination of a project simply for the lack of a small piece of equipment. Systems are becoming more complex and we have to be prepared to better guarantee reliable and rapid logistics. We can no longer rely on maintaining large costly over-stocked warehouses in anticipation of possible failures.

A permanent runway, in perspective, could make more autonomous the Italian expedition. In fact, whether the operations to activate the runway when the summer season starts would be reduced to a minimum, we could consider to reduce the opening crew.

At the end of the summer season, the last important assignment for the permanent runway would be the departure of the last expedition personnel. This was typically a job of the multipurpose vessel, and a great cost to the program. The use of an aircraft for this transportation is much less costly for our program and the environment. The charter of an aircraft is much cheaper than a charter of a ship, and the charter time of an aircraft for this task is a few hours versus several days for the ship to accomplish the same mission.

The fuel burned by the vessel is of an order of magnitude higher than that used by the aircraft, thus having both an economic and an environmental impact. The economic advantage is direct and obvious. For the environment one only has to note the reduced fuel burn with the corresponding lessened emissions.

The possible users of the permanent runway are not limited only to the Italian program.

Gondwana Station is only 13 kilometres from MZS in Terra Nova Bay area. Gondwana is older than MZS and belongs to the German BGR. It is a small summer station and it is not manned every season. PNRA often shares logistic operations with BGR. About the construction of the permanent runway, BGR already stated its interest formally.

KOPRI recently built the new Jang Bogo Station (JBS) at Terra Nova Bay. Since the time of the preliminary surveys for the construction site, PNRA began an exchange of reciprocal support with the Korean Program. In informal contacts, KOPRI declared more than once its interest for the permanent runway and it is supporting the current activities of the test site.

Of course, the French program IPEV will benefit from the proposed facility, because we share with it the managing of Concordia and the permanent runway will improve the resupply activities and the personnel movements to/from Concordia.

Furthermore, IPEV is currently experiencing very difficult conditions in resupplying its main station, Dumont d'Urville, because of the sea ice conditions in the area of East Antarctica. Every year IPEV relies more on our support to move people and light freight. A permanent runway, available the entire season, will increase the ability to support the French agenda.

In informal contacts, also Antarctica New Zealand declared its interest in the permanent runway, mainly due to safety enhancements. In fact, in the area AntNZ operates aircrafts, such as the Hercules C130, the Orion P-3 and the Boeing B757, which have not enough range to fly back to New Zealand in case of weather problems at their destination airport. A primary permanent runway, near the main airway, 200 miles from McMurdo will dramatically increase safe air operations by providing a reliable safe alternate airfield for the increasing air traffic in the Ross Sea area.

USAP also showed their interest in this new infrastructure for the same safety reasons. USAP manages a wide fleet of aircraft in this area which could benefit from the availability of a year round runway.

Lastly, the Polar Research Institute of China is going to build a new station at Inexpressible Island, in the Terra Nova Bay area. Although no formal talks have been made, it is likely the Chinese may also have an interest in having a permanent runway in the Ross Sea area.

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3. Alternatives to the Proposed Activity

During the preparation of the Draft CEE and the following analysis of the alternatives to the proposed activity, full reference has been given to many international public laws as the Antarctic Treaty System, the Convention on Biological Diversity, the Kyoto Protocol on Climate Change, the Protocol of the International Convention for the Prevention of Marine Pollution from Ships (MARPOL 73/78) and the Convention on the Dumping of Wastes at Sea as well as Italy's relevant laws and regulations. The guidelines and documents for environmental impact assessment developed by the COMNAP and SCAR have been followed in the course as well.

3.1. Situation of skiway operations at Mario Zucchelli station

As anticipated, the Italian National Antarctic Research Program operates two Antarctic stations: Mario Zucchelli Station (MZS) and Concordia Station, the last one together with the French IPEV. MZS operates usually from mid October to mid February and is essential for supporting continental transport of personnel and freights to and from Concordia Station during summer.

For the intercontinental transport of personnel and freights, the Italian Program relies on several resources. Flights operated by PNRA itself, the multipurpose ice class vessel ITALICA (which is used also to refuel the station and for the oceanographic campaigns), flights and ships operated by other Antarctic programs as support exchanges in the framework of PNRA international cooperation.

Since 1990, PNRA chose to operate a sea-ice runway, which is located in the Gerlache Inlet close to MZS (Figure 3.1, red line). The possibility to land nearby the Station permitted to open the Station earlier than it would have been possible operating only the ship, thus allowing a longer period to scientific activities. Actually, thanks to the ice runway availability, the standard MZS summer operability starts in mid-October, instead of mid-December as it would be by ship, due to the compact ice sheet surrounding the station for several miles till begin of December.

PNRA flights are currently operated chartering an Hercules aircraft and using the MZS ice runway that is suitable for landing of wheeled aircrafts. Usually the availability of such ice runway ends in early December, when the ice sheet thickness and strength decrease to unsafe values, whereupon any personnel and freights transport would stop completely, but the US NSF air support via McMurdo station, till the arrival of the Italian or Korean vessel in Terra Nova Bay on mid-December. Besides the increasing temperatures, katabatic wind events in Terra Nova bay also contribute to modulate the ice airstrip shutdown in summer, pushing offshore the broken ice sheets.

PNRA also operates smaller aircrafts (Twin Otter and Basler), mainly for the continental flights from MZS to MCM, Concordia and DDU Stations. For that activity several skyways are prepared every year around MZS station, and most of them are indeed used for the entire summer season. These snow strips can be used only by aircrafts equipped with skis

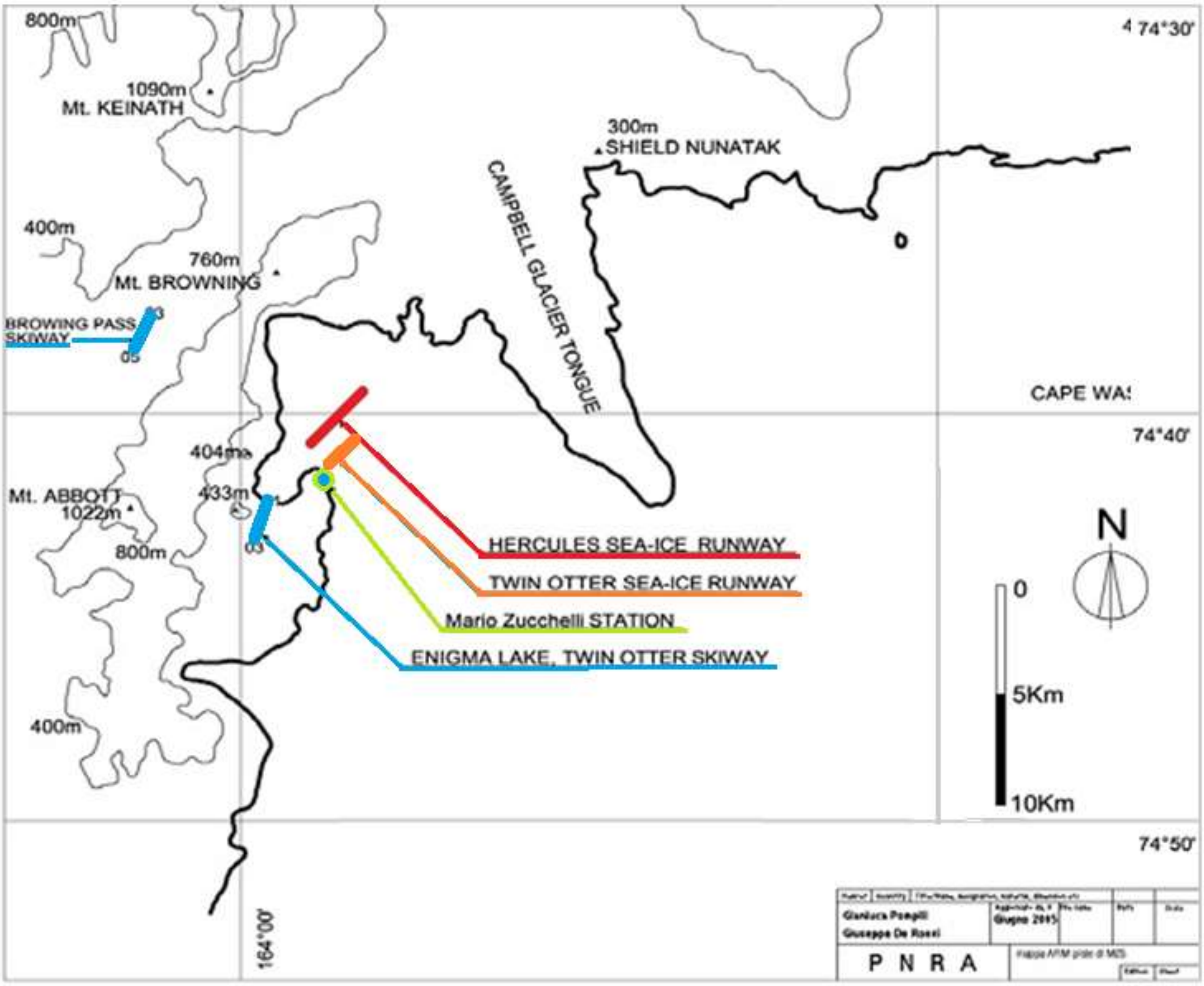

Figure 3.1: Locations of the available icestrips (red line for the Hercules icestrip and blue/orange lines for Twin Otter icestrip/skiways respectively) around MZS (green line).

In the past seasons, other more suitable landing areas were investigated and for a few years a blue ice runway located on the Nansen Ice Sheet was seldom used (IEE: Construction and Operation of Nansen Ice Runway, Terra Nova Bay, Ross Sea, Antarctica; 2007) which allowed the intercontinental operations of large wheeled aircrafts as the Hercules L100/30.

At this moment, however, the Gerlache Inlet ice runway remains the only facility for PNRA to operate intercontinental flights to MZS in early summer.

Indeed, in the last ten years an earlier increase of fast ice temperatures over the airstrip area, during the summer season, was observed, along a thinning of the ice sheet, observed during some years. Both those phenomena resulted in an increasing shortening of the operability period of the ice airstrip that affected the flights schedule causing logistics difficulties to PNRA and to other

National Antarctic Programs as well. One of the main reasons of such a change in Gerlache Inlet was identified in the observed abrupt reduction of Campbell Ice Tongue extension in 2005.

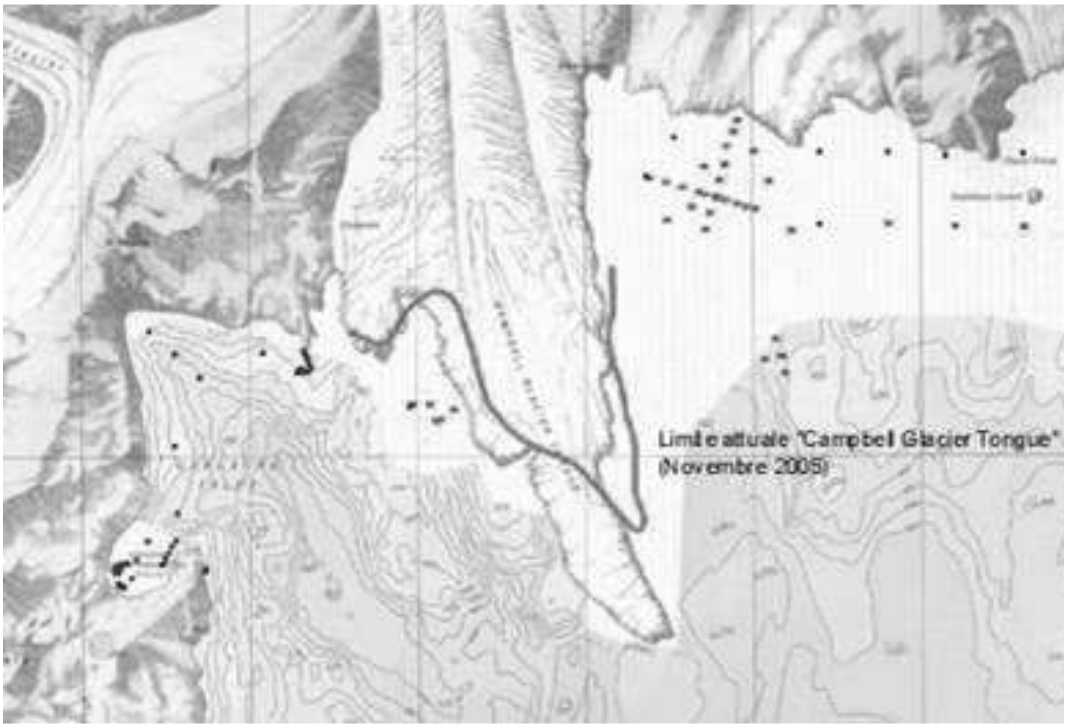

Figure 3.2: The Campbell Ice Tongue before and after November 2005.

Campbell Glacier (74°25′ S, 164°22′ E), originated from the end of Mesa Range in Victoria Land in East Antarctica, is an outlet glacier flowing into the Terra Nova and forming a seaward main ice stream of 13.5 km long and 4.5 km wide. The protection of this ice stream against the stormy sea waves permits every year the formation of a thick fast ice in the Gerlache Inlet. Unfortunately the Campbell Ice Tongue experienced an abrupt truncation in 2005 that resulted in a curtailment of its extend of about 5 miles (Figure 3.2) and consequently a much less effective defence of the area from the oceanic storms, that are considered among the main causes of a premature breakdown of the fast ice sheet.

After 2005, every summer expedition of PNRA suffered of logistic difficulties mainly related to no reliability of planning because the unpredictable lasting of the sea ice runway. Fortunately the favourable US-NSF support avoided to our activities to be too seriously affected, but PNRA had to strongly increase both his dependence upon the cooperation agreements with other Antarctic Programs and the related impact of its own activities on those Programs, especially when the vessel Italica is not chartered.

3.2. Evaluation of the naval alternative to the skyway operations in MZS

As already anticipated, in the last decade and every two years PNRA chartered the vessel Italica (Figure 3.3) to transport fuel and heavy loads to MZS. In addition the ship was well instrumented for oceanographic research.

Figure 3.3: The vessel Italica.

The main technical characteristics of the vessel are briefly shown in the table below.

ITALICA Master Data	
Size:	121 m x 17 m
Gross Tonnage:	5,825 ton
Net Tonnage:	2,473 ton
Consumption at cruising speed:	15 ton/day Antarctic diesel (19 ton/day for ice cruising)

This vessel represents a unique means for the transport of fuel and heavy loads to the station, as well as for oceanographic studies and transport of personnel in/out from Antarctica in January. However its very limited period of use greatly reduces the capability to achieve successful scientific projects but the oceanographic ones, without the means of air operations.

Moreover, the necessity to rent every year the vessel would lead to a costly low filling coefficient due to its large load capacity that overcome the needs of MZS supply (of fuel and other not perishable goods with large loads).

We must also consider the increase of the environmental impact of PNRA operations in Antarctica in case of use of Italica vessel during each austral summer, due to the estimated 500 tons of Antarctic Diesel needed in addition for marine transportation. Although comparable tons of aviation kerosene are likely needed due to the increased air traffic on the planned gravel runway, the global environmental impact of the aviation means result less than the marine ones.

According to the emission factors given by the Appendix 5 of KOPRI Final CEE for Jang Bogo Station, the summer increase of total annual emissions of various pollutants for the two means of transport is estimated in Table 3.1.

Table 3.1: Estimated fuel consumptions and total emissions for use increase of the two means of transportation.

Source	*Fuel Type*	*Total Fuel Consumption (ton)*	*Emission Pollutants*	*Emission factor (g/kg)*	*Total Emission (ton)*
Vessel Italica (+ 25 day / years)	Antarctic diesel	500	CO	0.71	0.36
			NOx	3.41	1.71
			SO_2	33.44	16.72
			PM10	0.28	0.14
			CO_2	879	439.5
Aircraft Hercules L100/30 (+ 10 flights / year)	Aviation kerosene	500	CO	12	6
			NOx	0.19	0.095
			SO_2	0.72	0.36
			PM10	0.2	0.1
			CO_2	859	429.5

All emitted pollutants will cause some impact on air quality and atmospheric composition. However, the impact for both the means (aircraft or vessel) is small, considering it take place not continuously but only in the summer season.

Ship emissions are especially relevant for deposition of sulphur and nitrogen compounds, which generally cause acidification /eutrophication of natural ecosystems. Therefore a reduction of NO_x, SO_2 and particle emissions in the area, resulting from a different management system involving a less frequent chartering of the vessel, will likely have beneficial impacts on air quality, acidification and eutrophication of the Antarctic region, according also to the recent policy interest to globally reduce ship emissions [3.1].

3.3. Using other operative airstrips

3.3.1. **Efficiency of the airway facilities around MZS**

As already mentioned, PNRA operates a sea-ice runway for Hercules L100/30 aircraft, which is located in the Gerlache Inlet close to MZS (Figure 3.1, red line). In the vicinity of that facility, a smaller sea-ice runway for Twin Otter aircraft is usually operated as well (Figure 3.1, orange line). That two facilities end their operability in mid-November, when the sea-ice sheet breaks and fast disappears.

Then, the air operations continue on two skiways located in the interior, at Enigma Lake and at Browning Pass sites (Figure 3.1, blue line). These two skiways are suitable just for the small Twin Otter operations, while the larger Hercules L100/30 is anyway forced to end operations in mid-November. In addition, during XXX expedition, on 6th January, 2015 the Enigma Lake ice strip experienced for the first time an unpredictable partial liquefaction of its surface, with presence of large melting snow puddles in its middle part (Figure 3.4), that resulted in a premature closure of the air activities on the site. The episode confirms the experienced warming trend in summer over the area during the last decade.

Figure 3.4: Enigma Lake ice strip showing a large melting puddle in the middle (6th January 2015).

Beyond such facilities, PNRA has to rely on the support of foreign Antarctic programs for moving personnel and stuffs in/out of Antarctica, especially when the Italica vessel is not chartered.

From the air operation point of view, important agreements with USAP lead to operational help by their aircraft operations. For that, usually one Twin Otter or two helicopters have to bring personnel and stuffs from MZS to McMurdo airport (> 400 km trip), a costly and inefficient operative way.

A most effective way comes from the support of KOPRI, that during the last season helped the PNRA operations by means of the Araon vessel, usually reaching the close Jang Bogo Station every year in austral summer.

3.3.2. **Effectiveness of the Nansen ice sheet airstrip**

In April 2007, the *Consortium for implementation of the Italian Antarctic Scientific Programme* (PNRA S.r.c.) presented at the XXX Antarctic Treaty Consultative Meeting an Initial Environmental Evaluation (WP67) entitled "Construction and Operation of Nansen Ice Runway (Terra Nova Bay, Ross Sea, Antarctica)".

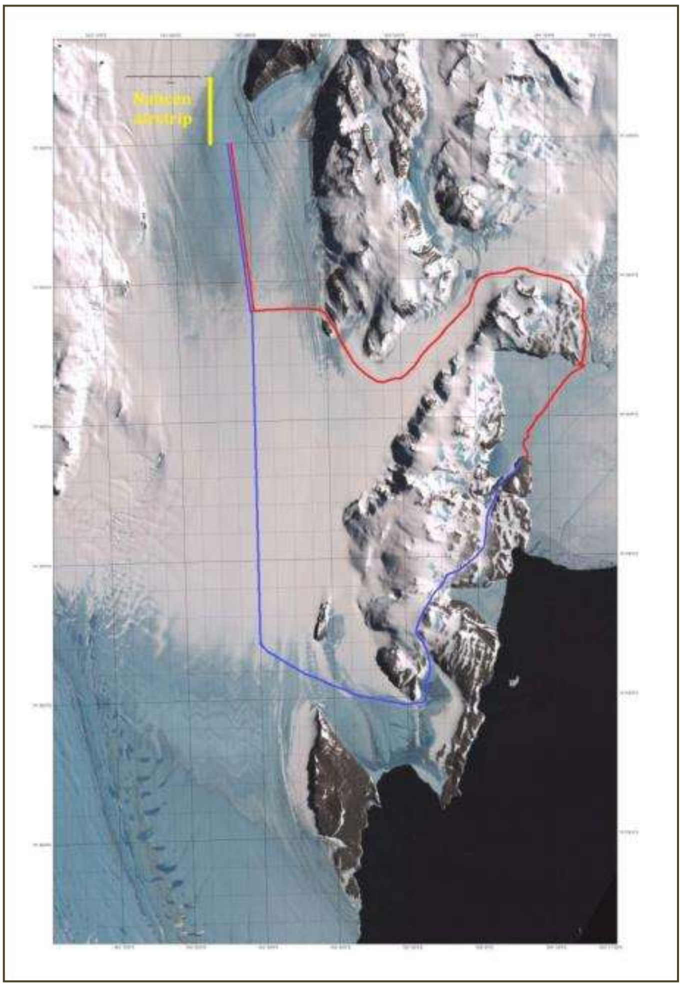

Figure 3.5: Locations of Nansen ice strip (yellow line) and the track of the two roads from MZS.

The proposed activity consisted of preparation and construction of a runway on blue ice in the Nansen glacier area, 30 km away from the Mario Zucchelli Station. The site was chosen because the ice surface was particularly flat and smooth due to the erosion caused by the strong winter katabatic winds. That airstrip was considered necessary in order to allow the landing of heavy aircraft when the fast ice that normally covers Gerlache Inlet, in front of the Station, does not show the needed safety margin, because of the seasonal ice temperature increasing along with a thickness decreasing.

Actually, the choice of the site was really dictated from our wish to fix the problems related to the fast ice runway having impacts on the environment less than transitory, despite the long distance of the chosen site, over 50 km away, via surface track, from the operative area of MZS.

The Nansen blu ice runway was operated for 2 seasons, but from 2009, due to climate changes in the area, the surface of the glacier was no more smooth enough to allow landing and take-off of large aircrafts.

The main troubles encountered were the loss of flatness caused by the increased water streams on the glacier and the consequent presence of ruts, unsmoothed by wind during winter season. Afterward, all the attempts to re-open the facility were unsuccessful, because the recent changes in environment temperatures and wind intensity resulted in a lower natural ablation of the surface and in the impossibility to use the road connecting MZS to Nansen ice runway, considering the available equipment at MZS. In fact, considering the distance of the airstrip from the Station, besides the hard environment where the connection snow road had to be placed (Nansen glacier with small crevasses somewhere), the average transit time was as long as 2 hours for each leg, making the airstrip operations logistically complex.

Finally, in 2010 the area of the Nansen ice runway was reinstated to its pristine behaviour and any future aircraft operation was cancelled.

3.4. An alternative site for the gravel runway: Campo Antenne

As early as September 1990, the Italian Engineering for Airports company - ITAL AIRPORT, on request of the Italian National Antarctic Research Program (PNRA), carried out a study entitled "Finding an airport site in the de-iced area of the Italian base at Terra Nova Bay, a preliminary analysis ". The study, aimed at the localization of suitable sites for the airstrip construction, was carried out on the basis of a few elements including detailed weather-climate of the area (about 4 years of data), the geo-morphological map of the Northern Foothills (scale 1: 20,000 dated 1987) and other topographic maps with medium detail provided by PNRA.

3.4.1. **Description of the site**

After 25 years, thanks to the efforts of the researchers and logistic engineers of PNRA, the knowledge has been greatly improved. Since 1990 several topographic surveys were conducted over the area, including mapping at 1: 10,000 by aerial photographs (developed on the basis of the American flight Trimetrogon of 50’s) and, more recently, an upgrade to topographic scale of 1: 2,500 (drawn up on the basis of Geoeyes satellite images of Terra Nova Bay). The new mapping made it possible a considerable detailing of the work done in the 90’s as well as the identification of one additional area, potentially suitable as alternative airstrip location (Figure 3.6).

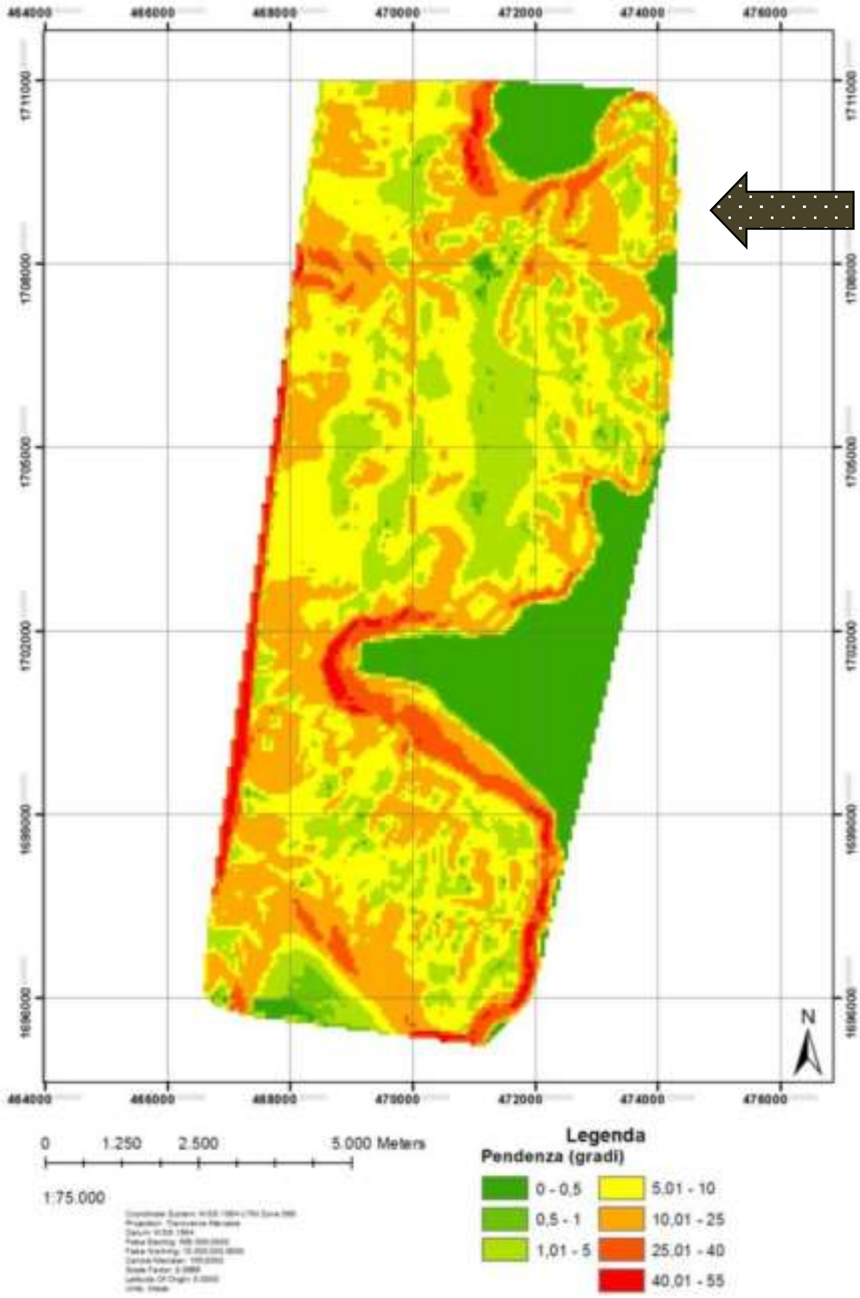

Figure 3.6: A slope map of the area around the station and the alternative location for the airstrip at Campo Antenne (black arrow).

The site of Campo Antenne is located behind the MZS, at an average altitude of about 100 m a.s.l. In the outcrop is present in the unit of Abbot in his felsic facies (granite of Abbot). The morphology of the area is gently undulating for about 1,000 meters and then take a significant slope to the south.

As the name indicates, Campo Antenne (namely field of antennas) is the location close to MZS station chosen for the installation of most of the larger antennas used for the scientific and logistic activities during summer and winter. A map of all those facilities is shown in Figure 3.7.

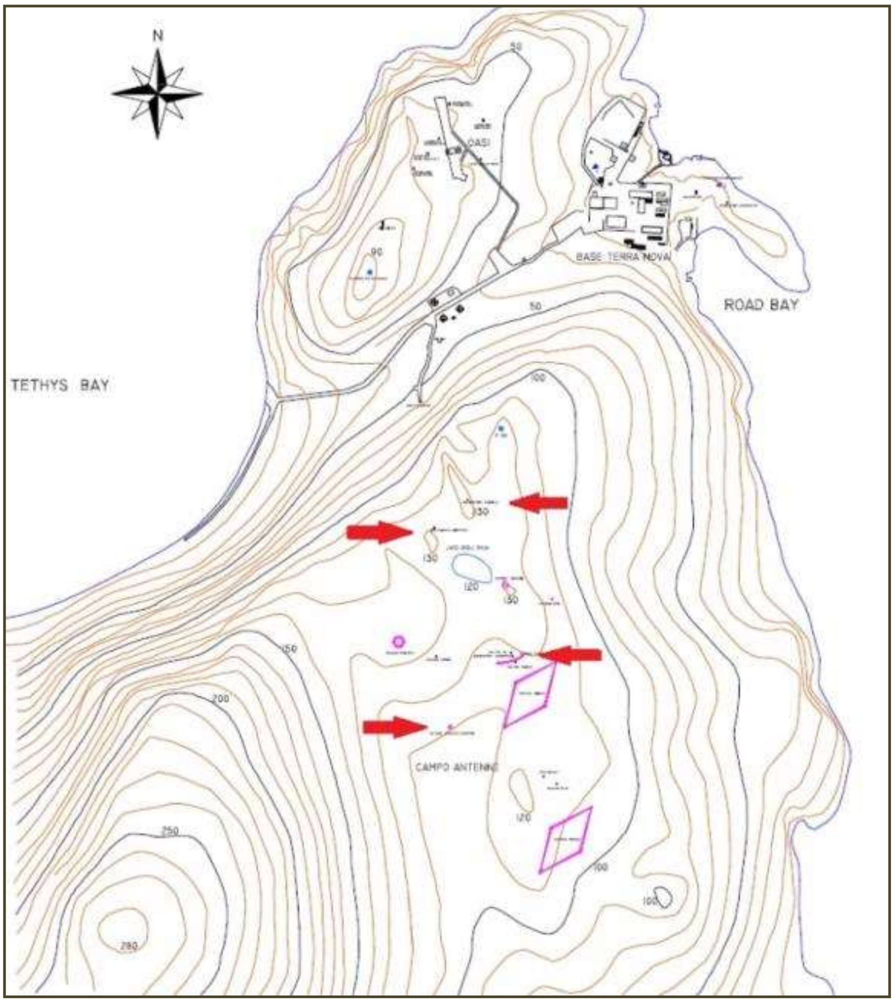

Figure 3.7: Locations of both the ionospheric and environmental observatories (red arrows) and the larger antennas fields (pink lines) at Campo Antenne site.

Most of the antennas are devoted to communications (pink coloured on the map), while some antennas and shelters are involved in scientific researches mainly as relay of meteorological automatic stations located on the west side of the peninsula and as ionospheric and environmental observatories (red arrows on the map).

All the electronics equipment, installed to drive the antennas, are powered by a long line of cables originating from the automatic electric generator (PAT), located on the west side of the MZS.

The realization of a runway on site entails a repositioning of the entire field to a different suitable location, still close to the station. Even overlooking the deep impact that such a change would have on the ionospheric and environmental observatories located in the area since 1990, the effort in moving the entire set of antennas, scientific shelters and power connections to a new location would be huge. Actually the only place around MZS showing the flatness behaviour requested for the larger antennas displacement is exactly Boulder Clay, faraway several miles from the station.

3.4.2. **Feasibility of the alternative airstrip**

The realization of a gravel airstrip in the site of Campo Antenne shows large differences of operational effort and impacts with respect to the Boulder Clay site.

From a geomorphological point of view, Campo Antenne is part of the Northern Foothills. A detailed analysis of Northern Foothills is reported on Chapter 4.1 of the present work. Here it is important to anticipate that Campo Antenne site shows similar origin and geomorphological behaviour of the bedrocks around Boulder Clay site (see in Chapter 4.1, Figure 4.2).

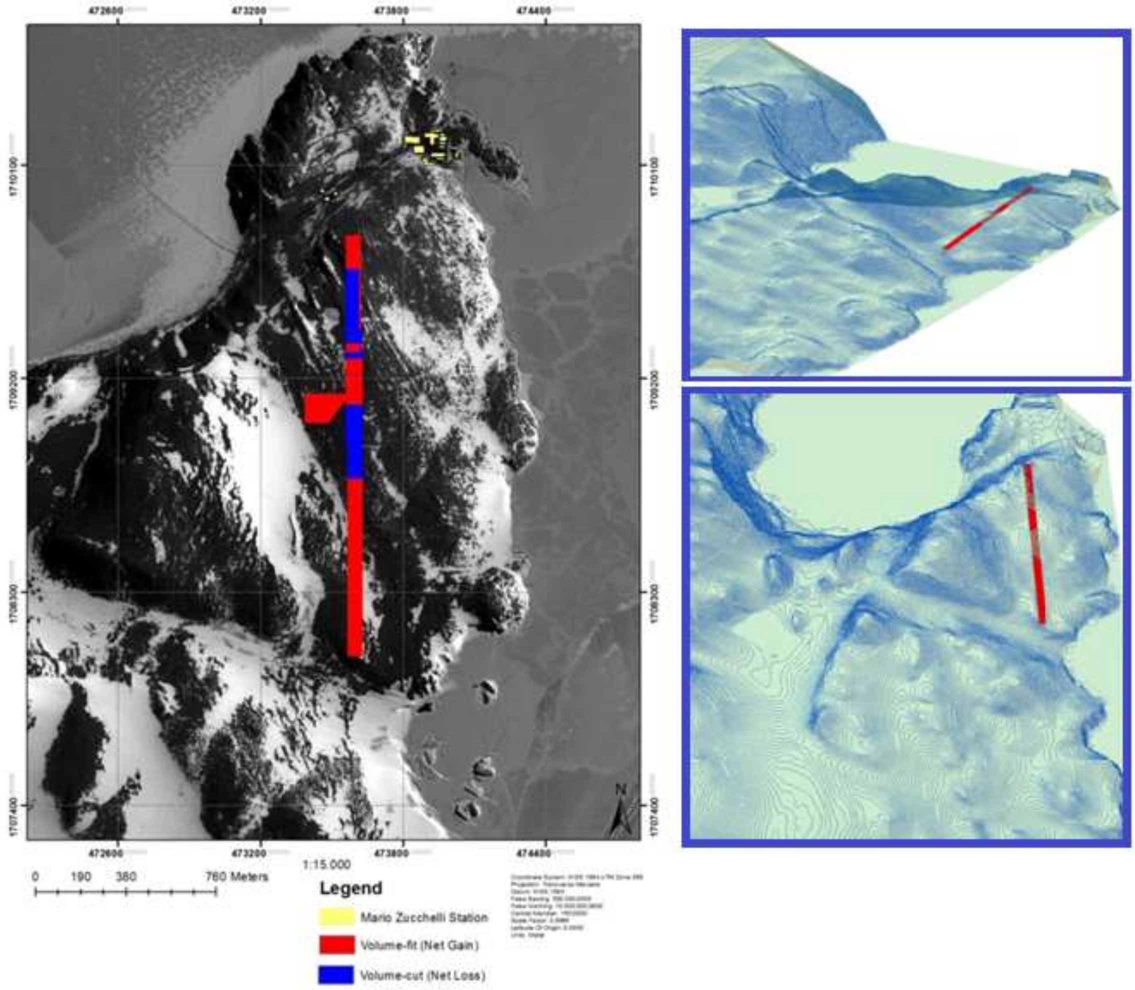

Figure 3.8: A satellite map (left) and 3-D height contour map (right) of the Campo Antenne area close to Mario Zucchelli Station, with the alternative location for the airstrip. Filling and cutting areas (red and blue code respectively) are also presented.

The planned location of the airstrip, in its full extension of 1,700 m long and 66 m wide, lying approximately along the meridian 164°06’20’’E, is drawn in Figure 3.8. A longer extension is forbidden by the southward deep slope of the site, resulting in an unworkable filling volume in case of a length extension.

The track is southward and shows an average slope of about 2% (altitude 125 m northward at the track head, decreasing smoothly southward to about 90 m).

The realization would be performed with a cut-and- fill technique based on volumes calculated on a precise GPS elevation profile by data taken during the XXVIII Italian expedition in November 2012 (Figure 3.9). For the chosen runway position, the GPS measurements were taken on three parallel tracking lines, one on central axis and two on 33 meters distance sides, westerly and easterly from the central axis respectively. Each line was walked two times, to the South and back to the North, to get redundant data and so minimizing the errors. In addiction more GPS measurements on crossing transects between parallel lines were performed, when the terrain behaviour was clearly showing inhomogeneous slopes.

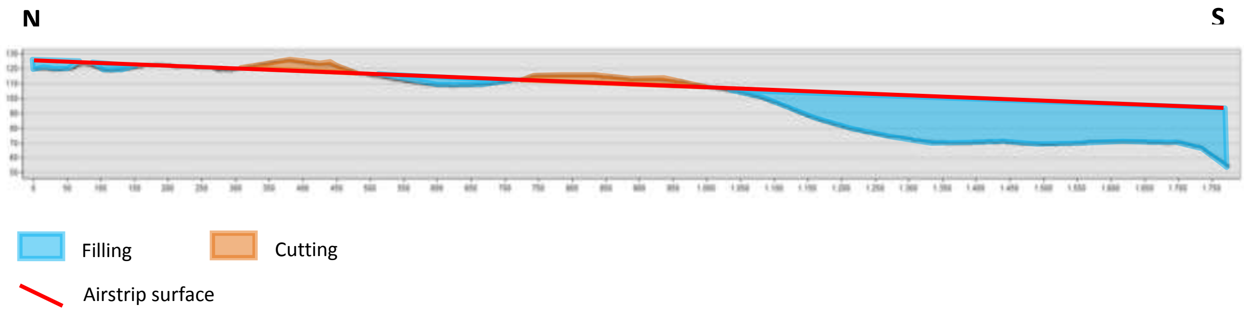

Figure 3.9: A slope cut of a possible airstrip 1770 m long at Campo Antenne (A). The average slope of the airstrip is also shown (red line) with filling and cutting areas (blue and orange code respectively). A description of the runway area with its cross-section is also reported (B).

Effective volumes of granite to be moved in the cut-and-fill operations were calculated, resulting in an estimate of the overall moved volume (including the parking area) of about 1,500,000 m^3, with about 200,000 m^3 of cutting and the remaining volume to be filled.

From the characteristics of the location, the removal of compact granite rock outcrops would be possible only by means of a large use of explosives, while over 1,000,000 m^3 of material not produced by means of explosive in the cutting operations has to be retrieved from other locations, still by mean of explosives, or from debris deposits placed in an area as wide as possible around the site. Large part of the necessary embankments is located around the southward sloping part of the track, where most of the volume to be filled is present. A minor impact in terms of filled volume could be achieved shortening the length.

The much larger impact of the construction operations is the first important difference of this site choice compared to the Boulder Clay one, where on the contrary most part of the rocks are moraine debris already available on site and to be just partly reduced in size.

Besides the second important difference is the maximum length allowable, limited below 1,700 m in Campo Antenne compared to 2,200 m in Boulder Clay, consequently strongly limiting the types of aircrafts allowed for landing on the airstrip.

3.4.3. Flight clearances at the site

According to the in force ICAO regulations, no obstruction must longitudinally pierce the surface approach. This surface, that starts 60 m away from the airstrip threshold, has an inner edge 300 meters wide (150 m for each side of the track) that is orthogonal to the axis of the runway, with an ascending slope of 2% (1:50) and diverging until it meets the side surfaces.

A safety zone side (LSZ) is prescribed for a distance of 150 m on each side, starting from the central axis of the runway. With the exception of assistance essentials for landing, there should be no obstacles within this area (including aircraft parked). From its outer edge a surface inclined upwards and outwards (gradient 1:7) starts, that meets the surface of approach and that must be clear from any obstacle. According to the above prescription, the possible airstrip results safe all around the horizon but southward, where the height of few small hills limits the clear surface on the mountain side.

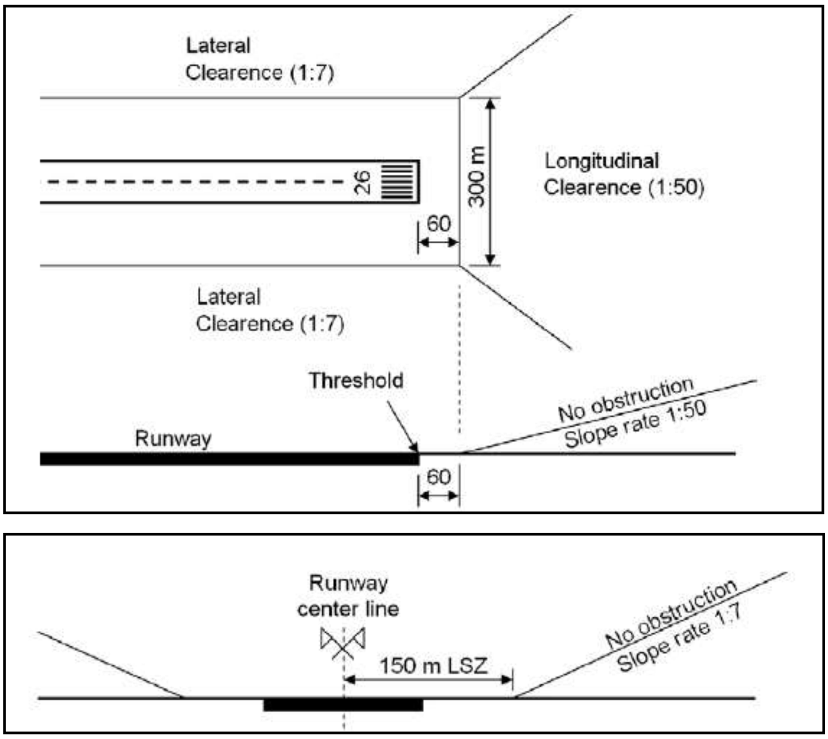

Figure 3.10: Behaviours of flight clearance surfaces at Campo Antenne

3.4.4. Climate and meteorology

The Meteorological Observatory of PNRA has a long historical series of data. Among all the historical weather stations installed around MZS, one (Eneide) is very close to Campo Antenne site and therefore allowed for long term on-site data collection of pressure, temperature, humidity, wind speed and direction, solar radiation. In addition for the proposed activity, considering possible wind shear effects and to assess on site turbulence critical for safety of air operations, in summer campaign 2013 two additional automatic weather stations were installed and operated in the area of

Campo Antenne, K4 upwind and K5 median with respect to the proposed runway location (Figure 3.11).

The data set collected by the AWS stations confirms that the climate in the area is cold and arid. The annual path of average monthly temperatures shows the typical behaviour of the Antarctic coastal regions with the lack of a well-defined winter minimum, a short summer, the absence of intermediate seasons and the reversal of the temperature pattern in mid-winter.

The mean monthly air temperature recorded in the last decades by Eneide station ranged between -16 and -3.5°C in the summer period (1993-2011 period), with a mean annual temperature of -14°C. The region receives around 270 mm water equivalent precipitation per year.

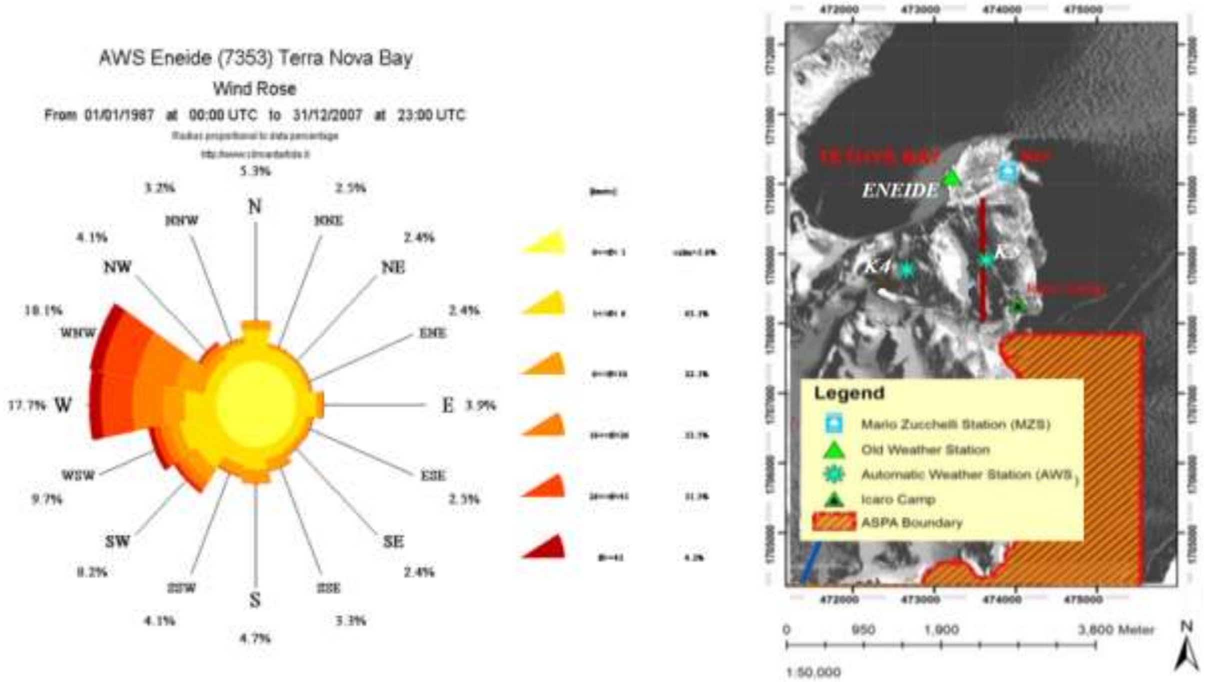

Figure 3.11: Wind rose of decadal averaged winds measured by Eneide meteorological station, on the right the location of Eneide, K4 and K5 AWS meteorological stations.

From the wind rose from Eneide presented in Figure 3.11, the prevailing winds in this part of Northern Foothills area blow from western sectors. They are associated mainly with the katabatic flow coming from interior of the continent and the wind speed can reach values over 40 knots. October and February are the summer months in which the episodes of winds with speeds higher than 30 knots were recorded more than 20% of the time.

According to ICAO regulations, take-off or landing are not allowed in presence of a transverse wind component stronger than 19 km/h (10 knots), 24 km/h (13 knots) and 37 km/h (20 knots) for aircrafts that require a track with a length shorter than 1,200m, between 1,200 and 1,500 and longer than 1,500 m respectively. As can be seen from the wind rose of Eneide station, it is unlikely that winds exceed 40 km/h, thus allowing operations in safety in most cases when an Hercules L100/30 aircraft is considered.

3.5. Alternative solution studied for the realization of the Boulder Clay embankment

A variety of engineered solutions have been taken into account for the Boulder Clay moraine embankment in order to prevent the potential permafrost degradation. These includes: thermosyphon tubes; ventiduct embankments; shading boards/awnings; expanded polystyrene insulation etc.. Each method has its own advantages and disadvantages often heavily dependent on local environmental and logistical conditions.

- Thermosyphons are usually used where the frozen state of the soil must be maintained. A thermosyphon is a sealed tube which is pressurized and filled with a low boiling point liquid (Freon, ammonia or carbon dioxide). Damages during transport and operations are very detrimental (depressurization, obstruction of the cooling fins) and could be render these devices useless.
- Ventiduct embankments typically utilize a traditional soil embankment with the inclusion of pipes placed across the embankment. These pipes serve as "air culverts" allowing air to pass through the embankment centre and draw heat out from the soil. The flow air reduction, over time, due to snow or debris, may also increase maintenance potential and reduce effectiveness.
- Awnings/shading boards function in several ways, but primarily by reducing the influence of solar radiation on the embankment. These structures can be constructed of several types of material (wood, metal frame with soft canvas sides, or stiff composite structure placed on the embankment shoulders). Damage due to natural occurrences such as katabatic wind may reduce their effectiveness and increase maintenance costs.
- Expanded Polystyrene used to increase the insulation and the thermal resistance of the embankment. In general, polystyrene provides good strength properties, resists water absorption and mechanical damage. The Polystyrene Insulation has been discarded due to the strict rules related to polystyrene presence in Antarctica.

In conclusion, the decision to use an "Air Convection Embankments" technique was taken to preserve the environment and reduce the infrastructure maintenance. The choice to use only local, selected material (from boulder to gravel) without introducing foreign structures (pipes, shading boards or insulating polymers), has been evaluated as the lowest impacting on the moraine area environment.

Nevertheless, the choice as been determined also in consideration of the logistical costs of the transporting to Antarctica of necessary material (thermosyphons or ventiduct) necessary to cover 2,200 m of runway; in fact, that would require a few turnaround of the ship between the New Zealand ant Terra Nova Bay, with a considerable amount of emissions.

Other techniques have been demonstrated not suitable considering the type of application and the local climatology (shading boards) and to respect the local environment (polystyrene insulation).

3.6. BIBLIOGRAPHY

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4. Initial Environmental Reference state on the site

The Italian Mario Zucchelli Station is located in the Northern Foothills, this is a line of coastal hills on the west side of Terra Nova Bay (Victoria Land), lying southward of Browning Pass and forming a peninsular continuation of the Deep Freeze Range.

The Northern Foothills represent an ice-marginal, high latitude periglacial environment. The area is partially covered only by local glaciers and snowfields and it is extended in shape from the south to the north, parallel to the coast and spaced by ice free areas, which step down to the sea.

Local glaciers develop on an inherited Plio-Pleistocene landscape and they are considered dry based. Close to the Italian Station the main orographic features is represented by Boulder Clay Glacier, a dead glacier that begins in the Enigma Lake area and arrives at Adelie Cove where degrades towards the sea. In the area a late glacial ablation till, called Boulder Clay moraine, overlies the body of the glacier (some hundreds meters large and 4.5 km long). The surface features include perennially ice-covered ponds with icing blisters and frost mounds, frost-fissure polygons and debris islands.

At the bottom of the Boulder Clay Glacier (Adelie Cove) there is an area that hosts an Adélie penguins rookery quite big, some thousands of couples. The penguin colony is located in front of the marine protected area ASPA n°161 of Terra Nova Bay.

4.1. Geomorphological and Geological framework

A detailed geomorphological map of the area was elaborated by Baroni [4.1] at scale 1:200,000, (Figure 4.1), based on a topographical map at scale of 1:10,000 supported by aerial photographs interpretation. Landform and deposits mapped include those related to glaciers, cryogenic activity, wind and sea action, weathering and geological structures.

In the Northern Foothills area a pattern conditioned by the topography, by the geological structure and by the glacier history can be outlined. Several zones parallel to the coast can be signed out:

- a first lower belt is characterized by coastal landforms, strongly conditioned by salt weathering and snowing organogenous features. Due to the isostatic rebound, the marine influence during the Holocene directly interested a belt ranging in altitude from the present sea-level up to about 30 m a.s.l. A wider coastal zone is indirectly conditioned by sea through salt weathering, strongly efficient on the coarse granitic rocks;
- a second belt can be recognized up to about 450 m a.s.l., corresponding to the area covered by the ice during the last glaciation. A discontinuous sheet of glacial sediment is present; it is locally ice-cored and widely affected by ice-wedge polygons. Large areas of debris covered glaciers are also present;

- a third belt develops at higher than 450 m up to the maximum eight present in the area. Large bedrock outcrops with a thin and highly discontinuous cover of glacial sediments occur in this belt. Rock surfaces are strongly oxidized, with frequent cavernous weathering and locally pseudo-karren fractures.

From a geological point of view the Northern Foothills have been studied by Skinner [4.2] [4.3] [4.4] Carmignani et al. [4.5] and Rocchi et al. [4.6] (Figure 4.2).

In the entire area the following lithology are present (Figure 4.2 [4.6]):

- Granite and granodiorite ("Abbott Granite": coarse porphyritic leuco-granite; "Canwe Granodiorite": biotite and biotite-orneblenda quartz diorite to granodiorite with K-feldspa phenocrysts; Ordovician);
- Mafites ("Browning Mafites": diorite and gabbros with strong differentiation to granites; Ordovician).
- Metamorphic rocks ("Priestley formation", Precambrian, Early Ordovician): Metamorphosed dominant politic, thinly bedded argillite sequences with subordinate quartz-feldspatic grey-wache. Amphibolite facies metasediment, "Priestley Shist" [4.7];
- Volcanic rocks (basalt), dykes ("McMurdo volcanic", Late Caenozoic-quaternary).

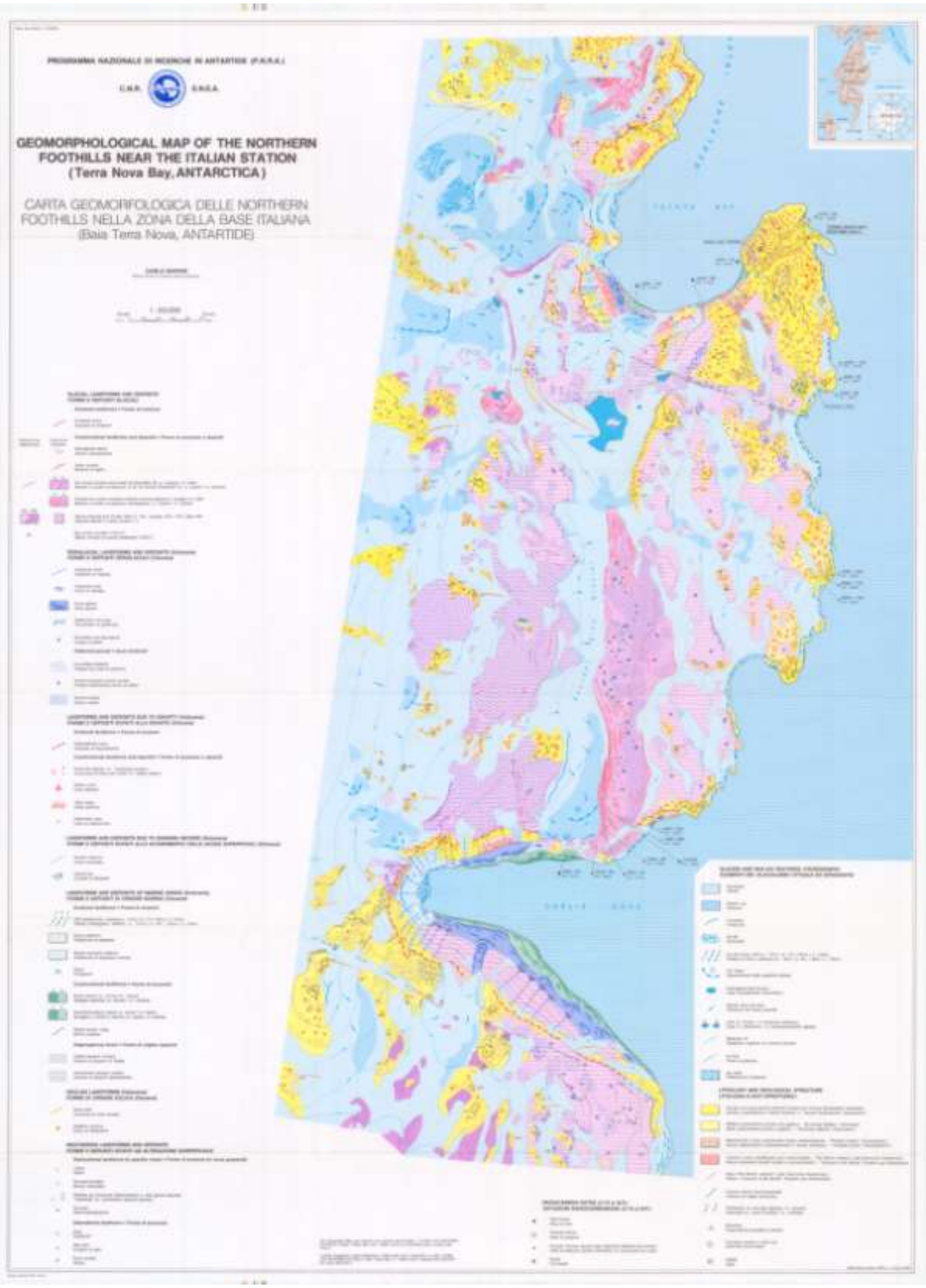

Figure 4.1: Geomorphological map of the Northern Foothills near the Italian Mario Zucchelli Station (MZS) [4.1].

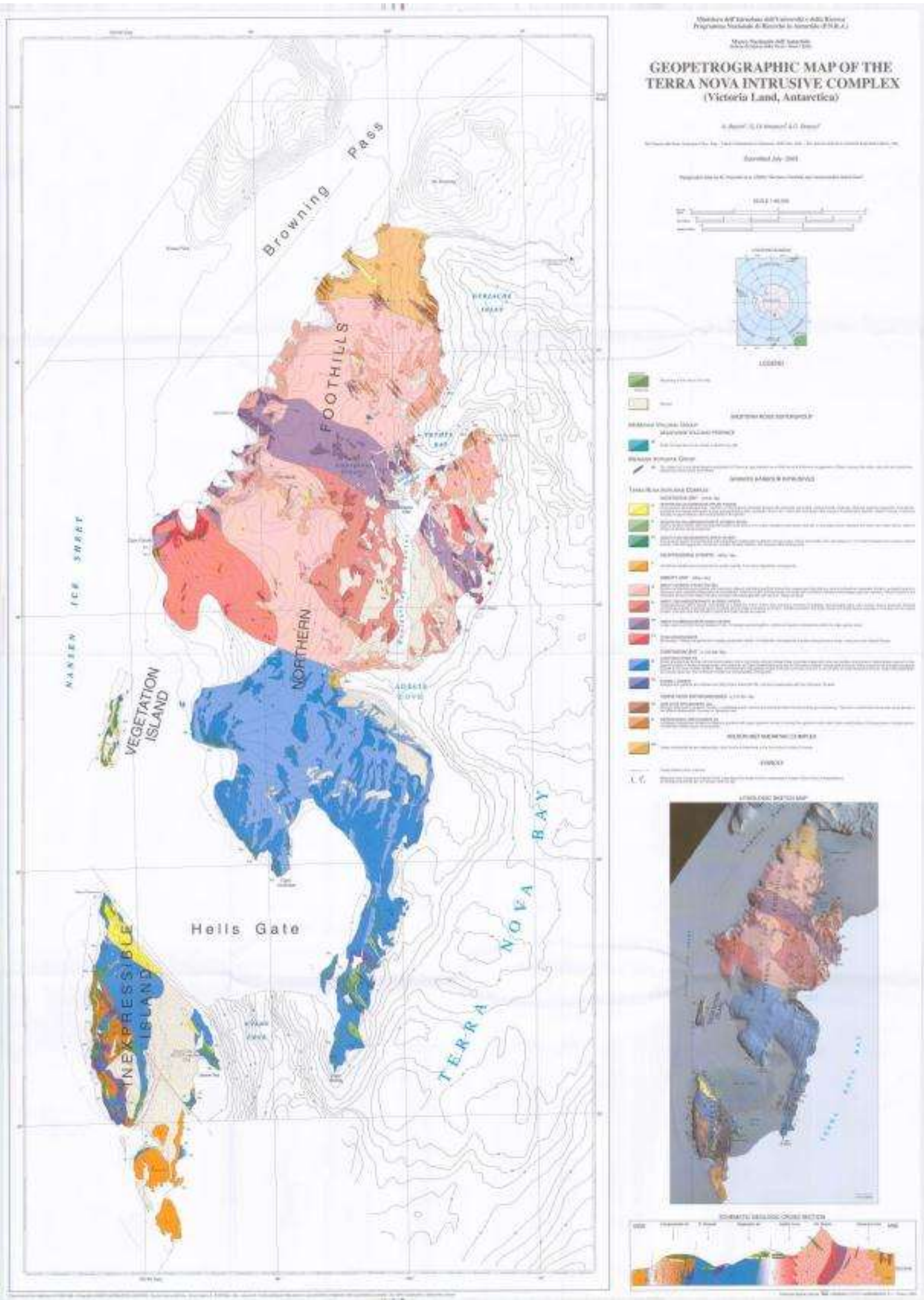

Figure 4.2: Terra Nova intrusive complex Geo-petrographic map [4.6].

4.1.1. The Boulder Clay Moraine features

The Boulder Clay area is a gentle slope mainly dipping to S-SE with a N-S elongation, just a few km southward of the MZS station and placed along the eastern margin of the Boulder Clay glacier. The area ends on the northern coast of Adelie Cove.

Traditionally the area of Boulder Clay was described as an area of scarce glacial sediments outcropping, discontinuous and generally thin and referred to the drift informally named TN I [4.8]. In particular the area of the strip is mainly on a younger debris-covered glacier according to the geomorphological map of Baroni [4.1]. According to [4.8], there are many patterned grounds and in particular, ice and sand wedges polygons and nets on Upper Pleistocene glacial drift (TN I) but also on the debris-covered glacier.

More recently the most western part of the Boulder Clay area was geophysically investigated and a D.C. electric sounding were carried out not far from the eastern margin of the glacier. Immediately to the north of the beginning of the morainic ridges (oriented N-S) it revealed a layer of at least 65 m of thickness with a resistivity of 1,600 kΩm below a thin unfrozen layer of only 10 cm depth. The high resistivity body could be interpreted as a glacier relict ice but also as permafrost with a very high ice content [4.9].

According to French and Guglielmin [4.10] [4.11] the polygons, that characterized the surface of the Boulder Clay area, were mainly frost fissure polygons although a few debris islands (0.4–0.8m in diameter) are present in the area. The last ones are not sorted and they are produced probably by the upwards squeezing of finer material from within the coarser matrix of the ablation till [4.12].

The larger polygons are thermal-contraction-crack polygons, 15–20 m in dimensions bordered by shallow inter-polygon furrows or troughs, 0.2–0.5 m deep and 0.5–1.0 m wide. In plan form, the majority of polygons assume either a random orthogonal or hexagonal pattern. While the polygons mostly assume a convex surface morphology, some of them present shallow ramparts, 0–15 cm high, border the interpolygon furrows. As demonstrated for other localities by French and Guglielmin [4.10] [4.11] these ramparts cannot result from the lateral thrusting caused by the growth of the wedge but more likely they result from the radially outwards thermal expansion of the active layer from the polygon centres.

The other three main morphological elements of the area according to the literature are: a) morainic ridges; b) debris cones; c) perennially frozen lakes.

The morainic ridges are mainly concentrated in the northern and southern tips of the area and closer to the eastern margin of the Boulder Clay Glacier. According to Baroni [4.1] map also a few other morainic ridges occur on the eastern margin of the drift area and in the middle. In reality some ridges 0.5-3 m high occur elsewhere in the area and they show random orientations and form (although mainly WSW-ENE oriented or curved). A recent GPR investigations revealed an ice core with the surface roughly parallel to the topographic surface.

In some cases along these ridges and along the ridges previously mapped it could appear also some debris cones that can exceed also 2 m in height.

The debris cones despite of their similar shape are not all the same, in fact at least in one case they appear to consist of almost pure mirabilite [4.13] suggesting that the sediment originated in a localized, highly saline water body such as a kettle or ice-marginal lake.

Many of them are located along the main morainic ridges or they lie close to glacier margin. In all the investigated features of this type it was found a core of ice beneath a shallow (< 1.0 m) superficial debris cover [4.13] [4.14] [4.15]. The debris mantling these cones is similar to the "Younger Drift" of the surrounding area and they were interpreted by Orombelli [4.15] as ablation phenomena associated with debris-covered dead-ice terrain.

On the other hand several of the cones appear intimately associated with the small perennially frozen lakes in which they occur [4.10] [4.11].

French and Guglielmin [4.10] [4.11] suggested that some of these small mounds in the Northern Foothills are hydrologic phenomena analogous to the seasonal frost blisters described in the Arctic territory (e.g. [4.16] [4.17]). According to Guglielmin and French [4.10] [4.11] the isotopical signature of the intrusive ice is more similar to the buried relict glacier ice of Boulder Clay than to the lake ice, but the intrusive ice (without any foliation or stratification) in a classical plot $\delta\ ^{18}O$-δD lies along a line with a slope much lower than the GMWL along which the buried ice is located. Therefore the authors hypothesized that the highly negative isotopic values reflect a combination of intrusion and segregation ice that formed at variable depth within the perennial lake-ice water or under the bottom of the lake.

The debris cones related to the perennially frozen lake are therefore more correctly "frost mounds" that are not seasonal but at least in the one case dated exceed 1,000 year (1,020 year BP) [4.18].

The perennially frozen lakes are widespread along the Boulder Clay area and in many cases they are characterized by the occurrence of another permafrost feature: the icing blisters.

Lake-ice blisters are circular to elliptical in plan and have ridge-like or slightly domed cross-sections. Most have one major longitudinal dilation crack and several narrower radial cracks larger at the surface than at depth. Their depth vary but in general it is not exceeding the blister height. These blisters have a mean length around 11 m and a mean height of 0.44 m. Maximum length is 35 m and maximum height is 1.6 m, but fewer than 10% exceed 0.8 m in height or 20 m in length [4.19]. Their volume is 10 m^3 on average, although the largest can reach more than 150 m^3. These blisters show a positive correlation between lake area and total ice blister volume that varies from one year to the next [4.19]. In each lake also the number and the position of the blisters vary. According to Guglielmin et al. [4.19] only one third of the lakes have all the years at least one blister. The icing blisters, as in Arctic, are seasonal features. During the warmest summer in the period 1985-2010 (summer 2001-02) all ice blisters disappeared. These blisters indicate clearly that there is liquid water at the bottom of the lakes [4.19].

The existence of supra-permafrost taliks can be eliminated because water flow within the active layer has not been observed in any of the many trenches excavated over the years in the immediate proximity of the lakes with blisters. The same authors reported also that there are few evidence of groundwater flow in intra-permafrost talik, the terrain around the lakes is gently sloping and it does not appear conducive to generating hydraulic pressures. Nevertheless open hydro-chemical taliks exist as demonstrated by the layer of brine, 25 cm thick, liquid at a temperature around -14°C and with a salinity at least four times higher than the seawater, found beneath the frozen lake-bottom in a borehole drilled in 2003 [4.19]. In the same lake for the first time the existence of quite relevant hydraulic pressure was measured as well.

More recently, during the summer 2013-2014, for the first time since the beginning of the monitoring, some lakes were partially melting. From the same campaign it can be confirmed that open talik cannot be excluded in the Boulder Clay area.

Active layer measurements were performed within the Boulder Clay CALM grid, which is a 100 m x 100 m grid. The station uninterrupted monitoring has continued since 1996. The measurements were carried out on each of the 121 grid points through two different methods: (a) ground probing according to the CALM protocol [4.20] [4.21] and (b) measurement of the thermal profiles (down to a depth of 30 cm) according to Guglielmin [4.22]. In the second case the active layer thickness was then calculated as the 0°C depth by extrapolating from the two deepest temperature measurements [4.22]. Ground surface temperatures were monitored at 2 cm depth with thermistors with an accuracy of 0.1°C (acquisition time every 10 min).

In the period 1996–2012, the mean annual air temperature (MAAT) ranged between -15.3°C (2008) and -12.5°C (2011), with an almost stable trend [4.23]. In the same period, summer air temperature (DJFAir) ranged between -6°C (2008) and -2°C (2011), being apparently stable (Figure 4.3).

Air temperature and incoming solar radiation were recorded by the PNRA at AWS Eneide (74°41' S 164°05' E) located in the middle of the coastal latitudinal gradient.

The snow cover data are available since 2000 at the Boulder Clay CALM grid, with only three years lacking (2007–2009). Snow cover showed a relatively large inter-annual variability, both relating to the mean (6–18 cm) as well as the maximum values (<50–130 cm). Snow cover distribution is strongly controlled by the meso-morphological features and, in particular, by the central E–W oriented depression that acts always as the main accumulation zone. The possible spatial variations are related to micro-morphological features (<10 m), such as big boulders, and some small concavities and convexities that produce snow accumulation, mainly N–S or NE–SW oriented, when the prevailing wind blows from the NW, as it did in 2013.

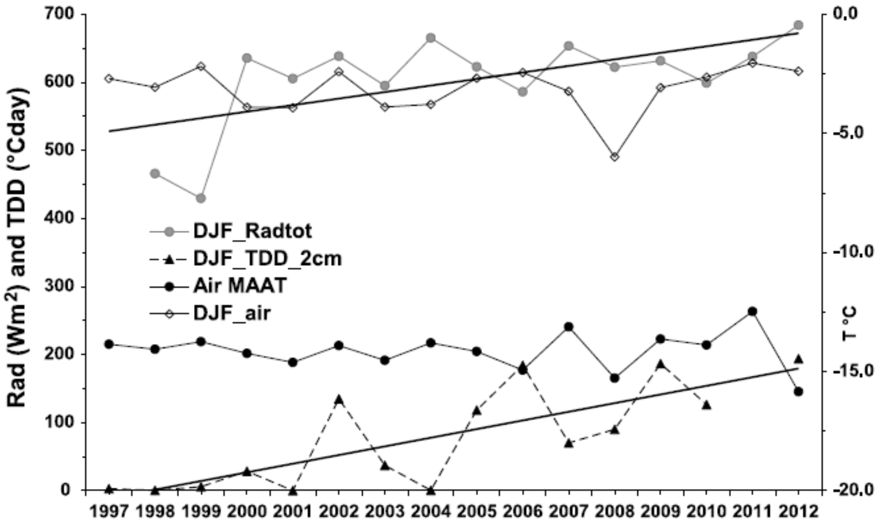

Figure 4.3: Climate trends in the period 1996–2012 with special reference to: mean annual air temperature (Air MAAT) and summer air temperature (DJF_air), summer total incoming radiation (DJF_Radtot) and the summer soil thawing degree days (DJF_TDD 2 cm). All data are kindly provided by the AWS Eneide with the exception of DJF_TDD 2 cm, which was provided by the Boulder Clay permafrost station [4.23].

At the Boulder Clay CALM grid, the active layer thickness showed a large variability (Figure 4.4), both for its mean values (from 2 to 18 cm) and its ranges (maximum values between 23 and 92 cm), with a slight increasing trend. For all years (with the exception of 2001), at intra-annual level, the active layer thickness was strictly linked to the ground temperature at a depth of 10 cm (data not shown). The correlation between the active layer thickness at Boulder Clay with the ground temperature is testified also by the summer thawing degree days of the ground surface temperature (DJF soil TDD) recorded at the boulder clay permafrost station, which exhibited a statistically significant increase, although with a less pronounced trend than until 2009 [4.23].

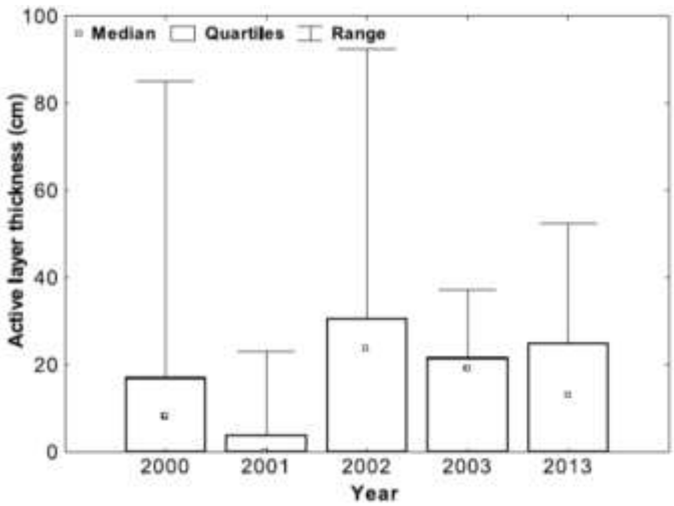

Figure 4.4: Active layer thickness (cm) (median, quartiles and range) measured at the Boulder Clay CALM grid (100 m x 100 m, 121 nodes) in the period 2000–2013 (please note that there is a gap between the 2003 and 2013 measurements) [4.23].

4.1.2. Boulder Clay GPR survey

In order to achieve more information about the till moraine located at Boulder Clay Glacier, several geophysical activities were carried out, from ENEA-UTA, during the summer Antarctic expeditions 2013-2014. In particular, Ground Probing Radar (GPR) survey were initialized focusing on the finalization of the project and trying to perform a comprehensive evaluation of its related impacts.

The glacial environment usually represents a very suitable context for GPR. This technique can be considered a powerful tool for bedrock mapping in glacial environment because of the strong contrast between ice or snow and rock (ice and snow have a good dielectric properties featured by a low attenuation of the GPR pulse).

In the GPR survey, a GSSI Sir3000 unit equipped with different frequency antennas (100-200 MHz) was used. The main goals of the survey were:

a) define the average thickness of debris along the till moraine;
b) define the bedrock morphology in the Boulder Clay area;
c) define a model of the lake-ice blisters present in the area.

Reflection arrival times (TOF) were converted in depth using a EM wave speed of 0.168 m/ns where direct analyses as common mid point acquisition or hyperbola diffractions were not possible to achieve. Due to the extension of the surveyed area, both airborne and ground measures were collected. The airborne measures (only at 200 MHz frequency, see Figure 4.5) were mainly conducted for covering the moraine area where a ground survey path was impossible to realize. Twin path surveys have been collected with different recording time window (TWT, 450 ns and 900 ns) in order to get information about a) and b) objectives respectively. The on-ground measures were instead focused on b) and c) objectives and both the bistatic 100 MHz antennas and the monostatic 200 MHz were used. All the profiles were positioned by a synchronized GPS acquisition and post-processed by vertical and horizontal band-pass filtering, predictive deconvolution, gain equalization and migration. Where possible the bedrock and the debris thickness data were mapped by a Kriging operator (linear variogram model) and reported as maps on a 2012 GeoEye satellite image of the area.

a) Debris thickness on the till moraine

The Figure 4.5 reports the map of the average debris thickness data recorded by the airborne survey.

As reported, debris coverage heavily hamper signal penetration at relatively high frequencies but, nevertheless, we connected the presence of diffractions as a consequence of presence of debris in the ice. In Figure 4.6 it is possible to observe two examples of radargrams (Sections A-A' and B-B') where the ice surface reflection (flight height) and an highly irregular and diffractive shallow part is clearly visible. Keeping into account the signal hampering, it seems clear that ice matrix increases quickly with depth. In order to uniform the dataset, only the variation of the bright upper diffractive layer was picked and mapped.

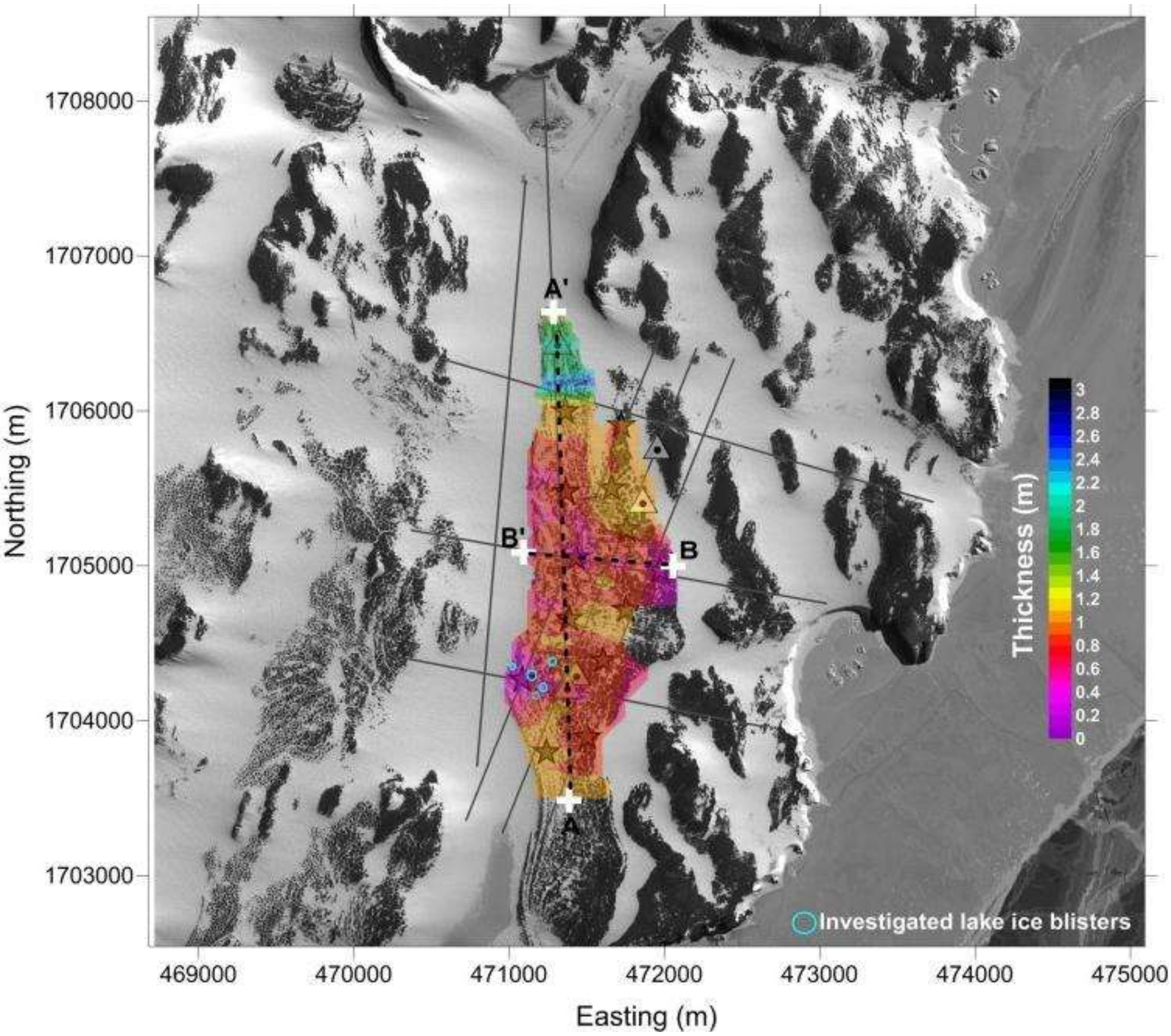

Figure 4.5: Map of debris thickness carried out by means of airborne survey.

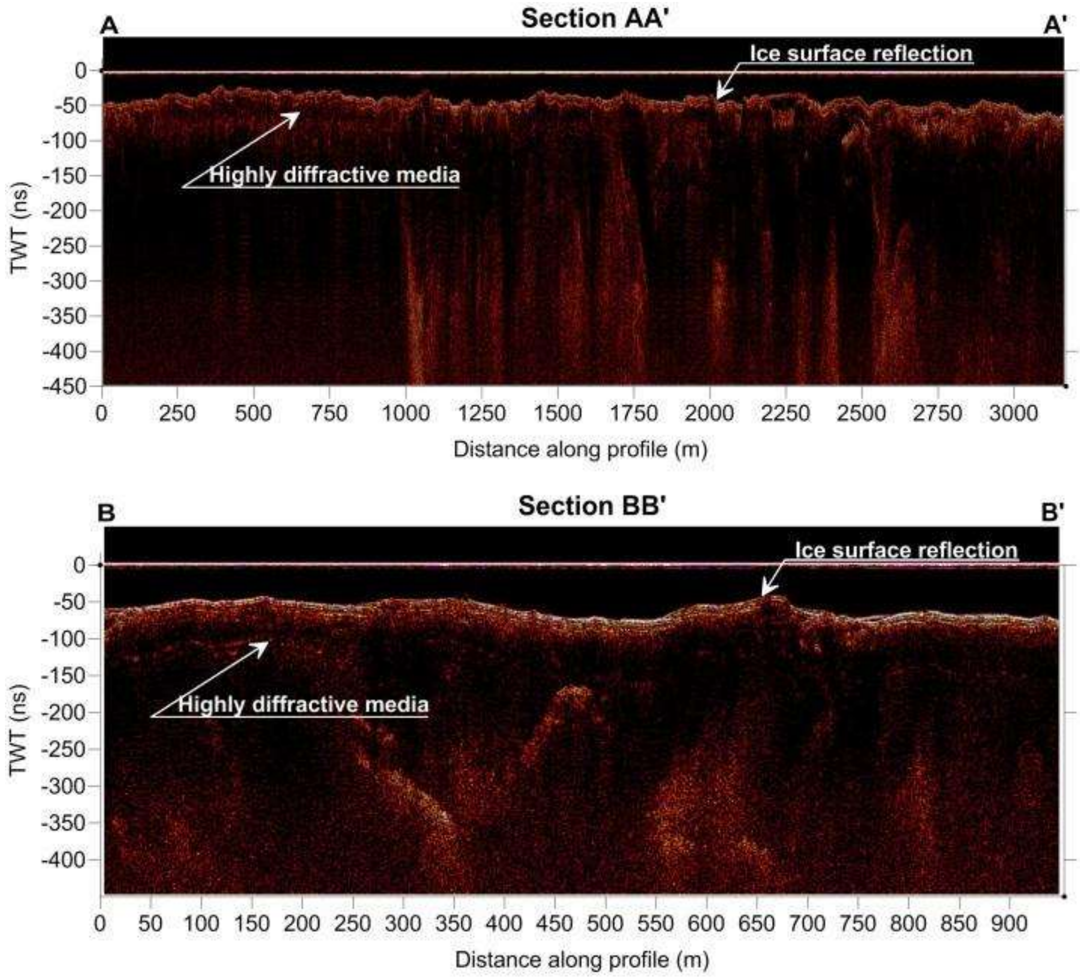

Figure 4.6: Representative radargrams and map of debris thickness.

b) Bedrock morphology in the Boulder Clay area

These sections are reported as radargrams in Figure 4.8 and were collected respectively by the ground survey (100 MHz pair antennas; Section AA') and by the airborne survey (200 MHz; Section BB' and CC'). Each profile was topographically corrected on the base of the Geoeye DEM (10 m resolution) while the vertical exaggeration factor used is 2 for Section AA' and 4 for Sections BB' and CC'.

The section AA' (Figure 4.8a) crosses the glacier valley from ridge to ridge and it is tangent to the northern limit of the moraine (see Figure 4.7). The echoes reflected from the bedrock are very clear only in the first and in the last part of the profile for about 200 m, steeply descending and rising when the profile approached the valley sides. In the middle the ice thickness is probably greater than 80 m. The black dots box, shows the side view of the ice-cored moraine that probably fill a large part of the ice, where the bedrock echoes are missed, and it seems to set up of an accumulation of largely inhomogeneous materials. The blue dot box shows the part of the glacier where there is a positive snow accumulation. It appears as a well stratified area of about 350 m long and with a maximum recognizable thickness of about 25 m.

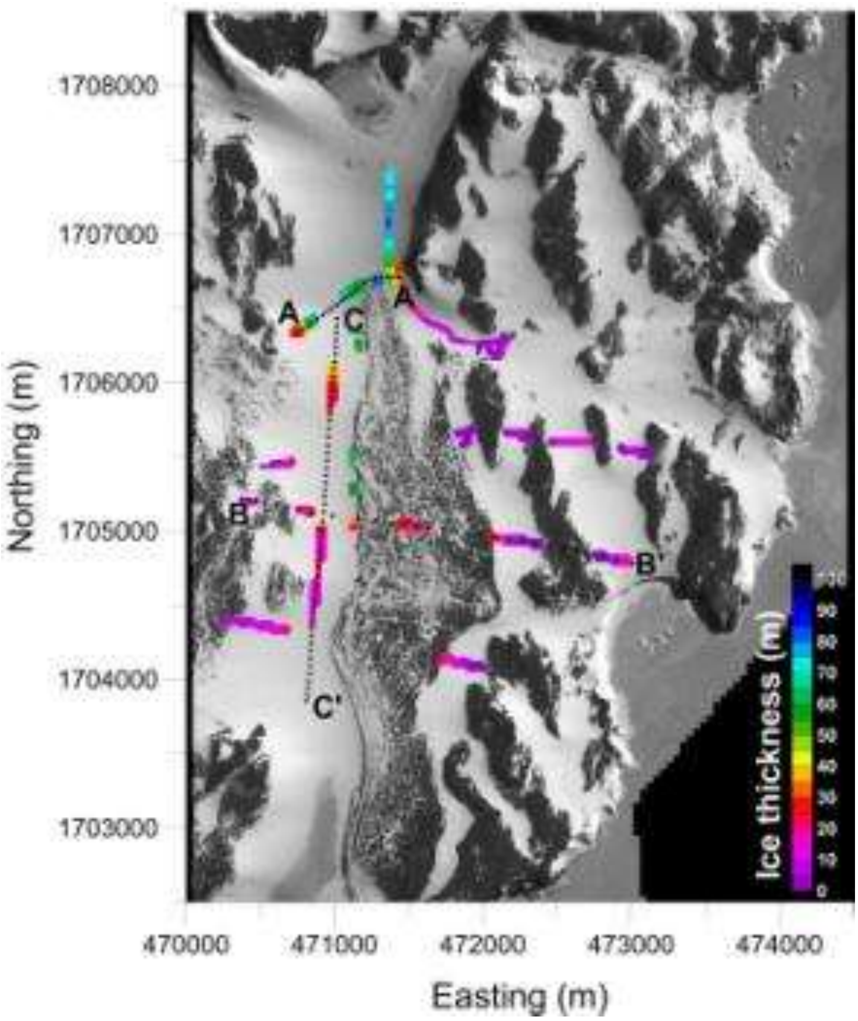

Figure 4.7: Map of interpolated ice thickness in the Boulder Clay Glacier.

The section BB' (Figure 4.8b) crosses the Boulder Clay Glacier from West to Est in its middle part. The profile starts in a small ice-filled depression (first 200 m) located in the higher part of the bedrock outcrop. The bedrock steeply falls into the glacier body at about 500 m from the beginning, remaining visible for about 180 m where the ice reaches a thickness of about 30 m. Along this part and according with the change in topographic slope, it is possible to recognize again the lee-side snowfield with positive accumulation (blue dot box) for a total length of about 260 m and a thickness of about 30 m. The part comprised between 800 and 1,700 m along the profile is flown over the moraine. As expected, in this area high scattering effect occurs hampering the signal penetration but, however, small parts of coherent deeper reflections are visible (i.e. from 1,050 to 1,200 m and from 1,360 to 1,400 m). From 1,700 m to the end of the profile, the bedrock reflection is present again rising up to the surface, where the bedrock emerges at about 2,000 m, and submerge again from 2,400 m to the end of the profile.

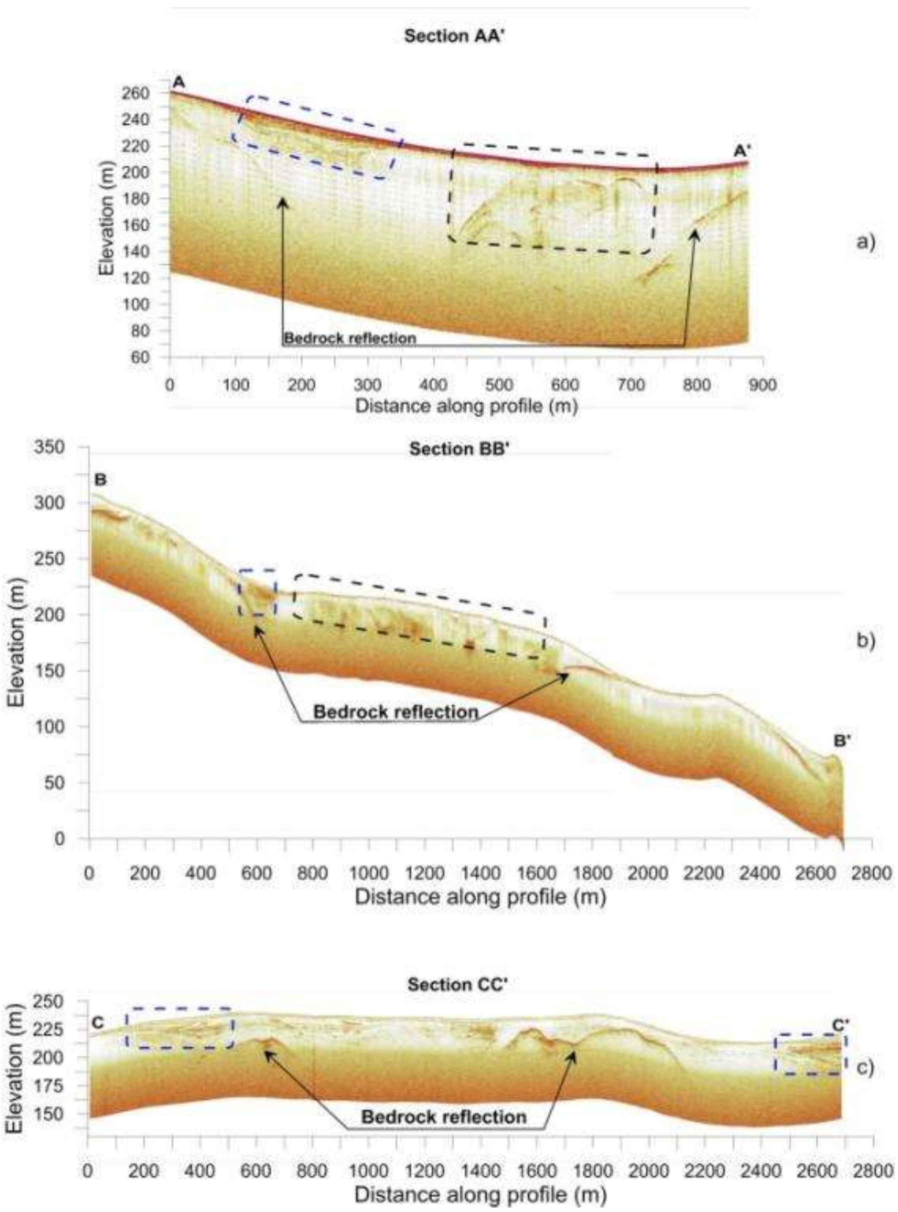

Figure 4.8: Representative radargrams from sections in Figure 4.7. Blue dot boxes are for detected accumulation area; black dot boxes indicate the moraine area on the profiles.

The section CC' (Figure 4.8c) reports part of the profile flew from North to South along the glacier elongation direction. It shows two bedrock structures rising from 500 to 750 m and from 1,460 to 2,170 m where the minimum ice thickness values are 20 m and 8 m respectively. These structures drive also the topography altitude along the profile that reaches its maximum over them. Besides, the upper part of the profile clearly shows also the variation in snow accumulation along a large part of the lee-side snowfield.

c) Model of a lake-ice blister

As the runway project is based on the moraine area, it was also important to get information on shallow glacial features (lakes, blister lakes, crevasses, etc.). On this task, the airborne survey was doubled reducing the instrument recording window (250-400 ns) and the flight speed. The presence of supraglacial frozen lakes in Northern Foothills area, and thus on Boulder Clay Glacier, is well known. Some of them were catalogued as lake-ice blisters that typically occur on small perennially ice-covered lakes. Figure 4.9 (Section DD') represents a good example of how, these features, can appear on radargrams. The red circle indicates a really small depression (25 m long; 1 m deep) filled with quite homogenous ice (no sign of internal reflections) and impossible to recognize on the Geoeye image (see Figure 4.9a insert). The yellow circle indicates instead as lightly larger lake (80 m long; 3.5 m deep) in which it is possible to recognize two reflection surfaces under a cover of homogenous ice. This intermediate layer could be ascribed to the accumulation of heterogeneous material on the lake bottom. During the summer time, dark stones warmed by the sun start to penetrate the ice cover falling on the bottom especially if the lake becomes completely unfrozen. Besides, the presence of a full homogeneous ice-cover could be also interpreted as a sign of a complete melting of the ice cover during the warmer period. Because of the larger dimension, this lake is easily recognizable also on the Geoeye map (insert in Figure 4.9a). The last example reported (cyan circle) points out another lake (110 m long; 4.7 m deep) where it is possible to observe a not complete-homogenous ice coverage in the latter part of the profile. It is noteworthy that the lake flanks appear sharply sloped and associated in depth with diffractions that look similar to crevasses. The hyperbolic-shaped diffractive area detectable at about 310 m along the profile (15 m deep) seems to support this hypothesis. The left side of cyan circle lake well represents this particular situation where the ice surface looks collapsed and tilted as a rigid block and subsequently filled by snow that could be partially melted during the warmer season.

In order to enhance the geophysical characterization of these small melting lakes we took the chance for acquiring (late November 2013) a small on-ground survey on one (indicated by the white circle) of the frozen lakes located inside the red dot rectangle in Figure 4.9a.

The ice surface was characterized by a raised topographic bump close to its centre of about 40 cm where ice was also fractured. The strong flat reflections present in Sections AA' and BB' (Figure 4.10) are ascribable to the presence of a free melt water surface. In fact, it returns a large amount of the transmitted energy because of the strongly increased contrast in dielectric properties moving from an ice/rock to an ice/water interface. This strong reflected energy generates also a multiple effect observable particularly in Section AA'. Because of the presence of water at lake bottom, it was not possible to define the real lake bed geometry limiting the maximum recorded depth to the ice/water interface (about 3.5 m). It is noteworthy that there is an accumulation of debris material located near the lake centre and elongated in NE-SW direction where also the ice surface bump occurs.

Many of these lakes appeared completely melt in the late summer season in contrast of their believed "perennially frozen" status. Moreover, the shape of these kind of lakes and their middle-placed accumulation material represent a reliable marker to recognize them on satellite images (see Paragraph 4.1.4).

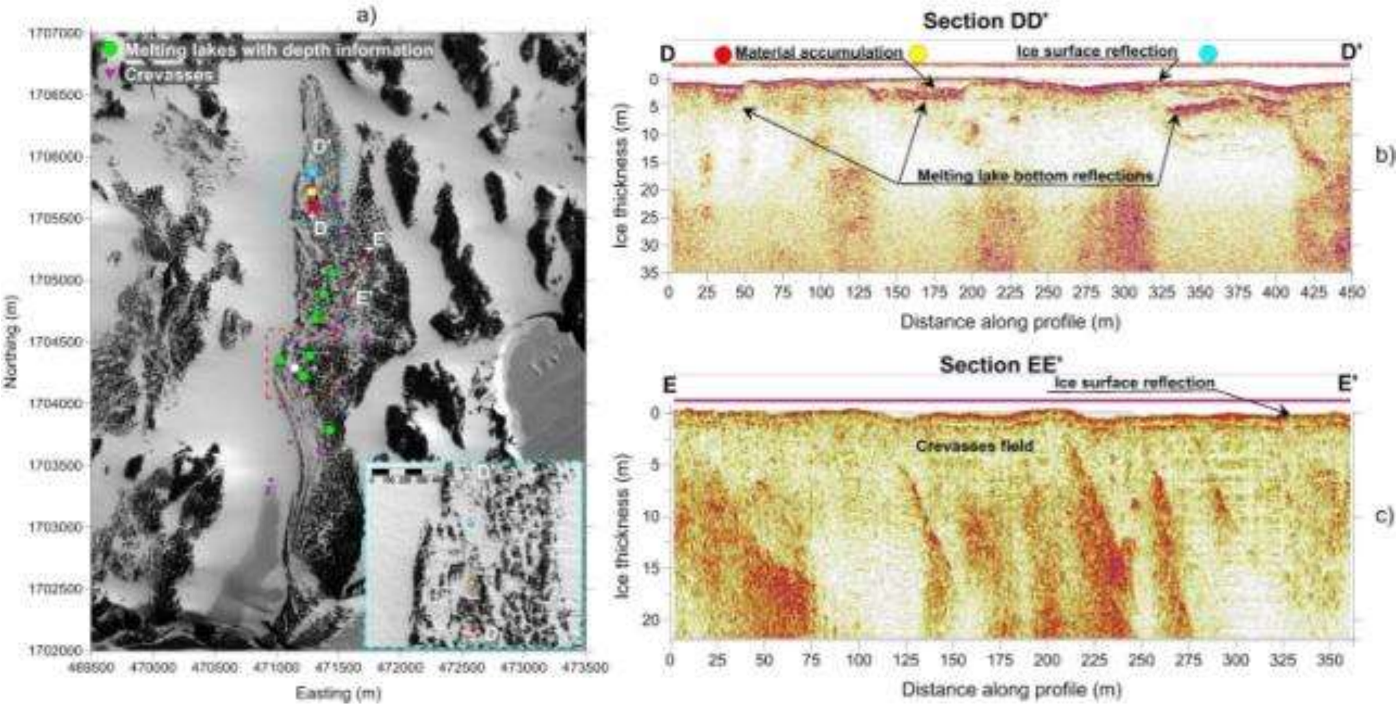

Figure 4.9: a) Map of melting lakes detected by the GPR airborne survey. In the insert, a zoomed view of the cyan dot rectangle; b) Example radargram of melting lake signature on airborne GPR data; c) Example of crevasses signature on airborne GPR data.

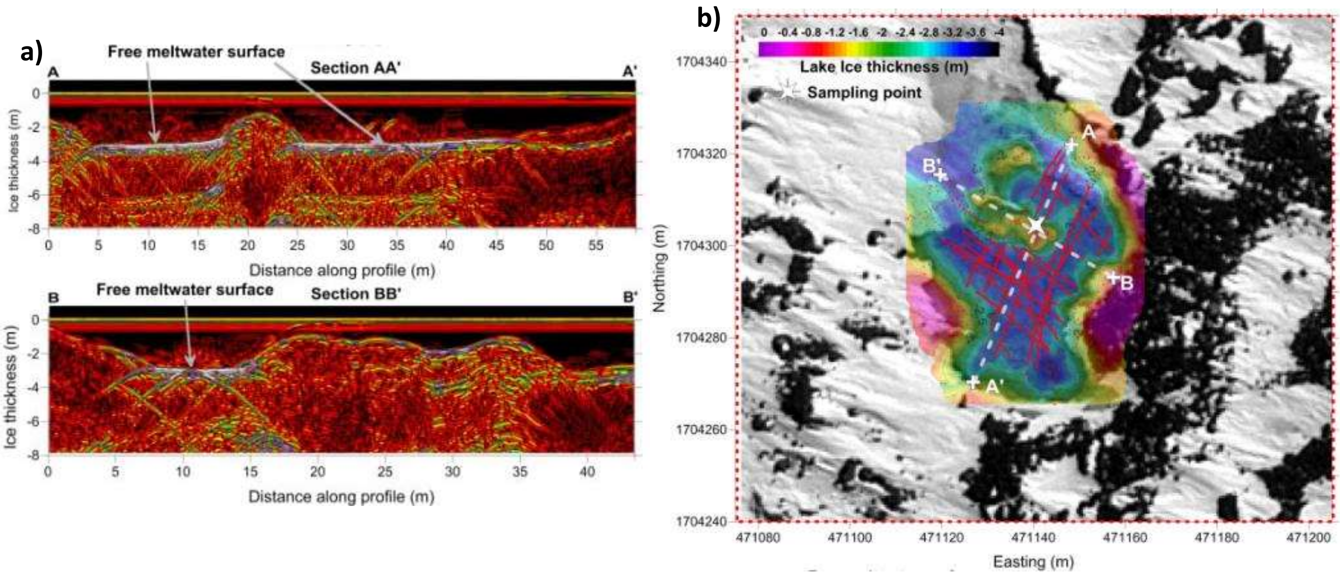

Figure 4.10: a) Representative radargrams, b) map of lake ice blister.

During Georadar survey (Nov. 22nd, 2013), ENEA-UTA performed water sampling in ice blister lake of Figure 4.10b, through a coring positioned in correspondence of intersection A-A' and B-B'. In situ measurement, at a depth of 1.5 m, was made with a multi-parametric probe (HI 9828), physicochemical parameters of the water fined at the bottom of the lake are reported in Table 4.1.

Table 4.1: Physical-chemical parameters of lake ice blister water performed in situ.

Parameters	Value
Dissolved oxygen (mg/L)	0.28
pH	9.00
Temperature (°C)	0.14
Resistivity (MΩ/cm)	0.0002
Conductivity (μS/cm)	4091
Total dissolved solids (ppm)	2045
Salinity	2.13
Oxidation-Reduction Potential	-154.4

The same water sample characterized in situ has been later analysed in ENEA Laboratories (*Technical Unit for Prevention, characterization and environment remediation – Bio-geochemical Environmental laboratory*) to determine the main cationic and anionic contents (Sample 1 of Table 4.2). In addition in same summer campaign (Jan. 28th, 2014) after the partial melting of the lake, a new sample has been taken and analysed in the same laboratory (Sample 2 of Table 4.2).

Table 4.2: Composition of water sampled in the lake ice blister of Fig. 4.10b.

Sample	COND.	pH	Ca	Mg	Na	K	HCO3	SO4	Cl	NO3
	uS/cm		*mg/L*							
1	4,120	6.3	144	36	737	29	21	875	618	<0.1
2	56	6.1	3.2	0.4	6.3	0.5	7	9.4	4.9	<0.1

The compositional variation of water before and after the ice melting is evident from results reported in Table 4.2, indeed the high salinity water located in the lake bottom during cold season is gradually diluted by the ice melting.

ENEA-UTA and other researchers [4.24] found life in this particular lakes ice blister, both in high salinity and melted fresh water seasonal condition. The microorganisms that can survive at such conditions (salinity and temperature) are commonly found in the Victoria land and other Antarctica regions and are briefly reported in Table 4.3.

Philodina gregaria
Philodina alata
Adineta grandis

Table 4.3: Microorganisms found in Lake ice blister.

4.1.3. Geodetic survey

A geodetic network of 15 points was set up on the moraine in December 2013 to evaluate a possible differential displacement along the runway path. The first measures (zero measure) and the second ones (November 2014) were performed using a differential GPS instrument (DGPS). The network was positioned on the base of a preliminary multi-temporal analysis carried out using aerial and satellite images. Figure 4.11 summarizes the displacements magnitude and the relative directions of all the points located and measured on the moraine.

The displacement measured is in the order of centimetres and this testifies the absence of significant differential movements along the moraine. Further evaluations about the moraine deformations have been deduced by means of an interferometric study carried out on the area on the base of CosmoSkyMed satellite images.

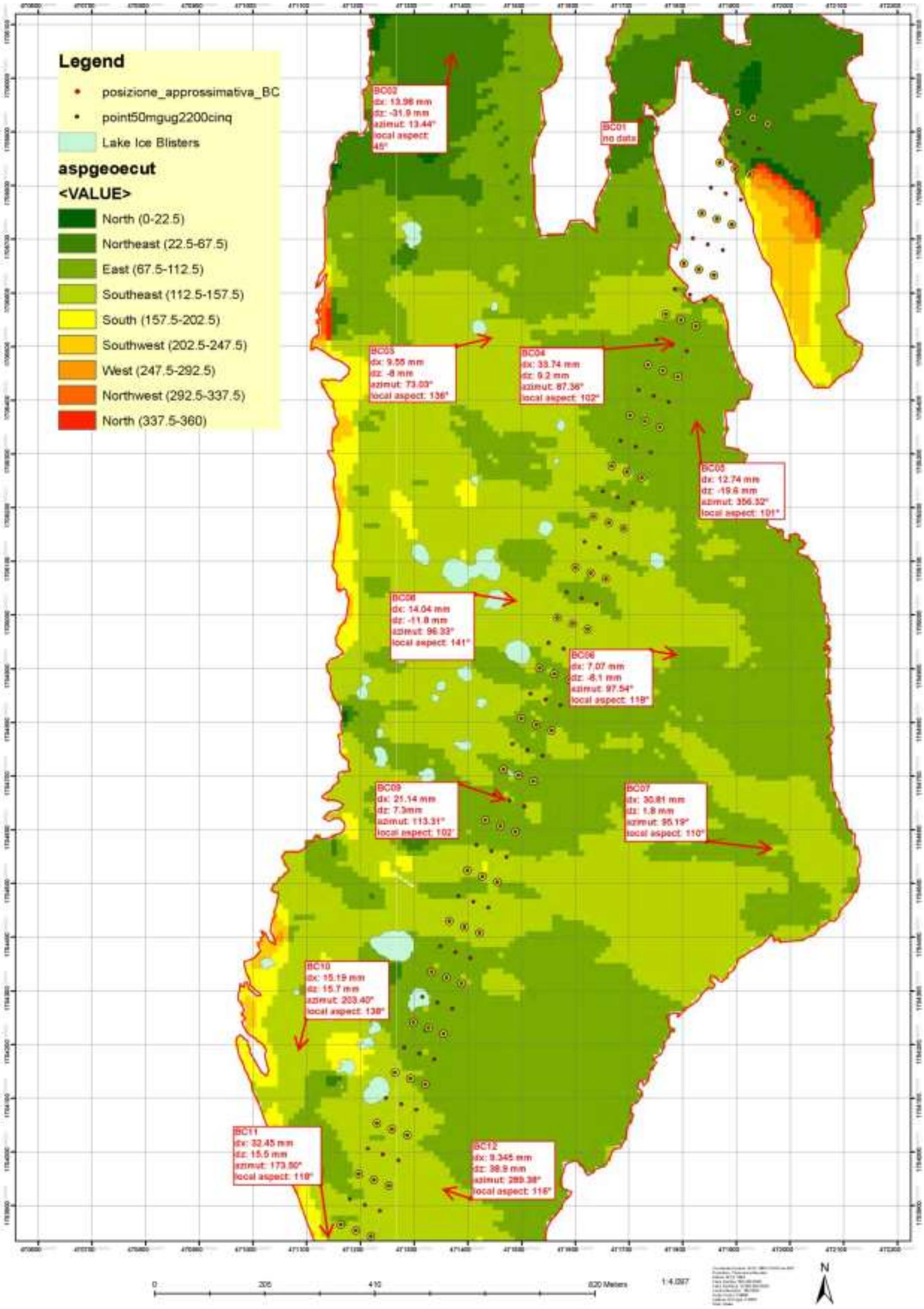

Figure 4.11: DGPS results of the geodetic network survey carried out on the moraine (December 2014-November 2015).

4.1.4. Moraine deformation by satellite SAR interferometry

One the most important uncertainties related to the construction of a gravel airstrip above a moraine is the natural displacement of the ice substrate. An investigation, performed by using archive Synthetic Aperture Radar (SAR) satellite images, was carried out in order to detect and characterize potential deformation processes affecting the area of interest.

Selection of satellite SAR data, data analysis and preliminary considerations

The analyses have been performed by using SAR images collected by the satellites of COSMO-SkyMed constellation, managed by the Italian Space Agency (ASI). More in details, 102 archive images acquired in descending orbital pass have been selected. The scenes have been acquired in "Stripmap Himage" mode with a nominal resolution of 3x3 m. Minimization of the temporal decorrelation (i.e. loss of interferometric information between two images, which occurs when reflectivity characteristics of the objects on the ground changes in time) has been the main criteria for the data selection. For this purpose we have selected a stack characterized by:

i) low temporal baseline (i.e. the time interval between the acquisition of consecutive images);

ii) high number of images to optimize the advantages offered by A-DInSAR methods.

Selected images have been analysed as two different datasets: the Dataset A related to 2013 and the Dataset B related to 2014. Specifically, the first dataset (53 images) covers the period from Feb. 25th to Dec. 10th 2013, while the second dataset (49 images) covers the period from Jan. 11th to Dec. 1st 2014.

The investigated area was selected based on the following requirements: i) analysis pixels of the SAR images characterized by a good signal quality, thus increasing the reliability of the results; ii) ensure sufficient coverage of the area of interest.

Maps of displacement

Figure 4.12 shows the displacement maps derived by A-DInSAR processing of SAR images acquired by COSMO-SkyMed. All displacement values are expressed in millimetres and refer to the Line Of Sight (LOS) of the satellite sensor (i.e the direction joining the satellite to ground targets). The SAR images used in this work, are characterized by a LOS direction about 325°N and an incidence angle with respect to the flat ground of about 45° (please consider that the incident angle varies over the AOI depending on the local topography).

The displacement values estimated for each dataset are differential with respect to reference points (selected following quality criteria of the radar signal) that have been chosen outside of the moraine, at the rocky outcrops located East of the moraine itself.

In particular, Figure 4.12 (a and b) shows the results derived from the A-DInSAR analyses on data-stack related to periods Feb. 25th - Dec. 10th 2013 (Dataset A) and Jan. 11th - Dec. 1st 2014 (Dataset B), respectively. The colours identify the movements (along the LOS) occurred in the study area according to the following coding: warm colours (negative values) identify movements away from the satellite, while cool colours (positive values) identify movements toward the sensor. Values close to green colour indicate stable areas or movements near to the data accuracy available for this area.

The maps have been generated applying the appropriate quality thresholds (based on the temporal coherence) for the estimated displacement results, in order to increase the reliability of the results.

The analysed area includes, in addition to the moraine and rock outcrops located in the East sector, also the final portion of a coastal glacier (well visible from SAR images) that bounds the southern sector of the moraine along the western side.

The deformation processes, interesting this portion of the study area, were much more evident and clearly visible during the preliminary stages of A-DInSAR analysis. However this part of the area will be not interested by the airstrip displacement and then the relative higher drift speed will not be considered as a problem for the project.

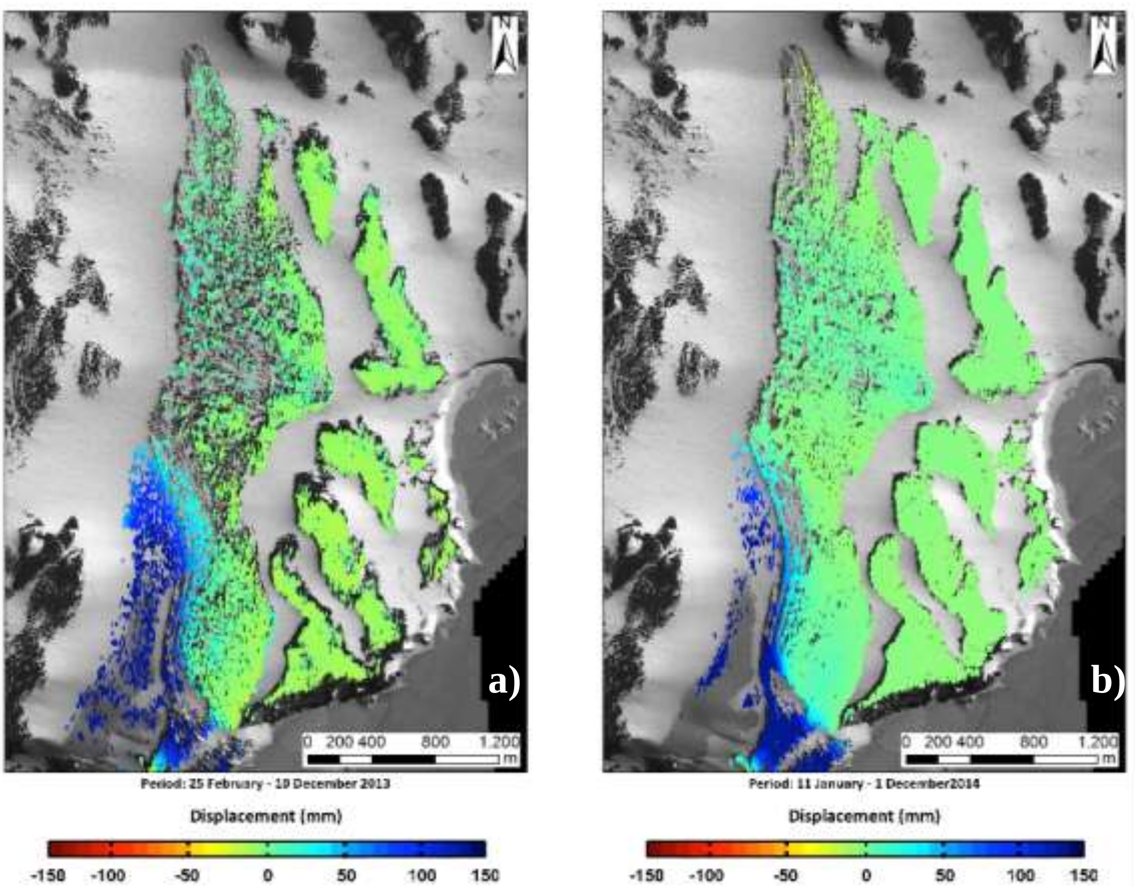

Figure 4.12 a and b: Displacement map related to Dataset A (2013) and Dataset B (2014). Only pixels characterized by good quality signal falling within the investigation area have been analysed. Displacements are expressed in millimetres and refer to the whole period. Positive values (cool colours) identify movements toward the satellite. Negative values (warm colours) identify movements away from the satellite. Values close to green colour indicate stable areas or movements near to the data accuracy.

Conclusive remarks on the GPR, DGPS and A-DInSAR analyses

Figure 4.13 shows a differential interferogram computed from two SAR images acquired by the COSMO-SkyMed constellation in "StripMap Himage" mode (nominal resolution 3x3 m). The figure represents the area as seen from the satellite and the North arrow is located in the upper left. The colours are related to the differential interferometric phase between two images acquired on May 11th, 2014 and on Dec. 6th, 2014.

The multicolour area at the top represents the sea (pack) surface and appears to be strongly affected by decorrelation, i.e. with no useful information. The blue areas on the background do not contain any information.

Particularly interesting is the area covered by more or less concentric fringes in the upper right portion of the image (South-West), which shows the displacements of the coastal glacier (the solid white line identifies the area).

Each interferometric fringe, i.e. a whole red-blue colour cycle (from $-\pi$ to $+\pi$) represents displacement along the line of sight equal to half of the wavelength (λ) of the used sensor. For COSMO-SkyMed, λ is equal to 3.1 cm, and then each fringe represents a displacement of about 1.5 cm along the line of sight (LOS) that is parallel to the vertical axis of the image (white vertical arrow). In this case a displacement of about 6 cm, which occurred between May 11th and June 6th 2014, is observable in the central area characterized by the concentric fringes in the glacier.

Figure 4.13 summarizes, as a part of the comprehensive study of surface processes in the Boulder Clay area, the movement along the line of sight. The rock glacier maintains an excellent coherence during the 2 years of analysis. This testify an overall stability of the moraine confirmed from vanishingly small velocity in the central and northern part of the area of interest.

A significant displacement is however evident in the south-western sector where the final portion of the Boulder Clay glacier moves with an important velocity in the direction of Adelie Cove site. The distribution of the fringes (from red to orange) in the upstream of the glacier (ellipses in white dotted line) would confirm the hypothesis of a power of the glacier from the right (with reference to the image), or from the West. Anyway, this displacement does not affect the infrastructure imposition area and in addition, no evidences of movement linked to this movement are visible in the nearby area such as the formation of superficial tension crack on the moraine and relevant buried crevasses in the glacier.

This is probably due to the particular topography of the bedrock buried beneath the moraine as we have seen in Figure 4.8c.

Figure 4.14 reports the overlay of the measured GPS vectors on the GPR main results. GPS vectors confirm that bedrock saddles (red dot in the figure) operate an ice separation on Boulder Clay moraine in three main parts. The northern part of the Boulder Clay moraine is characterized by small (northward) or null movements, while the centre part seems to have a slight eastward flow in direction of the narrow funnel-shaped valley on the right of BC07 station. Crossing the southern saddle, ice clearly flows toward Adelie Cove with a source area clearly placed in the western sector.

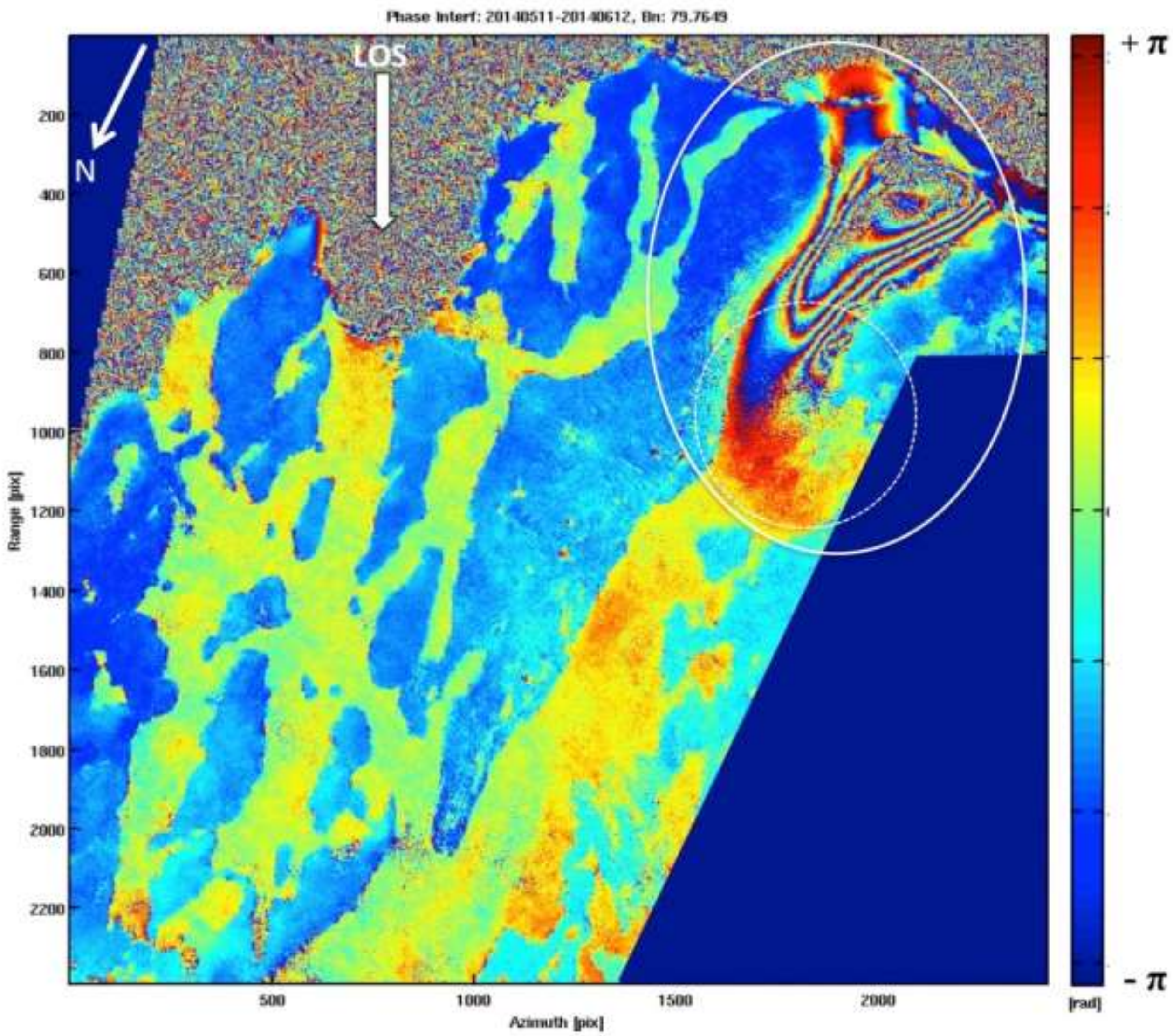

Figure 4.13: Boulder Clay area differential interferogram.

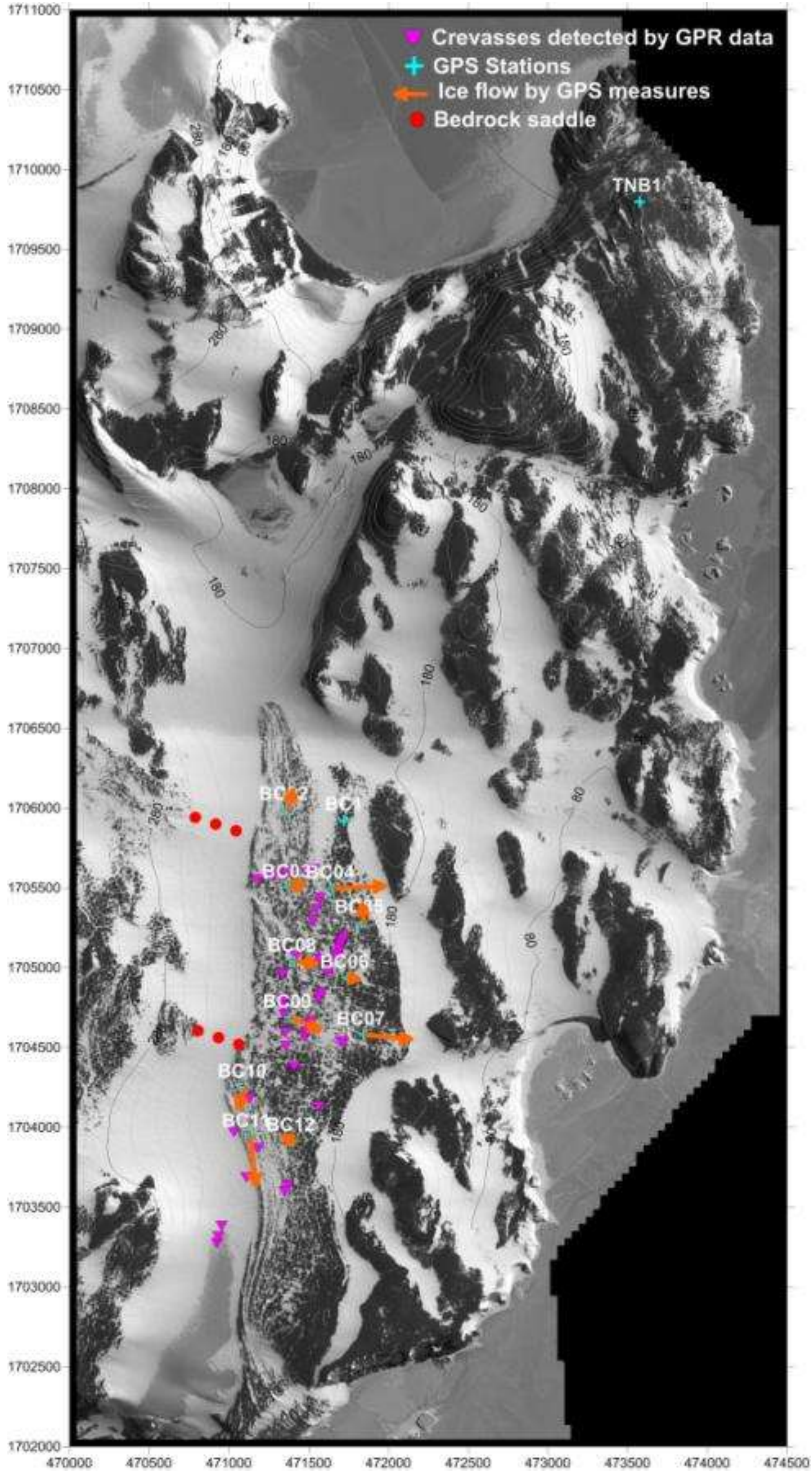

Figure 4.14: GPS Stations movement vectors.

4.2. Climate and meteorology

The *Meteo-Climatological Observatory* of PNRA has collected 28 years of meteorological data since the installation of the first permanent Automatic Weather Station (AWS) ‘Eneide’ in 1987. Among the AWS belonging to the Italian monitoring network, the most representative in the area of interest are Eneide and Rita (Table 4.4 and Figure 4.15).

AWS	LAT	LON	ARGOS ID	HEIGHT	ALTITUDE	SENSORS	INSTALL. DATE
ENEIDE	74°41' 45.3" S	164°05' 31.8" E	7353	10 m	91.94 m	Pressure Temperature Humidity Wind speed Wind direction Solar radiation	Jan. 1987
RITA	74°43' 29.9" S	164°01' 59.3" E	7354	10 m	267.67 m	Pressure Temperature Humidity Wind speed Wind direction	Jan. 1993

Table 4.4: Coordinates and features of Eneide and Rita weather stations in MZS area.

In order to monitor the candidate sites for the construction of the runway, and in particular to characterize the behaviour of the wind vector, on February 2013 (XXVIII Italian Expedition) five new automatic weather stations (K1 - K5) were installed in the ‘Boulder Clay’ and ‘Campo Antenne’ areas (Table 4.5 and Figure 4.15).

AWS	LAT	LON	HEIGHT	ALTITUDE	SENSORS
K1	74°44' 37.3" S	163°56' 24.6" E	6 m	475.3 m	Pressure Temperature Humidity Wind speed Wind direction (*Anemometer and wind wane at 6m*)
K2	74°43' 47.9" S	164°03' 14.6" E	10 m	146.2 m	Pressure Temperature Humidity Wind speed Wind direction (*Anemometer and wind wane at 6m, plus ultrasonic 3D anemometer at 10m*)
K3	74°45' 03.4" S	164°01' 17.0" E	6 m	183.1 m	Pressure Temperature Humidity Wind speed Wind direction (*Anemometer and wind wane at 6m*)
K4	74°42' 30.0" S	164°04' 22.4" E	6 m	276.0 m	Pressure Temperature Humidity Wind speed Wind direction (*Anemometer and wind wane at 6m*)
K5	74°42' 19.4" S	164°06' 17.7" E	6 m	117.3 m	Pressure Temperature Humidity Wind speed Wind direction (*Anemometer and wind wane at 6m*)

Table 4.5: Coordinates and features of Eneide and Rita weather stations in MZS area.

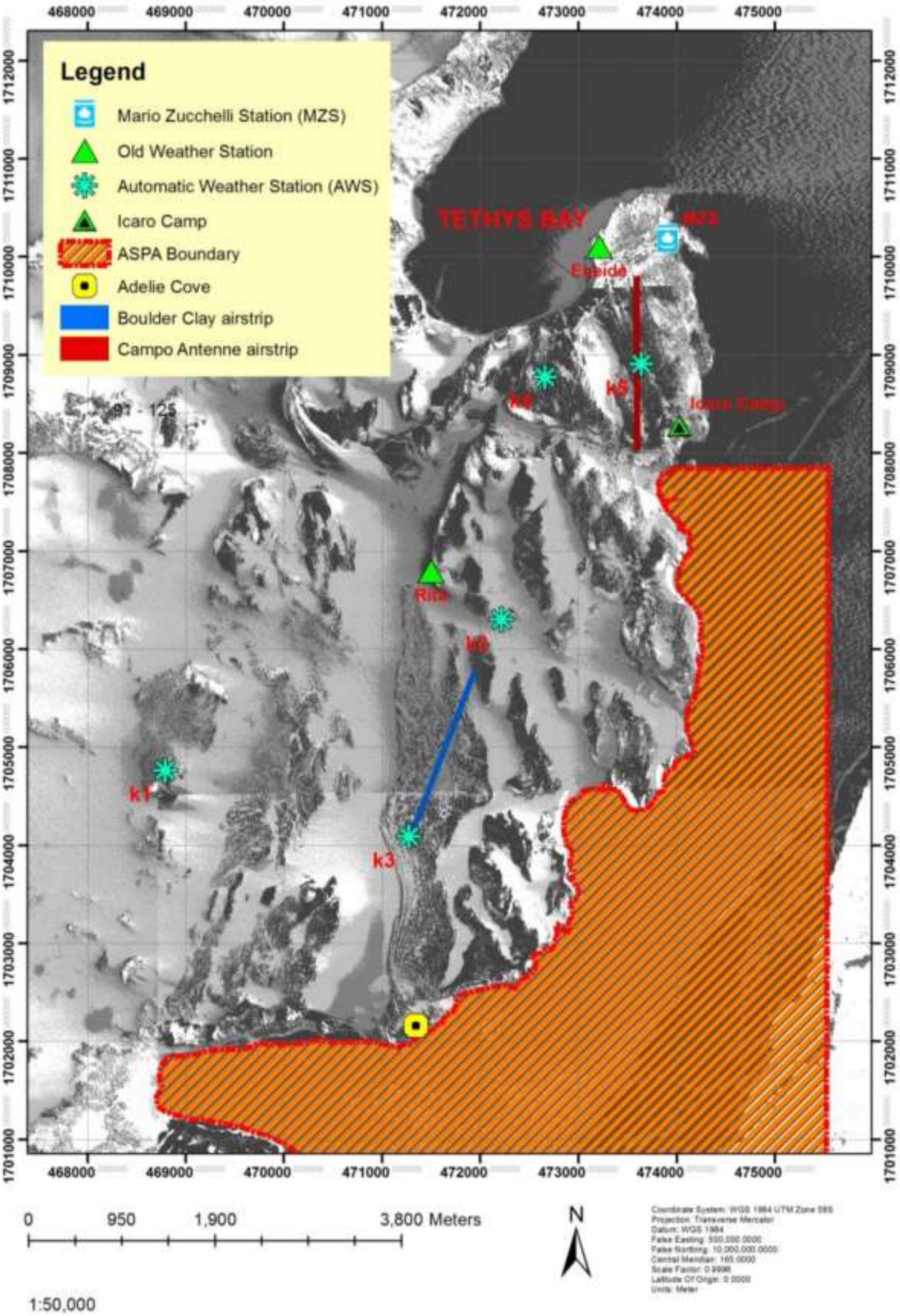

Figure 4.15: Detail of the area of interest, showing airways and automatic weather stations (Eneide, Rita, K1, K2, K3, K4 and K5).

4.2.1. **Temperature**

The climate in the Terra Nova Bay area is heavily conditioned by the circulation of the Ross Sea and the strong orographic influence of the Transantarctic Mountains. Climatological studies have shown that many observed sub-synoptic scale disturbances and mesoscale cyclogenesis occurring around Terra Nova Bay area are linked to the interaction between a relatively warm air over the Ross Sea and strong katabatic outbreaks descending from the high plateau through the Reeves and Priestly glaciers [4.25].

The trend of monthly mean values of air temperature recorded by AWS Rita and Eneide during the year is nearly identical, with AWS Rita temperature values are constantly some degrees lower than those of AWS Eneide (Figure 4.16 and Figure 4.17).

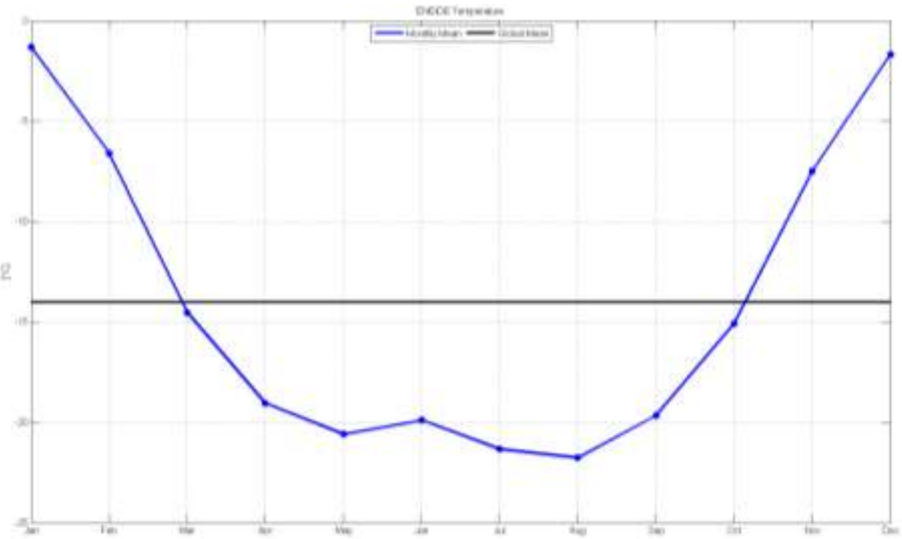

Figure 4.16: Monthly mean temperature collected by AWS Eneide (data from Feb. 1987 to Nov. 2011).

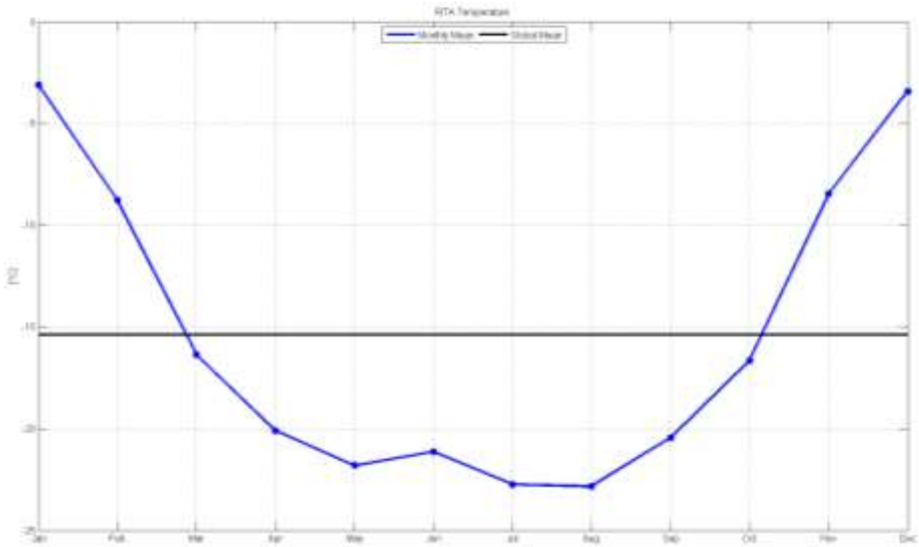

Figure 4.17: Monthly mean temperature collected by AWS Rita (data from Jan. 1993 to Nov. 2011).

The monthly mean temperature shows the typical behaviour of the Antarctic coastal regions, with a short summer, from late November to January, a "coreless" winter and very short transition seasons (spring and autumn) interposed [4.25].

Temperature values acquired by AWS K1 (Figure 4.18), K2 and K3 during about two years of operation, confirm qualitative characteristics of this behaviour, although showing, in correspondence of central months of austral winter, wider fluctuations, which nevertheless fall within the range of values recorded during more than 20 years also by AWS Eneide and Rita.

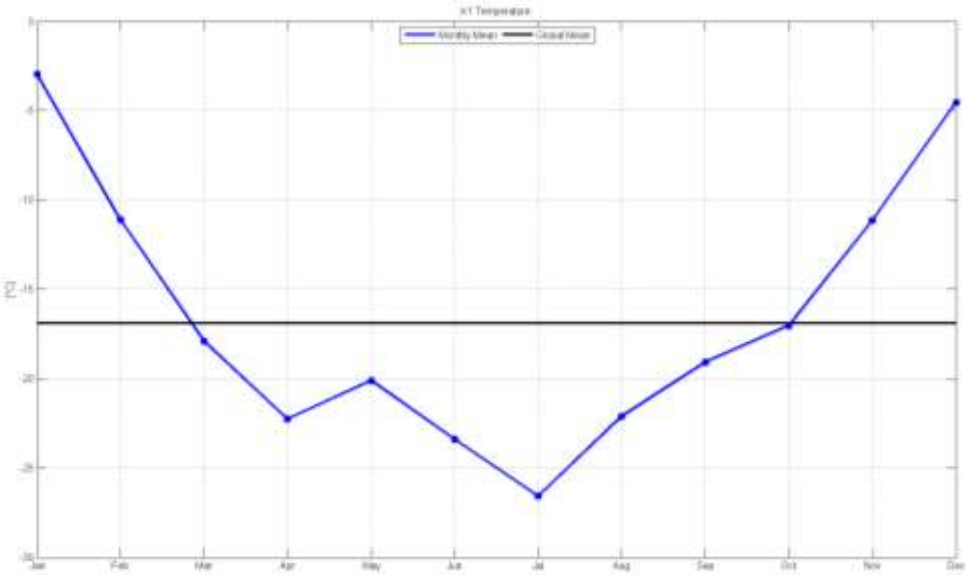

Figure 4.18: Monthly mean temperature collected by AWS K1 (data from Feb. 2103 to Jan. 2015).

4.2.2. **Wind**

Terra Nova Bay area is characterized by three different surface wind types, well distinct from one another [4.26] [4.27]:

- the katabatic wind, coming from W-WNW: it originates on the high central Antarctic plateau and after channelling through the canyons of Priestly and Reeves glaciers blows hard against the Northern Foothills;
- the "barrier" wind, originated by the flow of cold and stably stratified air that crosses the Ross Ice Shelf and moves towards W: when it impacts with the Transantarctic Mountains, not possessing enough energy to cross them, is diverted to N, till reaching even the Northern Foothills area;
- surface winds locally generated by different combinations of gradients of temperature and pressure.

The meteorological data collected during more than 20 years by the AWS Eneide (summer season in Figure 4.19) and Rita (summer season in Figure 4.20) show that the prevailing wind in the area comes from W and WNW.

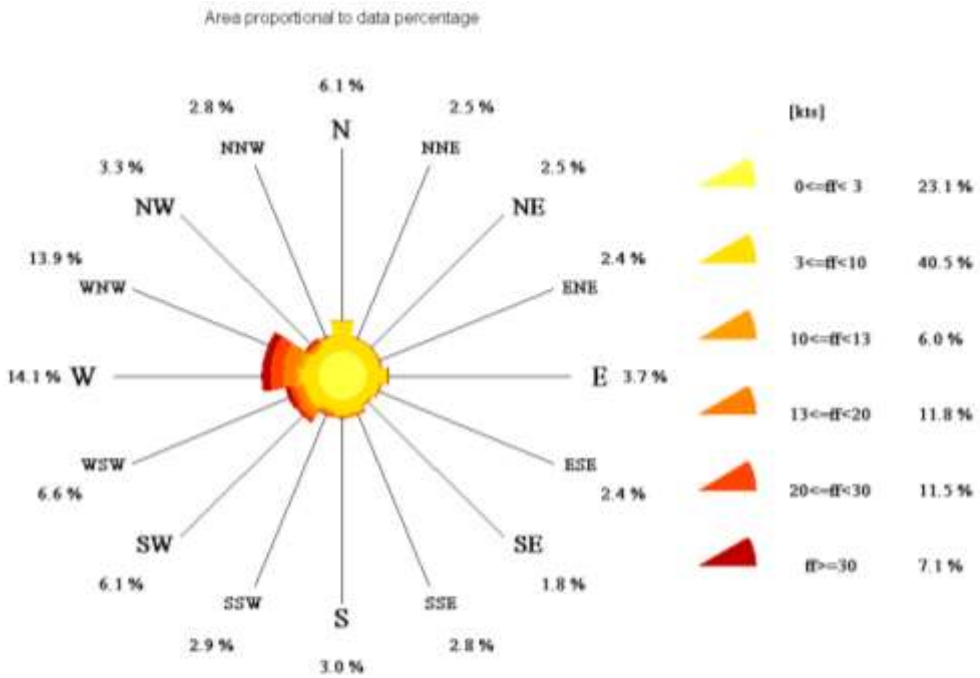

Figure 4.19: Wind speed and direction recorded by AWS Eneide in summer seasons (Oct.-Feb.) (hourly data from Feb. 1987 to Nov. 2011).

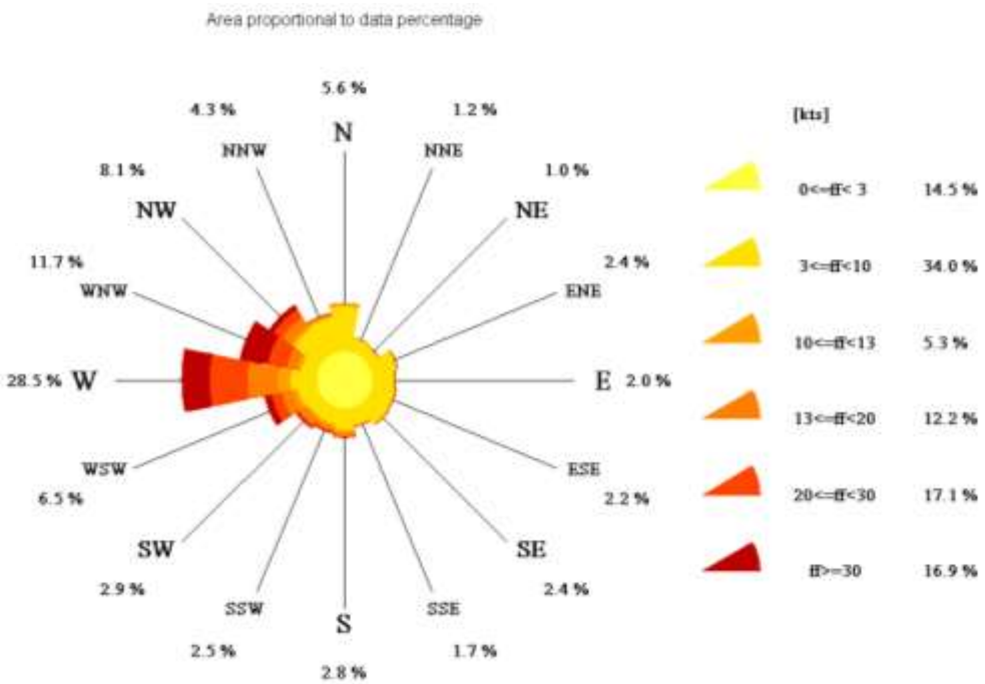

Figure 4.20: Wind speed and direction recorded by AWS Rita in summer seasons (Oct. – Feb.) (hourly data from Jan. 1993 to Nov. 2011).

In the station Rita this characteristic is considerably more marked by an increased percentage concentration of frequency and intensity for these two directions, as summarized in Table 4.6.

	October - February				**March - September**			
	W		**WNW**		**W**		**WNW**	
	Dir. %	ff % ≥ 30 kts	Dir. %	ff % ≥ 30 kts	Dir. %	ff % ≥ 30 kts	Dir. %	ff % ≥ 30 kts
ENEIDE hourly data (Feb 1987 - Nov 2011)	14.1 %	2.8 %	13.9 %	2.5 %	16.7 %	5.8 %	19.2 %	6.3 %
RITA hourly data (Jan 1993 - Nov 2011)	28.5 %	9.0 %	11.7 %	5.6 %	30.7 %	15.7 %	15.3 %	10.3 %

Table 4.6: Comparison of AWS Eneide and Rita frequency and intensity of W and WNW wind directions.

Data acquired by AWS K1, K2 and K3 (Table 4.7), besides confirming this characteristic of the area, reveal that, at the site of the runway, also the WSW wind origin assumes significant frequencies and intensities. This wind origin direction (WSW), better aligning with the orientation of the runway (NNE-SSW) and thereby reducing the crosswind component, can represent, from the point of aviation activity, a rising of opportunities to use the runway during the months above indicated.

	October	**November**	**December**	**January**	**February**	**Summer** (*Oct – Feb*)	**Winter** (*Mar – Sep*)
K1	11.6	16.0	26.7	29.5	21.0	20.7	9.6
K2	11.4	11.7	18.2	24.5	18.5	16.6	10.4
K3	6.3	15.4	18.5	20.6	17.1	16.8	10.0
RITA	3.7	5.7	7.3	7.0	4.5	5.7	4.3

Table 4.7: Comparison of AWS K1, K2, K3 and Rita percentage distribution of WSW wind direction (hourly data, AWS K1, K2, K3: Feb. 2013 – Jan. 2015; AWS Rita: Feb. 2013 - Oct. 2014).

While in the point of observation of AWS Rita the WSW wind origin can be considered as a secondary one, in the runway area it has values comparable with those belonging to the main directions, till rising to the role of local prevailing direction for K1 and K2 in the months of December and January.

4.2.3. Wind shear

Detailed orography in the vicinity of the runway shows the presence of many reliefs measuring no more than 500 meters in height and mostly aligned parallel to the axis of the runway: when the flow of the prevailing wind hits them before reaching the runway itself, the wind's dynamic characteristics could be altered, favouring conditions that might originate the wind shear.

The wind shear, from an environmental point of view, could significantly alter the dynamics of expected dispersion of polluting substances while, from an aeronautical point of view, could result in a significant reduction in visibility caused by the flow of blowing snow, but above all, it could generate dangerous effects of turbulence during the take-off or the landing of the aircrafts.

According to the Manual on Low-level Wind Shear (Doc 9817) by ICAO [4.28] the most generalized explanation of wind shear is “a change in wind speed and/or direction in space, including updrafts and downdrafts”.

The intensity of the wind shear is commonly expressed in meters per second per 30 m (m/s per 30 m) or in knots per 100 ft (kts per 100 ft) and classified according to the interim criteria recommended by the Fifth Air Navigation Conference (Montreal, 1967), as reported in Table 4.8.

Interim criteria for wind shear intensity	
LIGHT	0 to 4 kts inclusive per 30 m (100 ft)
MODERATE	5 to 8 kts inclusive per 30 m (100 ft)
STRONG	9 to 12 kts inclusive per 30 m (100 ft)
SEVERE	above 12 kts per 30 m (100 ft)

Table 4.8: Wind shear classification recommended by the Fifth Air Navigation Conference (Montreal, 1967) [4.27].

In the runway area vertical wind shear has been calculated at the position of AWS K2, using AWS Rita as the upper air measuring point: although the two points are shifted by about 800 meters from each other, their location, related to orography and prevailing wind, allows with a good approximation to equate the values of the wind detected by AWS Rita with the wind that blows on the vertical axis of K2, at the same altitude of Rita.

The graph of Figure 4.21 shows the distribution of intensity and direction of the vectors of vertical wind shear at the point of K2 in the whole period of observation, where the colored areas refer to the corresponding criteria of ICAO: results are that almost all of the episodes (about 98%) can be classified as light or moderate.

Along the longitudinal axis of the runway the horizontal wind shear has been calculated using the values of AWS K2 and K3. The graph in Figure 4.22 shows for the entire period of observation wind shear vectors with very low intensities, all classified as light.

More detailed analysis will be performed using a mathematical model of the wind field centred in the area of interest, which is currently under development as part of a technical-scientific cooperation with the Italian Air Force.

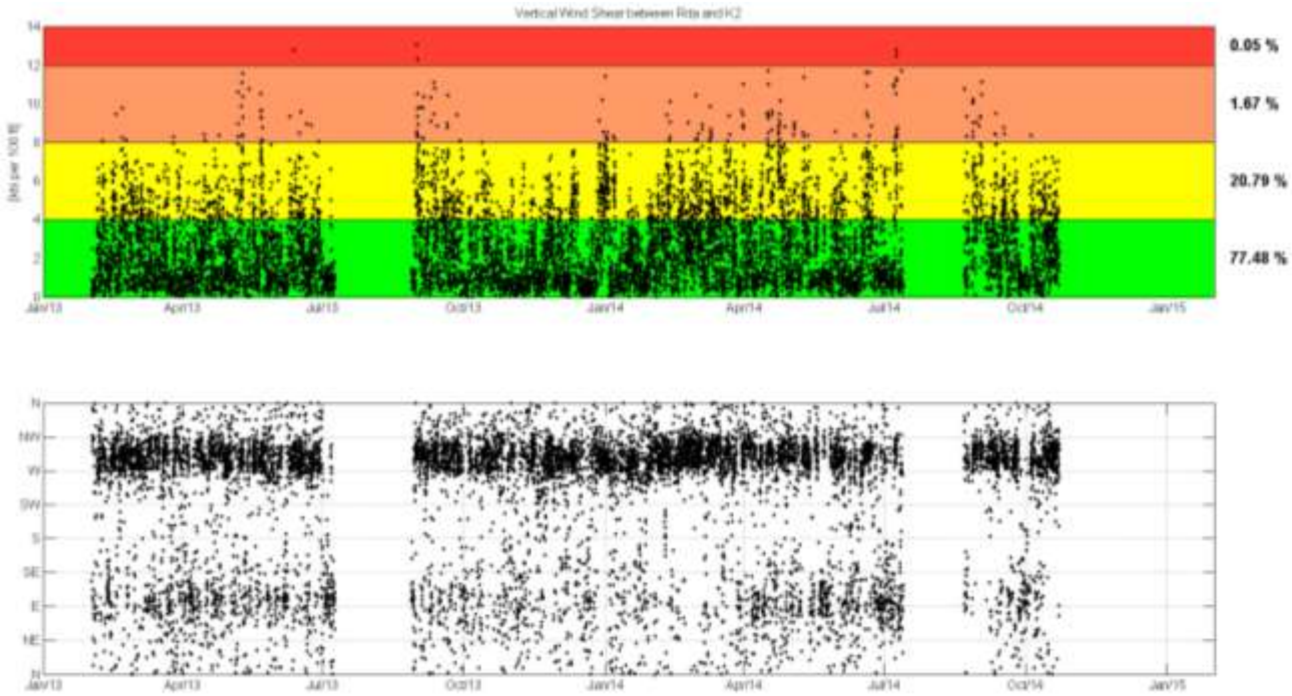

Figure 4.21: Intensity and direction distribution of vertical wind shear between Rita and K2 (LIGHT (green), MODERATE (yellow), STRONG (pink), SEVERE (red); hourly data from Feb. 2013 – Oct. 2014).

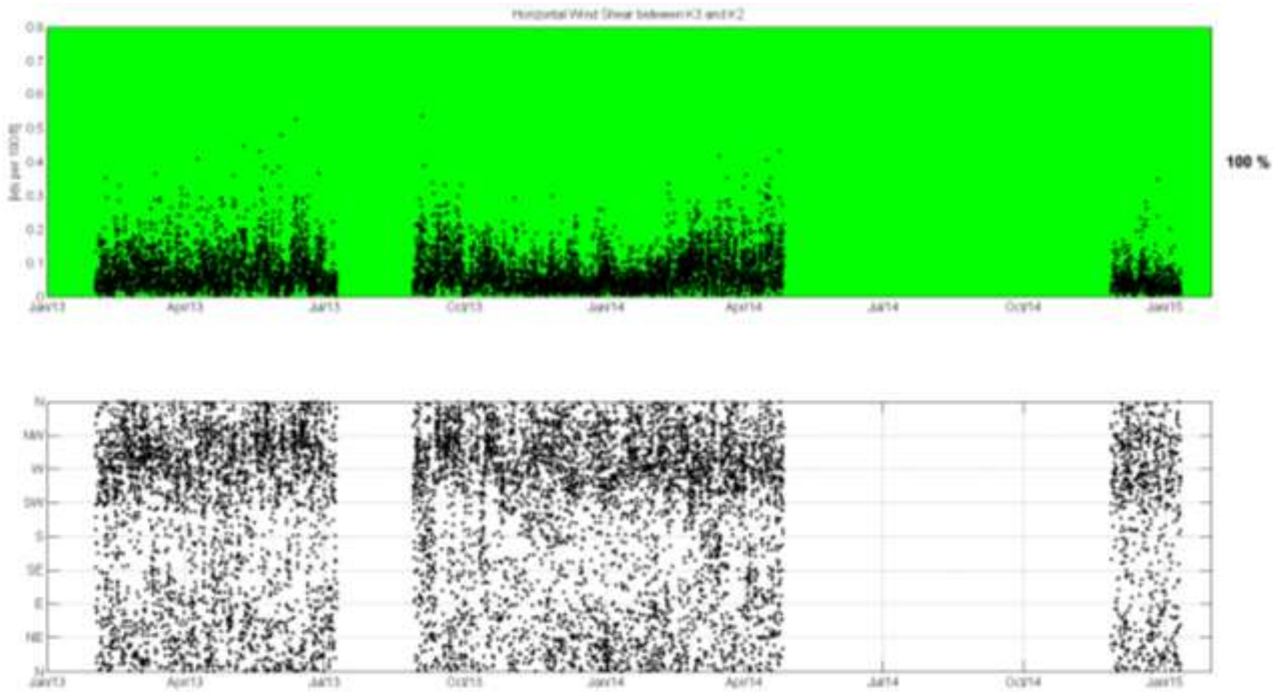

Figure 4.22: Intensity and direction distribution of horizontal wind shear between K3 and K2 (LIGHT (green), MODERATE (yellow), STRONG (pink), SEVERE (red); hourly data from Feb. 2013 – Jan. 2015).

4.2.4. Precipitation

In the Northern Foothills precipitation, almost entirely in the form of snow, approximates the 270 mm/year of water equivalent [4.29].

The site of Boulder Clay is more exposed to the katabatic winds from the inland areas and the roughness of the ground, caused by the stones that make up the till, favours the development of numerous accumulations of snow drifts, generally aligned SE- NW [4.22].

4.3. Biology and natural environment

4.3.1. Fauna

Terra Nova Bay area has been widely investigated in the last 25 years, through an extensive geological, oceanographic, marine, ecological and biological research.

The land and coast and the open sea within the TNB area include a variety of marine, terrestrial and freshwater habitats, some of these systems are unique to the Antarctic.

Wood Bay and Terra Nova Bay areas are among the most biologically and ecologically diverse in Antarctica with many species of bryophytes, lichens, marine birds, mammals and invertebrates.

These organisms are present on both marine and terrestrial ecosystem and whole marine system produces a clear influence on regional ecological processes, for instance South polar skuas (*Catharacta maccormicki*) breed within the Area with one of the most numerous colony of the Victoria Land.

Besides TNB includes Edmonson Point ASPA n° 165, TNB marine protected area (ASPA n°161), a small area near the Italian station, Mount Melbourne (ASPA n°118), Cape Washington and Silverfish Bay (ASPA n°173). Furthermore the area is characterized by Adélie and emperor penguin colonies and skua colonies at Edmonson Point, Cape Washington, Adelie Cove and Inexpressible Island.

The area includes the summer Italian MZS and the seasonal German Station of Gondwana only 8 Km from MZS and the new Korean Base (Jang Bogo Antarctic Research Station), just 1 km from German Station.

Impacts of human activities on the Antarctic environment date back to the 18th century with the arrival of the first exploring and sealing expeditions.

Over the past decade, the intensity and diversity of human activities have continued to increase and for these reasons also sources of contamination are increasing.

Recent studies have further defined the nature of local chemical contamination in Antarctica and the main sources of contamination are now well established: fuel spills, heavy metals, polychlorinated biphenyl (PCB), contamination derived from other persistent contaminants such as polycyclic aromatic hydrocarbons (PAH) and polychlorinated dibenzodioxins (PCDDs) from combustion processes.

Adélie penguins (*Pygoscelis adeliae*), the most numerous species in the area, need ice-free land with a supply of small rocks used to build nests, and although they are very nimble they are unable to climb tall cliffs. Also, they don't like to walk very far over ice to find the open water they need for feeding. They preferably form colonies on moraines. These deposits supply the stones used by Adélie Penguins to build their nests. For this reason a colony of Adélie penguins is present at the end of the moraine deposits of Boulder Clay when the physical conditions permit the presence of this species.

Adelie Cove penguin colony, located on the Northern Foothills, is one of the three breeding sites for Adélie penguin in the Terra Nova Bay area.

Measurements of the size of Adélie penguin colonies of the southern Ross Sea are among the longest biologic time series in the Antarctic.

Baroni et al. [4.30] show as in Terra Nova Bay exist two abandoned site and an active site of Adélie penguins.

Harper et al. [4.31] count in Terra Nova Bay approximately 10,000 pairs of Adélie penguins and they could reasonably represent the penguins colony of Adelie Cove near Boulder Clay site. In more recent works new measurements of the size of Adélie penguin colonies in Victoria Land were recorded [4.32] , and some of them, in the surrounding of Terra Nova Bay, are reported in Table 4.9.

Table 4.9: Mean colony counts of nesting territories along the Victoria Land coast between 1981 and 2012.

Colony	Mean colony count (2012)
Franklin Island West	60,540
Inexpressible Island	24,450
Terra Nova Bay	**11,234**
Wood Bay	1,890
Coulman Island	24,010
Mandible Cirque	16,837
Cape Phillips	3,921
Cape Wheatstone	2,746
Cape Cotter	38,252
Cape Hallett	42,628
Foyn Island	30,494
Possession Island	111,306
Downshire Cliffs	19,617
Cape Adare	227,000

The Northern Foothills are considered an important area for seabirds where skua and Wilson Storm Petrel nests were observed [4.33] despite the fact that today exist just few pairs scattered around the MZS. One can reasonably think that this is due to increased human presence [4.31] [4.34] following the construction of Italian scientific Station since 1986.

The Adelie Cove penguin colony is located 1.8 km from the end of the proposed airstrip of Boulder Clay, on a coastal slope 50-100 m a.s.l. (ASPA n°161) and 8 km south of MZS.

In general population responses of penguins to changing ecosystems can be complex. They have been well described in many scientific papers about, space-temporal variation in climatic variables resulting from phenomena such as long-term climate change, or shorter-term decadal atmospheric variation [4.32] or changes in sea-ice conditions such as concentration, extent and thickness, air temperatures, winds, sea surface temperatures (SST) and precipitation [4.35], or changes in the abundance of their prey and/or structure and function of the marine ecosystem owing to other factors [4.36].

When considering the upcoming construction of airstrip at Boulder Clay the future operations for the track and other human activities (scientific research activities and logistics, including infrastructure construction and support).

Disturbance for aircraft operations on birds has been described in the analysis of “detection-death” scale, [4.37].

The long-term impacts that may be taken into account are noise exposure, particulate emissions, oil spills and increased human presence.

The behaviour of penguins (both adults and juveniles) as a result of the approach of an aircraft has been studied [4.38], but in this regard even more complex environmental factors that may also affect the dynamics of the population should be taken into account [4.39].

During the Italian Antarctic campaign in 2013 reaction tests at noise during the approach of an aircraft were made using the overflight of a L100/30 at low altitude with piecing and output towards the end of the future Boulder Clay runway.

The response resulting from sound measurements and video has been very positive, highlighting a state of apparent calm inside the penguin colony.

Of course the minimum distances overflight of aircraft during operations near the Adelie Cove penguin colony follow the guidelines on aircraft operations near concentration of birds in Antarctica proposed by Harris [4.37].

As far as possible also the recommendation on the conduct of operations, outside of the sensitive breeding seasons will be respected.

The major event of disturbance for the penguin colony can happen when touch and go procedure for safety reasons need to be performed. However, even in this unlikely case, the worst situation, namely that of overflying at low altitude on penguin colony, will be avoided by the need to return the portion in direct line with the axis of the track and then to a vertical distance of slightly less than the limits considered by Harris [4.37].

During the last 2 decades of human activities, particularly construction and transportation, have contributed in substantial manner to the increasing of impact particularly on flora and fauna.

Considering the continuing expansion of human activities in Antarctica, a more effective implementation of a wide range of measures is essential as an effective environmental impact assessments, long-term monitoring, and mitigation measures.

The presence of the Italian Station during the last 25 years has produced inevitable impacts around the area due to the construction and growth of the Base, to the construction of runway on ice, wharf, helicopter site and field camp.

Since 80's PNRA carried out a monitoring program to assess and mitigate possible impacts following the current environmental management regime (primarily Environmental Protocol and CCAMLR).

It is comprehensible to consider the scientific research essential for the understanding of new climatic and environmental challenges, but the value of Antarctica should be weighed against the environmental impact of scientific work and its logistic support [4.40].

In conclusion it is correct to assert that in view of the probable continuing expansion in intensity and diversity of human activities in Antarctica, and having the awareness that the processes that make Terra Nova Bay particularly valuable occur at a spatial scale which is larger than the existing one, it is desirable that management and conservation measures should be applied at a larger scale.

4.3.2. **Flora**

Vegetation of Victoria Land is entirely cryptogamic and vascular plants are absent. The recorded flora comprises 57 lichens, 11 mosses, one liverwort and various species of algae and cyanobacteria [4.41].

Lichens are one of the principal components of Antarctic terrestrial ecosystems, and were studied since the early Antarctic expeditions; their knowledge, however, remained unsatisfactory for a long time, mainly because of a very confused state of their taxonomy. In the last decades lichenological research in Antarctica has experienced a new development.

The recent comprehensive account of lichens of Antarctica and South Georgia by Ovstedal and Lewis Smith [4.42] [4.43] lists a total of 444 taxa. From the whole Antarctic Continent (excluding the Antarctic Peninsula) 92 taxa are reported, many of which having a broad, circum-Antarctic distribution.

At the present state of knowledge, lichen diversity of continental areas seems to be rather low and uniform if compared to the other Antarctic biota, and characterized by a high incidence of both bipolar (widespread in the cold regions of Earth) and endemic species.

Victoria Land supports one of the richest lichen floras within the continental Antarctic with 57 taxa recorded during all previous investigations [4.44] to [4.51]. Other six new species to this region (four of them are also reported for the first time from Antarctica) were added by Smikla [4.52].

A network for monitoring change in the vegetation communities to assess the impact of future climate changes was established in Victoria Land in 2002 and 2003 [4.53] with 19 permanent plots, two of which located in the Boulder Clay area. A description of the project and related network is found in the following Section 4.6.1.

The retrieved information about the presence of lichens in the studied area is present in "victoria", an information system on Antarctic lichens searchable on-line, developed within the PNRA available at *http://dbiodbs.univ.trieste.it/antartide/victoria*. It provides information and identification keys of the 57 lichen species reported by Castello [4.41] from the Terra Nova Bay area.

Flora at Boulder Clay site

The Boulder Clay vegetation includes bryophytee communities dominated by Sarconeurum glaciale, Bryum subrotundifolium and Syntrichia princeps with terricolous and epiphytic lichens such as Lecidella siplei, Caloplaca approximata and Candelariella flava and, in some cases, with Cyanobacteria [4.53] . The epilithic communities colonize the big erratic boulders which are very common throughout all the site and is characterized by macrolichens as well as by crustose epilithic lichens. The macrolichen vegetation accounts for Umbilicaria decussata, Usnea sphacelata, and Pseudephebe minuscula as companion. The crustose lichen community is dominated by Buellia frigida mainly associated to Xanthoria elegans [4.53].

A detailed list of species distribution in 25 sites at Victoria Land, including Boulder Clay, is reported in Table 4.11, taken from the vegetation monitoring of Cannone [4.53].

Among the 49 species listed and the 15 ones found in Boulder Clay site, Caloplaca approximate (orange highlighted) alone appears as peculiar specie of Boulder Clay (red highlighted). Caloplaca approximate is well known bipolar lichen found in circumpolar-Arctic region [4.54], in South Orkney Islands and in Victoria Land, although it should be considered a relatively rare species in Antarctica, according to Castello [4.41].

Floristic composition, expressed as average % coverage of each species on the total vegetation coverage, is reported in the table below, for the two permanent plots of the network located in the Boulder Clay area [4.53].

Table 4.10: Floristic composition expressed as average % in the Boulder Clay area.

SPECIES AT PP10	***%***		***SPECIES AT PP11***	***%***
Bryum subrotundifolium	4.1		Bryum subrotundifolium	0.4
Schistidium antarctici	2.2		Schistidium antarctici	0.01
Physcia caesia	0.06		Pseudephebe minuscula	0.8
Candelariella flava	0.1		Umbilicaria decussata	7.3
Lecidella siplei	0.5		Usnea sphacelata	3.5
Acarospora gwynnii	0.06		Xanthoria elegans	0.03
Buellia frigida	3.4		Lecidella siplei	0.8
Lecidea cancriformis	0.1		Acarospora gwynnii	0.2
			Buellia frigida	6.6
			Lecidea cancriformis	0.08
			Rhizocarpon geographicum	0.01

A specific two days photographic survey, approximately along the path of the proposed facility at Boulder Clay, was also performed on the ground in November 2013 by PNRA personnel with the aim to investigate the presence of mosses and lichens in the part of the location where the construction operations are foreseen to have highest impacts on the ground. A map of the points where species were found (only snow free areas), along with their images are reported in Figure 4.23.

Figure 4.23: Map of the points where species were found at Boulder Clay site (only snow free areas) during a survey in November 2013, along with the taken images of the found species.

	CH	RR	CC	CK	AI	CP	EP	CW	GO	MK	BC	II	CS	SC	TF	LI	PI	SN	CR	GI	KP	FP	DI	MP	FL
Buellia cladocarpiza Lamb																								•	
Buellia darbishirei Lamb																								•	
Buellia frigida Darb.		•	•	•		•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•			
Buellia grimmiae Filson				•									•				•					•			
Buellia lignoides Filson													•												
Buellia pallida Dodge & Baker		•		•					•	•	•														
Buellia papillata (Sommerf.) Tuck.				•			•						•			•		•				•		•	•
Buellia subfrigida May. Inoue								•					•												
Caloplaca approximata (Lynge) Magn.											•														
Caloplaca athallina Darb.				•	•	•											•	•							
Caloplaca citrina (Hoffm.) Th. Fr.		•		•		•			•				•				•			•		•		•	
Caloplaca conversa (Kremp.) Jatta s. lat.					•								•												
Caloplaca cf *frigida*						•																			
Candelaria murrayi Poelt				•													•	•						•	
Candelariella flava (Dodge & Baker) Castello & Nimis	•	•	•	•	•	•	•	•	•		•				•	•	•	•		•		•	•	•	
Candelariella vitellina (Ehrh.) Müll. Arg.				•												•	•	•					•	•	
Carbonea vorticosa (Flörke) Hertel													•												
Huea sp. Dodge & Baker		•																							
Lecanora expectans Darb.			•	•	•	•	•		•		•						•	•		•		•		•	
Lecanora fuscobrunnea Dodge & Baker					•	•	•		•	•			•	•			•								
Lecanora aff *geophyla* (Th. Fr.) Poelt					•		•						•												
Lecanora mons nivis Darb.							•			•															
Lecanora aff *orosthea* (Ach.)Ach.						•		•	•	•															
Lecanora physciella (Darb.) Hertel		•	•							•								•							
Lecidea andersonii Filson																						•			
Lecidea cancriformis Dodge & Baker						•	•		•	•	•		•	•	•	•	•					•			
Lecidella siplei (Dodge & Baker) May. Inoue				•	•	•	•		•	•	•		•		•	•	•	•	•	•	•	•		•	
Leproloma cacuminum (A. Massal.) J.R. Laundon					•		•		•			•	•			•	•	•		•	•	•	•		•
Physcia caesia (Hoffm.) Fürnr.		•	•	•	•	•	•		•		•	•			•			•		•	•	•		•	
Pleopsidium chlorophannum (Wahlenb.) Zopf						•			•	•	•		•		•										
Pseudephebe minuscula (Nyl. ex Arnold) Brodo & Hawksw.		•		•					•		•		•	•	•	•	•	•				•			
Rhizocarpon adarense (Darb.) Lamb													•												
Rhizocarpon geminatum Körb.		•		•					•													•			
Rhizocarpon geographicum (L.) DC.										•				•	•										
Rhizoplaca cf *mcleanii*		•			•																				
Rhizoplaca melanophthalma (Ram.) Leuckert & Poelt		•	•	•	•	•	•		•								•	•			•	•			
cf *Rhizoplaca mcleanii* /*R.* sp. 1										•															
Rinodina sp. 1							•																		
Rinodina olivaceobrunnea Dodge & Baker	•												•				•					•			
Tephromela atra (Huds.) Hafellner ex Kalb						•																			
Umbilicaria aprina Nyl.							•		•		•										•	•			
Umbilicaria decussata (Vill.) Zahlbr.		•	•	•	•	•	•		•	•	•		•		•			•				•			
Umbilicaria rufidula (Hue) Filson		•																							
Usnea antarctica Du Rietz				•	•						•						•	•							
Usnea sphacelata R. Br.		•	•	•	•	•			•							•	•	•							
Xanthoria elegans (Link) Th. Fr.		•	•	•	•	•	•		•		•	•			•	•	•	•		•	•	•			
Xanthoria mawsonii Dodge	•	•	•	•	•	•	•		•								•	•		•		•			
ALGAE and CYANOBACTERIA																									
Prasiola crispa (Lightfoot) Menegh.	•		•	•		•	•										•	•		•			•		
Nostoc sp.																									•
Cyanobacteria	•			•	•		•		•		•						•		•	•		•	•		

Legend: CH = Cape Hallett, RR = Redcastle Ridge, CC = Crater Cirque, CK = Cape King, AI = Apostrophe Island, CP = Cape Phillips, EP = Edmonson Point, CW = Cape Washington, GO = Gondwana, MK = Mount Keinath, BC = Boulder Clay, II = Inexpressible Island, CS = Cape Sastrugi, SC = Simpson Crags, TF = Tarn Flat, LI = Lamplugh Island, PI = Prior Island, SN = Starr Nunatak, CR = Cape Ross, GI = Gregory Island, KP = Kar Plateau, FP = Finger Point,

Table 4.11: Species distribution from Cannone [4.53].

Flora registered at the alternative site

The lichens presence at Campo Antenne alternative site is prevalently around relict penguin colonies and skua nests.

A list of recorded species (17) at Icarus Camp (a location in the northeast side of Campo Antenne, see Figure 4.24) are reported in Table 4.12 [4.52].

Table 4.12: Recovered taxa at Icarus Camp area.

Acarospora gwynnii
Amandinea coniops
Buellia frigida
Buellia grimmiae
Caloplaca athallina
Caloplaca citrina
Caloplaca tominii
Candelariella flava
Lecanora expectans
Lecanora fuscobrunnea
Lecidella siplei
Lepraria alpina
Physcia caesia
Pseudephebe
Usnea antarctica
Xanthomendoza borealis
Xanthoria elegans

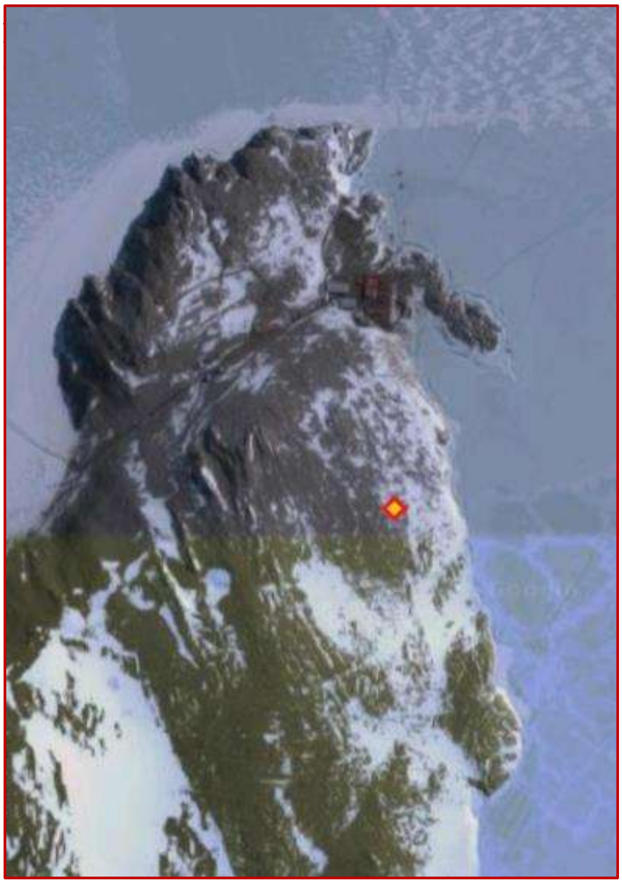

Figure 4.24: The Icarus Camp location inside the *Campo Antenne* area

4.4. Antarctic protected areas

Up to 1991 the Antarctic Consultative Parties (ATCPs) have adopted five categories of protected areas :

- Specially protected areas (SPAs);
- Sites of Special Scientific Interest (SSSIs)
- Historic Sites and Monuments (HSMs)
- Multiple-use Planning areas (MPAs)

Annex V of the Protocol of Environmental Protection to the Antarctic Treaty rationalizes the existing protected area designation, and distinguishes more clearly between protected sites and managing sites. The two new categories have been established:

- Antarctic Specially Protected areas (ASPAs);
- Antarctic Specially Managed areas (ASMAs);

Entry into an ASPA is prohibited except in accordance with a permit as specified in the Managing Plan. Entry into an ASMA does not require permits, but activities are directed by a code of conduct set out in the Management plan.

4.4.1. **ASPA n°161**

The proposed runway at Boulder Clay is located 1,600 m far from the Antarctic Specially Protected area (ASPA) n°161. The alternative site, Campo Antenne, is located 500 m far from the beginning of ASPA n°161. This area comprises a coastal marine area encompassing 29.4 km^2 between Adelie Cove and Icarus Camp. The map of Figure 4.25 shows the marine ASPA of Terra Nova Bay and the penguin colony at Adelie Cove. The Area is confined to a narrow strip of waters extending approximately 9.4 km in length immediately to the south of MZS and up to a maximum of 7 km from the shore. No marine resource harvesting has been, is currently, or is planned to be, conducted within the Area, nor in the immediate surrounding vicinity. The site typically remains ice-free in summer, which is rare for coastal areas in the Ross Sea region, making it an ideal and accessible site for research into the near-shore benthic communities of the region.

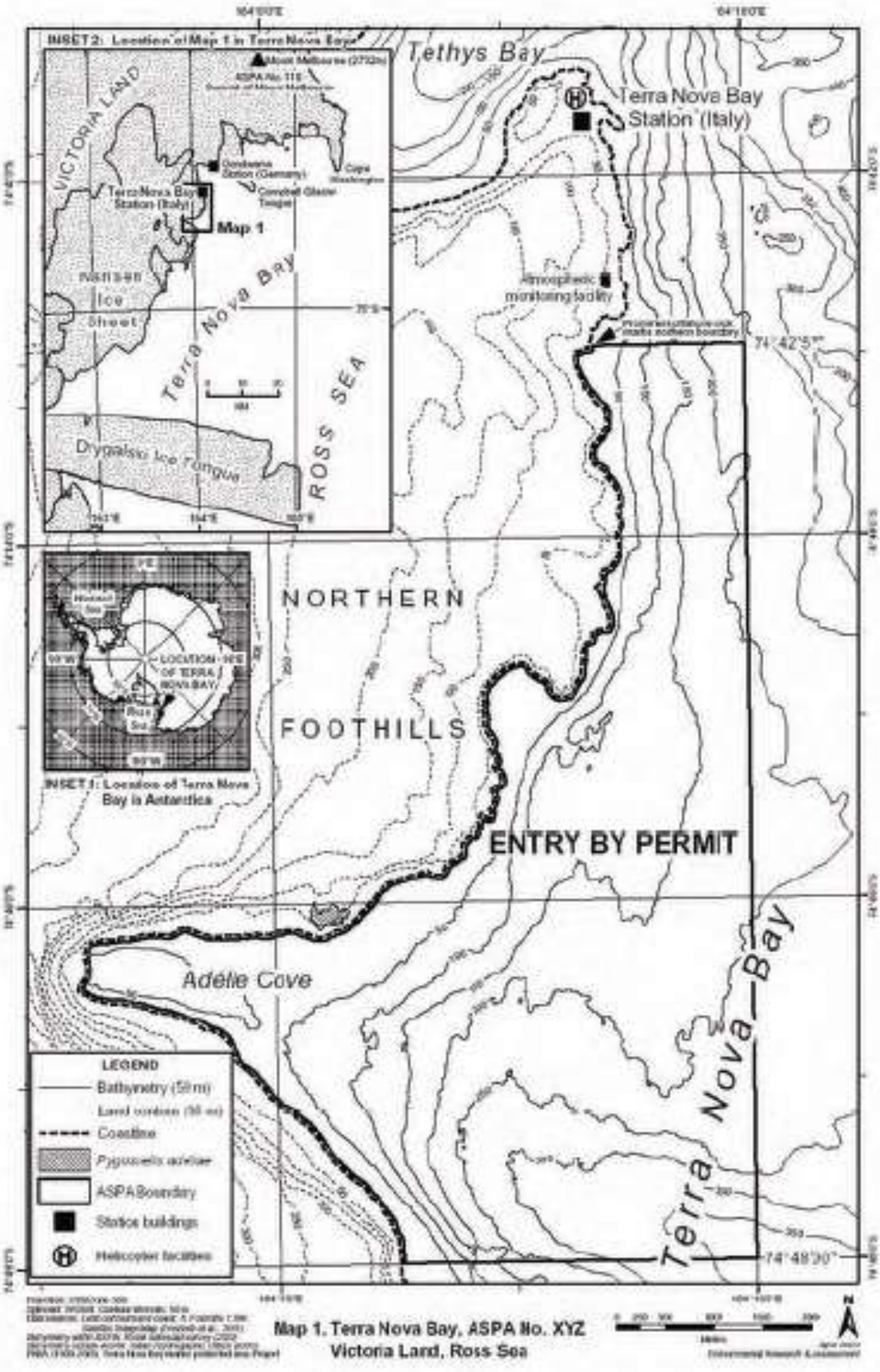

Figure 4.25: Map of Terra Nova Bay ASPA n° 161.

4.5. Air quality

The presence of synthetic and toxic chemicals in the Antarctic ecosystems is partially associated with the activities of the scientific stations; nevertheless, the main source of pollutants for this remote continent is the atmospheric transport. Volatile or semi-volatile contaminants may be transported to the remote Antarctic continent mainly by air. Persistent organic pollutants (POPs) include several groups of chemicals with similar structures and physical–chemical properties that elicit same toxic effects. All these chemicals are synthetic, ubiquitous, persistent, and hydrophobic, show long-range transport potency and can be accumulated by organisms.

The POP accumulation and distribution in the Terra Nova Bay trophic webs have been studied since the 90's and results were published in peer reviewed international scientific journals [4.55] to [4.61]. Organisms living in the marine ecosystems of the Terra Nova Bay area have been studied during a time span of twenty-five years, and some speculations can be done on their health status from an ecotoxicological point of view. For instance, the profile of PCB contamination in these organisms is often different from that of other parts of the world including other Antarctic regions [4.60]. Ice melting is reported as one of the major causes of contamination in polar regions as contaminants trapped in the ice can be released in the seawater during summer. Because ice melting occurs at different times in different sites, levels detected in planktonic organisms may vary a lot depending on the time of collection.

The coasts and seawater of the Terra Nova Bay area are populated by penguins and other flying seabirds (skuas, petrels) and they have been monitored during the last twenty years as these species are at risk, being top predators. The highest levels of chemicals were detected in migrating seabirds (South polar skua) > sub-Antarctic species (snow petrel) > Antarctic species (penguins), suggesting the bioaccumulation in polluted areas for those birds overwintering in northern ranges [4.61].

Research stations may be sources of local contamination and data related to Mario Zucchelli (formerly Terra Nova Bay) Station revealed that these scientific base had a low impact on organisms in the 90's [4.60]. The release of low amounts of POPs into the surrounding environments is a normal consequence of scientific stations. The contaminant accumulation and the lipid characterization were studied in many species of the ASPA n°161, located in the area of MZS at Terra Nova Bay and levels were low suggesting that their presence in this protected marine area is due to global transport from other parts of the planet, rather than local sources.

Monitoring of the air particulate (PM10) has been performed during the last 25 year at Campo Icaro near site 1 (Campo Antenne) and at MZS. The main heavy metals analysed have been: Cd, Cr, Ni, Pb, V, Co, Mn.

Polycyclic Aromatic Hydrocarbons (PAH) (see Table 4.13) have, indeed, been taken in account to evaluate organic pollution related to combustion processes. Relative concentration of PAH and metals in the atmospheric particulate could be connected to the different sources of contamination present at Mario Zucchelli Station (3 Km north respect to Icaro Camp):

- power unit system;
- vehicles and aircraft;
- incinerator;
- heating system.

Table 4.13: Considered PAH for the monitoring survey.

Polycyclic Aromatic Hydrocarbons (PAH)	**Name**
Fenantrene	PHE
Antracene	AN
Fluorantene	FA
Pirene	PYR
BNT	BNT
Benzo(ghi)fenantrene	BghiPHE
CPP	CPP
Benzo(a) antracene	BaA
Crisene	CHR
Benzo(b+j)fluorantene	BbF+BjF
Benzo(k9)fluorantene	BKF
Benzo(e)pirene	BeP
Benzo(a)pirene	BaP
IndenoPirene	IP
Dibenzo(a,h)antracene	DBahA
Benzo(ghi)perilene	BghiP

The medium values, at Icaro Camp, particularly of PAH, and partially of Fenantrene, Antracene and Fluorantene show always values in an order of magnitude lower than the Italian Law for air contamination regulation and often are under detection levels.

Measured pollution concentrations of IPA and heavy metals generally remain similar year by year, but depending from wind speed and direction, light differences were observed in different years and during the same season too.

At MZS the variability and the level of IPA and heavy metal concentration results much more higher than Icaro site, because of the proximity to the sources but always plenty below the Italian regulation values.

Regarding the Boulder Clay monitoring area, possibly at the beginning of the runway operation construction, it should be useful to install a sampler of air particulate to study, year by year, the possible contribution of the runway to the atmospheric environment.

4.6. Research activities

4.6.1. Permafrost and active layer study at Boulder Clay

Boulder Clay is close to an automatic monitoring station of permafrost thermal regime and presents within injection cones consisting mostly of gravel and pebbles. The station is located at 205 m a.s.l., it shares and records time values, incident solar radiation, air temperature at 4 m height on the ground and soil temperature at six different depths up to 360 cm.

Active layer measurements were performed by annual probing of the maximum thickness of seasonal thaw within a 100 m x 100 m grid with each of the 121 grid points marked in the field by wooden stakes, according to the CALM protocol [4.22]. Ground temperatures at Boulder Clay were monitored within boreholes from 2 cm to 3.6 m. Climatic parameters (e.g. air temperature, solar radiation) were recorded simultaneously [4.22]. Ground temperature was recorded at depths of 2, 30, 60, 160, 260 and 360 cm. At Boulder Clay the upper two thermistors were installed directly in the ground, parallel to the surface, while the deepest ones were installed in boreholes cased with plastic tubing and insulated from each other with clay packs.

The project is still in progress and it is important to monitor the area.

4.6.2. Research activities in ASPA n°161

In the face of the Northern Foothills, along the coast is the marine protected area of Adelie Cove (ASPA n°161). It submits for 7 km offshore and 9 km along the coast towards the Mario Zucchelli Station. ASPA n°161 is an important littoral area for well-established and long-term scientific investigations.

The shelf area of Terra Nova Bay is one of the few temporary ice free areas in the Ross Sea and presents peculiar ecological features, showing a higher productivity in biomass of phytoplankton, particulate matter and abundance in zooplankton compared to other areas of the Victoria Land coast, and hosting a benthic community characterized by a remarkable species richness.

Research activities were carried out in the area during the austral summers since the nineties.

Human disturbances can be induced by a variety of research activities, but the impact on lichens and mosses is almost negligible given their locations and densities of distribution. In addition, the impact on skua and Adélie penguin habitats will be indirect and minor during the operation of the runway because the colonies are located at a safe distance from the proposed site.

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5. Identification and Prediction of Environmental Impact, Assessment and Mitigation Measures of the Proposed Activities

The runway construction and aircraft operation include activities that impact directly or indirectly on the environment.

An Environmental Impact Assessment comprises three major phases: analysis of proposed activities and identification of the impacts on the current environment, prediction and assessment of the impacts, and suggestion for mitigation measures and following monitoring and verification. This draft CEE for the construction and operation of a gravel runway at Boulder Clay, Victoria Land, Antarctica, is prepared according to this process.

5.1. Environmental impact identification, prediction and assessment

The direct environmental impact on ice, snow, air, ecosystem and other environmental receptors will be caused by the activities as construction and operation of the gravel runway, emission of exhausted gas and oil spilling, waste production, noise from vehicles and personnel and influence from the interference of visitors.

5.1.1. Estimation on fuel consumption

Fuels to be used during the construction and operation at the station include:

- Aviation Kerosene JA1 (helicopter, aircraft, and diesel vehicles)
- Lubricating oil and hydraulic oil (mechanical equipment and vehicles)

The atmospheric emission during the construction period will mainly arise from the consumption of fuels used for vehicle's operation and power supply.

Aircrafts and ship emissions are here taken in account, but they will be spread over a wide area en route to and within Antarctica. The emissions from these sources will be rapidly dispersed and will not affect ambient air quality, but will contribute to the cumulative impact of operations in Antarctica.

Fuel consumption for construction

The construction will last four years and the fuel consumption will be due to: 1) power generation, 2) operating machines (excavator, wheel loader, tracked loader, dozer, dumper, grader, roller compactor), 3) motor vehicles.

During construction the use of the operating machines won't be constant in time, but it will depend on the working phase. Fuel consumption will vary accordingly.

Table 5.1 reports the fuel consumption per construction phase.

Source	Fuel type	Phase 1 (ton)	Phase 2 (ton)	Phase 3 (ton)	Phase 4 (ton)	Apron (ton)	Total fuel consumption (ton)
Generator 68 kW (used for camps and facilities)	JA1 + additive	9	8	17	5	7	**46**
Costruction equipment and vehicles	JA1 + additive	93	76	177	48	72	**482**

Table 5.1: Estimated fuel consumption required during construction of the runway (tons).

Fuel consumption for operation

The designed time-life of the runway is 20 years. The average traffic per season is foreseen in 30 flights. The aircraft fuel flow rate is 2,600 l/h. The Jet A-1 (JA1) density is 0.8 kg/litre.

Aircraft exhausts will be spread on a wide area, this dilution will reduce the emission impact on the environment, keeping the hazardous combustion products (CO, CO_2, NO_x, SO_2, PM10) some order of magnitude under Italian guidelines

The following table presents the total amount of fuel consumed for a turnaround flight, but the impact due to the aircraft's exhausted at the Boulder Clay area, in reality is reduced only in 10 km from the mentioned area along approach and take off/climbing ways. The overall time for all these phases can be considered an half hour.

By means of this data we can calculate the fuel consumption of the operation. Other fuel consumption, as vehicles or the terminal power generator, are negligible compared to the aircraft fuel consumption.

Source	Fuel type	Fuel consumption per flight (ton)	Total fuel consumption per season (ton)
Aircraft	JA1	29	**870**
Generators 68 kW + 28 kW (used for terminal and facilities)	JA1 + additives	0.10	**3**
Vehicles	JA1 + additives	0.2	**6**

Table 5.2: Estimated fuel consumption required during operation of the gravel runway (tons).

Assessment of the atmospheric emissions impact

Impact on air will depend on several factors as the weather condition, and the time for fuel transport or construction material. The considered window time of construction will be 4 austral summer seasons. The most part of construction material will be taken from the ground around, worked with riddles and moved by mechanical shovels and trucks. If necessary, part of the material will be obtained blasting granite bed rock available in the nearby area. During construction, there will be more human and vehicle activities and the corresponding atmospheric emission will be higher than the operational routine.

Substances derived from fuel combustion are: carbon dioxide, sulphur dioxide, nitrogen oxide and particulates etc. These substances will cause some impact on air quality. However, generally speaking, the impact is small. Emissions during the construction are the more environmental costly, while, instead, during operation phase, only a small part of the aircraft combusted fuel can reach the soil. Therefore, the emitted pollutants will spread to a very low concentration condition The main natural mitigation factor is the wind that will mainly spread in east direction the exhausts, avoiding in maximal part the penguin (and skua) colony direction. Sporadic likens in the area could be used as test to evaluate the accumulation respect time of organic pollutants and metals.

The estimated impact includes those on the snow and ice surface of the runway area. This kind of pollution may affect part of the scientific value of the area. The particulates may exist in the snow and ice for a long time.

The pollutants will accumulate, and some emitted gas will affect the atmospheric environment of the area. CO will stay in the air for about 1 month, and will finally change to CO_2.

CO_2 is the product of maximum quantity in the combustion process. It will not directly affect human's health. However, as a greenhouse gas it will obstruct heat spreading from the earth into the atmosphere, thus having the possibility of warming up the earth.

Estimated atmospheric emissions in the construction stage

The construction stage will cover four austral summers, and each construction stage will last for approximately 3.5 months. During the austral summers from 2016 through 2019 it is estimated that each year 75-160 tons of JA1 fuel will be needed for construction equipment. The total annual emissions of various pollutants in each year during the construction will be as shown in Table 5.3.

Source	Fuel Type	Phase 1 (ton)	Phase 2 (ton)	Phase 3 (ton)	Phase 4 (ton)	Apron (ton)	Emission Pollutants	Emission factor (ton/ton)	1°year Emission (ton)	2°year Emission (ton)	3°year Emission (ton)	4°year Emission (ton)	Apron (ton)	Tot (ton)
Generator (68 kW)	JA1 + additives	9	8	17	5	7	**CO**	0.009	0.008	0.017	0.005	0.007	0.047	**0.009**
							NO_x	0.1323	0.1176	0.2499	0.0735	0.1029	0.6909	**0.1323**
							SO_2	0.0081	0.0072	0.0153	0.0045	0.0063	0.0423	**0.0081**
							PM10	0.0117	0.0104	0.0221	0.0065	0.0091	0.0611	**0.0117**
							CO_2	5.526	4.912	10.438	3.07	4.298	28.858	**5.526**
Costruction equipment and vehicles	JA1 + additives	93	76	177	48	72	**CO**	0.0010	0.093	0.076	0.177	0.048	0.072	**0.466**
							NO_x	0.0147	1.3671	1.1172	2.6019	0.7056	1.0584	**6.8502**
							SO_2	0.0009	0.0837	0.0684	0.1593	0.0432	0.0648	**0.4194**
							PM10	0.0013	0.1209	0.0988	0.2301	0.0624	0.0936	**0.6058**
							CO_2	0.6140	57.102	46.664	108.678	29.472	44.208	**286.124**

Table 5.3: Estimated total annual emission during construction of the gravel runway (tons).

Estimated atmospheric emission in the operation stage

During the operation stage there will be an almost constant fuel consumption and, then, constant emission. Table 5.4 shows these data.

Source	Fuel Type	yearly consumption (ton)	Emission Pollutants	Emission factor(ton/ton)	yearly emission (ton)
Aircraft	JA1	870	**CO**	0.0113*	**9.831**
			NO_x	0.0292*	**25.404**
			SO_2	0.0008*	**0.696**
			PM10	0.0011	**0.957**
			CO_2	0.859	**747.33**

Table 5.4: Estimated total annual emission (30 flight/year) during operation of the gravel runway (tons) *[5.1].

5.1.2. Evaluation of noise emission

Noise will be generated from landing, taxing, take off operation of the aircraft and during the construction activities from the vehicles involved in the embankment preparation. Levels of noise during the construction of the embankment has been estimated lower than the aircraft noise impact. In this optic the worst condition has been simulated [5.2] and reported in Figure 5.1 and it considers the following boundary conditions (Table 5.5).

The noise level evaluated in correspondence of the Adelie Cove colony does not exceed 40 dB(A) overall the natural noise level evaluated in the colony in 20 dB at 125 Hz frequency.

Boundary condition	
Source noise	Hercules L100/30
Noise pressure (dB(A))	100 (measured at 50 m.) [5.3]
Simulation frequency (Hz)	125
Wind direction (°)	270° (West)
Wind speed (knots)	10
Temperature (°C)	-5
Relative humidity (RH %)	50
Natural noise (dB(A))	20

Table 5.5: Boundary condition applied for noise level prediction during the aircraft take off procedure.

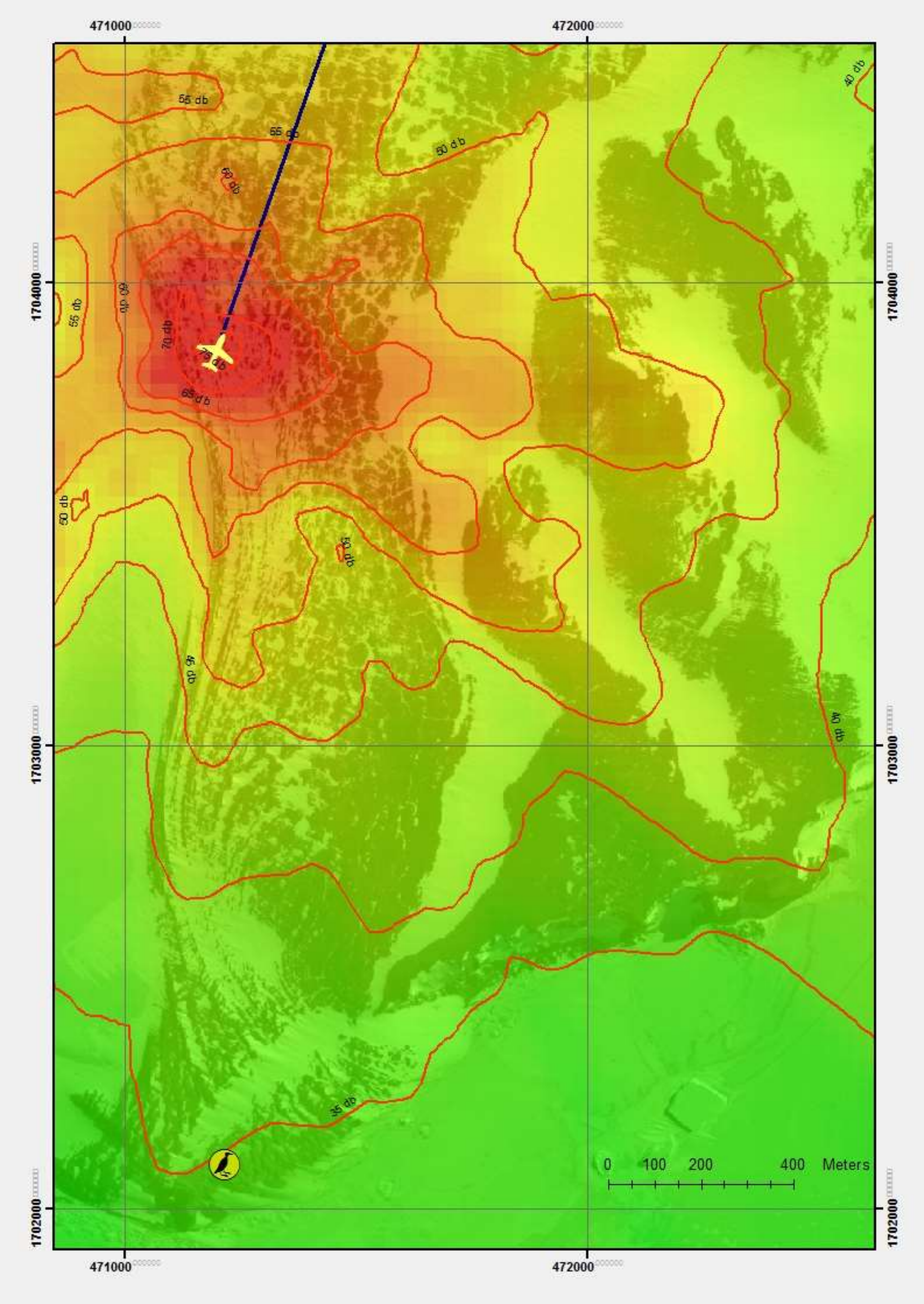

Figure 5.1: Estimated noise level over natural noise condition (20 dB(A)), at 125 Hz, during full engine power of Hercules L100/30, in take-off procedure.

5.1.3. **Impact on snow and ice**

Since most construction of the runway will be set up on the ground without snow in summer, the environmental impact on snow and ice resulting from the construction will be limited.

The exhausted gas arising from all the activities could in any case reach the snow area. However, it is in a small amount and only due to the stable west-east wind direction, blowing in the direction of the open sea.

5.1.4. **Impact on ecosystem**

Impact on flora

The construction of the runway will impact significantly exclusively on about 0.15 km^2 of the Boulder Clay moraine interested by the embankment construction and not more than 0.25 km^2 from few quarries highlighted in Figure 2.29.

The flora, most of which are lichens and few mosses, is sporadic with a low distribution density and a coverage degree of less than 5% in average nearby the proposed site of the runways and quarries [4.23]. In any case the impact has been evaluated in term of medium/high level of disturbance, because they are expected to be partially destroyed during the construction of the runway, especially during earthmoving work. An in-depth study and assessment on the potential impact on the flora is being prepared and measure of mitigation will be sought for and implemented.

Impact on Adélie penguins and skuas

The construction and operation of the proposed runway may slightly affect the surrounding ecosystem. Main disturbance sources foreseen in this study are noise and pollution generated during construction and operation phases, but both have been evaluated only to impact marginally on the local fauna.

The air pollution generated from construction and operation of the runway has been estimated of minor impact on the ecosystem, but to assess a real time evaluation of the air quality, an air sampler will be installed considering the prevalent wind direction respect the site.

The colony of Adélie penguins and the skuas located at Adelie Cove will not be directly disturbed by the construction and operation of the runway but indirect impacts are expected. The shortest distance between the colony and the site is approximately 1.8 km and the difference in elevation between colony and runway is about 70 meters.

A noise generated level has been simulated by a model, for the worst condition, consisting in the aircraft take-off phase, but less than 35 dB(A) has been expected in the colony area.

The heavy equipment operation during construction will produce significantly less noise and will be located most of the time at a higher distance (4-5km), thus this phase will not provide significant impact on the colony.

The approach and the take-off ways are defined in consideration of CEP guidelines for operation of aircraft near concentration of birds in Antarctica, reported in Annex to Resolution 2 (2004):

- Flight altitude on bird colonies higher than 2,000 ft;
- Landing site with a linear distance greater than ½ nautical mile;
- No planned passing over wild life concentration areas;
- Maintaining a vertical separation from the coastline of 2,000 ft where possible.

In the map reported in Figure 5.2, planned flight routes of operative landing/taking off (green line) and of emergency missed approach instrumental procedure (red line) are reported, over layered with bird colonies and ASPA 161/173 borders. The most close point interested by the operative landing of the aircraft is the South end of the runway, placed 1,8 km far from the Adelie Cove community.

In exceptional event of missed approach non-instrumental procedure, for safety reasons the aircraft will overflight he colony at an altitude higher than 600 ft. A statistical comparison of the casuistry recorded for the fast ice runway used in early stage of the summer season, from 1989 to present, at MZS, has been performed, considering the similar orientation, position and weather condition of the 2 strips. In a conservative amount of 200 landing performed in the fast ice runway in 25 years, the missed approach procedure has never been applied.

In the light of the above, this particular emergency event is likely to happen less than once every 5 years assuming 30 flights per season.

However a monitoring program on penguins and skuas population, for assessing the effective stress degree caused by the runway construction and operation activities, will be implemented and immediate measures to mitigate the effects will be accordingly taken.

Impact on other wildlife species

Leopard Seals are rarely found swimming throughout the Adelie Cove bay, but no seal colony is present in the area. The impact on seals is likely considered indirect, thus not significant.

Impact on ASPA n°161

The ASPA n°161 coastal marine area does not require strict flying rules according to the CEP Guidelines for marine areas.

The approach and take off paths do not cross the ASPA borders. Passing over the ASPA will only be considered for safety reasons during missed approach procedure (instrumental or non-instrumental).

An air quality monitoring will be activated, with the installation of an air sampler close to the coast pertinent to the ASPA, according to the runway position and the prevalent winds direction.

Impact on ASPA n°173

The ASPA n°173 consists of coastal marine and terrestrial area of scientific importance for the Emperor Penguin Colony at Cape Washington. The overflight of part of this ASPA is permitted over 2,000 ft, according to CEP guidelines. The planned path for aircrafts coming from Christchurch does not over flight any part of the ASPA (transit through ZUKKY point). Otherwise aircrafts coming from McMurdo, Antarctica (transiting through KALVA point), will fly over the extreme West of ASPA n°173, in an non restricted area close to Campbell Glacier, at an altitude over 2,000 ft. ZUKKY and KALVA access points are nowadays used for intercontinental flights with Hercules L100/30, landing on fast ice runway close to MZS. No impact related to air operations was registered on the area, so no direct neither indirect impact is expected on this ASPA for the gravel runway air operations, according to the altitude and the position of the planned flight paths.

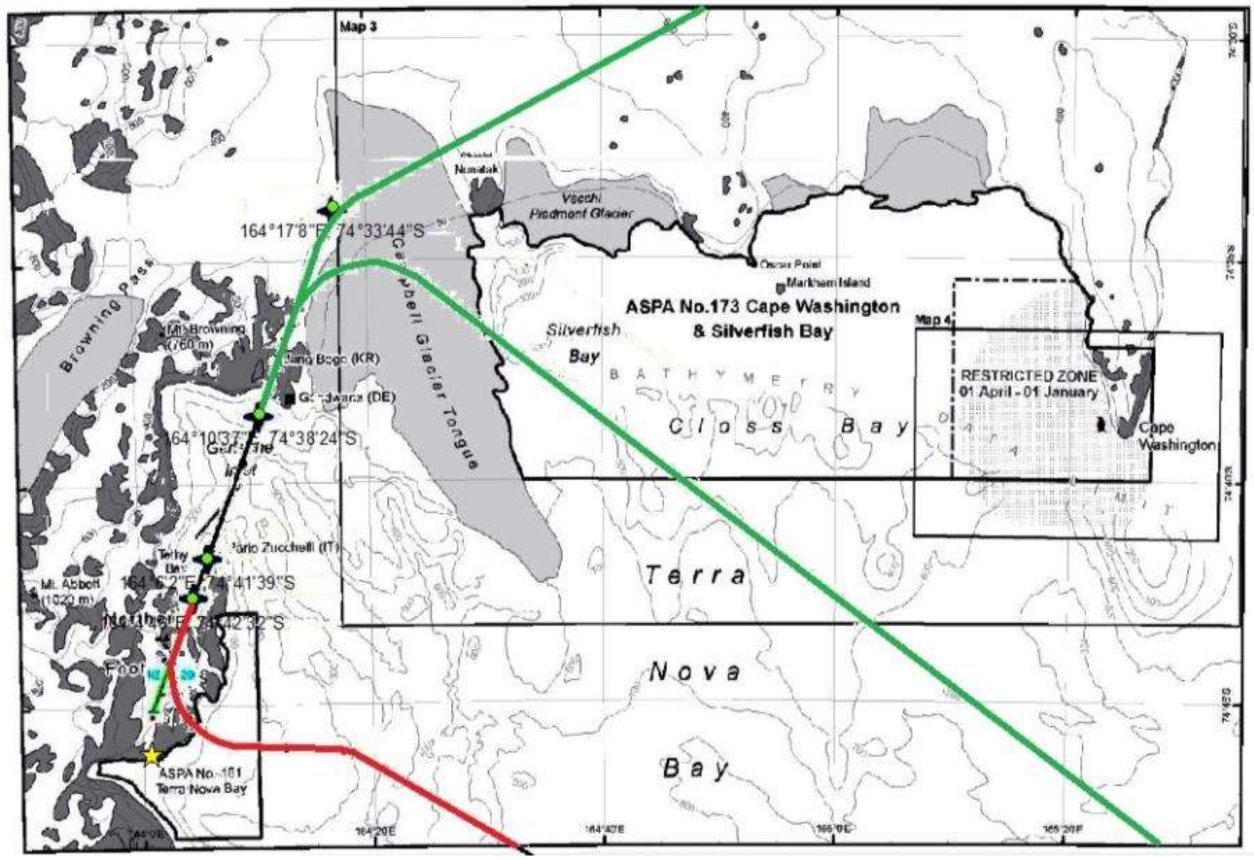

Figure 5.2: The area around MZS with the planned flight routes of operative landing/taking off and of emergency missed approach (green and red lines respectively), over layered with bird colonies (yellow star) and ASPA 161/173 borders (black lines).

5.1.5. **Impact on wilderness and aesthetic values**

The proposed site is an area where there are exposed bedrock outcrops and glacial moraines. The horizontal glacial sedimentary layers develop relatively flat topography, and the construction of buildings and routes may nevertheless result in, though minor and local, a visual disturbance to the natural landscape of the region.

The runway is planned to have a minimum impact on the landscape and to maintain the aesthetics of the region. Of course part of the hill situated on left in the runway direction towards south will be levelled. The buildings and facilities at the runway will be contained within the proposed area to reduce the influence on the local scenery as much as possible. Tracked vehicles will only be used on the designated routes to minimize the disturbances to the land surface.

The use of vehicles and mechanical equipment will be done through a new road (just in part planned in a previous environmental evaluation (BRASILIA 2014). The final part of the collecting road will be done correspondently with the runway and it is considered to have only transitory and minor impact.

The runway will implement the Waste Management Plan of the Mario Zucchelli Station to treat the produced waste and bring it out of Antarctica. In addition, the Environmental Management Plan will also be implemented to reduce the negative impact on the local environment.

5.1.6. **Impact of solid waste collection and disposal**

During the activity of the runway construction and operation, a certain amount of solid waste will be produced.

According to the definition of Annex III (Paragraph 8) of the Protocol on Environmental Protection to the Antarctic Treaty, solid waste is classified into the following categories:

- Recoverable garbage (metal, plastic, paper, wood and glass, etc.);
- Organic waste (mainly from foodstuff);
- Hazardous waste (batteries, oil sludge etc.);
- Unclassifiable garbage;
- Fuel drums.

Solid waste produced in the construction stage

In the construction stage of the runway, and in particular during the operation a considerable amount of no dangerous solid waste will be produced, which will mainly be packing materials and building materials, including metal, plastics, glass and wood, etc. Depending on many factors, an estimate amount of wastes possibly produced in the construction and operation stage of the runway at the moment it is very difficult to foresee.

5.1.7. **Risk assessment of oil spill**

Various fuels and lubricants will be used during the construction and operation of the runway. Fuel and oil spills may occur during the processes of construction and equipment, and fuel transfer procedures between transit and fuel tanks. Fuel spills (JA1 or gasoline spilt) may also occur during refuelling aircraft, vehicles and generators cracked fuel pipelines and damaged fuel tanks are also potential sources of fuel spills, but the possibility of leakage is very limited.

Fuel or oil spills can seriously affect the environment. Spills, if occur in the station, are expected to be confined at the site. Besides, most of the fuel used is relatively volatile and expected to vaporize quickly in case of spills, but a waxy residue may remain.

However, fuel spills may permeate through rock cracks or pore spaces of moraines.

Furthermore, inland fuel spills may contaminate the soil and also adversely affect the flora living in the cracks between rocks.

5.2. Methodology

The following criteria are used to identify the character of the impact and to make the qualitative and quantitative assessment on the potential environmental impact.

A matrix is used to summarize the environmental impact of construction and operation of the runway and it is based on the reference reported below:

Sector

It means the character of the impact caused by the activities on potential receptors.

Sources

It is used for identification of the impact possibly associated with the activities and it is in compliance with the Environmental Protocol.

Description of potential impact

It is qualitatively classified as the direct impact, indirect impact and cumulative impact. Specific descriptions of these three categories of impact are shown in Article 3 of Annex 1 of the Protocol Environmental Protection to the Antarctic Treaty.

Evaluation of impact

It is classified in relation to extent, duration, intensity, probability.

Extent

It means affected geographical areas ranging from local, regional, Antarctic to global areas.

Duration

It is classified as "very short term" (minutes to days), "short" (weeks to months),"medium" (years), "long" (decades), "permanent" and "unknown". There may be a lag time between the occurrence of the result and the time of the impact.

Intensity

The general impact level is assessed at different degrees (low, medium and high). Low degree means that there is only small effect on the natural function or process, and this effect is reversible; medium degree means that there is an effect on the natural function or process, but the process is not affected by a long-term change and this influence is reversible; high degree means there is a long-term or cumulative effect on the natural function or process, and such impact is probably irreversible.

Probability

The possibility of impact is described at different extents like low, medium, high, corresponding respectively to unlikely, likely, certain.

Mitigation measures

Mitigation and prevention measures are considered to limit the possible impact in the different matrices caused by different sources.

5.2.1. **Impact matrices**

According to the criteria mentioned above and the mitigation measures, the table of impact matrix which summarizes the environmental impact of the construction and operation activities is prepared. The output and the resulting environmental impact of each activity are identified. Based on the references given in Methodology (Section 5.2), the extent, duration, intensity, probability and significance of the impact are then ranked in Table 5.6.

Table 5.6: Impact matrices				
Sector	Sources	Description of potential impacts	Evaluation of impact	Mitigation
Air				
Emission to air	Use of kerosene or JA1 for aircraft and vehicles releases combustion gases.	Combustion gases released into the atmosphere can contribute to the greenhouse effect both directly and indirectly. Air quality in general may be affected by releasing combustion compounds into the atmosphere. This fact could affect atmospheric research in the region. The frequency of provided flights will be low (8/month for 4 month/year) so the expected impact will be restrained.	Extent: M Duration: L Intensity: M Probability: H	Emissions are inevitable but will be minimized by well planned logistics to reduce flights. Well maintained vehicles will be used. High energy efficient fuel will be used The site will be monitored and the flight will be managed to limit the impacts.
Soil/ice				
Accidental oil spill	Fuel and oil spills may occur during aircraft refuelling and fuel transfer procedures between transit and fuel tanks.	Fuel spills may permeate through rock cracks or pore spaces of moraines. Fuel spills may contaminate the soil and also adversely affect the flora living in the cracks between rocks and the surrounding fauna.	Extent: L Duration: M Intensity: M Probability: L	To prevent fuel spills, fuel reservoirs will be double-skinned and posed on confined structures made of impermeable layer and concrete and with adequate capacity. Suitable absorbent mats will be used to underlay the pipelines. Fuel pipelines for generators will be designed double-skinned to minimize the possibility of oil leakage Oil spill contingency plans and equipment and training (cf. aircraft requirements), due care and attention, use of appropriate spill prevention material when refueling, reinforced by education and training.

Table 5.6: Impact matrices (continue)				
Flora				
Emission to air	Use of kerosene or JA1 for aircraft and vehicles releases combustion gases. Take-off and landing, can raise dust	Uptake of combustion products may in the long run inhibit growth and reproduction in plants. Sensitivity in plants may vary, and changes in species composition may occur. It is expected that the limited exposure to output will hinder any significant impact.	Extent: H Duration: L Intensity: L Probability: H	Use of "clean" fuel as far as possible to prevent gaseous emissions
Fauna				
Emission to air	Use of kerosene or JA1 for aircraft and vehicles releases combustion gases. Take-off and landing, can raise dust	Ingestion through food not likely due to marine diet. Low Inhalation due to distance from source. Exposure could in the long run affect respiratory system and other vital functions. It is expected that the limited exposure and the adequate prevention measures will hinder any significant impact.	Extent: L Duration: L Intensity: M Probability: L	Coordination of flight to ensure as few as possible flights are conducted Use of "clean" fuel as far as possible to prevent gaseous emissions The site will be monitored and the operation of flights will be adequately managed.
Noise				
		Aircraft operations and the produced noise have the potential to disturb and to impact negatively on bird life. A gradient of increasing behavioral response is evident in birds when exposed to increasing aircraft stimulus. The most major disturbance is likely to lead to impacts on the health, breeding performance and survival of individual birds, and perhaps bird colonies. The exposure is time limited.	Extent: M Duration: L Intensity: L Probability: H	Minimum horizontal and vertical separation distances for aircraft operations close to concentrations of birds in Antarctica as recommended by the SCAR Bird Biology Subgroup, are verified. Also the recommendations of the new guidelines adopted by the Antarctic Treaty Consultative Parties in June 2004 will be respected. Take-off and landing will be in the opposite direction respect to the penguins colony. So the aircraft never overfly the colony.

Table 5.6: Impact matrices (continue)				
Obstruction		Birds killed in aircraft encounters is relatively high in the more populated parts of the world (see e.g. www.birdstrike.org). In the case of this runway the number of such incidents is expected to be very low (if any) due to the low number of flights and the observed flight patterns for the birds. Only a few individuals would be affected, and no ripple effect would be expected.	Extent: M Duration: L Intensity: L Probability: M	No mitigation measures
Landscape				
Mechanical actions and obstructions		A permanent modification of the landscape is expected. The impacted area in the case Boulder Clay site is very confined and the expected impact is restricted. For Campo Antenne site higher impact is expected.	Extent: M Duration: H Intensity: L (site 2), H (site 2) Probability: H	No mitigation measures

5.3. Mitigation measure

5.3.1. **Present protection status and envisaged measure**

Recently the establishment of spatial protection for marine biodiversity has been identified as a priority issue by both the CEP and SC-CAMLR.

Ross Sea Region under consideration as a future MPA was identified in the 2007 CCAMLR Bioregionalization Workshop. Herein the Terra Nova Bay area was proposed as SSRU (small scale research unit). The SSRU proposal for Terra Nova Bay is consequent to a wider proposal for Ross Sea Marine Protected Area (MPA) that should include part the CCAMLR statistical subareas 88.1 and 88.2 (Ross Sea). Inside this area some smaller MPAs with valuable ecosystem components were allocated: Marine ASPA n°161 (Terra Nova Bay), ASPA n°165 (Edmonson Point), ASPA n°173 Cape Washington and Silverfish Bay.

The main objectives for enlarging protection measures in the TNB area are to conserve and protect the unique and outstanding environment of the Terra Nova Bay region, an outstanding example of near-pristine marine ecosystems on Earth, by managing the variety of activities and interests in the area with the scope to ensure that its important values are protected and sustained in the long term.

International regulation of the impacts of human activities in Antarctica can be resumed in four principal organizations, the Whaling Commission (IWC) 1948, the Antarctic Treaty 1961, the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) 1982 and The Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol, 1998).

During fifty years the Antarctic has suffered the presence of more than 80 Scientific Bases and the unavoidable impact on its environment.

Over the past decade, the intensity and diversity of human activities have continued to increase and for this reason also sources of contamination are increasing.

Recent studies have further defined the nature of local chemical contamination in Antarctica and the main sources or types of chemical contamination are now well established: fuel spills, heavy metals (copper, lead, zinc, cadmium, mercury, arsenic) and polychlorinated biphenyl (PCB), contamination derived from other persistent contaminants such as polycyclic aromatic hydrocarbons (PAH) and polychlorinated dibenzodioxins (PCDDs) from combustion processes.

A significant amount of persistent atmospheric contaminants is also transported to Antarctica from other continents, especially in the Southern Hemisphere. The import of trace gases such as carbon dioxide (from the burning of biomass and fossil fuels) and chlorofluorocarbons (CFCs, used as flame-retardants and refrigerants) has significantly changed the Antarctic atmosphere in recent decades. Through sea ice, persistent atmospheric contaminants are also transferred to water and organisms and can accumulate in tissues and biomagnifying in food chains.

Human activities, particularly construction and transport, have affected Antarctic flora and fauna. Considering the continuing expansion of human activities in Antarctica, a more effective implementation of a wide range of measures is essential as an effective environmental impact assessments, long-term monitoring, mitigation measures for non-indigenous species, management of marine living resources and new regulation for the management of tourism activities that during the last 2 decades have contributed in substantial manner to the increasing of impact particularly on flora and fauna.

The presence of the Italian Base during the last 25 years has produced inevitable impacts around the area due to the construction and growth of the Base, to the construction of runway on ice, wharf, helicopter site and field camp.

By the end of eighties Italian Program carried out a monitoring program to verify and mitigate possible impacts following the current environmental management regime (primarily Environmental Protocol and CCAMLR)

It is comprehensible to consider the scientific research essential for the understanding of new climatic and environmental challenges, but the value of Antarctica should be weighed against the environmental impact of scientific work and its logistic activities [4.40].

5.3.2. **Mitigation measures for Atmospheric pollution.**

Fuel JA1 will be used for every vehicles or machinery. All vehicles and mechanical equipment will be selected and procured under the condition that they must have excellent performance and are technically advanced. JA1 has appropriate density, high calorific value, and good combustion performance. The combustion process is fast, stable, continuous and complete. It has few carbon deposits but high cleanliness. It has no mechanical impurity or water content. Its content of sulphur, especially mercaptan is low, thus resulting in much less corrosion to machine elements.

5.3.3. **Prevention and mitigation measures of oil spills**

Accidental oil and fuel spill can be overcome using the best practice during refueling and transportation.

To prevent fuel spills, fuel tanks will be double-skinned and posed on confined structures made of impermeable layer and concrete and with adequate capacity.

Suitable absorbent mats will be used to underlay the pipelines. Fuel pipelines for generators will be designed double-skinned to minimize the possibility of oil leakage.

The following response equipment is at all times to be available at the station:

1) Oil absorbing mats for refuelling sites;
2) Spill kits containing absorbent pillows and fabric for vehicles and field parties;
3) Protective plastic barrels for 200 liter fuel drums;
4) Plastic bags;
5) Protective masks and rubber gloves.

The likely migration of accidental oil spills.

The migration pattern of oil spill depend on soil characteristics and covered conditions as reported below:

Snow free conditions

In the case of on ground of frozen moraine underlying by permafrost (as Boulder Clay) oil spilled on such ground will seep into the underlying material. Clean-up of such spills is difficult. If the spill occurs on impermeable ground, the oil will run off from rock and concentrate in puddles, and the ground will seem to be coated with oil.

Ice-covered ground

Oil spilled on ice-covered ground is likely to remain on the surface and not penetrate much into the ice as long as there are no cracks.

Snow covered ground

Oil spills on snow-covered ground will seep into the snow. Due to capillary effects, the oil will also spread horizontally. The vertical spreading is always bigger than the horizontal, at least in the upper layers. If the quantities spilled are large, the oil will reach into layers of higher density until it reaches the ground or an impermeable layer of ice.

5.3.4. **Sensitive location for accidental oil spill**

Nesting bird near site 1 (Boulder Clay). There is nesting penguins, which could possibly be affected by spill. Also skuas are present. The direct and/or indirect impact on possible skua nests will be considered, even if no nest has been observed at any distance from the runway construction site. For that during construction, additional protective measures will be taken to minimize the possible impact, such as for example the installation of noise barriers.

To conserve the skuas and penguins community in the southern area, it will be not allowed any access to the colony area to workers and other personnel.

In addition, all the personnel will be provided with a specific site-guidance on minimizing anthropogenic disturbance to the skua and Adélie Penguin colony. Monitoring on the skua and Adélie Penguin colony will be taken in consideration by biologists to devise additional effective mitigation measures in case an unexpected impact occurs.

Vegetation

Spills on snow-free ground may affect micro-fauna and lichens occurrences in the area. In oil spill affected areas these are likely to perish.

5.3.5. **Mitigation measures against the loss of wilderness and aesthetic values**

In the design of the runway, the local environmental conditions will be taken into full consideration. The harmonization with the local environment will be made to the greatest possible extent so as to minimize visual impact.

Highly efficient vehicles and mechanical equipment will also be adopted so as to minimize the emission to the atmosphere.

In the area the use of vehicles, mechanical equipment and aircraft will be reduced as much as possible and gradually mark out the driving lines of vehicles to ensure that the number of tracks can be kept at the lowest level.

5.3.6. **Mitigation measures for noise prevention**

The simultaneous operation of construction equipment will be limited in order to minimize the impact of noise on the colonies of penguins and skuas, although the predicted levels of noise under the simultaneous operation condition are negligible. In addition, possible use of machines of low noise and vibration-reduction technologies will be considered.

Efforts will be made to minimize the operations, aircraft, vehicles and mechanical equipment etc. Noise-absorbing materials will be installed in power generator facilities. If it is necessary to operate aircraft, its flight will be kept within the height and space limitation stipulated in the Antarctic Flight Information Manual formulated by COMNAP, Maintenance and service will be provided regularly for vehicles, generators and mechanical equipment etc. so as to keep noise to the lowest level.

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6. Environmental Management and Environmental Impact Monitoring Plan

6.1. Environmental management plan

The construction of a new gravel airstrip will inevitably bring about some changes in the location and its surroundings. A detailed assessment of potential environmental impacts and the corresponding mitigation measures have been specified in Chapter 5. In order to accurately understand the actual impact derived from the construction and operation of the runway, along with the effectiveness of planned mitigation measures, PNRA will formulate, before the start of phase 1 of the runway construction, an Environmental Management Plan (EMAP).

The EMAP will define duties and responsibilities of relevant personnel to monitor the facility activities, to assess their environmental impact, to ensure their minimization and finally to fulfil mitigation measures. EMAP will also include the aircraft refuelling and fuels transportation procedures, to prevent the occurrence of environmental accidents and to minimize environmental impact of such operations.

Among the main targets of the EMAP, it will be the management on the protection measures for the penguin colony at Adelie Cove and the monitoring of the on-site flora changes at Boulder Clay moraine. This monitoring after the completion of construction of the facility will be considered as a part of the major scientific researches and it will be reviewed and modified according to the achieved scientific results.

6.2. Environmental monitoring plan

The monitoring objective is to evaluate and analyse the surrounding environmental impact due to the activities of the runway during the construction and operation phases. The environmental monitoring plan (EMOP) will cover both the two aspects of environmental impact and relevant operation information of the facility.

Monitoring the environmental impacts will allow PNRA to take immediate actions to reduce or eliminate such impact. An important feed-back of this aspect will be an improved understanding of the interactions between the on-site human activity and the surrounding Antarctic environment, along with a better assessment of the predicted impacts issued in the present Draft CEE.

On the other side, EMOP will include monitoring and recording of the airstrip operations, including air traffic and fuel consumption data, fuel spill events, personnel number in transit through the facility, eventually waste production and its disposal route to MZS. All this information will help

PNRA to determine whether the impacts conform to those estimated in the present CEE and if the proposed mitigation measures are still valid, or an immediate review should be considered.

6.2.1. Air quality

The atmosphere monitoring covers the entire area influenced by the sources of air pollution. The MZS area has a long history of air quality monitoring network (see Chapter 4). The present PM10 sampler network will be extended to Boulder Clay area and new monitoring sites will be allocated around the pollution sources, while samples will be taken also outside of direct influenced area of the air traffic to be used as background reference. Heavy metal and IPA can be determined by PM10 sampler. If necessary also CO, CO_2, SO_2 and NO_x could be determined as well.

6.2.2. Snow and ice

A spatial and temporal sampling schedule of snow and ice will be defined and samples will be periodically taken from many points around the runway area. Snow and ice samples will be analysed for TSS and pH.

6.2.3. Soil and oil spills

A spatial and temporal sampling schedule of soil will be defined and samples will be periodically taken from many points along the road between the MZS and over the taxiway of the facility, to have under control any possible oil spill event. Also TPH of soil will be determined.

6.2.4. Environment and life

On the flora side, as already detailed in Chapter 4, in Boulder Clay moraine a vegetation exclusively composed of cryptogams (microfungi, cyanobacteria, algae, lichens, bryophytes) is present, with lichens and bryophytes being the dominant components of most terrestrial ecosystems and characterized by a high degree of biodiversity. Moreover a CALM grid has been installed on site, as part of the main vegetation-permafrost monitoring network of Victoria Land, operated by PNRA.

The construction of a new gravel airstrip will inevitably bring about some changes in the location and its surroundings, impacting on the CALM monitoring grid and on ecosystem as well. In order to accurately understand the actual impact derived from the construction and operation of the runway to the vegetation in the permafrost of Boulder Clay area, PNRA will enhance the biologic researches on site, enlarging the monitoring grid and tuning the mitigation measures with the new scientific results achieved.

On the fauna side, a penguin colony is located at Adelie Cove, 1.8 km away from the nearest side of the proposed facility. Alhough a negligible impact of the airstrip construction and operation to the birds is foreseen, our respect to these important living organisms railroads in any case a monitoring of any possible impact on ther life. With this aim, the research on the Adelie Cove penguins will be enhanced and a monitoring of human produced noise will be set up on the closer border of the penguin colony, along with the already explained air quality monitoring.

The plan will allow PNRA to rapidly identify any change in the penguin activities or population dynamics, and to connect or not such changes to the human activity at Boulder Clay, taking in case immediate measures for a mitigation of the resulting impacts, even included a reduction of the flight activities in the facility.

6.2.5. **Tables of monitoring schedule**

A summary of the main monitoring activities, as they are scheduled during construction and operation stages, are reported in the tables below.

Table 6.1: Schedule for monitoring - Construction stage.

Item	Object	Reporting	Frequency
Staff	Wastewater and solid waste	Wastewater and waste logs	Once a month
Material	Construction material used and its source	Construction material and sources log	Once a week
	Use of explosives	Quantity of explosive and sites log	Once a week
Equipment operation	Fuel supply and consumption	Fuel log	Once a month
	Oil change, waste oil for construction equipment	Motor oil log	Once a month
Noise protection	Temporary noise barrier toward Adelie Cove	Barrier status	At installation

Table 6.2: Schedule for monitoring - Operation stage.

Item	Object	Reporting	Frequency
Ecology	Alien species invasion	Invasive species	Once a year
	Changes in habitat	Habitat observation of penguin colony	Once per two weeks during construction. Once a year during operation.
	Community structure changes	On-site fauna/flora	Once a year
	Population dynamics	Penguin population	Once per two weeks during construction Once a year during operation
Snow	TSS, pH	Snow quality	Twice a year
Soil	TPH	Soil analysis in 4 points at parking sites	Once a year
Air quality	CO_2, PM2.5, PM10, NOx	Air quality analysis - Airstrip - Penguin colony	Twice a year
Noise	Noise level	Noise level at site near penguin colony	Once a week during construction On flight arrival during operation
Air traffic	Monitoring of flight traffic	Air traffic log	Once a year
Waste	Monitoring of domestic waste	Recycling and storage status	Once a week
Aircraft and power generator operation	Fuel supply and consumption	Fuel log	Once a month
	Oil change, waste oil	Motor oil log	Once a month

7. Gaps in knowledge and project uncertainties

The site for the proposed facility is the Boulder Clay moraine, located on the East side of the Northern Foothills beside the Boulder Clay glacier. While the glacier is dynamic, pouring ice towards north (Enigma Lake) and mainly towards south (Adelie Cove), the moraine is much more stable (see Chapter 4). Such stability appears strictly related to the underlying orography, an issue deeply investigated during the last campaigns by means of several instruments and techniques (see Chapter 4). Important peculiar features of the moraine has been assessed with an high degree of confidence. However still some important questions remain open and should be addressed in very next future, also implementing specific tests on site.

7.1. A runway over a glacier moraine

The Boulder Clay moraine is composed by an upper layer of debris with several big boulders spread out over the surface and with an average thickness of 80 cm. Below the debris layer an ice sheet incorporating scattered debris is present, over 80 m thick and lying on the bedrock. On the south-western flattest part of the moraine, there are several small frozen lakes, partially defrosting during the summer period. Only one of those lakes will be partially incorporated by the airstrip body.

During the warmest part of the summer and for a short period, an ephemeral hydrographic system appears, which drains westward the liquid water produced by the melting snow present on the moraine.

The idea to build a permanent runway over a moraine was for the first time considered in the early nineties. One of main reasons of this possible solution was our firm belief that such kind of runway would have, generally speaking, the minor possible impact on the environment, compared to other solutions. Actually we decided to explore the possibility to have a permanent runway over a moraine, well after having considered and unsuccessfully tried several other options (see Chapter 3).

The solution of the moraine seems to be in between two existing solutions for airstrip in Antarctica. It will be a blue ice runway (i.e. on a glacier), but topped with a layer of earth. In some way it is similar to the ice pier utilized in McMurdo since many years. The ice pier is an artificial iceberg topped with gravel to protect it from the sun and the heat of the summer period. The gravel thickness is calculated to be an efficient insulator, but to be not so heavy to sink the iceberg.

The moraine runway should work in a similar way.

However, as far as we know, no runway was ever built over a glacier moraine, being the moraine naturally both made of debris and moving in times.

Anyway we can affirm that the natural drift has spatial and time scales too large for likely affecting our facility (see Chapter 4). So, for our time scale of operations (tens of years), we assumed that it is stable.

Of course having no previous similar experience elsewhere, the proposed solution lacks information on the long-term ice response to the new stress of the weight of overlying airstrip. Such gaps in knowledge will be filled up with specific studies and preliminary tests during phase 1 of construction. Moreover the monitoring plan, set up once the construction will be ended, will include such ice response along with the environmental impact of the operations.

7.2. Moraine surveys for filling gaps in knowledge

To fill up as much as possible the gaps in knowledge of the proposed site, several investigations with different techniques were conducted on the moraine:

- Maps of the entire area at several resolutions (the highest resolution < 50 cm of level);
- Monitoring of short and long term moraine movements by means of differential geodetic GPS and satellite Synthetic Aperture Radar (SAR) interpherometric method;
- Drill coring in several points and soil samples, for analysis and classification;
- A complete georadar mapping investigation, both with an airborne and ground-based technique at different frequencies, to retrieve a detailed glacier cross-section;
- Sampling and analysis of the ice and water from the small lakes present over the area;
- Measurements of the bearing capacity of the natural soil, carried out in different periods of the season.

7.3. Construction method and preliminary tests

The construction method foresees the addition of debris over the existing till moraine. The natural surface is quite flat for its length, but has transverse slope, which has to be corrected adding material in east side to make the runway's cross-section flat.

On top of the levelled and compacted material a layer of 60 cm of gravel will be applied. This layer will be the runway surface and will have the bearing capacity to support the aircraft weight, but will have the task to insulate the underlying material, avoiding its thawing.

To contain the added material two rock shoulders have to be built. The one in the west side, in the higher side of the moraine, will be small, the second one, in the east side, will be much bigger and, for a short section, it will higher than 5 m.

To verify the design calculation about gravel size and layer thickness and compaction, the most useful tool is to carry out in situ tests. As declared in the IP57 at the XXXVII ATCM, during the

2014-2015 summer Antarctic campaign tests were performed to define the most suitable way to realize the embankment.

In the next summer Campaign 2015-16, a section of the future runway over the moraine will be replied. The test site will be instrumented with a network of thermometers to check the thermal behaviour of the section with the real materials that will be used for the construction. The data that will come out from the test site will be used to better adjust the design of the runway.

7.4. Convection embankment

The shoulders will be made of big stones to promote air circulation inside of the embankment.

A cautious approach for the construction of an infrastructure over permafrost soil needs to be carried out. We already made a preliminary study of the problems encountered in the Arctic and the solutions adopted. In the Arctic there is much more experience in the infrastructures' construction and the thawing phenomenon is more magnified. We decided to adopt a design which exploit the natural convection effect.

One of the risks in putting an infrastructure over a permafrost soil is the possible heat transmission to the soil, so inducing local thawing. To mitigate this risk, in Arctic the design of the airstrip constructions exploits the convection effect. The convection effect, driven by the difference between the air temperature and the soil temperature, allows to super-cool the soil at the base of the construction during the winter time, permitting to the permafrost a better withstanding to the summer heating.

During the winter time the air temperature is lower than the soil temperature. In a structure where the air can circulate, the cold and dense air falls in the embankment, because of the convection effect, then it pushes up the warmer air which is inside. This circulation super-cools the embankment and the local soil, therefore activating an air movement inside of the embankment.

Vice versa in summer time, there will be a static situation for the air. The cooler and denser air stays lower in the embankment, while the outer air is warmer, because of the sun heating, and stays upper.

7.5. Managing future activity and monitoring plan

The kind of the runway surface will allow an easy and cost effective maintenance of the infrastructure. Just adding, spreading and compacting gravel will be sufficient to make the standard maintenance to the runway.

At the early stage of the runway activity will be appropriate to consider operations from October to late December and from late January through March, avoiding operations in the warmest period.

This timing of the operations will not affect the expedition's planning because the most of the intercontinental movements are concentrated in the two above mentioned periods.

Once experience has been gained, activity in early January can be considered, at least planning operations in the early hours of the day.

For winter operations the same rule of the experience will apply. Once the pilots will get used to the runway, the environment and the climatology of the area, also winter operations can be considered.

For the night lighting easy solutions already exists. A removable systems from military applications, named MosKit, based on portable lamps with batteries, allows an easy and rapid deployment of lights on any runway.

Since for some aspects this runway represent a new typology of construction, it is wise to establish a monitoring plan to be able to detect any preliminary sign of change, to identify the reason and to act accordingly.

Different studies will be carried out: a local airflow and wind simulation model to consent an accurate aeronautical and dust transport evaluation; a vapour diffusion model to quantify the vapour flow within the moraine with the aim to foresee the local displacement.

A network of fixed posts, to record all these data, will be put in place in the area and a laser station will be acquired to make a quick periodic controls of the geometry.

From the environmental point of view, a monitoring program of the Adelie Cove penguin colony will be established. The purpose will be to detect any possible change in penguin's behaviour, to assess if it could be considered as consequence of the activity on the runway and, in case of positive response, to put in place as fast as possible mitigation measures.

8. Conclusion

Starting the scientific expeditions in the Antarctic in 1985/86, Italy established the Mario Zucchelli Station (MZS) at Terra Nova Bay. Then, in the nineties, together with France, PNRA started to build up Concordia Station at 1,200 Km from MZS inside the Plateau.

MZS is located at Terra Nova Bay where also the German Station of Gondwana is present and the new Korean Jang Bogo Station is working and has concluded its first winterover.

For the intercontinental transportation of personnel and freights, the Italian Program relies on two methods: flights and a multipurpose ice class ship, which is used also to refuel the MZS and for the oceanographic campaigns. International cooperation provide also an essential support.

Flights are currently operated chartering an Hercules aircraft which lands on a seasonal ice runway realized in the Gerlache Inlet in front of MZS.

ENEA proposes the construction and operation of a new gravel runway in Terra Nova Bay pertinent the Mario Zucchelli Station, Antarctica.

The new facility will allow intercontinental air operation for an extended period, thus overcoming the time restriction of the fast ice runway that is currently operated in the Gerlache Inlet.

The runway will potentially be a logistic hub for many Antarctic Programs in the Ross Sea region, gaining a more flexible turnover in Antarctica for Italian and foreign scientists, so contributing to develop international and multidisciplinary research activities.

The embankment over the moraine at the Boulder Clay site is designed to be realized only with local, selected material (from boulder to gravel) without introducing foreign structures.

The impact of the construction and operation of the gravel runway at Boulder Clay on the environmental and on the ecosystem will be minimized applying appropriate mitigation and monitoring measures.

The result of CEE suggests that the benefits that will be obtained from the permanent runway will grossly outweigh the “more than a minor or transitory” impacts of the runway on the environmental and on the ecosystem.

On these basis, the establishment of the proposed facility is highly recommended.

Italy welcomes further comments and suggestions toward the submission of the Draft CEE.

9. Authors and acknowledgment

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