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Draft
Comprehensive Environmental Evaluation

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

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TABLE OF CONTENTS

Figure Index

Table Index

List of Acronyms

AAD	Australian Antarctic Division, Kingston Tasmania, Australia
AASHTO	American Association of State Highway and Transportation Officials (USA)
ACE	Air Convection Embankments
AntNZ	Antarctica New Zealand, Christchurch, New Zealand
ARP	Aerodrome Reference Point
ASI	Agenzia Spaziale Italiana, Roma, Italia Italian Space Agency
ASMA	Antarctic Specially Managed Area
ASPA	Antarctic Special Protected Area
ASTM	American Society for Testing and Materials
ATCM	Antarctic Treaty Consultative Meeting
ATCP	Antarctic Treaty Consultative Party
AWS	Automatic Weather Station
BC	Boulder Clay
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Germany Federal Institute for Geosciences and Natural Resources
CALM	Circumpolar Active Layer Monitoring
CBR	California Bearing Ratio
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CEE	Comprehensive Environmental Evaluation
CEP	Committee for Environmental Protection
CFC	ChloroFluoroCarbons
CNR	Consiglio Nazionale delle Ricerche, Roma, Italia National Research Council
COMNAP	Council of Managers of National Antarctic Program
CSNA	Commissione Scientifica Nazionale per l'Antartide National Scientific Committee for Antarctica
DDU	Dumont d'Urville Station
EMAP	Environmental Management Plan
EMOP	Environmental Monitoring Plan
ENEA	Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile, Roma, Italia National Agency for New Technologies, Energy and Sustainable Economic Development
Environmental Protocol	The Protocol on Environmental Protection to the Antarctic Treaty
FAA	Federal Aviation Administration (USA)
FOD	Foreign Object Debris
GPR	Ground Penetrating Radar
GPS	Global Positioning System
GPU	Ground Power Unit
HSM	Historic Site and Monument
ICAO	International Civil Aviation Organization
IEE	Initial Environmental Evaluation

IP	Information Paper
IPEV	Institut Polaire Français – Paul Emile Victor, Plouzané, France French Polar Institute
ISO	International Organization for Standardization
IWC	International Whaling Commission
JA1	Fuel Jet A-1
JBS	Jang Bogo Station
KOPRI	Korea Polar Research Institute, Incheon, Korea
LSZ	Lateral Safety Zone
LWD	Light Weight Deflectometer
MAAT	Mean Annual Air Temperature
MARPOL	International Convention for the Prevention of Pollution from Ships
McM	McMurdo Station
MIUR	Ministero dell'Istruzione, dell'Università e della Ricerca, Roma, Italia Italian Ministry for Education, University and Research
MPA	Multiple-use Planning Area
MZS	Mario Zucchelli Station
NSF	National Science Foundation, Arlington, VA, USA
OLS	Obstacle Limitation Surfaces
PAH	Polycyclic Aromatic Hydrocarbons
PCB	PolyChlorinated Biphenyl
PCDD	PolyChlorinated DibenzoDioxins
PNRA	Programma Nazionale di Ricerche in Antartide Italian National Antarctic Program
POP	Persistent Organic Pollutant
SAR	Synthetic Aperture Radar
SCAR	Scientific Committee on Antarctic Research
SPA	Specially Protected Area
SSRU	Small Scale Research Unit
SSSI	Site of Special Scientific Interest
TNB	Terra Nova Bay
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solid
USAP	United States Antarctic Program
USCS	Unified Soil Classification System
UTA	Antarctic Technical Unit
WP	Working Paper

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

Non-technical summary

I Introduction

This *Draft* 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 in accordance with Annex I of the Protocol on Environmental Protection to the Antarctic Treaty (1998) and with the Guidelines for Environmental Impact Assessment in Antarctica (Resolution 4, XXVIII ATCM, 2005).

This *Draft* CEE was prepared by ENEA-UTA, which is in charge of the implementation of the Italian Antarctic expeditions, logistics and maintenance of the stations, and CNR for the scientific contributions related to the actual state of the environment, monitoring and mitigation measures. The document was submitted to the Italian Ministry of Environment and Protection of Land and Sea (MATTM) and to the Institute for Environmental Protection and Research (ISPRA) to get contributions aimed to improve the document itself, and allowed for submission by the Italian Ministry of Foreign Affairs and International Cooperation (MAECI).

The following contents are outlined:

- Purpose and description of the proposed activity;
- Alternatives to the proposed activity;
- Site selection and initial environmental reference state;
- Construction, operation, maintenance and decommissioning of the proposed activity;
- Potential environmental impacts during construction, operation, maintenance and decommissioning;
- Monitoring programme;
- Prevention and mitigation measures;
- Gaps in knowledge and uncertainties.

Considering the past studies reported in Information Papers (XXV, XXXVI, XXXVII ATCMs, respectively IP41, IP80, 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 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.

II Need of Proposed Activities

In the last ATCMs, Italy presented several Information Papers (IP41- ATCM35/CEP15, IP80 ATCM36/CEP16, IP57 ATCM37/CEP17) and a Working Paper (WP 30/XXXVIII ATCM) informing the Antarctic community of the need of PNRA to find a long term solution to increase the reliability of its transportation system in terms of adequate arrival of personnel and delivery of materials, allowing greater effectiveness of scientific research and a more reliable multi-year programming. This need, in particular, was driven by the climatic changes experienced in the recent past that affected logistic activities and consequently scientific activities.

The construction of a gravel runway could be this long term solution: an important permanent infrastructure to share with the other Antarctic programs favouring cooperation and lowering of logistics costs, 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. This would lower the actual human footprint of the Italian expeditions and would meet general recommendations related to the reduction of logistical costs in favour of research activities funding.

Sharing of infrastructures results in environmental impact reduction and costs cutting as Concordia Station and the Dronning Maud Land Air Network are already testifying. Finding ways to implement co-operative air transport is also recommended at the international level (Resolution 1 (2015) - ATCM XXXVIII - CEP XVIII, Sofia)

The construction of this airstrip from one side would reduce PNRA logistic naval activities and from the other side would increase safety, becoming an alternate airstrip for McMurdo air operations and an emergency way in winter for the near Korean Jang Bogo Station.

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, USAP and AntNZ showed interest, opening to future agreements.

III Site selection and alternatives

In the Southern area of the Northern Foothills with respect to MZS, inspections were conducted on many sites to assess the preliminary technical feasibility of this infrastructure, considering the length that aimed to be built, the aeronautical constraints and the orography of the terrain.

For the proposed activity, no alternative facilities already exist: the fast ice runway realized at the beginning of the summer campaign in the Gerlache Inlet bay, does not last for the needed time as at the end of November the ice conditions are not suitable.

The "not proceeding" alternative would mean finding alternative solutions for the transportation of personnel at the end of the season: this could only mean chartering an ice class vessel every year. In effect, without the US NSF support, Italian scientific activities would be seriously affected, as the Italian National Antarctic Program is strongly dependent upon neighbouring Programs, especially when the multipurpose ice class ship is not chartered. That is why the Italian National Antarctic Program needs a long term solution to increase the reliability of its system in terms of adequate arrival of personnel and delivery of scientific materials, allowing greater effectiveness of scientific research and easier multi-year programming.

Only two locations on the land were retained as possible sites and considered adequate, for technical reasons, for the construction of the gravel runway. These were "Boulder Clay" (BC) 74° 44'45''S, 164° 01'17''E, 205 m a.s.l., and "Campo Antenne" (74°4219,2"S, 164°06'19,6"). Another site (Nansen Ice Sheet) had already been investigated for a permanent blue ice runway, but although used in the past a few times for landing, resulted not suitable anymore and of unpredictable availability, due to climatic conditions.

Boulder Clay site is located in the Northern Foothills, about 6 km South of the Italian Antarctic Research Station Mario Zucchelli. The site is an ice-free area located on a very gentle slope (5°) with South-Eastern exposure. Campo Antenne site is located on a predominantly flat granitic outcrop, very close to the MZS. This site presently hosts MZS antenna farm.

Boulder Clay was finally chosen, through an evaluation process that kept in consideration to minimize the overall environmental impact of the proposed activity, especially during the construction phase (as an example: in terms of rock volume to displace and related impacts, in the Campo Antenne option they would be around three times larger), thus guaranteeing efficiency and safety in relation with wind direction. Moreover, this site, allowing the construction of a longer runway with respect to Campo Antenne, could even permit landing of aircrafts with enough fuel autonomy to avoid refuelling in Antarctica.

The exact location of the runway in the Boulder Clay area reflected these considerations and the project was developed to minimize any impact on the existing environment (as will be discussed in the next chapters). 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 proposed site for the airstrip is close to the other neighbouring stations: about 13 km from Gondwana Station, 15 km from Jang Bogo Station and 16 km from the location proposed by China for its new station at Inexpressible Island. Distance from McMurdo Station and Scott Base will be around 400 km. This could favour international cooperation and sharing of logistic resources between the neighbouring National Antarctic Program, thus reducing the overall human impact on the area.

IV Description of the Proposed Activity

The activities described in this CEE concern construction and operation of the airstrip and related terrestrial connexions and facilities, temporary facilities on site during the construction phase, installation and use of machineries, and decommissioning of the airstrip.

The gravel runway project includes the following facilities: the gravel runway itself (a gravel embankment of 2,200 m long and 60 m wide that will be constructed using materials available in the nearby area) endowed, at the end of the airstrip, with an apron (130x134 m) for 2 aircrafts; an helipad (30x30 m) for safety reasons; a service area (70x22 m) equipped with a little parking for vehicles, a reception structure (MZS terminal) assembled with 6 ISO 20 insulated containers and containing a waiting room for passengers, offices and a chemical toilet, and a shed (14x7x5 m) that will host two fire trucks and related equipment, the unloading material for the aircraft (i.e. forklift), a store and a little workshop. A small taxiway (70 m long, 25 m width) will connect the runway with the apron. On the opposite side of the apron (with respect to the service area), a double walled stainless steel tank of 44 m^3 capacity will store the minimum fuel required for two operations. This tank will be refilled from MZS via appropriate tanker for fuel transportation.

Access to this facility will be allowed prolonging the already existing road that connects MZS to Enigma Lake skyway of 3,4 km.

The choice of facilities positioning is the result of considerations aiming at the maximum reduction of the volume needed for the embankment and works, following, to the maximum possible extent, the natural orography of the moraine.

The dimensions of the service installation follow ICAO standards and the Italian legislation.

For air operations control, a new operation room (2 ISO 20 insulated containers) will be installed at the top of the hill close to the existing weather station AWS Rita. This will allow personnel to have a clear view over all the runways used (fast ice runway, Enigma Lake skyway and the future gravel runway) and to increase safety of operations.

All buildings are modular and will be composed of preassembled structures. Globally the total occupied area will be around 0.15 km^2 with the longitudinal centreline of the entire embankment running in the direction NNE-SSW, at an elevation of about 200 m a.s.l.

Concerning electrical power and heating of the installations, the buildings will be provided with a solar photovoltaic power plant for the production of electrical energy combined with a traditional power generator of 20 kW that will act like backup system only. The use of this generator, in any case, will not be continuous but will be dependent upon the planned flight activities. For the heating and hot water production, solar thermal collectors will be installed. Both, the electrical and thermal systems should cover the energy needs of these installations.

The runway will require, as maintenance, only an annual snow removing and small levelling adjustment. This prediction is the result of seasonal surveys of the well-known area of Boulder Clay, of the meteorological data acquired on site in the last years and of the accurate determination of the behaviour of long term moraine ice drifts by means of interferometric satellite data.

This infrastructure aims to become a permanent one and its expected life span will be therefore over 20 years, as long as it will be possible to run it and MZS will be operational. When its use will be no longer possible, decommissioning operations will take place and all buildings will be dismantled and removed from the site. To allow recovery of the landscape, depending on the state of the ecosystem that will be evaluated at the moment of dismantling, the embankment will be partially or totally removed distributing the rocks over the surface following to the maximum extent the natural orography of the moraine. Considering the volumes of rock that compose the embankment, any other solution such as complete rock removal from site and disposal, would result in a higher environmental cost.

V Initial Environmental Reference State

The Boulder Clay area, interested by the construction of the runway, is a predominantly snow-free area where the Boulder Clay Glacier, an old glacier that extends from the Enigma Lake area to Adélie Cove where it degrades toward the sea, is the main orographic feature.

The Boulder Clay moraine, where the runway will be constructed, is a late glacial ablation till that overlies the body of the glacier. Surface includes perennially ice covered ponds with icing blisters, frost mounds and debris islands.

The Meteorological Observatory of the Italian National Antarctic Program has a long historical series of data. The climate in the area is cold and arid. The mean monthly air temperature recorded ranged between -16 and -3,5°C in the summer period, with a mean annual temperature of -14 °C. The region receives around 270 mm water equivalent precipitation per year. The prevailing winds in the area blow from western sectors (W, WNW and WSW). They are associated mainly with the katabatic flow coming from Reeves and Priestley Glacier and the wind speed can rarely reach values over 40 knots.

Vegetation in the area covers less than 5% of the surface and is entirely cryptogrammic as vascular plants are absent. Boulder Clay vegetation includes thirty-four lichens that are one of the principal components, seven mosses, one liverwort and various species of algae and cyanobacteria. In particular in the Boulder Clay site, the observed lichens are prevalently nitrophilous.

At the bottom of the Boulder Clay glacier on the East coast there is an Adélie penguins rookery of some thousands of couples. This site is, at the sea level, 1.8 km far from the end of the proposed Boulder Clay gravel runway and 200 m below. The penguin colony is located in front of the marine protected area ASPA 161 of Terra Nova Bay. This site is not included in ASPA n°161 but close to its limits. In the penguin rockery area there are colonies of storm petrels and skuas.

Depending on temperatures, a partial melting of some icing blisters was observed in the Boulder Clay area and the presence of biological life (bdelloidea rotifers, protists and platyhelminthes) in water sampled in these lakes was confirmed.

The presence of MZS produced inevitable impacts in the last 30 years around the area. Since the beginning of the Italian operations, a monitoring program was carried out to identify and mitigate possible impacts. Polycyclic Aromatic Hydrocarbons (PAH) and heavy metals (mainly As, Cd, Pb, V, Ni, Cu) in PM10 were identified as a good indicators of human activity as these markers can be simply correlated to sources such as incomplete combustion processes. The baseline of pollutants was evaluated by placing PM10 sampling equipment in “Campo Icaro”, which is located at a distance of approximatively 2,5 km from MZS and close to the selected site for the runway construction. Results of analyses conducted over 27 years showed that concentrations of the above pollutants remained close to the detection limit. Therefore, this monitoring station will allow the measurement of the changes resulting from the infrastructure construction and operation.

Data related to MZS revealed that this scientific base had a low impact on organisms since the 1990s . The contaminant accumulation and the lipid characterization were studied in many species in the ASPA no. 161 and levels suggested that their presence in this protected marine area was due to global transport from other parts of the planet, rather than local sources.

The main research activities conducted and still present in the Boulder Clay area, consist of CALM experiment: a monitoring programme established in 1999 with a grid of 100x100 m measuring permafrost and active layer temperature, and a shallow permafrost borehole with temperature monitoring records. This monitoring network will be interested by the proposed activity and actions will be planned with the scientific community to reduce the impact.

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

Potential impacts of the runway were evaluated considering all the life cycle of this infrastructure, including construction, operation and decommissioning. Since the design phase, the runway site and the runway facilities were chosen, positioned in such a way as to limit the volume of material to collect, transport, screen, and level. However, as long as it will be used, this infrastructure is expected to have a permanent impact on the landscape (limited by the use of local material for the construction of the embankment) and an impact on the surrounding environment, especially during the construction phase.

Construction phase

In the construction phase, direct impacts will affect the atmosphere with the unavoidable release of exhaust gases and PM_{10} from the operation of trucks, vehicles and generators, and of dust produced by scraping of the surface, rock crushing and screening using heavy equipment.

For the construction of the apron and of some ridges present on the moraine along the airstrip area (3000 m^3) blasting operations will be conducted. These will release dust and generate noise and vibrations. The noise generated by all these operations may disturb birds, raise stress level and increase metabolism. However the distance between the Boulder Clay area and the Adélie penguins colony and skuas (1.8 km horizontal and 200 m vertical from the proposed site) is expected to be adequate to mitigate the disturbance.

An estimation of the total amount of expected pollutants was done and adequate maintenance procedures will be put in place to limit these emissions.

Other potential impacts could be generated by accidental spills of fuel or lubricants and by disposal of produced wastes and of wastewater from chemical toilets.

Operation phase

During the operational phase the source of the biggest impacts will be aircraft activity.

A maximum amount of 20 flights per operative season and 6 per month is expected and related emissions, considering the aircraft presently used, were calculated.

Air operations will have an impact on the atmosphere with the release of exhaust gases from engines, will generate noise and increase the potential of accidental fuel spill and related impact because of the large quantities of fuel involved. Accidents of bird strike could also occur.

Other impacts may arise from operation of vehicles during the routine annual maintenance and from fuel transfer and refuelling process, as well as accidental leakage from fuel tanks and by disposal of produced wastes and wastewater from chemical toilets.

Decommissioning phase

During the decommissioning phase, direct impacts will affect the atmosphere with the release of exhaust gases and PM_{10} from the operation of trucks, vehicles and generators. All buildings will be disassembled and removed from the site while, depending upon the conditions of the ecosystem, the embankment will partially levelled to better follow the natural orography of the moraine.

Other impacts may arise from disposal of wastes and of wastewater from chemical toilets.

Two months of work are expected for this activity.

Mitigation Measures

Particular attention will be paid to lower the probability of accidents by means of adequate procedures and equipment both in the construction, operation and decommissioning phase.

The *Guidelines for the Operation of aircraft near Concentrations of Birds in Antarctica (Resolution 2, 2004)* were taken in consideration since the design phase and, concerning noise and disturbance to fauna, the runway was designed as a one-way runway in the Boulder Clay project, to avoid flight at any altitude over the colony. Aircraft flight path for landing and taking-off therefore will be kept off the Adélie Cove area in addition to important limitations in height and space flight in overpasses of ASPA n°161 area. The proposed infrastructure complies with the Minimum Distances for Aircraft Operations Close to Concentration of Birds (WP 10-ATCM27)

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

- Specific environmental training for the personnel involved in the construction and operation of the runway.
- The facilities annexed to the runway will be provided with thermal solar panels to limit to the maximum the use of fossil fuels in generators for heating and power supply.
- Mono fuel JA1 will be used for every vehicles or machinery;
- All vehicles and mechanical equipment will be maintained under best condition and their use will be reduced as much as possible;
- Low noise machines, including noise-absorbing materials in power generators will be used;
- Fuel spills will be prevented by using double-skinned fuel tanks posed on confined structures made of impermeable layer. Suitable absorbent mats, pumps and appropriate equipment will be available on site in accordance with guidelines such as the COMNAP Fuel Manual;
- Transportation of fuel will be done in appropriate tankers and special transportation procedures will be set to ensure maximum safety
- All wastes and wastewaters produced on the runway site will be collected and transported to MZS for appropriate treatment or recycling.

Concerning pollutant and dust monitoring, a new monitoring station will be installed in the vicinity of the runway. It will be useful to better evaluate the variations of the main environmental parameters during the phases of construction and operation of the runway so as to identify and provide early warning on adverse effects and allow for mitigation actions.

Concerning the impact of noise, minimal/medium disturbance to the local ecosystem is expected considering the distances involved (well above the minimum distances for aircraft operations close to concentration of birds). However monitoring of the birds will be conducted to identify potential excessive disturbance, thus allowing to take measures such as a review of the working schedule in terms of daily working time and planning of activities.

VII Environmental Impact Monitoring Plan

To allow early identification of possible unpredicted impacts, an Environmental Monitoring Plan (EMOP) has been developed to evaluate changes in the ecosystem during construction and operation.

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

VIII Gaps in Knowledge and Uncertainties

The construction of a runway over an old glacier moraine is a challenging project, as no other examples are available. The stability of the moraine, however, has been deeply investigated during the last campaigns by means of several instruments and techniques, obtaining encouraging results.

Identified gaps in knowledge and uncertainties for the construction and operation of the new gravel airstrip include:

- Climate conditions during the construction phase;
- Possible human induced physiological changes on wildlife not manifesting into behavioral changes (WP 27- ATCM 38);
- 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.

IX Conclusions

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.

No touristic activity will be allowed for this infrastructure.

The impact of the construction, operation and decommissioning of the gravel runway at Boulder Clay on the environmental and on the ecosystem were considered since the design phase and 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 (MIUR) 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 Antarctic Technical 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 Brasilia 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 also 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 provides an essential support to the PNRA logistics.

Since beginning of 90’s, PNRA operates 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 uses 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.

At this moment, the implementation of national scientific programs is quite tricky due to a PNRA lack in assuring them the necessary logistic support, following on from the difficulty for PNRA of a clear schedule of personnel and staff movements in/out at MZS. In addition, a support from the transport services of NSF-USAP is requested every year, 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, to date 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 NSF-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 agreements with KOPRI, helping PNRA operations by means of the Araon vessel, usually reaching the close Korean Jang Bogo Station every year during the 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, that 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 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). The proposed airstrip could became an important hub for KOPRI air operations and would increase the safety of all the operations in the area. 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 developed by the Antarctic Technical Unit (UTA) of ENEA, 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).

This work should be considered as the 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 reviewing process continued with the presentation of a "*In Progress CEE*" document, annexed to the WP 30/XXXVIII ATCM, with the aim to gather preliminary comments and inputs from the Italian institutions involved in the governance of the PNRA and of the Antarctic Treaty, and from the international Antarctic community.

The present document is currently digitally available on PNRA website, while a paper copy will be circulated to each Contracting Party, and submitted as a Working Paper to Antarctic Treaty Consultative Meeting (ATCM) XXXIX (23 May 2016, Santiago, Chile) and the Committee for Environmental Protection (CEP) XIX.

1.4. Laws, standards and guidelines

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.

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, 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.

Four summer seasons are estimated to be necessary to perform the construction works. So, starting the project timeline in the next Antarctic season, the construction of the gravel airstrip is expected to be completed in 2019-20. Limited trail air operations are planned one season earlier. 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 also used to refuel the station and for the oceanographic campaigns. International cooperation provides an essential support.

Flights are currently operated chartering an Hercules L100/30 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 the opening of MZS in late October. 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 and some test flights were carried out with positive result. However, 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, especially for the evacuation of personnel at the end of the operative season, upon the establishment of cooperation agreements in particular 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.

The use of this infrastructure will not be allowed for touristic activities.

2.2. Location of the activity

The proposed site for the runway is located about 6 km South of the Italian Antarctic Research Station Mario Zucchelli, in the Northern Foothills, 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 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.

In the same area are also located the German *Gondwana Station* and the Korean *Jang Bogo Station* (Figure 2.2), while recently the construction of a new research station at Inexpressible Island (about 25 km South of MZS) has been proposed by China.

In this area only two locations on the land were considered as adequate for the construction of a gravel runway (Figure 2.3), "Boulder Clay" (BC - 74° 44'45''S, 164°01'17''E, 205m a.s.l.) and "Campo Antenne" (74°42'19"S, 164°06'20"E 100m a.s.l.).

The criteria that guided the choice of the locations for the airfield were:

- Minimum impacted surface;
- Levelness of the surface;
- Soil type;
- Orientation of the runway direction to the stronger winds;
- Absence of obstacles on the flight line of approach;
- Accessibility to the area from MZS station.

The two identified sites show some of the above mentioned features in a complementary way. Campo Antenne site has the great advantage of being closer to the station and with a good quality of the soil (granite rock). By contrast the runway would have a slope at the upper limit of the air traffic regulations and a maximum length at limit for the Lockheed Hercules requirements.

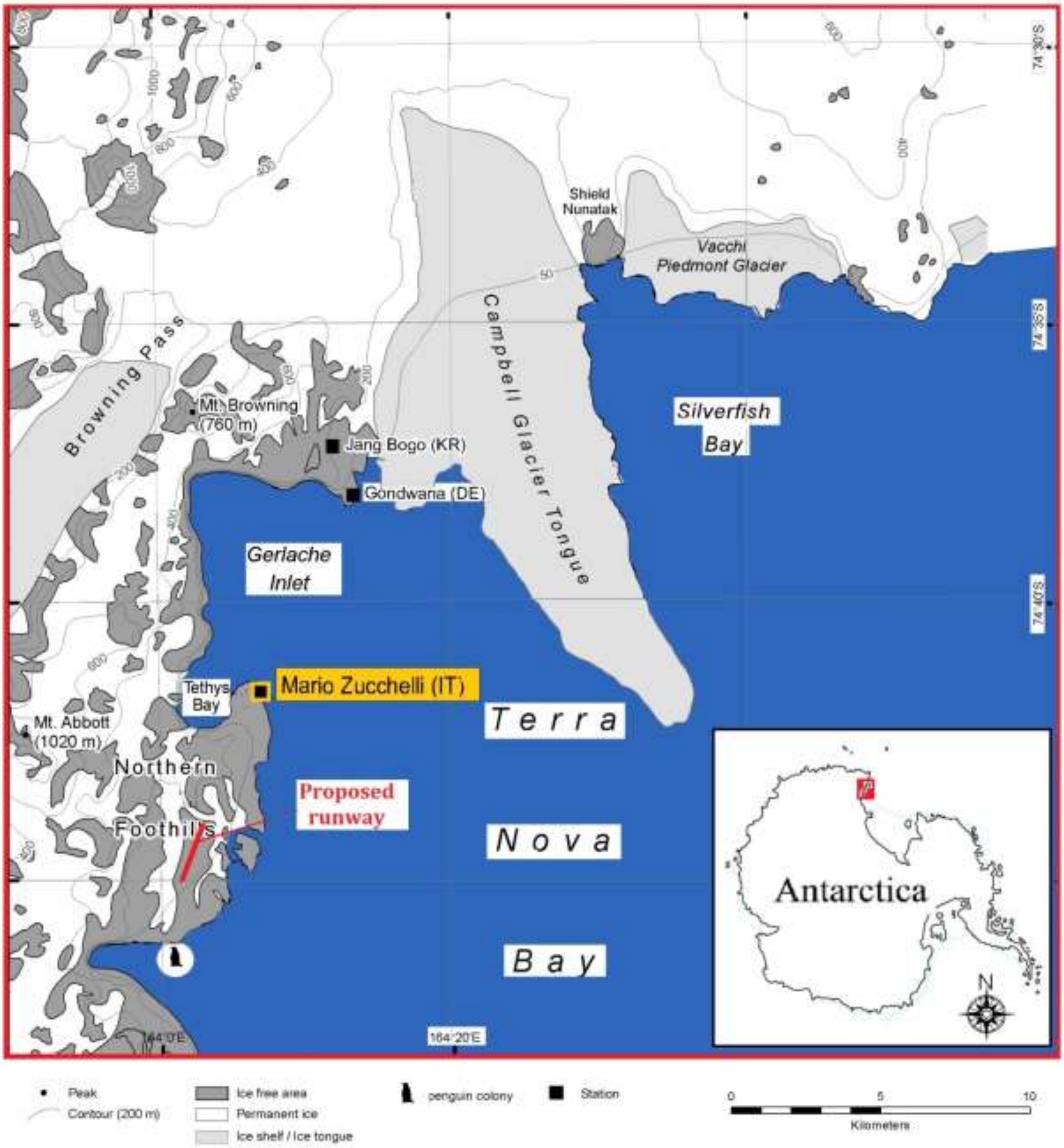


Figure 2.2: Regional map of the Terra Nova Bay area.

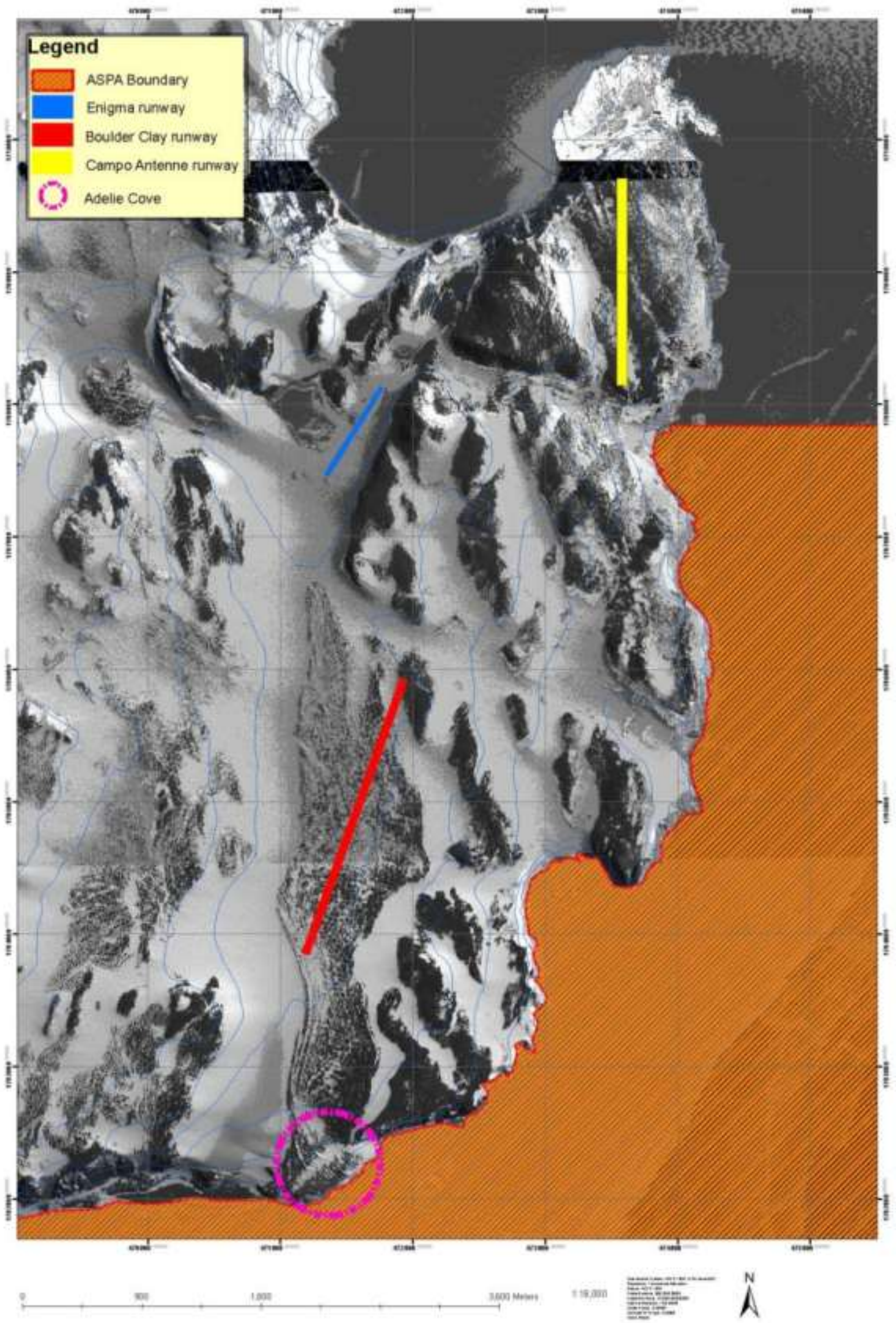


Figure 2.3: Evidence of ASPA n°161 and Adélie Cove respect Boulder Clay runway, Enigma Lake skiway and the alternative site of Campo Antenne.

On the other side Boulder Clay site, even though more distant from the station and being a moraine soil resting on a glacier, has flight approaches free from obstacles, its realization requires less than half of the construction effort compared to Campo Antenne and allows a development in length up to 2200 m. The last feature should allow in the future PNRA to partly replace the Hercules aircraft with more eco-friendly "liners" (jet aircrafts produced in very large numbers and used by airline companies due to their longer flight endurance and lower both chemical pollution and noise emission). The long range aircrafts should also have a clear environmental advantage of not refuelling in Antarctica. Moreover, a longer airstrip would become the alternate runway in the area of the Ross Sea (not available at present) for aircrafts other than Hercules, flying for the national Antarctic programs as the C-17, the Boeing 757, the A-319, the Orion P -3 and the Challenger.

For the above mentioned features and keeping in major consideration the reduction of the overall environmental impact of the proposed activity, Boulder Clay site was finally chosen. A detailed description of the alternative site of Campo Antenne and the evaluation of its features will be given in the next chapter.

Boulder Clay 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), 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, 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 oriented parallel to the coast, elongated for about 6 km from south to north (about 1.5 km wide) between Adélie 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 of 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 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, was proposed by Italy as Antarctic Special Protected Area (ASPA), being 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 2.3).

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.

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. This allowed to design and position the embankment and the related facilities minimizing the volume needed for works, following, to the maximum possible extent, the natural orography of the moraine

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 of 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.

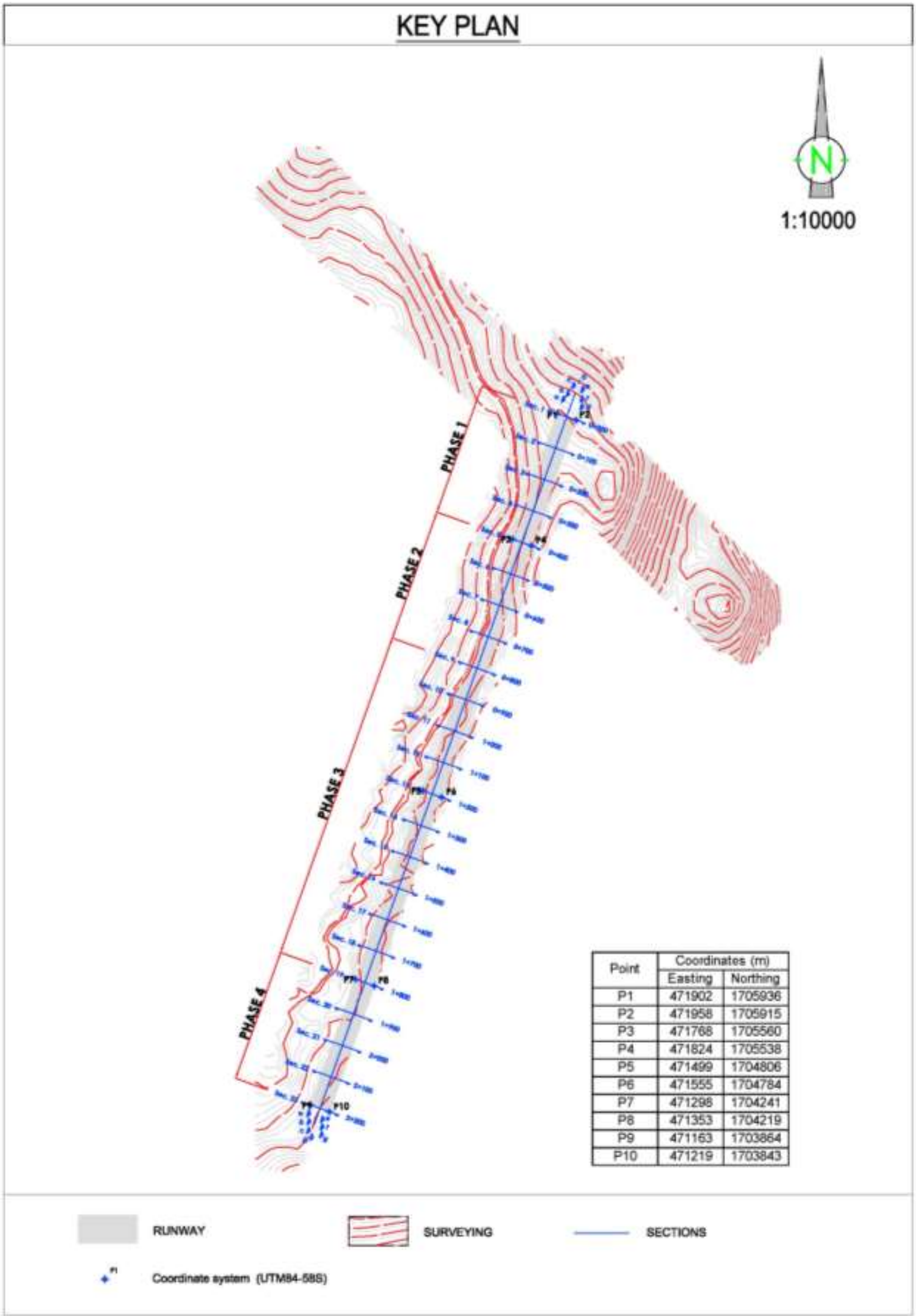
The runway has been designed for 0% transversal slope and very limited longitudinal slope (up to 0.8%). The runway layout has been designed to avoid the superimposition on the lake ice blisters present in the moraine. The runway embankment is intended to be constructed using the material available from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

Figure 2.4 (a) and (b) shows the moraine and the lake ice blister, respectively.

(a)

(b)

Figure 2.4: Boulder Clay Moraine (a) and Lake ice blister (b) at Boulder Clay Site (11 November 2014).



Point	Coordinates (m)	
	Easting	Northing
P1	471902	1705936
P2	471958	1705915
P3	471768	1705560
P4	471824	1705538
P5	471499	1704806
P6	471555	1704784
P7	471298	1704241
P8	471353	1704219
P9	471163	1703864
P10	471219	1703843

Figure 2.5: Runway layout with the four construction phases.

2.3.3. Runway facilities

Figure 2.6 illustrates the planned facilities. The different areas object of the project will be :

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

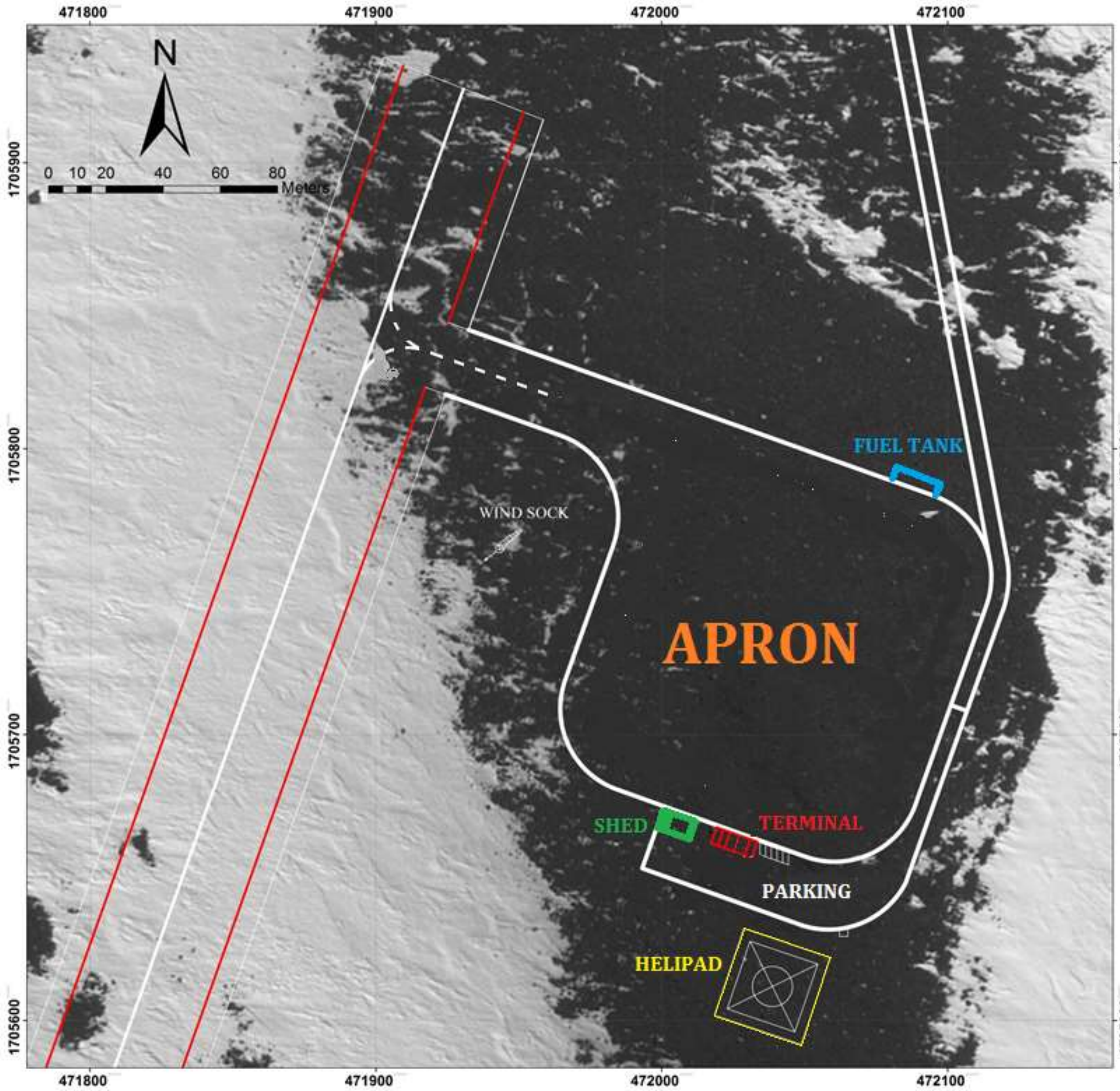


Figure 2.6: Runway facilities: Apron, taxiways, fuel tank, helipad, and vehicle access road.

Taxiway

The traffic routes in question consist of a single way (70 m long, 25 m width) 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 general criteria proposed for fire services follows ICAO standards.

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 this airstrip is classified in ICAO 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 shed to recover at least two 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 (Jet A-1 category) will be stored in a double walled stainless steel tank, with a total capacity of 44,000 l (see Figure 2.6) enough to provide the refuelling capacity needed for two Hercules intercontinental flights. The tank will be mounted on sledge, facilitating the transportation and dismantling.

Refuelling will be provided by 2 truck tanks moved from MZS to the Apron.

Terminal and shed

The reception facility will be installed on the south side of the apron. The structure, constituted by 6 20-foot ISO standard equipped insulated container, will consist in waiting room, offices and chemical toilet services. The preassembled structure will be totally modular, simplifying extension, moving and dismantling.

A shed (14x7x5 m) will be installed in the southward side of the apron, in a underlying platform. The preassembled structure, similar to other warehouse and hangar present at MZS, will store the GPU (ground power unit) for the aircraft, the refuelling pump, firefighting vehicles and forklift.

Operation room

An operations room close to AWS Rita, at 265 m a.s.l. will be installed and will serve the two skiways at Enigma Lake and the future Boulder Clay runway. 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 operation room will, in prospective, be equipped with a state of the art remote sensing and camera system that would allow remoted management of landing, taxing, ground handling and taking-off. This has been demonstrated for the case of Örnsköldsvik Airport (Sweden) connected to Remote Tower Centre of Sundsvall-Timrå Airport (Sweden). ICAO regulation will be followed at this regard.

The facility, conceived as two 20-foot ISO standard 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.

Power

Concerning electrical power and heating of the installations, the buildings will be provided with a solar photovoltaic power plant of 25 kW for the production of electrical energy combined with a traditional power generator of 20 kW, that will act like backup system only. The use of this generator, in any case, will not be continuous but will be dependent upon the planned flight activities. For the heating and hot water production, solar thermal collectors of 5 kW will be installed. Both, the electrical and thermal systems should cover the energy needs of these installations

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 Clegg Hammer compaction tests and dynamic Light Weight Deflectometer (LWD) tests performed on the natural and non-compacted morainic debris. The laboratory tests consist in sieve analyses, Modified Proctor test and Standard Proctor test.

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

The site investigations carried out with the Clegg Hammer tests in early November 2013 reported an average CBR of 39%, in agreement with the site investigation carried out with the LWD in the same period (average 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.

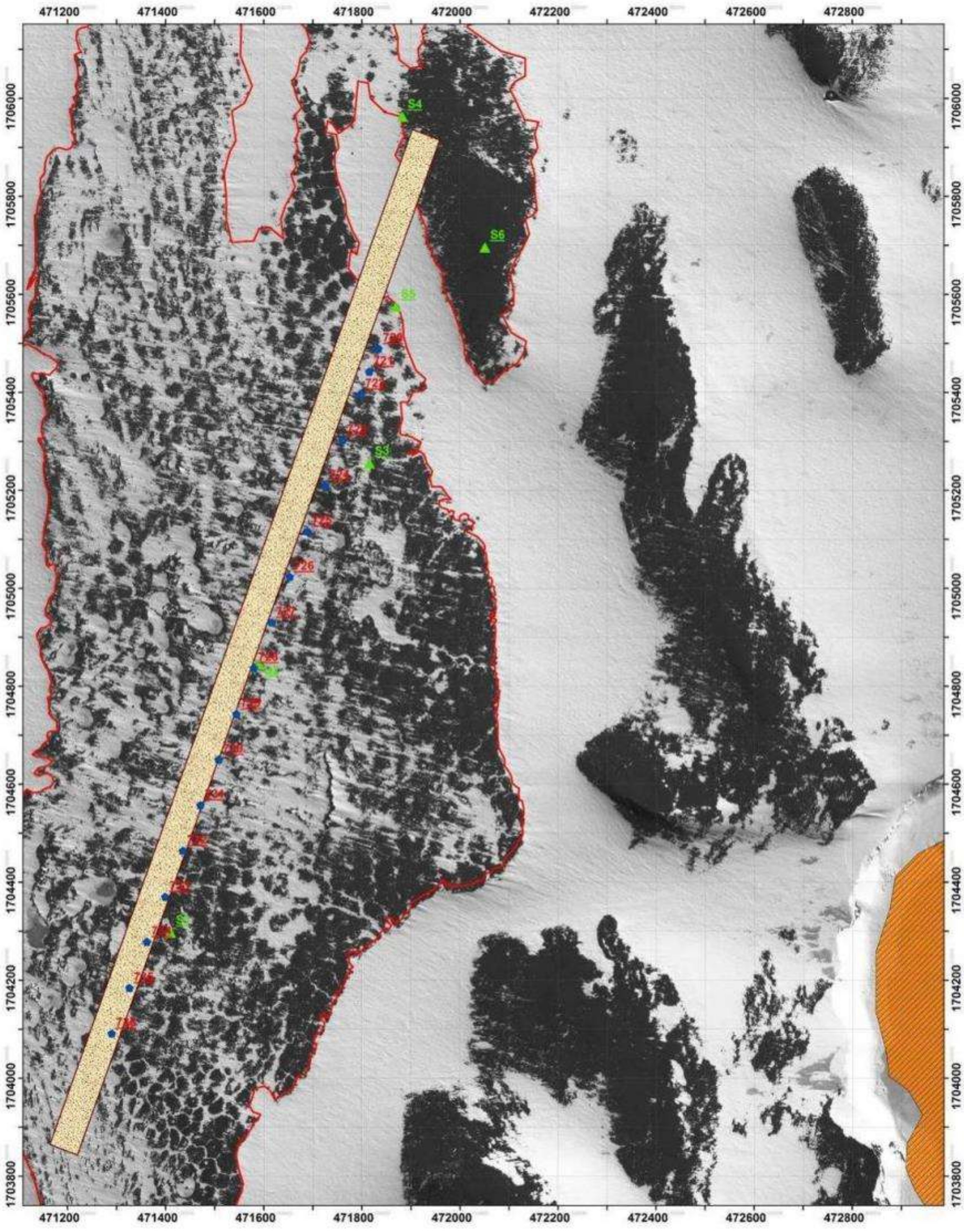


Figure 2.7: Ground investigations location (blue labels =XXIX Antarctica expedition, green labels = XXVIII Antarctica expedition).

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 4% 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.

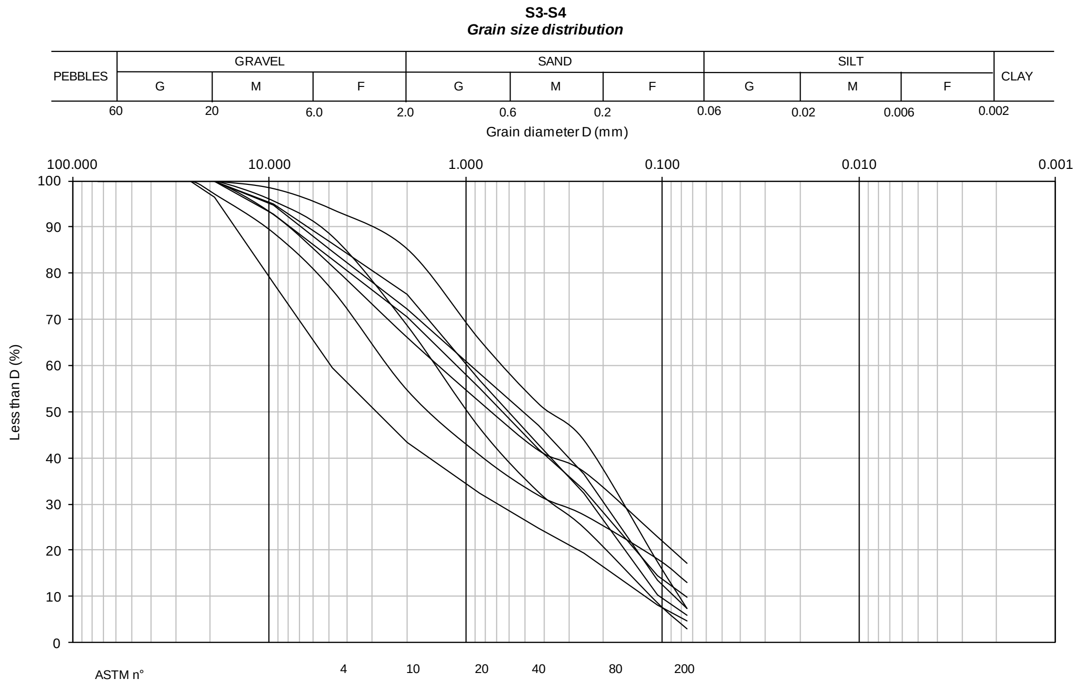


Figure 2.9: Grain size distribution (XXIX Antarctica expedition).

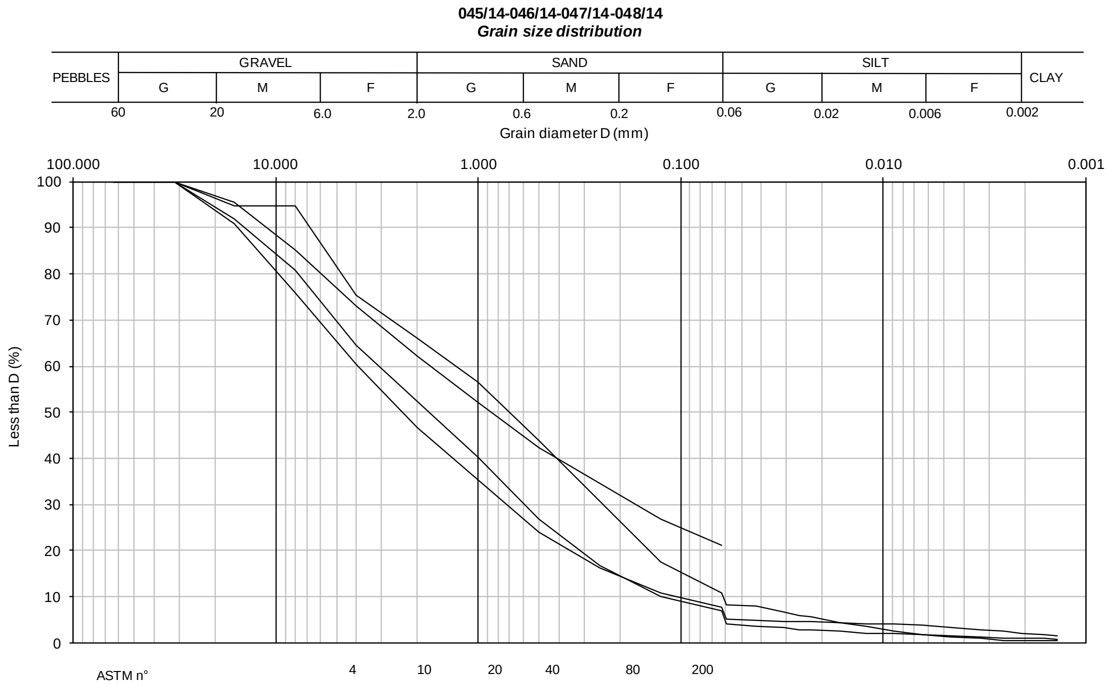


Figure 2.10: Grain size distribution (XXVIII Antarctica expedition).

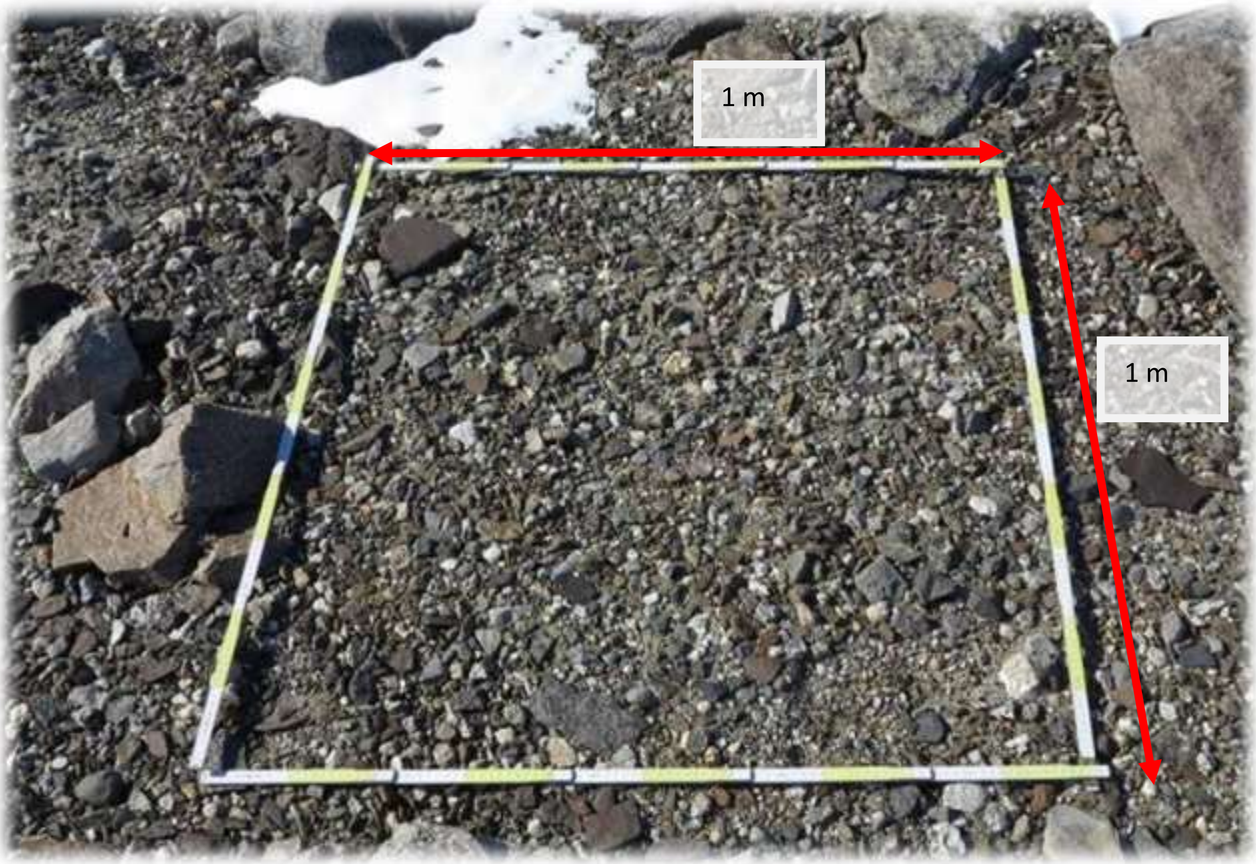


Figure 2.11: Moraine material at Boulder Clay site in a square meter (12 November 2014).

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/ft^3)	(kN/m^3)	
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.

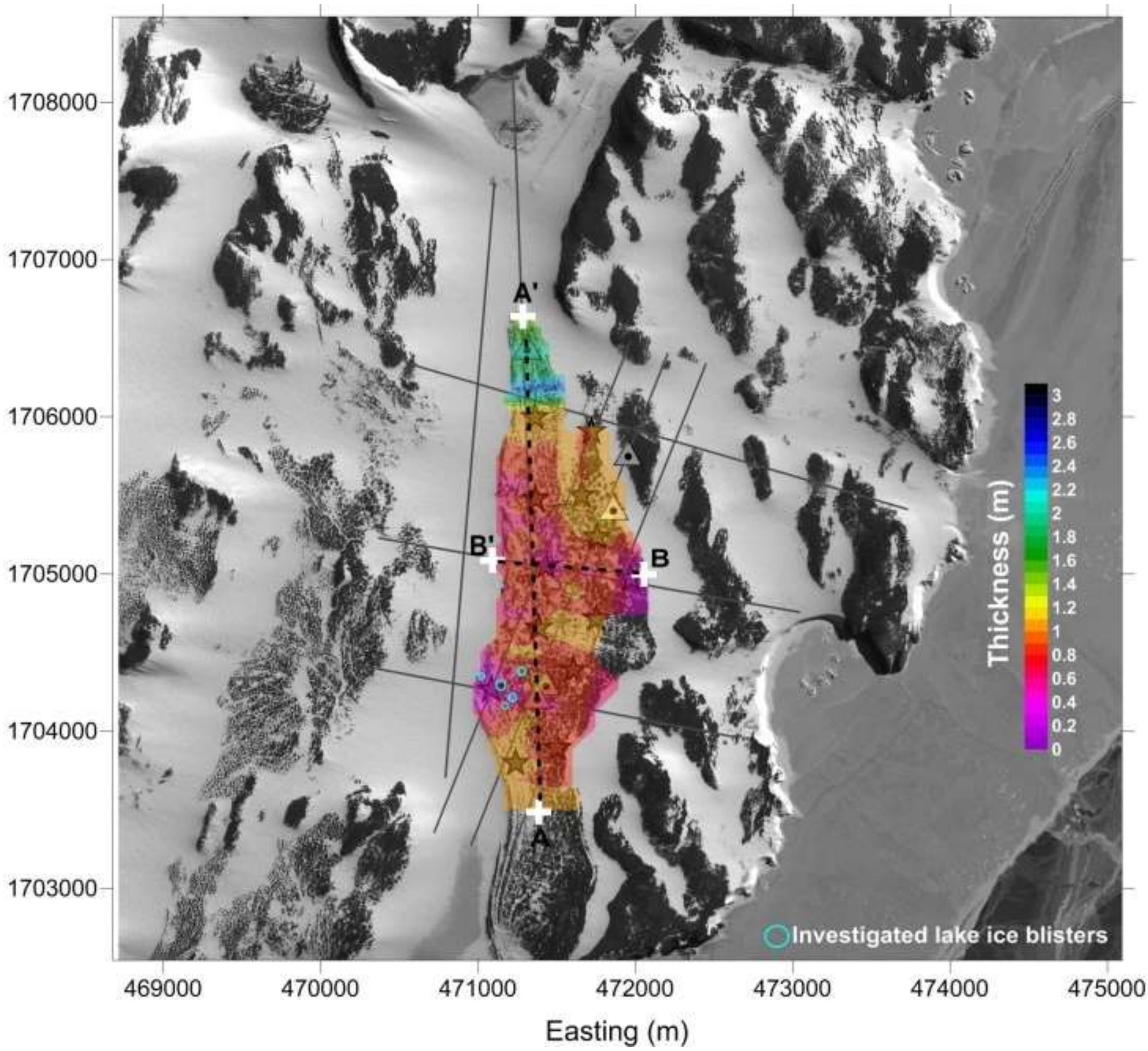


Figure 2.15: Representative map of debris thickness.

2.4. Airstrip construction and maintenance

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 the particular environmental Antarctic conditions, the embankment design took into account the following aspects:

- Permafrost protection.
- Geotechnical characteristics, according to U.S. Department of Transportation [2.6] and Transport Canada [2.7].
  Minimum volume of rock needed for the embankment and works

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).

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 following the results of a trial embankment carried out on site. 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.

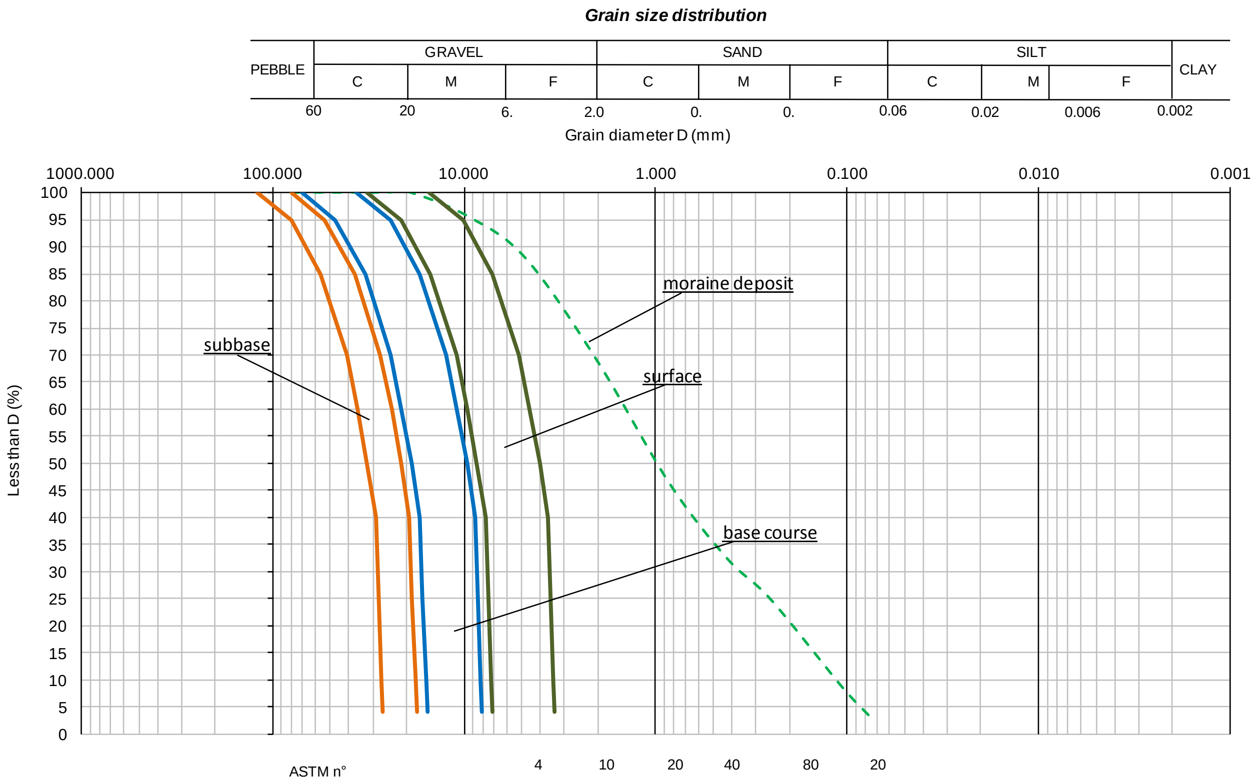


Figure 2.16: Sub-base, base course, surface Grain size distribution and relative layers

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 and environmental aspects

In order to determine the minimum embankment thickness (thus reducing the environmental impact related to the scraping of the surface, rock crushing and screening using heavy equipment), 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.

Table 2.2: Soil Frost Groups [2.6].

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

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)

Table 2.3: Reduced Subgrade Strength ratings [2.6].

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	

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% (measured on the natural morainic debris). This degradation of the subgrade takes place during a very limited period of the year (middle December to late January) 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.

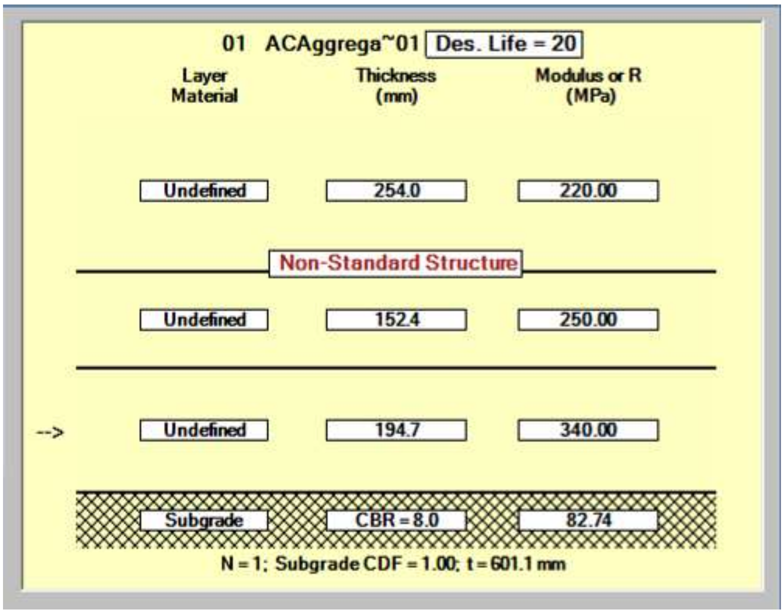


Figure 2.18: FAARFIELD software results for a subgrade with a reduced CBR=8% [2.6].

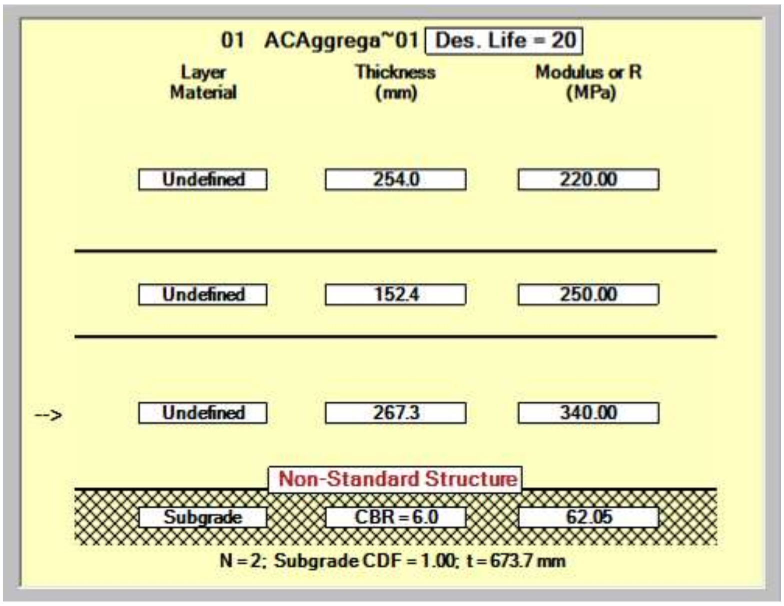


Figure 2.19: FAARFIELD software results for a subgrade with a reduced CBR=6% [2.6].

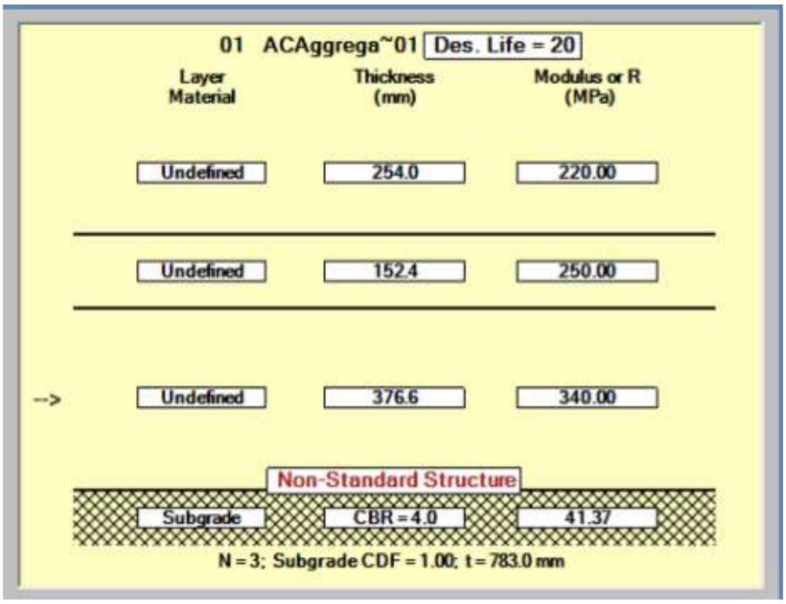


Figure 2.20: FAARFIELD software results for a subgrade with a reduced CBR=4% [2.6].

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.

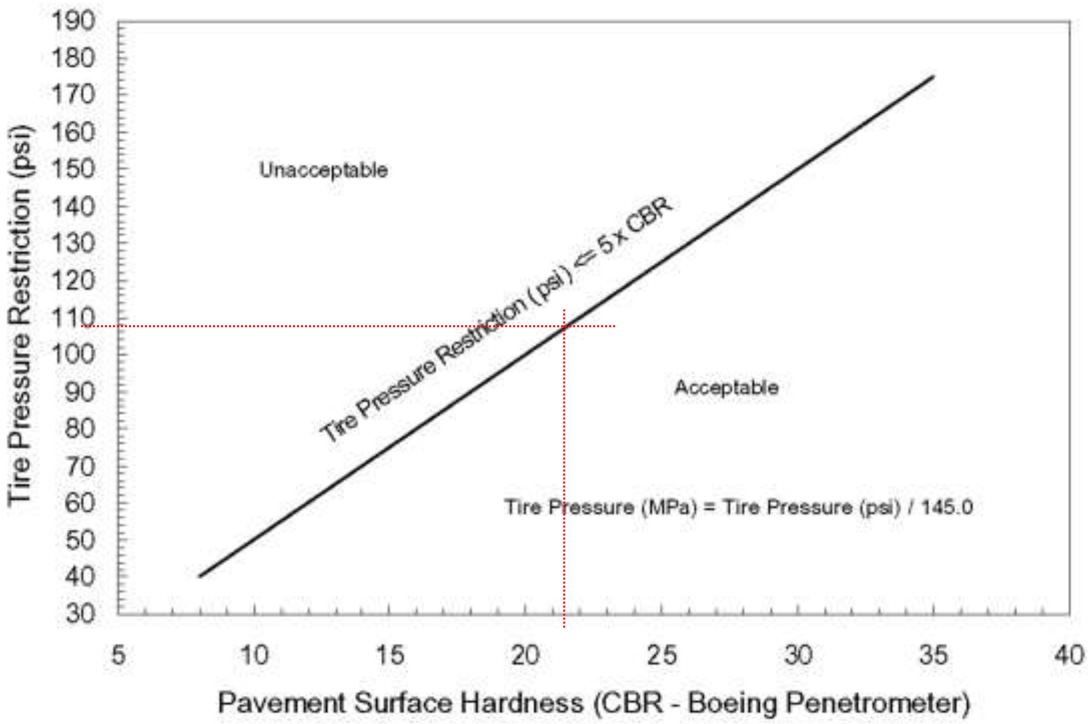


Figure 2.21: Tire Pressure Restriction vs CBR Measured with Boeing Penetrometer [2.7].

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.

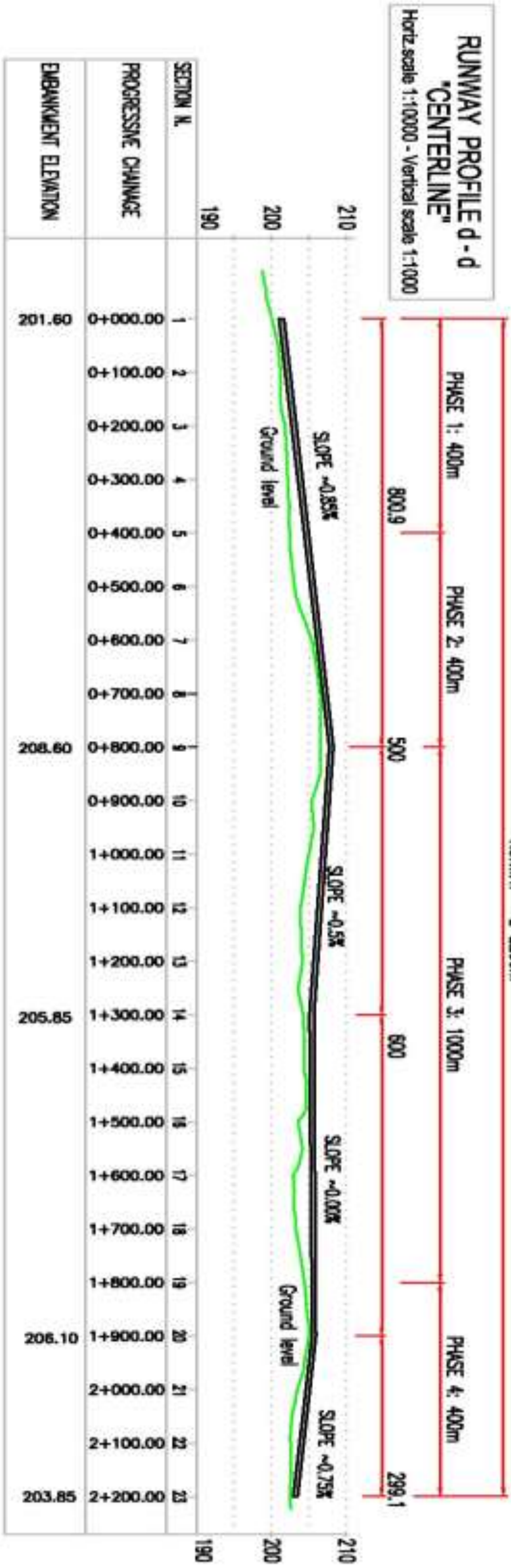


Figure 2.22: Runway profile d-d (centreline).

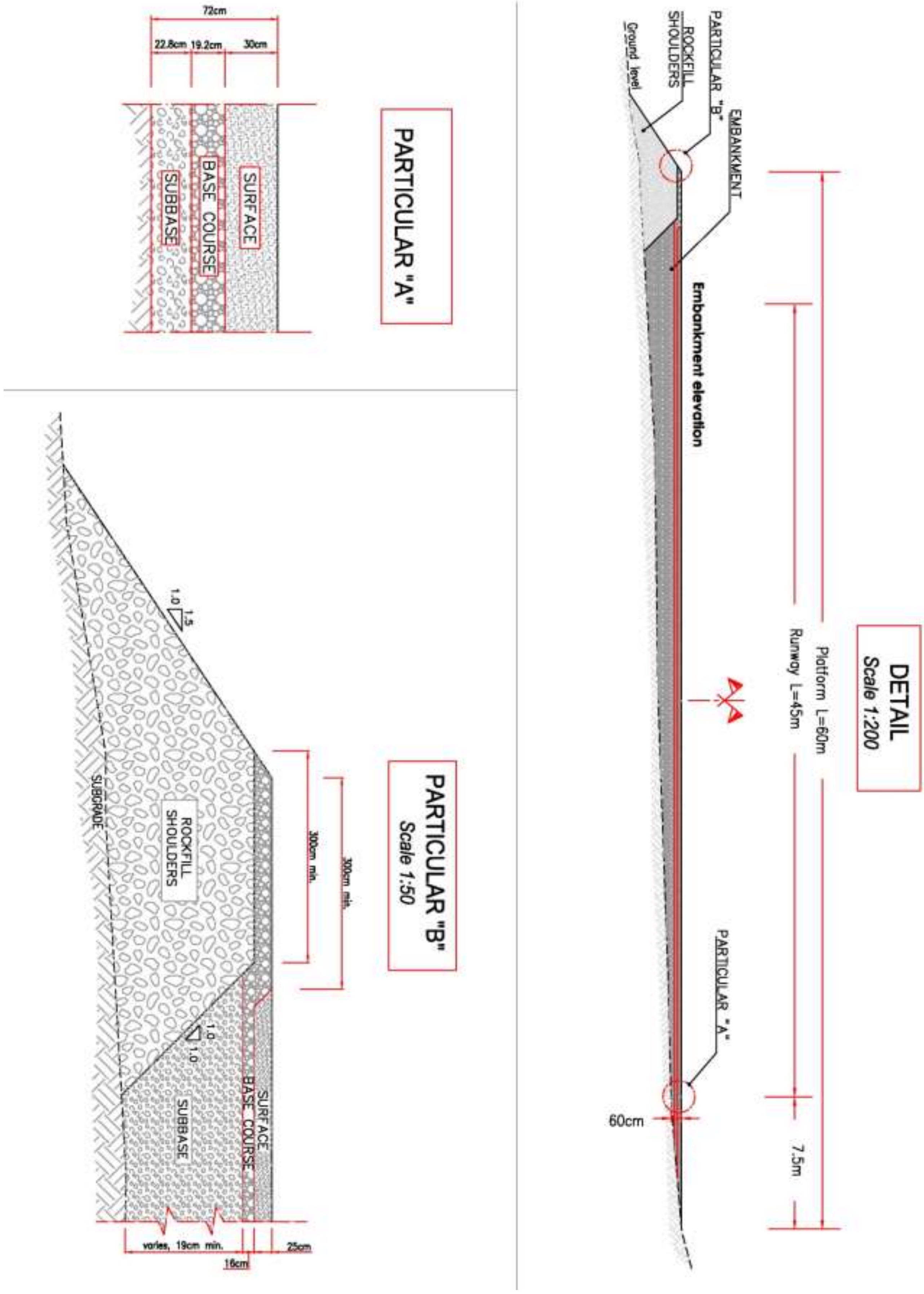


Figure 2.23: Detail of Runway section, with embankment and shoulders profile.

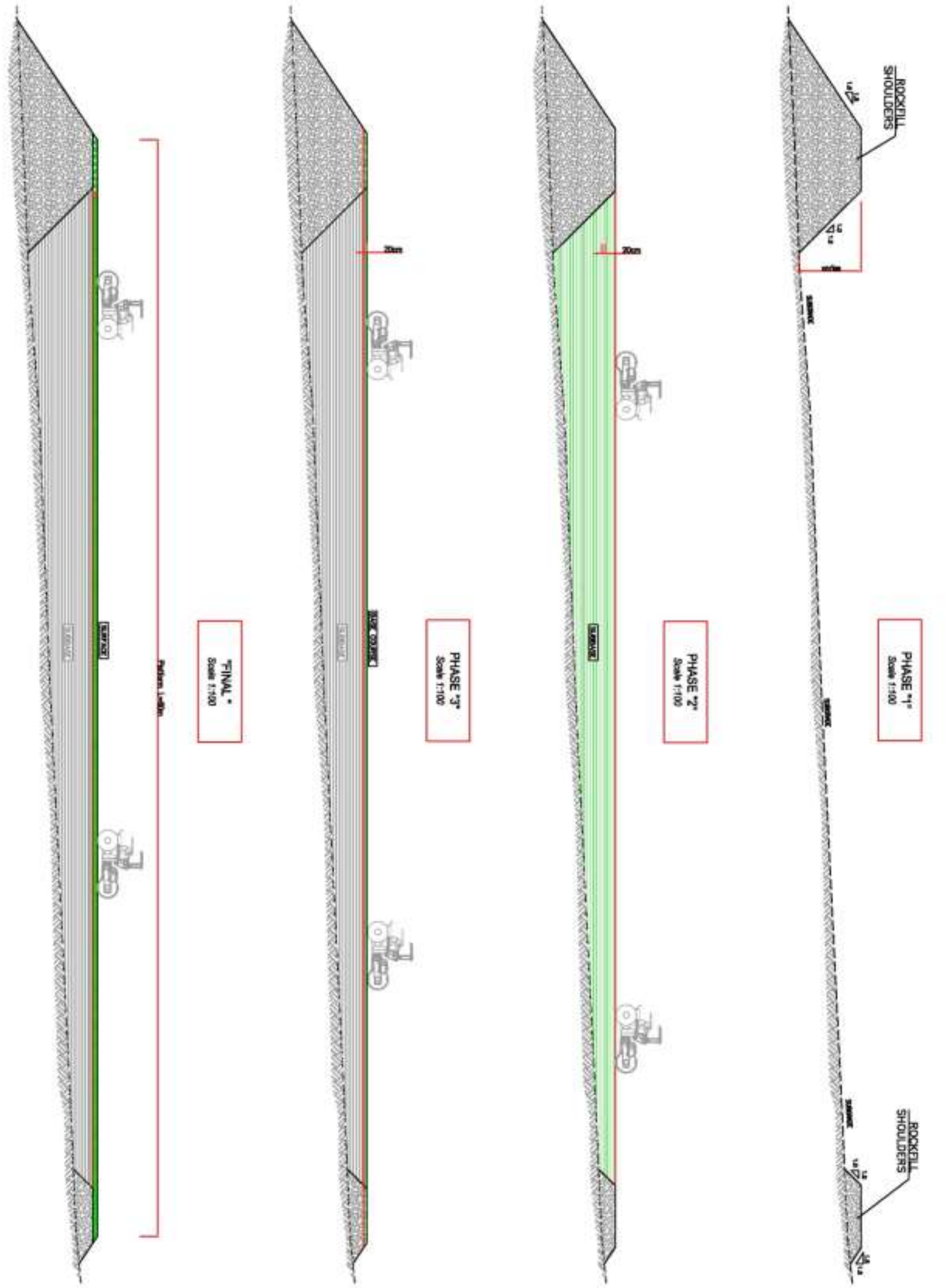


Figure 2.24: Construction phases.

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

Figure 2.25and 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 sub-base material has been used to model the side shoulders and the base-coarse layers.

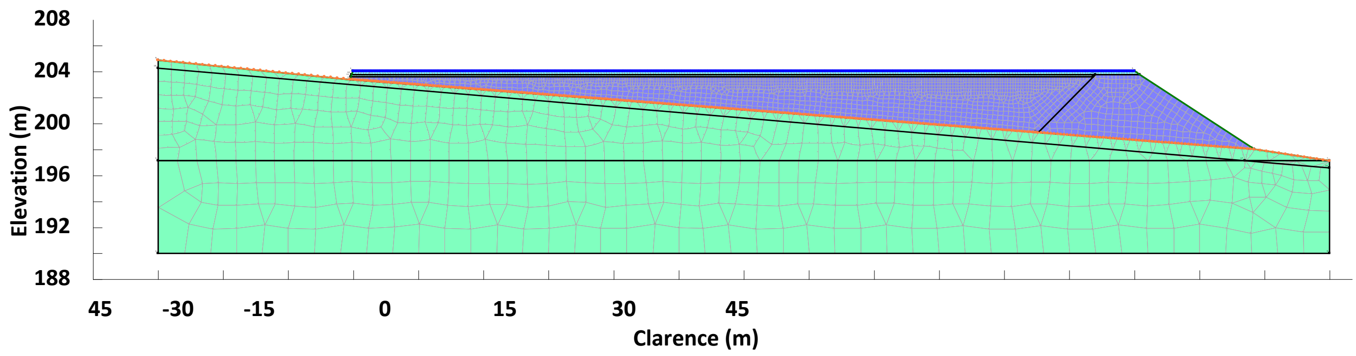


Figure 2.25: Model geometry.

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.

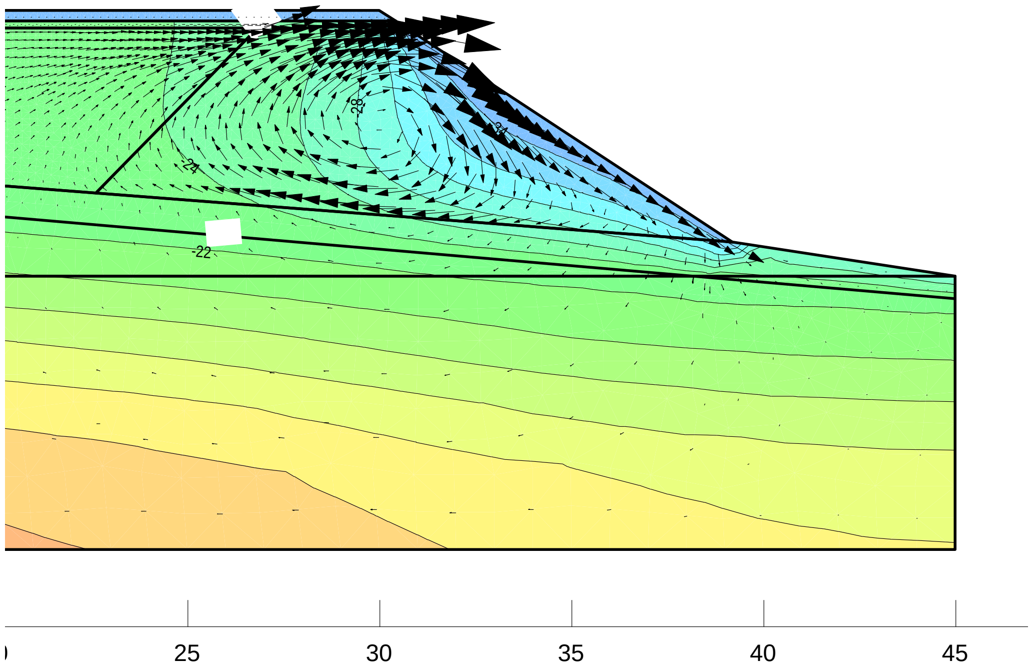


Figure 2.26: Numerical result – convective cells and temperatures (Day 220).

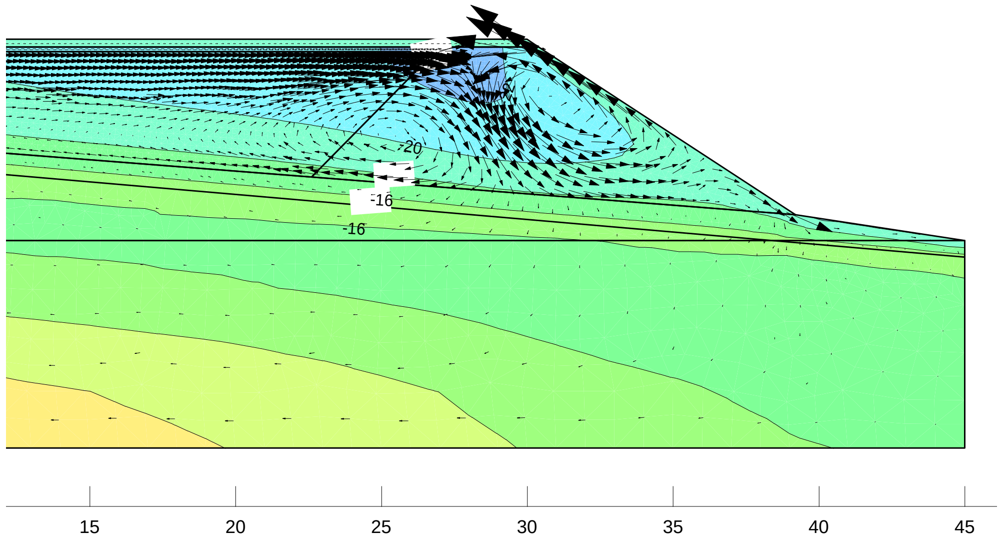


Figure 2.27: Numerical result – convective cells and temperatures (Day 270).

The analysis herein presented gave a basis for the design by assessing the development of natural convection of the pore air in the gravel embankment due to temperature gradients.

2.4.4. Material requirements and quarries

On the basis of the available survey, the discussed layout and the embankment profile, the volume of material required to form the embankment was estimated. 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.

Table 2.5: Volume of material required to realize the embankment

	L (m)	Volume (m^3) Main platform of the embankment	East side Rockfill shoulder	West side Rockfill shoulder	Shoulders + 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 (quarries identified with the n° 1 in Figure 2.29) 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 (see also Table 2.6).

The total area of the quarries pointed out in Figure 2.29 is 285,000 m^2, assuming a digging depth of about 1 meter we obtain a volume of 250,000 m^3 of debris. This material, which will constitute the necessary amount for the gravel embankment, would be exclusively extracted by mechanical excavation.

Table 2.6: Quarries data (see figure 2.29).

Quarries	Area (m^2)	Volume (m^3)
1	18,000	15,750
2	80,000	70,000
3	60,000	52,500
4	70,000	61,250
5	25,000	21,875
6	35,000	30,625

The sites where we intend to carry out a blasting excavation are the apron zone and the ridges present on the moraine along the airstrip area at 1,450 m from the north extremity for a total volume evaluated at about 3,000 m^3. The expected explosive's quantity to be used is 1.0 ton (yield of 0.30 kg/m^3).

In these areas blasting activities 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.

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.

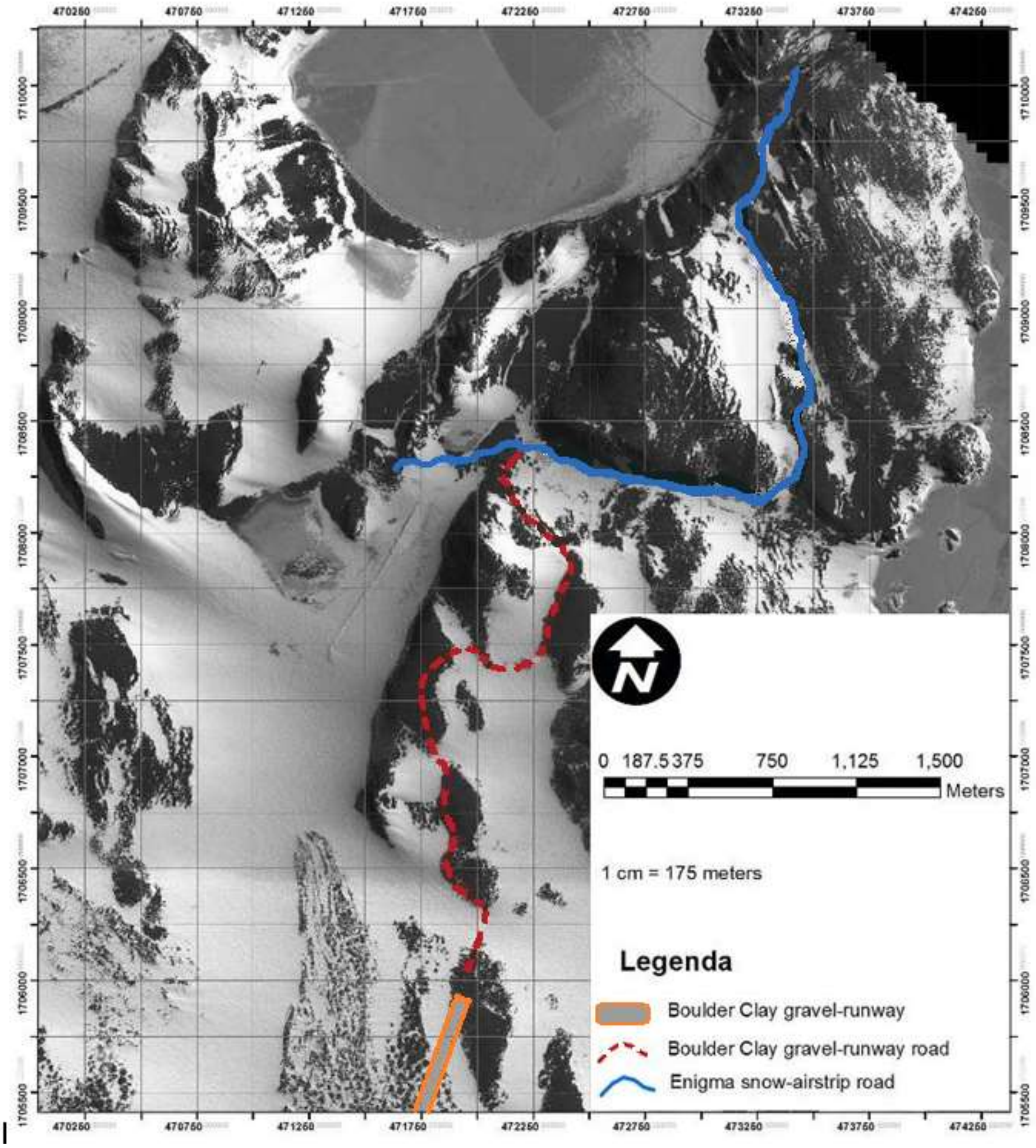


Figure 2.28: Roads to access the runway site at Boulder Clay.

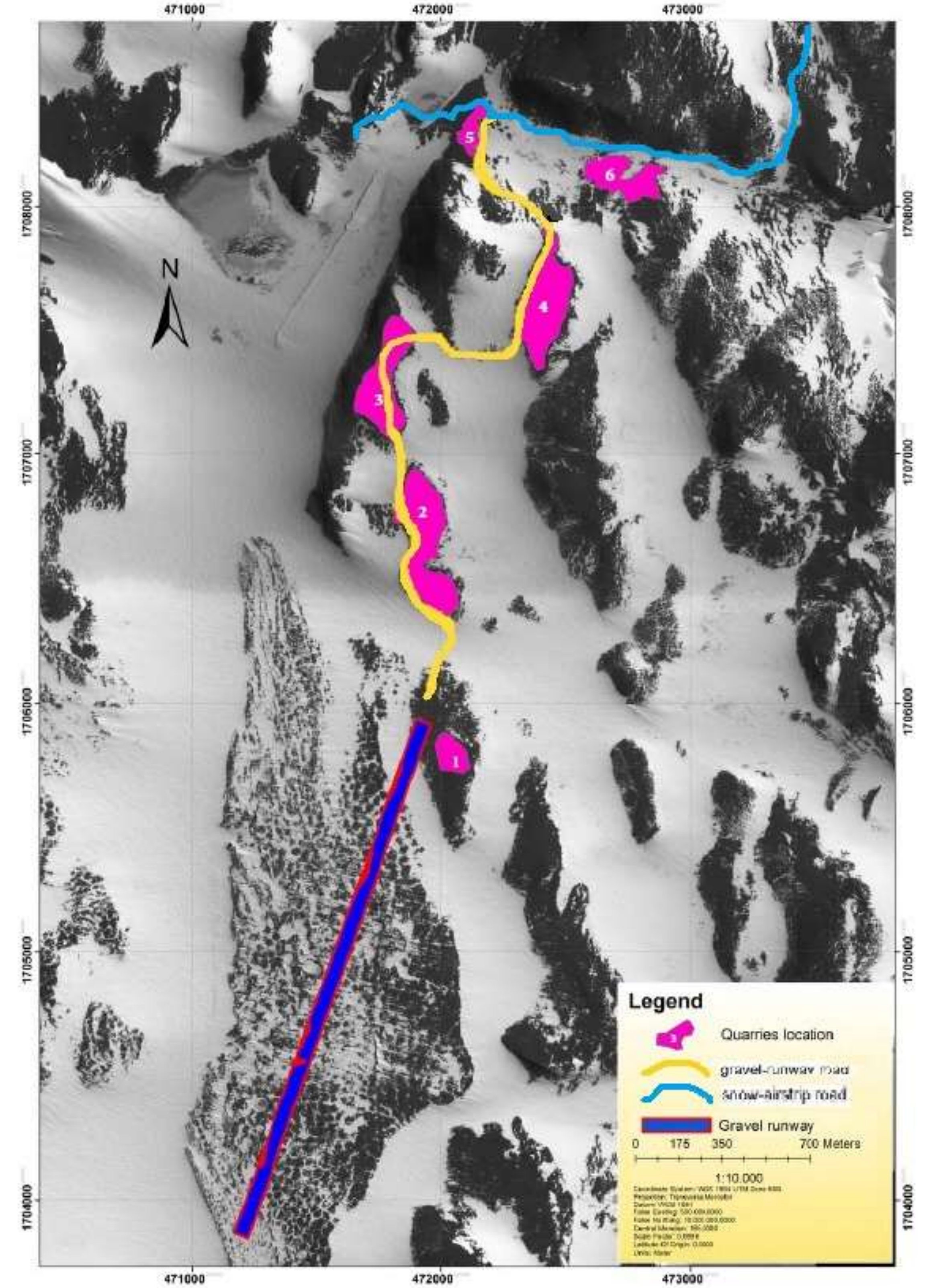


Figure 2.29: Potential quarries location (in magenta).

2.4.5. Construction Method

Case histories: The definition of the method for the runway construction and maintenance took into account the results of similar works and tests regarding convection embankment or unpaved gravel runway carried out mainly in the Arctic, where the climatic conditions more resemble those of MZS.

- *Tasiujaq Airport (Canada),* a runway located in the south-western part of Ungava Bay at 58°71'N and 69°82'W, that suffered depressions along the shoulders caused by an accelerated thaw of the permafrost underneath, likely due to the conventional embankment of the airstrip;
- *Fairbanks Test Site (Alaska),* an experimental air convection embankment designed and constructed in 1992-93, that gave indications on the effectiveness of air convection embankment in limiting or eliminating thaw of permafrost;
- *Nunavik airfields (Québec),* where in 2005 and 2006 the MTQ (Ministère des Transports du Québec) studied and assessed the air convective embankment as the mitigation methodology to be implemented against permafrost degradation affecting the integrity of transportation infrastructures and paved access roads;
- *Leismer Airport (Canada),* where APMS (Airfield Pavement Management Systems, Velsen-Suid, the Netherlands) executes test procedures and calculations for assessing successful usability of unpaved gravel runways for aircraft operations in cold environment.

Excavation: Before beginning excavation the area will be cleared from cobbles and rock fragments having dimension greater than 15 cm approximately. The suitability of material to be placed in embankments will be subject to prior qualification. Excavation will be performed only locally where ridge formations have been recorded in order 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 will 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.

Blasting: Blasting is planned to be implemented only when mechanical excavation will not be possible. The sites where blasting will be conducted are the apron zone and the ridges present on the moraine along the airstrip for a maximum evaluated volume of 3000 m3. A vibration consultant will be consulted, to advise on explosive charge weights per delay and to analyse records from seismograph recordings and record of each blast fired, its date, time and location will be kept;.

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 will 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.

Site work operation: The construction phase will be mainly articulated in the following actions: scraping, grading, transporting and compacting operations.

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

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

In addition, other heavy equipment will be provided 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 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

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.

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.

The repair material will be collected in the same quarries used for the construction phase.

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.

2.5. 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, as in Table 2.7:

Table 2.7: Runway characteristic points

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 205.66 m and the elevation of THR 20 is 201.60 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.

Figure 2.23 shows an example of the runway profile. The cross slope of this runway is 0.0%.

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

- L100/30;
- C130/J.

Aircraft characteristics are summarized in Table 2.8.

Table 2.8: Design aircrafts characteristics

Aircraft	Gear Type	Equivalent single gear load (kg)	Tyre 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

Figure 2.30 shows a typical layout of a C130 cargo aircraft.

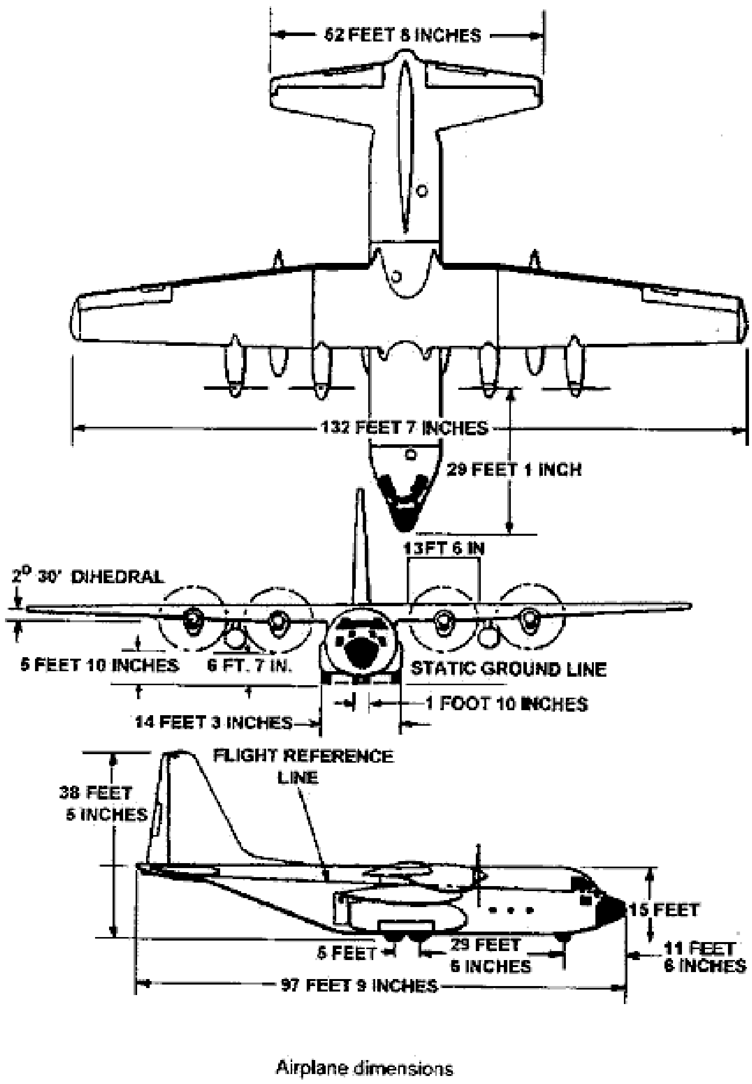


Figure 2.30: Typical C130 Cargo dimensions

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2.5.2. **Runway Considerations**

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

Table 2.9: Runway characteristics

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

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

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.

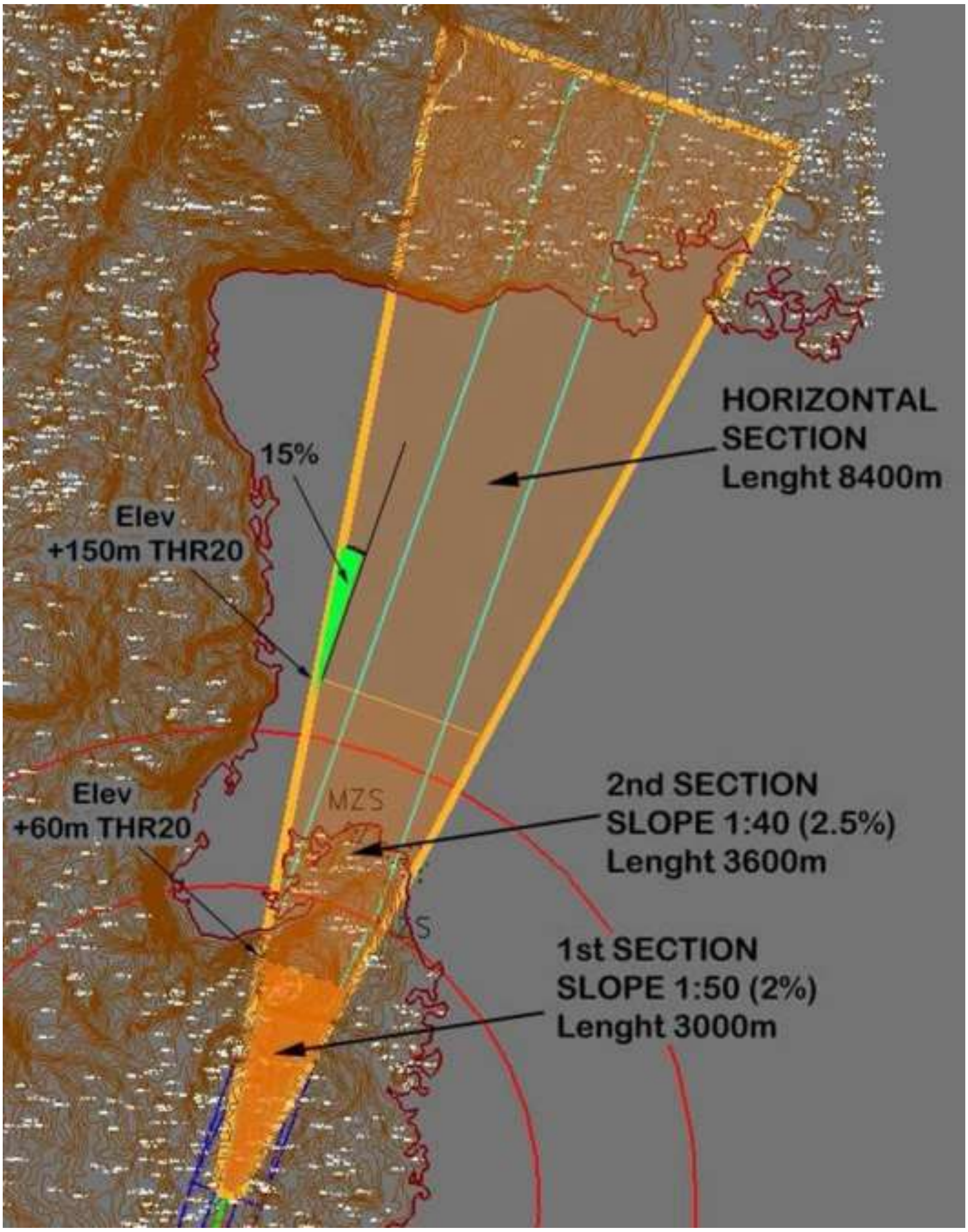

Figure 2.31: Approach Surface RWY20 (AS RWY20).

2.6. Operation plan and international profits

Having a permanent runway will allow intercontinental air operations to be distributed throughout the entire summer season. This will make the planning implementation 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, avoiding 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.

Italy does not pursue any intention to operate touristic companies on this gravel runway.

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 could no longer rely on maintaining large costly over-stocked warehouses in anticipation of possible failures.

2.6.1. **Airstrip operation plan**

Despite the airstrip design set on 30 flights/year, the Italian needs at mid-term range wouldn’t require a significant increase of flights respect 6-8 seasonally made for each research expedition. The moved personnel and freights are determined by the size and the needs of the 2 Italian Station, with about 70 accommodations for Concordia (shared with IPEV) and about 100 for MZS.

We expect not more than 15 flights/year operated with the built up gravel runway at BC, with the main advantage to spread the intercontinental aircraft activity throughout the campaign period.

A realistic aircraft planning in case of the presence of the Boulder Clay airstrip would be the following:

- First period flights operated, as usual, on ice pack, for a reasonable number (from 5 to 7), to start the scientific and logistic activity (mid-October to mid-November);

- second (December) third period (mid-January to mid-February), with flights scheduled on the gravel runway: 2 (or 3) mid-season connections to rotate personnel and 3 (to 5) flights in the last portion of the campaign to close the Stations, move people and freights back to NZ.

It must also be considered that this schedule would be subject to the actual logistic and scientific needs, changing year by year.

In this configuration (with less than 15 flights) the increase in fuel consumption would not be excessive and compatible with the present planned biyearly fuel resupply of MZS.

At present, average calculated (over last 6 years) fuel consumption for intercontinental flights weight the 25% of to the total annual fuel consumption of MZS. We intend to close the gap related to the increase of flights, with the new gravel runway by improving the energy efficiency of MZS that can reduce up to the 50% the total annual fuel consumption.

2.6.2. **International profits**

The possible users of the permanent runway are not limited only to the Italian program. Gondwana Station that belongs to the German BGR is only 13 kilometres from MZS in Terra Nova Bay area. The small summer station it is not manned every season and for intercontinental connections and logistic operations BGR often relies on PNRA. For these reasons BGR has been already formally stated the interest about the construction of the permanent runway at BC.

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 and Korean Program began an exchange of reciprocal support. 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.

The French program IPEV will benefit from the proposed facility, because PNRA 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 difficult conditions in resupplying its main station, Dumont d'Urville, by vessel (Astrolabe), because of the sea ice accumulation 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 schedule.

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 the safety in air operations by providing a reliable alternate airfield.

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.

The Polar Research Institute of China announced the interest in establishing a new research station in the Ross Sea area, investigating the site of Inexpressible Island, in the Terra Nova Bay area. Although no formal talks have been made, it is likely the Chinese Program may also have an interest in having a permanent runway close to this new station.

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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, particular attention was given to ensure compliance with the Antarctic Treaty and the Madrid Protocol, as well as Italy's relevant laws and regulations.

Full reference has been given to the Convention on Biological Diversity, to 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.

In the Southern area of the Northern Foothills with respect to MZS, inspections were conducted on many sites to assess the preliminary technical feasibility of this infrastructure, considering the length that aimed to be built, the aeronautical constraints and the orography of the terrain.

Only two locations on the land were retained as possible sites and considered adequate, for technical reasons, for the construction of the gravel runway. These were “Boulder Clay” (BC) 74° 44’45’’S, 164° 01'17’’E, 205 m a.s.l., and “Campo Antenne” (74°4219,2”S, 164°06’19,6”). Another site (Nansen Ice Sheet) had already been investigated for a permanent blue ice runway, but although used in the past a few times for landing, resulted not anymore suitable and of unpredictable availability, due to climatic conditions.

Boulder Clay was finally chosen, through an evaluation process that kept in consideration to minimize the overall environmental impact of the proposed activity, especially during the construction phase, thus guaranteeing efficiency and safety in relation with wind direction.

3.1. Situation of skiway operations at Mario Zucchelli Station

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 air 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

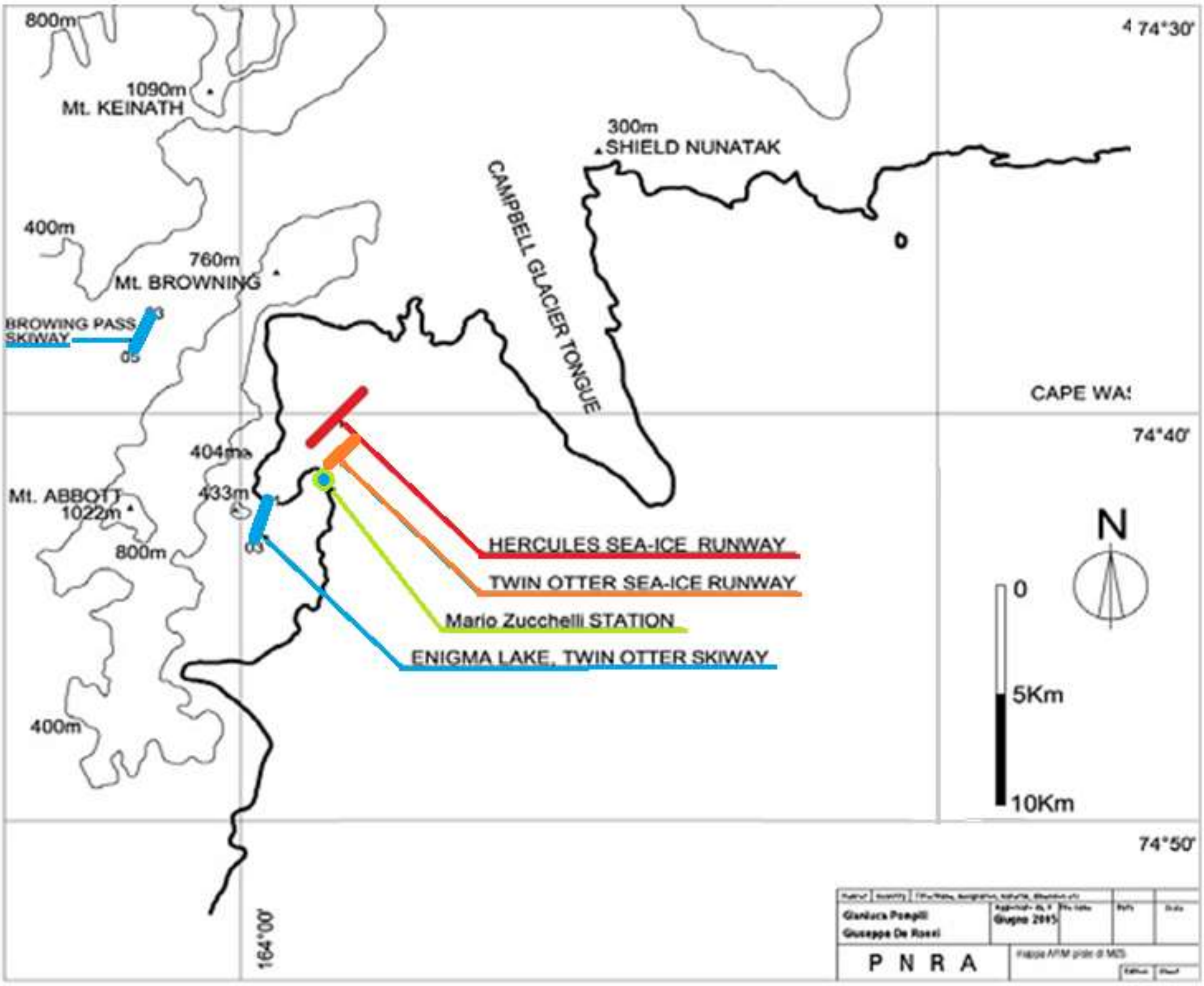

Figure 3.1: Locations of the available icestrips around MZS

(red line for the Hercules icestrip and blue/orange lines for Twin Otter icestrip/skiways respectively)

PNRA flights are currently operated chartering an Hercules aircraft and using the MZS ice runway that is suitable for landing of wheeled aircrafts, as much as it is possible. Usually the availability of such ice runway ends in late November - early December, because the ice sheet thickness and strength decrease to unsafe values. Therefore autonomous personnel and freights transport stops completely (except for what is kindly ensured by the US NSF air support via McMurdo station), till the arrival of the Italian 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 durability in summer, pushing offshore broken ice sheets and eventually causing premature shutdowns.

PNRA also operates smaller ski equipped aircrafts (Twin Otter and Basler), for the continental flights connection between MZS , Concordia, DDU and McMurdo Stations. For this activity, to face changes in weather and skiway conditions, several skiways 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

For landing of intercontinental flights operated by large wheeled aircrafts as the Hercules L100/30, in the past seasons, other landing areas were investigated and for a year 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) and then resulted not anymore suitable and, due to climatic conditions, of unpredictable availability during the season.

Currently the Gerlache Inlet ice runway remains the only facility for PNRA to operate intercontinental flights to MZS in early summer.

In the last ten years, during the summer season, an earlier increase of fast ice temperatures over the airstrip area, was observed. In addition also a thinning of the ice sheet was measured. 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. Also other National Antarctic Programs experienced such difficulties. 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.

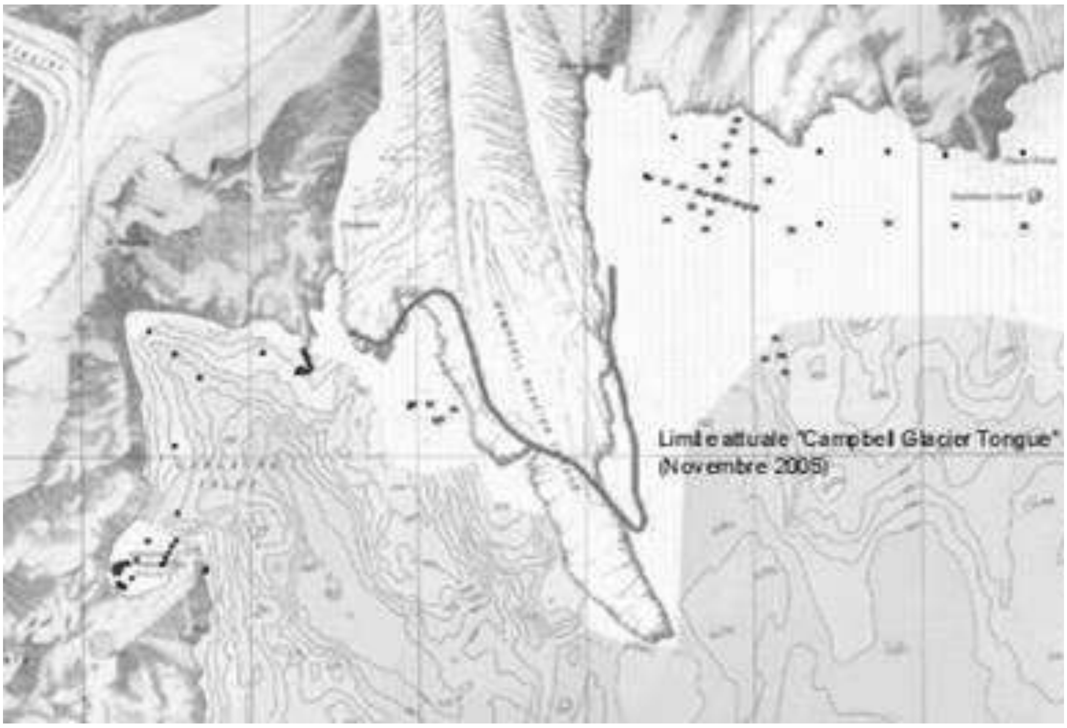

Figure 3.2: The Campbell Ice Tongue before and after November 2005.

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.

As a consequence, 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 activities to be too seriously affected, but PNRA dependencies strongly dependent upon the establishment of 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. Non proceeding alternative: evaluation of the naval operations

As already anticipated, in the last decade and every two years PNRA chartered the vessel Italica (Figure 3.3) to transport fuel, heavy loads and personnel to MZS, as well as to run oceanographic research.

Figure 3.3: The vessel Italica.

The main technical characteristics of this ice class vessel are briefly shown below.

ITALICA Master Data	
Size:	121 m x 17 m
Gross Tonnage:	5,825 ton
Net Tonnage:	2,473 ton
Consumption at cruise 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. Between mid December (earlier arrival is not possible due to sea ice conditions) to beginning of February, it is also the only autonomous mean of transportation of PNRA personnel in/out from Antarctica. This means that, without the US NSF and other neighboring Antarctic Programs support, Italy would be obliged to charter the vessel every year to ensure the transportation of personnel at the end of the season.

In this hypothesis, that corresponds to the non-proceeding alternative, the flue gases emissions and related human footprint of the PNRA expedition would increase a lot, as demonstrated also by IP32 (ATCM 36), whose conclusions after analysis of the DROMLAND air system vs transport on the vessel POLARSTERN were that "*the produced emissions per passenger by air are lower than the value produced with Polarstern*". The contrary was observed for cargo transportation.

Similarly, only considering at the end of the season, half a month of cruise dedicated for personnel transportation, the vessel, would need the equivalent in fuel of 10 intercontinental two-way fights made with Hercules L100/30.

Fuel consumption and total emissions in the hypothesis of autonomous maritime transportation of personnel at the end of the season are estimated in Table 3.1.

Table 3.1: Estimated fuel consumption and total emissions in the hypothesis of autonomous maritime transportation of personnel at the end of the season (15 g cruise).

Source	*Fuel Type*	*Total Fuel Consumption (ton)*	*Emission Pollutants*	*Emission factor (g/kg)*	*Total Emission (ton)*
Vessel Italica	Antarctic diesel	250	CO	0.71	0.18
			NO_x	3.41	0.85
			SO_2	33.44	8.36
			PM10	0.28	0.7
			CO_2	879	219.7

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 more efficient management system involving the lower possible chartering of the vessel, would 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. Alternative airstrip sites

3.3.1. Efficiency of intercontinental operations at MZS

The sea-ice runway for Hercules L100/30 aircraft, located in the Gerlache Inlet close to MZS (Figure 3.1, red line). ends its operability in late November, when the sea-ice sheet does not anymore guarantee safe operations.

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. After November, 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). Although the USAP help was fundamental in these years, transiting through McM has an impact on US-NSF operations and remains a costly and less efficient operative way.

A more effective transportation way comes from the support of KOPRI, that during the last seasons helped the PNRA operations by means of the Araon vessel, usually reaching the close Jang Bogo Station every year in austral summer. However the available capacity of support of KOPRI cannot cover all PNRA needs, as also in this case, this would result in an impact on their own Antarctic Programme.

3.3.2. 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)".

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 this site was dictated from the wish to fix the problems related to the fast ice runway. The IEE resulted in a work having impacts on the environment less than minor or transitory, despite the long distance of the chosen site, over 50 km away, from the operative area of MZS to be covered via surface truck,.

The Nansen blue ice runway was operated in a few episodes 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.

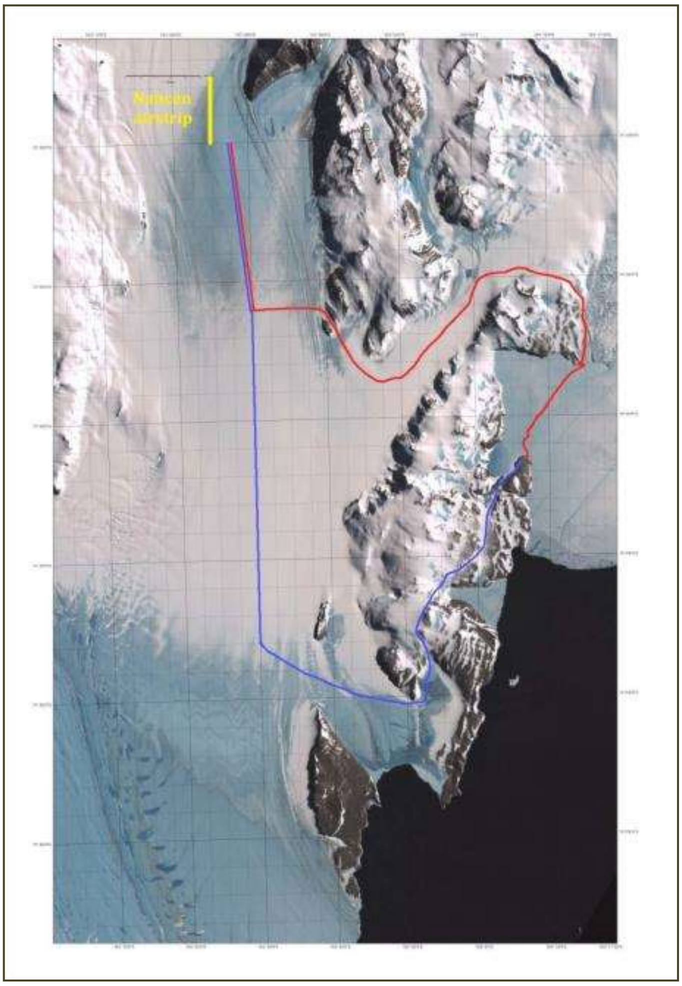

Figure 3.4: Locations of Nansen ice strip (yellow line) and the track of the two roads from MZS.

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. After 25 years, thanks to the efforts of the researchers and logistic engineers of PNRA, the knowledge has been greatly improved.

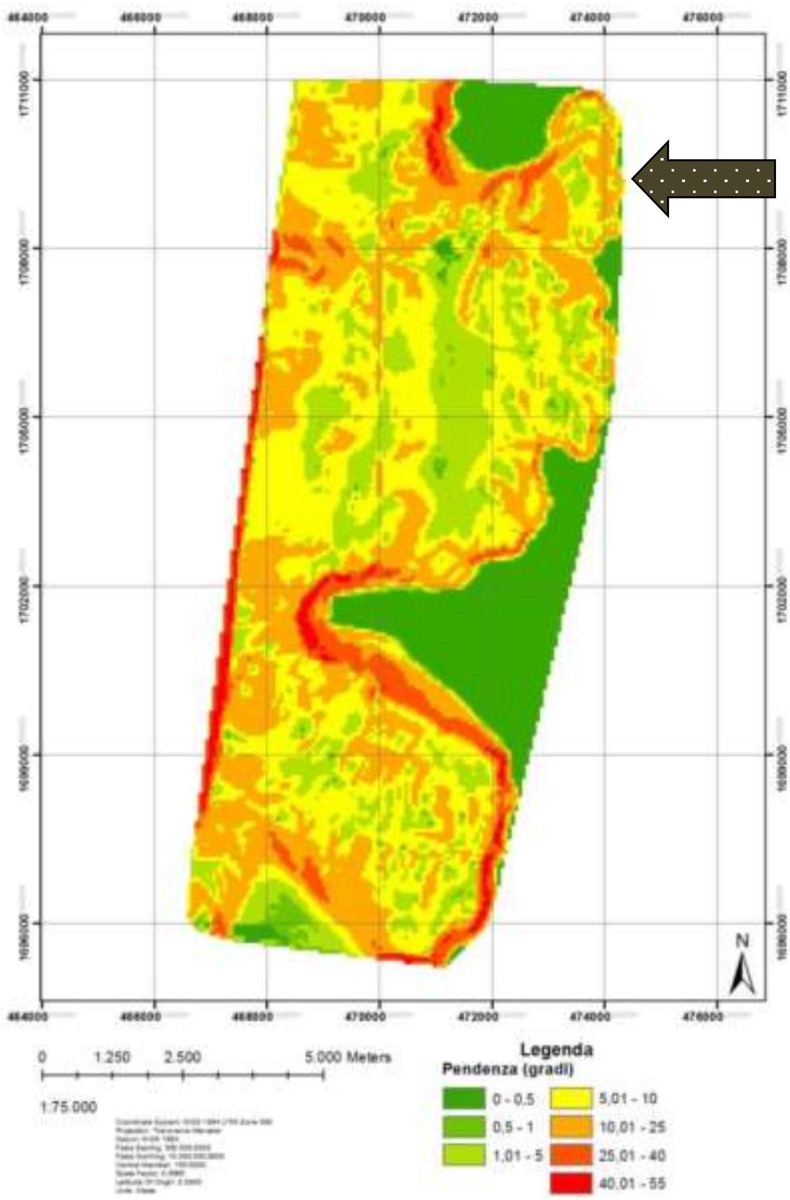

Figure 3.5: A slope map of the area around the station and the alternative location for the airstrip at Campo Antenne (black arrow).

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 detailed the work done in the 90's and identified one additional area, Campo Antenne, potentially suitable as alternative airstrip location.

The larger impact of the construction operations (including blasting) at this site is the first important difference between the Boulder Clay site, where most part of the rocks are moraine debris already available on site and to be just partly reduced in size.

3.4.1. **Description of the alternative site**

The site of Campo Antenne is located behind MZS, at an average altitude of about 100 m a.s.l. 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.

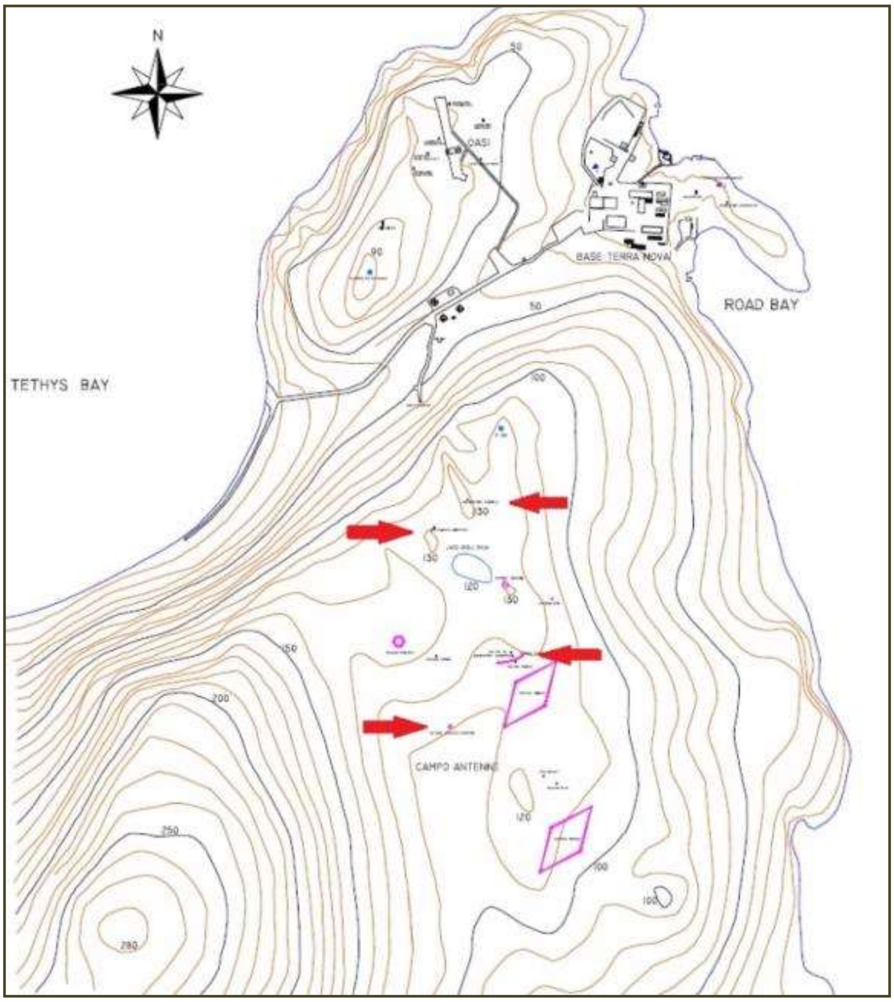

Figure 3.6: Locations of both the ionospheric and environmental observatories (red arrows) and the larger antennas fields (pink lines) at Campo Antenne site.

As the name indicates, Campo Antenne (namely field of antennas) is the location close to MZS station chosen for the installation of the antenna farm hosting 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 3.6.

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 antenna farm to a different suitable location, still close to the station, thus impacting scientific and logistic activities. In effect such a change would have a deep impact on the ionospheric and environmental observatories located in the area since 1990. In addition the effort in moving the entire set of antennas, scientific shelters and power connections to a new location would be huge. Actually the only adequate place, around MZS, showing the flatness behaviour requested for the larger antennas displacement would be exactly Boulder Clay, faraway several miles from the station.

3.4.2. **Feasibility of the alternative airstrip**

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).

The planned location of the airstrip would allow a maximum extension of 1,700 m long and 66 m wide, lying approximately along the meridian 164°06'20"E, is drawn in Figure 3.7. A longer extension is impossible due to 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 of the infrastructure 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 3.8). 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.

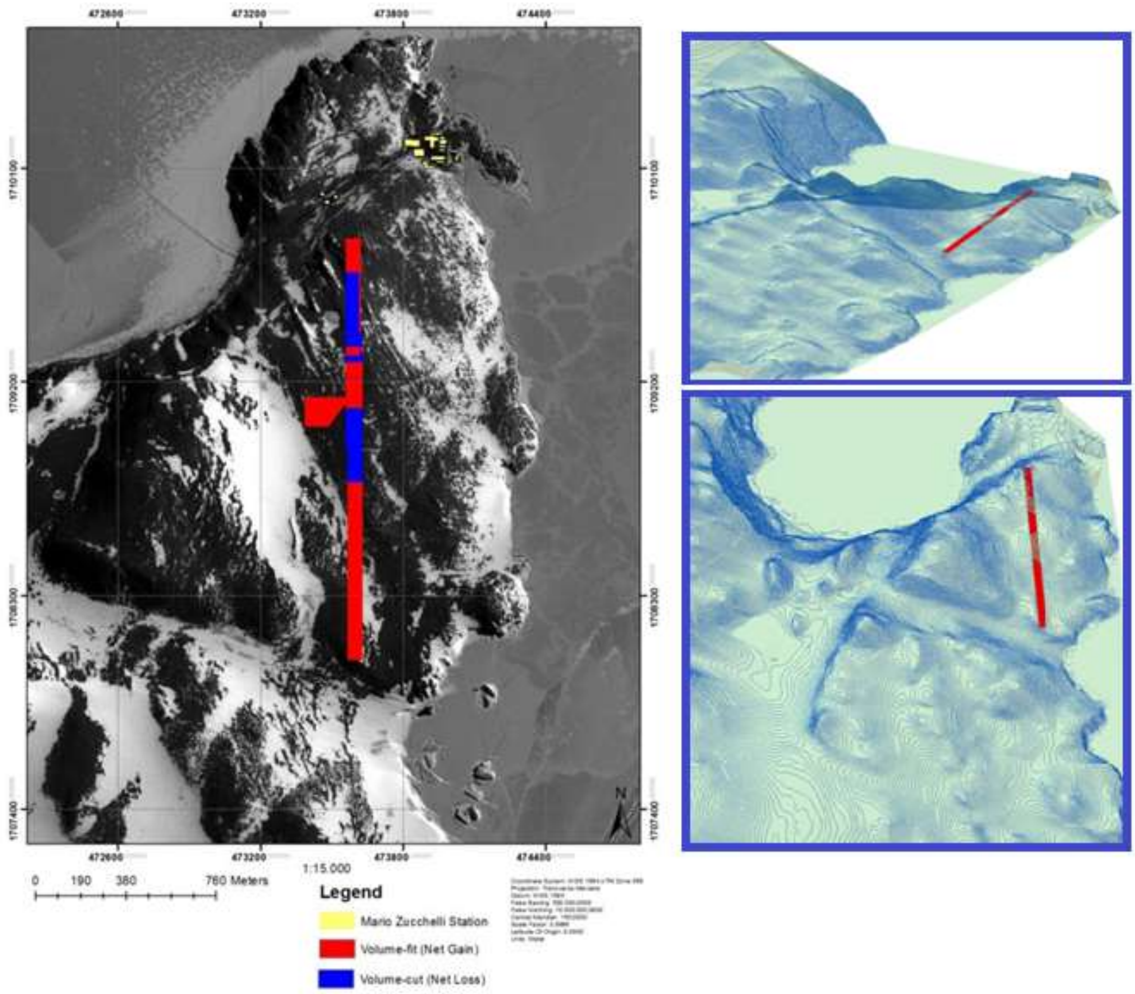

Figure 3.7: A satellite map (left) and 3-D height contour map (right) of the Campo Antenne area close to MZS with the alternative location for the airstrip.

Filling and cutting areas (red and blue code respectively) are also presented.

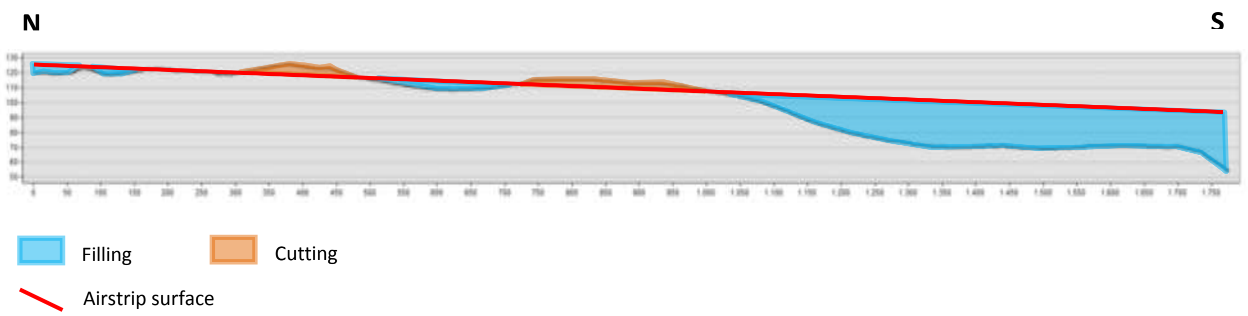

Figure 3.8: A slope cut of a possible airstrip 1770 m long at Campo Antenne

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.

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 would have to be retrieved from other nearby locations, still by mean of explosives, or from debris deposits placed in an area as wide as possible around the site. A large part of the necessary embankment is located around the southward sloping part of the track, where most of the volume that needs to be filled is present. A minor impact in terms of filled volume could be achieved only shortening significantly the length.

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 that could be allowed for landing on the airstrip. This, in perspective, can result in a higher impact of operations. On the contrary, the long term goal is to operate aircrafts with a greater fuel autonomy in order to minimize refuelling operations in Antarctica.

3.4.3. **Aeronautical 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.

Behaviours of flight clearance surfaces at Campo Antenne are shown in Figure 3.9.

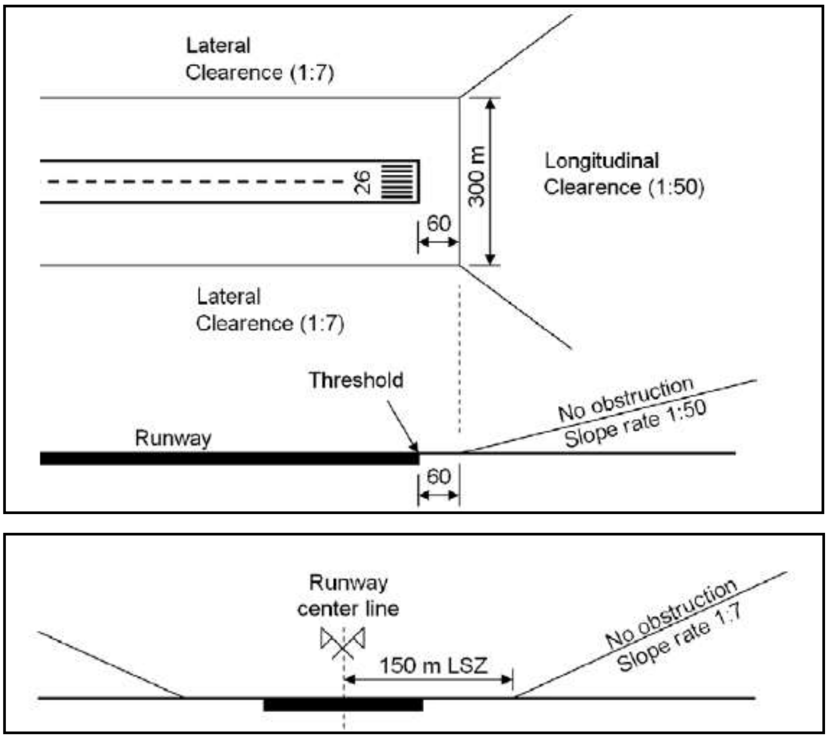

Figure 3.9: Behaviours of flight clearance surfaces at Campo Antenne

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 (see Figure 4.14).

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.

From the wind rose from Eneide presented in Figure 3.10, 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 rarely reach values over 40 knots.

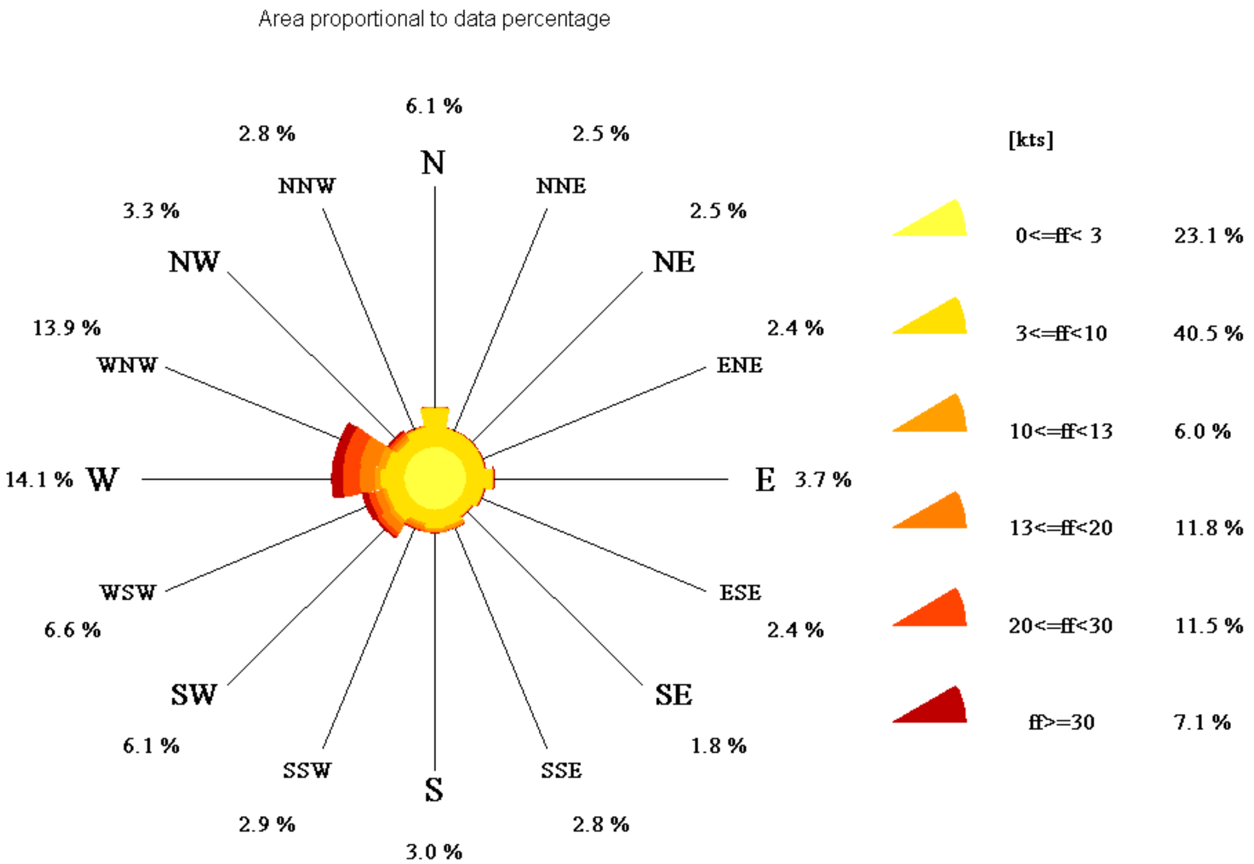

Figure 3.10: Wind rose of decadal averaged winds measured by Eneide meteorological station during summer (Oct.-Feb., hourly data from Feb. 1987 to Nov. 2011).

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.

3.5. Alternative methods 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 and ensure minimum environmental impact associated with maintenance operations. 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 Boulder Clay site

The Italian Mario Zucchelli Station is located in the Northern Foothills, 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].

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).

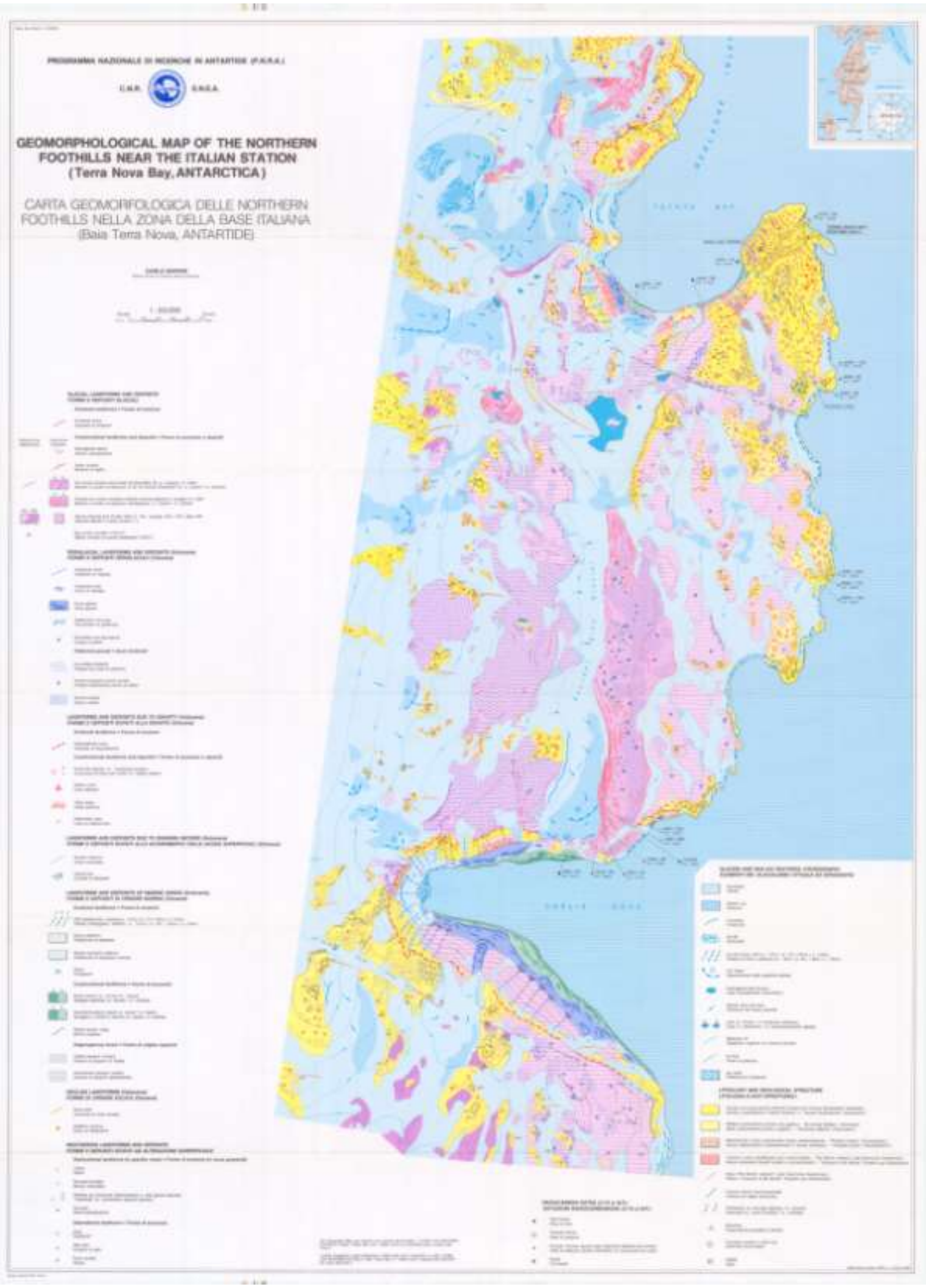

Figure 4.1: Geomorphological map of the Northern Foothills near MZS [4.1]

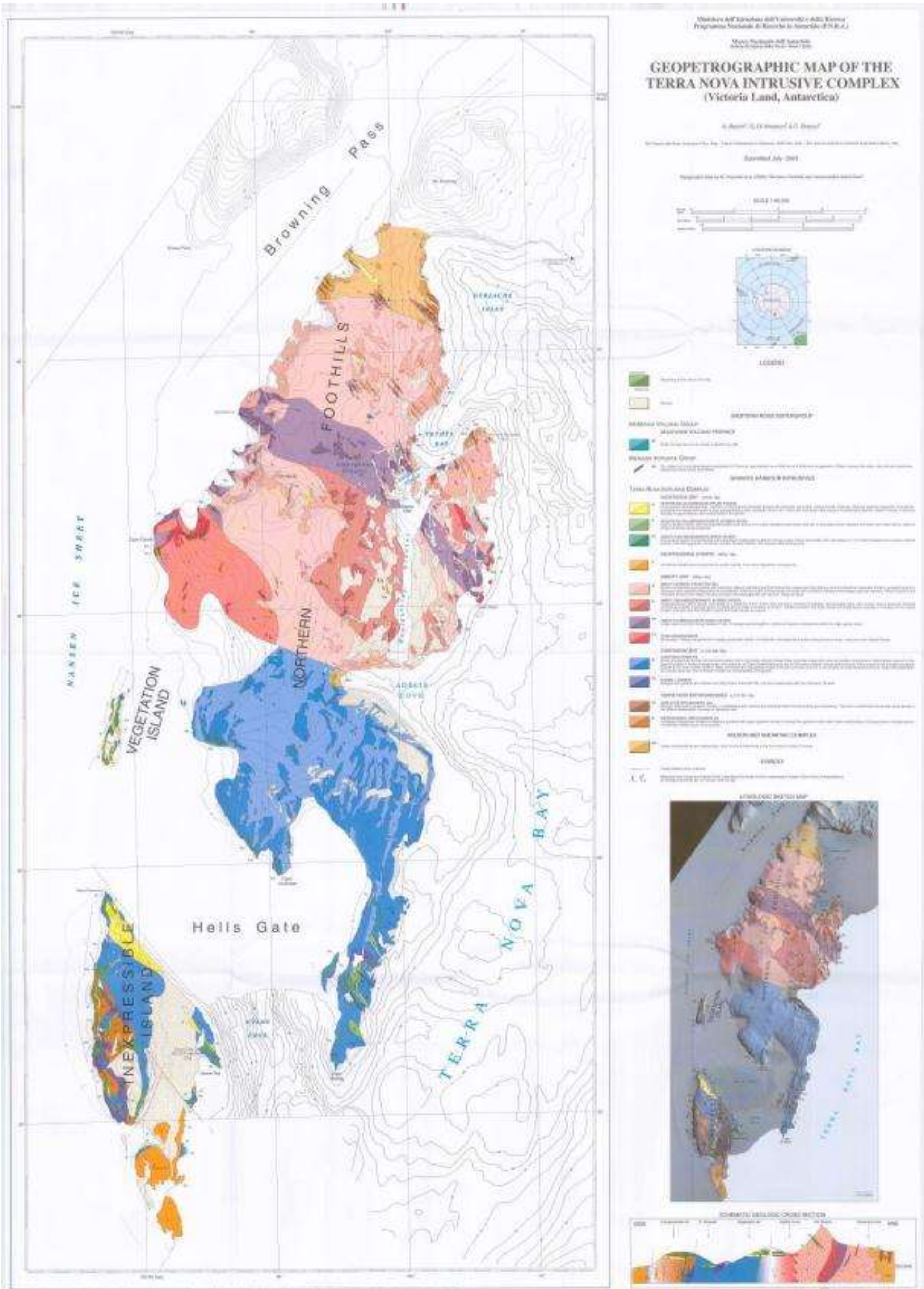

Figure 4.2: Terra Nova intrusive complex geo-petrographic map [4.6]

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.

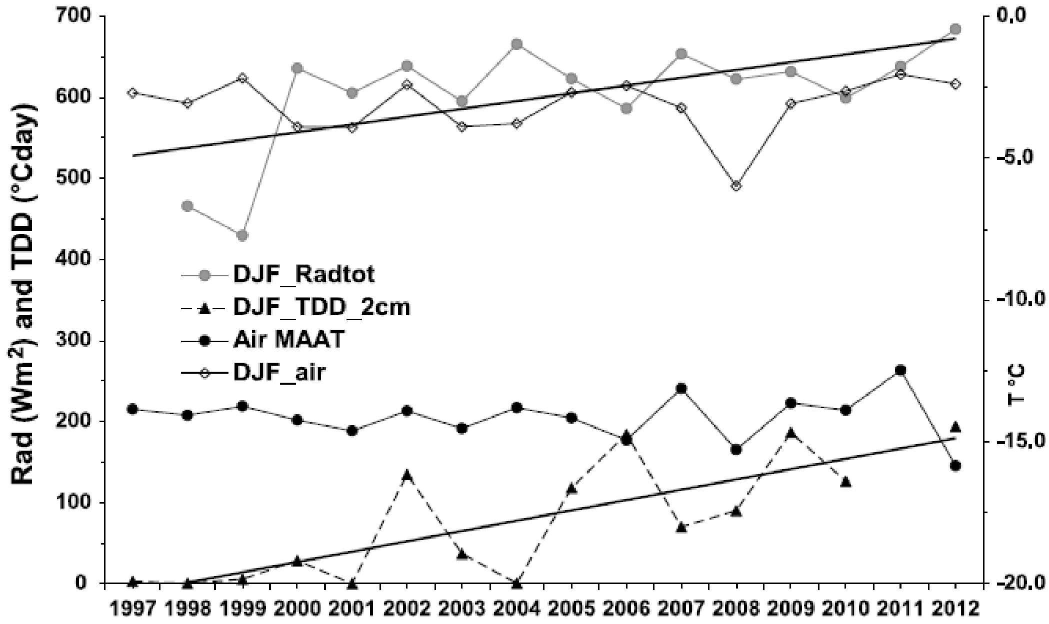

Figure 4.3: Climate trends in the period 1996–2012
with special reference to: mean annual air temperature (Air MAAT) and summer air temperature (DJF_air), summer total incoming radiation (DJF_Radtot) and the summer soil thawing degree days (DJF_TDD 2 cm). All data are kindly provided by the AWS Eneide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

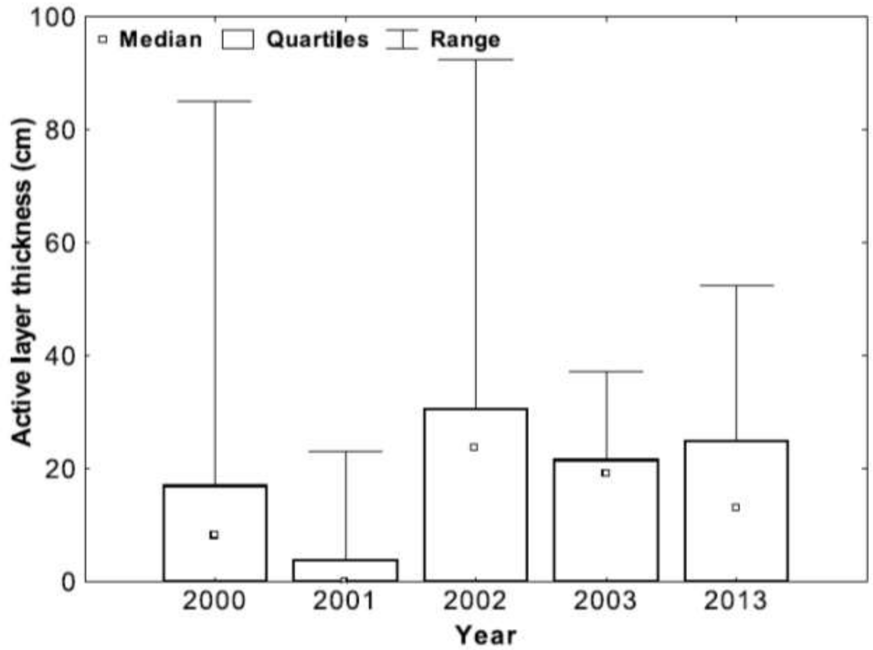

Figure 4.4: Active layer thickness (cm) (median, quartiles and range) measured at the Boulder Clay CALM grid (100 m x 100 m, 121 nodes) in the period 2000–2013
(please note that there is a gap between the 2003 and 2013 measurements) [4.23].

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].

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) surveys 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

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.

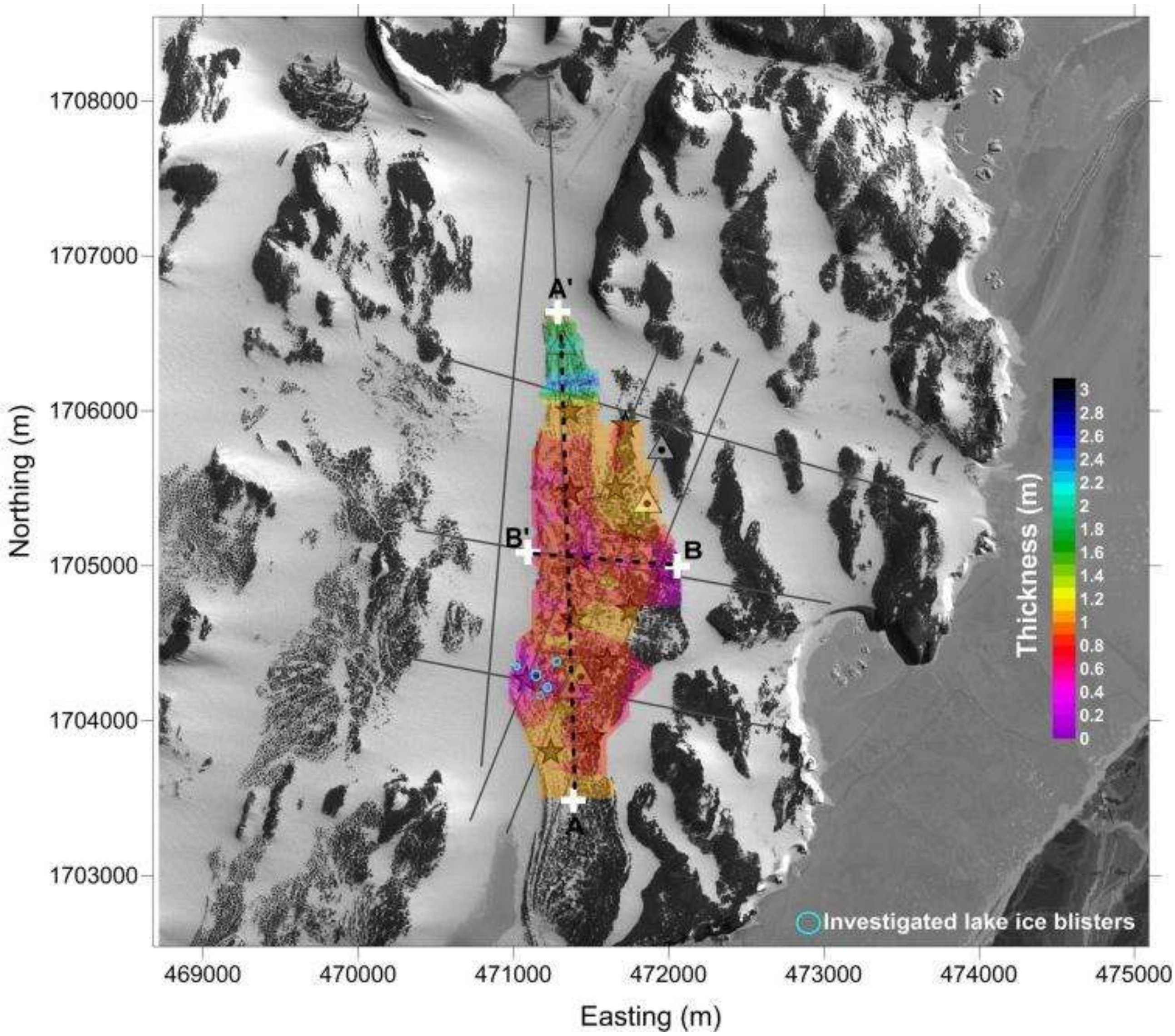

Figure 4.5: Map of debris thickness carried out by means of airborne survey.

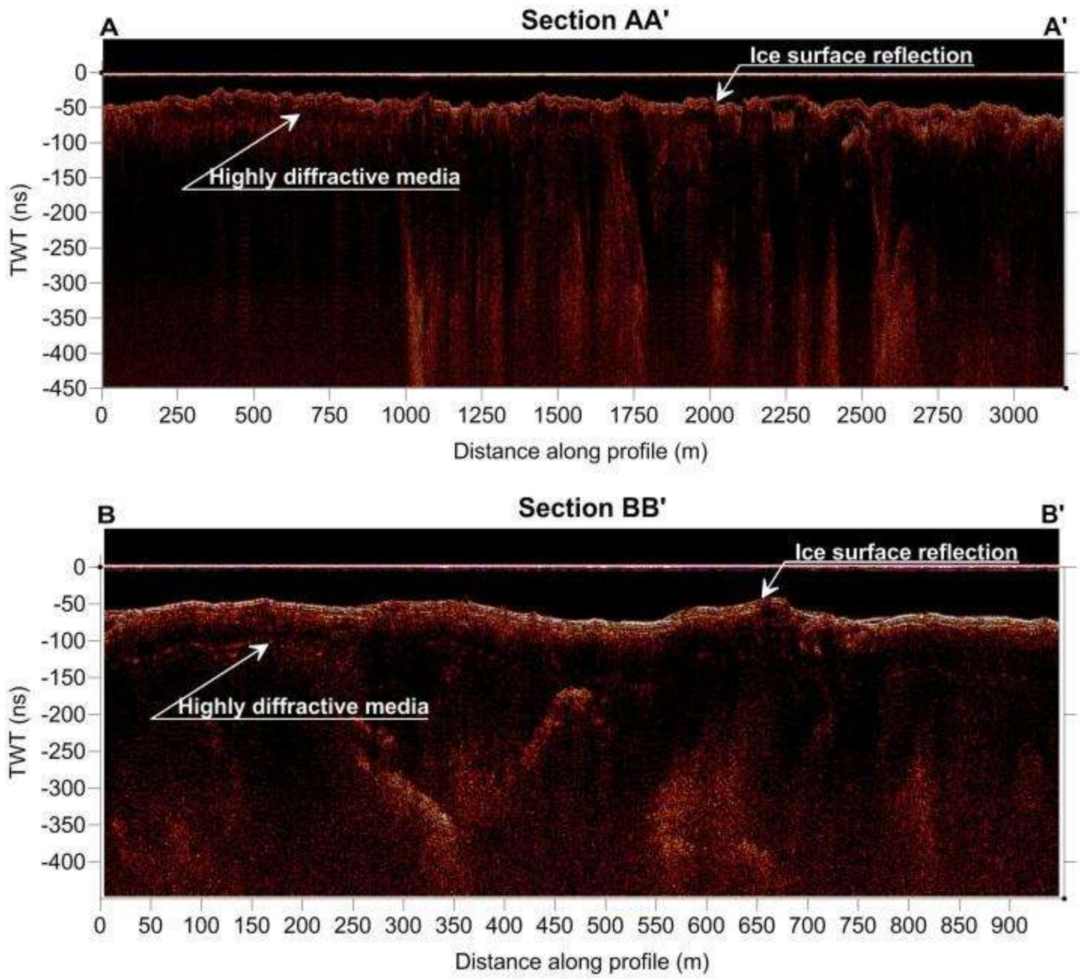

Figure 4.6: Representative radargrams and map of debris thickness.

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 4.8 a) 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.

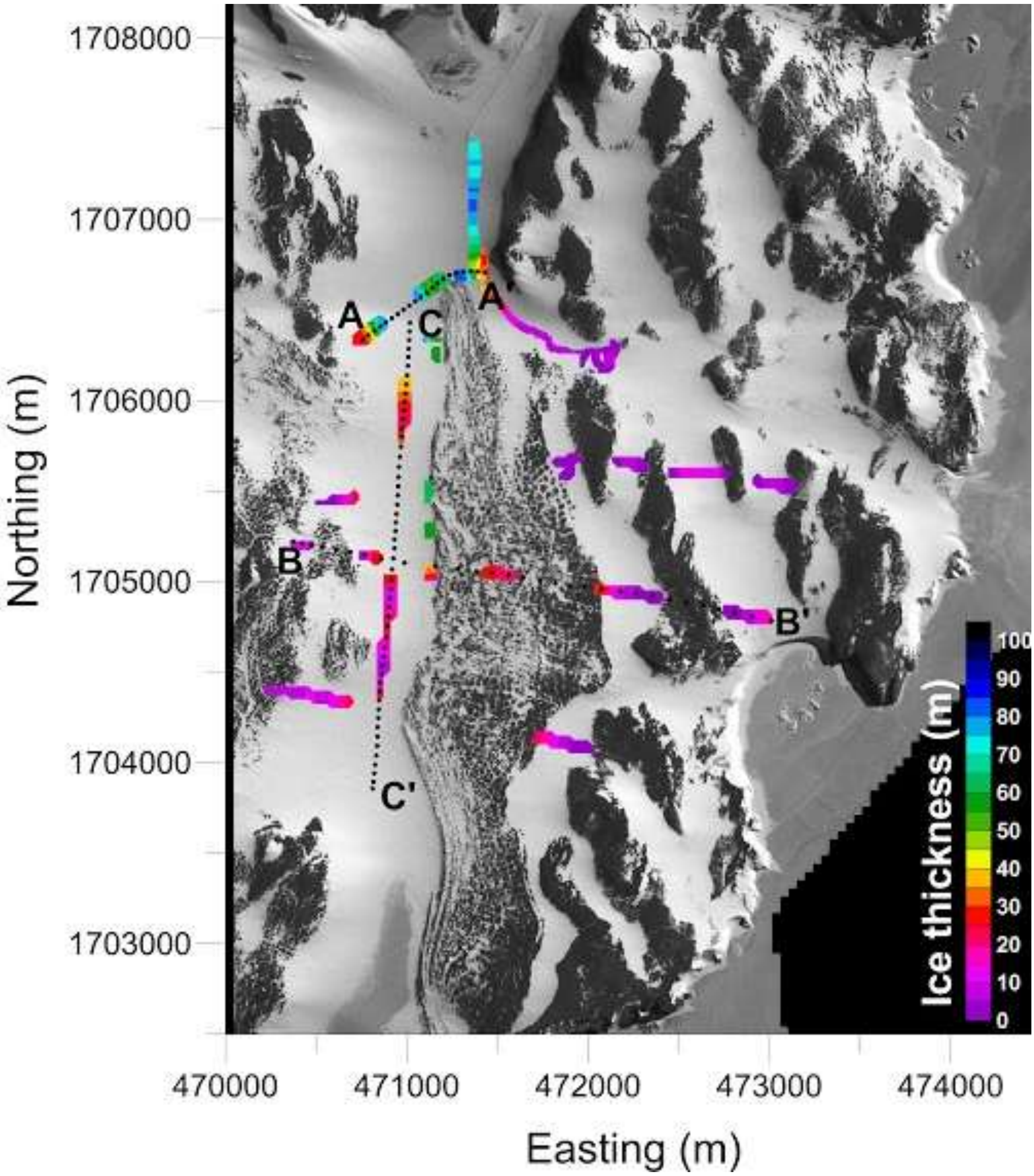

Figure 4.7: Map of interpolated ice thickness in the Boulder Clay Glacier.

The section BB' (Figure 4.8 b) 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.

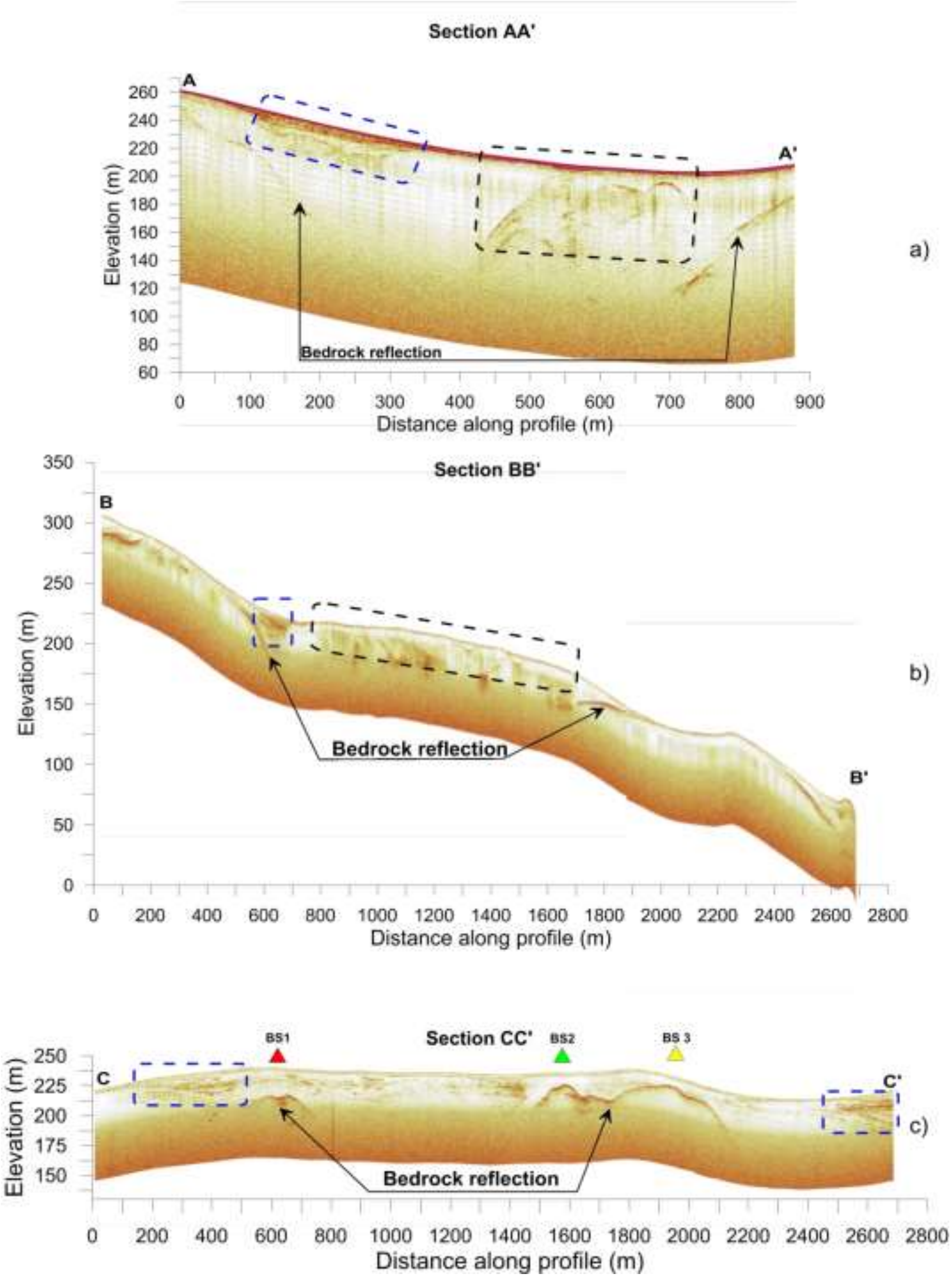

Figure 4.8: Representative radargrams from sections in Figure 4.7.
Blue dot boxes are for detected accumulation area; black dot boxes indicate the moraine area on the profiles; triangles indicate the buried saddles.

The section CC' (Figure 4.8 c) 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.

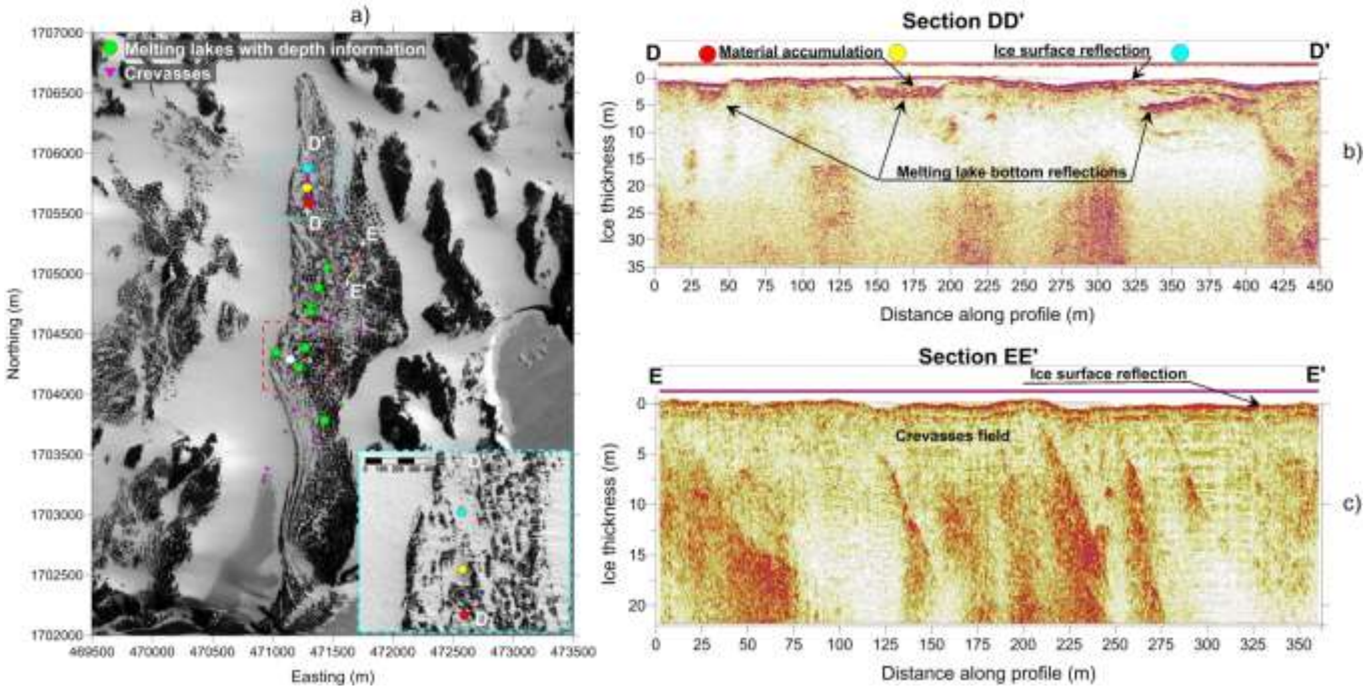

Figure 4.9: a) Map of melting lakes detected by the GPR airborne survey. In the insert, a zoomed view of the cyan dot rectangle; b) Example radargram of melting lake signature on airborne GPR data; c) Example of crevasses signature on airborne GPR data.

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.

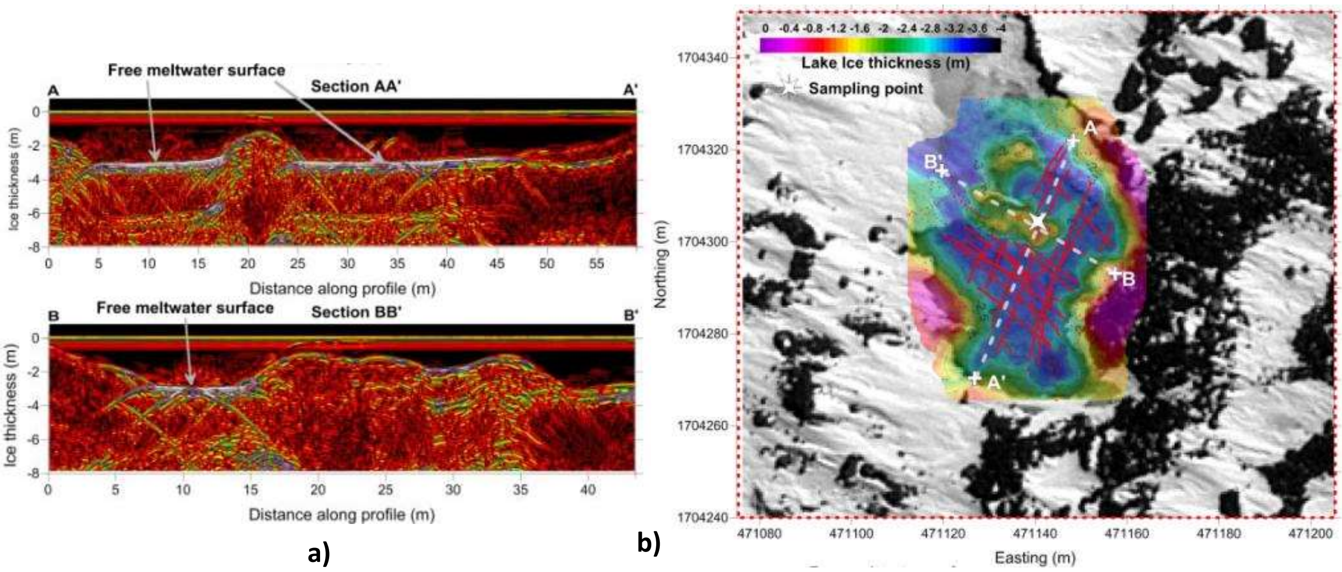

Figure 4.10: a) Representative radargrams, b) map of lake ice blister.

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).

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.

Table 4.3: Microorganisms found in Lake ice blister.

Philodina gregaria
Philodina alata
Adineta grandis

4.1.3. Geodetic survey

A geodetic network of 12 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), the second ones (November 2014) and the third ones (December 2015) 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. The next Table 4.4 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.

Table 4.4: Two years geodetic network displacement

id	Lat	Long	Planimetric (m)	Altimetric (m)	Azimuth (°)	local aspect (°)
BC01	471723.0011	1705921.4166	0.004	0.013	238	57
BC02	471361.8207	1705988.1361	0.009	0.005	92	45
BC03	471377.8654	1705501.1607	0.020	0.016	136	136
BC04	471651.5283	1705494.8237	0.038	0.033	109	102
BC05	471833.4165	1705280.4518	0.021	0.010	100	101
BC06	471741.0899	1704935.2880	0.023	-0.001	142	118
BC07	471845.2494	1704578.0558	0.077	0.009	108	110
BC08	471411.9954	1705038.4927	0.037	0.022	145	141
BC09	471382.1638	1704686.5689	0.037	0.017	123	102
BC10	471099.9735	1704249.4648	0.032	0.022	144	138
BC11	471126.2390	1703939.2565	0.082	0.017	173	150
BC12	471404.4502	1703913.2448	0.008	0.043	162	116

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 (AOI).

Maps of displacement

Figure 4.11 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 4.11 (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.

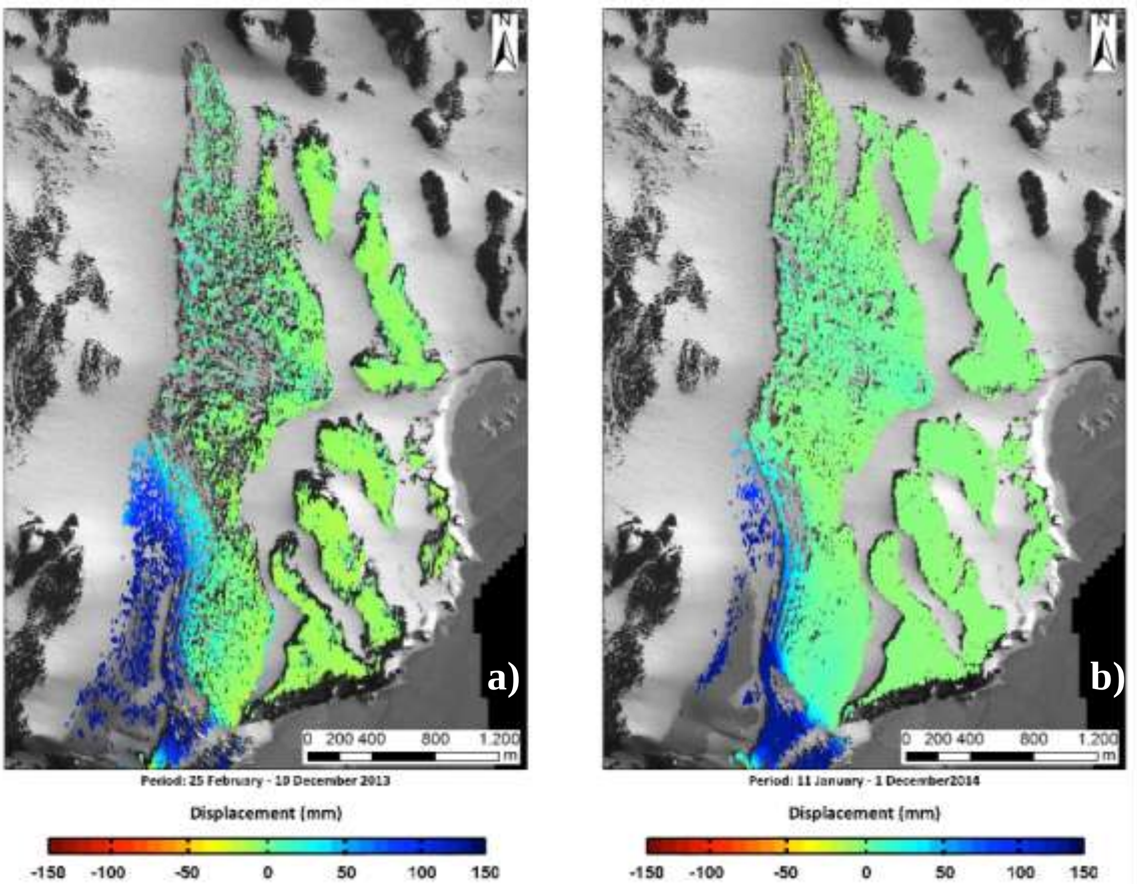

Figure 4.11: a and b - Displacement map related to Dataset A (2013) and Dataset B (2014). Only pixels characterized by good quality signal falling within the investigation area have been analysed. Displacements are expressed in millimetres and refer to the whole period. Positive values (cool colours) 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 4.12 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 4.12 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 4.13 reports the overlay of the measured GPS vectors on the GPR main results. GPS vectors confirm that bedrock saddles (red, green and yellow triangles 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 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.

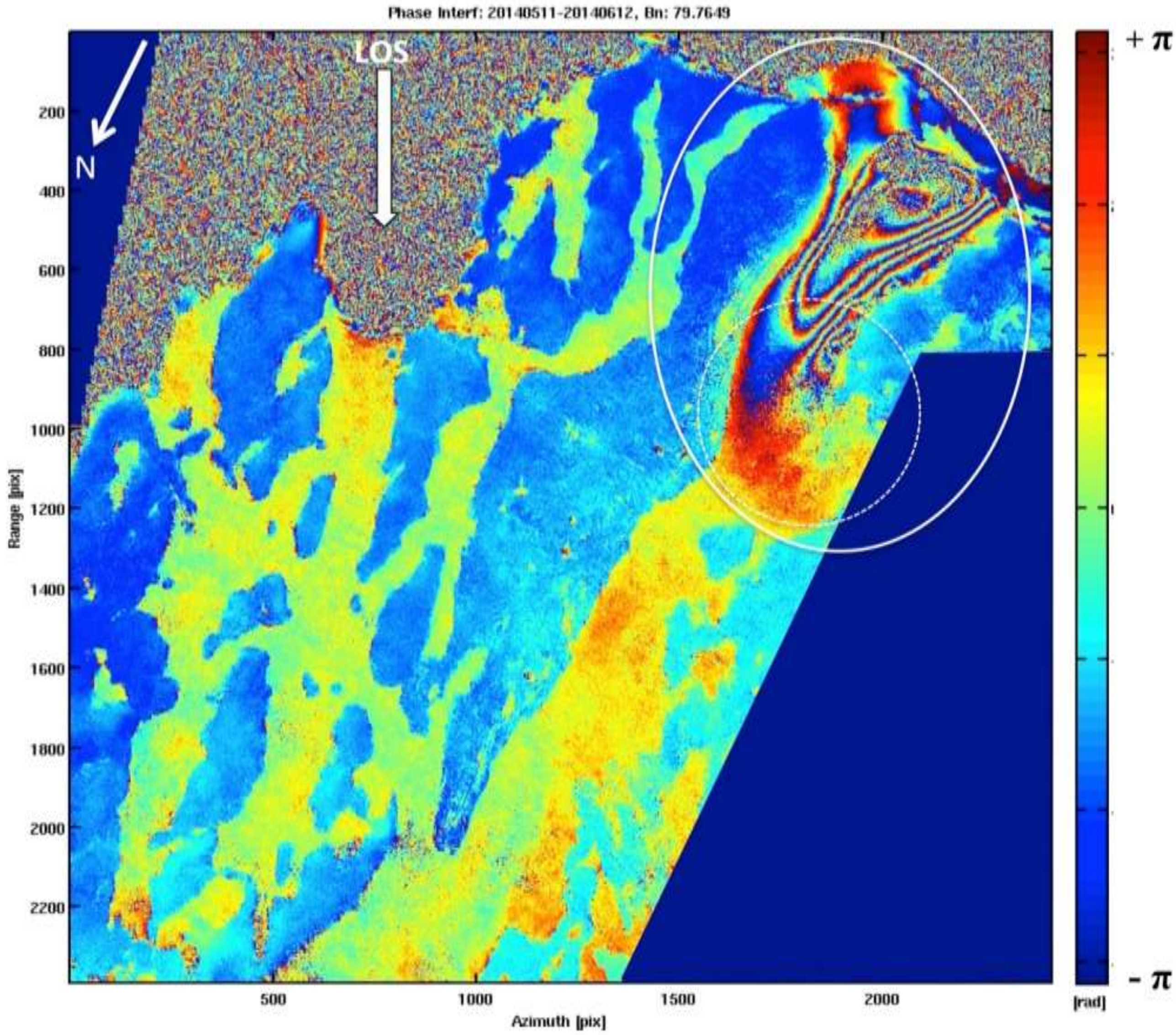

Figure 4.12: Boulder Clay area differential interferogram.

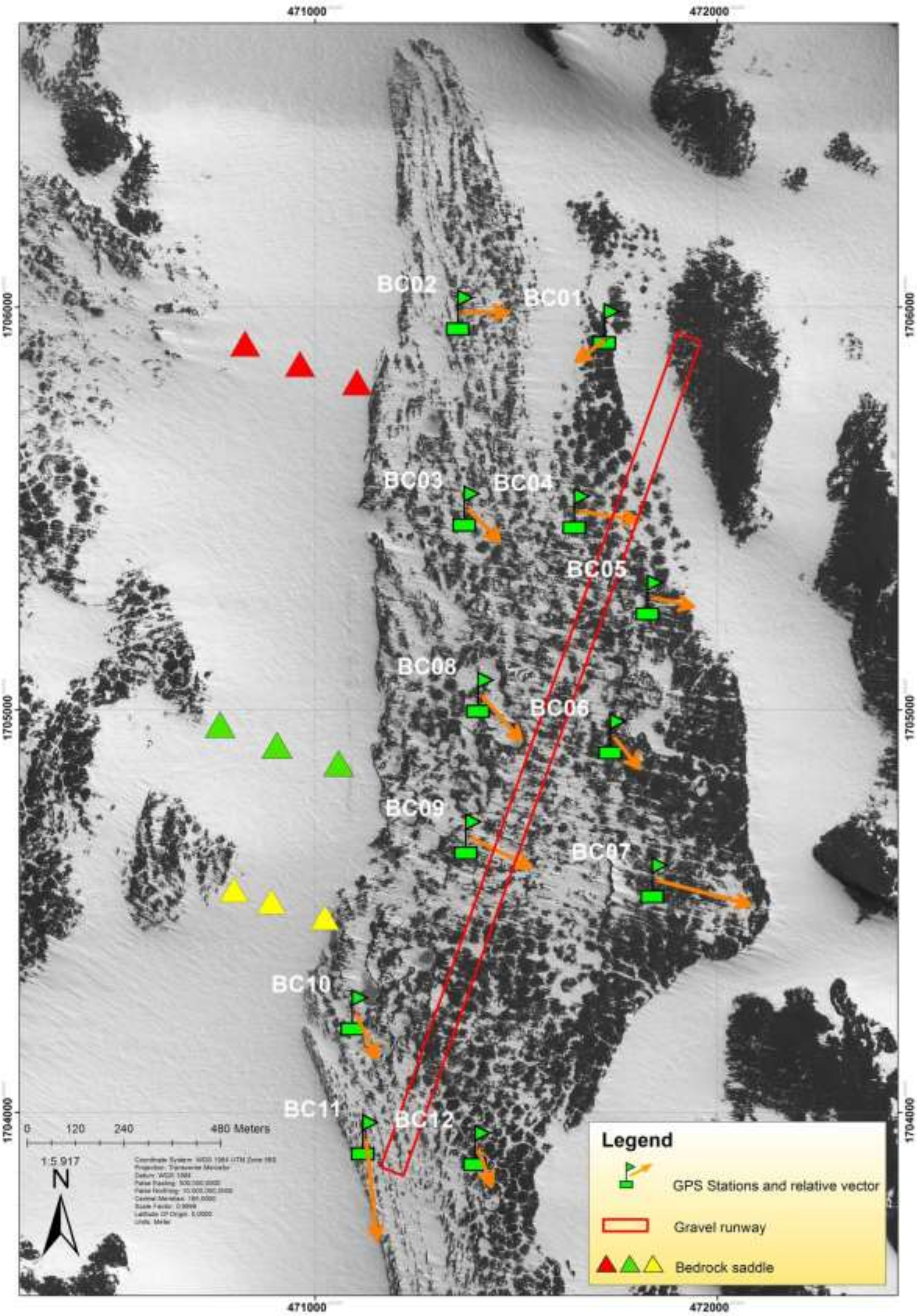

Figure 4.13: GPS Stations vectors (December 2013-November 2015) and buried bedrock saddles.

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 4.5 and Figure 4.14).

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

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

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 4.6 and Figure 4.14).

Table 4.6: Coordinates and features of K1, K2, K3, K4, K5 weather stations in MZS area.

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*)

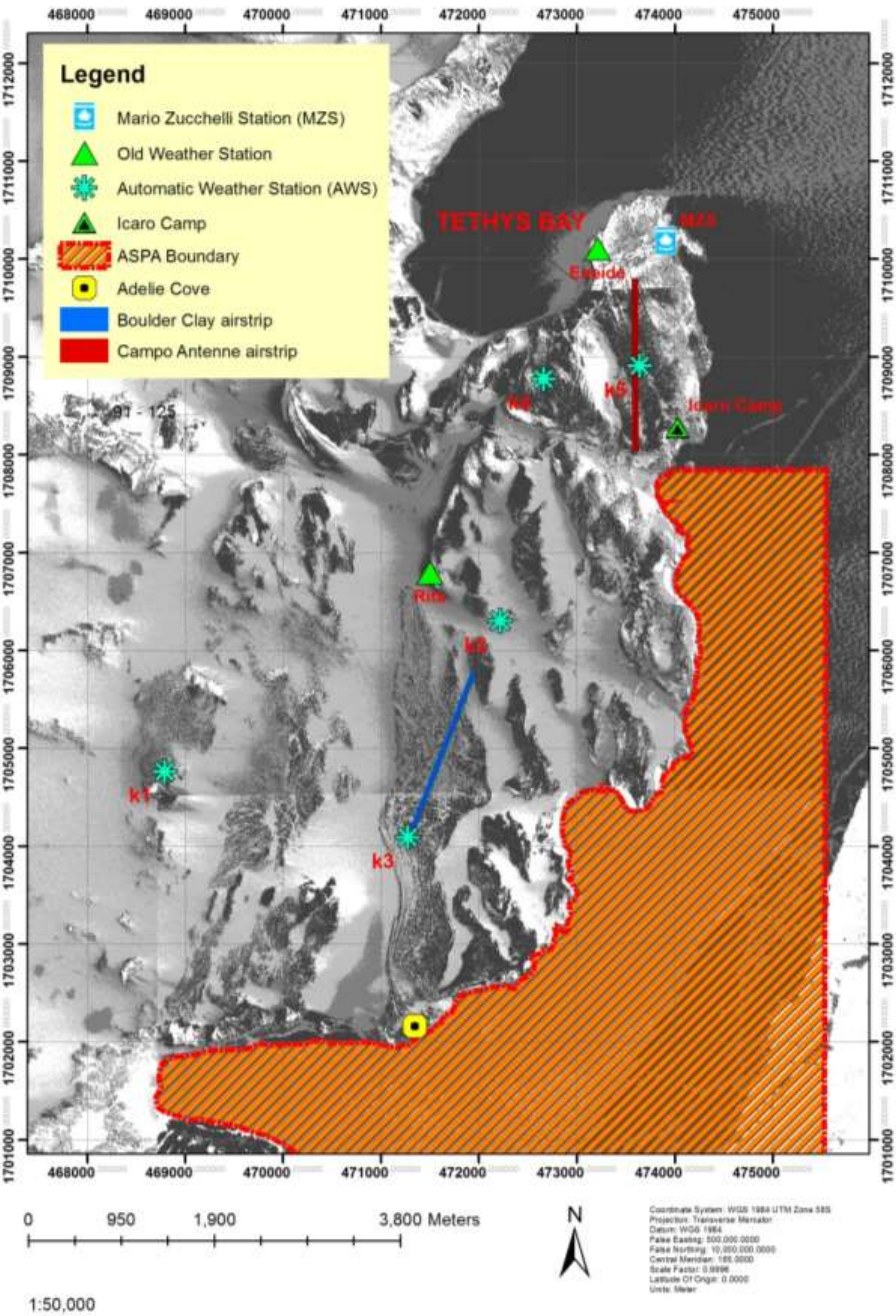

Figure 4.14: Detail of the area of interest, showing airways and automatic weather stations (Eneide, Rita, K1, K2, K3, K4 and K5).

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 4.15 and Figure 4.16).

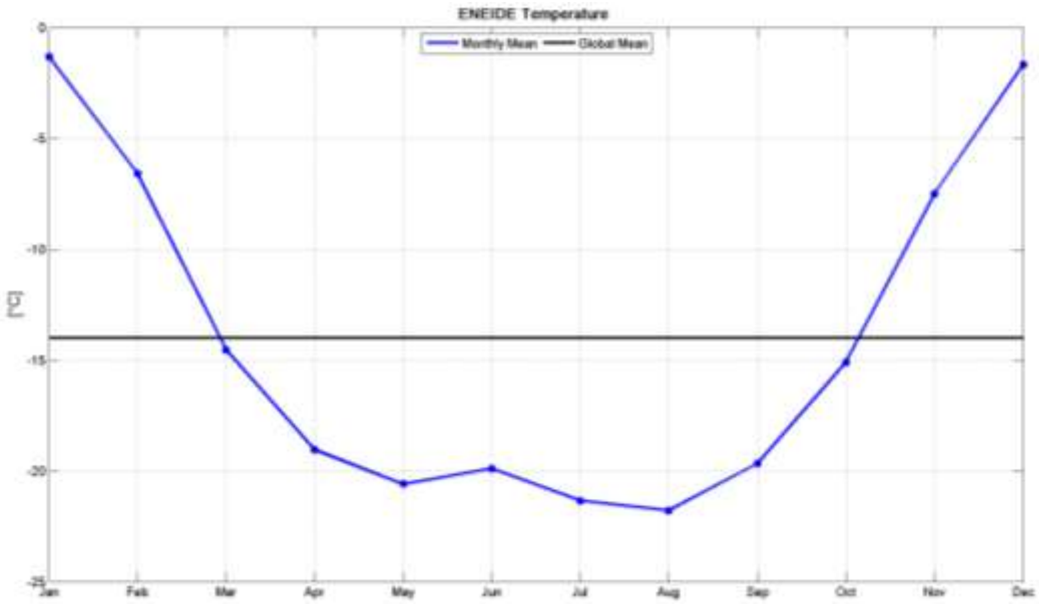

Figure 4.15: Monthly mean temperature collected by AWS Eneide (data from Feb. 1987 to Nov. 2011).

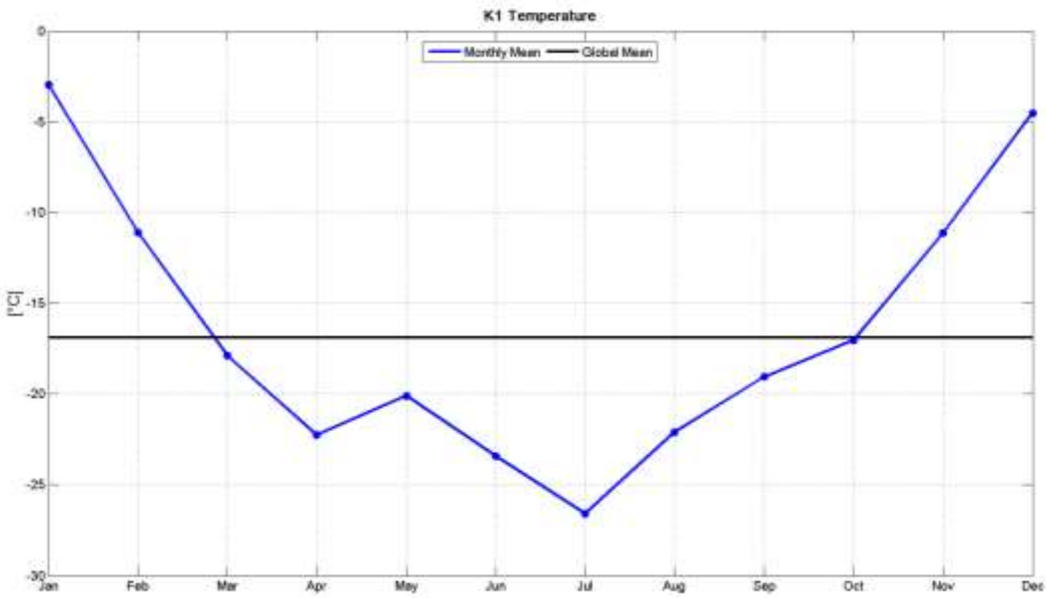

Figure 4.16: Monthly mean temperature collected by AWS Rita (data from Jan. 1993 to Nov. 2011).

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 4.17), 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.

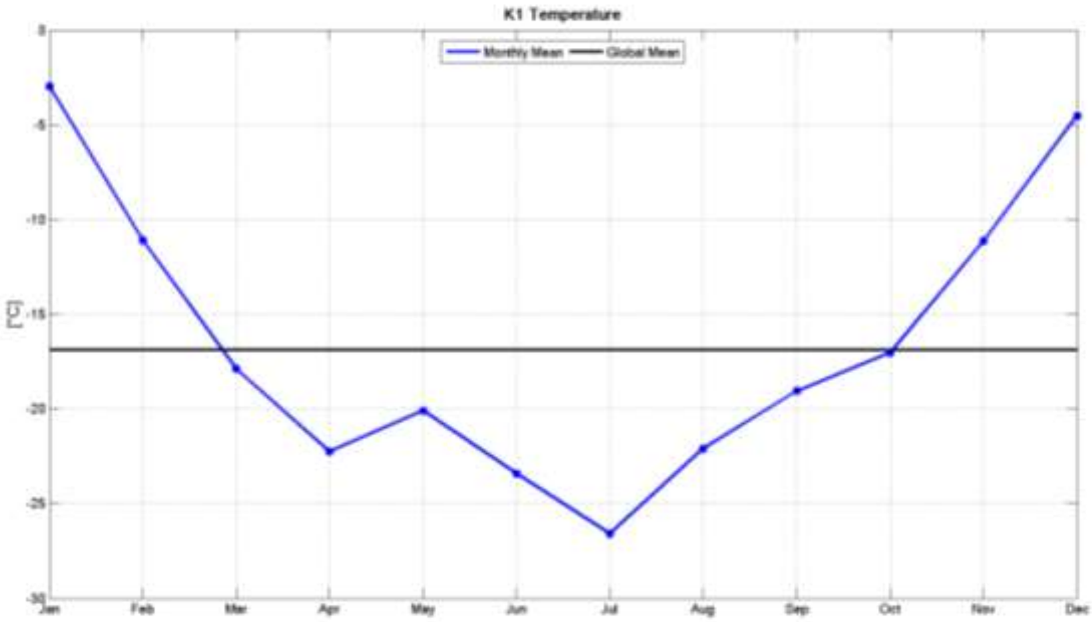

Figure 4.17: Monthly mean temperature collected by AWS K1 (data from Feb. 2103 to Jan. 2015).

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 Rita (summer season in Figure 4.18) and in years 2013-2015 by K2 placed on airstrip extremity RWY20 (summer season in Figure 4.19) show that the prevailing wind in the area comes from W, WNW and WSW.

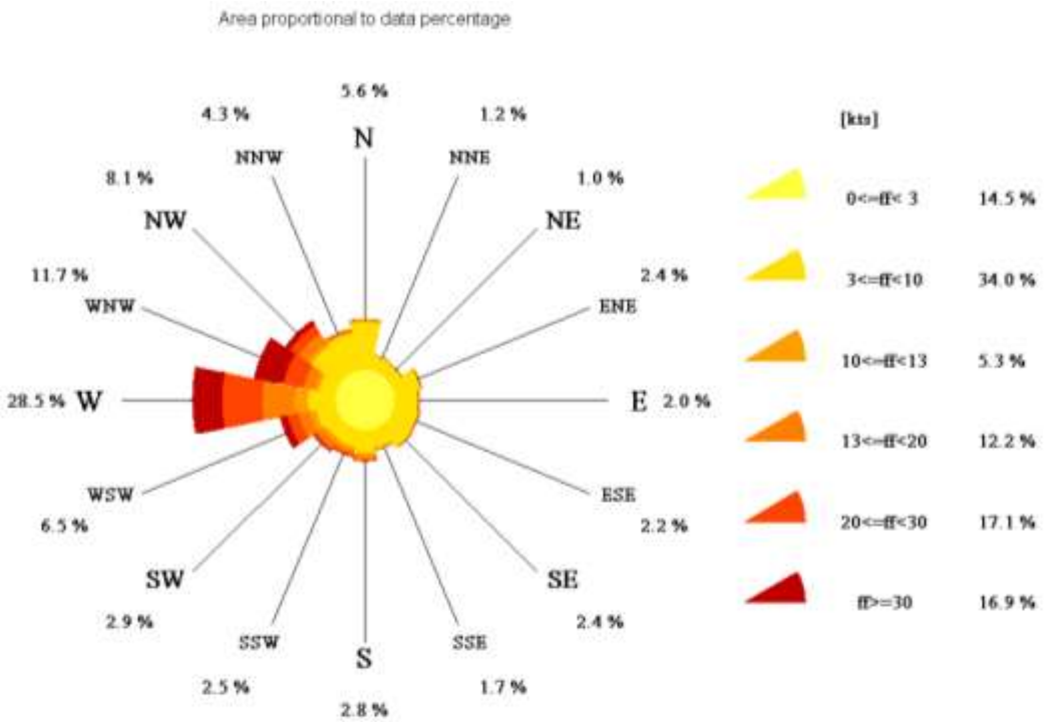

Figure 4.18: Wind speed and direction recorded by AWS Rita in summer seasons (Oct. – Feb., hourly data from Jan. 1993 to Nov. 2011).

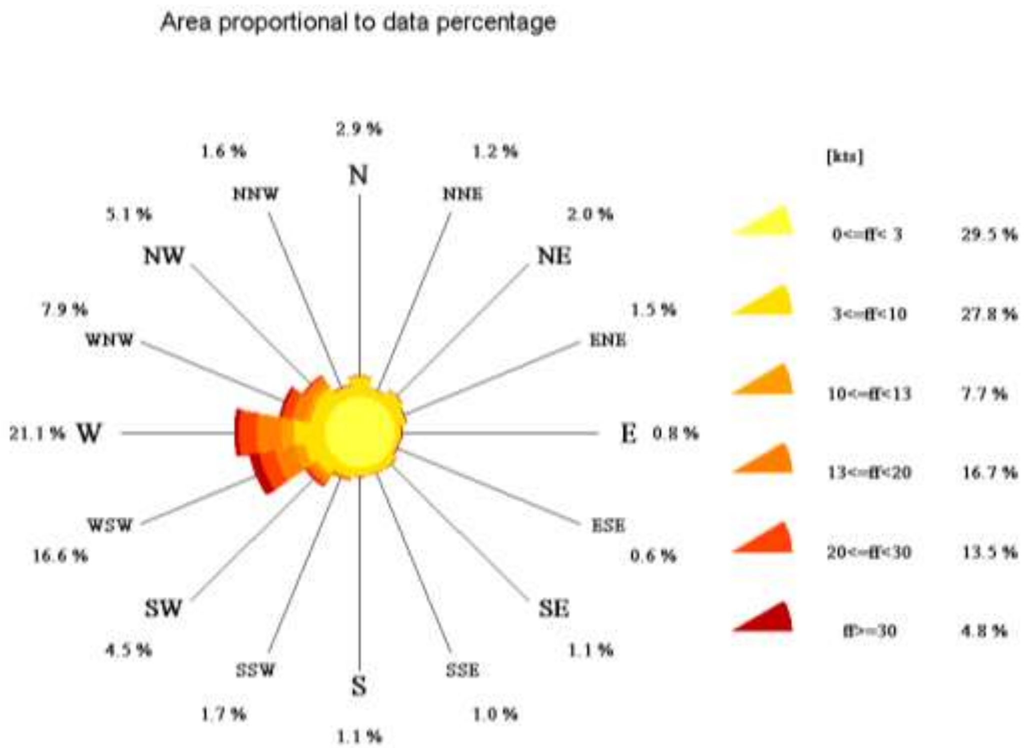

Figure 4.19: Wind speed and direction recorded by AWS K2 in summer seasons (Oct. – Feb., hourly data from Feb. 2013 to Jan. 2015).

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 4.7

Table 4.7: Comparison of AWS Eneide and Rita frequency and intensity of W and WNW wind directions.

	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 %

Data acquired by AWS K1, K2 and K3 (Table 4.8), 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.

Table 4.8: Comparison of AWS K1, K2, K3 and Rita percentage distribution of WSW wind directions (hourly data, AWS K1, K2, K3: Feb. 2013 – Jan. 2015; AWS Rita: Feb. 2013 - Oct. 2014).

	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

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. 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 4.9.

Table 4.9: Wind shear classification recommended by the Fifth Air Navigation Conference (Montreal, 1967) [4.27].

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)

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 4.20 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 4.21 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.

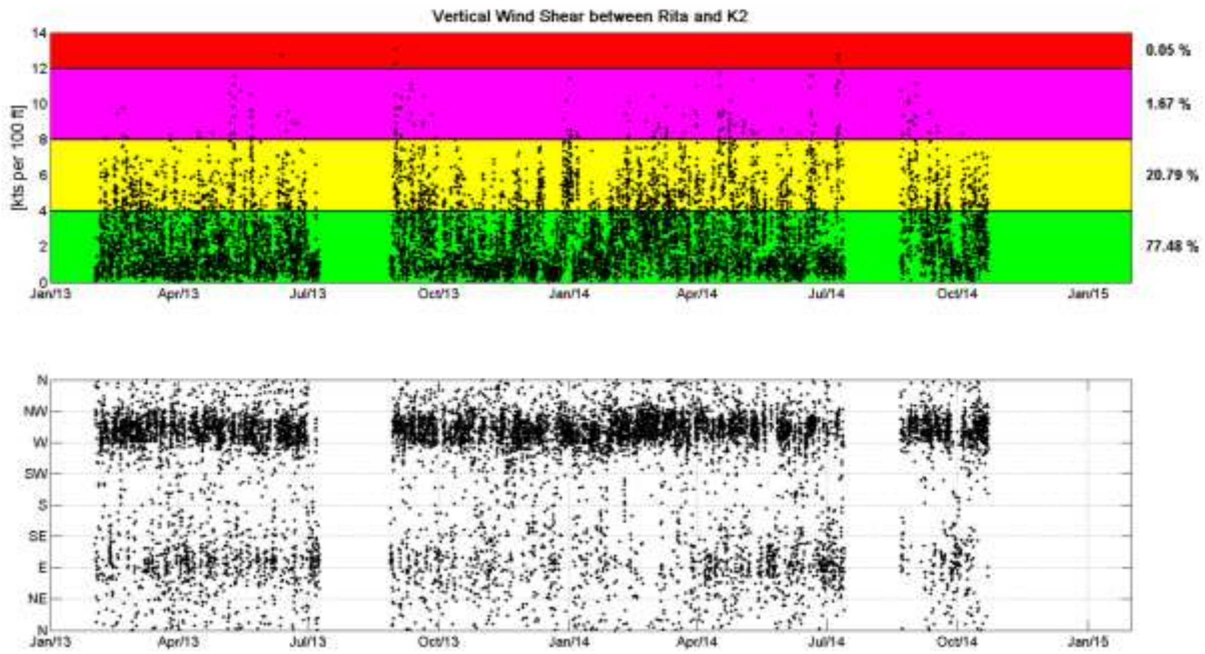

Figure 4.20: Intensity and direction distribution of vertical wind shear between Rita and K2 (LIGHT (green), MODERATE (yellow), STRONG (pink), SEVERE (red); hourly data from Feb. 2013 – Oct. 2014).

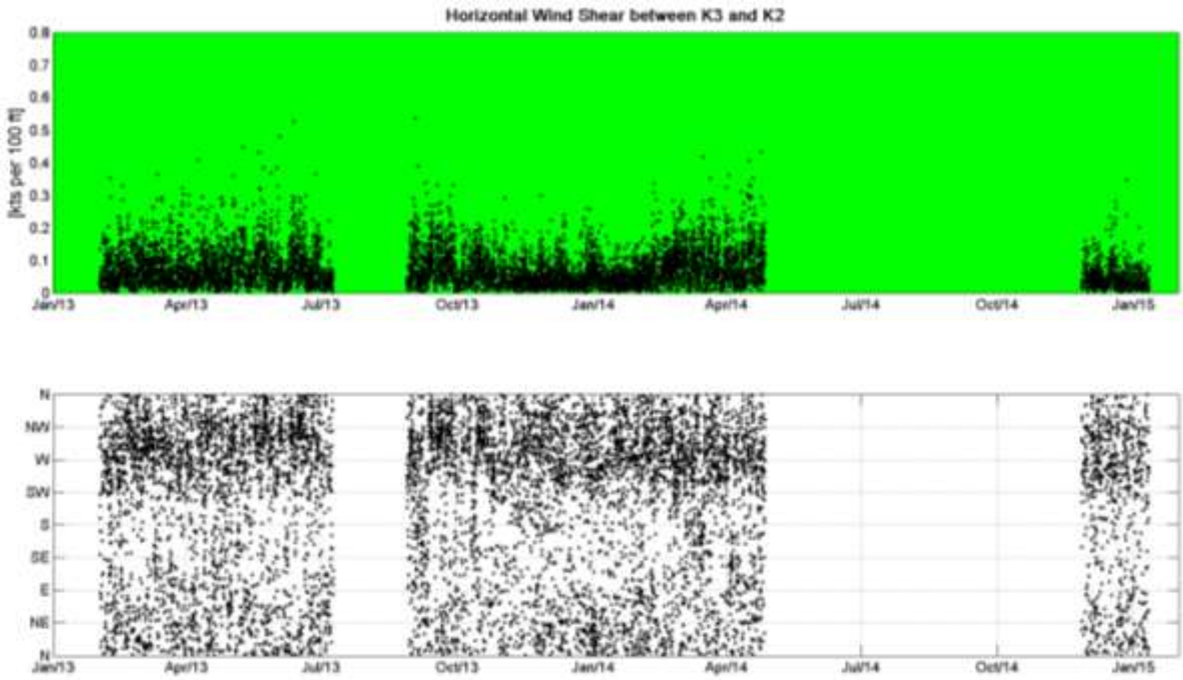

Figure 4.21: Intensity and direction distribution of horizontal wind shear between K3 and K2 (LIGHT (green), MODERATE (yellow), STRONG (pink), SEVERE (red); hourly data from Feb. 2013 – Jan. 2015).

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

The whole Terra Nova Bay and Wood Bay area (immediately at North of Terra Nova Bay) are particularly valuable sites for biological science due to the extraordinary presence of marine and terrestrial flora and fauna, with a database on their living resources running since 20 years. Extensive marine ecological research has been carried out at Terra Nova Bay since the middle of the eighties contributing substantially to our understanding of communities not previously well described. High diversity at both species level and community level gives to this area a high ecological and scientific value.

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, a colony of South polar skuas (*Catharacta maccormicki*) breed within the area.

In the Terra nova Bay area, the following protected areas are present: Edmonson Point (ASPA n° 165), Terra Nova Bay marine protected area (ASPA n°161), 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.

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

Over the past decade, the intensity and diversity of human activities in Antarctica have continued to increase and sources of contamination and impact on flora and fauna are increasing as well. Regarding the human activities in the area of Terra Nova Bay, they are mainly related to the already mentioned summer Italian MZS station, seasonal German Gondwana Station and new Korean Jang Bogo Station.

4.3.1. **Fauna**

The fauna of Terra Nova Bay area comprises 5 species of seabirds, 2 species of seals and 3 species of whales:

Adélie penguin (*Pygoscelis adeliae*)
Emperor penguin (*Aptenodytes forsteri*)
South Polar skua (*Stercorarius maccormicki*)
Snow petrel (*Pagodroma nivea*)
Wilson's Storm Petrel (*Oceanites oceanicus*)
Leopard seal (*Hydrurga leptonyx*)
Weddell seal (*Leptonychotes weddellii*)
Killer whales (*Orcinus orca*)
Antarctic minke whale (*Balaenoptera bonaerensis*)
Arnoux's beaked whale (*Berardius arnuxii)*

During the Antarctic summer season about 30 skua pairs breed close to the penguins, and leopard seals (Hydrurga leptonyx) were sighted several times in different years at the end of the slope that penguins climb to reach the colony site, or ice floes adjacent to the cove (Figure 4.22).

Adélie penguins, 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 one of the three breeding sites for Adélie penguin in the Terra Nova Bay area is located on the Northern Foothills at the end of the falling edge of the moraine deposits of Boulder Clay, where the physical conditions permit the presence of this species.

In general the Northern Foothills appear an important area for seabirds, where also more than 70 skua nests and some Wilson Storm Petrel nests were observed [4.30]. The South Polar skua colony surveyed by Ainley in the 80's [4.31] nearby Terra Nova Bay no longer exists and although there are still a few pairs scattered around the Italian station. With regard to the Wilson Storm Petrel, nesting sites were observed at Campo Icaro [4.30] and also several species of toothed and baleen whales have been recently reported for the Terra Nova Bay area [4.32].

Baroni et al. [4.33] showed as in Terra Nova Bay two abandoned sites of Adélie penguins exist along with the active site of Adelie Cove. This colony is located on a coastal slope 50-100 m high from the sea level (ASPA n. 161) 8 km South from MZS (Figure 4.22) and is one of the oldest in the Terra Nova Bay area being occupied since 5000 years BP (see Lorenzini et al. [4.34] and reference herein). Lyver et al. [4.35] estimates a number of 11.234 breeding pairs during the 2012 summer season.

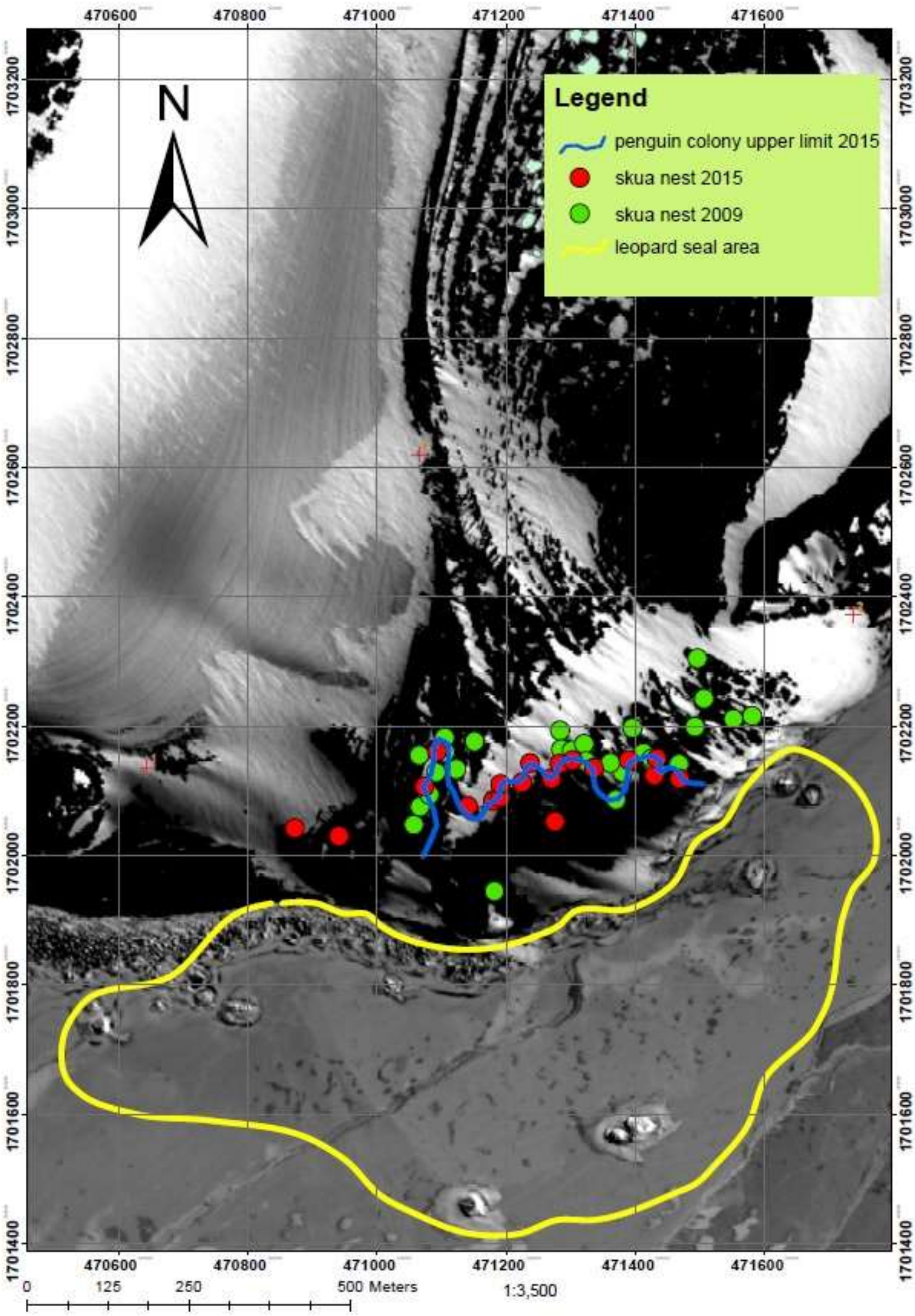

Figure 4.22: Map of the points where skua nests were found at Boulder Clay site during surveys in summer 2009 and 2015, along with the upper limit of the penguins colony and the marine boundaries of leopard seals area.

Measurements of the size of Adélie penguin colonies of the southern Ross Sea are among the longest biologic time series in the Antarctic. Since 1984, Harper et al. [4.36] counted in Terra Nova Bay approximately 10,000 pairs of Adélie penguins, reasonably representing the penguins colony of Adelie Cove near Boulder Clay site. Colonies in the surrounding of Terra Nova Bay, are reported in Table 4.10.

Table 4.10: Mean colony counts of nesting territories along the Victoria Land coast in 2012. [4.35]

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

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 [4.35] or changes in sea-ice conditions such as concentration, extent and thickness, air temperatures, winds, sea surface temperatures (SST) and precipitation [4.37], or changes in the abundance of their prey and/or structure and function of the marine ecosystem owing to other factors [4.38].

When considering the upcoming construction of airstrip at Boulder Clay and the future operations for the track and other human activities (scientific research activities and logistics, including infrastructure construction and support), disturbance on birds from aircraft operations like noise exposure, particulate emissions, oil spills and increased human presence should be taken into account, along with the long-term impacts.

Disturbance for aircraft operations on birds has been described in the analysis of “detection-death” scale [4.39].and behaviour of penguins (both adults and juveniles) as a result of the approach of an aircraft has been studied [4.40], although in this regard even more complex environmental factors may affect the dynamics of the population [4.41].

During the Italian Antarctic campaign in 2013, reaction tests to 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. This condition would represent a very conservative event, because the colony is outside the route of the aircraft, and flying over the colony would be an accidental event. Phonometric record of that noise test was reported in the IP57 presented by Italy at the ATCM37/CEP17. 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 [4.39]. 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 [4.39].

4.3.2. **Flora, vegetation and land use**

The vegetation of continental Antarctica is exclusively composed of cryptogams (microfungi, cyanobacteria, algae, lichens, bryophytes), with lichens and bryophytes being the dominant components of most terrestrial ecosystems.

Victoria Land (Ross sector) is characterized by the highest levels of biodiversity (in terms of species richness, α diversity) among the different sectors of continental Antarctica, with the documented occurrence of c. 57 species of lichens [4.42] [4.43] (although some papers report up to 92 lichen species [4.44]) and of 14 species of bryophytes [4.45] [4.46].

Boulder Clay is one of the ice free areas with the highest levels of biodiversity observed at Victoria Land, with the occurrence of 7 species of mosses, 1 of liverworts and 34 species of lichens (of which 8 relatively rare), accounting >50% of the whole bryophytes flora and c. 60 % of the lichen flora of Victoria Land, according to Castello [4.44]. The high species richness and the occurrence of several vegetation communities, although with scattered coverage, indicates that this site provides different ecological niches available for vegetation colonization and development.

The vegetation of Boulder Clay belongs to different community types, ranging from different types of epilithic lichen communities, to bryophytes dominated communities both with pure bryophytes as well as with lichen encrusted bryophytes. These information are referred to the CALM grid area, where a long-term monitoring of permafrost (1996), active layer thickness (1999) and vegetation (2001/2002) has been carried out and is still ongoing [4.47] [4.23].

In particular, the following vegetation communities occur in the Boulder Clay area [4.43]:

- *Usnea antarctica –Umbilicaria decussata*;
- *Buellia frigida*;
- *Lecidella siplei*–Bryophytes;
- *Pseudephebe minuscula–Lecidella siplei*–Bryophytes;
- Epiphytic lichen encrusted *Schistidium antarctici*;
- Epiphytic lichen encrusted *Bryum argenteum*;
- *Lecidea–Rhizocarpon*;
- *Bryum argenteum*–Cyanobacteria;
- *Schistidium antartici*–Cyanobacteria.

Field Survey and Mapping Criteria

To assess the impact of the runway on flora and vegetation of Boulder Clay, a detailed vegetation survey has been carried out in December 2015 being the previous available information limited to the CALM grid area [4.47] [4.23] and therefore included only a small part of the runway track/path.

The 2015 survey aimed to: a) identify and map the occurrence of single vegetation species of mosses and lichens, b) identify the vegetation communities and map their distribution and coverage, c) quantify the species richness associated to the mapped communities.

Moreover, vegetation was surveyed also in the neighbour areas surrounding the runway to assess whether the runway vegetation was different from that occurring outside the runway path and to identify the species and/or communities deserving special protection and being priorities for environmental protection and mitigation. In all areas (runway and adjacent areas) the vegetation survey has been carried out using the phytosociological method (vegetation relevés). Among the analyzed area, particular attention and detail was devoted to the runway path. In the field the occurrence of each single vegetation species and/or of each vegetation community was recorded in detail. Particular attention has been devoted to the occurrence and distribution of bryophytes and lichen species, while for algae and cyanobacteria the survey was not performed at the species level but they were recorded as the generic categories (Algae; Cyanobacteria).

For each survey point the following data have been recorded:
- GPS position,
- size of the vegetated area,
- total vegetation coverage (%),
- list of the species of bryophytes and lichens observed in the field and their % coverage;
- vegetation formation and community.

In addition small vegetation samples have been collected to assess in laboratory the occurrence of other species not recognizable in the field.

As in most cases the size of the vegetated areas was very small (with the smallest vegetation patches having a size of about 10 x 10 cm and most patches being ≤ 1m^2), each single species/vegetation patch recorded has been reported in the map as single points, while only the patches having a size larger than 10m^2 have been represented as polygons in the map. For what concerns the vegetation formations and communities, they have been recognized following the criteria identified by [4.43] analyzing flora and vegetation of Victoria Land.

All the vegetation data have been reported in a GIS system to develop specific maps providing information concerning the occurrence and distribution of single species as well as of vegetation communities and, hence, of their ecology.

Flora and Vegetation of the Runway track/pathway

Along the runway track/pathway for the vegetation survey were carried out 368 vegetation relevés and was recorded the occurrence of 2 species of bryophytes, 19 species of lichens, Algae and Cyanobacteria (Table 4.11).

All the formations, orders and alliances identified by Cannone & Seppelt [4.43] for Victoria Land have been observed and mapped within the runway path. The relevés data were elaborated to identify the occurrence of specific vegetation communities, which provided detailed information on the edaphic conditions at the local scale. Most communities belong to eight of the fourteen associations described by [4.43] for Victoria Land. In addition, also the community *Schistidium antarctici*, occurring both in pure stands with Cyanobacteria as well as with lichenized by epiphytic lichens, have been observed within the runway.

All the runway path was characterized by a diffuse epilithic colonization extended on wide areas, with mean coverage ranging between 10% and 25%, and only few areas where the epilithic colonization was less than 1% (Figure 4.23). These diffuse epilithic communities mainly included two different formations: a) microlichen vegetation dominated by *Buellia frigida*, b) mixed micro- and macrolichen vegetation (mainly observed in the central and northern part of the runway), characterized by the occurrence of the macrolichens *Usnea antarctica* and/or *Umbilicaria decussata* and/or of *Pseudephebe minuscule*, occurring with *Buellia frigida* and other crustose microlichen species (e.g. *Acarospora gwynii*, *Lecidea cancriformis*).

Table 4.11: List of the species occurring in Boulder Clay area, within the runway path and in the quarry areas

Bryophytes	**Boulder Clay Area**	**Runway Path**	**Quarries**
Bryum argenteum	X	X	X
Bryum pseudotriquetrum	X		X
Ceratodon purpureus	X		
Hennediella hiemii	X		
Schistidium antartici	X	X	X
Syntrichia magellanica	X		X
Syntrichia sarconeurum	X		X
Liverworts			
Cephaloziella exiliflora	X		
Lichens (Lichenes)			
Acarospora gwynnii	X	X	
*Acarospora flavocordia**	X		
Buellia darbishirei	X		
Buellia frigida	X	X	
*Buellia grimmiae**	X	X	
Buellia lignoides	X		
Buellia pallida		X	
*Buellia papillata**	X		
*Caloplaca approximata**	X		
Caloplaca athallina	X	X	
Caloplaca citrina	X		
Caloplaca lewis-smithii	X		X
Candelaria murray	X		
Candelariella flava	X	X	X
*Candelariella vitellina**	X		
Carbonea vorticosa	X		
Lecanora expectans	X	X	X
Lecanora fuscobrunnea		X	X
Lecanora mons-nivis	X		
Lecanora physciella	X		
*Lecanora sverdrupiana**	X		
*Lecidea andersonii**	X		
Lecidea cancriformis	X	X	X
Lecidella siplei	X	X	X
Lepraria cacuminum	X	X	X
Physcia caesia	X		X
Pseudephebe minuscula	X	X	X
Rhizocarpon geminatum	X	X	X
*Rhizocarpon geographicum**	X	X	X
Tephromela atra	X		
Umbilicaria aprina	X		X
Umbilicaria decussata	X	X	X
Usnea antarctica	X		X
Usnea sphacelata	X		
Xanthomendoza borealis	X		
Xanthoria elegans	X	X	X

The single vegetation relevés allowed to identify twelve different vegetation communities, in particular:

1) *Bryum argenteum* in pure stands with Cyanobacteria;
2) *Bryum argenteum* lichenized by epiphytic lichens (*Lepraria cacuminum*, *Lecidella siplei*) with Cyanobacteria;
3) *Schistidium antarctici* in pure stands with Cyanobacteria;
4) *Schistidium antarctici* lichenized by epiphytic lichens (*Lepraria cacuminum*, *Lecidella siplei*) with Cyanobacteria;
5) Lichen encrusted *Bryum argenteum* and *Schistidium antarctici*;
6) Bryophytes (*Bryum argenteum* and *Schistidium antarctici*) with *Pseudephebe minuscula*;
7) *Usnea antarctica* with *Buellia frigida*;
8) *Usnea antarctica* with *Umbilicaria decussata*;
9) *Umbilicaria decussata* with *Buellia frigida*;
10) *Buellia frigida*, both alone and, in some cases, with other epilithic lichens as companion species including *Acarospora gwynnii*, *Lecidea cancriformis*, *Rhizocarpon geographicum*;
11) Pure stands of Cyanobacteria;
12) Pure stands of Algae.

Each community is characterized by different ecological requirements and may provide indirect information on the edaphic conditions along the runway path.

Among the bryophytes, *Bryum argenteum* is a mesic species, while *Schistidium antarctici* is more linked to xeric conditions and indicate lower water availability. The occurrence of lichen encrusted bryophytes in most cases indicate a further decrease of water availability and increasing xericity, respect to their occurrence in pure stands.

Among the lichen dominated communities, the occurrence of *Pseudephebe minuscula* is often associated to late melting snow. Indeed, in many cases (also within the runway path) *P. minuscula* is associated to bryophytes and occurs in sheltered plates where snow accumulates more and tends to melt later, providing a longer and/or larger water supply. Similar ecology, although less mesic, characterizes *Usnea Antarctica*, a species typical of Northern Victoria Land.

Umbilicaria decussata is an epilithic species with wide ecological amplitude concerning water availability and may occur in xeric as well as in mesic habitats, both in pure stands (or associated with other epilithic lichen species) and associated to xeric bryophytes (such as *Schistidium antarctici*, as observed along the runway path). Pure stands of Algae indicate the occurrence of higher water availability and nutrient enrichment, while Cyanobacteria tend to occur in pioneer conditions and/or where there is soil disturbance.

45% of the relevés were pure bryophytes stands (1, 3), with *Shistidium antarctici* occurring with a frequency more than the double than *Bryum argenteum*. About 27% of the relevés were lichen encrusted bryophytes (communities 2, 4, 5), while only 7.3% were pure Cyanobacteria stands (11).

The macrolichen dominated communities (6-9) occurred in 14.1% of the relevés, while the microlichen communities (10) involved only 4.3% of the relevés and the pure stands of Algae were limited to 1.6%. The diffuse epilithic colonization on wide areas has been reported in the map as polygons showing the type of the main epilithic formations occurring within the runway and their mean percentage coverage (%) (Figure 4.23 left side). The highest % coverage of the epilithic vegetation was observed at the northern edge of the runway, while the largest occurrence of diffuse epilithic vegetation by macrolichens (mainly Usnea, Umbilicaria and Pseudephebe) occurred in the central part of the runway.

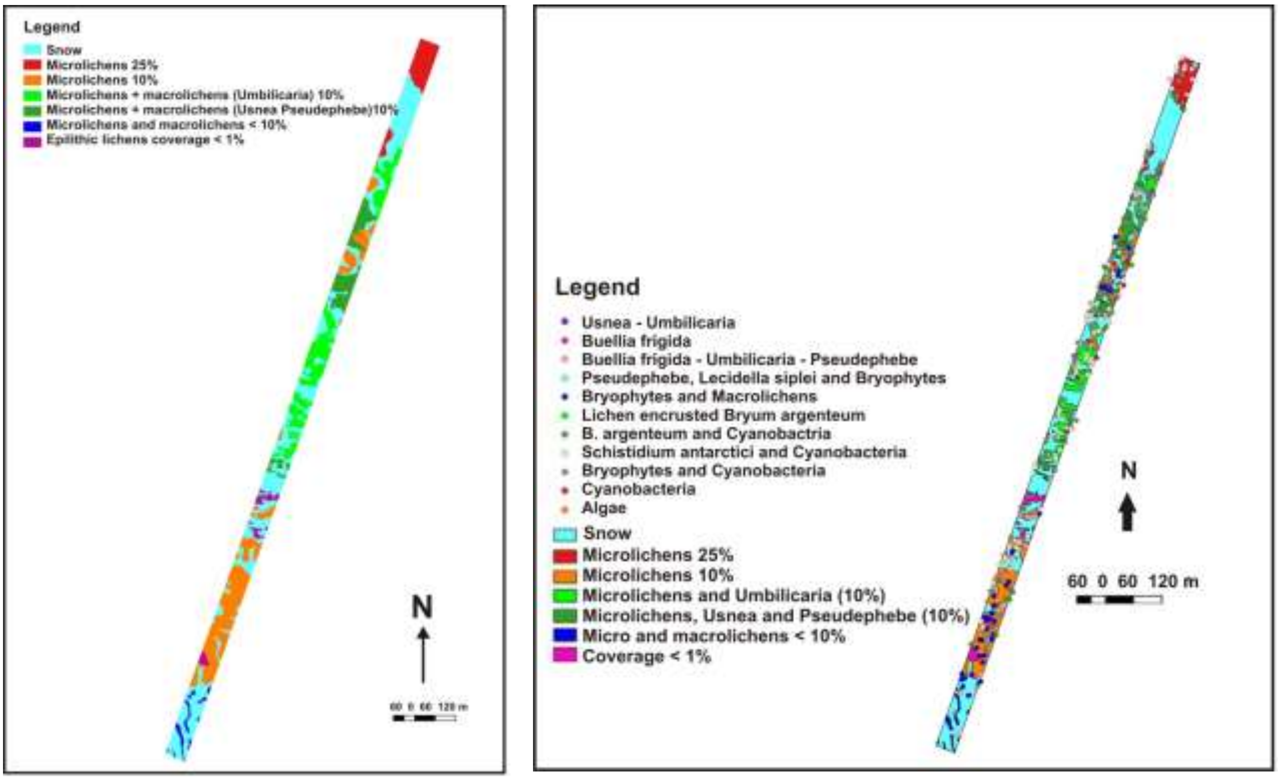

Figure 4.23: Maps of the diffuse epilithic colonization on runway area showing the type of formation(microlichens vs macrolichens and mixed macro- and microlichens) and their mean % coverage (left side) along with the community types of each single relevés (right side).

In combination with this topic, the location of each single relevés on the basis of the community types described above has been added in a new map (Figure 4.23 right side) showing in detail where and which vegetation communities occurred in single small patches along the runway path, along with the main characteristics of the diffuse epilithic colonization occurring on wide areas . From this map, it is possible to observe that most relevés were composed of bryophyte dominated communities, both in pure stands as well as lichenized by epiphytic lichens. The relevés characterized by the occurrence of macrolichens and/or of bryophytes associated to macrolichens were mainly located in the central and southern side of the runway, closer to the area characterized by the largest occurrence of frozen lakes and closer to the CALM grid area. In addition, the percentage coverage (%) of the vegetation has been reported in Figure 4.24 (left side). Here the data referred to the % coverage of each single relevées and of the polygons representing the diffuse epilithic colonization on wide areas. The epilithic coverage was highest in the northern extreme of the runway and higher in the central and in part of the southern side of the runway. The coverage of bryophytes and of the other mapped communities was higher in the northern and central part of the runway. This is in agreement with the occurrence, in southern Boulder Clay, of several frozen lakes. A last map reported the species richness associated to each single relevés, obtained as the number of species recorded (Figure SR). As the vegetation samples are still in travel, this map is provisory.

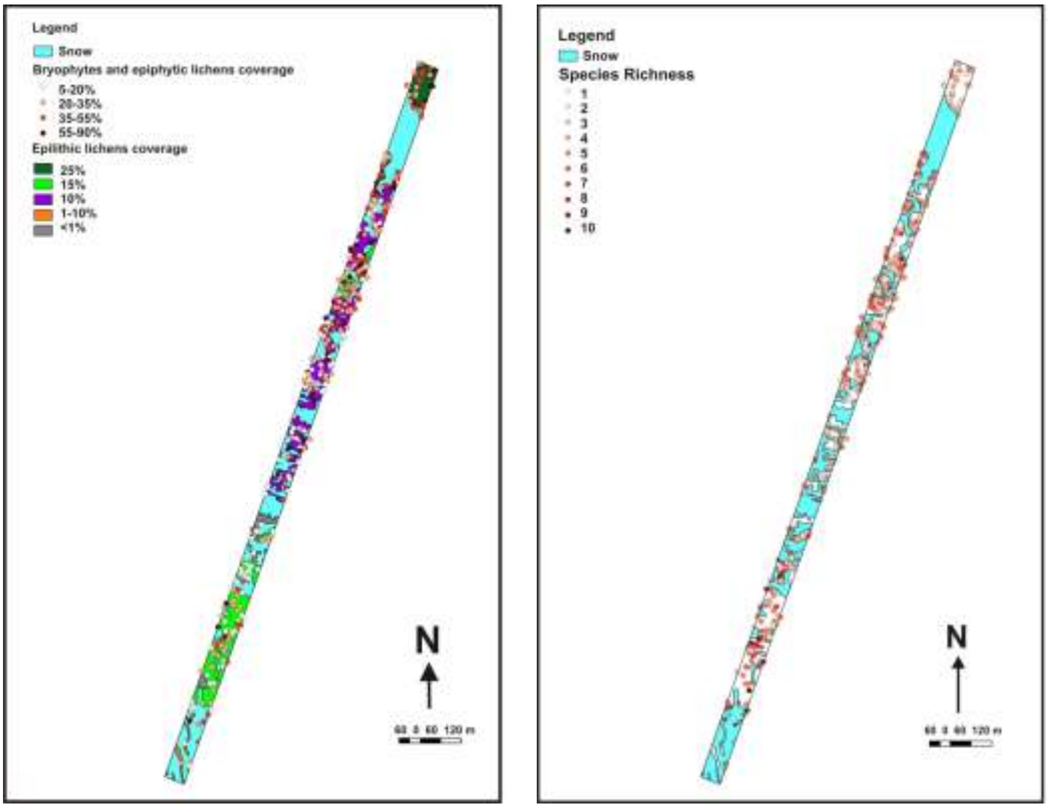

Figure 4.24: Percentage coverage (%) of the vegetation within the pathway obtained by the % coverage of each single relevés as well as of the polygons representing the diffuse epilithic colonization on wide areas (left side), along with the species richness (number of species recorded for each relevés) (right side).

<u>Flora and Vegetation of the areas neighbour to the Runway track/pathway</u>

The vegetation of the areas surrounding the runway path was analysed to assess whether and how it was similar or not to the vegetation occurring within the runway path. These data allowed to perform a comparison (runway path vs surrounding areas) to identify the species and/or communities deserving special protection and being priorities for environmental protection, biodiversity conservation and selected as priorities for the mitigation actions within the runway.

For what concerns the bryophyte dominated communities, the vegetation of the surrounding areas was enough similar to that of the runway concerning the vegetation formations, with similar communities, although the surrounding areas were characterized by lower coverage and less extensive patches of pure bryophyte stands.

The most important difference between the runway and the surrounding areas concerned the macrolichen vegetation. Indeed, the surrounding areas were characterized by a much more limited occurrence of macrolichen dominated vegetation, with special reference to *Usnea antarctica*, *Pseudephebe minuscula* and *Umbilicaria decussata*.

Priority Areas at higher risk along Runway track/pathway and suggestions for the transplant operations

The analysis of the vegetation relevés carried out within the runway path and their comparison with the vegetation occurring in the surrounding areas, allowed to select the priority areas for the mitigation actions focused on biodiversity conservation and environmental protection.

The criteria to select the priority areas were the following:

- Areas representative of the vegetation occurring within the runway path;
- Areas with communities showing high coverage of the target/dominant species located in a limited area (in most cases ≤ 1 m2), with very healthy individuals;
- Areas with vegetation communities with the characteristics described above and representing community types rare or with limited distribution/occurrence both within the runway path as well as in the surrounding areas;
- Areas with vegetation characterized by the occurrence of rare species and/or with large and/or particularly healthy individuals.

The priority areas were selected among all vegetation community types (with the exception of the Algae community) occurring within the runway path, in order to preserve the natural biodiversity of the area which will be erased by the runway construction.

Totally 77 priority areas at higher risk have been identified within the runway path (Figure 4.25):

- 15 patches dominated by *Bryum argenteum* with Cyanobacteria;
- 18 patches dominated by *Schistidium antarctici* with Cyanobacteria;
- 12 patches dominated by *Umbilicaria decussata* with *Buellia frigida*;
- 7 patches dominated by *Pseudephebe minuscula*;
- 5 patches dominated by *Usnea antarctica*;
- 3 patches with *Buellia frigida* and *Acarospora gwynnii*;
- 3 patches with *Rhizocarpon geographicum*, 1 patch with *Rhizocarpon geminatum* and 1 patch with *Caloplaca athallina*;
- 8 patches characterized by high levels of species richness;
- 4 patches with Cyanobacteria in pure stands

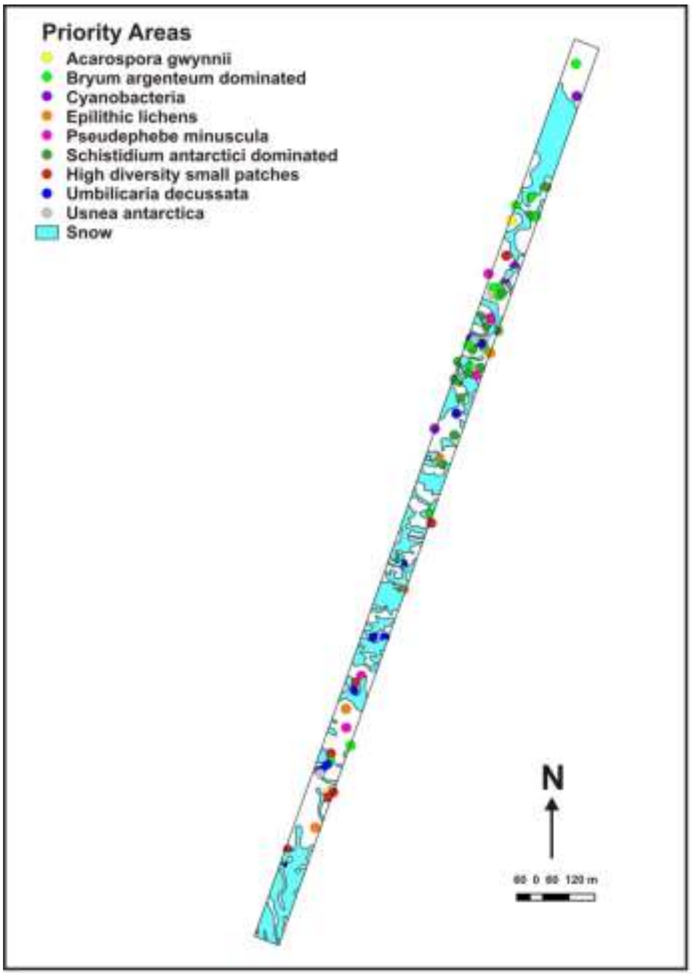

Figure 4.25: Priority areas indicating the vegetation patches selected for the transplant operations finalized to the mitigation measures

These areas are proposed for the transplant operations in the frame of the mitigation plan, in order to reduce as much as possible the damage induced by the runway construction to the preservation of the native flora and vegetation of Boulder Clay. In most cases (54 patches on a total of 77) the size of each high priority areas was $\leq 1m^2$ to facilitate their transplant in safe areas.

Areas adjacent/neighbor to the runway suggested for the location of the transplant operations

The safe areas suitable and proposed for the transplant operations were located on the upward side of the runway, which is leeward and therefore should be more protected from the potential negative impacts of the pollution associated to the runway activity (and transported by the dominant winds).

The criteria to select the areas suitable to host the transplanted vegetation patches are the following. The candidate areas need to be characterized by scattered but not absent vegetation, thus providing ecological indication of the edaphic conditions at the local scale suitable for the location of the transplanted patches. Moreover, the candidate area need to be characterized by the availability of physical surfaces enough large to host the transplanted vegetation patches. Their specific location for each of the 77 priority areas still needs to be defined. The details of these operations will be defined within the development of the mitigation plan in the future seasons.

Quarry areas

There are six areas (Q1-Q6) which have been identified as potential quarries for the supply of the lithic materials to be used for the runway construction (see Figure 2.29). These areas have been surveyed in December 2015 to analyse the patterns of vegetation colonization refer to Figure 4.26).

- Quarry 1: it has very scarce and scattered vegetation (mean coverage ≤ 5-10%) composed by microcrustose epilithic lichens and is almost devoid of vegetation. This is the closest quarry to the runway area.
- Quarry 2: also in this area vegetation is scattered (mean coverage ≤-10%). Vegetation is composed of two different community types: a) lichen encrusted *Schistidium antarctici* with Cyanobacteria; b) macrolichen (*Usnea antarctica*, *Pseudepehebe minuscula*) epilithic vegetation.
- Quarry 3: again vegetation here is scattered (mean coverage ≤-10%) and mainly constituted by epilithic macrolichens with *Usnea antarctica* as dominant with *Umbilicaria decussata* and *Pseudephebe minuscula* as companion species.
- Quarry 4: in this area vegetation coverage is the lowest (with Q1), being less than 5%. The vegetation is dominated by *Schistidium antarctici* with epiphytic lichens and Cyanobacteria.
- Quarry 5: this area is very similar to quarry 4 but with lower mean vegetation coverage (5-10%).
- Quarry 6: this is the area where vegetation is more developed and which would deserve special attention. Indeed the vegetation is still discontinuous but with higher mean coverage (20-25%) and is composed by *Schistidium antarctici* with *Bryum argenteum* and *B. pseudotriquetrum* as companion species and Cyanobacteria. This is the furthest area from the runway and it will be used for the runway construction as last choice.

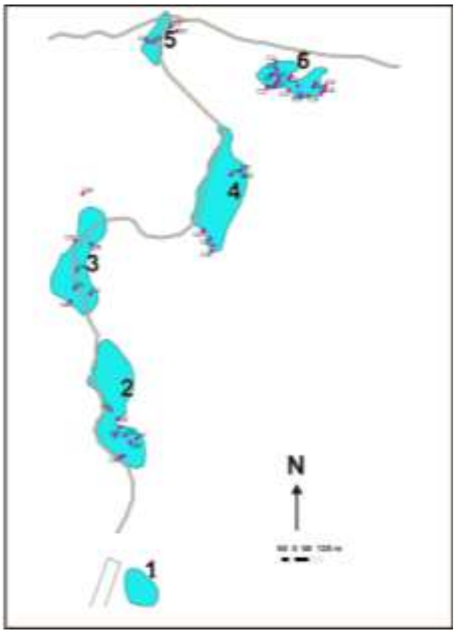

Figure 4.26: Location of the six quarry areas.

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. ASPAs in the Ross Sea region

In the Ross Sea area, in a range of 100 km 4 ASPAs are present (Figure 4.27-A):

ASPA n°173 is located at Cape Washington and Silverfish Bay (centred at 164°57.6'E, 74°37.1'S). The ASPA, jointly proposed by Italy and United States covers an area of 286 km^2, of which 279.5 km^2 is marine (98 %) and 6.5 km^2 is terrestrial (2 %). The primary reasons for designation of the Area are the outstanding ecological and scientific values: one of the largest Emperor Penguin (*Aptenodytes forsteri*) colonies in Antarctica breeds on sea ice adjacent to Cape Washington, with around 20,000 breeding pairs comprising approximately eight percent of the global emperor population and ~21% of the population in the Ross Sea.
The centre of the protected area is approximately 30 km far from the middle of the airstrip, but the Emperor Penguins breeding area is more than 40 km far from the activity area.

ASPA n°165 located in Edmonson Point (74°20'S, 165°08'E, 5.49 km^2) was proposed by Italy. The Area includes ice-free ground and a small area of adjacent sea at the foot of the eastern slopes of Mt Melbourne, which is of limited extent and is the subject of ongoing and long-term scientific research. The outstanding ecological and scientific value of the Area is related to the terrestrial and freshwater ecosystem, composed by 2000 pairs of Adélie penguins (*Pygoscelis adeliae*), 120 pairs of south polar skuas (*Catharacta maccormicki*), >50 Weddell seals (*Leptonychotes weddellii*), at least 30 lichen species and high diversity of algal and cyanobacterial species.
The ASPA is located more than 50 km far form the construction site.

ASPA n°161 site, a coastal marine area encompassing 29.4 km^2 between Adelie Cove and Campo Icaro (74º21'S 164º42'E), that is the closest ASPA to Boulder Clay area.
ASPA n°118 site in Mt. Melbourne (2733 m, 74º21'S 164º42'E) was jointly proposed by New Zealand and Italy on the grounds that these areas contain geothermal soils that support a unique and diverse biological community. The warmest areas of ground created by fumaroles support patches of moss, liverwort and algae along with one species of invertebrate protozoan.
The ASPA is located more than 50 km far form the construction site.

4.4.2. **ASPA n°161**

The proposed runway at Boulder Clay is located about 1,600 m far from the ASPA n°161, while the alternative site of Campo Antenne is only 500 m far from the beginning of this ASPA. The Figure 4.27: -B shows the marine ASPA n° 161 and the marine/terrestrial ASPA n° 173 along with the penguin colonies at Cape Washington and Adelie Cove. The ASPA n° 161 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.

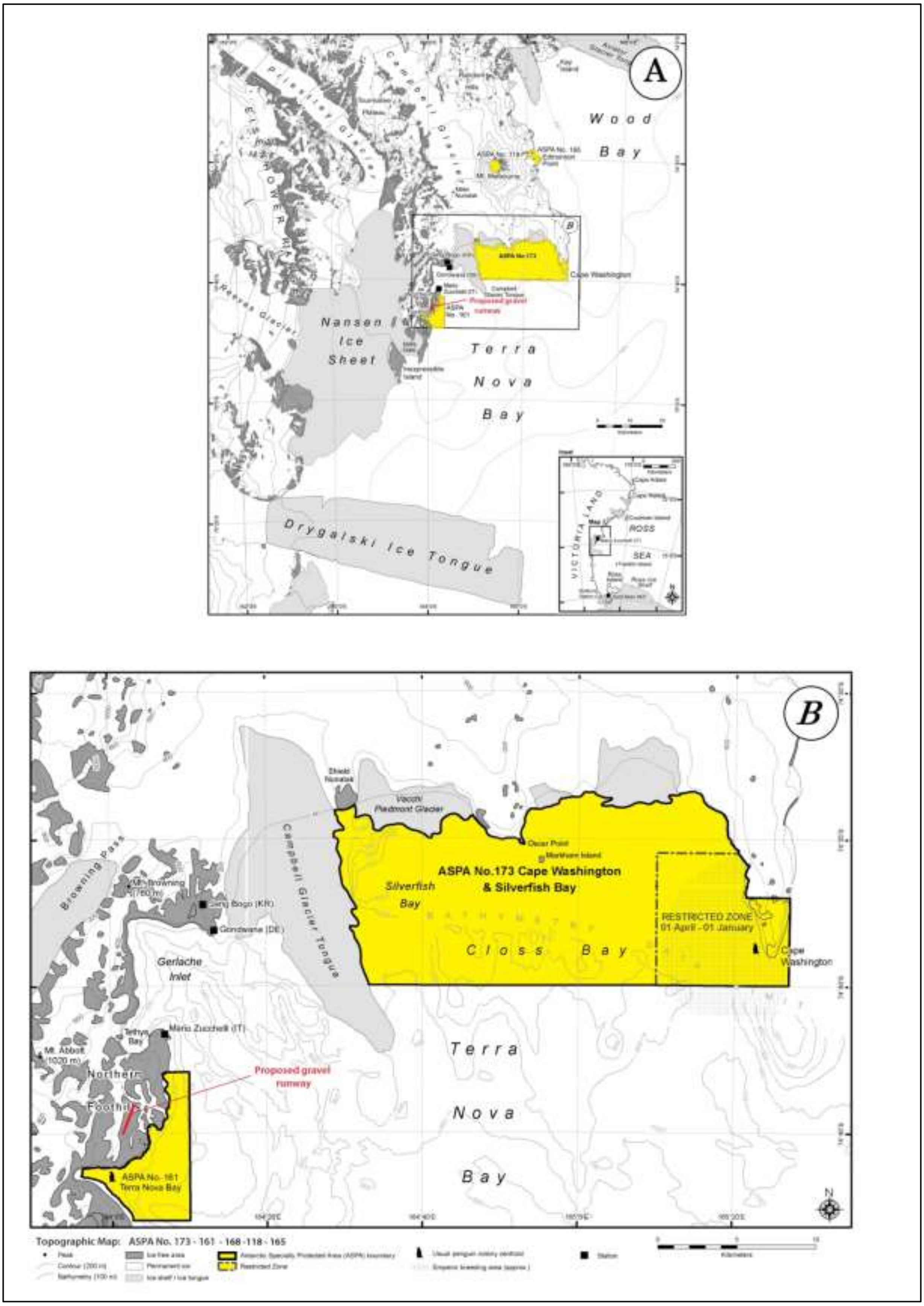

Figure 4.27: Map of Terra Nova Bay ASPAs (A) with a detailed map of ASPA n° 161 and ASPA n° 173 (B).

4.5. Air quality monitoring

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 [4.48] to [4.54]. 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 [4.53]. 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 [4.54].

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 [4.53]. 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.

4.5.1. **Air quality data at Terra Nova Bay**

Monitoring of the air particulate (PM10) has been performed during the last 20 year at Campo Icaro (as natural background site) and MZS (as polluted area). Available and comparable data for both sites range from 2000 to date. Several heavy metals have also been analysed, including Cd, Cr, Ni, Pb, V, Co, Mn.

Polycyclic Aromatic Hydrocarbons (PAH) monitoring (see Table 4.14) has been performed to evaluate organic pollution related to combustion processes. Relative concentration of PAH and metals in the atmospheric particulate at Campo Icaro are strictly connected to different sources of contamination present at MZS:

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

Table 4.12: Considered PAH for the monitoring survey.

Polycyclic Aromatic Hydrocarbons	Name
Fenantrene	PHE
Antracene	AN
Fluorantene	FA
Pirene	PYR
Benzo(a) antracene	BaA
Benzo(b+j)fluorantene	BbF+BjF
Benzo(k9)fluorantene	BKF
Benzo(a)pirene	BaP
IndenoPirene	IP
Dibenzo(a,h)antracene	DBahA
Benzo(ghi)perilene	BghiP

The average concentrations of PAH at Campo Icaro, particularly 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 concentrations of PHA and heavy metals generally remain enough similar year by year, but, depending on wind speed and direction, light differences were observed in different years and during the same season too.

The average values (pg m^{-3}) of the total concentration for each individual PAHs at Campo Icaro between XVI and XVII Antarctic Campaign are reported in Table 4.15. The sum of the average values for each PAH and sampling period is also shown as histogram in Figure 4.28

Table 4.13: PAH average concentrations (pg m-3).

PAH / *EXPEDITION*	*PHE*	*AN*	*FA*	*PYR*	*BaA*	*CHR*	*BbjF**	*BaP*	*IP*	*DBahA*	*BghiP*
XVI	3,0		1,6	3,4							
XVII	1,01	0,12	0,24	0,46	0,12	0,15	0,12	0,05	0.16		2,90
XVIII	1,0	0,2	0,4	0,4	0,1	0,2	0,2	0,1	0,1	0,1	0,2
XIX	4,7	0,36	0,2	0,3	0,35	0,8	0,7	0,3	0,4	0,1	0,7
XX	0,9	0,12	0,6	0,83	0,2	0,4	0,4	0,2	0,28	0,17	0,40
XXI	1,7	0,2	0,5	1,7	0,3	0,2	0,2	0,12	0,17		0.38
XXII	3,7	0,1	0,25	1,50	0,24	0,28	1,15	0,19	0,94	0,10	1,28
XXV	2,0	0,23	1,1	2,4	0,3	1.0	1,3	0,2	0,2	0,2	1,3
XXVI	2,0	0,8	1,3	2,8	0,1	0,9	1,2	0,29	0,6		0,8
XXVII	1,6	1,0	1,8	3,6	0,23	1,1	0,4	1,0	0,2	0,22	0,6

*** = Sum of BbjF e BkF**

The histogram in Figure 4.28 shows values of PAHs at Campo Icaro near the detection limit with minor changes in the years.

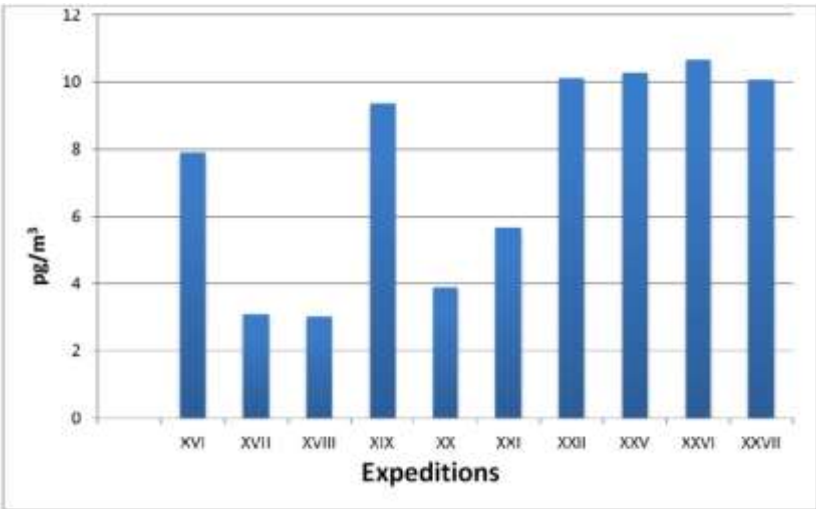

Figure 4.28: Average values of the total PAHs considered at Campo Icaro, for each Expedition.

The average values of concentrations for individual sampling periods (72 hours) do not exceed 12 pg m^{-3}, the point values being always under 10 pg m-3 mainly for phenanthrene, fluoranthene and pyrene. These values are in line with typical values relating to remote areas that, as reported in the literature, range likely from the detection limit for the method used up to a few hundred pg m^{-3}.

Observations at Campo Icaro often resulted below the detection limit of the adopted method of measure (on average about 0.1 pg m^{-3}), especially for anthracene, indeno [1,2 , 3-c, d] pyrene, benzo [a] pyrene and dibenzo [a, h] anthracene. This result means that the location of Campo Icaro is not affected by the contamination from MZS and that the long-range transport from remote industrialized areas is negligible.

For comparison in Figure 4.29 a similar histogram of total PAHs of Fig. 4.25 is reported, but for MZS site. As expected the values in MZS are almost 2 order of magnitude larger than in Campo Icaro. Anyway they are always well below the maximum Italian regulation values.

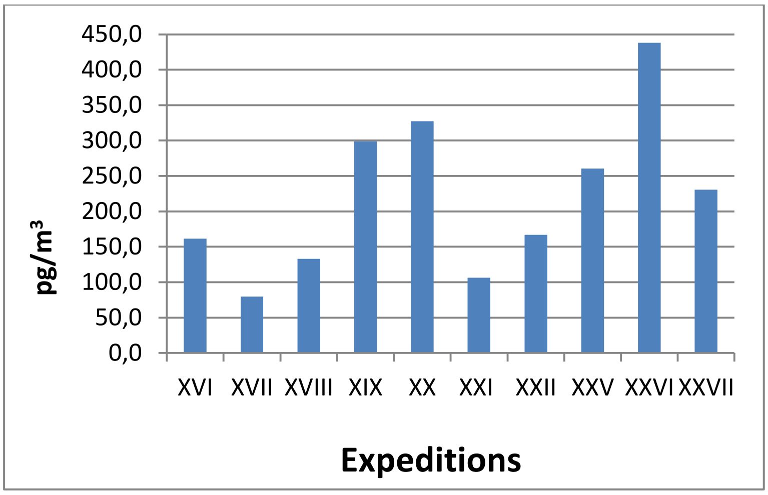

Figure 4.29: Average values of total PAHs considered at MZS, for each Expedition.

The seasonally averaged concentrations of each measured PAH (not shown), for any campaign a similar behaviour shows up, with relative higher concentrations of PYR, BbjF, IP and BghiP constantly present during the summer season.

Heavy metal concentrations were calculated using standard tests with certified values. Often the data are below the detection limit of the method for both MZS (Table 4.16) and Campo Icaro (Table 4.17). The data are reported in ng/m^3

Metals concentrations at MZS site, show sometimes quite high values, mainly copper and lead.

As for PAHs, heavy metal concentrations result much higher at MZS than at Campo Icaro site, because of the proximity to the pollution sources.

The data however confirm that the Antarctic environment is a relatively untouched, highlighting the absence of significant contamination produced by scientific and logistic activities in the area of Terra Nova Bay.

Table 4.14: Heavy metal concentrations at MZS, ng/m^3.

Expedition	Cd	As	Cr	Cu	Mn	Ni	Pb	V
XVII	0.016	0.015	nd	10.8	nd	0,6		0.5
XIX	0.020	0.01	nd	0.41	nd	nd	0.18	
XX	0.026	nd	0.96	24.2	nd	0.25	0.3	0.4
XXI	0.019	0.026	nd	10.5	nd	0.27	0.25	0.21
XXV	0.043	nd	nd	13.9	1.48	0.19	0.19	0.23
XXVI	0.049	nd	nd	12.3	1.45	0.15	0.16	0.2
XXVII	0.014	nd	nd	nd	1.27	0.17	0.18	0.19

Table 4.15: Heavy metal concentrations at Campo Icaro, ng/m^3.

Expedition	Cd	As	Cr	Cu	Mn	Ni	Pb	V
XX	0.08		0.59	0.134	nd	0.145	0.094	0.022
XXI	0.002	0.012	nd	0.84	nd	0.144	0.086	0.021
XXII	0.002	0.011	nd	0.32	nd	0.150	0.082	0.015
XXV	0.003	nd	nd	0.88	0.09	0.02	0.024	0.008
XXVI	0.0017	nd	nd	0.95	0.15	0.03	0.064	0.025
XXVII	0.0019	nd	nd	0.43	0.07	0.05	0.027	0.011

It is unlikely that the main sources of pollution (incinerators, vehicles and aircraft, heating system) give the most significant contribution to the total concentration of PAHs, due to the low number of means available and/or their limited use in time. It is reasonable to assume that the main contribution to the emission of PAHs comes from power unit system running continuously throughout the whole summer season.

Looking at the local circulation, the data suggest that, in accordance with the direction of the prevailing wind and the geographical location of the Base, the sea of Terra Nova Bay would be the main receptor affected by environmental contamination of PAHs and of particulate on the assets of the Italian station.

4.6. Research activities

4.6.1. Scientific activities and long-term monitoring on permafrost and active layer at Boulder Clay

As anticipated above, the runway will include also a large part of the long-term monitoring site "Boulder Clay CALM grid" (Figure 4.30). This is one of the longest-term monitoring areas in continental Antarctica for the assessment of climate change impacts on ecosystems and on their associated physical environment (in particular cryosphere).

Continental Antarctica represents the last pristine environment on Earth and is one of the most suitable contexts to analyse the relations between climate, active layer and vegetation. Moreover, high latitude areas of both hemispheres are expected to be highly sensitive to the impacts of climate change. There is a shortage of data available on vegetation long-term changes in continental Antarctica (e.g. Brabyn [4.55] for Cape Hallett, Melick & Seppelt [4.56] for Wilkes Land).

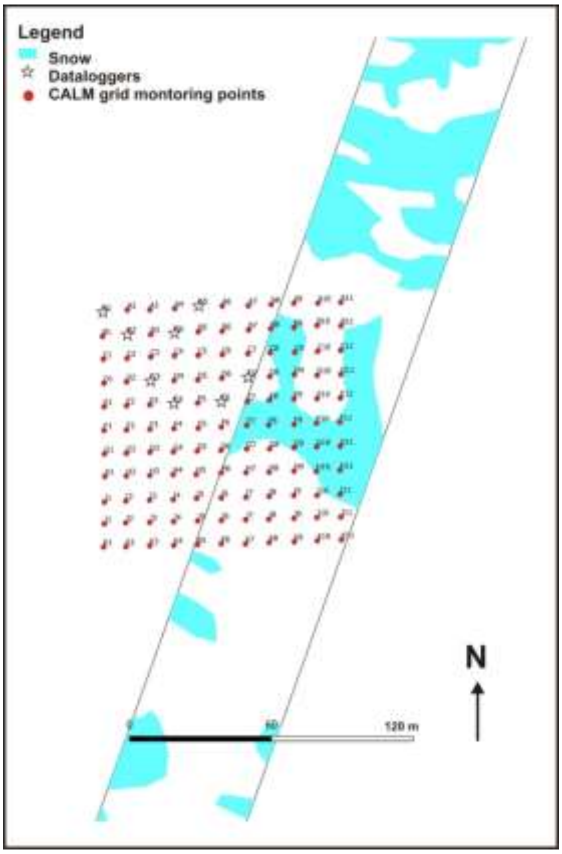

Figure 4.30: Location of the runway respect to the CALM grid and indication of the part of the CALM grid which will be destroyed by the runway.

In 2000 started the long-term monitoring of the climate, permafrost, active layer and vegetation in Victoria Land. This activity has been established in the frame of international panels, with special reference to the SCAR project RiSCC (Regional Sensitivity to Climate Change in Antarctic terrestrial and limnetic ecosystems), then prosecuted as EBA (Evolution and Biodiversity in Antarctica), and to the Latitudinal Gradient Project (LGP).

Moreover, this site is part of a monitoring network extended along a latitude gradient from Cape Hallett (72°76'S, 169°56'E) to Finger Point (77°35'S, 163°20'E) [4.47], with two plots which were installed at Boulder Clay since 2001/2002. These plots were located within the CALM grid for the long term monitoring of permafrost and active layer thickness installed at this site since 1999. The first permanent plot (PP10) was on loose morainic deposits colonised by scattered bryophytes (*Bryum subrotundifolium*, *Schistidium antarctici*) with terricolous and epiphytic lichens (*Lecidella siplei*). The second permanent plot (PP11) was in epilithic vegetation (*Umbilicaria decussata*, *Usnea sphacelata*, *Buellia frigida*, *Pseudephebe minuscula*) on the pebbles, large boulders and outcropping bedrock that were widespread in this proglacial area.

A detailed description of the vegetation (on 50 x 50 cm plots) occurring at each of the 121 nodes of the Boulder Clay CALM grid (100 x 100 m) was carried out in 2001/2002 (on 121 nodes) and repeated in 2012/2013 (on 25 nodes, due to logistical and time constraints) [4.23]. The vegetation of the boulder clay CALM grid was composed exclusively of cryptogams (bryophytes; epilithic, epiphytic and ubiquitous lichens; cyanobacteria and algae), occurring in discontinuous and scattered patches. According to the survey carried out in 2002, almost all of the 121 nodes of the CALM grid were characterized by the occurrence of communities dominated by bryophytes with epiphytic lichens and cyanobacteria colonizing the sediments with finer grain size, coupled with communities dominated by epilithic lichens, mainly occurring on pebbles and blocks. In 2002 the dominant bryophyte species were *Schistidium antarctici*, followed by *Bryum argenteum*, while other species such as *Syntrichia sarconeurum* and *Ceratodon purpureus* occurred only sporadically across the grid. Several epiphytic lichens were associated with *Schistidium antarctici* and other bryophyte species, such as *Buellia grimmiae*, *B. papillata*, *Candelariella flava* and *Lepraria spp*. Cyanobacteria occurred both associated with the bryophyte dominated communities, as well as alone as crusts on the finer sediments. The epilithic communities were mainly composed of crustose lichens (dominated by the placodioid *Buellia frigida*), but included also foliose (mainly *Umbilicaria decussata*) and fruticose lichens (*Usnea antartica*).

In the period 2002-2013, analysing the vegetation changes in the selected 25 nodes of the CALM grid, there was a generalized decline of vegetation, both for the total coverage and for the coverage of the main groups of cryptogams (bryophytes, cyanobacteria), with the exception of lichens [4.23]. The spatial distribution of vegetation within the selected 25 CALM grid nodes showed that the vegetated areas almost coincided between 2002 and 2013 and that their coverage accounted decreases of bryophytes (and cyanobacteria) and increases of lichens. The multivariate analyses emphasized that the floristic composition of vegetation changed slightly comparing 2002 and 2013, with two main groups of species: (a) the community dominated by *Schistidium antartici* is preferentially associated with sites with less snow cover, higher topographic position, thicker active layer and higher ground temperature, (b) the communities of epilithic lichens (*Buellia frigida*, *Umbilicaria decussata*), are mainly associated with the availability of blocks, larger snow accumulation and thinner active layer. The community dominated by *Bryum argenteum* and epiphytic lichens showed wider ecological requirements. The shift between the 2002 and 2012 sites emphasized that in the 10year period the vegetation changed and that, in most cases, these changes depended on the decrease of coverage of one or more species, while the floristic composition within the plots remained relatively stable.

The decline of bryophytes can be related to the active layer thickening, increasing solar radiation and decrease of ground water availability. Indeed, only the xeric *Schistidium antarctici* persisted in this site, while the other bryophyte species in most cases declined since 2002. Conversely, the epilithic lichens increased slightly because they are mainly located on blocks in sites were the drifted snow accumulates, providing water supply independently of the active layer thickness changes/dynamics.

Compared with other high latitude areas, Continental Antarctica provides a unique opportunity to assess the natural dynamics and responses of cryptogams to climate change and provides significant advantages: a) in continental Antarctica vegetation dynamics are not subject to the disturbance effect due to the competition with vascular plants (such as in maritime Antarctica and in the Arctic), as well as b) the impact of grazing (such as in the Arctic), or c) of fur seals and animal disturbance (such as in maritime Antarctica [4.57] [4.58]).

The runway construction will imply the destruction of almost half of the CALM grid and the loss of data for future monitoring.

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, 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, operation and decommissioning 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.

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

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

Fuel consumption for operation

The designed time-life of the runway is 20 years. Structural design of the airstrip considered 30 flights/year, but the PNRA foreseen average needs will not exceed 15 flights/year as presented in Paragraph 2.6, even though the facility could also work as a hub for other Research Program in the Ross Sea Region. The impact on environment related to the fuel handling would be in any case reduced due to the minor number of fights performed each season respect to the designed number of flights for the airstrip and with a well-proven procedure applied during the aircraft refuelling phase.

The overall time for all these phases (taxing, approaching/climbing, take-off/landing) can be considered an half hour, with an aircraft fuel flow rate of 2,600 l/h (density 0.8 kg/litre for Jet A-1 (JA1)).

Table 5.2: Estimated fuel consumption during operation of the gravel runway (tons) for the designed situation (30 flights/year).

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

Table 5.2 presents the total amount of fuel consumed in the round trip flight, in case of the structural design conditions (30 flights/year), that will be almost double than the realistic plans for the facility operation. Data represent almost the overall fuel consumptions, being those related to vehicles active during approaching and landing operations, or the terminal power generator, negligible compared to the aircraft fuel consumption.

It should be noted that only less than a half of the total amount of JA1 consumption reported in Table 5.2 basically will be refuelled in Antarctica.

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 bedrock 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. Emission factors reported in the table are derived from technical documentation provided by manufactures of vehicles.

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

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	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**

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, making use of the emission factor reported by Starik [5.1].

Table 5.4: Estimated total annual emission (15 flight/year) during operation of the gravel runway (tons) [5.1]

Source	Fuel Type	yearly consumption (ton)	Emission Pollutants	Emission factor(ton/ton)	yearly emission (ton)
Aircraft	JA1	435	**CO**	0.0113*	**4.9155**
			NO_x	0.0292*	**12.702**
			SO_2	0.0008*	**0.348**
			PM10	0.0011	**0.4785**
			CO_2	0.859	**373,665**

As reported in the above Fuel Consumption Paragraph, although the runway has been designed for an activity of 30 flights/year, the PNRA foreseen average needs will not exceed 15 intercontinental flights/year, as reported in Paragraph 2.6.

The impact due to the aircraft's exhausted at the Boulder Clay area, is considered to be negligible since 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) orders of magnitude below limits reported in the Italian guidelines.

5.1.2. Evaluation of noise emission

Noise will be generated from landing, taxing, ground handling and taking-off operations 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 have been estimated and appear significantly lower than the aircraft noise during take-off, with the exception for blasting activities. As reported in Paragraph 2.4.4 explosives use will be reduced as much as possible and blasting activity areas are likely located at enough distance from Adelie Cove:

- Apron (3.7 km from Adelie Cove)
- Ridge at 1450 m North of the runway threshold (2.5 km from Adelie Cove)

The potential noise propagation during airplane take-off were estimated assuming the worst conditions on the field: take-off of the airplane from the head of the airstrip (i.e. the closest point to the Adelie Cove) and noise propagation at low frequency (low frequencies propagate in air farther than high frequencies). Moreover calculations were performed at 125 Hz, a band where the highest intensity peak for Hercules L100/30 engine are recorded.

The model used for the simulation is SPreAD-GIS, a GIS tool specifically developed by the Colorado State University [5.2] for modelling anthropogenic noise propagation in natural ecosystems. The noise input value at take-off was assumed from the "RAF - C130 Noise Assessment Technical Report" [5.3], while seasonal averages of temperature, relative humidity and prevailing wind speed/direction, as observed in summer by the closest AWS meteorological station (K3, see Figure 4.14), were used as input values for the propagation model.

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

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

The noise level estimated by the model in correspondence of the Adelie Cove colony is just above 35 dB(A) overall the natural noise level in the colony, evaluated in 20 dB at 125 Hz frequency (Figure 5.1).

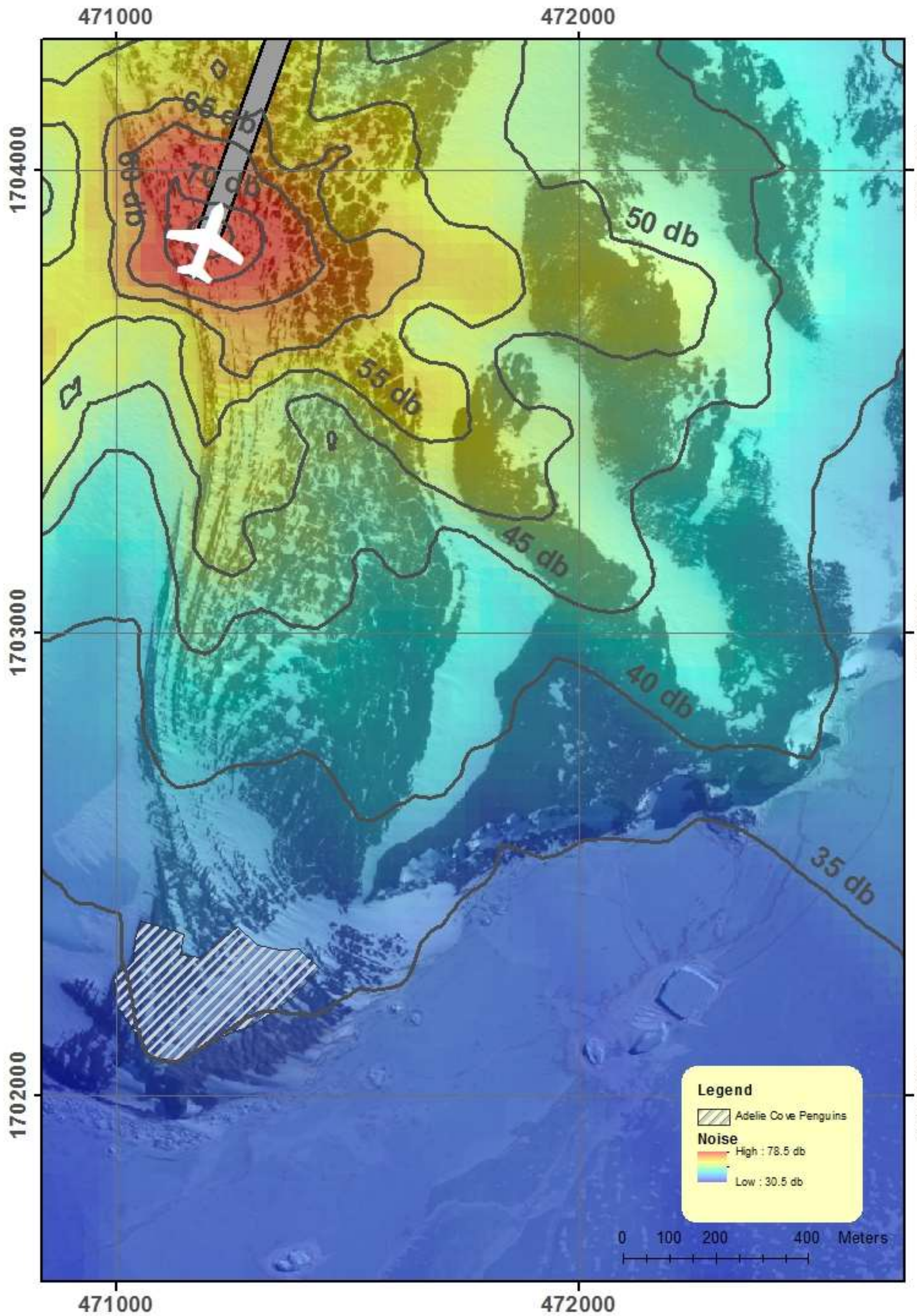

Figure 5.1: Estimated noise level over natural noise condition (20 dB(A)) at 125 Hz, during full engine power of Hercules L100/30, in take-off procedure.

5.1.3. **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. We are considering here only episodes connected with normal operation. Risk arising from severe events, like damaged fuel tanks, are classified as risk being not expected at all in normal operations.

5.1.4. **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.

5.1.5. **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 (from 4 to 5 km), 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.

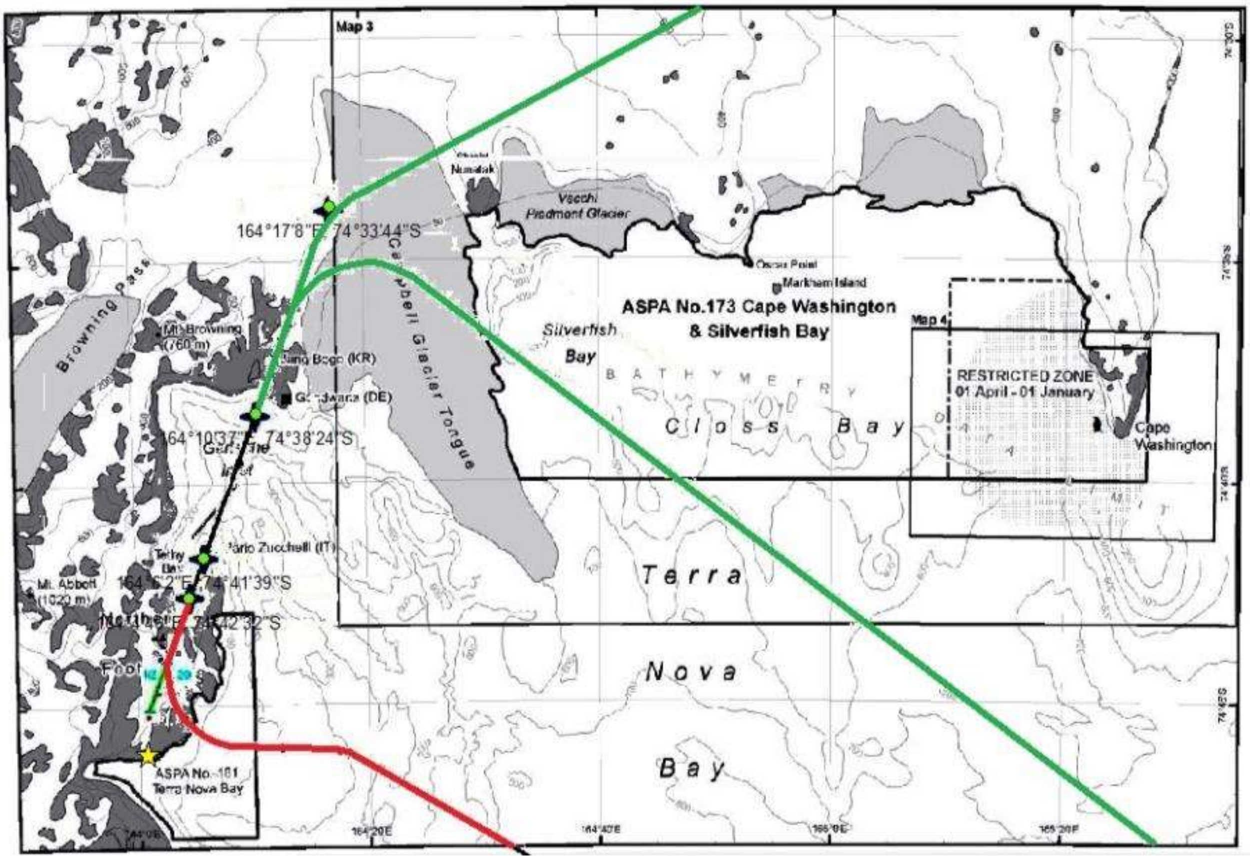

Figure 5.2: The area around MZS with the planned flight routes.
Operative landing/taking off and of emergency missed approach (green and red lines respectively), over layered with bird colonies (yellow star) and ASPA 161/173 borders (black lines).

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.

Impact on other ASPA in Ross Sea Region

In Ross Sea area have been proposed and established other two ASPAs, as presented in Figure 5.3 (ASPA n°165 and ASPA n°118). These protected areas are both situated more than 50 km far from the centre of the airstrip and the flight path does not intersect any of their boundaries, maintaining a consistent distance from the areas. With this evidence we can foresee there will be neither major nor minor direct or cumulated impacts on these ASPAs.

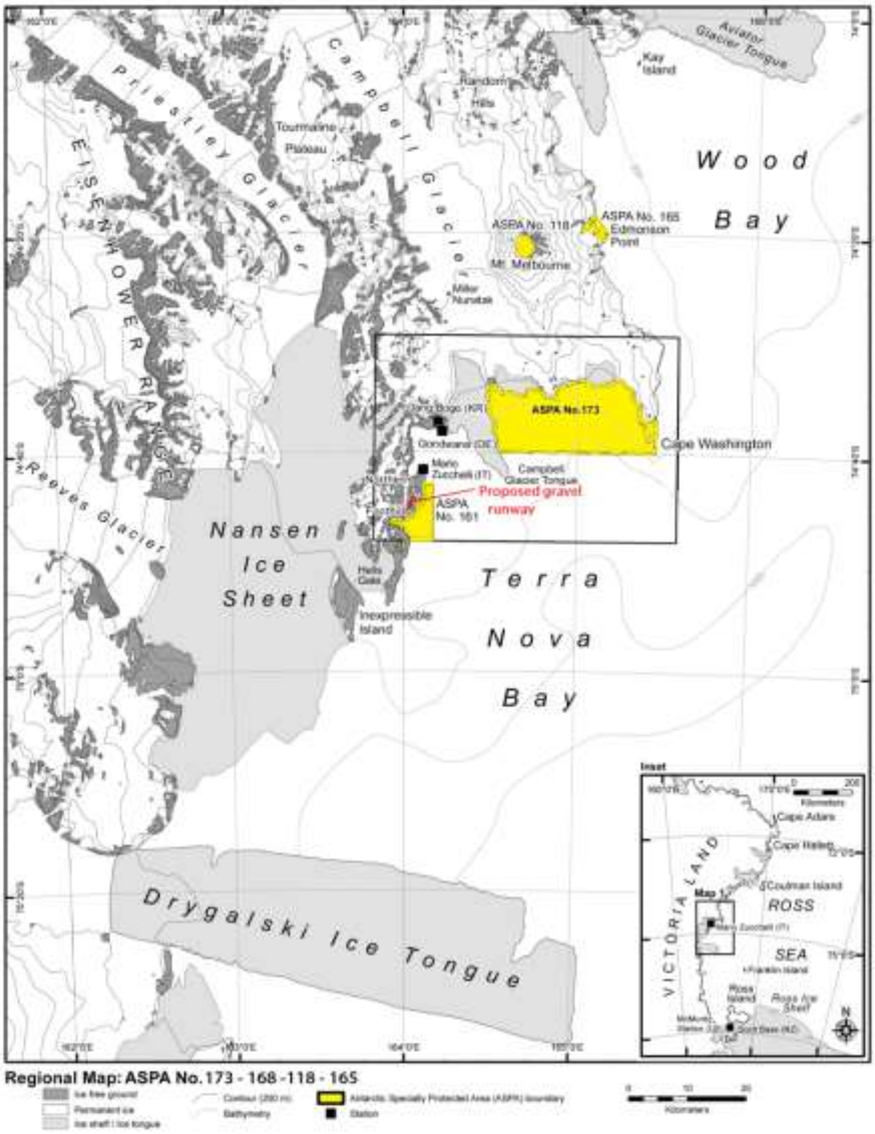

Figure 5.3: ASPAs of Terra Nova Bay and Wood Bay area

Introduction of foreign species

In general in the evaluation of the impacts on the ecosystem for intercontinental carrying should take in account the possible introduction of foreign species.

It's already known the presence of many non-native species on the Antarctic continent (eg. seeds, grasses, algae, fruit flies, worms, spiders, midges, microorganisms) caused by natural transportation by migratory birds, the anthropogenic activity. Alien species introductions problem had been finally recognized of utmost importance in the Resolution 6 (ATCM XXXIV CEP XIV Buenos AIRES 2011) related to Non Native Species Manual.

Development of human activities recorded in recent years in these regions (including science, logistics, tourism, fishing and recreation), will increase the risk of unintentional introductions of organisms.

With this sight a precautionary approach should be applied to minimise the risk of human transport of non-native species, as well as the risk of intra-regional and local transfer of propagules to pristine regions. Nevertheless, prevention is the most effective means of minimising the risks associated with the introduction of non-native species and their impacts.

A monitoring plan and mitigation measures (Paragraph 5.3.6) on non-native species must be applied to minimise the risk of human-mediated introduction of non-native species, as well as the risk of intra-regional and local transfer.

5.1.6. **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.

Wilderness of the area would be respected limiting the interaction with local environment, using only the access road, training the passengers regarding conservation of flora and fauna measures.

The runway will implement the Waste Management Plan of the MZS 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.

5.1.7. **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 and operations

In the construction stage of the runway, and in particular during the operation a considerable amount of no dangerous solid waste will be produced. Wastes will be mainly composed of food, human and domestic wastes. Besides we will have building materials, including metal, plastics, glass and wood.

Following the operative instruction for management of field camp (MZS field camp management manual system) in Table 5.6 we classify the wastes produced in field camp and correspondent type of storage.

Table 5.6 Wastes produced in field camp and the pertinent storage system.

Waste	Storage
Paper, cardboard, kitchen waste	Plastic sealed envelope
Wood	Box, cartons, sealed envelope
Metal	Box, cartons, sealed envelope
Plastic	Box, cartons, sealed envelope
faeces	Cartons, cartons inside lined with sealed envelope
Toxic waste or fuel spill products	Airtight metal drum

As appropriate, according to rules, wastes will be separately collected, following PNRA procedures, in the following way: solid wastes (i.e. cardboard, packaging material, wood, plastics, glass, batteries) will be separated by type, compacted if possible, and temporary stored in MZS and shipped back to Italy with m/n Italica when necessary (following Antarctic Treaty regulation on wastes). The storage area in the construction camp will be chosen to less impact on environment, and to simplify handling and transportation back to MZS.

At MZS, wastes such as paper, cardboard, wood and food are incinerated in a two-stage incinerator (with post-combustor at T=1000° C). The incinerator follows the Italian environmental law and the gas exhausts released in atmosphere are monitored (i.e. SO_x, NO_x, PAH, …). Bottom and fly ashes are collected, sealed in drums and, as required, sent back in Italy at the end of the operations. Plastics and all other wastes are compacted, packaged, labelled, and removed from the Antarctic Treaty area. Wastewaters will be collected in appropriate containers and subsequently transported to MZS, where they can be treated in a physicochemical wastewater treatment plant that fulfils the requirements of the Italian Environmental law.

Potential impacts will be handled following PNRA policies and procedures currently in place, such as waste management protocols for separating, containing, and returning wastes from field camp sites.

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.

Roughly, excluding metal and wood used into the construction site, we can consider about 2-3 Kg of waste for person per day. Total amount to manage could be about 25-40 Kg of human waste (seawage, plastic, paper) per day, corresponding to 1 ton for month.

Besides from environmental point of view, should be very important avoid the access to waste for skuas attracted on site by noise and food not preserved. In this way we can also guarantee the area free from skuas during construction and particularly during operation stage.

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:

Type

We classify the impacts as direct, indirect or cumulated impact.

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 type (direct, indirect, cumulated), extent, duration, intensity, probability (high, medium, low) and significance of the impact are then ranked in Table 5.7.

Table 5.7: 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.	Type: D 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. Renewable energy sources will be implemented on yhe site and at MZS.
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.	Type: D 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. 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 5.7: 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.	Type: D/C 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.	Type: D/C 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.	Type: D 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 5.7: 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.	Type: D 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.	Type: D 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 [5.4].

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. **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.

The blasting activity will be considered only for areas where the rock soil level must be reduced. These ridges are located sufficiently far from Adelie Cove: the distance would be enough to consider the activity without major effects on the penguins colony.

To further mitigate the impact, this activity will be reduced as much as possible, with a calculated soil volume to be blasted less than the 2% of the total material needed for the embankment.

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.

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

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

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.

These measures will be sufficient to prevent and minimize oil spill episodes that could arise during normal operations. Equipment listed above will be much more relevant in case of oil spill as consequence of unexpected conditions or breaks in equipment, aircraft etc. These cases are correctly included in the risk analysis (Cap. 7).

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.

Mitigation actions finalized to biodiversity conservation and against the loss of wilderness will be carried out, starting before and to prosecuting during the construction of the runway, in particular for what concerns the vegetation component.

Indeed, the runway construction will imply the total destruction and erase of all the vegetation growing within the runway path and in all the service areas directly interested by the construction works, including the quarry areas. For these reasons it is mandatory that the mitigation actions will start before the runway construction and will prosecute also during it. For the vegetation component, the only possible mitigation action is the transplant of patches of vegetation (and the underneath soil) from the runway and service areas into safe neighbour areas where the runway impacts will be negligible and where the edaphic and ecological local conditions will be similar to those of the original sites located within the runway.

The mitigation actions will be developed in different phases:

Preliminary phase pre-construction 1: analyses of the vegetation occurring within the runway path and in the surrounding neighbour areas to identify the areas with highest conservation priorities

Preliminary phase pre-construction 2: selection of the priority areas candidate for the transplant actions;

Preliminary phase pre-construction 3: identification and mapping of the areas devoted to host the vegetation patches transplanted from the runway;

Phase 4 before and during runway construction: removal of the selected high priority vegetation patches and their transplant in the selected safe areas;

Phase 5 during and after runway construction: long-term monitoring of the success of the transplant actions in safe areas.

The transplant actions need to be performed during the runway construction but with a temporal advantage, allowing to have time to move the selected priority vegetation patches in safe places the before the destruction of the original runway path.

5.3.6. **Mitigation measures against non-native species introduction**

Non-native species may be introduced through the usual means of access to the Antarctic continent (eg. ships, aircraft, containers, vehicles, materials, science, personnel). Up to now at MZS or Concordia Station, no evidence of non-native species introduction was observed, however Italy is aware that prevention is the most effective means of minimizing the risks of introduction.

The PNRA already addresses this risk. Currently intercontinental flights are performed in the first part of the season and once every two/three years the multi-purpose vessel Italica is chartered for transportation of fuel, goods, personnel and for scientific research. The Non-native Species Manual (Non-native Species Manual. – 1st ed. - Buenos Aires : Secretariat of the Antarctic Treaty, 2011) and the checklist distributed by COMNAP for supply chain managers of National Antarctic Programmes for the reduction in risk of transfer of non-native species are followed. Prevention focuses on pre-departure measures and specific information on the risks of non-native species introduction is currently given to Italian personnel going to Antarctica, during the training course and during the pre-departure briefing at Christchurch, NZ.

Controls are always carried out before departure for Antarctica, on containers and freight loading. Equipment, food and personnel clothing is also always checked before boarding. In particular, fresh food is properly packed and food wastes are incinerated. The Antarctic clothes provided (when not new) are always washed at high temperature, while boots washed and sanitized. Controls are accurate especially in the parts containing Velcro fasteners, pants, cuffs where seeds and other species are more likely to be found. Scientific instruments are also sanitized where possible and necessary.

The proposed gravel runway will not result in a transitory increased movement of personnel and material, during the construction phase and we expect to have 10-15 more persons on site than usual.

Once in operation, an increase of personnel arriving and departing from Boulder Clay is expected instead of arriving at MZS via Basler or Twin Otter from/to McMurdo Station, however no significant increase in the overall presence of Italian personnel is actually expected.

If, as expected, exchange of logistic services with neighbouring countries will result in an increase of activities in the area, the PNRA will ensure, in cooperation with the other neighbouring Antarctic Programs, more stringent controls on clothing and materials transported.

Good baseline data on native fauna and flora is already available, as previously discussed, and monitoring of eventual non-native species introduction will be performed through regular observations.

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6. Environmental Monitoring Plan and Dismantling

6.1. 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. Together with this fundamental aim, the environmental monitoring plan (EMOP) will be buil to also provide simultaneously 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.

It should be noted that highest priority in terms of a monitoring program should be those values that are the most sensitive, those most likely to be significantly impacted, those that are most important to protect, or a combination of these factors. Potential indicators of impact, defined as "signs or symptoms of changes, potentially due to numerous factors, in an environmental feature or features", along with their relative parameters, are shown in Table 6.1.

Table 6.1: Some potential indicators and parameters for use in monitoring programmes in Antarctica.

Indicator	**Parameter**
"Footprint"	Area subject to human activity, e.g. spatial coverage of buildings, number and location of field expeditions
Air quality	SO_2, particulates (metals, PAH)
Soil quality	Metals, TPH, PAH
Sea water quality	TSS, DO, BOD, COD, pH, conductivity (ASPA 161)
Snow and ice quality	Metals, TPH, TSS
Vegetation quality	Spatial extent, metals
Wildlife health	Population size, breeding success
Fuel handling	Amount consumed, number, size and location of spills,
Aircraft/vehicle operations	Distance travelled, number of landings, fuel consumed
Solid and liquid waste	Waste types (including hazard), volume / weight
Field activities	Number of person days in field, location of field camps
Introduced organisms	Species, distribution, population size

On the base of analysis developed along the document up to now (mainly those reported in Cap. 4 on the Initial Environmental Status), with respect to the environmental impacts, EMOP will put attention to 5 areas: (1) permafrost and ice-blisters; (2) fauna (including penguins, skua, etc.); (3) vegetation; (4) air quality; (5) deformation processes.

EMOP will be implemented and managed by PNRA involving for each specific area above listed, experts arising from the scientific community, identified on the basis of the specific knowledge of peculiar characteristics of the Boulder Clay and Terra Nova Bay area.

Preliminary monitoring activities have been developed in previous year and more systematically during the austral campaign 2015-16, with aims to (i) ameliorate the knowledge on the environmental status of the Boulder Clay area with respect fauna, vegetation and permafrost and (ii) be able to start monitoring activities since the beginning of construction phase.

Below detailed monitoring plan for the 5 elements are reported.

6.1.1. **Permafrost and ice blisters**

Boulder Clay runway will be realized in a continuous permafrost area with a general high ice content because the major part of the track is planned on a debris-covered glacier. As already mentioned in chapter 4, in the actual climate change frame this area is experiencing an active layer thickness increasing despite the substantial stability of the air temperature [4.23]. Therefore a correct monitoring plan of permafrost conditions is essential both to record the environmental impacts of the runway but also to manage its maintaining actions.

To monitor the changes of permafrost conditions is mandatory monitor the following parameters: (i) the spatial and temporal variability of snow cover, (ii) the thermal regime of the active layer and of the upper permafrost, (iii) the permafrost hydrology and the ice blisters and hypersaline brines ecosystems along the runway (upward and downward the track).

The monitoring plan here described includes the ante-operam actions necessary to define the natural state of the snow cover variability and of active layer and permafrost variability and above all the Post-Operam actions to assess the impacts of the runway itself.

<u>Ante-Operam Monitoring</u>

The monitoring plan during the first phase will have to include a) the upgrading of the existent CALM grid, b) the installation of a monitoring system along the runway and c) the installation of the monitoring system of the permafrost hydrology of the frozen lake close to the CALM grid.

(a) The upgrading of the CALM grid will be realized with the installation of at least 4 snow cams and 121 snow stakes to monitor the snow variability. At least two of the snow cams should be equipped with infrared camera to record also the changes of the snow cover during the austral night. It should be also upgraded the monitoring of the thermal regime of the active layer through the upgrading of the monitoring system of the temperature within the active layer and the upper permafrost (down to 1 m of depth) to reach a minimum number of 36 nodes equipped with a minimum of 4 thermistors in each node. In each node should be monitored at least at 2 different depths also the water content.

(b) The monitoring system along the runway will be composed by at least 25 shallow boreholes of 1 m of depth located upward, downward and on the thinner border of the embankment in selected transects along the runway track. The upward and downward boreholes will allow to monitor the thermal differences induced by the changes in the snow accumulation produced by the embankment while the third type of boreholes will allow the monitoring of the direct impact of the runway.

In each borehole should be replicate the same configuration planned for the CALM grid nodes. The snow monitoring along the runway will be achieved installing two couples of snow cams in two different transect along the runway.

(c) The permafrost hydrology will be monitored in only one selected frozen lake along the runway track because this type of installation is more expansive and not standardized. The installation will be located on the lake 16 (Guglielmin et al., 2009) and will be composed by three new deep boreholes (at least 10 m) of which one located upward the lake, one within the lake and the third one downward the lake and downward the runway track. In each boreholes a thermistors string and a multiparameter probe will be installed. The brine eventually occurring within the boreholes will be sampled every year for chemical and microbiological analysis (under sterile conditions). The installation will be completed through the installation of a snow cam and a net of sublimation stakes on the lake. Technical details of the installations will be provided during the executive projects of the monitoring plan.

Post-operam Monitoring

The Post-operam monitoring plan consists in the maintaining of all the monitoring structures realized in the ante-operam phase with a possible upgrading of all or some selected structures to allow the satellite transmission of the data that could be useful to the management of the runway.

6.1.2. **Fauna**

The construction and operation of the proposed airstrip can affect with possible direct impact on penguins and skuas population nesting at Adélie Cove. Although airstrip minimum distance from the penguin colony meets the SCAR guidelines (Harris 2005, [4.39]) and the wind directions from the runway to the colony are favourable (see chapter 4, Figure 4.19), the lack of natural protection (i.e. hills or geographical features) will not mitigate any impact on the colony. From a temporal point of view, moreover, aircraft operations need to overlap entirely with the delicate stages of reproduction such as those that characterize the first part of the breeding season. The suspension of activities in the sensitive period, as suggested by SCAR guidelines, in this case cannot be met.

Beyond the direct impact other forms of indirect impact (aircraft operations, infrastructure construction, support and maintenance for the airstrip, see in Woehler et al [6.1]) can potential affect marine wildlife foraging in the bay of Adélie Cove (eg seals) and seabirds species breeding in the inference of the airstrip, i.e. in the terrestrial and marine coastal area from Terra Nova Bay to the Northern Foothills.

With the intention to develop specific guidelines for the management of the site of interest, monitoring will characterize rigorously and through quantitative measures as many forms of potential impact.

A pre-construction (ante operam) phase aiming to describe baseline data has been started and shall be used in later years as a baseline dataset. A following long term monitoring program with novel collection of data will be used to assess wildlife population trends in order to early identify potential impacts. The parameters are chosen for giving short term information in order to quickly correct any deficiencies and suggest adjustments for management or mitigation measures.

<u>Ante-operam monitoring</u>

Highest priority for monitoring is to establish a pre-disturbance baseline for several parameters. For this reason a description as accurate as possible of the Adélie penguin colony, of the wildlife and its positioning was carried out in 2015-2016 Antarctic campaign (see Chapter 4, Figure 4.22):

- desktop study and documentation of the penguin colony size and estimation and distribution of population of seabirds species in the area from MZS to Adélie Cove, according to existing literatures and previous surveys carried out by Italian researchers;
- georeferencing the upper limit of the Adelie penguins' colony;
- georeferencing the skuas nesting areas nearby the penguin colony.

This will allow to detect any possible future deviations from the current situation, especially with regard to the upper margin of the colony (the one farthest from the sea and closest to the runway), as for example the displacement of group of nests, as well as significant changes in the consistency of the species. Marine birds and mammals (i.e. snow petrels, wilson storm petrels, leopard and weddell seals, killer whales and baleen whales) occurring in the stretch of coastal area that goes from Terra Nova Bay to the Northern Foothills and Adélie Cove will have to be included, as they can be potentially affected by the approaching route of the aircraft to the runway.

Additional data still required will be:

- satellite images of the area of interest during different stages of the breeding season;
- observation and survey of marine mammals in the area during the Antarctic summer;
- colony's noise level during normal activities (e.g. no disturbance).

Construction and operational phase monitoring

Three main risks are likely to have the greatest potential of impact to wildlife during airstrip construction and operational phases. These are disturbance from noise and visual presence of operations, bird strikes and disturbance at breeding sites arising from increased human visitors.

Noise and Visual impacts

There is a potential for disturbance to the wildlife from aircrafts through noise and visual impacts. The image of the aircraft it may be associated with a possible element of danger (e.g. predator), while different levels of noise may have increasing impacts during reproductive phases (cfr. de Villiers [6.2]).

Both of these components of the impact must be quantified by standardized behavioural observations by an operator recording animal’s different reactions to the approaching aircraft. Measures of behaviour will be carried out by researchers also with the aid of a camera. Noise measurements in the proximity of the colony will be included, installing control units for the background noise and an automated image acquisition camera to measure the behavioural response during the various stages of the project. Measuring should be repeated and continue for a period of time long enough to accurately assess the potential impacts.

Bird strikes

The risk of collision of aircraft with flying birds is low. Although unlikely strikes are a possible security risks and it is proposed to carry out a risk assessment of bird strikes and the development of management procedures designed to reduce to zero the chances of impact. Skuas may be attracted in the runway area by the possibility of gathering food, e.g. wastes, for this reason management procedures should then be taken strictly as routine procedures especially by staff operating on the airstrip during construction phase and during its normal operations.

Human presence and Mitigation of the impact of visitors.

Adélie Cove penguin colony is easily accessible from MZS. This makes this area one of the most visited by Italian Antarctic personnel. The presence of a road, as a facility for the airstrip project, will undoubtedly increase the number of people visiting the colony. Increased human presence and potential impacts from airstrip project can add up causing additional stress levels on birds especially in a sensitive period such as the reproduction.

Regulated visits may however become a moment of leisure and education through aware and respectful observation of the wildlife. Specific regulations will be developed to manage the flow and the behaviour of visitors.

A further step in mitigation could be placing an observation hut from which unseen visitors could then observe and photograph animals from a safe distance.

<u>Post-operam and long term monitoring</u>

In addition to the above actions, the following assessment will be carried out in the long run to assess the potential cumulative impacts of the airstrip project:

- monitoring of the Adélie penguin breeding population in the study area; year to year variations of the distribution, reproductive success and population size and comparisons with other two control colonies, Edmonson Point and Inexpressible Island;
- estimation of seabirds and marine mammals abundance and sightings frequency to be compared with the ante operam scenario;
- non-destructive sampling of tissues (i.e. unhatched eggs, feathers, blood) for the quantification of potential impacts of contaminants and the presence of genotoxicity caused by the presence of chemical compounds in the biota.

6.1.3. **Vegetation**

The assessment of the priority areas for the mitigation actions finalized to reduce the negative impacts have already been discussed in paragraph 5.3.5. Besides that, the monitoring plan focusing on the impacts on vegetation is organized in the main activities described below.

<u>Ante-operam monitoring</u>

Vegetation analysis and mapping within the runway path and at highest risk of negative impacts is available. More details on this topic are already been provided in paragraph 4.3.2. During the field campaign 2015/2016, the available vegetation information have been integrated with the new data provided by a specific survey carried out within the runway path, the surrounding areas and the quarry areas. These data allow to have a detailed knowledge of the flora and vegetation occurring along the runway, to identify differences in terms of floristic composition and/or coverage comparing the runway with the surrounding areas and to identify the areas suitable for the mitigation actions (transplant operations). Moreover, the vegetation survey allowed to identify the quarry areas suitable to provide the construction material and to indicate the quarry areas where vegetation conditions made them not suitable for these operations. All these data will provide the starting reference for all future long-term monitoring for the assessment of the runway impacts on flora and vegetation of Boulder Clay.

<u>Construction and operational phase monitoring</u>

The traditional bio-monitoring is performed using single individuals of lichens and bryophytes to assess their bio-accumulation of pollutants and the eventual damages induced by air and soil pollution on their structure, morphology and reproduction (see the following point). These activities will be finalized to the long-term monitoring at the species and community level, selecting vegetation patches of different community types occurring in the areas surrounding the runway path and installing there permanent plots. Each plot will be characterized in terms of floristic composition, species coverage and distribution within each plot, sampling of vegetation and soils, soil temperature and soil moisture monitoring. Indeed, the runway construction will induce changes of the original topography of Boulder Clay and may induce impacts also on the snow accumulation and its redistribution by wind, with consequences on the soil thermal regime and on soil hydrology as well as on the water supply (mainly provided by snow melting) for vegetation. For the long-term monitoring of vegetation and soil will be adopted the protocol adopted for the long-term monitoring network developed in Victoria Land since 2002 and extended over 6 degrees of latitude (72°-78°S). The monitoring frequency will be once per year during the runway construction and for the first five years of runway operation. After that date and based on the observed impacts and the obtained results, the monitoring could be performed every 3 years.

Post-operam and long term monitoring

The long-term monitoring of the transplanted areas (see details in paragraph 5.3.5) will be performed using the same protocol adopted for the permanent plots long-term monitoring and will be finalized to assess the success of these biodiversity conservation actions.

The transplanted areas monitoring will be performed once per year for a minimum duration of 10-15 years.

Bio-monitoring using bryophytes and lichens in the areas adjacent/neighbour to the runway

The runway activity could imply the risk of air pollution and, due to the pollution transportation by winds, also of soil pollution, with impacts on vegetation and soil. Air and soil pollution may induce: a) bio-accumulation of pollutants within organisms and in soils, b) morphological and/or structural changes of organisms, c) changes of the species composition at community level. In most cases the bio-monitoring activities are performed using lichens, however, considering the high frequency of bryophytes occurring in the area and that also bryophytes can be used as bio-indicators of pollution, we considered a further environmental insurance to couple the lichen bio-monitoring with the bryophytes bio-monitoring and the soil sampling. For this aim, the surrounding areas located along the runway path were investigated to identify the sites suitable for the biological monitoring using a) lichens and b) bryophytes.

The monitoring design has been organized according to the following criteria. The monitoring sites have been identified at three different positions along the runway path: a) the northern edge, b) central part and, c) southern edge of the runway. For each position (a, b, c) one location leeward and on location windward were selected (al; aw; bl; bw; cl; cw). At each side and position (al; aw; bl; bw; cl; cw) three sub-sites with the occurrence of epilithic lichens and three sub-sites with the occurrence of bryophytes were selected, in order to provide true replications. These three sub-sites were located at increasing distance from the runway (20, 40, 60 m): this design will allow also to assess whether and how the pollution impact would decrease with distance from the runway.

Totally 18 sub-sites for the lichen bio-monitoring (example in Figure 6.1 left side) and 18 sub-sites for the bryophytes bio-monitoring were selected (Figure 6.1 right side).

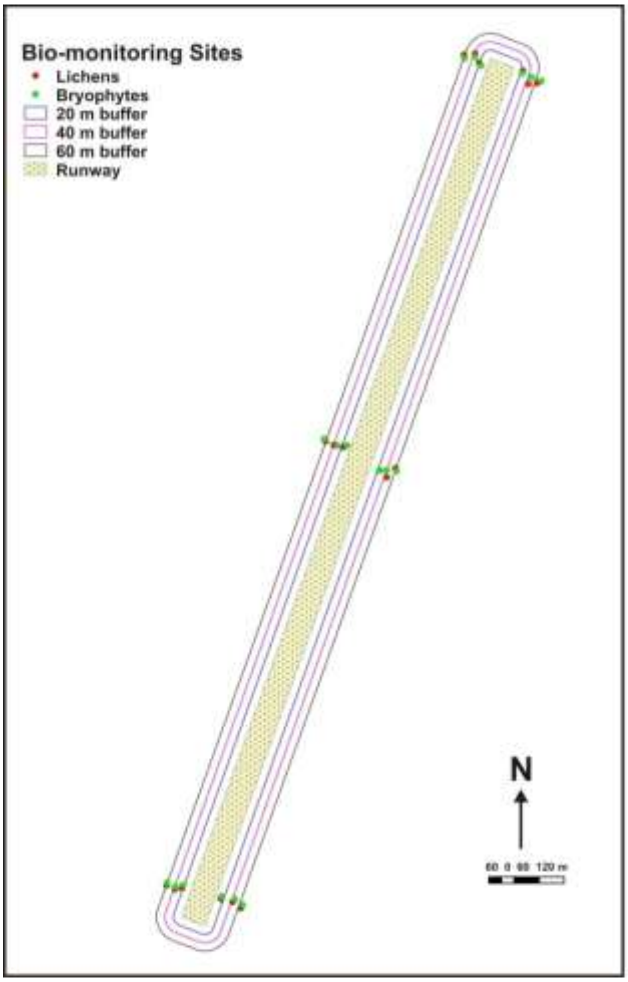

Figure 6.1: Example of a suitable site for lichen bio-monitoring (left side) and location of the sites for the bio-monitoring of pollution impacts on lichens and bryophytes (right side)

Detailed descriptions of these sub-sites will be performed in future seasons, as well as the installation of the specific monitoring grids devoted to the long-term monitoring of lichens and mosses, their sampling (for chemical analyses), and the sampling of the soil underneath.

Accidental introduction of alien species.

Once per year will be performed a monitoring (through an extensive and detailed survey of the areas surrounding the runway and of the path from the runway to the research station) to identify the eventual occurrence of alien species accidentally introduced in the area. This activity will need to be carried out both during the construction of the runway as well as during its operation.

6.1.4. **Air quality**

It is planned to install two control units for the air quality monitoring that operate regularly both during runway construction than later during the operational phase of the infrastructure. Based on the geographical location of the runway and local orography, we can identify two prevailing direction for the transport of pollutants emitted as a result aircraft operations: trail head - in the direction of Mario Zucchelli Station; country track - towards Adelie Cove and the colony of Adelie Penguins. Based on above remark, we will therefore install two stations for monitoring air quality at the top and bottom of the runway.

Each station will include a sampling system of the PM10 fraction (Atmospheric Particulate with aerodynamic equivalent diameter of less than 10 um) atmospheric aerosol. Such a system will ensure the sampling of aerosols on two different substrates: Teflon filters and quartz filters. The Teflon filters will be used for the determination of ionic composition (anions and inorganic cations and organic anions selected for ion chromatography) and of metals (with techniques of atomization plasma with spectrophotometric detection - ICP-AES-or by mass spectrometry - ICP -MS). The filters quartz will be used for the determination of components of the carbon cycle, with particular regard to fractions Elemental Carbon (EC) and Organic Carbon (OC) and selected organic pollutants (Polycyclic Aromatic Hydrocarbons - PAHs).

Two samplers channel Tecora Skypost units for each measurement site, for a total of 4 systems, will be acquired. These samplers can work continuously for 15 days, with samplings of 24 hours, or 30 days, with samples on alternate days or 48 hours (in order to have a quantity of sample sufficient for the analysis of trace metals). So they will offer the possibility to reduce considerably maintenance and need of manual operations.

Compared to the use of just two samplers in two heads, samplers single channel allow a greater flexibility, a better response to possible malfunctions and a simplified electronic (important requirement for systems that must work in critical conditions of temperature and humidity).

The two stations will be located close to the weather stations, already envisaged for monitoring the activities of the runway. Co-location will simplify combined analysis of concentration measurements of aerosol chemical components against weather parameters.

In addition to these samplings, will be also evaluated the usefulness to monitor the atmospheric concentration and size distribution of the particulate matter at the surface, making use of an OPC (Optical Particle Counter) with a time resolution of 10 minutes.

<u>Atmospheric precipitation sampling and analysis</u>

In addition to the air quality monitoring through aerosol sampling, periodic measurements of the chemical composition of the snow deposited in the Boulder Clay will be carried out. In this respect snow samples will be collected with a weekly or 15 day time resolutions in 4 stations: trail head, background track, sea side, side moraine. The snow samples will be analysed for the same chemical components already listed for atmospheric aerosol, with the exception of the fractions EC/OC.

6.1.5. **Deformation processes and micro landslide**

<u>InSAR monitoring</u>

Ongoing deformation processes in the Area of Terra Nova Bay will be observed through the Differential SAR Interferometry (DInSAR) and Advanced DInSAR (A-DInSAR) techniques.

The detection and measurements of the moraine displacement, including monitoring of continuous impacts of ice substrate processes, are a mandatory work to know the gravel airstrip stability. A-DInSAR techniques, based on the use of multi-temporal stacks of SAR images allow to produce deformation time series and mean velocity maps of a study area by exploiting many images acquired through time over the same area, thus improving the understanding of a very wide spectrum of geohazards.

Interferometric techniques will be applied to multi-platform SAR data and in particular, to COSMO-SkyMed images acquired by ascending and descending orbits to monitor the slow movement of the moraine, place of the construction of the airstrip. The use of high resolution SAR data as well as the very low revisit time of the satellites (typical at polar region), will allow to derive the ground deformation history of each coherent pixel of SAR scene and to compare it with previously conducted SAR analyses. Continuous monitoring of ground subsidence plays a key role in the assessment and mitigation of the associated risk and provides support for decision of airstrip construction.

The activity will use interferometric products of the X-band COSMO-SkyMed sensor to gain an improved understanding on the behaviour of a series of active moraine movement as well as to derive key information on the status of natural ice substrate in regions of interest.

Advanced space-based differential SAR interferometry (A-DInSAR) techniques will be applied to sequences of multi-temporal DInSAR interferograms, in order to detect and monitor the time evolution of surface deformation phenomena affecting Boulder Clay. It is well to notice that the temporal coherence in this area could be disturbed by the rapid change of reflectivity characteristics of the ground surface in the time (temporal decorrelation).

We will mainly focus on:

(i) the analysis of the deformation through several A-DInSAR approaches in the areas of interest, in order to improve our understanding on the underlying geological processes; in particular for proper monitoring will be combined ascending and descending orbits to get vertical and east-west components of deformation;

(ii) integrating ground deformation data coming from A-DInSAR and geodetic (spatial and terrestrial) techniques, into a unique solution that takes all the advantages of each single methodology;

(iii) integrated data coming from A-DInSAR analyses, other techniques and field data made available by ENEA, will be used to perform a geomorphological and geological/geotechnical interpretation of active processes observed over the moraine and surrounding areas, taking into account the peculiar environment and the final aim of the project.

DInSAR data

Future COSMO-SkyMed SAR acquisitions are expected to be available to us within the project. It is worth remarking that the future availability of a consistent set of SAR images is a very crucial issue for the achievement of the task aims, especially for what attains the generation of long-term deformation time-series by A-DInSAR techniques.

Technical specifications of ground velocity maps are:

- Spatial coverage: the rectangular outlines in Figure 6.2. indicate the trace of the satellite images that we will use to detect the ground velocities, depending on the considered SAR sensor, imaging mode and incidence angle.

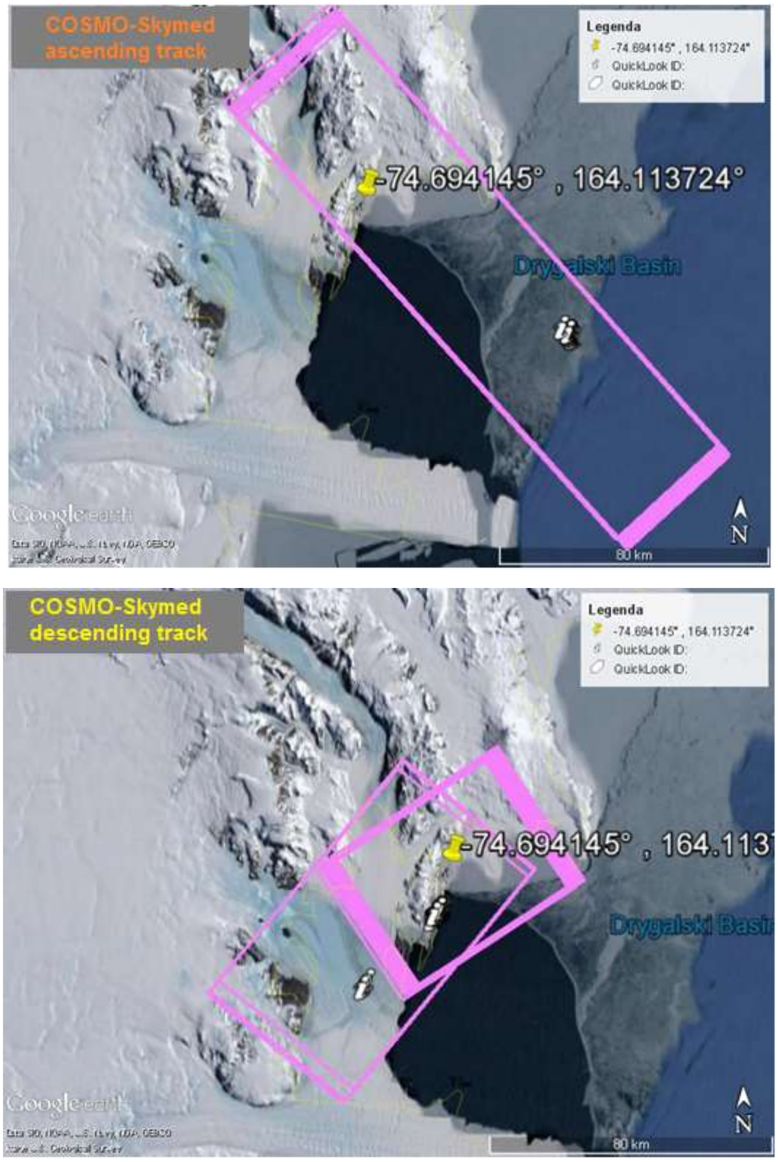

Figure 6.2: COSMO-Skymed ascending (upper) and descending (lower) tracks

Typically, the spatial coverage of the ascending and descending SAR image tracks used in the EGEOS portal is of about 40x40 km for the COSMO-Skymed data collected in the Stripmap mode The spatial coverage of the velocity map that will be generated is generally smaller, since the velocity signal can be correctly retrieved in correspondence to high coherence pixels, only. In the Up and East projected maps, derived by combination of two orbits, will have a spatial coverage that is reduced respect to common ascending and descending coherent pixels in the relevant maps.

- Ground resolution: the ground resolution for each map also depends on the SAR sensor, imaging mode and processing parameters. In our case, with reference to CSK sensor, the obtained results will have a resolution of about 5x5 m.

- Temporal extent: the temporal extent of the ground displacement time series depends on the satellite image dataset used for the processing and the ground velocity values are obtained by a linear fit to the ground displacement time series and are thus referred to the same period.

- Temporal resolution: the temporal resolution of the ground displacement time series depends on the satellite revisit time and on the archive completeness. Typical temporal resolutions vary between one to 30 images per month (considering the complete operation of the 4 COSMO-SkyMed sensors). For what concern ascending orbits only CSK1 is operating, whereas on the other orbit, the repeat pass is performed by the whole constellation.

- Unit of measure: the time series show ground displacements in millimeters, while the ground velocity is given in millimeters per year.

- Uncertainty of velocity values: the uncertainty associated to the displacement and velocity values depends on several parameters, as number of images in the temporal data set, temporal coherence, atmospheric noise, orbit stability, etc., and cannot be formally calculated. Validation tests carried out on several test sites by exploiting independent (external) data, also reported in the scientific literature, have demonstrated that uncertainties usually remain within 3-4 mm/yr.

- Reference frame of displacements and velocities: the ground displacements and velocity values in the maps are all referred to a common reference pixel within the SAR scene that is assumed stable (with zero deformation) in the considered time period. Such a pixel is defined during the processing phase (internal reference frame).

- Viewing geometries and line of sights: in the InSAR framework, ground movements are measured along the Line of Sight (LoS), which is the ideal line that connects the satellite and the ground resolution cell. Since SAR are side-looking instruments, usually borne on near-polar-orbiting satellites, LoS direction is nearly East-West oriented while SAR sensor is moving along North-South direction. For CSK LoS mean inclination from the vertical varies in the range ~15°- 50°. Accordingly, working directly with radar coordinate maps is rather difficult and prevents easy and effective analyses of the ground velocities in terms of crustal deformation. A way to circumvent this problem is to represent InSAR-derived maps in a more standard 3D Cartesian reference system, with respect to which the vertical (Up), the North, and the East-West (horizontal) components are portrayed.

- Data Interpretation: the available geological, geomorphological, geotechnical, glaciological and climatological data, will be used to carry out an interpretation aimed at correctly infer the results obtained from A-DInSAR analyses. The active deformation processes in the area will be investigated in consideration of the environmental dynamics, typical of these regions. In particular, the displacement rates of the Boulder Clay moraine, will be analysed in relation to the glaciers present in the study area and taking into account their geometrical and dynamic features. InSAR monitoring will allow for more advanced information about the actual distribution of the deformation fields on the study area and such surficial outcomes will be put in relationship with other in-depth data potentially available.

6.1.6. **Monitoring activities related to the construction and use of the airstrip**

As discussed above, more than information on Environmental Impacts, EMOP will put attention also on the building yard operations during the construction phase and on airstrip operations. A summary of the activities related on this part of EMOP, as they are scheduled during construction and operation stages, are reported in Table 6.2 and Table 6.3, respectively.

Table 6.2: 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 week
	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 6.3: Schedule for monitoring - Operation stage.

Item	Object	Reporting	Frequency
Ecology	Alien species invasion	Invasive species	Once a year
	Flora	Observation in community structures changes	Once a year
	Fauna	Observation in community structures changes and population dynamics	Twice a year
Snow	TSS, pH	Snow quality analysis	Twice a year
Soil	TPH	Soil analysis in 4 points at parking sites	Once a year
Air quality	PM10, heavy metals, PAH	Air quality sampling log - Airstrip - Penguin colony	Continuous during operation
Noise	Noise level	Noise level at site near penguin colony	On flight arrival and departure
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 week
	Oil change, waste oil	Motor oil log	Once a month

6.2. Dismantling of the facility and environmental restoring

The *Guidelines for environmental impact assessment in Antarctica*, which were developed in 1999 and revised by Resolution 4 (2005), insist on the need to consider the complete remediation of the environment to the original condition after each impact have occurred. Following Resolution X (Annex C) to WP42 (XXXVI ATCM) we carefully considered the dismantling procedure of the facility, its costs and the remediation of the environment to the pristine status.

6.2.1. **Decommissioning of the facility and waste removing**

The simplest structure of the services pertinent to the airstrip have been considered during the project designing with the main aim to promote the best and fast material removing and environmental restoration.

The modular structure proposed for operation room and waiting room/office as well as sledge fuel tank can be easily disassembled and moved back to MZS. The dismantling operation would involve 4 persons for 4 days, in consideration of both dismounting, and transportation to MZS, with no significant impact on the Campaign costs. The transport of waste produced in the dismantling, considering a volume of about 9 containers (270 m^3) could be brought back by the Italian vessel Italica, without drastically affecting on its cargo capability (4500 m^3).

The Shed pertinent to the apron will require at about 500 hours man of work do dismantle and transport to MZS the materials.

6.2.1. **Wilderness and aesthetic values remediation**

For the embankment realization has been considered only inert from local quarries, this will greatly reduce the impact on the wilderness of the area.

The possibility of restoring this material into the quarries area has been discarded because it would impact on environment more than the no-action possibility, considering noise and pollution made by operating heavy equipment in time and number similar to what is necessary for the realization of the airstrip.

What we observed from satellite surveys summarized in Figure 4.11 (a,b) the moraine is subject to a displacement in the range between 20 to 50 mm/year. This wouldn't affect the airstrip activity in a major manner for the foreseen designed lifetime of the facility (20 years), but would allow without any further action the restoring of the pristine landscape.

6.3. BIBLIOGRAPHY

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7. Gaps in knowledge and project uncertainties

About risk analysis we focus on two main aspects:

- risks connected to the deformation processes occurring in the area of Boulder Clay;
- risks related to accidental large oil spill due to breaks in infrastructures (tanks) or equipment (tracks, airplane).

With respect to movement process, part of the risks arise from a gap of knowledge while others are the cumulative effects of changes produced by the new runway construction and operations, added to the ordinarily planned operations, supporting the research activities.

7.1. A runway over a glacier moraine

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.

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.

The gravel runway is planned to be used with no major adjustments for 20 years, based on the data of the last 30 years we do not expect radical climatic changes on the area. If an unexpected fast temperature rise happen, this would not probably allow the airstrip utilization, but the same phenomena would accelerate the restoring of pristine environmental aspect.

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

In the summer Campaign 2015-16, test activities have been continued, replying a section of the future runway over the moraine. The test site, instrumented with a network of thermometers to check the thermal behaviour of the section with the real materials, provides important data to better adjust the design of the runway and to monitor the construction phase.

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 cumulative risks

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.

Increase observations of the ongoing deformation processes (see paragraph 6.1.2) through the Differential SAR Interferometry (DInSAR) technique, using two and not more one observing tracks from COSMO-SkyMed, will provide a complete perspective not only of the Boulder Clay area but also of surroundings, able us to detect immediately any significant deformation signal, including those very difficult to observe at the ground. It than will represent the best possible early warning instrument.

7.6. Managing severe oil spill events

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.

Likely migration of accidental oil spills.

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

- In the case of snow free conditions, oil spilled on ground of frozen moraine underlying by permafrost (as Boulder Clay) 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.
- 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.
- 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.

Sensitive locations for accidental oil spills

More sensitive locations for accidental oil spills are areas where flora and fauna must be protected.

The likelihood of such an accident is low, fortunately; however, an assessment of possible measure to be taken to manage and recover these accidental events will be conducted in the near future.

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.

Italy 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

This *Draft CEE* has been prepared by the Antarctic Technical Unit of ENEA (ENEA-UTA), which working group was composed of:

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For specific design aspects of the project, ENEA entrusted studies to specialized engineering consultants:

- SGI s.r.l. (*Studio Geotecnico Italiano*) of Prof. M.B. Jamiolkowski, for geotechnical evaluation and project implementation;
- ENAV s.p.a. (*Italian Air Navigation Service Provider*) for aeronautical design;
- NHAZCA s.r.l (*Sapienza University of Rome, spin-off*) for the interferometric study on the moraine.

Scientific aspects of the document, mainly related to the assessment of the current status of the environment and to the environmental monitoring plan, were coordinated by Dr. Vito Vitale and Dr. Anna Maria Fioretti (National Research Council), integrating specific paragraphs from:

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- Prof. Nicoletta Cannone (*University of Insubria*) for information on the initial state of the flora in Boulder Clay area and related monitoring and mitigation plan;
- Prof. Mauro Guglielmin (*University of Insubria*) for contributing to the geomorphological and geological framework and to the monitoring plan for the permafrost and the ice lake-blisters;
- Dr. Silvia Olmastroni *(University of Siena)* for information on the initial state of the fauna in Boulder Clay area and related monitoring and mitigation plan;
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- Dr. Roberto Udisti (*University of Florence*) for contributing to the air quality monitoring plan.

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Annex A: Climate and Meteorology

Wind Rose statistics (%) from October to February

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Tot
																	23.1
	5.9	2.4	2.4	2.3	3.6	2.2	1.6	2.1	2.2	1.7	2.5	2.3	3	2.4	1.6	2.5	40.5
	0.1	0.1	0	0.1	0.1	0.1	0.1	0.5	0.4	0.4	0.8	0.6	1	1.2	0.4	0.1	6
	0.1	0	0	0	0	0	0.1	0.2	0.3	0.6	1.6	1.4	3	3.7	0.6	0.1	11.8
	0	0	0	0	0	0	0	0	0	0.2	0.9	1.3	4.3	4.2	0.5	0	11.5
	0	0	0	0	0	0	0	0	0	0.1	0.3	1.1	2.8	2.5	0.3	0	7.1
Tot	6.1	2.5	2.5	2.4	3.7	2.4	1.8	2.8	3	2.9	6.1	6.6	14.1	13.9	3.3	2.8	100

AWS ENEIDE: percentage distribution of wind speed and direction (period October – February): hourly data from February 1987 to November 2011

Wind Rose statistics (%) from March to September

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Tot
																	27.1
	1.8	1	0.9	1	2	1.4	1.6	2.1	3	1.9	3.3	3.4	3.1	1.9	1.1	1	30.3
	0.1	0.1	0.1	0	0.1	0.1	0.2	0.4	0.4	0.3	0.3	0.3	0.8	1.2	0.4	0.2	5
	0.1	0	0	0	0.1	0.1	0.1	0.2	0.3	0.3	0.7	0.7	2.5	3.9	0.8	0.2	9.9
	0	0	0	0	0	0	0	0	0.1	0.1	0.7	0.9	4.5	5.9	0.7	0.1	13
	0	0	0	0	0	0	0	0	0	0	0.7	1.4	5.8	6.3	0.4	0	14.6
Tot	2.1	1.1	1	1	2.1	1.6	1.9	2.7	3.7	2.6	5.7	6.6	16.7	19.2	3.4	1.5	100

AWS ENEIDE: percentage distribution of wind speed and direction (period March – September): hourly data from February 1987 to November 2011

Wind Rose statistics (%) from October to February

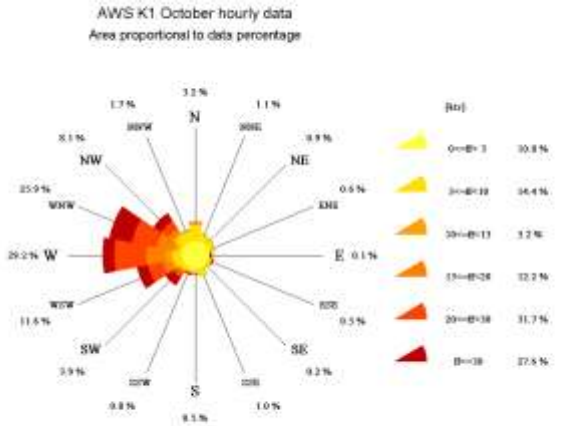
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Tot
																	14.5
	5.1	1.1	0.9	2.3	1.9	2.1	2.2	1.5	1.9	1.4	1.3	1.7	2.4	1.3	3.3	3.6	34
	0.3	0.1	0	0	0.1	0	0.1	0.1	0.3	0.3	0.4	0.6	1.7	0.4	0.6	0.2	5.3
	0.2	0	0	0	0	0	0	0.1	0.4	0.4	0.8	1.5	5.6	1.3	1.6	0.3	12.2
	0	0	0	0	0	0	0	0	0.2	0.2	0.4	1.6	9.8	3	1.8	0.1	17.1
	0	0	0	0	0	0	0	0	0	0.1	0.1	1.1	9	5.6	0.9	0	16.9
Tot	5.6	1.2	1	2.4	2	2.2	2.4	1.7	2.8	2.5	2.9	6.5	28.5	11.7	8.1	4.3	100

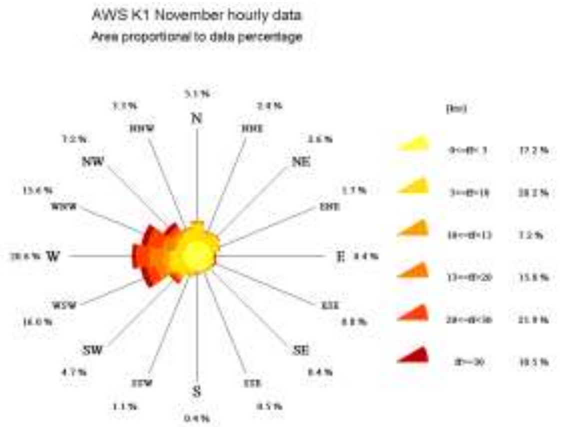
AWS RITA: percentage distribution of wind speed and direction (period October – February): hourly data from January 1993 to November 2011

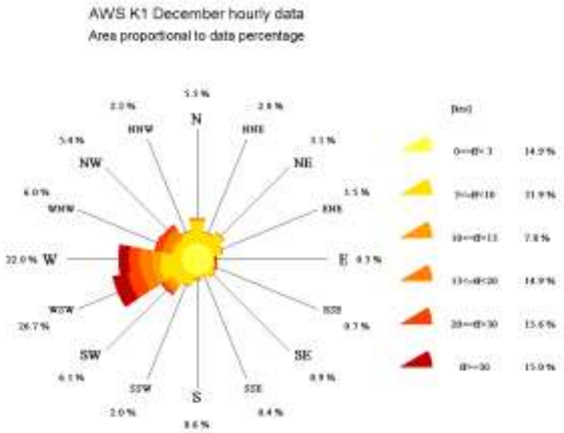
Wind Rose statistics (%) from March to September

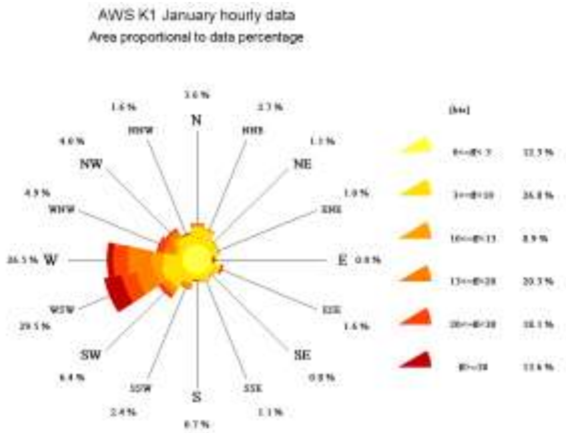
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Tot
																	17.6
	2.1	0.8	0.6	0.6	1.2	1.2	1.2	1.1	1.9	1.4	1.2	1.3	2.1	1.9	4.2	2.9	25.7
	0.3	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.9	0.4	0.5	0.3	3.6
	0.4	0.1	0	0	0	0	0	0	0.1	0.1	0.2	0.5	3.5	0.9	1.3	0.5	7.7
	0.1	0	0	0	0	0	0	0	0.1	0	0.2	0.9	8.5	1.9	2.7	0.3	14.7
	0	0	0	0	0	0	0	0	0	0	0.1	1.7	15.7	10.3	3	0.1	30.7
Tot	2.9	1	0.7	0.7	1.3	1.3	1.3	1.2	2.2	1.7	1.8	4.7	30.7	15.3	11.7	4	100

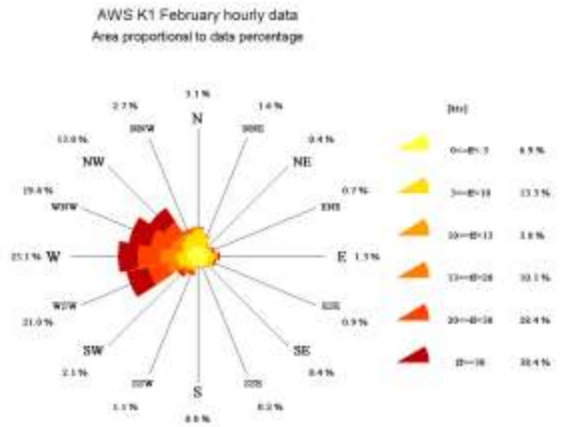
AWS RITA: percentage distribution of wind speed and direction (period March – September): hourly data from January 1993 to November 2011



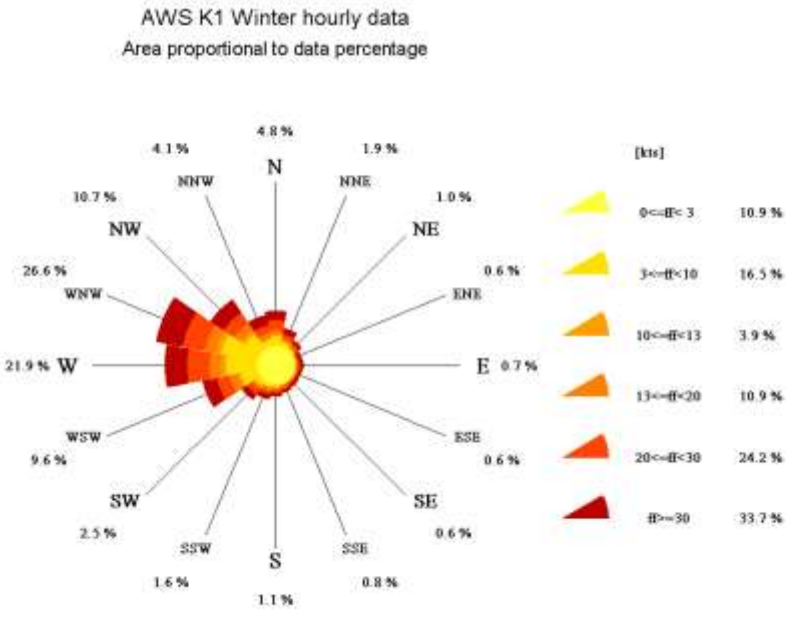






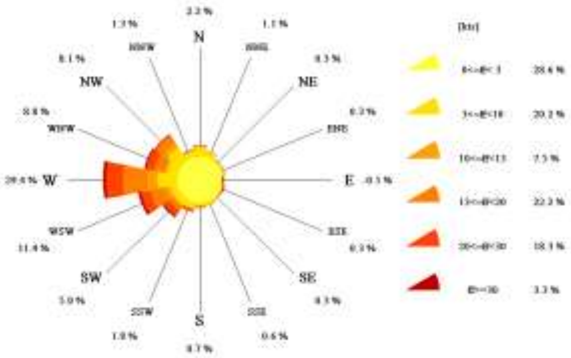


AWS K1: wind speed and direction (October, November, December, January, February):hourly data from February 2013 to January 2015

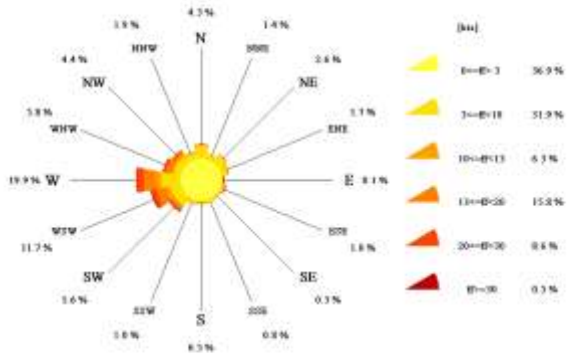


AWS K1: wind speed and direction, Winter period (March - September): hourly data from February 2013 to January 2015

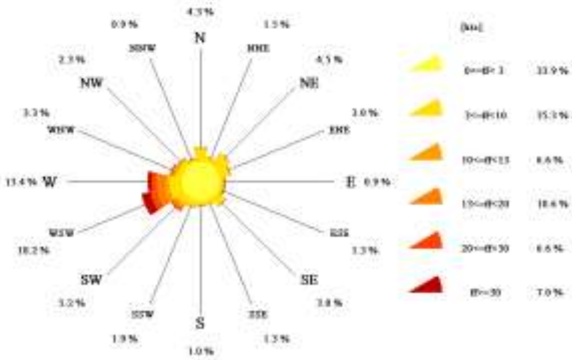
AWS K2 October hourly data
Area proportional to data percentage

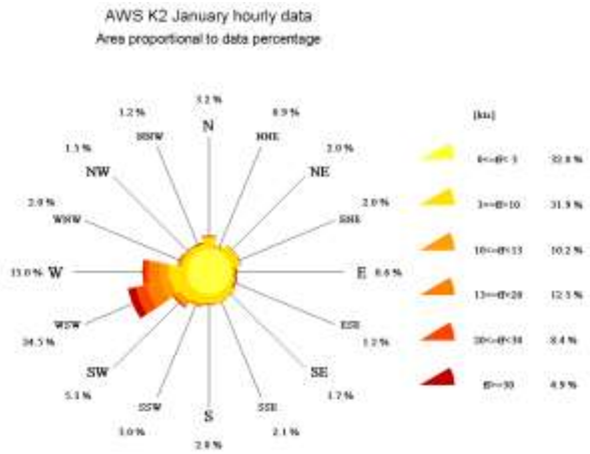


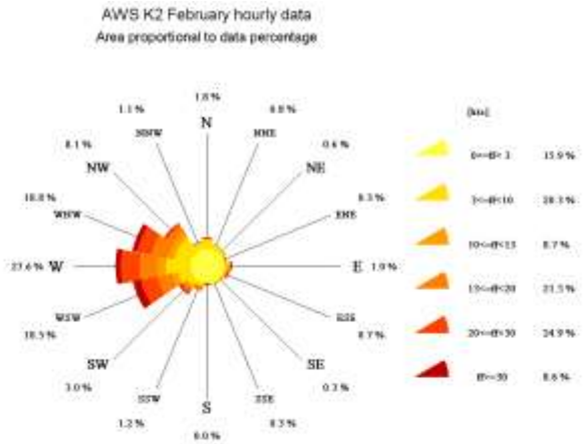
AWS K2 November hourly data
Area proportional to data percentage



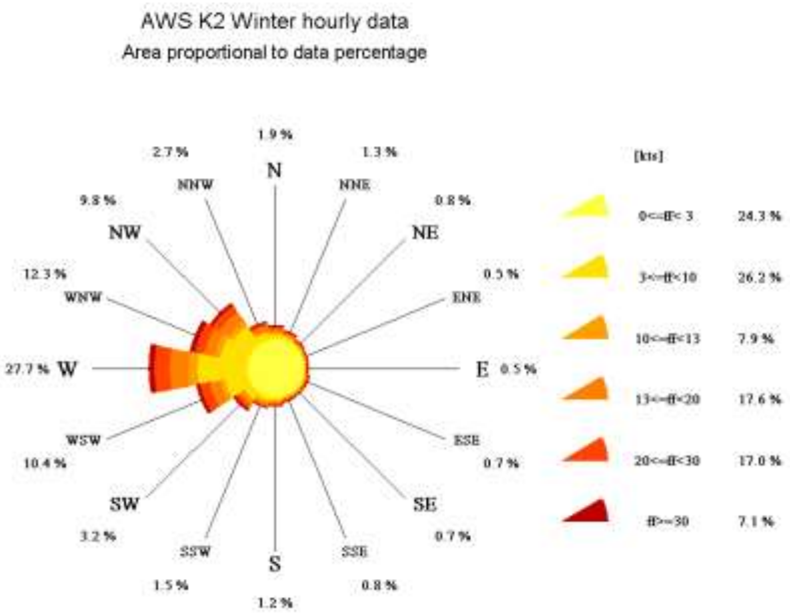
AWS K2 December hourly data
Area proportional to data percentage







AWS K2: wind speed and direction (October, November, December, January, February): hourly data from February 2013 to January 2015



AWS K2: wind speed and direction, Winter period (March - September): hourly data from February 2013 to January 2015