Project of Strategic Interest NextData

Deliverable D1.4.1
Report of the field activities and drilling sites selection

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Introduction

In the framework of WP 1.4 UNIMIB and URT Ev-K2-CNR have profited from their multiannual experience in the management of research activities in remote areas and high altitude glaciers in mid-latitudes and polar areas, to plan the drilling operations and the effective implementation of field activities for the sampling of cores at high altitudes envisioned in the project.

In addition to the tasks planned for the first year in the Executive Plan, which included the definition of field activities and the selection of the sampling sites, we performed an ice core drilling mission on the Colle del Lys (Valle d'Aosta), including storage of ice cores and visual determination of the visible levels of ice and Saharan dust. This has allowed to test directly in the field the logistics, the techniques and the management of ice coring on a remote glacier in preparation of similar activities in remote areas with greater logistical difficulties. Visual and geophysical surveys have been scheduled in order to assess the logistical requirements. It is clear that the Alpine site has many advantages over remote Asian sites, and a new drilling at the Colle del Lys is scheduled for 2013.

Scientific results and discussion

Mid-latitude glaciers provide shorter ice core records than polar glaciers (EPICA Community, 2004; Petit et al., 1999; Delmonte et al., 2002): indeed, the longest records only cover a couple of centuries (Maupetit et al., 1995; Preunkert et al., 2001, 2003). In order to avoid disturbances only records from high altitude glaciers, where the risk of melting is low, can provide environmental and climatic proxy data (Maggi et al., 2006, Smiraglia et al., 2000, Wagenbach, 1989). Although restricted to a regional scale and to relatively short timescales, glaciers in the European Alps can be very useful natural historical archives. Unfortunately, mid-latitude glaciers with the appropriate characteristics for preserving glacio-chemical and glacio-meteorological records are quite scarce (Wagenbach, 1989). In the European Alps only few areas have been identified as sites potentially suitable for ice-core studies (De Angelis and Gaudichet, 1991; Maupetit et al., 1995; Wagenbach, 1989; Smiraglia et al., 2001; Schwikowski et al., 1999; Gabrielli et al., 2012). The atmospheric compounds which reach Alpine glaciers originate from several different air masses, including compounds from the free troposphere, from the underlying mixing layer, and large-sized aerosol (i.e soil dust, biomass compounds, anthropogenic compounds) derived from areas surrounding the glaciated mountains (Maggi et al. 2006, Wagenbach, 1989). Large amounts of soil dust from North Africa are injected into mid-troposphere and transported eastward across the Atlantic Ocean toward Central and North America (Prospero and Lamb, 2004). Moreover, atmospheric dust can also reach the Alpine chain, far away from source regions in the south (Bucher, 1983; Prodi and Fea, 1978; Goudie and Middleton, 2001; Nicholson, 2000). The sites chosen for ice core drilling need to meet many characteristics in order to allow for a reconstruction of climate and environmental features. Between them, at least the following two are essential: 1) the presence of a basically flat topography that may correspond to accumulation basins with plateau or saddle geometry; the Colle del Lys falls into this category, as it is a saddle in the area between the accumulation basin of Lys Glacier and Gorner Glacier (Switzerland); 2) mean annual temperatures need to be low enough to reduce or avoid surface melting, as shown in Fig.1 (Haeberli and Alean., 1985). Alpine areas with glaciers that meet both requirements are few, usually located in the mid-western part of the chain. Among them, the best ones are the Colle del Lys and Colle Gnifetti, in the Monte Rosa and the Col du Dome, on the French side of Mont Blanc (all in Valle d'Aosta). Drilling sites with high accumulation rates permit to determine changes at a seasonal scale and to effectively compare the resulting records with climatic data from weather stations and global-to-local scale modelling. In-fact, previous works indicated that the high-resolution records from Colle del Lys will be able to detect the seasonality of many different parameters such as mineral dust (work by UNIMIB) and stable isotopes (Stenni pers. comm.; Wagenbach et al., 2012). Furthermore, other glaciers will be selected for ice core drilling activities, but after a precise site selection. It is important to choose a reliable topography, with a surface as flat as possible and without important ice movements. This selection will be performed using measurements by aerial or satellite images (in collaboration with WP 2.4) and radar surveys (of which part has already been completed). The sites also need to be located at altitudes high enough to reduce melting. Some sites which have been evaluated are a saddle close to the Breithhorn Mnt at 3700 m and the Pian di Neve (3200-3400m) in the Adamello group, both below 4000 m.

The field work on the Colle del Lys, Valle d'Aosta, held from June 17 to 23 represented a close collaboration between national and international research groups, in particular: University of Milano-Bicocca, URT Ev-K2-CNR, ENEA, National Antarctic Research Program, the Alpine Guides of Alagna (VC), Pakistan Meteorological Department and technical staff from Nepalese Ev-K2-CNR Pyramid. Since this drilling will serve also for the purpose of training the staff who will be engaged in the most remote and extreme glaciers, the working group consisted of 11 people including technical and scientific staff. In particular: 2 persons for the scientific and ice core management, 3 persons for the drilling and operation of the ice drilling system, 2 persons for the management and security on field, 2 persons for the management of ice boxes and samplings of snow-pits, 2 persons from Pakistan and Nepal as training for the possible activities in Asia.

During the working week on the Colle del Lys the following activities were carried out: drilling 32 m ice cores with 8 mm in diameter, sampling of waste chips for analysis of low contamination, sampling of a trench 1.5 m deep to better define the upper part of the ice core, which could be contaminated by the drilling operations for low-density cores. The field activities have also allowed us to verify the instrumentation used and the critical points of the drilling system.

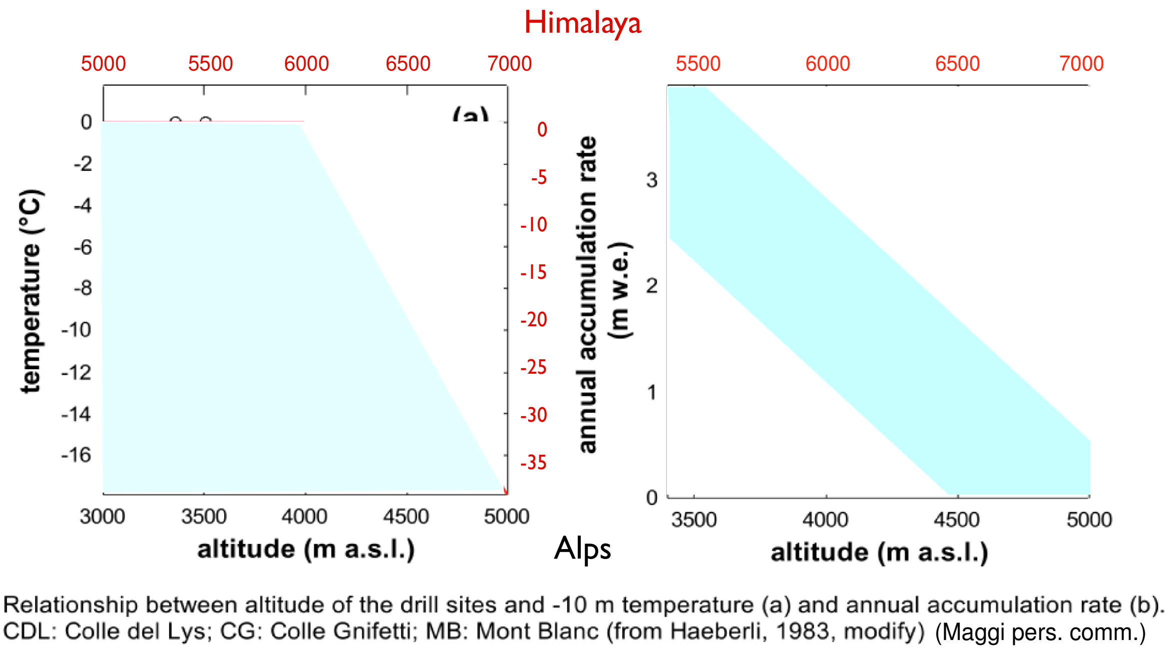

Figure 1 . Relationship between altitude-temperature at -10 m depth (a) and average accumulation rate (b) (Haeberli, 1985; UNIMIB results).

The drilling site was defined by the the group of University of Milan Bicocca, coordinated by Valter Maggi, using radar profiles obtained in a previous Italian project (PRIN 2008) titled "Effects of climate change on glaciers, permafrost and the resulting water. Quantification of the changes taking place in the environment of the Italian Alps and analysis of the impacts and future projections", in particular in the sub-project "Impact of climate change on some testing glaciers: simulation on ice and water resources". The coordinates of the drilling site have been defined by geophysical measurements carried out in 2010-2011 on the basis of previous measurements performed in 1997. Measurement of the glacier thickness allowed to reconstruct the map of the bedrock, and to define an area of ice whose thickness exceeds 100 m. This is the area were the drilling system has been located. The entire remote field has been reconstructed upstream from this site (Figure 2).

The Lys Glacier has already been studied by the research groups which participate in the NextData project. In particular its accumulation basin has always represented an area of particular interest for glaciological, environmental and climatic reconstructions. The high snow accumulation of 1.3 to 1.5 m of water equivalent, calculated on the basis of previous drillings, allows us to reconstruct records with a strong seasonality, accumulating information at very high resolution.

Drilling operations were carried out at night, in order to exploit the colder hours and to minimize melting problems. The employed drilling system FELICS© consists of a rotating core barrel, with a chamber for the recovery of waste chips. The upper part of the drilling system is composed of the motor for rotation and springs for maintaining the rotation to the well walls. All these are controlled from the surface through a cable that transfers electrical current and signals. The 250 m-long cable allows reaching the planned depth without problems, even if it is not able to operate in liquid. The probe is mounted on a tilting tower: in the horizontal position emptying and maintenance operations can be carried out, while the vertical position is used for drilling.

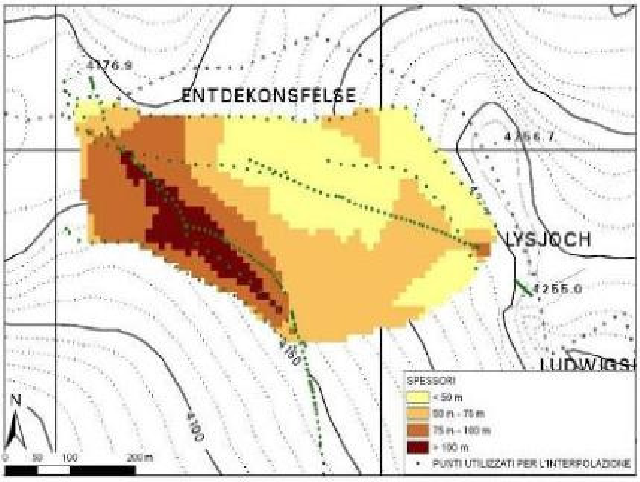

Figure 2. Spatialization and mapping of the ice thickness in the area of the Colle del Lys.

The depth of drilling has been recorded in a specific log with all information obtained from the drilling system (Figure 3). Each ice core was numbered, measured in length, in diameter and weighed. An accurate log of all these measures has been filed for the sampling and laboratory measurement. The ice cores were packed in a PET bag, numbering each bag and marking the orientation of the ice core (top). The packed ice cores were placed in insulated boxes and preliminary stored until they were stored in a trench ad hoc dug, and covered with snow to protect them from daytime insolation.

Figure 3 - (left) Drilling camp on Colle del Lys; (right) ice core on surface.

This work will also help to understand the atmospheric systems that affected the Alps, including a reconstruction of the rainfall patterns in the past century, to understand the human impact on high mountain areas (the site is located within one of the most industrialized areas of the world), and to test new systems for drilling activities in remote mountainous regions. The annual accumulation of snow in the area of Colle del Lys is particularly high and allows a seasonal resolution of the measurements. The 32 m of drilling will expand the existing record, which was sampled in 2003, and which showed changes in chemical and physical properties of the atmosphere in its various aspects starting from the 1930's.

In the Eurocold Lab of University of Milano Bicocca the ice cores were processed to obtain a more precise stratigraphy, density profiles and samplings of mineral dust, chemical and isotopic analysis. The density measurement is of particular importance because it allows to provide important information on both the drilling site and on the possible evolutionary characteristics of the ice itself. Of particular importance is the depth of closure of the porosity of the firn, which represents the true transition to glacier ice. This parameter is normally estimated when the density of the firn reaches 0.85 g/cm^3, called the density close-off (Paterson and Cuffrey, 2010). The ice cores have been measured in length and diameter, their volume has been computed, they have been individually weighed and their density has been reconstructed.

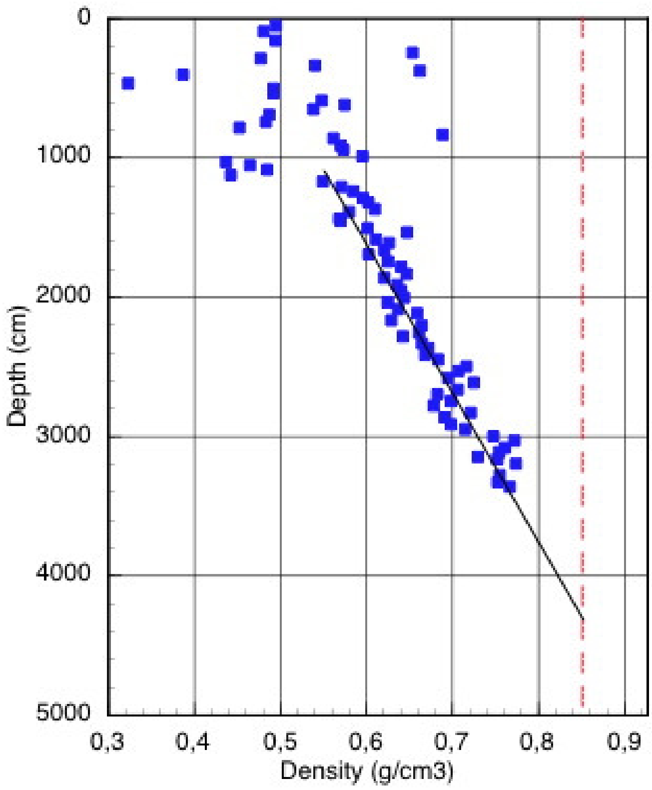

Figure 4. Density profile of the ice drilling at Colle del Lys in 2012 (CdL12). In black the correlation line for the data below 11 m depth. The red dotted line represents the density of close-off.

As can be seen from the graph in Fig. 4, there are at least two different zones, a superficial part, up to about 11 m depth, with strong scattering of data, and a deeper part below 11 m depth, displaying more linearity. Based on the mechanisms of transformation of snow into ice, the upper part is the one that most undergoes changes due to the transformation/reduction of snow crystals in grains, and consequent mechanical packing predominantly of this material. The high accumulation leads to a strong differentiation of the layers in part related to snowfall with different characteristics (temperature, water content, crystal size, etc. ..), which can strongly distort the measurements.

The Colle del Lys is located at high altitude and low mean temperature and, in general, the Alps are located within the westerly winds that carry moist air masses. This can lead to particular accumulation conditions with extreme variability in the physical characteristics of the snow, and to important variations in density measurements. Below the maximum mechanical packing (around 11 m depth), mechanisms of sublimation and deposition become dominant, leading to sintering of the grains of ice. In this part a rapid homogenization of grain sizes is observed and, due to successive snowfalls, an increase of the lithostatic load. Additionally, some grains grow at the expense of the others, leading to a progressive reduction of the porosity of the firn. The end result is a decrease of scattering of the density data and a progressive increase with depth. The density trend in this part allows to extrapolate the density data down to the close-off, which is estimated at a depth of about 42-46 m, in line with the data from previous drilling activities. Application of the Lin (1985) equations, valid for the dry snow zone (DSZ) glacier areas (Paterson and Cuffey, 2010), will allow to extrapolate the density profile using the exponential equation modified by Maggi (1995). The following equation explains the relationship between the maximum density of the ice (ρ_m), the surface density of the site (ρ_0) and the density (ρ) at depth z (in meters), with one constant related to the snow characteristics of the snow surface (λ):

$$(\rho_m - \rho)/(\rho_m - \rho_0) = e^{-\lambda z} \tag{1}$$

The λ parameter is strongly related to the site temperature, to the site annual accumulation rate and to the air masses which provide the precipitations. In figure 5 two extrapolations were calculated for two different values of the λ parameter, one using site temperature as the dominant effect, and one using the accumulation rate as the dominant effect.

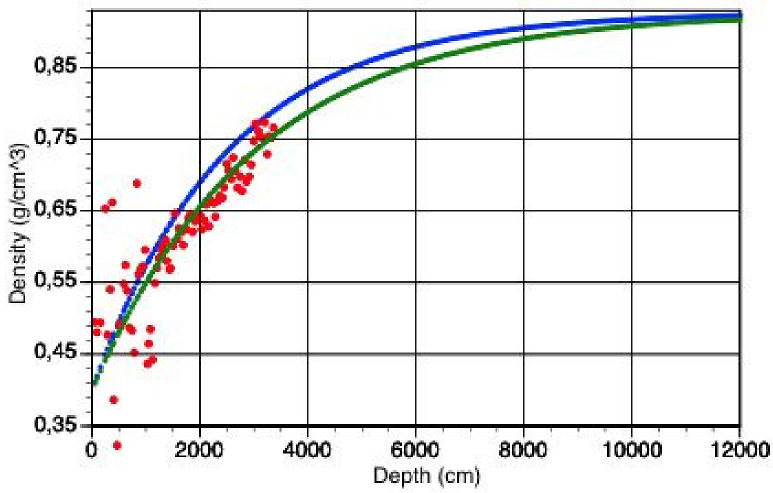

Figure 5. Density profile estimation applying the Ling (1985) equations. The blue curve is calculated using a λ parameter with accumulation rate being the dominant effect; the green curve is calculated using the λ parameter with temperature being the dominant effect.

It is possible to observe that temperature (green curve) seems to be dominant respect the accumulation rate (blue curve) in the density process. In any case both curves overestimate a close-off (50 to 60 m depth) with respect to the linear correlation in figure 4. This is the problem in the areas with high accumulation and seasonal percolation that can strongly influence the density of the snow layers, influencing or overlapping the normal physical densification processes.

The preliminary dating of the Colle del Lys ice core drilled in 2012 (CdL12) was performed using annual mean accumulations from ice cores previously drilled at the Colle del Lys (but not at the same site), and in particular the cores CdL96 (1996) and CdL03 (2003), which gave respectively 150 and 130 cm of water equivalent per year (Smiraglia et al. 2000; Maggi et al., 2000;UNIMIB unpublished results). Since we lack reference horizons in this preliminary phase of the study that would permit to calibrate these datings, we can use the errors which were determined at the bottom of the 32 m ice cores sampled between 1994 and 2000. This allows to expand the climatic and environmental record from 2003 (the date of the previous drilling) to today.

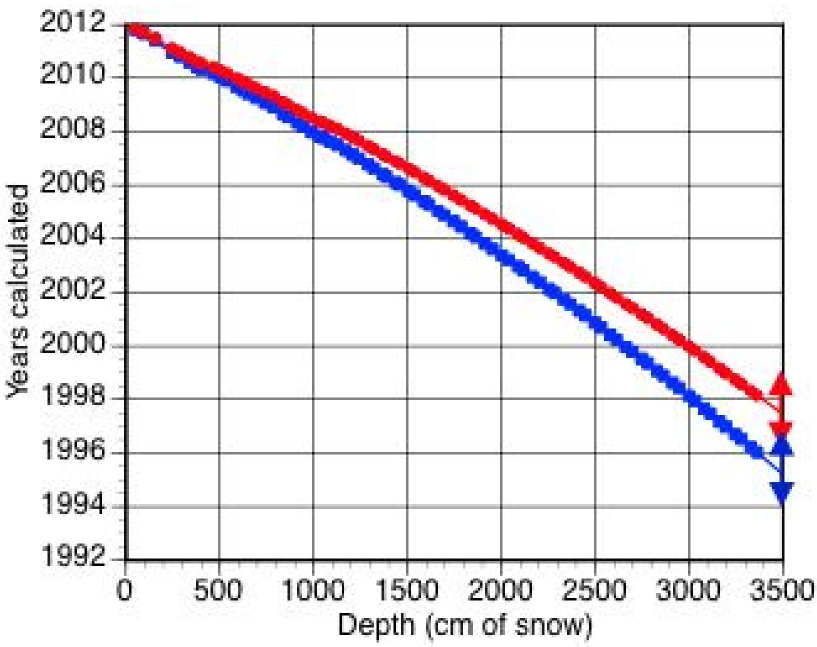

Figure 6. Preliminary dating of CdL12. Blue line and symbols is the depth-age estimate using 130 cm w.e., in red depth-age estimate using 150 w.e.

These data permit also to extrapolate preliminarily the base of the glacier, obviously considering a constant mean accumulation rate. In figure 6 it is possible to observe the depth-age dating in the area of drilling where the glacier can reach 120 m depth. The dating of the ice core at the bottom is between the late 1910's and early 1930's, as provided by the initial models of accumulation proposed in the design phase of the drilling activities. Even in this case we used a constant average annual accumulation and a change in density with depth that follows the laws of thickenings typical of polar/cold glaciers. Obviously this is a very preliminary extrapolation and only future drilling to the bedrock can allow us to date the ice precisely.

During the measurements we observed two ice lenses (about 10 cm thick) at depths of 14m and 28m. These correspond probably to the levels formed during hot summers where the percolation of melt water from the glacier surface has permeated the lower levels of the snow. If it were possible to date precisely these levels we could assign these lenses to particular summers and thus improve the accuracy of the dating of the core. Of particular interest is the fact that we did not detect levels of visible dust of particular thickness. Although there were quite well known local events long ago, in 1977 and 1986, it is particularly difficult to think that there was no level formation even later. A possible hypothesis, which has to be verified by measures, is that there have been episodes with significant transport from North Africa but no significant rainfall, leading to deposition of mineral dust.

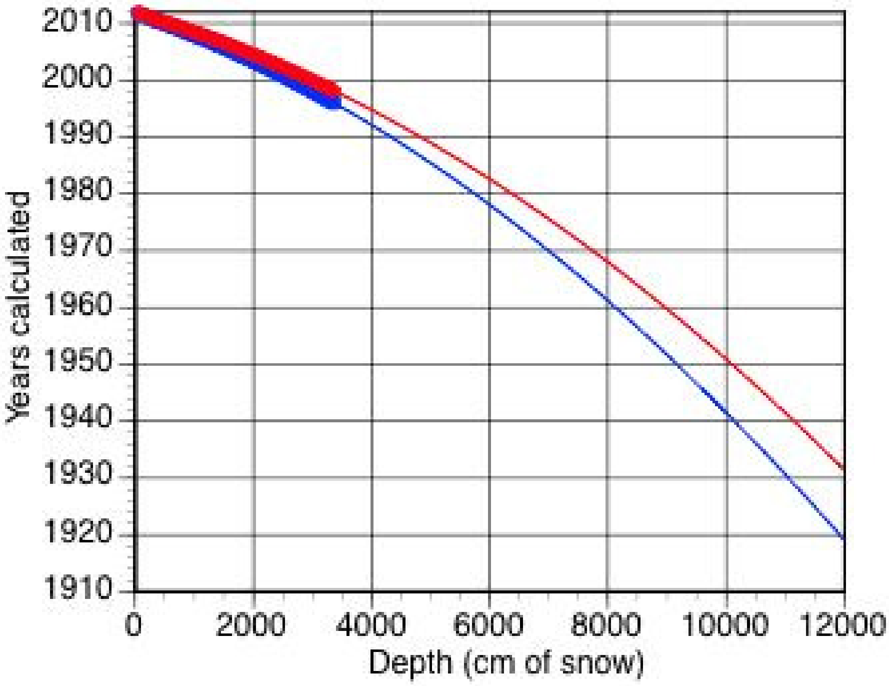

Figure 7. Extrapolation of the CdL12 dating down to 120 m, target depth of the bedrock at the point of the 2012 drilling. The colours are the same of the previous figure.

Mass balance modelling

Changes in glacier mass balance are related to changes in climate conditions. Most Alpine glaciers display a strong decrease in the last 50 years, but significant regional-to-local mass balance variability is observed as a response to climate change. A continuous mass balance record is available only for a few glaciers, and for still fewer, long enough mass balance data (more than 20 years) are available. It is thus important to reconstruct, by modelling methods, the evolution of glaciers at least in the last 50 years. When possible, the mass balance data will be extrapolated to longer (secular) time scales. This work will be done in collaboration with WP2.3. We shall concentrate the reconstruction activities on Alpine glaciers, and, when available, apply the models also to specific Himalayan or Karakoram glaciers (not debris covered). Another target is to define the possible future evolution of main Alpine glaciers, in terms of mass balance and water release, using different SRES Scenarios.

Activities for the second and third year

The activities for the next two years will include the definition of a series of ice cores activities along the transect Alps-Karakoram. We have identified 2 glaciers, one per sector, which may be drilled in the next two years. In particular the sites are the Colle del Lys, at 4250 m above sea level on Monte Rosa (Valle d'Aosta), the plateau of the Abruzi Glacier, one of the Baltoro

Glacier confluents north of the top of Gasherbrum I (Pakistani Karakoram) at 6700 meters above sea level.

Alpine glaciers are located in the westerly wind circulation regime, with transport processes which are strongly related to the Nord Atlantic Oscillation.

The programme for the second and third years are scheduled with 1) a new drilling activity again at Colle del Lys, to reach the bedrock at 120 m depth and 2) the exploration of two other possible sites for future activities, the Colle Felik, close to the Colle del Lys, and the Breithorn Saddle Close to the Cervino Massif; both the site are located above 4000 m with almost flat surface. These two sites could be interesting for ice core activities and climate/environmental studies, also because the ice thickness is estimated to be between 50 and 80 m. Unfortunately, no radar measurements were done till now, so the details of the future activities will be defined only after a preliminary survey. Some interest can be maintained for the Colle Gnifetti because it represents the most "polar" site of the Alpine range, and it will be used as a more reliable testing site for Karakorum activities. Moreover, except for a few works (i.e. Wagenbach and Geis, 1989), very little information on atmospheric dust is currently provided by the available Colle Gnifetti measurements. North Africa atmospheric dust transport events can be measured in Alpine ice cores and they can be used to determine air mass trajectories in the Mediterranean areas in the past (decades to century, Maggi et al., 2006). Because of the high accumulation, Colle del Lys permits a high resolution (seasonal) record of mineral dust; on the other hand, the Colle Gnifetti, having less accumulation, can record longer back in time (centuries).

The two Asian glaciers are influenced by different types of meteorological systems: the Karakoram glaciers are mainly affected by winter precipitation carried by midlatitude Western Weather Patterns coming from the Mediterranean and the Middle East, while the Himalayan glaciers are mainly influenced by the summer Indian monsoon. So it is important to understand the relationship between the monsoon system, strongly influencing the Himalayan glaciers, and the oriental branch of the westerly perturbations reaching the Karakoram chain. Despite the fact that circulation models can provide regional transport pathways, the complicate topography of this part of the world can modify significantly the trajectories of air masses. For the Karakoram, topography can have a strong influence on the deposition rates. Ice core records can provide information on the past deposition and provide data on human/natural relationships in these mountain areas, two important reasons for having choosen the drilling sites in these two areas. In fact, the Himalaya-Karakoram-Tibet area cover a surface which is about two times the Mediterranean area, but less than 10 sites were drilled there (most of the sites are around Everest Mount). In the Karakoram area, only the Guliya ice cap (located to the margin of the Taklimakan Desert, Northern Tibet) was drilled in the past. We suggest to drill in the inner part of the Karakoram chain, along the main divide, where there is the possibility to directly record the eastern branch of the westerlies crossing the Asia. Until now, very poor data are available from this area, especially for the last centuries. In Summer 2013, a group of geophysicists plans to obtain a radar survey of the Geasherbrum glacier to define ice depth and internal layering. The ice core drilling activities are planned for November 2014.

The activities in the coming months will be devoted to the definition of the working group that will follow various mountaineering and scientific field surveys and will work in close collaboration with the constructor of the Felics drilling system. With the idea to have a backup drilling system we acquired a new drilling probe, ECLIPSE, from Icefield inc. (Canada), which allows to reach 500 m of depth, using also a possible drilling fluid. Both probes will be equipped with systems for the generation of electricity by solar panels since the high altitudes do not guarantee the generation of electricity using liquid fuel. The perforation on the Colle Gnifetti, scheduled for June 2013, will help to refine the drilling techniques, particularly for the the aspects for which there are still doubts as to execution. In addition it will provide additional cycles of training in field management and in using the drilling system, and will help to define the logistical needs. The organization of the field activities will also allow the accurate definition of a plan for the transport of samples from Pakistan and Nepal to Italy under refrigerated conditions, which guarantee the non-alteration of ice cores.

International framework

The WP1.4 activities have sinergies with other international initiatives, an important point to improve the scientific relevance of the work. In particular, the ice core activities were included in the IPICS 2k Array (International Partnership in Ice Core Science - Network of ice core climate and climate forcing records for the last two millennia), with the goal to provide atmospheric/climate information on the last 2 centuries from all the glaciated areas of the Planet. For the Karakoram and Himalaya the activities were done in collaboration with SHARE-Ev-K2-CNR and PAPRIKA (CryosPheric responses to Anthropogenic PRessures in the HIndu Kush - Karakoram - HimalayA regions: impacts on water resources and Availability) programmes and the starting France project HIMICE (Anthropogenic impact in Himalayan Monsoon Systems from Ice Cores), for drilling the Mera Peak glacier in Himalaya.

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