Ice tales

Changes in the glaciers

Observations of the front variations include monitoring changes in shape and position of the front of a glacier. Once, this operation used to be carried out "by hand", patiently drawing the profiles of the front, more recently photographing them from fixed positions, and measuring their retreat with mechanical instruments. Today, these operations are carried out generally using the GPS and aerial or satellite photographs, which enable a comparison of the variations year by year. Every year, the Comitato Glaciologico Italiano (Italian Glaciology Committee) promotes campaigns to measure the frontal variations of all the glaciers of the Alps and organizes interesting courses for those who wish to become glaciology operators.

Glacier Mass Balance

Calculation of the Glacier Mass Balance is a more complex operation - in fact a series of measurements and surveys must be carried out :

- quantification of the additional constituents, measuring the amount of precipitations on the ice, also bearing in mind the so-called "hidden precipitations", such as hoarfrost, or ice formed by sublimation, and contribution by avalanches. In order to do this, the height of snow precipitation, during winter and spring, in fixed, special points of the glacier, is measured. Usually this is carried out by fixing special long, thin rods, only a couple of centimetres in diameter, called "stakes" into the glacier in summer and inferring the thickness of the sheet of snow from the height of the protruding stoke. Since for the balance, snowfall must be transformed into equivalent millimetres of water, also the density of the snow must be known. For this purpose, special trenches are dug into the layer of snow, and its density is measured at various depths. These operations must be carried out in different points of the glacier, at different depths, so as to have a representative picture of the entire glacier.
- quantification of losses, determining the amount of ice removed by ablation. Most of the ablation, in the case of Alpine glaciers, is due to ice melting. In order to measure this parameter, series of stakes (which are usually the same used to measure the thickness of the snow layer), numbered and labelled, are positioned on the surface of the glacier with the help of special drills, up to a given depth. Periodically, during the summer period even daily, the height of the stake getting free as ice melts is measured. It is therefore possible to measure the thickness of ice that is lost in a determined period of time, and from this, with repeated measurements, to estimate the overall quantity of ice that is lost during the course of summer.

On the Forni glacier, in the Ortles-Cevedale Massif, for example, during the summer period, approximately 3-3.5 m of ice are removed by ablation, and between mid July and mid August melting reaches peaks of 4-5 cm a day (source of data : Smiraglia). The same stakes can also be used, measuring their movements vis-à-vis fixed points outside the glacier, to quantify the speed of the glacier movement downstream. Since a large quantity of ice also melts at the glacier base, where it collects forming sub-glacial lakes and streams, in the glacier mass balance it is important to include the measurement of the outflow of the streams springing out of the glacier front. The amount of water produced by surface ablation should be subtracted, in order to obtain overall basal melting.
The determination of Glacier Mass Balance is a complex operation, and in Italy recordings are carried out systematically every year only of a very limited number of glaciers, among which Careser (since 1966), Sforzellina (since 1986) in the Cevedale range, Chardonay (since 1992) in the Gran Paradiso range. A general indication can also be obtained from observations, using aerial photographs, of the ratio between accumulation areas, covered with snow, and ablation areas at the end of the summer, or of the snow-limit: if this is at a low altitude, the balance will be probably positive even it is not possible to obtain specific quantitative indications. Observation of the characteristics of the glacier front can also be

indicative : at a similar altitude, a high and swollen front generally indicates a positive balance, while a "depressed" thinner front indicates the opposite.

Measurement of the speed

The measurement of the speed at which a glacier is moving was certainly one of the first operations carried out by the first glaciologists in the 19th century, along with the observation of the front variations. In order to measure the speed at which the ice is moving, it is necessary to determine a fixed point on the glacier, easy to recognize thanks to some particular feature (e.g. a large boulder on the surface), or else marking it with one or more stakes, and constantly taking measurements (a number of times a year for a number of consecutive years) of the glacier movement vis-à-vis a fixed observation point outside the glacier.

Today, the use of aerial photographs and satellite images, together with use of particular instruments such as GPS, make this operation much easier, rapid and precise than in the past when operators had to take measurements directly on the glacier, often having to face a number of difficulties in reaching the measurement points. By means of more complex observations, made by aligning masses or glacier sinkhole systems, it has been possible to identify different areas moving at different speeds in the glacier. The speed at which glaciers move varies greatly in different glacier structures. The speed can vary during the year (usually slowing down in winter) and also from one year to another.

Measurement of the thickness

The thickness of a glacier can be obtained, with special formulae, once the speed, inclination and width are known along with some characteristics of the ice such as its density and viscosity. However, since these parameters are difficult to evaluate and vary in different parts of the glacier, it is a very rough estimate. The oldest and most direct method of measuring the thickness of a glacier consists in digging a hole that reaches the rock substratum. However, this method is very expensive, it requires heavy machinery difficult to transport, especially in the mountains and gives the thickness only at a fixed point and not along the entire glacier. The ice is extracted by perforation in the form of long and thin cylinders called "cores" and can be studied to obtain a lot of information. An indirect method of measuring the thickness of a glacier is by using geophysics, a special branch of geology that studies anomalies in the Earth's gravitational field and the propagation of seismic and electromagnetic waves in order to obtain information about the substances that compose the Earth's crust, including the ice of the glaciers. Seismic reflection profiling is the most commonly used technique for glaciers: blasting an explosive charge or ramming a heavy hammer on the surface of the ice generate waves that travel in the ice and are reflected by the underlying bedrock. By studying the course of the waves and knowing the speed at which they travel in different materials it is possible to calculate the thickness of the ice. Electric profiling , instead, is based on the study of the difference in potential created by the passage of electric current between two measuring points inserted in the ice, utilising the different conduction properties of ice and rock. A recent technique, that is very fast and efficient, is based on the reaction of ice to radar waves passing through it as if it were transparent. The novelty of this technique is that the required instruments can be placed on airplanes that can fly over vast areas: in this way, in fact, it has been possible to reconstruct the morphology of the bedrock and ice-sheet thickness in Antarctica and Greenland. This innovative technique was discovered by chance by some pilots who noticed the 'anomalous' behaviour of the radar altimeters on board their planes while they were flying over the Antarctic.

Cores and perforations

The presence of solid impurities and air bubbles trapped within the ice provide vital information about the chemical composition of the atmosphere and the temperature at the time of ice formation. It is of course essential that the ice should not have undergone melting processes, which would disperse the air bubbles: therefore, for these kinds of studies, one has to work on cold glaciers in polar regions. In some parts of the Earth, ice can be very old, like at the base of the great ice-sheets of Antarctica and Greenland, where ice can be older than 300,000 – 500,000 years. From the study of ice in these places it is therefore possible to reconstruct in detail the variations in temperature and in chemical composition of the atmosphere over a very long lapse of time, enabling us to gain access to a precious source of data regarding the climate in the past. For these studies drillings are carried out that extract long cylindrical ice samples which must not have any interruptions or missing parts from the surface up to the depth reached: in Antarctica, drilling reached a depth of over 2,000 m, as in Dome C (a project in which Italy participated) or in the Vostok perforation (Soviet), where the longest core, covering a time span of 420,000 years, was obtained.

Bubbles in the ice

Temperature of the trapped atmosphere can be obtained by studying the ratio between the heavy isotopes of oxygen, such as 18O, and the more commonly found one 16O. The ratio 16O/18O is then compared to the composition of a standard sample of sea water, the so-called SMOW (Standard Mean Oceanic Water), and the difference is calculated (δ18O‰). Ice formed in a cold period has a lower content of heavy isotopes, such as 18O, therefore δ18O‰ is negative compared to ice formed at higher temperatures. Specific tables allow us to calculate the average temperature of the air on the basis of the value of δ18O‰. This type of analysis, carried out on different cores in Antarctica and Greenland have permitted us to establish, for example, going back in time, the end of the last glaciation, around 13,000 years ago and its beginning, around 75,000 years ago; the interglacial period between the latter and older glacial episodes (120,000-140,000 years ago) had a warm climate and temperature was over 2°C higher than present, according to the reconstruction that was made using the Vostok core.
The analysis of the chemical composition of trapped air takes into account mainly the greenhouse gases, such as carbon dioxide and methane, considered the main cause of global warming. In fact, the analysis of the core shows that the content of these gases is naturally lower during the cold periods, corresponding to glacial periods, and increases when temperature increases. By studying numerous cores, it has been possible to reconstruct the trend in time of the two main greenhouse gases, and to identify different cold and hot periods. The most significant result of this analysis is, however, the dramatic increase of these gases in the last 200 years - starting from the development of industrial activities – an increase that has no comparison with any other in the last 160,000 years. From the end of the last glacial episode to the beginning of the Holocene (a period of time of about 2-3,000 years), the carbon dioxide concentration in the atmosphere has increased by 70 ppm, and the same increase has been recorded from pre-industrial times until today (less than 200 years)! Data inferred from the study of glaciers thus allow us to reconstruct with great detail information on the climate and on the atmosphere of the past – essential in order to understand how the climatic system of our planet works and at the same time it rings a warning bell that should make us reflect and take necessary measures. Will we be able to make good use of the ‘advice’ our glaciers give us?

“Dirty” ice

During its formation, glacier ice traps air bubbles and numerous solid impurities, that can be opportunely studied and provide important and precious data on the history of our planet. The coarser debris usually come from the mountain slopes closer to the glacier or to its base: the examination of glacial deposits is very important to reconstruct glaciers that are now extinct however they do not usually supply interesting information regarding present-day glaciers (which we already have information about with regard to expanse and position). Smaller fragments, fine dusts that may come from far away carried by the wind, are more interesting. Observing their distribution one can, for example, reconstruct the direction of winds, while an analysis of the dust composition can occasionally lead to some surprises: grains of sand from the Sahara Desert are wide-spread on Alpine glaciers, and it is not improbable to find traces of particularly violent volcanic eruptions in the form of great amounts of volcanic ash. The study of the composition of these ashes often allows us to identify the volcano from which they derive, and this provides us with information on the winds that carried them and on the strength of the explosion. If the ashes comes from historic volcanic events it is also possible to date the level of ice in which these were found. On the other hand, the possibility of dating the different levels of ice makes it possible to assess the time of very ancient volcanic events. The study of dust in Antarctica and in Greenland, for example, shows that the concentration during the last glacial episode is much higher than today: this fact makes us infer that during glaciation, atmospheric circulation along the meridians was more ‘energetic’ due to greater differences in temperature between the tropical and polar zones and that the arid and desert zones were more wide-spread. The discovery of pollutants of industrial origin in cores of glaciers very far from anthropic settlements, such as those of the Himalayas or of the Karakorum, enable us to study how these substances are propagated in the atmosphere and, in some cases, to establish who is the “culprit”.

The age of ice

Glacier ice is far from being a homogenous material and is usually stratified in layers, due to the progressive annual accumulation of layers of snow of various thicknesses: the older parts can be found at the base and the younger ones closer to the surface. Usually summer ice has a glassier appearance, often full of dark dusts and it is less thick, while winter ice is white and thicker. In a way similar to that used to measure the yearly growth in trees by the number of rings, it is possible to ‘count’ the different layers and therefore infer the number of years. This method, however, can be used only until the growing pressure within the glacier cancels the ice stratigraphy. For the old and deep ice, indirect and more complex methods are used, taking into consideration the air bubbles trapped in ice. The radiocarbon method utilizes carbon 14C contained in trapped carbon dioxide in a way similar to that used to date handicrafts and organic material, but this method is rarely utilized due to the great quantity of material required . The most frequently utilized method analyses the heavy isotopes of oxygen present in the air bubbles. For the older and deeper layers other methods must be used based on mathematical models of the ice flow. The finding of levels rich in dust, particularly volcanic ashes, is important: when it is possible to associate them with a known volcanic eruption , it is possible to give a precise age to the layer level at which they have been found.