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Snow Cover on the Mountains: Still White and Pure?

The cryosphere is the body of the world's frozen water, composed of sea and continental ice, snow cover, and perpetually frozen soil and rocks (permafrost). Mountain glaciers cover about 160,000 km^2 (World Glacier Monitoring Service 2008), sometimes reaching the lowlands and the sea. Awareness of their importance for water supply is rapidly increasing, as is their vulnerability as frozen "water towers" for the millennium. The snow cover is the outer surface of the cryosphere, with greater exposure to dust, pollutants, and ultimately contamination. There is a general perception of the importance of the cryosphere as a crucial thermodynamic system capable of storing water (when not needed) during the cold season and giving it back during the hot season (when necessary). At the same time, knowledge of the pattern and amount of contamination and the dynamics and interactions between pollutants and snow before, during, and after the melting processes is poor. Preliminary results of current research in Europe show a strong ionic release concentrated during the first phases of the melting season that could have a noticeable impact, not only on drinking water. The Environmental Monitoring of Snow project applied a relatively simple methodology to monitor the contamination of snow in Italy's mountains. This methodology could easily be used in other parts of the world, alerting the public to potential risks menacing water quality.

A new concept of snow

We usually have a simplified perception of the behavior and the properties of an apparently simple element such as snow, which, we know, melts easily when temperature rises, can be used for skiing, etc. But if we want to understand the kaleidoscopic features and importance of snow, we need to zoom in closely on it (Figure 1). The climate is rapidly changing all over the world: differences in the amount of snow precipitation, the distribution and permanence of snow cover, the pattern of snow-melted waters, spring regimes, and torrent water discharges are affecting not only Mediterranean mountain areas but others as well, making it difficult to manage everyday reality in the winter season and beyond.

Moreover, not only the quantity but also the quality of snow is changing. Looking deeply below and inside the white mantle, we are really surprised to find a rich content of particles, dust, and chemical/radiochemical compounds, with implications for the quality of meltwater and, consequently, for the health of people.

FIGURE 1 Sampling of snow layer for pH and electrical conductivity PROFILE determination in Prati di Tivo, Abruzzo, Italy. (Photo courtesy of Pinuccio D'Aquila)

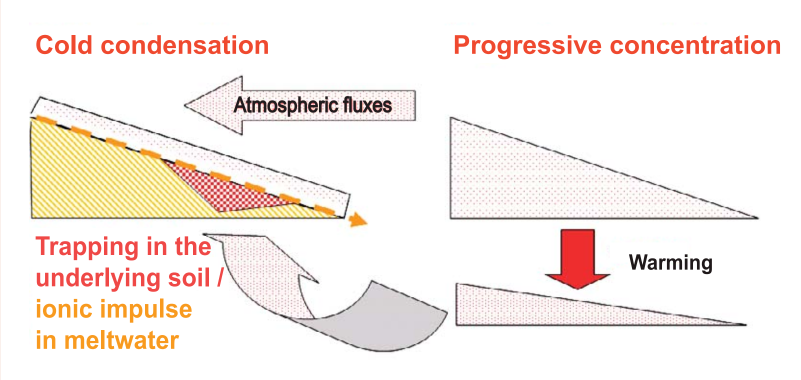
Snow in particular and—more generally—the environment at high altitudes are impacted by global processes: neither is as clean as expected or as hypothesized in studies.

The presence of "residual" deposition from long-range global transportation mechanisms can always be surveyed and revealed, from both the chemical and the radiochemical points of view; the prolonged presence of polluted air masses ("brown clouds") in time and space has alerted the scientific community to study this phenomenon's evolution and implications by means of global monitoring networks. For instance, SHARE (Station at High Altitude for Research on the Environment) is particularly dedicated to mountain areas and high altitudes.

Monitoring snow and pollutants

Locally and under particular circumstances (depending on boundary conditions, ie morpho-climatic, physical/chemical processes, animal/human action), concentrations can be progressively enriched in all the environmental matrixes, with the final destination of water resources passing (more or less rapidly) through hydrogeological bodies (soil, rock, permafrost, ice). These processes are simplified in Figure 2, where the outer snow layer (corresponding to the last single precipitation event) behaves like an "environmental sponge" with respect to the atmospheric streams, due to the high density of pores, thus promoting the dry deposition of fine particles. These are particulate matter, such as Saharan dust, sea spray and particles originating from volcanoes, dust storms, forest and grassland fires, and contaminants produced by fuel burned for automobiles and industrial and power plants (inorganic compounds such as nitrates, sulfates, ammonia), by chemical industrial production cycles (volatile and persistent organic compounds: VOCs and POPs), and by nuclear explosions and incidents (radioisotopes such as ^{137}Cs). Most of these are toxic or carcinogenic. They are usually also incorporated into the core of the snow crystal during the initial phases of solid sublimation. In both cases, the snow cover promotes a scavenging action, also concentrating particles within the snow layers.

FIGURE 2 Schematic representation of the different internal (in red) and external physical processes (in black) that play an active role during the evolution of the snow cover and the concentration of pollutants. (Diagram by Massimo Pecci)



The positive values of temperature, strictly depending on the beginning of the melting season and enhanced by global warming, promote the melting process; this is immediately accompanied by the leaching and diffusion of particles and pollutants, in turn producing an ionic impulse in meltwater or trapping phenomena at the soil–snow interface. The intensity and the dynamics of such an ionic impulse, even if reported in literature, are not well known, nor is the impact on drinking water.

The Environmental Monitoring of Snow project

Since the winter season of 2005–2006, the experimental Environmental Monitoring of Snow research project has been focusing on quick in situ checking of the chemical features of the snow cover in several sample sites in the Italian Alps and Apennines (Box 1). Measurements concern pH value, electrical conductivity, and radioactivity, immediately indicating the general degree and the possible source of pollution. In the winters of 2006–2007 and 2007–2008, these activities were also added to routine surveys of the snowpack profile needed for the avalanche risk daily bulletin.

The experimental goals for each project year were:

1. Check the feasibility of the proposed "quick chemical–environmental snowpack profile" (PROFILE in brief) during routine surveys of the snowpack profile; define the field sites, the

Groups involved in the Environmental Monitoring of Snow project

Quick surveys were performed at test sites by the following 5 research units:

Italian Mountain Institute (M. Pecci and P. D'Aquila) in the *Gran Sasso d'Italia (Prati di Tivo)*, central Apennine, Italy, at 1800 m;

Arabba Snow and Avalanche Center of the Environmental Agency of the Veneto Region (M. Valt, V. Cagnati, T. Corso, and J. Gabrieli) in the *Dolomiti Bellunesi (Monti Alti di Ornella),* northeastern Italian Alps, at 2250 m;

Bormio Snow/Meteorological Center of the Environmental Agency of the Lombardia Region (A. Praolini, E. Meraldi, and F. Berbenni) in *Bormio (Monte Vallecetta),* central Italian Alps, at 2232 m;

University of Turin, Laboratory for Alpine Soil and Snow (M. Freppaz, P. Della Vedova, and G. Filippa) in the *Valle d'Aosta (Fontainemore),* western Italian Alps, at 1825 m;

MeteoSwiss (G. Kappenberger) in the *Val Maggia* (*Ghiacciaio Basodino*), Swiss Alps, at 2700–3000 m.

FIGURE 3 The portable and easy-to-use instrument for standardized measurements of pH (blue probe in the front) and electrical conductivity (black probe). (Photo by Massimo Pecci)

measuring features, and a shared methodology (Year 1);

2. Define and use standardized methods and tools; conduct an experimental check of the validity of the measures in terms of interest, utility, and representativeness (Year 2);
3. Compare data produced by the PROFILE and results of laboratory analyses on the same samples of snow, in order to make them "routine work" (Year 3, in progress).

(For more detailed results on the first 2 years, see Further Reading.)

(Easy) methods and (simple and cheap) tools

As we were dealing with the quality of the snow cover—roughly defined as a shift from a "pure condition," ie from chemical neutrality with a very low ionic charge—we decided to measure pH and electrical conductivity with a compact instrument (Figure 3) on a sample of meltwater, directly on the field, or, depending on environmental conditions, over 24 hours. After digging a snow pit on the slope, a sample was collected from each easily detectable snow layer, with particular care to avoid any contamination (see Figure 1). Finally, the environmental snow and air quick radiocontamination were surveyed with the help of a Geiger counter (Figure 4).

The pH (*pondus hydrogenii*) indicates the (potential) activity of hydrogen and is an indication of acidity or alkalinity. In pure water at 25°C, the concentration of H^+ equals the concentration of hydroxide ions (OH^-) and the pH value is 7. The lower the pH values are, the higher the concentrations of hydrogen ions (high acidity); the higher the pH values are, the lower the concentrations of hydrogen ions (high alkalinity).

The electrical conductivity is the measure of a material's ability to conduct an electric current: the higher the electrical conductivity, the more ions. Values of conductivity greater than 10–15 µS/cm (micro-Siemens per centimeter) in meltwater (with a contemporaneous value of pH ranging from 5 to 4) can usually be correlated with "acid" precipitations, with a high presence of sulfates and nitrates (acidifying compounds).

FIGURE 4 PROFILE radioactivity measurement with a Geiger counter and an external probe. (Photo courtesy of Tiziana Corso)

Unexpected snow features

In Table 1 the easier-to-understand and general statistical results in terms of pH and electrical conductivity are reported for the first and second winters of surveys and observations (for a detailed and numerical discussion, see Further Reading). They clearly highlight a composite distribution, generically far from neutrality, and a more or less significant contamination of the snow cover. Just to give an indication of the environmental quality of the snow, the lower values of pH (4–4.5) are typical of an acidic beer, and the higher (7–7.3) are typical of human body fluids (blood, saliva, etc). Again, the "acid shift" is more pronounced than the alkaline one, and therefore needs to be taken into account.

From the radiochemical point of view, the presence and concentration of pollutants (particularly ^{137}Cs)—even in high altitudes—have been surveyed in mountain ranges all over the world (see Further Reading). For this reason several temporally and spatially random radioactivity measurements were also performed during the first and second winters of the project, and a regular weekly "quick radioactivity profile" was recorded during winter 2007–2008 in the PROFILE and the air of the Prati di Tivo site. The Geiger counter revealed very low but always recordable doses (often close to the measuring limits), both for snow and air. The measurements matched well with the preliminary results obtained during specific research by the NGO Ultra Montes ad Altum Onlus. The preliminary results of this spot monitoring activity highlight a far-from-pure condition of the Italian snow cover, which must be the subject of further in-depth study, above all concerning implications for the quality (temporary or perennial?) of meltwater and possible mitigation activities and tools.

TABLE 1 Basic statistical parameters of measured values related to pH and electrical conductivity (EC) in the winters of 2005–2006 (total of 468 measures) and 2006–2007 (total of 483 measures).

Parameter	Value
Max pH	**10.2** (Monte Vallecetta)
Min pH	**4.07** (Prati di Tivo)
Average pH	**5.99**
Percentage of measurements with pH = 6.5–7.0	**85** (only in the Alps)
Percentage of measurements with EC = 0 (μS/cm)	**19**
Max EC (μS/cm)	**163.00** (Monte Vallecetta)
Min EC (μS/cm)	**0.00** (Prati di Tivo)
Average EC (μS/cm)	**8.13**

Can such snow monitoring be useful?

It seems extremely important to collect the footprint of the chemical/radiochemical presence of pollutants in the snowpack with quick and low-cost methods and tools, in order to monitor the quality of the snow and the water resources after the melting process. At the same time, such weekly direct quick environmental monitoring could be (and actually was in the study cases) an "early warning tool" to highlight extreme and dangerous phenomena—directly surveyable on the snow—such as fallout of unknown natural or anthropogenic explosions or activities, undetected by existing monitoring networks.

The operations for the PROFILE can be coupled to routine surveys for avalanche prevention, requiring only a few minutes more for an expert. At any rate, the proposed PROFILE method seems to be easy to learn and simple to apply to all mountain environments and ranges.

The working experimental network in Italy could be improved by the addition of 2 more sites in the southern and northern Apennines, in order to have greater homogenous spatial distribution and monitoring action. It would also be important to spread and enhance the network as soon as possible at the regional and global scales, with a few selected sites.

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