MINERAL DUST IN THE SEASONAL SNOWPACK: AN INTEGRATED STUDY ON AN ITALIAN ALPINE GLACIER

Claudio Artoni[1,2,*], Llorenç Cremonesi[1,3], Deborah Fiorini[1], François Yves Burgay[4,2], Sarah Pizzini[5,2], Elena Barbaro[6], Clara Turetta[6], Biagio Di Mauro[7], Marco A. C. Potenza[3], Barbara Delmonte[1]

[1]: *Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy.*
[2]: *Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Venice Mestre (VE), Italy.*
[3]: *Department of Physics, University of Milan, Milan, Italy.*
[4]: *Laboratory of Environmental Chemistry, Paul Scherrer Institute (PSI-LUC), Villigen PSI, Switzerland.*
[5]: *Institute for Marine Biological Resources and Biotechnology, National Research Council (CNR-IRBIM), Ancona, Italy.*
[6]: *Institute of Polar Sciences, National Research Council (CNR-ISP), Venice Mestre (VE), Italy.*
[7]: *Institute of Polar Sciences, National Research Council (CNR-ISP), Milan, Italy.*

ABSTRACT: On a global scale, mineral dust accounts for the major contribution to the mass load of airborne particles in the atmosphere. It consists of micron-sized minerals mainly depleted from arid and semiarid regions by eolian processes. Dust can affect glaciers, reducing the albedo and transforming the physical characteristics of the snowpack; for example, dust leads to the formation of melting-refreezing crusts and hoar crystals weak layers, that are particularly important in avalanche risk assessment. Mineral dust also preserves the imprint of environmental and climate changes that occurred at different times in the past: to evaluate all these processes, snow and ice cores provide a privileged archive and can be used as powerful tools to assess the impact of human activities on the environment. For these reasons, we performed for the first time an integrated study (optical properties and chemical composition) on shallow snow cores, representative of the winter season, on the top of the Rutor Glacier (Aosta Valley, Italy, 46.637° N, 7.016° E - 3200 m a.s.l.).

KEYWORDS: Mineral dust; Optical properties; Chemical composition; Anthropogenic tracers; Glaciers; Alps.

1. INTRODUCTION

High-albedo surfaces of the planet are deeply in interaction with the solar radiation, thus affecting the Earth's energy budget. When mineral dust is suspended into the atmosphere it can implement a number of interactions with the solar electromagnetic radiation, while once deposited on highly-reflecting snowy surfaces it drastically reduces albedo, thus resulting in significant net radiation input to the snowpack. Because of its capability to affect the snowpack, e.g., inducing metamorphism processes such as the formation of hoar crystals and melting-refreezing crusts, mineral dust can contribute to the formation of weak layers, cult snowpack layers in avalanche risk assessment.

2. RUTOR GLACIER

The Rutor Glacier is located in the upper part of La Thuile valley, in the Aosta Valley region, Italy (46.637° N, 7.016° E) between 2600-3420 m a.s.l. Covering an area of 7.5 km², it is one of the ten biggest glaciers in the Italian Alps. Its basin is bound to the South-West by the French/Italian border and the accumulation area is open to the western Atlantic fluxes.

Since 2005, the Rutor Glacier has experienced a considerable mass loss due to strong summer ablation (Fig. 1).

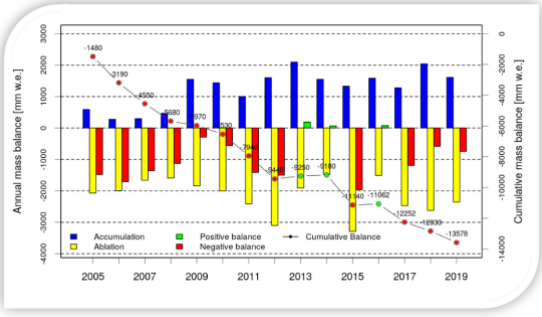

Figure 1: Annual and cumulative mass balance of the Rutor Glacier from 2005 to 2019.

3. MATERIAL AND METHODS

Three shallow snow cores (3-4 m long), representative of the previous winter season, were collected in June 2015, 2016, and 2017 on the top of the Rutor Glacier. Samples were divided into sections (~8 cm) for parallel physical analyses at the EuroCold laboratory of the

* *Corresponding author address:*
Claudio Artoni
Department of Earth and Environmental Sciences, University of Milano-Bicocca,
Piazza della Scienza, 1 - 20126 Milan, Italy;
Tel: +39 02 6448 2815
E-mail: claudio.artoni@unimib.it

University of Milano-Bicocca and for chemical analyses at the Institute of Polar Sciences and Ca' Foscari University of Venice.

3.1 *Single Particle Extinction and Scattering*

Insoluble particles in the micrometric length scale (~0.5-5 µm) are characterized with the Single Particle Extinction and Scattering (SPES) method (Potenza et al., 2015) to assess their main optical parameters, which are responsible for the darkening of the snow layer. Small sections of the snow cores are melted and flown through an in-line instrument (EOS Classizer™ ONE). Particles are driven across a focused laser beam with a wavelength of 635 nm. By measuring the interference between the transmitted and the scattered field, we measured both the extinction cross-section (C_{ext}) and the dimensionless optical thickness (ρ) of single particles. Finally, we also characterized the stratigraphic number concentration of such particles in the snow cores. Characterizing such parameters is aimed at identifying critical layers where sunlight-triggered metamorphisms might occur, hence a structural weakening of the snowpack even way below its surface.

3.2 *Hyperspectral analysis*

The hyperspectral set-up is a non-destructive scanning system, specifically designed to measure the spectral reflectance of ice, firn, and snow samples, to extract highly-resolved images (~0.1 cm) of snow. The instrumental set-up consists of both fixed and in motion parts. The mobile components are a hyperspectral spectrometer and a halogen light source (600 W), both able to translate back and forth to scan the selected snow samples. The spectrometer collects spectral radiance in 841 bands in VIS-NIR wavelengths (380-1000 nm), with a spectral resolution of about 2-3 nm. The main fixed-position component is the solid-dark base support where samples are accurately positioned, in order to maximize the images spatial resolution. A white reference, positioned at the top of sections, reproduces an ideal reflectance equal to 1 to be associated with a Dark Current measure that simulates a 0 reflectance. A software allows the calculation of a reflectance matrix, extracted from each image's pixel, averaging on a defined surface area in the center of snow sections to avoid reflectance artifacts. From reflectance, various spectral descriptors can be extracted, such as albedo, Snow Darkening Index (SDI), and Impurity Index (II). In particular, the SDI considers red-green wavelengths in order to be sensitive to the snow surface darkening, while the II is more sensitive to snow-grains shapes and considers also NIR wavelength.

Future analysis will allow us to extract a spectral characterization of mineral dust settled on snow, to enhance the knowledge about dust microphysical parameters, which can trigger various processes within the snowpack.

3.3 *Chemical analysis*

The chemical analyses performed are devoted to the quantification of inorganic and organic species. We focused on the high-temporal resolution quantification of heavy metals, crustal elements, and Levoglucosan as biomass burning key-tracer, and on the year-averaged quantification of a set of organic contaminants (i.e. Poly- and Perfluoroalkyl substances, PFASs and their precursors; Polycyclic aromatic hydrocarbons, PAHs; Polybrominated diphenyl ethers, PBDEs; Polychlorinated biphenyls, PCBs; Polychlorinated dibenzo-*p*-dioxins and furans, PCDD/Fs), providing the first comprehensive environmental quality study of the Rutor Glacier. The chemical composition of the snow cores was investigated using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for the inorganic species, High Performance Liquid Chromatography coupled to tandem Mass Spectrometry (HPLC-MS/MS) for the Levoglucosan and PFAS determination, and Gas Chromatography coupled both to Low-Resolution and High-Resolution Mass Spectrometry (GC-LRMS, GC-HRMS) for the other organic species. The aim of the analyses is to assess: 1) the environmental impact of high-altitude biomass burning activities (Gambaro et al., 2008); 2) a winter-average of the most common (PAHs, PBDEs, PCBs, PCDD/Fs) and emerging (PFASs and their precursors) organic pollutants; 3) the potential release in the environment of organic and inorganic pollutants due to the melting of the glacier.

4. Preliminary Chemical Results

The preliminary results obtained from the chemical analyses have shown that both natural (crustal elements) and anthropogenic (ex-SO_4^{2-}, $EF_{Pb/Ti} > 100$) sources influence the Rutor Glacier during the winter season. The high correlation between Cl^- and Na^+ ($r = 0.986$, p-value < 0.001) and the Cl^-/Na^+ ratio (2.3 ± 0.9), similar to the marine one (1.8), suggest the presence of marine sources, with the Cl^- excess likely explained by anthropogenic contribution.

With regard to the organic analytes, the biomass burning tracer Levoglucosan showed high concentration and variability (1.2 ± 0.9 ng L^{-1}),

and PAH diagnostic ratios (Tobiszewski and Namieśnik, 2012) clearly suggest their pyrogenic origin from combustion sources. Unexpectedly high year-averaged concentration of PFASs, in the range 16.0 - 51.3 ng L^{-1}, is observed in all the snow samples (Fig. 2), and their precursors, 6:2 (1.06 - 7.57 ng L^{-1}) and 8:2 fluorotelomers (0.05 - 3.99 ng L^{-1}) are also detected.

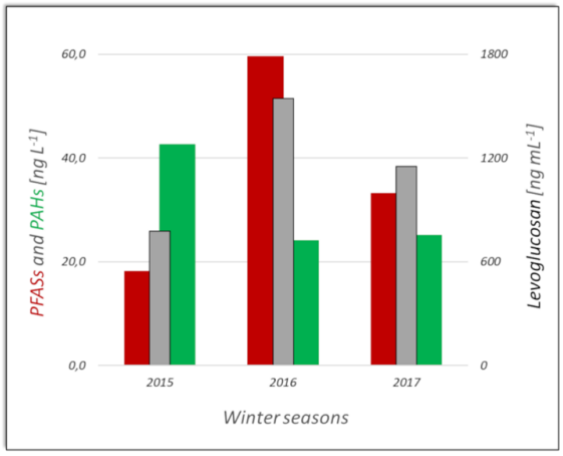

Figure 2: Year-averaged concentrations of PFASs (Poly- and Perfluoroalkyl substances), PAHs (Polycyclic aromatic hydrocarbons), and Levoglucosan detected in the snow cores from 2015 to 2017.

5. Integrated Stratigraphy

We compared the stratigraphic trend of the Levoglucosan concentration, the average optical thickness (ρ), and the average extinction cross-section (C_{ext}).

Data are shown in Figure 3 where are plotted the stratigraphy of the 2015, 2016, and 1017 with the data obtained by the micro-physical and chemical analyses. In the stratigraphy box the snow cores codes, the visual stratigraphy, and the samples collected are shown.

The green lines and dots represent the Levoglucosan data, while the red lines and dots represent the average optical thickness (ρ), and the blue lines and dots represent the average extinction cross-section (C_{ext}).

6. Conclusions

Preliminary analyses showed a mild correlation between chemical and optical parameters. Specifically, we can observe an increase in the optical thickness in the samples characterized also by an increase of Levoglucosan concentrations. A high value in the optical thickness during these events is probably due also to an increase of the size of the particles and to an abundance of lighter ones. Analyzing the trend over the various years, it can be noted that in the upper part of the snowpack in 2015 and 2016 the extinction cross-section is higher than the optical thickness and this is probably due to the presence of more light-absorbing particles, that are less present at the bottom of the 2015 and 2016 snowpack and in the entire 2017 snowpack.

The Rutor Glacier is affected both by natural (terrestrial and marine) and anthropogenic sources. Biomass burning has a relevant contribution as demonstrated by the high detected Levoglucosan concentration and by PAH assemblages. A back-trajectory study will help in determining the biomass burning and other pollution sources.

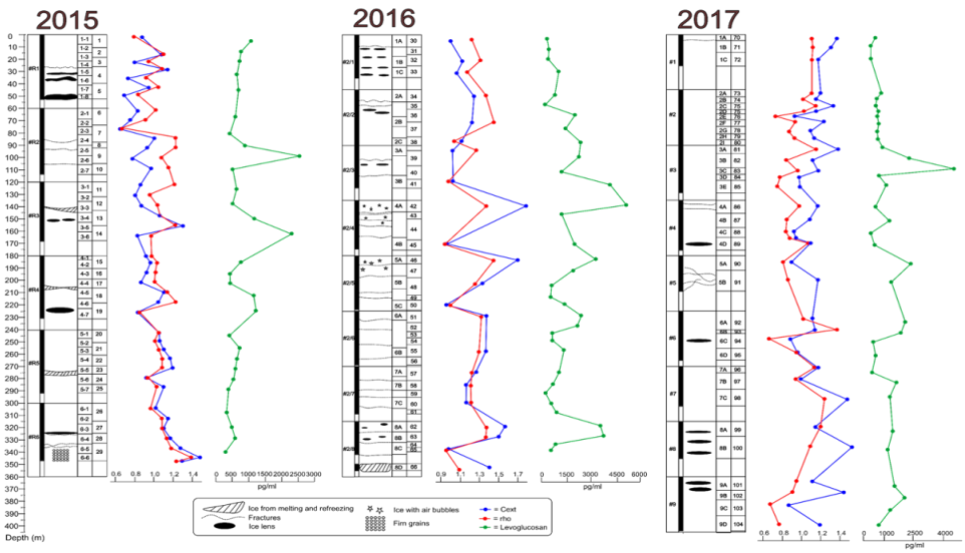

Figure 3: Integrated stratigraphy of the snow cores from 2015 to 2017.

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