The Multidisciplinary Ice Core

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Abstract: Ice-core physics and climate research undoubtedly form a very successful partnership. Nevertheless, even the best union may sometimes suffer under the wearing of time. Multidisciplinarity may support the stability of this partnership, by helping ice-core physics to become more independent and dynamic, as well as a better partner to other disciplines —including climate research.

Key words: ice core, ice sheet, ice physics, polar science, multidisciplinarity.

> *Today it has become fashionable in the sciences to appeal to the specialized knowledge and authority of experts* [...]. *But science and rationality have really very little to do with specialization and the appeal to expert authority. On the contrary, these intellectual fashions are actually an obstacle to both. For just as the fashionable thinker is the prisoner of his fashion, the expert is a prisoner of his specialization. And it is the freedom from intellectual fashions and specializations that makes science and rationality possible.*
>
> Sir Karl R. Popper [7], p. ix

1 Introduction

As in most areas of human activity, science has also its protagonists. Some are called *heroes*, others *authorities*. There is, however, a fundamental difference between a hero and an authority of science: we may praise and admire heroes even when we disagree intellectually with them, for heroes are defined by their inspiring attitude, not by their supremacy.[1] In contrast, authorities can only be feared and obeyed, hardly ever defied.

According to Popper [7], a field prone to being partitioned into fashionable specializations is a very effective environment for the proliferation of authorities. This phenomenon is indeed evidenced in many areas of scientific research today. Admittedly, modern science is not the appropriate environment for polymaths... but a certain degree of interdisciplinarity is still a wholesome attitude against intellectual despotism.

Also in ice-core physics we may perceive the influence of authorities. In this case, their influence is mainly exercised through the exploitation of a serious cause: *the climate issue*. The importance of ice cores for understanding this crucial issue is obvious. However, this fact has often been emphasized in a biased manner, such as to suggest that ice-core physics is merely a subordinate to climate research. This is a dangerous misconception, for just as paleoclimate records are not an exclusivity of ice cores (they are found in different ways in sediment cores, tree rings, etc.), also the physics of ice cores does not have its raison d'être in climatology.

In this note I defend the thesis, supported by an increasing number of scientists, that enhanced interdisciplinarity and a greater diversity of interests beyond the climate issue may help ice-core physics to recover its independence, to become a more dynamic subject and also a better partner to other disciplines —including climate research.

2 The three crucial questions

It is an indisputable fact that the cryosphere constitutes an essential part of Earth's climate system, and it is also widely recognized that natural ice contains invaluable records of the global climate of the last million years. Therefore, the harmony between ice-core physics and climatology *must* be cultivated. Before all, it is only through this partnership, which has already been established in the early times of glacier and polar-ice research, that we may decipher *correctly* the paleoclimate records in ice cores and determine *precisely* the role of glaciers and ice sheets in Earth's climate.

These two features, *correctness* and *precision*, are the main qualities that the fundamental research in ice-core physics may offer to ice-core climatology. Without this fundamental (chemico-)physical research, the interpretation of paleoclimate records from ice cores, their dating, and the predictions of glacier and ice-sheet models become merely putative, Baconian empiricism.

At this point we arrive at our first crucial question: what is the proper means of cultivating the partnership between ice-core physics and climatology? A spontaneous answer would be: "Let them grow together." This has in fact been the course taken so far, with consider-

[1] The notion of "hero of science" depends to great extent upon one's own sensibilities and experiences. Intrepid explorers are in principle as meritorious as brilliant theoreticians or polemic personalities. Therefore I refrain here from particular nominations.

able success indeed. However, the escalating popularity of the climate issue produced recently an unexpected "side-effect": the misconception of the role of ice-core physics ... by regarding it as a mere assistant to the interpretation of paleoclimate records.

There is in fact a simple historical explanation for this misconception. The first interpretations of ice-core paleoclimate records, performed several decades ago, evidently required intensive investigations of the physics of natural ice. At that time, any small piece of physical information represented a substantial improvement in the paleoclimate-record analysis. Thus, it seemed natural for ice-core physicists to perform their investigations using samples from ice cores originally produced for climate studies, also called *climate-motivated cores*.

Be that as it may, much has changed since the pioneering times. While interpretations of ice-core paleoclimate records still rely strongly on the fundamental results delivered by ice-core physics, it is now recognized that the fundamental physical results derived from climate-motivated cores are deficient and imprecise. *More and better physical information is urgently needed.*

But how to obtain such high-quality information? This is our second crucial question. We all know that progress in science entails not only expansion of knowledge, but also re-evaluation of established customs. In the particular case of polar ice cores, a custom requiring urgent re-evaluation is the persistent disregard of the fact that climate-motivated cores are generally extracted from rather extraordinary sites (viz. characterized by unusual flow conditions, e.g. domes), which are supposed to provide excellent paleoclimate records but also the most unrepresentative and even pathological physical data. Clearly, this disregard serves solely to nourish empiricism in polar climatology through the hindering of consequential advances in ice-core physics.

The time is ripe to realize that substantial progress in ice-core physics can be achieved in a continual manner only through the production of *physically motivated deep ice cores*, that is, deep ice cores especially produced for the study of the physical properties of polar ice, extracted from sites that are representative of the most common physical processes taking place in polar ice sheets (e.g. flow instabilities, changes in ice rheology, subglacial phenomena, etc.).

Evidently, the production of such physically motivated cores is not a trivial task. First, close collaboration with drilling programs dedicated to climate-motivated cores is essential to avoid conflicts of interests. This should not be a critical problem, however, because the results derived from physically motivated cores would certainly be of great value for the interpretation of climate ice-core records. Second, this would be an excellent opportunity to improve the technology of deep ice-core drilling, seeing that most technological advances in this sector have been devoted to the extraction of climate-motivated cores. For instance, for a structural glaciologist it is upsetting to recognize that consequential conclusions about the interplay between ice-sheet microstructure and flow have been impaired by the mere fact that no deep-drilling equipment is currently capable of recording the absolute orientation of an ice core (which is irrelevant for standard climate studies). Third, a coherent drilling program for physically motivated ice cores should include also the drilling of deep *ice-shelf* cores. To my knowledge no "deep" ice core has been extracted from Antarctic ice shelves during the last fifteen years (cf. [5]), most probably because all the manpower available for drilling has been concentrated on continental deep ice-core drilling, inasmuch as ice-shelf cores are generally not expected to provide valuable paleoclimatic records.

So far I have discussed only the difficulties related to the *implementation* of a physically motivated deep-drilling program. However, the most obvious difficulty is not of practical but rather of *financial* character: an independent deep-drilling program is clearly a rather expensive project. This brings us to our third and last crucial question: how to obtain the necessary financial support for such a costly enterprise? Possibly the best answer to this question is *diversification*, or in scientific terms, *multidisciplinarity*: ice-core physicists must make evident the value of their knowledge and research to the greatest possible variety of disciplines.

The industry has been experimenting with diversification for more than a century, and proved that this is indeed a very effective strategy for reducing dependence on a particular sector of the market. Evidently, science is not business, but why not using similar marketing strategies to convince funding agencies and policy makers of the real significance of physically motivated ice cores for a wide range of applications? After all, there is so much to be explored in the physics of polar ice! Earth and planetary scientists are enthralled by the flow of ice sheets, which they visualize as unique deformation experiments carried by Nature on size and time scales that could never be achieved in laboratory [4, 10]. Physicists and engineers are fascinated by the remarkable physical properties of polar ice and the lessons it may teach us about hydrogen bonds, polycrystal physics, and recrystallization [1, 3, 11]. Crystallographers are allured by the whimsical structures and complex dynamics of air hydrates, negative crystals and other symmetric structures enclosed in polar ice samples [2, 6]. Mathematicians are seduced by the intricate topology of the porous structure of polar firn and its metamorphism into bubbly ice [8, 9]. And these are just few examples.

3 Conclusion

My intention with the arguments presented here is not to plead for divorce between ice-core physics and climate research, on the contrary: *climate research is and should continue to be one of the main applications of ice-core physics*. Rather, my claim is that the sought-after formula to maintain this partnership flourishing in the coming times consists in affording new opportunities for ice-

core physics, by stimulating its interactions with other disciplines.

New interdisciplinary collaborations may not only enrich ice-core physics with innovative ideas, but also reveal its still unexplored potential for natural and engineering sciences. In order to explore all these inestimable possibilities, an increasing number of ice-core physicists have been trying to join forces with other scientists. They know they need new, motivated partners from diverse disciplines. They know they must convince funding agencies and policy makers of the necessity of an international drilling program for physically motivated deep ice cores. They know that this is the time to take the next step in ice-core science and state resolutely: *with physically motivated deep ice cores we can do more, we can do better!*

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