From the Geosphere to the Cosmos: ASPERA Workshop

Abstract

Environmental Sciences in Glacial Ice

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In 1999 Price led an international consortium that proposed to the U. S. NSF to create a Science and Technology Center called DeepIce. Astroparticle physicists within AMANDA (the forerunner of IceCube) were to collaborate with environmental scientists on projects that exploited the special features of glacial ice at or near the South Pole. The institutions included 24 from U. S. and 11 from other countries. Although they reached the final round in the competition, they were not funded. Nevertheless, many of the ideas they generated have led to important advances in glaciology, climate research, volcanology, propagation of acoustic and radio waves in ice, and extremophile biology.

One important spinoff of the brainstorming sessions of DeepIce members was the optical dust-logger, which reads out concentrations of dust particles and volcanic ash down a several-thousand-meter borehole in one day with a depth resolution of ~1 mm. Dust logs in Antarctic and Greenland ice revealed an apparent causal relationship between abrupt climate changes and faint volcanic fallout layers. By the end of 2010 Ryan Bay will have mapped particles down to depths of 2450 m in nine hot-water boreholes drilled during IceCube construction. These images have permitted reconstructions of dust and paleowind records of unparalleled quality, and reveal a complex pattern of glacial flow from more than one upstream source. The detailed characterization of South Pole ice made possible by IceCube has made the site a leading candidate for the next deep U. S. ice core project. After discovering a thick layer of high dust concentration at ~2100 m corresponding to ~65,000 years ago, IceCube elected to concentrate optical modules deeper, where the dust concentration is extremely low, in order to create a volume of ice capable of recording neutrinos down to a few GeV in energy.

There is much uncertainty and concern about the stability of large ice sheets; at the same time, the potential impacts of shearing have long been a concern for IceCube. Thermistors and microinclinometers installed in IceCube show that South Pole ice undergoes rigid-body flow at depths shallower than ~2450 m, below which shear flow is being detected at rates of order 0.1 degree per year. For the first time, the shear strain rate of a large volume of ice can be studied in three dimensions as a function of stress, impurity content and temperature down to -35oC.

In discussions among DeepIce participants about possible life in subglacial lakes, Price worked out a quantitative model, later confirmed by others, of how microbes less than several microns in size could live in liquid veins at triple junctions of ice grains. The ecology of microbes in ice is now an active field. For example, excesses of gases such as methane and nitrous oxide at several depths in ice have been shown to be the products of metabolism by microbes living in ice. A quantitative analysis of the concentrations of the gases and of the microbes enables one to calculate the average metabolic rate as a function of temperature.

Using autofluorescence techniques and flow cytometry, the Berkeley group has discovered that the dominant microbial taxa in glacial ice at several sites are submicron-size cyanobacteria whose fluorophors are chlorophyll and phycoerythrin. Their sources are wind-transport from shallow Arctic and Antarctic ocean waters onto the growing icepack. The group speculates that one can trace mutations of cyanobacteria over more than 106 generations in the ocean by analyzing changes in their genomes as a function of depth in glacial ice.

The completion of IceCube in January 2011 will provide new opportunities in particle astrophysics that exploit the IceCube hot-water drill and the ability to reject backgrounds of charged particles within the IceCube volume. Examples include a proposed search for new supernovae extending to a distance of 10 Mpc using a large array of PMTs in ice; flavor oscillations of neutrinos produced in Earth’s atmosphere; and a search for the dark matter wind.

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