A new project for high-resolution ice core analysis at Colle Gnifetti, Swiss-Italian Alps, in comparison with historical climate records

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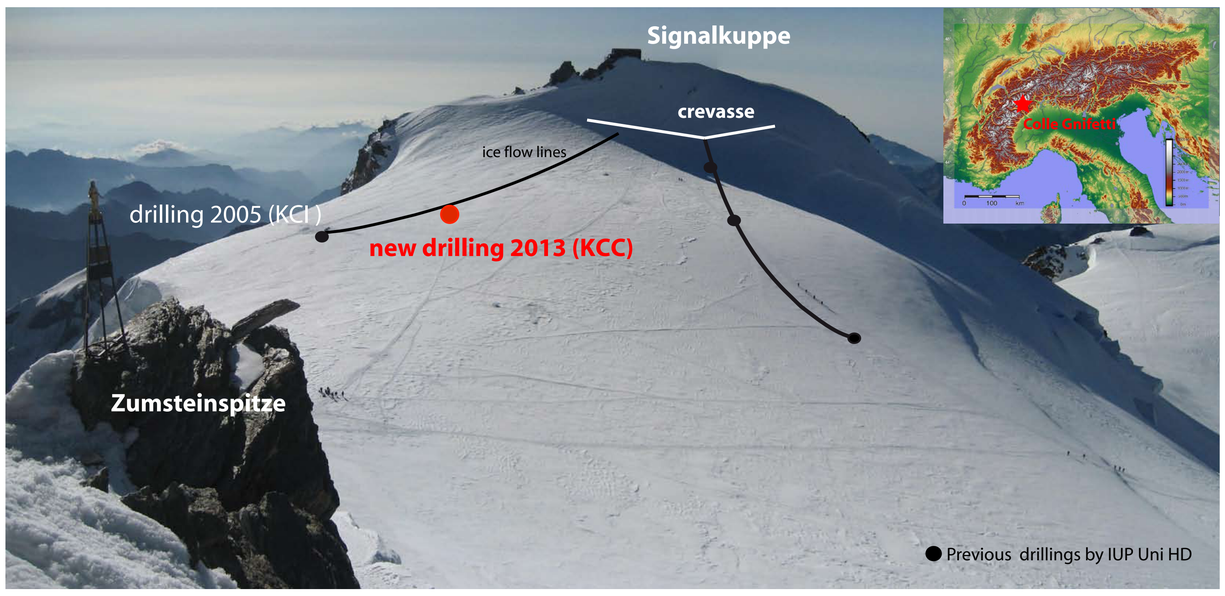
Abstract

Ice core studies performed on mountain glaciers in mid-latitudes can provide paleoclimate records closer to human settlements that are complementary to polar ice cores. For the European Alps, the small-scale Colle Gnifetti glacier saddle (4450m asl, Monte Rosa, Swiss-Italian Alps) is the only ice core drilling site with an annual net snow accumulation low enough to archive multi-millennial records in spite of ice thickness barely exceeding 100 m. So far, however, the interpretation of paleoclimate records from an existing Colle Gnifetti ice core array has been hampered by two primary dating concerns: (i) annual layer counting gets increasingly ambiguous beyond approximately 100 years and, (ii) age uncertainty prevents clear linkage of volcanic and mineral dust horizons to historical records. Both challenges are fundamentally connected to the rapid thinning of annual layers, and may thus be tackled by state-of-the-art laser-based impurity analyses at ultra-high depth resolution.

Here we present the first results comparing laser ablation inductively-coupled plasma mass spectrometry measurements (LA) of mineral dust components with previous measurements from continuous flow analysis, already available at cm resolution. The comparison indicates that the LA yields additional high frequency information, potentially reflecting annual signals not resolved by conventional impurity analyses. From LA-based annual layer counting, we aim at obtaining a reliable ice core chronology over the last millennium and possibly beyond. Then and only then can we use the cornucopia of climate ice core signals, particularly the stable water isotope record, for cross linking with historical evidence. Moreover, LA ice core profiling may also be used to study mineral dust events, which may be associated with written accounts of "blood rain," including the possibility of quantifying their frequency of occurrence.

The Colle Gnifetti Ice Core Array



- Typical ice thickness <100 meters; (140 meters max)
- Englacial Temperature: -14° C at 20 meters; ice frozen to bedrock
- Exposed firn saddle at 4450 meters above sea level
  - *Strong wind erosion*
- Mean net accumulation only 10% of annual snow fall
  -0.15 – 0.5 meters/yr (H_2O equivalent)

...it is thus the

unique Alpine drill site for long-term ice core records!

but it also has...

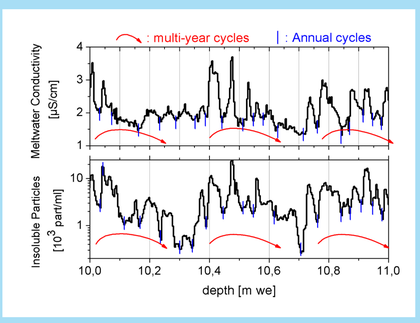
- high spatio-temporal variability in net accumulation

- layer thinning beginning at much shallower depths than at typical polar sites

- strong non-linearity in age-depth relation at small relative depth

The Challenge: Extend Annually Counted Chronology to 1000 yrs (and beyond)

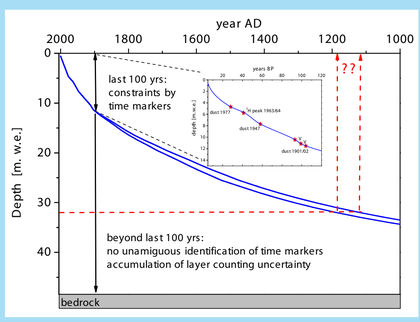
Interpreting ice core records as climate time series requires a reliable age-depth scale



Primary dating tool: Counting of annual layers using summer/winter contrast in impurity profiles

Beyond a few 100 yrs: Conventional cm-resolution analysis does not allow for unambiguous identification of annual layers

Is it possible to improve annual layer counting in deep/old ice core sections through ultra-high resolution impurity analysis?

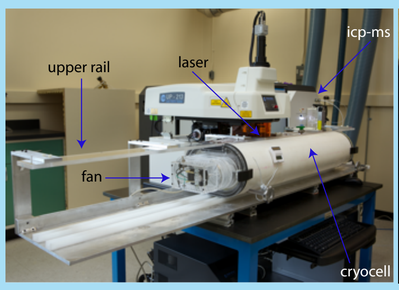


Non-linearity in the age-depth profile hampers identification of absolute time markers needed to constrain dating uncertainties- illustrated here by two blue lines representing alternate dating scenarios.

We will analyze the impurity content of KCC at ultra-high depth resolution by means of an innovative technology developed in the University of Maine W.M. Keck Laser Ice Facility:

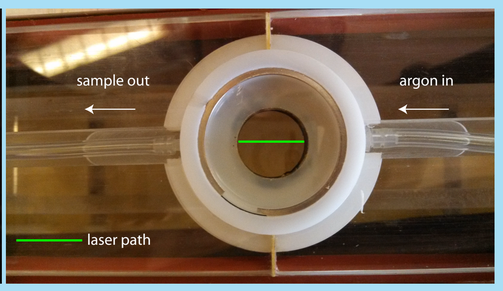
Laser Ablation (LA)
Inductively-Coupled Plasma Mass Spectrometry (ICP-MS)

The Innovation: Laser Ablation Sample Introduction



The LA system consists of a fixed upper and lower rail, a centered ablation chamber and a movable 1 meter cryocell. A servo motor, Kevlar belt, mechanical risers, and an electronic flow meter all coordinated using a programmable logic controller are used to move the cell along the ice and create the required seal.

Cooling of the cryocell is achieved through a recirculating chiller connected at the right end cap to coils of copper tubing that run along either side of the cell. A fan is mounted onto the left end cap to provide a uniform temperature of about -20ºC. The ablation chamber is centered in the fixed upper rail.



The top of the chamber is a round laser window 5 cm in diameter and the bottom opening is ringed with gasket material to form a seal with the ice core. There are inlet and outlet ports at opposite sides of the chamber for the argon carrier gas. The 1064 nm Nd:YAG laser (frequency quadrupled to 213 nm) vaporizes ice prior to introduction into the ICP-MS.

-Elements relevant to climate and anthropogenic activities, including Na, Mg, Ca, Fe, Mn, Al, Cu, Pb, Cd, Co, and As can be measured at the parts per trillion level.

- Method is essentially non-destructive; ice is preserved for future analysis using yet-to-be-invented technologies.

Typical set-up (100 µm beam width, 20 µm resolution) increases the obtainable data points per cm from approximately 1 to 500.

First Results

Before approaching the 2013 core (KCC), the initial stages of our research sought to determine if annual layers could be resolved using impurity profiles from the LA system for a previously drilled CG ice core (KCI, 2005).

- For KCI: Data on impurity content available from previous conventional analysis at cm-resolution

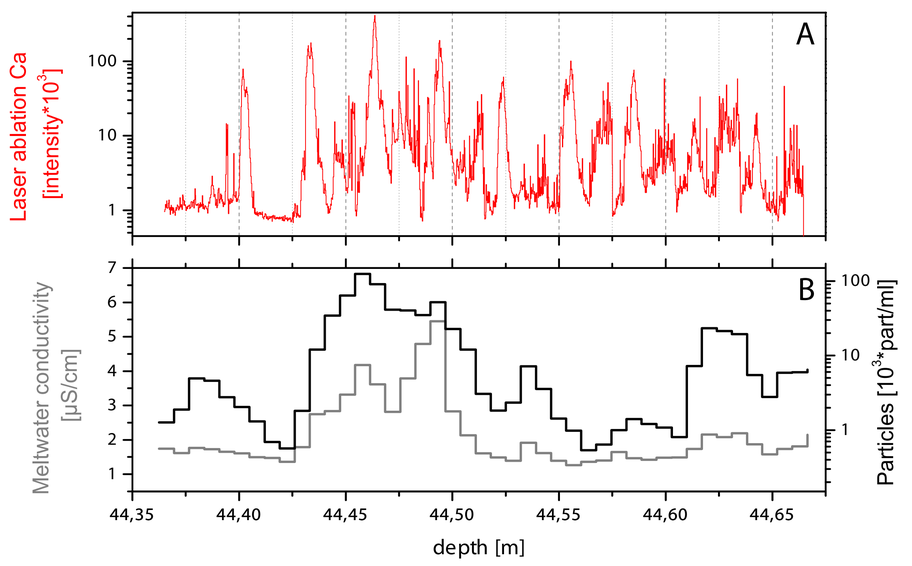
- The continuous records of insoluble particle content and meltwater conductivity have been deployed for dating by annual layer counting

- On the right: Example comparison of existing conventional impurity data (panel B) with high resolution LA measurements of calcium (panel A).

Sample from 70% relative core depth: Annual layers could not be identified in conventional datasets (panel B).

Tentative counting:
14 (± 2) cycles per 20 cm within LA Ca profile (panel A).

Agrees with prediction of annual layer thickness from existing dating hypothesis!

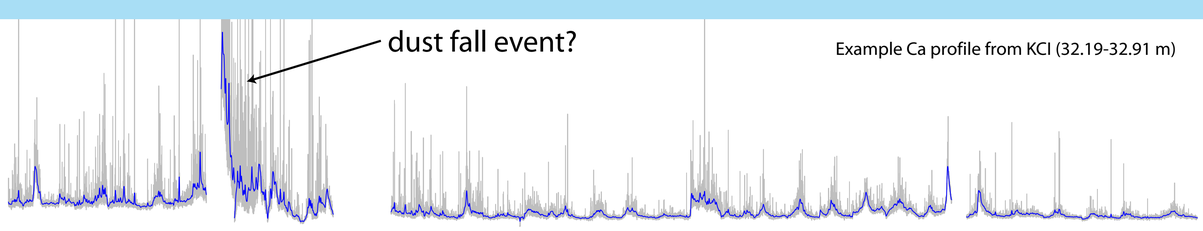


Next Steps

LA-ICP-MS measurement of Ca within the bottom 35 meters and continuous flow analysis of the entire ice core (including Ca) should be completed by Feburary/March 2014.

Comparison of the Ca profiles (which may appear similar to the one below) will be used to teach the evaluator to recognize annual layers within the high frequency LA-ICP-MS data.

Ca will also be used to preliminary identify depths with high impurity concentrations (i.e. volcanic eruptions or Saharan dust falls) that could potentially be used as tie-points for the chronology.



Bridging Disciplines

If a reliable long-term chronology can be established we will explore our ice core climate record in comparison with historical accounts. For the latter we will utilize the Harvard University Digital Atlas of Roman and Medieval Civilization (DARMC). A central question is: "On what time scale can the two records be linked?"

Cenntenial/Decadal: Impact of prolonged warm/cool, dry/wet periods on society building

Multi-Annual/Annual: Evidence for climate impact on famine and disease occurrence. Correlation of climate with changes in length of growing season and times of first harvest.

Multi-Day/Daily: Storm/dust fall frequency, including "blood rains".

A layer of Saharan dust, notable for it's red/brown color, is logged in the KCC ice core.

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