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Colle Gnifetti Ice Core (KCC) Progress Report (Year One)—Arcadia Ice Core Proposal: Initiatives on the Science of the Human Past

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Colle Gnifetti ice core (KCC) Progress Report (Year One)
Arcadia Contract with Harvard

Submitted by the Climate Change institute (CCI, University of Maine)

Table of Contents

Note: (1)This report is a collection of lists that describe the tasks accomplished to date. (2) Examples of some results are included as figures with captions and/or as a summary of key points.

1. Milestones to date

1.1 Drilling: August 2-13, 2013 (Colle Gnifetti, Swiss/Italian Alps)

- KCC GPS coordinates (11.08.2013) N 45.928933 E 7.876267
- Total drilled depth according to logging (including snowpit): 7293 cm

1.2. Ice core processing: September 16-28, 2013 (AWI, Bremerhaven, Germany)

- Deployed new logging of KCC – special care given to alignment of all cuts.
- Measured bulk density of all core pieces.
- Performed dielectic profiling (DEP) measurements with the AWI DEP-bench.
- Performed CT-scans to obtain a high-resolution density record
- Performed Linescan measurements .
- Cut the core according to a pre-determined cutting plan and packed samples for shipment to CCI.

1.3. First working group meeting: February 26, 2014 (Innsbruck, Austria)

- Discussed completed and ongoing measurements.
- Decided future directions.
- Participated in 18th Apline Glaciology Meeting to discuss initial results.

2. Preliminary results

2.1 Tritium-peak

Maxiumum at 20.87 m abs or 11.20 m w.e., corresponds to a mean net accumulation of 22.4 m.w.e./a.

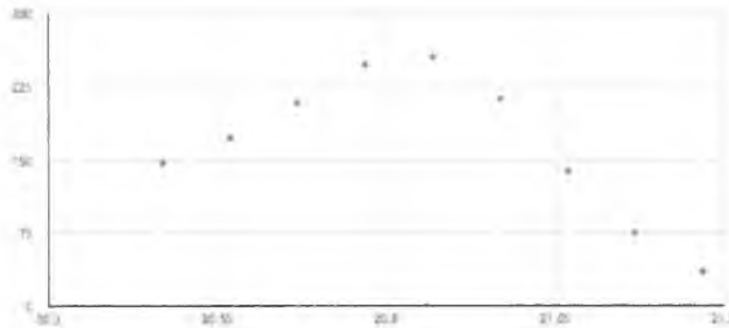

Figure 1: Results from high resultion tritium analysis. Tritium-Units on y-axis, absolute depth on x-axis.

2.2 Micro radiocarbon dating of ice

Objectives accomplished since February:

- Gas Ion Source in Mannheim now running on a routine base.
- About 25 samples of different sizes measured thus far.
- Successful measurements of samples down to 4µg carbon (carbonates, foraminifera).
- Results coincide with expected values within range of error and are reproducible.

Work in progress:

Analyses of Saharan dust from Colle Gnifetti

- Filtration of three snow samples collected at Colle Gnifetti 2013 done.
- Radiocarbon measurements pending.

Setup of new ice sample preparation system:

- Online combustion of sample should lead to better extraction efficiency of carbon.
- System was broken, fixed now, will be reinstalled as soon as possible.
- Lastest tests were promising, efficiency and blank measurement were satisfactory.
- Should be operational soon after minor repairs.

Verification of method with selected KCI samples:

Four selected samples of "known" age from KCI will be processed with the old setup and dated to verify the method.

If POC dating of selected samples successful:

- Process deeper KCI samples.
- Develop sampling strategy for KCC.

- KCC samples could be started in June or July, depending on methodology progress.

2.3 CFA data and basal ice

March 5th: Small CFA-wrap up and basal cutting campaign.

Transport of Heidelberg CFA equipment and discrete CFA samples to IUP HD.

CFA Data:

- Ongoing discussion about preliminary CFA data interpretation using principal component analysis.
- Extraction of timing information for the continuous isotope data is complete.
- Discrete sampling information is not yet done (work not yet started).

Stable isotope data:

- Data processing still to be done.

Discrete samples for ion chromatography:

- Samples repacked and successfully shipped to CCI for measurement of SO_4 by ion chromatography. Important for identification of volcanic eruptions as constraints for annual layer counting.
- Measurement of 38 additional trace elements by liquid ICP-MS by CCI.

Basal section:

- Cutting of the basal section of the CFA piece into 2 samples at 1.5 cm depth intervals.
- Section 1 shipped to CCI, Maine, section 2 remains in Bern for isotope analysis.
- Isotope samples will be measured by the Bern Leuenberger Group (likely including delta ^{17}O).

2.4 Preliminary age-depth relation from annual layer counting

Datasets: CFA-data considered for annual layer identification and counting includes: calcium, dust, dust (logarithmic scale), ammonium and meltwater conductivity.

Software utilized: Ice Core Dating software developed by CCI
http://climatechange.umaine.edu/Research/software/icd.html

Counting strategy: Start by training the counter's eye. Count annual layers within the last 100 years, check for consistency with dust horizons, but most of all the tritium peak. Develop strategy to identify annual layers using multiple impurities.

Annual layer counting within the last 100 years:

When dust and ^3H horizons were not used as strict tie points - counting is in agreement with these markers by +/- 1-2 year.

Within the last 100 years the datasets reveal:

- The presence of multi-year oscillations known from previous ice cores.
- Distinct periods of very low-level impurity concentration potentially corresponding to the deposition of winter snow. These events are seen throughout the entire core.

Initial results:

- We have a first draft chronology that needs further refinement. This should include an uncertainty estimate using different counting scenarios with cross-checking of the counting.
- The results offer an estimate of annual layer thickness and interesting target sections for comparison with CCI laser data.
- The annual layer counting worked equally well using ammonium as well as logarithmic dust, an important result with respect to the dating attempt of the 2005 ice core.
- Counting would greatly benefit from additional tie-points, most of all by identification of volcanic events in sulfate data forthcpming from IC and ICP-MS.

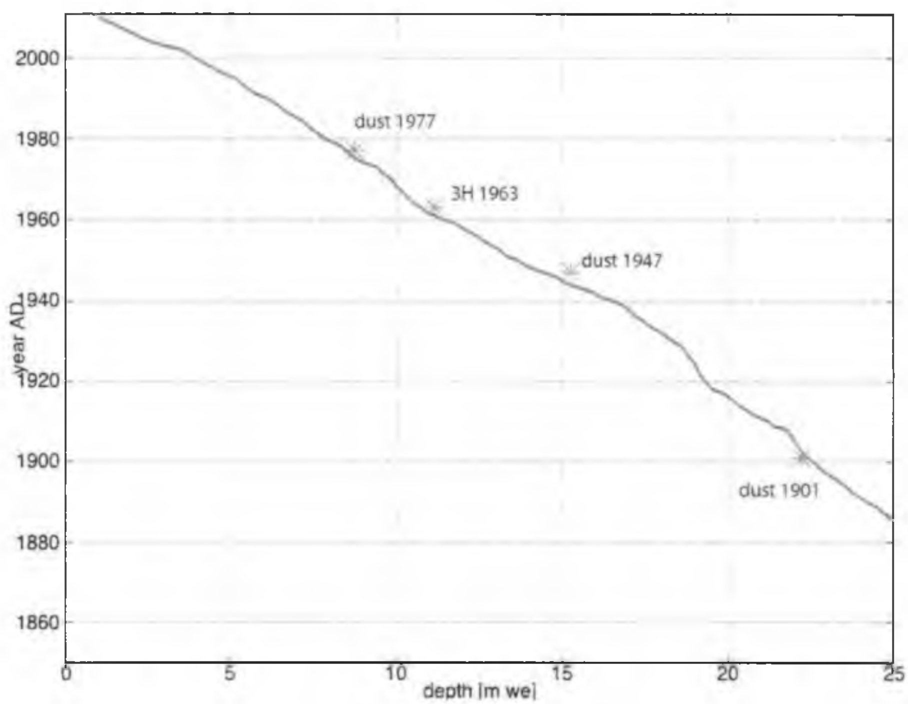

Figure 2: The last 100 years of age-depth relation from annual layer counting in CFA impurities (red curve). The age offset to absolute horizons (blue stars) is 1-2 years maximum. The fact that this curve has a non-analytic shape, e.g. has bends, inflection points etc. is typical for Colle Gnifetti ice cores, not least a result of annual layer thickness variability with depth (see Figure 3)

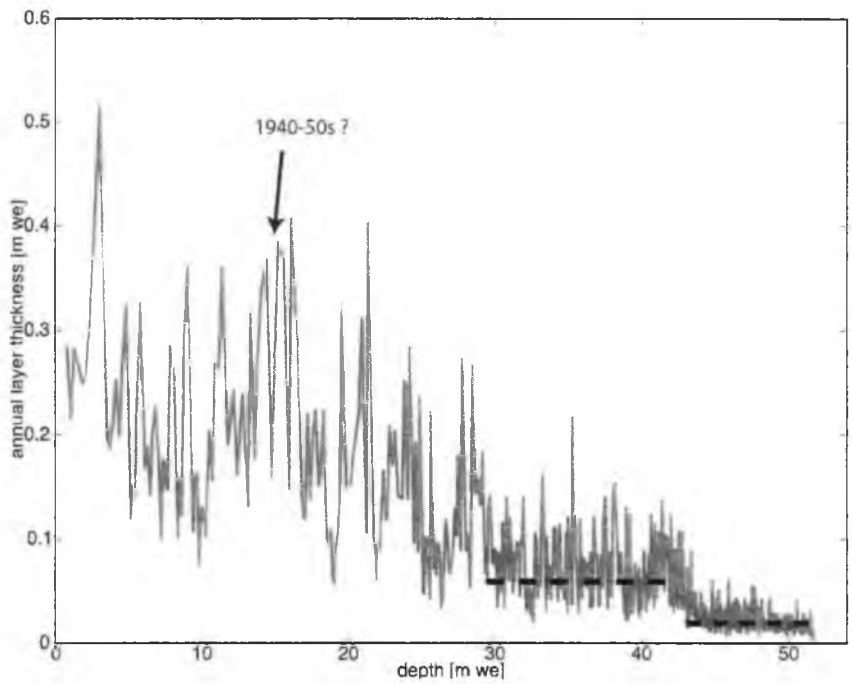

Figure 3: Annual layer thickness versus depth derived from annual layer counting in CFA impurities. Warm summers during the 1940s-50s are indicated as potentially leading to systematically larger annual layers due to increasing snow deposition. Dashed black lines show two plateaus with a sharp transition in between. This effect has been observed with the previous KCl cores and thus far has been interpreted as a potential bias from counting multi-year oscillations.

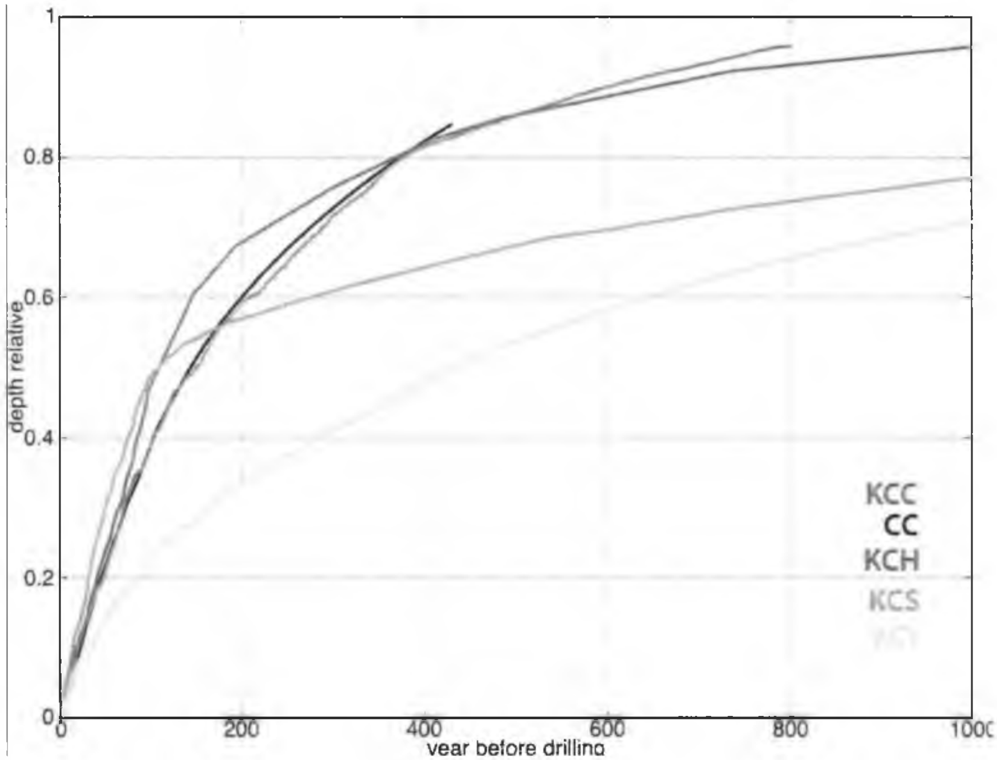

Figure 4: Preliminary KCC age scale compared with existing datings from previous Colle Gnifetti ice cores, on a relative depth scale (0= surface, 1= bedrock). Note how the KCC age scale is similar to CC, which was used as a model-core in net accumulation to select the KCC drilling site. Also note that any values for KCC beyond the last 200 years are highly uncertain and must be regarded with great caution at this stage.

2.5. Dielectric profiling and ground-penetrating radar

Dielectric profiling (DEP)

- Annual layering has been successfully identified in the dielectric signal, used for additional consistency check with CFA based counting within the last 200 years.
- Separation of dielectric signal into density- and conductivity-related information by means of DECOMP algorithm (Frank Wilhelms, AWI) still to be done.
- Resulting density signal to be assessed against XCT density.
- Resulting conductivity signal to be assessed in more detail against CFA impurities.

Ground-penetrating radar (GPR)

- GPR data measured in November 2013 by Achim Heilig & Christoph Mayer to be processed with AWI software.
- Focus within this project: Flowline profile linking KCI and KCC, to link core dating and obtain information on upstream net accumulation variability.
- Basis for simple flow modeling.

2.6 Laser ablation ICP-MS measurements and data interpretation

Instrument characteristics and data treatment:

- Various experiments were designed and conducted to demonstrate reproducibility and to investigate ultra-high frequency signal components.
- Reproducibility is high, both when ablating the same line several times and when ablating multiple parallel lines (Figure 5).
- For initial viewing ultra-high frequencies are removed from the data by SSA filtering.

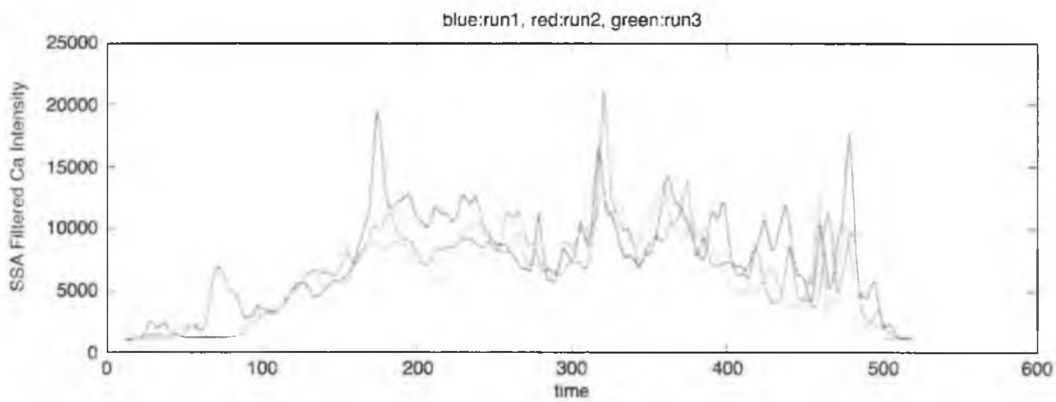

Figure 5: Demonstration of lateral reproducibility. Multiple lines were run parallel to eachother on a block of artifical ice. Ultra-high frequencies were removed by SSA filtering.

First results for the Calcium CFA – laser compariso

- We are focusing first on obtaining a complete Ca++ profile, i.e. measuring one element, Ca, at a time only, for all LA-ICP-MS samples for quality assurance.
- Thus far, core sections 49a-58 and 75b-80 have been measured, corresponding roughly to 5m and 3m respectively.
- The CFA Ca-signal fits well with the underlying general trend or baseline of the LA Ca-signal (Figure 6).

Future steps:

- First results seem promising regarding the identification of annual signals in thr LA signal by comparison with CFA data (Figure 6).
- The shallowest sections measured are just around 30 m.w.e., where annual layer counting may already start to be biased in CFA (Figure 3).

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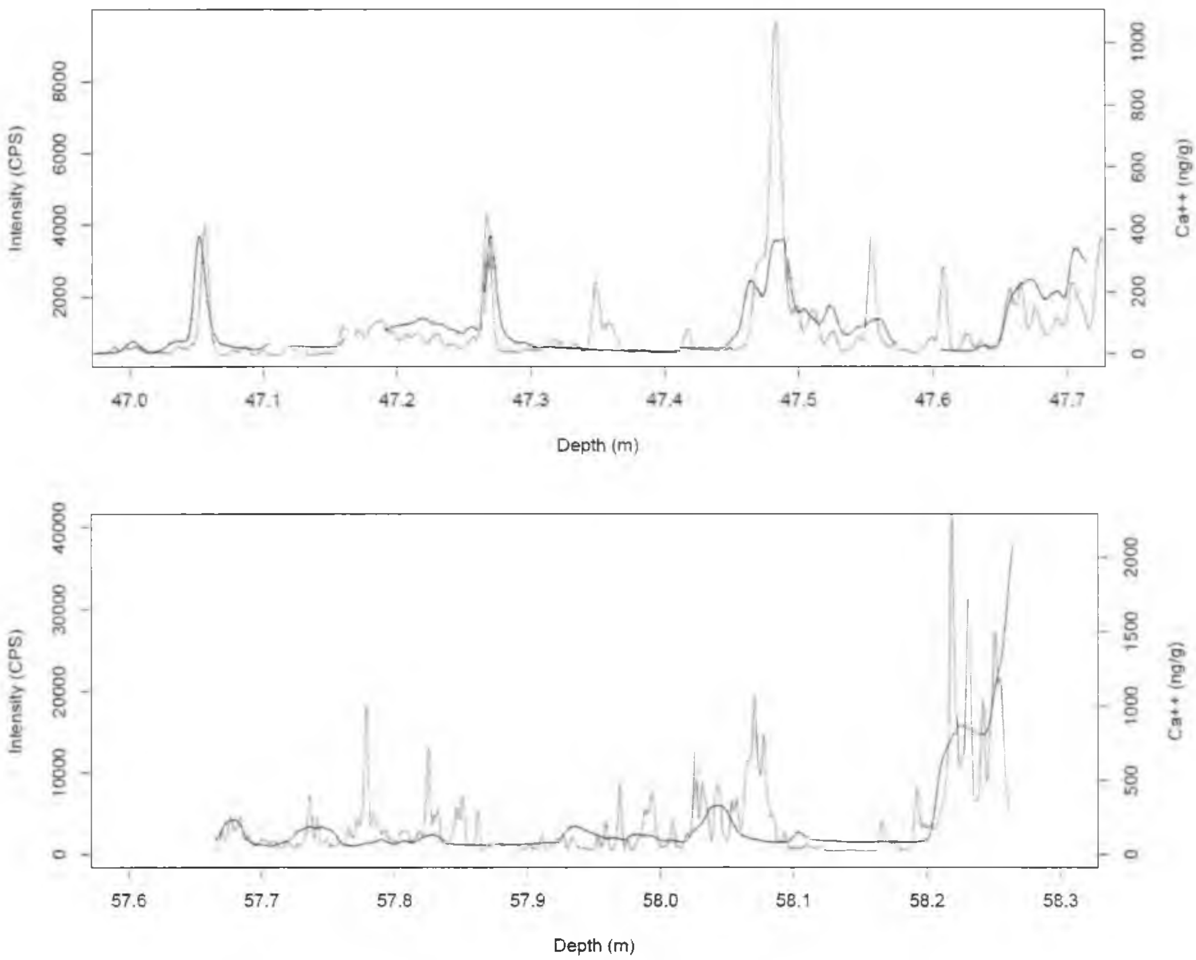

Figure 6: Two examples of the comparison between CFA Ca-signal (black line) and LA Ca-signal (red line). Note that for the upper section, both curves display the same peaks (except for one exception around 47.35m). For the lower section the black line follows the underlying baseline of the red curve.

2.7 Annual layer counting using laser ablation Ca data and CFA Ca and NH4 data

- Laser ablation profile completed thus far - 43.9904 – 49.323 m absolute, 29.076 – 33.782 m abs
- Mean annual layer thickness for this interval from CFA counting: 0.072 m w.e. This corresponds roughly to absolute depth since this interval is below the firn-ice transition (approx. 35m) – equivalent to ~14 years per meter.

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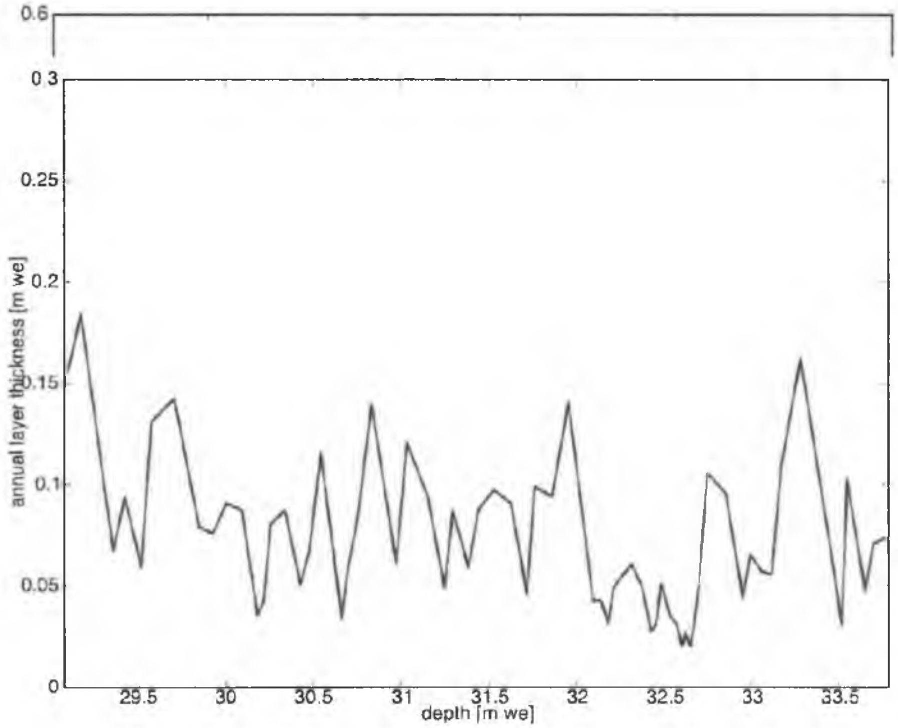

Figure 7: Annual layer thickness from CFA annual layer counting. Top: Compete profile with the depth interval measured by LA marked by a black box. Bottom: Close up for the depth interval measured by LA.

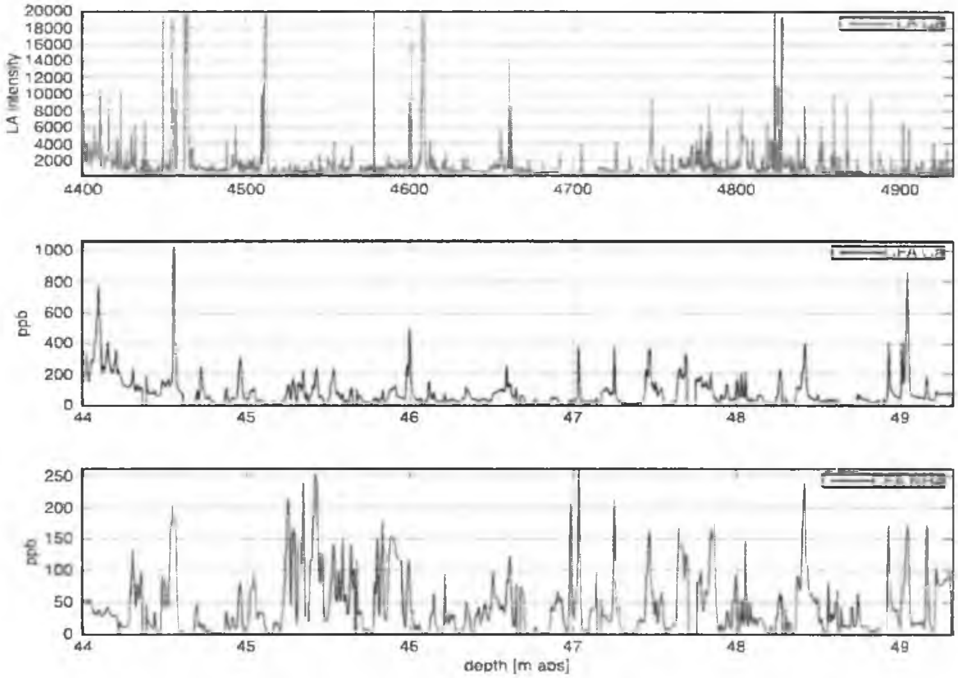

Figure 8: Laser ablation Ca signal (red) vs CFA Ca (black) and NH_4 (blue). The CFA NH_4 was one of the components used for annual layer counting. CFA Ca has not been used until now.

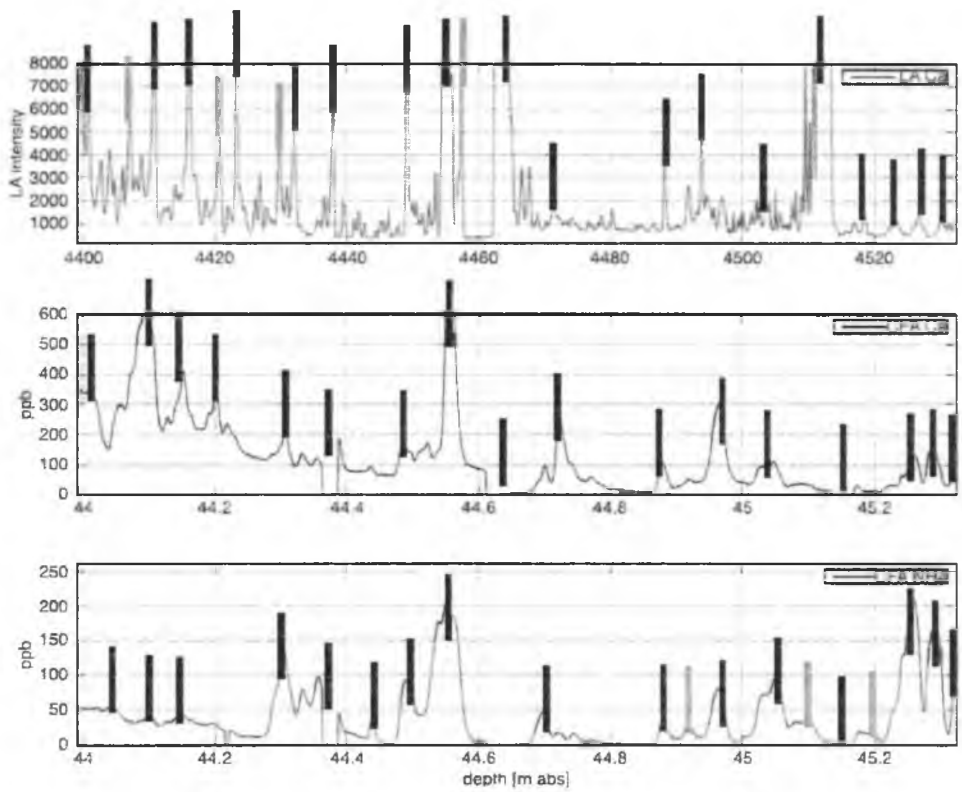

Figure 9: Example of a depth section (1 out of 4): Counting of annual layers is indicated by black lines, potential additional years in an optimistic counting scenario are indicated as grey lines. Results: CFA: (16+4)

years, LA: (18+4) years, or 12 years/m and 13.5 years/m, respectively.

Results:

- The CFA Ca signal appears feasible for annual layer counting, with roughly the same results as counting using CFA NH_4.
- The LA Ca signal displays oscillating patterns and frequent peaks that can be counted with minimal ambiguity.
- The results from annual counting in CFA data and the LA Ca signal are in agreement within counting uncertainty. Detailed results from 4 depth segments follow:
  - 44 – 45.35 m: CFA: (16+4) years, LA: (18+4) years, or 12 years/m and 13.5 years/m, respectively
  - 45.35 – 46.65 m: CFA: (22+3) years, LA: (21+4) years, or 16.5 years/m and 15.8 years/m, respectively
  - 46.65 – 48 m: CFA: (22+3) years, LA: (18+4) years, or 16.5 years/m and 13.5 years/m, respectively
  - 48 – 49.3 m: CFA: (19+6) years, LA: (21+3) years, or 14.3 years/m and 15.8 years/m, respectively
- The foregoing will be further validated and cross-checked for additional upper core segments.
- For lower sections, the main question is at what depth the CFA and LA cyclicities start to decouple, i.e. The LA signal shows a number of distinct peaks with the CFA data only resembling the overall baseline or trend of the LA signal. This pattern has already been observed at lower segments around 58 m abs.
- The identification of annual layers is the primary basis for future investigation into potential sub-seasonal information contained in the LA data.

2.8 Age estimates

- CFA and LA analysis reveal a large Ca anomaly at 58.3 meters depth (41.3 meters water equivalent – m.w.e.). The Ca peak is the largest observed in all 73 meters.
- A similarly anomalous peak found in the 2005 Colle Gnifetti ice core (KCI) at 38.1 m.w.e. has an estimated age of 538 AD.
- Greater than 10 meters of ice remain below this peak, in which preliminary annual layer counting of CFA data suggests at least 30 years per meter (Figure 7 - Top).
- Multi-year oscillations are known in the CFA data at these depths, thus the number of years per meter will increase when the more highly resolved laser Ca is counted.

2.9 Potential sub-seasonal/storm-frequency signals

- When a chronology has been determined using all available data, Spaulding and Bohleber will return to the raw data to assess potential sub-seasonal and storm-frequency data (Figure 10).
- The core will also be re-scanned for a variety of elements relevant to climate (Na, Mg, K for atmospheric circulation; Fe, Si, S for dust and volcanics) and anthropogenic activities (Fe, Pb and Cu for smelting).
- Special attention will be given to periods of historical interest, as identified at a collaborators meeting with Harvard colleagues in July 2014.

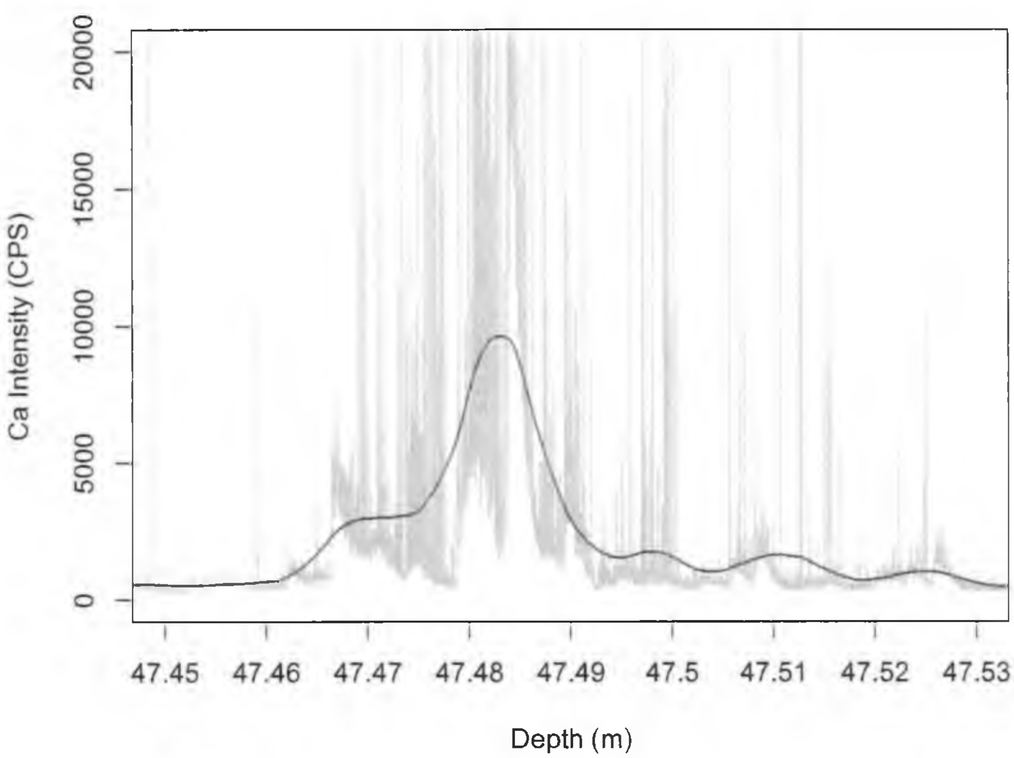

Figure 10: Sub-seasonal oscillations and storm events in the raw (gray) LA Ca signal. Note that within each peak resolved for the highly smoothed LA Ca-signal (red line), which was shown to be analogous to the CFA Ca signal in Figure 6, there are multiple peaks in the raw data.

2.10 Physical properties / crystal orientation fabric analysis

Results:

- Thus far only raw data i.e. pictures from thin sections and a few Schmidt plots of whole 10cm-sections (see "KCC Working Group Meeting - 26.02.14"), nothing new in terms of plots or numbers.
- Ongoing discussion with Tobias Binder (Uni Heidelberg) about the statistical methods to analyse the thin sections, including extensive discussion and introduction related to the analyzing tool he developed; a new option to combine LASM und fabric analyzer pictures for clearer distinction of grain boundaries and thus improved statistics.

Further steps:

- Produce plots which show the low resolution development within the lower half of the core (ice).
- Experiment with different ways to statistically analyze the pictures in high i.e. cm-scale resolution.
- Further measurements at AWI in the upper part of the core (firn) are planned for early July.