Solar Variations and Climate Change: The View from Ice Cores

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How much Sun is in the Ice?
Thanks

- Eawag-Group
- AMS-Group ETH Zürich
- SORCE
Outline

- Solar Variations: Direct Observations
- Solar Variations: Indirect Observations
  - Cosmogenic Radionuclides
- Ice as an Archive of Solar Variation and Climate Change
- Some Results
- Summary and Outlook
Sunspots

![Graph showing the number of sunspots over the years from 1600 to 2000. The x-axis represents the years, and the y-axis represents the number of sunspots. The graph is labeled with the initialism SIDC.]
Solar Variability and Cosmic Rays

![Graph showing the relationship between sunspot number and neutron count rate over time, with two datasets labeled SIDC and CLIMAX.](image)
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Cosmic Rays in the Heliosphere
Cosmogenic Radionuclides: Production & Transport

Galactic cosmic rays

- Secondary particles
- Nuclear reactions
- Production of cosmogenic radionuclides
- Transport & deposition
- Storage in archives (ice)
10Be Information from Cosmogenic Radionuclides
Mean Atmospheric Residence Time

- **Pressure [hPa]**
  - 1000, 100, 10, 50, 0, 50, 100, 1000

- **Latitude**
  - South, 0, North

- Mean Atmospheric Residence Time
$^{10}\text{Be}$ Deposition Flux 1986-1990

Be-10 total deposition [at/m$^2$/s], Ave 1986-1990

Heikkilä, 2007
$^{10}$Be expected versus measured

Usookin et al. (2005) JGR 110
Sunspots and Φ (1600 - 2000)
11-y Schwabe cycle

Berggren et al, GRL, 2009

10Be Dye3 concentration (8-16y)
10Be NGRIP concentration (8-16y)

Dye3
NGRIP

1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950
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Archive Ice
Formation of an Ice Sheet
\( \delta^{18}O \) GRIP versus Depth and Age

**Graph Details:**
- **Y-axis:** \( \delta^{18}O \)
  - Range: -45 to -30
  - Values: -45, -40, -35, -30
- **X-axis:**
  - Depth: 0 to 3000 m
  - Age: 0 to 250 ka
  - Scale: 50 m per tick mark
- **Legend:**
  - Warm
  - Cold

**Graph Description:**
- The graph shows the variation of \( \delta^{18}O \) with depth and age, indicating changes in temperature and possibly climate conditions over time.
GRIP Ice Core

Dome GRIP
1990-1993

NGRIP

GRIP

Ice Core

Dye 3
Detection

Decay counting technique: 10 tons of ice
AMS technique: <1 kg of ice
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Solar Modulation Potential $\Phi$

![Graph showing Grand Maxima and Grand Minima over time](image)
Total Solar Irradiance (TSI)

Steinhilber et al., GRL, 2009

TSI [Wm$^{-2}$]

Age [cal y BP]

low-pass 100 y
low-pass 500 y
Powerspectrum $^{10}$Be (GRIP Ice Core)

Period

Amplitude (rel. units)

- 950-y Eddy
- 87-y Gleissberg
- 208-y de Vries

Be-10 (300 – 9300 y BP)
87-y Gleissberg Cycle

Be-10 bandpass filtering (cut-offs: 1/97 1/77)

Year

-0.1
-0.05
0
0.05
0.1
8000 6000 4000 2000
Solar Variation (TSI) and Climate Change (Asian Monsoon)

Steinhilber et al, PNAS, 2012
Wang et al, Science, 2005
Evidence from glacier (Aletsch)

5.9.2009
Length of the Aletsch Glacier

Hydrologischer Atlas, H.P. Holzhauser
Holzhauser et al., Holocene 15(2005)789
Schnidejoch (2760 m)

Neolithic  Bronze  Roman

Age [cal y BP]

[S Wm ^{-2}]

low-pass 100 y

low-pass 500 y

Steinhilber et al., GRL, 2009

Schnidejoch (2760 m)
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Summary and Outlook

- **Grand Minima**
  - ~20 per 10,000 y
  - 70-110 y duration, cluster
  - Dynamo running

- **Grand maxima**
  - ~all instrumental information: active Sun
  - long-term periods: 87, 104, 150, 208, 506, 950, 2200-y cycles
  - stable periodicities, variable amplitudes
Prediction of past 500 y intervals
Predictions of future 500 y

Steinhilber & Beer, Prediction of solar activity for the next 500 years, JGR, 2013
Kauri trees: $^{14}$C back to 50,000 BP

Thanks!
Literature