Active geophysics on Ekströmisen and Halvfarryggen

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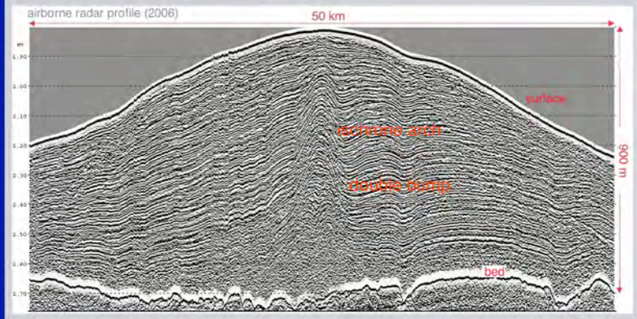
Abstract

Halfvarryggen is a small ice dome bordering the catchment area of Ekströmisen (figure →). It is a candidate for drilling one IPICS 2k/40k ice core. Near the actual dome, three ice divides merge in a triple point. Halvfarryggen's internal structure has been imaged with airborne radio-echo sounding (RES) in the past years, which indicate upwarping internal layers, so-called isochrone arches (or partly Raymond bumps), which develop into a double bump at larger depths (figure ↓). Modelling studies (Martin et al., 2009) indicate that the crystal orientation fabric (COF) at larger depths at ice domes like Halvfarryggen should be highly anisotropic. As changes in COF not only change the dielectric permittivity, but also the acoustic impedance contrast, such changes should also be detectable with seismic methods. We present an overview and preliminary results of a geophysical LIMPICS campaign at Halfvarryggen in 2009/10, involving reflection seismics, shallow ground-penetrating radar (GPR) and other glaciological studies. Main scientific goals were to detect internal reflection horizons along a profile nearby the ice dome with seismics and GPR, image the internal layer architecture along hexagons crossing all three ice divides, detect the ice-bed interface and image the upper tens of meters of the underlying bedrock.



↑ Cross-section through Halvfarryggen at the dome position. Displayed is the differentiated airborne-radar profile 063102 (see map sketch ↗) corrected for elevation, recorded at 150 MHz with a 60 ns pulse. The profile runs across the dome from SSW to NNE. Internal layers are visible over the whole ice thickness, with a 5 km wide isochrone arch right at the dome position. At about 50% of the ice thickness the isochrone arch splits and forms a double bump at larger depths.

Goals 2009/10 field season:

Neumayer III & PALAOA:
- hhhuuummm vs. boom – vibro- vs. explosive seismics to establish source calibration & vibroseis suitibility
- quantitative basis for future environmental evaluations of seismic surveys with calibrated hydrophones at PALAOA

(see poster by Kristoffersen et al., this session CR1.3)

Halvfarryggen:
- radar profiles: image isochrone geometry to deduce ice-dynamic properties
- seismic profiles: does crystal orientation fabric change vertically?

(see talk by Hofstede et al., this session CR1.3)

Background

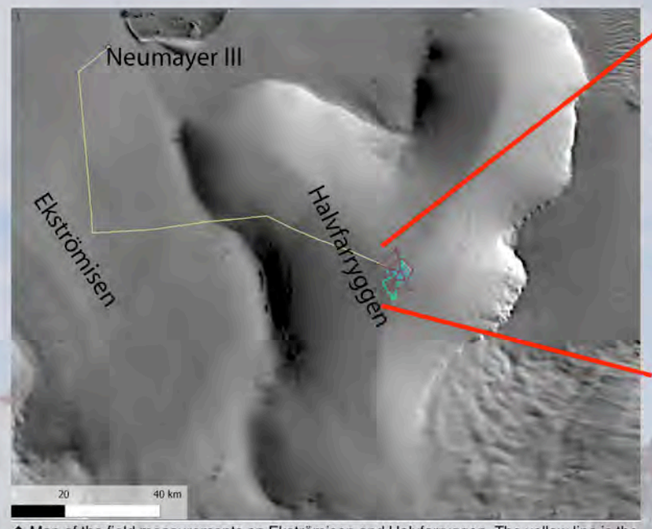
What is LIMPICS?
- "Linking micro-physical properties to macro features in ice sheets with geophysical techniques"
- DFG Emmy Noether Independent Research Group

LIMPICS objectives:
geophysics on ice – physical properties of ice, bed, ...
→ data assimilation in flow models (boundary conditions)
→ estimate property distribution without ice cores

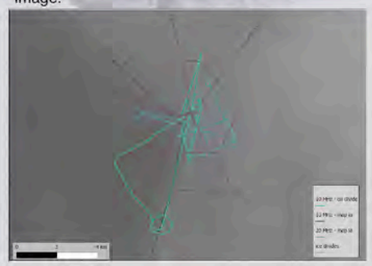
What for?
Improve understanding of . . .
- ice dynamics
- mass balance
- ice-core interpretation

Why Halvfarryggen?
- potential IPICS 2k/40k drill site:
  - high accumulation rate, Atlantic sector
  - complementary pre-site survey
  - ice dome with known isochrone arches
- interesting ice dynamics: anisotropy?
- boundary of Ekströmisen catchment
- complete sheet–shelf system observable over 150 km

Measurements: within four days instead of three weeks:
- 1 km explosive seismic profile, single fold coverage
- more than 100 km of GPR data on Halvfarryggen
- GPS measurements for surface velocities, strain figure
- kinematic GPS for surface elevation
- servicing IMAU's AWS 11
- one firn core

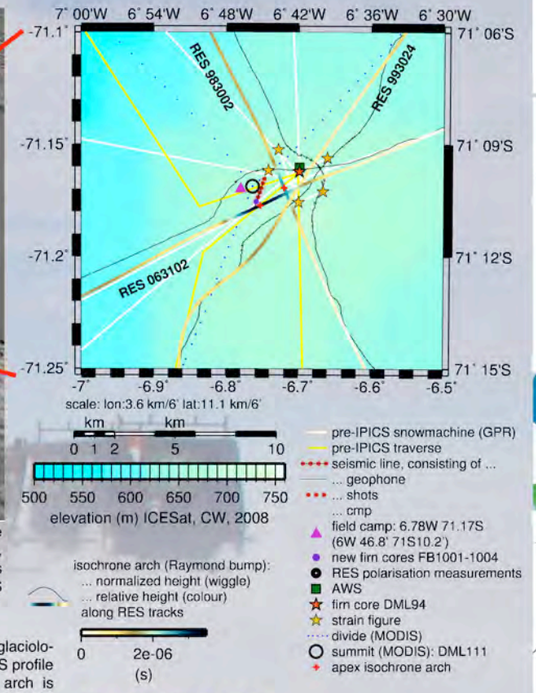


↑ Map of the field measurements on Ekströmisen and Halvfarryggen. The yellow line is the traverse route from Neumayer III to the dome, which has been measured with GPR. Blue, brown and green lines show the GPR profiles obtained around the dome. Ice divides merging at the dome are clearly identifiable by changing shades of gray in the MODIS image.



↗ Sketch of available geophysical and glaciological data. On top of each airborne RES profile the relative height of the isochrone arch is plotted in color code and its normalized height is shown as wiggle along the profiles (pre-IPICS: 2006 season).

← Close-up of measured GPR profiles overlaid on MODIS satellite image. The center corresponds to the dome position, where the three ice divides (black) meet.



Instruments

Ground-penetrating radar
- damped dipole antennas, frequency range 1-5 MHz
- Narod & Clarke transmitter, freely running
- data acquisition with storage oscilloscope
- trace spacing about 10 m
- internal layers observable to about 300 m depth
- ice thickness observable to about 900 m at 1 MHz

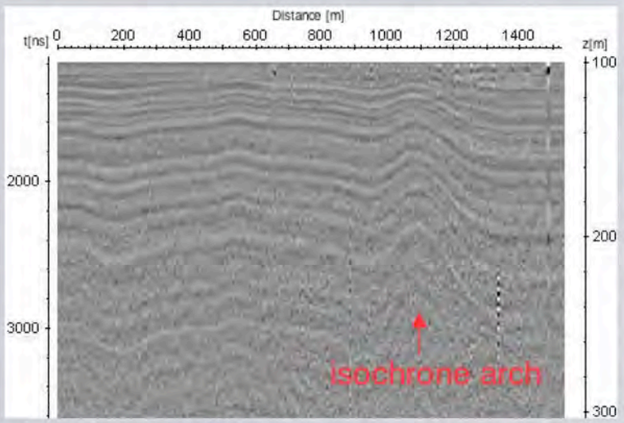
Seismic recording
- GEOMETRICS 24 channel Strataview RX 24 Bit exploration seismograph
- sample rate 500 ms
- 24 single-component vertical geophones at 10 m increment
- combining two shots with 25 m and 265 m near offset yields total of 470 m, 48 channel recording

Explosives
- 250 g Pentolite (PETN-TNT mixture)
- borehole depth 8-10 m, established by using an ice-core drill

Acknowledgments
Fieldwork for these investigations has kindly been enabled by the LIMPICS project financed by DFG grant EI 672/5-1 to Olaf Eisen and the Alfred Wegener Institute. We thank all our logistic and scientific colleagues at the Neumayer III station for their valuable help during the difficult time of the field season. Without their support the measurements would not have been possible.

Halvfarryggen Major Results I: isochrone arches under each ice divide

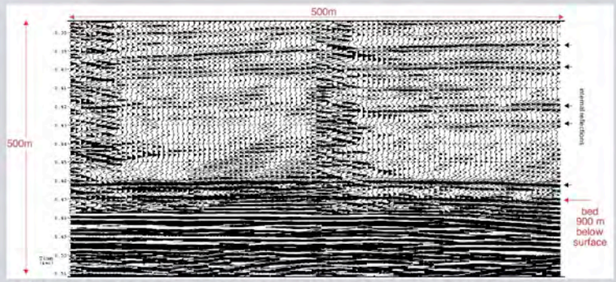
GPR survey indicates isochrone arches (cupola) up to 100 m below surface (figure ↓)
→ dome likely stable over characteristic time scale
- interplay accumulation–dynamics important
- no simple age-depth estimation recommendable



↗ Ground-penetrating radar data across all three ice divides show upwarping layers underneath the ice divide up to 100 m below the surface, as in this example.

Halvfarryggen Major Results II: seismic internal layering

- several internal layers in lower 50% of ice thickness
- continuous over >1 km of seismic profile (figure ↓)
→ changing COF likely
→ ice viscosity anisotropic and function of space
→ comparison with model results desirable



↗ Seismic section derived from the combination of four seismic shots shows continuous internal layering from about 400 m downwards. Visible here are at least five distinct layers.

References
Martín et al., On the effects of divide migration, along-ridge flow, and basal sliding on isochrones near an ice divide, JGR-F, 2009, doi:10.1029/2008JF001025.

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