Direct current (DC) resistivity and induced polarization (IP) monitoring of active layer dynamics at high temporal resolution

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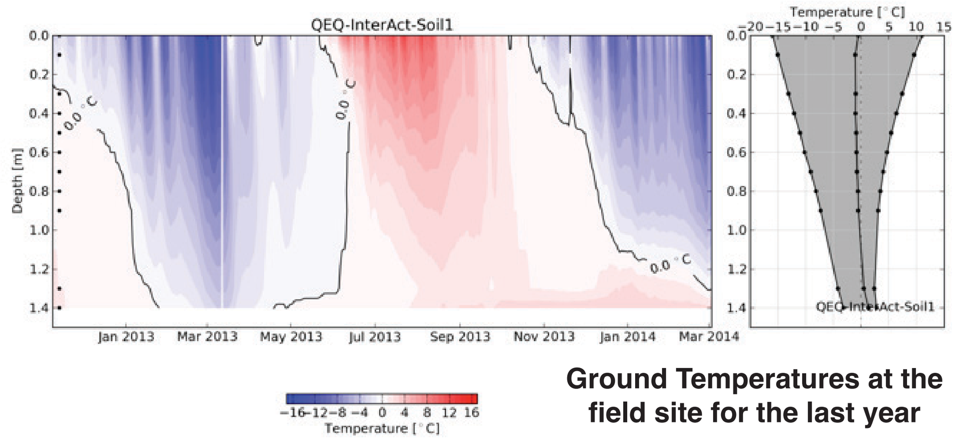
1. Introduction

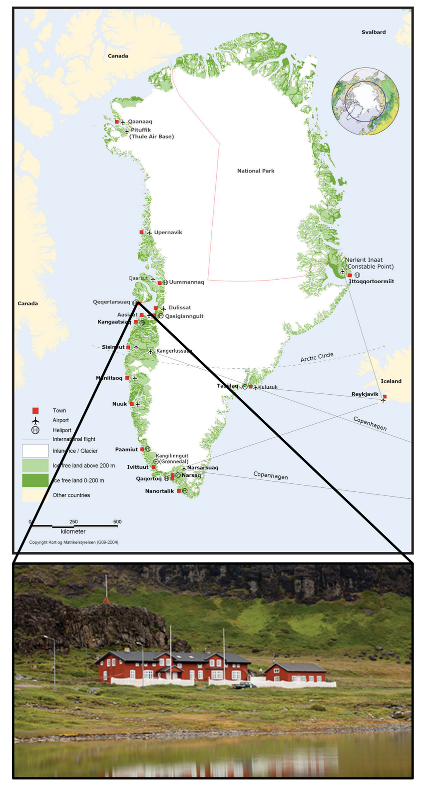
- About 20% of the Arctic is covered with permafrost, which is permanently frozen soil or rock.
- Due to global warming permafrost is thawing over large tracts of the Arctic. Thawing increases the decomposition by microorganisms of the enormous stock of organic material stored in permafrost soil.
- During the decomposition carbon dioxide, methane and other greenhouse gases are released to the atmosphere, potentially increasing global warming.
- The active layer and processes within the active layer play a critical role for the permafrost thawing and the release of greenhouse gases.

2. Disko island field site

- Arctic Station on Qeqertarsuaq, west coast of Greenland (N69°, W53°)
- CENPERM: Center for Permafrost, Copenhagen University
- Mean air temperatures are 7.1°C in July and -16.0°C February
- Vaccinium/Empetrum heath tundra
- Depth to permafrost unknown, no permafrost in the top 3 m



Ground Temperatures at the field site for the last year



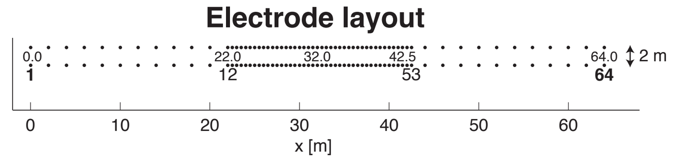
Arctic station and its position in Greenland

3. DC/IP acquisition setup

Acquisition profiles

- 2 parallel lines with 64 electrodes each
- 0.5 m electrode spacing at line center, 2 m outside
- 64 m line length; line spacing 2 m
- 10 x 10 cm steel plate electrodes for high surface area and good coupling

Electrode layout



Monitoring Setup

- Setup for automatic monitoring and remote control (power and internet available)
- Automatic data acquisition implemented in ABEM Terrameter LS
- Data backup to local network storage and synchronization with server at Aarhus University

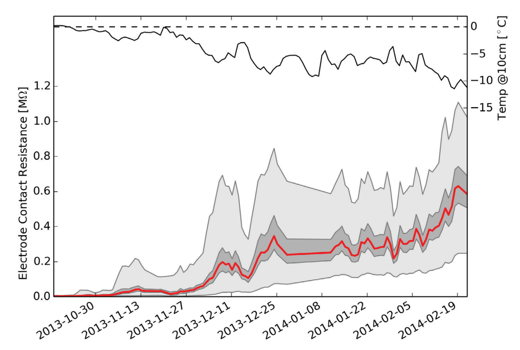
Acquisition scheme

- 244 gradient-type configurations on "short profile", with 0.5 m elecrtode spacing; 6-12 data sets per day
- 866 gradient-type configurations on long profile (using 64 electrodes); 1 data set per day
- Daily electrode contact resistance check

4. Raw data analysis and pre-processing

Acquired data

- 225 days of continuous acquisition
- 1348 data sets, 708.000 DC data points
- Increasing electrode contact resistance with freezing ground
- Reduced injection current when contact resistances are high



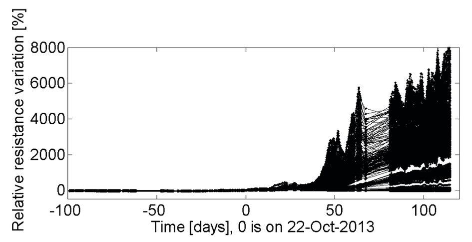
Contact resistances and their increase with time

Data variation with freezing

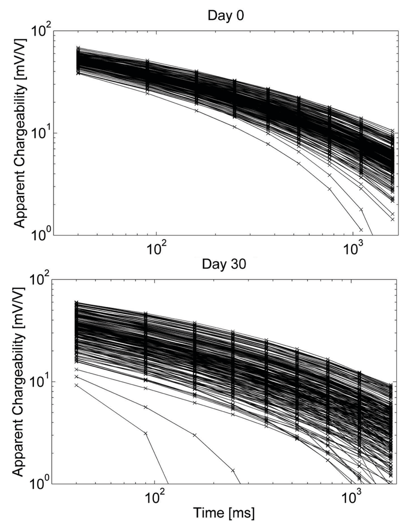
- Strong increase of apparent resistivities for most, but not all configurations
- Decrease of apparent chargeability for many, but not all configurations; wider spread of apparent chargeabilities

Error estimation

- 1 mV absolute voltage error plus
- 2% relative DC error
- 10% relative IP error



Relative variation of resistances with time



IP decays with unfrozen (day 0) and partly frozen (day 30) ground

5. Time domain spectral IP inversion

Full-decay inversion for spectral information

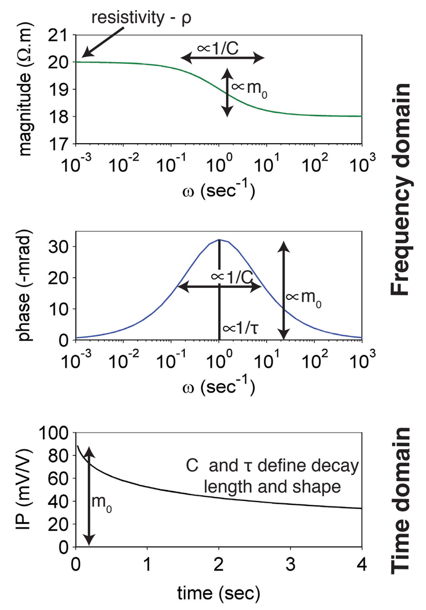
- Simultaneous inversion for resistivity and Cole-Cole parameters using AarhusInv (Fiandaca, G. et al., 2013, GJI **192**, 631)
- Cole-Cole parameters

ρ - resistivity
m_0 - chargeability
τ - relaxation time
C - frequency exponent

complex resistivity $\zeta(\omega) = \rho\left[1 - m_0\left(1 - \frac{1}{1+(i\omega\tau)^C}\right)\right]$

frequency - ω

Illustration of the Cole-Cole parameters



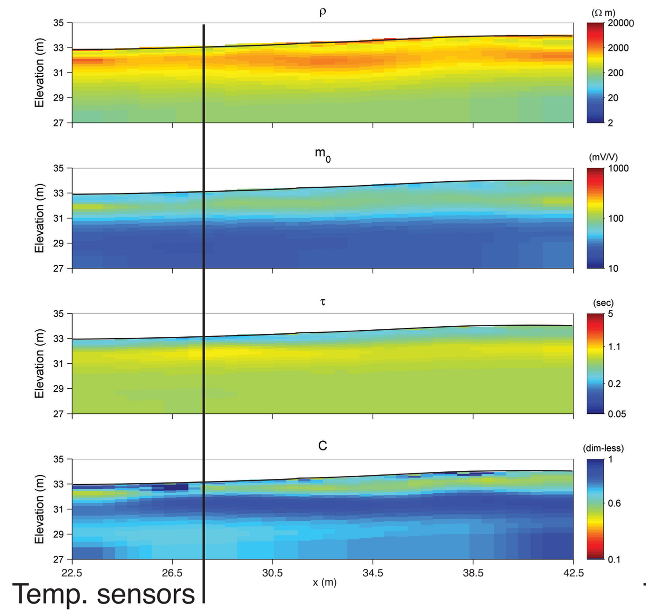
Baseline inversion

- Baseline inversion with pre-freezing data (Oct. 22, 2013)
- High ρ layer at surface and around 1 m depth; low ρ (<200Ωm) below 3 m depth
- High m_0 layer ~1 m depth

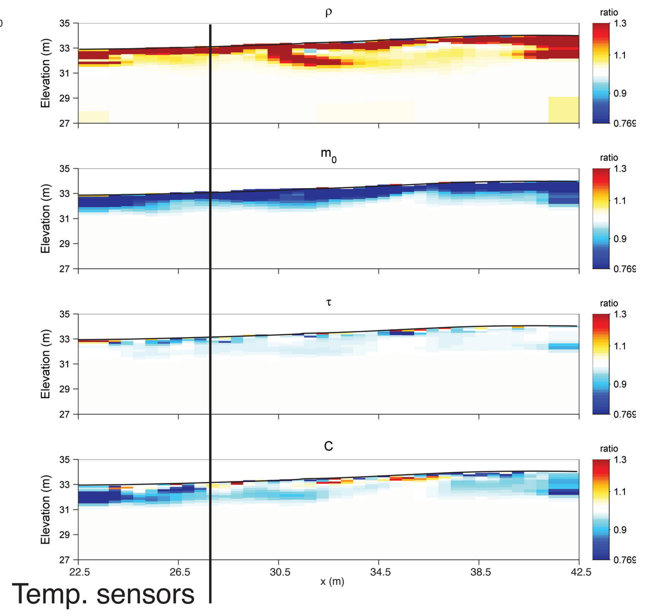
Time-lapse inversion

- Invert for difference from baseline inversion result
- Daily DC inversion from 01.09.2013 - 22.02.2014
- Daily DC/IP inversion until 30.11.2013
- Inversion shows increasing ρ and decreasing m_0 in shallow layer with freezing

Baseline inversion



Time-lapse (day 30) inversion



6. Comparison of DC/IP and temperature data

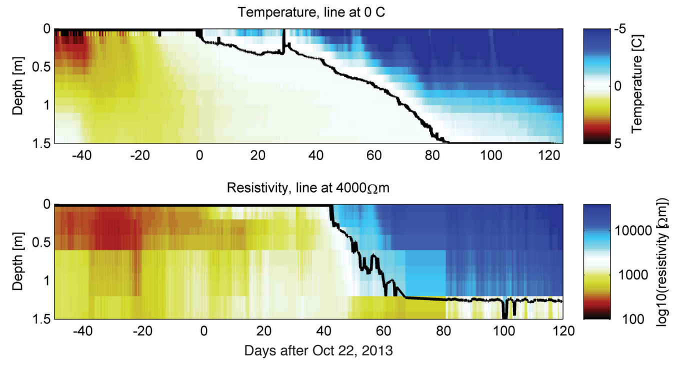
Data for comparison

- borehole with 15 temperature sensors, 10 cm depth spacing, 0.1 - 1.5 m depth
- Extract depth profile of ρ, m_0, τ, C at borehole location for each inversion
- Create surface plot with color coding of temperature, ρ, m_0, τ and C as a function of depth and time

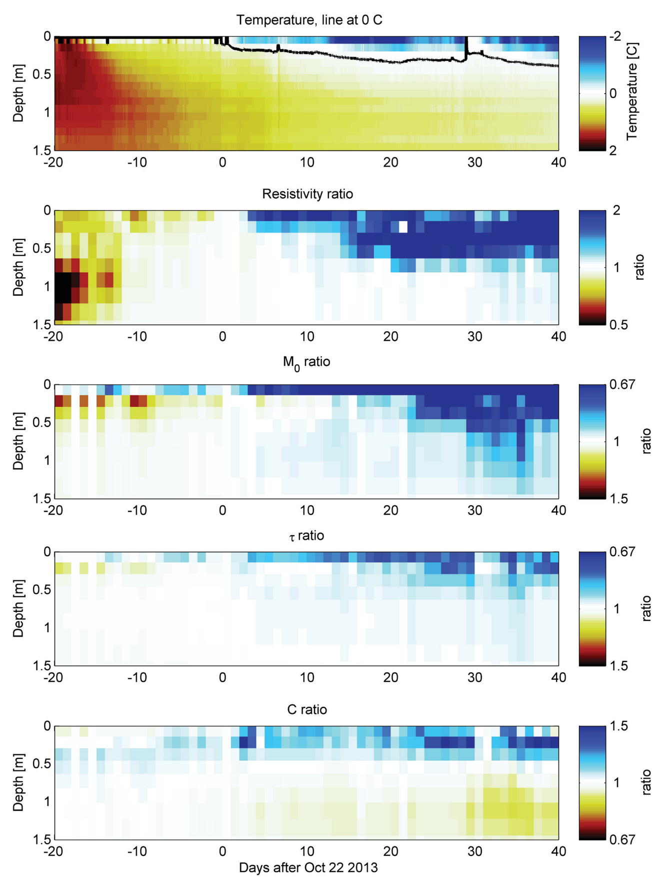
Results

- ρ increases strongly with freezing of the ground, but a single resistivity threshold for defining 0°C is not possible
- m_0 decreases in frozen ground:
  smaller pore space => smaller chargeability
  higher ion concentration => smaller chargeability
- τ decreases:
  smaller pore space => smaller diffusion length => shorter decay
- Scatter plot reveals linear relationship between log-resistivity and temperature (for temperatures below 0°C)

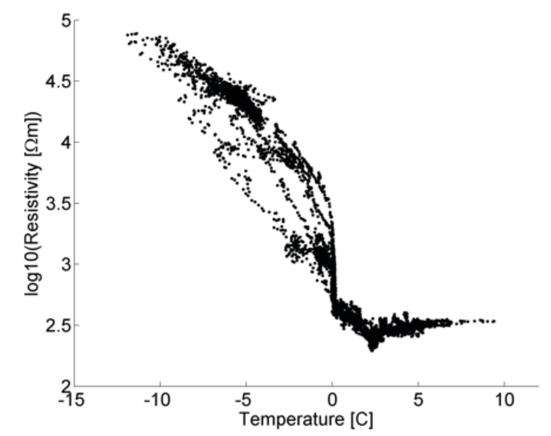
DC-only inversions and temperature from Sept. 2013 - Feb. 2014



DC/IP inversions and temperature from Oct. - Nov. 2013



Scatter plot of log-resistivity and temperature



7. Conclusions

- High-quality DC/IP monitoring data acquired from July 2013 to February 2014
- Increasing electrode contact resistance makes IP acquisition difficult after first month of freezing (Nov. 30, 2013)
- High temporal sampling allows detailed comparison and correlation between temperature, resistivity and IP parameters
- **Increase in resistivity with freezing of the ground can be reliably imaged**
- **IP parameters show clear signal of freezing: chargeability and decay length decreasing**

Acknowledgements

- The Arctic Station supplied data and provided the logistical platform as well as permits.
- We would like to thank technician Simon Ejlertsen for his support and Charlotte Sigsgaard for compiling the weather data.
- Funding was kindly provided by the Danish National Research Foundation (CENPERM DNRF100).

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