Permafrost monitoring at Mölltaler Glacier and Magnetköpfl

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Introduction

Changes of climate parameters due to global warming generate increased permafrost warming and deglaciation in alpine regions. These processes are mainly responsible for an increasing rock fall activity and decreasing slope stability in these areas. Consequently permafrost thawing will produce serious environmental and engineering problems, which can also affect regions below the permafrost (e.g. large rock falls). As details about the underlying processes are still not fully understood it seems to be an interesting field of research. Especially geoelectric monitoring could be a promising method to analyse melting and freezing processes of the shallow subsurface and the status of the permafrost at deeper areas, because of the large resistivity contrast between frozen and melted soil or rock.

The application of the geoelectric method for permafrost investigations is reported by many authors, e.g. Hauck, 2002; Hauck and Vonder Mühll, 2003; Kneisel, 2004; Marescot et al., 2003.

The activities in permafrost regions of the Department of Geophysics of the Geological Survey of Austria started in the year 2006 with the installation of a first geoelectric test profile equipped with the GEOMON^{4D} (Supper and Römer, 2003) on the summit of the Sonnblick Mountain (3106 m a.m.s.l.). The very special conditions at this location lead to several problems in data acquisition which result in a discontinuous data set. Additionally the quality of the collected data was unsatisfying due to the impact of various steel installations in the summit area of the mountain. Nevertheless the gain in experience for the operation of a monitoring system at these high alpine conditions was invaluable. All further improvements of the monitoring system for permafrost measurements are based on this knowledge.

Technological developments

The resistivity of frozen soil can reach values of several hundred kOhmm. Commercial geoelectric systems and also our GEOMON^{4D} system are not constructed to deal with these high resistivities. The main problem is the unrestricted current injection which leads to potential differences that are out of the system range (+/- 10 V for the GEOMON^{4D} system). Theoretical calculations of the potential difference for a specific injection current in a high resistivity environment (homogeneous halfspace) using a simple Wenner configuration show the importance of the input current reduction. Fig. 1 shows calculated potential differences related to subsurface resistivity for a constant input current of 10 mA.

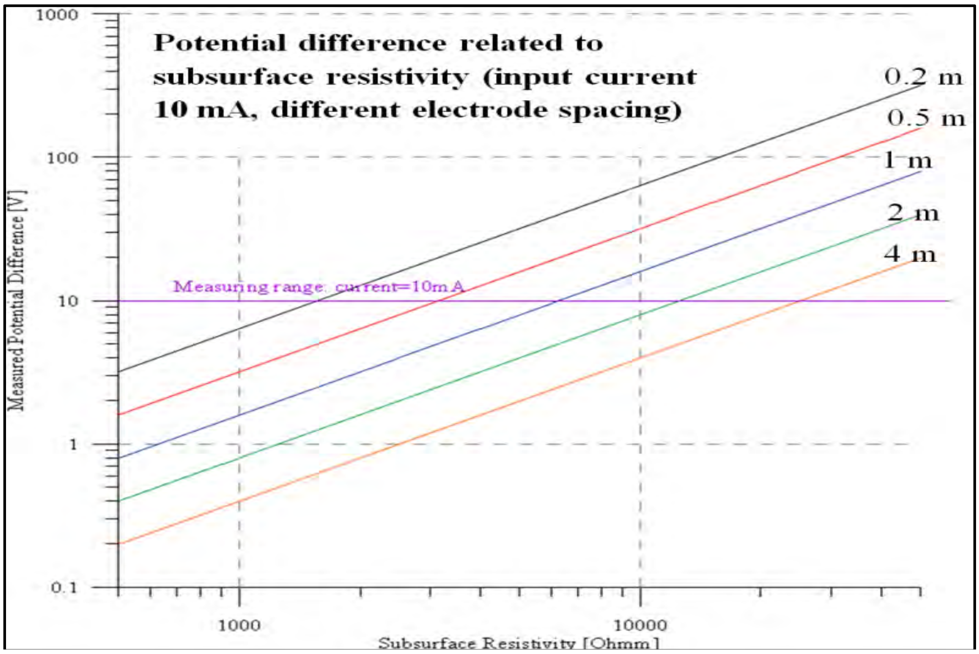

Fig. 1: Theoretical calculation of potential differences for a constant input current using a Wenner configuration with different electrode spacing.

The purple line represents the maximum input voltage of our monitoring system so that the intersection with the calculated potential differences defines the highest subsurface resistivity at which a reliable measurement can be achieved. Fig. 1 shows clearly that with the given input current, which is already quite low, it could be even for the largest considered electrode spacing difficult to perform measurements at permafrost conditions, where we expect resistivities higher than 50 kΩm. Based on these theoretical considerations we adapted the power supply of the GEOMON^{4D} to this special demand, changing it from a constant output voltage (48 – 391 V for common applications) to a constant output current (2 – 20 mA) balanced at a level which takes into account the maximum input voltage of +/- 10 V. This adaption ensures reliable measurements at subsurface resistivities up to several hundred kOhmm. Although it is a feasible solution to force the potential differences within the measuring range of the system, it should be considered to enlarge this range in future to improve the data quality, which is in most cases directly dependent on the amount of injected current.

Our experience from the test measurements on the Sonnblick showed that it is essential to use a lightning protection to fuse the device from overvoltage occurring along the monitoring profile. The sources for the appearance of this overvoltage are still not completely clear but the fact that damages to the system occurred especially during summertime indicates a clear correlation to thunderstorms. The used lightning protection cannot resist voltages which would occur in the very unlikely case of direct lightning strike to the monitoring profile, but it is very effective for the more likely case of a lightning event in the surrounding area with corresponding high potential differences in the subsurface. However, the implementation of the lightning protection results in clear reduction of maintenance work involving damages of electronic components of the device.

The areas of interest for permafrost monitoring are placed in high alpine areas, so in most cases there is no connection to the power grid. Even though we had this opportunity at the test site on the Sonnblick (connection to the power grid of the meteorological observatory) it turned out as a disadvantage, because the measurements were disturbed by various installations in the surrounding of the building. Consequently it is necessary to use an independent power supply. We solved this problem with a fuel cell system (Fig. 2), consisting of the fuel cell SFC Efoy Pro© 600 with a charging capacity of 600 Wh/day and a current of 1 A, which is connected to 72 Ah batteries. The system includes two methanol canisters with a total capacity of 56 l and a GSM modem for remote control.

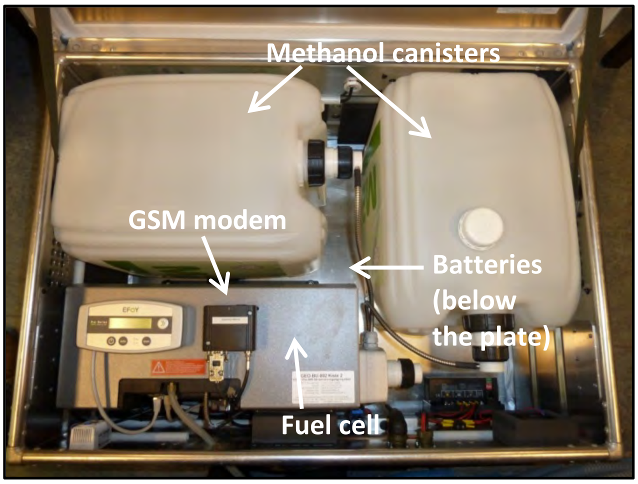

Fig. 2: The used fuel cell system.

Our experience at the monitoring site Mölltaler Glacier (2750 m a.m.s.l.) showed that it is very reliable even at extreme conditions during wintertime. The low fuel consumption (depending on the measurement activity and temperature conditions) allowed a maintenance free operation for about 8 months.

Monitoring site Mölltaler Glacier

This monitoring site is placed within the Mölltaller Glacier skiing area (Carinthia) on a plateau at an altitude of about 2750 m a.m.s.l. close to the mountain station of the “Eissee” cable car (see Fig. 3). There were several reasons why we chose this area for our investigations. First of all it is very easy accessible due to the well-developed infrastructure of the skiing area and secondly it is near to the Sonnblick mountain (about 5 km linear distance), where we have access to soil temperature data.

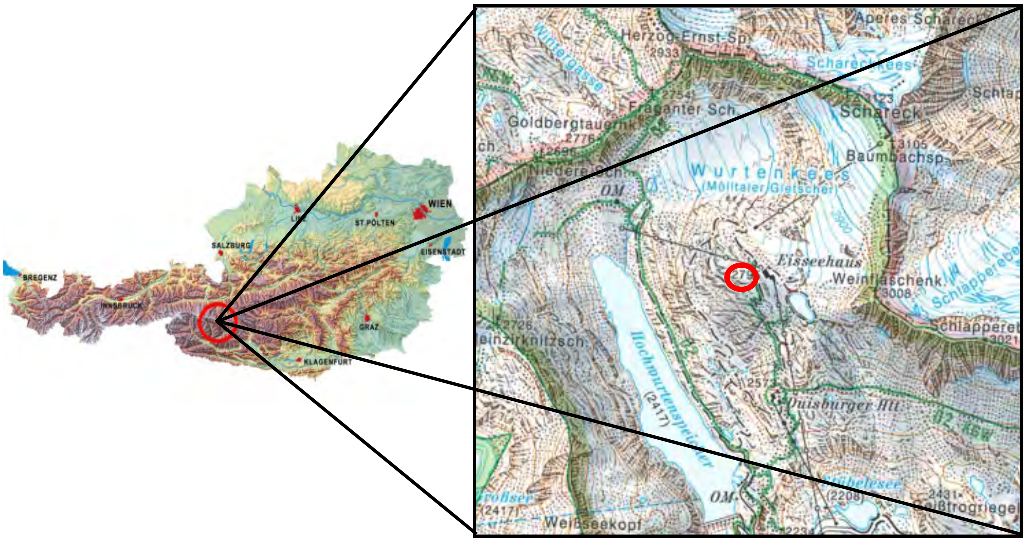

Fig. 3: Location of the monitoring site (indicated by a red circle).

The geoelectric profile was installed in NW – SE direction and it was equipped with the adapted GEOMON^{4D} powered by a fuel cell system (see previous section). The profile consists of 81 electrodes with a spacing of 1 m. The maximum depth of investigation for this configuration is about 15 m. The system started its operation on the 28th of September 2010. The measurement, a gradient array containing 2590 data points, is executed automatically once a day and the data is sent the following day by e-mail to the office in Vienna. The data processing which is partly performed automatically is split in two different parts. The output of the first part is a large number of apparent resistivity time series of different electrode combinations. This data is plotted and compared to the soil temperature data from the Sonnblick observatory. The second part of the data processing consists of the data inversion and produces 2D resistivity models of the subsurface.

Fig. 4 shows two examples for the comparison between time series of soil temperature and relative apparent resistivity for electrode combinations which are related to different depths of penetration.

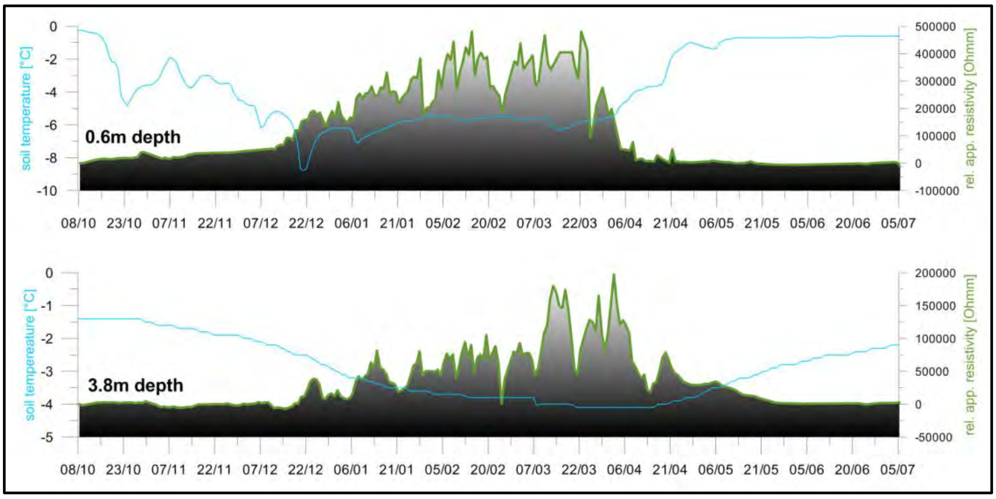

Fig. 4: Comparison between relative apparent resistivity and soil temperature for two different depths.

In both examples there is a clear correlation between low soil temperatures and very high apparent resistivities. Apart from the fact that we have different ranges of soil temperature at these two depths there is a clear time shift in areas with lowest temperatures and highest resistivities as well. This is caused by the behaviour of the temperature wave travelling through the subsurface. Although this example shows a nice correlation between soil temperature and apparent resistivity the interpretation has to stay on a quantitative level, because of the strong dependence of soil temperature on local conditions (e.g. lithology, slope position and angle, elevation). This shows the importance that additional measurements (especially soil temperature) should be performed on site, to enable a detailed and verified interpretation of geoelectric data. Fig. 5 shows inversion results calculated with the AGI Earthimager 2D software of the whole monitoring period. It starts with the 9th of October 2010 and ends with the inversion result of the 24th of June 2011 with an interval of about 15 days.

The shallow part of the subsurface (the first 3 m) shows strong temporal changes of the resistivity. This behaviour is correlated with the freezing and melting process of the topmost layer. A continuous increase of resistivity in this part is seen for the results 1-12. Result 12 which corresponds to the end of March shows the largest extension of the high resistivity (frozen) zone. In result 13 (9th of April) there is already a decrease of resistivity (especially on the surface) visible. The following resistivity models illustrate the melting process till the end of June. At this time we reach more or less the initial resistivity distribution in the shallow part of the subsurface (9th of October 2010).

At deeper parts of the depth section hardly any resistivity changes took place and due to the relatively low values of 1000 to 15000 Ωm we conclude that there is no indication for permafrost at this location. This could be explained by the fact that our profile is placed on a southwest facing slope, where permafrost is very unlikely at this altitude.

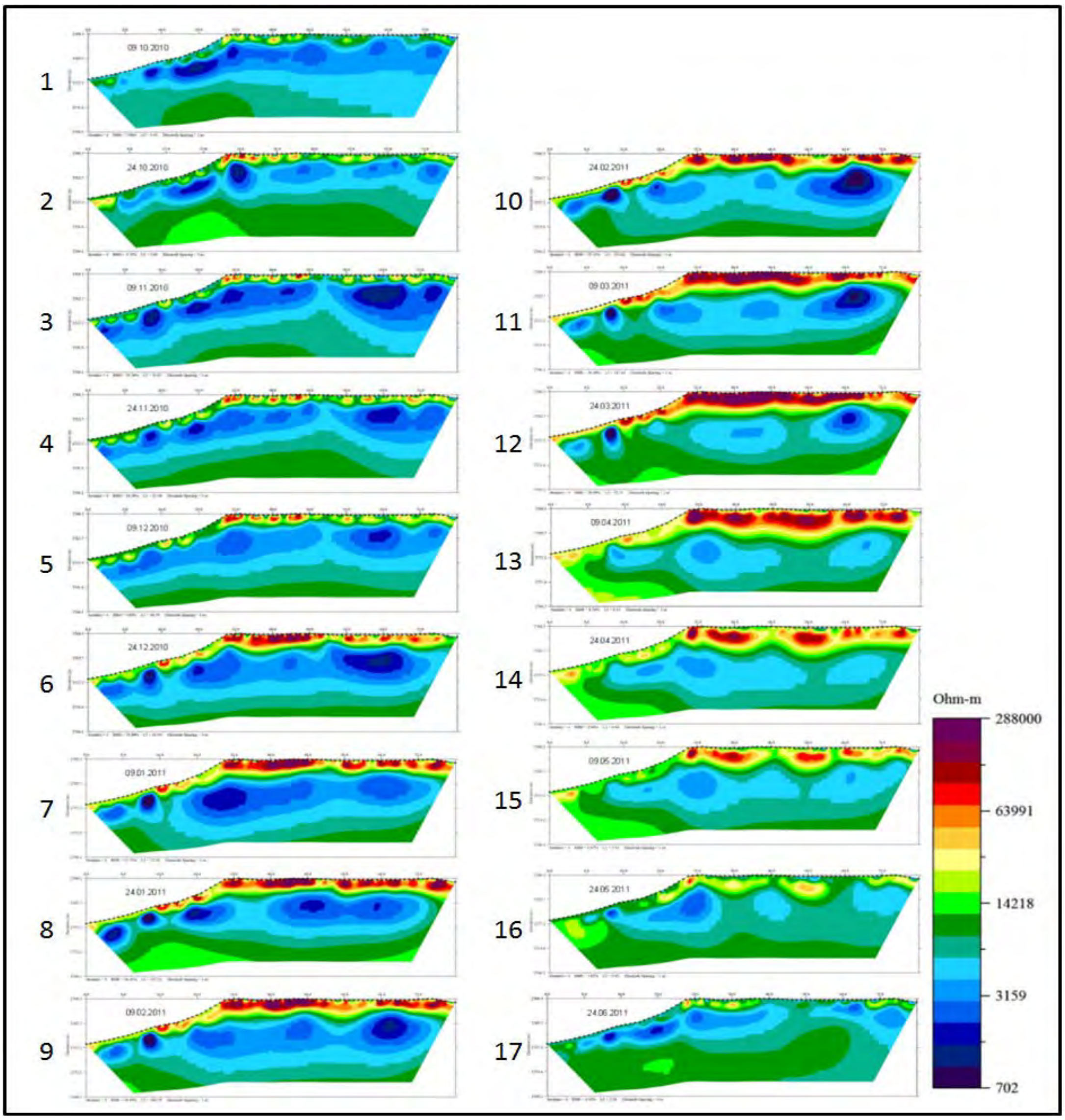

Fig. 5: Selected inversion results covering the whole monitoring period.

Altogether the operation of the monitoring system was very successful and we produced a high quality geoelectric dataset for almost a whole seasonal period. As there was no expectation for new information if we continue our measurements at this location, we decided to search for a new monitoring site where additional measurements (e.g. soil temperature) should be available on site.

Monitoring site Magnetköpfl

This monitoring site where our measurements started in October 2011 is placed on the Magnetköpfl (2957 m a.m.s.l.) which is a peak below the Kitzsteinhorn (Salzburg). A major advantage of this location is the availability of additional data (e.g. soil temperature, ERT), which is collected in the framework of the MOREXPERT project (alpS – Centre for Climate Change Adaptation Technologies, Innsbruck, Austria). In addition to several measuring points of near surface rock temperature in the surrounding area we have also two measuring points (near surface rock temperature) directly on the geoelectric profile. Soil temperature data from two boreholes (30 m depth) is also available. We used the same monitoring system as on the Mölltaler Glacier working with same settings. As the investigations are still going on we can present at this time only preliminary results. Unfortunately soil temperature data of our monitoring period is not available yet.

Fig. 6 shows inversion results of the freezing process in late autumn 2011. Especially in the shallow part there is a significant increase of resistivity visible. In deeper areas in comparison the changes are much smaller and considering the displayed colour bar we see that the resistivities are in the range of 100 to 150 kΩm. These high values and the negligible change during the freezing process indicate the presence of permafrost at depth. In the left part of the depth section we have the strongest influence of the freezing process to the measured resistivities. This could be explained by the fact that we have solid rock at this part, where low temperatures penetrate much faster than at weathered conditions with rock waste what we observed along the rest of the profile. We are confident that with additional information of soil temperature data we will be able to verify these assumptions.

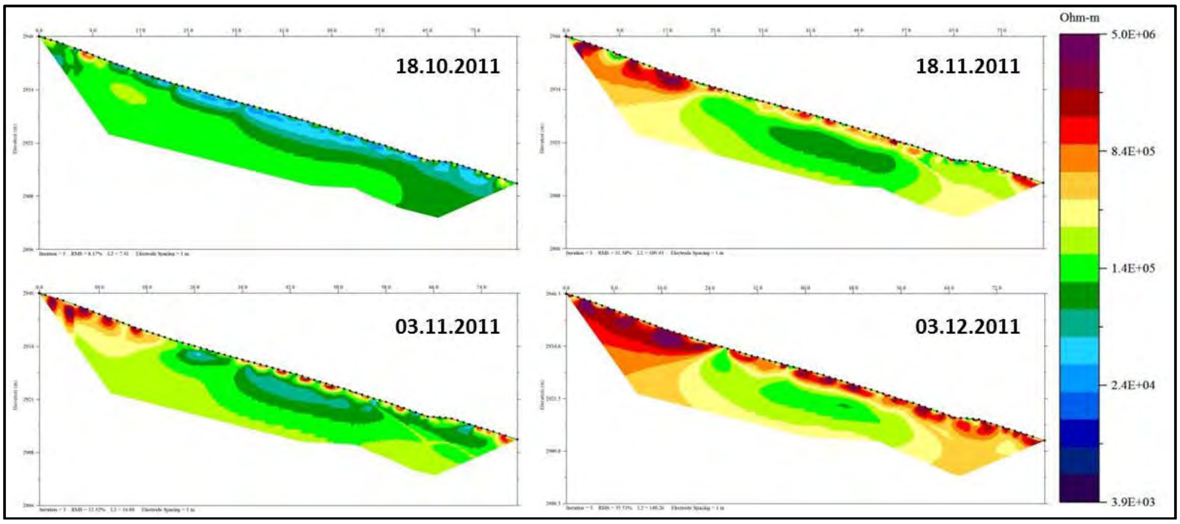

Fig. 6: Inversion results covering the freezing process.

We plan to continue our geoelectric monitoring at the Magnetköpfl at least to summer 2012 to cover an entire seasonal period.

Conclusions

With our monitoring measurements we showed that resistivity is a very useful parameter for the detection of permafrost as well as for the investigation of freezing and melting processes in the topmost layer. Nevertheless there is still the need of some improvements to ensure a detailed and verified interpretation of geoelectric data.

Acknowledgements

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