How much rain is too much for a GPR survey? Results of the Borre Monitoring Project

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Abstract
Soil moisture variation is complex and depends on a range of factors, which complicates the formulation of recommendations for GPR surveys. Low amounts of soil moisture produced GPR data of higher quality. However, precipitation rates as well as chronological sequence of precipitation/thawing processes and the GPR survey are of importance. Winter months can offer favorable conditions for GPR surveys if temperatures remain negative over a prolonged time period, allowing for frost to build in the ground. Results of the Borre Monitoring Project (BMP) are valid only for sites with similar settings as Borre; the monitoring approach, however, can be transferred to larger regions with more representative sites.

Keywords
archaeological prospection; cultural heritage management; electromagnetic wave propagation; ground penetrating radar; soil science

Introduction

In 2016, Vestfold and Telemark County Council, together with the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology and the Norwegian Institute for Cultural Heritage Research initiated the Borre Monitoring Project (BMP). This project emerged from a GPR survey in 2015, which failed to detect two large hall buildings at the Late Iron and Viking Age site Borre in Norway (Fig. 1), in contrast to three previous surveys conducted in 2007, 2008, 2013. Details about the discovery and interpretation of these archaeological structures can be found in Trinks (2007) and Tonning et. al (2020).

Preliminary findings of BMP were reported at ICAP 2017 (Schneidhofer et al. 2017), while data acquisition was still on-going. This paper presents the final results of BMP. A detailed description of the project and its findings can be found in Schneidhofer et al. (2022).

Methods

GPR surveys using a 500 MHz Noggin single-channel antenna were conducted across a test area of ca. 0.76 ha covering two large hall buildings roughly once a month between July 2016 and September 2017. The aim was to capture potential variations in data quality during different environmental conditions. To gain a better understanding of the underlying causes for these variations, volumetric water content (VWC), bulk electric conductivity (BEC), ground temperature as well as precipitation rates were measured in-situ at three locations within the test area. In addition, soil and sedimentological analyses of the subsurface materials present at the test site, including grain size distribution and organic content, were conducted at the Institute for Archaeology, Conservation and History (University of Oslo) to better understand water infiltration and movement underground. Data were processed using ApRadar (Trinks et al. 2018) and analyzed using the custom Python program Schlitzi+ and ArcGIS 2.80.

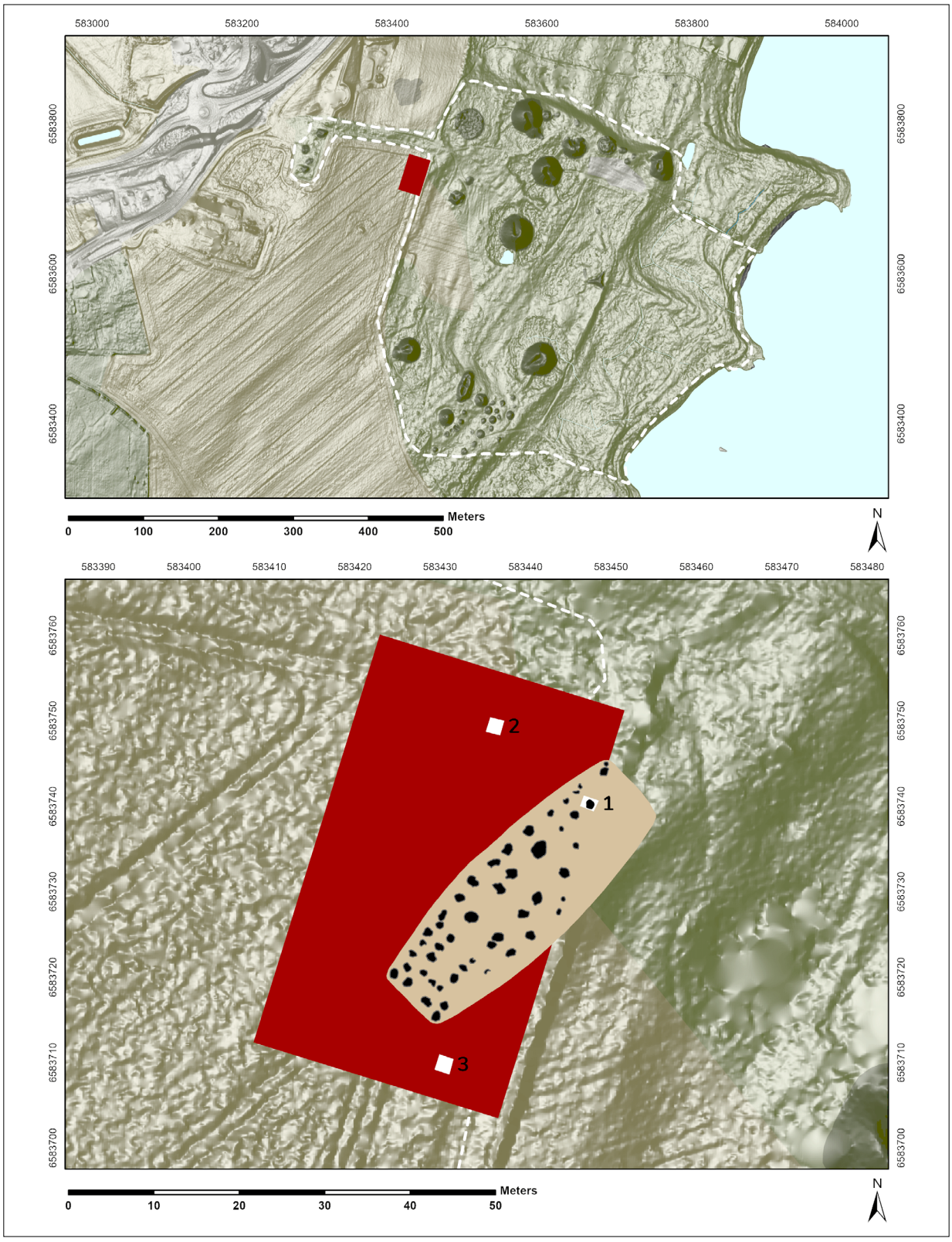

Fig. 1: Location of hall building A just outside the Borre National Park. The test area is marked in red.

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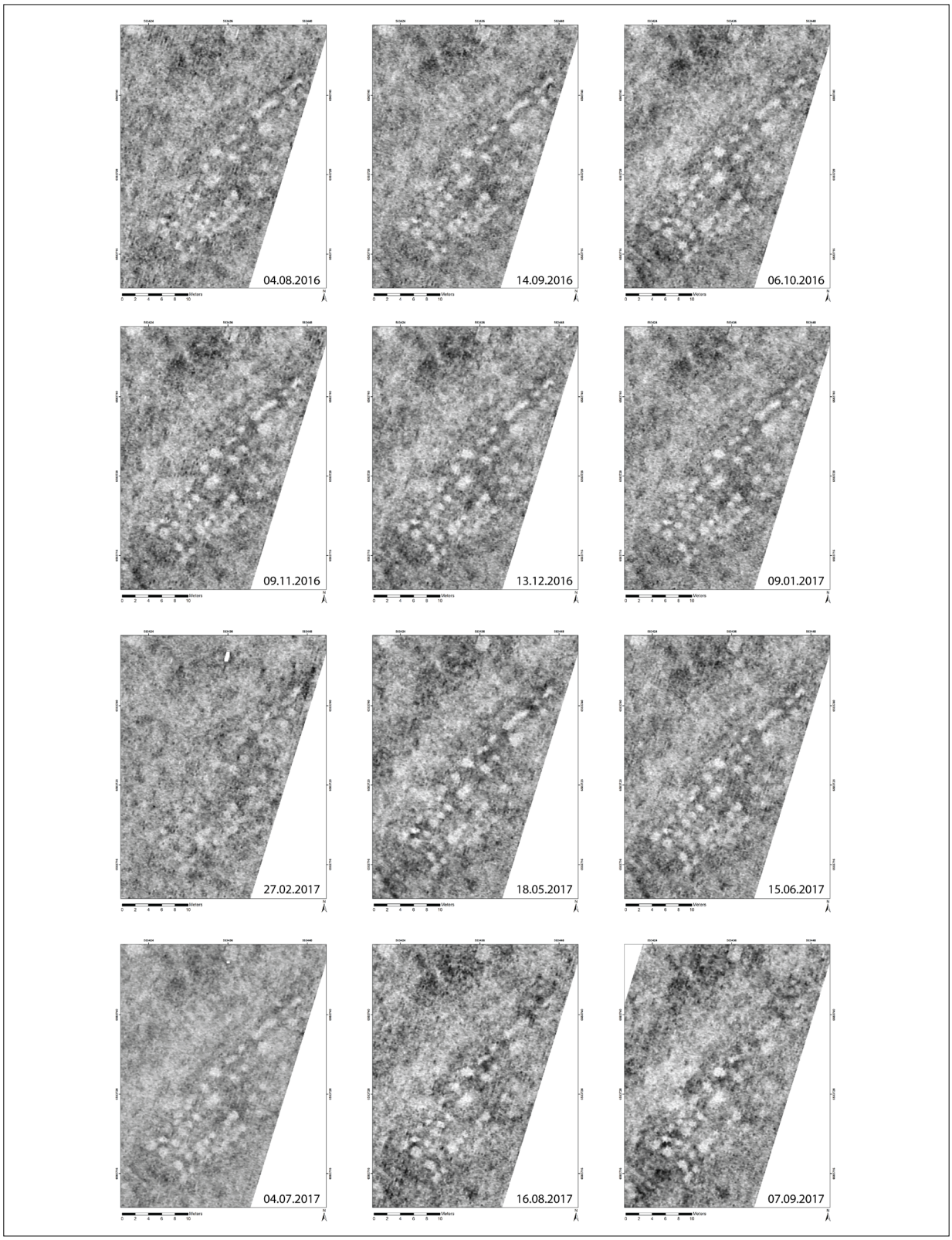

Fig. 2: Depth-slices 40-80 cm of all twelve data sets acquired between July 2016 and September 2017. High amplitude values are displayed in black, low amplitude values in white. Crossline spacing: 25 cm, in-line spacing 5 cm.

Fig. 3: Comparison of VWC, BEC and ground temperature values (Sensors 1-4) measured in-situ at monitoring station 1 during each of the GPR surveys. The blue bar represents precipitation rates in the week prior, the black line in the 24 h prior to the respective surveys.

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Results and discussion

Over the course of 14 month, twelve GPR data sets (Fig. 2) could be collected under different environmental conditions (Fig. 3) and subsequently were classified qualitatively into groups of high and low quality. Quantitative measures to categorize the data sets using statistical and pixel-based methods proved unexpectedly challenging and only confirmed data sets at the lowermost end of the quality spectrum.

Six of the twelve surveys (14092016, 06102016, 09112016, 13122016, 09012017 and 04072017) were conducted in dry conditions, when less than 5 mm of rain had fallen in the week before to the survey. The 24 hours before these surveys did generally not see any precipitation. Surveys 13122016 and 09012017 conducted in December 2016 and January 2017 under very cold and dry conditions with temperatures well under 0 degrees C displayed data of the highest quality.

Five surveys were conducted under wet conditions. In August 2016 (04082016), the survey was conducted directly after a rainfall event (ca. 10 mm in the 24 hours prior), while data collection in May (18052017), June (15062017) and August 2017 (16082017) was characterized by the highest amounts of precipitation (48-58 mm) recorded for the week before the respective surveys. Data set 27022017, classified both quantitatively and qualitatively as being of lowest quality, was acquired in February 2017 amid a thawing process, which created surface puddles and unfavorable conditions in the topsoil.

Of the twelve data sets, eleven did show the hall building; only the data set collected in February 2017 failed to do so. At first glance, this result seems encouraging for the use of GPR in Norway. However, as the test site is located on well-draining ground and surveys were generally not undertaken in very unfavorable conditions, this outcome needs to be treated cautiously.

In general, data showed no seasonality, but were instead governed by small-scale weather patterns, most notable precipitation rates and changes in air temperature. As expected, results supported the long-standing rule that dry conditions are beneficial for electromagnetic wave propagation, when signal attenuation is reduced and more energy can enter the subsurface. The longer these dry periods persisted at Borre, the higher the quality of the GPR data turned out to be. Data sets of lower quality, conversely, were characterized by higher amounts of soil moisture, whereby the chronology of events was of importance. Precipitation shortly before an intended survey would leave the water little time to drain. In this respect, the 24 hours before a survey proved particularly crucial for data quality.

The winter months, when conditions had been very cold and dry for several weeks and frost had built up in the ground, proved more promising for GPR surveys than previously anticipated. Water in its frozen state diminishes signal attenuation and this effect could be clearly seen in the data sets acquired in December 2016 and January 2017. However, a sudden rise in temperature as transpired right before the survey in February 2017, can quickly reverse these favorable conditions.

Upon completion of BMP, the results were tested by surveying a previously discovered ship burial located inside the Borre National Park under favorable conditions following the unusually dry summer of 2022. The collected GPR data were of high quality and a subsequent data interpretation revealed a previously unknown ring ditch around the interred ship.

Conclusion

The results of the Borre Monitoring Project have broadened our understanding of the influence environmental factors, first and foremost soil moisture, exert over the quality of GPR data.

The specific findings at Borre are valid only for sites with similar environmental and archaeological settings. Obviously, not every survey site can be subjected to a monitoring project. However, monitoring projects at sites representative for environmental settings and archaeological structures of a geographical region are feasible. Such an endeavor is currently under way for Vestfold County, Norway. The Vestfold Monitoring project VEMOP (https://www.vtfk.no/meny/tjenester/kultur/kulturarv/vemop/) aims to provide recommendations for the use of GPR in the Vestfold region based on the monitoring of four different test sites and over 100 surveys.

Due to time and financial reasons, GPR surveys can and will not always be conducted under ideal environmental conditions. A deeper understanding about this complex issue, however, can aid in limiting unwanted effects during data processing and interpretation as well as in post-survey measures.

References

Schneidhofer P, Tonning C, Lia V, Baldersdottir B, Øhre Askjem JK, Gustavsen L, Nau E, Kristiansen M, Trinks I, Gansum T, Neubauer W, Paasche K. Investigating the influence of seasonal changes on high resolution GPR data: the Borre Monitoring Project. In: Jennings B, Gaffney C, Sparrow T, Gaffney S, editors. AP2017: 12th International Conference of Archaeological Prospection: 12th-16th September 2017, University of Bradford; 2017 Sept 12-16; Bradford, United Kingdom. Oxford: Archaeopress; 2017. p. 224-26. url: https://bradscholars.brad.ac.uk/handle/10454/13511

Schneidhofer P, Tonning C, Cannell RJS, Nau E, Hinterleitner A, Verhoeven GJ, Gustavsen L, Paasche K, Neubauer W, Gansum T. The influence of environmental factors on the quality of GPR data: the Borre Monitoring Project. Remote Sensing 2022; 14:3289-3322. doi: 10.3390/rs14143289

Tonning C, Schneidhofer P, Nau E, Gansum T, Lia V, Gustavsen L, Filzwieser R, Wallner M, Kristiansen M, Neubauer W. Halls at Borre: The discovery of three large buildings at a Late Iron and Viking Age royal burial site in Norway. Antiquity 2020; 94: 145–163. doi: 10.15184/aqy.2019.211

Trinks I. Borre October 2007. Unpublished Report Prepared for Vestfold County Council. 2007.

Trinks I, Hinterleitner A, Neubauer W, Nau E, Löcker K, Wallner M, Gabler M, Filzwieser R, Wilding J, Schiel H, Jansa V, Schneidhofer P, Trausmuth T, Sandici V, Ruß D, Flöry S, Kainz J, Kucera M, Vonkilch A, Tencer T, Gustavsen L, Kristiansen M, Tonning C, Zitz T, Paasche K, Gansum T, Seren S. Large-area high-resolution ground-penetrating radar measurements for archaeological prospection. Archaeological Prospection 2018; 25: 171-195. doi: 10.1002/arp.1599