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Optimal CSEM survey design for CO_2 monitoring at Smeaheia offshore Norway

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Geophysical monitoring is essential for CO_2 storage projects and mandatory Measurements, Monitoring, and Verification (MMV) plans. Various geophysical methods can be used to estimate, from measured data, selected properties (e.g. velocity, density, and resistivity) of the subsurface. Accurate knowledge of those properties in turn makes it possible to quantify important reservoir parameters such as CO_2 saturation and pore pressure, giving the operator valuable information for predictable CO_2 injection and storage.

A combination of seismic and non-seismic technologies is usually part of the CO_2 monitoring plan throughout the project lifecycle (pre-injection, injection, and post-injection phases). The EM4CO2 project investigates whether marine Controlled Source Electro-Magnetics (CSEM) can be a cost-efficient complement to seismic in such monitoring plans. The main focus of the project is on demonstrating sufficient sensitivity of the technology and on further developing CSEM for time-lapse applications in areas with potentially interfering infrastructure. While improved data processing, imaging, and inversion techniques is often the subject of large research efforts, less attention is usually paid to developing better survey design strategies (rather relying on conventional methods). The work described here relates to the development and demonstration of new strategies for optimization of 4D survey design. Such optimization could decrease the large costs associated with acquisition of geophysical data (in this case CSEM), which could otherwise be a hurdle when proposing large-scale CO_2 storage as a means to mitigate climate change.

Conceptually, survey design aims at selecting the data acquisition that optimally resolves the subsurface model parameters of interest while maintaining the cost as low as possible. In other words, it consists of finding the best trade-off between data value and data collection cost. In this work, the CSEM survey design strategy is based on the analysis of the eigenvalue spectrum of the data misfit Hessian. A Python notebook was implemented for interactive prototyping and testing of various optimization strategies. A few examples of survey design are given for a model of the Sleipner storage site, showing how well a given regular survey can be decimated without significant loss of information. The main part of the work is, however, focused on survey optimization for potential CO_2 storage in the Smeaheia formation at about 1000 m depth below the sea surface, offshore Norway. This study shows how to determine the most valuable electric field components, most important frequencies, and source/receiver positions to use for reliable monitoring of a target region of choice. Initial results indicate that measuring the vertical component in addition to the horizontal electric field adds relevant information, and that lower frequencies (0.1-0.5 Hz) carry more information than higher (0.75-5 Hz) about the target depth. It is also clear that the method identifies sources and receivers distributed mainly above the target region as the most important.