J. Ind. Geophys. Union, 28(4) (2024), 235-246

Application of seismic inversion based maximum likelihood methods to monitor CO_2 plume in Sleipner Gas Field, Norway

Ajay Pratap Singh[1*], S. P. Maurya[1], Ravi Kant[1], Nitin Verma[1], Raghav Singh[1], K. H. Singh[2], Prabodh K. Kushwaha[1], M. K. Srivastava[1], G. Hema[1], Harsha Raghuvanshi[1] and Richa[1]

[1]Department of Geophysics, Institute of Science, Banaras Hindu University, Varanasi-221005, India
[2]Department of Earth Sciences, Indian Institute of Technology, Bombay, Mumbai-400076, India
* Corresponding author: ajaygeop21@bhu.ac.in

ABSTRACT

Seismic inversion is a computational technique used in geophysics to infer the properties of subsurface geological formations by analyzing seismic data. In order to lower the concentration of CO_2 in the atmosphere, as a part of carbon capture and sequestration operation, these inversion techniques are essential for detecting CO_2 leaks injected underground. While there are other ways to carry out this inversion, such as band-limited inversion or model-based seismic inversion, the current study used maximum likelihood (ML) inversion techniques. In this technique, a probabilistic framework is used to quantify uncertainties in both the seismic data and the model parameters. The inversion process involves iteratively adjusting the model parameters to minimize the misfit between the observed seismic data and the data predicted by the model. The misfit is typically quantified using a measure such as the difference between observed and predicted seismic waveforms or attributes. The ML method is faster and provide higher resolution subsurface information in comparison with other traditional methods. In this study, to increase accuracy and comprehension of the dynamic behavior of the injected CO_2 plume, time-lapse inversion and analysis of 4D seismic data are being used. The analyses of 4D seismic data includes predictability, temporal shift, cross correlation, and other crucial elements to learn more about the reservoir's response to CO_2 injection. For the analysis of Sleipner Gas Field, Norway's seismic data recorded in 1994 (pre-injection) and 2001 (post-injection) are used. The comparison of inverted impedance section from pre-injection and post-injection clearly shows the movement of CO_2 plume in the subsurface. Also the use of ML inversion methods over traditional model based seismic inversion provides more accurate and less computation time and computation cost which is very important for any developing country to adopt CCS project.

Keywords: Time-lapse, Seismic inversion, Calibration, Normalized root mean square, Carbon Capture and Storage (CCS), Sleipner Gas Field (Norway)

INTRODUCTION

Seismic inversion is a mathematical techniques used to integrate seismic and well log data together to estimate subsurface rock properties such as acoustic impedance, elastic impedance etc (Maurya et al., 2020). These impedances provide subsurface layer information, whereas seismic data provides interface information only. Seismic data has frequency range from 10-80Hz, whereas well log has frequency in the range of 0-120kHz hence is both are included together that can certainly enhance subsurface information.

By interpreting inverted seismic reflection data, geoscientists can infer crucial information such as lithology, porosity, fluid content, and structural features like faults and stratigraphic boundaries. Seismic inversion plays a pivotal role in various applications including hydrocarbon exploration, reservoir characterization, geothermal resource assessment, and geological modeling (Kushwaha et al., 2021). Its ability to provide high-resolution images and quantitative information about subsurface properties makes it an indispensable tool for understanding Earth's geology and for guiding exploration and development activities in the energy industry and beyond.

A variety of seismic inversion methods such as, elastic impedance inversion, pre-stack simultaneous inversion (Clochard et al., 2009), band-limited inversion, colored inversion (Gotz et al., 2014; Wang et al. 2018), model-based stochastic inversion (White and Weyburn Geophysical Monitoring Team, 2011) and others are available to invert seismic data. The efficacy of inverted results is largely dependes on these inversion methods and hence one chooses with care before their application. The present study uses Maximum Likelihood seismic inversion methods to invert seismic data and to estimate subsurface fluid information (Maurya and Singh, 2018). Maximum Likelihood seismic inversion methods offer several advantages. They provide a rigorous statistical framework for inversion, allowing for the incorporation of prior information and the propagation of uncertainties through the inversion process. Additionally, they can handle complex data sets and non-linear relationships between the model parameters and the seismic data. Examples of Maximum Likelihood seismic inversion methods include Bayesian inversion, where prior information about the model parameters is combined with the likelihood function to estimate posterior probability distributions, and Monte Carlo inversion,